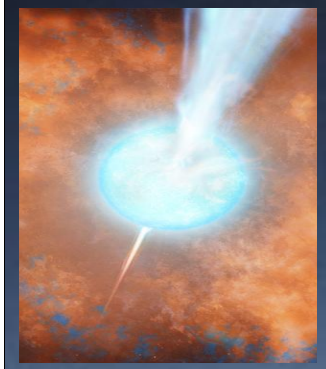
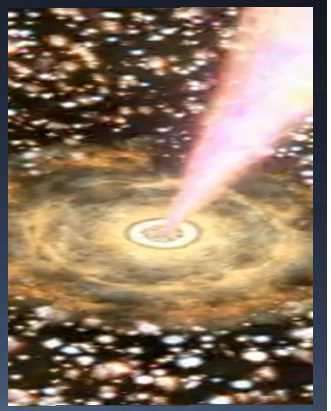
Magnetic field structure in relativistic jets

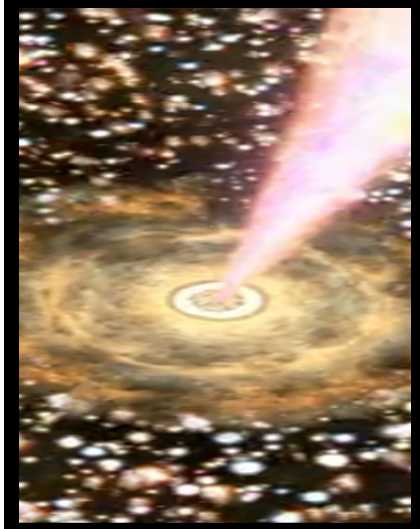




Helen Jermak,
Liverpool John Moores University, UK

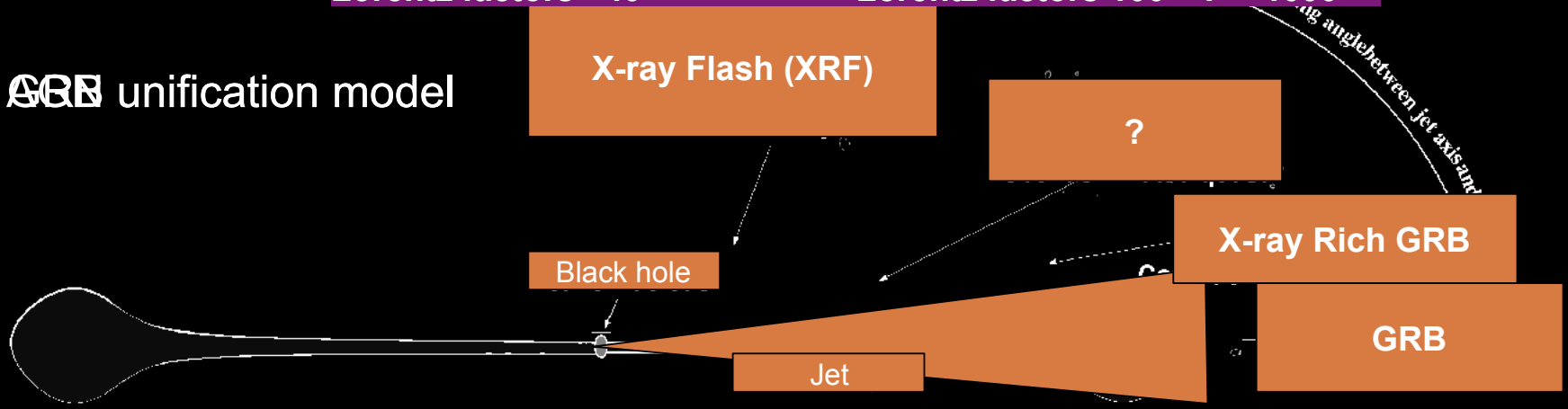
In collaboration with:
The Liverpool GRB Team :
Rich Harrison, Shiho Kobayashi, Carole Mundell, Francisco Virgili, Doug Arnold, Iain Steele, David Bersier, Chris Mottram and Rob Smith

Blazars and Gamma-ray bursts



Blazars (AGN)	GRBs
Accretion of matter onto a BH producing relativistic jets from polar regions of BH.	
Orientated with the jet pointing within a small opening angle of the observer.	
Supermassive BH	Stellar mass BH
SMBH at centre of galaxy	NS-NS/NS-BH merger or massive stellar collapse
Continual emission	Single episode of hyperaccretion
Lorentz factors <40	Lorentz factors 100 < Γ < 1000

