Polarised Emission from GRB Jets

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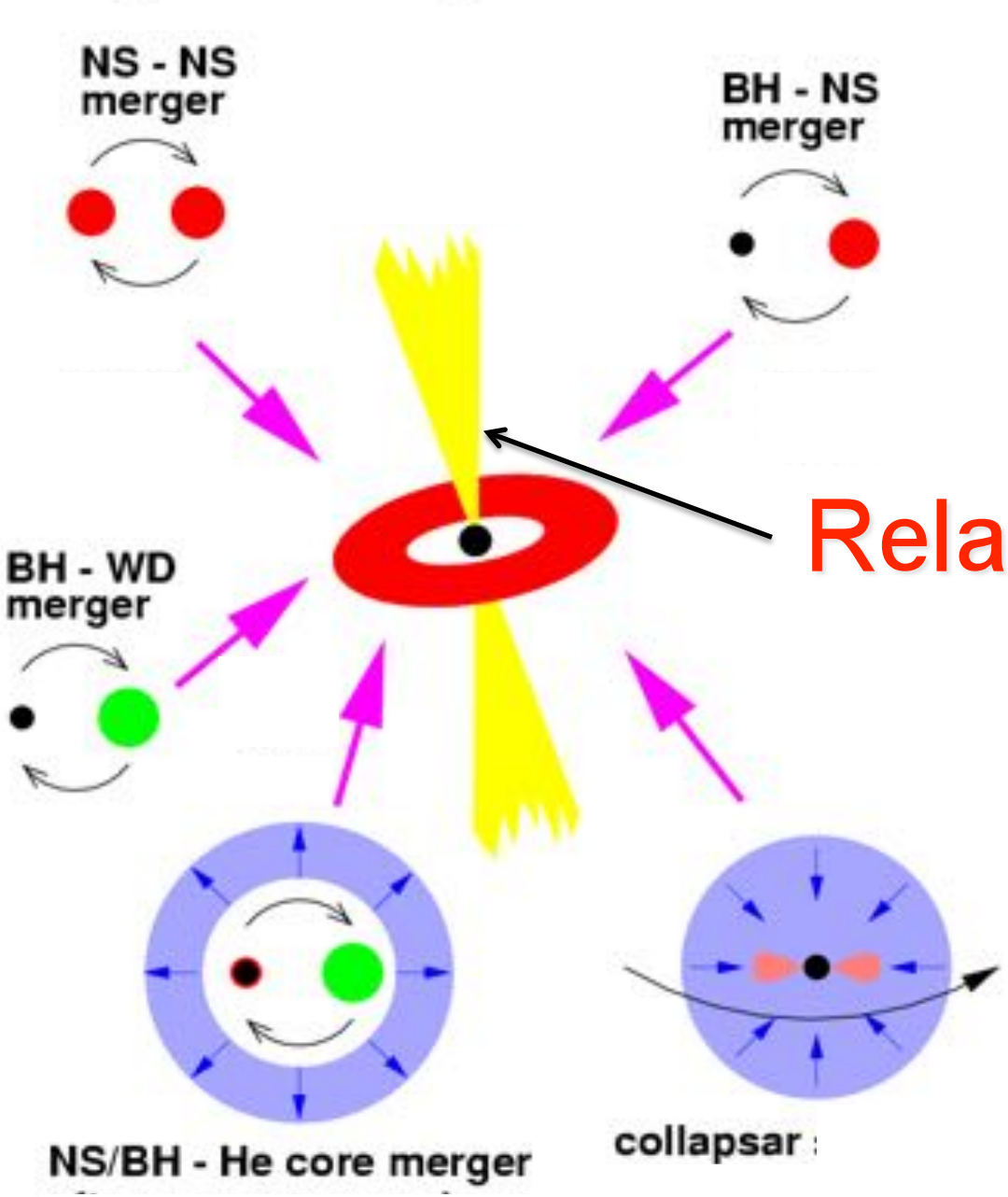
Image credit:ESO/A. Roquette

How have polarization signals been discussed in GRB studies?

Some basics physics and mechanisms

- Jet breaks and Jet Structures
- Early Afterglow and Magnetic Fields in Jets
- Optical circular polarization



Carole Mundell's talk

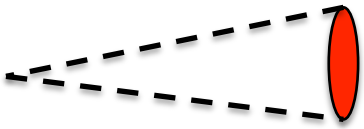
Blazars and GRBs

Both are powered by BH-accretion disk system (different BH masses)
Magnetic acceleration?

Long timescale, continuous

$$\Gamma = 10$$

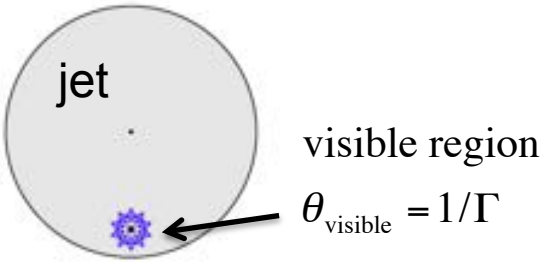
$$\theta_{jet} \approx 1^{\circ} < 1/\Gamma$$



catastrophic transient, optically thin

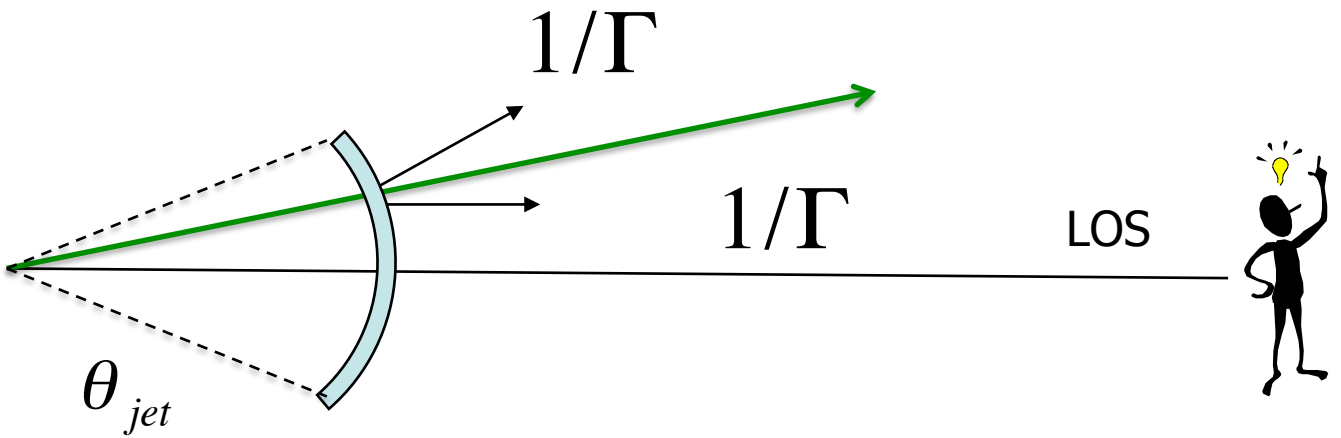
$$\Gamma = 100 - 1000$$

$$\theta_{jet} \approx 5^{\circ} >> 1/\Gamma$$



Jet Collimation and Relativistic Beaming

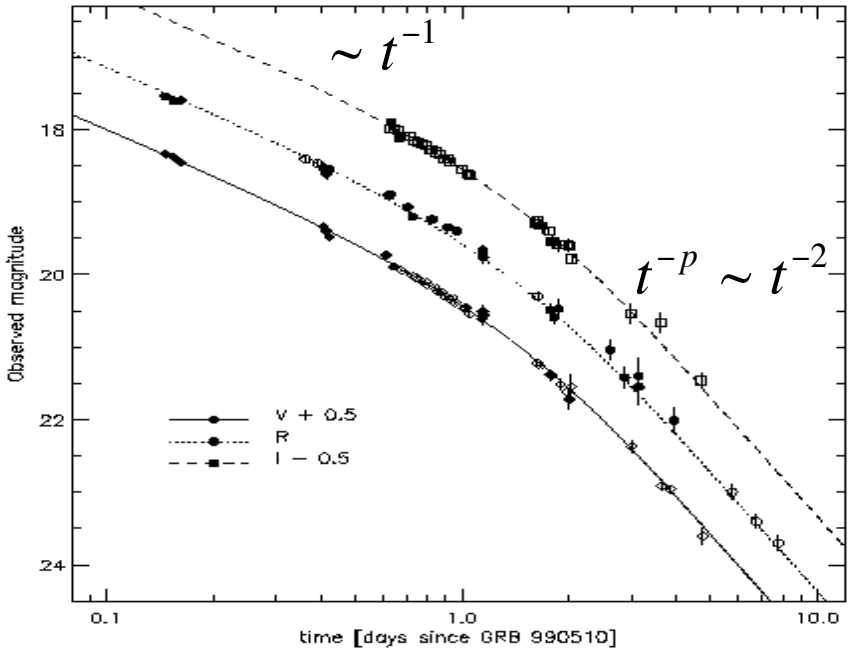
We can see only a small portion of the jet around the line-of-sight.



However, the jet decelerates, so we eventually see the edge of the jet.

