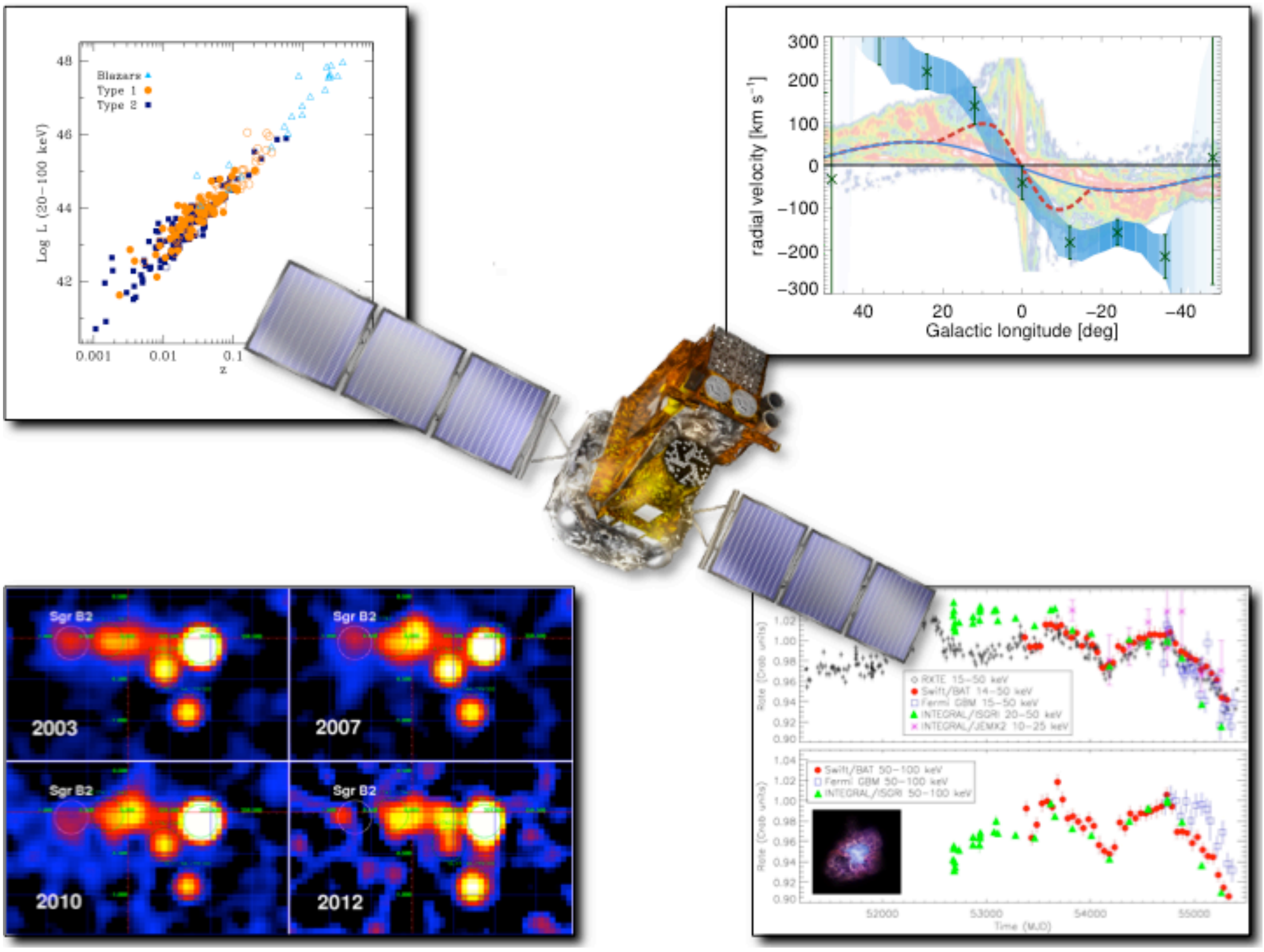
INTEGRAL

The International Gamma-Ray Astrophysics Laboratory

Mission Extension 2012: INTEGRAL Science Case

Appendix A



Compiled by the INTEGRAL Users Group

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References

(A) Gamma-ray lines from nucleosynthesis in supernovae and novae, and from e± annihilation

[C11] Churazov, E. et al.: Positron annihilation spectrum from the Galactic Centre region observed by SPI/INTEGRAL revisited: annihilation in a cooling ISM? MNRAS 411, 1727, 2011

[Da06] Darnley, M. et al.: Classical novae from the POINT-AGAPE microlensing survey of M31 - II. Rate and statistical characteristics of the nova population. MNRAS 369, 257, 2006

[D06] Diehl, R. et al.: Radioactive ^{26}Al from massive stars in the Galaxy. Nature 439, 45, 2006

[G12] Grebenev, S. et al: Hard X-ray emission lines from the decay of ^{44}Ti in the remnant of Supernova 1987A. Nature, in press, 2012

[H04] Hernanz, M. & José, J.: Gamma-rays from classical novae: expectations from present and future missions. New AR 48, 35, 2004

[I11] Isern, J. et al.: Bounds to the gamma--ray flux emitted by SN 2011fe before the maximum of light as obtained by INTEGRAL/SPI. ATel 3683, 2011

[I12] Isern, J. et al.: Observation of SN 2011fe with INTEGRAL. I. Pre-maximum phase. A&A, to be submitted, 2012

[K05] Knödlseder, J. et al: The all-sky distribution of 511 keV electron-positron annihilation emission. A&A 411, 513, 2005

[K12] Kretschmer, K.: A&A, to be submitted, 2012 (based on PhD Thesis, TU München, 2011)

[L12] Lennarz, D. et al.: A unified supernova catalogue. A&A 538, A120, 2012

[M10] Martin, P. et al.: Predicted gamma-ray line emission from the Cyg complex. A&A 511, A86, 2010

[P11] Prantzos, N. et al.: The 511 keV emission from positron annihilation in the Galaxy. Rev Modern Physics 83, 1001, 2011

[R06] Renaud, M. et al.: The Signature of ^{44}Ti in Cassiopeia A Revealed by IBIS/ ISGRI on INTEGRAL. ApJ 647, L41, 2006

[V12] Voss, R. et al.: Energetic feedback and ^{26}Al from massive stars and their supernovae in the Carina region. A&A 539, A36, 2012

[W07] Wang, W. et al.: SPI observations of the diffuse ^{60}Fe emission in the Galaxy. A&A 469, 1005, 2007

[W08] Weidenspointner, G. et al.: An asymmetric distribution of positrons in the Galactic disk revealed by gamma-rays. Nature 451, 159, 2008

(B) Emission mechanisms in white dwarfs, neutron stars, and stellar black holes

[B12] Becker, P. et al.: Spectral Formation in Accreting X-Ray Pulsars: Bimodal Variation of the Cyclotron Energy with Luminosity. A&A in press, arXiv: 1205.5316, 2012

[B09] Beloborodov, A.: Untwisting Magnetospheres of Neutron Stars. ApJ 703, 1044, 2009

[B10] Beloborodov, A.: Overview of theory of magnetars and their transient behaviour. Proc. 38th COSPAR Scientific Assembly, Symp. E, session 16, #E16-0011-10, 2010

[B11] Bouchet, L. et al.: Diffuse Emission Measurement with the SPectrometer on INTEGRAL as an Indirect Probe of Cosmic-Ray Electrons and Positrons. ApJ 739, 29, 2011

[Bu12] Burkert, A. et al.: Physics of the Galactic Center Cloud G2, on Its Way toward the Supermassive Black Hole. ApJ 750, 58, 2012

[C03] Courvoisier, T. et al.: IGR J16318-4848. IAUC 8063, 2003

[G12] Gillessen, S. et al.: A gas cloud on its way towards the supermassive black hole at the Galactic Centre. Nature 481, 51, 2012

[J12] Jourdain, E. et al.: The Emission of Cygnus X-1: Observations with INTEGRAL SPI from 20 keV to 2 MeV. ApJ 744, 64, 2012

[K12] Klochkov, D. et al.: Outburst of GX 304-1 monitored with INTEGRAL: positive correlation between the cyclotron line energy and flux. A&A 542, 28, 2012

[Kr07] Krivonos, R. et al.: Hard X-ray emission from the Galactic ridge. A&A 463, 957, 2007

[Kr10] Krivonos, R. et al.: INTEGRAL/IBIS 7-year All-Sky Hard X-ray Survey. I. Image reconstruction. A&A 519, 107, 2010

[Kr12] Krivonos, R. et al.: INTEGRAL constraints on the Galactic hard X-ray background from the Milky Way anticenter. A&A 537, 92, 2012

[Ku06] Kuiper, L. et al.: Discovery of Luminous Pulsed Hard X-Ray Emission from Anomalous X-Ray Pulsars 1RXS J1708-4009, 4U 0142+61, and 1E 2259+586 by INTEGRAL and RXTE. ApJ 645, 556, 2006

[Ku12] Kuiper, L. et al.: Temporal and Spectral Evolution in X- and γ-Rays of Magnetar 1E 1547.0-5408 since its 2008 October Outburst: The Discovery of a Transient Hard Pulsed Component after its 2009 January Outburst. ApJ 748, 133, 2012

[L11] Laurent, P. et al.: Polarized Gamma-Ray Emission from the Galactic Black Hole Cygnus X-1. Science 332, 438, 2011

(B) Emission mechanisms in white dwarfs, neutron stars, and stellar black holes (continued)

[L04] Lebrun, F. et al.: Compact sources as the origin of the soft gamma-ray emission of the Milky Way. Nature 428, 293, 2004

[L05] Lutovinov, A. et al.: INTEGRAL insight into the inner parts of the Galaxy. High mass X-ray binaries. A&A 444, 821, 2005

[N06] Negueruela, I. et al.: Supergiant Fast X-ray Transients: A New Class of High Mass X-ray Binaries Unveiled by INTEGRAL. ESA-SP 604, 165, 2006

[P06] Paizis, A. et al.: Average hard X-ray emission from NS LMXBs: observational evidence of different spectral states in NS LMXB. A&A 459, 187, 2006

[P11] Porter, T.: Testing the Origin of High-Energy Galactic Cosmic Rays. Proc. 32nd ICRC 6, 193, 2011

[R04] Revnivtsev, M. et al.: Hard X-ray view of the past activity of Sgr A* in a natural Compton mirror. A&A 425, L49, 2004

[S06] Sguera, V. et al.: Unveiling Supergiant Fast X-Ray Transient Sources with INTEGRAL. ApJ 646, 452, 2006

[S11] Sidoli, L. et al.: Supergiant Fast X-ray Transients as transient sources in High Mass X-ray Binaries. Proc.: "The Extreme and Variable High Energy Sky", Chia Laguna, Sardegna (Italy). PoS (Extremesky 2011) 010, 2011

[T10] Terrier, R. et al: Fading Hard X-ray Emission from the Galactic Center Molecular Cloud Sgr B2. ApJ 719, 143, 2010

[T06] Tsygankov, S. et al.: V0332+53 in the outburst of 2004–2005: luminosity dependence of the cyclotron line and pulse profile. MNRAS 371, 19, 2006

[W11] Wilson-Hodge, C. et al.: When a Standard Candle Flickers. ApJ 727, 40, 2011

[Z12] Zdziarski, A. et al.: The MeV spectral tail in Cyg X-1 and optically thin emission of jets. MNRAS 423, 663, 2012

(C) Supermassive black holes in Active Galactic Nuclei (AGN)

[Ba07] Bassani, L. et al.: IGR J22517+2218=MG3 J225155+2217: A New Gamma-Ray Lighthouse in the Distant Universe. ApJ 669, L1, 2007

[Ba12] Bassani, L. et al.: IGR J12319-0749: evidence for another extreme blazar found with INTEGRAL. A&A, in press, arXiv: 1205.3037, 2012

[B09] Beckmann, V. et al.: The second INTEGRAL AGN catalogue. A&A 505, 417, 2009

[B11] Beckmann. V. et al.: The hard X-ray emission of Centaurus. A&A 531, 70, 2011

[Br12] Brightman, M. & Ueda, Y.: The evolution of the Compton thick fraction and the nature of obscuration for active galactic nuclei in the Chandra Deep Field South. MNRAS 423, 702, 2012

[C11] Castangia, P. et al.: Water maser and hard X-ray emission in AGN. Proc.: "The Extreme and Variable High Energy Sky", Chia Laguna, Sardegna (Italy). PoS (Extremesky 2011) 068, 2011

[C07] Churazov, E., et al.: INTEGRAL observations of the cosmic X-ray background in the 5-100 keV range via occultation by the Earth. A&A 467, 529, 2007

[E12] Elitzur, M.: On the Unification of Active Galactic Nuclei. ApJL 747, L33, 2012

[G11] Ghisellini, G.: Powerful extragalactic jets. Proc.: "The Extreme and Variable High Energy Sky", Chia Laguna, Sardegna (Italy). PoS (Extremesky 2011) 053, 2011

[G12] Ghisellini, G.: Electron positron pairs in blazar jets and gamma-ray loud radio-galaxies. MNRAS, in press, arXiv: 1205.0549, 2012

[K12] Krivonos, R. et al.: INTEGRAL/IBIS 9-year Galactic Hard X-Ray Survey. A&A, in press, arXiv: 1205.3941, 2012

[M12] Malizia, A. et al.: The INTEGRAL/IBIS AGN catalogue I: X-ray absorption properties versus optical classification. MNRAS, in press, arXiv: 1207.4882, 2012

[Ma12] Masetti, N. et al.: Unveiling the nature of INTEGRAL objects through optical spectroscopy. IX. Twenty two more identifications, and a glance into the far hard X-ray Universe 2012. A&A 538, 123, 2012

[M09] Molina, M. et al.: The INTEGRAL complete sample of type 1 AGN 2009. MNRAS 399, 1239, 2009

[P11] Panessa, F. et al.: Narrow-line Seyfert 1 galaxies at hard X-rays. MNRAS 417, 2426, 2011

(C) Supermassive black holes in Active Galactic Nuclei (AGN) (continued)

[R11] Ricci, C. et al.: Reflection in Seyfert galaxies and the unified model of AGN. A&A 532,102, 2011

[S08] Sazonov, S. et al.: Cumulative hard X-ray spectrum of local AGN: a link to the cosmic X-ray background. A&A 482, 517, 2008

[T11] Tarchi, A. et al.: Narrow-line Seyfert 1 galaxies: an amazing class of AGN. A&A 532, 125, 2011

[T10] Türler, M. et al.: INTEGRAL hard X-ray spectra of the cosmic X-ray background and Galactic ridge emission. A&A 512, 49, 2010

(D) Gamma-ray bursts

[A08] Abbott, B. et al.: Implications for the Origin of GRB 070201 from LIGO Observations 2008. ApJ 681, 1419, 2008

[F08] Foley, S. et al.: Global characteristics of GRBs observed with INTEGRAL and the inferred large population of low-luminosity GRBs. A&A 484, 143, 2008

[F07] Frederiks, D. et al.: On the possibility of identifying the short hard burst GRB 051103 with a giant flare from a soft gamma repeater in the M81 group of galaxies. AstL 33, 19, 2007

[G09] Götz, D. et al.: Variable Polarization Measured in the Prompt Emission of GRB 041219A Using IBIS on Board INTEGRAL. ApJ 695, L208, 2009

[K07] Kalemci, E. et al.: Search for Polarization from the Prompt Gamma-Ray Emission of GRB 041219a with SPI on INTEGRAL. ApJS 169, 75, 2007

[L11] Laurent, P. et al.: Constraints on Lorentz Invariance Violation using INTEGRAL/IBIS observations of GRB 041219A. PhRvD 83, 121301, 2011

[M08] Mazets, E. et al.: A Giant Flare from a Soft Gamma Repeater in the Andromeda Galaxy (M31). ApJ 680, 545, 2008

[Mc07]McGlynn, S. et al.: Polarisation studies of the prompt gamma-ray emission from GRB 041219a using the spectrometer aboard INTEGRAL. A&A 466, 895, 2007

[M03] Mereghetti, S. et al.: The INTEGRAL Burst Alert System. A&A 411, 291, 2003

[S12] Savchenko, V. et al.: Timing properties of gamma-ray bursts detected by SPI-ACS detector on board of INTEGRAL. A&A 541, 122, 2012

[V09] Vianello, G. et al.: The updated spectral catalogue of INTEGRAL gamma-ray bursts. A&A 495, 1005, 2009

