Spin and thermal evolution of compact stars

…and more

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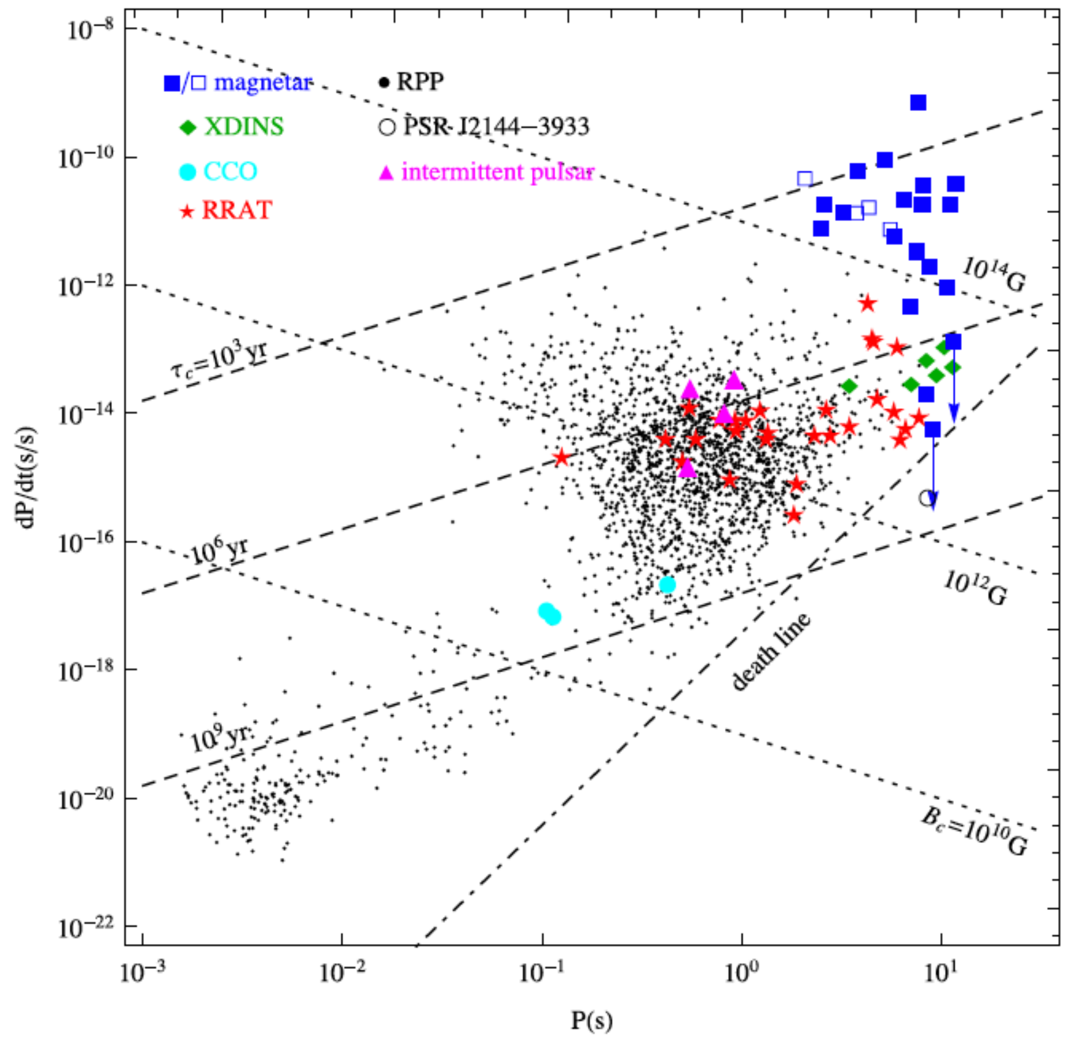
Outlines

- Background
- What we have done
    - Cooling
    - Longest spin period
    - R-mode instability
- Future prospects

Background

Observations

- Mass and radius measurement of compact objects
- Thermal emission from compact objects
- Spin history: spin period, glitch, breaking index
- GW radiation from binary neutron star merger



Zhou et al., 2017, MNRAS

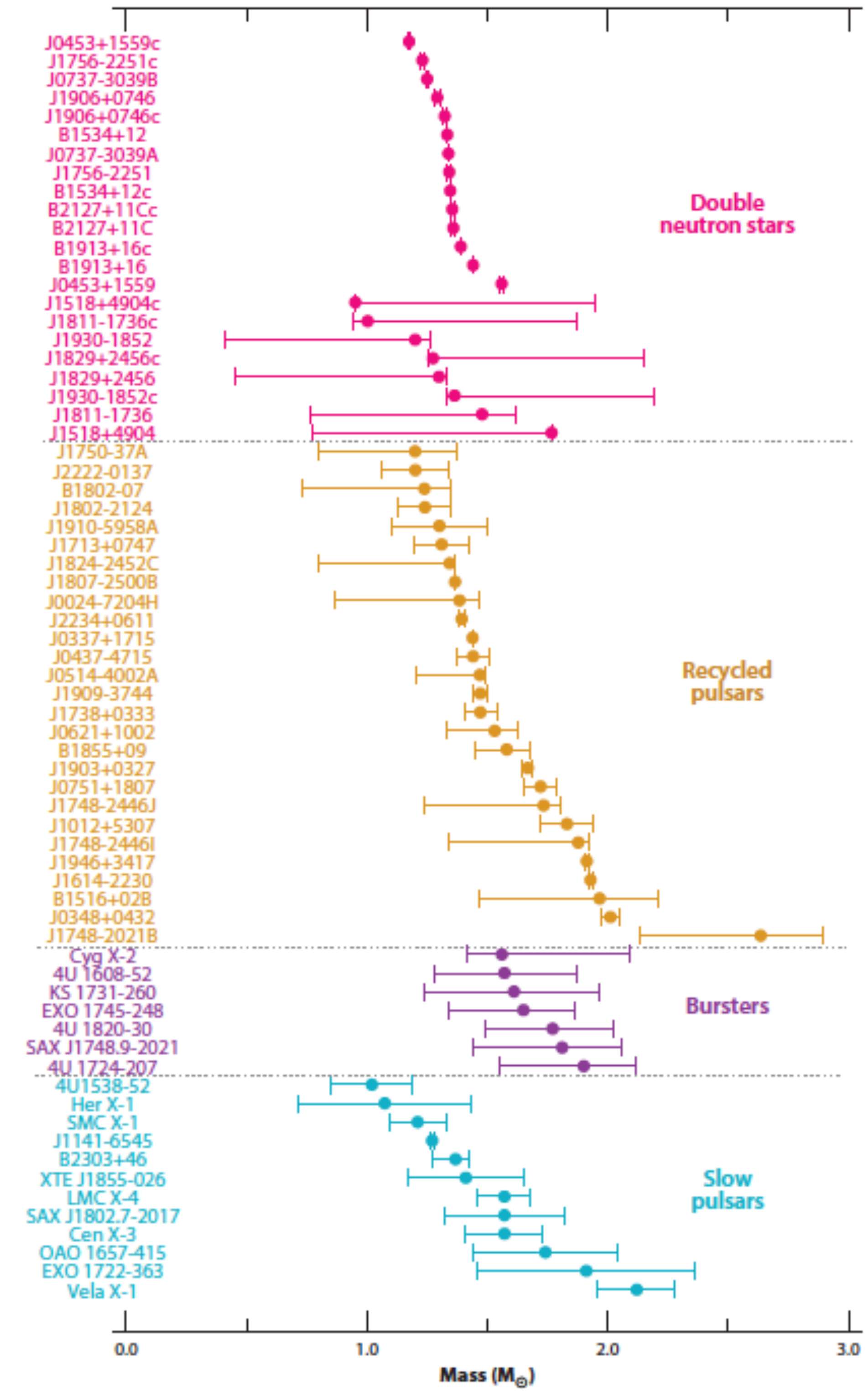
Observation constraints on the dense matter in the interior of compact stars

