INTEGRAL and GRBs

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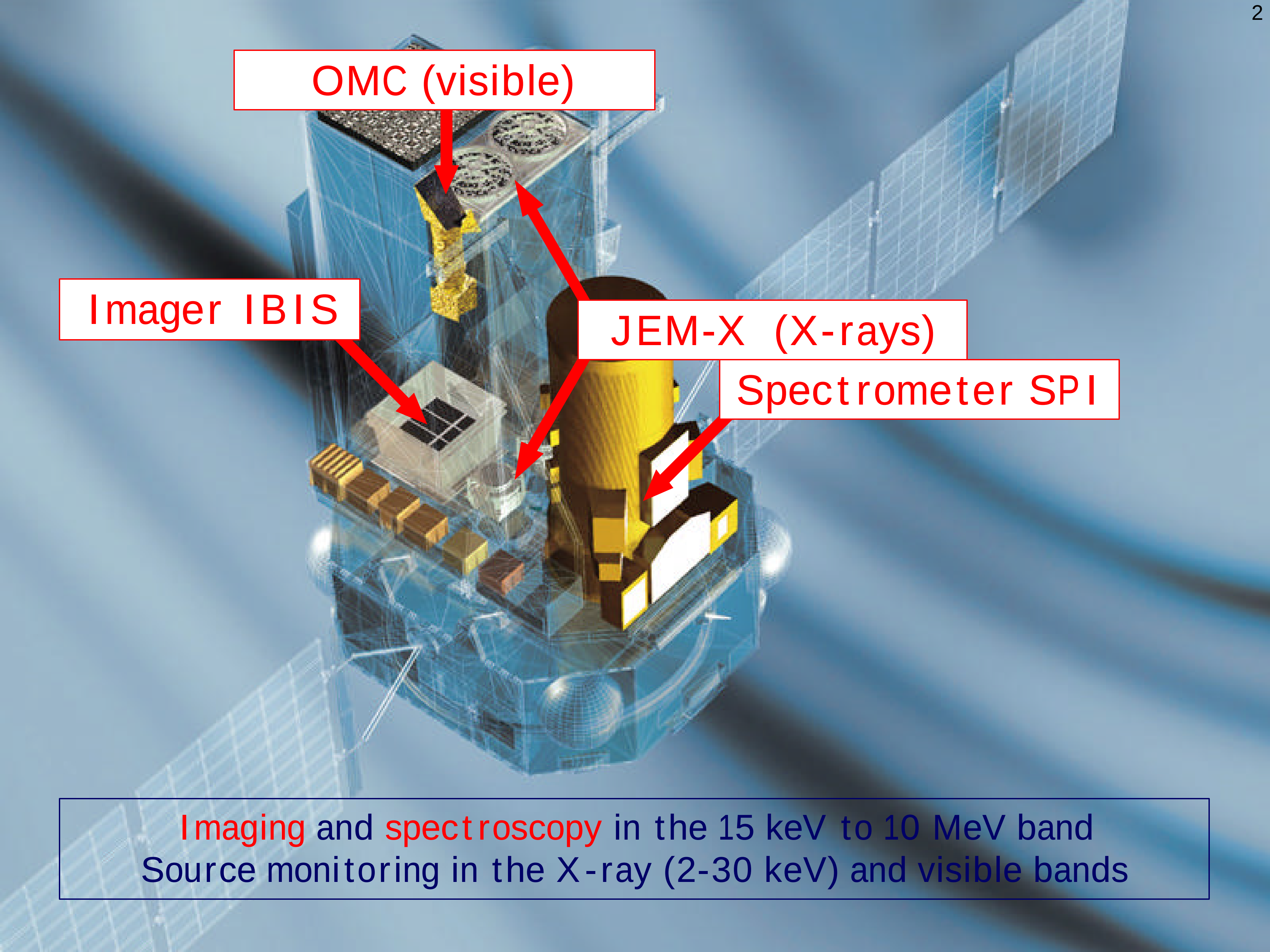
http://ibas.iasf-milano.inaf.it/



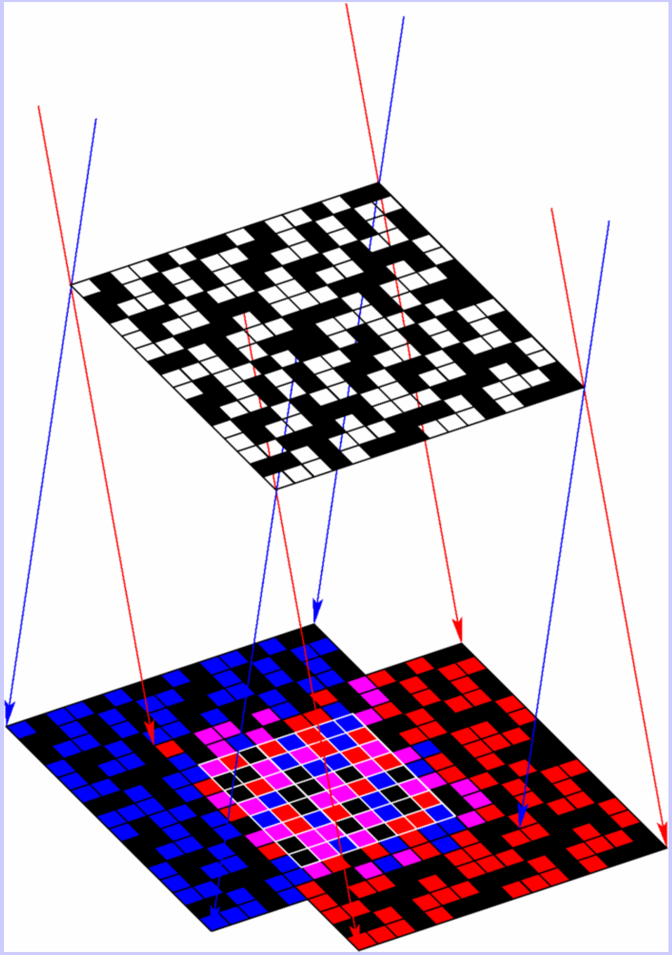
Imaging and spectroscopy in the 15 keV to 10 MeV band
Source monitoring in the X-ray (2-30 keV) and visible bands

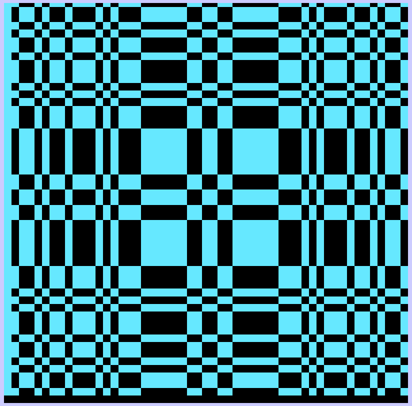
Coded Masks advantages and drawbacks

- Allows imaging at high energy with large field of view and adequate resolution for confused regions (e.g. Galactic Bulge)

- Direct measurement and subtraction of background

- “Cross Talk” of all sources detected in fov → requires simultaneous analysis with complex recursive algorithms



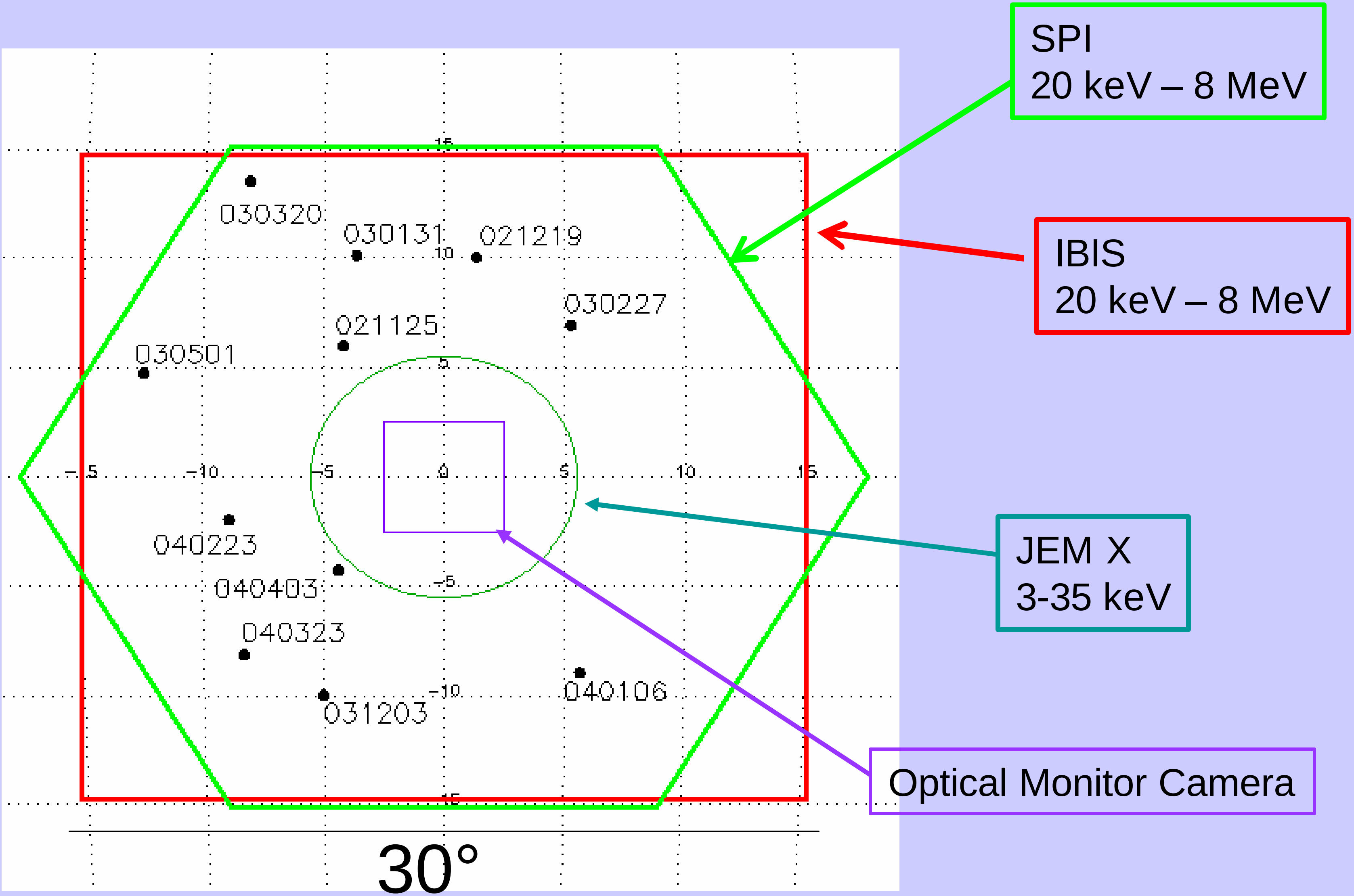


MURA basic pattern 53x53

IBIS mask

95x95 tungsten elements 16 mm thick

Fields of view of INTEGRAL instruments



IBIS = Imager on Board INTEGRAL Satellite

- **Coded mask + Hybrid detector:**
  CdTe 20 keV – 1 MeV
  CsI 200 keV – 8 MeV

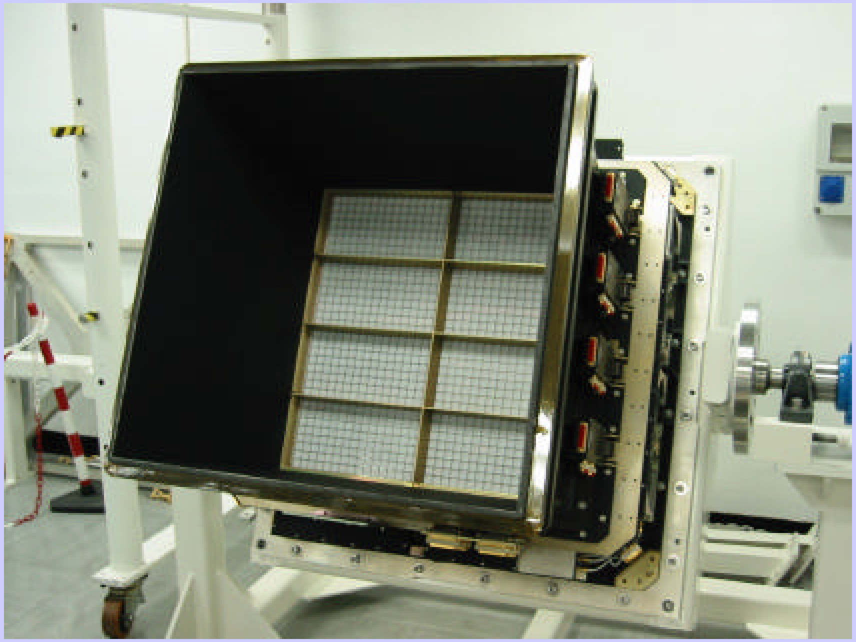
- **Large field of view ~29°x29°**
  (10°x10° at full sensitivity)

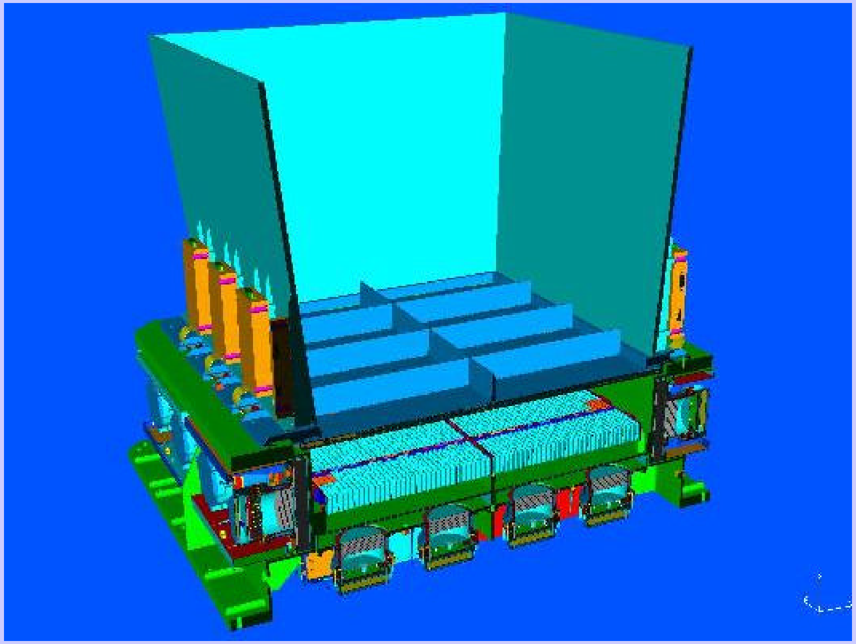
- **Angular resolution 12 arcmin**

- **Source location accuracy ~1-2 arcmin**
  or less (down to 0.7 arcmin) depending on source significance

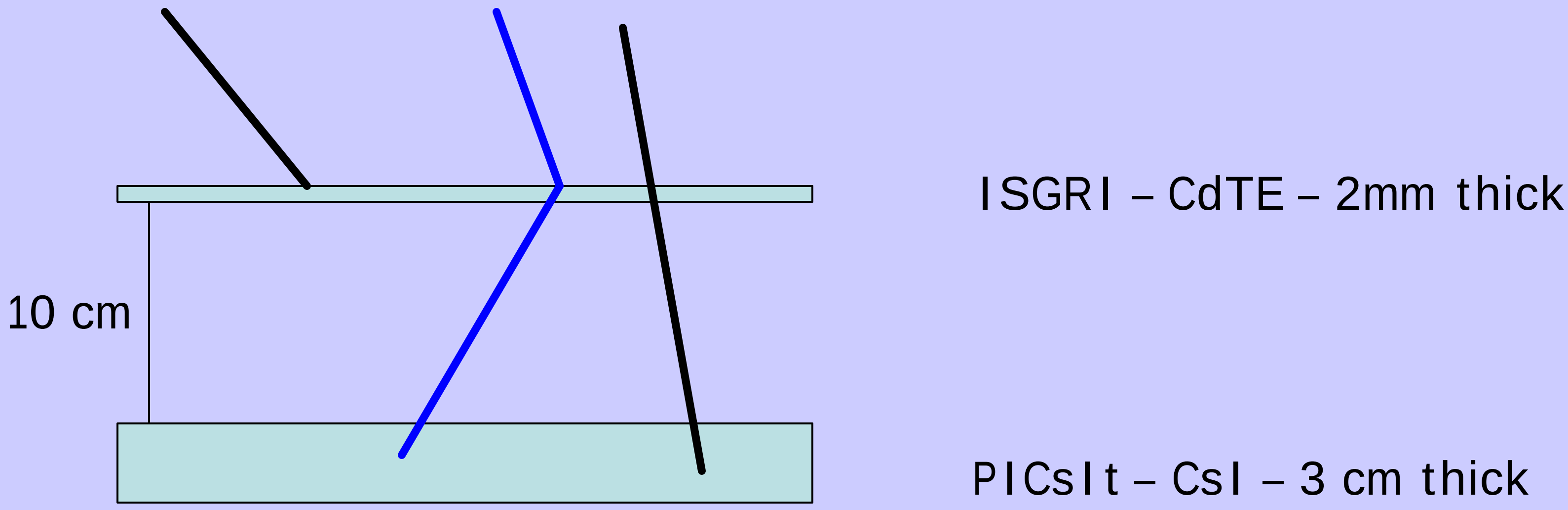
- **Sensitivity (15-300 keV)**
  ~ 40-50 mCrab in a typical pointing of ~30 min
  ~ 1 mCrab by summing many pointings (~Msec)

IBIS





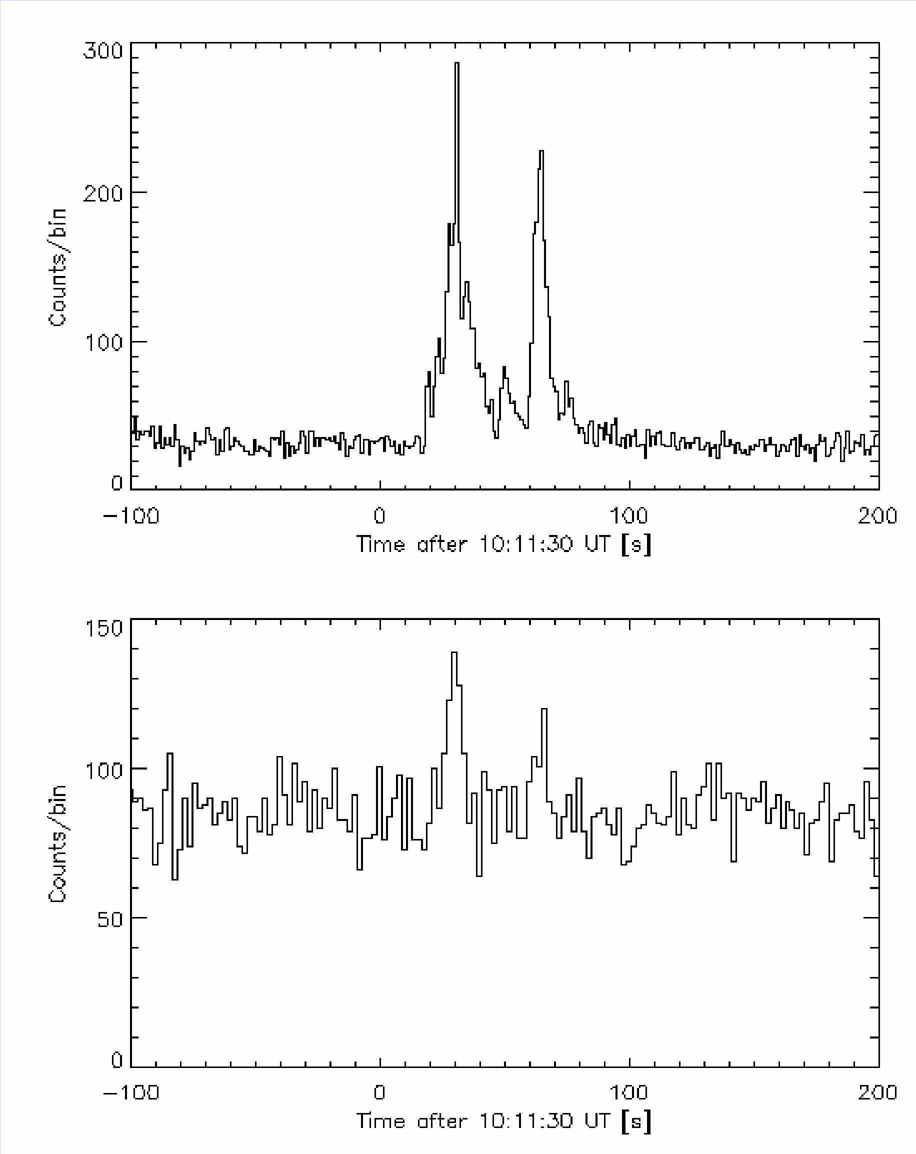
IBIS consists of 2 detectors



Some photons interact in the two detection planes →

1. Use as a Compton telescope (see Marcinkowski's talk)
2. Polarization

But the efficiency of this "Compton mode" is quite small ~ few % at E>200 keV



GRB 030320

Fluence ~ 10^{-5} erg/cmq
but large off-axis angle

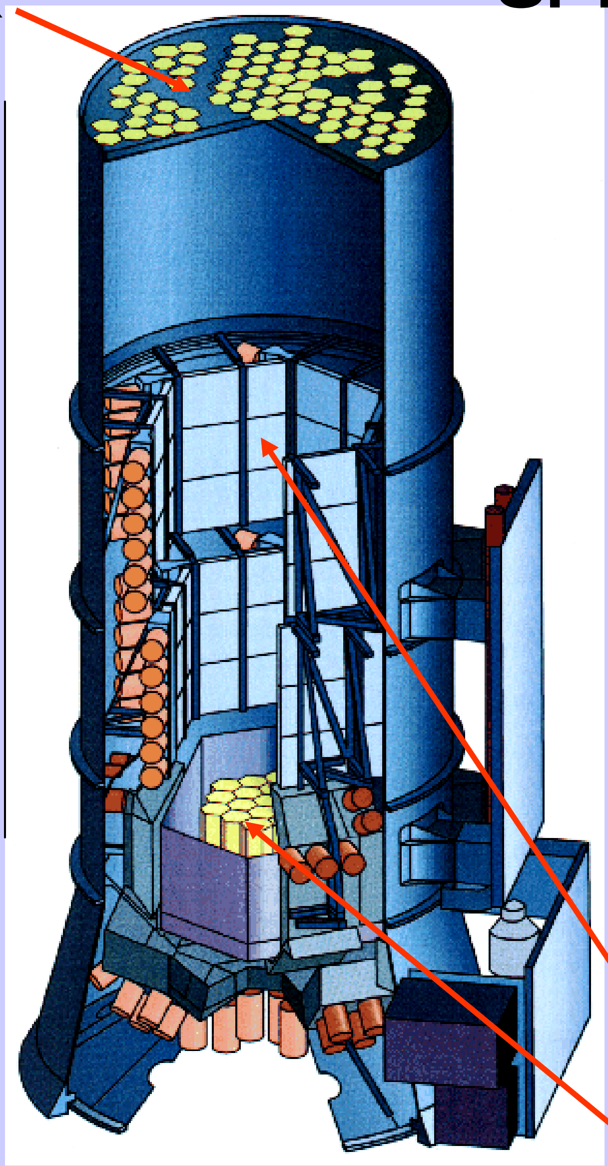
~3300 photons in ISGRI

~250 Compton events
(ISGRI+PICsIt)

SPI (Spectrometer on INTEGRAL)

Mask

1.7 m



15 keV - 10 MeV

Field of view: 30° ∅

Angular resolution: 2°

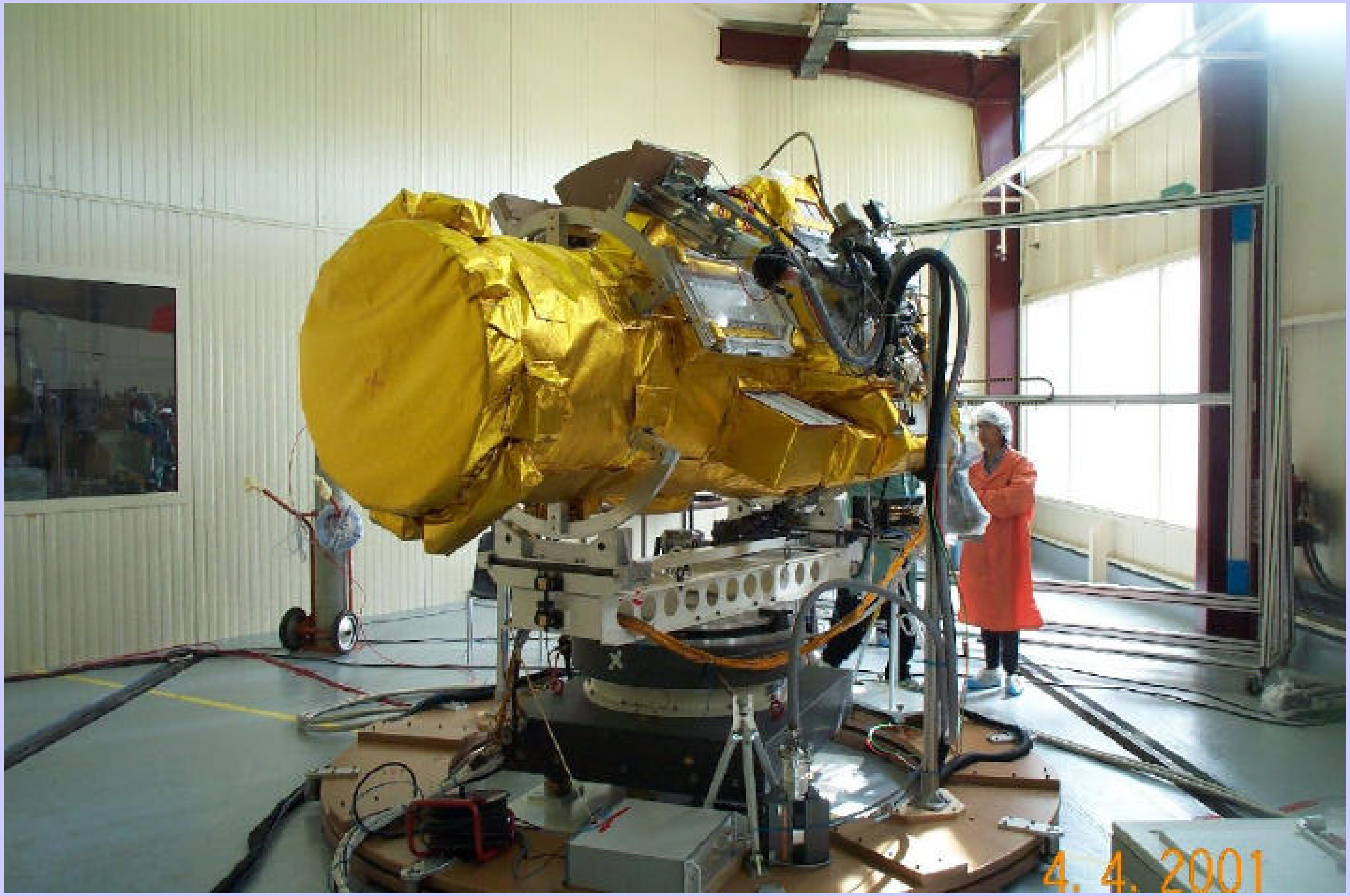
ENERGY RESOLUTION:

