Viability of a nano-satellite Compton space telescope

F. Berlato[1] R. Rando[2,3] S. Andreetta[3]

[1]Max Planck institute for Extraterrestrial physics (MPE), Garching

[2]Istituto Nazionale di Fisica Nucleare (INFN), Padua

[3]University of Padua, department of physics "Galileo Galilei"

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Compton telescopes

- Around 1 MeV, the main interaction of photons with matter is Compton scattering. Dedicated instruments are required to observe astrophysical sources in this energy range.
- After the COMPTEL space telescope (1991-2000), no new Compton detectors have been launched.
- Right now, there some projects in an advanced stage of development, such as e-ASTROGAM (ESA) or AMEGO (NASA). However, in case one is approved, the timescale before they are ready to take data is $\sim$10 yr.

A different approach to the problem

- We instead propose a different solution: we opt for a smaller and cheaper nano-satellite detector by making use of the successful CubeSat standard.
- In particular our design uses four units (each $10 \times 10 \times 10$ cm^3), two of which are occupied by the actual scientific payload.
- By using such a small spacecraft we could potentially build and launch a new Compton telescope in a timescale of ~ 1 yr with a very modest budget of ~ 500 k€.

Size comparison with COMPTEL

- Our detector is only 10 cm wide and 20 cm tall.
- For comparison COMPTEL was much bigger, being 1.7 m wide and 2.6 m tall.
- Even with the difference in technology, achieving the same performance level is no trivial task.

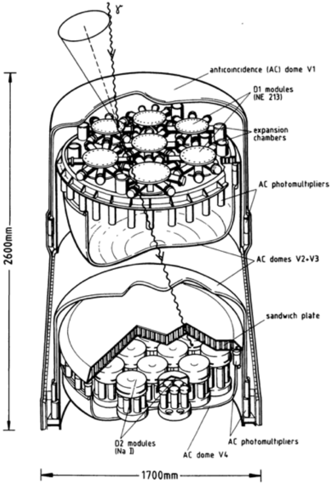


Fig: schematic of COMPTEL.

Scientific payload

- The detector consists of a silicon double-sided strip tracker on top of a CsI(Tl) crystal calorimeter, in a similar fashion to the Fermi LAT.
- Additionally, we can install a lateral calorimeter around the tracker to absorb scattered photons which would otherwise be lost (since they would just exit the detector).
- The payload is in fact very similar to what is planned for e-ASTROGAM and AMEGO. This would additionally grant our detector a pathfinder role, thus testing the same technology to be used in the larger missions.

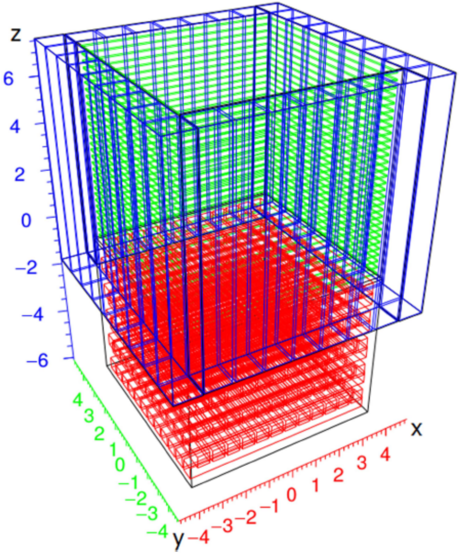
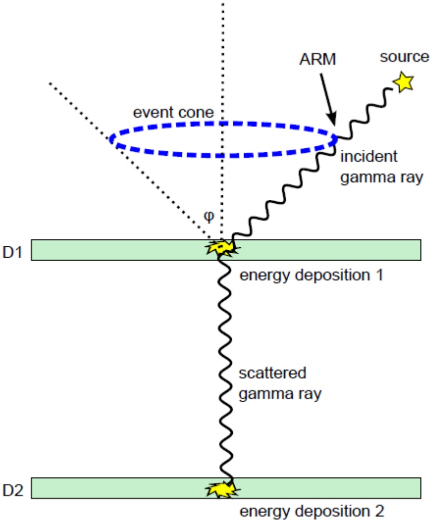
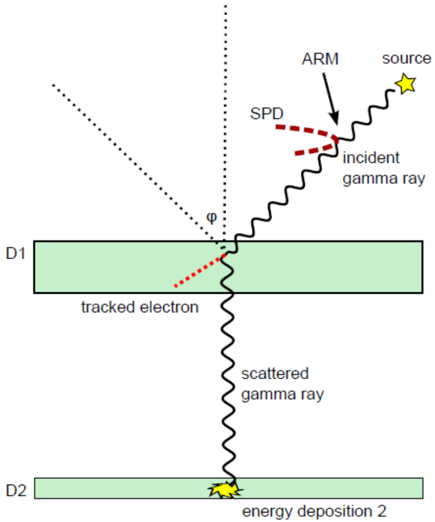


Fig: a schematic of the detector (no anticoincidence shield).