AGN unification model



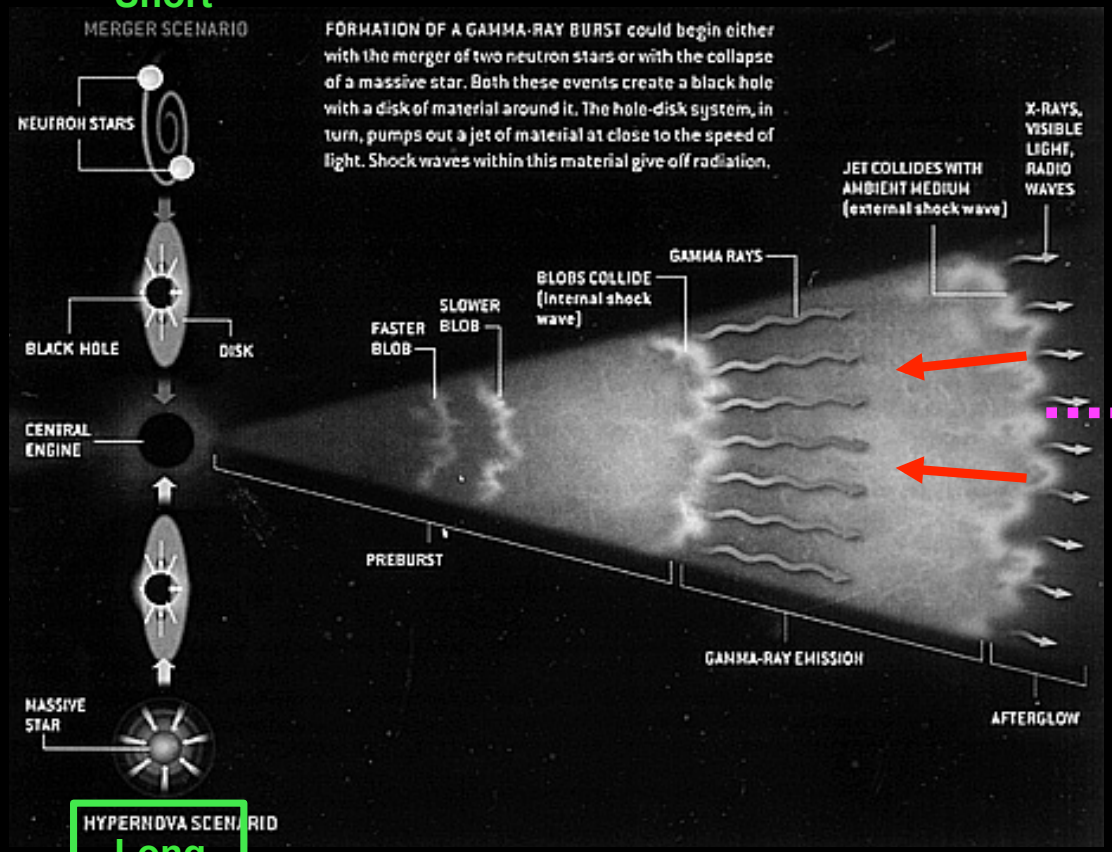
- X-ray flash ~ Radio Galaxy
- ? ~ Radio Lobe dominated Quasar
- X-ray Rich GRB ~ Core dominated Quasar
- GRB ~Blazar

GRB jet models; light curves

Theory predicts that the strength of the reverse shock emission depends on magnetisation (σ). (Zhang & Kobayashi 2005, Fan, Wei & Wang, 2004).

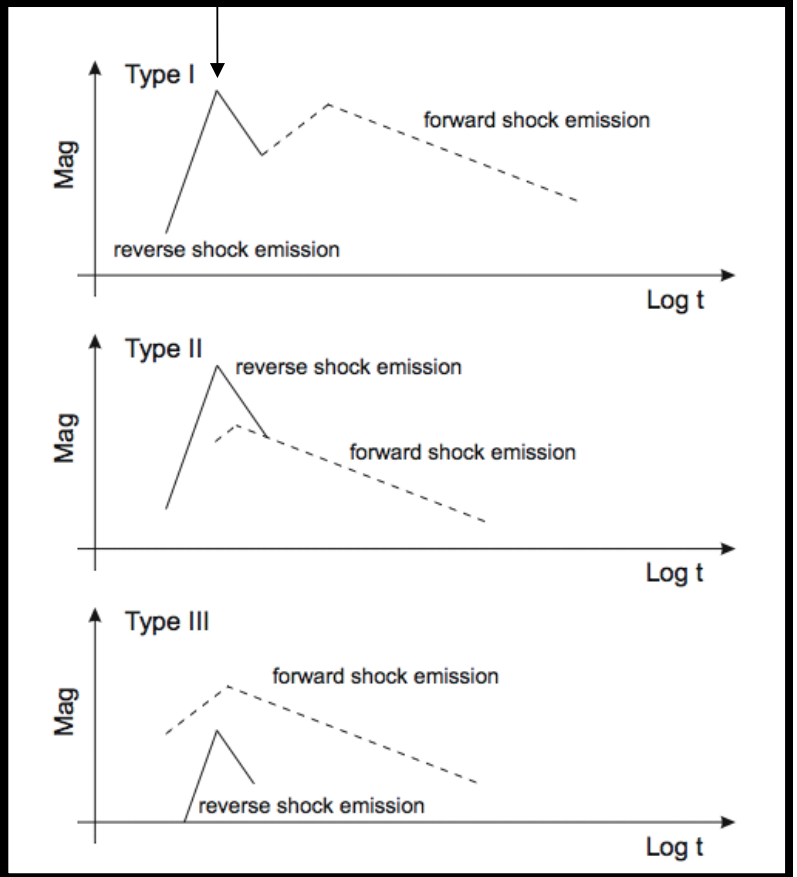
- Reverse shock = polarised
- Forward shock = low or no polarisation

Short



Long

Deceleration of fireball



Gomboc et al. 2009

Need to observe in the early stages of outburst to gain the most information.

Liverpool Telescope

- 2 metre fully autonomous robotic telescope

http://telescope.livjm.ac.uk

- Specialises in time variable and rapid reaction astronomy (real-time physics).

- Fast slew 2°/second

- Fully open enclosure; 'unencumbered view of the sky'

- Intelligent dispatch scheduler (*not* queue scheduled); 'Space probe on the ground'

