Giant Flare of SGR 1806-20 from a Relativistic Jet

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Soft gamma repeaters (SGRs) are…

Sources of short (~0.1s),

repeating bursts of soft γ-rays (<100 keV).

4 (or 5?) are known (3 in our Galaxy, 1 in the LMC).

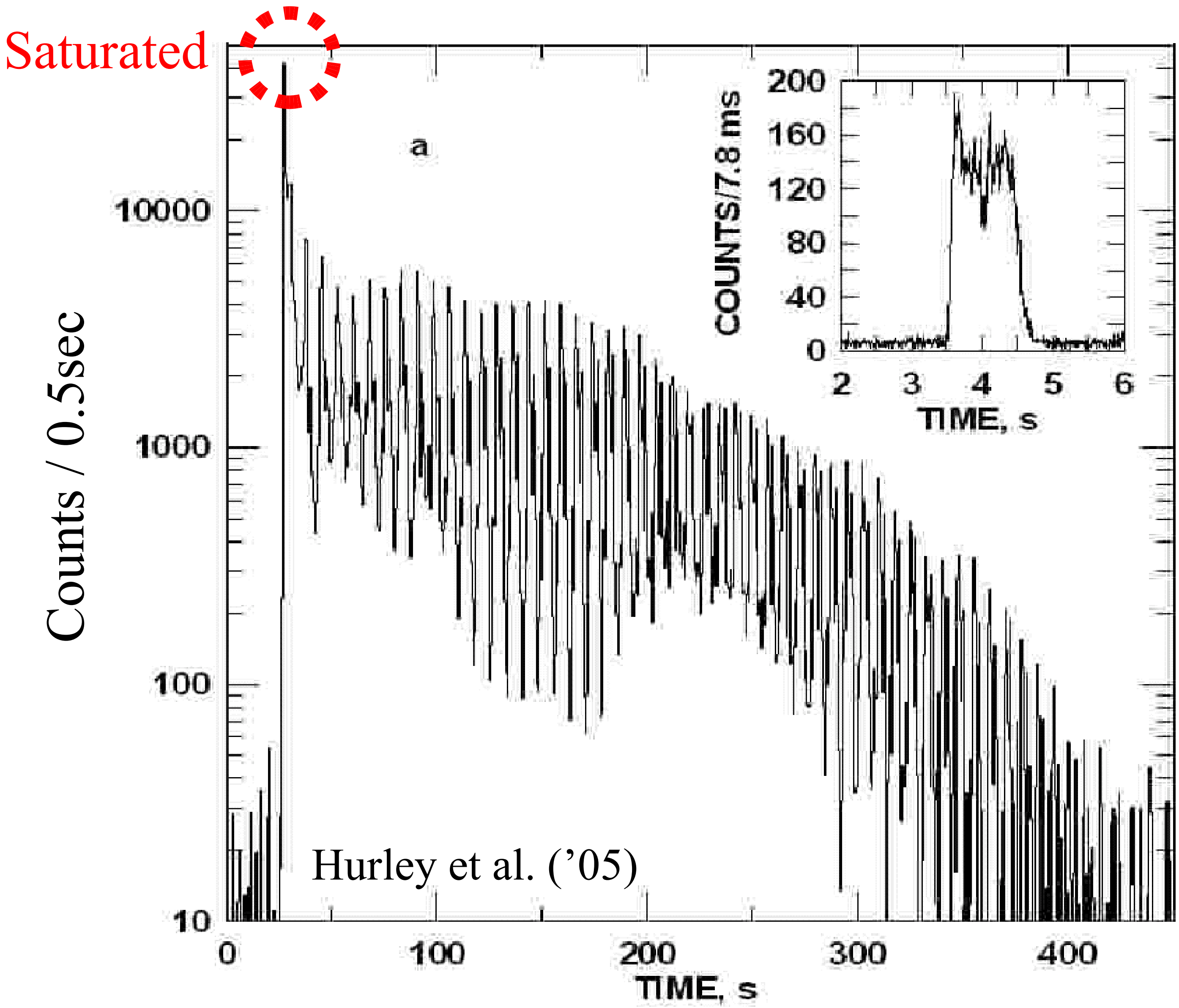
The SGRs are quiescent soft X-ray sources (2-10 keV).

They have rotation periods in the 5-8 s range.

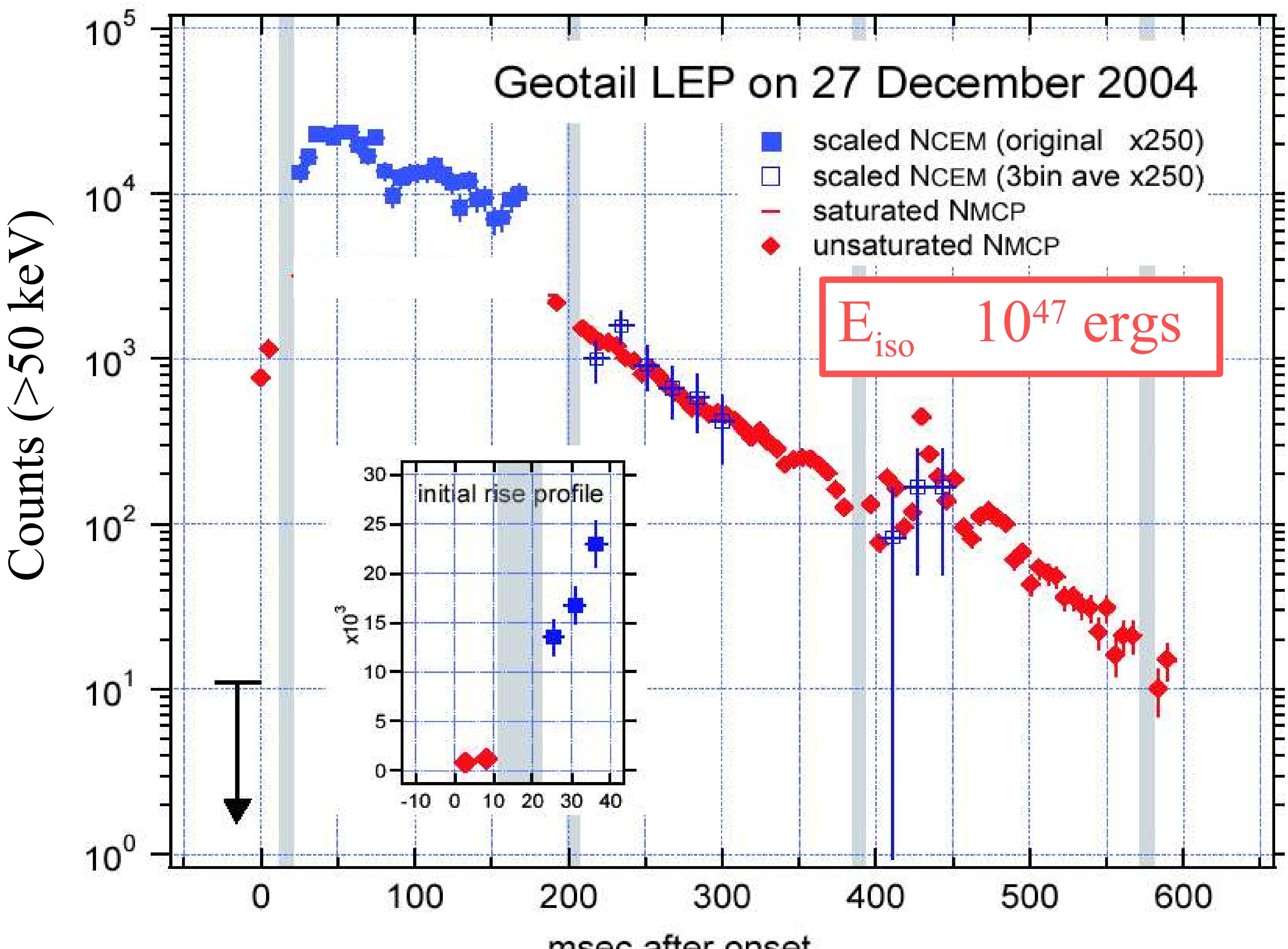
SGRs are most likely highly magnetized neutron stars (*magnetars*), that have a magnetic field of $\sim 10^{15}$ G.

