Giant Flares from Soft Gamma-Ray Repeaters

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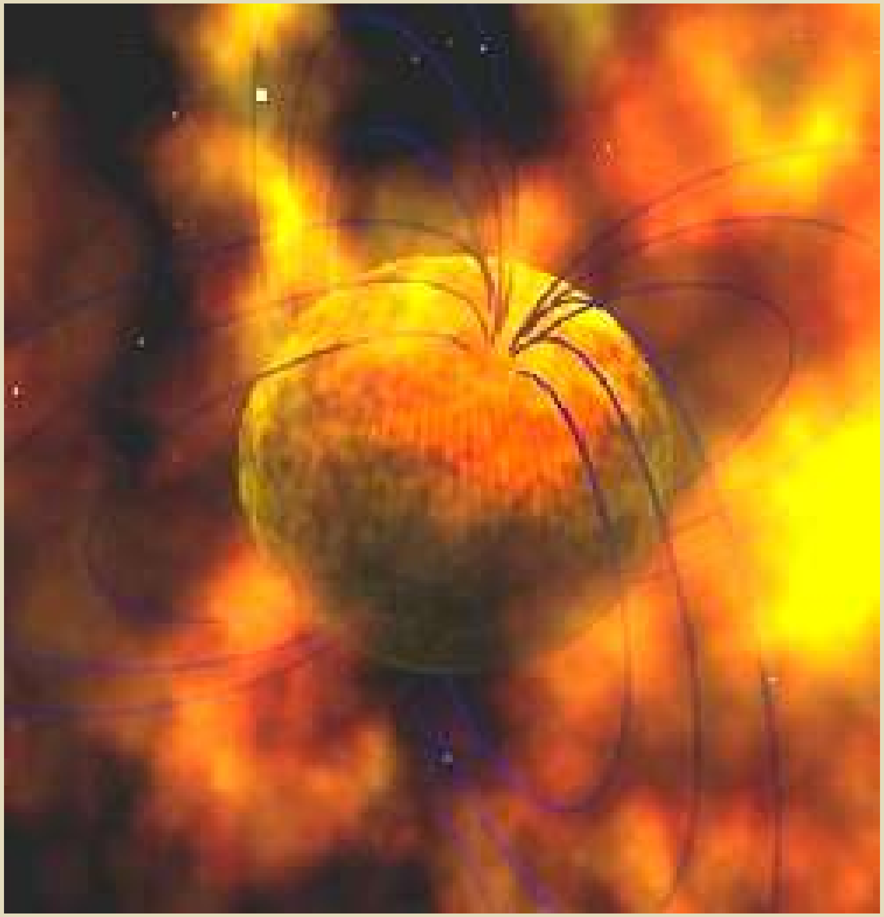

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SGR giant flares and GRBs: short flash of γ-rays followed by an afterglow.

1) What is the energy source of the afterglow?

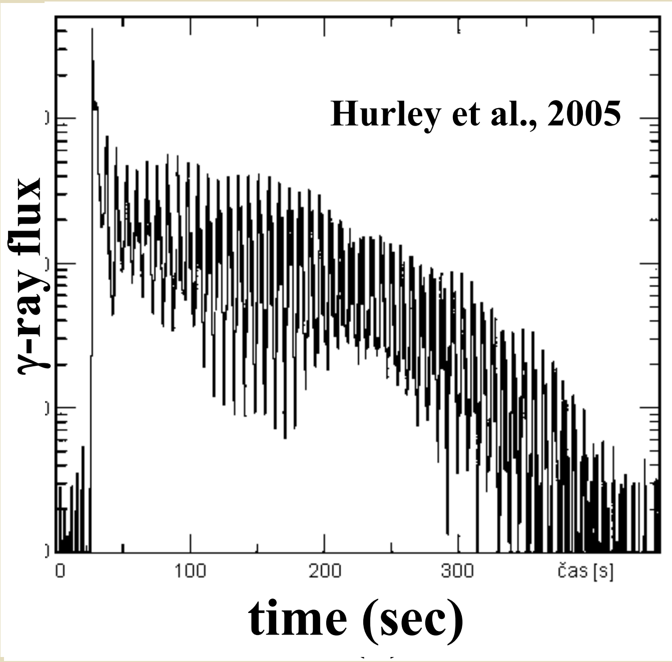
2) What is the rate of giant flare (or extragalactic flares as short GRBs) ?

