2016 APCTP STATUS REPORT

March 24, 2017

Asia Pacific Center for Theoretical Physics

Contents

I. Foreword

Foreword

As we celebrated our 20th anniversary in March 2016, APCTP finds itself in a very different environment than when it began in 1996. The dramatic economic improvement in the Asia-Pacific region has been striking, particularly in the last decade. With this economic improvement has come increased funding for science and technology and the development of more institutes and programs in physics research at both the national and regional level. Korea is now home to three other theoretical physics centers in addition to APCTP. There are new theoretical physics institutes in other member countries such as China and Vietnam as well. It is in this context that the Center embarks on its third decade and determines how to maintain its leading role in theoretical physics research.

There were a number of significant developments at the Center in 2016 that reflect its current ongoing role as a regional center. The Association of Asia Pacific Physics Societies (AAPPS) decided at their Council Meeting in Brisbane, Australia, to locate their headquarters to APCTP. The Center already publishes the AAPPS Bulletin, and the co-location of AAPPS and APCTP will strengthen both as hubs for Asia-Pacific physics networks. In June the Center hosted the first "APEC Centers" Cooperation Conference, where APTCP and seven other APEC-endorsed centers adopted the Pohang Declaration, a statement to promote collaboration and cooperation among the centers. We welcomed Canada to be our sixteenth member country and had institutes in Uzbekistan, Iran, and Armenia join the Center as partner institutes.

The Centers ongoing scientific programs continue to be productive, such as the Focus Research Programs and the Academic Programs both within and outside Korea. The in-house research programs continue to publish excellent papers by nine Junior Research Groups (JRG) and eight Young Scientist Training (YST) program participants. This year two JRG groups completed their missions, and one new JRG Group was formed. The Benjamin Lee Professorship Lecture was delivered by Prof. Janos Kertesz in June. The Center hosted the first meeting of ICTP Affiliated Centers (ICAC) in November. The Visitor Program supported 23 scientists in short and extended periods at the Center. The Scientific Outreach Programs held two well received events in Pohang: "Science in City Hall" and "Pohang Family Festival". The number of visitors to the Center approached 3,500 this year.

At its meeting in November, the Board of Trustees formed a Search Committee for the APCTP President and asked me, as Board Chair, to serve as Acting President until the next President is appointed. The Center would like to extend its thanks for support from the Ministry (MSIP), Gyeongbuk Province, the city of Pohang, POSTECH, and member countries.

Won Namkung
Chair of Board of Trustees and Acting President

II. Overview of the APCTP

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1. Introduction

The Asia Pacific Center for Theoretical Physics (APCTP) is an international research center that pursues excellence in research, trains young scientists in all areas of theoretical physics, and promotes international cooperation among scientists from member countries/regions in the Asia-Pacific region and beyond. Under the leadership of Prof. C. N. Yang, the founding president, the Center was established in June, 1996, in Korea. As an international Non-Governmental Organization (NGO), its current member countries include Australia, Beijing, Canada, India, Japan, Kazakhstan, Korea, Lao PDR, Malaysia, Mongolia, Philippines, Singapore, Taipei, Thailand, Uzbekistan and Vietnam.

■ The Center aims:

· To lead research excellence in the field of theoretical physics;
· To facilitate international cooperation;
· To contribute to the advancement of physics by training young physicists;
· To improve science-based communication with the public.

■ To this end, the Center:

· engages in topical research in all areas of theoretical physics and beyond;
· pursues international academic collaboration and exchange of scholars;
· educates and trains young scientists;
· publishes a web journal and creates high-quality literary contents;
· offers distinguished lectures and activities accessible to the public.

2. Milestones

Feb. 1993 The International Planning Committee (IPC) is formed.

May 1994 IPC recommends Korea as the host of the APCTP headquarters.

Nov. 1994 Association for Science Cooperation in Asia (ASCA) endorses the proposal to host the APCTP in Korea.

Sep. 1995 UNESCO PAC, IUPAP, and AAPPS endorse the proposal for APCTP.

June 1996 Inauguration conference is held and APCTP is established.
The Agreement of Collaboration is exchanged with ICTP.

Nov. 1996 The president of Korea announces the supports for APCTP at APEC Science Ministers Meeting in Seoul.

Jan. 1997 The Board appoints Prof. C. N. Yang (1957 Nobel Laureate for Physics) as the 1st President and Chairperson.

Apr. 1997 APCTP Foundation is registered at the Korean Ministry of Science & Technology.

May 1998 Biannual APCTP Bulletin is launched.

Oct. 1998 The Agreement of Collaboration is exchanged with CRM.

Dec. 1999 The Agreement of Collaboration is exchanged with NCTS.
An annex building is opened in Kangnam-gu, Seoul for KFAS.

Jan. 2001 Activity-Financing Contract is made between UNESCO and APCTP.

Apr. 2001 Prof. A. Arima (Former Minister of Education of Japan) is elected as the 2nd Chairperson of the Board of Trustees.

July 2001 The Agreement of Collaboration is exchanged with PIMS.

Aug. 2001 APCTP Headquarters move to the campus of POSTECH.
Seoul Branch Office opens in the annex building of the KOFST.

Mar. 2003 The Agreement of Collaboration is exchanged with ECT*.

June 2003 The Agreement of Collaboration is exchanged with TPI.

Apr. 2004 The Board appoints Prof. R. B. Laughlin (1998 Novel Laureate for Physics) as the 2nd President.

Nov. 2004 Young Scientist Training Program is launched.

Feb. 2005 Science Communication program is launched.

Mar. 2005 The APCTP headquarters are relocated to Hogil Kim Memorial Building of POSTECH.

July 2005 The Agreement of Collaboration is exchanged with ITP.

Oct. 2005 APCTP Web journal "Crossroads" is launched.

Dec. 2005 Prof. N. V. Hieu is elected as the 3rd Chairperson of the Board.

July 2006 The Agreement of Collaboration is exchanged with JINR.

Nov. 2006 APCTP 10th Anniversary Celebration Ceremony is hold.

Nov. 2006 The Agreement of Collaboration is exchanged with RIKEN.
Lao PDR and Mongolia are admitted as new members of the APCTP.

Jan. 2007 The Agreement of Collaboration is exchanged with IPNS/KEK.

Mar. 2007 The Board appoints Prof. P. Fulde as the 3rd President.
The Agreement of Collaboration is exchanged with YITP.

Aug. 2007 The Agreement of Collaboration is renewed with ICTP.

Oct. 2007 The Agreement of Collaboration is exchanged between APCTP, MPG and POSTECH.
The Agreement of Collaboration is exchanged with IOP, ISSP.

Mar. 2008 India is admitted as a new member of APCTP.

June 2008 Junior Research Groups (JRG) is launched.

Oct. 2008 The Agreement of Collaboration is renewed with TPI.

Nov. 2008 The Agreement of Collaboration is exchanged between ASEAN and APCTP.

Jan. 2009 The Agreement of Collaboration is exchanged with AAPPS.

Apr. 2009 The Agreement of Collaboration is exchanged with IOP/VAST.
The Agreement on the Consortium of Asian Physics Institutions (KITPC/ITP, ICTS, IPNS/KEK, CQUeST, KIAS, and APCTP) is exchanged.

June 2009 The Agreement of Collaboration is exchanged with PI.

Mar. 2010 The Agreement of Collaboration is exchanged with ITAP.

Apr. 2010 The Board appoints Prof. P. Fulde as the 4th President.
Prof. Won Namkung is elected as the 4th Chairperson of the Board.
The Agreement of Collaboration is exchanged with ThEP.

Dec. 2010 The Agreement of Collaboration is exchanged with NBIA/NBI.

Apr. 2011 Uzbekistan is admitted as a new member of APCTP.

Mar. 2012 The Agreement of Collaboration is exchanged with NORDITA.

Dec. 2012 The Agreement of Collaboration is exchanged with KEK as a new member entity of Japan.

July 2013 The Board appoints Prof. Seunghwan Kim as the 5th President.

Nov. 2013 The Agreement of Collaboration is exchanged with IUPAP.
Kazakhstan is admitted as a new member of APCTP
Prof. Paul A. Pearce is elected as the 5th Chairperson of the Board.

Apr. 2015 APCTP is reconnected with APEC PPSTI as an APEC Endorsed Center.

June 2015 The Board appoints Prof. Bum-Hoon Lee as the 6th President.
The Agreement of Collaboration is exchanged with INP RK and IETP.

Nov. 2015 The Agreement of Collaboration is exchanged with RCNP.

Mar. 2016 APCTP 20th Anniversary Celebration Ceremony is held.
Canada is admitted as a new member of APCTP. (The Agreement of Collaboration is exchanged in June)

Apr. 2016 The Agreement of Collaboration is renewed with IBS.

June 2016 The 1st APEC PPSTI Centers Cooperation is held. (Pohang Declaration is adopted)

Oct. 2016 The Agreement of Collaboration is renewed with AAPPS.

Nov. 2016 The Agreement of Collaboration is renewed with IUPAP.

The Agreement of Collaboration is exchanged with NUUz.

The Agreement of Collaboration is exchanged with SCS.

The Agreement of Collaboration is exchanged with IPM.

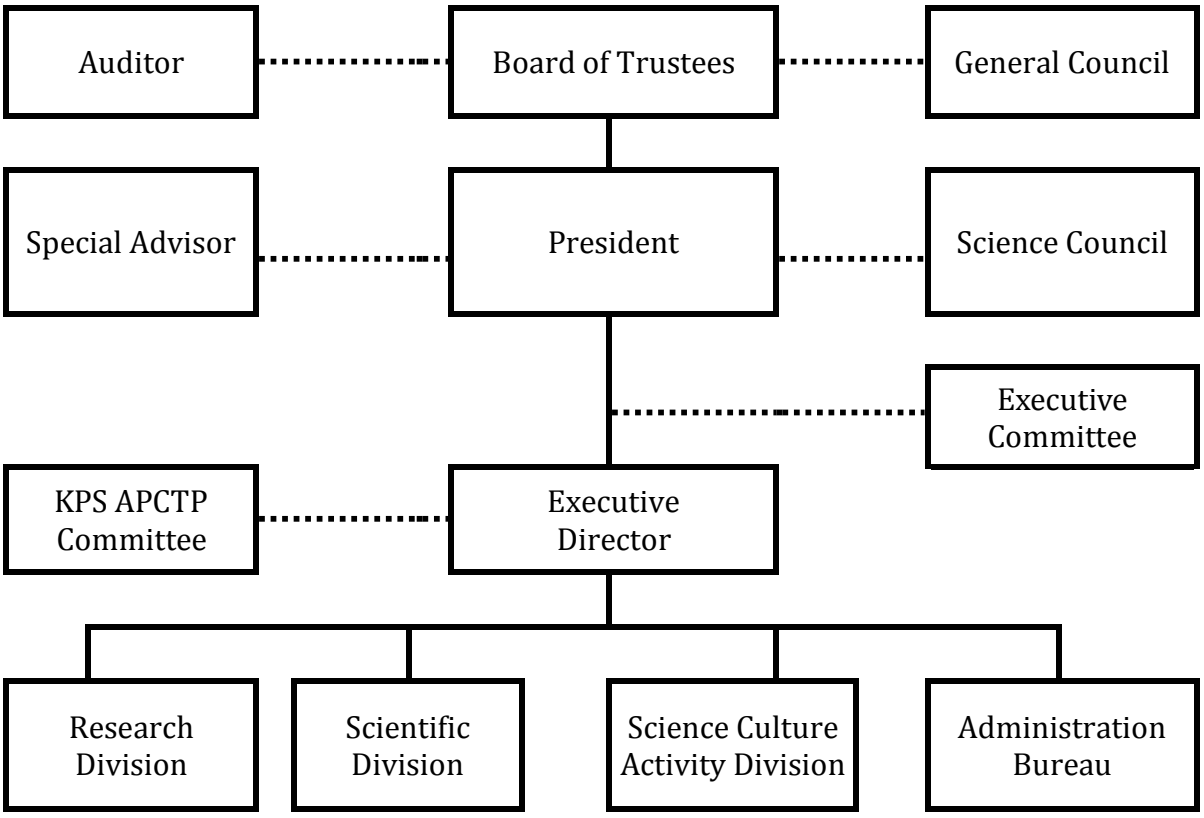
The Board appoints Prof. Won Namkung as the 6th Chairperson of the Board and Acting President.

3. Organization Chart

■ **Board of Trustees: 13 Trustees and 2 Auditors**
- Chairperson and Acting President (Won NAMKUNG, Korea)

■ **General Council: Representatives from 16 member countries**

■ **Science Council: 10 world-renowned scholars including Acting President and Executive Director as Ex-Officio**



4. Member Countries and Membership Fees

▣ 2016 Membership Overview

It has been a meaningful year for the Center, with joining a new member country, Canada and its representing institution CAP (Canadian Association of Physicists). It is expected more distinguished research institutes in the region would join the Center considering that Canada is the first member country from the American Continent on the Pacific Rim.

In terms of existing membership, the Center has signed up a membership agreement with the Institute of Advanced Studies (IAS), Singapore and Academia Sinica (AS), Taipei to keep memberships tidy. More stable and sustainable cooperation is now possible based on these written agreements.

▣ Member Countries and Entities

■ Australia: Australia Research Council (ARC)
■ Beijing: Chinese Physical Society (CPS)
■ Canada: Canadian Association of Physicists (CAP)
■ India: India Association for the Cultivation of Science (IACS)
■ Japan: Institute of Particle and Nuclear Studies,
High Energy Accelerator Research Organization (IPNS/KEK)
■ Kazakhstan: National Academy of Sciences of the Republic of Kazakhstan (NAS RK)
■ Korea: National Research Foundation of Korea (NRF)
■ Lao PDR: Research Institute of Science, Science Technology
& Environment Agency (RIS-STEA)
■ Malaysia: Malaysia Institute of Physics (MIP)
■ Mongolia: Mongolian Academy of Sciences (MAS)
■ Philippines: National Research Council of the Philippines (NRCP)
■ Singapore: Institute of Advanced Studies (IAS)
■ Taipei: Academia Sinica (AS)
■ Thailand: National Research Council of Thailand (NRCT)
■ Uzbekistan: Uzbekistan Academy of Science (UAS)
■ Vietnam: Vietnam Academy of Science and Technology (VAST)

▣ Payment Status of Membership Fees

(Unit: USD)

Items		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
Australia	Date	May20	May30	May13	Jun.03	May16	Apr.24, 2013	May19, 2014	Mar.26, 2015			110,000
	Amount	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000			
Beijing	Date	Apr.23	May20	May22	Jun.01	Apr.25	May24	May10	Jul.23	Apr.16	Apr.25	210,000
	Amount	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	
Japan	Date	Mar.29	Jan.18 Jun.09	May22	Jun.04	Sep.30	May11	Feb.22	Mar.25	Mar.23	May25	186,953
	Amount	10,000	20,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	
Lao PDR	Date	exempted	exempted	exempted	exempted	exempted	exempted	exempted	exempted			-
	Amount											
Malaysia	Date											6,509
	Amount											
Mongolia	Date	exempted	exempted	exempted	exempted	exempted	exempted	exempted	exempted			-
	Amount											
Philippines	Date											10,000
	Amount											
Singapore	Date						Feb.21, 2013	Feb.21	Jul.23	Mar.18 2016	Feb.24 2017	52,500
	Amount						10,000	10,000	10,000	10,000	10,000	
Taipei	Date	Jun.05	Nov.14	May22	May13	May20	Jul.23	Oct.04	Aug.07	Mar.25	Jul.04	210,000
	Amount	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	
Thailand	Date		Aug.20	Jul.16	Jun.09	Jun.09	May31					63,890
	Amount		6,945	10,000	10,000	10,000	10,000					
India	Date		Jun.20		Aug.17	Mar.30	Mar.28	May24	Aug.11	Aug.03	Nov.08	90,000
	Amount		10,000		20,000	10,000	10,000	10,000	10,000	10,000	10,000	
Vietnam	Date	Apr.27	Jun.19	Jul.01	Dec.10	Jun.17	Aug.31	May28	Jul.24	Mar.23	May10	210,000
	Amount	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	
Uzbekistan	Date					exempted	exempted	exempted	exempted			-
	Amount											
Kazakhstan	Date							exempted	exempted			-
	Amount											
Canada	Date										Jul.07	5,000
	Amount										5,000	
Total		50,000	76,945	60,000	80,000	70,000	80,000	70,000	70,000	60,000	65,000	1,154,852

Continued (Unit: USD)

Items		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Australia	**Date**		Dec.02	Apr.24								Sep.08
	Amount		10,000	10,000								10,000
Beijing	**Date**	May21	May28	Jan.22	Nov.23			Feb.14	May30	Oct.04	May10 Jul.28	May22
	Amount	10,000	10,000	10,000	10,000			20,000	10,000	10,000	20,000	10,000
Japan	**Date**	May22	Aug.21	Jul.13	Oct.28		Mar.08	Mar.13	Mar.24	Apr.13	Apr.11	Jul.04
	Amount	10,000	4,244	3,742	4,789		4,178	10,000	10,000	10,000	10,000	10,000
Lao PDR	**Date**											
	Amount											
Malaysia	**Date**			Mar.23								
	Amount			6,509								
Mongolia	**Date**											
	Amount											
Philippines	**Date**				Jul.26							
	Amount				10,000							
Singapore	**Date**				Jan.09							
	Amount				2,500							
Taipei	**Date**	Jul.15	Oct.13	May20	Aug.19	Dec.07	Dec.19		Mar.07	Aug.04	Apr.25	Jul.12
	Amount	10,000	10,000	10,000	10,000	10,000	10,000		20,000	10,000	10,000	10,000
Thailand	**Date**					Jun.29	Jan.05					
	Amount					10,000	6,945					
India	**Date**											
	Amount											
Vietnam	**Date**	Jun.11	Jul.26	Jun.05	May04	Aug.11	May31	Apr.18	May07	Jul.01	Jun.17	Jun.14
	Amount	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Uzbekistan	**Date**											
	Amount											
Kazakhstan	**Date**											
	Amount											
Canada	**Date**											
	Amount											
Total		40,000	44,244	50,251	47,289	30,000	31,123	40,000	50,000	40,000	50,000	50,000

5. Partnerships

▣ 2016 Partnership Overview

The Center has extended an existing MoU with the Institute for Basic Science (IBS), AAPPS (Association of Asia Pacific Physical Societies) and IUPAP (International Union of Pure and Applied Physics) respectively and looks forward to continued engagement for further strengthening of ties with each institution.
In addition to the extension of existing MoUs, the Center has expanded its cooperation scope over the Caucasus and Central Asia. The Center has signed a new partnership agreement with NUUz (National University of Uzbekistan named after Mirzo Ulugbek) in Uzbekistan, SCS (State Committee of Science, Ministry of Education and Science, Republic of Armenia) of Armenia and IPM (Institute for Research in Fundamental Sciences) in Iran.

▣ Partner Institutes

- ICTP (International Center for Theoretical Physics), Italy
- NCTS (National Center for Theoretical Science), Taipei
- PIMS (Pacific Institute for the Mathematical Sciences), Canada
- ECT* (European Centre for Theoretical Studies in Nuclear Physics and Related Areas), Italy
- ITP/CAS (Institute of Theoretical Physics, Chinese Academy of Sciences), Beijing
- MPI-PKS (Max Planck Institute for the Physics of Complex Systems), Germany
- JINR (Joint Institute for Nuclear Research), Russia
- IPNS/KEK (Institute of Particle and Nuclear Studies of High Energy Accelerator Research Organization), Japan
- YITP (Yukawa Institute for Theoretical Physics, Kyoto University), Japan
- IOP/CAS (Institute of Physics, the Chinese Academy of Sciences), Beijing
  ISSP (Institute for Solid State Physics of the University of Tokyo), Japan
- KPS (Korean Physical Society), Korea
- AAPPS (Association of Asia Pacific Physical Societies)
- IOP/VAST (Institute of Physics, Vietnam Academy of Science and Technology), Vietnam
- ThEP (Thailand Center of Excellence in Physics), Thailand

- IBS (Institute for Basic Science), Korea
- IUPAP (International Union of Pure and Applied Physics)
- INP RK (Institute of Nuclear Physics), Kazakhstan
  IETP (Scientific Research Institute of Experimental and Theoretical Physics), Kazakhstan
- RCNP (Research Center for Nuclear Physics), Japan
- Indonesian Physical Society
  National University of Laos
  Myanmar Physical Society
  Mongolian Physical Society
  Vietnamese Physical Society
- NUUz (National University of Uzbekistan named after Mirzo Ulugbek), Uzbekistan
- SCS (State Committee of Science, Ministry of Education and Science, Republic of Armenia), Armenia
- IPM (Institute for Research in Fundamental Sciences), Iran

6. 20th Anniversary

On 24th of March, 2016, a ceremony marking the 20th anniversary of the APCTP's founding was held in the POSCO International Center with around 100 well-wishers in attendance from the academic communities, government officials and so on. During the event, the Center awarded Certificates of Appreciation and Achievement to those who have contributed to the development of the Center for the last 20 years. The then President Bum-Hoon Lee also used this occasion to enunciate the 'Declaration of APCTP for the future of the science community in the Asia-Pacific region'.

In addition, to celebrate the 20th anniversary, the Center organized various events such as a basic science policy forum, scientific symposium and outreach program. All events successfully culminated with full of pleasure and great wish for the next 20 years of the APCTP.

■ List of events marking 20th Anniversary

Title	Date/Time	Venue
The 20th Anniversary Ceremony	5 pm ~ 6 pm 24 March(Thu.), 2016	POSCO International Center Pohang, Korea
2016 Asia-Pacific Forum on Basic Science Cooperation	9:30 am ~ 4 pm 24 March(Thu.), 2016	POSCO International Center Pohang, Korea
APCTP Symposium on Current Trends in Physics	9:30 am ~ 4 pm 25 March(Wed.), 2016	POSCO International Center Pohang, Korea
Public Lecture Science in City Hall	10:30 am ~ 12:15 pm 26 March(Thu.), 2016	Dajam hall, Pohang Cityhall Pohang, Korea

■ Photos related to the events

7. APCTP Executive Members

▣ Board of Trustees & Auditors

Position	Name	Nationality	Affiliation	Term
Chairperson &President	Won NAMKUNG	Korea	POSTECH	Nov. 26, 2016 -until new President is elected
Trustee	Byung-Seon JEONG	Korea	Ministry of Science, ICT and Future Planning	Ex-Officio
Trustee	Jae Il LEE	Korea	Korean Physical Society	Ex-Officio
Trustee	Doochul KIM	Korea	Institute for Basic Science	Nov. 26, 2016 -Nov. 25, 2019
Trustee	Yunkyu BANG	Korea	Chonnam National University	〃
Trustee	Sung-Chul SHIN	Korea	KAIST	〃
Trustee	Moo-hyun CHO	Korea	POSTECH	Nov. 28, 2015 -Nov. 27, 2018
Trustee	Hong-Sang JUNG	Korea	APEC Climate Center	Nov. 26, 2016 -Nov. 25, 2019
Trustee	Kazuo FUJIKAWA	Japan	The University of Tokyo	〃
Trustee	Mei-Yin CHOU	Taipei	Academia Sinica	〃
Trustee	NGUYEN Ba An	Vietnam	Vietnam Academy of Science and Technology	〃
Trustee	Yue-Liang WU	Beijing	University of Chinese Academy of Sciences	〃
Trustee	Paul A. PEARCE	Australia	University of Melbourne	〃
vacancy				
vacancy				
Auditor	MooYoung CHOI	Korea	Seoul National University	Nov. 28, 2015 -Nov. 27, 2017
Auditor	Fumie HARA	Japan	KEK	〃

▣ Executive Director

Name	Nationality	Affiliation	Term
Woo-Sung JUNG	Korea	POSTECH	Nov. 26, 2016 -until new President is elected

▣ General Council Members

Nationality	Name	Affiliation	Term
Australia	TBA (Recommendation is under consideration)		
Beijing	Gui Lu LONG	Tsinghua University	Jan. 1, 2017 -Dec. 31, 2019
	Zhong-can OU-YANG	Chinese Academy of Sciences	〃
	Yue-Liang WU	University of Chinese Academy of Sciences	〃
Canada	Manu PARANJAPE	Université de Montréal	Jun. 15, 2016 - Jun. 14, 2019
India	Krishnendu SENGUPTA	Indian Association for the Cultivation of Science	Mar. 29, 2014 -Mar. 28, 2017
Japan	Masaki OSHIKAWA	University of Tokyo	Jan. 1, 2017 -Dec. 31, 2019
	Tetsuo HATSUDA	Program Director of iTHEMS, RIKEN	〃
	Satoshi ISO	KEK	〃
Kazakhstan	Medeu ABISHEV	National Academy of Sciences of the Republic of Kazakhstan	〃
Korea	Sung-Won KIM	Ewha Womans University	〃
	Sang-Pyo KIM	Kunsan National University	〃
	Ha-Woong JEONG	KAIST	〃
Lao PDR	TBA (Recommendation is under consideration)		
Malaysia	TBA (Recommendation is under consideration)		
Mongolia	TBA (Recommendation is under consideration)		
Philippines	Cristine VILLAGONZALO	University of the Philippines	Mar. 20, 2015 -Mar. 19, 2018
Singapore	TBA (Recommendation is under consideration)		
Taipei	Chong-Sun CHU	National Center for Theoretical Sciences	Mar. 20, 2015 -Mar. 19, 2018
	Kin-Wang NG	Academia Sinica	Mar. 24, 2017 -Mar. 23, 2020
Thailand	TBA (Recommendation is under consideration)		
Uzbekistan	Mirzayusuf MUSAKHANOV	Uzbekistan Academy of Sciences	Apr. 1, 2014 -Mar. 31, 2017
Vietnam	NGUYEN Dai Hung	Vietnam Academy of Science and Technology	Jan. 1, 2017 -Dec. 31, 2019

▣ Science Council Members

Name	Nationality	Affiliation	Term
Won NAMKUNG	Korea	POSTECH	Ex-Officio
Woo-Sung JUNG	Korea	POSTECH	Ex-Officio
Peter FULDE	Germany	MPI-PKS	Jul. 26, 2013- until new President is elected
Steven G. LOUIE	USA	University of California at Berkeley	Jul. 1, 2014- Jun. 30, 2019
Spenta WADIA	India	International Center for Theoretical Sciences	Sep. 1, 2015- Aug. 31, 2018
Mahn Won KIM	Korea/USA	GIST	Mar. 1, 2013- Feb. 28, 2018
Seunghwan KIM	Korea	POSTECH	Dec. 16, 2016- until new President is elected
Yunkyu BANG	Korea	Chonnam National University	〃
Bum-Hoon LEE	Korea	Sogang University	〃
Han-Yong CHOI	Korea	Sungkyunkwan University	〃

▣ KPS-APCTP Committee

Position	Name	Affiliation	Term
Chairperson	Sung-Won KIM	Ewha Womans University	Jan.1, 2017 -Dec.31, 2018
Member	Kimyeong LEE	KIAS	〃
〃	Byung Yoon PARK	Chungnam National University	〃
〃	Inyong CHO	SEOULTECH	〃
〃	Sang-Pyo KIM	Kunsan National University	〃
〃	Ha-Woong JEONG	KAIST	〃
〃	Hyoung Joon CHOI	Yonsei University	Jan.1, 2013 -Dec.31, 2018
〃	Kicheon KANG	Chonnam National University	Jan.1, 2017 -Dec.31, 2018
〃	Jin-Hee YOON	Inha University	Jan.1, 2015 -Dec.31, 2018
〃	Keon-Ho YOO	Kyung Hee University	Ex-Officio
〃	Woo-Sung JUNG	POSTECH	Ex-Officio

▣ Program Coordinators

Name	Nationality	Affiliation	Term
Yongseok OH	Korea	Kyungpook National University	Sep. 1, 2015 -Aug. 31, 2017
Soon-Hyung YOOK	Korea	Kyung Hee University	Aug. 1, 2016 -Jul. 31, 2018
Nak-woo KIM	Korea	Kyung Hee University	Jul. 1, 2015 -Jun. 30, 2017
Seung-Hoon JHI	Korea	POSTECH	Aug. 1, 2015 -Jul. 31, 2017

▣ Science Culture Committee

Name	Nationality	Affiliation	Term
Sang Wook KIM	Korea	Pusan National University	Jan. 1, 2017 -Dec. 31, 2018
Sang Joon PARK	Korea	POSTECH	〃
Myung-Hyun RHEE	Korea	Science Writer	〃
Seung Woo SON	Korea	Hanyang University	〃

▣ Policy Commissioner

Name	Nationality	Affiliation	Term
Sung-Nam IM	Korea	(Corp.)Media GyeongBuk	Jan. 1, 2017 -Dec. 31, 2017

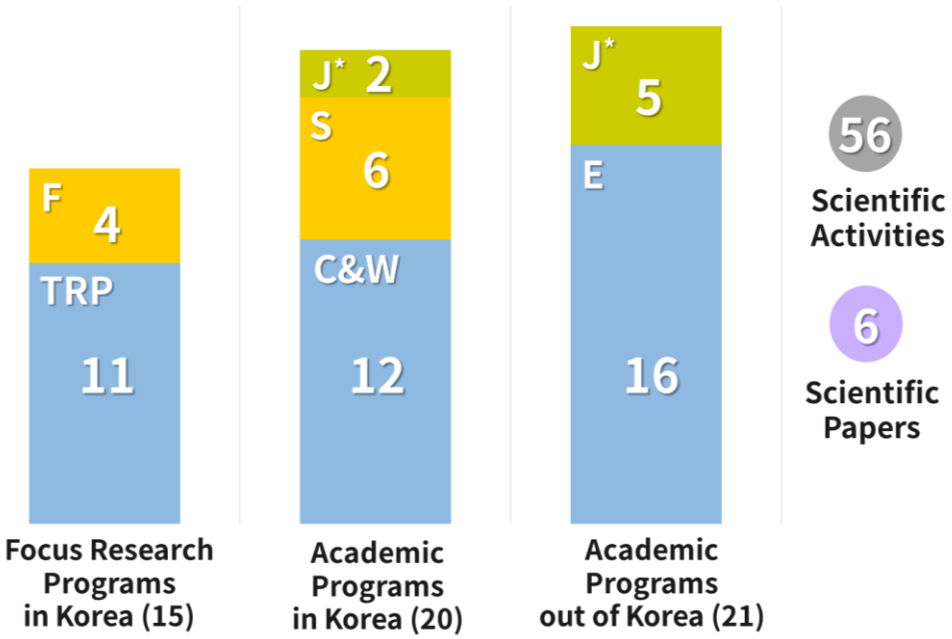
III. APCTP Activities in 2016

1. Summary of APCTP Activities in 2016

1-1. Scientific Activities

The Center pursues the highest quality topical research in focused areas of theoretical physics and promotes cooperation among scientists from its member countries/regions and beyond. In order to promote the research activities and international cooperation, the Center supports Scientific Activities such as Focus Research Programs (Focus Programs, Topical Research Programs), Academic Programs (Schools, Conferences & Workshops and External/Joint Activities) on the current issues of physics societies.

- **Focus Research Programs: 15**
  - Focus Programs (4)
  - Topical Research Programs (11)
- **Academic Programs: 41**
  - Schools (6)
  - Conferences & Workshops (12)
  - External Activities (16) in Australia, China, India, Japan, Taipei, Thailand, Uzbekistan and Vietnam
  - Joint Activities (5) with AAPPS, ICTP, ITP/CAS, JINR, KEK, NCTS, RCNP and YITP out of Korea
  - Joint Activities (2) with ICTP and IACS in Korea
- **Scientific Papers: 6 publications** (Refer to P. 159)



1-2. Research Programs

APCTP conducts research and training in advanced topics of theoretical physics and related areas through the following APCTP research programs.

