Japanese Future Space Programs for High Energy Astrophysics

KAZUHISA MITSUDA
Institute of space and astronautical science, Sagamihara 229-8510, Japan

ABSTRACT. Japanese future space programs for high energy astrophysics are presented. The Astro-E2 mission which is the recovery mission of the lost Astro-E has been approved and now scheduled to be put in orbit in early 2005. The design of the whole spacecraft remains the same as that of Astro-E, except for some improvements in the scientific instruments. The wide energy-band and high energy-resolution spectroscopies are the major features of the mission. The NeXT mission, which we propose to have in 2009, succeeds and extends the science which Astro-E2 will open. It will carry four sets of X-ray telescopes which utilize super-mirror technology to enable hard X-ray imaging up to $\sim 60$ keV. In early 2010’s, we consider to participate in the ESA’s XEUS project, and at the same time hope to continue small missions of $\sim 400$ kg sizes.

1. Introduction

Since the launch of the first Japanese X-ray astronomy satellite, Hakucho, in 1979, Japanese space high energy astrophysics missions have played significant roles in the field. After the failure of Astro-E2 launch and the earth reentry of ASCA, we have no Japanese X-ray astronomy satellite in operation now. In this paper, I summarize the Japanese future space high energy astrophysics missions in 2000’s and early 2010’s.

The approved and proposed missions are summarized in Figure 1.

2. Astro-E2; wide-band, high energy-resolution X-ray spectroscopies

Astro-E2 is the recovery mission of Astro-E (Ogawara 1999) which was lost because of the failure occurred in the first stage of the launch vehicle, ISAS M-V rocket, in 2000. The cause of the failure was identified, and the necessary design modifications have been made. A ground firing test of a first stage motor of the improved design was successfully performed in 2004.

Fig. 1. Future space programs for high energy astrophysics considered in Japan. Astro-E2 and MAXI (An all sky monitor on ISS JEM (Kiboh) module) are approved.
completed recently. The first launch of the new M-V will be made in December 2002 carrying the interplanetary mission MUSES-C. Astro-E2 will be the fourth launch after the improvements. It is now scheduled in early 2005.

The basic design of the Astro-E2 mission remains the same as that of Astro-E because of limited time and resources for the mission development. High-sensitivity broad-band and high-resolution X-ray spectroscopies are the major features of the Astro-E/E2 missions (Mitsuda 1999), which was designed to complement the spectroscopic capabilities of the Chandra and XMM Newton observatories now in orbit. Although the start of the observation has slipped by five years, the capabilities of Astro-E2 is still unique and its science remains timely and important.

The two unique capabilities of the observatory, the wide energy band of 0.4 – 600 keV and high energy-resolution (FWHM=12 eV) spectroscopy in the 0.5-12 keV band, are realized by five sets of soft X-ray imaging telescopes (XRT; Serlemitsos 1998) and a non-imaging hard X-ray detector (HXD; Kamae et al. 1988). On the focal plane of the five imaging telescopes, we have two different types of X-ray detectors; an X-ray CCD camera named the X-ray Imaging Spectrometer (XIS; Tsunemi et al. 1999) for four of the telescopes, and an X-ray microcalorimeter array called the X-Ray Spectrometer (XRS; Mitsuda and Kelley 1999) for the remaining one telescope. The focal length of the telescopes are 4.7 m for the XIS and 4.5 m for XRS. The HXD utilizes silicon PIN detectors and BGO scintillators, both of which are placed inside 16 sets of well-shaped GSO active shields. In Figure 2 we have shown schematic views of the spacecraft and its interior structure including the layout of five X-ray mirrors, the XRS dewar, some of
the XIS cameras, and the HXD. In Table I, we show key parameters of the instruments and in Figure 3, the effective areas of the telescopes as functions of energy.

The XRT and the XRS are being developed by international collaboration supported by Institute of Space and Astronautical Science (ISAS) and National Aeronautics and Space Administration (NASA).

2.1. Improvements in XRS

The most unique feature of the Astro-E2 is the high resolution spectroscopy with the XRS which utilizes an X-ray microcalorimeter array operating at a cryogenic temperature of 60 mK. This achieves a spectral resolution of about 12 eV (FWHM) and a high quantum efficiency of 20 - 80 % in the 0.5-12 keV energy band. The mission period of the XRS is limited by the lifetime of the cryogens; 30 litters of superfluid liquid helium and 120 litters of solid neon. For Astro-E, it was estimate to be 1.95 years (Mitsuda and Kelley 1999). We decided to add a single-stage Stirling-cycle mechanical cooler to Astro-E2. The estimated life time is then 2.4 to 3.7 years depending on the operating power of the cooler, which will be adjusted according to the susceptibility of the detector to the microphonics from the cooler and the spacecraft power budget. On the other hand, even if the cooler should fail at the beginning of the mission, we still be able to keep a life time of 1.9 years.

The baseline design of calorimeter array is the same as that of Astro-E and consists of 32 pixels of bilinear geometry (Stahle et al. 1999). In the ground calibrations of Astro-E, an energy resolution of 12 eV (FWHM) was obtained at 5.9 keV even when we sum up spectra from all the pixels of the array (Gendreau et al. 1999). We are investigating
some improvements of the calorimeter array; better energy resolution and better array geometry (e.g. a 6 × 6 square array).