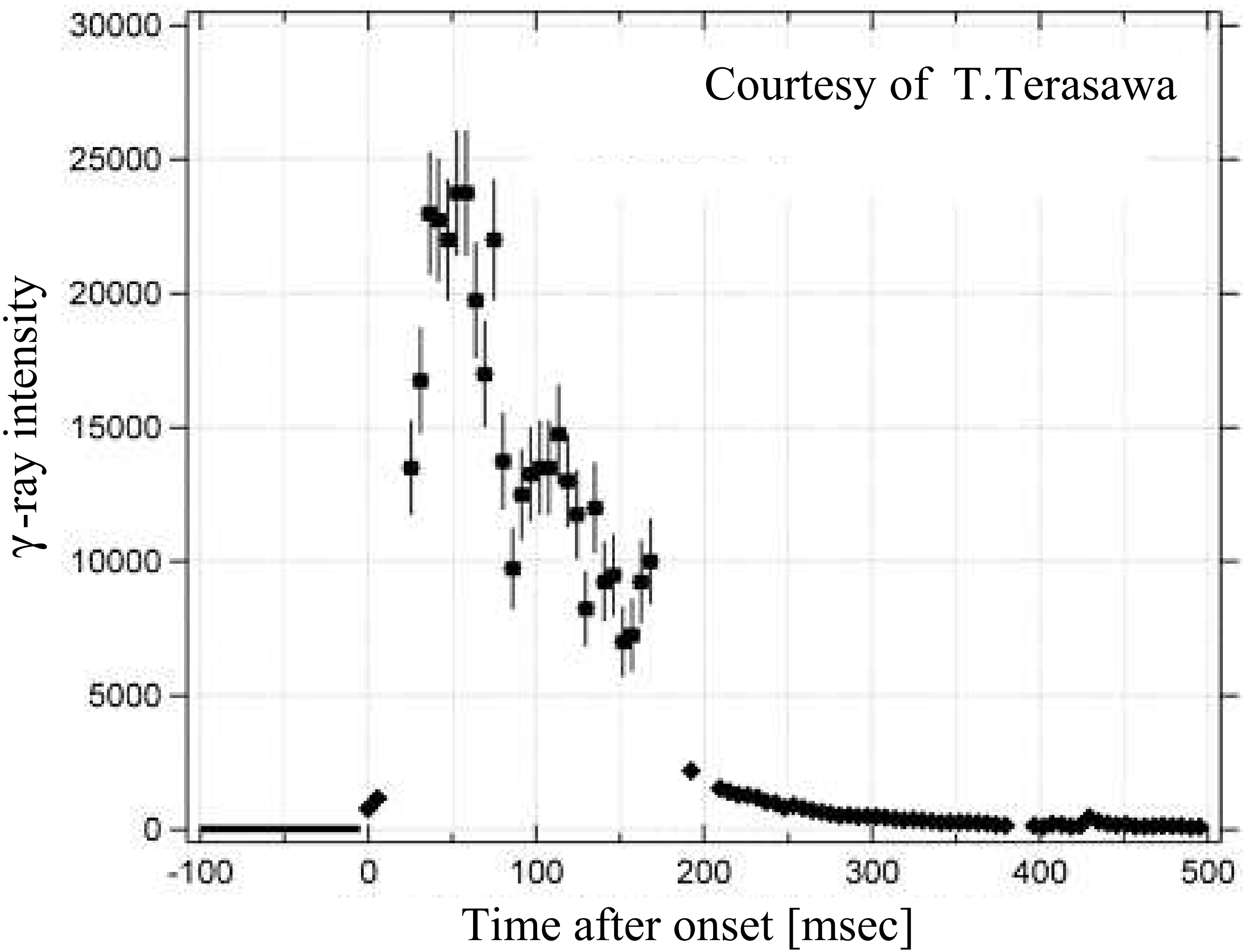
SGRs emit hard *giant flares*, at a rate of once per ~30 yrs.

Giant flare from SGR 1806-20 (2004, Dec. 27)



Terasawa et al. 2005: GEOTAIL observation



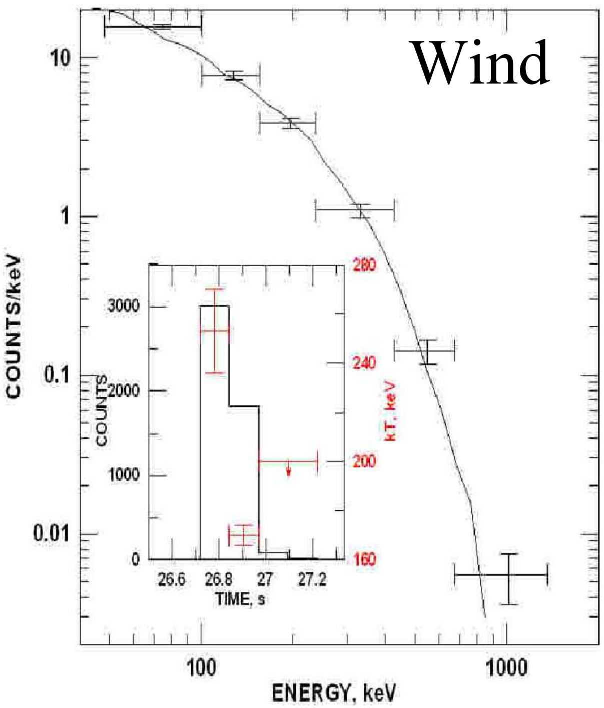


Courtesy of T.Terasawa
30000
25000
20000
15000
10000
5000
0
-100
0
100
200
300
400
500
γ-ray intensity
Time after onset [msec]

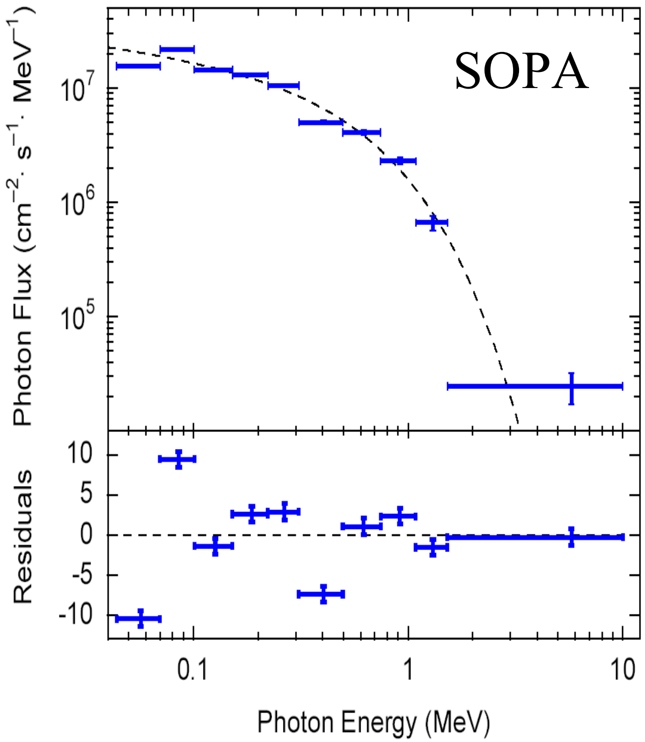
Spectrum of the initial spike

Highly uncertain …

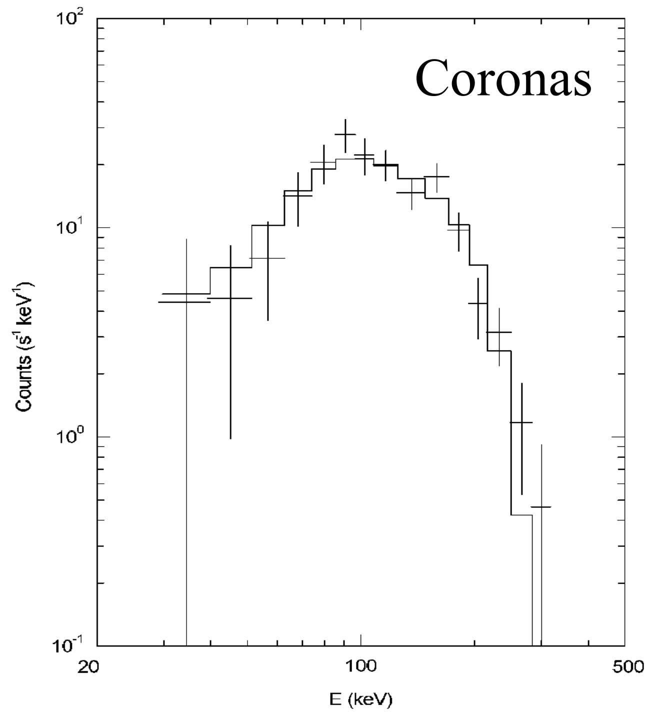
Hurley et al. ('05)



Palmer et al. ('05)



Mazets et al. ('05)



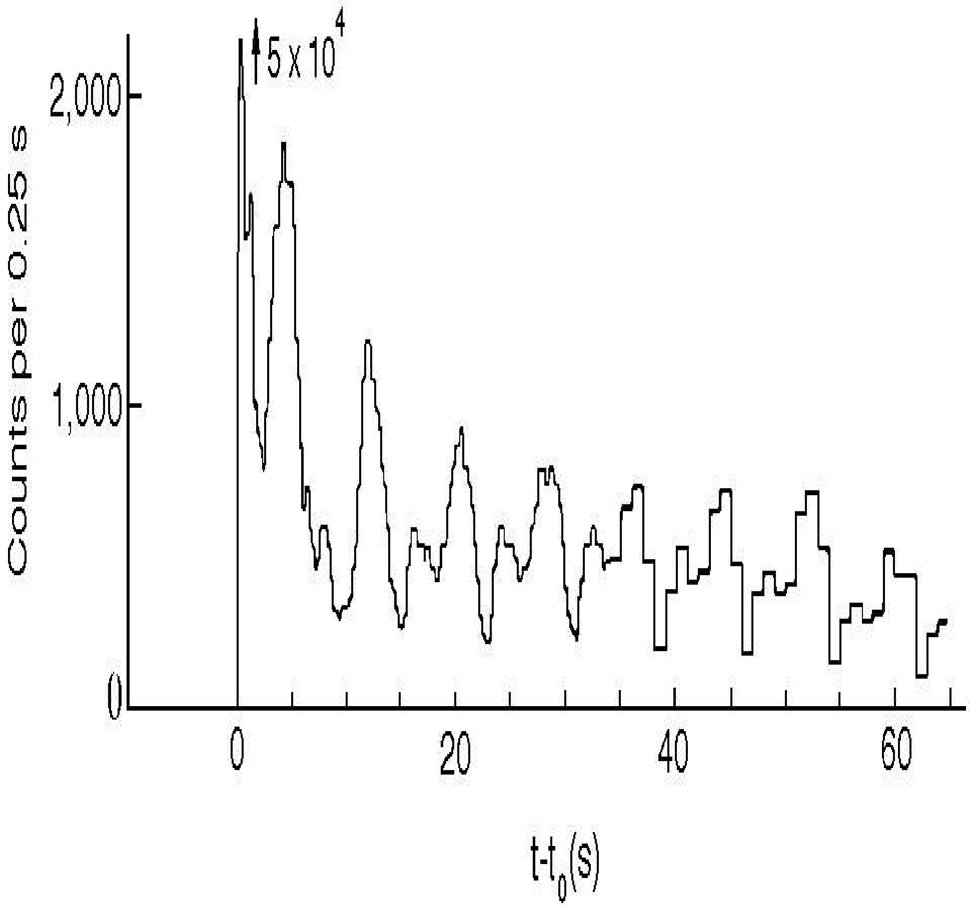
Initial *100 msec,
BB: kT>127 keV

Initial 160 msec,
power law (α = -0.2)
+ exp. cut. (480keV)

