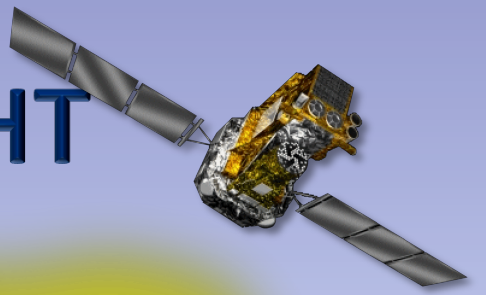
INTEGRAL HIGHLIGHT



The first 10 years: latest results

17 October 2002 Baikonur

P. Ubertini, IAPS/INAF

Vulcano Workshop 2012

Frontier Objects in Astrophysics and Particle Physics

28 May - 2 June 2012

The INTEGRAL Observtory

IBIS and SPI are t

★ SPI optimised for

★ IBIS optimis eV

IBIS is the

s)

y operates 17-600 keV

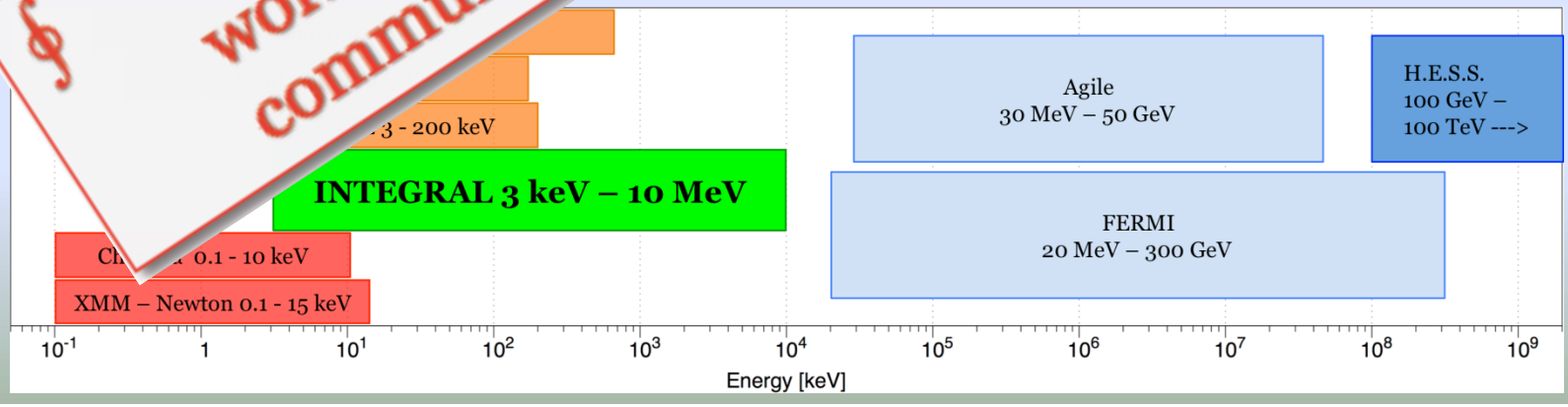
eV

0.1mCrab for deep exposures

s)

EM-X and OMC are the Monitors

INTEGRAL will remain the only observatory world-wide providing these capabilities to the community in this decade



INTEGRAL STATUS

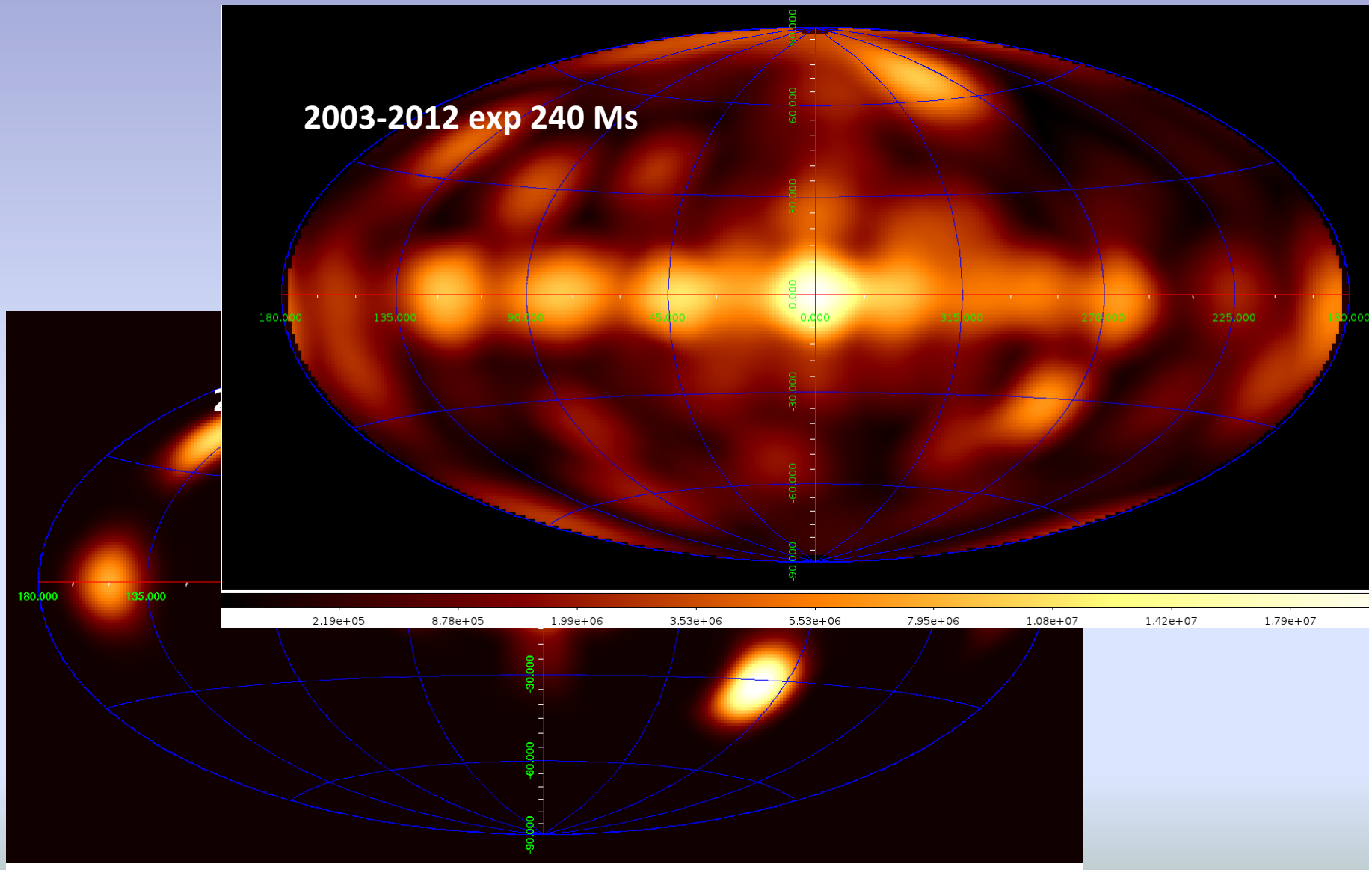
- Spacecraft, ground and flight operations: nominal
- Payload: in good shape after 9 years in orbit !

Instrument	Healthy detectors (%)	Change in sensitivity compared to launch (%)
SPI	15/19 = 79%	12%
ISGRI	96 %	2 %
PICsIT	98 %	1 %
JEM-X	77 %	13 %
JEM-X: both detectors operational as of 10 October 2010 (rev 976).		

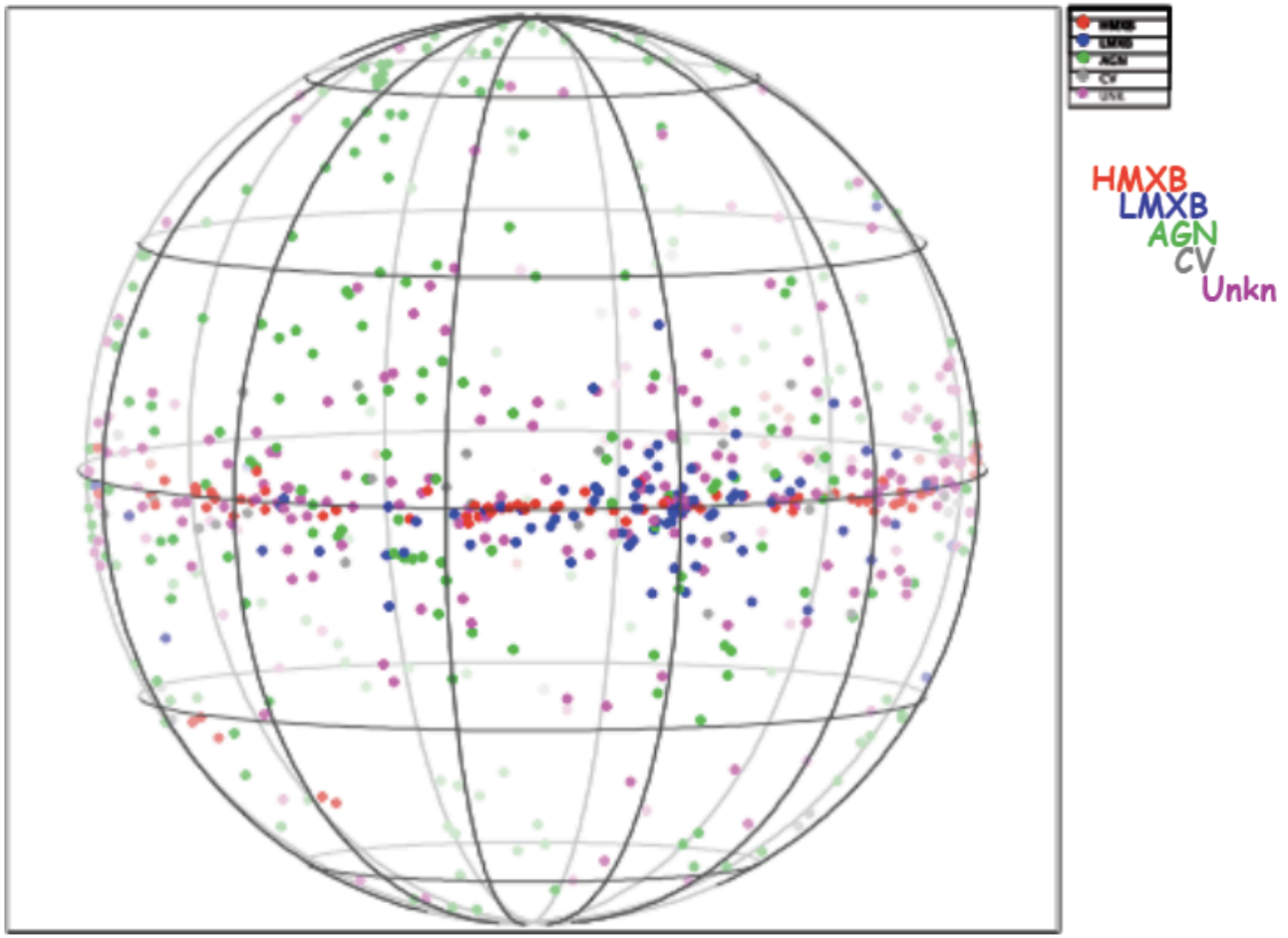
IBIS: started hunting new γ-ray sources … and, now monitoring weak old known

