Probing the physics of GRB afterglows with linear and circular polarimetry (GRB 091018)

(MNRAS accepted, arXiv:1203.4265)

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With (very) many others

afterglow physics…

In the Swift era we see odd things happening in lightcurves.

- Geometric / jet origins (viewing angle, jet structure)
- Varying microphysics (p, ε_B, ε_e), non-synchrotron emission
- Energy injection(s)
- Variations in circumburst medium properties
- Other (magnetar emission, reverse shocks, flares, etc etc)

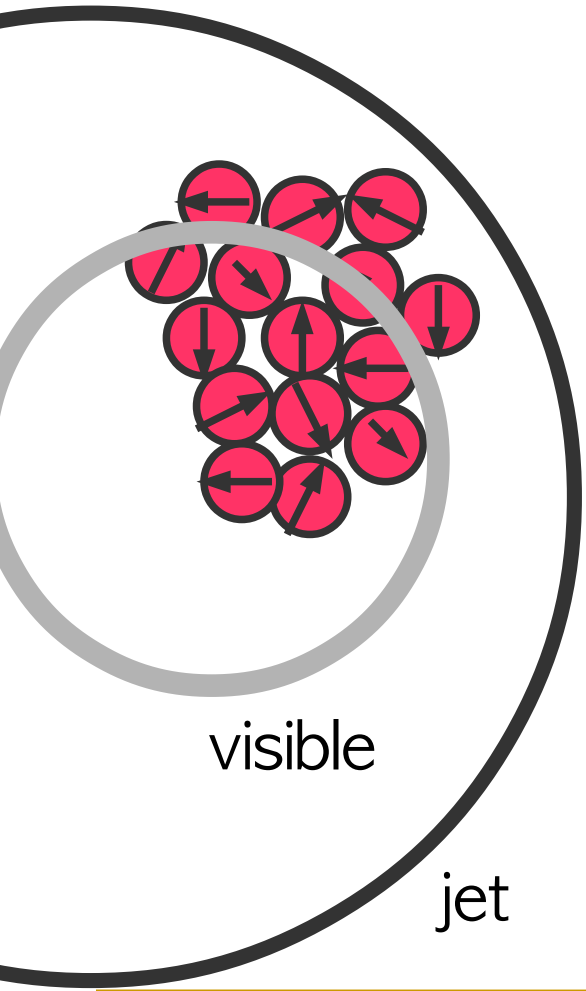
→ need very good SEDs to distinguish, generally not available.

Ingredients fireball model:

- Particle acceleration (emission process)
- Ultrarelativistic motion (aberration)
- Physical beaming (jets: lack of spherical symmetry)

→ predictions for lightcurves, spectra and polarisation degree and position angle

Polarimetric signals we might expect



Large polarisation?

Synchr with strong coherent field

Synchr with small-scale random field at particular viewing angle

Compton scattering

Small patches of strong coherent fields?

See summed signal over the observed part of the jet. Should see erratic variations of polarisation PA.

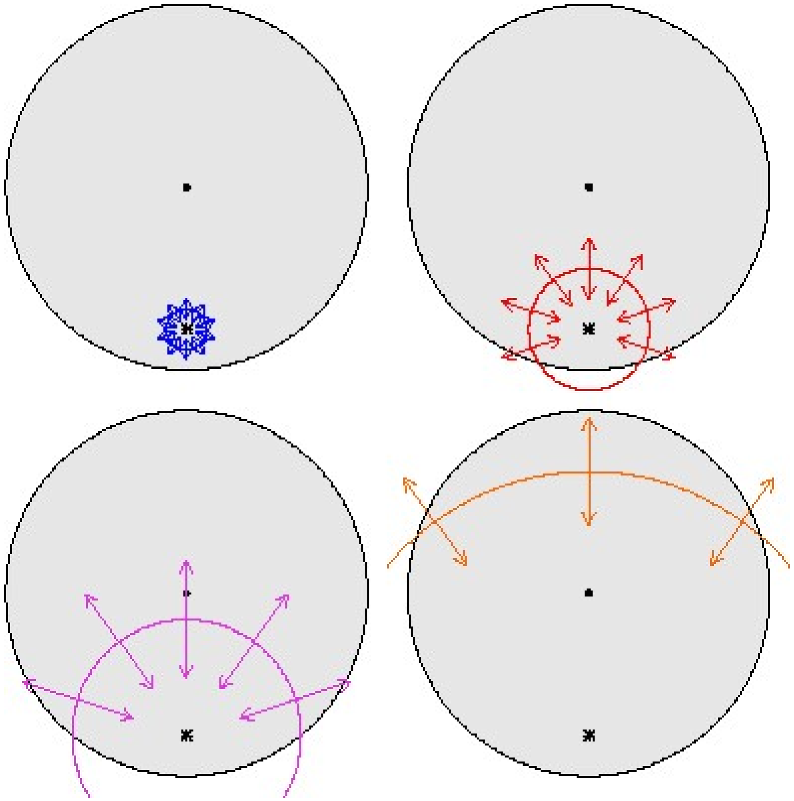
Jet break?

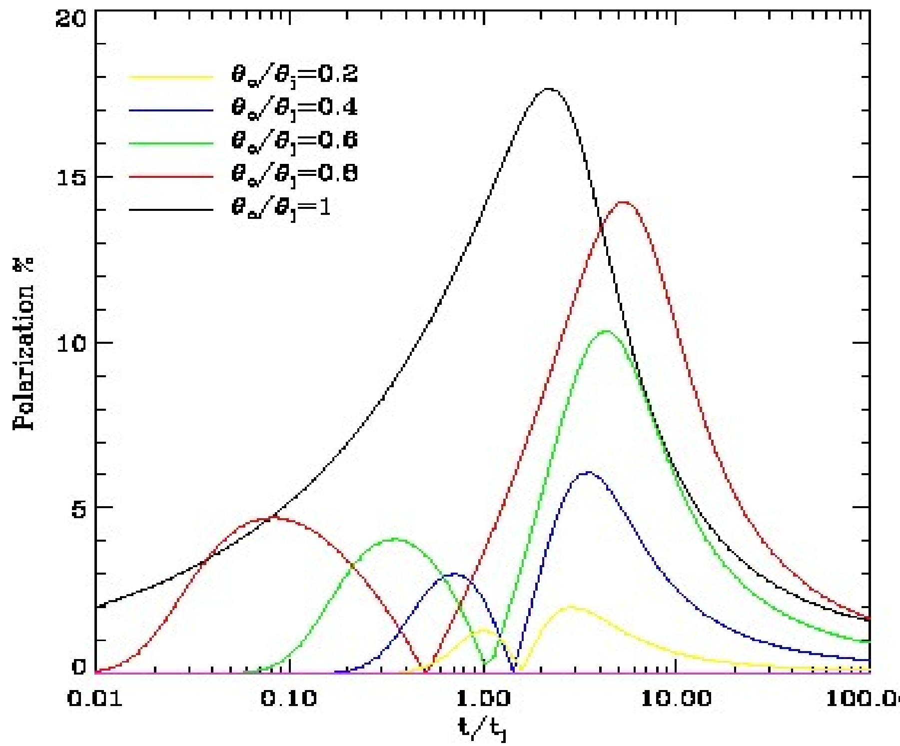
When you start seeing the edge of the jet, polarisation appears