- Junior Research Groups for pursuing joint research projects with scientific leaders of next generation
- Young Scientist Training Programs for training young scientists mainly of APCTP member countries
- Visitors Program for encouraging short and long-term visits

■ **Junior Research Groups (JRG): 30 PhDs and 6 students in 9 JRGs**
- Scientific Activities
: 46 Visitors, 7 Workshops (163 participants), 4 Seminars (36 participants)

■ **Young Scientist Training Program (YST): 8 PhDs**

■ **Visitors Program: 23 visitors**

■ **Benjamin Lee Professorship: 1 winner**

■ **Scientific Papers: 66 Publications published by JRG/YST** (Refer to P. 152)

1-3. Scientific Outreach Programs

- **Publication**
  - A monthly on-line Web-journal “Crossroads”
- **Forums, Lectures, Schools, etc.**
  - Science Communication Forum/Lecture (15)
  - Science Communication School
  - “Best Science Book 10” selected by APCTP
  - Science in City Hall held with Pohang City
  - Pohang Family Science Festival held with Pohang City

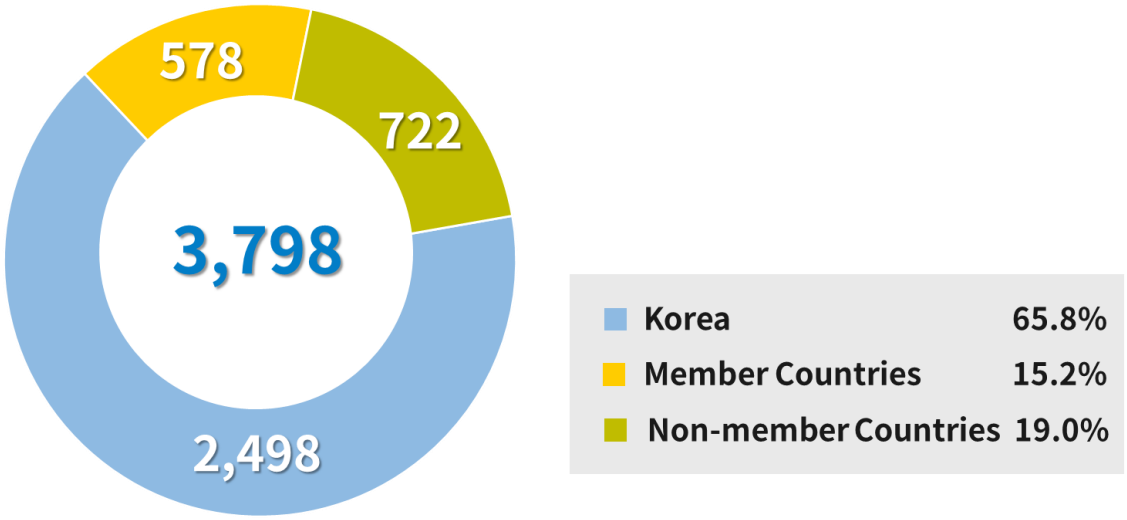
2. Statistics of APCTP Activities in 2016

2-1. Statistics of Scientific Activities

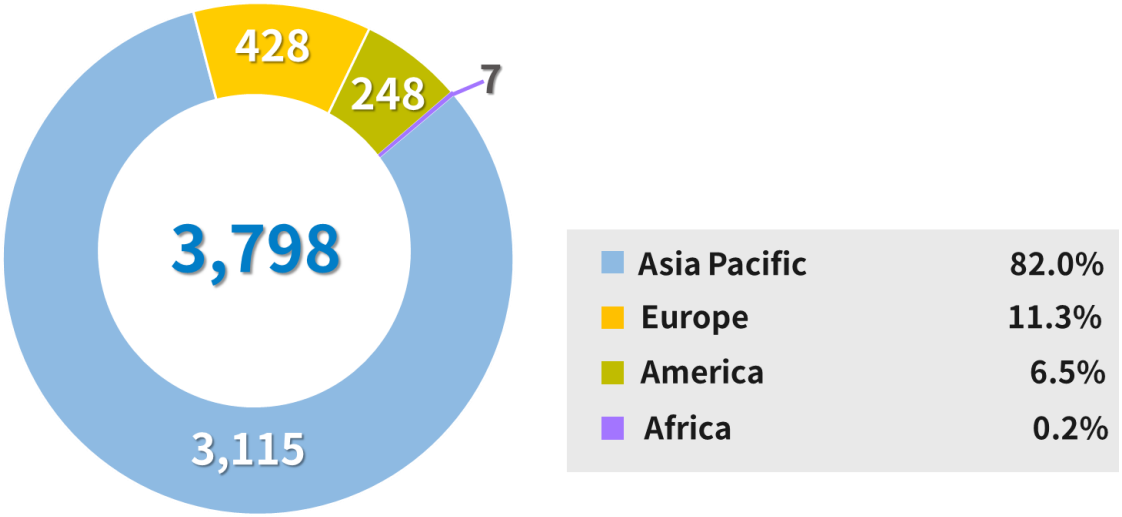
■ Number of Participants for Activities in Korea

Total	Member Countries		Non-Member Countries	Number of Women
	Korea	Other Members		
3,798	**2,498** (65.8%)	**578** (15.2%)	**722** (19.0%)	**510** (13.40%)

- By APCTP Membership: **3,076 Participants from 13 Member Countries**



- By Participants' Nationality: **3,798 Participants from 55 Countries**



Countries		No. of Participants
Asia Pacific Region	Korea	2,498
	Beijing	210
	Japan	205
	India	43
	Australia	38
	Taipei	26
	Singapore	19
	Iran	15
	New Zealand	12
	Israel	10
	Pakistan	8
	Vietnam	6
	Philippines	6
	Mongolia	5
	Cambodia	3
	Uzbekistan	2
	Malaysia	2
	Bangladesh	2
	Argentina	2
	Qatar	2
	Indonesia	1
Total		**3,115**
Africa Region	Tanzania	2
	Tunisia	2
	Ethiopia	1
	Egypt	1
	South Africa	1
Total		**7**

Countries		No. of Participants
Europe Region	Germany	100
	UK	77
	Italy	41
	France	40
	Spain	29
	Switzerland	27
	Poland	18
	Austria	18
	Netherlands	13
	Russia	8
	Greece	7
	Belgium	7
	Denmark	5
	Sweden	5
	Romania	5
	Czech	5
	Hungary	4
	Norway	4
	Turkey	3
	Portugal	3
	Finland	3
	Island	2
	Ukraine	2
	Croatia	1
	Slovenia	1
Total		**428**
America Region	USA	217
	Canada	16
	Brasil	11
	Mexico	4
Total		**248**

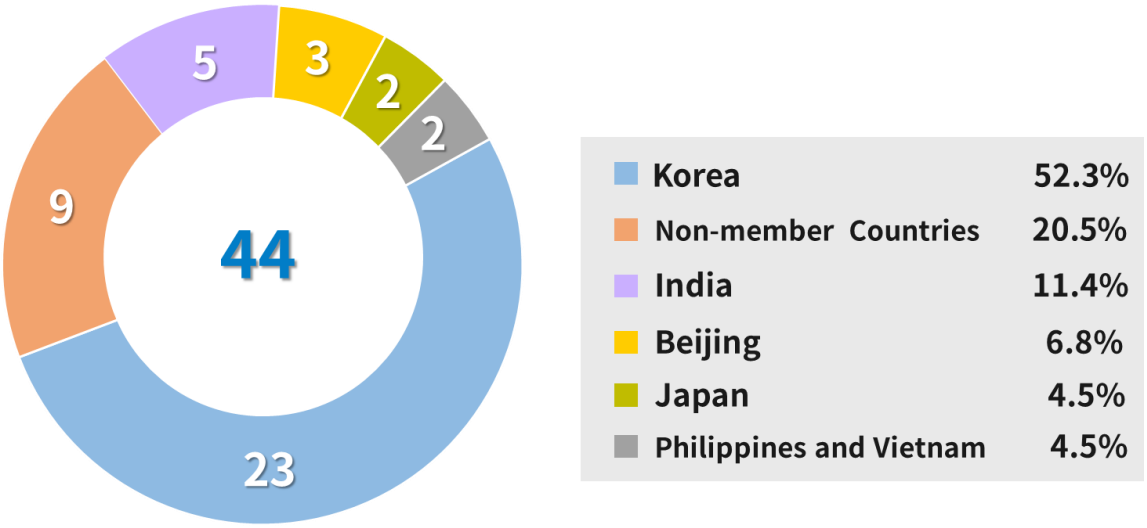
2-2. Statistics of Research

■ Number of Faculty and Researchers

Program	Number of Faculty and Researchers			
	Prof.	Dr.	PhD. Stud.	Total
JRG	9	21	6	36
YST	-	8	-	8
Total	**9**	**29**	**6**	**44**

Item	Member Countries					Non-Member countries[2)]	Total
	Korea	Beijing	Japan	India	Etc.[1)]		
Persons	23	3	2	5	2	9	44
Percentage	52.3%	6.8%	4.5%	11.4%	4.5%	20.5%	100%

1) Member countries: Philippines and Vietnam
2) Non-member countries: Brazil, Iran, Indonesia, Ireland, Italy and UK



■ Reprint of APCTP

Item	Reprint	SCI	Impact Factor
APCTP members	66	100 %	4.468
Supported by APCTP	6	100 %	3.102
Total	72	100 %	4.355

■ Excellence in Research Papers in 2016

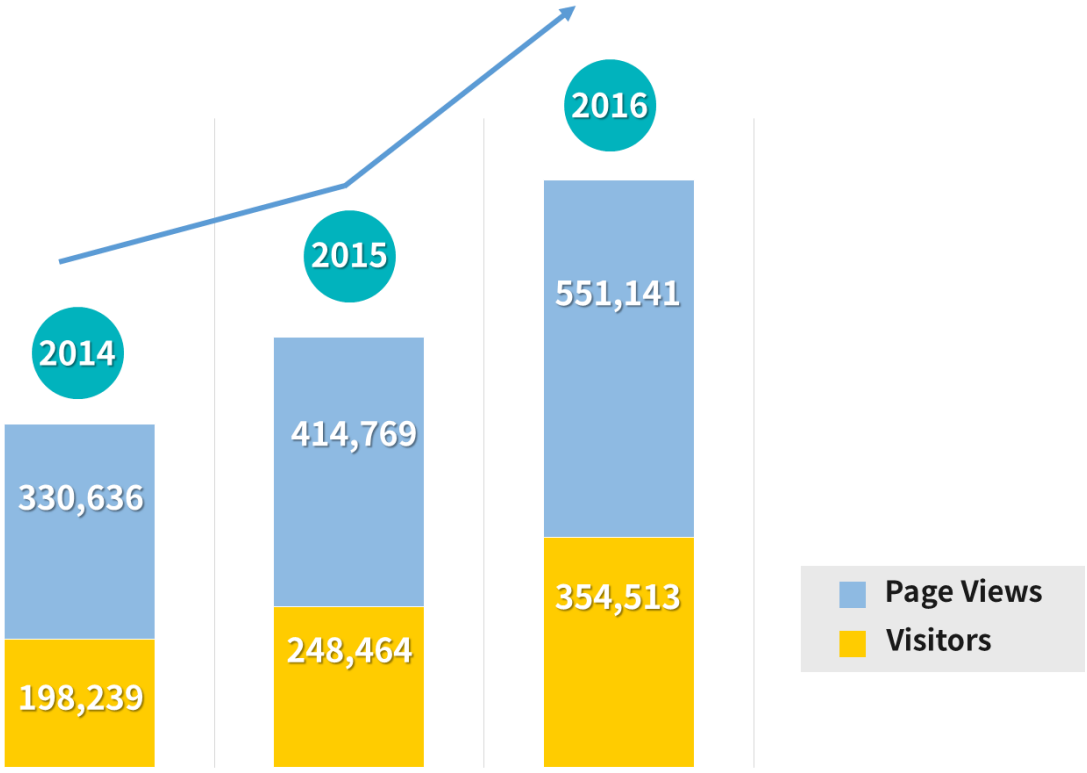
Item	All R&D Project in Korea*	Major R&D Project in Korea*	APCTP SCI rated Papers
Impact Factor(IF)	2.77 (year of 2014)	3.7 (year of 2014)	4.355 (year of 2016)
Number of SCI rated papers/Billion KRW	0.86 (year of 2014)	10.34 (year of 2014)	23.14 (year of 2016)

*The 2015 Performance Analysis Report of Ministry of Science, ICT and Future Planning R&D Program, P. 8, NRF

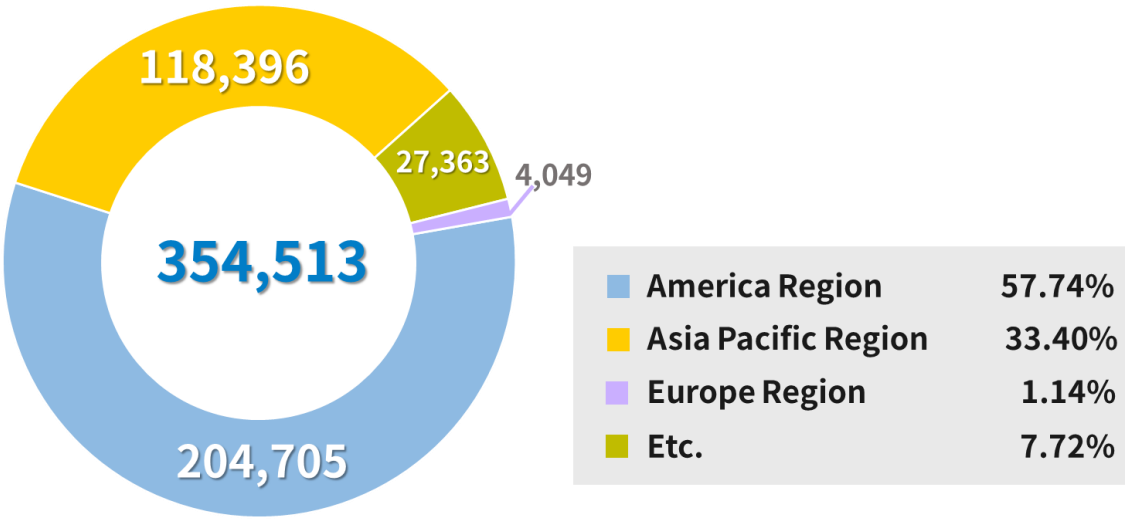
2-3. Statistics of Scientific Outreach Programs

■ On-line Web-journal "Crossroads"

▣ Total Number of Visitors and Page Views from 2014 to 2016



▣ The Number of Visitors Worldwide in 2016



IV. Reports of Scientific Activities in 2016

1. Summary of Scientific Activities

1-1. Programs and Participants of Scientific Activities

●: Domestic ●: International

		2015					2016				
		No. of Programs	No. of Participants				No. of Programs	No. of Participants			
			Total	K	M/C	Non M/C		Total	K	M/C	Non M/C
Focus Research Programs	Focus ●	3	94	54	11	29	**4**	**141**	**98**	**18**	**25**
	Topical Research ●	12	1212	1,129	41	42	**11**	**875**	**815**	**39**	**21**
FRP Total		**15**	**1,306**	**1,183**	**52**	**71**	**15**	**1,016**	**913**	**57**	**46**
Academic Programs	Schools ●	8	596	499	66	31	**6**	**346**	**332**	**10**	**4**
	Conferences &Workshops ●	12	725	589	78	58	**12**	**1,972**	**925**	**429**	**618**
	External ●	13	1,926	314	975	637	**16**	**2,365**	**112**	**1,770**	**483**
	Joint ●●	5	475	45	148	282	**7**	**441**	**101**	**228**	**112**
AP Total		**38**	**3,722**	**1,447**	**1,267**	**1,008**	**41**	**5,124**	**1,470**	**2,437**	**1,217**
Total		**53**	**5,028**	**2,630**	**1,319**	**1,079**	**56**	**6,140**	**2,383**	**2,494**	**1,263**

1) **K:** Korean Participants
2) **M/C:** Participants from Member Countries excluding Korea
3) **Non M/C:** Participants from Non-Member Countries

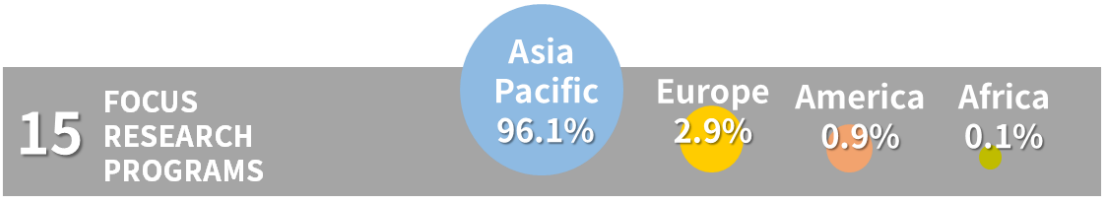
1-2. Publications produced by Scientific Activities

■ 6 Publications (SCI: 6 Publications, IF: 3.102) (Refer to P. 159)

1-3. Numbers in APCTP Scientific Activities

■ Participants of Focus Research Programs in Korea

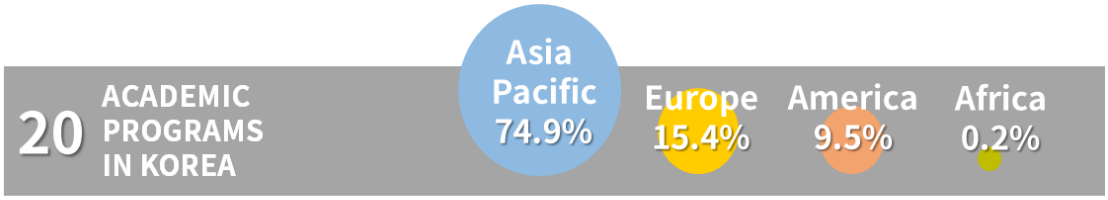
: **Total 1,016 Participants from 27 Countries**



Region	Country	No. of Participants
Asia Pacific (11)	Korea, Japan, Beijing, India, Vietnam, Argentina, Taipei, Iran, Pakistan, Mongolia, Cambodia	976
Europe (14)	Greece, UK, France, Sweden, Russia, Romania, Hungary, Germany, Italy, Austria, Belgium, Denmark, Turkey, Island	29
America (1)	USA	10
Africa (1)	Ethiopia	1
	Total	1,016

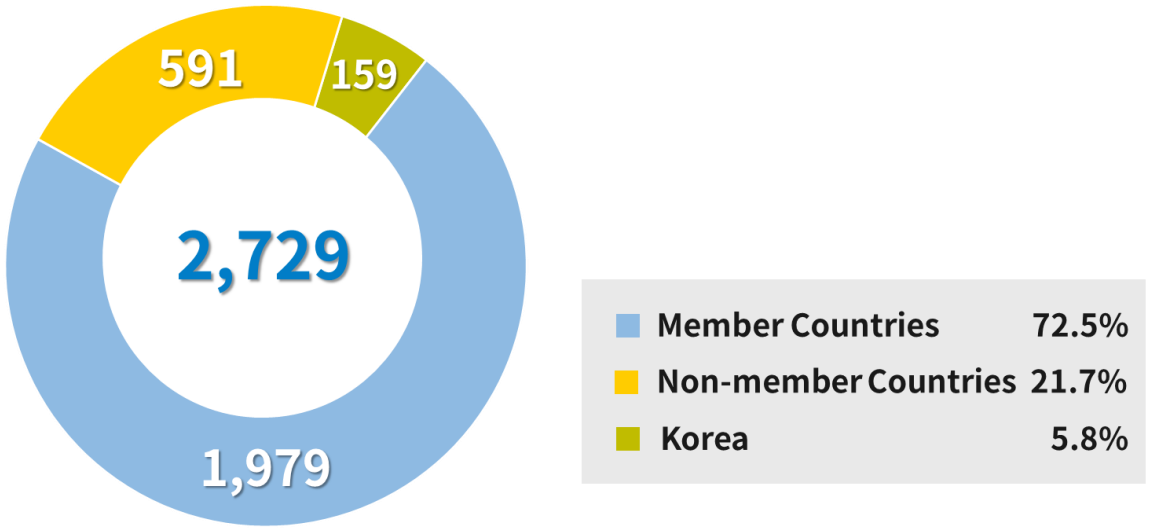
■ Participants of Academic Programs in Korea

: **Total 2,395 Participants from 51 Countries**

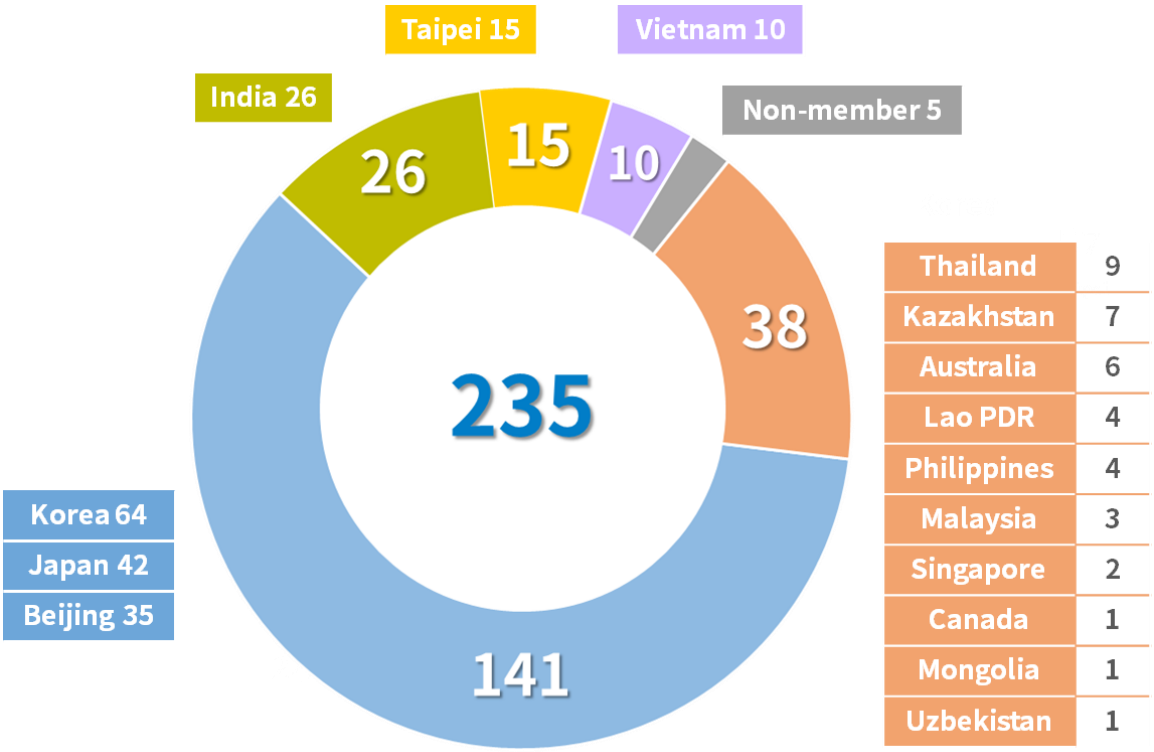


Region	Country	No. of Participants
Asia Pacific (19)	Korea, Beijing, Japan, India, Australia, Taipei, Singapore, Iran, New Zealand, Israel, Pakistan, Vietnam, Philippines, Mongolia, Cambodia, Malaysia, Bangladesh, Qatar, Indonesia	1,793
Europe (24)	Germany, UK, Italy, France, Spain, Switzerland, Poland, Austria, Netherlands, Russia, Greece, Belgium, Denmark, Sweden, Romania, Czech, Norway, Turkey, Portugal, Finland, Island, Ukraine, Croatia, Slovenia	368
America (4)	USA, Canada, Brasil, Mexico	228
Africa (4)	Tanzania, Tunisia, Egypt, South Africa	6
	Total	2,395

■ Participants of Academic Programs out of Korea: **Total 2,729 Participants**



■ Beneficiaries of External/Joint Programs: **Total 235 Beneficiaries**



1-4. List of Scientific Activities

■ Focus Research Programs (15)

- Focus Programs (4) in Korea

(1) Duality and Novel Geometry in M-theory / Jan. 26~Feb. 4, APCTP Pohang Headquarters

(2) 1. Beyond Landau Fermi liquid and BCS Superconductivity near Quantum Criticality & 2. Real-space Renormalization Group Approach / May 16~28 & Jun. 6~18, APCTP Pohang Headquarters

(3) Holography and Topology of Quantum Matter / Aug. 22~29, APCTP Pohang Headquarters

(4) Liouville, Integrability and Branes (12) / Dec. 7~14, APCTP Pohang Headquarters

- Topical Research Programs (11) in Korea

(1) Hunting BSM Physics in the Era of High Energy LHC

(2) Gravity and Cosmology

(3) String Theory and Cosmology

(4) Statphys Monthly Meeting

(5) Physics in Economic and Social System

(6) Innovative Workshop on Soft/Bio Material

(7) Discussion Meeting on Polymer Physics Theory

(8) Toward fundamental understanding of hadrons and nuclei

(9) The origin and evolution of the Universe

(10) Heavy-Ion collisions: doorways from quarks to nuclei to neutron stars

(11) Pairing interaction of high temperature superconductors

- TRP Mini-Workshops and Seminars (42) in Korea

[Hunting BSM Physics in the Era of High Energy LHC]

(1) Introduction to Dark Matter Searches, May 21, Chung-Ang University

(2) Understanding the Chiral World, Sept. 29, Yonsei University

(3) Supersymmetry and Particle Phenomenology, Nov. 17, Chung-Ang University

(4) The Standard Model: From the Past to the Present, Dec. 10, Yonsei University

[Gravity and Cosmology]

(5) The 128th Meeting of Numerical Simulation Working Group, Aug. 5, APCTP Seoul Branch Office

(6) The 52nd Workshop on Gravity and Cosmology, Nov. 18~19, Sungkyunkwan University

(7) Lecture on Gravity and Cosmology, Dec. 13, Sungkyunkwan University
(8) The 130th Meeting of Numerical Simulation Working Group, Dec. 22, APCTP Seoul Branch Office

[String Theory and Cosmology]

(9) 2016 FRP Workshop on String Theory and Cosmology, June 3, APCTP Seoul Branch Office
(10) Workshop on String Theory and Cosmology, Dec. 2, APCTP Seoul Branch Office

[Statphys Monthly Meeting]

(11) The 92nd Statphys Monthly Meeting, Mar. 26, KIAS
(12) The 93rd Statphys Monthly Meeting, May 21, KIAS
(13) The 94th Statphys Monthly Meeting, Sept. 24, KIAS
(14) The 95th Statphys Monthly Meeting, Nov. 19, KIAS
(15) The 96th Statphys Monthly Meeting, Dec. 10, KIAS

[Physics in Economic and Social System]

(16) Physics in Economic and Social System Winter Workshop, Feb. 22~23, Chosun University
(17) The 3rd International Workshop on Physics of Social Complexity, May 27~28, APCTP Pohang Headquarters
(18) Social Simulation Workshop, Aug. 18, NIMS

[Innovative Workshop on Soft/Bio Material]

(19) The 21st Innovative Workshop on Soft/Bio Materials, Apr. 1, KAERI
(20) The 22nd Innovative Workshop on Soft/Bio Materials, Nov. 16, KAIST

[Discussion Meeting on Polymer Physics Theory]

(21) The 7th Discussion Meeting on Polymer Physics Theory, June 3~4, APCTP Pohang Headquarters

[Innovative Workshop on Soft/Bio Material& Discussion Meeting on Polymer Physics Theory]

(22) The 23rd Innovative Workshop on Soft/Bio Materials & 8th Discussion Meeting on Polymer Physics Theory, Dec. 16~18, The Ocean Resort (Yeosu)

[Toward fundamental understanding of hadrons and nuclei]

(23) Hadron-production Reactions via Photon Beams, Sept. 2~3, APCTP Pohang Headquarters
(24) Hadron Productions: Theory and Experiment, Nov. 25~26, APCTP Pohang Headquarters
(25) 2016 HaPhy Summary Meeting, Dec. 10, APCTP Seoul Branch Office

[The origin and evolution of the Universe]

(26) The Origin and Evolution of the Universe, Apr. 1, KAIST
(27) The Origin and Evolution of the Universe, June 17, APCTP Pohang

Headquarters

(28) The Origin and Evolution of the Universe, Sept. 2, Chonnam National University

(29) The Origin and Evolution of the Universe, Nov. 4~5, Jeju National University

[Heavy-Ion collisions: doorways from quarks to nuclei to neutron stars]

(30) Heavy-Ion Collisions: Doorways from Quarks to Nuclei to Neutron Stars, May 26~27, Yonsei University

(31) Heavy-Ion Physics, Status and Outlook, Oct. 21~22, Chonnam National University

(32) Nuclear Transport and Reports from Young Heavy-ion Physicist, Nov. 25~26, IBS

[Pairing interaction of high temperature superconductors]

(33) Pairing Interaction of High Temperature Superconductors, Jan. 18, APCTP Seoul Branch Office

(34) Pairing Interaction of High Temperature Superconductors, Mar. 3, APCTP Seoul Branch Office

(35) Pairing Interaction of High Temperature Superconductors, Apr. 8, Yonsei University

(36) Pairing Interaction of High Temperature Superconductors, May 20, Hanyang University

(37) Pairing Interaction of High Temperature Superconductors, June 10, Incheon National University

(38) Pairing Interaction of High Temperature Superconductors, July 11, APCTP Seoul Branch Office

(39) Pairing Interaction of High Temperature Superconductors, Sept. 2, APCTP Seoul Branch Office

(40) Pairing Interaction of High Temperature Superconductors, Oct. 7, APCTP Seoul Branch Office

(41) Workshop on Pairing Interaction of High Temperature Superconductors, Nov. 7~9, Sungkyunkwan University

(42) Pairing Interaction of High Temperature Superconductors, Dec. 15, APCTP Seoul Branch Office

■ Academic Programs (41)

- Schools (6) in Korea

(1) 20th APCTP Winter School on Fundamental Physics / Jan. 18~24, APCTP Pohang Headquarters

(2) 13th KIAS-APCTP Winter School on Statistical Physics / Jan. 18~22, POSCO International Center
(3) Computational Neuroscience Winter School (2016) / Jan. 26~29, POSCO International Center
(4) 2016 Nuclear Physics School / June 20~24, APCTP Pohang Headquarters
(5) 2016 Biophysics Summer School: Information and Energy in Life / July 4~6, APCTP Pohang Headquarters
(6) 2016 Summer School and Workshop on Numerical Relativity and Gravitational Waves / June 26~July 1, KISTI&KAIST

- Conferences & Workshops (12) in Korea

(1) Quantum Materials Symposium 2016 / Feb. 22~26, Homeplus Academy
(2) 11th International School and Conference on Network Science_NetSci 2016 / May 30~June 3, The K Hotel Seoul
(3) International Workshop for String theory and Cosmology 2016 / Aug. 17~19, Hanyang University
(4) Young Computational Neuroscience: All about Dynamic Brain 2016 / Oct. 4, KAIST
(5) International Symposium on Recent Progress of Superconducivity / July 6~8, Yong Pyong Resort
(6) Computational Neuroscience 2016 (CNS 2016) / July 2~7, International Convention Center Jeju
(7) The 25th International Conference on Atomic Physics / July 24~29, COEX
(8) APCTP-CTPU-GSDC 2016 LHC Physics Workshop @Korea / Aug. 2~4, Konkuk University
(9) XLVI International Symposium on Multiparticle Dynamics (ISMD2016) / Aug. 29~Sept.2, Seogwipo KAL Hotel
(10) The 5th School of Mesoscopic Physics / May 26~28, Lotte Buyeo Resort
(11) International Workshop on Frontiers of XFEL Science / Dec. 7~9, POSCO International Center
(12) The third New Physics Korea Institute (NPKI) workshop: The lesson from the first results of Run2 of the LHC / June 12~17, Korea University

- External Activities (16) out of Korea

(1) Australia (1)
- 13th International Symposium on Cosmology and Particle Astrophysics (CosPA 2016) / Nov. 28~Dec. 2, University of Sydney, Sydney

(2) Beijing (3)

- International Conference on frontiers of science on "Quantum Cosmophysics" / July 29~31, UCAS, Beijing
- New Trends in Low-Dimensional Physics: Quantum Integrability and Applications / Sept. 1~15, CAS, Beijing
- The 8th APCTP Workshop on Multiferroics / Oct. 7~10, Shanghai University, Shanghai

(3) India (1)

- 6th Asian Triangle Heavy Ion Conference / Feb. 15~19, India International Centre, New Delhi

(4) Japan (1)

- AAPPS-DACG RESCEU APCosPA Summer School on Cosmology and Particle Astrophysics jointly organized with Planet2 School / Aug. 24~28, Hotel Garyu –no-Sato, Takayama

(5) Taipei (3)

- Summer Institute 2016 (Workshop/Summer School on Particle Physics and Cosmology) / Aug. 17~23, Le Midi Hotel, Nantou
- 8th International Conference on Highly Frustrated Magnetism / Sept. 6~11, National Taiwan University, Taipei
- The 19th Asian Workshop on First-Principles Electronic Structure Calculations (ASIAN-19) / Oct. 31~Nov. 2, National Chiao Tung University, Hsinchu

(6) Thailand (1)

- IF-YITP GR+HEP+Cosmo International Symposium VI / Aug. 3~5, Naresuan University

(7) Uzbekistan (1)

- International Conference "Recent Advances in Photovoltaics: Novel materials and device concepts for flexible and thin-film solar cells" / Sept. 28~Oct. 1, Bukhara

(8) Vietnam (5)

- 22nd Vietnam School of Physics (VSOP22) / Sept. 1~12, Quy Nhon
- Hanoi international activity "Gravitation and the Universe" / Oct. 29~Nov. 1, Hanoi
- The 9th Asian Symposium on Intense Laser Science (ASILS 9) / Nov. 6~10, Ninh Binh
- The 9th International Conference on Photonics and Applications (ICPA-9) / Nov. 6~10, Ninh Binh

- The 8th International Workshop on Advanced Materials Science and Nanotechnology (IWAMSN 2016) / Nov. 8~12, Halong

- Joint Activities (7) in and out of Korea

(1) AAPPS (1)

- Joint 13th Asia Pacific Physics Conference and 22nd Australian Institute of Physics Congress / Dec. 4~8, Brisbane Convention and Exhibition Centre, Australia

(2) ICTP (2)

- Spring School on Superstring Theory and Related Topics / Mar. 10~18, ICTP, Italy
- APCTP-ICTP Joint Workshop: Quantitative Life Sciences / Nov. 21~24, APCTP Pohang Headquarters, Korea

(3) ITP/CAS, NCTS, YITP (1)

- 2016 AP Summer School and Workshop on Gravitation and Cosmology (APCTP-ITP-NCTS-YITP Joint Program) / June 19~26, Hunan Normal University, Beijing

(4) JINR, RCNP (1)

- International workshop: The 10th APCTP-BLTP/JINR-RCNP-RIKEN Joint Workshop on Nuclear and Hadronic Physics / Aug. 17~21, RIKEN, Japan

(5) KEK (1)

- 10th Asian Winter School on Strings, Particles and Cosmology / Jan. 6-16, OIST, Japan

(6) IACS (1)

- 8th IACS-APCTP-KIAS Joint Conference on Emergent Phenomena in Novel Oxide Materials and Low Dimensional Systems / Dec. 15~17, APCTP Pohang Headquarters, Korea

2. Report of Scientific Activities : 2016

2-1. Focus Research Programs

2-1-1. Focus Programs

■ Duality and Novel Geometry in M-theory

(1) Period: Jan. 26~Feb.4, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Nakwoo Kim (Kyung Hee University), David Berman (Queen Mary University of London), Martin Cederwall (Chalmers University of Technology), Kanghoon Lee (Korea Institute for Advanced Study), Jeong-Hyuck Park (Sogang University), Minwoo Suh (Sogang University), Eoin O Colgain (APCTP)

(4) Total Participants: 40persons

(5) Scope of Program

Recently a lot of progress has been made on extension of supergravity based on extended symmetry principles. The topic is usually called Double field theory, or Exceptional field theory. We hope to invite foreign as well as domestic experts on (super)-gravity, to foster atmosphere for collaboration and new discovery.

(6) Organizers' self-evaluation and comments

In total, 40 participants attended this event with great enthusiasm and and we had intensive discussion every day. World-wide experts doing frontier research, and active young researchers on the subject of Double Field Theory gathered and participated intensive discussions after each presentation of talks. Throughout the workshop, stimulating new ideas and questions arised.

We plan to organize the second meeting in two years.

■ 1. Beyond Landau Fermi liquid and BCS Superconductivity near Quantum Criticality & 2. Real-space Renormalization Group Approach

(1) Period: May 16~28 & Jun. 6~18, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Jeehoon Kim (POSTECH), Ki-Seok Kim (POSTECH), Chanyong Park (APCTP), Sung-Sik Lee (Perimeter Institution), Filip Ronning (LANL)

(4) Total Participants: 51persons

(5) Scope of Program

The present lecture series are prepared for Ph. D. students not only in condensed matter physics but also in high energy and statistical physics, who are interested in non-perturbative phenomena in strongly correlated electrons such as quantum criticality and beyond-BCS superconductivity. The first lecture series focus on actual physical phenomena beyond the perturbative theoretical framework. The second concentrate on how to understand these non-perturbative phenomena. As a non-perturbative theoretical framework, real-space renormalization group approaches are discussed intensively in various aspects.