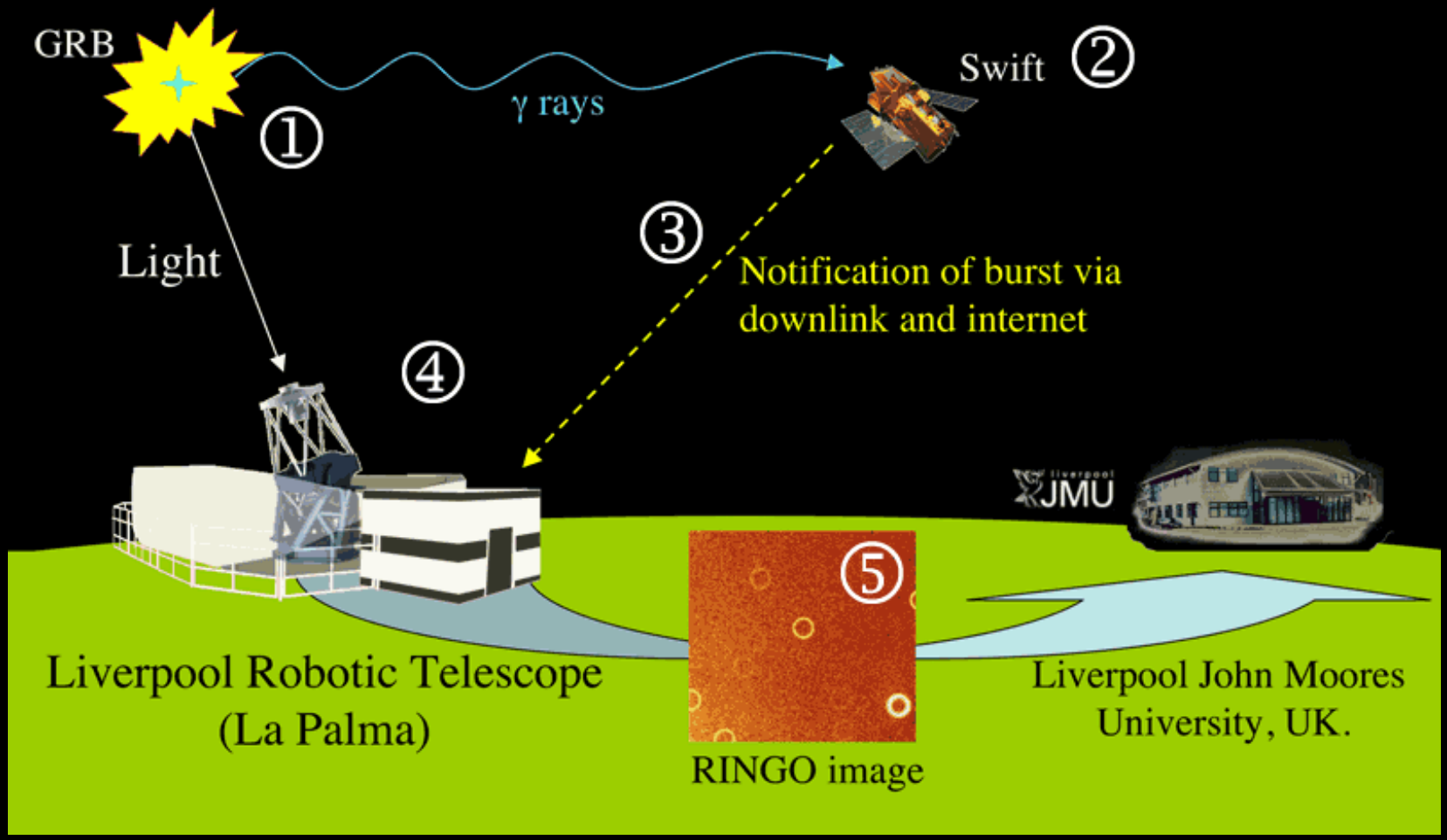
- Located in La Palma, Canary Islands (*not* Liverpool!)

- Faulkes Telescopes (LT clones)

Liverpool Telescope

- Observations co-ordinated with other facilities;
  Swift

- GRB triggers gamma-ray satellite which alerts the robotic Liverpool Telescope which quickly responds and observes the source.



Still have the problem of light curve ambiguity; need polarisation measurements

The RINGO Polarimeter 2006-2009

- Novel design (D. Clarke & D. Neumayer 2001)

- Designed for rapid (< 5 minutes) follow-up observations of GRBs

- Wavelength range 460 – 720 nm

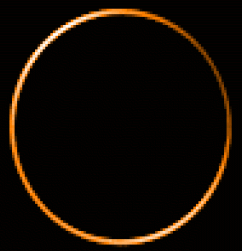
- Fast rotating Polaroid modulating the incoming beam of light

- Followed by co-rotating deviating optics that transfer each image into a ring which is recorded onto a CCD.

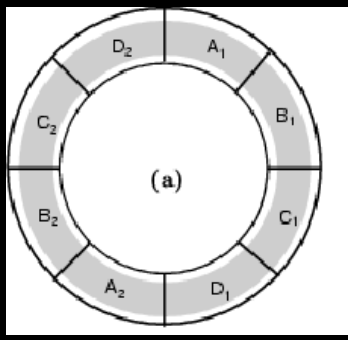
- Any polarisation signal in the incoming light is mapped out around the ring in a sin2θ pattern.

- Each point source is a ring.

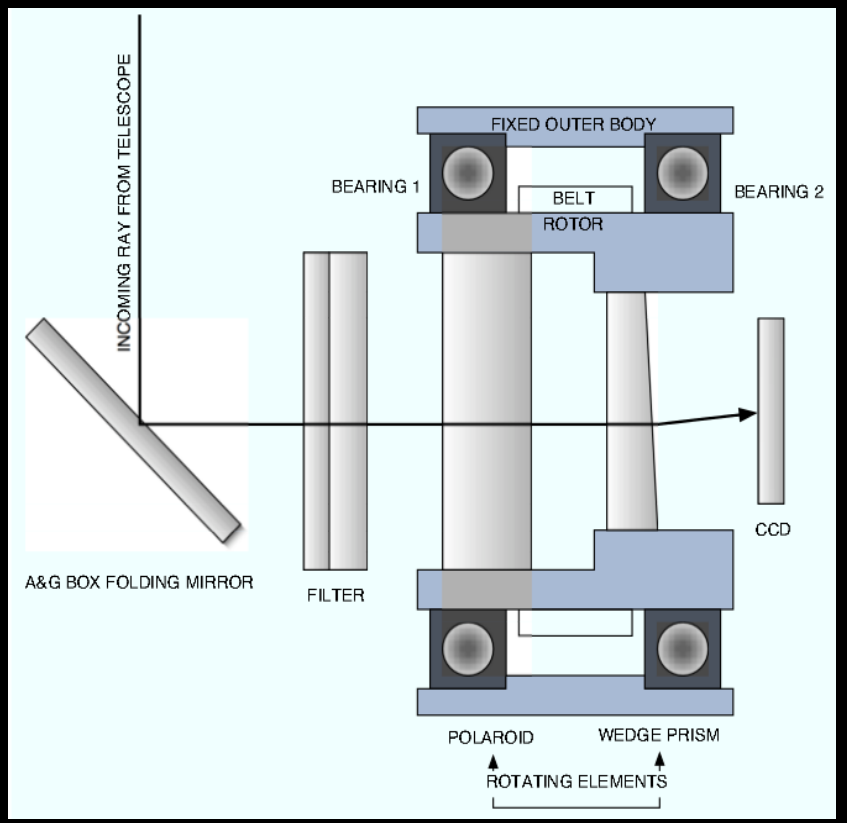
- First operational in 2006 when it detected its first GRB (060418).



