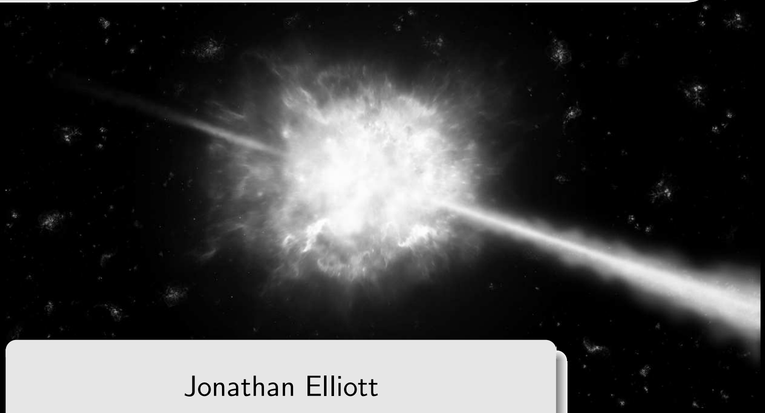
Using γ-ray bursts as tools

prompt emission mechanism



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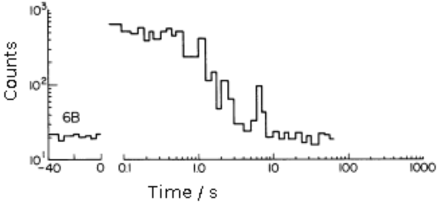
Ph.D. Defence Presentation

History of GRBs

Gamma-ray bursts (GRBs) were first discovered by the Vela military satellites. They are the brightest object in the Universe (Luminosities$\sim 10^{53}\,\mathrm{erg\,s^{-1}}$).



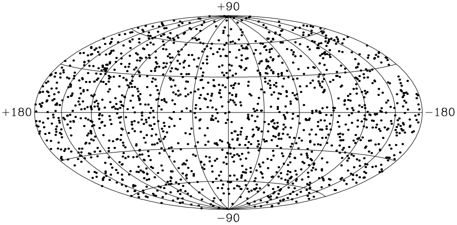
Klebesadel+73

They had the two main properties:

1. Isotropic
2. Two classes based on temporal duration

Isotropic

1. The distribution of GRBs in the sky was seen quite early to be isotropic.

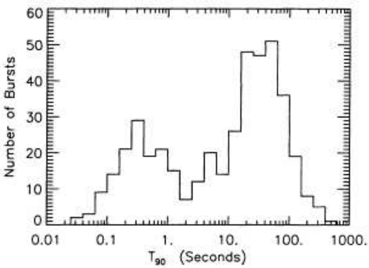


Paciesas+94

This was believed to be a result of the fact that GRBs were cosmological and later proven by a spectroscopic redshift.

Two Classes

1. The duration of the gamma-ray emission in the observer frame gives rise to two distinguishable classes.



NASA+13

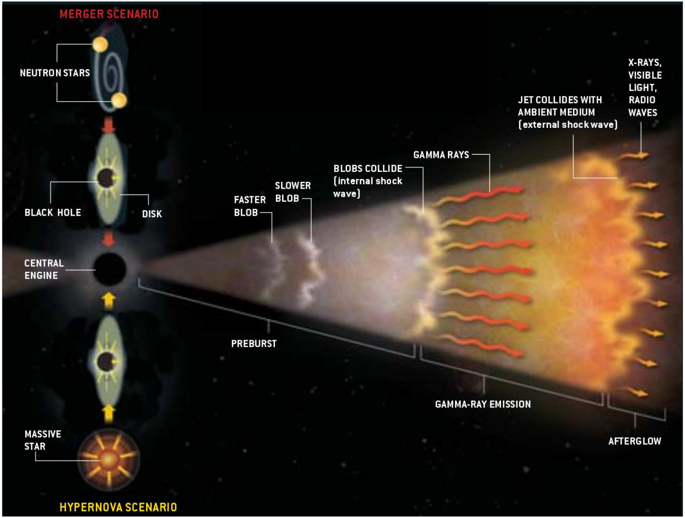
Note: T_{90} is the time in which 90% of the gamma-ray flux was emitted.

