Anisotropic structure of synchrotron polarization

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with Jungyeon Cho

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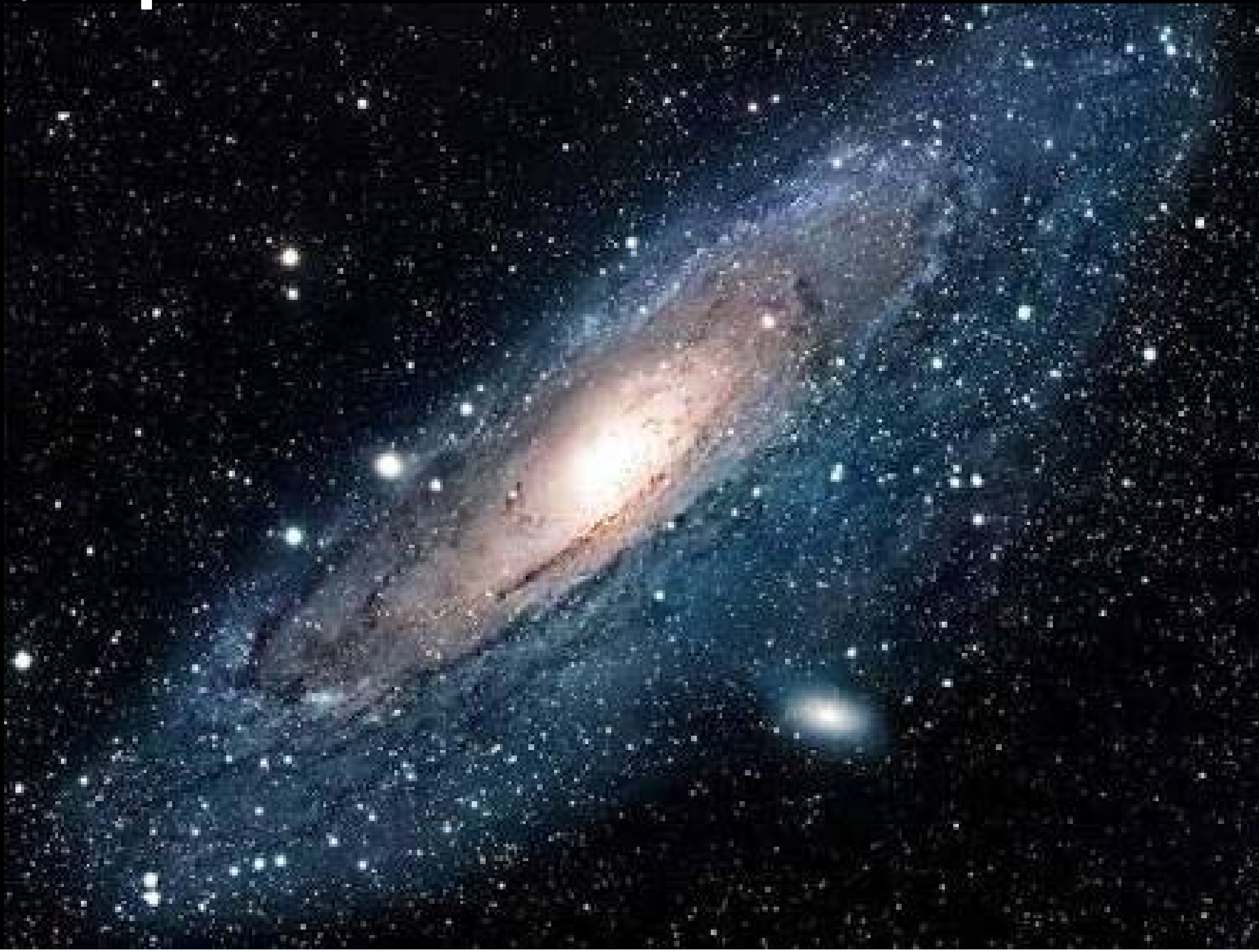
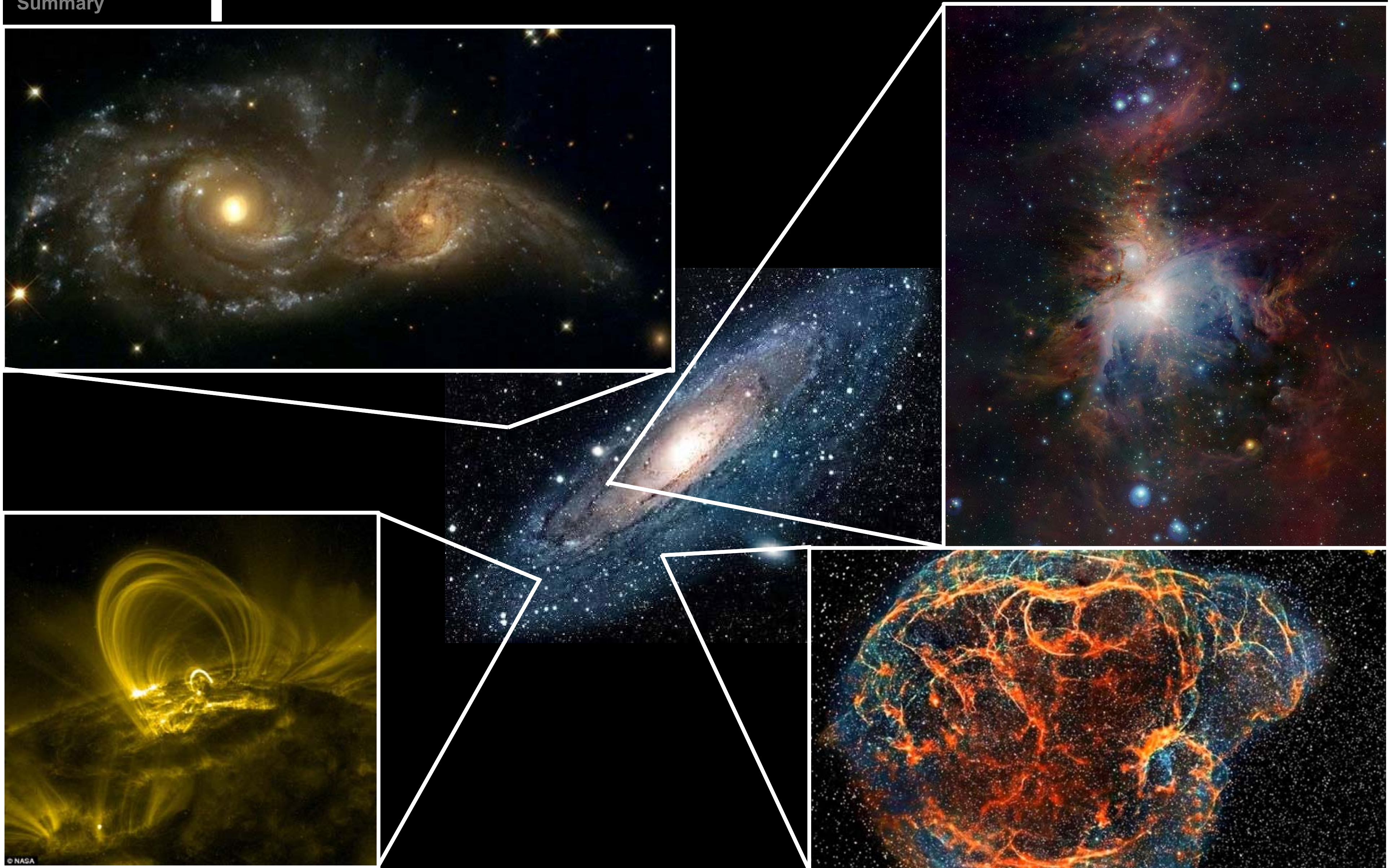
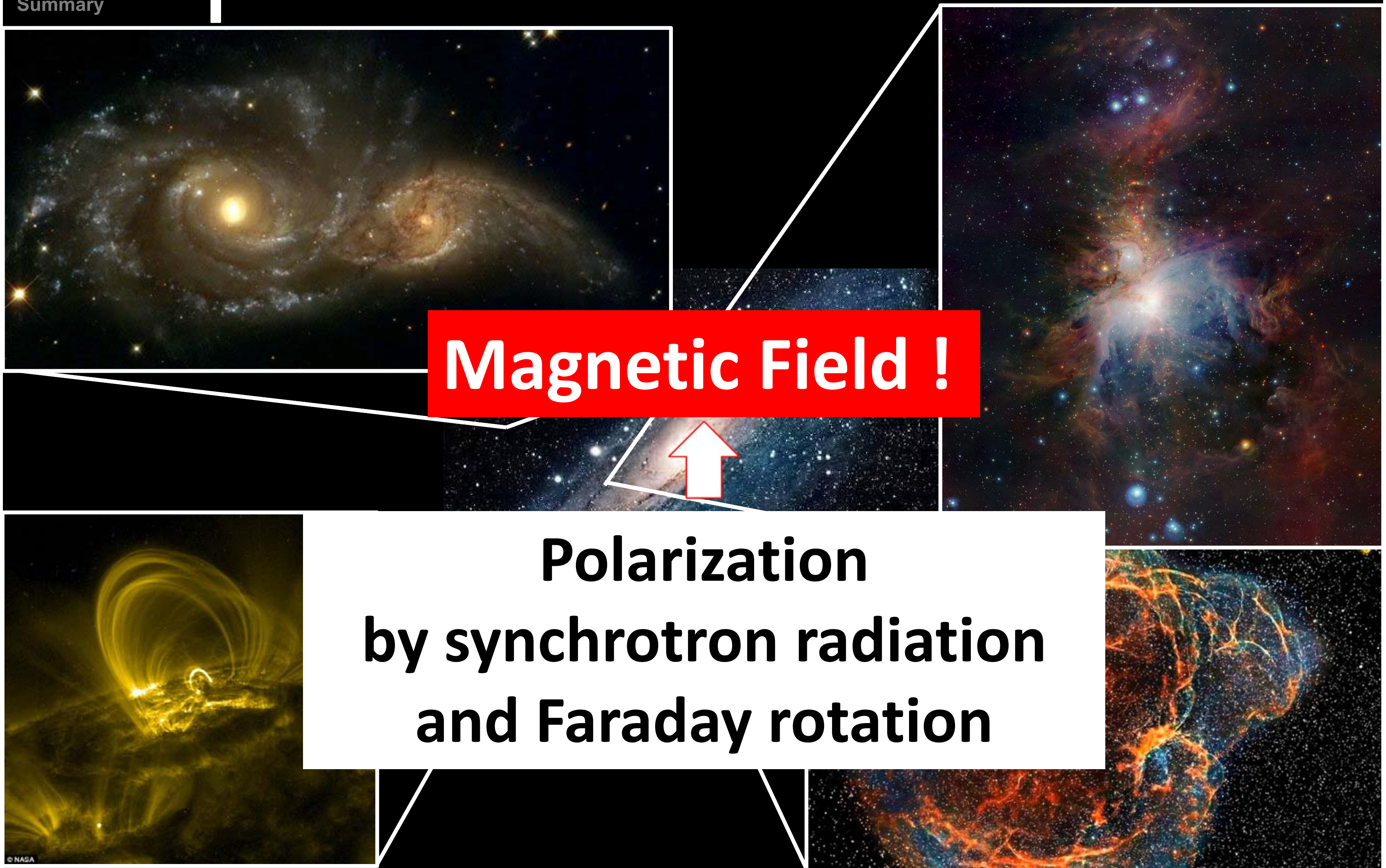
MHD turbulence in universe



MHD turbulence in universe



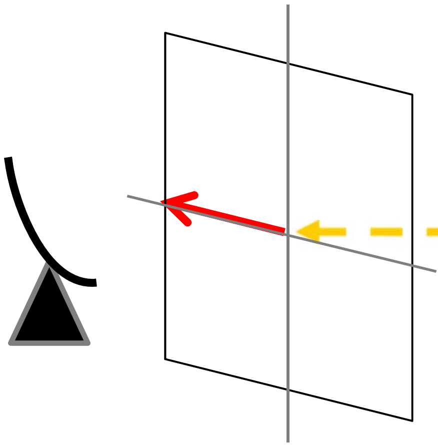
MHD turbulence in universe



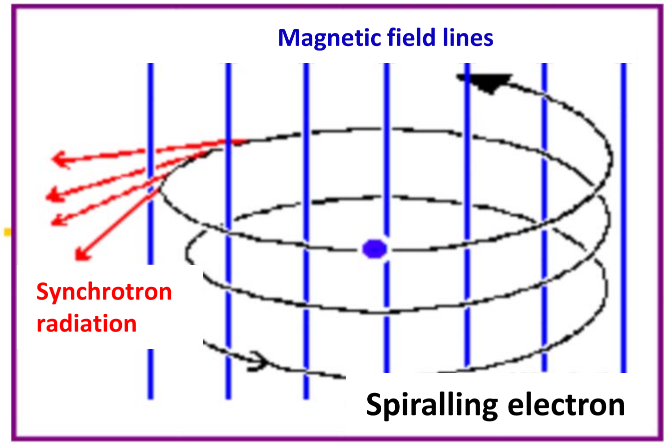
Magnetic Field !

