Unveiling obscured accretion with a new soft gamma-ray survey

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Abstract: Accretion in active galactic nuclei (AGNs) is obscured by gas and dust that surround the central super-massive black hole. This intervening matter efficiently absorbs the primary photons up to X-ray energies, while at higher energies (> 15 keV) a larger fraction of photons pierces through. At these energies most sensitive large area surveys are performed by the two coded-masks telescopes the *INTEGRAL* Soft Gamma-Ray Imager (IBIS/ISGRI) and the *Swift* Burst Alert Telescope (BAT). However coded-mask detectors suffer from heavy systematic effects (errors) preventing them from reaching their theoretical limiting sensitivity. Here we show that BAT and IBIS/ISGRI observations can be combined with resampling, merging, and cross-calibration techniques that minimize the errors and produce the nowadays deepest large area survey at soft gamma-rays. This survey of our virtual new gamma-ray mission allows detecting the obscured AGNs. It extends over a wide sky area of 6200 deg^2 sampling 113 sources. The flux sensitivity is 2-4 times better than current parent surveys. We discuss the evolution of AGNs through the luminosity function. Our results are then compared to other missions. We discuss also the expected results when applying this survey to the entire extragalactic sky.

Keywords: Surveys, Active Galactic Nuclei.

1 Introduction

Active Galactic Nuclei (AGNs) host a super-massive black hole in their center. Accretion onto this black hole provides a large contribution to the energy radiated over cosmic time. Indeed, the shape and the intensity of the diffuse extragalactic X-ray emission (the so-called Cosmic X-ray Background), predicts that a large fraction of the AGN population is obscured by gas and dust that surrounds the central engine of the AGN. This intervening matter efficiently absorbs the primary radiation from the central engine. Therefore, surveys at energies below 10 keV are biased against obscured AGN. Instead surveys at energies above 15 keV sample photons that are energetic enough to pierce through the absorbing matter. At these energies the current most sensitive available large area surveys are performed by the *Swift* [1] and the *INTEGRAL* [2] missions with their respective coded-mask detectors the Burst Alert Telescope (BAT) [3] and the Imager on Board the *INTEGRAL* Satellite (IBIS) [4] that hosts the *INTEGRAL* Soft Gamma-Ray Imager (ISGRI) [5].

However, imaging the sky with coded-mask telescopes has major drawbacks. The coded-mask, positioned on top of the pixellated detecter, blocks $\sim$50% of the incident photons causing and increase of statistical noise. Furthermore, because of their large collecting area, coded-mask telescope suffer also from large systematic effects (errors). As a consequence the detection of extragalactic sources is still challenging. The detection of the very weak emission of obscured AGNs, of the most distant blazars, and of Clusters of Galaxies is therefore a major aim. Here we show that it is possible to overcome the limits of coded-mask telescopes by combining the observations of BAT and of IBIS/ISGRI. We call the combined observations the SIX survey that stands for *Swift* – *INTEGRAL* hard X-ray survey. We show the results related to AGNs of this survey applied to an extragalactic field of 6200 deg^2.

2 Merging the observations of BAT and IBIS/ISGRI

The IBIS/ISGRI and the BAT coded-mask telescopes represent a major improvement for the imaging of the sky above 15 keV. The two imagers are close enough in design that their observations can be combined. IBIS/ISGRI operates in the energy range from 17 – 1000 keV, while BAT detects photons in the energy range 15 – 150 keV. We perform the SIX survey in the 18 – 55 keV energy range. The result is a new sky survey less susceptible to noise and artifacts deriving from the coded-mask systems. The three steps in performing the SIX survey are the following: 1) The independent sky images of IBIS/ISGRI and BAT are performed. We reduced IBIS/ISGRI data according to the standard Off-line Scientific Analysis (OSA) software[1] version 7.0 [6] and time dependent background models are obtained and subtracted [8, 9]. The BAT analysis method and software are described in [7]. 2) IBIS/ISGRI and BAT sky images are resampled by interpolating quadratically the nearest neighbor intensities [8, 9]. The matrix notation is given by:

$$I(x,y) = \begin{bmatrix} 1-x & x-u \end{bmatrix} \begin{bmatrix} I(u,v) & I(u,v+1) \\ I(u+1,v) & I(u+1,v+1) \end{bmatrix} \begin{bmatrix} 1-y \\ y-v \end{bmatrix} \quad (1$$

where $I(u,v)$, $I(u,v+1)$, $I(u+1,v)$ and $I(u+1,v+1)$ are known and $I(x,y)$ is the inferred intensity at an arbitrary point (x,y).

