MeV Space Observatories

Hitomi/SGD, e-ASTROGAM, AMEGO

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Hitomi (JAXA, ESA, NASA ++)
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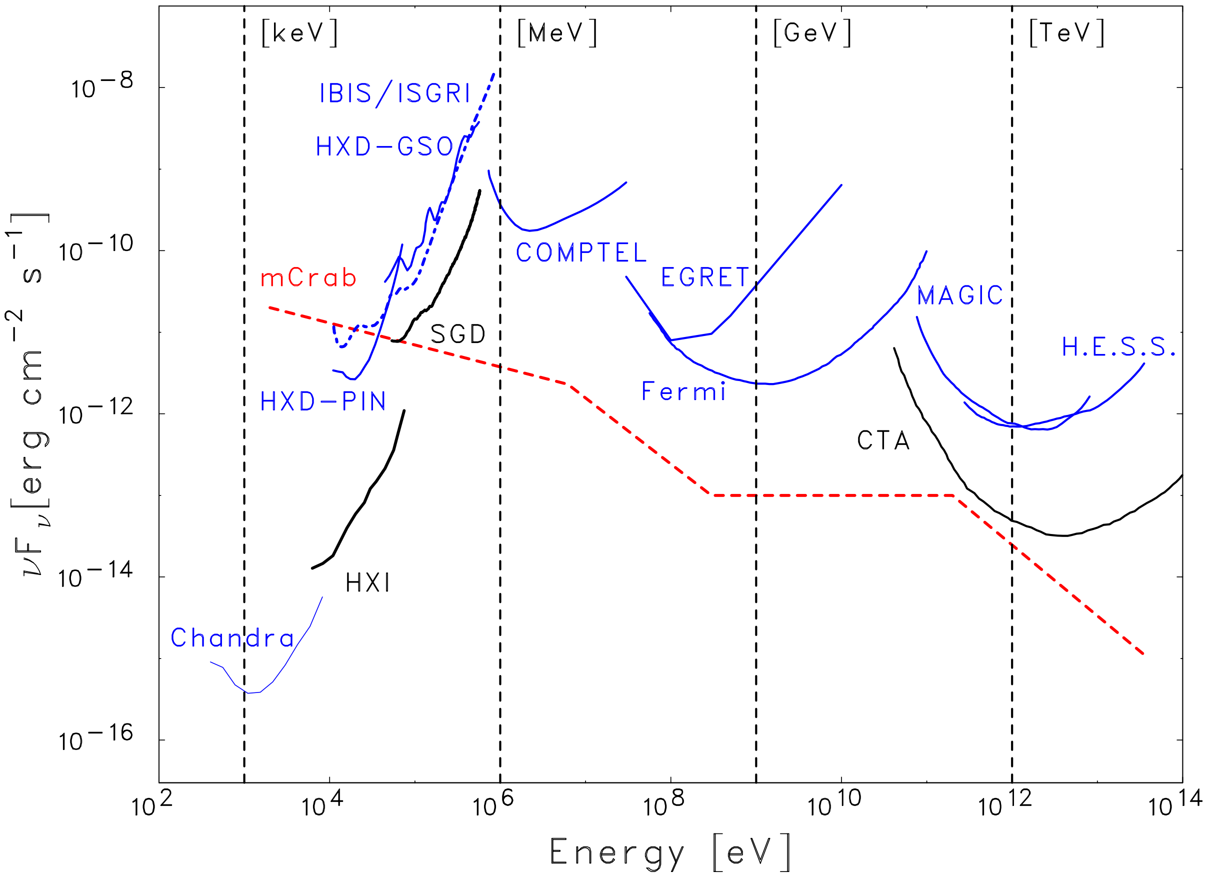
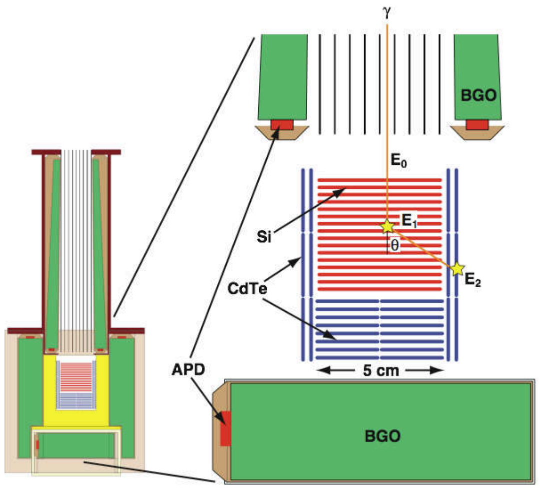
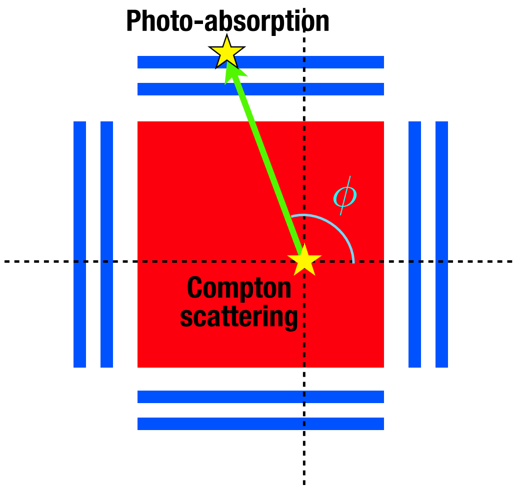
The **Soft Gamma-ray Detector (SGD)** implemented as a non-focusing detector onboard the **Hitomi (ASTRO-H)**. The SGD measured soft gamma-rays via reconstruction of the Compton scattering in the Compton camera, covering the energy range of 40–600 keV with sensitivity at 300 keV of more than 10 times better than the Suzaku Hard X-ray Detector. The SGD was capable of measuring the polarization of bright celestial sources.