FWHM ~ 2 keV at 511 keV

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

19 Ge detectors (500 cm^2)

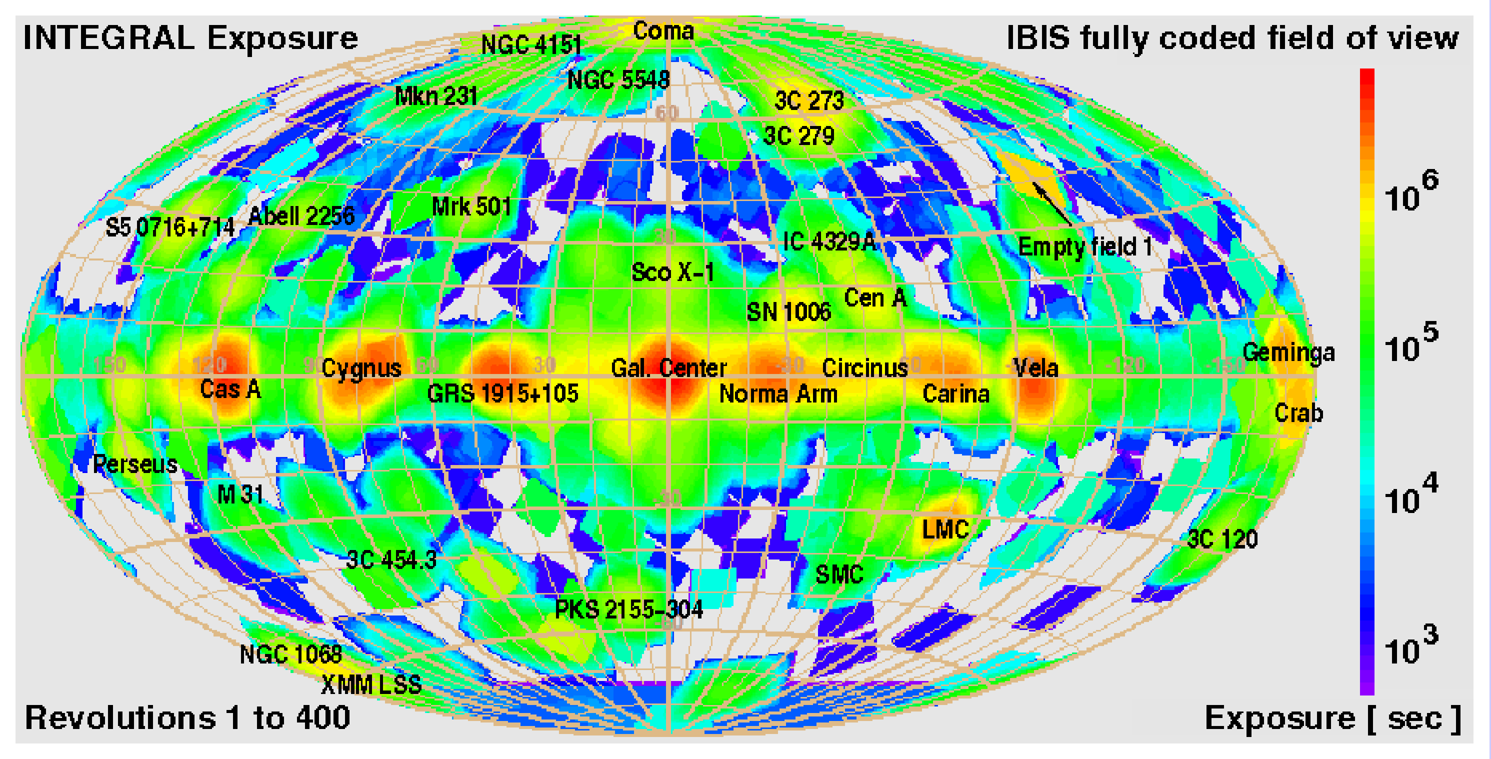
SPI during ground calibrations



Integral Observing Program

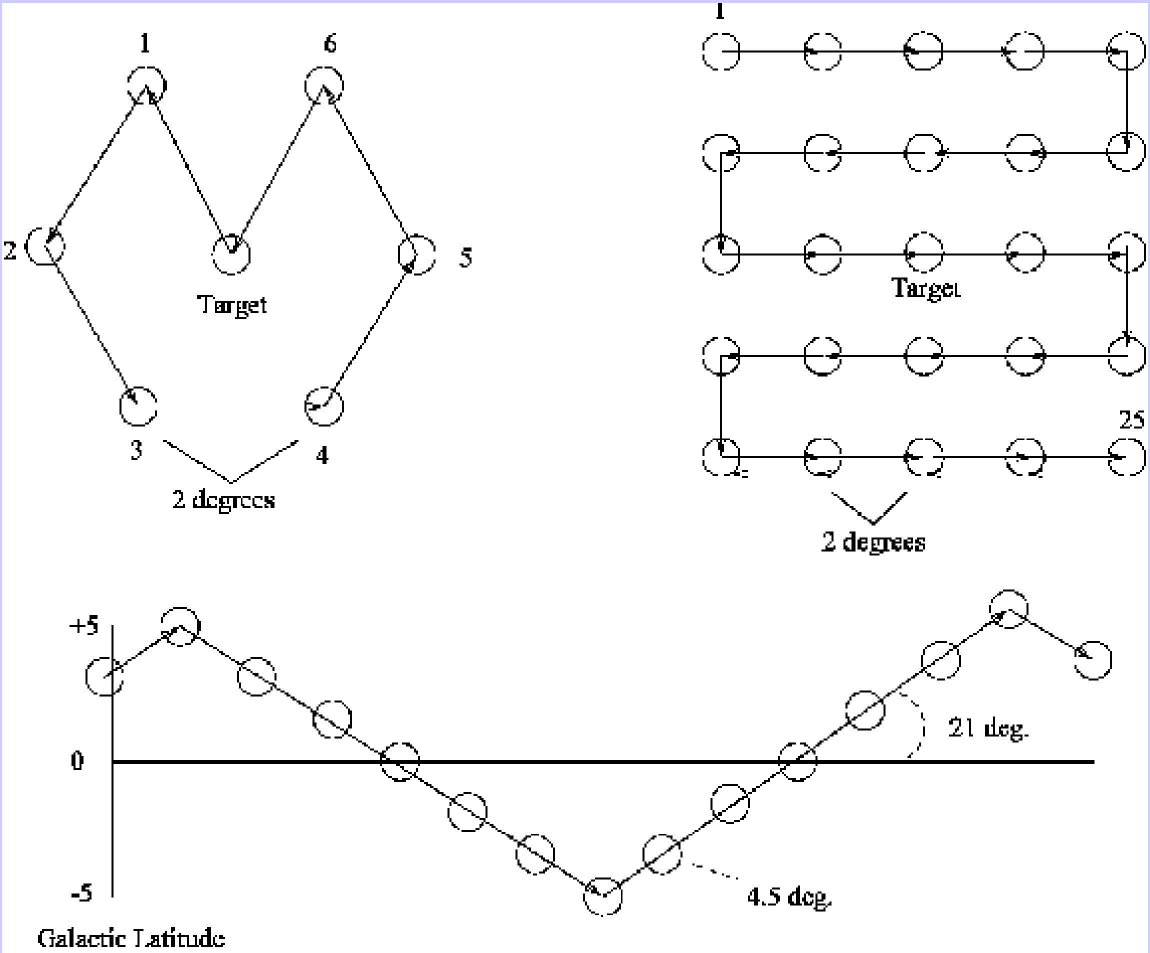
- Most of the time at low Galactic Latitude
  (galactic sources, nucleosynthesis with γ-ray lines)
- Serendipitous extragalactic sources and GRBs thanks to wide FoV

Sky coverage after ~3 yrs (courtesy N.Mowlavi ISDC)



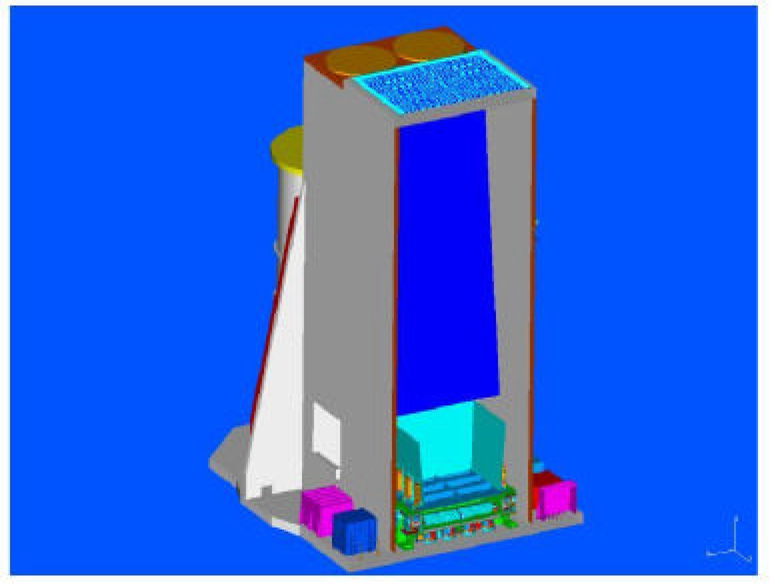
Dithering to improve image quality

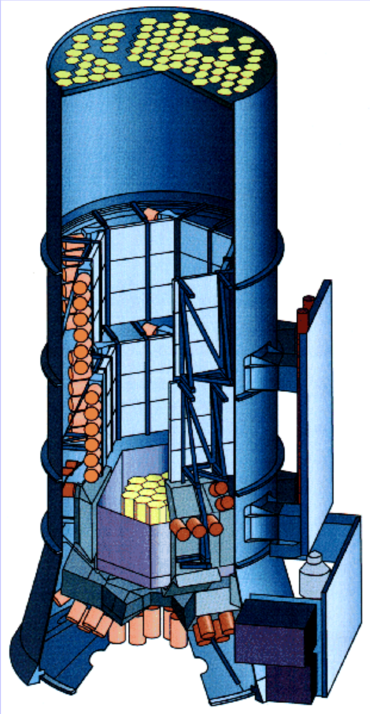
observations are composed of many pointings (~half hour each) on a raster scan pattern



IBAS= INTEGRAL Burst Alert System

Pre-flight performance predictions





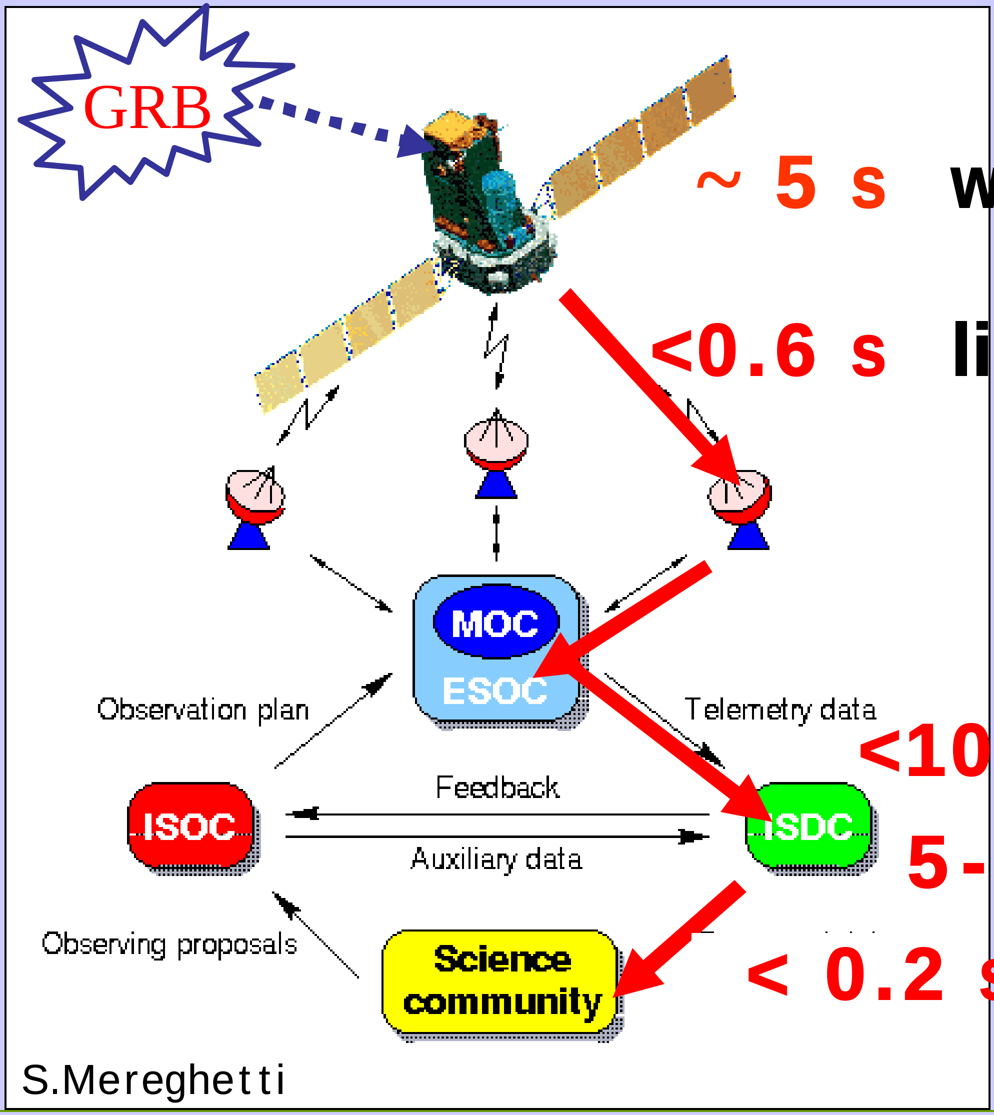
IBIS : GRBs in FoV
Based on ISGRI only

~ 1 GRB/month localized at 3 arcmin
Positions distributed in real time

SPI: GRBs in ~ whole sky
Based on Anticoincidence Shield

~ 1 GRB/2-3 days
Light curve available after 10 min
No position – Use with IPN

IBAS time performance



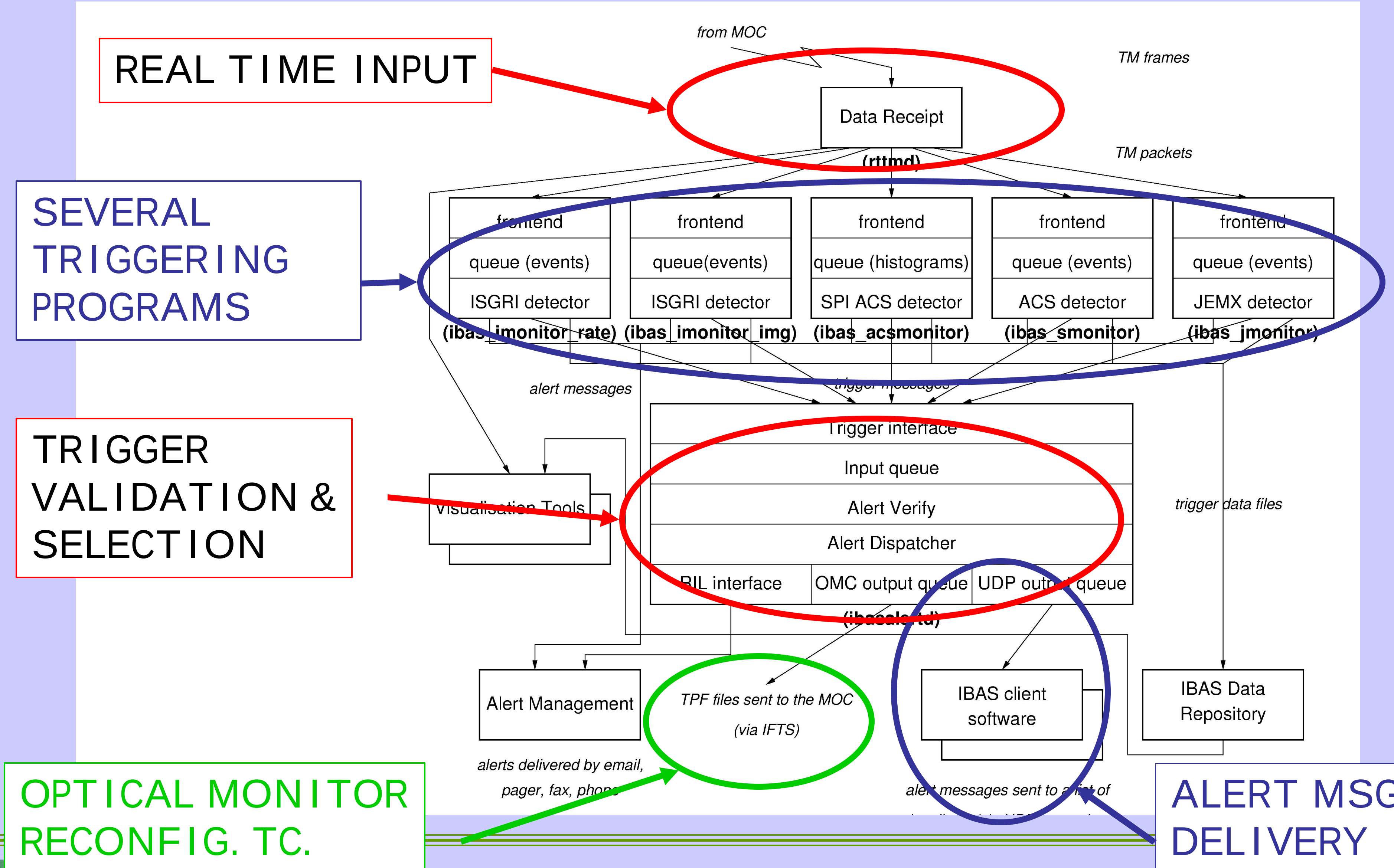
~ 5 s within satellite

<0.6 s light-travel time

<10 s to reach ISDC

5-10 s to derive position

< 0.2 s to reach users


REAL TIME INPUT
from MOC
TM frames
Data Receipt
(rttmd)
TM packets
SEVERAL TRIGGERING PROGRAMS
frontend
queue (events)
ISGRI detector
(ibas_imonitor_rate)
frontend
queue(events)
ISGRI detector
(ibas_imonitor_img)
frontend
queue (histograms)
SPI ACS detector
(ibas_acsmonitor)
frontend
queue (events)
ACS detector
(ibas_smonitor)
frontend
queue (events)
JEMX detector
(ibas_jmonitor)
alert messages
trigger messages
TRIGGER VALIDATION & SELECTION
Visualisation Tools
Trigger interface
Input queue
Alert Verify
Alert Dispatcher
RIL interface
OMC output queue
UDP output queue
(ibasalertd)
trigger data files
Alert Management
alerts delivered by email, pager, fax, phone
TPF files sent to the MOC
(via IFTS)
IBAS client software
alert messages sent to a list of
IBAS Data Repository
OPTICAL MONITOR RECONFIG. TC.
ALERT MSG DELIVERY

Current IBAS configuration

- Sun Ultra 5, 500 MHz CPU, 0.5 Gbytes RAM
- Sun fire 100, 400 MHz CPU, 384 Mbytes RAM

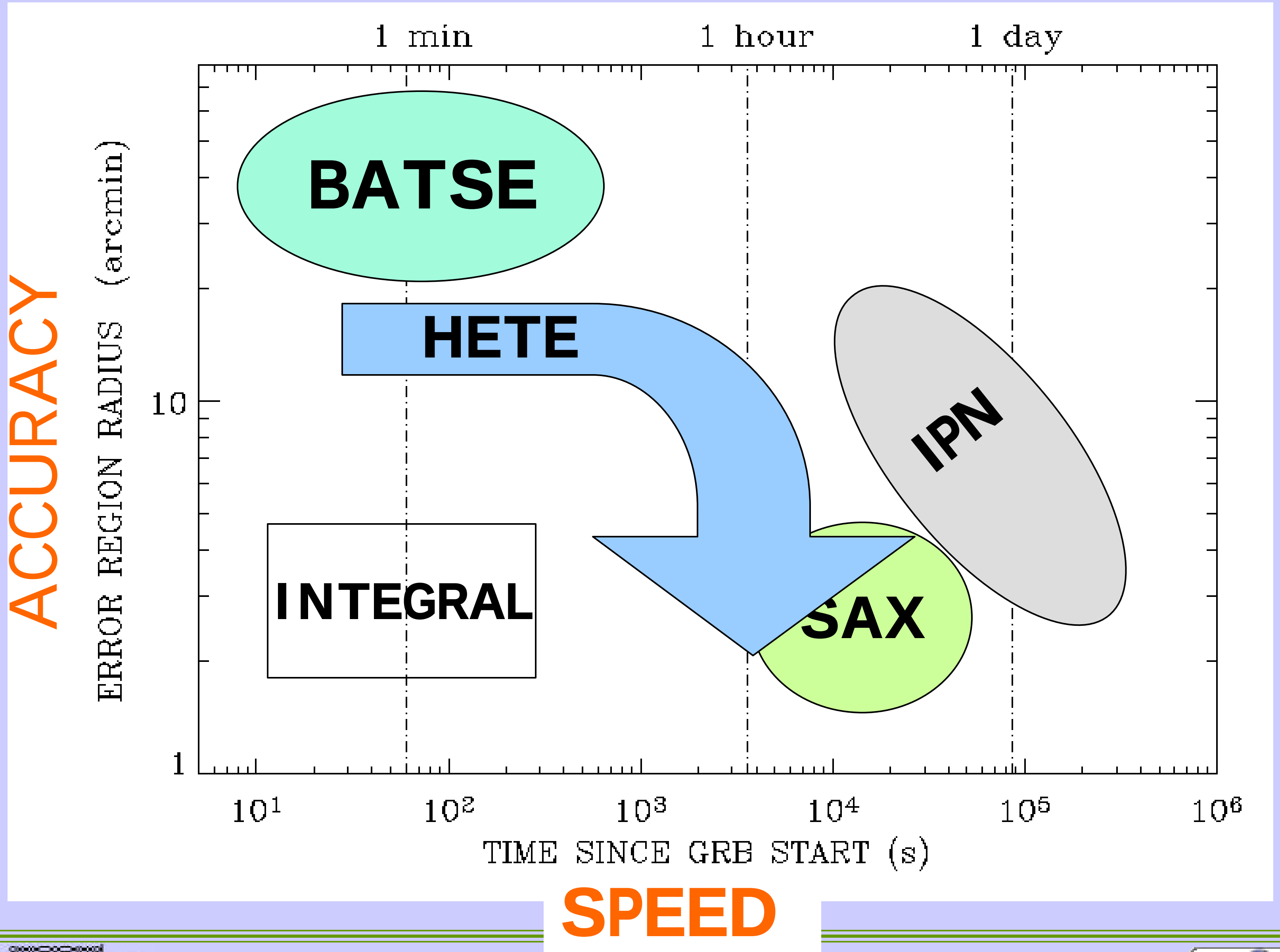
- **Imaging monitors**

15-200 keV	10 sec
15-200 keV	20 sec
15-200 keV	40 sec
15-200 keV	100 sec
15-40 keV	10 sec

- **Rate monitors**

15-200 keV	2, 8, 32 msec
15-200 keV	80, 320, 1280, 5120 msec
40-200 keV	10, 40, 160, 640 msec

GRB LOCALIZATION PERFORMANCES – PreSwift Era !