Soft Gamma-Ray Repeaters

3 known in our galaxy and one in the LMC

Persistent x-rays:

- $L \sim 10^{35}$ erg/s
- Period ~ several seconds
- $P/2\dot{P} \sim 10^3 - 10^4$ yr



Repeating soft γ-ray flares:

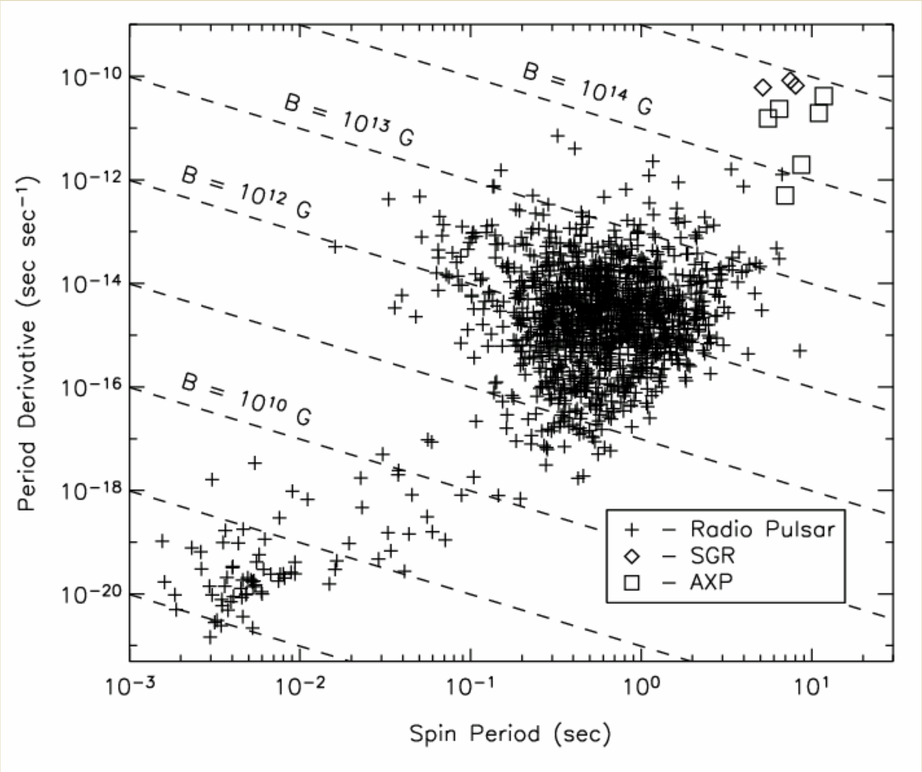
- $E \sim 10^{41}$ erg
- $T \sim 0.1$ sec

Mini-Giant γ-ray flares (observed twice before):

- $E_{spike} \sim 10^{44}$ erg ; $E_{tail} \sim 10^{44}$ erg
- $T_{spike} \sim 0.1$ sec ; $T_{tail} \sim 200$ sec

Magnetar model

(Duncan &Thompson 1992; Paczynski 1992)



An isolated, slowly rotating, neutron star with B ~10^{14}-10^{15} G

$$B_{dipole} \approx 3\times10^{19}\sqrt{P\dot{P}}\ \mathrm{G} \sim 10^{14} - 10^{15}\ \mathrm{G}$$

- **Not enough rotational energy!**

- **Magnetic energy: $R^3B^2 \sim 10^{47}$erg**

- **Energy source of the Giant flares** **(Thompson & Duncan '95):**

Global shifts of the crust and reconnection of the external field.

