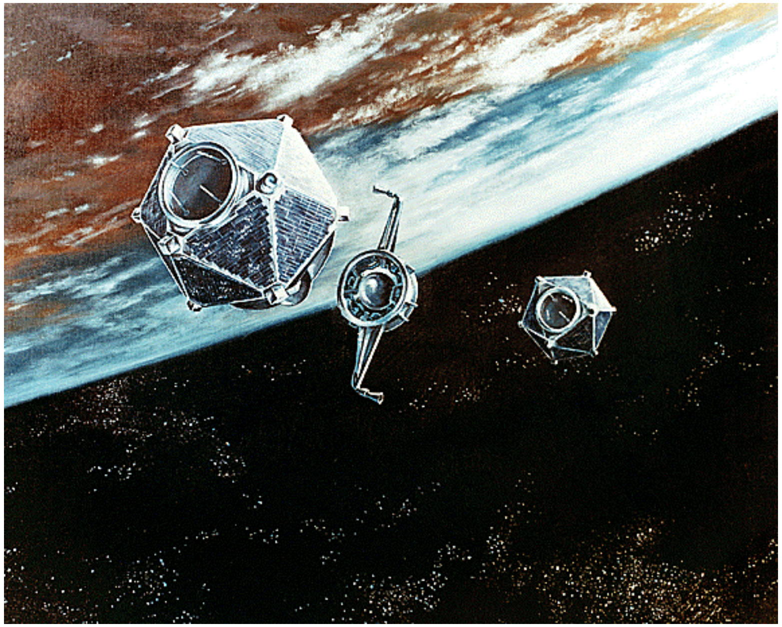
GRB history

Discovered 1967 Vela satellites

classified!

Published 1973!

Ruderman 1974 Texas: More theories than bursts!



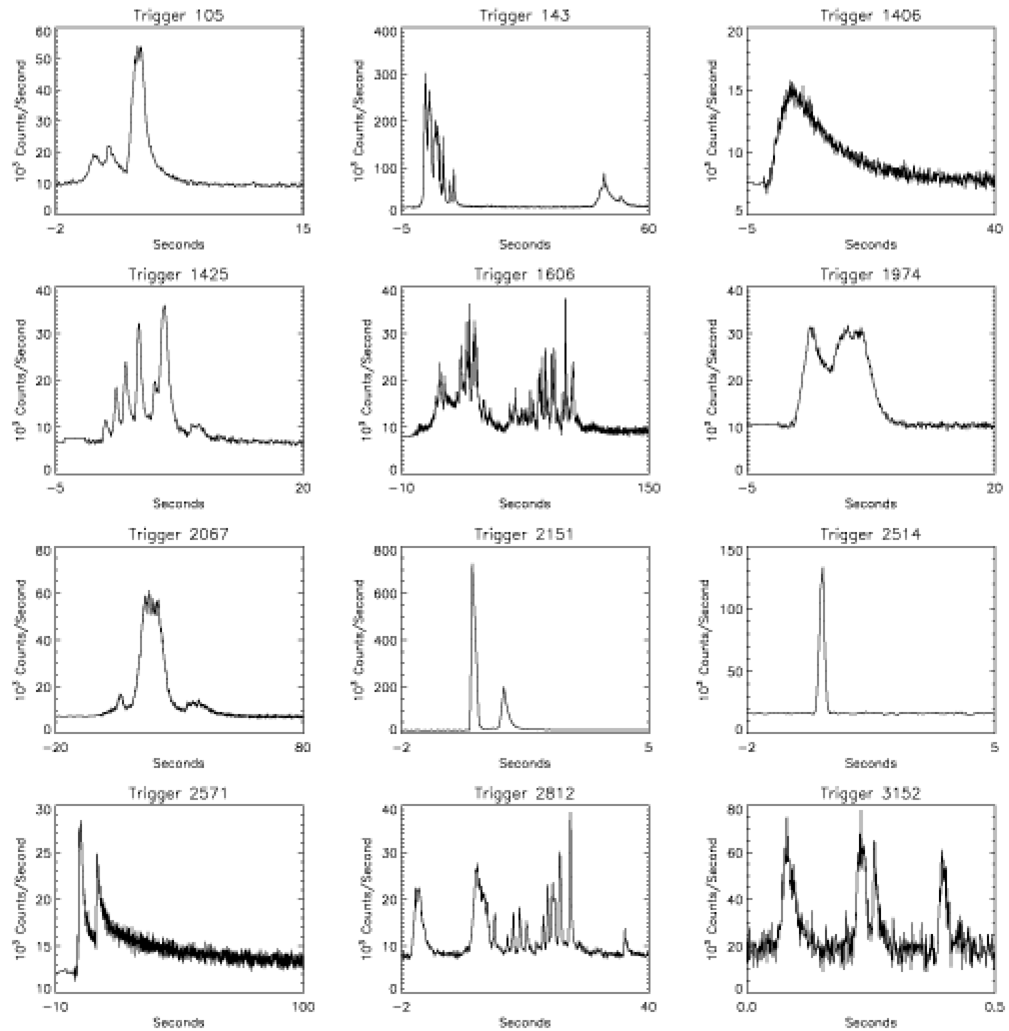
Burst diversity

$E_{peak} \sim 300$ keV

Non-thermal spectrum

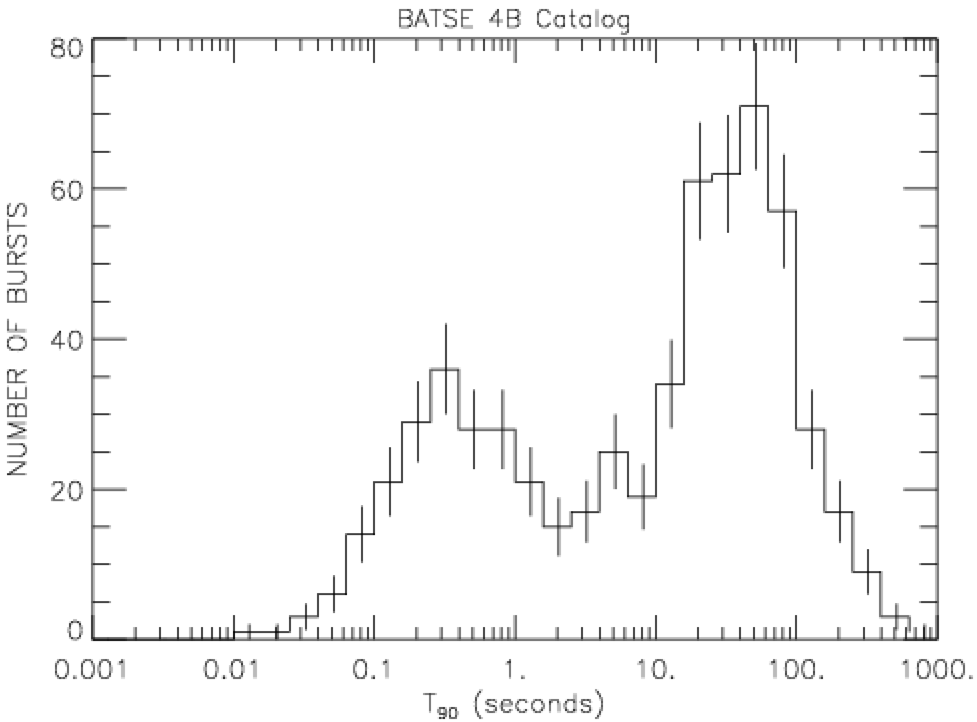
In some thermal contrib.

