Observations of Gamma-Ray Bursts and Giant Flare of SGR 1806-20

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GRB and SGR

Gamma-Ray bursts:
Explosion in the distant Universe

-- Death of massive stars; Birth of black holes

Soft Gamma Repeater:
Explosion in the Milky Way

-- Starquake of highly magnetized neutron star

Common to both:

- Very intense gamma-ray emission
- Variability on short time scales

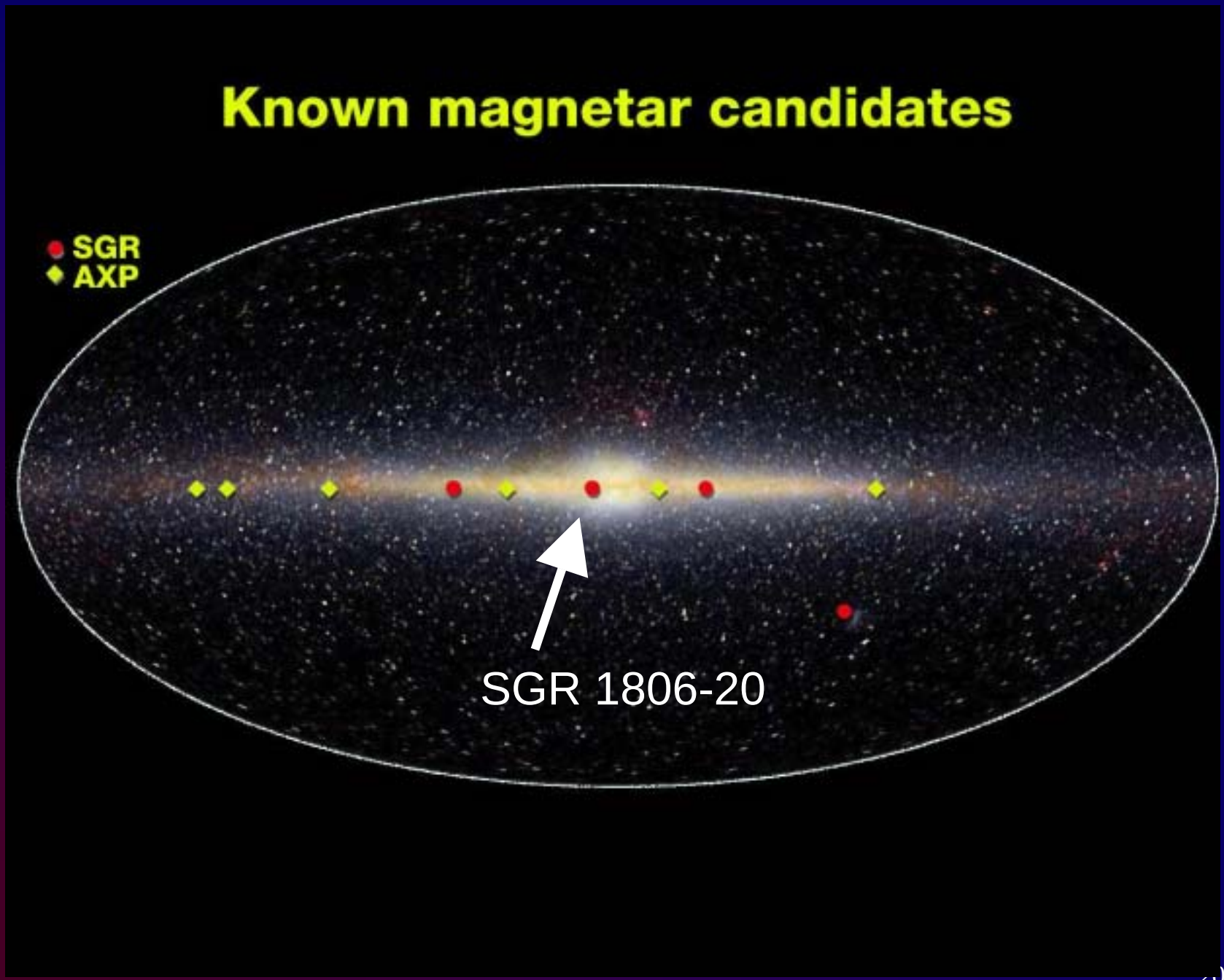
→ Emission from relativistic fireball?

Topics

- Soft gamma repeater (SGR)
  - Giant flare on 2004 December 27
- Gamma-ray bursts (GRB)
  - “Standard Candle”
    Correlation between “Peak energy” and “Radiated energy”
  - Radiation efficiency

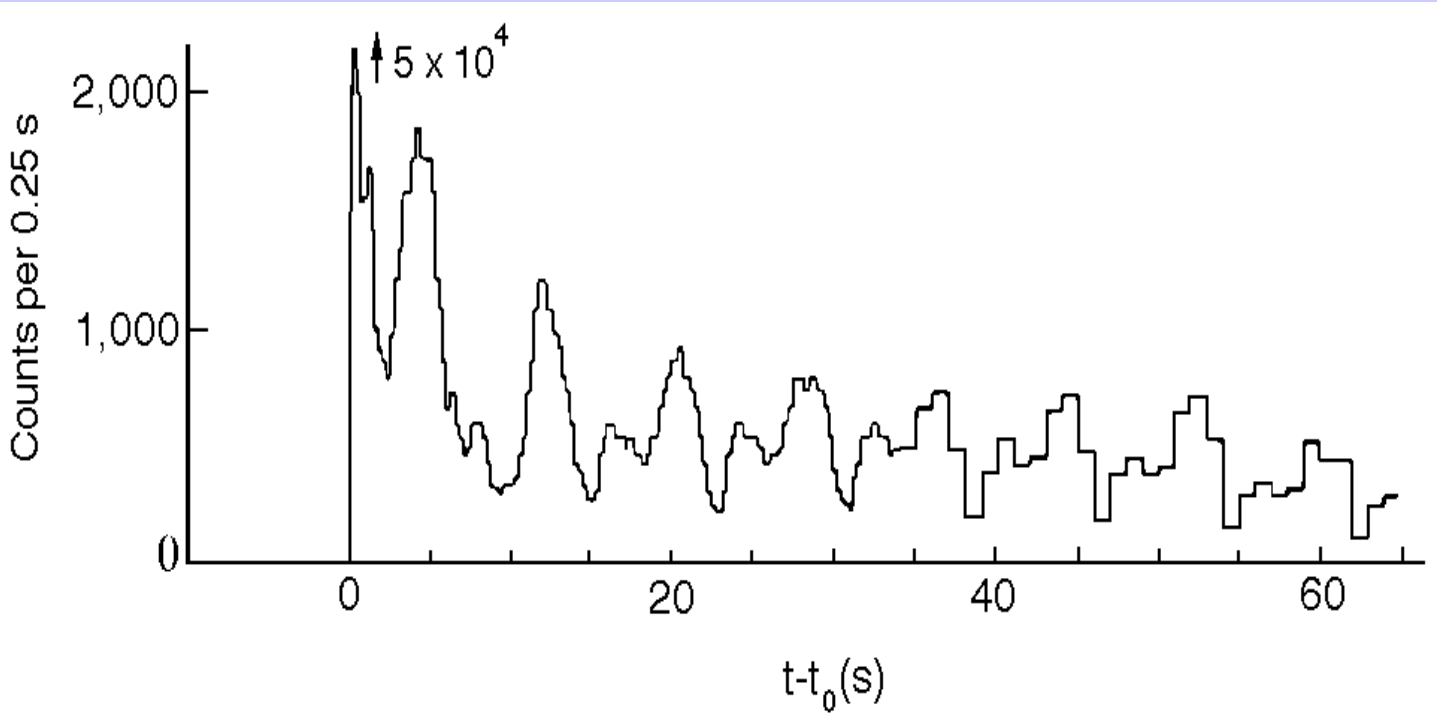
Giant flare on 27 Dec 2004

- First reported by INTEGRAL
- Detected by >20 spacecrafts
- Saturated most detectors in the first 0.5 s
  - More γ flux than the most intense solar flare recorded in history
- Pulsation (7.6 s) and direction consistent with SGR 1806-20
  - 5 degrees from the Sun
  - Only γ and radio observations