- ★ Takes advantage of the large FOV (~1000sq deg) for multiple source detection also in complex region (Galaxy Centre etc)
- ★ Unbiased search of the IBIS datasets: ~8 years of operations
- ★ Looking for weak persistent sources only visible on long timescales: spans a duration of > 2900 days→190Ms unprecedented long (no basic systematic errors ≈4.5σ limit averall)
- ★ Looking for transient sources on various timescales (ms to y)
- ★ Follow-up of new sources in other waveband (25-30% are unidentified)
- ★ Overall analysis of all the sources: Spectra, timing, states

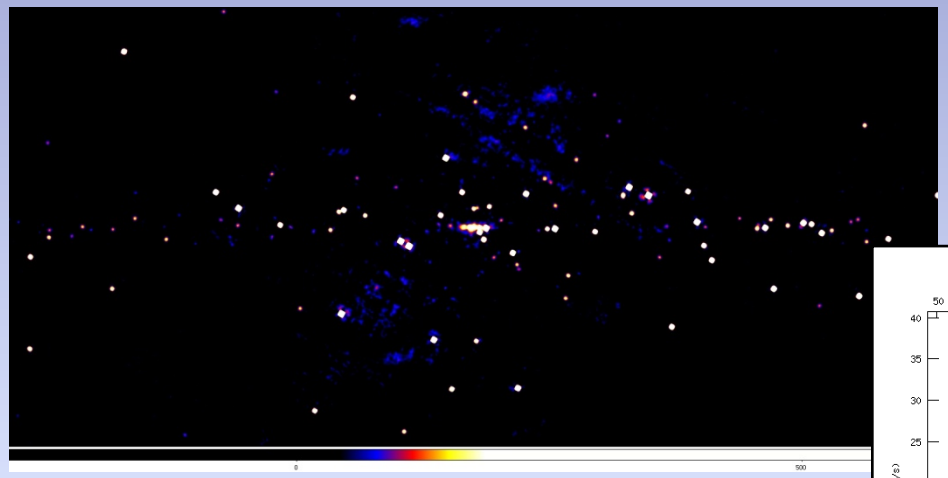
INTEGRAL Legacy: EXPOSURE TIME



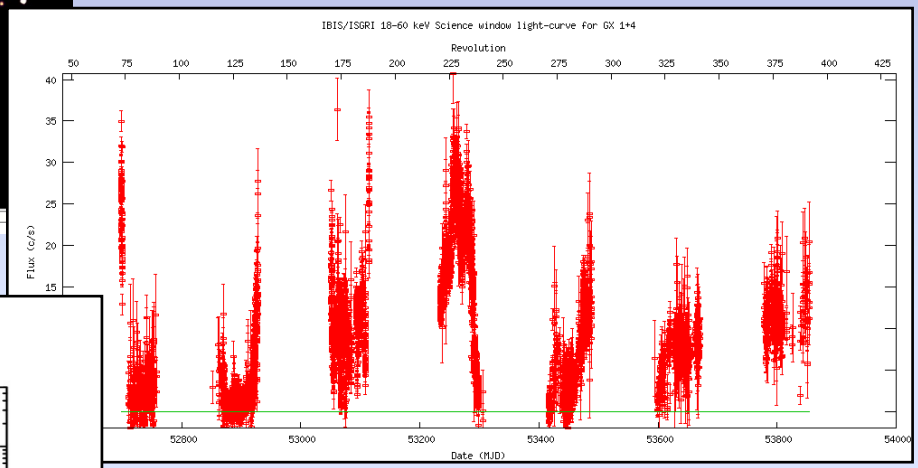
The Cat4 sources: the deepest picture of the soft gamma ray sly

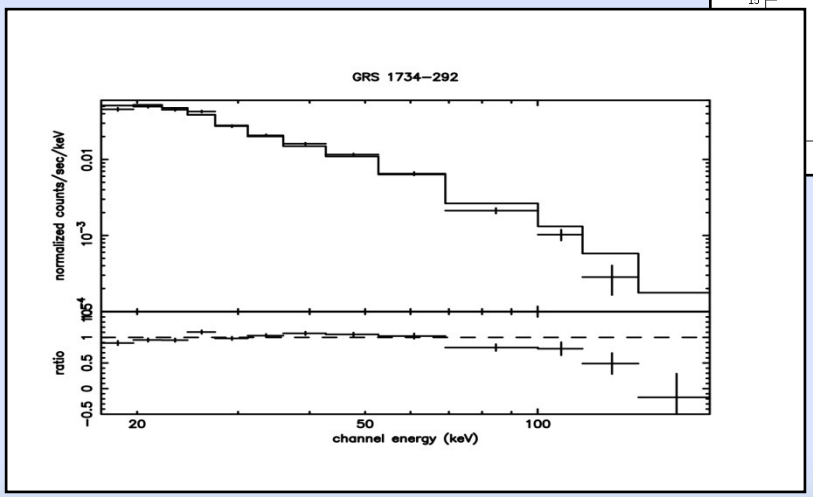


IBIS STANDARD Survey products and Legacy



images from (cat 4:746) maps





light curve

spectrum

for every source

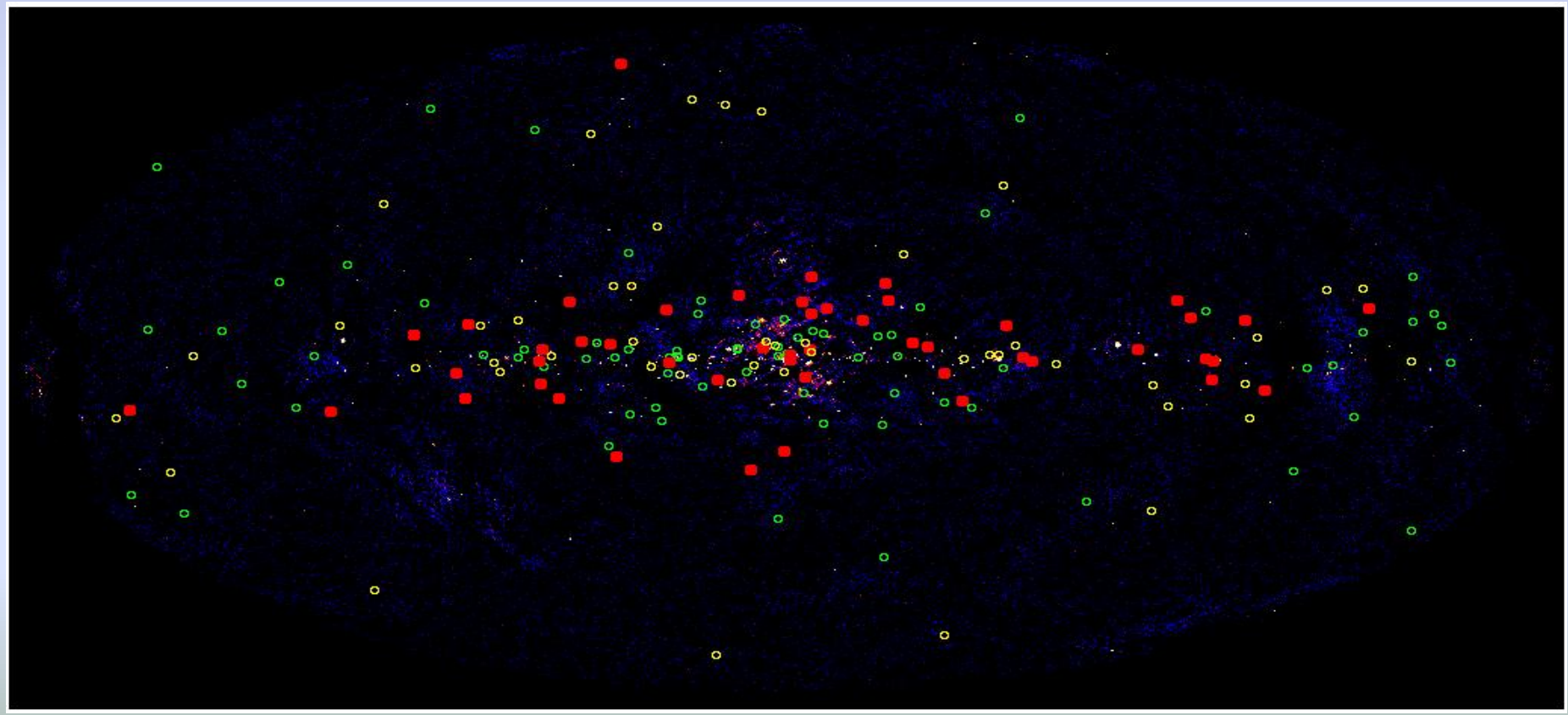
IGRs/unknown transients in the IBIS latest Cat

