Polarized emission from the GRB photosphere

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with
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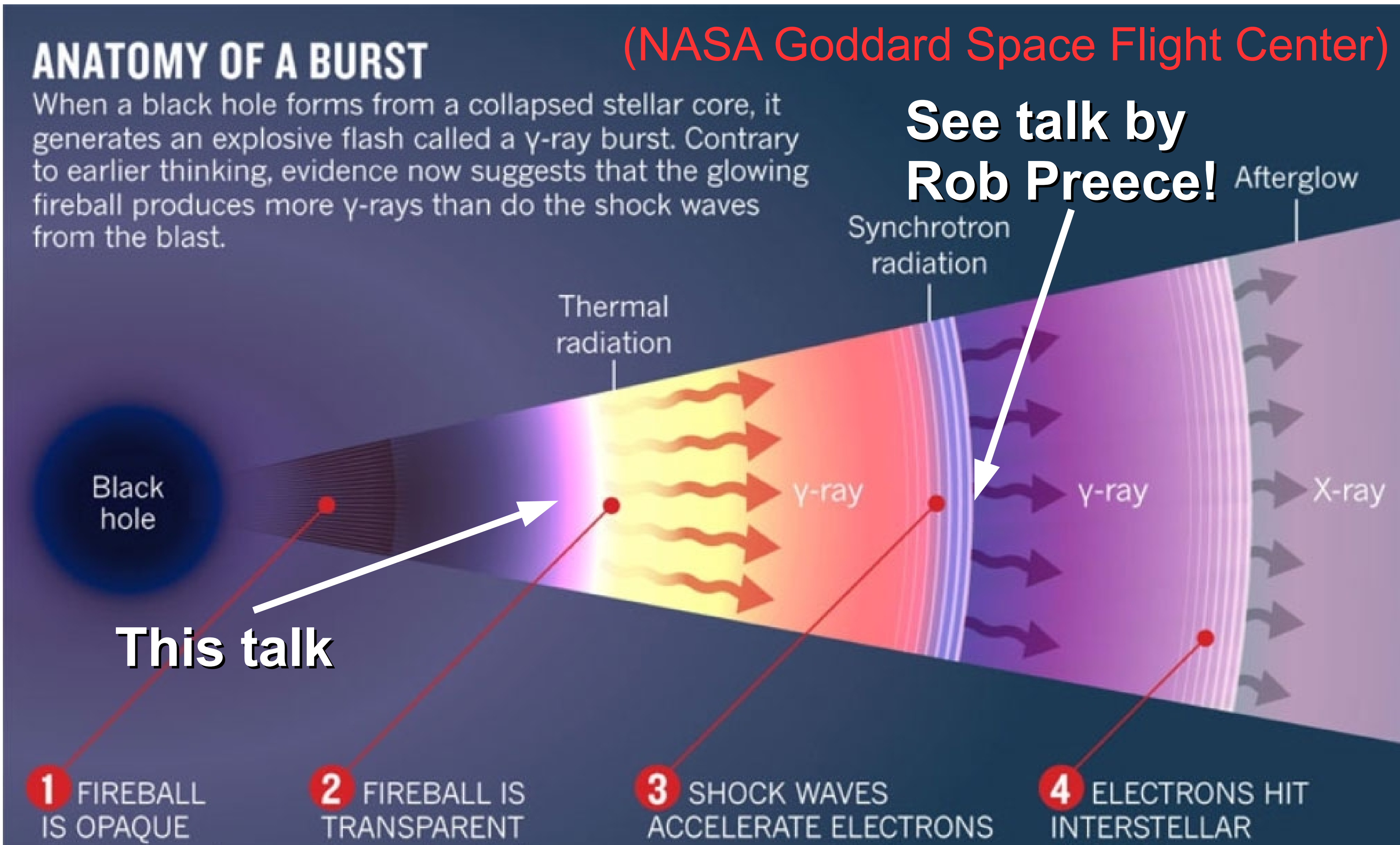
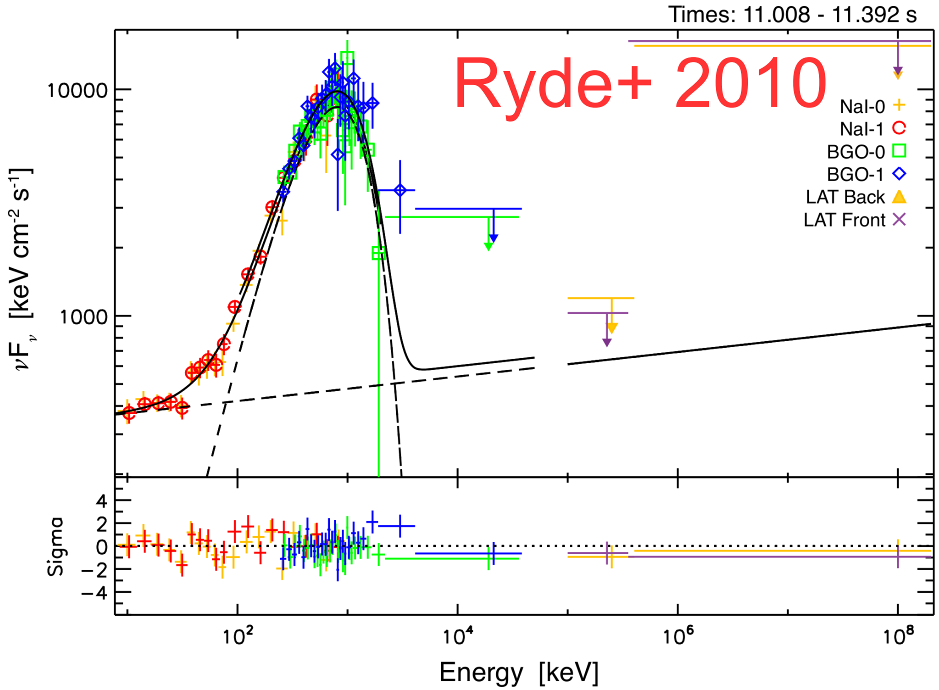
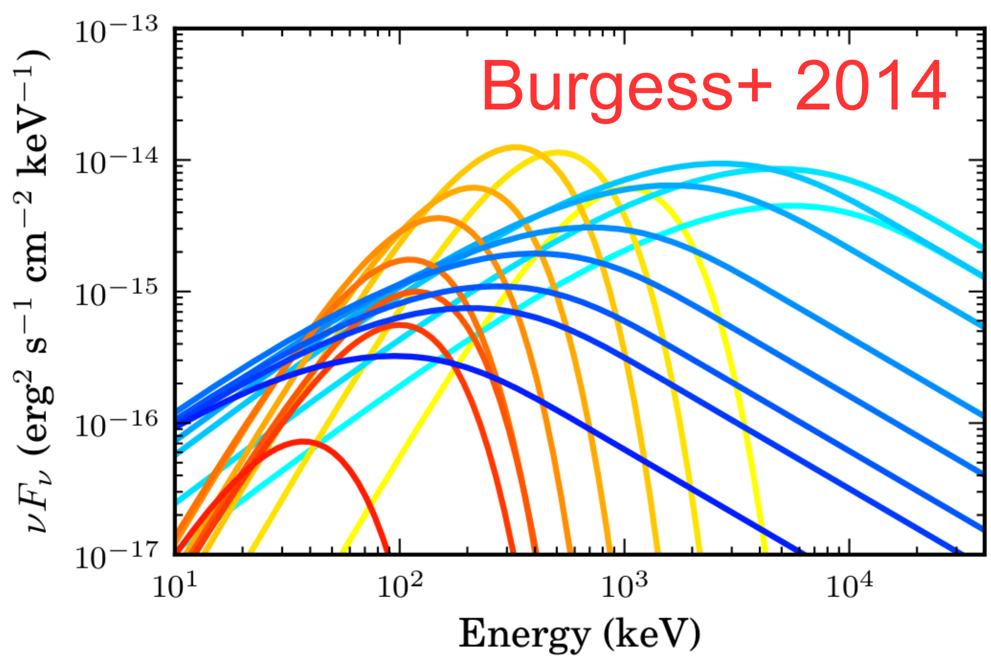
Where in the jet does the gamma-ray emission come from?