Mass and radius measurement

- high maximum-mass of massive pulsars
  - PSR J1614-2230: $M = 1.93 \pm 0.02 M_{\odot}$
  - PSR J0348+0432: $M = 2.01 \pm 0.04 M_{\odot}$
  - PSR J0740+6620: $M = 2.14^{+0.1}_{-0.09} M_{\odot}$
- radii measurements
  - Smallest radius: self-bound QS

(Zhou et al., 2017,MNRAS)

- GW170817: tidal deformability->EoS

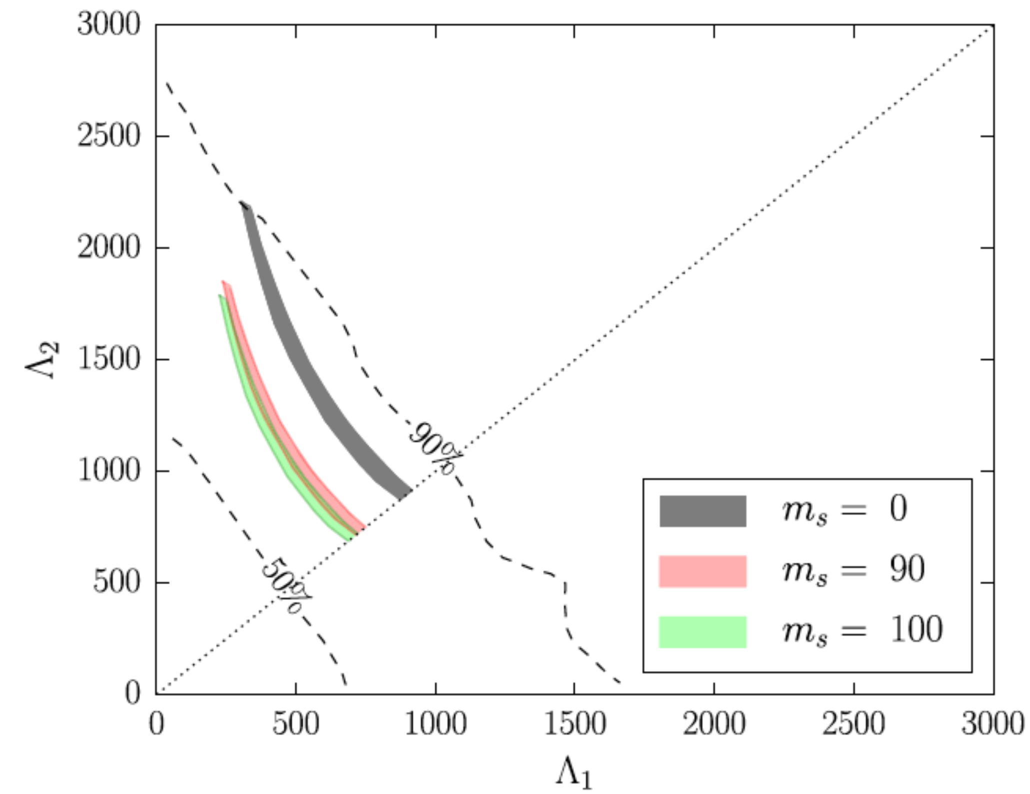


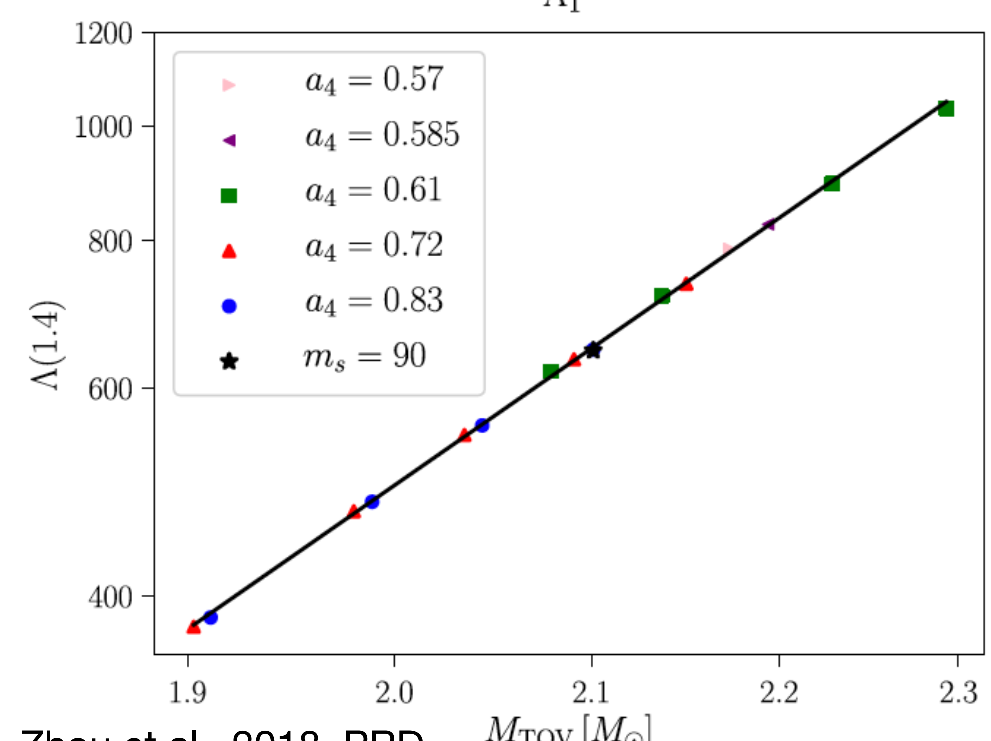
Ozel & Freire, 2016, Ann. Rev. AA

Mass and radius measurement

- Constraints on inter-quark interaction parameters with GW170817 in a binary strange star scenario
  - New parameter ranges from GW170817
  - Strong $\Lambda(1.4) - M_{TOV}$ correlation
  - $M_{TOV} \leq 2.18$ (2.32 with superfluid) for quark star within MIT model
  - Possible future： More massive pulsars can not reconcile in the model, QS out?