Polarization
by synchrotron radiation
and Faraday rotation

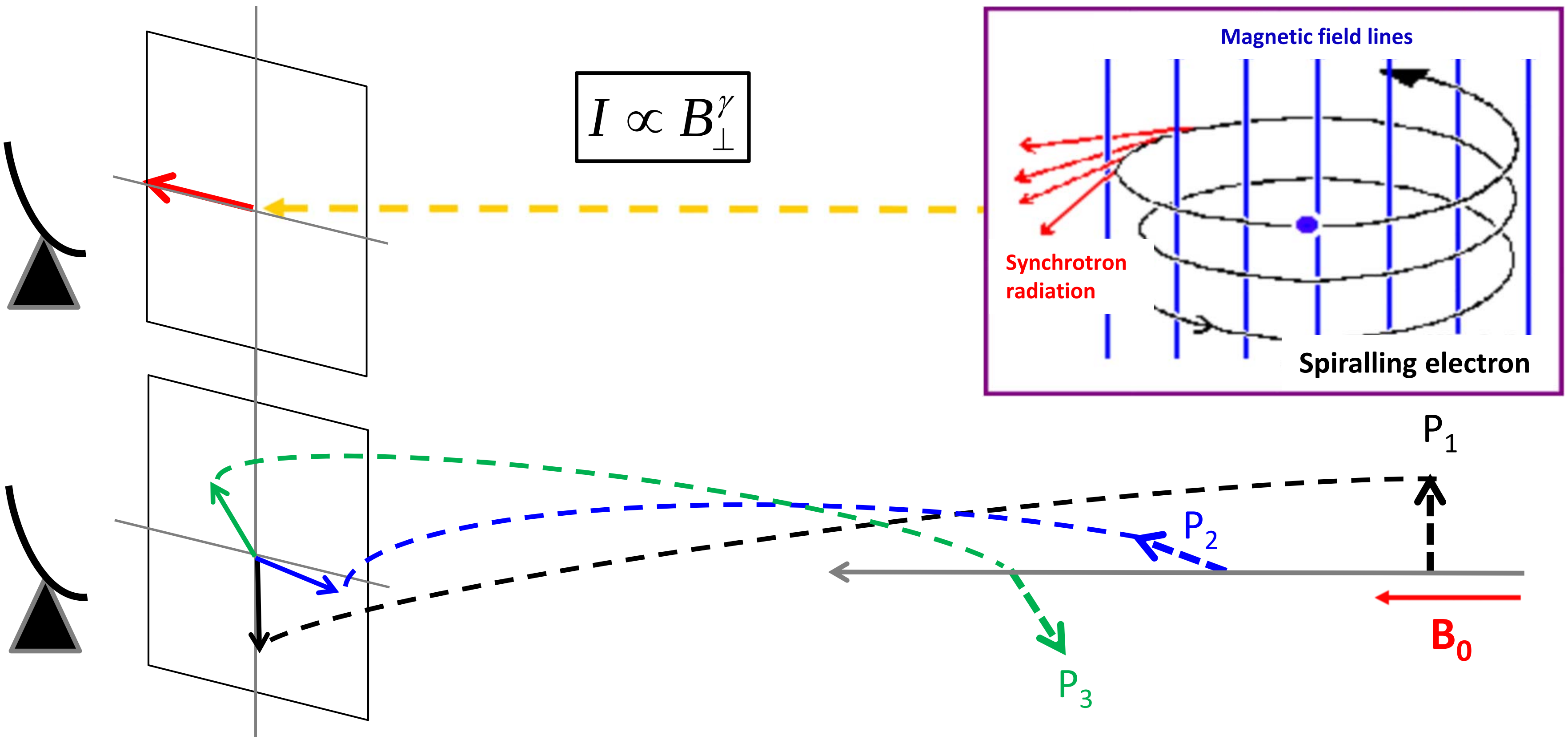
Polarization – Synchrotron radiation



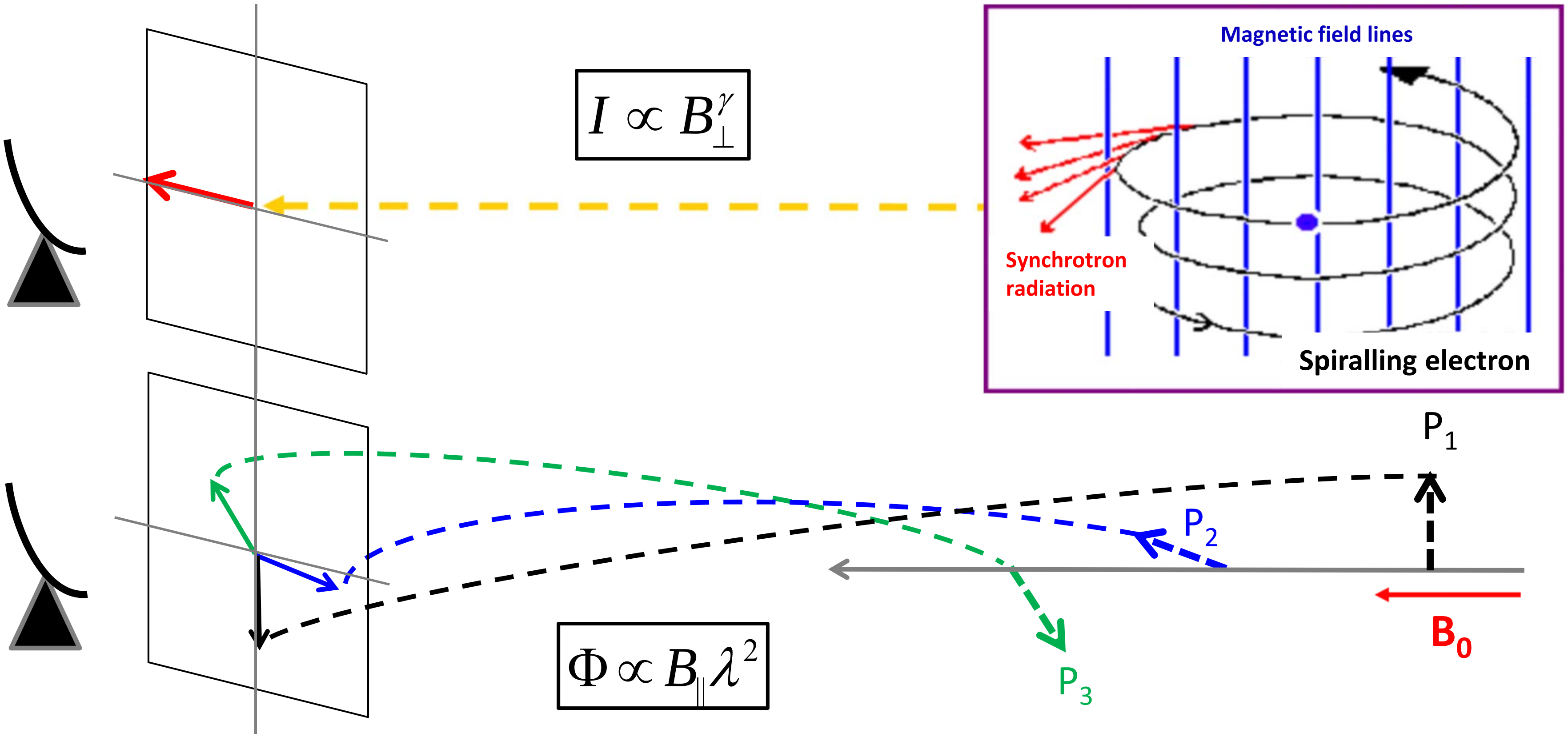
$$I \propto B_{\perp}^{\gamma}$$



Polarization – Faraday rotation

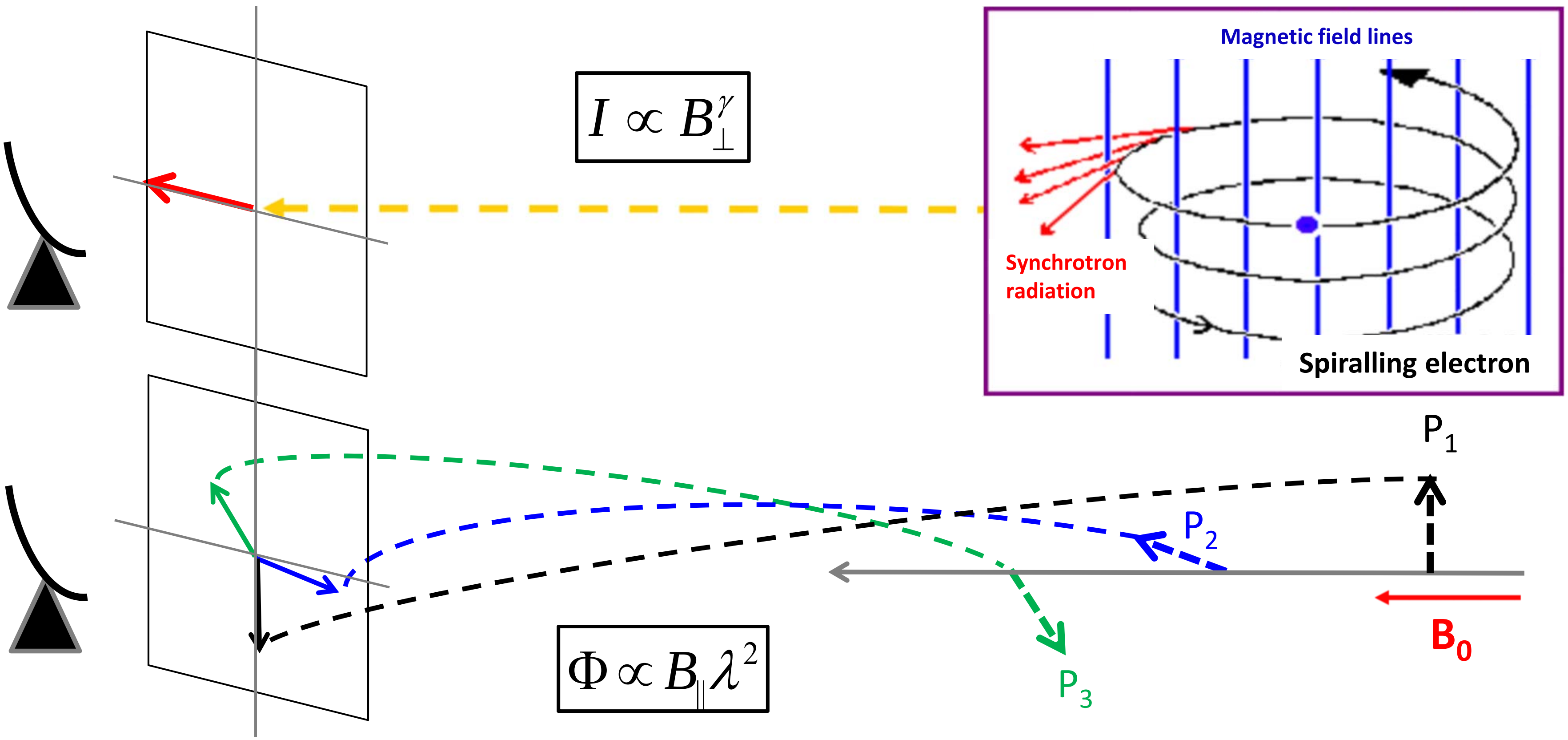


Polarization – Synchrotron & Faraday



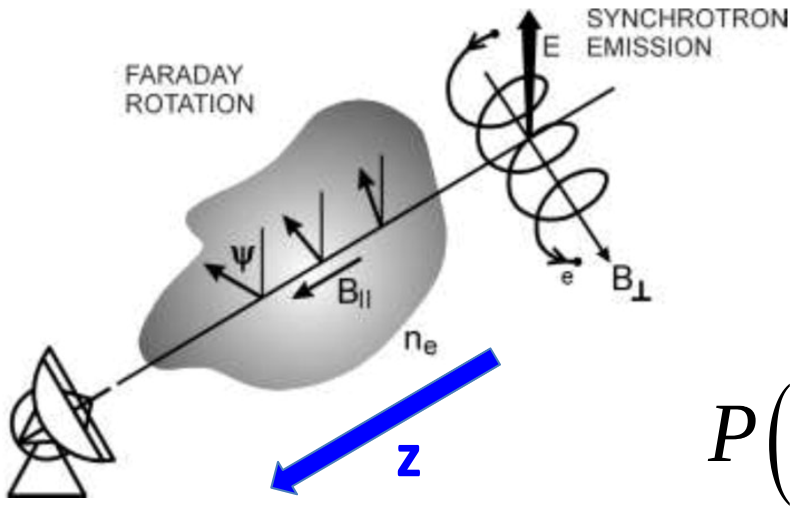
PDF | **Power spectrum** | **Structure function** | **•••**

Polarization – Synchrotron & Faraday



PDF | **Power spectrum** | **Structure function** | **•••**

Polarization from synchrotron rad.



- Polarized intensity observed at a 2D position **X** on the plane of the sky at wavelength λ

$$P(X,\lambda^2) = \int_0^L dz P_j(X,z) e^{2i\lambda^2 \Phi(X,z)},$$

Intrinsic polarization defined by the Stokes parameters Q and U :

$$P_j = Q_j + iU_j$$

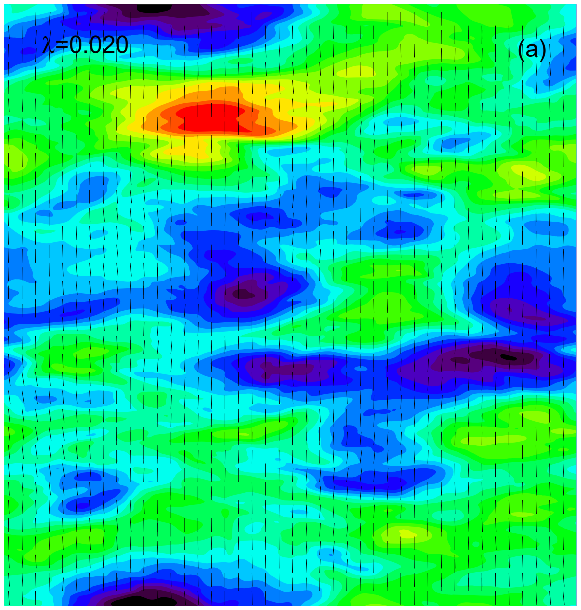
Faraday rotation measure

$$\Phi(X,z) = \int_0^z \left(\frac{n_e(z)}{0.01 cm^3}\right)\left(\frac{B_z(z)}{1.23\mu G}\right)\left(\frac{dz}{100\,pc}\right) rad\,m^{-2}$$