→ Geometry + jet/B-field structure

Gruzinov & Waxman 99

Jet breaks





Very small coherence:
shape: viewing angle
Jet structure
medium
PA: 90° swing

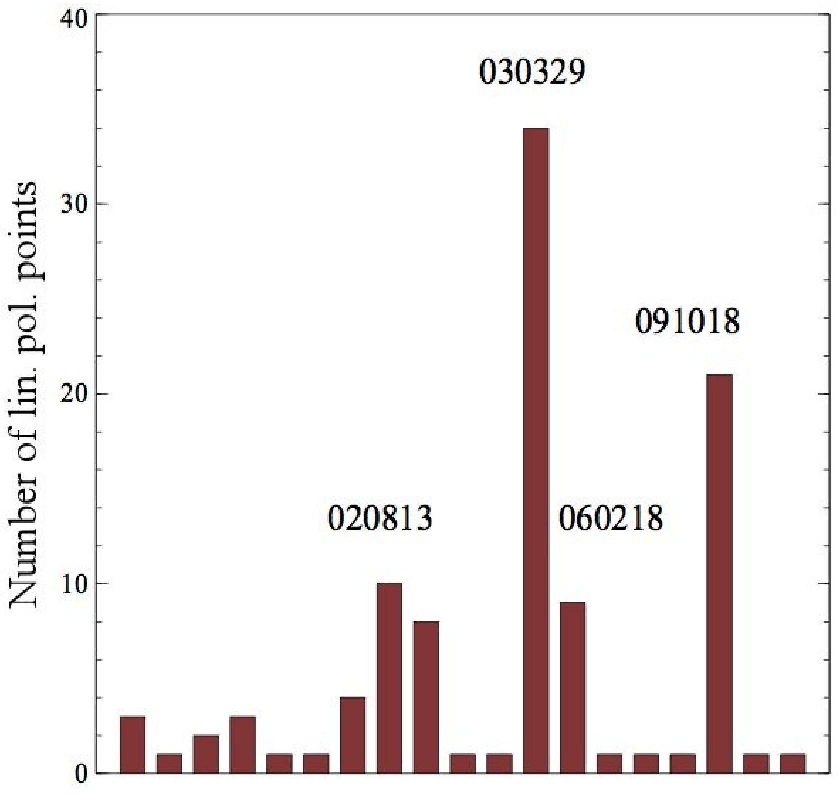
Lazzati 2006

The afterglow polarimetry sample

19 GRBs (Swift: 6)
Most datapoints: 030329

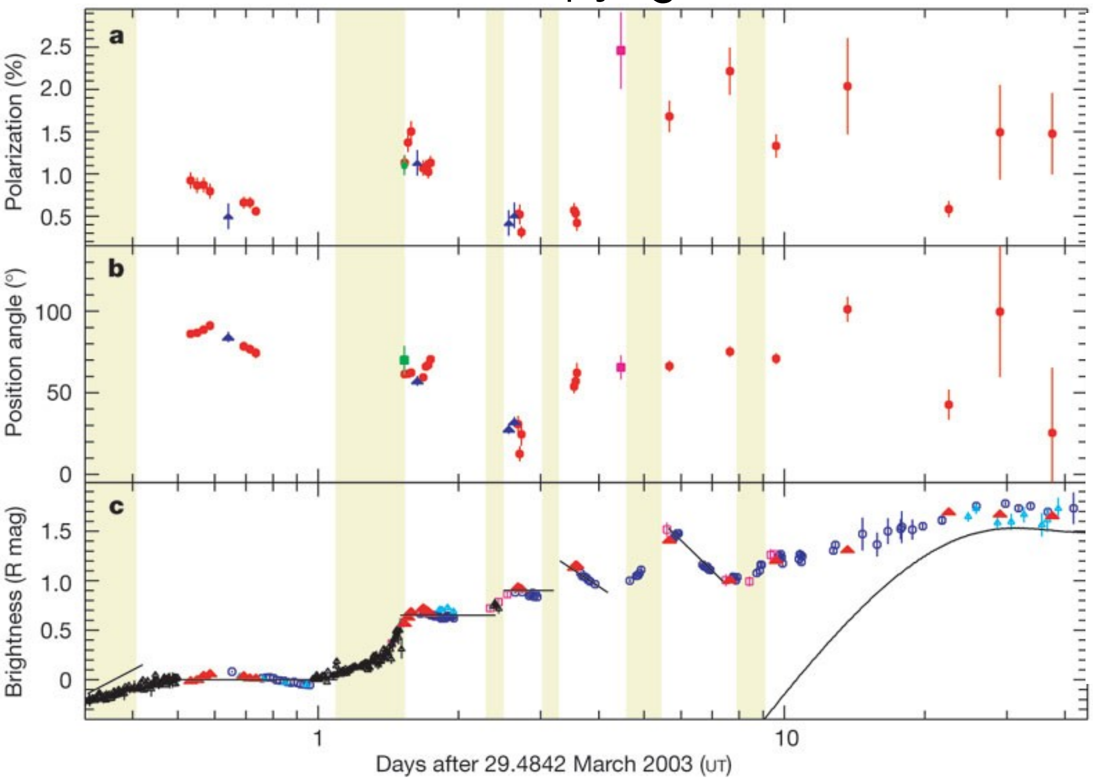
Less than a handful of cases with any chance of seeing a jetbreak

