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Science with Simbol-X

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Abstract. Simbol-X is a French-Italian mission, with a participation of German laboratories, for X-ray astronomy in the wide 0.5-80 keV band. Taking advantage of emerging technology in mirror manufacturing and spacecraft formation flying, Simbol-X will push grazing incidence imaging up to $\sim$ 80 keV, providing an improvement of roughly three orders of magnitude in sensitivity and angular resolution compared to all instruments that have operated so far above 10 keV. This will open a new window in X-ray astronomy, allowing breakthrough studies on black hole physics and census and particle acceleration mechanisms. We describe briefly the main scientific goals of the Simbol-X mission, giving a few examples aimed at highlighting key issues of the Simbol-X design.

Key words. Black Holes – Particle Acceleration – Hard X–rays

1. Introduction

A seminal result obtained with HEAO-1 at the end of the 70' is the precise measure of the spectrum (from a few keV up to $\sim$ 100 keV) of the isotropic, extragalactic Cosmic X-Ray Background (CXB), discovered by Riccardo Giacconi, Bruno Rossi and collaborators during one of the first rocket-borne X–ray experiments in 1962. The HEAO1 data showed that the CXB energy density has a broad max-

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imum around 30 keV, where it is about 5 times higher than at 1 keV and 50% higher than at 10 keV. It was soon realized that the CXB is most likely due to the contribution of many discrete sources at cosmological distances (Setti & Woltjer 1979). Most of these sources are active galactic nuclei, AGN, implying that the CXB energy density provides an integral estimate of the mass accretion rate in the Universe, and therefore of the super-massive black hole (SMBH) growth and mass density. Unfortunately, the integrated light from all sources detected in HEAO1 all-sky survey could directly explain only less than 1% of the CXB. Indeed, the use of collimated detectors on board first UHURU and Ariel-V, and then HEAO1 in the 1970 decade led to the discovery of $<$ 1000 X-ray sources in the whole sky.

X-ray imaging observations, performed first by *Einstein* and ROSAT in the soft X-ray band below $\sim$ 3 keV, and then by ASCA, BeppoSAX, XMM–Newton and Chandra up to 8-10 keV, detected tens of thousands of X-ray sources, and resolved nearly 100% of the CXB below a few keV and up to 50% at 6-8 keV. These observations increased by orders of magnitude the discovery space for compact objects (both Galactic neutron stars and black holes and AGN) and for thermal plasma sources. However, they still leave open fundamental issues, such as what is making most of the energy density of the CXB at $\sim$ 30 keV.

Above 10 keV the most sensitive observations have been performed so far by collimated instruments, like the BeppoSAX PDS, and by coded masks instruments, like INTEGRAL IBIS and Swift BAT. Only a few hundred sources are know in the whole sky in the 10-100 keV band, a situation recalling the pre–*Einstein* era at software energies. A new window in X-ray astronomy above 10 keV must be opened, producing an increase of the discovery space similar to that obtained with the first X-ray imaging missions. This will be achieved by Simbol-X, a formation flight mission currently under preparation by France and Italy, with a participation from German laboratories. Very much like the *Einstein* Observatory, this mission will have the capabilities to investigate almost any type of X-ray source, from Galactic and extragalactic compact sources, supernova remnant (SNR), young stellar objects and clusters of galaxies, right in the domain where accretion processes and acceleration mechanisms have their main signatures. This paper summarizes the main scientific goals of the Simbol-X mission, putting the emphasis on the core science objectives.

2. Main scientific objectives of the Simbol-X mission

Taking advantage of emerging technology in mirror manufacturing (Pareschi et al. these proceedings) and spacecraft formation flying (La Marle et al. 2007), Simbol-X will push grazing incidence imaging up to $\sim$ 80 – 100 keV, providing an improvement of roughly three orders of magnitude in sensitivity and angular resolution compared to all instruments that have operated so far above 10 keV (Fig. 3 in Ferrando et al., these proceedings, compares the predicted Simbol-X sensitivity to that of previous experiments in the 1-100 keV band). The very wide discovery space that Simbol-X will uncover is particularly significant for the advancement of two large and crucial areas in high-energy astrophysics and cosmology:

1. Black hole physics and census
2. Particle acceleration mechanisms.

These two broad topics define the core scientific objectives of Simbol-X.

Because of the tight links between galaxy bulges and their central SMBH, obtaining a complete and unbiased census of SMBH, through direct observations at the energies where the Cosmic X-ray Background (CXB) energy density peaks, is crucial for our understanding of the formation and evolution of galaxies and their nuclei. Furthermore, BH environment is the only known place in the Universe where general relativity can be tested beyond the weak-field limit.

