Hard X-ray Polarisation of Gamma Ray Bursts

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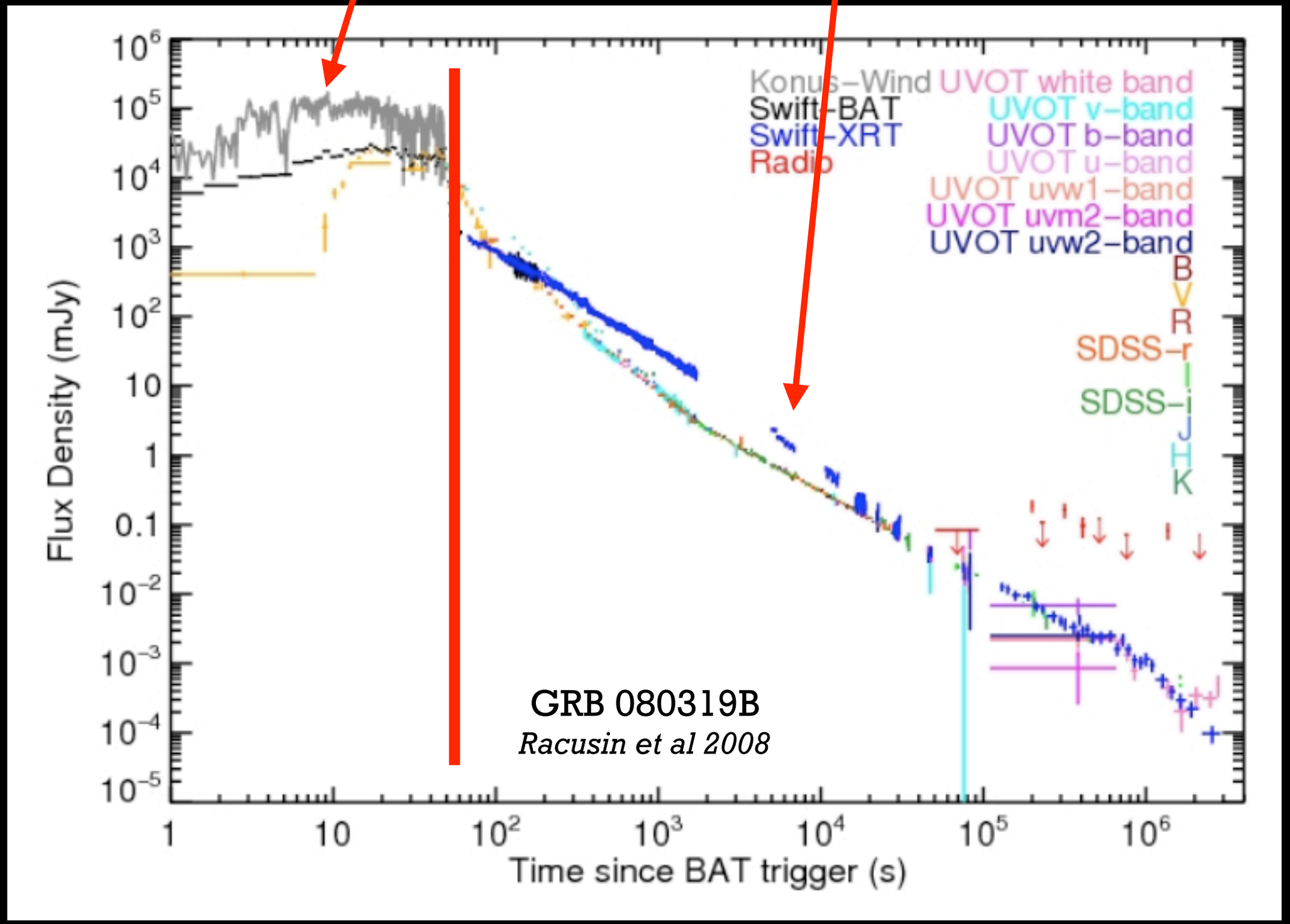
Hard X-ray Polarisation of GRBs relate to the Prompt Emission phase

GRB emission

prompt and afterglow



Detection of GRB polarisation

- CGRO/BATSE
  1993-1996
- RHESSI
  2002
- INTEGRAL
  2004-present
- IKAROS/GAP
  2010-2012

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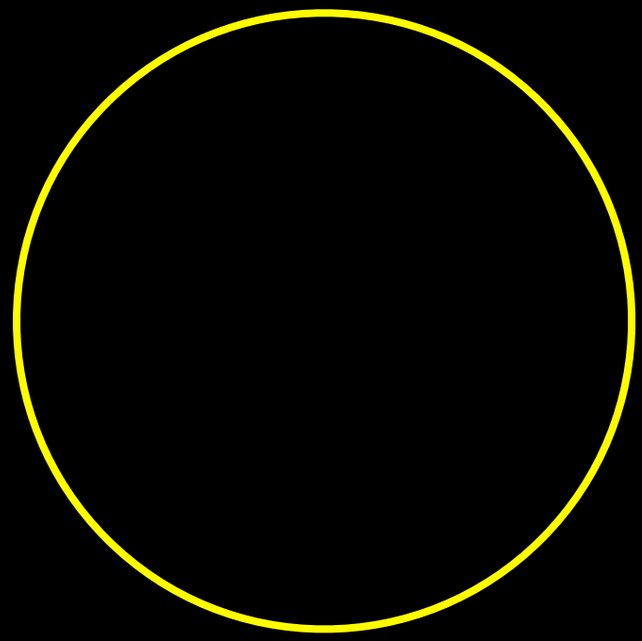
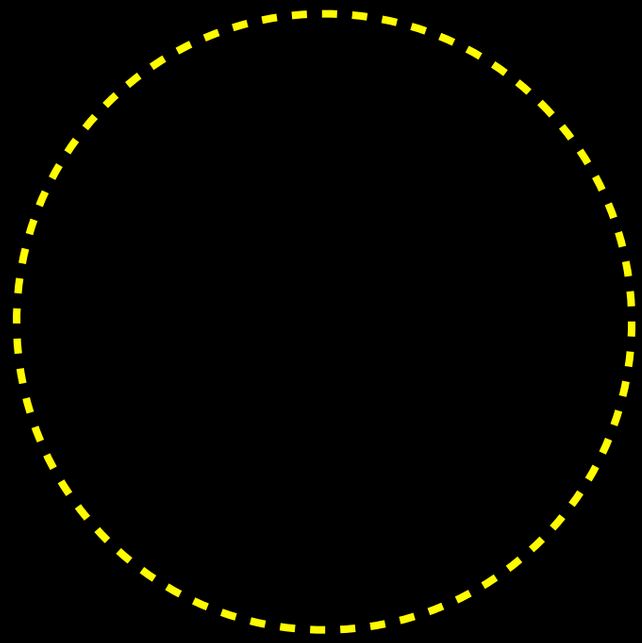


ASTROSAT
2015-present



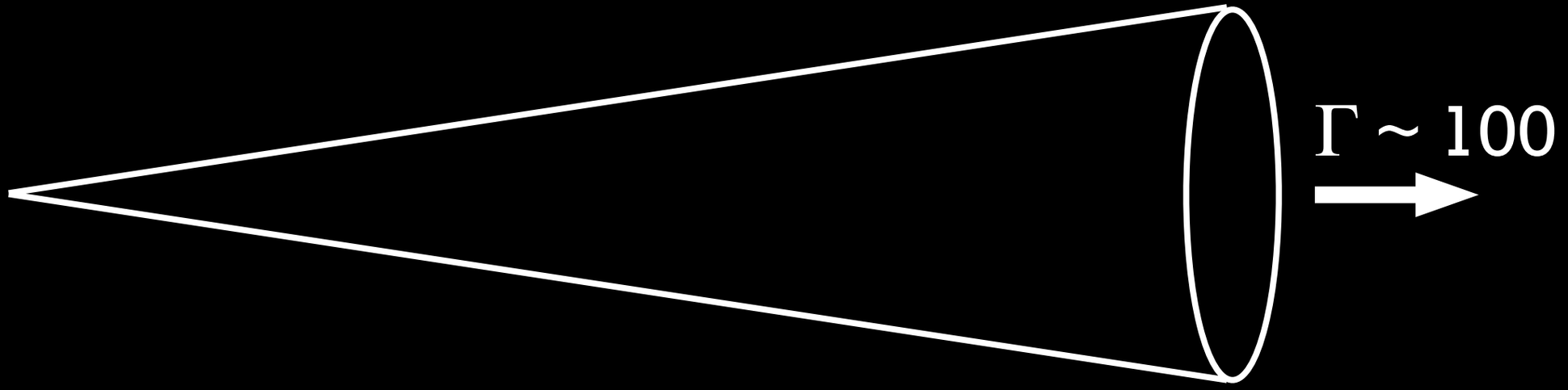
POLAR
2016-present

Why is GRB polarisation important?

- Prompt Emission mechanism largely unknown
- Polarisation a key indicator of emission mechanism

Basic things known about GRB prompt emission

Highly relativistic outflow (*cf. compactness problem*)