Polarized Intensity

λ

λ = **0.02**



B_0

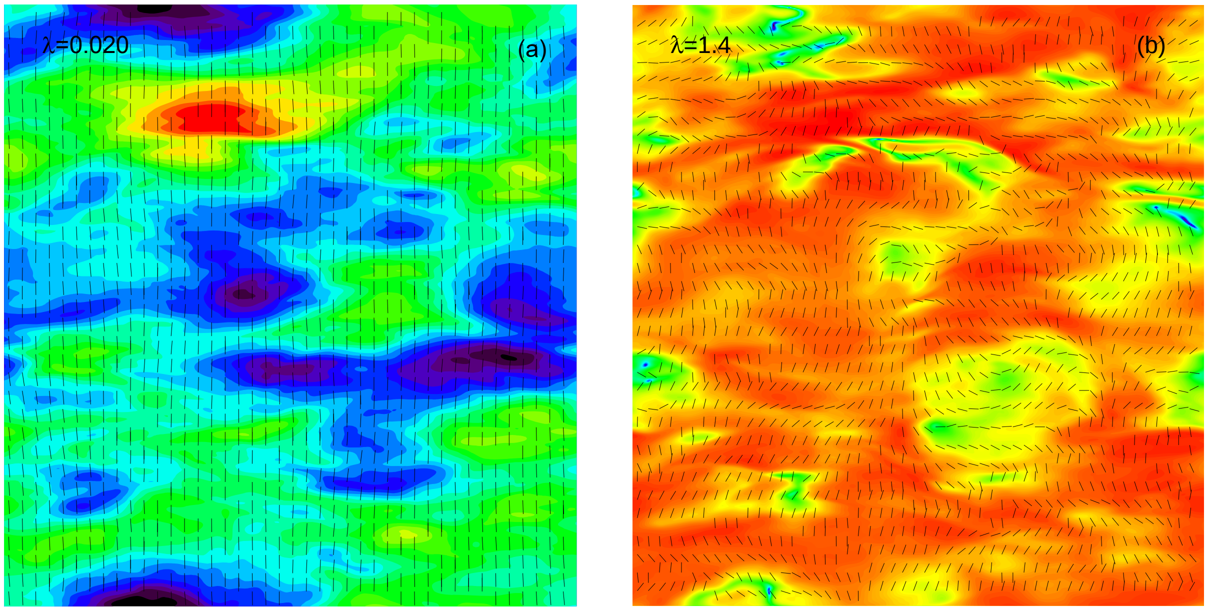
color (contour) : polarized intensity

vectors : direction of polarization

Polarized Intensity

λ

λ = **0.02** λ = **1.04**

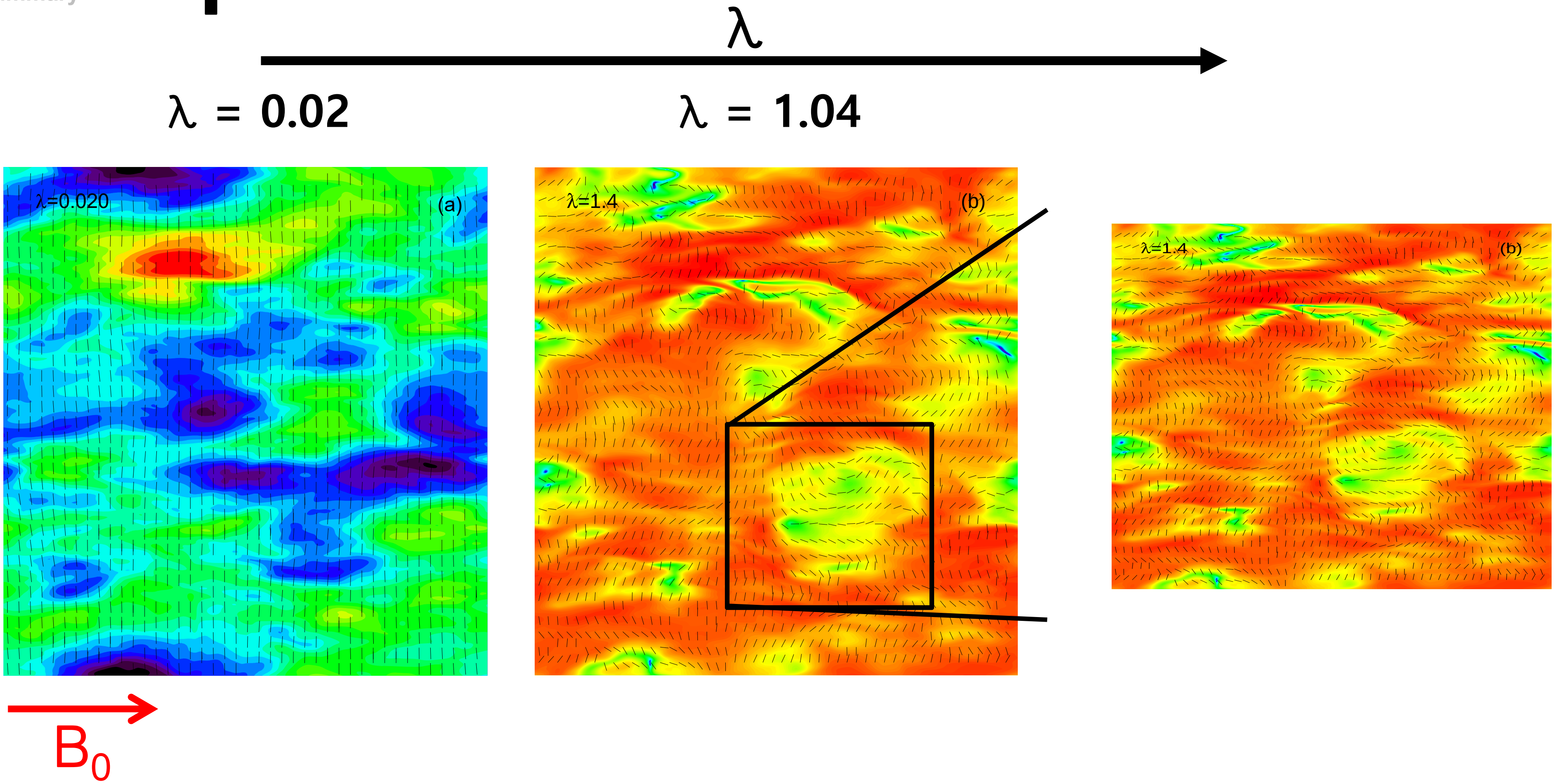


B_0

color (contour) : polarized intensity

vectors : direction of polarization

Polarized Intensity

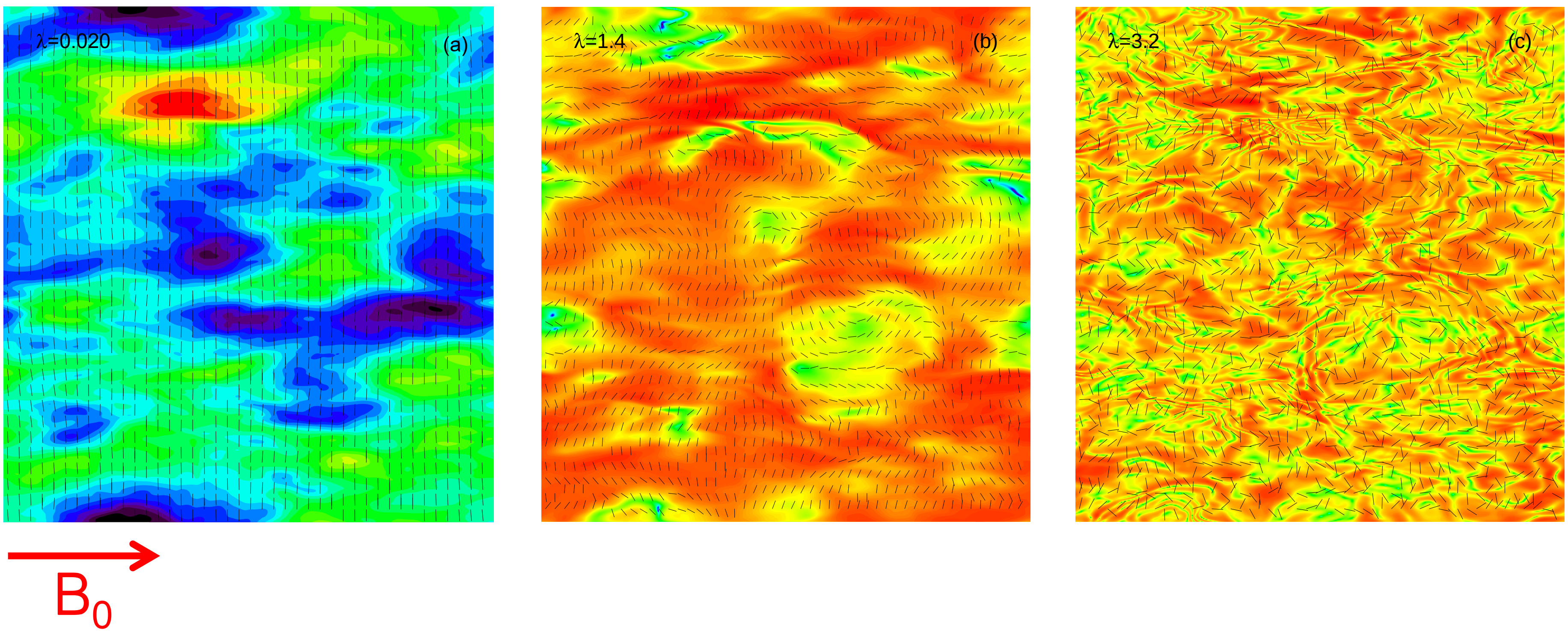


color (contour) : polarized intensity

vectors : direction of polarization

Polarized Intensity

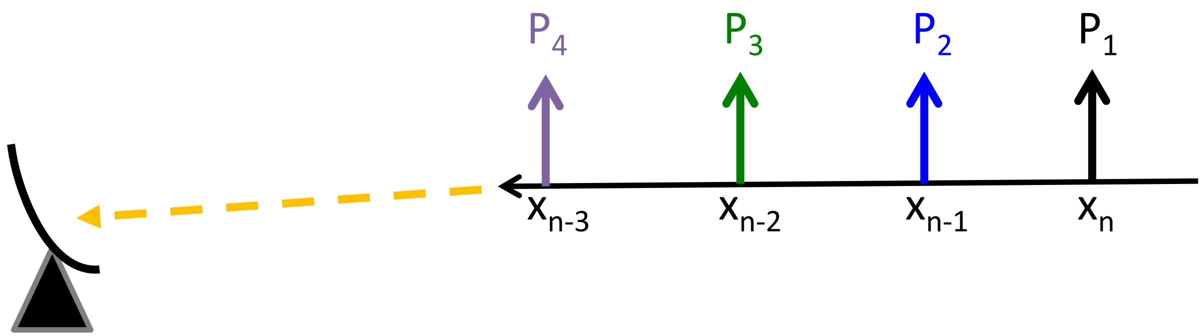
λ = 0.02 **λ = 1.04** **λ = 3.2**



color (contour) : polarized intensity

vectors : direction of polarization

Explanation of depolarization



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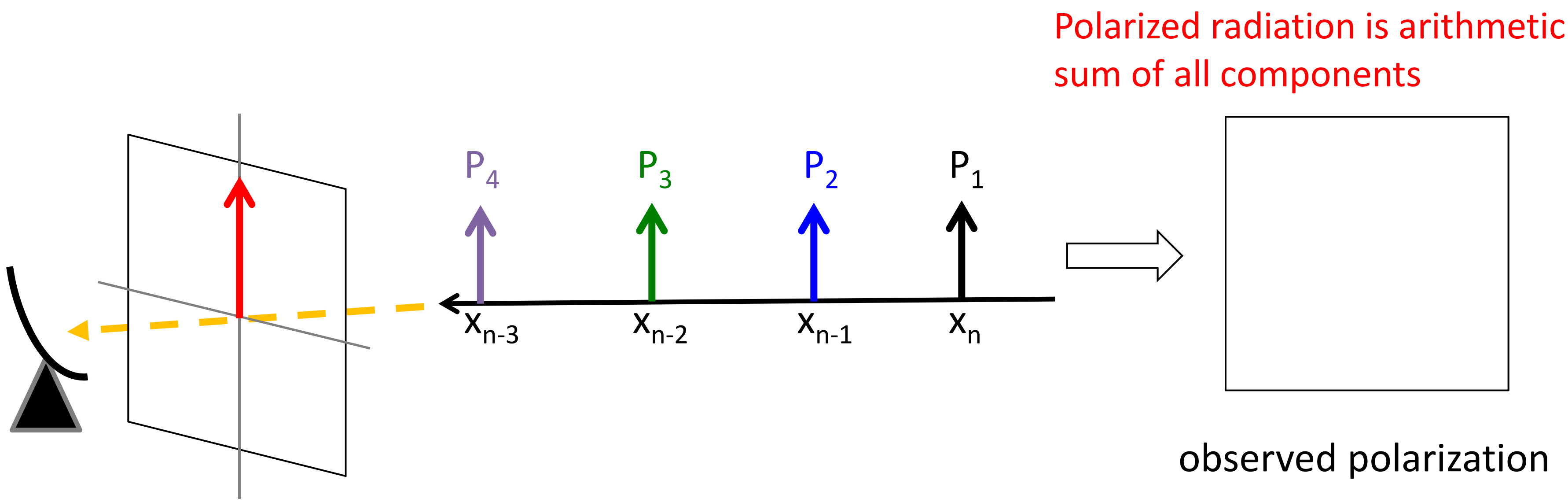
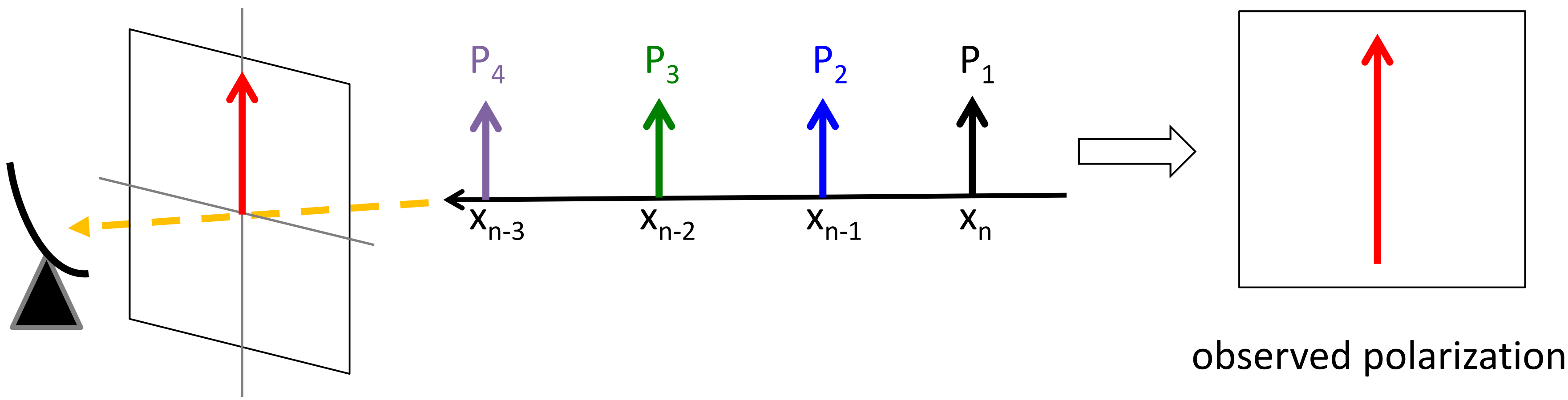


