The *INTEGRAL*/IBIS and *Swift*/XRT long-lasting partnership

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ABSTRACT

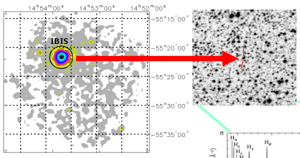
The last 20 years have been studded with a wealth of unexpected results in high energy astrophysics, as typified by discoveries made by Swift/INTEGRAL and other high-energy observatories. Here we would like to highlight the major role played by Swift/XRT in supporting INTEGRAL results and in consolidating new findings, allowing a better classification/characterization of unknown sources, and studying known ones, thus paving the way to a better knowledge of the sky above 100 keV. Few case studies and some overall statistics are presented to describe this 20-year-long journey.

SOURCE IDENTIFICATION/CLASSIFICATION

Swift/XRT data have been used primarily to pinpoint X-ray counterparts to INTEGRAL sources, by reducing the positional uncertainty; as a by-product, this allowed optical classification of many objects as well as their broad-band spectral characterisation. Up to now we have been able to identify, classify, and characterise more than 300 INTEGRAL unknown/unclassified sources. The method used is highlighted in the following two examples, describing one of the closest and one of the furthest objects detected and classified so far.

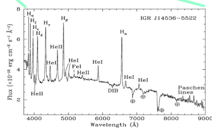
GALACTIC ASSOCIATION

IGR J14536-5522 (D=190 pc)



0.3-10 keV XRT image

IGR J14536-5522 is a newly discovered IBIS source classified as a magnetic Cataclysmic Variable (CV) of the Polar type through optical and imaging spectroscopy (Masetti et al. 2006, A&A, 459, 21).

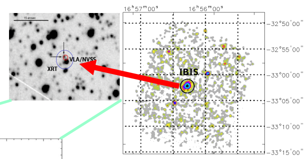


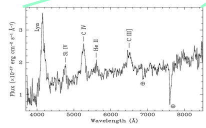
By combining XRT and IBIS data, we were able to characterise the source spectrum (0.3-100 keV): a soft black body component (kT ~60 eV), plus a hard bremsstrahlung one (kT ~16 keV). We also find the presence of a complex absorber: one totally (with N_H ~7 x 10^{20} cm^{-2}) and one partially (with N_H ~1.2 x 10^{23} cm^{-2}) covering the source (~58%) (Landi et al. 2009, MNRAS, 392, 630).

EXTRAGALACTIC ASSOCIATION

IGR J16562-3301 (z=2.4)

IGR J16562-3301 is instead a blazar at z=2.4; at this distance the source 20-100 keV luminosity is $\sim10^{48}$ erg s^{-1}, making this one of the most distant and brightest object in the hard X-ray Universe.





The source broad-band spectrum (XRT+IBIS data), can be described by a power law (Γ ~1.6) with a hint of spectral curvature below ~2 keV, possibly due to intrinsic absorption (N_H ~7×10^{22} cm^{-2}) local to the source or to a slope change (ΔΓ ~1) (Masetti et al. 2008, A&A, 480, 715).

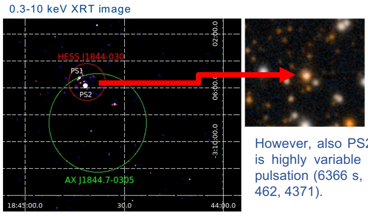
BRIDGING THE GAP FROM LOW TO HIGH FREQUENCY WAVEBANDS

A number of INTEGRAL sources are detected up to GeV and even TeV energies. Combined XRT/IBIS data allow us to study these sources across wavebands as illustrates in the following two examples, where X-rays data provide information on the environment of a keV/TeV Galactic source and to explore the nature of a new keV/GeV extragalactic one.

AX J1844.7-0305 = HESS J1844-030

HESS J1844-030 is an unidentified point-like TeV source spatially associated with an IBIS/ASCA object (AX J1844.7-0305, Malizia et al. 2021, Universe, 7, 135). XRT observations indicate the presence of two sources (PS1 and PS2, see left figure) in the combined error circles, as well as possible diffuse emission as also confirmed by Chandra and XMM-Newton observations (Petriella, 2019, A&A, 626, A65).

0.3-10 keV XRT image



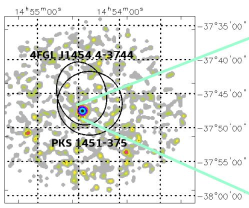
So far the best interpretation for this source is that of a SNR/PWN (the diffuse X-ray emission) powered by a pulsar (PS1).

