Models for gamma-ray bursts

Cosmological distance scale ⇒ large energies.

Together with the short time scale of variability (which implies a small size) only a few plausible progenitors.

For isotropic emission, we had:

$$E = S \times 4\pi d^2$$

- E: burst energy
- S: measured fluence of the burst (integrated flux, units erg cm^{-2})
- d: distance, can be measured if the distance to the host galaxy can be determined

Around ~30 GRBs with known distances - largest inferred burst energy is 3 x 10^{54} erg.

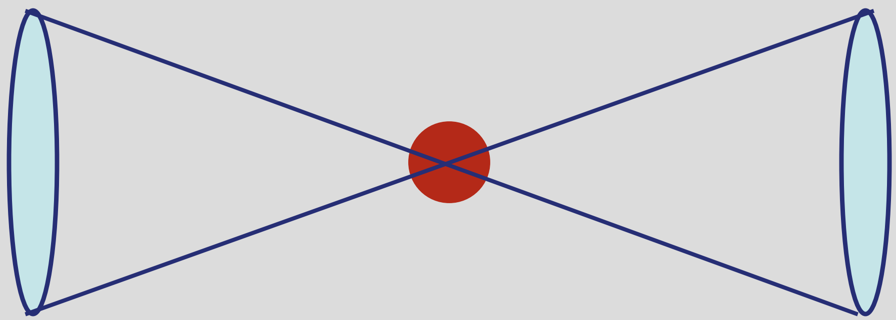
Can use $E = mc^2$ to determine the rest mass equivalent of this much energy:

$$m = \frac{E}{c^2} = \frac{3 \times 10^{54} \text{ erg}}{\left(3 \times 10^{10} \text{ cm}\right)^2} \approx 3 \times 10^{33} \text{ g} \approx 1.5\, M_{sun}$$

Almost impossible to envisage a stellar process that could convert the energy equivalent of a Solar mass of matter into just gamma rays.

Implies that the assumption of isotropic emission is too simple.

Suppose that the emission is not isotropic, but rather **beamed** into cones with solid angle Ω:



→ see a gamma ray burst

↘ see `something else' instead

For an event that beams energy into a fraction of the whole sky:

$$f \equiv \frac{\Omega}{4\pi}$$

Energy required to produce a time integrated flux S at distance d is reduced to:

$$S = f \times 4\pi d^2 S$$

If the beaming factor f ~ 10^{-2}, then the inferred energy of most bursts drops to 10^{52} ergs or less - comparable to the energetics of ordinary supernovae.

Corresponding *rate* of events increases by f^{-1} - most bursts aren't `aimed' in our direction so we never see them.

Two classes of model have been suggested as progenitors:

- Neutron star mergers: A GRB arises when two neutron stars in a close binary coalesce due to the emission of gravitational radiation.

- Collapsars or hypernovae: A GRB arises from the collapse of the cores of (some) massive stars. Different from Type II supernovae in that much of the energy goes into a jet rather than a spherically symmetric explosion.

How can these models be distinguished observationally?

First test: stellar population where the GRB goes off:

