ComPair – A Compton-Pair Telescope for Future MeV Astronomy

Alexander Moiseev, Elizabeth Ferrara, Roopesh Ojha, Andrew Smith (all CRESST/NASA/GSFC and UMD, USA), Elizabeth Hays, Julie McEnery, John Mitchell, Jeremy Perkins, Judith Racusin, David Thompson (all NASA/GSFC, USA), James Buckley (Washington University, St. Louis, USA), Regina Caputo (UCSC and SCIPP, Santa Cruz, USA), Marco Ajello, Dieter H. Hartmann (Clemson University, USA)

ABSTRACT. **T**he gamma-ray energy range from a few hundred keV to a few hundred MeV has remained largely unexplored, mainly due to the challenging nature of the measurements, since the pioneering, but limited, observations by COMPTEL on the Compton Gamma-Ray Observatory (1991- 2000). This energy range is a transition region between thermal and non-thermal processes, and accurate measurements are critical for answering a broad range of astrophysical questions. We are developing a MIDEX-scale wide-aperture discovery mission, ComPair (Compton-Pair Production Space Telescope), to investigate the energy range from 200 keV to > 500 MeV with high energy and angular resolution and with sensitivity approaching a factor of 100 better than COMPTEL. This instrument will be equally capable to detect both Compton-scattering events at lower energy and pair-production events at higher energy. ComPair will build on the heritage of successful space missions including Fermi LAT, AGILE, AMS and PAMELA, and will utilize well-developed space-qualified detector technologies including Si-strip and CdZnTe-strip detectors, heavy inorganic scintillators, and plastic scintillators.

Motivation

Between soft X-rays (less than 10 keV) and hard gamma rays (greater than 100 MeV) lies an energy range of transition in the Universe. Thermal sources dominate at lower energies, while non-thermal processes prevail at higher energies. Missions like NuSTAR and INTEGRAL at the low end of this transition region and Fermi Gamma-ray Space Telescope at the upper end point to the region, particularly between a few MeV and 100 MeV, as being critical for answering a broad range of astrophysical questions.

This transition region has remained largely unexplored since the pioneering but limited observations by COMPTEL on the Compton Gamma-Ray Observatory. The same advances in detector technology that enabled the dramatic success of the Fermi mission can now be applied to this transition region, allowing measurements of the two relevant processes of photon interaction, Compton scattering and pair production.

We believe that it is possible to design a cost-saving single instrument that will be capable to detect both kinds of photon interaction processes. **The proposed ComPair instrument will operate in the extended energy range 0.2 – 500 MeV, optimizing its performance in the 1 – 100 MeV range, complementing Fermi and improving on the COMPTEL performance by a factor of 50-100.** The ComPair heritage includes both Fermi-LAT and the proposed but not flown instruments MEGA and GRIPS.