378 INTEGRAL sources, IGRs, accounting for 50% of the total in 2009

262 IGR now identified (not in cat4)

68% are transient and strongly variable sources

- 49 Bursticity > 4
- 76 Bursticity > 1.2
- 48 Bursticity < 1.2



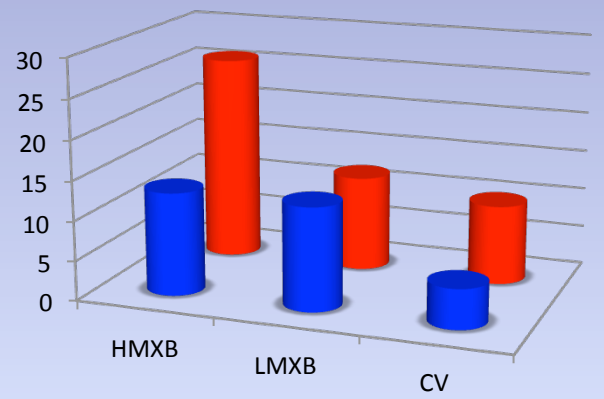
Status of the IGRs source identification process

378 IGR

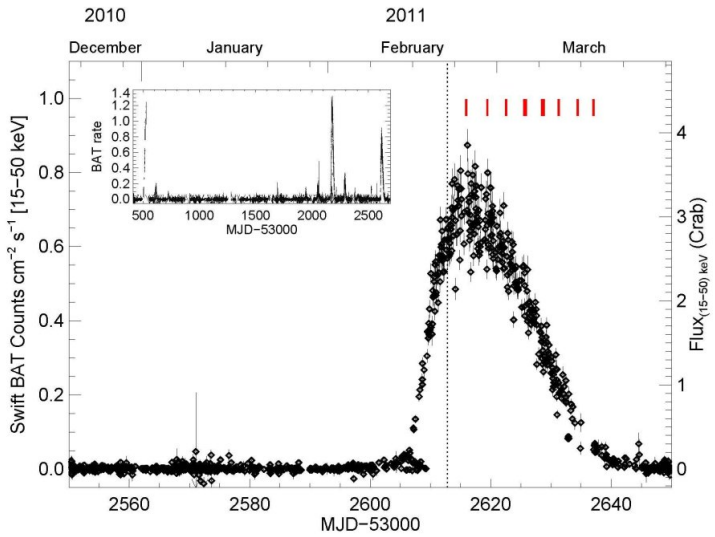
- 236 identified
  - 142 AGN
  - 48 HMXB
  - 20 LMXB
  - 21 CV
  - Others
- 142 unidentified
  - 78% high bursticity
  - 22% persistent

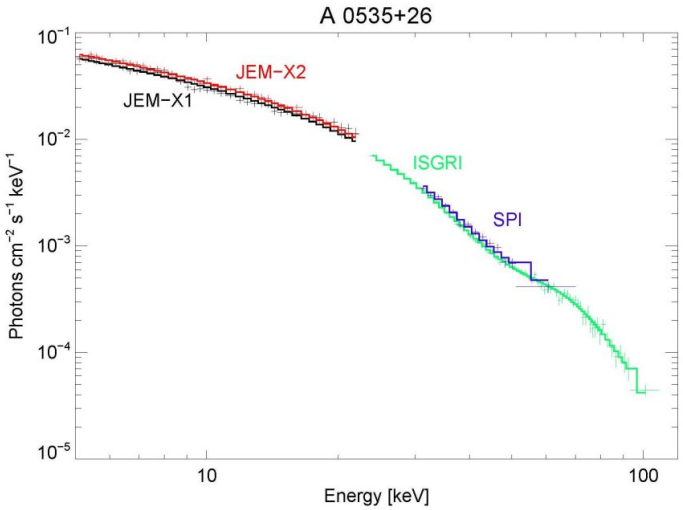
…. XRT follow-up campaign is still on going …

New identifications
Cat4 identifications



INTEGRAL on Galactic X-ray Binaries: Neutron Stars: cyclotron line are visible again!



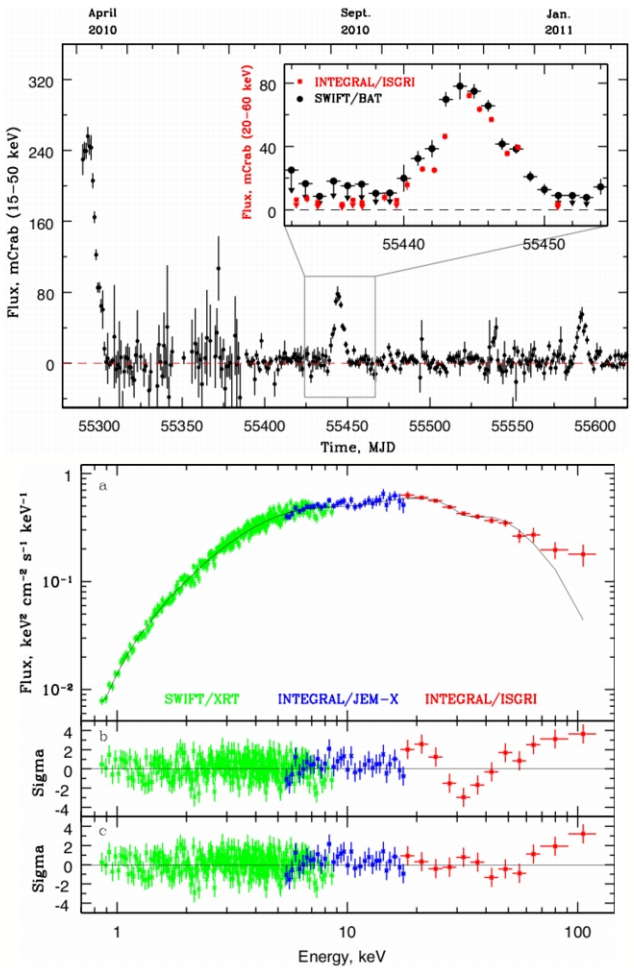


After 2 attemps in 2011 INTEGRAL finally caught a 3.8 Crab outburst from A0535+26

Figure refers to this outburst. In the top panel the Swift/ BAT light curve during the outburst is reported, with red ticks indicating the times of the INTEGRAL observations. The vertical dotted line indicates the time of periastron. The insert shows the long term Swift BAT light curve, including the past 2005 and 2009 giant outbursts. Weaker normal outbursts in 2005, 2009 and 2010, also observed by INTEGRAL, are also visible.

The INTEGRAL broad-band photon spectrum of the source during one of the observations of the 2011 outburst is shown in the bottom panel. Flux corresponds to ~0.47 Crab (15-50 keV range) and the fundamental cyclotron line is observed at E=45.7 ± 0.7 keV. Caballero I. et al, in preparation.

INTEGRAL on Galactic X-ray Binaries: Neutron Stars



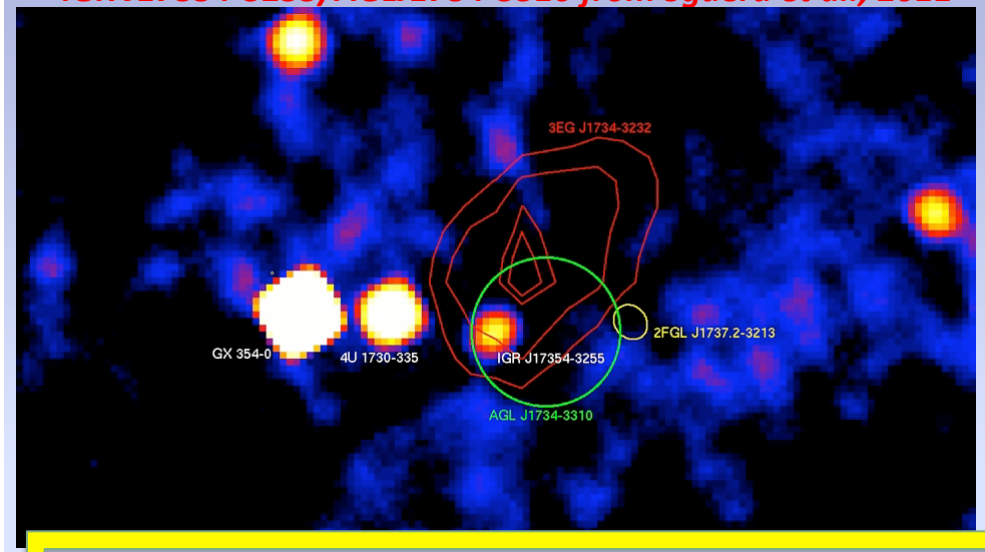
RX J0440.9+4431, known as persistent low-luminosity binary with Be companion harboring a slowly rotating neutron star (pulse period ~202.5 s).

In March 2010 the MAXI all-sky monitor reported the first evidence of the pulsar outburst activity. During a new outburst, in September 2010, INTEGRAL was used to investigate the properties of RXJ0440.9+4431 in hard X-rays for the first time. Spectral analysis of data obtained with INTEGRAL during the 2010 September outburst revealed a ~32 keV cyclotron resonant scattering feature in the source spectrum, that allowed to estimate the magnetic field strength of the neutron star as $B = 3.2 \times 10^{12}$ G . It makes RX J0440.9+4431 only the second persistent Be/XRP system (after X Persei) with known magnetic field strength and orbital period (155 d) as derived from the 3 outbursts.

In the figure the top panel shows the light-curves obtained by Swift (black) and INTEGRAL (red) while in the bottom panel the composite spectrum is shown using (a) data from Swift (green), INTEGRAL/JEM-X (blue) and INTEGRAL/IBIS(red). The residuals to the fit are shown without (b) and with (c) a 32 keV cyclotron absorption line (S. Tsygankov et al, in press).