30 second RINGO exposure of BD +64 106



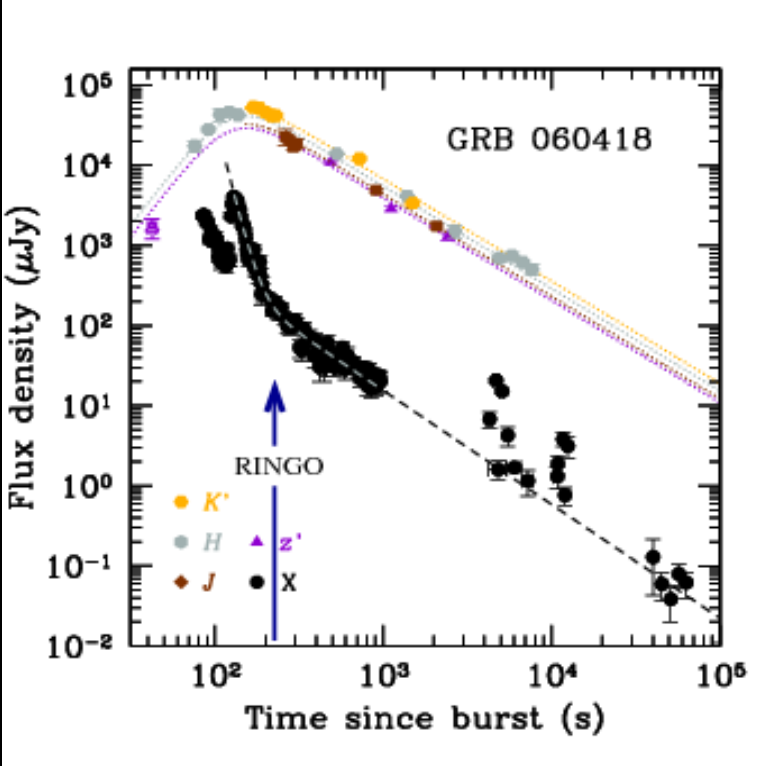
Clarke & Neumayer, 2001.

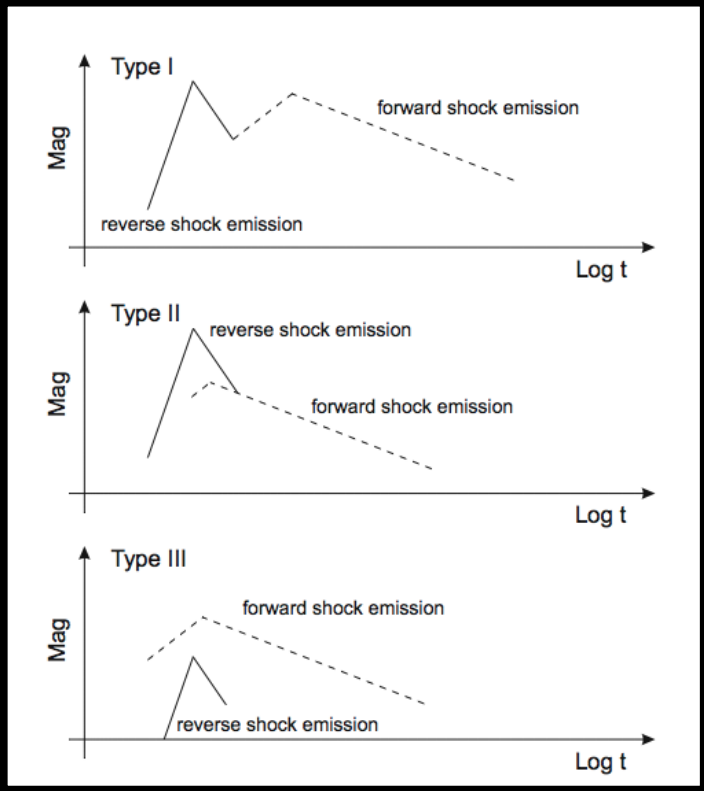


These measurements can be used to eliminate or constrain current models.