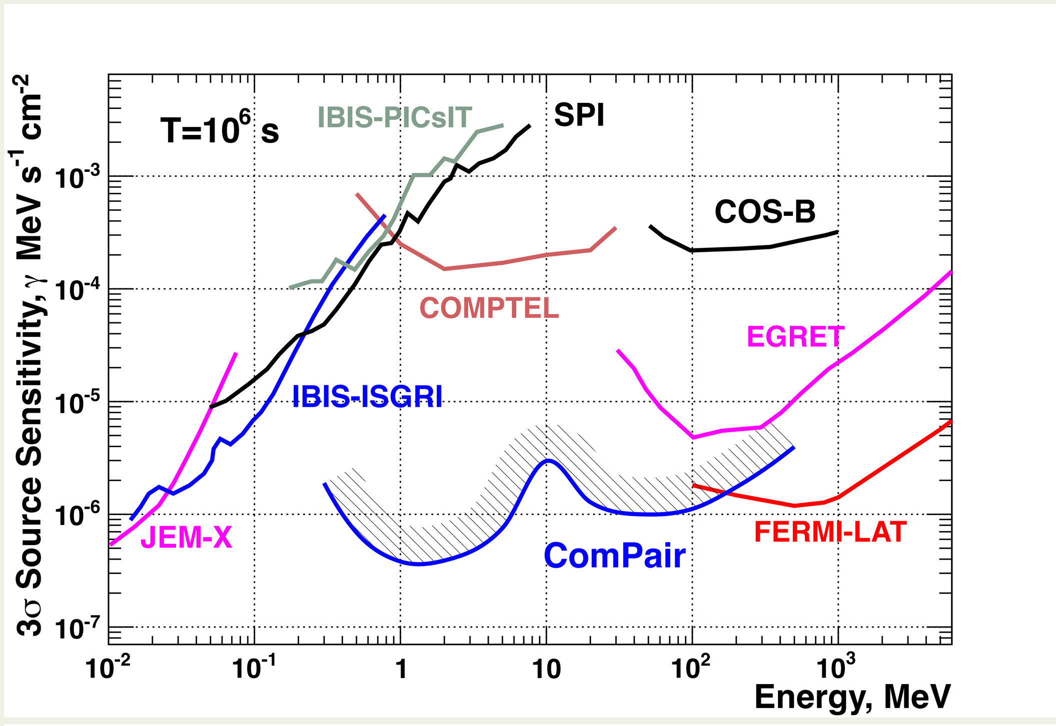

Fig. 1 – Sensitivity of the proposed ComPair instrument compared with other measurements (preliminary calculation)

Instrument Concept is based on the scheme of previous gamma-ray telescopes EGRET [1], Fermi-LAT [2], AGILE [3], and on the exploratory studies for MEGA [4] and GRIPS [5] (Fig.2):

Multi-layer Si-strip Tracker – identifies photon interactions and measures particle tracks produced in the photon interactions

Combined CdZnTe-strip and CsI(Tl)-log Calorimeter – measures energies and provides direction information for Compton events.

Plastic scintillator Anticoincidence Detector discriminates the photons from the vastly more abundant charged particles in the space environment

The baseline Trigger is a five-fold coincidence of the hits in two consecutive Si planes (both sides in each plane) and the presence of a signal from the Calorimeter

