GRBs @ IASF-MI

Sandro Mereghetti

Presentation to the Visiting Committee

Jan 9, 2008

IASF-Mi contributions to the GRB field:

- INTEGRAL Burst Alert System (IBAS)
- X-ray afterglows – Dust halos
- Soft Gamma Ray Repeaters (Magnetars)
- FUTURE: An X-ray telescope for the SVOM Satellite

People:

- 1 Staff: S.Mereghetti
- 3 senior PostDoc: A. Tiengo, A. De Luca, A. Paizis
- 2 PhD Students: G. Vianello, P. Esposito

Results:

- GRBs: 27 refereed papers in last 5 years
- Magnetars: 22 refereed papers in last 3 years

CONCLUSIONS

CONCLUSIONS 1/4

We have led the proposal, development and implementation of the IBAS system:

- First to give GRB localizations at arcmin level in near real time

- important results on several interesting GRBs

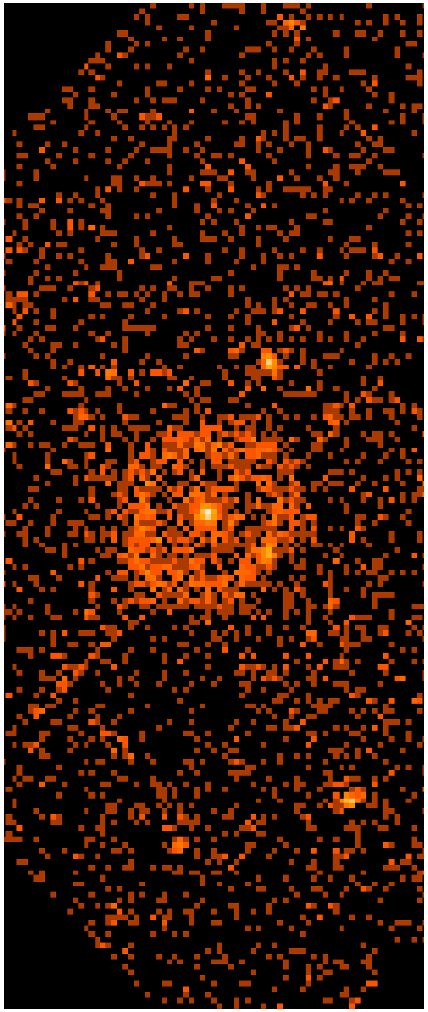
- INTEGRAL extended until 2012

  is it useful to continue with IBAS in the ``Swift'' era ??
  → YES

CONCLUSIONS 2/4

Dust scattering rings discovered with XMM around GRBs can be used to:

- derive very accurate distances of galactic dust clouds
- infer the properties of GRB prompt emission in X-rays



We have developed a new method to analyze faint dust scattering halos around GRBs

Succesfully applied also to Swift XRT data

CONCLUSIONS 3/4

Magnetars are isolated neutron star powered by <u>magnetic energy</u> $B \sim 10^{14}$-10^{15} G

Only 13 known (4 Soft Gamma Repeaters + 9 Anomalous X-ray Pulsars) but very interesting for physics and astrophysics

Recent IASF-MI highlights on Magnetars

- 1st gamma ray afterglow of a SGR giant flare (Dec 2004 event)
- Discovery of <u>persistent</u> hard X-rays from SGRs with INTEGRAL
- Correlations between bursting activities and X-ray emission properties

We will continue our long term monitoring of SGR 1806-20 with XMM-Newton, INTEGRAL, Suzaku

CONCLUSIONS 4/4

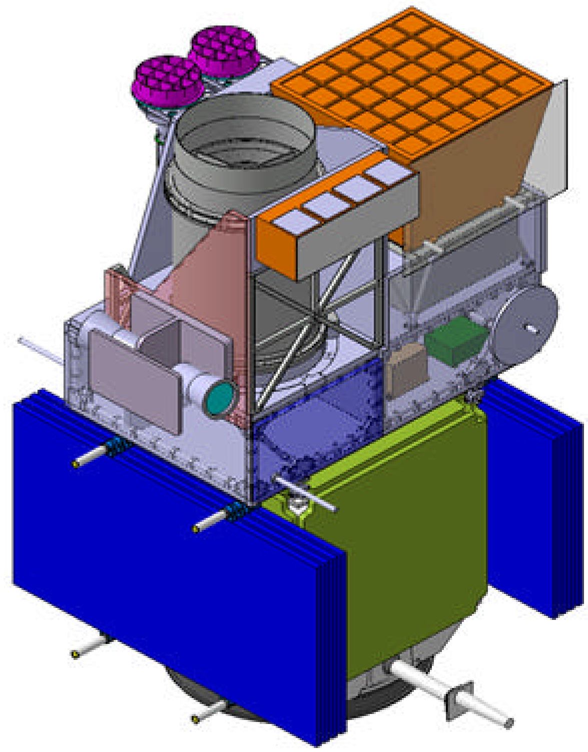
SVOM is a French-Chinese mission satellite for GRB studies

To be launched in 2012-13

Two major improvements wrt. Swift

We plan to add a small focusing X-ray telescope on SVOM

We led a proposal submitted to the recent ASI Call for Missions of Opportunity



QUESTIONS TIME

SUMMARY

- **The IBAS system:**
  - important results on several interesting GRBs
  - First localizations at arcmin level in near real time
  - INTEGRAL extended until 2012: is it useful to continue with IBAS in the ``Swift'' era ? YES

- **Dust scattering rings**
  - New analysis method with higher sensitivity
  - distances of dust and X-ray GRB prompt information

- **MAGNETARS highligths**
  - 1st gamma ray afterglow of a SGR giant flare (Dec 2004 event)
  - Discovery of persistent hard X-rays from SGR
  - Correlations between bursting activities and X-ray emission properties

- **The SVOM Satellite**
  - scientific requirements and expected performances

EXTRA SLIDES

IBAS

- 1973: GRB discovery announced
- ~1992: BATSE results

Angular Distribution
Log N - Log S

↓

"Great Debate"

- 1997: BeppoSAX afterglows lead to optical/radio identifications

- 1994/95: Selection of INTEGRAL instruments

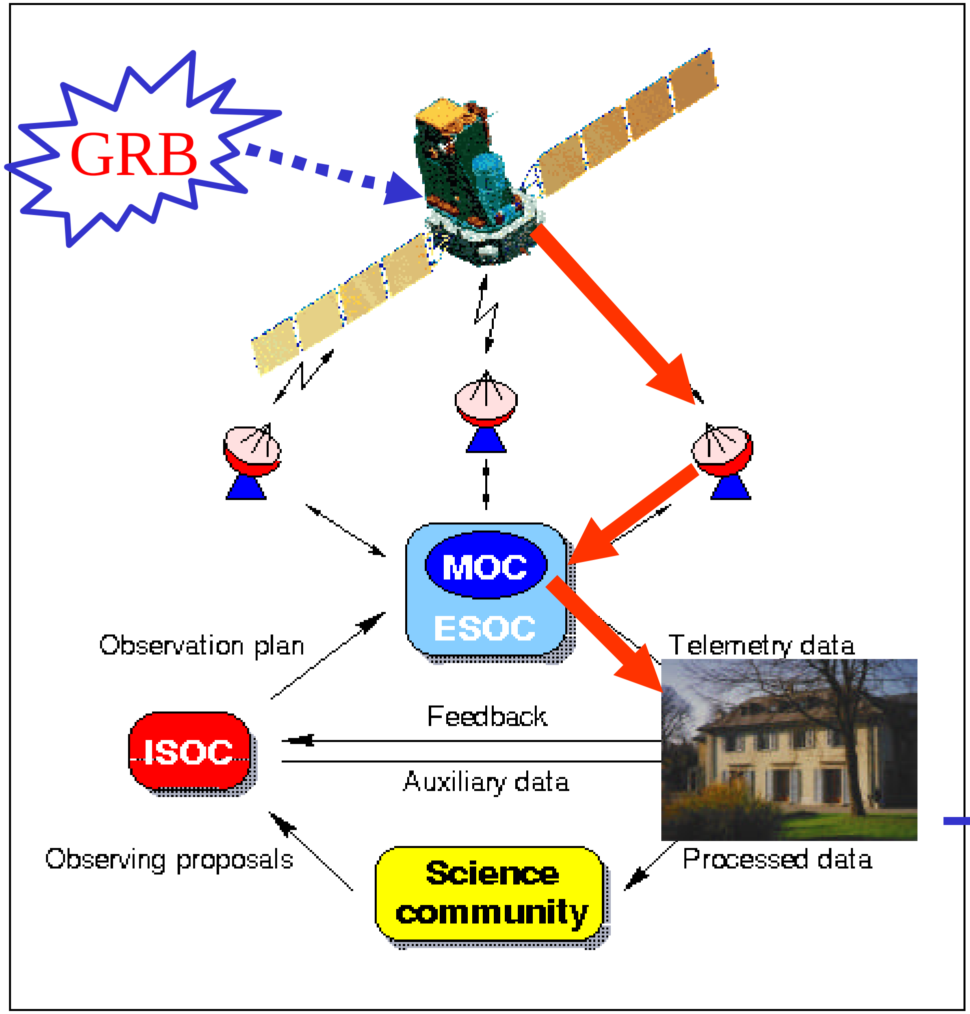
estimates of number of GRB in the INTEGRAL field of view

↓

proposal for a Burst Alert System <u>on board</u>

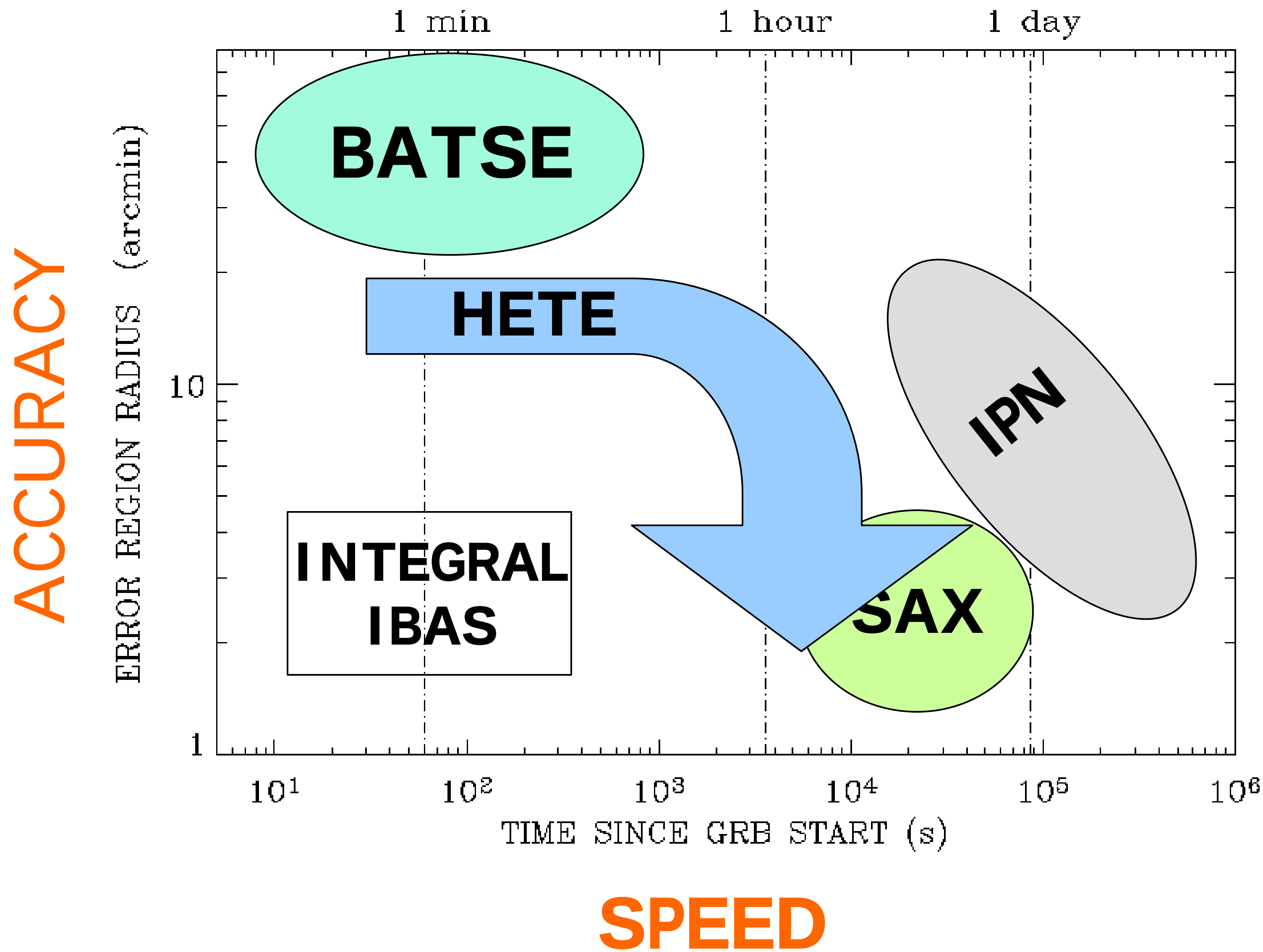
- 1997/98: Consolidation of IBAS concept <u>on ground</u>

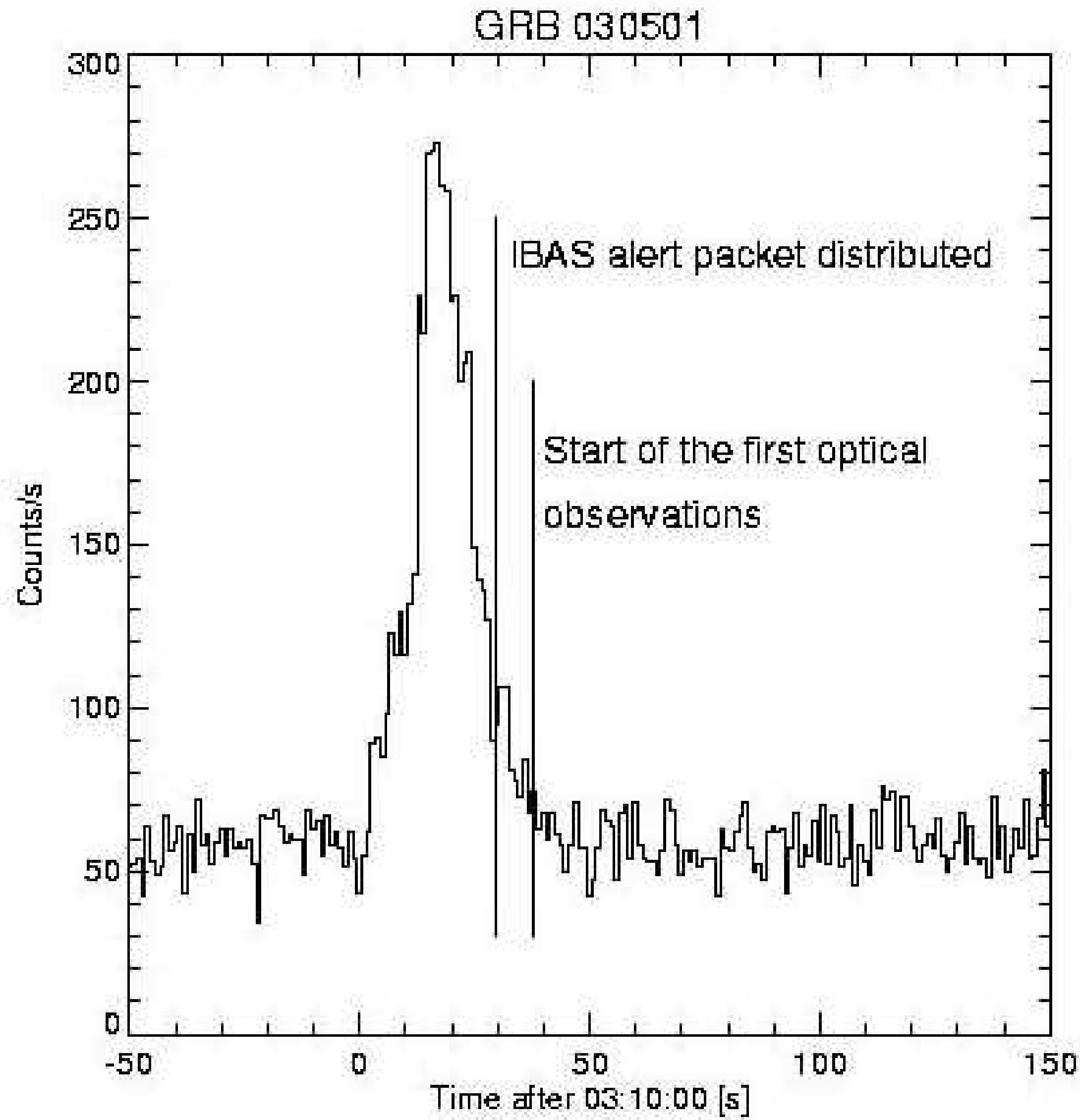
IBAS = Integral Burst Alert System



- Arcmin localization for ~1 GRB/month
- It is part of the contribution given by IASF-Mi to the INTEGRAL Science Data Center

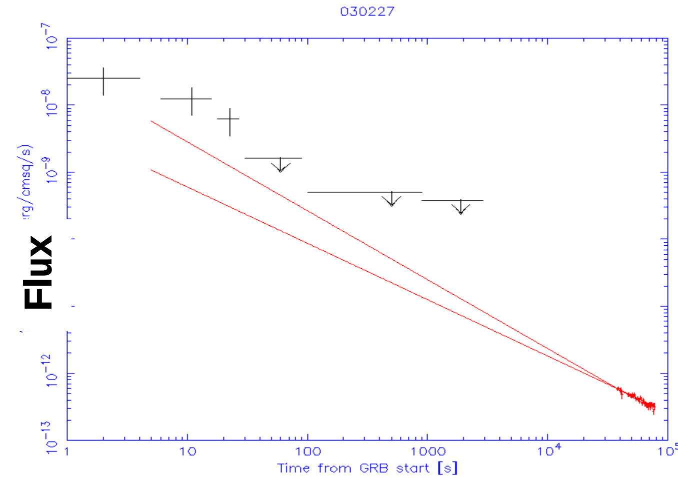
GRB LOCALIZATION PERFORMANCES – PreSwift Era !



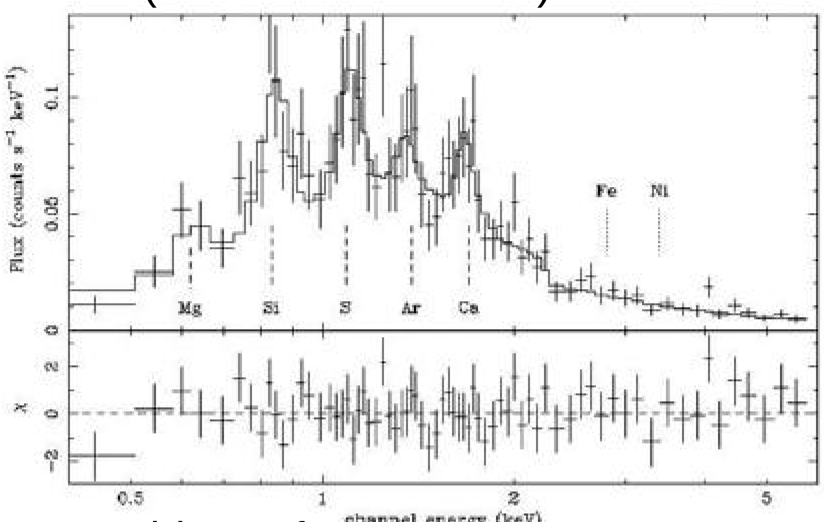

GRB 030501
IBAS alert packet distributed
Start of the first optical
observations
Counts/s
Time after 03:10:00 [s]
300
250
200
150
100
50
0
-50
0
50
100
150

GRB 030227

The first INTEGRAL GRB with an XMM-Newton follow up

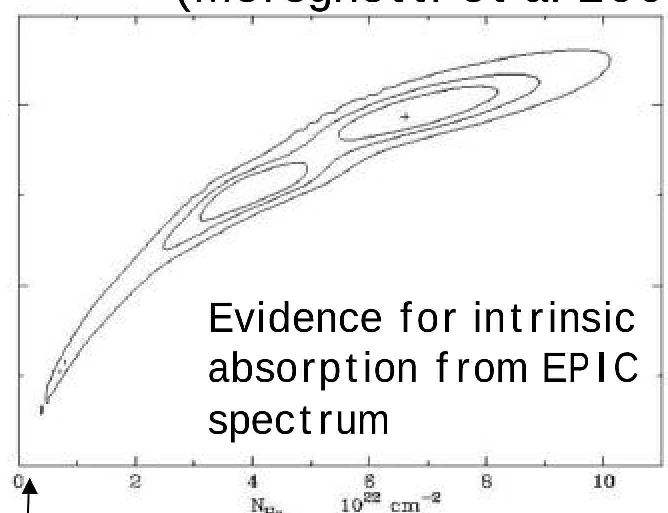


(Watson et al. 2003)



Evidence for
Mg, Si, Ar, Ca lines at z=1.4

(Mereghetti et al 2003)



Absorption

Galactic $N_H = 2 \times 10^{21}$ cm^{-2}

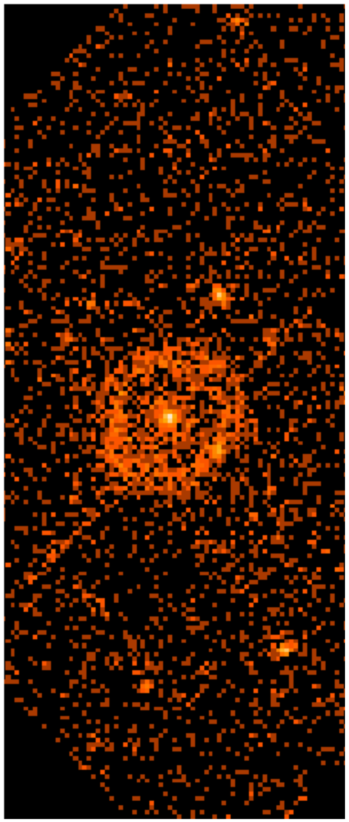
GRB 031203 z=0.1

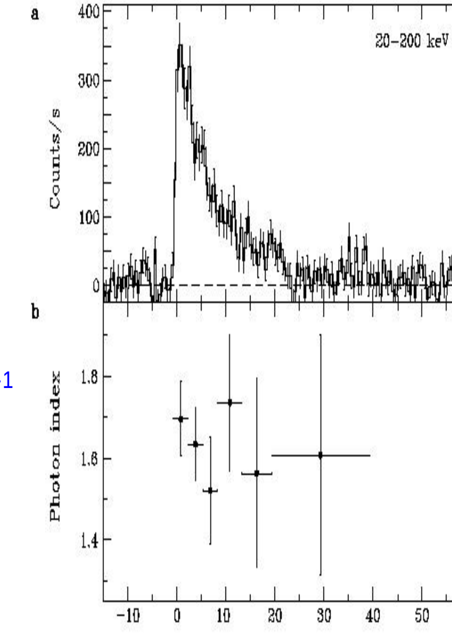
Spectroscopic SN association

Apparent outlier of correlations

Dust scattering rings

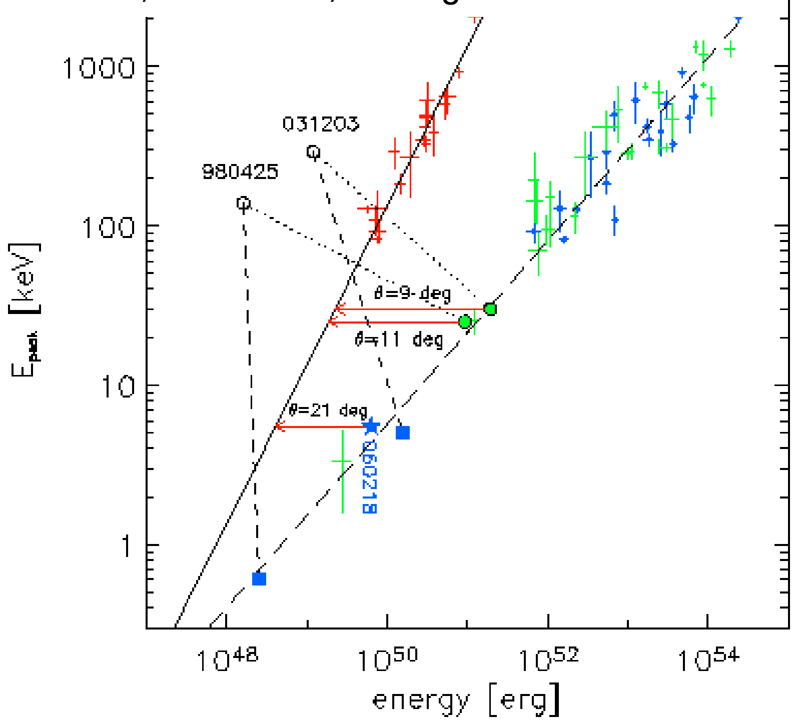
- hard GRB spectrum (Sazonov et al 2004)
- E_{iso} ~ 6-14 x 10^{49} erg s^{-1}

