



# MeV Observations of Compact Objects with IBIS/PICsIT

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Cocco<sup>(1)</sup>, A. Goldwurm<sup>(2)</sup>, G. Malaguti<sup>(1)</sup>, T. Mineo<sup>(3)</sup>

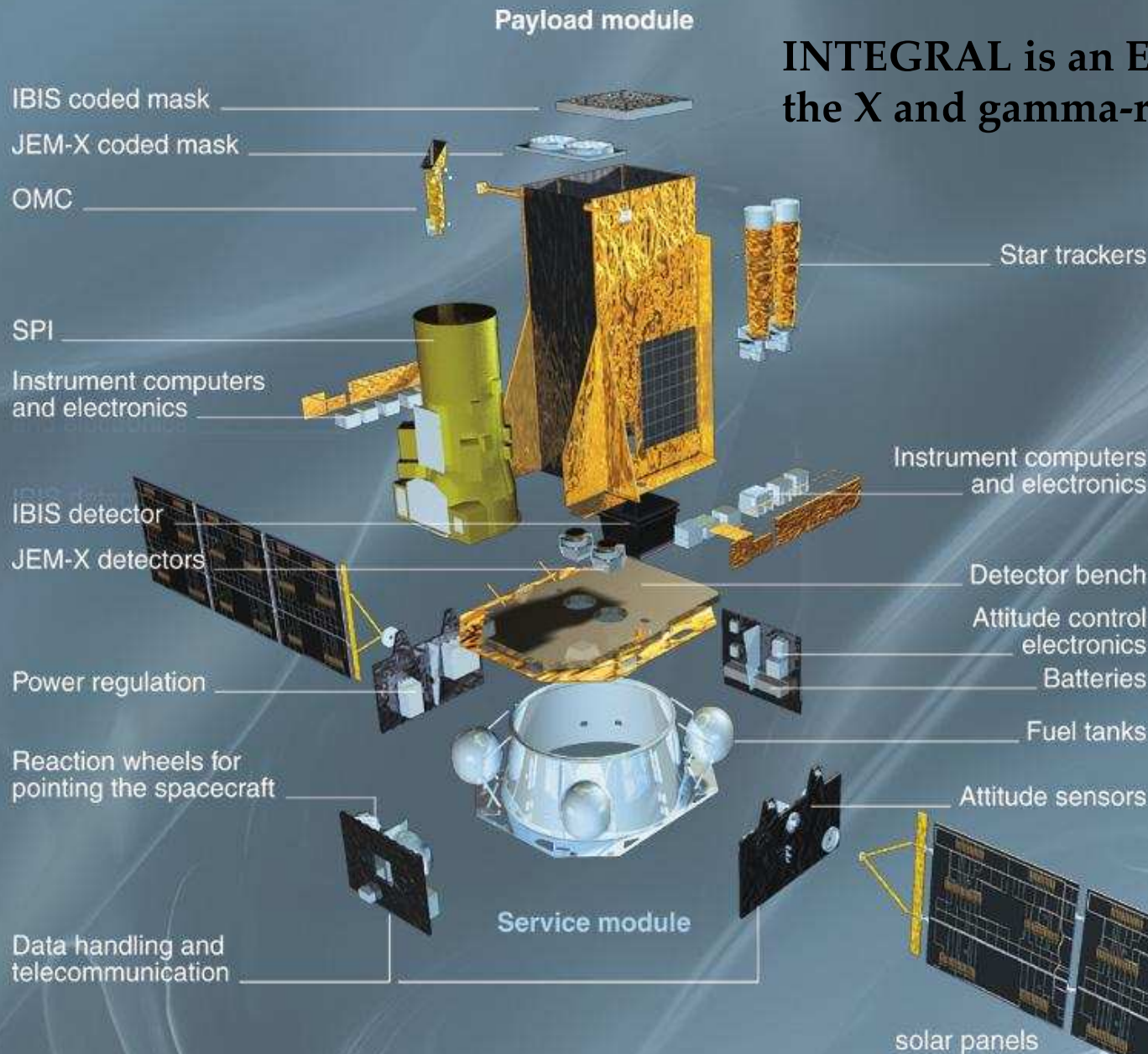
(1) INAF/IASF-Bologna; (2) SAp/CEA-Saclay; (3) INAF/IASF-Palermo



*4th National Meeting on Compact Objects*  
Padova, 23-25 November 2005



**INTEGRAL is an ESA mission dedicated to the X and gamma-ray astrophysics.**

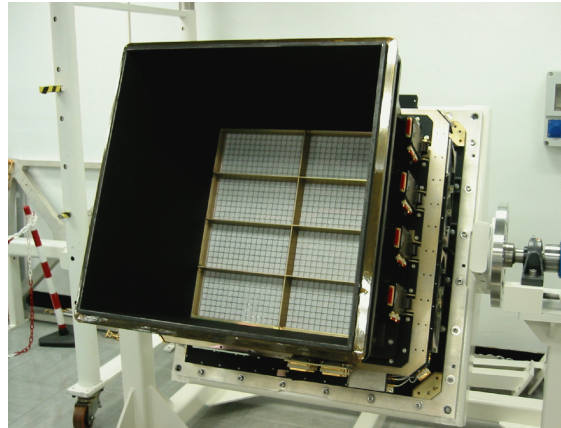
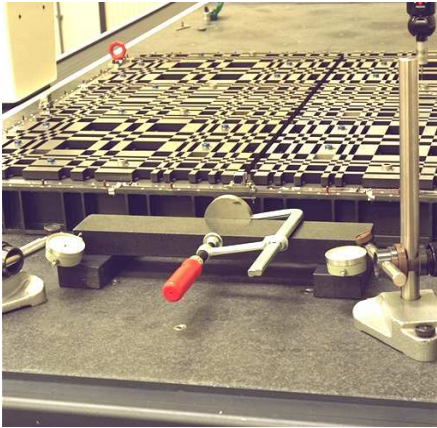


**Launched with a Russian Proton rocket from Baikonhour on 17/10/2002.**

**INTEGRAL Satellite Exploded View**



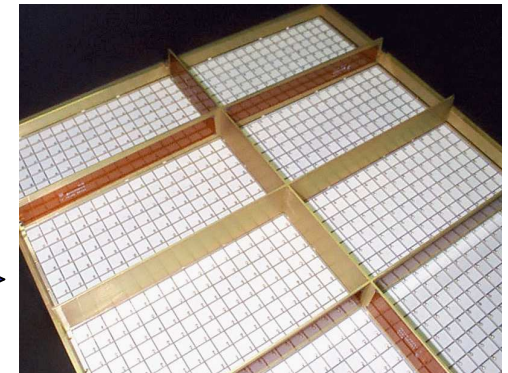
# IBIS (Imager on Board the Integral Satellite)



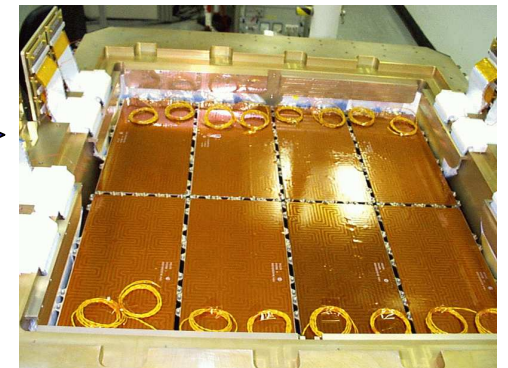
**IBIS** (Ubertini P., Lebrun F., Di Cocco G., et al, 2003, A&A 411, L131) is optimized for high-resolution (12'), wide FOV ( $29^\circ \times 29^\circ$ ), point sources imaging and moderate energy resolution (8% @ 100 keV, 10% @ 1 MeV). It is composed of 2 detectors:



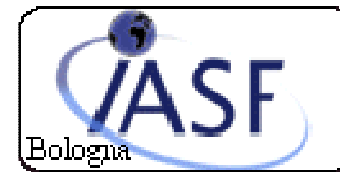
**ISGRI**, CdTe detector in the range 15 keV – 1 MeV; 128x128 pixels organized in 8 modules; 5' pixel (Lebrun et al., 2003, A&A 411, L141).