Short time variability down to ms



Duration: $10^{-2} – 10^{3}$ s Often substructure

Bimodal distribution



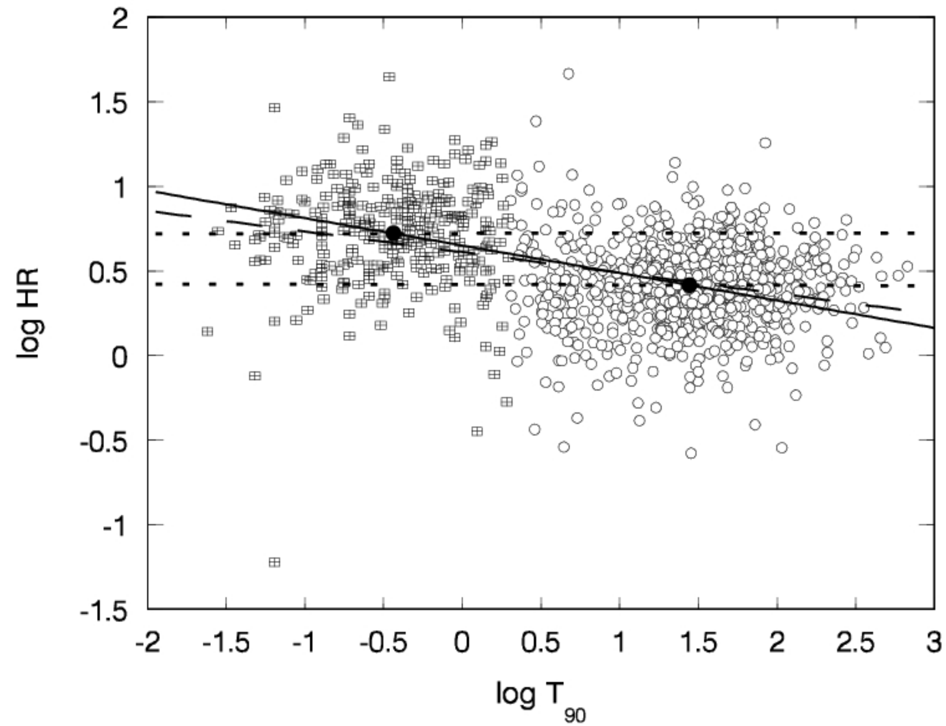
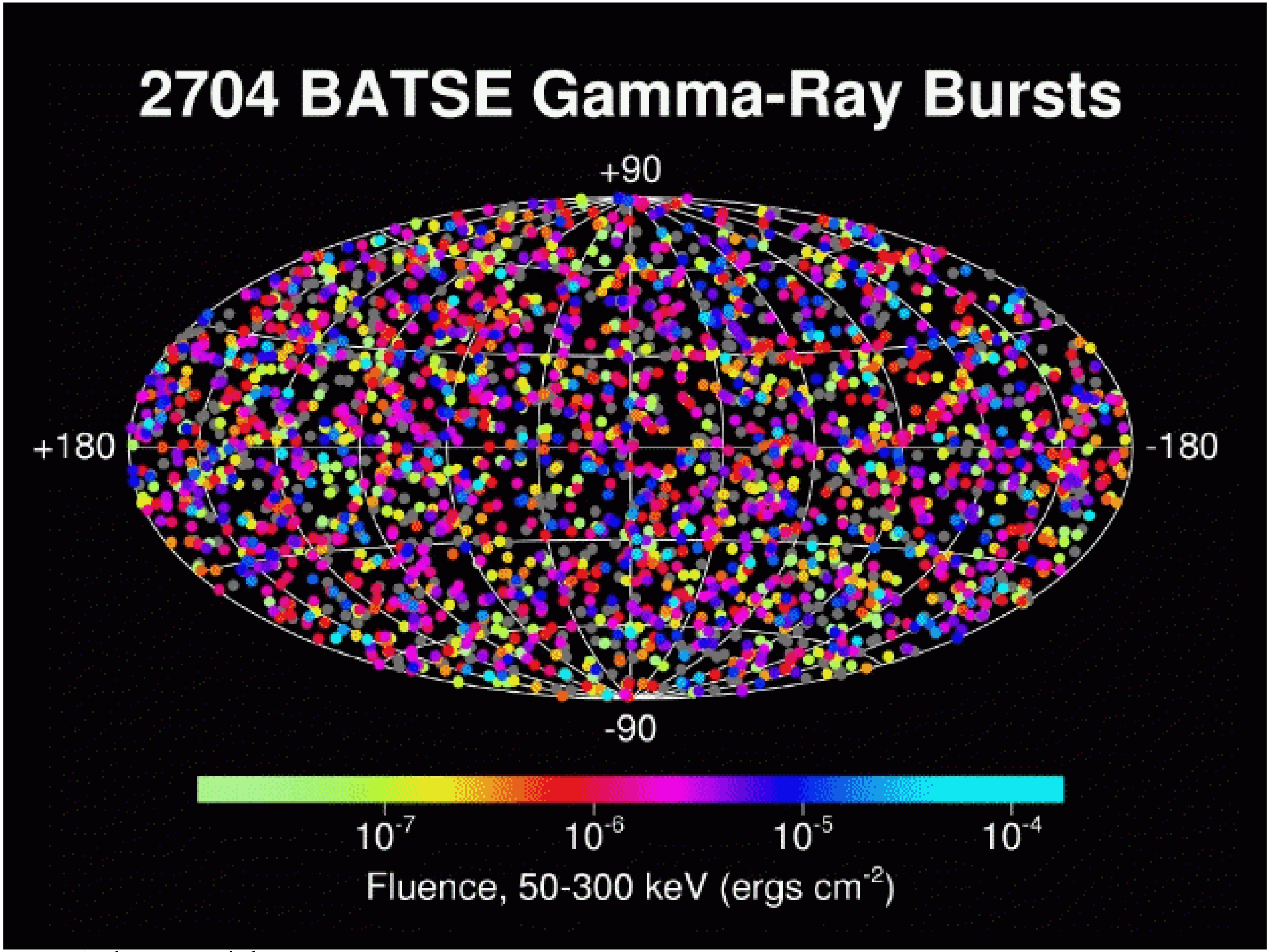


Fig. 1

Short: $t < 2$ s $\quad t_{mean} \sim 0.2$ s $\quad$ ¼ $\quad$ Hard

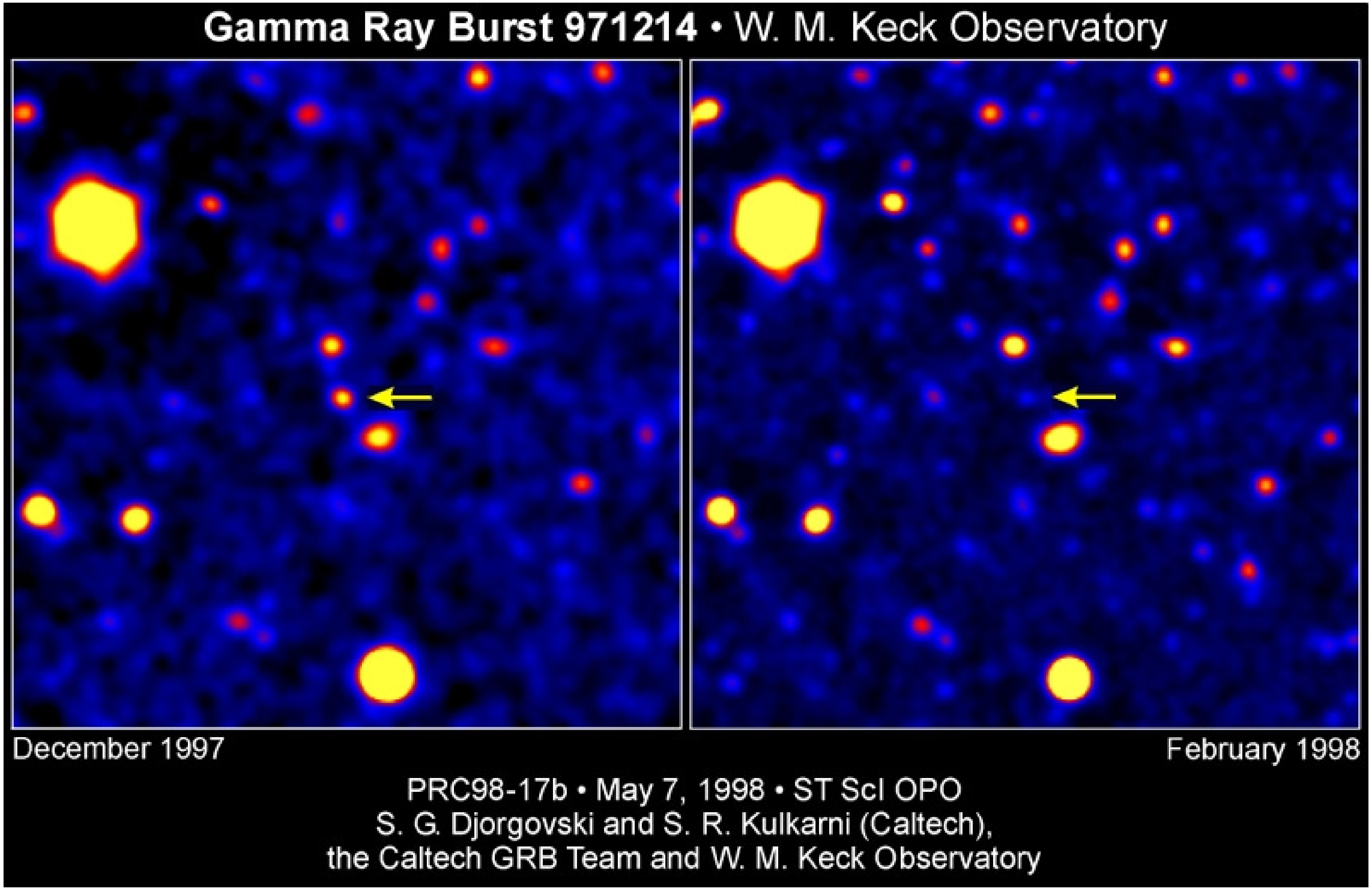
Long: $t > 2$s $\quad t_{mean} \sim 35$ s $\quad$ ¾ $\quad$ Soft



~ 1 burst/day

Isotropic distribution: 1. Cosmolgical
2. Distant halo contribution > 100 kpc

Beppo/SAX satellite



First GRB afterlow: GRB970228

First with redshift: GRB970508
z=0.835 from absorption lines

GRBs are cosmological!!

