

# The MEGA Advanced Compton Telescope Project

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## Abstract

The goal of the Medium Energy Gamma-ray Astronomy (MEGA) telescope is to improve sensitivity at medium gamma-ray energies (0.4–50 MeV) by at least an order of magnitude over that of COMPTEL. This will be achieved with a new compact design that allows for a very wide field of view, permitting a sensitive all-sky survey and the monitoring of transient and variable sources. The key science objectives for MEGA include the investigation of cosmic high-energy particle accelerators, studies of nucleosynthesis sites using gamma-ray lines, and determination of the large-scale structure of galactic and cosmic diffuse background emission. MEGA records and images gamma-ray events by completely tracking both Compton and pair creation interactions in a tracker of double-sided silicon strip detectors and a calorimeter of CsI crystals able to resolve in three dimensions. We present initial laboratory calibration results from a small prototype MEGA telescope.

*Key words:* gamma rays: observations, instrumentation: detectors, space vehicles: instruments, surveys

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## 1 Introduction

Since the demise of the COMPTEL instrument on CGRO, the medium energy gamma-ray region of the spectrum (0.4–50 MeV) has been left unattended

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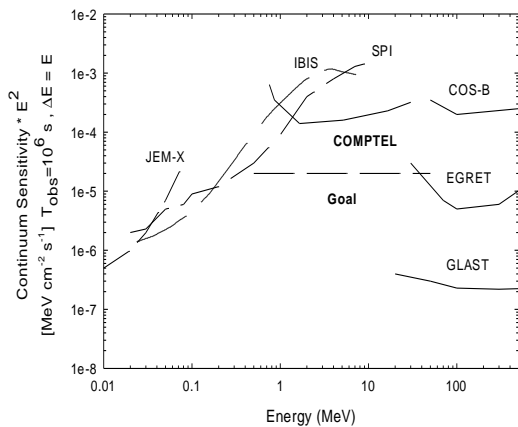


Fig. 1. Sensitivity levels for continuum point sources for various past and future missions. The goal for MEGA is shown by the dashed line.

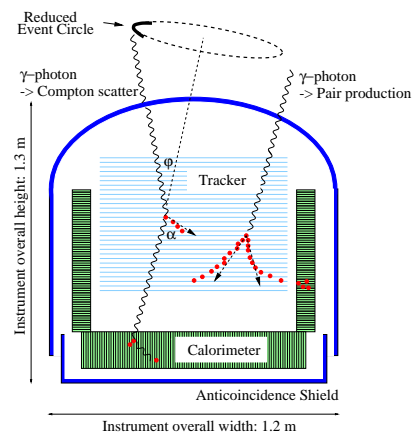


Fig. 2. Schematic of the MEGA design, showing tracker and calorimeter. Both Compton scatters and pair production events can be recorded.

and will not be adequately covered by currently-planned missions. While the INTEGRAL mission (2002) will provide pointed observations of line and continuum sources up to 10 MeV and the AGILE ( $\sim 2003$ ) and GLAST ( $\sim 2006$ ) missions promise great advances at energies above 100 MeV, an Advanced Compton Telescope (ACT) mission, with all-sky survey capabilities and a narrow line sensitivity of  $10^{-7}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  (a factor of 100 better than COMPTEL), lies at least a decade in the future. Figure 1 shows the sensitivities of past and planned gamma-ray missions. It is obvious that, at high energies, technological advances have produced three “generations” of instruments (COS-B, EGRET, and GLAST), each with a factor of  $\sim 10$  improvement in sensitivity. In a similar fashion, using technology that is available today, a second-generation medium energy mission could provide an intermediate step toward ACT and improve the sensitivity of COMPTEL by a factor of 10 (indicated by the dashed line in Figure 1). Beginning this project now would allow a launch in  $\sim 2006$  and permit simultaneous observations with GLAST; such broadband spectral coverage was shown by CGRO to be invaluable. The Medium Energy Gamma-ray Astronomy (MEGA) project at MPE aims to provide this intermediate step.

