Statistical study of turbulence from polarized synchrotron emission

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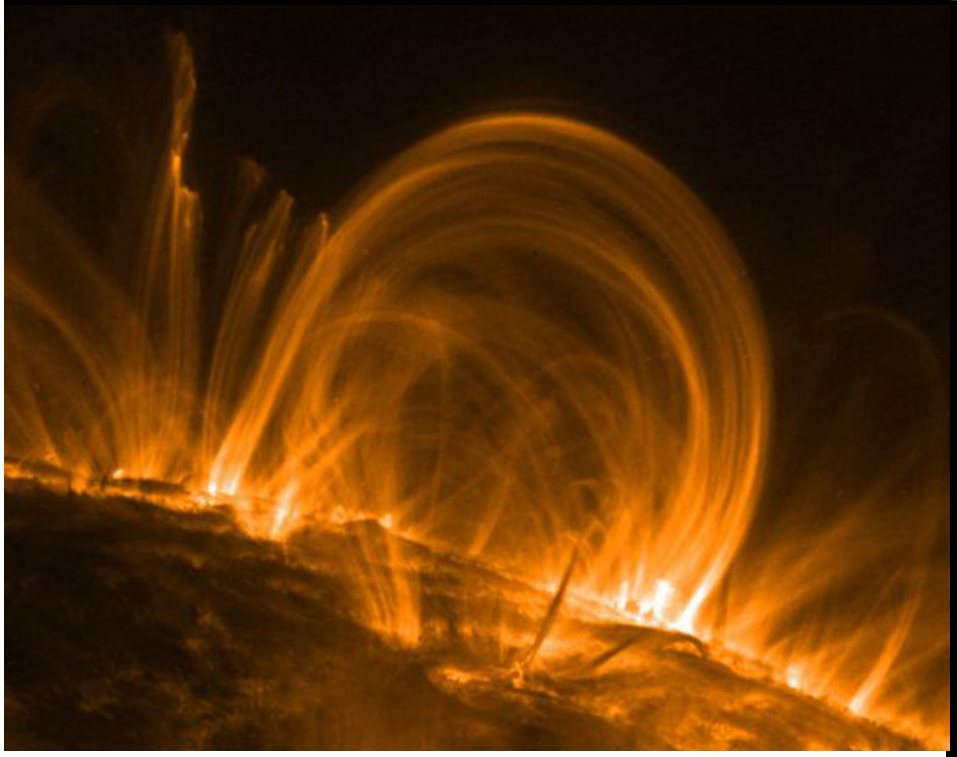
Motivation

Magnetic reconnection

Magnetohydrodynamic Turbulence



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star formation

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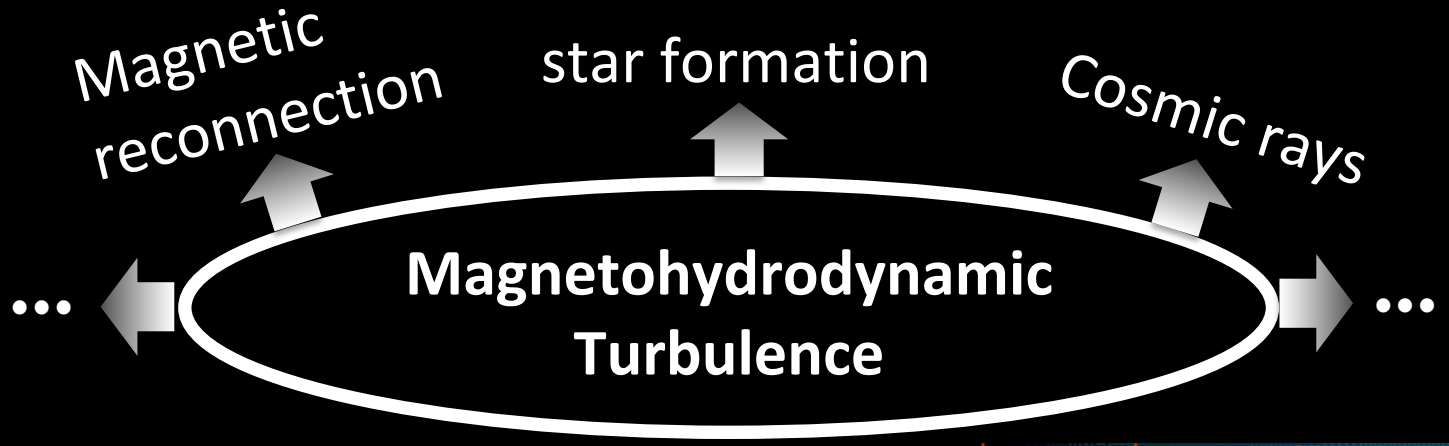
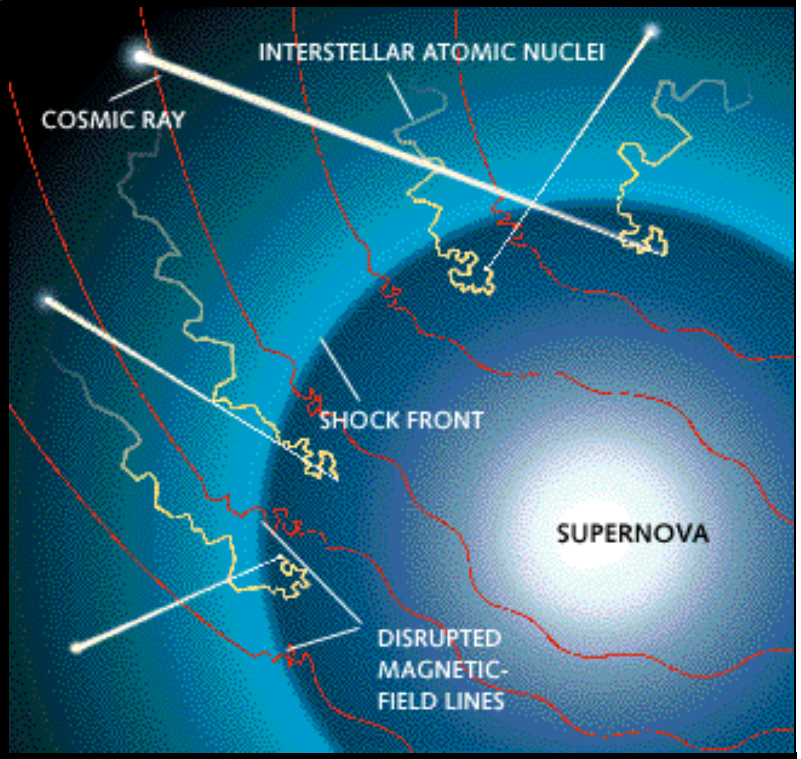
Motivation


Magnetic reconnection
star formation
Cosmic rays
...
Magnetohydrodynamic Turbulence
...