Untracked event reconstruction



Tracked event reconstruction



Simulation methodology

- We simulated the detector behaviour by using MEGAlib (see for example https://doi.org/10.1016), software based on GEANT 4 and specialized in simulating gamma detectors.
- Various different designs have been tested to try to achieve the best optimization for the detector.
- The viability of each design was evaluated through its performance parameters such as effective area, angular resolution...particular importance is placed on the sensitivity as an overall performance parameter.

Effective area

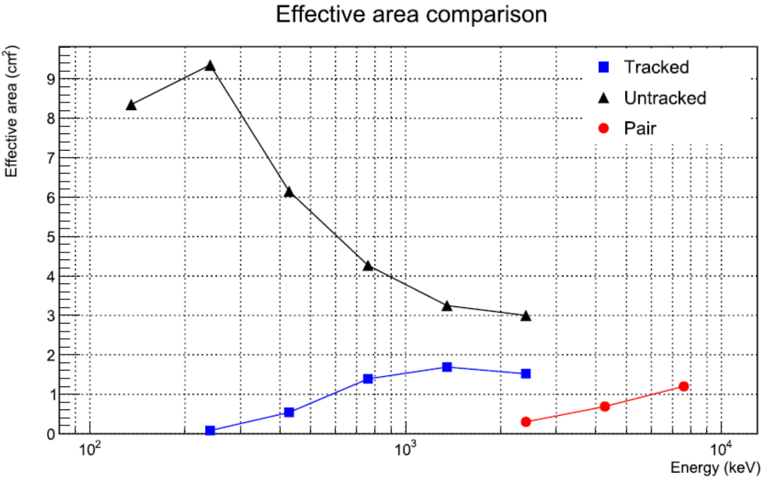


Fig: estimated effective area for different types of events.

- While tracked events are less numerous ($\sim$25% at $\sim$1 MeV), they have a much better total angular resolution, which improves considerably the SNR.
- At lower energy, there are almost no tracked events, but still a significant number of untracked ones. While this implies a worse angular resolution, this is partially compensated by the much bigger effective area associated to the untracked events.
- We are also able to detect pairs. However, due to the small detector size, we cannot absorb photons above a few MeVs in a effective way.

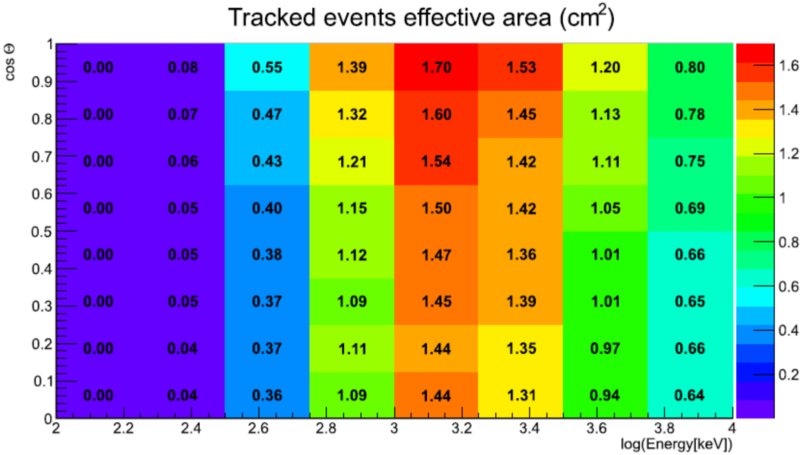


Fig: effective area for tracked events as function of incident photon energy and angle.

Background sources

Aside from electronic noise, we have four main sources of background:

- **Extra-galactic background** (EGB).
- **Charged background** due to cosmic rays.
- **Earth's gamma emission** (or Earth's gamma "albedo").
- **Activation**, that is the radioactivity induced in the detector materials by the continuous flux of cosmic rays.

- The EGB is weak source of background. We also estimate a contribute of the same order of magnitude for the charged background, given that installing a simple anticoincidence shield can prevent $> 99.99\%$ of the triggers.
- The main contribution comes from the Earth's albedo, which flux in this energy range is very high. It is also extremely difficult to remove from a data analysis standpoint.
- Activation may also be problematic, although to what extent precisely is still being studied. The small size of the satellite should be able to limit this contribution to reasonable levels.