Energies 10^{50}-10^{54} erg/s if isotropic

Prompt phase

t ~ 10 -1000 s

rapid variability milli sec – sec

Gamma-rays

Both short and long bursts

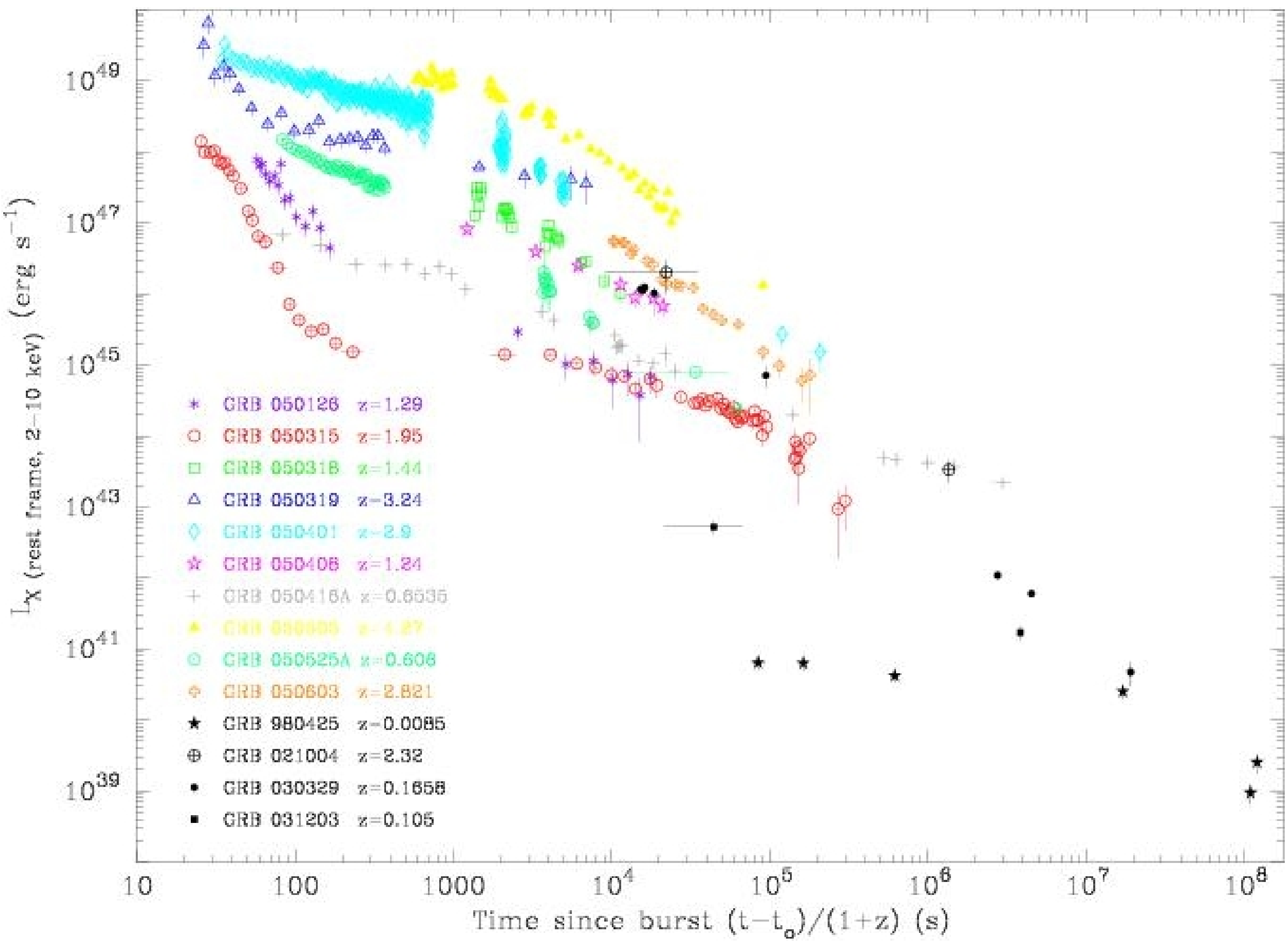
Afterglow

t ~ 100 s – years

X-rays, optical, radio

smooth evolution, often power law decay

Until SWIFT only long, now also short



L_X (rest frame, 2–10 keV) (erg s^{-1})
10^{49}
10^{47}
10^{45}
10^{43}
10^{41}
10^{39}
GRB 050126 z=1.29
GRB 050315 z=1.95
GRB 050318 z=1.44
GRB 050319 z=3.24
GRB 050401 z=2.9
GRB 050406 z=1.24
GRB 050416A z=0.6535
GRB 050505 z=4.27
GRB 050525A z=0.606
GRB 050603 z=2.821
GRB 980425 z=0.0085
GRB 021004 z=2.32
GRB 030329 z=0.1658
GRB 031203 z=0.105
10
100
1000
10^4
10^5
10^6
10^7
10^8
Time since burst $(t-t_o)/(1+z)$ (s)

t (s)

Relativistic expansion?

Photon-photon pair production

$$\gamma + \gamma \rightarrow e^+ + e^- \qquad h\nu > 2 m_e c^2$$

$$\tau_{\gamma\gamma} \approx \sigma_T n_\gamma R \approx \sigma_T f_p \frac{L}{4\pi R^2 c m_e c^2} R$$

$$R \approx c \Delta t \qquad L = 4\pi D^2 F / \Delta t$$

$$\tau_{\gamma\gamma} \approx \frac{\sigma_T f_p F D^2}{(\Delta t c)^2 m_e c^2} \approx 3 \times 10^{14} f_p \frac{F}{10^{-6}} \left(\frac{\Delta t}{10^{-2} s} \right)$$

$$\tau_{\gamma\gamma} \gg 1$$

thermalisation: black-body!

Consequences of relativistic expansion

If relativistic, i.e., $\Gamma \gg 1$

$$\nu_{obs} \approx \Gamma \nu_{em}$$

Observed MeV photons become X-rays in rest frame: No pair production

$$f_p \propto \Gamma^{-2\alpha} \ll 1$$

Consequences of relativistic expansion II

$$t_1^{obs} = t_1^{em} + (D - r_1)/c$$

$$t_2^{obs} = t_2^{em} + (D - r_2)/c$$

$$dt^{obs} = dt^{em} - dr/c = dt^{em} - V\,dt^{em}/c = dt^{em}(1 - V/c)$$

$$dt^{obs} = dt^{em}(1 - \beta)$$

$$\Gamma^2 = \frac{1}{(1-\beta^2)} = \frac{1}{(1+\beta)(1-\beta)} \approx \frac{1}{2(1-\beta)} \qquad if\ \beta \approx 1$$

Consequences of relativistic expansion III

$$dt^{obs} = \frac{dt^{em}}{2\Gamma^2}$$

1. Observer sees everything slower compared to comoving frame

$$dt^{em} = 2\Gamma^2 dt^{obs}$$

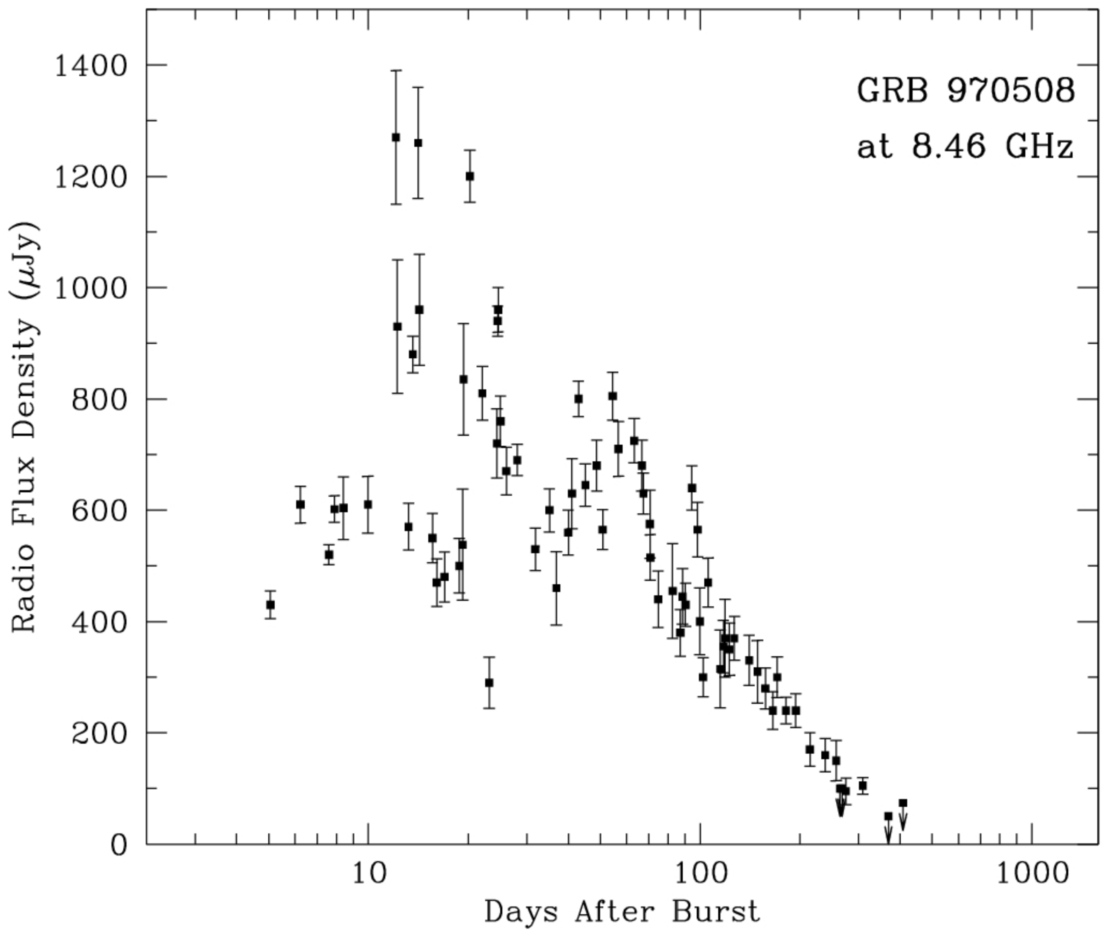
2. Size of object is NOT $c\,t^{obs}$ but $c\,t^{em} = 2\,c\,t^{obs}\,\Gamma^2$

3. Solves compactness problem!

$$\tau_{\gamma\gamma} \propto \Gamma^{-2(\alpha+1)}$$

$$\alpha \approx 2 \quad \Rightarrow \quad \tau_{\gamma\gamma} \propto \Gamma^{-6}$$

Interstellar scintillations



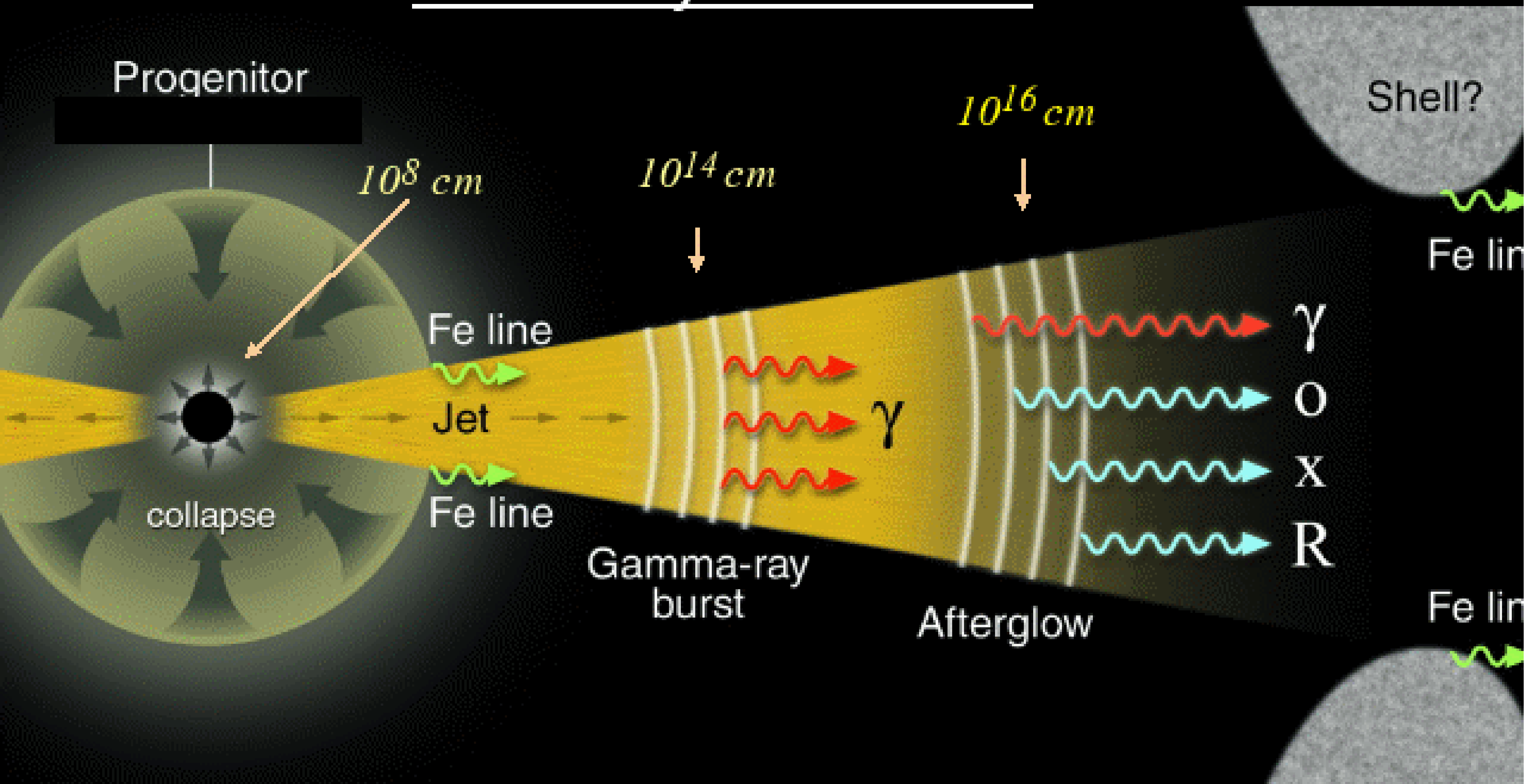
Size larger than scintillating elements $> 10^{17}$ cm
Needs relativistic expansion