About particle acceleration, we are still lacking firm evidences of hadron acceleration in astronomical sites (despite clearly seeing huge electron accelerations), and we are still searching for the origin of the high-energy photons and cosmic rays. Hard X-rays observations, possibly combined with γ–ray and TeV observations, are invaluable tools to identify the processes at work in acceleration sites such as SNR and jets.To achieve its core scientific objectives Simbol-X should:

1.1 resolve at least 50% of the CXB in the energy range where it peaks, thus providing a more complete census of SMBH;
1.2 solve the puzzle on the origin of the hard X-ray emission from the Galactic centre, which harbors the closest SMBH;
1.3 constrain the physics and the geometry of the accretion flow onto both SMBH and solar mass BH;
1.4 map the messy environment around SMBH characterized by the coexistence of gas components with different dynamical, physical and geometrical properties;
2.1 constrain acceleration processes in the relativistic Jets of blazars and GRB;
2.2 probe acceleration mechanisms in the strong electromagnetic and gravitational fields of pulsars;
2.3 measure the maximum energy of electron acceleration in supernova remnants shocks, and search for hadron acceleration in these sites;
2.4 search for and map the non-thermal emission in clusters of galaxies, and if confirmed, determine its origin and its impact on clusters evolution.

In addition to these top priority objectives Simbol-X will be capable of performing breakthrough studies on several other areas like:

1. the equation of state and the magnetic field of neutron stars;
2. nucleosynthesis in young SNR;
3. the formation of stars and planets;
4. non-thermal emission of active stars;
5. shocks in the intracluster medium pervading groups and clusters of galaxies;
6. extended thermal plasmas in Galactic and extragalactic sources.

Of course we cannot discuss here in detail all above topics, these are exhaustively presented in all papers in this volume. We limit ourselves to provide a few examples, highlighting the key issues about the Simbol-X design with respect to possible competitors, and the synergies with other large observational infrastructures that are already producing data or that will produce data at the time of the Simbol-X mission (2013-2018).

2.1. The cosmic X-ray background and the census of SMBH black holes

The CXB is currently regarded as the integrated output of the accretion processes which took place during the cosmic history. These processes led to the growth of SMBH in galactic nuclei (e.g. Marconi et al. 2004), which we observe in an active phase in AGN and in a quiescent phase through their dynamical effects on their surroundings, at the centre of nearby galaxies and indeed in our own.

AGN making most of the CXB below a few keV have a spectrum much softer than the CXB energy density spectrum, implying that the maximum at 30 keV would be missed by a factor about 3. A simple solution of this “paradox” was proposed again by Setti and Woltjer (1989), and requires a population of AGN highly obscured in soft X-rays by photoelectric absorption. The size of this population should be 2-3 times that of the unobscured AGN to reproduce the CXB spectrum (see Comastri et al. these proceedings). Chandra and XMM-Newton surveys have been able to detect many obscured, Compton-thin AGN ($N_H < 10^{24}$ cm^{-2}). However, due to their limited band pass, Chandra and XMM discovered only a handful of Compton-thick AGN (CT; $N_H > 10^{24}$ cm^{-2}). Therefore, at present, only a few CT AGN are known beyond the local Universe (see Della Ceca et al. these proceedings).

According to both the most up-to-date AGN synthesis models for the CXB (Gilli et al. 2007), the volume density of CT AGN should be of the same order of magnitude of that of the unobscured and moderately obscured AGN. High sensitivity, hard X-ray observations like those that Simbol-X will be able to perform in the 10-60 keV band hold the key to uncover, and study in detail, this long