Takahashi, Uchiyama & Stawarz 2013

Differential sensitivities of different X-ray and gamma-ray instruments for an isolated point source. Lines for the Chandra/ACIS-S, the Suzaku/HXD (PIN and GSO), the INTEGRAL/IBIS, and the ASTRO-H/HXI,SGD are the 3sigma sensitivity curves for 100 ks exposures. Note that the XMM-Newton instruments have a slightly better sensitivity than Chandra for 100 ks, while SWIFT/BAT is characterized by almost the same sensitivity limit as IBIS/ISGRI within the range from 15 keV up to 300 keV. The sensitivities of the COMPTEL and EGRET instruments correspond to the all-lifetime all-sky survey of CGRO. The curve denoting Fermi-LAT is the pre-launch sensitivity evaluated for the 5sigma detection limit at high galactic latitudes with 1/4-decade ranges of energy in a one-year dataset. The curves depicting the MAGIC stereo system and H.E.S.S. are given for 5sigma detection with > 10 excess photons after 50 h exposure. The simulated CTA configuration C sensitivity curve for 50 h exposure at a zenith angle of 20 deg Red dashed line denotes the differential energy flux corresponding to the mCrab unit in various energy ranges as adopted in the literature.





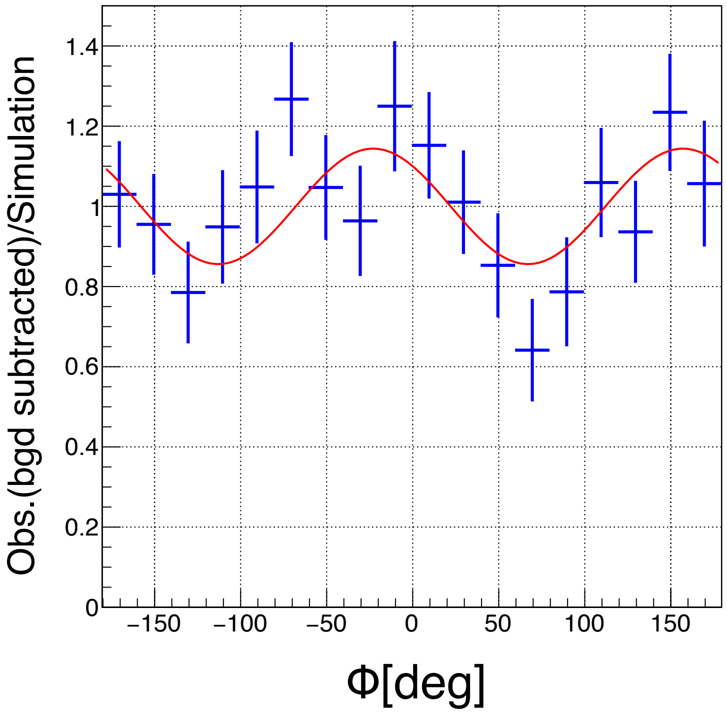


Schematic drawing of a single Compton camera unit of the SGD. The left panel shows a side view and the right panel presents the top view. The system measures two interactions (normally, Compton scattering and photo-absorption) and determines geometrical information on the scattering, namely the scattering angle θ and the azimuth angle ϕ.

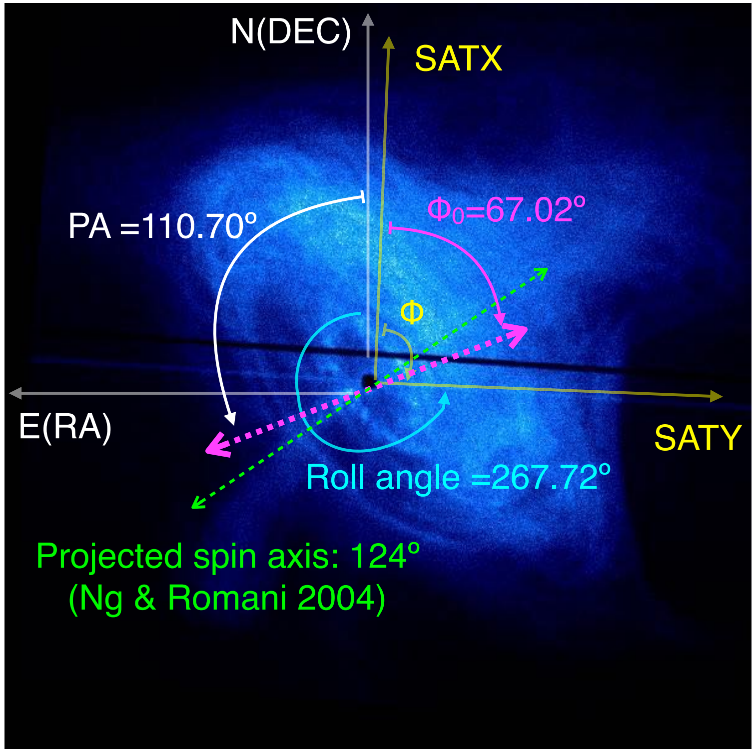
Hitomi Collaboration, 2019

The polarization measurement by the SGD utilized the anisotropy of the scattering direction of Compton scattering: the instrument determined the scattering process of an incident photon in the sensitive detectors by measuring the deposited energies and positions of the interactions.

