INTEGRAL

A New Gamma-Ray Astronomy Mission

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On behalf of the INTEGRAL Science Working Team

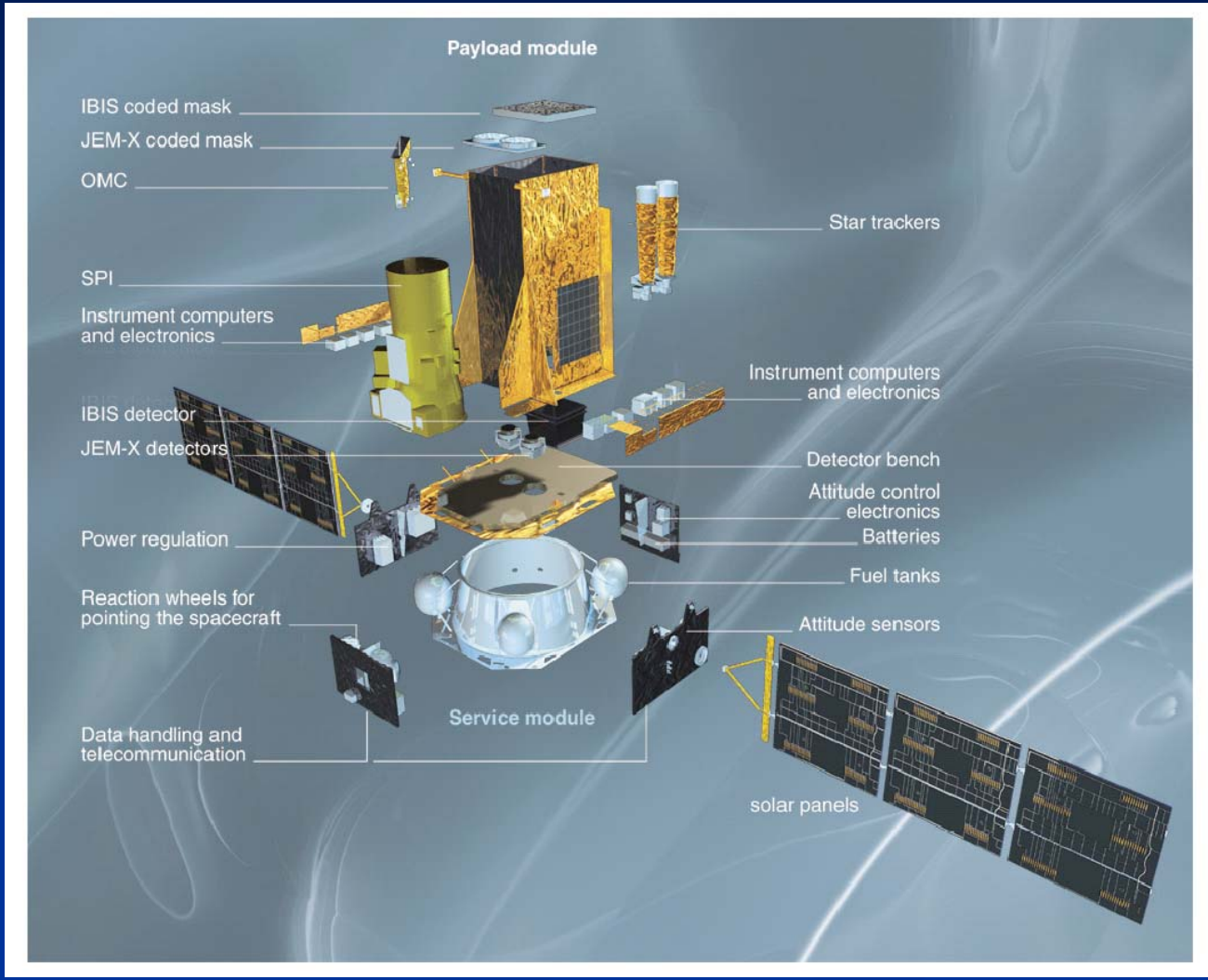
Mission Description

- European Space Agency (ESA) mission
  - Launched 17 Oct., 2002
- Mission Science
  - Gamma-ray astronomy in 15 keV - 10 MeV range
  - Supporting x-ray and optical monitoring
- Payload
  - Main Instruments
    - SPI: germanium spectrometer
    - IBIS: CdTe + CsI imager
  - Monitor Instruments
    - JEM-X: x-ray monitor
    - OMC: optical monitor

Mission Description (cont.)

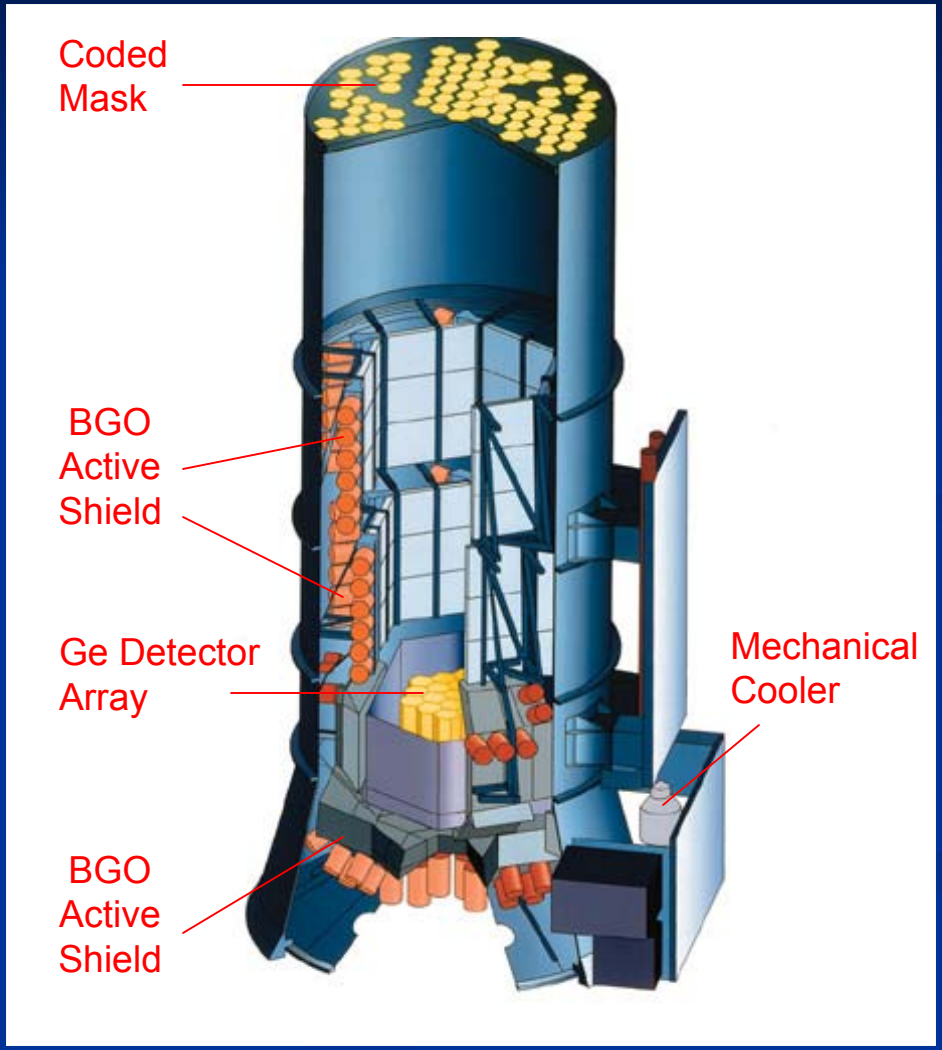
- FOLLOW-ON TO COMPTON GAMMA-RAY OBSERVATORY(CGRO).
- NEW TECHNOLOGIES RESULT IN SIGNIFICANT IMPROVEMENTS IN PERFORMANCE OVER CGRO.
  - Germanium detectors $\Rightarrow$ ~ 50 x better energy resolution
  - CdTe detectors $\Rightarrow$ ~ 15 x better angular resolution
- FORMS COMPLEMENTARY SET WITH SWIFT (gamma-ray bursts) AND GLAST (high-energy gamma-rays).

INTEGRAL SPACECRAFT



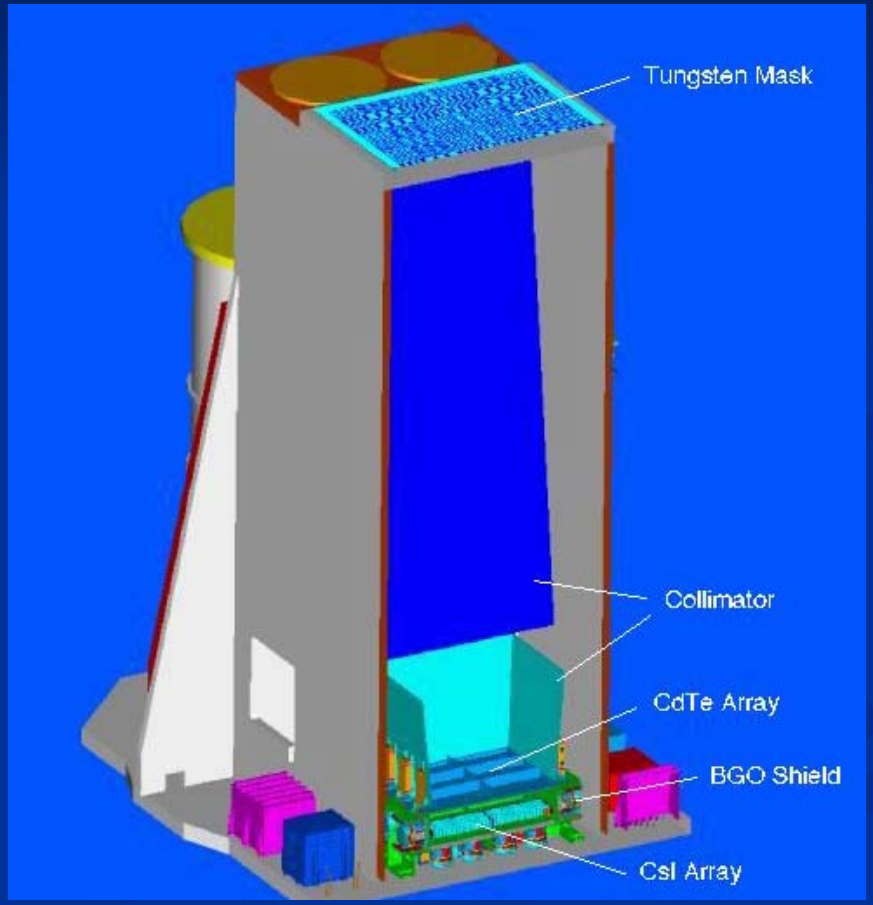
INTEGRAL SPECTROMETER (SPI)

- Coded aperture gamma-ray telescope
  - 3° angular resolution
  - 16° field-of-view (fully-coded)
- Cooled germanium detector array
  - 19 detector array
  - Energy range: 20 - 8000 keV
  - Energy resolution E/ΔE ~ 500
- Active BGO shielding
  - 550 kg of BGO scintillator
  - Key to achieving low instrument background



