INTEGRAL Y4+
The New Soft Gamma-Ray Sky

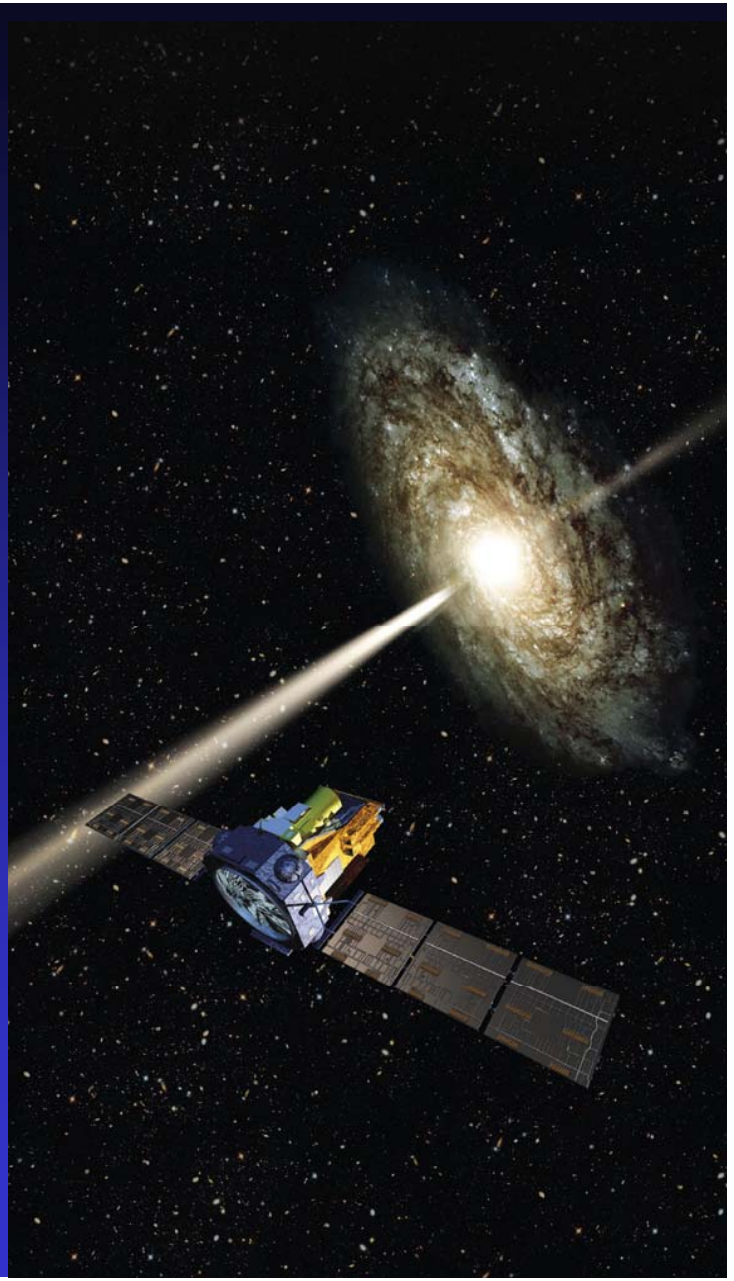
Introduction

Main scientific results

KeV to TeV connection

INTEGRAL

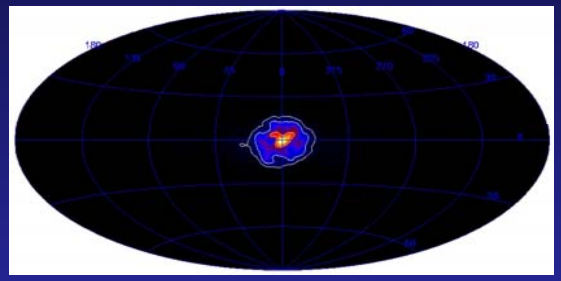
- ★ Gamma-ray observatory
- ★ 15 keV – 10 MeV
- ★ High resolution spectroscopy (SPI) and fine imaging (IBIS) within large FOV
- ★ Medium-size mission (ESA, Russia, NASA), launched in Oct 2002
- ★ Observatory type
- ★ Community involved via
  - AO programme (AO-4: 142 proposals, x 8 over-subscribed)
  - Public archive access
  - IUG, ISWT, TAC

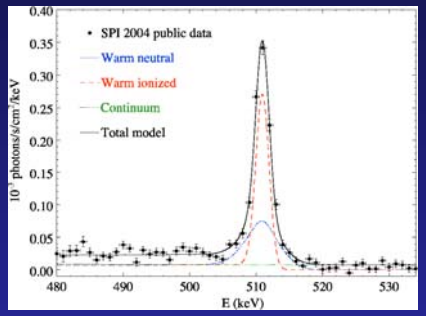


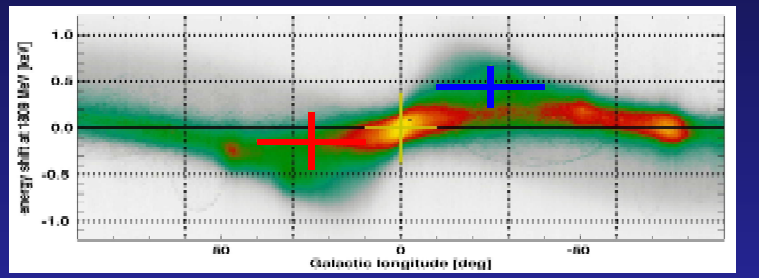
INTEGRAL resuluts: SPI & IBIS Complementarity

SPI/INTEGRAL: THE unique spectrometer for nuclear-line astrophysics.

- INTEGRAL science of nuclear lines is not done by any other current nor foreseeable instrument, with broadest application in astrophysics.

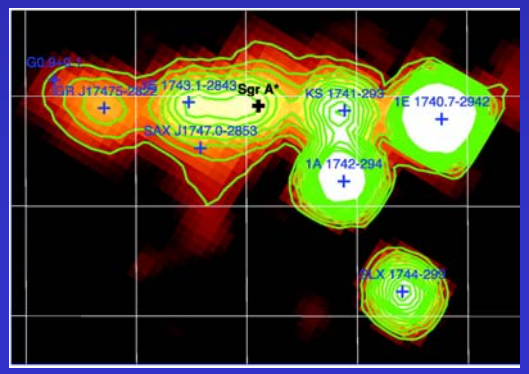


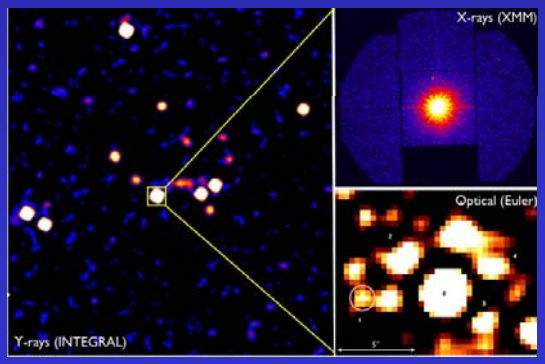


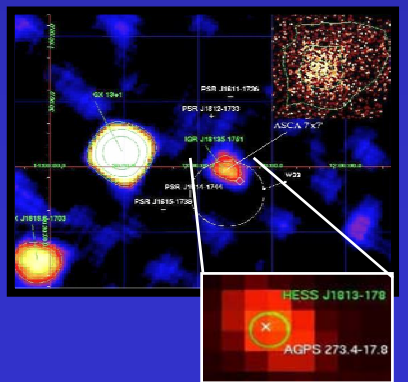


IBIS/INTEGRAL: THE unique imager for high energy point sources

- Fine imaging of high energy sources and monitoring of large parts of the highly variable sky is crucial for astrophysics at all wavelengths

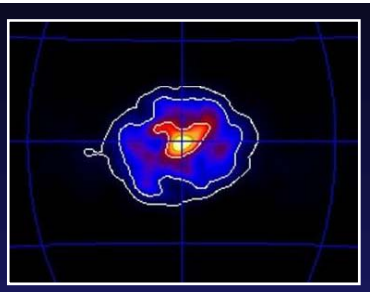




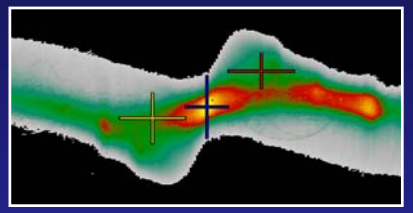


Great science achieved

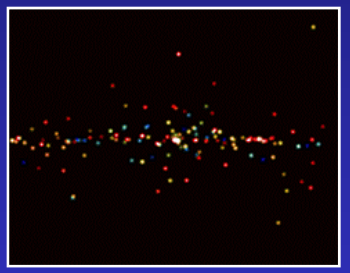
- ★ Annihilation of e^- with e^+ presents a <u>unique</u> view of the Galaxy



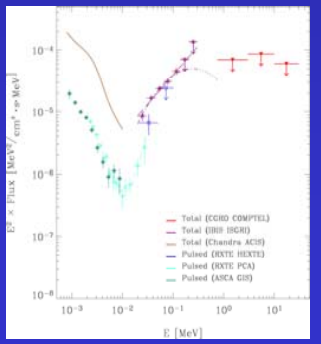
- ★ Radioactivity yields directly the Galactic supernova rate