Sensitivity

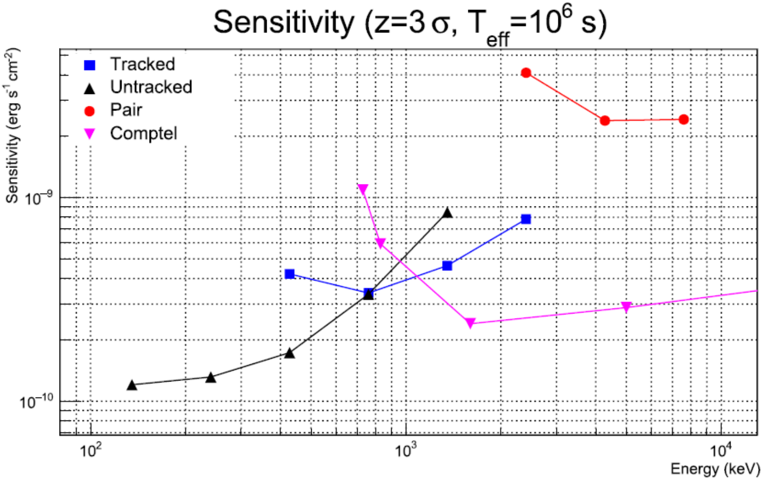


Fig: sensitivity for the detector compared to COMPTEL's (no activation background).

A first activation estimate

- The simulations for the activation are run using FLUKA, a fully integrated particle physics MonteCarlo simulation package.
- This is done by using a simplified geometry for the detector, without the lateral calorimeter, but adding the aluminium frame if the spacecraft.
- The simulated cosmic rays are for now only protons for an orbit at ~ 550 km, from Corti (arXiv:1511.08790).

- Activation comes mainly from the CsI calorimeter, with emissions of the order ~ 0.1 Hz. Trigger efficiency for such events is however of the order $\sim 10^{-3}$.
- Aside from the emission lines, there is a significant continuum in the emission which needs to be carefully evaluated.
- Most of the activation comes from the protons with energy > 10 GeV passing through the detector.

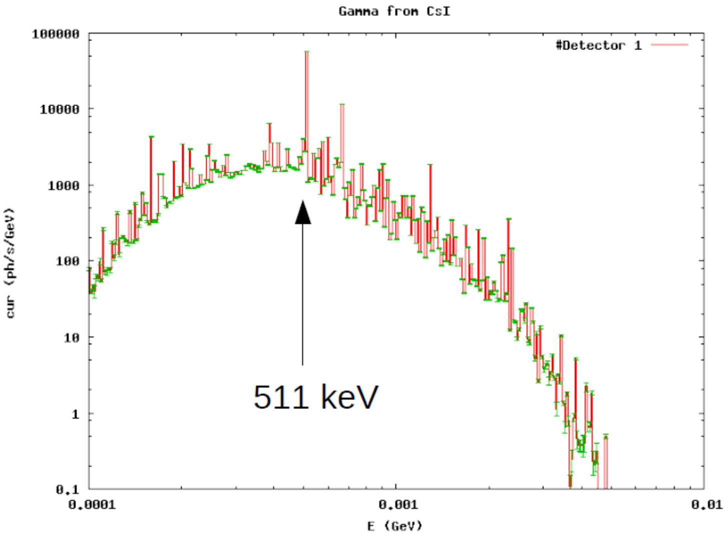


Fig: gamma photons exiting the calorimeter due to activation.

Conclusions

- The studies done so far show promising results, given that we are able to reach about the same level of COMPTEL performance by using a very small nano-satellite with a modest budget.
- Further studies are however required to estimate precisely the impact of activation and electronic noise on the overall performance.
- The results here presented come mainly from F. Berlato and G. Lucchetta master's theses and also from Lucchetta et al. Activation estimates are instead taken from S. Andreetta bachelor's thesis.

Thank you for your attention

Crab Nebula

- As a reference value we computed how many photons we expect to see from the Crab Nebula.
- We consider only Compton events for a time $T = 10^6$ s at normal incidence, we neglect activation.
- We expect $1.7 \cdot 10^4$ ph for the tracked events with a SNR$= 25\%$.
- For the untracked events we instead have $2.0 \cdot 10^5$ ph with a SNR$= 6\%$.