SGD observed the Crab nebula during the initial test observation phase of Hitomi, and successfully detected polarized gamma-ray emission with only about 5 ks exposure time. The obtained polarization fraction of the phase-integrated Crab emission (sum of pulsar and nebula emissions) is (22.1±10.6)% and, the polarization angle is (110.7±13.2)deg in the energy range of 60–160 keV (The errors correspond to the 1 sigma deviation). The confidence level of the polarization detection was 99.3%. The polarization angle measured by SGD is about one sigma deviation with the projected spin axis of the pulsar, (124.0±0.1)deg. This is as expected for the soft gamma-ray emission arising predominantly from energetic particles radiating via the synchrotron process in the toroidal magnetic field in the Crab nebula, roughly symmetric around the rotation axis of the Crab pulsar.

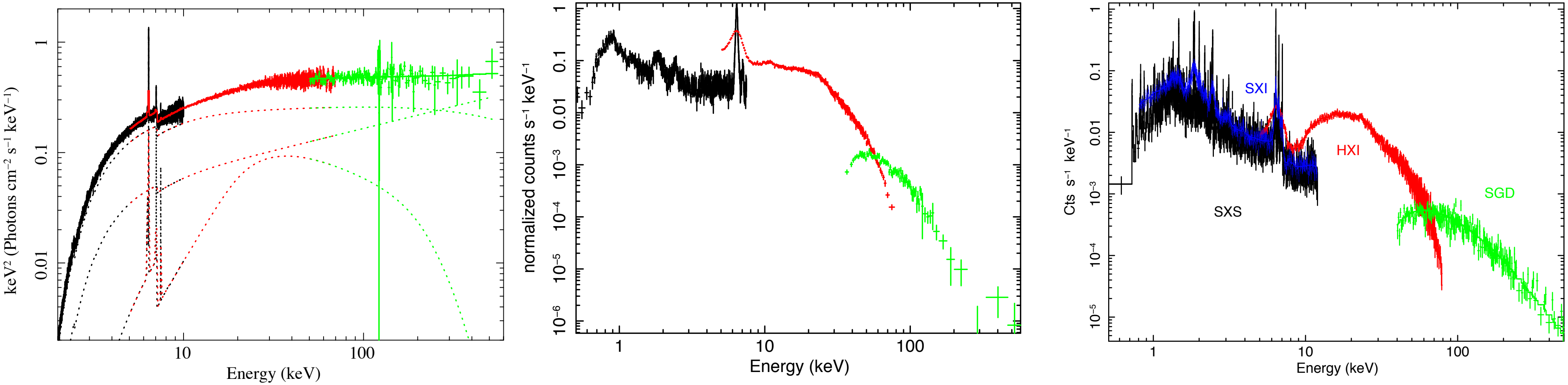


Modulation curve of the Crab nebula observed with SGD. The data points show the ratio of the observation data subtracted the background to the unpolarized simulation data. The error bar size indicates their statistical errors. The red curve shows the sine curve function substituted the esti- mated parameters by the log-likelihood fitting.

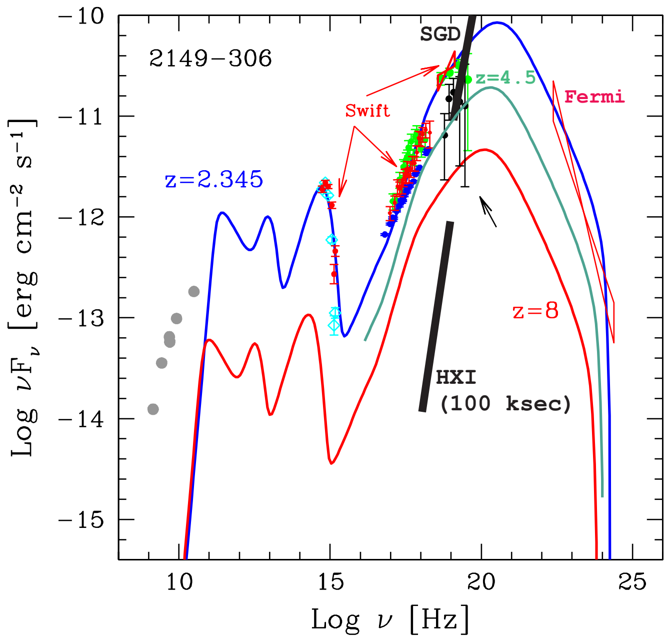


The polarization angle of the gamma-rays from the Crab nebula determined by SGD. The direction of the polarization angle is drawn on the X-ray image of Crab with Chandra.