PSR J2215+5135: $2.27^{+0.17}_{-0.15} M_{\odot}$ (Linares et al., 2018, ApJ)





Zhou et al., 2018, PRD

Cooling of compact stars

- Detection of thermal emission from compact objects
- Thermal evolution equations

$$\frac{L_r}{4\pi\kappa r^2} = -\sqrt{1-\frac{2Gm}{rc^2}}e^{-\Phi_g}\frac{\partial}{\partial r}\left(Te^{\Phi_g}\right) ,$$

$$\frac{1}{4\pi r^2 e^{2\Phi_g}}\sqrt{1-\frac{2Gm}{rc^2}}\frac{\partial}{\partial r}\left(e^{2\Phi_g}L_r\right) = -Q_\nu - \frac{C_v}{e^{\Phi_g}}\frac{\partial T}{\partial t}$$

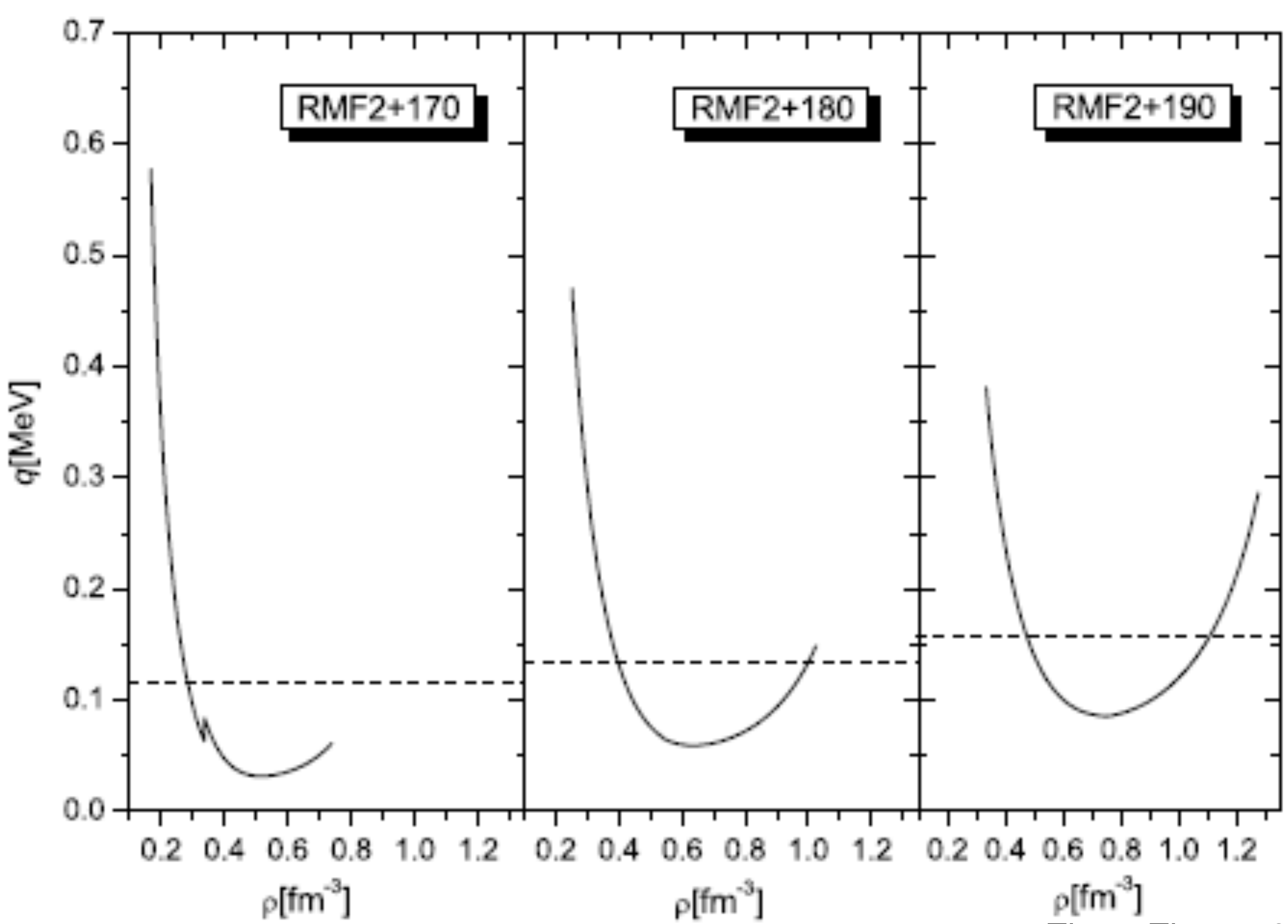
  - Neutrino emission: fast cooling/slow cooling, superfluid,
  - Heating mechanism: energy conversion(Zhu et al., 2017, CPC; Zhou& Zheng, 2009APRIM, 2014PLB)
  - Envelope models: heavy elements/light elements(e.g. H/He induce higher surface temperature)
  - Age: characteristic age, kinetic age

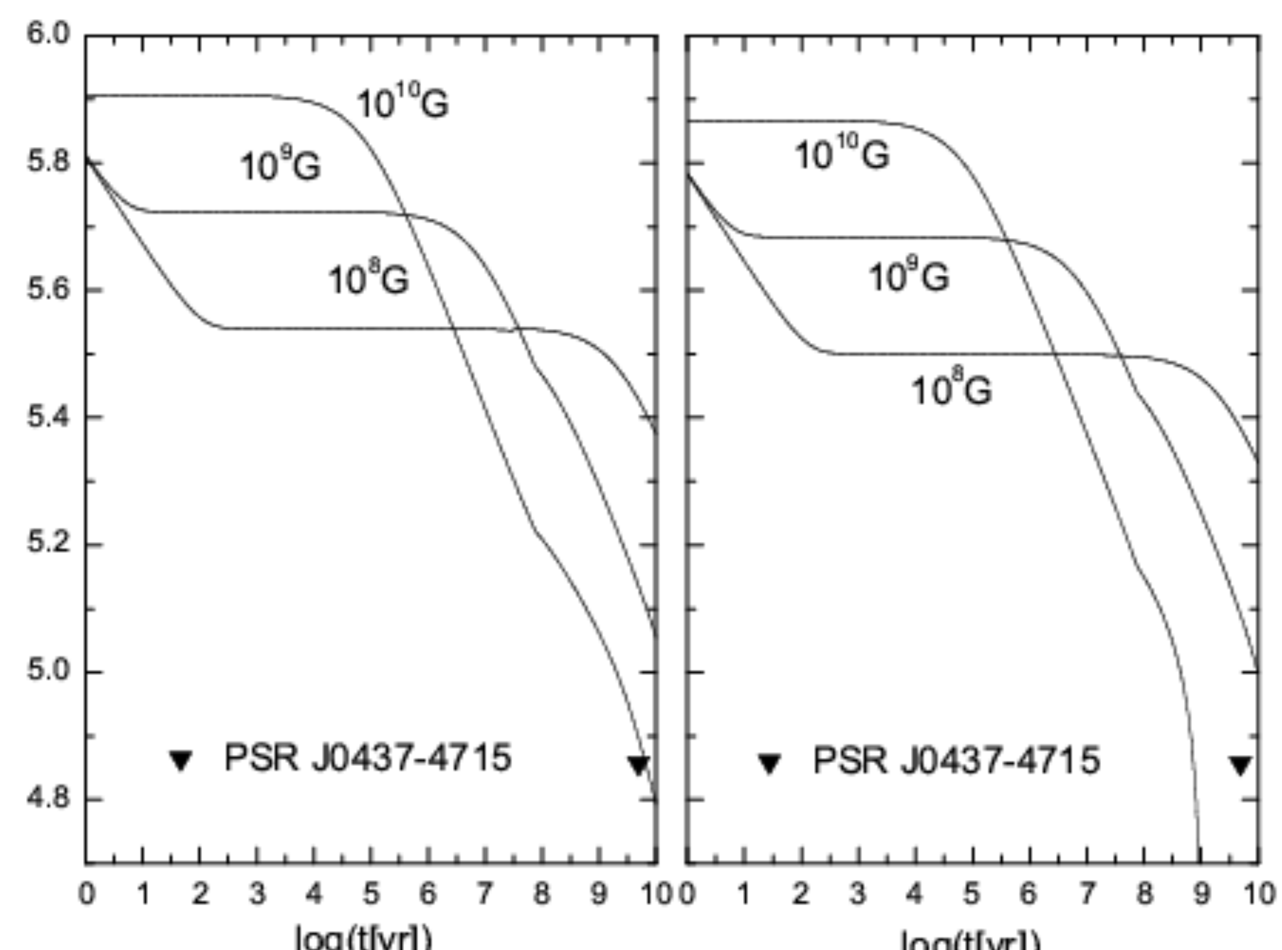
Cooling of compact stars

- Heating mechanisms: deconfinement heating

We present self-consistent thermodynamics description and identify the microphysics responsible for the confinement processes.