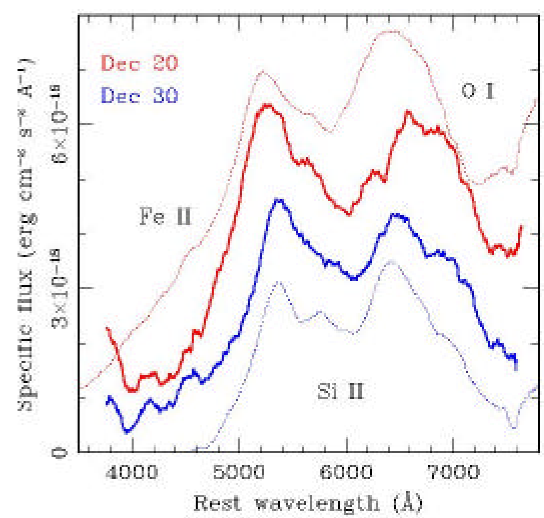




SN 2003lw (Malesani et al 2004)

Ghisellini, Ghirlanda, Mereghetti et al. 2006

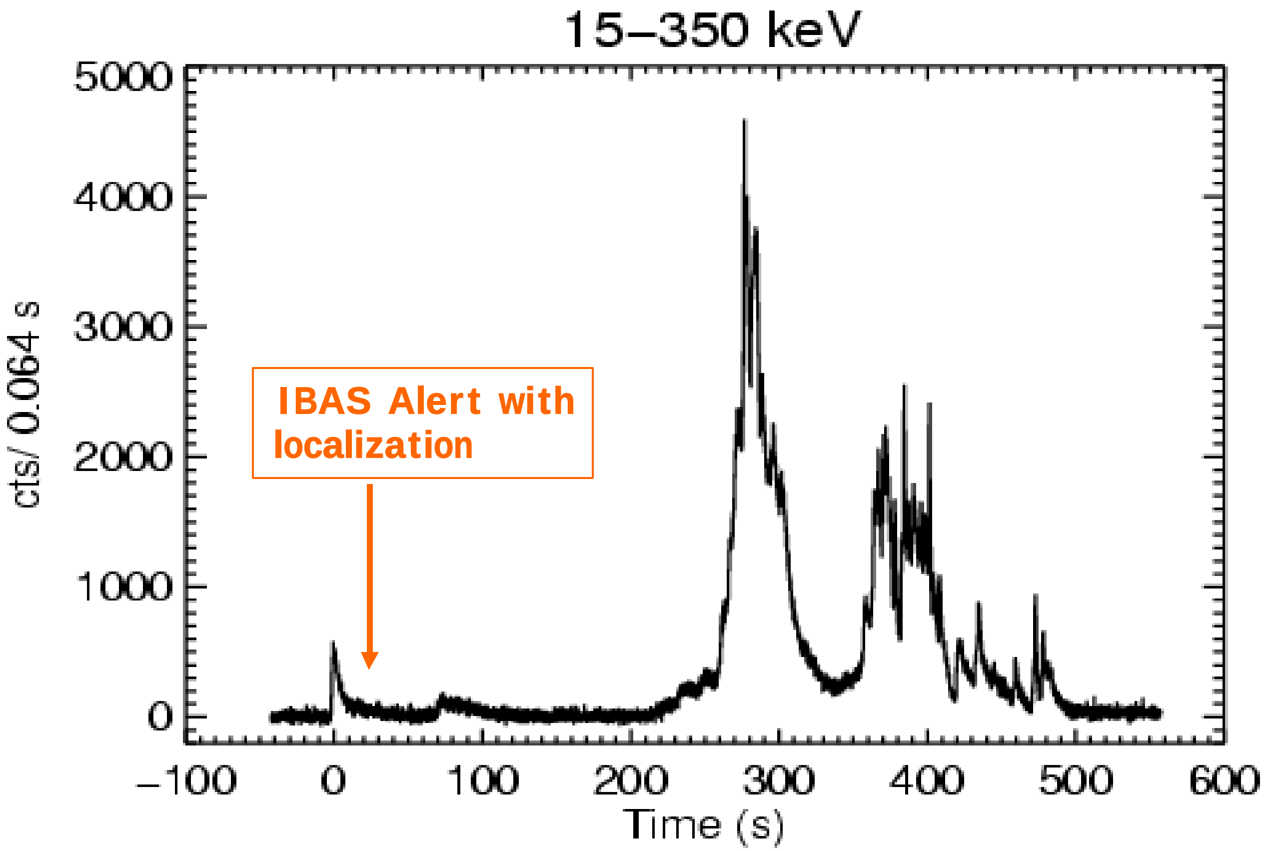




GRB 041219

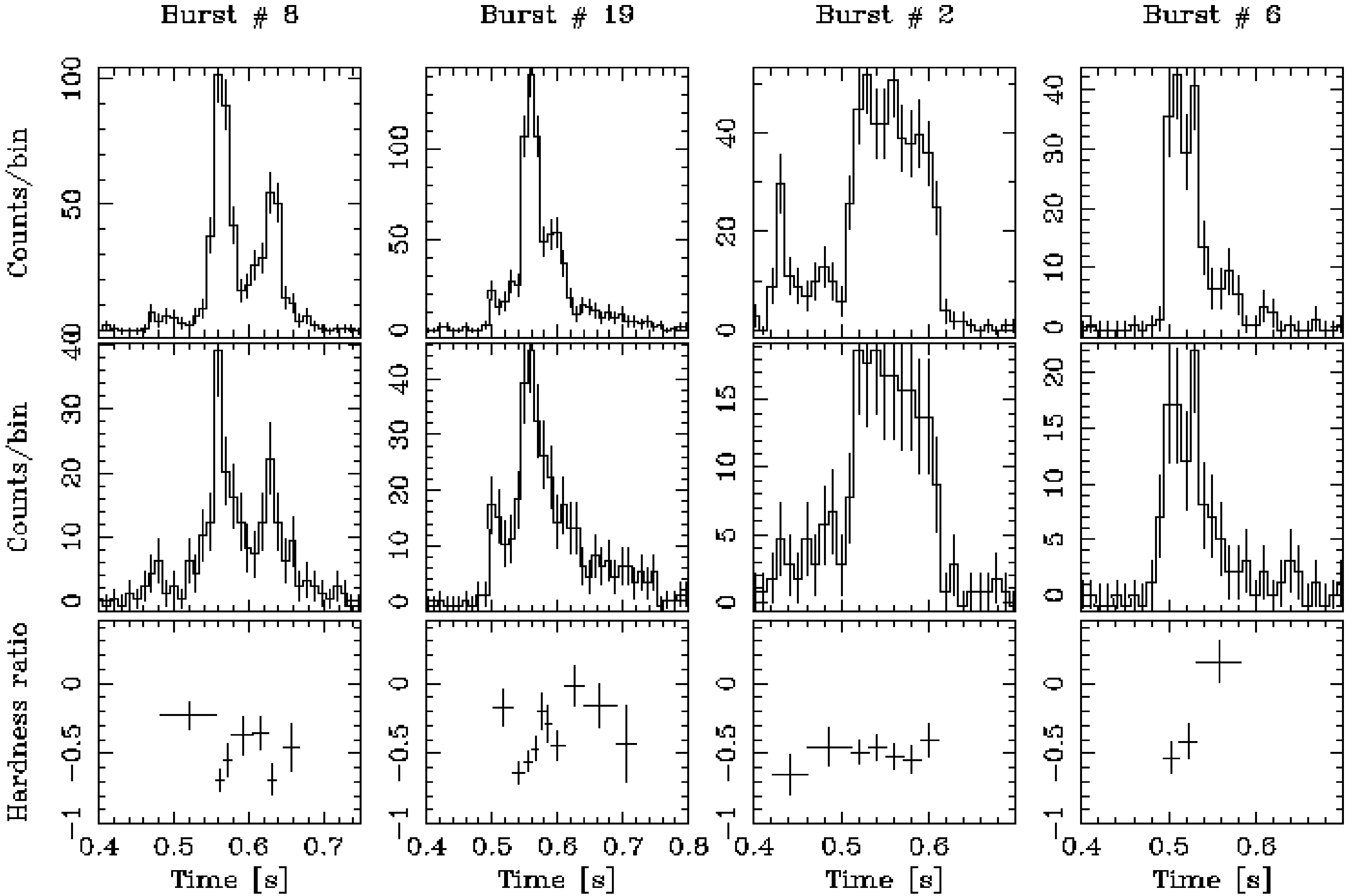
IR flash K~15.5

(Blake et al. 2005, Nature,   Vestrand et al. 2005 Nature)



Thanks to the rapid IBAS localization (2.5 arcmin) robot telescopes could observe during the GRB emission

Bursts from SGR 1806-20 seen with IBAS



Götz, Mereghetti, Hurley & Mirabel 2004, A&A 417, L45

DUST RINGS

For dust grains of radius ***a*** :

$$\text{SIZE OF HALO} \approx \frac{10\,\text{arcmin}}{\text{E [keV]} \;\; \text{a [0.1}\,\mathit{m}\text{m]}}$$

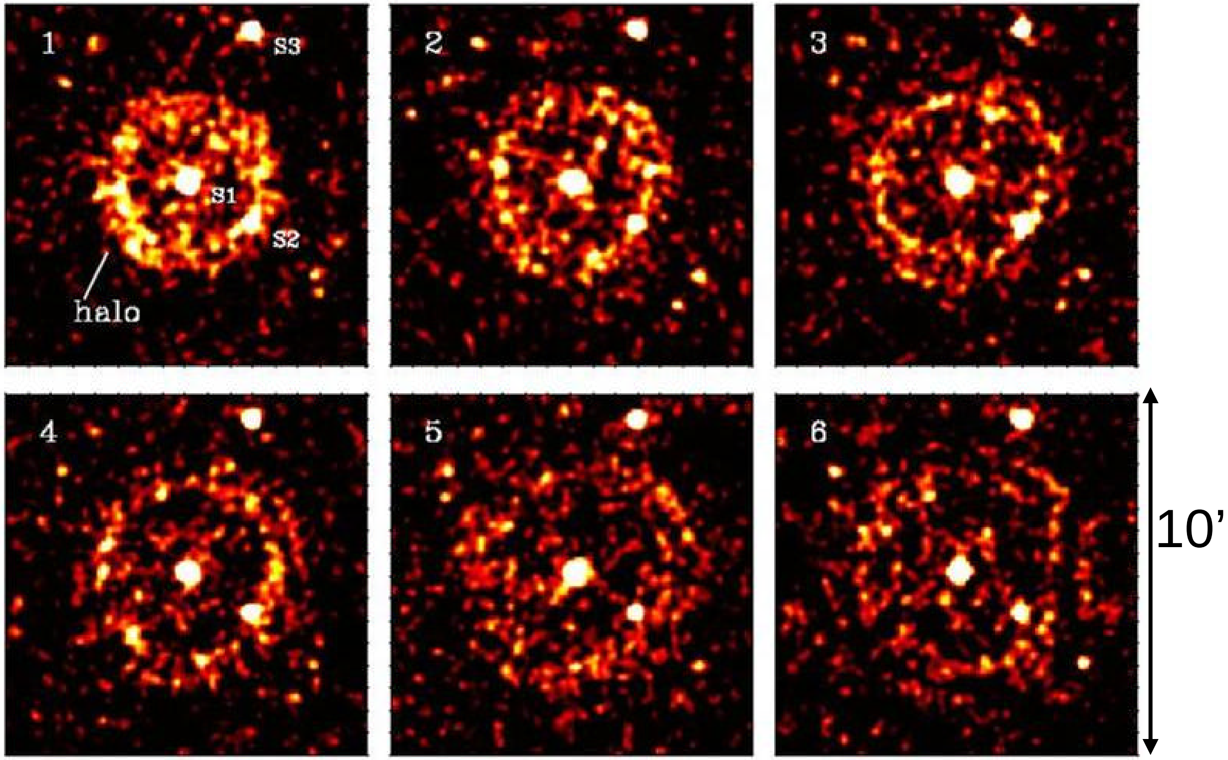
Halo profile is energy-dependent
and is determined by:

- grain properties:
    - composition (e.g. silicates / carbonaceus)
    - size distribution

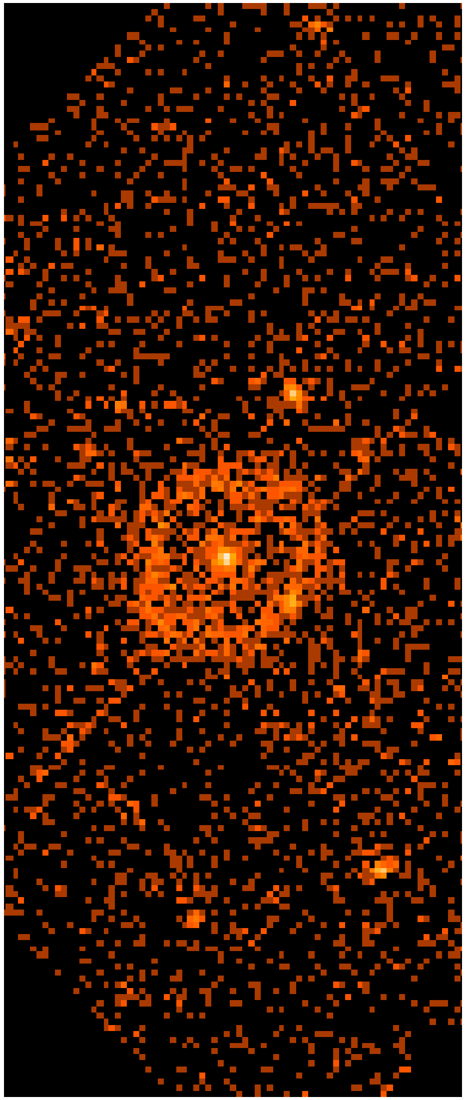
- dust distribution along line of sight

GRB 031203

EPIC MOS (Vaughan et al 2004)



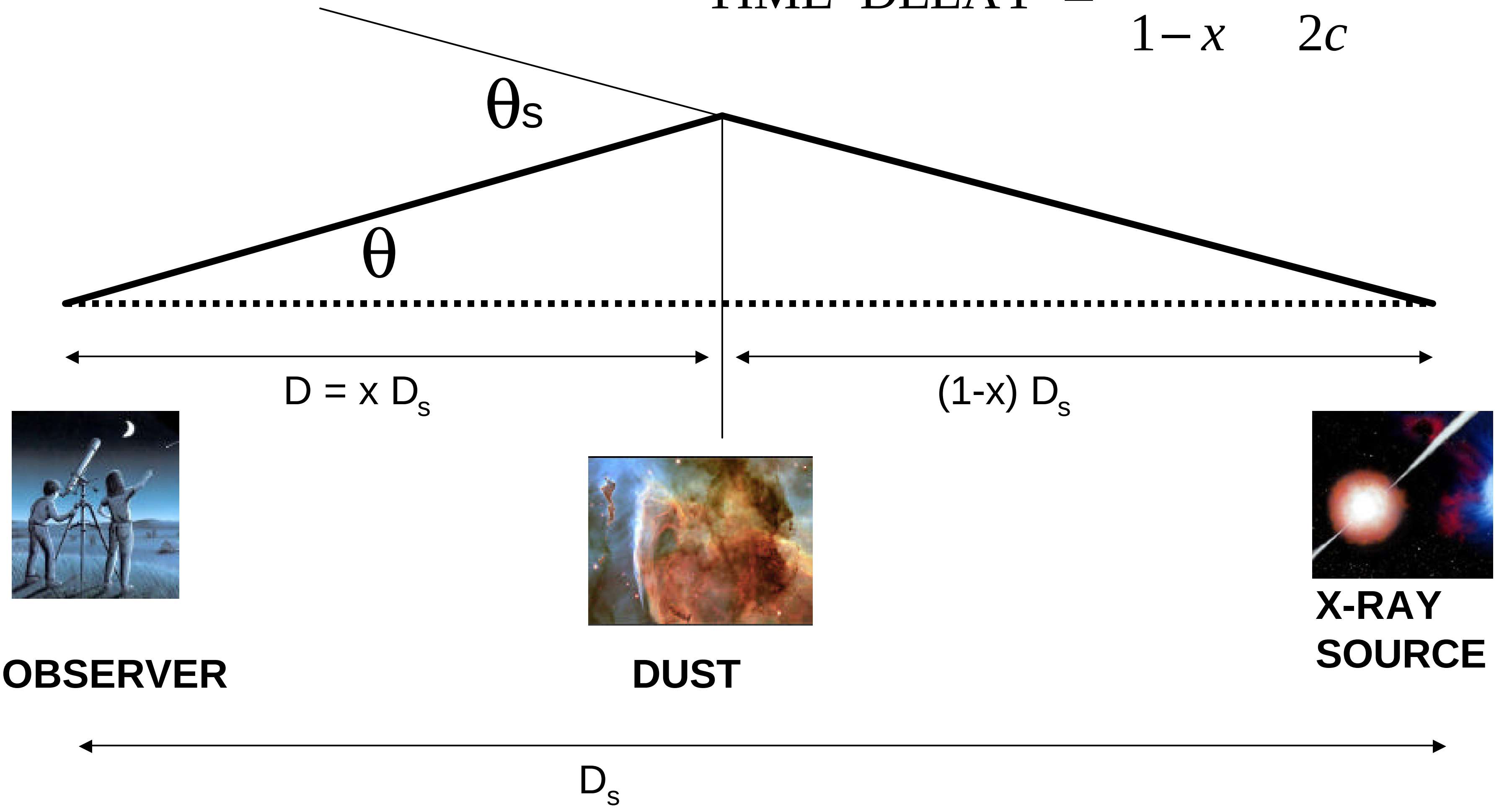
EPIC pn



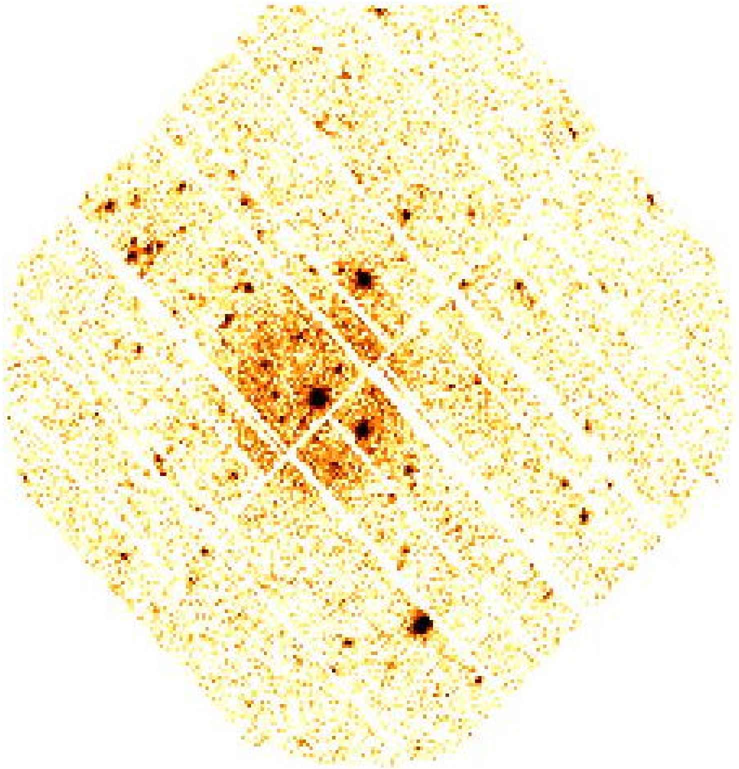
58 ks observation starting at t_o+ 6 hrs

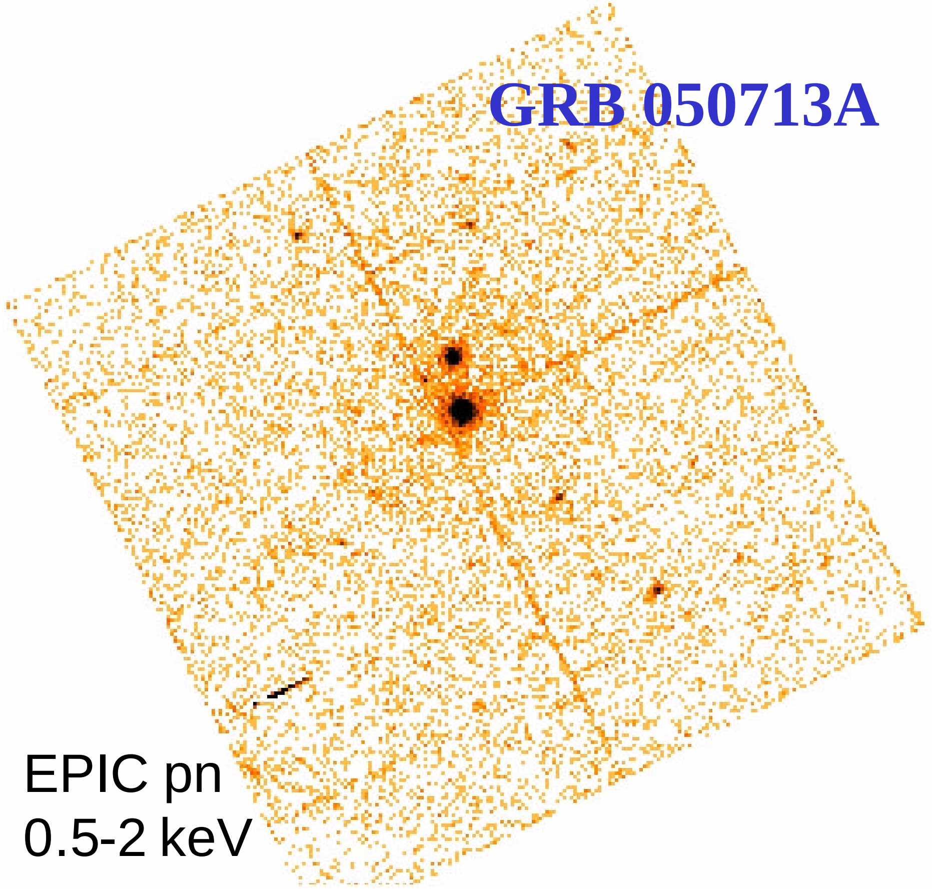
Two dust layers at D=880 pc and D=1390 pc

$$\text{TIME DELAY} = \frac{x}{1-x}\,\frac{D_S\, q^2}{2c}$$



How can we see much fainter halos than in GRB 031203 ?