INTERSTELLAR ATOMIC NUCLEI
COSMIC RAY
SHOCK FRONT
SUPERNOVA
DISRUPTED MAGNETIC-FIELD LINES

Motivation

Magnetic reconnection

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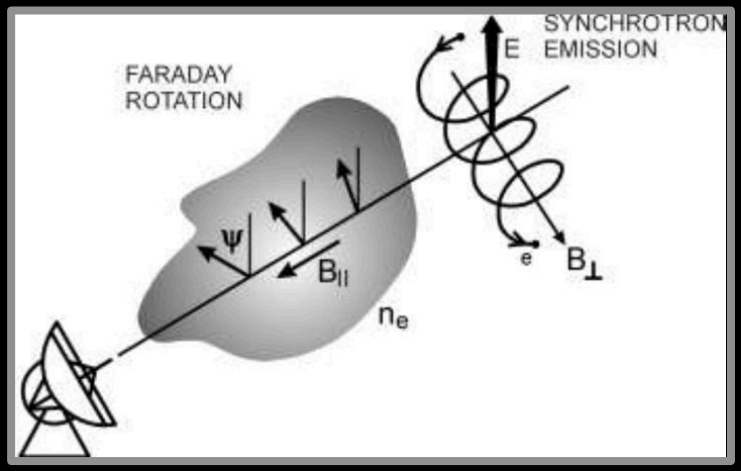
...

Magnetohydrodynamic Turbulence

...

$\Phi \propto B_{||}$

$\propto \lambda$



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

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

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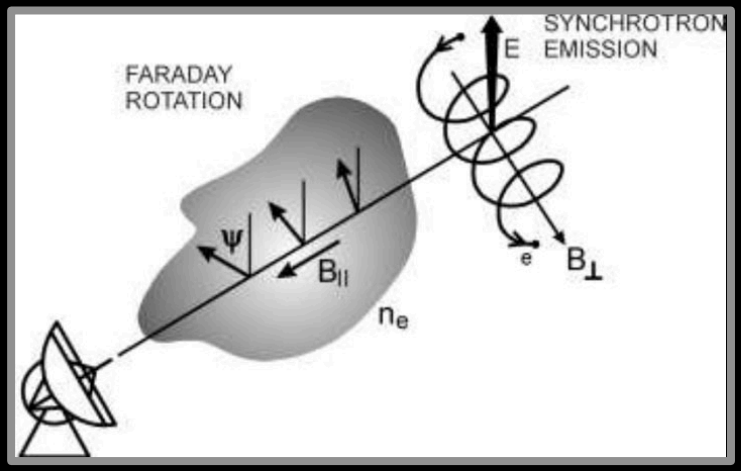

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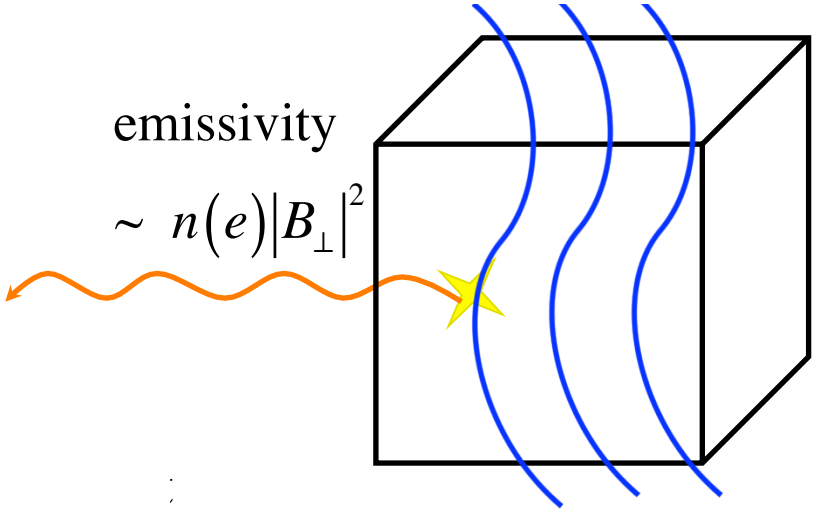
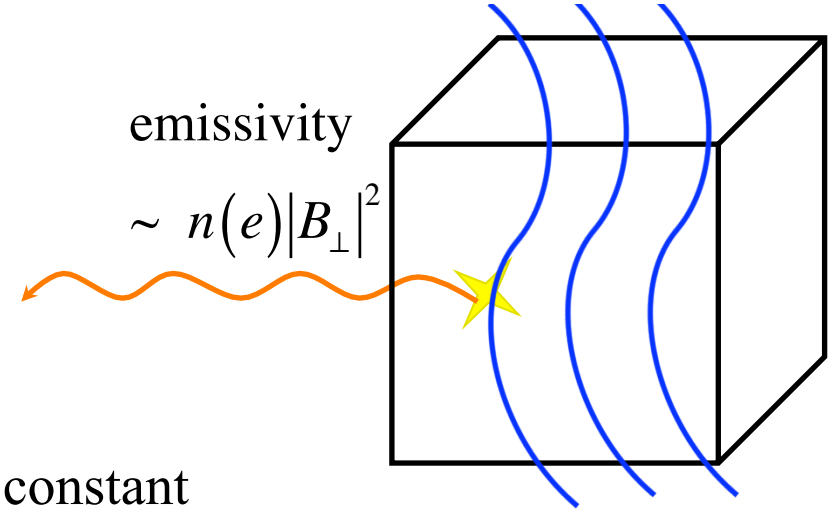
PDF **Power spectrum** **Structure function** ...