## 2 Scientific Objectives

The medium energy gamma-ray band is of particular importance for a wide variety of important high-energy astrophysical problems, specifically those involving nuclear, non-thermal, and relativistic processes. The production of elements in massive stars and supernovae results in unstable isotopes, such as  $^{26}\text{Al}$  and  $^{44}\text{Ti}$ , that produce radioactive decay lines in the MeV range. Compact objects, including black hole binaries and gamma-ray pulsars, pos-

sess Doppler-shifted nuclear de-excitation lines as well as continuum spectral slopes, breaks, and cutoffs in the gamma-ray band that are characteristic of relativistic particle acceleration and are highly variable. Outside the galaxy, active galactic nuclei (AGN) are prodigious producers of gamma-rays, some especially so in the MeV range. These sources are also highly variable, and therefore must be monitored constantly. Continuous monitoring is also needed to study gamma-ray bursts, which produce the bulk of their energy around 1 MeV. In addition to such discrete sources, both galactic and extra-galactic diffuse gamma-ray emission exists as well. The former arises from both cosmic-ray interactions in the interstellar medium and radioactive material ejected from supernovae; the latter is likely the superposition of distant AGN. The combined instruments of CGRO provided a first taste of all these phenomena, but many were only marginally detected. For example,  $^{56}\text{Co}$  line emission from SN1991T, the only supernova Type Ia possibly seen in gamma-rays, was detected by COMPTEL at the 3–4  $\sigma$  level (Morris et al. 1998), and about half of the 10 “MeV blazars” are also seen near COMPTEL’s detection threshold. Larger samples with higher significance of all these phenomena, together with continuous monitoring, are needed to learn more.

### 3 Instrument Design

Achieving the desired improvement in sensitivity for an instrument with good imaging and spectroscopy abilities in the MeV range is a difficult task. At these energies the overall interaction cross section goes through a minimum, and the primary photon interaction produces long-range secondary photons and/or electrons. At about 8 MeV (in silicon, for example) the most likely interaction changes from Compton scattering to pair production. In order to make full use of all interacting photons one then requires both sufficient material depth to achieve high detection efficiency and good spatial and energy resolution to track the secondary particles. Solutions to this problem that are available with today’s technology include Xenon time projection chambers (Aprile et al. 2000), stacks of germanium detectors (Boggs & Jean 2000), and combinations of solid-state detectors and scintillators (O’Neill et al. 2000).

The basic MEGA telescope design is shown in Figure 2. It consists of a *tracker*, in which the primary Compton scatter or pair creation event takes place, and a *calorimeter*, which absorbs and measures the secondary particles. The tracker contains 32 layers of double-sided Si strip detectors ( $6 \times 6$  wafers of  $6 \text{ cm} \times 6 \text{ cm}$  each,  $500 \mu\text{m}$  thick, with a pitch of  $470 \mu\text{m}$ ). The tracker is enclosed on five sides by the calorimeter, made of CsI cells ( $5 \text{ mm} \times 5 \text{ mm}$  cross section, 8 cm long on the bottom, 4 cm long on the sides) read out by Si PIN diodes. For incident photon energies above  $\sim 1.5 \text{ MeV}$  the Compton recoil electron in most events receives enough energy to be tracked through multiple

silicon layers; the origin of the photon can then be constrained to lie on only a small segment of the standard Compton event circle (“reduced event circle” in Figure 2), reducing background in crowded fields. Electron-positron pairs may be similarly tracked. The locations and energy deposits of all interactions may be analyzed to reconstruct a most likely sequence for each event, which leads to very efficient suppression of background events. The entire MEGA assembly is further surrounded by a plastic anticoincidence shield.

Simulations based on the MEGA prototype (see Section 5) using GEANT3 indicate an effective area of about  $100 \text{ cm}^2$  at 2 MeV for the full MEGA telescope, with an angular resolution of  $\sim 4^\circ$  FWHM and an energy resolution of  $\sim 8\%$  FWHM at 2 MeV. The field of view is quite large,  $\sim 130^\circ$  FWHM, allowing all-sky survey operations. Replacing the PIN diodes in the calorimeter with low-noise silicon drift diodes could improve the angular resolution to  $\sim 2^\circ$  and the energy resolution to  $\sim 4\%$ . An exciting prospect for an instrument based on Compton scattering through large angles is high sensitivity to polarization. Our calculations indicate that MEGA should be sensitive to polarization levels of  $\sim 15\%$  for energies less than 1 MeV from a Crab-like source after 100 hours of observation.

