Gamma Ray Burst Polarimetry with the Liverpool Telescope

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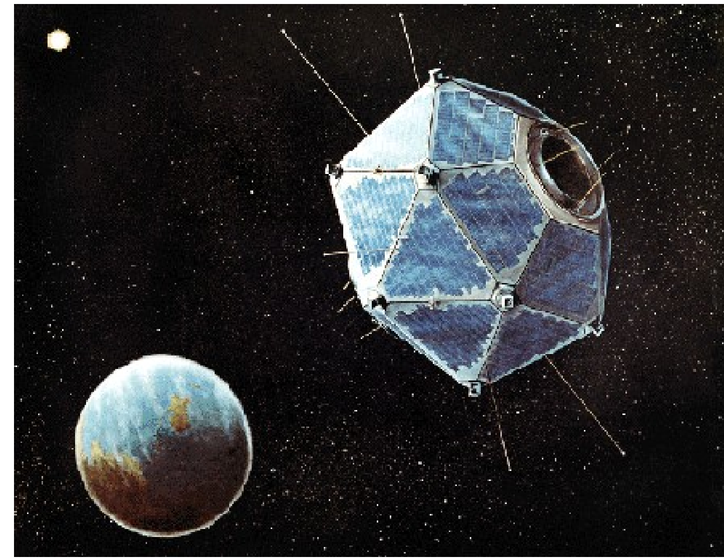
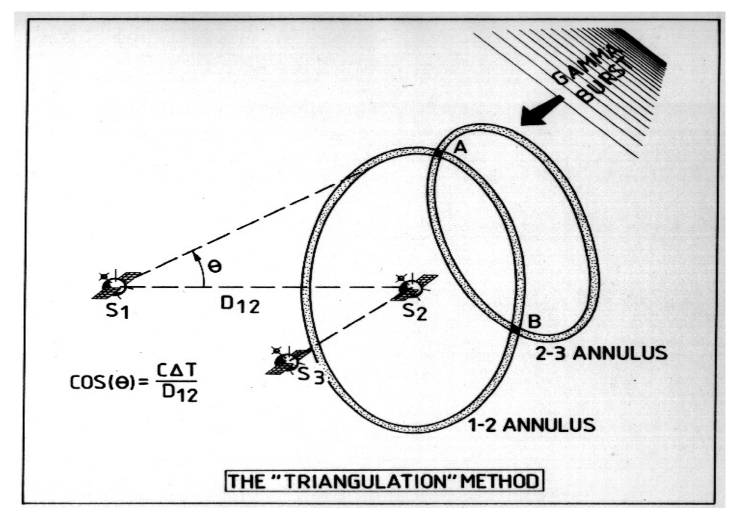
Overview

- History of Gamma Ray Burst (GRB) Studies
- Our Current Understanding of GRBs
- The Swift era of GRB ground based follow-up
- The Liverpool and Faulkes Telescopes follow-up capability
- Polarimetry and the RINGO series of instruments on the LT
- Results of polarimetry of 6 GRBs from RINGO2

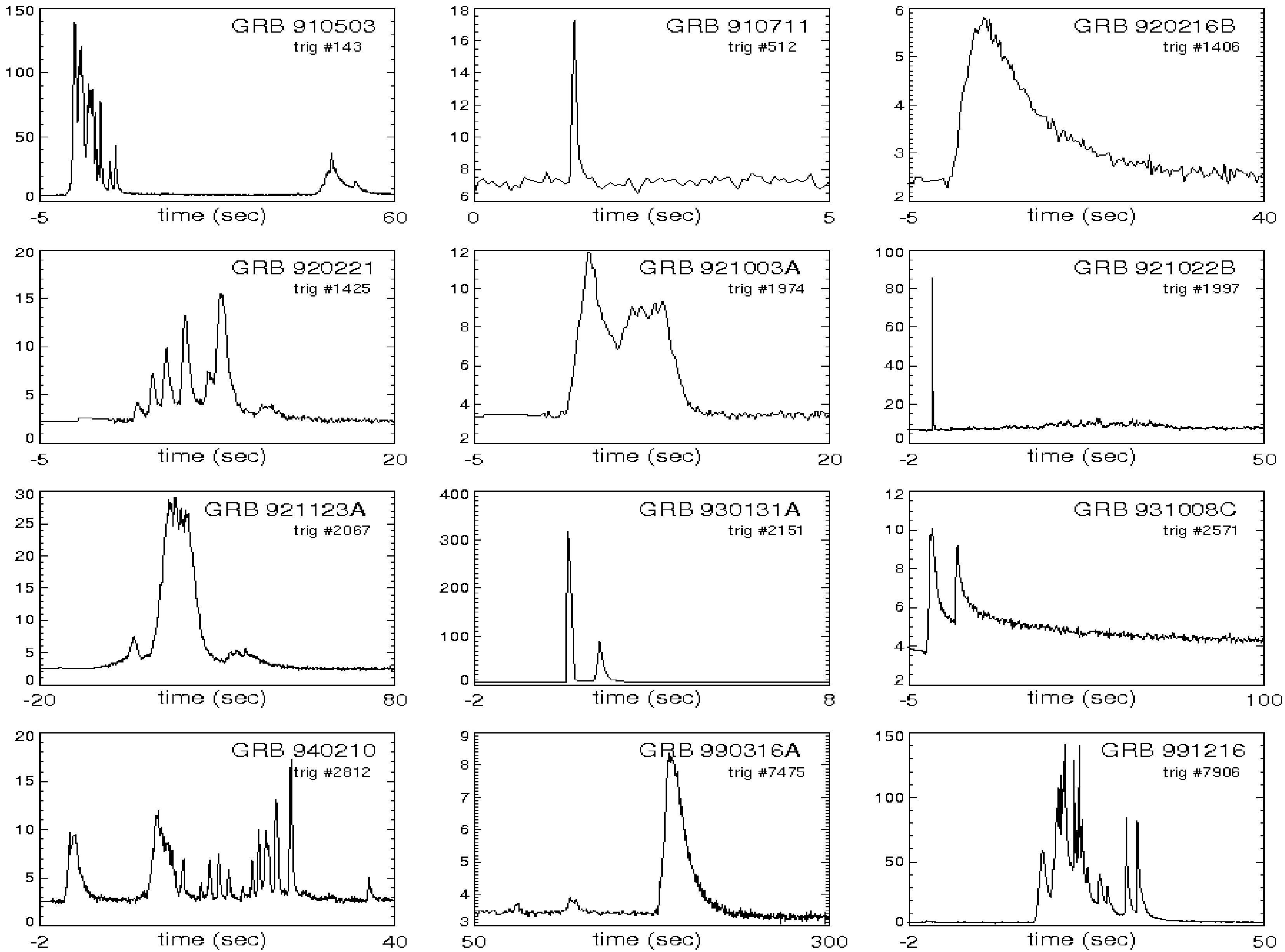
First Detections

- First Detected by The Vela Satellites in the 1960s
- Intense short bursts of Energetic Radiation
- A non terrestrial source