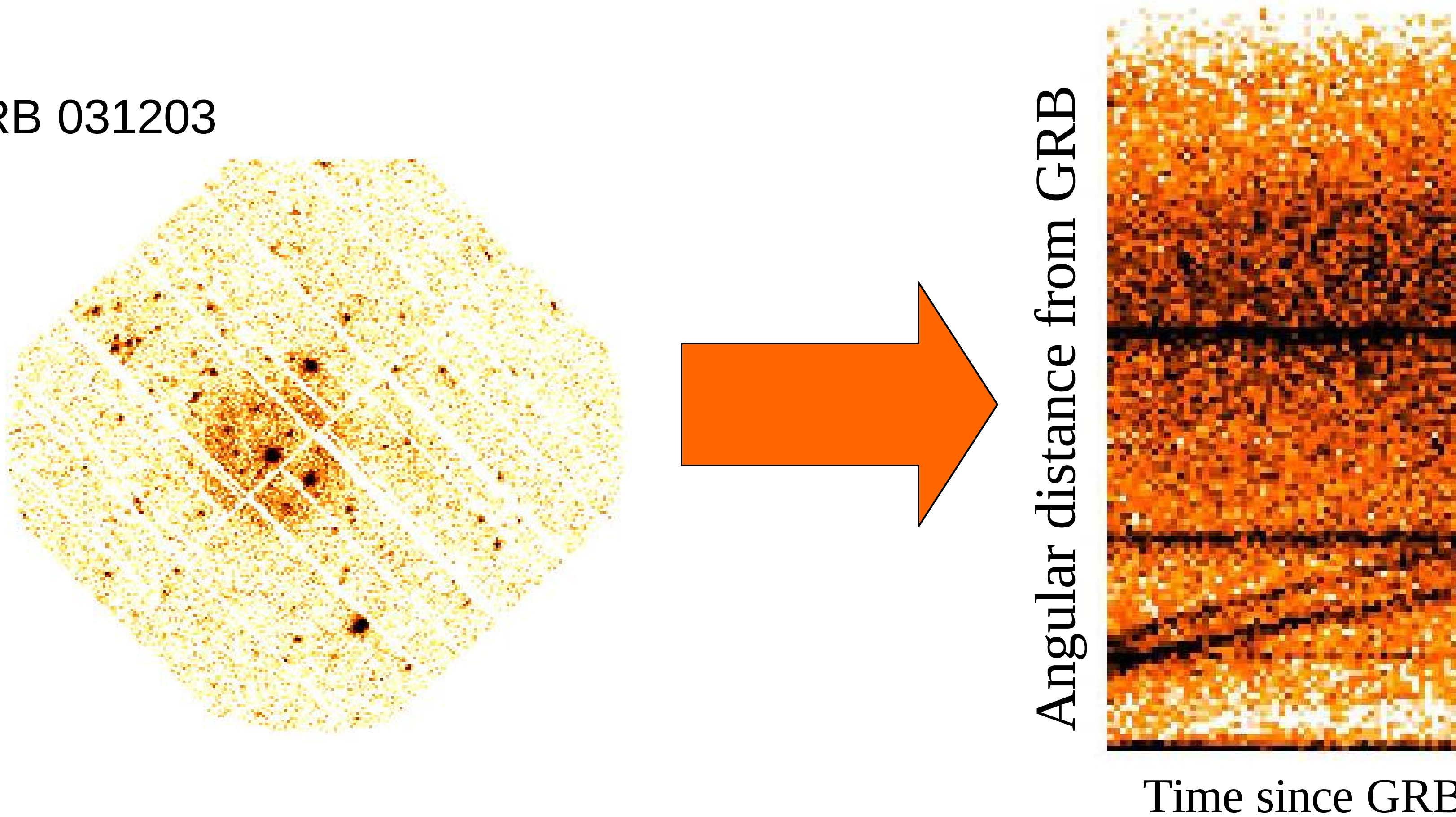




A new method for detection of faint expanding rings → **“dynamical images”**

(Tiengo & Mereghetti 2006, A&A 449, 203)

GRB 031203



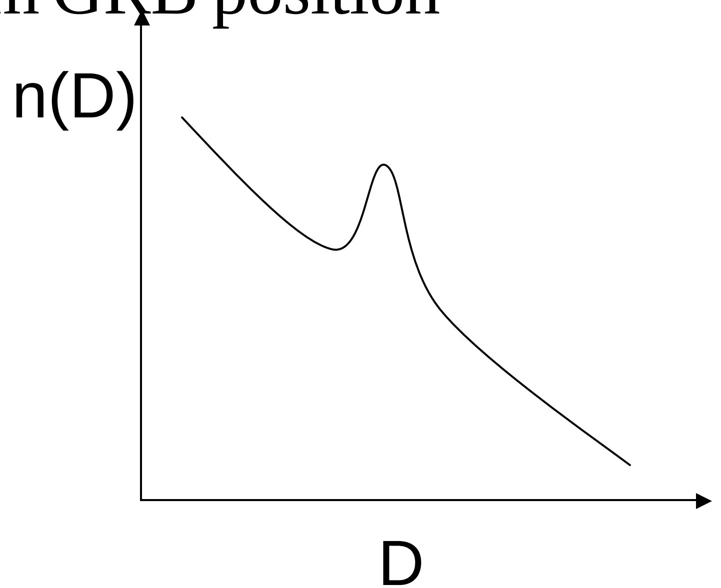
For each count detected in the X-ray image compute the quantity:

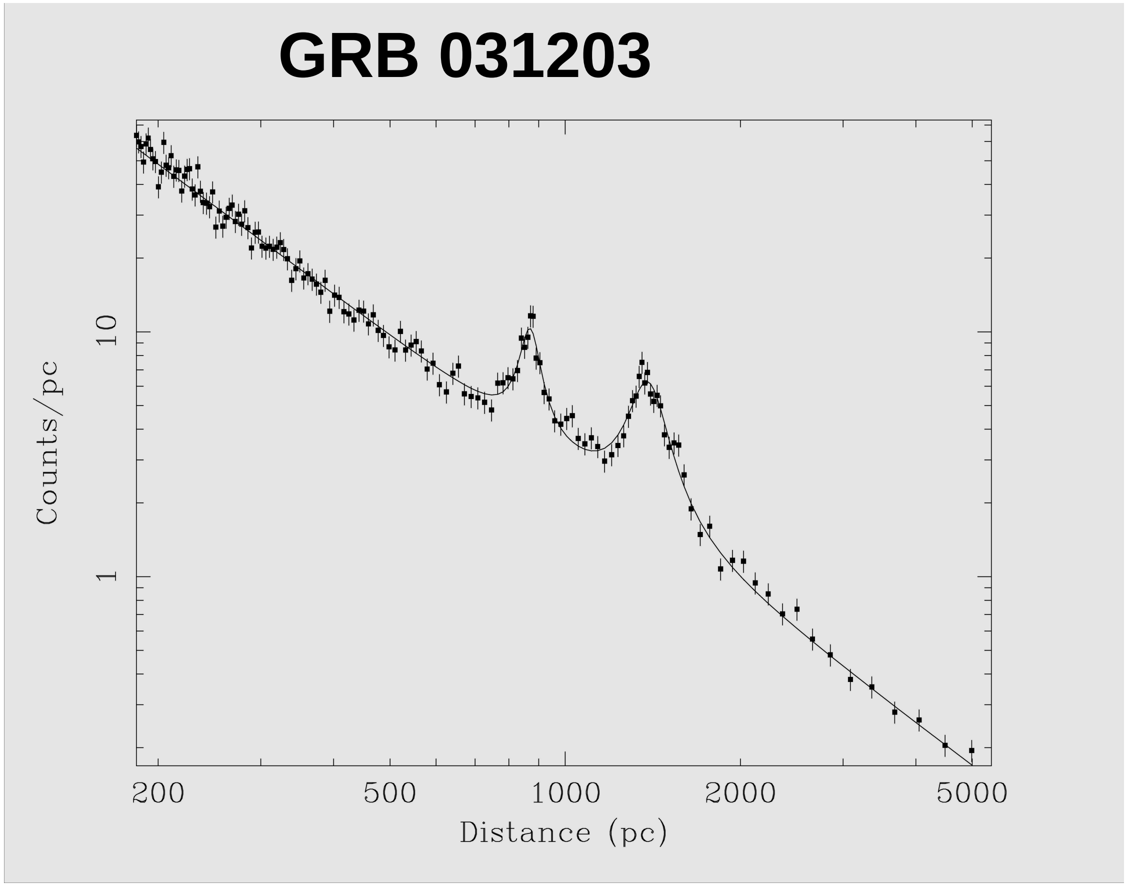
$$\frac{2ct_i}{q_i^{\,2}} \equiv D_i$$

t_i = time from the GRB

q_i = angular distance from GRB position

and plot the distribution of the D_i values





$$D_1 = 870 \pm 5 \text{ pc}$$

$$N_1 = 840^{+210}_{-180} \text{ counts}$$

$$FWHM_1 = 82^{+17}_{-14} \text{ pc}$$

$$D_2 = 1389 \pm 5 \text{ pc}$$

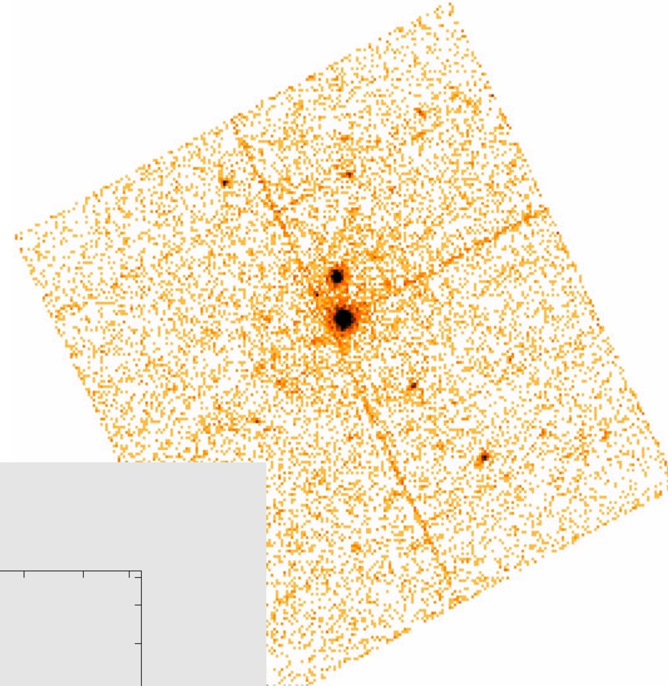
$$N_2 = 1740^{+270}_{-240} \text{ counts}$$

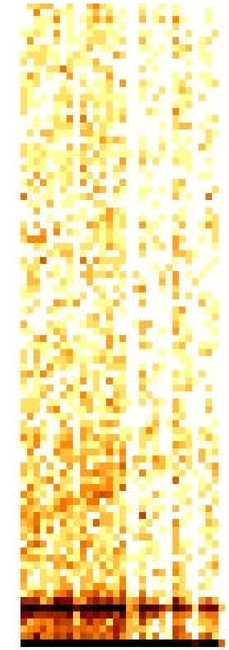
$$FWHM_2 = 240 \pm 30 \text{ pc}$$

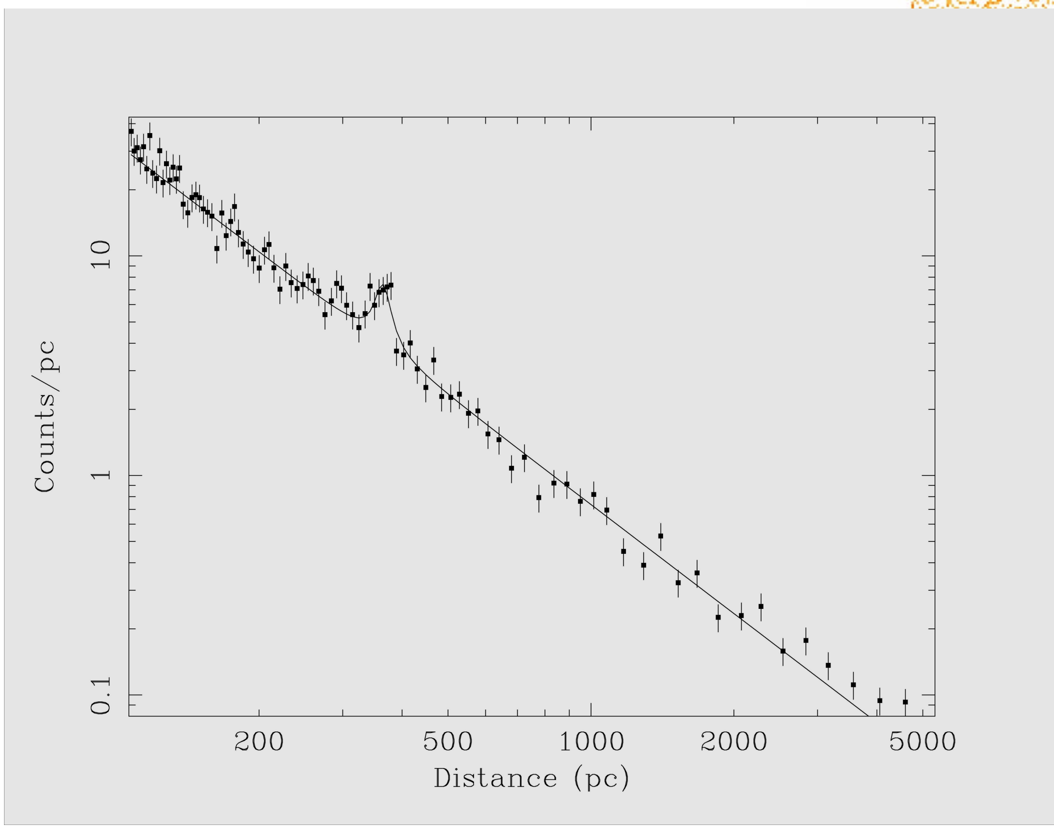
By fitting the peaks with Lorentzians one gets number of counts in the rings and distance of the dust layer

Can be done in different energy bins to extract halo spectrum

GRB 050713A



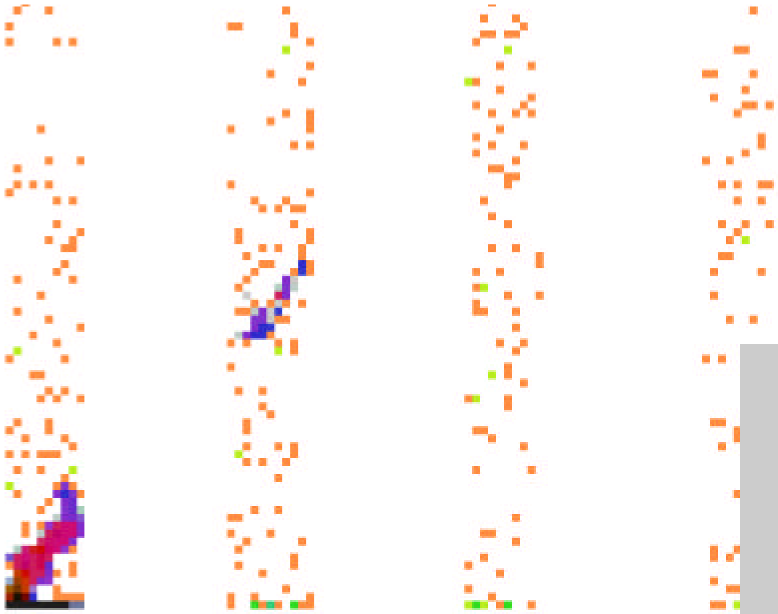




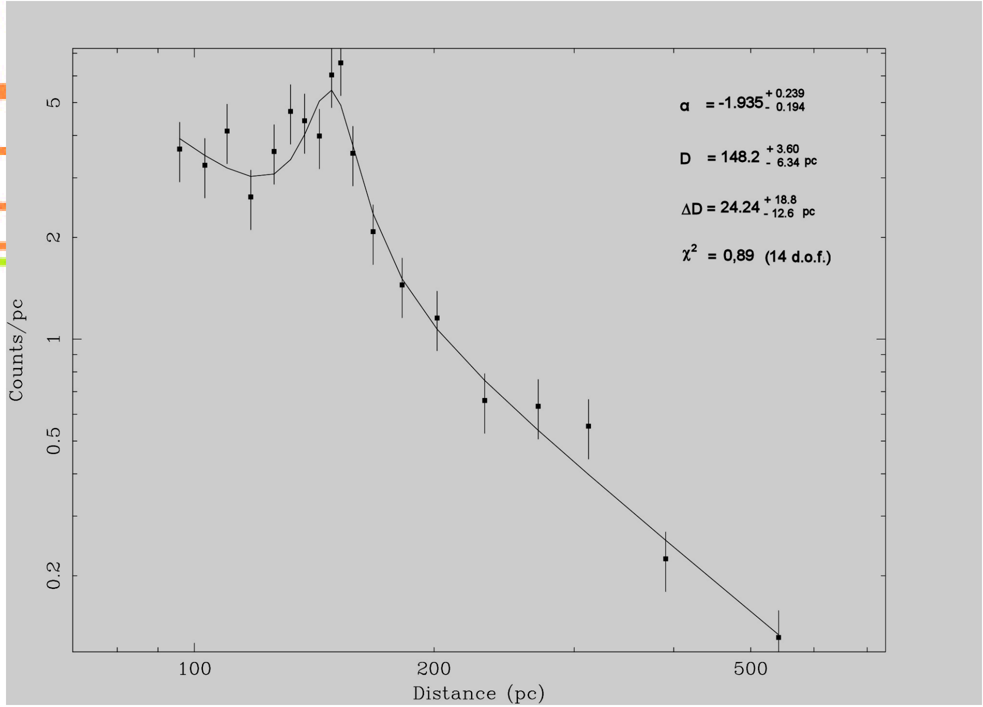
$$D = 364^{+6}_{-7} \ \text{pc}$$

$$N = 185^{+120}_{-90} \ \text{counts}$$

$$FWHM = 33^{+18}_{-12} \ \text{pc}$$



GRB 050724
0.2 – 5 keV

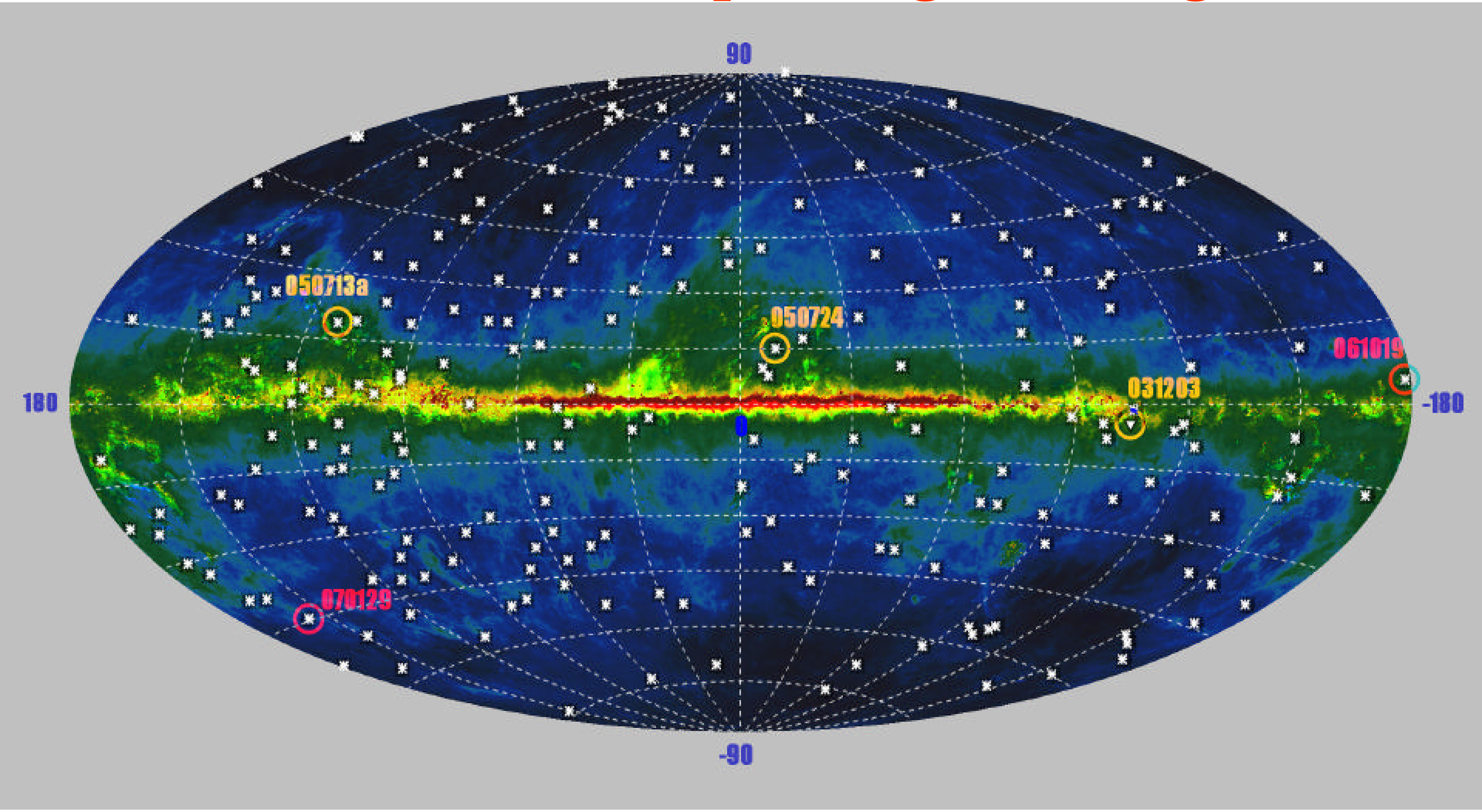


$$D = 148^{+4}_{-6} \ \text{pc}$$

$$N \sim 130 \ \text{counts}$$

$$FWHM = 24^{+19}_{-13} \ \text{pc}$$

5 GRBs with expanding dust rings



Vianello, Tiengo & Mereghetti, 2007, A&A

Information on the prompt emission

Uncertainties on: - measure of halo intensity I_{HALO}

- knowledge of $\tau = \sigma_{scat}\, n\, D$

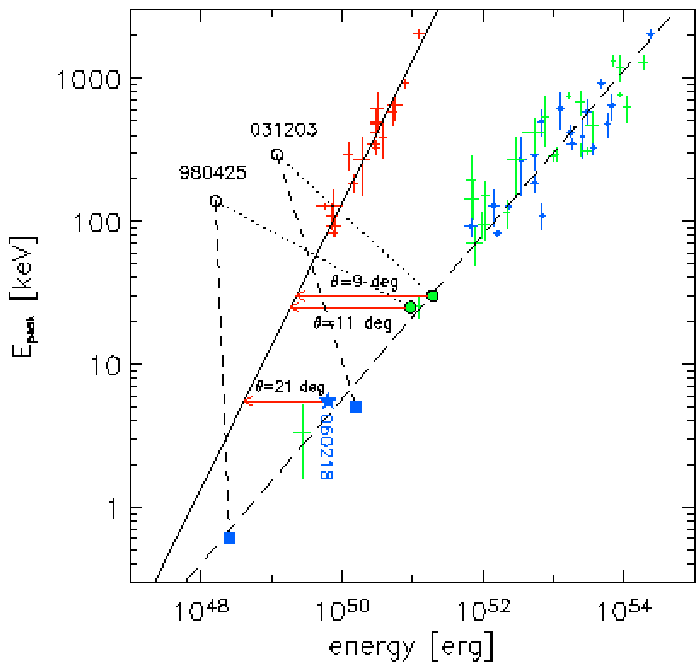
$$I_{HALO} = I_{GRB}\left(1 - e^{-t}\right) \cong I_{GRB}\, t$$

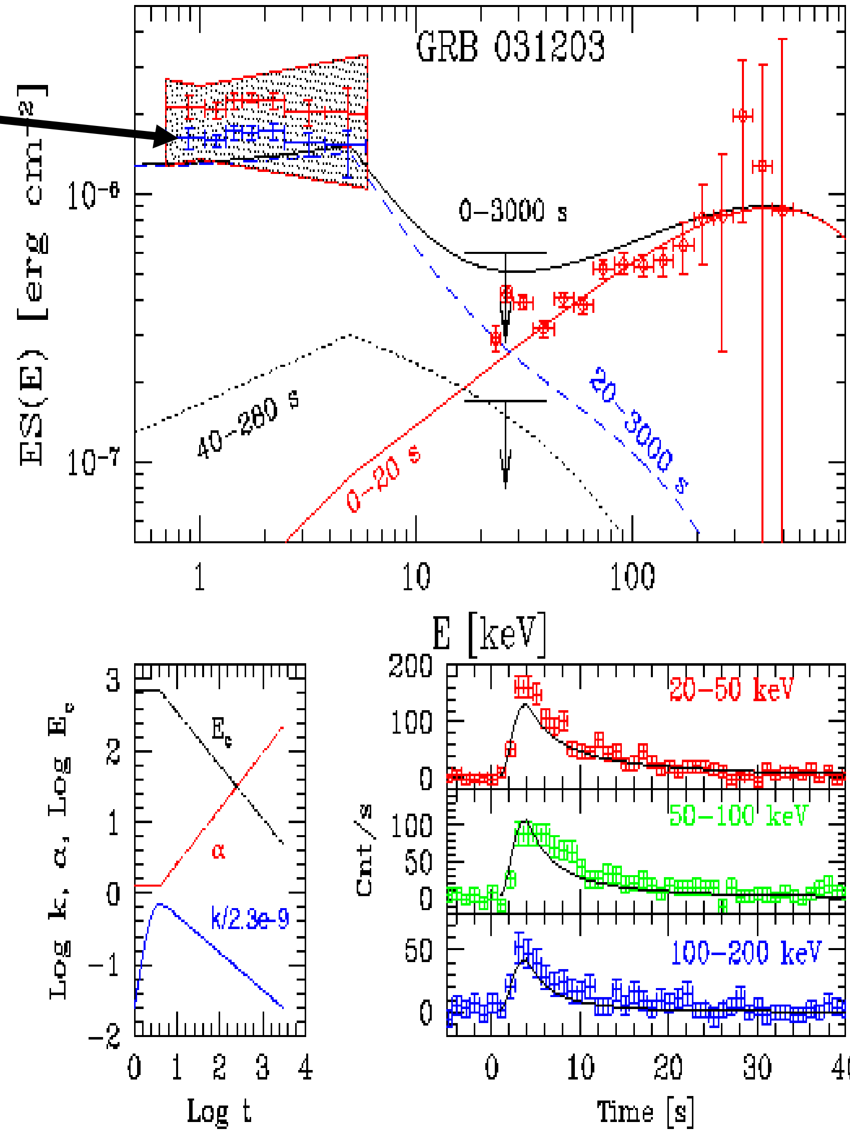
τ can be estimated from optical absorption:

Draine & Bond 2004 → $t \approx 0.15 A_V E_{keV}^{-1.8}$

Predehl & Schmitt 1995 → $t \approx 0.056 A_V E_{keV}^{-2}$

X-ray prompt estimated from dust halo





Ghisellini, Ghirlanda, Mereghetti et al. 2007, MNRAS

MAGNETARS

What is a Magnetar?

