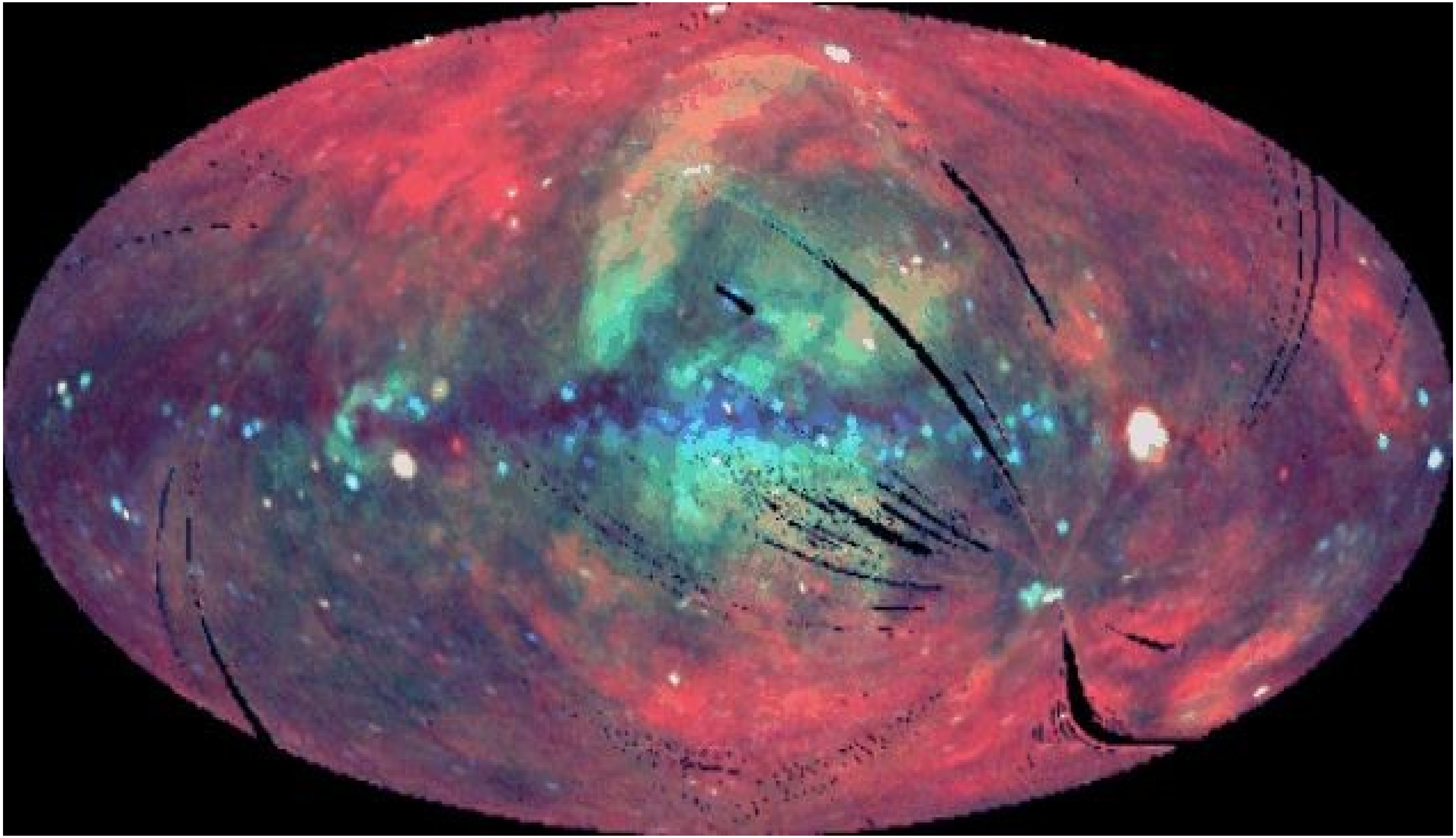
X- and gamma-rays from the Universe

imaging and spectral analysis techniques

Telescopes	Collimation Occultation Triangulation X-ray mirror Gamma-ray lens Coded mask Compton imaging
INTEGRAL off-axis GRBs	Direct Compton Images Spectral Analysis

UV – soft X-rays: 0.1-2.5 keV



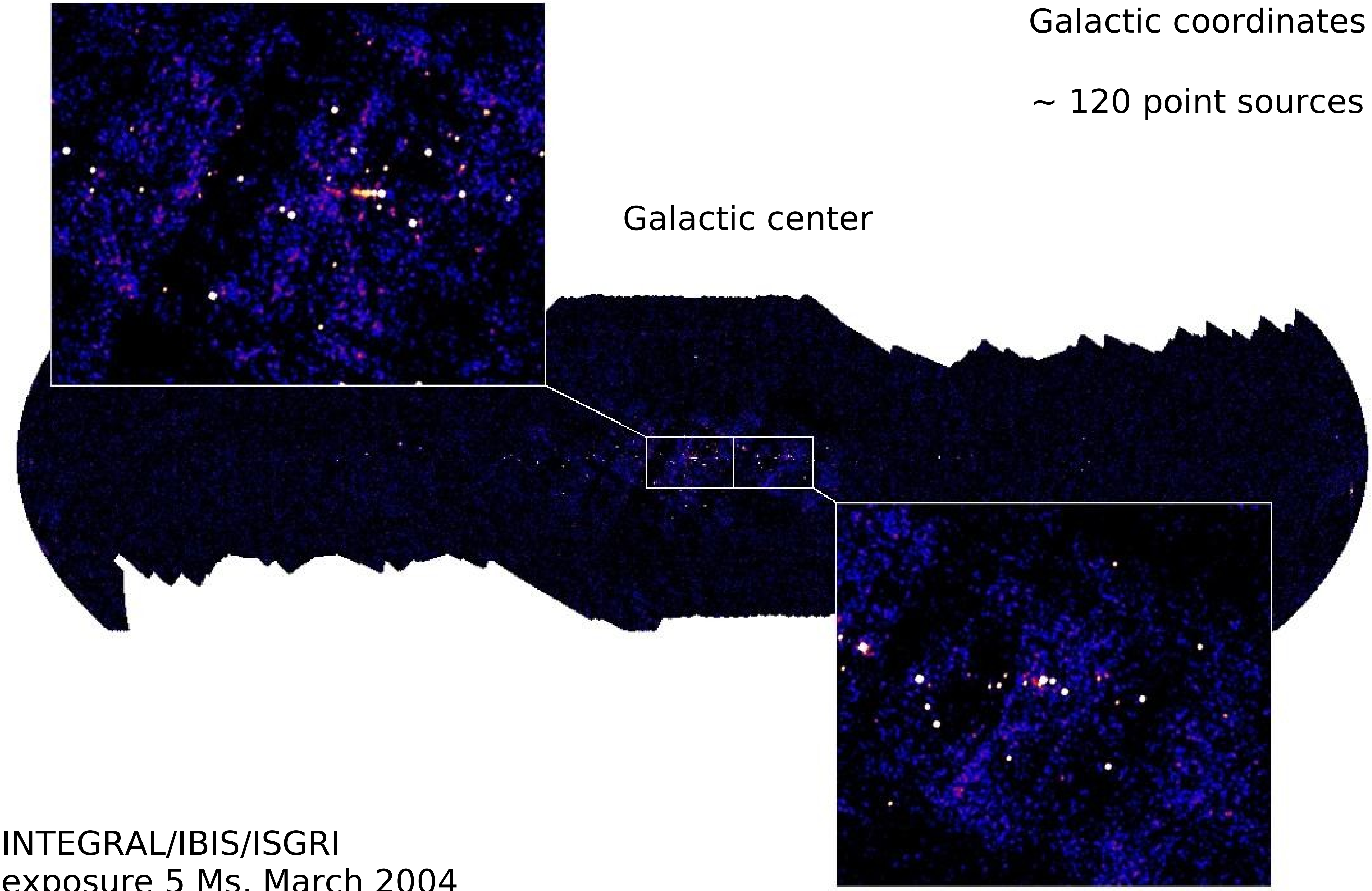
ROSAT, 1990-1999, all sky map

Galactic coordinates

Hard X-rays 30-50 keV

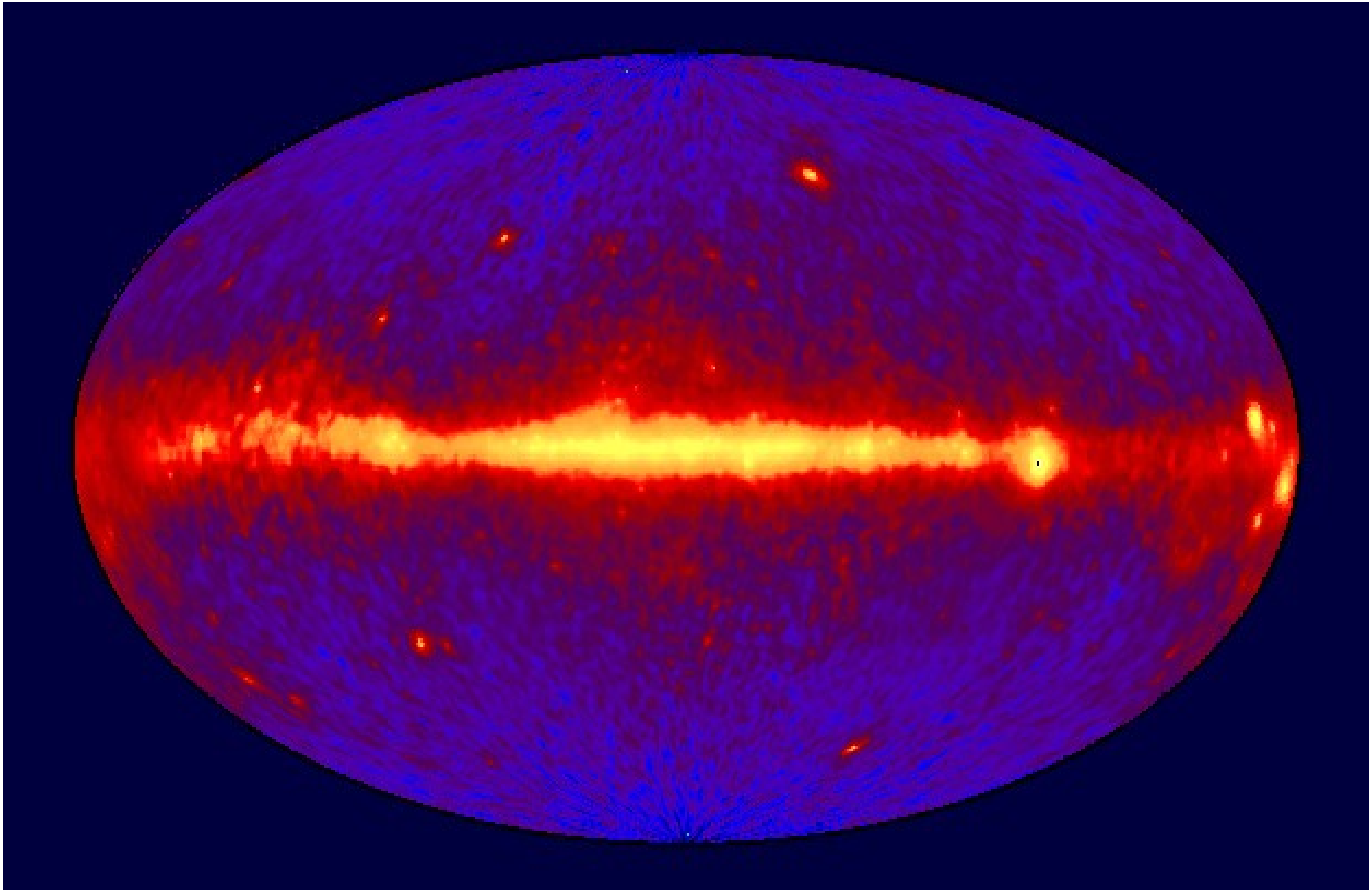
Galactic coordinates

~ 120 point sources



INTEGRAL/IBIS/ISGRI
exposure 5 Ms, March 2004

Gamma-rays: > 100 MeV



CGRO/EGRET Galactic coordinates

What sort of instrumentation we need to do the high energy (10keV-5MeV) science of the cosmic radiation?

Point sources:

- Images with the angular resolution > 1'
- Spectra with dE/E ~1-5 %, overall spectral shape
- Timing ~ precision ~10 microsecond (pulsars, other variability)

Diffuse emission:

- Images with > 1^{o} angular resolution
- Spectra with “nuclear” resolution (line mapping)

Problems:

- Instrumental background (high level, space structures)
- Autonomous (satellite) operations, limited telemetry

Telescopes

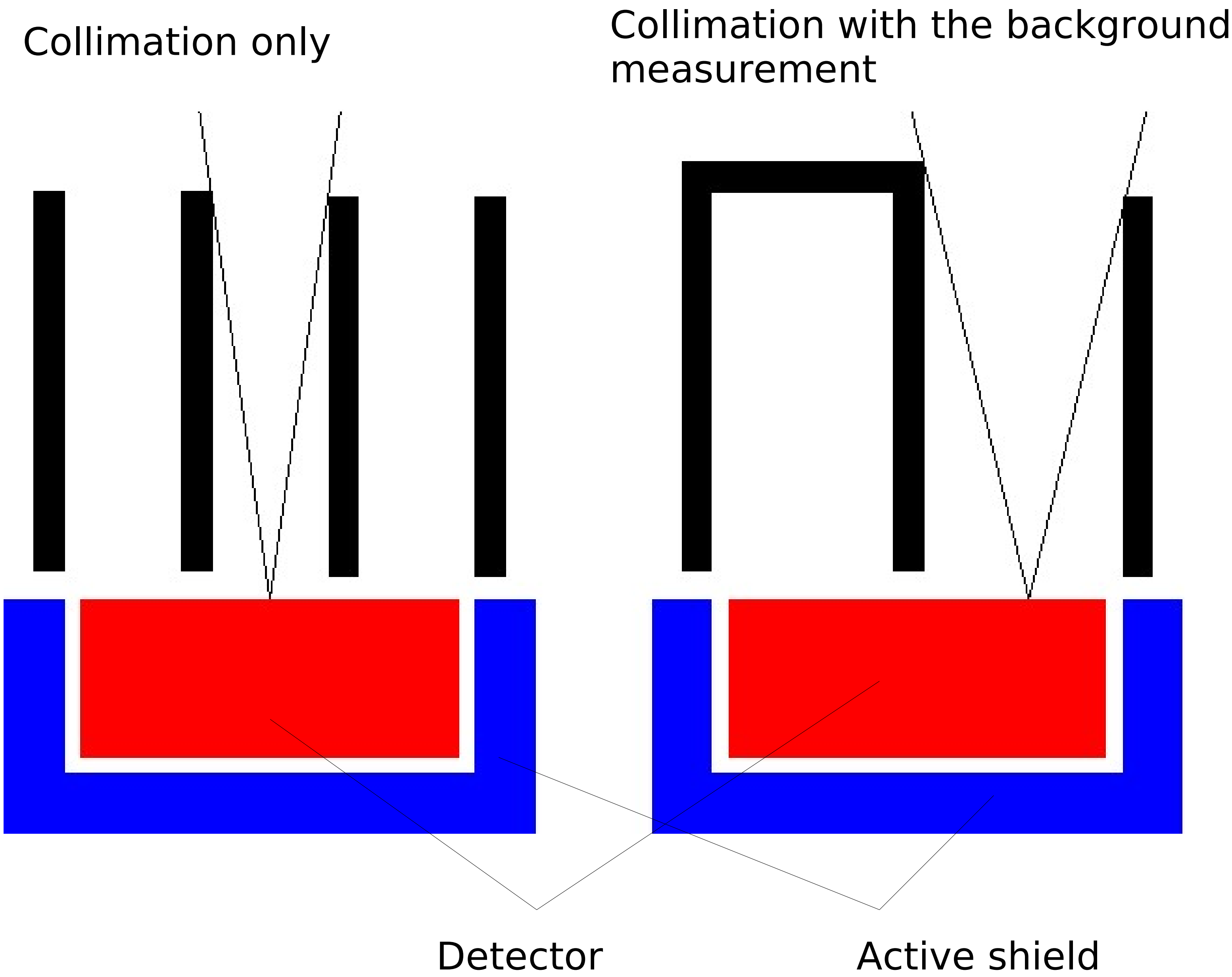
Goals:

- Determine the direction of incident photons
- Subtract the background

Techniques:

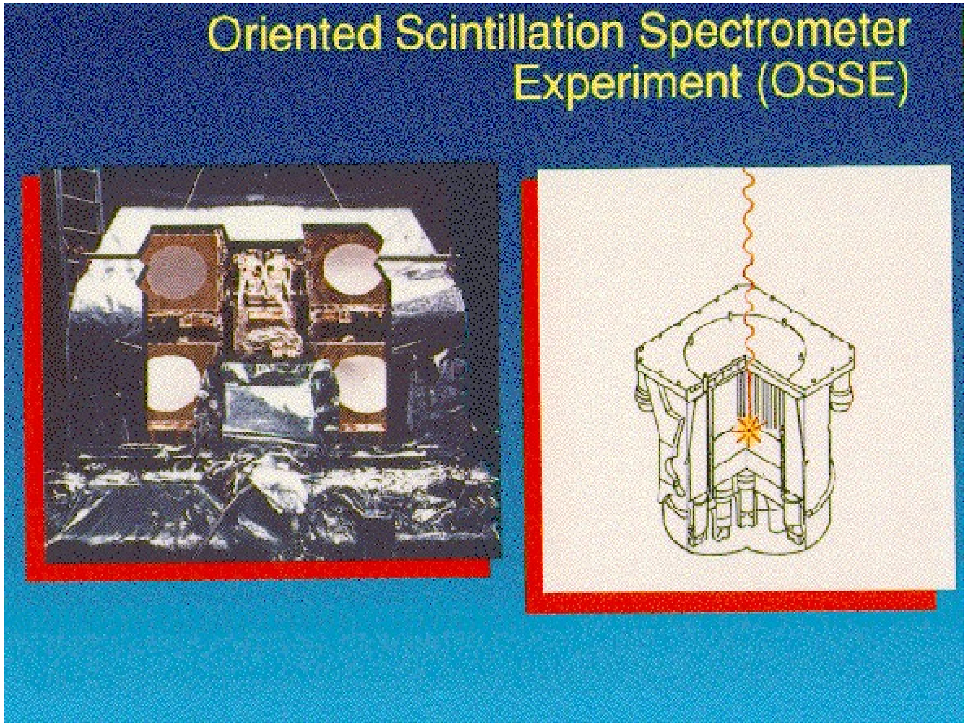
- Collimation
- Occultation
- Triangulation
- X-ray mirror
- Gamma-ray lens
- Coded mask
- Compton imaging

Collimation



Collimation - CGRO/OSSE

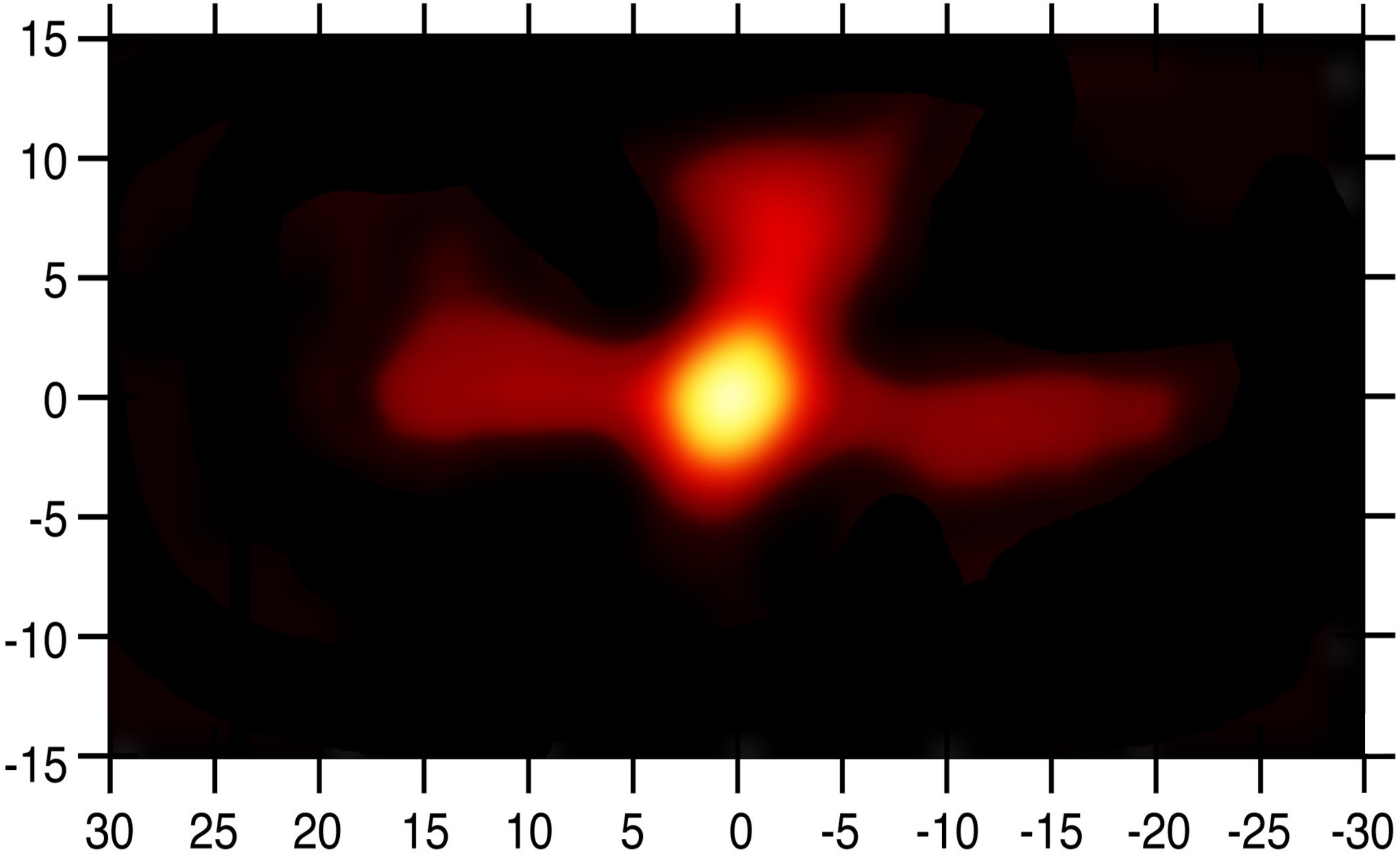
Compton Gamma Ray Observatory



OSSE:

Field of view: 4.6 x 11.6 deg
4 detectors: NaI(Tl) scintillator
Energy range: 20 keV – 10 MeV

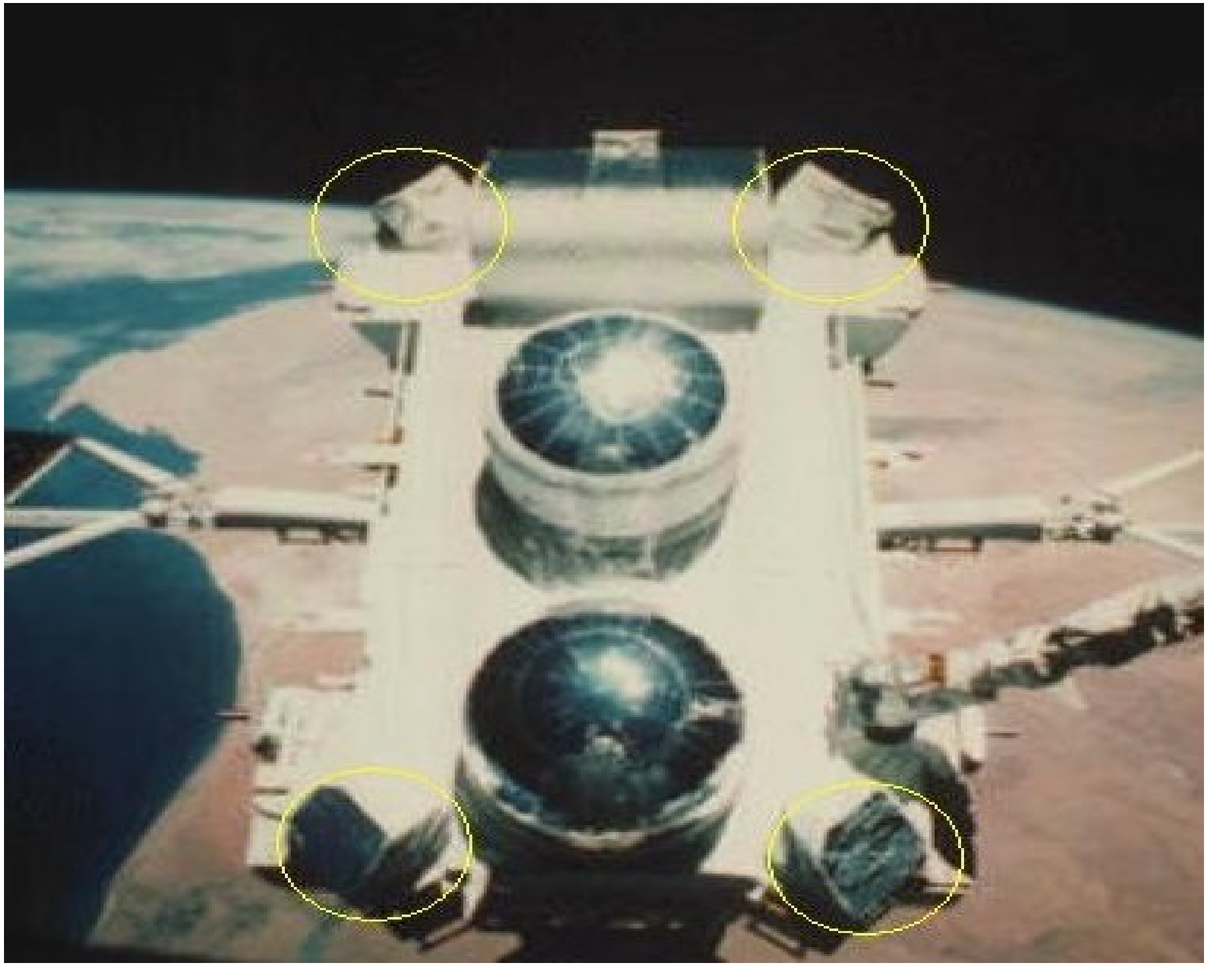
Collimation – CGRO/OSSE - results



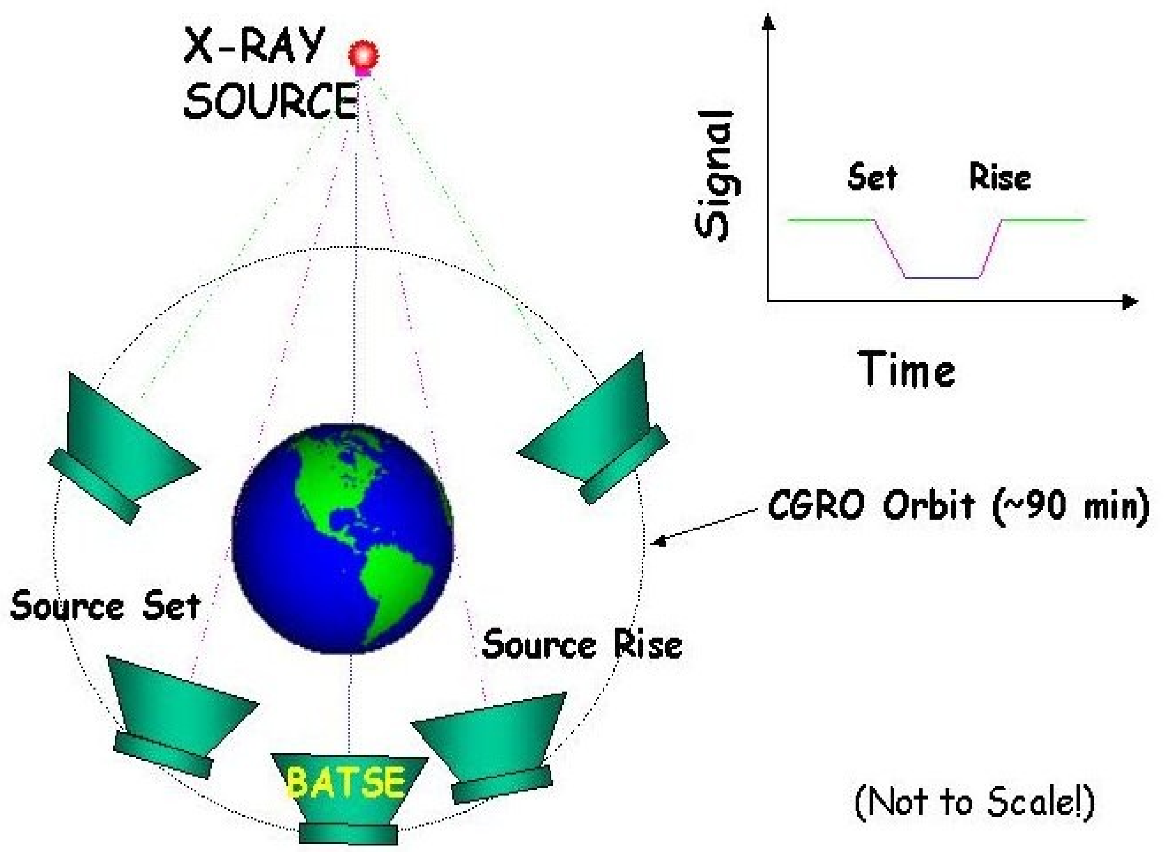
~511 keV emission line, Galactic Center region

Occultation - CGRO/BATSE

8 detectors
NaI(Tl) scintillator
20 keV - 2 MeV

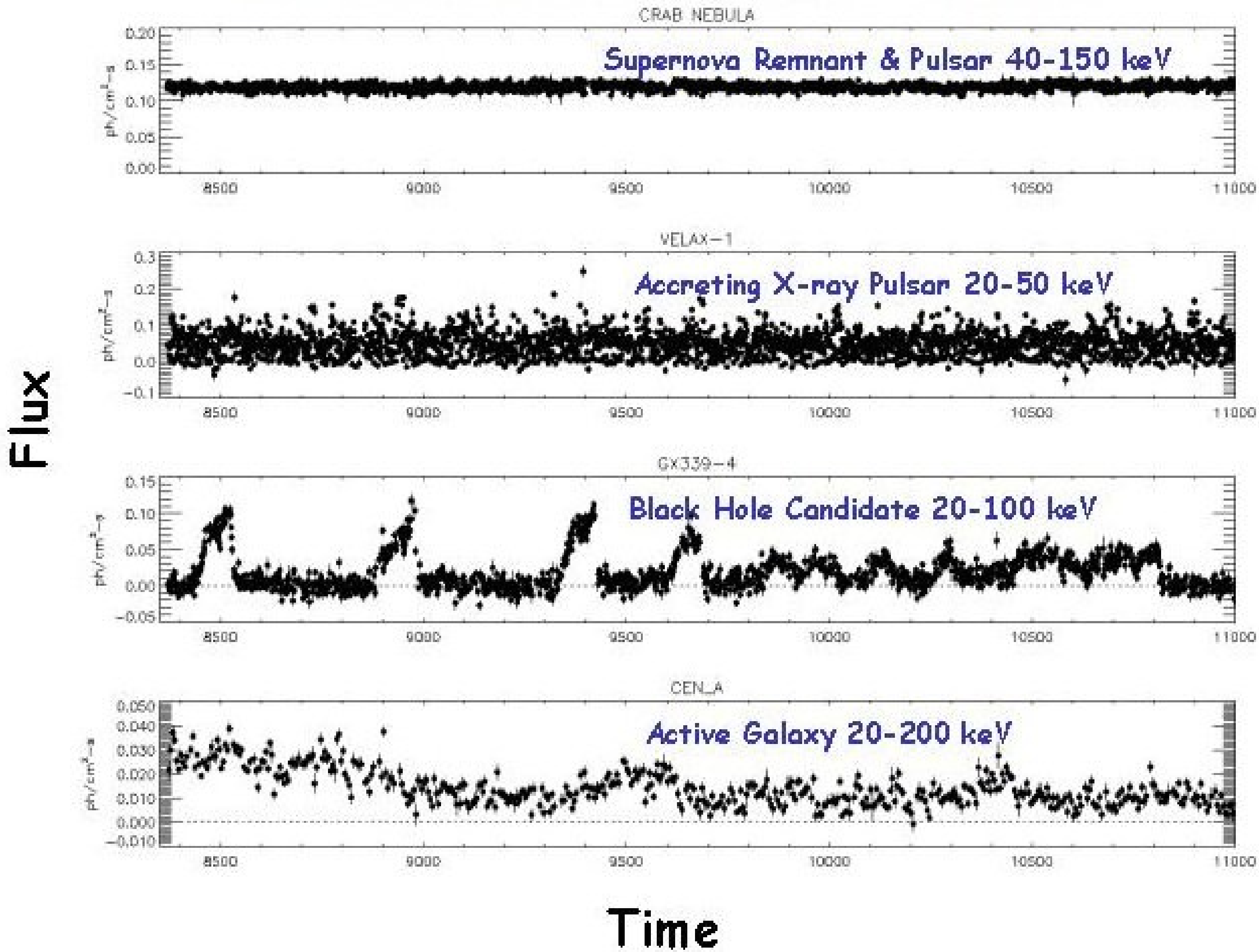


Occultation - CGRO/BATSE - Observations



- Sky model (sources with known position)
- Orbit model
- Detector count rate
- Fit source flux

Occultation - CGRO/BATSE – results



Triangulation – method

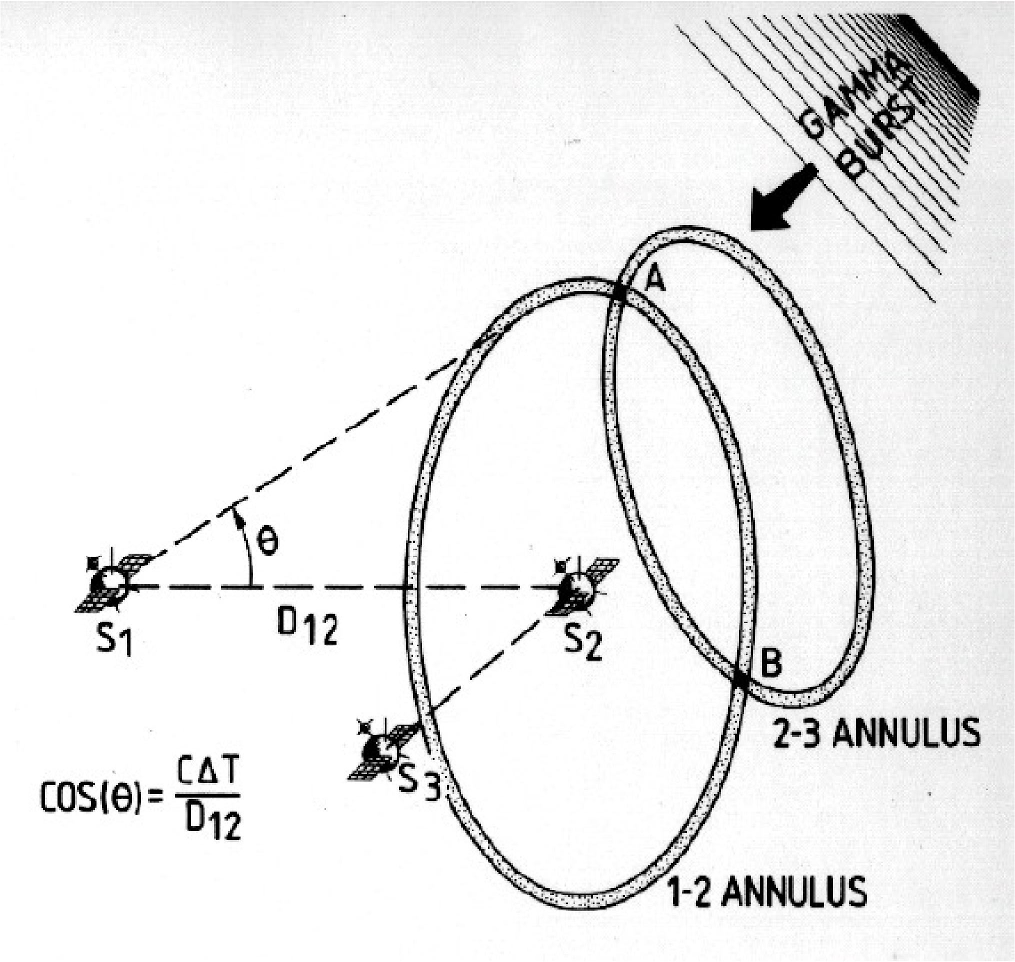
Strong, transient source

At least 3 satellites: 1,2,3

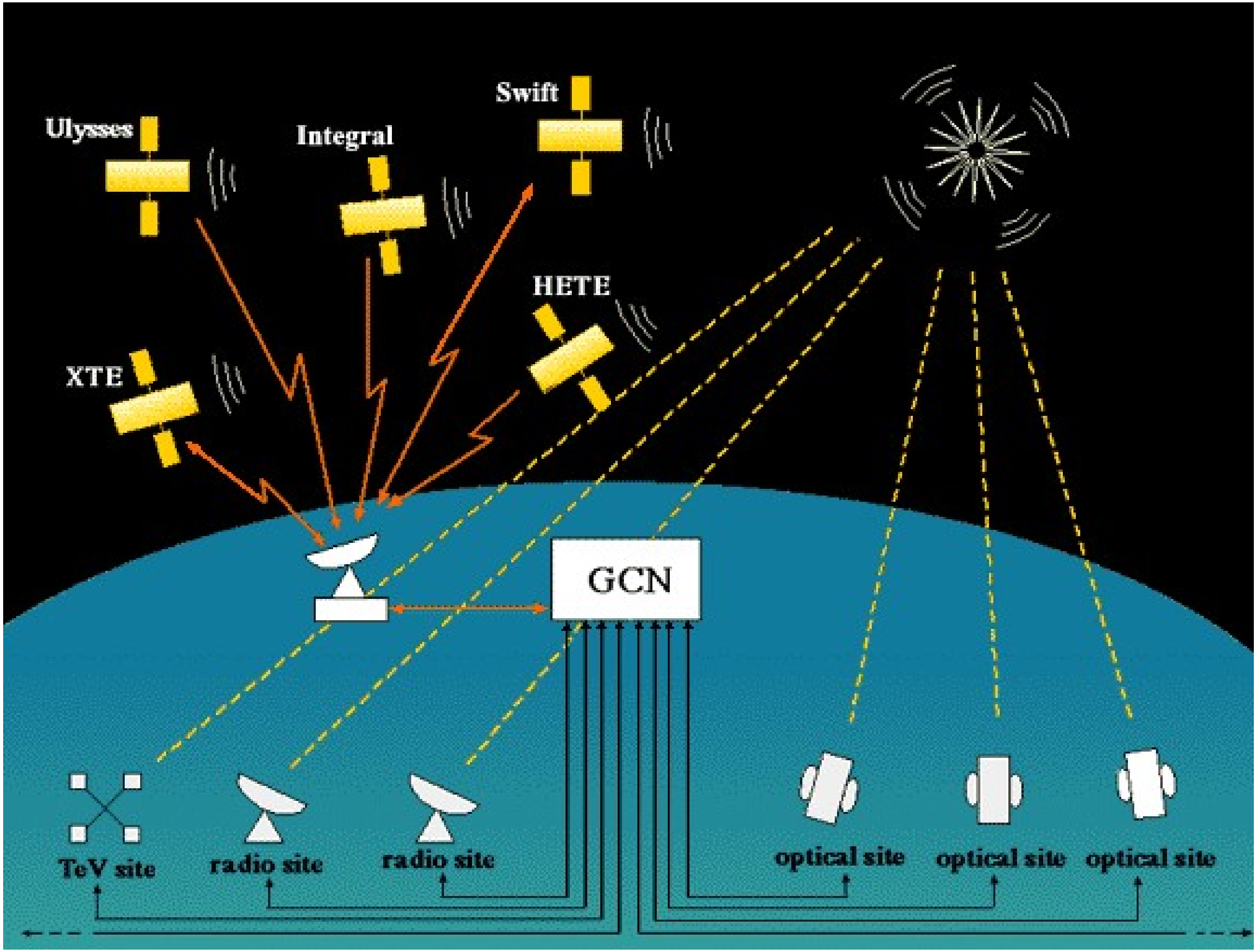
Known distances: d12, d23

Annuli open angles:
theta12, theta23

Two possible source positions:
A, B



Triangulation – 3rd IPN



TITLE: GCN CIRCULAR
NUMBER: 5684
SUBJECT: IPN triangulation of GRB060928 (long, exceptionally bright)
DATE: 06/10/03 00:09:40 GMT
FROM: Kevin Hurley at UCBerkeley/SSL <khurley@ssl.berkeley.edu>

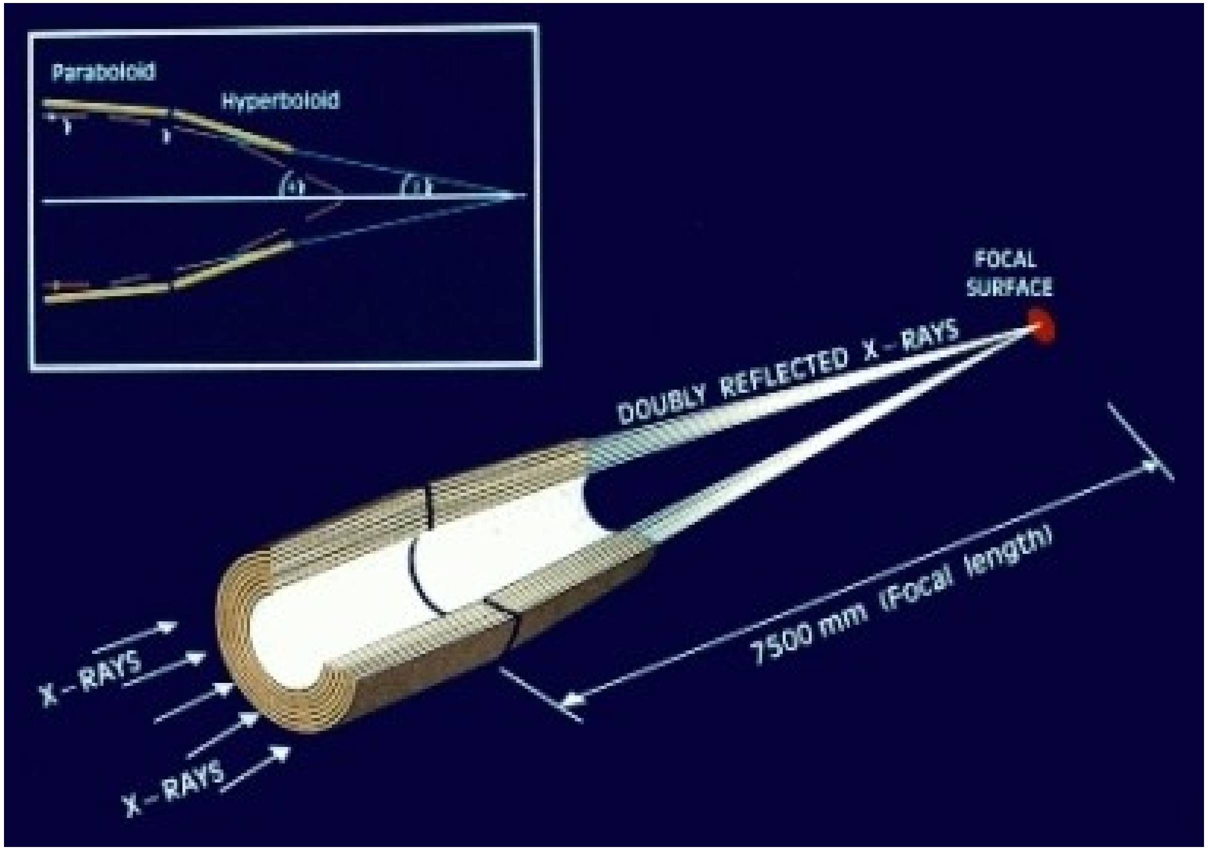
K. Hurley ....

