

Future Hard X-ray and Gamma-ray Observations

Tadayuki Takahashi

*Institute of Space and Astronautical Science, Sagami-hara, Kanagawa,
229-8510, Japan*

Tuneyoshi Kamae

Department of Physics, Stanford University, Stanford, CA 94305-4060

Kazuo Makishima

*Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0033,
Japan*

1. Introduction

Hard X-rays and gamma-rays are important frequency windows for exploring the energetic universe. It is in these energy bands that the non-thermal emission, mostly due to accelerated high energy particles, becomes dominant. In fact, the results from *ASCA* and *BeppoSAX* showed that sensitive observations in these bands are necessary to constrain the continuum spectra of many classes of X-ray sources. However, the lack of sensitive instruments prevents us from further studying the non-thermal spectra. As clearly shown in Fig.1, the situation is much worse in the hard X-ray and soft gamma-ray bands, where the reduction of background is difficult. The *CGRO* satellite revealed the fact that a variety of gamma-ray sources exist in the sky and the improved angular and spectral resolution by the *INTEGRAL* satellite will be a good advance, but the sensitivity of instruments are far from the level achieved by the current X-ray missions employing focusing telescopes in the energy band below 10 keV.

In order to fully explore the dynamic universe, hard X-ray and gamma-ray instruments in the 21st century should provide much improved sensitivity for both point and extended sources over the instruments in use today.

2. Hard X-ray Imaging Observations

In the 10–100 keV band, the most promising approach is to extend the energy coverage of the focusing telescope to higher energy. This could be achieved by a multi-layer, grazing incidence hard X-ray mirror (“super mirror”, Kunieda et al. 2001). In addition to the focusing capability, the small volume of a hard X-ray imaging detector as a focal plane instrument significantly reduces the background, since the background flux generally scales with the size of the detector. In order to cover the field of view of the telescope, the detector should have an area of several cm². Fast timing of several hundred ns will be required for active shielding, which provides a low background environment in space. Detectors should have a fine position resolution of a few 100 μm and a high energy resolution better than 1 keV (FWHM) in this energy range. Research

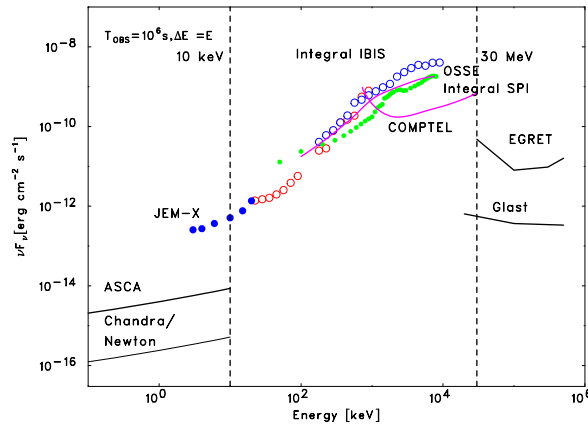


Figure 1. The sensitivity for point-sources with a continuum spectrum for various past and future X-ray and gamma-ray missions.

and development toward these goals are under way by several groups by utilizing high-Z semiconductor materials such as CdTe (e.g. Takahashi et al. 2001)

Since the super mirror is able to cover the energy range from ~ 0.5 keV up to 40–60 keV, the focal plane detector is required to cover a very wide energy band. For this, a combination of a back-illuminated X-ray CCD and a pixelated CdTe detector has been proposed as a new concept (Takahashi et al. 1999). In this “hybrid detector” (Fig. 2), soft X-rays will be absorbed in the X-ray CCD, and hard X-rays will penetrate the CCD and be absorbed in the CdTe pixelated array (see also Tsuru et al. 2001).

3. Applications of Compton Scattering

The sensitivity of observations with hard X-ray and gamma-ray detectors are limited by the background rate. The phoswich configuration and the narrow field of view obtained by a tight active “well-type” shield developed for the Astro-E Hard X-ray Detector (HXD) is the solution to achieve a very low background rate in the energy range up to several hundred keV (Makishima et al. 2001). In the well-type configuration, the detection part is surrounded in almost all directions by the active shield. Therefore, background photons which deposit some of their energy in the shield through Compton-scattering are rejected efficiently.

