NEW MISSION CONCEPT: GALACTIC EXPLORER WITH A CODED APERTURE MASK COMPTON TELESCOPE (GECCO)

One who wants to do something will find a way; one who does not will find an excuse
(Socratus, Confucios,… Abraham Lincoln, Russian saying)

Alexander Moiseev (UMCP and CRESST/GSFC)
For the GECCO Team

The GECCO Team

David Asner (BNL, USA)

Matthew Baring (Rice University, USA)

Peter Bloser (LANL, USA)

Alexey Bolotnikov (BNL, USA)

Eugenio Bottacini (Padova, Italy, and Stanford U., USA)

Terri Brandt (GSFC, USA)

Nickolas Cannady (UMBC/GSFC, USA)

Gabriella Carini (BNL, USA)

Werner Collmar (Max-Plank, Germany)

Adam Coogan (Netherlands)

Georgia DeNolfo (GSFC, USA)

Seth Digel (SLAC, USA)

Vincent Eberle (Max Plank, Germany)

Torsten Ennslin (Max-Plank, Germany)

Isabelle Grenier (Saclay, USA),

Alice Harding (GSFC, USA)

Dieter Hartmann (Clemson U., USA)

Sven Hermann (BNL, USA)

Demos Kazanas (GSFC, USA)

Matthew Kerr (NRL, USA)

Roman Krivonos (IKI, Russia)

Philippe Laurent (SACLAY, France)

Francesco Longo (Trieste, Italy)

John Mitchell (GSFC, USA)

Alexander Moiseev (UMCP, USA) - PI

Logan Morrison

Aldo Morselli (Tor Vergata, Italy)

Igor Moskalenko (Stanford U., USA)

Richard Mushotzky (UMCP, USA)

Michela Negro (UMBC, USA)

Elena Orlando (Trieste, Italy; Stanford, USA)

Stefano Profumo (UCSC, USA)

Makoto Sasaki (UMCP/GSFC, USA)

Chris Shrader (UMCP/GSFC, USA)

Gerry Skinner (University of Birmingham, UK)

Floyd Stecker (GSFC, USA)

Andrew Strong (Max Plank, Garching, Germany)

Steven Sturner (UMBC/GSFC, USA)

Peter Shawhan (UMCP, USA)

Lucas Smith (UMCP, USA)

Hiro Tajima (Japan)

Dave Thompson (GSFC, USA)

John Tomsick (UCB, USA)

Zorawar Wadiasingh (UMCP, USA)

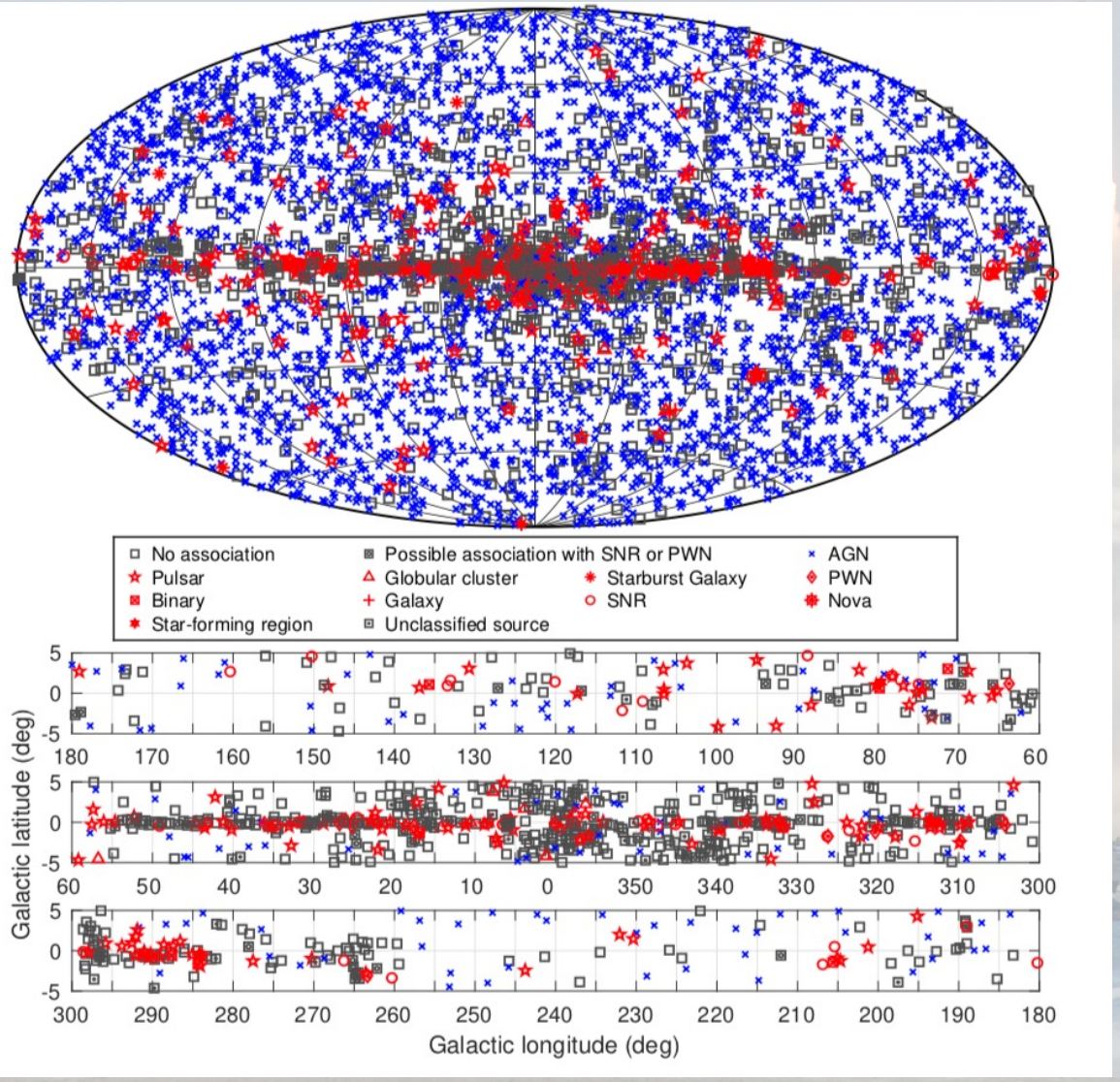
Richard Woolf (NRL, USA)