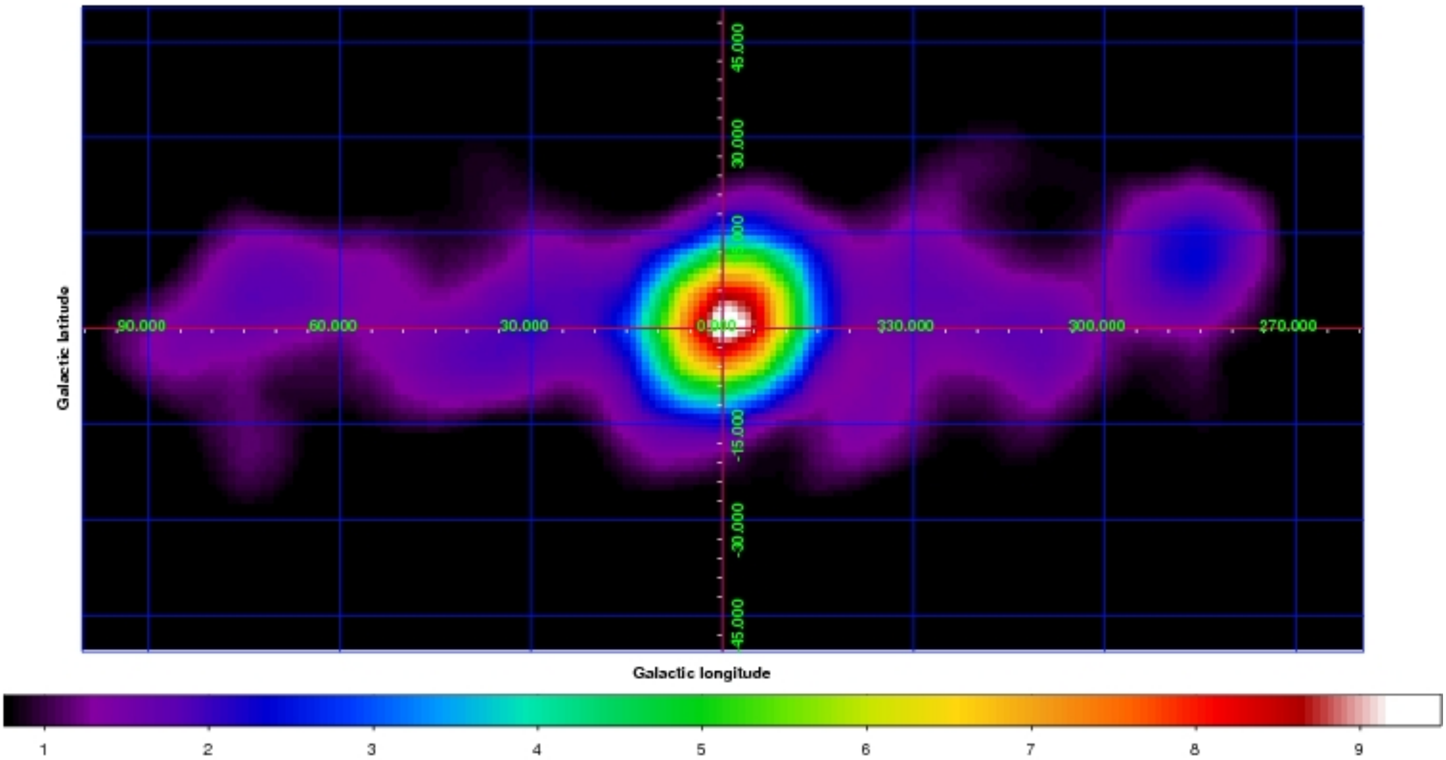

Figure 1: Spatial distribution of the 511 keV positron annihilation emission in the Galactic Centre. Long INTEGRAL exposures show a dominant central bulge and surprisingly weak emission from the disk. Although an earlier analysis was interpreted in terms of an asymmetry in the disk (Weidenspointer et al., Nature 451, 159, 2008), a more recent one is shown here, as a significance map of the electron-positron annihilation emission in the 508 to 514 keV range, using data from six years of observation. It uses an alternative background modeling technique, suggesting that if any asymmetry is present, it is more likely associated with an offset of the bulge. Clearly, more observations are needed to understand the precise morphology and so provide key clues as to the origin of the positrons and how and where they annihilate (Figure adapted from Bouchet et al., ApJ 720, 1772, 2010).

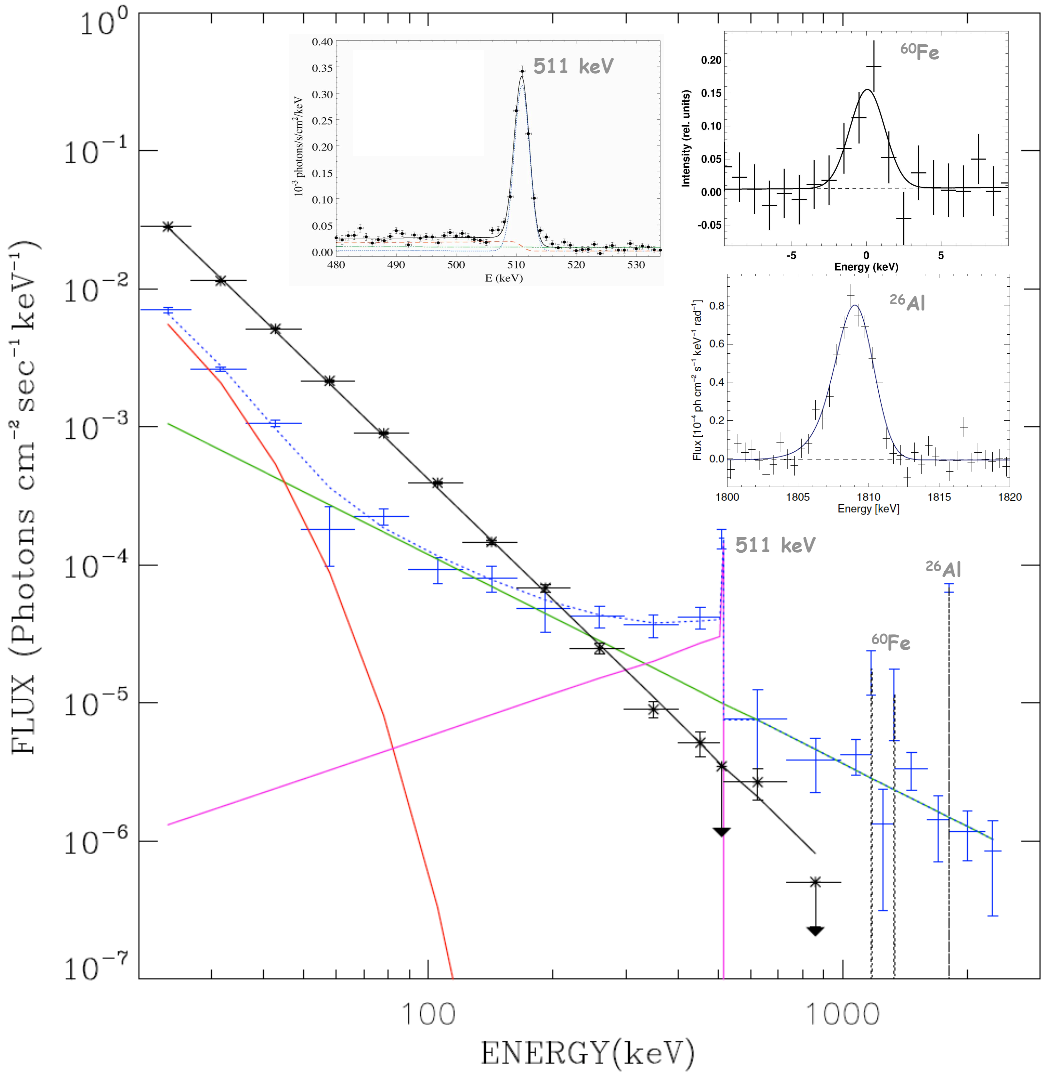

Figure 2: INTEGRAL spectra from the central galactic radian. Black: total emission of resolved point sources; Blue: total diffuse emission; Magenta: 511 keV annihilation radiation (positronium continuum and line emission); Green: emission from the galactic ridge resulting from interstellar particle interaction; Red: accreting magnetic white dwarfs (Bouchet et al., ApJ 739, 29, 2011). The vertical dotted lines indicate the narrow lines. Inserts show the fine spectroscopy analysis of selected lines (from Jean et al., A&A 445, 579, 2006; Wang et al., A&A 469, 1005, 2007; Wang et al., A&A 496, 713, 2009).

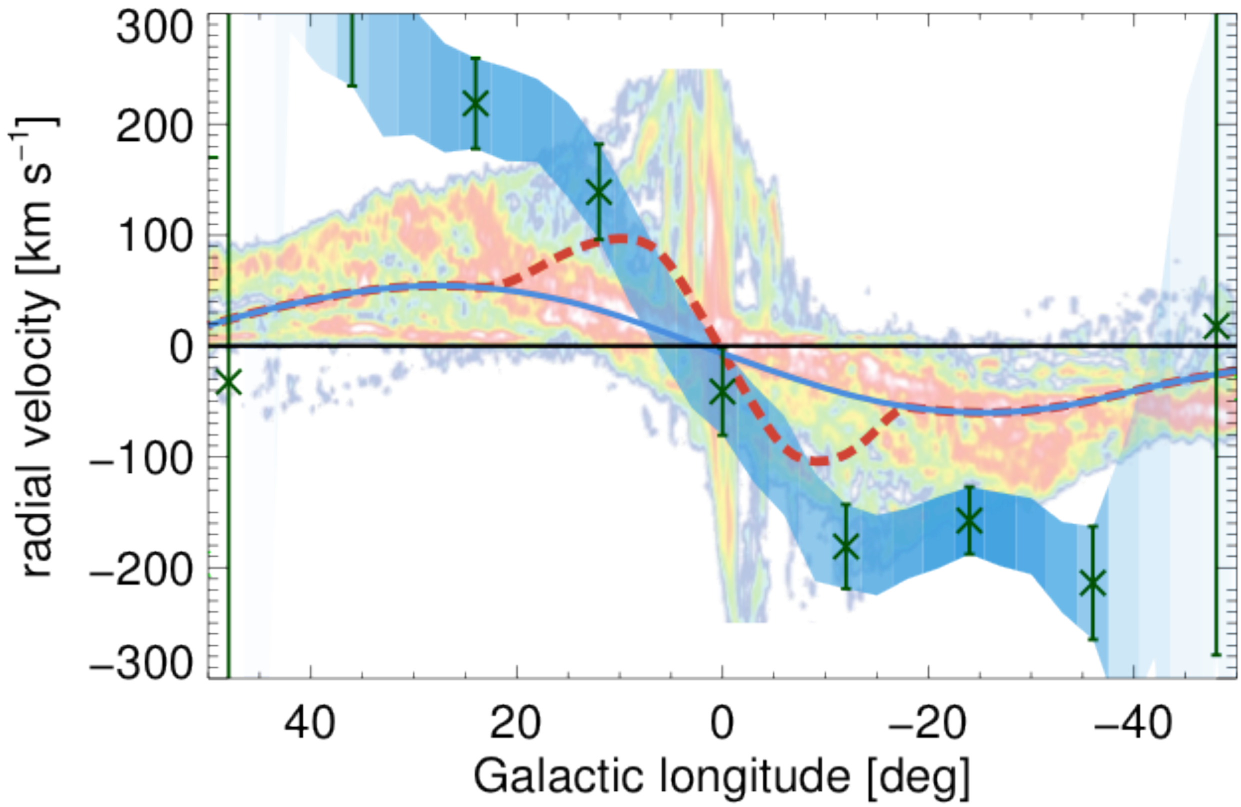

Figure 3: The systematic Doppler shift of the ^{26}Al gamma-ray line with Galactic longitude along viewing directions towards the inner Galaxy reflects the large-scale motion from Galactic rotation: The data points show ^{26}Al line energy (1808.63 keV) measurements with uncertainties for 12° bins in Galactic longitude, and the blue-shaded band indicates allowed ^{26}Al-gas velocities derived from our analysis, including additional sliding-window analysis offsetting these bins. The longitude-velocity diagram from molecular gas as measured in CO is shown in color, with irregular and large velocities in the very centre from molecular clouds in the vicinity of the Galaxy's supermassive black hole, and the Galactic ridge showing a linear velocity change between -20° and 20° from about -50 to 50 km s^{-1}. The blue continuous line reflects what would be seen if ^{26}Al were distributed in the large-scale Galactic disk as modeled with free-electron emission and following a standard Galactic rotation curve. An analogous sliding-window analysis was performed on such-simulated SPI data. The red-dashed line shows expected results if 1/3 of the ^{26}Al sources would rather be distributed along the bar of our Galaxy, and 2/3 in the disk as before. The hot and tenuous interstellar gas as traced by radioactive ejectae apparently display systematic larger velocities by up to 100 km s^{-1}, and some association to sources in the Galaxy's bar is suggested (Figure updated from Kretschmer, PhD thesis, TU München 2011; Kretschmer et al., 2012, in preparation).

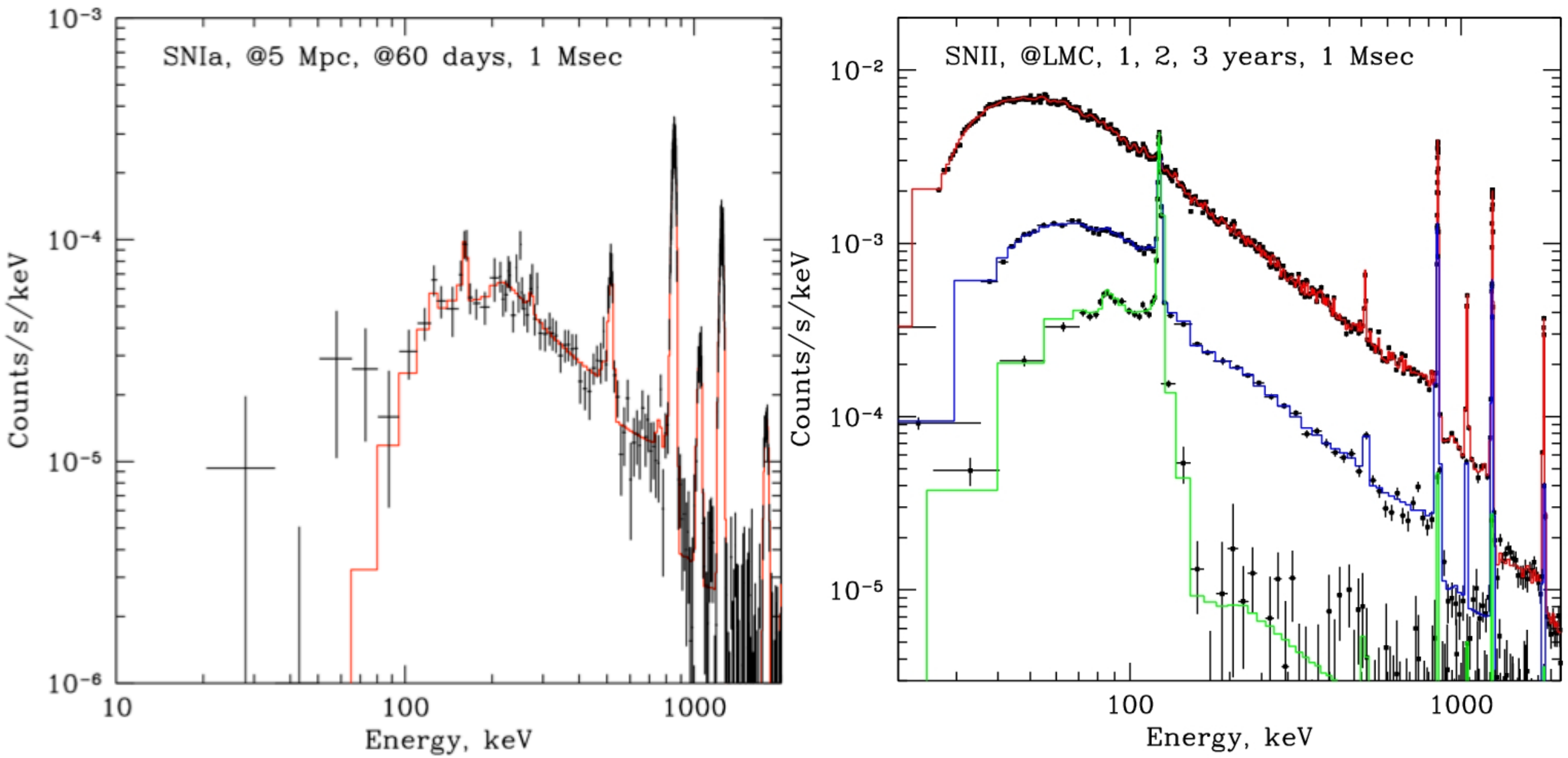

Figure 4: Predicted INTEGRAL/SPI spectra of nearby Supernovae. Left panel: SN Ia at a distance of 5 Mpc, 60 days after onset, 1 Ms integration. Model assumptions include: M_{total} = 1.4 $M_\odot$, with 0.7 $M_\odot$ (^{56}Ni), 0.02 $M_\odot$ (^{57}Ni); $v_{expansion}$ ~ 10^4 km/s, with uniform mixing. Prominent emission lines are at 847 keV and 1238 keV (^{56}Ni). Right panel: SN II in the LMC (distance = 50 kpc), at 1, 2, and 3 years after onset, respectively, 1 Ms integration. The model parameters are similar as for SN 1987A. Prominent emission lines are at 122 keV (^{57}Ni), 847 keV and 1238 keV (^{56}Ni) (figures produced by E. Churazov).