IBAS capabilities ...not only GRBs

- Soft Gamma Repeaters
- Type I X-ray bursts
- (re)-activation of known transients
- New sources with faint and/or short outbursts (e.g. IGR J17544-2619)

It is possible to receive alerts only for selected classes of sources

more on IBAS and INTEGRAL GRBs at

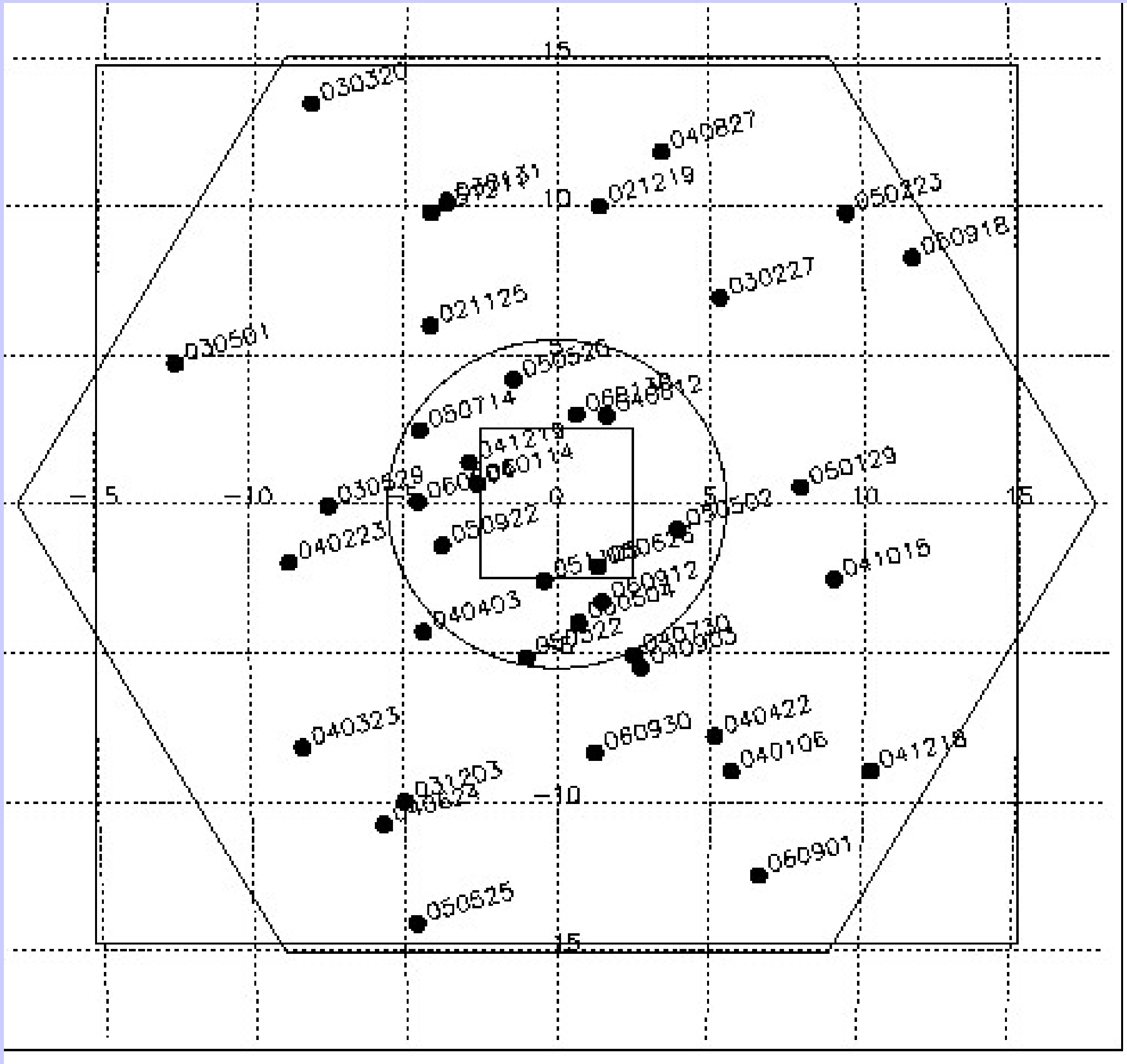
http://ibas.iasf-milano.inaf.it

IBAS is successful thanks to the excellent work and continuous support of many people, in particular:

D.Götz, J.Borkowski, N.Mowlavi, S.Shaw, A. von Kienlin, A.Paizis

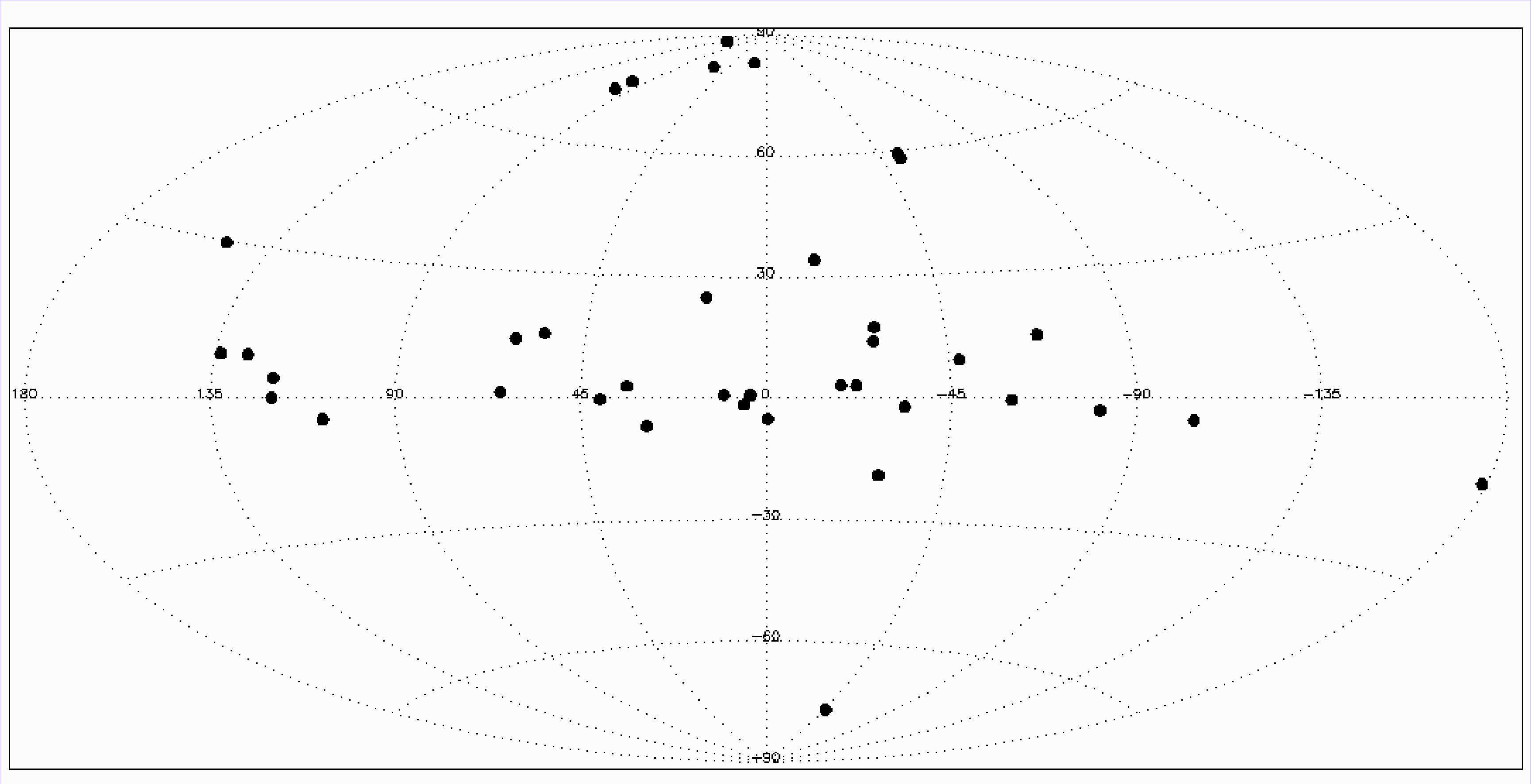
and many other at the ISDC, ESTEC/ESOC, and in the Instrument Teams…

40 GRBs detected with IBAS



40 GRBs detected with IBAS

Sky positions in Galactic coordinates



Some statistics

- 40 GRBs / 46 months ~ (0.9 ± 0.1) GRB/month

- Time distribution:

  2 in Nov-Dec 2002
  6 in 2003
  13 in 2004
  13 in 2005
  6 in 2006 (up to now...)

- Sometimes long gaps:

  e.g. May-Nov 2003, March-Aug 2006

  or several per month:

  e.g. 5 in May 2005, 3 in Sept 2006

some more statistics

- Speed of alerts:

Rapid	26	~ seconds
Slow	14	~ hours (9 below thresh.; 5 IBAS off)

- Counterparts:

~15 X-ray afterglows (~100% of follow-ups)

~10 Optical/IR transients

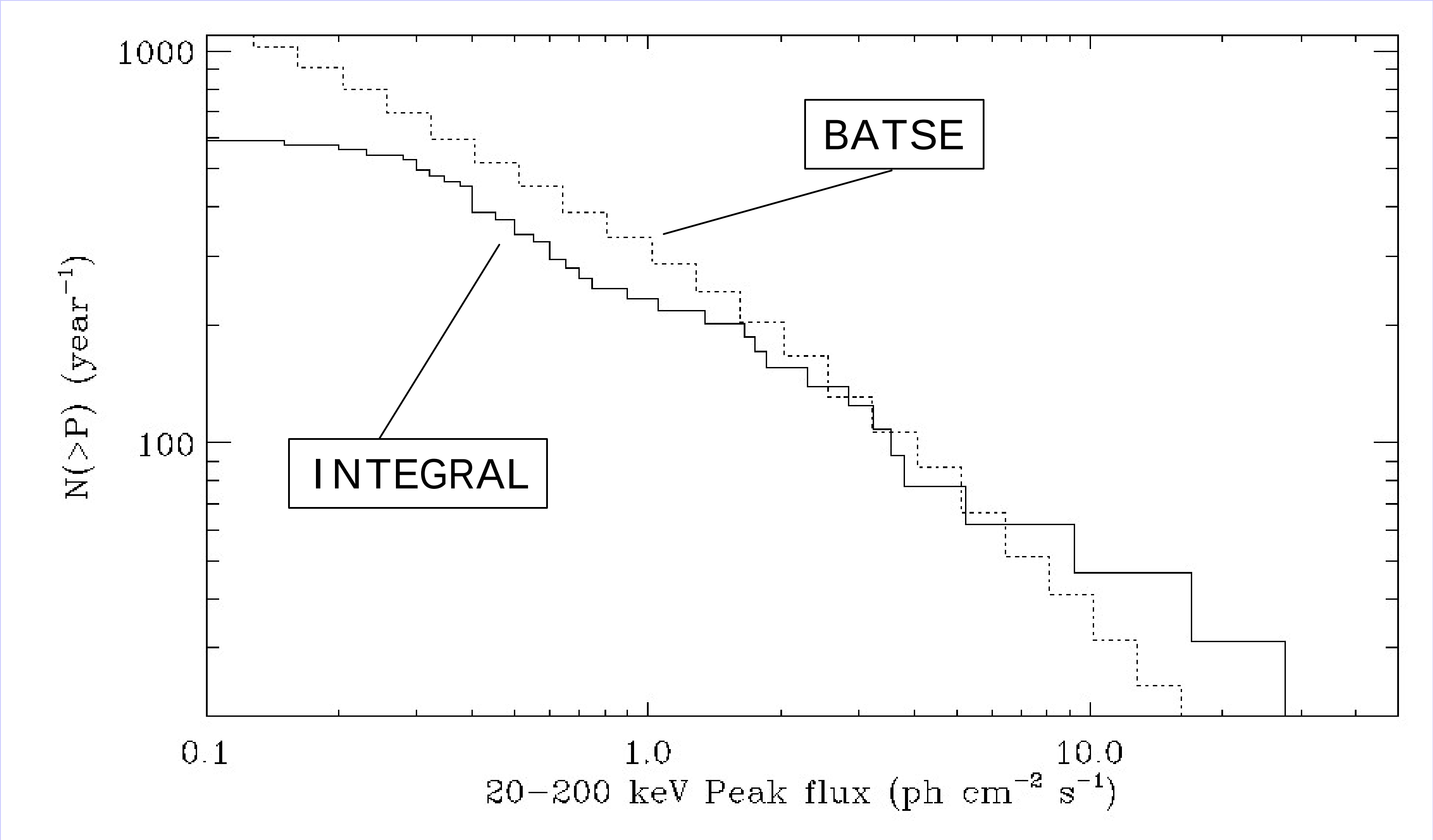
plus a few interesting upp. Limits

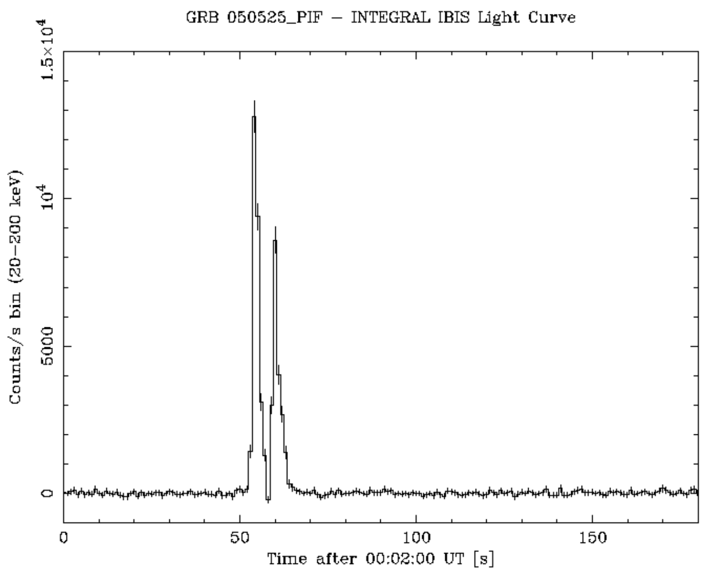
2 redshift ($z=0.1$; $z=0.6$)

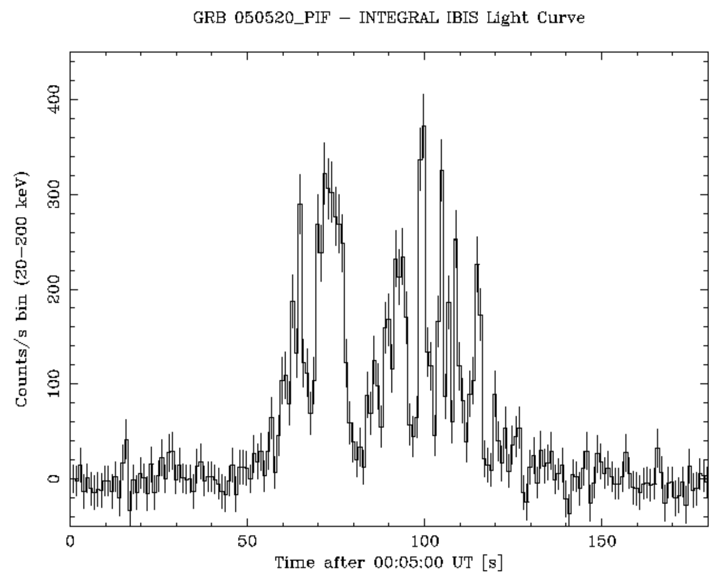
1 simultaneous IR flash

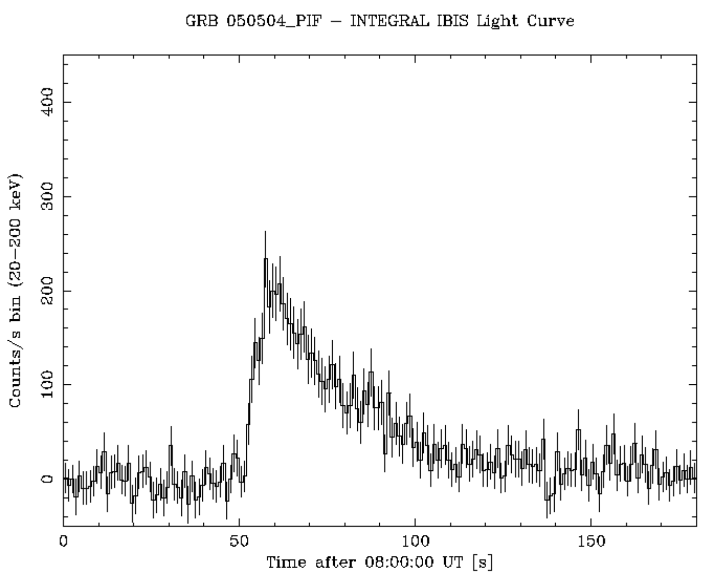
PRELIMINARY INTEGRAL LogN-LogP

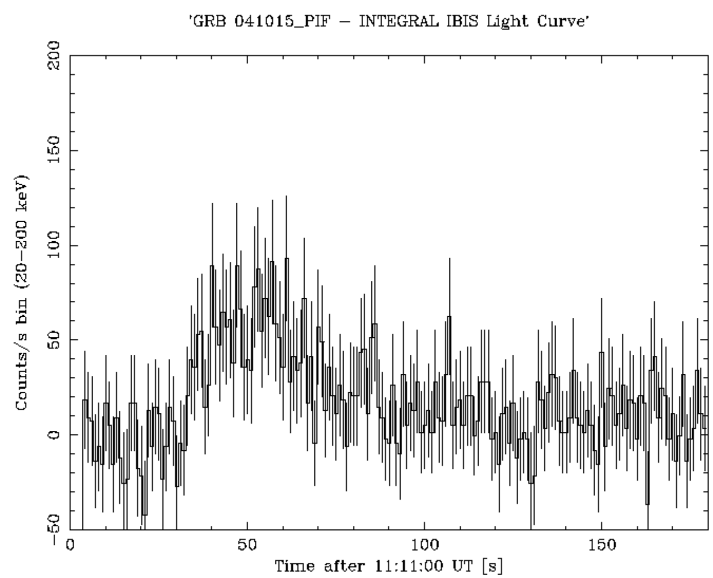
(40 GRB assuming 3 yrs effective time and FOV~0.27 sr)

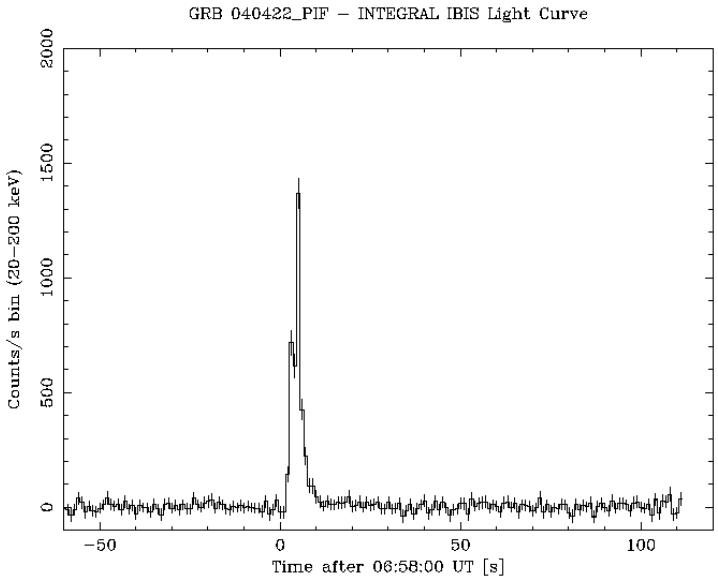


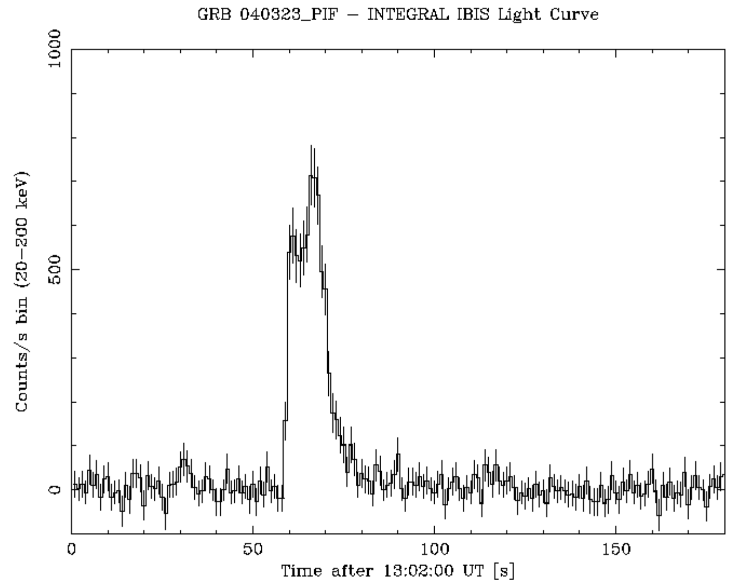

GRB 050525_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
Time after 00:02:00 UT [s]

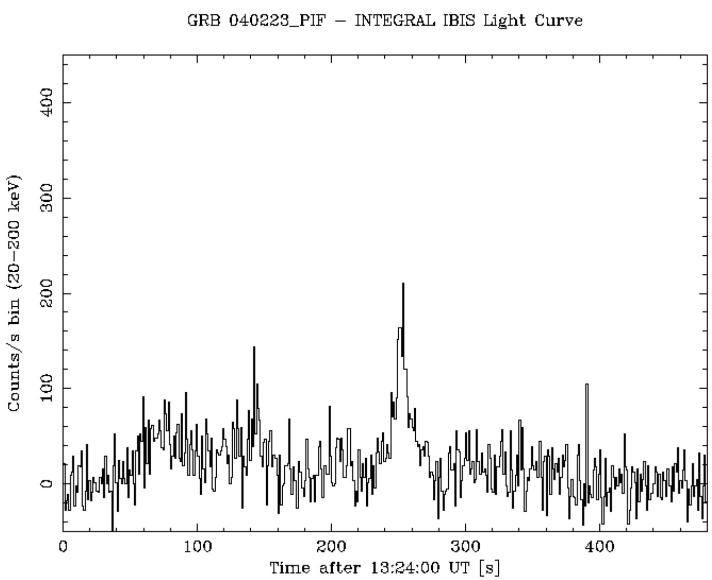

GRB 050520_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
Time after 00:05:00 UT [s]

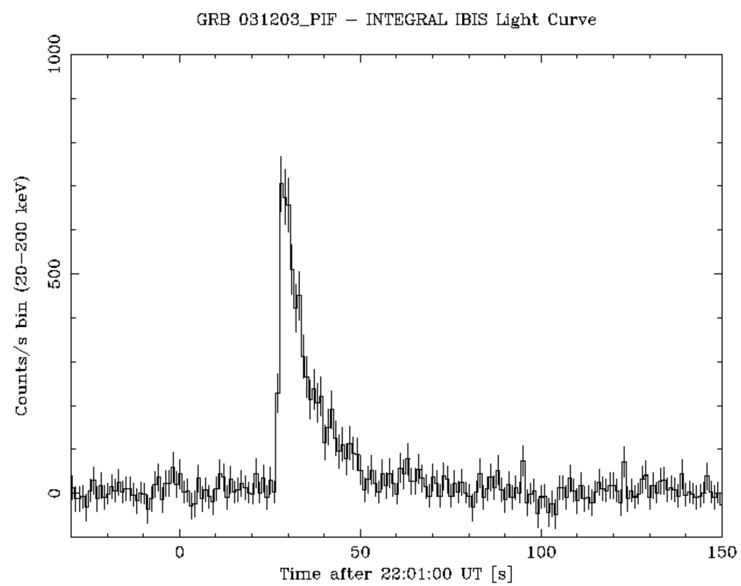

GRB 050504_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
Time after 08:00:00 UT [s]


'GRB 041015_PIF – INTEGRAL IBIS Light Curve'
Counts/s bin (20–200 keV)
Time after 11:11:00 UT [s]


GRB 040422_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
0
500
1000
1500
2000
−50
0
50
100
Time after 06:58:00 UT [s]


GRB 040323_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
0
500
1000
0
50
100
150
Time after 13:02:00 UT [s]

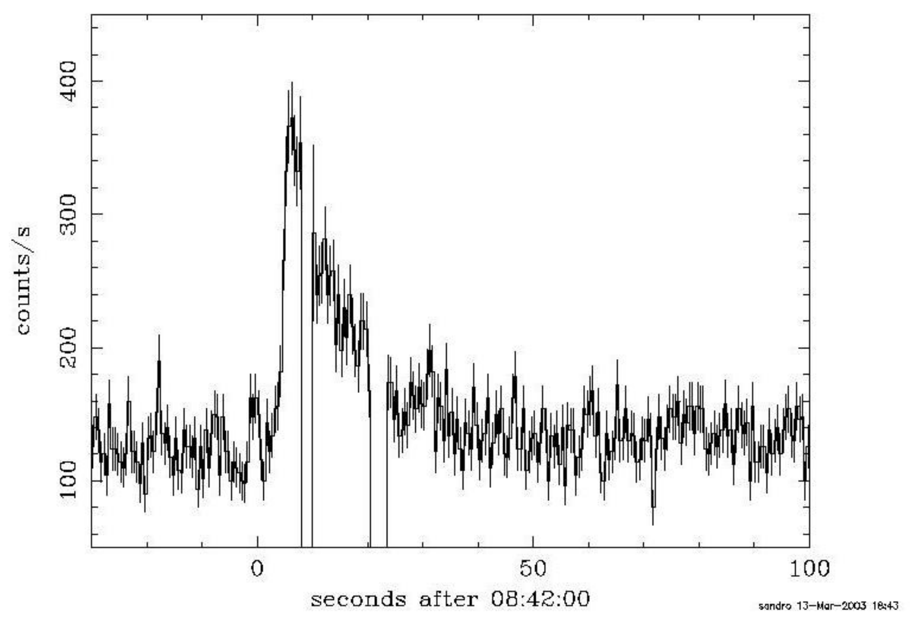

GRB 040223_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
0
100
200
300
400
0
100
200
300
400
Time after 13:24:00 UT [s]

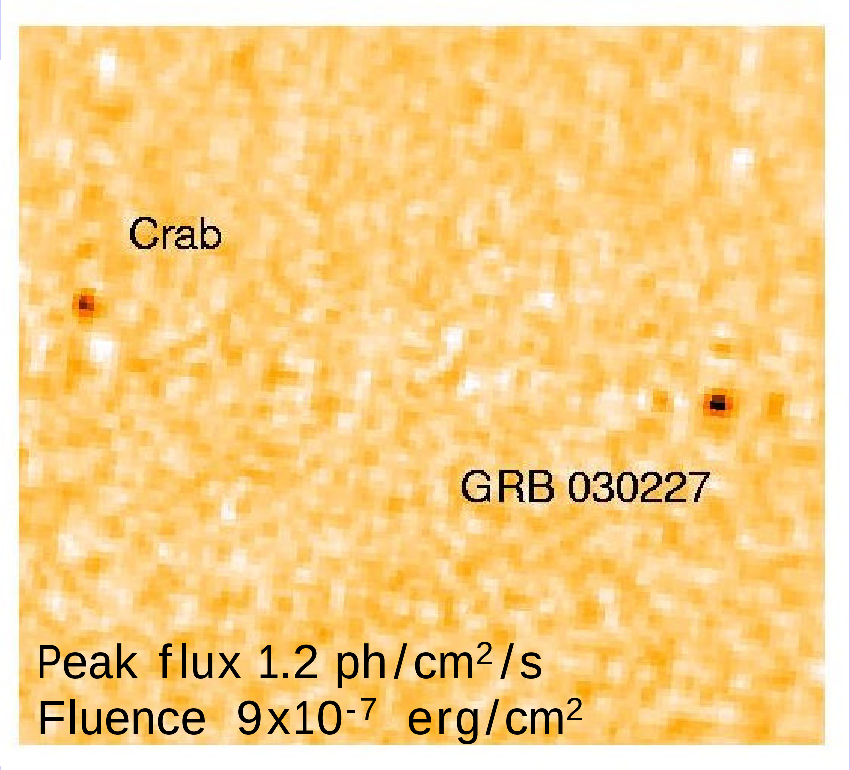

GRB 031203_PIF – INTEGRAL IBIS Light Curve
Counts/s bin (20–200 keV)
0
500
1000
0
50
100
150
Time after 22:01:00 UT [s]