Isolated neutron star powered by magnetic energy $B \sim 10^{14}$-10^{15} Gauss

How do we observe magnetars?

1) "Persistent" X-ray emission
   - $L_X \sim 10^{35}$ erg/s soft: kT~0.5 keV
   - P ~ 5-12 s spin-down 10^{-11} – 10^{-13} s/s
   - $dE_{ROT} / dt \ll L_x$
2) Short (<1 s), super-Eddington bursts kT~30 keV
3) Giant Flares - rare events! $L \sim 10^{44}$ – $>10^{46}$ ergs

How many are known?

9 AXPs + 4 SGRs in our Galaxy and in Magell. Clouds

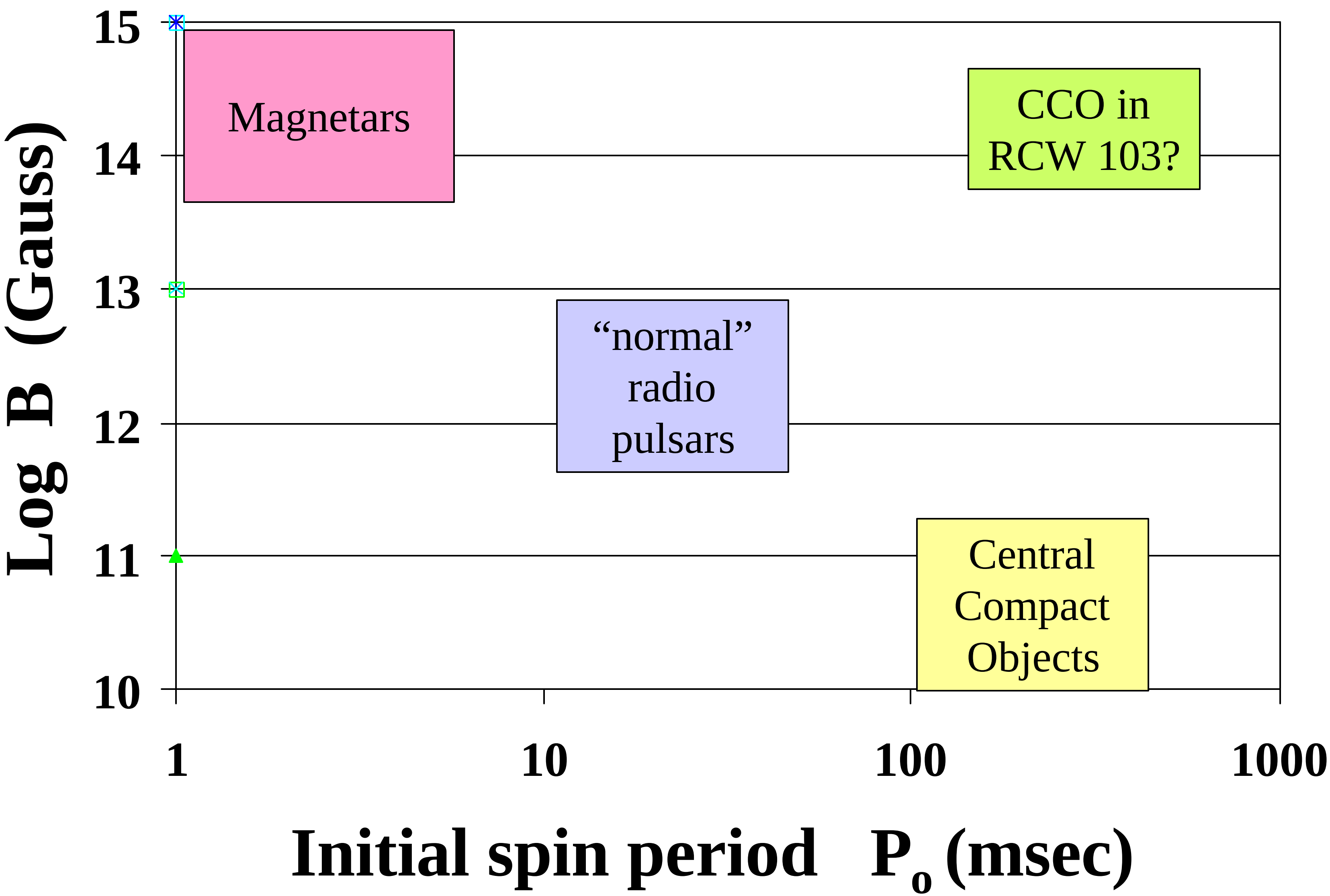
Importance of Magnetars

- **Physics**:
  unique laboratories to study processes in high magnetic fields

- **Astrophysics**:
  a different perspective on neutron stars and massive stars evolutionary end points

  we are biased by 40 yrs of radio pulsars observations

A variety of initial conditions

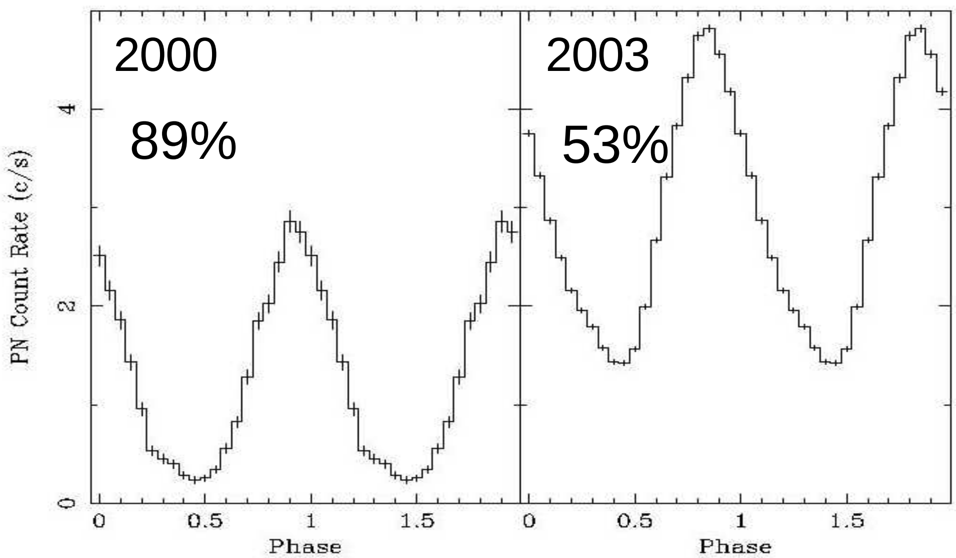


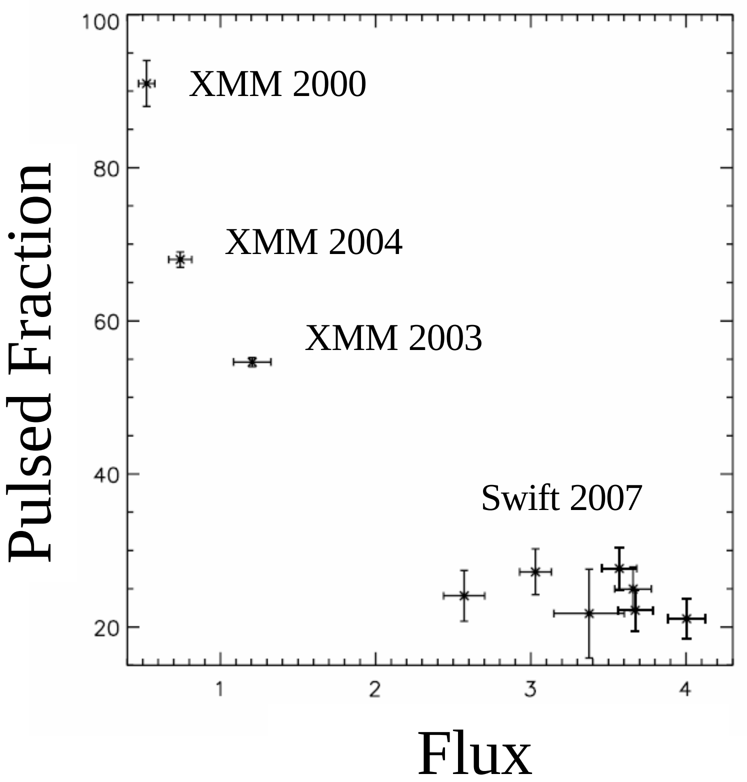
IASF-Milano contribution to magnetar studies

- AXPs recognized as a new class of X-ray pulsars: *Mereghetti & Stella 1995, ApJ 442, L17*
- In the last 3 years:
  - 12 refereed papers as first authors
  - 11 refereed papers as co-authors

AXP 1E 1048.1-5937

(Tiengo et al. 2002, A&A 383, 182; Mereghetti et al. 2004, ApJ 608, 427; Tiengo et al. 2005, A&A 437, 997)





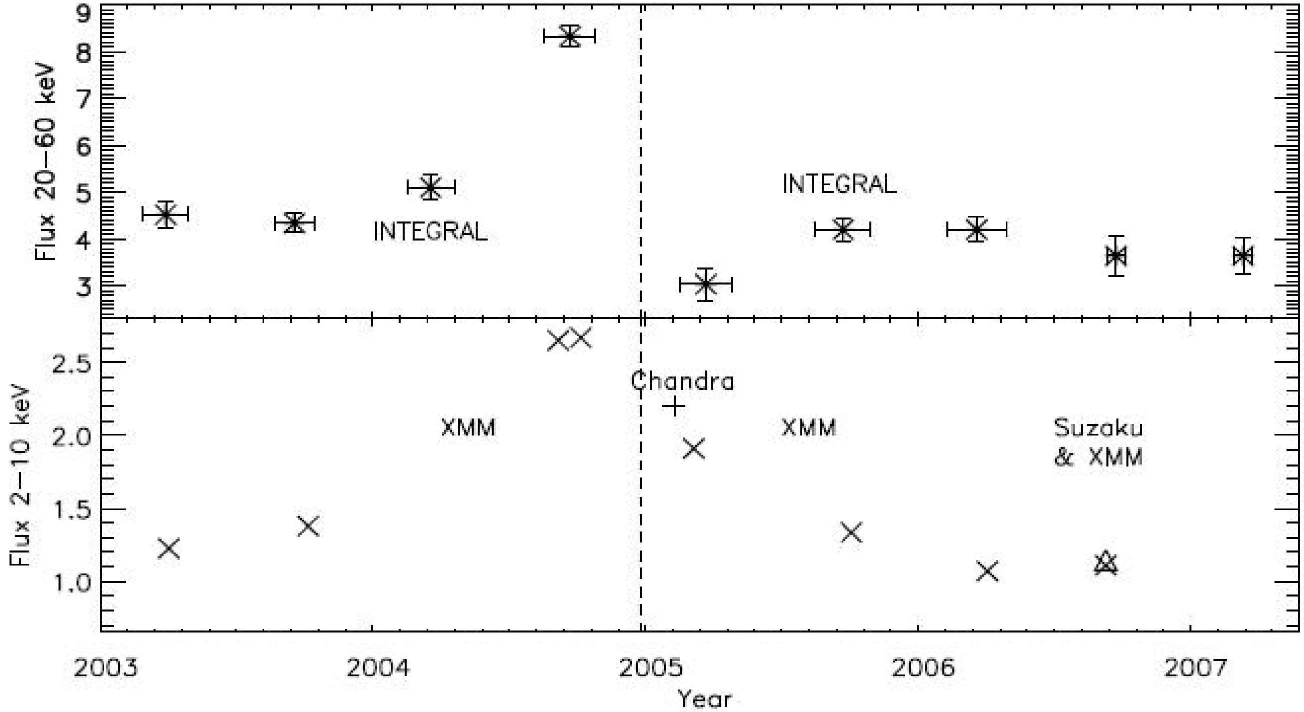
- First clear flux variability in AXP
- Anticorrelation between flux and pulsed fraction

SGR 1806-20

•Long term monitoring with XMM-Newton, INTEGRAL, Suzaku
(Mereghetti et al. 2005, ApJ 628, 938; Tiengo et al. 2005, A&A 440, L63; Esposito et al. 2007, A&A 476, 321; Esposito et al. 2008, in preparation)

Hard X-rays

Soft X-rays



➢Flux (and burst rate) increase in hard and soft X-rays before the Giant Flare
➢From XMM data: pulsed fraction reduction and spectral softening in first observation after the Giant Flare

SGR 1806-20

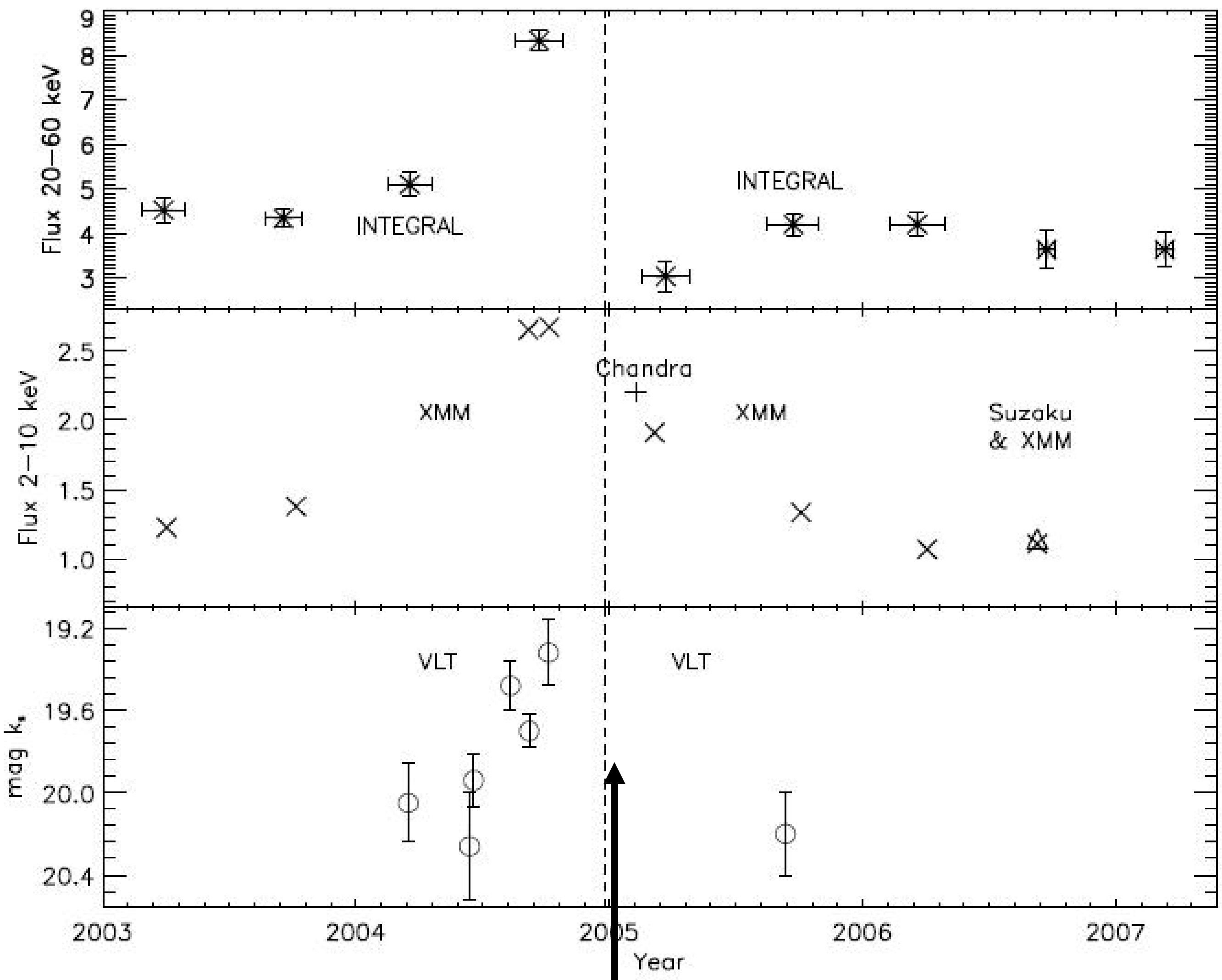
- Discovered in 1979 (Laros et al. 1986) and very active since then
- P = 7.5 s Pdot = $8x10^{-11}$ s/s → B = 8×10^{14} G
  (Kouveliotou et al 1998)
- High absorption: $N_H \sim 6x10^{22}$ cm^{-2} Av~30
- Giant Flare on 2004 December 27
  (Hurley et al. 2005, Palmer et al. 2005, Mereghetti et al. 2005a)
- Variable NIR counterpart K~19-20
  (Israel et al. 2004, 2005; Kosugi et al 2005)
- Distance is debated: >6 kpc ; 8-15 kpc ??
  (Cameron et al. 2005, McClure-Griffiths & Gaensler 2005,)
  we assume 15 kpc (Corbel & Eikenberry 2004)
- Persistent 20-150 keV emission discovered with INTEGRAL
  (Mereghetti et al. 2005b, Molkov et al. 2005)