Ulysses, Konus-Wind, RHESSI, INTEGRAL (SPI-ACS), Suzaku (WAM), and Swift (BAT) observed this hard-spectrum GRB starting around 04621 seconds. It had a duration of about 215 s in two distinct episodes, and a fluence of about 3 x 10^-4 erg/cm^2. We have triangulated it to a preliminary ~855 sq. arcmin. error box (3 sigma), whose coordinates are:

Center: 127.639, -42.210
Corners: 127.490, -42.705
127.737, -43.008
127.555, -41.399
127.774, -41.726

This error box may be improved. It was outside the Swift BAT field of view for both episodes, and therefore Swift did not image the burst, although it did detect it. However, in the course of a later, preplanned observation beginning at T+10 minutes, BAT imaged a weak source within the IPN error box, at RA, Dec= 127.630, -42.696, which could be the gamma-ray afterglow. A ToO observation of this source has been requested. Further details of the energy spectrum will be given in a forthcoming GCN.

X-ray mirrors – X-ray satellite: Newton XMM



- 58 coaxial mirrors, 30 to 70 cm in diameter
- focal length 7.5 m, resolution 5 arcsec FWHM
- detecting area 4300 cm2 at 1.5 keV
- energy range: 0.1 - 12 keV

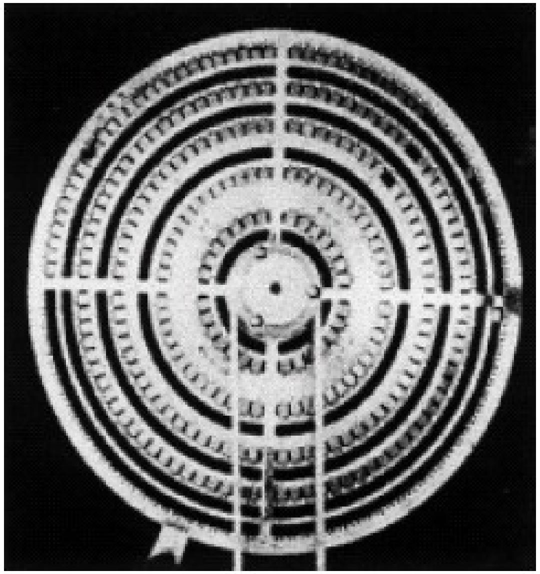
X-ray mirrors – XMM – results

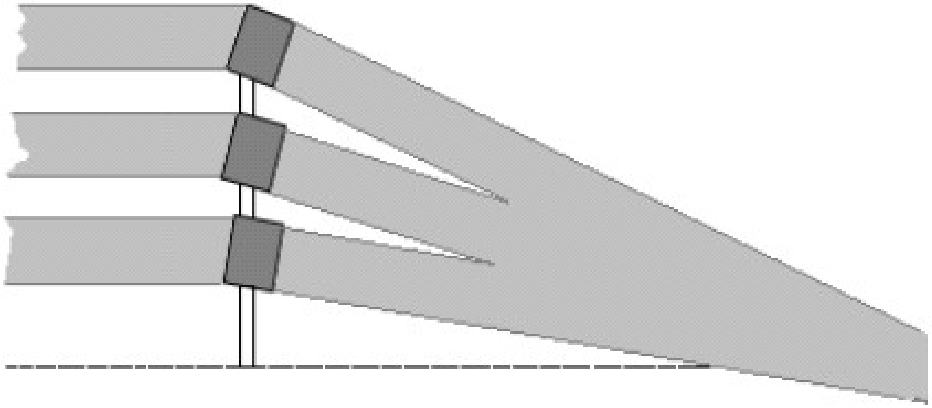
Slews of the past 4 years covered 25% of the sky.
Catalogue of more than 2700 very bright sources.

Gamma-ray lens

Laue refraction of the gamma-ray:

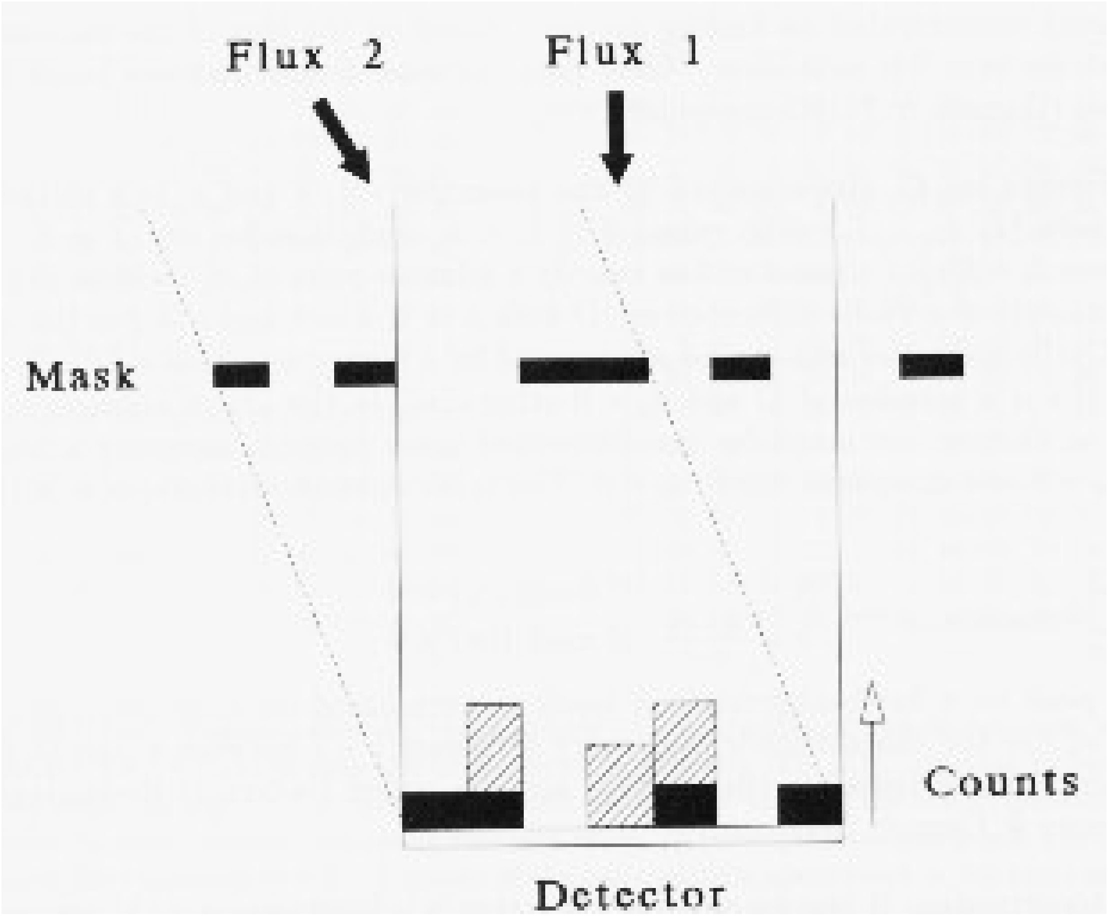
wave_length=2dsin(theta)





Focal length @ 100 keV ~ 5 m
gamma-ray concentrator

Coded mask



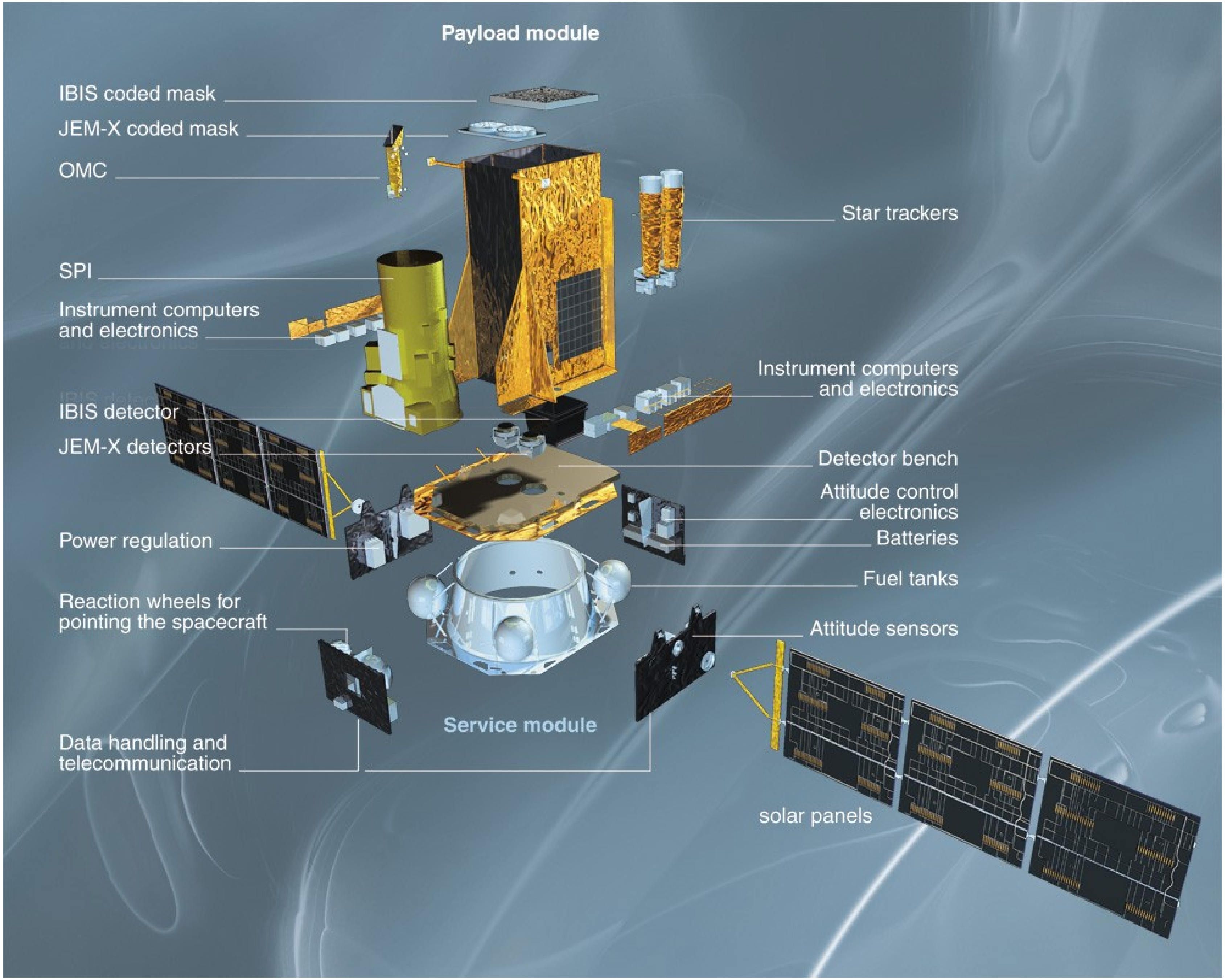
$$D = M*S + B$$

D – detector image
M – mask pattern
S – sky
B – background

Idea:

design M in such a way that having D one can determine B and S, and S is an unique solution

Coded mask – INTEGRAL



Coded mask – INTEGRAL: IBIS

Modified Uniformly Redundant Array (MURA) 53x53 basic pattern
Pixel size 11.2x11.2mm and 16mm thick
The total coded area 1064x1064mm

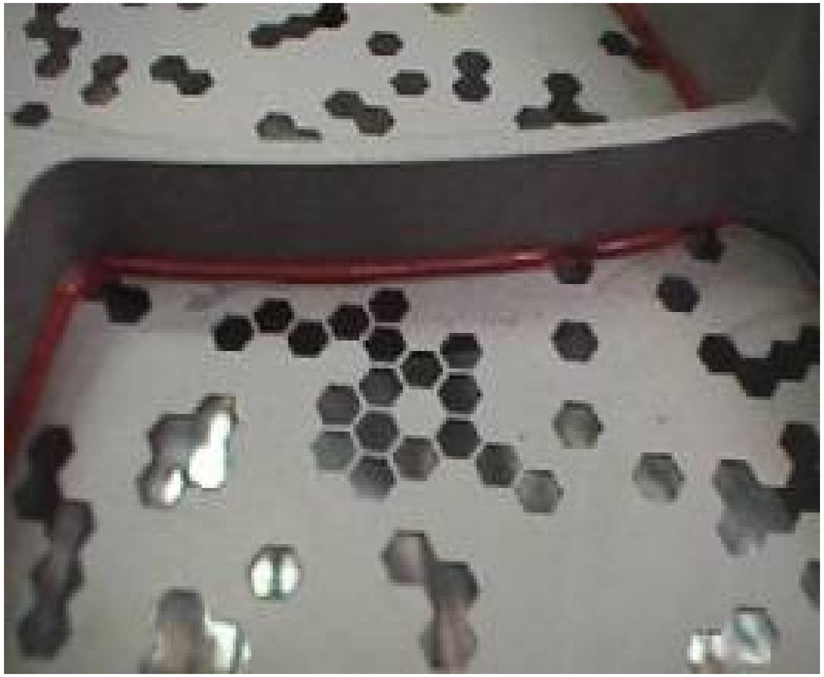
Opacity 70% at 1.5MeV)
Transparency on axis 75% and off axis 60%, at 20keV

Coded mask – INTEGRAL: SPI

Hexagonal Uniformly Redundant Array (HURA), 127 hexagonal cells
95 % opaque @ 1 MeV
60 % transparent @ 20 KeV & 80 % transparent @ 60 KeV

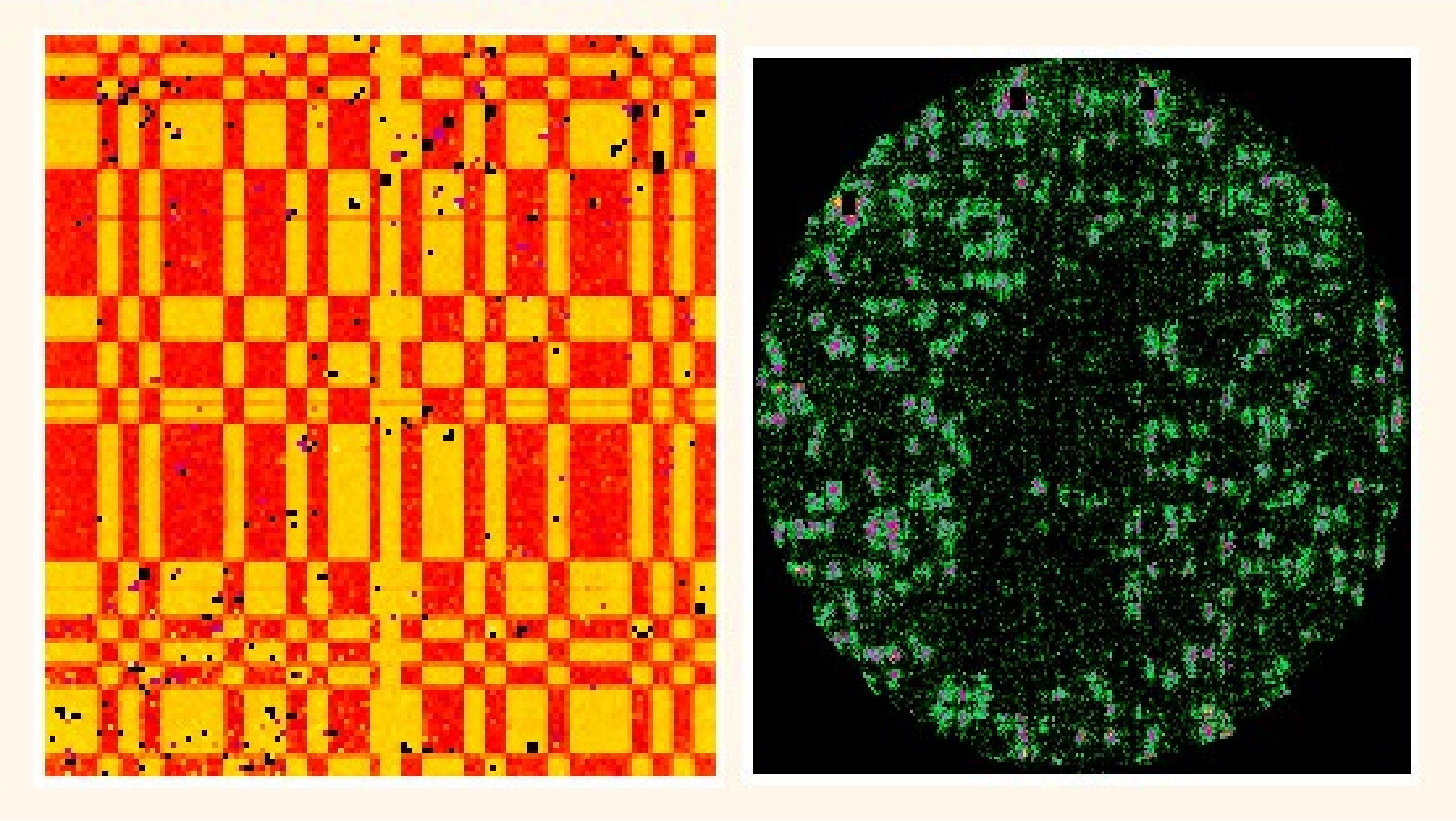
The pattern has a 120º symmetry
cells size 60 mm side-to-side by 67.55
overall dimensions 692.72 mm by 770 mm
tungsten 30 mm. thick

Coded mask – INTEGRAL: JEM-X



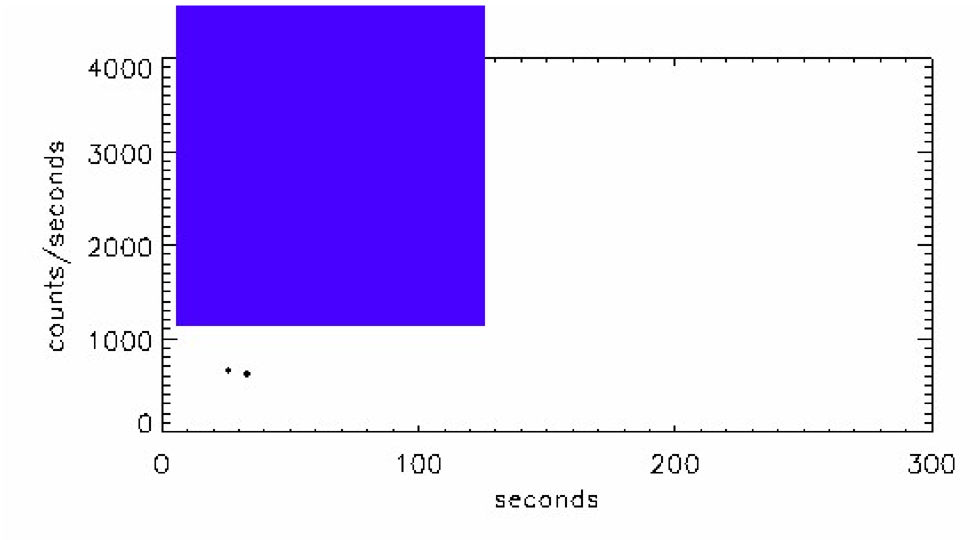
Hexagonal Uniformly Redundant Array (HURA) of 22501 elements