GRB 030227

The first INTEGRAL GRB with an XMM-Newton follow up

(Mereghetti et al 2003)

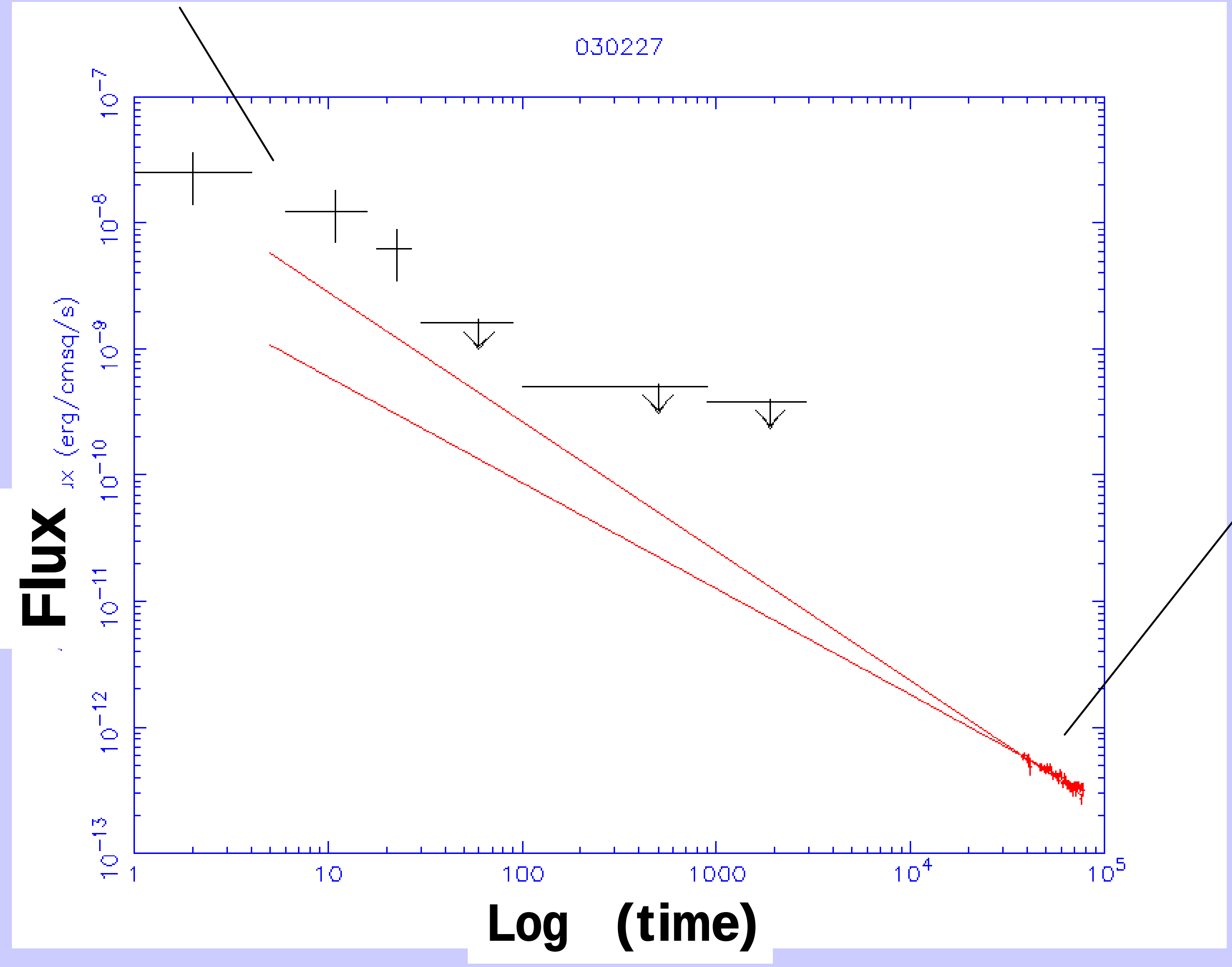




Peak flux 1.2 ph/cm^2/s

Fluence 9×10^{-7} erg/cm^2

GRB 030227
IBIS

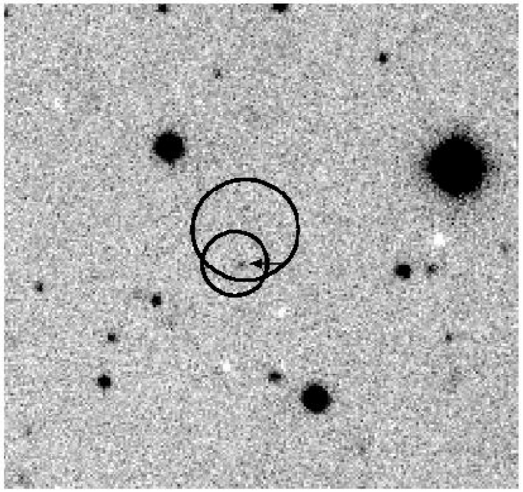


X-ray afterglow
XMM-Newton

GRB 030227

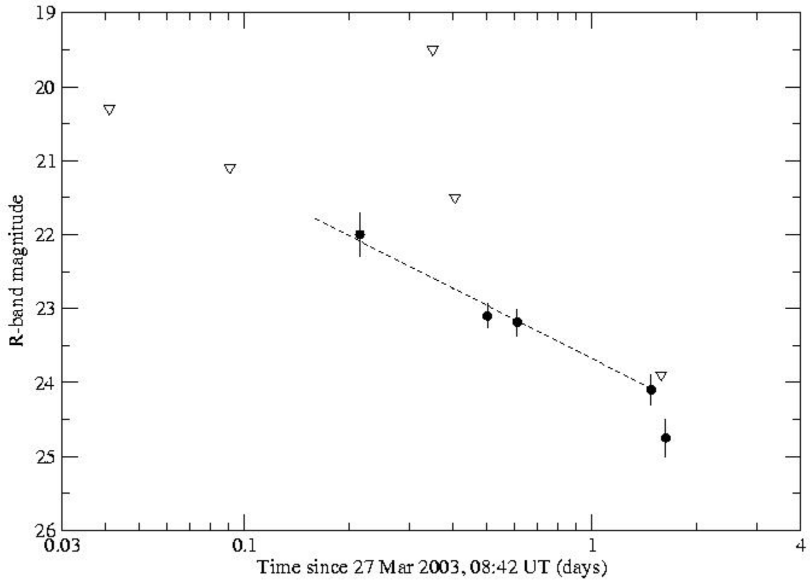
OPTICAL AFTERGLOW

(Castro-Tirado et al 2003)



2.5 m INT - R band

R ~ 22 @ 5 hr



GRB 030227

X-ray afterglow with XMM-Newton

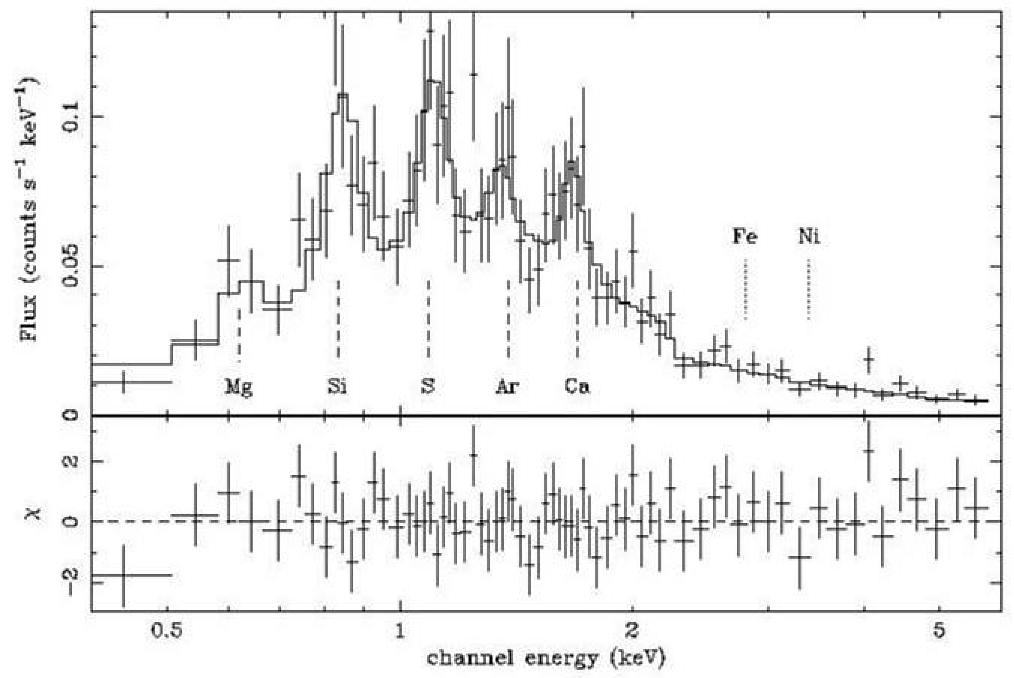
Evidence for lines in last 10 ks of observation

Mg, Si, Ar, Ca,

at z=1.4

but no Fe, Co, Ni

(Watson et al. 2003)

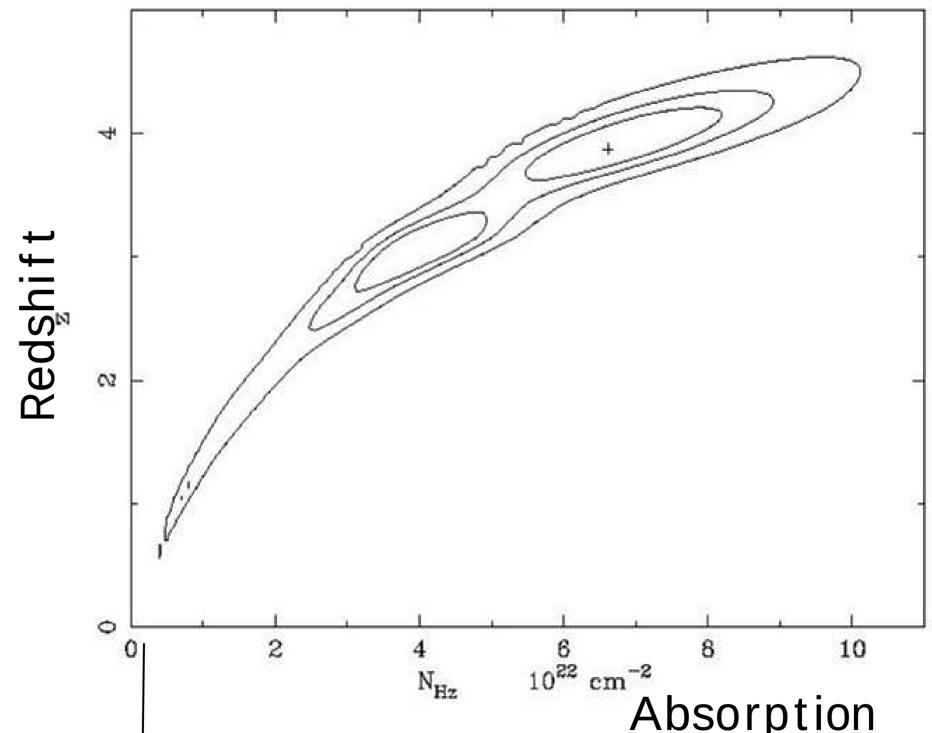


GRB 030227

X-ray afterglow with XMM-Newton

Evidence for intrinsic absorption from EPIC spectrum

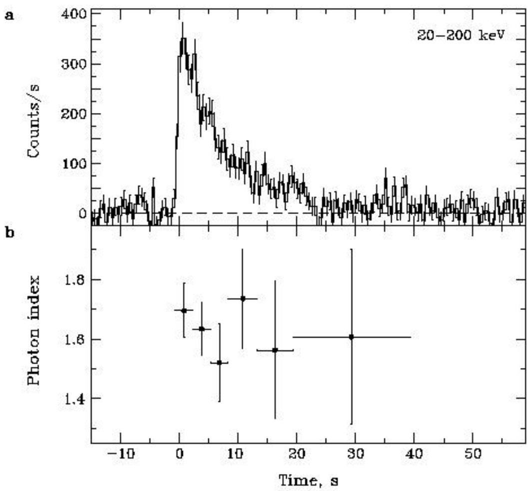
(Mereghetti et al 2003)



Galactic $N_H = 2x10^{21}$ cm^{-2}

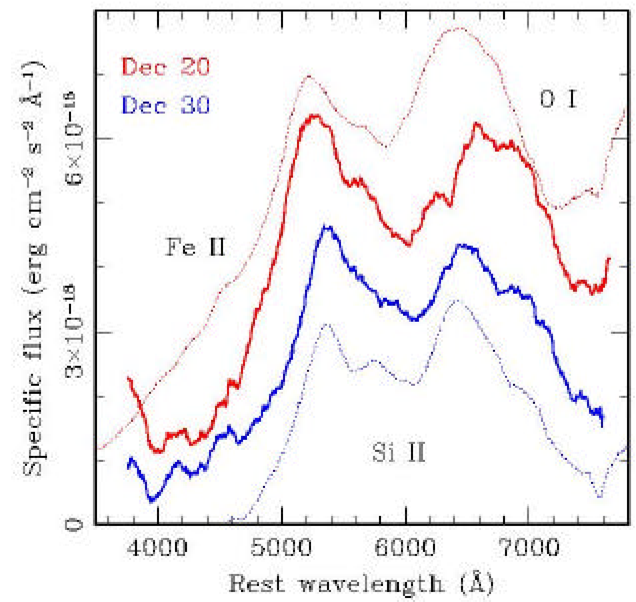
GRB 031203

z = 0.1   (Prochaska et al 2004)



• hard GRB spectrum (Sazonov et al 2004)

•E_{iso} ~ 6-14 x 10^{49} erg s^{-1}



SN 2003lw
(Malesani et al 2004)

→ It does not fit the Amati relation !

GRB 031203 - XMM-Newton TOO

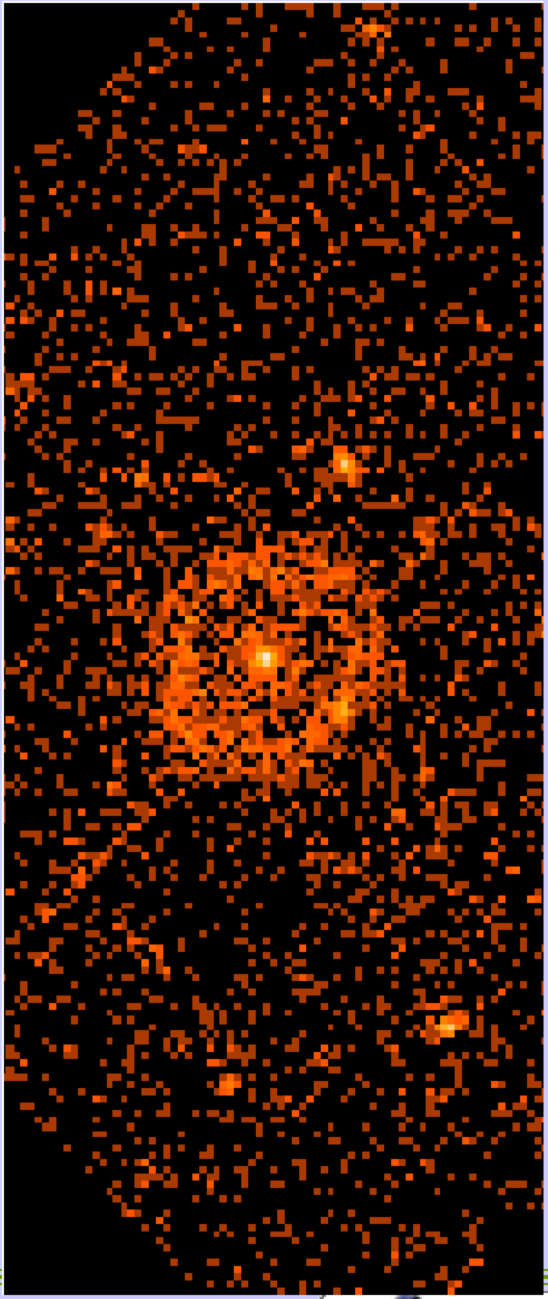
- The X-rays scattered by dust in the halo arrive with a variable delay of a few hours due to the different path-length

delay = $(D_{Earth\text{-}dust}) \times \Theta^2 / 2c$

- → $D_{Earth\text{-}dust}$ = 882 and 1388 pc

- In the halo we are seeing the <u>prompt</u> X-ray emission

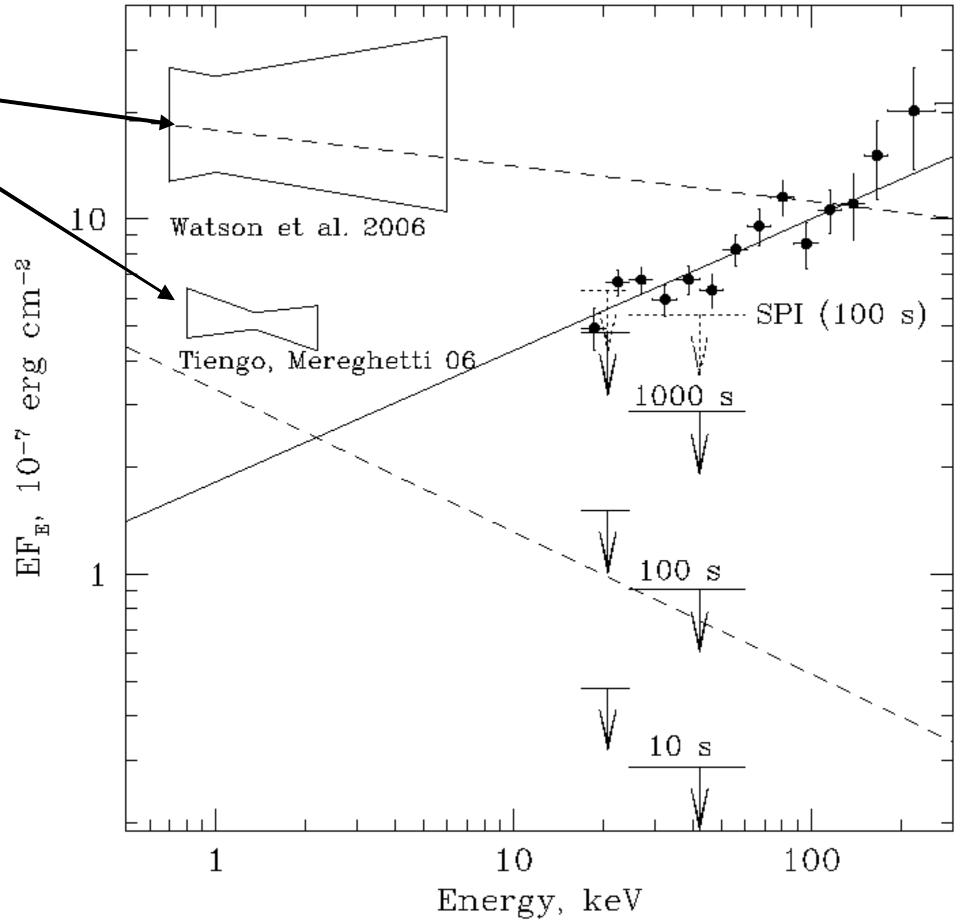
→ we can estimate its flux



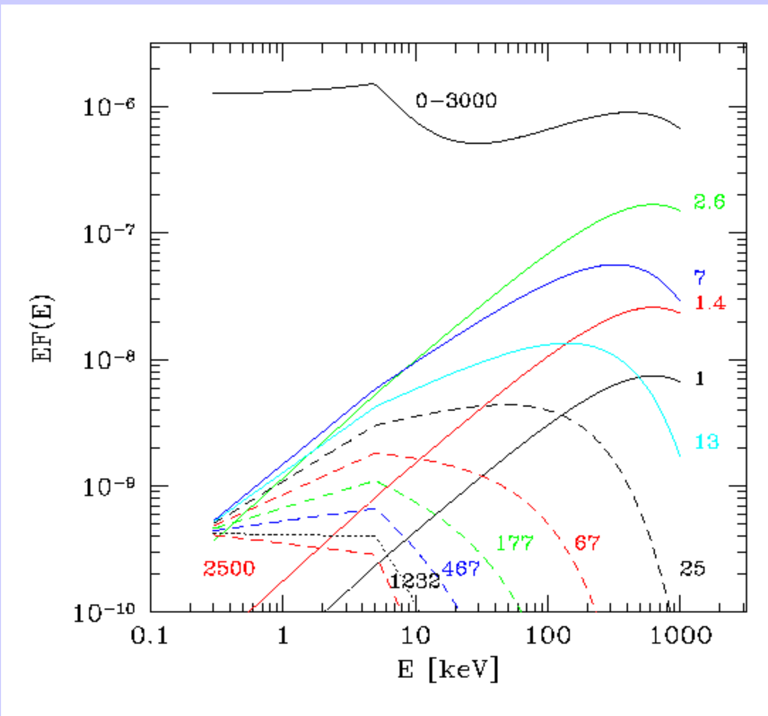
The estimate of the X-ray "prompt" emission is subject to a large uncertainty

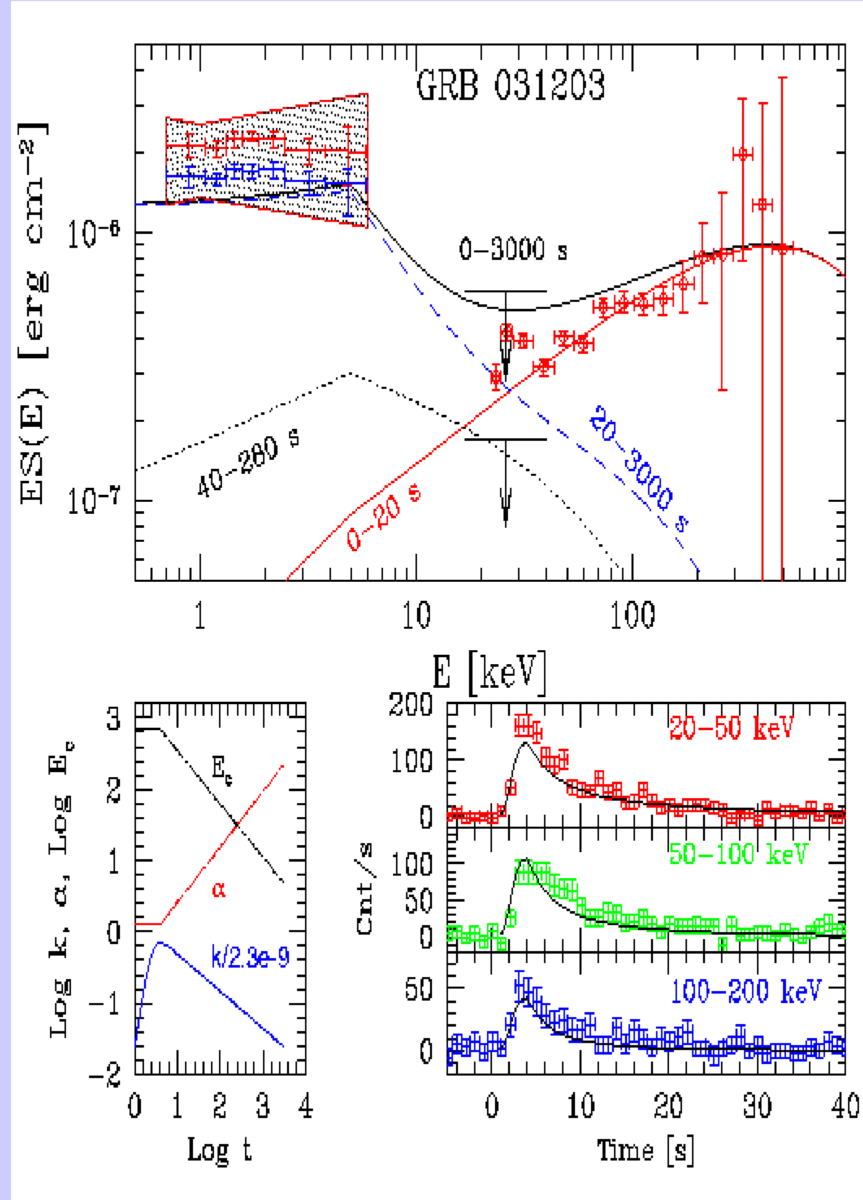
… but even the most conservative value is above the extrapolation of the high energy INTEGRAL spectrum