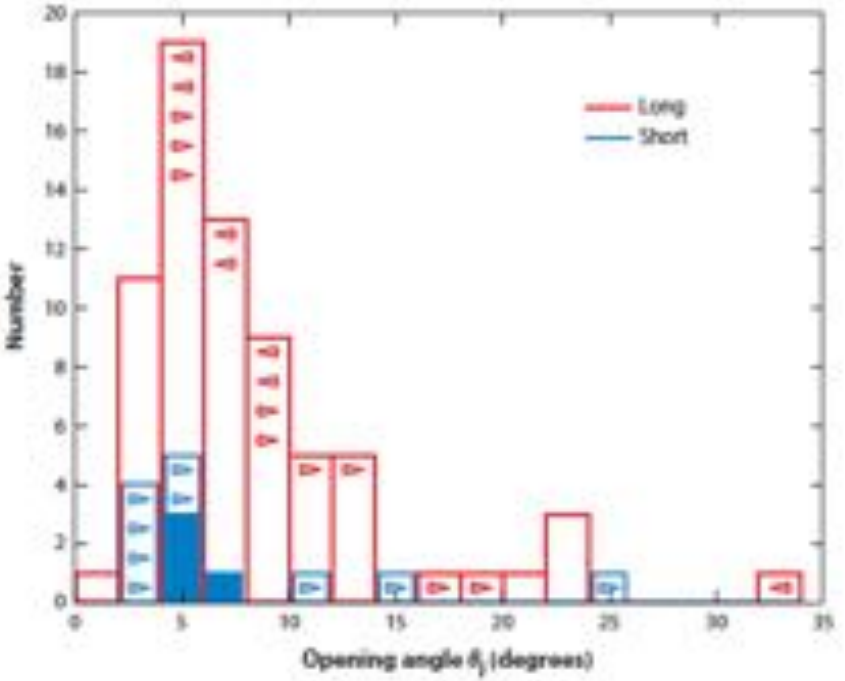
$$1/\Gamma \approx \theta_{jet}$$

“Jet break” in afterglow light curve



$$N(\gamma_e) \sim \gamma_e^{-p} \quad \text{for } \gamma_e > \gamma_{e,\min}$$

Jet Opening Angles



Berger 2014

$$\Gamma \approx 6(E_{52}/n)^{1/8} t_{day}^{-3/8} : \text{ blast wave}$$

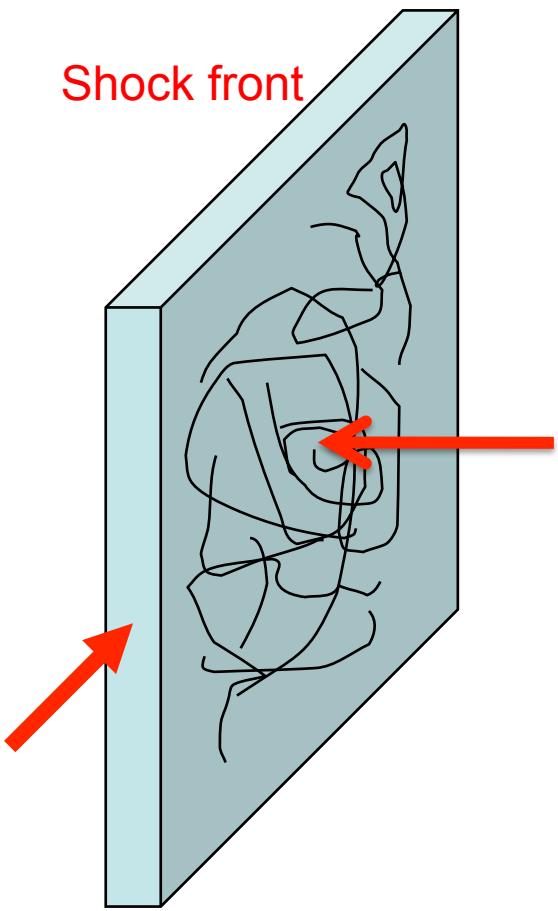
$$\theta_{jet} \approx 1/\Gamma(t_b)$$

Sari et al. 1999

- Around a jet break, the emission is expected to be polarized.

- The time evolution of the polarization degree and angle can be used to study the jet structure.

Magnetic fields generated by plasma instabilities in collisionless shocks.



Random, but maybe anisotropic
(e.g. special direction: shock normal)

$$\left\langle B_{//}^2 \right\rangle << \left\langle B_{\perp}^2 \right\rangle$$ Medvedev&Loeb1999

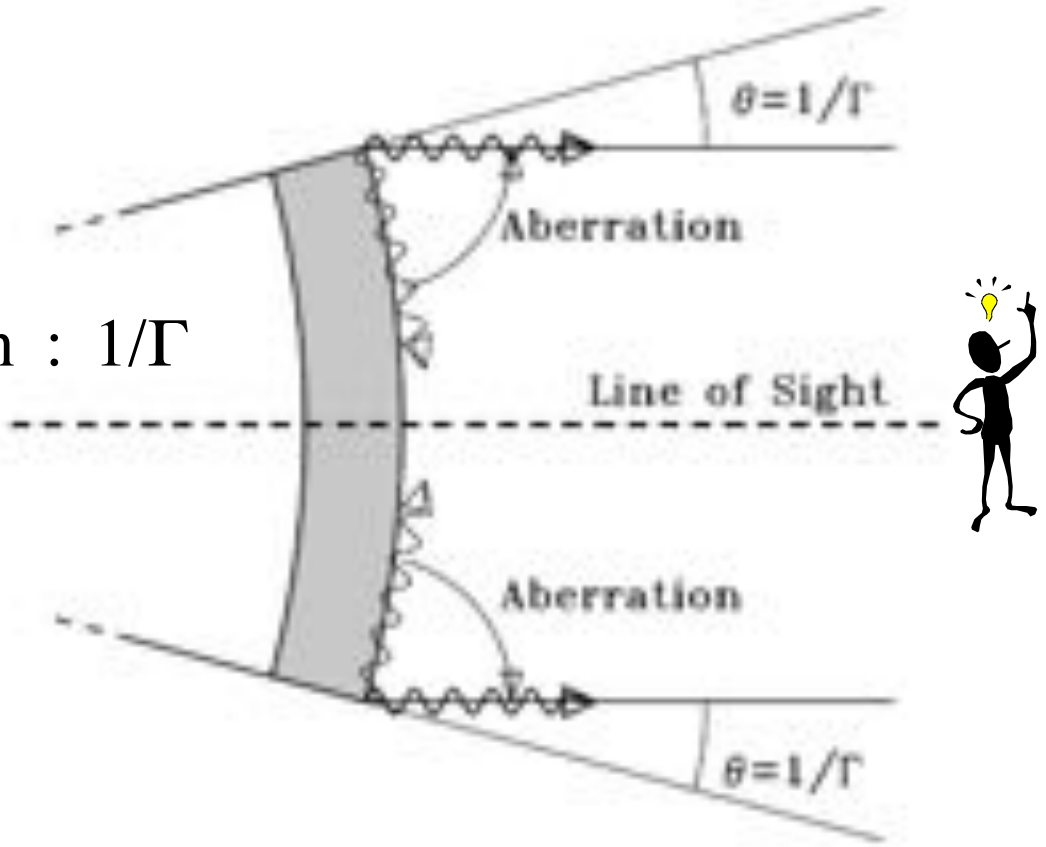
Synchrotron emission
Face-on: not polarized
Edge-on: polarized

Bulk Compton emission : Tania Garrigoux's talk also should be polarized in the same way.

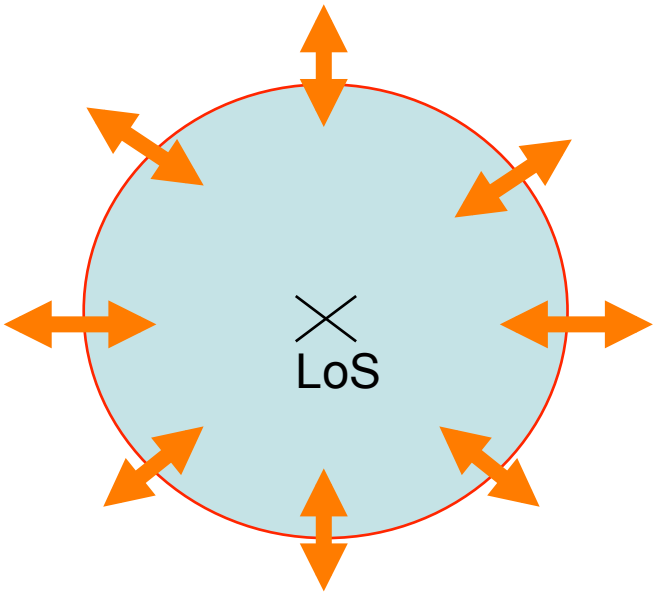
Relativistic aberration

$$\text{Shock frame}: \ \theta' = \pi/2 \Rightarrow \ \text{Lab frame}: \ \theta = 1/\Gamma$$