INTEGRAL new discoveries:
SFXTs & their possible association to MeV transient

IGR J17354-3255/AGLJ1734-3310 from Sguera et al., 2011



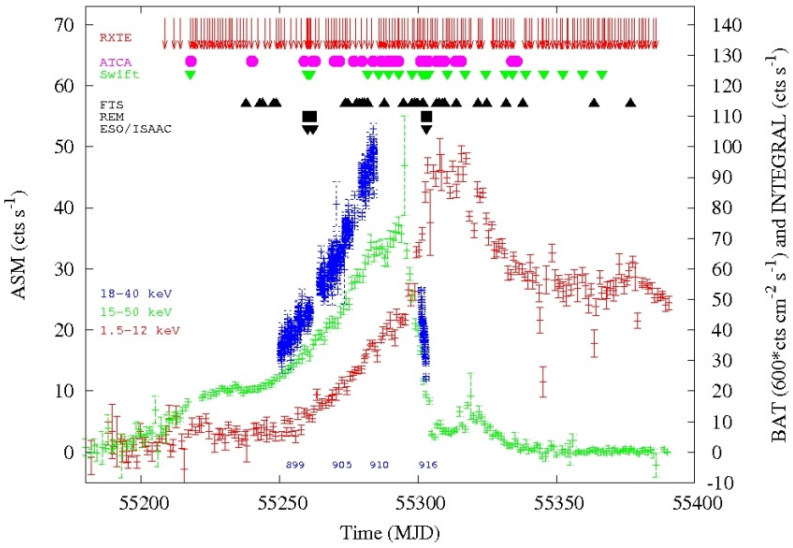
Fermi & AGILE are detecting several similar unidentified MeV transients on the Galactic plane. Identification of their counterparts is a very challenging task: *INTEGRAL* results on possible associations between unidentified transient MeV sources and SFXTs are:

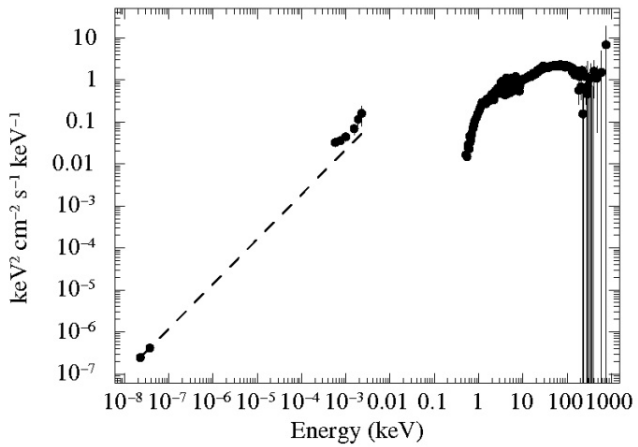
AX J1841.0-0536 /3EG J1837-0423
IGR J11215-5952 /EGR J1122-5946
IGR J20188+3657/ AGL J2022+3622
and
IGR J17354-3255 / AGL J1734-3310

IGR J17354-3255: outbursts duration, high dynamic range, orbital period, strong variability on short timescale, X-ray luminosity suggest that is an intermediate SFXT. It is spatially correlated with the transient unidentified MeV source AGL J1734-3310 discovered by AGILE on 14 April 2009.
Extensive and systematic search for transient gamma-ray emission revelead 10 fast gamma-ray flares with typical duration 1-2 days at significance detection in the range 3σ - 5σ leading to a 7σ detection centered at l = 355.805 and b = -0.26 error circle radius of 0°.46 (Bulgarelli et al, in preparation) .

In figure the IBIS/ISGRI deep mosaic significance image (~ 10 Ms, 18-60 keV) is showed with other possible counterparts. The probability of an association by chance between IBIS/AGILE is ~ 1%;
3EG J1734-3232: variable and persistent with average flux very similar to AGL J1734-3310
2FGL J1737.2-2312: NON variable and persistent (possibly associated with SNR or PWN),with average flux one order of magnitude lower than that of AGL J1734-3310/3EG J1734-3232

INTEGRAL on Galactic X-ray Binaries: Black Holes





On January 3, 2010, GX 339-4 entered a new outburst followed with INTEGARL during the initial and declining hard X-ray phases. The most comprehensive collection of simultaneous multi-wavelength data collected so far during an outburst of GX 339-4 was obtained.

On the top panel the high-energy data from RXTE/ASM (red), Swift/BAT (green) and INTEGRAL/ISGRI (blue) observations of GX 339-4 are shown with also observation timelines from ATCA, Faulkes South, REM/ROSS, REMIR and ESO/ISAAC telescopes.

On bottom panel the spectral energy distribution from radio to soft gamma-rays at around 2010 March 4-6 (~ MJD 55260) is shown. Clear evolutions in the disc and hot medium components were seen; the relative flux and contribution of the latter decreased on average.

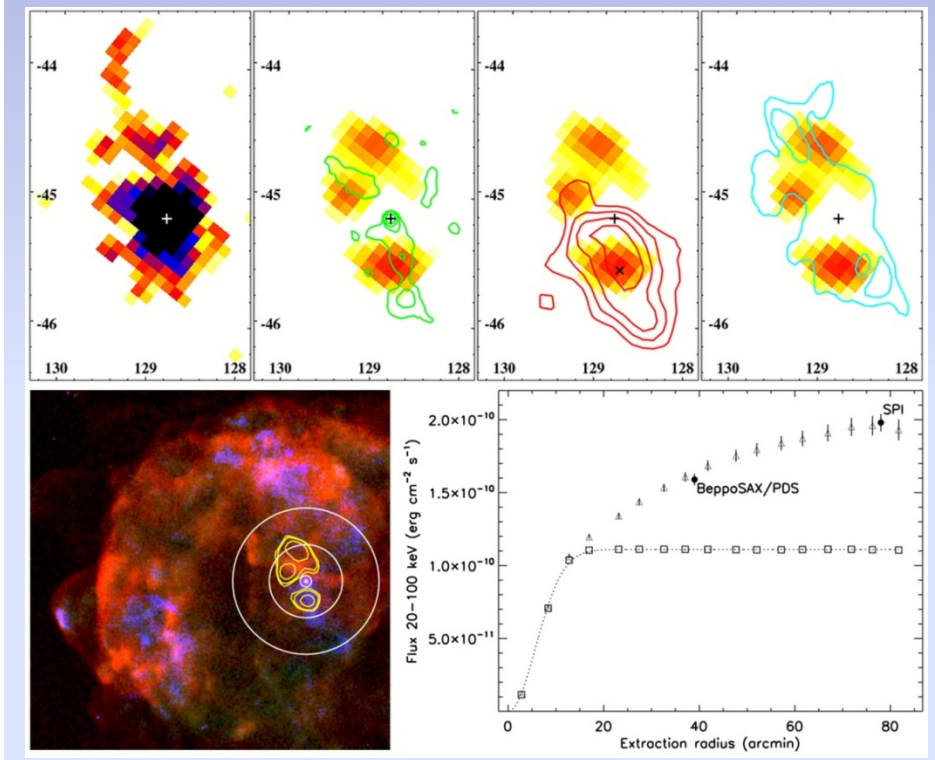
For the first time, a jet being quenched in many wavebands has been observed, after it had been bright and powerful before as observed in the radio, near-infrared and optical. Variations are observed on various time scales, down to at least 11 sec possibly related to the varying size of the acceleration zone above the jet base, or to the magnetic field (M. Cadolle Bel et al., A&A 534, A119, 2011)

New insight on Cyg X-1 will be presented by A. Zdziarski

INTEGRAL on PULSAR WIND NEBULAE

***INTEGRAL* discovery of extended emission above 18 keV from the Vela nebula.**

F. Mattana et al.ApJ 743, L18 (2011)

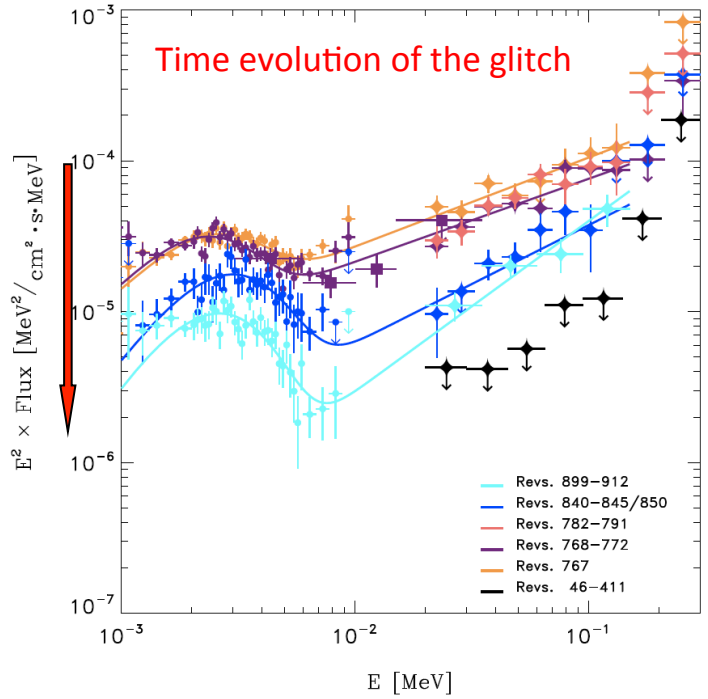


In the IBIS/ISGRI significance map at 18-40 keV (top panel) an extended emission is visible beyond the bright point-like source (black pixels in left panel), which encompasses the inner structured PWN resolved by Chandra and the pulsar. After subtraction of the point-like source, the northern side appears larger and more significant than the southern one, which is in turn partially coincident with the cocoon detected by ROSAT in the soft X-ray band (green contours) and by H.E.S.S. at very high-energy gamma-rays above 1 TeV (red contours). The morphology of the whole extended emission also matches the one found by the Birmingham Spacelab 2 telescope in 2.5-10 keV (cyan contours). The IBIS/ISGRI flux integrated in concentric circles centered on the pulsar at increasing radii recovers the BeppoSAX/PDS and SPI fluxes at radii comparable with their PSFs (bottom-right panel, ISGRI flux data = triangles)

Broadband modeling implies a magnetic field higher than 10 μG in this region. The nature of the northern emission might be due to fresh particles injected after the passage of the reverse shock.

INTEGRAL on MAGNETARS

Recently, INTEGRAL has been able to study in great detail the evolution of the temporal and spectral characteristics of the persistent ***total*** and ***pulsed*** emission of 1E1547.0-5408 between ~1 and 300 keV from October 2008 to January 2011, **Kuiper et al., 2012**.