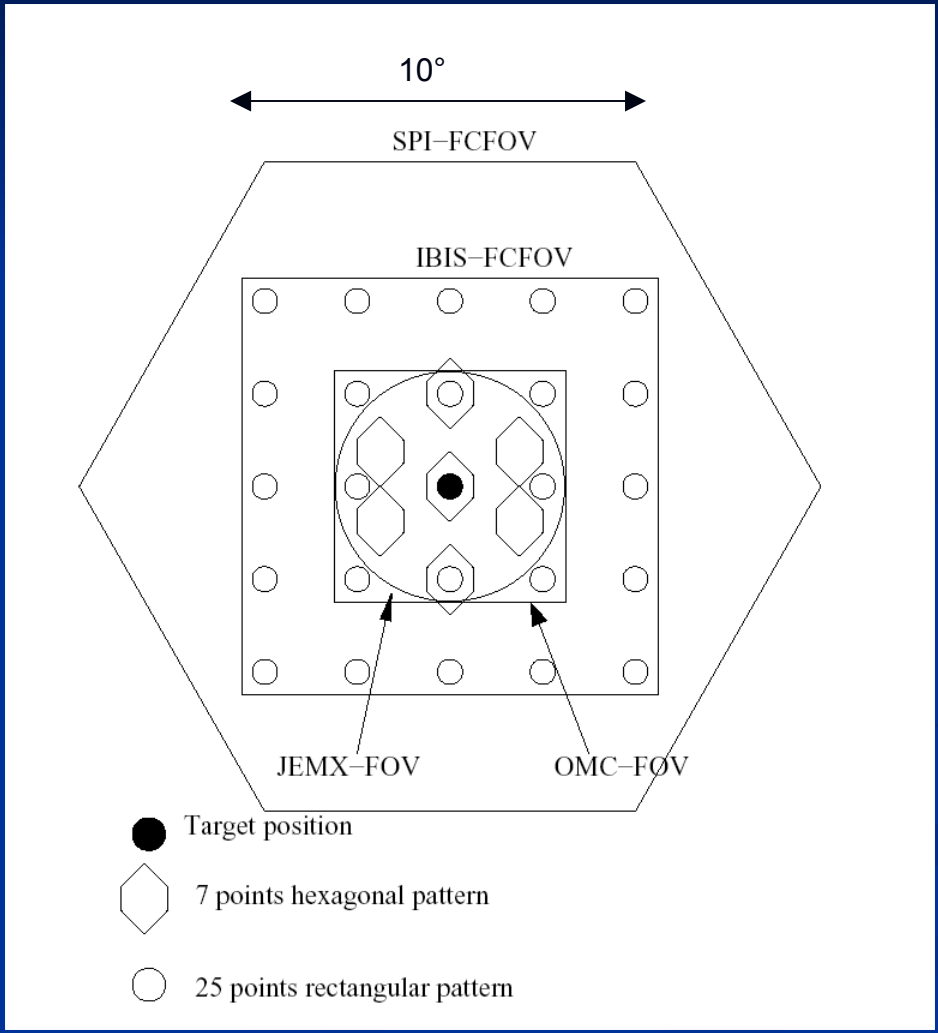
INTEGRAL IMAGER (IBIS)

- Coded aperture imager
  - 12 arcmin angular resolution
  - 9° X 9° field-of-view
- Two-layer detection plane
  - CdTe
    - ~ 16,000 detector array
    - Energy range: 15-1000 keV
  - CsI
    - ~ 4000 detector array
    - Energy range: 100-10000 keV
- Active BGO shielding

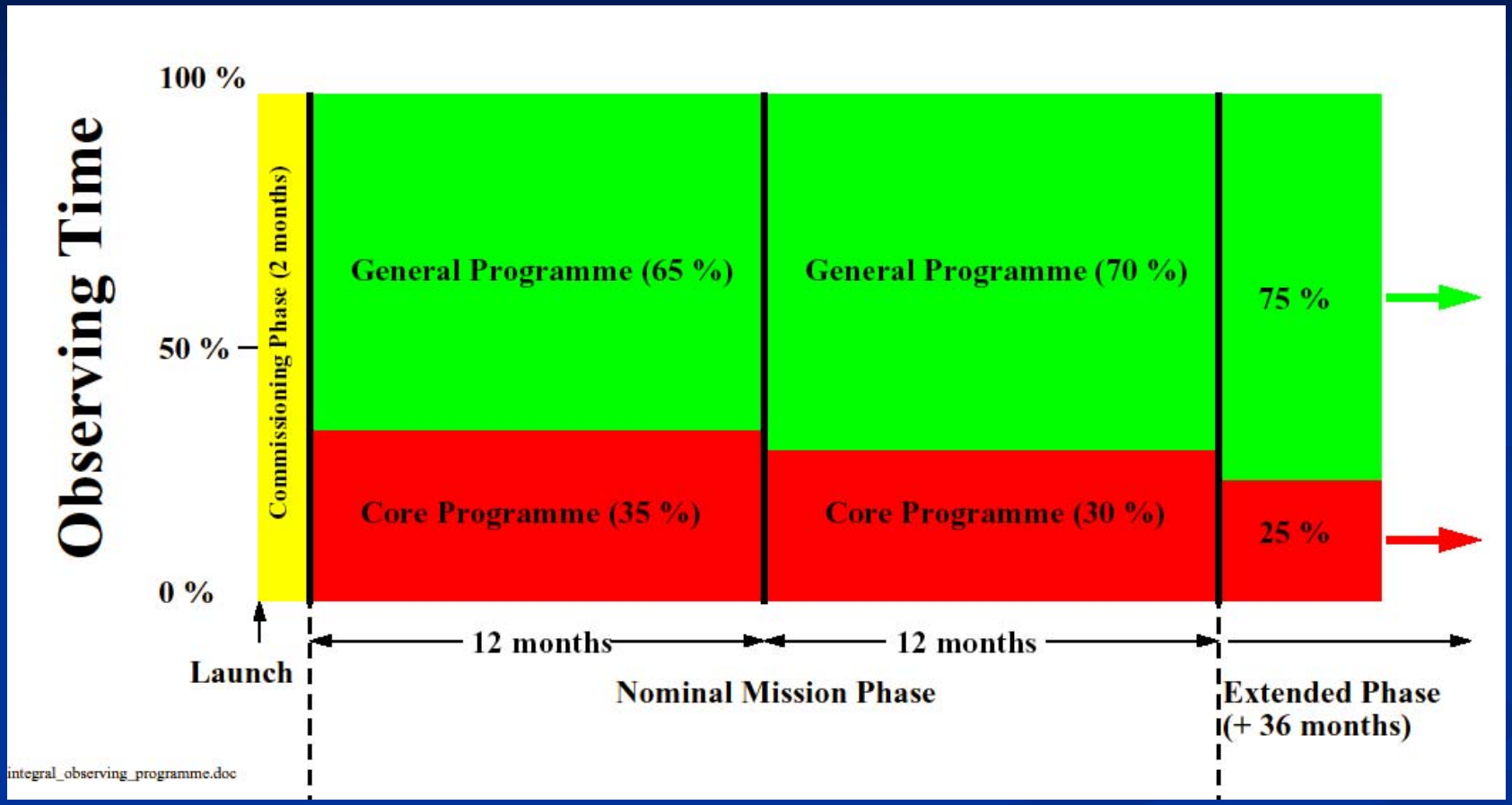


INTEGRAL FIELDS -OF-VIEW

FCFOV = fully-coded field-of-view



INTEGRAL OBSERVING PROGRAM



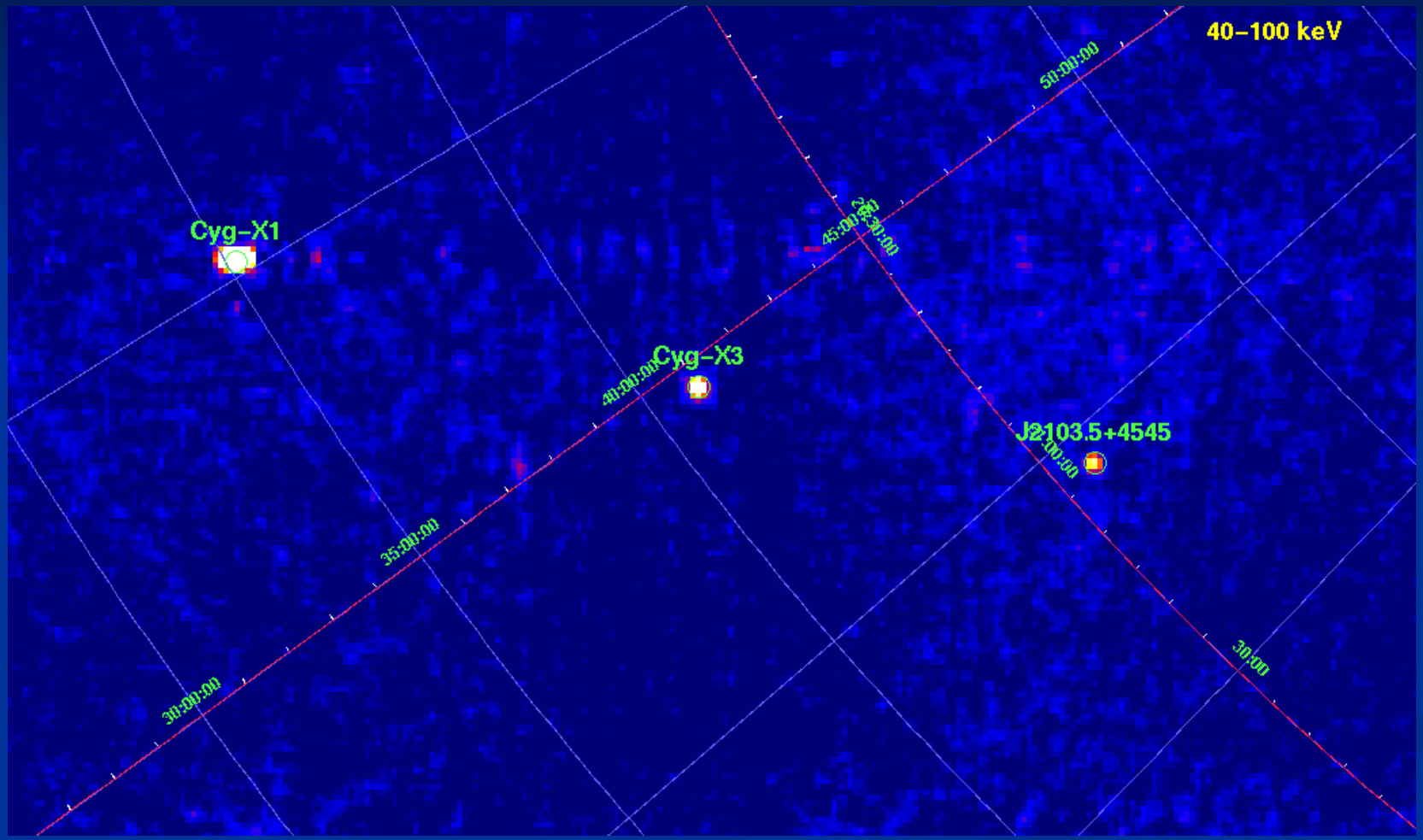
Note: Core Program is guaranteed time for instrument teams.