(6) Organizers' self-evaluation and comments

We are proud of scientific excellence of the lecture series on "(1) Beyond Landau Fermi liquid and BCS superconductivity near quantum criticality and (2) Real-space renormalization group approach". It covered various non-perturbative phenomena in strongly correlated electrons such as quantum criticality and beyond-BCS superconductivity, which much attention has been paid to in condensed matter physics as well as in high energy physics. In particular, we provided sufficient chances sessions for intensive discussions and encouraged various collaborations of participants working in different research areas.

The present lecture series may be regarded to be one of the driving forces in condensed matter physics as well as high energy physics. We hope that the related workshops will be continued due to the importance of this research topic. One important suggestion is that it is necessary to make an introductory course involved with the workshop two or three days before of the workshop, in order to encourage the participation of students.

■ Holography and Topology of Quantum Matter

(1) Period: Aug. 22~29, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Sang-Jin Sin (Hanyang Univeristy), KeunYoung Kim (GIST), Deog-Ki Hong (Pusan National University), Piljin Yi (KIAS), Nakwoo Kim (Kyunghee University)

(4) Total Participants: 30persons

(5) Scope of Program

Strongly interacting many body system is one of the most important problem in 21st century physics. Recently gauge/gravity dual idea was proposed as a new frame for such system. The purpose of this program is to investigate the problem in coherent manner by inviting both string theorists and condensed

matter theorists. This year, we discuss various aspects of holography including its role in topological matter.

(6) Organizers' self-evaluation and comments

Two most relevant main speakers gave six well prepared talks on globally hot issues on holography, topology and quantum matter. One of the results are published in the physical review letters and selected as "Editor's suggestion".

We will continue to have activity on the same topic 2017 and establish a vital community on the theoretical condensed matter by collaboration and communications.

■ Liouville, Integrability and Branes (12)

(1) Period: Dec. 7~14, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Soo-Jong Rey (Seoul National University & Institute for Basic Sciences), Dongsu Bak (University of Seoul), Michael Douglas (Simons Center for Geometry and Physics)

(4) Total Participants: 20persons

(5) Scope of Program

The focus program aims at enhancing collaboration between Korean and Asian theorists and top-flight international researchers in the field of Liouville theory, Branes and Integrability. These are the key topics which propelled impressive progress in string theory and related theoretical endeavours during the last three decades. Every year, new progress was made and pushed ahead the frontline of our understanding on these notoriously difficult subjects. Korea is well positioned in this field and core Korean participants are highly and widely recognized by the international string theory community. For this year, we intend to focus on integrability, strong field effects and related nonperturbative physics in quantum field theory, quantum gravity and string theory. Particular emphasis will be given analytic structure of perturbation theory, supersymmetric conformal bootstrap, topological string approach to supersymmetric gauge theories, black hole information paradox, relation between entanglement and geometry.

(6) Organizers' self-evaluation and comments

The program this year were as excellent as the previous years, with its own unique characters. The main programs by Alexander Monin, Aki Hashimoto, Hiroyuki Shimizu were both excellent, and has inspired already several meaningful collaboration started within. The topics of these newly started

collaborations are also remarkably rich and diverse. They range from conformal bootstrap, foundational issues in statistical mechanics and critical phenomena and its implications in AdS/CFT, new regimes of subtle brane dynamics, little string theory, and F-theory compactifications. The lectures by Yuho Sakatani and Kanghoon Lee exemplified our sustained collaboration that started from the activities of previous years. They cover extended field theories of gauge and gravitational dynamics, such as double field theories and exceptional field theories.

This focus program is already world renowned, so keeps attracting top-flight researchers around the world. Therefore, we plan to continue this annual activity for forthcoming years, while maintaining the same format.

2-1-2. Topical Research Programs

■ Hunting BSM Physics in the Era of High Energy LHC

(1) Period: Jan.1-Dec.31, 2016

(2) Organizers

Hyun Min Lee (Chung-Ang University), Seong Chan Park (Yonsei University)

(3) Scope of Program

Since the High Energy (HE) LHC at 13TeV started running in June 2015, we have become for the first time in the human history in a position to probe the fundamental nature of particle physics beyond TeV energies. We continued our Focus Research Program of the previous year in APCTP with group activities of the field by focusing on the study on BSM physics in the HE LHC. Recently there were hints for new heavy resonances near 2TeV in the boosted dijet searches or excesses for diphoton resonance at 750GeV at the LHC. In this FRP meeting, we discussed the collider implication of a neutral resonance which decays to several diboson final states such as WW, ZZ, $\gamma\gamma$ and $Z\gamma$ via a minimal set of effective operators. Taking both CP-even and CP-odd bosonic states with various spins in the effective field theory approach, we investigated the production cross sections for the bosonic resonance states and the branching fractions at the LHC, based on the effective operators for the heavy resonance. We demonstrated a broad parameter space that could accommodate the recently-reported intriguing excesses at the LHC, and discussed how the CP states and spin information of the resonance can be extracted at the LHC run II. Connections to precision Higgs physics and dark matter searches were discussed. Although the diboson bumps are not significant any longer with more data, it was a fruitful exercise to invent models explaining anomalies and propose ways of testing them.

(4) Scientific Activities: 4 Seminars (Participants: 91)

(5) Organizers' self-evaluation and comments

Our FRP programs on Hunting BSM physics in the era of High Energy LHC hosted outstanding speakers who are working actively in the fields of particle physics and cosmology. Professors, postdocs and graduate students, mainly in Seoul area, gathered and had informal and lively discussions on the current topics from gauge theories and the establishment of the SM to dark matter experiments and dark matter phenomenology in supersymmetric models. The seminars delivered by the speakers motivated researchers and students to get more interested into the topics and start up new projects. As it comes to the advanced topics during the seminars, researchers working on those made appropriate comments and suggestions and initiated the discussion for new collaborations. Therefore, our

FRP programs have been very useful for both researchers and graduate students. The FRP programs have been also a cornerstone for building a strong tie between universities and institutes noy only in Seoul but also IBS in Daejeon and getting new collaborations ready at a next level.

We continue our program with APCTP in 2017 under the title of "BSM physics in the post Higgs era" aiming to discuss theoretical ideas for Beyond the Standard Model(BSM) at the LHC and also future colliders, ILC and also 100 TeV machines. Our focus would be on extrapolation of the Standard model physics to a high scale and also its extension with TeV scale new physics. We also wish to discuss physics of new dark matter models including WIMP, SIMP and also WIMPZillas. Moreover, we will strengthen synergic effects by considering particle physics and cosmology all together when BSM physics is relevant. Therefore, timely setting up a Topical Research Program on phenomenological study on BSM physics in APCTP, we would like to develop the tools of analyzing the LHC results and the cosmological data and discuss their implications for new physics.

■ Gravity and Cosmology

(1) Period: Jan.1-Dec.31, 2016

(2) Organizers

Inyong Cho (Seoul National University of Technology), Gungwon Kang (Korea Institute of Science and Technology Information), Kyoung Yee Kim (Inje University), Hee Il Kim (Seoul National University), Hyeong-Chan Kim (Korea National University of Transportation), Sang Pyo Kim (Gunsan National University), Sung-Won Kim (Ewha Womans University), Chang-Hwan Lee (Pusan National University), Hyung Mok Lee (Seoul National University), Hyung Won Lee (Inje University), Wonwoo Lee (CQUeST, Sogang University), Yun Soo Myung (Inje University), John J. Oh (National Institute for Mathematical Science)

(3) Scope of Program

Gravity and Cosmology Foucus Research Program (FRP) has two main activities. One is aiming for exchanging recent developments and progress in numerical relativistic simulation by holding the three or four group meetings. The other is informing and reporting members' recent works by holding the one or two workshops. In our FRP in year 2016, we will focus on the progress of both theory and data related to gravitational wave. Also black holes, inflation, and large scale structure formation and evolutions will be discussed based on both theories and observations.

Detail plan is following.

Four meetings of numerical simulation working group (March, June, September and December, at APCTP Seoul branch or KISTI).

One workshop and one mini workshop (June and September, APCTP Seoul branch or others)

The expected participants are around 15 for numerical simulation working group meeting and around 30 for workshop. Free discussions and promotion for collaboration between participants are encouraged.

Topics: Gravitation, Numerical Relativity, Astrophysics, Inflation, Cosmology, Quantum gravity, Quantum cosmology, and Gravity/Gauge duality

(4) Scientific Activities: 4 Meetings, 1 Mini-Workshop (Participants: 52)

(5) Organizers' self-evaluation and comments

We had three numerical simulation working group meetings, one workshop, and one lecture for year 2016. In three numerical simulation working group meeting, progresses in general relativistic hydrodynamics and topics on black holes have been discussed. These meetings are continued for 130 times and much contributions have been done for Korean numerical simulation research. In the workshop, various topics related to gravity and cosmology were discussed and reported. These included black holes, inflation, large scale structure, gravitational waves, and etc. Introductory talks were helpful for students to learn the basic knowledge and seminar style talks were useful to discuss recent development of related topics. In the lecture, the equivalence between Jordan Frame and Einstein Frame are discussed in classical and quantum level. Our participants are from undergraduate students to professors and free discussions between various participants are very fruitful for them.

We hope that this program will provide a place for domestic researchers to introduce their research and discuss various researches, and to introduce the latest trends and actively developing fields and to establish a joint research field. It also expects to contribute to the foundation and continuous development of the domestic research environment.

■ String Theory and Cosmology

(1) Period: Jan.1-Dec.31, 2016

(2) Organizers

Inyong Cho (Seoul National University of Technology), Hang Bae Kim (Hanyang University), Hyeong-Chan Kim (Korea National University of Transportation), Kyung Kiu Kim (Yonsei University), O-Kab Kwon (Sungkyunkwan University), Jungjai Lee (Daejin University), Yun Soo Myung (Inje University), Soonkeon

Nam (Kyung Hee University), Chanyong Park (APCTP), Sang-Jin Sin (Hanyang University), Hyun Seok Yang (CQUeST)

(3) Scope of Program

The program is composed of two mini-workshops and some sub-group activities.

The mini-workshops hold in June and December. This mini-workshop includes several seminars and lectures on the subject of string cosmology, entropic gravity, dark matter and dark energy. The main goals of this activity are to make participants discuss about interesting topics as well as to increase their general knowledge in string theory and cosmology.

(4) Scientific Activities: 2 Mini-Workshops (Participants: 38)

(5) Organizers' self-evaluation and comments

Since 2009 the miniworkshop on string theory and cosmology have played important roles in this field and this year there were 2 miniworkshops at June 3 and December 2. For the mini-workshop at June 3, the main subject of the workshop was cosmology, gravity, and dark energy. On the other hand, for the workshop at December 3, the main subject was string/M theory and gauge/gravity duality.

As a result, there have been many discussion among attendants and this program gave young researchers opportunities for presenting their results. And also domestic researchers could know what other researchers are studying.

Thanks to this program young post-docs and female physicists can have chances for presenting their works in string theory and cosmology, and the important role of APCTP in this field is introduced.

■ **Statphys Monthly Meeting**

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Youngkyun Jung (KISTI), Hyunggyu Park (KIAS), Jeong-Man Park (Catholic University), Byungnam Kahng (SNU), Hyuk-kyu Pak (UNIST), Hyeong-Chai Jeong (Sejong University), Jae Dong Noh (University of Seoul), Beom Jun Kim (Sungkyunkwan University), Soon-Hyung Yook (Kyunghee University), Hawoong Jeong (KAIST), Hyungtae Kook (Gachon University), Kwang-Il Goh (Korea University)

(3) Scope of Program

We will provide a room for local scientists to construct a strong infrastructure for statistical physics research and maintain close interactions to make a new development on the subjects. We will invite two speakers each month during

the semester and cover the various subjects in statistical physics including phase transitions and critical phenomena, non-equilibrium fluctuation theorem, synchronization, percolation, evolutionary dynamics, random walks, polymer and biopolymer system, molecular dynamics and Monte-Carlo simulations, and so on.

(4) Scientific Activities: 4 Meetings, 1 Mini-Workshop (Participants: 131)

(5) Organizers' self-evaluation and comments

The Statistical Physics Monthly Meeting in Korea has now become a traditional meeting in the Korean physicists' community. We already had 96 meetings since 2002, and the Monthly Meeting has become one of the most important activities within Korean Statistical Physics community. We strongly believe that the active and lively atmosphere in the monthly meeting have not only provided profound impact on our speakers in making their research progress, but also affected enthusiasm among participating young graduate students and researchers.

We strongly believe that in order to catch up recent research achievements in statistical physics and related areas, regular meetings of scientists in statistical physics and related areas are very important. Ongoing financial support from APCTP ensures that this Monthly Meeting will make a success of its purpose.

■ **Physics in Economic and Social System**

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Jae-Woo Lee (Inha University), Beom Jun Kim (Sungkyunkwan University), Woo-Sung Jung (POSTECH), Gabjin Oh (Chosun University)

(3) Scope of Program

Society for Physics in Economic and Social System (PESS) was established in January, 2011. The PESS plans four meetings in the year of 2016 consisting of several sessions such as Tutorial, Seminar.

1. Tutorial session, will give lecture series on the long-needed training for econophysics and social physics tools such as complex network and agent-based model.

2. Seminar introduces the current research activities in econophysics and social physics field.

(4) Scientific Activities: 3 Seminars (Participants: 106)

(5) Organizers' self-evaluation and comments

The TRP focused on the education activity through seminar and mini-workshop. Through the TRP, we would like to teach the basic theory and research tool as well as the strength and the capability as a physicist in the field

The lectures were provided by the scholars from academia as well as industry such as financial firms

We would like to strengthen the community activity and capability in Korea and the Asia-Pacific area

We will develop the activity and the community, in particular, nurturing young scholar in the next year

■ Innovative Workshop on Soft/Bio Materials

(1) Period: Jan.1-Dec.31, 2016

(2) Organizers

Mahn Won Kim (GIST), Myungchul Choi (KAIST), YongKeun Park (KAIST), YongSeok Jho (APCTP), Joon Heon Kim (GIST), Byung Mook Weon (SKKU), Ji-Yong So (KAERI), Bopil Gim(KAIST)

(3) Scope of Program

The overall objective of "Innovative Workshop on Bio & Soft Materials" proposed program is to provide avenues for close interactions between international/domestic researchers in the field of Bio/Soft Matter Physics. It will also provide unique opportunities for the researchers to find collaborative projects and track the cutting-edge research results.

Three workshops were held in KAERI, KAIST and Yeosu during 2016 (April, Nov, Dec).

There was a focus topic each session, and four invited speakers in the field presented research results, followed by discussion sessions.

(4) Scientific Activities: 3 Workshops (Participants: 141)

(5) Organizers' self-evaluation and comments

- Scientific excellence: excellent

Though innovative workshop, domestic and international leading research groups were participated and shared the most important scientific problems such as water and interfaces. In addition, participants discussed informally without time limitation.

- Research cooperation: excellent

This workshop provided various ways for finding great co-works, who may have different backgrounds of research but have similar research interests. It was also great opportunities for finding complementary researcher between experimentalist and theorists.

- Networking with global groups: excellent

We invited researchers in international leading groups as speakers and attending participants such that domestic researchers can make the connection to global groups.

- Output (article): very good

Five SCI papers was published or will be submitted in 2016, which has been addressed in the above "6. Product".

Soft/Bio materials is the most fast growing interdisciplinary field, although the history of field is short and the community is small such that interactions between groups are lack. The goal of Innovative Workshop on Soft/Bio materials is to overcome this problem and further lead the field.

Since Mahn Won Kim started the 1st Workshop on the fall of 2013, the 23th workshop was held on Dec of 2016 with the organizer Myung Chul Choi at KAIST and co-organizers Jaseung Koo at KAERI, Jeaup Kim at UNIST and Changbong Hyeon at KIAS.

The researchers working on many different fields such as Physics, Materials, Mechanical engineering, Medicine etc. are invited in the workshop and provide and share their current research interests.

We also provided the field experiences and recent cutting-edge works to the undergraduate and graduate students who just start the research in soft/bio area.

Innovative workshop on Soft/bio materials will continue in 2017. Many issues on Water, Membrane, Bio/Brain materials will be dealt in the workshop in 2017.

We expect that many products (papers) of collaborative research inspired via the workshop will be achieved in 2017.

■ **Discussion Meeting on Polymer Physics Theory**

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Jaeup Kim (UNIST), YongSeok Jho (APCTP)

(3) Scope of Program

This group meeting covers general theory of polymers and other soft matters, including block copolymers, polyelectrolytes, biopolymers and other soft matter complex. Thanks to the support of APCTP, we have hosted these meetings for four years (2013~2016). For the 8th meeting (fall 2016), we received approximately 25 million won support from KIAS in addition to the APCTP fund. The meeting, jointed with the 23rd Innovative Workshop on Soft/Bio Materials, is upgraded to a large symposium.

Various theoretical methods and techniques are introduced in the meeting as a form of lecture and/or research seminar. We encourage researchers in the meeting to find applications of the theory and to build collaboration network with theorists and/or experimentalists.

(4) Scientific Activities: 2 Mini-Workshops (Participants: 91)

(5) Organizers' self-evaluation and comments

For the past few decades, polymer physics and chemistry community in Korea has grown up enormously, and it has become one of the leading countries in those areas. However, most of the achievements are restricted in the experimental area and there were few theorists who work on these subjects.

With the support of APCTP, we started a new meeting which encourages the local scientists to communicate, build up collaborations, and find connection with experimentalists. The 7thmeeting was successfully held at APCTP in June 2016. In the winter, we successfully collaborated with the organizers of "Innovative Workshop on Soft/Bio Materials" and with the support from KIAS, we hosted a joint meeting at Yeosu in December 2016.

For the year 2016, our major focus was on the expansion of the local network between theorists in the polymer physics area, and we evaluate that such an objective was successfully fulfilled. In the sixth meeting, we invited 8 international researchers renowned in the soft matter and polymer physics area and the number of participants greatly increased (~85 people).

We achieved a great progress of this meeting in the year 2016. During 2016, we hosted one mini workshop and one larger joint workshop with the support of APCTP. At least one small workshop will be held in 2016. In addition, with the support from UNIST, we are planning to host one symposium, jointed with the Innovation Workshop.

A UNIST campus IBS in the area of Soft Matter is led by Steve Granick. We are having good supports for this type of networking events. If both institute, APCTP and UNIST provide an active support for this meeting, it can contribute to the fast growth of the Soft Matter community.

■ Toward fundamental understanding of hadrons and nuclei

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Jung-Keun Ahn (Korea University), Myung-Ki Cheoun (Soongsil University), Emiko Hiyama (RIKEN), Daisuke Jido (TMU), Kyujin Kwak (UNIST), Hyun-Chul Kim (Inha University), Youngman Kim (RISP/IBS), Jie Meng (Peking University), Seung-il Nam (PKNU), Bing-Song Zou (ITP)

(3) Scope of Program

Progress in Strangeness Physics at J-PARC

Study of Element Abundances in the Cosmos by RAON

Properties of hadrons

(4) Scientific Activities: 3 Meetings (Participants: 32)

(5) Organizers' self-evaluation and comments

We held three meetings this year and all of them were performed successfully. In the 1st meeting, we could extend our knowledges on hadron physics via a new open atmosphere. Also, many foreign researches were invited in the 2nd meeting, and it stimulates young Korean researchers. In the summary meeting, the LOC members discussed future development of the HaPhy meeting. As a consequence, we can conclude that the HaPhy meetings as FRP help much to enhance the academic atmosphere for domestic hadron and nuclear physics society into a new level.

In 2017, we also proposed the HaPhy meetings as FRP in the title of "Understanding of the hadrons in various environments". We plan three or four meetings including seminars, workshops, and lectures by inviting domestic and foreign researchers.

■ The origin and evolution of the Universe

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Kyungjin Ahn (Chosun University), Ki-Young Choi (KASI), Jinn-Ouk Gong (APCTP), Seoktae Koh (Jeju National University), Seokcheon Lee (KIAS), Chan-Gyung Park (Chunbuk National University)

(3) Scope of Program

We aim to have a regular meeting of Cosmology group in Korea to exchange recent developments and information in their research fields and promote the collaborations between each other. Especially we encourage the young postdoctoral researchers and students to participate to make actual collaboration and in-depth study. Further we will invite foreign researchers in the Asia Pacific area to make international cooperation.

In the Focus Research Program in the next year (2016) we will focus on the evolution of the early Universe, and the structures formation of large scale structures in the Universe with its theories, observation and the analysis. The WMAP and Planck data on the cosmic microwave background (CMB) improved our understanding about the Universe. The further observations are going on

for the polarization of the CMB and for large scale structure and they will help to understand the properties of dark matter and neutrinos.

For this purpose, we include the experts of this field and discuss on the present issues thoroughly.

Our plan is as follows. The program is composed of 5 meetings in a year for every 2-3 months. The expected dates are late February (1 day, APCTP Seoul branch), mid-April(1 day, APCTP Seoul branch), late August(2 days, APCTP Pohang), mid-November (1 day, APCTP Seoul branch), and late December(1 day, APCTP Seoul branch). Each meeting will be held for 1 day or 2 days as shown in the bracket. The meetings will be held mainly in the APCTP Seoul branch or headquarters at Pohang and occasionally in the homeplace of local organizer such as Jeju National University, KASI, Gwangju etc.

Each time we expect around 25 participants. The theme of the meeting will include presentations of the recent work and discussions. we encourage free questions and discussions and motivate mutual collaboration through the meeting.

Possible lecture titles: Inflation, statistical methods in cosmology, baryogenesis, cosmic microwave background, large scale structure formation etc.

(4) Scientific Activities: 3 Seminars, 1 Workshop (Participants: 41)

(5) Organizers' self-evaluation and comments

This year of 2016, we had three meetings and one workshop. For seminar, we could invite the most relevant topics of the current issues. Especially the observation of gravitational waves was the most striking discovery since the general relativity. We could invite a member of the Korean LIGO group and could learn about the discovery. We also invited two experts on the particle cosmology and discussed on the recent researches on the particle physics and cosmology. We also invited a postdoc who is at the Zurich University and had discussion on the general relativity and the astrophysical observations. In November we had a workshop with the domestic cosmologists and astroparticle physicists, who are interested in our topics. This time especially young research joined more and had fresh discussions.

This meeting is very valuable to the domestic young cosmology group. From this meeting, we could make regular meetings and discussion. The workshop give a opportunity to meet together and think about the current issues and future directions. In 2017, we will try to make a meeting with Japanese cosmologists together and make connections more tightly between two countries and strengthen domestic cosmology.

■ **Heavy-Ion collisions: doorways from quarks to nuclei to neutron stars**

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Byungsik Hong (Korea University), Ju-Hwan Kang (Yonsei University), Eun-Joo Kim (Chonbuk Nat'l University), Youngman Kim (Institute for Basic Science), Min Jung Kweon (Inha University), Young Il Kwon (Yonsei University), Chang-Hwan Lee (Pusan National University), Su Houng Lee (Yonsei University), Kang Seog Lee (Chonnam National University), June-Tak Rhee (Konkuk University), Ghi Ryang Shin (Andong National University), Sang-Jin Sin (Hanyang University), In-Kwon Yoo (Pusan National University), Jin-Hee Yoon (Inha University), Inkyu Park (University of Seoul), Yongseog Oh (Kyungpook National University), Sungtae Cho (Kangwon National University), Dong Ho Moon (Chonnam National University)

(3) Scope of Program

The main purpose of the program is twofold: to understand the nature of matter under extreme conditions and to establish an internationally recognizable Korean heavy-ion physics community.

For the last 20 years, intense theoretical studies and various experiments, performed at the Relativistic Heavy Ion Collider (RHIC) at BNL and the Super Proton Synchrotron (SPS) at CERN, have revealed solid evidences for the existence of strongly interacting matter at high temperature. Furthermore, the Pb+Pb collisions at the Large Hadron Collider (LHC) at CERN provided us extremely valuable experimental data set at the unprecedented beam energy of $\sqrt{s_{NN}}$ = 2.76 TeV. A lot of interesting results have been published and their physical implications are being discussed. The coming years will be crucial in quantitatively characterizing the strongly interacting QCD matter at high densities as more accurate heavy-ion data will be available, especially, from LHC. In the April meeting, we will discuss new experimental results from the LHC and the RHIC at new energy ($\sqrt{s_{NN}}$ = 5.1 TeV for Pb-Pb and $\sqrt{s}$ = 13 TeV for pp) and luminosity after long shutdown at the LHC and detector upgrade at RHIC. Due to the high-statistics, multi-dimensional analyses with respect to centrality, event plane and multi-particle correlations will be possible with high precision, which allow us to have quantitative understanding of the QCD matter created.

In addition to the relativistic heavy-ion physics at RHIC and LHC, we plan to devote the August meeting for the possible collaboration between physicists participating different future experiments in Korean nuclear physics society. The new equipment for rare-isotope beam, RAON, will be under construction soon in Korea. The facility for antiproton and ion research, FAIR, is under

construction at GSI in Germany and the physics studies and the design for the future circular collider at CERN are under discussion. We will review the physical quantities of future experiments and where they stand in preparation. We will also focus on the subjects which can be explored KOBRA (KOrea Broad acceptance Recoil spectrometer and Apparatus) at RAON such as nuclear structure of exotic nuclei near the drip lines, nuclear reactions important in nuclear astrophysics, rare event study (Super Heavy Element, new isotopes, etc), and nuclear physics with polarized beam/target. As the day 1 experiment at RISP will be performed with KOBRA in end of 2019, it is of urgent importance for the Korean heavy-ion community to prepare well in advance and contribute to the national project with continuity.

Through the previous programs, we were able to gather domestic researchers regularly, giving them an opportunity for active discussion on the current research topics. We also invited several world-leading experts in the field in order to be up-to-date on current issues and to discuss the new experimental data and various theoretical developments in this fast developing research field. These activities have been quite fruitful as we have begun to develop several collaborations with them.

We have also made efforts to promote the international character of the program by initiating the ATHIC (Asian Triangle Heavy Ion Conference) in 2006 in Seoul, which was followed by the three subsequent conferences in Japan (2008), China (2010), Korea (2012), and Japan (2014). As the ATHIC conference is beginning to enjoy worldwide recognition, India has joined the last conference. This biannual conference is the main international collaboration of heavy-ion collision society in Asia-Pacific region. The HIM in Korea is playing the leading role in this society by the benefit of APCTP. We hope to continue this leading role and to expand our influence into international society with the continuing support from the APCTP.

Another major achievement of our 11-year long effort is that the number of participating graduate students and young researchers has increased quite substantially. The heavy-ion meetings have played a very important role in providing opportunities for the students to present and discuss their own results. In parallel, their academic strength has also grown substantially. The quality of the original results obtained by Korean students is often recognized in the international community. For example, the poster by Mihee Jo, a Ph.D. student of Korea University, was selected as one of the eight flash talks (out of ~400) in the Quark Matter conference (QM2011). It was regarded as the highest honor for students to present their own results in front of more than 800

participants in the plenary auditorium of the conference. We expect the number of similar recognitions, especially for students and young research fellows, increase quite substantially in the forthcoming years.

The coming year is a transition period in relativistic heavy-ion collision experiments. The LHC will produce many interesting physical results after the upgrade made last year and the new equipment in Korea called RAON will be under construction soon. Therefore it will be very crucial for the Korean heavy-ion collision study group to be promoted internationally. To get renowned we will renew a set of activities that are focused on realizing more concrete outcome of domestic as well as international collaborations and enhancing our expertise on focused topics. We also plan to make a concerted effort to engage people in high-energy physics and astrophysics in active discussions. It will broaden our interest on the physics topics related to the rare-isotope accelerator experiments to be built in Korea.

(4) Scientific Activities: 3 Meetings (Participants: 91)

(5) Organizers' self-evaluation and comments

Through HIM workshops this year, we have developed ideas about how to study precursor phenomena of QCD vacuum change in dense matter at RAON. RAON is a heavy ion accelerator to be built up by 2021 in Korea. In addition, to make sure a nuclear transport code developed in Korea for nuclear matter study at RAON, during the third HIM meeting we had an intensive seminar and discussion on the BUU transport code that has been developed and used at SIAP in China. We concluded that the transport code developed in Korea by some of HIM members is working as good as the SIAP code.

Also, we have organized in-depth seminars and discussions on the relativistic heavy-ion physics at RHIC and LHC among domestic heavy ion experts, young scientists and international experts. Out of these in-depth discussions, we could get up-to-date scientific issues in relativistic heavy-ion physics and determine future research directions in this field.

During the three HIM meetings this year, we had opportunity to communicate with internationally renowned experts in heavy ion physics such as Prof. Fuqiang Wan (Perdue U.), Prof. Shinichi Esumi (Tsukuba U.) and Prof. Jun Xu (SIAP). We also had extensive discussions on heavy-ion physics among domestic heavy ion experts, young scientists and international experts. As a result, we could get up-to-date scientific issues in relativistic heavy-ion physics and determine future research directions in this field.

This year we tried to encourage young scientists to give talks at HIM on their research achievements. Next year, we will focus on QCD phase diagram which is an important subject of low and high energy heavy-ion physics.

■ **Pairing interaction of high temperature superconductors**

(1) Period: Jan. 1-Dec. 31, 2016

(2) Organizers

Jungseek Hwang (Sungkyunkwan University), Han-Yong Choi (Sungkyunkwan University), Yunkyu Bang (Chonnam National University), Xingjiang Zhou (Chinese Academy of Sciences), Jae Hoon Kim (Yonsei University), Soonjae Moon (Hanyang University), SeungRyong Park (Incheon National University)

(3) Scope of Program

Through this Focus Research Program we will perform a focused research subject titled "Pairing interaction of high temperature superconductors". Since the discovery of superconductivity phenomenon in copper oxide high-temperature superconductors a lot of intensive studies have been done. However, the driving mechanism of the superconductivity has not been figured our yet. Through this program we will focus on studying to find out the mechanism of formation of electron-electron pairs in the high temperature superconducting materials.

We plan to get together one every month to share our research results and invite several scholars in this filed. We will also hold a workshop in fall of 2016.

(4) Scientific Activities: 9 Monthly meetings, 1 Mini-Workshop (Participants: 142)

(5) Organizers' self-evaluation and comments

In the monthly meetings we have invited well-known domestic researchers in Korean superconductivity society and related fields of study. We discussed deeply on the pairing mechanism of high temperature superconductors including cuprates, Fe-pnictides, and so on. These meetings play an important role to reconsider one of the most elusive topics in the condensed matter physics. We expect that the meetings will help the research groups in the superconductivity field collaborate each other in near future.

Particularly, the mini-workshop, which was held in November 7-9, 2016, was really successful in terms of some aspects: invitations of notable international and domestic speakers, intensive discussions on the pairing interactions, building international networking, and so on. We expect that in near future positive results initiated by this workshop will come out gradually.

I have learnt many things through this valuable program as one of organizers. Especially, as a fundamental researcher in the superconductivity field I had

chances to contact with oversea and domestic specialists, to meet them, and to share academic ideas through these academic activities. I think that other participants including other organizers in these activities could also get similar experiences as I had.

2-2. Academic Programs

2-2-1. Schools

■ 20th APCTP Asian Winter School on Fundamental Physics

(1) Period: Jan. 18~24, 2016

(2) Venue: APCTP Pohang Headquarters

(3) Organizers

Chanju Kim(Ewha Womans University), Nakwoo Kim(Kyunghee University), Kimyeong Lee (KIAS), Soonkeon Nam (Kyunghee University), Jaemo Park (POSTECH), Chaiho Rim (Sogang University), Hyeonjoon Shin (POSTECH), Sang-Jin Sin (Hanyang University), Seok Kim (Seoul National University)

(4) Total Participants: 50persons

(5) Scope of Program

The school is intended to provide graduate students from member countries with an opportunity for important basic subjects in fundamental physics which include quantum field theories, string theories, quantum gravity, particle physics and cosmology. The lectures will be pedagogical with emphasis on basic concepts and technical details which will help students understand current research papers and start their own independent research.

(6) Organizers' self-evaluation and comments

The 20th APCTP Winter School on Fundamental Physics was held in APCTP headquarters for 7 days. The audience consisted of Ph. D Students, post-doctoral fellows as well as active. In this school, we were able to invite 4 world-class leading experts in string theory and particle physics from Korea, Japan and USA. They gave very intensive lectures for 27 hours in total. We also organized 5 TA sessions and a discussion session to encourage active participation and discussion. The subjects covered in this school include introduction to supersymmetry, duality of supersymmetric gauge theories, Seiberg-Witten theory, and branes and black holes in supergravity. The quality of the lectures were excellent and we are proud that we were able to organize this school.

We thank APCTP for the support and encouragement throughout the school. Especially this year was 20th anniversary of the school. We hope that we continue the school to provide young researchers and students with basic research tools in quantum field theories, string theories, particle physics and cosmology.

■ 13th KIAS-APCTP Winter School on Statistical Physics

(1) Period: Jan. 18~22, 2016

(2) Venue: POSCO International Center, Pohang

(3) Organizers

Su-Chan Park (The Catholic University of Korea), Hyunggyu Park (KIAS), Jeong-Man Park(The Catholic Univ. of Korea), Soon-Hyung Yook (Kyunghee University/ APCTP), Woo-Sung Jung (POSTECH)

(4) Total Participants: 91persons

(5) Scope of Program

The school provides an opportunity for graduate students and young researchers to learn about traditional skills as well as recent topics in the field of statistical mechanics. Invited lecturers will give mini courses of five hours at the level of junior graduate students. In this winter school, fluctuations in equilibrium and nonequilibrium systems are discussed.

(6) Organizers' self-evaluation and comments

1. Format

I think the format of the winter school is now well-settled, so I didn't feel it necessary to change the format compared to the previous one.

2. Lectures

We had 3 lecture series by three professors for 5 hours each. Because the lecturers prepared for a lot of contents for this winter school, they had to spend extra time to finish their lecture. We had a lot of discussion during the lecture and even after the lectures students were waiting for their turn to ask questions to the lecturers.

3. Projects

The prominent feature of this winter school is the project session. All graduate students are grouped by 2 or 3 persons and each group solved problems assigned by the lecturers. We had a presentation session of the project in the last day. All students had been actively participated and the presentation by students showed, as always, their potential to be a good statistical physicists.

4. Venue

There was one problem due to the projector in the auditorium in the PIC. The projector was so dim that it was too difficult for the attendees in the last line of the seats to see the screen clearly. Except this, the venue was very nice.

5. Summary

The winter school consists of three parts, lecturers, students, and venue. We invited highly qualified lecturers and students actively attended the project

session as well as the lectures. Although there was a small problem in the venue, this winter school can be evaluated as a big success.

In 2017, 14th Winter School will take place.