B and synchrotron radiation

synchrotron emissivity $\propto n(e)|B_{\perp}|^2$



B and synchrotron radiation



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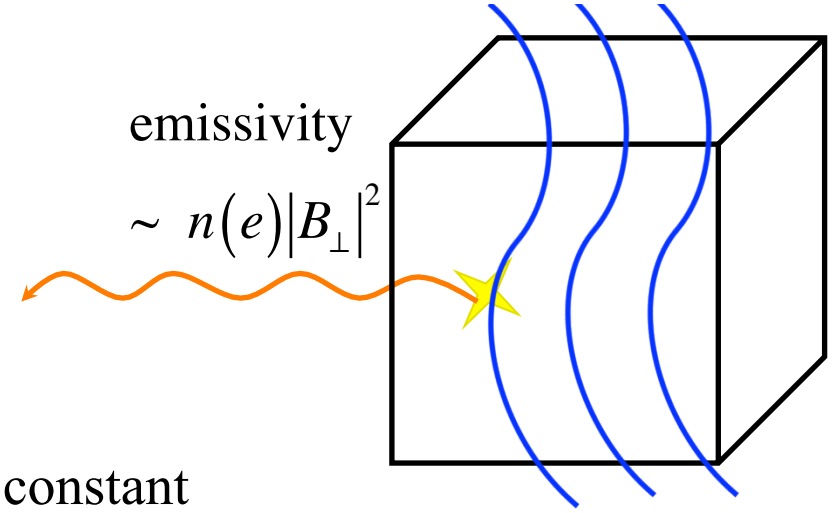
observed intensity $\propto \sum |B_\perp|^2$ ← if $n(e)$ is constant

B and synchrotron radiation



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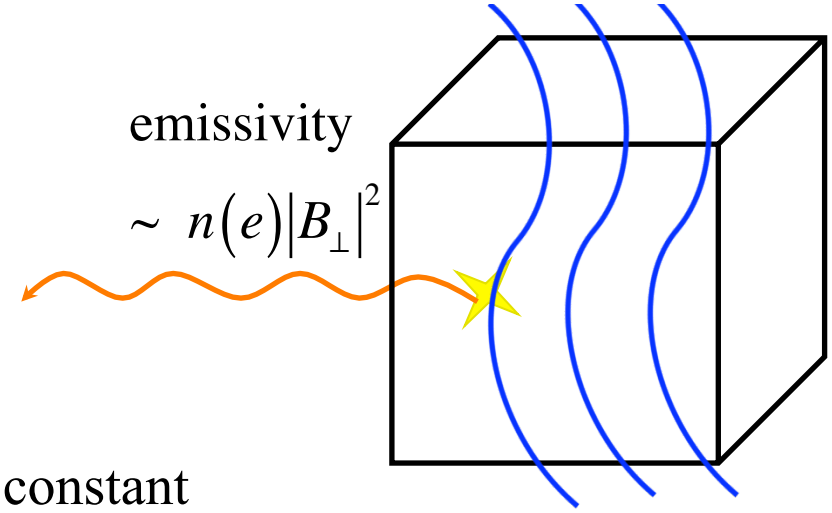
$$= \boxed{\sum |B_{\perp,0} + \delta b|^2}$$

B and synchrotron radiation



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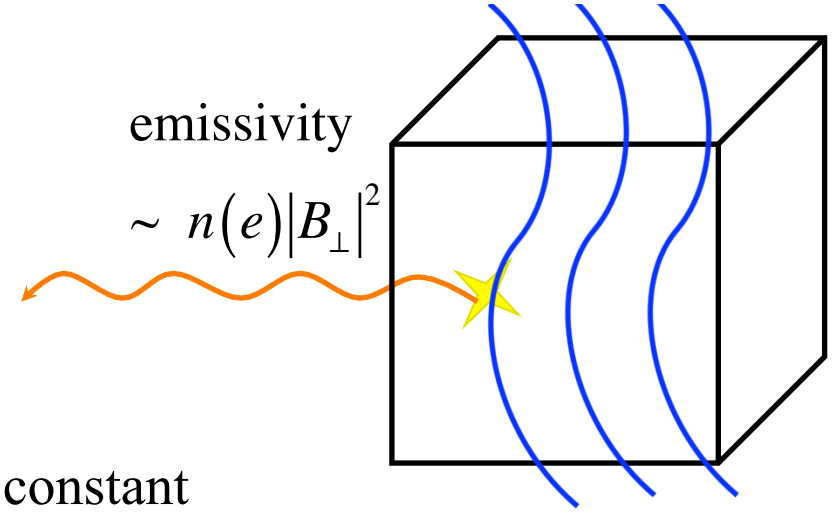
$\leftarrow B_{\perp,0}$ = mean-field (we assume $B_{\perp,0} > \delta b$ for simplicity)

$\approx C_1 + C_2 \sum \delta b + O\left(\frac{\delta b}{B_{\perp,0}}\right)^2$

B and synchrotron radiation



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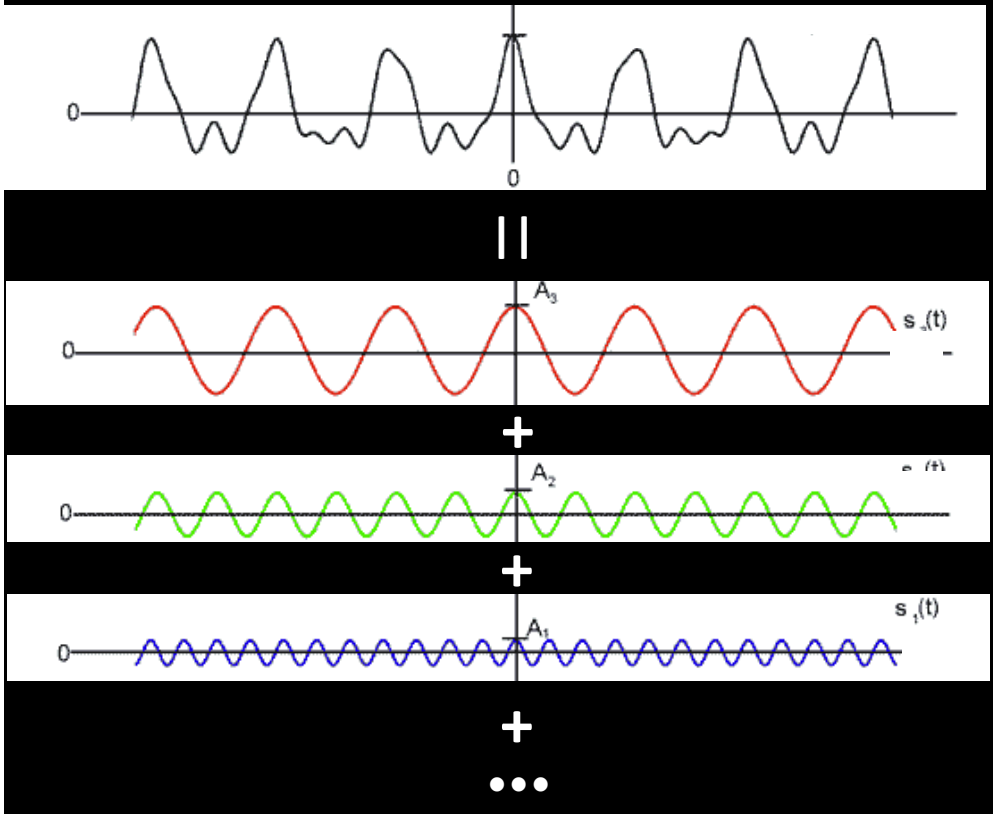
$$\approx \boxed{C_1 + C_2 \sum \delta b} + O\left(\frac{\delta b}{B_{\perp,0}}\right)^2$$