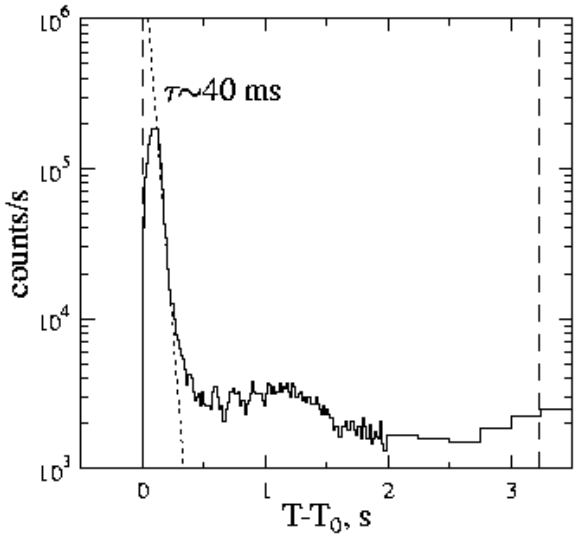

Known magnetar candidates
SGR
AXP
SGR 1806-20

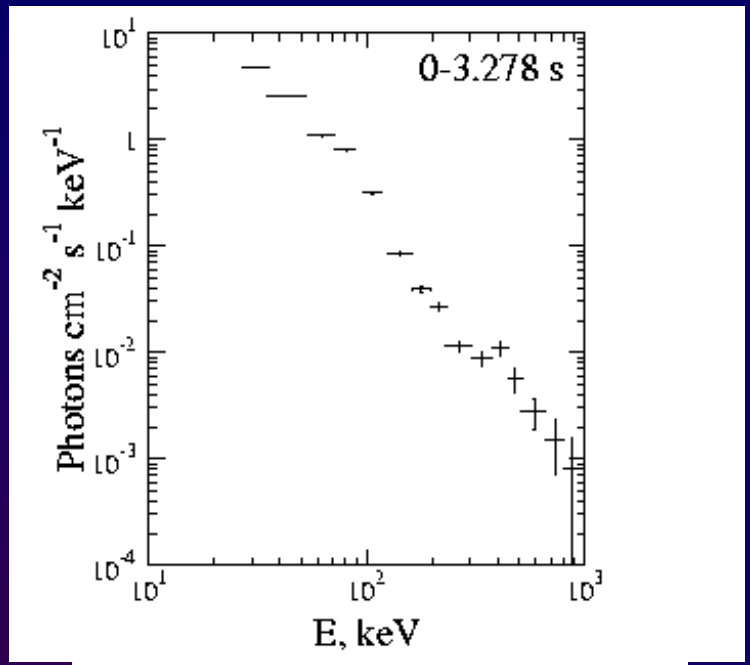
GRB790305

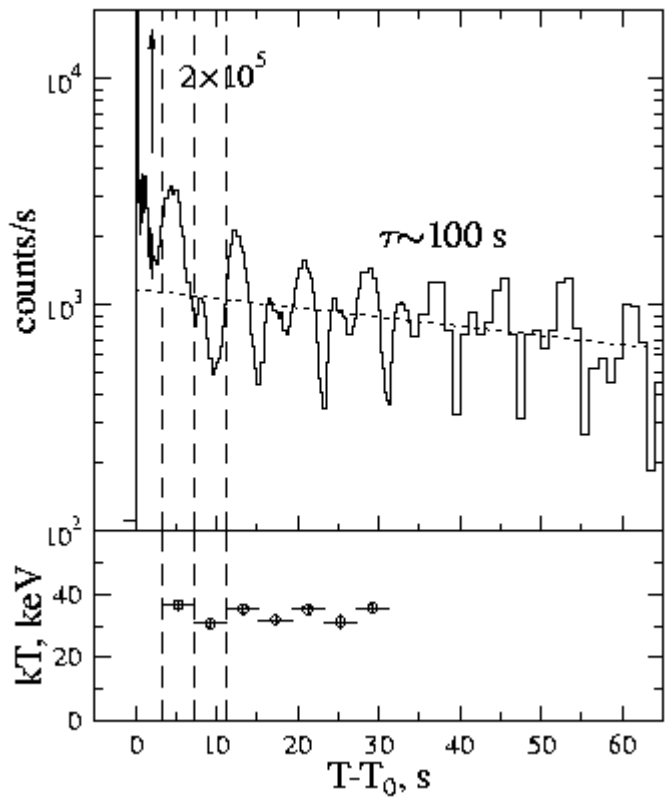
from SGR 0520-66

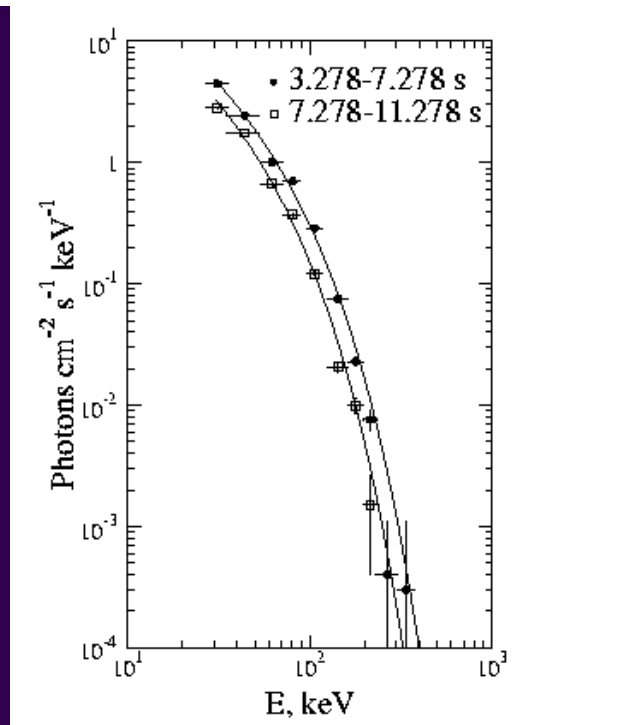


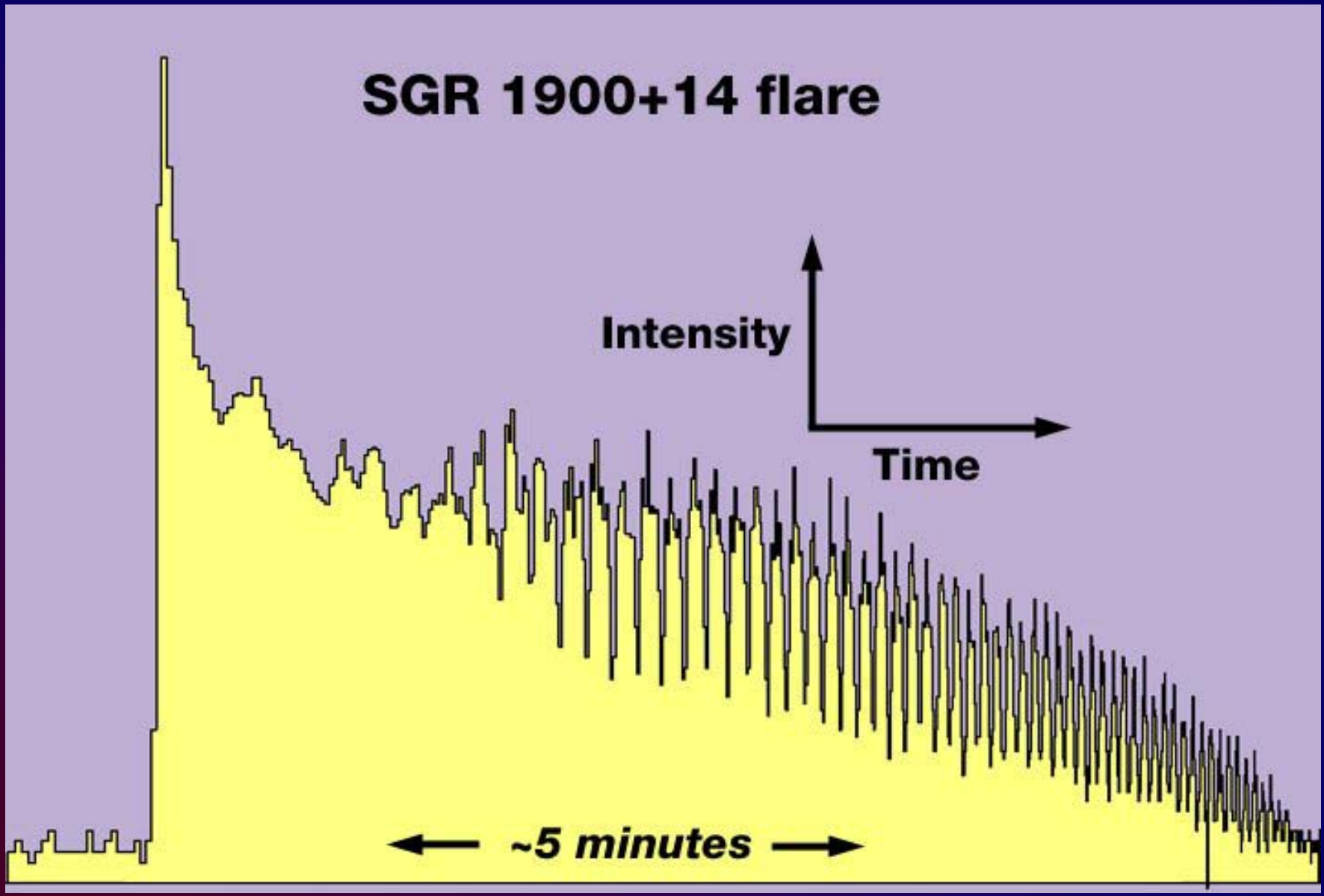
Mazets et al. 1979


τ~40 ms
counts/s
T-T0, s


0-3.278 s
Photons cm-2 s-1 keV-1
E, keV


2×10^5
τ~100 s
counts/s
kT, keV
T-T0, s


3.278-7.278 s
7.278-11.278 s
Photons cm-2 s-1 keV-1
E, keV



Hurley et al.

Giant flare of SGR1900+14 on 1998/08/27

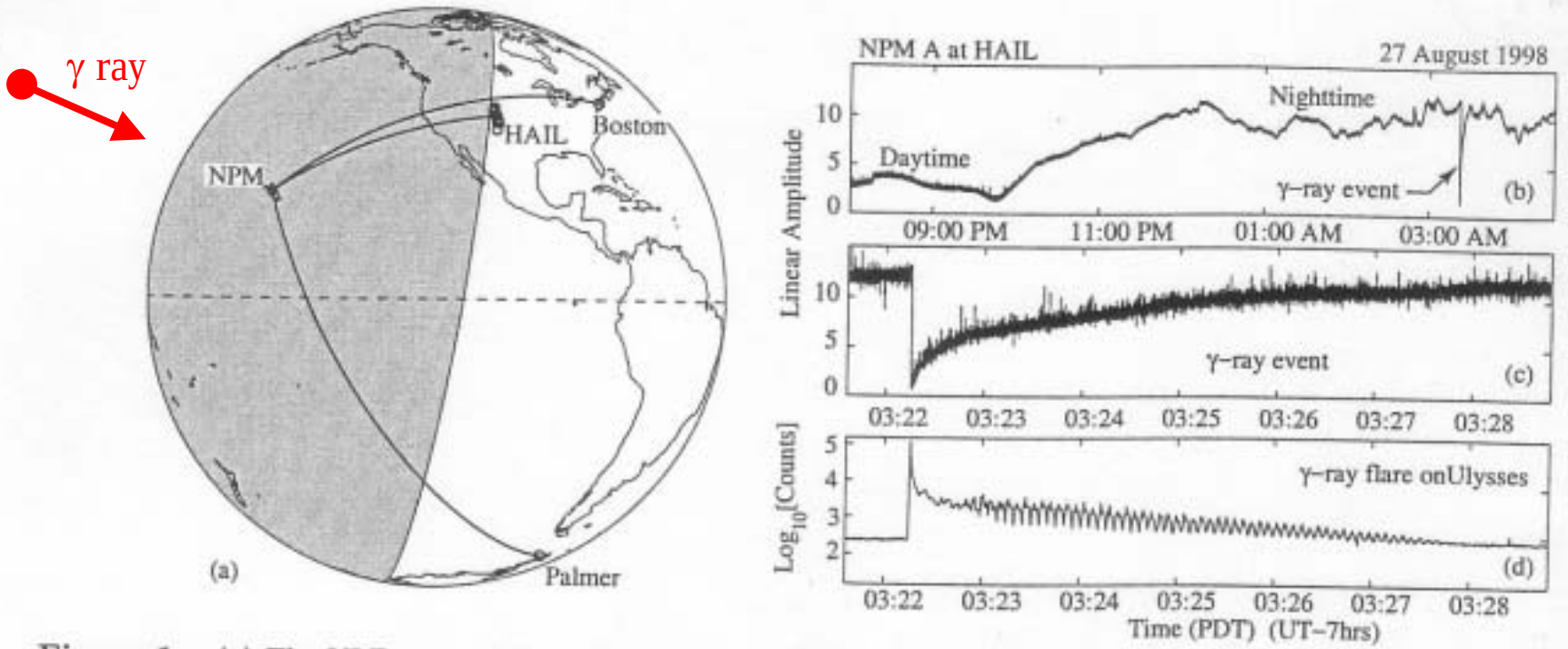
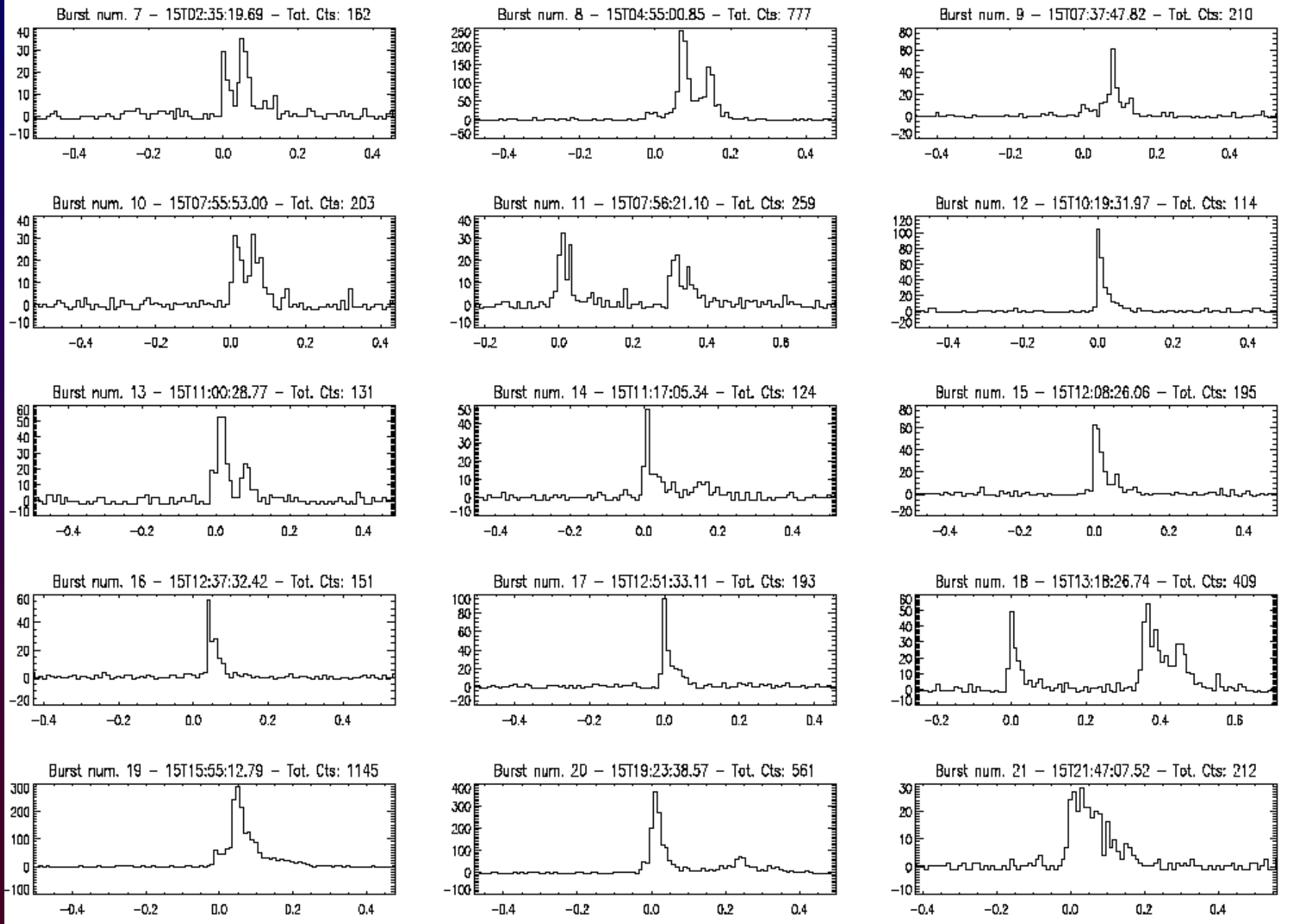


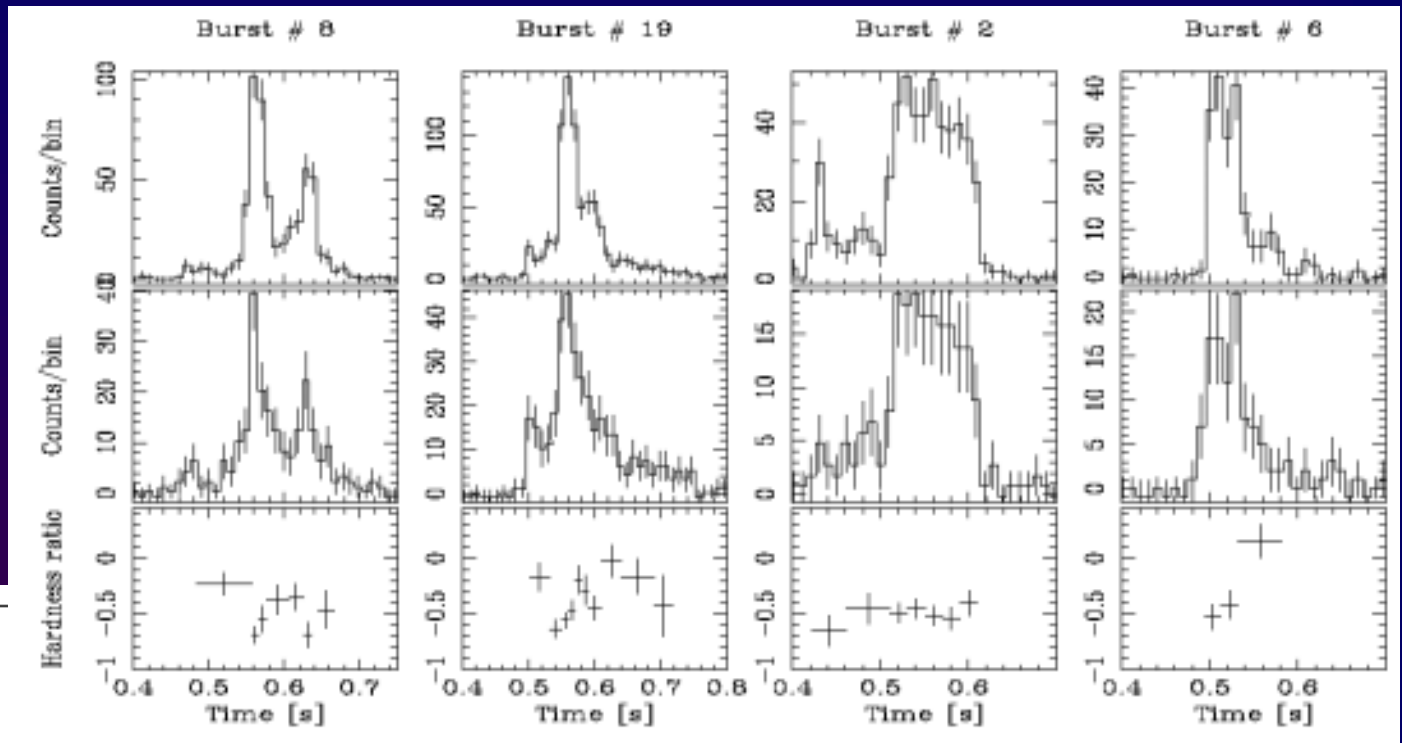
Figure 1. (a) The VLF great-circle paths from the NPM transmitter to Boston, Palmer, and the HAIL network. The part of the globe illuminated by the γ−ray flare is indicated by shading. (b) The amplitude of the 21.4 kHz NPM signal observed in Trinidad, Colorado. (c) Expanded record of the γ−ray flare event which occurs at ~3:22 am PDT. (d) The intensity of the giant flare observed on Ulysses (from [*Hurley et al.*, 1999]).