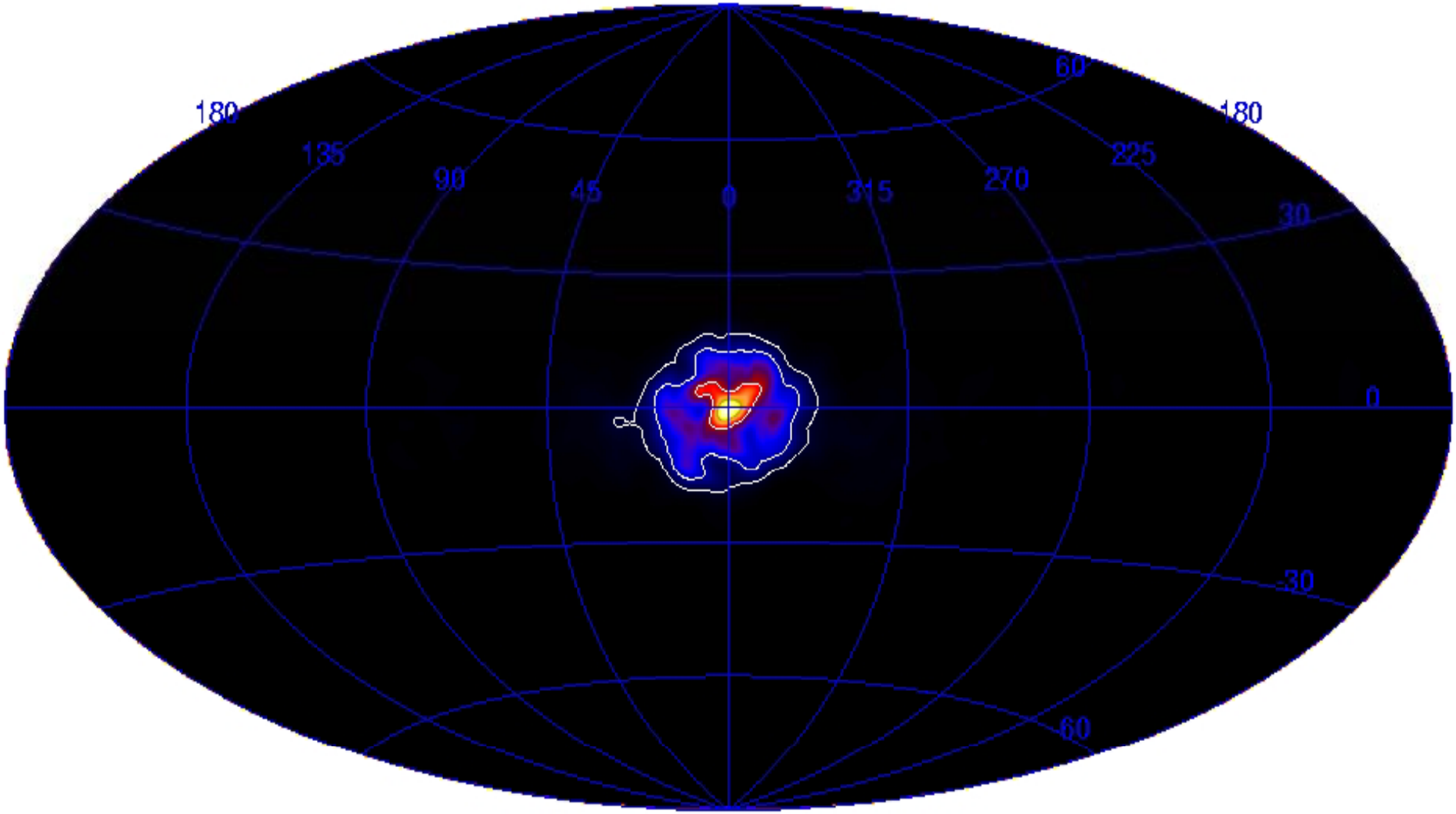
- ★ Accreting binaries within dense clouds



- ★ Previously unknown early phases of neutron stars



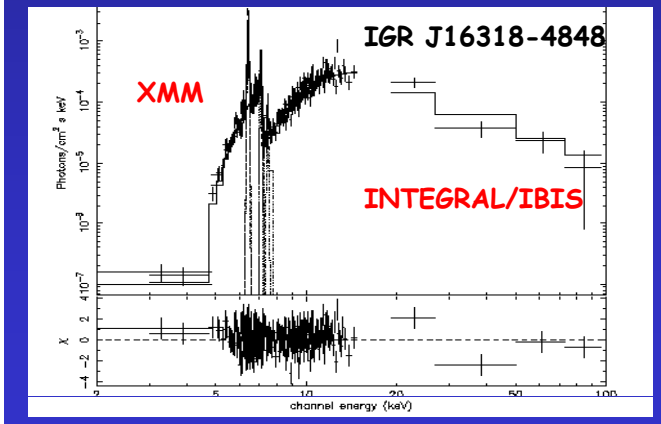
INTEGRAL: Galaxy Plane Deep exp. & SPI achievement



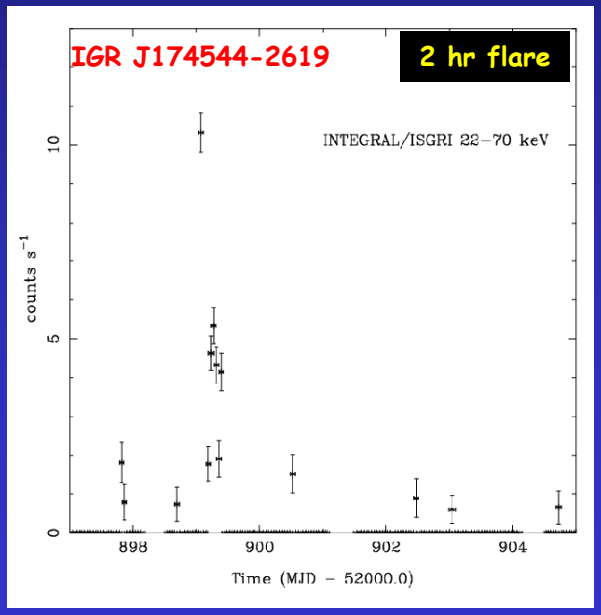
511 sky map, 1 year, J. Knödlseder et al., 2005

Examples of important unexpected INTEGRAL discoveries

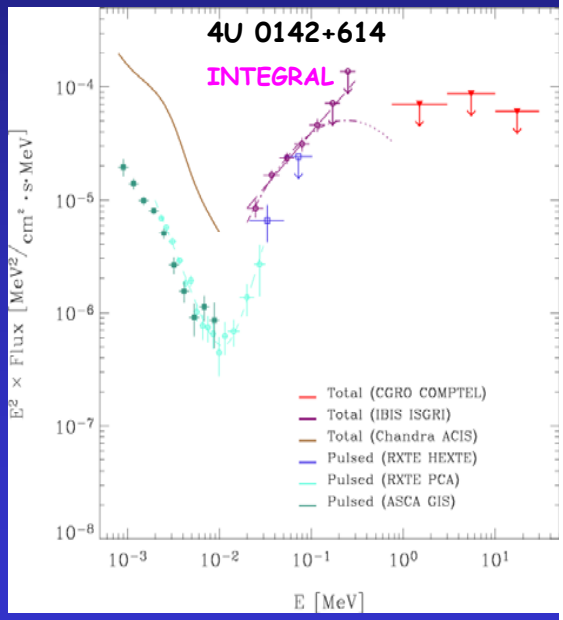
1. the highly absorbed (mostly transient) binary systems as a new class of HMXB (slow pulsar in a giant cocoon)
2. the super-giant fast transients: a new (sub) class of super-giant HMXB (wind accretion in blobs?)
3. very hard emission from anomalous X-ray pulsars (AXP) – The inial pulsar life



R. Walter et al., A&A 411, L427, 2003



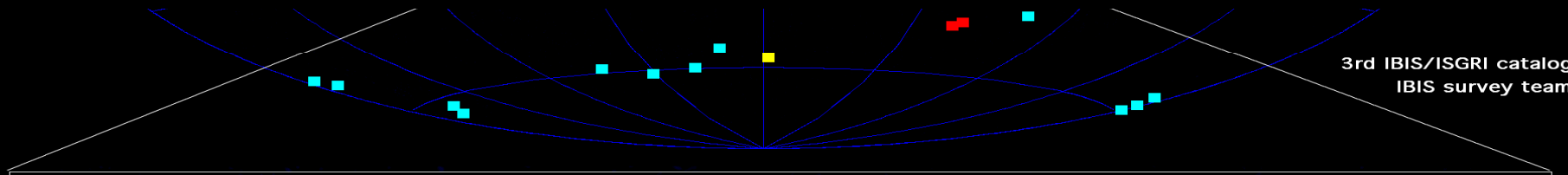
V. Sguera et al., ApJ 646, 453 2006



L. Kuiper et al., ApJ 645, 556, 2006

The INTEGRAL Sky

The lower image shows a false colour image of the central region of our galaxy. This is a composite image based on all-sky IBIS/ISGRI maps in three energy windows between 17 and 100 keV and represents the true 'X-ray colours' of the sources.
Red sources are dominated by emission below 30 keV, while blue sources have harder spectra, emitting strongly above 40 keV.

