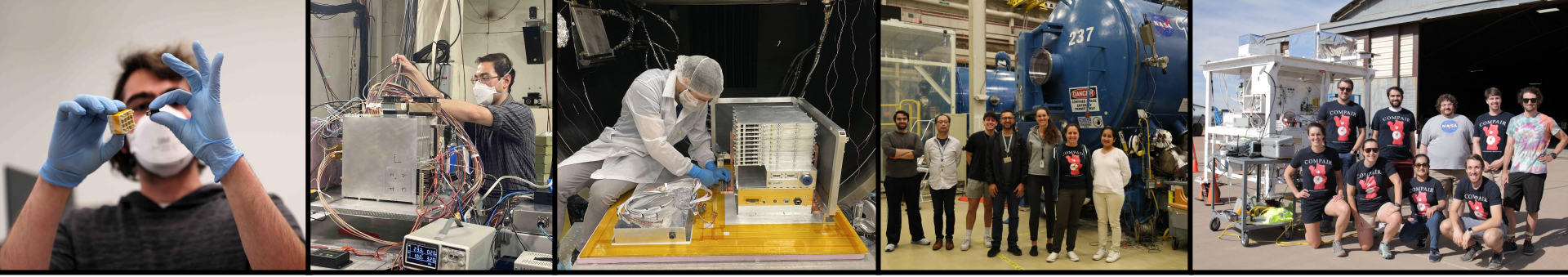

The Compton Pair prototypes

A next-generation MeV γ-ray observatory

Janeth Valverde
UMBC / NASA GSFC

on behalf of the ComPair Team

ComPair Team

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Hiroshima Tajima

Adrien Laviron

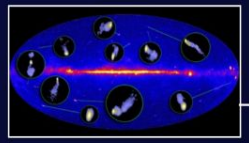
Taylor Shin

Abe Falcone

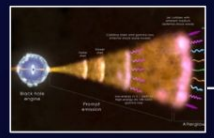
With engineering support from:
Dave Durachka, Iker Liceaga, Marco Marrufo, Adam Schoenwald, Sandy Shuman.