Motivating our study: Has photospheric emission been detected?





(also see Ryde 2005, Ryde & Pe'er 2009, Guiriec+ 2011, Axelsson+ 2012, Iyyani 2013, Preece+ 2014)

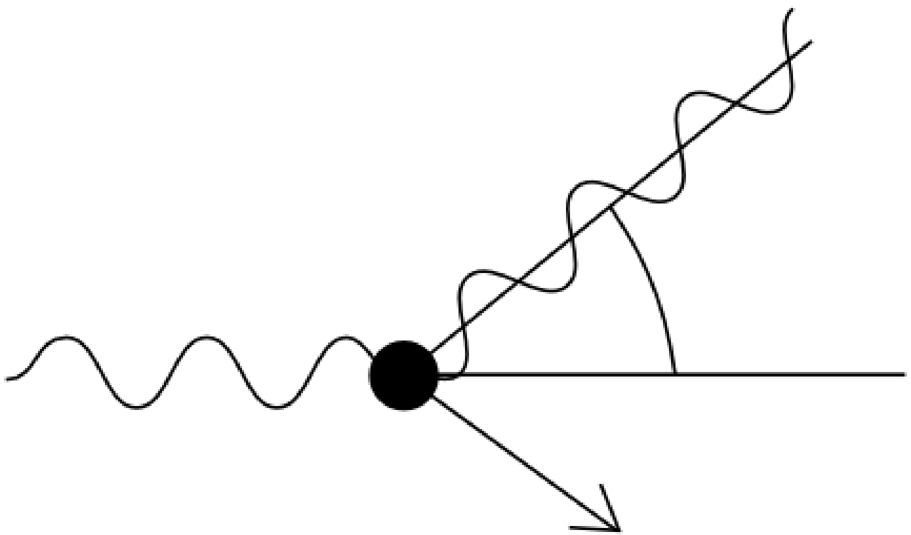
- Photosphere detected at sub-MeV energies
- **Same energy region where polarization can be measured!**

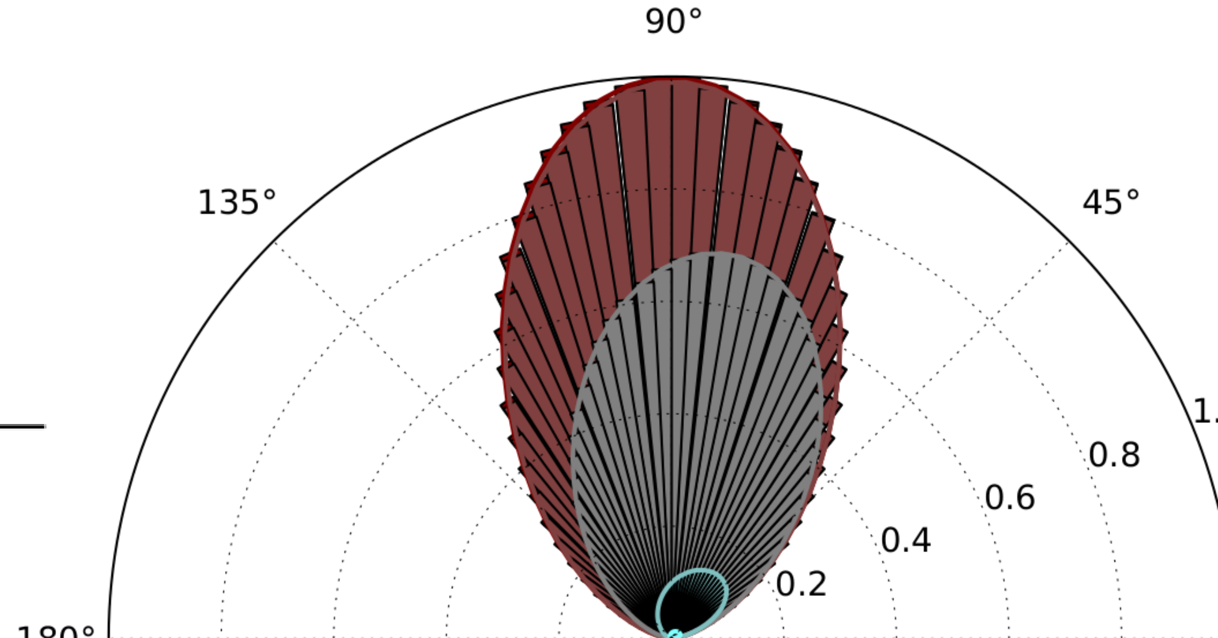
What ingredients are needed to produce polarized emission from the photosphere?