Explanation of depolarization

Polarized radiation is arithmetic sum of all components



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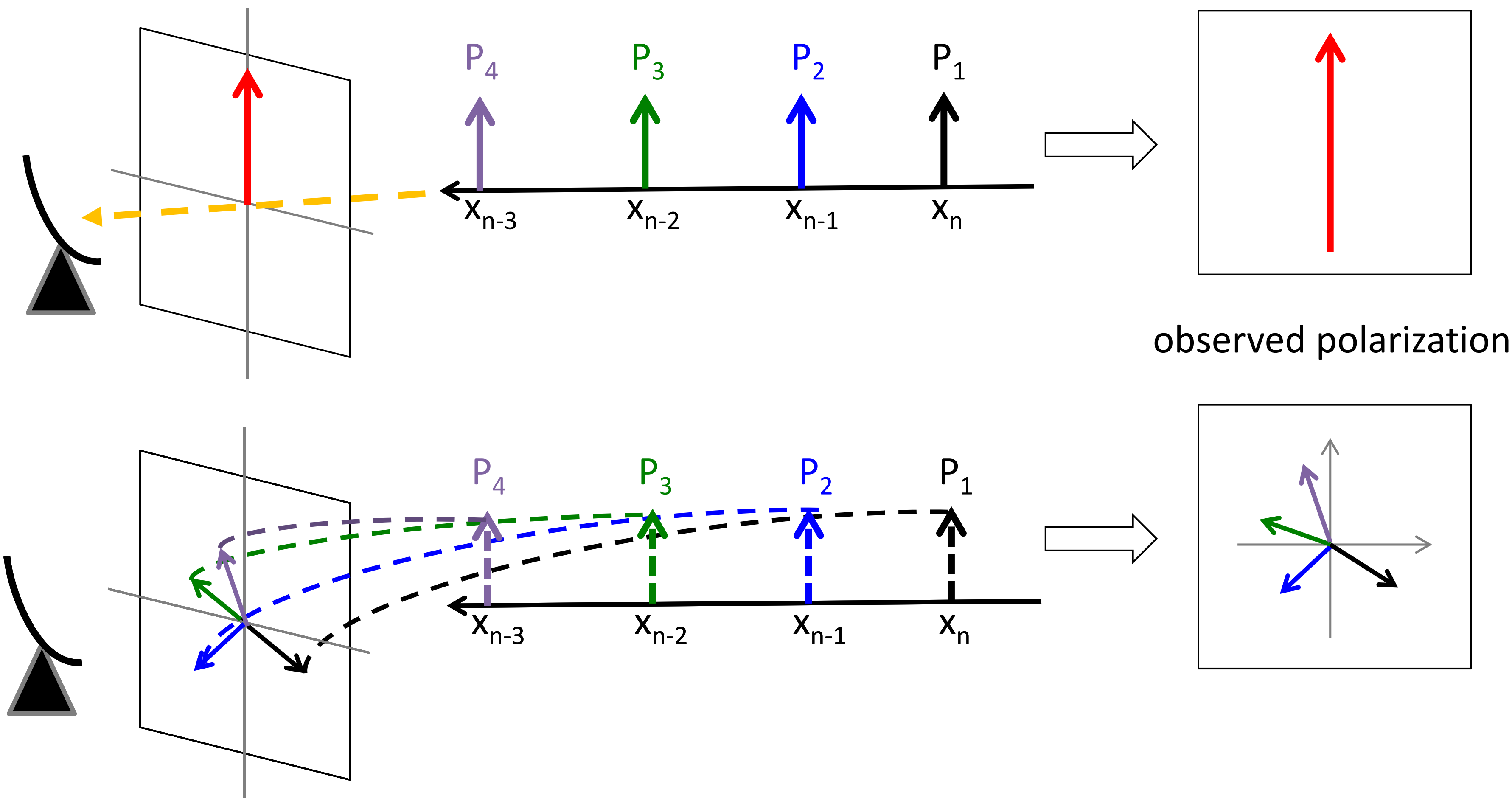
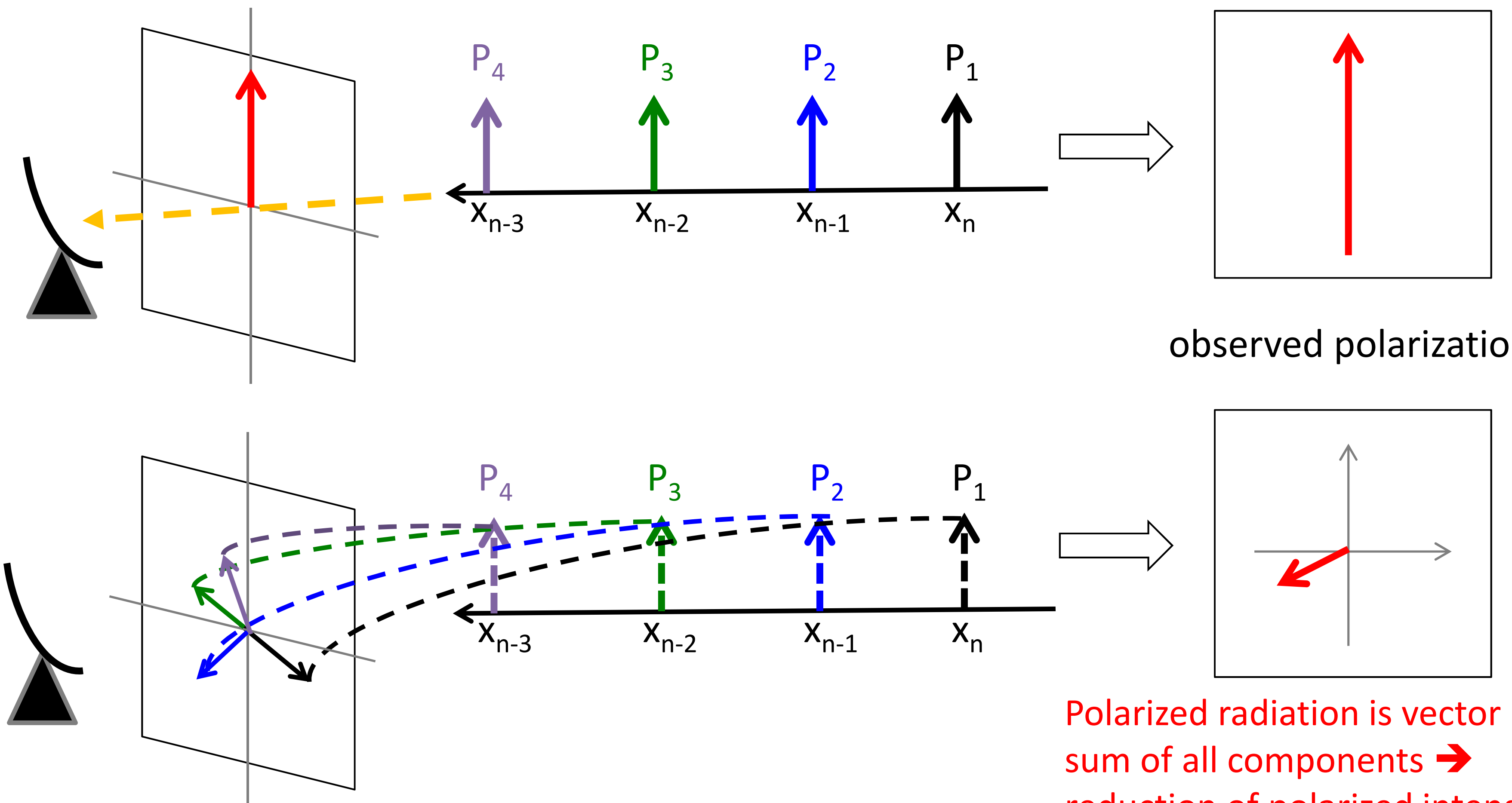


Explanation of depolarization

Polarized radiation is arithmetic sum of all components

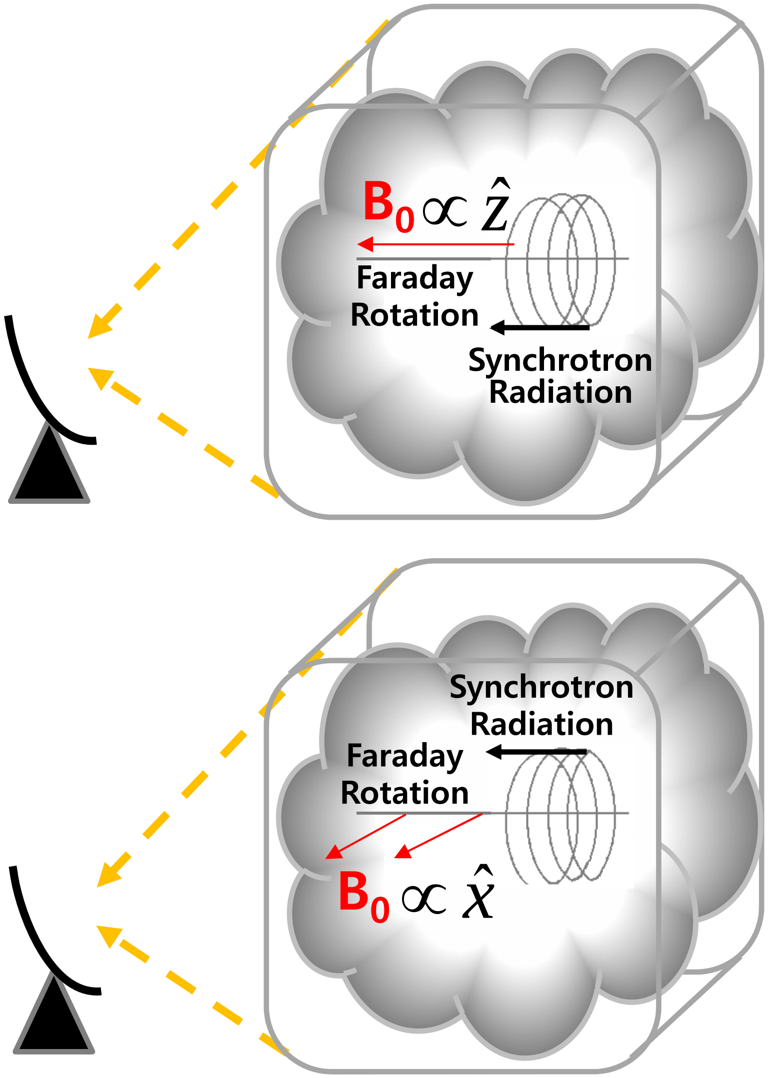


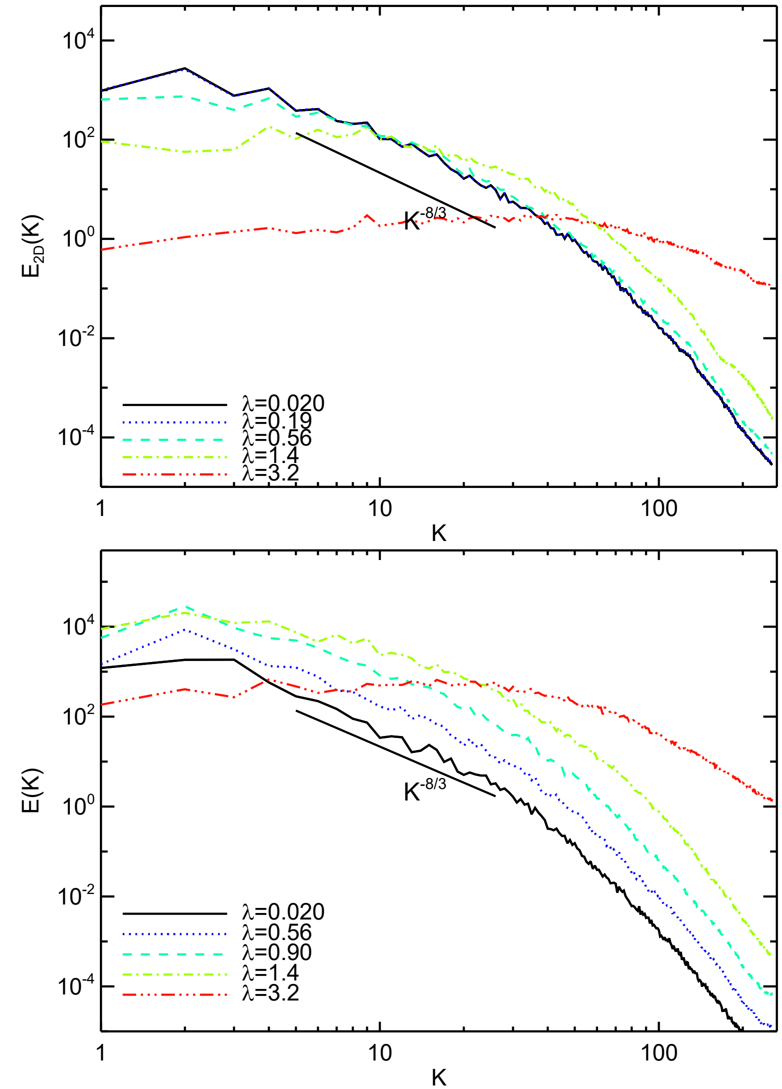
Polarized radiation is vector sum of all components ➔ reduction of polarized intensity

[Statistics]

1. Power Spectrum
2. Quadrupole Moment

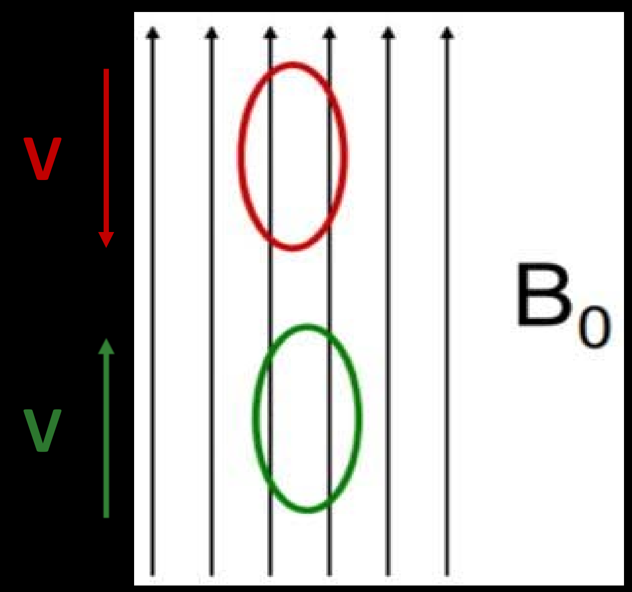
Power spectrum



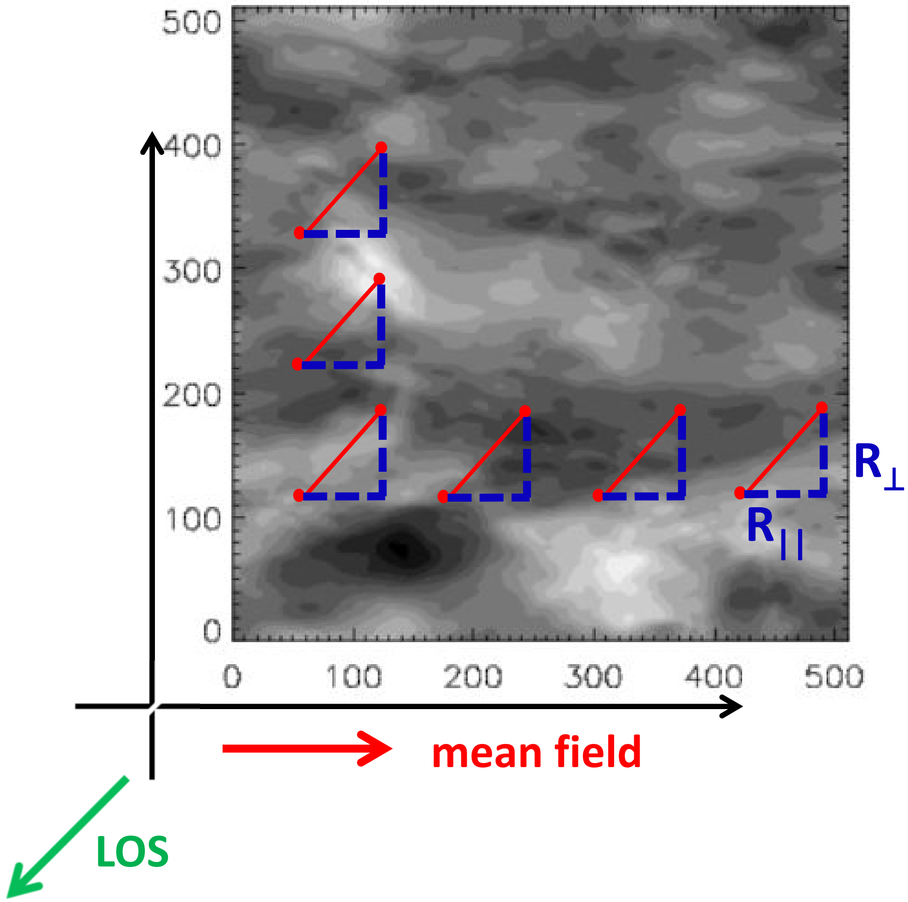


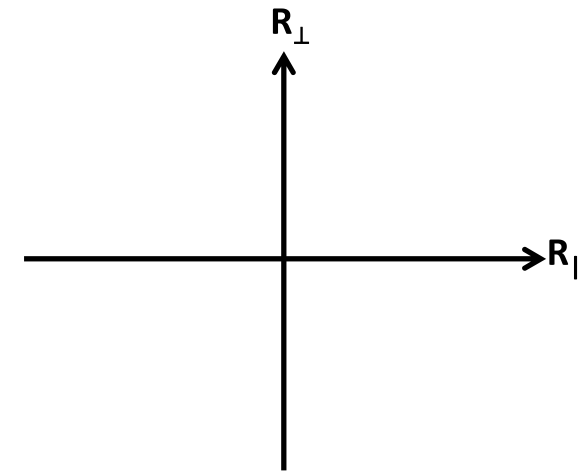
[Statistics]