$$q \equiv \delta\mu = \left(\left(\frac{\partial e}{\partial \rho} \right)_{\eta} - \frac{de}{d\rho} \right) \left(\frac{d\eta}{d\rho} \right)^{-1}$$

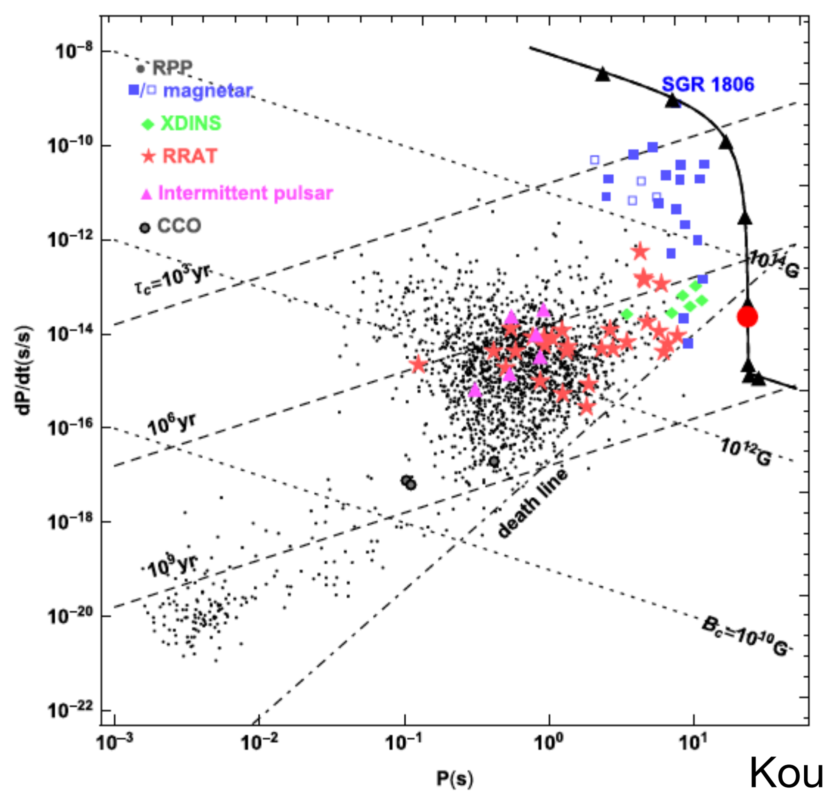


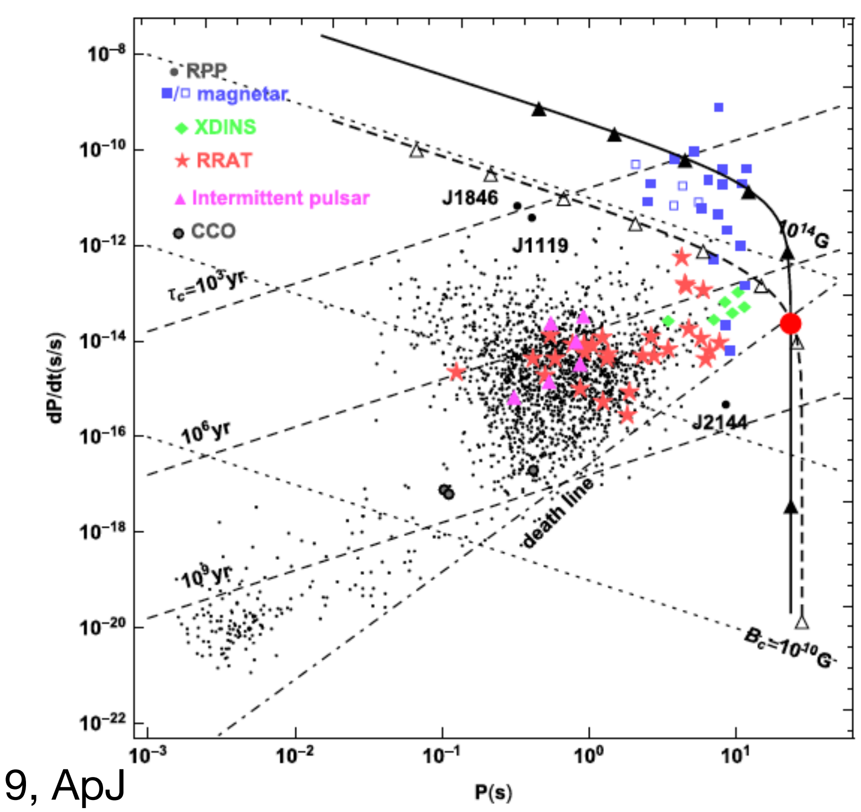


Zhou, Zheng, 2009APRIM, 2014PLB

Spin history

- Spin history: braking mechanism, glitch, longest spin-period
  - PSR J0250+5854: $P = 23.5s, \dot{P} = 2.7 \times 10^{-14} s/s$
    - the lowest rotating radio pulsar detected to date
    - spin-down models of magnetospheric evolution and magnetic field decay





Kou et al., 2019, ApJ

GW from rotating compact stars

- f-mode instability
- r-mode instability
- Magnetic deformations
- Mountains
- Pulsar glitches