Part I: The photon field in the **local comoving frame** must be **anisotropic**

Part II: The observed emitting region must be **asymmetric**

Part I: Scattering dominates the photosphere opacity

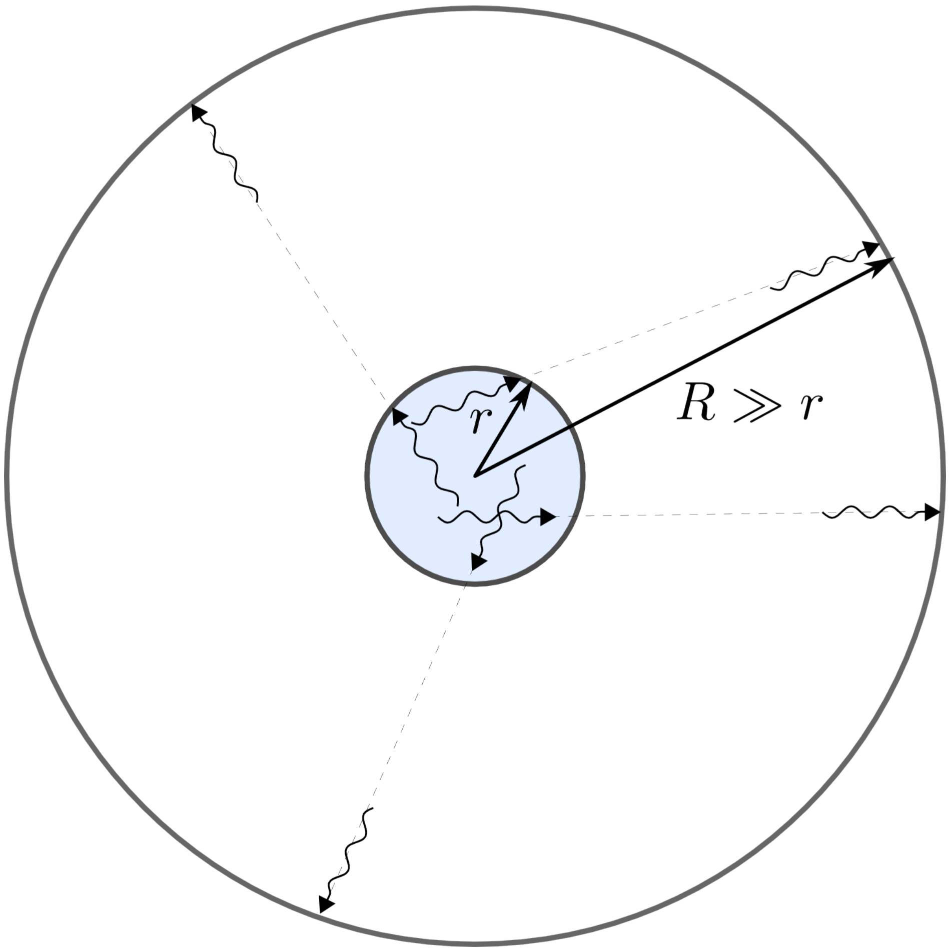


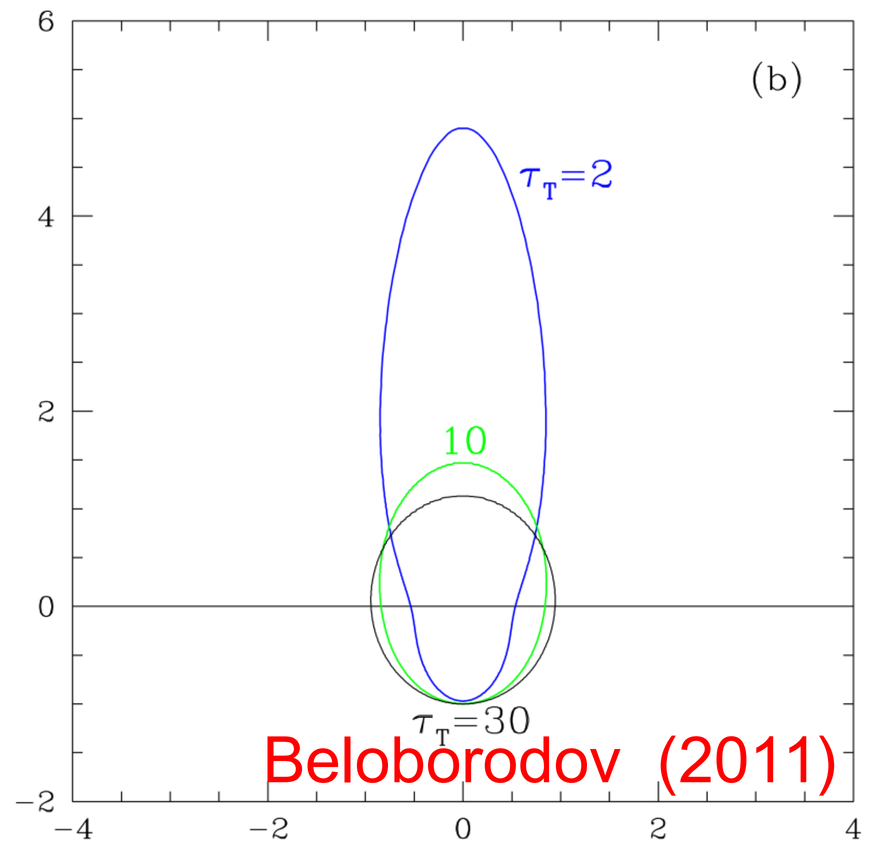


Polarization degree for $E/mc^2 = [10^{-2}, 10^{-1}, 10^{0}, 10^{1}]$

- Therefore, **inherent potential for polarized photospheric emission**
- Crucial ingredient for polarization from scattering: **anisotropy**

Part I: Anisotropy increases as the fluid approaches the photosphere





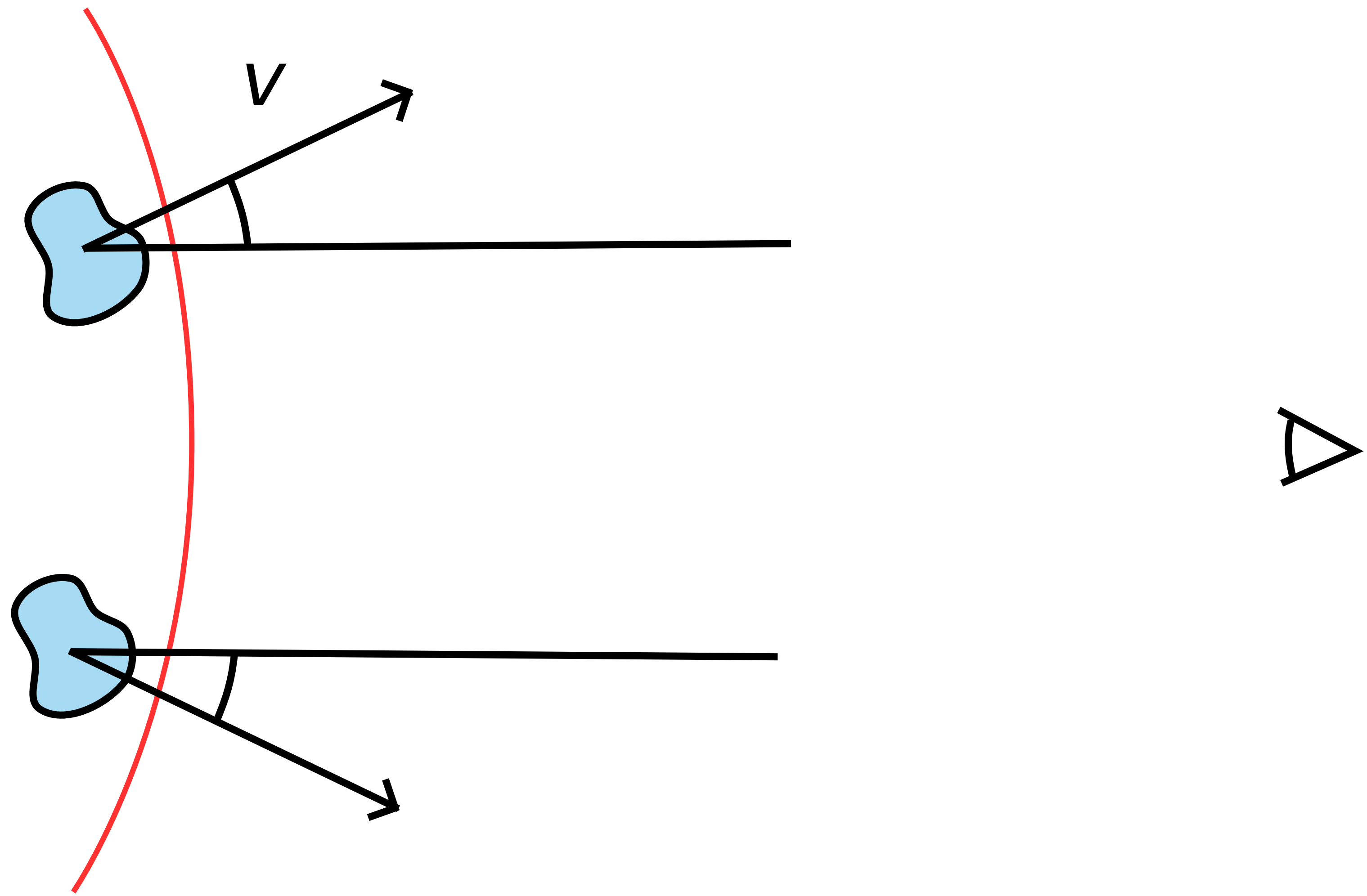
Intensity becomes **anisotropic in the comoving fluid frame** → emission is polarized after last scattering at photosphere

What ingredients are needed to produce polarized emission from the photosphere?

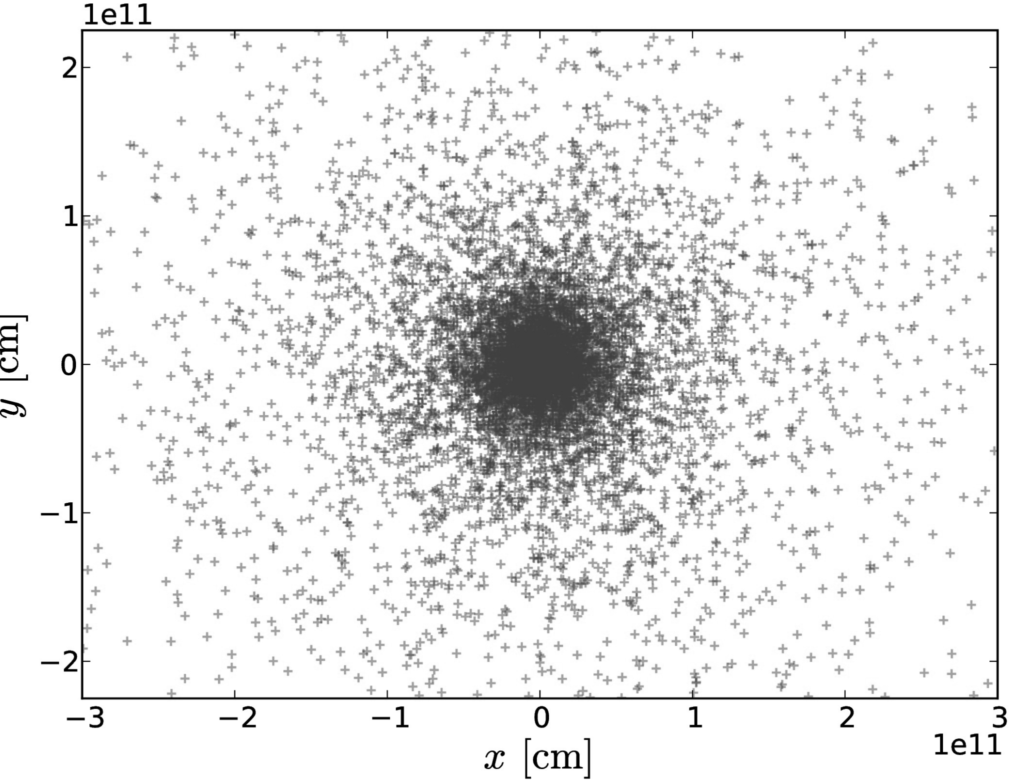
Part I: The photon field in the **local comoving frame** must be **anisotropic** **OK**