Long-duration: $T_{90} > 2\,\mathrm{seconds}$
Short-duration: $T_{90} < 2\,\mathrm{seconds}$

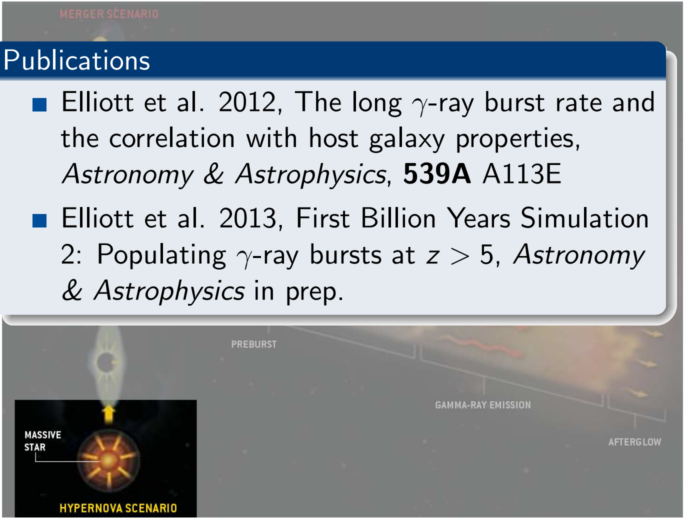
Summary of Properties

1. Long-soft GRBs ($T_{90} > 2\,\mathrm{s}$) up to $\sim 300\,\mathrm{s}$
2. Short-hard GRBs ($T_{90} < 2\,\mathrm{s}$)
3. Cosmological sources
4. γ-ray, X-ray and Optical detections
5. Power law spectra and light curves

Standard Models



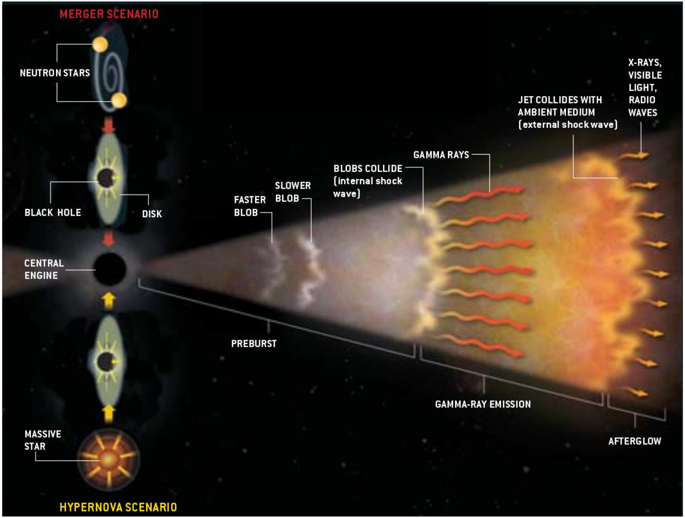
Standard Models



Publications

- Elliott et al. 2012, The long γ-ray burst rate and the correlation with host galaxy properties, *Astronomy & Astrophysics*, **539A** A113E
- Elliott et al. 2013, First Billion Years Simulation 2: Populating γ-ray bursts at $z > 5$, *Astronomy & Astrophysics* in prep.

