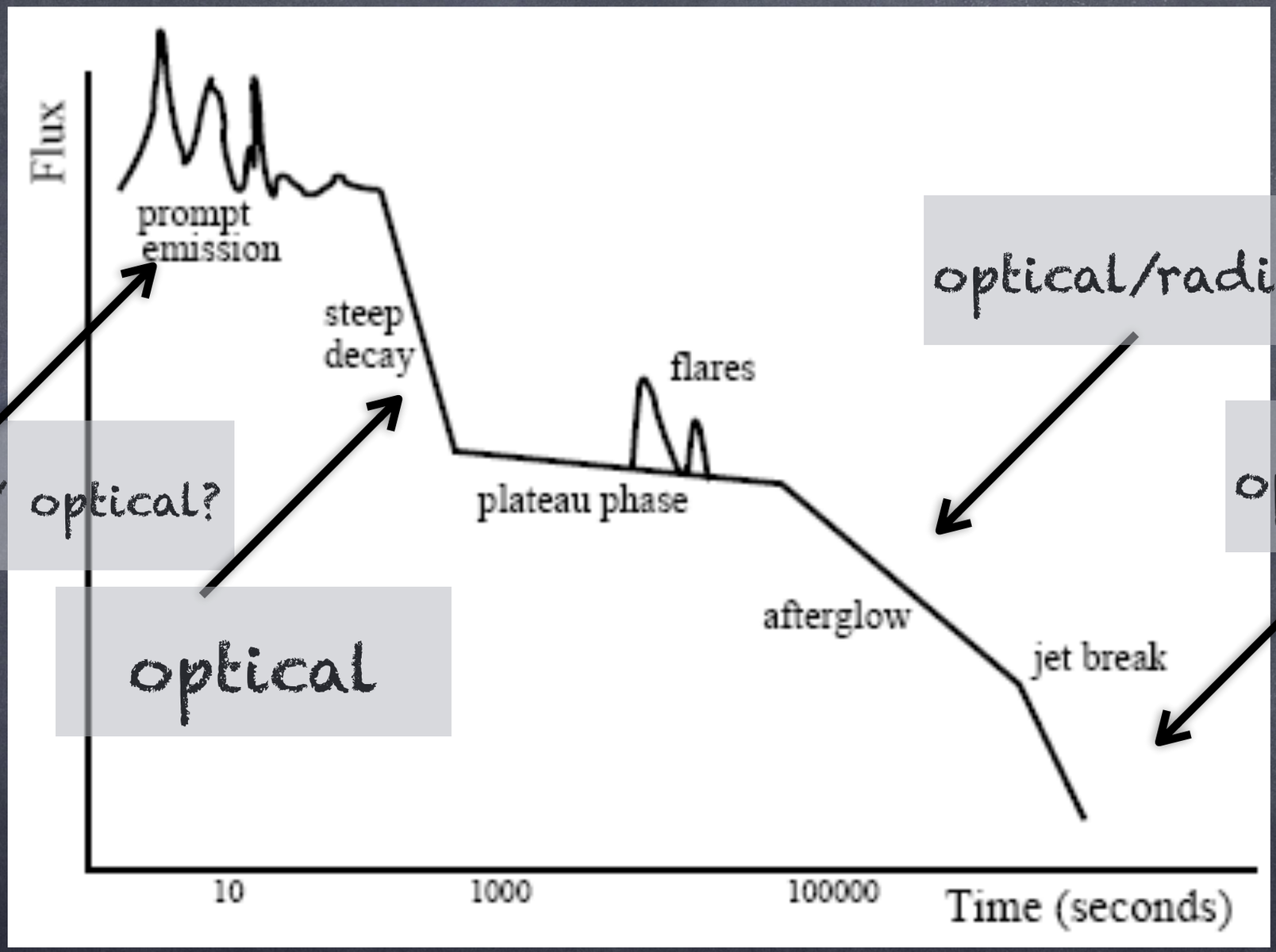
Polarimetry of GRBs: peering at the shock front

Stefano Covino
INAF / Osservatorio Astronomico di Brera
Diego Götz
CEA / Saclay - Irfu
Klaas Wiersema
University of Leicester