3) The resampled sky images of IBIS/ISGRI and BAT are cross-calibrated with the Crab spectrum. Finally, the two sky images from IBIS/ISGRI and BAT are merged that consists in simply summing the maps by weighting for the errors. A detailed description of this method can be found in [8]. Two major advantages are obtained by merging the

1. http://www.isdc.unige.ch/*INTEGRAL*/download/osa_doc

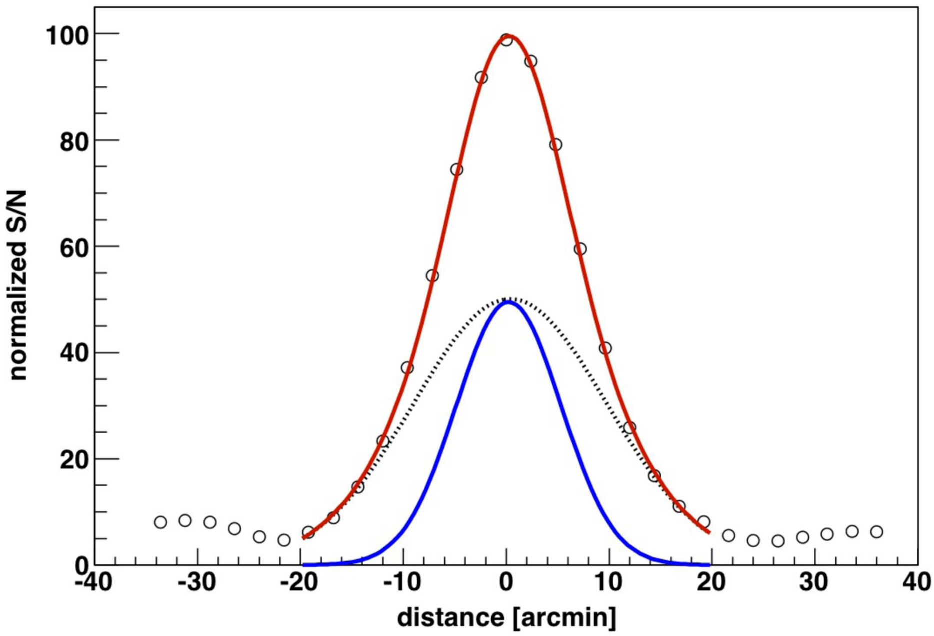

Figure 1: The *SIX* PSF (solid red line) is a linear combination of the BAT PSF (dotted gray line) and IBIS/ISGRI PSF (solid blue line).

observations of BAT and IBIS/ISGRI: 1) the exposure is greatly enhanced (sum of BAT and IBIS/ISGRI) and therefore the sensitivity is improved; 2) the systematic errors of both instruments are not correlated and therefore the resulting SIX survey suffers less from systematic uncertainties.

3 Results

We have applied the SIX survey to 6200 deg^2 of sky area. The area extends from the North Ecliptic Pole region to the COMA region. We have analyzed data from the 60 months observations of BAT [10]. IBIS/ISGRI data were analyzed spanning from the beginning of the mission (year 2002) to revolution 829 (year 2009). To give a first glance on the performances of the survey, we show in Figure 1 the resulting point spread function (PSF) that we extract.

The PSF is extracted from a large number of sources from the significance mosaic image without any preferred direction. This can be used to test the symmetry and the shape of the PSF. The single PSFs of the sources were normalized so that we can compute an overall mean PSF. The open circles in Figure 1 are the data points of the mean PSF. The PSF profile (red line) can be modeled by a linear combination of the BAT PSF (dotted line) and the IBIS/ISGRI PSF (blue line). The resulting shape is the SIX PSF that is symmetric with standard deviation of 6.8 arcmin.

The catalog of sources of the SIX survey contains in total 113 sources. It is composed of 74 Seyfert-like AGNs, 12 blazars, 5 Galaxies, 2 Galaxy clusters, 3 Galactic sources, 3 previously detected unidentified X-ray sources, and 14 unidentified sources. The results from the SIX survey are used to derive cosmological informations. The fit to our source number density corresponds to a power-law. By integrating this differential function we obtain an Euclidean slope (index 1.5). This corresponds to a non–evolving source population in the local Universe. This result is in good agreement with previous measurements [10, 11].
We have applied the V/V_{MAX} method proposed in [12] in order to determine the evolution of the AGN. With this method we find a constant source number–density within co–moving volumes. Therefore, the SIX AGNs do not show any evolution. In addition we have compiled the luminosity function. The function is fit with a broken power-law model. The best-fit parameters agree well with previous analysis [10].