Extreme astrophysical environments

Neutrino Counterpart searches

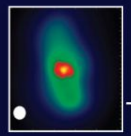


Blazars

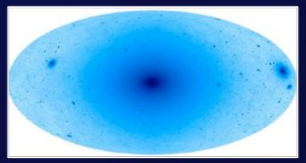


Gamma Ray Bursts

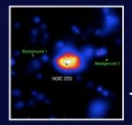
Gravitational Wave Counterparts



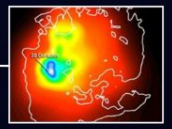
Radio Galaxies



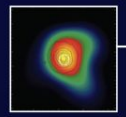
Dark Matter searches



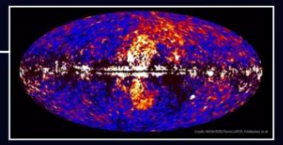
Starburst Galaxies



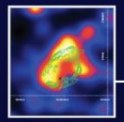
LMC & SMC



Globular Clusters

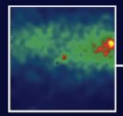


Fermi Bubbles



Supernova Remnants & Pulsar Wind Nebulae

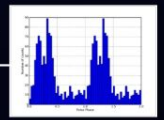
γ-ray Binaries



Novae

Galactic

Extragalactic

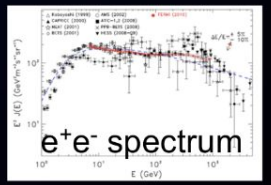


Pulsars: isolated, binaries, & MSPs

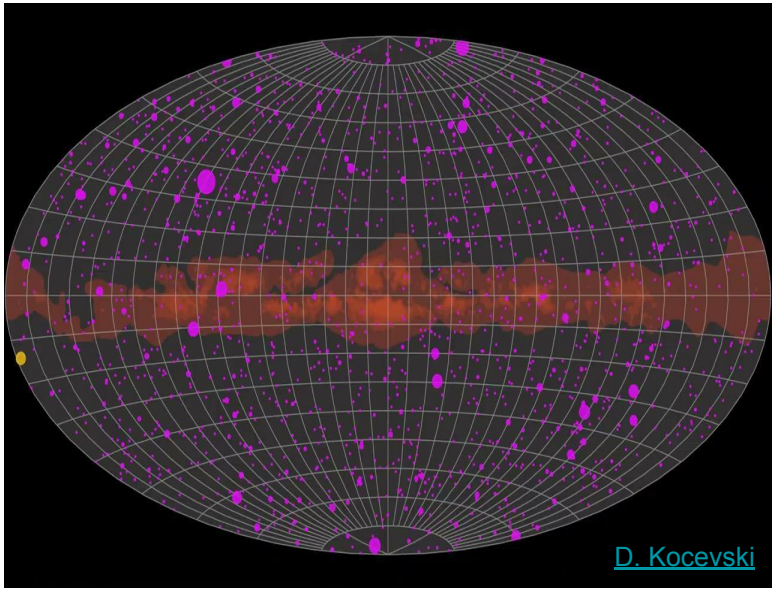
Unidentified Sources

Sun: flares & Cosmic Ray interactions

Terrestrial γ-ray Flashes



Cosmic Rays



μs ms s minutes hours days months years

Photon Timing

All Sky Cadence

Pulsars

Solar Flares

Crab Flares

Novae

γ-ray Binaries

Terrestrial γ-ray Flashes

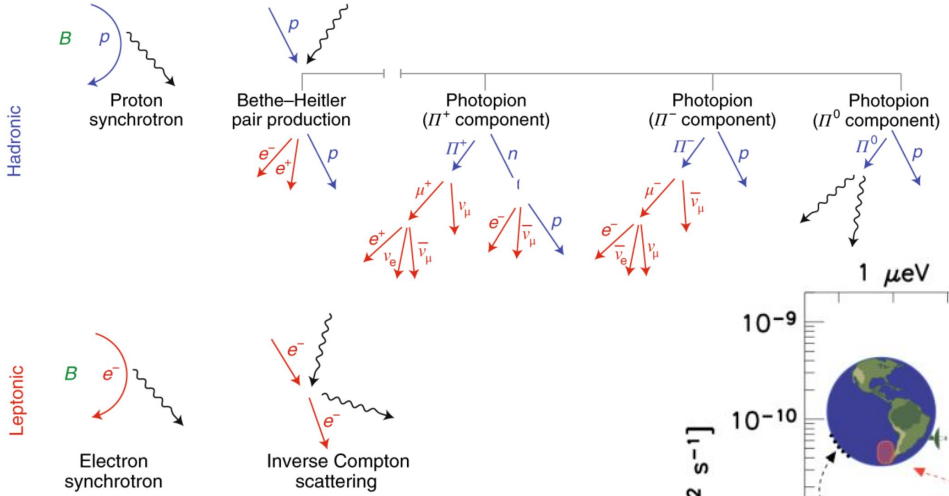
GRBs

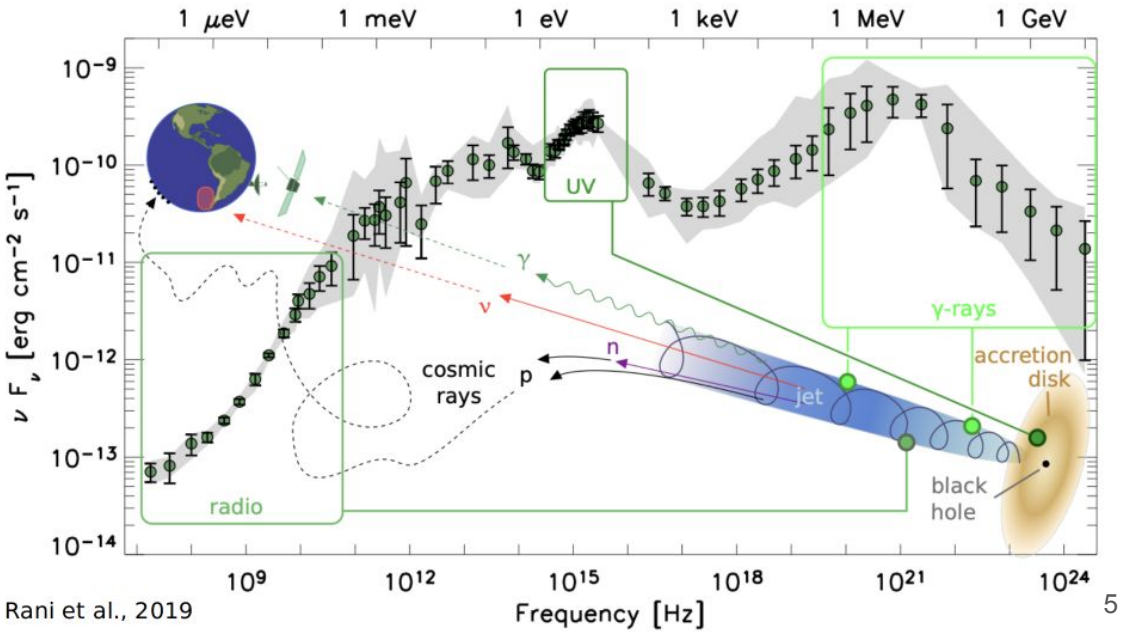
Magnetar Flares

Blazar Flares

Not to scale

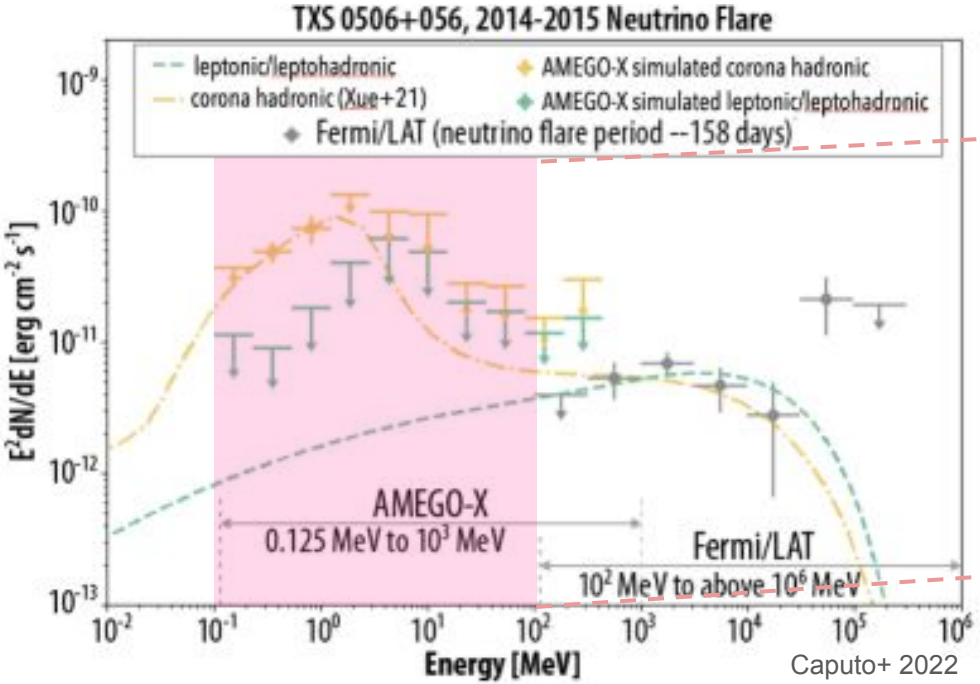
SMBH & their connections to ν and cosmic rays

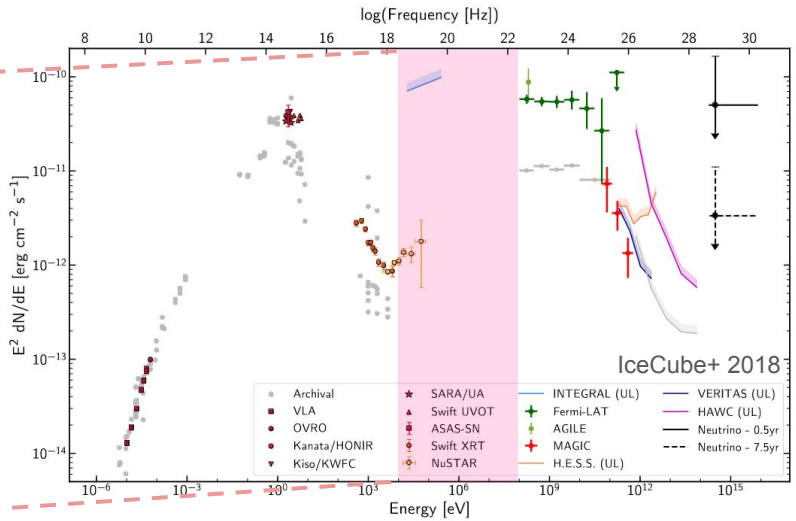




- Proton accelerators?
  →ν or MeV polarization.
- MeV SMBH population.

Time domain and multimessenger astrophysics

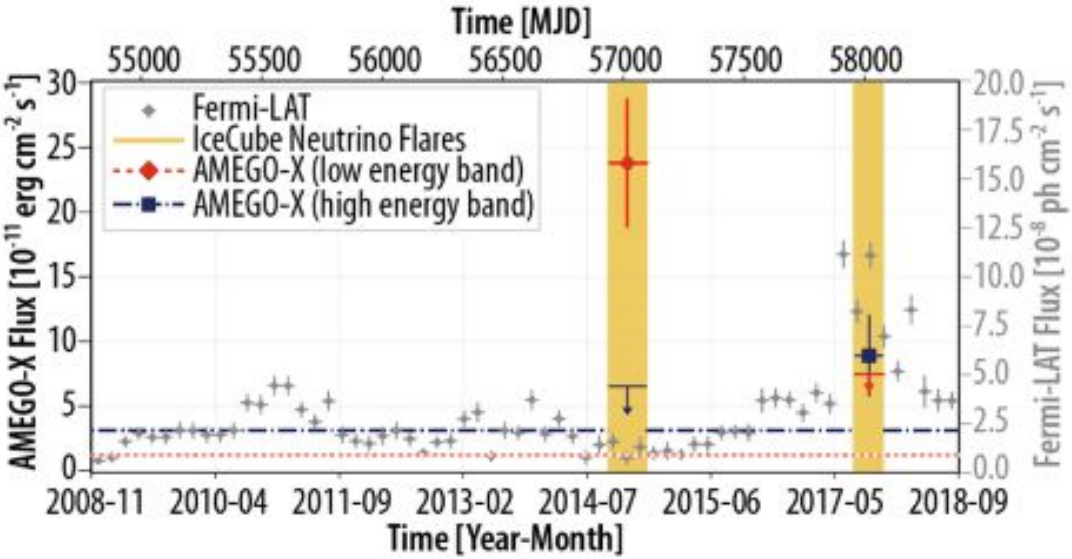


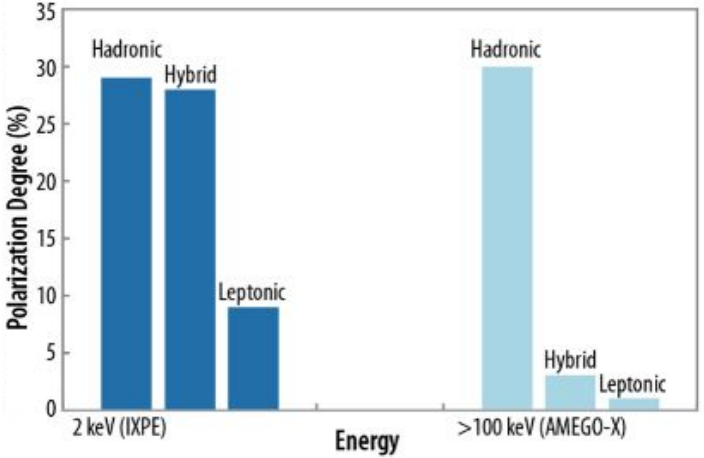


- Some hadronic models predict γ rays absorbed by jet photons, then processed into MeV photons that scape the jet.