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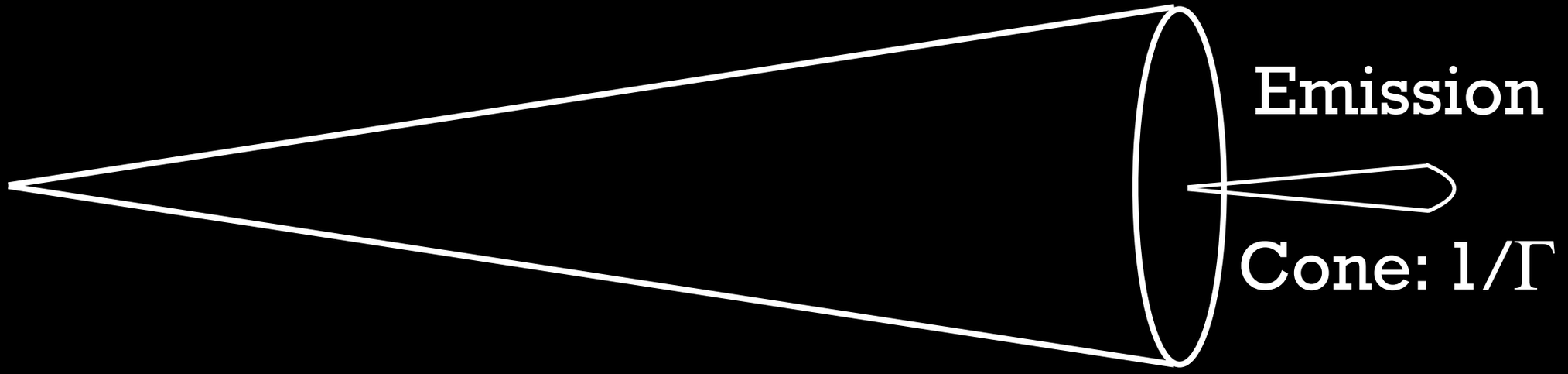
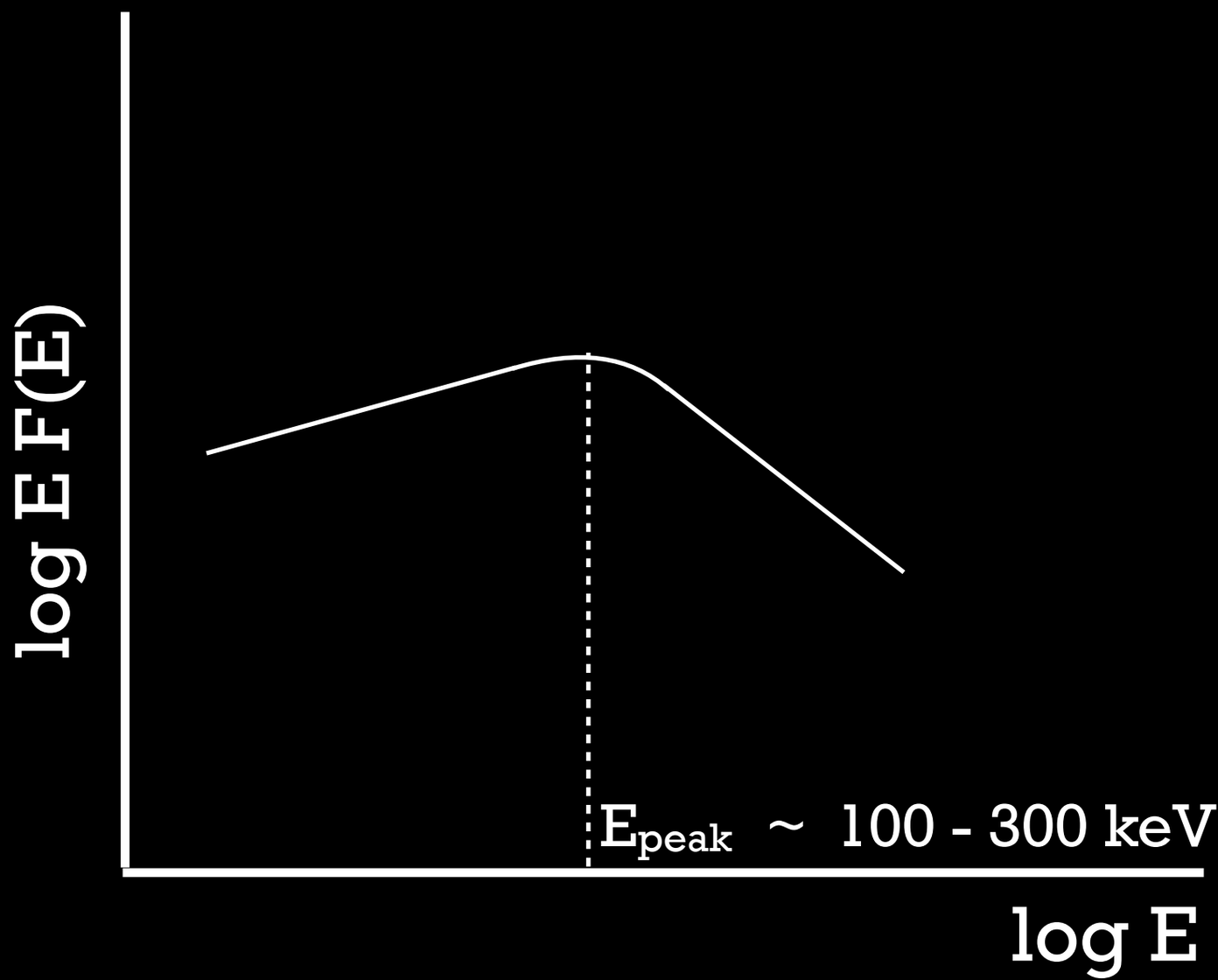


Spectrum typically a double power law (*Band function*)



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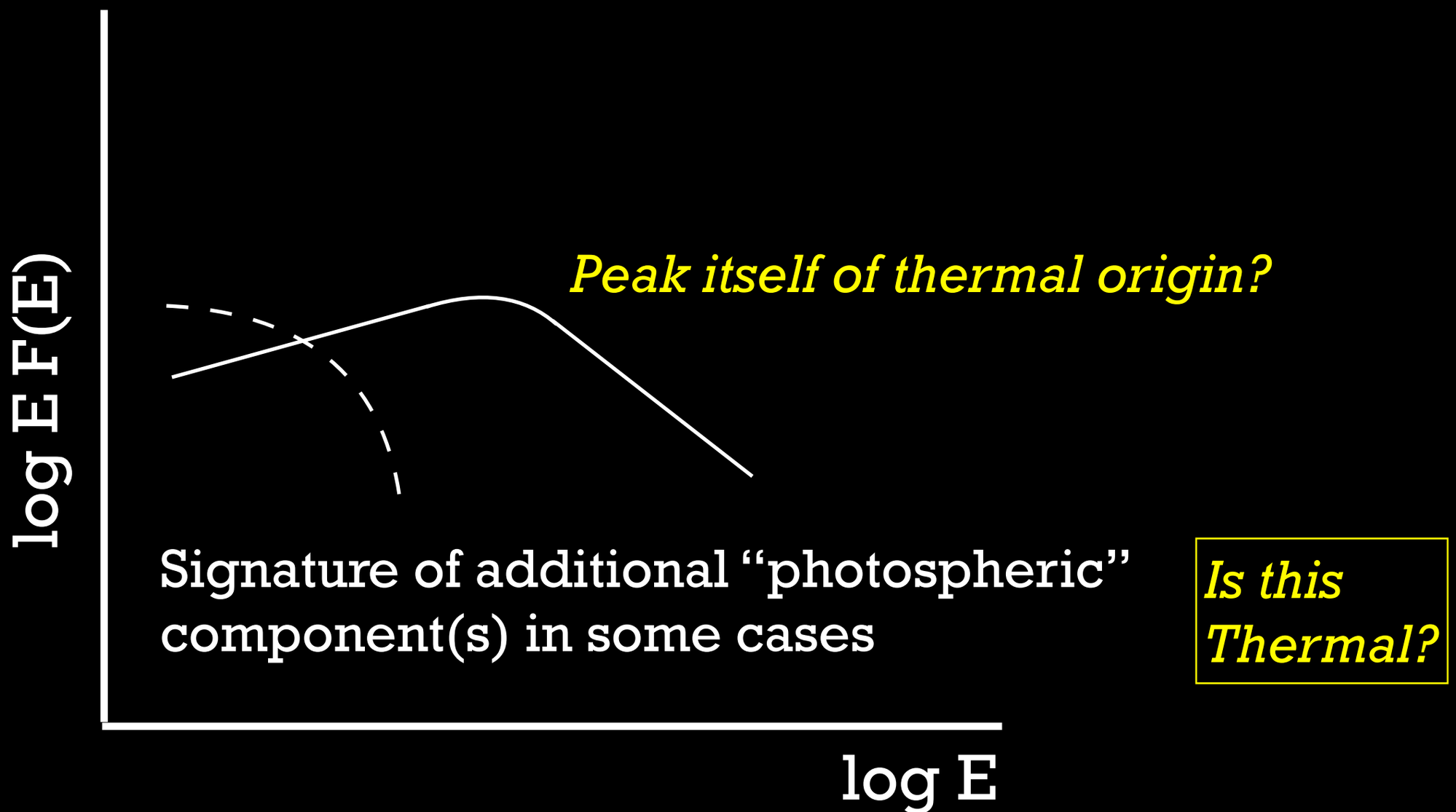


Polarisation

Distinguish Thermal / Non-thermal

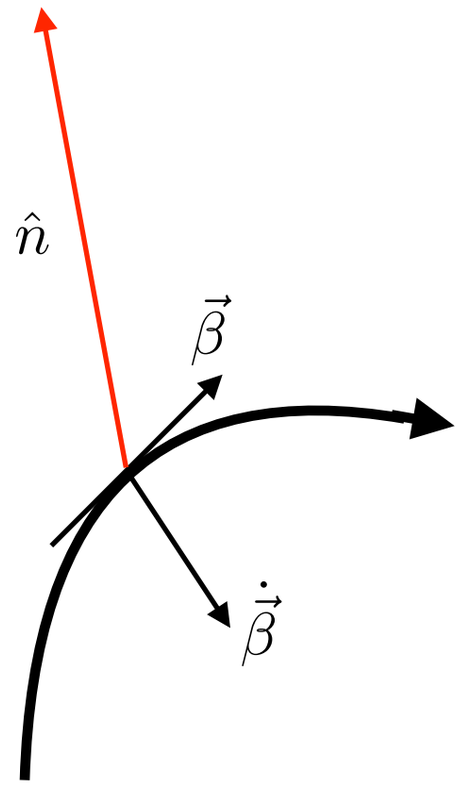
Constrain emission mechanism

Spectral and Temporal dependence

Correlation with burst energetics

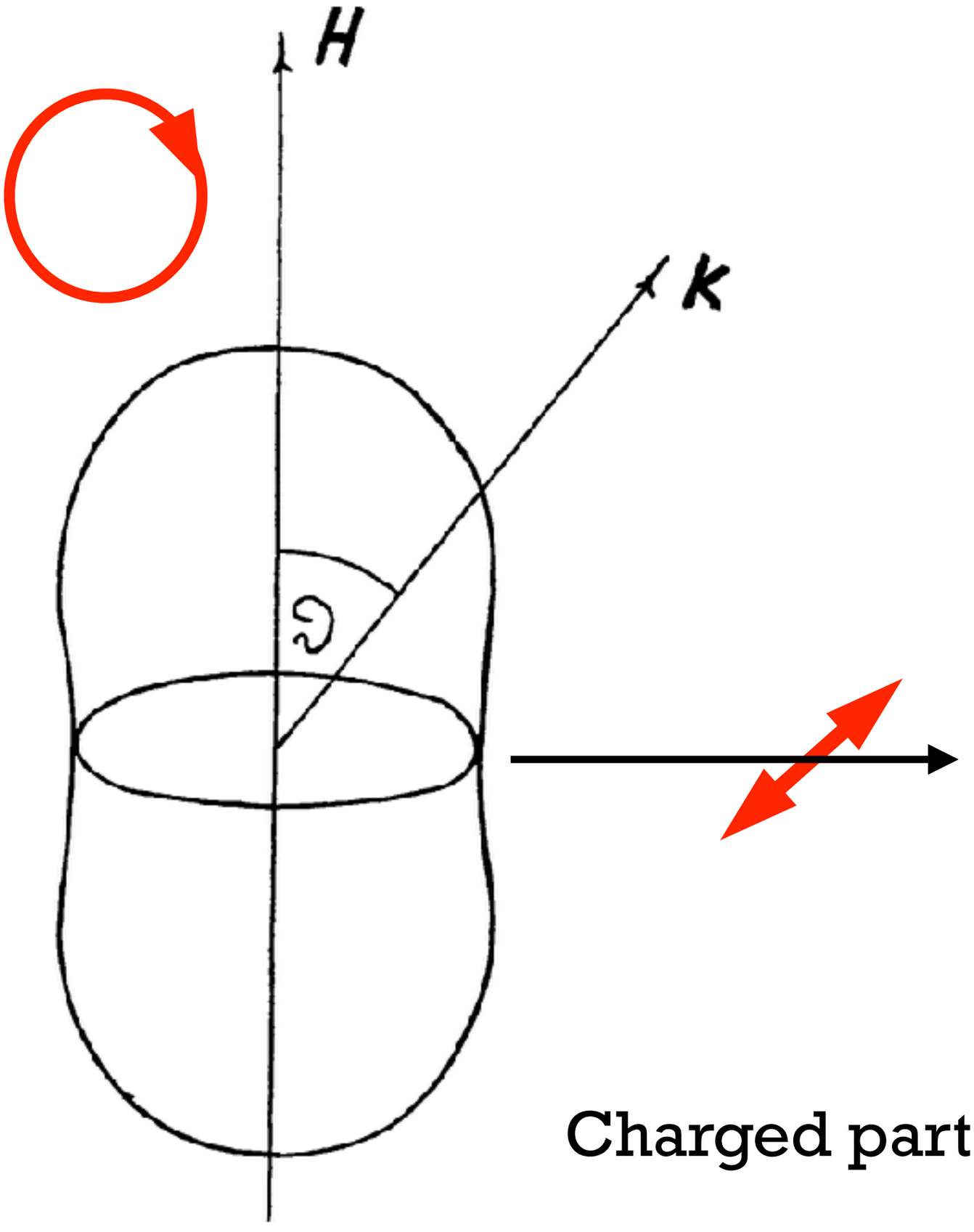
Polarisation of emission from an accelerated charged particle