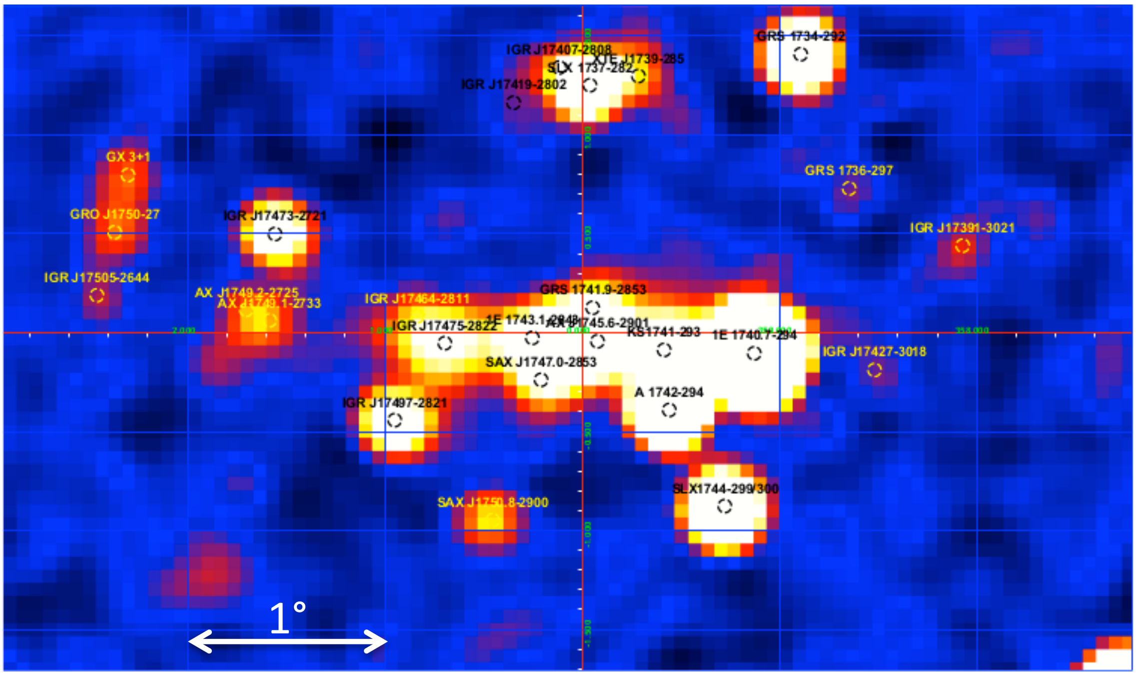

Figure 5: INTEGRAL view of the Galactic Centre (35-80 keV), obtained from all IBIS observations during 2003-2012. Main sources are indicated by circles. The vast majority of sources, detected in this energy band are binaries with accreting neutron stars and black holes. The source IGR J17475-2822 is the hard X-ray emission from the molecular cloud Sgr B2 , illuminated by previous outburst of the galactic supermassive black hole Sgr A*. See also Fig. 6, below (Figure produced by R. Krivonos).

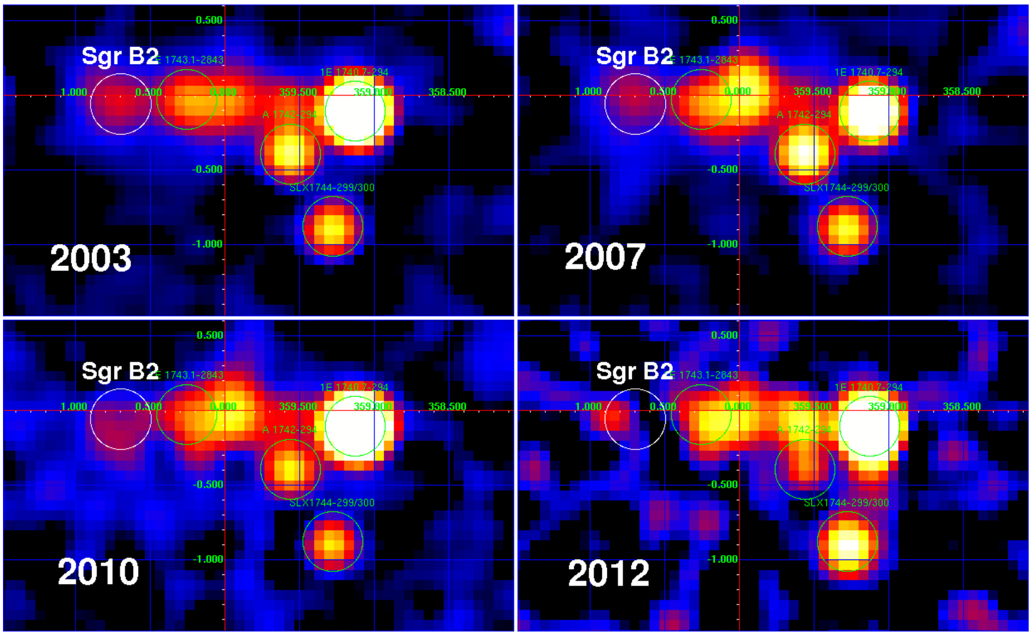

Figure 6: INTEGRAL/IBIS 17-60 keV images of the Galactic Centre region (3.5°× 2°) from 2003 until 2012. The positions of some known sources are shown by circles. The white circle shows the position of the molecular cloud Sgr B2 (see Fig. 5, above). Hard X-ray emission from Sgr B2/IGR J17475-2822 clearly declines over the last years 2003-2012 (The figure is based on Terrier et al., ApJ 719, 143, 2010, and Krivonos et al., A&A in press, arxXiv.org:1205.3941, 2012).

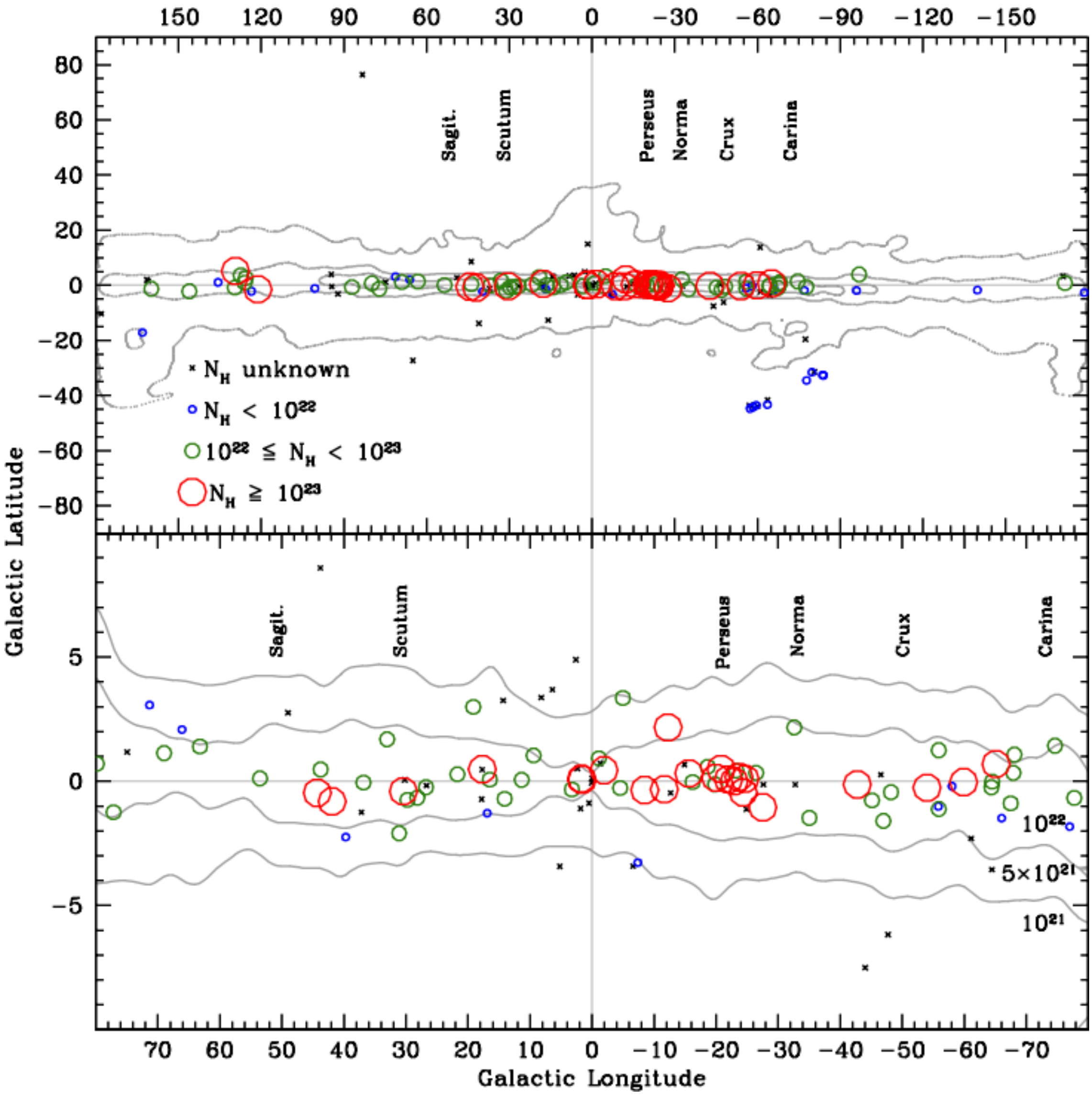

Figure 7: Spatial distribution of sources detected by INTEGRAL/IBIS for which absorbing columns have been reported. The symbol size is proportional to the column density n_H. Top panel: whole sky, including extragalactic sources. Bottom panel: galactic bulge region, excluding extragalactic sources. Contours denote galactic absorption levels of 10^{21}, 5×10^{21}, and 10^{22} cm^{-2} obtained from 21 cm data (Figure produced by Bodaghee, 2011, based on Bodaghee et al., A&A 476, 585, 2007).

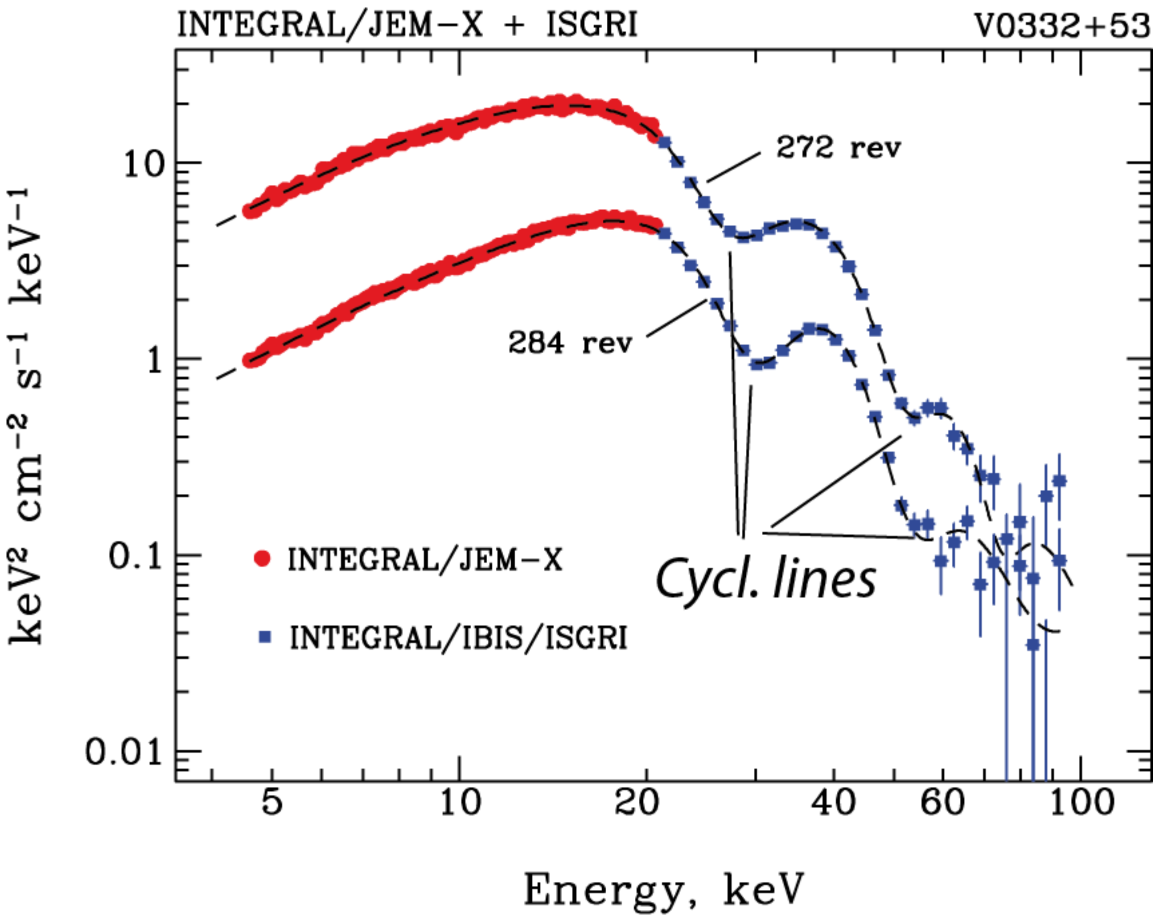

Figure 8: Energy spectra of the transient pulsar V 0332+53 observed by INTEGRAL during two states in January 2005 (revolution 272) and in February 2005 (rev 284). The positions of the cyclotron absorption lines are indicated. The displacement of the cyclotron line position indicates the change of structure of the accretion column near the neutron star surface (Tsygankov et al., MNRAS 371, 19, 2006).

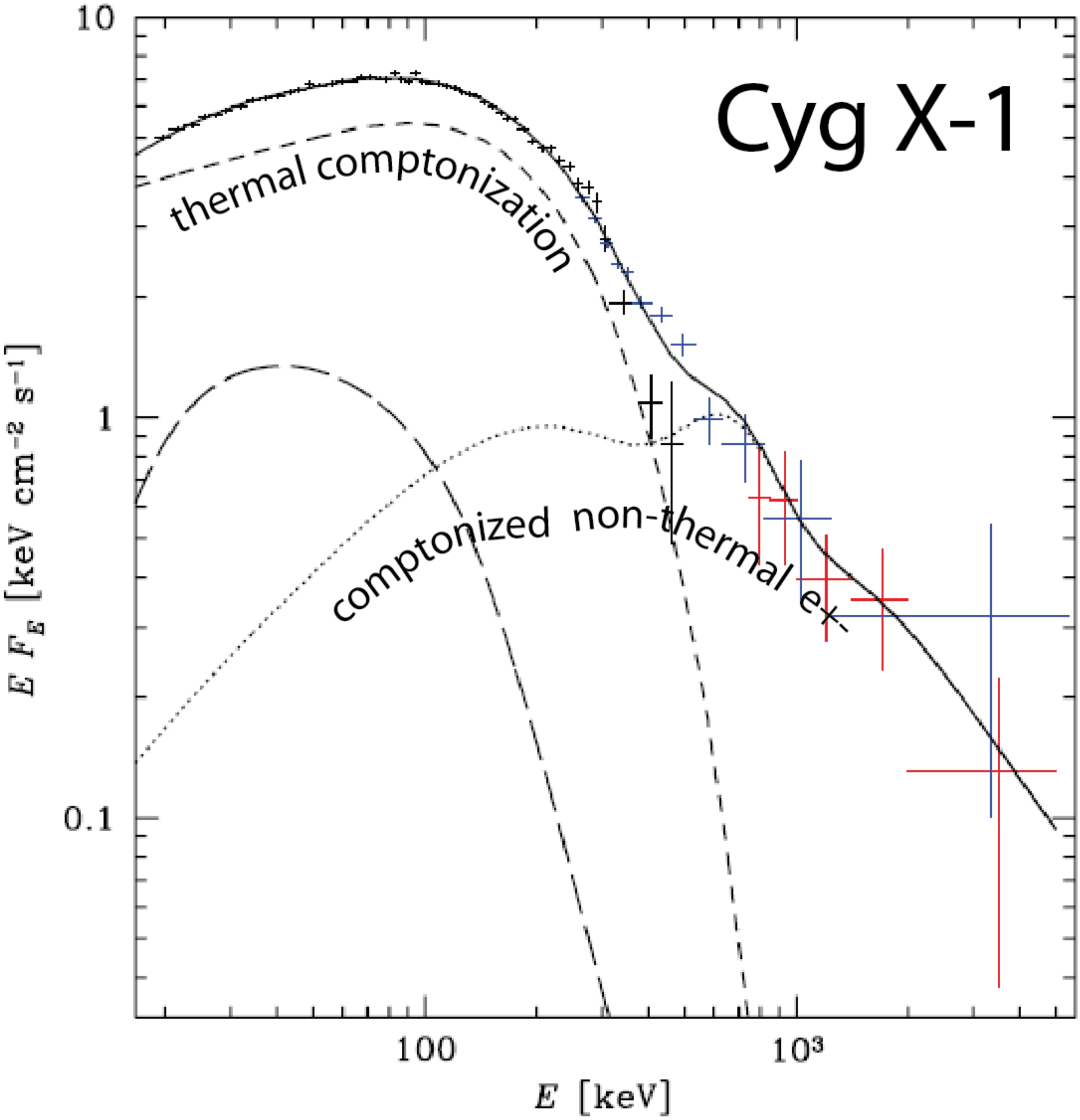

Figure 9: The average 20 keV– 5 MeV spectra from Cyg X-1 using INTEGRAL and CGRO data. INTEGRAL/IBIS/ISGRI: black data points; INTEGRAL/IBIS/PICsIT: blue, CGRO/Comptel: red. The emission due to thermal Comptonization in a hot coronal flow near the black hole is shown by the dashed curve. The dotted curve shows the Compton emission from the non-thermal e^+/e^- pairs, and the annihilation spectrum from the e^+/e^- pairs (Zdziarski et al., MNRAS 423, 663, 2012).