6

Time domain and multimessenger astrophysics



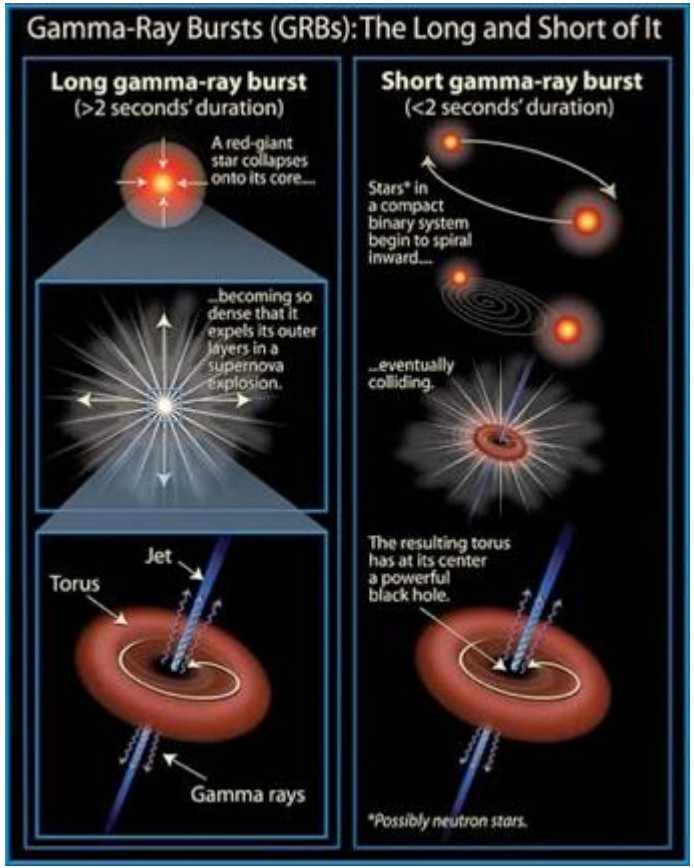


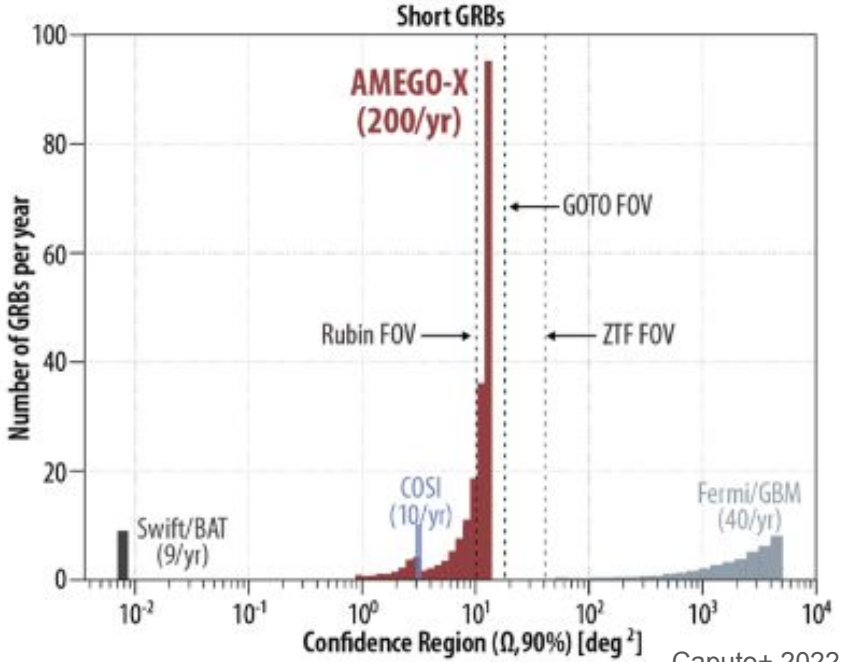
Caputo+ 2022

- Brightest ν events might not be detected by Fermi-LAT in γ because of opacity due to radiation fields.
- Powerful blazars crucial to determine their contribution to mysterious IceCube diffuse ν flux.
- MeV polarization prominent in hadronic scenario.

7

Binary neutron star mergers: GRBs





Caputo+ 2022

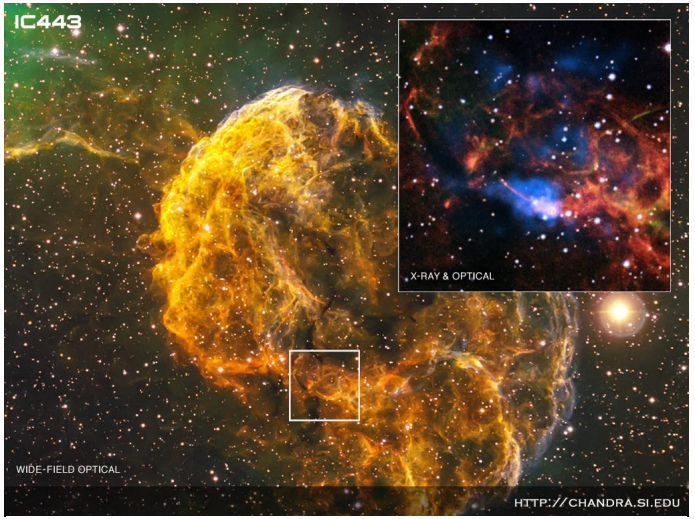
Model-dependent statistical fractions.
Structure of GRB jets.

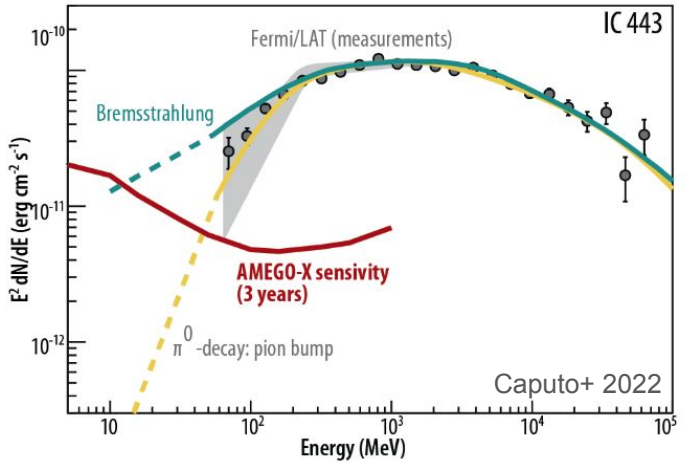
Cosmic ray sources in the galaxy

Supernova remnants, novae & star-formation regions (SFR).

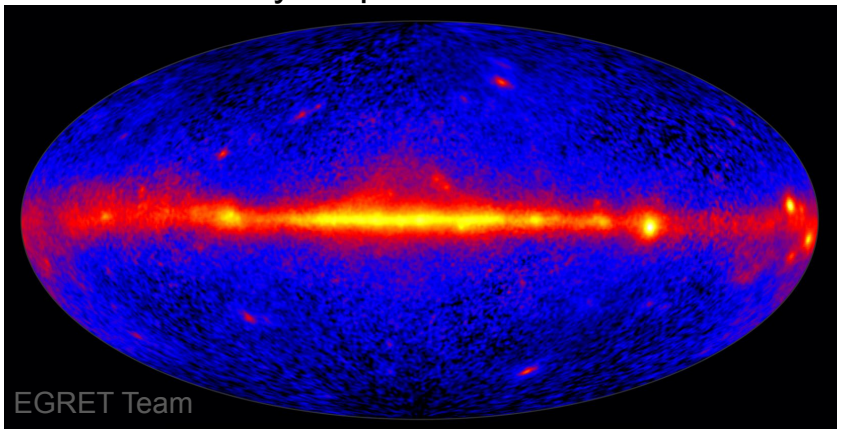
- Smoking gun of proton accelerators: π^0 decay to two gammas, each with 67.5 MeV (in π^0 rest frame).
- SNR: Protons accelerated by strong shock.
- In Novae, material acreted on white dwarf from companion undergoes thermonuclear burning, which creates shocks.
- SFR: SN shocks & massive stars' winds.
- Lack of observations < 60 MeV →model ambiguity.

Galactic positron excess caused by pulsars?

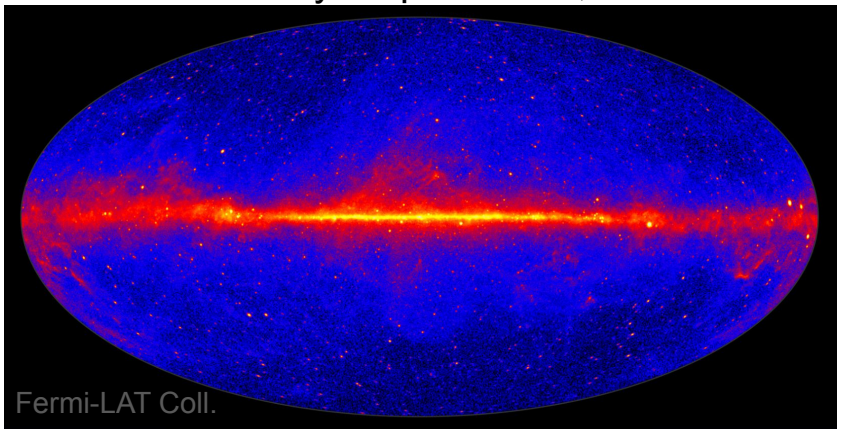




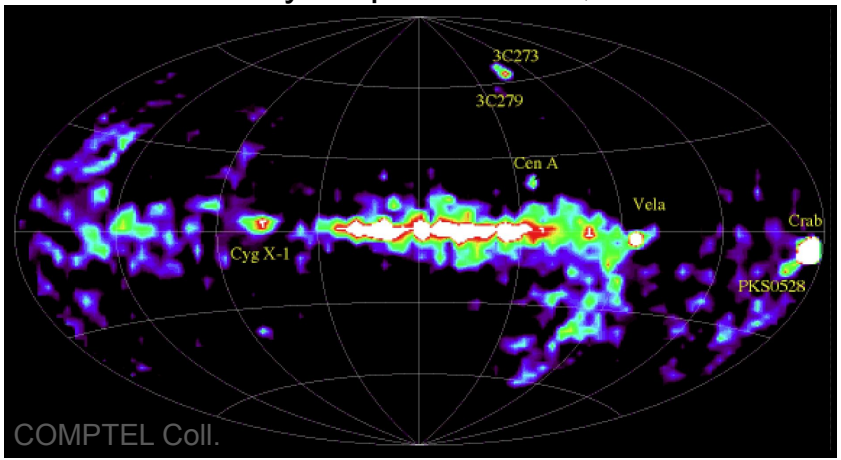
EGRET All-Sky Map > 0.1 GeV ~200 sources