GW from rotating compact stars

- f-mode instability
- **r-mode instability**
- Magnetic deformations
- Mountains
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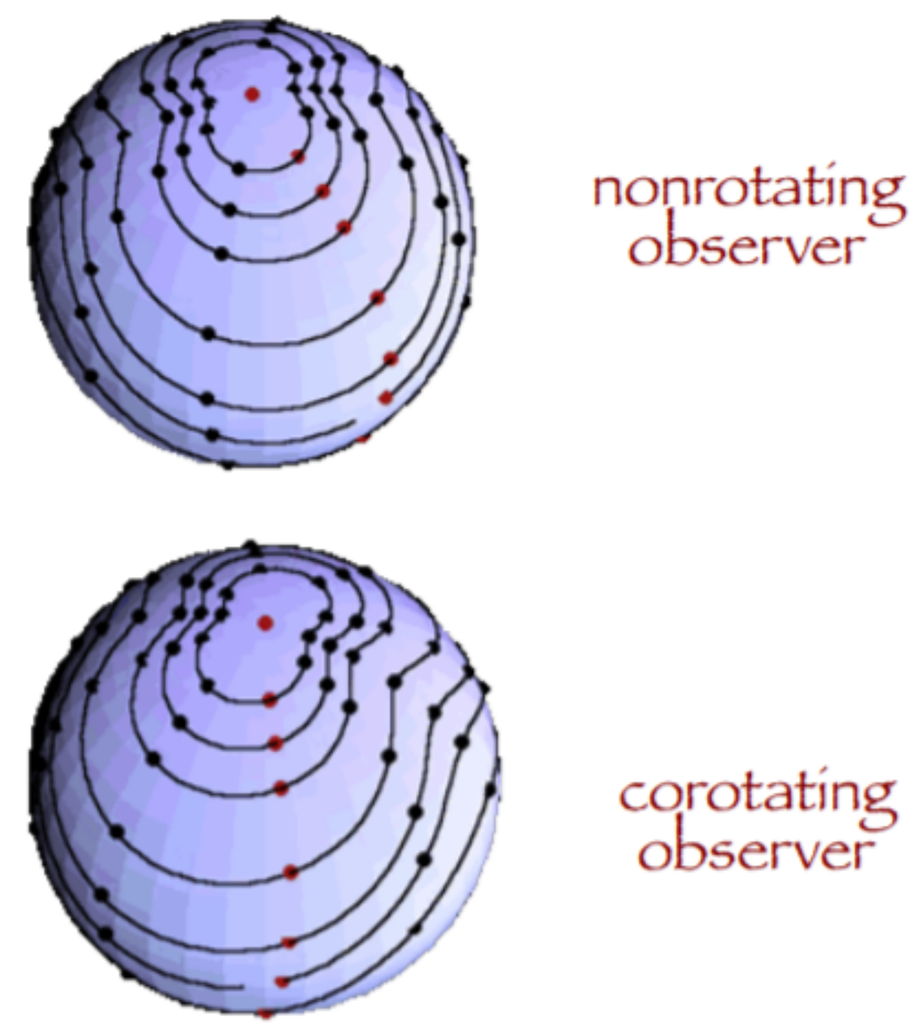
r-mode instability

R-modes in a perfect fluid star with arbitrary rotation arise due to the action of the Coriolis force with positive feedback increasing gravitational radiation (GR)
(Andersson 1998; Friedman & Morsink 1998)

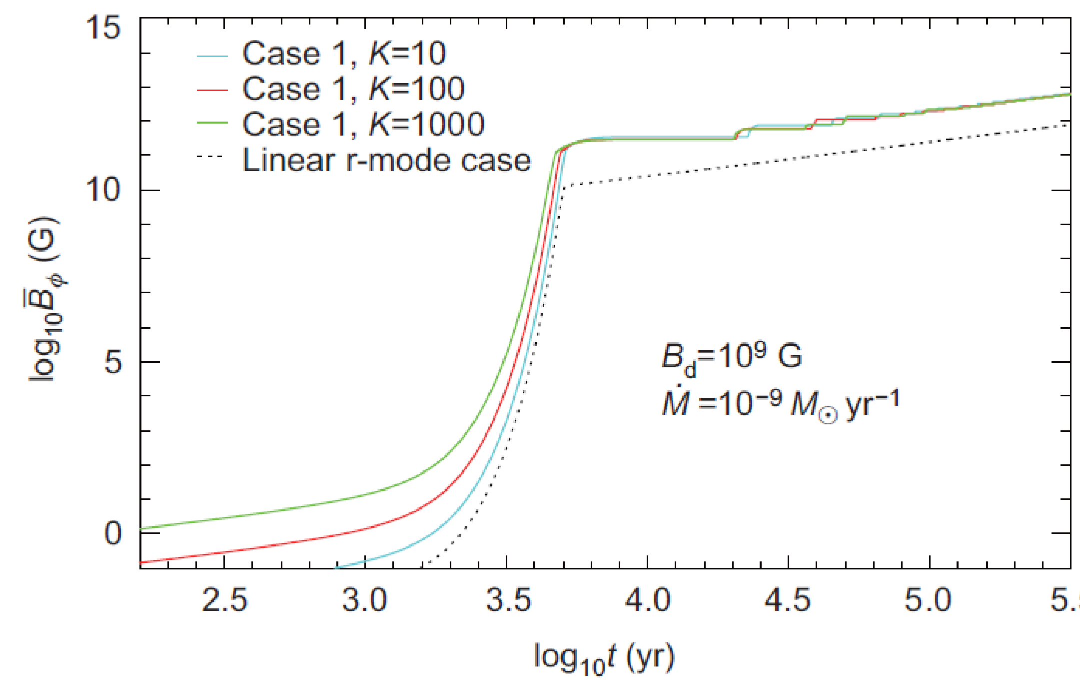
- Way R-modes could be interesting
  - R-modes can produce Gravitational waves
  - direct way to probe the interior of compact stars: damping mechanism, EoS
  - Spin and thermal evolution of compact stars are coupled with each other