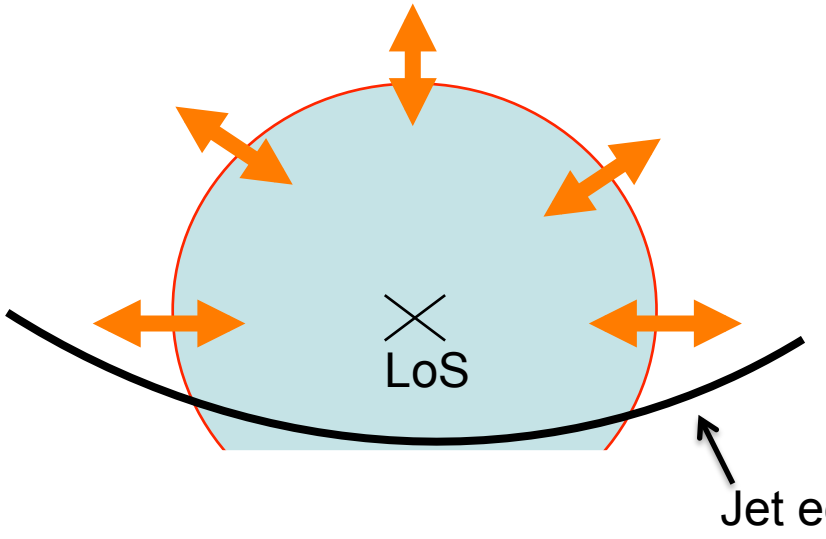
Visible Region : $1/\Gamma$



Ghisellini & Lazzati 1999



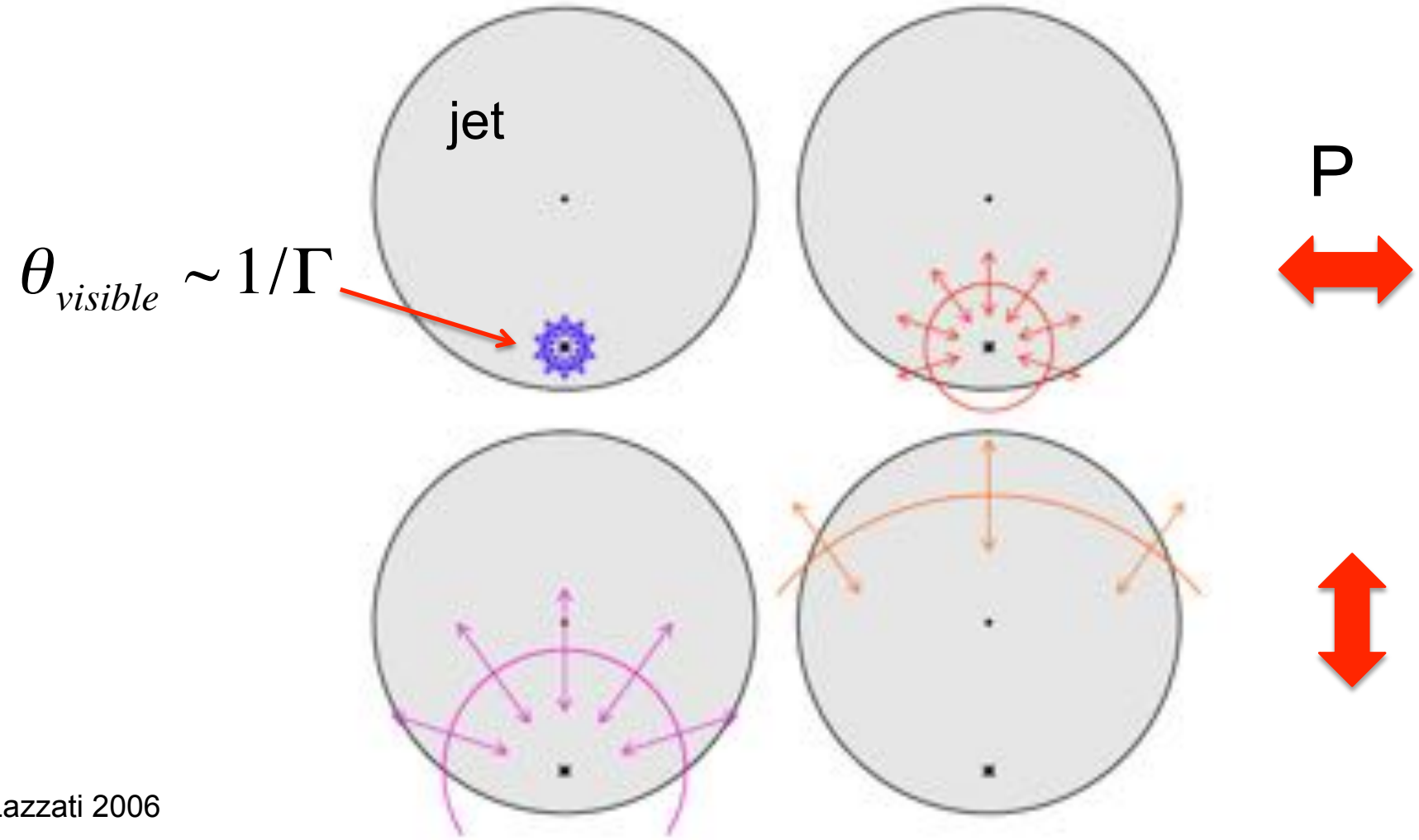
Emission is polarized at the edge.
However, the net polarization is zero.



If LoS is close to the jet edge,
the net becomes non-zero.