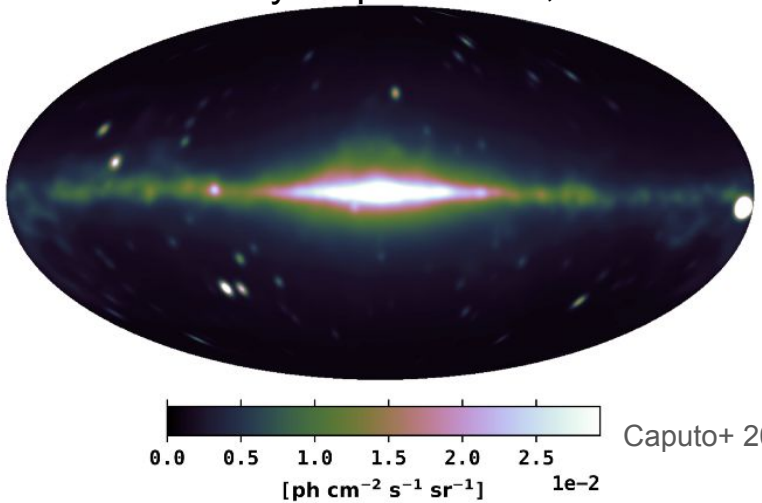
Fermi-LAT All-Sky Map > 1 GeV, >7k sources



COMPTEL All-Sky Map 1–30 MeV, ~10s sources

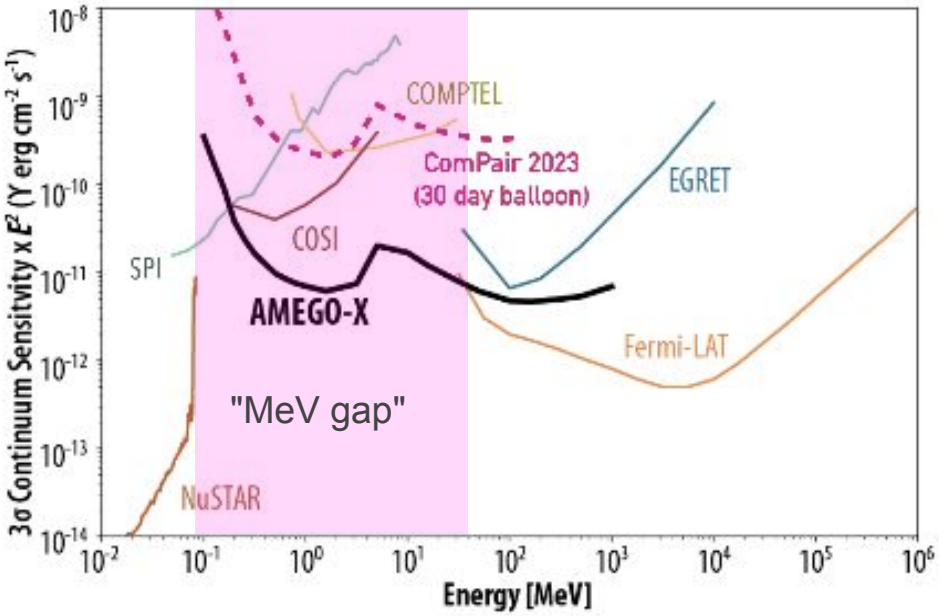


AMEGO-X All-Sky Map > 25 keV, ~100s sources



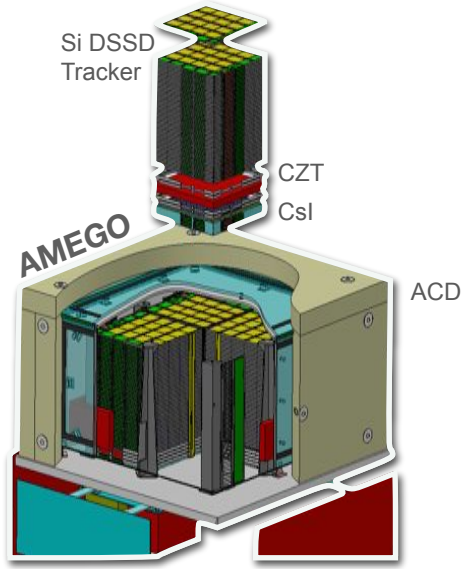
Caputo+ 2022

Gap in High-Energy Astrophysics



Multi-messenger science.
All sky monitoring in MeV.

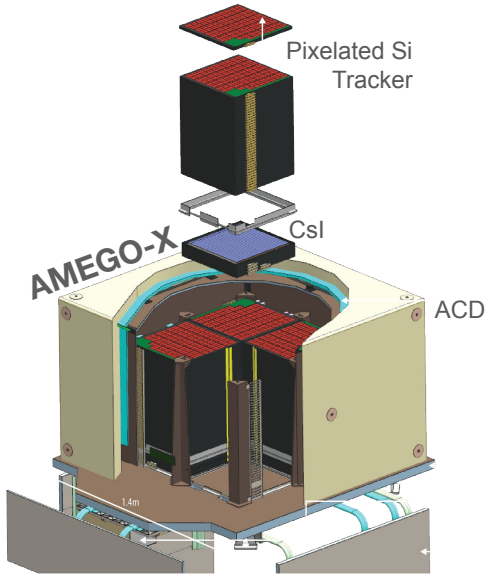
Mission concepts & their prototypes



AMEGO mission concept
0.2 MeV – > 5 GeV

⇓

ComPair-1 prototype, funded 2015.



AMEGO-X concept (2021 MIDEX AO)
25 keV – > 0.1 GeV

⇓

ComPair 2 prototype, funded 2023.

ComPair goals:

1. Develop the necessary technologies to enable a future MeV mission spanning the Compton and pair regime.
2. Design, build, and test the prototype instruments in a beam test and balloon flights.

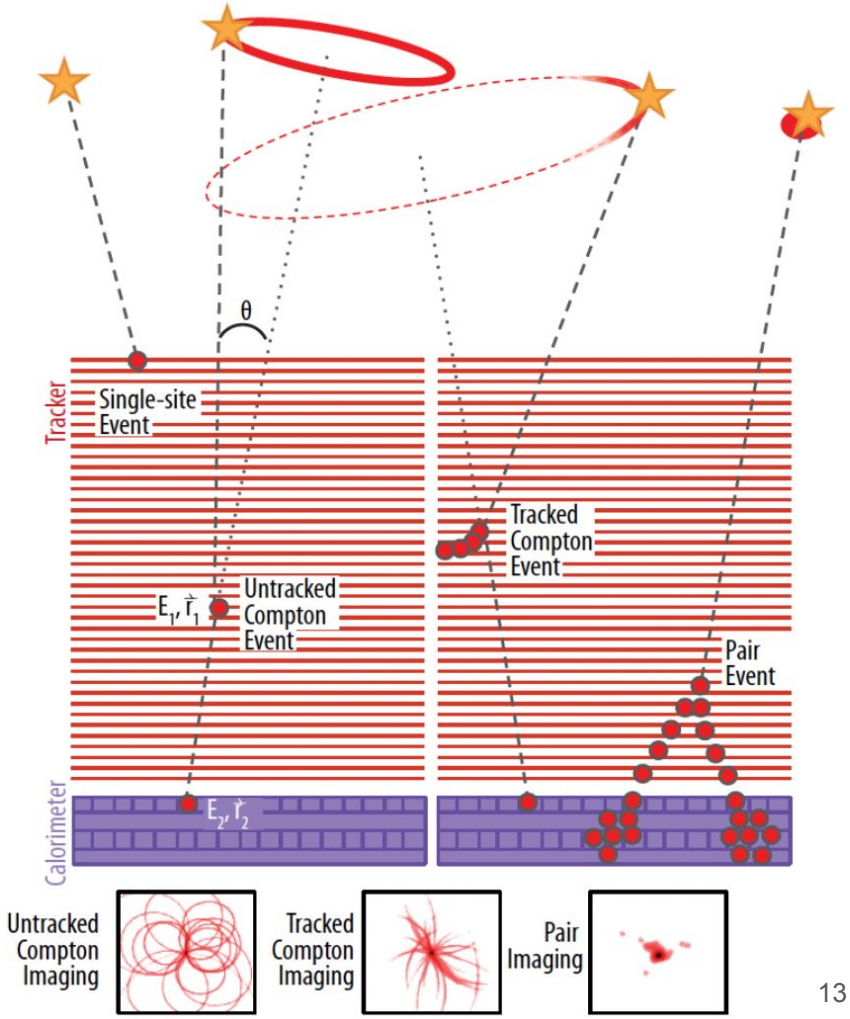
Detection Principle

Tracker and Calorimeter together characterize gamma-ray events from 25 keV to > 100 MeV.

Single-site events increase the sensitivity and low energy response (100 keV) for transients only.