GRB Results 2006

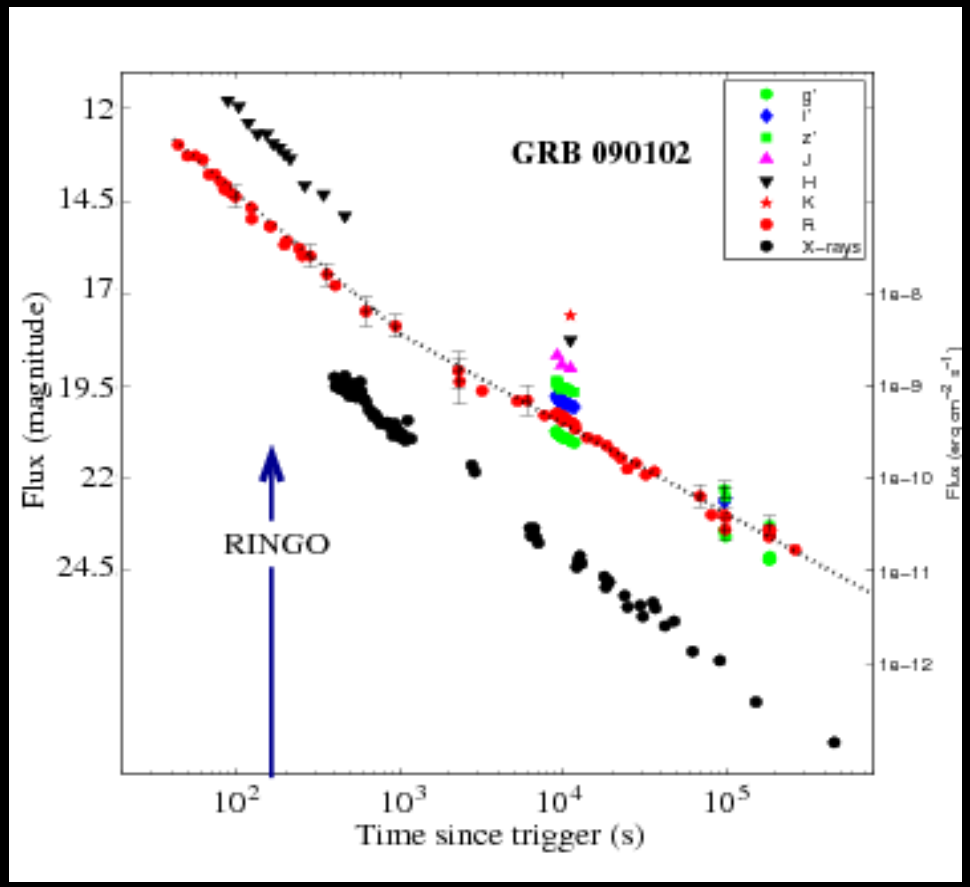
- 2006; GRB 060418 (Mundell et al. 2007)
- Earliest ever optical detection; close to peak in optical light curve at time of fireball deceleration.
- 203 seconds after outburst. 30 second exposure
- Prompt emission (from gamma-rays) lasted 50 seconds, would expect to see reverse shock on light curve (if Type I)
- Upper limit <8 % polarisation; suggests no ordered large-scale magnetic field at early times
  – supports models of hydrodynamical jets in which the magnetic field in the regions of the prompt and afterglow emission is driven by local processes in the fluid.

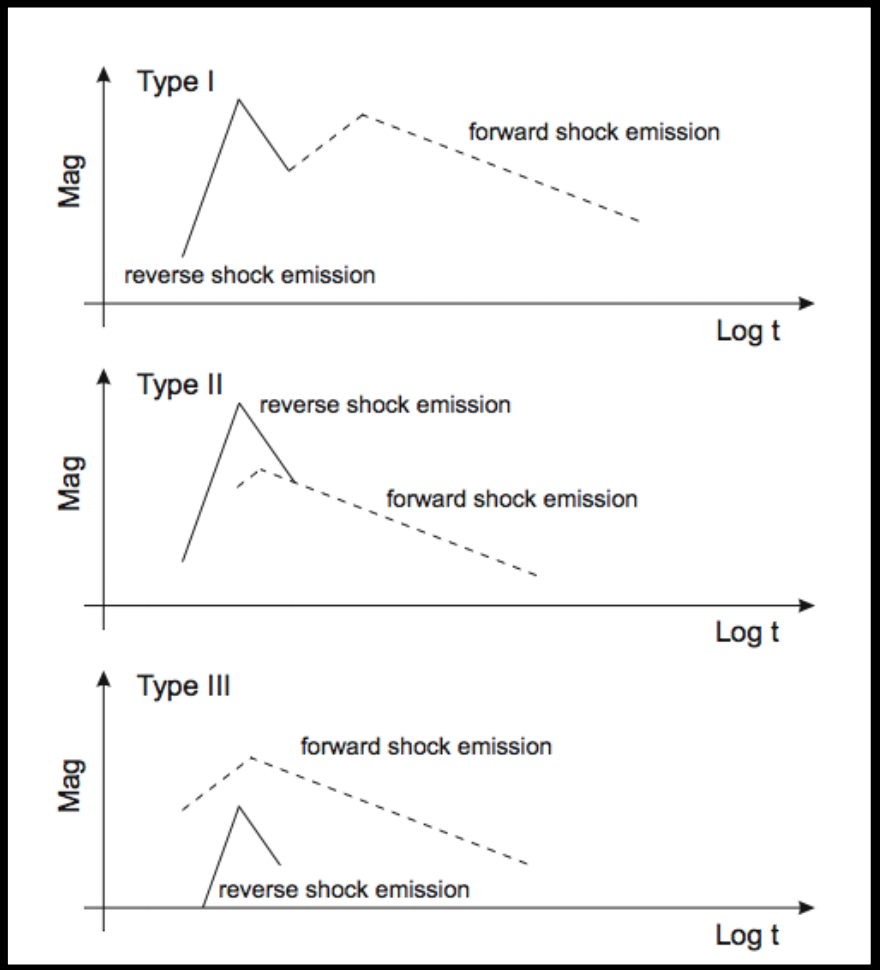




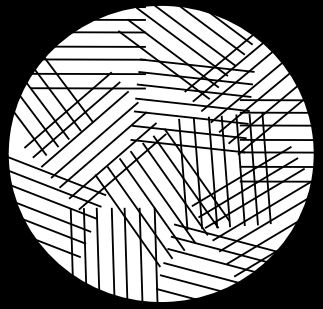
GRB Results 2009

- GRB 090102 (Steele et al. 2009)
  - 160 seconds after trigger time
  - Single 60 second exposure
  - 10.2 ± 1.3% polarisation





