

Technology Development for X-ray and Gamma-Ray Polarimetry

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Measurements of linear polarization between 0.1 keV and 100 MeV will provide a revolutionary tool for probing a variety of astronomical sources. Despite major progress in imaging, spectroscopy, and timing, there have been only modest attempts at polarimetry at these energies. Progress in this area has been hindered by several factors, including the slow development of suitable technologies, the challenge of making measurements at low signal-to-noise levels (made even worse by the fact that an already small signal be further divided into a number of angular bins), and the challenge of dealing with measurements that are highly susceptible to systematic instrumental effects. Those few measurements that have been reported, particularly those above several tens of keV, have often been of limited statistical significance. The technology challenge that we must face is to further refine and develop our ability to make sensitive high-quality polarization measurements over a broad energy band using a variety of different experimental techniques. Polarimetry does not necessarily require a dedicated mission. In many cases, polarimetry can be incorporated into missions that can also gather spectroscopy, timing, and imaging data. The development of imaging polarimetry with arcsec angular resolution would be an extremely important step forward.

Several different techniques must be employed to measure photon polarization over this entire energy band. The first measurements were made at soft X-ray energies using a narrow-band Bragg polarimeter. In the future, the development of laterally-graded multilayer-coated mirrors will enable broad-band measurements at energies below 1 keV using a dispersive spectrometer. At energies below ~50 keV, photoelectric absorption can also be exploited to make polarization measurements. The angular distribution of the K-shell photoelectron emitted as a result of the photoelectric absorption process depends upon the polarization of the incident photon, with the photoelectron preferentially emitted in a direction parallel to the electric field (polarization) vector of the incident photon. This requires technology that can precisely locate the interaction site and subsequently track the photoelectron as it emerges from the interaction site. For this purpose both gas pixel detectors (GPD) and time projection chambers (TPC) are being developed.

Compton scattering (or its low-energy equivalent, Thompson scattering) can be exploited at energies down to a few keV. In this case, the scattered photon preferentially scatters in a direction perpendicular to the polarization vector of the incident photon. This requires a precise measurement of both the scattering site and the subsequent interaction of the scattered photon. An arrangement of scintillator and/or semiconductor detectors can be used to measure the scattering geometry, preferably in three dimensions. Compton telescopes, by their very nature, can provide the necessary measurements, but this depends on several factors, including the instrument geometry and the ability to spatially resolve the interaction sites. Spatial and timing resolution are especially critical for scattering polarimeters.

At energies above ~10 MeV, pair production also provides a signature for polarization, but this requires a careful measurement of the outgoing electron-positron tracks. Pair production telescopes like EGRET and Fermi have both been subject to electron scattering issues which have limited their polarization sensitivity. Polarimetry at these energies will require technologies that avoid multiple scattering issues of the electron-positron tracks.

In addition to these standard methods, new and innovative methods must also be considered. For example, the use of dichroic filters for separating radiation of different polarizations (feasible at energies near elemental absorption edges) would be a useful development. The measurement of circular polarization presents an even greater challenge, one that has not yet been addressed.

It is clear that technologies could be deployed in small orbital or sub-orbital missions in the next few years that can provide the first surveys in several energy bands. In the long term, however, the development of new technologies will be required to move us from the exploratory phase into a discovery phase, one where high resolution imaging polarimetry will allow us to probe the X-ray and gamma-ray universe in a new and exciting way.