■ Computational Neuroscience Winter School (2016)

(1) Period: Jan. 26~29, 2016

(2) Venue: POSCO International Center, Pohang

(3) Organizers

Jaeseung Jeong (KAIST), Se-Bum Baek (KAIST), Seungkee Han (Chungbuk National University), Hyungtae Kook (Gachon University)

(4) Total Participants: 44persons

(5) Scope of Program: The brain is one of the most challenging complex systems in both the dynamical and the structural aspects. Theoretical and computational studies of the brain have attracted explosive attention of physicists. As the study of the brain is interdisciplinary, the lectures in the school covers all the area of theoretical modeling, biological experiments, and engineering applications. We expect that the winter school will serve to promote young physicists to communicate with the biologists, the medical scientists, and the engineers to solve the common question: how the brain functions.

(6) Organizers' self-evaluation and comments

This winter school introduced students to the recent researches in neuroscience and various techniques in theoretical and computational neuroscience. It was a great chance for students to get familiar with these materials, not just in theoretical aspects, but also in general scope of the study of brain.

It is strongly expected to be held every year, to encourage the application of theoretical physics to interdisciplinary science.

■ 2016 Nuclear Physics School

(1) Period: June 20~24, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Jung Keun Ahn(Pusan Nat'l Univ.), Insik Hahn(Ewha Womans Univ.), Eun-Joo Kim (Chonbuk National University), Yongseok Oh (Kyungpook National University), Chang Ho Hyun (Daegu University), Yong Man Kim (RISP, IBS)

(4) Total Participants: 41persons

(5) Scope of Program

A series of lectures on nucleon-nucleon interaction and nuclear Structure for young students and postdoc fellows with intensive discussion sessions.

(6) Organizers' self-evaluation and comments

Very good. Very lucid lectures on fundamental understanding about NN interaction and nuclear structure.

Theoretical calculation sessions and experimental lab sessions will be prepared in 2017.

■ 2016 Biophysics Summer School: Information and Energy in Life

(1) Period: July 4~6, 2016

(2) Venue: APCTP Headquarters, Pohang

(3) Organizers

Nam Ki Lee (POSTECH), Junghyo Jo (APCTP), Wokyung Sung (POST ECH), Seunghwan Kim (POSTECH), Jong-Bong Lee (POSTECH), Woo-Sung Jung (POSTECH), YongSeok Jho (APCTP), Pan-Jun Kim (APCTP), Changyong Song (POSTECH)

(4) Total Participants: 40persons

(5) Scope of Program

We live in an exciting era for life science. Advanced tools for observing life and accumulated information of biological systems give great opportunities for unveiling what life is. This school aims to encourage the next generation of biophysicists by introducing fundamental questions in life, experimental tools for observing life, and theoretical/computational methods for integrating data. We select information and energy in life as our third theme following the series of previous themes, information and information processing in life. In particular, we focus on metabolism in biology and information thermodynamics in physics. This school introduces intriguing questions: how living systems generate and store energy; and how they maintain their vitality by consuming energy and processing information.

(6) Organizers' self-evaluation and comments

Since 'life' becomes one important topic of physics, biophysics has been actively contributing to provide deep insights of what life is. Therefore it is very important to introduce biophysics to the next generation of biophysicists. Unfortunately, however, we did not have good programs for undergraduate students in Korea. Our school is contributing to introduce them about life science, theoretical/experimental biophysics since 2014. Furthermore, we helped them to develop their academic career by providing opportunities of lab tour and individual meeting during the school.

Recently, information becomes an important theme to understand life in biophysics. Therefore, we chose 'information and energy in life' as our topic.

Then we introduced the topic with various perspectives from information thermodynamics in physics to energy production/storage in life science to energy conversion through metabolism in chemical engineering. The interdisciplinary nature of the school allowed academic stimuli between participants and new research idea.

Our school aims to help students formulate specific questions for answering what life is. Therefore we helped students seriously think about the fundamental question by stimulating with various lectures and providing plenty of time for active discussions. It is important to show big pictures on subjects with various lectures. However, it may be equally important for students to follow the specific research processes to answer given questions by providing series of lectures. We will consider to harmonize these two strategies in our future school.

■ **2016 Summer School and Workshop on Numerical Relativity and Gravitational Waves**

(1) Period: Jun. 26~July 1, 2016

(2) Venue: KAIST&KISTI, Daejeon

(3) Organizers

Peter R. Saulson (Syracuse University), Bernard F. Whitening (University of Florida), Kajita Takaaki (ICRR, University of Tokyo), Peter Diener (Louisiana State University), Gabriella Gonzalez (Louisiana State University), Nobuyuki Kanda (Osaka City University), Gungwon Kang (KISTI), Hyung Mok Lee (Seoul National University), John J. Oh (NIMS), Masaru Shibata (YITP, Kyto University), Kyuman Cho (Sogang University), Kazuaki Kuroda (ICRR), Zong-Hong Zhu (Beijing Normal University), Chang-Hwan Lee (Pusan National University), Hyung Won Lee (India University), Sang Hoon Oh (NIMS), Yu-ichiro Sekiguchi (YITP), Edwin J. Son (NIMS)

(4) Total Participants: 80persons

(5) Scope of Program

This summer school aims to train domestic graduate students and junior level or researchers that have a special interest in gravitational-wave physics and astronomy, numerical relativity, and computational skills in these fields. The lectures are mainly consist of two parallel programs in gravitational-wave data analysis and numerical relativity. Each program covers theoretical overview, technical methodologies, and practical exercises.

(6) Organizers' self-evaluation and comments

Comparing with the similar activities, there were a number of registered participants, which is presumably due to the discovery of gravitational waves this year by LIGO. In particular, over 50% among the total participants were undergraduate students. This can be an affirmative signal to the relevant community. We have decided to give lectures in Korean, with systematic course on gravitational-wave data analysis and numerical relativity. This decision could offer useful and helpful opportunities of discussions and questions to participants. The program consisted of two tracks-one plenary session including 1) basic course of general relativity 2) post-Newtonian theory, and two parallel sessions of gravitational-wave data analysis and numerical relativity.

The most popular subject was the basic course of general relativity, reflecting participants' general interest on the fundamental theory. Next popular ones were python programming course and astro-statistics course. Those are very rare topics in the regular course of Korean Universities.

On the other hand, even if there were some comments and complaints on the school, almost participants were willing to join this school next year. Therefore, we conclude that this activity made a great deal to almost participants. Moreover, this successful activity can be realized by unlimited support of APCTP staffs.

We asked all participants to fillout a questionaire during the school and received many fruitful comments and suggestions on the management and topics for the next school. Reflecting all these, we will prepare for the upgraded version of the summer school.

2-2-2. Conferences & Workshops

■ Quantum Materials Symposium 2016

(1) Period: Feb. 22~26, 2016

(2) Venue: Homeplus Academy, Muii

(3) Organizers

Yunkyu Bang (Chonnam University), Changyoung Kim (Yonsei University), Junghoon Han (Sungkyunkwan University), Jegeun Park (Seoul National University), Kwon Park (KIAS), Kee Hoon Kim (Seoul National Universtiy), Jaejun Yu (Seoul National University)

(4) Total Participants: 165persons

(5) Scope of Program

Winter workshop 2016 on Quantum Materials Symposium will be held between Feb 22 - Feb 26, 2016. Topics that will be covered in the workshop are high temperature superconductivity (cuprates and pnictides), multi-functional materials, strongly correlated materials and topological insulators. The focus will be on novel quantum phenomena that originate from correlations among charge, spin and lattice.

(6) Organizers' self-evaluation and comments: Quantum Materials Symposium is becoming a well-established and well-recognized annual international symposium on quantum materials (especially on correlated materials). QMS 2016 followed the trend and has contributed to solidifying the status of QMS in the community. Advanced topics as well as high quality presentations were given by renowned scientists from all over the world who were also impressed by the high level presentations. Active discussions among participants were present during the symposium, which are expected to result in international collaborations. Financial as well as administrative support from APCTP was essential in the success of the symposium. We hope to continue the tradition of the QMS.

■ 11th International School and Conference on Network Science_NetSci 2016

(1) Period: May 30~Jun. 3, 2016

(2) Venue: The K hotel, Seoul

(3) Organizers

Hawoong Jeong (KAIST), Albert-Laszlo Barabasi (Northeastern University), Kwang-il Goh (Korea University), Petter Holme (Umeå University), Yong-Yeol Ahn (Indiana University), Soon-Hyung Yook (KyungHee University)

(4) Total Participants: 321persons

(5) Scope of Program

NetSci is the flagship conference on Complex Networks promoted by the NetSci Society. NetSci aims to promote cutting-edge research in network science, foster new talent, and develop interdisciplinary scientific research. The scope of the conference covers a wide range of topics including:

- Random graph theory
- Complex network theory
- Biological networks
- Technological networks
- Social networks
- Big data

(6) Organizers' self-evaluation and comments

NetSci is the flagship conference on Complex Networks promoted by the NetSci Society. The 11th NetSci conference was held at The-K Hotel in Seoul. Consisting of a two-day network science school followed by a three-day main conference, NetSci aims to promote cutting-edge research in network science, foster new talent, and develop interdisciplinary scientific research. All the past conferences were held in Europe and United State. This year's conference, sponsored by Asia Pacific Center for Theoretical Physics (APCTP), began with school and the satellite meeting. The school provided eight lectures by Prof. Gardenes, Prof. Sporns, Prof. Bianconi, Prof. Pardo, Prof. Soriano, Prof. Clauset, Prof. Thurner, and Prof. Leskovec, which provides a complete guide for the students and the new researchers in the network science. The main conference was headlined by four keynote addresses by Prof. Barabasi (Northestern Univ. USA), Prof. Kim (KIAS, Korea), Prof. Kertesz (Central European University, Hungary), and Prof. Sporns (Indiana Univ. USA), who are the leading scientists in network science. In addition, ten invited talks also covered diverse disciplines from social to medical networks as well as physics. There were 113 contributed talks and 177 poster presentations, showing the vibrancy of the field and the keen interests shared by a truly international group of interdisciplinary scholars. Especially, the NetSci conference successfully provided good opportunities that the domestic researchers can easily follow up the recent world-wide trends and developments in network science. In addition, since this is the first time that the conference held outside Europe and US, through this year's NetSci conference the researchers in this Asia-Pacific area could interact with the world class researchers, and we provided an environment that the world-class researches in complex networks in the Asia-Pacific area become more active. Through this conference, we also provided the chances to the Asia-Pacific researchers to share their recent achievements and to extend their knowledge (140 talks and presentations by Asia-Pacific researchers). Additionally, by encouraging the participants of graduate student and young scientists in Asia-Pacific area (including Philippines and Malaysia), the conference provided chance to take a look over the recent trends in their own research fields and suggested a new ideas and directions for future studies.

The NetSci 2016 conference has provided great opportunity for graduate students and young scientists by introducing recent trends of leading scientist in network science. In addition, for the domestic researchers, the conference provided good chances to discuss new trends and their recent interests with leading scholars over the world and make a research network over the world. Throughout the networks of network studies, we especially expect that the

researchers in the Asia Pacific region have promoted the globalization of domestic groups. In this perspective, with the contribution of APCTP, we hope to strengthen the connections between Asia Pacific researchers and leading scholars over the world.

■ International Workshop for String Theory and Cosmology 2016

(1) Period: Aug. 17~19, 2016

(2) Venue: Hanyang University, Seoul

(3) Organizers

Snag-Jin Sin (Hanyang University), Kyung Yee Kim (Inje University), Inyong Cho (Seoul National University of Science and Technology), Rong-gen Cai (Institute of Theoretical Physics), Nobuyoshi Ohta (Kinki University), Yungui Gong (Huazhong University of Science and Technology), Yun Soo Myung (Inje University), Yoonbai Kim (Sungkyunkwan University), Hyeong-Chan Kim (Korea National University of Transportation), O-Kab Kwon (Ewha Womans University), Chan-yong Park (Ewha Womans University), Jae-Hyuk Oh (Hanyang university), Hyung Won Lee (Inje University)

(4) Total Participants: 41persons

(5) Scope of Program

String Theory, AdS/CFT, Theoretical and Observational Cosmology, Quantum gravity

(6) Organizers' self-evaluation and comments

We invite 20 speakers studying on quantum gravity, phenomenological gravity, string inspired gravity and theoretical/observational cosmology. Especially, this year, 3 talks about quantum gravity field are presented and they are rare to learn. Also we invite an observational cosmologist to probe the current development of the observational data to refresh ourselves studying theoretical issues mostly.

This workshop was supported mainly by APCTP. However, it was not possible unless other participants' individual supports. We will try to extend the number of Asian countries in the next year workshop.

■ Young Computational Neuroscience: All about Dynamic Brain 2016

(1) Period: Oct. 4, 2016

(2) Venue: KAIST, Seoul

(3) Organizers

Hyungtae Kook (Kyungwon University), Changwoo Shin (SAIT), Dong-Uk Hwang (NIMS), Amir Raz (McGill University), Jaeseung Jeong (KAIST)

(4) Total Participants: 35persons

(5) Scope of Program

The brain is an immensely complex system, making it hard to account for the brain's high-level functions, such as cognitive, emotional, and social components. The impairments of these circuits often lead to mental illness.

A new approach, dubbed as computational psychiatry, combines experiments with computational modelling to provide the means to prevent psychiatric disorders. This workshop discusses recent advances in applying neuroeconomics, computational neuroscience, artificial intelligence to the study of decision making, learning and memory. A deeper insight into these functions is expected to permit development of model-based diagnosis of mental disorders.

APCTP-KAIST Young Computational Neuroscientist workshop has been held from 2006 funded by Asia-pacific center for theoretical physics (APCTP) and KAIST (formerly known as APCTP-KAIST Brain Dynamics Summer School). This one-day workshop provides young neuroscientists with an opportunity to share their recent studies on structures and functions of the brain and to communicate each other APCTP-KAIST Young Computational Neuroscientist workshop has been held from 2006 funded by Asia-pacific center for theoretical physics (APCTP) and KAIST (formerly known as APCTP-KAIST Brain Dynamics Summer School). This one-day workshop provides young neuroscientists with an opportunity to share their recent studies on structures and functions of the brain and to communicate each other.

(6) Organizers' self-evaluation and comments

This was small but intensive workshop for discussing physics applications to psychiatry, in other words, computational modeling of brain disorders. Most of the attendees are young researchers who are grad students and postdoc working on physics neuroscience and mathematics and their applications to psychiatry. The presentations are all excellent and active participation (questions and answers and discussions) in the workshop was impressive.

Young computational neuroscience workshop was initially designed on the competition-basis recruitment for speakers, but many young postdocs were applying to this workshop for presentation without competition. Thus, we would be better to modify this workshop from next year without competition like this year. In addition, we should not confine the topics to computational neuroscience and expand to general neuroscience in this workshop.

■ **International Symposium on Recent Progress of Superconducivity**

(1) Period: July 6~8, 2016

(2) Venue: Yong Pyong Resort, Pyeongchang

(3) Organizers

Yunkyu Bang (Chonnam National University), Hanyong Choi (Sungkyunkwan University), Yong-Joo Doh (GIST), Kee Hoon Kim (Seoul National University), Beongki Cho (GIST), Hyoung Joon Choi (Yonsei University), Tuson Park (Sungkyunkwan University), Younjung Jo (Kyungpook National University), Jungseek Hwang (Sunkyunkwan University), Jeehoon Kim (POSTECH)

(4) Total Participants: 90persons

(5) Scope of Program

The international Workshop on recent progress in superconductivity (IWRS 2016) is to provide an exciting opportunity to discuss recent progress in superconducting materials and its pairing mechanism. Major topics that will be treated in the symposium will include, but not limited to

- New superconducting materials
- Cu/Fe-based high-Tc superconductivity
- Heavy fermions superconductivity (quantum critical superconductivity)
- Superconductivity in low-dimensional compounds
- Recent progress in theory on superconductivity.

(6) Organizers' self-evaluation and comments

The international workshop on recent progress in superconductivity was an avenue to discuss various forefront research topics among world renowned scholars and local Korean reserchers in a friendly, relaxed environment. There were many pariticipants from the nations in the Asia-Pacific rims such as China, Japan, United States of America, and Korea, providing a unique opportunity to begin or enhance collaborative research among participants.

In this workshop, we had 18 invited talks and 7 posters both from experimental and theoretical colleagues from around the world and a total of about 80 participants in the workshop. Among the participants are Philip Kim from Harvad University and Laura Greene from National High Magnetic Field Laboratory (a member of US National Academy of Science). This international workshop was well represented by international community, where scientists from X countries (Y foreign institutes and Z domesitc institutes) participated. Poster sessions and plenty of recess time was incorporated in the workshop fomat to encourage open discussion among participants, especially between world renowned scholars and young scientists, including students.

Applied science in Korea has been very strongly supported, but research on the superconductivity and strongly correlated quantum matter was very rare because its importance has been less well represented. This workshop provided an excellent opportunity to expose not only the importance of superconductivity and complex quantum matter, but also the important role of international collaboration.

An important purpose of this workshop was to expose graduate students and postdoctoral researchers to the exciting science of complex adaptive quantum matter. In order to encourage participation of students and postdoctoral researchers who are early in their careers, 1) invited young scientists for oral talks, and 2) gave students poster awards for excellent presentations and research quality. Even though the workshop was successful overall, we feel that seven poster presentations are too small. It will be imperative to encourage students or postdoctoral researchers to be more involved in the discussion and presentations in the future workshop.

■ Computational Neuroscience 2016 (CNS 2016)

(1) Period: July 2~7, 2016

(2) Venue: International Convention Center, Jeju

(3) Organizers

Jaeseung Jeong (KAIST), Seungki Han (Chungbuk National University), Sebum Paik (KAIST), Jee Hyun Choi (KIST)

(4) Total Participants: 311persons

(5) Scope of Program

The annual meeting is designed to provide graduate students and postdoc and young researchers who are finding principles underlying the structures and functions of the brain with recent findings in neurophysics and theoretical neuroscience. This is one of the largest conferences in theoretical neuroscience and first held in Asian countries.

(6) Organizers' self-evaluation and comments

More than 350 researchers were attending in this conference and 22 speakers provided excellent talks on theoretical neuroscience and neurophysics. Particularly, foreign attendees are more than 250 who really enjoyed the conference and Korean culture. 100 Korean attendees had a very good chance to study design principles of the brain and their dynamics using physical methods and tools. This conference emphasized the topics of connectome, integrative models, brain-machine interface, and brain-inspired Artificial intelligence.

This conference will provide Korean and foreign physicists with a platform for recognizing the frontiers of physics working on the investigation of design principles of the structures and functions of the brain and offer a chance to contribute to discovering brain dynamics using physical tools and methods. It will be a very good opportunity for physicists to study and communicate with other researchers who are in other fields including neuroscience, psychology, neurobiology.

■ The 25th International Conference on Atomic Physics

(1) Period: Jul. 24~29, 2016

(2) Venue: COEX, Seoul

(3) Organizers

Wonho Jhe (Seoul National University), Donghyun Cho (Korea University), Young Soon Kim (Myongji University)

(4) Total Participants: 582persons

(5) Scope of Program

This ongoing series of ICAPs, held every even-numbered year since 1968, is devoted to fundamental studies of atoms and their interactions with each other and with external fields. The conference presents an outstanding program of invited speakers and the topics encompass forefront research subjects in the field of atomic physics, such as precision measurements (including atomic clocks and fundamental constants), quantum optics and cavity QED, ultracold atoms and molecules, Bose-Einstein condensates, degenerate Fermi gases, optical lattices, quantum computing with atoms and ions, mesoscopic quantum systems, and ultrafast and intense field interactions.

Besides the main conference held in COEX, we had the following satellite events:

1) ICAP 2016 summer school

The ICAP 2016 Summer School was held at the Korea Institute for Advanced Study in Seoul from July 18th to July 22nd the week preceding the ICAP 2016 conference. The summer school was designed for beginning graduate students and advanced level undergraduate students in atomic physics and related fields, and also for other researchers just moving into theses areas of research. We had four outstanding lectures, Wolfgang Ketterle (MIT, USA), Peter Zoller (Innsbruck, Austria), Paul Julienne (UMD, USA), and Myungshik Kim (ICL, UK), covering all of the topics of modern atomic physics. The number of student participants was limited to 100.

2) ICAP2016 Satellite Workshop: Workshop on Optical Clock

The ICAP 2016 Satellite Workshop was held at the KRISS in Daejeon from July 22 to July 23. The workshop was organized by Istituto Nazionale di Ricerca Metrologica (INRIM), Italy and Korea Research Institute of Standards and Science (KRISS). The goal of the meeting was to gather some of the most eminent researchers in optical clocks, and to discuss the scientific challenges in this field. In the main session, we had 15 invited speakers from many countries including Korea, USA, Germany, France, Italy, and Japan.

(6) Organizers' self-evaluation and comments

The total number of registered participants was 581 from 33 countries. The conference delivered 48 plenary talks and 396 poster presentations, providing the international Atomic Physics community with an excellent opportunity for sharing their research outcomes and discussing their future research plans.

We expect that many cooperative efforts will be made in many diverse research levels. In particular, in the fields of optical clock systems and quantum information science, which were specially discussed between international participants and domestic researchers in the satellite meeting of the conference, we believe that immediate collaborations will come out.

■ APCTP-CTPU-GSDC 2016 LHC Physics Workshop @ Korea

(1) Period: Aug. 2~4, 2016

(2) Venue: Konkuk University, Seoul

(3) Organizers

Soonkeon Nam (Kyunghee University), Jihn E Kim (Seoul National University), Eung Jin Chun (KIAS), Deog-Ki Hong (Pusan National University), Sun Kun Oh (Konkuk University), Yongkyung Kwon (Konkuk University), Jeonghyeon Song (Konkuk University), Toru Sugitate (Hiroshima University), Kiwoon Choi (IBS-CTPU), Inkyu Park (University of Seoul), Bum Hoon Lee (APCTP & Sogang University), Frank Zimmermann (CERN), Hwidong Yoo (Seoul National University), Youngjoon Kwon (Yonsei University)

(4) Total Participants: 103persons

(5) Scope of Program

The organizers have tried to invite as many as possible speakers and audiences in order to make the workshop an ideal venue for communication, discussion, information exchange, and enhancement of human network of the high energy community. Since 2007, there have been an outstanding increase in Korea in human resource for the LHC experiments, as the Korean Government has signed an MOU with CERN through the Korea-CERN cooperative program. Within the program as well as beyond it, many Korean researchers have been

able to participate the LHC experiments in a long-term basis. It is such a rare opportunity for the high energy community in Korea.

The scope of the APCTP-CTPU-GSDC 2016 LHC Physics Workshop @ Korea is to provide the venue where Korean scientists can share their ideas and activities, discuss the international trend and Korean stance, and provide for future prospect. The workshop also invites theoretical physicists whose topics are related to the LHC experiments, as well as the IT expert who are contributing the WLCG network for LHC experiment.

In recent years, as IBS has well established and showed good performance, a number of academic activities are held year round. Some of them are closely related to this workshop. Redundant, some might say, but not overlapping. One is the Korea Hadron Collider Workshop, which has been mainly aimed for Korean high energy physicists, both experimental and phenomenological, to review Korean activities in the existing hadronic collider experiments and to prepare the forthcoming LHC experiments. Another is Korea-CERN theoretical physics workshop, which has offered fruitful discussions mainly from the theoretical point of view. Both of the two workshops are still prospering and continuing.

(6) Organizers' self-evaluation and comments

As described several times, it is quite evident that the outcome of the workshop would contribute to the high energy physics community in the Asia/Pacific region, not only because the workshop is open to everyone who is involved in the LHC physics but also because the workshop provides the opportunity for the participants to communicate, discuss, and distribute their ideas and initiatives with other people in the region.

The experience of the workshops in last three years have been very fruitful and instructive, in the sense that many colleagues in the community of Korean high energy physics have recognized that this workshop is necessary and essential for them. They assert that, among a number of workshops and conferences that are scattered all year round, this workshop takes the right place at the right time. Although the LHC is located in the European continent, and the people at the LHC are mostly non-Asian, the high energy physicists in the Asia/Pacific region are quite well qualified, motivated, and interested in the physics that may be discovered at the LHC. In fact, a lot of physicists of Asia/Pacific origin are actively working at the LHC in one way or another. And it is true that much more people are eager to participate in the LHC physics and contribute to our understanding of the Universe and the world we are living in.

The workshop will be a good example of the APCTP activities that help the physics community in the Asia/Pacific region to promote their potentials, seeking to pursue the highest quality of research, train young scientists in all areas of theoretical physics, and promote international cooperation among scientists from its member countries in the Asia-Pacific region and beyond. The workshop will for sure lead in the research of theoretical physics, facilitate international collaborations, and contribute to the advancement of physics by training young physicists from the Asia Pacific region.

The organizers have tried to establish the workshop as an academic annual event that is well recognized and attended. In that sense, the workshop has become more successful year by year. The organizers hope that the Center will continue to support the workshop in the future, and hope that the workshop would be included in the list of the most successful academic activities of the Center this year. Indeed, the number of presentations has increased year after year. And the number of applications has already exceeded the saturation level. The workshop may extend its duration or increase the number of parallel sessions in the future if the number of presentations continues to increase.

Another point to notice this year is that students have attended significantly in large number. The students from the host institution, Konkuk University, have indeed participated in majority, but many students from Inha University, Yonsei University, KAIST, SKKU, Seoul National University, and Postech have also participated in the workshop. This tendency may be continued next year and should be encouraged.

One of the main targets of the workshop was to encourage young researchers who stay in Korea in hot summer to convene a meeting place where they could share and discuss what they do. The level of the honorarium for them was as high as those for world renowned scientists. They have been treated as the world class researchers, at least during their talks.

This philosophy has been shared by the organizers. Inviting world famous scientists might be organized by other workshops or conferences. In fact a large number of meetings take place throughout the year; some of them invite Nobel-prize winners. Some others invited young foreign experts of specific topics. These meetings are therefore complementary among them and specialized in the sense of the characteristics of speakers. Our workshop is more comfortable and friendlier.

On the other hand, the organizers also face two problems that should be solved in the future. One is the venue. The other is the period.

First, the venue has always remained a dilemma. If the venue is located in downtown Seoul, like Konkuk University, the accessibility is very convenient and may gather a large number of participants. On the other hand, it has also a drawback. Many participants may come and go at their convenience. Suppose the venue is located in a remote place and transportation is not so convenient. In this case, the number of participants may not be as large as in the case of the downtown venue, but they would remain faithfully throughout the workshop. Accommodations should also be provided if the venue is away from downtown. This implies the increase of the workshop budget by a significant amount. Thus, APCTP has always been the second option for the venue to Konkuk University.

Second, the possibility of adjusting the period of the workshop is also under consideration. It has been, as a fixed rule, always the second Tuesday in August to start the workshop. The time sometimes coincide with the typhoon season and is usually the hottest holiday season in Korea. Many researchers go abroad during summer vacation. Nevertheless, it is encouragingly nice to find that more than 100 participants are staying in Korea during the period of the workshop, and willing to participate in the workshop and present their research activities.

■ **XLVI International Symposium on Multiparticle Dynamics (ISMD2016)**

(1) Period: Aug. 29~Sep.2, 2016

(2) Venue: Seogwipo KAL Hotel, Jeju

(3) Organizers

Byungsik Hong (Korea University), In-Kwon Yoo (Pusan National University), Suyong Choi (Korea University), Inkyu Park (The University of Seoul), Chang-Hwan Lee (Pusan National University), Yong-Joo Kim (Jeju National University), Jong-Kwan Woo (Jeju National University), Sergey Chekanov (Argonne National Lab.), Tamás Csörgő (RMKI, Budapest), Eddi de Wolf (Antwerp University), Igor Dremin (Lebedev Physics Institute – Moscow), James Dunlop (BNL), Fabrizio Fabbri (INFN Bologna), William Gary (UC Riverside), Paolo Giacomelli (INFN Bologna), Gösta Gustafson (Lund University), Yogiro Hama (S. Paulo University), Hannes Jung (DESY), Vyacheslav Kuvshinov (Academy of Science), Larry McLerran (BNL), Carlos Pajares (Santiago Compostela University), Gunther Roland (MIT), Peter Seyboth (MPP-Munich), Zack Sullivan (Illinois Institute of Technology), Michal Sumbera (Nucl. Phys. Inst. Rez), Chung-I Tan (Brown University), Thomas Trainor (Washington University), Nick van Remortel (Antwerp University), Georg Wolschin (Heidelberg University), Yuanfang Wu (Huazhong University – Wuhan), Nu Xu (LBNL), Wojciech Broniowski (Kielce University)

(4) Total Participants: 98persons

(5) Scope of Program

The International Symposia on Multiparticle Dynamics (ISMD) are a series of major international high-energy physics conferences for theorists and experimentalists from three different but closely related communities (high energy, nuclear/heavy-ion and astroparticle physics), with a common interest in reactions involving large number of particles in the final state. The symposium started in Paris in 1970, and devoted to yearly summary of the most interesting results concerning the processes of multiparticle production. Thus far, the symposia have been hosted by Asian countries only four times: Goa, India (1979), Wuhan, China (1991), Datong, China (2001) and Miyajima-island, Japan (2011). The 2016 symposium in Korea was the 46th in a series, and the 5th meeting in Asia. The program of ISMD2016 included experimental and theoretical plenary talks spread over 5 days. The goal was to provide a pleasant and stimulating environment for presentations and discussions of recent experimental results as well as new developments in theory.

(6) Organizers' self-evaluation and comments

The ISMD2016 had only plenary sessions (no parallel sessions), which helped a lot for the participants to focus on talks and discuss the subjects in depth. The speakers gave talks on recent theoretical and experimental results on high-energy particle physics, heavy-ion physics, astronomy, and astrophysics. In particular, the Symposium organizers invited several speakers for the new particle search at LHC, Quark-Gluon Plasma, and the first observation of the gravitational wave, which made the participants to think about the future direction of the fields.

One the other hand the Symposium also held the poster session for graduate students and young researchers. There were 18 posters presented this year. The Franco Rimondi Association in Italy donated 1,000 euros for the best poster awards. Total seven members including Dr. Fabrizio Fabbri, a senior researcher at INFN, formed the poster evaluation committee. They selected four best posters, and each presenter received 250 euros with certificate.

As the internationally renowned Symposium was held in Korea, many Korean researchers including graduate students were greatly benefitted as they could attend the meeting with relatively low cost. Especially, they heard the most recent development and results in their research fields and actively participated in the discussions. These activities, on one hand, stimulated the domestic researchers and, on the other hand, also widened their scopes and vison for their future researches.

Finally, the support by APCTP was essential for ISMD2016. APCTP supported not only partial budget, but also three staffs during the Symposium. The financial support by APCTP was partly used to help the speakers who did not have enough travel money. As several speakers could travel to Korea for ISMD2016 with financial aids by APCTP, the program of the Symposium became more complete.

As we hosted ISMD2016, one of the world-renowned meetings, in Korea, the high-energy, heavy-ion, and astronomy communities were benefitted a lot. Therefore, we plan to discuss among domestic researchers the possibility to host the other meetings like Strangeness Quark Matter (SQM) or Hard Probes(HP) that is not big in size, but great value for cost.

■ **The 5th School of Mesoscopic Physics**

(1) Period: May 26~28, 2016

(2) Venue: Lotte Resort, Buyeo

(3) Organizers

Yunchul Chung (Pusan National University), Mahn-Soo Choi (Korea University)

(4) Total Participants: 70persons

(5) Scope of Program

The “School of Mesoscopic Physics" is a meeting to promote the information exchange, scientific discussions, and collaborations among scientists working on mesoscopic or nanoscale systems. It is part of the activities of the Mesoscopic Physics Society of Korea. Since it was first launched in January 1999, it has been held twice a year, each time inviting three or four experts in the field as lecturers. It is particularly composed of three-hour lectures rather than usual one-hour seminal talks so that the participants can learn and discuss thoroughly the topics from the very basic knowledge to newly developed concepts. This year it focused on recent experimental and theoretical developments worldwide in the field of 2D electron systems, including

- Quantum electron transport in 2D
- Topological matters including quantum Hall effects
- Quantum oscillations
- Emerging 2D materials such as ultraclean graphene, black phosphorus, MoS2, etc

(6) Organizers’ self-evaluation and comments

The purposes of the school are to provide a good place for students to learn current issues of condensed matter physics and also to promote research

collaborations among researchers. We believe that the school was successful, fulfilling its goals, based on the followings:

- All the lectures were of good quality. Students could learn very basic knowledge of Schottky barriers in contacts, quantum coherence and quantum oscillations in solids, and topological phases from quantum Hall effects to Weyl materials. The school provides a unique setting covering the above issues.
- All the lectures were also useful for researchers, as they cover newly developed concepts such as quantum spin Hall effects, quantum anomalous Hall effects, Weyl materials, electron transport in van der Walls 2D materials, and optical properties of 2D semiconductors.
- There were numerous discussions between invited speakers and audience. We believe that the school provided a chance for fruitful collaborations

We plan to organize a school in the next year 2017. Financial and administrative assistance by APCTP would be of great help to the activity. We appreciate it very much.

■ International Workshop on Frontiers of XFEL Science

(1) Period: Dec. 7~9, 2016

(2) Venue: POSCO International Center, Pohang

(3) Organizers

Ki Bong Lee (POSTECH), Hyunjung Kim (Sogang University), In Soo Ko (POSTECH), Ishikawa Tetsuya (RIKEN), Ting-Kuo Lee (Academia Sinica), Miao John (UCLA), Changyong Song (POSTECH), Do Young Noh (GIST)

(4) Total Participants: 87persons

(5) Scope of Program

The workshop has covered two major topics in XFEL science of ultrafast dynamics and single particle imaging. Extension of the subject to include membrane protein crystallography and high-energy density matter was made, which provides good perspective of cutting edge science applications with XFELs in general. The workshop has invited key players in the fields: Prof. Iwata of Kyoto University and RIKEN as the world leader in membrane crystallography, Prof. Robinson of Imperial College London as a world leader in coherent diffraction imaging, Dr. T. Tschentscher, the science director of European XFEL in Germany, along with many others. Despite its first effort in the series in Korea, this workshop has provided excellent opportunity to domestic and international researchers by presenting the most up-to-dated progress on XFEL single particle imaging and ultrafast dynamics along with other topics including membrane protein crystallography and warm-dense

matter research. As mentioned, all invited speakers are prominent and well-respected researchers internationally. Spanned topics were very timely and also the contents were delivered with enough depth and breath. One of the most valuable products of the workshop is in the nurturing of young researchers. Tightening and also newly establishing international research networks is the outcome.