2.2. Science with Astro-E2

At energies above 2–3 keV, the XRS has larger effective area and better energy resolution than the transmission gratings onboard XMM Newton and Chandras. Contrary to these missions, the XRS can observe extended sources without degrading the energy resolution. Therefore the major scientific objectives of the XRS observations will be hard-band (> 2 keV) spectroscopy of point-like sources and wide band (0.5 – 12 keV) spectroscopy of extended sources, e.g. (1) plasma diagnostics, in particular with the fine structure of Fe K emission lines, of cataclysmic variables, accretion disk corona sources, etc, (2) diagnostics of chemical compositions and their evolutions utilizing various emission lines from supernova remnants and clusters of galaxies, (3) diagnostics of dynamical motion and gravitational potential utilizing doppler shifts and broadening of emission lines from accretion disks, jets (e.g. P Cygni profiles), super nova remnants (SNRs), and clusters of galaxies. With Fe-K line, ~300 km/s of motion can be detected.

On the other hand, the wide-band spectroscopy with the XIS and the HXD will be powerful tools for the studies of (4) highly absorbed active galactic nuclei, e.g. infrared luminous galaxies, Seyfert 2, BAL quasars, (5) non-thermal emission from supernova remnants and clusters of galaxies.

Recent discoveries of the spatial unisotropy of cosmic rays of energies up to 10^{18} eV (Hayashisha et al. 1999) and TeV gamma ray emissions from SNRs, e.g. SN 1006.
TABLE II
Proposed Concept of NeXT

<table>
<thead>
<tr>
<th>Supper-mirror telescopes</th>
<th>Energy range</th>
<th>0.3-60 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of telescopes</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Effective area (total)</td>
<td>~ 6000 cm²</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~ 1'</td>
<td></td>
</tr>
<tr>
<td>Detectors</td>
<td>CCD + CdTe Hybrid</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Soft X-ray telescopes</th>
<th>Energy range</th>
<th>0.3-12 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of telescopes</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Effective area (total)</td>
<td>~ 3000 cm²</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~ 1'</td>
<td></td>
</tr>
<tr>
<td>Detectors</td>
<td>TES microcalorimeter array</td>
<td></td>
</tr>
</tbody>
</table>

(Tanimori et al. 1998), suggest that cosmic rays of energies up to $10^{18}$ eV are accelerated in our galaxy. On the other hand, acceleration site of higher energy up to $10^{20}$ eV should exist in the universe. Cluster of galaxies is one of the candidates. High resolution spectroscopy with the XRS will enable us to study the macroscopic motions of matter, which provide us a direct evidence of shock waves. On the other hand, non-thermal emission studied with the HXD and the XIS will constrain the energy density of the accelerated particles. Thus with the Astro-E2, we can study the accelerators both from the energy input and output.

3. NeXT; hard X-ray imaging and imaging high resolution X-ray spectroscopy with the New X-ray Telescopes

The energy range above 10 keV is covered with non-imaging X-ray detectors for Astro-E2, thus it will be difficult to constrain the site of the non-thermal emissions inside the SNRs and/or the clusters of galaxies. The major advantage of the NeXT (New X-ray Telescope) mission, which we are proposing to put in orbit in 2009, is hard X-ray mirror imaging up to 60 keV. The innovative high throughput X-ray mirrors with multi-layer coating (so called super mirrors) have been developed by Nagoya University and ISAS (Yamashita et al. 1998). A prototype model was tested in the recent balloon experiment, InFOCuS. Although because of the trouble in the attitude control system of the balloon platform, the integration time was very short, the hard X-ray image of Cyg X-1 was successfully obtained, which proves the high-throughput hard X-ray imaging capability of the super mirrors (Kunieda et al. 2001, private communication). As a candidate focal plane detector, a hybrid detector consisting of an X-ray CCD and a CdTe pixel detector is being developed. The imaging high resolution spectroscopy is another key observation for the study of the acceleration site. For this purpose we hope to cover larger ($\sim 7' \times 7'$) area with $\sim 1000$ pixels with a TES (Transition Edge Sensor) microcalorimeter array. In Table II we summarize the basic concepts of the NeXT mission.
4. Further future

It is inevitable that the scientific instruments becomes larger and larger when the science evolves. Thus the international collaborations become more and more important. XEUS (X-ray Evolving Universe Spectroscopy; XEUS steering committee 2000) is a mission proposed by ESA. One of the major scientific goal of the mission is to study the history of the hot universe from the beginning; the study of the first massive black holes and the first cluster of galaxies. Considering the importance of the science and the size of mission, ISAS decided to participate in the mission and to make major contributions. Construction of the detector spacecraft (DSC-1) is one possibility. We have also studied possibility to implement the super-mirror technology in the XEUS telescope. As shown in Figure 4, we can obtain significant sensitivity in 10 - 40 keV range with supper mirrors on XEUS.

Although the large missions with international collaboration are in the main stream of the high energy missions in 2010’s, we recognize at the same time importance of small missions for timely, challenging, thus sometimes risky sciences. Thus we hope to keep capability of launching small (∼ 400 kg) spacecrafts in near earth orbits in 2010’s.

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References

Hayashida, N. et al. 1999, Astroparticle Physics, 10, 303.
Kelley, R.L. et al. 1999, SPIE, 3765, 114
Ogawara, Y. 1999, Proc. of IAU Symposium no. 188, p75.
Serlemitsos, P.J. 1998, AAS Meeting 193, 80.03.
Tsunemi, H. et al. 1998, AAS Meeting 193, 80.05.
Yamashita, K et al. Proc. of IAU Symposium no. 188, p.337.
Xeus Steering Committee 2000, The XEUS mission summary (ESA SP ; 1242).

DISCUSSION

S.Colafrancesco: Which are the FOV and spatial resolution at $E > 500$ keV in Astro-E2 and NeXT?

K.Mitsuda: The GSO active shield is efficient up to 600 keV. Thus the FOV at 500 keV is 4.6°. Since the HXD is non-imaging detector, the spatial resolution is the same as the FOV. The super mirror on NeXT cannot reach 500 keV. Thus we plan to have a non-imaging hard X-ray detector on NeXT. The details are not determined yet.