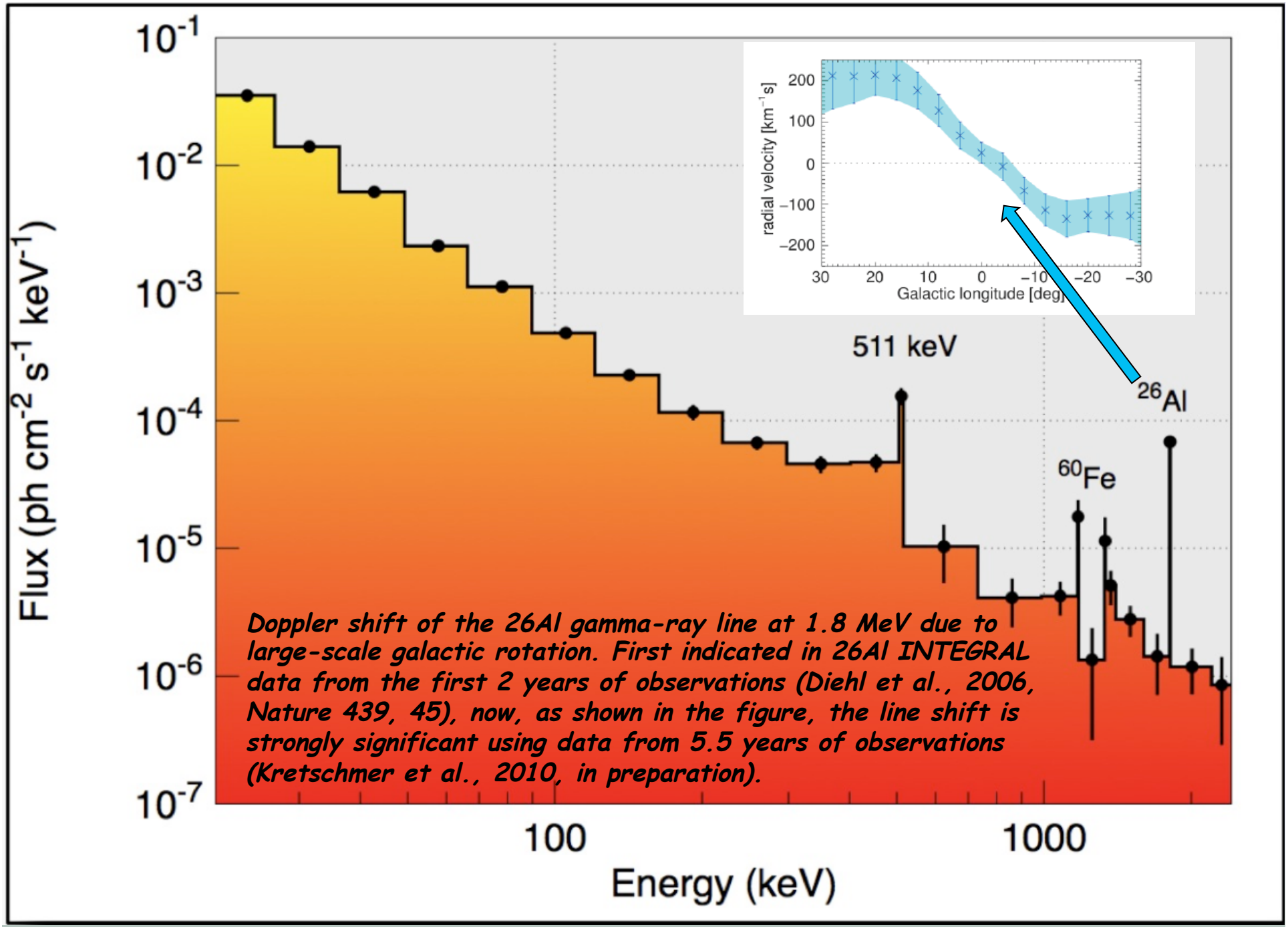
From Kuiper L. et al., 2012

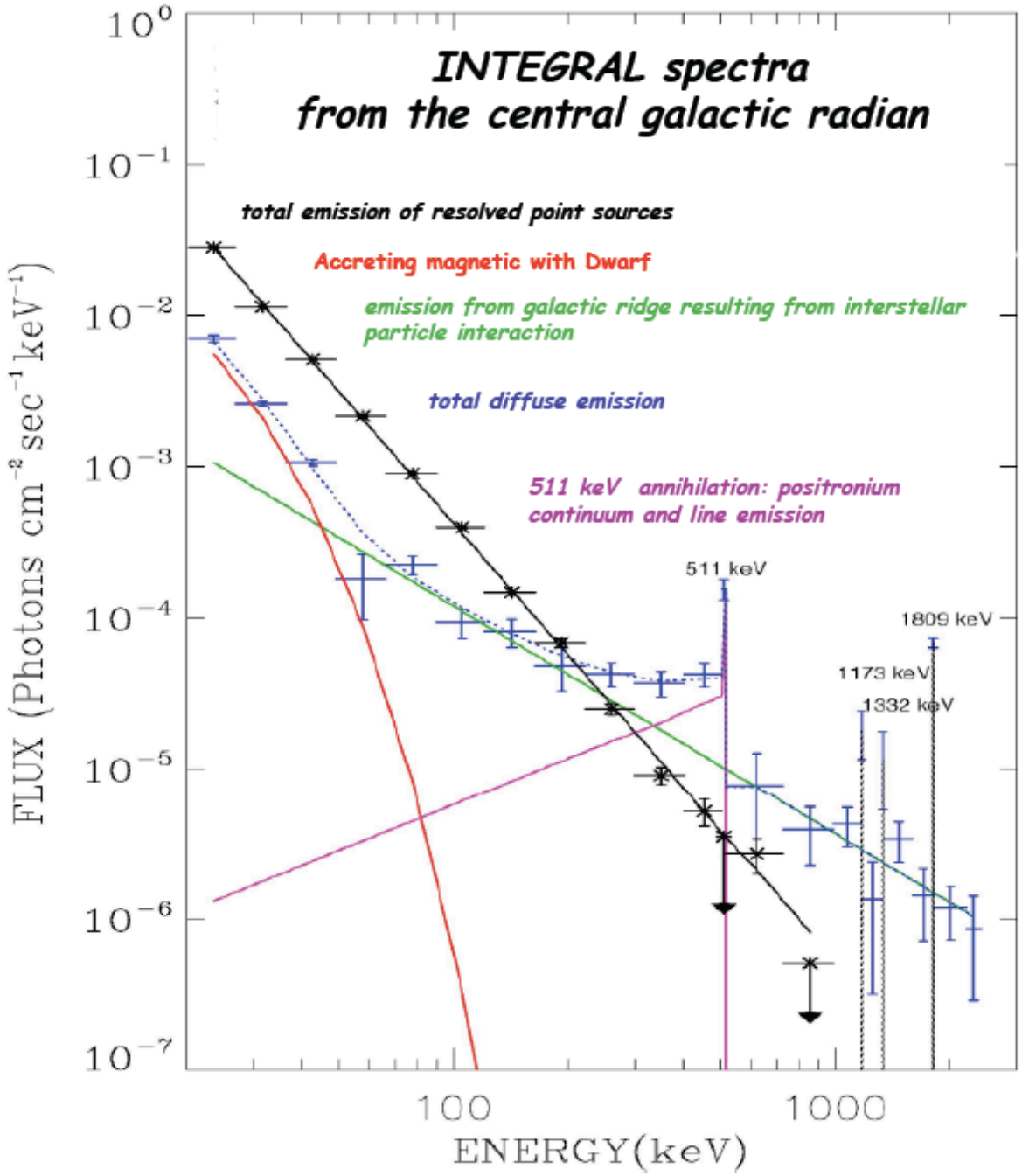
Pulsed emission: **for energies 2.5-10 keV all pulsed spectra are very soft (Γ -4.6—3.9) while for energies 10-150 keV , after a major frequency derivative jump, hard non-thermal spectra similar to the ones for AXPs is detected. The pulsed hard X-ray emission was at maximum after 70±30 days after the glitch followed by gradual decrease by a factor of 10 over 300 days.**

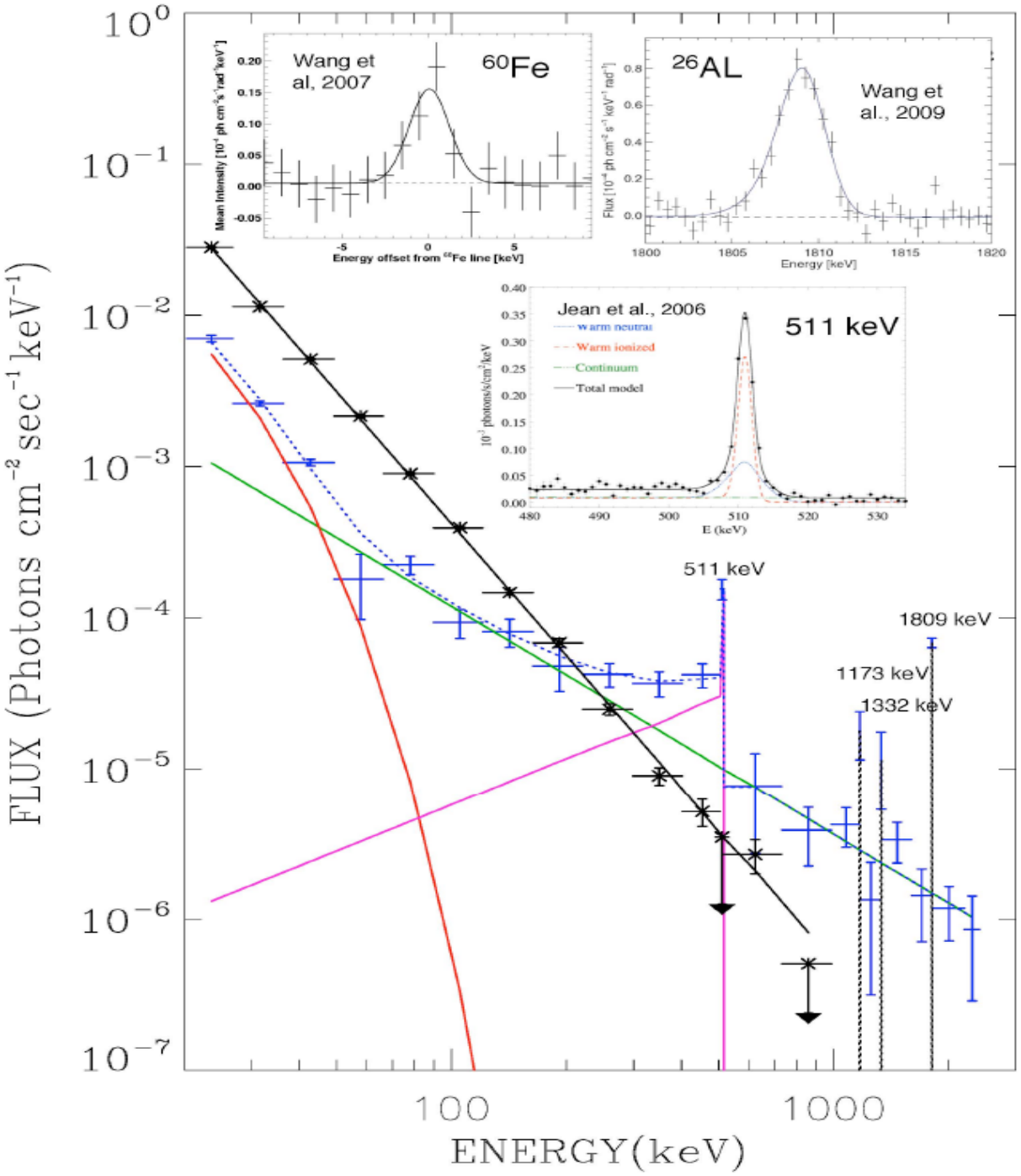
Total emission: **Both the soft and hard X-ray were maximal already 2 days after the the outburst, decayed by a factor > 3 over 400 days. The total spectra can be described with a balck-body (kT values 0.57-0.74) plus a single power-law model with Γ exhibiting a hardening from -1.4 to -0.9 with time that is correlated with a decresing flux in the 20-300 keV band.**