$$\vec{E} \propto \hat{n} \times [(\hat{n} - \vec{\beta}) \times \dot{\vec{\beta}}]$$



Net observed polarisation involves average over the particle's trajectory, and over the distribution of emitting particles.

Polarisation of Cyclotron Radiation

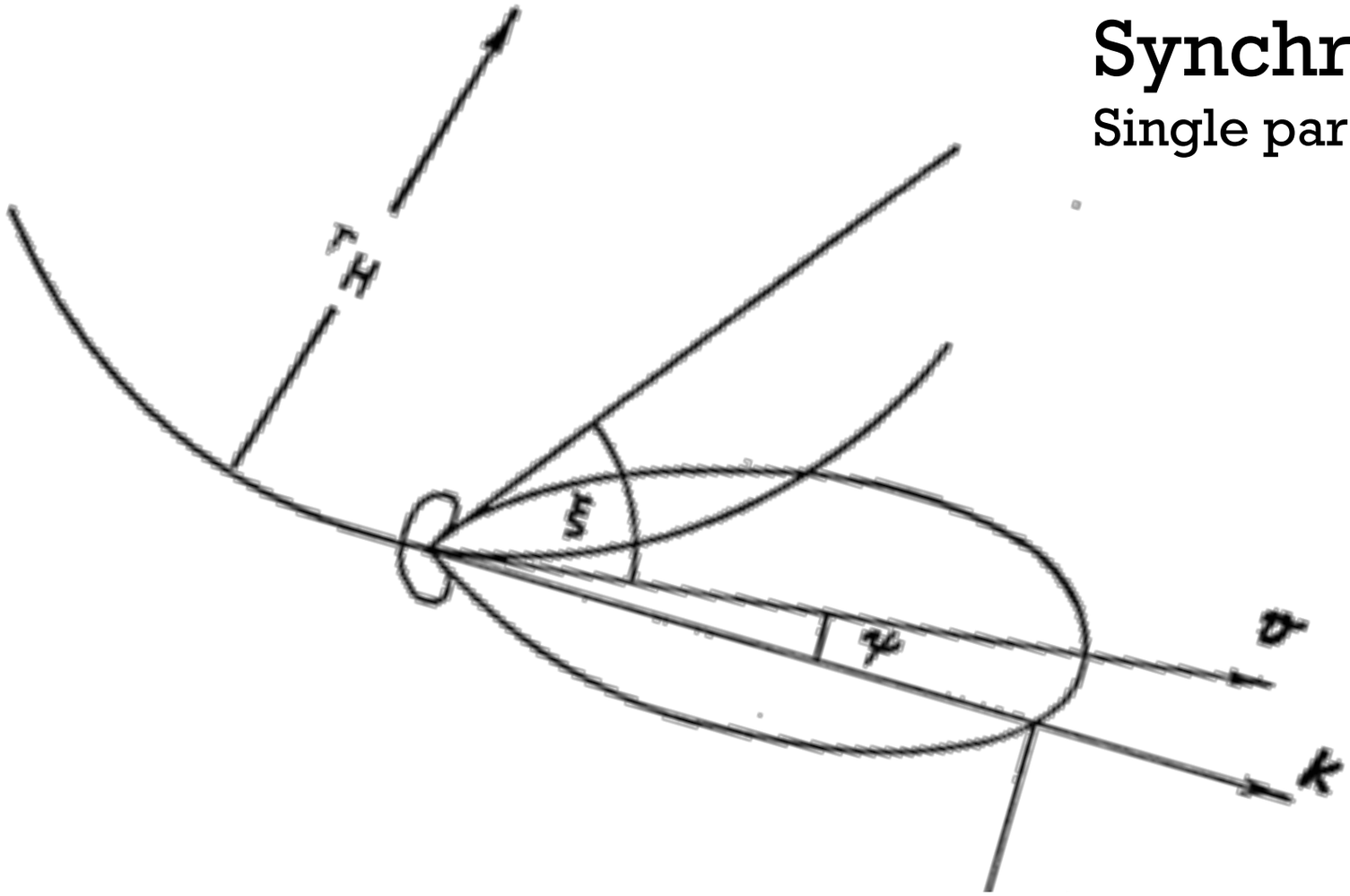


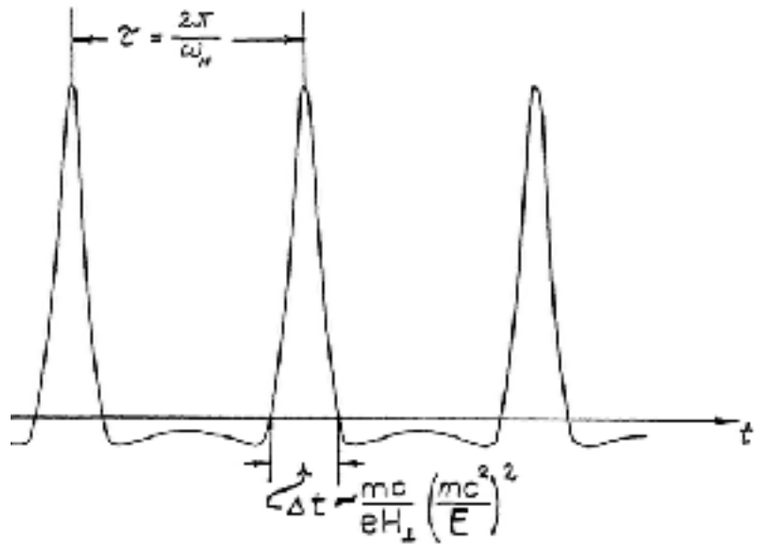
Charged particle in a magnetic field

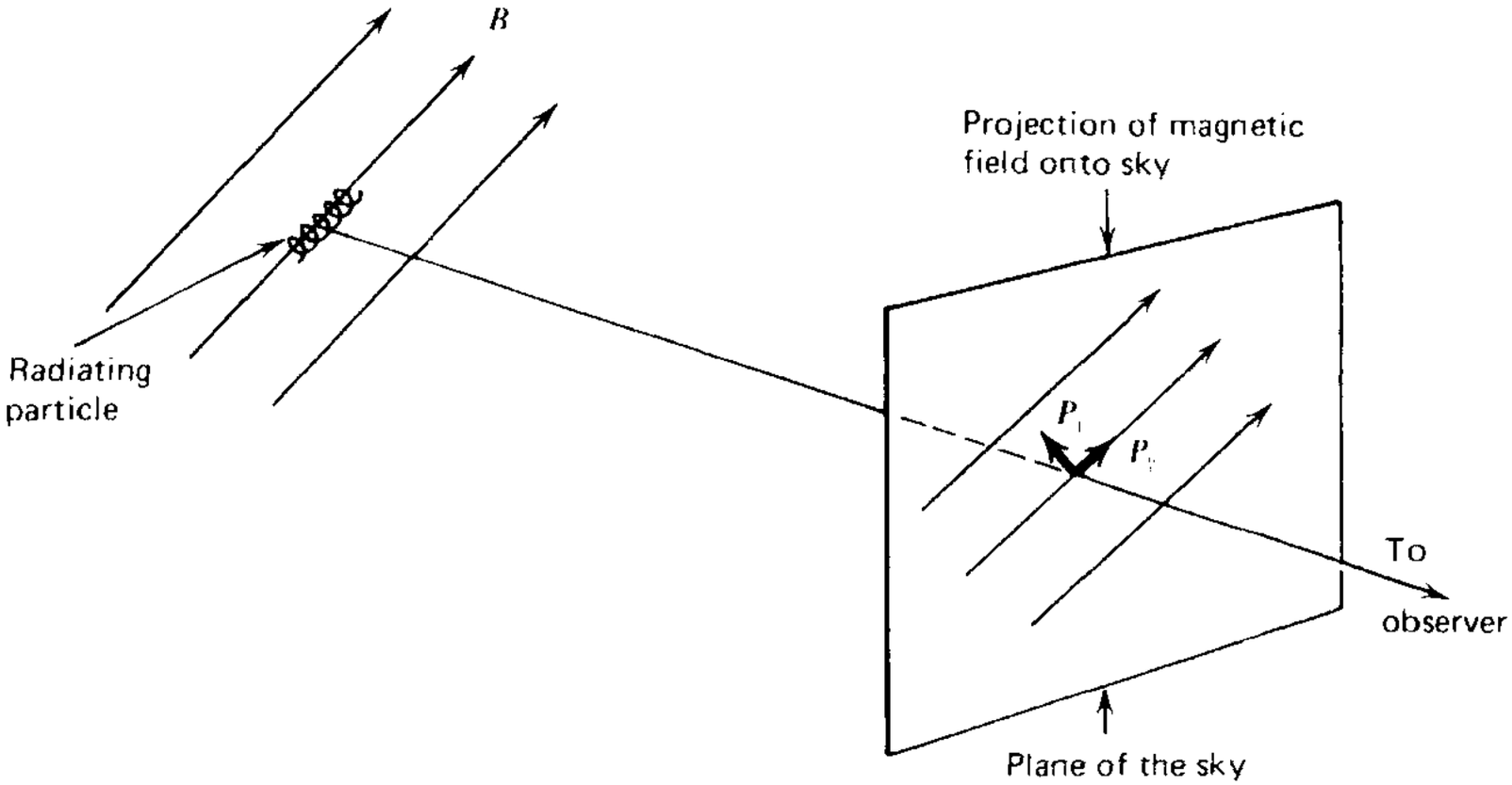
Ginzburg & Syrovatskii 1964

Synchrotron Polarisation:

Single particle







Rybicki & Lightman 1979,2004
Ginzburg & Syrovatskii 1964

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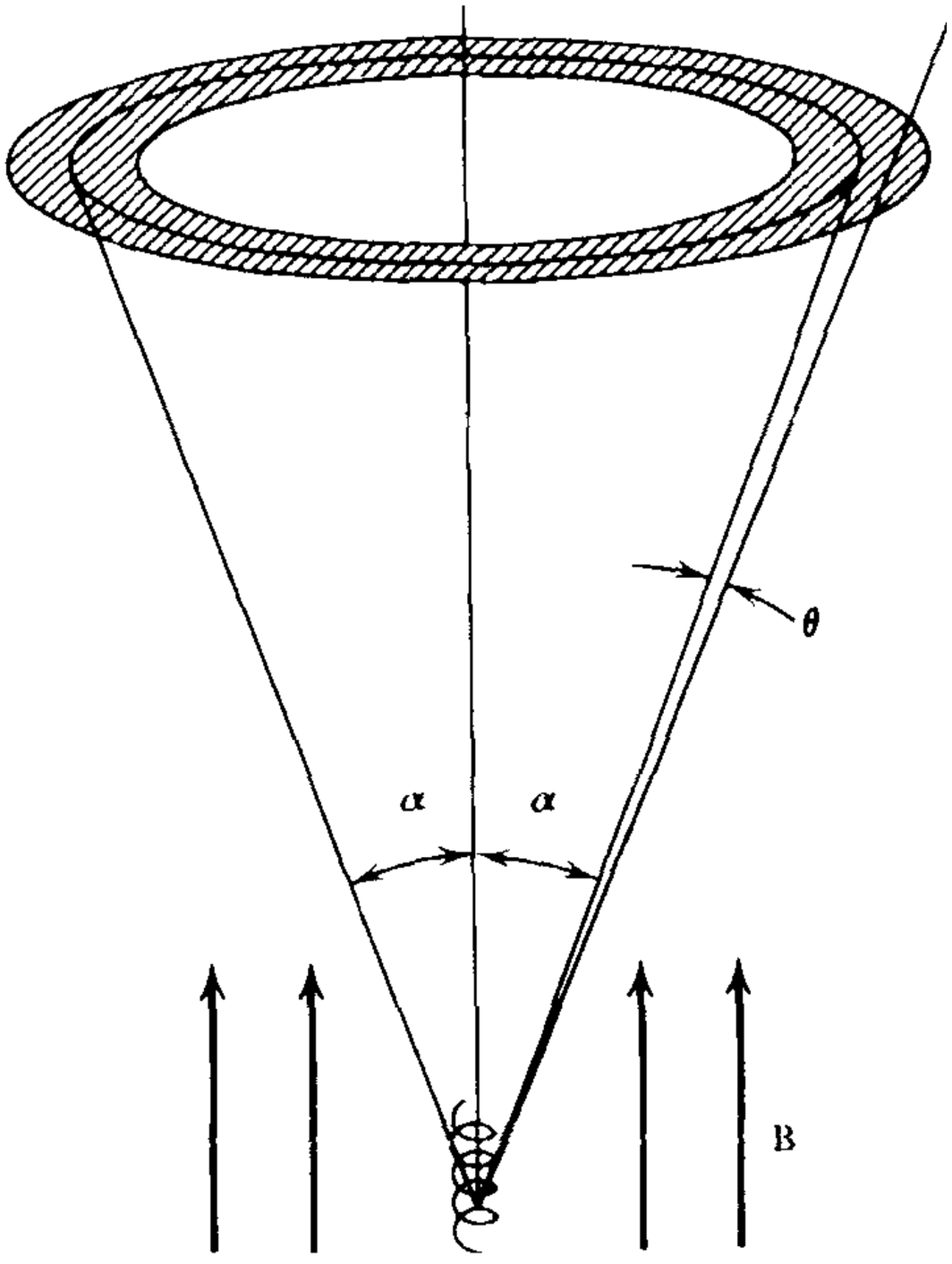
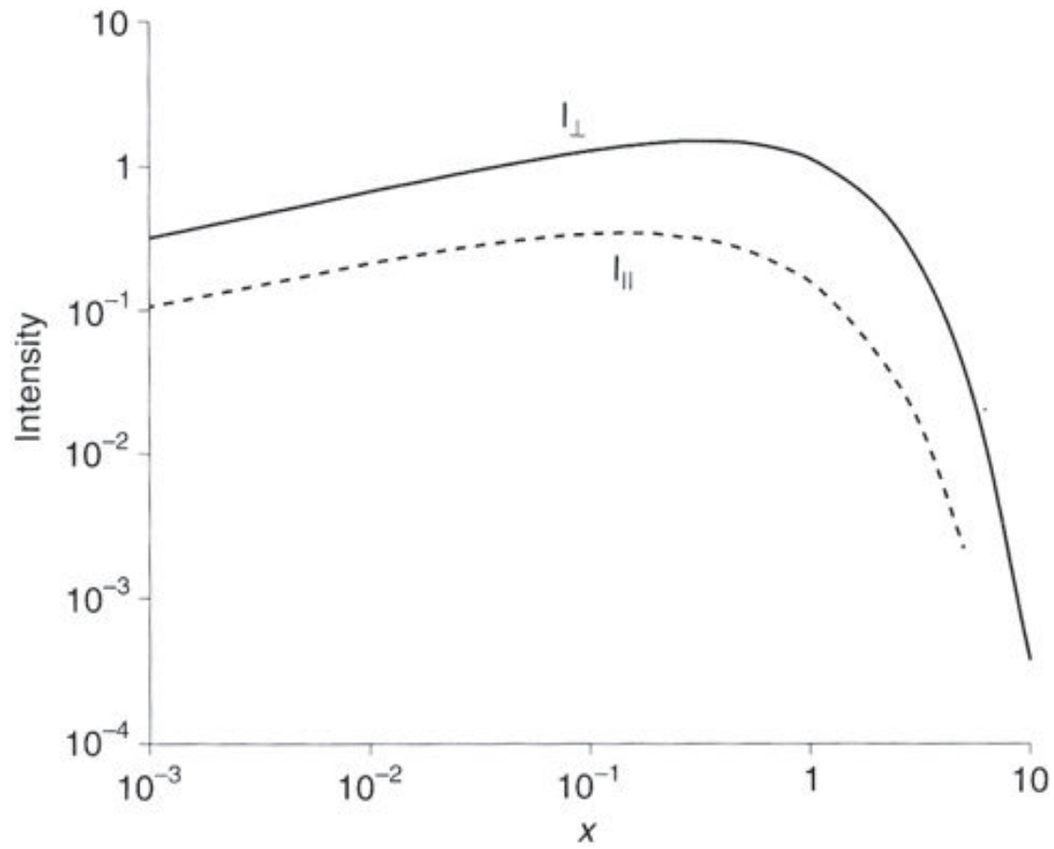
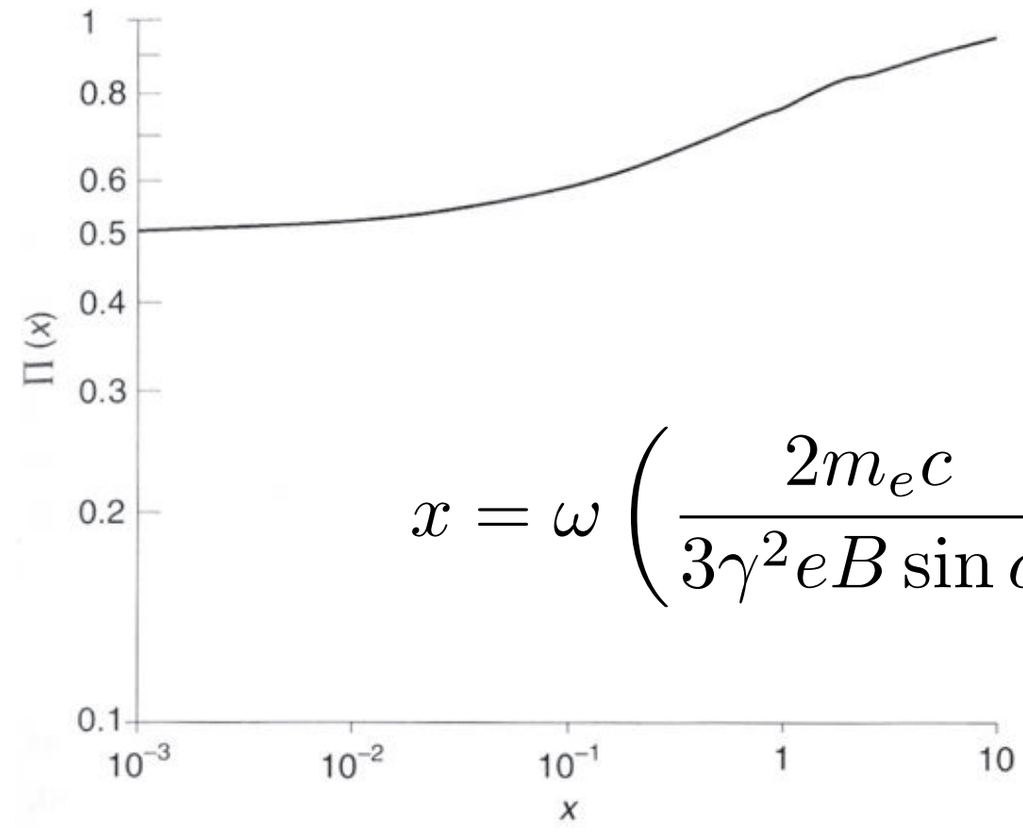
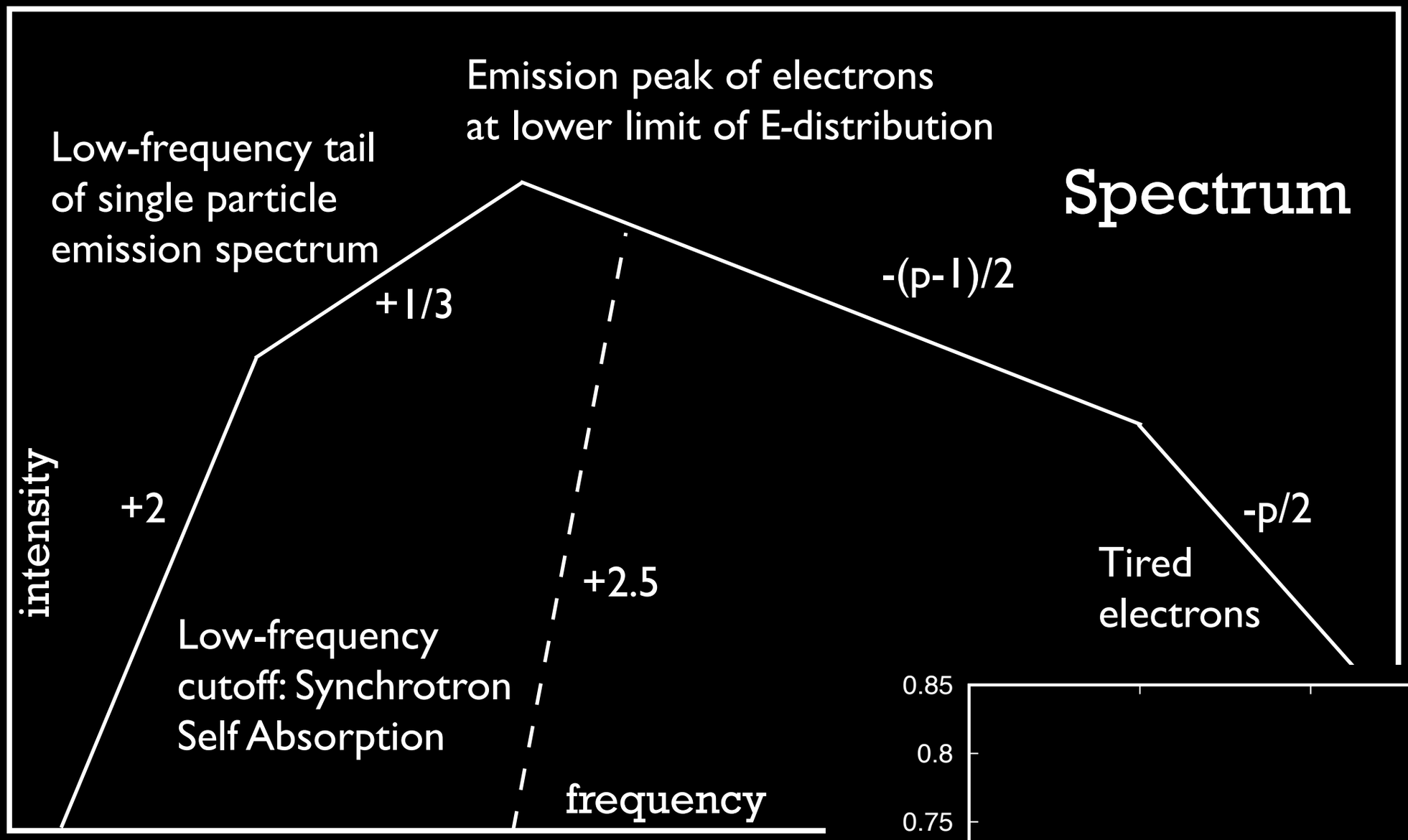
Single particle

