Looking inside jets:
Optical polarimetry as a probe of Gamma-Ray Bursts physics

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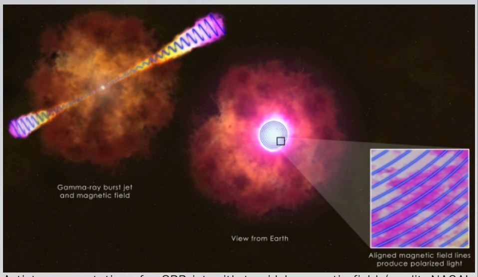
Introduction

Gamma-Ray Bursts (GRBs) are powered by accretion of matter by black holes, formed during massive stellar collapse or compact binary mergers, which launch ultra-relativistic, collimated outflows or jets. They are among the most luminous and distant objects in the Universe, detected up to redshift z < 10.



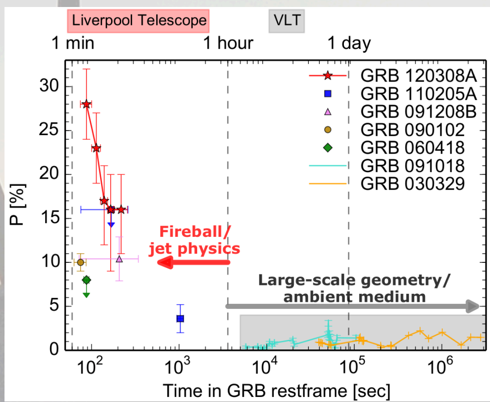
Artist representation of a GRB jet with toroidal magnetic field (credit: NASA's Goddard Space Flight Center/S. Wiessinger).

The nature of the progenitor star, the structure of the jet, and the underlying mechanisms that drive the explosion and provide collimation, remain key unanswered questions in modern astrophysics. Early time-resolved polarimetry is the only direct probe of the magnetic fields structure. Measurements of early time GRB polarization obtained by fast RINGO polarimeters mounted on the Liverpool Telescope provide most up-to-date clues on the physical conditions in GRB outflows.

Current state of the art

> 2 GRBs with RINGO:
GRB 060418 and GRB 090102
> 9 GRBs with RINGO2:
Upper limits, except GRB 120308A
Sample paper in preparation
> RINGO3 project is ongoing

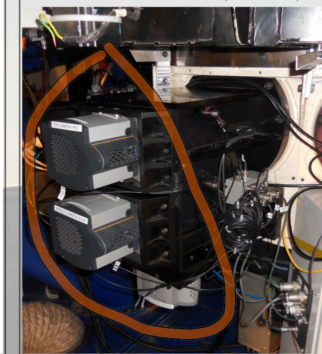
At early times (up to a few minutes after GRB explosion), properties of the original fireball are still encoded in the emitted light, while at later times (hours or days after explosion), the emission is coming from the shocked interstellar medium.



Polarization vs. restframe time of observations (Mundell et al. 2013). The figure shows importance of early time polarimetry to probe magnetic field properties.

The Liverpool Telescope and RINGO polarimeters

Prof Mike Bode in front of the Liverpool Telescope.



RINGO3 polarimeter with 3 cameras, fitted at the Cassegrain focus on the LT (credit: H. Jermak).

The Liverpool Telescope (LT), located on the Canary Island of La Palma, is the world's largest, fully autonomous, robotic optical telescope. It is owned and operated by the Astrophysics Research Institute (ARI), part of Liverpool John Moores University (Steele et al. 2004).

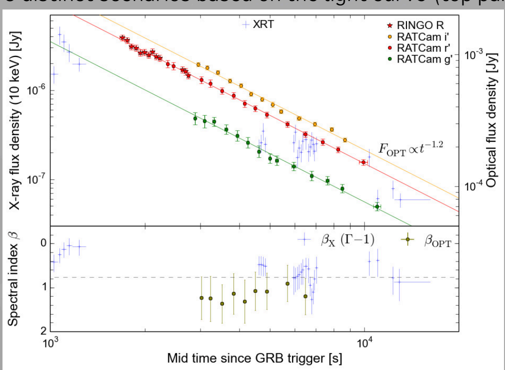
Its fast and rapid response enables photometric, polarimetric, and spectroscopic follow-up of transient events in the first minutes of identification, making it especially useful for early time observations of GRBs.