Eric Yates (UMCP, USA)

Klaus-Peter Ziock (ORNL, USA)

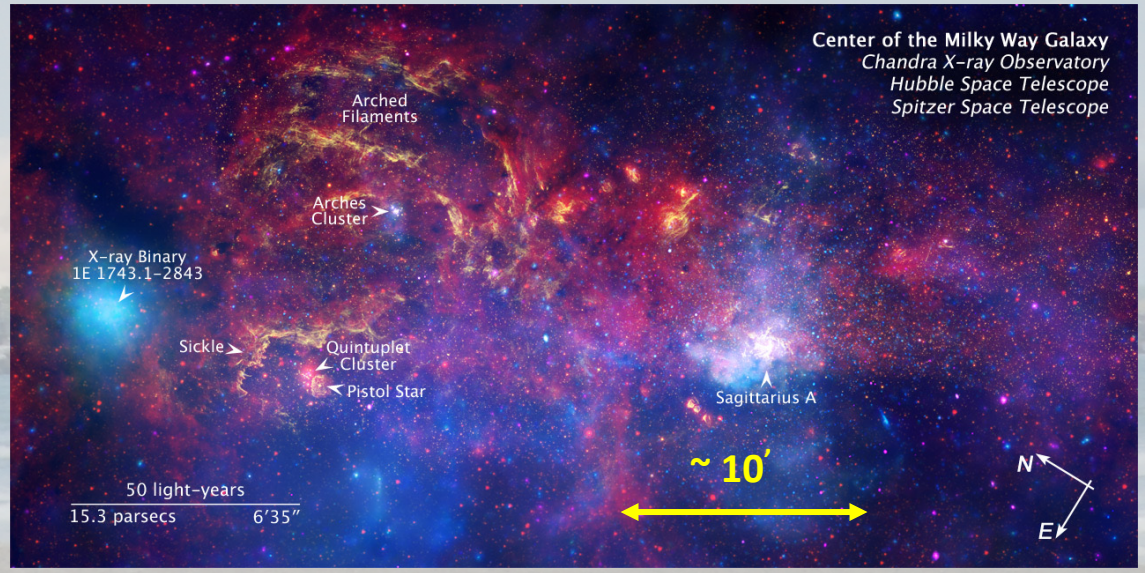
Andreas Zoglauer (UCB, USA)

Motivation, first push: Fermi-LAT unassociated sources

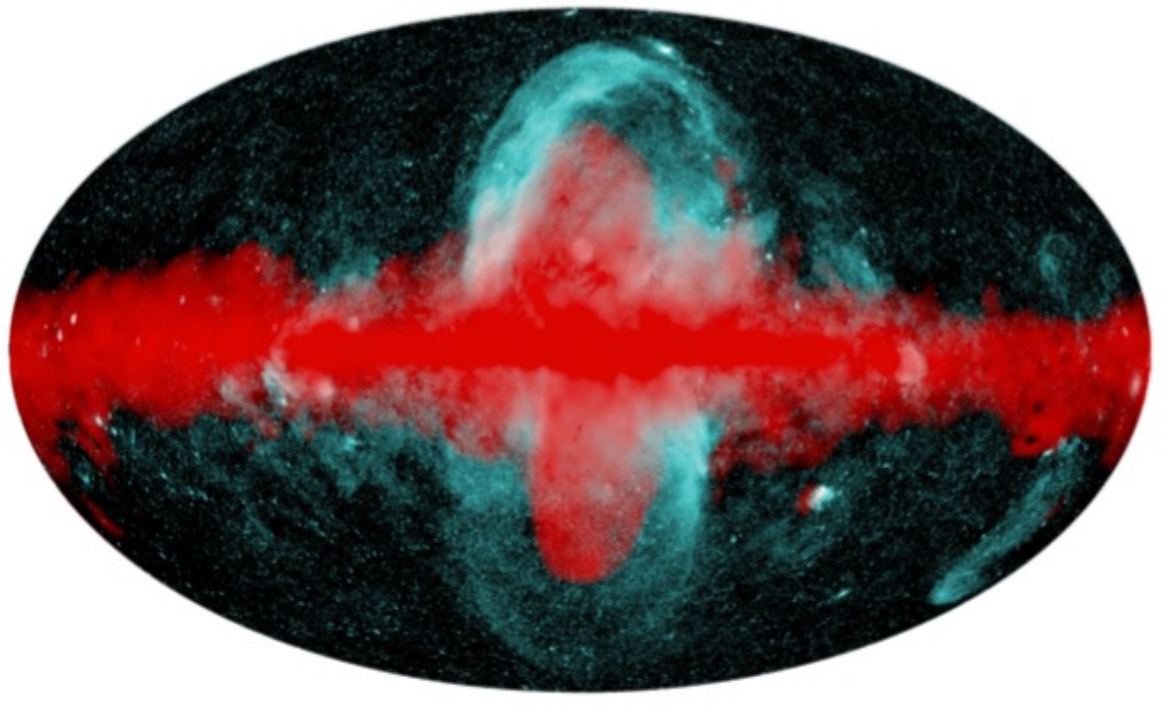


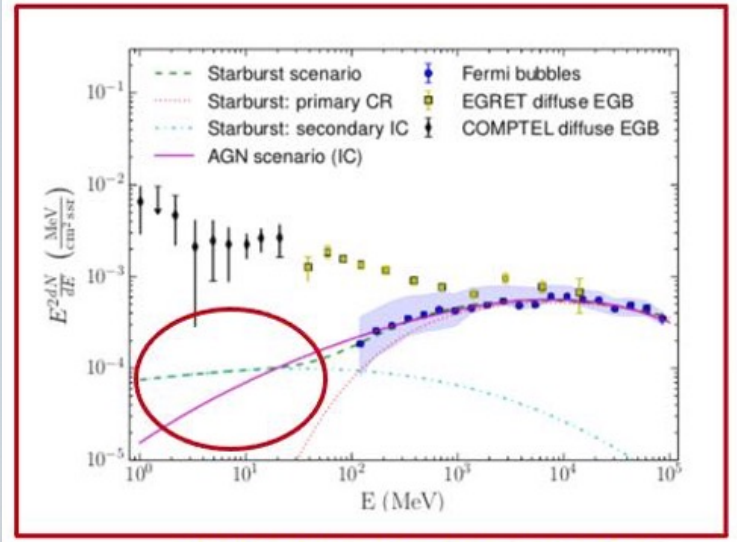
- 5,065 sources (4th Catalog)
- 1,323 sources (~25%) do not have associations with other wave-length sources, with majority in GP and GC: Why not associated? and Who Are They?
- **Position resolution of ~arcmin will help to resolve**

Source population density in the GC (Chandra/Hubble/Spitzer data) **is <arcsec (however most of them do not radiate in MeV range)**



The Fermi Bubbles: one of the most unexpected (?) and spectacular discoveries by Fermi LAT, and now - eROSITA !!!