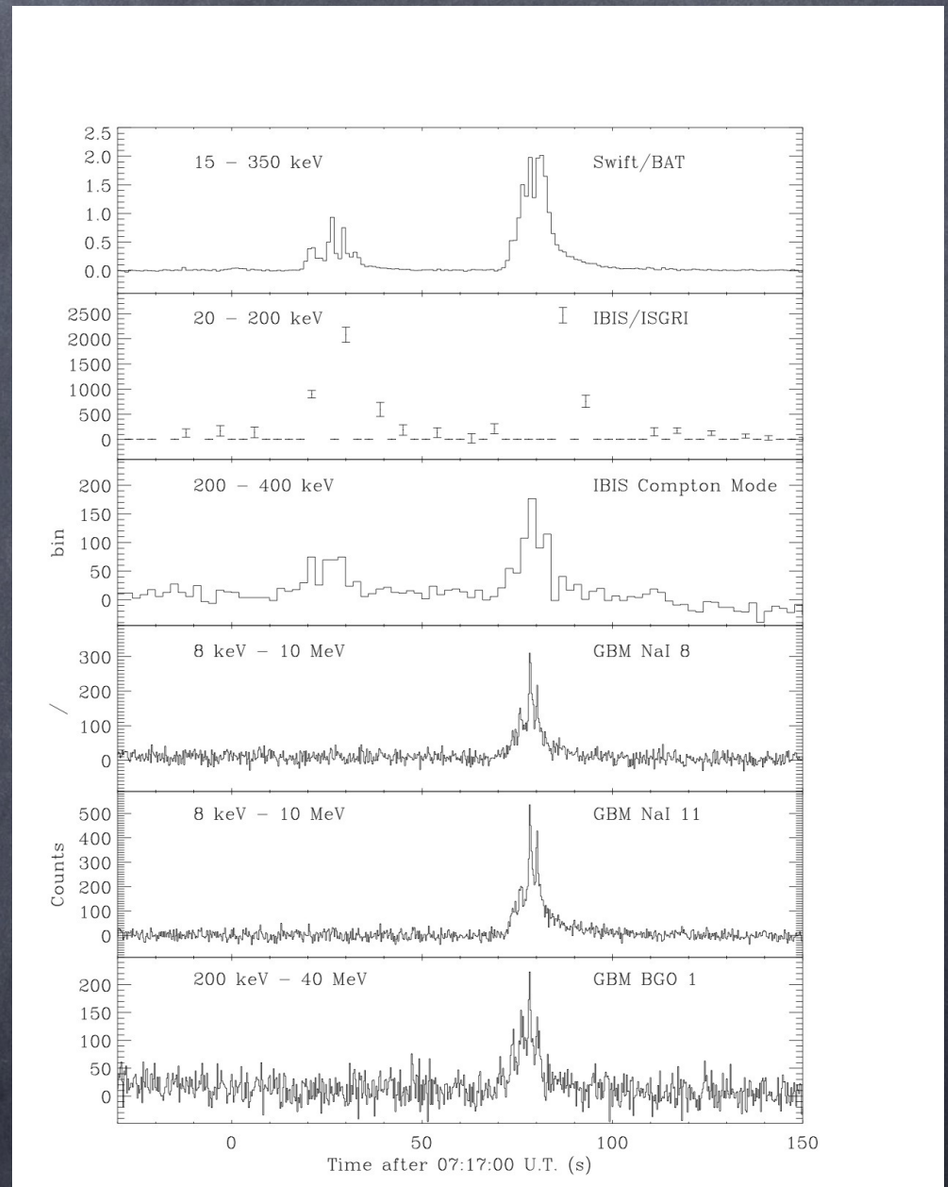
GRB polarimetry



GRB "typical" time evolution

Prompt emission

- Several cases reported with INTEGRAL and IKAROS: i.e. GRB140206A, GRB110301A, GRB100826A, GRB061122, GRB110721A, GRB041219A (Götz et al., McGlynn et al., Yonetoku et al., etc.)
- Results still partly controversial due to calibration issues and no single measurement is at 3σ
- However, considered together, they look rather convincing.
- Typically P ~ 30-50%, with rapidly varying position angles if multiple observations were possible.



GRB140206A (Götz et al. 2014)

What does it mean?

- The "polarized" GRBs are rather common events in terms of spectral properties. "Only", they are among those with the highest fluence.

- Prompt polarization is a common feature?

- Several scenarios are compatible with the observations. Polarization can be due to, e.g., synchrotron radiation in ordered magnetic fields, jet structure, observer's viewing angle, etc. (Götz et al. 2014)

- It appears to be difficult to distinguish among the various possibilities with (the presently available) prompt data (Toma et al. 2009).

LIV limits

$$\omega^2 = k^2 \pm \frac{2\xi k^3}{M_{Pl}} \equiv \omega_{\pm}^2$$

$$\omega_{\pm} = |k|\sqrt{1 \pm \frac{2\xi k}{M_{Pl}}} \approx |k|(1 \pm \frac{\xi k}{M_{Pl}})$$

$E = \hbar\omega$, $p = \hbar k$, M_{Pl} is the Planck Mass.

$$\Delta\theta(p) = \frac{\omega_+(k) - \omega_-(k)}{2}\, d \approx \xi \frac{k^2 d}{2M_{Pl}}$$