Coded mask – shadowgramms



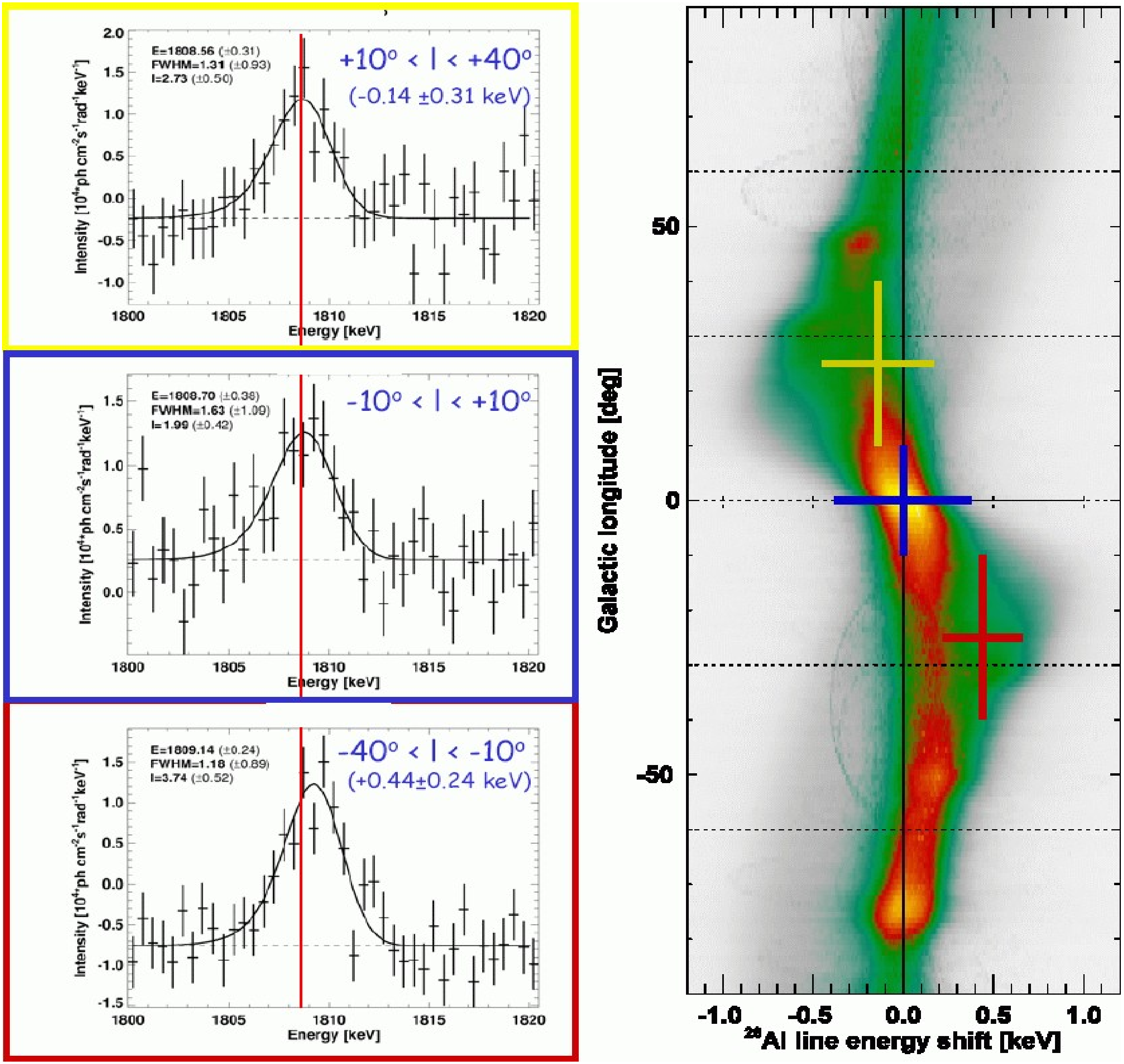
Ground calibration detector images: ISGRI & JEM-X

Coded mask – INTEGRAL – ISGRI imaging a GRB



GRB 030312 in the coded field of view of ISGRI

Coded mask – INTEGRAL – SPI – mapping Al26



Compton direct imaging and off-axis GRBs analysis with INTEGRAL

M.Denis, CBK PAN

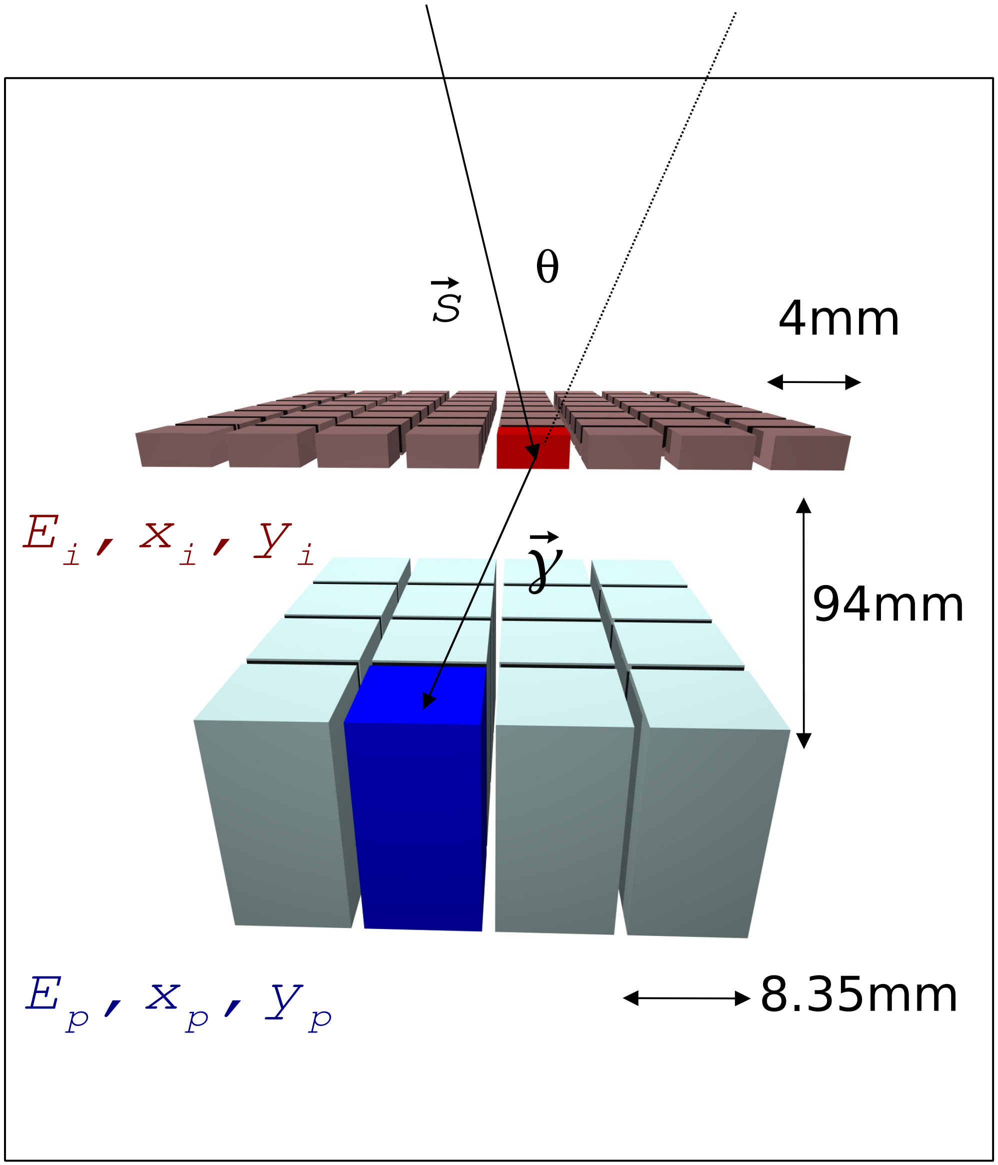
T.Bulik, CAMK, OAUW

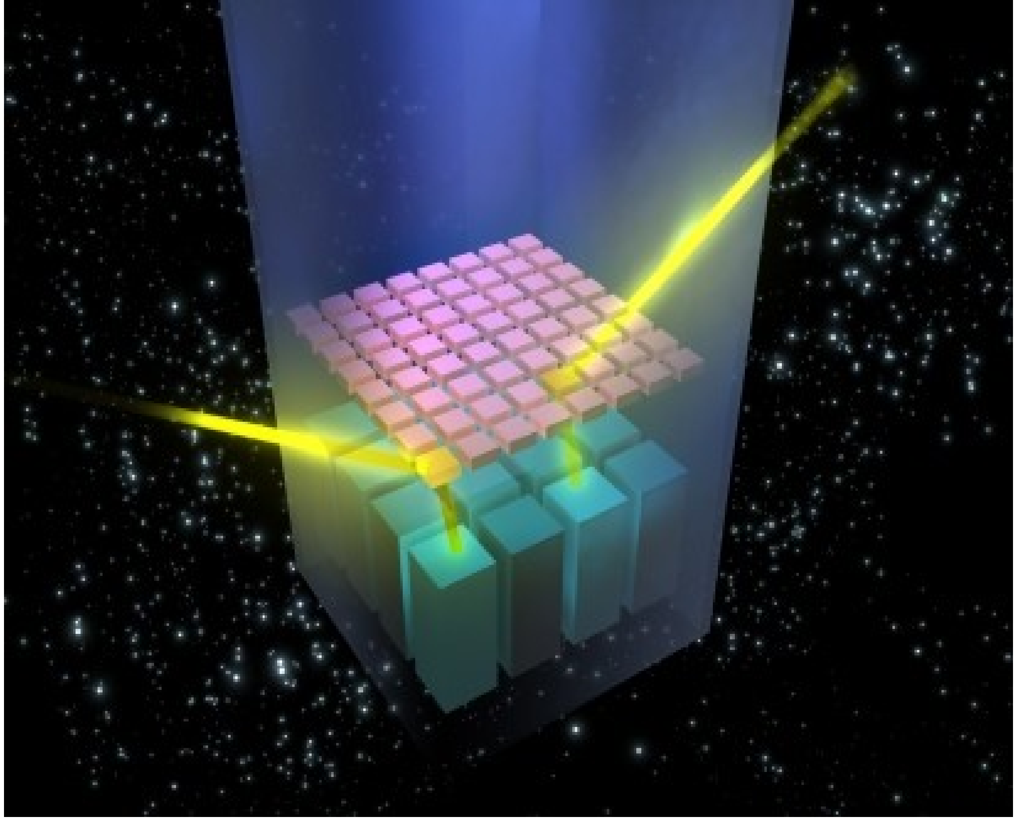
R.Marcinkowski, IPJ Swierk

Ph.Laurent, Sap/CEA Saclay

P.Goldoni, Sap/CEA Saclay

Compton imaging

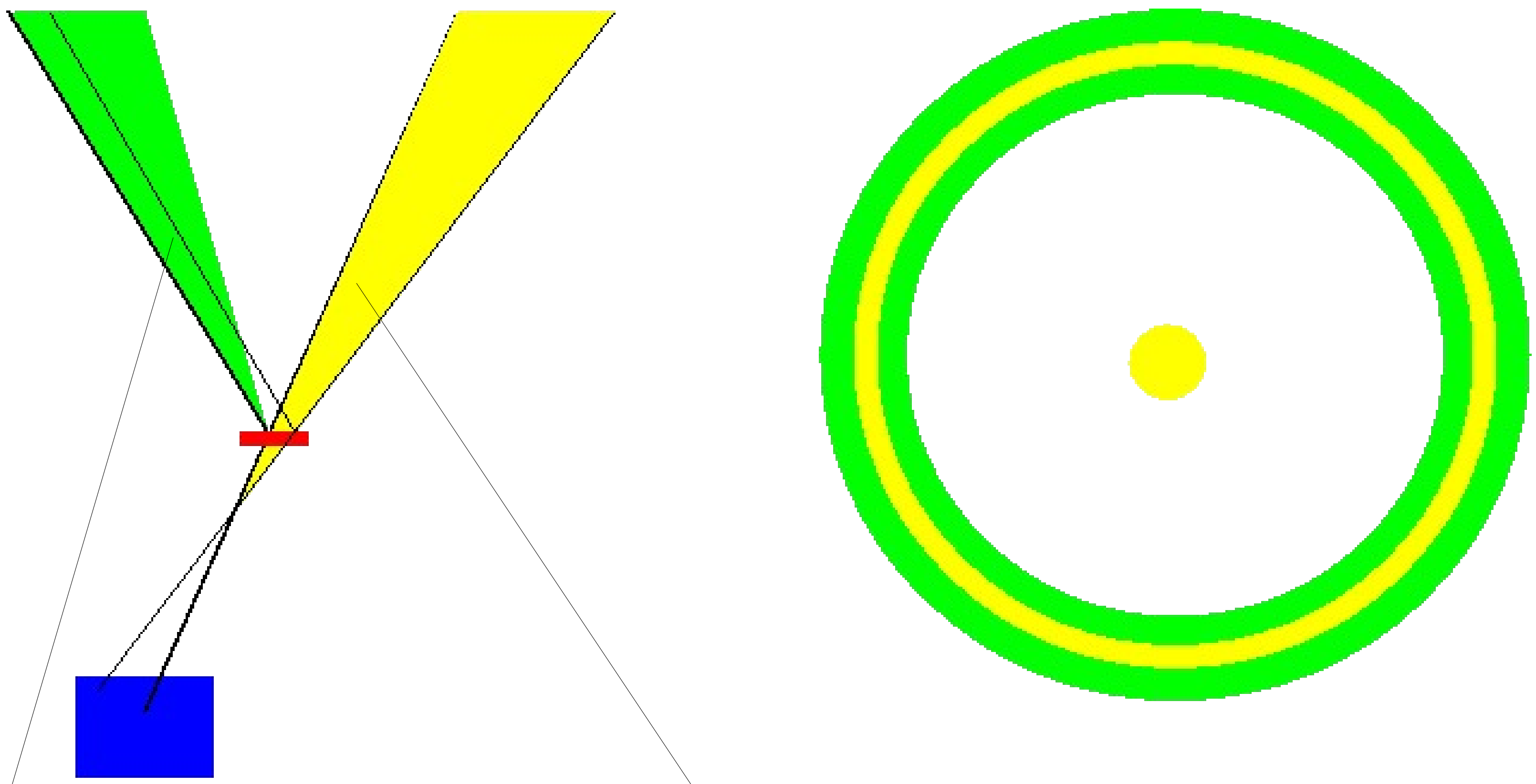




Compton scattering formula:

$$\cos(\theta_c) = 1 - \frac{511}{E_i} + \frac{511}{E_i + E_p}$$

Compton imaging – inaccuracies

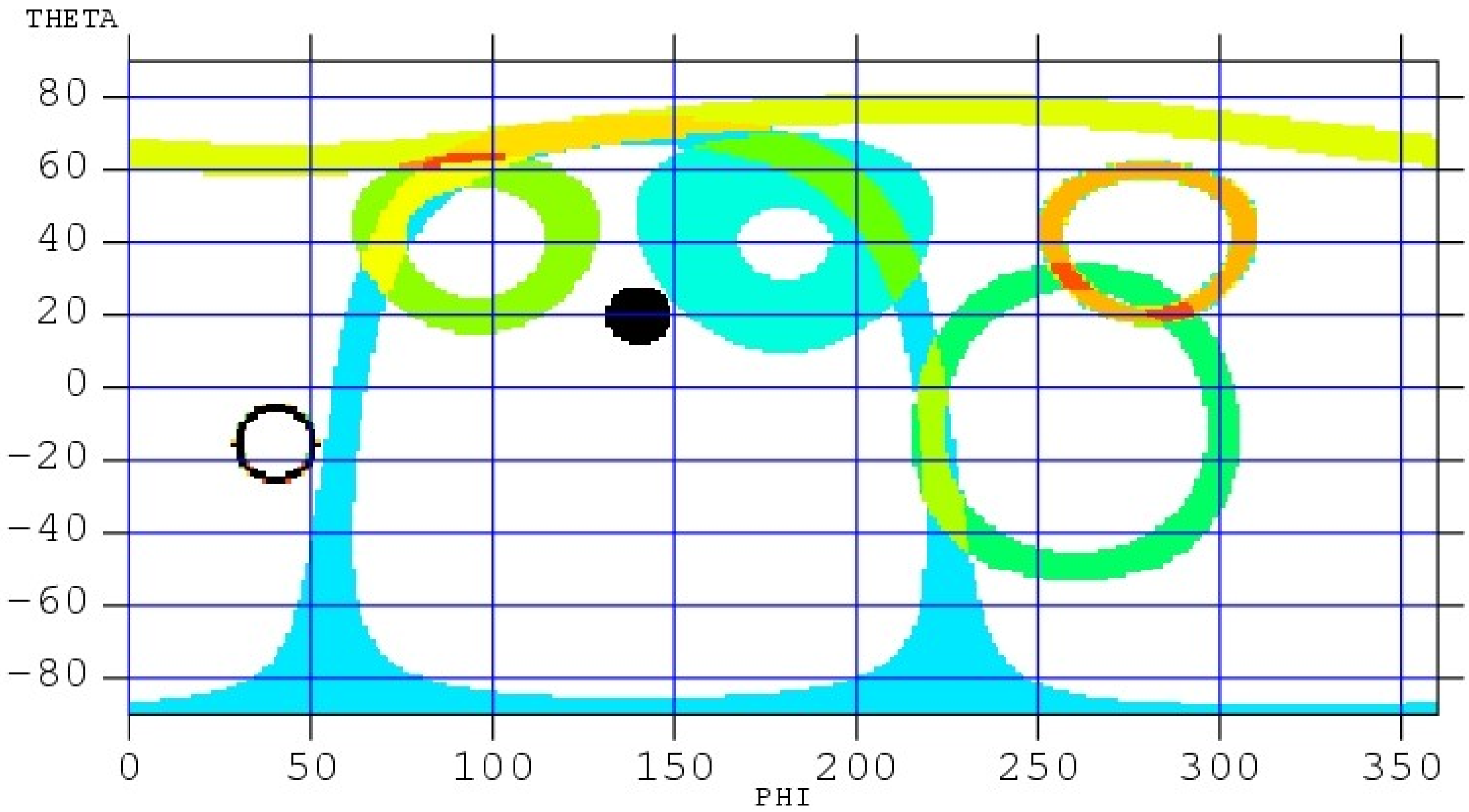


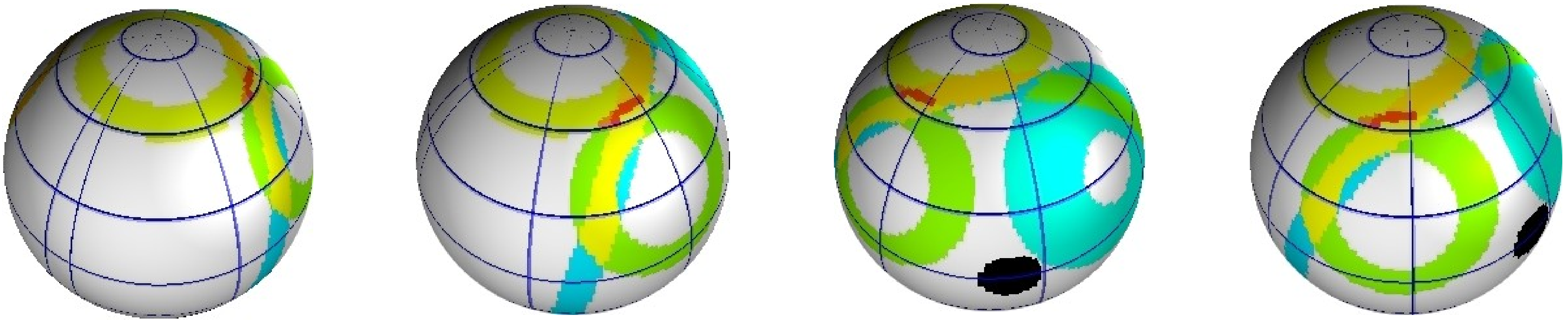
Geometrical error (dPosition)

Physical error (dEnergy)