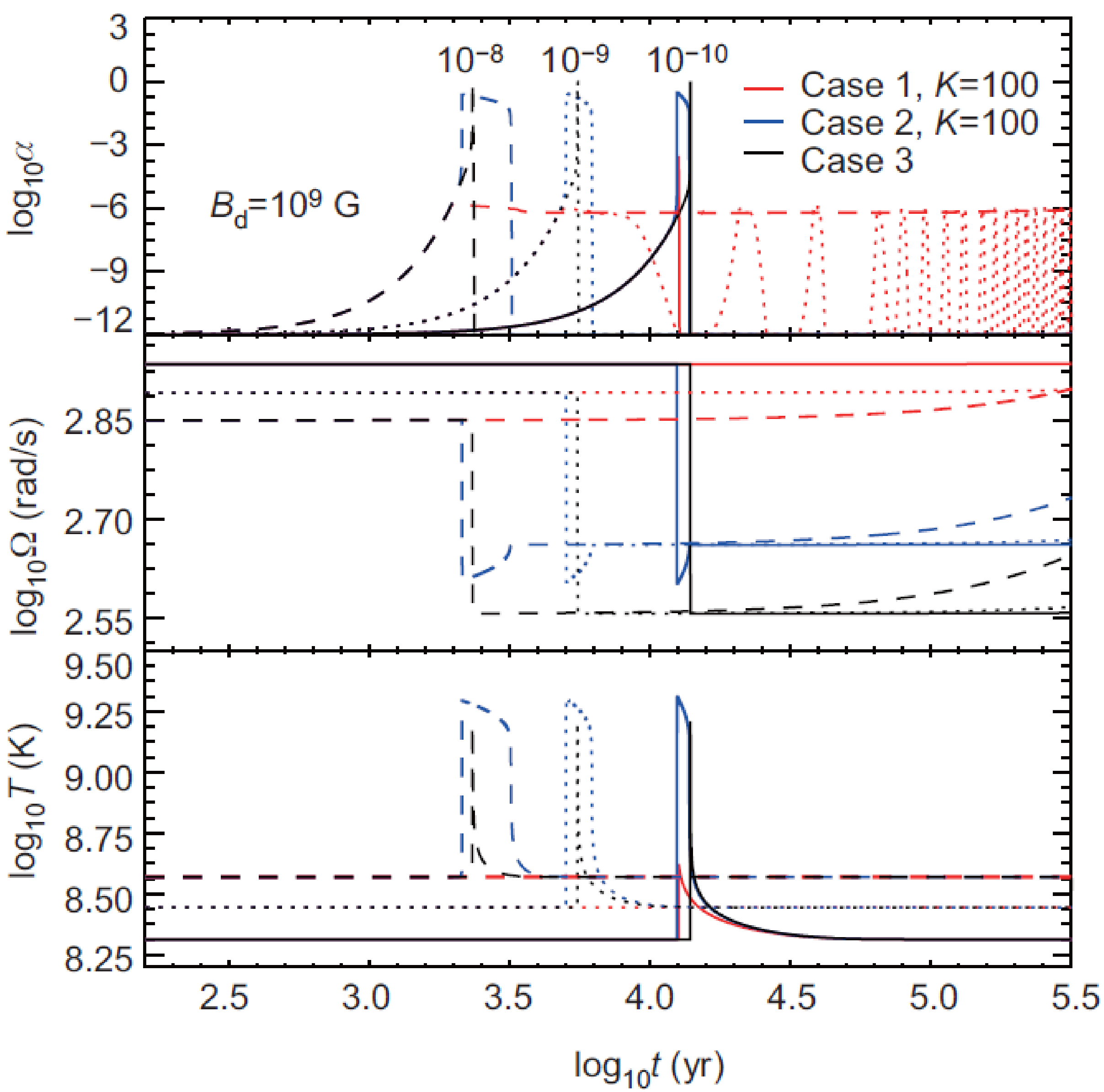


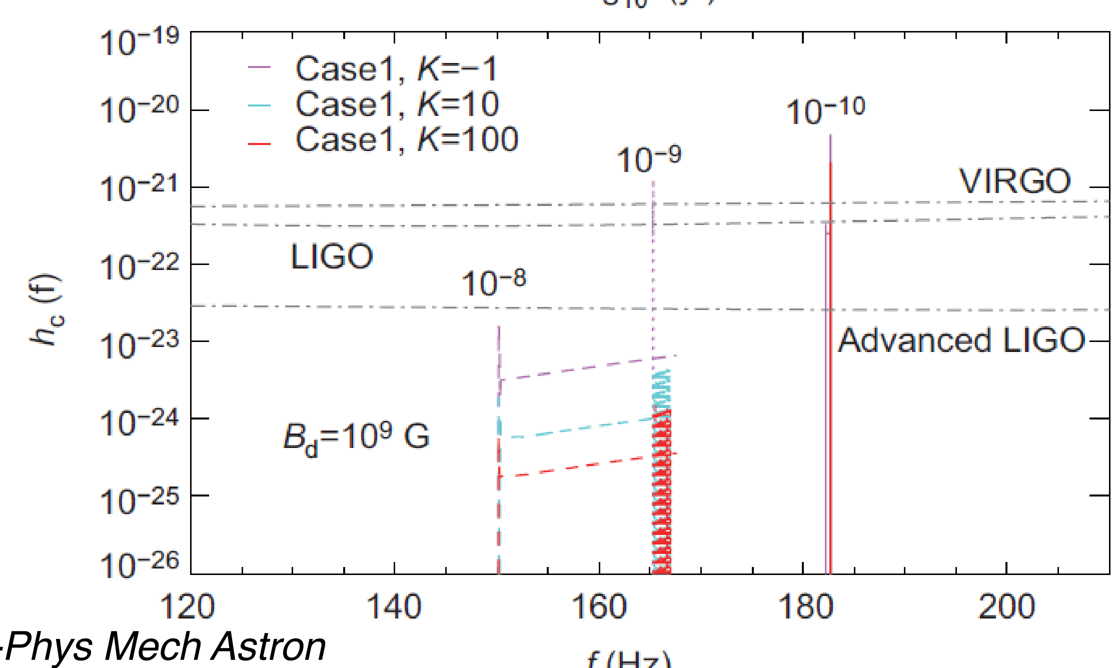
Picture by Prof. B. J. Owen

r-mode instability

Magnetic damping: the magnetic damping suppressed the nonlinear evolution of r-modes and we could obtain a stronger generated toroidal magnetic field in the second-order r-mode theory. GW might be detected by the aLIGO under some constrained situations