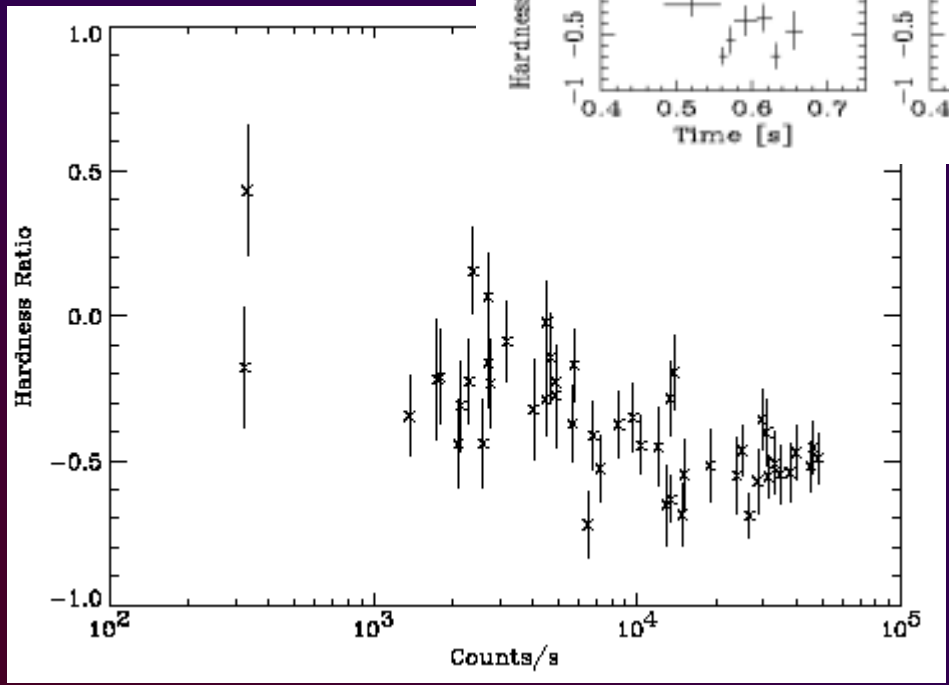
[Inan et al., GRL, 1998]

SGR1900+14 at 7 kpc from Earth caused disturbance in the ionoshere

Goetz et al. 2004







Goetz et al. 2004

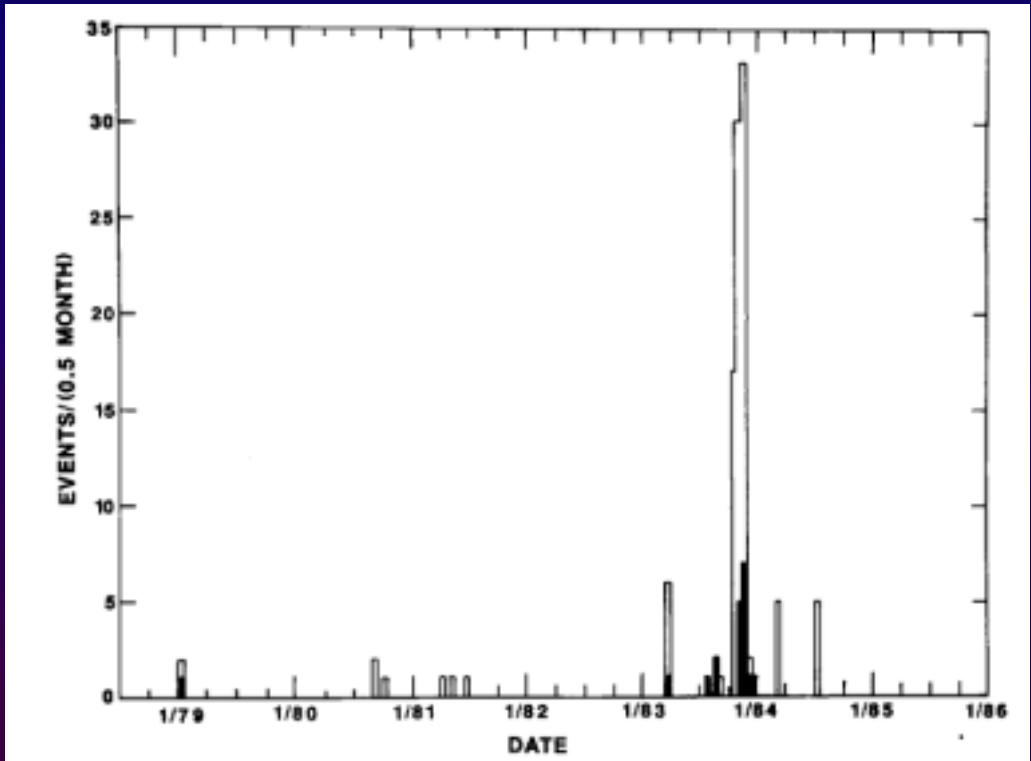
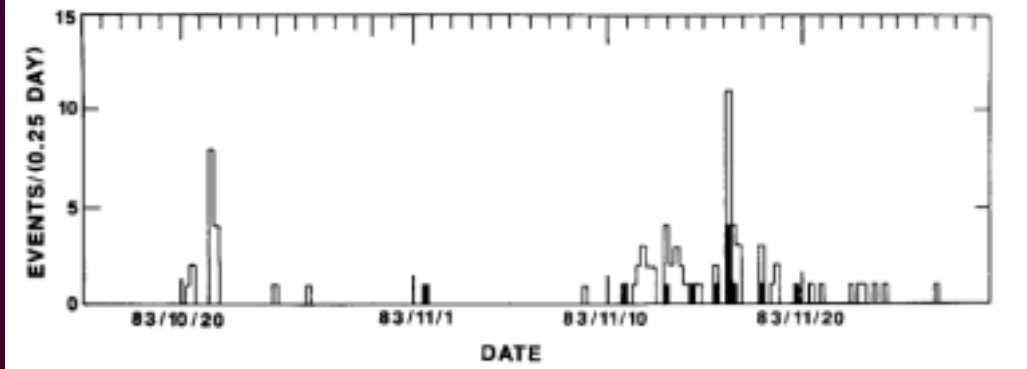
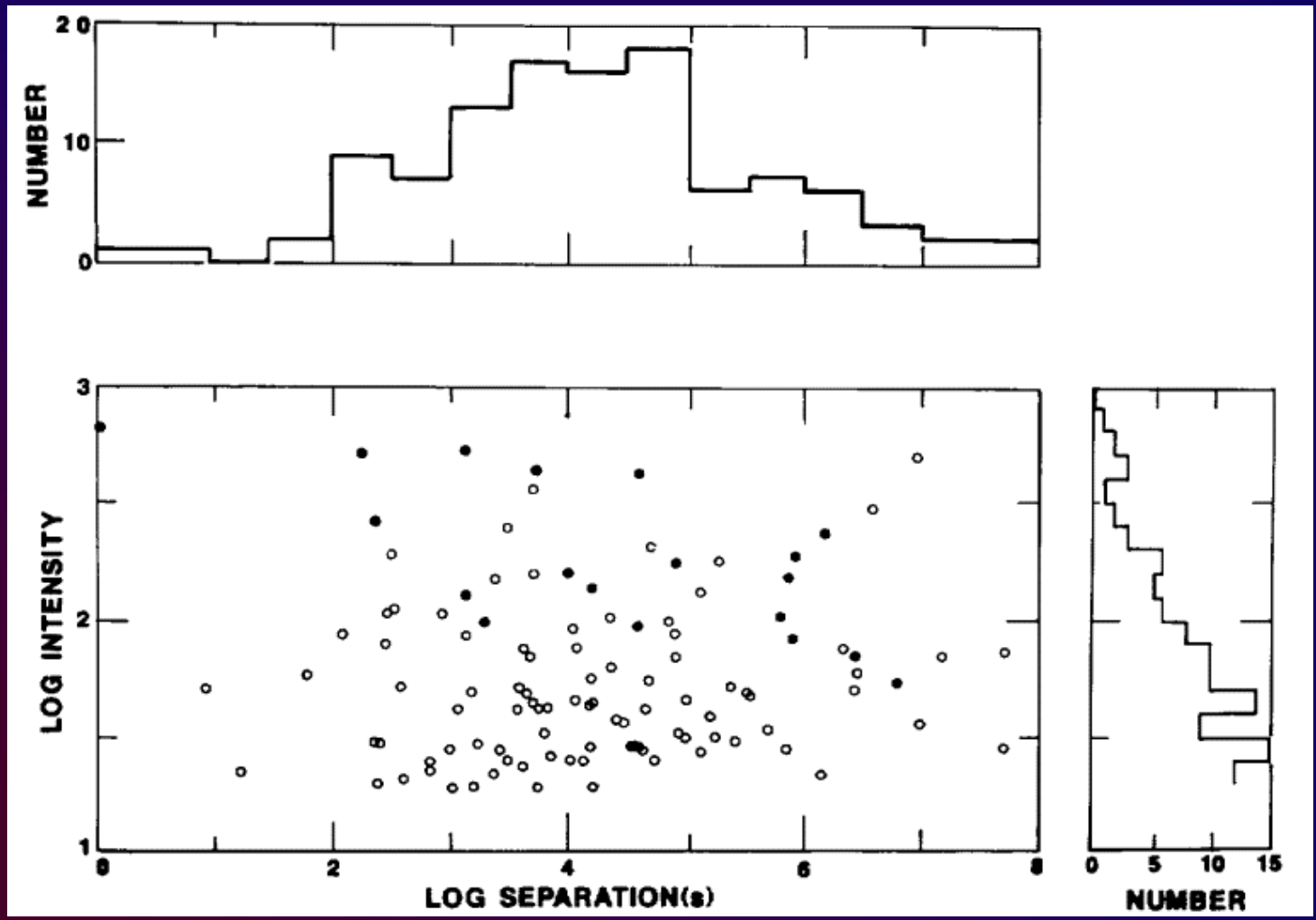
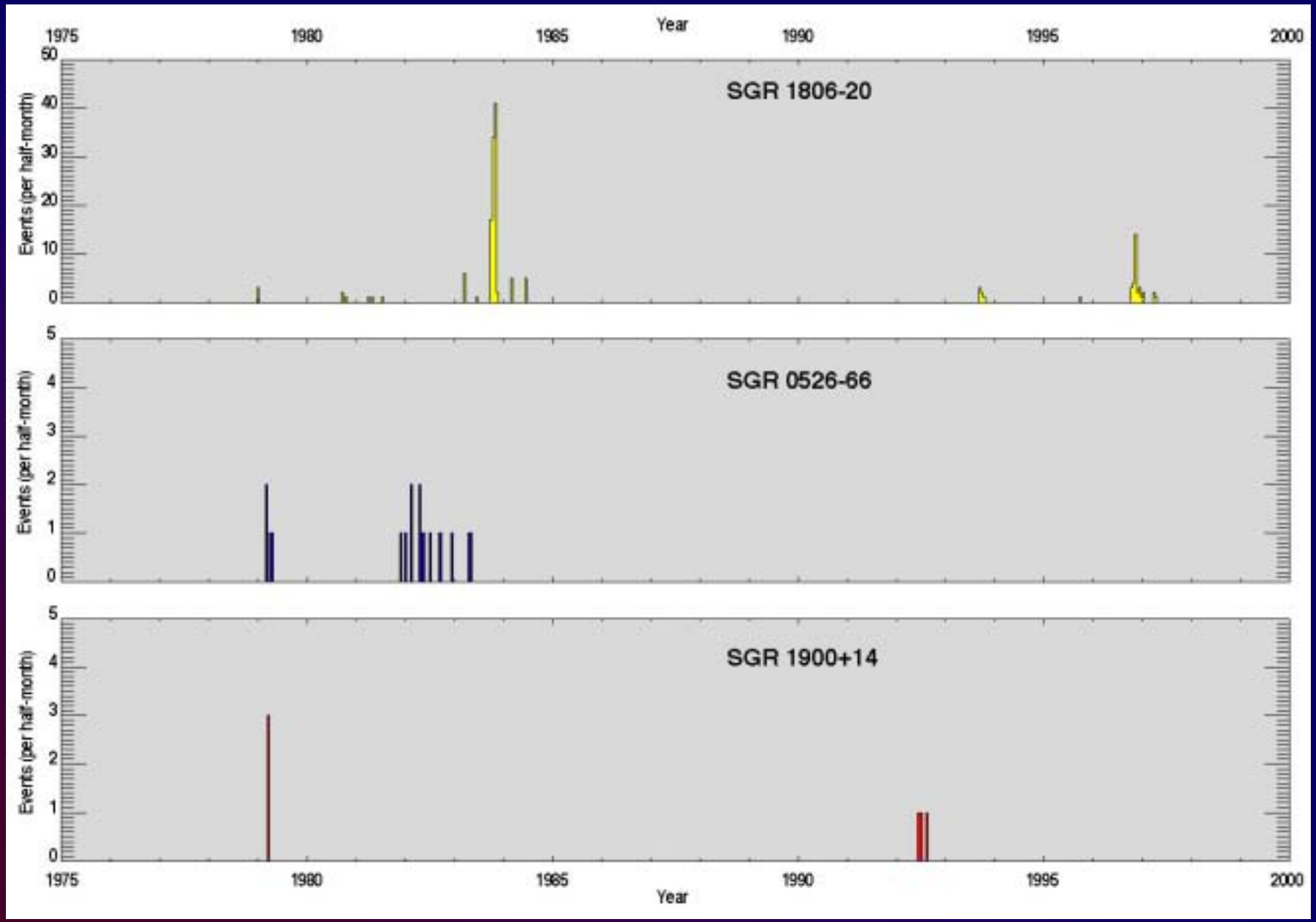


FIG. 1a



Laros et al. 2004


NUMBER
20
10
0
LOG INTENSITY
3
2
1
0
2
4
6
8
LOG SEPARATION(s)
0
5
10
15
NUMBER


Year
1975
1980
1985
1990
1995
2000
SGR 1806-20
SGR 0526-66
SGR 1900+14
Events (per half-month)
0
10
20
30
40
50
1
2
3
4
5

DISCOVERY OF CYCLOTRON RESONANCE FEATURES IN THE SOFT GAMMA REPEATER SGR 1806–20

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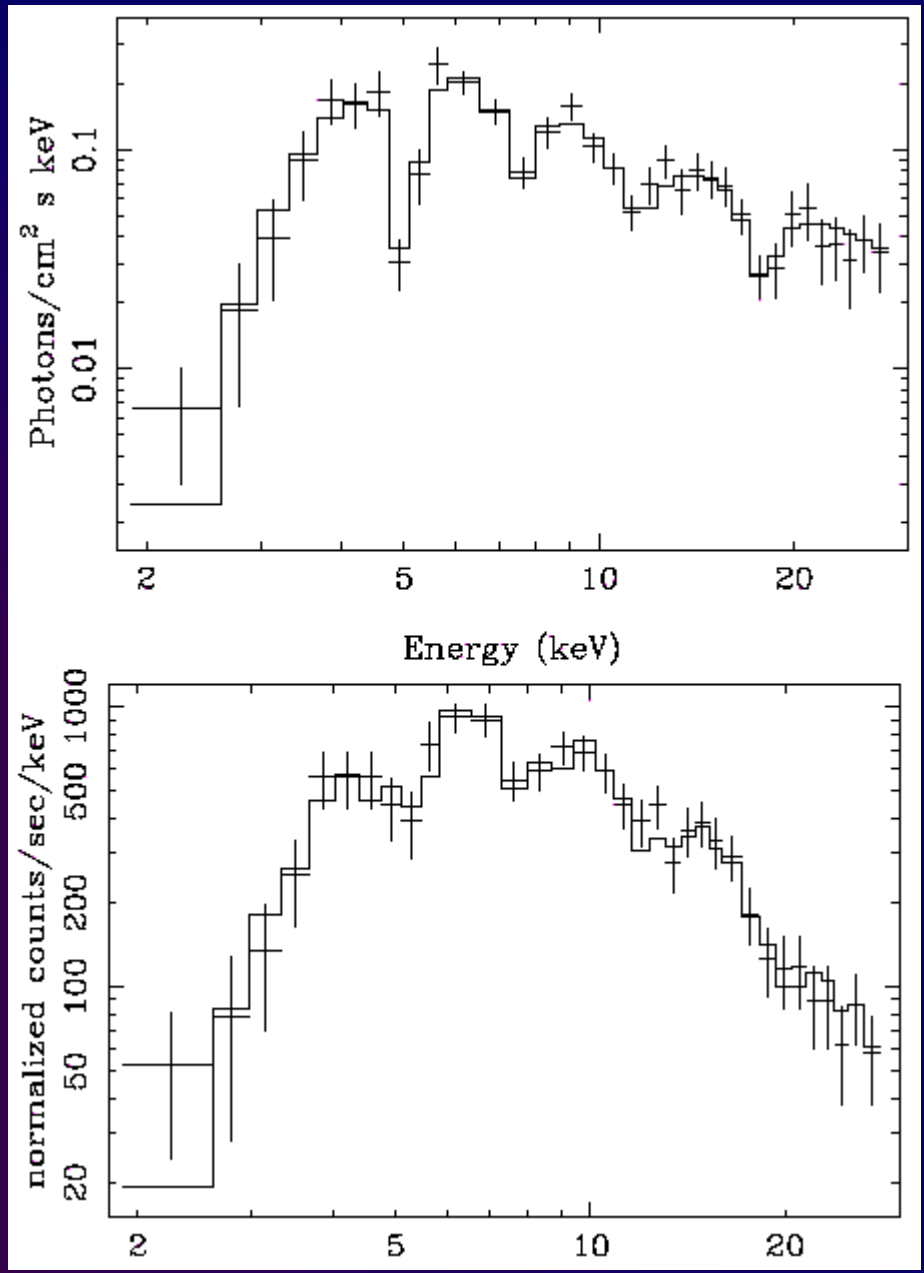
Published in the 2002 July 20 issue of the Astrophysical Journal Letters, 574, L51
Received 2002 May 1; Accepted 2002 June 17; Published 2002 June 26