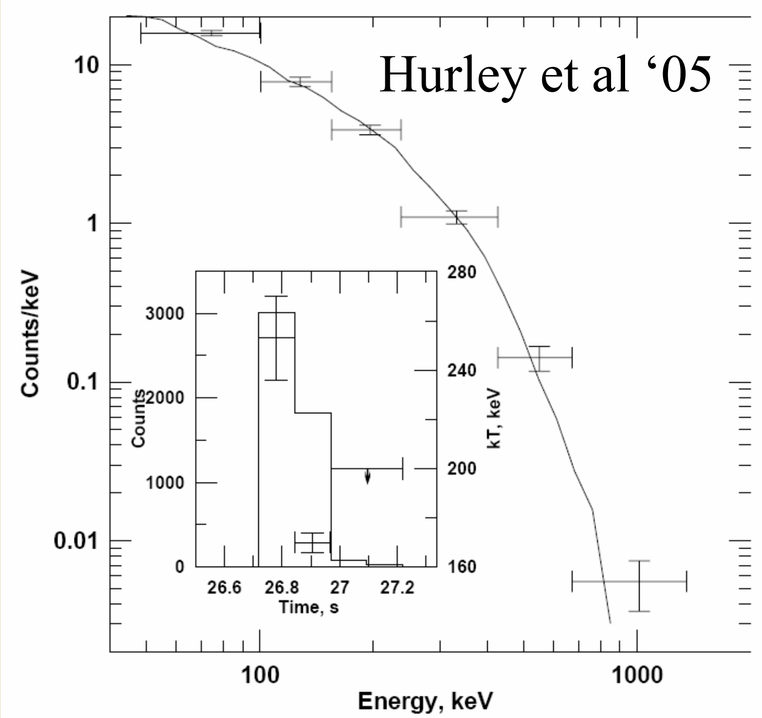
- **Flares time scales:**

$T_{rise} \sim$ msec – Alfven crossing time of the magnetosphere
$T_{decay} \sim$ 0.1 sec -Alfven crossing time of the interior

Giant Flare from SGR 1806-20

The initial spike

Almost all γ-ray detectors were saturated



Duration ~ 0.2 s

$F \approx 1$ erg/cm^2

$E_{iso} \approx 3\times10^{46} d_{15}^{2}$ erg

(prediction by Eichler '02)

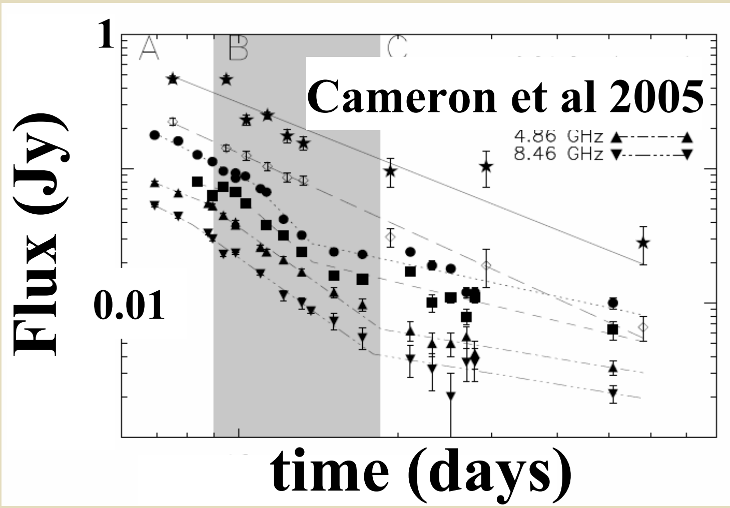
Spectrum:

BB with T≈200 keV (Hurley et al '05)

$E^{0.8}\exp[-E/480\mathrm{keV}]$ (Palmer et al '05)

Consistent with estimates based on the reflection of the flare from the moon (Nakar et al 2005; Mazets et al 2005)