Baryon loading

$$E = \Gamma M c^2$$

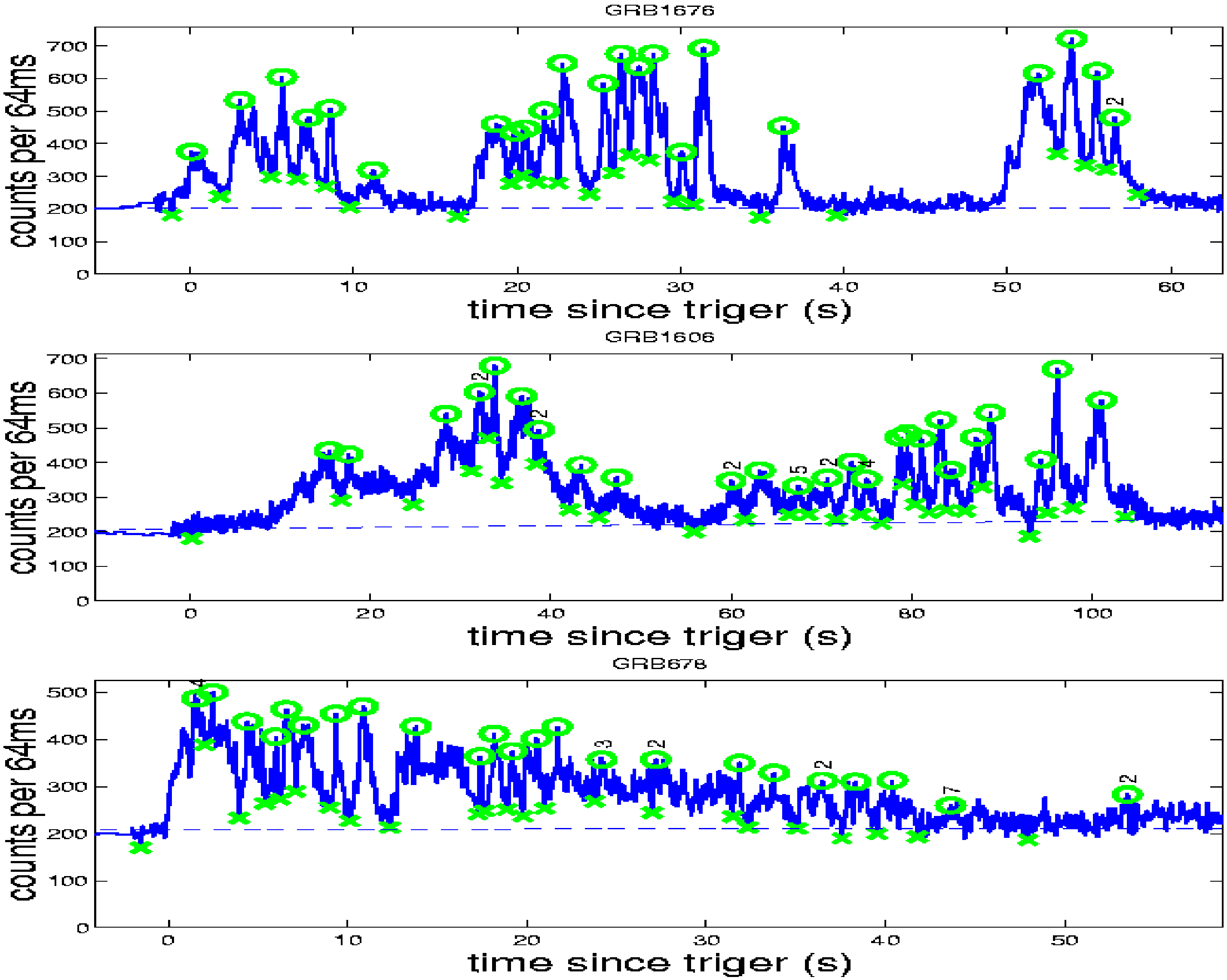
$$M \approx 5 \times 10^{-6} \left(\frac{\Gamma}{10^3} \right)^{-1} \left(\frac{E}{10^{52} erg\, s^{-1}} \right)^{-1} M_O$$