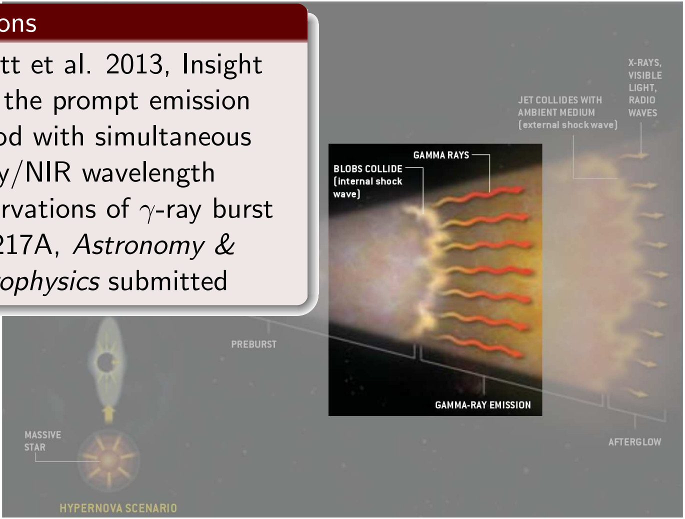
Standard Models



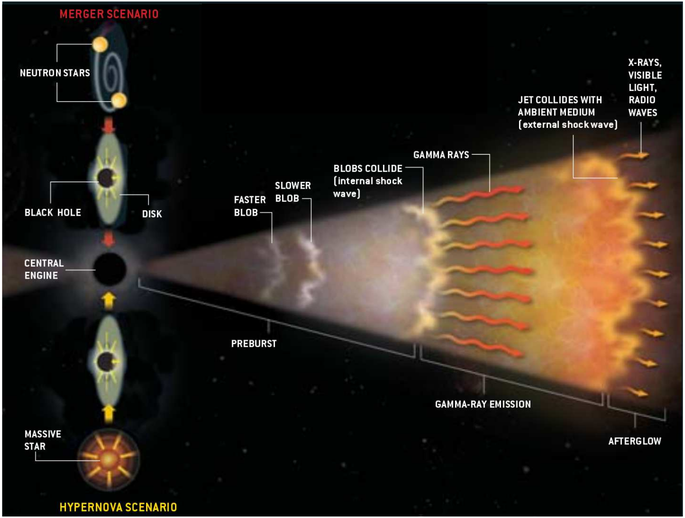
Standard Models

Publications

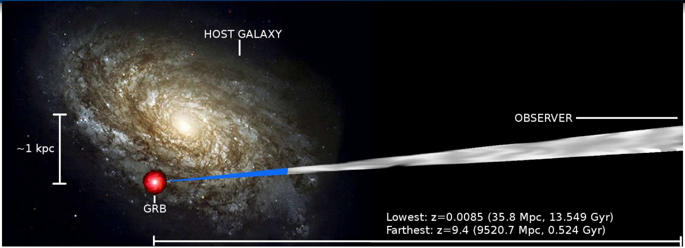
- Elliott et al. 2013, Insight into the prompt emission period with simultaneous γ-ray/NIR wavelength observations of γ-ray burst 121217A, *Astronomy & Astrophysics* submitted



Standard Models

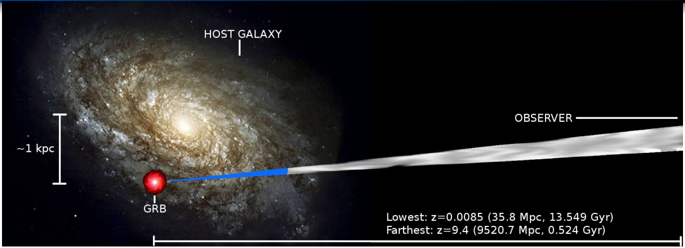


Standard Models



What does the environment and it's galaxy tell us?

Standard Models

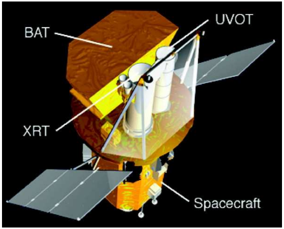


What does the environment and it's galaxy tell us?