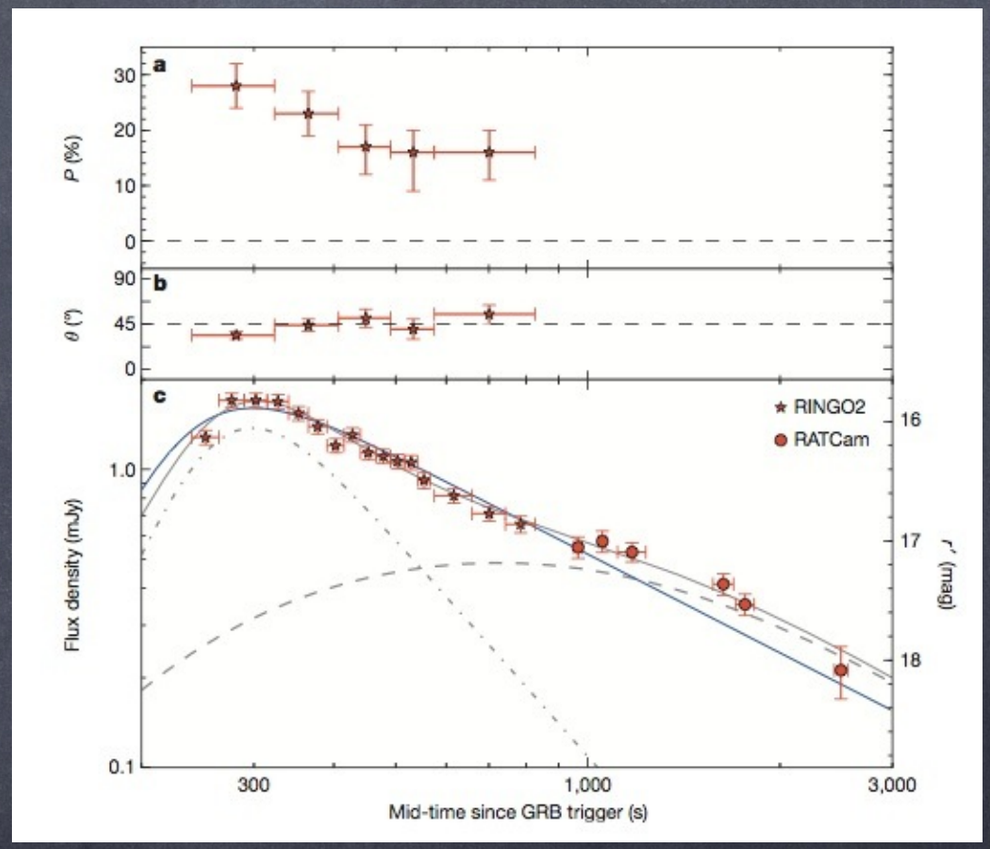
$$\xi < \frac{2M_{Pl}\Delta\theta(k)}{(k_2^2 - k_1^2)\, d} \approx 1 \times 10^{-16}$$

Laurent et al. (2011), Götz et al. (2014)

- In some quantum gravity theories Lorentz Invariance Violation is predicted at Planck energy scale.
- The light dispersion relation generates a rotation of the polarization plane of photons with a given helicity.
- Simplifying, polarization of cosmological sources should vanish! If not, limits on QG scale can be derived.

Early afterglow

- Data for a few events: GRB120308A, GRB110502A, GRB090102, GRB091208B, GRB060418 (Mundell et al., Cucchiara et al., Uehara et al., Steele et al.).
- However now measurements highly significant.
- In general polarization is associated to the reverse shock.
- Typically P ~ 15%, stable position angle.
- In the best case ever observed, GRB120803A (Mundell et al. 2013), the polarization degree decreases monotonically in time.



GRB120308A (Mundell et al. 2013)

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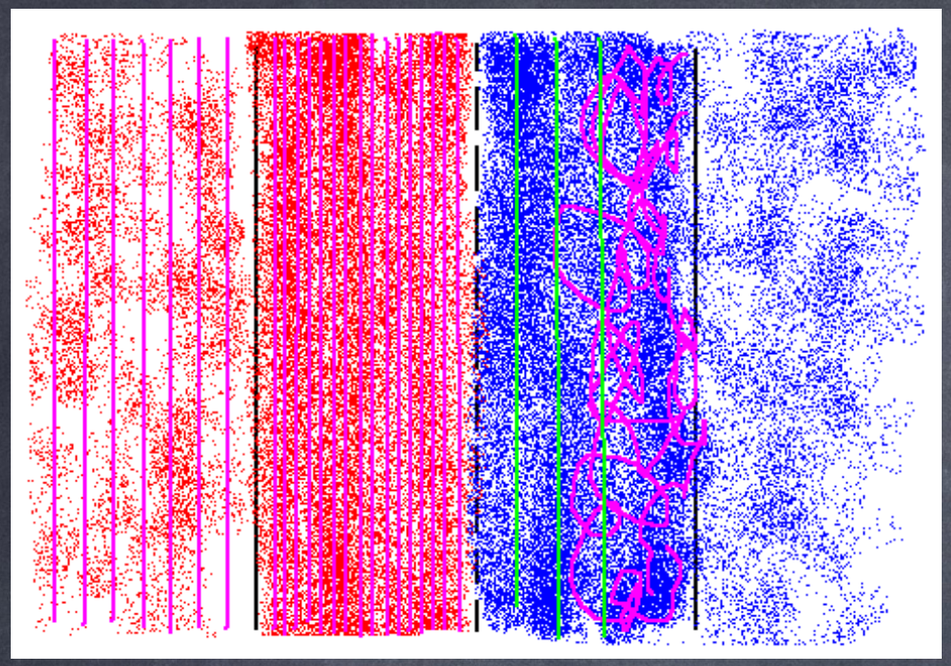
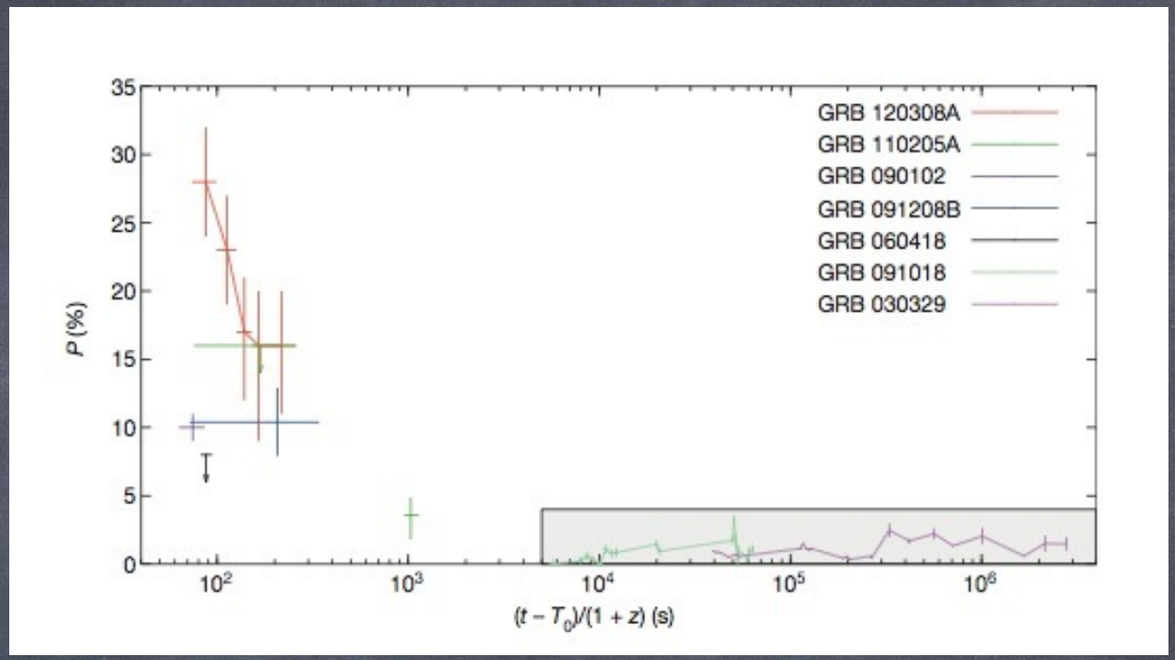