Credit: I. Grenier, I. Moskalenko, E. Orlando

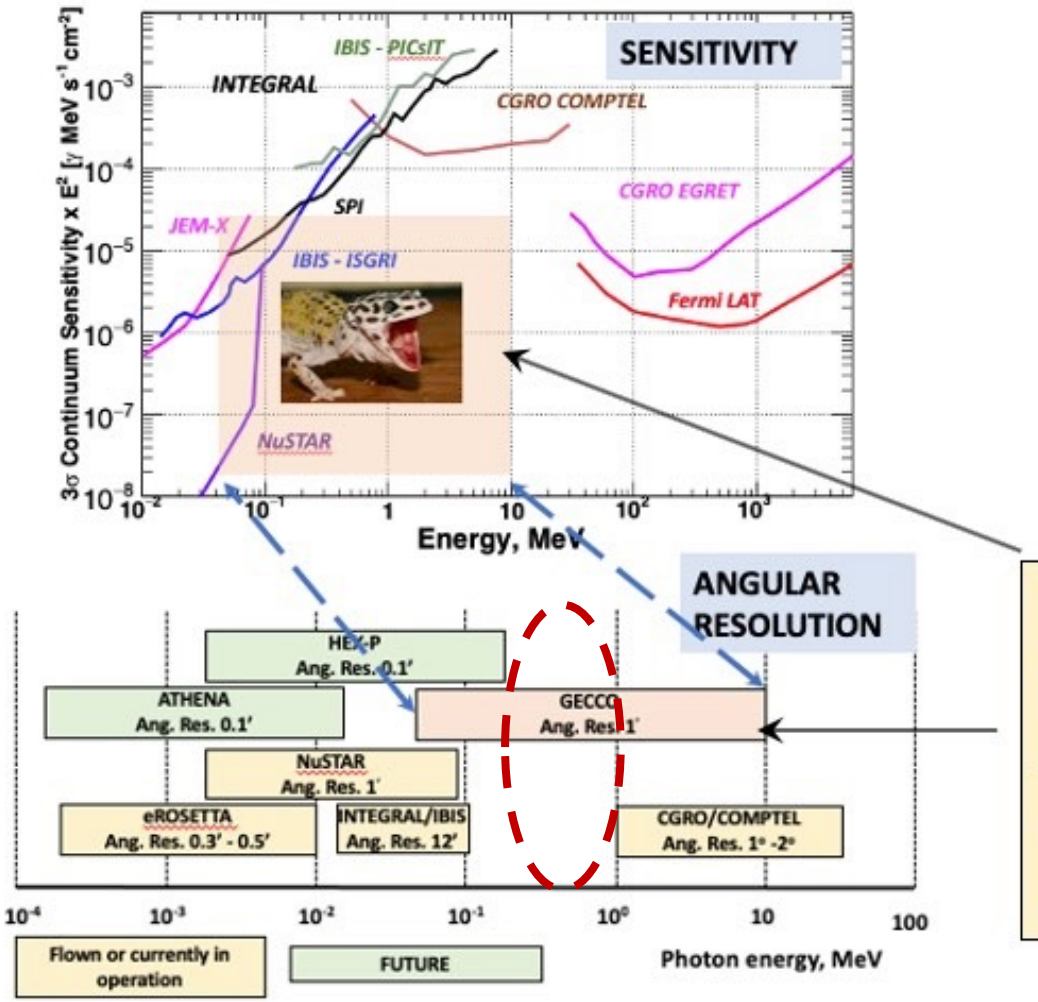
Comparison of the morphology of the γ-ray (Fermi-LAT, >50 MeV, shown by red) and X-ray (eROSITA, 0.6-1 keV, shown by cyan color) Bubbles (P. Predehl et al., Nature 2020)

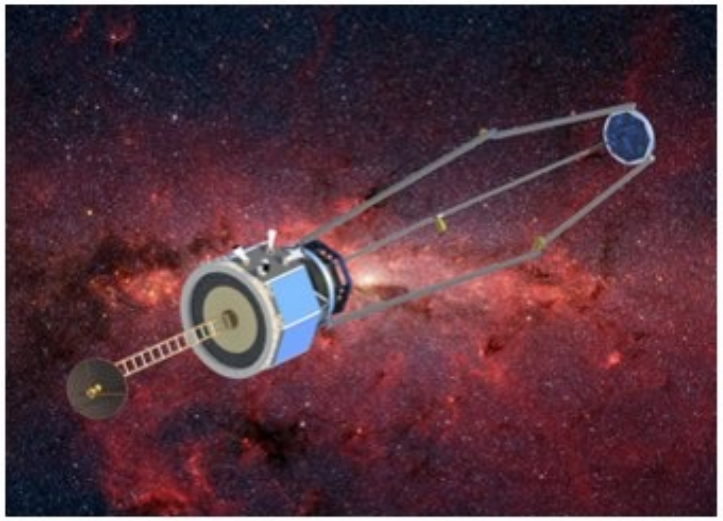
- Likely Fermi and eROSITA Bubbles have different nature
- What to expect in sub-MeV (GECCO) energy range?

Where are we in MeV-GeV γ–ray Astronomy?