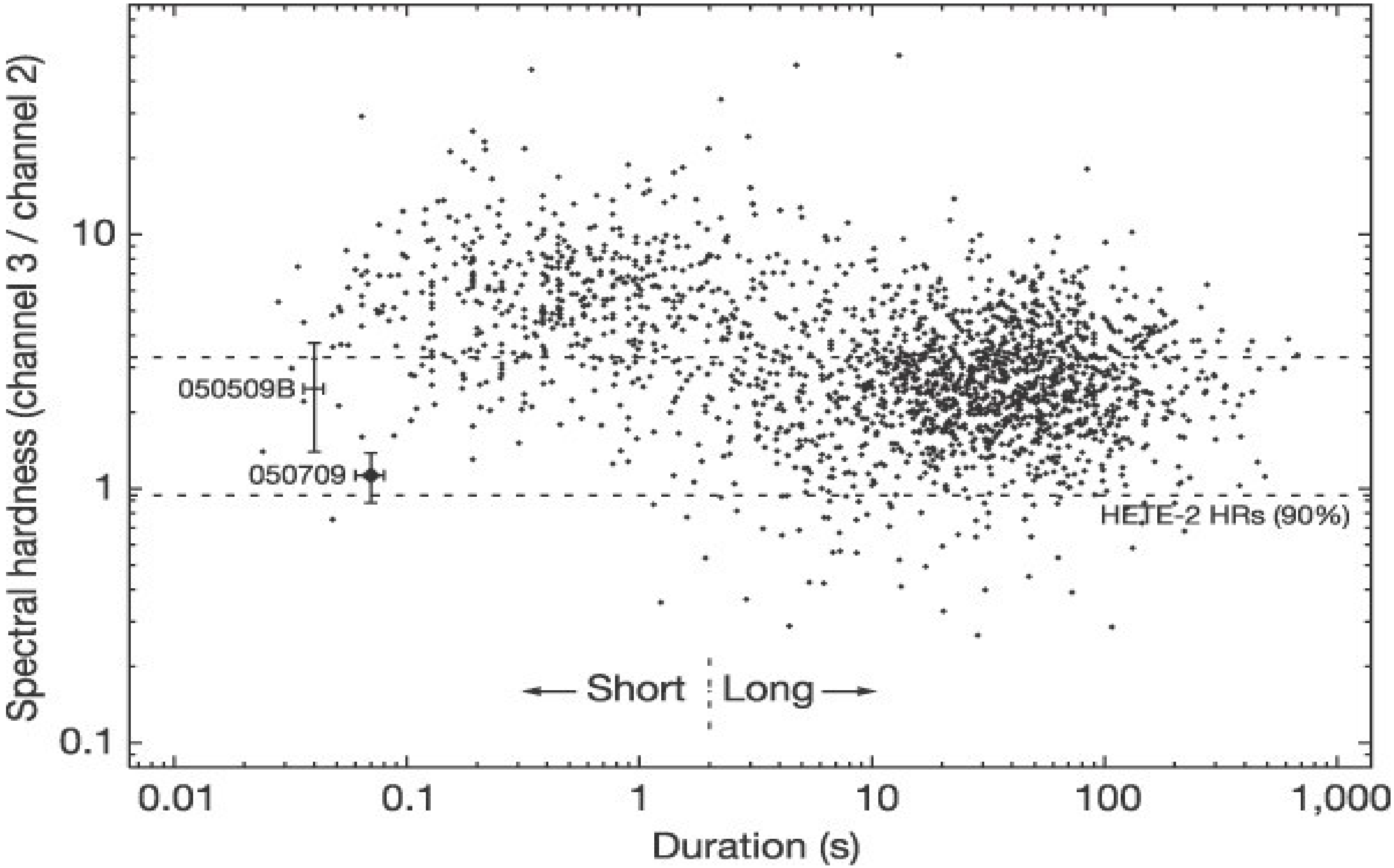




Prompt Emission Characteristics

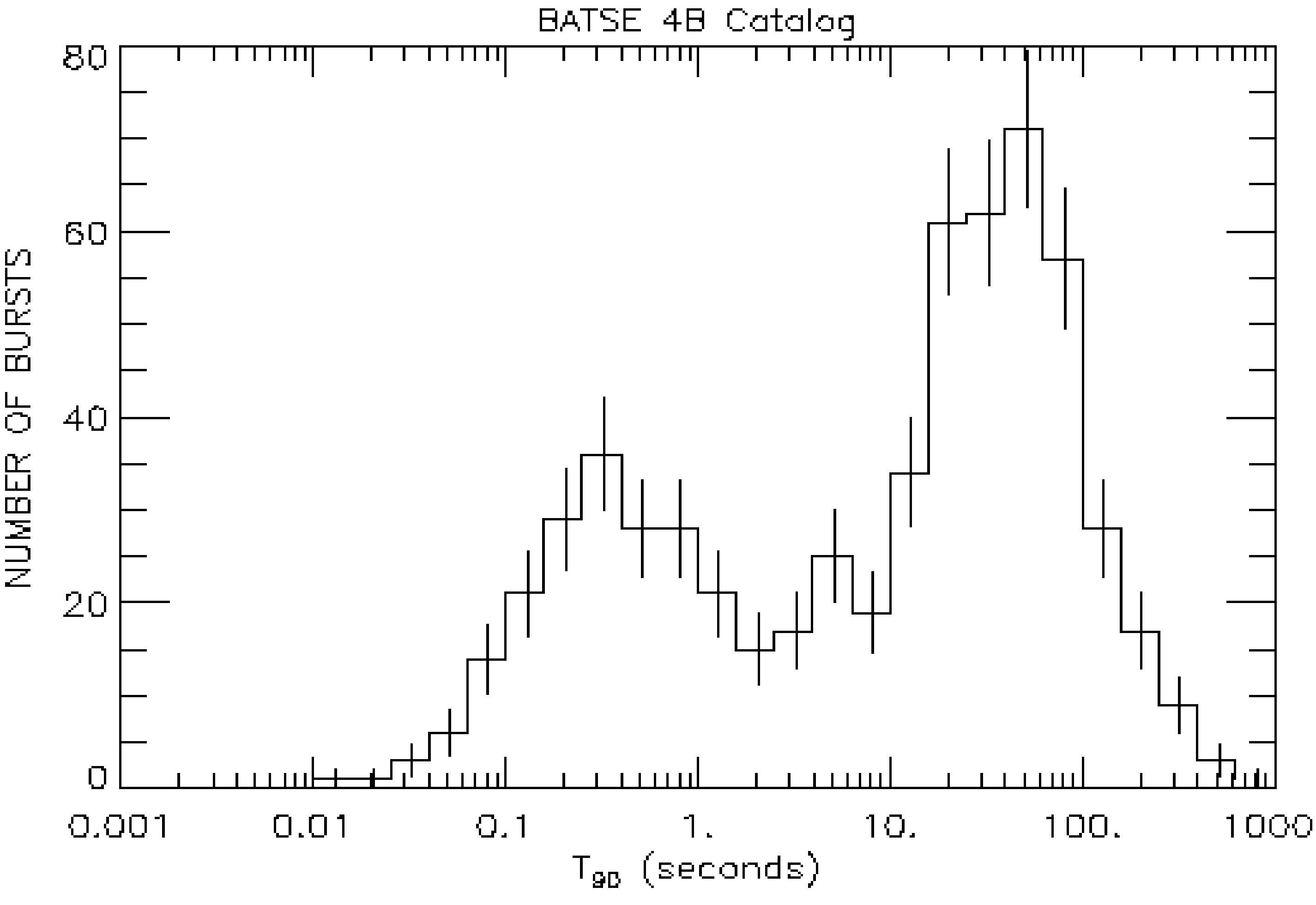


Two Non-discrete Populations



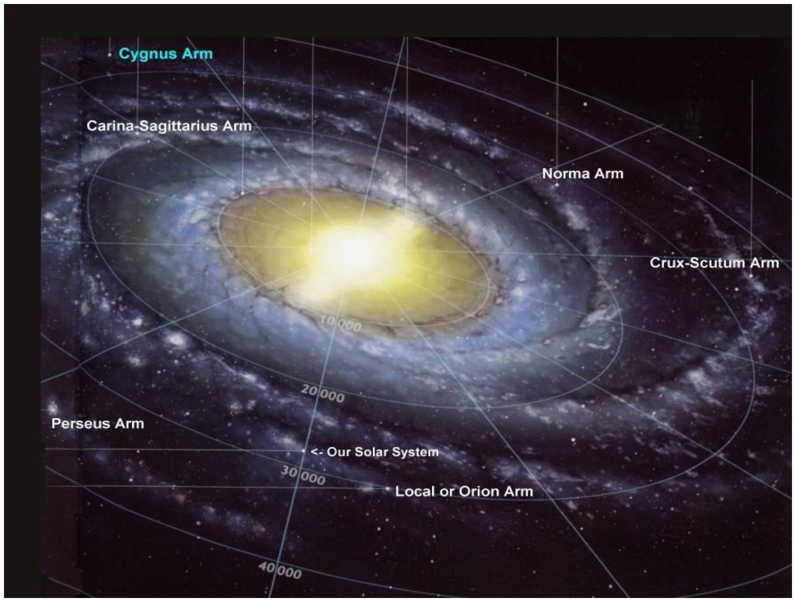
Two overlapping populations shown from Compton GRO BATSE data.

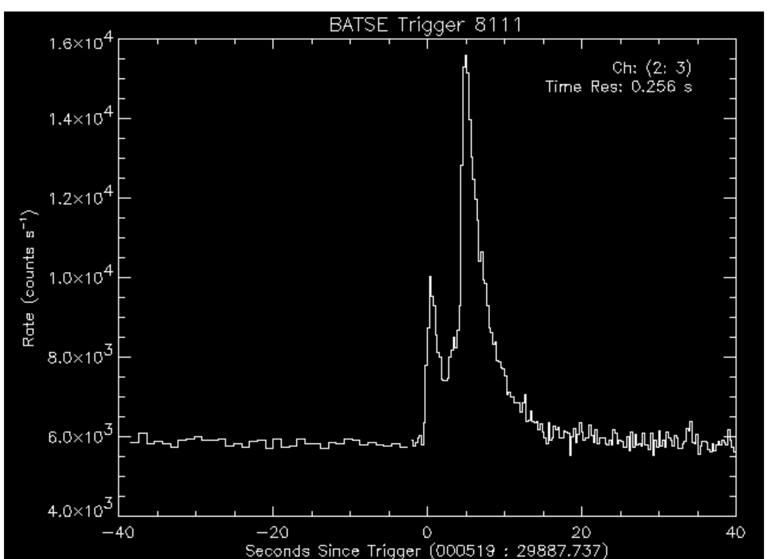
Two Non-discrete Populations



Two overlapping populations shown from Compton GRO BATSE data.

The Great Debate

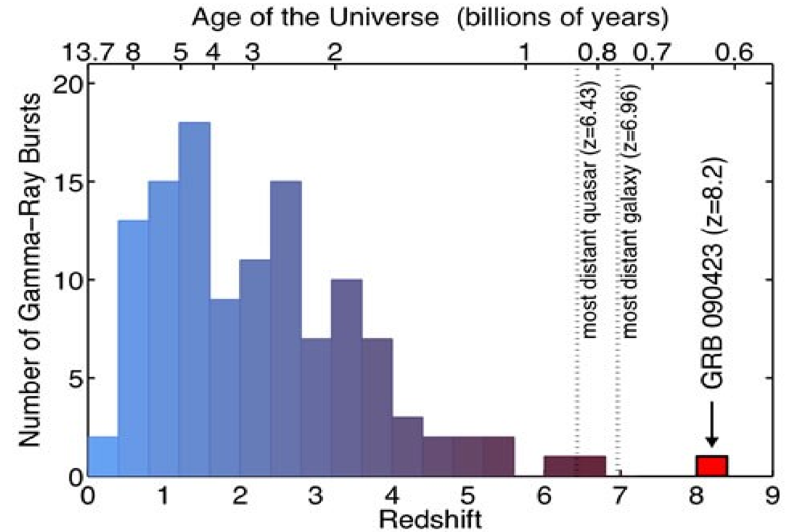




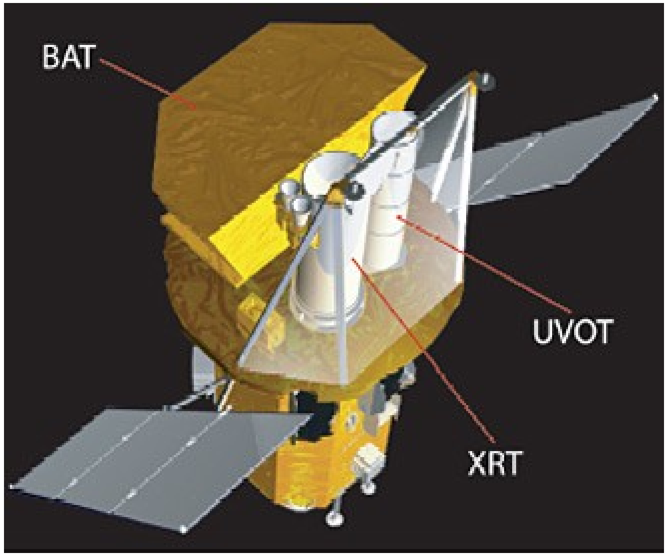
- Paczynski vs Lamb in 1995 in Smithsonian's Natural History Museum
- The BATSE on Compton GRO provided evidence of an isotropic population from a sample of over 600 bursts.
- Distribution and energies pointed to sources at cosmological distances.
- But this has huge implications on energy requirements.
- The light crossing time of the 'event' is very short.