➔ Spectrum of observed synchrotron radiation reflects spectrum of δb

[Statistics]

1. power spectrum
2. quadrupole ratio

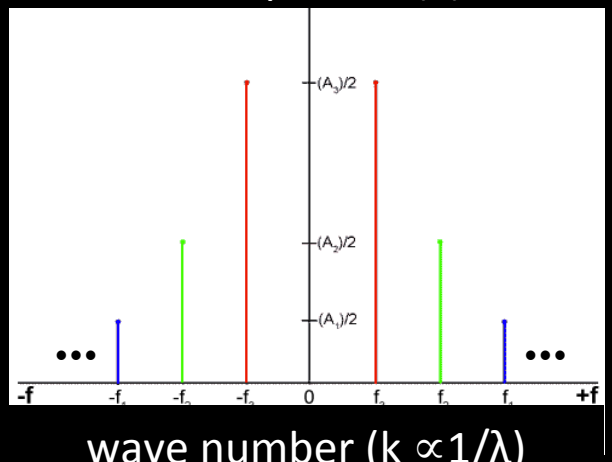
1. power spectrum



real-space distribution of v(r), b(r), ρ(r), …

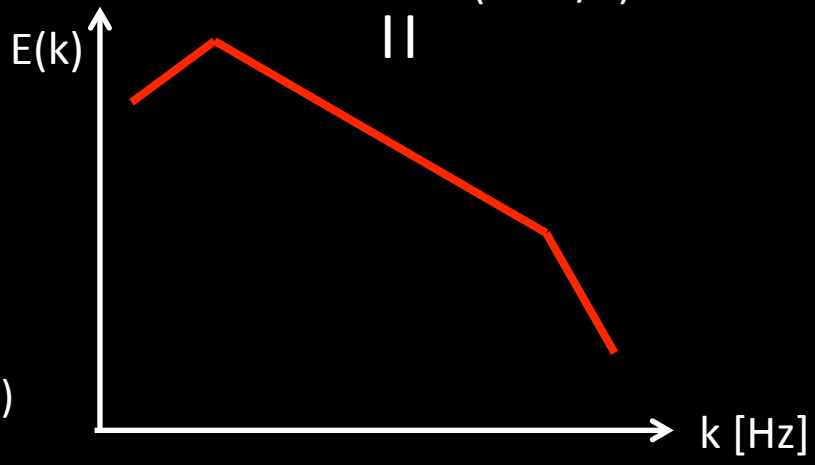
Fourier transform

Amplitude (S)



wave number (k ∝1/λ)

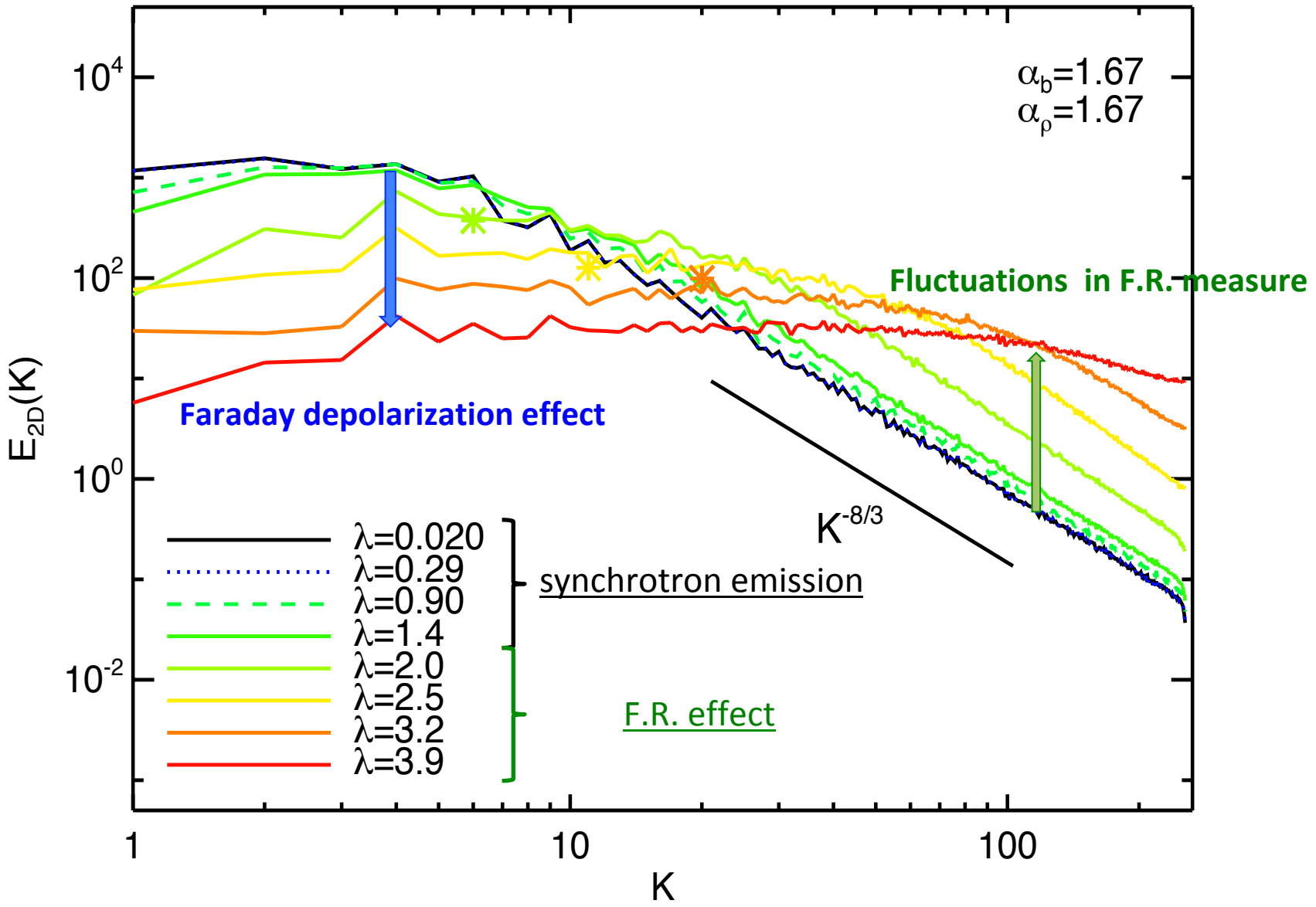
=



Power spectrum : E(k)