Fermi-LAT (GLAST): 2008 – currently operating

Currently available measurements





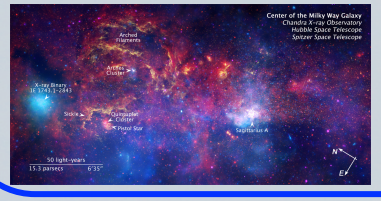
GECCO

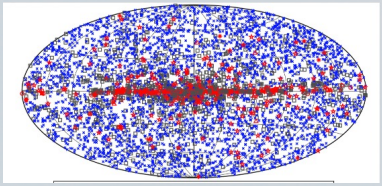
GECCO will be aiming to fill the poorly explored MeV gap in gamma-ray astronomy, with high sensitivity and high angular resolution measurements

GECCO Science and Observations Capabilities

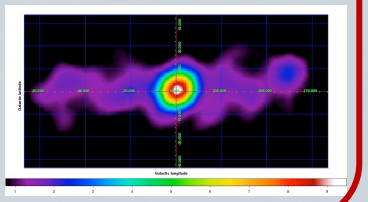
See poster by E. Orlando

Understand the nature of the central supermassive black hole environment and sources, including >1,000 unassociated Fermi sources at the Galactic Center; address the enigma of Galactic Center excess (a bulge)

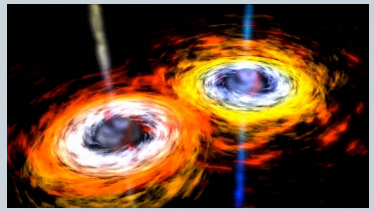


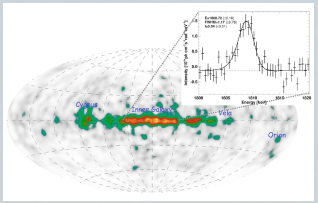


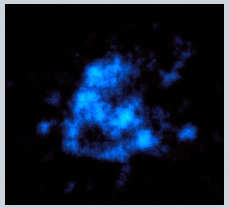
Localize and clarify the origin(s) of the 511 keV positron annihilation line



Identify and precisely localize the source of the gravitational wave and neutrino events

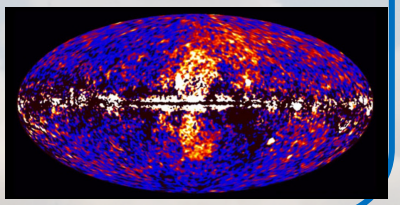






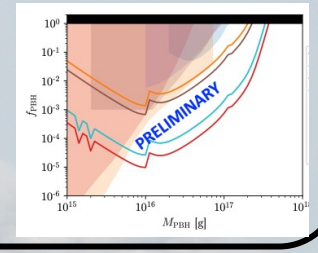
Resolve Galactic chemical evolution and sites of explosive element synthesis

Investigate the origin(s) of the Fermi Bubbles by mapping them, especially their bases near the GC

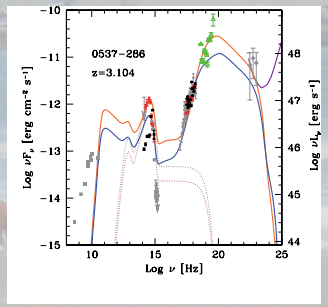


Resolve heavily populated sky regions, including tangential directions to the spiral arms in the Galactic plane

Test as-yet unexplored candidates for the dark matter



Detection and identification of high-redshift blazars



Prioritization of the science objectives, as well as the observation strategy will be made closer to the Proposal time to be aligned with newest developments and standing problems

Galactic Center Environment: Measurements approach

Galactic Center γ-ray excess (a bulge) has been recently confirmed by Fermi LAT

To understand its Origin, the contribution from unresolved point sources has to be identified and separated. Spatial resolution of arcmin-level is needed.

The Goal: reach the "Bottom" of the GC γ-radiation, or actual diffuse, or continuum, radiation. After subtraction of known contributors: is there going to be any residual, unexplainable component?

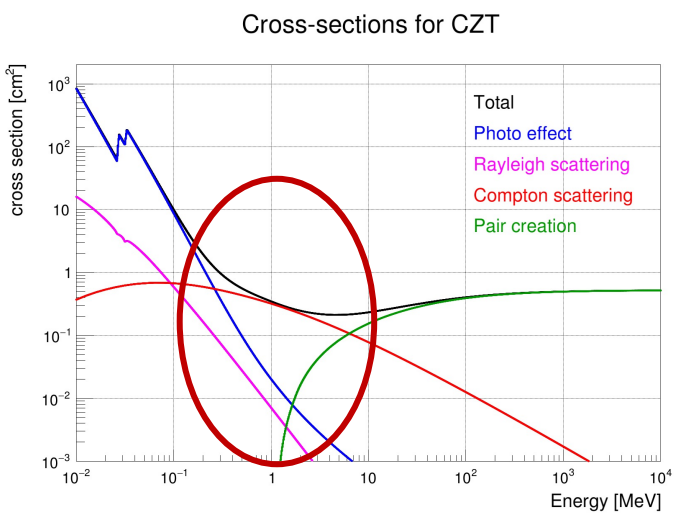
Potential contributors: MSP, PBH, binaries, DM, what else?

Expected ~1,000 pulsars within 1^o around GC, or **~ 0.3 pulsar/arcmin^2**

Star-forming regions (LMC, M31): also γ-ray excess: need to resolve sources within fraction of degree

Mission Concept and Requirements for GECCO:

1. **Investigation of fine structure and the composition of inner Galaxy in γ-rays: requires ~arcmin angular resolution for the point sources, capability to measure diffuse radiation, and 1-2 % energy resolution**
2. **Probing Galactic chemical evolution and sites of explosive element synthesis: requires ≲1% energy resolution**
3. **Contribution to the multimessenger astrophysics (GW and neutrino events): requires quick re-pointing to the target area**
4. **In GECCO concept we make all possible efforts to reduce all known backgrounds to maximize its sensitivity**