1. Power Spectrum
2. Quadrupole Moment



statistical description : structure function

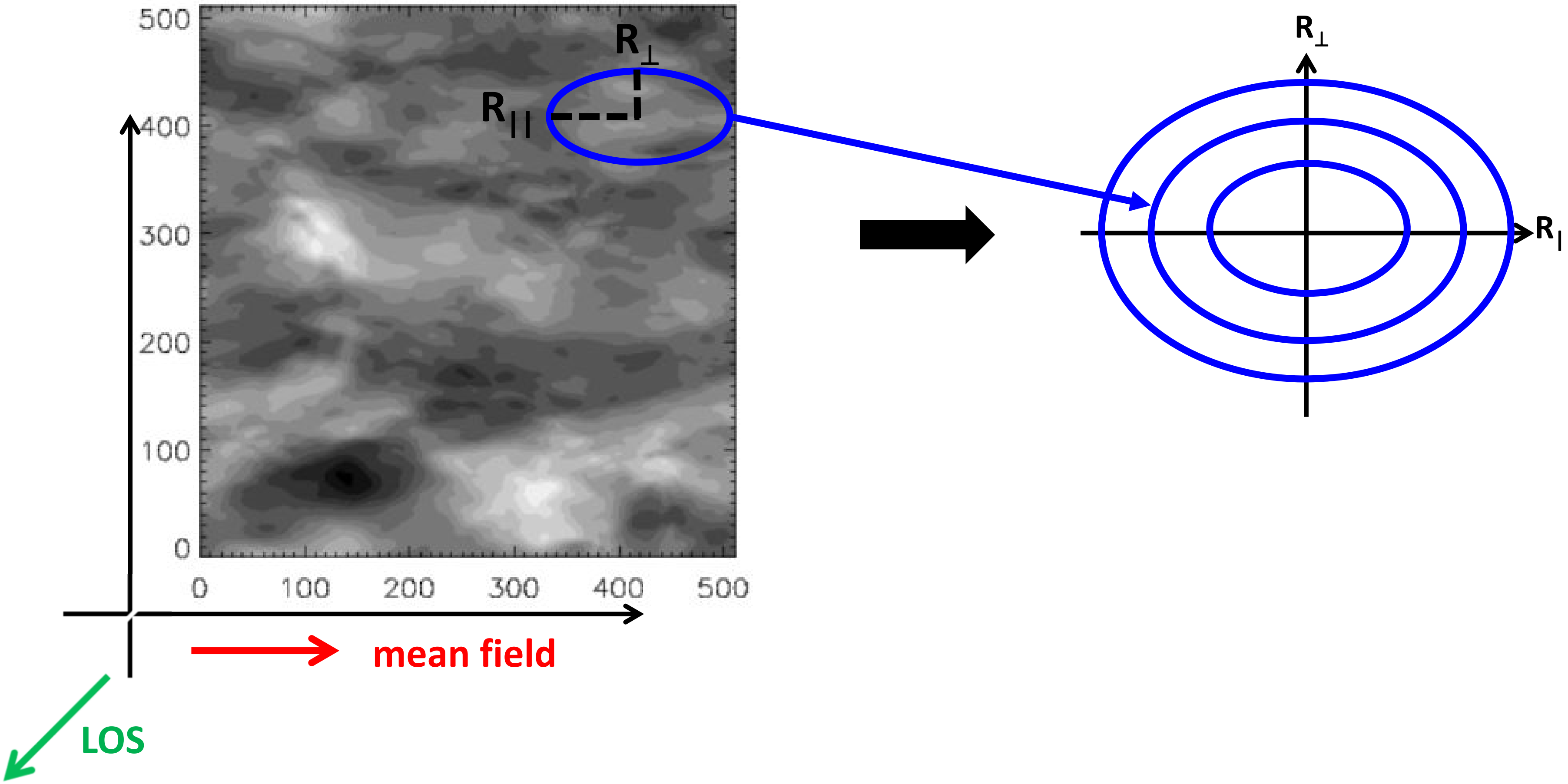




2-nd order structure function

$$D_I(\vec{R}) = \left\langle \left(I(\vec{X}) - I(\vec{X}+\vec{R}) \right)^2 \right\rangle, \quad \vec{R} = \vec{R}_{\parallel} + \vec{R}_{\perp}$$

statistical description : structure function



2-nd order structure function

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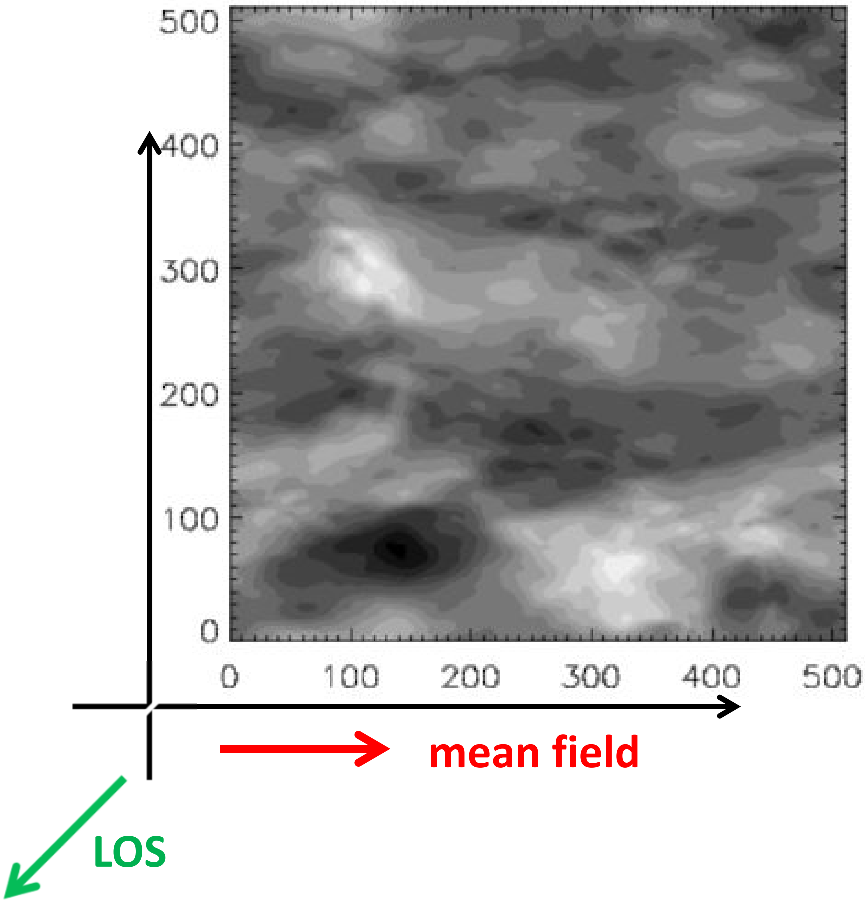
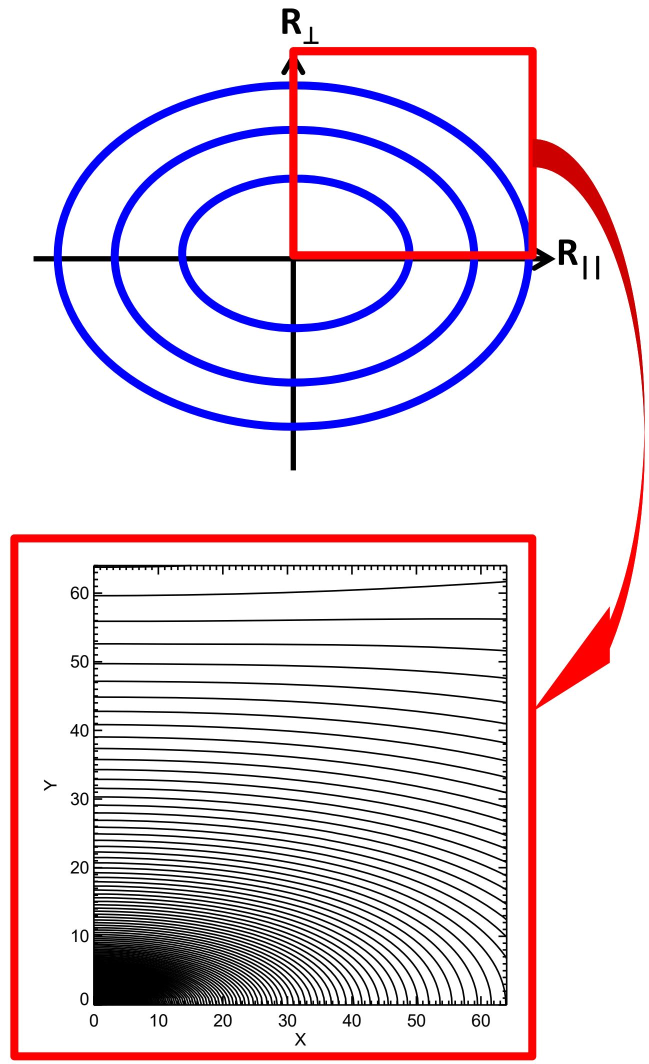
Polarization structure

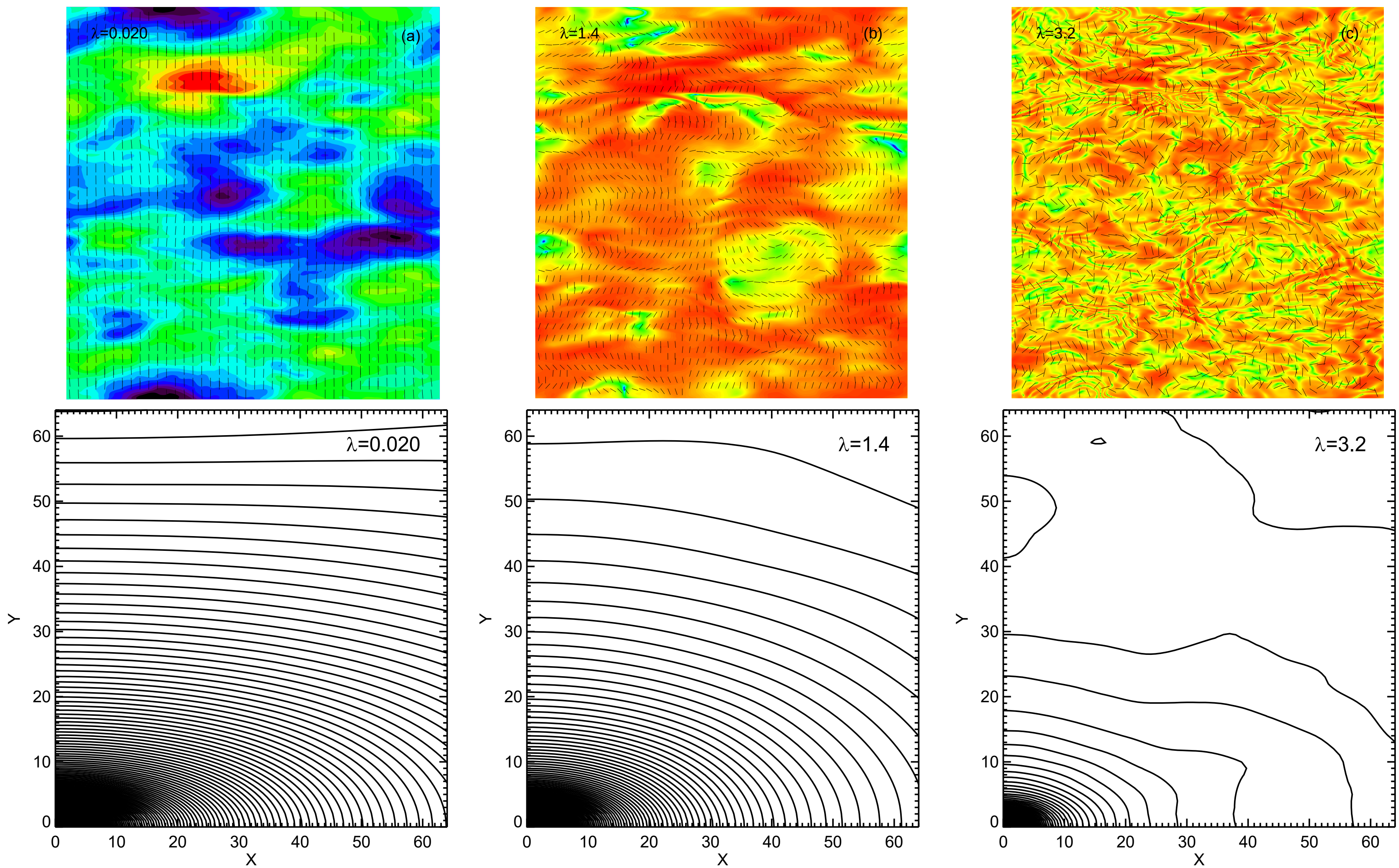




2-nd order structure function

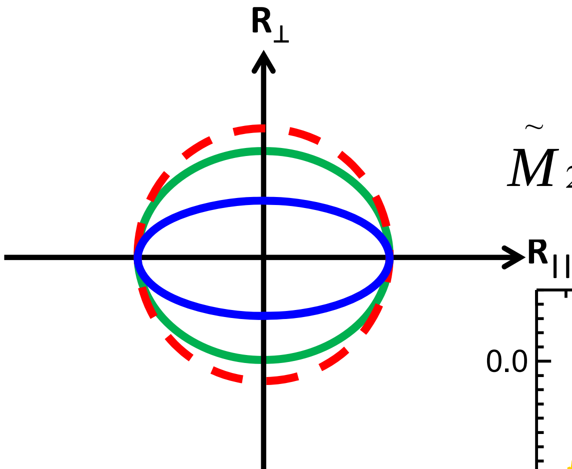
$$D_I(\vec{R}) = \left\langle \left(I(\vec{X}) - I(\vec{X}+\vec{R}) \right)^2 \right\rangle, \quad \vec{R} = \vec{R}_{\parallel} + \vec{R}_{\perp}$$