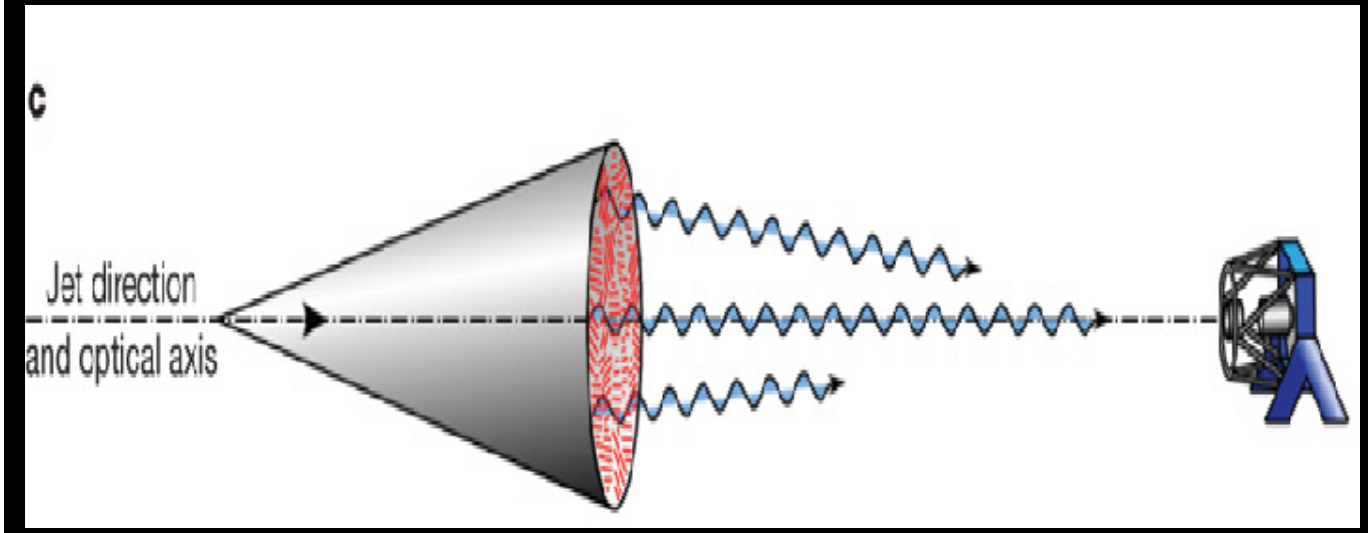
What is the structure of the magnetic field?

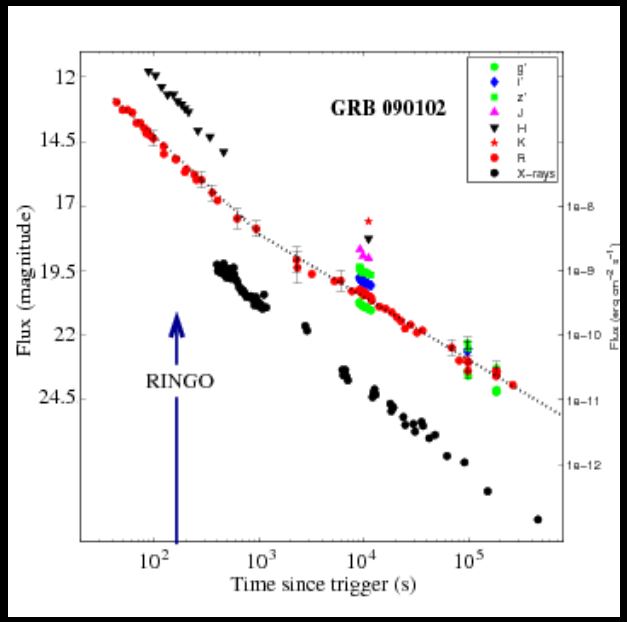


GRB jet models; polarisation (1)

Coherent patches of magnetic field

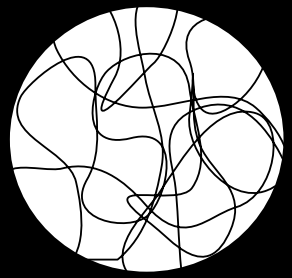
Magnetic field generated by shock instabilities (1)





- Each patch ~70% but max polarisation = $\Pi_0/\sqrt{\#patches}$ = ~10%
- Expect to see a decrease in polarisation percentage
  - Increasing number of coherent patches visible as observable region expands.

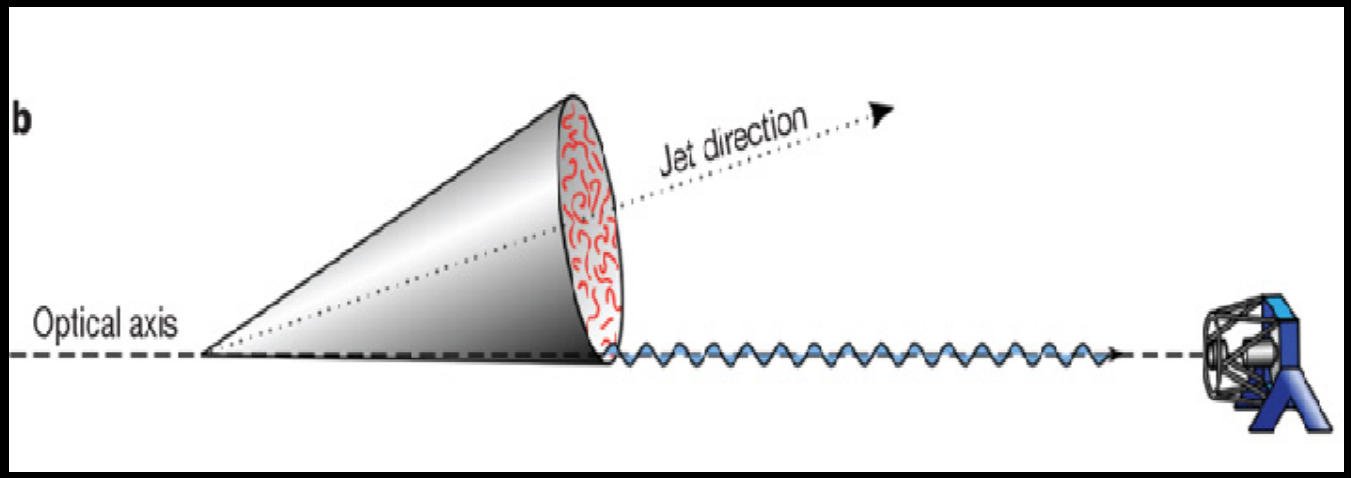
- Polarisation angle fluctuates as patches have fluctuating angles