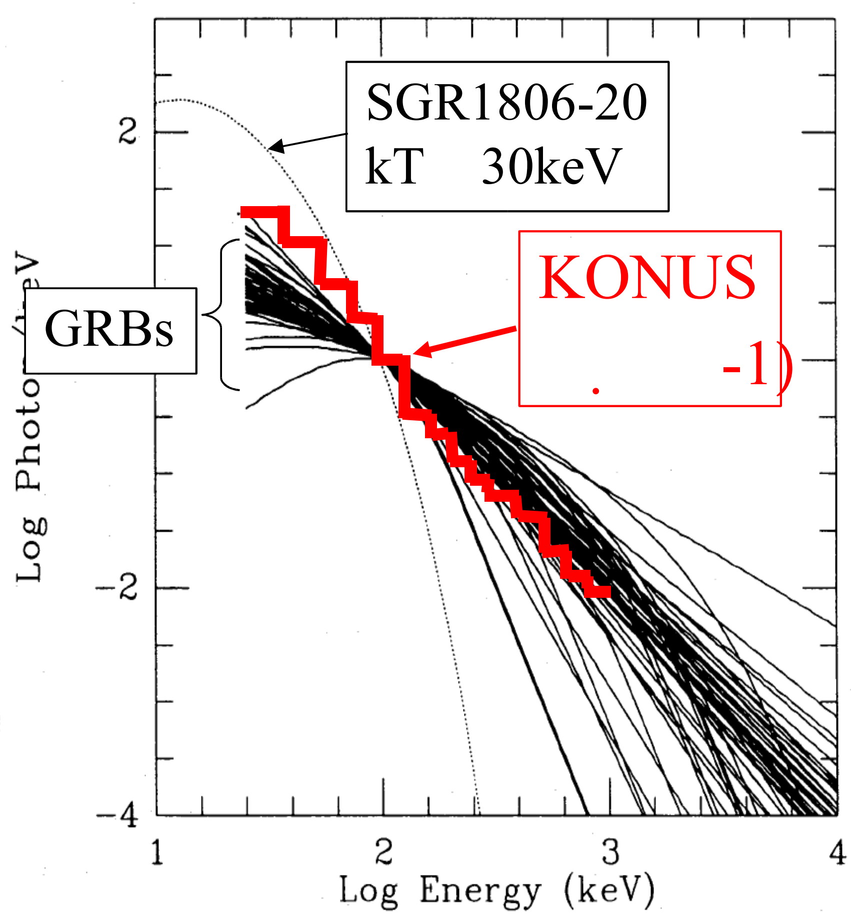
Initial 200 msec,
power law (α = -0.7)
+ exp. cut. (800keV)

Initial spike of 1979 March 5 event

Likely nonthermal.

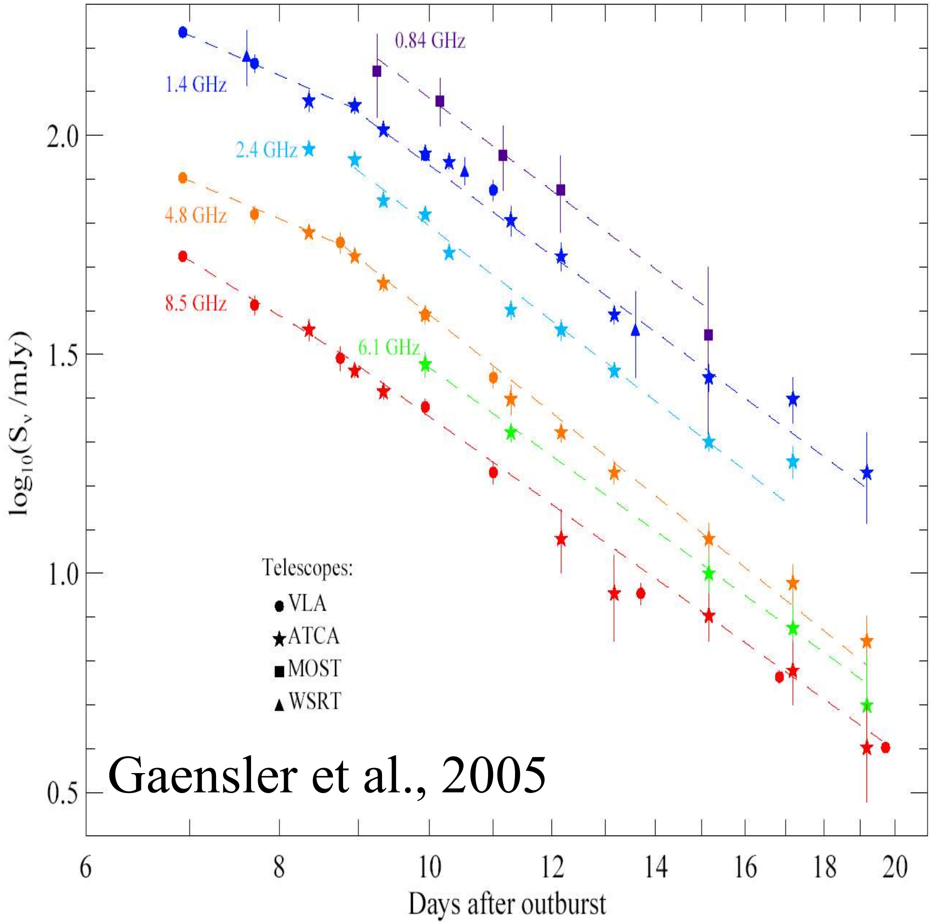


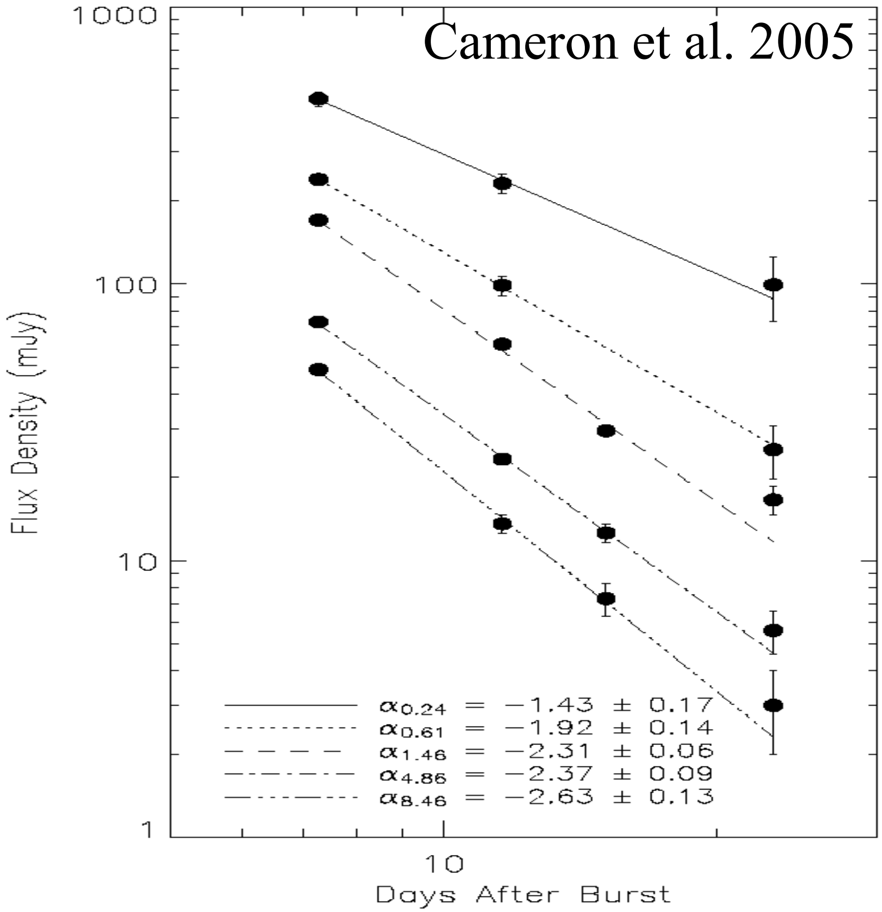
Cline et al. 1980



Fenimore et al. ('96)

Radio afterglow of 2004 Dec. 27 event





Minimum energy required for observed radio luminosity:

$$E_{\rm min} = 4 \times 10^{43}\ d_{15}^{17/7}[(1+\kappa)F_{100}]^{4/7} f^{3/7}\theta_{50}^{9/7}\ \text{ergs.}$$