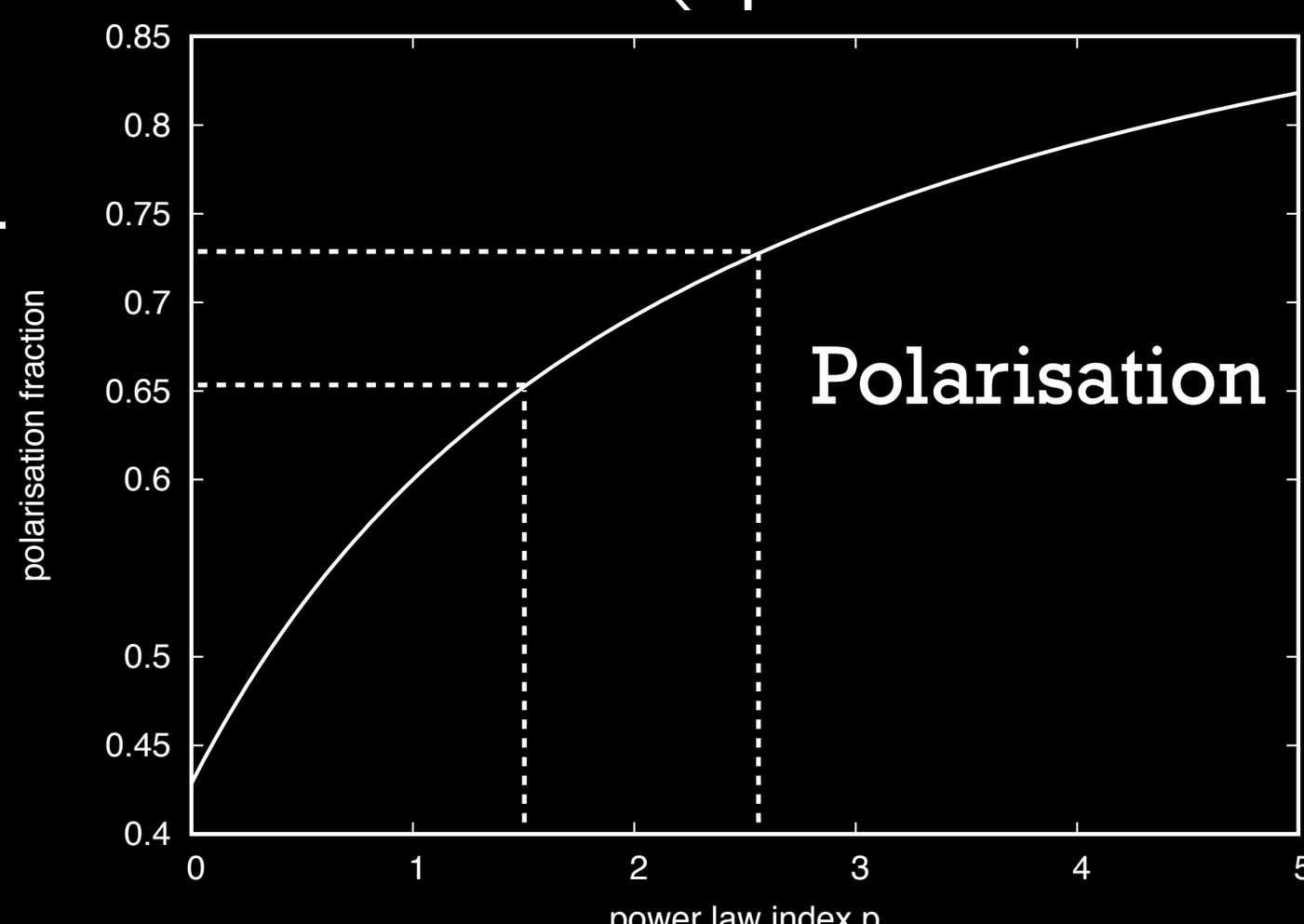






$$x = \omega \left(\frac{2m_e c}{3\gamma^2 e B \sin \alpha} \right)$$

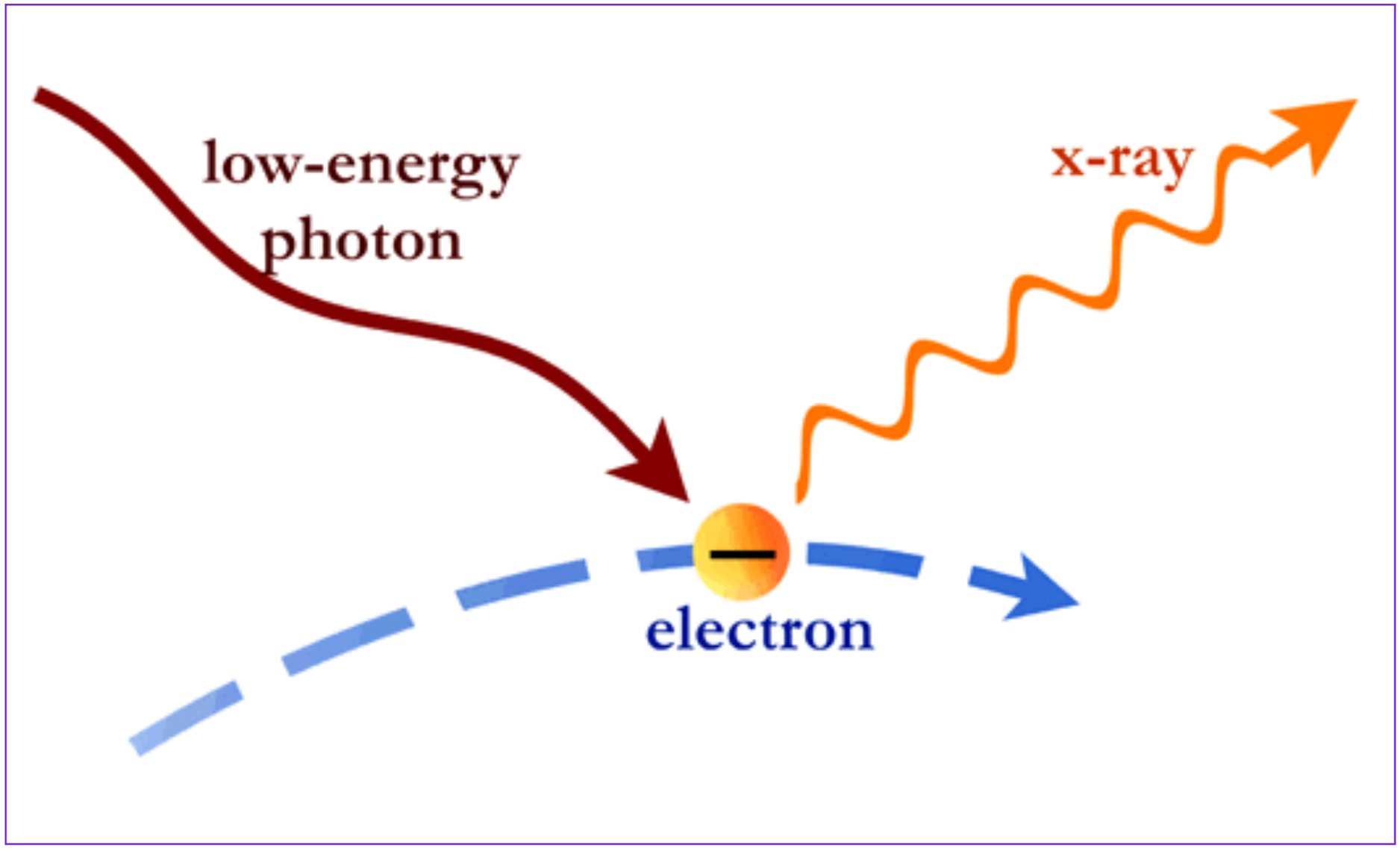




Power-law electron energy distribution

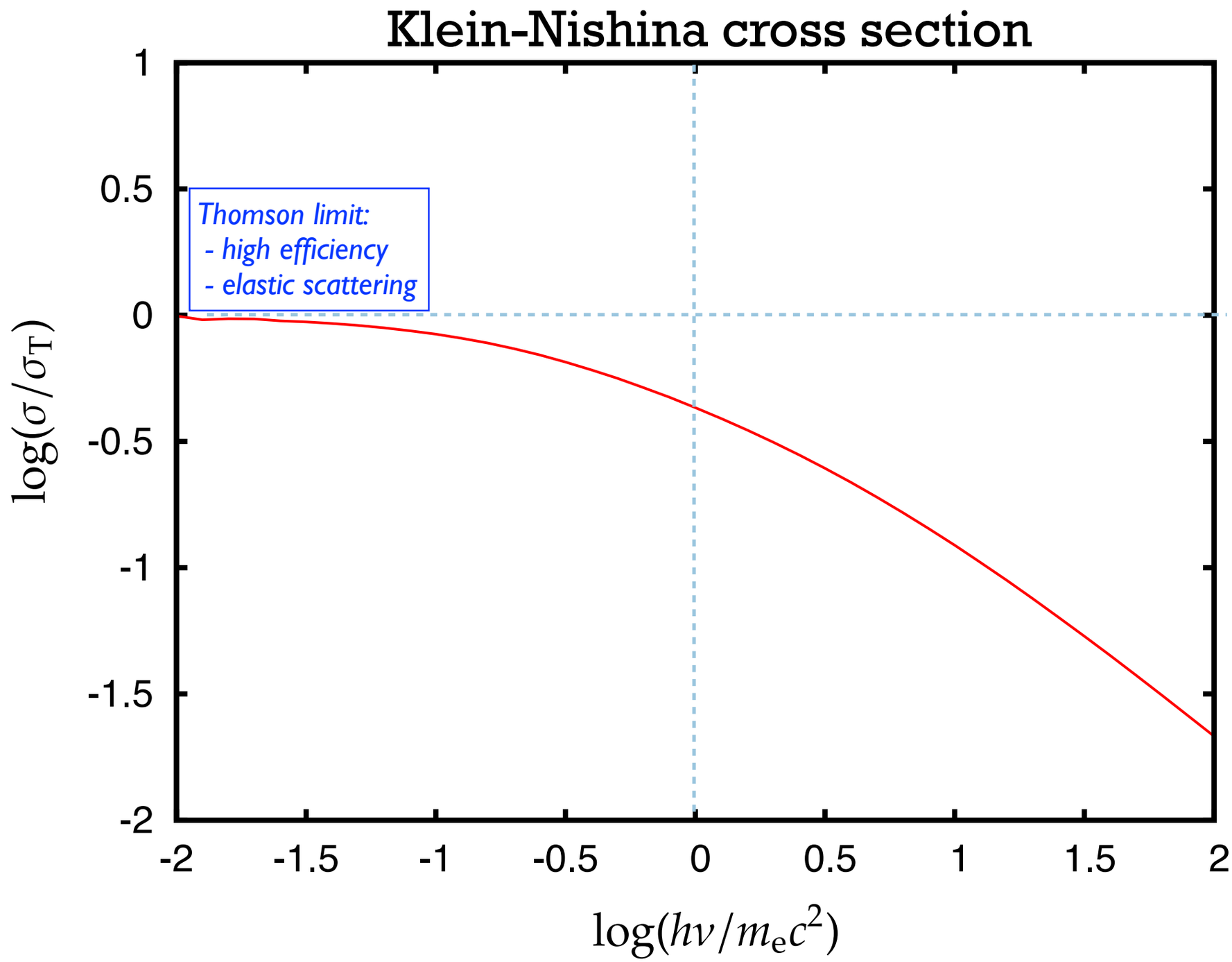