Ghisellini & Lazzati 1999; Sari 1999

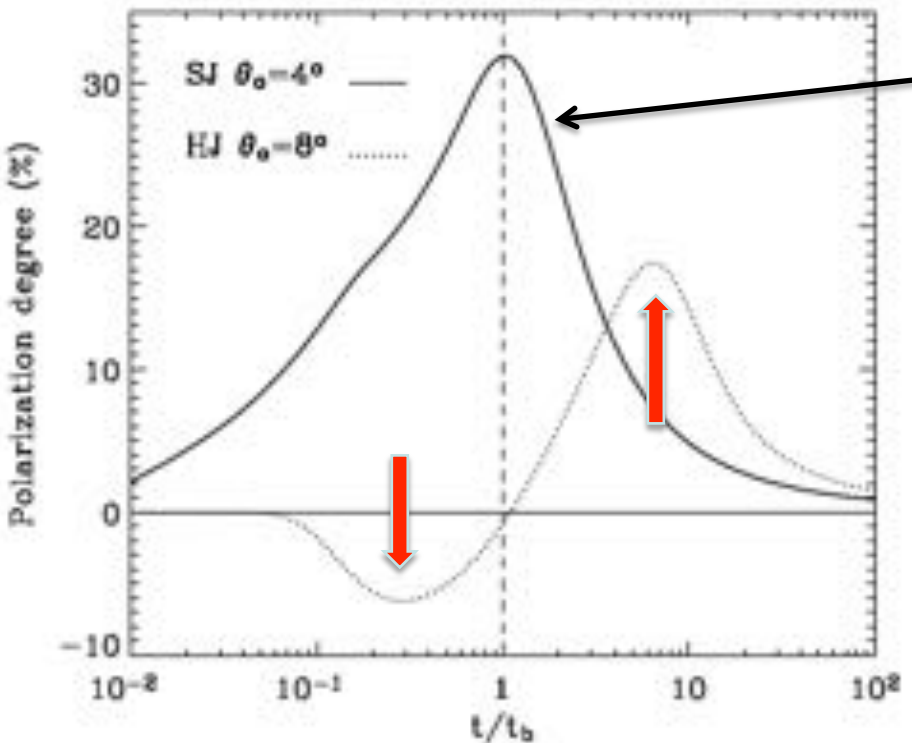
Jet break and Polarization Evolution

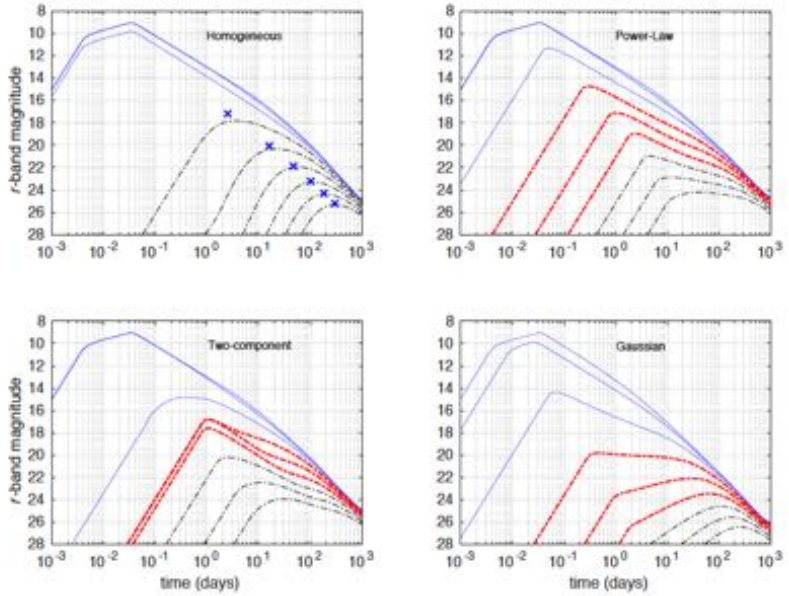


Lazzati 2006

Ghisellini & Lazzati 1999
Sari 1999

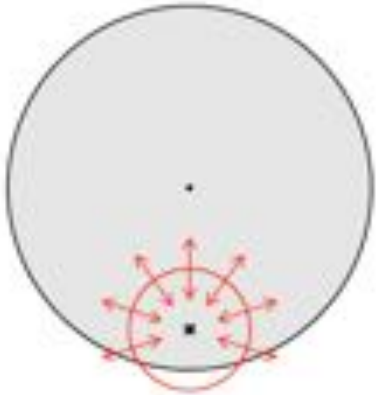
Polarization angle is rotated by 90 deg





if $\varepsilon \propto \theta^{-2}$,

we have a single peak in the P curve

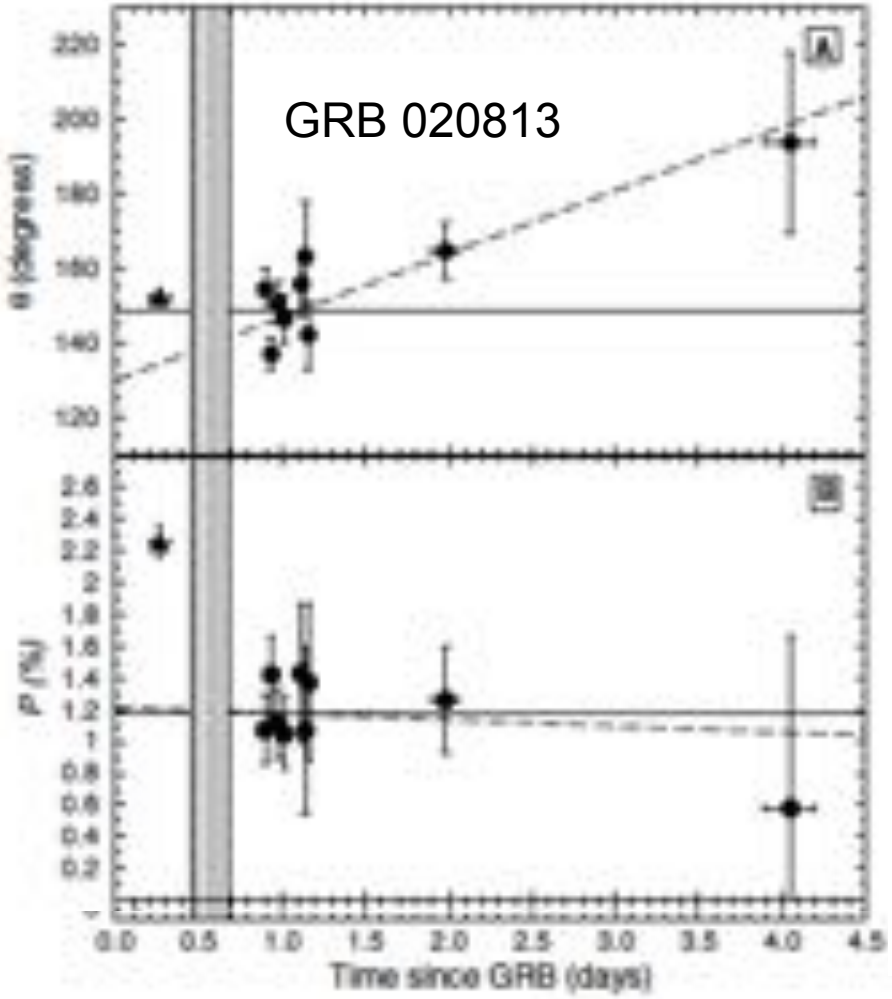


Light curves rather insensitive to the jet structure

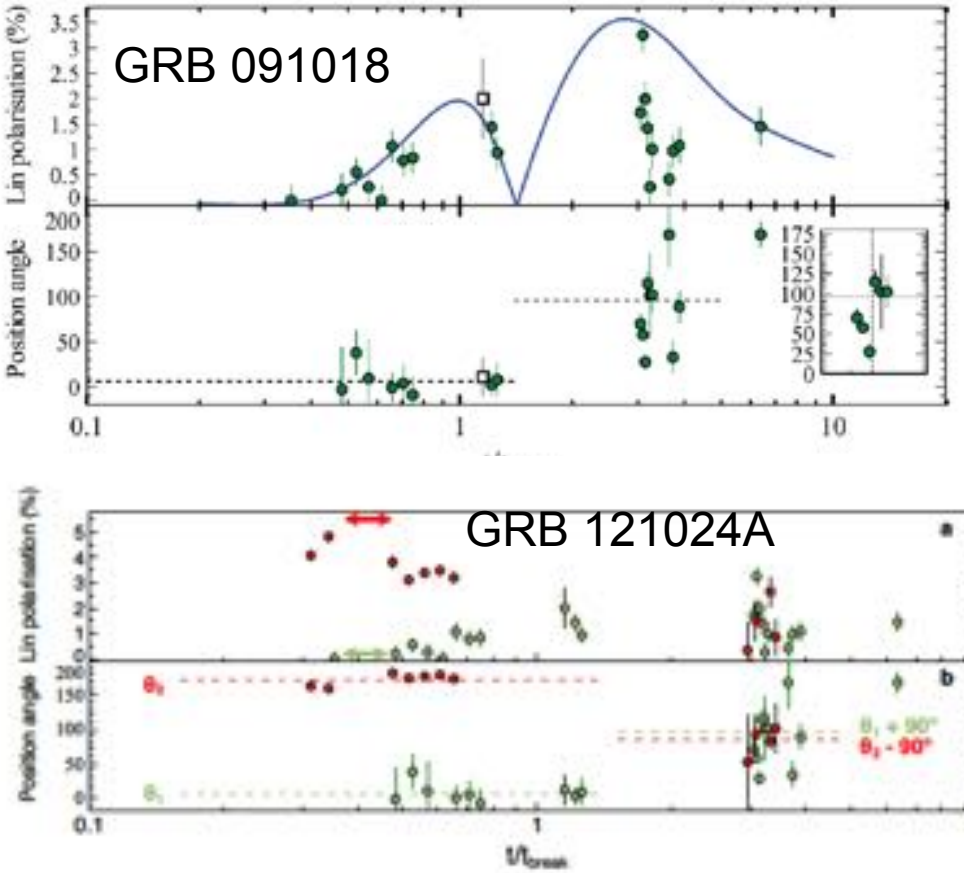
The time evolution of P can be used to study the structure.

Lazzati 2003; Rossi et al. 2003
Lamb&SK 2017

Optical Polarimetry



Gorosabel et al. 2004



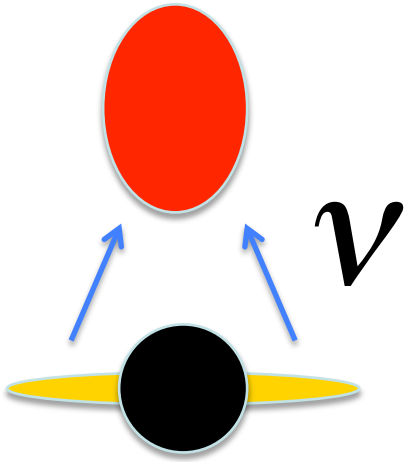
Wiersema et al. 2012, 2014

VLT: t_b ~ 0.5 days

Two Competing Jet Models

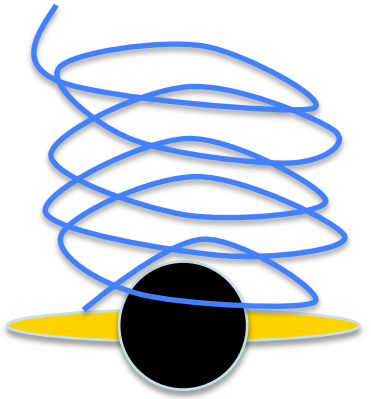
- Baryonic jets
  - Fireball, Thermal pressure
  - Tangled magnetic fields generated locally by instabilities in shock.

Zhang&Meszaros 2004; Piran 2005
Medvedev&Loeb 1999; Nishikawa et al. 2003; Spitkovsky 2008

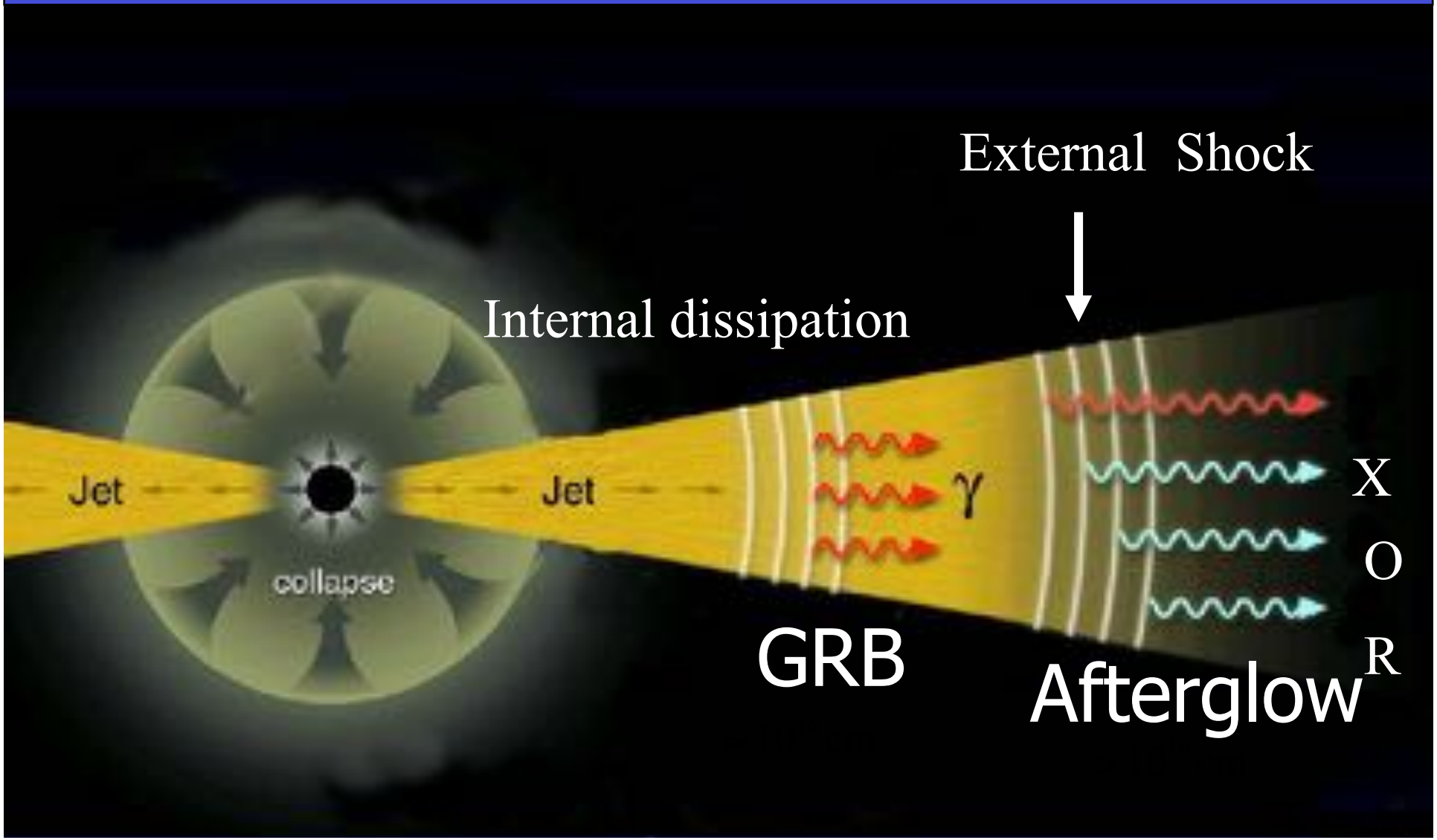


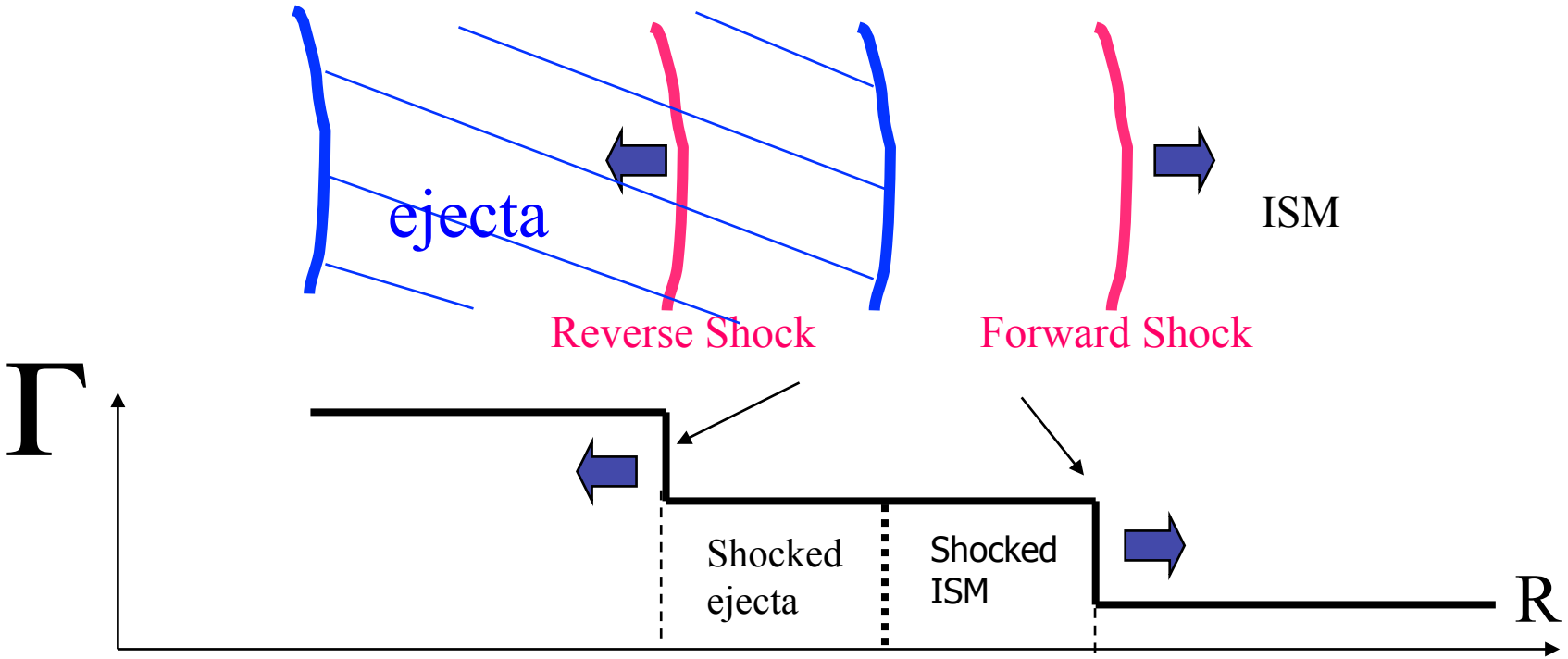
- Magnetized jets
  - Rotating BH system, Magnetic pressure
  - Threaded with globally ordered fields