Publications

- Elliott et al. 2013, The low-extinction afterglow in the solar-metallicity host galaxy of γ-ray burst 110918A, *Astronomy & Astrophysics*, **556** A23

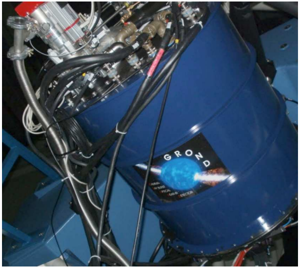
GRBs are detected using space-based observatories. We primarily use the two NASA satellites *Swift* and *Fermi*.



A. *Swift* has Burst Alert Telescope (BAT), an X-ray Telescope (XRT) and an Ultra-Violet/Optical Telescope (UVOT)
   8.3 pm (150 keV) → 192.8 nm (6.5 eV)
B. *Fermi* has a Large Area Telescope (LAT) and a Gamma-Ray Burst Monitor (GBM)
   4.1 am (300 GeV) → 0.2 nm (8 keV)

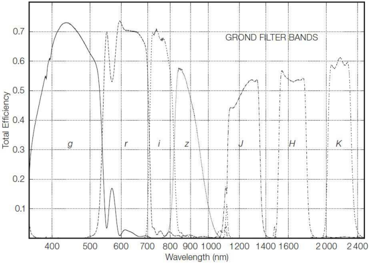
GROND

The **G**amma-**R**ay burst **O**ptical **N**ear-infrared **D**etector (**GROND**) is a multi-channel imager located in Chile at La Silla (the chair).



GROND's Filters

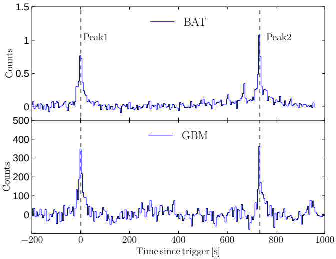
GROND has seven filters: four optical bands ($g'r'i'z'$) that are similar to the Sloan digital sky survey, and three near-infrared (JHK) channels like the two-micron sky survey.



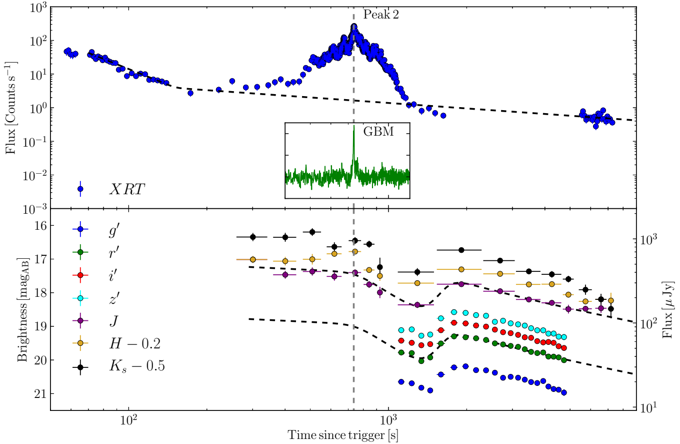
The unique ability of GROND is that all seven filters are exposed at the same time.

GRB Detection

1. Detected on 17th December 2012 by *Swift*
2. Observed with:
   - *Swift*/BAT/XRT(/UVOT - no detection)
   - *Fermi*/GBM
   - GROND
3. Two discernible peaks



X-ray/NIR/Optical Light Curve



Why is this interesting?

The main drivers for investigating this GRB are:

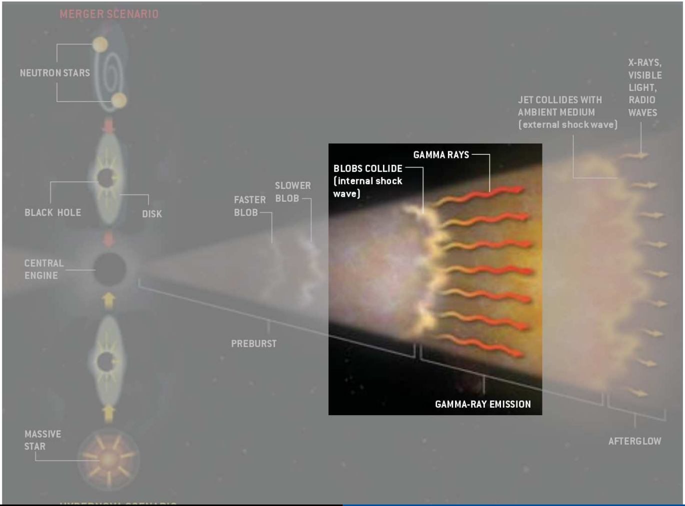
1. Limited number of detections of optical emission during the prompt period
2. Limited samples have a range of selection criteria
3. Each burst has shown different results, still no consensus
4. Even if they are observed, they do not always have more than one filter