SGR 1806-20

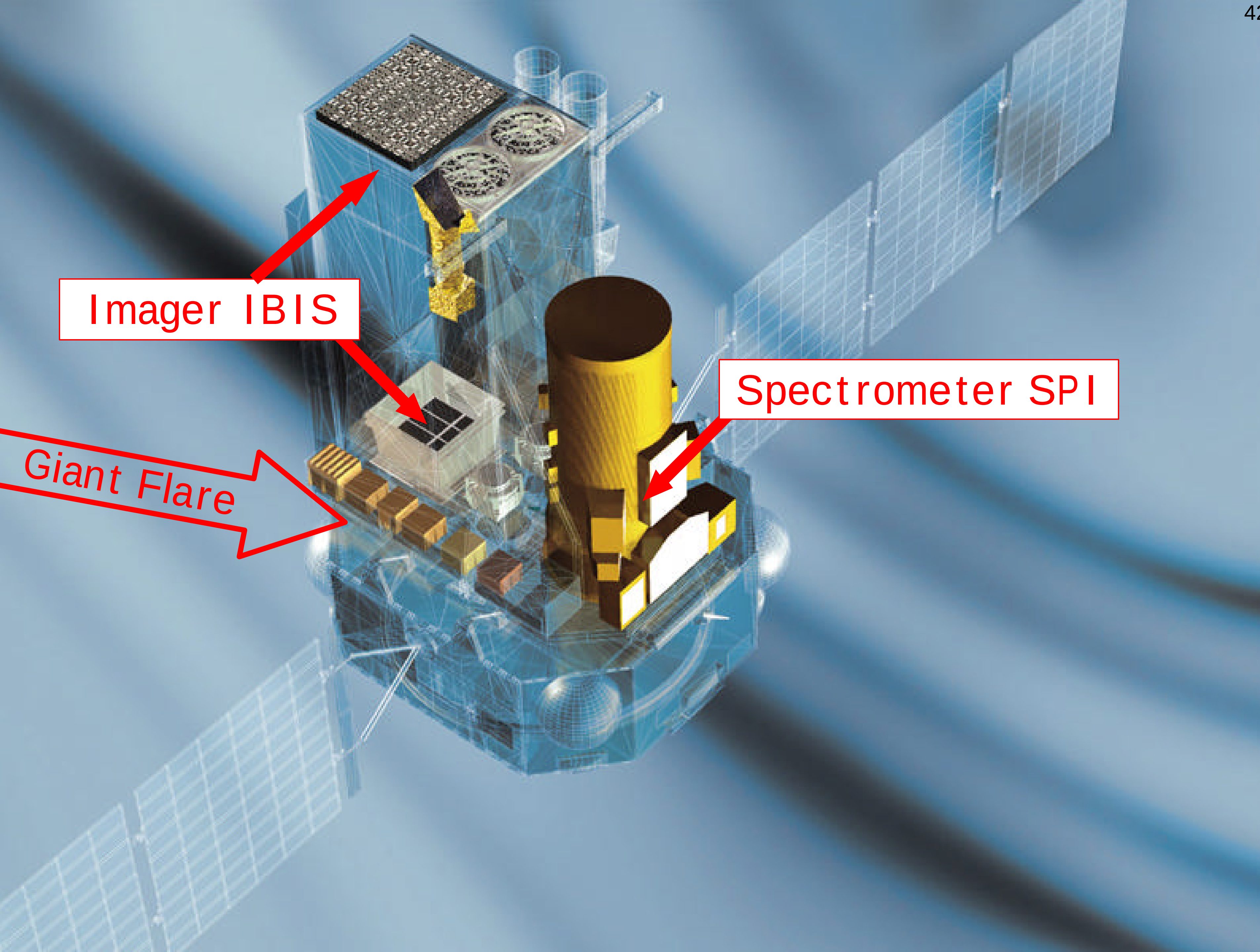
Hard X-rays

Soft X-rays

Near Infra Red

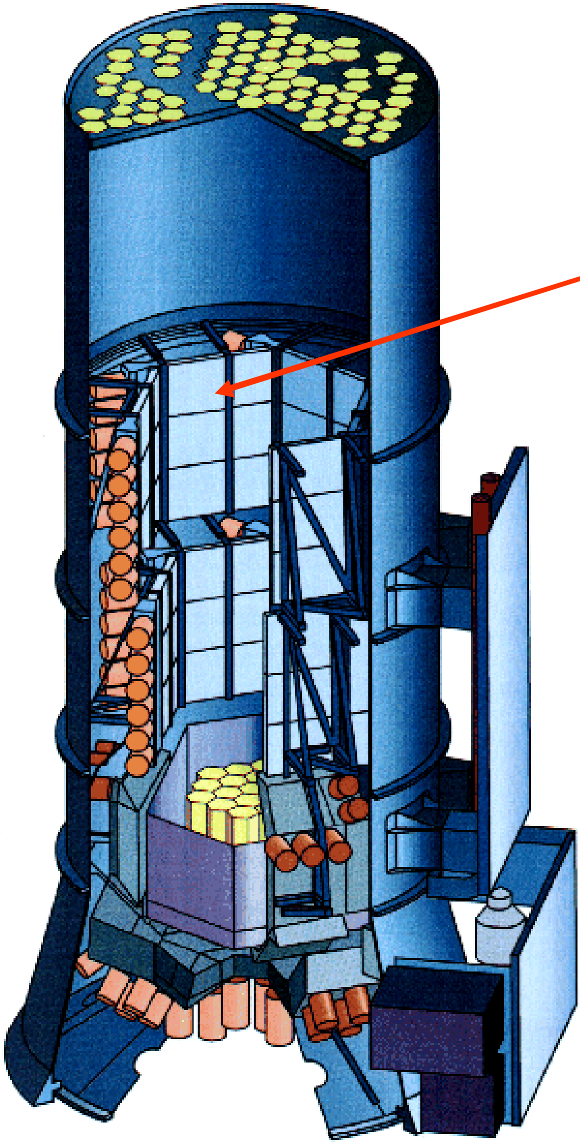


Dec. 2004 Giant Flare



Imager IBIS
Spectrometer SPI
Giant Flare

INTEGRAL SPI /ACS

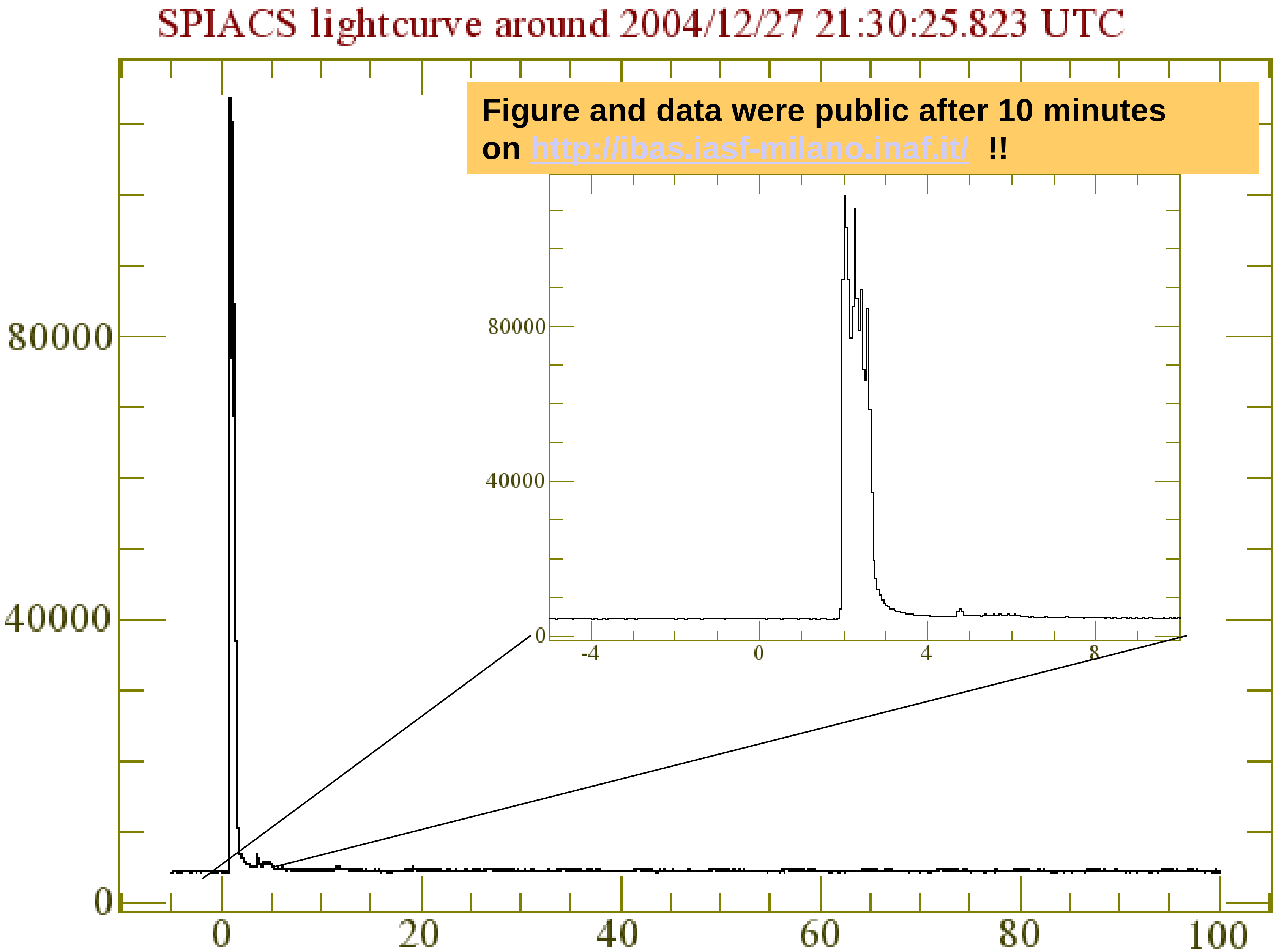


Anti Coincidence Shield (ACS)
(512 kg, 91 BGO blocks)

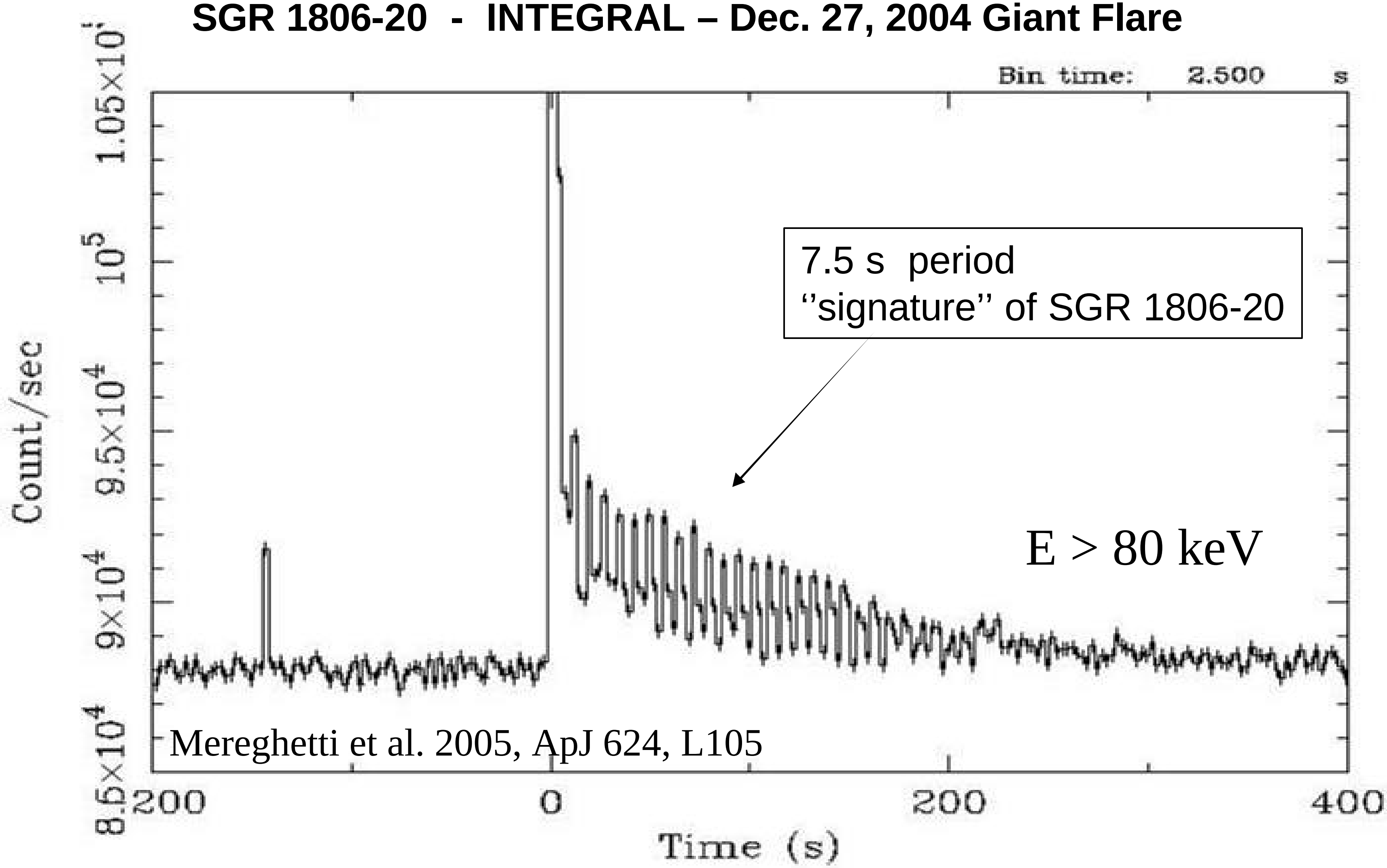
The ACS is also used as an omni-directional GRB detector (E > 80 keV)

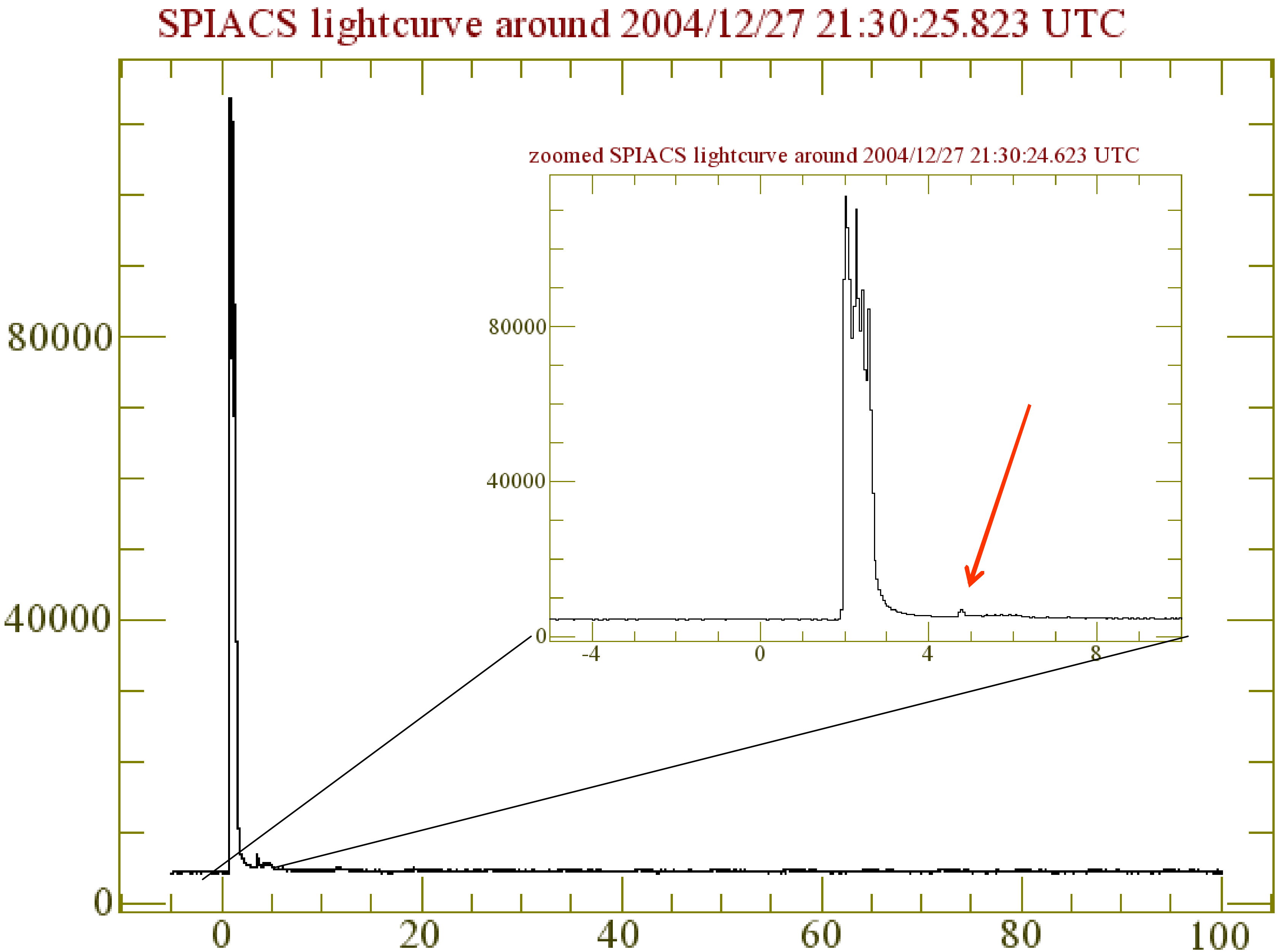
Provides:

- 50 ms light curve
- No direction information
- No energy information


SPIACS lightcurve around 2004/12/27 21:30:25.823 UTC
Figure and data were public after 10 minutes
on http://ibas.iasf-milano.inaf.it/ !!
80000
40000
0
0
20
40
60
80
100
-4
4
8

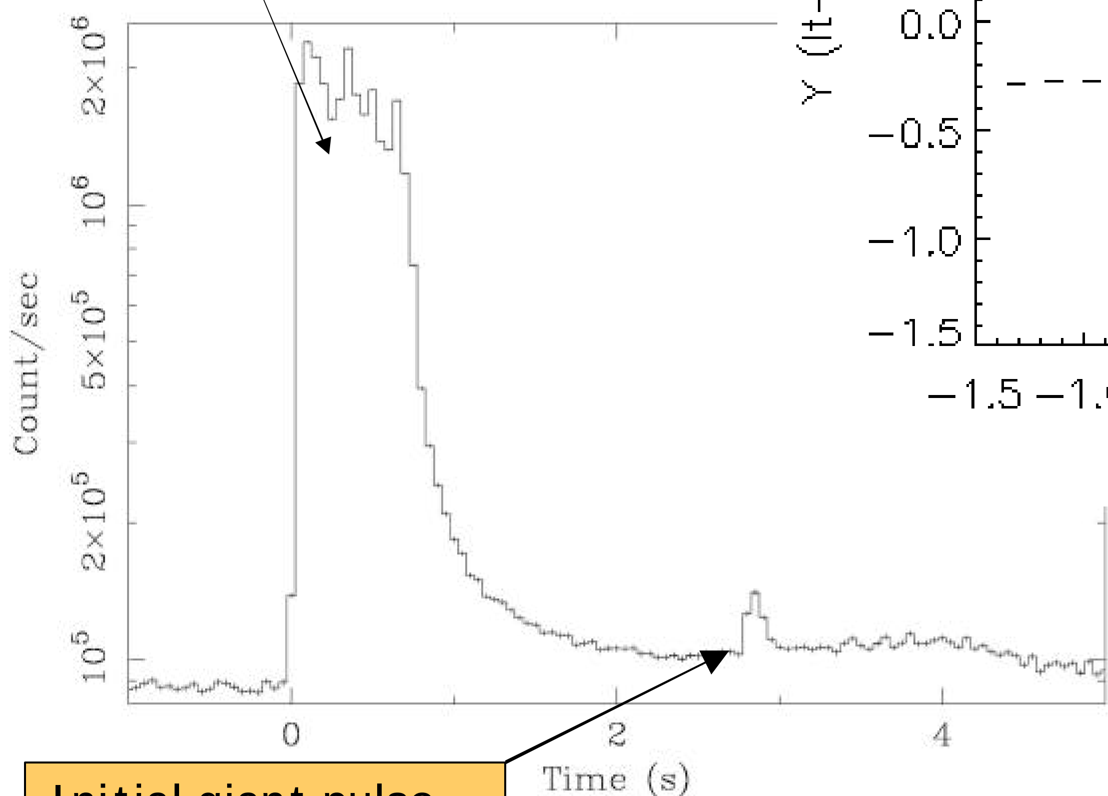
SGR 1806-20 - INTEGRAL – Dec. 27, 2004 Giant Flare



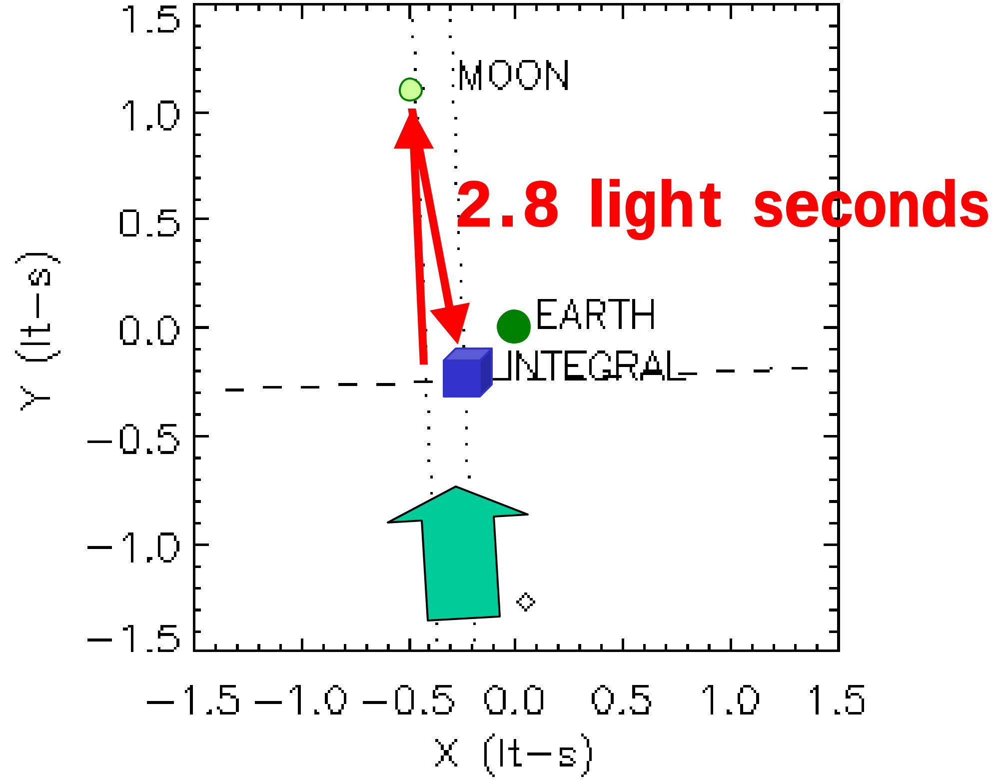

SPIACS lightcurve around 2004/12/27 21:30:25.823 UTC
zoomed SPIACS lightcurve around 2004/12/27 21:30:24.623 UTC
80000
40000
0
-4
0
4
8
80000
40000
0
0
20
40
60
80
100

Peak affected by instrument saturation

Mereghetti et al. 2005, ApJ 624, L105



Initial giant pulse backscattered by the Moon

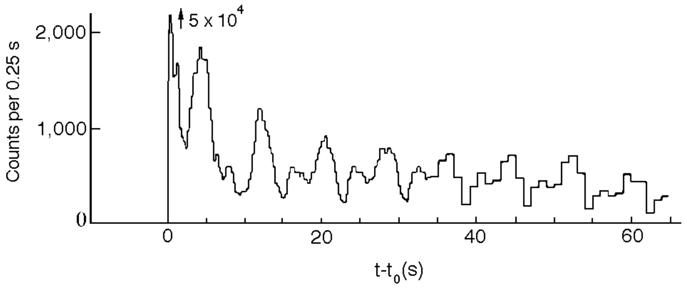


SGR 1806-20
Giant Flare
2004 Dec 2004

3 Giant Flares from SGRs

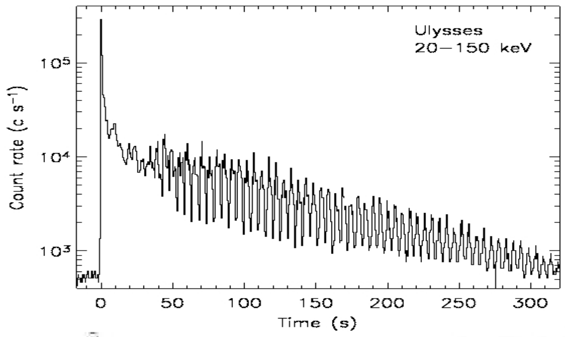
1979 March 5 - SGR 0626-66

Initial spike: 1.6 10^{44} erg   Pulsating tail: 4 10^{44} erg



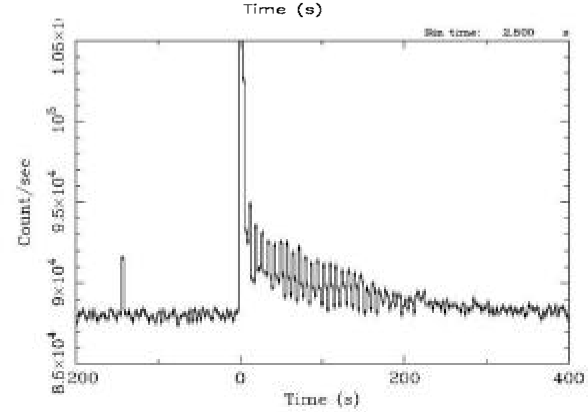
1998 August 27 - SGR 1900+14

Initial spike: > 7 10^{43} erg   Pulsating tail: 5 10^{43} erg

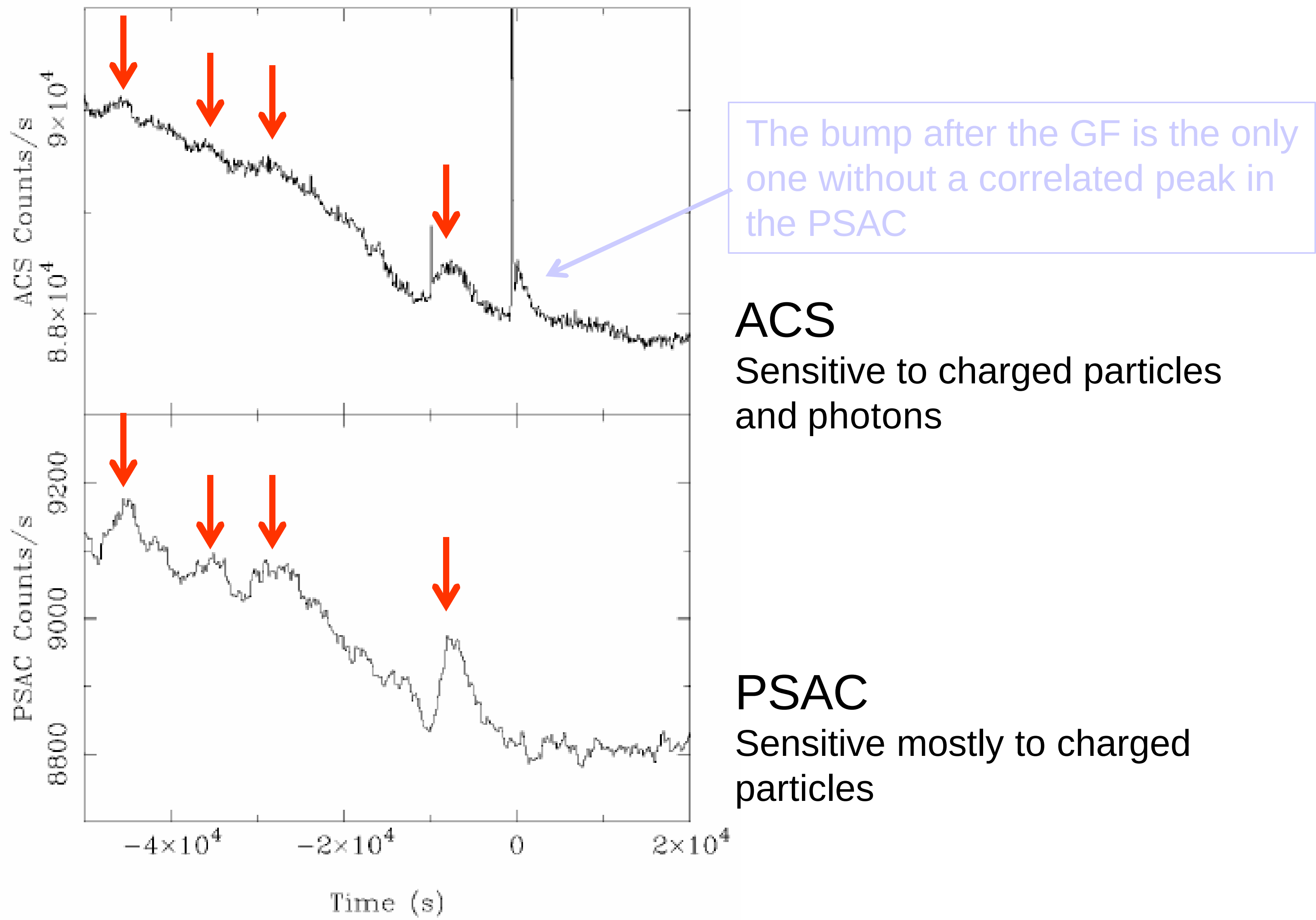


2004 December 27 – SGR 1806-20

Initial spike: 4 10^{46} erg   Pulsating tail: 10^{44} erg



(Hurley et al. 2005, Palmer et al. 2005, Mereghetti et al. 2005, Terasawa et al. 2005, Boggs et al. 2007, Frederiks et al. 2007)