**PICsIT**, CsI detector in the range 175 keV – 10 MeV; 64x64 pixels organized in 8 modules; 10' pixels (Di Cocco et al., 2003, A&A 411, L189).



## IBIS coded mask

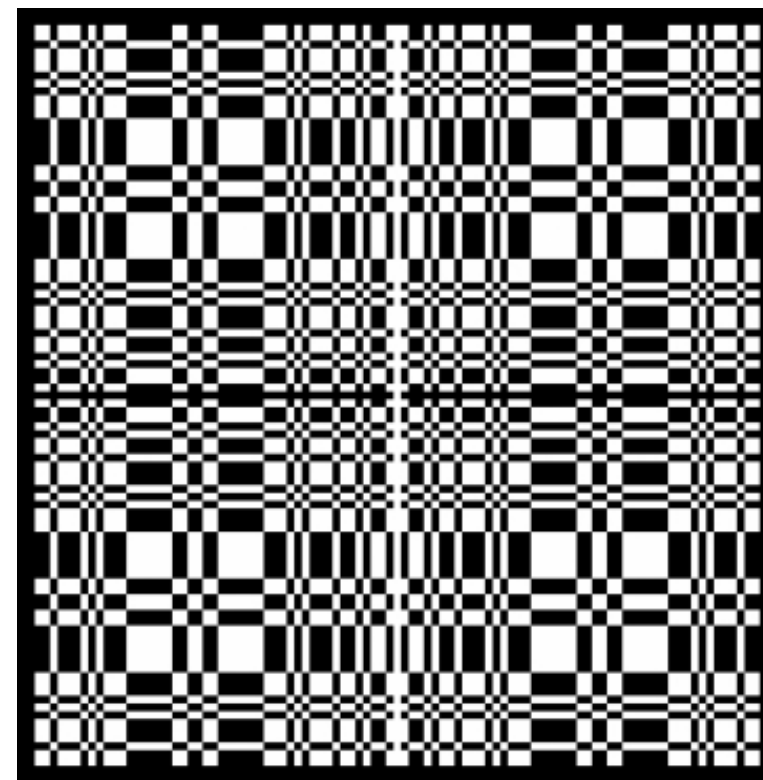


Coded masks are used in gamma-ray astronomy and different patterns are used according to the performances requested.

Black = Closed  
White = Open



For IBIS, the **Modified Uniformly Redundant Array (MURA)** mask is used to maximize performances in point-sources reconstruction.