Untracked and **Tracked** Compton events provide imaging < 10 MeV.

Pair events enable imaging > 10 MeV using the same detection techniques as Fermi-LAT.



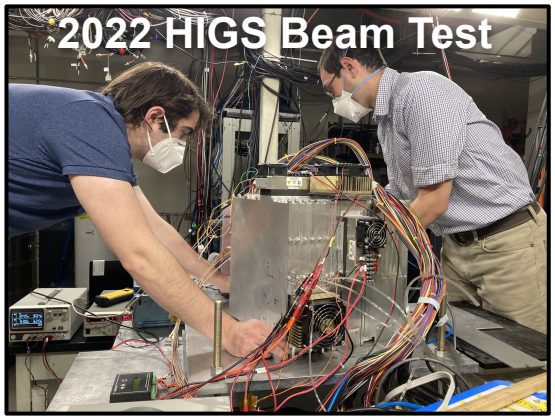
ComPair-1 prototype: 4 subsystems, 0.05 – 25 MeV

ComPair CAD vs. integrated prototype, showing the tracker (Griffin+ SPIE 2020), CZT (Moiseev+ ICRC 2019), CsI (Woolf+ IEEE 2018) and ACD subsystems.

ComPair-1 Tests

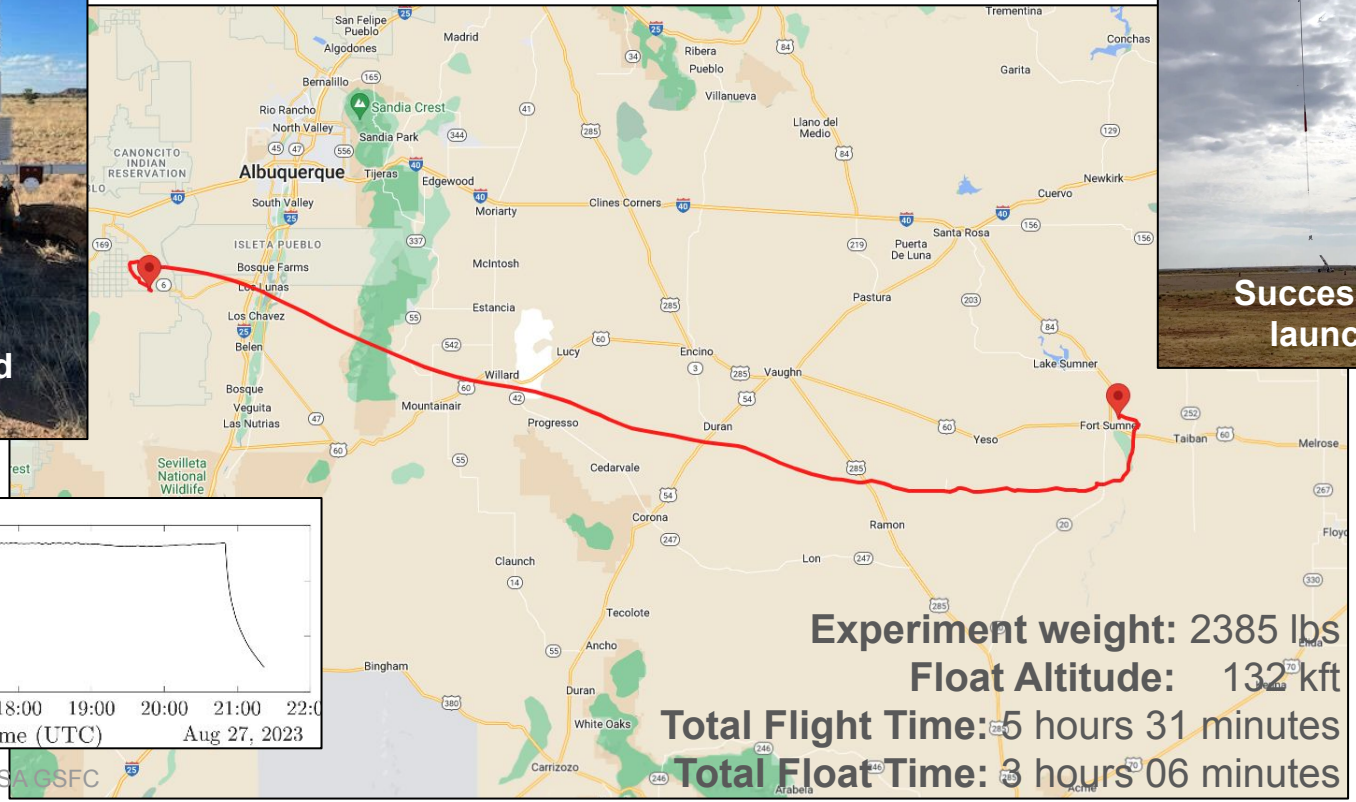
ComPair-1 integrated and tested at GSFC, with hardware contributions from NRL, BNL and LANL.

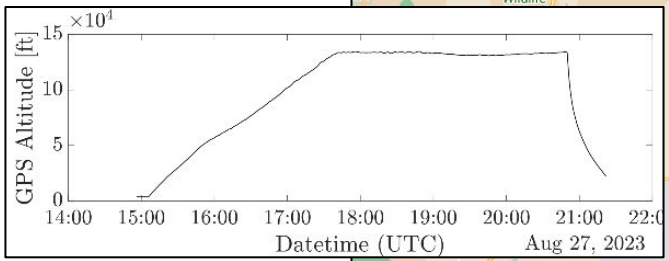
- ComPair tested at Duke University's High Intensity Gamma-ray Source (HIGS) April 2022: Mono-energetic beam of 2 - 25 MeV (Shy+ SPIE 2022).
- Validated Compton and pair event detection capabilities with laboratory sources and gamma-ray beam test.



ComPair-1 Engineering Balloon Flight

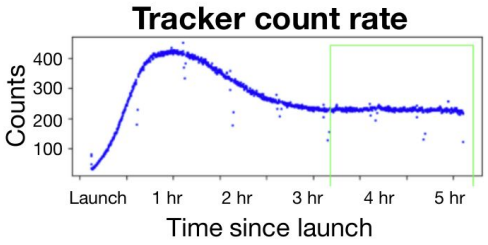
Launched on: 27 August 2023 08:57:20 MT.
From: Fort Sumner, NM, USA.

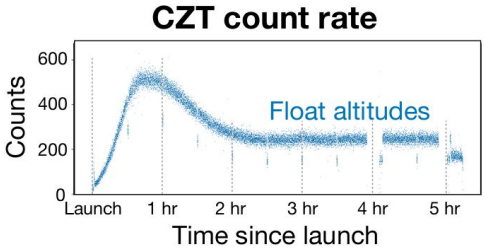


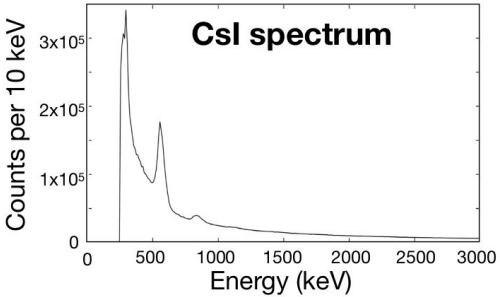


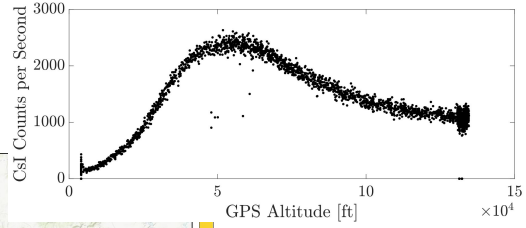
Experiment weight: 2385 lbs
Float Altitude: 132 kft
Total Flight Time: 5 hours 31 minutes
Total Float Time: 3 hours 06 minutes