Confirmation of Cosmological Distances and New Era of Follow-up

- 1997 – 2002 BeppoSAX satellite provides a sample of 37 GRBs. 90% followed up with X-ray telescope. 50% with optical and 40% with radio.
- Confirmation of range of Redshifts z>1
- However, error circle and latency of GRB alerts was less than ideal.
- 2004 brought the Launch of Swift and a new era of Rapid Follow-up.
- Error Circles of 4' and alerts a matter of seconds post trigger.



Credit: Edo Berger (Harvard/CfA)



Liverpool Telescope and LT-TRAP

- Created by C. Guidorzi and deployed in 2006
- Self detection of optical transient
- Automated production of lightcurves calibrated muti-band light curves
- Intelligent observation based on OT properties

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The Automatic Real-Time Gamma-Ray Burst Pipeline of the 2 m Liverpool Telescope

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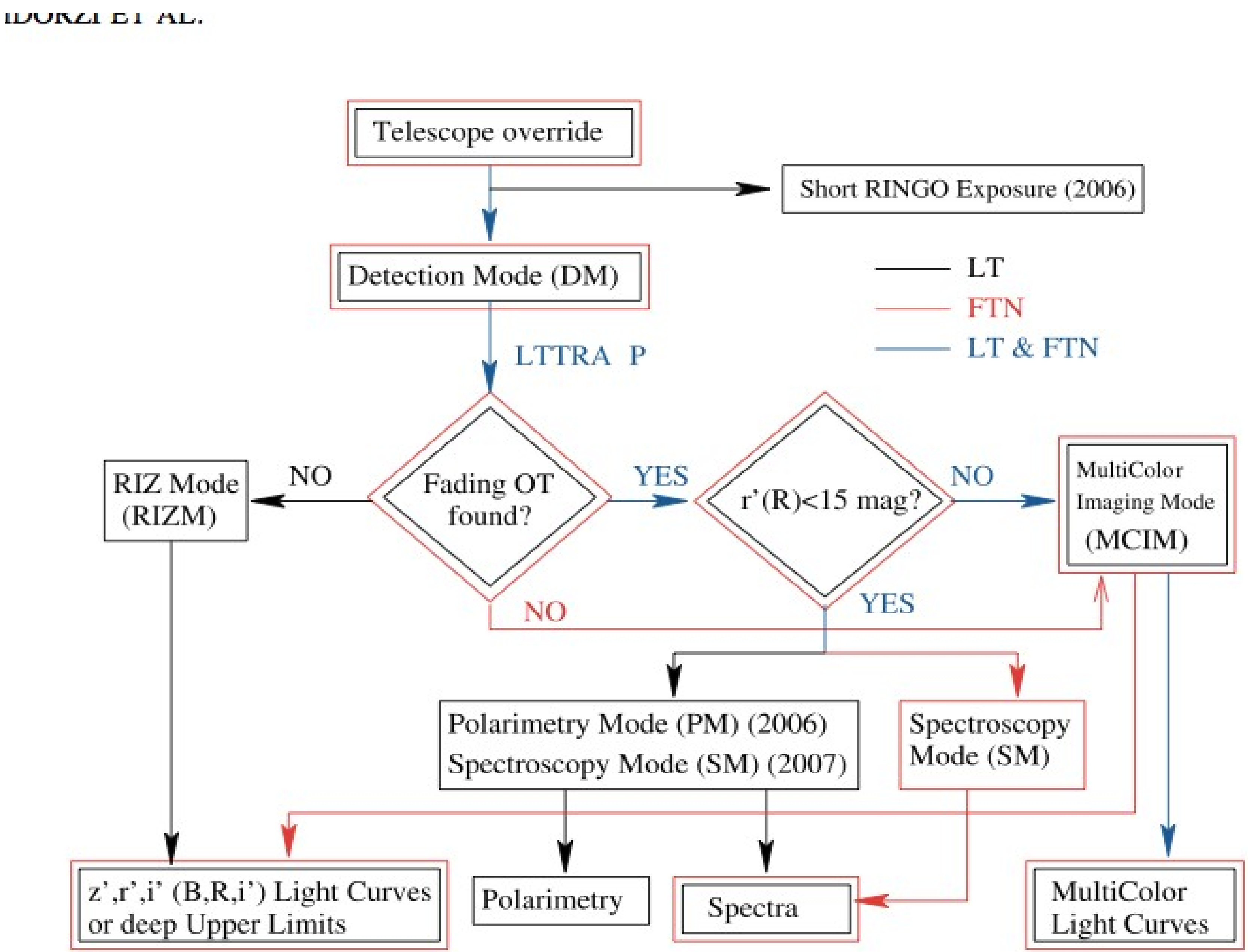
ABSTRACT. The 2 m Liverpool Telescope (LT), owned by Liverpool John Moores University, is located in La Palma (Canary Islands) and operates in fully robotic mode. In 2005, the LT began conducting an automatic gamma-ray burst (GRB) follow-up program. On receiving an automatic GRB alert from a gamma-ray observatory (*Swift*, *INTEGRAL*, *HETE-2*, or IPN), the LT initiates a special override mode that conducts follow-up observations within 2–3 minutes of the GRB onset. This follow-up procedure begins with an initial sequence of short (10 s) exposures acquired through an r' band filter. These images are reduced, analyzed, and interpreted automatically using pipeline software developed by our team, called LT-TRAP (Liverpool Telescope Transient Rapid Analysis Pipeline); the automatic detection and successful identification of an unknown and potentially fading optical transient triggers a subsequent multicolor imaging sequence. In the case of a candidate brighter than $r' = 15$, either a polarimetric (from 2006) or a spectroscopic observation (from 2007) will be triggered on the LT. If no candidate is identified, the telescope continues to obtain z', r', and i' band imaging with increasingly longer exposure times. Here we present a detailed description of the LT-TRAP and briefly discuss the illustrative case of the afterglow of GRB 050502a, whose automatic identification by the LT just 3 minutes after the GRB led to the acquisition of the first early-time (<1 hr) multicolor light curve of a GRB afterglow.