RINGO generations of polarimeters were designed for use on LT (Steele et al. 2006). All versions consisted of rotating polaroid (once per second). In RINGO2, a single fast readout EMCCD camera was used, while RINGO3 uses a pair of dichroic mirrors which split the light beam into three wavelength bands (approximately VRI), recorded by 3 separate EMCCD cameras (Arnold et al. 2012). This provides 3-colour polarimetry and photometry, to study also the spectral energy distribution.

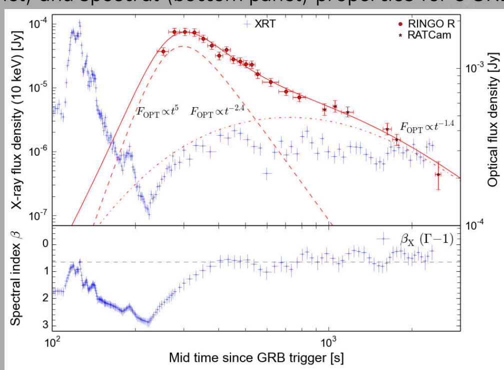
For more information visit the LT webpage.

Case study for 3 GRBs

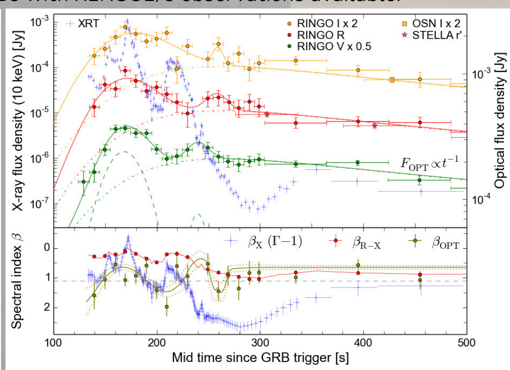
3 distinct scenarios based on the light curve (top panel) and spectral (bottom panel) properties for 3 GRBs with RINGO2/3 observations available:



GRB 120327A (preliminary results, in prep.)
> Peak brightness: R = 16.6 mag
> RINGO2 first epoch from 1660 - 2260 seconds
> Low limits of optical polarization:
P < 3 % (1sigma), throughout first epoch
> Late time observations
> Light curve interpreted as due to
forward-external shock afterglow



GRB 120308A (Mundell et al., 2013)
> Peak brightness: R = 15.8 mag
> RINGO2 data from 240 - 840 seconds
> High degree of polarization: P = 28(+- 4) %
decreasing down to P = 16(+5, -4) %
> Stable polarization position angle
> Light curve interpreted as combination of
reverse- and forward-external shock (afterglow)
> Magnetized baryonic jet probed by reverse-shock



GRB 140430A (Kopac et al., 2015, submitted)
> Peak brightness: R = 16.5 mag
> RINGO3 data from 120 seconds onwards
> Optical flares coincident with prompt
gamma/X-ray emission (internal shock emission)
> Relatively low limits of optical polarization
during flares: P < 12 % (1sigma)
> Summing over many distinct flares can lower the
net polarization if polarization angle is different

Discussion

The question remains whether GRB outflows contain ordered large-scale magnetic fields, which could be advected from the central source, or whether magnetic field is generated locally by plasma instabilities within the shock region. Recent studies showed that in some cases, high polarization (40 - 60 %) was measured also in gamma-ray band by various satellites (Yonetoku et al. 2012, Goetz et al. 2009, 2013). Observations across wide wavelength range are needed, which would provide information not only about the degree of polarization, but also about the origin of early optical emission (internal shock flares vs. external shock afterglow).

References

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