ACS
Sensitive to charged particles and photons

PSAC
Sensitive mostly to charged particles

Hard X-ray emission lasting ~1 hr after GF

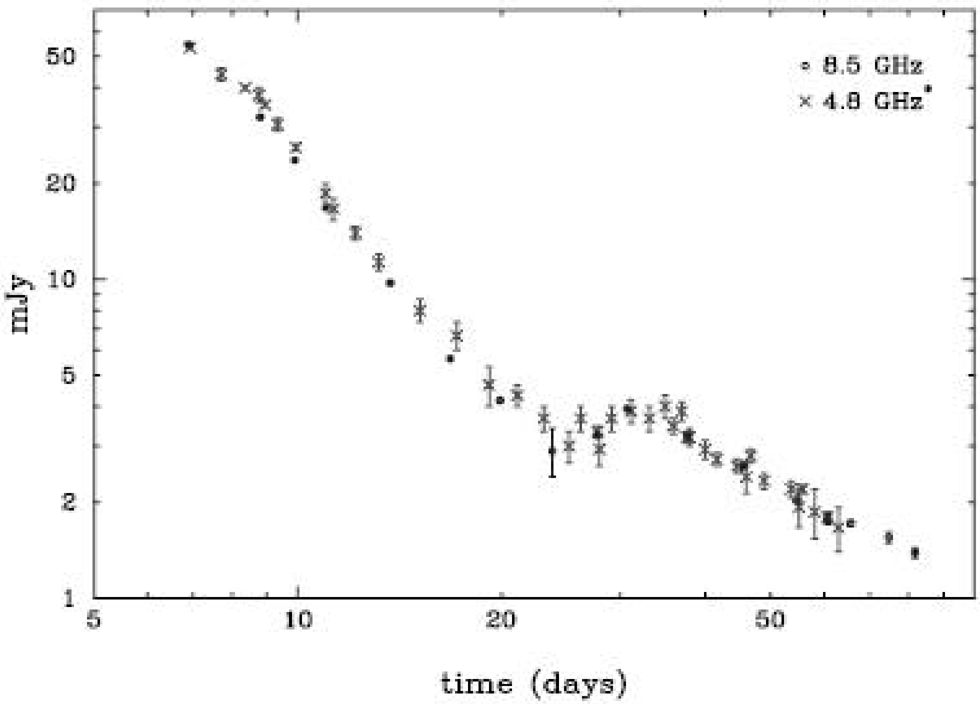
- E > 80 keV - No spectral information
- No pulsations
- Power law time decay $F(t) \sim t^{-0.85}$
- Same counts fluence as in pulsating tail
  ($3\ 10^{-4}$ ergs cm^{-2} assuming kT~30 keV)
- *Apparently* seen only by INTEGRAL

The first hard X-ray afterglow seen in a SGR ?

[Mereghetti et al. 2005, ApJ 624, L105]

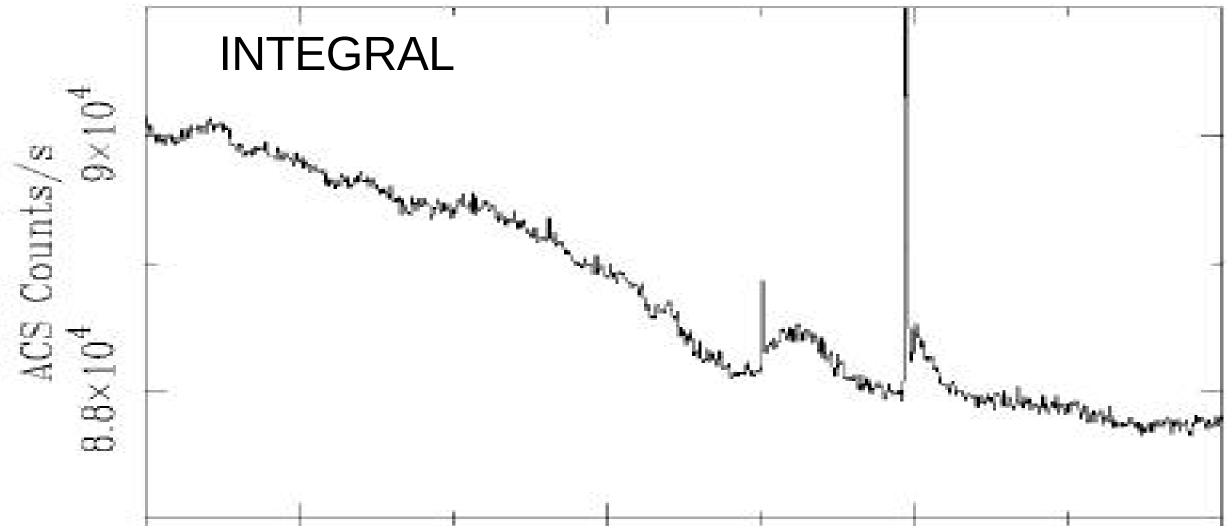
Mildly relativistic asymmetric outflow expanding in the ISM

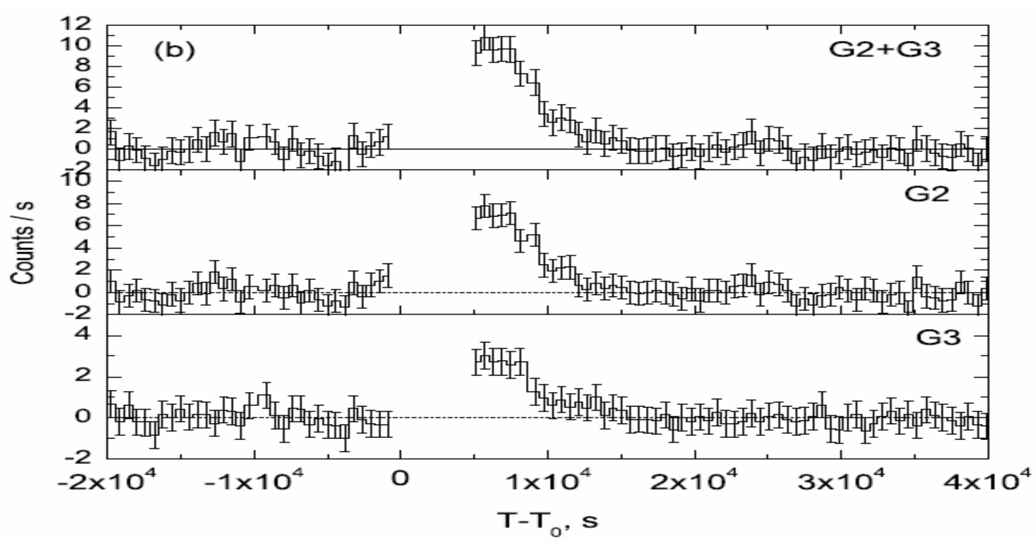
Flux evolution of radio nebula after the Giant Flare



v/c ~ 0.5 — 0.8

Gaensler et al. 2005
Taylor et al. 2005
Gelfand et al. 2005
Granot et al. 2006
Salmonson et al. 2006





G3/G2 ratio → Hard power law spectrum: $\Gamma \sim 1.6$

Summary

Long lasting hard X-ray / soft gamma-ray emission discovered by INTEGRAL has recently been confirmed by two other satellites

Evidence for hard spectrum - photon index ~ 1.7

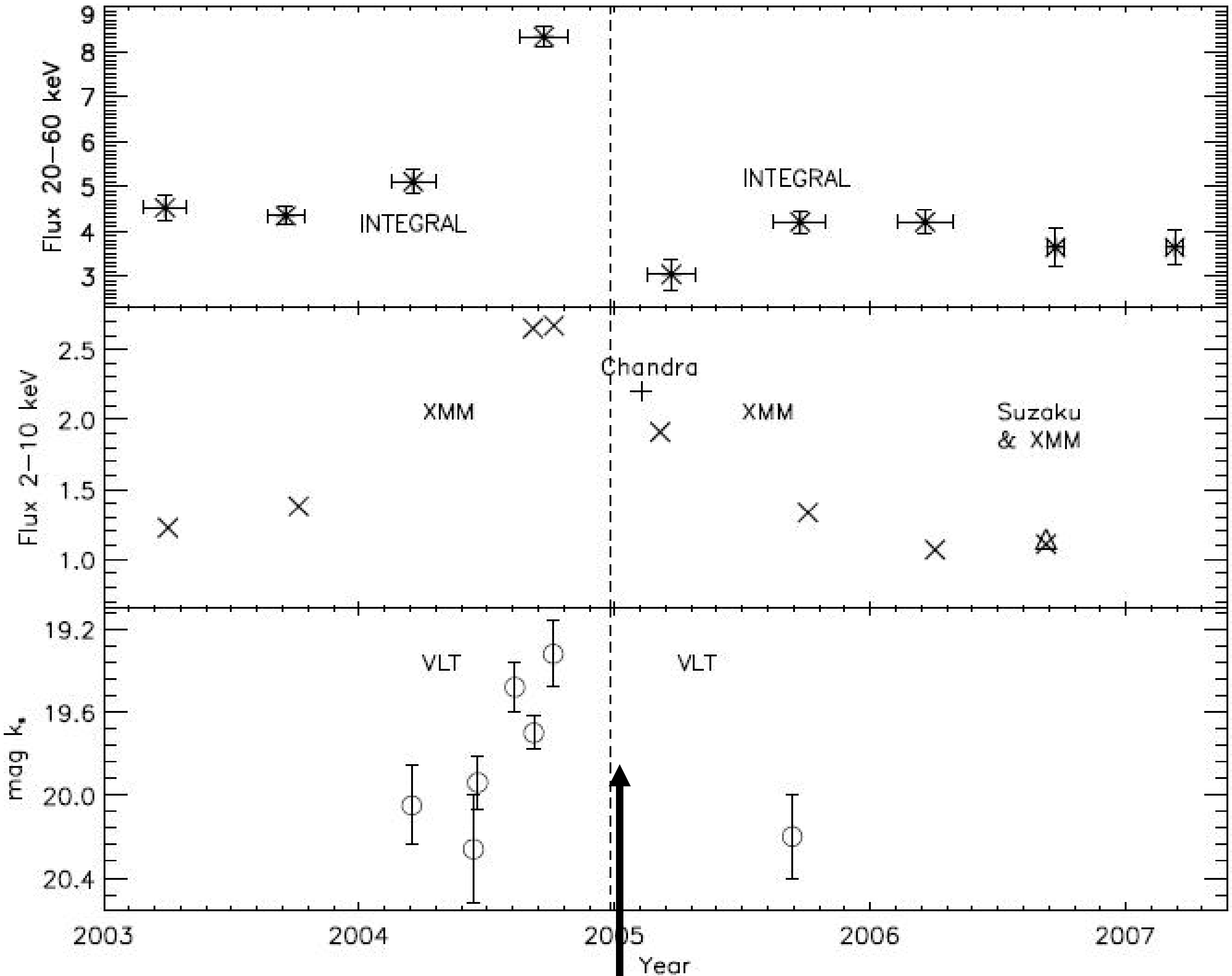
If it is indeed an afterglow emission due to relativistic outflow could help in breaking degeneracy of models for the expanding radio nebula

SGR 1806-20

Hard X-rays

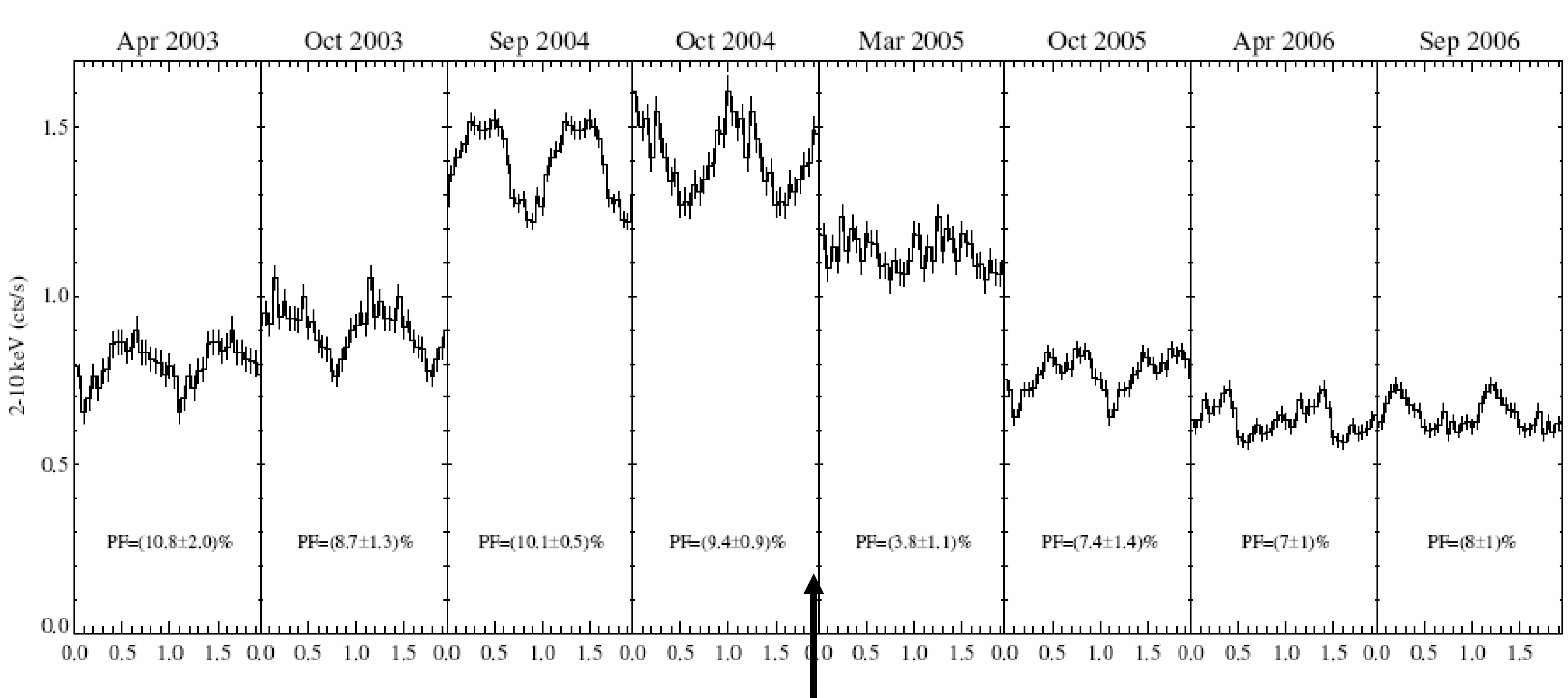
Soft X-rays

Near Infra Red



Dec. 2004 Giant Flare

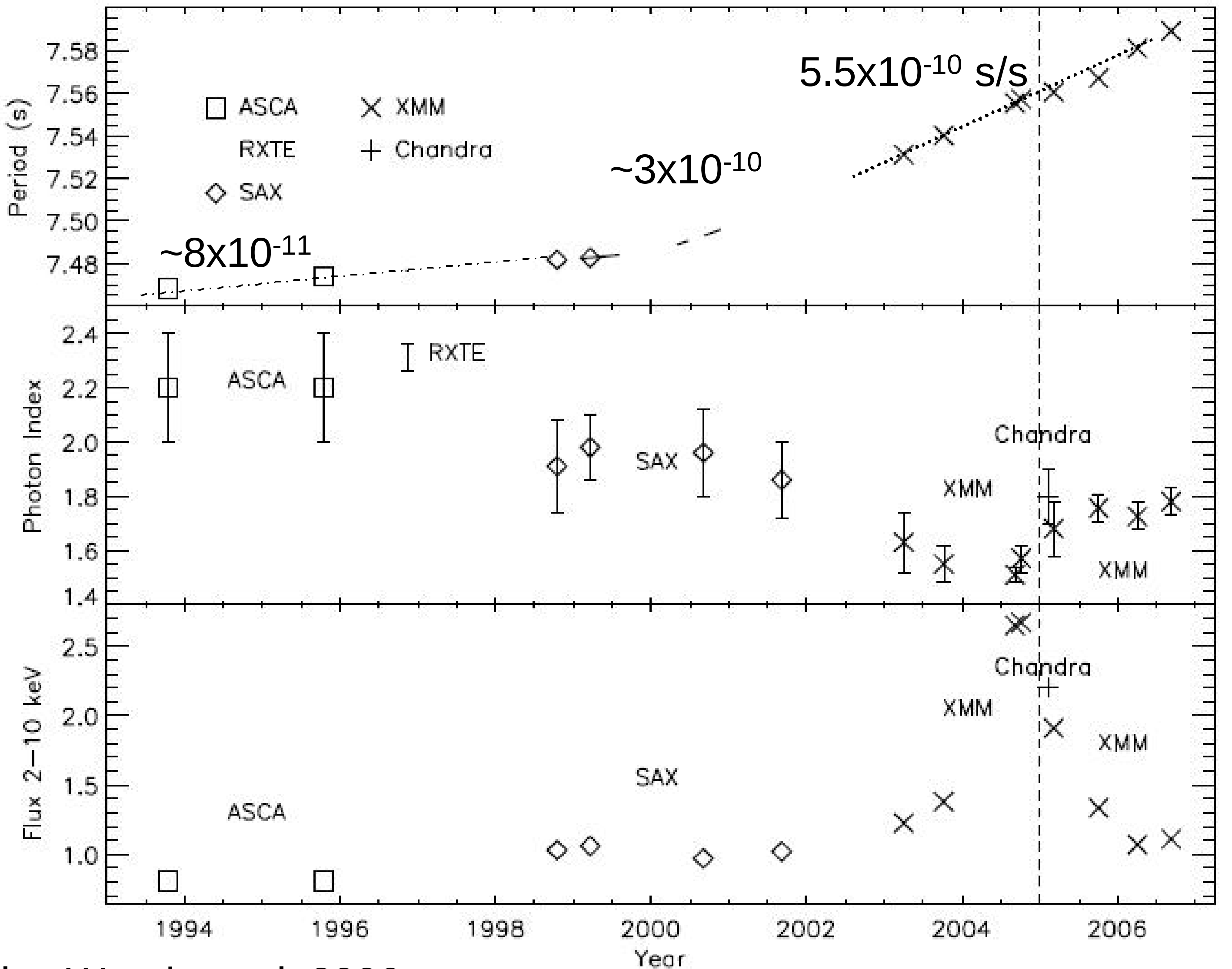
8 XMM-Newton observations of SGR 1806-20



27 Dec 2004 Giant Flare

Folded light curves
at P=7.5 s

(Mereghetti et al. 2005b, Tiengo et al 2005, Rea et al. 2005)



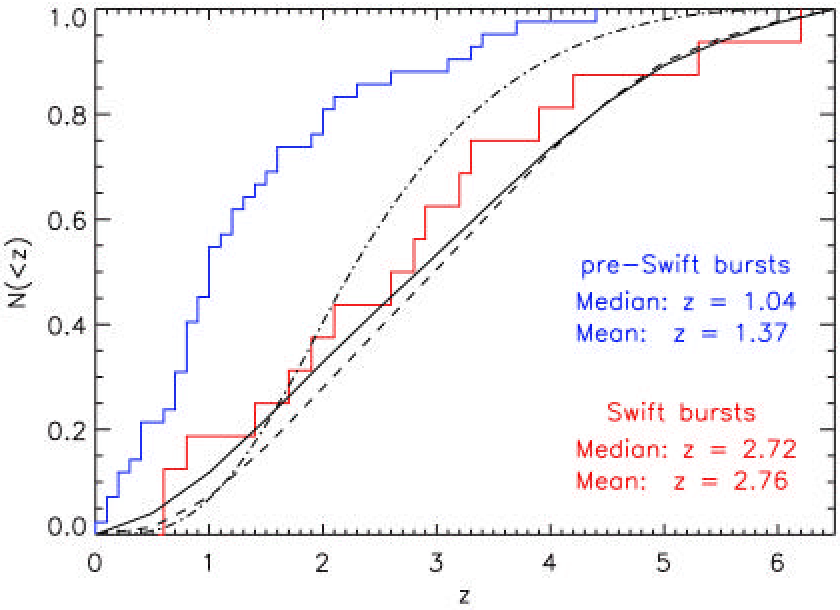
See also Woods et al. 2006

SVOM

SVOM scientific requirements

1) Obtain the redshift for the majority of the detected bursts

→ Provide quickly accurate GRB positions
→ Optimize pointing strategy for ground telescopes
→ Optimize detection of high redshift GRBs (trigger logic, soft E range)



Swift detected a larger number of high redshift GRBs than previous missions

But z is known for only <30% of Swift GRBs !!

SVOM scientific requirements

1) Obtain the redshift for the majority of the detected bursts

→ Provide quickly accurate GRB positions
→ Optimize pointing strategy for ground telescopes

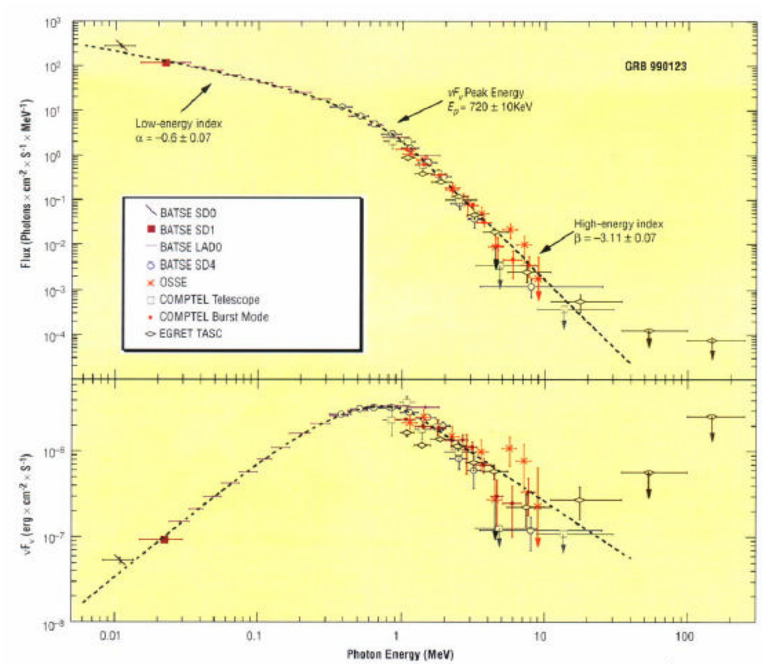
(cfr.: redshift is known for only <30% of Swift GRBs !!)