Liverpool Telescope and LT-TRAP

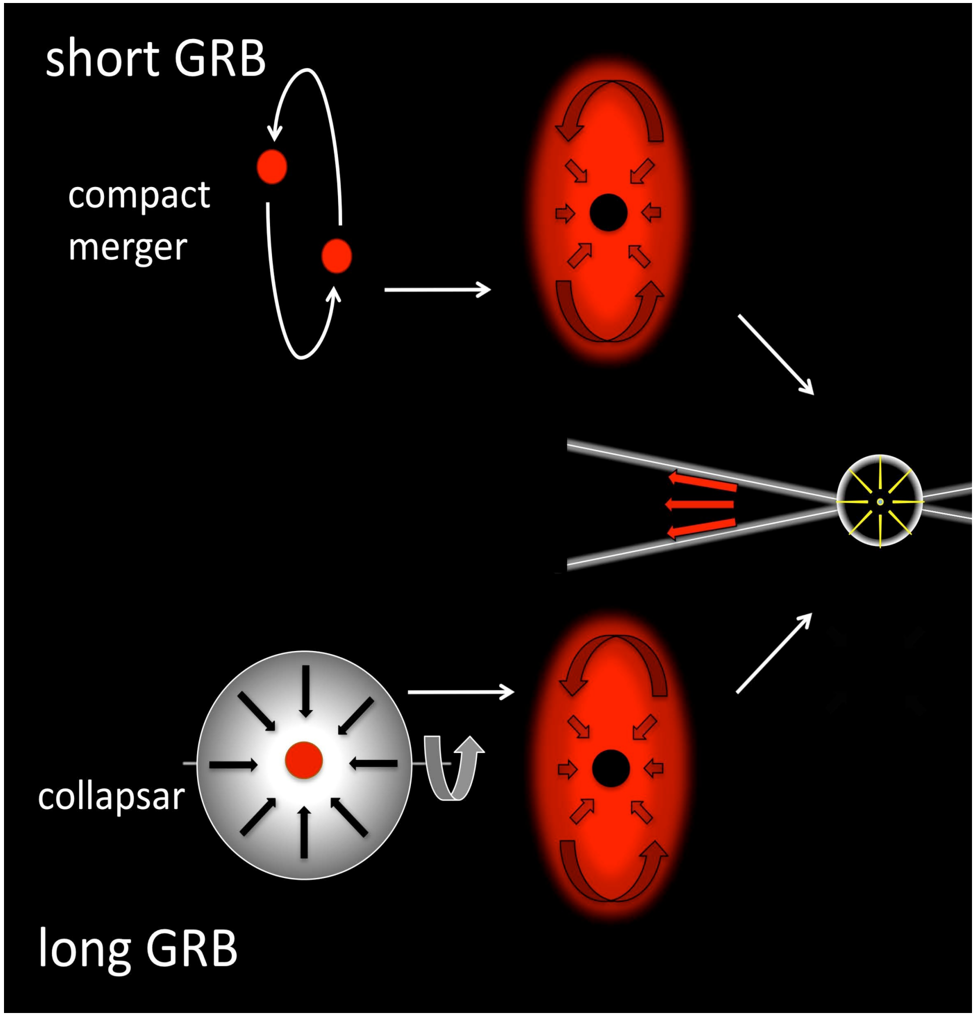


Liverpool Telescope and LT-TRAP

GRB	Telescope	Spacecraft	Filters	Start[a] (minutes)	Result	Frames	LT/FTN GCN Circulars
050412	FTN	*Swift*	$BVRi'$	2.5	$R > 18.7$	23	None
050502a	LT	*INTEGRAL*	$BVr'i'$	3.1	$r' \sim 15.8$	25	3325
050504	FTN	*INTEGRAL*	$BVRi'$	3.7	$R > 19$	38	3351
050520	LT	*INTEGRAL*	$r'i'$	4.5	$r' > 16.6$	18	3437
050528	LT	*Swift*	$r'i'$	2.5	$r' > 17.2$	36	3497
050713a	LT	*Swift*	r'	2.4	$r' \sim 19.2$	3	3588
050713b	FTN	*Swift*	R	3.3	$R > 18.2$	6	3592
050716	FTN	*Swift*	$BVRi'$	3.8	$R > 19.8$	20	3625
050730	LT	*Swift*	$r'i'$	50	$r' \sim 17.3$	36	3706
050904	LT	*Swift*	$r'i'$	3.8	[b]	31	None
050925	FTN	*Swift*	$BVRi'$	3.3	$R > 19.0$	12	4035

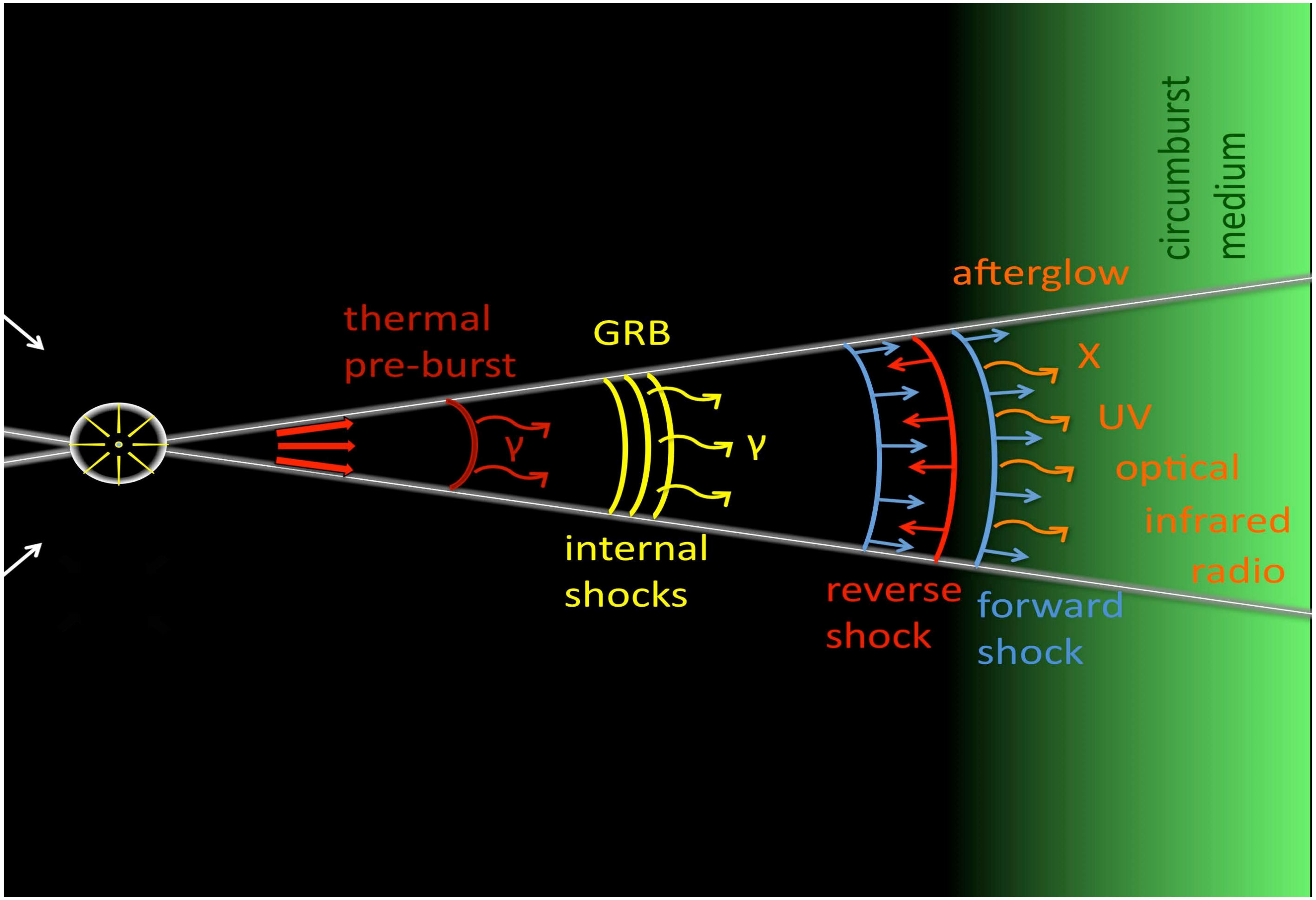
[a] This corresponds to the time delay with respect to the GRB trigger time.

Progenitors of GRBs



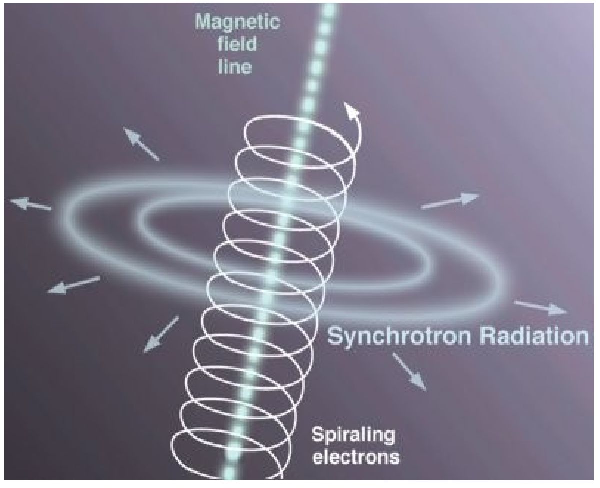
- Short GRBs thought to be from NS-NS or NS-BH mergers.
- Long GRBs from massive stellar explosions such as hypernovae or collapsars

The Fireball Model



T.Piran 1998

Fireball Magnetisation

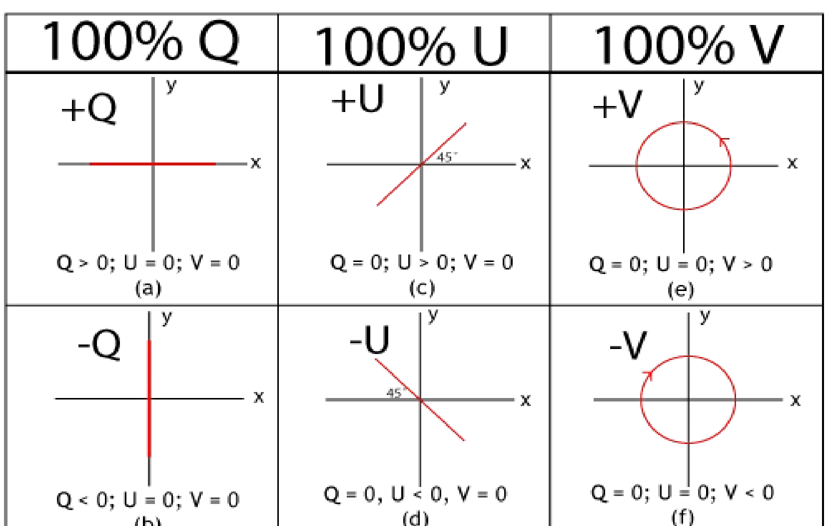


- Standard Model (Synchrotron Radiation)
  - Baryon Dominated Jet creates tangled B-Field in shock layer
  - Explains High variability in prompt emission
  - However conversion of bulk to radiated energy is too inefficient
- Alternative Model (Poynting Flow)
  - Powerful Magnetic fields twisting outwards
  - Provide powerful acceleration and collimation
  - May have dispation of energy via magnetic recombination
  - Energy Transfer details are still unknown

Polarimetry

- Polarisation of light is caused by non homogeneity in sources and represented mathematically by Stokes Vectors

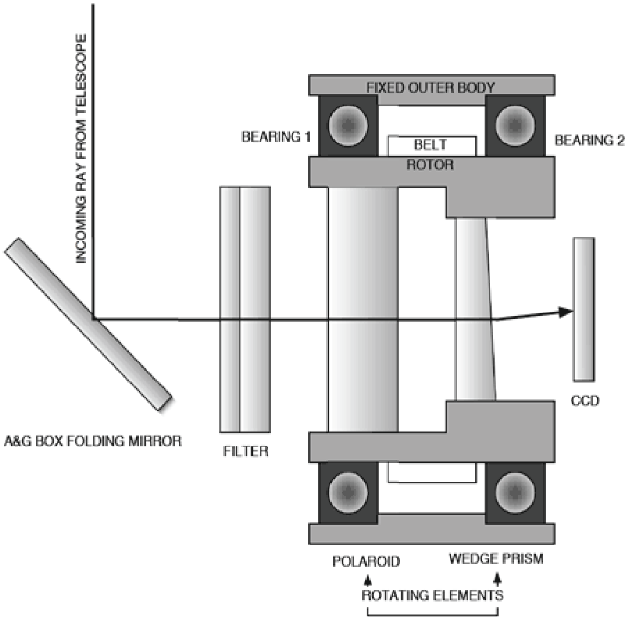
$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