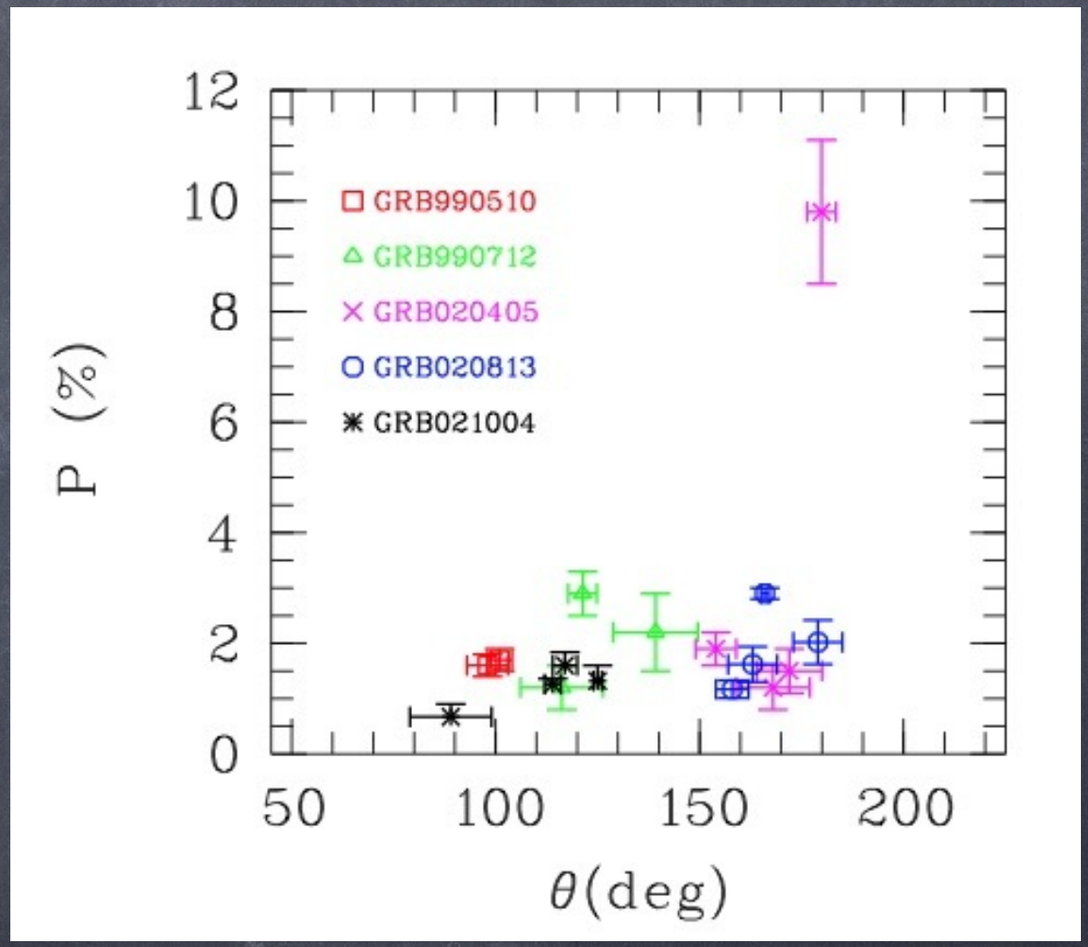


GRB120308A (Mundell et al. 2013)

- Again, it seems a rather common feature of the bright early afterglows. A bias against faint events is of course present (reverse shock → bright).
- Magnetic energy density in the reverse-shock turns out to be higher (> 30, or much more) than in the forward-shock.
- The high polarization degree requires an ordered magnetic field.