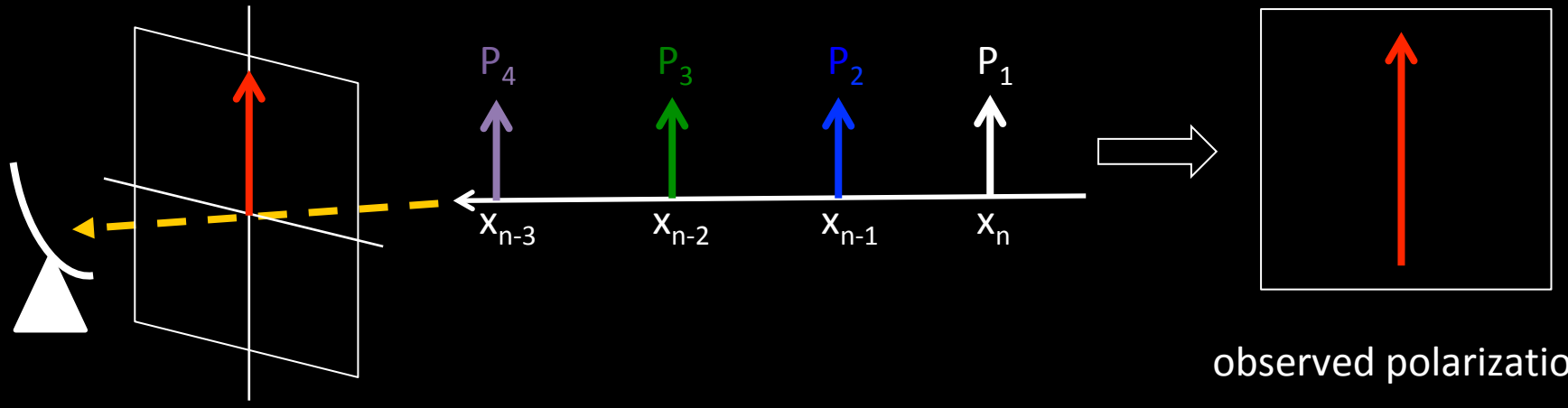
e.g) $E(k) \sim k^{5/3}$ (Kolmogorov spectrum)