2) Derive the GRB spectral parameters, E peak

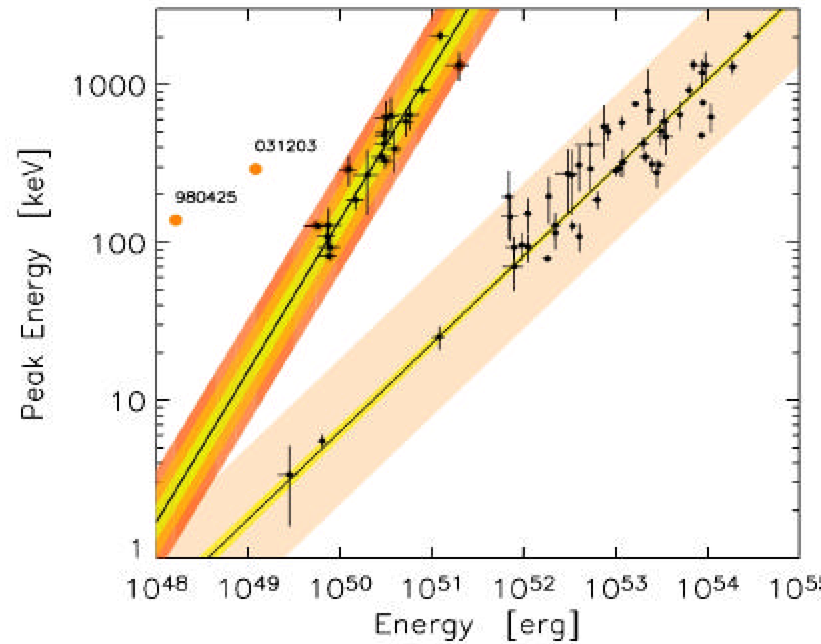
→ Broad energy range
→ high energy spectrometer

(cfr: Epeak is measured only for ~15% of Swift GRBs)

Flux

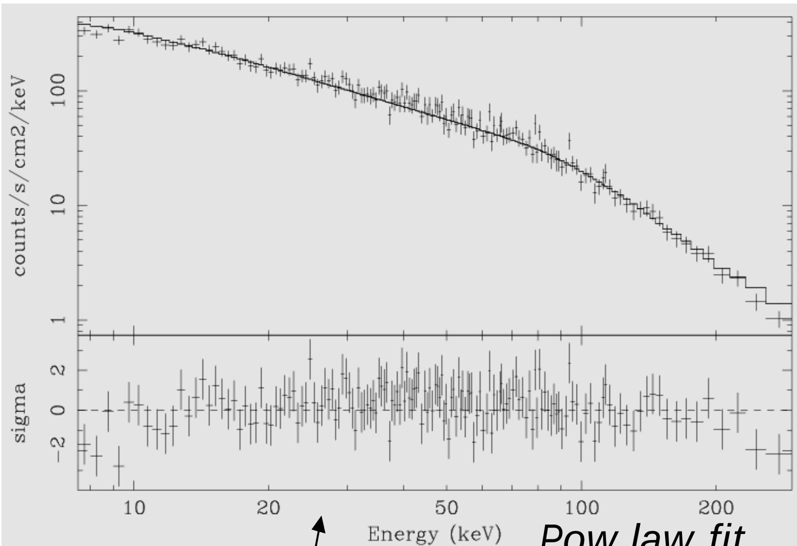


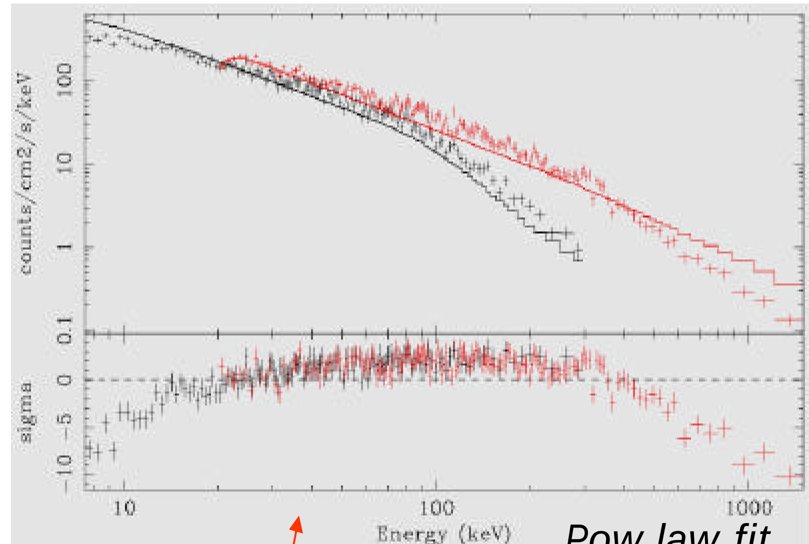
Energy



E_{peak} is fundamental quantity in all empirical correlations to use GRBs as "standard candles"

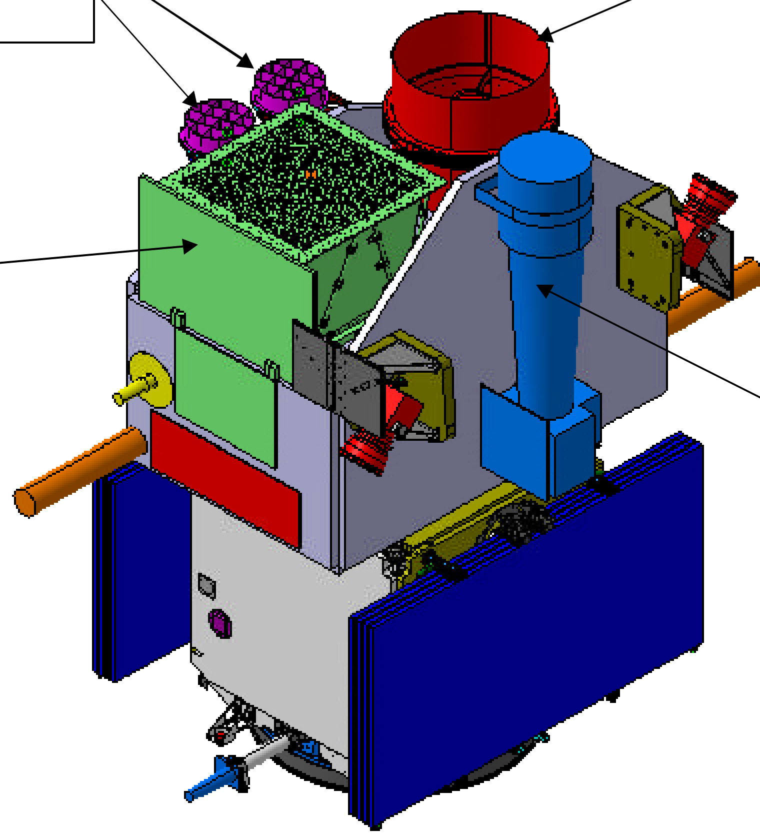
GRB with 15-150 keV fluence 10^{-6} erg cm^{-2} and Ep=300 keV.



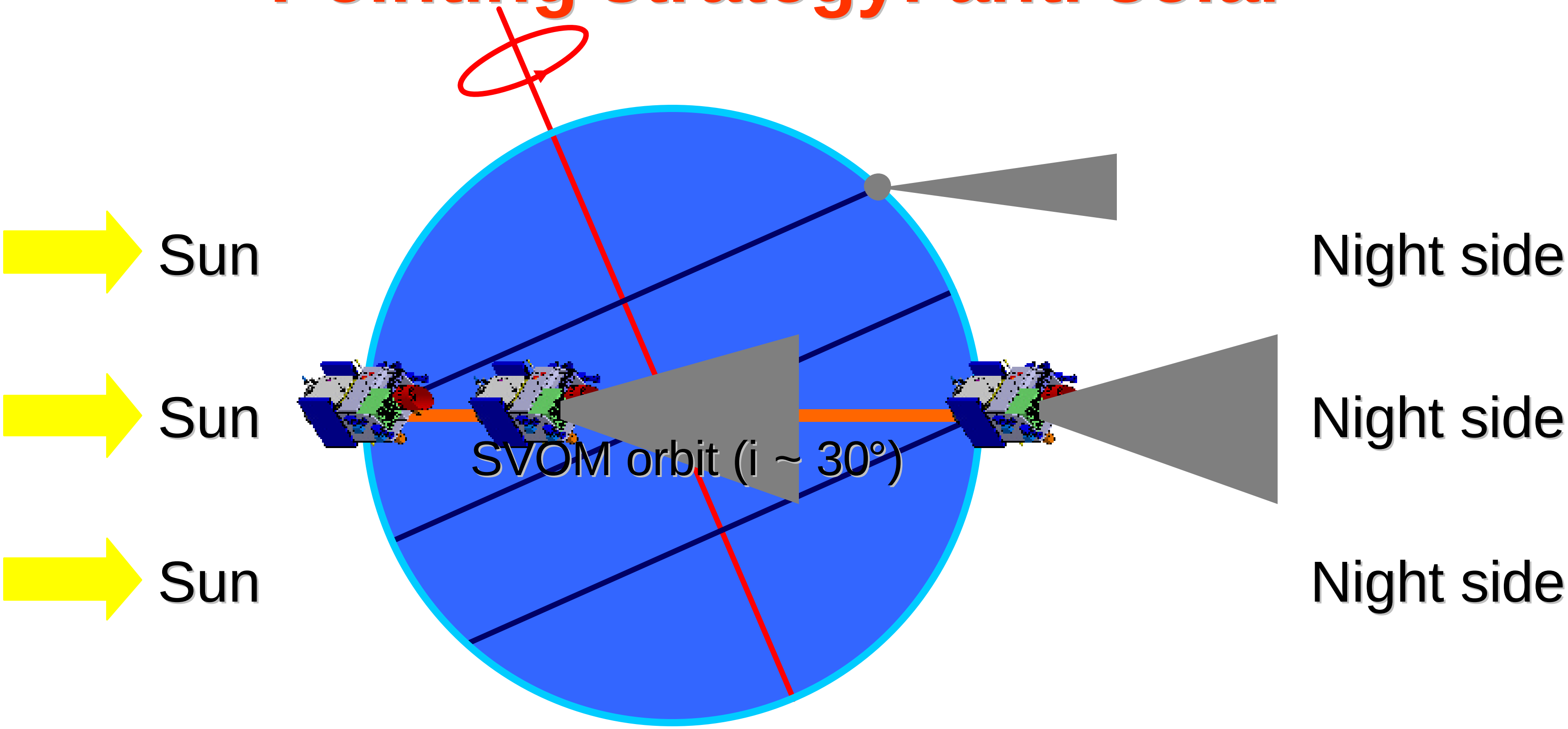


Spectral studies with Swift/BAT (and INTEGRAL) suffer from the limited energy range and poor sensitivity at high E

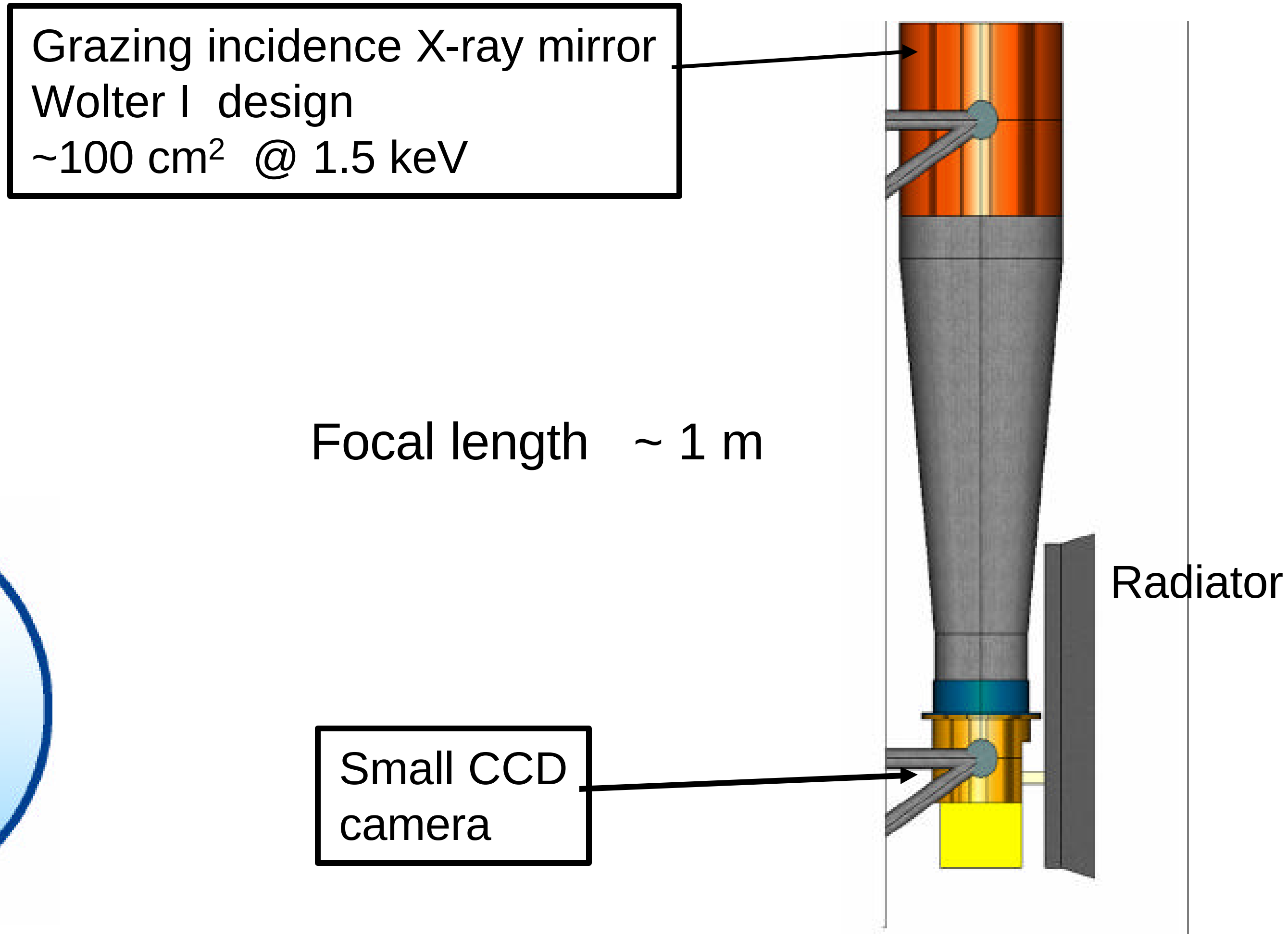
Addition of a high E detector (e.g. Scintillator) is required to measure spectral curvature


GRM
Gamma Ray burst Monitor
50 keV-5 MeV
2π sr FoV
2 Phoswich detectors
VT
Visual Telescope
45 cm aperture
400-900 nm
CXG
Camera X Gamma
4 – 300 keV
2 sr FoV
Coded mask +
CdTe array
XIAO
X-ray Imager
for Afterglows
Observations
0.3-2 keV
FoV 23’x23’

Pointing strategy: anti solar



The center of the ECLAIRs field of view will be well above the horizon of large ground based telescopes all located at tropical latitudes


Grazing incidence X-ray mirror
Wolter I design
~100 cm^2 @ 1.5 keV
Focal length ~ 1 m
Radiator
Small CCD
camera

Summary of XIAO performances

• Energy range	0.3-2 keV
• Field of view	23 x 23 $arcmin^2$
• Ang. Resolution	30 arcsec HEW
• Effective area	~80 cm^2 @ 1.5 keV
• Localiz. Accuracy	~10 arcsec for ~5σ source < 5 arcsec for >10σ source
• Sensitivity (5σ)	~10 mCrab in 10 s 5-10 μCrab in 10 ks
• Throughput	1 mCrab = 0.4 ct/s for N_H=3x10^{21} = 1 ct/s for N_H=3x10^{20}
• Energy resolution	~150 eV FWHM @ 1.5 keV
• Time resolution	~10 ms in standard mode ~0.1 ms in timing mode

XIAO

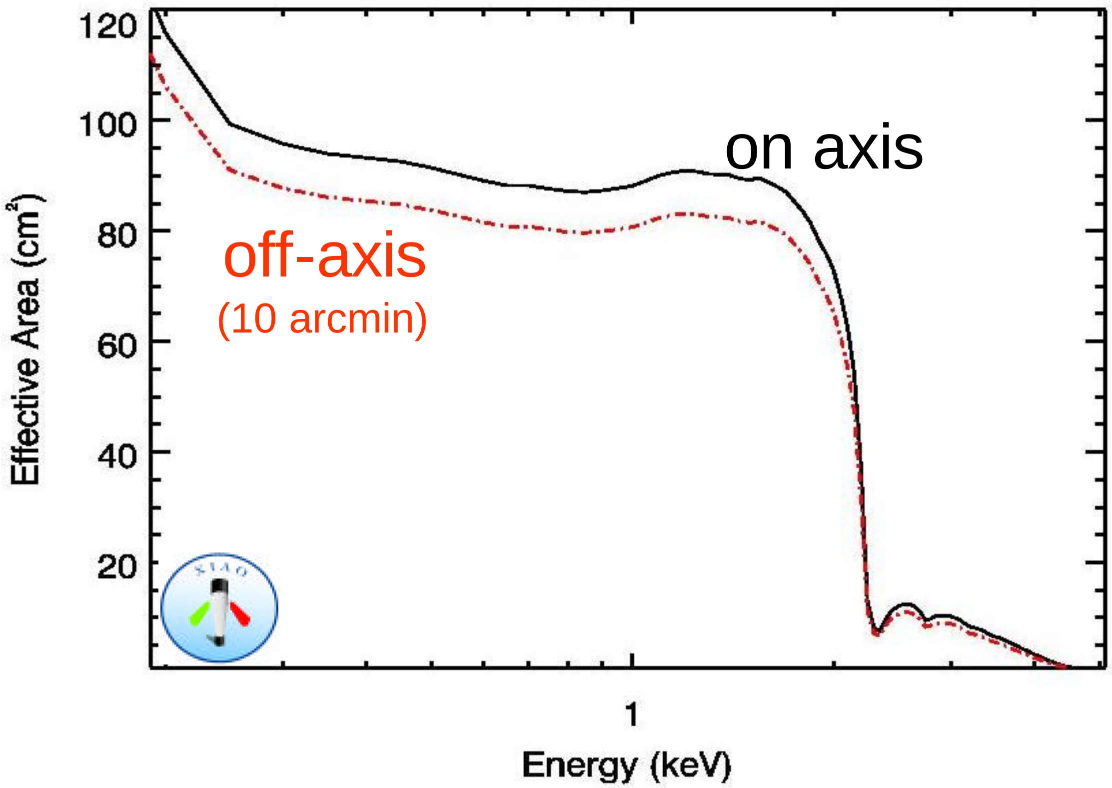
X-ray
Imager for
Afterglows
Observations

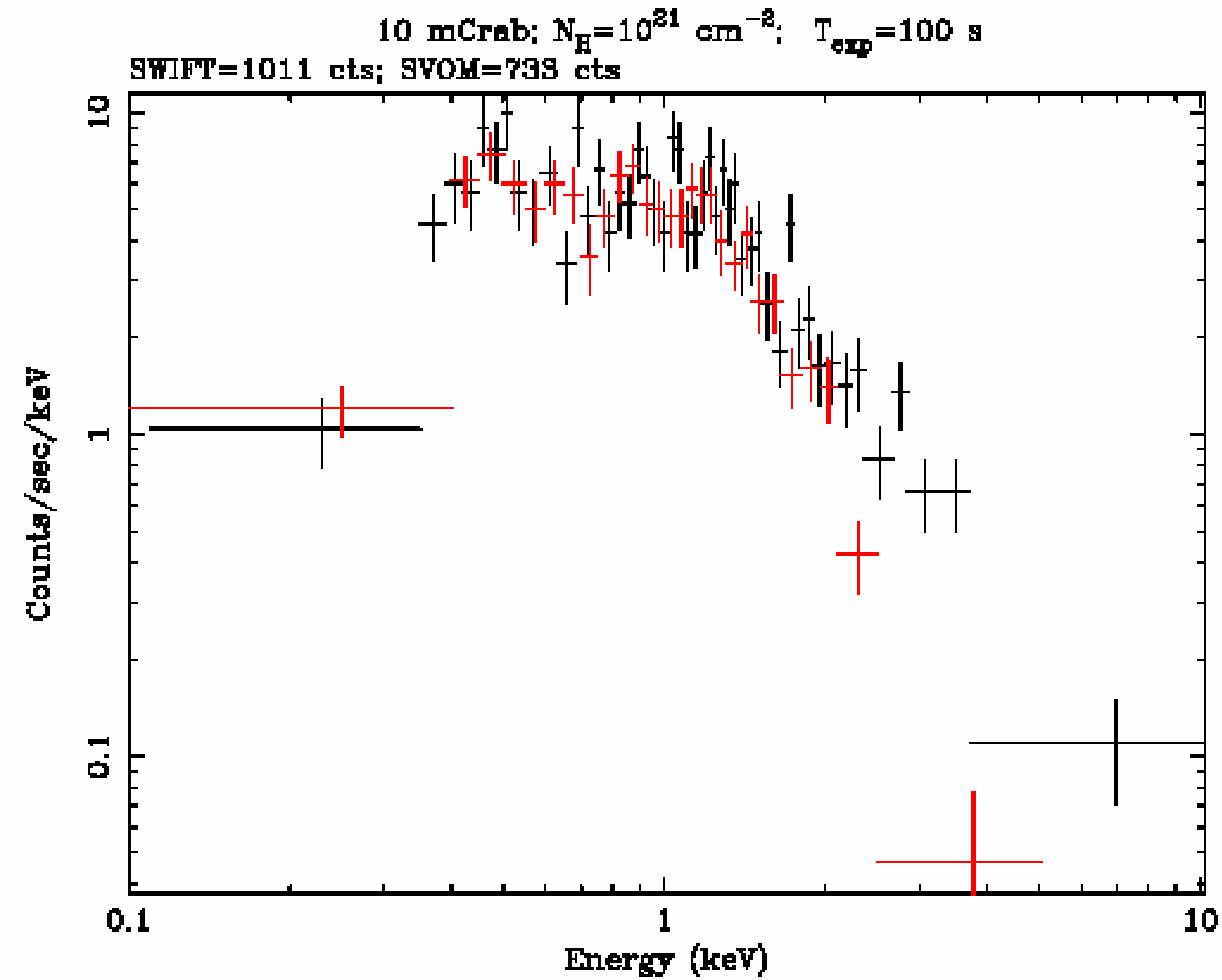
PRELIMINARY OPTICS DESIGN

H = 30 cm Ø = 14 – 22 cm Au coating Ang. Resol 30'' HEW

11 shells 0.3 mm thickness ~5 kg (mirrors only)

Focal length
100 cm




10 mCrab; $N_H=10^{21}$ cm^{-2}; T_{exp}=100 s
SWIFT=1011 cts; SVOM=733 cts
Counts/sec/keV
Energy (keV)
10
1
0.1
0.1
1
10

XIAO expected count rates

(0.2- 5 keV)