Less than half have polarimetry using more than 1 photometric band

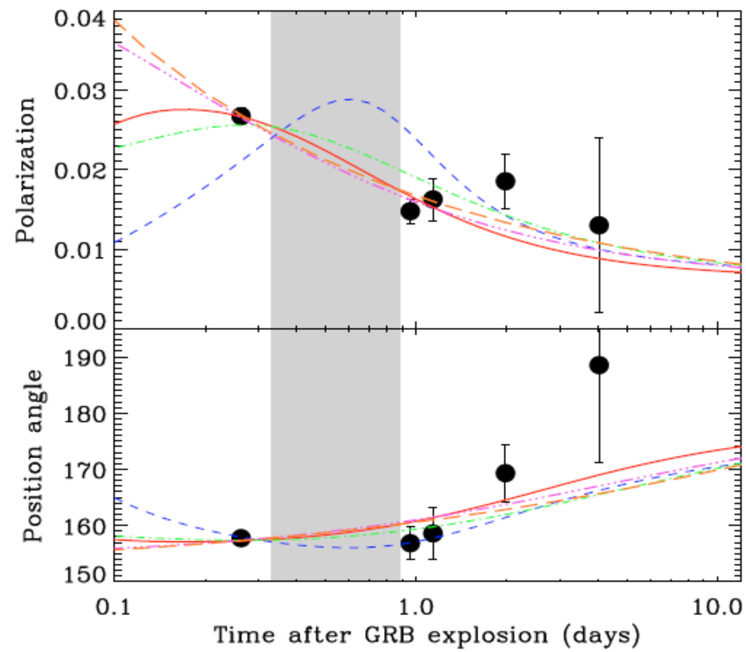


Best we have pre-Swift

GRB 030329: bumpy light curve



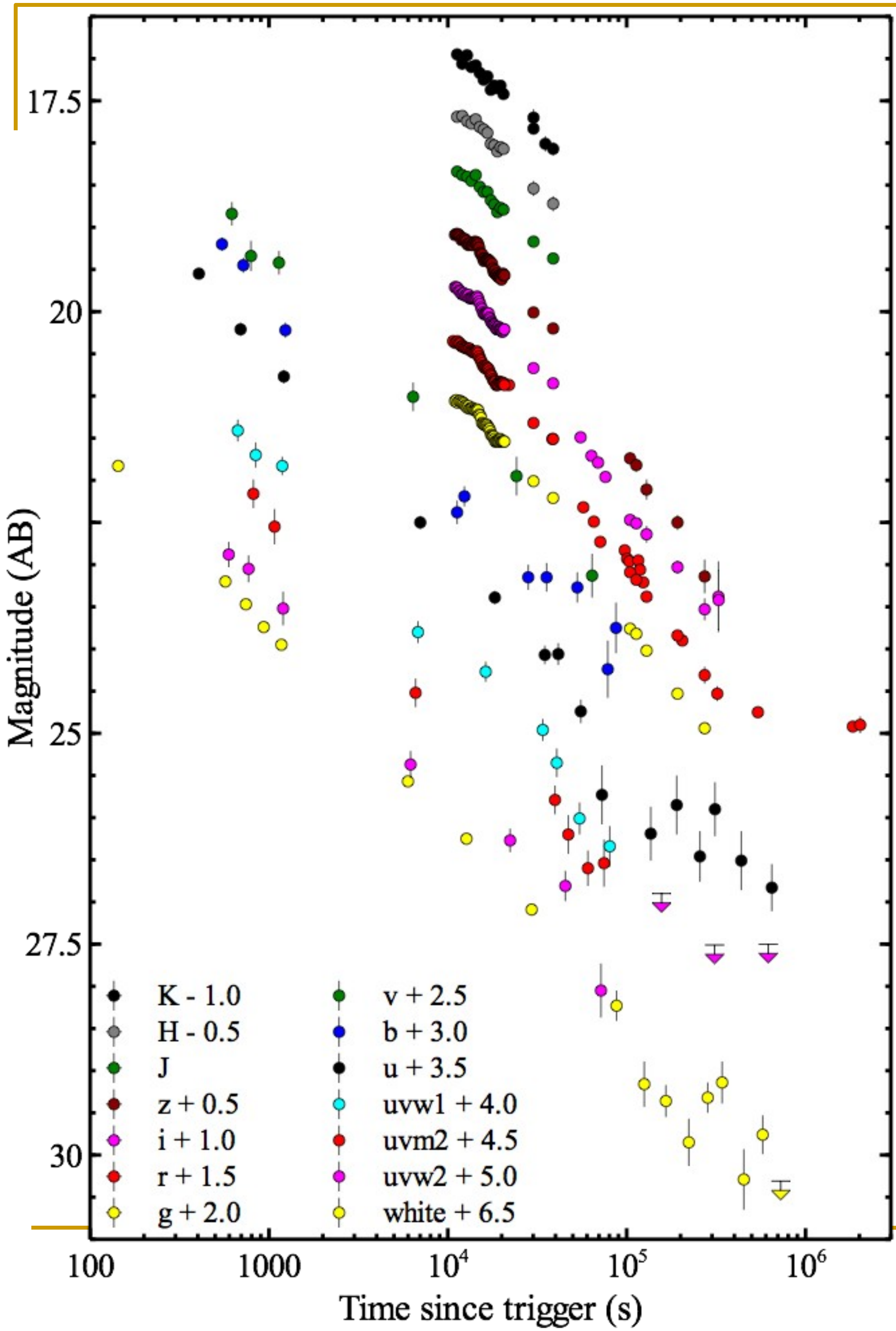
GRB 020813: smooth



No jet PA swing: is there a (weak) ordered field dominating P (with emissivity dominated by random tangled field made by postshock turbulence)?

Change of polarization angle by 90 degrees is not seen

(Greiner et al 04; Lazzati et al 04; Granot & Königl 03)



091018

Long GRB (T90=4.4s).

VLT polarimetry triggered based on UVOT brightness:

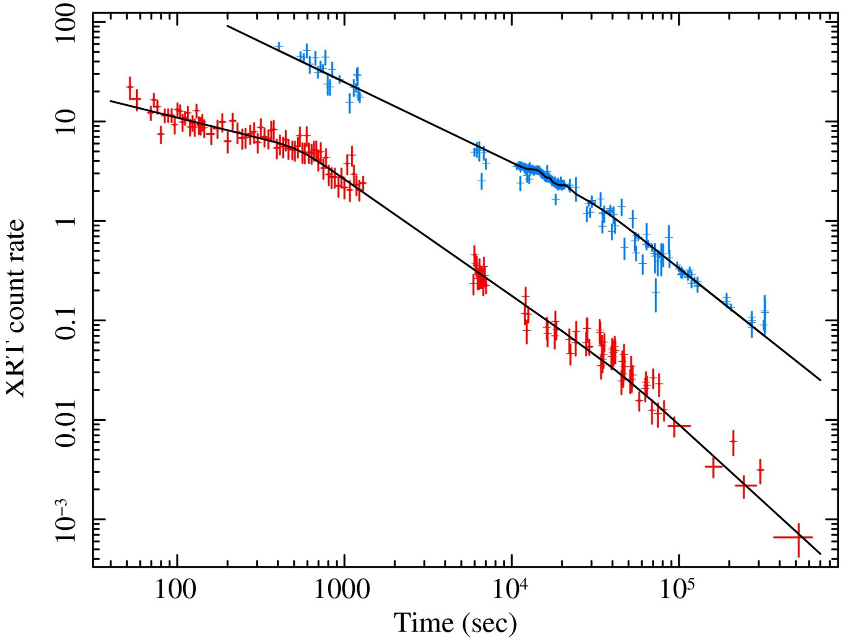
FORS2 R lin pol, FORS2 R circ pol
ISAAC K lin pol, X-Shooter spectra

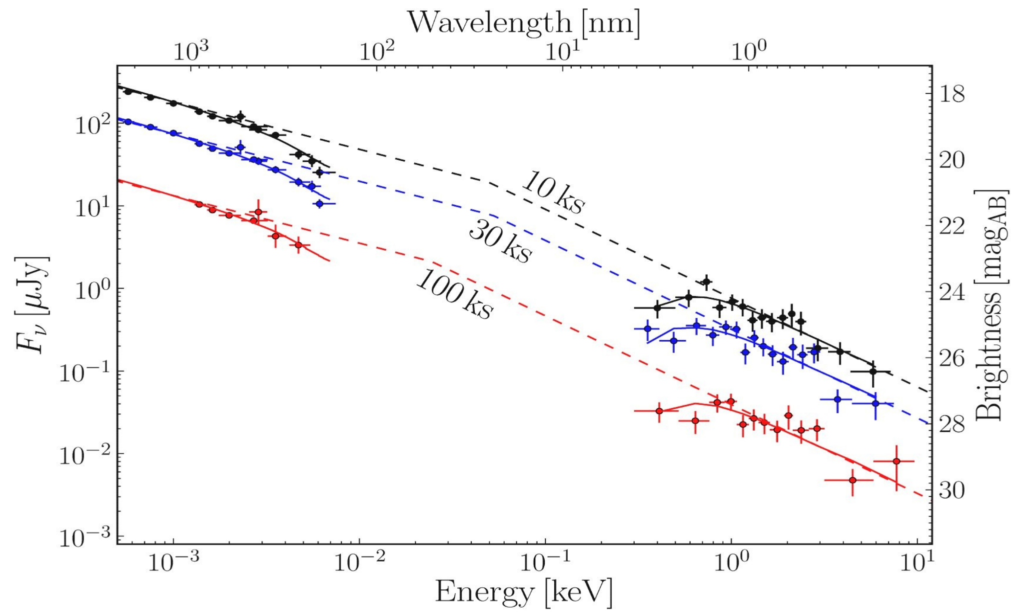
3 out of 4 UTs

Lightcurves from Swift (XRT+UVOT), GROND, Gemini-S, FT-S, VLT FORS2+ISAAC

Wiersema et al 2012

091018





* Break in lightcurve at $3.2\mathrm{x}10^4$ sec. No change in SED.

* Low amplitude bumps

Jet break?