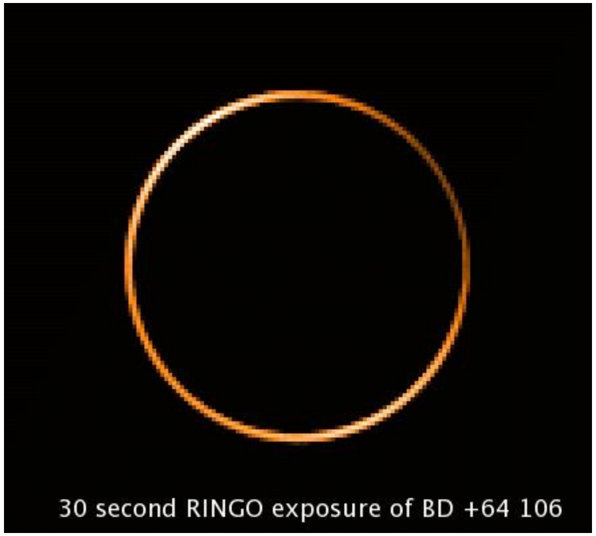


$$\begin{pmatrix} S_0{}' \\ S_1{}' \\ S_2{}' \\ S_3{}' \end{pmatrix} = \begin{pmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix}.$$

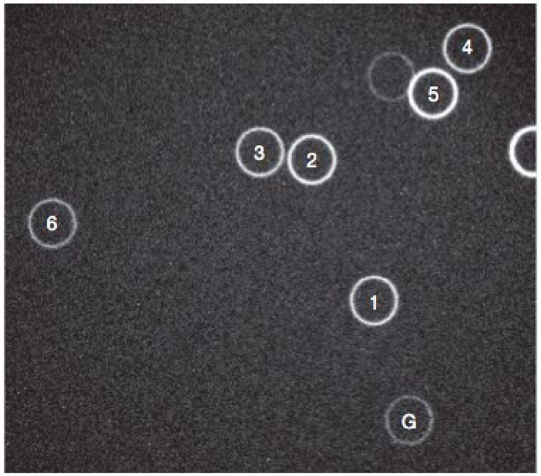
RINGO

- Novel design incorporating rapidly rotating polaroid and prism.
- Ringed stellar images contain the average linear polarisation state of the source.
- By taking the flux in 8 Segments polarisation is calculated as per Clarke and Nuemayer 2002





RINGO Science Successes



- First confirmation of polarised afterglow
- 10% Linear Polarisation from GRB 090201
- However, limited to brightest bursts R~16
- No capability to look into variations in polarisation during integration time.

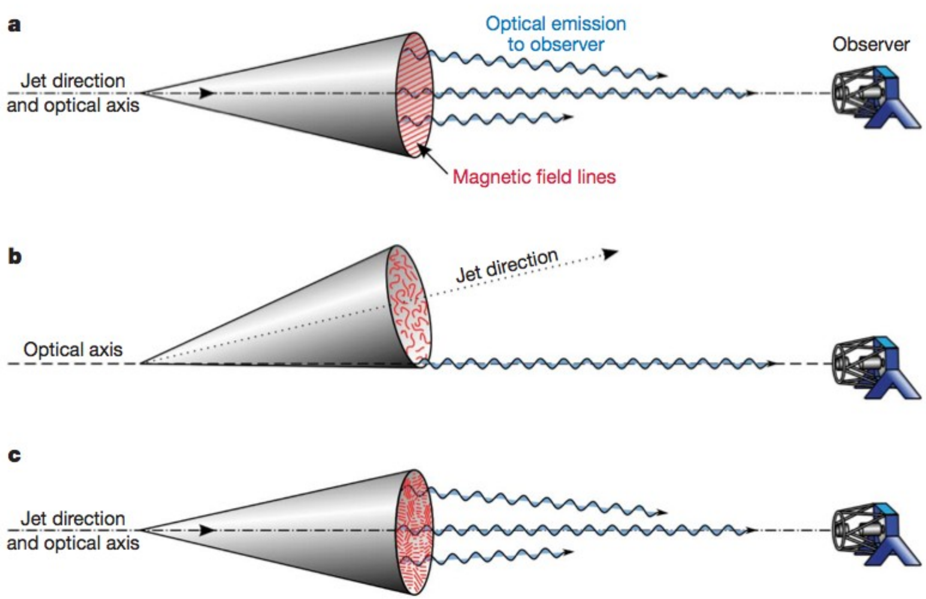
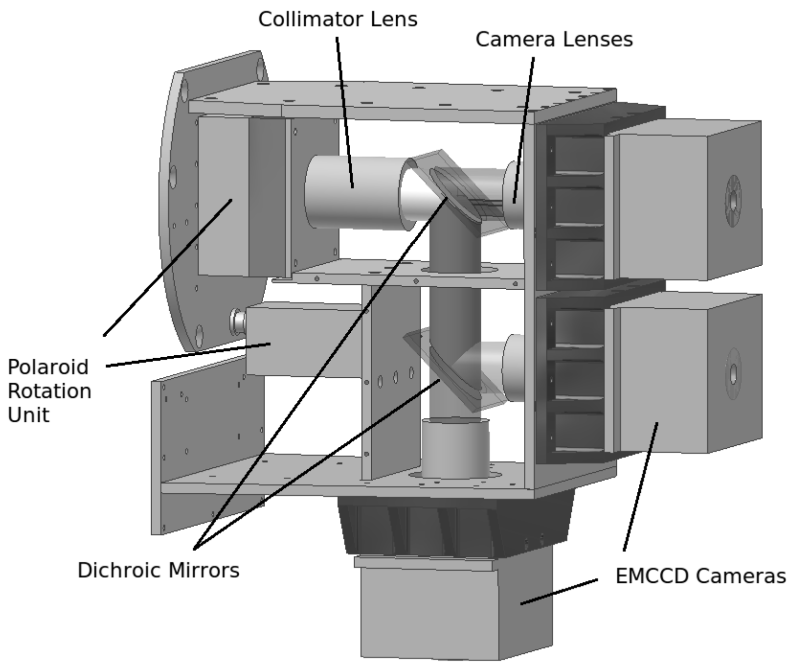


Figure 4 | Competing models of GRB magnetic field structure. The schematic shows three representations of a GRB outflow in the context of the standard fireball model for a variety of magnetic field structures and different orientations to the observer's line of sight (optical axis). A large degree of polarization is predicted when the ejected material is threaded with a large-scale ordered magnetic field as shown in **a** and is the favoured model to explain the measured polarization in GRB 090102. Alternatively, if no ordered magnetic field is present and instead a tangled magnetic field is produced in the shock front, the detected light will be polarized only if the observer's line of sight is close to the jet edge (**b**). In this case, however, the predicted steepening of the light curve that is expected when observing an off-axis jet is inconsistent with the flattening exhibited in the light curve of GRB 090102. A compromise is shown in **c** in which the shock front contains a number of independent patches of locally ordered magnetic fields; a measured polarization of 10% is at the very uppermost bound for such a model.

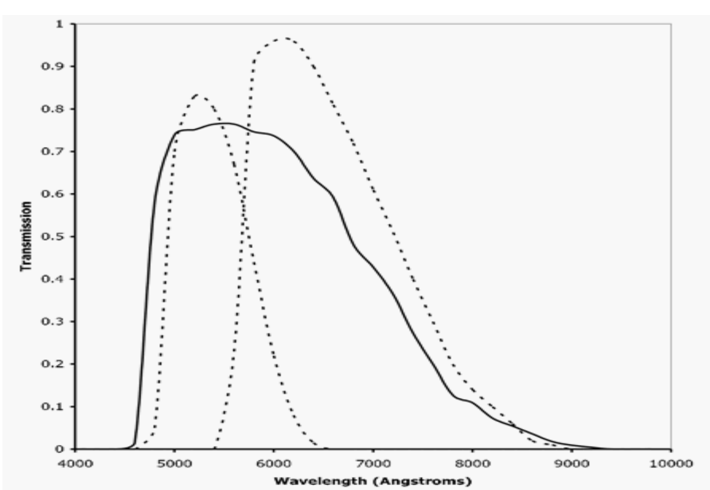
RINGO2 and RINGO3

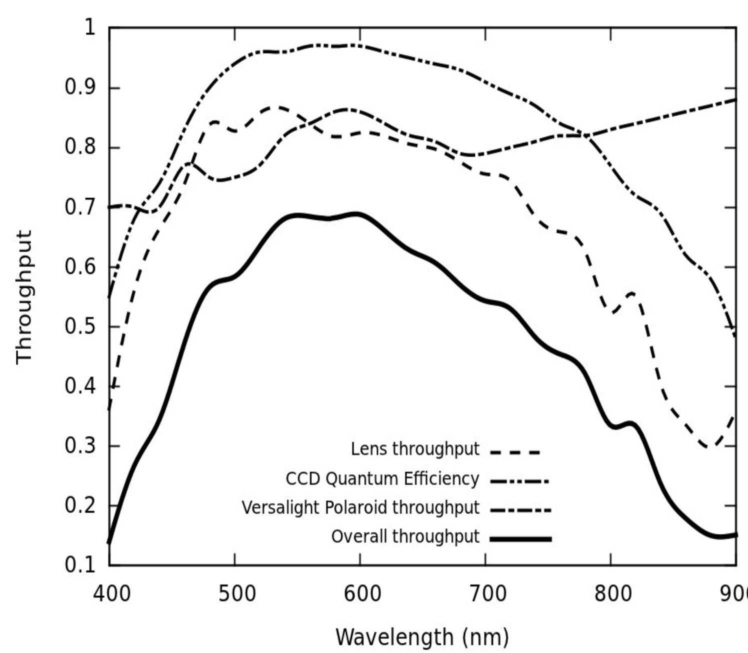
- Using fast readout ANDOR EMCCD Cameras.
- Take 8 frames per rotation of the polaroid (~8Hz).
- Normal imaging allows more bursts to be observed (down to 17th Mag).
- Capable of accurate photometry and polarimetry on variable time scales.