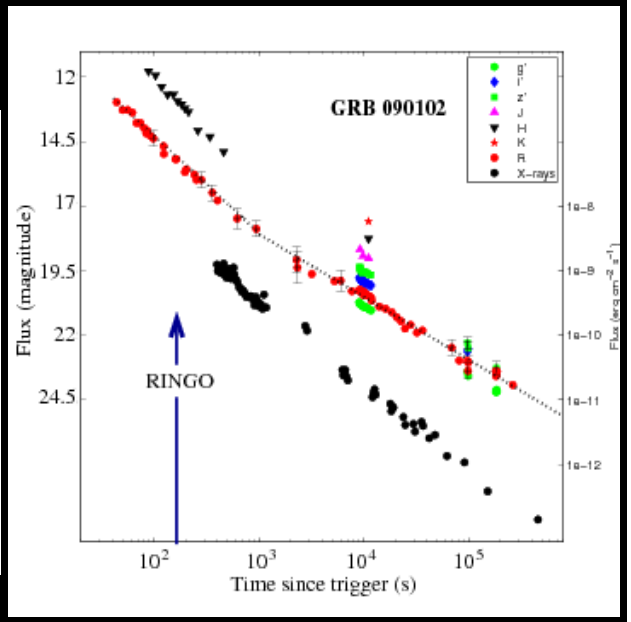


GRB jet models; polarisation (2)

Random magnetic field

Magnetic field generated by shock instabilities (2)

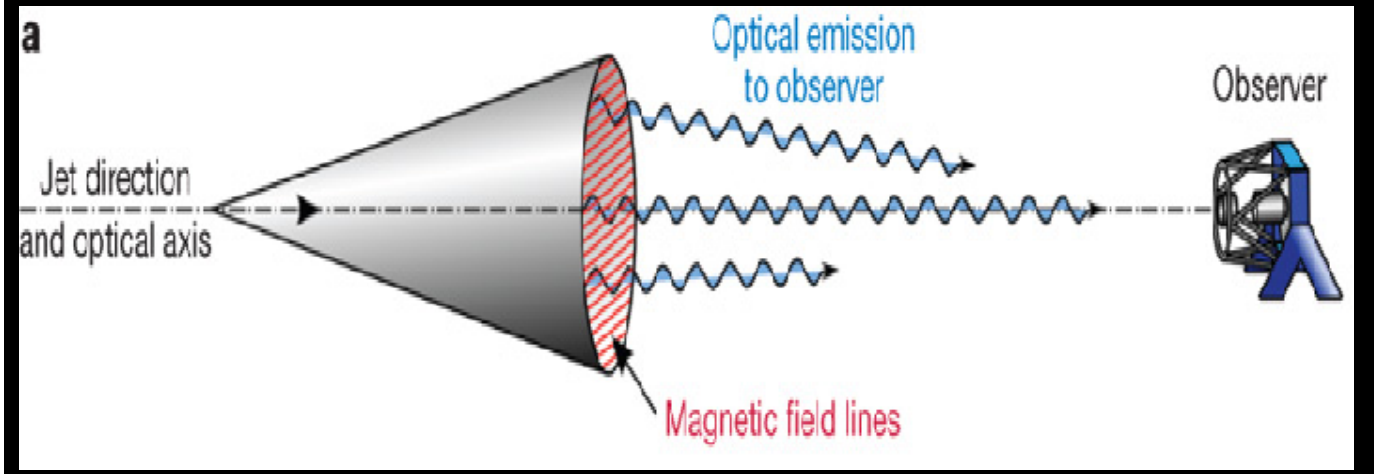


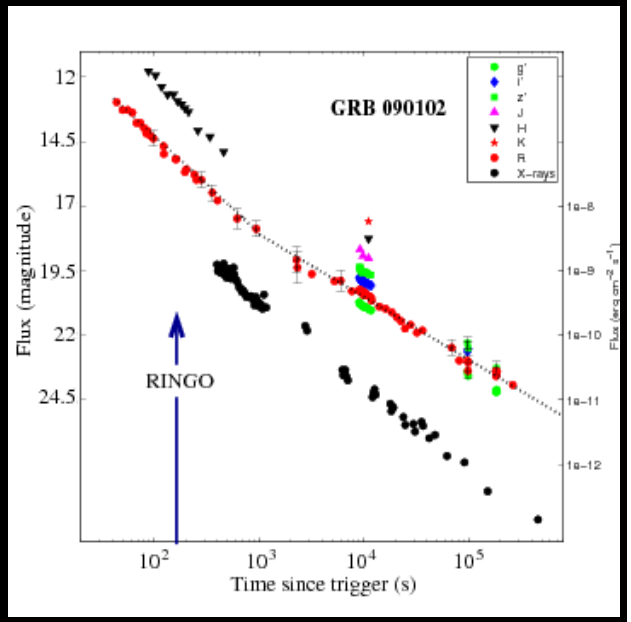


- Magnetic fields are parallel and perpendicular to the shock front
- Shocked fields are 'ordered'; polarised light emitted at 90º angle to jet
- Polarisation cancels out when viewed along optical axis.
- Expect a steepening of the light curve (“jet break”) rather than the observed flattening
- Expect a sudden flip in polarisation angle coincident with jet break

GRB jet models; polarisation (3)

Large scale ordered magnetic fields





- Constant polarisation angle
- Decrease in polarisation percentage as reverse shock decelerates
- Most *likely* model for GRB 090102
- "First direct evidence that large-scale ordered magnetic fields are present when significant reverse shock emission is produced." Steele et al. 2009.