Late afterglow

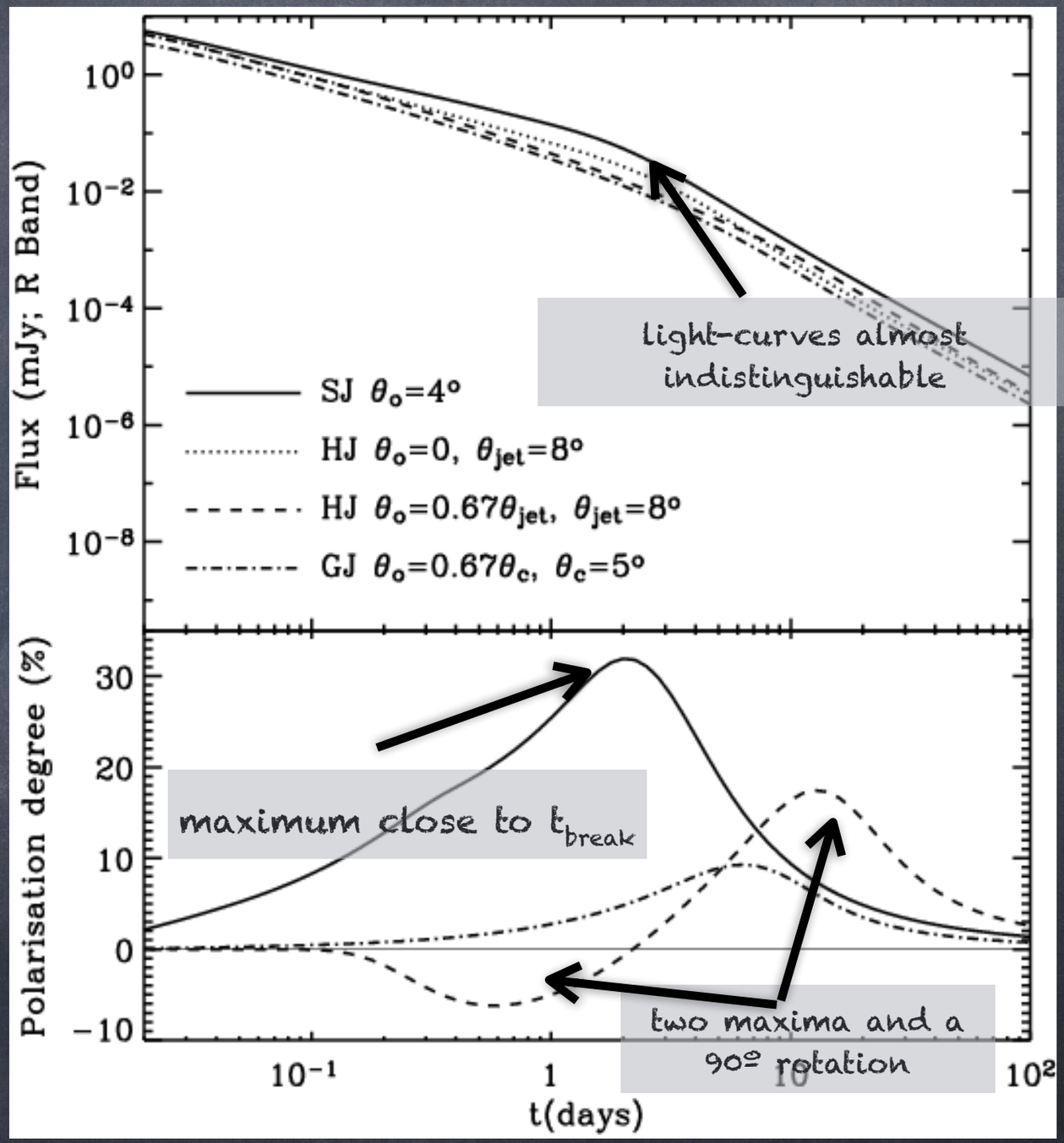
- A lot of data for about two dozen of events (Covino et al. 2004, Wiersema et al. 2012, 14).
- Typically P ~ 2-3%, variable in time, and with position angles both variable and constant depending on the specific event (Covino et al. 2004).
- Historically, the "smoking gun" for synchrotron emission from GRB afterglows (Covino et al. 1999; Wijers et al. 1999).
- Highly diagnostic but with also totally puzzling events: e.g. GRB030329 (Greiner et al. 2003).