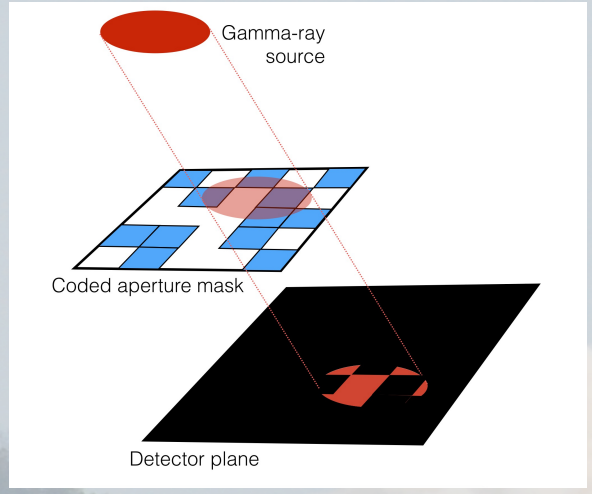
Credit: A. Zoglauer

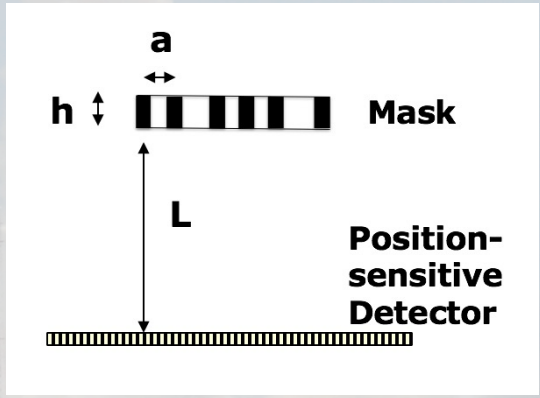
Angular Resolution: Even 1 degree of angular resolution is extremely difficult, or impossible to achieve in direct photon detection in energy range ~ 0.2-10 MeV with use of Compton effect

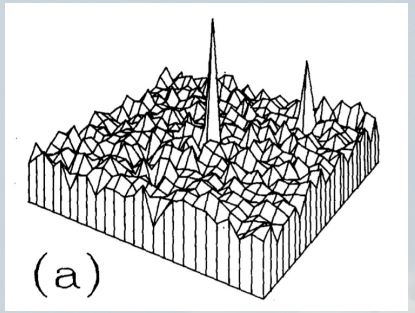
Moving to indirect measurement of photon arrival direction with a Coded Aperture method: cross-correlation of the coded mask pattern with its image on the detector plane, created by the parallel flux from point source

Coded Aperture Mask: the only feasible way to provide arcmin-level resolution in this energy range.

A Coded Aperture Mask (array of transparent and opaque elements) modulates the incident photon flux and creates its shadow (image) on the detector.

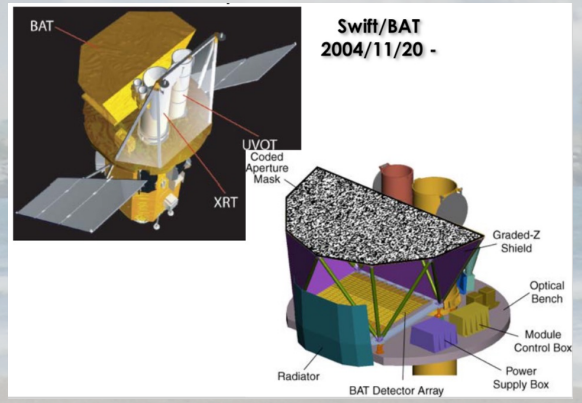




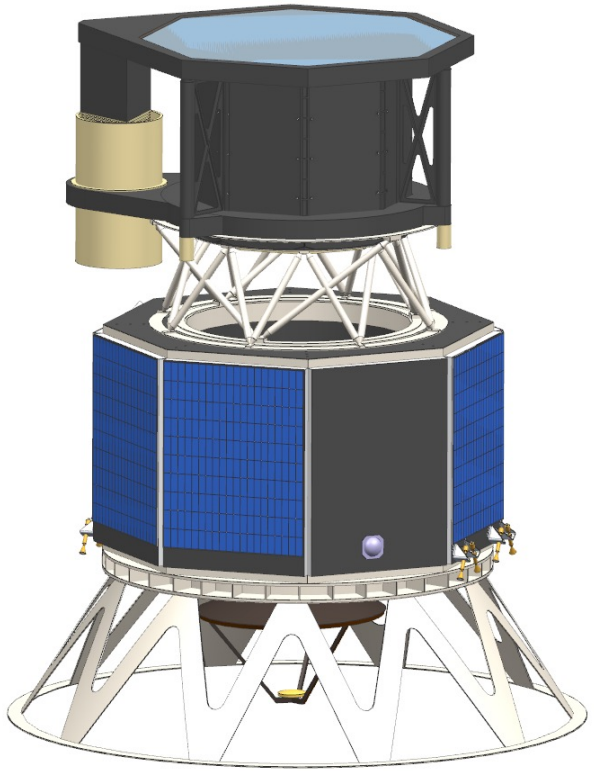


Angular resolution of the system is ~a/L. It can be made as good as we want if the Mask is placed at a large distance from the detector.

INTEGRAL - SPI

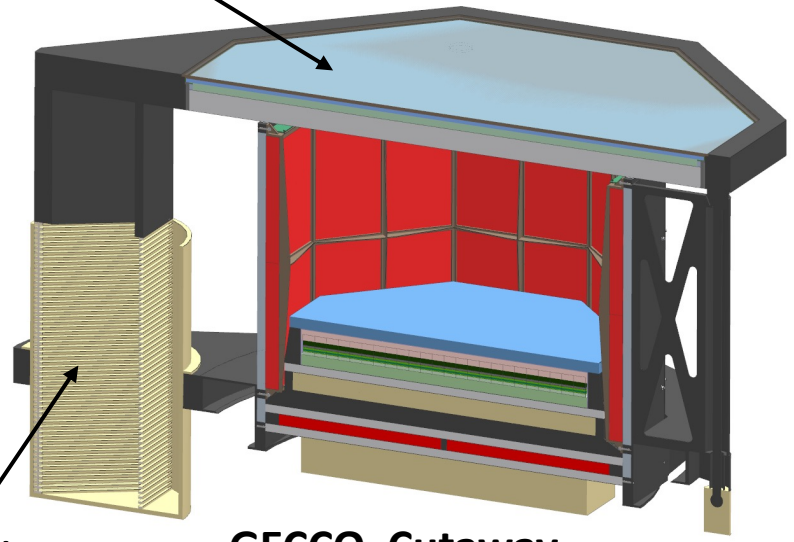


GECCO Conceptual Design: Compton telescope with deployable coded aperture mask



GECCO with Mask in stowed position, and notional SC bus

Incident photon flux is modulated while passing through the **Mask** and creates an image on the **CdZnTe** detector plane.