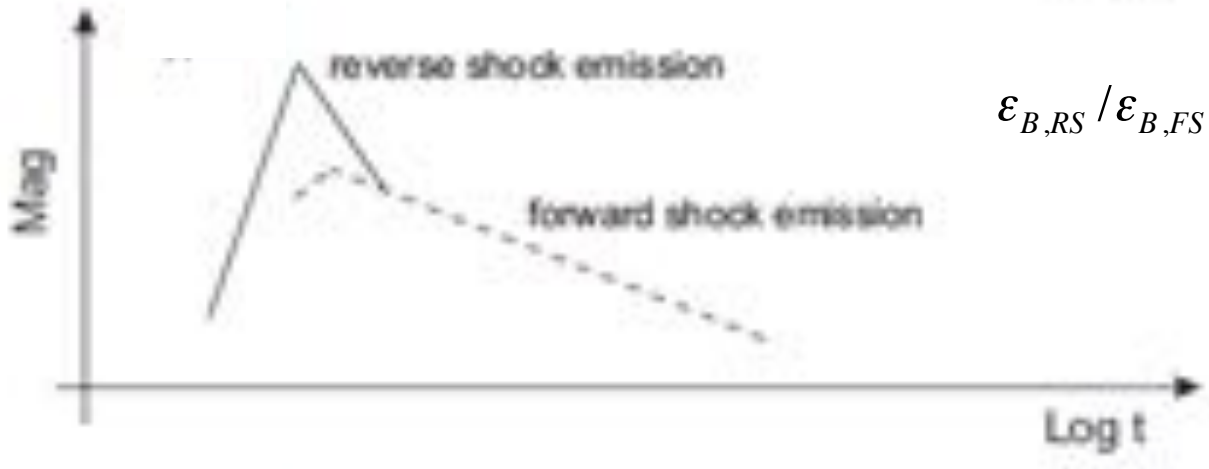
Tchekhovskoy et al. 2008; Mckinney&Blandford 2009; Komissarov et al. 2009
Drekhahn&Spruit2002; Lyutikov 2006; Giannios 2008; Mimica et al. 2009;
Zhang&Yan 2011; Narayan et al. 2011; Granot 2012



Fireball Model







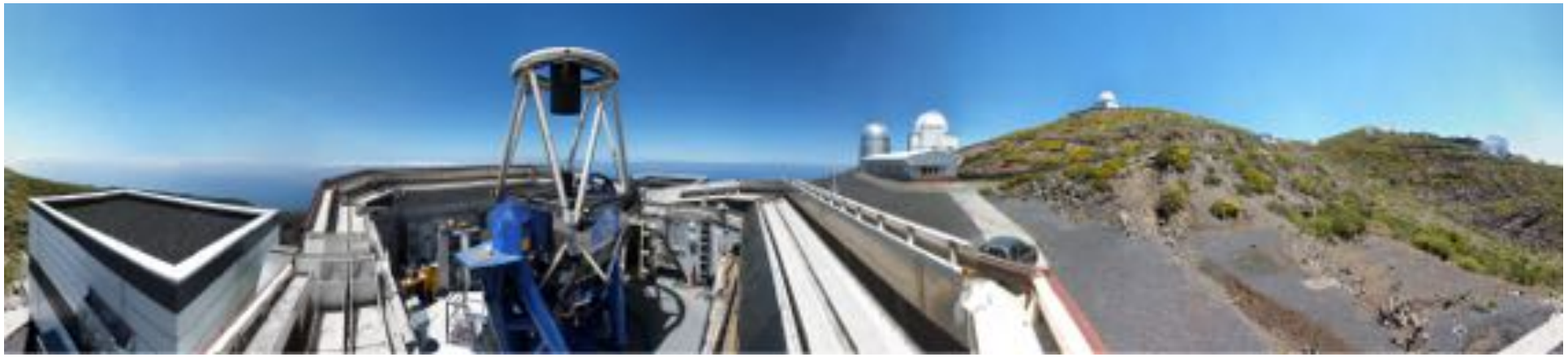
$\varepsilon_{B,RS}/\varepsilon_{B,FS} \sim 6000$ (GRB 990123)

~ 200 (GRB 090102)

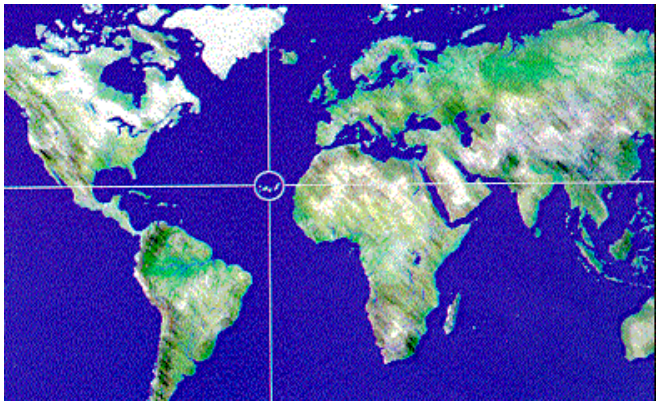
Mundell's talk

Sari, Piran 1999; SK 2000, SK&Sari2000, Zhang,SK&Meszaros2003
Gomboc,SK+2009; Harrison&SK2013

Liverpool Telescope

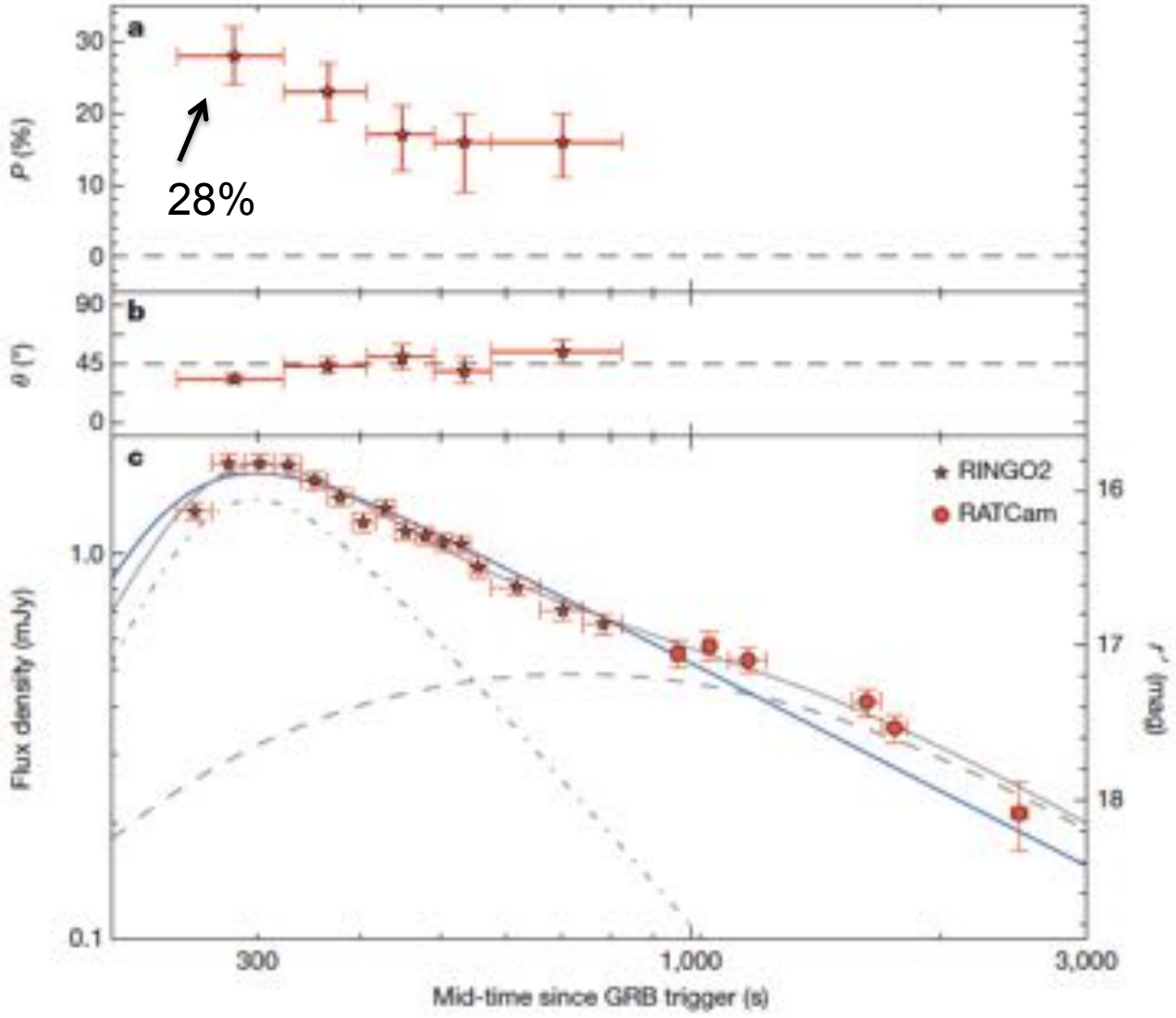


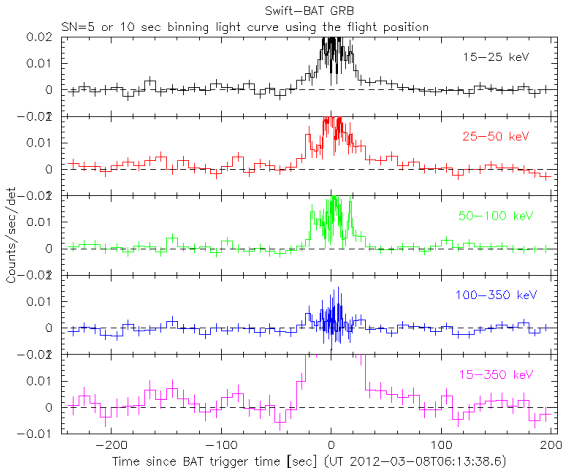
- 2m robotic telescope at the Canary Island, La Palma
- New 4m robotic Telescope