Initial outflow was likely ultra-relativistic…

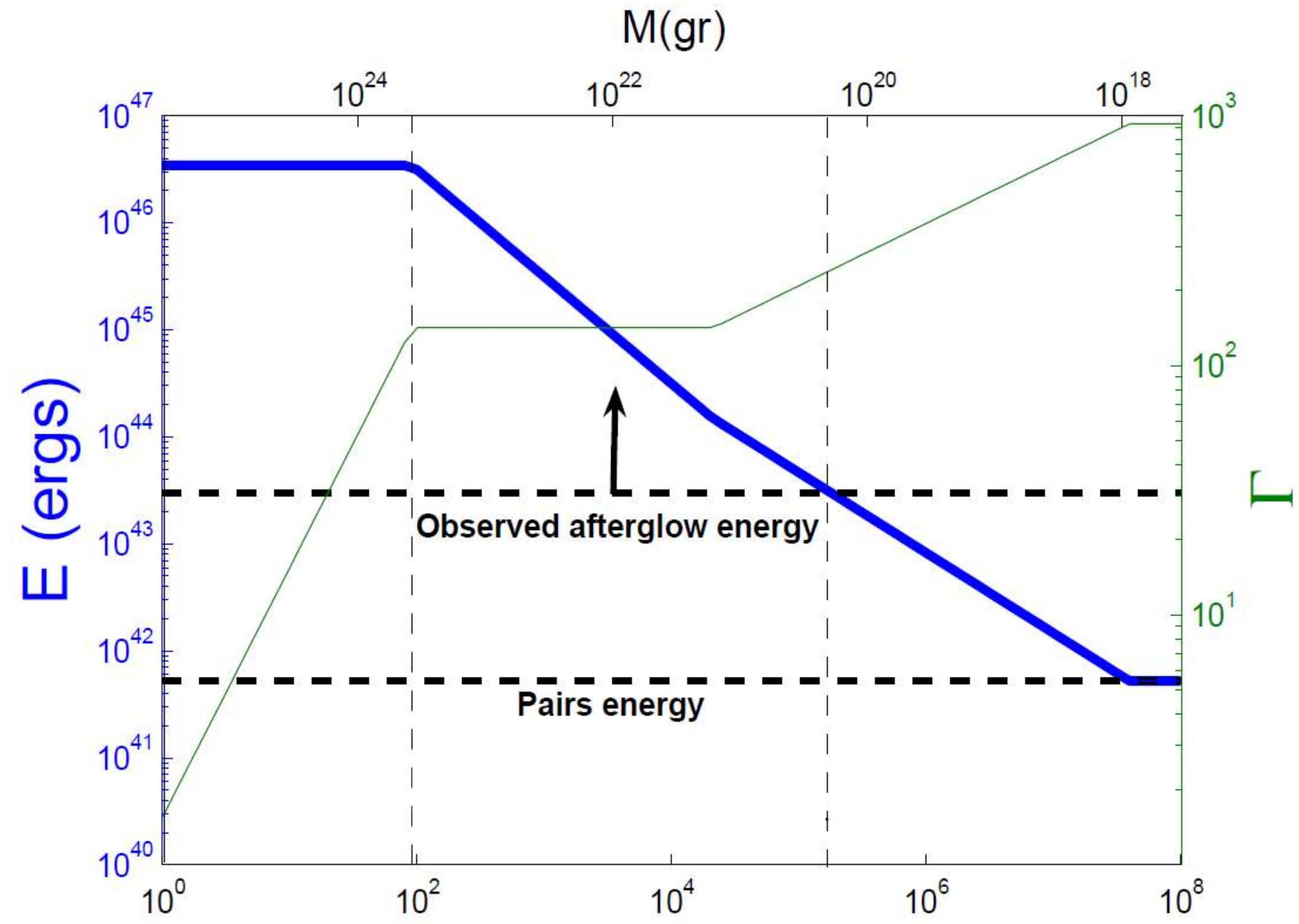
Because luminosity is hyper-Eddington.

$$L_{obs}/L_{Edd} \qquad 10^{10}$$

Especially, when the spectrum is non-thermal, "compactness problem" constraints on the initial Lorentz factor: $\Gamma_0 > 30$.

Nakar et al. 2005

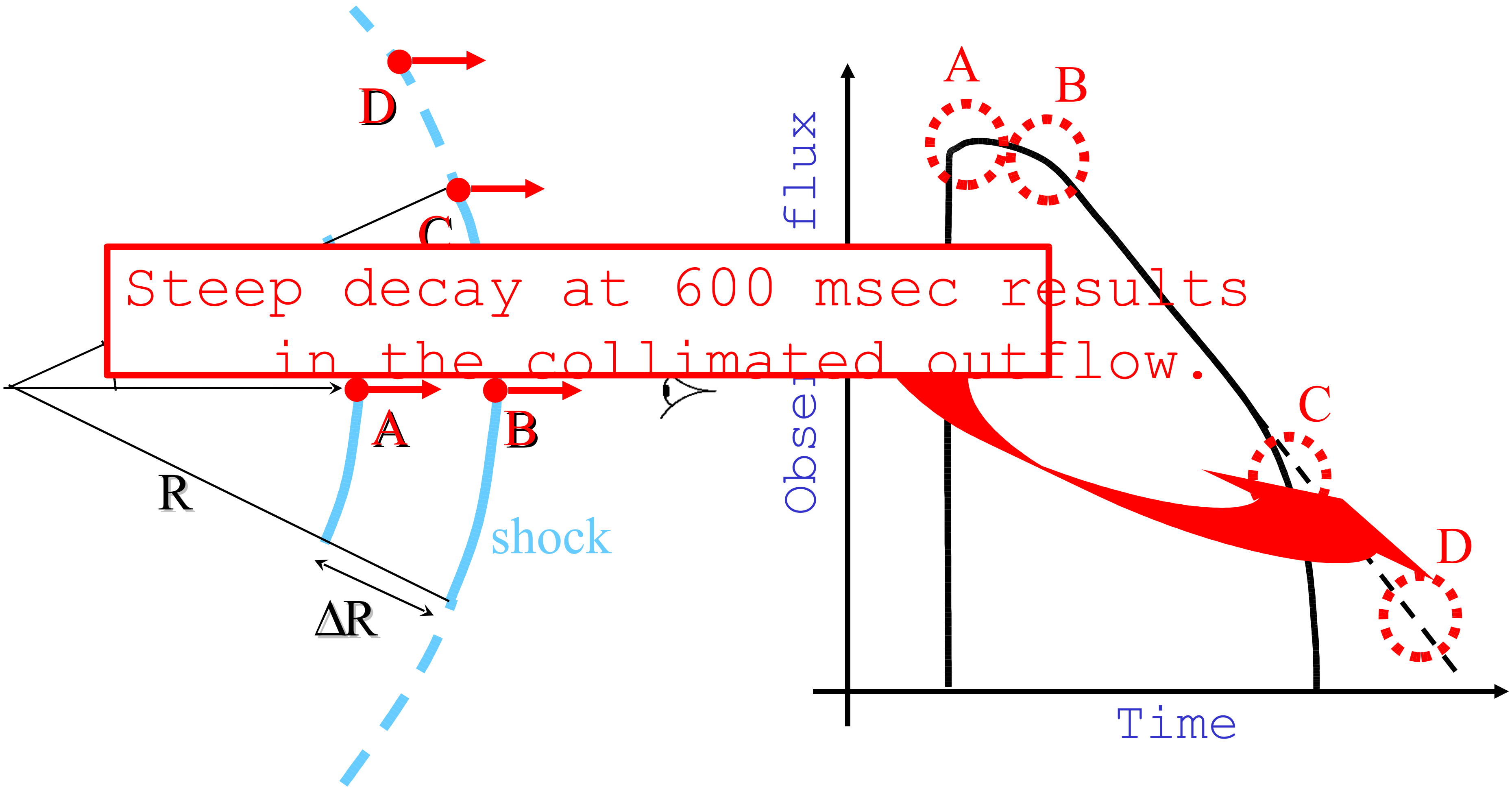
Pure radiation fireball is unlikely (from the radio observation).