EGB reconstruction

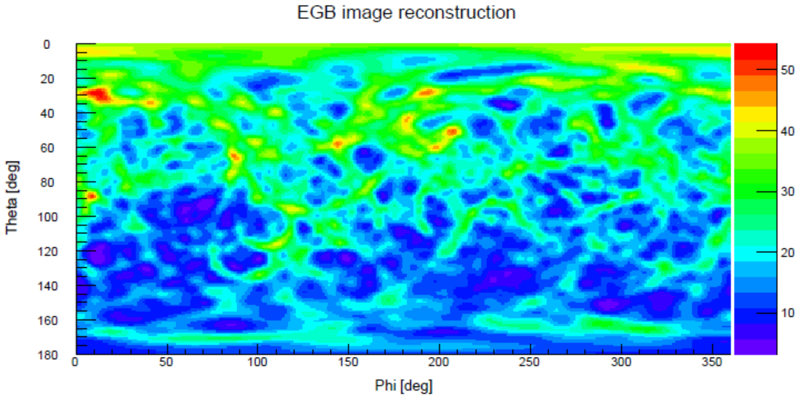


Fig: EGB reconstruction with the detector pointing normally outwards the Earth.

Albedo reconstruction

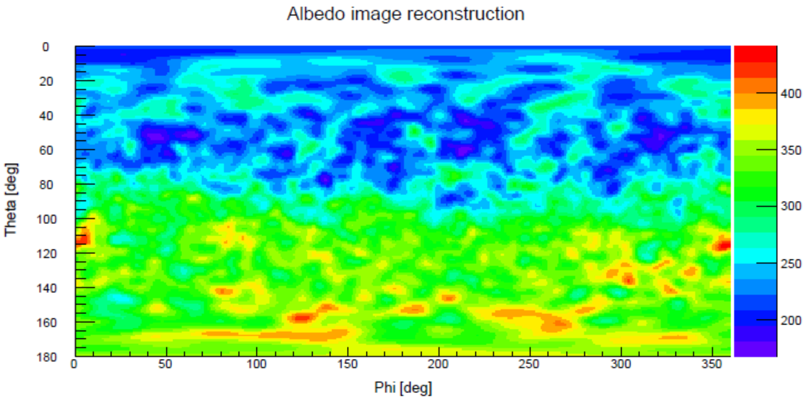


Fig: Albedo reconstruction with the detector pointing normally outwards the Earth.

Signal-to-noise ratio

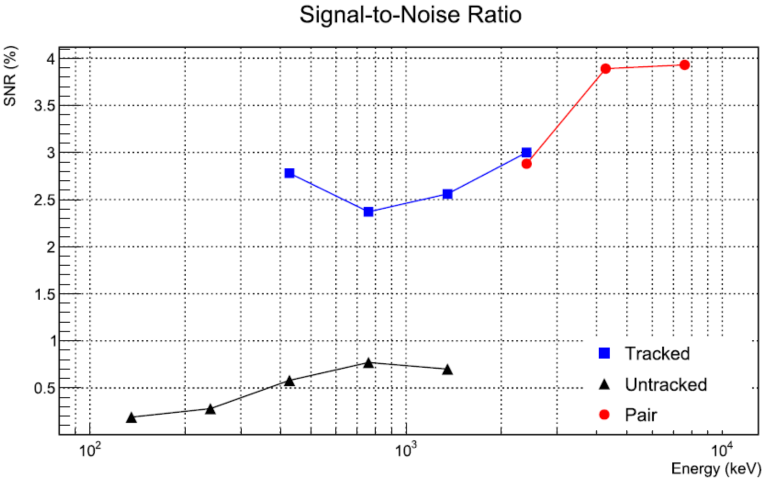


Fig: SNR for different types of events (no activation background).

Angular resolution

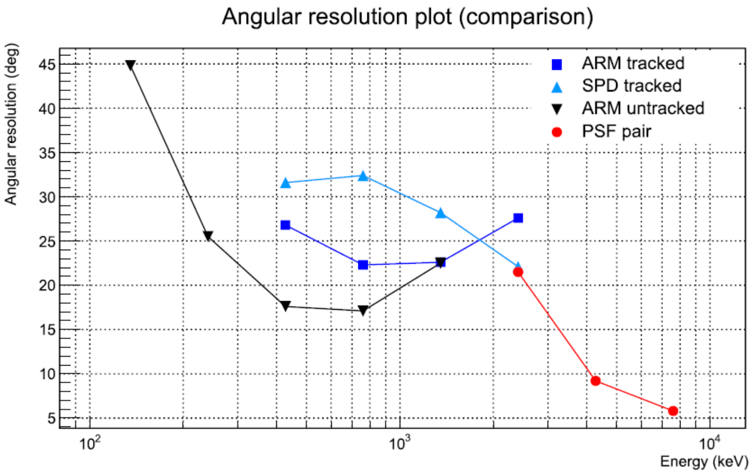


Fig: angular resolution for different types of events.