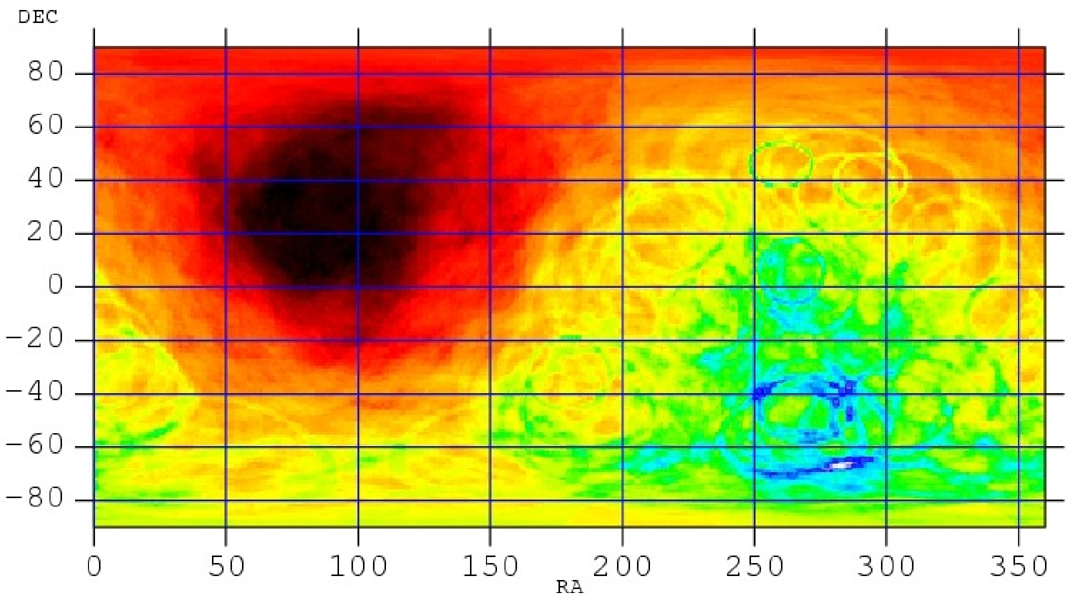
Angular resolution > 2-3 deg

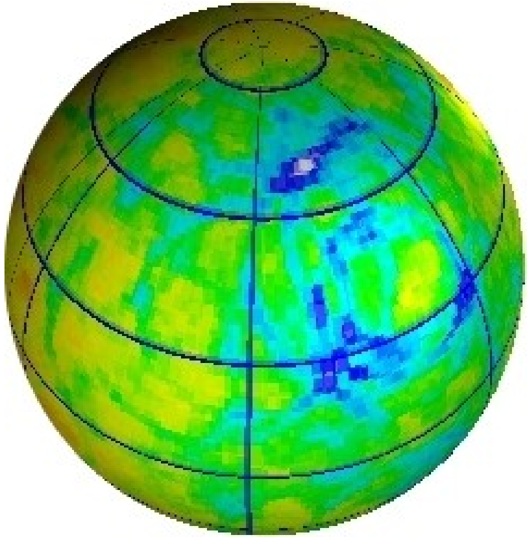
Compton imaging – example of Compton circles



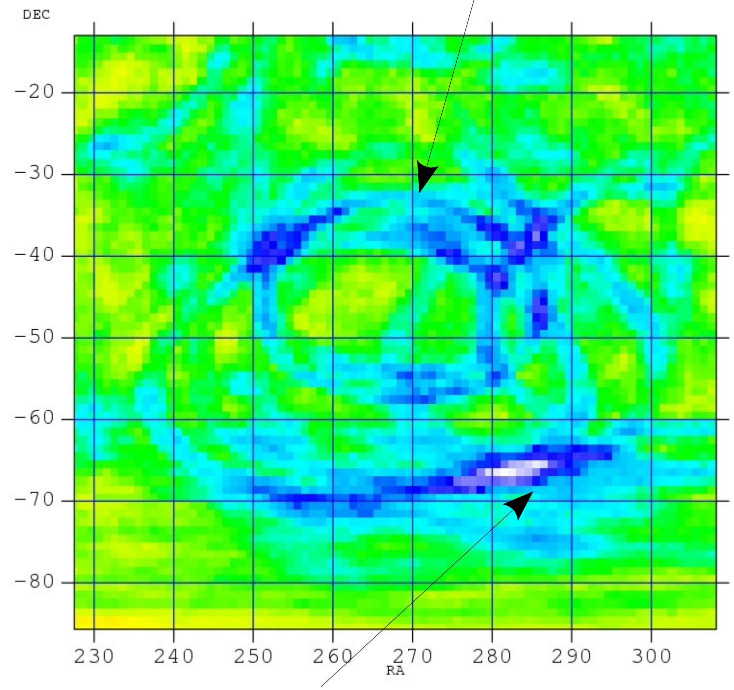


Compton imaging - GRB030406





Center of the coded FoV

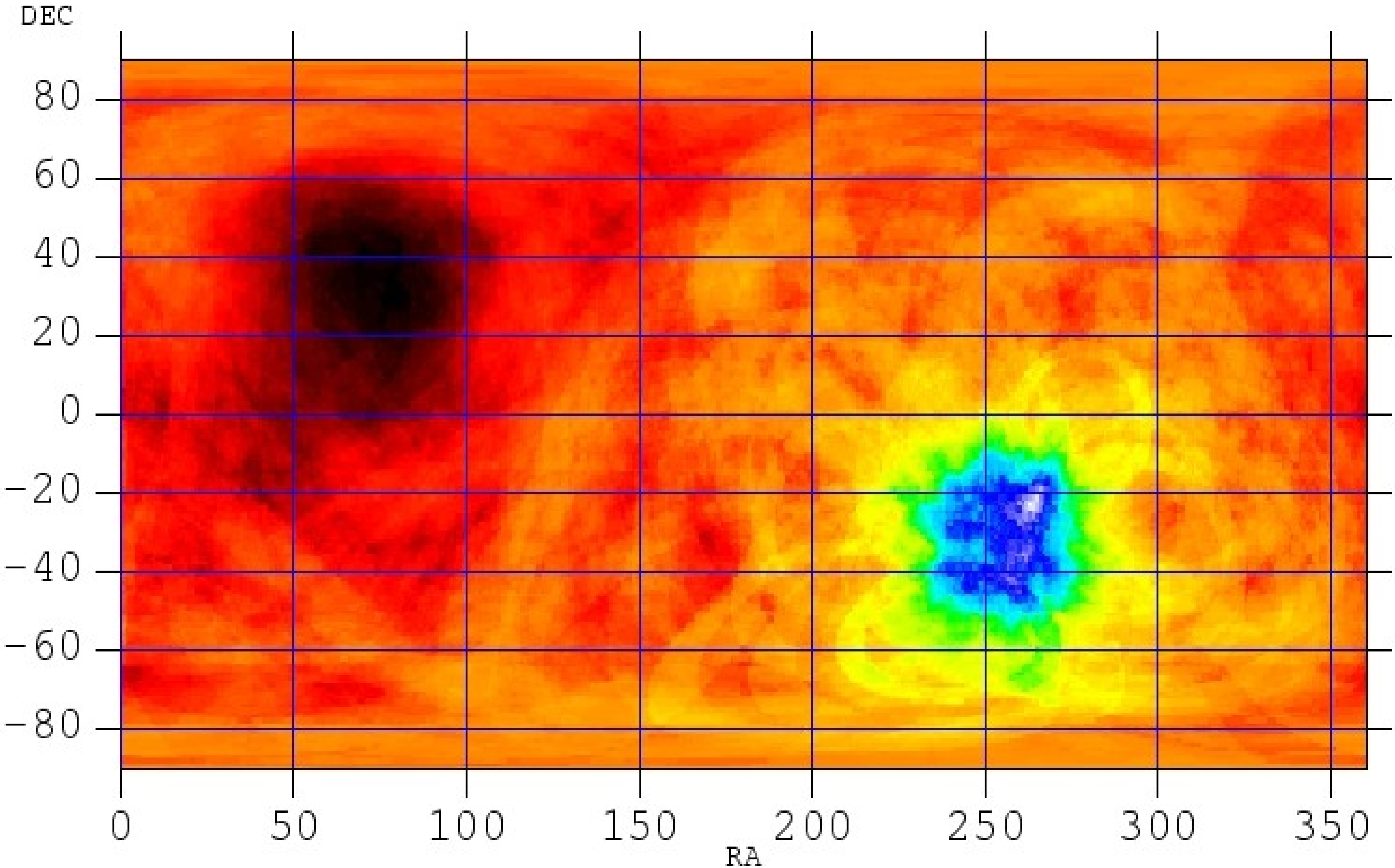


GRB030406

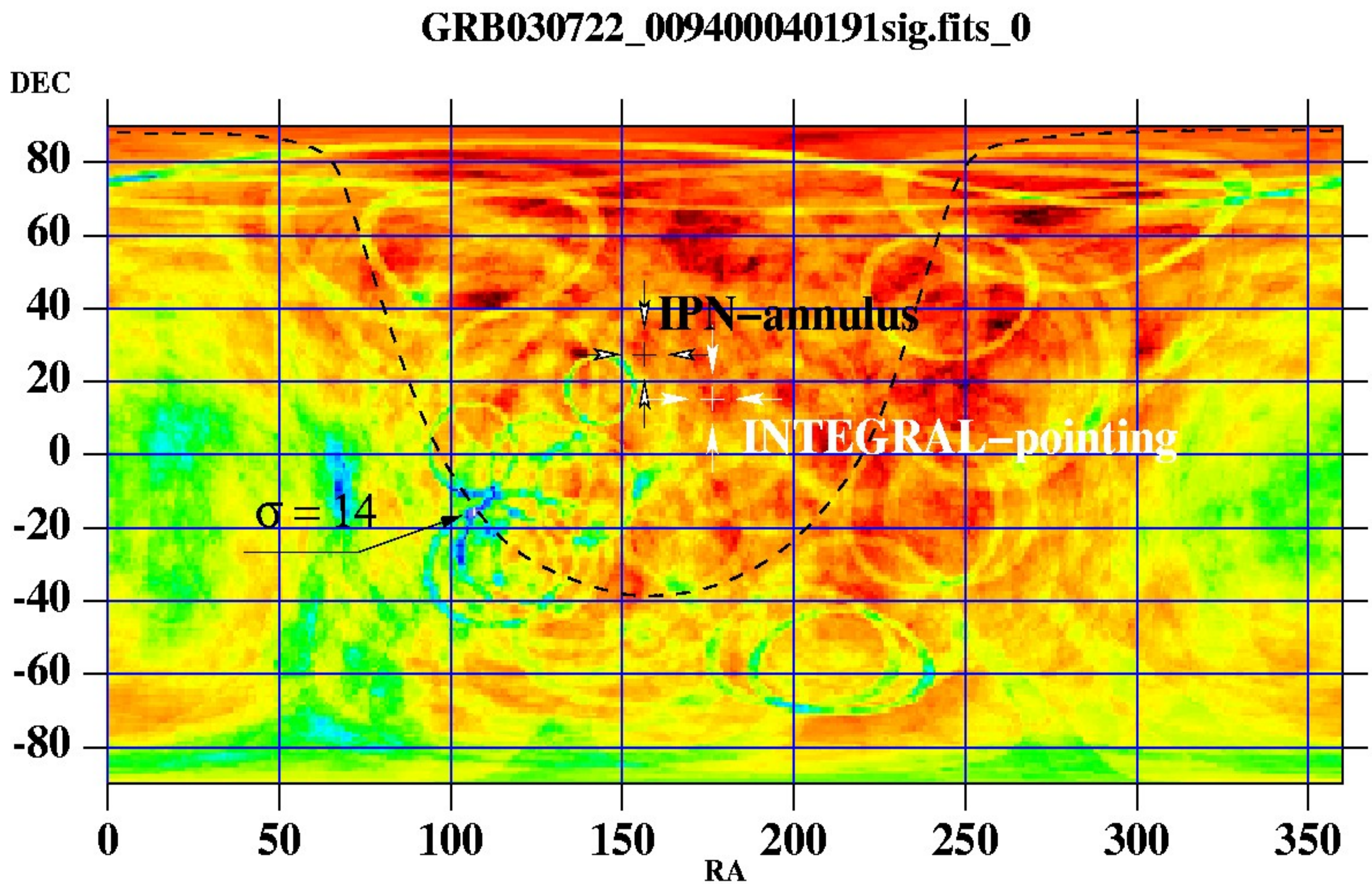
GCN/ IPN, K. Hurley et al.
http:/ / gcn.gsfc.nasa.gov/ gcn3/ 2127.gcn3