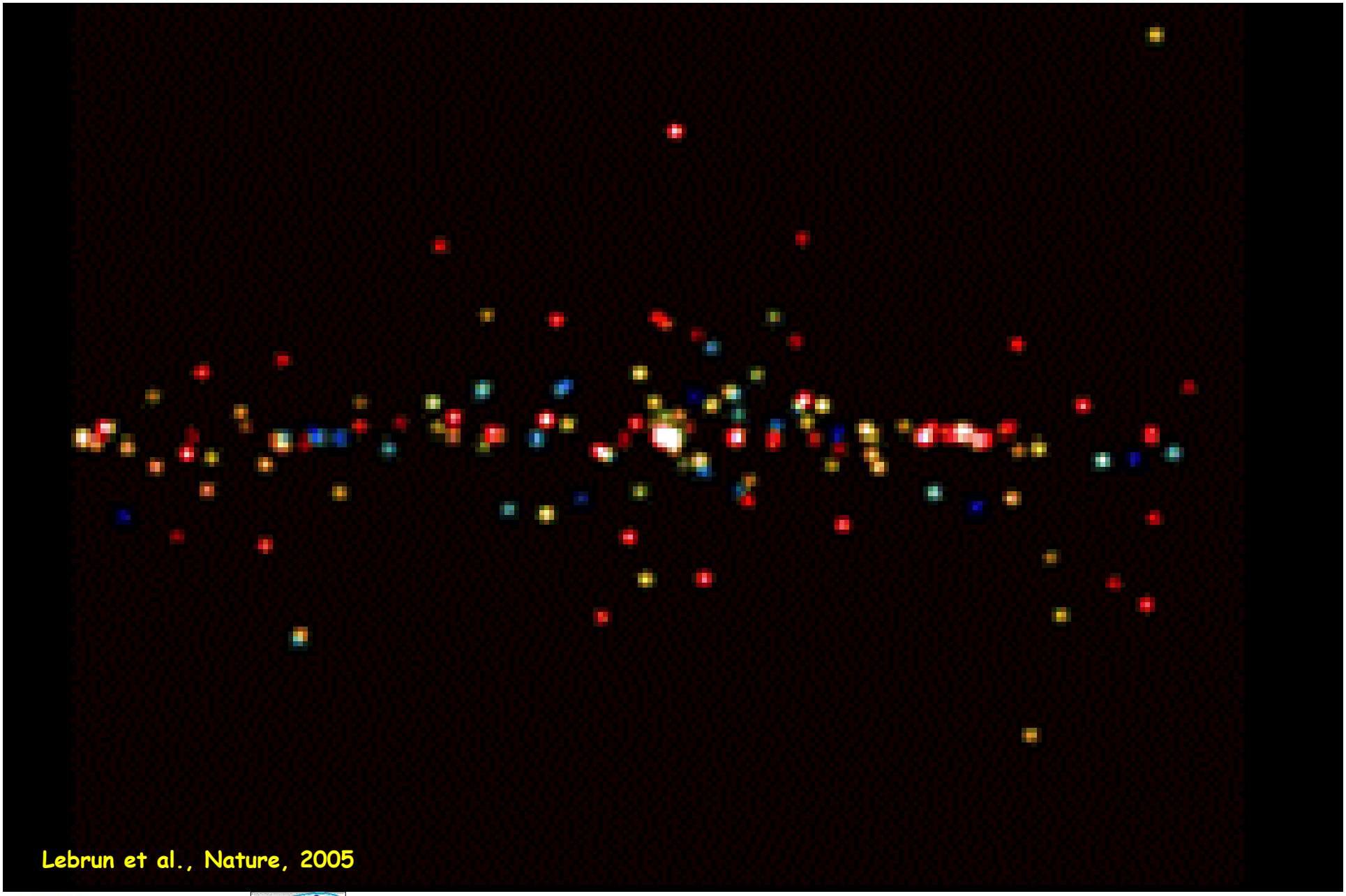


3rd IBIS/ISGRI catalog
IBIS survey team

Zoom of the Central Radiant of the Galaxy

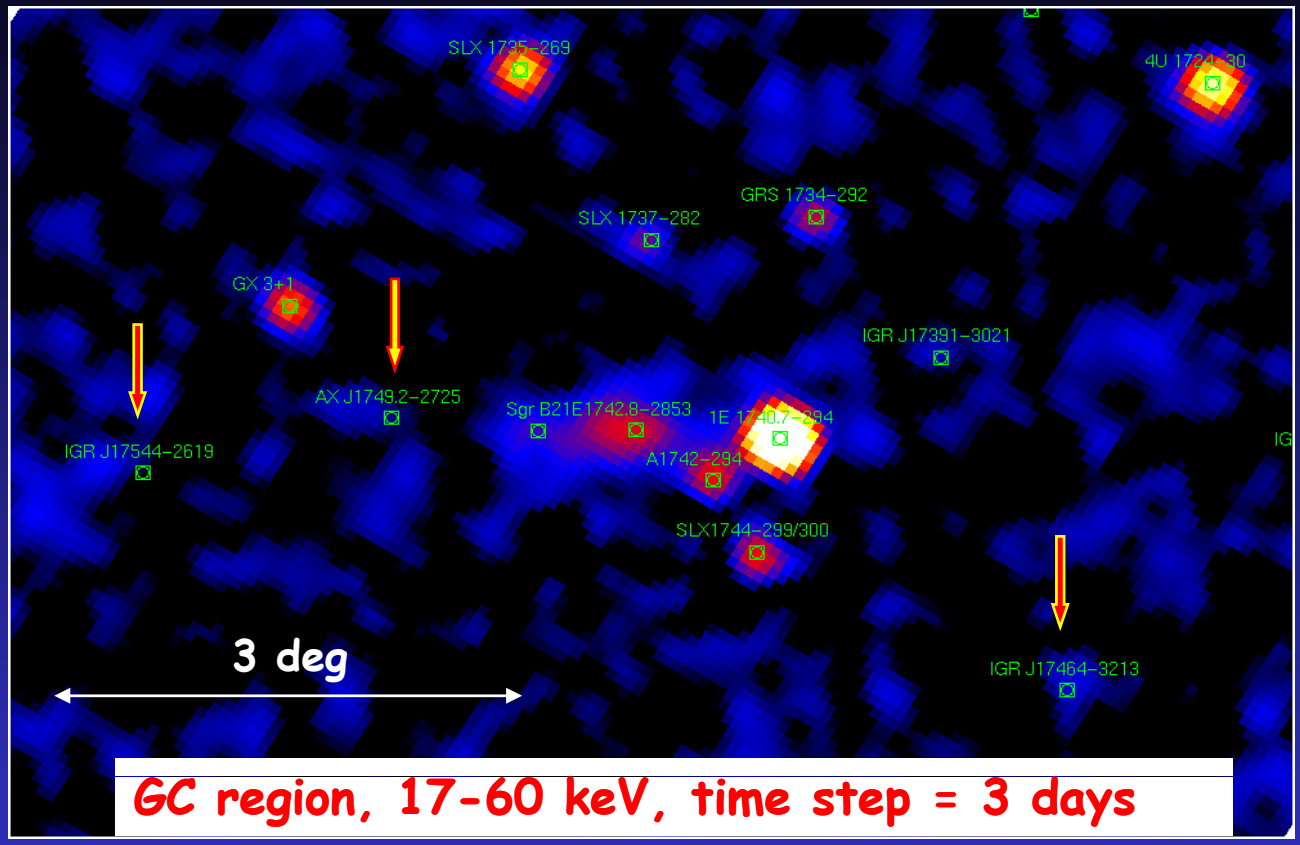
The upper image shows the distribution on the sky of four of the main populations observed in the third INTEGRAL/IBIS survey catalogue.
Of the known systems, the low-mass X-ray binaries (LMXB) are old systems mainly populating the galactic bulge, the high-mass X-ray binaries (HMXB) are younger systems seen along the galactic plane, and the active galactic nuclei (AGN) are extragalactic sources seen over the whole sky.
Around one in four of the sources seen by INTEGRAL are unidentified, and their distribution is also shown.

The IBIS: Central Radiant, no Diffuse Ridge Emission



Lebrun et al., Nature, 2005

The variable high-energy sky

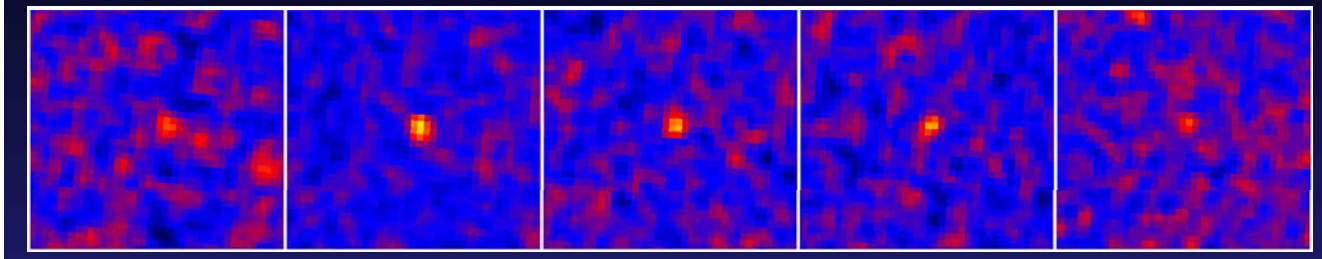


★ The high energy sky is highly variable and ToO's are important

★ 35 ToO follow-up observations (~ 10 Ms, Jan 03 – Dec 06)

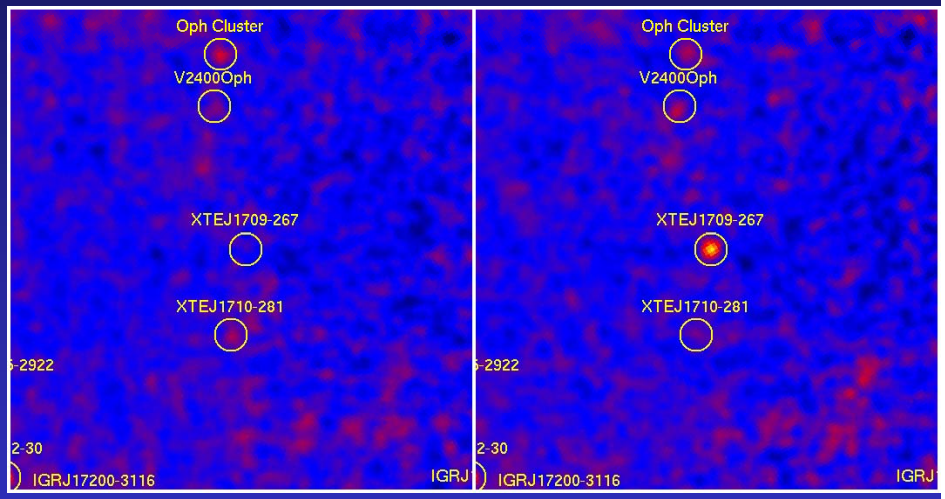
☞ **Monitoring the sky in this energy range is of fundamental importance (as are multi-λλ follow-ups)**

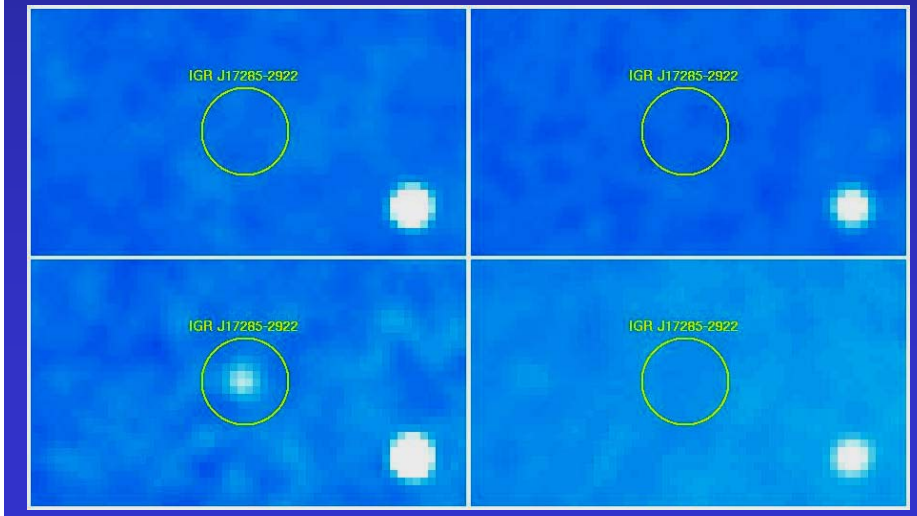
High-energy sources appear on all time-scales