Fireball Model

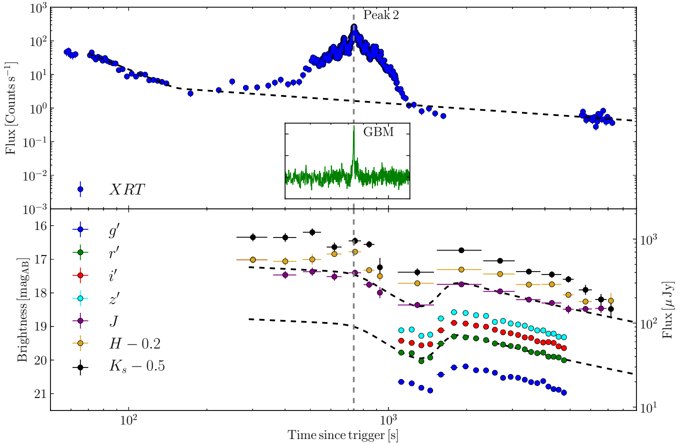
The most tested (favoured) model of the prompt emission is the *internal shock* model. This entails:

1. Shells of electron/positron/photon fireballs with varying Lorentz factors are emitted from a central engine
2. These shells cross one another and create internal shocks
3. These shocks accelerate electrons via Fermi acceleration
4. These electrons cool via **synchrotron emission** $\rightarrow$ *Power law*

Fireball Model Cont.

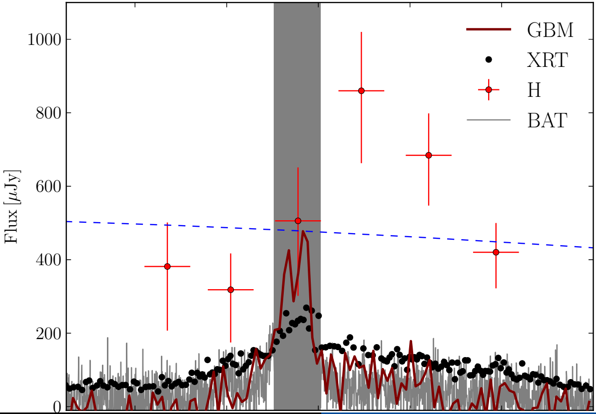


Fireball Model Cont.

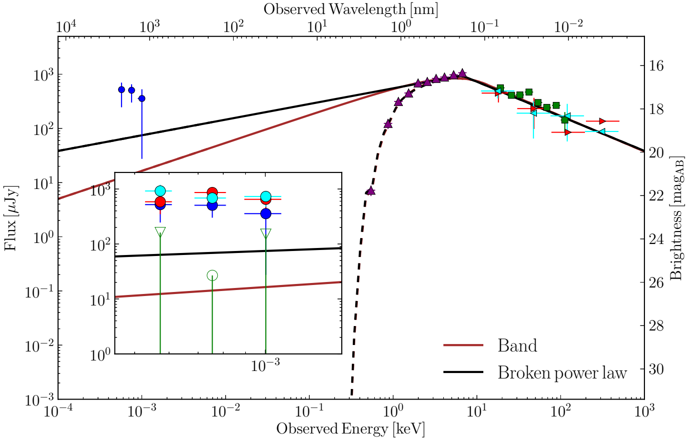


Fireball Model Cont.