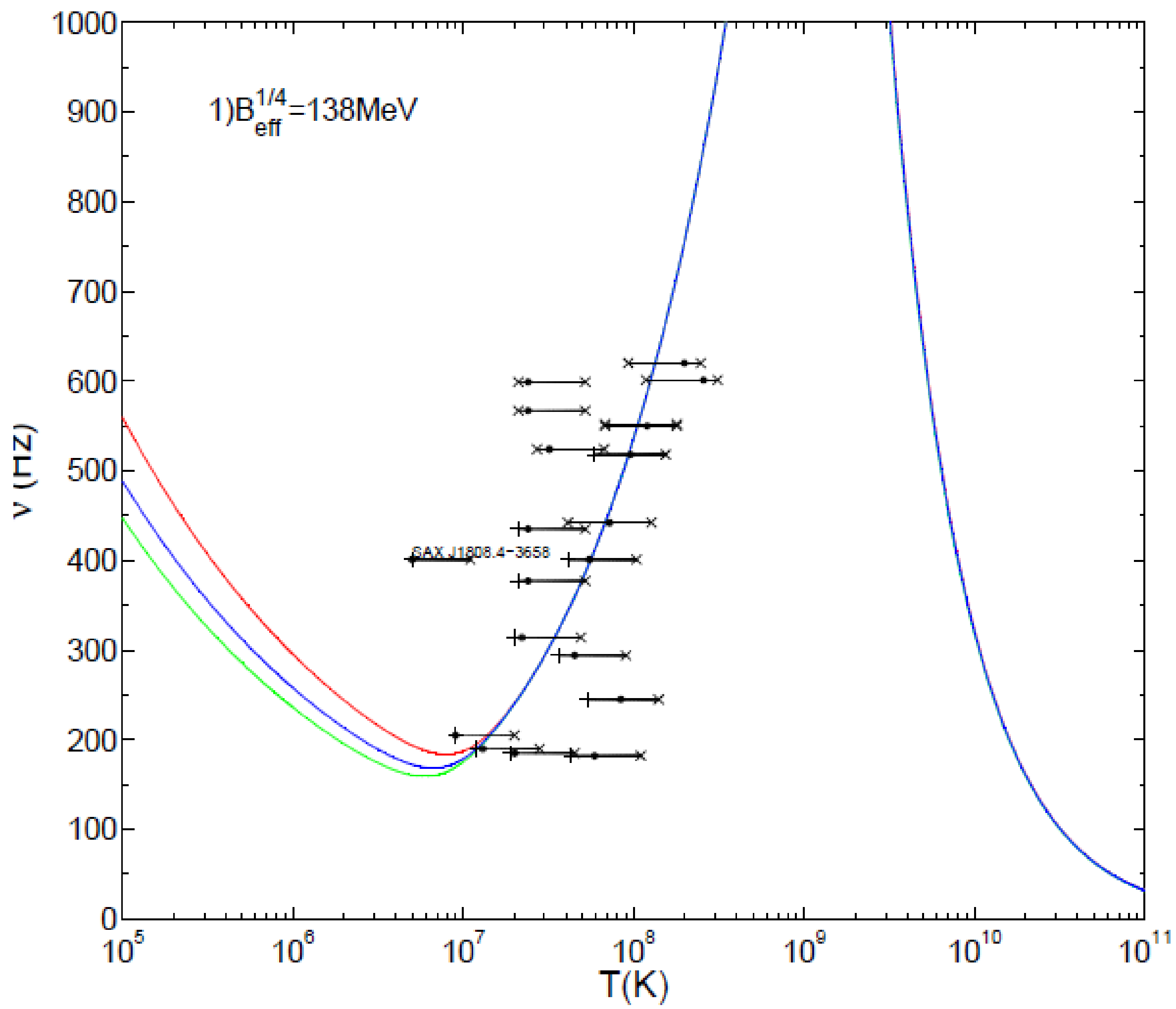


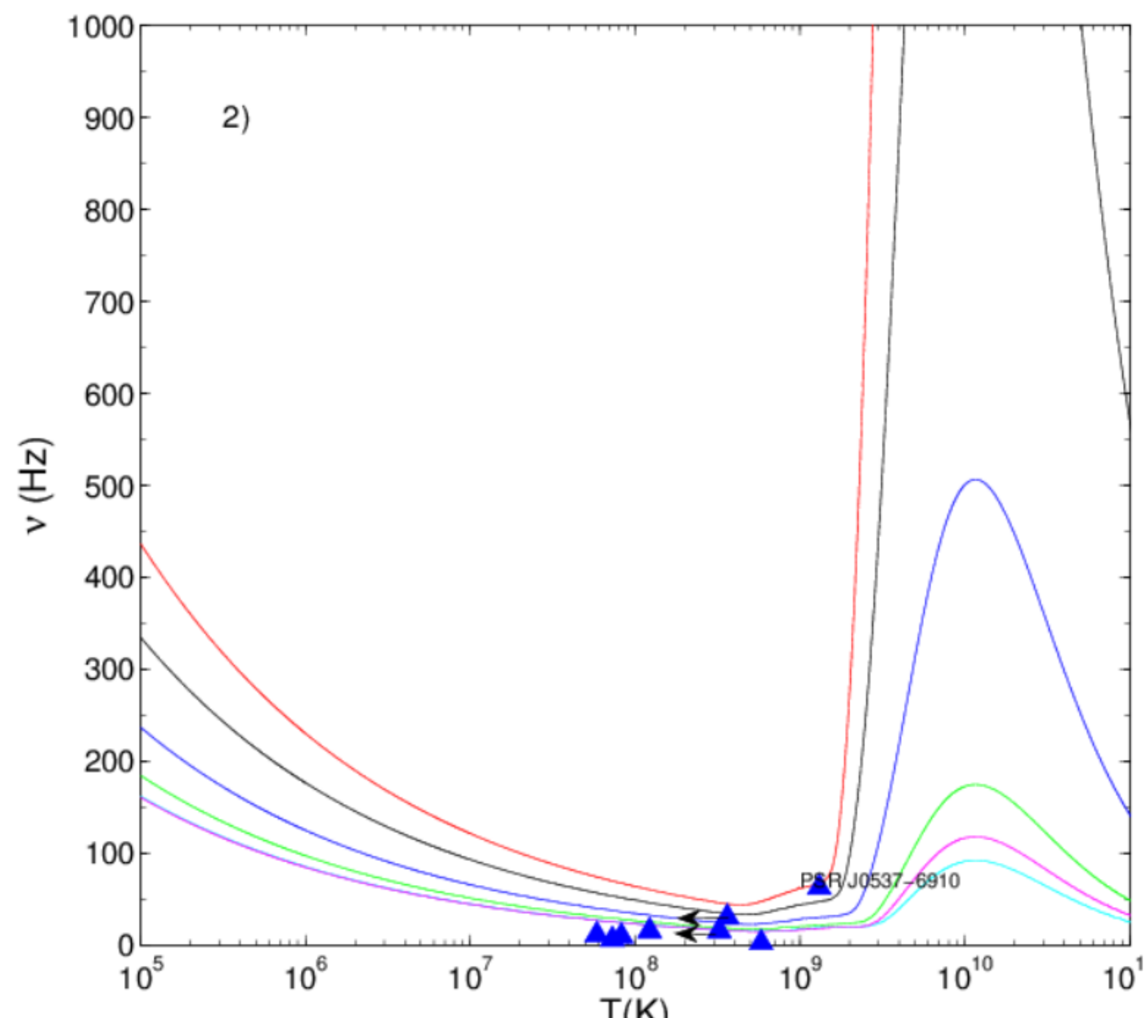
Cao et al.,2015,*Sci China-Phys Mech Astron*

r-mode instability

R-mode instability window of CFL phase strange stars

Constraints on interquark interaction parameters with GW170817 and two-solar-mass pulsar observations(Zhou et al. 2018, PRD)