ABSTRACT

We report evidence of cyclotron resonance features from the Soft Gamma Repeater SGR 1806–20 in outburst, detected with the *Rossi X-ray Timing Explorer* in the spectrum of a long, complex precursor that preceded a strong burst. The features consist of a narrow 5.0 keV absorption line with modulation near its second and third harmonics (at 11.2 keV and 17.5 keV respectively). The line features are transient and are detected in the harder part of the precursor. The 5.0 keV feature is strong, with an equivalent width of ~ 500 eV and a narrow width of less than 0.4 keV. Interpreting the features as electron cyclotron lines in the context of accretion models leads to a large mass-radius ratio ($M/R > 0.3\,M_{\odot}$/km) that is inconsistent with neutron stars or that requires a low $(5-7)\times 10^{11}$ G magnetic field that is unlikely for SGRs. The line widths are also narrow compared with those of electron cyclotron resonances observed so far in X-ray pulsars. In the magnetar picture, the features are plausibly explained as ion cyclotron resonances in an ultra-strong magnetic field that have recently been predicted from magnetar candidates. In this view, the 5.0 keV feature is consistent with a proton cyclotron fundamental whose energy and width are close to model predictions. The line energy would correspond to a surface magnetic field of 1.0×10^{15} G for SGR 1806–20, in good agreement with that inferred from the spin-down measure in the source.

Subject headings: Pulsar: Individual (SGR 1806–20) — Stars: Magnetic Fields — Stars: Neutron — Stars: Magnetar — X-Rays: Bursts — Gamma Rays: Bursts

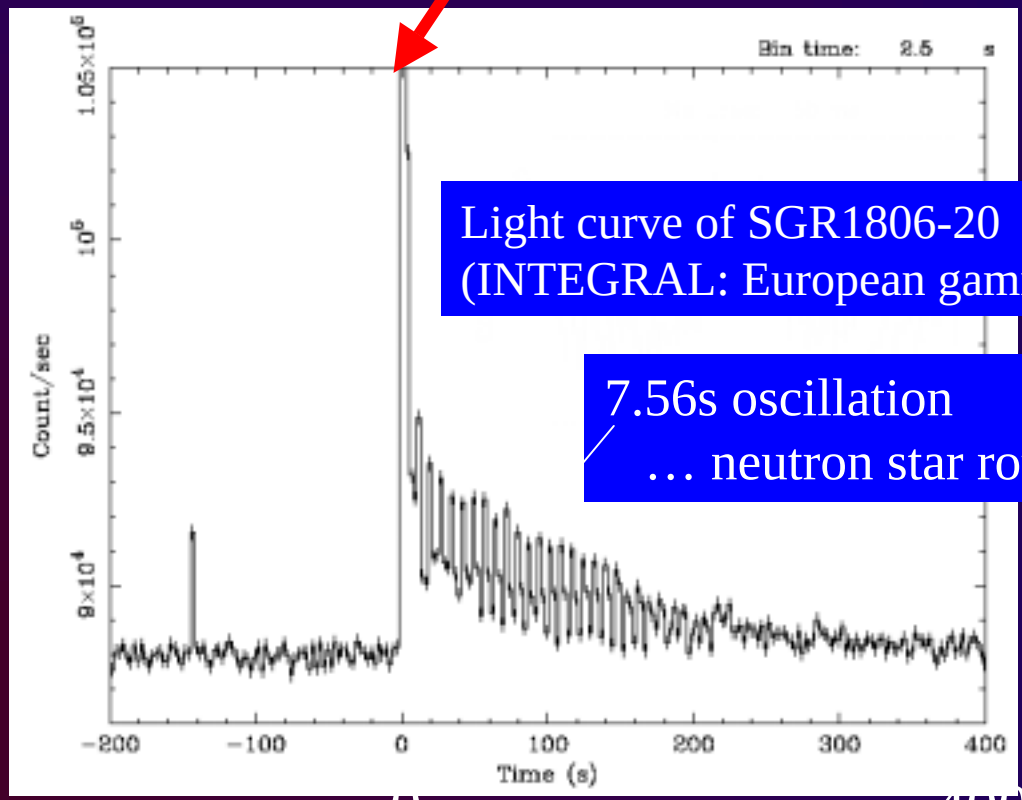

Photons/cm^2 s keV
0.1
0.01
2
5
10
20
Energy (keV)
normalized counts/sec/keV
20
50
100
200
500
1000
2
5
10
20

The giant flare on 27 December 2004:

The peak intensities of hard X/γ-ray photons are even stronger (by a factor of ~100) than those from the largest solar flares!

All known X/γ-ray detectors on astronomical satellites (RHESSI, INTEGRAL, SWIFT, WIND, …) were saturated for ~0.5 s around the peak.

Initial peak (~0.5s) was too strong: detector saturated

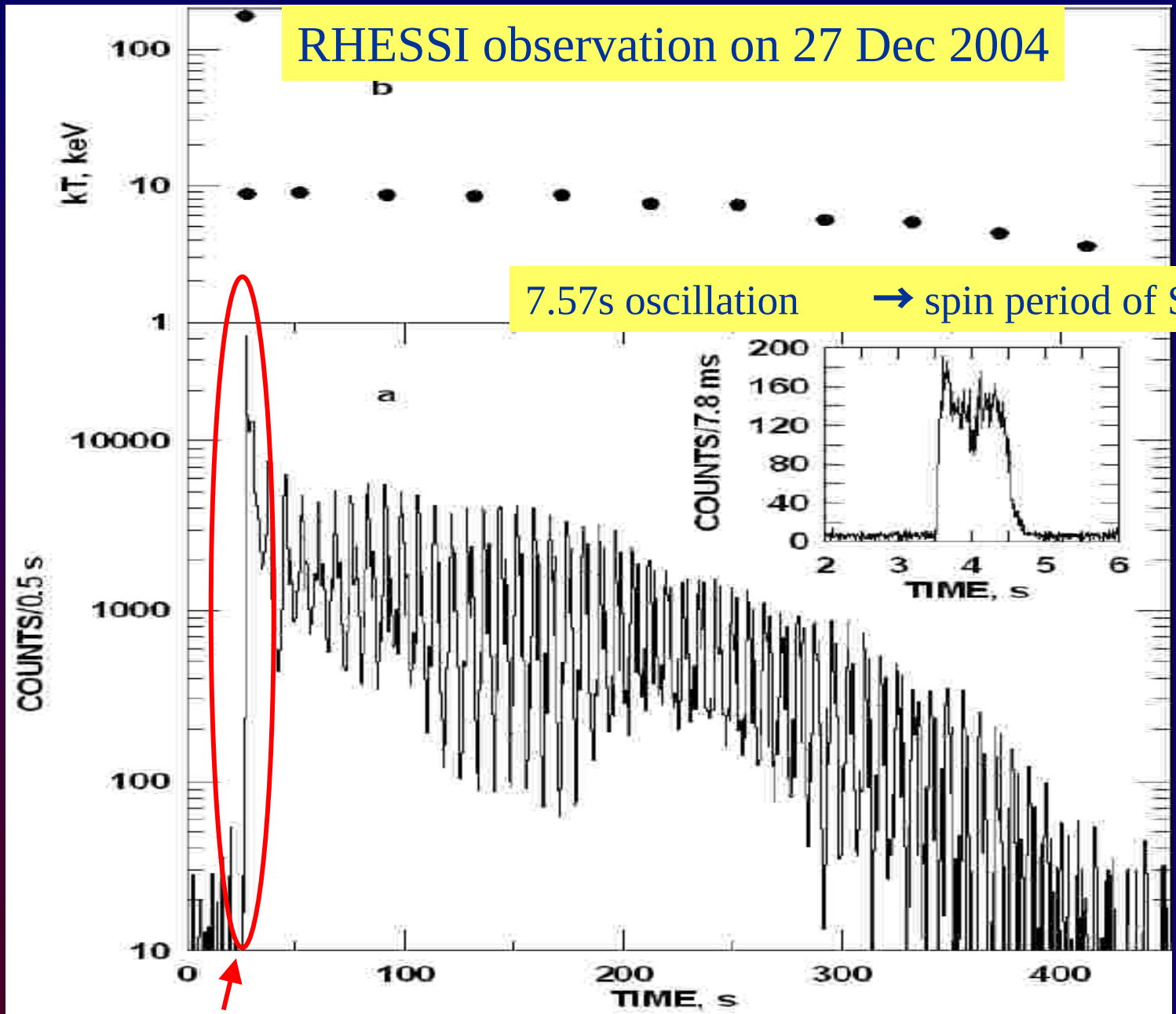


Light curve of SGR1806-20
(INTEGRAL: European gamma ray satellite)

7.56s oscillation
… neutron star rotation period

0 400 sec

RHESSI observation on 27 Dec 2004



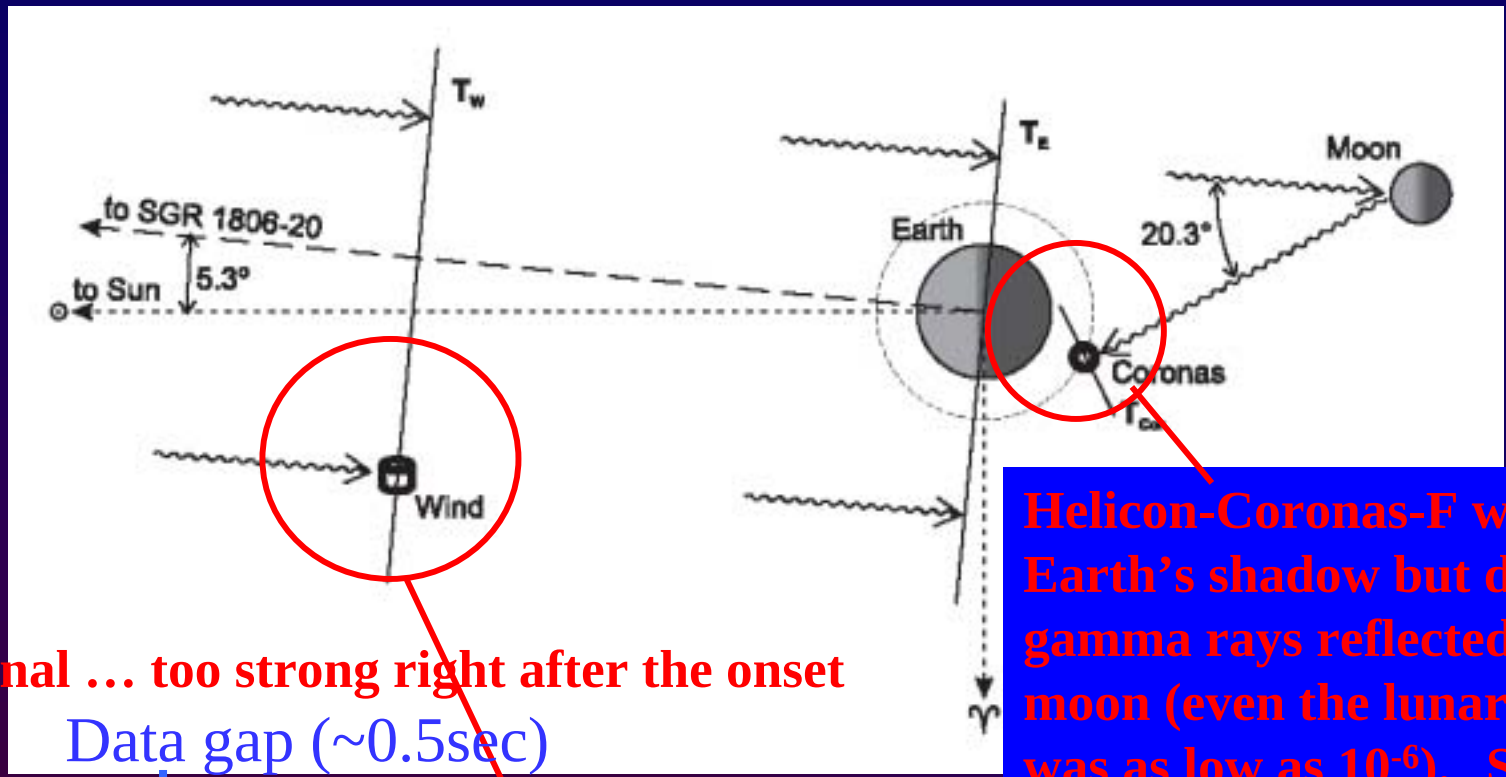
7.57s oscillation → spin period of SGR1806-20