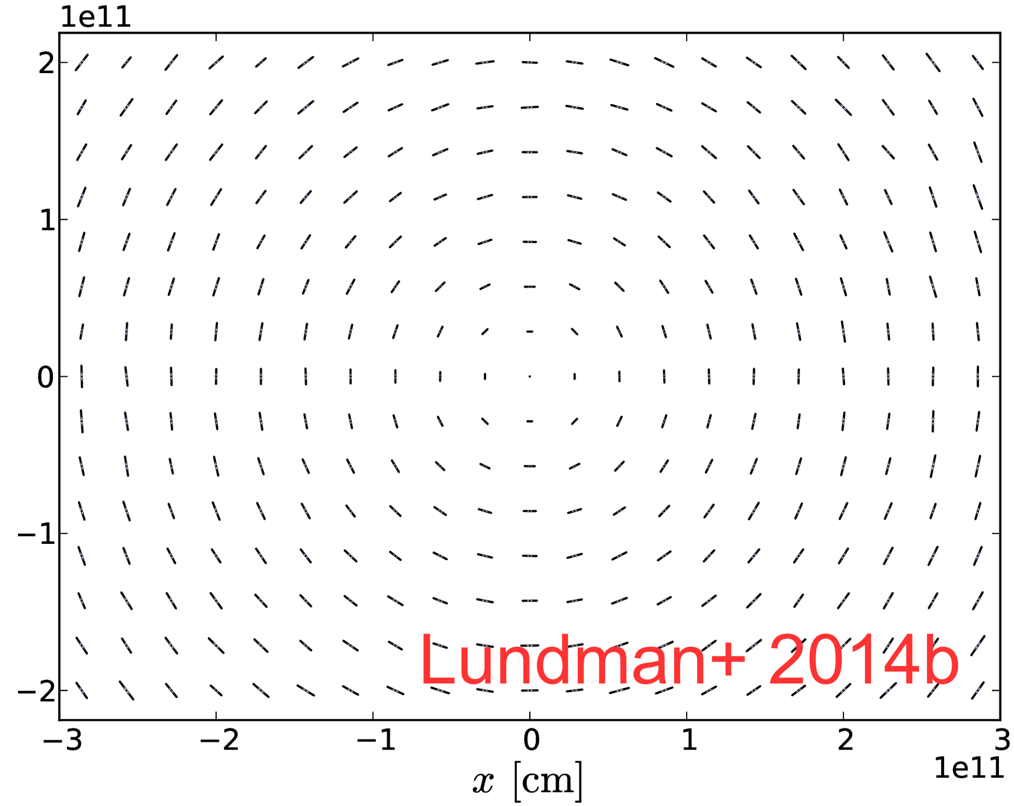
Part II: The observed emitting region must be **asymmetric**

Part II: Individual fluid elements at the photosphere emit polarized emission



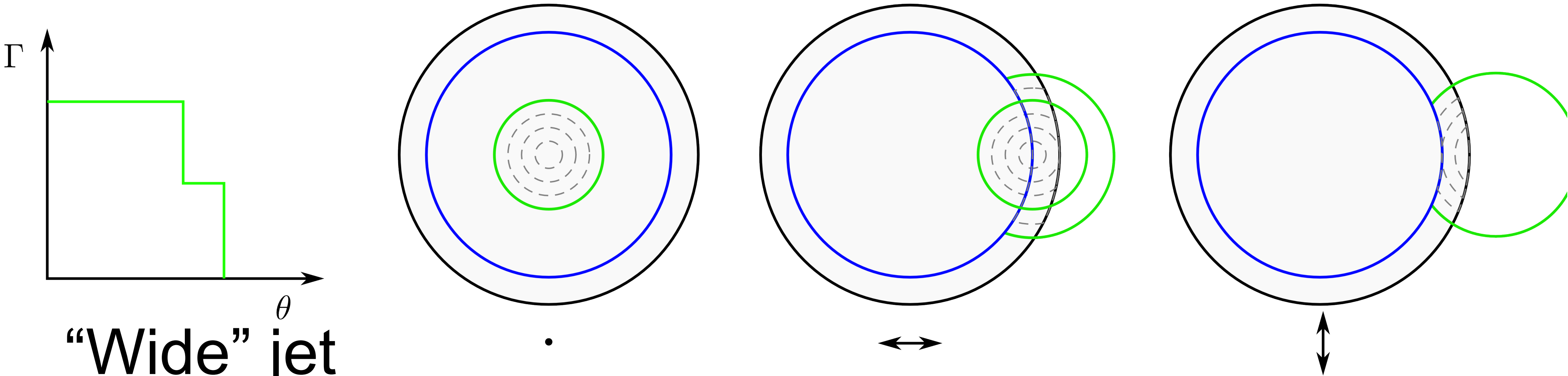
Part II: Polarized emission from **spherical outflows**?



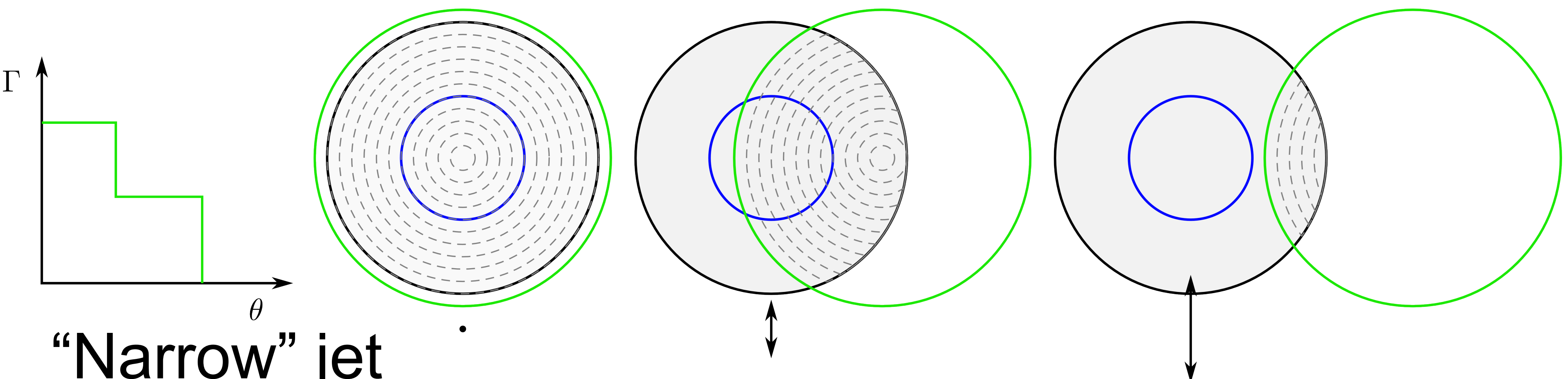


- Averaging over the emitting region **cancels the polarization signal**
- However, emission is polarized if “rotational symmetry” of the emitting region is broken