Anatomy of a GRB



See Piran 1999; Mészáros 2002 (ARAA) for reviews

Temporal Variability

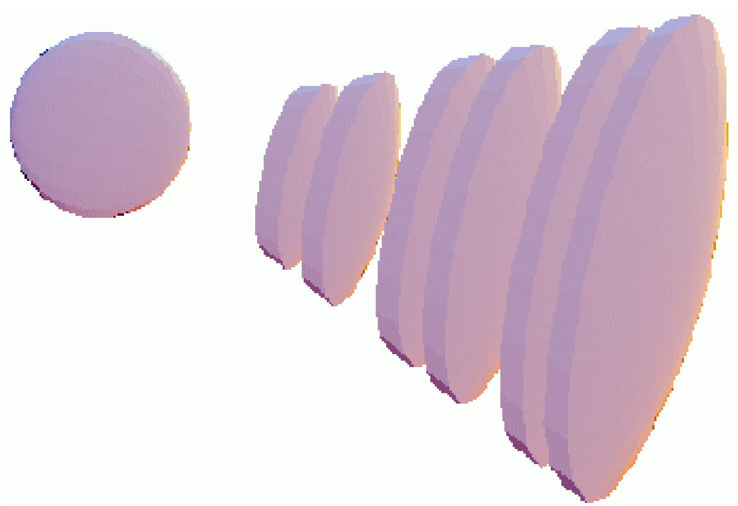


Prompt burst scenarios

- **Internal Shocks**

↓

many colliding shells

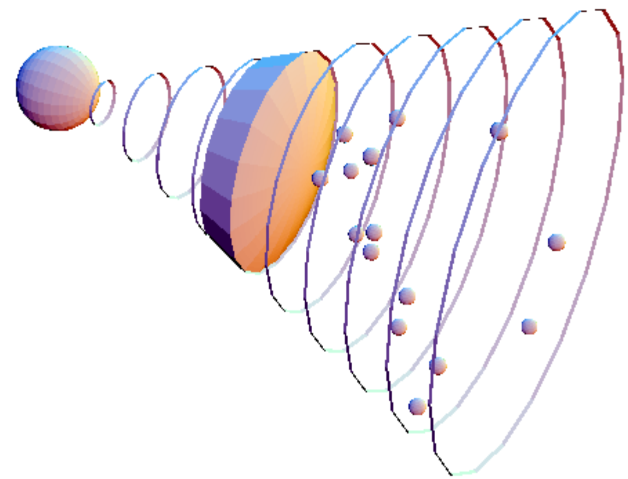


- Complex, Long Lasting Engine

- **External Shocks**

↓

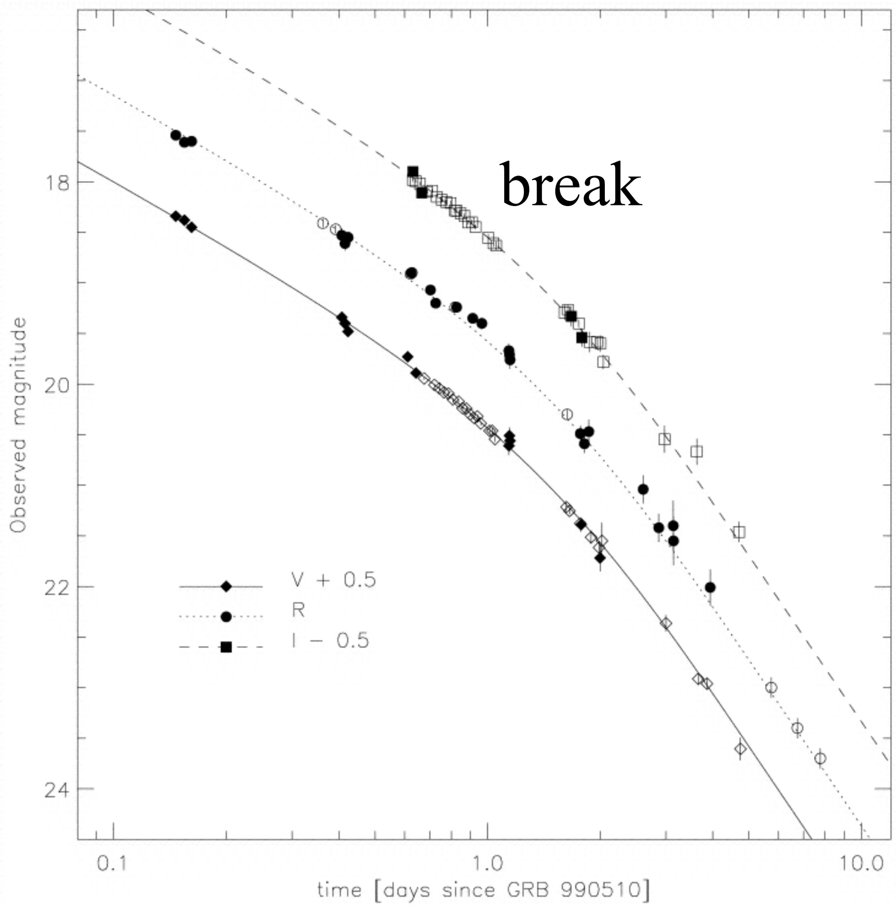
irregular surrounding

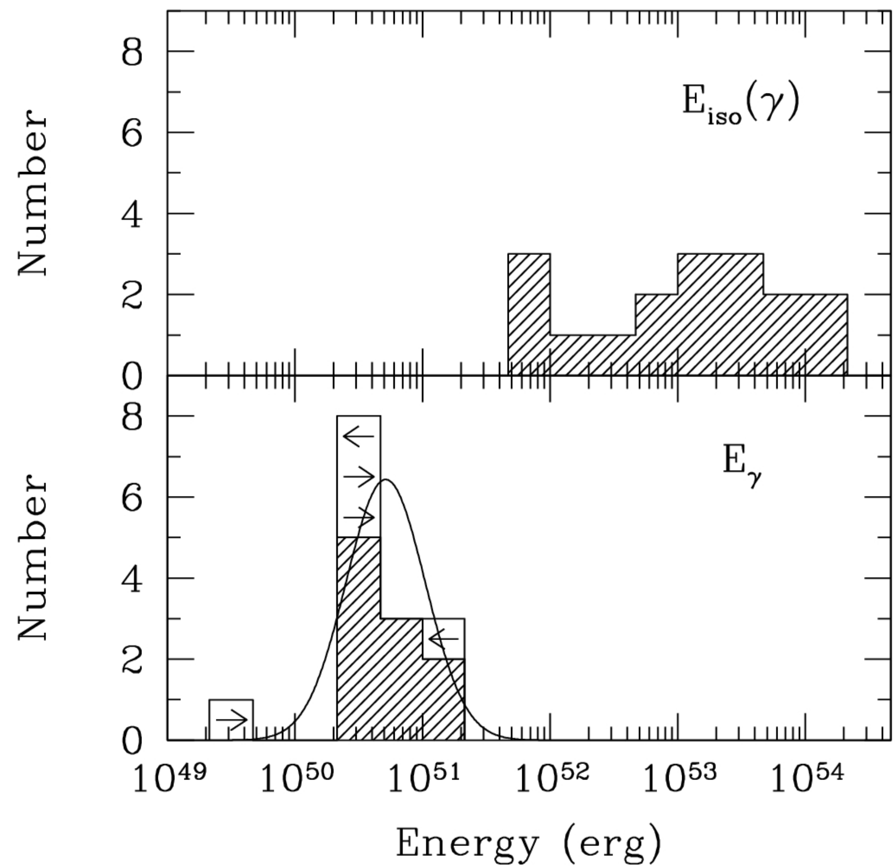


- Simple “Explosive” Engine

Sari

Jet steepening





Relativistic abberation

$$\cos\theta = \frac{\cos\theta' + \beta}{1 + \beta\cos\theta'} \quad \Rightarrow \quad \theta \approx \frac{1}{\Gamma}$$

Correct for opening angle gives total energy. Nearly constant ~ 10^{51} ergs

Close to 'normal' supernova energy! θ ~ 5-10 degrees

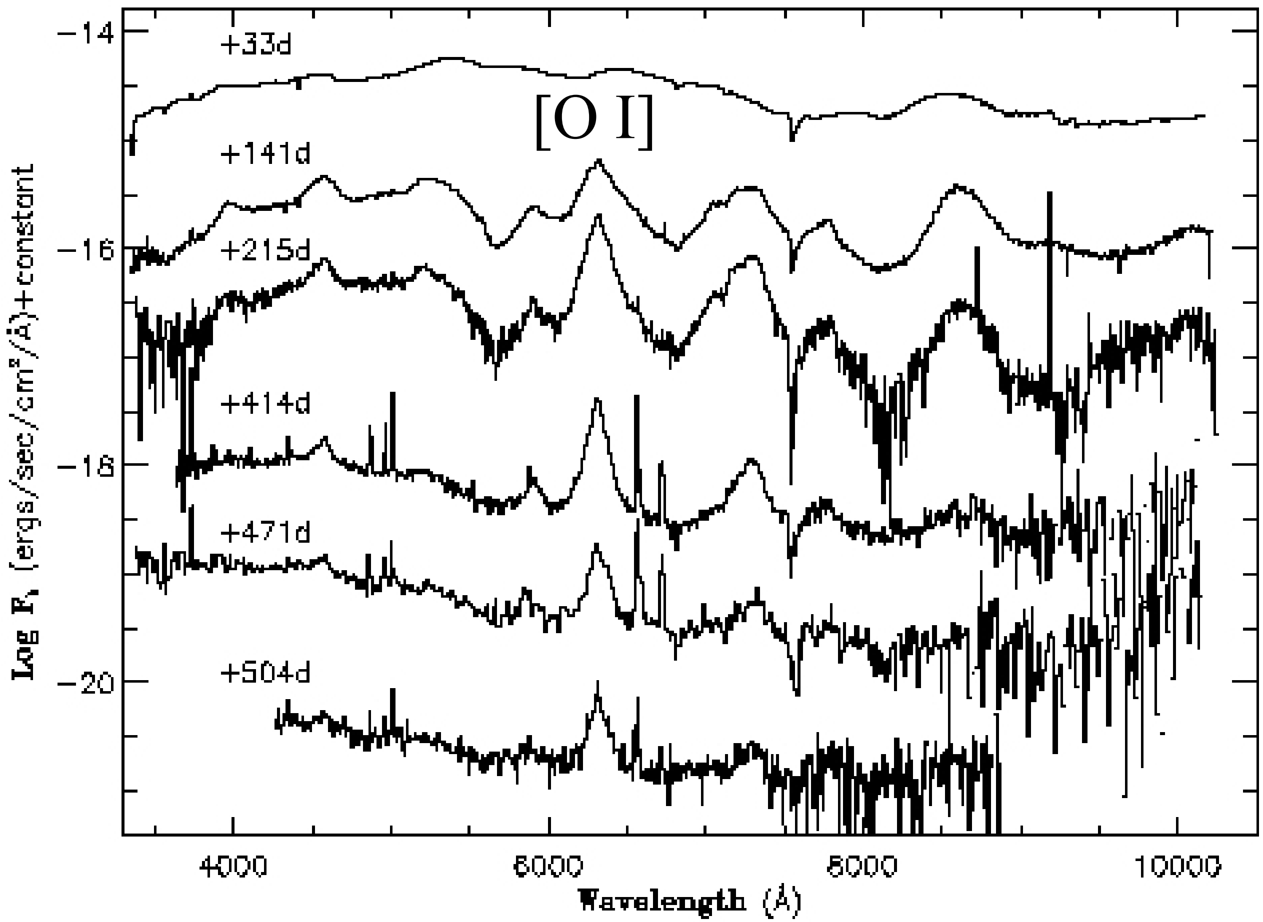
Beaming $\Delta\,\Omega \sim 0.03$. Only one of 100-500 GRBs seen by us