The measured timing glitch is the most extreme istantaneous frequency derivative jump detected so far.

Many similarity with X & hard X characteristic of AXPs, however for 1E 1547.0-5408 it is a transient variable phenomenon both above and below 10 keV while the non-thermal persistent emission of AXP appeared stable within the statistical errors of 20% over more than 10 years.


Flux (ph cm^{-2} s^{-1} keV^{-1})
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
100
1000
Energy (keV)
511 keV
^{26}Al
^{60}Fe
radial velocity [km^{-1} s]
200
100
0
−100
−200
30
20
10
0
−10
−20
−30
Galactic longitude [deg]
Doppler shift of the 26Al gamma-ray line at 1.8 MeV due to large-scale galactic rotation. First indicated in 26Al INTEGRAL data from the first 2 years of observations (Diehl et al., 2006, Nature 439, 45), now, as shown in the figure, the line shift is strongly significant using data from 5.5 years of observations (Kretschmer et al., 2010, in preparation).

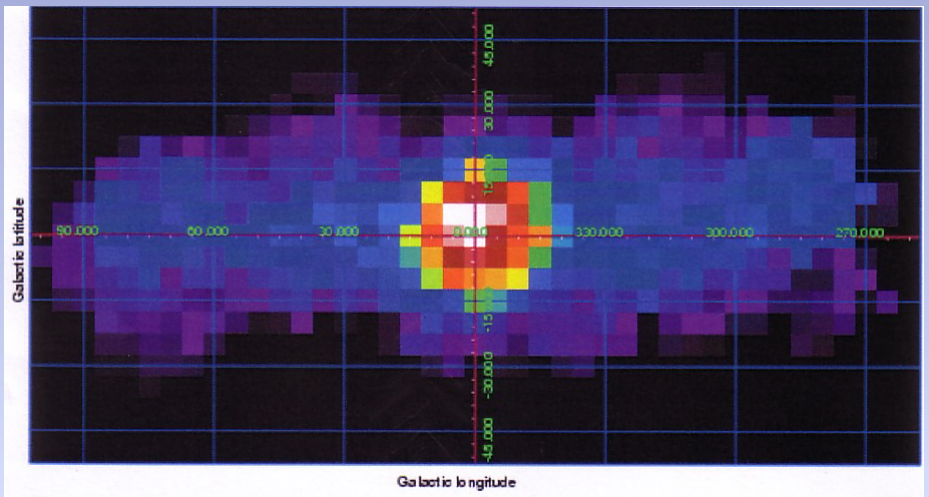

INTEGRAL spectra
from the central galactic radian
total emission of resolved point sources
Accreting magnetic with Dwarf
emission from galactic ridge resulting from interstellar particle interaction
total diffuse emission
511 keV annihilation: positronium continuum and line emission
511 keV
1809 keV
1173 keV
1332 keV
FLUX (Photons cm⁻² sec⁻¹ keV⁻¹)
ENERGY(keV)
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
100
1000



Inserts show the fine spectroscopy analysis of selected lines (from Jean et al., 2006, A&A 445, 579; Wang et al., 2007, A&A 469, 1005; Wang et al., 2009, A&A 496, 713)

Galactic Bulge 511 keV emission

Bouchet L. et al., 2010



Detection of the 511 keV positron annihilation line emission from the Galactic centre region was one of the main objective of the INTEGRAL Mission as one of the early important success of Gamma-ray Astronomy. To this aim the SPI instrument took advantage of the long exposure time of the Bulge to refine the morphology and to possibly unveil the origin of the Galactic positron. On the left the SPI smoothed 50.25-513.75 significance map as from Bouchet et al., 2010 while below the most recent result making use of data from 2003 to 2009.

Summary of results

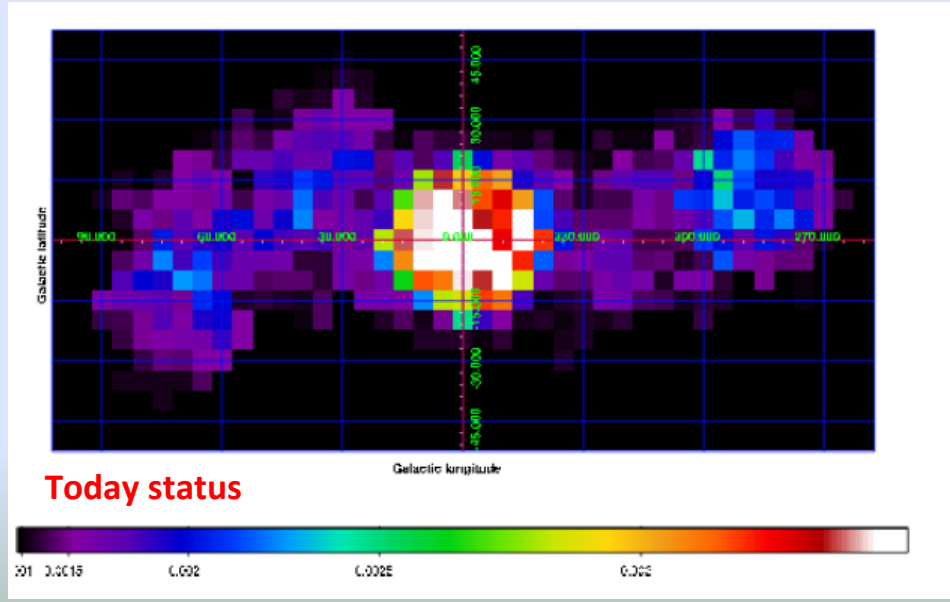
-511 keV emission is detected at 70σ towards the Galactic bulge and at 25σ from the Galactic disk

-no evidence of point-like source in addition to diffuse emission

-extended disk distribution suggesting old stellar population as main Galctic positron source favoured among disk geometries

-the hypothesis of disk asymmetry reported in 2008 by Weidenspointer is not supported

-the Bulge emission appears spherically symmetric around the G.C. with an extension of 12° with its centre shfted towards l= -0.64± 0.20°



Bouchet L. et al., 2011

Diffuse Emission

Hard X-ray emission from the Galactic Ridge is know since 1972 and subsequently observed from keV to MeV energies. Previous INTEGRAL data up to 100 keV showed that about 80% of the total emission from the inner Galaxy is due to point sources while the associated diffuse emission is 1/10 and dominate above 300 keV (Lebrun et al., Nature, 2004).

New results on 6 years of data collected by SPI (Bouchet et al., 2012) in the range 20 keV 2.4 MeV show the diffuse emission as due to superposition of several different processes and summarized as:

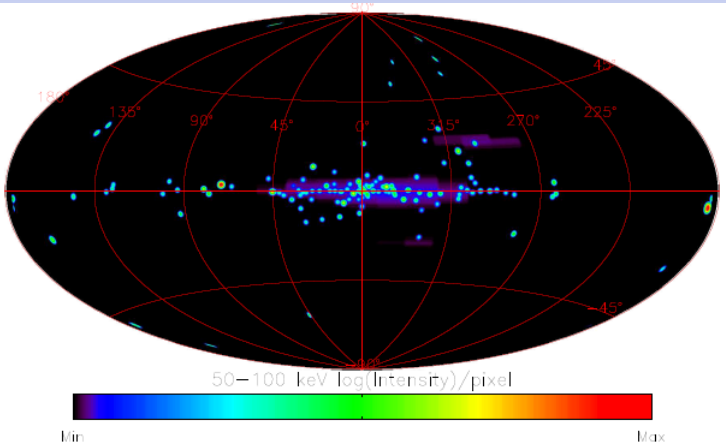


Fig. 2.— 50–100 keV intensity sky map including both sources and diffuse emission. The diffuse part of the image has pixels of different size and is first downsampled to a common pixel size of $3° \times 2.6°$, thereafter the image is smoothed by a 3×3 pixels boxcar.

Diffuse emission in the centaral radian is estimated as 1/10 of the total below 100 keV and 1/3 in the 100-300 keV band

Spectral components:

Diffuse continuum spectrum fittted by power law, Γ=1.4-1.5

Decomposed in 2 spatial components: Inverse Compton with Γ=1.8, and another weak component with Γ=1.0

The diffuse continuum flux at 1 MeV is consistent with old COMPTEL measurement

An additional component is required below 50 keV that is modeleld with the NIR/DIRBE 4.9 μm map and interpreted in terms of the stellar origin as previously proposed by Krivonos (2007) .