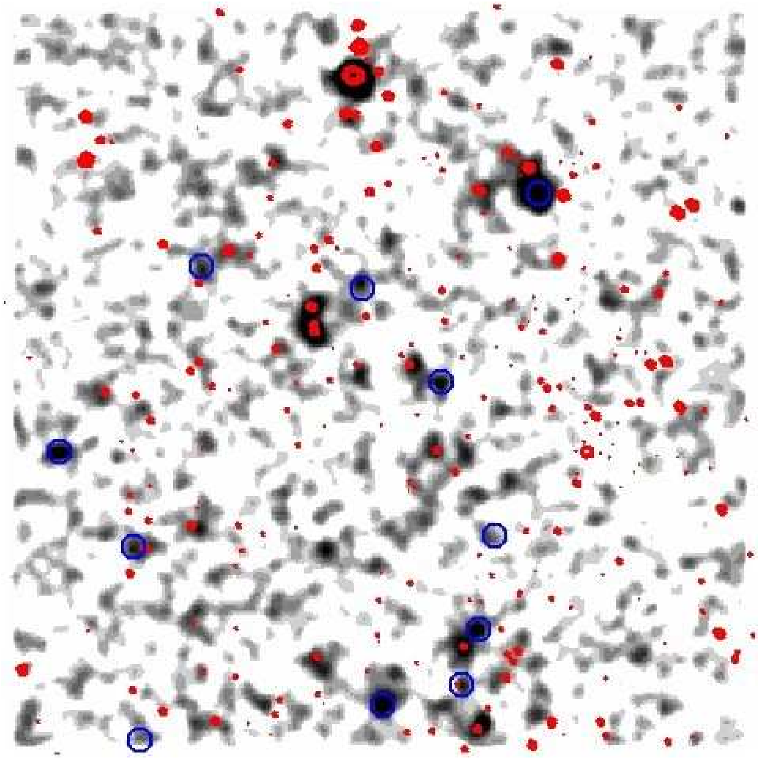

Fig. 1. The combined CZT+SDD 1M sec image of the CDFS in the 10-40 keV band (the exposure in the SDD camera is half of the total elapsed time to account for dead time). Red contours are Chandra count rates, circles identify the highly obscured, infrared selected sources. For the Chandra sources we have computed the 10-40 keV fluxes extrapolating the 2-10 keV fluxes using a spectral model consistent with the Chandra hardness ratios. For the IR selected sources we converted their 24μm fluxes using typical IR to X-ray unabsorbed flux ratios, $\alpha_E = 0.8$ and N_H in the range $10^{24} - 10^{25}$ cm^{-2}.

sought population of CT AGN, thus detecting directly most SMBH accretion luminosity in the Universe. Obtaining a complete census of accreting SMBH through the cosmic epochs is a crucial step to constrain nuclear accretion efficiency and feedbacks on the host galaxies, which are key ingredients toward the understanding of galaxy formation and evolution. The Simbol-X main contributions in this field will be the discovery and the characterization of the sources making the main contribution to the peak of the CXB. Simbol-X will allow us to evaluate the luminosity function of obscured AGN and its evolution, and to measure the fraction of obscured AGN as a function of luminosity and redshift with little observational biases. To these purposes the following observational strategies can be envisaged:

[1.] A spectral survey of local CT Seyfert 2 galaxies and moderately obscured QSOs previously discovered by BeppoSAX, XMM, INTEGRAL, Swift and Suzaku. This may be accompanied by a survey of infrared bright galaxies which have not shown strong X-ray emission below 10 keV, to search for highly CT objects. These observations will allow the precise measure of the absorbing column density, and therefore the determination of the N_H distribution of a large sample AGN sample, including CT objects (Della Ceca et al. these proceedings). They will also allow us to put constraints on the physical status of the absorbing gas and on its covering fraction.

[2.] Deep observations to search for higher redshift CT AGN.

[3.] A serendipitous survey over a large area to search for high luminosity CT AGN.

[4.] A survey of candidate CT AGN selected using their infrared emission and Spitzer/Herschel surveys, see Feruglio et al. these proceedings.

These observations will quantify the obscured AGN volume density as a function of the Cosmic time and univocally confirm and identify the IR selected CT AGN as hard X-ray AGN, contributing to the CXB.

2.1.1. The CDFS: a case study

As an example of what Simbol-X can achieve in the field extragalactic deep survey, Fig. 1 shows a simulation of a 1Msec observation of the Chandra Deep Field South area in the 10-40 keV band. We have included in the simulation two source populations: 1) the X-ray sources detected by Chandra below 10 keV; 2) the candidate CT AGN selected in the mid-infrared by Fiore et al. (2007). For the former sources we extrapolated their flux in the 10-40 keV band using a spectral model consistent with the Chandra hardness ratios. For the IR selected CT AGN we converted their 24μm fluxes to X-ray unobscured fluxes using typical templates (Fiore et al. 2007). We than computed observed 10-40 keV fluxes by assuming $\alpha_E = 0.8$ and N_H in the range $10^{24} - 10^{25}$ cm^{-2}. Note as a few IR selected AGN are detected also by Chandra, but several others can be detected only by Simbol-X above 10 keV. A single Simbol-X 1Msec observation will be able to resolve about 50% of the CXB in the 10-40 keV band. We will be able to probe nearly all kind of AGN, from unobscured to moderately obscured to CT AGN. Since the fraction of CT AGN rises steeply below 10^{-14} erg cm^{-2} s^{-1}(10-40 keV band) pushing the flux limit just below this value would strongly increase the chance to discover relativaly large samples of these elusive objects (see Comastri et al. these proceedings for further details).