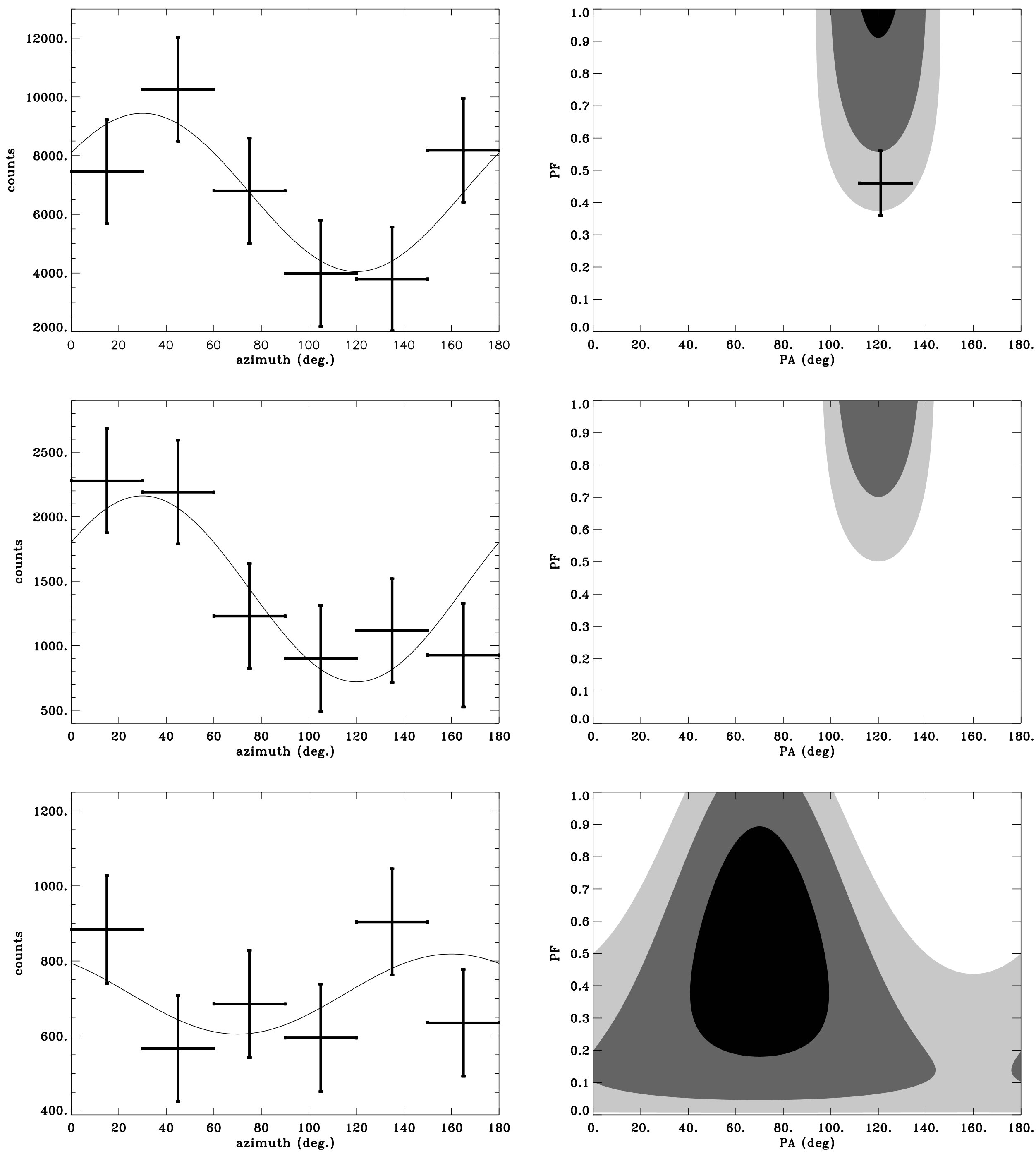

Figure 10: Azimuthal profile, polarization angle (PA), and polarization fraction (PF) as measured by INTEGRAL/IBIS for the Crab nebula and pulsar between 200 and 800 keV, in the off-pulse (top), off-pulse and bridge (middle), and two-peak (bottom) phase intervals. The error bars for the profile are at 1σ. The 68%, 95%, and 99% confidence regions are shaded from dark to light grey. The independent INTEGRAL/SPI result (Dean et al., Science 321, 1183, 2008) is indicated in the top right figure by a cross (Forot et al., ApJ 688, L29, 2008).

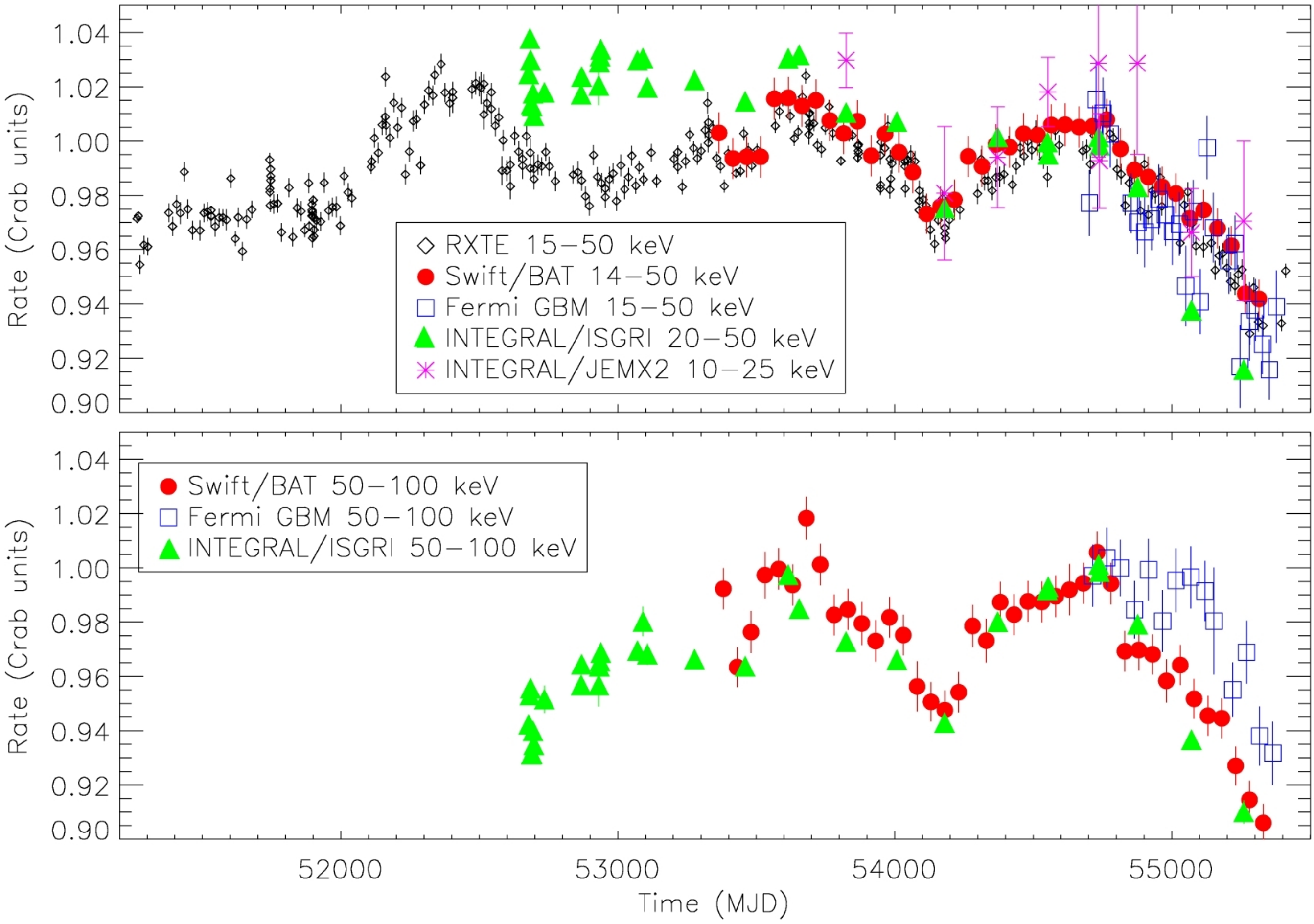

Figure 11: The Crab does not entirely radiate like a standard candle. Based on observations made by NASA's Fermi Gamma-Ray Burst Monitor (GBM), the Swift Burst Alert Telescope, the Rossi X-Ray Timing Explorer (RXTE), and INTEGRAL, a real, intrinsic decline of the Crab Nebula's flux can be discerned from the year 2008 of about 7% in the 15 - 50 keV energy band; a similar decline can be seen in the 50 - 100 keV band [MJD 55000 (53000) = 18 June 2009 (27 Dec 2003)]. Moreover, the Crab had brightened and faded by as much as 3.5% a year since 1999. The flickering arises from the nebula, and not from the pulsar located inside, as no unexpected variations are detected in the pulsed flux. Unlike the NASA spacecraft involved in the study, which are on Low Earth Orbits, INTEGRAL is operating in a highly eccentric orbit. Therefore, the INTEGRAL orbital environment has a different level of background radiation with respect to the other spacecraft, and this allows to exclude any orbital induced background effects in the Crab Nebula's flickering (Wilson-Hodge et al., ApJ 727, 40, 2011).

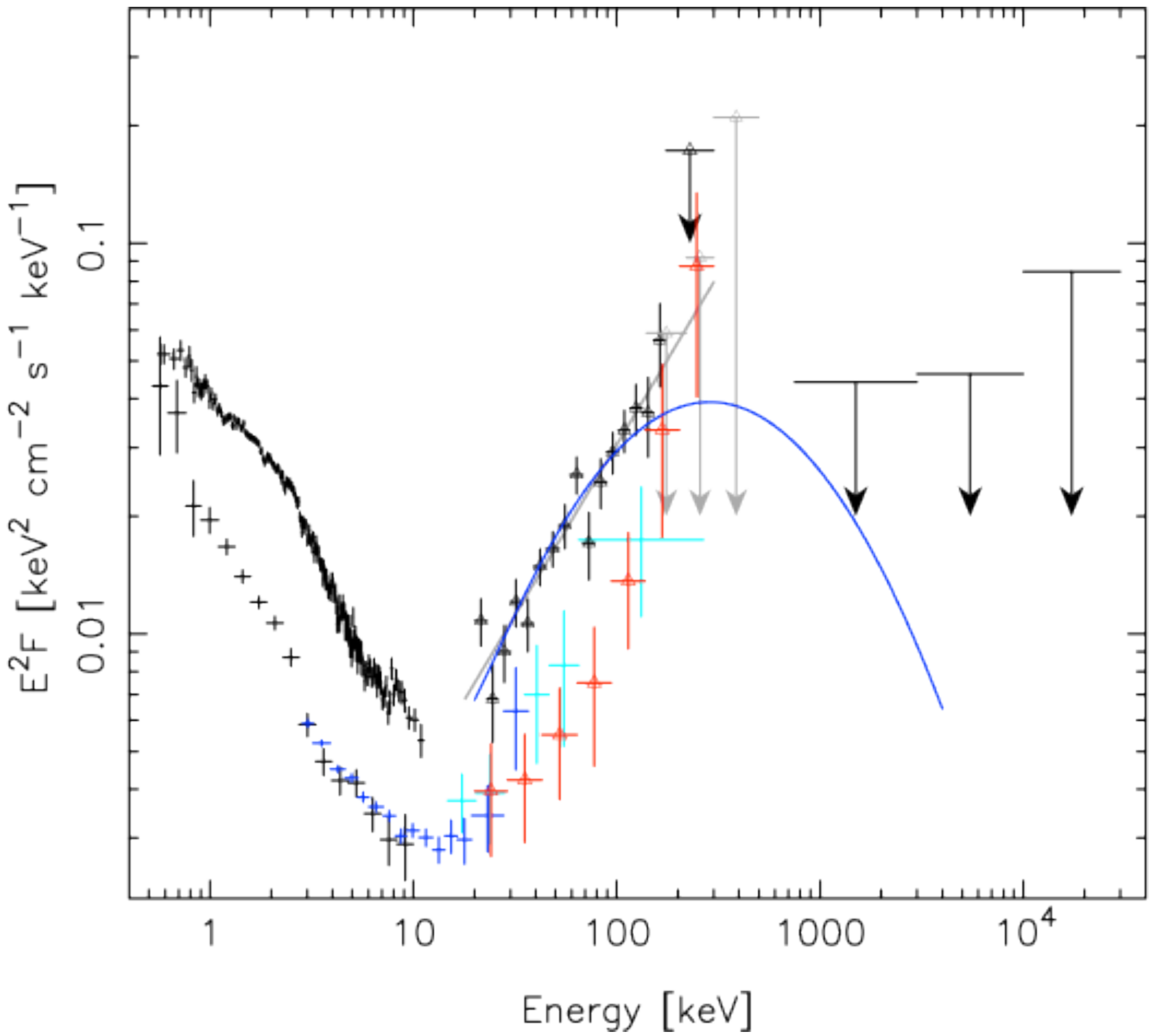

Figure 12: The luminous non-thermal emission from magnetars above 10 keV was discovered by INTEGRAL and still remains unexplained. Black data points show the total energy spectrum of 1RXS J1708-40 from XMM-Newton (<12 keV), INTEGRAL/IBIS (triangles), as well as upper limits from INTEGRAL/SPI (grey upper limits) and CGRO/COMPTEL (black upper limits). A fit to the INTEGRAL spectrum is consistent with either a power law (grey) or a log-parabola (blue), however, the COMPTEL upper limits require a break in the spectrum around a few hundred keV. The pulsed component of the emission is weaker and shown here using data from XMM-Newton (black), RXTE-PCA (blue), HEXTE (cyan), and INTEGRAL/IBIS (red) (den Hartog et al., A&A 489, 263, 2008).

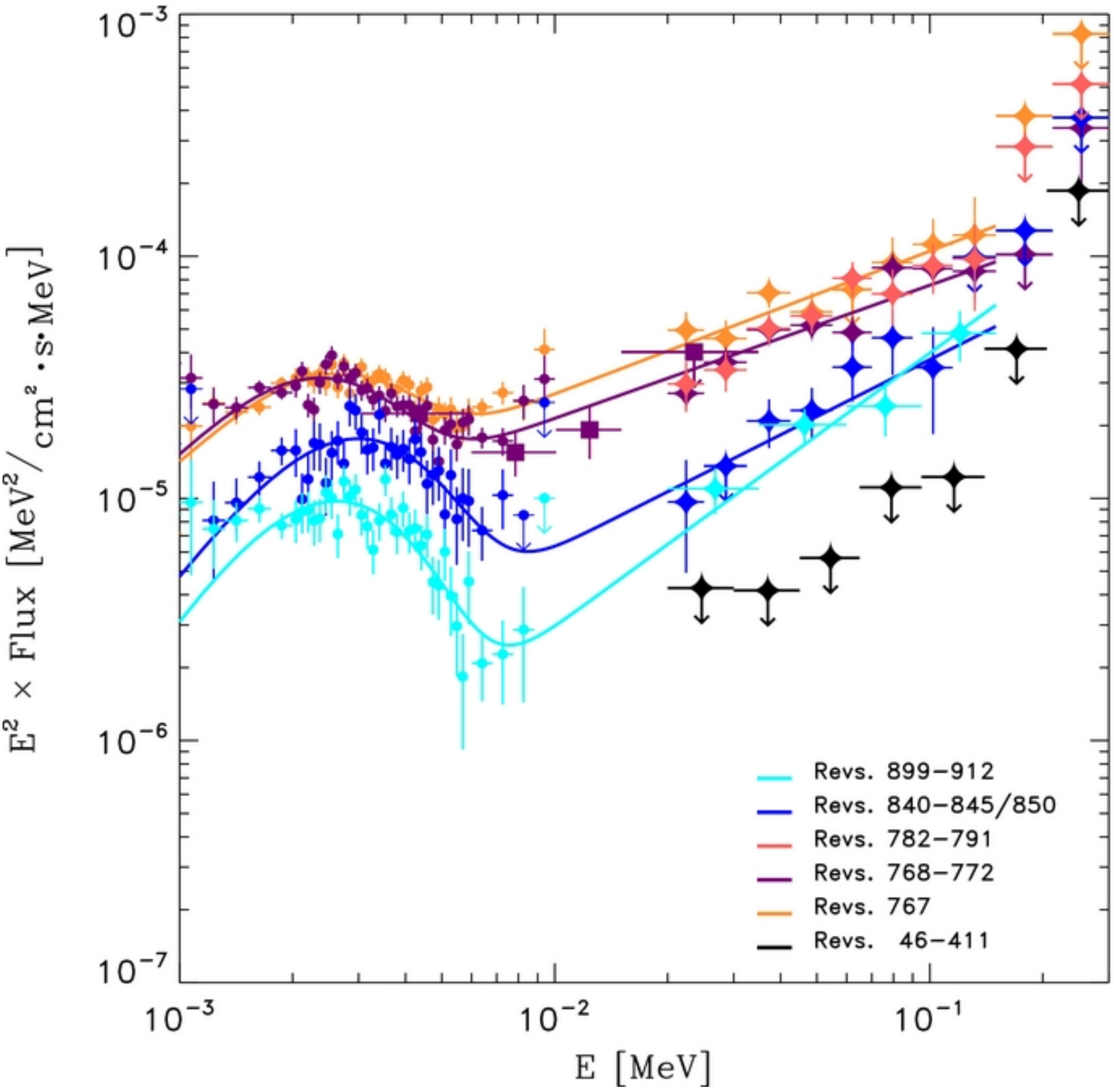

Figure 13: Spectral evolution after the timing glitch/outburst in January 2009 up to April 2010 of the total (unabsorbed) emission of 1E 1547.0–5408 in the 1-300 keV band as measured by Swift/XRT (PC mode; filled circles), INTEGRAL/JEM-X (filled squares), and INTEGRAL/ISGRI (filled diamonds). BB plus Pl-model fits for the combined fluxes are shown. The different colors indicate the INTEGRAL observations (revolutions) with (nearly) contemporaneous Swift observations. Note that for revs. 782-791 no XRT/PC mode observations have been performed. Black 2σ upper limits are shown for the combined exposure of ~4 Ms of all INTEGRAL observations (prior to the October 2008 outburst) from March 2003 to February 2006 (Kuiper et al., ApJ 748, 133, 2012).