$\Delta T = 9.75$ s
170 keV < E < 950 keV

Compton imaging - GRB 030320 - Integral FoV



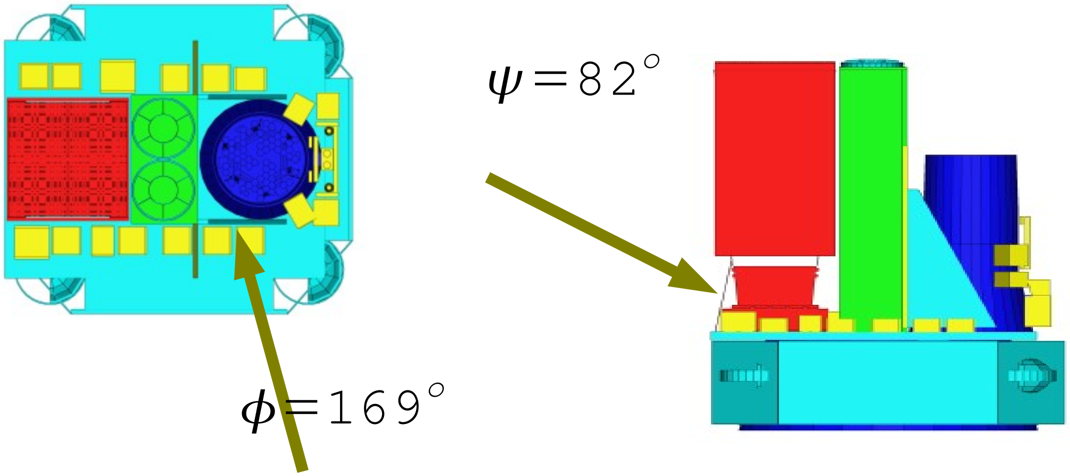
Equatorial coordinates

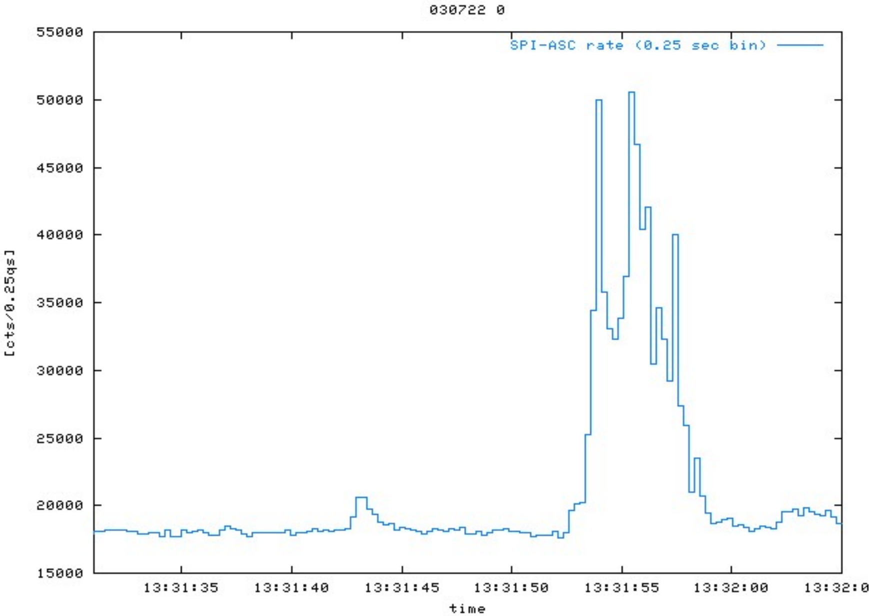


GRB 030722

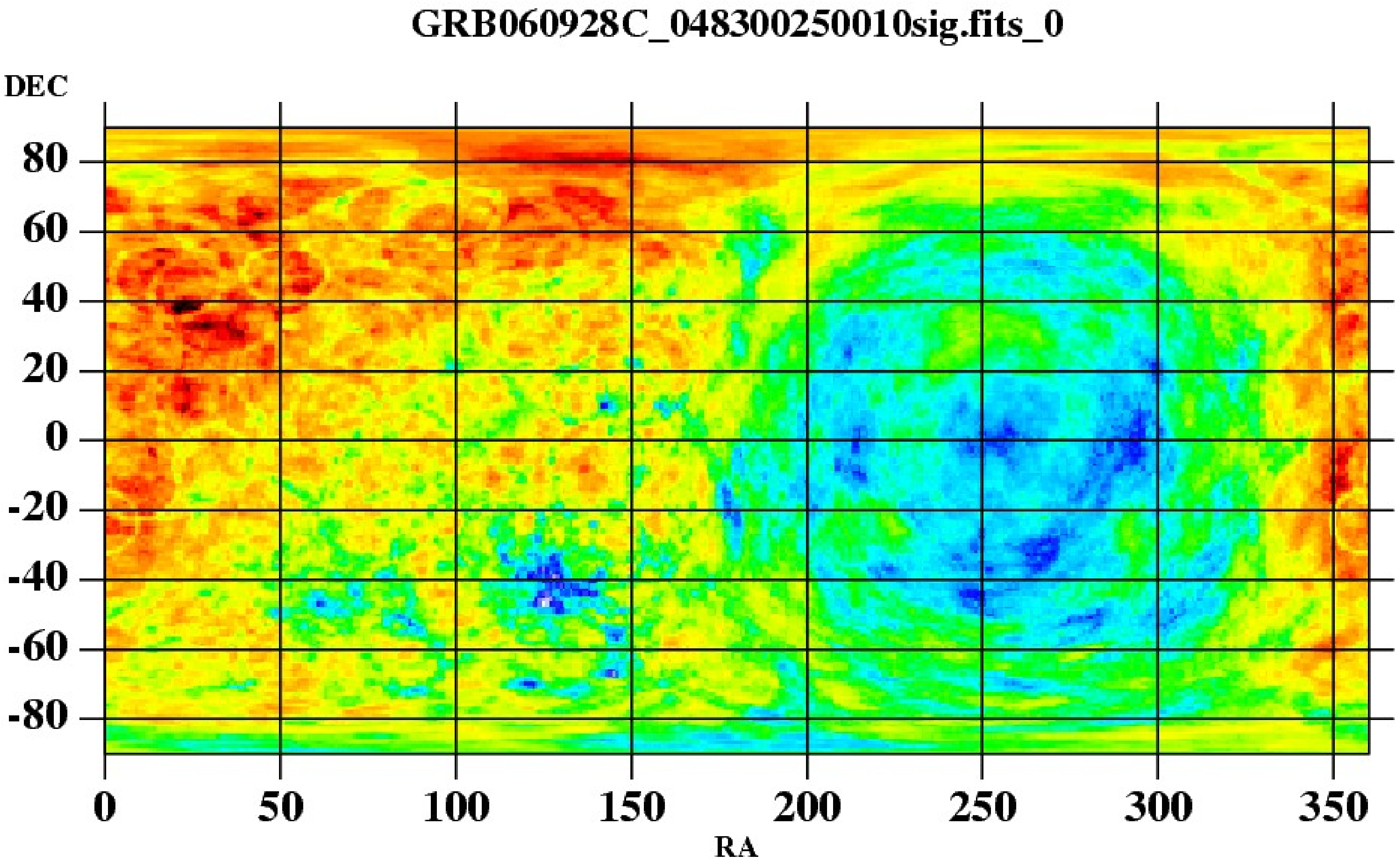
IPN: annulus only

Compton Image max:
RA = 106.5
Dec =-15.5



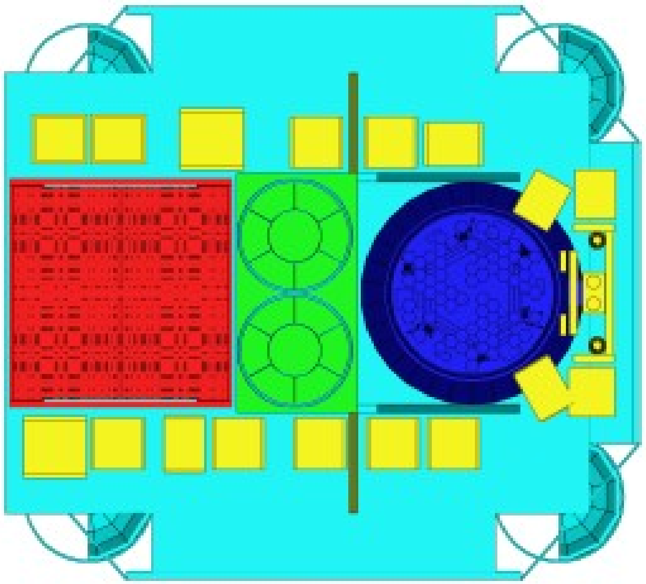


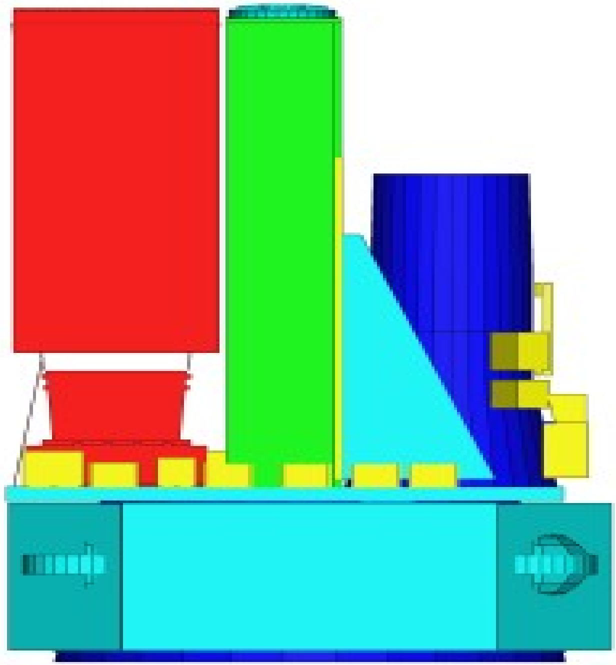
Compton imaging - GRB060928



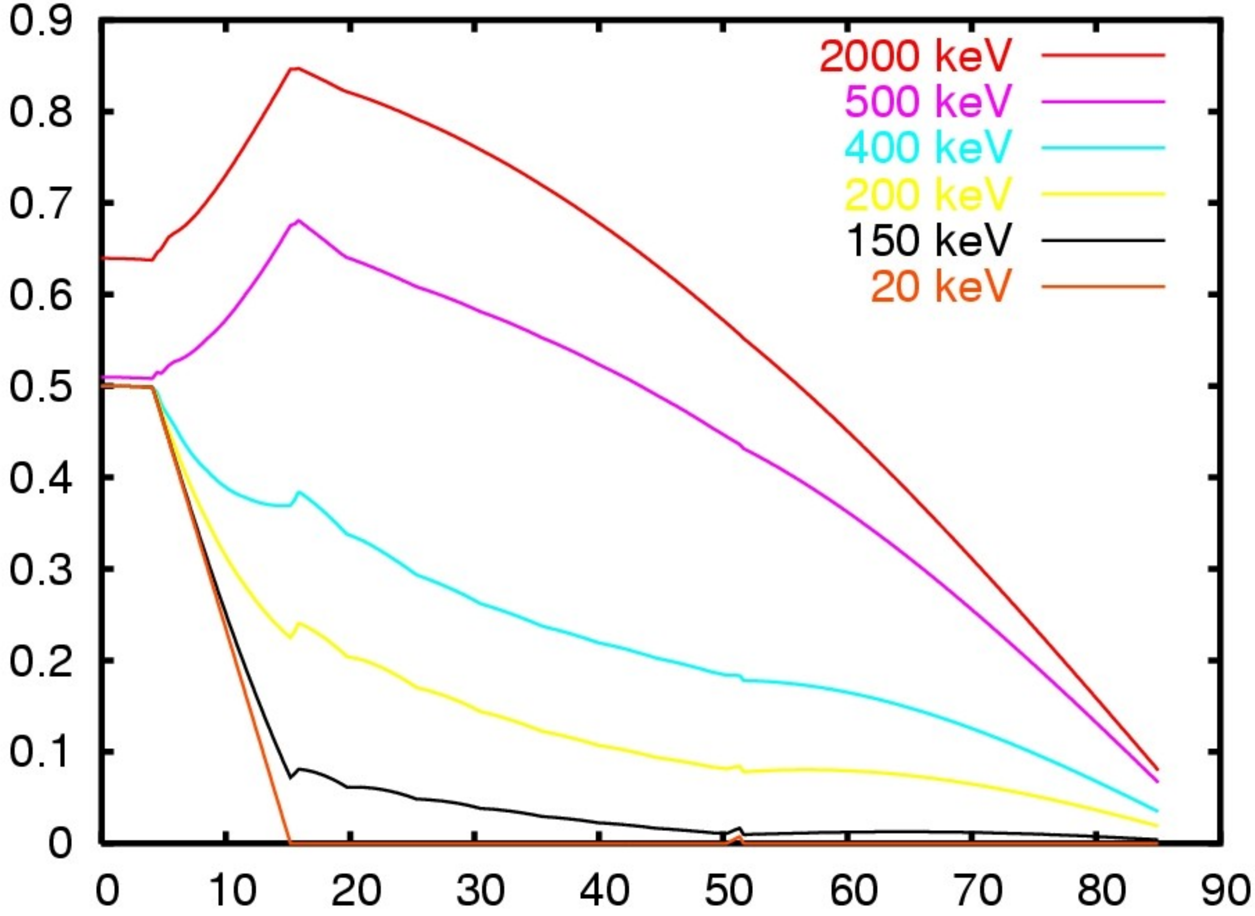
Spectral Analysis - Integral Mass Model

CERN geant3 simulation tool





IBIS tube transparency



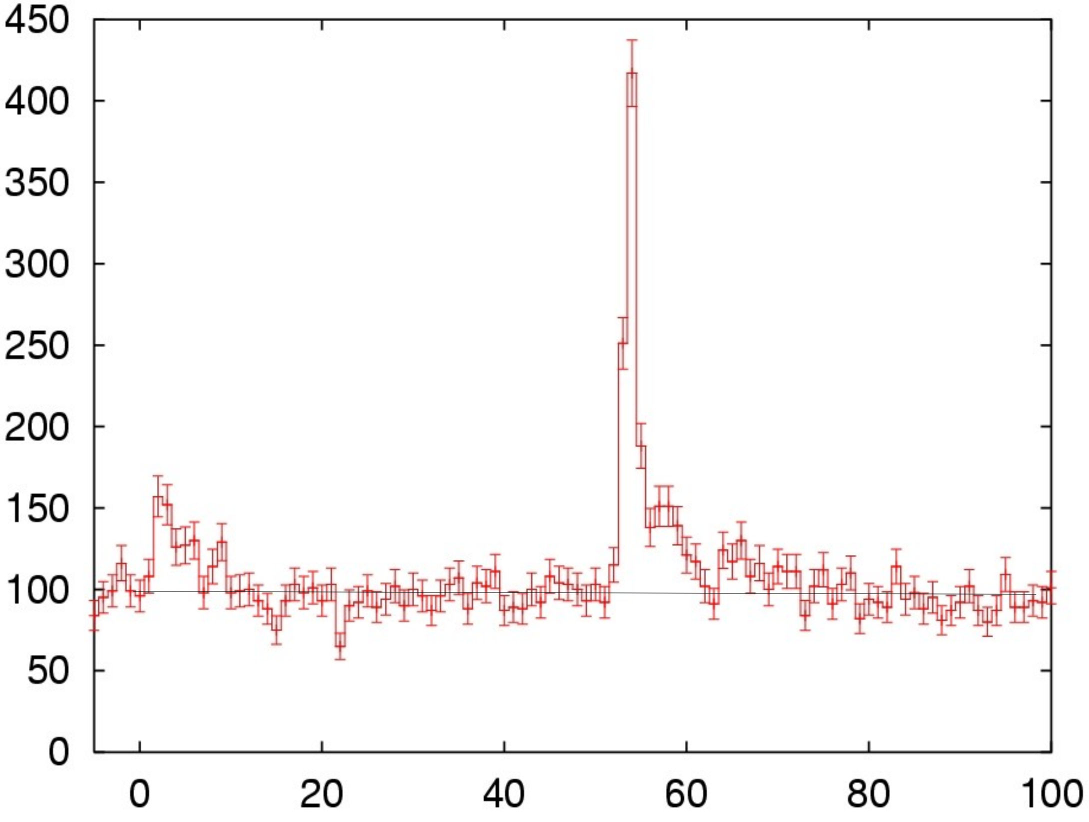
Off-axis angle [º]

IBIS off-axis spectral analysis

- Background subtraction
- Response modeling

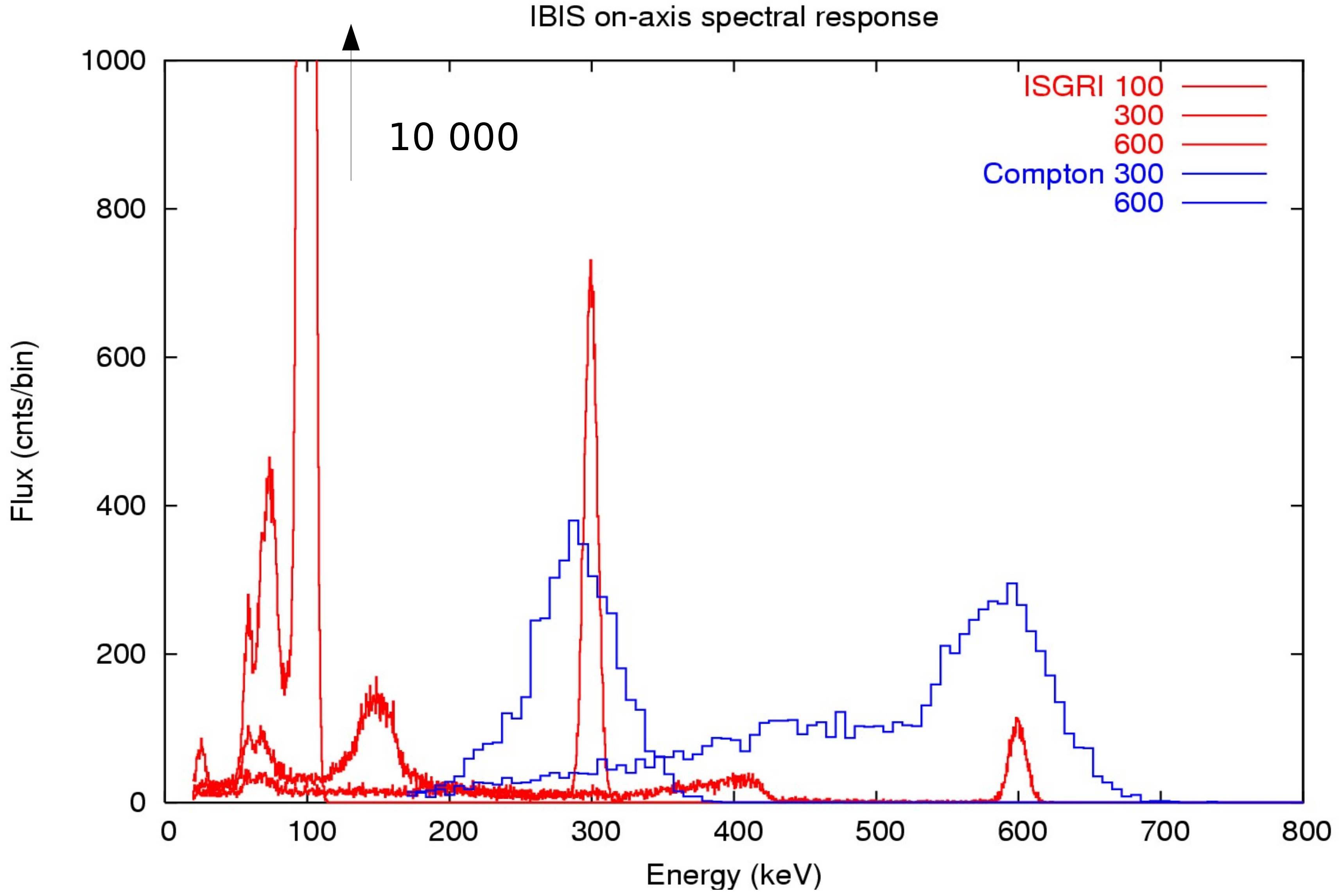
  (direction dependent, GRB position must be known!)
- Model fitting (xspec tool)

GRB030406 Compton cnt/s



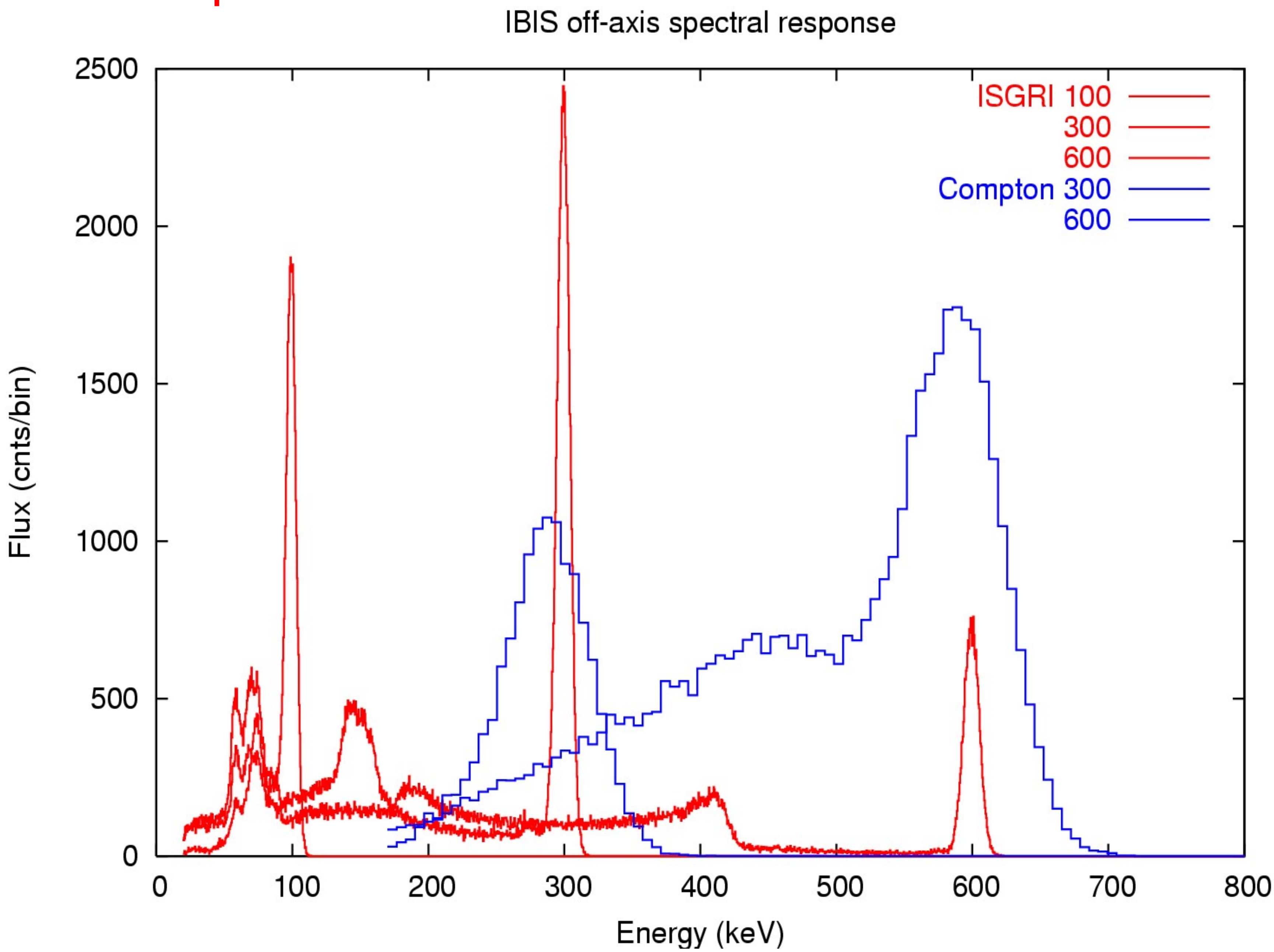
IBIS response

$$\phi = 0.0^\circ, \quad \psi = 0.0^\circ$$

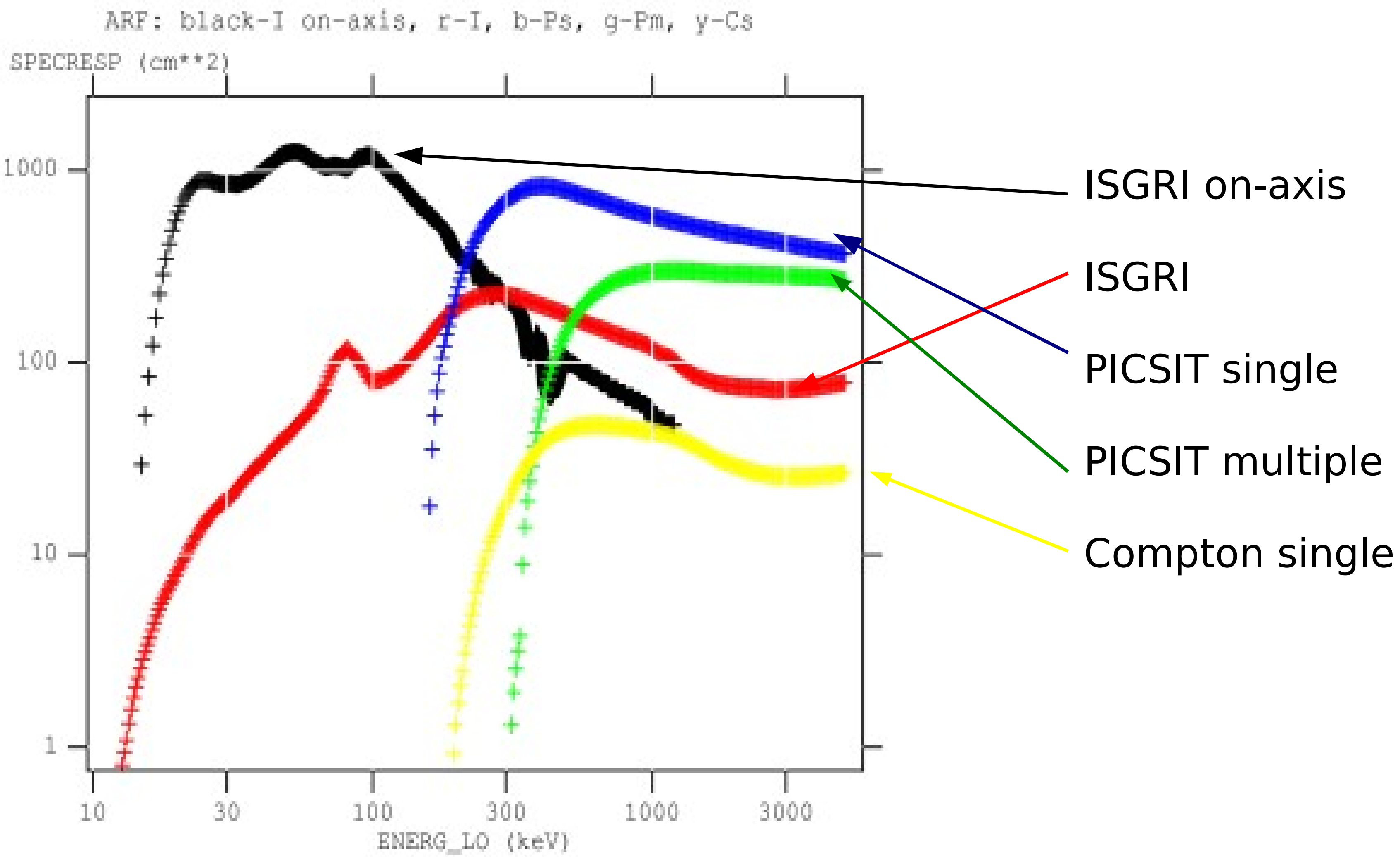


IBIS response

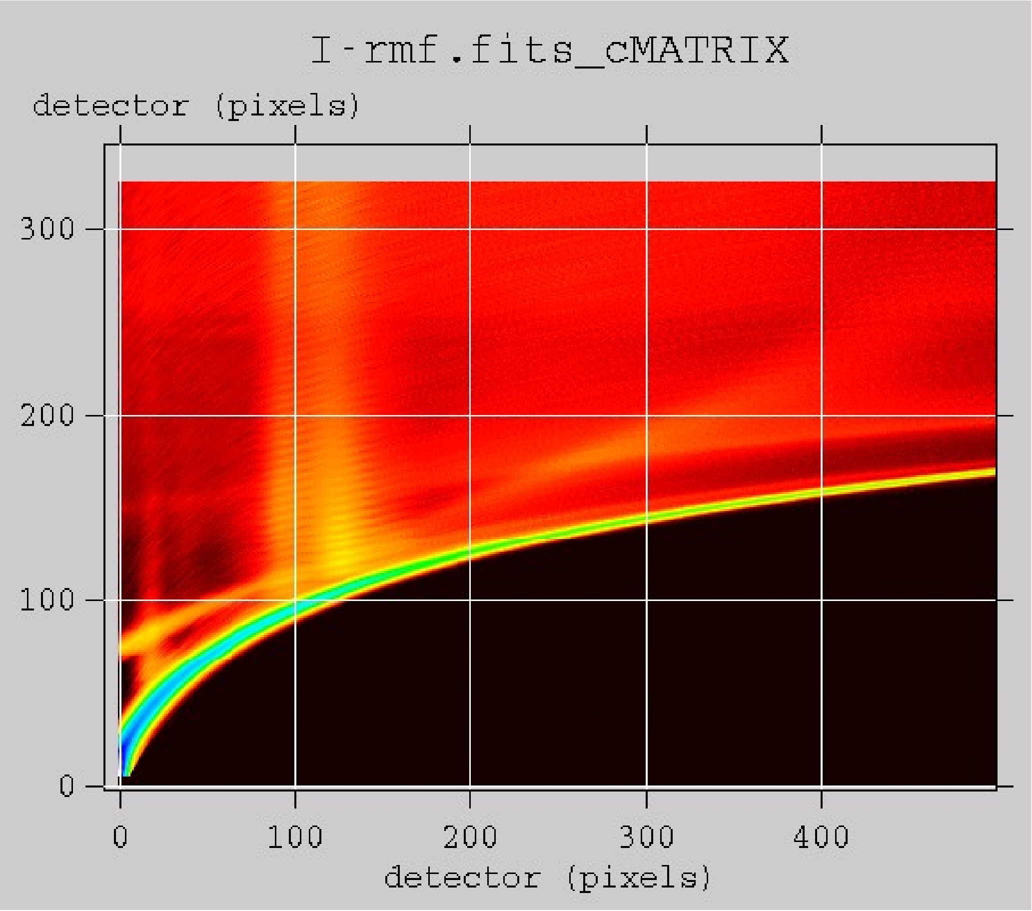
$\phi = 281.036^{o}$, $\psi = 36.827^{o}$