1-3 GRBs observed per day. Total rate 100-1000 per day

1 GRB per 10^5 - 10^6 years per galaxy

Compare 1-2 SNe per galaxy per 100 years, i.e. 1 GRB / 10^3 – 10^4 SNe

SN 1998bw = GRB 980425



Sollerman et al

Type Ic supernova z=0.0085 in ESO 184-G82 Radio: $\Gamma \sim 2$

Optical: Expansion velocity ~ 60,000 km/s $M(^{56}Ni) \sim 0.7\ M_O$

$E \sim 10^{48}$ erg/s, low compared to 'normal' GRBs

No H or He in spectrum. Exploding Wolf-Rayet star

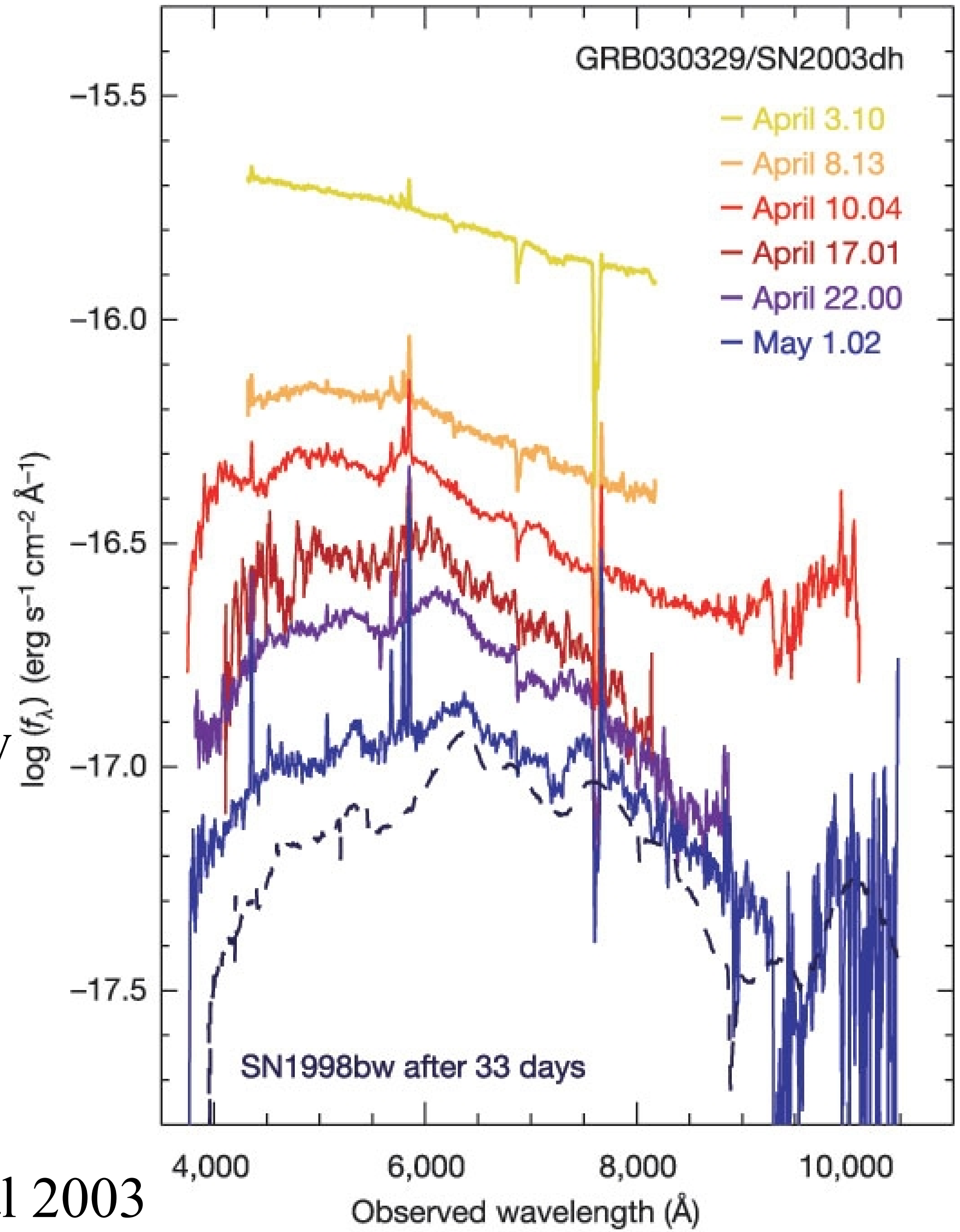
GRB 030329 = SN 2003dh

z = 0.17 . Starforming dwarf galaxy

'Normal' gamma-ray burst energy

Type Ic spectrum after ~ 1 month

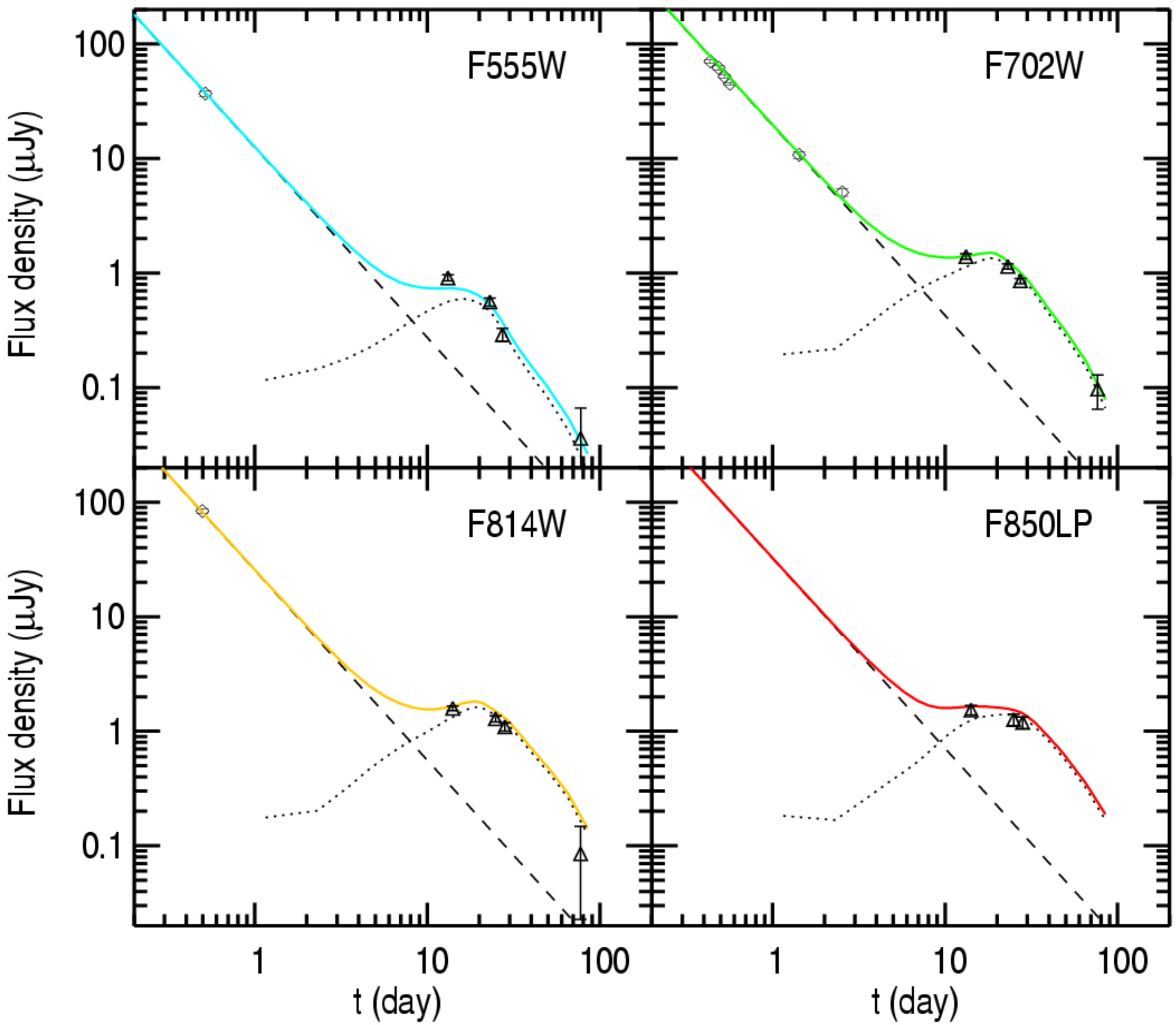
Spectrum identical to SN 1998bw



Hjorth et al 2003

Bump in light curves

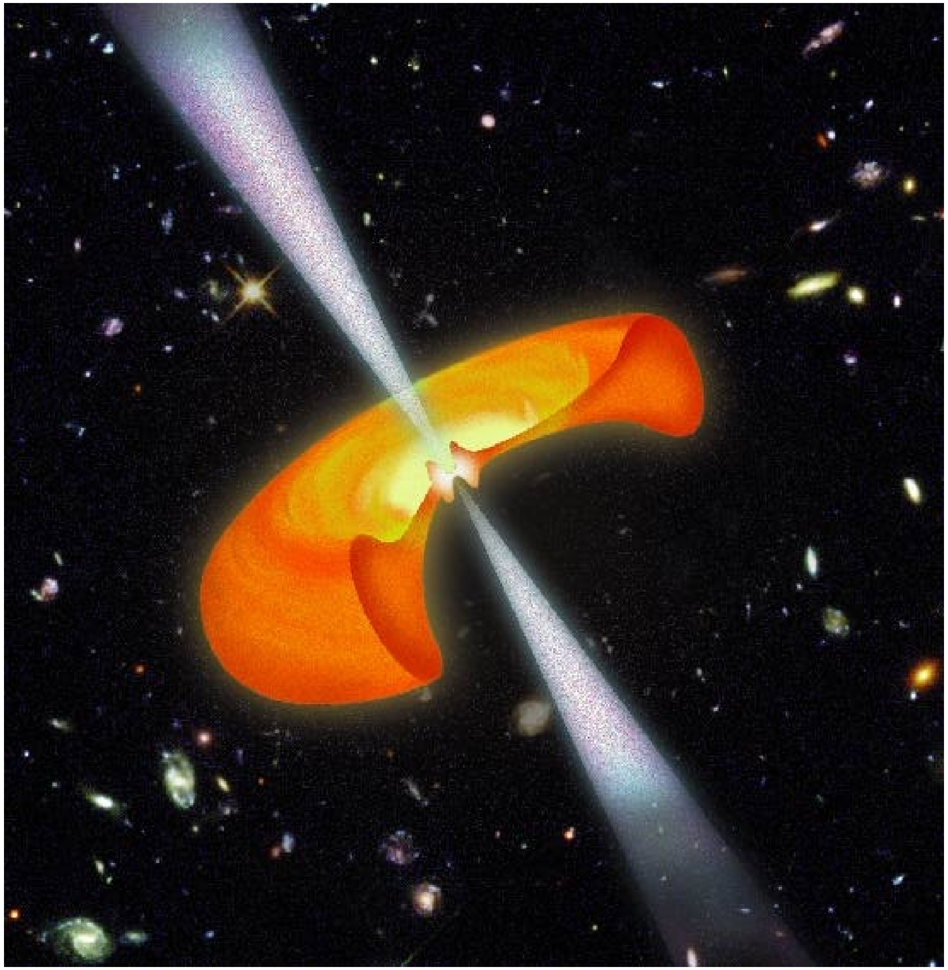
GRB 011121



Bloom et al

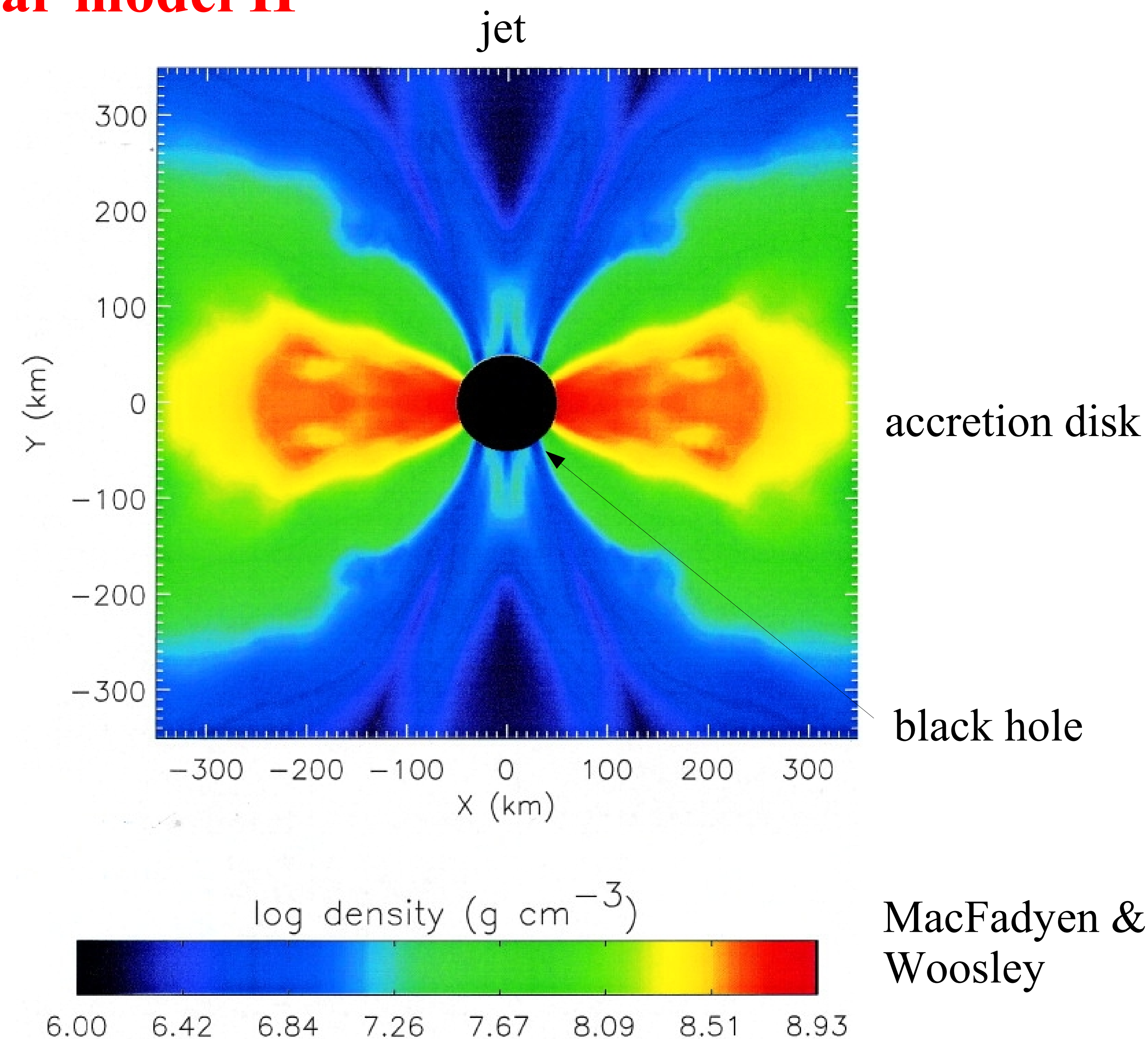
Bump at ~ 1 month well fitted with SN 1998bw supernova light curve