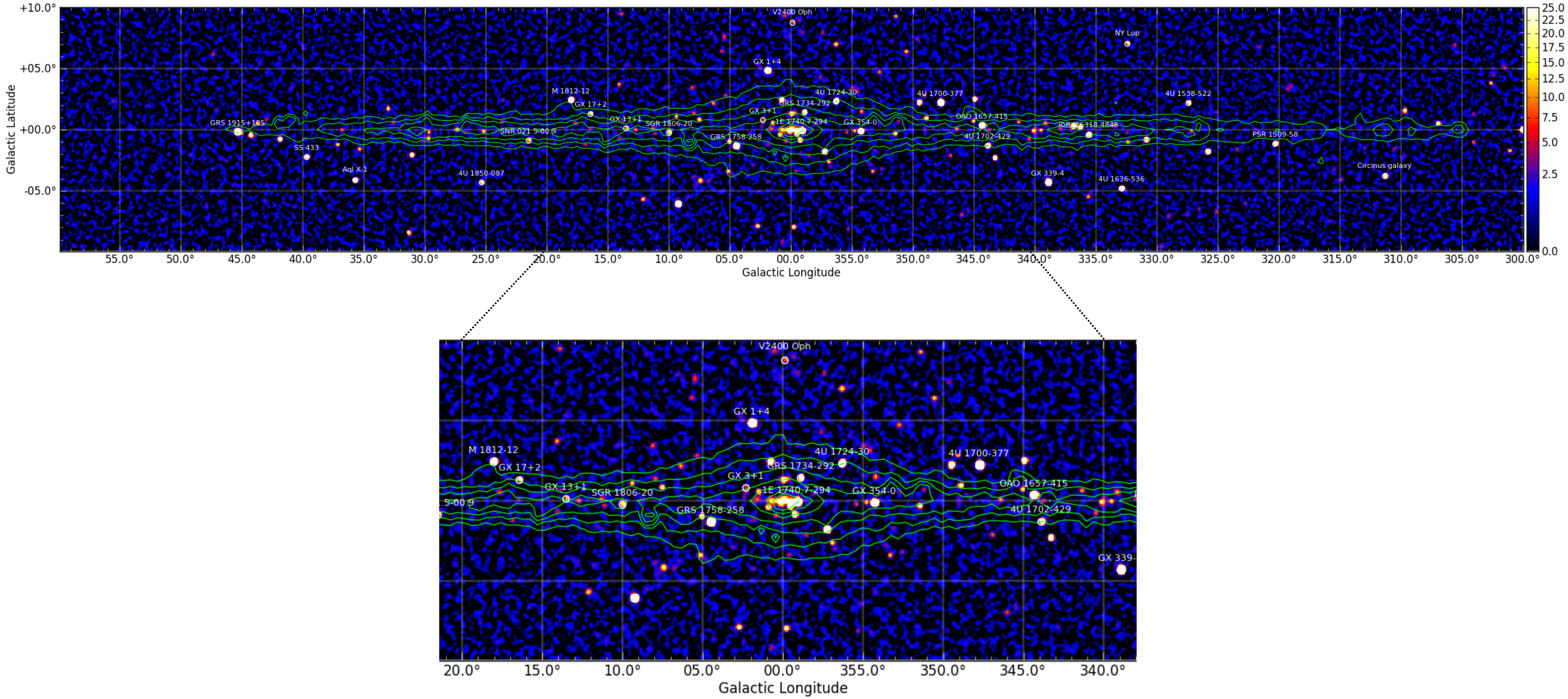

Figure 14: Deepest ever obtained image (35-80 keV) of the Galactic plane, not affected by absorption of the interstellar medium. The contours denote the surface brightness of the Galaxy in the near infrared spectral band, indicating the typical spatial extent of the Galactic stellar population. Labels show positions of some known X-ray sources, mostly accreting compact objects with white dwarfs, neutron stars and black holes, including supermassive black holes in outer galaxies. In total, 164 statistically significant sources were detected by INTEGRAL within the sky area shown (Krivonos et al., A&A, in press, 2012, arXiv:1205.3941).

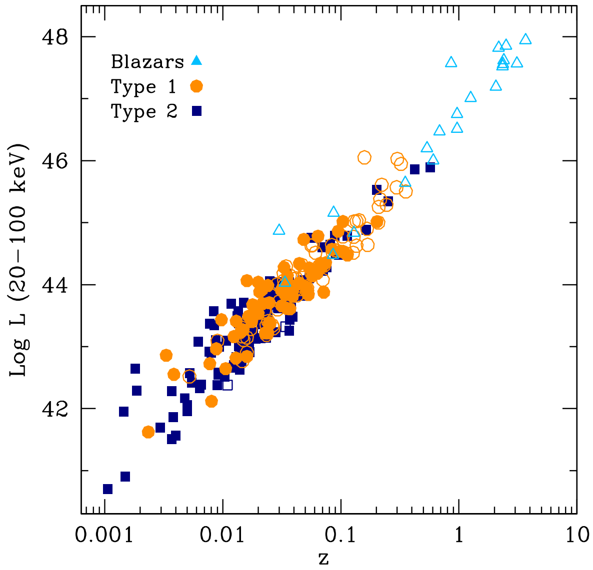

Figure 15: Hard X-ray luminosity versus redshift for a sample of INTEGRAL AGN including 272 objects which have been characterized in the optical and X-ray regime. Seyfert 1 = circles; Seyfert 2 = squares; Blazars = triangles. Open symbols are objects where no intrinsic absorption has been measured (Malizia et al., MNRAS, in press, arXiv: 1207.4882, 2012).

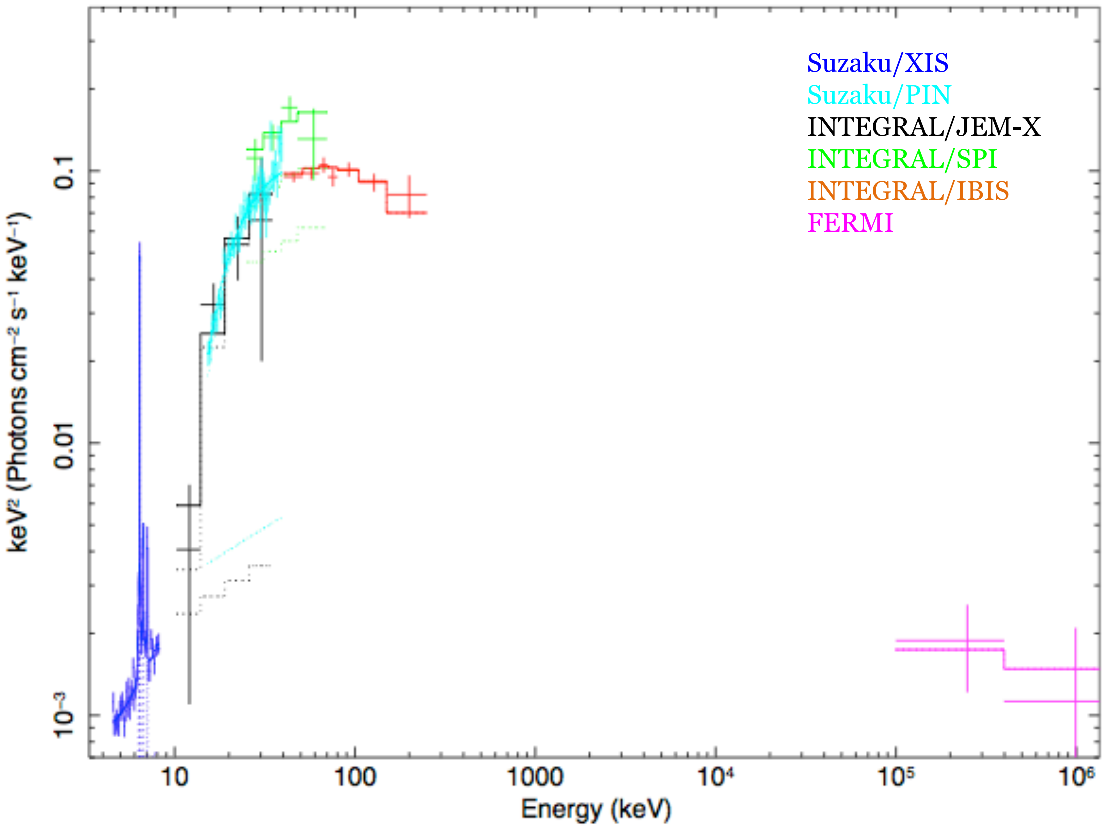

Figure 16: Unfolded $E^2 \times f(E)$ spectrum of the highly absorbed Seyfert-2 galaxy NGC 4945 using data from Suzaku (4.5 – 40 keV), INTEGRAL (10 - 250 keV) and Fermi (150 MeV – 2.5 GeV) (Menzel et al., Proc.: "The Extreme and Variable High Energy Sky", Chia Laguna, Sardegna (Italy), PoS (Extremesky 2011) 075, 2011).

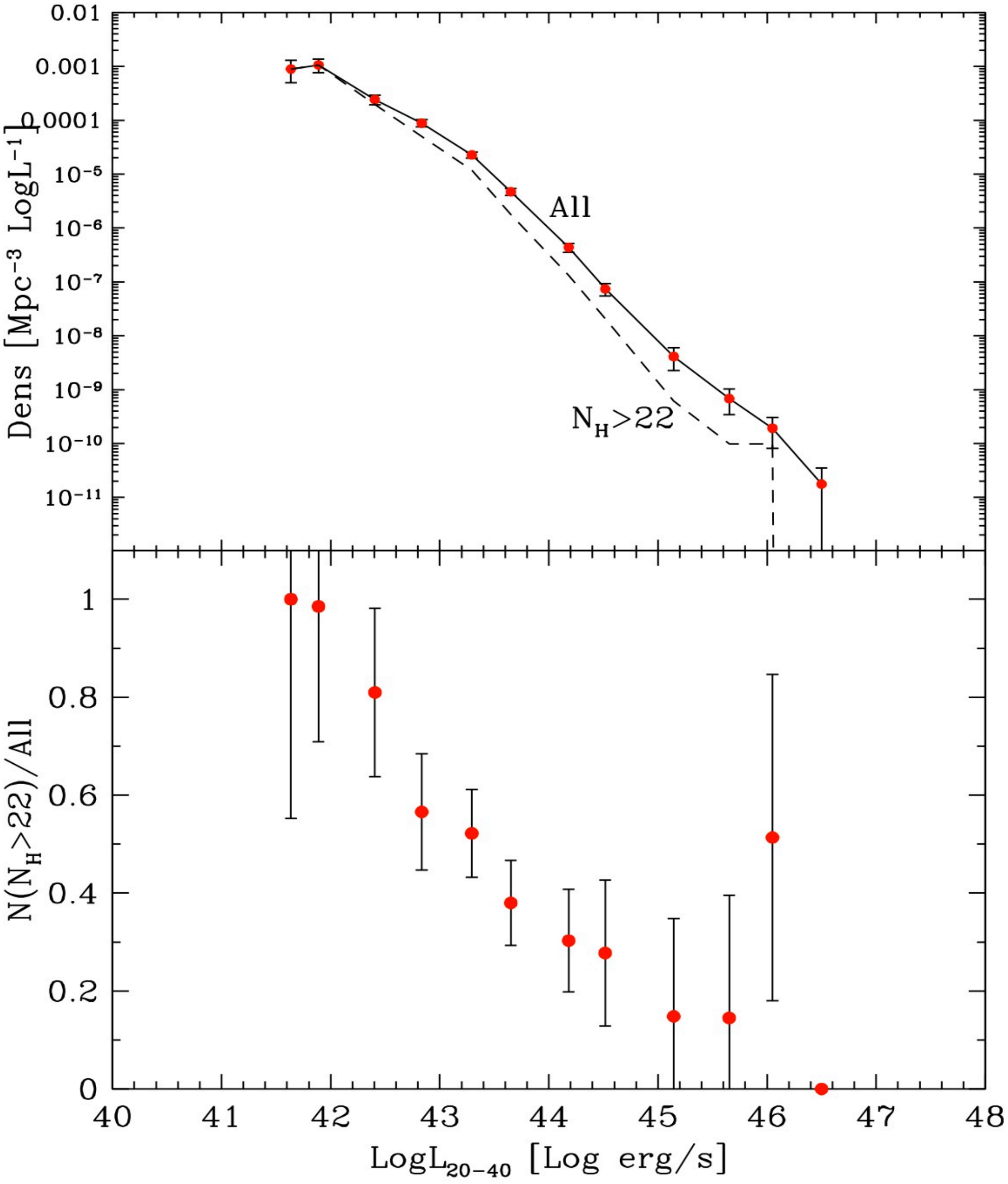

Figure 17: Top panel: the luminosity function for all AGN detected in the third IBIS catalogue (solid line) and for those with absorption greater than 10^{22} cm^{-2}. Bottom panel: the ratio between these two curves. It can be seen, that at low luminosities, AGN with $N_H > 10^{22}$ cm^{-2} constitute almost 100% of the sample, while this ratio is decreasing at higher luminosities. For these curves the loss of highly absorbed AGN at higher redshift has been taken into account (La Franca & Malizia, in preparation, 2012).

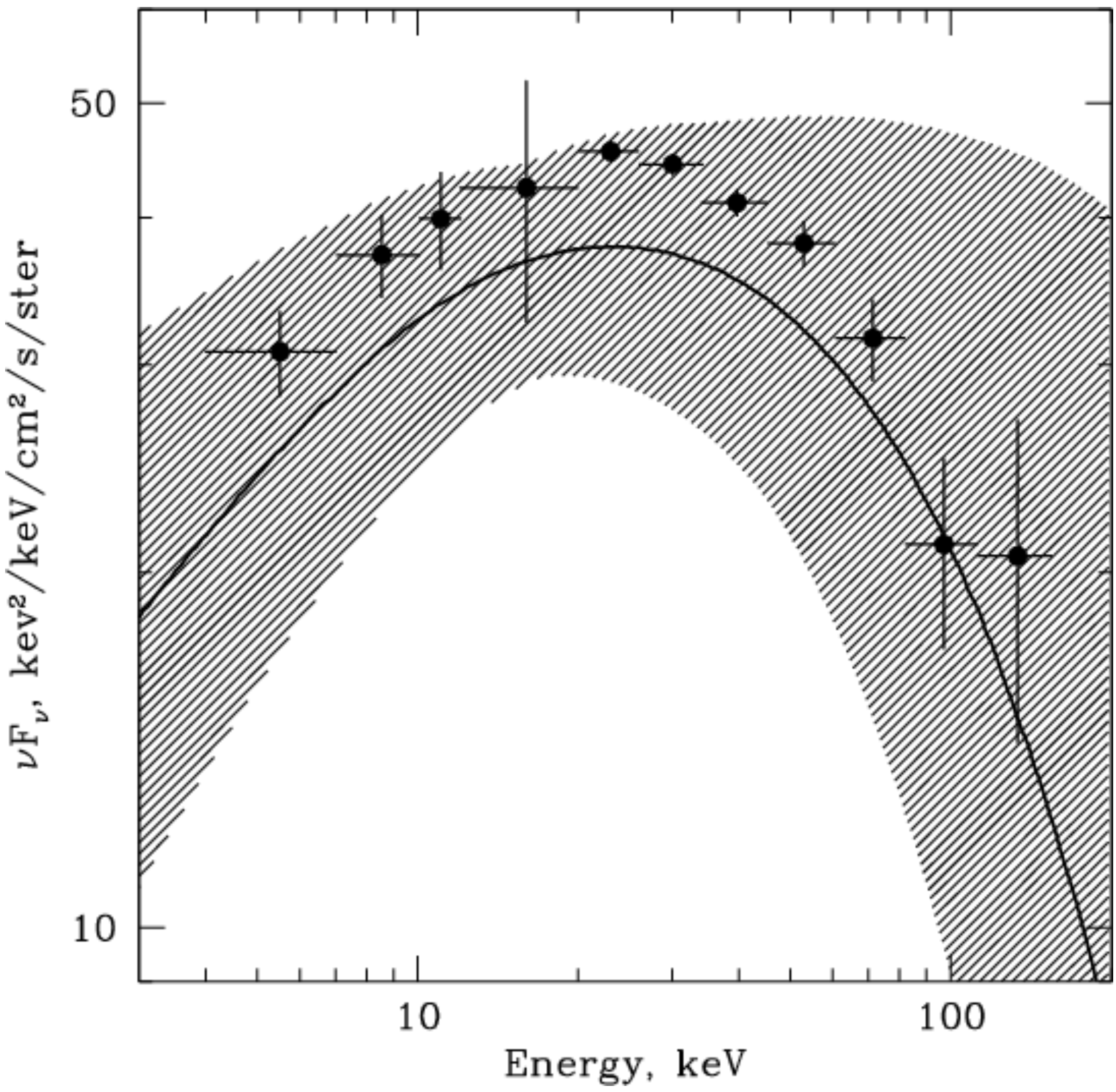

Figure 18: The convolution of the cumulative spectral energy distribution (SED) of local AGN with a redshift evolution function of the AGN luminosity density. The solid line is the best estimate of this redshift-integrated AGN SED. The shaded region represents the 1σ uncertainty in the spectral shape combined with the 20% uncertainty in the normalization. The data points with error bars show the CXB spectrum measured with the JEM-X, IBIS/ISGRI and SPI instruments on INTEGRAL (Sazonov et al., A&A 482, 517, 2008).