COMMISSIONING PHASE

- First 2 months of mission
- Long (~ 3 wk) observation of Cyg X-1.
  - Followed later by Crab observation
- Because of wide fields-of-view several other sources serendipitously observed.
  - Cyg X-2
  - Cyg X-3
  - EXO 2030+375

INTEGRAL/IBIS IMAGE OF CYGNUS REGION

(Vilhu et al., submitted to A&A)

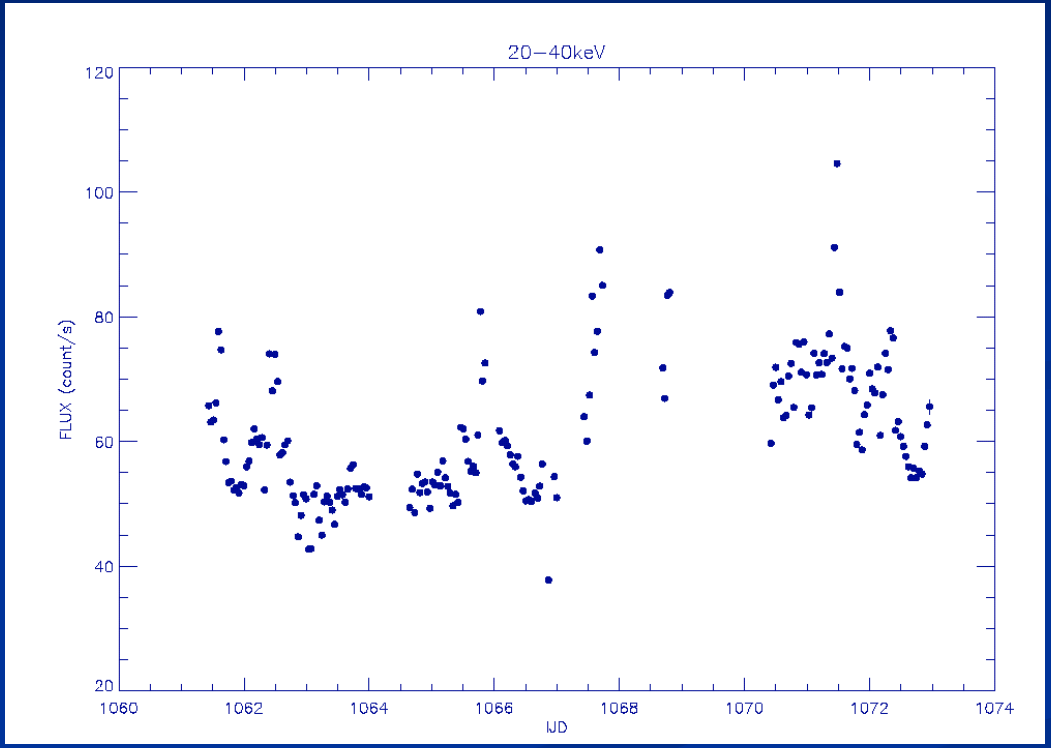


Cygnus X-1

(Bazzano et al., submitted to A&A)

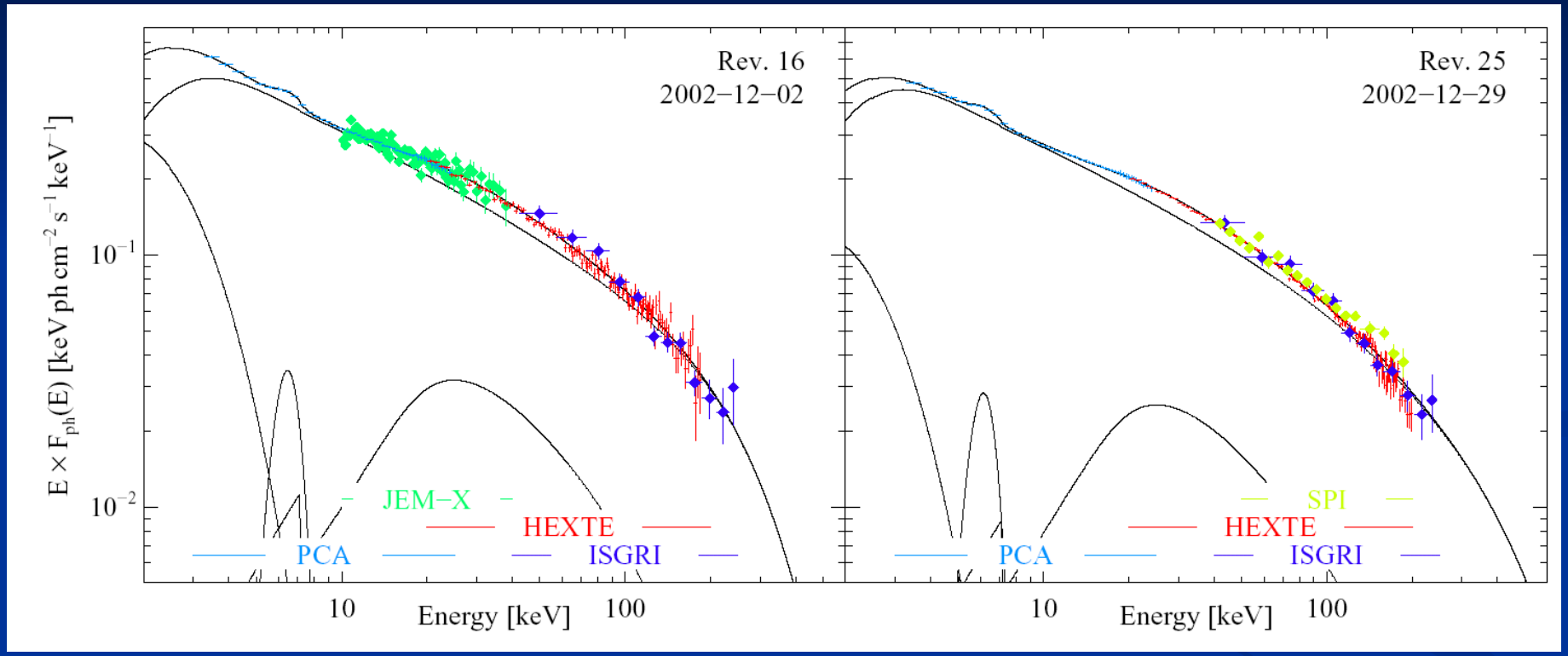
- First INTEGRAL target.
  - Long (~ 2 wk) observation
- First established binary black hole.
  - Mass ~ 7 M_{sun}
- In orbit around B0 supergiant star
  - Period: 5.6 days
- Complex temporal and spectral behavior.
  - Variability on scales of msec to yr.
  - 4-5 different spectral states.

Cyg X-1 Light Curve



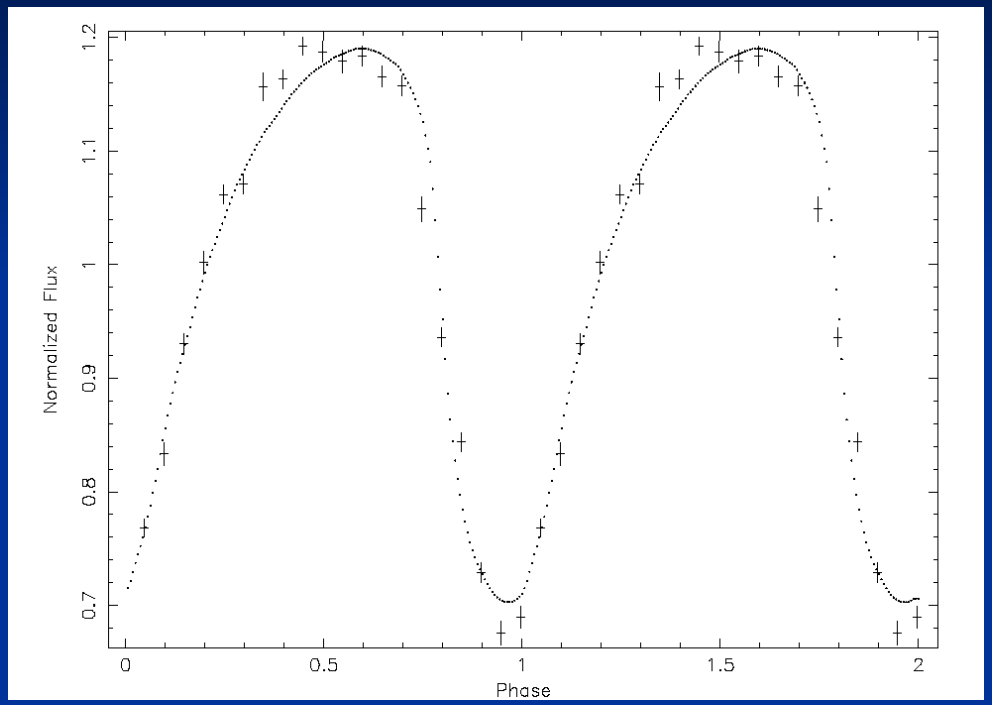
Cygnus X-1

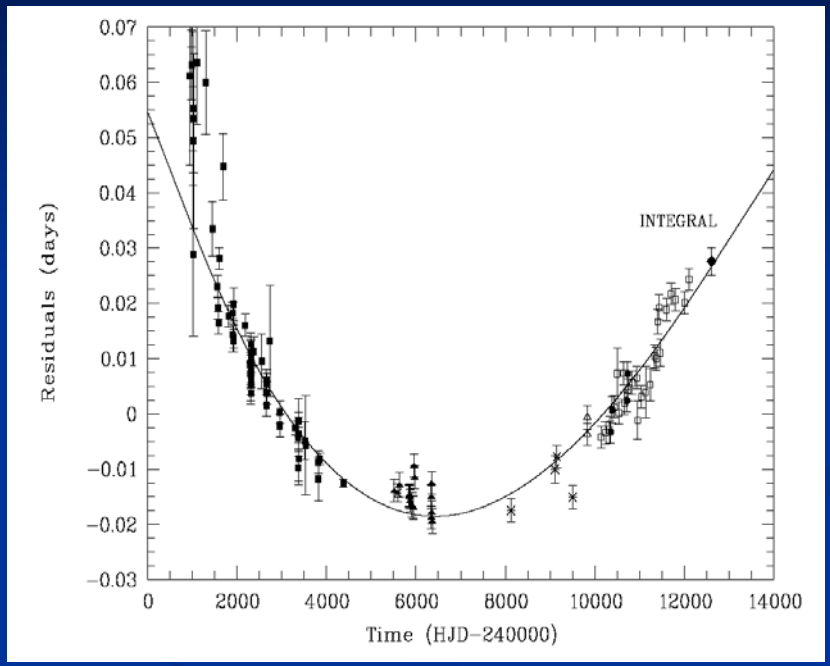
(Pottschmidt et al., submitted to A&A)



- Comptonization + reflection model
  - Covering factor $\Omega < 0.3$
  - $T_{plasma} \sim 80$ keV
  - $\tau_{plasma} \sim 1\text{-}1.5$
- Flux normalizations still a problem
  - ± 20% SPI, IBIS/ISGRI
  - JEM-X, factor of 2

Cygnus X-3
(Goldoni et al., submitted to A&A)