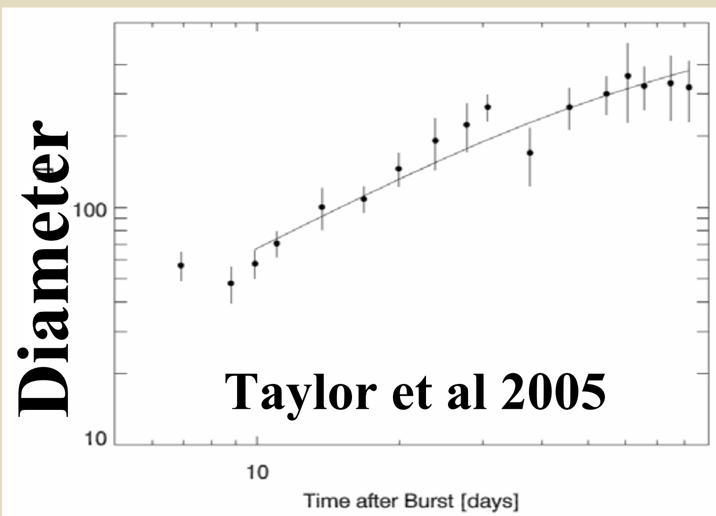
Radio afterglow



$R \sim 10^{16}$cm

$v \sim 0.5c$

(Cameron et al 2005; Gaensler et al 2005)



One sided jet, coasting until ~30d and then start decelerating (Taylor et al 2005)

$E_{aft} > 3 \cdot 10^{43}$ erg ($>5 \cdot 10^{44}$erg ; Granot et al ’05)

What is the source of the afterglow energy?

(Nakar, Piran & Sari 2005)

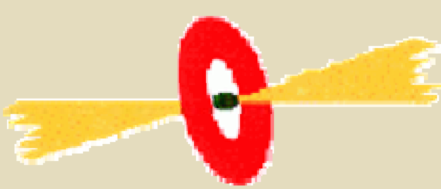
Fireball evolution (in context of gamma-ray bursts): Paczynski (1986) ; Goodman (1986) ; Shemi & Piran (1990); Piran et al. (1993); Meszaros et al. (1993); Grimsrud & Wasserman (1998)

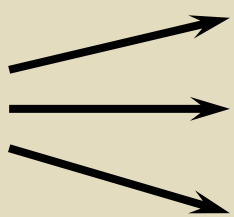
A prompt flash of g-rays + extended afterglow

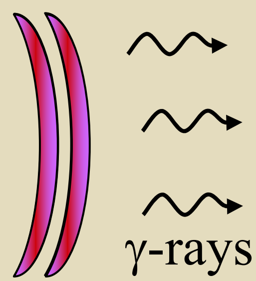
A GRB mechanism !!

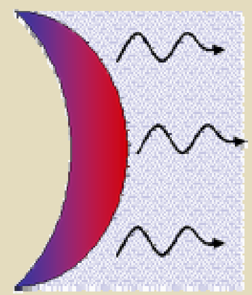
GRBs: High Luminosity + Short time scale + Hard non-thermal photons

Compact source	Relativistic wind	Energy Dissipation $E_\gamma = \varepsilon E$ ($\varepsilon < 1$)	Afterglow $E_{aft} = E(1-\varepsilon)$







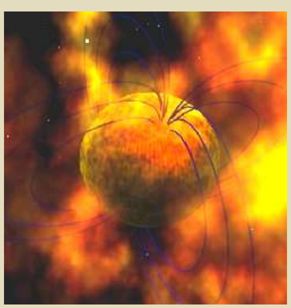


A prompt flash of g-rays + extended afterglow

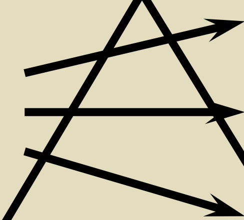
A GRB mechanism ??

SGR: High Luminosity + Short time scale + Hard ~~non-thermal~~ photons

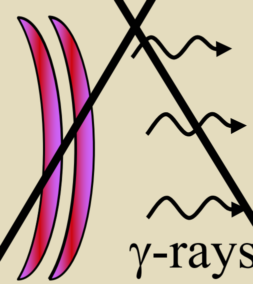
Compact source



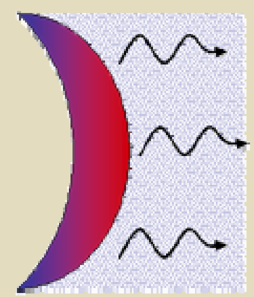
~~**Relativistic wind**~~



~~**Energy Dissipation $E_\gamma=\varepsilon E$ ($\varepsilon<1$)**~~



Afterglow E_{aft}=???