Sources can appear in ~ 1000s

Or in a few days





Or in a few weeks

3rd IBIS/ISGRI soft gamma-ray source catalogue

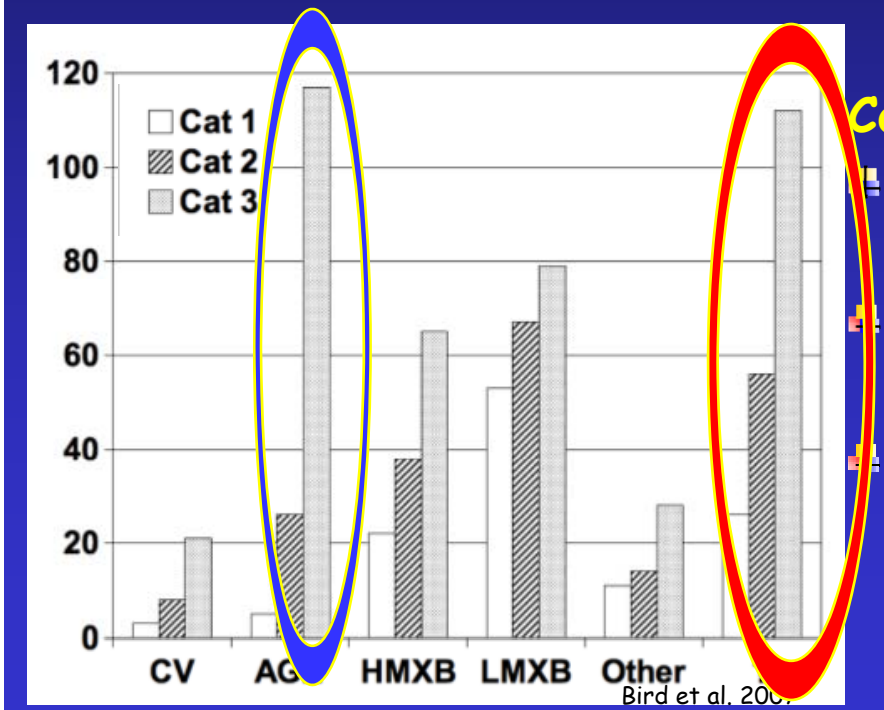
The catalogue includes 421 sources detected in the energy range 17–100 keV :

41% galactic accreting system

29% extragalactic objects

8% other types

26% not classified i.e. unknown origin



Bird et al. 200

Comparison to previous IBIS/ISGRI surveys:

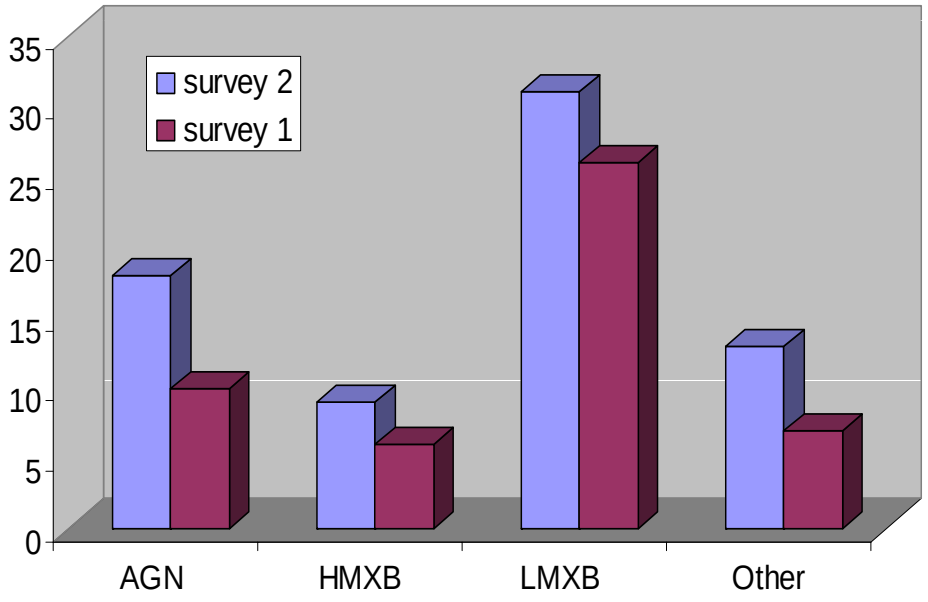
- Increase in AGN number due to a increased exposure away from the GP
- Increase of the rate of discovery of HMXB
- The percentage of sources without an identification has remained constant

2nd HARD IBIS/ISGRI gamma-ray source catalogue

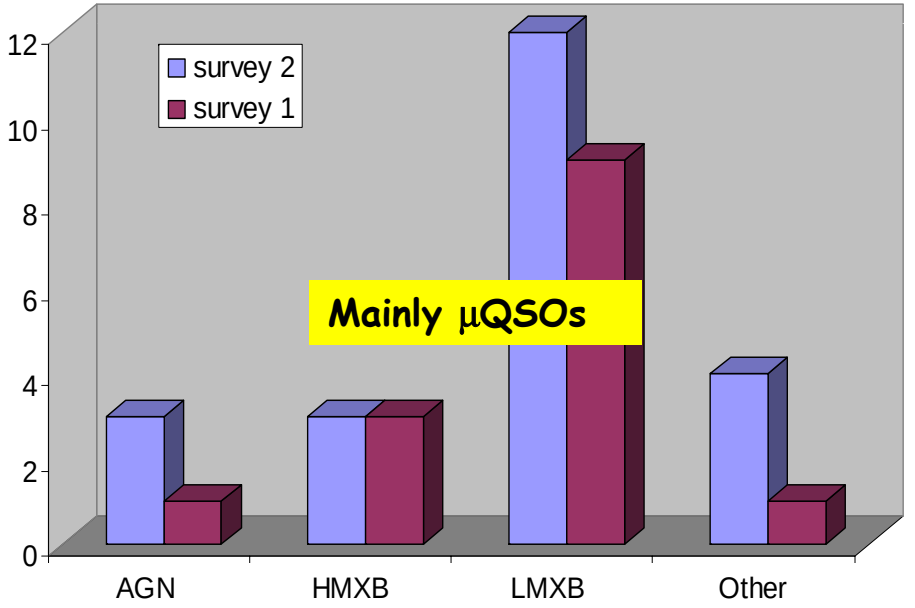
The 2nd IBIS "high energy" catalogue, in the range 100-150 keV and 150-300 keV, is based on public and Core Program observations performed in between end **March 2003 to the end of April 2006** including special "staring" observations and does not including observations performed before the first Crab calibration in February 2003.

An absolute initial threshold of 4.5σ has been applied to combine initial list that has been then checked for appropriate PSF shape and systematic map artefacts.

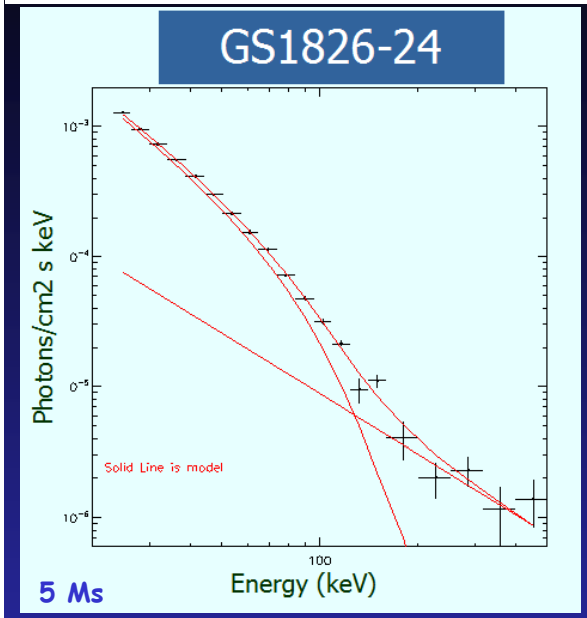
100-150 keV



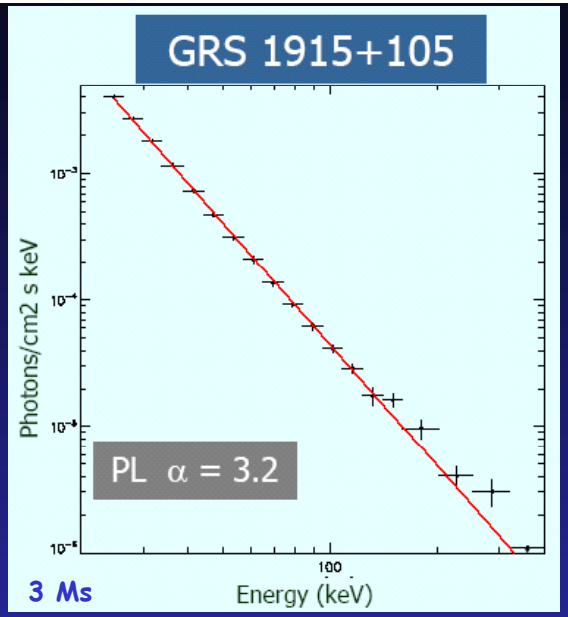
150-300 keV



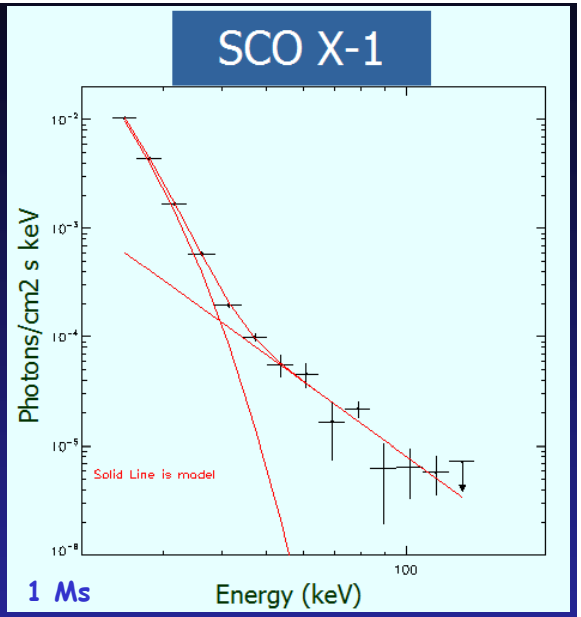
NS, BHC and μQSOs at E > 100 keV



Neutron star



Black hole candidate



Neutron star with transient hard tail (observed 30% of time)

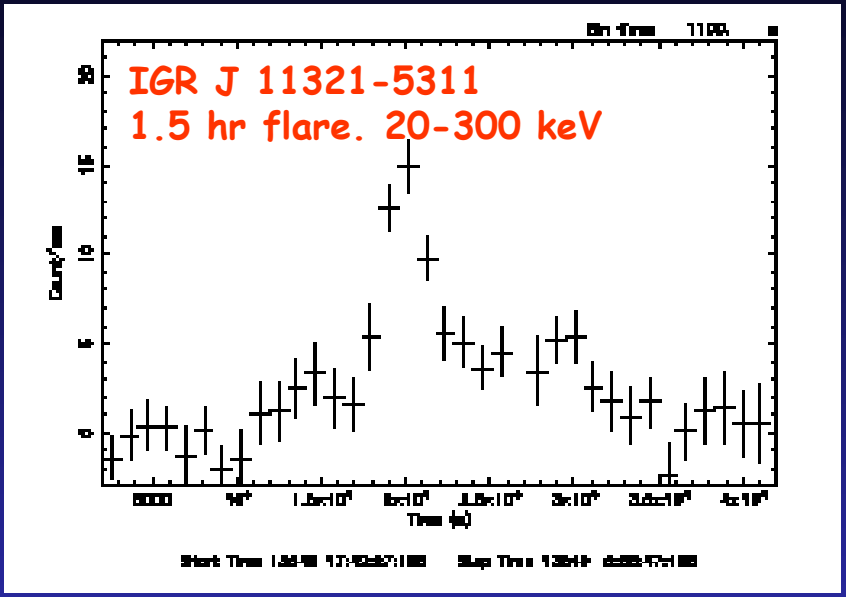
SPI data from E. Jourdain et al., 2006

- ★ A good fraction of NS/BHC emit > 100 keV with or without cut-off
- ★ Long duration integrated spectra needed -> Physics > 100 keV :
  - Transition primary/reflected components
  - Transition thermal/non-thermal emission
- ★ Variable high tail
  - Origin: jet ? ….how the gravitational disk energy become a jet??