(6) Organizers' self-evaluation and comments

The workshop was realized thanks to the generous financial support from the APCTP and excellent administrative support from the staffs. It would be indeed great for the APCTP to keep continuing this effort in supporting international workshop series.

We evaluated that the workshop successfully fulfilled the spirit of APCTP; establishing networking among scientists in Asia-pacific region (14 invited speakers) and also in US and Europe (4 invited speakers), introducing research activities at the very forefront line of X-ray free electron laser science, nurturing next-generation scientists especially with the dedicated tutorial session implemented to the main science sessions. Active participation of audience from India and China was observed as well as Korean students. The portion of woman researchers was ~ 20% or more, and this indicates that the workshop complied with the equal-opportunity spirit in regard to gender and ethnic distributions.

■ **The third New Physics Korea Institute (NPKI) workshop: The lesson from the first results of Run2 of the LHC**

(1) Period: Jun. 12~17, 2016

(2) Venue: Korea University, Seoul

(3) Organizers

Csaba Csaki (Cornell University), Christophe Grojean (DESY), Gilad Perez (Weizmann Institute of Science), Seung Joon Lee (Korea University)

(4) Total Participants: 69persons

(5) Scope of Program

(6) Organizers' self-evaluation and comments

The workshop successfully brought together a mix of most active theorists working on all aspects of beyond the standard model physics as well as LHC experimenters. It provided a relaxed program with ample time for discussions, which allowed the active discussion among participants for the cutting-edge topics in electroweak symmetry breaking as well as dark matter physics. It was arguably one of the most interesting workshops in particle physics in year 2016 world widely, and definitely the most interesting workshop in Asia.

In this workshop, a famous physicist, Lisa Randall from Havard University, who is well known with her public books in Korea, participate in the workshop, and also gave a public talk as a public outreach, and had a tremendous success with several mess media coverage was done by major newspapers and TV interview. We have invited 5 key women physicist, who gave important talks, which results in active women participation.

Lastly, we provide an invaluable opportunity for domestic young people to join and give a talk at the workshop, which contribute toward the discipline of young scientists.

This was the 3rd workshop of the series of NPKI workshop which takes place every two years in Korea, and we plan to make the 4th workshop on year 2018.

3. Report of Planned Scientific Activities: 2017

2017 APCTP
Scientific Activity Calendar

JANUARY

- K **14th KIAS-APCTP Winter School on Statistical Physics** (2017-01-09~01-13 / High1 Resort, Jeongseon)
- K **21st APCTP Winter School on Fundamental Physics** (2017-01-19~01-25 / APCTP HQ, Pohang)

FEBRUARY

- K **Computational Neuroscience Winter School** (2017-02-06~02-10 / PIC, Pohang)
- K **Quantum Materials Symposium 2017** (2017-02-19~02-24 / Yongpyong Resort, Pyeongchang)

MARCH

- I **Spring School on Superstring Theory and Related Topics** (2017-03-16~03-24 / ICTP, Trieste, Italy)

APRIL

- I **School on frustrated systems** (2017-04-03~04-12 / Chennai-Tamil Nadu, India)

MAY

- K **The 6th School of Mesoscopic Physics: Electron correlations in Quantum Devices** (2017-05-25~05-27 / PIC, Pohang)

JUNE

- K **Nuclear Physics School 2017** (2017-06-19~06-23 / APCTP HQ, Pohang)
- K **2017 Summer School on Numerical Relativity and Gravitational Waves** (2017-06-25~06-30 / Hongik Univ., Seoul)
- K **Biophysics School** (2017-06-26~06-28 / APCTP HQ, Pohang)
- K **The 19th International Conference on Recent Progress in Many-Body Theories** (2017-06-25~06-30 / PIC, Pohang)

JULY

- I **ICTP-ICGEB-APCTP joint workshop on systems biology and molecular economy of microbial communities** (2017-07-03~07-07 / ICTP, Trieste, Italy)
- I **International Conference on Relativistic Quantum Information North 2017 (RQI-N 2017)** (2017-07-04~07-07 / YITP, Kyoto, Japan)
- K **International Symposium on Recent Progress in Superconducivity** (2017-07-05~07-07 / Yongpyong Resort, Pyeongchang)
- K **International Workshop for String Theory and Cosmology 2017** (2016-07-05~07-07 / Hanyang Univ.)
- I **11th APCTP-BLTP JINR Joint Workshop** (2017-07-25~07-30 / Saint-Petersburg, Russia)

AUGUST

- K **APCTP-CTPU-GSDC 2017 LHC Physics Workshop @Korea** (2017-08-01~08-03 / Konkuk Univ., Seoul)
- I **IF-YITP GR+HEP+Cosmo International Symposium VII** (2017-08-03~08-06 / IF, Naresuan Univ., Phitsanulok, Thailand)
- I **The 9th Conference of the Asian Consortium on Computational Materials Science (ACCMS-9)** (2017-08-08~08-11 / Kuala Lumpur, Malaysia)
- K **Physics and Applications of Nanoelectronic and Nanomechanical Systems** (2017-08-28~08-30 / Yongpyong Resort, Pyeongchang)
- K **Workshop on Quantum Magnetism** (2017-08-28~08-30 / APCTP HQ, Pohang)
- K **Geometry and Holography for Quantum criticality** (2017-08-21~08-29 / APCTP HQ, Pohang)
- K **15th International Conference on Squeezed States and Uncertainty Relations** (2017-08-28~09-01 / Jeju Island)
- K **Tensor Network States** (2017-08-21~08-23 / Hongik Univ., Seoul)
- I **Summer Institute 2017 -Phenomenology of Elementary Particles and Cosmology** (2017-08-25~08-31 / Fuji-Yoshida, Japan)

SEPTEMBER

- K **Fields and Space-Time Dynamics by Discrete Method** (2017-09-18~09-24 / APCTP HQ, Pohang)
- K **International Workshop on Short-time Dynamics in Novel Superconductors and strong spin-orbit coupled systems** (2017-09-18~09-22 / IBS, Daejeon)

OCTOBER

- I **9th IACS APCTP Joint Conference on Novel Quantum Phases in Oxide Materials and Low Dimensional Systems** (2017-10-04~10-06 / IACS Kolkata & IIT Bombay, Mumbai, India)
- I **The 9th APCTP Workshop on Multiferroics** (2017-10-06~10-09 / Osaka Univ., Toyonaka, Japan)
- I **International workshop "New aspects of the Hadron and Astro/Nuclear Physics"** (2017-10-10~10-14 / Tashkent, Uzbekistan)

NOVEMBER

- I **The 20th Asian Workshop on First-Principles Electronic Structure Calculations** (2017-11-06~11-08 / Nanjing Univ., Jiangsu, China)

DECEMBER

- K **Liouville, Integrability and Branes (13)** (2017-12-08~12-17 / APCTP HQ, Pohang)

K Programs held in Korea

I Programs held outside Korea

PARTICLE PHYSICS

1. String Theory and Cosmology
2. BSM Physics in the post Higgs era

STATISTICAL PHYSICS / COMPLEX SYSTEMS

1. Statphys Monthly Meeting
2. Physics in Economic and Social System
3. Discussion Meeting on Polymer Physics Theory
4. Innovative Workshop on Soft/Bio Materials

ASTROPHYSICS / NUCLEAR PHYSICS

1. The origin and evolution of the Universe
2. Every corner of QCD phase diagram
3. Gravity and Cosmology
4. Understanding of the hadrons in various environments

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V. Reports of Research Programs in 2016

1. Summary of Research Programs

1-1. Junior Research Groups (JRG)

■ 9 JRGs

(1) Design Principles of Cellular Networks
(2) Generation and Evolution of Cosmic Structure
(3) Many-Body Theory and Correlated Systems
(4) Gauge/gravity Duality and String Theory
(5) Quantum Information and Many-Body Theory
(6) Supergravity and String Theory
(7) Particle Physics and the Early Universe
(8) Biological and Soft Matter Theory*
(9) Emergent Dynamics of Complex Living Systems*

* Group ended in 2016

■ Number of members: 36 Persons

- 9 Professors, 21 Postdoctoral Fellows, 6 Ph.D. Students

■ Scientific activities

- 46 Visitors, 7 Workshops (163 participants), 4 Seminars (36 participants)

1-2. Young Scientist Training Program (YST)

■ Training at the postdoctoral level: 8 persons

(1) Sangho KIM, Korea, Nuclear Physics
(2) Manoj Kumar MANDAL, India, Phenomenology
(3) Takahiro TERADA, Japan, Phenomenology
(4) Parada HUTAURUK, Indonesia, Nuclear Physics
(5) Yun-Long ZHANG, China, String Theory
(6) Kiesang JEONG, Korea, High Energy Nuclear Physics
(7) Heetae KIM, Korea, Statistical Physics
(8) Ilya BAKHMATOV, Russia, String Theory

1-3. Visitors Program

■ Visitors: 23 persons

Total	Member Country		Non Member Country
	Korea	Others	
23	7	9	7

1-4. Benjamin Lee Professorship

■ 1 person

The program is intended to invite a theoretical physicist of international prominence to stay at APCTP for an extended period and provide opportunities for the domestic scientists interact with a world-caliber theoretical physicist in their fields of study.

Name	Title	Affiliation	Field	Period
János Kertész	Prof	Central European University	Statistical Physics	May 23-28, 2016

■ Research Activities

(1) Benjamin Lee Professorship Colloquium & Lectures (May 25-26, 2016)

- Colloquium: Tracing people's digital footprints: A Statistical Physics Approach to Social Science
- Lecture 1: Complex Networks: An introduction
- Lecture 2: Dynamics on and of Networks
- Lecture 3: Cascading Phenomena

(2) Meetings and discussions with domestic scientists for the research cooperation

1-5. Publications of Research

■ 66 Publications published by JRG/YST (SCI: 66 Publications, IF: 4.468)

(Refer to P. 152)

2. Scientific Reports of Junior Research Groups

2-1. Design Principles of Cellular Networks

- **Leader:** Prof. Junghyo Jo (PhD., Seoul National University, Korea (2007))
- **Period:** Sep. 1, 2012~Aug. 31, 2017
- **Overview**

  Our group aimed to understand design principles of cellular/molecular networks. We have investigated (i) how the network of endocrine cells regulate metabolism; (ii) how the network topology of neuronal cells contribute to flexible and stable learning; and (iii) how the molecular network of immunological receptors effectively recognize pathogen peptides. Furthermore, we are also interested in fundamental problems in statistical physics such as fluctuation theorems and nonequilibrium/stochastic processes in life.

- **Research**

  (i) Design principles of pancreatic islets

  The islets of Langerhans, embedded within the pancreas, play a crucial role in maintaining blood glucose levels constant by secreting the counter-regulatory hormones, insulin and glucagon. Glucose homeostasis is important for brain function. Persistent elevation of glucose levels is by definition diabetes, an increasingly common metabolic disease. The islet micro-organ consists mainly of endocrine α, β, and δ cells. Although these components are differentiated from the same progenitor, α and β cells play opposite roles: at low glucose levels, α cells secrete glucagon to increase glucose levels, while at high glucose levels, β cells secrete insulin to decrease glucose levels. It seems that two counter-regulatory components are sufficient to control (increase/decrease) glucose levels. The role of somatostatin-secreting δ cells for glucose homeostasis is still a mystery.

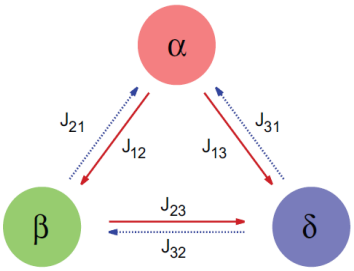


Figure 1. Cellular interactions between α, β, and δ cells. Red (blue) arrows represent positive (negative) interactions.

These endocrine cells secrete their hormones in pulsatile manners, and the hormone pulses have special coordination. At a very high glucose condition, glucagon and insulin pulses are out of phase, while insulin and somatostatin pulses are in phase. This suggests that α, β, and δ cells communicate to each other. Pieces

of the interactions have been observed in experiment (Fig. 1). We developed a mathematical model to describe the hormone pulses and their coupling by using a generalized Kuramoto model (Hong, Jo, and Sin, 2013). The model generated the out-of-phase coordination of glucagon and insulin pulses at high glucose conditions, which was consistent with previous observations. However, the model predicted an in-phase coordination of the two pulses at low glucose conditions. Furthermore, the model predicted that the special interaction symmetry of α, β, and δ cells allowed multiple coordination of hormone pulses at normal glucose conditions. This was distinct from the single coordination of the out-of-phase or the in-phase state at high or low glucose conditions. The change of possible coordination number, depending of glucose conditions, is a special feature of the interaction symmetry (Fig. 1). We will discuss on the physical meaning of the coordination-number change later.

Considering cellular interactions within a single islet, the spatial organization of α, β, and δ cells may have functional implications. Interestingly, different species have different architectures (cellular composition and arrangement) of islets for the glucose control. However, the islet size range (clusters of a few cells to several thousand cells) is similar across species having very different body sizes, suggesting the existence of an optimal islet size. In mice, β cells are located in the islet core, while non-β cells are located on the periphery. In contrast, human islets have more α cells (20-30% vs. 10-15% in mouse islets), and non-β cells are distributed throughout islets (Fig. 2).

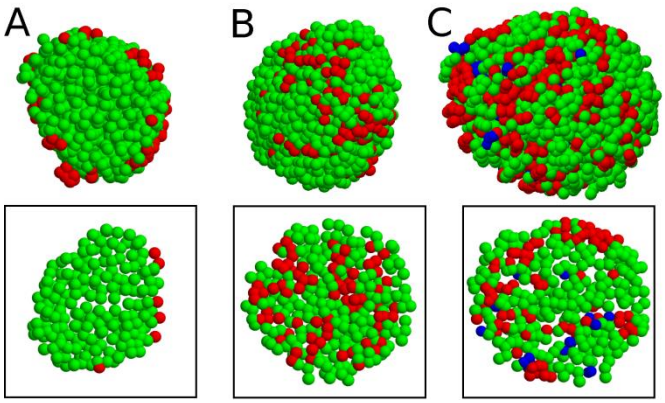


Figure 2. Cellular organizations of α (red), β (green), and δ (blue) cells in (A) mouse, and (B) human islets in the ignorance of δ cells. (C) A human islet with δ cells. Bottom pictures represent cross-sections of the top 3-dimensional islets to show their inner structures.

We developed a physical model to describe the cellular organization by adapting the differential adhesion hypothesis (Hoang, Jo, 2014). Based on the three-dimensional positions of individual cells in islets, we computationally inferred the relative attractions between cell types, and found a conserved rule that the attractions between homotypic cells were slightly, but significantly, stronger than the attractions between heterotypic cells commonly in mouse, pig, and human islets.

We thus concluded that the origin of the different islet structures is the cellular composition rather than their organization mechanism.

Based on these previous research on cellular interactions and islet architectures, we put the oscillator model of α, β, and δ cells on the observed islet structures, and examined structure-function relations in the system design for controlling homeostasis (Fig. 3). We found that the shell-core and the partial mixing structures are good for both synchronization and desynchronization of cells inside an islet (Hoang, Hara, and Jo, 2016). At emergency conditions such as low/high glucose conditions, the endocrine cells showed synchronized hormone pulses, while at normal glucose conditions, they showed desynchronized hormone pulses that could hide unnecessary hormone actions.

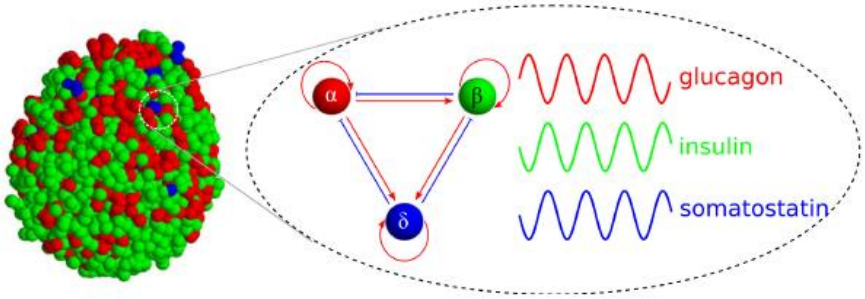


Figure 3. Cellular organization and interaction in pancreatic islets. Endocrine α, β, and δ cells generate pulses of glucagon, insulin, and somatostatin, respectively. They positively (red arrow) or negatively (blue bar-headed arrows) affect hormone pulses of neighboring cells.

In addition to the synchronization between cells inside an islet (intra-islet synchronization), the synchronization between islets in the pancreas (inter-islet synchronization) is another important issue in the islet-biology field. One potential hypothesis for the inter-islet synchronization is that the oscillatory glucose level entrains islets to be synchronized. We have found that the possible coordination between glucagon and insulin pulses changes with glucose levels (Hong, Jo, and Sin, 2013). This result lead us an intriguing hypothesis: The multiple coordination at normal glucose conditions may make islets harder to be entrained by the glucose oscillation. On the other hand, the unique coordination between glucagon and insulin pulses at low/high glucose conditions makes islets to be easily entrained by the glucose oscillation. We have confirmed this hypothesis with a whole feedback model of hormone secretion and glucose regulation (Fig. 4). Finally, we have found a functional meaning of the asymmetric interactions between islet cells (Fig. 1). The special network motif allows pancreatic islets to consume less hormones to stably regulate glucose levels, and it makes the synchronization of hormone secretions

controllable depending on glucose conditions (Park, Song, Hoang, Xu, and Jo, in revision).

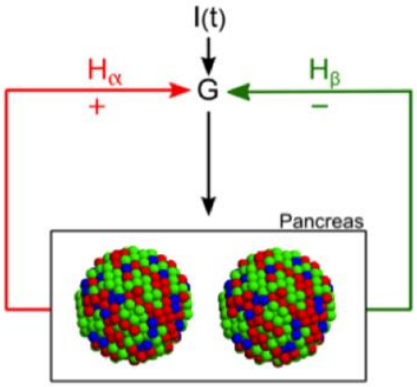


Figure 4. Glucose regulation with multiple islets. Pancreatic islets secrete glucagon (red) and insulin (green) to increase and decrease glucose levels, respectively, given external glucose infusion.

(ii) Machine learning of neural networks

We explore the robustness and adaptability of neural networks. The nervous system relies on cellular communications to a much larger extent than other physiological systems. Motivated by the study of neuronal connections, neural networks have been proposed to learn certain tasks. Recent studies have reported that neural networks in the brain are scale-free or small-world networks, as widely observed in biological and social networks. We plan to investigate how the network structures affect learning and memory through the machine learning of artificial neural networks. First, we examined optimal network size for memorizing patterns with various complexity. It is a rule of thumb that more complex tasks require larger networks. However, the design of optimal network architectures for specific tasks is still an unsolved fundamental problem. We considered three-layered neural networks for memorizing binary patterns (Fig. 5). We developed a new complexity measure of binary patterns, and estimated the minimal network size for memorizing them as a function of their complexity. We formulated the minimal network size (hidden layer size) for regular, random, and complex patterns (Pastor, Song, Hoang, and Jo, 2016).

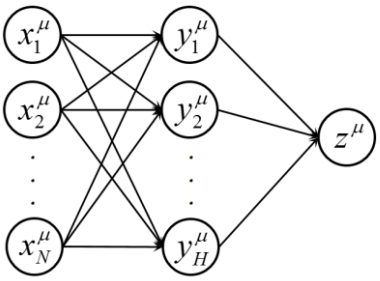


Figure 5. Feedforward neural network with input (x), hidden (y), and output (z) layers.

Discrimination and generation are two categorizations of machine learning. The above study was a discrimination problem of binary patterns using the back-

propagation algorithm. Second, we have investigated a generation problem using the Boltzmann machine algorithm. We considered a deep belief network and the generation of hand-written digit images using the MNIST database. The neural network has multiple layers of which node numbers decrease as layers become deeper from the input layer. We counted the configuration of node activities at different layers, and calculated the entropy of the frequencies. Then, we found that the entropy measure was correlated with the generation performance of hand-written digits (Song, Jo, and Marsili, In preparation). This new measure can suggest an optimal number and size of hidden layers for certain tasks.

(iii) Molecular recognition of immunological receptors

Finally, we study the mechanism how the immune system can distinctively recognize self and nonself molecules. The immune system recognizes pathogens such as viruses, bacteria, fungi, and parasites through membrane receptors that take part in communication between the cell and the outside world. Then, the system is expected to equip with an almost infinite range of specificities for the countless pathogens. If one gene encodes one receptor, the immune receptor diversity is implausible because human genome contains only ~20,500 genes which cover whole proteins, not just immune receptors, in the body. This puzzle has been resolved by the gene recombination mechanism. Human genome has multiple gene segments of V_1, V_2, ..., D_1, D_2, …, J_1, J_2, … regions for generating immune receptors. A specific receptor is then generated from the stochastic recombination (e.g., $V_2D_2J_1$) of the segments, called VDJ recombination. In addition to the segment selection variability, nucleotide deletion and insertion happens during the recombination process. This stochastic recombination thus has huge capacity for generating diverse receptors to recognize numerous pathogens.

Then, one following question is how the randomly-generated receptors recognize specific molecules. The success or failure of molecular recognition is determined by the binding energy between immune receptors and pathogen peptides. To model the recognition process, we considered the one-dimensional sequences of amino acids for receptors and peptides, and their pair-wise interaction energies by using the Miyazawa-Jernigan potential. Then, we have realized *cross-reactivity* in the molecular recognition: different receptors can recognize similar peptides, while similar receptors can recognize different peptides. Immunologists have already pointed out the importance of the cross-reactivity, because this concept can serve as a mechanism for explaining how finite receptor repertoire can cover infinitely many pathogens. However, we have recognized that the degree of cross-reactivity is heterogeneous between receptors. In other words, the distribution of cross-reactivity is broad (Xu and Jo, in preparation).

- **Members**

Name	Position	Nationality	Period
Junghyo Jo	Leader/Prof.	Korea	2012.09.01~2017.08.31
Danh-Tai Hoang	Postdoc	Vietnam	2013.01.08~2016.03.31
Dong-Ho Park	Postdoc	Korea	2014.03.01~2017.08.31
Taegeun Song	Postdoc	Korea	2016.02.01~2017.08.31
Juyong Song	PhD student	Korea	2013.01.01~2017.08.31
Jin Xu	PhD student	China	2013.09.01~2017.08.31

2-2. Generation and Evolution of Cosmic Structure

- **Leader:** Jinn-Ouk Gong (PhD., KAIST, Korea (2005))
- **Period:** Nov. 1, 2012 ~ Oct. 31, 2017
- **Overview**

  The Junior Research Group "Generation and evolution of cosmic structure" aims to develop cosmological perturbation theory to understand the nature of primordial perturbations that seeded the cosmic structure in the universe, and their novel observational signatures. We study three main topics in theoretical cosmology:

  a) Non-linear nature of cosmological perturbation

  In the simplest scenario of inflation, the primordial perturbation is essentially a free field so that it is linear and Gaussian. But the non-linear nature of gravity tells us that it possesses intrinsic non-linearity, despite the fact that it may be too small to be observed. Indeed, the most recent observation on the CMB gives the bound of the non-linear parameter, a convenient parametrization of non-linearity, $|f_{NL}|<10$, which means the universe is Gaussian on large scales up to 99.99%. However, the future observations are sensitive enough to discriminate f_{NL} as small as O(1). This appears as a non-vanishing 3-point correlation function, or the bispecrum, which may have a very complex shape and size. We will employ different approaches which complement each other to study the non-linear nature of cosmological perturbations.

  b) Effective theory of inflation

  A homogeneous and isotropic background postulates that the primordial perturbation is associated with time translational symmetry. This strongly restricts the form of the Lagrangian of the perturbation in such a way that a constant solution is always allowed, and we can write the effective operators of the primordial perturbation consistent with the requirement of its constancy. Further, this observation is based on the symmetry principle and thus should be valid non-perturbatively. Thus, the amplitude of the n-th order correlation function is given by the coefficients of the n-th order action. All this is independent of the specific model detail and is completely general. We are interested in extending this effective theory approach to broader contexts, like multi-field inflation, loop effects and so on.

  c) Signatures of early universe in LSS

  Essentially, the relation between LSS and the primordial perturbation is the same as that between that of CMB: the primordial perturbation is related to matter density perturbation produced by the annihilation and/or decay of the inflaton. Matter perturbation evolves by the gravitational interaction, and baryon is further concentrated to eventually form galaxies and their clusters which we can observe.

Thus, to study the early universe with LSS we should identify the relations between the primordial, gravitational, matter perturbations and the distribution of galaxies. The discrepancy between the distributions of dark matter and galaxies is parametrized by the so-called bias. We will study the contributions of non-linearity to the bias, which induces a novel scale dependence. The full general relativistic description of the bias is also of great interest.

- **Research**

a) Exact Analytic Solution for Non-Linear Density Fluctuation in a LCDM Universe

We derive the exact third-order analytic solution of the matter density fluctuation in the proper-time hypersurface in a ΛCDM universe, accounting for the explicit time-dependence and clarifying the relation to the initial condition. Furthermore, we compare our analytic solution to the previous calculation in the comoving gauge, and to the standard Newtonian perturbation theory by providing Fourier kernels for the relativistic effects. Our results provide an essential ingredient for a complete description of galaxy bias in the relativistic context. (Jaiyul Yoo, Jinn-Ouk Gong)

b) Path integral for multi-field inflation

We develop the path integral formalism for studying cosmological perturbations in multi-field inflation, which is particularly well suited to study quantum theories with gauge symmetries such as diffeomorphism invariance. We formulate the gauge fixing conditions based on the Poisson brackets of the constraints, from which we derive two convenient gauges that are appropriate for multi-field inflation. We then adopt the in-in formalism to derive the most general expression for the power spectrum of the curvature perturbation including the corrections from the interactions of the curvature mode with other light degrees. (Jinn-Ouk Gong, Min-Seok Seo, Gary Shiu)

c) Consistency relation and inflaton field redefinition in the delta N formalism

We compute for general single-field inflation the intrinsic non-Gaussianity due to the self-interactions of the inflaton field in the squeezed limit. We recover the consistency relation in the context of the delta N formalism, and argue that there is a particular field redefinition that makes the intrinsic non-Gaussianity vanishing, thus improving the estimate of the local non-Gaussianity using the delta N formalism. (Guillem Domenech, Jinn-Ouk Gong, Misao Sasaki)

d) Multi-field inflation and cosmological perturbations

We provide a concise review on multi-field inflation and cosmological perturbations. We discuss convenient and physically meaningful bases in terms of which

perturbations can be systematically studied. We give formal accounts on the gauge fixing conditions and present the perturbation action in two gauges. We also briefly review non-linear perturbations. (Jinn-Ouk Gong)

e) Features from the non-attractor beginning of inflation

We study the effects of the non-attractor initial conditions for the canonical single-field inflation. The non-attractor stage can last only several e-folding numbers, and should be followed by hilltop inflation. This two-stage evolution leads to large scale suppression in the primordial power spectrum, which is favored by recent observations. Moreover we give a detailed calculation of primordial non-Guassianity due to the "from non-attractor to slow-roll" transition, and find step features in the local and equilateral shapes. We conclude that a plateau-like inflaton potential with an initial non-attractor phase yields interesting features in both power spectrum and bispectrum. (Yi-Fu Cai, Jinn-Ouk Gong, Dong-Gang Wang, Ziwei Wang)

f) Curvaton as dark matter with secondary inflation

We consider a novel cosmological scenario in which a curvaton is long-lived and plays the role of cold dark matter (CDM) in the presence of a short, secondary inflation. Non-trivial evolution of the large scale cosmological perturbation in the curvaton scenario can affect the duration of the short term inflation, resulting in the inhomogeneous end of inflation. Non-linear parameters of the curvature perturbation are predicted to be $f_{NL} \sim 5/4$ and $g_{NL} \sim 0$. The curvaton abundance can be well diluted by the short-term inflation and accordingly, it does not have to decay into the Standard Model particles. Then the curvaton can account for the present CDM with the isocurvature perturbation being sufficiently suppressed because both the adiabatic and CDM isocurvature perturbations have the same origin. As an explicit example, we consider the thermal inflation scenario and a string axion as a candidate for this curvaton-dark matter. We further discuss possibilities to identify the curvaton-dark matter with the QCD axion. (Jinn-Ouk Gong, Naoya Kitajima, Takahiro Terada)

g) Correlated primordial spectra in effective theory of inflation

We derive a direct correlation between the power spectrum and bispectrum of the primordial curvature perturbation in terms of the Goldstone mode based on the effective field theory approach to inflation. We show examples of correlated bispectra for the parametrized feature models presented by the Planck collaboration. We also discuss the consistency relation and the validity of our explicit correlation between the power spectrum and bispectrum. (Jinn-Ouk Gong, Masahide Yamaguchi)

- **Members**

Name	Position	Nationality	Period
Jinn-Ouk Gong	Leader/Prof.	Korea	2012.11.01~2017.10.31
Godfrey Leung	Dr.	England	2014.10.20~2016.10.19
Sanggyu Biern	Dr.	Korea	2015.04.01~2017.03.31
Kitajima Naoya	Dr.	Japan	2015.10.01~2017.09.30
Aditya Aravind	Dr.	India	2016.09.01~2017.08.31
Wali Hossain	Dr.	India	2016.09.01~2017.08.31

2-3. Many-Body Theory and Correlated Systems

- **Leader:** Alireza Akbari (PhD., IASBS, Iran (2007))
- **Period:** Dec. 1, 2014 ~ Nov. 30, 2017
- **Overview**

  Correlations in many-body systems arising from interactions between electrons and electrons, electrons and phonons, and so on, can give rise to a variety of broken symmetry phases such as magnetism, superconductivity, and other ordered states. In our group we investigate the physics of such systems focusing especially on unconventional and high TC superconductors, observed for example in the Fe-pnictides, cuprates, and heavy fermion compounds, as well as trying to understand the close link between magnetism and superconductivity. We also investigate the physics of topological insulators and superconductors, which are distinguished from normal insulators by conducting edge states but are insulating in the bulk. We are particularly interested in those states protected by time-reversal symmetry, which can be detected via various spectroscopic techniques.

  Our main area of expertise is in theoretical condensed matter physics and statistical physics. We use many-body techniques based on Green's function approach to investigate the dynamics of the various broken symmetry states in strongly correlated systems. We also apply non-equilibrium methods such as the density-matrix method to understand ultrafast dynamics in superconductors and magnetic materials observed in pump-probe spectroscopy.

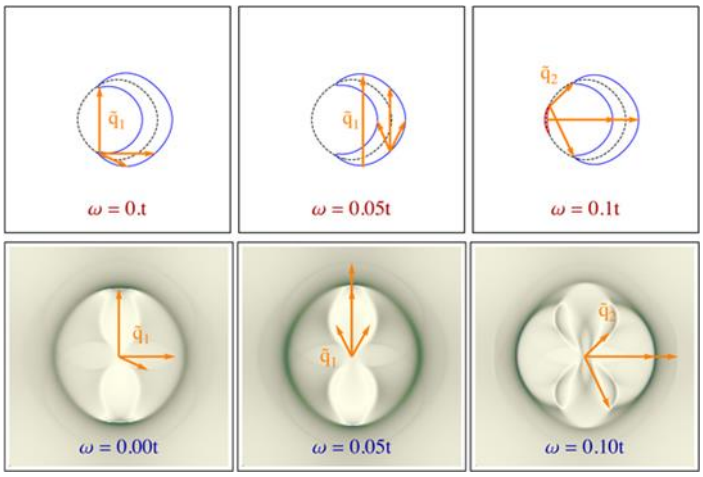
- **Research**

  Theory of quasiparticle interference (QPI):

  In recent years, quasiparticle interference (QPI) spectroscopy has emerged as an important tool to understand the pairing symmetry in unconventional and high T_C superconductors. This method is based on scanning tunneling microscopy (STM) and essentially involves investigating how the local density of states (LDOS) is modulated due to the presence of impurities [1]. Recently we have focused on the theory of quasiparticle interference as one of the main future techniques to estimate ordered phases such as magnetic and superconducting phases. Up to now, we have developed several theoretical analyses of QPI for different unconventional superconductors, heavy fermion systems and so on [2, 3]. Our predictions of superconducting gap symmetry using QPI spectroscopy in $CeCoIn_5$ [4] have been confirmed by two different experimental groups at Cornell and Princeton universities separately [5].

- Momentum space imaging of the FFLO state:

In a magnetic field superconductors (SC) with small orbital effect exhibit the Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) phase above the Pauli limiting field. It is characterized by Cooper pairs with finite center of mass momentum and is stabilized by the gain in Zeeman energy of depaired electrons in the imbalanced Fermi gas. The ground state is a coherent superposition of paired and depaired states. This concept, although central to the FFLO state lacks a direct experimental confirmation. We propose that STM quasiparticle interference (QPI) can give a direct momentum space image of the depaired states in the FFLO wave function. For a proof of principle we investigate a 2D single orbital tight binding model with a SC s-wave order parameter. Using the equilibrium values of pair momentum and SC gap we calculate the spectral function of quasiparticles and associated QPI spectrum as function of magnetic field. We show that the characteristic depaired Fermi surface parts appear as a fingerprint in the QPI spectrum of the FFLO phase and we demonstrate its evolution with field strength. Its observation in STM experiments would constitute a direct proof for FFLO ground state wave function. The results of this project are published in New Journal of Physics, 18, 063030 (2016).