$$N(E) \propto E^{-p}$$

Compton Scattering

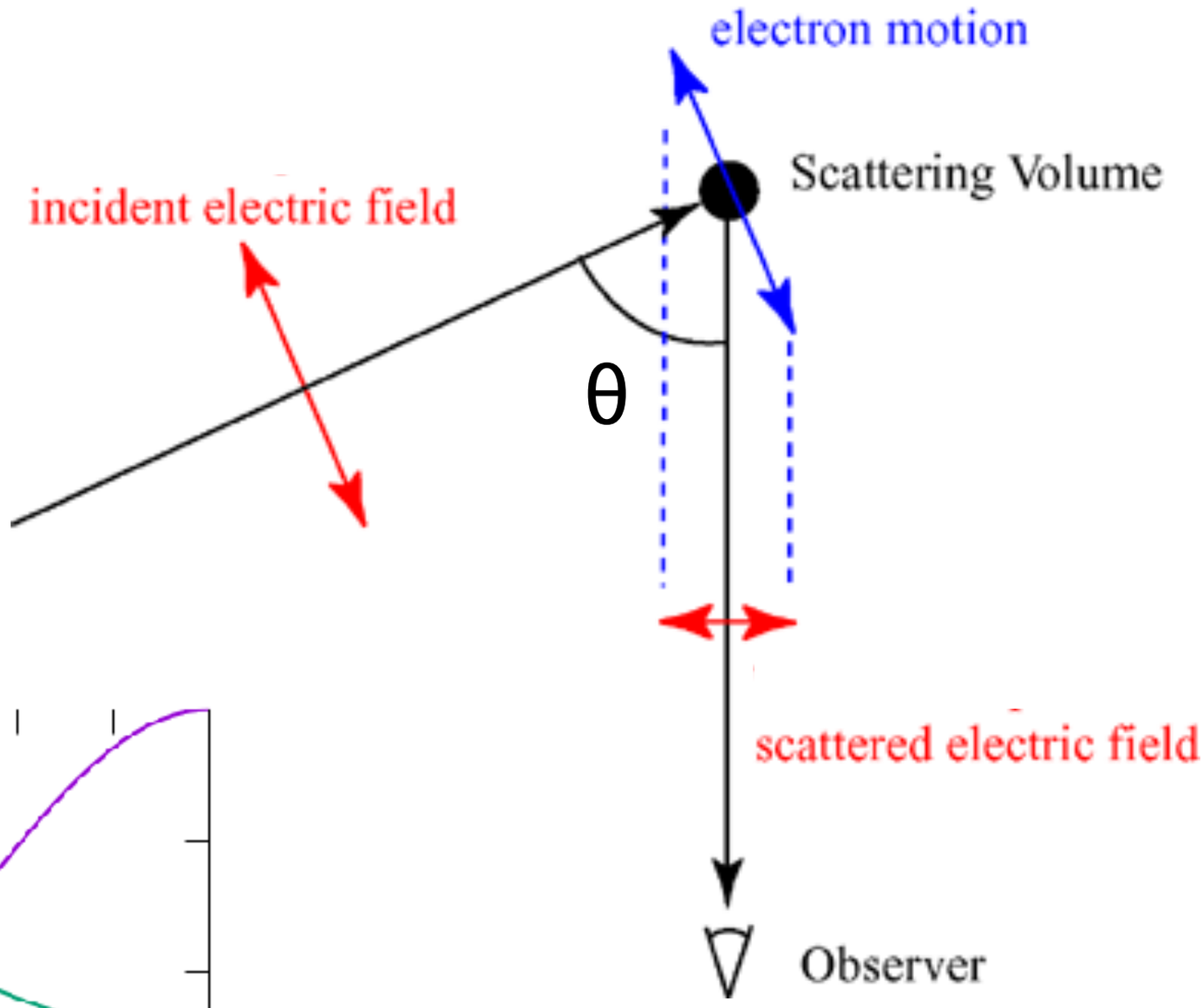


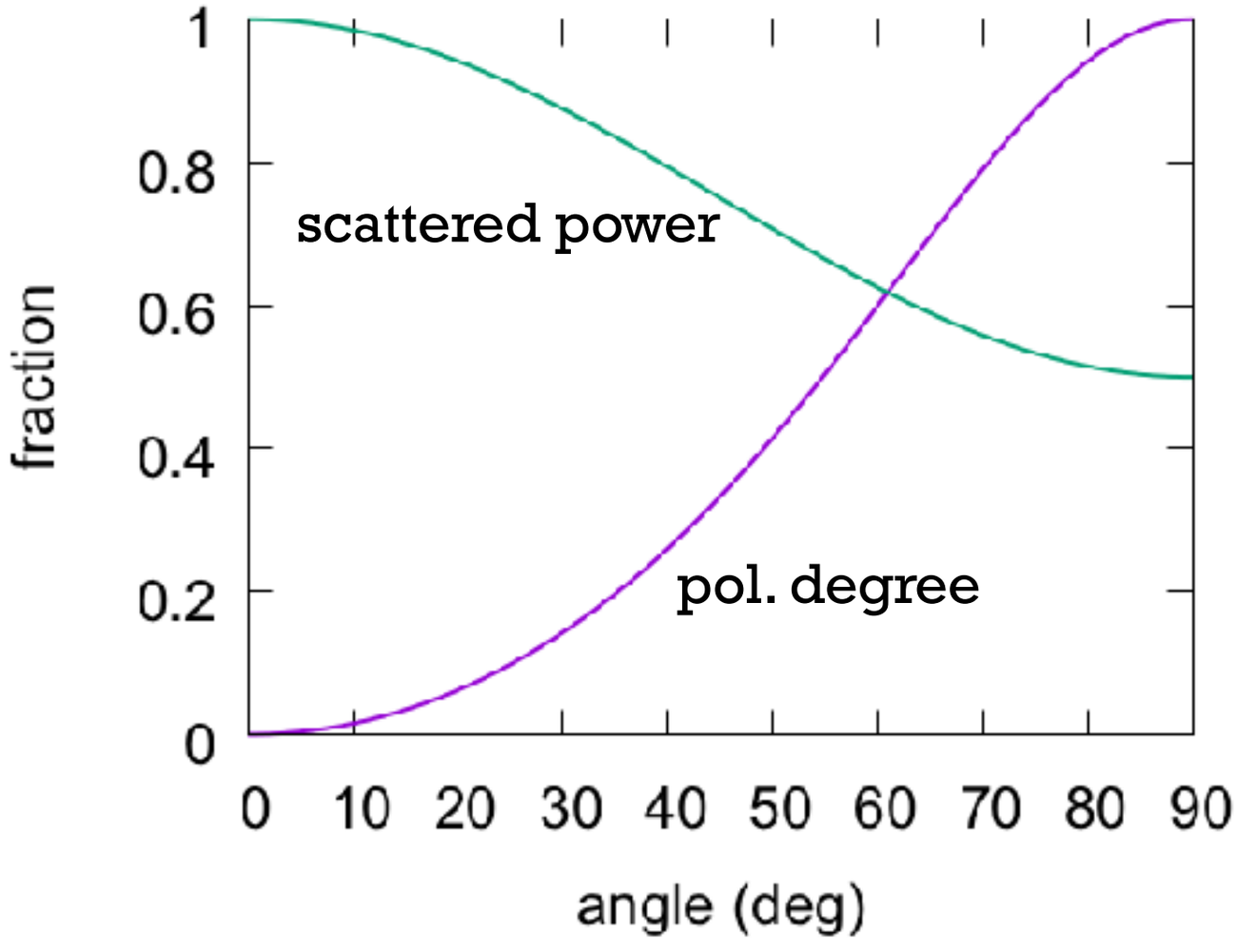
Compton Scattering

Thomson cross section $\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 = 6.65 \times 10^{-25}\,\mathrm{cm}^2$