# IBIS SPSF and FOV



## Basic definitions for IBIS:

### Fully Coded FOV

$$\text{FCFOV} = \arctan[(D_M - D_D)/L]$$

### Partially Coded FOV

$$\text{PCFOV} = \arctan[(D_M + D_D)/L]$$

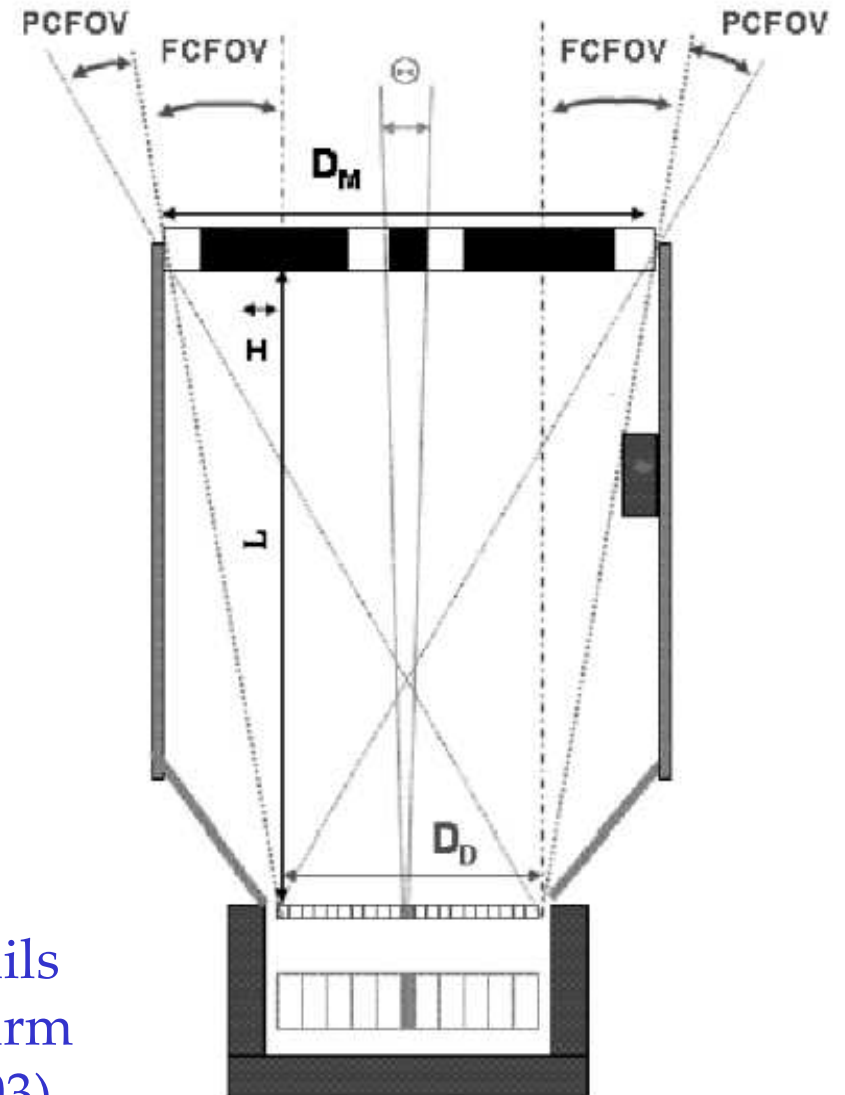
### Telescope Angular Resolution

$$\Theta = \arctan(H/L)$$

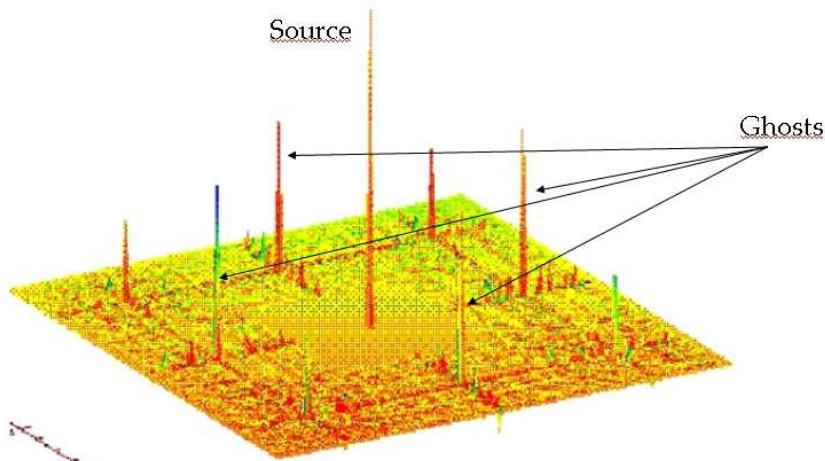
9°x9° IBIS

29°x29° IBIS

12' IBIS



## IBIS Point Spread Function (PSF)



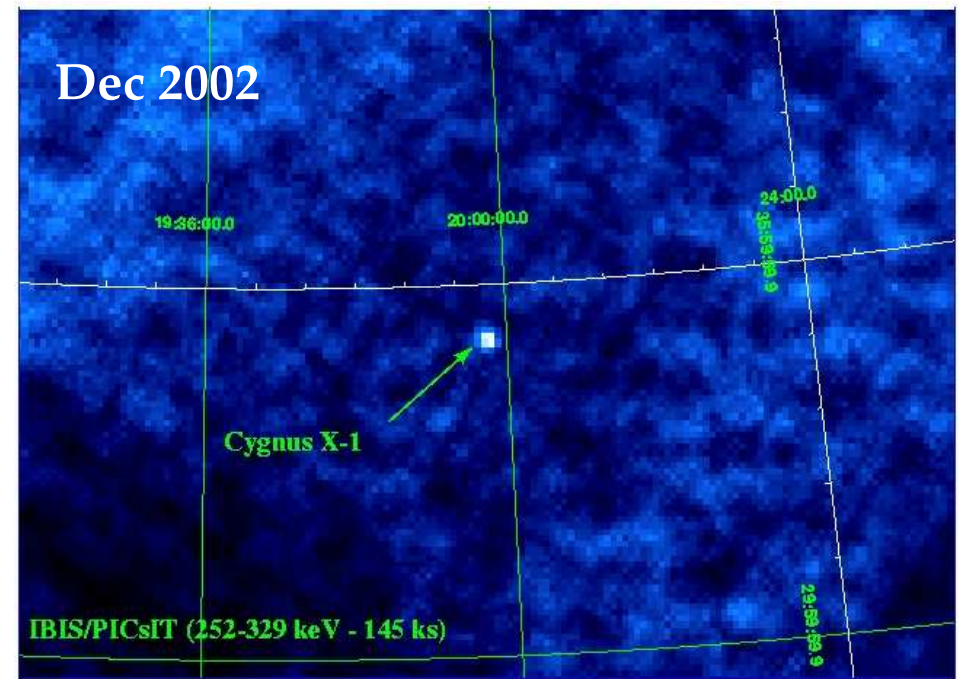
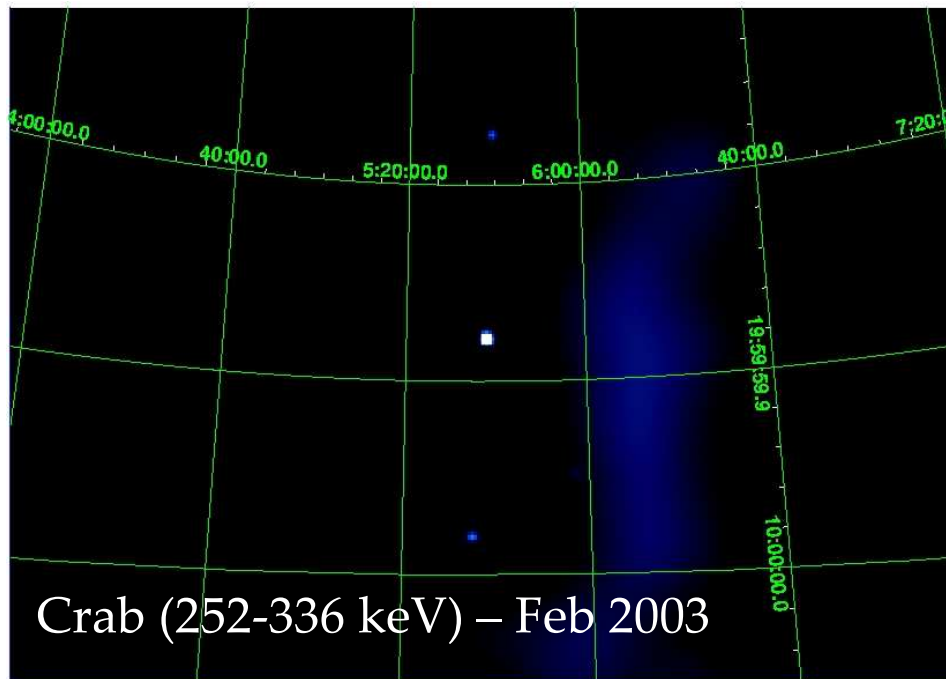
More details  
in Goldwurm  
et al., (2003)

# Compact Objects observed by PICsIT

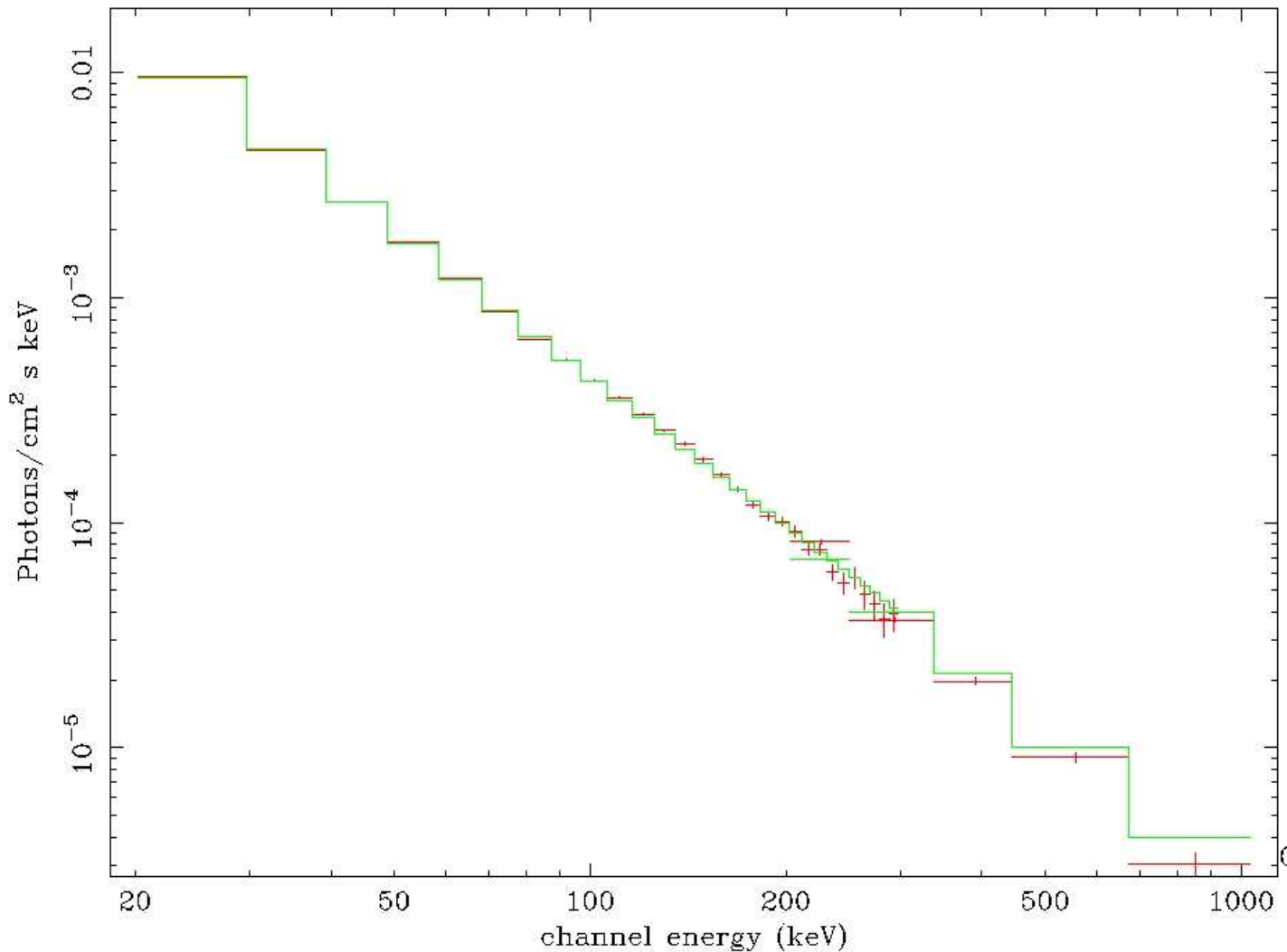


The present talk will outline the IBIS/PICsIT observations of 1 pulsar and 2 black holes:

- **Crab PWN:** well-known calibration source, observed twice every year (early PICsIT observations in Di Cocco et al. 2003);
- **Crab Pulsar:** Kuiper et al. (2003); Mineo et al. (2005);
- **Cygnus X-1:** first source observed by INTEGRAL during the PV phase, observed during AO1, and Core Programme (Cadolle-Bel et al., 2005);
- **XTE J1550-564:** observed during an outburst in 2003 (Foschini, 2005).



# Crab continuum with IBIS (0.02-1 MeV)



$$\Gamma = 2.19 \pm 0.01;$$

$$A = 10.4 \pm 0.5;$$

$$C = 0.93 \pm 0.01$$

5% Sys Err;

$$\chi^2 = 34.7$$

$$\text{dof} = 31$$

$$\text{Red. } \chi^2 = 1.12$$

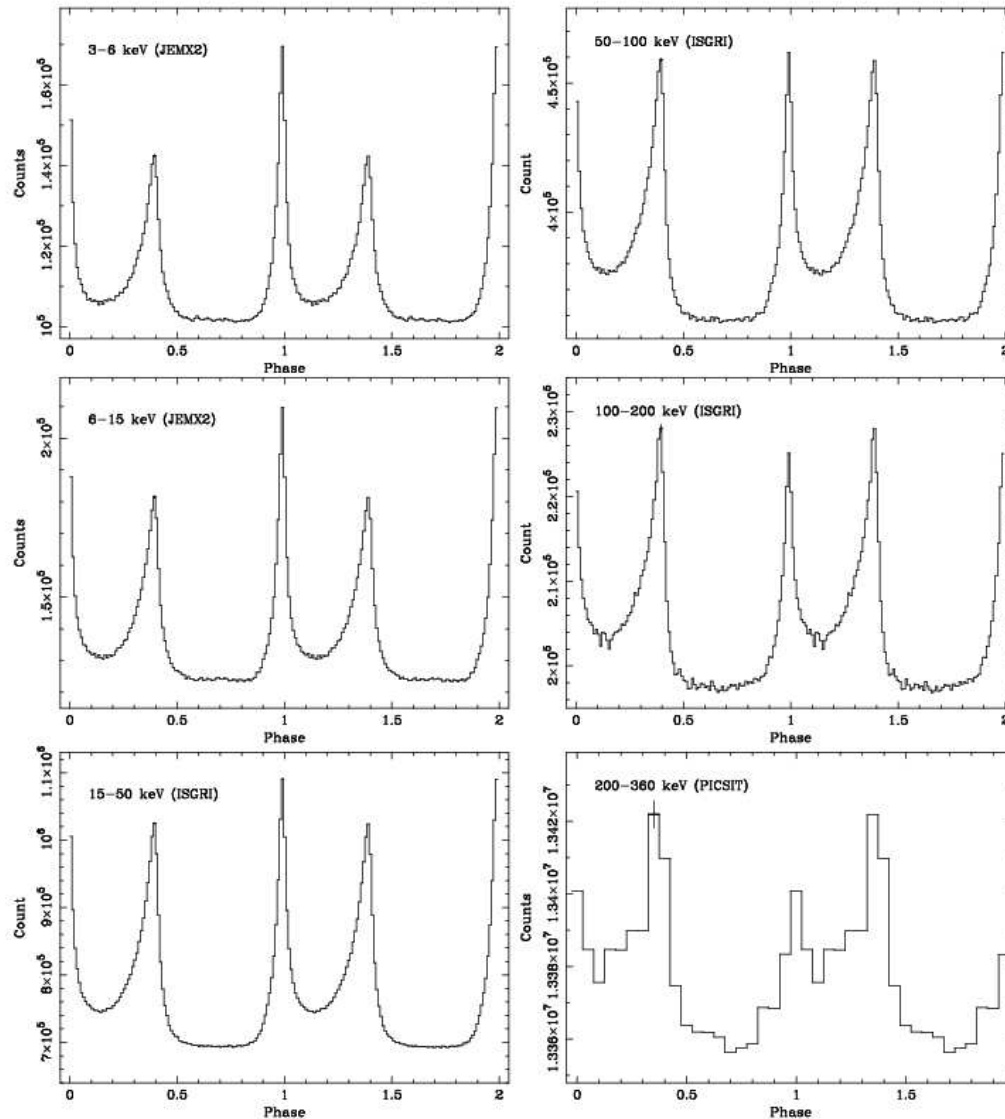
$$\text{Prob.} = 0.295$$

$$\text{Flux}[20-1000 \text{ keV}] = 3.5 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$$

$$\text{Flux}[\text{expected}] = 3.7 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$$

# Crab – Pulsar

(with IBIS and JEM-X onboard INTEGRAL)



Crab pulsar folded lightcurve in different energy bands with JEM-X, ISGRI, and PICSIT spectral timing data (200–360 keV). From Mineo et al. (2005)