In order to further reduce the background, we have proposed a new detector based on thin CdTe pixel or strip device and the well-type shield (Fig. 3). The key concept is the requirement of Compton kinematics for events which interact twice (one by Compton scattering and the other by photo-absorption) in the stacked detector. Since we require that gamma-rays should come from the narrow FOV of the well-type collimator and do not escape from the CdTe part, we can constrain the energy of two gamma-ray interactions from the measured scattering angle from the formula of Compton scattering. The energy resolution, again, is an important issue for this kind of configuration. Twenty four layers of a 0.5 mm thick CdTe detector give the sufficient detection probability of $\sim 20\%$ via single Compton scattering and subsequent photo absorption. One

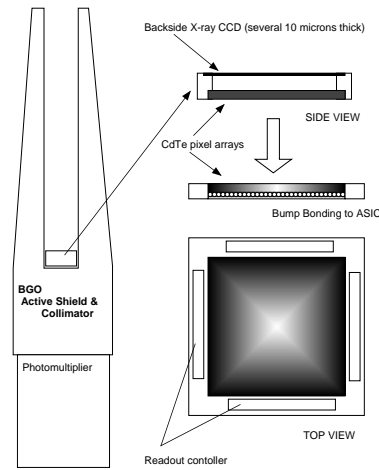


Figure 2. A schematic diagram of a wide band imaging spectrometer detector to be used at the focal plane of a super mirror. The detector is a combination of a back-illuminated X-ray CCD and a pixelated CdTe detector covering 0.1 - 60 keV (from Takahashi et al. 1999).

important aspect of this concept is that we can measure polarization from the azimuthal distribution of Compton scattered photons.

4. Next generation Compton telescope

As gamma-ray energy increases to the MeV region, the detection becomes very difficult. By utilizing the technique of the Compton telescope, the *COMPTEL* instrument on-board the *CGRO* satellite has achieved pioneering results in this energy region. In order to go beyond the level achieved by the *COMPTEL* and fill the gap, second generation Compton telescopes have been proposed by several groups (e.g. Kanbach et al. 2000). Among them, a concept called the Multiple Compton Method, which was originally proposed by Kamae et al. (1987), is very attractive. In this method, a stack of several tens (~ 50) of layers of thin semiconductor imaging detectors is used to follow multiple Compton scatterings. If at least the first three or four Compton scatterings take place in the layers and the energies and positions are recorded, we can find the correct order of the first two scattering points and then calculate the directions and the energies of the incident gamma-rays. The key points of this method is that, if the incident gamma-rays undergo multiple interactions which are sufficient to reconstruct the correct order, gamma-rays do not need to be fully absorbed by the detector and are allowed to escape. The conceptual Advanced Compton Telescope (Kurfess et al. 2000) uses the multi-Compton kinematics and has a very large area and intends to improve the sensitivity in the MeV region for two orders of magnitude in comparison with that of *COMPTEL*.

Since we have to handle many channels from many layers of imaging devices, we need advanced technology for both the materials and front-end electronics. In order to establish the concept of the multi-Compton camera, we are now working on a small

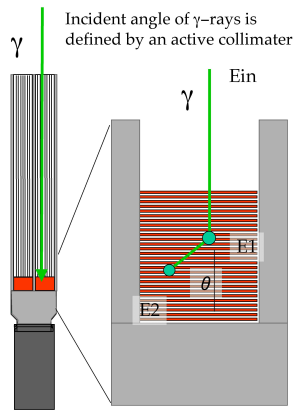


Figure 3. The conceptual design of the next generation well-type gamma-ray detector. A stack of CdTe pixel or strip detectors are buried in the deep BGO well.

detector for the detection of the polarization of gamma-rays from gamma-ray bursts, by combining high resolution Si and CdTe imaging detectors.

5. Conclusion

Our knowledge about the universe is very limited in the energy region above several 10 keV where the non-thermal emission, produced by energetic particles becomes dominant. However, when compared with X-ray Astronomy, gamma-ray astronomy is still immature and significant improvements should be done to obtain sensitivity comparable to that achieved in the energy band below 10 keV.

References

- Kamae, T. et al. 1987, Nucl. Instr. Meth., A260, 254
- Kanbach, G. et al. 2000, MEGA proposal
- Kunieda, H. et al. 2001, in this proceedings
- Kurfess, J. et al. 2000, in the Fifth Compton Symposium, (New York : AIP) 510, 789
- Makishima, K. et al. 2001, in this proceedings
- Takahashi, T. et al. 1999, Nucl. Instr. Meth., A436, 111
- Takahashi, T. et al. 2001, IEEE N.S. in press
- Tsuru, T. et al. 2001, in this proceedings