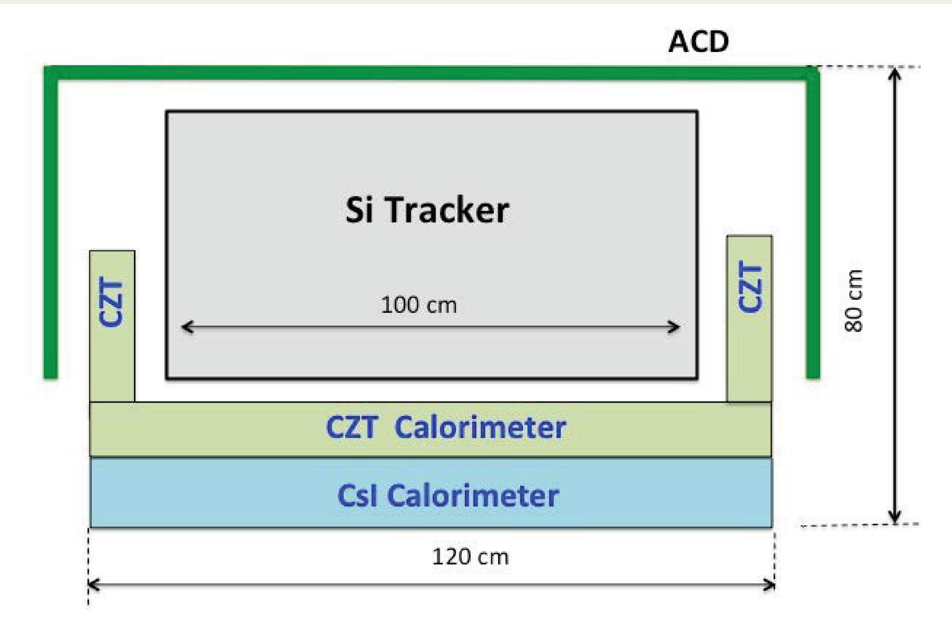

Fig.2 Conceptual design of ComPair

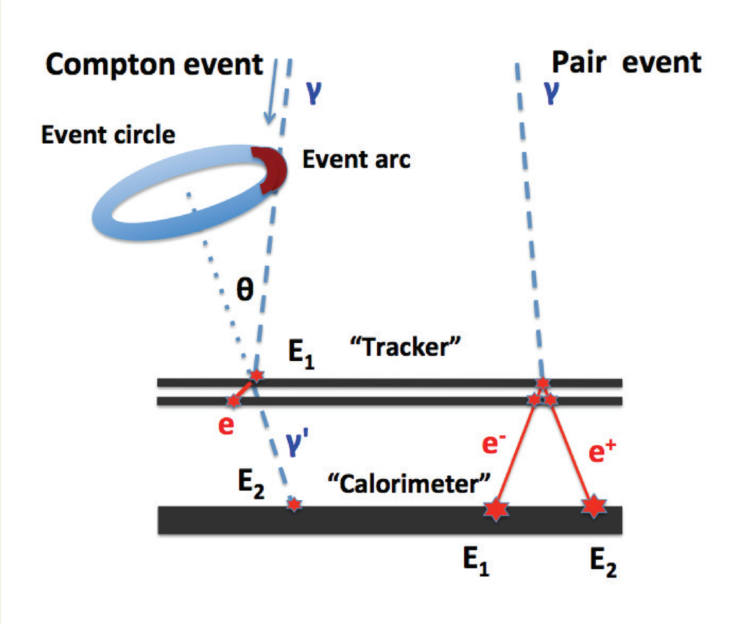

Fig.3 Event types for Compton-Pair telescopes

Detection of Pair-production events

- Photon conversion occurs in multi-plane Si-strip tracker. Arrival direction is determined by measuring tracks of pair components.
- Photon energy is determined in the calorimeter (both, in CZT and CsI sections).

Detection of Compton-scattered events

- First Compton scattering occurs in one of the Si tracker plane, creating low-energy electron and scattered photon
- The scattered photon can be absorbed in a calorimeter. Photon arrival direction (arc on the event circle) is determined by measuring the points of Compton scattering and photon absorption in a CZT calorimeter and measuring energy and direction of absorbed photon and in some cases of recoiled electron
- Baseline concept utilizes "tracked" events, when the recoil electron is detected. Corresponding effective area is smaller than if the "untracked" events are used, and detection threshold is higher, but the direction reconstruction is more reliable and background rejection (especially the atmospheric one) is more efficient

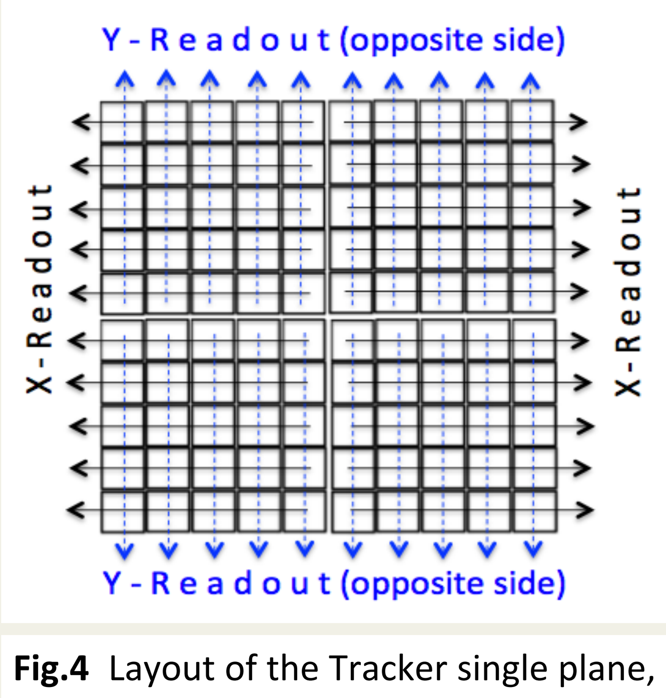

Fig.4 Layout of the Tracker single plane, divided in 4 segments, with 5x5 wafers in each (25x25 for CZT plane)

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Instrument Components:

Tracker:

- Stack of 50 double-sided (orthogonal X & Y) 0.5mm thick Si-strip detector planes, spaced by 1cm, with an area of 1m x 1m and strip pitch 0.25mm. No additional passive converter!
- Each plane is made of 10 x 10 double-side Si-strip detectors, 9.5 by 9.5 cm each, divided in four 5 x 5 wafer segments with daisy-chained strips in each direction and readout from the sides (Fig.4)
- Analog signal readout from strips to provide energy measurement