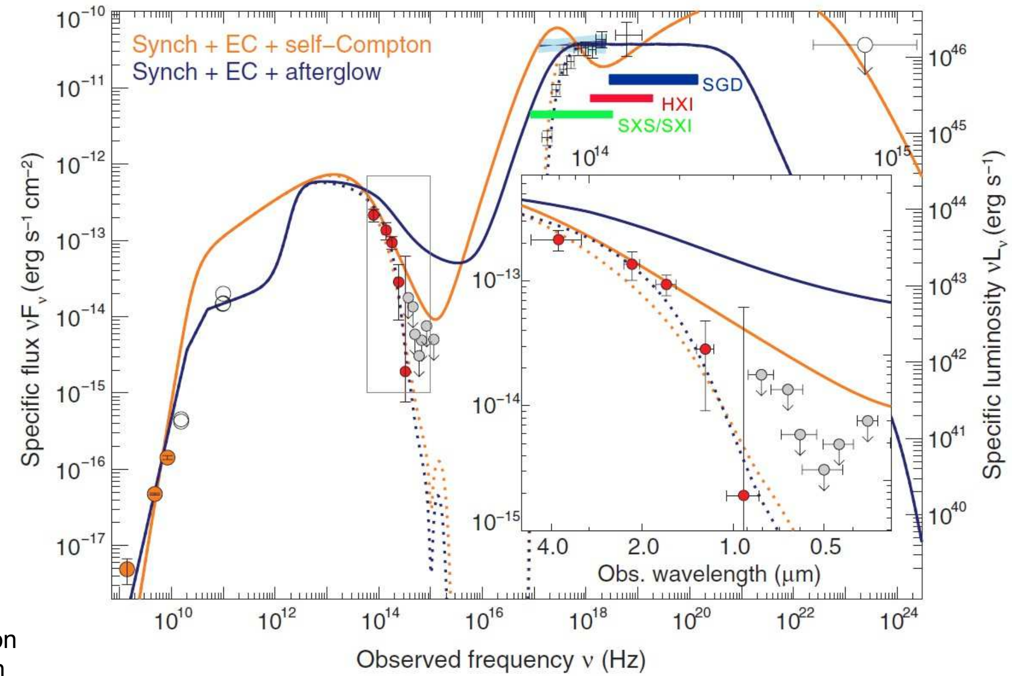
Coppi, Stawarz, et al. 2014: **Science with Hitomi/SGD**



Simulated (SXI, HXI, & SGD) broad-band spectra of Centaurus A (100ks exposure), Circinus (100ks), and NGC 4945 (150ks)



Broad-band spectral energy distribution of the $z = 2.345$ blazar 2149–306, alon with the spectral model fit (blue curve) adopted from Ghisellini et al. (2010). In addition, the green and red curves illustrate the source spectrum shifted to the redshifts $z = 4.5$ and 8, respectively. The HXI and SGD sensitivity curves corresponding to the 100 ks exposure are shown as thick black lines.