Polarization structure at different

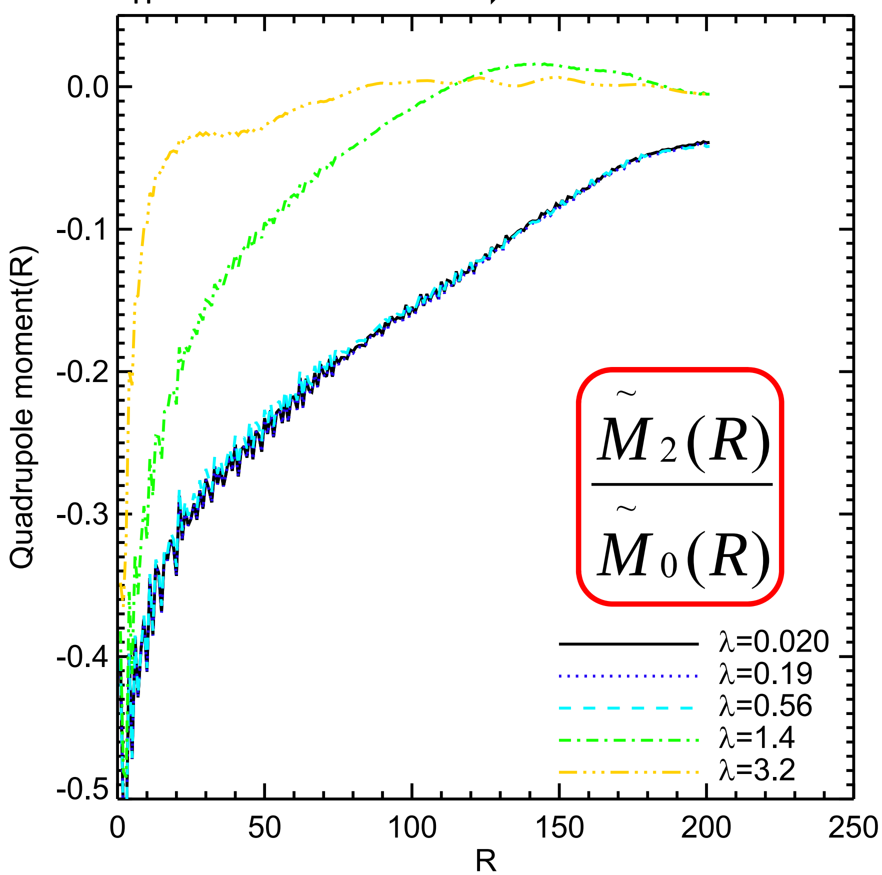


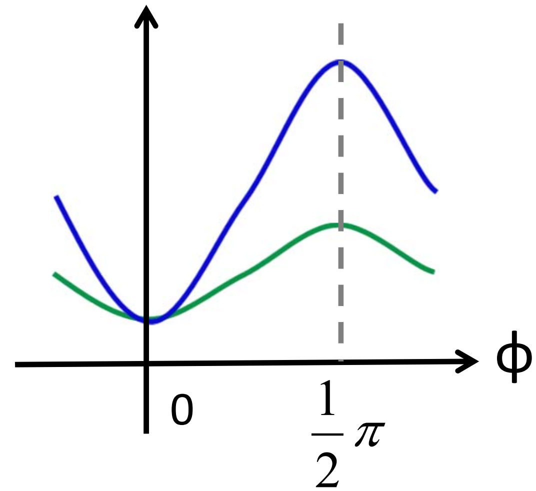
Quadrupole Moment

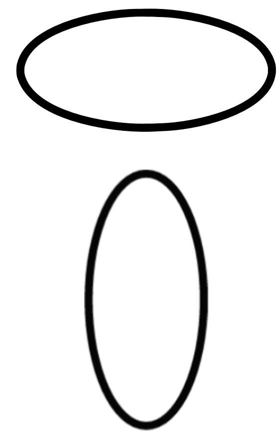
Quadrupole moment



$$\tilde{M}_2(R) = \frac{1}{2\pi}\int_0^{2\pi} e^{-2i\phi}\,\tilde{D}_I(R,\phi)\,d\phi$$





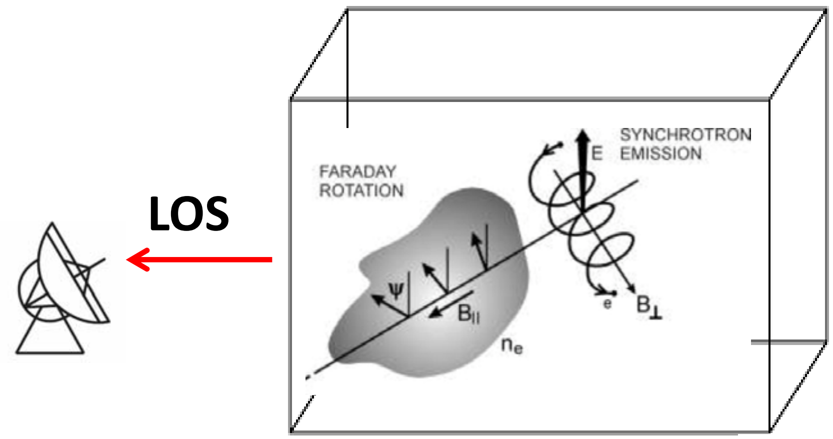


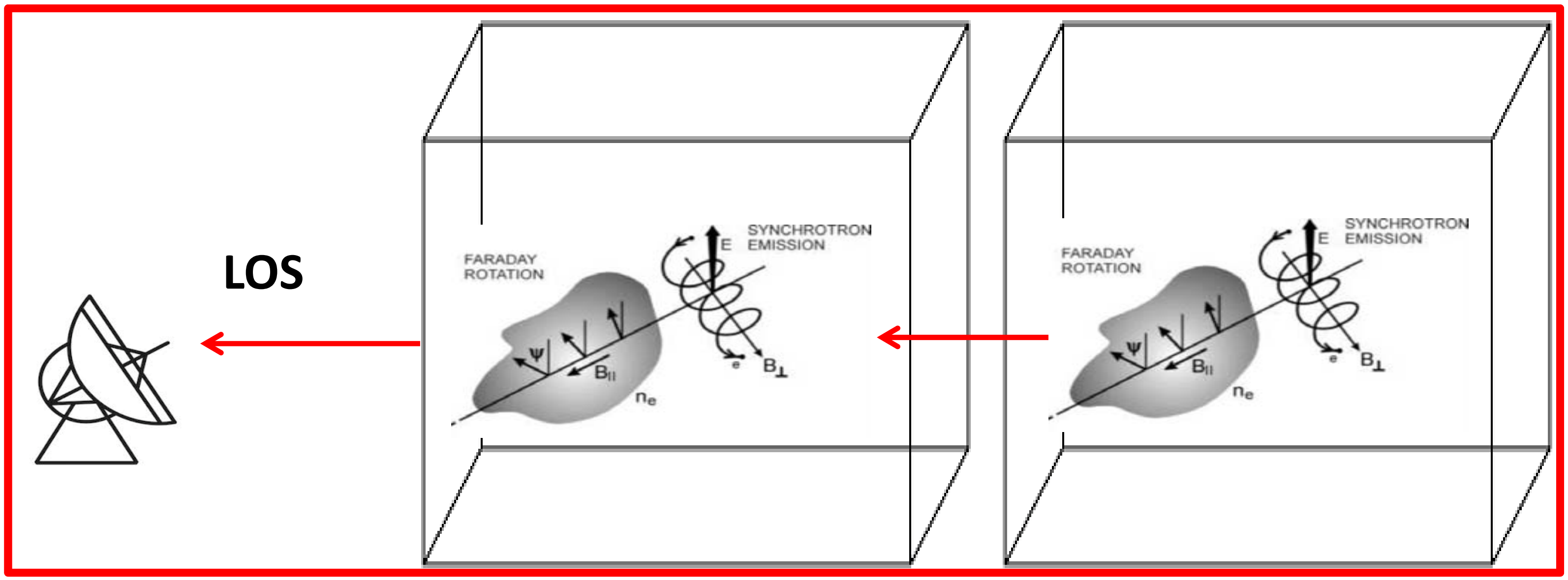
QM < 0

QM > 0

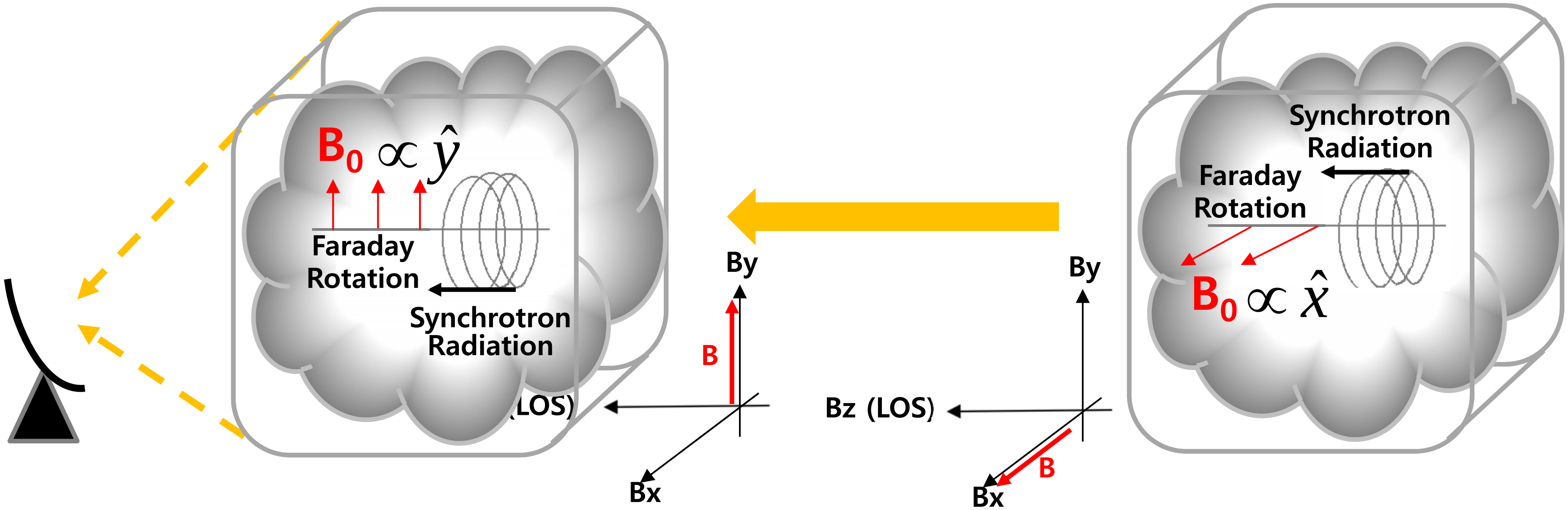
Statistics at regions

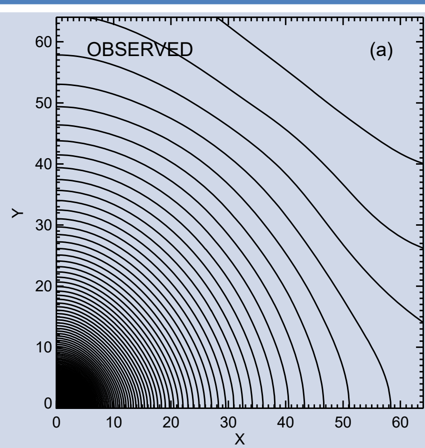
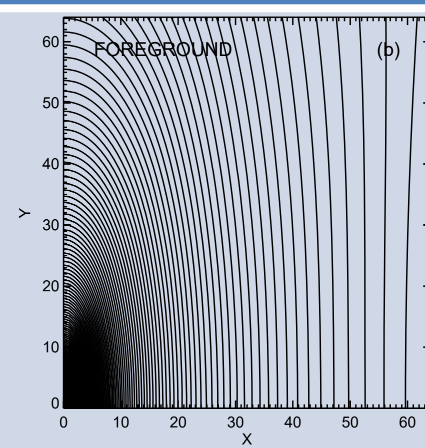
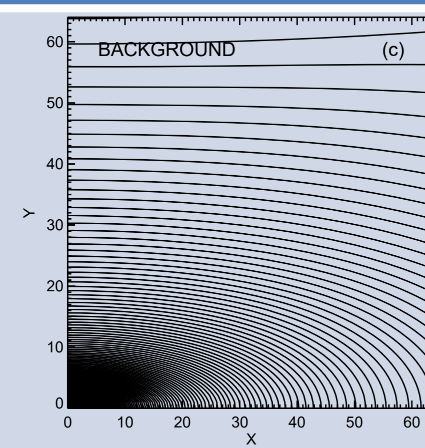
Condition 1	Condition 2
spatially – coincident regions	spatially – separated regions



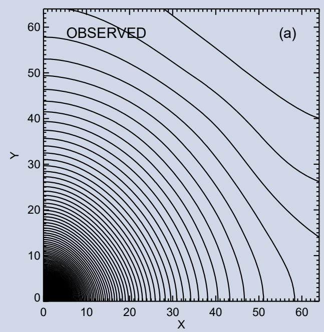
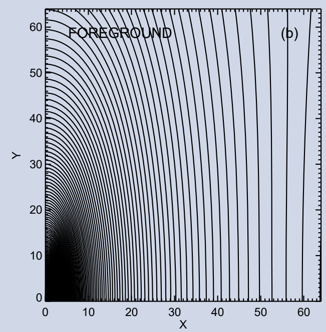
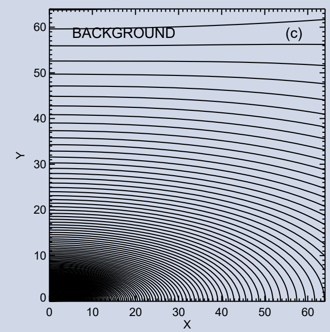
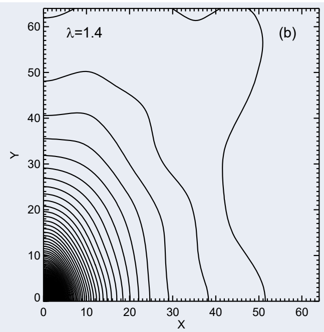
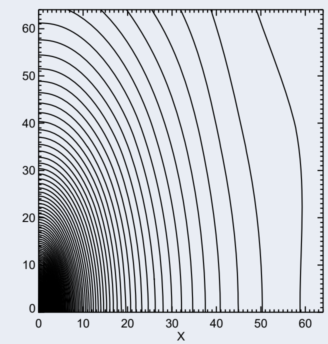
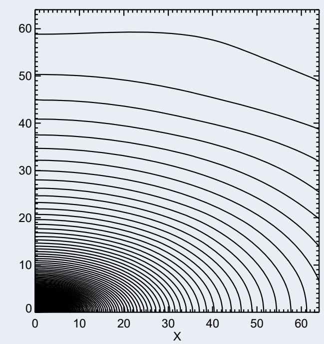
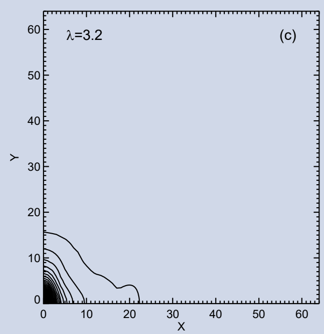
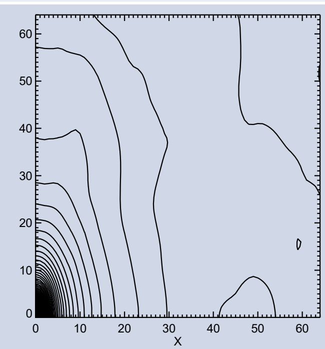
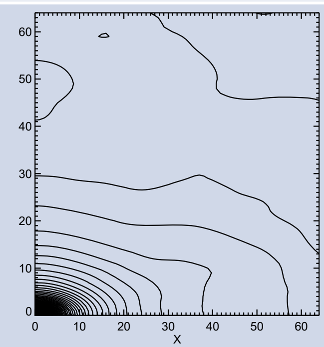