Main key issue in this field is the sharp image quality of the Simbol-X mirror (a Point Spread Function, PSF, with half power diameter, HPD< 20 arcsec, Pareschi et al. these proceedings). Other important factors are the relatively large field of view ($\sim$ 12 arcmin diameter) and the low internal background (see Laurent et al. these proceedings). Already mentioned synergies are with mid and far infrared space observatories like Spitzer, Herschel and JWST.

2.2. *AGN massive outflows: AGN feedback at work*

In addition of obtaining a complete census of SMBH, the other key observational ingredient to obtain a better understanding of galaxy formation and evolution is the quantification of the effects of AGN feedbacks on their host galaxies.

AGN can interact with the interstellar matter of their host galaxies through at least two main channels: radiation field and outflows. Winds and jets, both non-relativistic and relativistic, are common in AGN, see Cappi et al. and Tavecchio et al. these proceedings. The two key parameters are the mass outflow rate and the velocity structure of the outflow, because they give the energy and the momentum involved in the flow. Blue-shifted X-ray absorption lines detected by Chandra and XMM indicate very high velocities, up to a fraction of the speed of light, in a few sources. A comprehensive survey of absorption features in sizeable AGN samples in different bins of redshift and luminosity is however still lacking. Furthermore, the sensitivity of XMM decreases sharply above 9-10 keV, hampering the possibility of detecting high velocity outflows in nearby AGN. Simbol-X will be 2 to 5 times more sensitive to iron absorption features than XMM-Newton below 10 keV, and will open the window above 10 keV. This will allow the characterization of outflows of any velocity in statistical samples. The study of the variability of the absorption lines will set a scale for the size and location of the absorbing gas, and for its density, thus providing information on the mass involved in the outflow.

Key issue in this topic is the high Simbol-X throughput between 7 an 20 keV. Other important issues are the good energy resolution provided by the MPC detector and the broad band coverage, allowing a good constraint on the source continuum.

2.3. Acceleration mechanisms in supernova remnant

Non-thermal emission was originally discovered by ASCA in the shell-like supernova remnant (SNR) SN1006 (Koyama et al. 1995). We know today that most of the young SNR show non-thermal emission at some level. These are the best candidate sites for the acceleration of Cosmic Rays up to 10^{15} eV or even higher energies. Indeed, if the maximum energy of electron (E_{max}) is of this order, a strong synchrotron emission is expected in the X-rays band, with a cut-off at an energy E_{cut} depending on E_{max} and on the strength of the magnetic field. The magnetic field necessary for their scattering may be generated or increased by the accelerated particles themselves (the so called streaming instability). Evidences that this effect is at work were claimed thanks to Chandra observations of the thickness of the X-ray rims around the SN shock in the Tycho SNR (Cassam-Chenaï et al. 2007). The brightness profile of the rims is consistent with magnetic fields a few hundred times larger than the ISM field. However, this interpretation of the Chandra data is not unique. The direct measure of E_{cut} will then help understanding both which is the maximum energy of electron and the mechanism of diffusive shock acceleration in SNR shells (see Decourchelle et al. these proceedings).

Although we have plenty of evidences of electron acceleration in cosmic sources, direct proofs of proton and ion acceleration are still lacking. A direct signature of proton acceleration is GeV-TeV emission due to pion decay. HESS and MAGIC have revealed TeV emission from a few supernova remnants (e.g. Aharonian et al. 2006). A large fraction of the TeV photons are probably due to Inverse Compton (IC) emission. To disentangle between pion decay and IC emission one needs to estimate the expected IC emission through their synchrotron emission observed in the X-ray range. Combining hard X-ray and γ-ray observations holds the key to uncover pion decay emission.

Key issue in this field is a broad energy band, extending from $\sim$ 1 keV to $\sim$ 100 keV. This will allow the separation of thermal and non-thermal emission and the measure of E_{cut}. Extremely important here is to have a large field of view, to cover large fractions of SNR. Obvious synergies are with TeV Cherenkov telescopes and with GLAST and Agile.

3. Conclusions

Thanks to the emerging technology in X-ray mirrors (e.g. multilayer coating, see Pareschi et al. these proceedings) and spacecraft formation flying, Simbol-X will provide a large collecting area (of the order of 100-1000 cm^{-2}) from a fraction of keV up to $\sim$ 80 keV, thus overcoming the "10 keV limit" for high accuracy imaging and spectroscopy of all past and current X-ray observatories. This, together to the good image quality (PSF HPD$<$ 20 arcsec, FWHM$<$ 10 arcsec), relatively large field of view (12 arcmin diameter), good detector quantum efficiency, resolution and low internal background, will allow breakthrough studies on black hole physics and census, and particle acceleration mechanisms.

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