Post-break slopes shallow (α_{opt} =1.33; α_X =1.54)

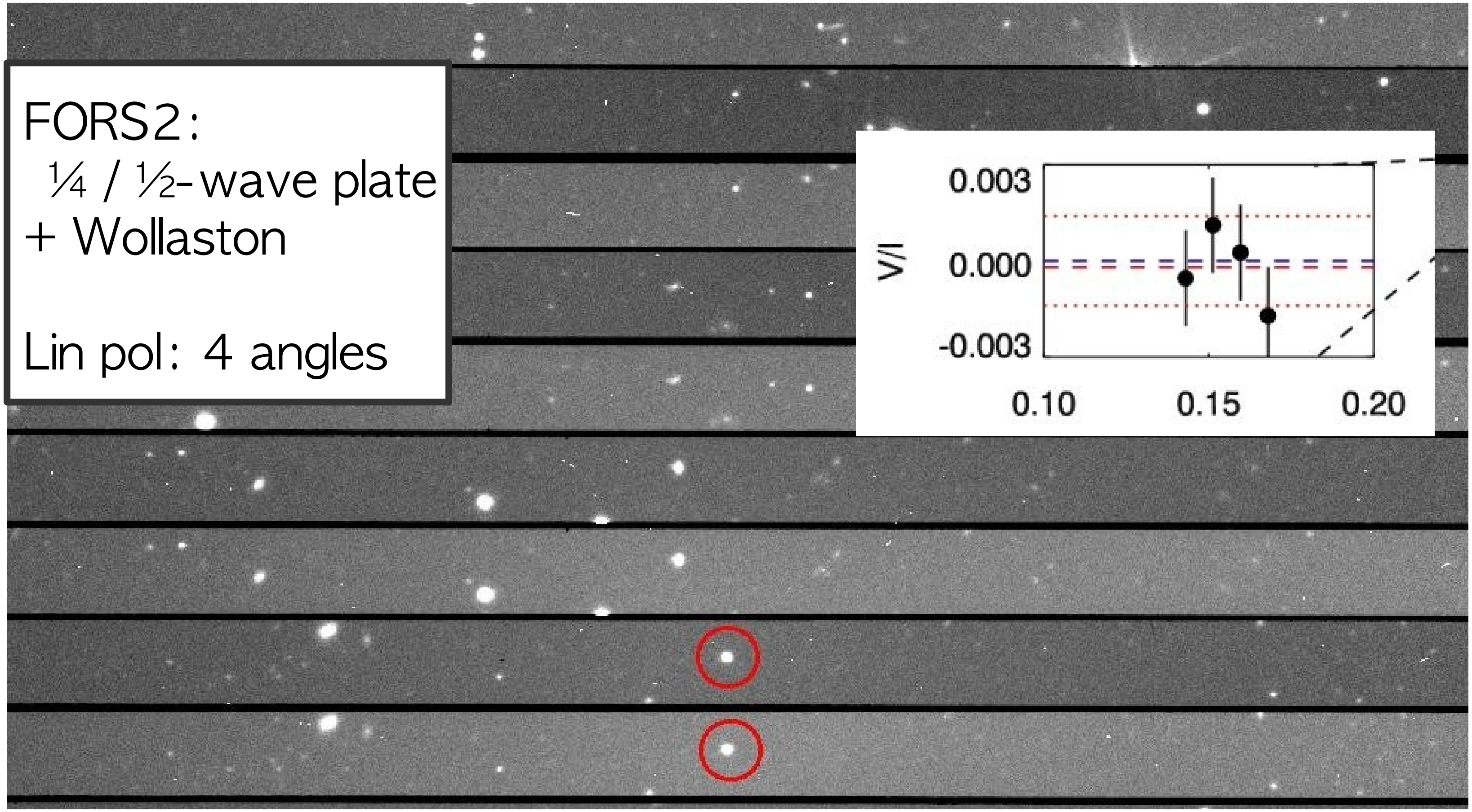
(but there are more jet break candidates like this)

Wiersema et al 2012

091018: circ polarimetry – ordered fields

FORS2:
¼ / ½-wave plate
+ Wollaston

Lin pol: 4 angles

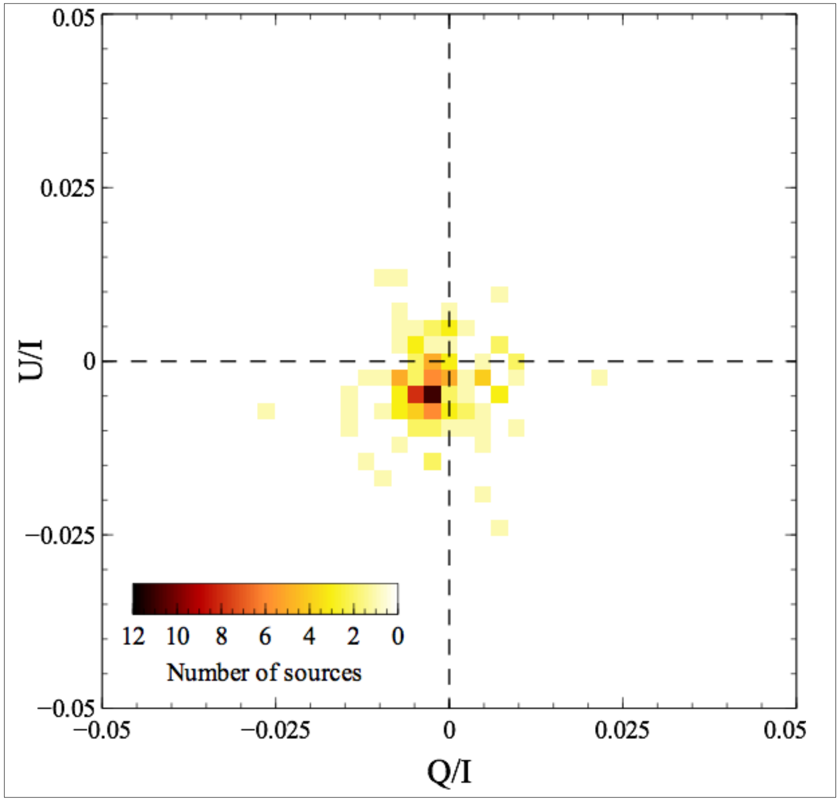


VLT FORS2, 0.15d after burst: V/I = -0.00020 +/- 0.00075
i.e. $P_{circ} < 0.23\%$ (3σ)