Result 1. power spectrum

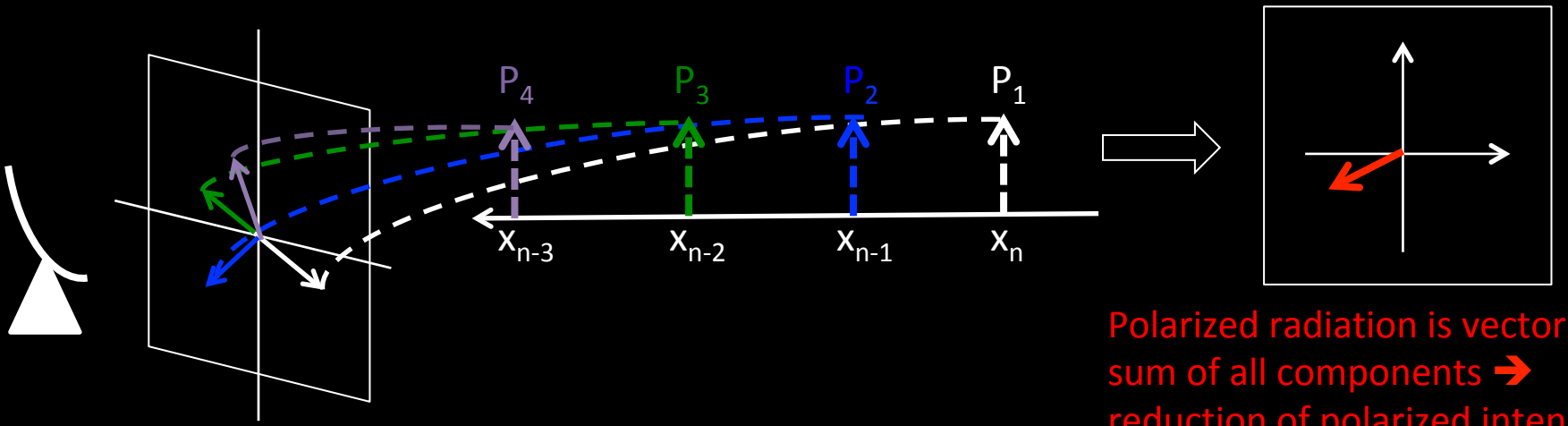


depolarization

Polarized radiation is arithmetic sum of all components



observed polarization

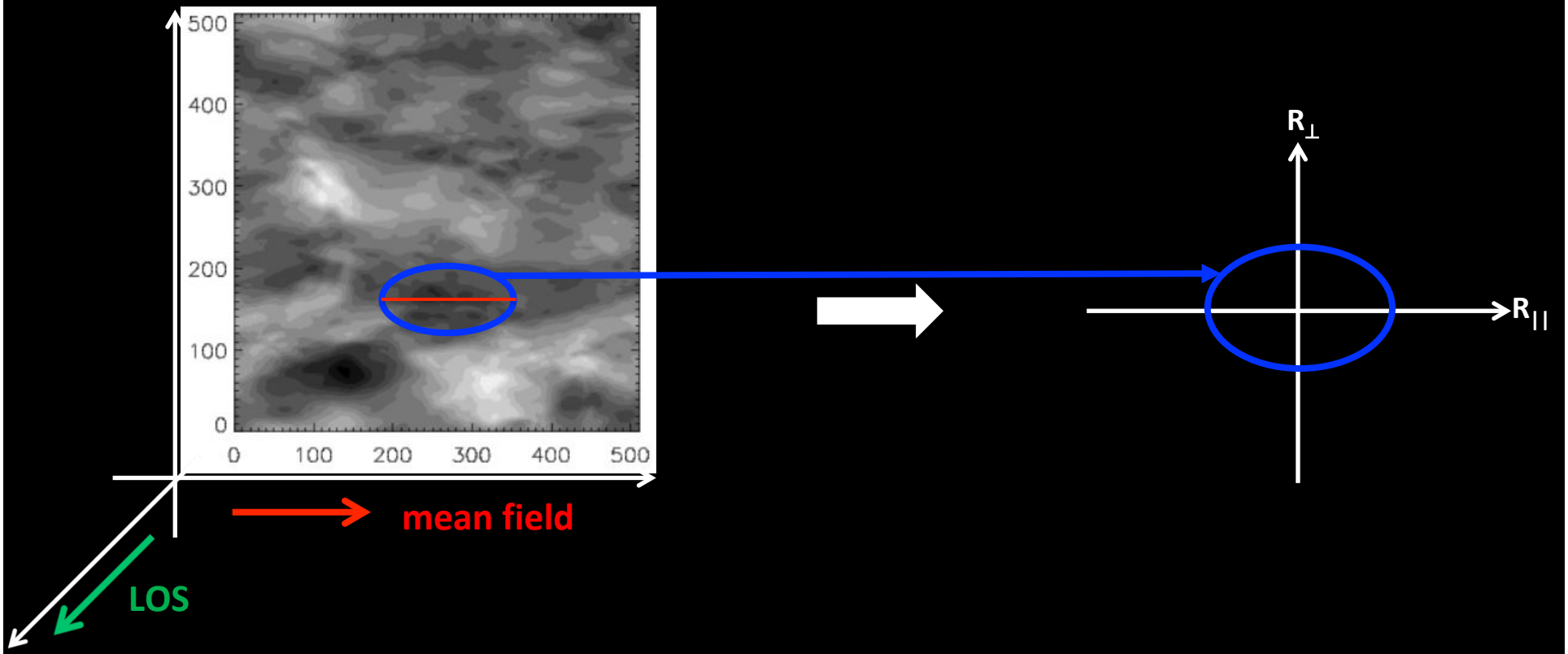


Polarized radiation is vector sum of all components ➔ reduction of polarized intensity

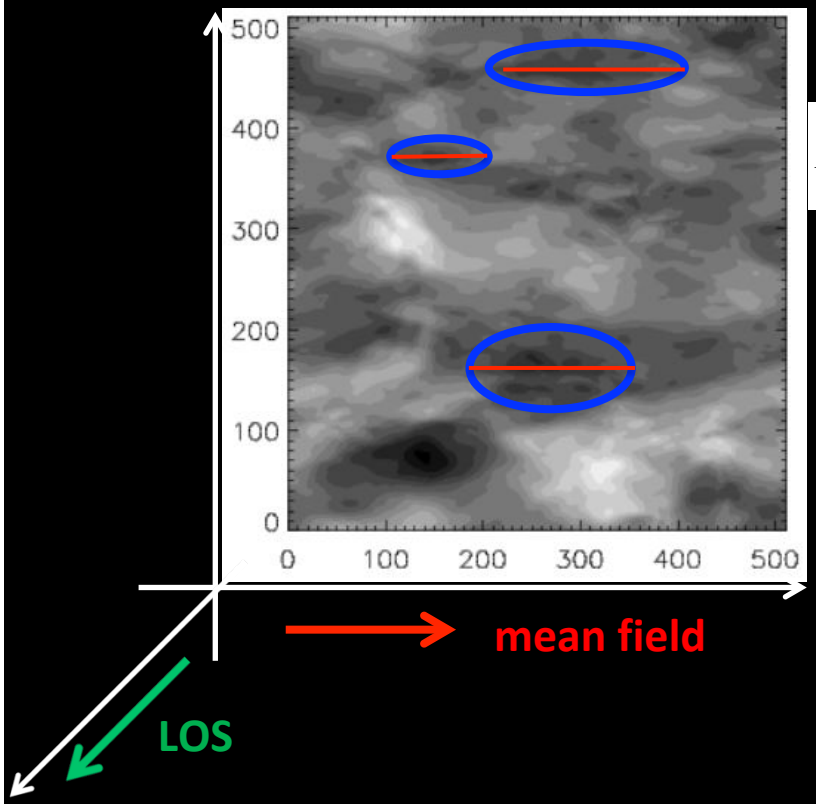
[Statistics]