Collapsar model



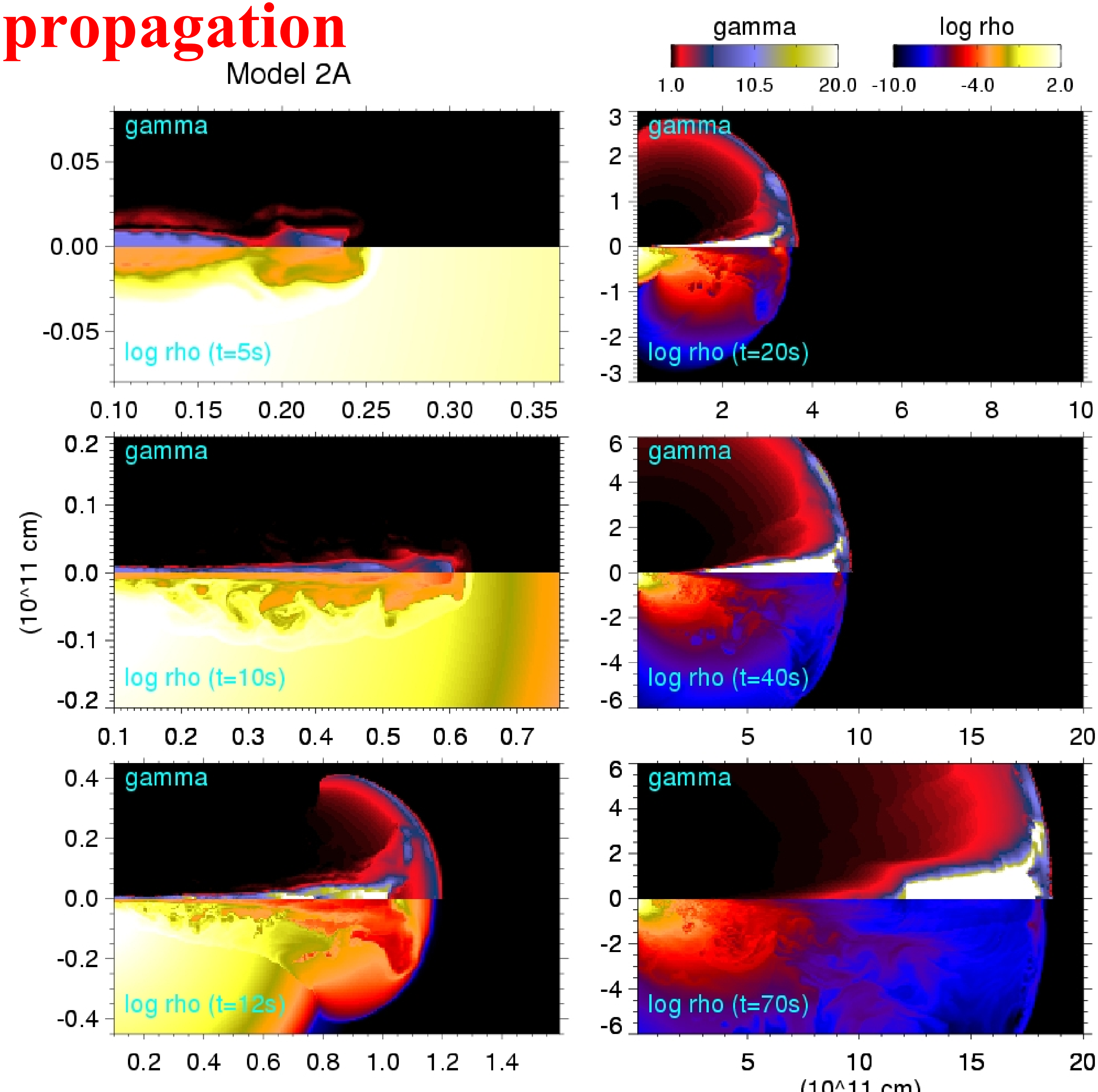
Collapse of a very massive star (M > 30 MO).
Needs compact progenitor, i.e., no H envelope = Wolf-Rayet star
Fast rotation gives accretion disk + jets.
Electromagnetic energy extraction ?

