Gamma-Ray Bursts

• How do GRBs make gamma-rays?

• What are the impacts of GRBs on Earth?
What isn’t known about GRBs?

- Where does the afterglow come from?
- How do they make gamma-rays?
- What conditions are needed to make a GRB?
- What powers them? (Neutron star or BH)
How does a GRB make gamma-rays?
GRB Observations

- 080916C

Zhang et al. 2010 arxiv: 1009.3338
Old Model: Internal Shocks

- Energy injected by central engine at $10^7 - 10^8$ cm
- As jet propagates, relativistic material accelerates and cools
- At photosphere ($10^{12} - 10^{13}$ cm), little internal energy, not much emission
- Internal variation in flow leads to shocks at $10^{14}-10^{15}$ cm
- Gamma-rays from synchrotron radiation
Synchrotron radiation

- Non-thermal radiation from particles in a magnetic field
- Power-law slope at low and high frequencies
Problems with Internal Shock Model

- Not very efficient, <10% of energy converted to gamma-rays
- Also problems reproducing observed spectrum
- Problem reproducing the Amati relation and other GRB correlations

New Models: Photospheric emission or magnetically dominated jets
GRB Simulation
In simulations, stellar envelope collimates the jet with oblique shocks.

- Opening angle at a few stellar radii only: 3-5°, not 10°
- Lorentz factor: ~20, not ~200
Jet Collimation

- Collimation keeps the jet hot
- Internal energy \(\sim\) rest mass energy
- Lorentz factor \(\sim 200\), not saturated at 400
Photospheric Emission

- Light curves
- $L_{\text{Bol}}$ up to $10^{52}$ erg/s
- Near the jet axis, there is a bright initial phase
- Off axis, dim then slowly brightens
Photospheric Efficiency

Very efficient, 20 % to 40%
Amati Relation
Amati Relation

- 16Tl
- $16Tl, L_{jet} = 1 \times 10^{50}$, $\Gamma_\infty = 100$
- 35OB
- $16O\l$
- $16Tl$, $L_{jet} = 1 \times 10^{50}$
- $16Tl$, $\theta_o = 5^\circ$
- $16Tl$, $t_{eng} = 67s$
- $16Tl$, $t_{eng} = 30s$

Graph showing the relationship between peak photon energy (keV) and isotropic equivalent energy (erg) with various markers and error bars.
Problems with Photospheres

- GRBs don’t look like a black body
- Need power law both below and above peak
- Black body is too steep at both ends
- Peak energy too low for Amati
GRB Observations

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Zhang et al. 2010 arxiv: 1009.3338
Magnetically Dominated Jets

- Hide photospheric emission by putting energy into magnetic field
- Instabilities lead to reconnection
- Convert magnetic field into particle energy
- Emits synchrotron radiation
Magnetically Dominated Jets

- Needs fast reconnection
- Not certain how particles are accelerated
- Not certain if observed spectrum can be reproduced
- Should not produce GeV neutrinos
GRB Summary

• Long GRBs made from jets inside a dying star
• We are looking down the jet, see very relativistic material making gamma-rays
• Still a lot that we don’t know about them
GRB Record Holders
GRB Records

- Most distant GRB measured at $z = 9.4$, Universe only 520 million years old.

- Closest GRB at $z = 0.0085$, 110 Mly away.

- Brightest GRB was $E_{\text{iso}} = 8.8 \times 10^{54}$ erg.

- Brightest afterglow reached mag. 5.8 in the optical, from $z = 0.937$ (7.5 Gly).
How close would brightest GRB need to be to be brighter than the Sun?

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- Would need to be at 2,328 light years
How far away does a typical GRB need to have more energy hit the Earth than the Sun does?

- Sun luminosity at Earth = 1300 W/s/m$^2$ = $1.3 \times 10^6$ erg/s/cm$^2$

- Typical GRB = $10^{51}$ erg/s
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• Sun luminosity at Earth = 1300 W/s/m² = 1.3 \times 10^6 \text{ erg/s/cm}^2

• Typical GRB = 10^{51} \text{ erg/s}

• Answer: about 7,800 light years
GRB Impacting Earth

- GRB 030329 had a measurable effect on the ionization of the upper atmosphere, from $z=0.168$ (2.1 Gly)