Polarized emission from two regions

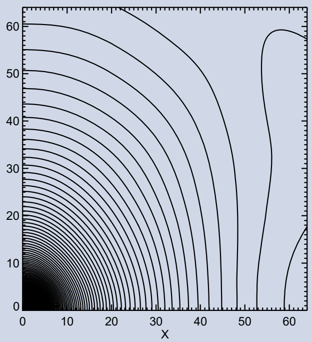
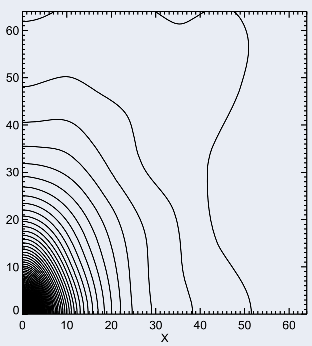
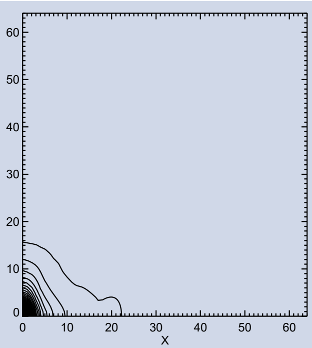


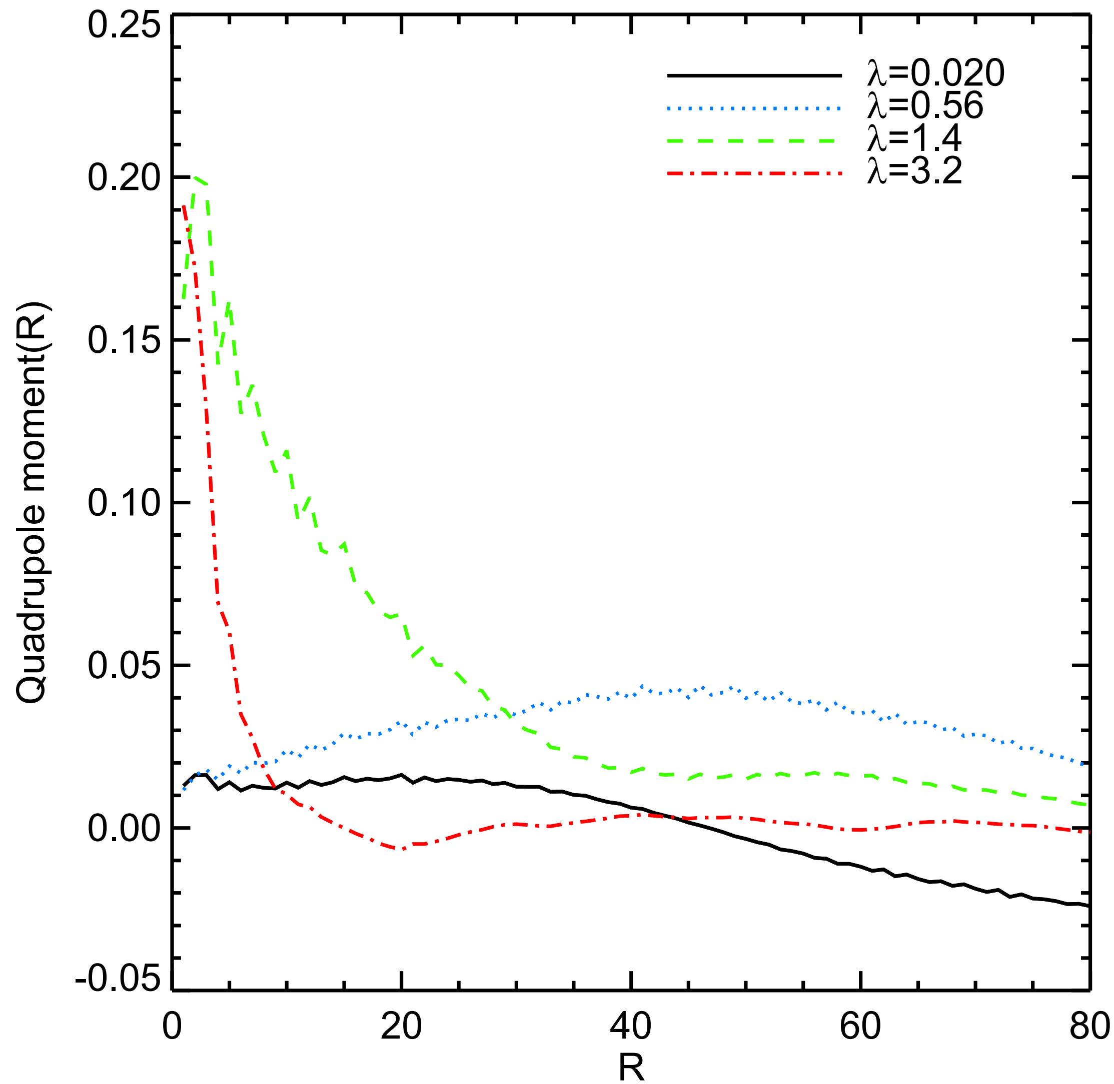
	Observed PI	Foreground region	Background region
PI			

Polarization at various λ

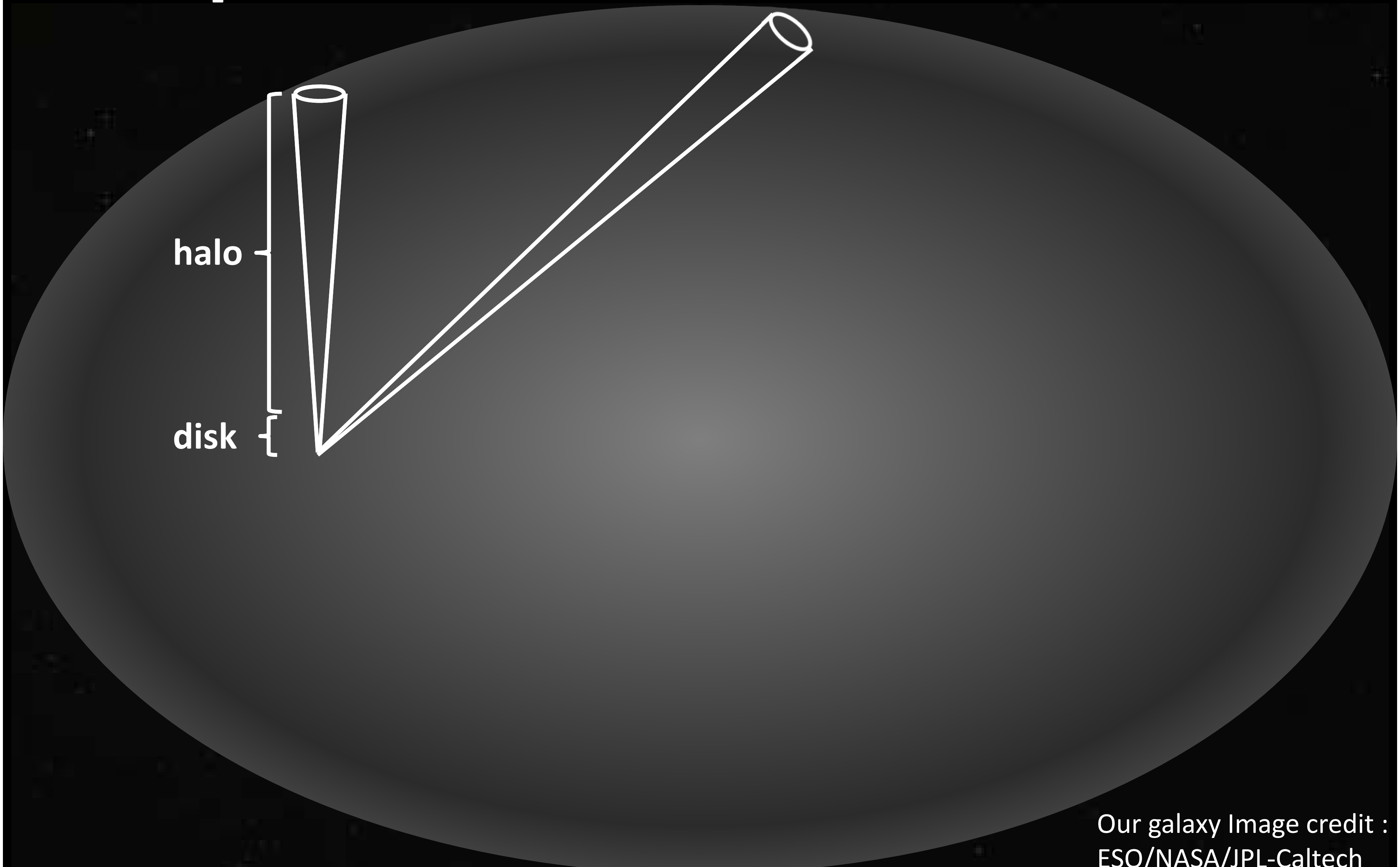
	Observed PI	Foreground region	Background region
0.02			
1.4			
3.2			

Quadrupole Moment at various λ

	Observed PI
0.02	
1.4	
3.2	



Different synchrotron emissivities

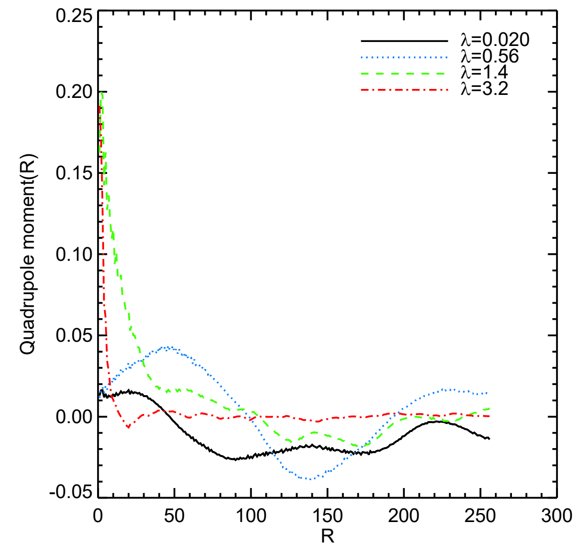


Our galaxy Image credit : ESO/NASA/JPL-Caltech

Summary

Our numerical results show that we can study MHD turbulence through polarized synchrotron emission.

Quantification of anisotropic structure for polarized intensity



Our present study paves the way for the successful reproduction of anisotropic structure using structure function at various λ.

Thank you for your attention!

Stokes parameter

$$I = 2F(p)\omega^{\frac{1-p}{2}} \int d\Omega \int dz \left(B_x^2 + B_y^2\right)^{\frac{p-3}{4}} \left(B_x^2 + B_y^2\right)$$

$$Q = -2G(p)\omega^{\frac{1-p}{2}} \int d\Omega \int dz \left(B_x^2 + B_y^2\right)^{\frac{p-3}{4}} \left(B_x^2 - B_y^2\right)$$

$$U = -2G(p)\omega^{\frac{1-p}{2}} \int d\Omega \int dz \left(B_x^2 + B_y^2\right)^{\frac{p-3}{4}} 2\left(B_x B_y\right)$$

ω=2πc/λ,

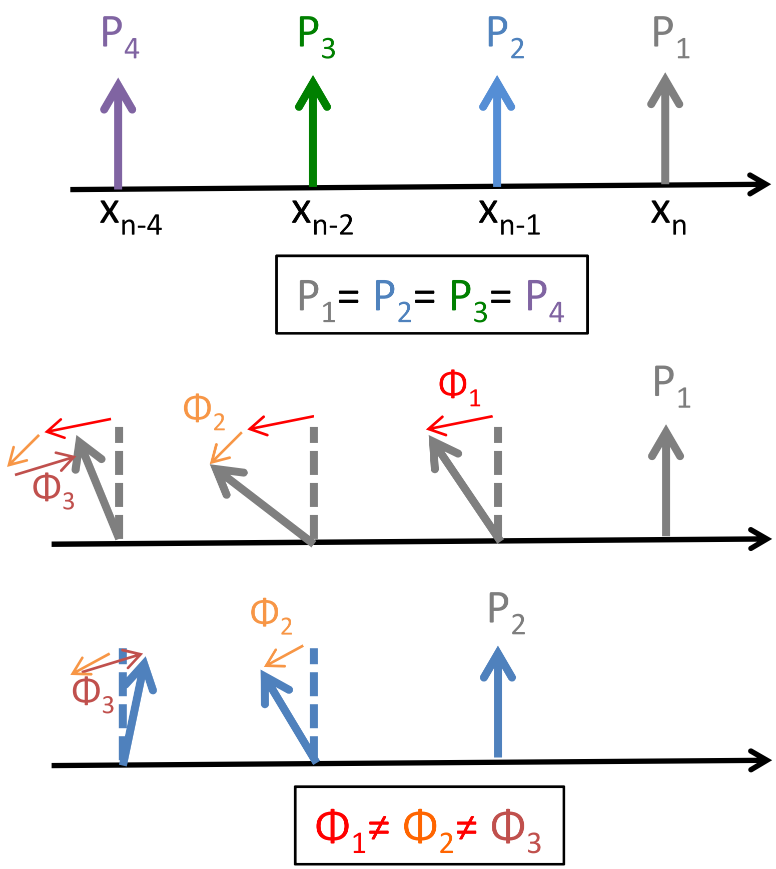
λ is the observation wavelength,

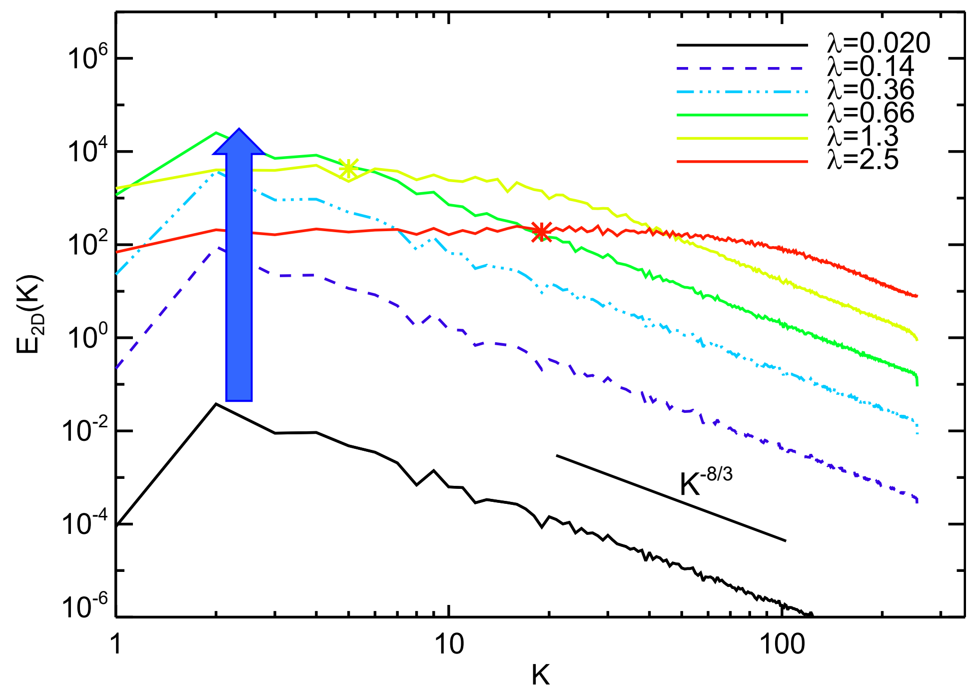
p is the spectral index of the electron energy distribution