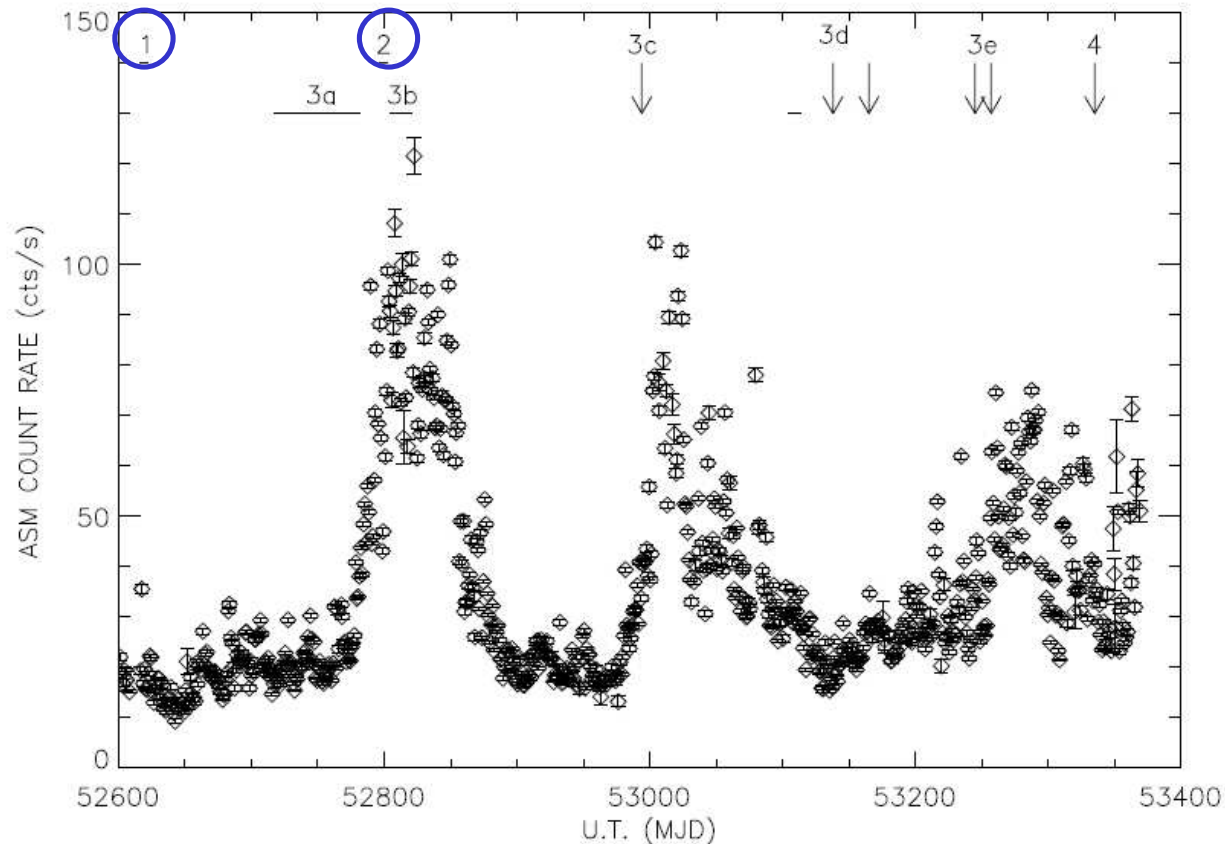


# INTEGRAL observation of Cyg X-1

Cadolle-Bel et al., 2005, A&A, accepted (astro-ph/0509851)



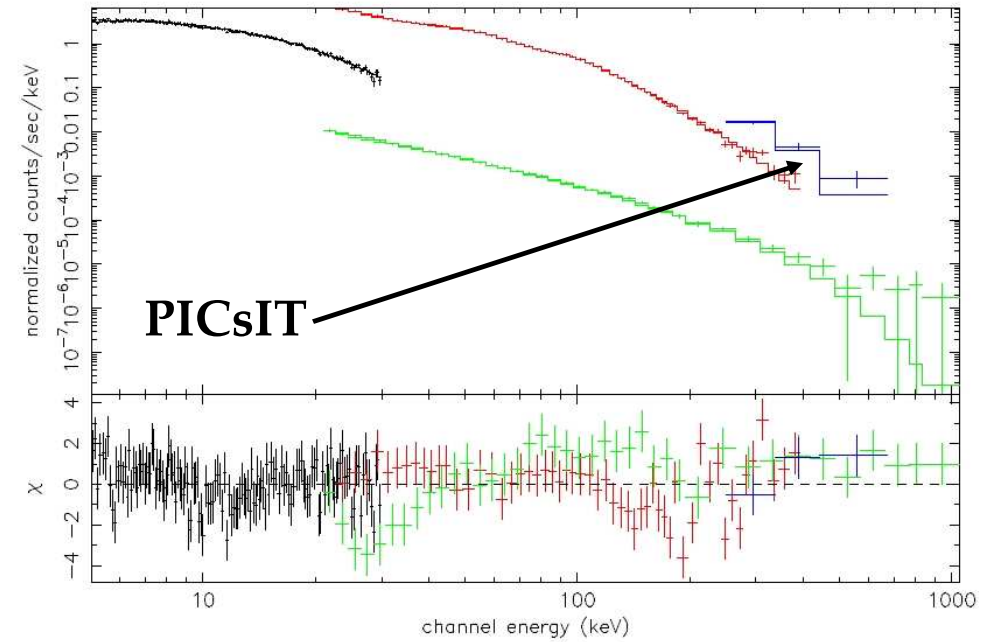
A summary of INTEGRAL observations of Cyg X1 in the period 2002-2004



RXTE/ASM daily averages (1.5-12 keV) of Cygnus X-1, with the INTEGRAL observation periods reported on the top.

# Cygnus X-1

Epoch 1: 9-11 December 2002  
 Cygnus X-1 in hard state (thermal  
 Comptonization + reflection)



**Table 2.** Best-fit parameters of Cygnus X-1 for the current thermal model in the different observation epochs.

| Epoch | Dates<br>(MJD) | Disc Norm. <sup>a</sup> | $kT_{\text{in}}$ or $kT_0$<br>(keV) | $kT_e$<br>(keV)   | $\tau$                 | $E_{\text{Fe}}$ line<br>(keV) | $\Omega/2\pi^b$        | $\chi^2_{\text{red}}$<br>(dof) |
|-------|----------------|-------------------------|-------------------------------------|-------------------|------------------------|-------------------------------|------------------------|--------------------------------|
| 1     | 52617–52620    | -                       | 0.20 (frozen)                       | $67^{+8}_{-6}$    | $1.98^{+0.21}_{-0.23}$ | -                             | $0.25^{+0.03}_{-0.04}$ | 1.45 (230)                     |
| 2     | 52797–52801    | $250^{+88}_{-59}$       | $1.16 \pm 0.07$                     | $100^{+23}_{-17}$ | $0.98^{+0.25}_{-0.28}$ | $7.07^{+0.12}_{-0.11}$        | $0.57^{+0.03}_{-0.06}$ | 1.69 (236)                     |
| 3a    | 52710–52780    | -                       | 0.20 (frozen)                       | $68^{+22}_{-12}$  | $2.08^{+0.51}_{-0.84}$ | $6.48 \pm 0.13$               | $0.32^{+0.05}_{-0.07}$ | 1.07 (190)                     |
| 3b    | 52801–52825    | $312^{+25}_{-24}$       | $1.15 \pm 0.03$                     | $93 \pm 42$       | $0.80^{+0.86}_{-0.40}$ | $6.40 \pm 0.73$               | $0.58^{+0.20}_{-0.18}$ | 0.93 (190)                     |
| 3c    | 52990          | $361^{+61}_{-67}$       | $0.99 \pm 0.08$                     | $58^{+54}_{-15}$  | $1.60^{+0.64}_{-0.80}$ | $6.96 \pm 0.19$               | $0.23^{+0.17}_{-0.09}$ | 0.99 (190)                     |
| 3d    | 53101–53165    | -                       | 0.20 (frozen)                       | $56^{+12}_{-7}$   | $2.28^{+0.30}_{-0.41}$ | $6.11 \pm 0.26$               | $0.27 \pm 0.06$        | 0.81 (190)                     |
| 3e    | 53240–53260    | $132 \pm 10$            | $1.39 \pm 0.77$                     | $48^{+20}_{-6}$   | $1.85^{+0.40}_{-0.07}$ | $6.49 \pm 0.38$               | $0.49^{+0.37}_{-0.32}$ | 1.56 (190)                     |
| 4     | 53335          | $232^{+21}_{-32}$       | 1.16 (frozen)                       | $128^{+84}_{-63}$ | $0.74^{+0.88}_{-0.38}$ | $7.78^{+0.44}_{-0.42}$        | $0.47^{+0.18}_{-0.14}$ | 0.97 (221)                     |

Notes:

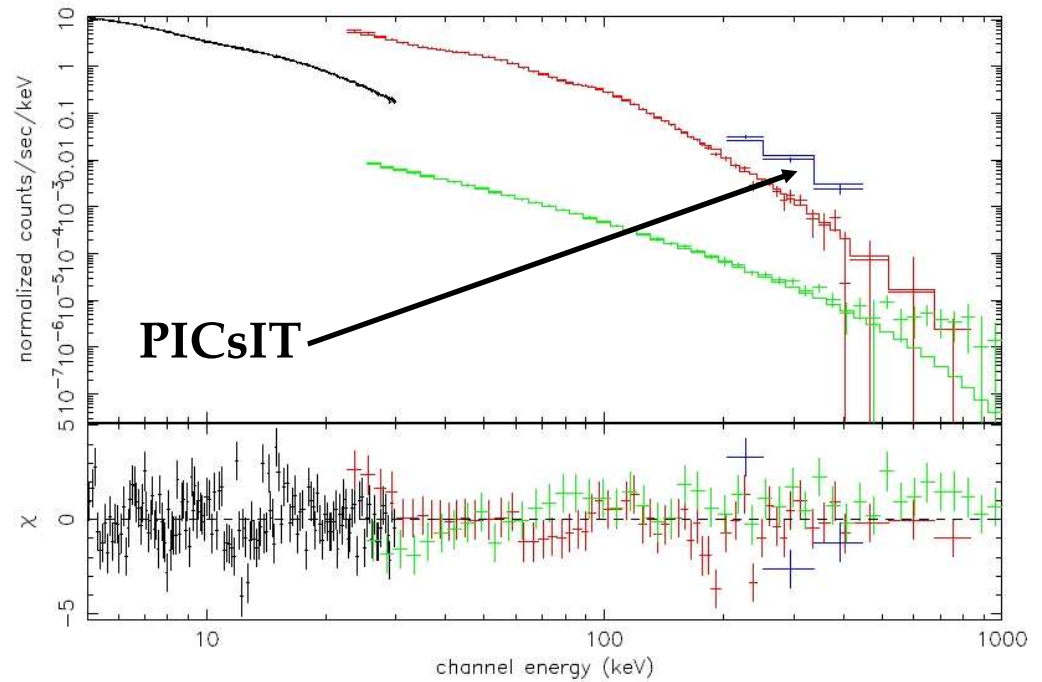
a) Disc normalization  $K$  is given by  $K = (R/D)^2 \cos \theta$  where  $R$  is the inner disc radius in units of km,  $D$  is the distance to the source in units of 10 kpc and  $\theta$  the inclination angle of the disc.

b) Solid angle of the reflection component.

Model applied in XSPEC notations: CONSTANT\*WABS\*(DISKBB+GAUSSIAN+REFLECT\*COMPTT) with  $N_{\text{H}}$  fixed to  $6 \times 10^{21} \text{ cm}^{-2}$  and  $kT_0$  value tied to disc  $kT_{\text{in}}$ . Errors are at 90% confidence level ( $\Delta\chi^2 = 2.7$ ).

# Cygnus X-1

Epoch 2: 7-11 June 2003  
 Transition to soft state  
 (intermediate state):  
 accretion disk, emission line, thermal  
 Comptonization, reflection



**Table 2.** Best-fit parameters of Cygnus X-1 for the current thermal model in the different observation epochs.

| Epoch | Dates<br>(MJD) | Disc Norm. <sup>a</sup> | $kT_{in}$ or $kT_0$<br>(keV) | $kT_e$<br>(keV)   | $\tau$                 | $E_{Fe}$ line<br>(keV) | $\Omega/2\pi^b$        | $\chi^2_{red}$<br>(dof) |
|-------|----------------|-------------------------|------------------------------|-------------------|------------------------|------------------------|------------------------|-------------------------|
| 1     | 52617–52620    | -                       | 0.20 (frozen)                | $67^{+8}_{-6}$    | $1.98^{+0.21}_{-0.22}$ | -                      | $0.25^{+0.03}_{-0.04}$ | 1.45 (230)              |
| 2     | 52797–52801    | $250^{+89}_{-59}$       | $1.16 \pm 0.07$              | $100^{+29}_{-17}$ | $0.98^{+0.25}_{-0.28}$ | $7.07^{+0.12}_{-0.11}$ | $0.57^{+0.09}_{-0.06}$ | 1.69 (236)              |
| 3a    | 52710–52780    | -                       | 0.20 (frozen)                | $68^{+12}_{-12}$  | $2.08^{+0.81}_{-0.84}$ | $6.48 \pm 0.13$        | $0.32^{+0.07}_{-0.07}$ | 1.07 (190)              |
| 3b    | 52801–52825    | $312^{+25}_{-24}$       | $1.15 \pm 0.03$              | $93 \pm 42$       | $0.80^{+0.86}_{-0.40}$ | $6.40 \pm 0.73$        | $0.58^{+0.20}_{-0.18}$ | 0.93 (190)              |
| 3c    | 52990          | $361^{+61}_{-67}$       | $0.99 \pm 0.08$              | $58^{+54}_{-15}$  | $1.60^{+0.64}_{-0.80}$ | $6.96 \pm 0.19$        | $0.23^{+0.17}_{-0.09}$ | 0.99 (190)              |
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Notes:

a) Disc normalization  $K$  is given by  $K = (R/D)^2 \cos \theta$  where  $R$  is the inner disc radius in units of km,  $D$  is the distance to the source in units of 10 kpc and  $\theta$  the inclination angle of the disc.

b) Solid angle of the reflection component.

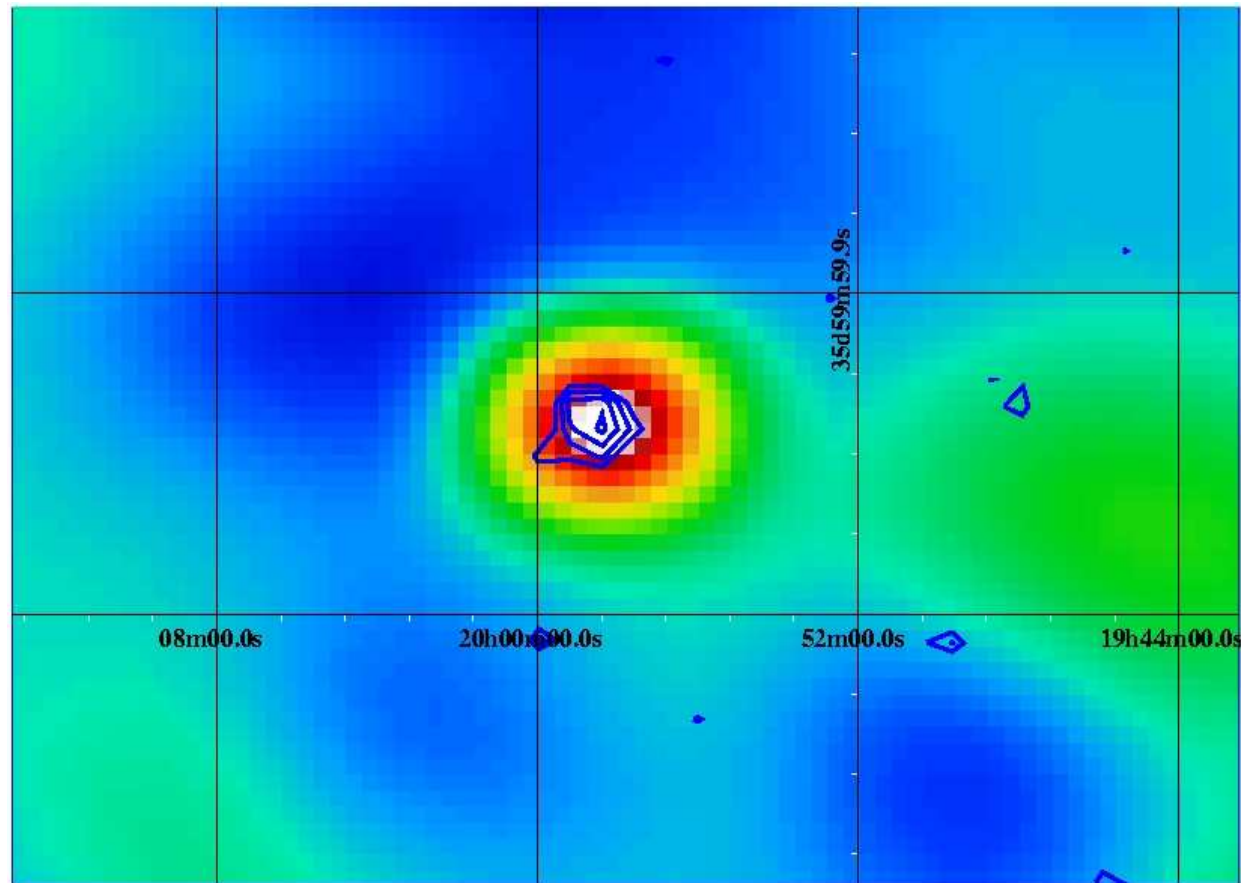
Model applied in XSPEC notations: CONSTANT\*WABS\*(DISKBB+GAUSSIAN+REFLECT\*COMPTT) with  $N_H$  fixed to  $6 \times 10^{21} \text{ cm}^{-2}$  and  $kT_0$  value tied to disc  $kT_{in}$ . Errors are at 90% confidence level ( $\Delta\chi^2 = 2.7$ ).