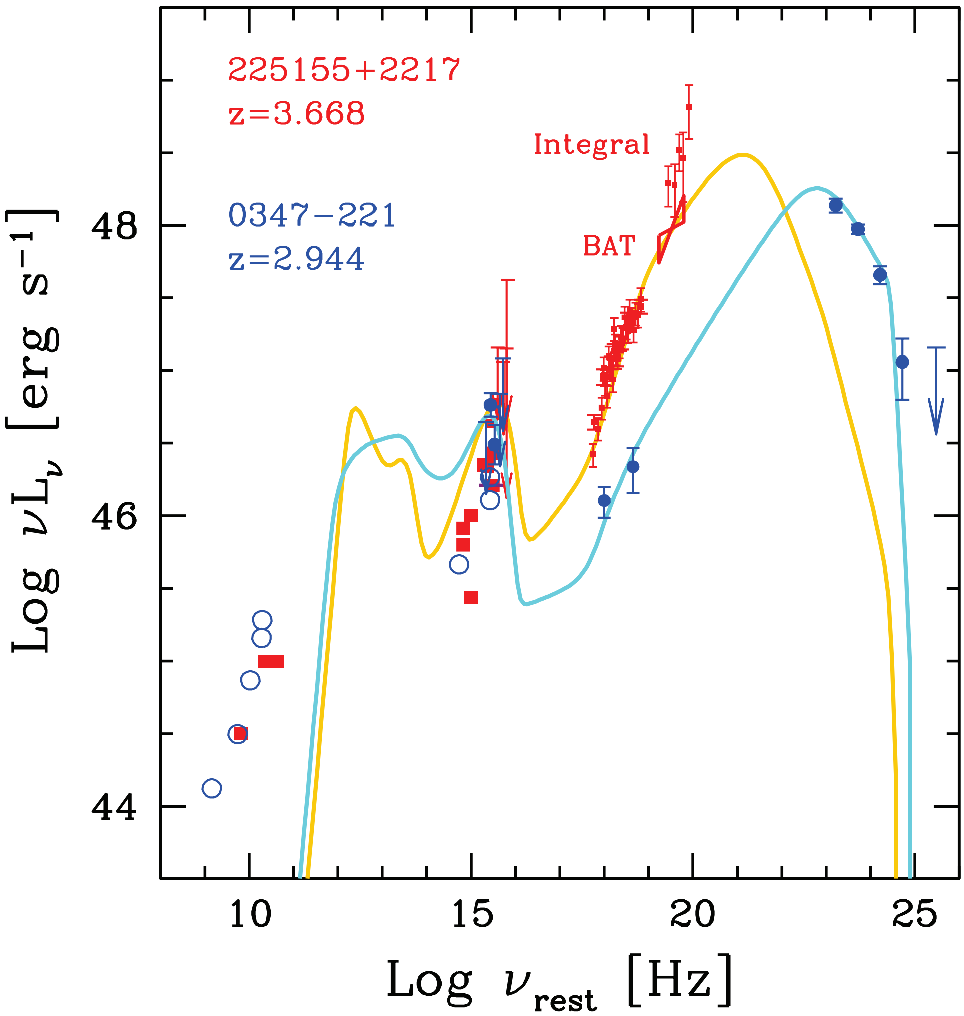

Figure 19: Comparison between the SED (rest frame frequency) of two distant blazars: IGR J225155+2217 (at z = 3.668), detected by INTEGRAL/IBIS and PKS 0347 221 (at z = 2.944) detected by Fermi/LAT. Solid lines refer to a single zone leptonic model that fits the data of each source. It is evident from the figure that IGR J225155+2217 is more powerful and its high energy peak is at around 1 MeV, while for the less powerful PKS 0347-211 the peak is at larger energies. This figure illustrates that hard X-ray surveys are more efficient than gamma-ray sources to select powerful blazars at high redshifts (Ghisellini: Proc.: "The Extreme and Variable High Energy Sky", Chia Laguna, Sardegna (Italy), PoS (Extremesky 2011) 053, 2011).

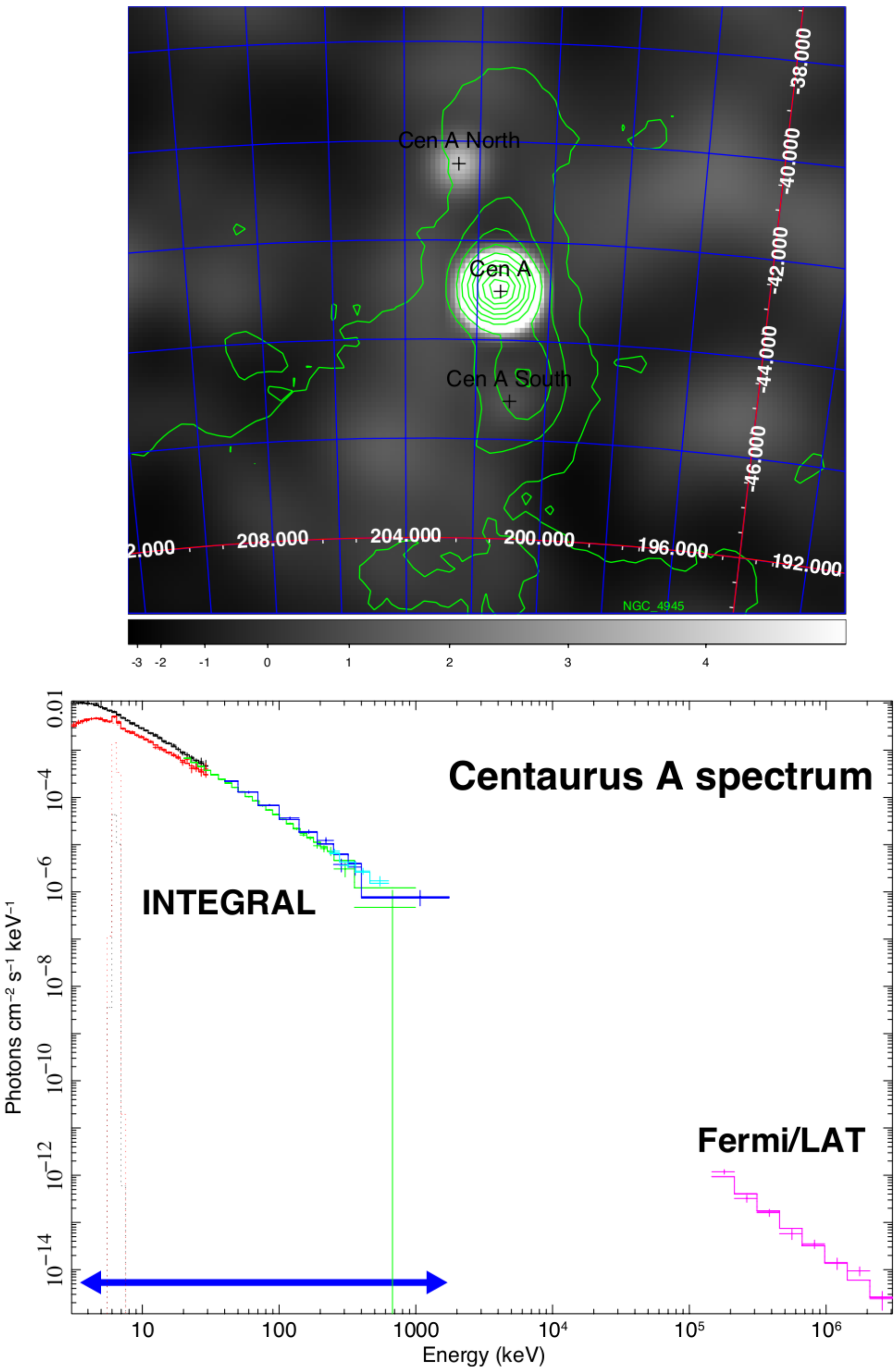

Figure 20: Top panel: INTEGRAL/SPI map (40 - 1000 keV) of the Cen A region overlaid with contours of the WMAP radio emission of Cen A, which shows the extended structure arising from the jets. Although SPI indicates some extended emission in the north of the core, the significance of this blob is too low to claim a detection, and using this as an upper limit for the hard X-ray emission, the results agree with what has been seen at other wavelengths. Bottom panel: spectrum of Cen A as observed by INTEGRAL: JEM-X1 and JEM-X2 (black and red), SPI (green), IBIS (blue). The whole spectrum appears to connect smoothly with Fermi/LAT at very high energies. The MeV gap remains, as since the decommissioning of the Compton Gamma-Ray Observatory in 2000 there is no instrument in space, which can detect photons here (Beckmann et al. A&A 531, 70, 2011).

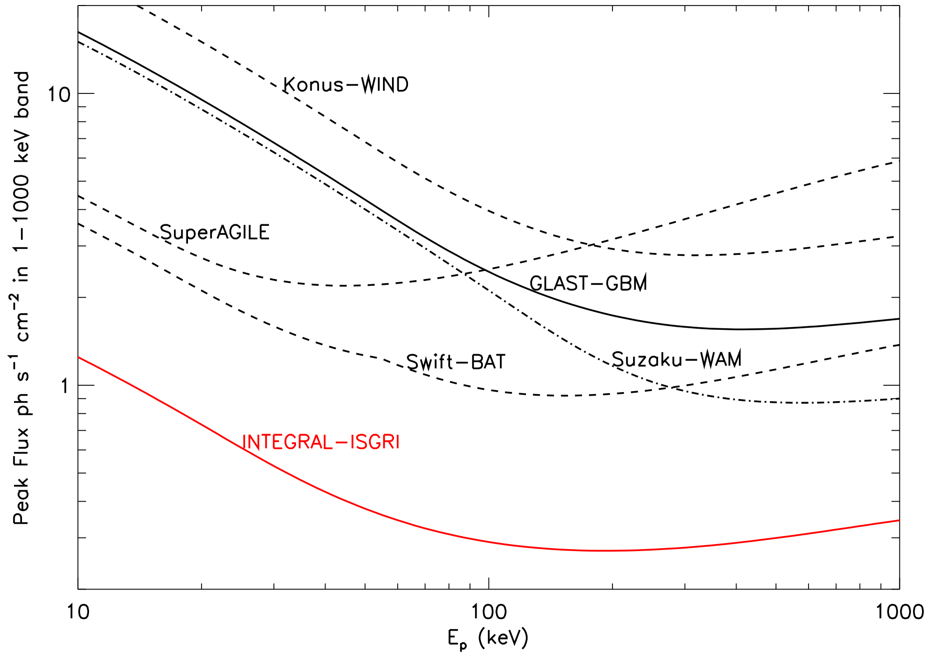

Figure 21: Sensitivity of current missions for the detection of faint GRB (Band, AIPC 1000, 121, 2008).

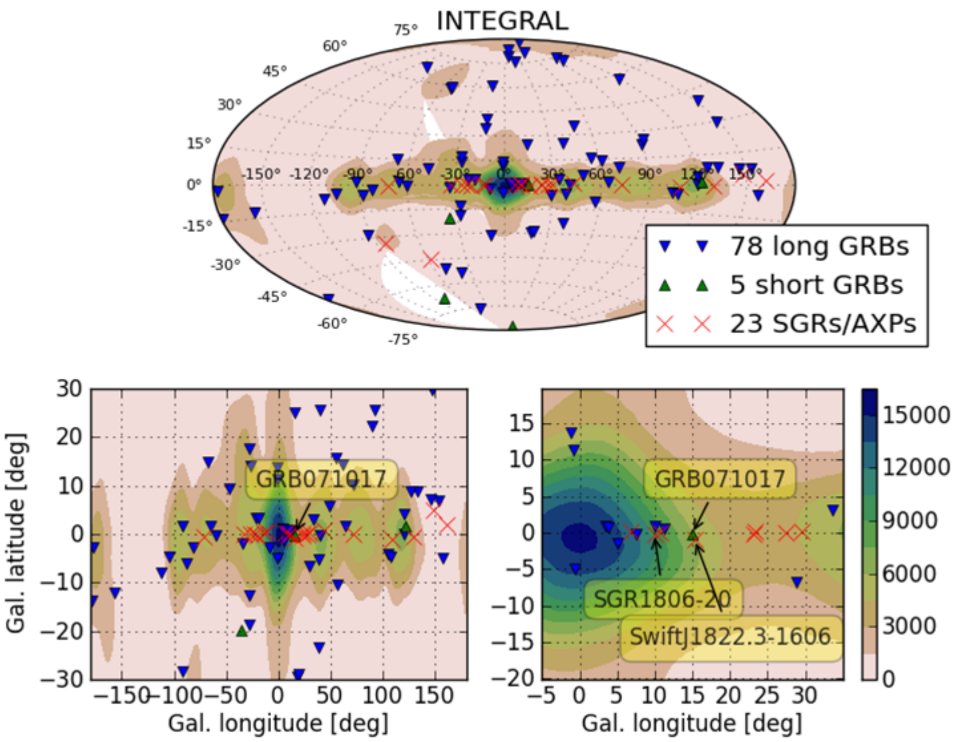

Figure 22: INTEGRAL GRB/SGR skymap (including 83 GRB) overlaid with sky exposure (Topinka & Hanlon, priv. communication, 2012).

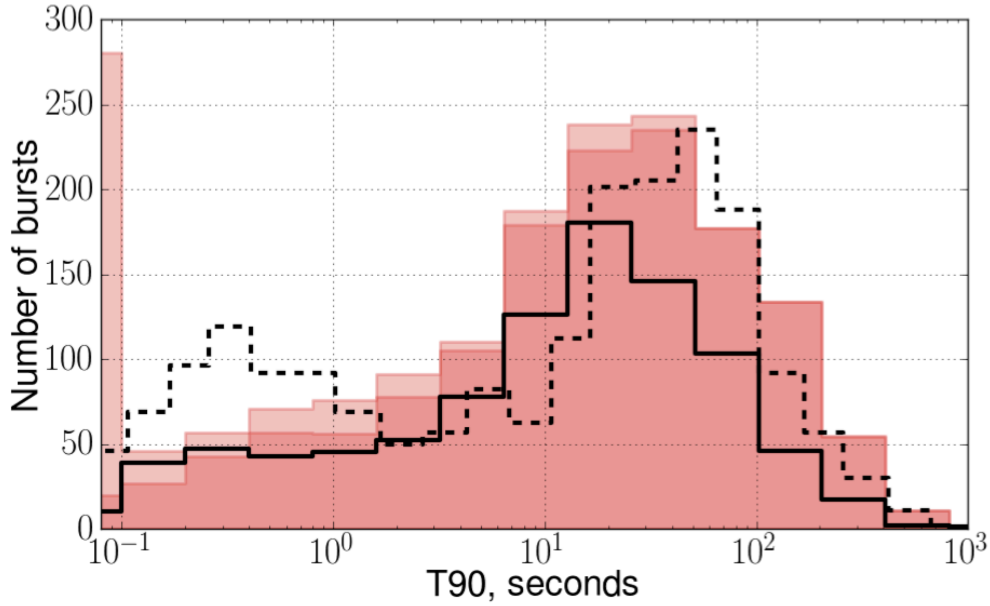

Figure 23: GRB detected by the SPI anticoincidence system: distribution of T90 durations. Dark and light shadings of the filled region correspond to 5 and 3 sigma confidence level for the event not being a spike. Solid black curve is for the confirmed bursts. The distribution of durations of GRBs from BATSE 4B GRB sample, scaled to match the normalization of the ACS sample, is shown by the black dashed line (Savchenko et al., A&A 541, 122, 2012).

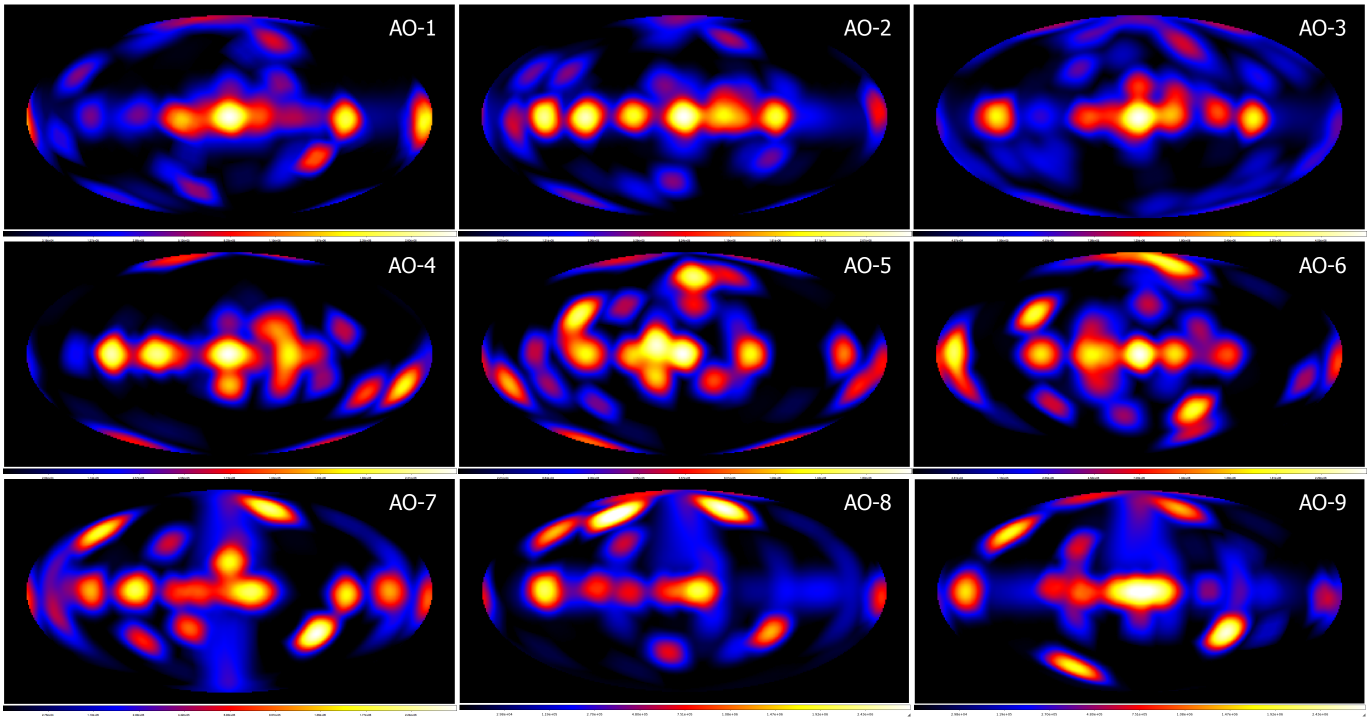

Figure A1: INTEGRAL sky exposure maps (IBIS, partially coded field of view) in galactic co-ordinates for AO-1 (2003) until AO-9 (2012). Exposure scale: 0 ks to ~ 3 Ms.