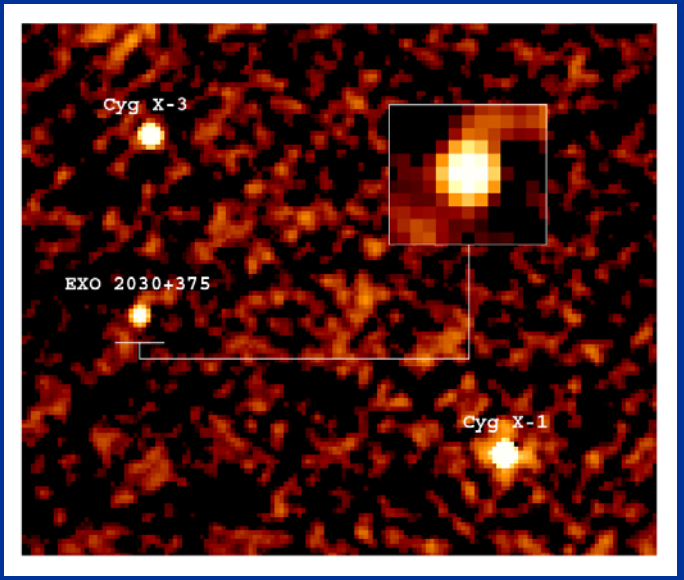


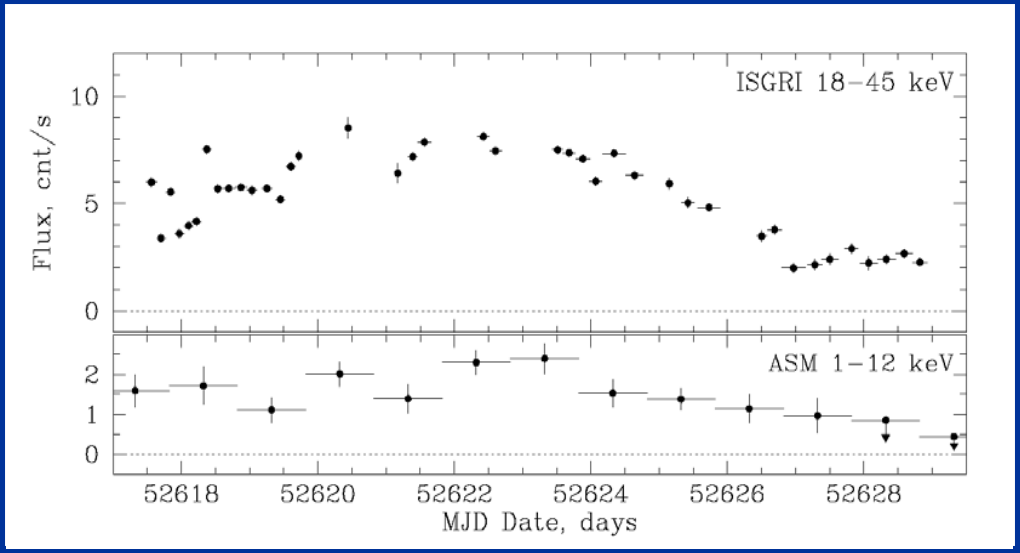
- Peculiar microquasar (compact binary with jet)
  - 4.8 hr modulation normally interpreted as LMXB
  - But IR observations indicate Wolf-Rayet (WR) star.

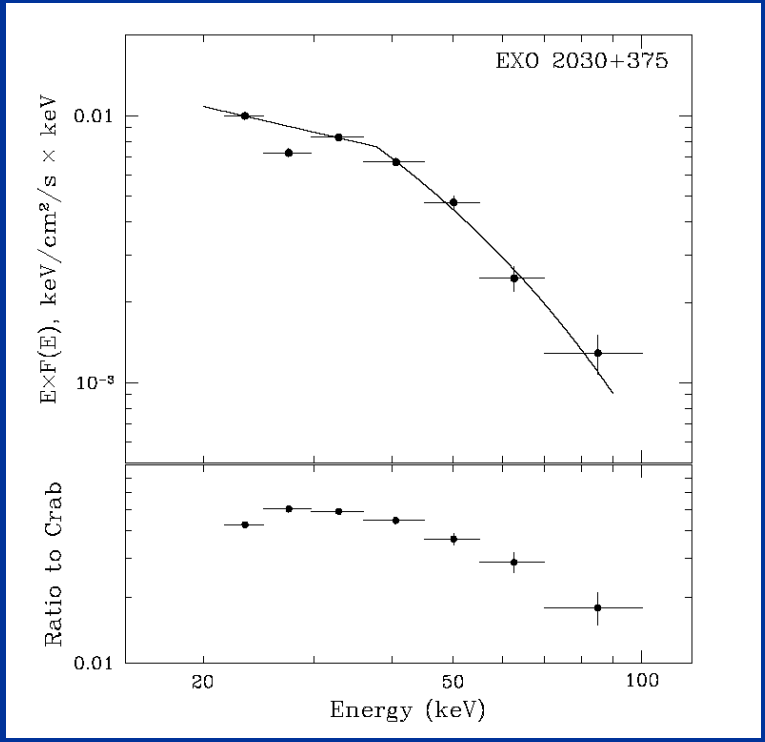
EXO 2030+375

(Kuznetsov et al., submitted to A&A)

- Be/X-ray transient (most common type of X-ray pulsar)
  - 42 s period
- Also 42 d period
- Possible cyclotron feature at ~ 36 keV (Rieg & Coe, 1999)







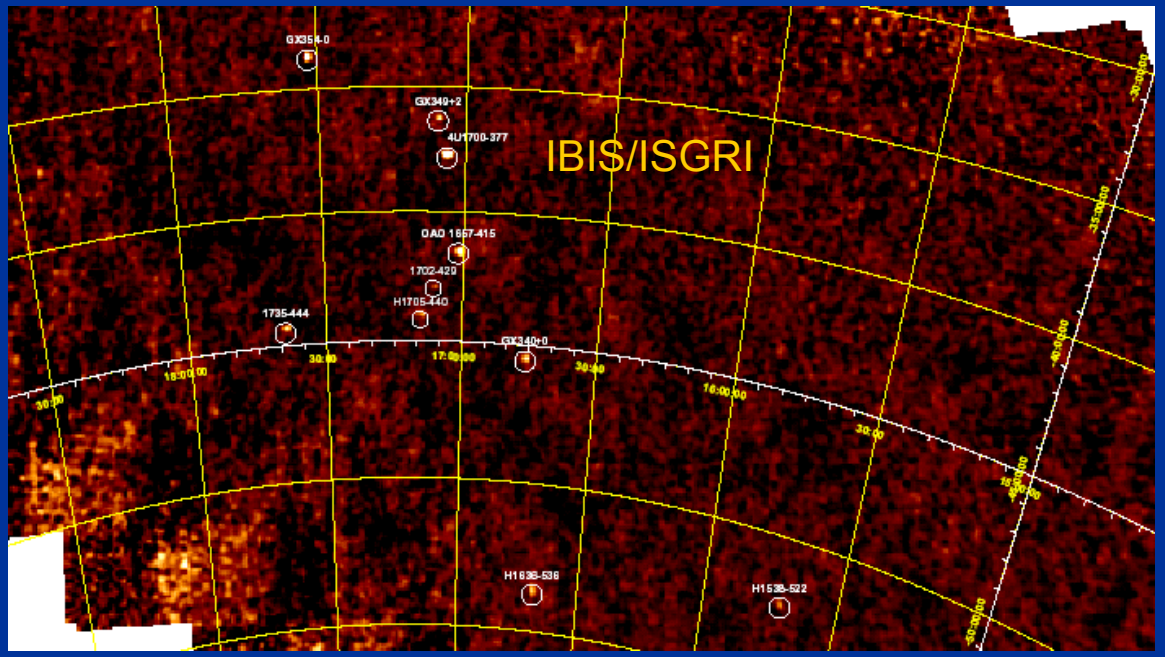
INTEGRAL CORE PROGRAM

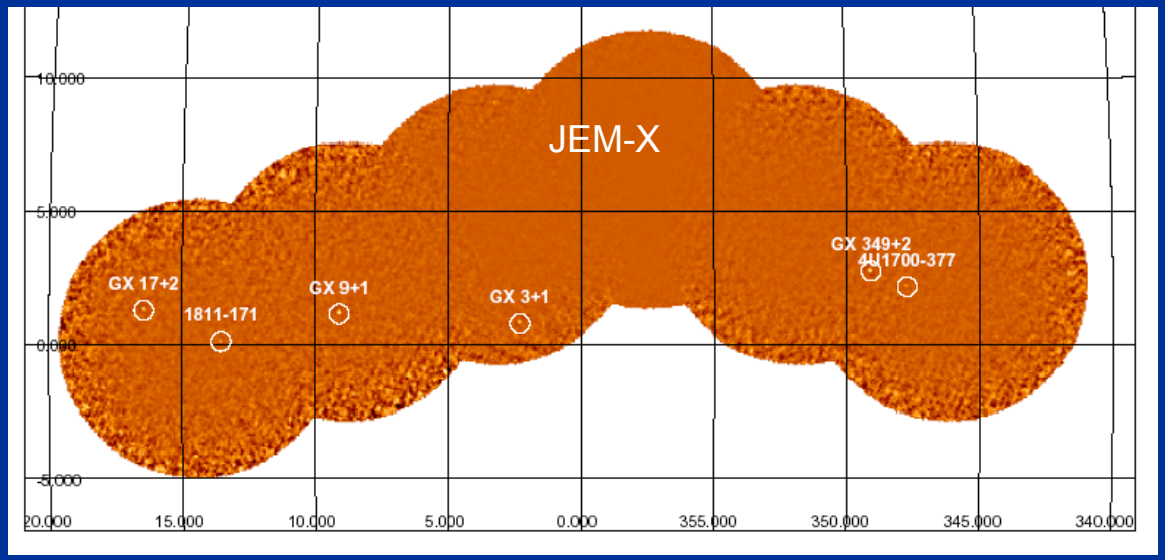
- Deep (4 Msec/yr) exposure of central radian of our galaxy.
  - Create maps of annihilation radiation and ^{26}Al lines.
- Regular scans of visible part of galactic plane (GPS).
- Selected known targets and TOO's (targets of opportunity)

GALACTIC PLANE SCANS

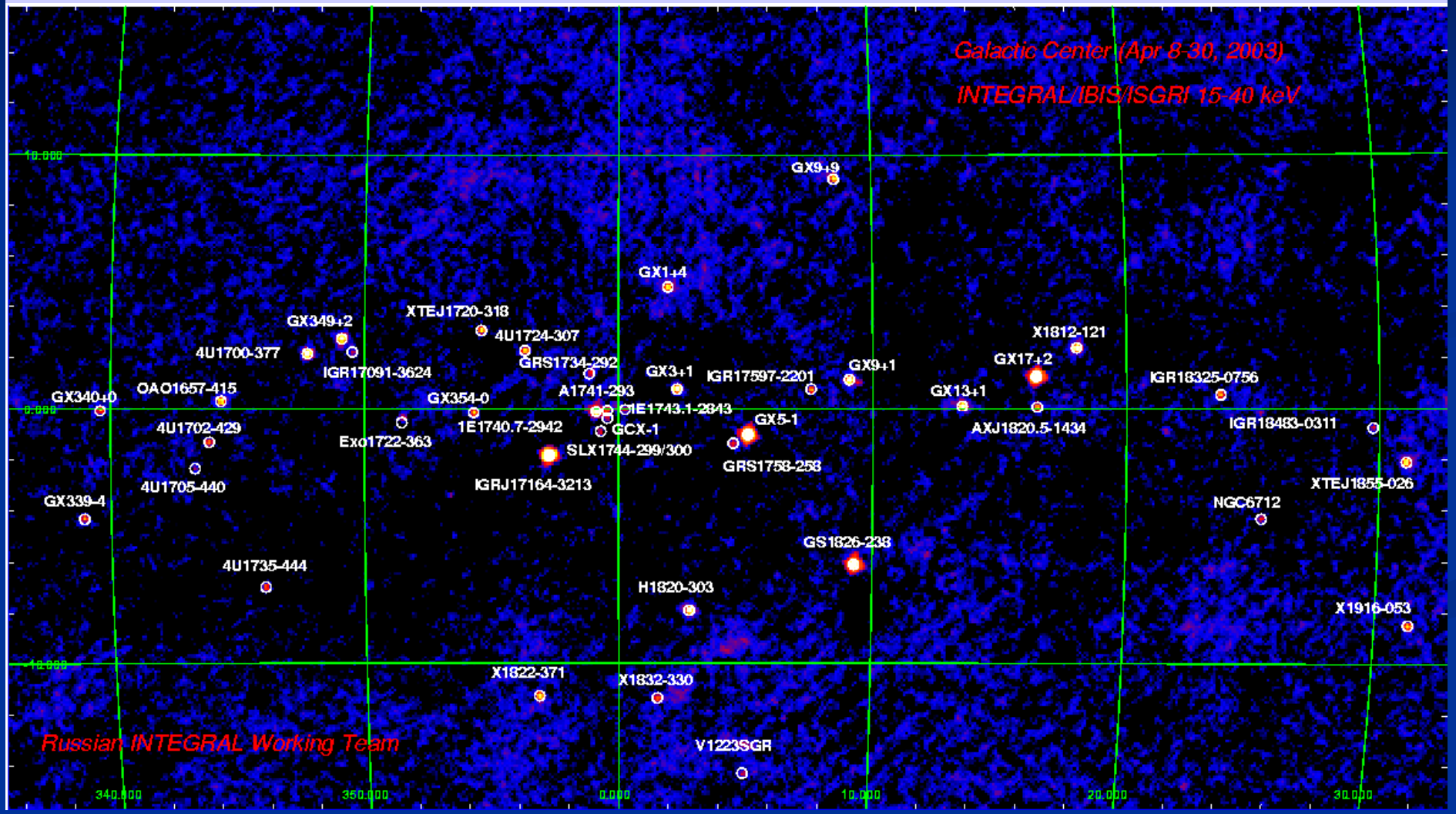
- Identify transient sources.
  - Potential follow-up observations (TOO's).
- Performed every 4th orbit (12 days).
- Sensitivity