GRB 031203

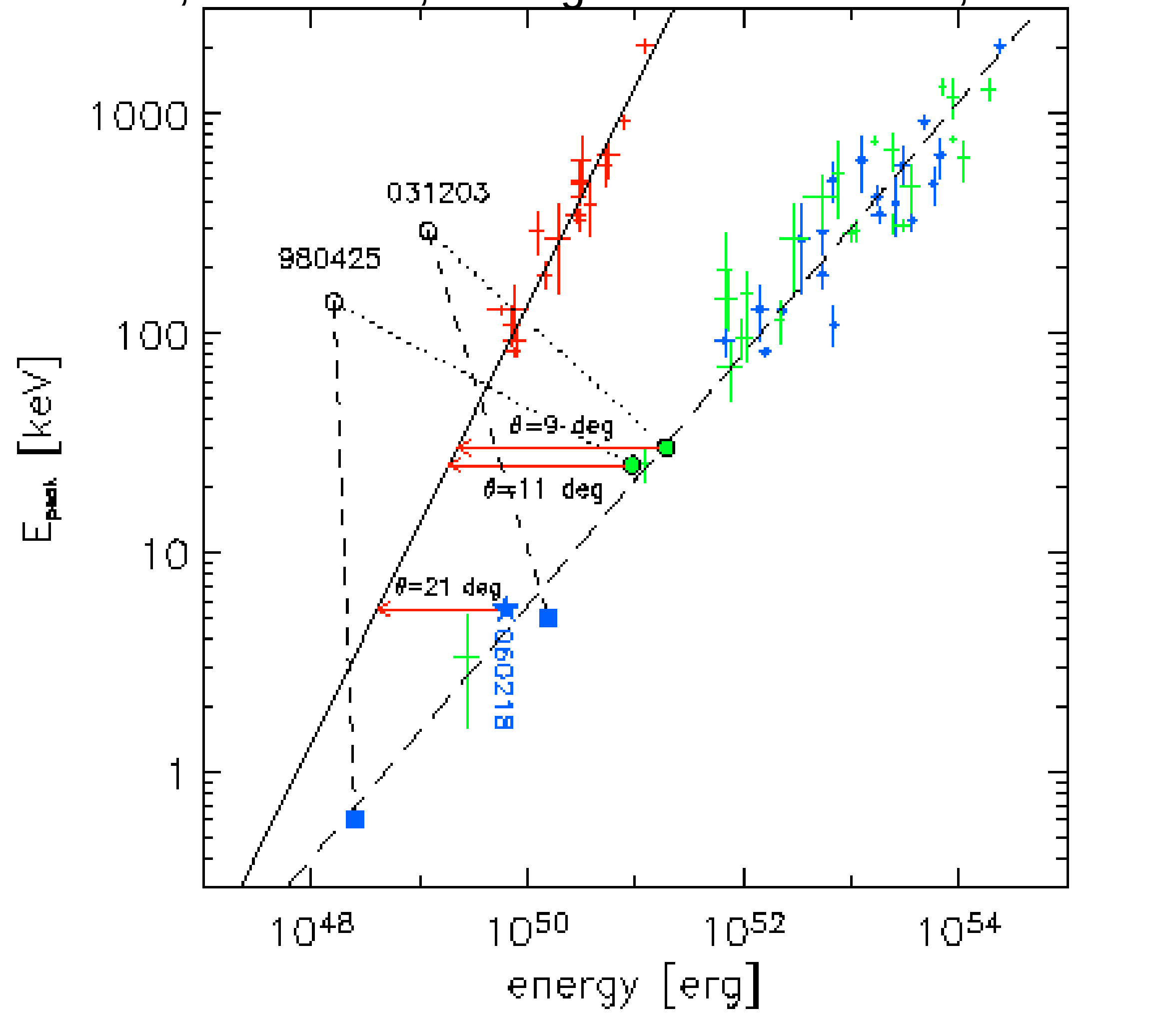


Sazonov et al. 2006, Astronomy Letters 32, 297

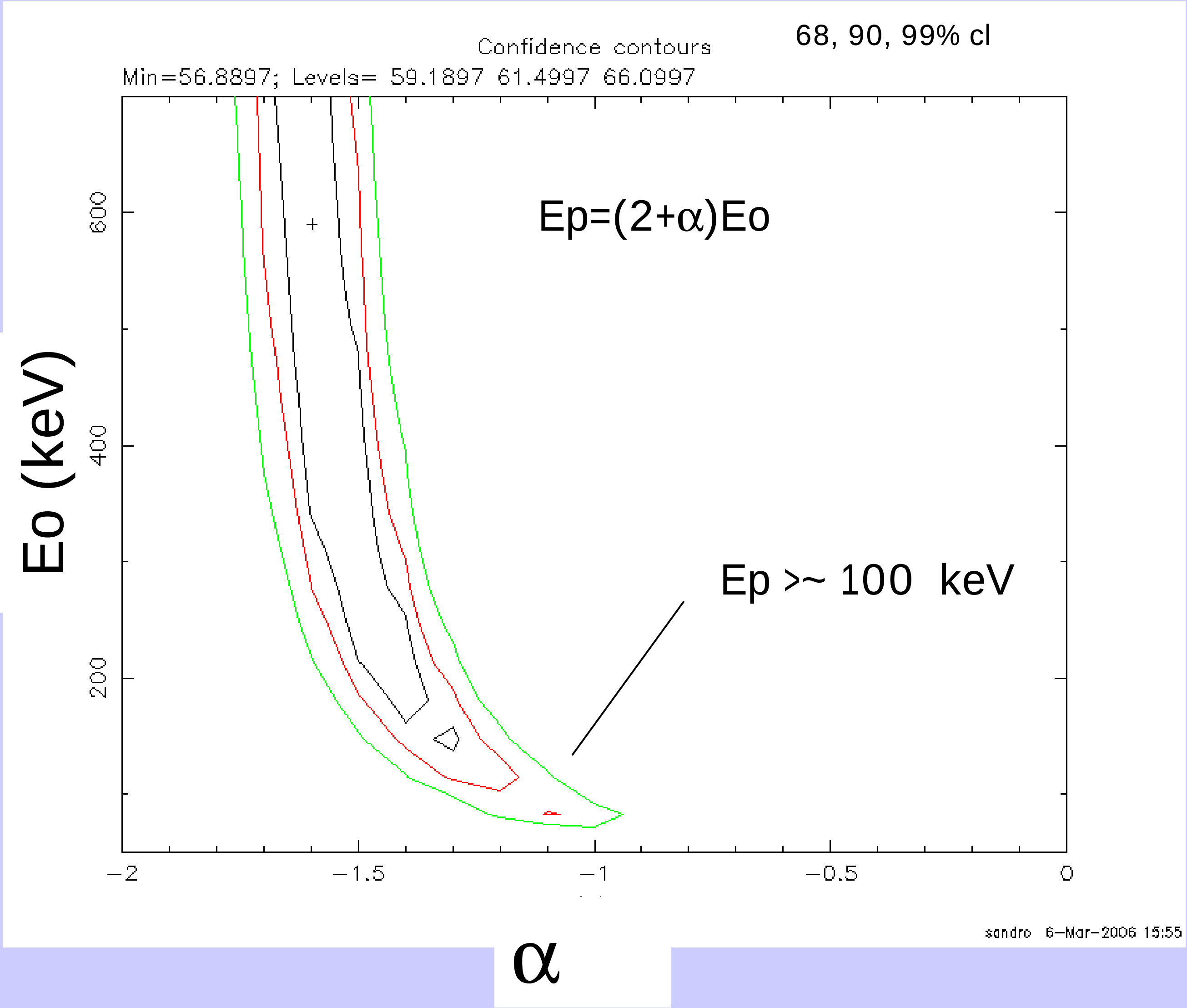

EF(E)
E [keV]
0.1
1
10
100
1000
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
0-3000
2.6
7
1.4
1
13
2500
1232
467
177
67
25


GRB 031203
ES(E) [erg cm⁻²]
E [keV]
1
10
100
10⁻⁶
10⁻⁷
0-3000 s
40-280 s
0-20 s
20-3000 s
Log k, α, Log E_c
Log t
E_c
α
k/2.3e-9
Cnt/s
Time [s]
20-50 keV
50-100 keV
100-200 keV

Ghisellini, Ghirlanda, Mereghetti et al. 2006, MNRAS



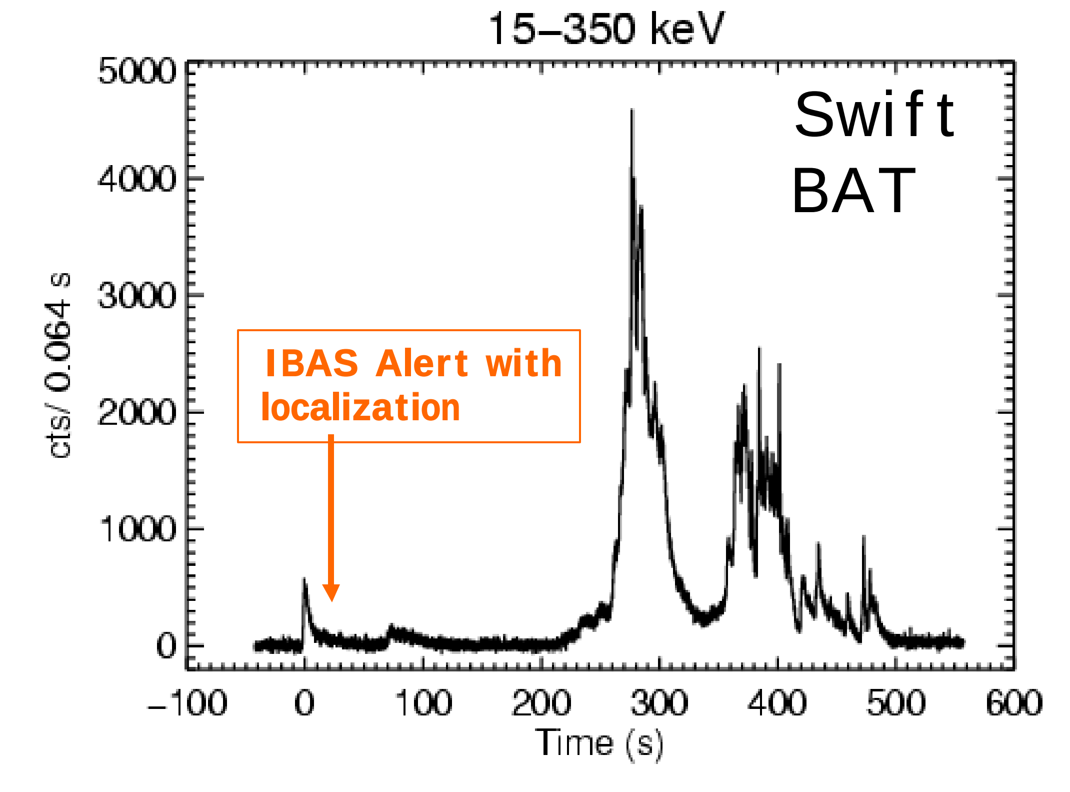
GRB 031203 – Fits with Band model



3 Swift GRBs seen by IBAS

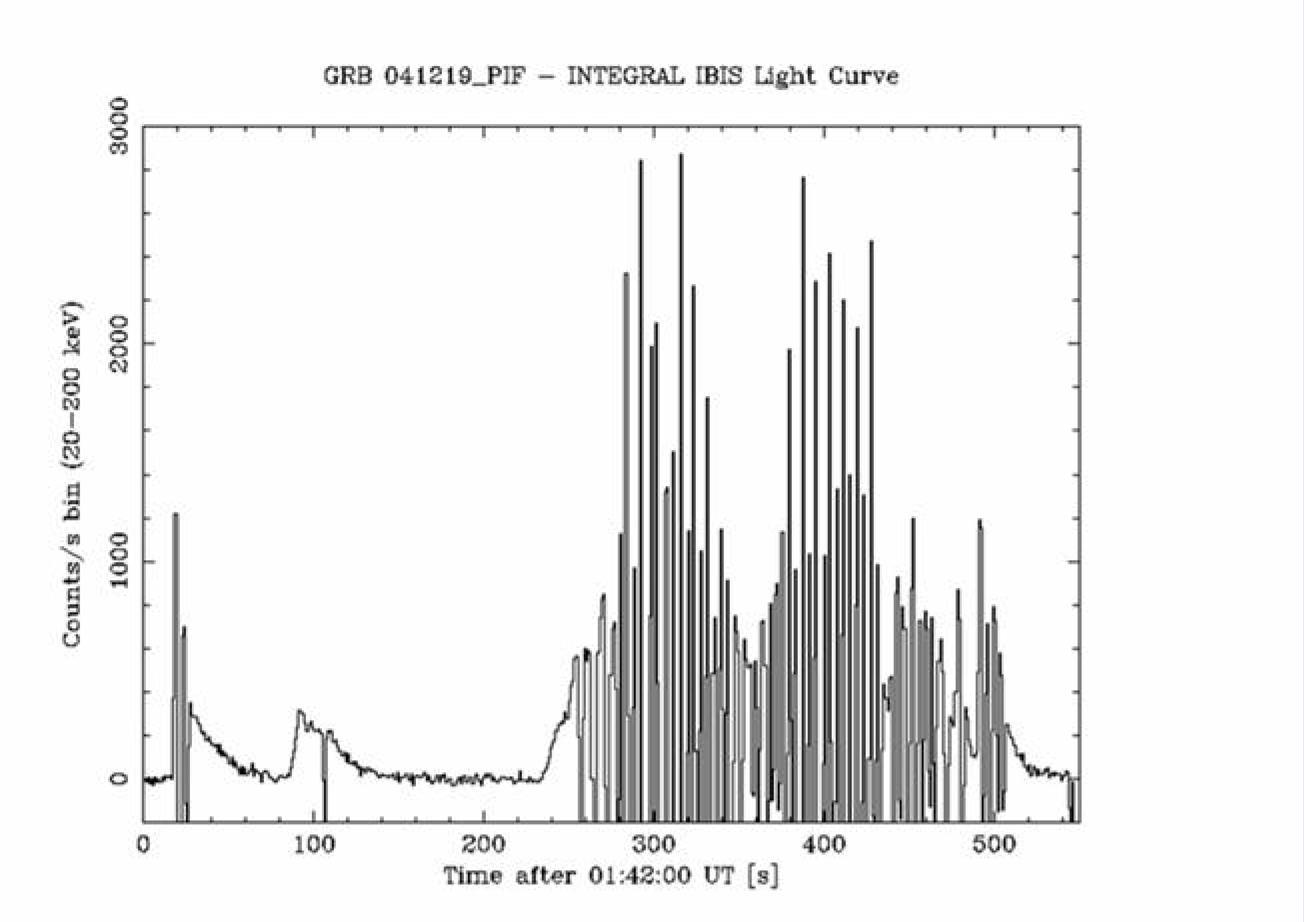
- GRB 041219
  discovered by IBAS; Swift not fully operational yet
- GRB 050223
  discovered by Swift; IBAS alerts temporarily disabled
- GRB 050525A
  discovered by Swift; very large IBIS off-axis

GRB 041219



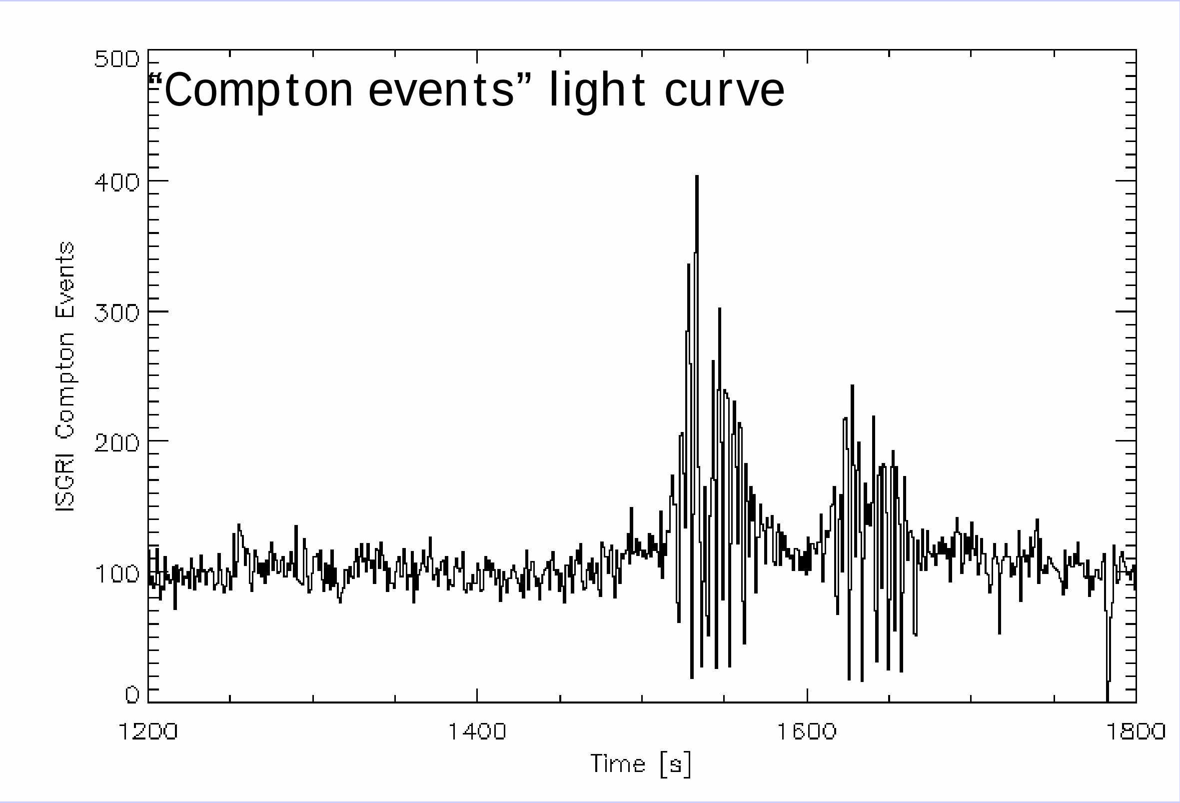
- Thanks to the rapid IBAS localization (2.5 arcmin) robot telescopes could observe during the GRB emission
- An IR "flash" K~15.5 simultaneous with the GRB was discovered (Blake et al. 2005, Nature, Vestrand et al. 2005 Nature)

GRB 041219

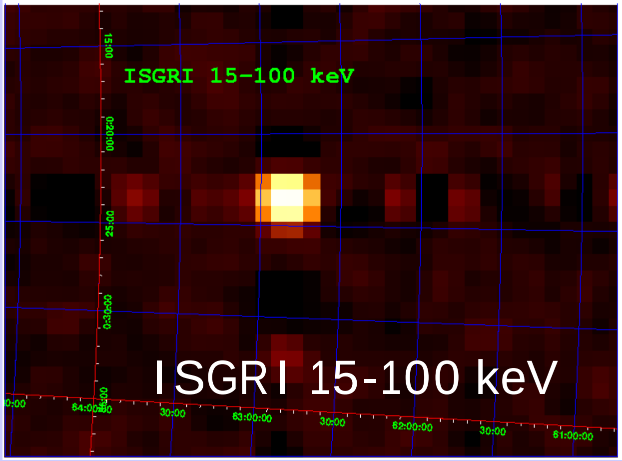


ISGRI light curve has gaps due to saturation of available telemetry

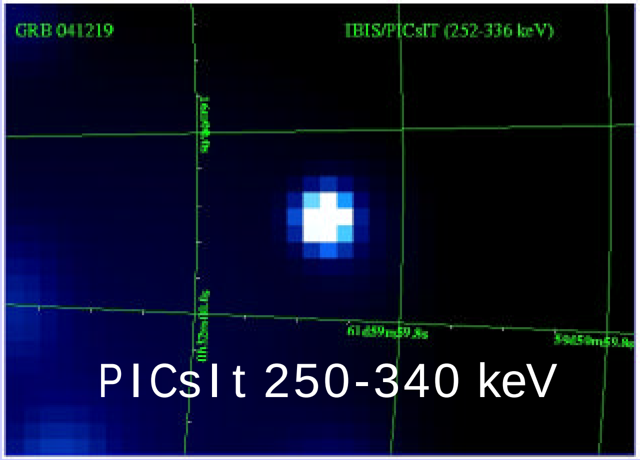
GRB 041219



"Compton events" light curve
ISGRI Compton Events
Time [s]
500
400
300
200
100
0
1200
1400
1600
1800

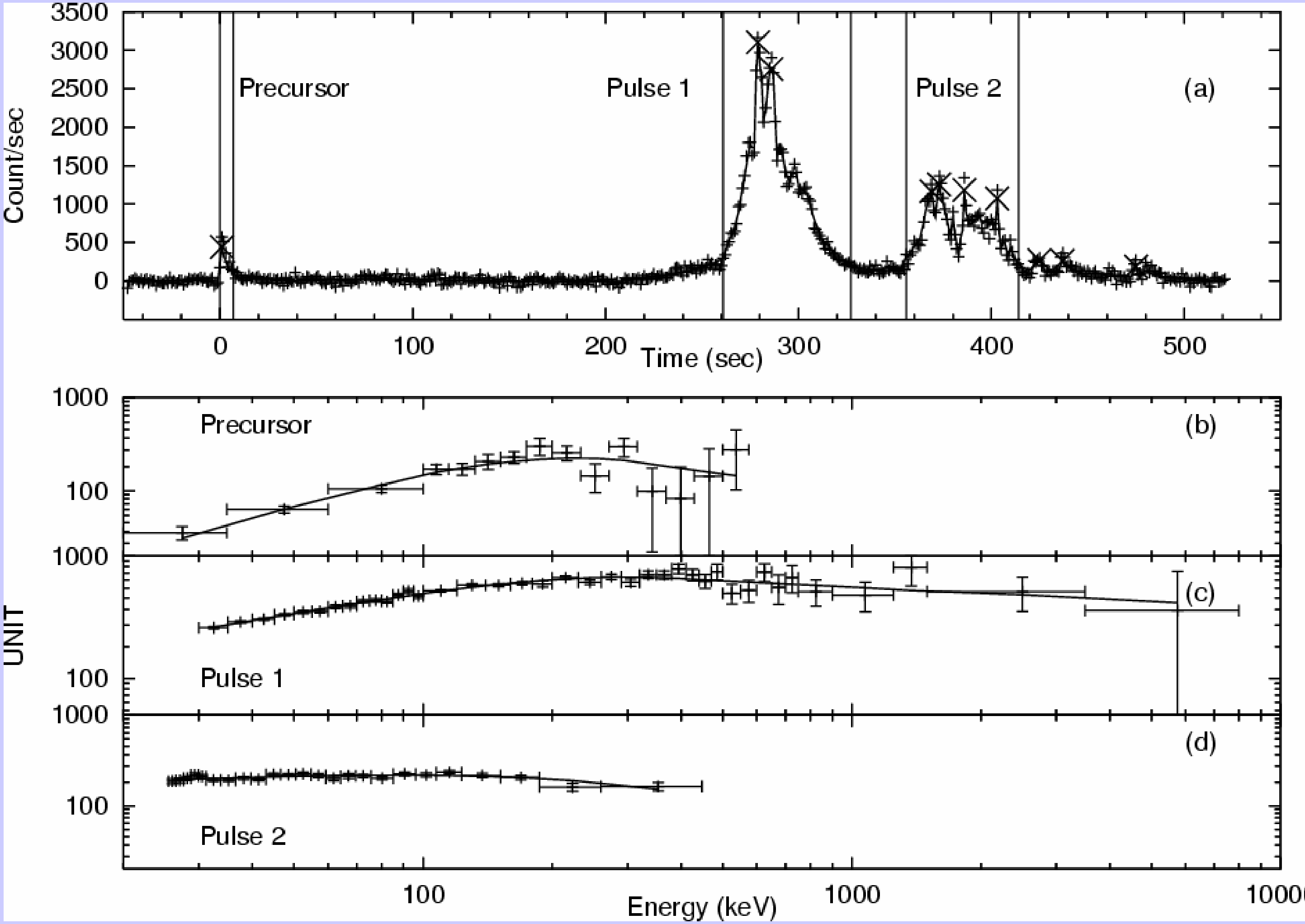


ISGRI 15-100 keV
ISGRI 15-100 keV



GRB 041219
IBIS/PICsIT (252-336 keV)
PICsIt 250-340 keV

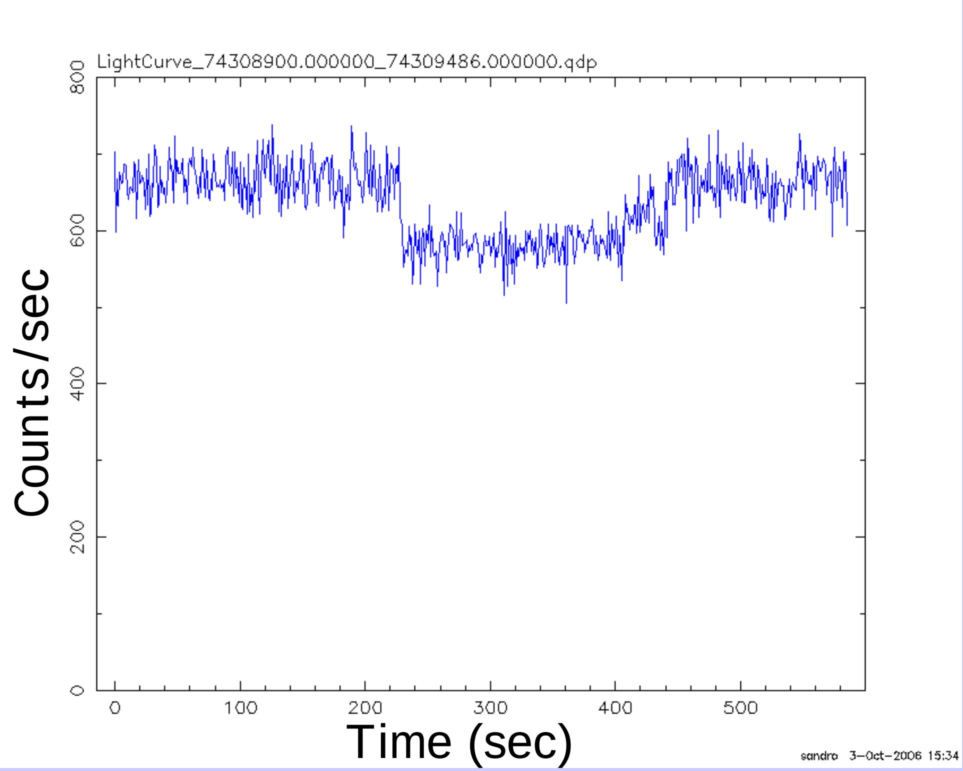
GRB041219 INTEGRAL SPI spectra - McBreen et al. 2005

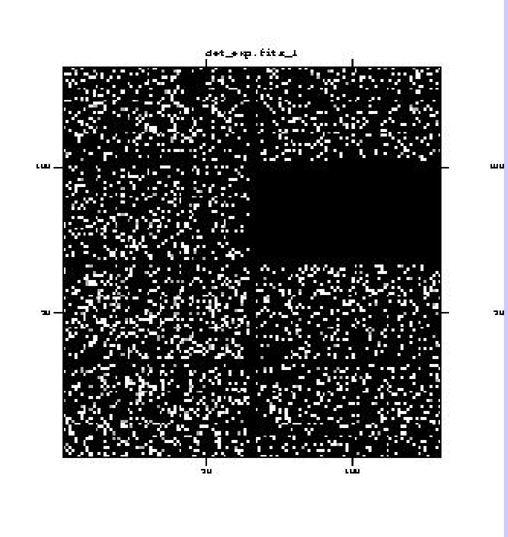


GRB 050223

GRB 050223
discovered by Swift;