Thomson scattering in electron rest frame





Scattered photon energy

$$\omega : \omega' : \omega'' = 1 : \gamma : \gamma^2$$

Compton Scattering in GRB

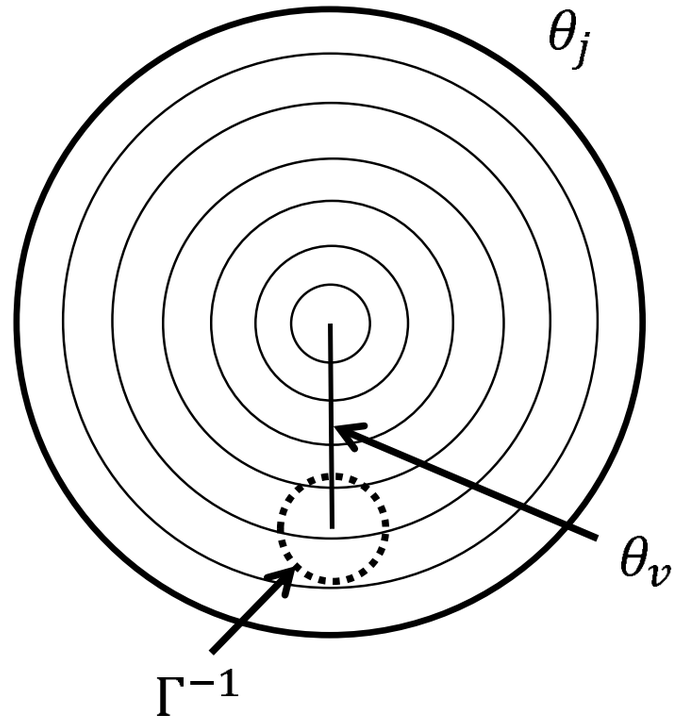
Self Compton: Seed photons in the comoving frame

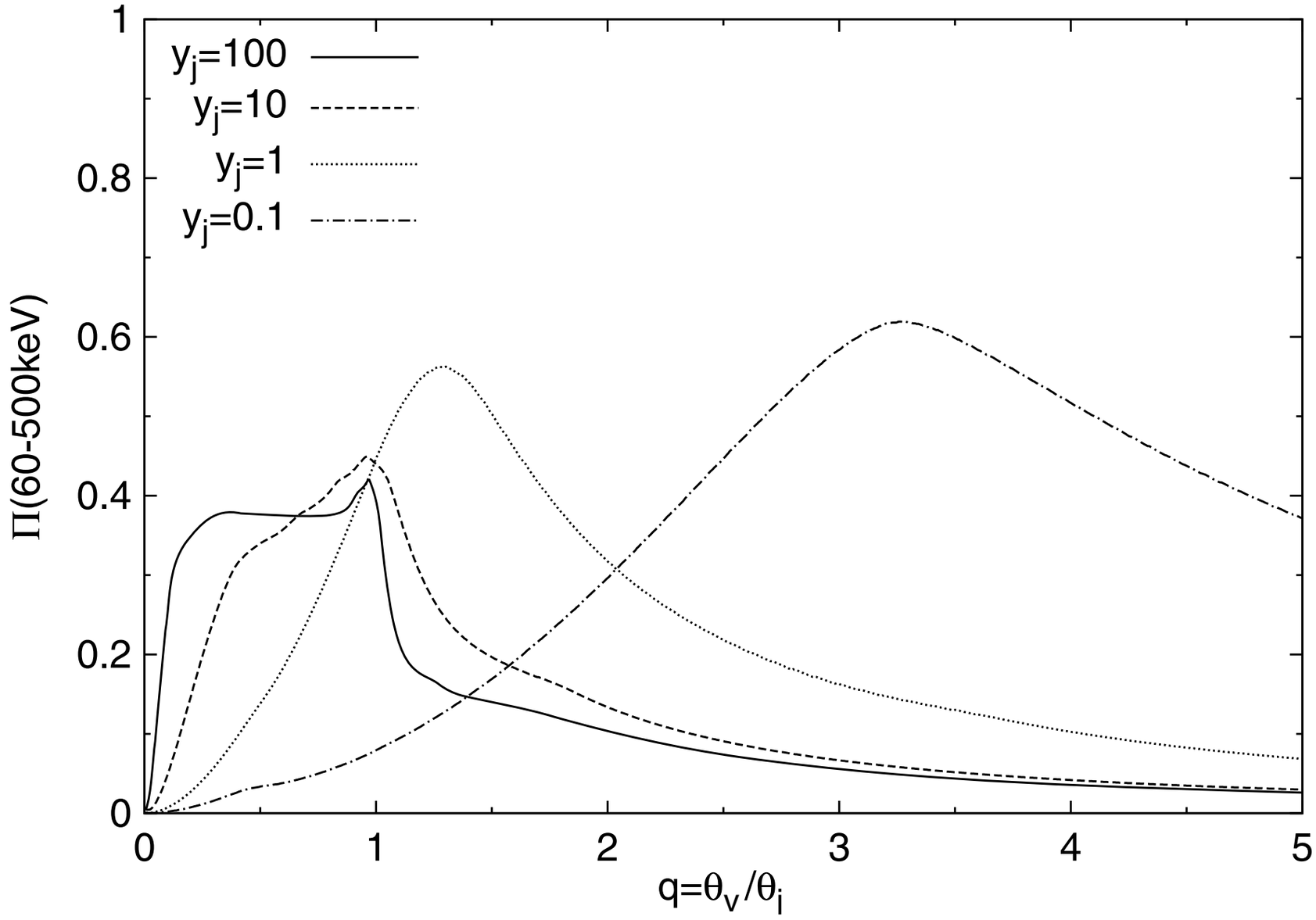
Seed photons generated locally
Scattering from random motion of particles
Thermal / Non-Thermal

External Compton: Seed photons in the ambient medium

Seed photons from ambient radiation field
Bulk comptotnisation from fast moving jet
Also called “Compton Drag”