Saturated in the First 0.5 seconds

Hurley et al. 2005

Gamma rays from the giant flare at SGR1806-20

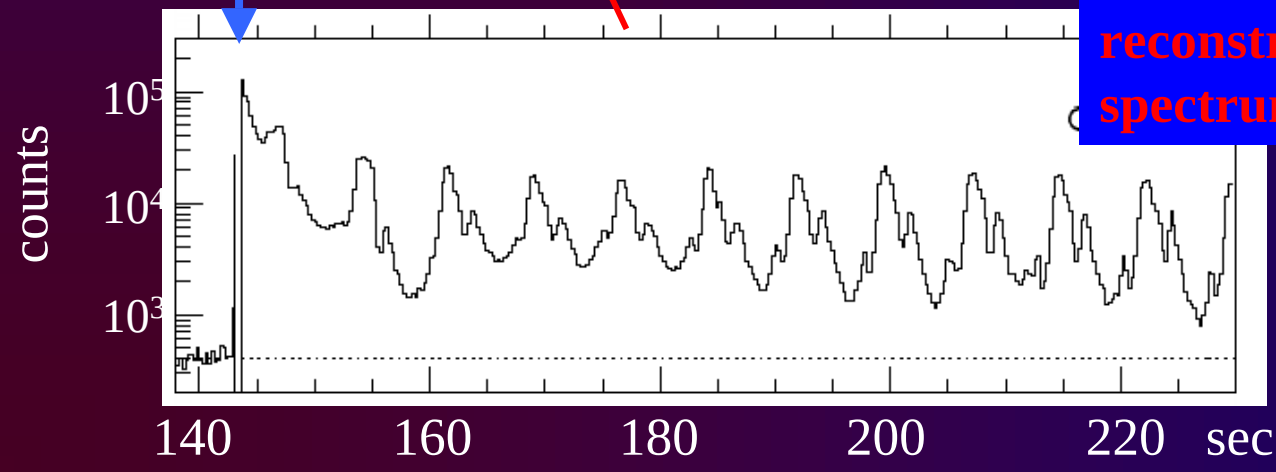
Mazets et al. (2005)



signal … too strong right after the onset

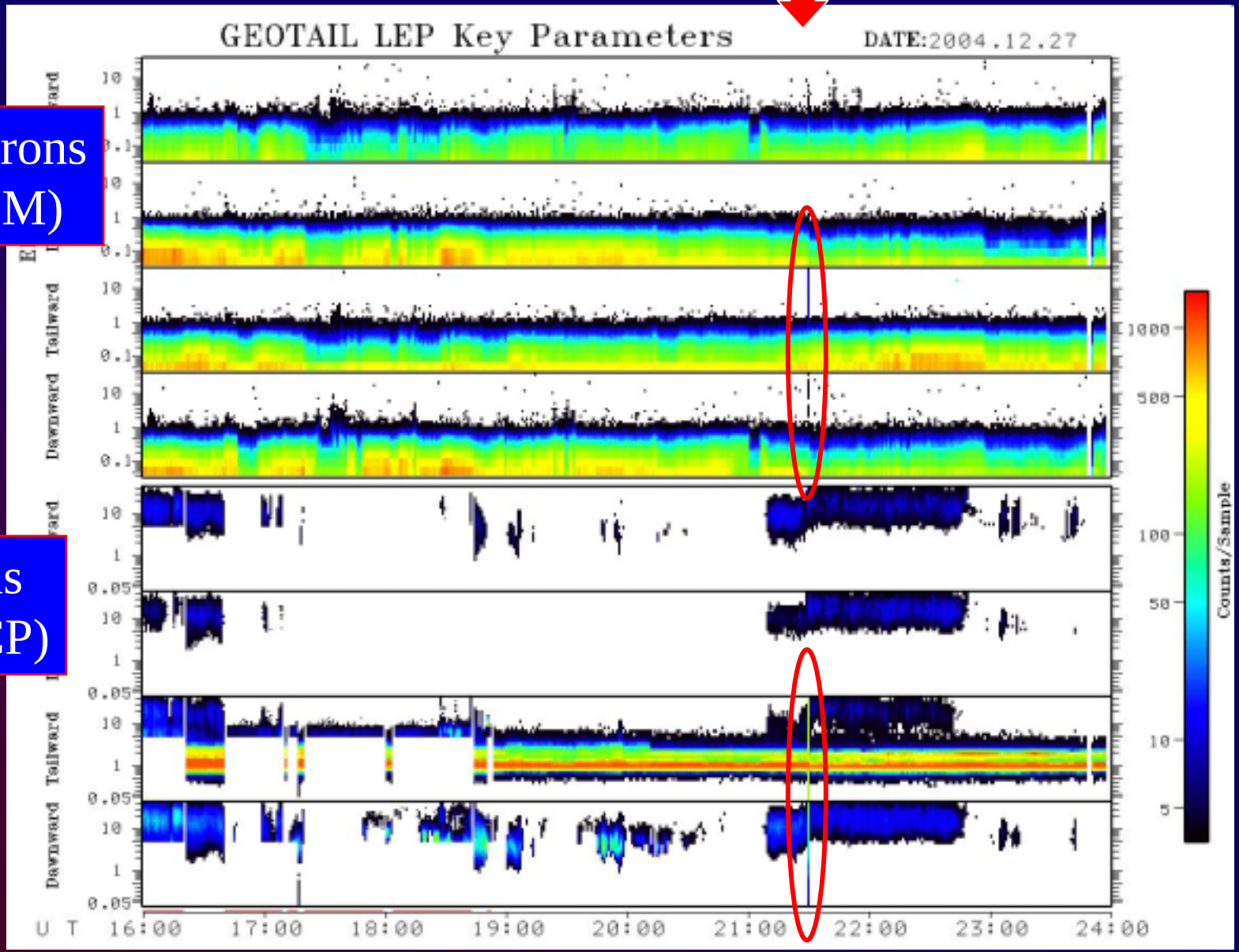
Data gap (~0.5sec)

Helicon-Coronas-F was in the Earth's shadow but detected gamma rays reflected by the moon (even the lunar albedo was as low as 10^{-6}). Since the albedo depends on the energy, reconstruction of the energy spectrum is not easy.



If you look at the ISAS LEP/QL, …

21:30:26 UT

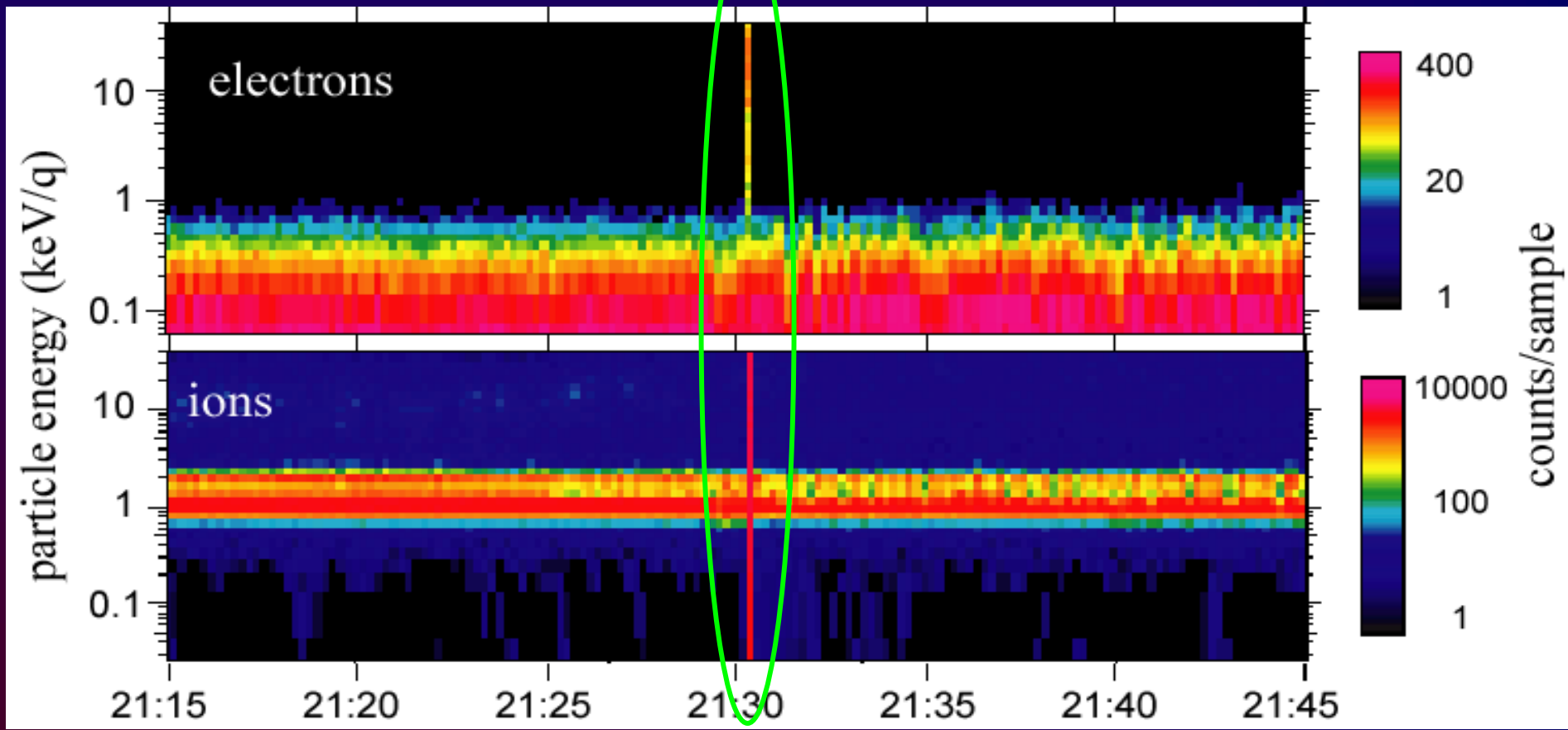


Electrons (CEM)

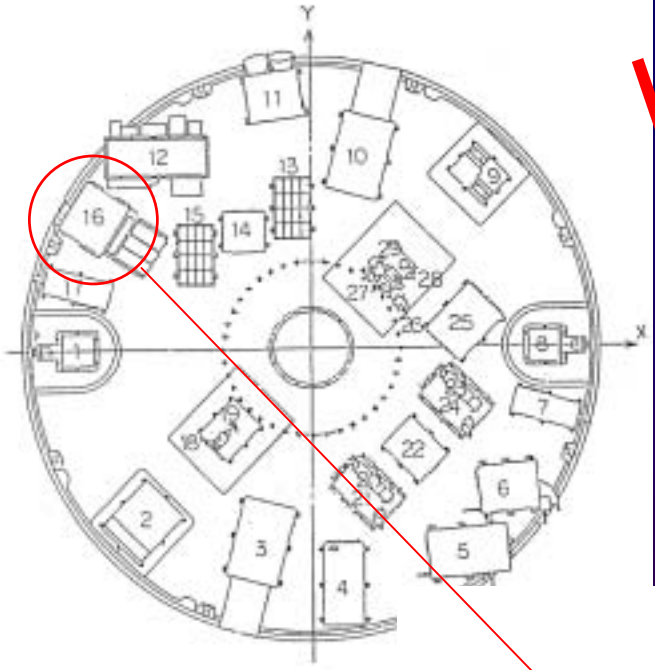
Ions (MCP)

http://www.stp.isas.jaxa.jp/geotail/QL/data3/04122703E_T.jpg

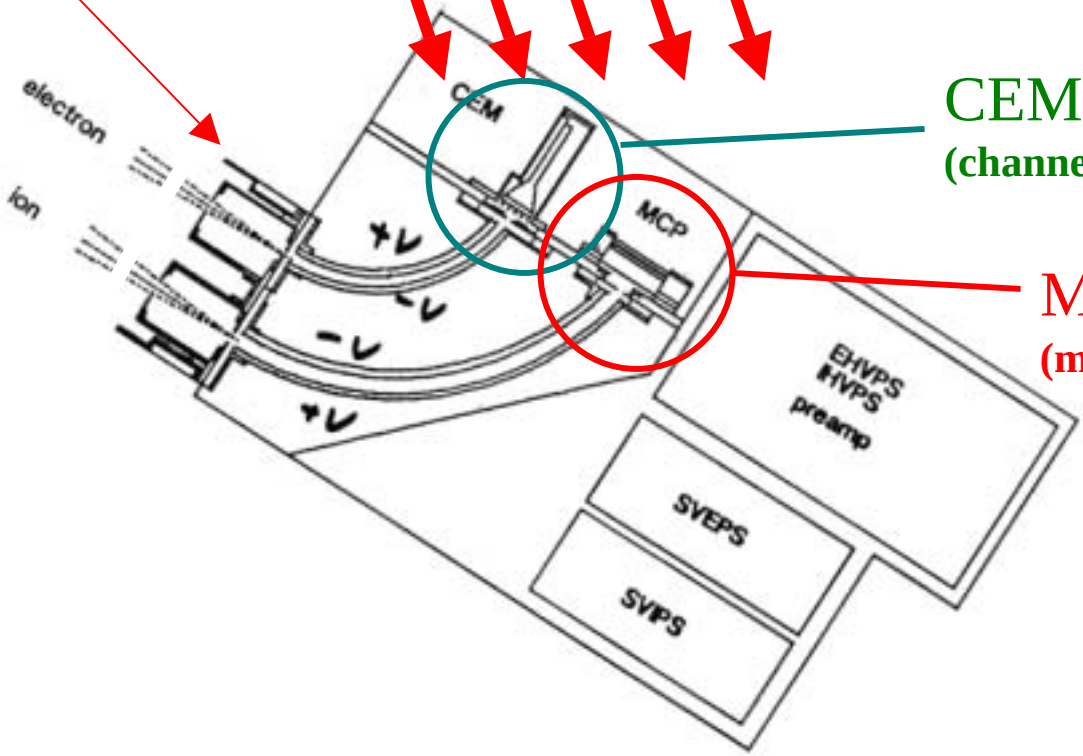
Hard X-ray ~ γ-ray photons from SGR1806-20



UT on 27 December 2004



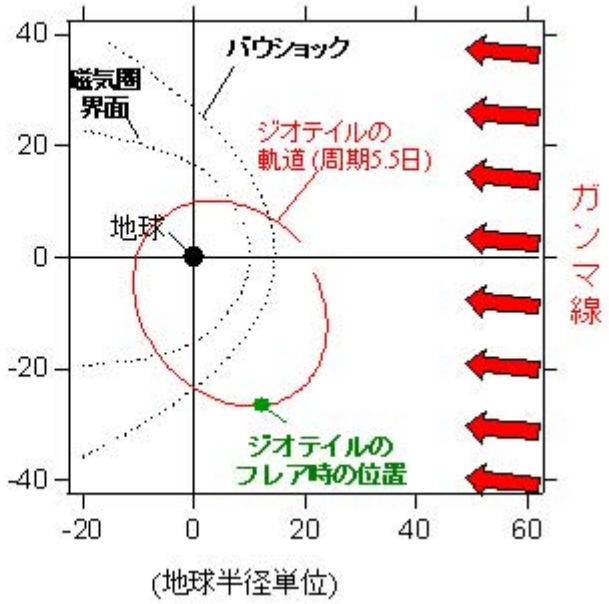
GEOTAIL wall (~1mm Al)