# Cygnus X-1

Epoch 2: 7-11 June 2003: SPI detects a **hard tail** at  $E > 400$  keV, although **not fully confirmed** by IBIS.

In the past, the hard tail has been also detected by CGRO/OSSE (McConnell et al. 2002).

What is the origin?



SPI significance map with  
IBIS/PICsIT significance  
contours superimposed  
(Energy 336-448 keV)



# The 2003 Outburst of XTE J1550-564

Table 1. Best Fit Parameters for COMPST, COMPTT, and PEXRAV Models<sup>a</sup>

| Rev | COMPST <sup>b</sup>  |                        |          | COMPTT <sup>c</sup>  |                        |                        | $\chi^2$ | $\Gamma$               | PEXRAV <sup>c,d</sup>     |                        |          |
|-----|----------------------|------------------------|----------|----------------------|------------------------|------------------------|----------|------------------------|---------------------------|------------------------|----------|
|     | kT (keV)             | $\tau$                 | $\chi^2$ | kT (keV)             | $\tau_p$               | $T_0$ (keV)            |          |                        | $E_{\text{cut}}$ (keV)    | R                      | $\chi^2$ |
| 55  | $41.2^{+1.9}_{-1.7}$ | $3.58^{+0.13}_{-0.13}$ | 334.9    | $52.6^{+6.2}_{-4.2}$ | $1.38^{+0.12}_{-0.15}$ | $0.58^{+0.10}_{-0.14}$ | 292.7    | $1.56^{+0.05}_{-0.05}$ | $441.4^{+242.2}_{-122.0}$ | $0.40^{+0.24}_{-0.22}$ | 303.7    |
| 57  | $41.3^{+1.9}_{-1.7}$ | $3.44^{+0.14}_{-0.14}$ | 325.1    | $49.4^{+4.5}_{-3.4}$ | $1.42^{+0.11}_{-0.12}$ | $0.56^{+0.11}_{-0.16}$ | 287.7    | $1.53^{+0.06}_{-0.06}$ | $310.3^{+130.9}_{-73.7}$  | $0.31^{+0.26}_{-0.23}$ | 313.1    |
| 60  | $36.4^{+1.3}_{-1.2}$ | $3.92^{+0.13}_{-0.12}$ | 389.4    | $43.2^{+2.5}_{-2.4}$ | $1.64^{+0.11}_{-0.10}$ | $0.34^{+0.39}_{-0.34}$ | 295.0    | $1.42^{+0.05}_{-0.05}$ | $201.0^{+44.2}_{-31.5}$   | $0.18^{+0.20}_{-0.18}$ | 300.9    |

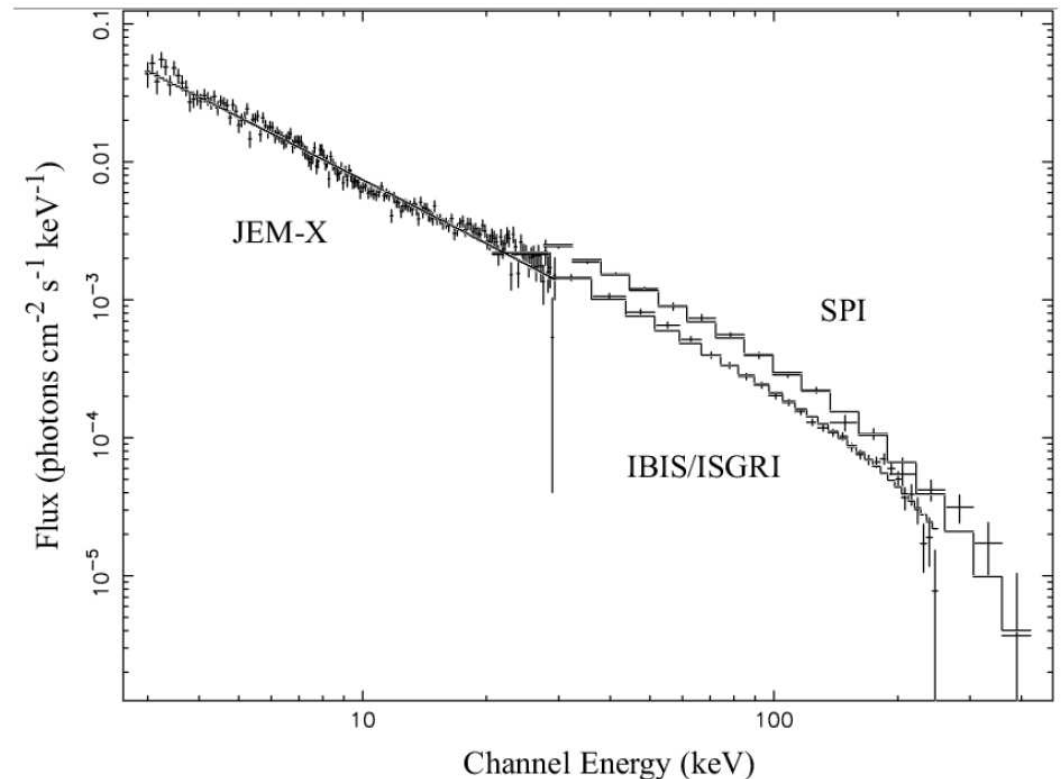
<sup>a</sup> $N_{\text{H}} \equiv 9 \times 10^{21}$ , errors are 90% confidence