1. power spectrum
2. quadrupole ratio

anisotropy

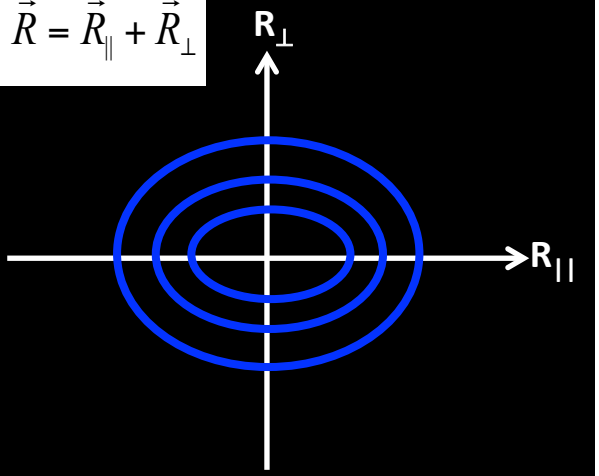

500
400
300
200
100
0
0
100
200
300
400
500
mean field
LOS
$R_\perp$
$R_{||}$

anisotropy

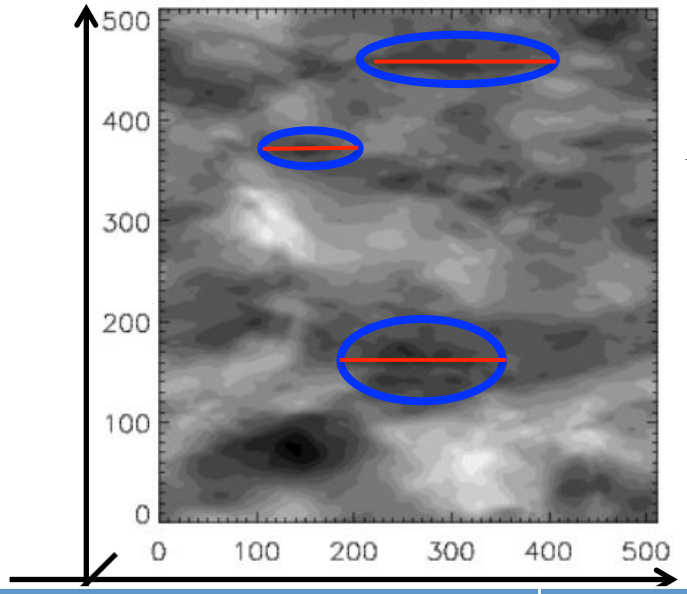


2-nd order structure function

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



Result 2. anisotropy



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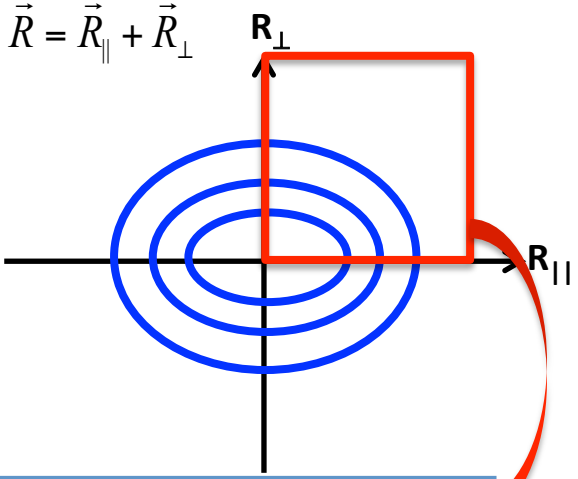
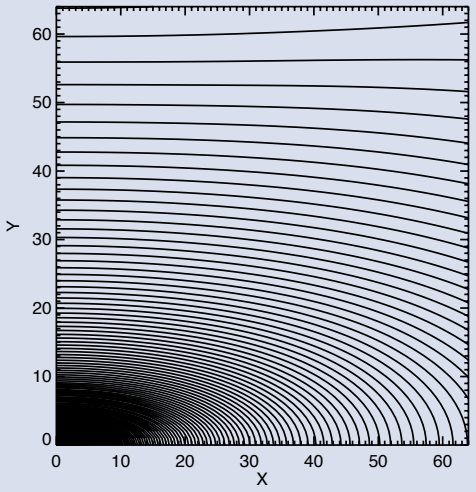
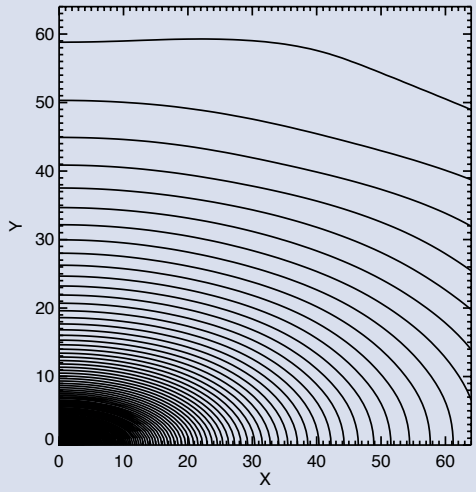
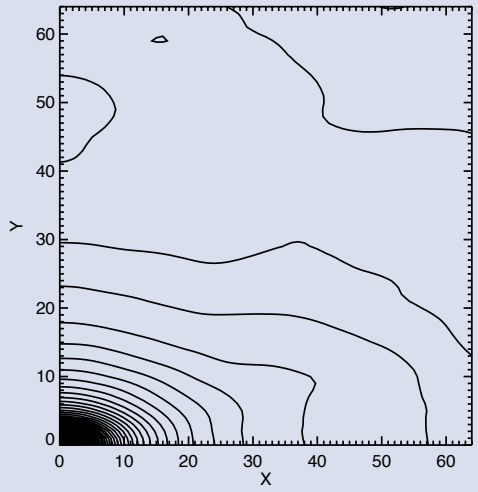
$$D_I(\vec{R}) = \left\langle \left(I(\vec{X}) - I(\vec{X}+\vec{R}) \right)^2 \right\rangle, \quad \vec{R} = \vec{R}_{\parallel} + \vec{R}_{\perp}$$