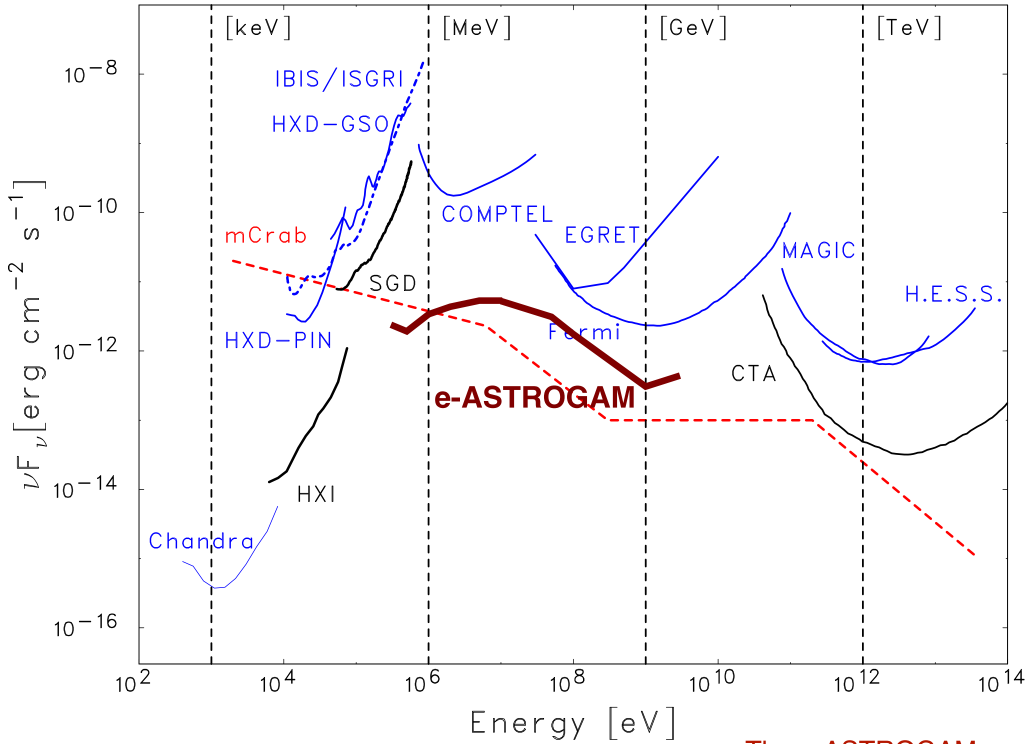


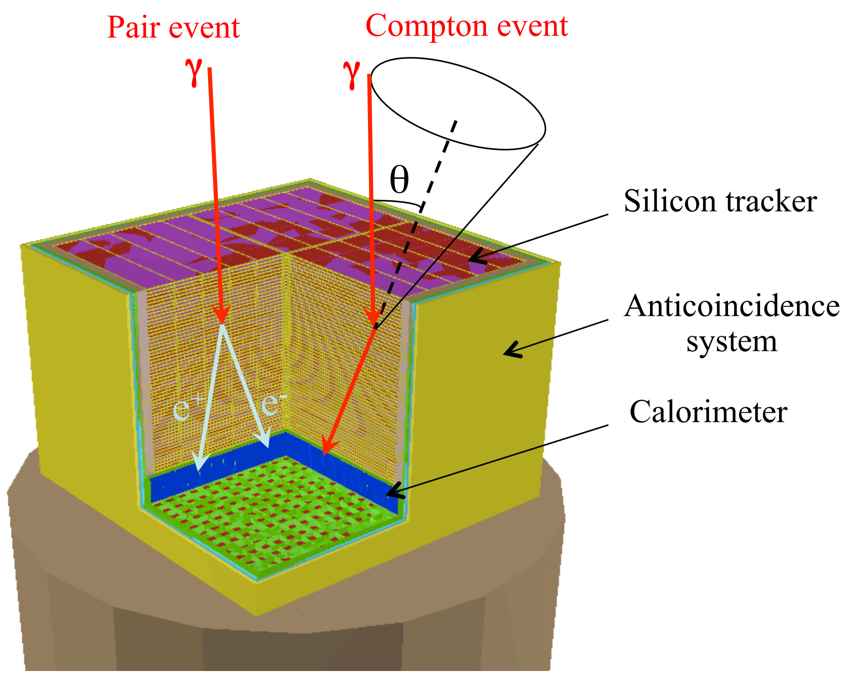
A snapshot of the spectral energy distribution of SWIFT 1644+57 and possible emission models to explain it, adapted from Bloom et al. (2011).

Tatischeff et al. 2016

The **e-ASTROGAM** telescope, originally proposed (ESA) to be made of three detection system: a silicon Tracker in which the cosmic gamma rays undergo a Compton scattering or a pair conversion, a Calorimeter to absorb and measure the energy of the secondary particles, and an anticoincidence system to veto the prompt-reaction background induced by charged particles.

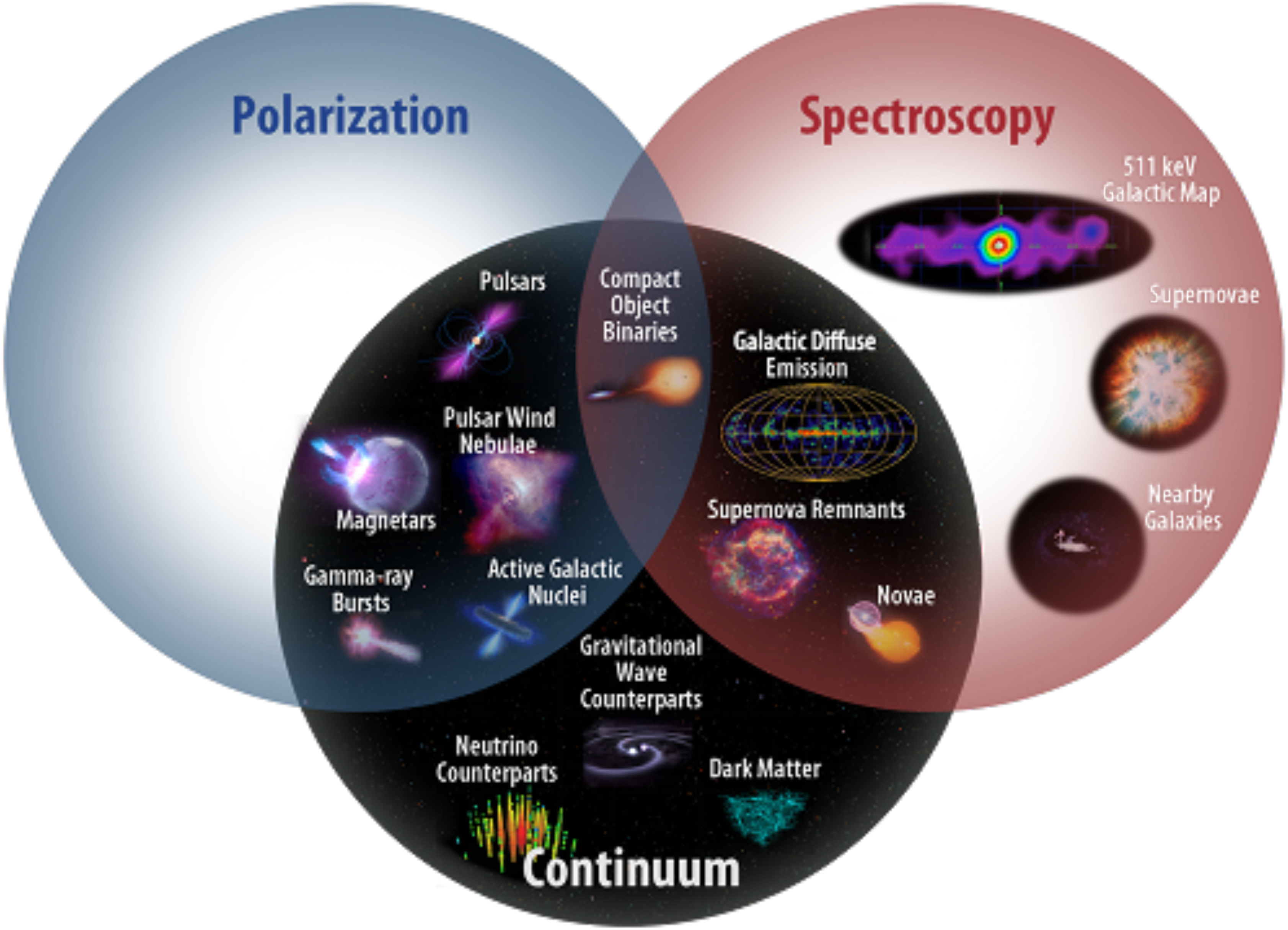
Large FOV, improved angular and energy resolution compared to COMPTEL, and much improved continuum sensitivity.