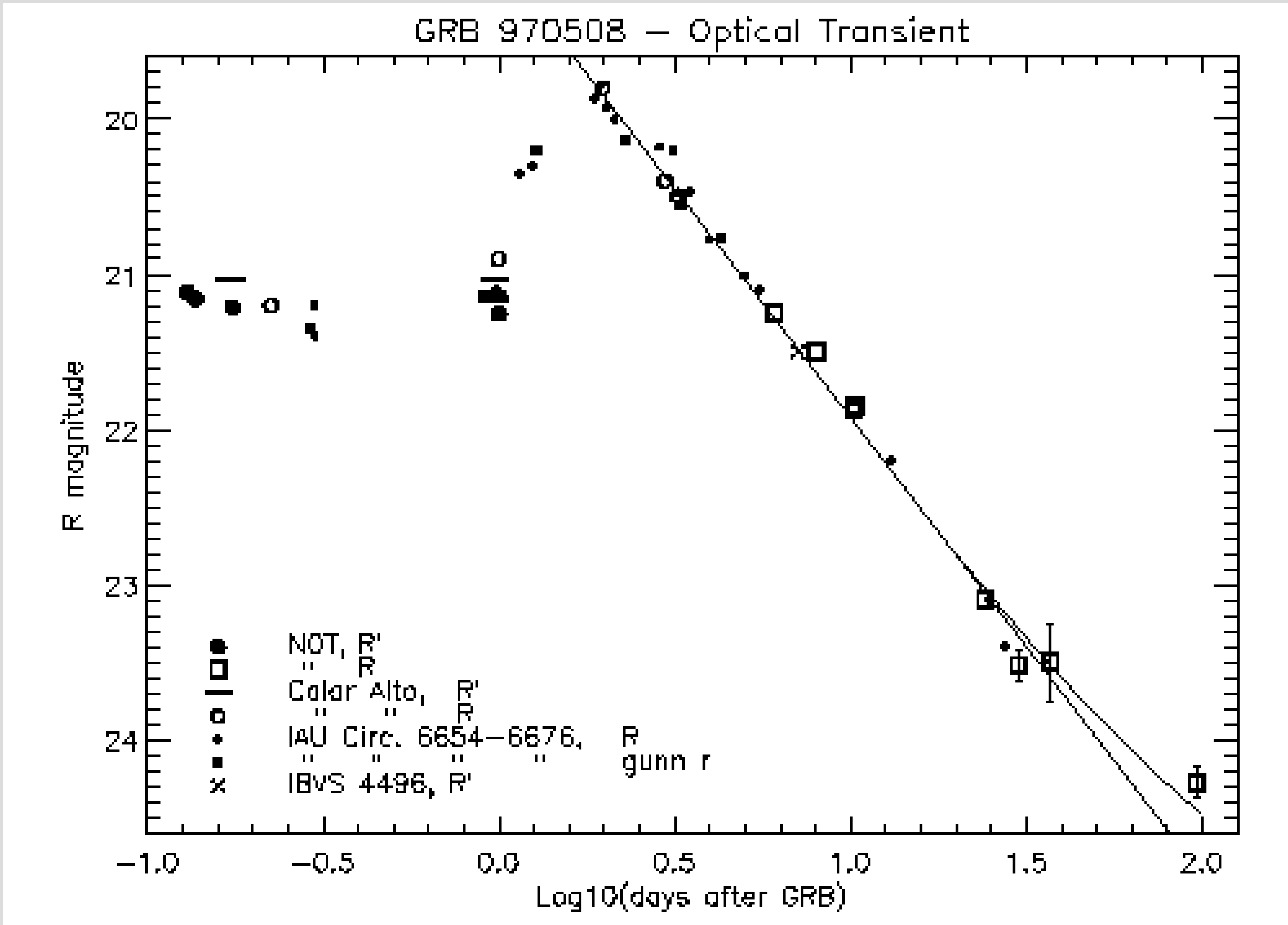
Collapsar: explosion of a very massive star, which had a short lifetime on the main sequence. Expect to see GRBs in regions with numerous young, massive stars. Observationally: blue and possibly dusty.

Neutron star merger: occurs at least ~10^8 yr after the supernova explosions that formed the neutron stars (have to wait until the orbits decay due to gravitational radiation). Expect to see GRBs in older, red stellar population.

Observations favor an association with star forming regions, and hence the collapsar model.