ComPair-1 Engineering Balloon Flight Preliminary Results

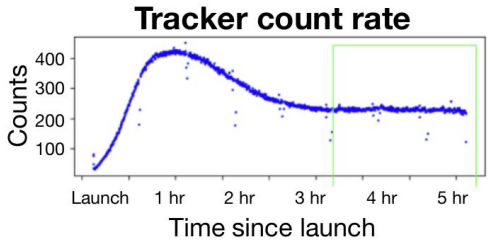


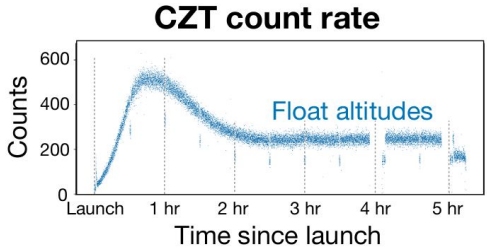


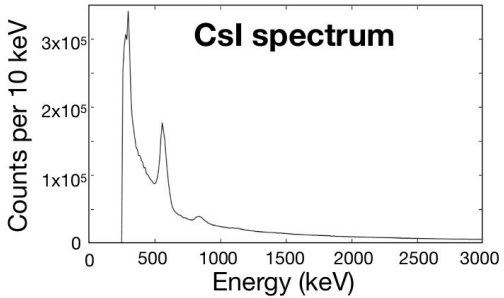


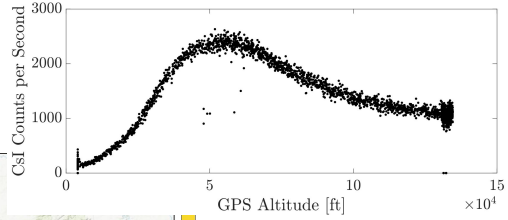


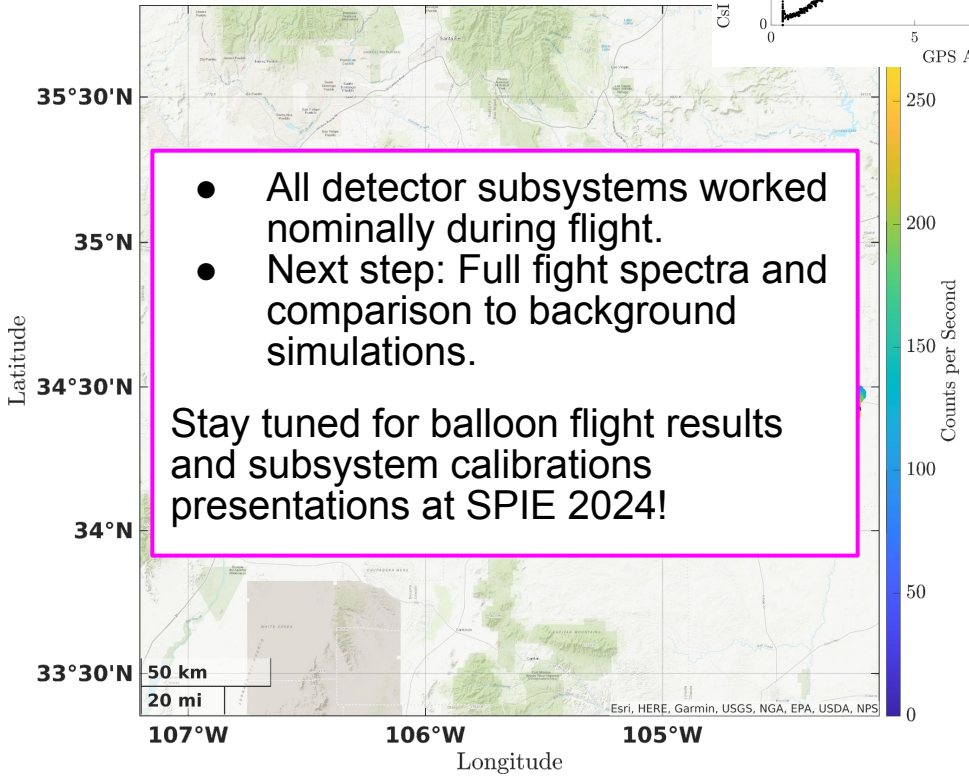
ComPair-1 Engineering Balloon Flight Preliminary Results











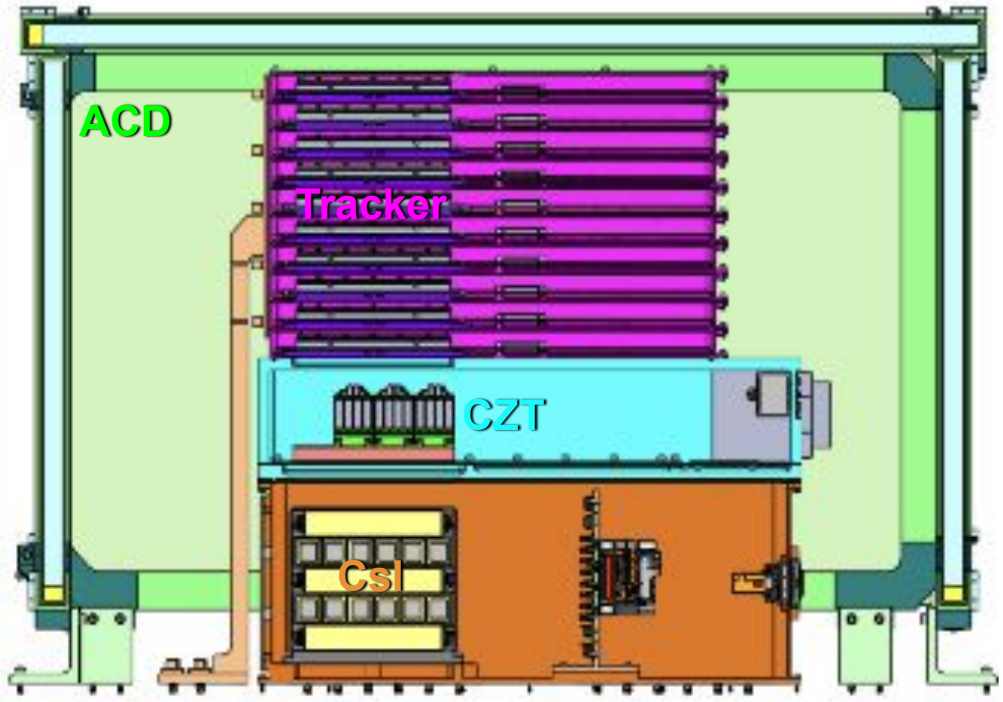
- All detector subsystems worked nominally during flight.
- Next step: Full fight spectra and comparison to background simulations.

Stay tuned for balloon flight results and subsystem calibrations presentations at SPIE 2024!

ComPair-1: Lessons learned

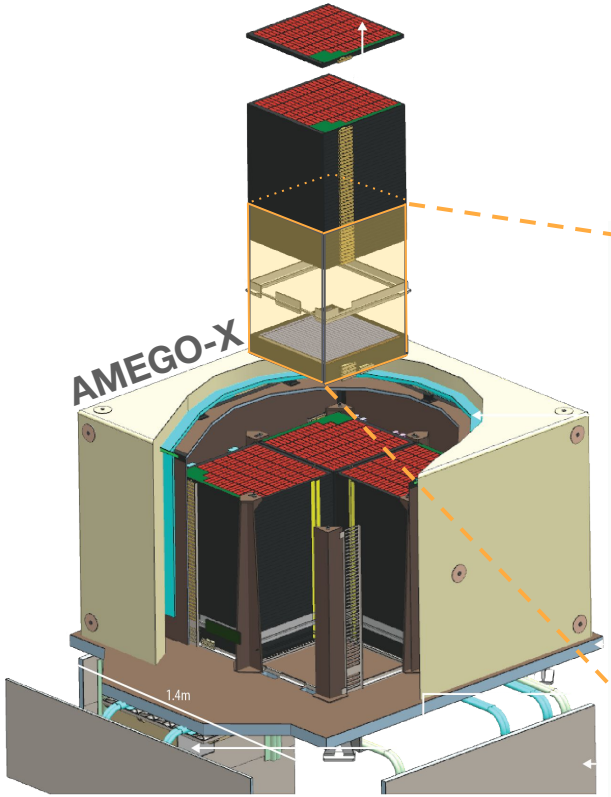
The balloon flight was a huge success! And we also found areas for improvement:

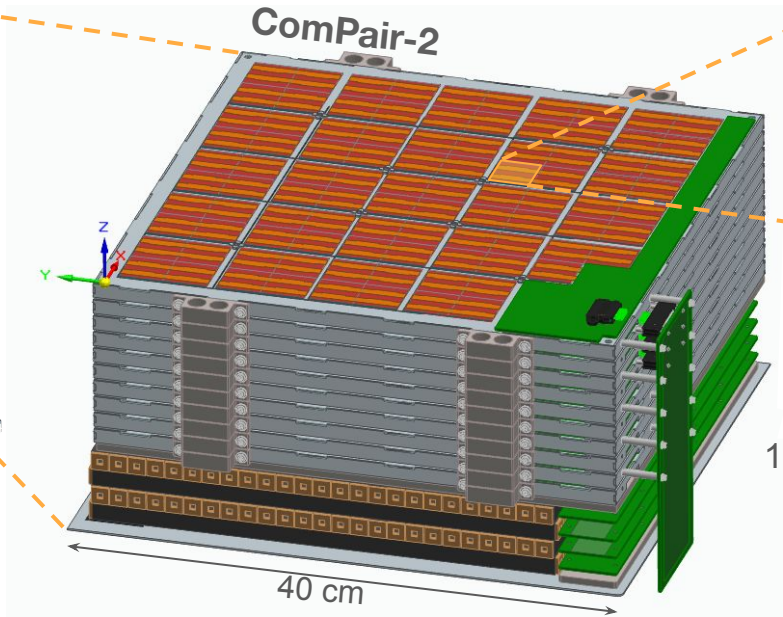
- Tracker double-sided strip silicon detectors ➡ large capacitance.
- Small detector area ➡ limited efficiency.
- Vertical geometry ➡ limited efficiency.
- Significant passive material ➡ limited efficiency, large background.
- Power hungry ➡ high detector temperature, cooling needed.
- Reconstruction tools limited in pair regime ➡ limited efficiency.