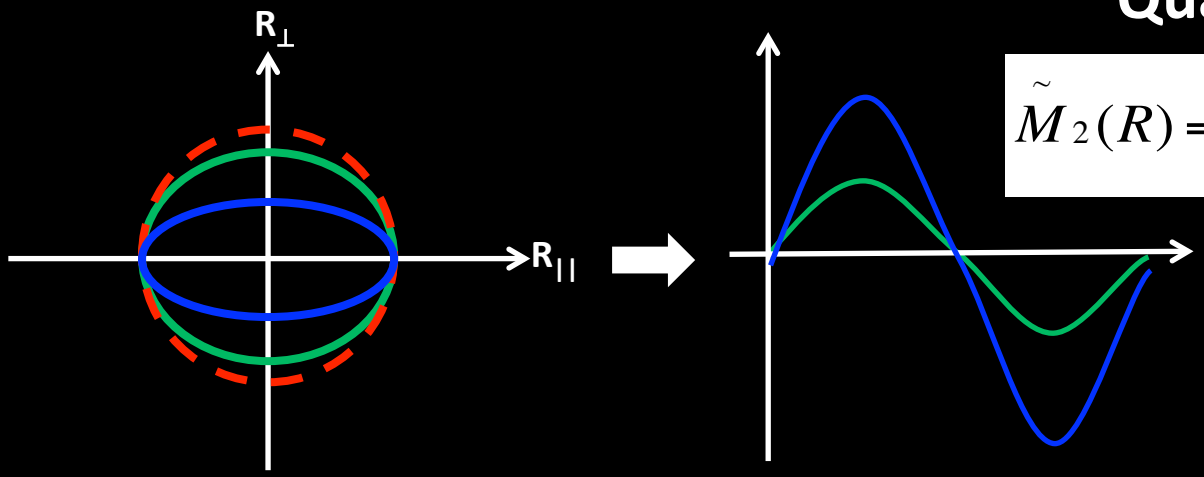
0.02	1.4	3.2







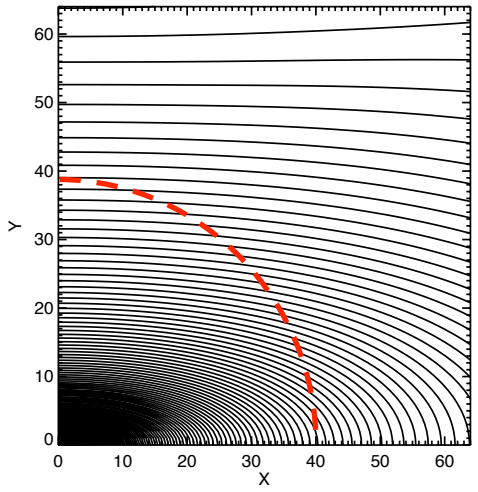
2. Quadrupole ratio

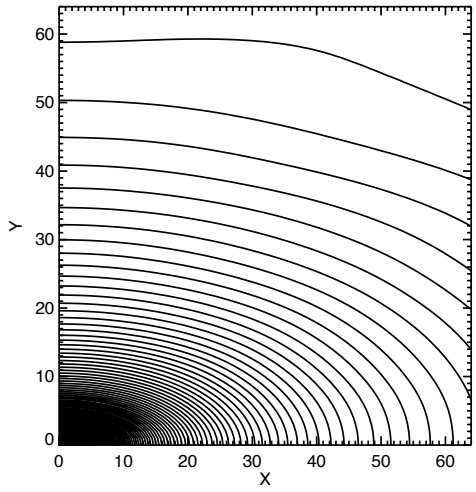


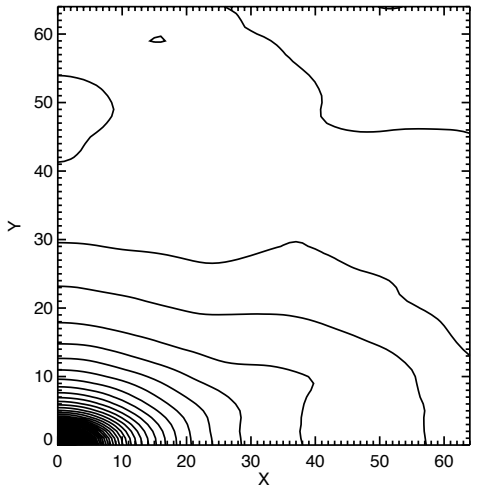
Quadrupole moment

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

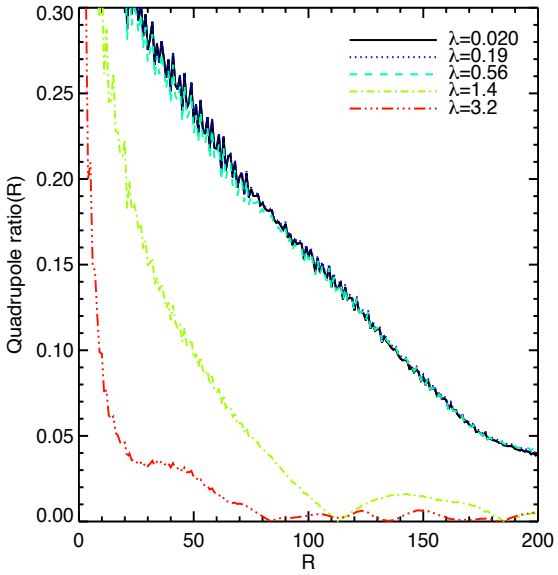
0.02	1.4	3.2







Result 3. Quadrupole ratio



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

$$\frac{\tilde{M}_2(R)}{\tilde{M}_0(R)}$$

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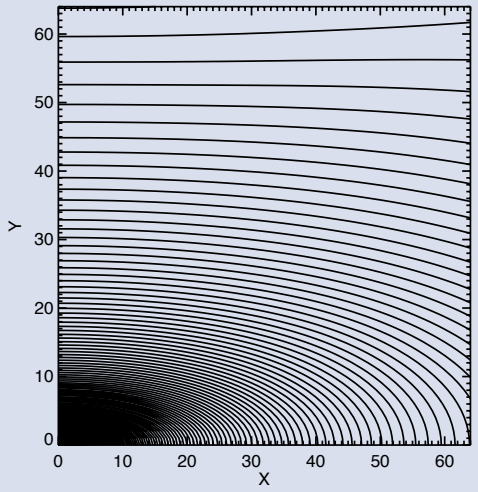	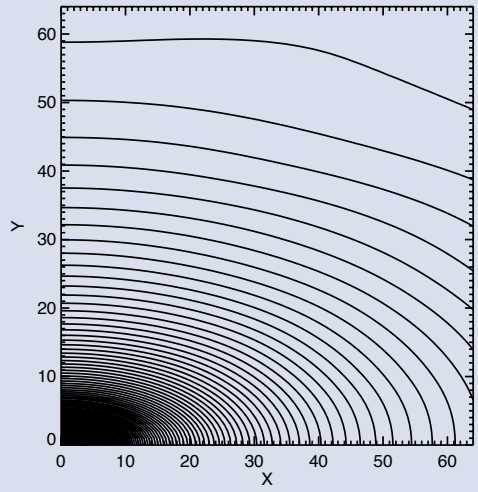	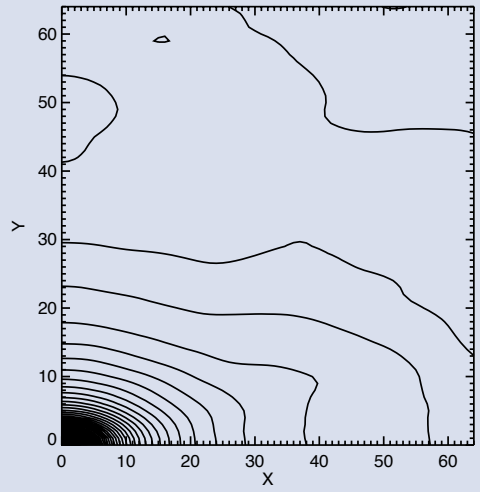

Summary

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

This study can be performed

- in the presence of Faraday rotation and depolarization caused by turbulent magnetic field,
- with statistics power spectrum and structure function

➔ **Our present study paves the way for the successful use of spectrum with observational data**

and

for the successful reproduction of anisotropic structure using structure function at various λ.

Any questions?

Thank you for your attention!