Second test: light curve of the optical afterglow

Typically the flux in the afterglow decays as a power-law for several weeks after the GRB itself.



optical flux ↑

time →

ASTR 3830: Spring 2004

Conclusive evidence for the association of at least some GRBs with supernovae was obtained last year: measured the light curve and spectrum of a supernova once the GRB afterglow had dimmed:

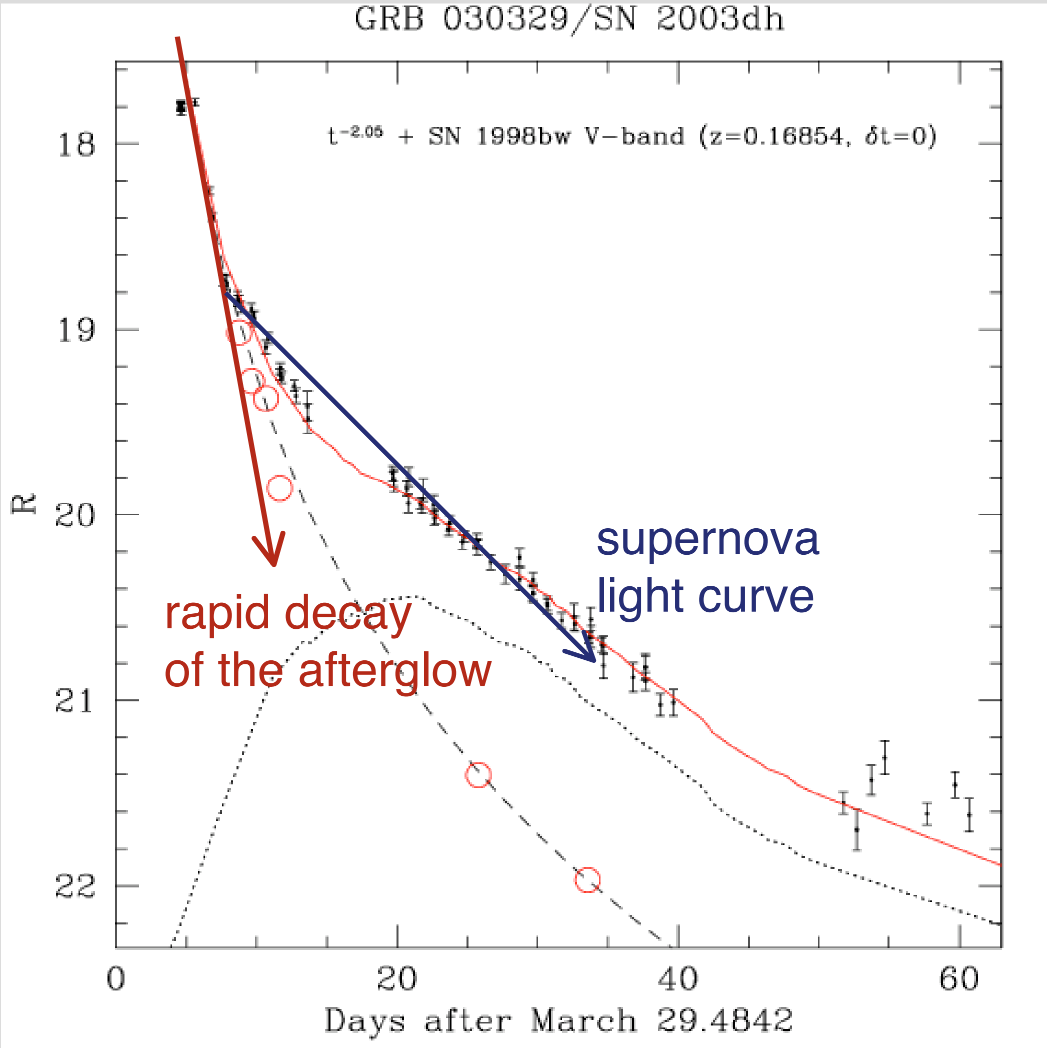


Figure from Matheson et al. 2003

Summary

So far, X-ray and optical afterglows have only been seen from the `long' duration gamma ray bursts:

Associated with massive star formation and, in at least some cases, supernovae. These events are almost certainly collapsars.

But:

- What about the short duration GRBs? Are these also collapsars, or perhaps neutron star mergers? If they're *not* neutron star mergers, what observable phenomenon *is* connected to mergers?
- Why do some core collapses lead to GRBs + SN, others just to SN?
- If a GRB goes off but the beam misses us, what do we see instead?