Wiersema et al 2012

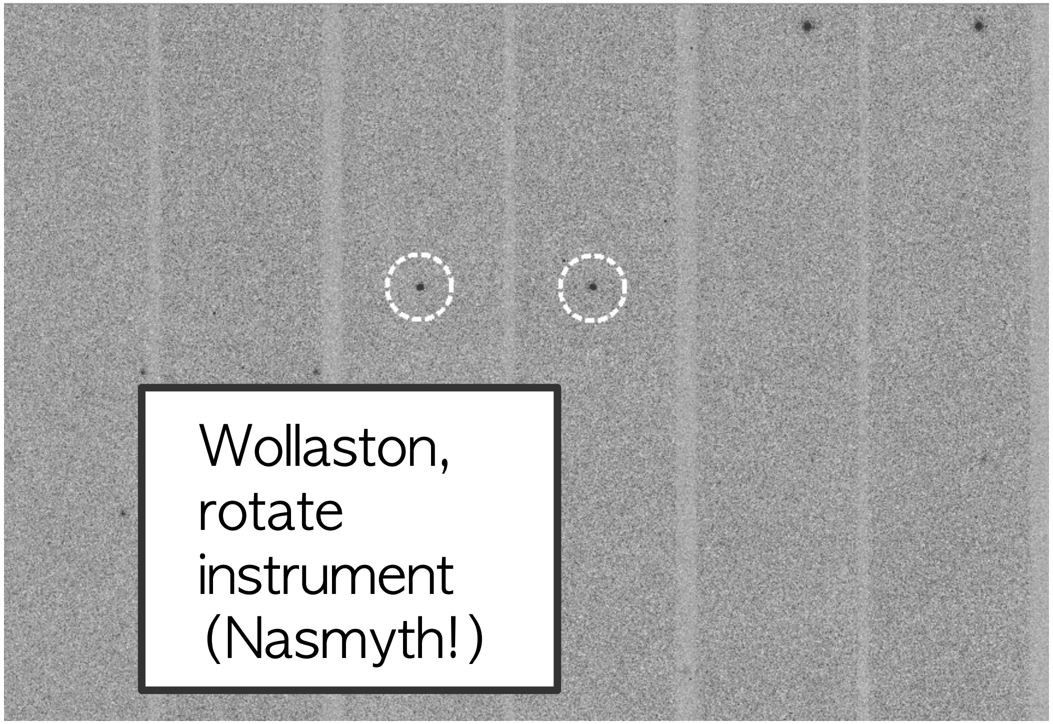
linear polarisation

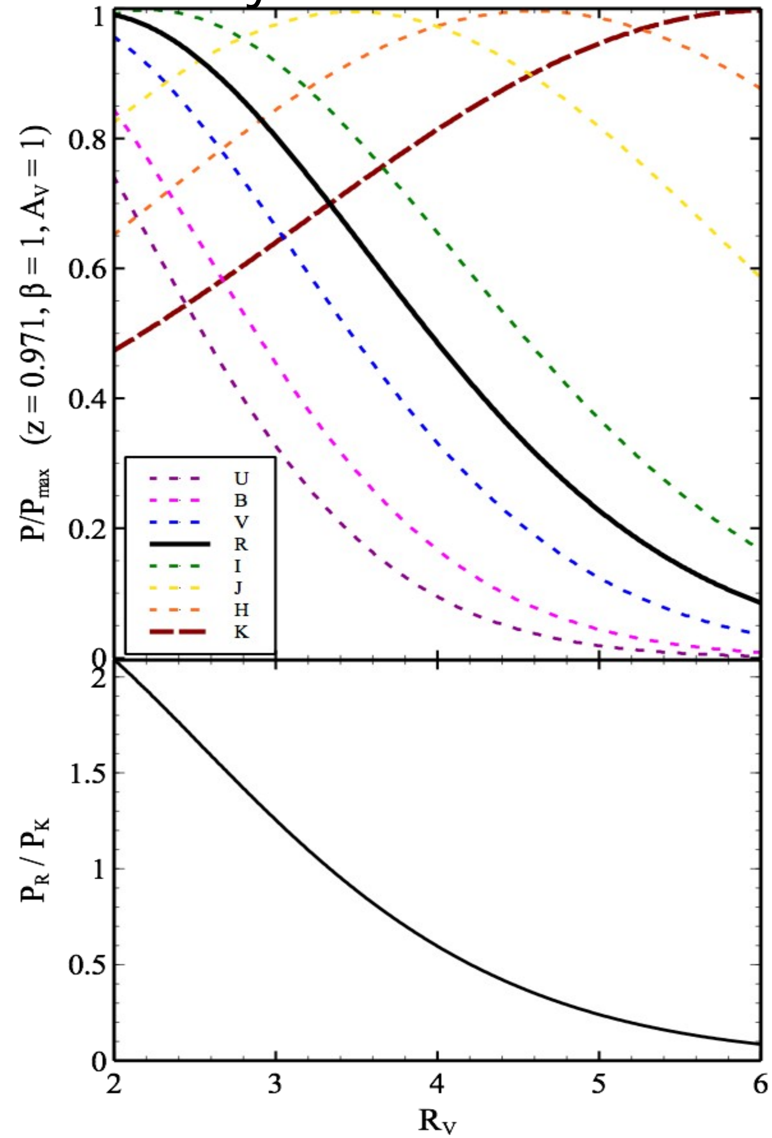
20 series with VLT FORS2 $R_{special}$ starting at t = 0.13d, ending at 2.4 days (3 nights), with densest sampling in night 1.
Aim: 〈0.3% errors throughout.



Dust scattering induces (wavelength dependent) linear polarisation

VLT ISAAC K band polarimetry



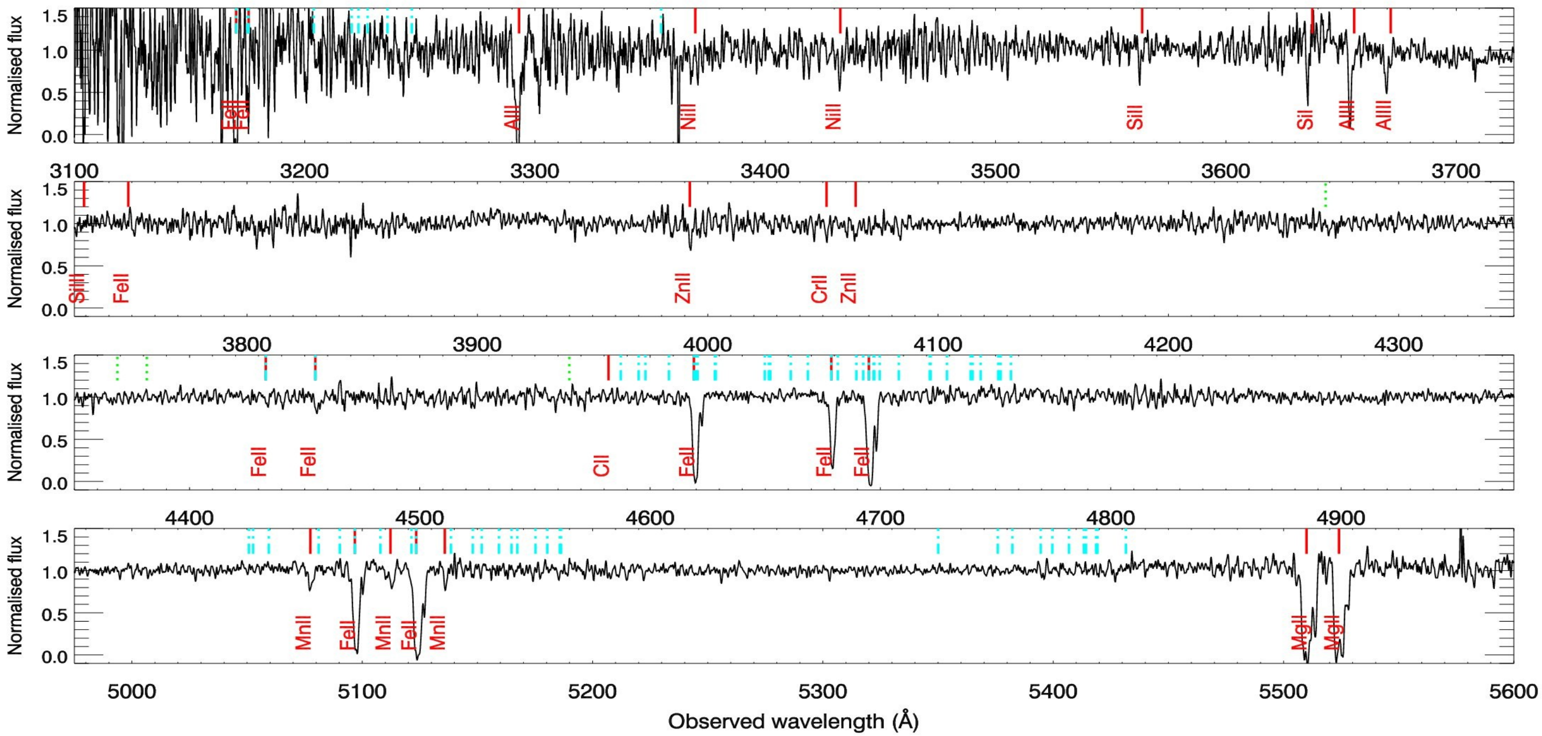


Deep data (1.5 hrs) simultaneous with FORS2 (other unit telescope)