## 4 Mission Concept and Expected Results

The baseline MEGA experiment has been considered in a pre-phase A study for a small satellite mission. Based on this study, the detector will have a mass of  $\sim 650 \text{ kg}$  and dimensions of 1.3 m diameter by 1.1 m length. Placed on a standard small satellite platform, the launch payload mass is about 950 kg with a diameter of 2 m and a length of 2.4 m. The electrical power requirement is  $\sim 400 \text{ W}$ , and the average telemetry rate  $50 \text{ kbit s}^{-1}$ . The development time of MEGA to launch would be about 5.5 years, after which a mission lifetime of 3–5 years is foreseen. This would allow considerable overlap with the GLAST mission, a highly desirable goal that should be pursued if at all possible. MEGA would be placed in a low earth orbit (500–550 km) in as low an inclination as possible in order to provide a low-background environment. MEGA would be operated in a zenith-pointing mode, performing a continuous all-sky survey. The wide field of view provides a nearly complete scan with each orbit and allows the constant monitoring of variable sources. Real-time satellite telemetry is planned through the TDRSS Demand Access System. The data will be analyzed promptly for bursts and transients, and appropriate alert messages will be sent to initiate follow-up observations.

The survey sensitivity of MEGA has been derived from simulations by calculating the relative number of source and background counts falling within a circular area on the sky with width  $3\sigma$  of the angular resolution. Figure 3

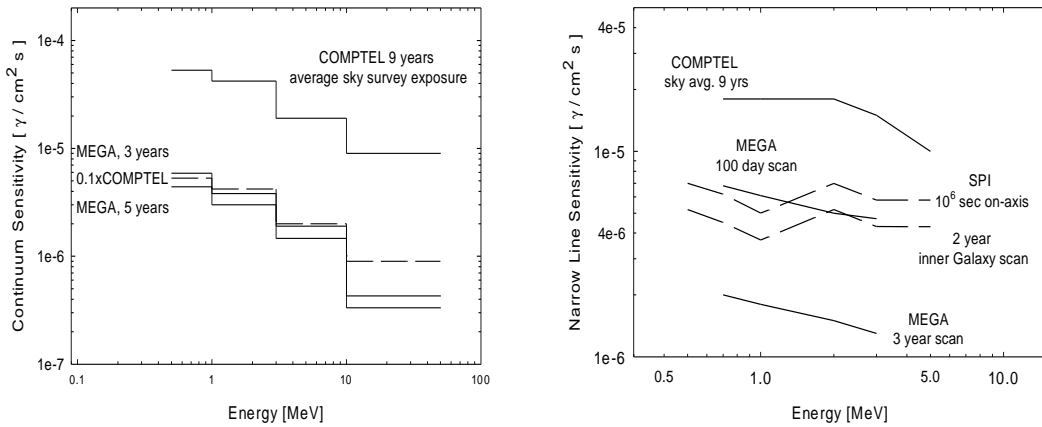


Fig. 3. Left: Sensitivity ( $3\sigma$ ) for MEGA for sources with continuous spectra for 3 and 5 year surveys. The dashed line shows a 10-fold improvement over COMPTEL. Right: Sensitivity (also  $3\sigma$ ) for narrow spectral lines, compared to COMPTEL and to SPI on INTEGRAL.

shows the results for continuum and narrow line sources. The MEGA in-orbit background was assumed to be equivalent to 3 times the in-flight spectrum recorded by COMPTEL at 5 GV cutoff rigidity, including events that appear as gamma-rays but are in fact caused by local background (concentrated in a bump in the nuclear line region of 1–8 MeV). This background assumption will have to be checked carefully once the instrument and satellite mass model and orbit have been precisely defined.

A preliminary estimate of the number of sources detectable by MEGA in a 3-year survey predicts that, within the galaxy, about 100 unidentified EGRET sources should be seen. The number of pulsars observed at MeV energies should grow to about 10, and about a dozen black hole binaries like Cyg X-1 should be detected. Although exact numbers are highly model-dependent, we also expect to discover several young supernova remnants through their  $^{44}\text{Ti}$  line emission, while a few novae should be detectable through their lines each year. Outside the galaxy, about 100 blazars and more than 10 radio and Seyfert galaxies should be visible. A gamma-ray burst will occur and be imaged in the large field of view of MEGA every  $\sim 2$  days. We should also see 2–3 supernovae per year. Far more detailed mapping of the spatial and spectral distribution of diffuse emission, both lines and continuum, will be possible than was the case with COMPTEL. Thus much larger samples will be available of all medium energy gamma-ray astronomical objects, allowing the first glimpse provided by CGRO to be expanded and explored. The tantalizing marginal results of COMPTEL will be unambiguously confirmed or denied, and science beyond mere detection will be possible.