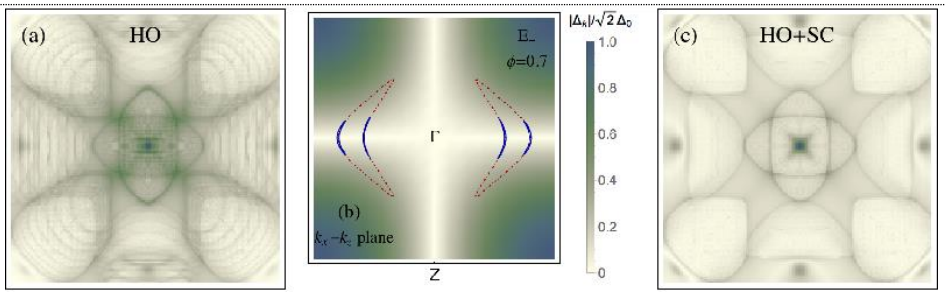


Spectral function and associated QPI spectrum for different energies in FFLO state: upper panel, shows the spectral functions and the bottom represents their corresponding QPI- spectrum in in Born approximation

- <u>Quasiparticle scattering image in hidden order phases and chiral superconductors</u>:

We have shown that quasiparticle interference can give important clues on the order parameters in chiral superconductors and hidden order phases. In the multi-gap p-wave triplet case of Sr_2RuO_4 the characteristic relative shift of minima and quasi-nodes of gaps on active and passive bands should lead to a corresponding shift of characteristic QPI vectors when tuning the bias voltage. Observation of this

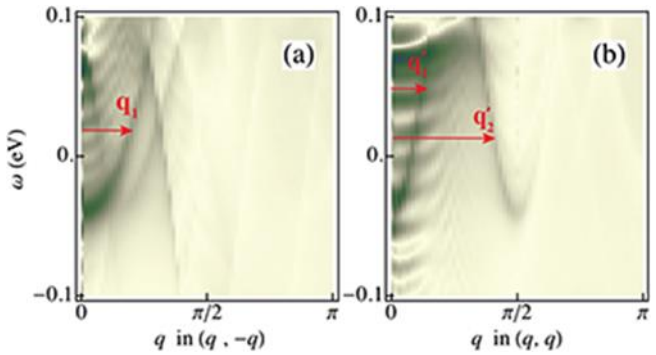
effect would lend strong support for the gap structure. In the heavy fermion compound URu_2Si_2 presumably single band chiral d-wave superconductivity exists deep inside high-rank 5 multipolar density wave phase. The Fermi surface reconstruction due to this exotic order leads to characteristic features in QPI spectrum, in particular possible tetragonal symmetry breaking. In the SC phase a crossover to quasi-2D quasiparticle bands occurs which suppresses this HO effect and should lead to more pronounced 2D-like QPI appearance.



(a) QPI spectrum for ω=0 in HO state (ϕ=0.7) with twofold symmetry. (b) Background coloring: |Δk| with kz=0 node line and (kx,ky)=(0,0) node points in bright color. HO (dashed) and HO+SC (full) FS sheets are indicated. (c) In the HO+SC phase the QPI is enhanced due to quasi-2D FS sheet, and fourfold symmetry is restored.

- <u>QPI in the double stripe phase of $Fe_{1+y}Te$:</u>

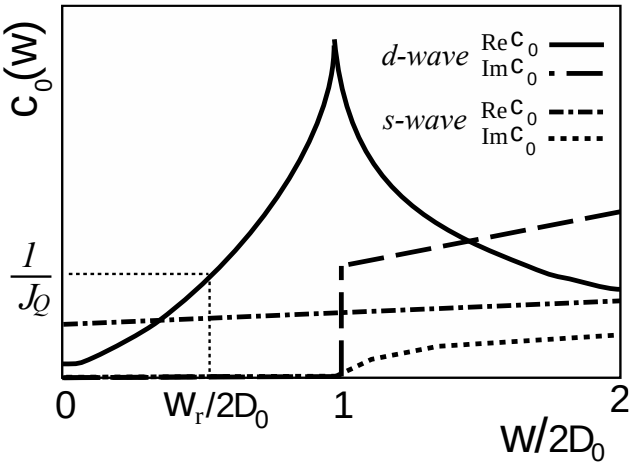
The Fe-chalcogenide family of compounds is unusual among the Fe-based superconductors since the parent compounds exhibit a (π /2, π /2) spin density wave, also called the double stripe (DS) phase, in contrast to the (π,0) phase seen in the Fe-pnictides. However, other types of magnetic structures, such as the orthogonal double stripe phase (ODS), have been proposed, which includes the (π /2, π /2) and (π /2,- π /2) wave vectors. Our goal was to investigate the tell tale signs left by the magnetic structure on the QPI pattern and thereby offering a means to classify the magnetic structures based on the QPI. What makes the idea interesting is that information on the magnetic structure can be obtained even when QPI occurs due to nonmagnetic impurities. Employing a realistic tight-binding model for $Fe_{1+y}Te$ with a Hubbard type interaction, we obtained self-consistent solutions for the different magnetic phases. The phases that we studied included the ODS phase, the DS phase, and a third phase in which the phase angle of the (π /2, π /2) SDW was set to zero. The QPI patterns were markedly different in the three cases structures and could be understood in terms of scatterings between quasiparticles on constant energy contours. The method has the potential to shed information about the magnetic structure of a compound based on the nonmagnetic-QPI patterns. The results of this work have been published in Europhysics Letters 114, 17001 (2016).



QPI dispersion along the -11 , and 11 directions for the double-stripe magnetic order in FeTe.

Theory of spin resonance excitations in unconventional superconductors:

Another active area of research in our group is the theory of spin resonance, which has been observed in numerous materials such as unconventional superconductors, heavy fermions, and Kondo lattice compounds. We have succeeded in explaining many features of these phenomena in various systems. Specifically, we have shown that the hybridization gap and hidden order parameters play the same role in Kondo systems and heavy Fermion metals, as does the superconducting gap in unconventional superconductors [7, 8].



Schematic frequency dependence of bare susceptibility (real and imaginary parts) for gap functions without (s-wave) and with (d-wave) sign change. The singular behaviour of real part of susceptibility leads to the formation of a spin exciton bound state at wave vector Q and energy < 2 times the gap value.

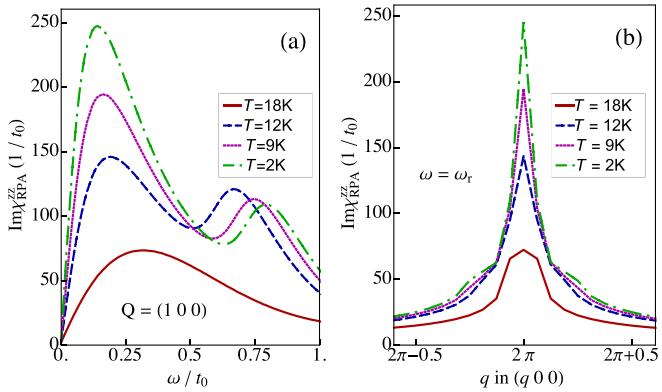
- <u>Resonant Spin Excitations in Unconventional Heavy Fermion Superconductors and Kondo Lattice Compounds:</u>

The heavy quasiparticle bands in Kondo materials which originate in the hybridization of f- and conduction electrons exhibit numerous, sometimes coexisting, broken symmetry phases. Most notable are unconventional superconductivity, itinerant small moment antiferromagnetism and hidden order of higher order multipoles of f-electrons which all lead to a gapping of the heavy

bands. In rare cases the chemical potential lies within the hybridization gap and the ground state is a Kondo semiconductor without ordering. The dynamical magnetic response of such gapped f-electron systems has been investigated with inelastic neutron scattering. It was found that collective spin exciton modes, which are due to residual quasiparticle interactions, appear below the threshold of superconducting or hidden order gap or directly the hybridzation gap. The spin exciton resonance is commonly located around a zone boundary vector Q with nesting properties in the normal state. In the superconducting case its appearance gives a strong criterion for the gap symmetry requiring a sign change $\Delta k+Q = -\Delta k$ due to the coherence factors. Therefore this many body effect with fundamental importance may also be used as a tool to discriminate between proposed gap models. While the spin resonance has been observed for many compounds we restrict our discussion here exclusively to the small group of f-electron superconductors CeCoIn5, CeCu2Si2 and UPd2Al3, hidden order Kondo compounds CeB6 and URu2Si2 as well as the Kondo semiconductor YbB12 [10].

- Collective spin resonance excitation in the gapped itinerant multipole hidden order phase of URu_2Si_2:

An attractive proposal for the hidden order (HO) in the heavy electron compound URu_2Si_2 is an itinerant multipole order of high rank. It is due to the pairing of electrons and holes centered on the zone center and boundary, respectively, in states that have maximally different total angular momentum components. Due to the pairing with a commensurate zone boundary ordering vector the translational symmetry is broken and a HO quasiparticle gap opens below the transition temperature *THO*. Inelastic neutron scattering (INS) has demonstrated that for $T<THO$ the collective magnetic response is dominated by a sharp spin exciton resonance at the ordering vector Q that is reminiscent of spin exciton modes found inside the gap of unconventional superconductors and Kondo insulators. We use an effective two-orbital tight-binding model incorporating the crystalline-electric-field effect to derive closed expressions for quasiparticle bands reconstructed by the multipolar pairing terms. We show that the magnetic response calculated within that model exhibits the salient features of the resonance found in INS. We also use the calculated dynamical susceptibility to explain the low-temperature NMR relaxation rate.



(a) Collective magnetic ($zz, \perp$) excitation spectrum: the imaginary part of the collective RPA susceptibility at the body centered tetragonal (bct) Z point versus energy. The position of the pronounced peak determines the (almost T-independent) resonance energy ω_r in the HO phase. (b) Evolution of the imaginary part of the RPA susceptibility at resonance energy $\omega_r(T)$ in q scan around bct Z point for different temperatures.

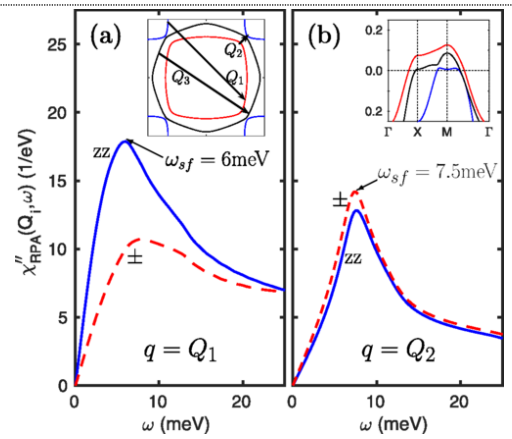
- Bismuth Sulfide Based Superconductors:

We are working on the pairing mechanism of BiS based superconductors as a novel discovered system, with significant attention due to striking similarities of its crystal structure with cuprate and iron-based high-Tc superconductors. Although the origin of superconductivity is not yet clear in these compounds, it was attributed to electron-phonon interaction. This seems reasonable in view of the low superconducting transition temperature and weaker electronic correlations of p-orbitals than in their 3d-counterparts. However, in the recent neutron scattering experiment, the observed almost unchanged low-energy modes indicated that the electron phonon coupling could be weaker than expected. Our goal was to develop the realistic minimal electronic model for these superconductors including the spin-orbit coupling based on first-principles band structure calculations. Due to strong spin-orbit coupling, characteristic for the Bi-based systems, the tight-binding low-energy model necessarily includes px, py, and pz orbitals. We analyzed a potential Cooper-pairing instability from purely repulsive interaction for small and intermediate doping concentrations and found d-wave and s^{+-}-wave symmetries, respectively, to be the dominant symmetries. Quasiparticle interference and spin response can be used to determine the symmetry of the order parameter in these systems. Overall our research results are very actual and interesting. Presently we are finalizing the manuscript and planning to submit it to Physical Review B.

- Stronthium Ruthenate Triplet Superconductor:

Although the Stronthium Ruthenate compound has been known for more than 20 years, there are some major features, which still remain unknown. Mainly, it is still not clear why is it a triplet superconductor and what is the Cooper pairing

mechanism. These features turn out to be even more striking when considering the similarity of its crystal structure and that of the high-Tc cuprates. Using our previous experience on bismuth sulfide based superconductor, our goal is to shed some light on the superconducting mechanism in this compound. In particular, we analyze the spin anisotropy of the magnetic susceptibility of Sr2RuO4 in the presence of spin-orbit coupling and anisotropic strain using quasi-two-dimensional tight-binding parametrization fitted to the angle-resolved photoemission spectroscopy results. Similar to the previous observations we find the in-plane polarization of the low-q magnetic fluctuations and the out-of-plane polarization of the incommensurate magnetic fluctuation at the nesting wave-vector Q1=(2/3π,2/3π) but also nearly isotropic fluctuations near Q2=(π/6,π/6). Furthermore, one finds that, apart from the high-symmetry direction of the tetragonal Brillouin zone, the magnetic anisotropy is maximal, i.e., χxx≠χyy≠χzz reflected in the x polarization of the intraband nesting wave-vector Q3=(π/2,π). This is a consequence of the orbital anisotropy of the t2g orbitals in momentum space. We also study how the magnetic anisotropy evolves in the presence of the strain and find strong Ising-like ferromagnetic fluctuations near the Lifshitz transition for the xy band. The results of this study s published in Phys. Rev. B 94, 224507 (2016).



Calculated imaginary part of the longitudinal and transverse components of the random-phase approximation (RPA) spin susceptibility of Stronthium Ruthenate at the antiferromagnetic wave-vectors (a) Q1=(2π/3,2π/3) and (b) Q2=(π/6,π/6). The insets show the Fermi-surface topology with corresponding nesting wave vectors as the electronic dispersion along high-symmetry lines, respectively.

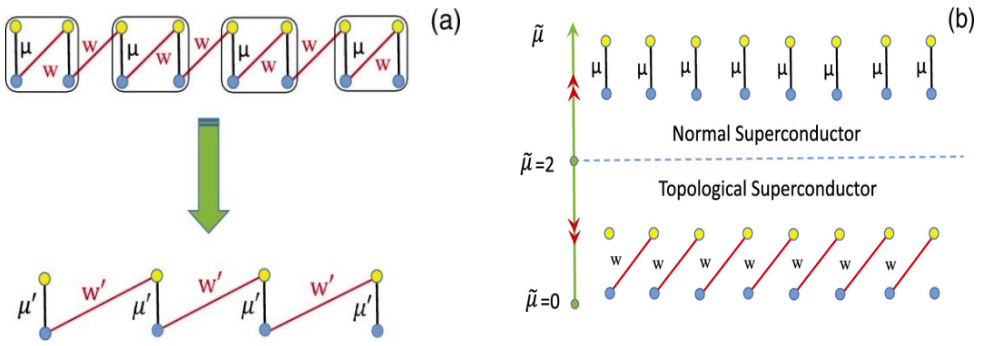
Quantum criticality gains long-time quantum correlations:

Using the general quantum compass model as an environmental system, the dynamical evolution of the decoherence factors, quantum correlations, and negativity of the central spins has been investigated for different initial states. The relation between the quantum-classical transition of the central system, and the

occurrence of an avoided level crossing quantum phase transition in its surrounding system has been analyzed. It is well known that the gapless quantum criticality enhances the decay of decoherence factors, while our calculations represent a different story for the gapped critical environment. The results that have been found show that long-time quantum correlations at the critical point are an effect of gapped criticality, and maximum decaying occurs away from the critical point. The role of the gapped critical spin chain is to prevent the complete drain of information from central systems to the environment and provides them a better environment for preserving quantum correlations. In other words, the amount of decoherence which travels into the central spin state depends on the excited states of the environment. Hence the energy gap could block the propagation of decoherence along the environment and consequently reduces its effect on the central spin. These results highlight the current outlook of using quantum spin chains as entanglers or quantum channels in quantum information devices. Besides, quantum gapped criticality may have potential applications in quantum computations [9].

Real Space Renormalization of Majorana Fermions in Quantum Nano-Wire Superconductors

We develop the real space quantum renormalization group (QRG) approach for Majorana fermions. As an example we focus on the Kitaev chain to investigate the topological quantum phase transition (TQPT) in the one-dimensional spinless p-wave superconductor. Studying the behaviour of local compressibility and ground-state fidelity, show that the TQPT is signalled by the maximum of local compressibility at the quantum critical point tuned by the chemical potential. Moreover, a sudden drop of the ground-state fidelity and the divergence of fidelity susceptibility at the topological quantum critical point are used as proper indicators for the TQPT, which signals the appearance of Majorana fermions. Finally, we present the scaling analysis of ground-state fidelity near the critical point that manifests the universal information about the TQPT, which reveals two different scaling behaviors as we approach the critical point and thermodynamic limit. This work is published in J. Phys. Soc. Jpn. 82, 024008 (2017).



(a) Renormalization scheme of Majorana fermions in nanowire superconductor, (top) where a block of four MFs is mapped to (bottom) a renormalized pair of MFs. (b) Phase diagram of the one-dimensional Kitaev Model.

Theory of ultra fast dynamics of pump probe spectroscopy:

We are also interested in the theory of time-resolved spectroscopy and short time dynamics. In recent years, numerous studies of non-equilibrium dynamics of multi-band superconductors have been performed using femtosecond time-resolved spectroscopy. The relaxation kinetics measured in these experiments gives important information on the electronic band structures, electron-phonon coupling strengths, as well as on the symmetry of the superconducting order parameters. Using density-matrix theory, our group at APCTP is interested in understanding the relaxation dynamics and the non-equilibrium evolution of multiband superconductors at times shorter than the relaxation time [6].

Transition metal oxides:

We are also working on the theory of magnetization in spin-orbit-coupled transition metal oxide-based *d*-electron systems such as the iridates and ruthenates. The quantum entanglement of the spin, orbital, and charge degrees of freedom of correlated electrons in oxides is also one of our main topics of interest.

- **Members**

Name	Position	Nationality	Period
Alireza Akbari	Leader	Iran	2014.12.01~2017.11.30
Fabrizio Cossu	Dr.	Italy	2016.05.27~2017.05.26
Mehdi Biderang	Stud.	Iran	2016.06.02~2017.12.31
Utkarsh Mishra*	Dr.	India	2016.03.04~2017.03.03

* Joint Researcher with Prof. Jaeyoon Cho

2-4. Gauge/gravity Duality and String Theory

- **Leader:** Chanyong Park (PhD., Hanyang University, Korea (2002))
- **Period:** Since Oct. 19, 2015 ~ Oct. 18, 2018
- **Overview**

  In physics, one of the important problems is to determine the spectrum of a given physical system, which is usually classified by the conserved charges caused by symmetry. From the symmetry point of view, the AdS/CFT correspondence can be easily expected by noting that a classical gravity theory on the (d+1)-dimensional Anti de-Sitter (AdS) space has the same symmetry group of a conformal field theory (CFT) defined at the boundary of AdS. After the Maldacena's conjecture, many theoretical physicists have tried to find more concrete examples for the AdS/CFT correspondence. There were significant progresses in checking the AdS/CFT correspondence by using the integrability and localization techniques. At present, the AdS/CFT correspondence has been widely believed as the correct duality of a conformal field theory. In general physics, however, the conformal symmetry is special in that it appears only in critical phenomena or fixed points. Since QCD and CMT phenomena we are interested in appear even in non-critical points, it is important to generalized the AdS/CFT correspondence into more general cases. Recently, there have been numerous attempts to develop it to the gauge/gravity applicable to non-conformal systems. This is quite interesting and important issue in theory as well as experiment. Finding some evidences for the gauge/gravity duality would be useful to improve our understanding about more realistic physical phenomena. The goal of our research group will be focused on the gauge/gravity duality and its application into realistic physical systems.

- **Research**

  1. Thermodynamic law from the entanglement entropy bound

  From black hole thermodynamics, the Bekenstein bound has been proposed as a universal thermal entropy bound. It has been further generalized to an entanglement entropy bound which is valid even in a quantum system. In a quantumly entangled system, the non-negativity of the relative entropy leads to the entanglement entropy bound. When the entanglement entropy bound is saturated, a quantum system satisfies the thermodynamics-like law with an appropriately defined entanglement temperature. We show that the saturation of the entanglement entropy bound accounts for a universal feature of the entanglement temperature proportional to the inverse of the system size. In addition, we show that the deformed modular Hamiltonian under a global quench

also satisfies the generalized entanglement entropy boundary after introducing a new quantity called the entanglement chemical potential.

2. Emergent geometry from field theory: Wilson's renormalization group revisited

We find a geometrical description from a field theoretical setup based on Wilson's renormalization group in real space. We show that renormalization group equations of coupling parameters encode the metric structure of an emergent curved space, regarded to be an Einstein equation for the emergent gravity. Self-consistent equations of local order-parameter fields with an emergent metric turn out to describe low energy dynamics of a strongly coupled field theory, analogous to the Maxwell equation of the Einstein-Maxwell theory in the AdS_d+2/CFT_d+1 duality conjecture. We claim that the AdS_3/CFT_2 duality may be interpreted as Landau-Ginzburg theory combined with Wilson's renormalization group, which introduces vertex corrections into the Landau-Ginzburg theory in the large−N limit, where Ns is the number of fermion flavors.

3. Meson's Correlation Functions in a Nuclear Medium

We investigate meson's spectrum, decay constant and form factor in a nuclear medium through holographic two- and three-point correlation functions. To describe a nuclear medium composed of protons and neutrons, we consider a hard wall model on the thermal charged AdS geometry and show that due to the isospin interaction with a nuclear medium, there exist splitting of the meson's spectrum, decay constant and form factor relying on the isospin charge. In addition, we show that the ρ-meson's form factor describing an interaction with pseudoscalar fluctuation decreases when the nuclear density increases, while the interaction with a longitudinal part of an axial vector meson increases.

4. Conductivities in an anisotropic medium

In order to imitate anisotropic medium of a condensed matter system, we take into account an Einstein-Maxwell-dilaton-axion model as a dual gravity theory where the anisotropy is caused by different momentum relaxations. This gravity model allows an anisotropic charged black hole solution. On this background, we investigate how the linear responses of vector modes like electric, thermoelectric, and thermal conductivities rely on the anisotropy. We find that the electric conductivity in low frequency limit shows a Drude peak and that in the intermediate frequency regime it reveals the power law behavior. Especially, when the anisotropy increases the exponent of the power law becomes smaller. In addition, we find that there exists a critical value for the anisotropy at which the DC conductivity reaches to its maximum value.

5. On black hole thermodynamics with a momentum relaxation

We investigate black hole thermodynamics involving a scalar hair which is dual to a momentum relaxation of the dual field theory. This black hole geometry is able to be classified by two parameters. One is a momentum relaxation and the other is a mass density of another matter localized at the center. Even though all parameters are continuous, there exists a specific point where its thermodynamic interpretation is not continuously connected to the one defined in the other parameter regime. The similar feature also appears in a topological AdS black hole. In this work, we show why such an unusual thermodynamic feature happens and provide a unified way to understand such an exotic black hole thermodynamically in the entire parameter range.

6. Holographic trace anomaly at finite temperature

Using the holographic renormalization, we investigate the finite temperature and size effect to the energy-momentum tensor of the dual field theory and its renormalization group (RG) flow. Following the anti-de Sitter/conformal field theory correspondence, the dual field theory of the AdS space is well known to be a conformal field theory that has no nontrivial RG flow. Holographically, that theory can be lifted to a finite temperature version by considering a AdS black hole solution. Because the black hole horizon associated with temperature is dimensionful, it breaks the boundary conformal symmetry and leads to a nontrivial RG flow. In this work, we investigate the finite temperature and size correction to a strongly interacting conformal field theory along the Wilsonian renormalization group flow.

7. Vacuum stability problem in QCD

The problem of the existence of a stable vacuum monopole condensation in a pure quantum chromodynamics (QCD) is revised. Our approach is based on using classical stationary non-linear wave type solutions with intrinsic mass scale parameters. Such solutions can be treated as quantum mechanical wave functions describing massive spinless states in quantum theory. We verify whether non-linear wave type solutions can form vacuum condensates stable against quantum fluctuations within the effective action formalism. We demonstrate that there is a special class of stationary regular solutions representing a Wu-Yang monopole dressed in gluon field which provides a stable color magnetic condensate in a pure QCD.

8. RG flow of entanglement entropy to thermal entropy

Utilizing the holographic technique, we investigate how the entanglement entropy evolves along the RG flow. After defining a new generalized entanglement temperature which satisfies the thermodynamics-like law even in the IR regime,

we show that the renormalized entanglement entropy and temperature in the IR limit approach to the thermal entropy and temperature of a real thermal system. Intriguingly, the thermalization of the IR entanglement entropy generally happens regardless of the detail of a dual field theory. We check such a universality for a two-dimensional CFT, a Lifshitz field theory, and a non-conformal field theory. In addition, we also show that for a two-dimensional scale invariant theory the first quantum correction to the IR entanglement entropy leads to a logarithmic term caused by the remnant of the short distance quantum correlation near the entangling surface.

9. Emergent metric as an order parameter for a topological phase transition in the Kitaev superconductor model

Applying the Kadanoff's block-spin transformation to the Kitaev superconductor model, we obtain renormalization group (RG) flows for coupling parameters, which differ from those of the RG analysis in momentum space. These RG equations allow us to extract out the metric structure of an emergent spacetime with an extra dimension. As a result, we find that the three dimensional Minkowski metric of a topologically trivial superconducting state evolves into an exotic spacetime metric of a topological superconducting phase through the AdS3 metric of the quantum critical point described by a conformal field theory. In particular, the emergent metric of the topological superconducting phase is characterized by the existence of physical singularity along the extra dimension.

- **Members**

Name	Title	Nationality	Period
Chanyong Park	Leader/Prof.	Korea	2015.10.19~2018.09.18
Siyoung Nam	Dr.	Korea	2016.06.01~2016.12.31
Yunseok Seo	Dr.	Korea	2016.03.01~2016.04.30
Daeho Ro	Dr.	Korea	2016.03.01~2017.02.28
Jung Hun Lee	Dr.	Korea	2016.09.01~2018.08.31
Minkyoo Kim	Dr.	Korea	2016.11.01~2016.12.31

2-5. Quantum Information and Mandy-Body Theory

- **Leader:** Jaeyoon Cho (PhD., KAIST, Korea (2005))
- **Period:** Nov. 1, 2015 ~ Oct. 31, 2018
- **Overview**

  Understanding the nature of strongly-correlated quantum many-body systems is one of the prime issues in modern theoretical physics. While weakly-correlated systems can be generally understood in terms of perturbation theories and various mean-field-type approaches, strongly-correlated systems defy standardized treatments. A conventional detour to such problems usually takes the framework of field theories and renormalization arguments. However, it allows for only empirical solutions. For arbitrarily given microscopic Hamiltonians, working out their static or dynamical properties still remains intractable.

  In this context, recent contributions from quantum information communities are remarkable. From the perspective of quantum information theory, entanglement is an important concept as an indication of the complexities of given many-body problems. This perspective has led to various ideas based on what are generally called “tensor network states”, such as the DMRG (Density Matrix Renormalization Group) method, which is so far the most effective numerical method to solve the ground states of one-dimensional systems, and MERA (Multi-scale Entanglement Renormalization Ansatz), which is suitable for studying critical phenomena.

  Astounding recent success of AMO (Atomic, Molecular, and Optical) physics also cannot be overlooked. The laser cooling and trapping technologies eventually led to the observation of Bose-Einstein condensation and Fermi degeneracies in trapped neutral atomic gases in 1990’s, whereby AMO physics met condensed matter physics. Furthermore, the superfluid-to-Mott-insulator transition was observed in Bosonic gases trapped in an optical lattice in 2002, which heralded that atomic systems entered the realm of strongly-correlated systems. Since then, both the theoretical and experimental studies of strongly-correlated atomic systems have proliferated to a huge extent.

  All in all, the borders between traditionally different disciplines in physics are becoming more and more obscure and this trend will probably be sustained. The aim of the “Quantum Information and Many-Body Theory” group is to combine the ideas from quantum information, AMO, and condensed matter theories to study strongly-correlated quantum many-body systems.

- **Research**

(1) Quantum phase transition and entanglement in topological quantum wires

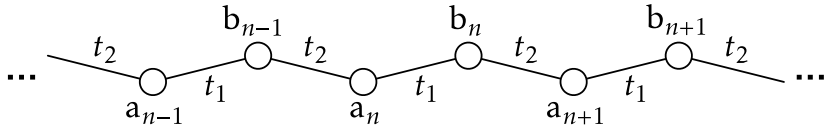
Quantum phase transition is one of the pillars underpinning condensed matter physics. Conventional wisdom states that different quantum phases are generally discriminated in terms of the symmetry carried by the ground state or other features that have an underlying topological interpretation. The former is described by local order parameters associated with the symmetries and the latter by topological orders, which are nowadays classified into intrinsic and symmetry-protected ones. In both cases, a continuous transition between different phases in mediated by a spectrally gapless critical point, in the vicinity of which thermodynamic quantities exhibit scaling behaviors classified into universality classes.

Modern understanding of quantum phase transition has been significantly enriched by incorporating the concept of entanglement. Quantum phases are determined after all by the way how different particles or different parties in the system are mutually related. In this sense, it is natural to expect that entanglement would bear the fingerprint of the quantum phase. This perspective is especially powerful in the study of topological orders, which are a purely quantum effect. For example, states with an intrinsic topological order have a long-range entanglement and a nonzero topological entanglement entropy. Symmetry-protected topological orders are signified by a degenerate entanglement spectrum. Topological quantum phase transition would then be thought of as a rearrangement of the pattern of entanglement.

While it is a common practice to study macroscopic bipartite entanglement in topological phases, they apparently reveal only a partial aspect of many-body entanglement and, on the practical side, are hardly accessible in experiments. It is thus worthwhile to carry out a more detailed inspection of the many-body entanglement for a deeper understanding of topological phases. In particular, when it comes to the aspect of phase transition, local entanglement may be enough to gain information on the critical singularities, as is suggested by earlier works on symmetry-breaking quantum phase transitions in Heisenberg spin chains. If then, an interesting question is how its singular nature differs from that of the symmetry-breaking transitions. Besides, from the viewpoint that different quantum phases are imprinted in different patterns of entanglement, to examine many-body entanglement in topological models is an interesting problem in its own right.

In this context, we have investigated the quantum phase transition of one-

dimensional topological models in terms of the two-site entanglements, namely, the concurrences, in the ground state. As a prototypical model, we considered the Su-Schrieffer-Heeger (SSH) model on a one-dimensional lattice:



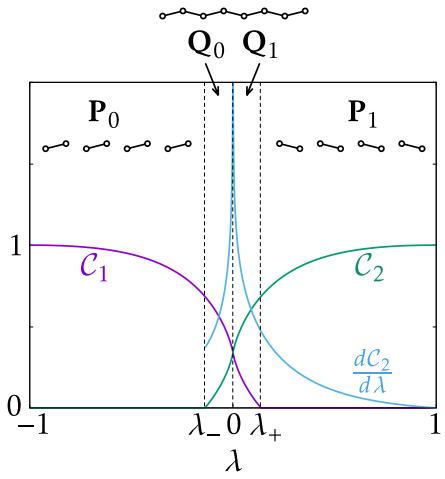
The system has N unit cells, each consisting of two sites $\{\mathrm{a}_n, \mathrm{b}_n\}$. The model Hamiltonian is given by

$$H = \sum_{n=1}^{N} \left(t_1 a_n^\dagger b_n + t_2 b_n^\dagger a_{n+1} + \text{H.c.} \right),$$

where $\{a_n, b_n\}$ denote the fermion operators for the n-th unit cell and the periodic boundary condition $\{a_{N+1}, b_{N+1}\} = \{a_1, b_1\}$ is taken. We take the hopping rates

$$t_1 = 1 - \lambda, \qquad t_2 = 1 + \lambda$$

to have a single control parameter $\lambda \in [-1,1]$. This system is in a topological phase for $\lambda > 0$ and in a trivial phase for $\lambda < 0$.



As a means to characterize the many-body entanglement, we represent the pairwise pattern of all the concurrences as a (simple) graph, where each edge means the existence of entanglement, i.e., a nonzero concurrence, between the two vertices (sites). We call this graph an "entangled graph". If two many-body states have different entangled graphs, we regard them as having different classes of many-body entanglement and hence belonging to different phases. This kind of characterization of many-body entanglement has a relatively long tradition. In this

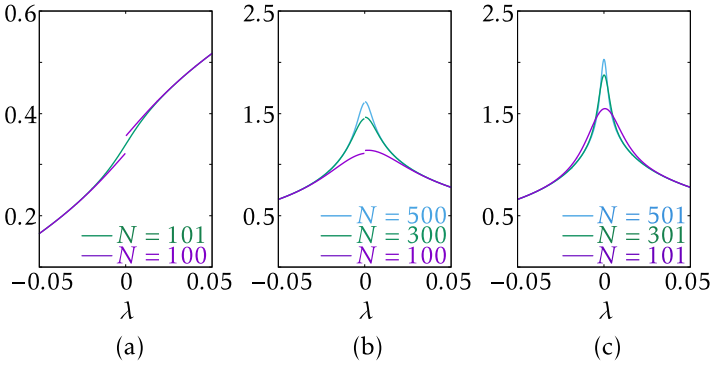
work, our particular motivation is coming from the fact that at two extreme phases $\lambda = \pm 1$, the ground state is dimerized in such a way that either two sites in every unit cell from a singlet ($\lambda = -1$) or every adjacent pair of sites across unit cells from a singlet ($\lambda = +1$), the entanglement of which can be naturally represented by the entangled graphs as shown in the figure above. The problem is then to figure out how the entangled graph for $\lambda \in (-1,1)$ interpolates between the two. It turns out that there can be only two nonzero concurrences $C_1(\lambda)$ and $C_2(\lambda)$, where $C_1(\lambda)$ denotes the concurrence between two sites in the unit cell and $C_2(\lambda)$ between two adjacent sites across unit cells. We can thus have only three phases of the entangled graph as shown in the figure. The two concurrences are related as $C_1(\lambda) = C_2(-\lambda)$.

The concurrences $C_1(\lambda)$ and $C_2(\lambda)$ have singularities at $\lambda_0 = 0$ and $\lambda_\pm \cong \pm 0.138$. The remaining task is to analyze those singularities.

The singularity at $\lambda_0 = 0$ is associated with the topological phase transition. In the thermodynamic limit, $dC_1(\lambda)/d\lambda$ diverges logarithmically at $\lambda_0 = 0$ as

$$\frac{dC_1(\lambda)}{d\lambda} \propto \log\left[\left(\frac{e}{2}\right)^2 |\lambda|\right].$$

This result is similar to the case of the symmetry-breaking quantum phase transition in the Heisenberg spin chain. However, due to the topological origin, there exists an interesting difference: for finite even N, the concurrence is discontinuous at $\lambda_0 = 0$ with a gap proportional to $1/N$, while it remains analytic for odd N as shown in the following figure:



This figure shows (a) $C_2(\lambda)$, (b) $dC_2(\lambda)/d\lambda$ for even N, and (c) $dC_2(\lambda)/d\lambda$ for odd N. This feature contrasts with the case of symmetry-breaking quantum phase transitions wherein the non-analyticity appears only in the thermodynamic limit. This phenomenon has a universal nature in one-dimensional topological phase transitions of non-interacting fermions. For example, in the case of the Kitaev chain, the local electron density exhibits the identical non-analyticity at the critical point.

The non-analyticity at $\lambda = \lambda_\pm$ is originated from the property of entanglement, which is defined as "not being separable". In the Hilbert space of bipartite density

operators, the set of all separable states forms a compact convex set. As a result, if one traces a continuous path in the Hilbert space from an entangled to a separable state, the entanglement suddenly disappears when one crosses the hyperplane separating the sets of separable and entangled states. When this occurs in a dynamical problem, the phenomenon is called an entanglement sudden death (or sudden birth in the opposite way). The entanglement sudden death is observed occasionally when a state evolves in a dissipative environment. However, it is rare to see an analogous phenomenon in the course of a quantum phase transition. It should be noted, however, that this transition should not be confused with conventional quantum phase transitions because it has nothing to do with a non-analyticity of the ground-state wavefunction itself.