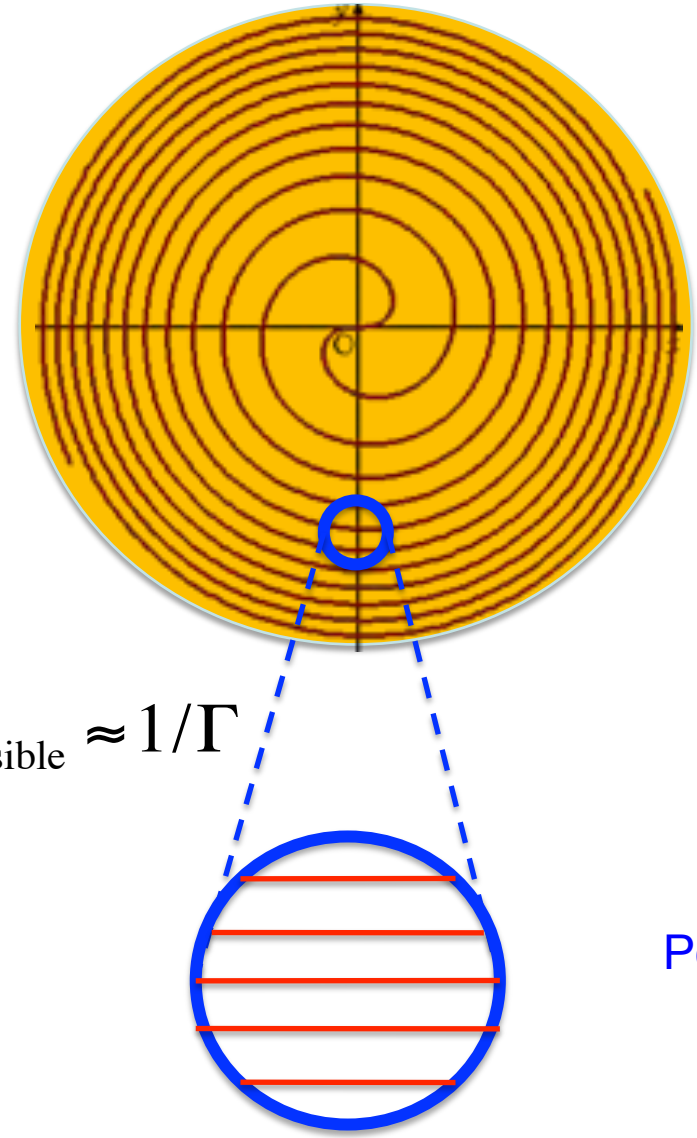
Highly polarized Afterglow

GRB 120308A : Mundell et al. Nature 2013

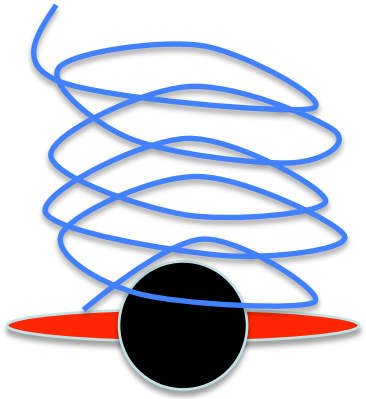




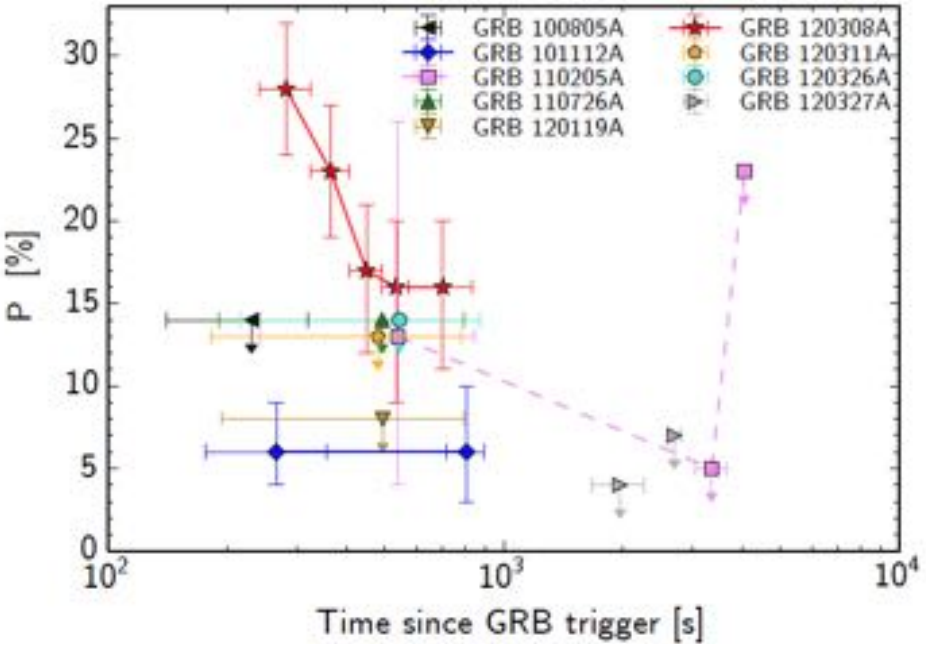
Toroidal Fields



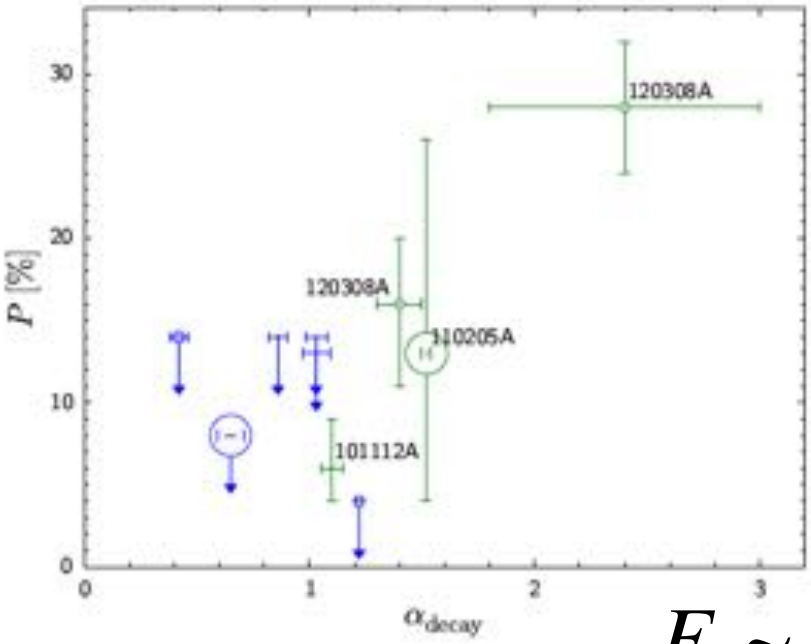
$$\theta_{\text{visible}} \approx 1/\Gamma$$



Polarization angle does not change with time



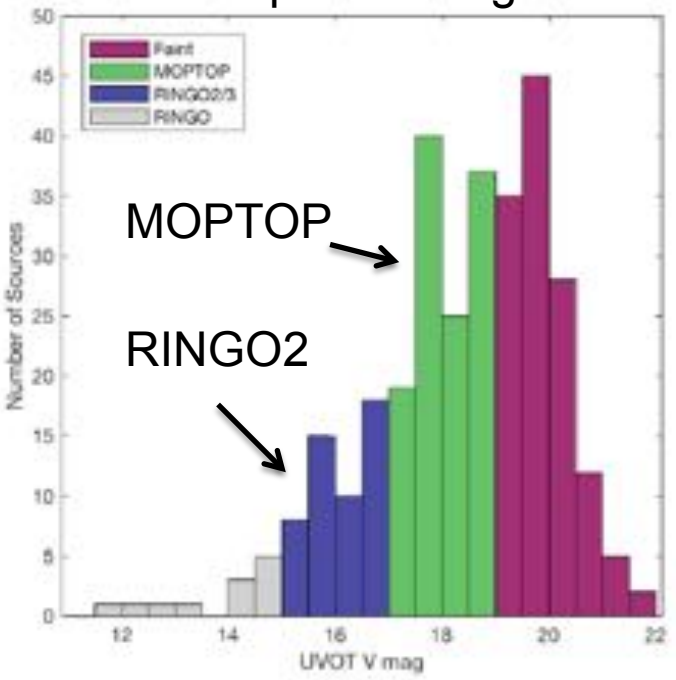
RINGO2 on LT
Aug 2010-Oct 2012
19 optical afterglow observed
9 sufficiently bright for polarimetry



Steele et al. 2017

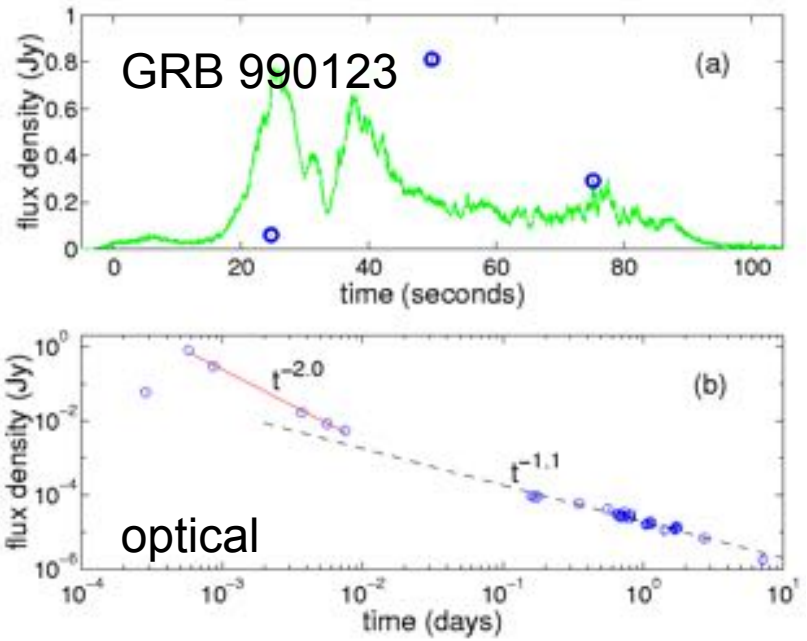
$$F \sim t^{-\alpha}$$

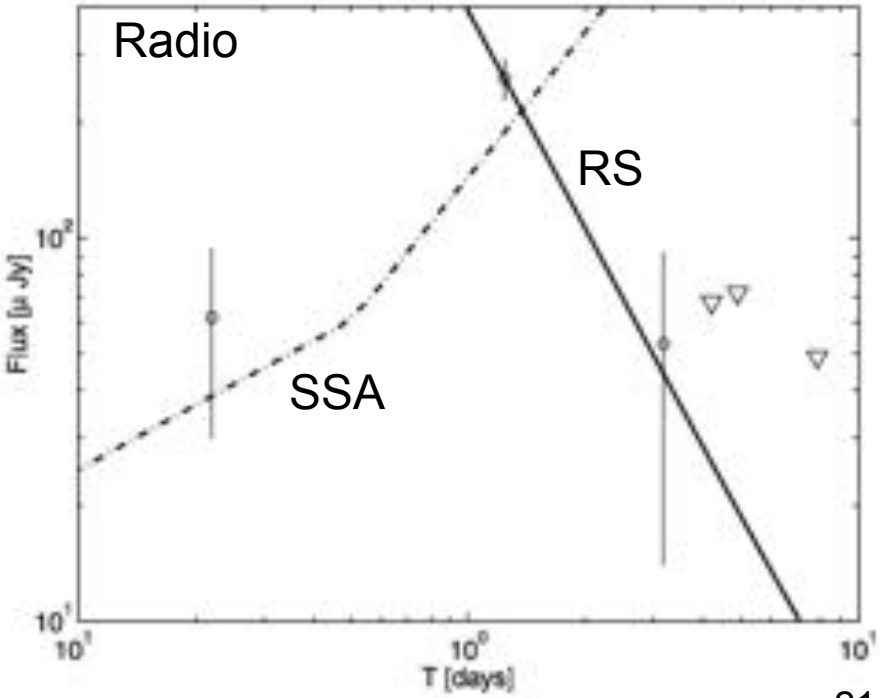
Swift optical afterglow



Radio Flares

- Reverse shocked ejecta:
  - adiabatically cooled, radiates at lower and lower freq
  - The emission peaks in the radio about 0.1-1day after GRB
  - Many flare events observed in radio (private communication with Frail, Kulkarni)