Covino et al. 2004

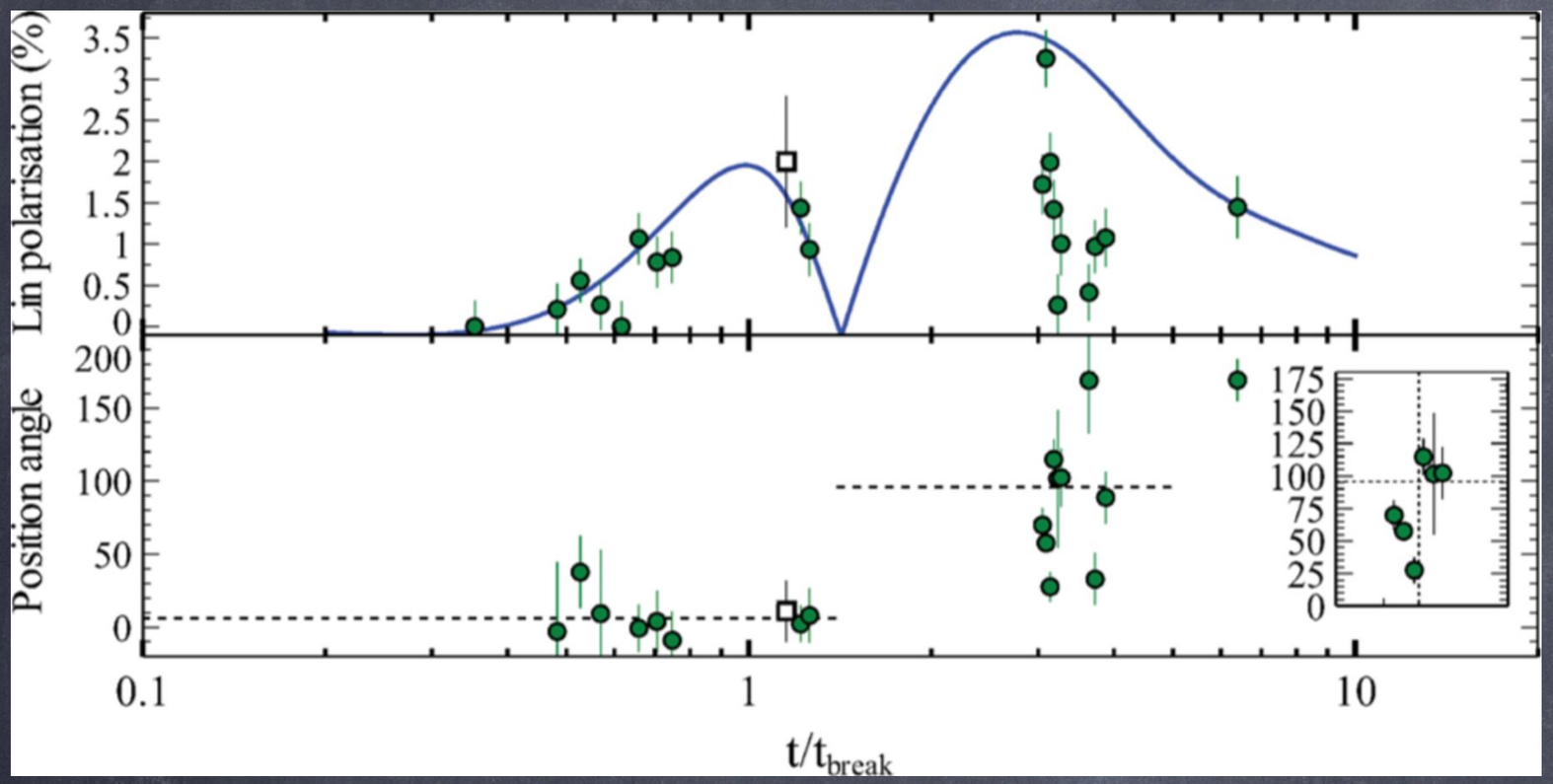
Outflow geometry

- During the late afterglow simple forward shock predictions are supposed to hold.
- Depending on the jet structure, markedly different polarization degree and position angle evolution are possible.
- Something testable, although with considerable observational efforts.