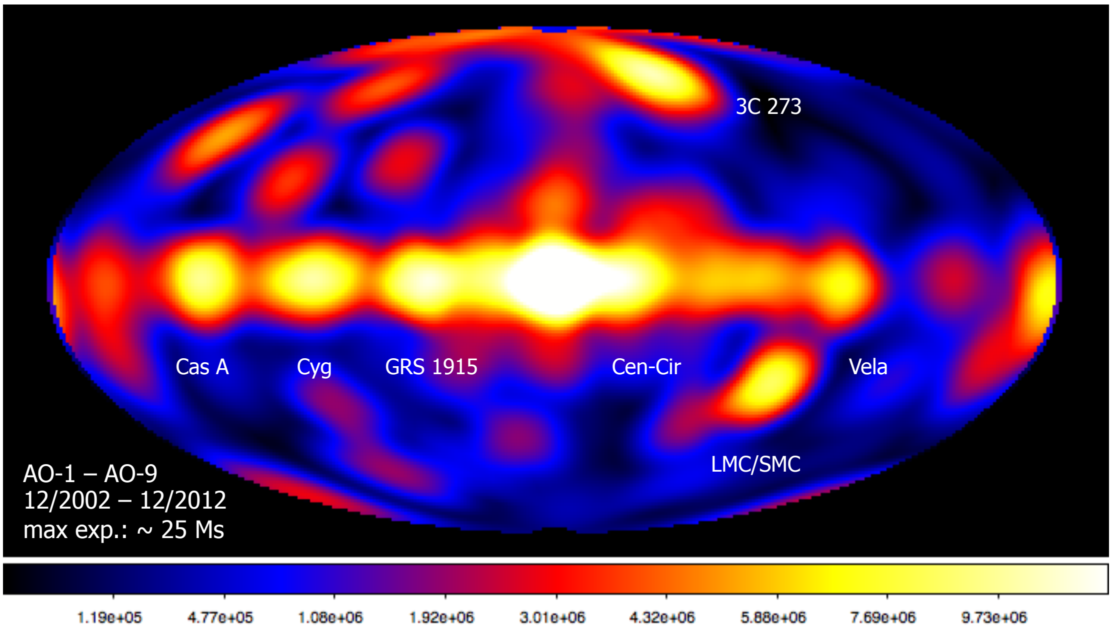

Figure A2: Integrated exposure map (IBIS, partially coded field of view) in galactic co-ordinates from AO-1 until AO-9 (from 30 December 2002 until 31 December 2012). The maximum exposure in the GC area is ~ 25 Ms. Units of exposure are in [s].

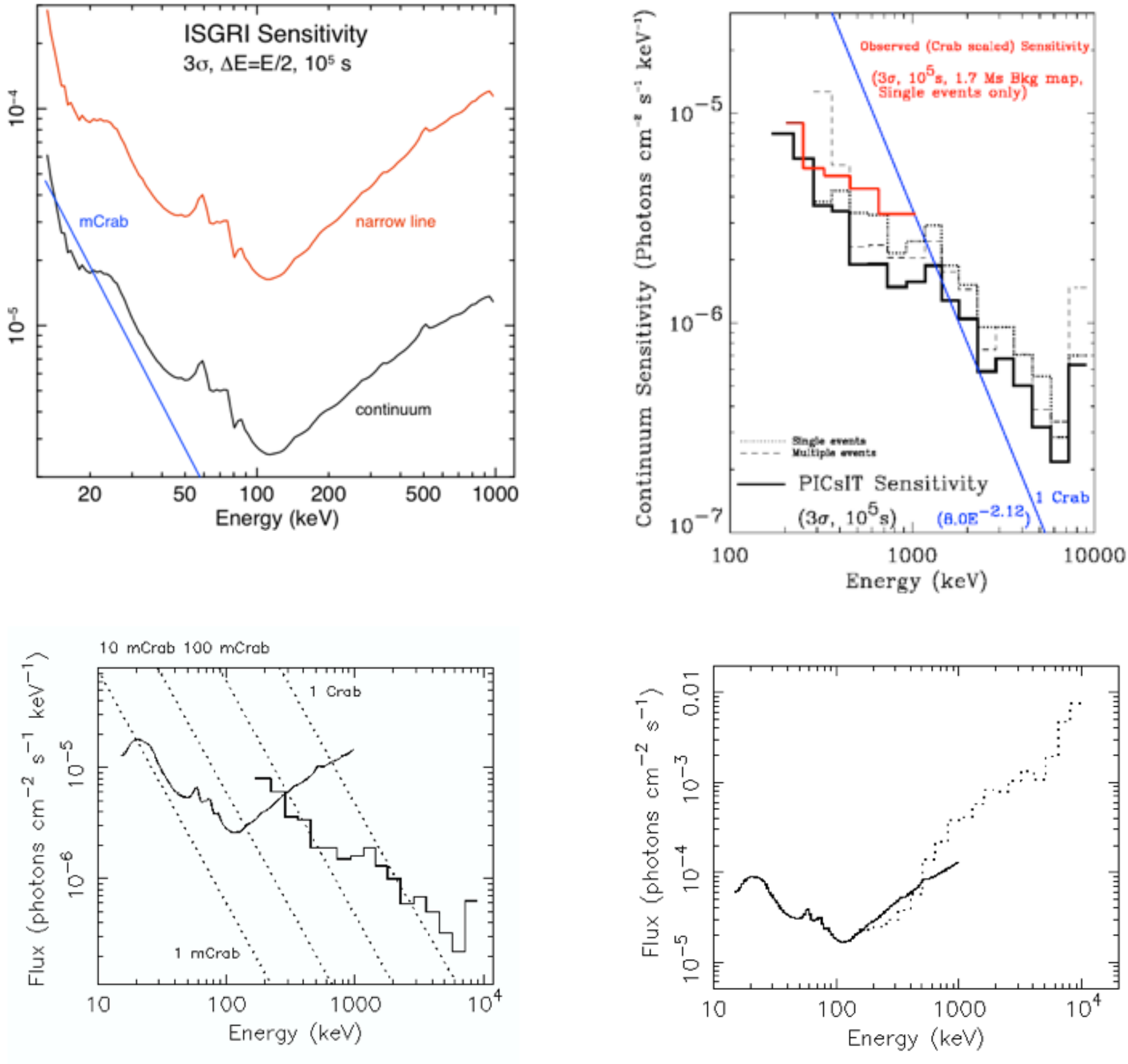

Figure A3: Sensitivity of INTEGRAL/IBIS. Top left: IBIS/ISGRI continuum (black: ph/cm²/s/keV) and narrow line sensitivity (red: ph/cm²/s) derived from 77 ks of empty field observations. Top right: IBIS/PICsIT statistically limited continuum sensitivity is given by the black histograms, from single events (dotted), multiple events (dashed), and combined (solid), all scaled to the in-flight background count rate, and compared with the sensitivity obtained by scaling from Crab observations (red; single events only). Bottom panels: IBIS broadband sensitivity as derived from empty field observations for a 3σ detection in 10^5 s for a continuum source (ΔE=E/2; left) and a narrow line (right). Systematic uncertainties (e.g., uniformity) are not taken into account. Reference fluxes are for a power law Γ=-2.

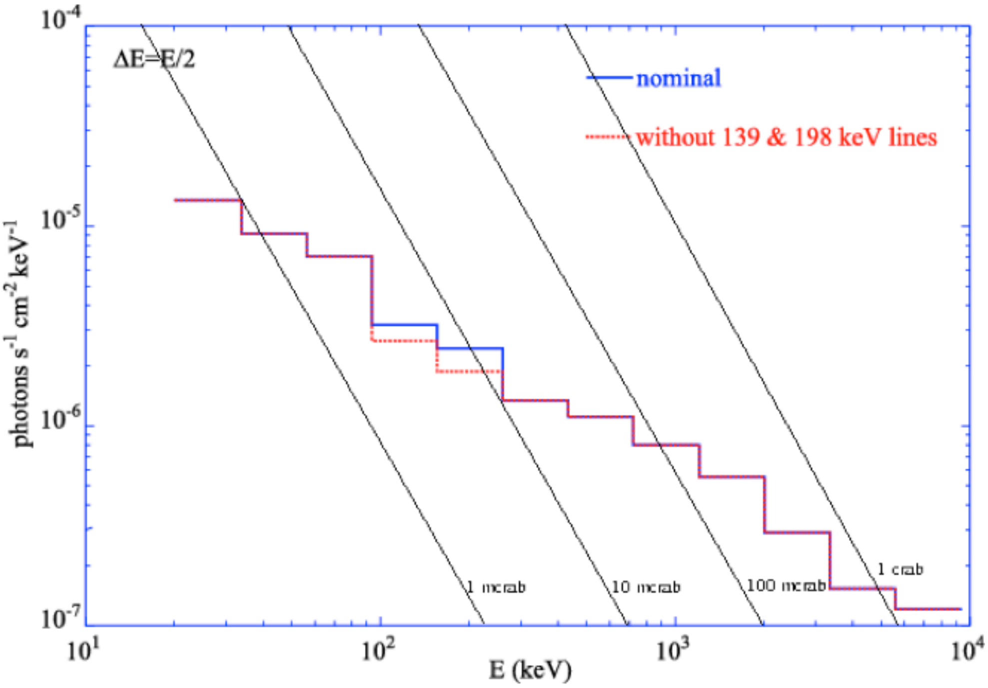

Figure A4: Continuum sensitivity of INTEGRAL/SPI for an on-axis, 3σ detection in 10^6 seconds. Fluxes are for ΔE=E/2. Dashed lines indicate extrapolation from X-rays using a power law with a photon index of -2.1 for 1, 10 and 100 mCrab, respectively. Corrections for failures of detector elements, source aspect angle and dithering must be applied when necessary.

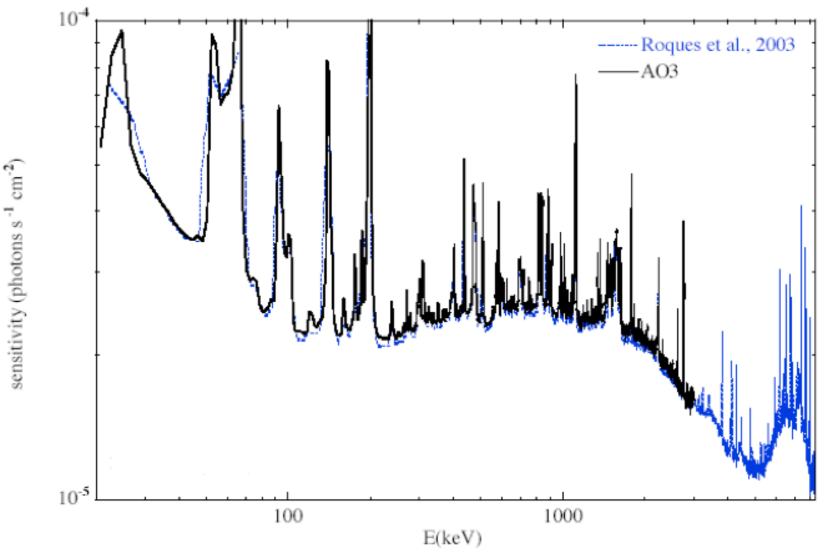

Figure A5: INTEGRAL/SPI 3σ sensitivity (statistical) to lines narrow compared with the instrument resolution for an on-axis point source, based on the combination of single (SE) and multiple (ME2) events. Integration time is 10^6 seconds for each data set. Corrections for failures of detector elements, source aspect angle and dithering must be applied.

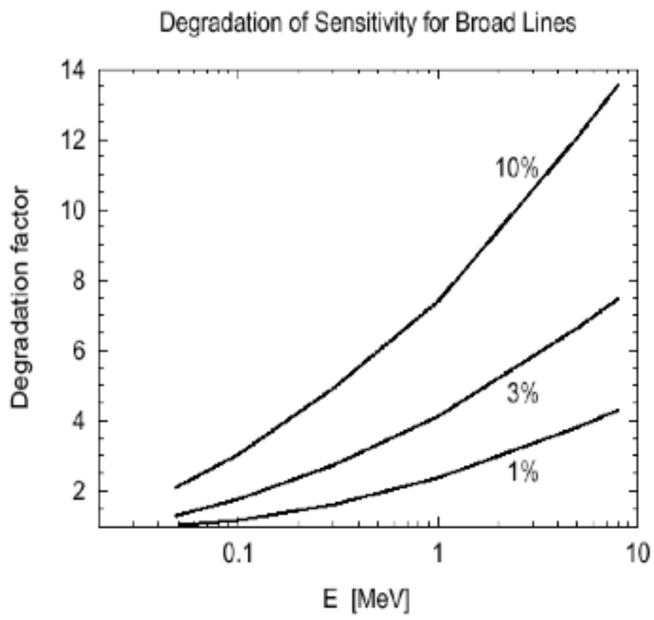

Figure A6: The SPI line sensitivity to broad lines is reduced compared to that for narrow lines as the line flux is distributed over multiple energy bins. For example, for a broad line at 1 MeV with a width of 3% of the line energy (30 keV), the line sensitivity is reduced by a factor ~4, compared to the value given in Figure A5.

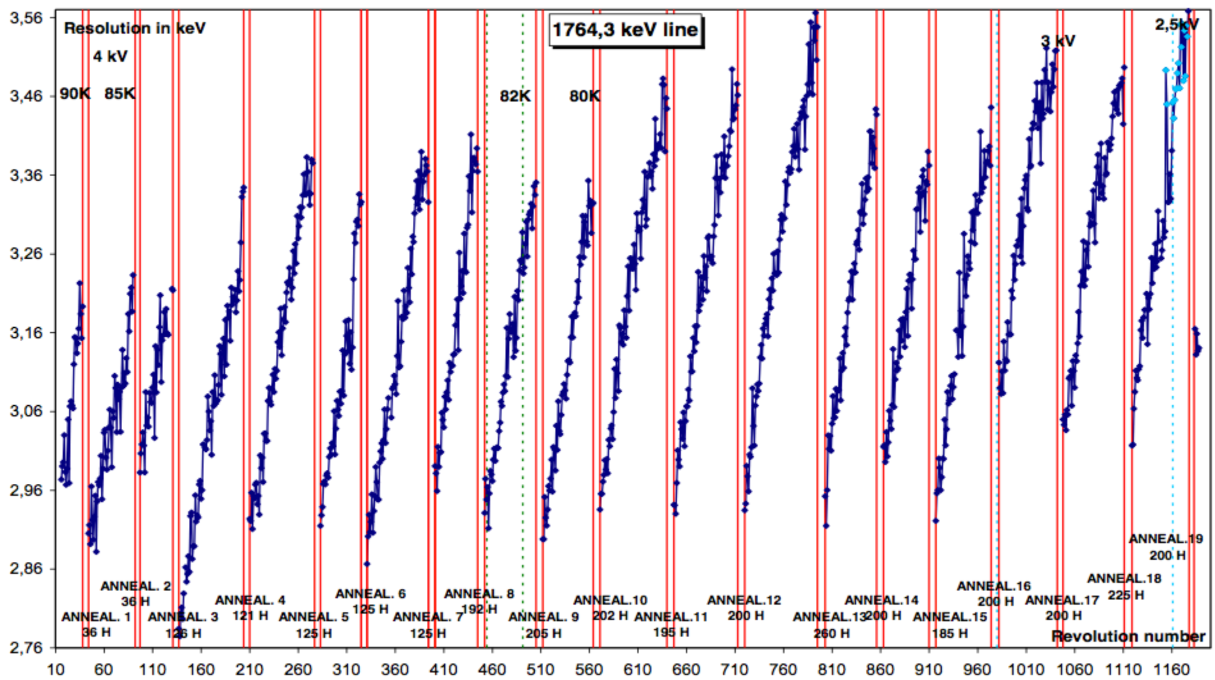

Figure A7: Evolution of the SPI energy resolution at 1764.3 keV since end of commissioning phase (orbital revolution #10). Until June 2012, nineteen annealing cycles (red vertical bars) have been successfully performed consistently recovering the nominal pre-launch energy resolution.