IBAS alerts temporarily disabled
due to one noisy ISGRI module

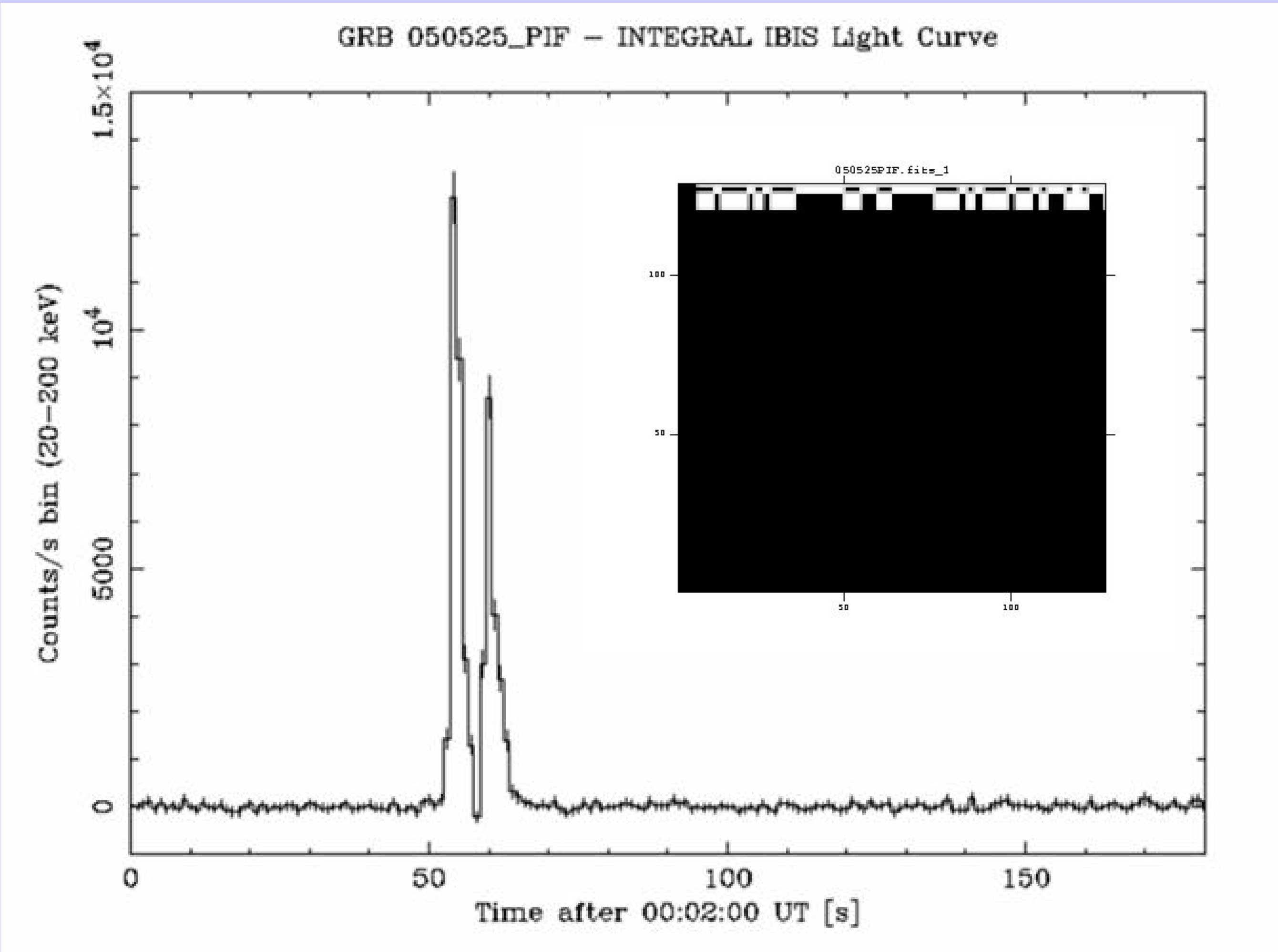


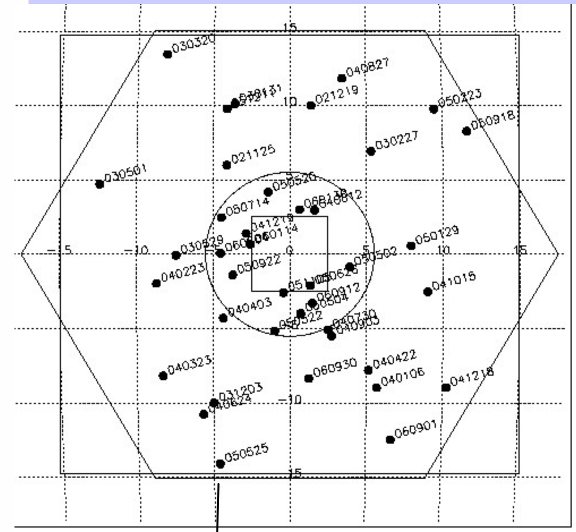


ISGRI detector is
divided in 8 modules

Switched off by on-board software when
become noisy

GRB 050525A





~14 degrees off-axis

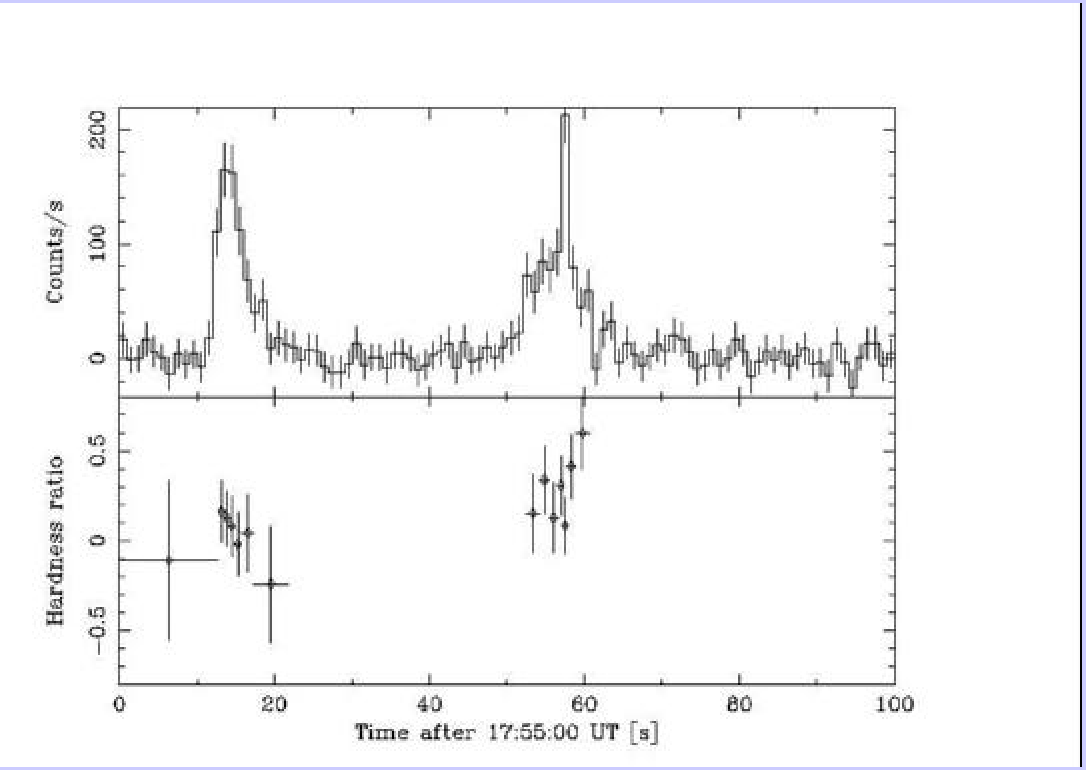
3 SWIFT GRBs seen by IBAS

- GRB 041219
  discovered by IBAS; Swift not fully operational yet
- GRB 050223
  discovered by Swift; IBAS alerts temporarily disabled
- GRB 050525A
  discovered by Swift; very large IBIS off-axis

No other Swift GRBs in INTEGRAL fov :

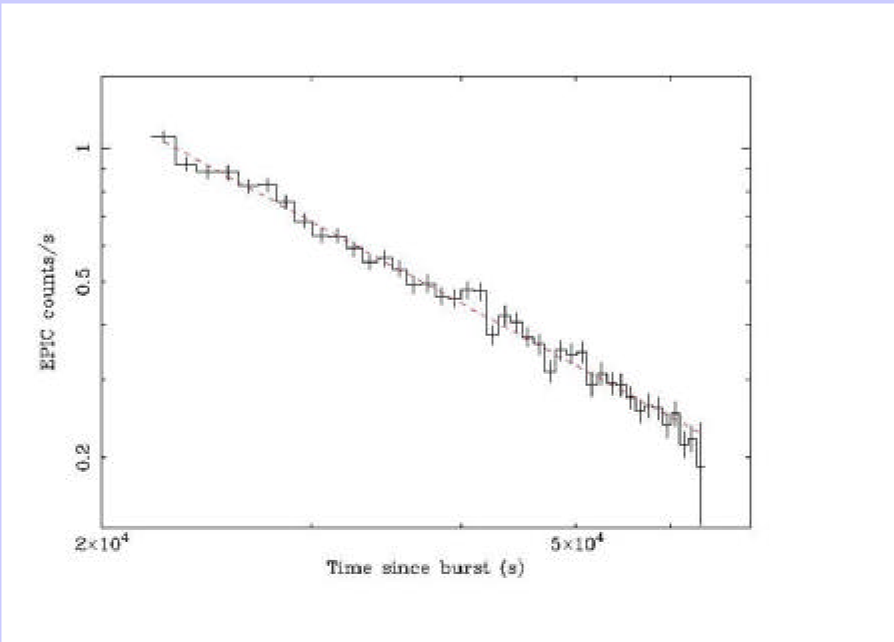
not surprising given different pointing constraints

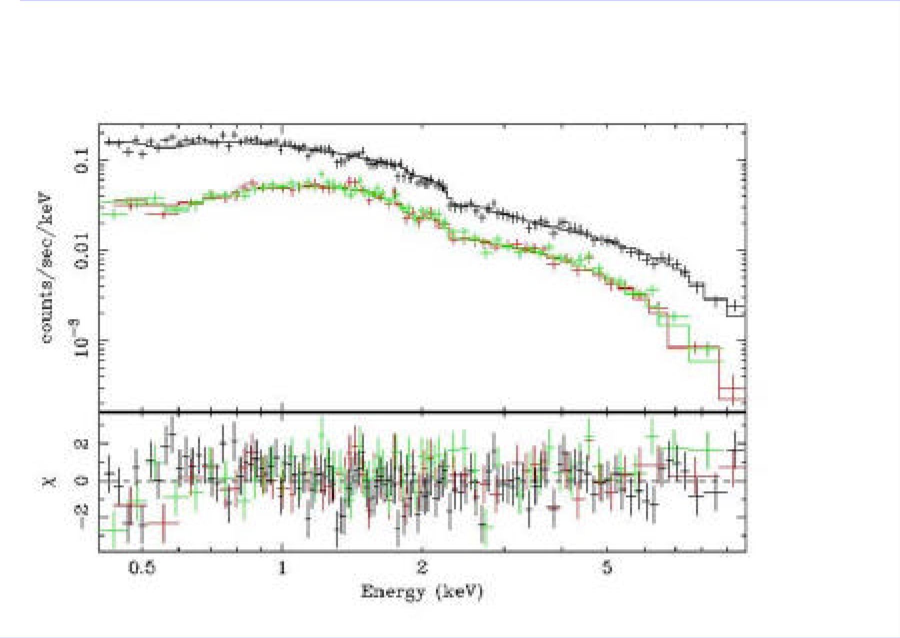
GRB 040106



Peak flux ~ 1 ph/cm^2/s
Fluence 8×10^{-7} erg/cm^2

GRB 040106
X-ray afterglow with XMM-Newton





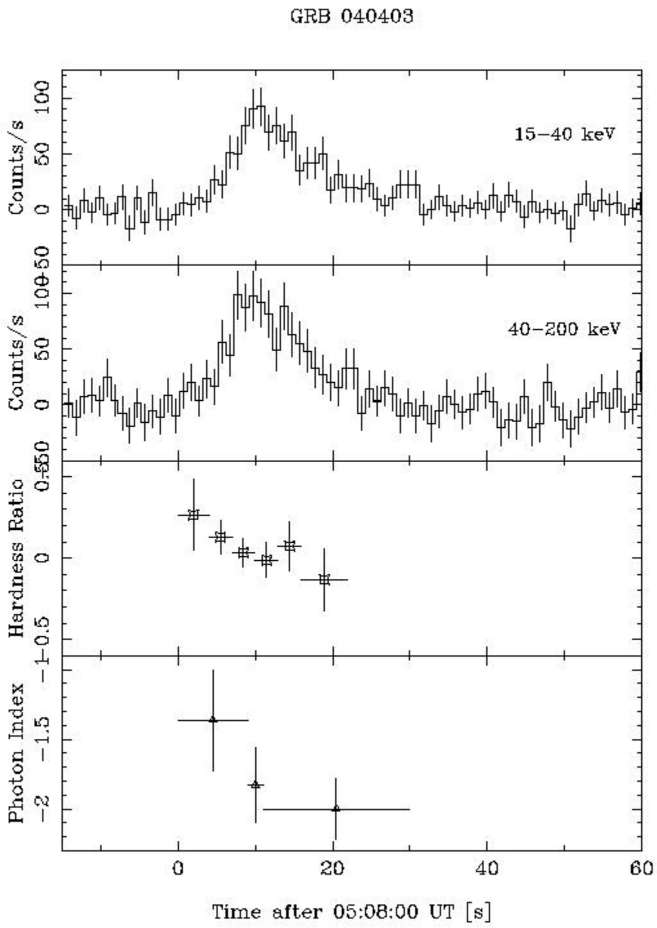
Time decay $t^{-1.46}$

Hard energy spectrum $N(E) \sim E^{-1.5}$

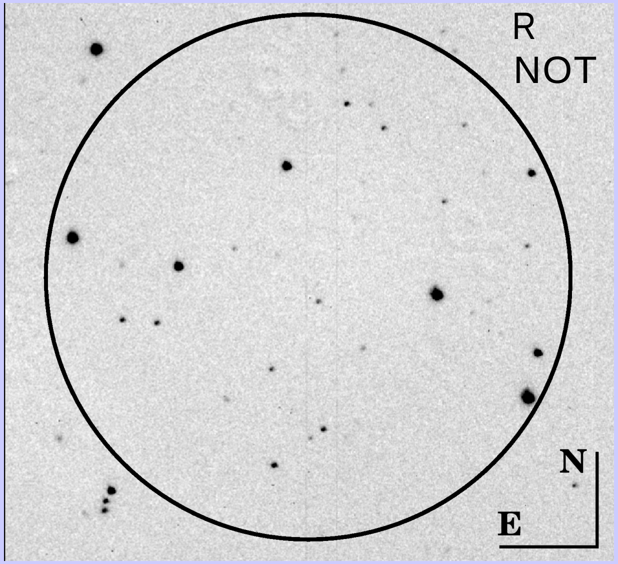
Evidence for expansion in a stellar wind (Gendre & Piro 2004)

GRB 040403

(Mereghetti et al 2004)

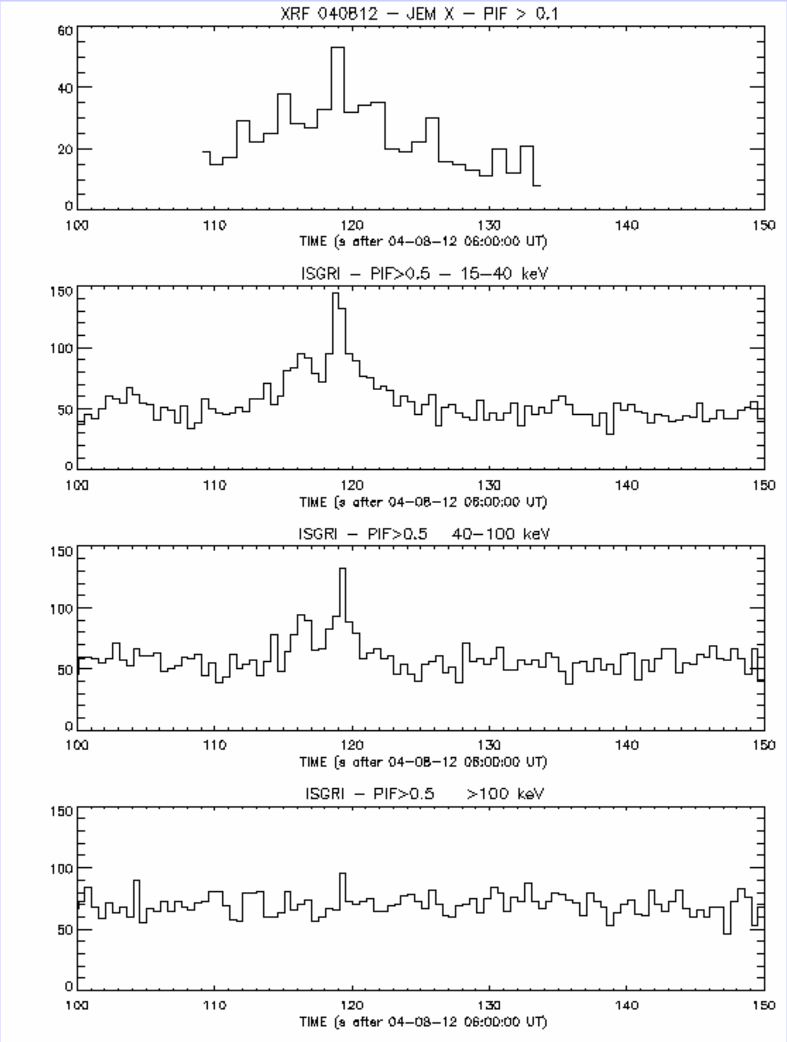


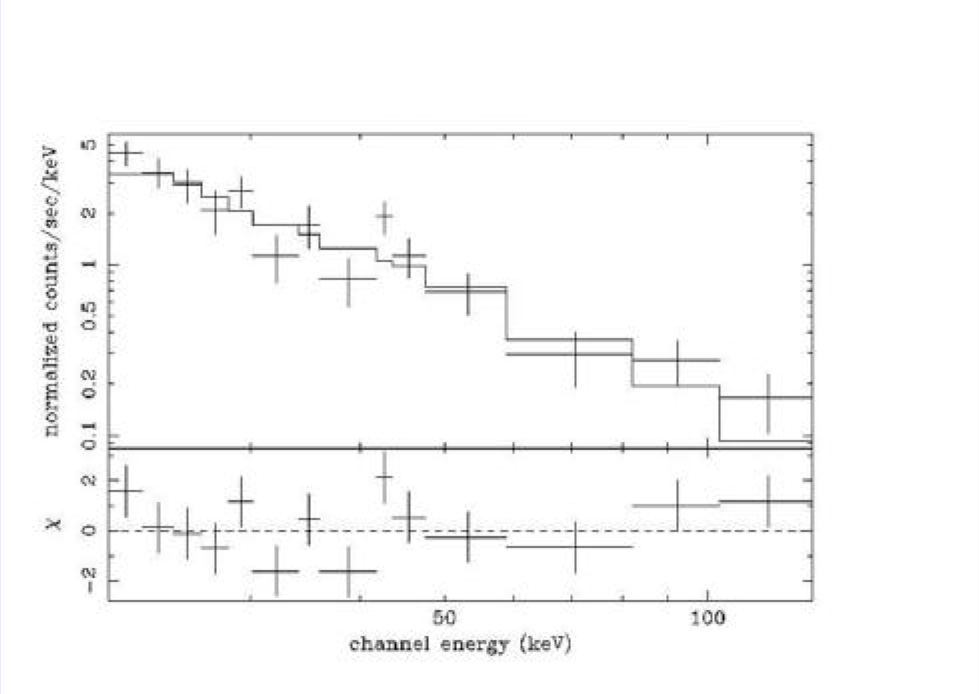
Peak flux ~ 0.5 ph/cm^2/s
Fluence 5x10^{-7} erg/cm^2



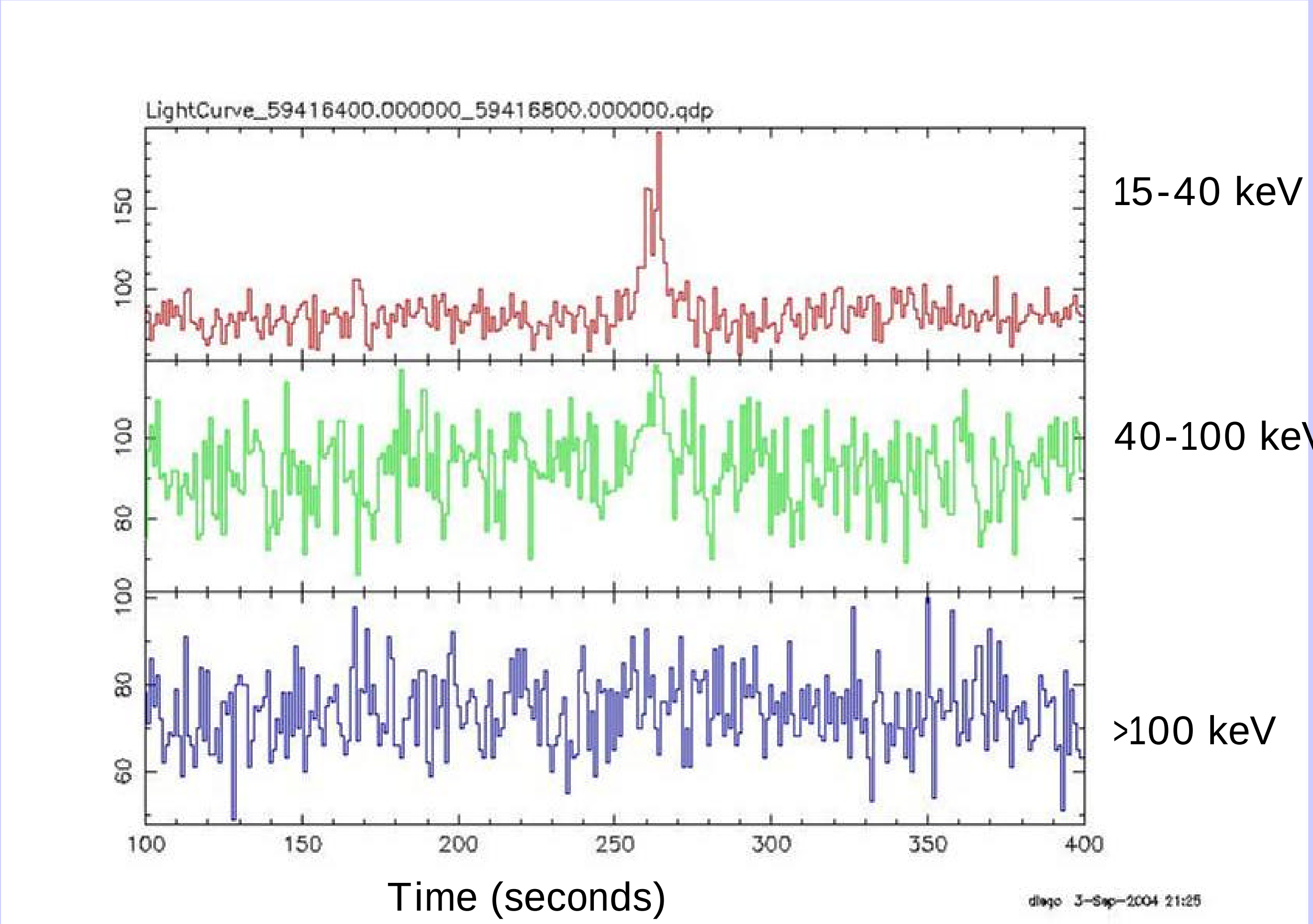
X-ray rich
Optically faint R>24.2 @ 16 hr