(2) Anomalous many-body localization in the quantum Ashkin-Teller model with random transverse fields

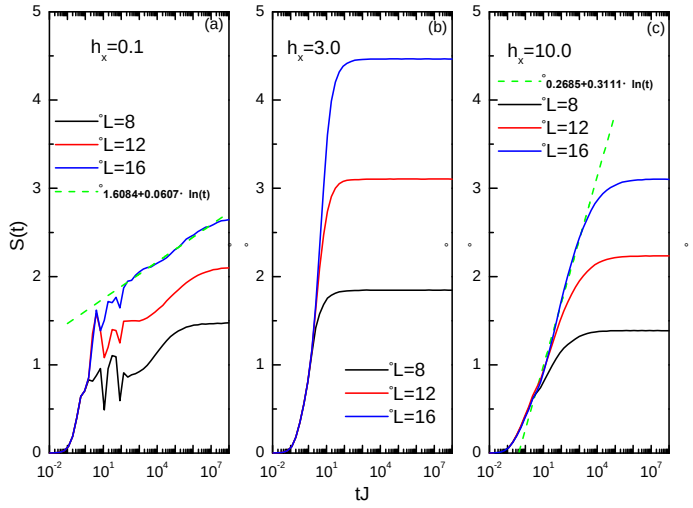
Over the recent years, disorder-induced localization in the presence of interaction, called many-body localization (MBL), has emerged as one of the central themes of study in condensed matter physics. Dealing with strongly-correlated systems, a thorough understanding of MBL in general situations is hard to come by at present. Nonetheless, as far as one-dimensional disordered systems are concerned, growing evidence has led us to a quite general agreement. In one dimension, while disorders typically thermalize a system, i.e., drive a system into an ergodic state, sufficiently stronger disorders can drive it into an MBL state, where the transition between the two different behaviors is believed to be a phase transition. The MBL phase is characterized by a Poissonian level statistics and a logarithmic growth of entanglement entropies in time. These features allow us to distinguish MBL phases from ergodic ones, which on the other hand exhibit a Gaussian Orthogonal Ensemble (GOE) level statistics and a much faster growth of entanglement entropies. Conceptually, the GOE distribution is the result of repulsion between neighboring energy levels, while the Poissonian distribution is originated from independent random energy levels.

In this work, we have demonstrated an intriguing example that defies the above consensus. We have studied the quantum Ashkin-Teller model with a random transverse field, the Hamiltonian of which is

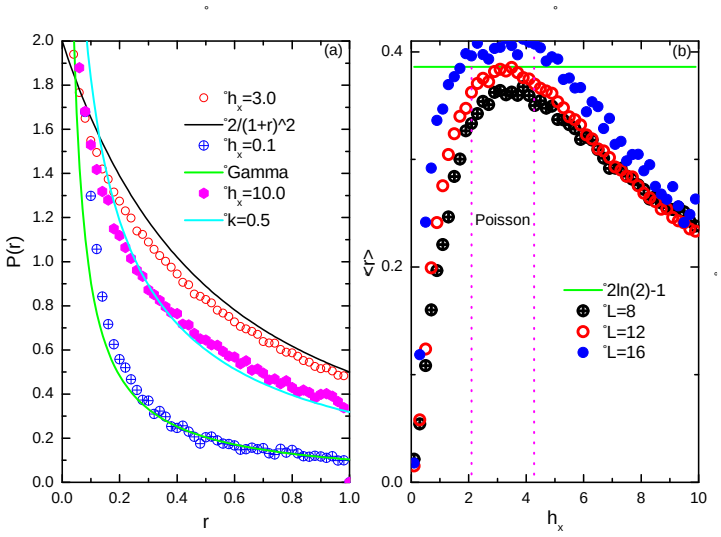
$$H = -\sum_{\alpha=1}^{2}\sum_{i}\left(J_i S_{\alpha,i}^{z} S_{\alpha,i+1}^{z} + h_i S_{\alpha,i}^{x}\right) - \sum_{i}\left(K_i S_{1,i}^{z} S_{1,i+1}^{z} S_{2,i}^{z} S_{2,i+1}^{z} + g_i S_{1,i}^{x} S_{2,i}^{x}\right),$$

where $J_i = K_i = g_i = 1$ is taken and h_i is chosen randomly and uniformly from

$[-h_x/2, h_x/2]$ with h_x being the disorder strength.



The above figure shows the growth of the entanglement entropy for different disorder strengths. For $h_x = 0.1$, the growth of the entanglement entropy shows a logarithmic scaling, which is a typical feature of MBL. This behavior disappears for stronger disorders. At present, it is unclear what will happen for $h_x \gg 10$.



The above figure shows (a) level statistics and (b) the average of the level spacing. For the Poissonian level statistics, $\langle r \rangle = 2\ln(2) - 1$. It can be seen that the level statistics is Poissonian, which is a typical feature of MBL, only around $h_x \sim 3$.

All in all, for $h_x = 0.1$, the growth of the entanglement entropy shows the feature of the MBL, but the level statistics is not Poissonian. On the other hand, for $h_x = 3.0$, the level statistics shows the feature of the MBL, but there is no logarithmic scaling in the growth of the entanglement entropy.

- **Members**

Name	Title	Nationality	Period
Jaeyoon Cho	Leader/Prof.	Korea	2015.11.01~2018.10.31
Utkarsh Mishra*	Dr.	India	2016.03.04~2017.03.03
Yang Zhao	Dr.	China	2016.04.14~2018.04.13

* Joint Researcher with Prof. Alireza Akbari

2-6. Supergravity and String Theory

- **Leader:** Eoin O Colgain (PhD., Imperial College London, UK(2007))
- **Period:** Since Dec. 1, 2015 ~ Nov. 30, 2018
- **Overview**

  Particle physics is at a crossroads. Recent results from the LHC suggest that supersymmetry, a conjectured symmetry between bosons and fermions, if it exists, is not realised at the energies probed by the collider. Moreover, direct detection experiments of dark matter, notably the most likely candidate (WIMP), have yet to yield positive results. While supersymmetry was expected to provide a method to stabilise the Higgs mass from radiative corrections, as well as providing a candidate for dark matter, this scenario is appearing less likely as days pass. It is a very interesting time for particle physics: the favoured paradigm is being severely challenged and the community is in a state of flux.

  On a more concrete note, there is renewed interest in gravitational systems. The Nobel prize in physics this year will be awarded for the direct detection of gravitational waves and for the discovery of (binary) black holes. Furthermore, the idea that dark matter/ energy may arise from modifications of Einstein gravity, is slowly gaining traction as direct detection experiments for dark matter impose more stringent bounds. As string theory offers a candidate UV completion for Einstein gravity, where the corrections may be determined, it will be interesting to see if there is any overlap between the corrections favoured by data (in the absence of particle dark matter) and those predicted by string theory.

  Separate from these concerns, one of the most exciting developments in high energy theory has been holography, since in principle it gives a way to model strongly coupled systems using simple gravitational systems. While this idea has its roots in supersymmetry, a setting where we have more computational control, it is expected to be more general, and holographic techniques have been applied to model a host of strongly coupled systems, including the quark-gluon plasma and high-temperature superconductors with qualitative success. The similarities suggest that holography is a generic phenomenon, as is evident from black hole physics, and it remains an important tool in the theoretical physics toolbox. The work of our group largely concerns holography.

- **Research**

  During 2016, I was still affiliated to the University of Surrey through my Marie Curie Fellowship. I published 3 papers, JHEP 1603 (2016) 188 (based on earlier work in 2015), Phys.Rev. D93 (2016) no.8, 086010, Phys.Rev. D94 (2016) no.10,

106006**,** and posted one arXiv preprint 1610.05638. With Thiago and Ilya we established a collaboration with scientists at Kyoto and IPM, Tehran. This resulted in the recent preprint 1702.02861, which we believe is a significant result. It is currently under review at Physical Review Letters. Thiago Araujo uploaded the preprint 1609.08008 on the arXiv, which is the result of a project he initiated while still in Brazil.

Our work in 2016 made the following contributions.

1) We revisited a classification of supersymmetric AdS3 x S2 x M6 geometries in 11D supergravity with Y. Lozano, J. Montero (Oviedo, Spain), O. Kelekci (Istanbul) and M. Park (KIAS, now IBS Caldes). We showed for internal six-dimensional manifolds with SU(3) structure that Calabi-Yau is the only possibility. When the structure is reduced to SU(2), there are two possibilities: either there is an emergent U(1) symmetry, and one recovers a class of geometries originally identified by N. Kim et al. (Kyung Hee), or there is an emergent two-sphere in the geometry, leading to one copy of large superconformal symmetry. The results were published in Phys.Rev. D93 (2016) no.8, 086010.

2) A long-standing problem concerns whether hidden symmetries in the scattering amplitudes of ABJM theory, a 3D superconformal Chern-Simons field theory, is manifest holographically. To demonstrate this, one should show that the AdS/CFT dual geometry AdS4 x CP3 is self-dual under a combination of bosonic and fermionic T-duality transformations. With A. Pittelli (Surrey, UK), we performed an exhaustive study of the fermionic T-dualities, showing in each case that a singularity in the transformation could not be avoided, Phys.Rev. D93 (2016) no.8, 086010. We reached the conclusion that fermionic T-duality, a transformation initially introduced by N. Berkovits and J. Maldacena, could not account for symmetries seen in the scattering amplitudes. We are currently looking for ways to generalise fermionic T-duality.

3) With H. Yavartanoo (Kavli Institute, Beijing), we studied entanglement entropy holographically. The motivation of this work was largely to provide a viable alternative to a method of Hubeny, Rangamani and Takayanagi (HRT) for identifying the extremal surfaces used in the calculation of holographic entanglement entropy. The HRT method, although general, is not very practical as it involves solving tricky second order equations. Our approach involved using supersymmetry, which suppresses the equations to first order. In the concrete case of AdS3 spacetimes, we showed that supersymmetry may be exploited to identify the extremal surfaces. The manuscript is under review at Classical & Quantum Gravity. We are in the process of extending this study to higher dimensions, so that the entanglement entropy of higher-dimensional CFTs may

also be determined holographically.

4) Our group initiated work with J. Sakamoto, K. Yoshida (Kyoto) and M. M. Sheikh-Jabbari (IPM, Tehran). We studied integrable Yang-Baxter deformations of the geometry AdS5 x S5 and noted that there is a corresponding open string metric that is always undeformed and all information about the original integrable deformation is encoded in a noncommutative parameter. We identified two new equations that the integrable deformations in this new description should satisfy and gave a physical interpretation for a known algebraic condition that distinguishes supergravity solutions. In the case of supergravity solutions, we showed that the noncommutative parameter must be divergence-free.

5) Thiago Araujo has led a project with H. Nastase (IFT Sao Paulo) on the pp-wave limit of a well-known AdS4 solution to massive IIA supergravity. This extends work that Thiago completed upon arrival at APCTP, arXiv: 1609.08008. We are in the process of finishing the project.

- **Members**

Name	Title	Nationality	Period
Eoin O Colgain	Leader/Prof.	Ireland	2015.12.01~2018.11.30
Thiago Araujo	Dr.	Brazil	2016.09.21~2018.08.31
Ilya Bakhmatov (with YST)	Dr.	Russia	2016.09.21~2017.09.20

2-7. Particle Physics and the Early Universe

- **Leader:** Chang Sub Shin (PhD., KAIST, Korea (2012))
- **Period:** Since Sep. 1, 2016 ~ Aug. 31, 2019
- **Overview**

  The group is performing systematic studies to answer the following questions.

  1) What is the nature of dark matter and its cosmological implication?

  2) What is the origin of matter-antimatter asymmetry and how can we identify it by experiments?

  3) What is the correct solution to the fine-tuning problems in the Standard Model (SM) of particle physics, and its unavoidable consequences?

  It is still unclear the form of new sector beyond the SM, because of no clear hint on that. The null results of the several experiments are stimulating to extend our understanding of new physics, and various possibilities are actively studied compared to several years ago. Their observable consequences are very interesting. One of the great hopes is that on-going and planned cosmological observations of CMB, gravitational waves, large and small scale structure can provide the information about the details of new sector and early history of the Universe. The systematic study on such possibilities is most important goal of the group, “particle physics and the early Universe”.

- **Research**

  This year, I with two students finished the work with a preprint number, APCTP Pre2016-021 [arxiv:1611.02287] about the effect of history of the early Universe on dark matter phenomenology. We study the effect of the elastic scattering on the non-thermal WIMP, which is produced by direct decay of heavy particles at the end of reheating. The non-thermal WIMP becomes important when the reheating temperature is well below the freeze-out temperature. Usually, two limiting cases have been considered. One is that the produced high energetic dark matter particles are quickly thermalized due to the elastic scattering with background radiations. The corresponding relic abundance is determined by the thermally averaged annihilation cross-section at the reheating temperature. The other one is that the initial abundance is too small for the dark matter to annihilate so that the final relic is determined by the initial amount itself. We study the regions between these two limits, and show that the relic density depends not only on the annihilation rate, but also on the elastic scattering rate. Especially, the relic abundance of the p-wave annihilating dark matter crucially relies on the elastic scattering rate because the annihilation cross-section is sensitive to the dark

matter velocity. We categorize the parameter space into several regions where each region has distinctive mechanism for determining the relic abundance of the dark.

- **Member**

Name	Title	Nationality	Period
Chang Sub Shin	Leader/Prof.	Korea	Sep. 1, 2016 ~ Aug. 31, 2019

2-8. Biological and Soft Matter Theory

APCTP RESEARCH REPORT

Asia Pacific Center for Theoretical Physics

Personal Data

- Name: YongSeok Jho
- Date of birth: July 22, 1976
- Nationality: Korea
- Email: ysjho@apctp.org
- Whole contract period (& expected): 2011. 5. 1 ~ 2016. 4. 15

Main Research Fields

- Soft matter physics

Topics of Research

(1) Structural water in bio- and soft matter

(2) Understanding of charged polymer complexes

(3) Searching for general interaction formula for nanoscale charged molecules in water beyond mean-field approximation

Summary of Research

The junior research group had successfully carried out its missions to understand the fundamental electrostatics and dynamics in bio- and soft-matter system. The JRG focused on three long term goals which are significant in bio- and soft-matter system because of its ubiquitous presence and generality. (1) Structural water in bio- and soft matter (2) Understanding of charged polymer complexes (3) Searching for general interaction formula for nanoscale charged molecules in water beyond mean-field approximation. All topics are the central issues in bio-and soft-matter society. The JRG had actively studied on these problems with original idea. For successful study, the JRG strongly interacted with theoretical and experimental groups in both domestic and international.

List of attending Conferences, Seminars, School etc.

Invited Talks

1. "The repulsion between oppositely charged planar macroions." 4th DMGT workshop, Sendai, Feburary 26-March3, 2012
2. "Charge interactions in biological systems", KPS Meeting, Daejeon, April 25-27, 2012
3. "Inhomogenieties in highly charged biosystem", Workshop on Coulomb Many-body Systems, Shanghai, June 11-15, 2012
4. "Inhomogeneity in charged colloids", Seminar, August 10, Lehigh University, 2012
5. "Interactions between charged colloids in bio-and soft-matter", September 19-20, ISBM opening workshop, Changwon national university, 2012
6. "Numerical studies on the projection domains of neurofilaments", KPS Meeting (special seesion), PyeongChang, October 24-26, 2012
7. "Electrostatics in bio and soft matter", Colloquium in Physics Department, PNU, April 3, 2013
8. "Charged polymers at interface", 4th IBSM workshop, CWNU, April 5, 2013
9. "Electrostatics of charged polymer brush", 고분자학회 (Korea Society of Polymer), Daejeon, April 11, 2013
10. "Charge interactions in soft matter (5 hours lecture)", Summer School on Soft Material Interfaces, CWNU, July 17-19, 2013
11. "Charge interaction in water", Sogang University, Seoul, July 24, 2013
12. "Charges in biological system", KSMB, Jeju, August 21, 2013
13. "연성물질 계의 하전현상", 에너지 공정 세미나, Sogang University, Seoul, Dec. 6, 2013
14. "Interaction and charge condensation of inhomogeneously charged colloids", ISM Seminar, Georgetown University, Jun. 20, 2014
15. "Bundle formation from like charged polymers", Korean Polymer Society Meeting, Daejeon, April. 9, 2015
16. "Charge condensation", Discussion meeting on Polymer Physics Theory, APCTP, Pohang, May 22, 2015
17. "Macroscopic Phase Separation of Like Charged Polymers", Korean Polymer Society Meeting, Daejeon, April. 8, 2016

List of Publications

1. "Long-Range Interaction between Heterogeneously Charged Membranes", **Y. S. Jho***, R. Brewster, S. A. Safran, and P. A. Pincus, Langmuir, (27) 4439, 2011
2. "Effect of Charge Inhomogeneity and Mobility on Colloid Aggregation", **Y. S. Jho***, S. A. Safran, M. In, and P. A. Pincus, Langmuir, (28) 8329, 2012
3. "Directed motion of elongated active polymers", M.B. Wan, and **Y.S. Jho***, Soft Matter, (9) 3255, 2013

4. “Nanomechanics of Cation–π Interactions in Aqueous Solution”, Qingye Lu, Dongyeop Oh, YongJin Lee, **Y.S. Jho**, Hongbo Zeng, Dong Soo Hwang, Angew. Chem. Int. Ed. (52) 3944, 2013
5. “Repulsion between Oppositely Charged Planar Macroions”, **Y.S. Jho***, Frank L. H. Brown, M. W. Kim, and P. A. Pincus, PLoS ONE, 8(8): e69436, 2013
6. “The synaptotagmin 1 linker may function as an electrostatic zipper that opens for docking but closes for fusion pore opening”, Ying Lai, Xiaochu Lou, **YongSeok Jho**, Tae-Young Yoon, and Yeon-Kyun Shin, BioChem J., (456) 25, 2013
7. “Limiting law excess sum rule for polyelectrolytes”, Phys. Rev. E, J. Landy, Y.J. Lee, **Y.S. Jho*** (88) 052315, 2013
8. “Phase transition in similarly charged rodlike polyelectrolyte solutions”, 4th international symposium on slow dynamics in complex systems, A. Constantinescu, and **Y.S. Jho*** (1518) 558, 2014
9. “Nematic Phase Emergence in Solutions of Similarly Charged Rodlike Polyelectrolytes”, JPSJ, A. Constantinescu, and **Y.S. Jho*** (83) 014002, 2014
10. “Contact time- and pH-dependent adhesion and cohesion of lowmolecular weight chitosan coated surfaces”, Chanoong Lim, Dong Woog Leeb, Jacob N. Israelachvilia, **YongSeok Jho**, Dong Soo Hwang, Carbohydrate Polymers, (117) 887, 2015
11. “Cation–π interaction in DOPA-deficient mussel adhesive protein mfp-1”, Sangsik Kim, Ali Faghihnejad, Youngjin Lee, **Yongseok Jho***, Hongbo Zeng*, Dong Soo Hwang*, J. Mater. Chem. B, (3) 738, 2015
12. “Electrostatic Interaction between Nonuniformly Charged Colloids: Experimental and Numerical Study”, Claire Derot, Lionel Porcar, YongJin Lee, Phillip A. Pincus, **YongSeok Jho***, and Martin In*, Langmuir, (31) 1649, 2015
13. “Charge renormalization for ellipsoidal macroions”, **YongSeok Jho***, J. Landy, P.A. Pincus, ACS Macro Letters, (4) 640, 2015
14. “Entangled polymer complexes as Higgs phenomena”, K.S. Kim, S. Dutta, **Y.S. Jho***, Soft Matter, (11) 7932, 2015
15. “General differential contact identities for macromolecules”, J. Landy, P.A. Pincus, **YongSeok Jho***, Physical Review Letter, (115) 167801, 2015
16. “Micro-structural change in water evaporation: from first order to second order phase transition”, S.M. Jeong, **Y.S. Jho***, X. Zhou*, Scientific Report, (5) 15955, 2015
17. “Hydration of ions in two-dimensional water”, S. Dutta, **Y.S. Jho***, Physical Review E, (92) 042152, 2015
18. “Strong Coupling electrostatic theory of polymer counterions close to planar charges”, S. Dutta, and **Y.S. Jho***, Physical Review E, (93) 012504, 2016
19. “Bundling in semiflexible polymers: a theoretical overview”, P. Benetatos, **Y.S. Jho***, Advances in Colloid and Interface Science, (232) 114, 2016
20. “Complexation and coacervation of like-charged polyelectrolytes inspired by mussels”,

Sangsik Kim, Ali Faghihnejad, Youngjin Lee, Sandipan Dutta, **Yongseok Jho***, Hongbo Zeng*, Dong Soo Hwang* PNAS, (113) E847-E853, 2016

21. "Shell formation in short like-charged polyelectrolytes in a harmonic trap", Sandipan Dutta, **Y.S. Jho*,** Physical Review E (93) 012503, 2016
22. "Adsorption of highly charged Gaussian polyelectrolytes onto oppositely charged surfaces", Sandipan Dutta, **Y.S. Jho*,** The Journal of Chemical Physics, (144) 094902, 2016
23. "Chiral nematic self-assembly of minimally surface damaged chitin nanofibrils and its load bearing functions", Dongyeop X. Oh, Yoon Jeong Cha, Hwaheon Je, **YongSeok Jho**, Dong Soo Hwang, Dong Ki Yoon, Scientific Reports (6) 23245, 2016
24. "Bundle formation in parallel aligned polymers with competing interactions", S. Dutta, P. Benetatos*, and **Y.S. Jho***, EPL, (114) 28001, 2016
25. "Bicontinuous Fluid Structure with Low Cohesive Energy: Molecular Basis for Exceptionally Low Interfacial Tension of Complex Coacervate Fluids", H.Y. Yoo, **Y.S. Jho***, S.I. Han*****, D.S. Hwang*****, ACS Nano, (10) 5051, 2016
26. "Inositol Pyrophosphates Inhibit Synaptotagmin-Dependent Exocytosis", Tae-Sun Lee , Joo-Young Lee , Yoosoo Yang , Seung Ju Park , Seulgi Lee , Igor Pavlovic , Byoungjae Kong , **YongSeok Jho** , Henning J Jessen , Dae-Hyuk Kweon , Yeon-Kyun Shin , Tae-Young Yoon , Seyun Kim, PNAS, (113) 8314, 2016
27. "Monte Carlo Simulation of the Neurofilament Brush", SeongMin Jeong, Xin Zhou, Ekaterina B. Zhulina*, and **YongSeok Jho***, Isr. J. Chem. , (56) 599, 2016

In what ways could APCTP be improved?

I believe that the APCTP researchers' competence is very high and can become leaders in physical society under the generous support of APCTP. Since the reputation of APCTP is mainly from the accomplishment of residential researchers, it would be good to have more chance to reflect residential researcher's idea to APCTP management. As an extension of this, the presence of permanent researchers can be helpful to defend the position of residence researchers.

Please add comments on living and study environments at APCTP.

Overall, I am most grateful for the strong supports from APCTP. It was my great honor being a part of APCTP. One and only thing I would like suggest is, if APCTP listen more to its researchers' opinion and perhaps let them be a part of the decision making process, researchers can improve their research environment which eventually improves their performance. This would be great benefit to APCTP, too.

Date: March 1, 2017

Name: YongSeok Jho

Signature: 

2-9. Emergent Dynamics of Complex Living Systems

APCTP RESEARCH REPORT

Asia Pacific Center for Theoretical Physics

Personal Data

- Name : Pan-Jun Kim
- Date of birth : Dec 3, 1979
- Nationality : Republic of Korea
- Email : pjkim@apctp.org
- Whole contract period (& expected): Dec 1, 2011 to Nov 30, 2016

Main Research Fields

- Biological Physics, Computational Systems Biology, Complex Systems

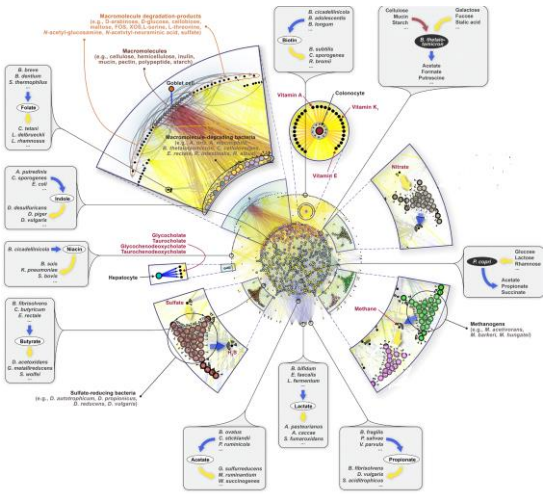
Topics of Research

I focus on a broad area of research activities at the interface between biology and physics. Recent technologies have generated enormous amount of biological data at various scales. Computational methodologies developed in physics, mathematics, and engineering enable analyses of such data, allowing scientists to gain insights that will bring leaps of fundamental understanding of complex biological processes, and may ultimately lead to breakthroughs in improving human medicine. I am interested in providing a quantitative framework for unraveling the collective behavior of biomolecules, cells, and organisms, aided by systematic analyses of large-scale biological datasets. Surprisingly, a number of key concepts developed by such biological research may also be useful to study a broad range of non-equilibrium systems other than just biological ones. The followings are specific research subjects addressed over the last five years: (i) core biomolecular networks in a cell, such as gene-regulatory circuits in circadian rhythm system, genome-scale metabolic networks, and transcriptomic signatures of disease phenotypes, (ii) organisms-and-environment interactions, such as microbe-microbe interactions, microbe-host interactions, host-nutrition interactions, indigenous microbes, and antibiotic-tolerant mechanisms, (iii) statistical methods to infer biological interactions from experimental datasets, and (iv) application of biological concepts to understand non-biological/miscellaneous systems.

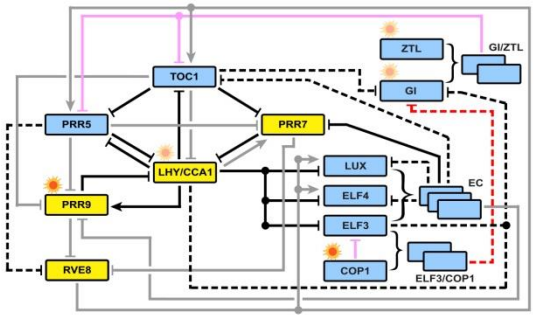
Summary of Research

Interim Statement

Systems biology of the human microbiome Numerous microbes in the human gut are metabolically interacting with each other and with the host. This complex ecosystem, often called the human gut microbiota, is linked not only to our normal physiology, but also to various disorders such as obesity, inflammatory bowel disease, cancer, and diabetes. I and my colleagues constructed the first literature-based global network of the human gut microbiota, with microbe-microbe and host-microbe metabolic interactions mediated by various chemicals (submitted to *Nature Communications*, under review). As a mechanistic way to explore disease-associated microbiota, our network analysis was conducted for type 2 diabetes (T2D) patients. It reveals core microbial groups with distinctively large metabolic influence, and commonalities in metabolic functions, but not in taxonomic profiles, across different patient populations. Interestingly, we found that supposedly benign gut microbes may contribute towards disease by their metabolic products (known to be nontoxic or even beneficial to the host), which can in fact maintain the structural integrity of a T2D-specific microbial community. Our system-level approach provides important insight into a therapeutic strategy against microbiota-related diseases.



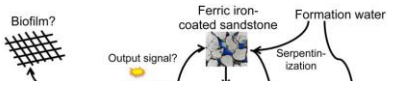
Network structure of the human gut microbiota, which I and my colleagues constructed (under review, *Nature Communications*).



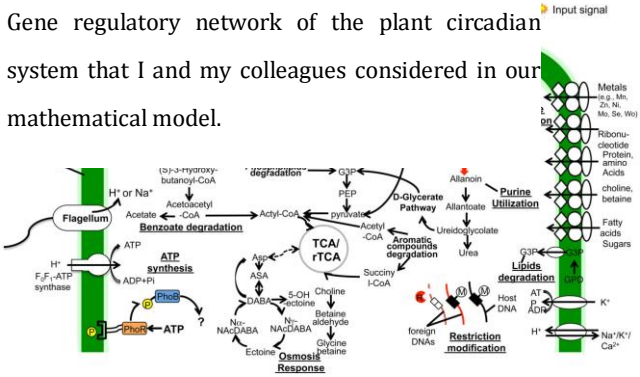
Predictive computational models of cellular or organismal phenotypes Gene regulatory networks and metabolic networks play an essential role in connecting genotype to phenotype. As an example of predictive models for the dynamics of gene regulatory networks, I and my colleagues built a highly accurate mathematical model of the circadian system in plant *Arabidopsis thaliana* (*PLOS Comput. Biol.* **12**, e1004748). Our analysis successfully identifies a critical genetic circuitry for clock function, and explains why the plant clock circuitry is overwhelmingly composed of inhibitory, rather than activating, interactions among genes. I also studied cellular metabolism with the genome-scale computational model

of yeast *Saccharomyces cerevisiae* to identify which genes can be knocked out to increase ethanol yield (*J. Biotechnol*. **194**, 48).

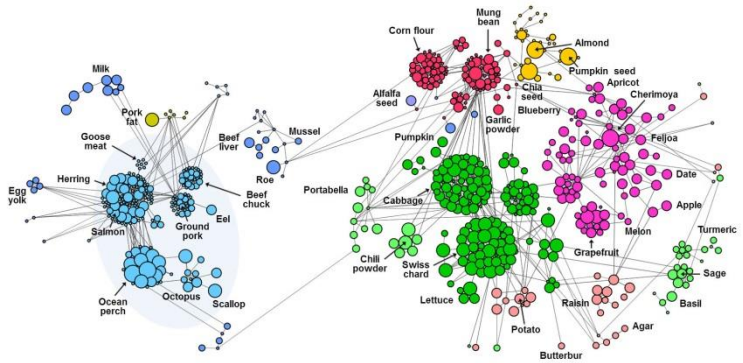
Metagenomic study of environmental microbial communities Astonishingly little is known of the subsurface reservoir of biodiversity, despite our civilization's regular access to and exploitation of subterranean environments. To address this gap in knowledge, we collected microbial samples from a sandstone reservoir 1.8 kilometers below the surface. A genomic study and analysis of the microbes revealed a microbial community dominated by *Halomonas sulfidaeris*-like bacteria. These bacteria are able to utilize iron and nitrogen from their surroundings and recycle scarce nutrients to meet their metabolic needs. Most importantly, we found that the microbes were capable of metabolizing aromatic hydrocarbons, a common component of petroleum.



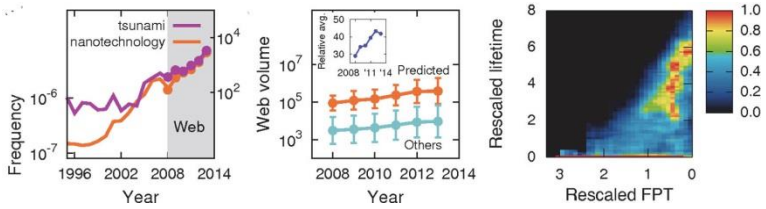
Gene regulatory network of the plant circadian system that I and my colleagues considered in our mathematical model.



Large-scale analysis of food and nutrition The study of foods and nutrients is essential for designing healthy diets. Using information from over 1,000 raw foods, we systematically identified nutritionally-precious foods, as well as the factors underlying their nutritional balance, from a global network of foods. One review article (Nutrition Bulletin 40, 296) described our work as *"An elegant paper published this year ... This computational framework has the potential to show unexpected associations and synergies that, in principle, could help to improve the quality of food-based dietary guidelines and thus encourage adoption and compliance."*



Technology evolution in society The quest for historically impactful science and technology provides invaluable insights into the innovation dynamics of human society. Here, we investigated scientific



evolution through systematic analysis of a massive corpus of digitized books published over ~200 years. Our data analysis with mathematical modeling reveals remarkable predictability for, and patterns of, scientific evolution. Our approach sheds light on unbiased and quantitative analysis of scientific evolution in society, and may provide a useful basis for R&D policy.

Interim Plan

1. Background and Motivation

Human microbiome I will devote my efforts to understanding, predicting, and controlling the dynamics and function of our resident microbial community, often called the human microbiota or microbiome, from a systems and mechanistic viewpoint. Among various microbial habitats on Earth, our human body is the site of an extraordinarily complex and dynamic ecosystem. The journal Science highlighted the human microbiome as one of the most important discoveries during the past decade. Recent advances in sequencing technologies and metagenomics have revealed significant associations between the human microbiome and our health and disorders, such as obesity, inflammatory bowel disease, cancer, and diabetes. Motivated by its scientific and medical significance, there exist large consortiums for the metagenomic study of the human microbiome, exemplified by "The Human Microbiome Project" in the United States and "Metagenomics of the Human Intestinal Tract" in Europe.

Rationale for the research Although there has been a rapid increase of worldwide scientific interest in the human microbiome research, a major challenge is to go beyond association studies and elucidate causalities and mechanisms.

In the human body, the most densely colonized is the large intestine, wherein colonic microbes survive and grow by consuming diet-derived and host-derived chemical compounds as well as metabolic byproducts excreted by other microbes. Undigested dietary macromolecules and host-derived substrates are broken down by microbial species, and then the solubilized molecules become available to other members of the community as public goods for uptake. Additionally, inherent microbial activities with importing metabolic resources and exporting metabolic byproducts give rise to competition for metabolic resources and cooperative relations such as cross-feeding of metabolic byproducts, among resident microorganisms in the gut environment. Furthermore, microbial metabolic byproducts have active roles in normal host physiology, and sometimes can be toxic to host tissues by impairing their function. These intricate microbe-microbe and microbe-host interconnections serve the formation of a complex ecological system in the human gut environment. The emergent community structure is forcing the realization that, notwithstanding the importance of

individual microbial species, the microbiome dynamics and consequent impact on the host would be largely attributed to the collective activities of numerous microbial species and chemical compounds, thoroughly interlinked by network relationships. This realization calls for an integrative systems approach for unravelling the complexity of the human gut microbiome and for designing its therapeutic interventions.

To make a breakthrough in this direction, I will develop a mathematical framework to describe complex microbe-microbe and microbe-host interaction dynamics at the gut ecosystem level and to elucidate the causal relationships between the microbial inner workings and host physiology. Through my predictive mechanistic modeling approach, I will analyze the emergent population dynamics of the gut microbiome and will further develop its effective control strategy. This research is required to achieve system-level mechanistic insights into the dynamics and function of the human microbiome.