Collapsar model II



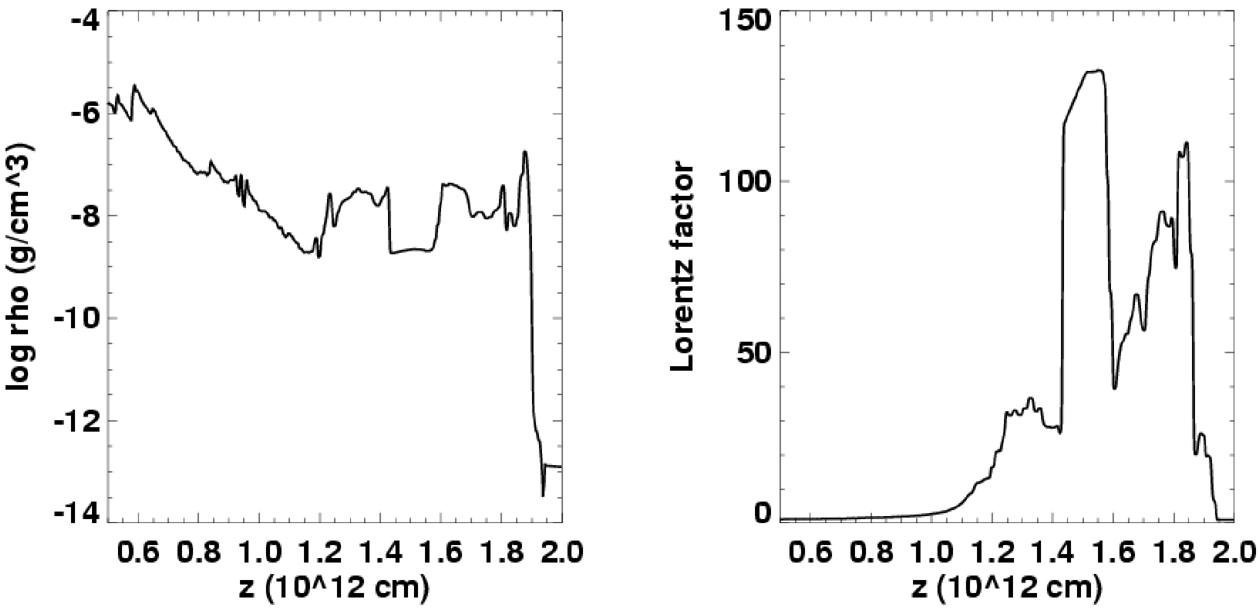
MacFadyen & Woosley

Jet propagation

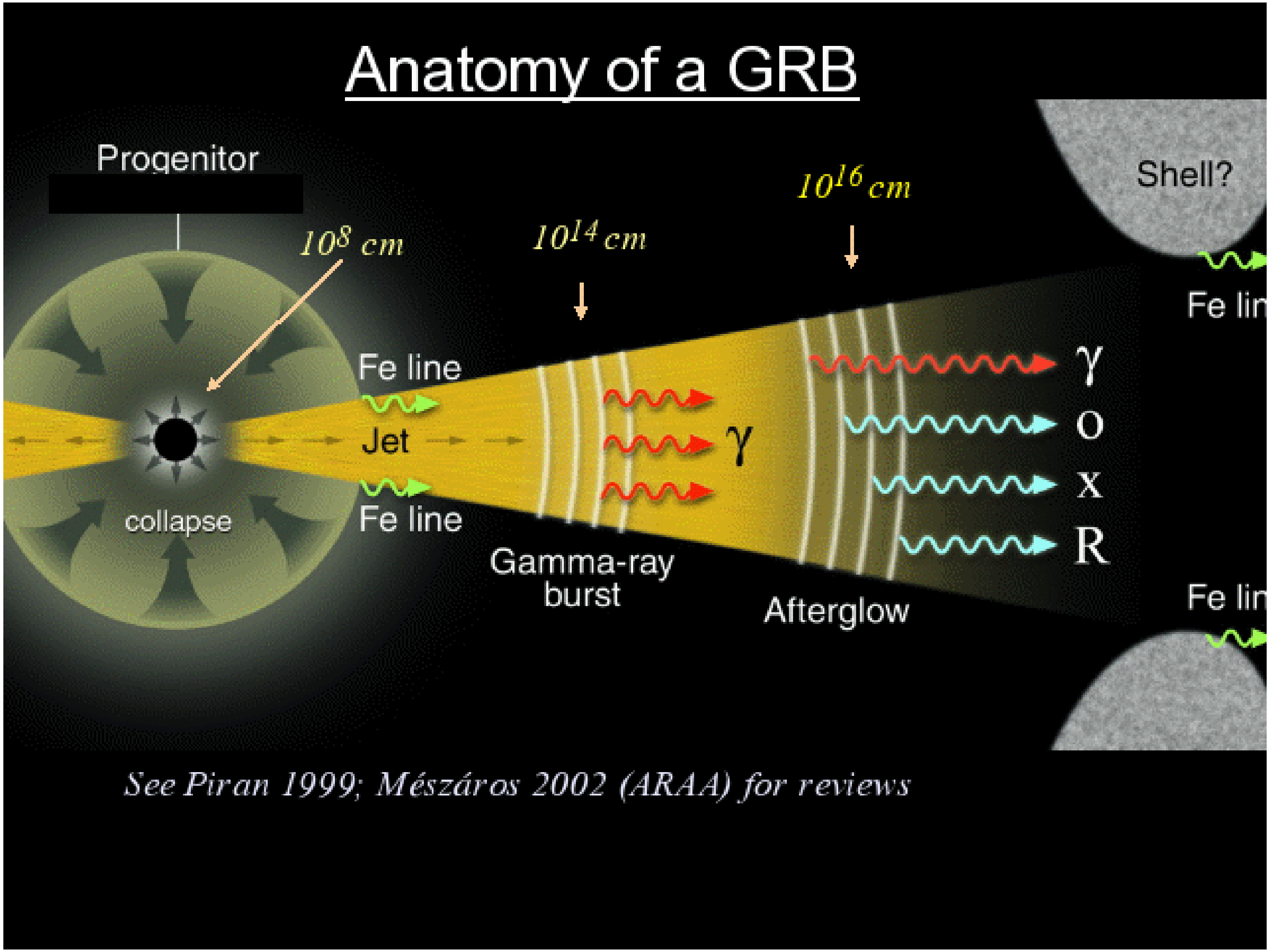


Stellar radius ~ 10^{11} cm, V ~ 50,000 km/s t ~ 20 s

Highly variable Lorentz factor source for internal shocks for the prompt burst

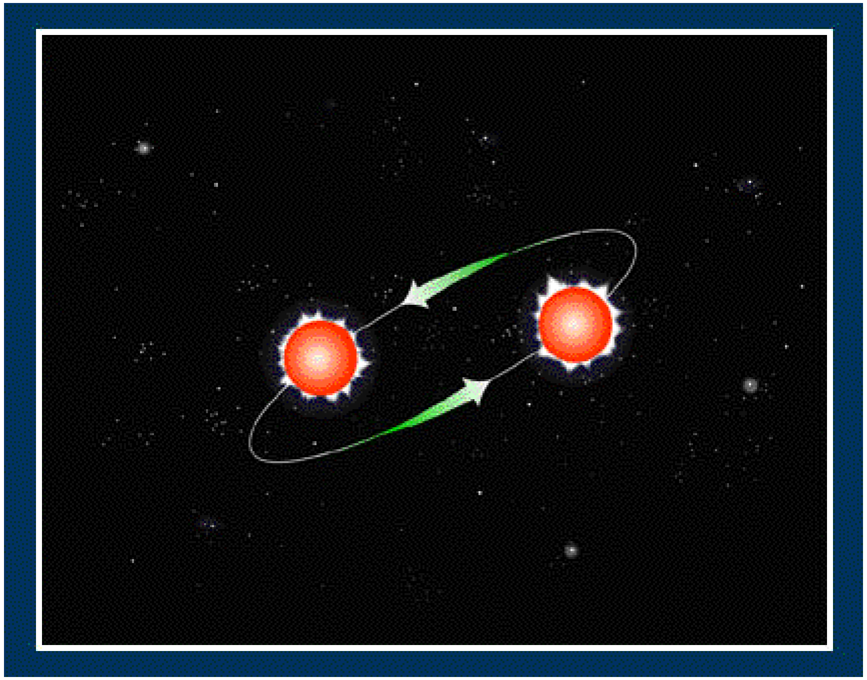


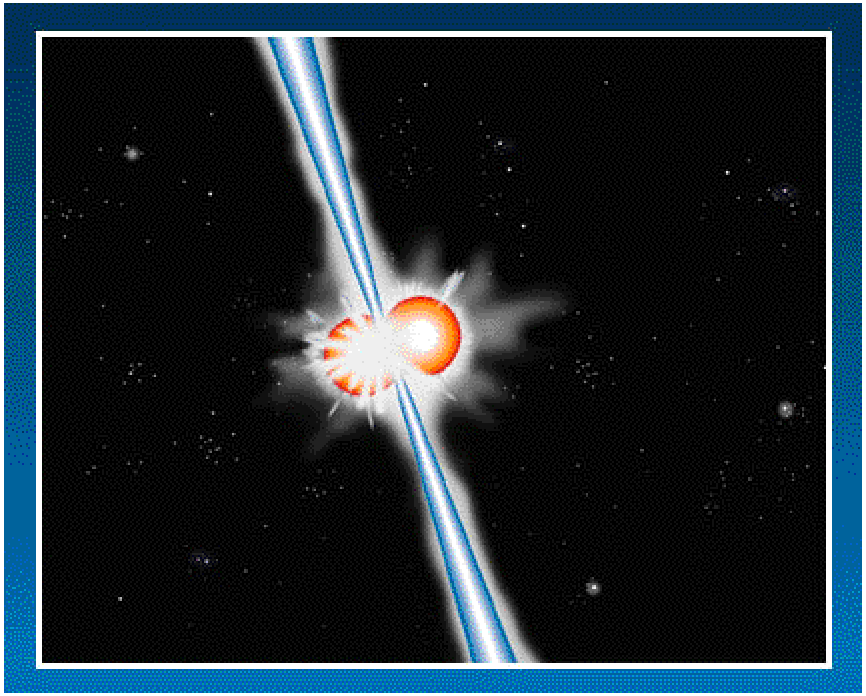
Difficult to get millisecond bursts Main candidate: Long bursts



Jet expansion in circumstellar medium gives afterglow

Neutron star merger





Progenitor: Close binary neutron star system. Energy loss by gravitational waves give spiral-in and merger within ~ 10^8 years
Final merger within ~ millisecond

Merger sequence

Merger → accretion disk

T ~ 10^{10} K

energy loss by neutrinos

Energy conversion by

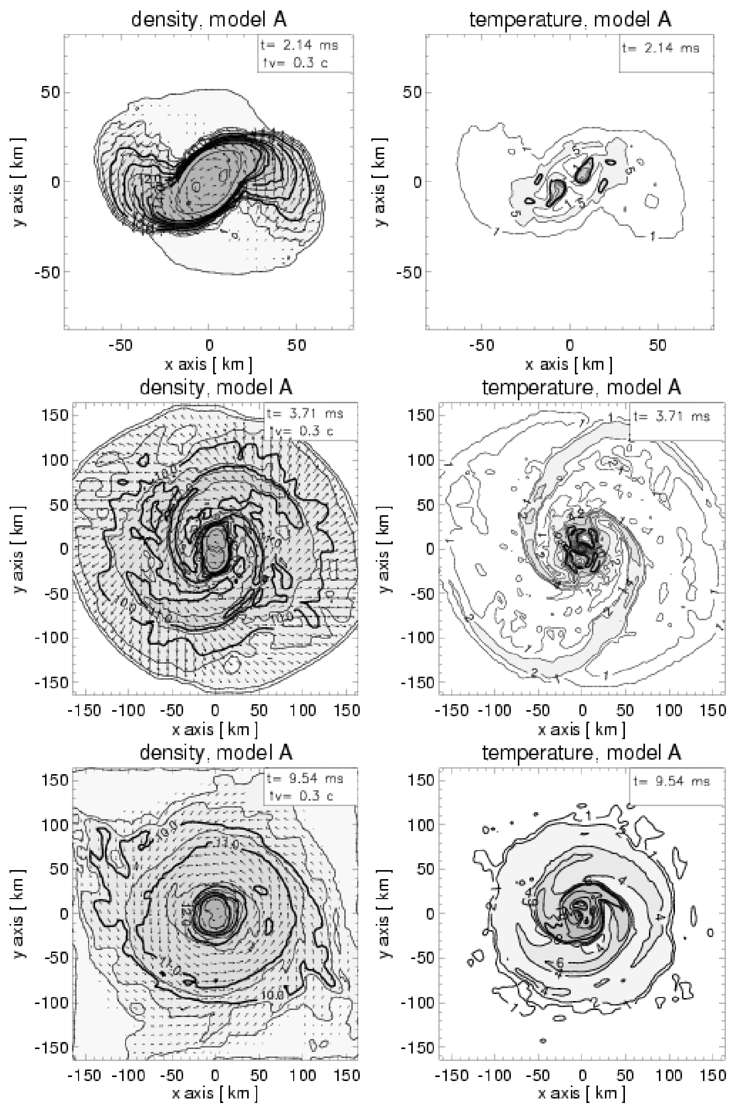
$$\nu + \bar{\nu}_e \rightarrow e^- + e^+$$

Pair plasma expands into ISM

All in milliseconds

No supernova in afterglow expected

Excellent candidate for short bursts



Short bursts with SWIFT

GRB 050509B, 050709, 050724

all short

X-ray afterglows!!

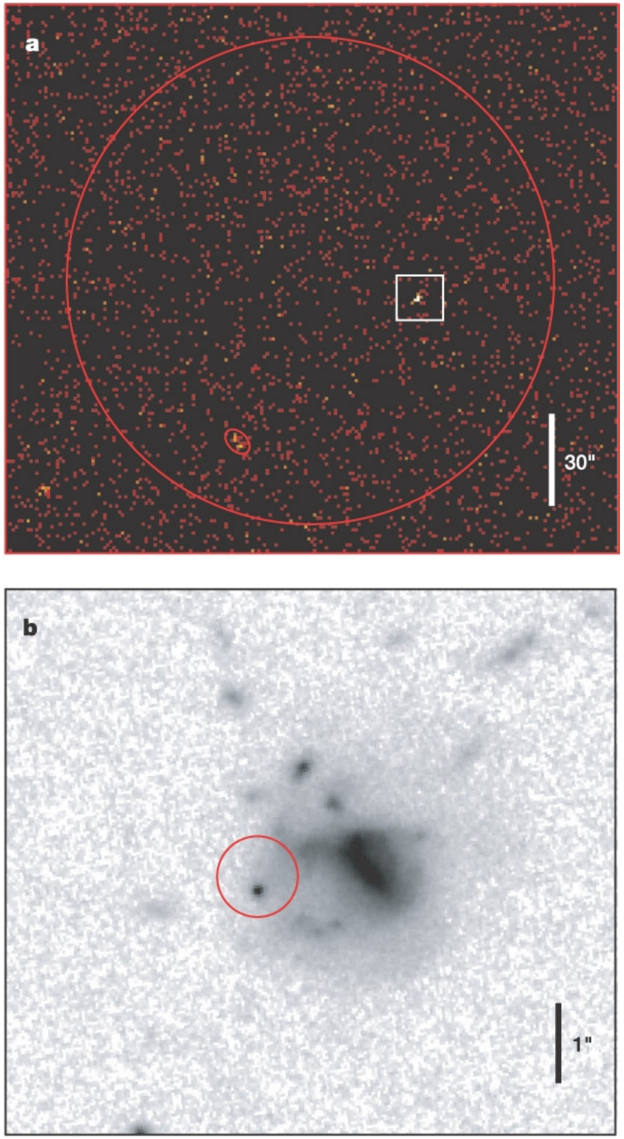
GRB 050709, 050724 also
optical afterglows

z = 0.16 – 0.25

E ~ 10^{50} ergs << Long

Two in ellipticals, one in a starforming galaxy

No supernova signature



All consistent with merging neutron star system. Could also be NS + BH