Part II: Natural way to break the symmetry - Jet structure



“Wide” jet



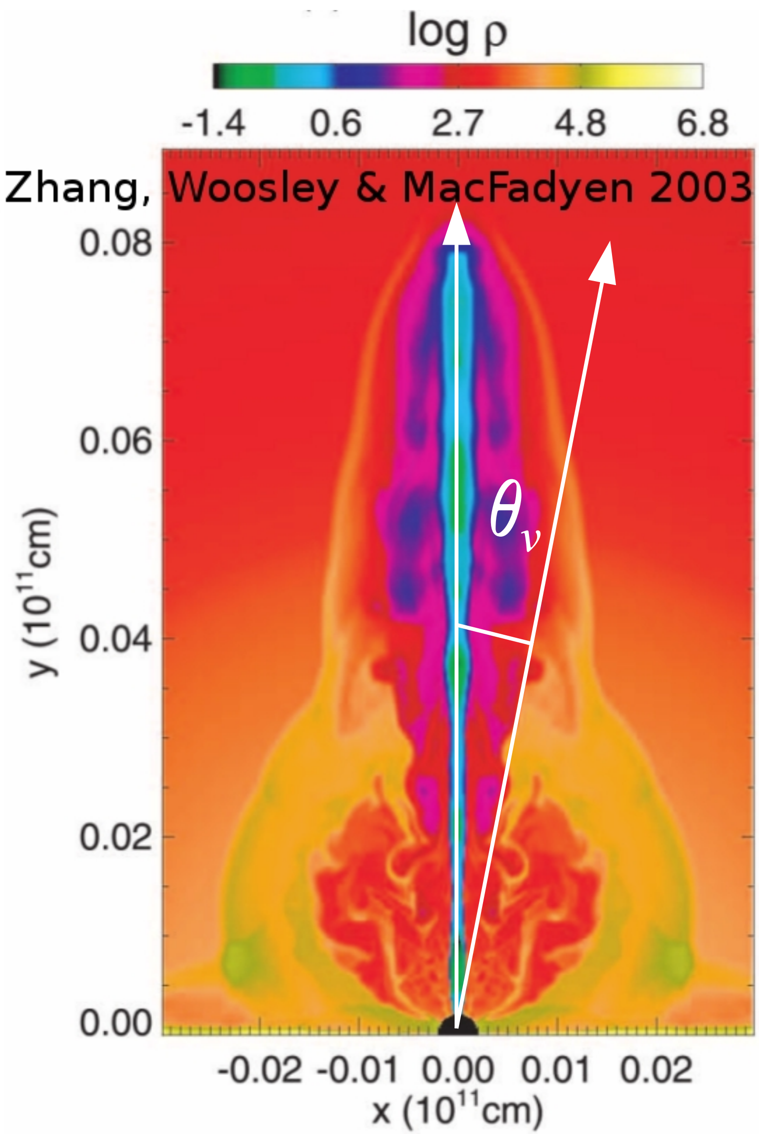
“Narrow” jet

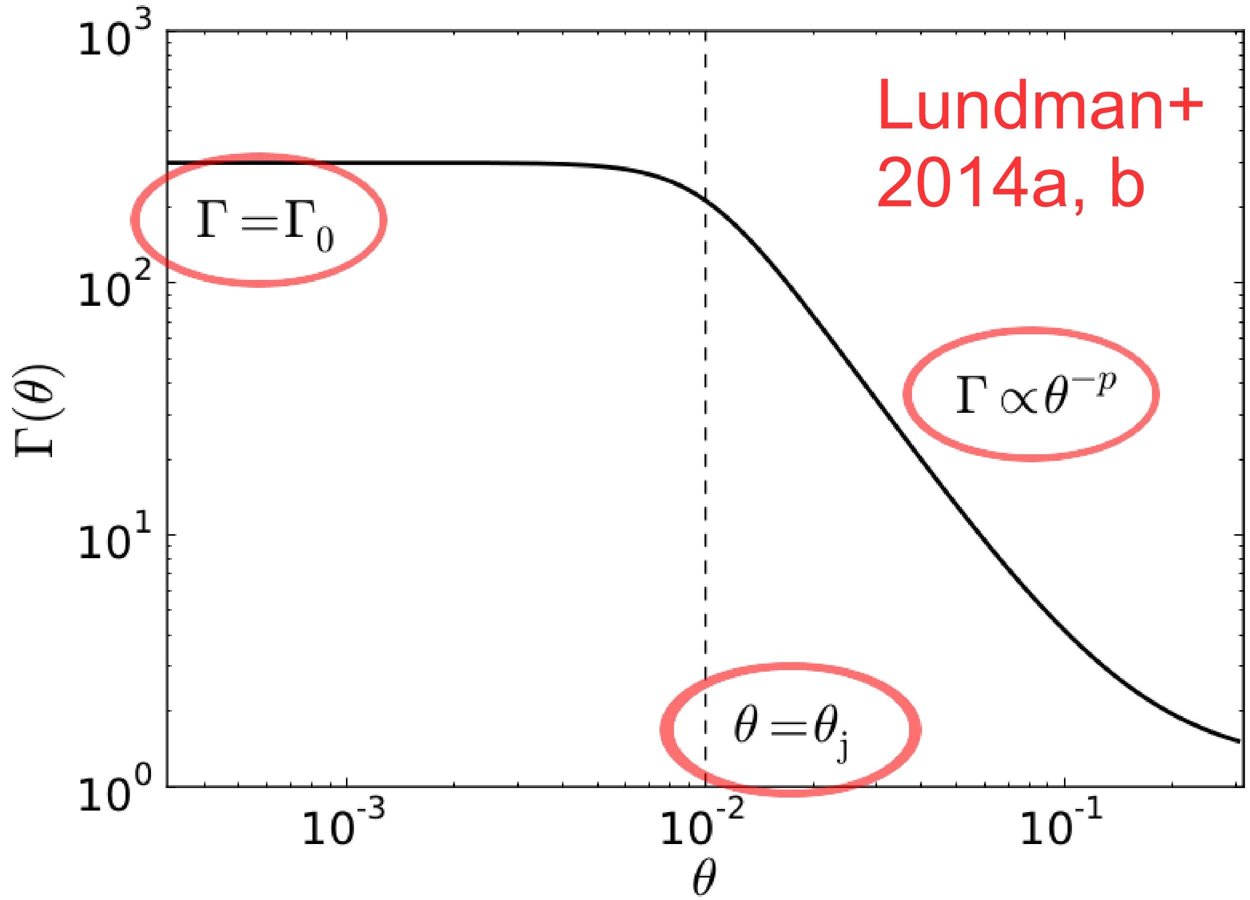
What ingredients are needed to produce polarized emission from the photosphere?

Part I: The photon field in the **local comoving frame** must be **anisotropic** OK

Part II: The observed emitting region must be **asymmetric** OK

We do: Polarized radiative transfer close to the jet photosphere





Inspired by hydrodynamical simulations, we consider a realistic jet structure

How we approach solving the problem

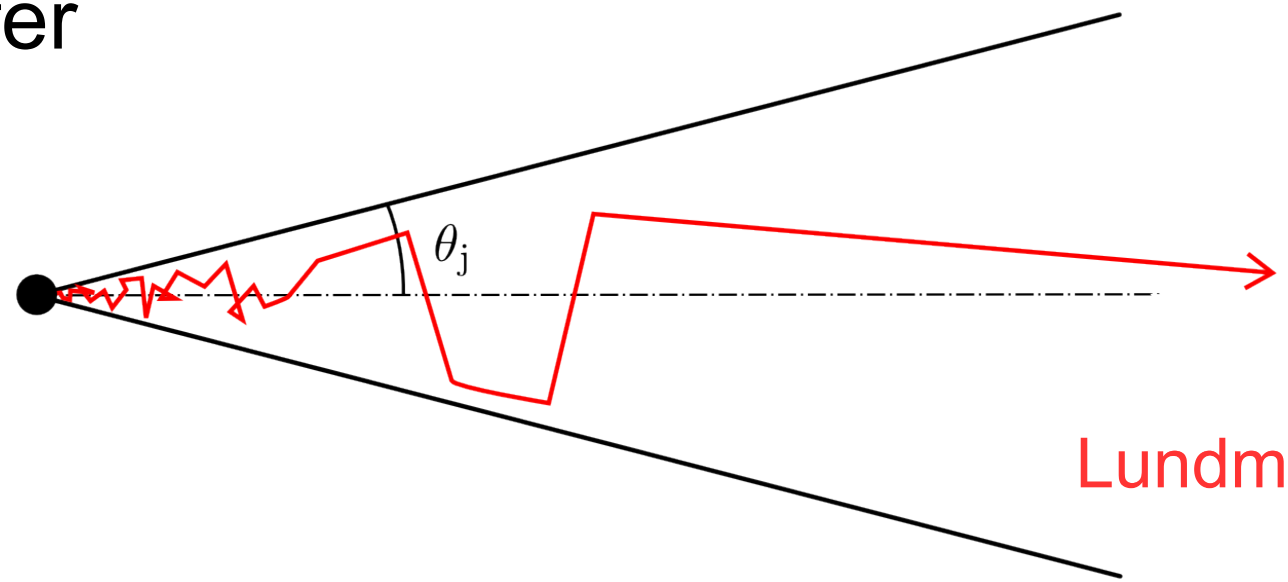
1) Analytical calculations

$$\frac{\mathrm{d}\dot{N}^{\mathrm{ob}}}{\mathrm{d}\Omega_{\mathrm{v}}}(\theta,\theta_{\mathrm{v}},R_{\mathrm{ph}}) = \frac{1}{4\pi}\int_{\Omega_{\mathrm{s}}} D^2(\theta,\theta_{\mathrm{v}})\frac{\mathrm{d}\dot{N}}{\mathrm{d}\Omega}(\theta,R_{\mathrm{ph}})\mathrm{d}\Omega$$