$\eta = E / M_b c^2$

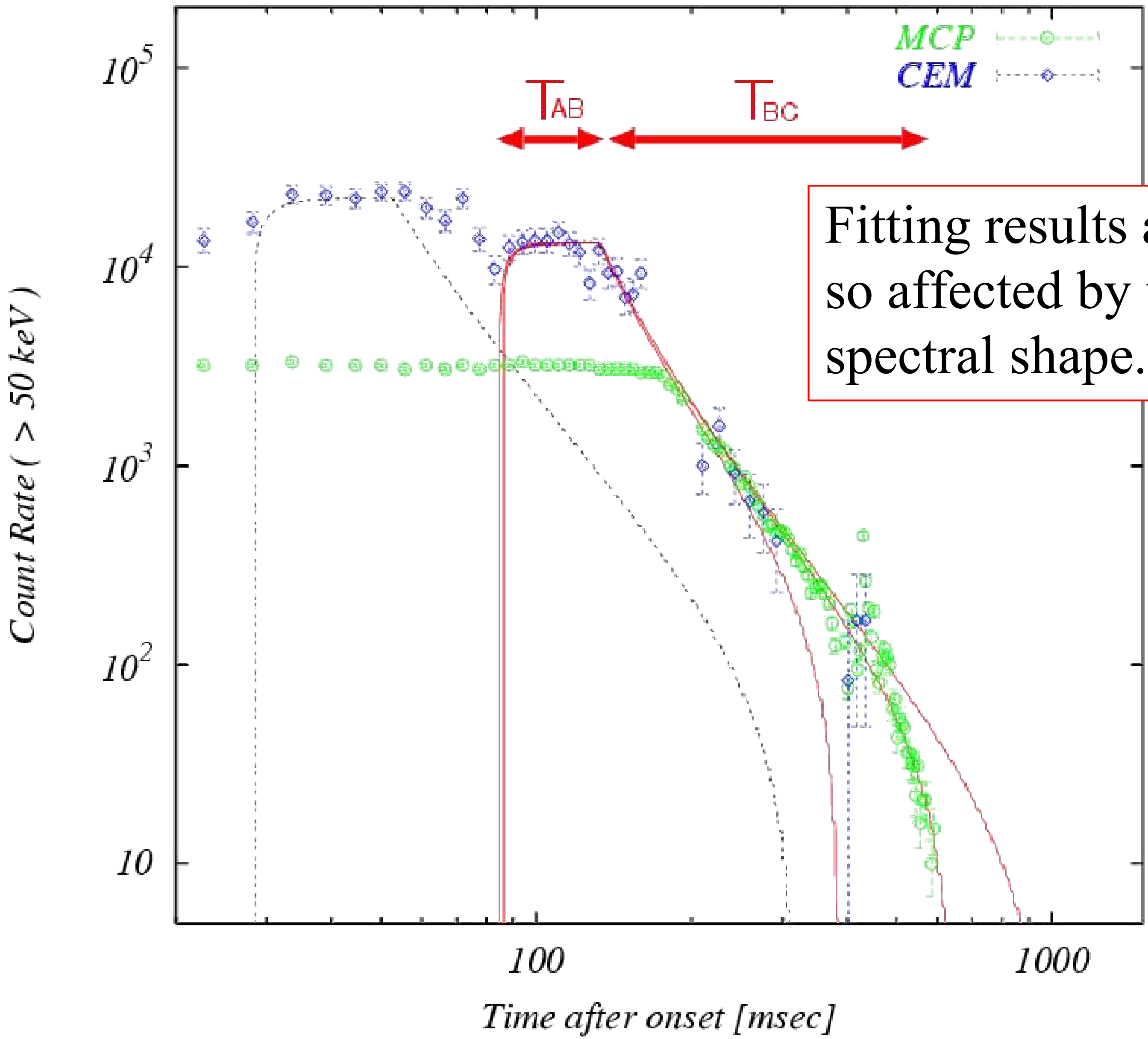
Evidence for jetted emission ?

Shock radiates between R and R+ΔR.



Steep decay at 600 msec results in the collimated outflow.

Yamazaki et al., 2005



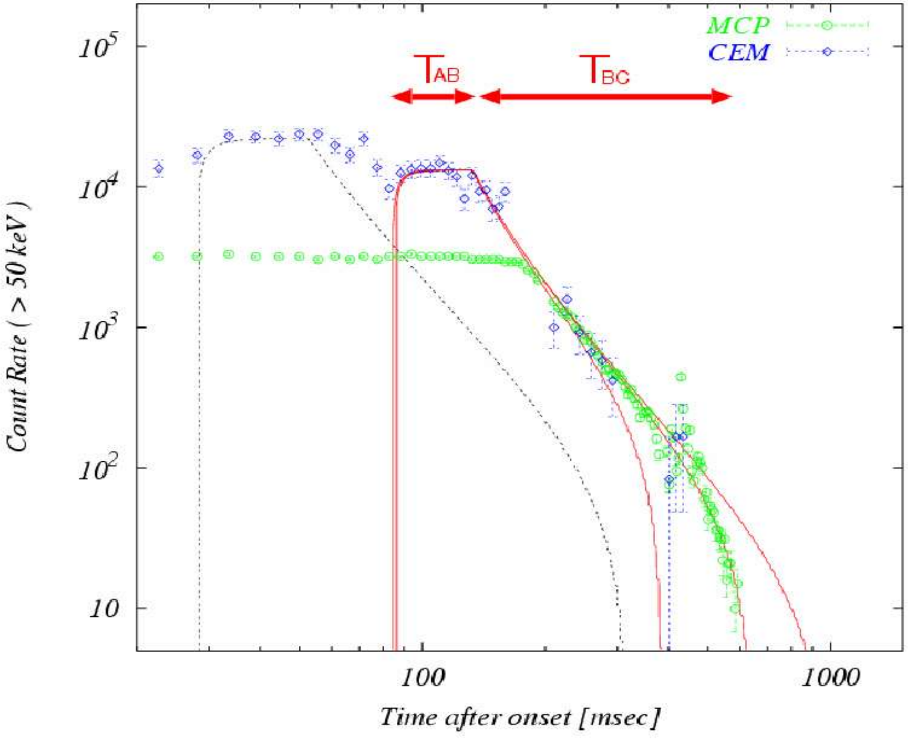
Fitting results are not so affected by the assumed spectral shape.

Upper limit of $\Delta\theta$

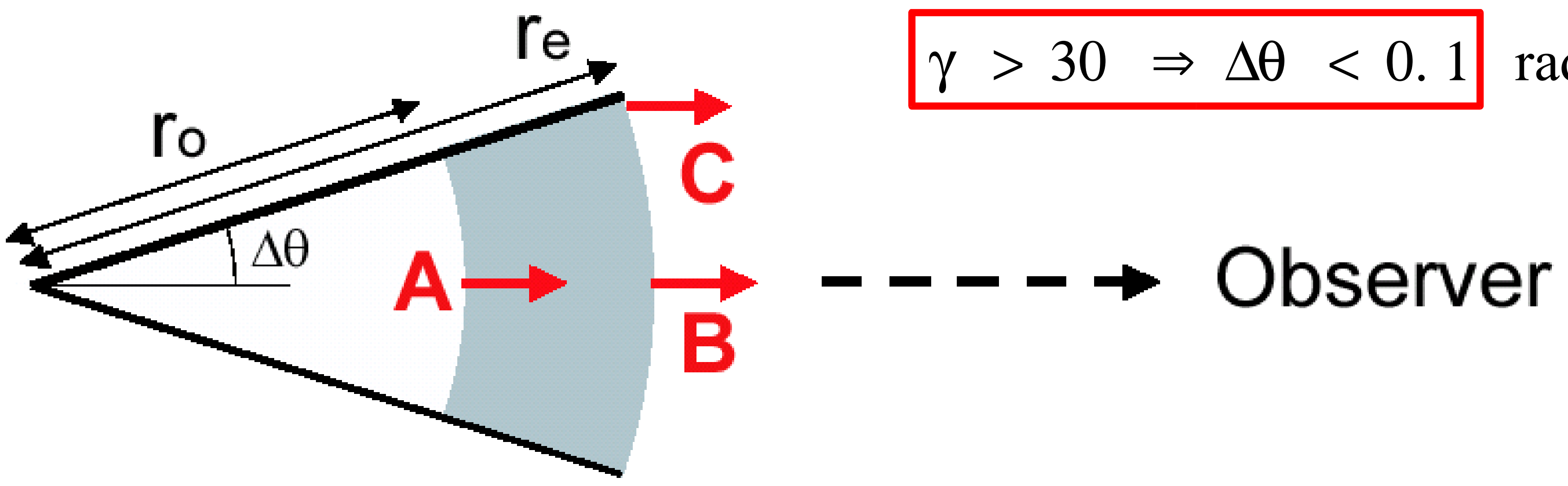
$$T_{AB} = \frac{(r_e - r_0)(1-\beta)}{c\beta} \sim (\kappa - 1)\frac{r_0}{2c\gamma^2} \sim 50 \text{ msec.}$$

$$T_{BC} = \frac{r_e(1-\cos\Delta\theta)}{c} \sim (\gamma\Delta\theta)^2 \kappa \frac{r_0}{2c\gamma^2} \sim 500 \text{ msec.}$$

$\kappa = r_e / r_0 > 1$



$$\Rightarrow \quad (\gamma\Delta\theta)^2 \sim 10(1-\kappa^{-1}) \lesssim 10 \text{ and hence } \gamma\Delta\theta \lesssim 3.$$



$\gamma > 30 \Rightarrow \Delta\theta < 0.1$ rad

Jet emission v.s. Isotropic emission

E : Total gamma-ray energy

Isotropic : E 10^{47} ergs (Terasawa et al. 2005)

Jet : E 10^{44} ($\Delta\theta$ / 0.1$)^2$ ergs

[c.f. Magnetic energy

E_{mag} $(B^2/8\pi)(4\pi R^3/3)$ 10^{47} ergs

for $B=10^{15}$ G, R=10 km]

⇒ Energetics is rather relaxed for jetted emission case.

Jet emission v.s. Isotropic emission (2)

Event rate of the giant flare (per magnetar)

of giant flares with E_γ (per SGR):

$$N < N_{max} \quad E_{Mag} / E$$

Event rate $\dfrac{N}{\text{Active time of magnetar } (10^4 \text{ yrs})}$

$$< \begin{cases} \text{Once per } 10^4 \text{ yrs} \quad \text{(isotropic)} \\ \text{Once per } 10^2 \, (\Delta\theta \; / \; 0.1)^2 \text{ yrs} \quad \text{(jetted)} \end{cases}$$

I want to see a giant flare again from SGR 1806-20 during my life...