Calorimeter

- The CZT calorimeter consists of 4 planes of 5mm thick double-sided CZT-strip detectors. Each plane is made of 2cm x 2cm x 0.5cm individual detectors, with four orthogonal readout strips on both sides of each detector. Each plane is divided in 4 segments, similarly to the tracker plane (Fig.4). Each segment contains 25 x 25 individual daisy-chained CZT detectors.
- The CsI(Tl) calorimeter design is similar to that of Fermi-LAT. It consists of 5 planes of 1.2cm x 1.2cm x 32cm CsI logs, with each log read out from both sides by SiPM. The logs in the planes are arranged alternatively along X and Y axis.
- The total depth of the bottom calorimeter is ~4.5 X_0

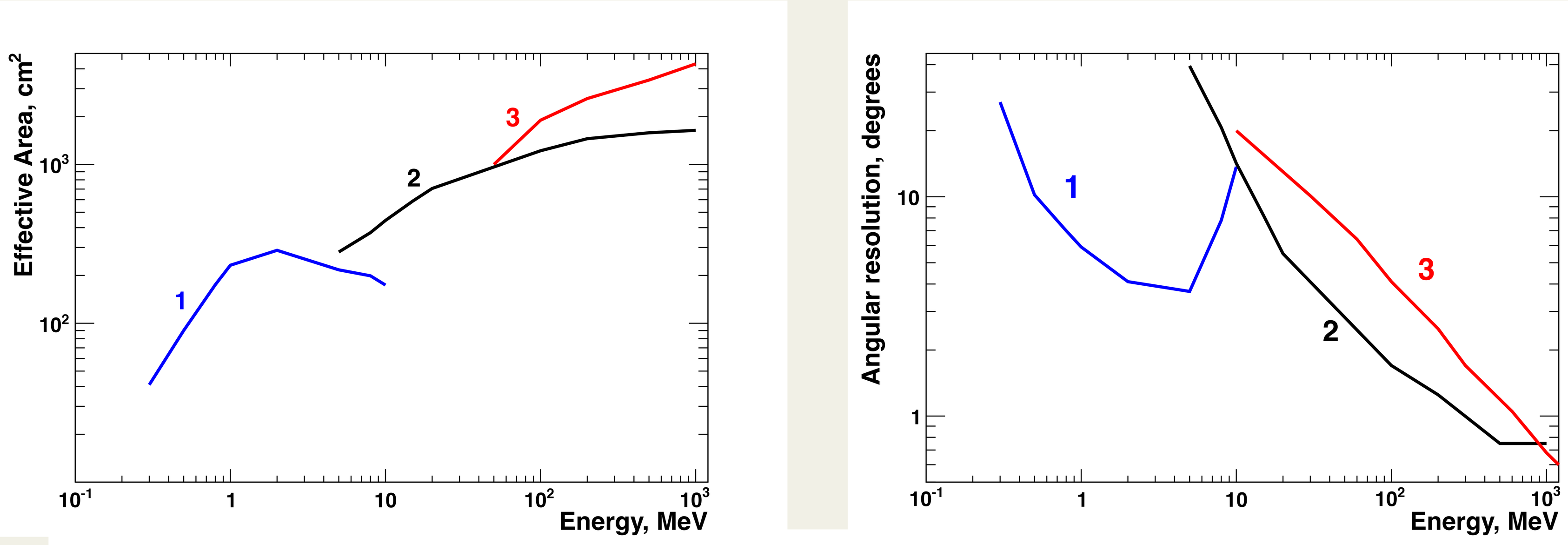

Fig.5 Left panel: Effective area. Right panel: angular resolution. Line 1: Compton events; line 2: pair events with ComPair; line 3: pair events with Fermi-LAT, front

Performance Simulations (Fig. 5) were performed with MEGAlib – the Medium-Energy Gamma-ray Astronomy library [6] and cross-checked with MGEANT [7]. MEGAlib is based on GEANT4 and has been successfully used for numerous simulations, including projects similar to ComPair: MEGA, GRIPS and ASTROGAM

Instrument Summary

Energy Range	0.5 – 100 MeV (0.2 – > 500 MeV)
Effective Area	50 – 250 cm^2 below 10 MeV, 200 – 1200 cm^2 above 10 MeV
Angular Resolution	~6^o (1 MeV) , ~10^o (10 MeV), ~1.5^o (100 MeV),
Energy resolution	2-5 % below 20 MeV, ~12% at 100 MeV
Field of view	~3 sr
Total Mass	~1,000 kg (science payload)
Power	< 1,000 W
Overall dimensions	diameter ~200cm, height ~120cm

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