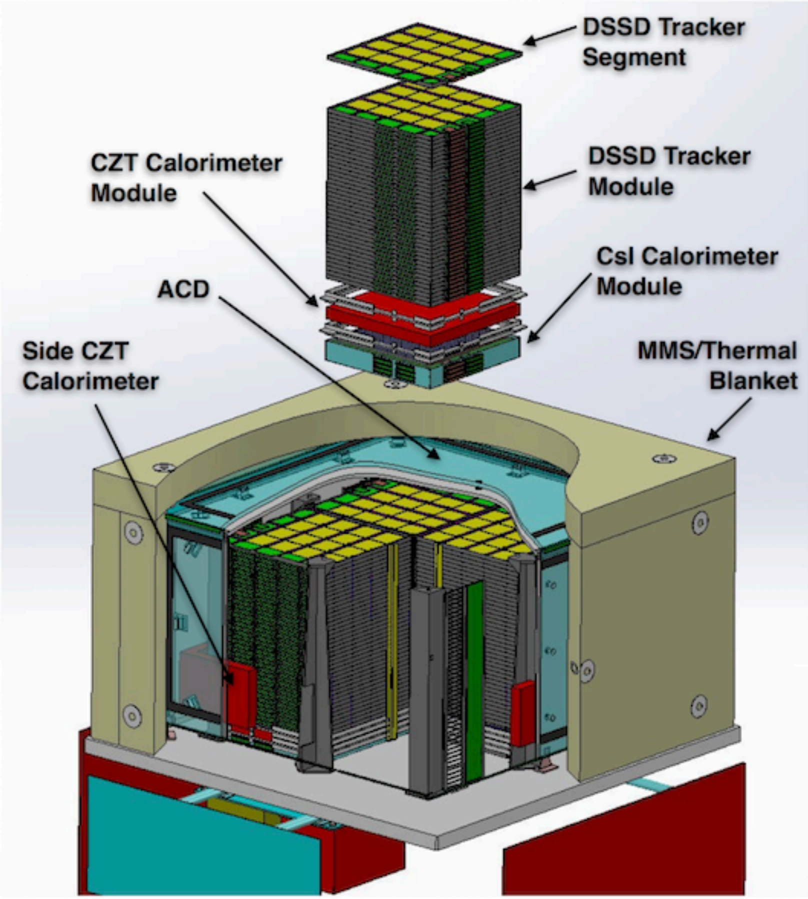




The e-ASTROGAM sensitivity is for an effective exposure of 1 year of a high Galactic latitude source

AMEGO, the All-sky Medium Energy Gamma-ray Observatory, is an Astrophysics Probe mission concept designed to explore the MeV sky, with a unique capability to provide sensitive coverage of both the Compton (0.2 - 10 MeV) and pair conversion (10 MeV - 10 GeV) regimes.