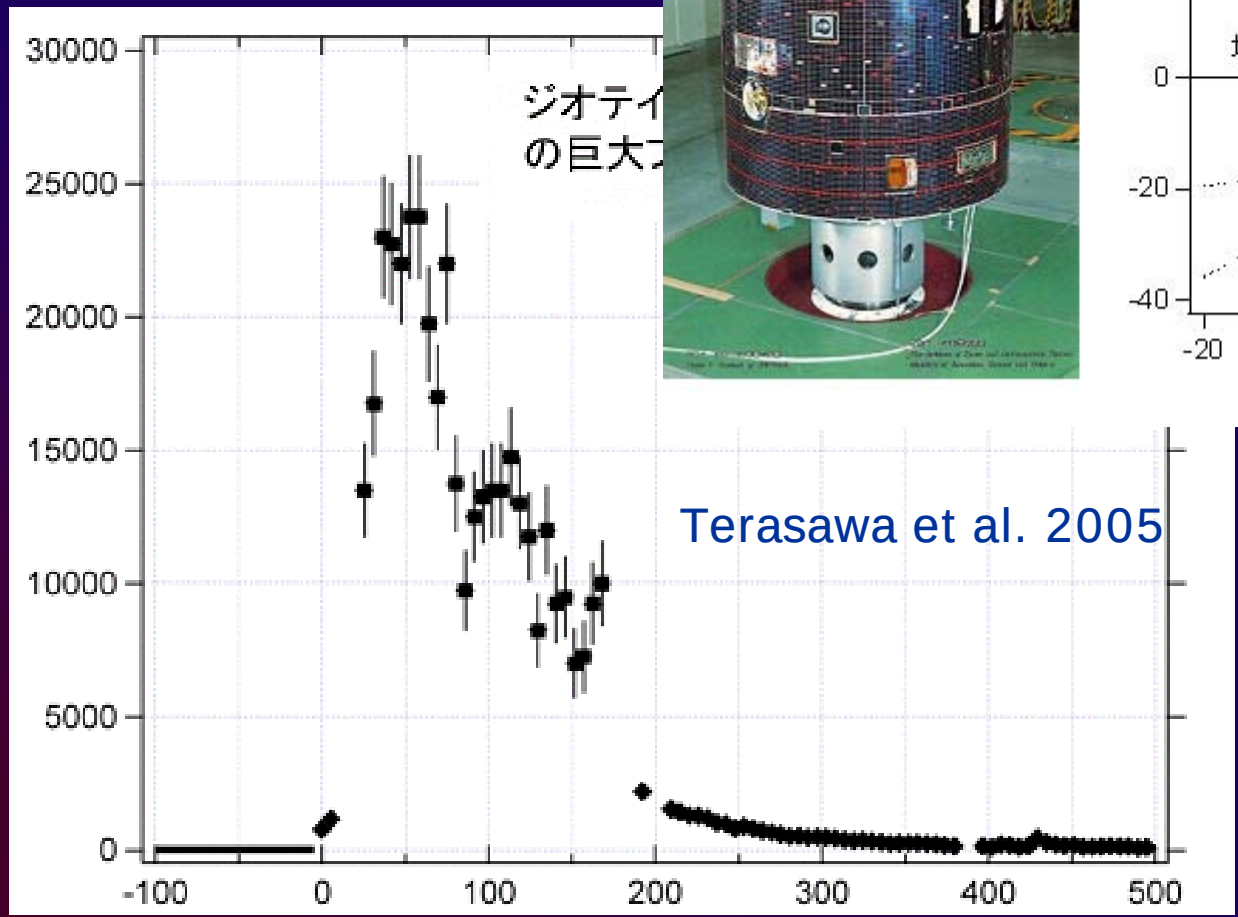


CEM
(channel electron multiplier)

MCP
(micro channel plate)

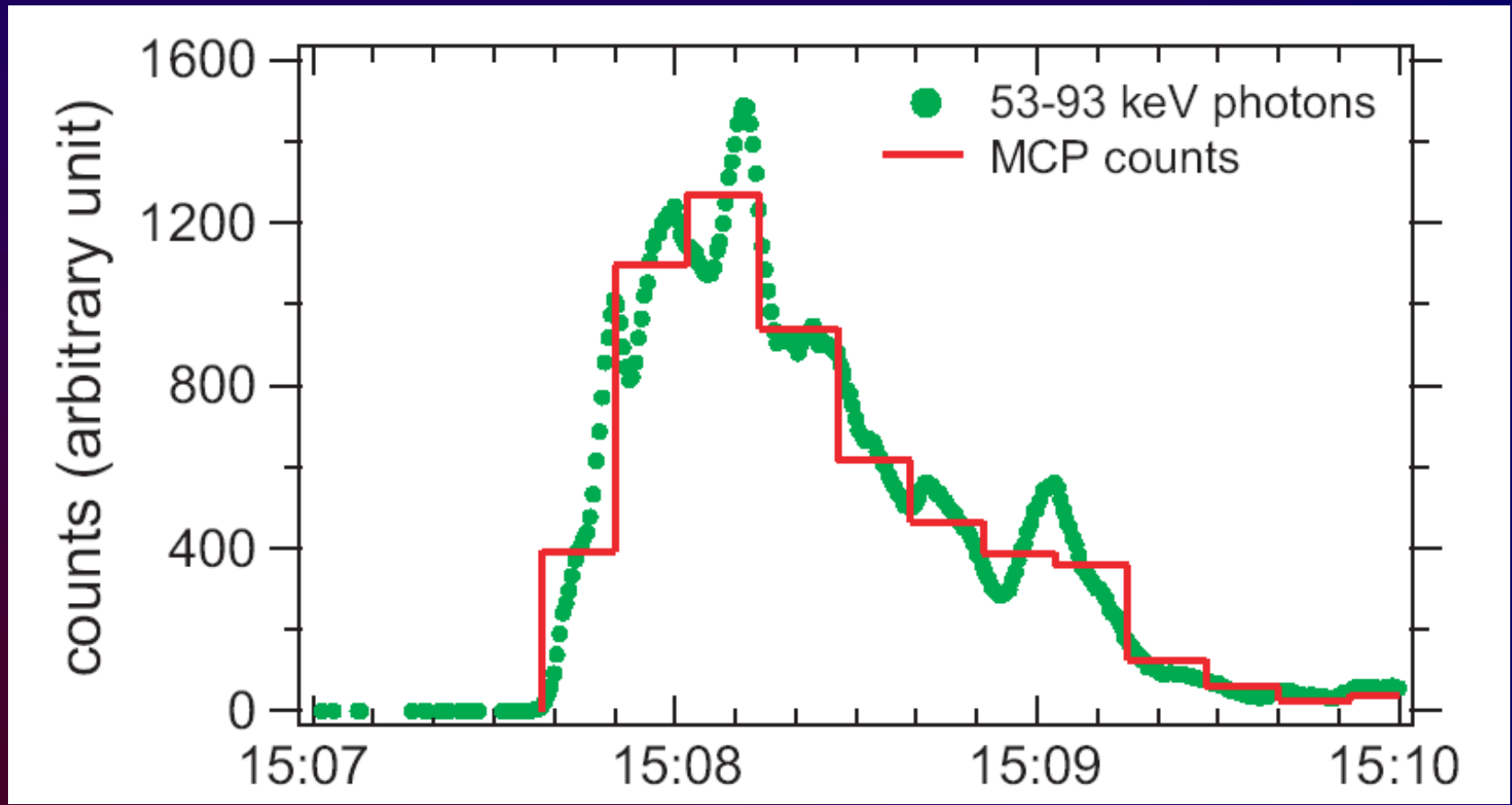
Geotail observation





How to 'Calibrate' LEP?

By comparing LEP count profiles with those of YOHKOH observations, we have concluded that LEP is sensitive to hard X-ray photons >~50 keV, and calibrated its sensitivity.

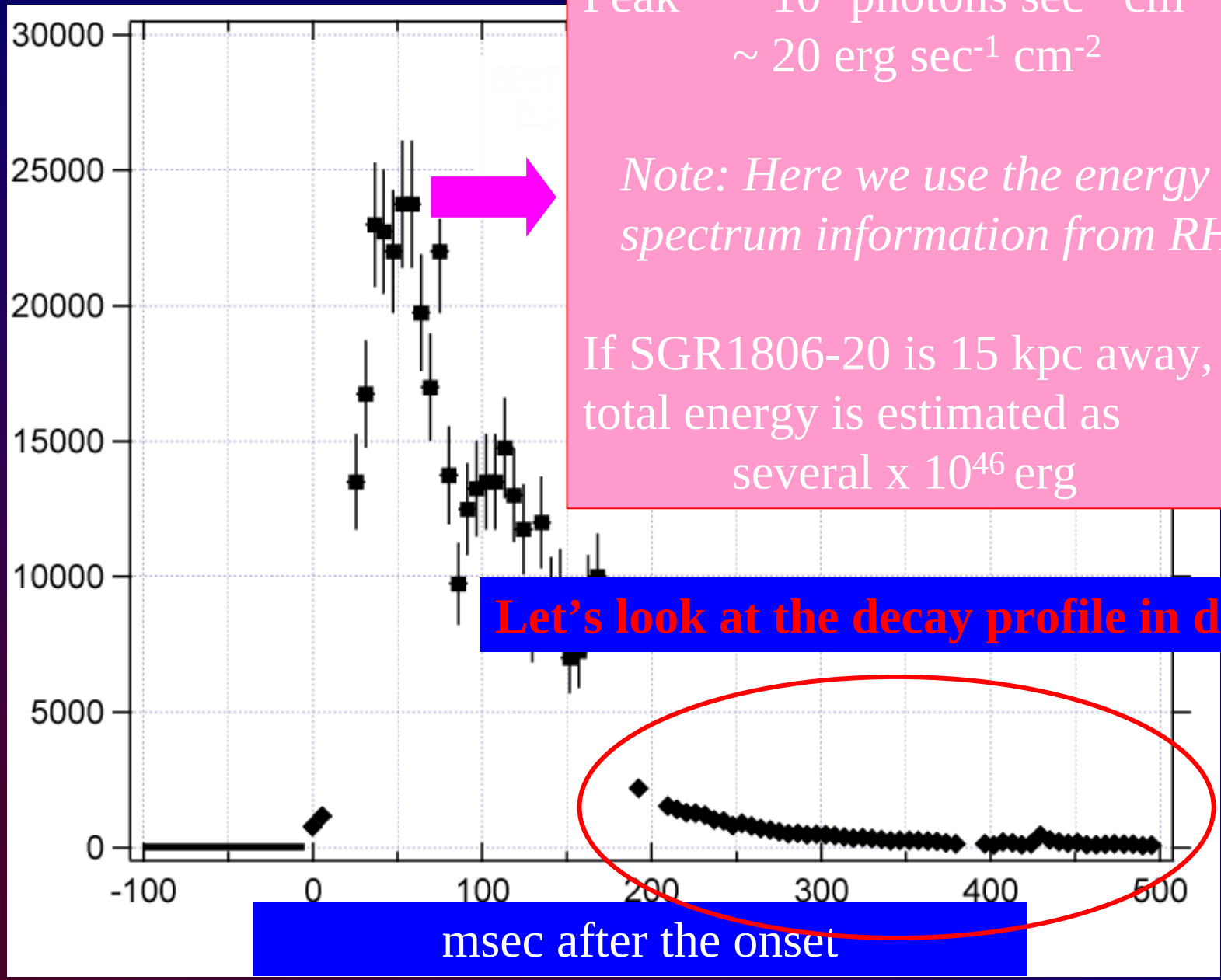


Solar flare on 24 Nov 2000 (X2.3)

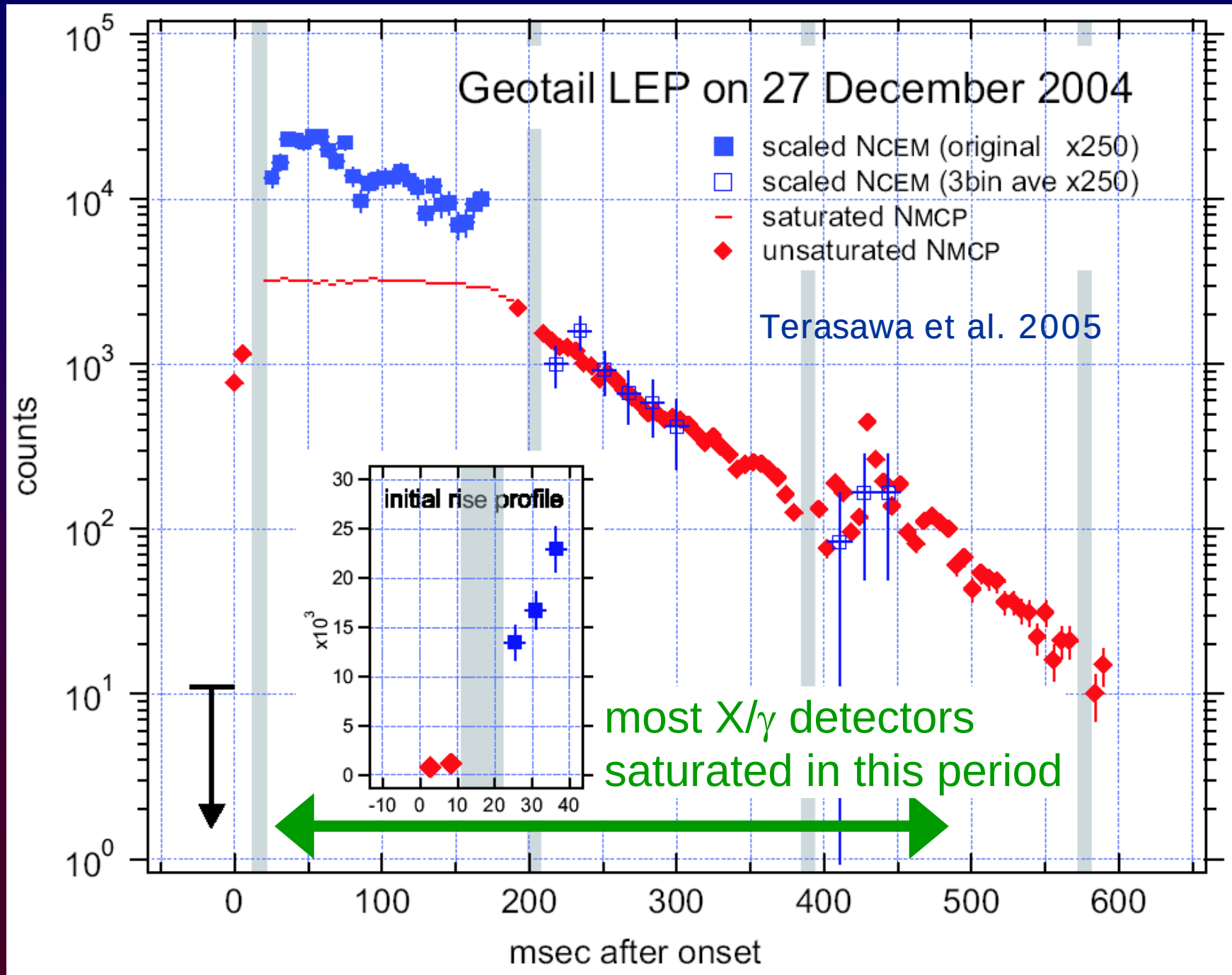
Peak ~ 10^7 photons sec^{-1} cm^{-2}
~ 20 erg sec^{-1} cm^{-2}

Note: Here we use the energy spectrum information from RHESSI.