Synchrotron with ordered field

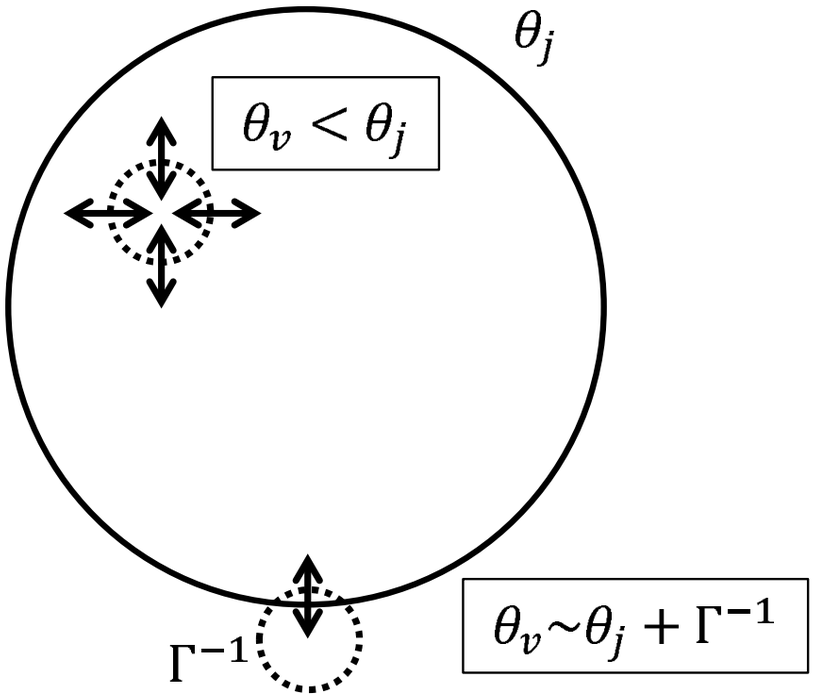


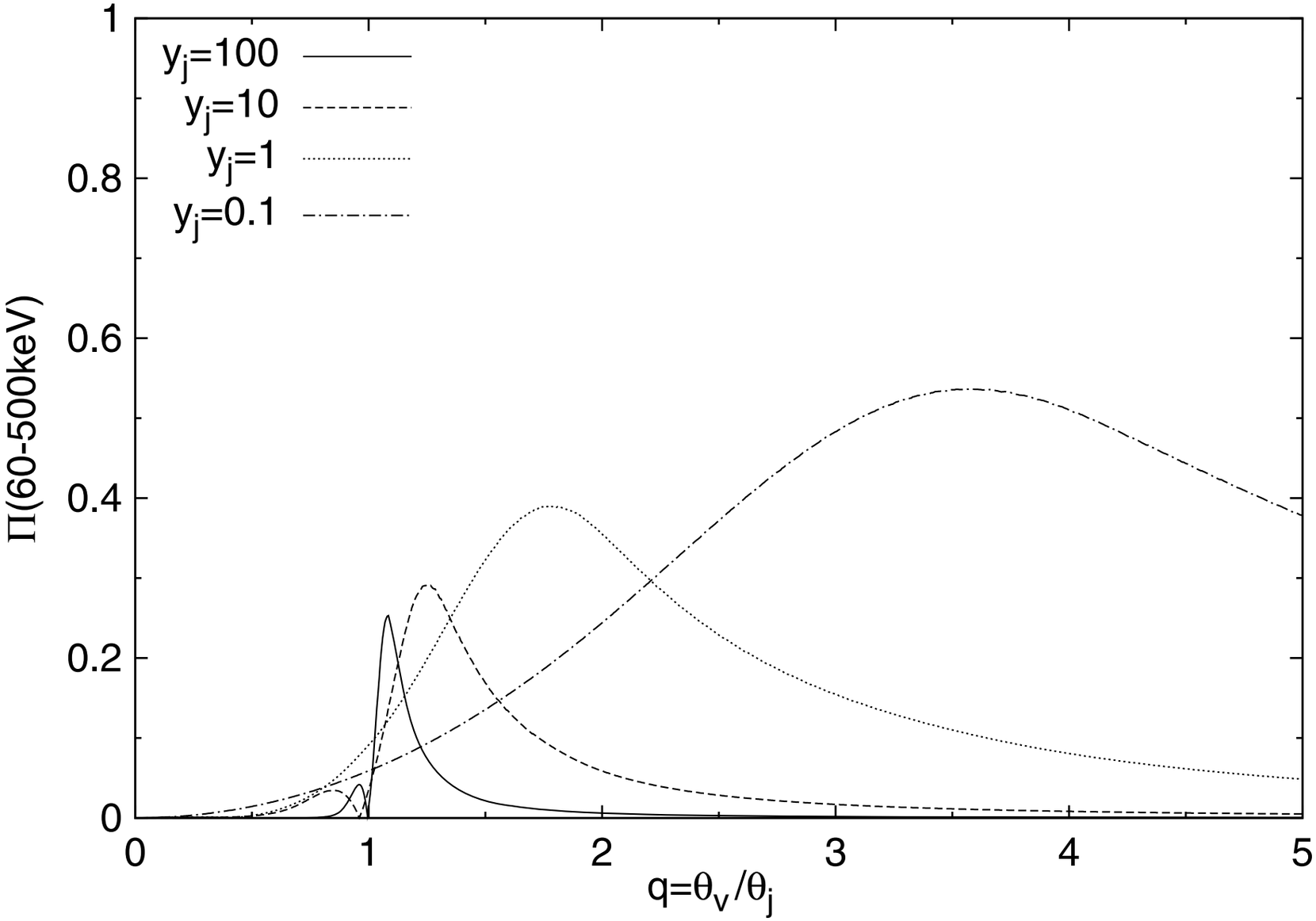


$$y_j = (\Gamma\theta_j)^2$$

Ghisellini et al 1999, Granot 2003,
Toma et al 2009, Toma 2013

Synchrotron with random field





Ghisellini et al 1999, Granot 2003,
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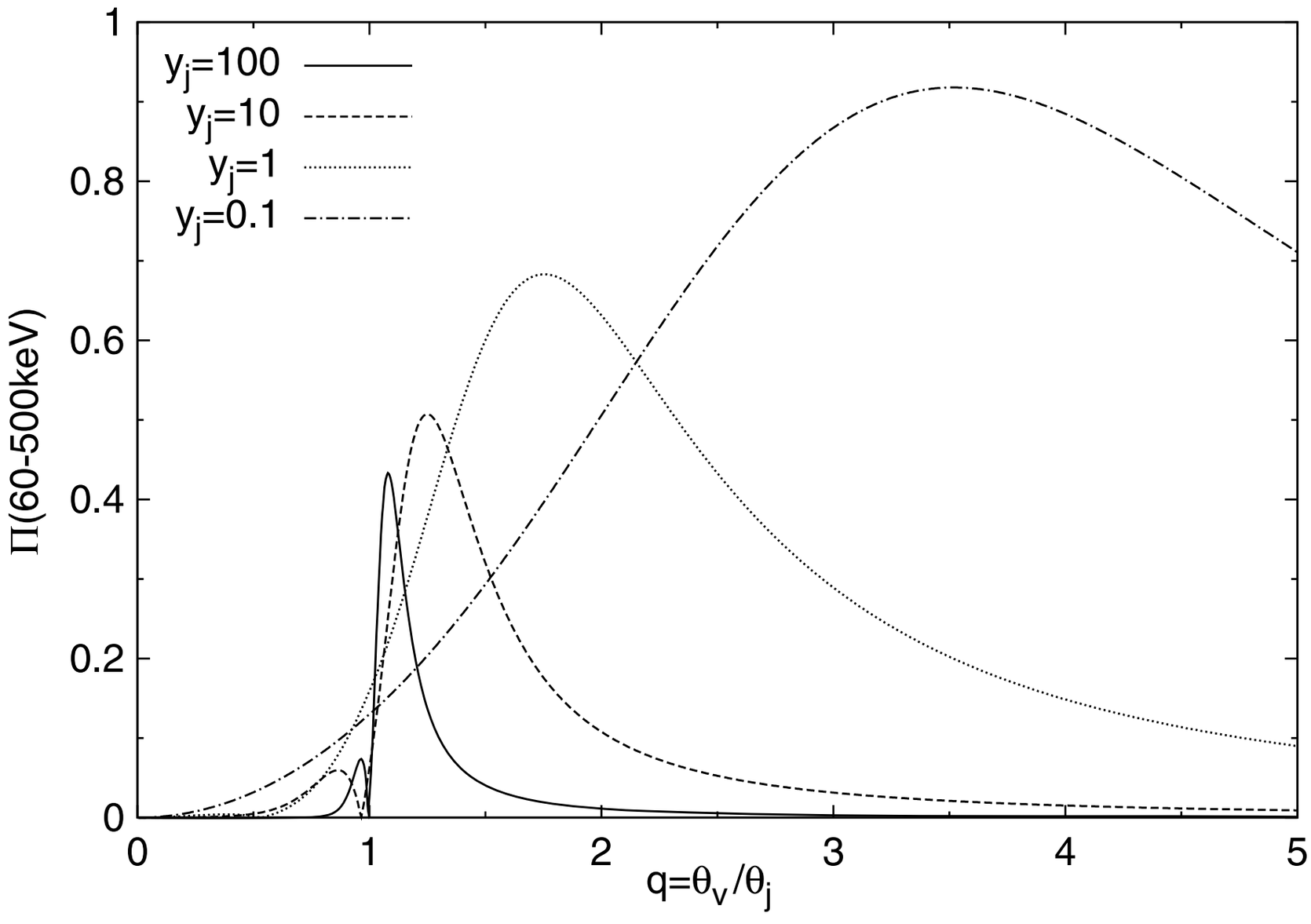
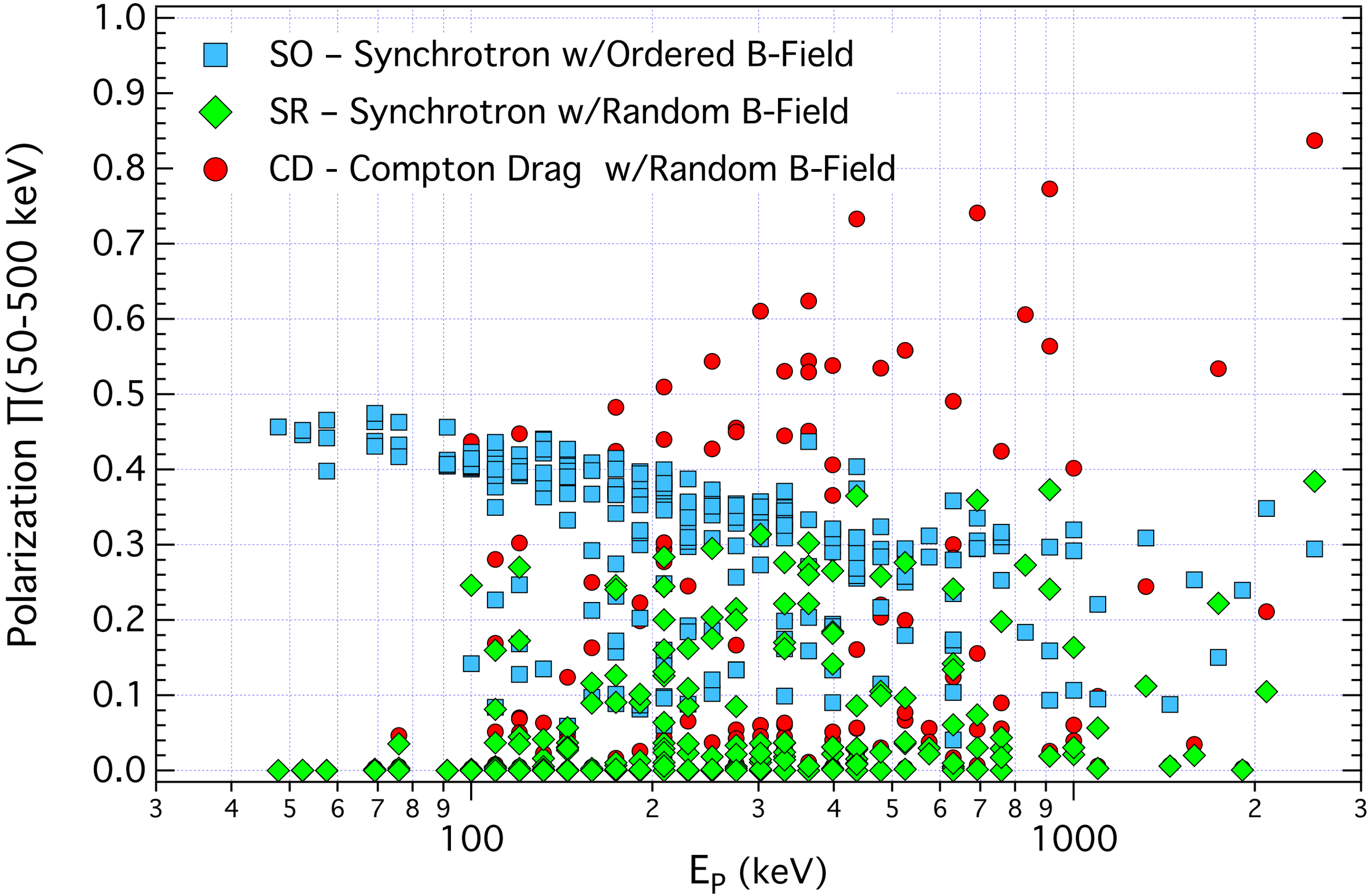
Compton Drag



Lazzati et al 2004, Lazzati 2010,
Toma et al 2009, Toma 2013

- Polarisation rises away from jet axis, but power falls
- Strongly polarised GRBs should have less observed flux
- GRB intrinsic luminosity distribution is wide
- Correlation exists between luminosity and E_{peak}
- Given a flux limit, polarisation should display correlation with observed E_{peak}
- Study of a large population of GRBs is needed



Toma et al 2009, McGlynn 2016

Detection of Hard X-ray Polarisation

Compton Polarimetry

$$\frac{d\sigma}{d\Omega} = \frac{3\sigma_{\mathrm{T}}}{16\pi}\left(\frac{\omega'}{\omega_0}\right)^2\left(\frac{\omega_0}{\omega'} + \frac{\omega'}{\omega_0} - 2\sin^2\theta\cos^2\eta\right)$$

$$\frac{\omega_0}{\omega'} = 1 + \left(\frac{\hbar\omega_0}{m_e c^2}\right)(1-\cos\theta)$$

Distribution of azimuthal scattering angle η w.r.t. the plane of polarisation is measured

count rate $\quad C(\eta) = A + B\cos^2(\eta - \phi)$

B = polarisation degree

ϕ = incident polarisation angle

GRB polarisation: reported detections

021206	RHESSI	150-2000 keV	80±20%
			< 4.1%
			41^{+57}_{-44} %

Scattering between multiple Ge detectors

uncertainty in scattered Event selection

Coburn & Boggs ’03, Rutledge & Fox ’04, Wiggs et al ’04

930131	CGRO/BATSE	20-1000 keV	35-100%
960924	CGRO/BATSE	20-1000 keV	50-100%

Used scattering from the Earth’s atmosphere

Not all systematics clearly known

Willis et al ’05

GRB polarisation: reported detections

041219a	INTEGRAL/SPI	100-350 keV	60±35%
	INTEGRAL/IBIS	200-800 keV	43±25%
061122	INTEGRAL/SPI	100-1000 keV	< 60%
	INTEGRAL/IBIS	250-800 keV	> 60%
140206a	INTEGRAL/IBIS	200-800 keV	> 48%

Limited statistics, detector systematics cannot be entirely ruled out

McGlynn et al ’07,’09; Gotz et al ’09,’13,’14

GRB polarisation: reported detections

100826a	IKAROS/GAP	70-300 keV	27±11%
110301a	IKAROS/GAP	70-300 keV	70±22%
110721a	IKAROS/GAP	70-300 keV	80±22%

Scintillator array
Dedicated GRB polarimeter

Yonetoku et al ’11,’12

ASTROSAT

CZT Imager: an all-sky, polarimetry-capable, GRB detector

Over 100 GRBs detected till date
11 subjected to polarisation analysis, from year 1 data

Results in presentation by Santosh Vadawale

POLAR results will start coming shortly

We are entering the era of population study of GRB polarisation - will begin to constrain emission models