Complementarity with the Fermi data has been discussed by Strong and the new available data will allow for unambiguous decomposition of the diffuse Gamma ray sky

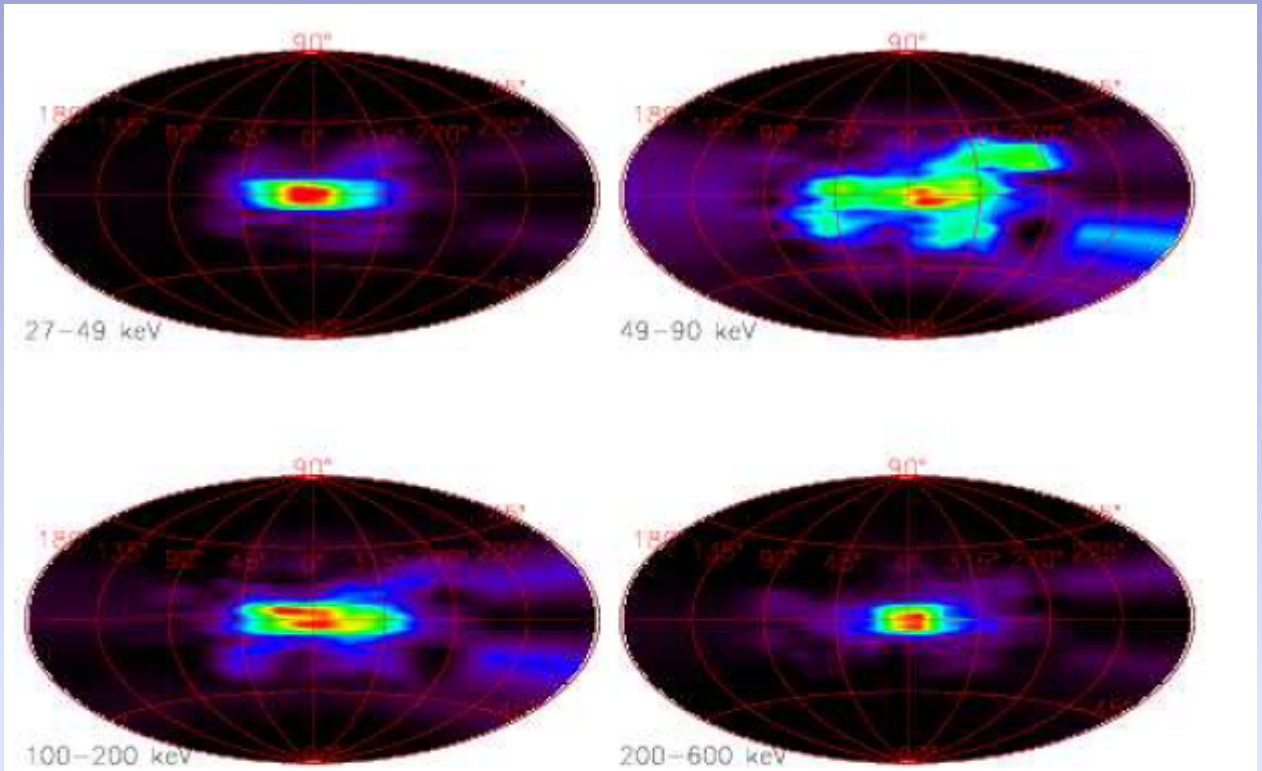


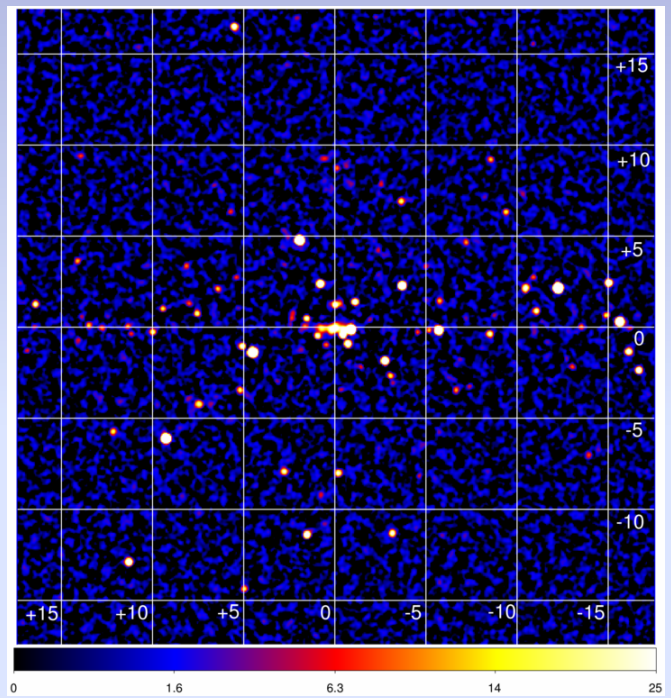
Fig. 3.— "Diffuse" emission intensity all sky maps. The energy bands are (top-left) 27–49 keV, (top-right) 49–90 keV, (bottom-left) 100–200 keV and (bottom-right) 200–600 keV. The original images have pixels of different size and are first downsampled to a common pixel size of $3° \times 2.6°$, thereafter they are smoothed by a 3×3 pixels boxcar. The "Diffuse" emission energy is minimum in the 50–100 keV band. The color intensity is the same as in Fig. 2.

Point Sources Contribution:

25- 50 keV= 254
50- 100 keV=123
100- 200 keV= 53
200- 600 keV= 26
600-1800 keV= 4

MOST RECENT Galactic Hard X-survey

Krivonos et al., 2012, submitted



35-80 keV map of the region around Galactic Centre corresponding to 26Ms

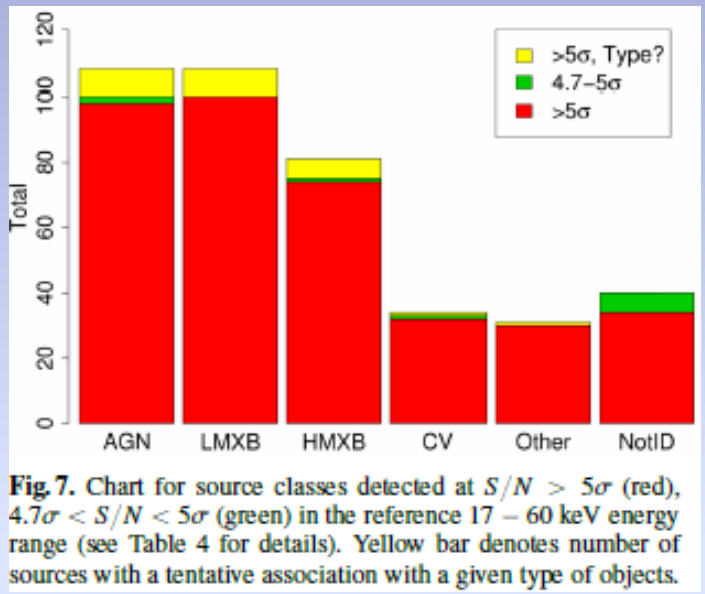
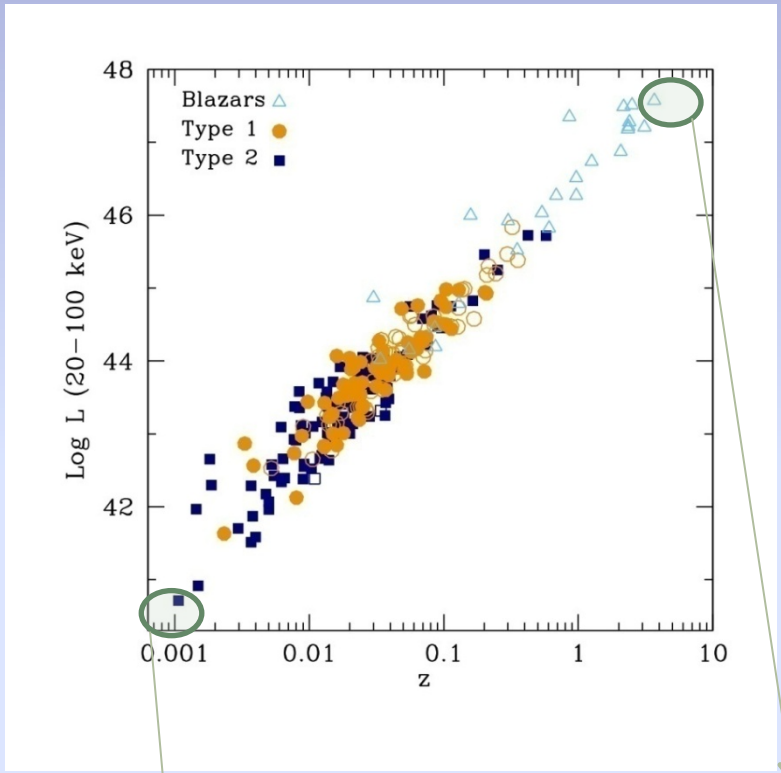


Fig. 7. Chart for source classes detected at $S/N > 5\sigma$ (red), $4.7\sigma < S/N < 5\sigma$ (green) in the reference $17 - 60$ keV energy range (see Table 4 for details). Yellow bar denotes number of sources with a tentative association with a given type of objects.

Selected 9 year averaged sky images,sensitivity maps and catalogue of detected sources in the Galactic Plane (|b|< 17.5° in 3 energy bands are presented. As a results there are ~40 new IGRs sources compared to the ones reported so far either in other catalogues or in most recent Atels. These 40 sources are: 8 AGNs, 8 Binaries , 1 Psr e 2 Stars besides 20 not identified.

The peak sensitivity of the survey is 3.3 x 10^{-12} erg s^{-1} corresponding to 0.23 mCrab in the 17-60 kev at a 5σ detection level.