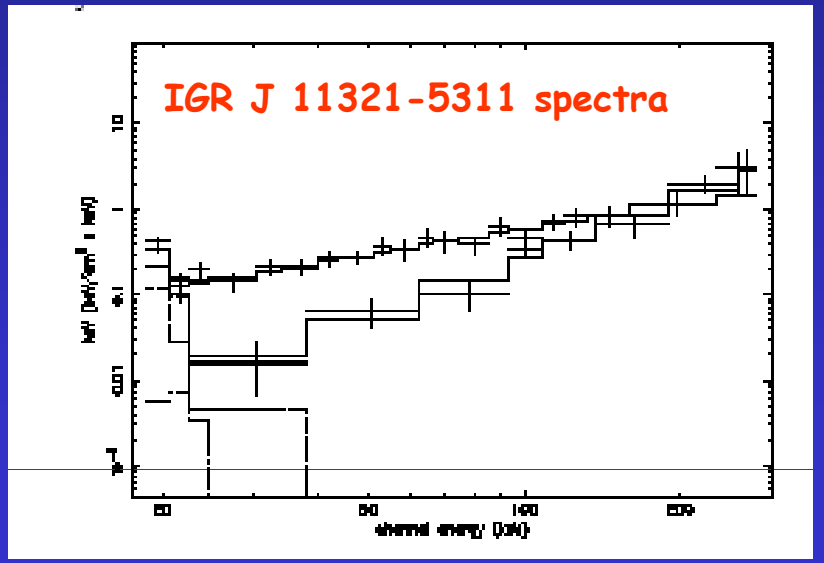
IGR J 11321-5311: a possible Magnetar B=10^{13-15} Gauss

Discovered in june 2005 with INTEGRAL is one of the hardest source in the gamma ray sky!! The detection is still the only reported one in the X-Gamma ray domain.

The spectrum of the total outburst activity (17–300 keV) is best fitted by the sum of a power law (Γ=0.55±0.18) plus a black body (kT=1 keV) with **no evidence for a break up to 300 keV.**



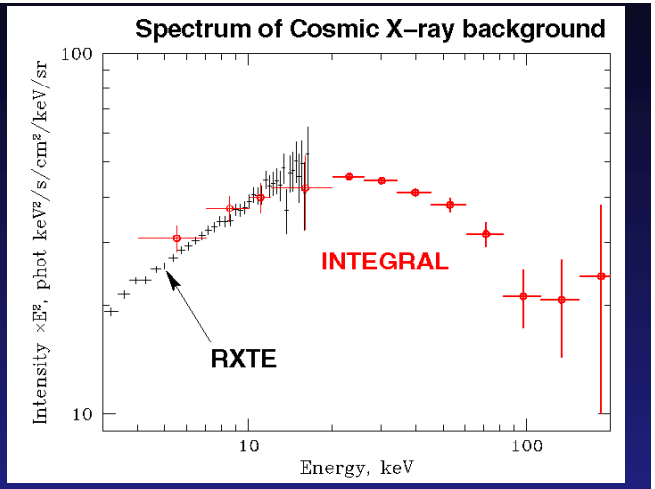
Conclusions: IGR J11321–5311 is an Anomalous X-ray Pulsar, though a different nature can not be firmly rejected at the present stage (V. Sguera. A. Bazzano et al, in press).



Cosmic diffuse X-ray background (CXB)

★ Initial CXB observations (2006) via Earth occultation were highly successful (test method, spectral normalisation)

➢ Need long observations during solar maximum (away from GP) to verify robustness of Earth atmospheric emission and to obtain CXB spectrum in broader range



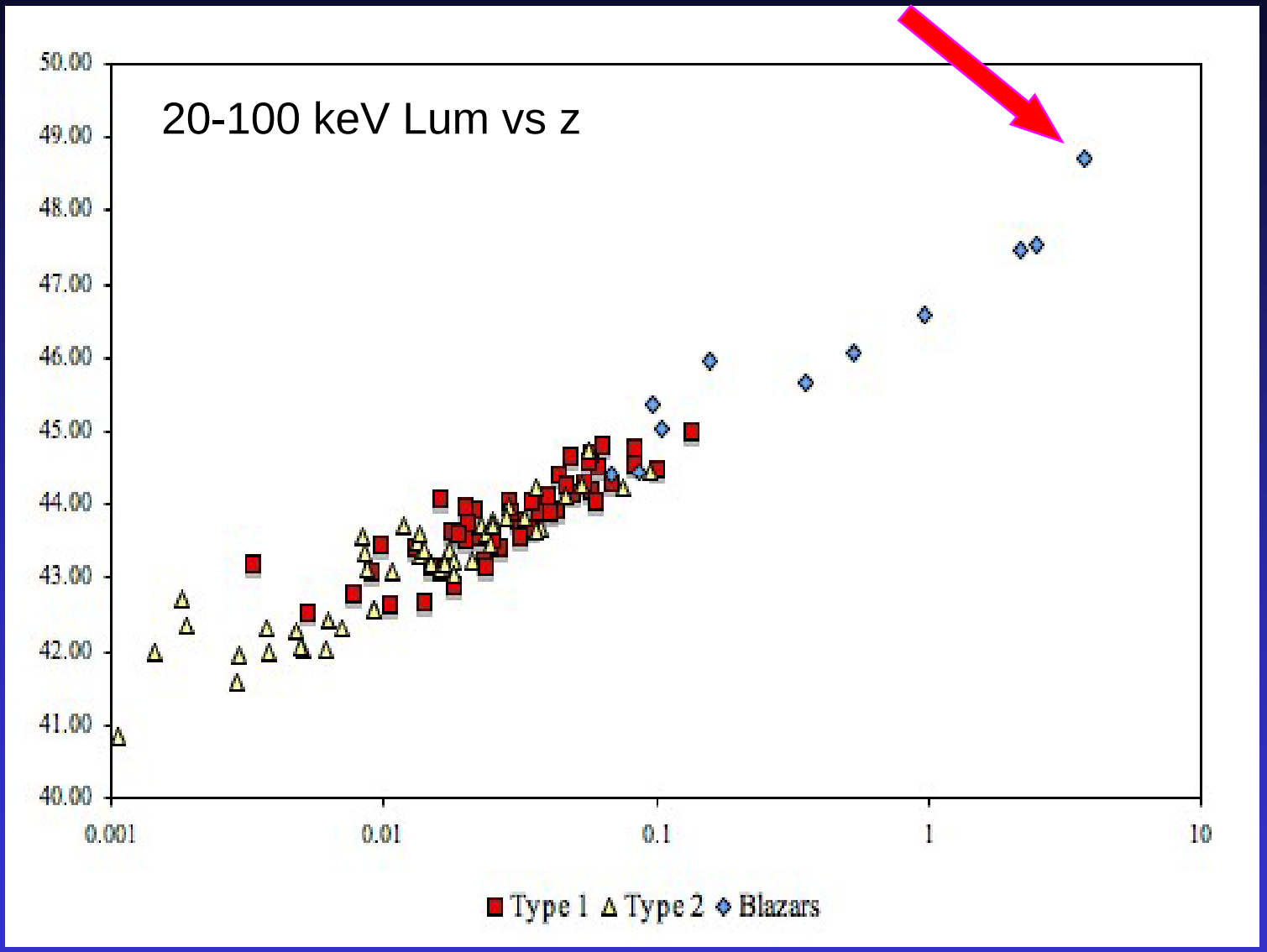
Churazov et al., A&A in press, 2006

★ The CXB luminosity peaks at 30 keV – what produces this radiation ?

- INTEGRAL's AGN ***INITIAL*** survey results find that "Compton thick" AGN contribute only a few % to the CXB
- Where are the super-massive BH's ?
  - Not in the local (z=0.022) universe where (the surrounding gas/dust torus has been "removed"), or,
  - Within the local universe, but much more "hidden" than assumed

INTEGRAL will probe AGN population deeply not to just increase numbers of AGN, but to measure properties of the population at faint flux levels

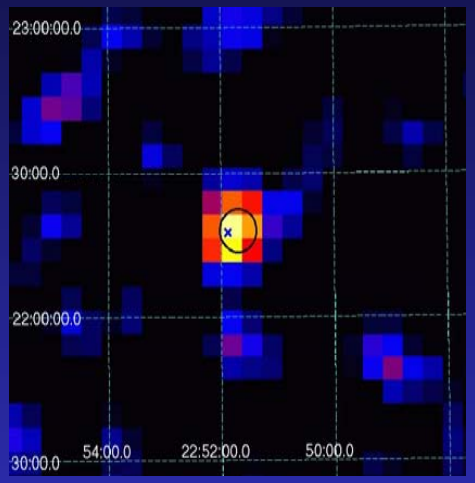
IGR J22517+2218=MG3225155+2217 (z~3.7): most distant AGN so far detected; rest frame $L_{\gamma\,(100\text{-}500\ keV)} = 5 \times 10^{48}$ erg/s



Swift-XRT/INTEGRAL-IBIS Observation of MG3225155+2217

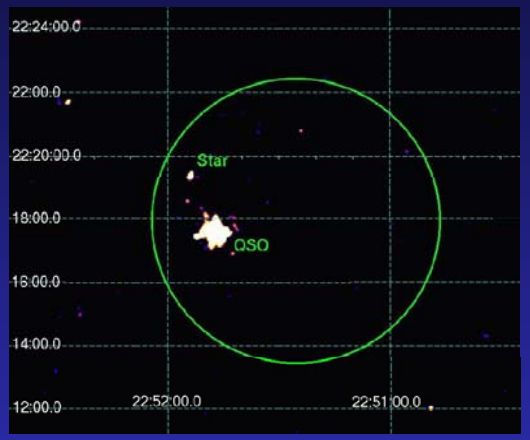
IGR J22517+2218 is a very interesting object with many peculiar features:

- **it is radio loud with a flat radio spectrum; core dominated radio emission (no extended features)**
- **it hosts a narrow line absorption system in optical;**
- **it shows a spectral curvature in X-rays either intrinsic or due to high absorption in the source rest frame;**
- **it is variable at high energies.**

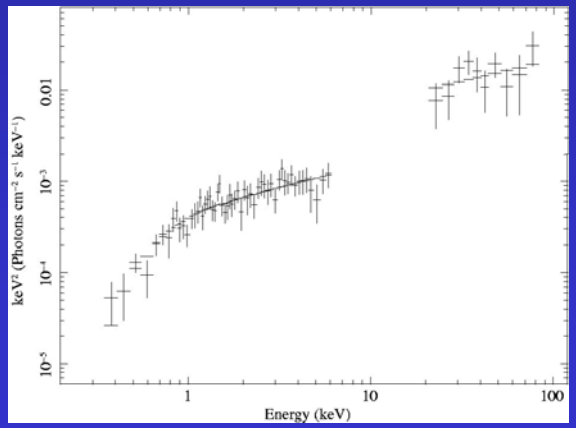


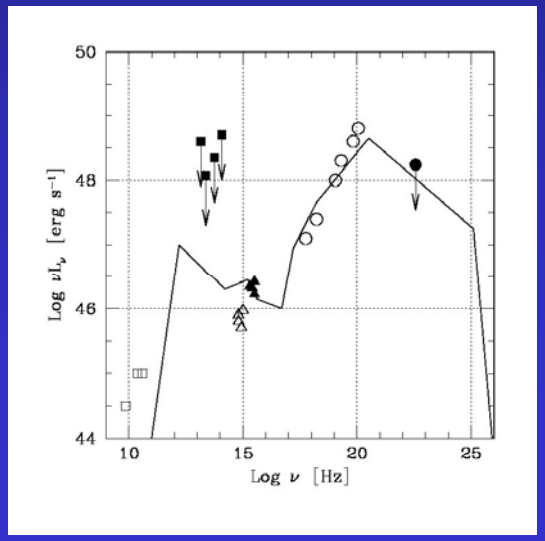
ISGRI mosaic 18-100 keV

XRT image 2-10 keV



Broad band spectrum X/gamma-ray spectrum





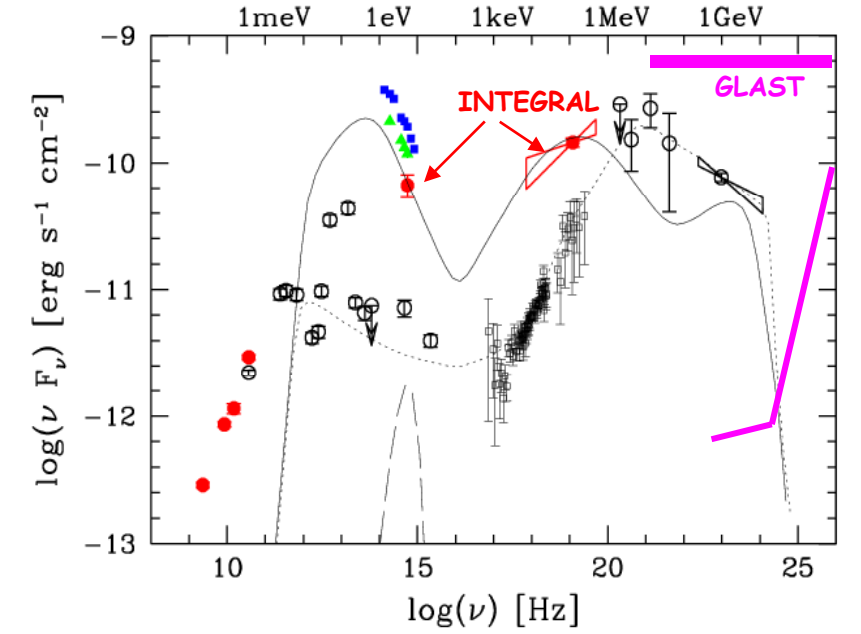
Rest frame source SED is also unusual among FSRQ as it is compatible with having the synchrotron peak in the X/gamma-ray band (i.e. much higher than generally observed) or alternatively with the Compton peak in the MeV range (i.e. lower than typically measured).

INTEGRAL and GeV science: AGILE, GLAST, TeV..

- ★ AGILE, 30 MeV – 30 GeV, launched 23 April 2007, operational through 2010+
- ★ GLAST, 20 MeV - >300 GeV, launch fall 2007, operational through 2010+

  - Most AGN are highly variable and multi-wavelength studies are crucial to simultaneously observe from hard X-rays/soft gamma-rays up to very high energy gamma-rays (also including HERSCHEL,HESS/MAGIC)

☞ GLAST will tell INTEGRAL "when to look": both for extragalactic and for galactic sources



Blazar 3C 454.3 in outburst
E. Pian et al., A&A 449, L21, 2006

HESS sources: a new exciting class emitting gamma-rays at $E>10^{12}$ eV. Search for counterparts at other wavebands

Step 1: Find positional agreement

Possible source nature:

1. SNRs
2. Pulsars and PWN
3. Microquasars and binaries
4. Background AGN
5. New class?

Most important wavebands:

1. Radio
2. X-rays (>few keV) ==> INTEGRAL

Then

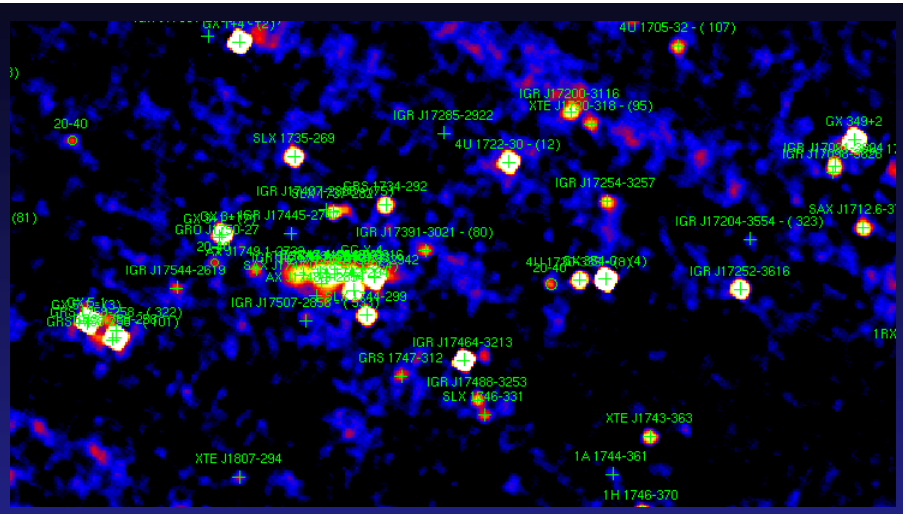
Step 2: Find a viable gamma-ray emission mechanism of the positional counterpart

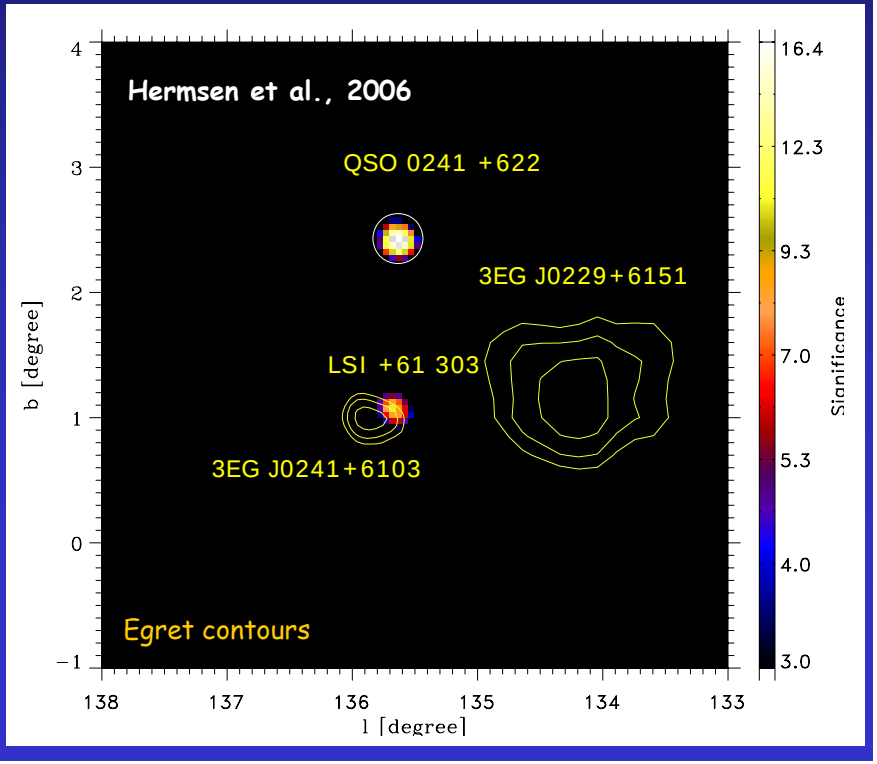
Step 3: Provide a consistent multi-wavelength picture

Additionally: if source extended – Study morphological match → time variability

Unidentified (very) high energy sources

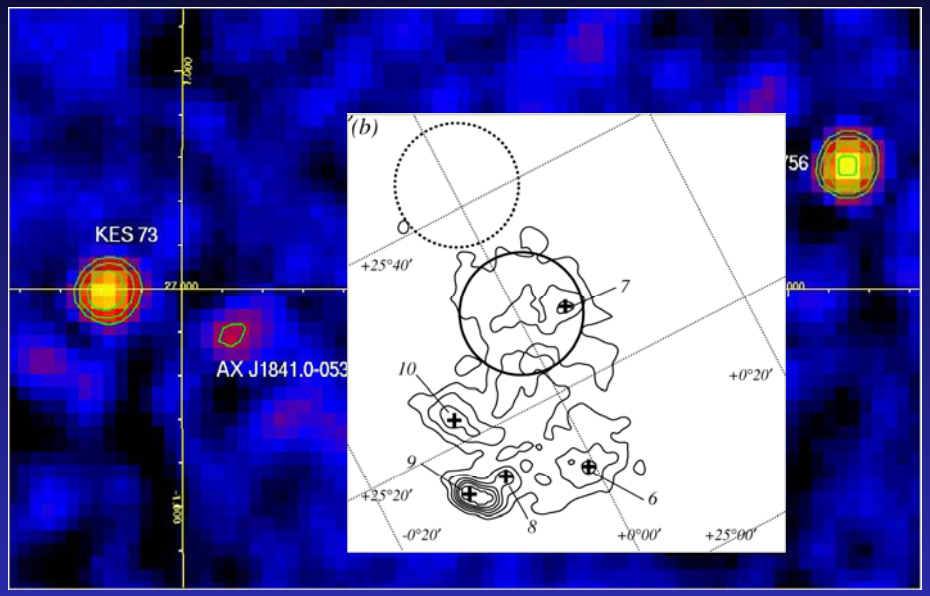
- ★ INTEGRAL deep sky maps are (and will remain) robust and unique to allow detection of yet un-identified very high energy sources fm COS-B, EGRET, AGILE, HESS, GLAST …
  - Persistent = normal pulsars and ms radio pulsars
  - Variable = micro-quasar/pulsar binaries
  - Extragalactic sources (variability studies: gain ~ time, not sqrt(time))
- ★ Need typically 10 Ms on plane for weak sources…
- ☞ Recent example: the Microquasar and TeV/EGRET/ COS-B source LSI +61 303 seen by INTEGRAL