Instrument	ΔE [keV]	5σ Sensitivity [mCrab]	Exposure [ksec]
IBIS	15 – 40	36	2.2
SPI	20 – 40	62	6.6
JEM–X	5 – 20	20	2.2





Galactic plane view with INTEGRAL (April 8-30, 2003)



NEW INTEGRAL (IGR) SOURCES

Source	Flux (mCrab) (15–40) keV	Flux (mCrab) (40–100) keV	Reference
IGR J18483–0311	10 (S/N ~21)	5 (S/N ~11)	2 May 2003 (ATEL 157)
IGR J17597–2201	5 (S/N ~10)	10 (S/N >14)	30 Apr 2003 (ATEL 155)
IGR J18325–0756	10	5	28 Apr 2003 (ATEL #154)
IGR J18539+0727	20	20	21 Apr 2003 (ATEL #151)
IGR J17091–3624	–	20	19 Apr 2003 (ATEL #149)
IGR J17464–3213	60	60	28 Mar 2003 (ATEL #132)
IGR J16358–4726	50	20	19 Mar 2003 (IAUC #8097)
IGR J19140+098	50–100		6 Mar 2003 (IAUC #8088)
IGR J16320–4751	10–50		1 Feb 2003 (IAUC #8076)
IGR J16318–4848	50–100		29 Jan 2003 (IAUC #8063)

A NEW CLASS OF X-RAY SOURCES?

(Revnivtsev, submitted to AL, Walter et al., submitted to A&A)

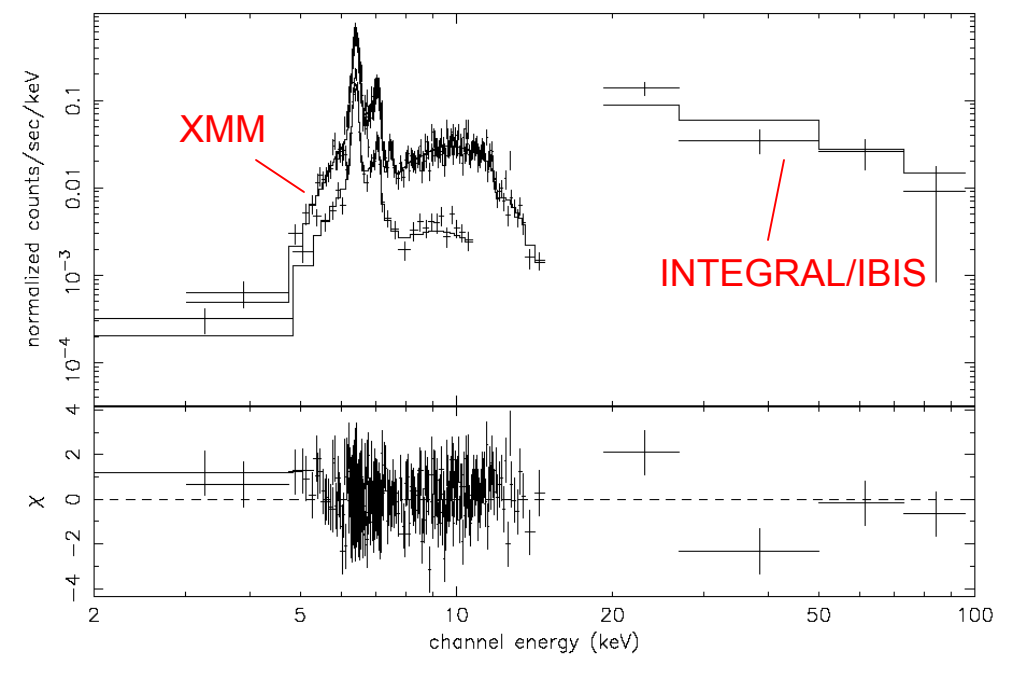
- Three newly discovered INTEGRAL sources with similar peculiar properties.
  - IGRJ16318–4848,
    IGR J16320-4751,
    IGR J16358-4726

- Heavily absorbed X-ray spectra with hard tails.

	N_H (cm^{-2})	α^*
IGRJ16318-4848	3.1×10^{24}	1.0
IGR J16320-4751	2.1×10^{23}	1.2
IGRJ16358-4726	4.0×10^{23}	1.1

* Power-law index

IGRJ16318-4848

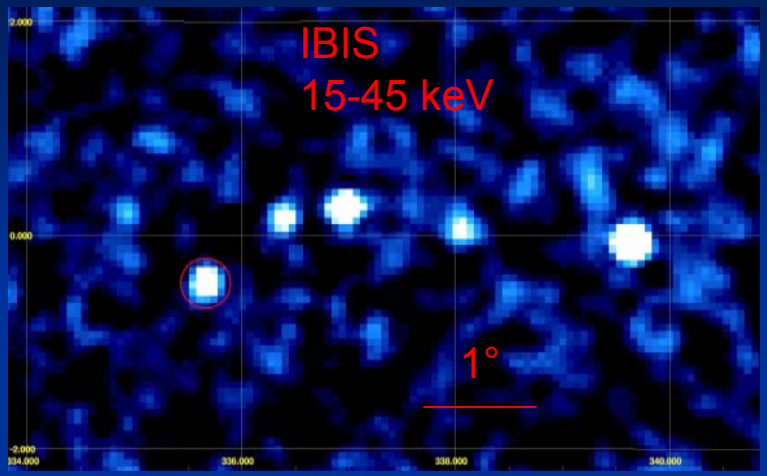


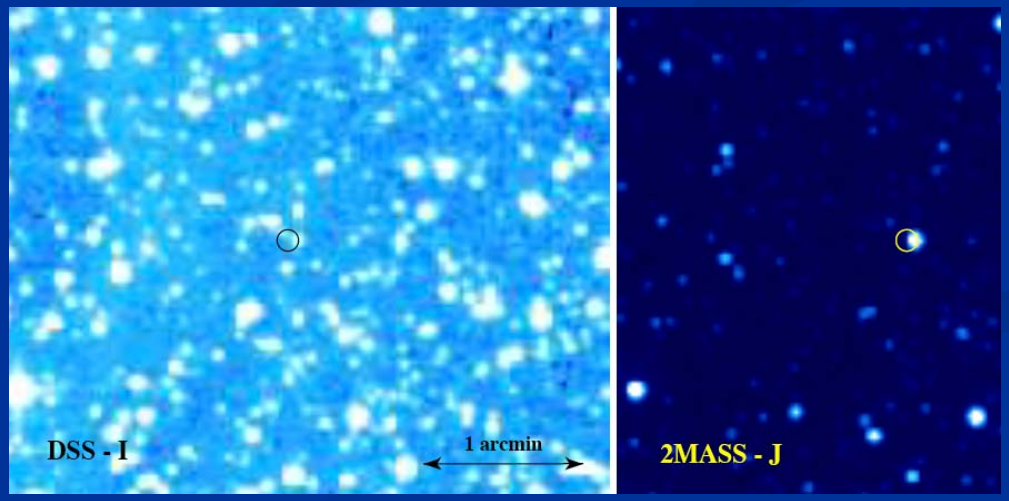
- Fe and Ni lines found in IGRJ16318-4848 (XMM)
  - Fe Kα (6.41 keV), Fe Kβ (7.07 keV), Ni Kα (7.46 keV)

A NEW CLASS OF X-RAY SOURCES? (cont.)

- Sources located within few degrees of each other in region of enhanced concentration of young massive stars (Norma arm).

- Probable Optical/IR counterparts found to IGRJ16318-4848.
  - Could be either low-mass red giant or super-massive giant depending on reddening.
  - Walter et al. suggest the source is binary system consisting of massive star and black hole in which dense absorbing shell is created by stellar wind.