GECCO, Cutaway

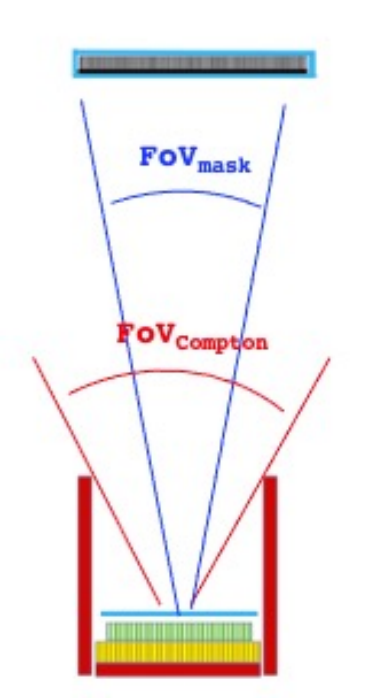
Plastic scintillator **anticoincidence detector** above the CdZnTe Imager provides protection against charged cosmic rays

The **CdZnTe** Imager provides detection of incident photons with a **position resolution of <1mm and with energy resolution of ~1%.**

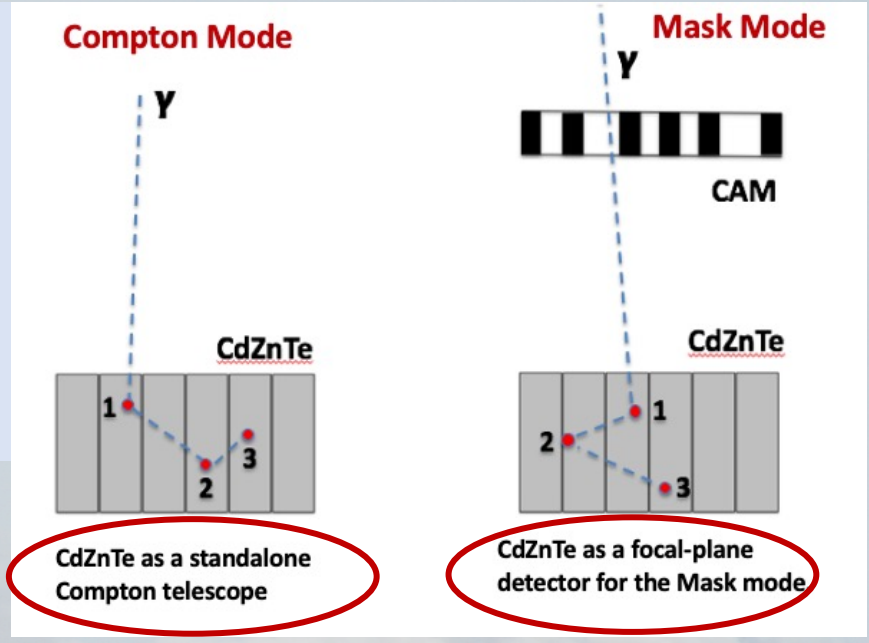
BGO shield provides absorption of natural background photons and vetoes production of background photons by charged cosmic rays

CsI 5-cm thick log calorimeter measures energy escaping from **CdZnTe Imager**

GECCO principle of operation: Compton Telescope + Coded Aperture Mask Telescope



- **Compton mode to measure large-scale diffuse**: CZT as a Compton telescope with 3-5° direction reconstruction accuracy and Field-of-View (FoV) ~ 1 sr
- **Mask mode to measure point sources and small-scale diffuse:** angular resolution ~1 arcmin and FoV ~ 4° (with Mask at 20 meters)



Why deployable Mask: angular resolution is inverse proportional to the Mask-detector separation

BUT the problem: huge side-entering background radiation.

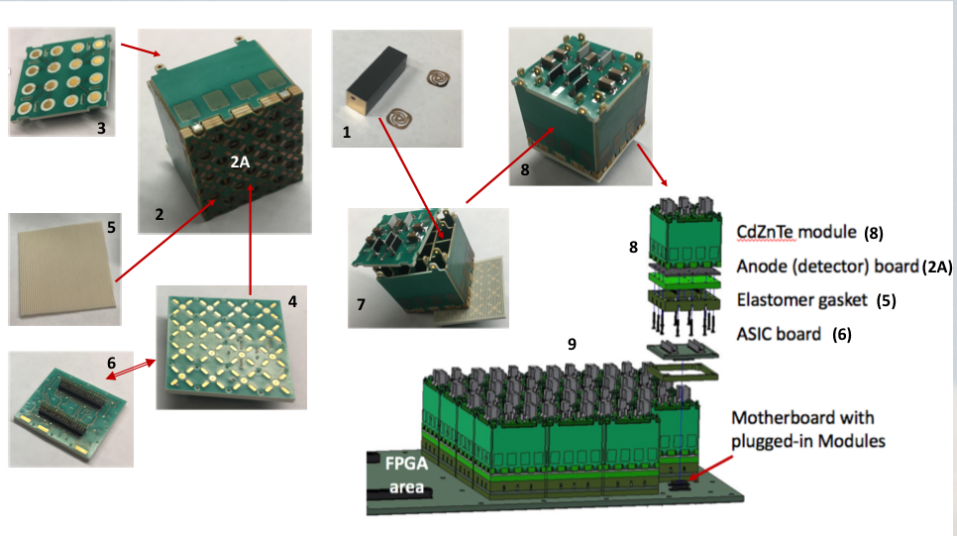
GECCO: Compton telescope is used to select photons arrived from the Mask area. Most of side-entering background photons are eliminated

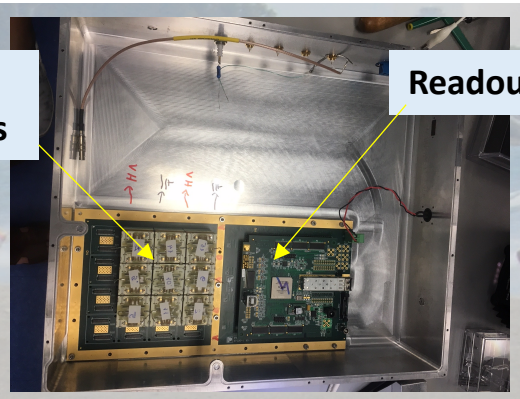
BGO shield helps to veto not fully-contained events