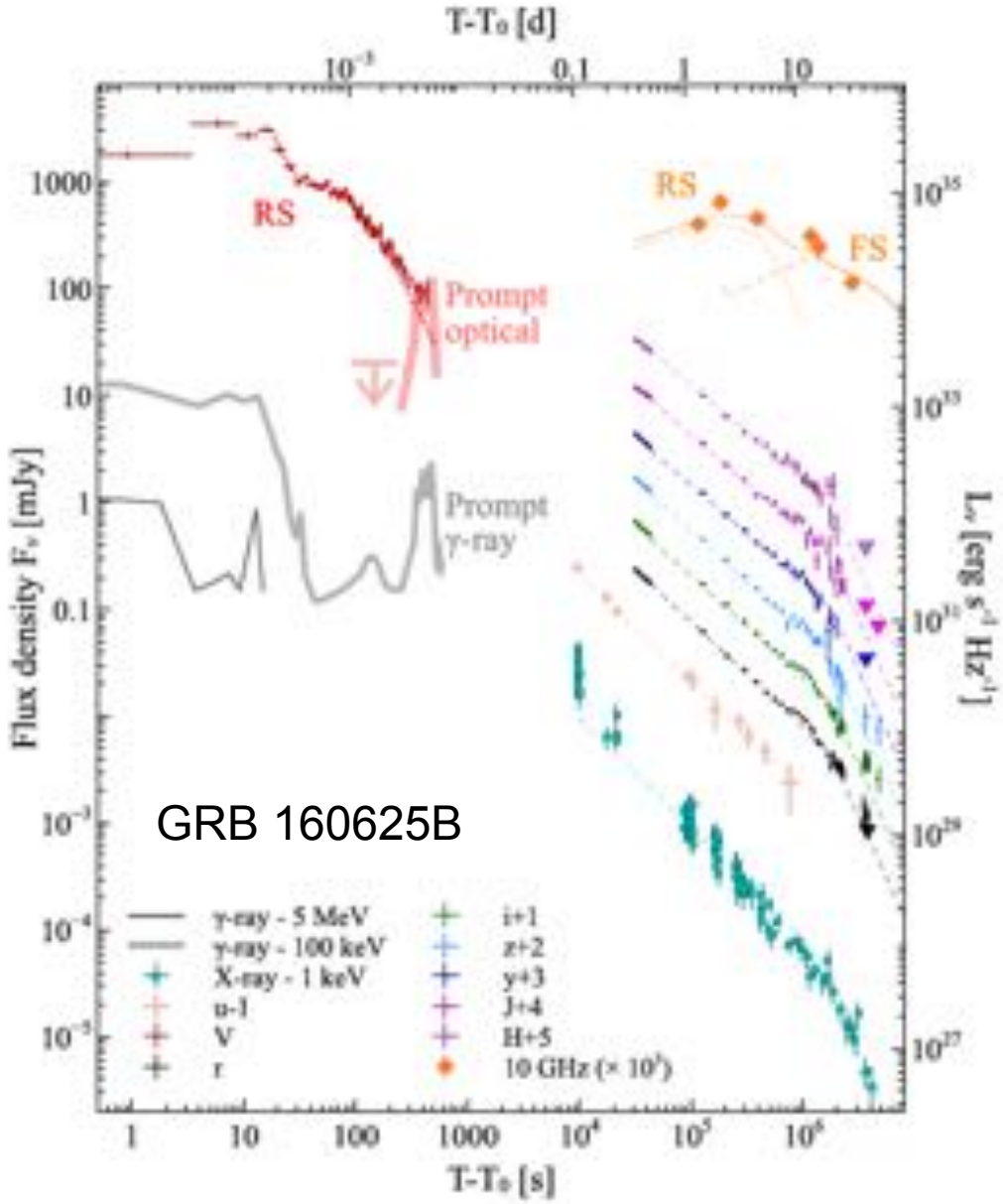
SK&Sari2000

Polarization Limits: Radio Flares

Granot & Taylor 2005

GRB	t (days)	t_j (days)	Π_L	Π_C	F_ν (μJy)
990123.....	1.25	≈ 2	<23%	<32%	242 ± 26
991216.....	1.49	~ 2	<11%	<17%	946 ± 56
	2.68	~ 2	<9%	<15%	634 ± 26
	1.49, 2.68	~ 2	<7%	<9%	715 ± 25
020405.....	1.19	$\sim 1-2$	<11%	<19%	492 ± 29

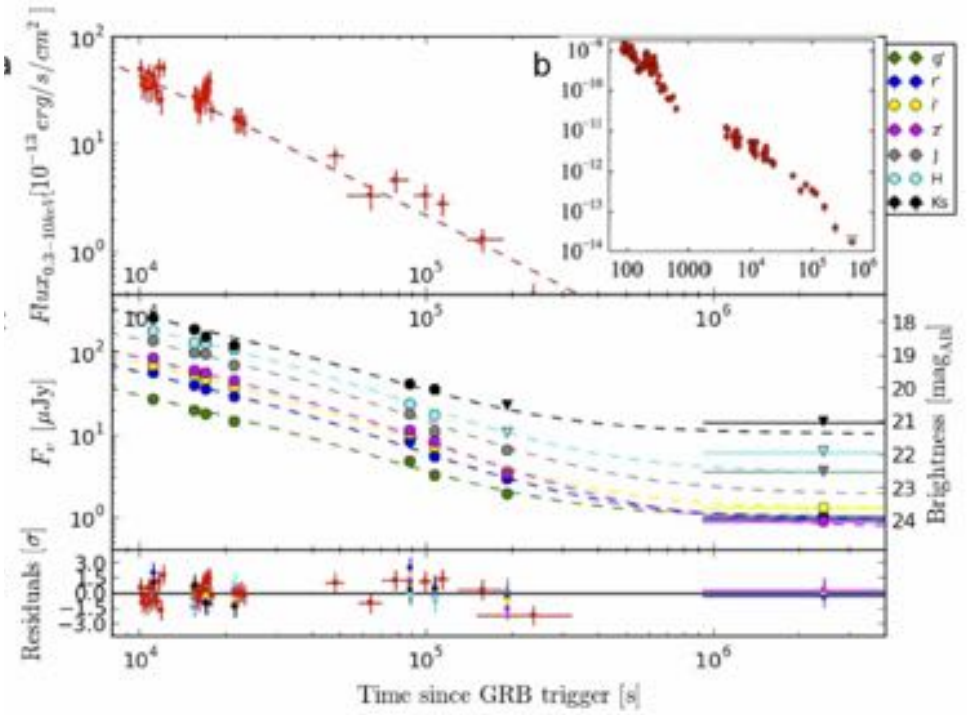
VLA observations at 8.46GHz



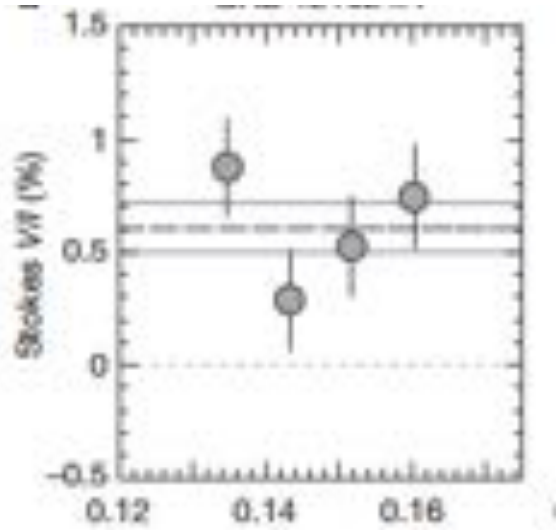
Troja et al. Nature 2017

Optical Circular Polarization

Wiersema et al Nature 2014



Circular polarization



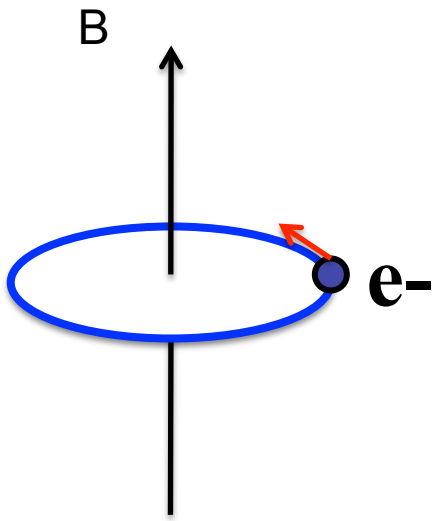
GRB 121024A

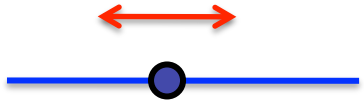
$$P_c \sim 0.6\%,\ P_L \sim 4\%,\ \ P_c / P_L \sim 0.15$$

theory

$$P_c,\ P_c / P_L \sim 1/\gamma_e \sim 10^{-4} \qquad \gamma_e \sim \frac{m_p}{m_e}\Gamma$$