<sup>b</sup>206 Degrees of freedom

<sup>c</sup>205 Degrees of freedom

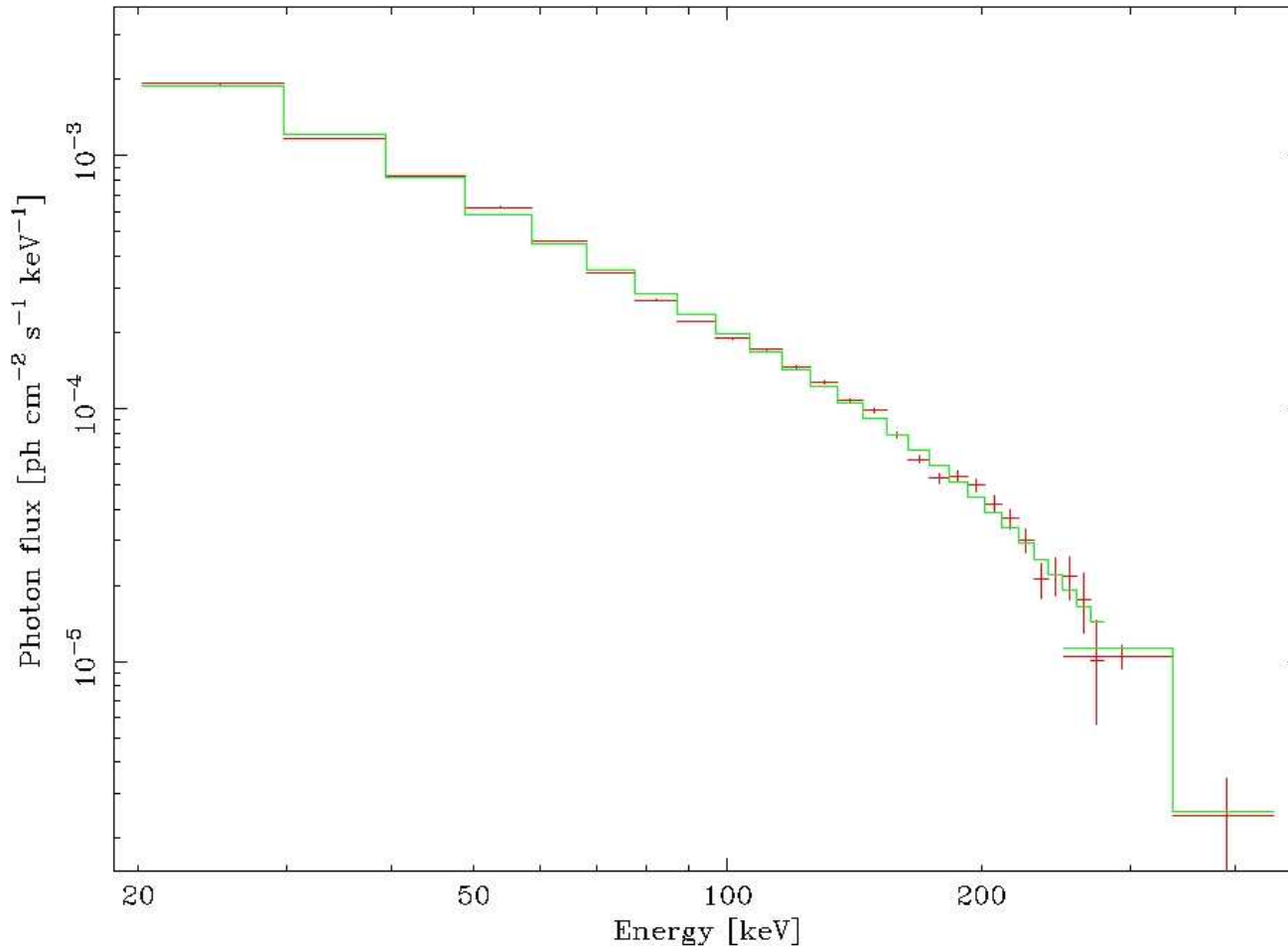
<sup>d</sup> $i \equiv 72.6^\circ$ , see Orosz et al. (2002)

Results obtained by Sturmer & Shrader (2005) with JEM-X, IBIS/ISGRI, and SPI.





# The 2003 outburst of XTE J1550-564: IBIS data



Comptonization model  
by Titarchuk (1994):

$$T_0 < 6.3 \text{ keV};$$
$$T_e = 50 \text{ } ^{+3}_{-2} \text{ keV}$$
$$\tau = 1.46 \text{ } ^{+0.04}_{-0.07}$$

5% Sys Err;  
Red.  $\chi^2 = 0.87$ ; Dof=25  
Prob. 0.656

**Consistent with Sturner  
& Shrader (2005)**

Flux 20-450 keV:  $7.4 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$   $\blacktriangleright$   $L = 2.5 \times 10^{37} \text{ erg s}^{-1}$

Flux 170-450 keV:  $1.6 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1} = 4.4 \times 10^{-3} \text{ ph cm}^{-2} \text{ s}^{-1}$

# IBIS/PICsIT Source Catalog (Web)

<http://www.iasf-bologna.inaf.it/Research/INTEGRAL>  
created and maintained by F. Schiavone



The screenshot displays two browser windows. The left window shows the main website navigation menu with links for [IBIS/PICsIT](#), [Scientific Res](#), [INTEGRAL Re Publications](#), and [Links](#). The right window displays the 'Gamma-Ray Bursts (GRB)' catalog page, which includes a table of sources ordered by time of event.

### Gamma-Ray Bursts (GRB)

The list of sources is ordered according to the time of the event.

| GRB     | Coordinates (RA, Dec, J2000) | First GCN     | Notes on PICsIT detection(*)                          |
|---------|------------------------------|---------------|---|
| 021125  | 19 47 57, +28 23 35          | 1706          | IBIS FOV, <a href="#">ppm; Malaguti et al. (2003)</a> |
| 021206  | 16 00 43, -09 43 24          | 1727          | Spt, (M. Denis, personal communication)               |
| 021223  | Annulus only                 | 1778          | Spt, (M. Denis, personal communication)               |
| 021226  | 02 54 58, +15 55 30          | 1779          | Spt, (M. Denis, personal communication)               |
| 030102  | 12 07 41, +37 36 07          | 1786          | Spt, (M. Denis, personal communication)               |
| 030204  | 00 03 20, +32 43 36          | 1854          | Spt, (M. Denis, personal communication)               |
| 030218  | 23 24 43, -41 49 34          | 1874          | Spt, (M. Denis, personal communication)               |
| 030228  | 23 10 30, -42 07 01          | 1918          | Spt, (M. Denis, personal communication)               |
| 030307  | 23 01 14, -42 08 31          | 1937          | Spt, (M. Denis, personal communication)               |
| 030320A | 17 51 36, -25 18 52          | 1941          | IBIS FOV, <a href="#">Spt</a>                         |
| 030320B | 10 43 41, +41 49 08          | 1944          | Spt, (M. Denis, personal communication)               |
| 030326  | 19 31 52, -11 43 13          | 1967          | Spt, (M. Denis, personal communication)               |
| 030329  | 10 44 49, +21 31 23          | 1985          | Spt, (M. Denis, personal communication)               |
| 030405  | 16 33 06, -24 09 09          | 2126          | Spt, (M. Denis, personal communication)               |
| 030406  | 19 01 43, -68 04 39          | 2127          | Spt, (M. Denis, personal communication)               |
| 030422A | Two error boxes              | 2162          | Spt, (M. Denis, personal communication)               |
| 030501  | 19 05 33, +06 15 57          | 2181          | IBIS FOV, Spt, (M. Denis, personal communication)     |
| 030509A | 05 26 24, +07 08 48          | 2221          | Spt, (M. Denis, personal communication)               |
| 030509B | 22 08 21, -36 23 46          | 2226          | Spt, (M. Denis, personal communication)               |
| 030518B | 22 07 15, -35 14 38          | 2231          | Spt, (M. Denis, personal communication)               |
| 030519  | 10 06 37, +35 07 26          | 2234          | Spt, (M. Denis, personal communication)               |
| 030523  | 22 07 09, -34 29 02          | 2248          | Spt, (M. Denis, personal communication)               |
| 030601  | 10 07 58, +33 12 18          | 2266          | Spt, (M. Denis, personal communication)               |
| 030605  | 10 07 57, +32 48 18          | 2272          | Spt, (M. Denis, personal communication)               |
| 030704  | unknown                      | not confirmed | Spt, (M. Denis, personal communication)               |
| 030711  | 22 46 15, -13 14 06          | 2296          | Spt, (M. Denis, personal communication)               |