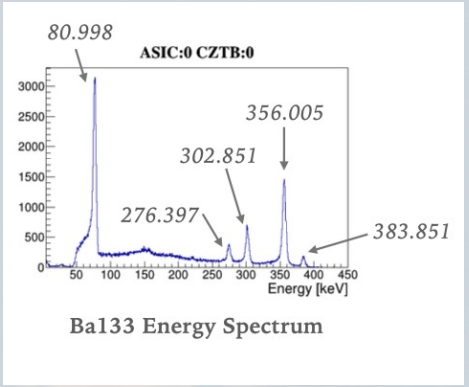
Modular CdZnTe Imaging Calorimeter

See poster by A. Bolotnikov

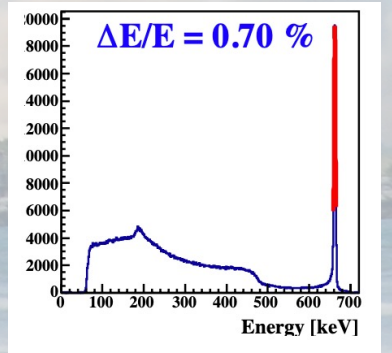
- Basic unit – the module, containing 16 CZT Virtual Frisch-grid bar detectors served by individual ASIC
- **Approach:** The Imager Can be made of practically **any needed area** by simply plugging needed number of basic units (the modules) into the Motherboard
- We designed and built the prototype containing **9 modules,** currently under comprehensive testing







Ba133 Energy Spectrum



Cs^{137} (662 keV)

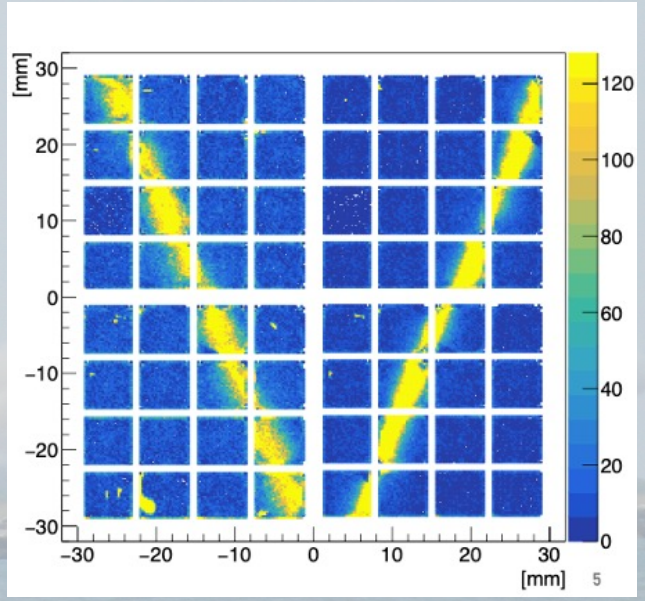
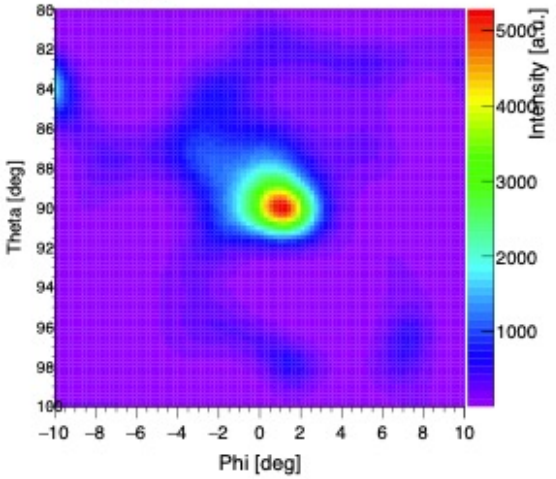
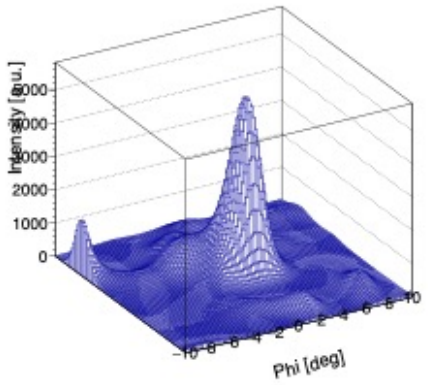


Image of the 1mm wide slit collimator, made with 4 CZT modules

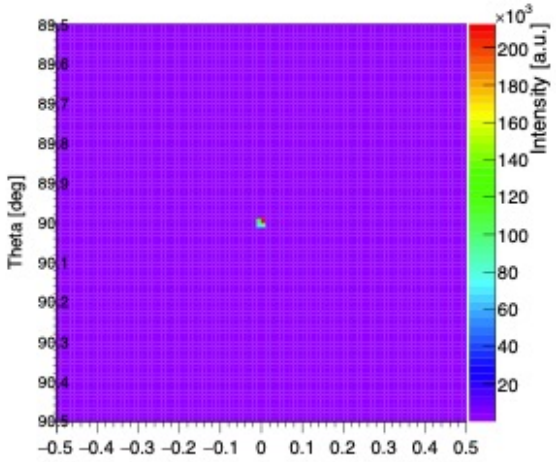
Simulated GECCO performance: imaging of the point source

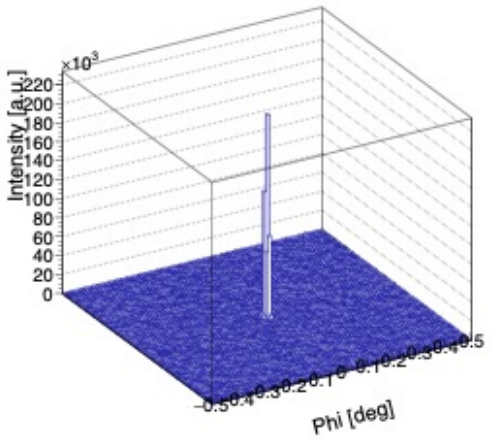
Compton analysis (FoV ~ 60°)