The luminosity function of the SIX survey allows us also to make predictions on the results of more sensitive surveys. This is the case of the recently launched NuSTAR mission [13]. This mission carries for the first time hard X-ray focusing instruments. If our luminosity function of the SIX survey does not change strongly in normalization or slope the estimated number of AGN per square degree at energies $\sim$30 keV is $\sim$100 for a limiting flux of 10^{-14} erg cm^{-2} s^{-1}. In Figure 2 we plot the luminosity-redshift plane of Seyfert-like AGNs. Gray circles represent AGNs from the BAT survey, while the red filled circles are detected in the SIX survey. The squares represent predicted NuSTAR data [14] for narrow field surveys: magenta squares for a shallow survey, green squares for the COSMOS survey (2 deg^2), and blue squares for the ECDF-S survey (0.25 deg^2) assuming an exposure of 6.2 Msec. NuSTARs surveys will not compete with the SIX survey, but rather they will be complementary. Indeed, if applied to the whole sky the SIX survey will fill the redshift and luminosity gap between the current surveys of IBIS/ISGRI and BAT alone and the NuSTAR surveys. The absorbed SIX sources at low redshift are easy follow up targets for NuSTAR.

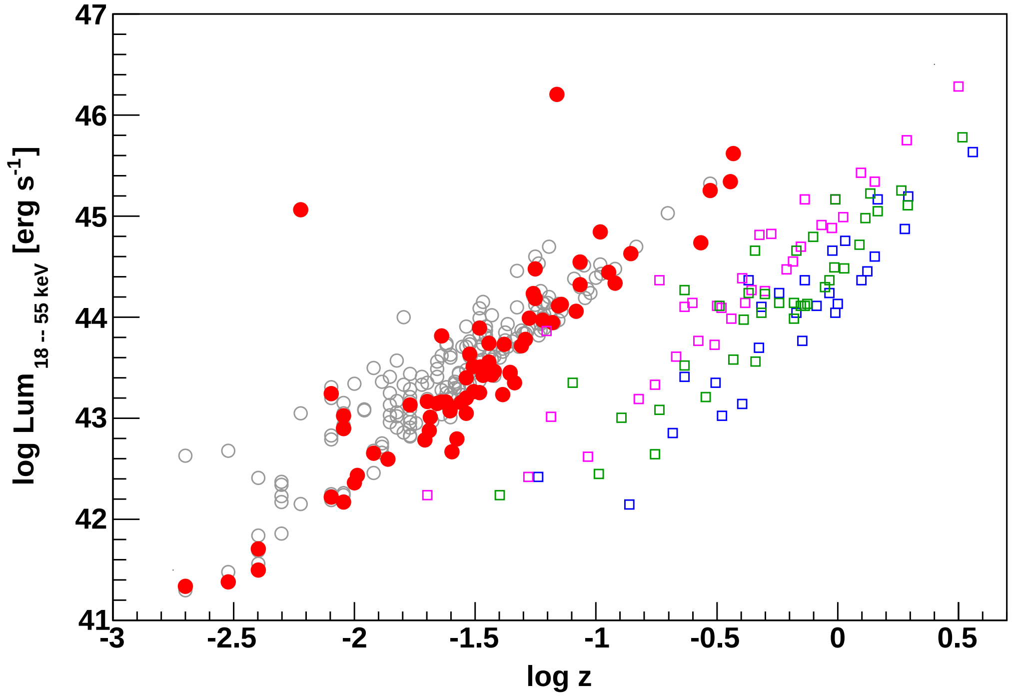

Figure 2: Luminosity-redshift plane of the BAT sample (gray circles), SIX sample (red circles), and predicted NuSTAR samples [14] for a 6.2 Msec exposure for different sky areas (magenta squares for a shallow survey, green squares for the COSMOS survey (2 deg^2), and blue squares for the ECDF-S survey (0.25 deg^2)).

4 Perspectives

Applying the SIX survey to the whole sky is a natural extension of the survey applied to the extragalactic sky [8] and on the Galactic center [9]. Based our source-number density of AGN we expect to detect ∼900 AGN over the whole sky. While the blazars will be ∼120. However, the most challenging sky area is the Galactic plane. This area is crowded and populated by very bright and variable sources. This introduces large uncertainties in the mosaic images. In order to demonstrate the feasibility of our approach also on the Galactic plane, we have performed a pilot SIX survey on the Galactic center [9] where 3 newly detected sources have no counterparts at soft X-rays.

5 Conclusions

We have shown a new approach to survey the sky at high energies. We combine the observations of *Swift*/BAT and *INTEGRAL*/IBIS. This results in a new and more sensitive survey named the *Swift* - *INTEGRAL* hard X-ray (SIX) survey.
This survey technique has been applied to ∼20% of the extragalactic sky. We have tested the evolution of the AGN to lowest fluxes ($\sim 3.3 \times 10^{-12}$ erg cm^{-2} s^{-1}).
In order to demonstrate that our approach can be expanded to the entire sky, we have applied the SIX survey also to the Galactic center [9].

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