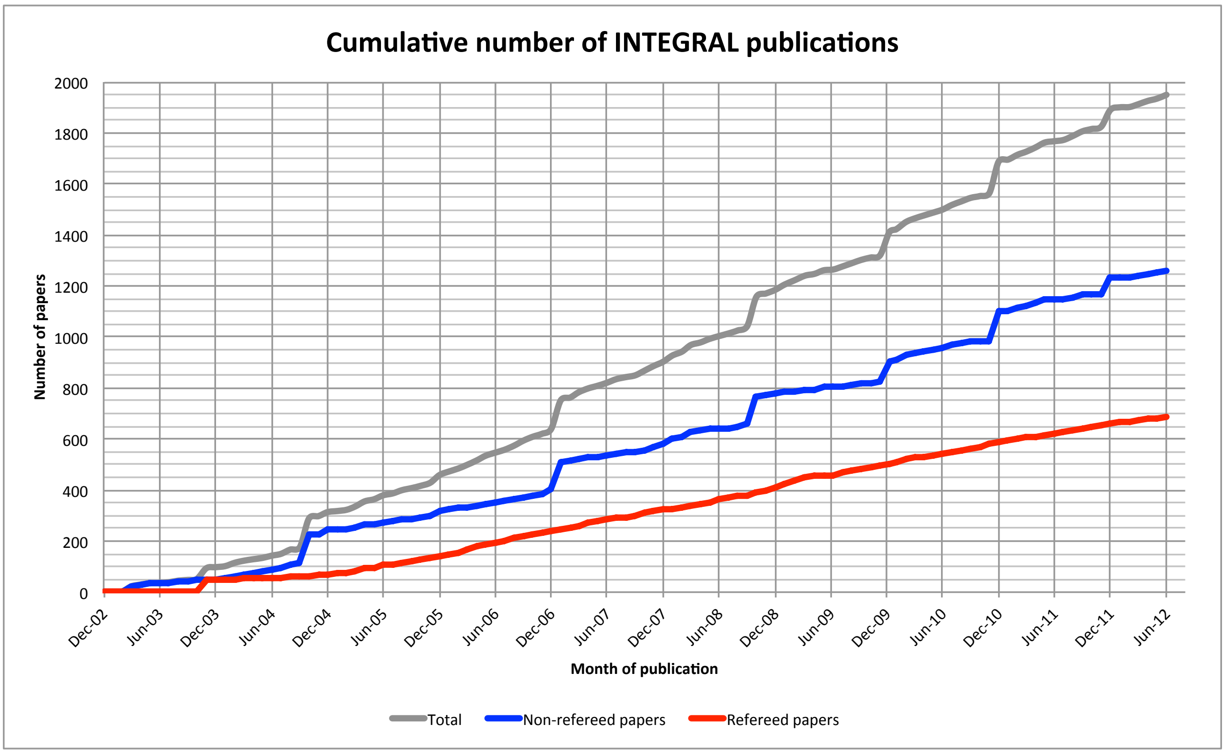

Figure A8: INTEGRAL scientific publications (690 refereed papers, 1260 non-refereed papers, 1950 in total), from launch (October 2002) until June 2012. (from http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname=Integral&libid=450176be03)

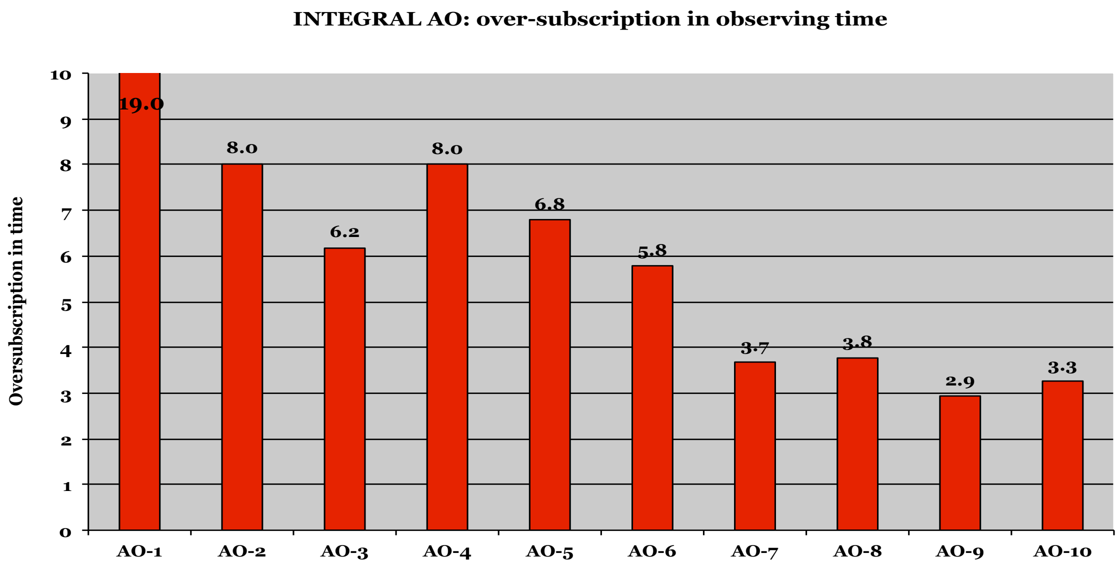

Figure A9: The over-subscription of INTEGRAL observing time remains at a high value reflecting the continued interest of the science community.

Table 1: INTEGRAL science and payload: complementarity

Instrument	Energy range	Main purpose
Spectrometer SPI	18 keV - 8 MeV	Fine spectroscopy of narrow lines
		Study diffuse emission on >1° scale
Imager IBIS	15 keV - 10 MeV	Accurate point source imaging
		Broad line spectroscopy and continuum
X-ray Monitor JEM-X	3 - 35 keV	Source identification
		X-ray monitoring of high-energy sources
Optical Monitor OMC	500 - 600 nm (V-band)	Optical monitoring of high-energy sources

Table 2: Key parameters for SPI & IBIS

Parameter	SPI	IBIS
Energy range	18 keV - 8 MeV	15 keV – 10 MeV
Detector	19 Ge detectors[iv] (6×6×7 cm^3), @ 85K	16384 CdTe detectors (4×4×2 mm^3), 4096 CsI dets (8.55×8.55×30 mm^3)
Detector area (cm^2)	500[v]	2600 (CdTe), 3000 (CsI)
Spectral resolution (FWHM)	3 keV @ 1.7 MeV	8 keV @ 100 keV
Field of View (fully coded)	16° (corner to corner)	8.3° × 8.0°
Angular resolution (FWHM)	2.5° (point source)	12'
Source location (radius)	< 1.3° (depending on source strength)	30"@100 keV (50σ source) 3' @100 keV (5σ source)
Absolute timing accuracy (3σ)	~130 µs	~90 µs
Mass (kg)	1309	746
Power [max/average] (W)	385/110	240/208

Table 3: Key parameters for JEM-X and OMC

Parameter	JEM-X	OMC
Energy range	3 keV – 35 keV	500 nm - 600 nm
Detector	Microstrip Xe/CH_4-gas (1.5 bar)	CCD + V-filter
Detector area	500 cm^2 for each of the two JEM-X detectors	CCD: (2055 × 1056) pixels Imaging area: (1024 ×1024)
Spectral resolution (FWHM)	3.6 keV @ 22 keV	--
Field of view (fully coded)	4.8°	5.0° × 5.0°
Angular resolution (FWHM)	3'	23"
10s source location (radius)	1' (90% confidence, 15σ source)	2"
Absolute Timing accuracy	~1 ms	> 3 s
Mass (kg)	65	17
Power [max/average] (W)	50/37	26/17

Author	Title	Reference	Citations
C. Boehm et al.	MeV dark matter: has it been detected ?	PhRvL 92, 1301, 2004	246
A.J. Bird et al.	The 3rd IBIS/ISGRI soft gamma-ray survey catalogue	ApJS 170, 175, 2007	214
R. Diehl et al.	Radioactive ^{26}Al from massive stars in the Galaxy	Nature 439, 45, 2006	205
J. Knödlseder et al.	The all-sky distribution of 511 keV electron-positron annihilation emission	A&A 441, 513, 2005	184
P. Jean et al.	SPI/INTEGRAL measurements of 511 keV line emission from the 4th quadrant of the Galaxy	A&A 407, 55, 2003	182
J. Knödlseder et al.	Early SPI/INTEGRAL constraints on the morphology of the 511 keV line emission in the 4th galactic quadrant	A&A 411, 457, 2003	139
D.P. Finkbeiner & N. Weiner	Exciting dark matter and the INTEGRAL/SPI 511keV signal	PhRvD 76, 3519, 2007	131
J.F. Beacom & H. Yüksel	Stringent Constraint on Galactic Positron Production	PhRvL 97, 1102, 2006	118
V. Sguera et al.	INTEGRAL observations of recurrent fast X-ray transient sources	A&A 444, 221, 2005	117
P. Jean et al.	Spectral analysis of the Galactic e+e- annihilation emission	A&A 445, 579, 2006	110
L. Kuiper et al.	Discovery of Luminous Pulsed Hard X-Ray Emission from Anomalous X-Ray Pulsars 1RXS J1708-4009, 4U 0142+61, and 1E 2259+586 by INTEGRAL and RXTE	ApJ 645, 556, 2006	110
V. Sguera et al.	Unveiling Supergiant Fast X-Ray Transient Sources with INTEGRAL	ApJ 646, 452, 2006	106
A.J. Bird et al.	The 4th IBIS/ISGRI soft gamma-ray survey catalogue	ApJS 186, 1, 2010	106
S. Sazonov et al.	Hard X-ray luminosity function and absorption distribution of nearby AGN: INTEGRAL all-sky survey	A&A 462, 57, 2007	105
A.J. Bird et al.	The 2nd IBIS/ISGRI soft gamma-ray survey catalogue	ApJ 636, 765, 2006	103
A.J. Bird et al.	The 1st IBIS/ISGRI soft gamma-ray galactic plane survey catalogue	ApJ 607, 33, 2004	103
R. Walter et al.	XMM-Newton and INTEGRAL observations of new absorbed supergiant high-mass X-ray binaries	A&A 453, 133, 2006	101
S. Sazonov et al.	An apparently normal GRB with an unusually low luminosity	Nature 430, 646, 2004	95
E. Treister et al.	The Space Density of Compton-thick AGN and the X-ray background	ApJ 696, 110, 2009	94
R. Krivonos et al.	INTEGRAL/IBIS all-sky survey in hard X-rays	A&A 475, 775, 2007	94

Table 4: Twenty most cited publications using INTEGRAL scientific data (as of August 2012, instrument descriptions excluded) using http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname=Integral&libid=450176be03. The majority of cited publications address the 511 keV emission and IBIS source catalogues

Table 5: Press and news releases on INTEGRAL (2002 – 2012)

- ^{44}Ti line emission from SN 1987A, ESA News, Autumn 2012 (co-ordinated with publication by Nature)
- Explore the high-energy universe – competition results, ESA Science & Technology, 31 May 2012.
- Massive glitch moves magnetar modeling forward, ESA Science & Technology, 12 April 2012.
- INTEGRAL reveals new facets of the Vela pulsar wind nebula, ESA Science & Technology, 25 Jan 2012.
- INTEGRAL deciphers diffuse signature of cosmic-ray electrons, ESA Science & Technology, 21 Dec 2011.
- ESA spacecraft reveal new anatomy around a black hole, ESA News, 29 September 2011.
- L'environnement d'un trou noir supermassif révélé, CNRS, 29 September 2011.
- INTEGRAL observations suggest unified model for Active Galactic Nuclei requires a rethink, ESA Science & Technology, 2 August 2011.
- INTEGRAL challenges physics beyond Einstein, ESA News, 30 June 2011.
- INTEGRAL spots matter a millisecond from doom, ESA News, 24 March 2011.
- INTEGRAL discovers γ-rays originating from black hole jets, ESA Science & Technology, 24 March 2011.
- The Crab nebula: standard candle no more ?, ESA Science & Technology, 12 January 2011.
- NASA satellites find high-energy surprises in 'constant' Crab nebula, NASA-FERMI News, 12 January 2011.
- INTEGRAL helps unravel the tumultuous recent history of the solar neighbourhood, ESA Science & Technology, 26 November 2010.
- Europe maintains its presence on the final frontier, ESA Space Science, 22 November 2010.
- INTEGRAL completes the deepest all-sky survey in hard X-rays, ESA Science & Technology, 11 August 2010.
- New INTEGRAL catalogue expands gamma-ray horizons, ESA Science & Technology, 07 July 2010.
- INTEGRAL researcher scoops Zeldovich Medal, ESA Science & Technology, 23 June 2010.
- The turbulent past of the Milky Way's black hole, CNRS, 27 May 2010
- Integral disproves dark matter origin for mystery radiation, ESA News, 22 July 2009.
- Galactic positron annihilation not a signal of dark matter, ESA Science & Technology, 22 July 2009.
- At last! After 10 years a new Soft Gamma Repeater is observed, ESA Science & Technology, 16 June 2009.
- Giant eruption reveals 'dead' star, ESA Space Science News, 16 June 2009.
- Galaktisches Röntgenlicht stammt aus Sternen, Max-Planck Gesellschaft, 29 April 2009
- Integral détecte pour la première fois la polarisation d'un sursaut gamma, CNRS, 23 April 2009.
- INTEGRAL sees variable polarization from GRB041219A, ESA Science & Technology, 03 April 2009.
- Dissecting a stellar explosion, ESA Space Science News, 03 April 2009.
- Magnetar observed during outburst thanks to rapid response of INTEGRAL, ESA Science & Technology, 27 January 2009.
- XMM-Newton and INTEGRAL clues on magnetic powerhouses, ESA Space Science News, 14 Nov 2008.
- Faint gamma-ray bursts do actually exist, ESA Space Science News, 13 October 2008.
- INTEGRAL locates origin of high-energy emission from Crab Nebula, ESA Space Science News, 29 Aug 2008.
- Origin of high energy emission from the Crab Nebula identified, ASI, 28 August 2008.
- Astronomers may have glimpsed tiny star's surface, ESA Space Science News, 17 June 2008.
- INTEGRAL reveals exotic and dusty binary systems, ESA Space Science News, 05 June 2008.
- Cosmic supermagnet spreads mysterious Morse code, SRON Press Release, 20 May 2008.
- INTEGRAL: Stellar winds colliding at our cosmic doorstep, ESA Space Science News, 20 February 2008.
- X-rays betray giant particle accelerator in the sky, ESA Space Science News, 24 January 2008.
- Anti-Elektronen in der Galaxis, Max-Planck Gesellschaft, 10 January 2008.

Table 5: Press and news releases on INTEGRAL (2002 – 2012), continued

- Le satellite Intégral révèle une fabrique d'antimatière au sein de la Voie lactée, CNRS, 9 Jan 2008.
- INTEGRAL discovers the galaxy's antimatter cloud is lopsided, ESA Space Science News, 9 Jan 2008.
- Understanding our neighbourhood in the universe, ESA Space Science News, 17 December 2007.
- Extension of ESA's INTEGRAL and XMM-Newton missions approved, ESA Space Science News, 14 November 2007.
- New scientific riches from INTEGRAL, ESA Space Science News, 07 November 2007.
- Science with INTEGRAL - five years on, ESA Space Science News, 17 October 2007.
- Gamma-ray lighthouse at the edge of our universe, ESA Space Science News, 03 October 2007.
- Radioaktives Eisen - Fenster ins Innere der Sterne, Max-Planck-Gesellschaft, SP /2007 (89), 26 June 2007.
- Radioactive iron, a window to the stars, ESA Space Science News, 25 June 2007.
- INTEGRAL expands our view of the gamma-ray sky, ESA Space Science News, 20 February 2007.
- INTEGRAL points to the fastest spinning neutron star, ESA Space Science News, 16 February 2007.
- INTEGRAL sees the Galactic centre playing hide and seek, ESA Space Science News, 18 January 2007.
- INTEGRAL catches a new erupting black hole, ESA Space Science News, 27 November 2006.
- ESA steps towards a great black hole census, ESA Space Science News, 07 September 2006.
- Where are the supermassive black holes hiding?, ESA Space Science News, 26 July 2006.
- INTEGRAL sees a GRB out of the corner of its eye, ESA Space Science News, 16 June 2006.
- INTEGRAL catches stellar 'corpses' by the tail, ESA Space Science News, 16 March 2006.
- INTEGRAL grijpt ‘dode sterren’ bij de start, SRON press release, 16 March 2006.
- INTEGRAL looks at Earth to seek source of cosmic radiation, ESA Space Science News, 13 Feb 2006.
- Exceptional manoeuvres enable unique INTEGRAL science, ESA Space Science News, 10 Feb 2006.
- INTEGRAL identifies supernova rate for Milky Way, ESA Space Science News, 05 January 2006.
- ESA's INTEGRAL and XMM-Newton missions extended, ESA Space Science News, 05 Dec 2005.
- INTEGRAL reveals new class of supergiant X-ray binary stars, ESA Space Science News, 16 Nov 2005.
- INTEGRAL: three years of insight into the violent cosmos, ESA Space Science News, 17 October 2005.
- Star eats companion, ESA Space Science News, 06 September 2005.
- Three satellites needed to bring out one 'shy star', ESA Space Science News, 13 July 2005.
- Gamma-Blitz traf die Erde, Max-Planck-Gesellschaft, SP 8/2005 (26), 18 February 2005.
- Un monstre cosmique, Université de Genève, communiqué de presse, 31 January 2005.
- Ein Schwarzes Loch mit greller Vergangenheit, Max-Planck Gesellschaft, 26 January 2005.
- INTEGRAL rolls back history of Milky Way's super-massive black hole, ESA SNR-2-2005, 26 Jan 2005.
- Ungewöhnliche Gammastrahlenblitze entdeckt , Max-Planck Gesellschaft, 05 August 2004.
- ESA's INTEGRAL detects closest cosmic gamma-ray burst, ESA SNR-18-2004, 05 August 2004.
- ESA's high-energy observatories spot doughnut-shaped cloud with a black-hole filling, ESA SNR-16-2004, 20 June 2004.
- Gamma-Observatorium INTEGRAL legt Herz der Milchstraße frei , MPG, 17 March 2004.
- ESA's INTEGRAL solves thirty-year old gamma-ray mystery, ESA SNR-5-2004, 17 March 2004.
- ESA's new view of the Milky Way - in gamma rays!, ESA SNR-23-2003, 10 November 2003.
- ESA's INTEGRAL discovers hidden black holes, ESA SNR-21-2003, 17 October 2003.
- A gamma-ray burst bonanza, ESA Space Science News, 24 March 2003.
- INTEGRAL's first look at the gamma-ray Universe, ESA IN-10-2002, 18 December 2002.
- ESA presents INTEGRAL's first images, ESA PR-79-2002, 11 December 2002.
- Europe opens a window onto a violent Universe, ESA PR-66-2002, 17 October 2002.
- ESA's INTEGRAL satellite ready for lift-off from Baikonur, ESA PR-63-2002, 4 October 2002.
- INTEGRAL -tracking extreme radiation across the Universe, ESA IN-8-2002, 1 October 2002.
- Rosetta and INTEGRAL getting ready for launch, ESA PR-42-2002, 7 June 2002.
- INTEGRAL Science Data Centre to be presented to the press, ESA PR-20-2002, 27 March 2002.