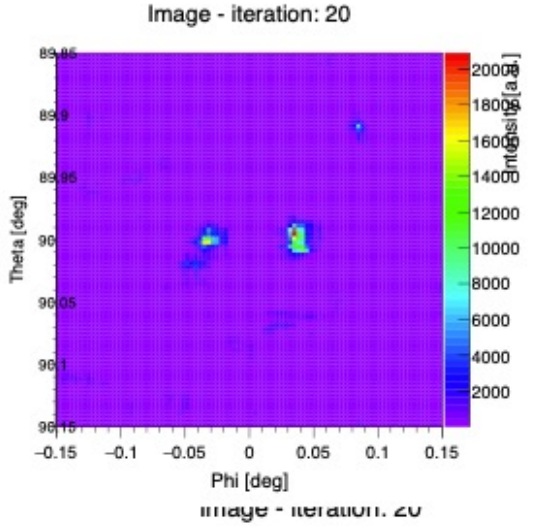


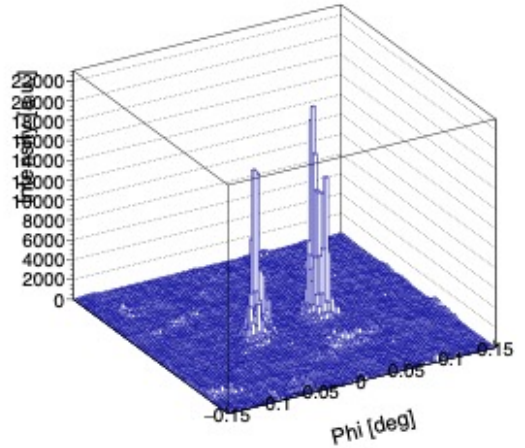
Mask analysis (FoV ~ 4°)



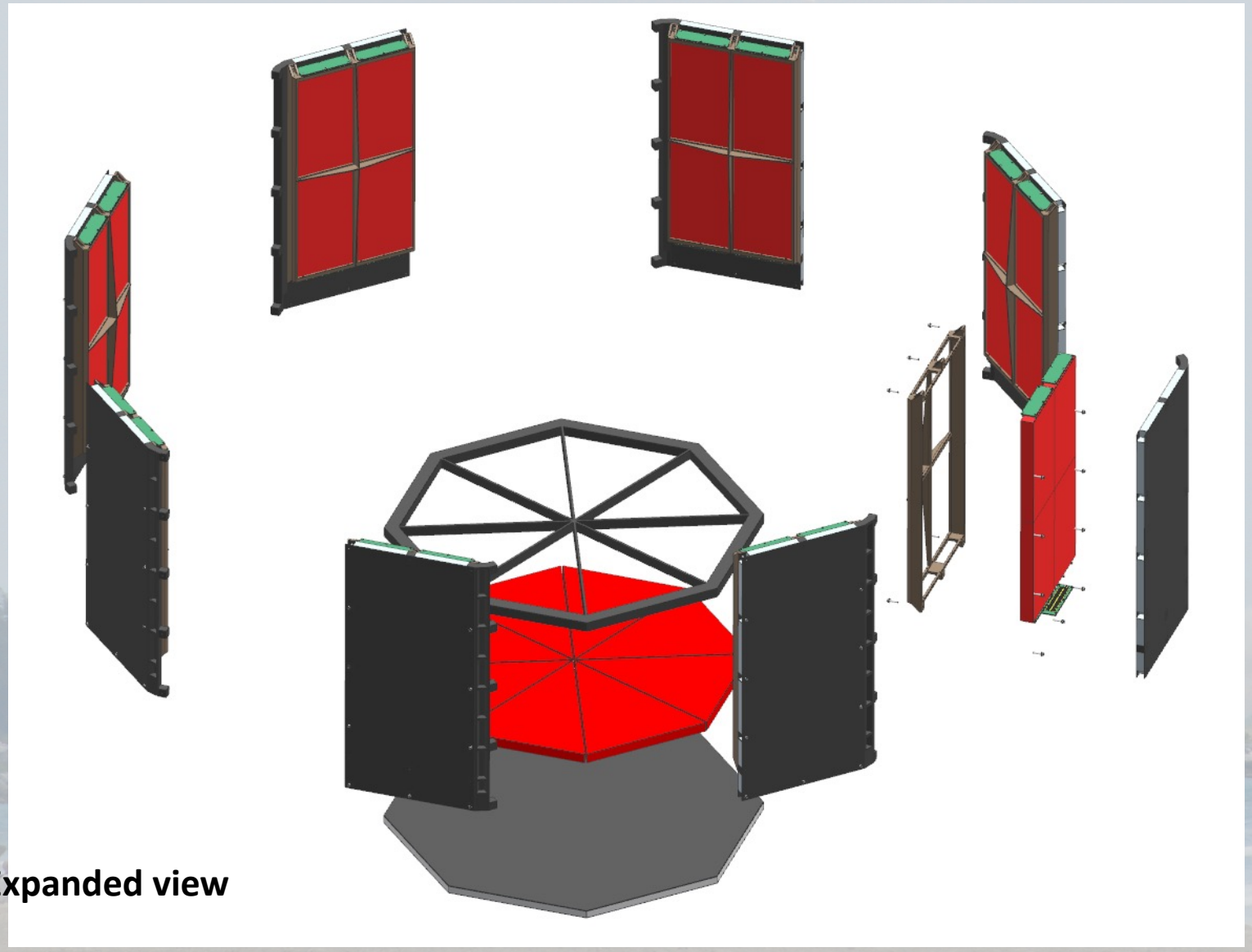


Two sources separated by 4’





BGO shield as GRB monitor: Burst Octagon



Expanded view

8 panels ~3,000 cm each + CZT Calorimeter: 9 directions for GRB detection and location with expected angular precision sufficient to re-point GECCO and use a full power of the Mask-provided source localization

GECCO Expected Performance

Energy Range: 50 keV – 10 MeV range,

Energy resolution: < 1% at 0.5 – 5 MeV.

Angular resolution:

~1 arcmin in the Mask mode with 3^o – 4^o field-of-view,

3^o – 5^o in the Compton mode with a 60^o field-of-view

Sensitivity: 10^{-4} - 10^{-6} MeV cm^{-2} s^{-1} over the entire energy range, depending on the observation time and analysis specifics

GECCO can be operated in either scanning or pointed mode, to be optimized according to the given science objective.

- In scanning mode it will be observing mainly the Galactic Plane,
- it can change to the **pointed mode** to either increase observation time for special regions of interest, e.g., to observe the **Galactic Center**, or to observe **transient events**, e.g., flares of different origin or gamma-ray bursts.

- **Main science objectives and observation strategy have been identified**
- **Baseline instrument concept is developed, main detectors are identified**
- **We are looking for the options to realize this ambitious project (scale of MidEx)**

THANK YOU!