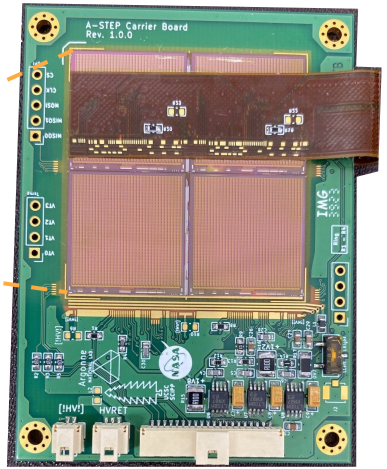


ComPair 2 prototype: 25 keV– ~50 MeV

Funded in 2023 to build a prototype with 2 detector subsystems of AMEGO-X

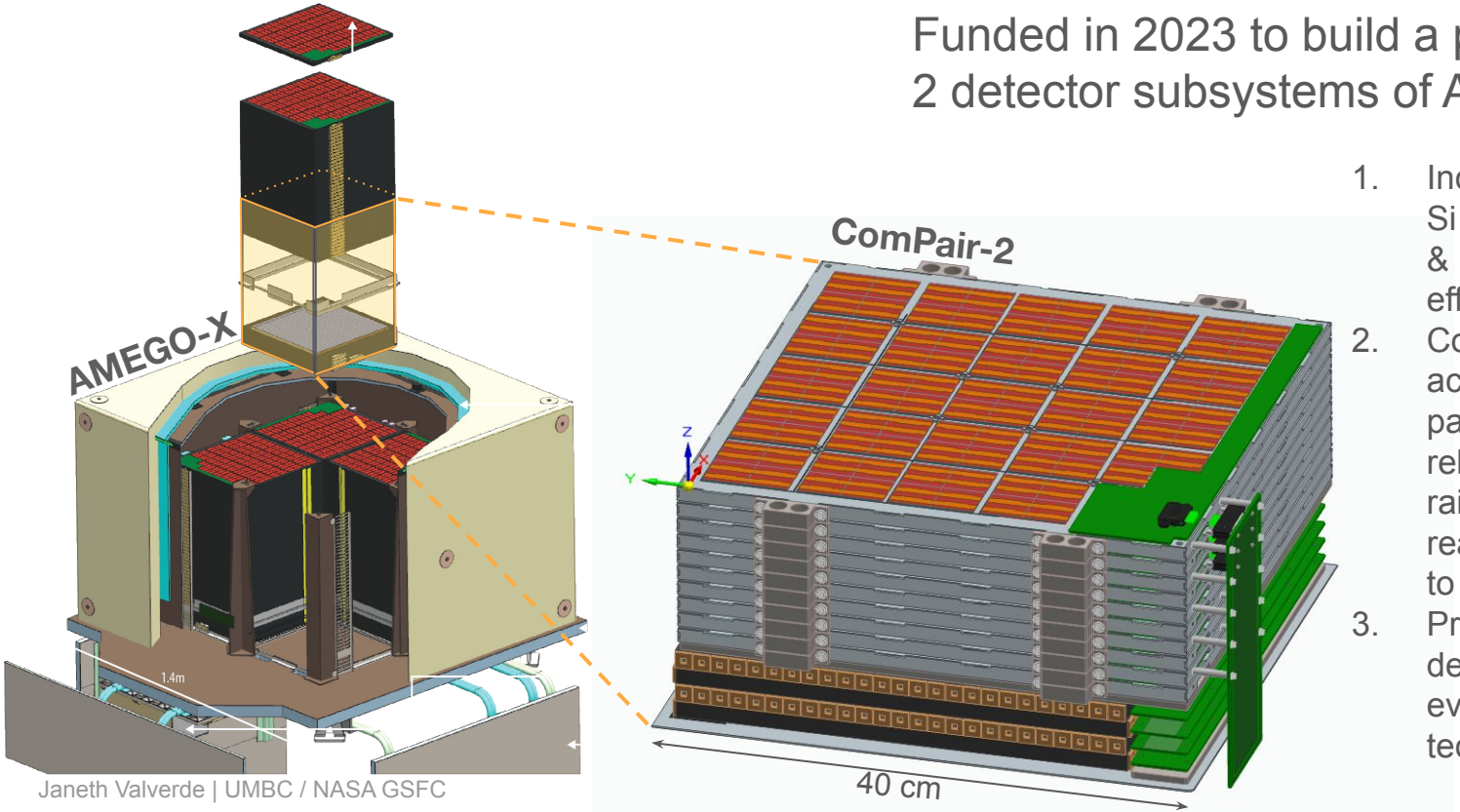






1. Incorporate pixelated Si detector (AstroPix) & increase Tracker effective area.

ComPair 2 prototype: 25 keV – ~50 MeV



Funded in 2023 to build a prototype with 2 detector subsystems of AMEGO-X

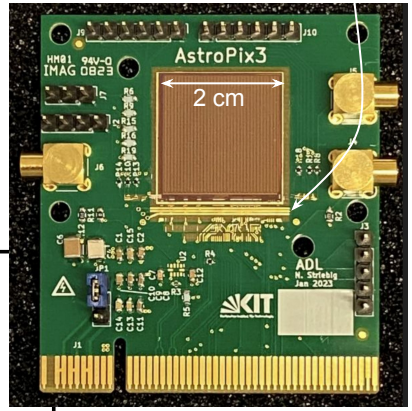
1. Incorporate pixelated Si detector (AstroPix) & increase Tracker effective area.
2. Confirm performance across Compton and pair regimes & in a relevant environment, raising technology readiness level (TRL) to 6.
3. Provide first hardware demonstration of novel event reconstruction techniques.

AstroPix :Pixelated Silicon for MeV Astrophysics

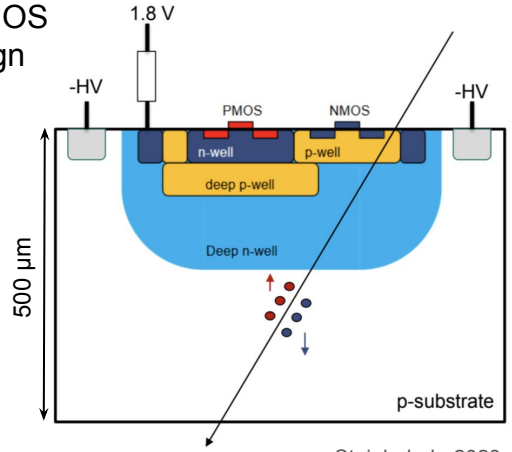
High Voltage monolithic silicon pixel CMOS detectors

- Developed for particle physics experiments (ATLASPix).
- Optimized for AMEGO-X through award funded in 2019.
- Low power (~1mW/cm^2), good energy resolution, minimal passive material.