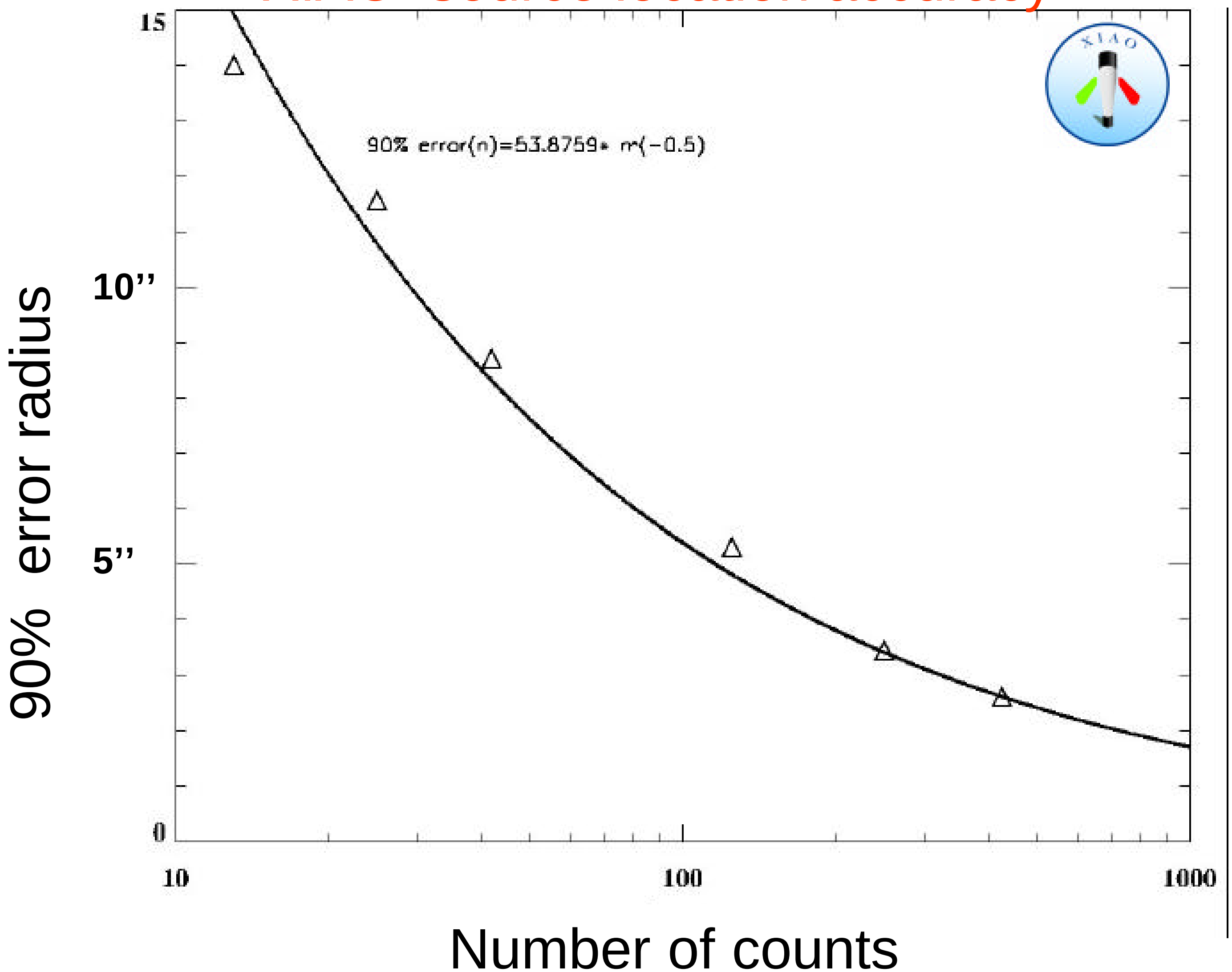
- 1 mCrab (~2x10^{-11} erg /cm^2/s 2-10 keV)

$N_H = 0$ → ~ 4 ct/s

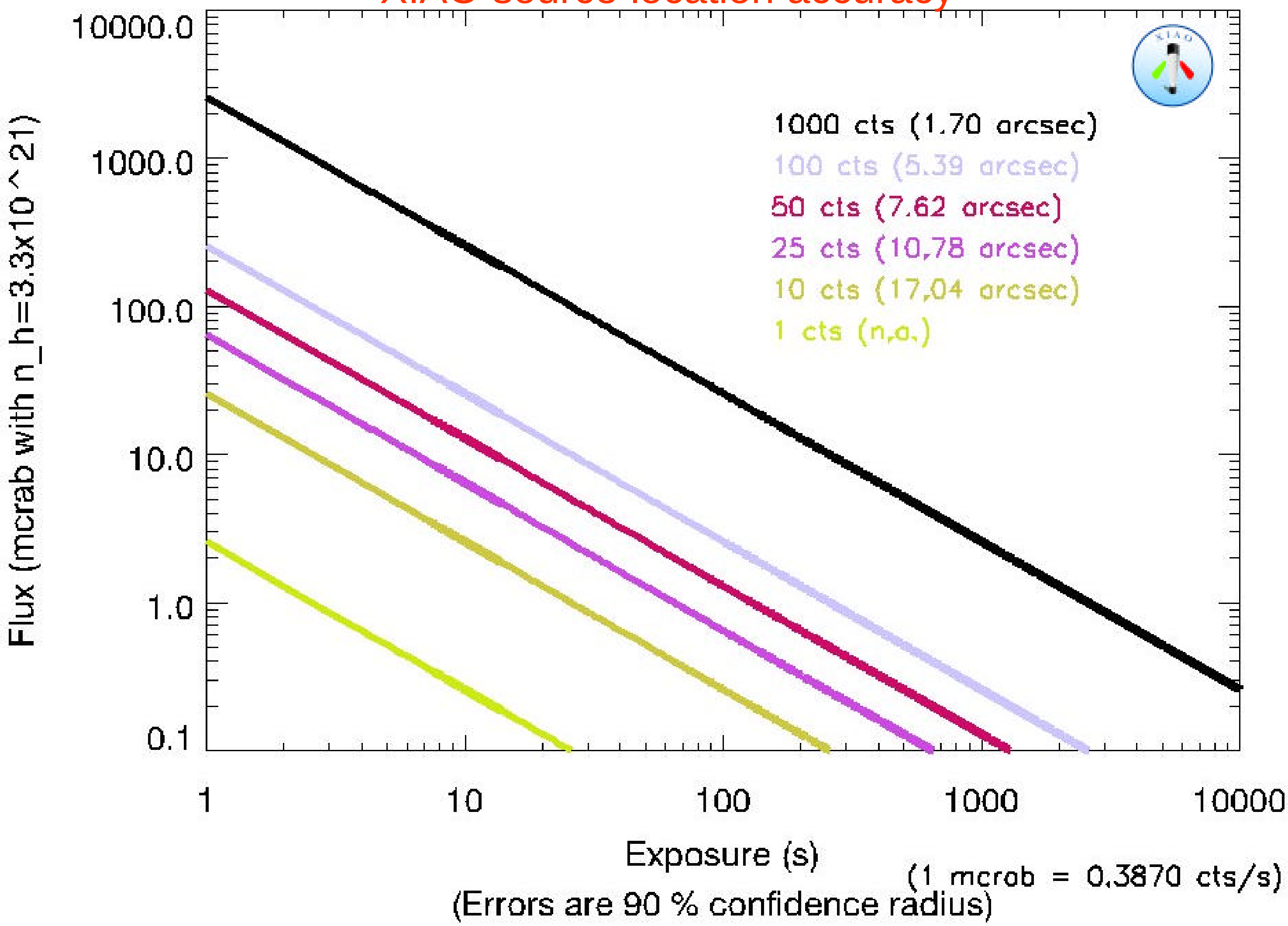
$N_H = 3\ 10^{20}$ cm^{-2} → ~ 1 ct/s

$N_H = 3\ 10^{21}$ cm^{-2} → ~ 0.4 ct/s

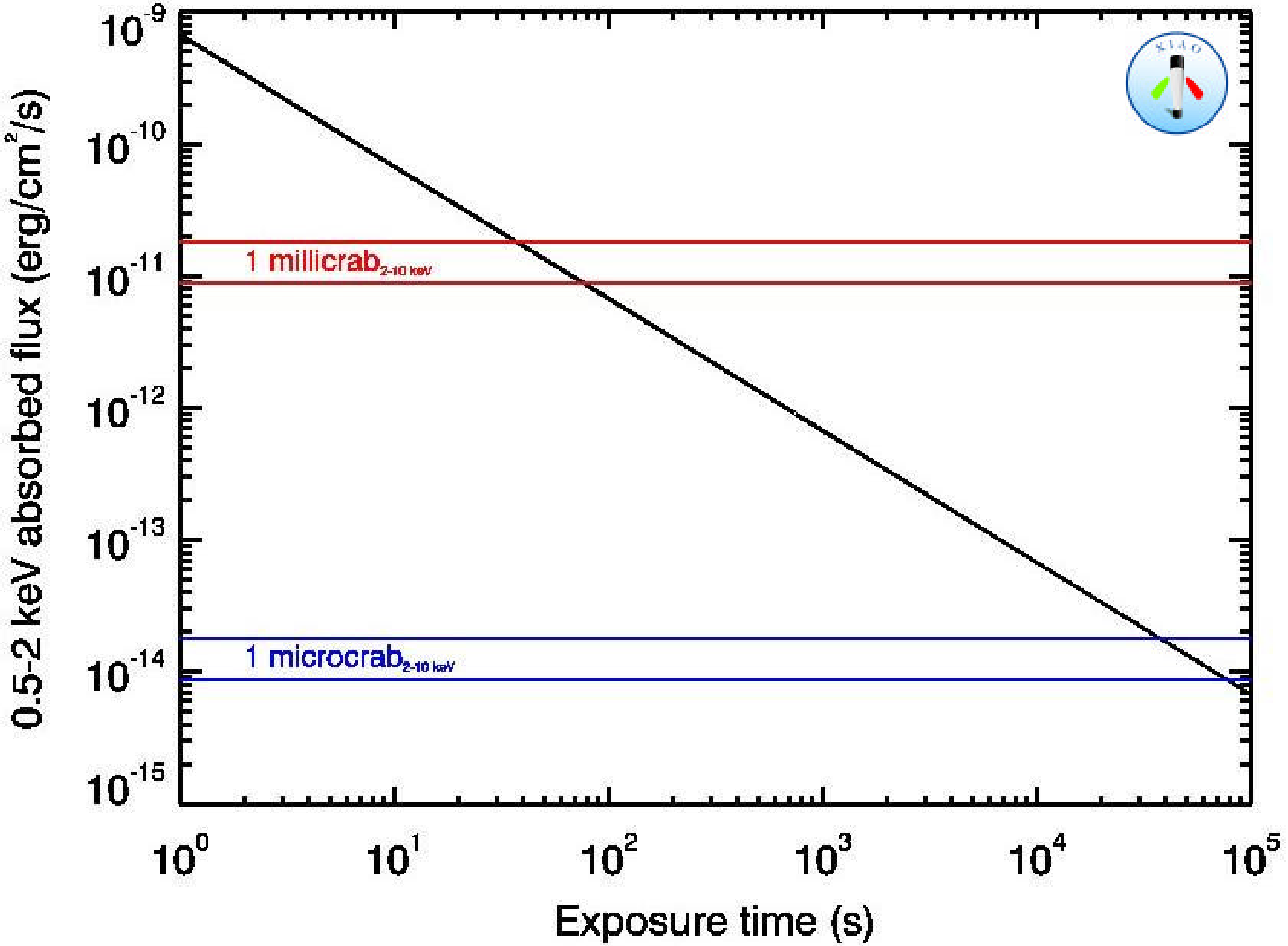
XIAO source location accuracy

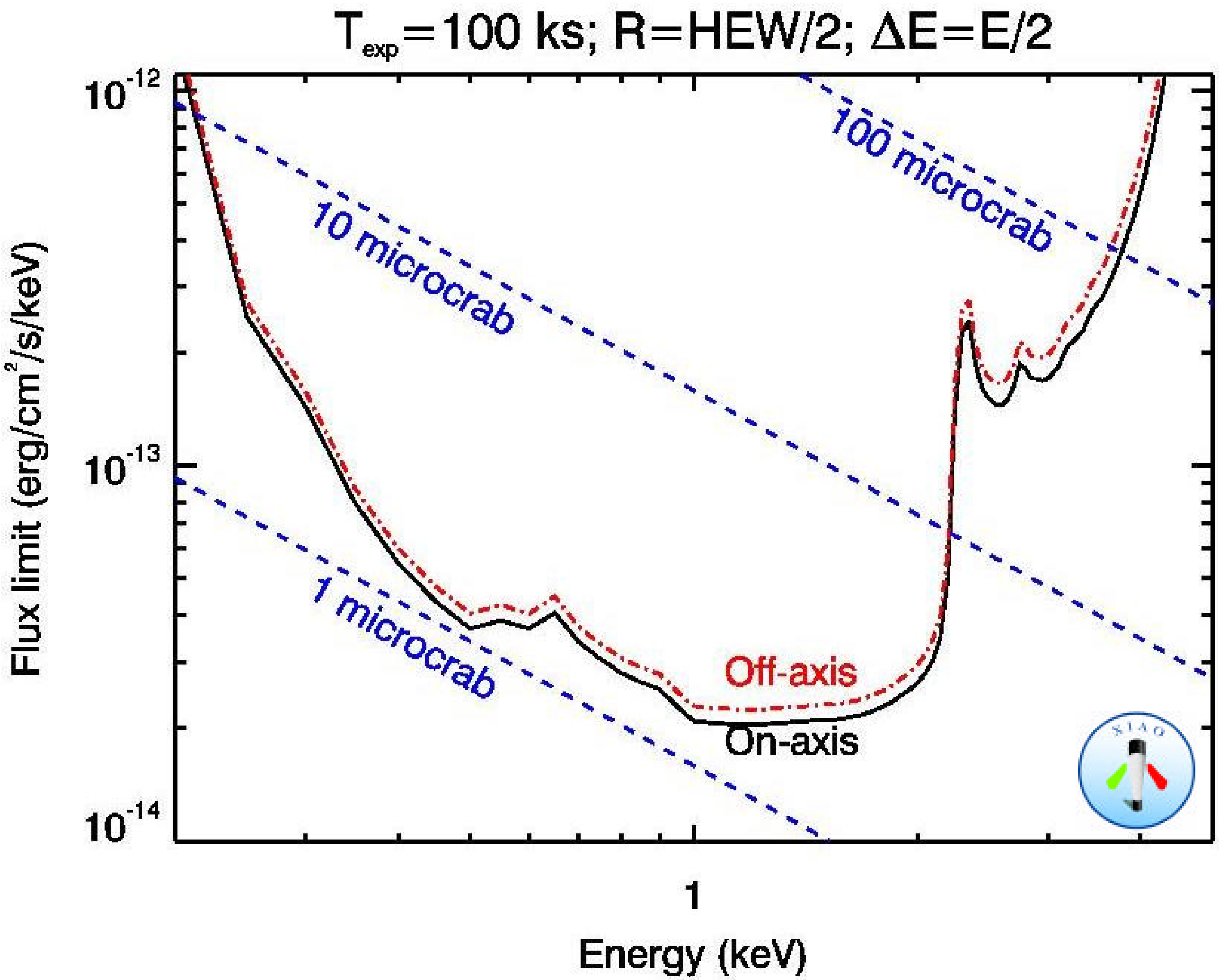


XIAO source location accuracy



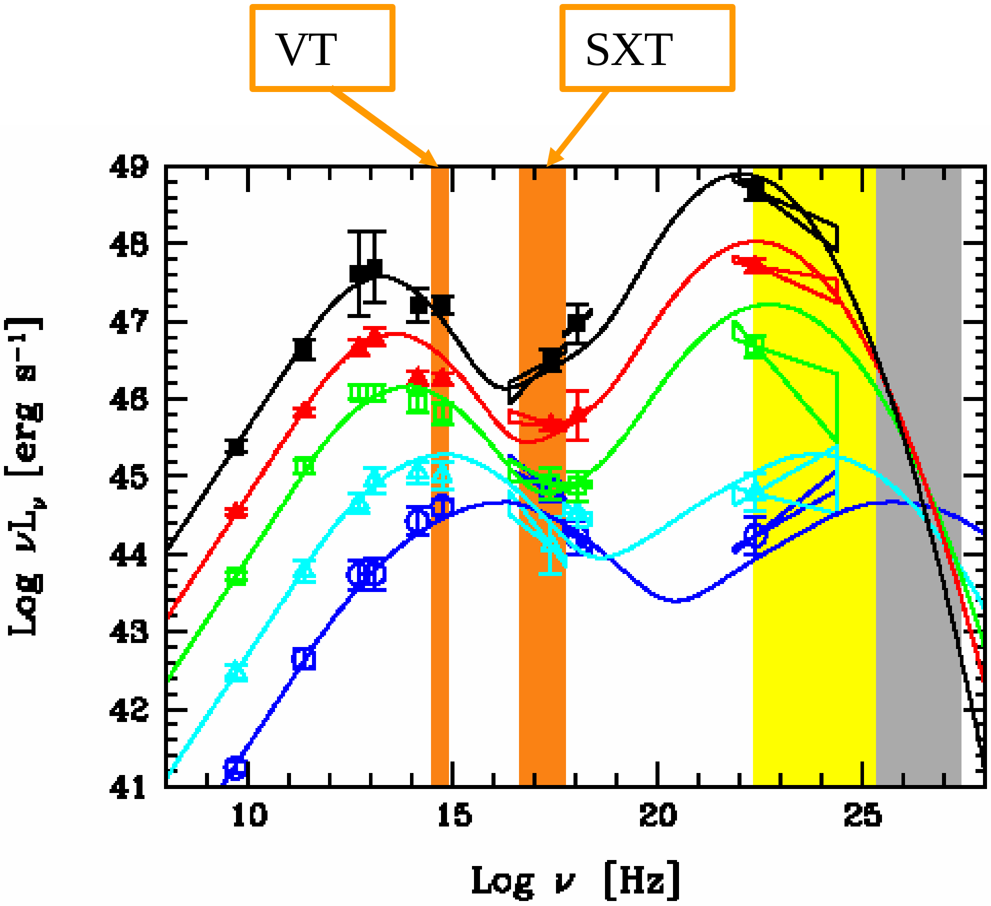
XIAO sensitivity (5 σ)





T_exp=100 ks; R=HEW/2; ΔE=E/2
Flux limit (erg/cm²/s/keV)
10^-12
10^-13
10^-14
1
Energy (keV)
100 microcrab
10 microcrab
1 microcrab
Off-axis
On-axis

Example of NON-GRB Science: 1 - Blazars



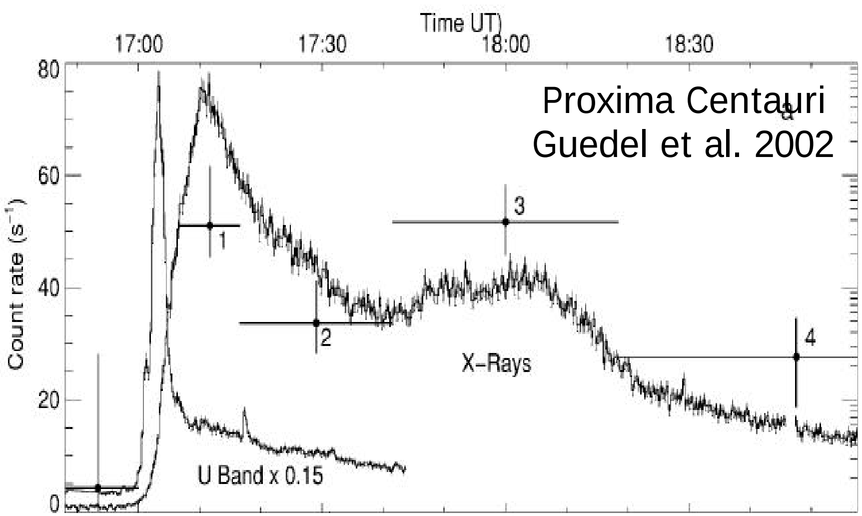
Simultaneous X-ray and optical observations to understand origin of second peak in spectral energy distribution

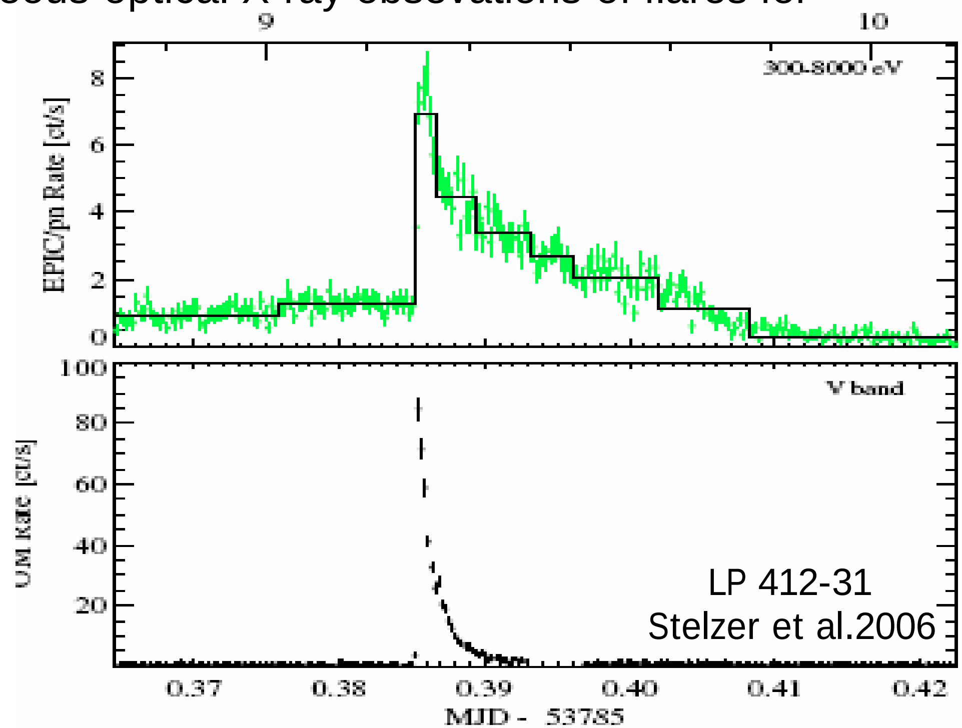
Example of NON-GRB Science: 2 - Active stellar coronae

Flares are the most spectacular manifestation of stellar magnetic activity

Simultaneous multi-λ observations of flares crucial to test flare models
– very relevant to understand coronal heating mechanisms

Very few simultaneous data secured so far because of logistic/observational difficulties (only ~3 cases so far!!)
SVOM multi-λ capabilities will allow simultaneous optical-X-ray obsevations of flares for different classes of active stars





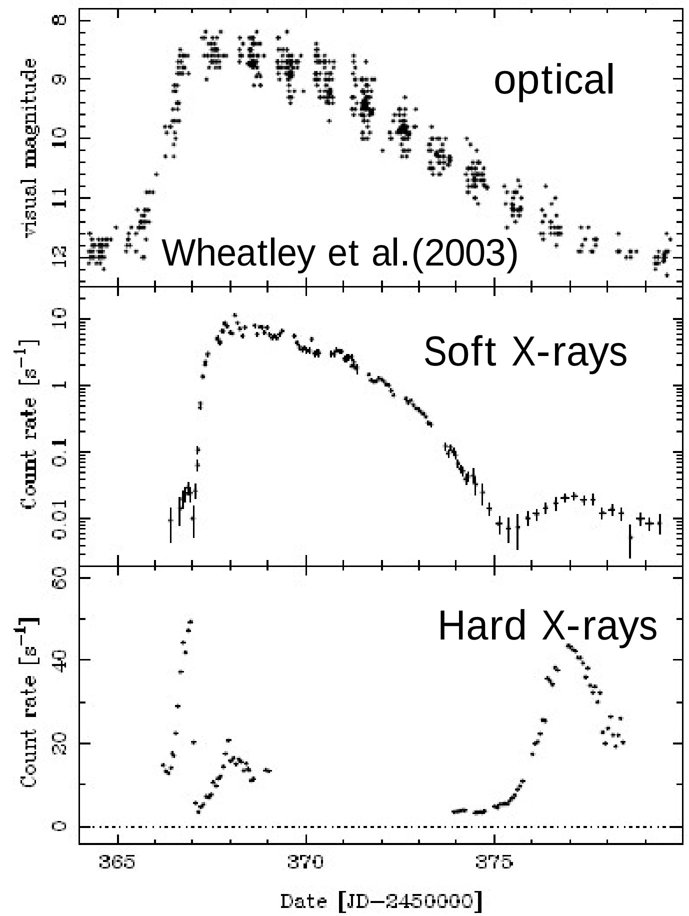
Example of NON-GRB Science: 3 - Cataclysmic Variables

Dwarf Novae show recurrent (from weeks to months), large outbursts

MWL simultanoeus observations, unveiling time behaviors in different ranges (including QPOs), crucial to test “disk instability” model for outbursts.

So far only fragmented (nearly) simultaneous data available due to difficulties in scheduling

175 dwarf Novae known at |b|>30º



SS Cyg: X-rays delayed wrt. Optical; Soft/Hard X-ray anticorrelation

- **Italian participation to SVOM / Eclairs**

Study performed with support from ASI/INAF contract *Astrofisica delle Alte Energie" (WP opportunita' di missioni)

- **XIAO proposal consortium**

INAF:

- IASF Milano
- Osservatorio Astronomico Brera
- IASF Bologna
- Osservatorio Astronomico Roma

Industries:

- Thales Alenia Space Italia (ex Laben)
- Media Lario
- BCV Progetti

- **Participation of other INAF structures is welcome**

- **Other contributions to SVOM:**
  - ASI ground station at Malindi (X- and S- band antennas)
  - ASI Science Data Center
  - Involvement in Dedicated Ground Based Telescopes