$$\frac{\mathcal{Q}}{\mathcal{I}} = \frac{\int_{\Omega_{\mathrm{s}}} D^2(\mathrm{d}\dot{N}/\mathrm{d}\Omega)\Pi(\theta_{\mathrm{L}})\cos(2\chi)\mathrm{d}\Omega}{\int_{\Omega_{\mathrm{s}}} D^2(\mathrm{d}\dot{N}/\mathrm{d}\Omega)\mathrm{d}\Omega}$$

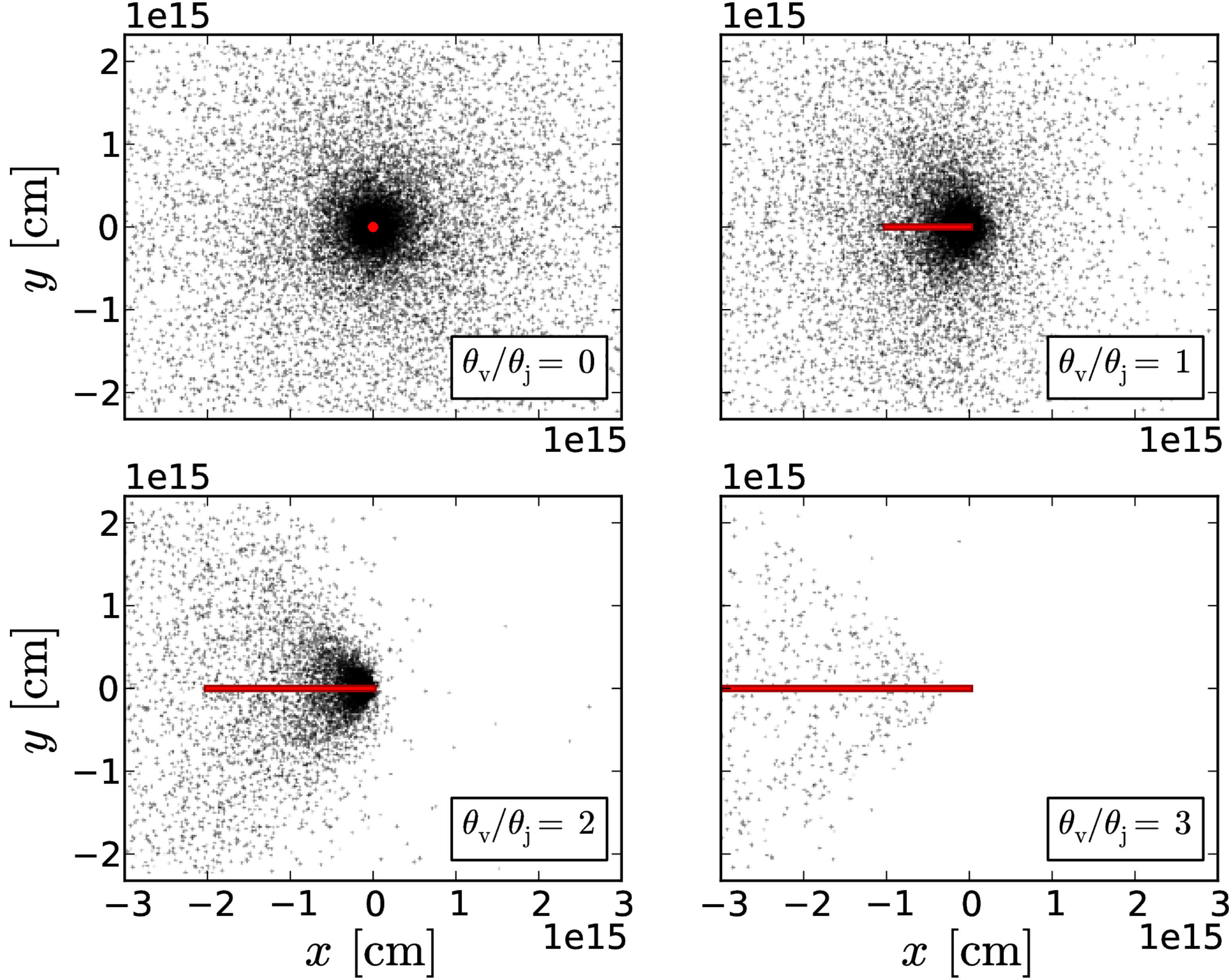
$$\Pi(\theta_{\mathrm{L}}) \simeq 0.45\frac{(1-\beta\cos\theta_{\mathrm{L}})^2-(\cos\theta_{\mathrm{L}}-\beta)^2}{(1-\beta\cos\theta_{\mathrm{L}})^2+(\cos\theta_{\mathrm{L}}-\beta)^2}$$