Evolution of a pure fireball

(Paczynski '86 ; Goodman '86)

The optical depth of pairs or gamma-rays is:

$$\tau_{\gamma\gamma} \approx 10^{11} L_{47} R_{0,6}^{-1}$$

Producing a pair-radiation plasma with temperature:

$$T_0 \approx 300\ L_{47}^{1/4}\ R_{0,6}^{-1/2}\ \text{keV}$$

The plasma expands:

$$\Gamma = R/R_0 \quad ; \quad T = T_0 R_0 / R$$

$$\mathbf{T_{obs} \approx T\Gamma = T_0}$$

Can the surviving pairs carry the afterglow energy?

Pairs freeze-out

$R \approx 20 R_0$

Pairs final Γ

$\Gamma \approx 680$

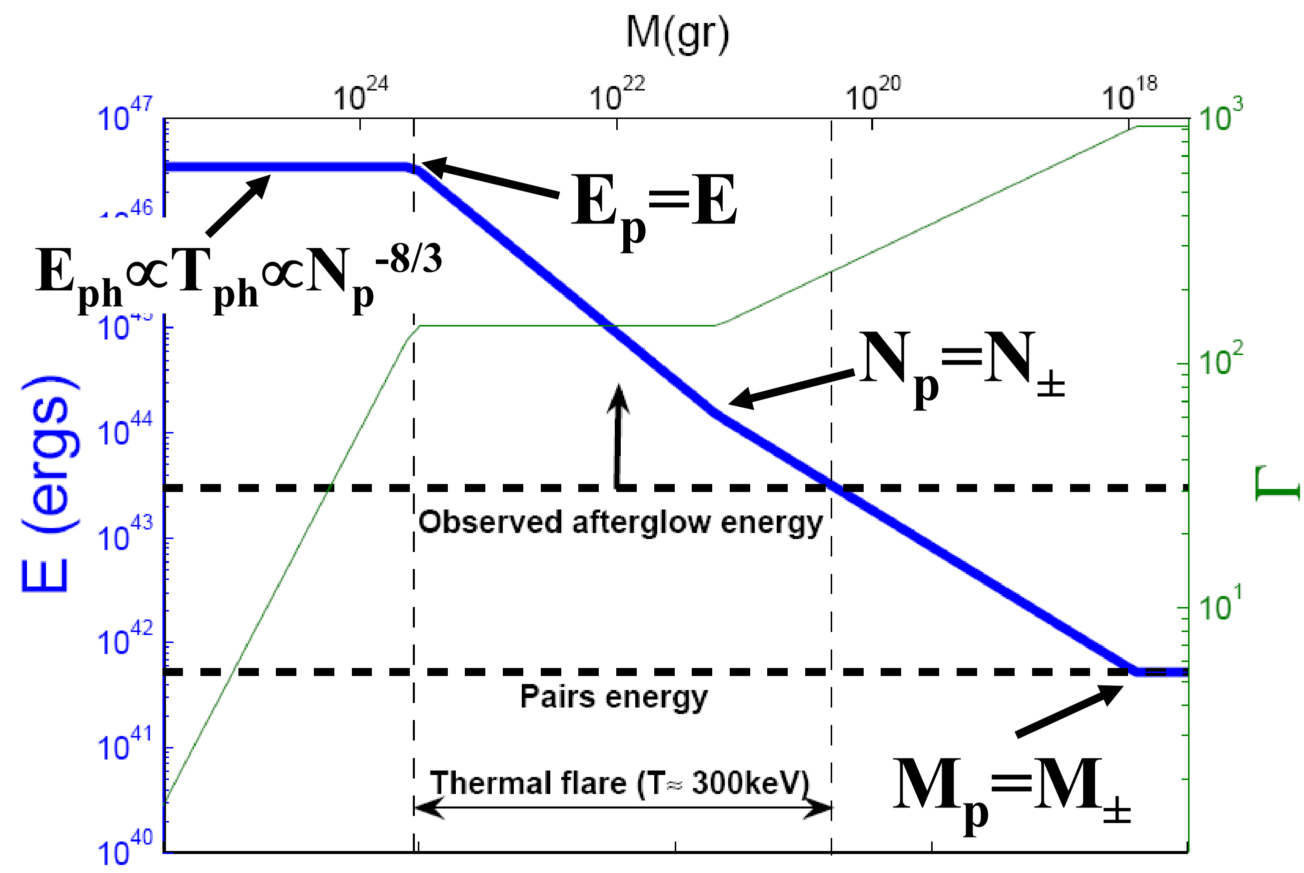
$$E_{\pm}/E \approx 10^{-5} R_{0,6}^{-3/4}$$

NO!

