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Polarimetry in X- and Gamma-Ray Astronomy: the Ultimate Dimension

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Polarization has been a powerful diagnostic tool in radio, microwave, and visible astronomy, providing details of photon production mechanisms on much smaller scales than can be directly imaged or deduced from photon intensity and energy alone. While polarimetry at other these wavebands (radio, microwave, and optical) is an established technique, high energy astrophysics lags far behind in this respect. Yet polarization analysis has the potential of revealing many details about the magnetic fields, geometries, and emission mechanisms found in high energy emitting sources. Deviations from spherical symmetry and/or the presence of ordered magnetic fields give rise to polarized radiation: some examples include anisotropy in solar flares, the presence of jets in microquasars and blazars, accretion disks around stellar and massive black holes, accreting and rotation-powered pulsars, and beams in gamma-ray bursts. In addition, null polarization detections from gamma-ray bursts at x-ray energies have been used as a test of fundamental physics by placing limits on the possible violation of Lorentz invariance.

The first attempt to measure astrophysical x-ray polarization was made in 1969 by R. Novick and his team at Columbia University. These measurements, using rocket payloads, provided the first detection of polarization of the Crab pulsar (5–20 keV) in 1971. This success led to a polarimeter on the OSO-8 mission that obtained upper limits to the phase resolved polarization of the Crab pulsar. Despite these early successes and a recognition that polarization capability can be an important tool at both x-ray and gamma ray energies, the development of instruments to measure high-energy polarization has progressed slowly.

Only in the last decade, in the soft gamma-ray domain (0.1–1 MeV), a few polarimetric measurements were performed by the SPI and IBIS instruments, onboard the ESA/INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) mission on the Crab pulsar and on the galactic black-hole Cygnus X-1, and on some high flux gamma-ray bursts.

More recently, the GEMS/PRAXIS (2-10 keV) and IXPE (2–8 keV) missions have been proposed and studied. The IXPE mission was selected by NASA as an explorer mission in 2016 with a launch date in late 2020. At gamma ray energies, the Agile (30 MeV–50 GeV) and Fermi (<100 MeV – 300 GeV) missions have been very successful, providing very sensitive, complete all-sky catalogs of high-energy sources. The design of these instruments, layers of silicon strips interleaved with high-Z metal foils precluded any significant polarization sensitivity. Two proposed follow-on instruments, AMEGO (0.2 MeV–10 GeV) and eASTROGAM (10–100 MeV), will achieve sensitivity in the medium-energy range by omitting the metal foils. However, the density of the silicon strips will severely limit the polarization sensitivity of these instruments.

Other instruments are being designed with gamma ray polarization sensitivity. At this time, only long-duration balloon payload flights have been flown and are planned for future flights. These include GRAPE (50–500 keV) a Compton scattering instrument, GRIPS (IR, 0.1–10 keV, 0.2–80 MeV) a solar flare observatory, COSI (0.2–5 MeV), a germanium Compton scattering instrument, and POGOLite/POGO+ (20-250 keV).

At higher energy, the AdEPT (5–200 MeV) (Advanced Energetic Pair Telescope for Medium-Energy Gamma-Ray Polarimetry) is being developed at NASA, and HARPO (MeV–GeV) is being developed at Ecole Polytechnique, CNRS/IN2P3, and IRFU CEA Saclay. Other space mission concepts submitted to ESA Cosmic Vision call, such as the Gamma-Ray Imager and the DUAL telescopes, both implementing new high energy focusing optics. A current space mission is the POLAR (50–500 keV) instrument, dedicated to GRB polarimetry, on the Chinese Space Laboratory TC-2 launched in 2016.

With interest in high-energy polarization increasing and instrumental techniques maturing, the guest editors of this special section, along with JATIS editor-in-chief Mark Clampin, agreed to a solicitation of manuscripts on high-energy polarization. Our goal was to bring together in one place a collection of papers describing the current work on high-energy polarization. It is our hope that this collection of papers will motivate future instruments and future sub-orbital and space missions.

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