GRB 040812 : first GRB in JEM X fov





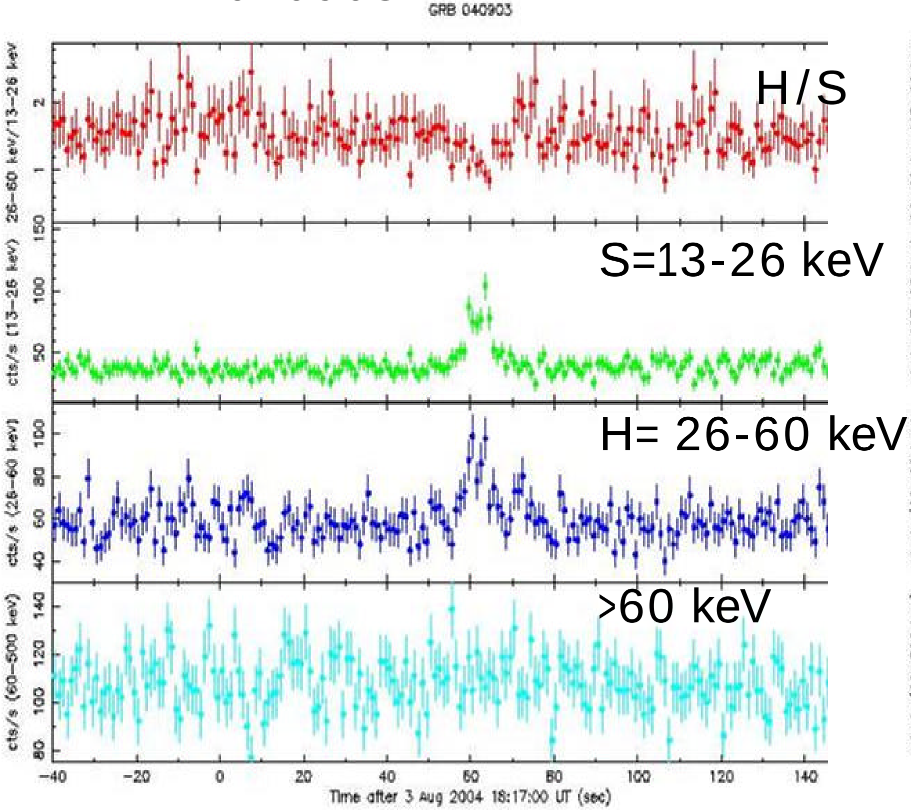
XRF 040903



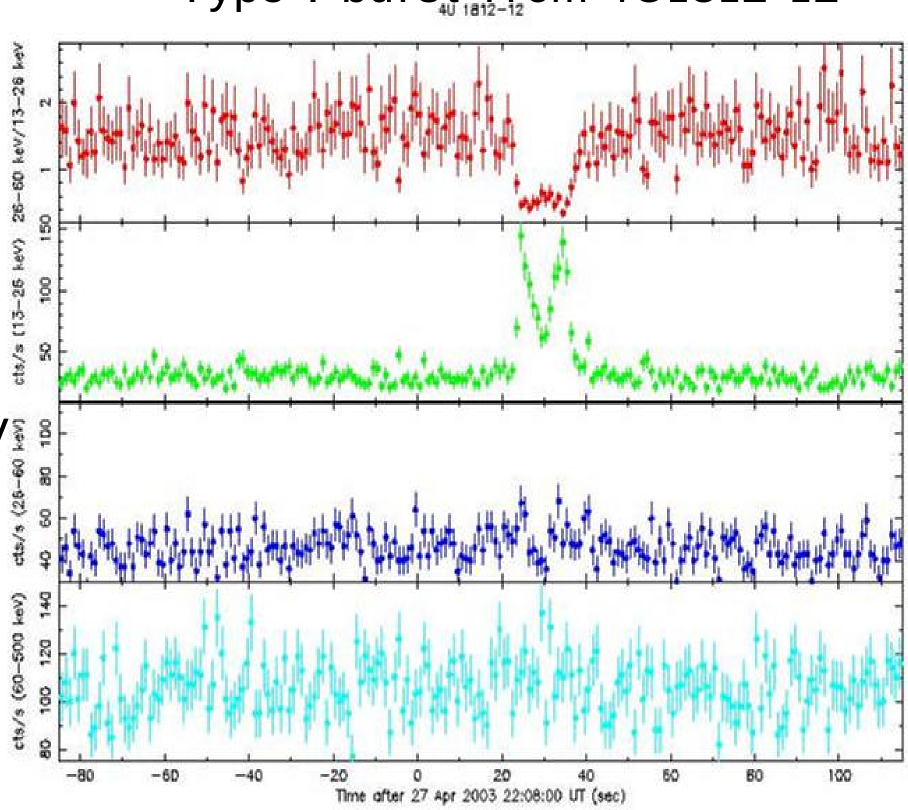
LightCurve_59416400.000000_59416800.000000.qdp
15-40 keV
40-100 keV
>100 keV
Time (seconds)
100
150
200
250
300
350
400
dlego 3-Sep-2004 21:25

XRF 040903

XRF 040903

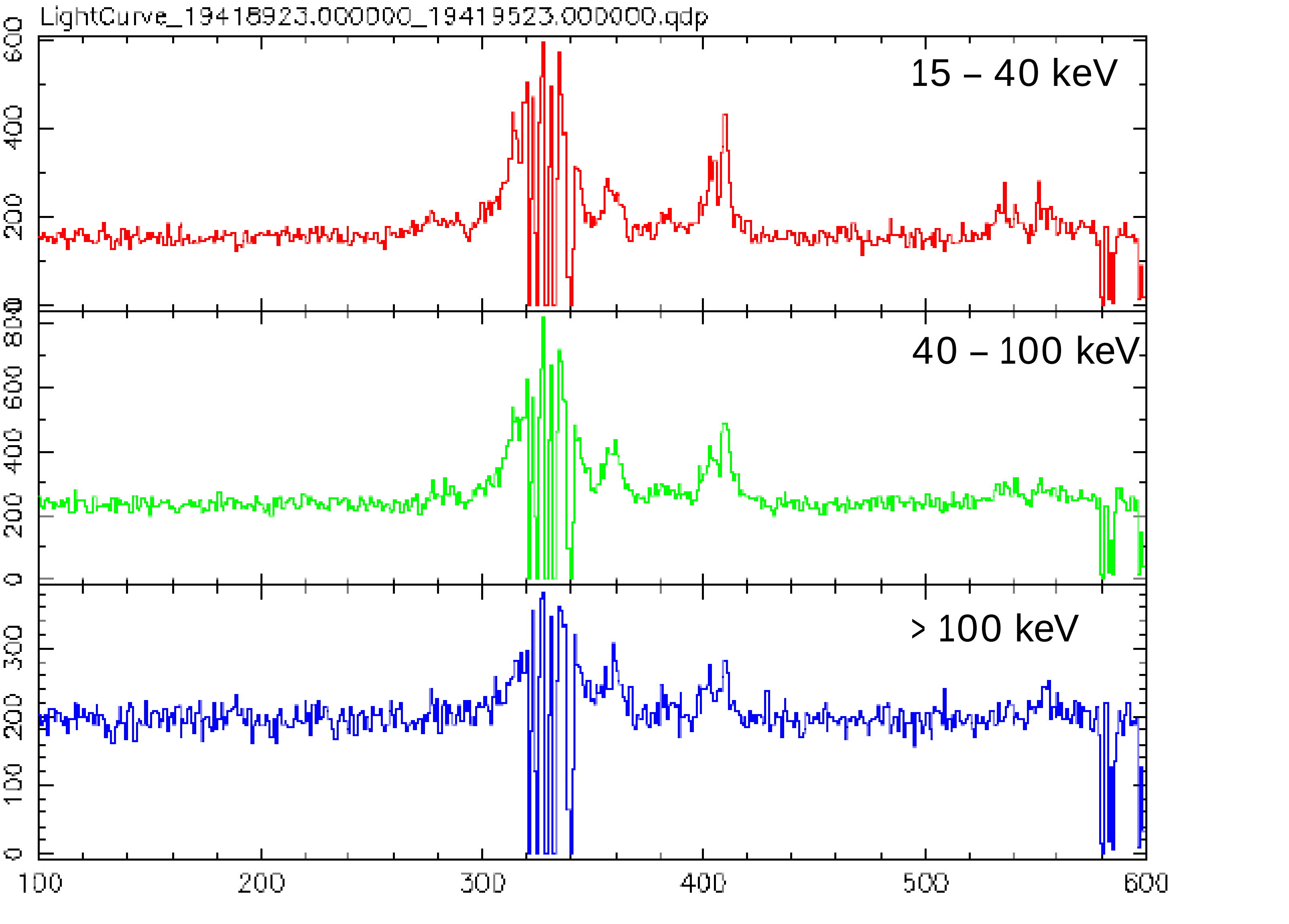


Type I burst from 4U1812-12

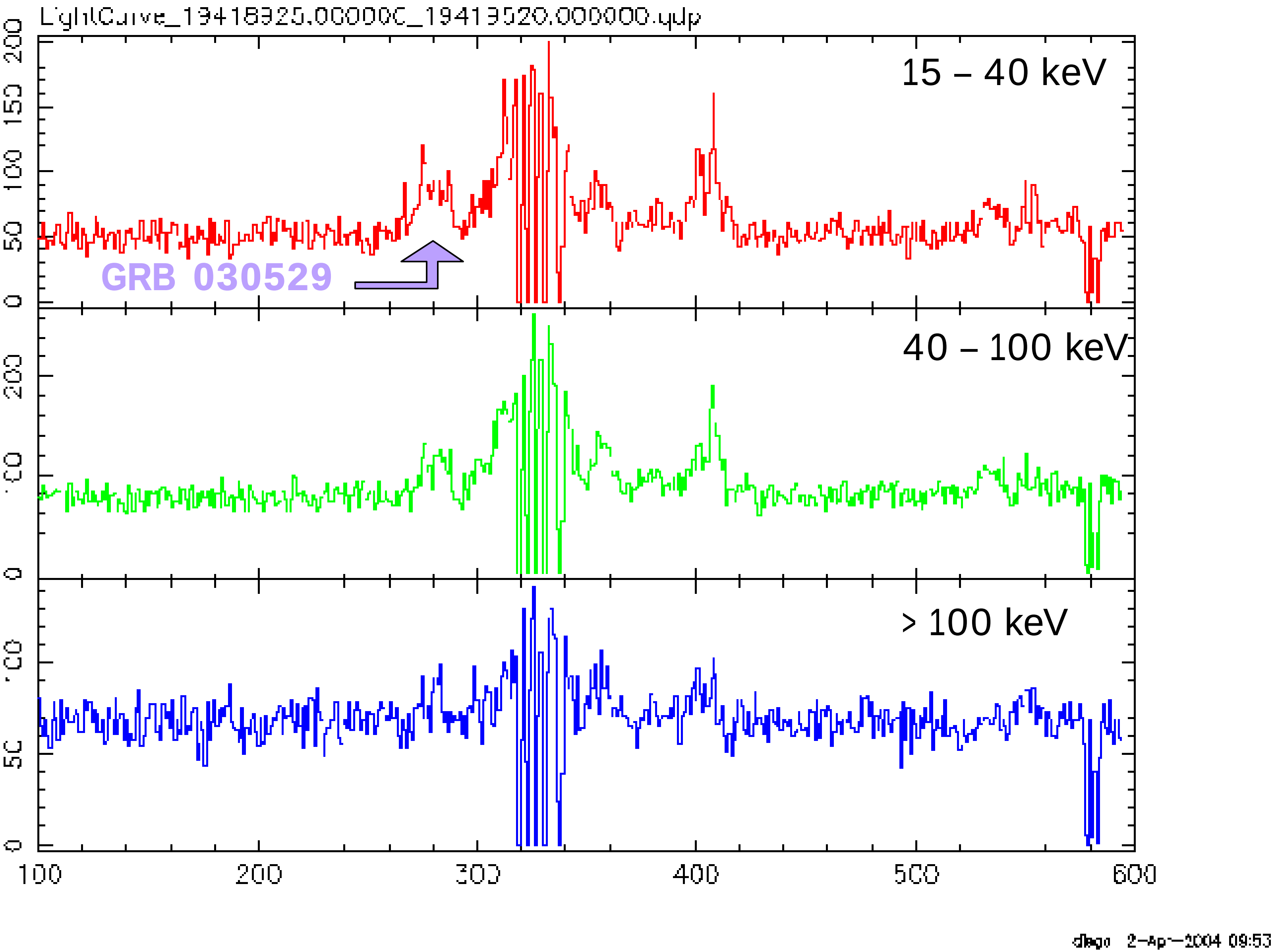


(Kuulkers et al. 2004, GCN Circ)

GRB 030529: an untriggered GRB



GRB 030529: an untriggered GRB



Dust scattering X-ray expanding rings

Now seen around 3 GRBs:

031203	INTEGRAL / XMM	Vaughan et al 2004
050713A	Swift BAT / XMM	Mereghetti & Tiengo 2006
050724	Swift BAT / Swift XRT	Vaughan et al. 2006

X-ray dust halos: brief history - 1

1965: **Overbeck** points out that celestial point X-ray sources should be surrounded by diffuse emission due to dust scattering (Overbeck 1965, ApJ 141, 864)

1970 → 1980: it is recognized that this can be an important tool to obtain information on size, spatial distribution and composition of interstellar dust
(e.g., Hayakawa 1970, Progr. Theor. Phys.43, 1224)

1983: first detections with **Einstein Observatory**
Rolf 1983 Nature 302, 46 (PSPC, GX 339-4)
Catura 1983 ApJ 275, 645 (HRI, several GX sources)

1985 → now: Many works on galactic sources with all imaging X-ray telescopes
Einstein Observatory: Mauche & Gorenstein 1986, ApJ 302, 371
ROSAT: Predehl & Schmitt 1995, A&A 293, 889
Chandra: Tan & Draine 2004, ApJ 606, 296; Xiang et al. 2006, ApJ 628, 769

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

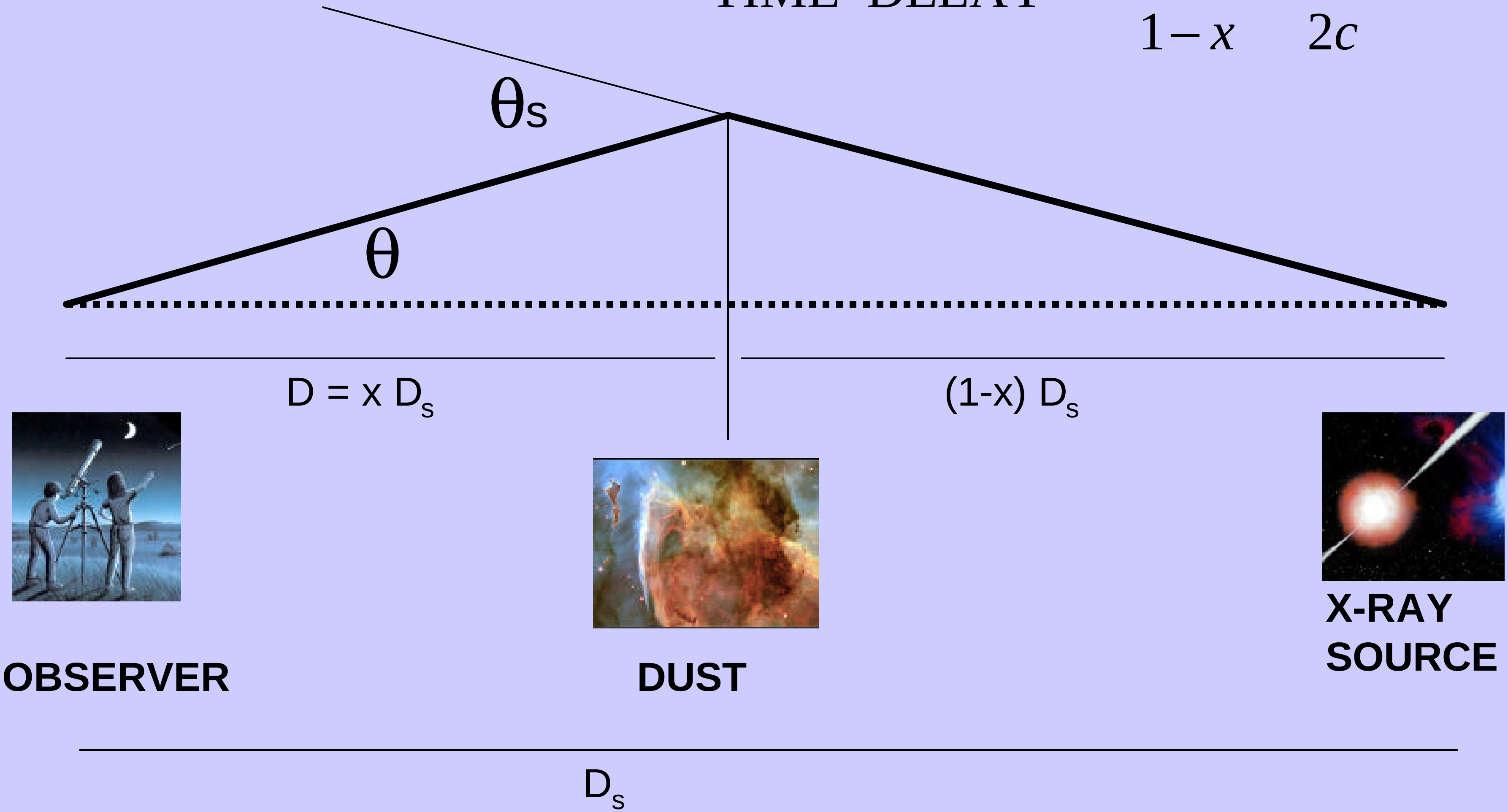
$$\text{SIZE OF HALO} \approx \frac{10\,\text{arcmin}}{E\,[\text{keV}]\;\; a\,[0.1\,m\text{m}]}$$

Halo profile is energy-dependent
and is determined by:

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

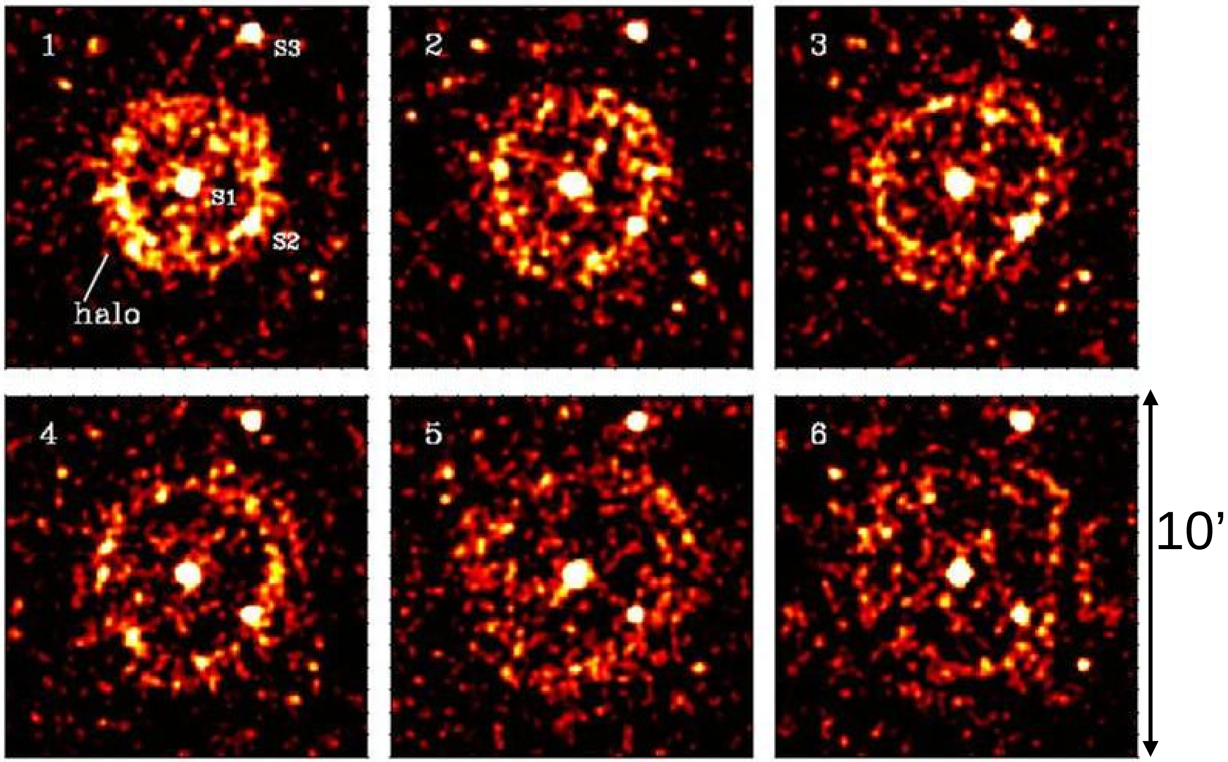
- dust distribution along line of sight

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

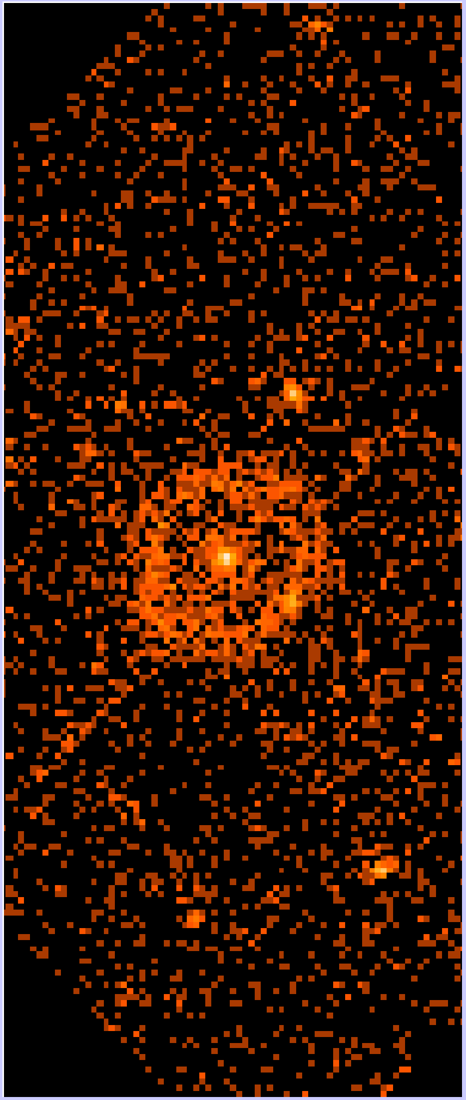


GRB 031203

EPIC MOS (Vaughan et al 2004)



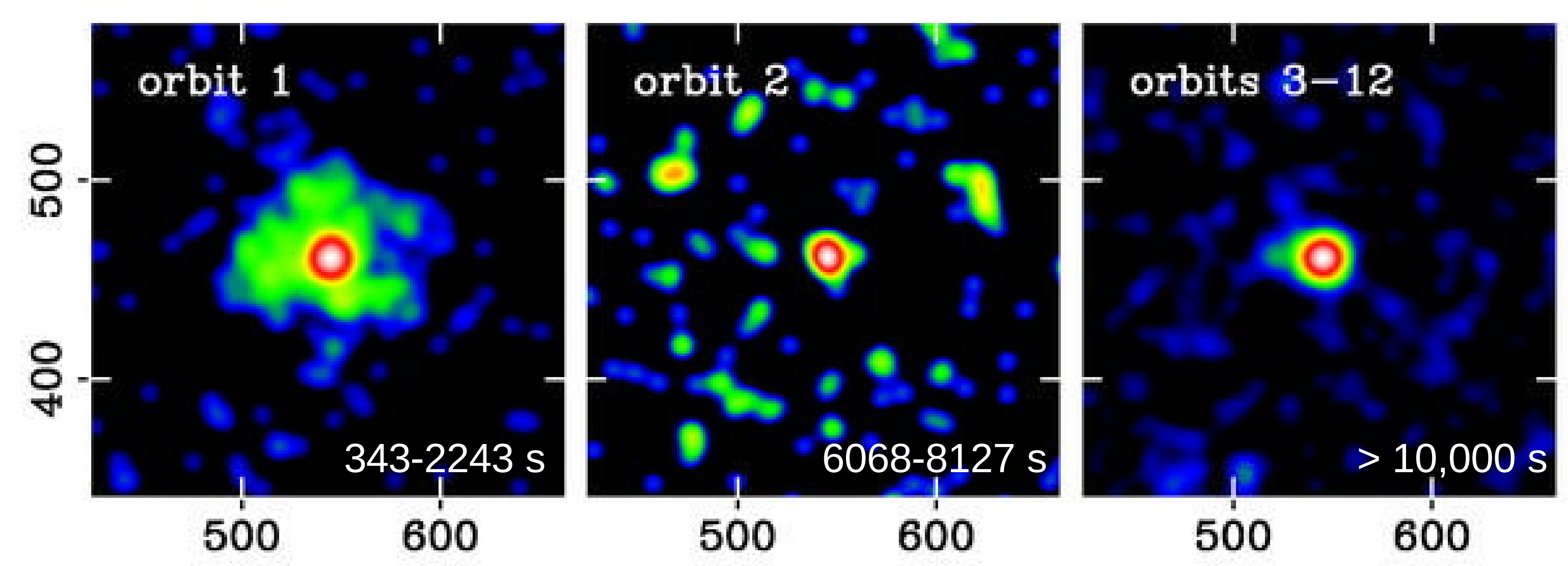
EPIC pn



58 ks observation starting at t_o+ 6 hrs

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

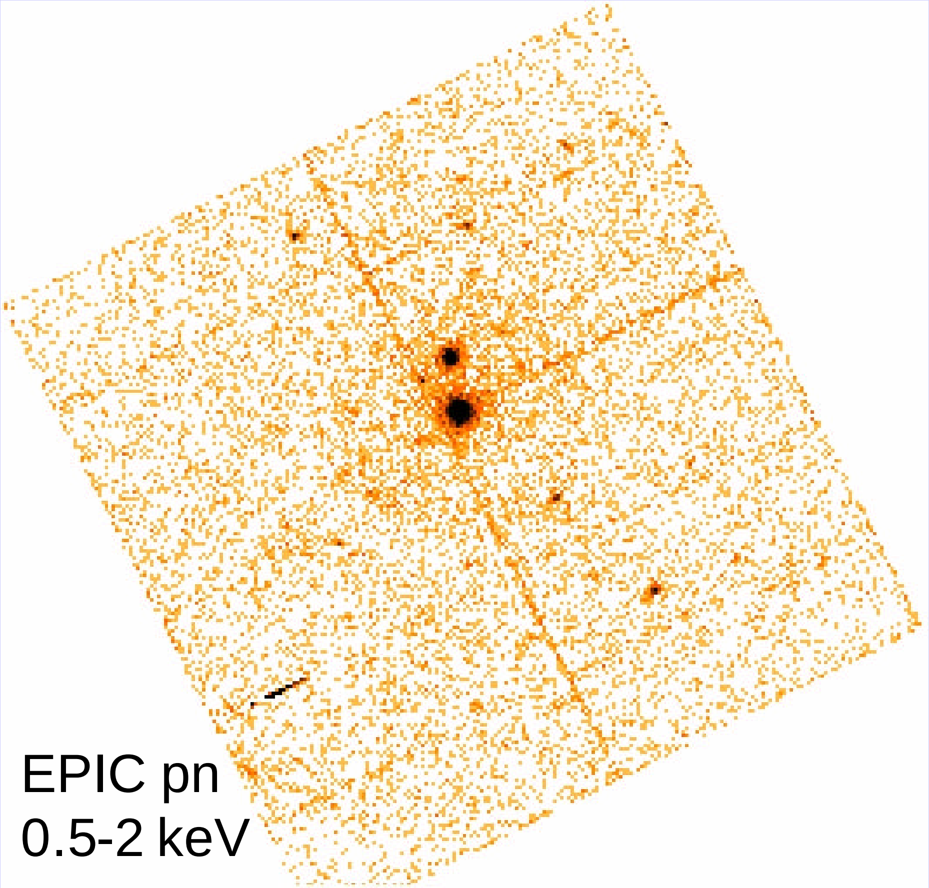
GRB 050724 (Vaughan et al. 2006)