If SGR1806-20 is 15 kpc away, the total energy is estimated as several x 10^{46} erg

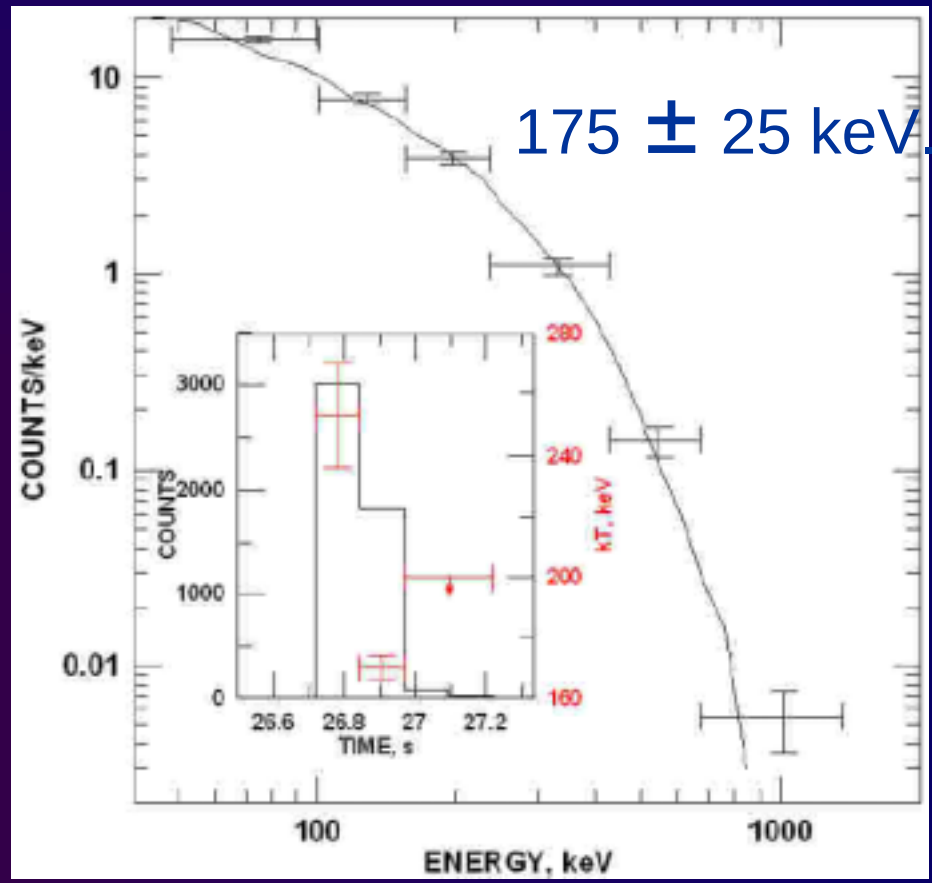


Let's look at the decay profile in detail


Geotail LEP on 27 December 2004
scaled NCEM (original x250)
scaled NCEM (3bin ave x250)
saturated NMCP
unsaturated NMCP
Terasawa et al. 2005
initial rise profile
x10^3
most X/γ detectors
saturated in this period
counts
msec after onset

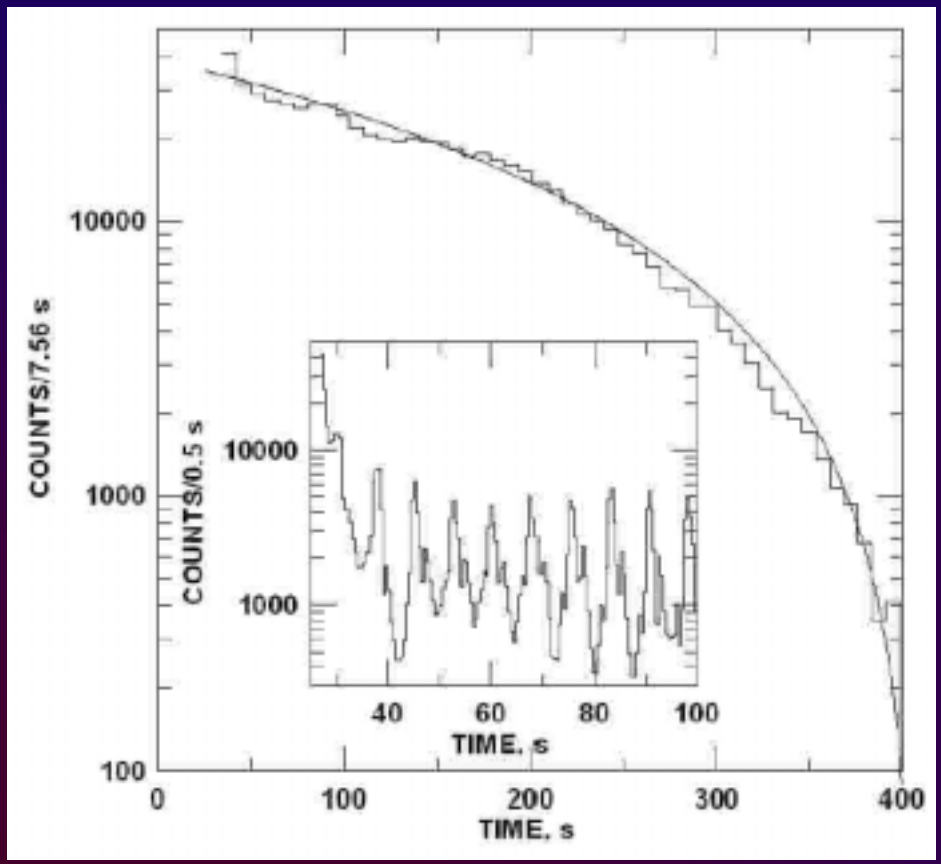
Spectrum of the initial spike

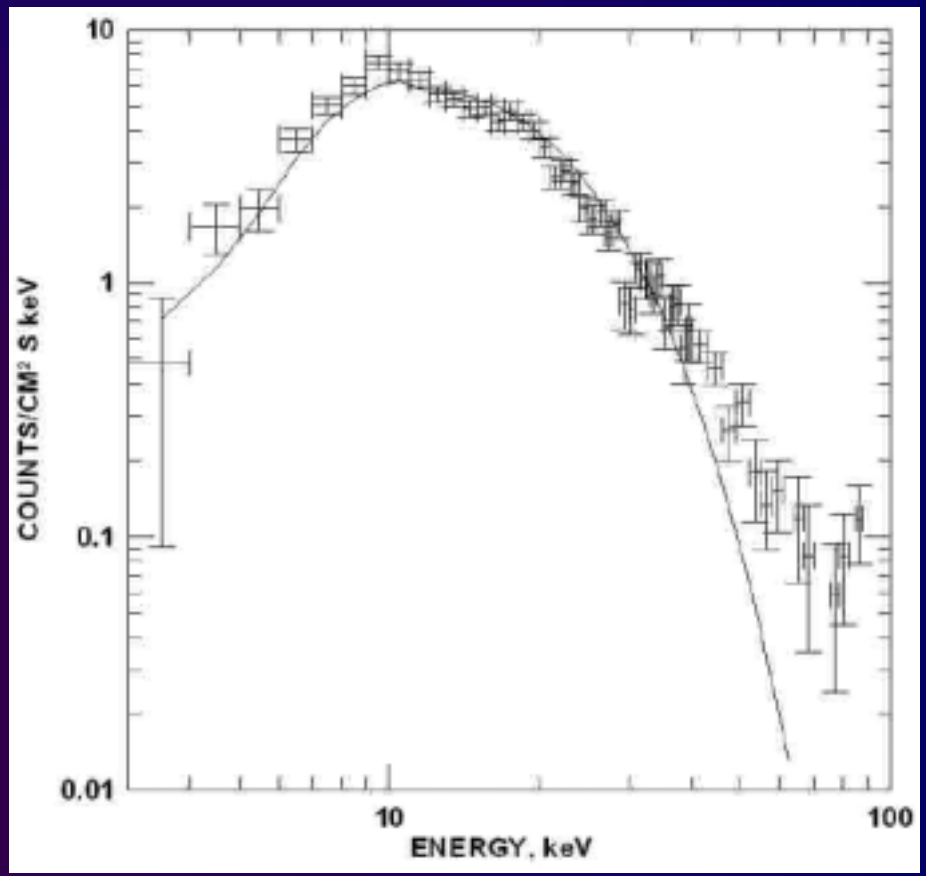
- Consistent with cooling blackbody
- kT = 230 → <100 keV
- 175 ± 25 keV (avg.)



Hurley et al. 2005

Pulsating tail
(period = 7.56 second)

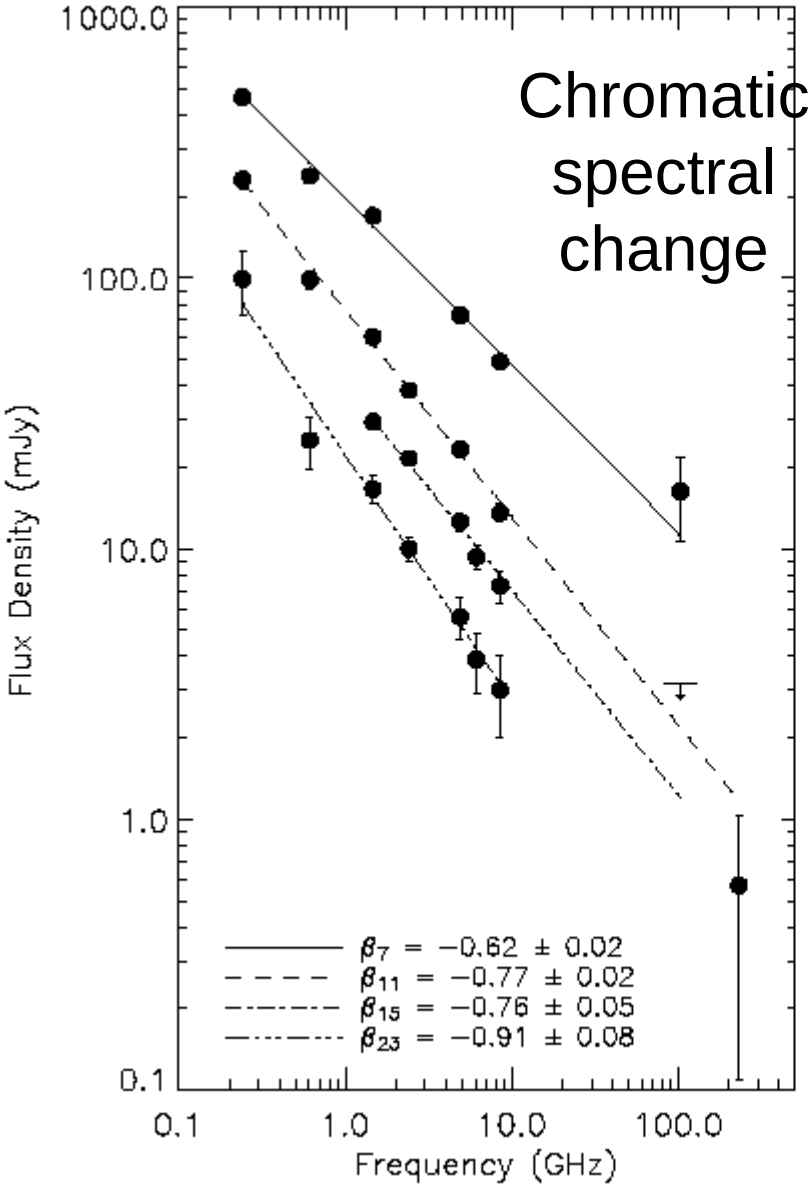


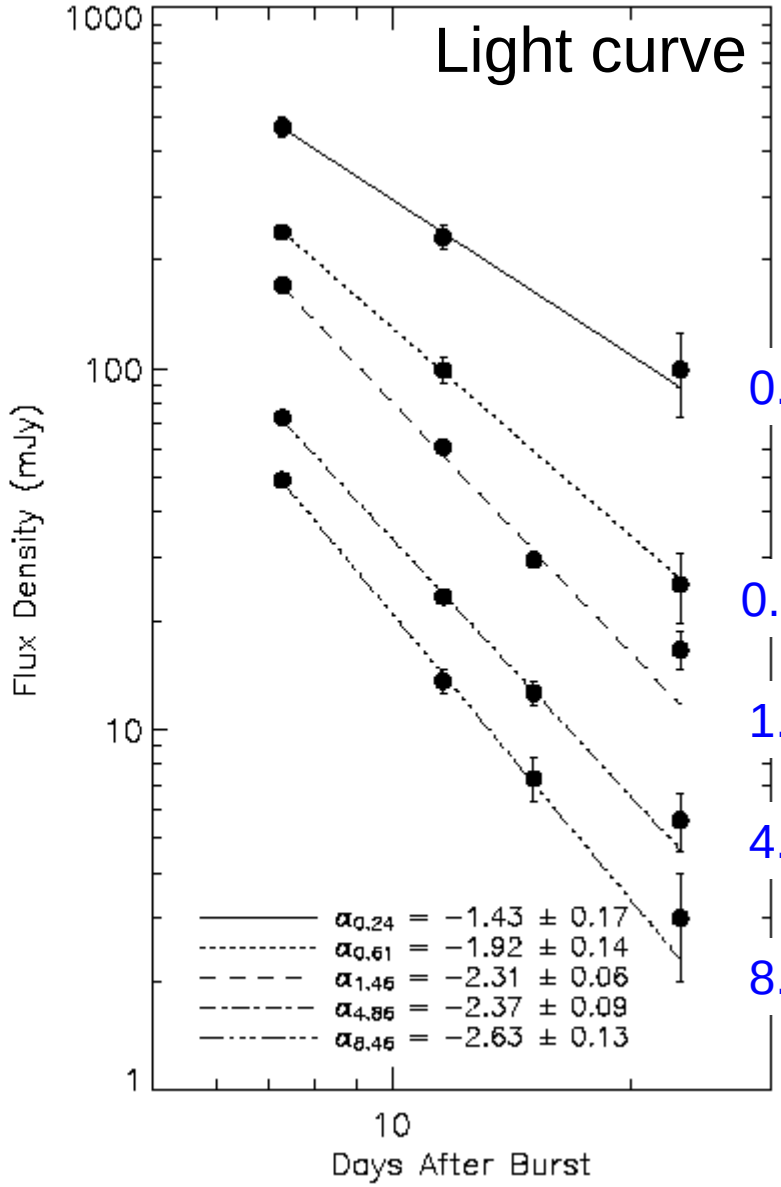


Hurley et al. 2005

Spectrum: Blackbody (kT=5.1 keV)