INTEGRAL Uncovered Two HESS Unidentified TeV Sources:

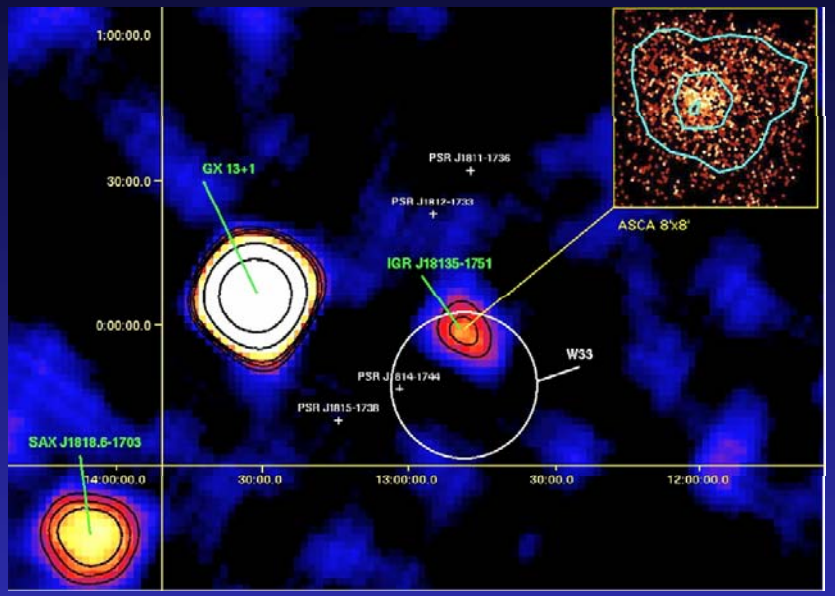
HESS J1837-069 = AXJ1838.0-0655



Soon associated with the SNR G25.5+0.0 complex (source 7) detected by ASCA also seen by INTEGRAL/ISGRI and BeppoSAX/PDS

IBIS/ISGRI 20-300 keV significance map showing the location of AX J1838.0-0655 - HESS J1837-069 (white circle) and the Einstein position (black cross). (Malizia et al., ApJL 630. 2005).

HESS1813-178 = IGR J18135-1751

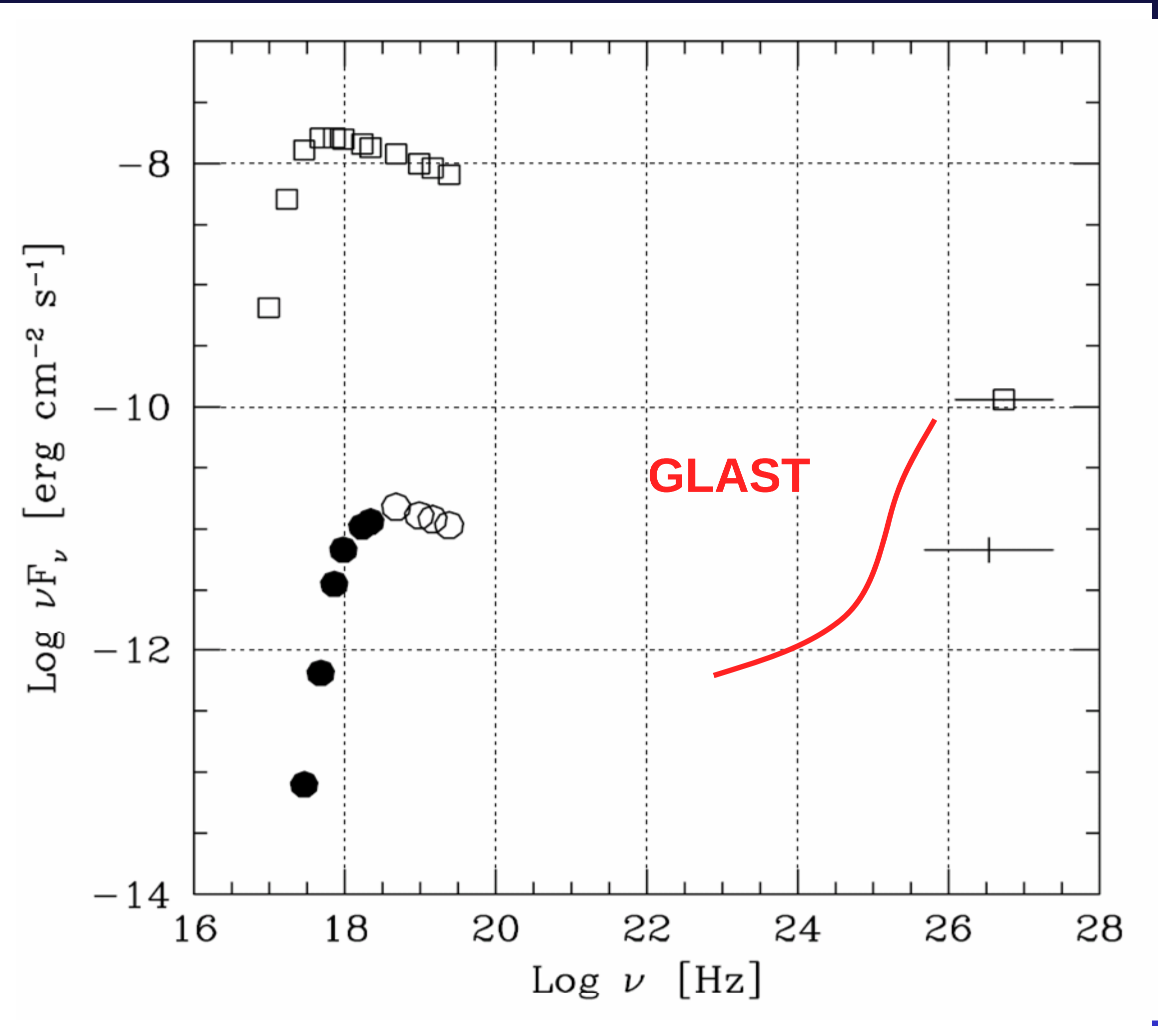


The IBIS/ISGRI 20-40 keV significance map showing the location of IGR J18135-1751. The extension of HESS J1813-178 and AGPS273.4-17.8 are both contained within the internal IBIS/ISGRI contour. The ASCA-SIS image is shown as an insert on the top right side of the figure. (Ubertini et al. 2005, ApJL, 629, 109)

INTEGRAL Uncovered Two HESS Unidentified TeV Sources: Spectral Energy Distribution

HESS J1837-069 + AX J1838.0-0655

HESS J1813-178 = IGR J18135-1751

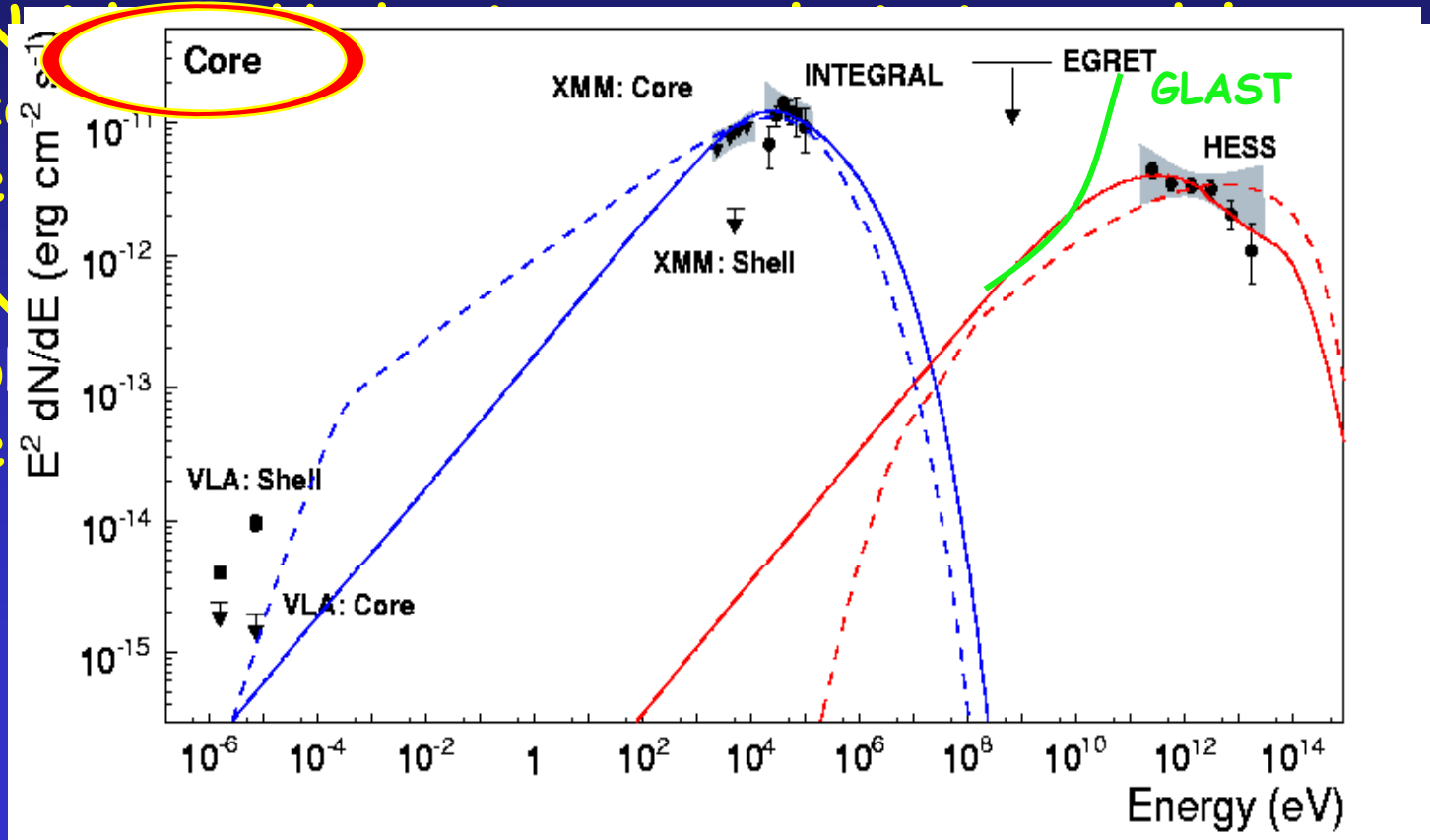


Spectral Energy Distribution (SED) of AX J1838.0-0655 from X-ray to TeV gamma-rays including EGRET upper limit and GLAST sensitivity curve for 1 year observation with LAT. The inset is blow-up of the combined ASCA and ISGRI spectrum.