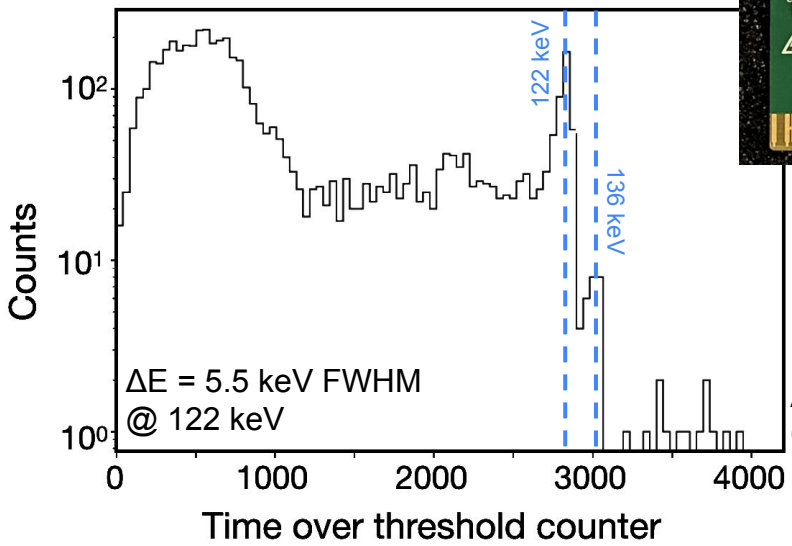
Matrix readout and contro on periphery



HVMOS design

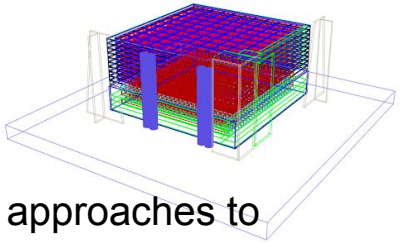


Steinhebel+ 2023
Striebig 2021



AstroPix v3
Co-57 spectrum

ComPair-2 Software Improvements

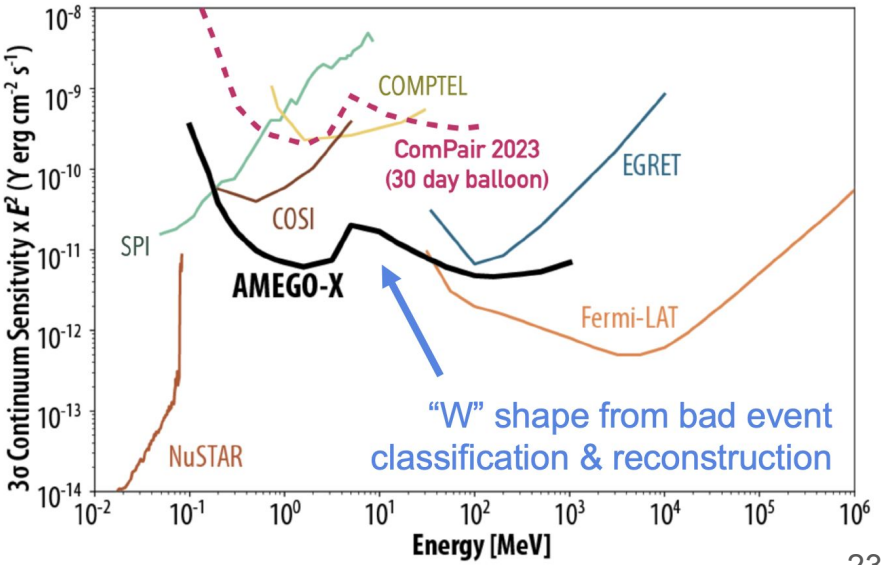


Building off A. Zoglauer funded project: "Applying supervised machine learning approaches to the reconstruction of high-energy tracked Compton and Low-energy pair events".

Goal: Improve tools to improve sensitivity estimates for AMEGO-X and perform first hardware demonstration of new tools with ComPair-2!

Current efforts:

- Machine learning techniques for Compton/pair event identification: 99% accurate!
- Pair event reconstruction techniques based on Fermi-LAT.
  - Kalman filter.
  - Energy corrections.
- Real-time on-board transient localization.



Current Status, Steps Forward, and conclusions

The ComPair project is raising the TRL of future MeV observatory technology.

Analysis of ComPair-1 balloon flight and calibration data underway.

→Presentations at SPIE and 3 PhD theses.

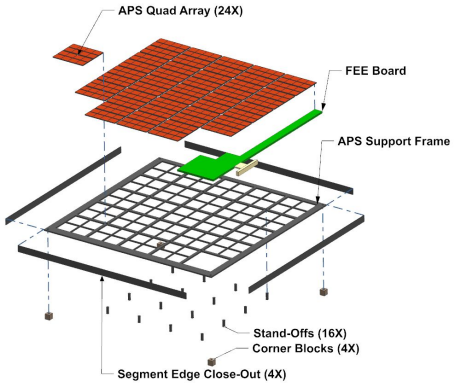
Beginning fabrication of ComPair-2 Tracker mechanical and electronics.

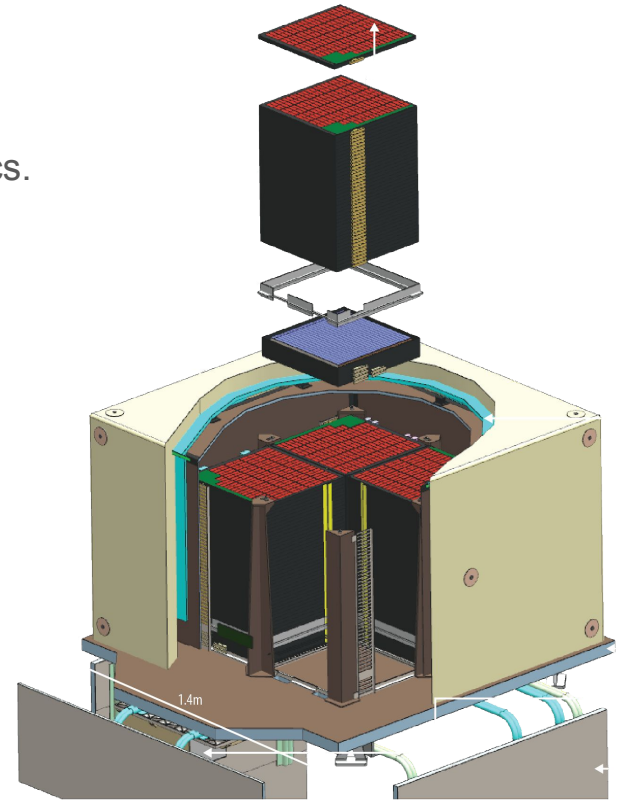
→TVAC and Vibe test of single Traker layer in 2024.

→Full system integration Q1 2026.

Plans for future balloon flight for ComPair-2.

Planning to submit AMEGO-X again to next MIDEX call in 2027.

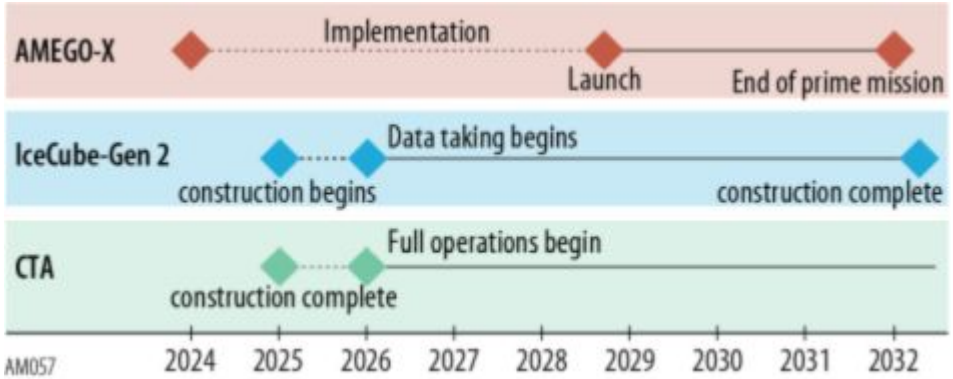


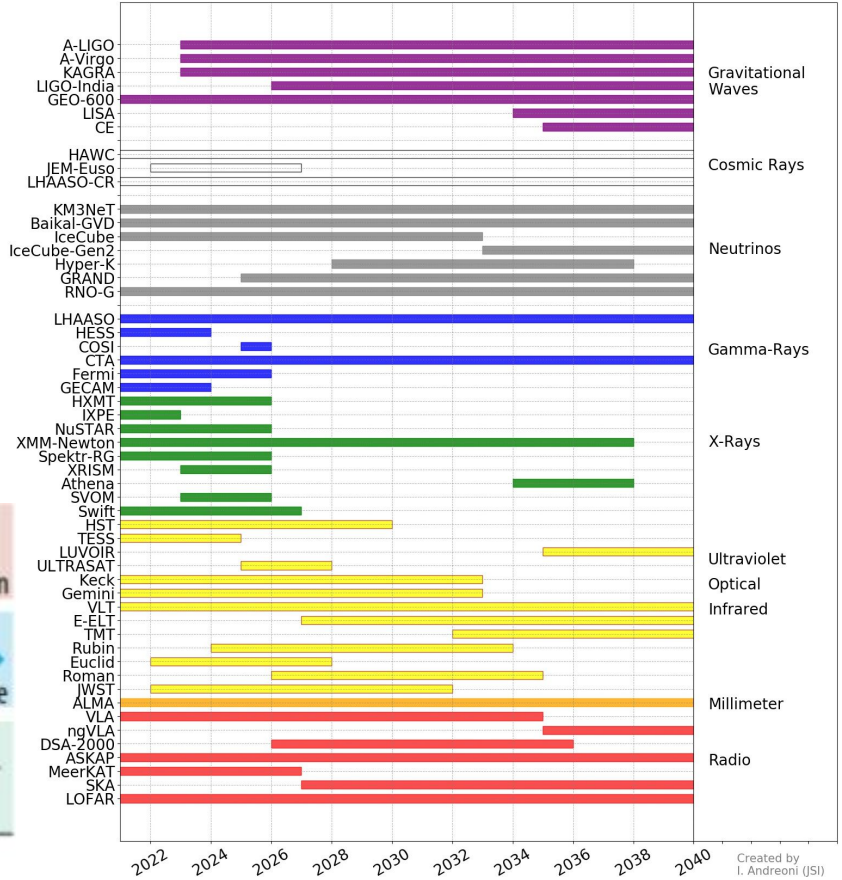


The future is exciting!

MeV mission needed to maximize the scientific return of:

- CTA→EGal survey & ν follow ups.
- IceCube-Gen 2 in ν.
- Time-domain era →Lifetime of LAT orbit extends into mid-2030s.





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Thank you!