Swift XRT observation starting at t_o+ 343 s

Narrow (<22 pc) dust layer at D=139 pc

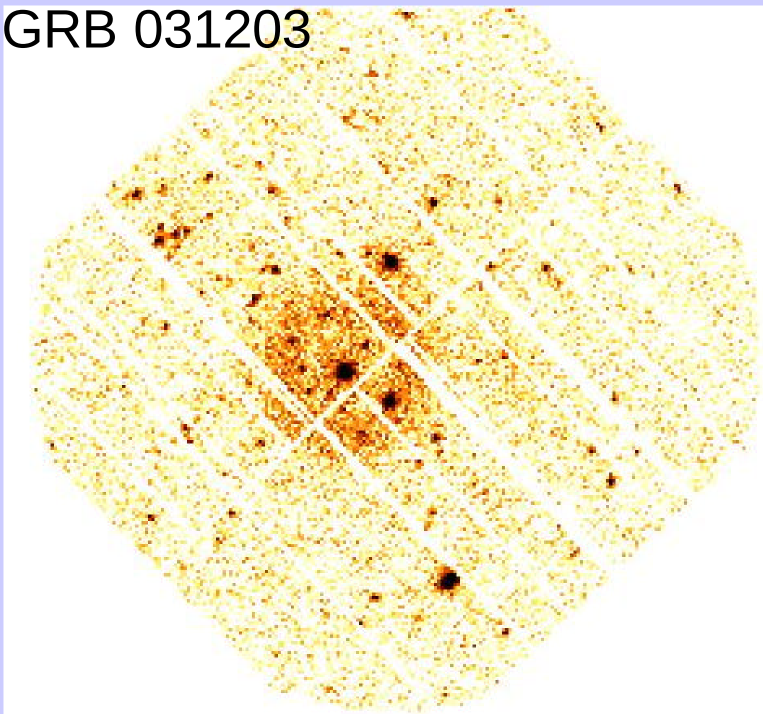
GRB 050713A



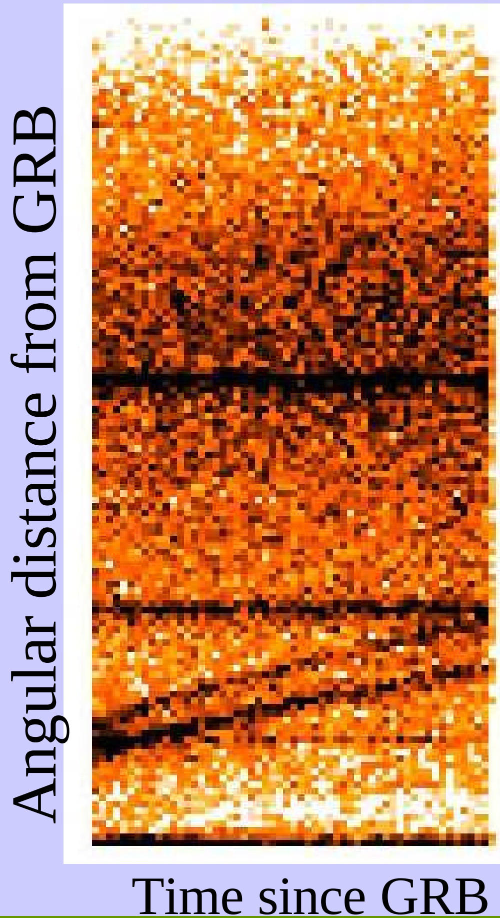
- Discovered by Swift
- XMM Observation starting at t_o+23 ks
- 30 ks long but only 9 ks useful due to high background

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

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



REBINNING



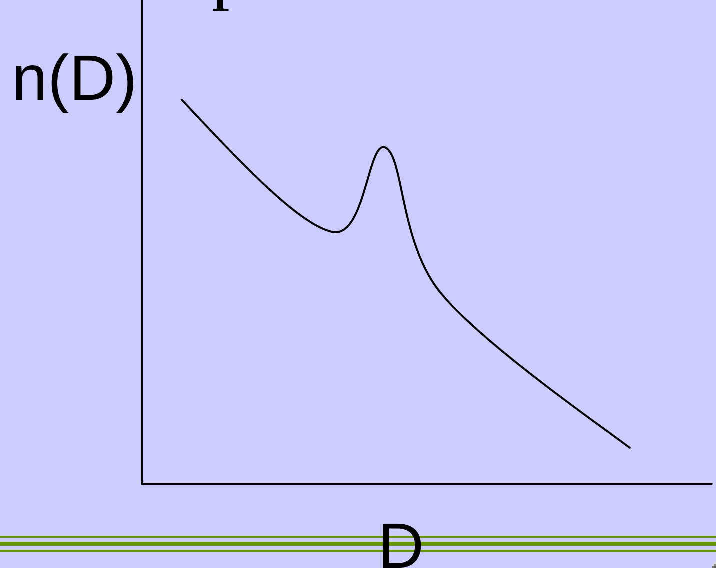
For each count detected in the X-ray image compute the quantity:

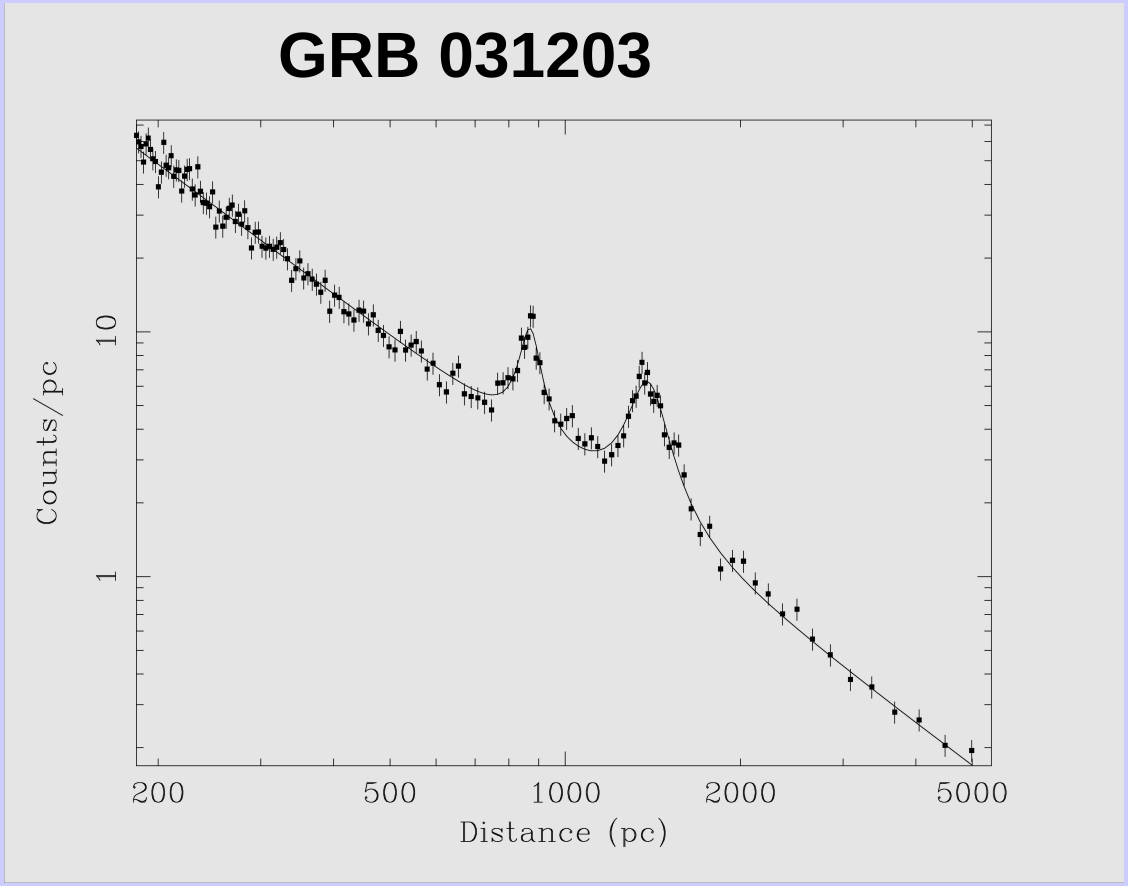
$$\frac{2ct_i}{q_i^{\,2}} \equiv D_i$$

t_i = time from the GRB

q_{i} = angular distance from GRB position

and plot the distribution of the D_i values





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

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

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

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

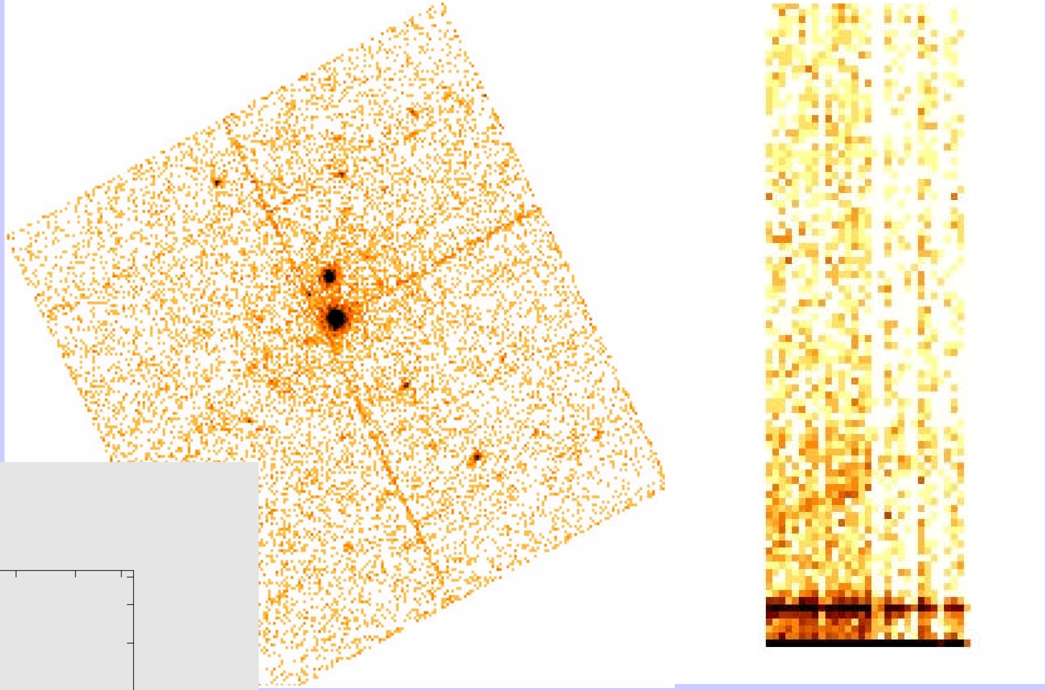
$$N_2 = 1740^{+270}_{-240} \text{ counts}$$

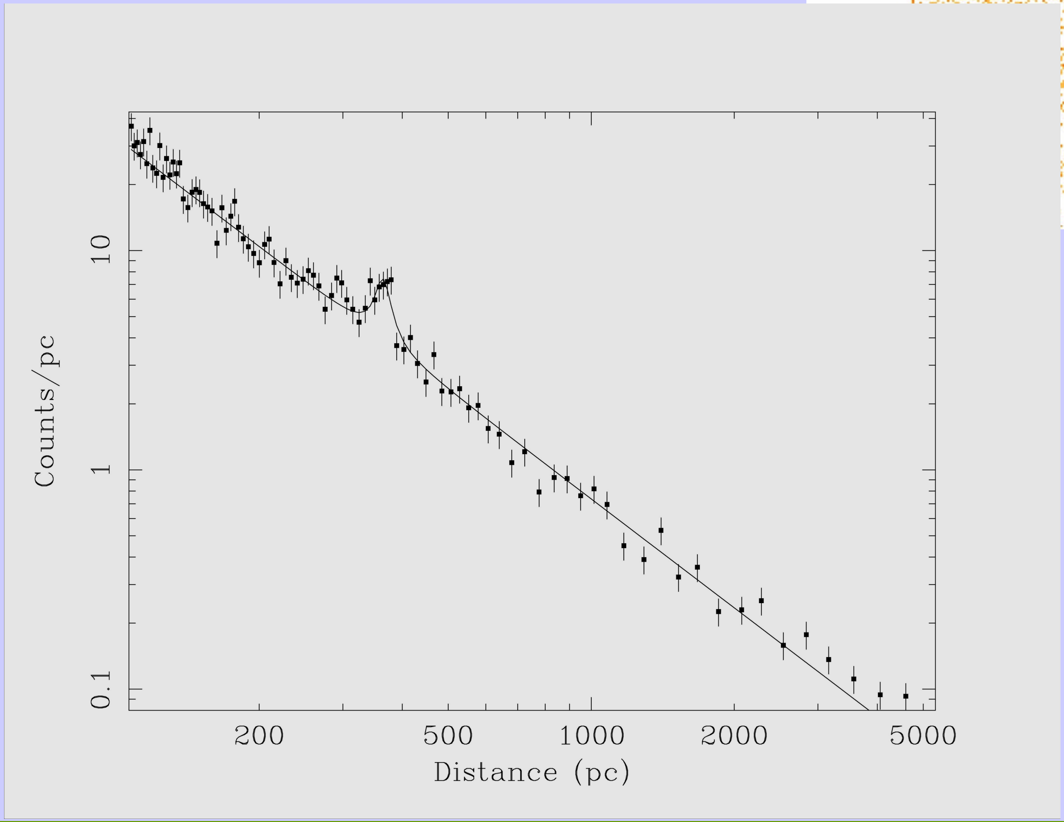
$$FWHM_2 = 240 \pm 30 \text{ pc}$$

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





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

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

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

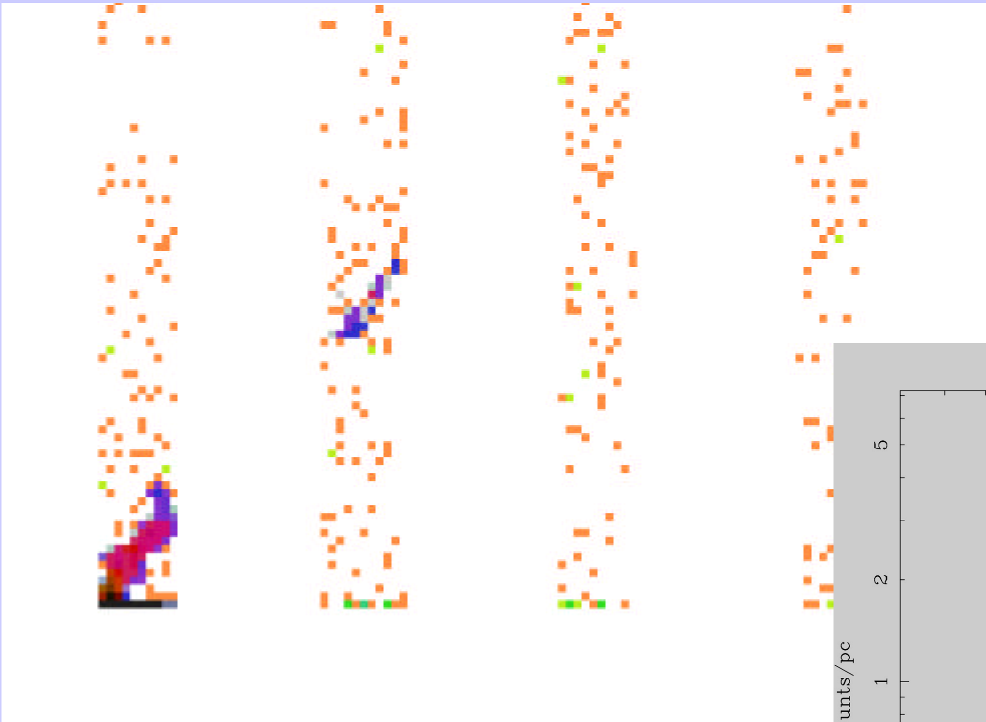
We applied this method to all GRBs observed with XMM-Newton and Swift

- XMM: 15 GRBs with follow-up observations starting at t ~ 20-60 ks and lasting few tens of ks

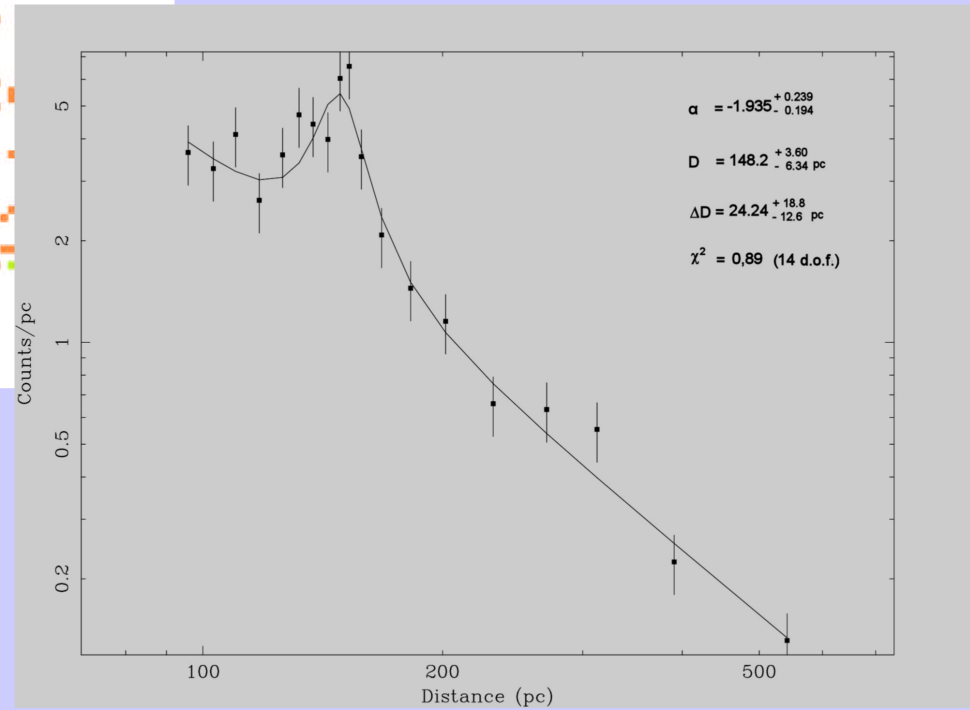
→ No other dust rings detected, besides 031203 and 050713A

- Swift: follow-up data for ~160 GRBs, with different quality/sensitivity

→ Only 050724 “rediscovered”



GRB 050724
0.2 – 5 keV

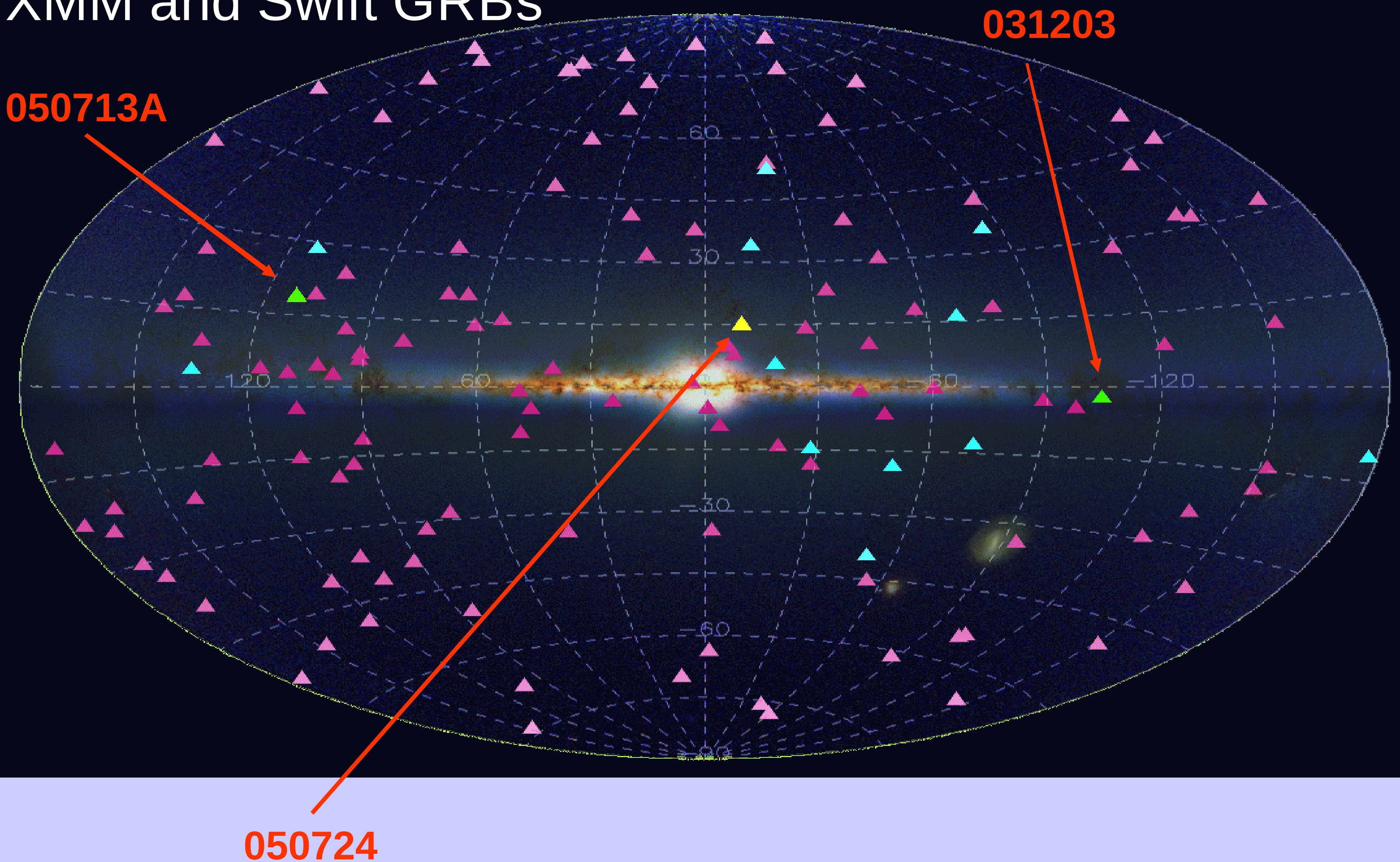


$$D = 148^{+4}_{-6} \ \text{pc}$$

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

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

XMM and Swift GRBs



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:

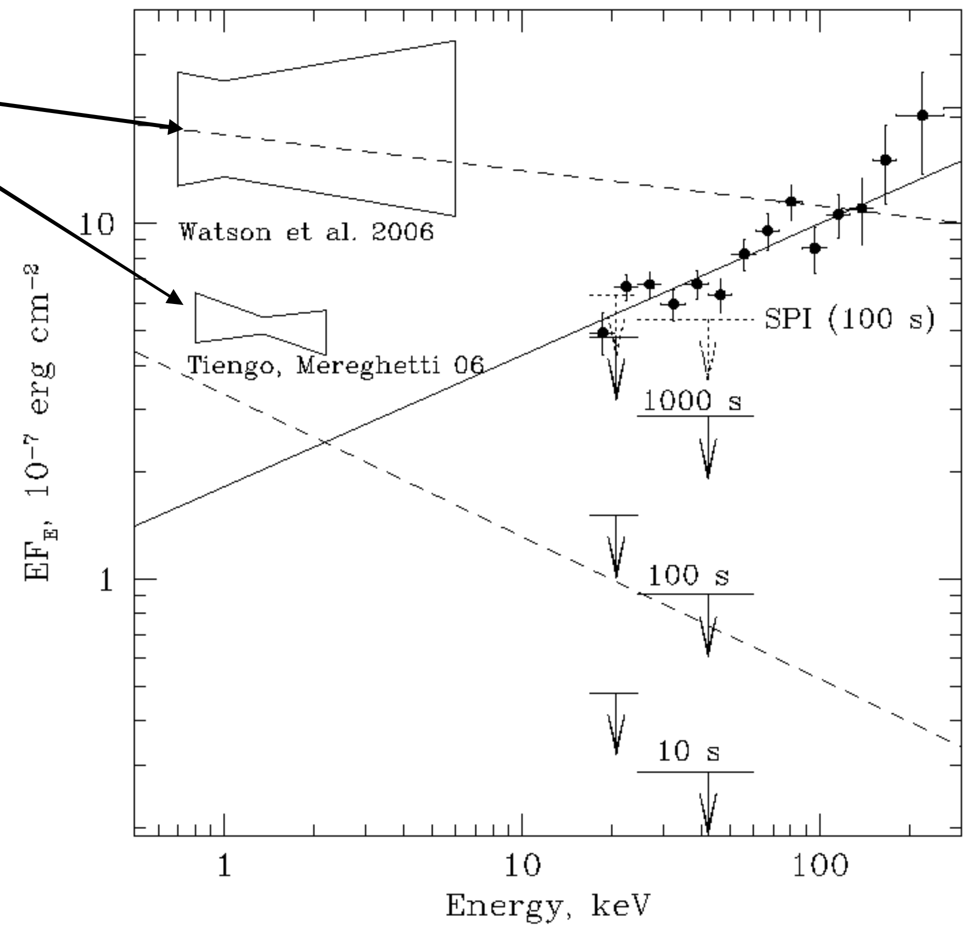
Draine & Bond 2004 → $t \approx 0.15 A_V E_{keV}^{-1.8}$

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

The estimate of the X-ray "prompt" emission is subject to a large uncertainty

… but even the most conservative value is above the extrapolation of the high energy INTEGRAL spectrum

GRB 031203



Sazonov et al. 2006, Astronomy Letters 32, 297

Summary

- Expanding dust rings detected in 3 GRBs (out of ~170)

- “Dynamical images” and distribution of “D” values offer a sensitive detection method

- *In principle* halos can provide information on prompt emission, not directly observed (e.g. GRB 031203)

- Very powerful to study dust properties and distribution when both direct and scattered radiation are detected (→ extremely accurate distance measurements for dust layers)

Final considerations

- INTEGRAL was not designed/optimized for GRB studies
- IBAS is one of the most successful achievement of INTEGRAL
- Data policy for INTEGRAL GRBs is now inadequate → action on IUG - all GRB data should be immediately public !!