Wide spread of Isotropic energy E_{iso}

Giant flares of SGRs

SGR1806-20:

E_{iso} 10^{47} ergs

E_γ $< 10^{44}$ ergs

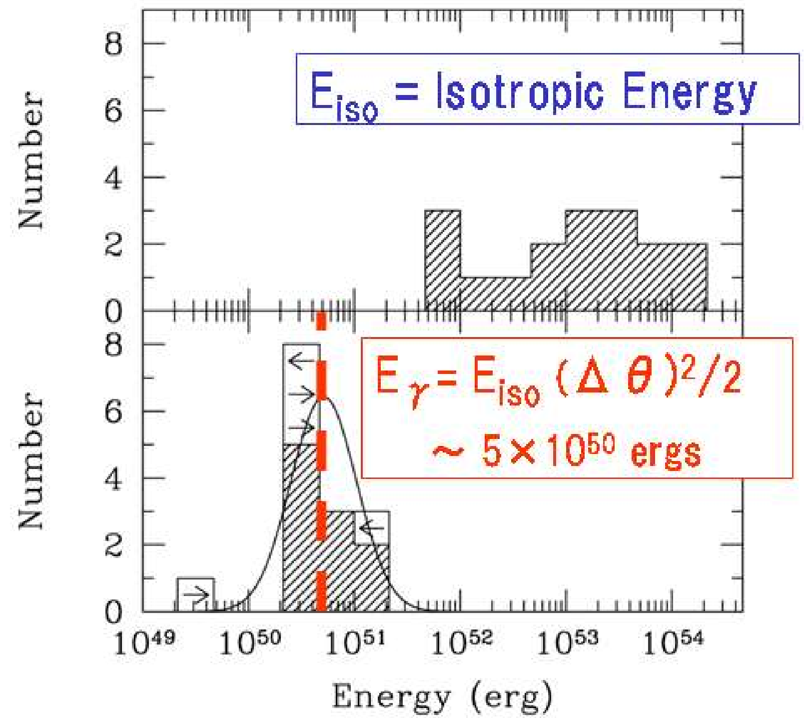
Past two events:

E_{iso} 10^{45} ergs

E_γ 10^{44} ergs !?

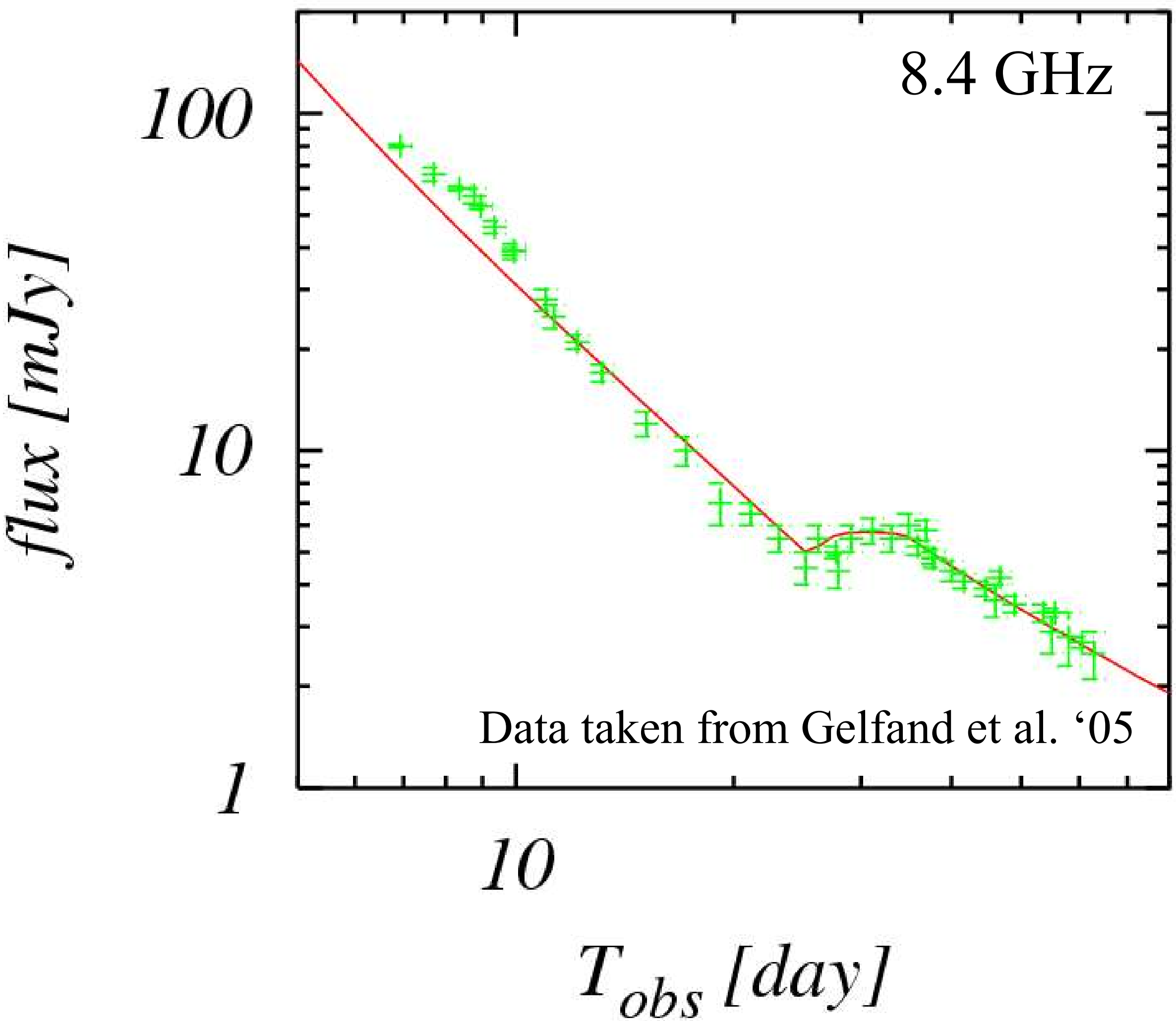
GRBs

Frail et al. (2001)



Radio afterglow light curve

may be fitted by the initially relativistic jet model.



$E_{kin} = 5\text{x}10^{45}$ ergs

$\Delta\theta$ = 0.1 rad

θ_v = 0 0.12 rad

γ_0 = 30 100

p=2.5

$_e$=0.03 $_B$ = 0.009

$n \propto r^{-2.5}$

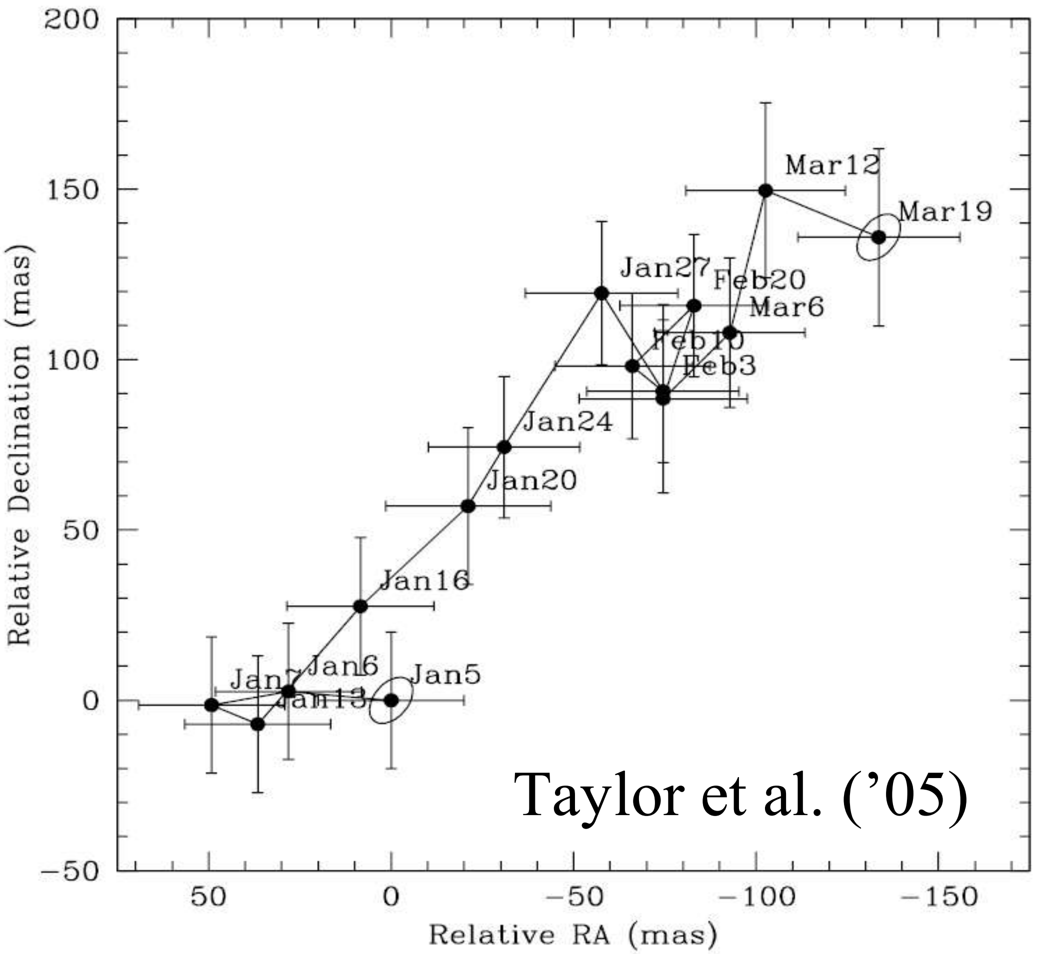
(with dense shell at $6\text{x}10^{18}$cm)

Yamazaki et al. in prep.

Proper motion of the radio image

may support the jetted emission ?