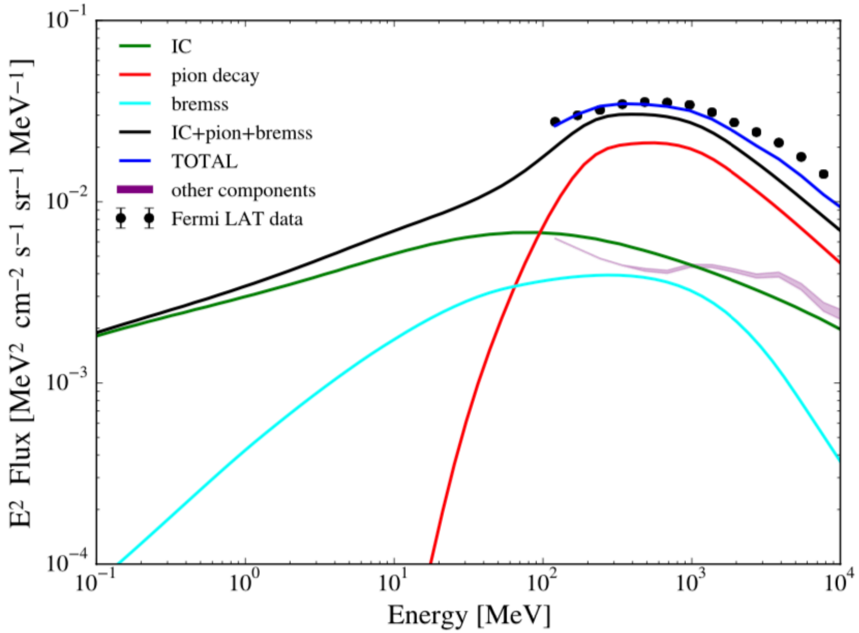


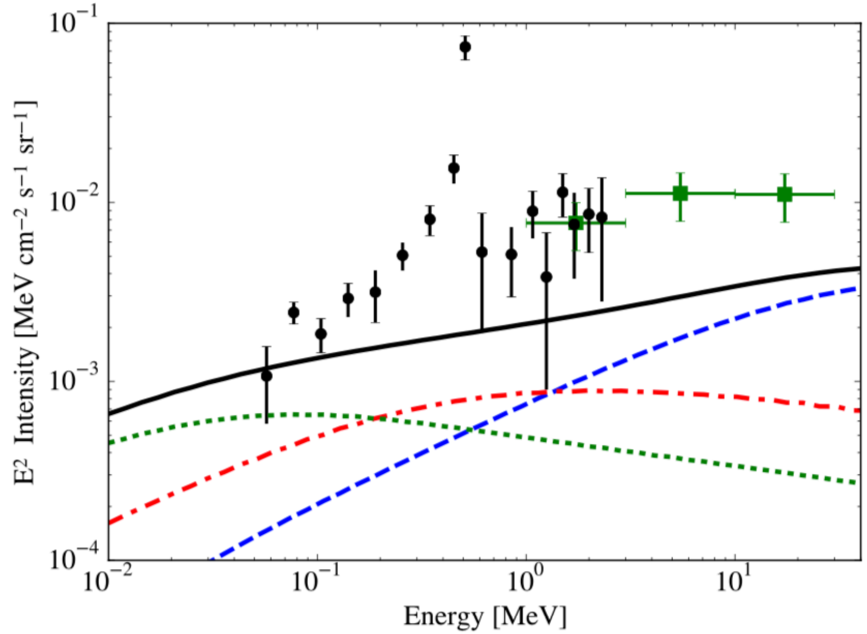
AMEGO will detect gamma-rays via Compton scattering at low energies (<~10 MeV) and pair production at higher energies (~>10 MeV). In the Compton regime, the use of solid state technology provides substantial performance improvements relative to COMPTEL, the Compton telescope flown on the Compton Gamma-Ray Observatory (CGRO). In the pair regime, AMEGO has been optimized for peak performance at lower energies relative to Fermi-LAT by minimizing passive material (e.g. conversion foils) in the tracker and enhancing low energy readout in the calorimeter.

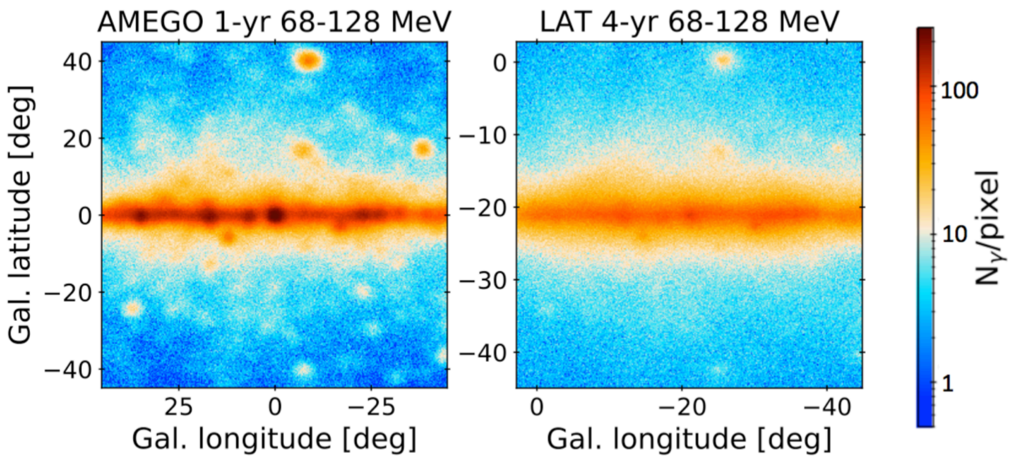
AMEGO will operate in low-earth orbit in two modes: a survey mode covering a large fraction of the sky every orbit and an inertially pointed mode. The large field of view allows a loose pointing requirement (~5°) with a requirement on pointing knowledge of ~20''.

Energy Range	0.2 MeV -> 10 GeV
Angular Resolution	3° (1 MeV), 10° (10 MeV)
Energy Resolution	<1% below 2 MeV; 1-5% at 2-100 MeV; ~10% at 1 GeV
Field-of-View	2.5 sr
Sensitivity (MeV s^{-1} cm^{-2})	$4x10^{-6}$(1 MeV); $4.8x10^{-6}$(10 MeV); $1x10^{-6}$(100 MeV)