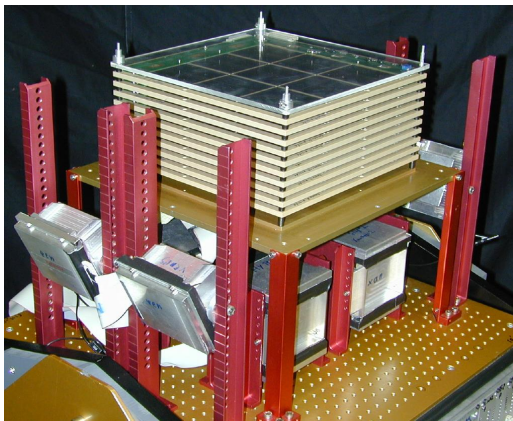


Fig. 4. The MEGA prototype detector, with 10 tracker layers and 4 CsI blocks visible.

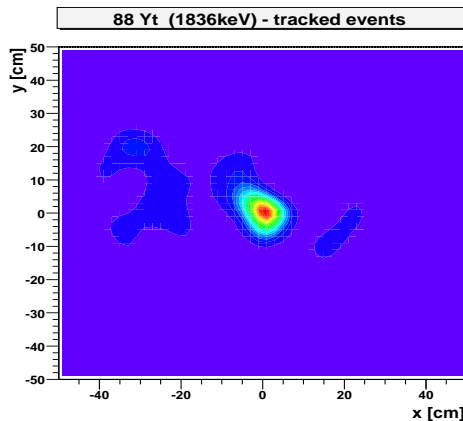


Fig. 5. Image of a  $^{88}\text{Y}$  source (1.836 MeV) located 80 cm from the prototype, using tracked events only.

## 5 Prototype Development

A prototype of the MEGA telescope has been constructed in the laboratory at MPE, and is shown in Figure 4. The prototype tracker has 10 layers of  $3 \times 3$  Si wafers each, and the calorimeter will comprise 20 modules of CsI detectors, each with a  $10 \times 12$  array of crystals either 2 cm, 4 cm, or 8 cm deep (Schopper et al. 2000). The 8 cm crystals have PIN diodes on both ends, which allows the depth of the photon interaction to be determined by the ratio of output light. Both the tracker and calorimeter detectors are read out by identical front-end ASIC chips (TA1.1 chip by IDE, self-triggering with 128 channels), custom-made front-end control units, and laboratory VME and NIM electronics. The individual detector units must be calibrated individually using laboratory radioactive sources, and then the entire telescope may be tested using higher energy sources and a coincident trigger. Each recorded event is reconstructed according to the most likely sequence of interactions in the tracker (electrons) and calorimeter (scattered photons). Images are reconstructed using a list-mode maximum-likelihood expectation-maximization method adapted from Wilderman et al. (1998). Figure 5 shows an image of a  $^{88}\text{Y}$  source (1.836 MeV), located  $\sim 80$  cm from the detector, constructed using only those events which produced tracks in the silicon layers. Only eight calorimeter modules were in place for this measurement. These results prove that the MEGA concept is viable and that the detector technology and data analysis techniques are presently available to construct a next-generation gamma-ray telescope.

In February 2002 the MEGA prototype will be taken to Duke University's High Intensity Gamma-ray Source for calibration measurements. This facility produces a gamma-ray beam with tunable energy between 2 MeV and 55 MeV using Compton back-scattering of UV laser photons in an electron storage ring. The beam is highly polarized, providing an additional, valuable test of

MEGA's sensitivity as a polarimeter. In June 2002 we plan to fly the MEGA prototype on a CNES balloon flight from Gap, France (in collaboration with CESR) to measure background and test detector performance under flight conditions. If all goes well, the MEGA concept will have proven itself suitable for a space mission.

## References

- Aprile, E., et al. 2000, Proc. SPIE 4140, 333  
Boggs, S. E., & Jean, P. 2000, A&AS 145, 311  
Morris, D. J., et al. 1998, Proc. of the Fourth Compton Symposium (AIP 410), 1084  
O'Neill, T. J., et al. 2000, Proc. of the Fifth Compton Symposium (AIP 510), 804  
Schopper, F., et al. 2000, NIM-A 442, 394  
Wilderman, S. J., et al. 1998, IEEE Trans Nucl Sci 45, 957