Jet may be one-sided (analogue to the solar flare)

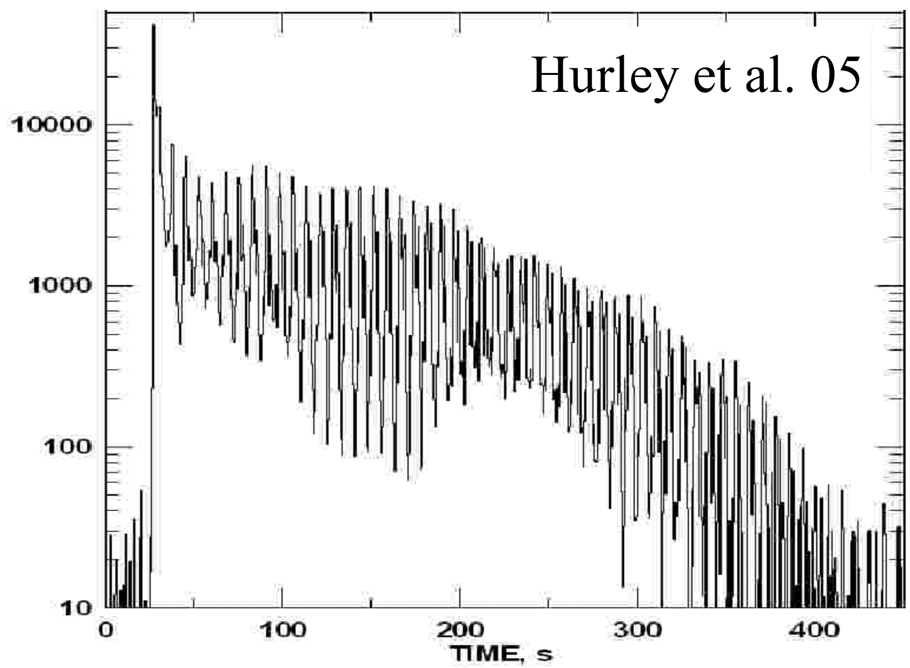


"Statistical" problem…

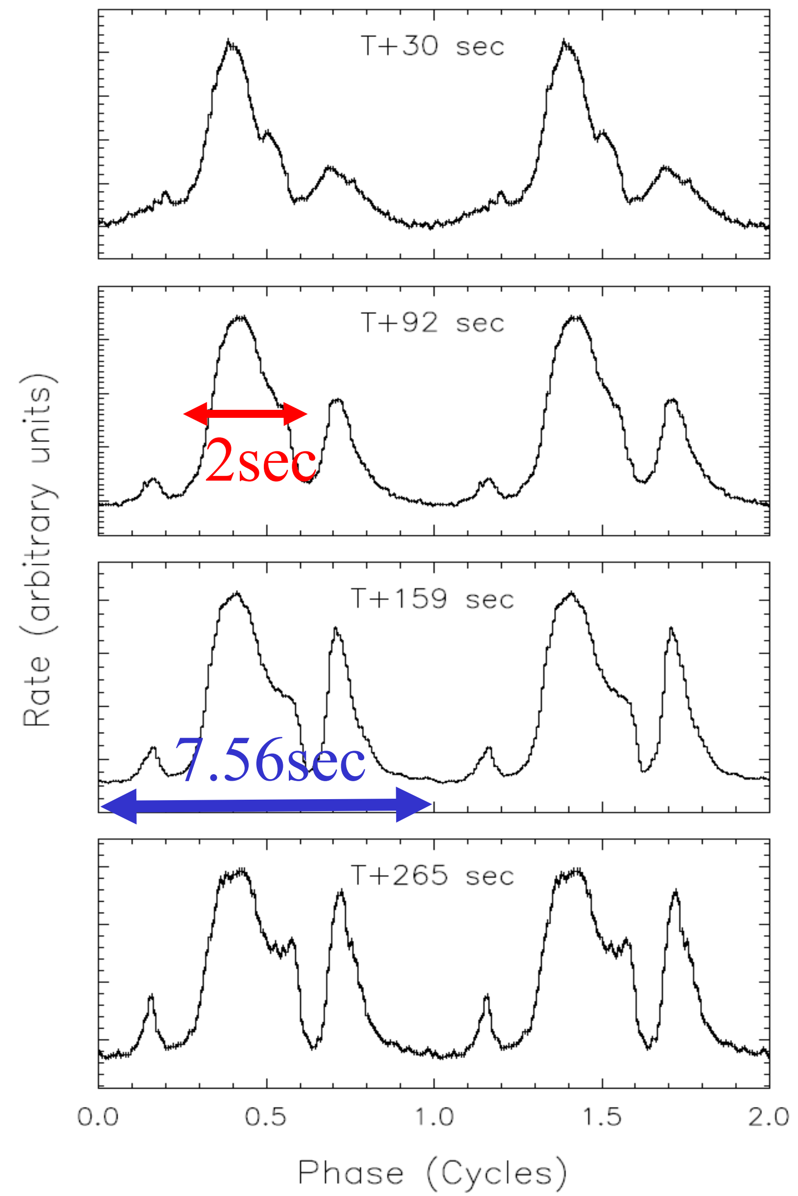
Pulsating tail is nearly isotropic.

When the initial spike is a jetted emission, many orphan pulsating tail should be detected by e.g., BATSE.

But ever detected pulsating tails always associate with the initial spike.



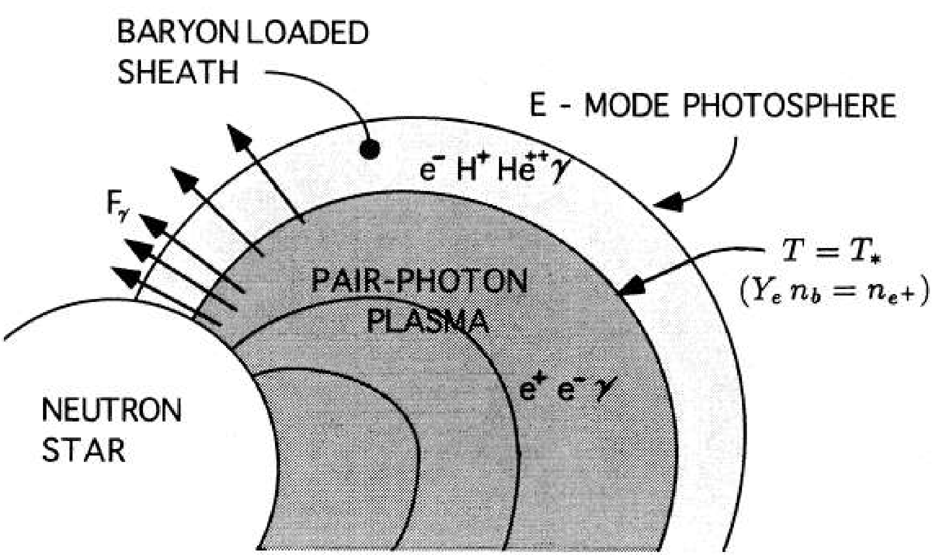
Averaged pulse profile of pulsating tail



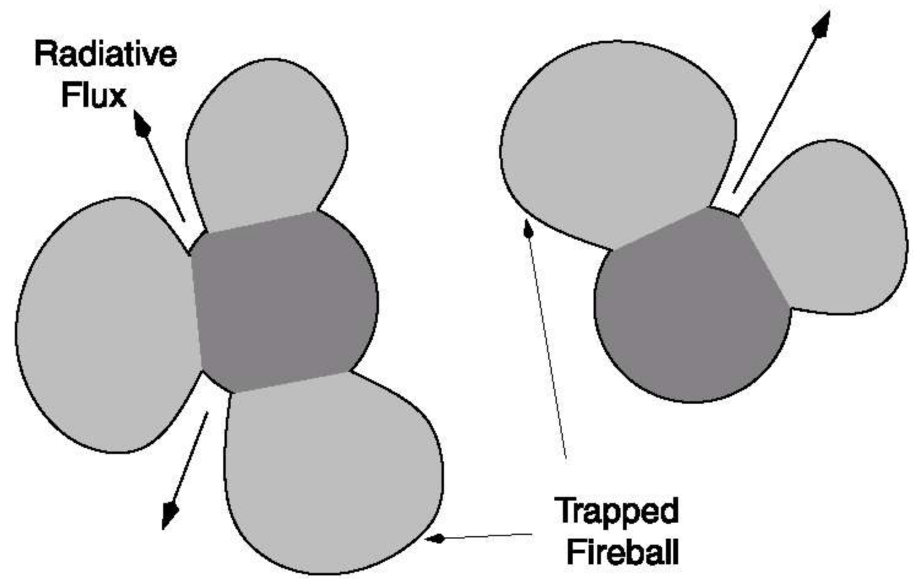
$\Delta\theta_{tail}$ (2/7.56) π 1 rad

Weakly collimated pulsating tail

$\Delta\theta_{tail}$ 1 rad is possible in magneter model.
(but collimation degree highly depends on B-field configuration.)