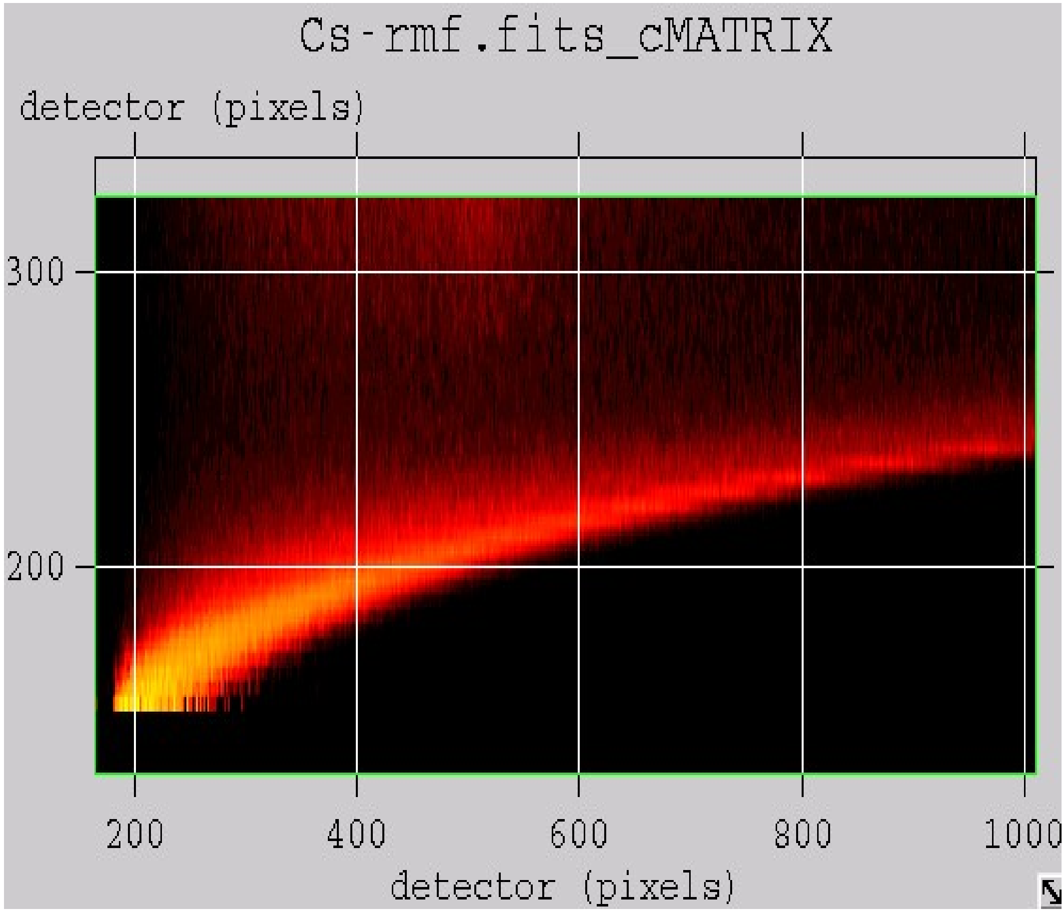


IBIS response – effective area



IBIS response matrices: ISGRI, Compton

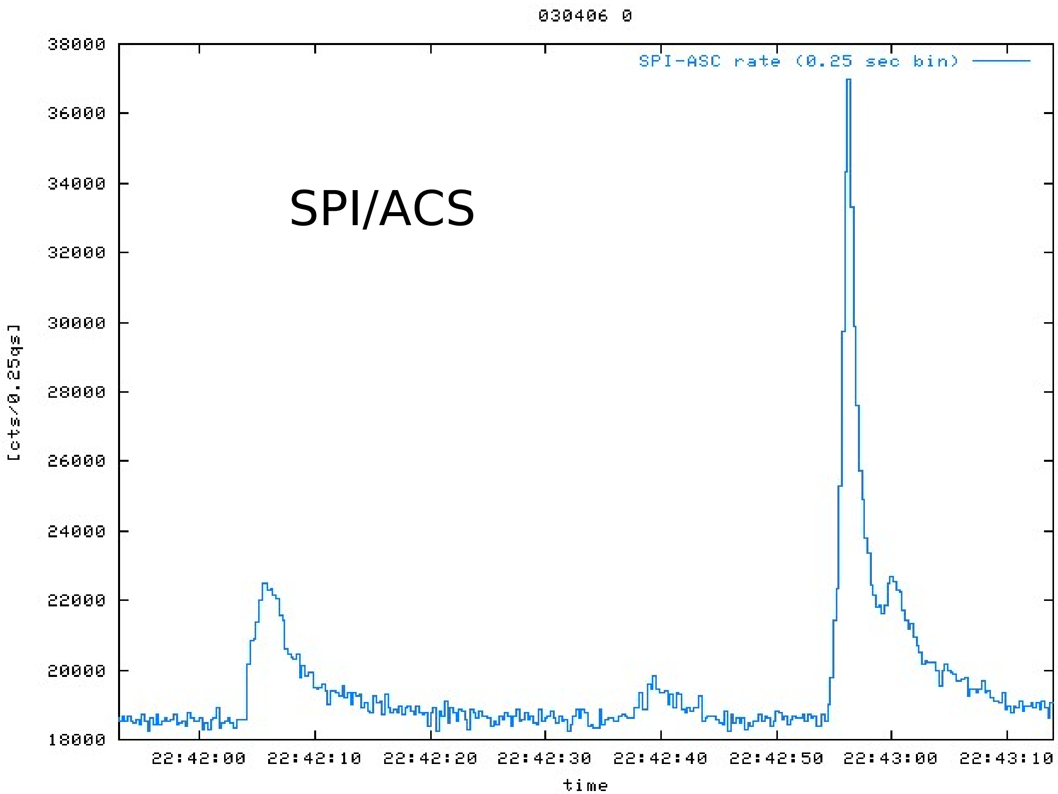


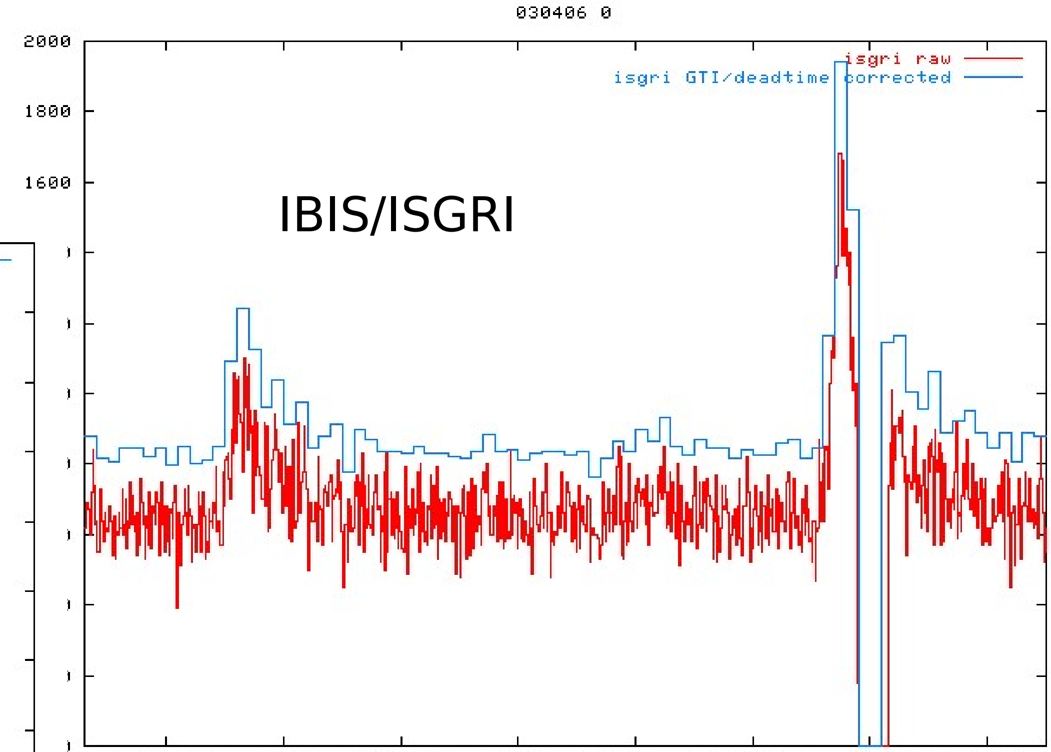


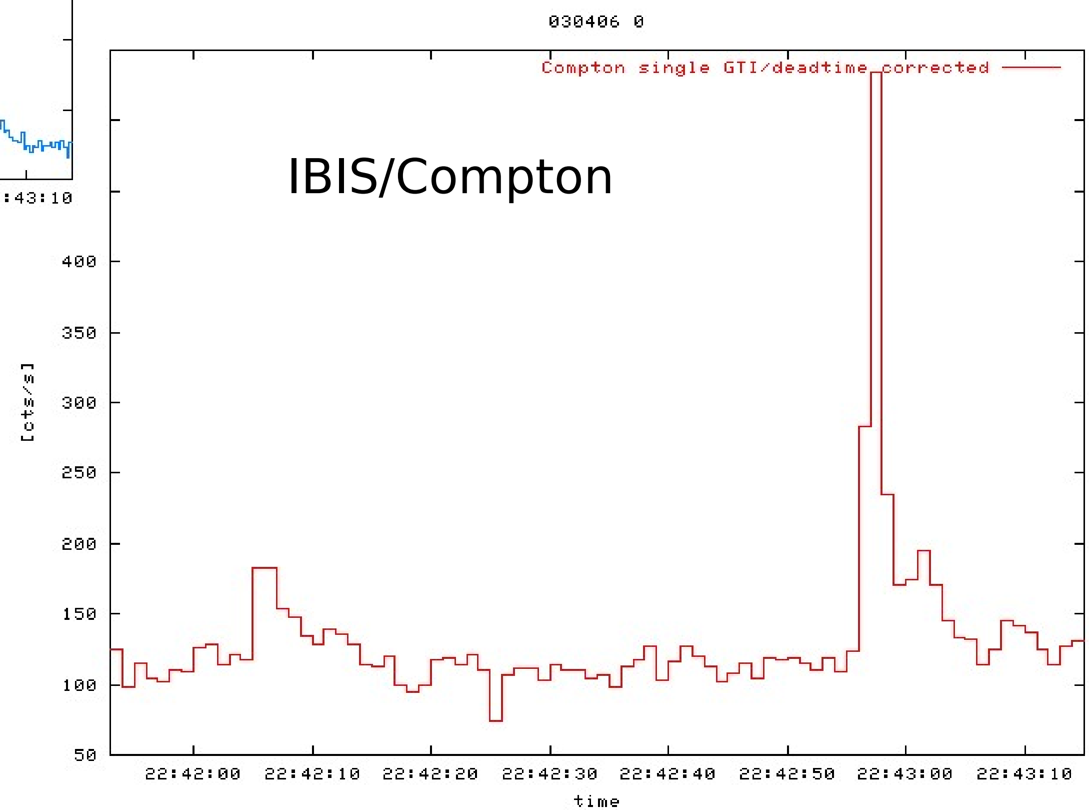
GRB spectral analysis

GRB	Polar angle (°)	Duration (s)
030406	36.9	70
030722	76.6	15
031111	53.6	10

GRB 030406 – light curve

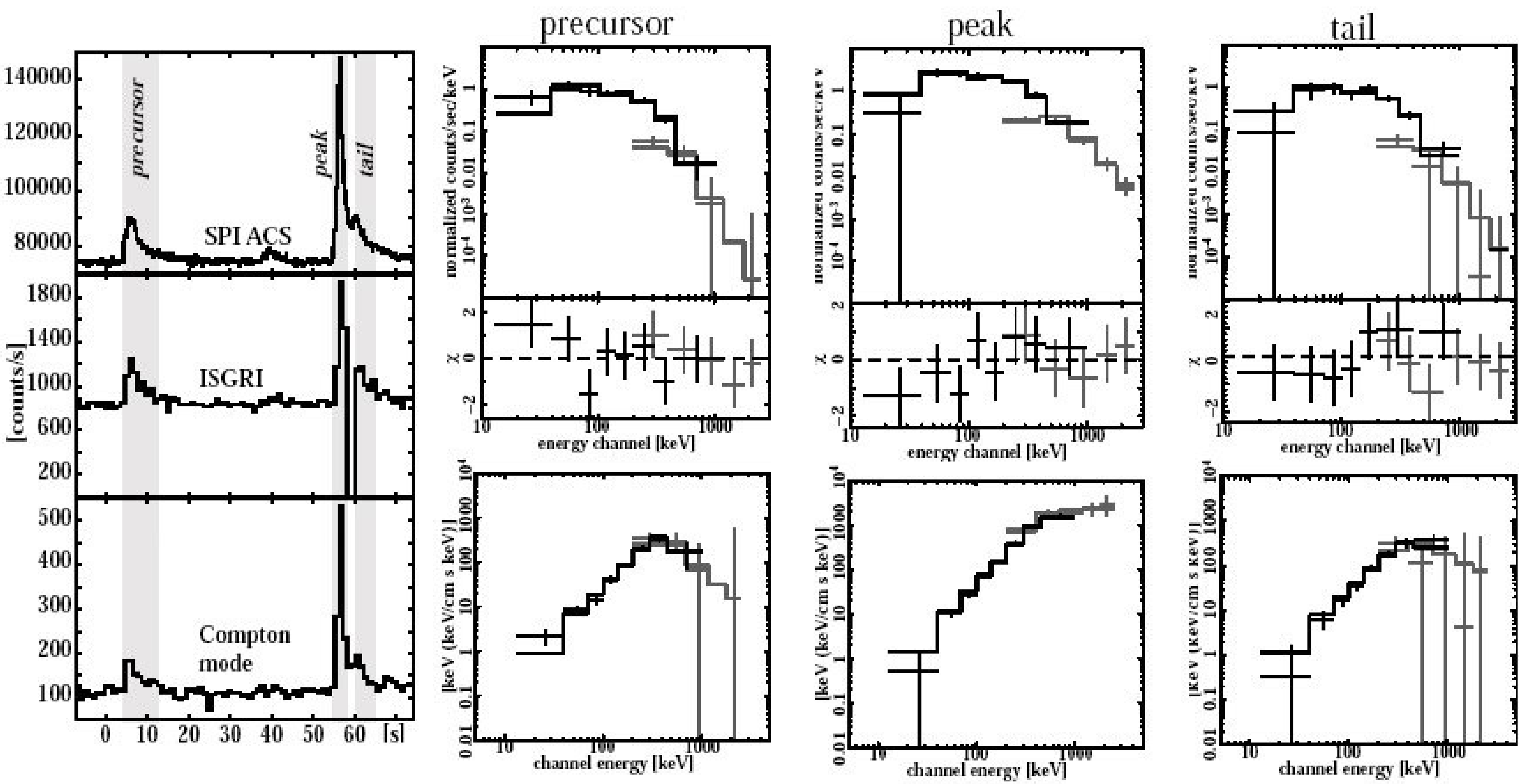






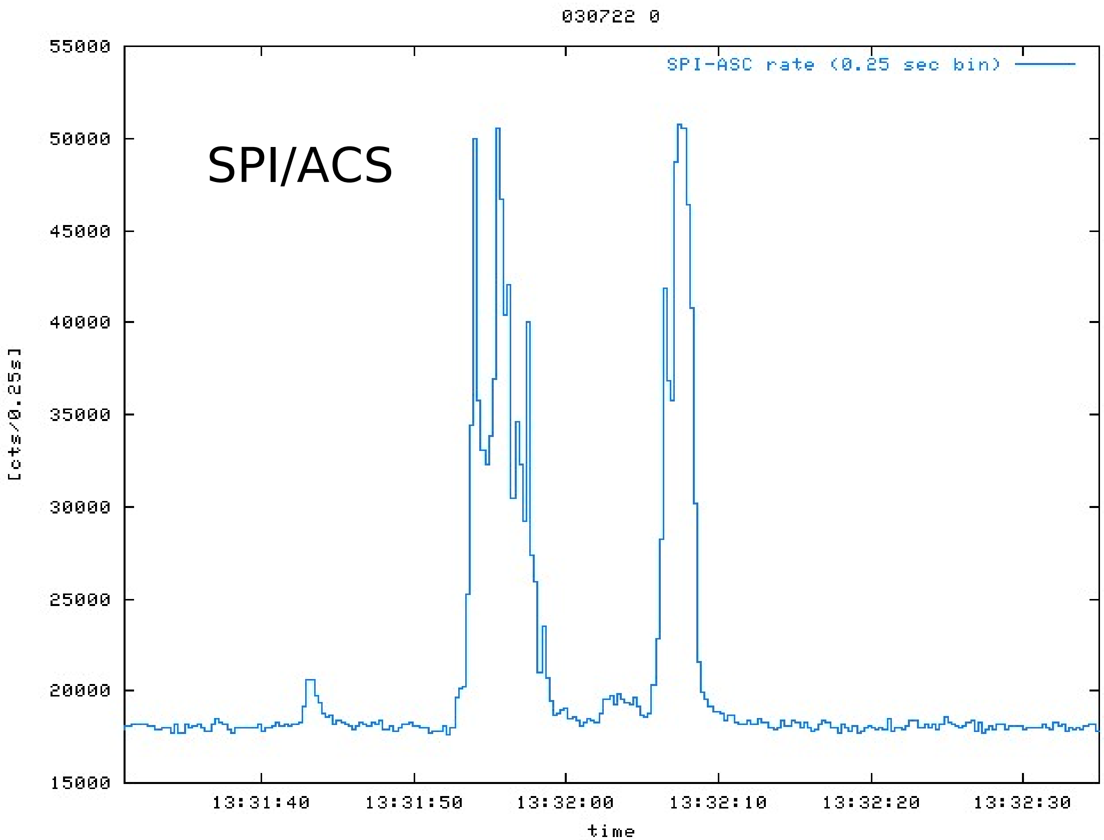
Position: IPN triangulation
and Compton imaging
duration = 70 s
off-axis = 36.9°