ISM polarisation affects jet effects (e.g. Lazzati et al 03)

Wiersema et al 2012

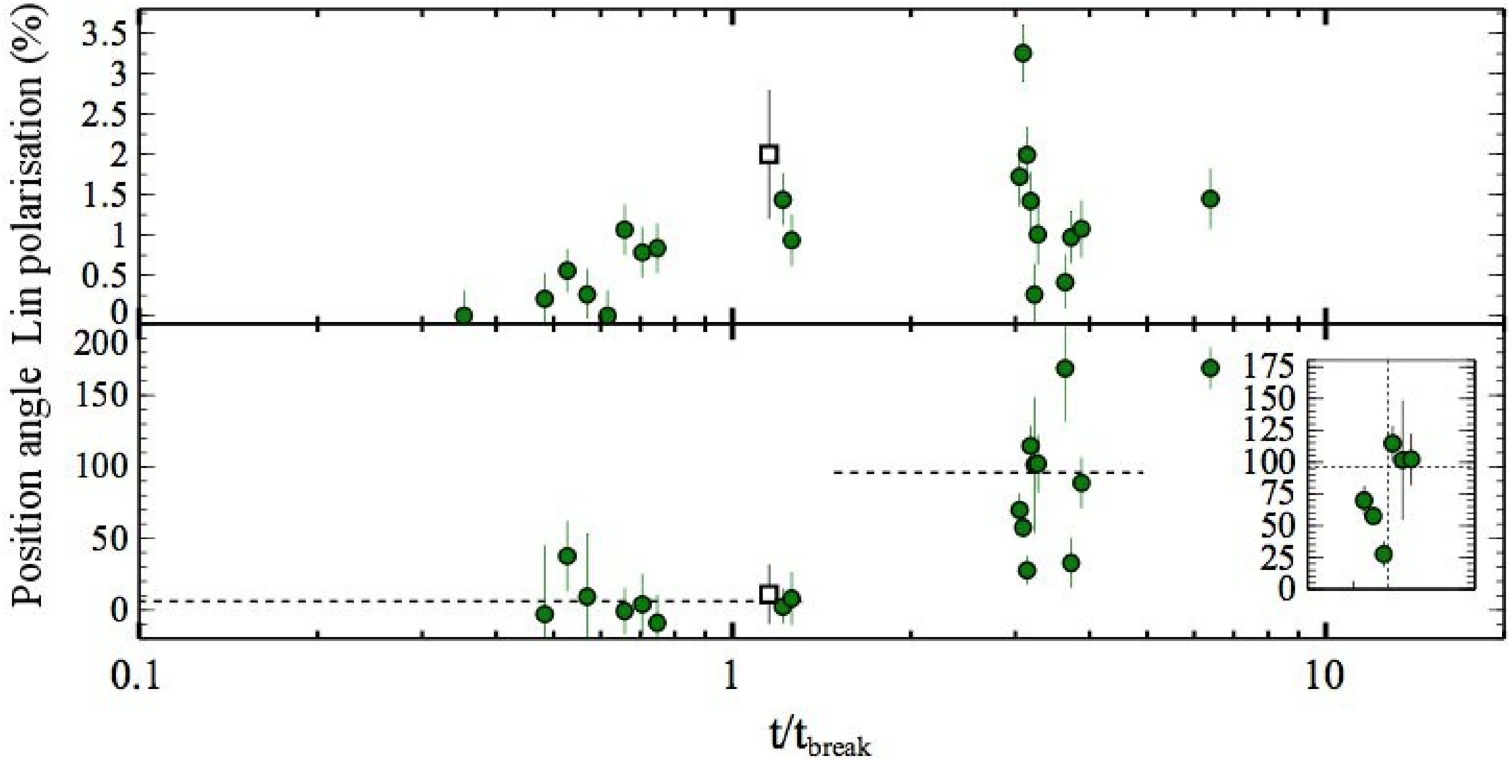
X-shooter spectroscopy



VLT X-shooter: excited finestr lines fix GRB z at $z = 0.971$
Probe dust chemistry and grainsize distribution