2) Monte Carlo simulation of polarized radiative transfer



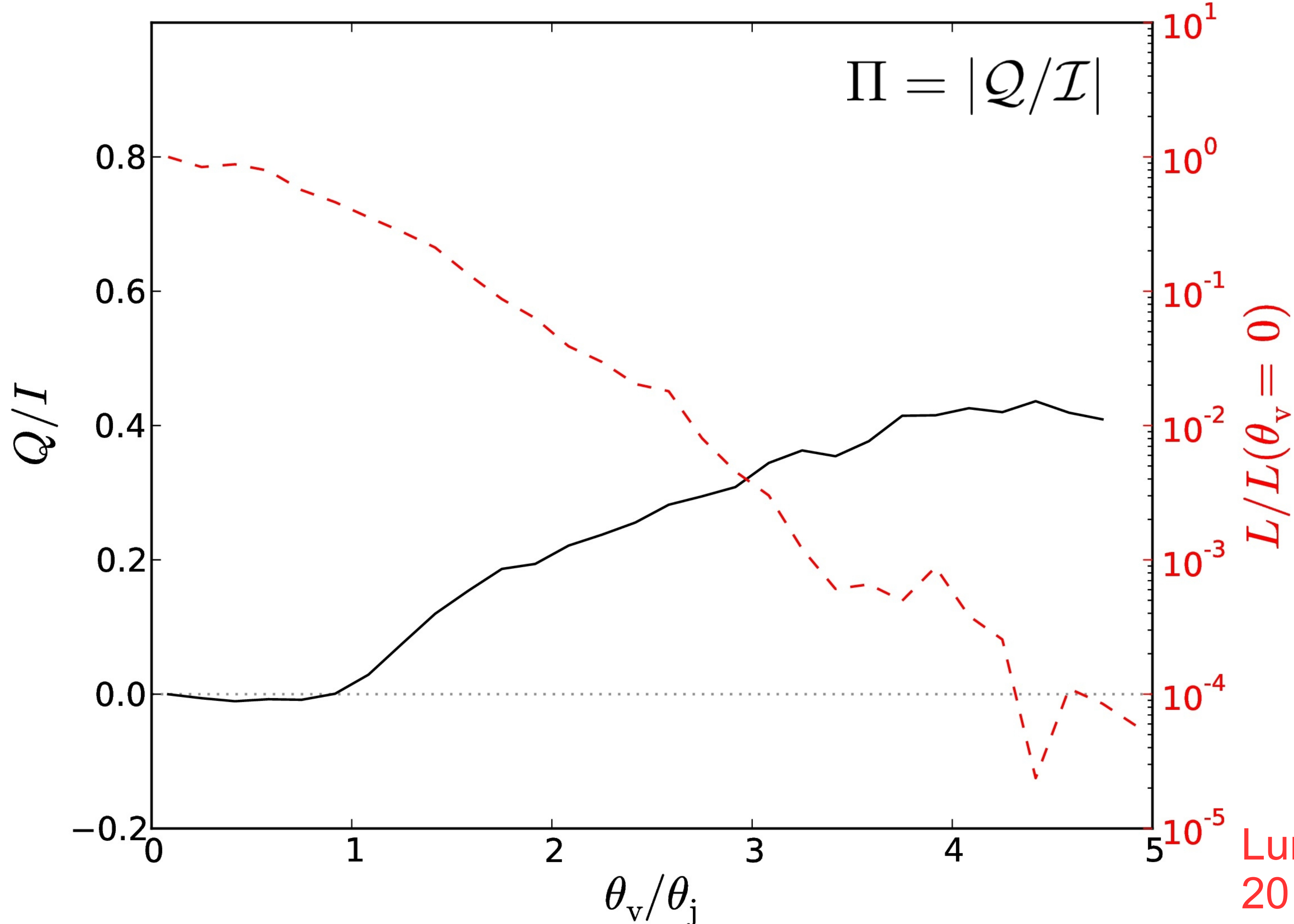
Lundman+ 2014a, b

Narrow jet results: Breaking the symmetry of the emitting region



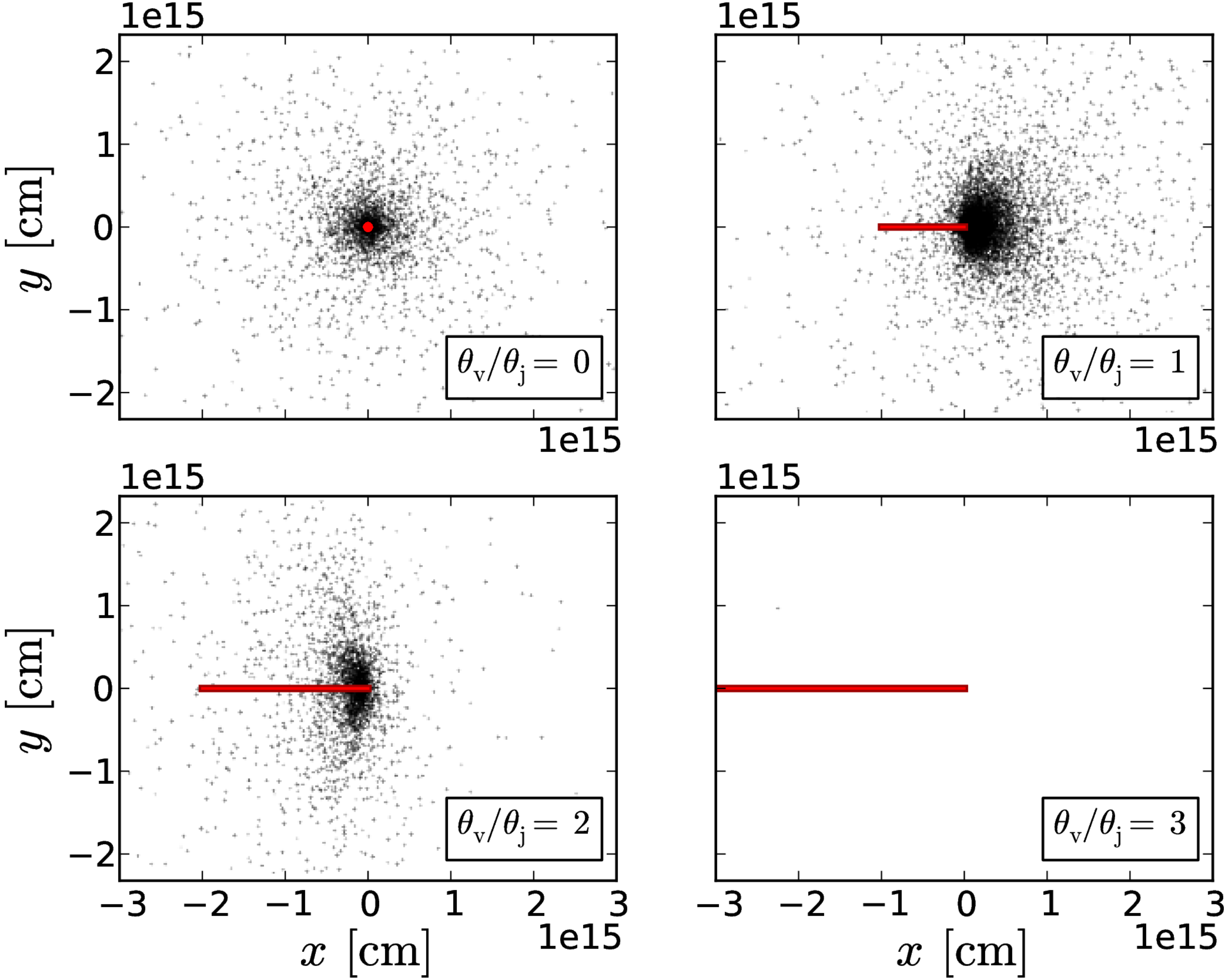
Lundman+ 2014b

Narrow jet results: Breaking the symmetry of the emitting region



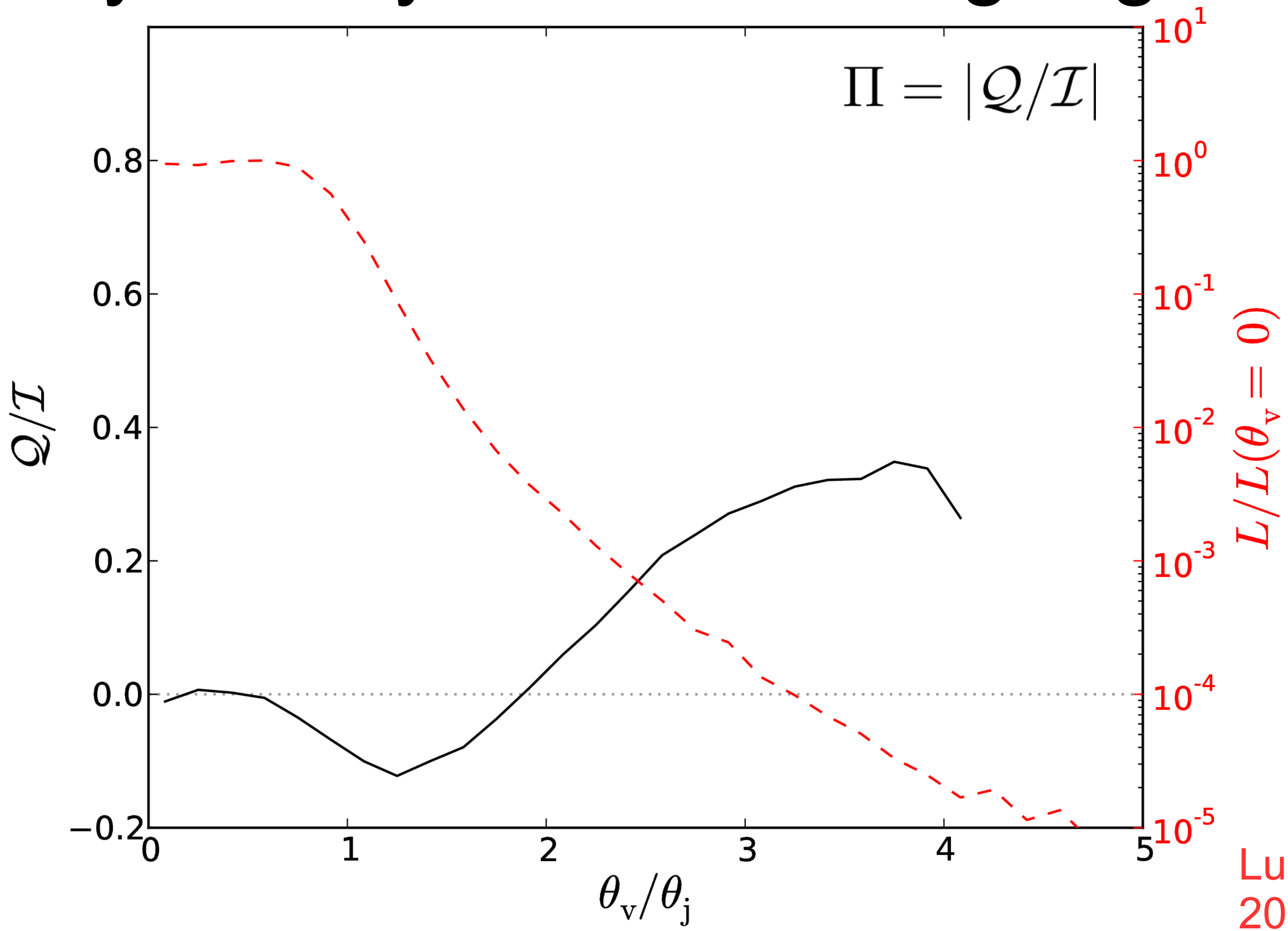
Lundman+ 2014b

Wide jet results: Breaking the symmetry of the emitting region



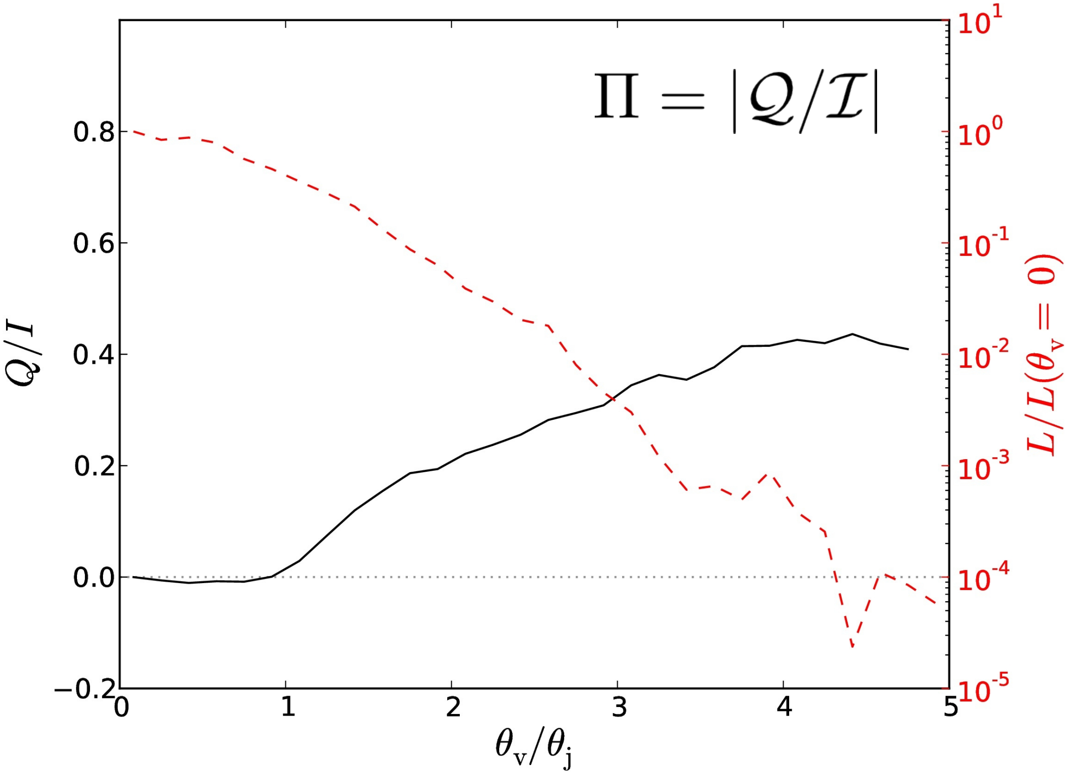
Lundman+ 2014b

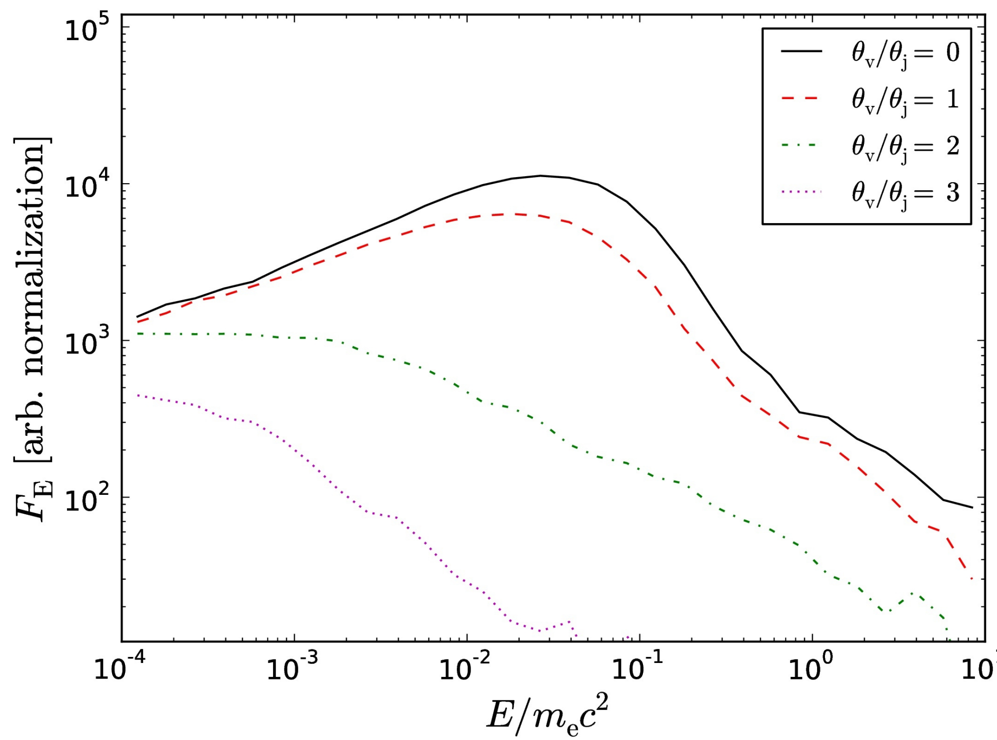
Wide jet results: Breaking the symmetry of the emitting region



Lundman+
2014b

Interesting consequence: Correlations between the spectral shape and the polarization degree





Polarization degree is up to 40%,

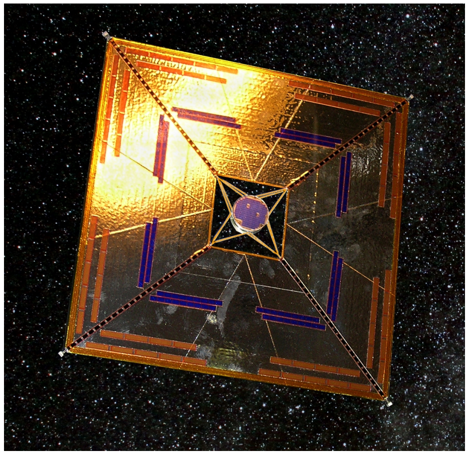
spectrum similar to typical GRB spectra!

Lundman+ 2014a, b

Summary: Polarized emission from the photosphere

- Polarized emission in range **0-40% expected** (depending on viewing angle and jet structure)
- **Only** a change in pol. angle of **90º** is possible (due to jet axisymmetry)
- If jet is wide, most obs. see low polarization (few percent)
- Correlations expected between spectrum and polarization

Comparison with interesting GAP observations



See talk by Yonetoku!

GAP observations of GRB100826A

- Polarization of prompt emission measured in two separate time bins
- First bin: $\Pi = 25\% \pm 15\%$
  $\phi = 159^\circ \pm 18^\circ$
- Second bin: $\Pi = 31\% \pm 21\%$
  $\phi = 75^\circ \pm 20^\circ$
- Consistent with a shift of $\Delta\phi \approx 90^\circ$