RINGO3 Design



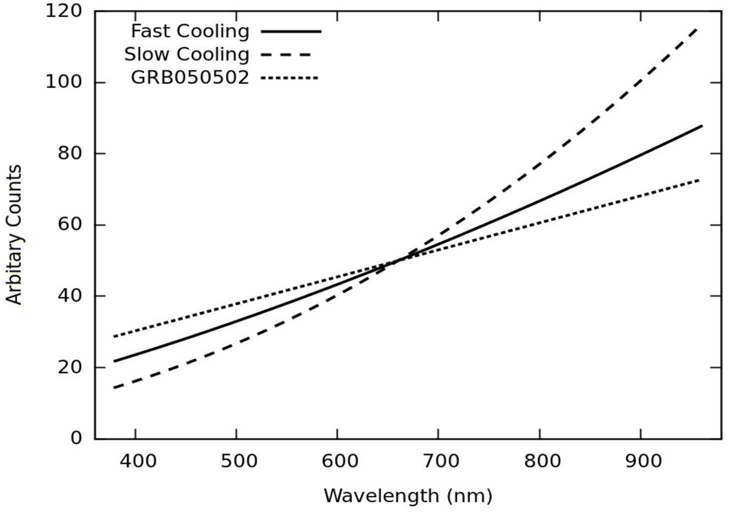
- An extension of RINGO2, to provide 3 simultaneous wavebands.
- Special Low polarisation dichroic mirrors split the beam.
- The beam is split to provide 3 bands with equal signal to noise ratios.
- Operating wavelengths 4000Å - 9000Å

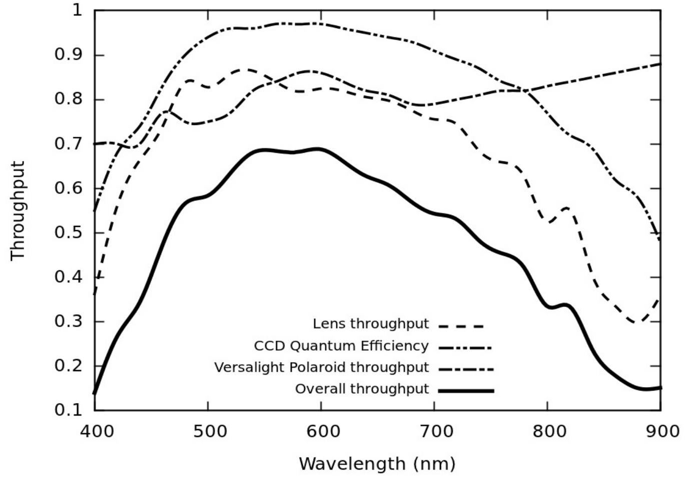


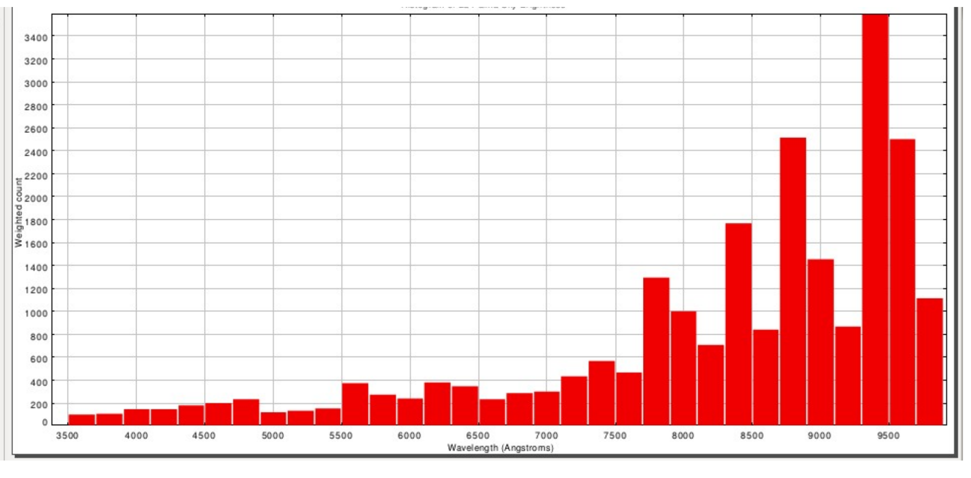


Determination of RINGO3 Wavebands

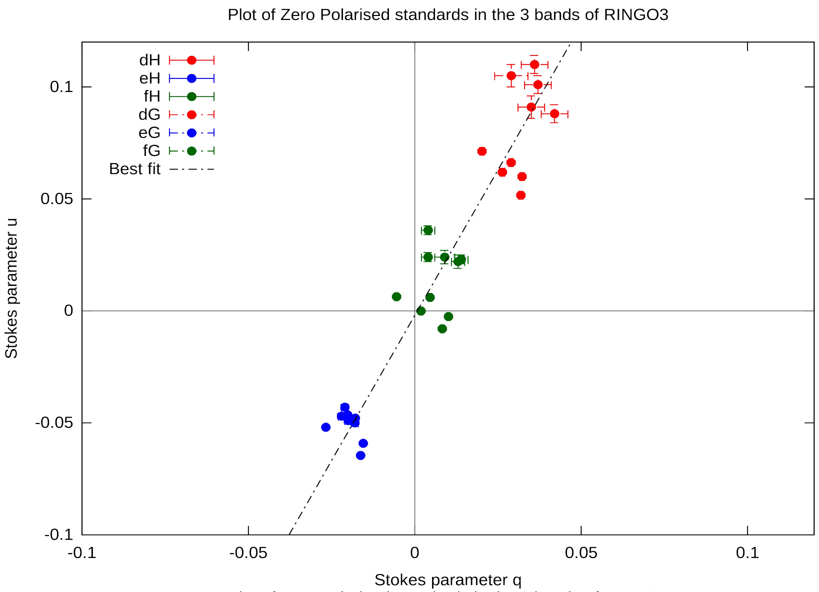
- Signal → Early time GRB Spectra from Models (Sari, Piran and Narayan 1998) and photometric observation (Guidorzi 2006).
- Noise → Sky Brighness of La Palma (Benn and Ellison 1998)
- Bands Calculated by modelling the Signal and Noise through the instrumental throughput.
- Ended up with broad BV band, R band and I band.