However, also PS2 is an interesting object: it is highly variable in X-rays and shows slow pulsation (6366 s, Israel et al., 2016, MNRAS, 462, 4371).

Its optical counterpart (see SDSS image, right figure) can be located to 1.6 Kpc and associated with an asymptotic giant branch star using Gaia data/colours (G=0.78, BP-RP=3.25); these stars are not expected to be X-ray emitters, unless they are in a binary system where coronal activity or accretion onto a companion produce high-energy emission. We therefore cannot discard PS2 as a possible association with the ASCA/IBIS source and possibly also with the TeV emitter.

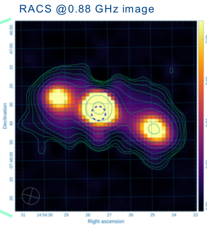
PKS 1451-375 = 4FGL J1454.4-3744

PKS 1451-375/4FGL J1454.4-3744 was found by cross-correlating the latest Fermi catalogue (4FGL DR4) and all recent INTEGRAL surveys. The source is a Seyfert 1.2 at z=0.314, whose 2-10 keV XRT spectrum is characterised by a power law with a flux of 3.18 x 10^{-12} cm^{-2} s^{-1}. A radio image from RACS @0.88 GHz image (right figure) shows a clear double lobe morphology (400 kpc in extension) around a strong core associated with the X-ray object, making this one extra example of the rare class of mis-aligned GeV AGNs (Molina et al. 2024, Mem. S.A.It., Vol. 75, 282).



0.3-10 keV XRT image

RACS @0.88 GHz image

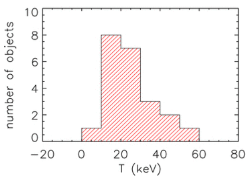


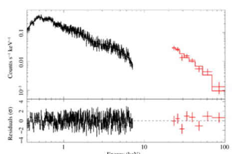
BROAD-BAND STUDIES

By joining INTEGRAL/IBIS and Swift/XRT observations, we were able to study, over a wide energy band (0.3-100 keV), the behaviour of some Galactic as well as extragalactic source population, thus characterising their average spectral properties.

CATACLYSMIC VARIABLES AT HIGH ENERGIES

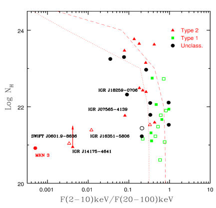
INTEGRAL led to the discovery of several new CVs, most of which turned out to be of the Intermediate Polar (IP) type, thus confirming that these objects are strong emitter in hard X-rays. Thanks to the wide energy coverage, obtained by combining XRT and IBIS data, it was possible, for the first time, to measure simultaneously the soft and hard components of a set of 22 CVs and estimate their temperatures. The soft emission is well described by a blackbody with temperatures in the range ~60–120 eV; the hard emission is indeed well modelled with a bremsstrahlung with average kT ~20 keV (figure on the right depicts the temperature distribution; Landi et al. 2009, MNRAS, 392, 630). In several cases the best-fit model includes also a complex absorber: one totally and one partially covering the source; only in a few cases do we find evidence for the presence of an iron line around 6.4 keV. Lower figure on the left shows the best-fit model for IGR J17303-0601.



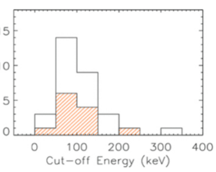


The measured X-ray (2–10 keV) and soft gamma-ray (20–100 keV) luminosities of our sample are found to span from 10^{32} to 10^{33} erg s^{-1}.

EXTRAGALACTIC CASE



In the AGN case, XRT+IBIS data allowed, for the first time, to define a diagnostic tool: N_H vs. F(2-10 keV)/F(20-100 keV) to discover highly absorbed objects i.e. Compton-thick ones (Malizia et al. 2007, ApJ, 668, 81). In the figure, open symbols represent upper limits of the column densities while lines correspond to expected values for an absorbed power law with photon index 1.5 (dot) and 1.9 (dash). Objects with flux ratio below 0.1 are Compton-thick.



At the same time, broad-band spectral analysis of bright objects provided the first stringiest constrain on the population high-energy cut-off (Malizia et al, 2014, ApJ, 782L, 25). The peak of Ec (~100 keV) has been confirmed by analysing simultaneous XRT and NuSTAR data (see inset in the figure; Molina et al., 2019, MNRAS, 484, 2735).

In the figure, the diagonally hatched histogram represents sources for which only lower limits on Ec are available.