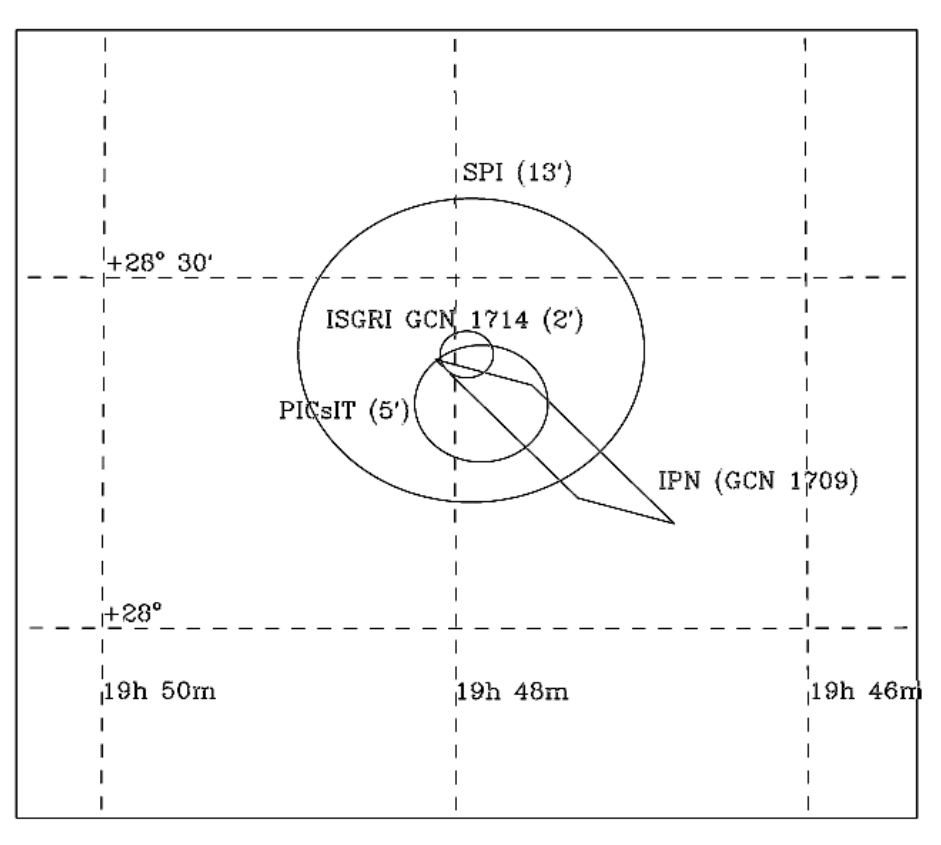


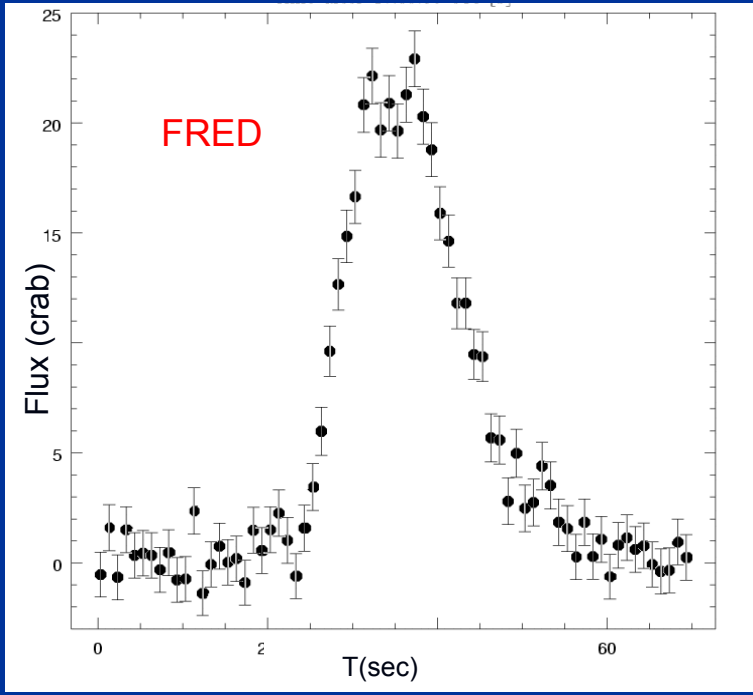
GAMMA-RAY BURSTS WITH INTEGRAL

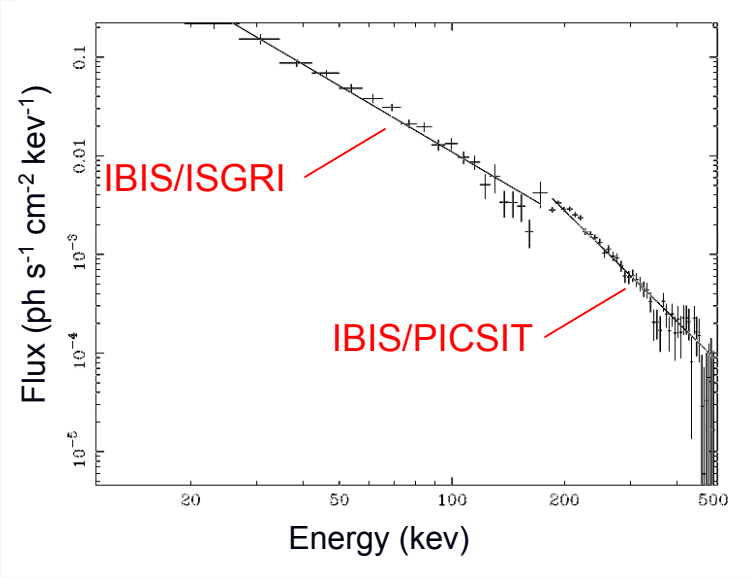
- All data from INTEGRAL recovered in real time.
  - > 80% duty cycle.
- Prompt automatic burst detection and position determination on ground.
  - Positions distributed to ground-based observers within sec. to min.
  - Accuracy: few arcmin (IBIS)
- GRB detection rate: ~ 1/mo
- INTEGRAL (IBIS) ~ 3 x as sensitive as CGRO/BATSE.
  - INTEGRAL will sample a fainter more distant population of GRB's.
- Burst polarization measurements are possible.

GRB021125

(Malaguti et al., submitted to A&A)

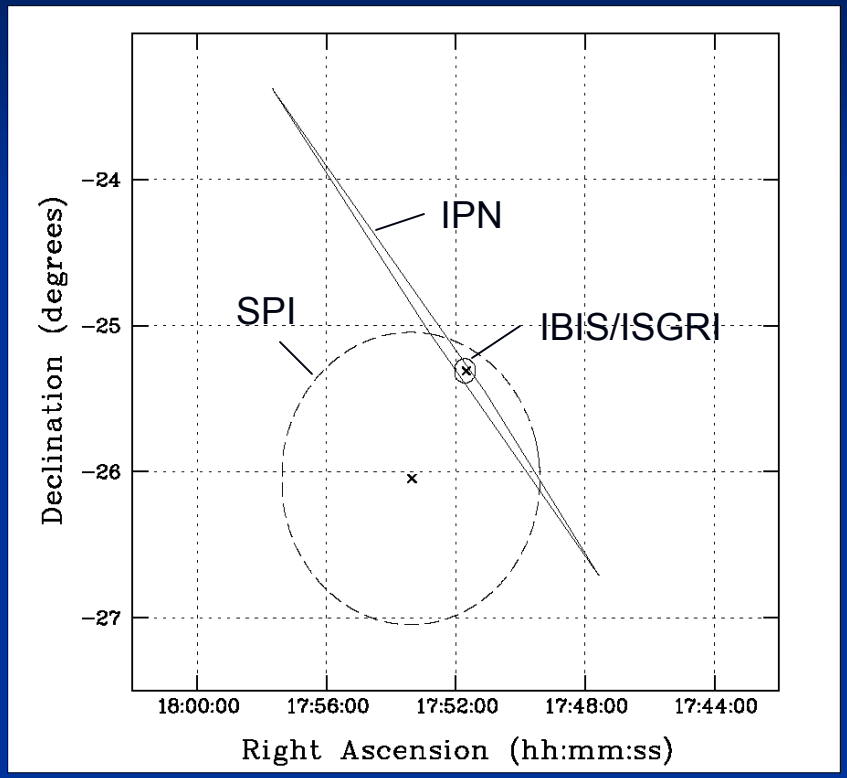


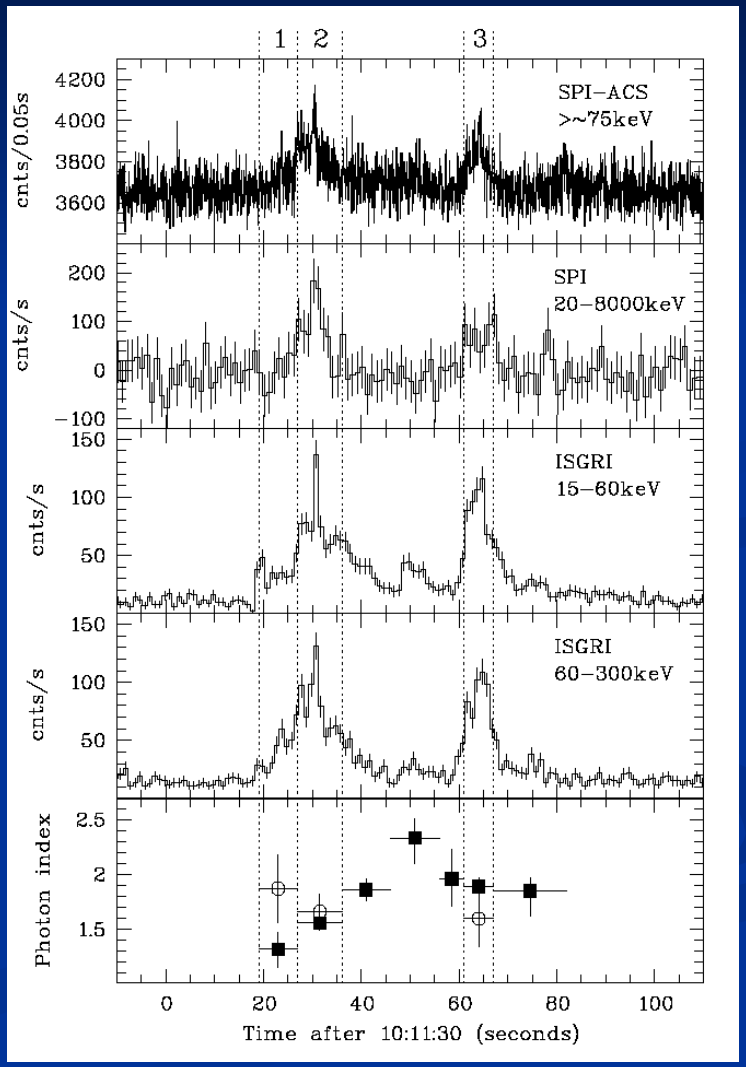




GRB030320

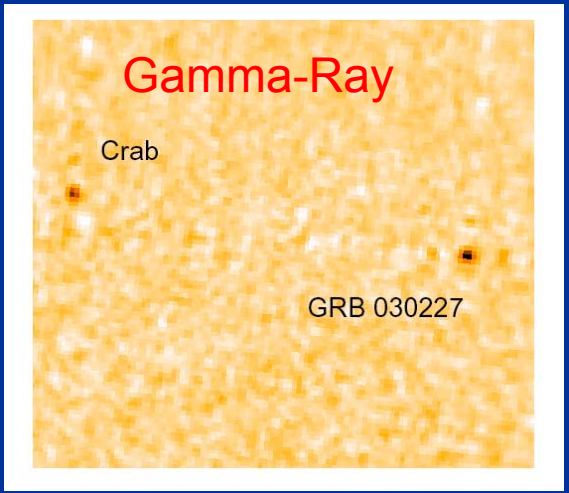
(von Kienlin et al., submitted to A&A)