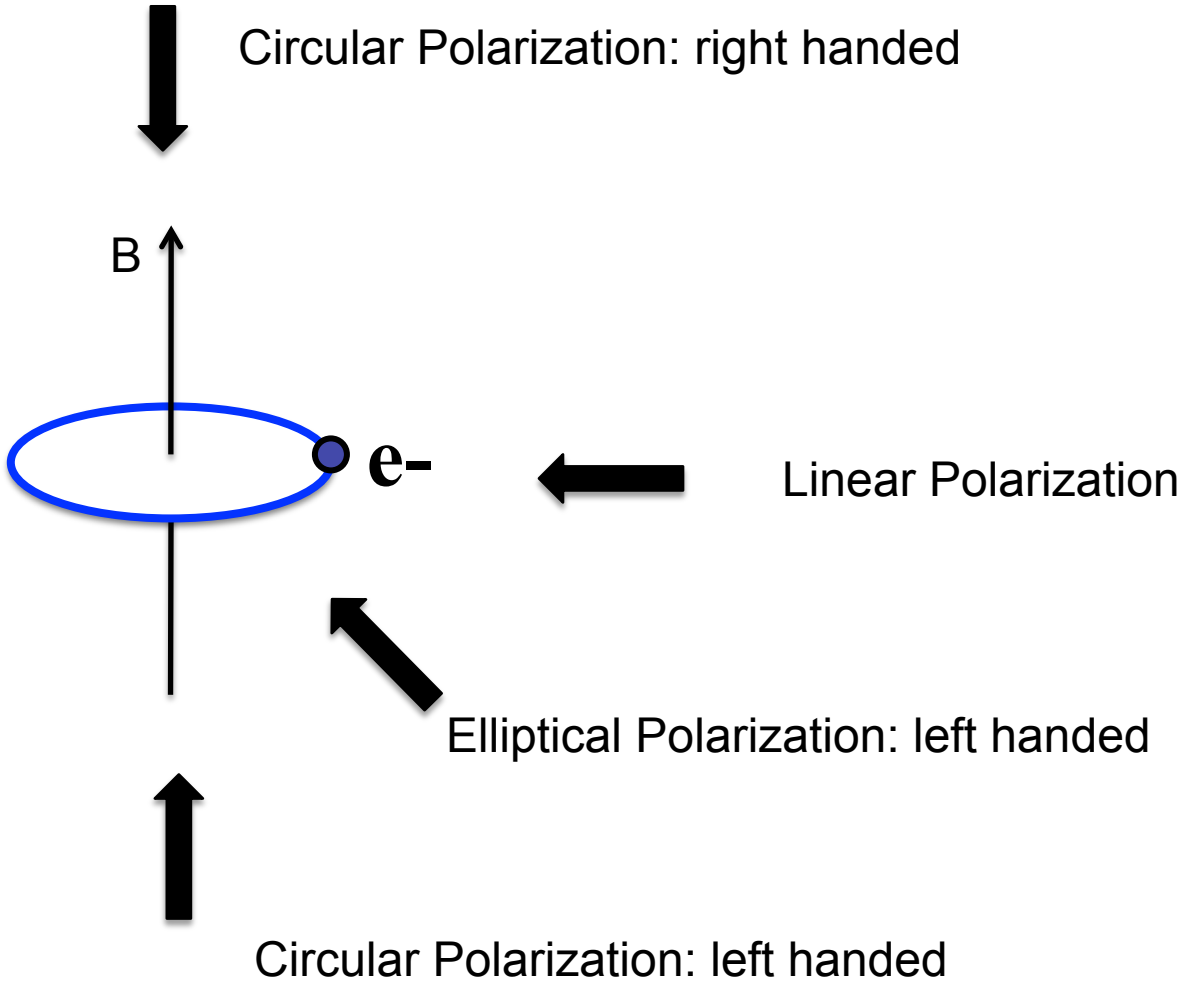
Emission of electrons gyrating in B-field





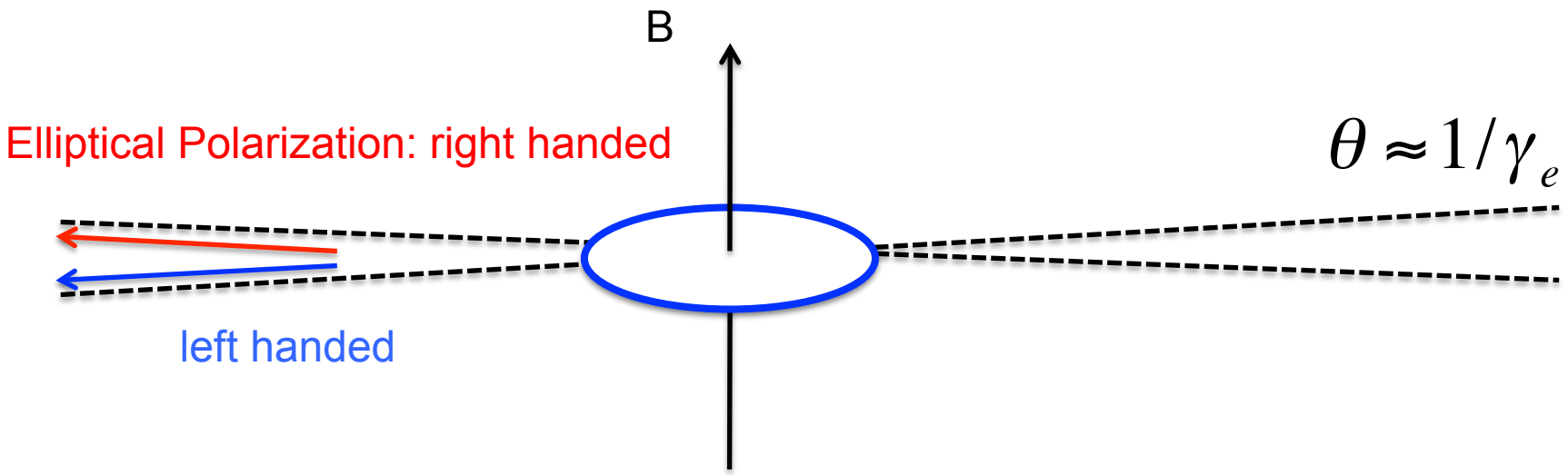
A point of view in the horizontal plane:

The electric field perturbation that creates the wave is in the horizontal direction, thus the emission is linearly polarized.

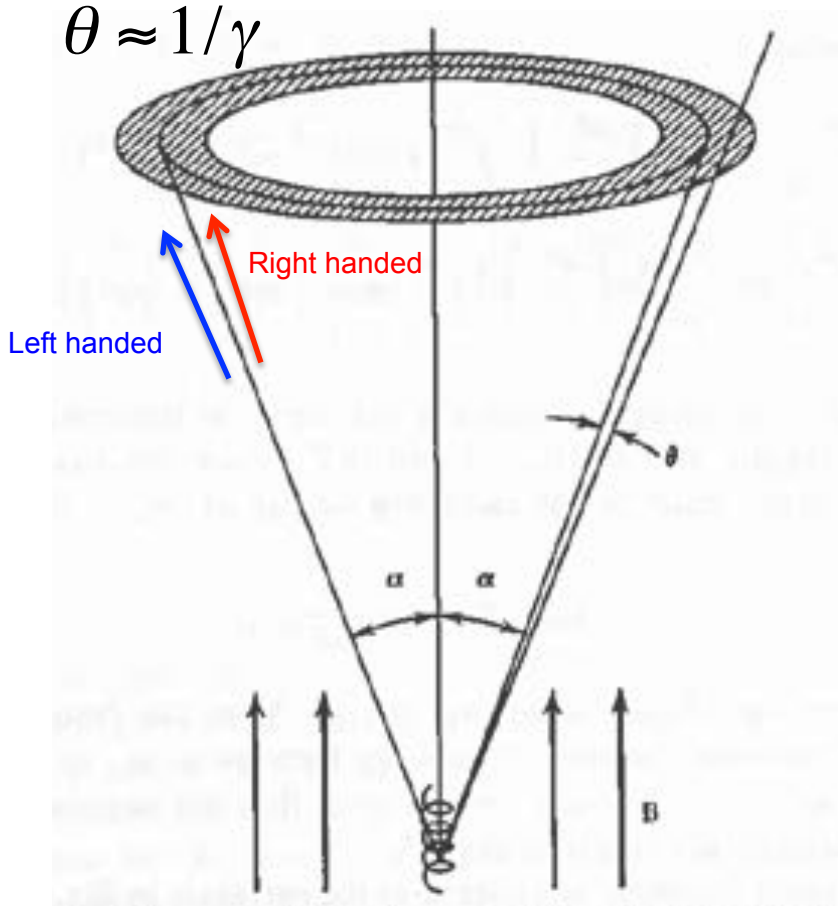

Circular Polarization: right handed
B
e-
Linear Polarization
Elliptical Polarization: left handed
Circular Polarization: left handed

Emission from a Relativistic Electron

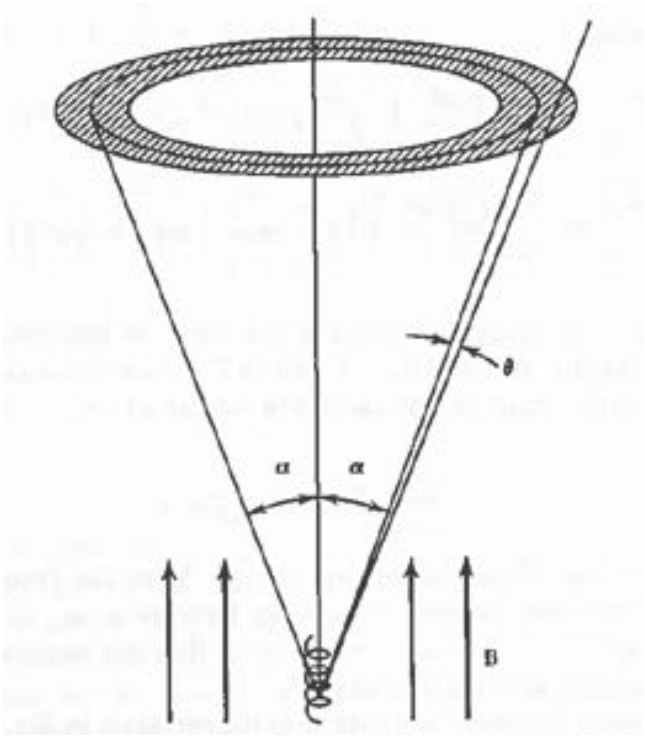
Relativistic beaming effect
Radiation is confined only around the horizontal plane



Emission from an electron with pitch angle



Emission from many electrons



For smooth pitch angle distribution,

the elliptical component is cancel out, as emission cones contribute equally from both sides of the line of sight.

Then, synchrotron radiation is linearly polarized.

Summary

- Jet Breaks and Polarized emission
  - Jet breaks at t > 1day
  - Forward shock emission, tangled B-fields locally generated.
  - Polarimetry can give constraints on the jet structures, but more observations needed.
- Early Afterglow Polarimetry
  - RS emission sensitive to the properties of central engine ejecta
  - Higher magnetization in RS region: 100-1000
  - Polarized RS emission (28%) indicates ordered B-field in ejecta
  - Radio Polarimetry (radio flares)
- Optical Circular Polarization
  - Highly anisotropic pitch angle distribution?
  - For extended sources, signals canceled out (Nava et al. 2016)