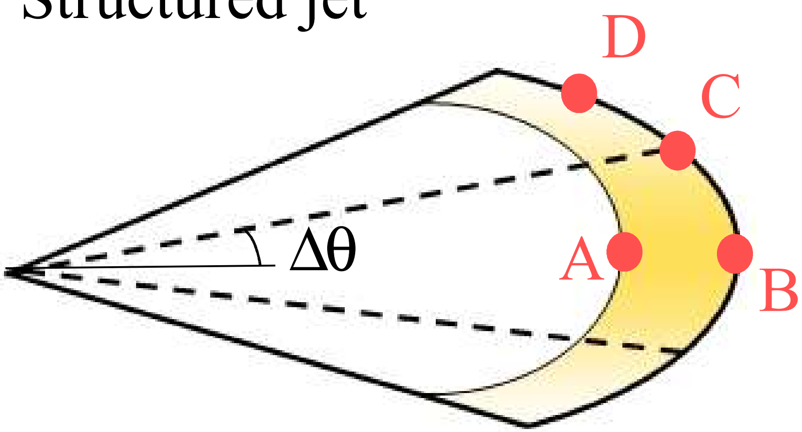
Thompson & Duncan (1995)



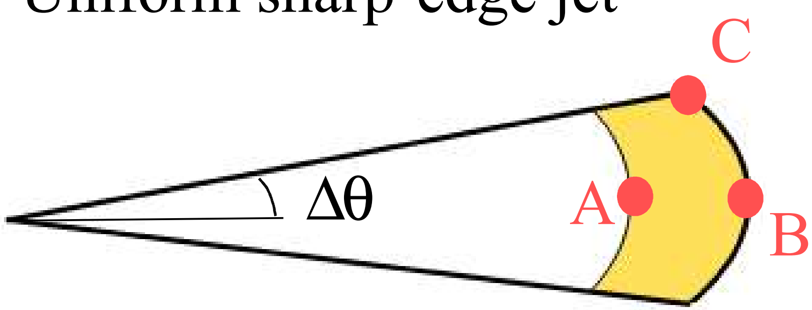
Thompson & Duncan (2001)

Emissions from structured jets ?

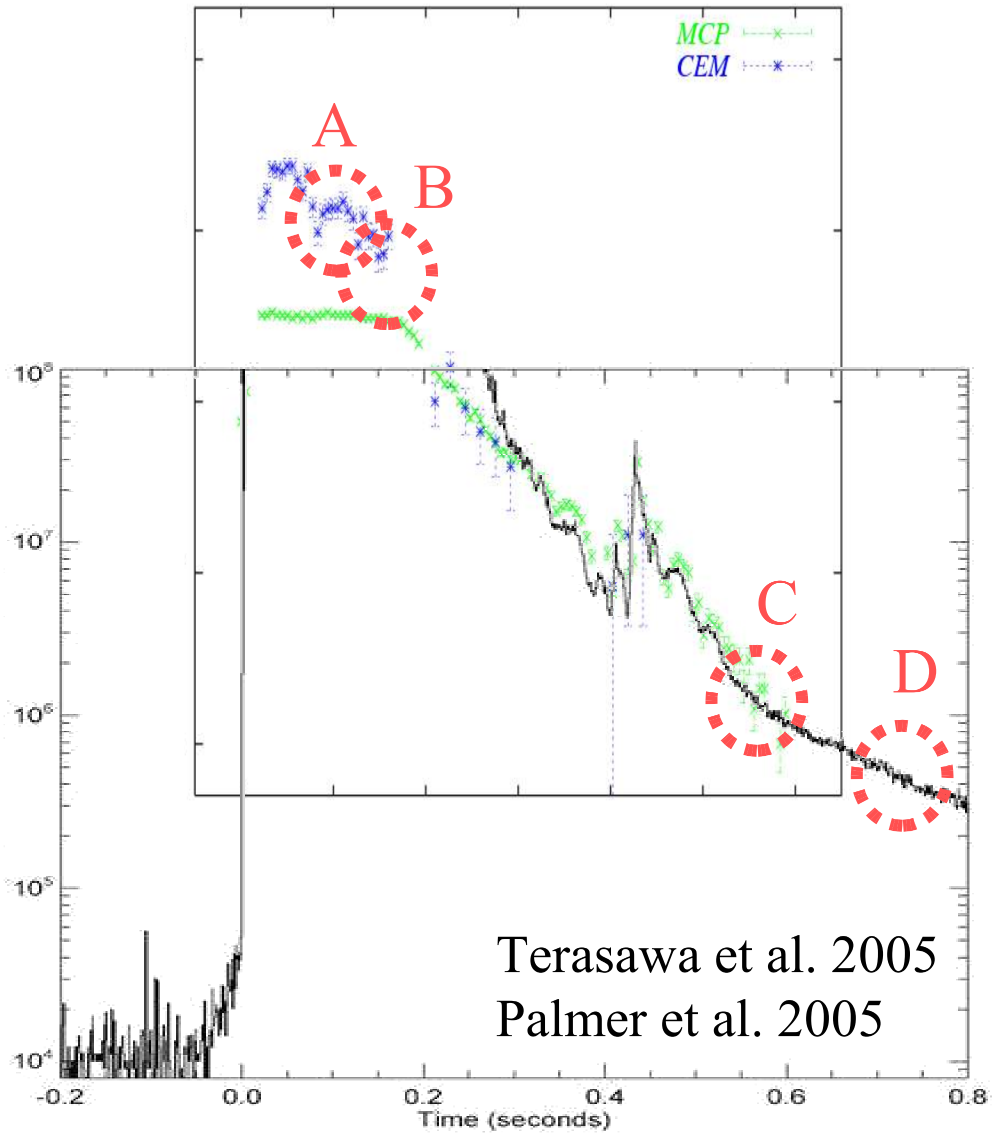
Structured jet

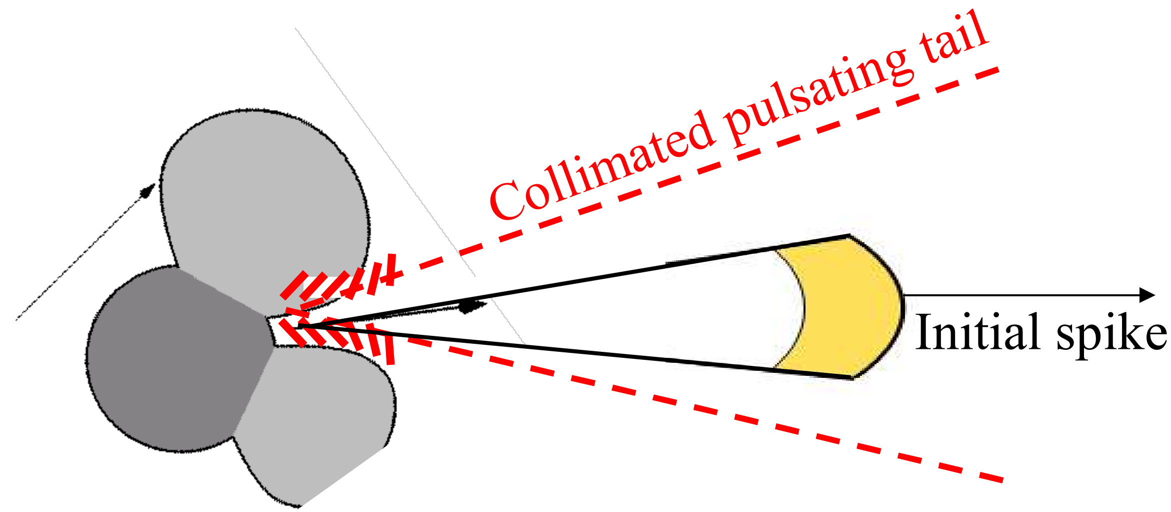


Uniform sharp-edge jet

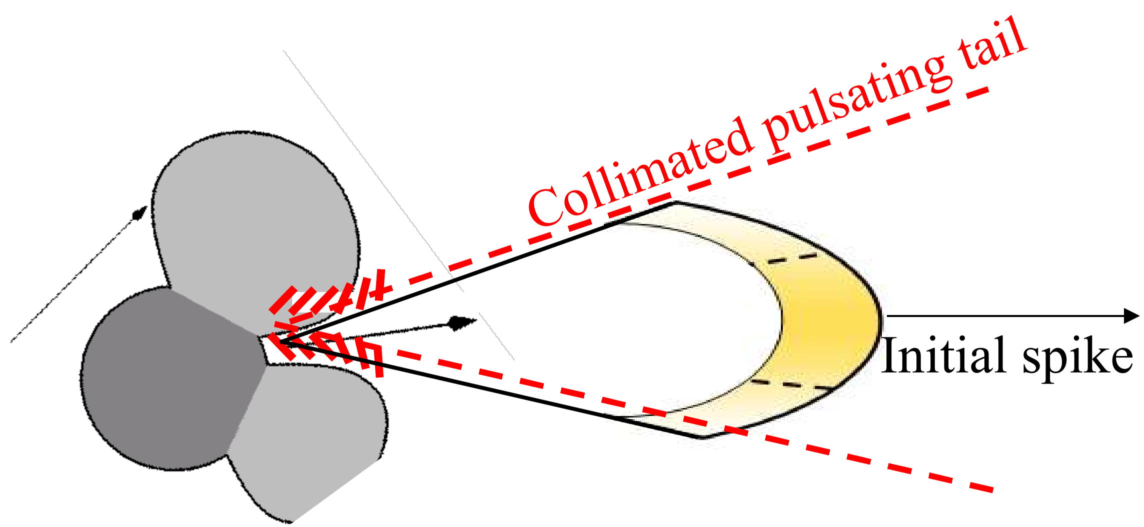


Swift(15-150keV) + GEOTAIL(>50keV)





“Statistical” problem arises



Summary

Initial outflow is (likely) relativistic (e.g. $_{0}>30$).

If so, the light curve of the initial spike of the giant flare of SGR 1806-20 indicate the collimated outflow.

Radio proper motion may support jetted emission?

“Statistical problem” is not serious if less-energetic envelope emission exists.

Prediction: SGR 1806-20 will cause again within this century.