Need to follow the temporal evolution of the polarisation.

RINGO2 2009-2012

Rotating polaroid (once/second) (8x 125 msec exposures)

Unlike RINGO which used deviating optics to spread the time-varying polarised signal into rings, RINGO2 has a fast readout camera to capture the signal as it changes in time.

Eight exposures obtained per second, synchronised with the rotation of the polaroid.

Combination of the eight images allows the polarisation to be determined.

Uses an electron multiplying charged coupled device (EMCCD) which reduces noise; fainter objects can be measured by stacking frames.

Allows the measurement of the temporal evolution of polarisation signal.

Constrain/eliminate magnetic field structure models

Observed every GRB during 3 year lifetime

To measure temporal AND spectral evolution...

RINGO3 2012-

- Third generation polarimeter

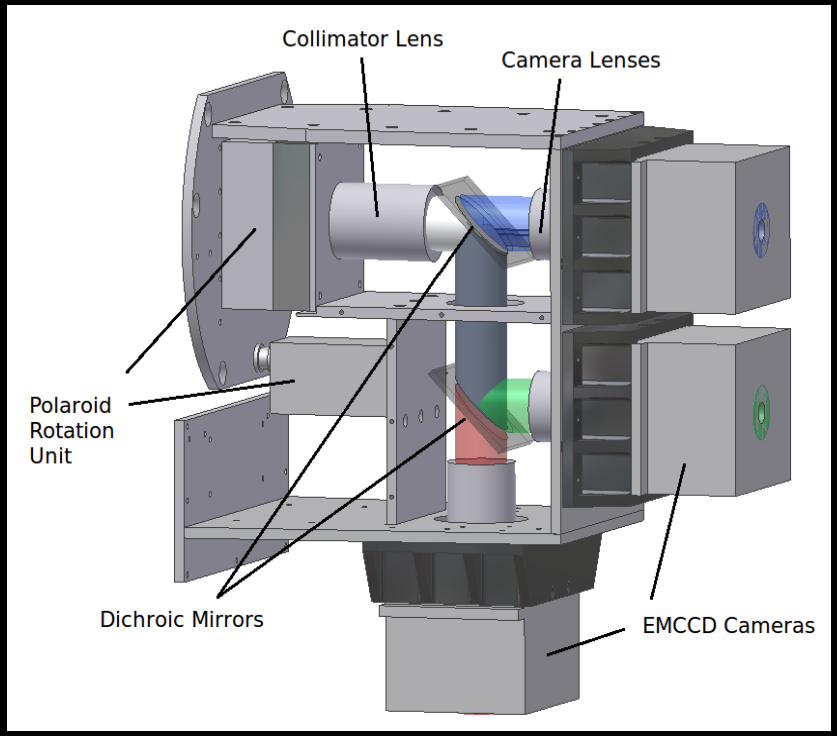
- Multicolour; covers:
  - 350 – 640 nm
  - 650 – 750 nm
  - 760 - 1000 nm

- Operational since December 2012

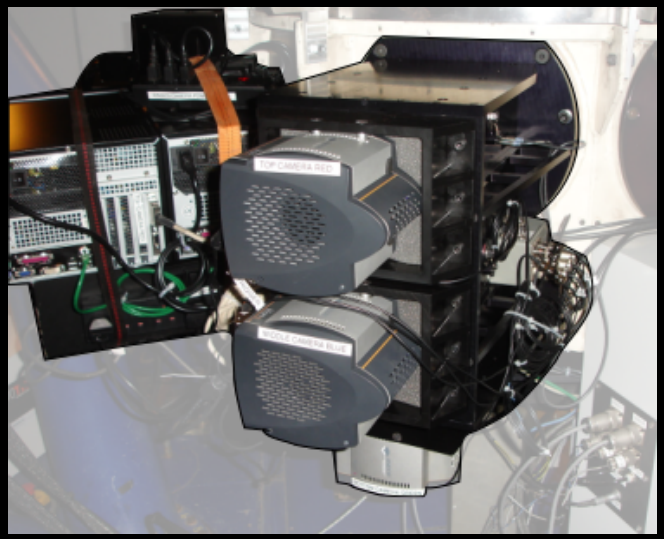
- Fast-readout imaging polarimeter uses a Polaroid that rotates once per second to modulate the polarised light going into a set of *dichroic mirrors* which separate the beam into three for simultaneous polarised imaging in three separate cameras.

- Each camera receives 8x 125 msec exposures; these are stacked to obtain final image

- Spectral evolution of polarisation from jets



http://telescope.livjm.ac.uk/Info/TelInst/Inst/RINGO3/



http://telescope.livjm.ac.uk/News/

Conclusion

- The orientation of GRBs and blazars makes it impossible to resolve the jet; → need to look at the light curve and the polarisation of the light coming from the jet in order to probe the structure of the magnetic field.

- Cannot predict when and where a GRB will occur; need a rapidly responsive, adaptable, robotic telescope to provide quick follow-up after outburst occurs.

↓

- Liverpool Telescope with RINGO3 polarimeter ideally suited for GRB follow-up, multicolour behaviour and monitoring of variable sources.

- Observations of optical polarisation angle and degree shortly after the GRB has been observed by gamma-ray telescopes can give insight into magnetic field structure in the jet by comparison with model predictions.

- GRB 060418 = no large-scale ordered magnetic field? GRB 090102 = large-scale ordered magnetic field?

- Cannot rule out possibility that each GRB outflow has very different polarisation (Kobayashi, 2012)

- Need a larger sample!!

Thank you for your attention.