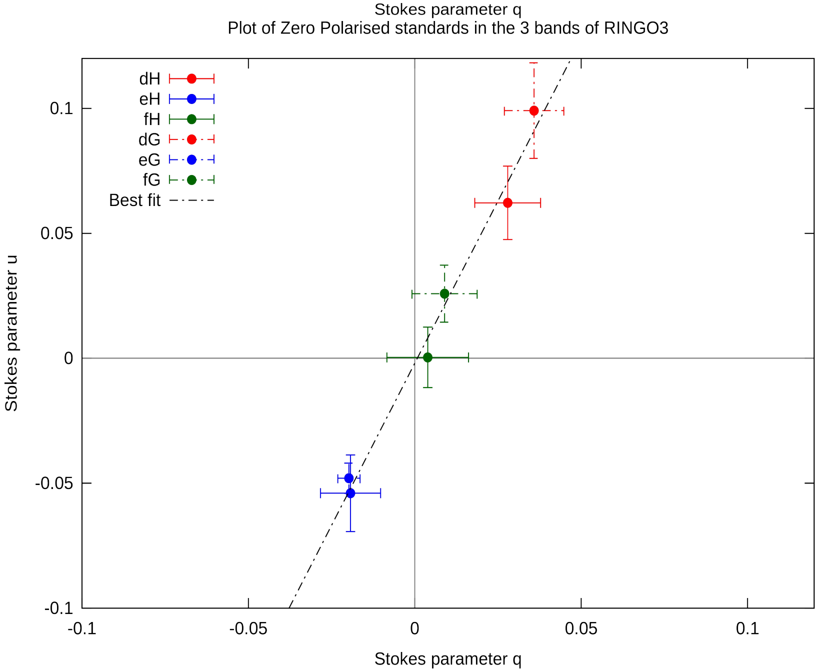






Initial RINGO3 Characterisation

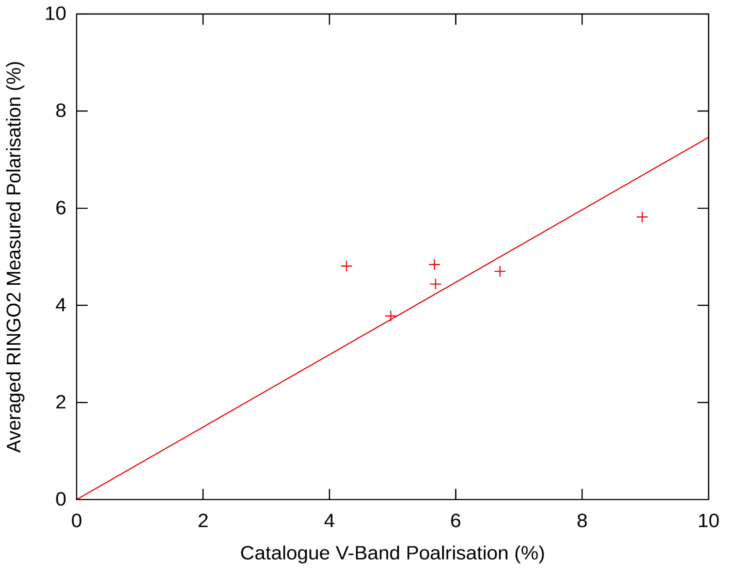


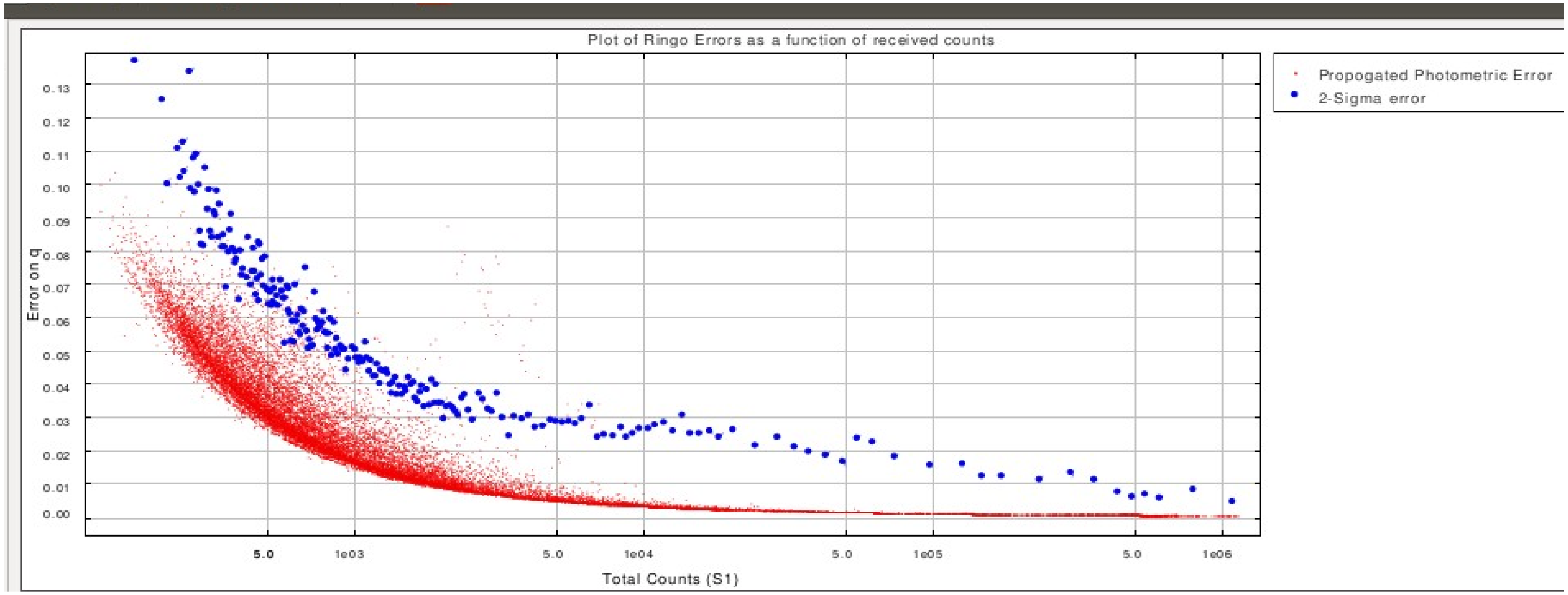


- Observations of zero polarised standards during commissioning showed some variance in the R and I bands.
- There are obvious sources of systematic error in these bands which needs to be chased down.
- RINGO3 has undergone final focusing of the 3 cameras and is now taking standards routinely.
- We will have to review the stability of the instrument soon.

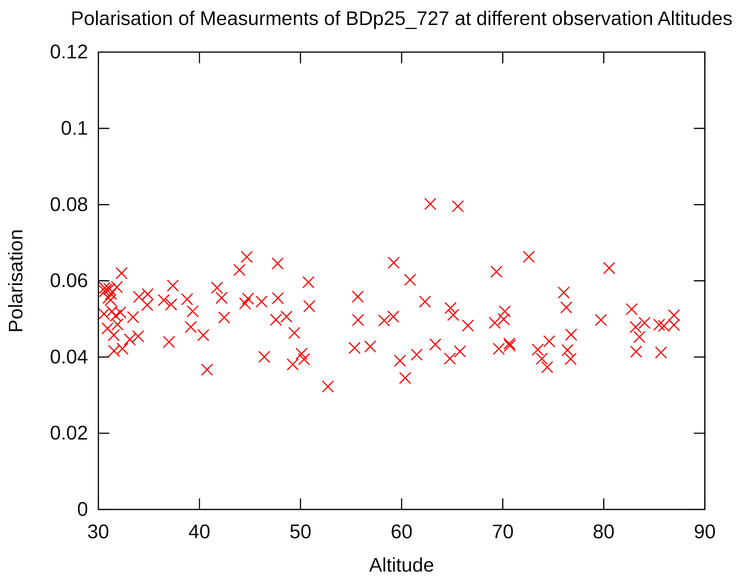
Characterisation of RINGO2

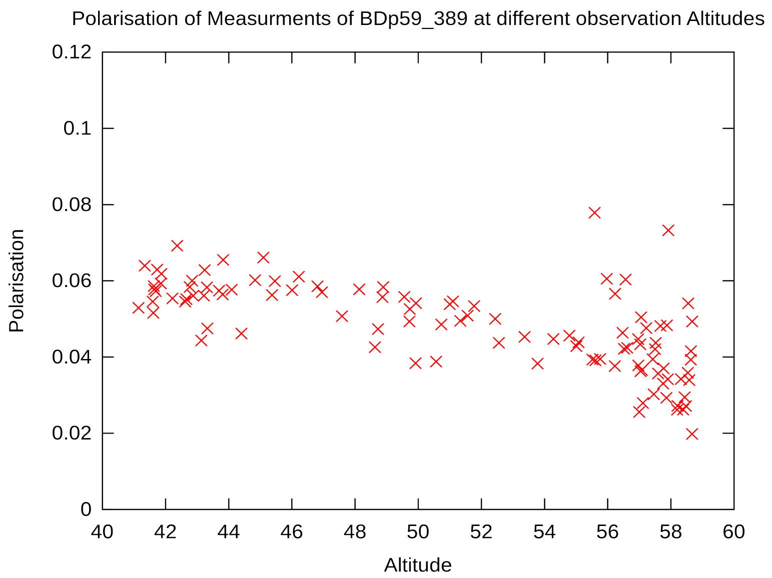
- Polarised and Unpolarised standards from Schmidt 1993 are observed nightly, with Cassegrain rotation zero.
- 18 months of observations yielded 2000 observations
- A pipeline was built to extract all sources in all fields and calculate the polarisation
- We checked the temporal stability of the instrument, calculated the instrumental polarisation, instrumental depolarisation and took a look at the variance of measurements due to systematics.

