A Concept for a High-Angular-Resolution MeV Coded-Mask Compton Telescope Building on the Legacies of INTEGRAL/IBIS Compton-Mode and Hitomi/SGD

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Abstract

MeV gamma rays provide unique insights into high-energy phenomena in the Universe, yet their observational sensitivity remains more than two orders of magnitude worse than that achieved at neighboring wavelengths. A key limitation arises from the angular resolution of Compton telescopes, which is fundamentally restricted to degree scales by Doppler broadening. This limitation leads to source confusion and constrains the achievable sensitivity. INTEGRAL/IBIS demonstrated the power of coded-aperture imaging in the hard X-ray and soft gamma-ray bands, achieving arcminute-scale angular resolution in crowded regions such as the Galactic center (e.g. Krivonos et al., 2012). It also included analyses based on Compton event reconstruction (e.g. Forot et al., 2007). In addition, the Soft Gamma-ray Detector (SGD; Tajima et al., 2018) onboard the ASTRO-H (Hitomi) satellite (Takahashi et al., 2014) demonstrated the low-background potential of a narrow-field-of-view Si/CdTe semiconductor Compton telescope. Building on these legacies, we propose the Soft Gamma-ray Imager (SGI), a new detector concept that combines a narrow-field-of-view semiconductor Compton telescope with a thick, small-pitch, high-aspect-ratio coded mask optimized for MeV gamma rays. SGI is designed to achieve an angular resolution of 15 arcmin and provide high-angular-resolution pointed observations complementary to wide-field MeV missions such as COSI. As a pathfinder for SGI, we are developing miniSGD, a balloon-borne prototype incorporating all key technologies required for the full-scale instrument. Using miniSGD, we have demonstrated depth-of-interaction reconstruction in CdTe detectors, coded-mask imaging with a thick tungsten mask, and electron-track reconstruction using semiconductor detector layers. These demonstrations enabled successful coded-aperture imaging at an angular resolution of 19 arcmin at 511 keV, and showed that electron-tracking event reconstruction is essential for extending the technique toward higher MeV energies, as demonstrated with the 1275 keV line from a 22Na source. These results demonstrate the feasibility of the SGI concept and provide a promising path toward high-angular-resolution, pointed MeV observations building on the legacies of INTEGRAL/IBIS Compton Mode and Hitomi/SGD.

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