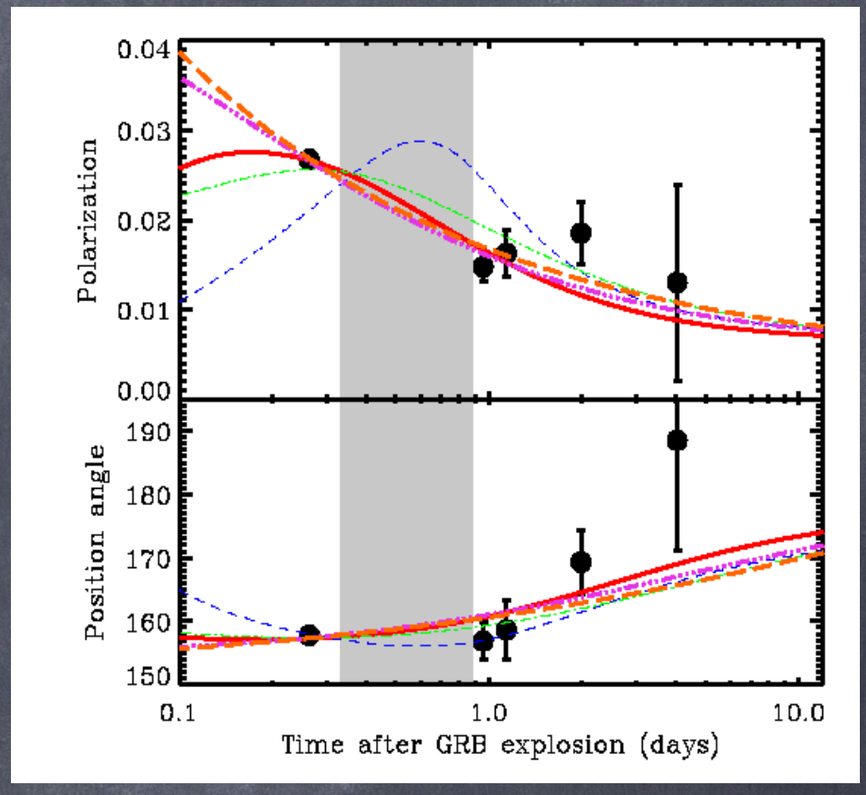


Rossi et al. 2004

rotation vs no rotation



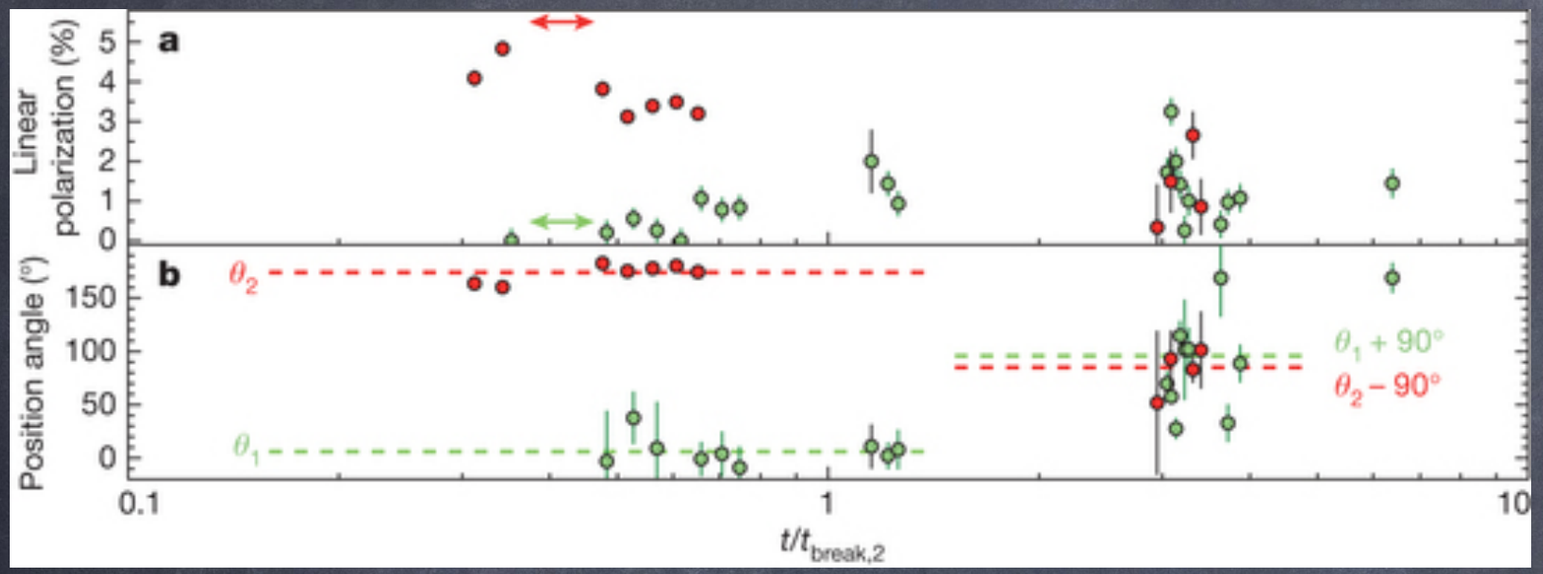
GRB091018 (Wiersema et al. 2012)

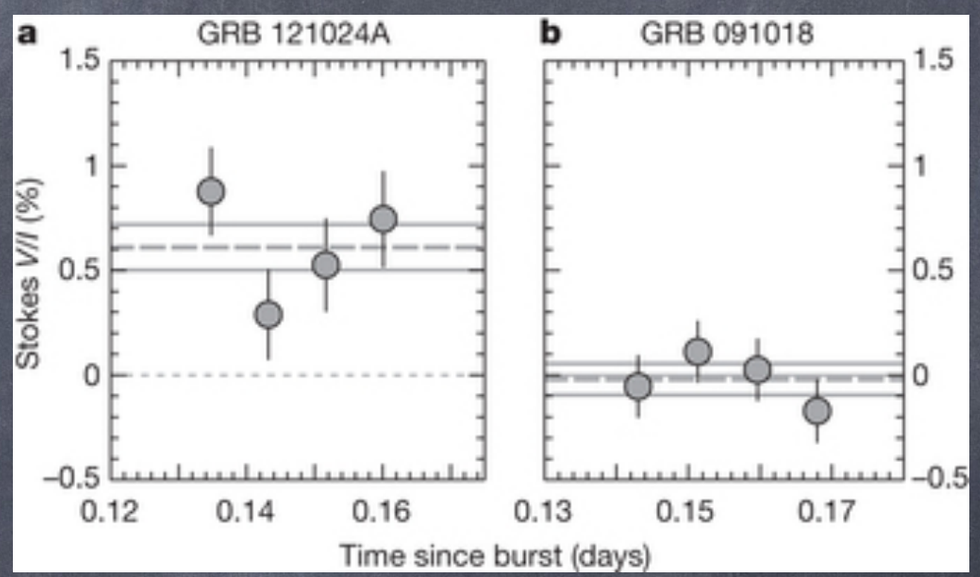


GRB020813 (Lazzati et al. 2004)

- At moderate polarization level dust induced polarization in the host galaxy can play a role.
- In addition, episodes of energy injection, circumburst matter density discontinuity, etc. can affect the observed polarization (e.g. GRB030329, Greiner et al. 2003).