Zoom light curve



Fireball Model Cont.



Fireball Model Cont.

Expect a power law from synchrotron theory

1. Broken power law spectrum:

$$F(\nu) = F_0 \left(\left(\frac{\nu}{\nu_m} \right)^{-\beta_1} + \left(\frac{\nu}{\nu_m} \right)^{-\beta_2} \right)$$

   - ν_m - the break frequency
   - β_1, β_2 - the slopes above and below the break frequency
   - F_0 - the normalisation of the spectrum at a given time and frequency (t_0, ν_0)

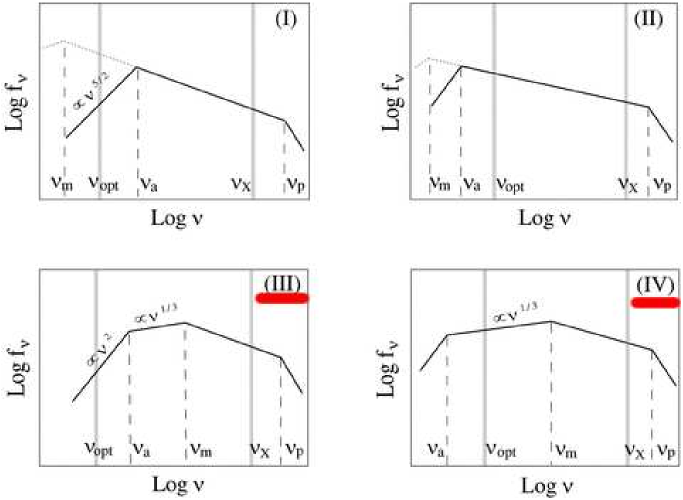
2. (another model: Band function completely empirical)

Fireball Model Cont.

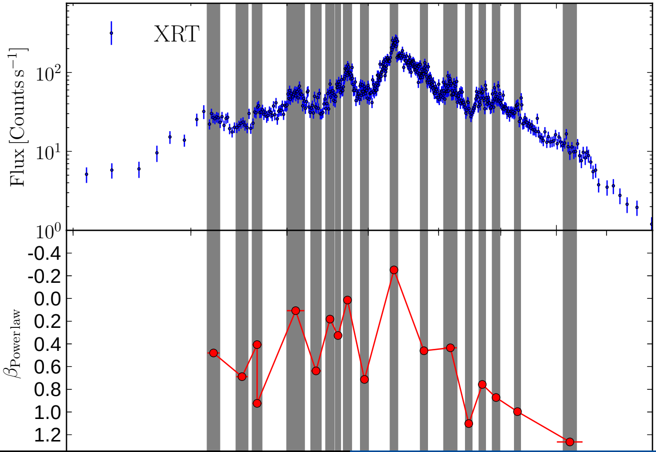
- $\beta_1 = -0.29 \pm 0.06$
- $\beta_2 = 0.64 \pm 0.05$
- $\nu_m = 6.06 \pm 0.86\,\mathrm{keV}$

But what do we expect from synchrotron theory?

Fireball Model Cont.



Fireball Model Cont.



Internal Shock Model Problems

There are still several problems with the internal shock model:

1. low radiative efficiency
2. incorrect peak energies
3. large magnetic fields can inhibit radiation
4. expect quasi-thermal photosphere component at high energies

Alternative Models

The synchrotron-like emission could originate from other mechanisms:

1. Magnetically heated outflow (synchrotron emission)
2. Poynting-flux dominated outflows (Band-like emission)

Summary & Outlook

1. We showed that the prompt-emission period of GRB 121217A can be explained by synchrotron emission and within the framework of the internal shock model
2. We were limited by spectral sampling during the prompt emission due to technical reasons
3. Observations are needed with high-time resolution and in multiple filters
4. This is currently possible at the Very Large Telescope (ESO), e.g.: NACO
5. Underlying problems that will continue to plague us: the possibility of triggering and the complexity of the emission