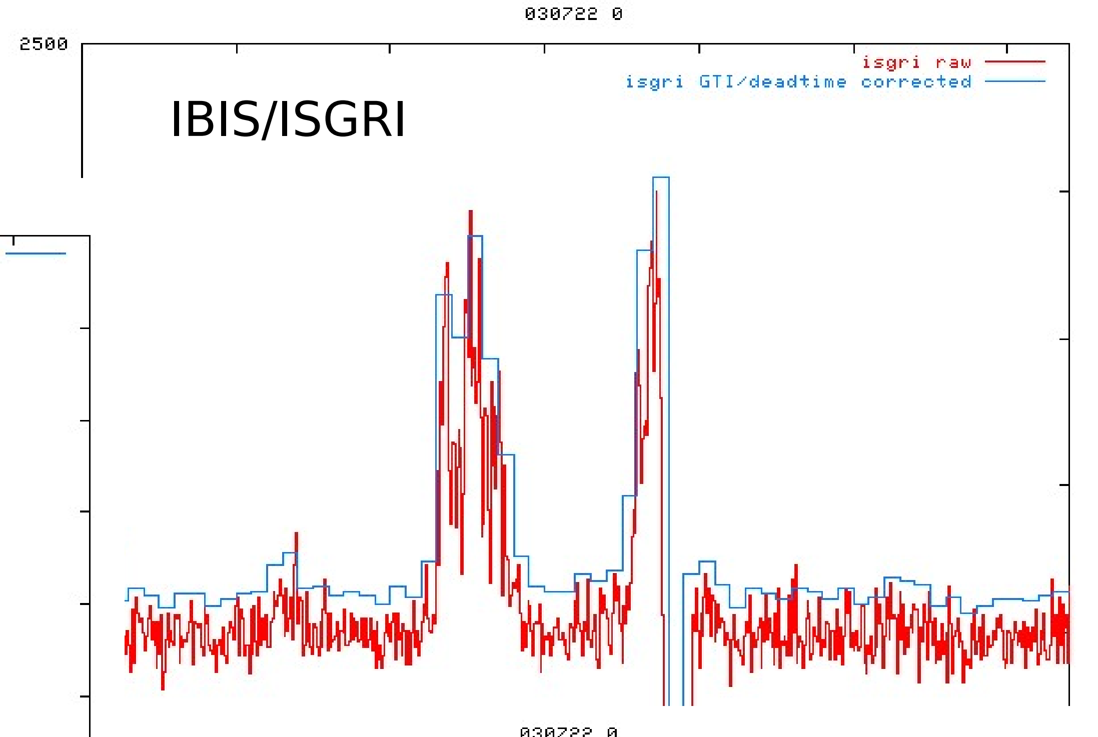
GRB 030406 – spectrum

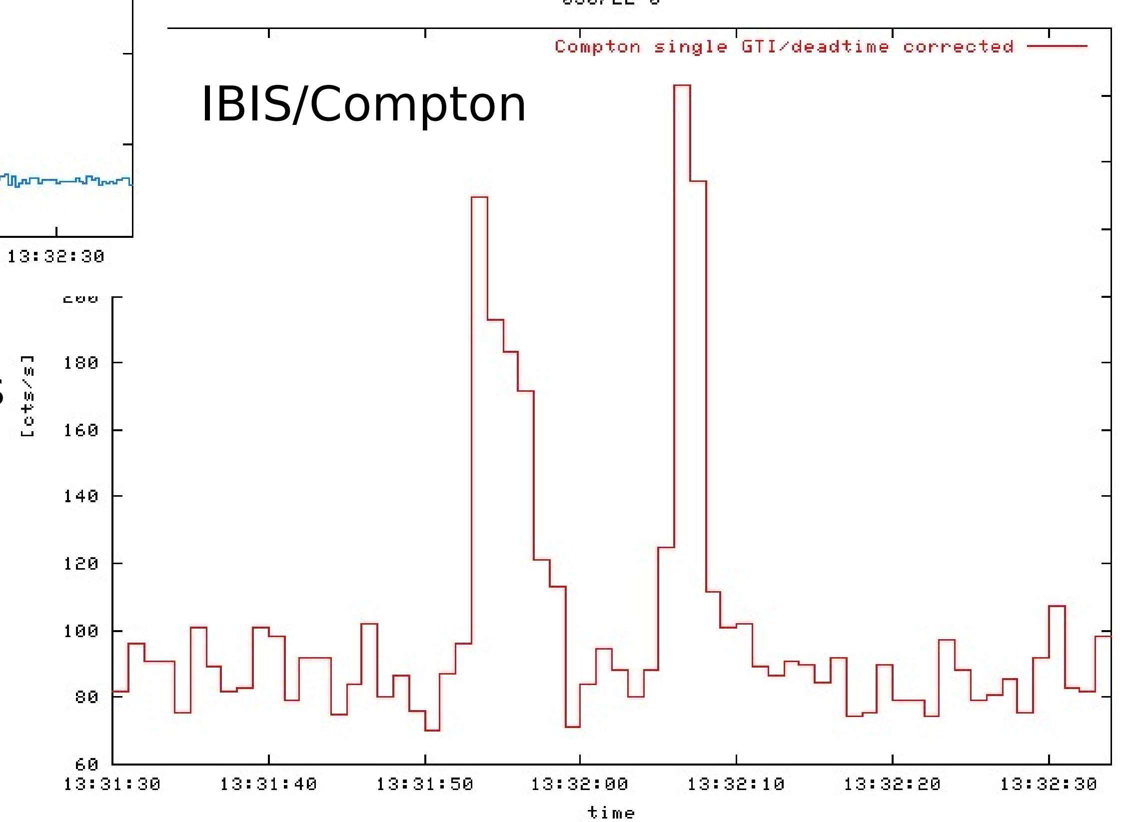


part	[s]	α	β	$E_{\rm break}$
precursor	7.3	$0.0^{+0.3}_{-0.3}$	9.0^{+1}_{-6}	490^{+40}_{-180}
peak	2.81	$-1.5^{+0.7}_{-1.0}$	$1.7^{+0.4}_{-0.3}$	390^{+60}_{-50}
tail	4.3	$-0.8^{+0.7}_{-2.2}$	$2.8^{+1.2}_{-0.6}$	270^{+70}_{-50}

GRB 030722 – light curve

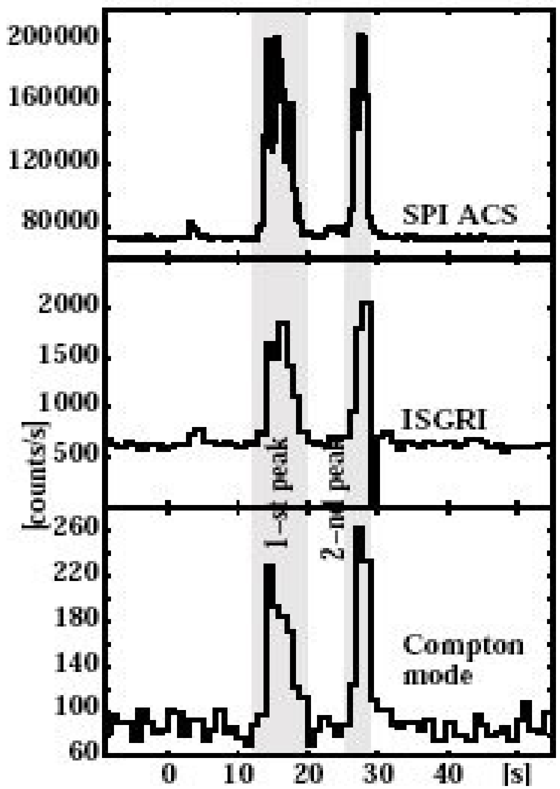


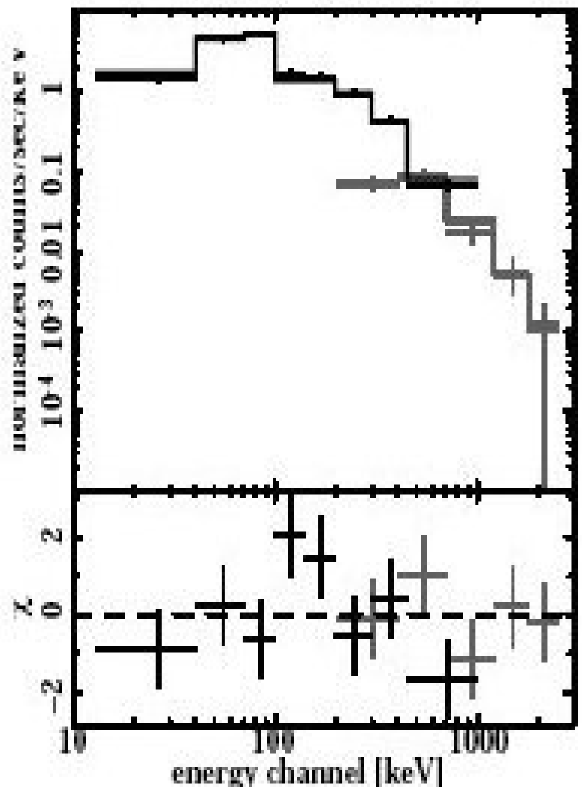




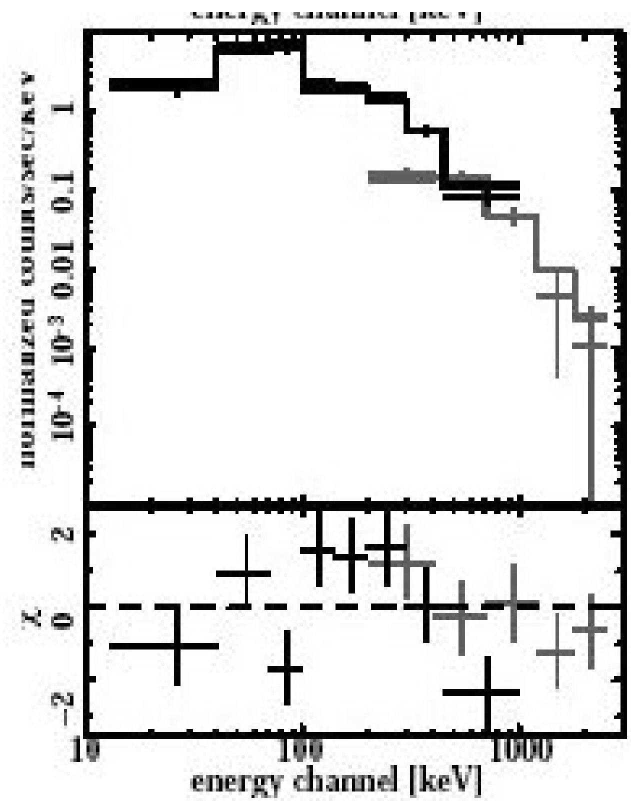
Position: IPN triangulation - annulus
and Compton imaging
duration = 15 s
off-axis = 76.6°

GRB 030722 – spectrum



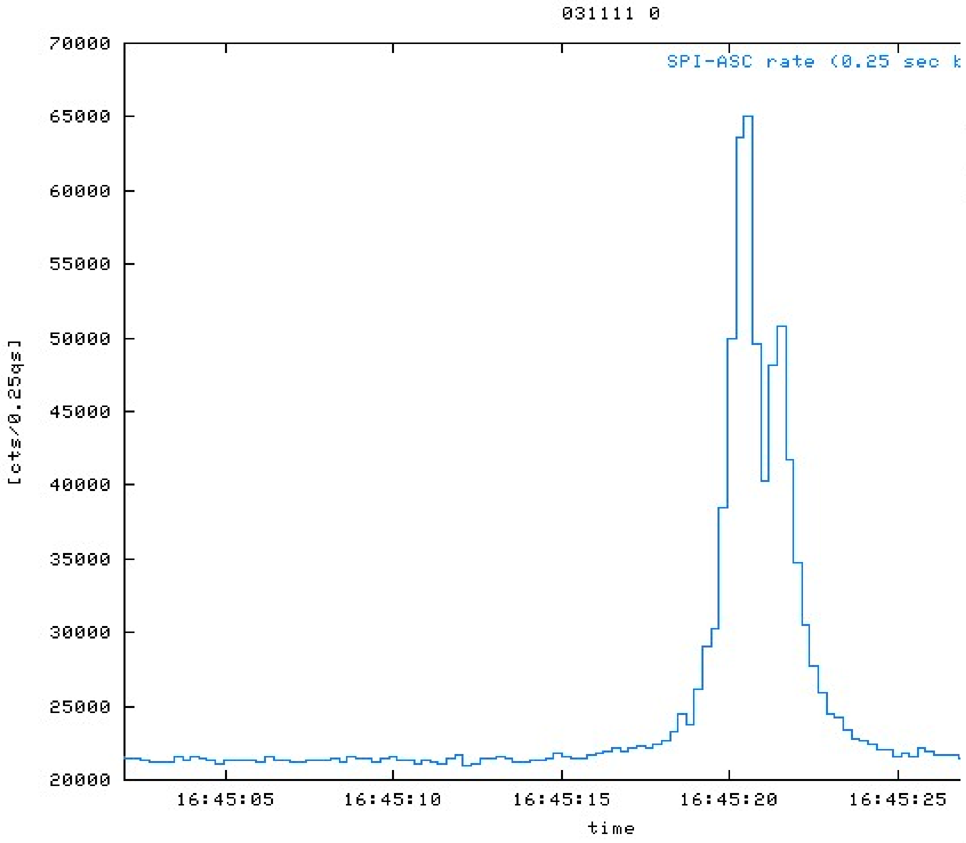


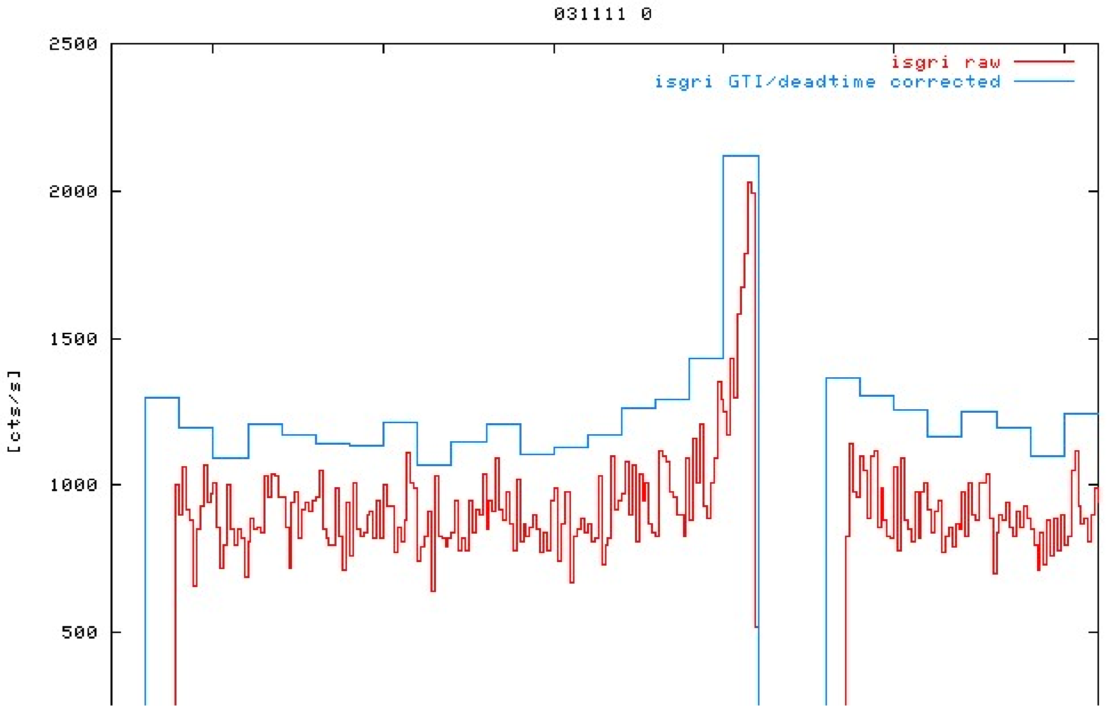
I=2.07+/-0.05
chi2/dof=1.23

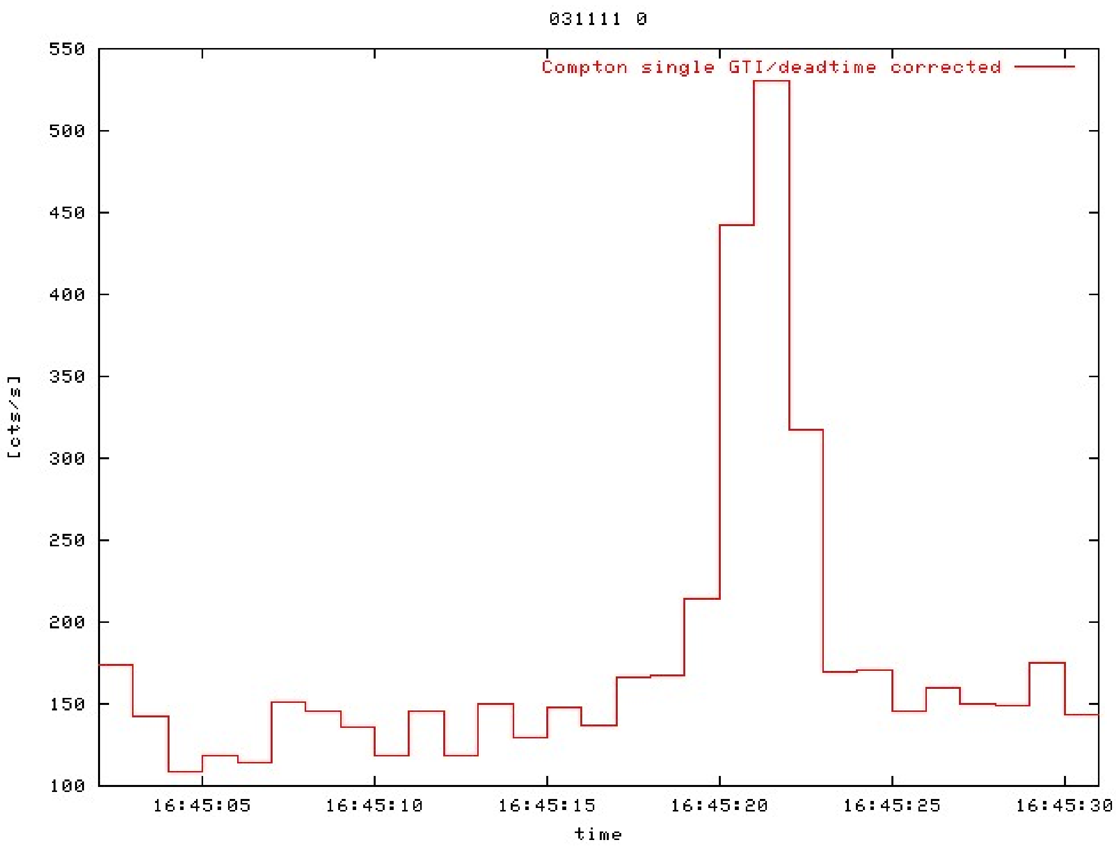


I=2.05+/-0.06
chi2/dof=1.9

GRB 031111 – light curve

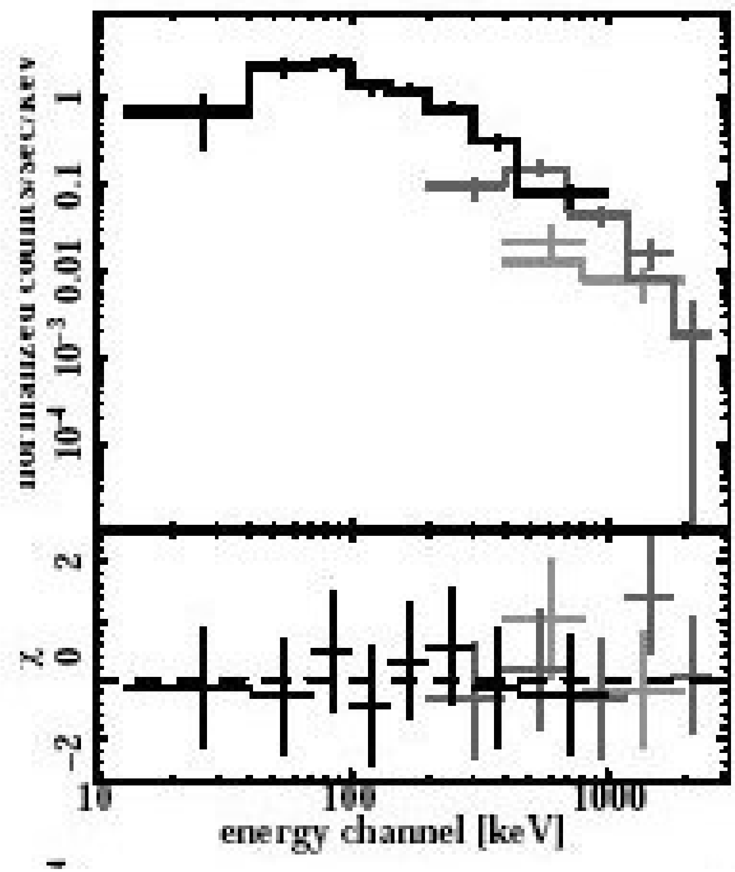


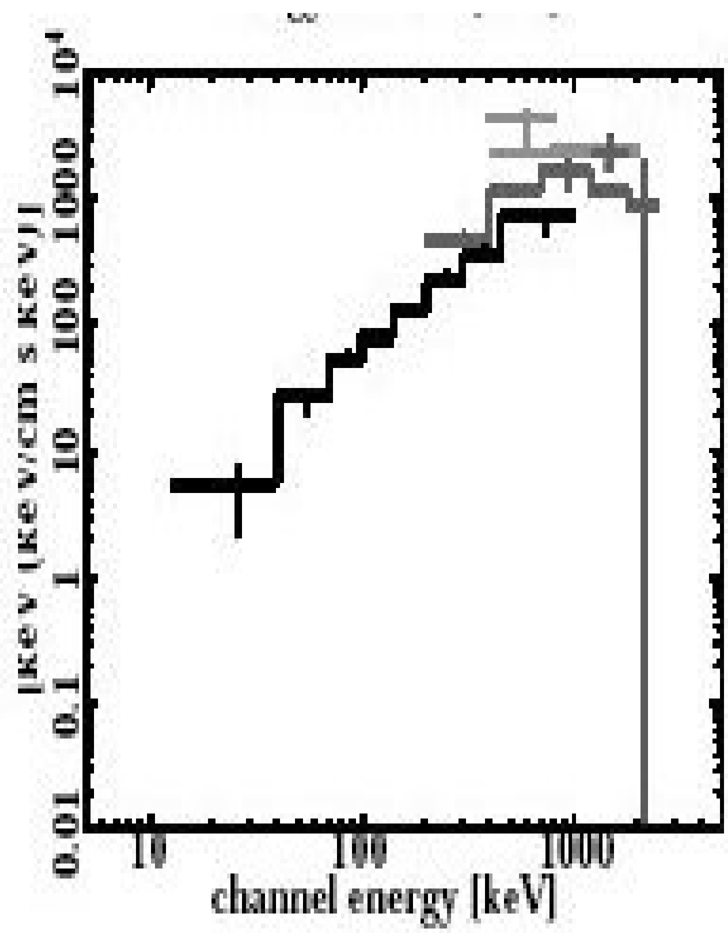




Position: IPN annulus,
Hete2 localization
duration = 10 s
off-axis = 53.5°

GRB 031111 – spectrum





i1=0.6+/-0.2
i2=2.8+/-0.7
Ebreak=770 keV

Summary of the Integral off-axis GRBs:

1. 60 off-axis GRBs detected per year
2. Spectral analysis possible for ~20 per year
   strong or/and long and localized
3. Special class of GRB: strong, hard, long, Epeak ~ MeV
4. Is there any limit for Epeak?