10^{15}G magnetic field at R_0 does not change this conclusion

Baryonic load - protons

Protons increase the inertia of the plasma while the accompanying electrons increase its opacity.



Nakar et al ‘06

Energizing the afterglow

- The surviving pairs cannot energize the afterglow

- Interaction of the radiation with the external medium cannot be the energy source.

- Tuned baryonic load can carry the afterglow energy as highly a relativistic ejecta.

- If the energy is ejected at ~0.5c then the line of sight is baryonic free.

- A viable solution is an angular dependent baryonic loading (Eichler ‘05).

What is the rate of giant flare or Extragalactic flares as short GRBs)?

One giant flare (E>10^{46}erg) was observed in 30 years:

$$\Re_{MW} = 1/(30^{+1270}_{-25})\mathrm{y}^{-1} \quad @\,95\%\ \mathrm{C.L.}$$

and

$$\Re_{SGR} = 1/(120^{+5000}_{-100})\mathrm{y}^{-1}$$

An external B=10^{15}G cannot supply the energy for a giant flare every 100yr

(Stella et al ‘06)

Constraints from extragalactic flares

The initial spike of the Dec. 27'th flare can be detected by BATSE to ~50 Mpc **(Duncan 2001; Eichler 2002; Boggs 2005)**

BATSE observed rate of such extragalactic flares is **(Dar 2005; Nakar et al 2005; Hurley et al 2005; Palmer et al 2005):**

$$\dot{N} \approx 150\,\mathrm{y}^{-1}\,\mathrm{d}_{15}^{3}\,\frac{\Re_{MW}}{1/30}\,\frac{3\mathrm{M}_{\odot}\mathrm{y}^{-1}}{SFR_{MW}}\,\frac{SFR_{loc}}{0.02\mathrm{M}_{\odot}\mathrm{y}^{-1}\mathrm{Mpc}^{-3}}$$

- At d>Mpc only the initial spike of a giant flare is observed, looking like a short GRB.
- The BATSE observed rate of short GRBs is ~170 y^{-1}

What is the fraction of SGR giant flares in the BATSE sample of short GRBs?

- **Examination of error boxes of 6 short GRBs → none is a similar flare (Nakar et al 2005).**

- **Recent observations of short GRBs with Swift - at most <u>1/14</u> is a giant SGR flare:**

$$1\% < f_{SGR} < 30\% \text{ @ } 95\% \text{ C.L.}$$

(see also Popov & Stern 2005; Palmer et al 2005; Lazzati et al 2005)

Ofek (2006) examine IPN localizations of 46 short GRBs and find that only 1 may be a giant flare:

$$1\% < f_{SGR} < 14\% \ (2\sigma)$$

↓

$$1000 \gtrsim \Re_{SGR}^{-1} < 5000 \text{ yr}$$

Can we exclude the possibility that exotic (10^{17}G) magnetars are the progenitors of the short GRBs?

- Old progenitor → not a remnant of core collapse SNe (Levan et al 06)
- 10^{51}erg → B~10^{17}G
- Undetected in our galaxy → short life time

Non-thermal spectrum & time scale?
Short and long GRBs are similar?

Summary

- The predicted SGR giant flares occur
- We were lucky to observe one - $R_{SGR} \sim 1/3000\ yr^{-1}$
- Although the observed behavior of SGR giant flares and GRBs is similar the evolution of the bursts is probably different.
- The line-of-sight was relatively baryonic free.
- The afterglow energy can be explained by:
  - medium and spherical baryonic loading
  - angular fluctuating baryon loading
  - Not acceleration directly by photons

Thanks!