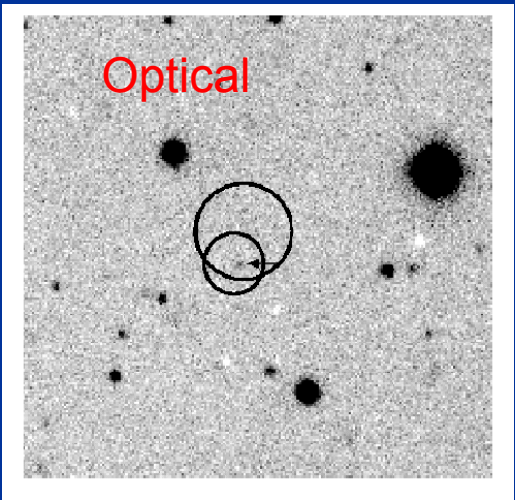


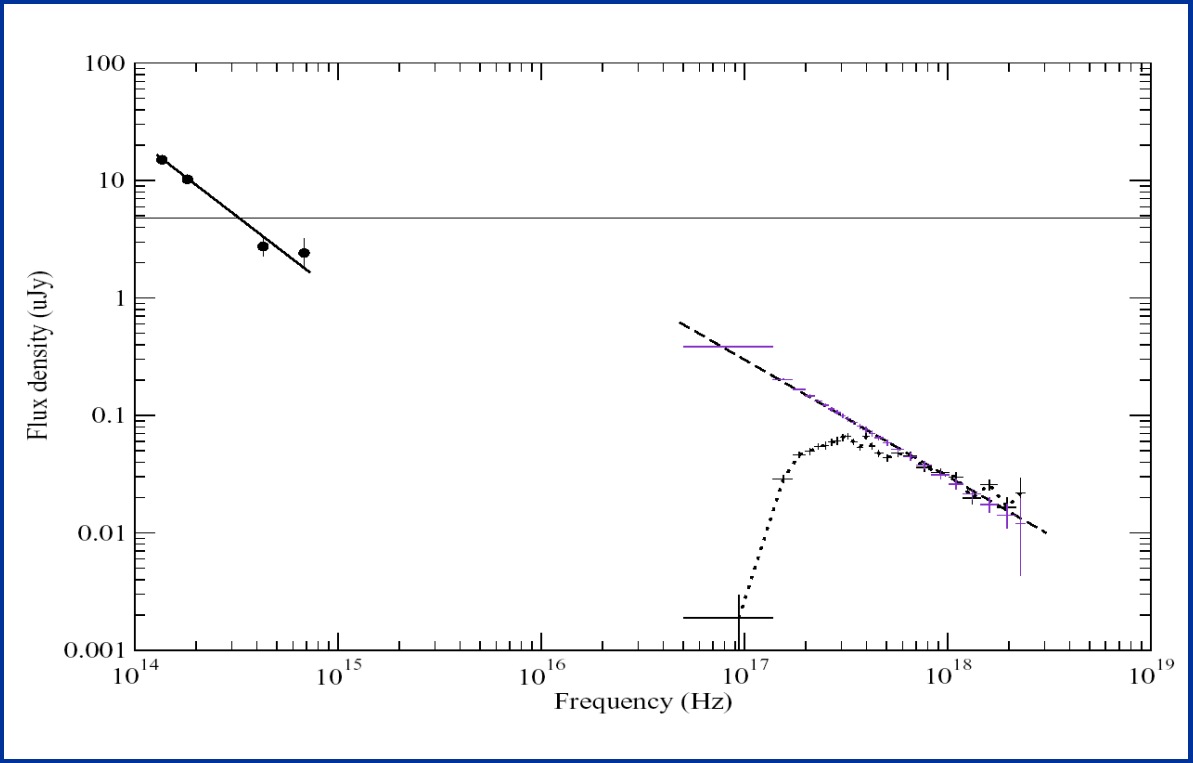


GRB030227

- First INTEGRAL GRB optical counterpart (Castro-Torado et al.)
  - Faint object: $m_R \sim 23$
- Redshift estimates
  - Z ~ 1.6 (Watson et al.)
    ~ 3-4 (Mereghetti et al.)
- Possibly “X-ray rich” GRB (Mereghetti et al.)
  - Brightest X-ray afterglow detected by XMM.
- Evidence for inverse Compton scattering.







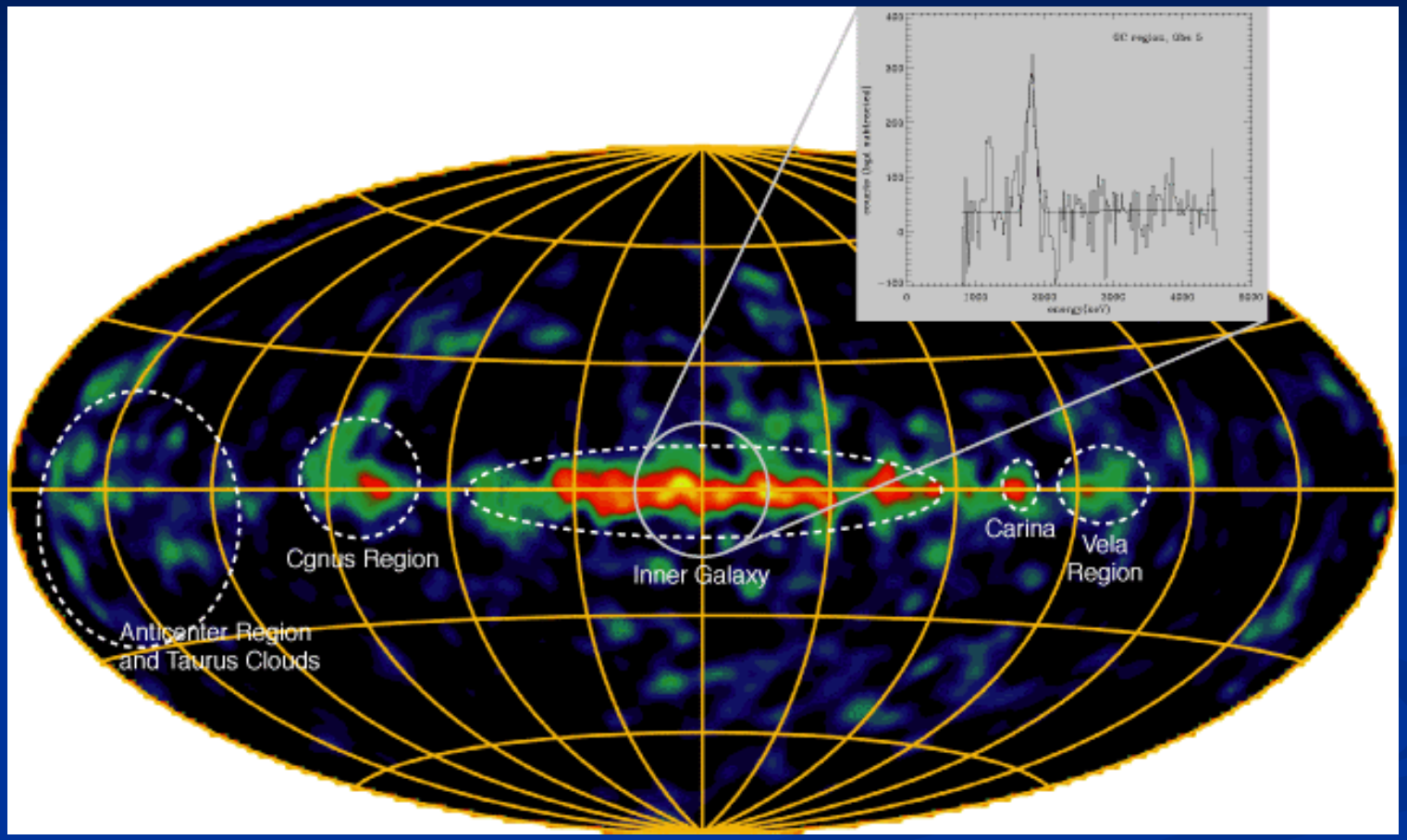
GAMMA-RAY LINE STUDIES WITH INTEGRAL

- Prime scientific driver for INTEGRAL.
- Spectrometer designed to detect and measure lines in 20-8000 keV range.
  - Energy resolution: ~ 2 keV
- Production mechanisms
  - Annihilation
  - Radioactivity (from nucleosynthesis)
  - Nuclear excitation (e.g. from cosmic rays)
  - Cyclotron absorption

KNOWN ASTROPHYSICAL GAMMA-RAY LINES

Line	Energy (keV)	Mean Life (yr)	Source(s)
e^+ - e^- annihilation	511	N/A	Galactic Center/Plane 1E1740.7-2942 Nova Muscae
^{26}Al	1809	1.03×10^6	Galactic Plane
^{60}Fe?	59, 1172, 1333	2.2×10^6	Galactic Plane
^{44}Ti	68, 78, 1156	91	Cas A, Vela region
^{56}Co	847, 1238	0.30	SN1987A
^{57}Co	122,137	1.07	SN1987A
^{2}H,^{12}C,^{16}O,….	2120, 4438, 6129….	prompt	Sun

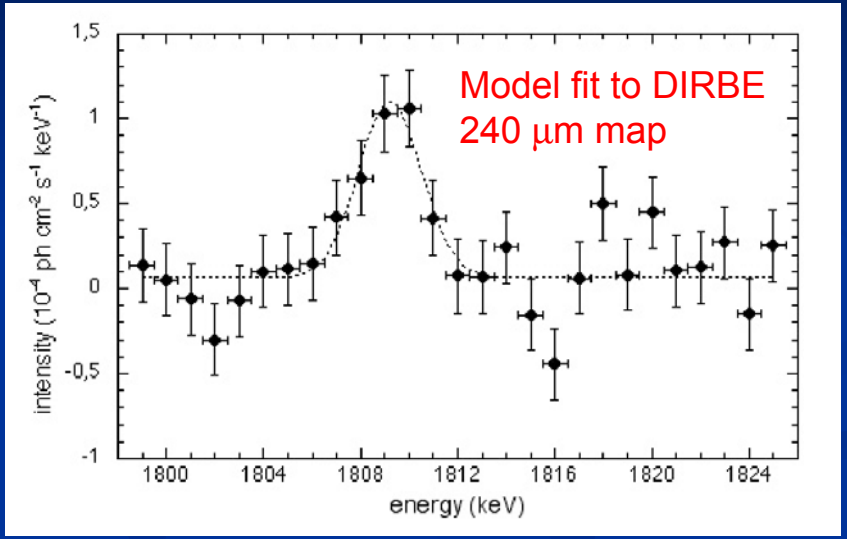
CGRO/COMPTEL ^{26}Al Map



FIRST INTEGRAL ^{26}Al RESULTS

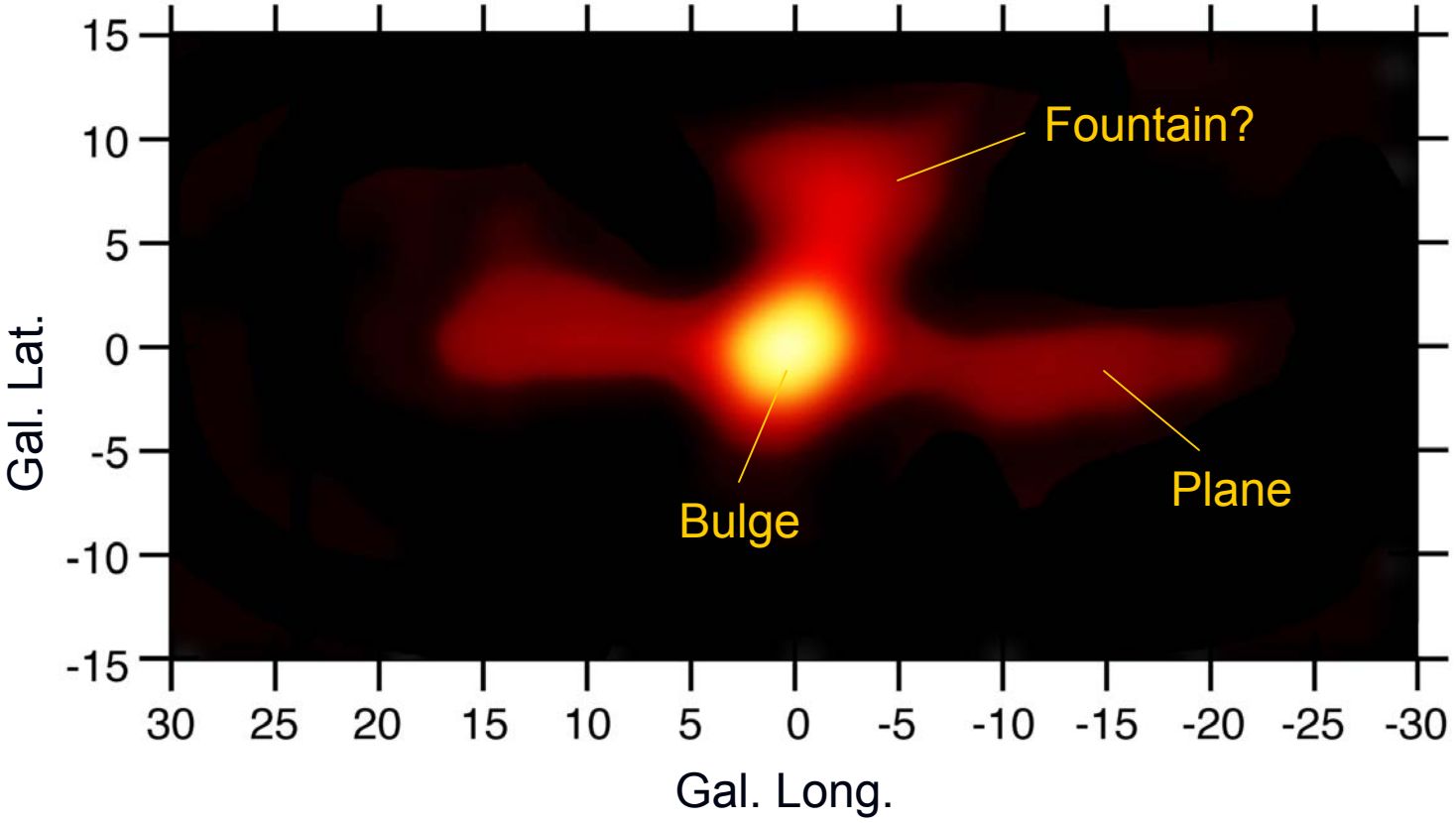
(Diehl et al., submitted to A&A)