INTEGRAL view of the EXTRAGALACTIC SKY:
the latest AGN catalogue



IGR J22517+2218 z=3.7
Log L=47.7, M 10^9 M_0

NGC4395 z=0.001
Log L=40.7, M~ 4×10^5 M_0

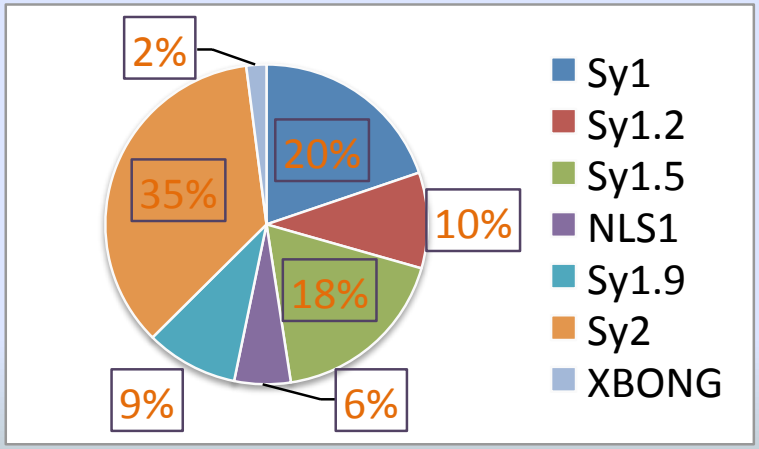
272 AGN

with complete optical & X-ray data
(Malizia et al. 2012)

4th IBIS catalogue
(Bird et al. 2010)

+

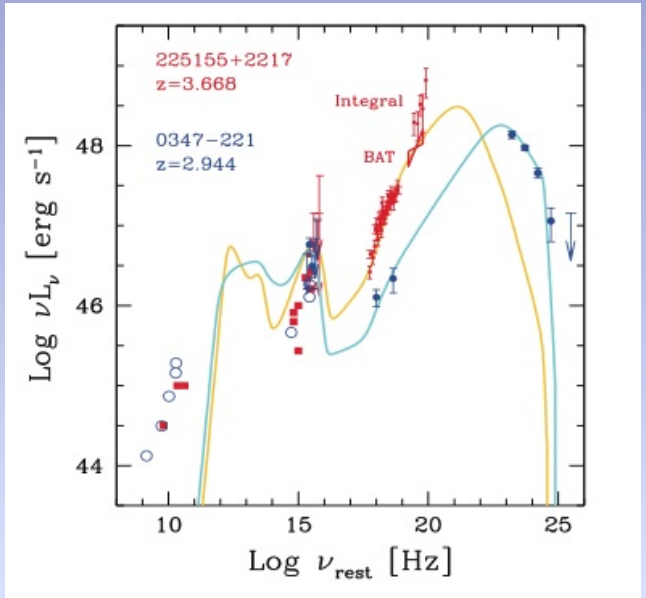
All-Sky Hard X-ray Survey
(Krivonos et al. 2010 +updates)



INTEGRAL finds EARLY and HEAVY black holes blazars

In very powerful FSRQs
the hard X–ray flux is close to the
emission peak
(Ghisellini et al. 2011)

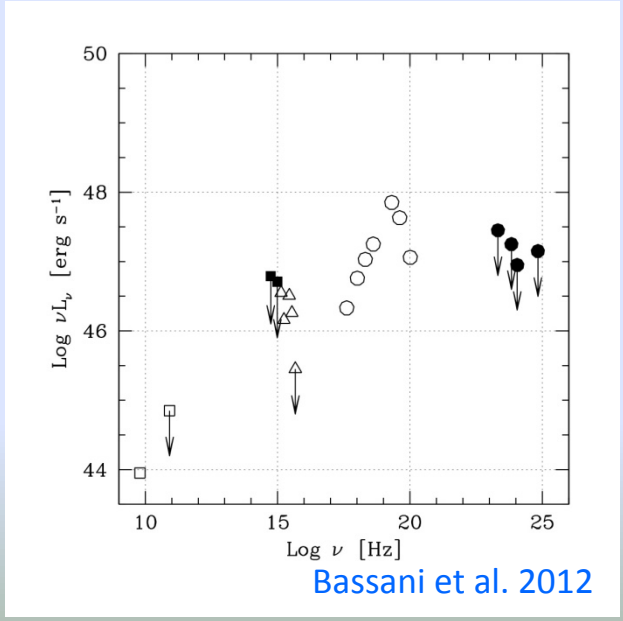
--> hard X–rays carry a very
significant fraction of the jet luminosity,
making them visible and detectable at
very high redshift



Most powerful jets!

INTEGRAL high redshift blazars:

Swift J0218.0+7348	*z*=2.367
PKS 0528+134	*z*=2.060
QSO J0539-2839	***z*=3.104**
QSO B0836+710	*z*=2.172
Swift J1656.3-3302	*z*=2.400
PKS 1830-211	*z*= 2.507
PKS 2149-306	*z*= 2.345
IGR J22517+2218	***z*=3.668**
IGR J12319-0749	***z*= 3.12**



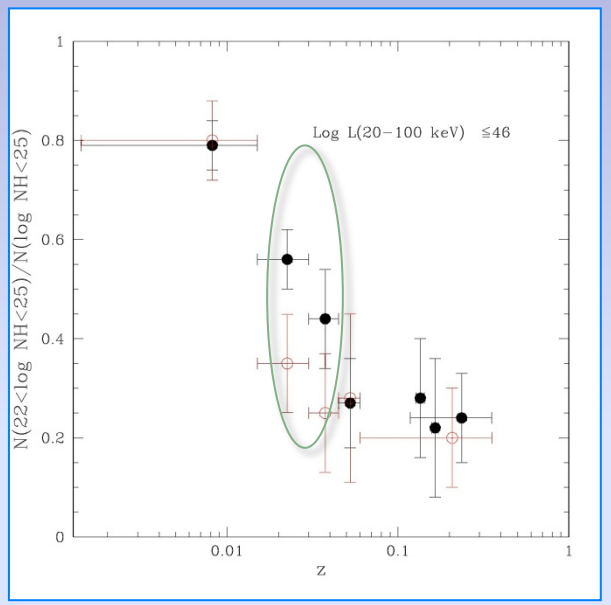
Bassani et al. 2012

New results

(Malizia et al. 2012)

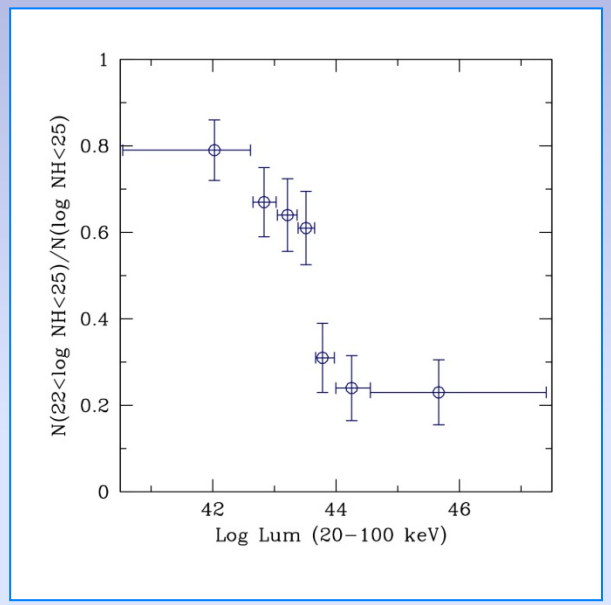
The fraction of absorbed sources

as a function of redshift



red points: cat3 Complete Sample
black points: cat4 extended AGN sample of 272 objects ⇨ as expected going deeper the fraction of absorbed AGN increases in the second bin while is unchanged in the first (z<0.015)

as a function of hard X-ray luminosity

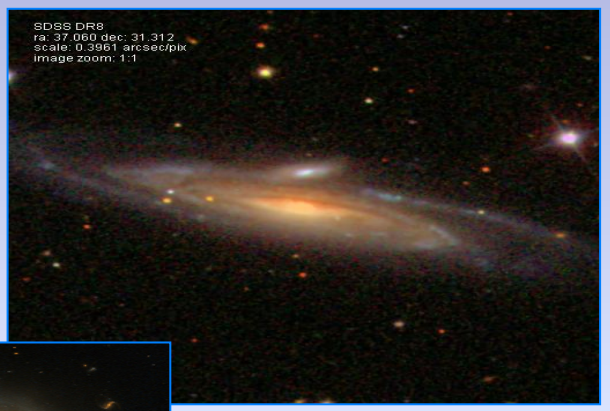


INTEGRAL confirms the decrease of the fraction of absorbed AGN with Luminosity

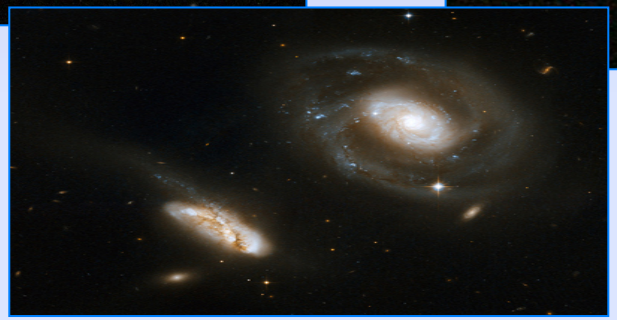
FUTURE WORK: HXLF TAKING INTO ACCOUNT THE N_H DISTRIBUTION

Galaxy interaction & merging:
a few examples from the INTEGRAL AGN catalogue

NGC 2992

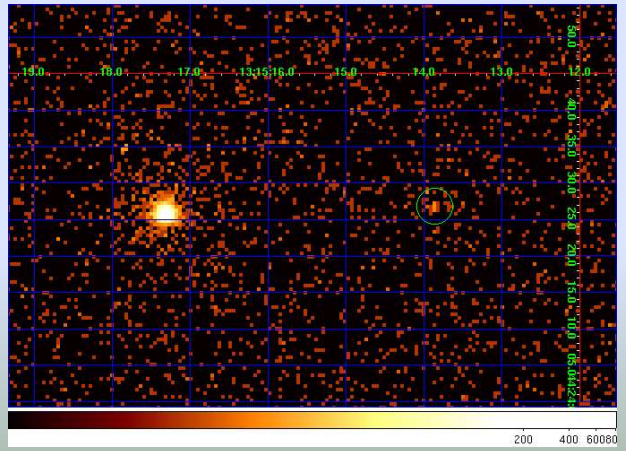


Mrk 1040



NGC 7469

UGC08327



--> not all of them have double active nucleus..
Interactions do Not means High Energies..

Thanks for your attention