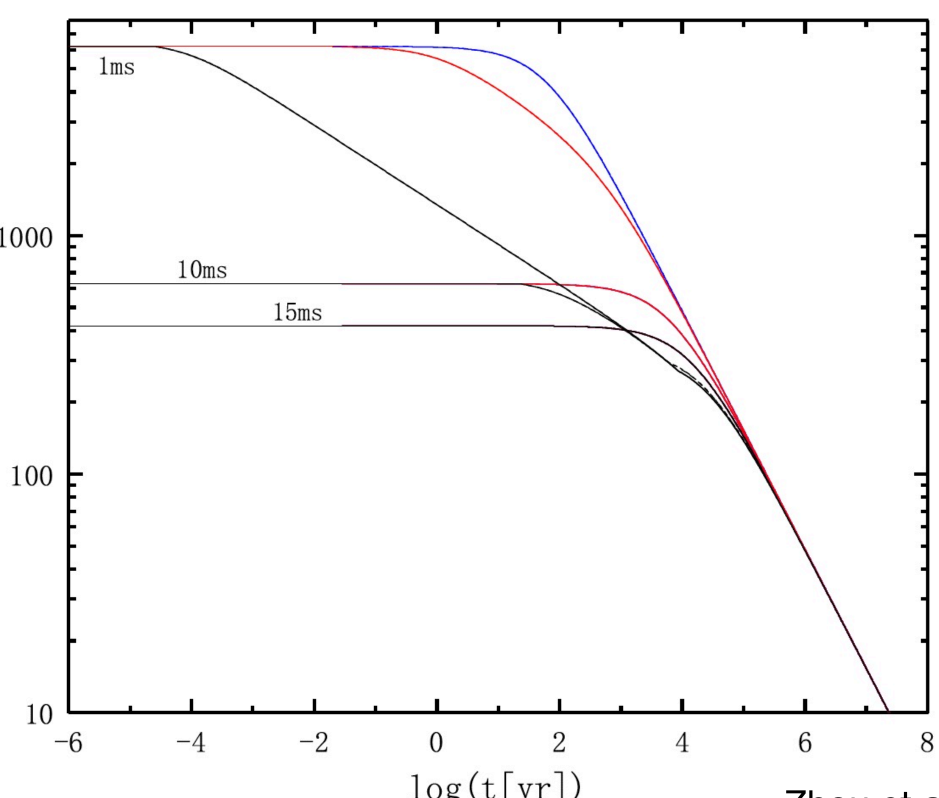
Wang et al. 2019, RAA

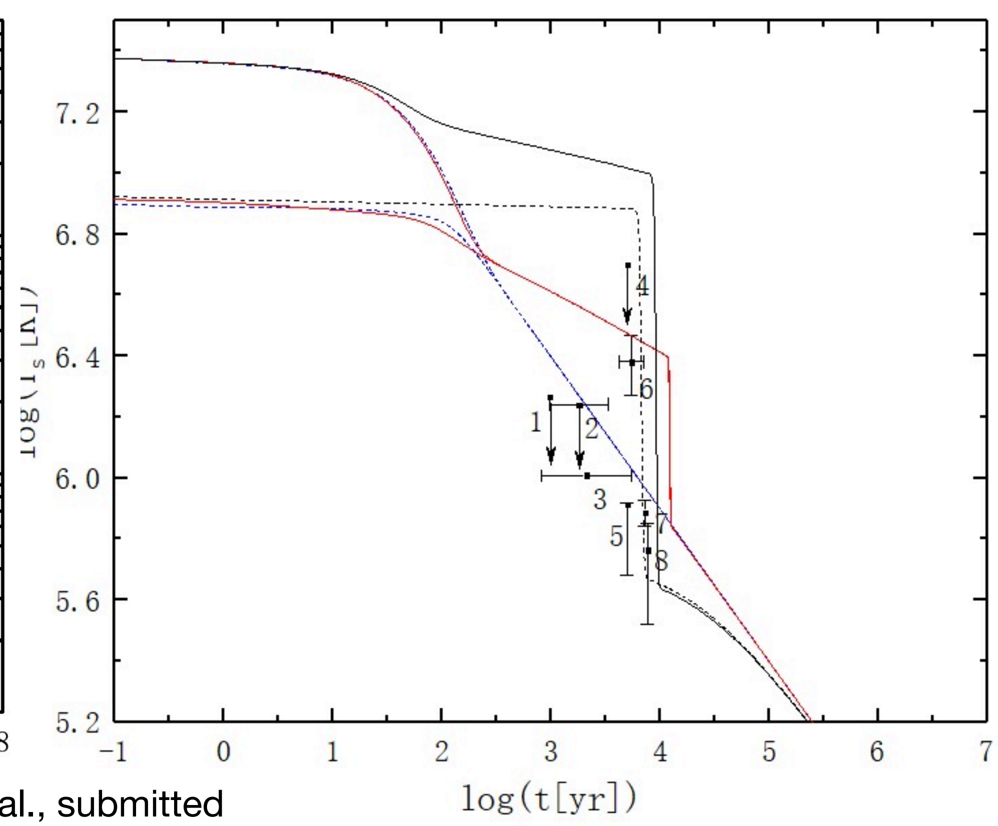
additional enhanced dissipation mechanism might be existing in SAX J1808.4-3658.
Fast spinning young pulsar PSR J0537-6910 is a primary source for detecting the gravitational wave from rotating strange stars, and young pulsars might be CFL phase strange stars

r-mode instability

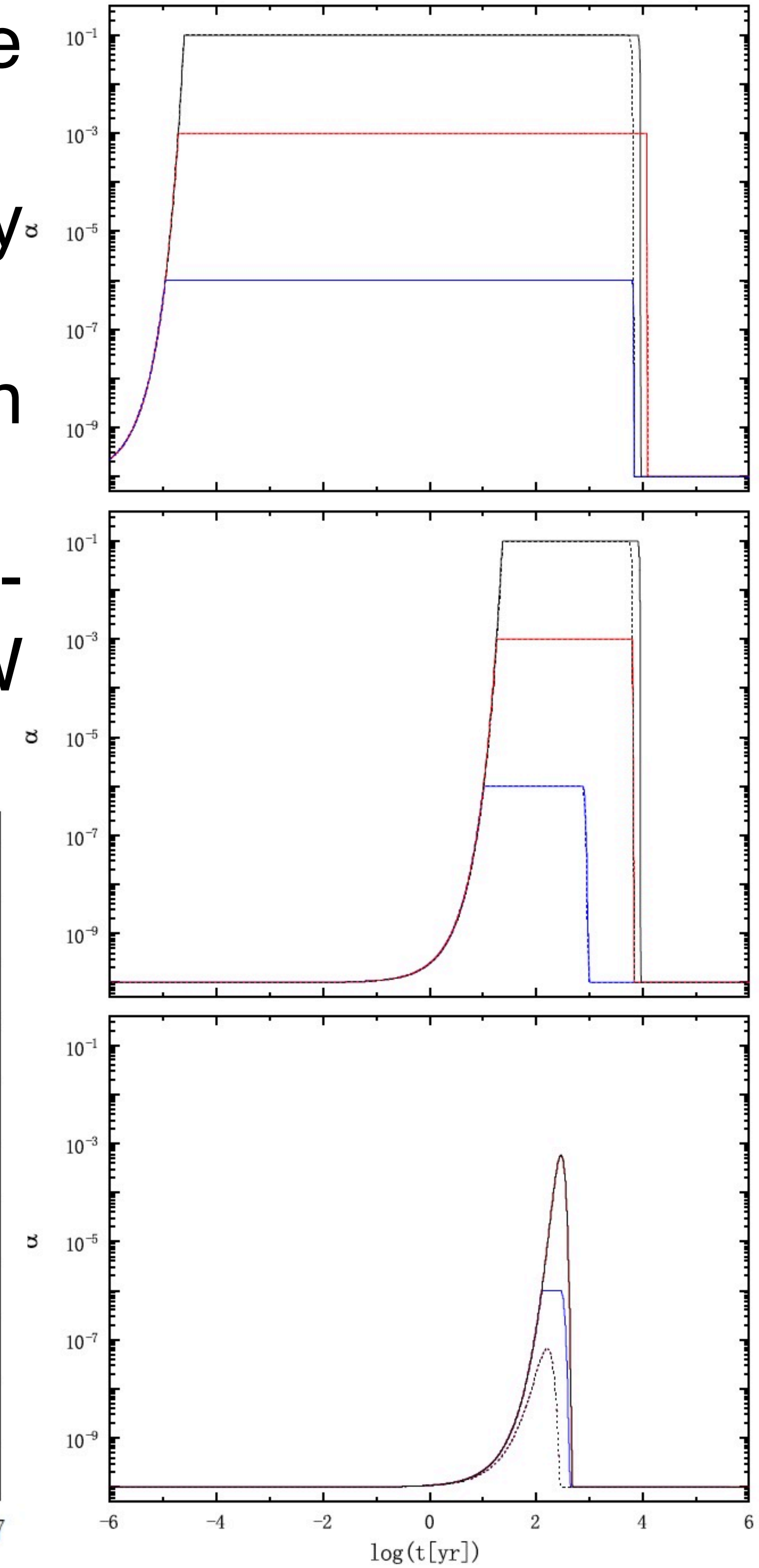
Evolution of rotating young pulsars: Effect of r-mode instability and PBF processes

- The model parameters are well constraint by observations in a reasonable range
- PBF process is very important at the early evolution stage
- The initial spin period is vital while discussing the r-mode evolution, it might be constrained by the GW detection and thermal emission data.





Zhou et al., submitted



Future prospects

Learning about dense matter from pulsar observations

- Observations maybe way out (FAST, SKA, QTT; NICER, eXTP; aLIGO/VIRGO,ET): electromagnetic radiation + GW radiation
  - Tidal deformability from more meter event
  - Upper bound of maximum mass
  - Better determination of radii
  - Braking index
  - …and so on

- Theory: EoS, magnetosphere of pulsars

Thank you !


View of QiTai Station