- $T_{exposure}$ = 1.6 Msec
- Flux = 3-5 x 10^{-4} ph cm^{-2} s^{-1} (depending on assumed model)
  - ~ 10 σ significance
  - COMPTEL: 2.8 ± 0.15 ph cm^{-2} s^{-1} (Oberlack et al., 1997)
  - RHESSI: 5.7 ± 0.54 ph cm^{-2} s^{-1} (Smith et al., 2003)
- Line width = < 3 keV
  - RHESSI: 2.08 (+0.78/-1.21) ph cm^{-2} s^{-1} (Smith et al., 2003)
  - GRIS: 6.4 (+1.2,-1.1) ph cm^{-2} s^{-1} (Naya et al., Nature, 1996)



CGRO/OSSE 511 keV Map

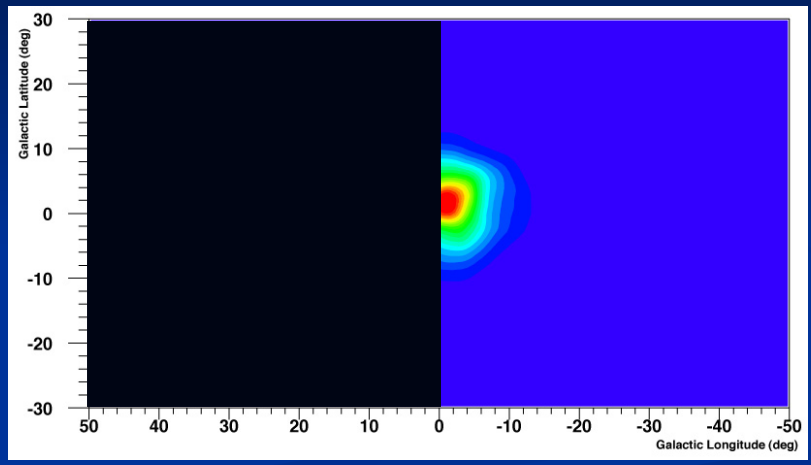
(Purcell et al., ApJ, 1997)



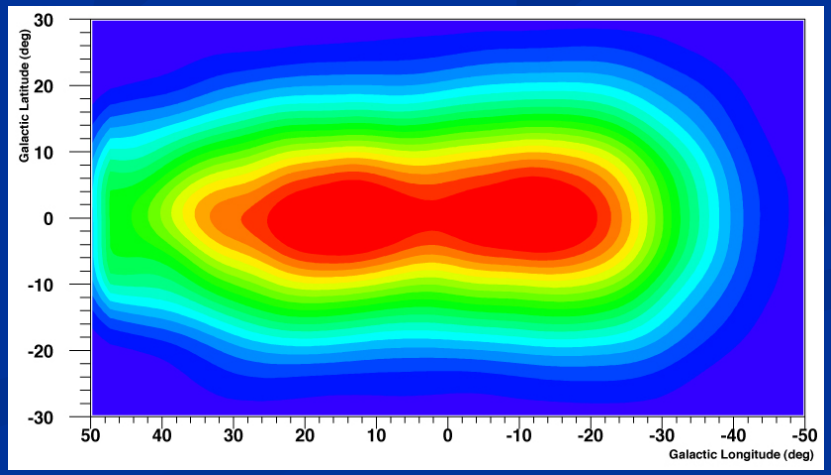
INTEGRAL/SPI 511 keV MAP

- Richardson-Lucy deconvolution of 511 keV line data (6° × 6° boxcar smoothing kernel).
- Spherically-shaped emission ("bulge") towards Galactic Center.
  - Spatial distribution is well-fit by symmetric gaussian centered at
  - l = 0, b = 0 with FWHM of 10°.
- No disk component or fountain detected so far.
  - More exposure needed.

511 keV Map

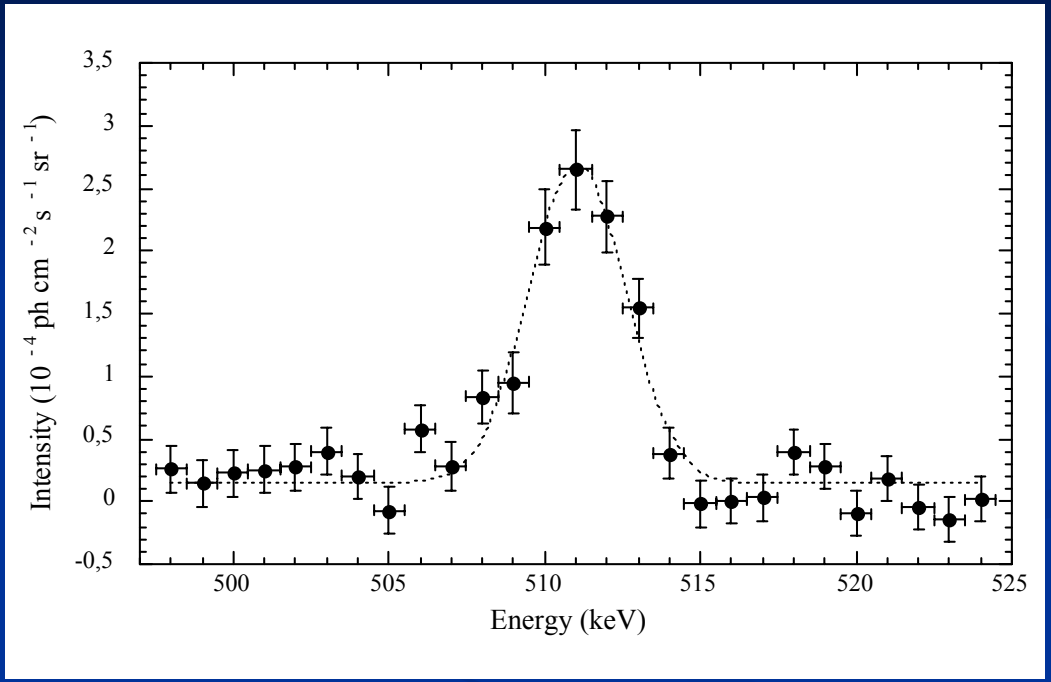


Exposure Map



INTEGRAL 511 keV SPECTROSCOPY

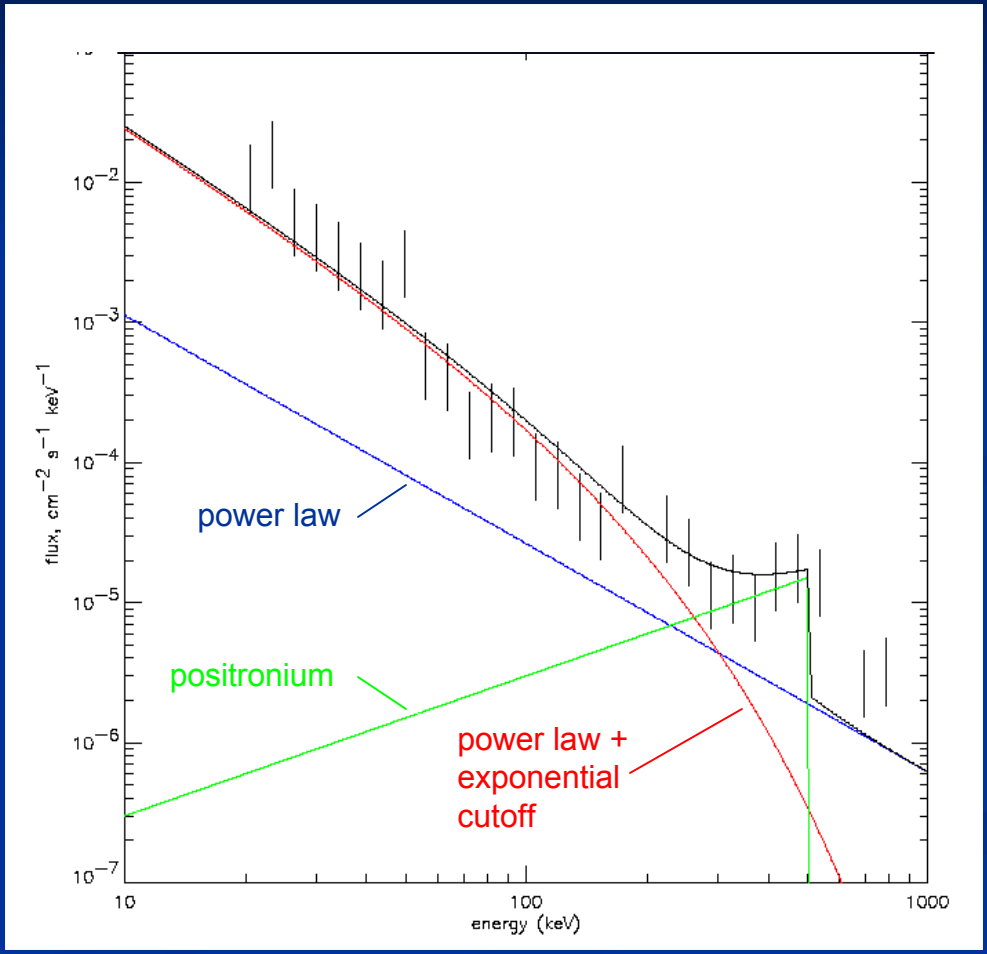
- Spatial model: symmetric gaussian centered at l = 0, b = 0 with FWHM = 10°
- Line parameters:
  - Flux: 0.99 (+0.47/-0.21) x 10^{-3} cm^{-2} s^{-1} (consistent with previous results)
  - Centroid:
    - 511.06 (+0.17/-0.19) keV
  - Width: 2.95 (+0.45/-0.21) keV
    - (somewhat higher than previous values)



POSITRONIUM

(Strong et al., submitted to A&A)

- e^+ and e^- can annihilate through formation of positronium (e^+ - e^- bound pair).
  - If spins are opposite --> two 511 keV photons
  - If spins are parallel --> 3 photon continuum, E_{max} = 511 keV positronium continuum
- Positronium fraction f_p
  - Fraction of total decays that go through positronium
  - Most prior results put f_p > 90%
  - Preliminary analysis indicates that INTEGRAL is in agreement.



POSSIBLE ORIGIN OF ANNIHILATION RADIATION

- Supernovae (SN)
  - Beta-decay of radioactive nuclei created in SN explosion and transported into interstellar medium (ISM) in expanding shell.
- Massive stars (e.g. Wolf-Rayet)
  - Positrons created by nucleosynthesis in stellar interior, convected to surface and transported into ISM by stellar wind.
- Black Holes
  - Pair plasmas believed to exist in BH jets.
  - Could either be aggregate emission from many BH in Galactic Center region or from a single massive BH at Galactic Center.