Cameron et al. 2005





0.24 GHz

0.61 GHz

1.46 GHz

4.86 GHz

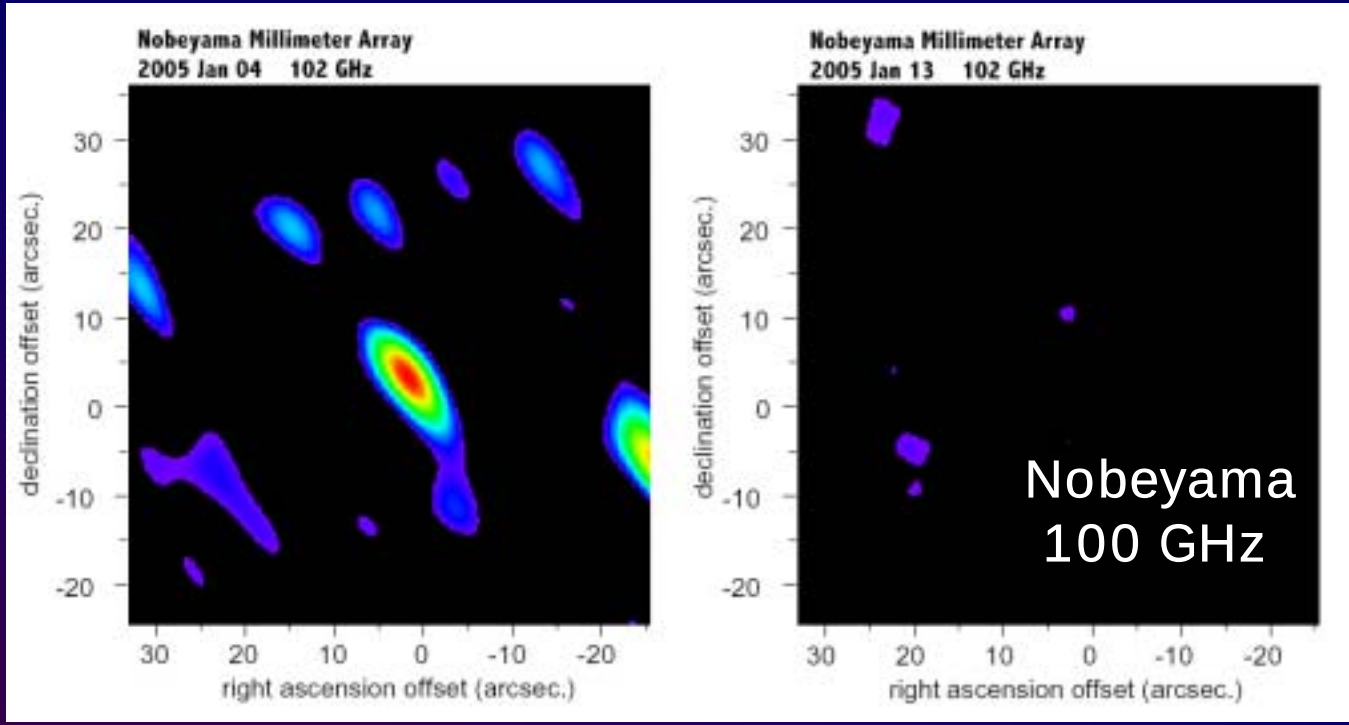
8.46 GHz

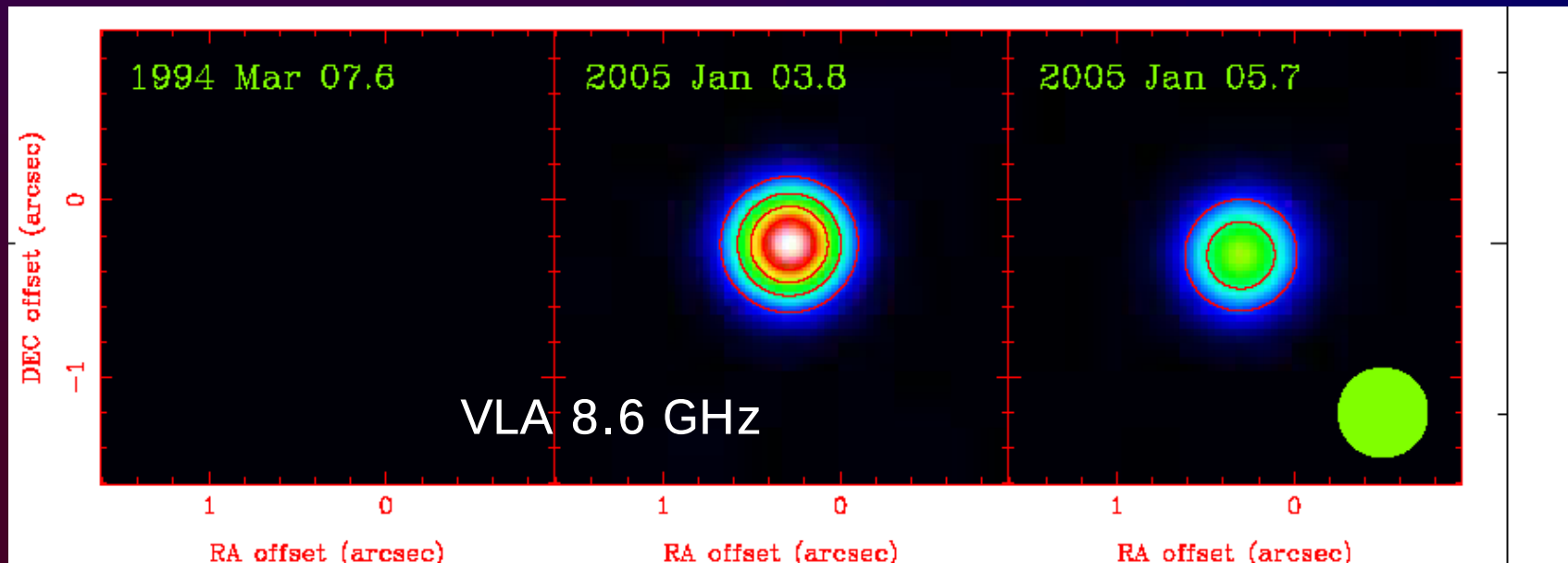
Radio Afterglow

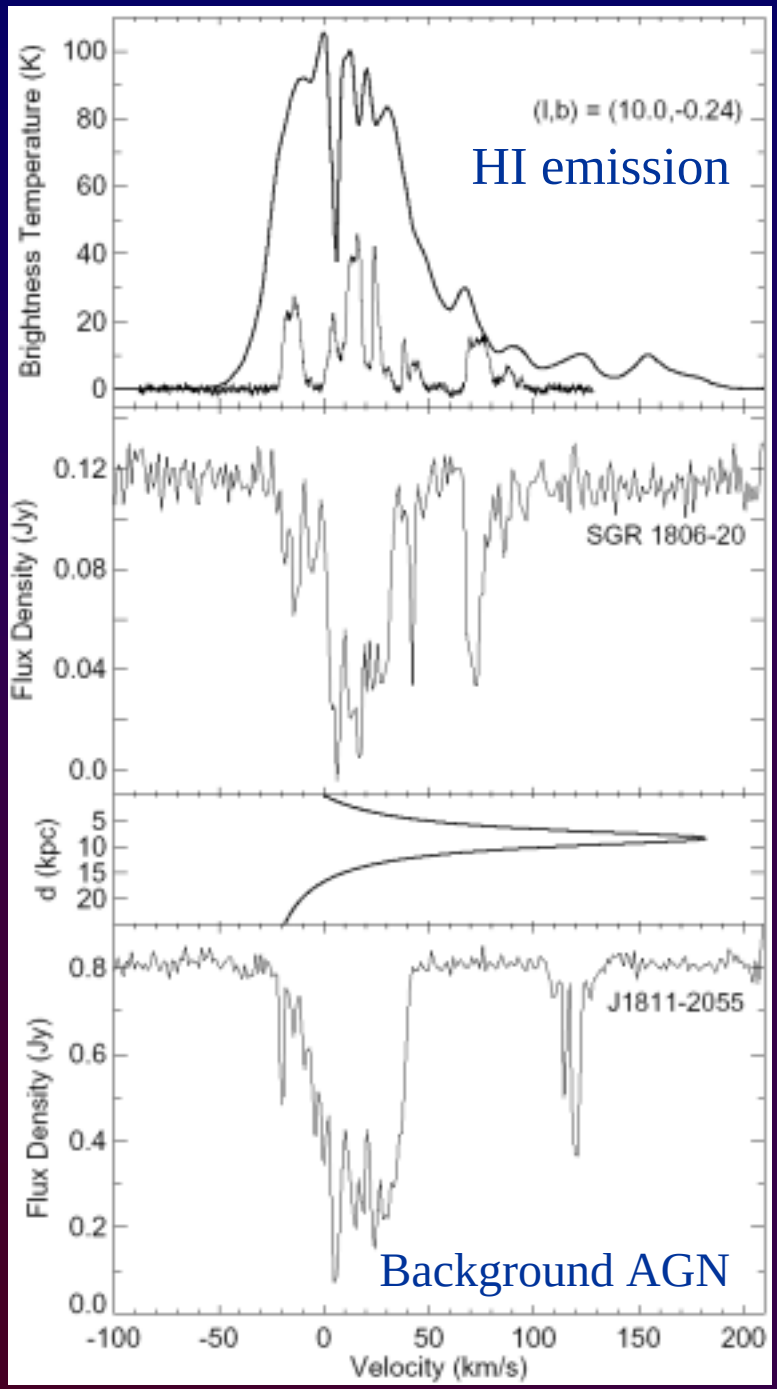
Miyazaki, Tsuboi, Okumura

(Cameron et al. 2005)

Gaensler et al. 2005



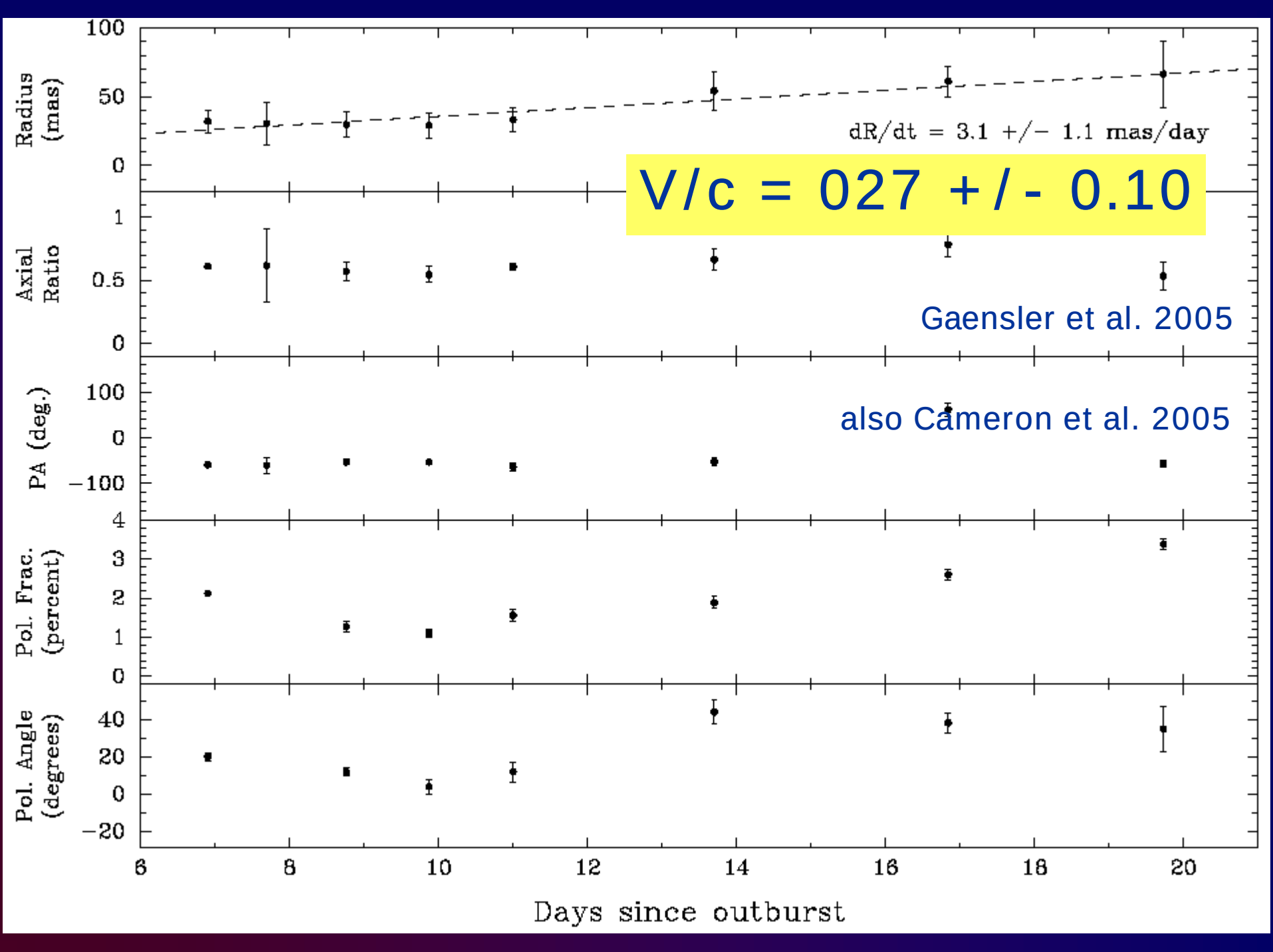




Reliable distance estimation with HI absorption

Distance: 6.4—9.8 kpc

Cameron et al. 2005


Radius (mas)
dR/dt = 3.1 +/− 1.1 mas/day
V/c = 027 +/- 0.10
Axial Ratio
Gaensler et al. 2005
PA (deg.)
also Cameron et al. 2005
Pol. Frac. (percent)
Pol. Angle (degrees)
Days since outburst

Three giant flares

- 5 Mar 1979: 6×10^{44} erg SGR 0520-66
- 28 Aug 1998: 2×10^{44} erg SGR 1900+14
- 27 Dec 2004: 3×10^{46} erg SGR 1806-20

- Common features
  - Initial intense spike (<0.5 s)
    - Exponential decay time ~ 30-60 ms
    - γ radiation up to > MeV

    → Relativistic expanding fireball (?)
  - Pulsating tail (~ several minutes)
    - Rotation period of neutron star (5—8 seconds)
    - Comparable energy
    - Blackbody (several keV)

    → trapped fireball (?)

Giant flare of SGR 1806-20

- Oscillatory tail: $E_{tail} \sim 10^{44}$ erg
  - Similar for three giant flares
- Peak characteristics (time scale and spectrum) similar to those of other giant flares

→Emission almost isotropic

  - (not collimated unlike GRBs)
- Total energy: 3×10^{46} erg
  - cf. $E_{mag} = 1.7 \times 10^{47} B_{15}^2 R_6^3$ erg
- Peak luminosity: 3×10^{47} erg/s
  - Instant release of magnetic twist in the crust (???)
- Blackbody, kT=175 keV

Radio afterglow

- Distance 6.4—9.8 kpc
  - Putative association with massive star cluster and LBV being questioned
- Consistent with a expanding synchrotron nebula
- $U_{(\text{radio nebula})} > 10^{43}$ erg
  - $U_{min}/E\gamma \sim 0.4\%$: similar to 27 Aug 1998 flare

  → strong beaming unlikely
- Relativistic expansion at v~0.3c

  → strong beaming unlikely

Lack of strong beaming

- Intense spike for all three giant flares
- No “pulsating tail only” events
- No radio flare for weak flares
- Same L_γ / L_{radio} for 1998 and 2004
- Moderate Γ (~0.3)

True Radiated energy $>10^{46}$ erg

GRB vs. SGR flare

	GRB	SGR
Energy	10^{51} erg	10^{47} erg
Γ	~1000	~1
B (gauss)	$\sim 10^{4}$?	$\sim 10^{15}$
Beamed	Yes	No
E_γ / E_{kin}	~1	~1000
Source	black hole	neutron star
N/yr/gal	10^{-5}	10^{-1}