2. Methods

Curation of the human gut microbiome network My research group has already constructed the global interspecies interaction network of the human gut microbiome mediated by metabolite transport. The information upon which the network architecture stands is primarily mechanistic and of high-quality literature annotations, reflecting current biological or experimental knowledge. However, the links between microbes and metabolic compounds in our current network reflect simple binary information of the presence or absence of the connections, but not their quantitative strength. For the mathematical modeling of microbial growth dynamics, this purely connectivity-based network structure is not enough by itself, and I will overlay the network with the information of each link weight. I expect that the resulting network will have the links categorized by their functional significance for each microbial species.

Modeling the community dynamics Mediated through the exchange of metabolic and signaling compounds, the network relationship between microbes, and between microbes and the host, will induce the compositional changes of the microbiome. To model such microbial community dynamics, I will consider several mathematical approaches. At the finest level, for well-characterized organisms, I can adopt constraint-based flux analysis, as these organisms have manually-curated genome-scale metabolic models. For the organisms which lack the detailed information of their biochemical pathways, I can employ relatively simple kinetic models based on literature evidence and –omics information. For the coarse-grained analysis of the whole community dynamics, the Boolean modeling can be considered – this is not for the actual population simulation itself, but for a posterior analysis of the simulation results. The model will consider both well-mixed and spatially-structured

environments, which will eventually mimic the human intestinal structure. I will model the host system separately, and will combine it with the microbial community model. This microbe-host interaction system will enable the simulation of its feedback processes and the resulting functional impacts. The simulation will be performed in various health and disease contexts, incorporating the context-specific meta-omics data. I will utilize the simulation results to account for and predicting the disease onset and progression by correlating the results to patient-derived time-course data.

Developing the community control strategy After constructing the model of the community dynamics, I will investigate the systematic methodology to find which combinations of microbial populations should be perturbed (added or removed) to modify or shift the whole system dynamics (specifically, the attractor of the system) into a desirable state. Likewise, a certain combination of chemical compounds can be added to the media to modify the system dynamics. The former is related to an application for the probiotics or targeted antibiotics to improve health and treat disease, while the latter corresponds to an application for the prebiotics for similar purposes. To this end, I will evaluate a global attractor structure of the system, and will calculate the minimal perturbations to shift one attractor to another.

Incorporation of experimental evidence The above modeling and control-strategy design works will be performed by intimate comparison with experimental knowledge and datasets. Time-course data of microbial populations and host physiology, various biochemical parameters, and meta-omics data will be used for the model construction, validation, and modification. To obtain the experimental data, I can either rely on publicly available data sources or can collaborate with experimentalists.

3. Significance

The study of the human microbiome from a systems perspective is highly compatible with scientific or engineering subjects in diverse disciplines, including microbial ecology, systems biology, and human medicine. I believe that my study will set the foundation for scientific endeavors, on both computational and experimental sides, to establish the fundamental principles of systems biology of microbial creatures and their relationships with host physiology. Furthermore, this work could offer a theoretical framework for the rational design of clinical strategies, such as in the selection of microbes or chemical compounds needing to be provided or removed for effective therapeutic interventions.

List of attending Conferences, Seminars, School etc.

Presentations

• "I am my microbes: the story of our gut ecosystem", APCTP 2016 Workshop on Frontiers of

Physics: Push the Envelope of Statistical Physics (POSTECH, Pohang, Korea, Dec 2016)

- "Network science approach to food, nutrients, and microbiome", The Asia Pacific Nutrigenomics and Nutrigenetics Organisation (APNNO) 2016 Inaugural Conference (Hilton Hotel, Gyeongju, Korea, Dec 2016)
- "Tackling large biological networks: circadian clock and human microbiome", APCTP-ICTP Joint Workshop: Quantitative Life Sciences (APCTP Headquarters, Pohang, Korea, Nov 2016)
- "The nutritional landscape of food", The 3rd International Disaster Management Workshop (KAIST, Daejeon, Korea, Sep 2016)
- "Gut microbiota, network, and immune system: towards a global mechanistic framework", School of Animal and Comparative Biomedical Sciences, University of Arizona (Tucson, Arizona, US, Sep 2016)
- "Large-scale approach to complex biological systems", Center for Theoretical Physics of Complex Systems, Institute for Basic Science (Daejeon, Korea, Aug 2016)
- "Core regulatory circuitry of the plant circadian system", Intelligent Systems for Molecular Biology (ISMB 2016) (Orlando, Florida, US, Jul 2016)
- "대사 네트워크 흐름의 전산 분석", 2016 Biophysics Summer School: Information and Energy in Life (APCTP Headquarters, Pohang, Korea, Jul 2016)
- "Tackling large-scale biological networks", The 7th Discussion Meeting on Polymer Physics Theory (APCTP Headquarters, Pohang, Korea, Jun 2016)
- "Scientific evolution in digitized books, modeling, and future perspective", Networks and Technology Evolution (Satellite Symposium of the International School and Conference on Network Science, NetSci 2016) (The K-Hotel, Seoul, Korea, May 2016)
- "Tackling large biological networks: circadian clock and human microbiome", I am My Phenotypes: Bringing Biological Networks into Phenotypic Contexts (NetIMP 2016; Satellite Symposium of the International School and Conference on Network Science, NetSci 2016) (The K-Hotel, Seoul, Korea, May 2016)
- "Global metabolic interaction network of the human gut microbiota with community-level disease implications", The 1st International Meeting on Intestinal Diseases in Conjunction with the Annual Congress of the Korean Association for the Study of Intestinal Diseases (IMKASID 2016) (Nine Tree Convention, Seoul, Korea, Apr 2016)
- "I am my genes, wire, and microbes", Center for Complex Networks and Systems Research, Indiana University (Bloomington, Indiana, US, Mar 2016)
- "Tackling biological complexity: circadian clock and human microbiome", Mathematical Biosciences Institute, Ohio State University (Columbus, Ohio, US, Mar 2016)
- "Large-scale approach to complex biological systems", APCTP 2015 Workshop on Frontiers of Physics (The Ocean Resort, Yeosu, Jeollanam-do, Korea, December 2015)
- "Core genetic circuitry for plant circadian rhythms", APCTP 2015 Workshop on Frontiers of Physics (The Ocean Resort, Yeosu, Jeollanam-do, Korea, December 2015)

- “Large-scale approach to complex biological systems”, 2015 Fall Department of Physics Colloquium (Pukyong National University, Busan, Korea, December 2015)
- “Large-scale approach to complex biological systems I”, ICTP Affiliated Center Kick-Off Workshop (APCTP Headquarters, Pohang, Korea, December 2015)
- “Uncovering the nutritional landscape of food”, 2016 Keystone Symposia Conference T1: Human Nutrition, Environment and Health (Beijing, China, October 2015)
- “Anatomy of scientific evolution based on millions of digitized books”, Quantitative Methods for Predicting, Explaining and Describing Technological Change: Conference on Complex Systems (CCS’15) Satellite Meeting (Tempe, Arizona, US, September 2015)
- “Core regulatory network of the plant circadian system”, Network Biology Monthly Meeting (Korea University, Seoul, Korea, June 2015)
- “Food, nutrients, microbes, and your health”, Network-Enabled Wisdom for the Personalized Medicine of the Complex Diseases (NetMed15; Satellite Symposium of the International School and Conference on Network Science, NetSci2015), (Zaragoza, Spain, June 2015)
- “Deciphering the kernel structure in the regulatory network of the plant circadian system”, Network Models in Cellular Regulation (NetSciReg'15; Satellite Symposium of the International School and Conference on Network Science, NetSci 2015), (Zaragoza, Spain, June 2015)
- “Global interaction network of the human gut microbiota”, The 11th Korea Genome Organization (KOGO) Winter Symposium 2015 (Daemyung Resort, Hongcheon, Gangwondo, Korea, February 2015)
- “Food and nutrition: what the human body wants”, Physics of Social Complexity (PoSCo) (POSTECH, Pohang, Korea, January 2015)
- “Emergent dynamics of complex living systems”, APCTP 2014 Workshop on Frontiers of Physics (Muju, Jeollabuk-do, Korea, December 2014)
- “Food and nutrition: what the human body wants”, Recent Progresses in Theoretical Physics (Gyeongju, Korea, December 2014)
- “Global metabolic interaction network of the human gut microbiota”, Research and Communication (NIH, Osong, Korea, November 2014)
- “Structure of scientific evolution based on millions of digitized books”, Quantifying Success 2.0: European Conference on Complex Systems (ECCS14) Satellite Meeting (IMT Institute for Advanced Studies, Lucca, Italy, September 2014)
- “몇 억년 간의 동행: 내 안에 너 있다”, Communication of Science, Culture and Art (Sobaeksan Optical Astronomy Observatory, Danyang, Korea, July 2014)
- “Global interaction network of the human gut microbiota”, The 22nd Federation Meeting of Korean Basic Medical Scientists 2014 (COEX, Seoul, Korea, June 2014)
- “Structure of scientific evolution based on millions of digitized books”, 81st Statphys Monthly Meeting (KIAS, Seoul, Korea, May 2014)

- "Systems biology of human gut microbiota", 2014 Spring Meeting of the Korean Physical Society (DCC, Daejeon, Korea, April 2014)
- "Global organization of human gut microbiota", 2014 Spring Meeting of the Korean Physical Society (DCC, Daejeon, Korea, April 2014)
- "Global analysis of human nutrition and food: what the human body wants", Network Frontier Workshop (Evanston, Illinois, US, December 2013)
- "Systems biology of human microbiome", The 2nd Discussion Meeting on Polymer Physics (APCTP Headquarters, Pohang, Korea, November 2013)
- "Evolution: what makes biology and technology look similar", Computational Methods for Bio and Complex Systems (KIAS, Seoul, Korea, July 2013)
- Advanced IT and Health System Joint Workshop POSTECH and Catholic University (POSTECH, Pohang, Korea, June 2013)
- "Metagenomic analysis of microbial systems", The 5th CWNU-KAIST-APCTP Innovative Workshop on Soft/Bio Materials (CWNU, Changwon, Korea, May 2013)
- "Collective dynamics in technology", Workshop on Interdisciplinary Approaches of Web Science (KAIST, Daejeon, Korea, April 2013)
- "Sociology in the genetic world", IES-APCTP Mini-Workshop on Quantitative Approach to Biological Complexity (POSTECH, Pohang, Korea, Feb 2013)
- "Criticality and neuronal dynamics", 2013 Winter School on Computational Neuroscience (POSTECH, Pohang, Korea, Jan 2013)
- "Cellular variability and biochemical reactions", Workshop on Dynamics and Regulation of Biomolecular Networks (Hong Kong Baptist University, Hong Kong, Dec 2012)
- "Sociology in the genetic world", TBC 2012 / BIOINFO 2012, Translational Bioinformatics & Genomics, 48 (Hyatt Regency Jeju, Jeju Island, Korea, Oct 2012)
- "Sociology in the genetic world", [수리적 뇌기능 판독을 통한 뇌 정보처리 방식 이해와 지능형 IT 원천기술] 공동 연구기관 워크숍 (Seacloud Hotel, Busan, Korea, June 2012)
- "Sociology in the genetic world", China-Japan-Korea International Conference on Mathematical Biology (Pusan National University, Busan, Korea, May 2012)
- "Microbes everywhere: Metagenomic perspective", 2012 Spring Meeting of the Korean Physical Society (DCC, Daejeon, Korea, April 2012)
- "Sociology in the genetic world", 67th Statphy Monthly Meeting (KIAS, Seoul, Korea, March 2012)
- "Sociology in the genetic world", 2012 Spring I-BIO Seminar (POSTECH, Pohang, Korea, March 2012)
- "Inferring networks from data", 9th KIAS-APCTP Winter School on Statistical Physics (POSTECH, Pohang, Korea, January 2012)
- "Biocomplexity and statistical physics", APCTP-JRG Workshop on Recent Topics in Theoretical Physics (APCTP Headquarters, Pohang, Korea, December 2011)

List of Publications

(marked with * for corresponding authors)

- J. Sung, S. Kim, J. J. T. Cabatbat, S. Jang, Y.-S. Jin, G. Y. Jung, N. Chia, P.-J. Kim*, "Global metabolic interaction network of the human gut microbiota with community-level disease implications", submitted to *Nature Communications* (under review)
- M. Foo, D. E. Somers, P.-J. Kim*, "Kernel architecture of the genetic circuitry of the *Arabidopsis* circadian system", PLOS Comput. Biol. 12, e1004748 (2016)
  – *Awarded by NetSciReg'15, "Best Abstract", and selected by ISMB 2016 as "Highlights Track"*
- J. Sung, V. Hale, A. C. Merkel, P.-J. Kim, N. Chia*, "Metabolic modeling with big data and the gut microbiome", Appl. Transl. Genomics 10, 10 (2016)
  – *Ranked as most downloaded articles*
- J.-S. Kim, D.-H. Cho, P. Heo, S.-C. Jung, M. Park, E. J. Oh, J. Sung, P.-J. Kim, S. Lee, D.-H. Lee, S. Lee, C. H. Lee, D. Shin, Y.-S. Jin*, D.-H. Kweon*, "Fumarate-mediated persistence of *Escherichia coli* against antibiotics", Antimicrob. Agents Chemother. 60, 2232 (2016)
- Y. Lee, W. Hwang, J. Jung, S. Park, J. J. T. Cabatbat, P.-J. Kim, S.-J. V. Lee*, "Inverse correlation between longevity and developmental rate among wild *C. elegans* strains", Aging 8, 986 (2016)
- S. Kim, J. Sung, M. Foo, Y.-S. Jin, P.-J. Kim*, "Uncovering the nutritional landscape of food", PLOS ONE 10, e0118697 (2015)
  – *Featured in major Korean news media*
  – *Selected by APCTP as "Remarkable Accomplishment in 2015"*
- J. Yun, P.-J. Kim*, H. Jeong*, "Anatomy of scientific evolution", PLOS ONE 10, e0117388 (2015)
  – *Featured in Physics Today "The Dayside" and MIT Technology Review "Other Interesting arXiv Papers"*
- M. Foo, D. E. Somers, P.-J. Kim*, "System identification of the *Arabidopsis* plant circadian system", J. Korean Phys. Soc. 66, 700 (2015)
- J. Quarterman, S. R. Kim, P.-J. Kim, Y.-S. Jin*, "Enhanced hexose fermentation by *Saccharomyces cerevisiae* through integration of stoichiometric modeling and genetic screening", J. Biotechnol. 194, 48 (2015)
- P.-J. Kim, "Systems biology: communication between physics and biology", Physics and High Technology, Jan/Feb, p 10 (2014)
  – *Invited review paper*
- Y. Dong, C. G. Kumar, N. Chia, P.-J. Kim, P. A. Miller, N. D. Price, I. K. O. Cann, T. M. Flynn, R. A. Sanford, I. G. Krapac, R. A. Locke II, P.-Y. Hong, H. Tamaki, W.-T. Liu, R. I. Mackie, A. G. Hernandez, C. L. Wright, M. A. Mikel, J. L. Walker, M. Sivaguru, G. Fried, A. C. Yannarell, B. W. Fouke*, "*Halomonas sulfidaeris*-dominated microbial community inhabits a 1.8 km-deep subsurface Cambrian Sandstone reservoir", Environ. Microbiol. 16, 1695 (2014)
  – *Featured in ScienceDaily, Science World Report, R&D Magazine, Astrobiology Web, Phys.org,*

and Technology.org

- J. Sung, P.-J. Kim, S. Ma, C. C. Funk, A. T. Magis, Y. Wang, L. Hood, D. Geman, N. D. Price*, "Multi-study integration of brain cancer transcriptomes reveals organ-level molecular signatures", PLOS Comput. Biol. 9, e1003148 (2013)
- P.-J. Kim, N. D. Price*, "Genetic co-occurrence network across sequenced microbes", PLOS Comput. Biol. 7, e1002340 (2011)

In what ways could APCTP be improved?

Regular faculty meeting between JRG Leaders and executive director is needed. It has been a while since the last meeting, and I think a some degree of regularity of this meeting will be helpful to connect the JRG Leaders themselves, and JRG Leader and the APCTP Leadership.

Whenever a new member joins APCTP (new JRG Leader, new YST, new postdoc, new visitor, etc), some formal or informal opportunity to introduce them to existing APCTP members are needed. Currently, such opportunities are seriously lacking except for occasional seminars organized by some Leaders who have interest in those new comers. Recently, it has taken significant time even for me to recognize who were new comers.

Because JRG Leader is a temporal position, there is no "senior" JRG Leader at APCTP. It means that, when a new JRG Leader joins APCTP, he or she should get a Leadership advice from his or her informal roots; otherwise, there is no intramural source for such advice. I suggest APCTP to manage its own orientation or mentoring program for new JRG Leaders.

Please add comments on living and study environments at APCTP.

It was excellent to me, and I have no further comment on the working environment itself.

Date: Dec 11, 2016

Name: Pan-Jun Kim

Signature: 

VI. Reports of Scientific Outreach Programs in 2016

1. Aim of Scientific Outreach Programs
2. Data of Scientific Outreach Programs
   2-1. Publications
   2-2. Forums, Lectures, Schools, etc.

1. Aim of Scientific Outreach Programs

- Enhance the importance of basic science and attract more people to world of physics
- Provide a friendly atmosphere where the general public and scientists can interact with each other to promote popularization of physics

2. Data of Scientific Outreach Programs

2-1. Publications

Creation and distribution of high-quality scientific literary contents by the AP scientist network

■ On-line Web-journal "Crossroads"

(1) Lead the Vision for Science, Future and Humanity
- Build up a network for scientist in the Asia-Pacific region and set an example of science web-journal
- Expand the base of science and lead its popularization by communicating with scientists

(2) Published monthly on-line in Korean
-Volume 12 Issue 1 ~ Issue 12

(3) Total number of 116 articles
- APCTP People (6), APCTP Plaza(12), Cross Street(24), Science Fiction(9), APCTP Everywhere(16), Special Section(49)

■ Total Number of Visitors and Page Views

Item	2014	2015	2016
Visitors (Page Views)	198,239 (330,636)	248,464 (414,769)	354,513 (551,141)

■ The Number of Visitors Worldwide

Year	Korea	USA	Japan	Canada	Beijing
2014	100,594	55,701	516	13,064	2,749
2015	74,222	123,679	658	18,016	2,511
2016	113,591	175,747	990	28,958	3,815
Year	**UK**	**Germany**	**Etc.**	**Total**	
2014	186	440	24,989	**198,239**	
2015	186	633	28,559	**248,464**	
2016	3,067	982	27,363	**354,513**	

2-2. Forums, Lectures, Schools, etc.

■ Science Communication Forum/Lecture

Science Communication Forums/Lectures demonstrate hot scientific issues of the year to the public. Physicists and Scientists are invited to share their research and discuss scientific issues.

No	Topic	Period	Venue	Speaker	Participants
1	Science Books Lectures(I)	Mar.10	Seodaemun Museum of Natural History	Beom Jun Kim (SKKU)	67
2	Science Books Lectures(II)	Mar.17	Seodaemun Museum of Natural History	San Ha Kim (The Biodiversity Foundation)	62
3	Science Books Lectures(III)	Mar.24	Seodaemun Museum of Natural History	Sin Yeong Yoon (Donga Science)	30
4	Science Books Lectures(IV)	Mar.31	Seodaemun Museum of Natural History	Gang Yeong Lee (Gyeongsang Nat'l Univ.)	62
5	Science Books Lectures(V)	Apr.7	Seodaemun Museum of Natural History	Jong Pil Lee (Konkuk Univ.)	52
6	Communication of Science, Culture and Art(I)	Jun.29-Jul.1	Sobaeksan Optical Astronomy Observatory	Jeong Won Lee (ETRI) & Dong Geun Gam (Ajou Univ.)	25
7	Science Books Lectures(VI)	Jul.14	Seodaemun Museum of Natural History	Dong Gwang Kim (Science Writer)	57
8	Science Books Lectures(VII)	Jul.21	Seodaemun Museum of Natural History	Sang Wook Kim (Pusna Nat'l Univ.)	71
9	Science Books Lectures(VIII)	Aug.11	Seodaemun Museum of Natural History	Ji Min Ahn (Daejeon Metropolitan Office of Education)	57
10	Science Books Lectures(IX)	Aug.18	Seodaemun Museum of Natural History	Ha Eung Lee (UNIST)	59
11	Science Books Lectures(X)	Aug.25	Seodaemun Museum of Natural History	Jin Yeong Park (Seodaemun Museum of Natural History)	52
12	Transdisciplinary Research(I)	Aug. 26	APCTP Headquarter	Yeong Min Song (GIST) & Jae Gwon Han (Hanyang Univ.)	10

13	Communication of Science, Culture and Art(II)	Sep.28-30	Sobaeksan Optical Astronomy Observatory	Geong Guen Oh (NIMS) & Min Soo Sin (KASI)	26
14	Transdisciplinary Research(II)	Oct.15	APCTP Branch Office	Beom Jun Kim (SKKU) & Gang Hwan Lee (Seodaemun Museum of Natural History)	6
15	Public Lecture:	Dec. 22	APCTP Headquarters	Pubit Yun (Mimer)	62
Total					698

■ Science Communication School

Science Communication Schools provide the university students with science writing class and debating & presentation programs at the Center.

Topic	Period	Venue	Participants
Survival in space	Feb. 1-3, 2016	APCTP, Pohang	23

■ "Best Science Book 10" selected by APCTP (December 2016)

(1) The best science books are selected and promoted by APCTP for a wide readership.

(2) The Asia Pacific Network Evening (To announce 'Best Science Book 10' and to express gratitude for supporting to the APCTP): APCTP Headquarters, Pohang, Dec. 23, 2016

No	Title	The date of Issue	Author
1	Genome Express	Aug. 18, 2016	Jin Ho Cho
2	Sang Wook Kim's Science Study	Jul. 6, 2016	Sang Wook Kim
3	Atom, the Immortal	Jun. 30, 2016	Gang Yeong Lee
4	Stuff Matters: The Strange Stories of the Marvellous Materials that Shape Our Man-made World	Apr. 1, 2016	Mark Miodownik
5	Artificial Intelligence: A Modern Approach	Jan. 29, 2016	Stuart Russell, Peter Norvig
6	The Invention of Nature: Alexander Von Humboldt's New World	Jul. 11, 2016	Andrea Wulf
7	Gravitational-wave, the Last Gift from Albert Einstein	Feb, 29, 2016	Geong Guen Oh
8	Murmurs of Earth	Sep. 2, 2016	Carl Edward Sagan, Ann Druyan
9	How Not to Be Wrong: The Power of Mathematical Thinking	Apr. 25, 2016	Jordan Ellenberg
10	When Science and Technology Studies (STS) is attentive to Science	Sep. 21, 2016	Seong Uk Hong

■ **Science in City Hall**

Science in City Hall is held with Pohang City which includes high quality science lectures and programs combining Science, Education, Art, and Experience.

No	Topic	Period	Venue	Speaker	Participants
1	The Value of Basic Science/Einstein's final gift, Gravity wave	Mar. 26, 2016	Pohang City Hall	Peter Fulde (MPKPKS), Chang Hwan Lee (Pusan Nat'l Univ.)	548

■ **Pohang Family Science Festival**

Pohang Family Science Festival is held with Pohang City to stimulate interest in science through wider participation and to nurture science leaders from the local area.

No	Topic	Period	Venue	Participants
1	Happy Pohang with Science!	Sep. 24-25, 2016	Pohang Sports Complex	130,000

VII. Reports of Cooperation with International Organizations in 2016

1. Cooperation with International Organizations in 2016

1. Cooperation with International Organizations in 2016

1-1. APEC

The Center was established with support of APEC two decades ago and active cooperation has been made based on the relation re-establishment with APEC in 2014. Further to the cooperation, in 2016, the Center opened a conference for cooperation and joint research with the other 7 APEC endorsed Centers. At the conference, the Pohang Declaration was adopted, and it was reported and approved at the 8th APEC PPSTI Meeting held in Lima, Peru.

■ Overview of the 1st APEC PPSTI Cooperation Conference

- Period: 9 ~ 11 June 2016
- Venue: POSCO International Center, Pohang
- Participants: around 30 people including delegations from 8 APEC PPSTI Centers

APEC PPSTI Centers	Est. Year & Location	Mission and Objectives
APCTP (Asia Pacific Center for Theoretical Physics)	1996, Korea	Lead the world in theoretical physics research, facilitate international collaboration, and contribute to the advancement of physics by training young physicists from the Asia Pacific region
APEC CTF (APEC Center for Technology Foresight)	1998, Thailand	Develop and diffuse foresight capability and leading edge planning tools to prepare APEC Economies for rapid change and major societal challenges
ACES (APEC Cooperation for Earthquake Simulation)	1999, Australia	Develop realistic supercomputer simulation models for the complete earthquake generation process, thus providing a "virtual laboratory" to probe earthquake behavior
APEC Center for Technology Transfer	2002, China	Provide integrated support to SMEs to enhance their STI capacity
APCC (APEC Climate Center)	2005, Korea	Enhance the socio-economic well-being of member economies by utilizing up-to-date scientific knowledge and applying innovative climate prediction techniques through climate prediction, interdisciplinary research, climate information services, and international cooperation.
AMGS (APEC Mentoring Center for the Gifted in Science)	2006, Korea	Promote cross mentoring research activities through a network between mentors & mentees and build and operate the mentor-mentee pool among scientist, science education professionals and gifted students in science from APEC economies for continuing exchange programs and joint research activities
APEC Center for Advanced Biohydrogen Technology	2010, Taipei	Solve problems of the air and water pollutions by creating a science-based collaboration framework between academia, research institute and private sectors for sharing the domain knowledge
ACTS(APEC Research Center for Typhoon & Society)	2010, Taipei	Through regional cooperation to improve scientific understanding of typhoon and heavy rain, promote socio-economic awareness on typhoon-heavy rain impacts and social vulnerabilities, and establish a platform that will facilitate experience sharing

- Pohang Declaration

Asia-Pacific
Economic Cooperation

Pohang Declaration

Pohang, Republic of Korea
June 11, 2016

We, the representatives of the APCTP (Asia Pacific Center for Theoretical Physics), APEC CTF (APEC Center for Technology Foresight), ACES (APEC Cooperation for Earthquake Simulation), APECTT (APEC Center for Technology Transfer), APCC (APEC Climate Center), AMGS (APEC Mentoring Center for the Gifted in Science), ACABT (APEC Research Center for Advanced Biohydrogen Technology), ACTS (APEC Research Center for Typhoon and Society), participating in the APEC-PPSTI "APEC Centers" Cooperation Conference, held in Pohang from 9 to 11 of June 2016, having considered the APEC and PPSTI's mission, and aiming to promote better life, sustainable economic growth, creation of jobs and tackling of common challenges including inter alia climate change and environmental issues for the region through science, technology and innovation, declare as follows:

1. We affirm that the Centers actively engage in and support the advancement of and cooperation in science, technology and innovation which contributes to the regional growth and development.

2. We reiterate the Centers' involvement in research and development pursuing PPSTI's mission and wider APEC goals.

3. We secure our human and financial resources, and with the support of APEC as appropriate, prepare adequate environments that support our longer term involvement.

4. We invite the member economies to engage constructively in the work of the Centers.

5. We encourage the Centers to promote cooperation, share information, conduct collaborative activities and joint projects, and regularly report outcomes to the PPSTI.

APCTP (Asia Pacific Center for Theoretical Physics) est. in 1996
APEC CTF (APEC Center for Technology Foresight) est. in 1998
ACES (APEC Cooperation for Earthquake Simulation) est. in 1999
APECTT (APEC Center for Technology Transfer) est. in 2002
APCC (APEC Climate Center) est. in 2005
AMGS (APEC Mentoring Center for the Gifted in Science) est. in 2006
ACABT (APEC Research Center for Advanced Biohydrogen Technology) est. in 2010
ACTS (APEC Research Center for Typhoon and Society) est. in 2010

1-2. AAPPS

At the AAPPS 33rd Council Meeting held in December 2016, AAPPS Headquarters installation at the Center's Headquarters was reported. Together with the renewal of MoU with AAPPS, the Center and AAPPS have agreed that the Center would carry out AAPPS administrative functions (general affairs, treasurer, etc.), manage and operate AAPPS Council homepage and AAPPS Bulletin homepage and operate AAPPS Bulletin. It is expected that the Center would take on role as the focal point of the Asia-Pacific physics community's international academic activities.

■ Extract from the Minutes

The Minutes of the 33rd Council Meeting of the AAPPS

The 33rd Council Meeting of the Association of Asia Pacific Physical Societies (AAPPS) was held at Brisbane Convention and Exhibition Centre, Brisbane, Australia, on December 4, 2016.

(omitted)

The president reported that the council (fifteen out of sixteen members) resolved the APCTP-AAPPS cooperation proposal through email voting on December 1, 2016. He proposed on November 14, 2016 that in order to facilitate the effective implementation and operation of the joint action initiative according to the MOU between AAPPS and APCTP renewed on October 15, 2016, AAPPS should expand and formalize the existing administrative functions at APCTP by making APCTP an administrative headquarters. He reported on the progress of its implementation and operation.

(omitted)

VIII. List of Publications in 2016

1. Publications by APCTP Researchers
2. Publications supported by APCTP

1. Publications by APCTP Researchers

■ Number of Publications : 66

1) Jaiyul Yoo, **Jinn-Ouk Gong**, Relativistic effects and primordial non-Gaussianity in the matter density fluctuation, Physics Letters B, 754 (Jan 2016) 94–98 DOI: 10.1016/j.physletb.2016.01.021

2) Sandipan Dutta, **Y. S. Jho**, Shell formation in short like-charged polyelectrolytes in a harmonic trap, PHYSICAL REVIEW E **93**, 012503 (Jan 2016), DOI: 10. 1103 / PhysRevE.93.012503

3) Sandipan Dutta, **Y. S. Jho,** Strong-coupling electrostatic theory of polymer counterions close to planar charges, PHYSICAL REVIEW E 93, 012504 (Jan 2016) DOI: 10.1103/PhysRevE.93.012504

4) Sangsik Kima, Jun Huang, **Yongjin Lee**, **Sandipan Dutta**, Hee Young Yoo, Young Mee Jung, **YongSeok Jho**, Hongbo Zeng, Dong Soo Hwang, Complexation and coacervation of like-charged polyelectrolytes inspired by mussels, PNAS E847-E853 (Feb 2016), DOI: 10.1073/pnas.1521521113

5) Panayotis Benetatosa, **YongSeok Jho**, Bundling in semiflexible polymers: A theoretical overview, Advances in Colloid and Interface Science 232 (Jan 2016) 114–126, DOI: 10.1016/j.cis.2016.01.001

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7) Tetsutaro Higaki, Kwang Sik Jeong, **Naoya Kitajima**, Fuminobu Takahashi, The QCD axion from aligned axions and diphoton excess, Physics Letters B 755 (Feb 2016) 13–16, DOI: 10.1016/j.physletb.2016.01.055

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DOI:10.1007/JHEP01(Jan 2016)026

9) **Sukjin Yoon**, Franco Dalfovo, Takashi Nakatsukasa, **Gentaro Watanabe**, Multiple period states of the superfluid Fermi gas in an optical lattice, New J. Phys. 18 (Jan 2016) 023011, DOI:10.1088/1367-2630/18/2/023011

10) **Mathias Foo**, David E. Somers, **Pan-Jun Kim**, Kernel Architecture of the Genetic Circuitry of the Arabidopsis Circadian System, PLOS1004748 (Feb 2016), DOI: 10.1371/journal.pcbi.1004748

11) **R Jafari**, Quench dynamics and ground state fidelity of the one-dimensional extended quantum compass model in a transverse field, IOP 1751-8113, DOI:10.1088/1751-8113/49/18/185004

12) Jun-Seob Kim, Da-Hyeong Cho, Paul Heo, Suk-Chae Jung, Myungseo Park, Eun-Joong Oh, Jaeyun Sung, **Pan-Jun Kim**, Suk-Chan Lee, Dae-Hee Lee, Sarah Lee, Choong Hwan Lee, Dongwoo Shin, Yong-Su Jin, Dae-Hyuk Kweon, Fumarate-Mediated Persistence of *Escherichia coli* against Antibiotics, Antimicrobial Agents and Chemotherapy 2232-2240 (Apr 2016), DOI:10.1128/AAC.01794-15

13) **Bhaskar Kamble**, **Alireza Akbari**, Ilya Eremin, Investigation of magnetic phases in parent compounds of iron-chalcogenides via quasiparticle scattering interference, EPL, 114 (Apr 2016) 17001, DOI: 10.1209/0295-5075/114/17001

14) **Chanyong Park,** Thermodynamic law from the entanglement entropy bound, PHYSICAL REVIEW D 93, 086003 (Apr 2016), DOI: 10.1103/PhysRevD.93.086003

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Phenomena of Ultracold Atomic Gases in Optical Lattices: Emergence of Novel Features in Extended States, *Entropy (Mar* 2016) *18*, 118, DOI:10.3390/e18040118

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25) Ryuji Daido, **Naoya Kitajima,** Fuminobu Takahashi, Level crossing between the QCD axion and an axionlike particle, PHYSICAL REVIEW D 93, 075027 (Apr 2016), DOI: 10.1103/PhysRevD.93.075027

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27) **Danh-Tai Hoang, B. Prasanna Venkatesh,** Seungju Han**, Junghyo Jo, Gentaro Watanabe,** Mahn-Soo Choi, Scaling Law for Irreversible Entropy Production in Critical Systems, SCIENTIFIC REPORTS 27603(Jun 2016), DOI: 10.1038/srep27603

28) Ki-Seok Kim, **Chanyong Park**, Emergent geometry from field theory: Wilson's renormalization group revisited, PHYSICAL REVIEW D 93, 121702(R) (Jun 2016), DOI: 10.1103/PhysRevD.93.121702

29) Jaiyul Yoo, **Jinn-Ouk Gong,** Exact analytic solution for non-linear density fluctuation in a ΛCDM universe, JCAP07(July 2016)017, DOI: 10.1088/1475-7516/ 2016/ 07/ 017

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2. Publications supported by APCTP

■ Number of Publications : 6

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IX. Photos in 2016

Photos of APCTP

▪ Focus Research Programs

Focus Programs

Topical Research Programs

▪ Academic Programs

Schools

Conferences & Workshops

External Activities

Joint Activities

▪ Junior Research Groups (JRG)

JRG Workshops

JRG Group Meetings

▪ Benjamin Lee Professorship

Lecture Series

▪ Scientific Outreach Programs

Pohang Family Science Festival

Science Books Lectures

Science Communication School

Communication of Science, Culture and Art

Science in City Hall