Wiersema et al 2012

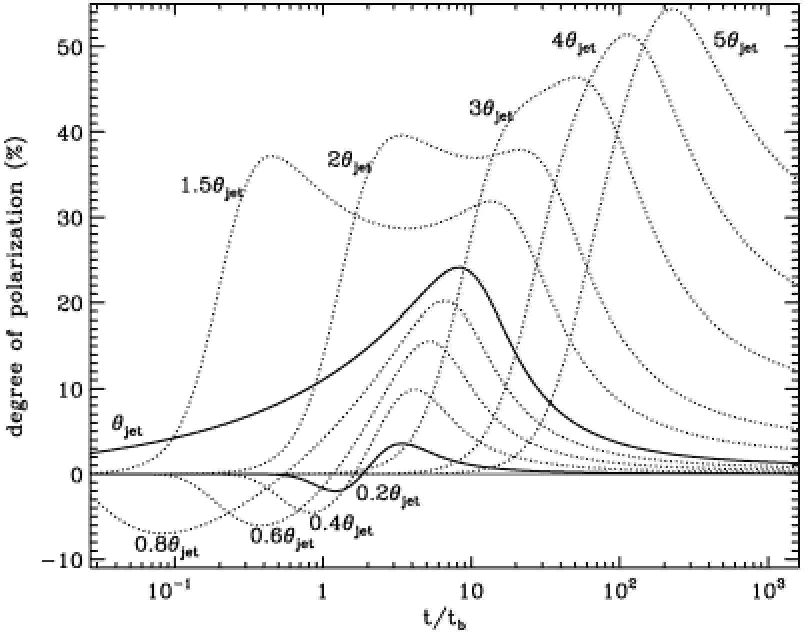
Linear polarisation curve

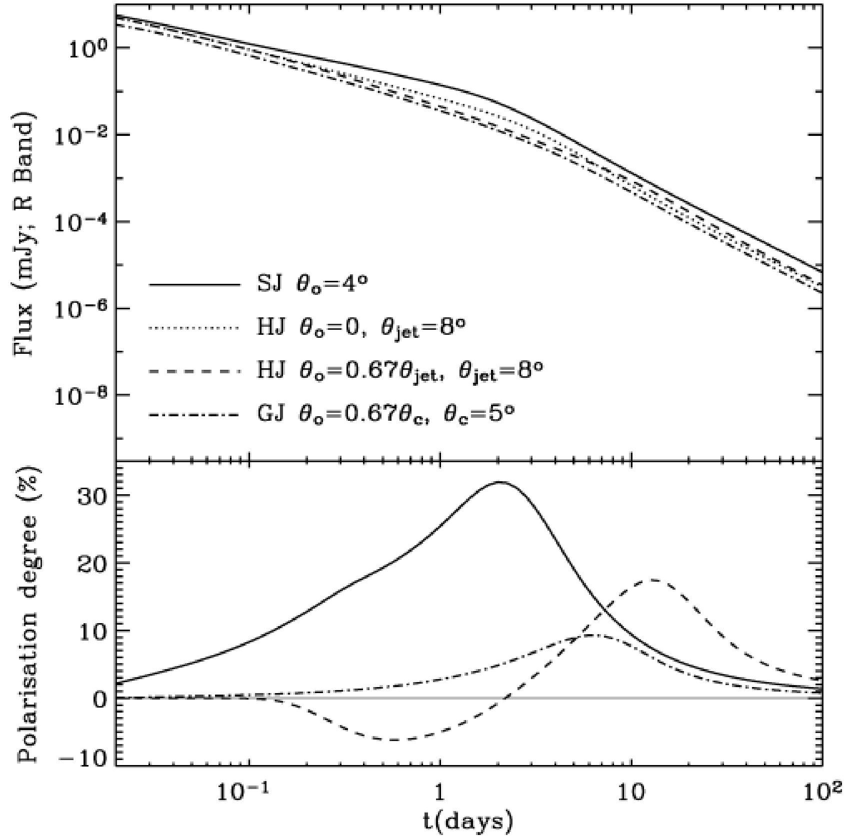


- Errors: dominated by MW dust correction uncertainty (i.e. points are in absolute frame)
- $P_R \approx P_K$ (no sign of dust scattering in host)
- Long & short timescale variation