Diffuse Galactic Emission





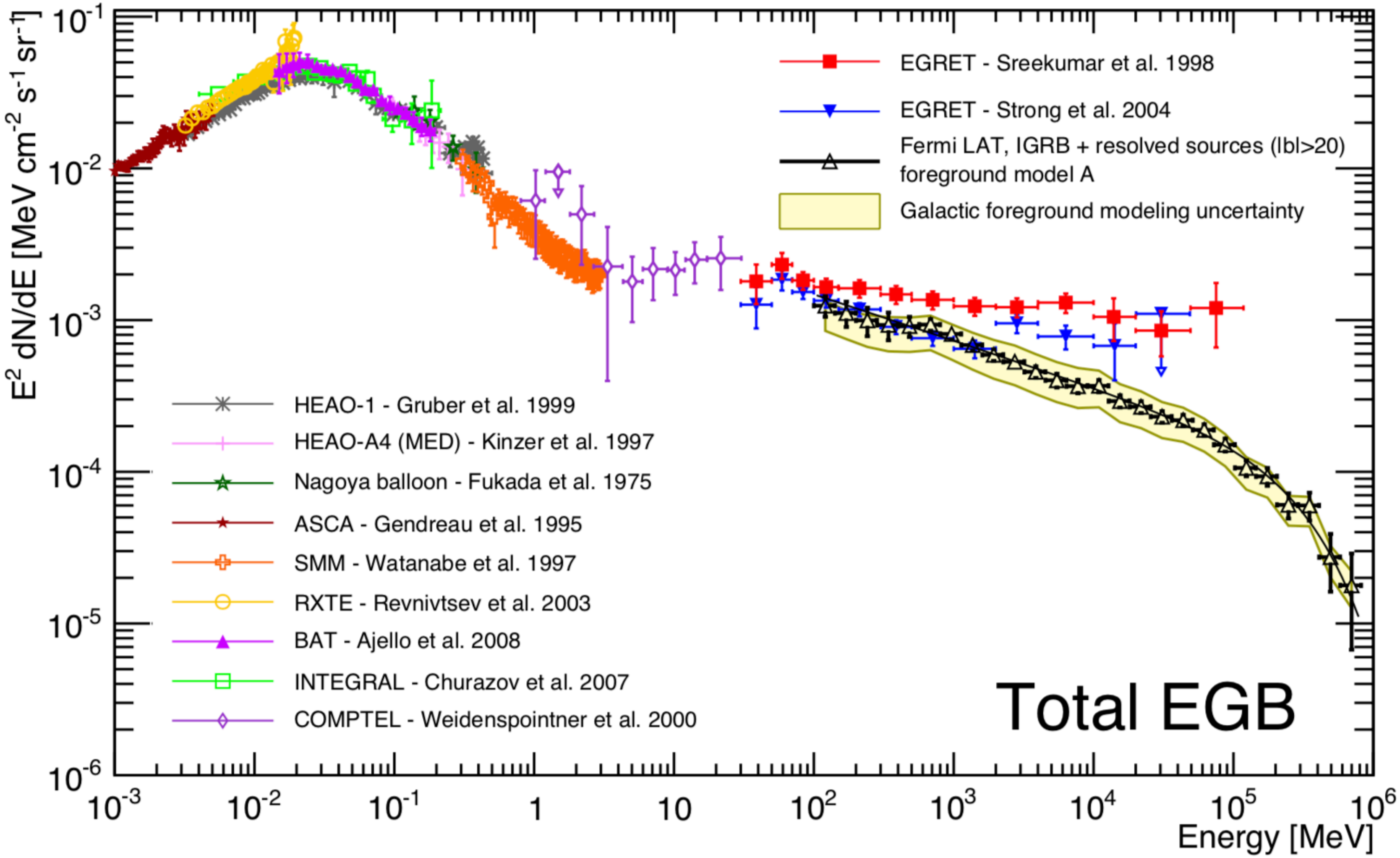


Orlando et al. 2019:

predictions of the large-scale interstellar emission from 10 keV to 10 GeV that fits latest Voyager 1 AMS02 data, and synchrotron radio-microwave data. Figure on the left shows the IC (green line), bremsstrahlung (cyan line), and pion decay (red line) model, along with their sum (black line) compared with the *Fermi* LAT data for a 10deg radius around the Galactic center (black points), while the figure on the right shows the predictions for the IC on the CMB (green dotted line), on the diffuse IR (red, dash-dotted line), and on the diffuse optical (blue dashed line), along with their sum (black solid line) compared to the INTEGRAL/SPI (black points) and COMPTEL (green points). An AMEGO-like instrument sensitivity is below the scale of the plotted area.

Extragalactic Background Radiation

Ackermann et al. 2015



The MeV Sky

- **The MeV domain is one of the most underexplored windows on the Universe!**
  Diffuse emission & point sources; lines and continuum emission, spectroscopy & polarisation…

- In the hard X-ray/soft gamma-ray domain, polarization signatures may arise from vastly different processes, including bremsstrahlung emission from anisotropic electron distribution, synchrotron emission in ordered magnetic fields, anisotropic Compton scattering, inverse-Comptonization of a polarized photon field, or photon propagation through a highly magnetized plasma. Hence, substantially polarized X-ray emission may in principle be expected in a variety of astrophysical systems such as stellar flares, pulsars, pulsar nebulae, magnetars, accreting white dwarfs, supernova remnants, black hole accretion disks and coronae, jetted AGN, microquasars, or gamma-ray bursts.

- COMPTEL instrument onboard the CGRO provided the first complete all-sky survey in the energy range 0.75 to 30 MeV. The First COMPTEL Catalogue includes 32 steady sources and about 50 transients; among the continuum sources are spin-down pulsars, XRBs, supernova remnants, interstellar clouds, AGN, gamma-ray bursts, and solar flares. The third IBIS/ISGRI catalog, based on >40Ms observations performed during 3.5 yrs of the *INTEGRAL* operation, includes > 400 sources detected in the 17–100 keV range. Finally, the *Swift*-BAT 70-month survey has detected 1171 hard X-ray sources in the 14–195 keV band down to a significance level of 4.8σ, associated with 1210 counterparts including various types of AGN, clusters, cataclysmic variables, pulsars, stars, supernova remnants, and XRBs. Thus, the hard X-ray/soft γ-ray sky is crowded indeed, being populated by a variety of high-energy emitters. Among these, some sources still remain to be identified, and many to be characterized precisely (regarding their spectral and timing properties) at >10 keV photon energies. This constitutes a space for potential new exciting discoveries with future MeV missions.