Announcements:
• Preflight 6 due next Monday noon

Last time: the Distance Scale to Gamma-Ray Bursts
Q: what is this scale? how do we know?
Q: what are population studies? how are they useful for GRBs?
Q: what’s difficult about quantifying burst timescale? spectra?
Q: how might you do it anyway?
GRB Populations: Timescales and Hardness

GRB lightcurves show wide diversity
→ difficult to characterize succinctly...but worth trying

timescale duration to see photon signal over background
depends on GRB fluence → distance, and detector sensitivity
largest confusion near background level so to avoid
use $T_{90} \equiv$ time interval for 90% of signal
  or $T_{50} \equiv$ time interval for 50% of signal
www: BATSE $T_{90}$ distribution

GRB detailed $\gamma$ spectra not available in BATSE
only broadband “colors”

hardness ratio of fluence in high- vs low-energy bands
a GRB “color index”
interesting to look at distribution and correlate with $T_{90}$
www: $T_{90}$--hardness correlation
GRB Populations: Two Classes

BATSE bursts show:

- clear bimodal separation in timescale separation at $T_{90} \sim 2$ sec
- less clear but bimodal separation in hardness
- groups in each are correlated → two GRB populations
  - short-hard bursts
  - long-soft bursts

Also note:
afterglows (almost) exclusively seen for the long-soft bursts
so only long-soft bursts have confirmed association with active star formation

few short-hard bursts afterglows, host galaxies found
but many are in elliptical galaxies,
and not in active star-forming regions
How Relativistic are Bursts?

burst energy density is enormous from know burst energies, timescales → huge photon energy density at source
εγ so high that γγ→e+e− efficient → photons should create pairs → rapidly thermalize
...but GRB emission nonthermal

cure: highly relativistic outflow
Lorentz factor Γ = 1/√1 − v²/c²
nonstandard symbol to avoid confusion with γ-rays

if Γ ≫ 1:
• blueshifting → smaller rest-frame photon energies
• to avoid thermalization: need Γ ≳ 100 !

bursts are ultrarelativistic!
Q: for comparison, what is ΓFermilab?
GRB Afterglows: Beaming

several lines of evidence point to beamed burst geometry
→ relativistic outflow confined to cone: opening angle $\theta$

special relativity: light source with $\Gamma$
has emission confined to region of angle $\sim 1/\Gamma$

thus: GRB emission initially highly collimated (radial photons!)
→ observer initially sees only small part of emitting region

but as burst decelerates, larger emitting region seen

$Q$: what happens when $1/\Gamma > \theta$?
if outflow is in jet of angle $\theta$
then when $1/\Gamma > \theta$, photons more isotropic than jet
→ more photons directed away from observer
→ substantial sudden decrease in afterglow brightness

afterglow lightcurves: show slope change “breaks”
imply significant beaming: $\theta \sim \text{few} \times 1^\circ$
→ fraction of solid angle:

$$f_{\text{beam}} \equiv \frac{\Omega_{\text{beam}}}{4\pi} = \frac{1}{2} (1 - \cos \theta) \approx \frac{\theta^2}{2} \sim \frac{1}{300} \quad (1)$$

Q: what does this imply for GRB properties? what changes, doesn’t?
Implications of Beaming: Event Rate, Energetics

given $f_{\text{beam}} = \Omega_{\text{beam}}/4\pi \sim 1/300 \ll 1$:
• we only see bursts aimed right at us
• energy output is highly anisotropic

ernergetics

typical isotropic energy output $E_\gamma = E^\text{iso}_\gamma = 4\pi d^2 F \sim 100$ foe

but this was an overestimate: correct value is

$$E_\gamma = \Omega d^2 F = f_{\text{beam}} E^\text{iso}_\gamma \sim 1$$ foe

rate per galaxy

from observed burst rate of $\lambda_{\text{obs}} = 1/\text{day/Universe}$

per galaxy we infer $\dot{N}_{\text{grb}} = \dot{N}^\text{iso}_{\text{grb}} = \lambda_{\text{obs}}/N_{\text{gal}} \sim 3 \times 10^{-5}$ GRB/century

but this was an underestimate, since $\lambda_{\text{obs}} = f_{\text{beam}} \lambda_{\text{tot}}$, so:

$$\dot{N}_{\text{grb}} = \frac{\lambda_{\text{tot}}}{N_{\text{gal}}} = \frac{1}{f_{\text{beam}}} \dot{N}^\text{iso}_{\text{grb}} \sim 10^{-3} \text{ GRB/century} \sim 0.1 \dot{N}_{\text{SN}}$$
Long GRBs and Supernovae

hints of supernova association with long-soft bursts:
• given beaming; long-soft burst energetics, rate in line with supernova blasts
• long-soft bursts found in regions of active star formation

direct evidence: supernova outbursts seen in GRB afterglows!
• SN 1998bw seen in unusually low-energy GRB 980326
• SN 2003dh seen in “vanilla” GRB 030329
• supernova spectra derived → no H, He I, Si II; lines all broad consistent with relativistic ejecta

all GRB-linked supernovae are Type Ic
• very massive star, winds/companion remove outer layers
  ...but not all Type Ic make GRBs
Collapsar Model

How does a supernova make a GRB?

collapsar model (Woosley)

- very massive progenitor, rapid rotation
- black hole formed in core, angular momentum $\rightarrow$ accretion disk
- relativistic jet created, punctures star

What makes the jet?
magnetohydrodynamic effects in GR?

www: Illinois Shapiro group GR magnetohydrodynamic collapse simulation