Wiersema et al 2012

Linear polarisation curve models



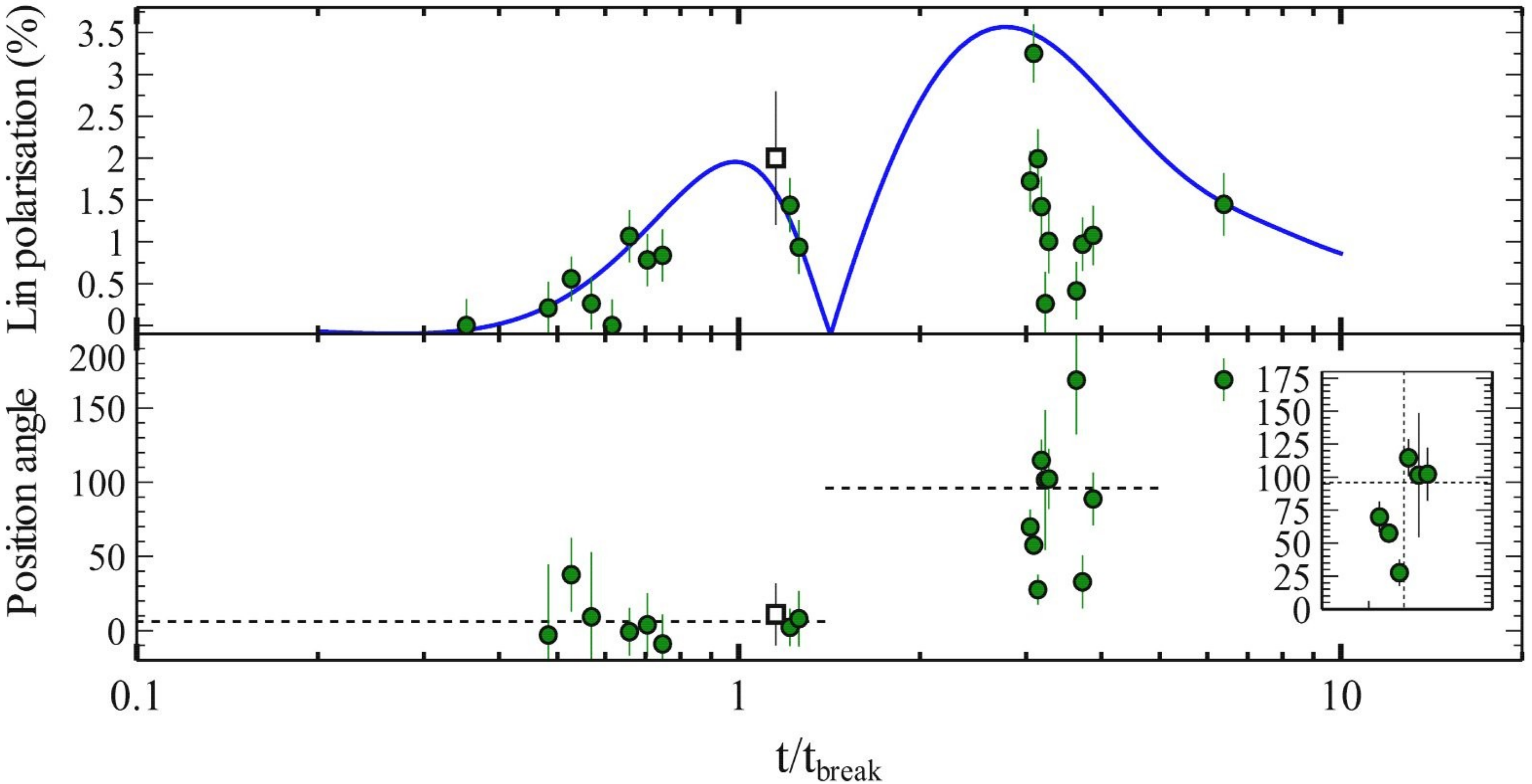


Different jet structures
Different viewing angle

→ different polarisation curves

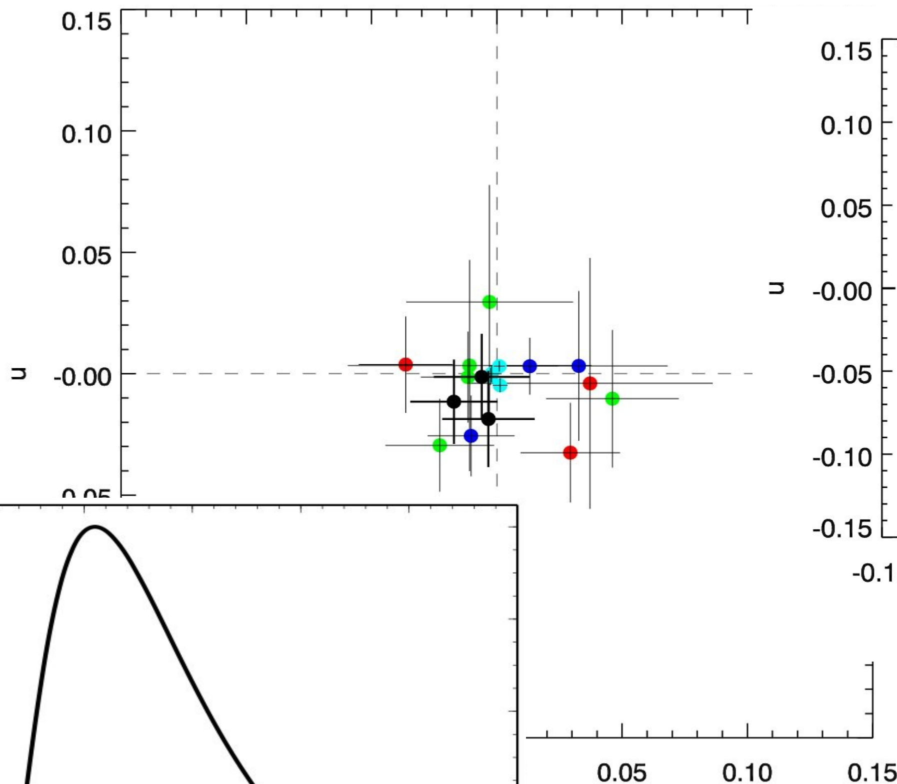
Rossi et al 04

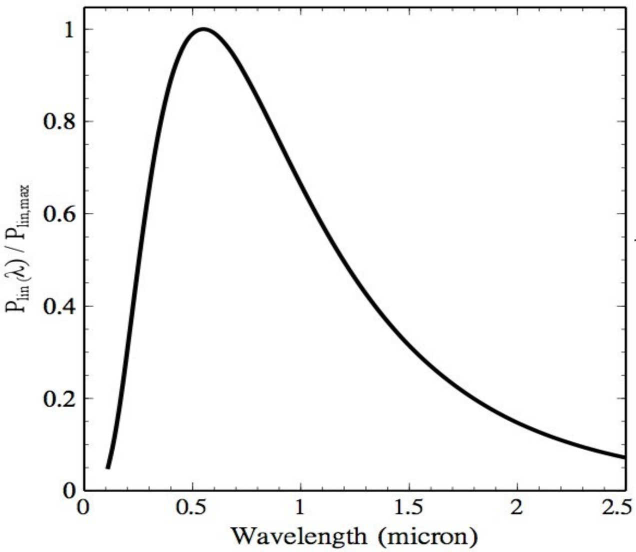
Linear polarisation curve models

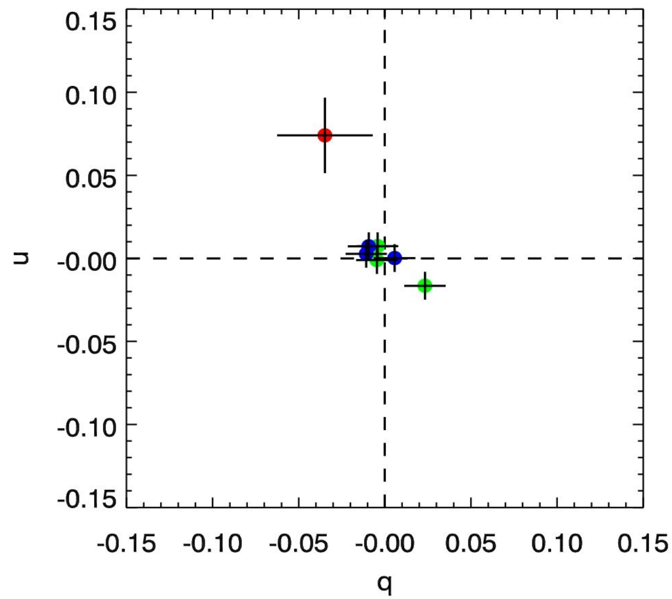


→ different polarisation curves

Rossi et al 04







Increase sample:
WHT Ks band afterglow polarimetry

Wiersema et al. 2012;
Wiersema et al in prep

Conclusions

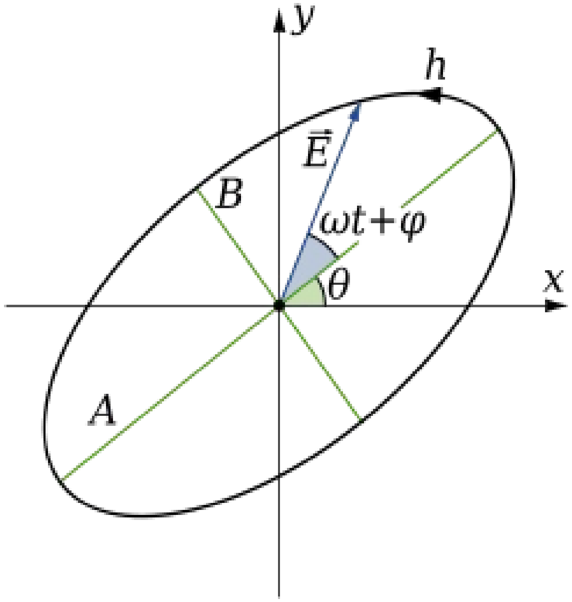
Polarimetry is important to understand (relativistic) jet physics. But it's very hard to get the required data (091018 cost ~20 hrs of 8m time).

We got a nice dataset to test models –

- Bumps
- No circ polarisation: no ordered field component visible.
- Low level "baseline" polarisation
- Variability around lightcurve break time
- Rapid variability, additional component?
- Probe dust scattering in the host

When developing new (lightcurve) models, please think about polarimetry.

Stokes parameters



$$I_p = \sqrt{L^2 + V^2}$$

$$\begin{aligned} |L| &= \sqrt{Q^2 + U^2}, \\ \theta &= \tfrac{1}{2}\tan^{-1}(U/Q). \end{aligned}$$

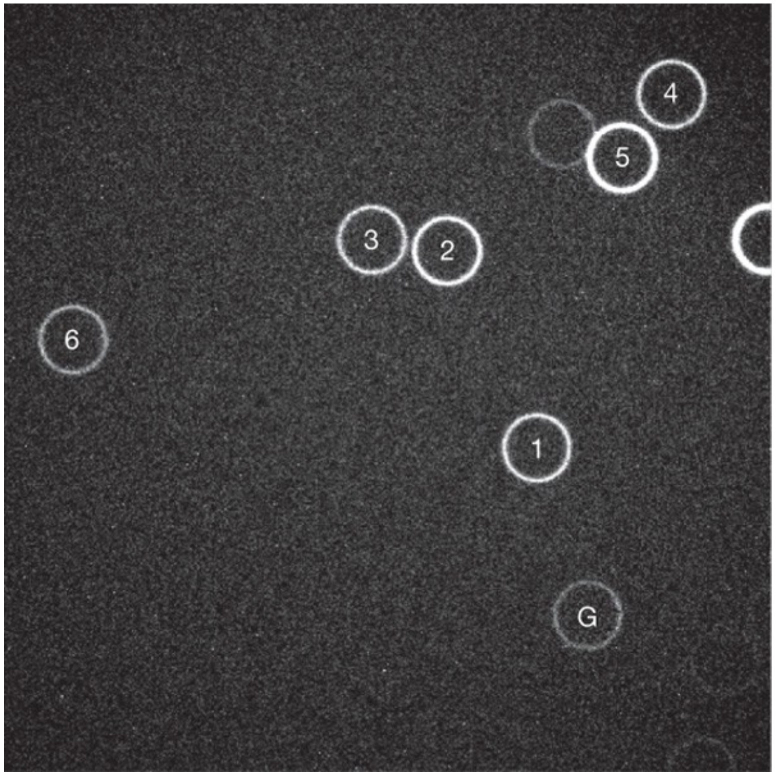
$$\begin{aligned} I_p &= A^2 + B^2, \\ Q &= (A^2 - B^2)\cos(2\theta), \\ U &= (A^2 - B^2)\sin(2\theta), \\ V &= 2ABh. \end{aligned}$$

$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

Convenient: you can express optics, calibration effects and coordinate transformations as matrices acting on the Stokes vector

Swift era: LT

LT/RINGO observation of the field of GRB 090102 observed 2009 Jan 2.



Steele *et al.* 2009)

10% linear polarisation
Probing times when reverse shocks are around. But: single epoch, no colours

Steele et al claim uniform component to B-field

Probe forward shock at late times: need a 8m (VLT + RRM) and a lot of observing time (PI Wiersema / Covino)
Plus dense multiwavelength lightcurves

Dear Santa, ...

Our wish list:

* Bright afterglow with slow decay– to get good polarimetric S/N
* Rapid response (reverse shock, funny XRT lc's) as well as multi-day monitoring (jet breaks)
* Smooth afterglow – as these are easiest to model
* Polarimetry in multiple bands - to model polarisation Induced by dust scattering in the host
* Circular polarimetry
* A 'simple' host – no dustlanes producing dust scattering polarisation
* Good spectrum – to model the dust properties of the host
* Low redshift (UV restframe dust polarisation tricky)