SED from radio to TeV of IGR J18135-1751 (bottom) and the Crab Nebula (top). ASCA X-ray data in 2-10 keV, the IBIS-soft g-ray 20 to 100 keV and HESS 0.2 to 10 TeV

HESS J1813-178=IGR J18135-1751: SED & emission models

No distinction is possible between a scenario in wich Gamma rays are emitted from the shell of the SNR or from the PWN. No pulsations have been revealed neither in radio nor X-ray (Funk et al. 2006, Ubertini et al. 2005).



Models:

Dashed line
E_{min}=25 GeV
E_{max}=15 PeV
Γ=2.4
B=4.2 μG

Solid line: leptonic model with electrons accelerated in the SNR shell

Solid-line
E_{min}=1 MeV
E_{max}=15 PeV
Γ=2
B=7.5μG

Dashed line: hadronic model

HESS J1616-508: likely powered by PSR J1617-5055

- ★ No X-ray counterpart in the HESS extension
- ★ Nearby offset pulsar (A) able to power the TeV emission (1.2% of the spin down losses is needed)
- ★ Detection of diffuse emission around the pulsar ➜ upper limit to the presence of a (yet unseen) PWN ~1.3 x 10-12 erg cm-2 s-1 in 2-10 keV
- ★ The relative sizes of the X/γ-ray and VHE sources consistent with the expected lifetimes against synchrotron and Compton losses for single source of parent electrons emitted from the pulsar

⇙ ⇘

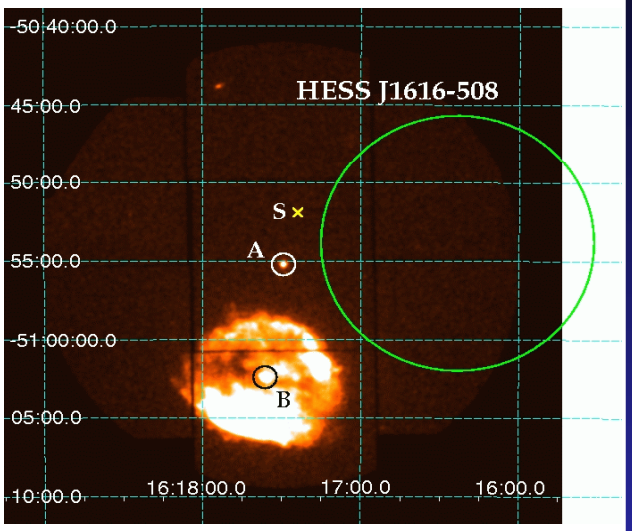
X/γ-ray emission due to uncooled electrons

TeV emission due to IC of the synchrotron cooled electrons on the CMB

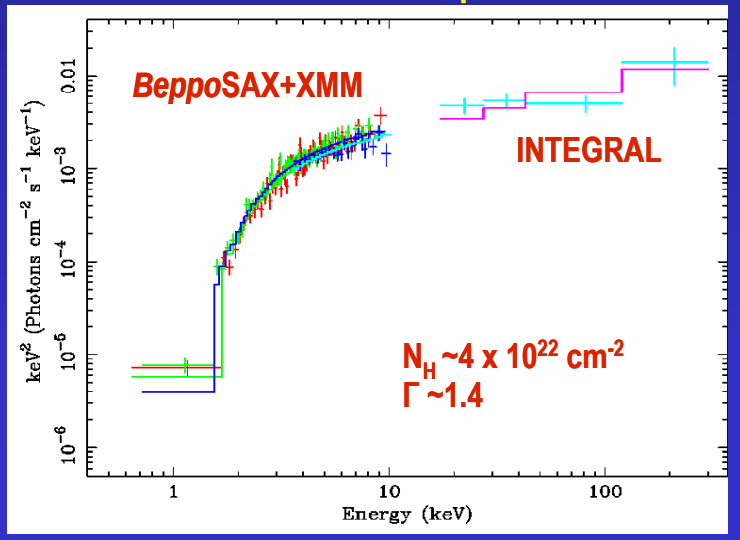
⇓

The observed spectral index of the X/γ-ray emission (Γ ~1.4) and that of the TeV emission (Γ ~2.4) are consistent with this scenario (R. Landi et al., in press)

XMM image



Broad band spectrum



PSR J1811-1925

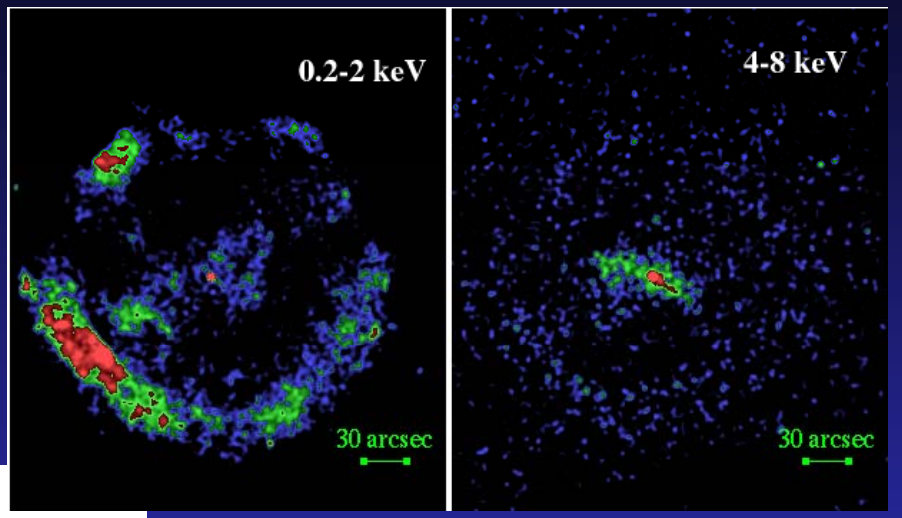
Integral and Jet spectra similar (hard); Chandra jet like emission in the HESS direction, not contemporary observed.

Both PSR energetics compatible with HESS

Pulsar	$\dot{E}$ (erg/s)	Distance (kpc)	$L_{HESS}(\% \dot{E})$
PSR J1811−1925	6.4×10^{36}	5	0.6
PSR J1809−1917	1.8×10^{36}	3.5	1.2

Dean et al., submitted

Chandra



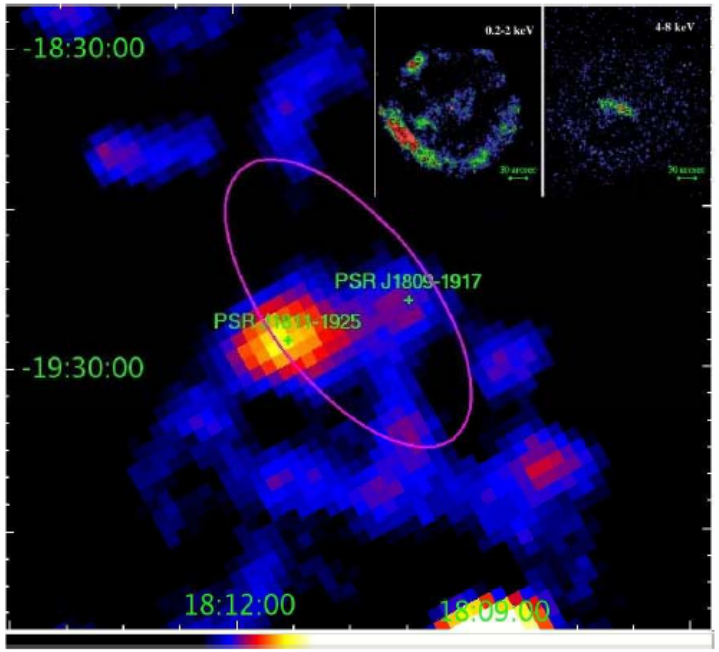


Fig. 1. *INTEGRAL* /IBIS/ISGRI image of the region around PSR J1811−1925. Note that the image structure around the position of PSR J1809−1917 is well below the detection threshold as determined by Bird et al. (2007) for the 3rd IBIS/ISGRI catalogue. The fit ellipse (Aharonian et al. 2007) of the extended HESS source is reported with a magenta ellipse. In the inset we show the *Chandra* images (~ 5′ × 5′) in 0.2–2 keV (left) and 4–8 keV (right).

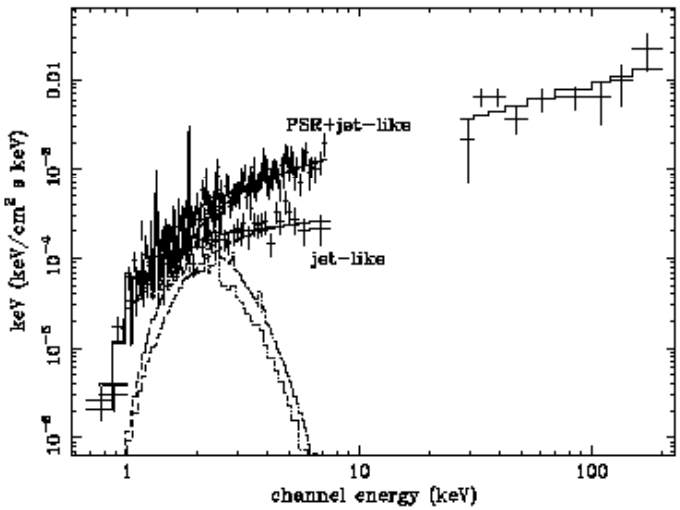


Fig. 2. Composite spectrum *Chandra* and *INTEGRAL* . The two data set in the *Chandra* energy range are the spectra extracted from the jet-like feature (region A in the text) and PSR+jet-like feature (region B in the text).

How can we distinguish the PWN vs SNR scenario?

PWN: detect the pulsar

a) pulsation

b) cooling of electrons through softening of the X-ray spectrum

==>deep hard X-ray observations with CHANDRA, XMM and INTEGRAL

Chandra and INTEGRAL for high and good angular-resolution soft X-rays ad soft-gamma observations

New light in the MeV-GeV region with the superior AGILE angular resolution and GLAST sensitivity.

end