Circular polarization

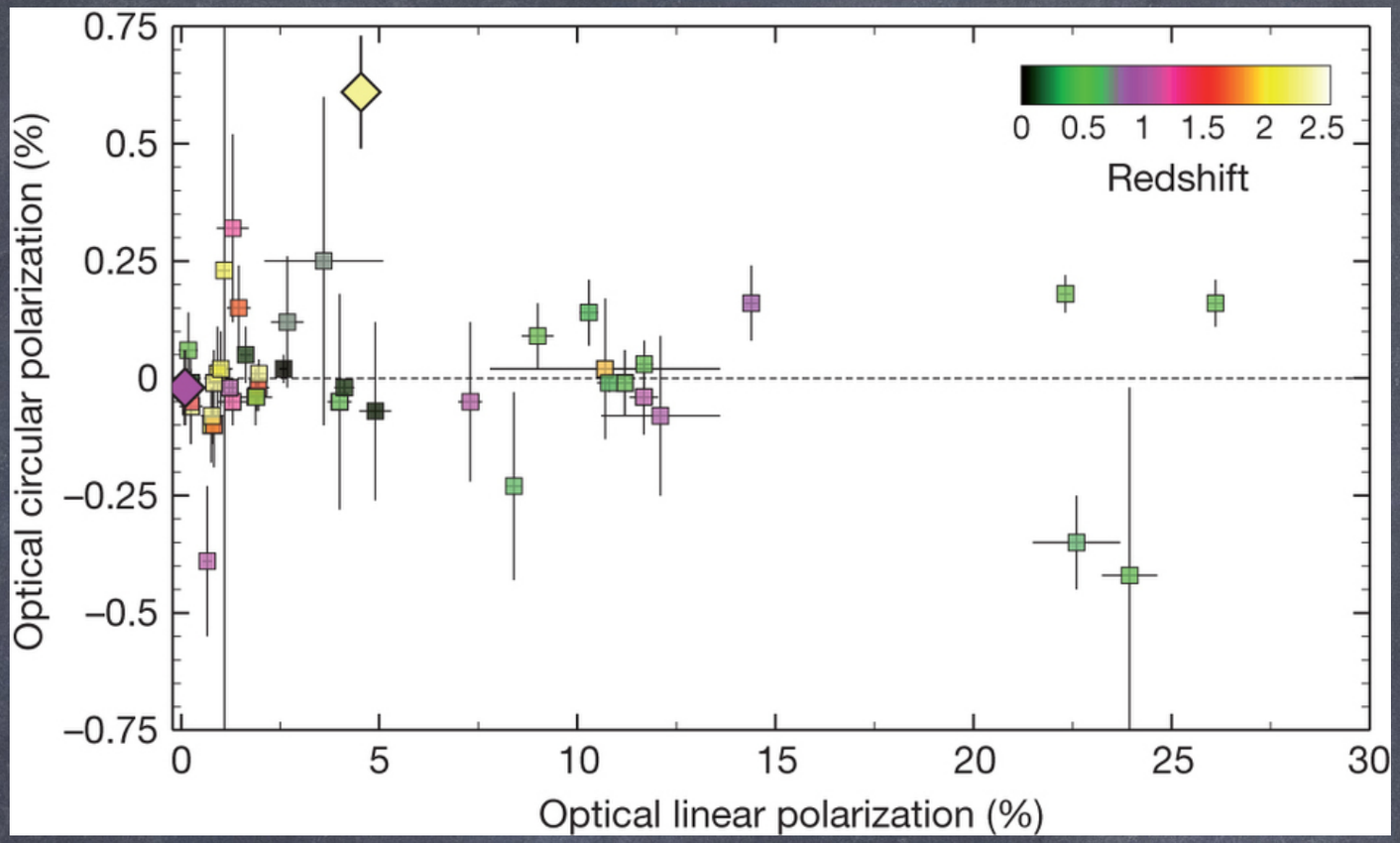




GRB091018 and GRB121024A (Wiersema et al. 2014)

- Quite unexpectedly, in GRB121024A circular polarization, V~0.6%, was detected (together with a 90º rotation of the P_{lin} position angle.).
- P_{lin}/P_{circ}~0.15, several orders of magnitude above expectations.
- Dust induced circular polarization is unlikely since host extinction is small and linear polarization is variable (i.e. mainly intrinsic).

Quasar circular polarization



Wiersema et al. 2014

- In standard forward shock theory $P_{circ} \sim \gamma_e^{-1}$, for isotropic electron distributions.
- (Highly) anisotropic distributions are a possibility (Spitkovsky 2008a, b).
- This require that the emitting plasma is mainly composed by electrons and protons.

Thanks for the attention!