Power spectrum

Effect of Faraday rotation

Fixed intrinsic synchrotron emission **(Q/I=1, U/I=0)**



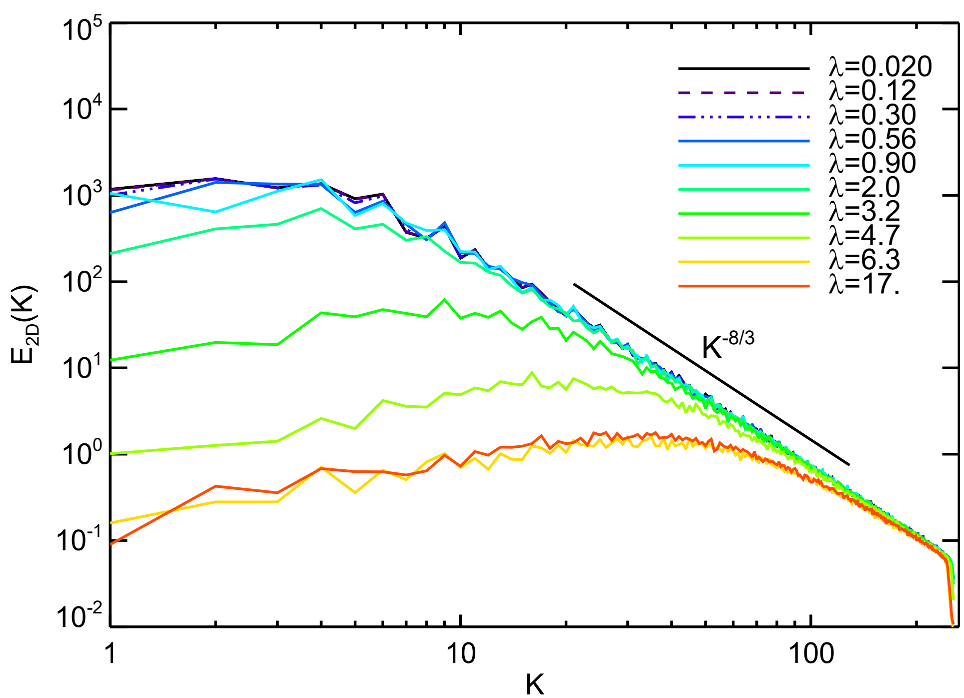


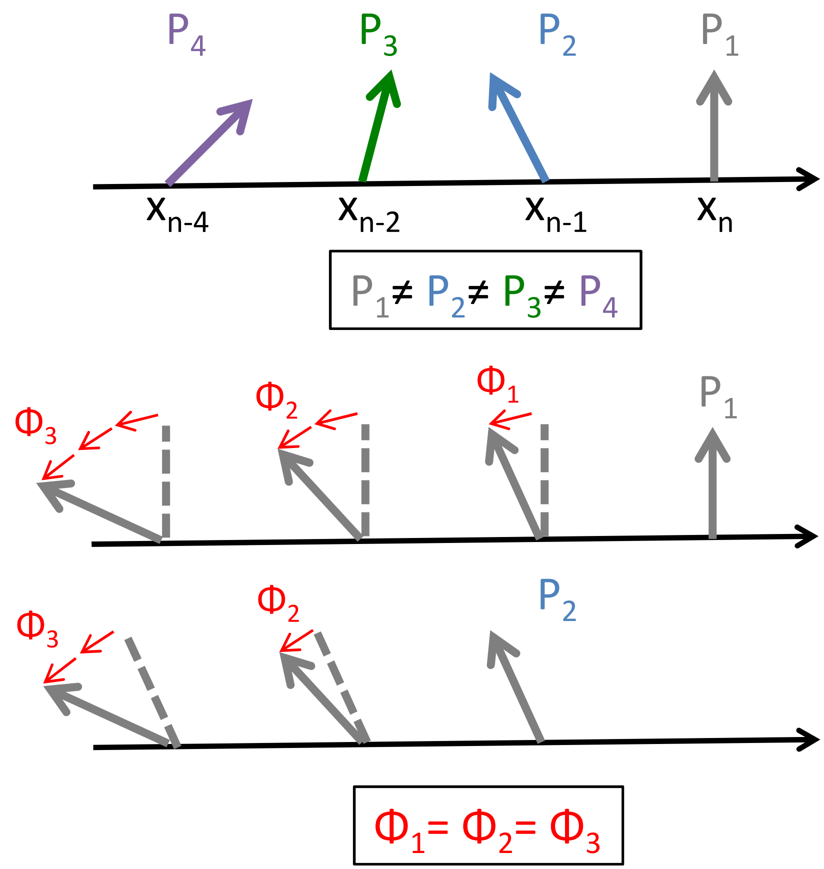
Power spectrum

Effect of Faraday depolarization

Uniform Faraday rotation

($n_e(z)=1$, $B_z(z)=1$)





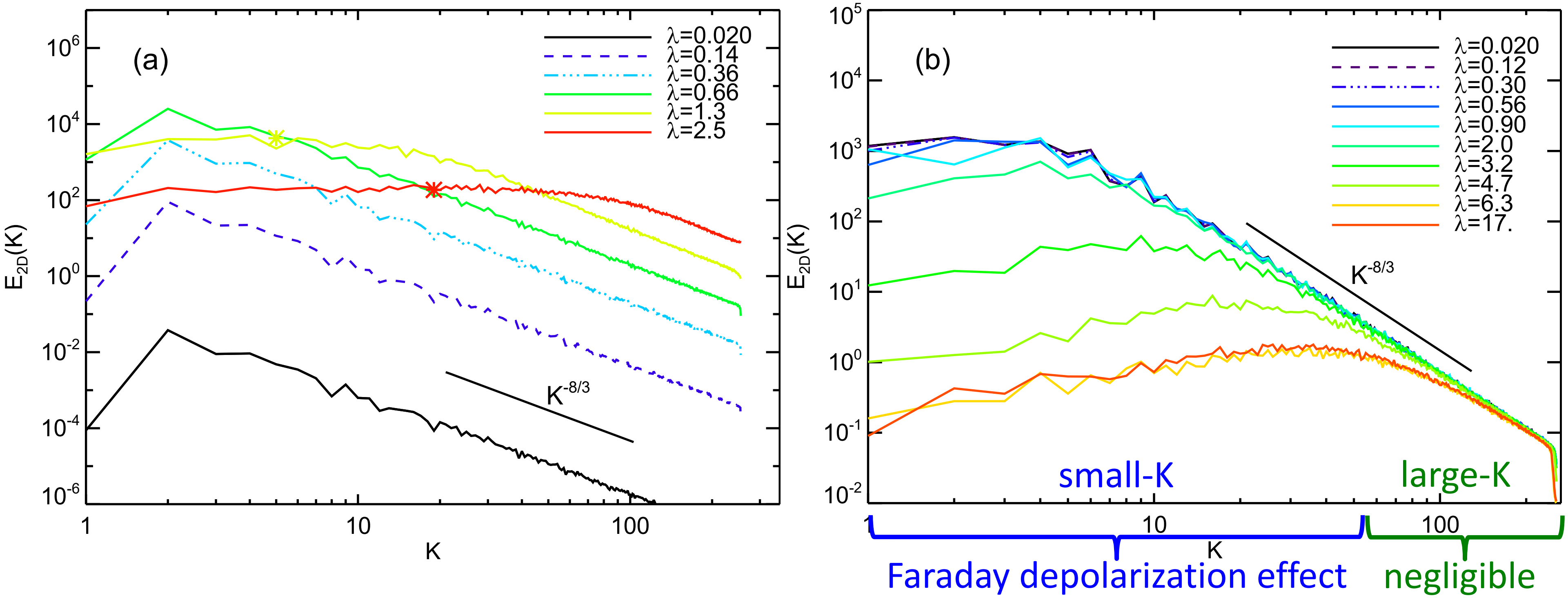
Power spectrum

Effect of Faraday rotation

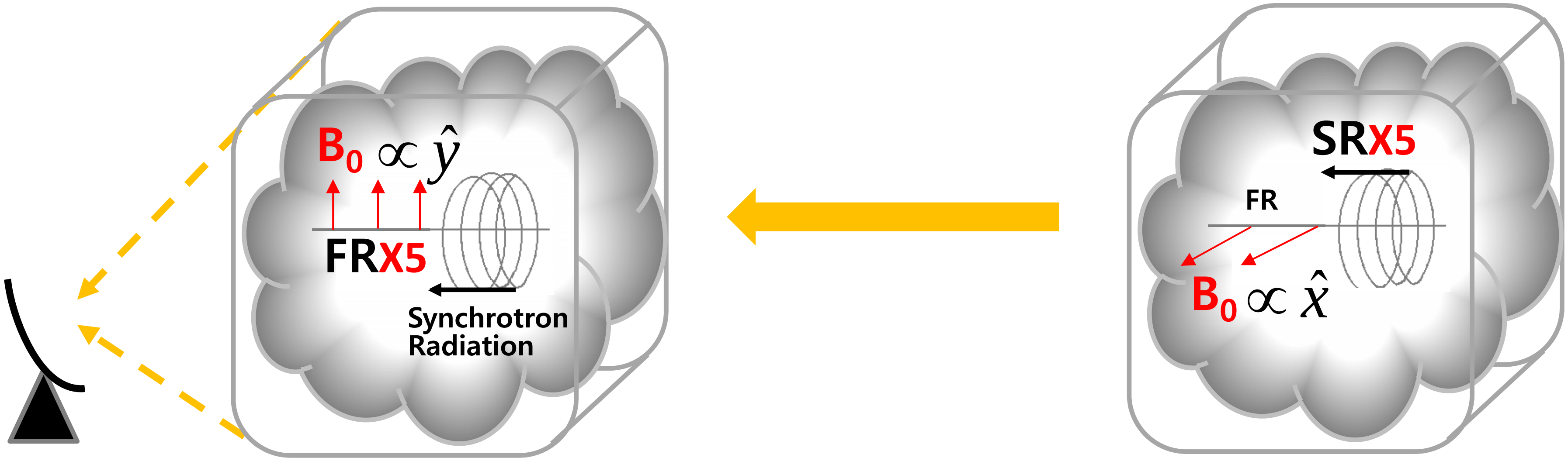
Fixed intrinsic synchrotron emission **(Q/I=1, U/I=0)**

Effect of Faraday depolarization

Uniform Faraday roatation **($n_e(z)$=1, $B_z(z)$=1)**



Different synchrotron emissivities



<table>
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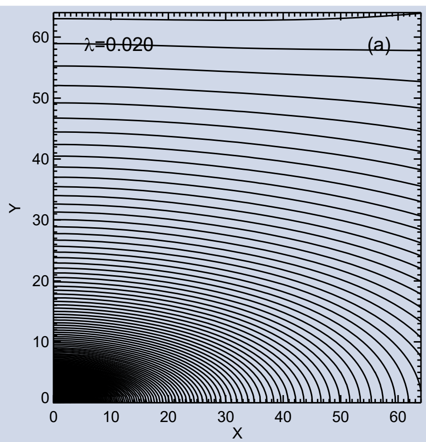
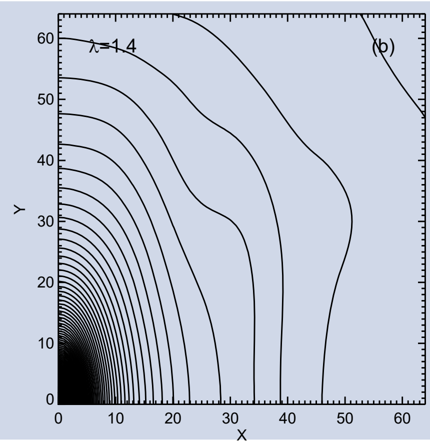
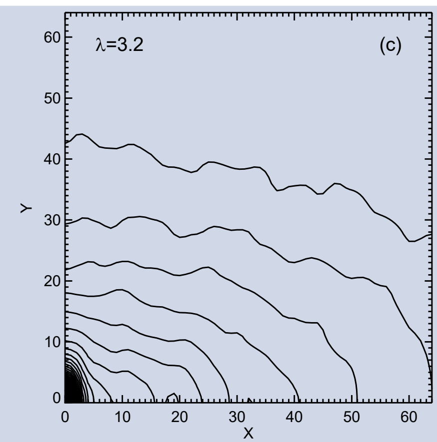
<tr><td>PI</td><td>
</td><td>
</td><td>
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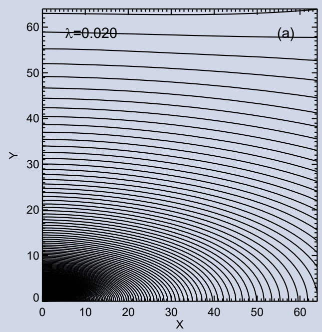
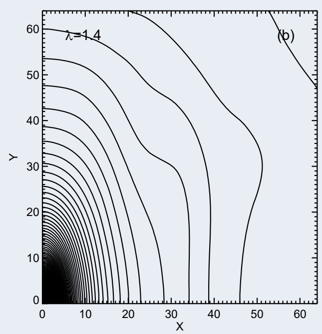
Quadrupole Moment at various λ

	Observed PI
0.02	
1.4	
3.2