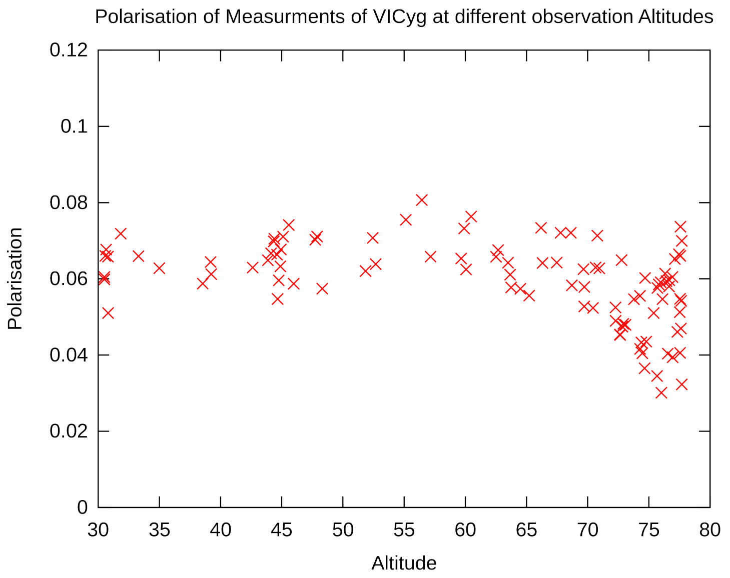


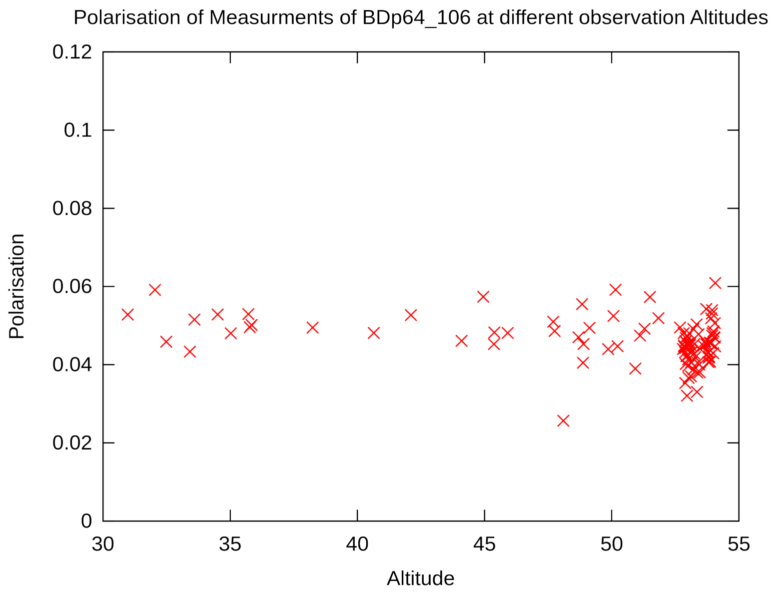


Characterisation of RINGO2

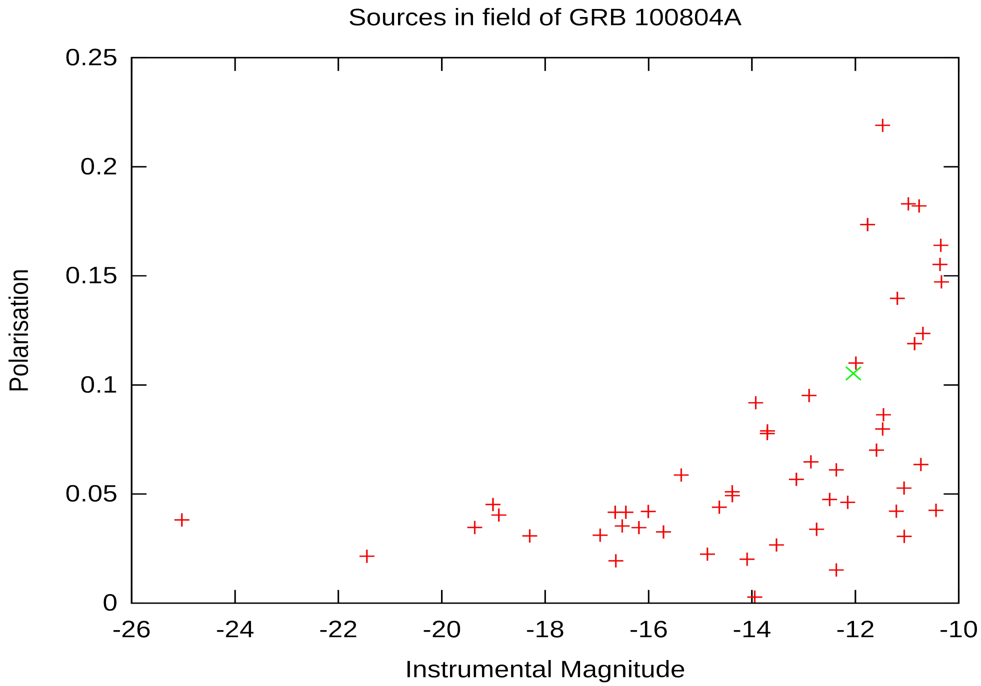


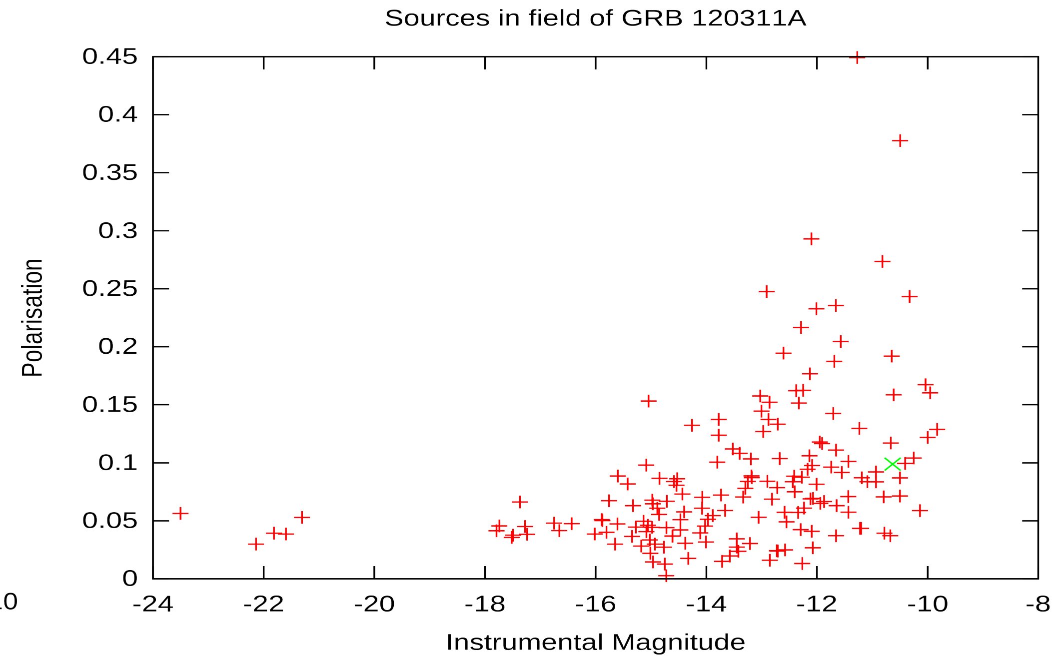






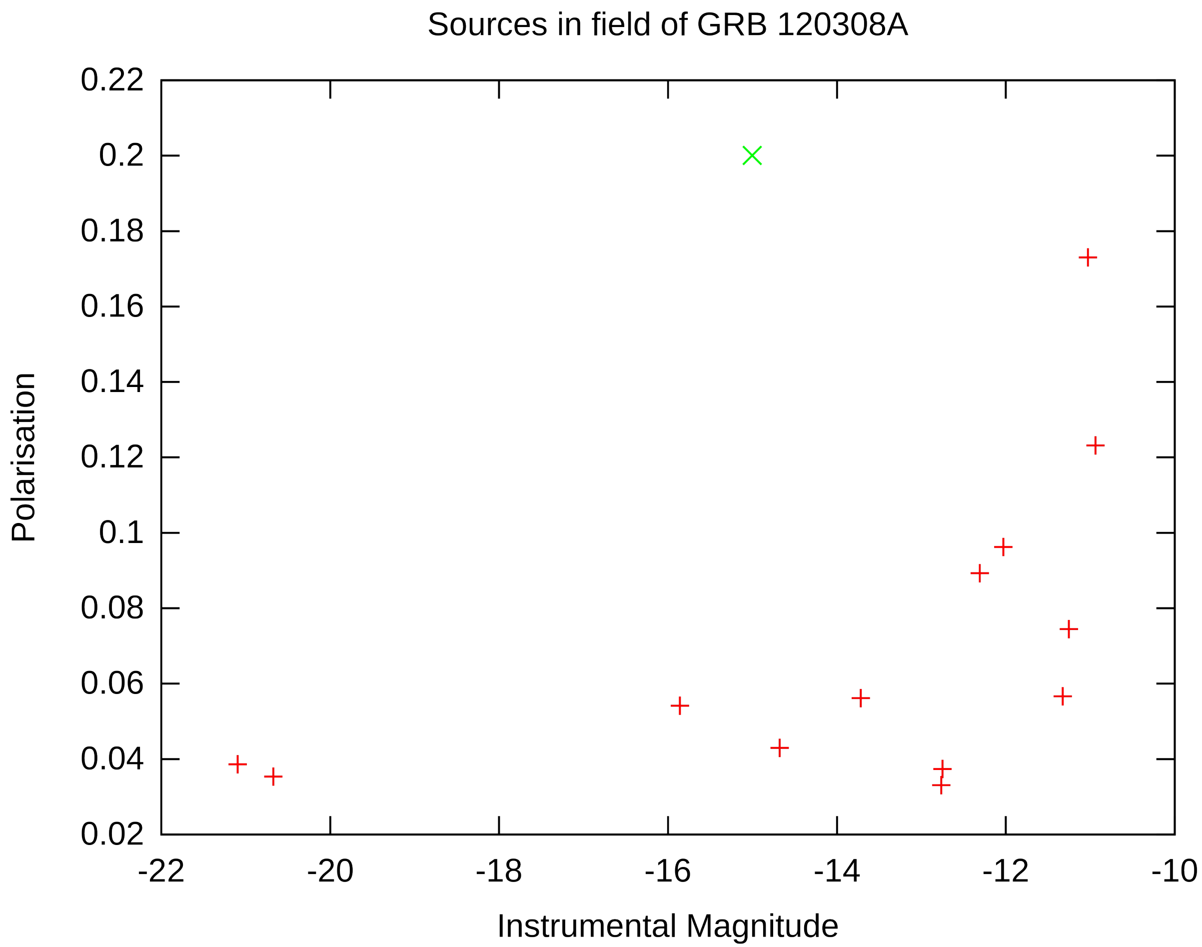
Analysis of RINGO2 GRB data





- Initial plots take the form of Magnitude vs Polarisation plots of all sources in the field of the science capture.
- These are the full 700s worth of frames stacked, and an average polarisation for the full 700s is calculated.
- By comparing with the polarisation caused by photometric error, we can deduce instantly if a GRB has a significant level of polarisation.
- Of the 6 burst sample, 5 are upper limits of polarisation. Only 120308 shows significant polarisation.

GRB 120308



Sources in field of GRB 120308A
Polarisation
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
-22
-20
-18
-16
-14
-12
-10
Instrumental Magnitude

Temporal data of GRB 120308A

	Inst Magnitude	Polarisation	Angle Degrees
120308a	-16.53	0.25	12
120308b	-16.12	0.24	179
120308c	-15.52	0.18	167
120308d	-15.79	0.15	176
120308e	-15.11	0.19	1
120308f	-14.58	0.17	7
120308g	-14.09	0.15	175

Next Steps

- Need to finalise analysis of 6 RINGO GRBs and publish.
- RINGO3 needs to be characterised and sources of error identified.
- Investigations into viability of RINGO3 as an OT identification instrument.

THANKYOU!