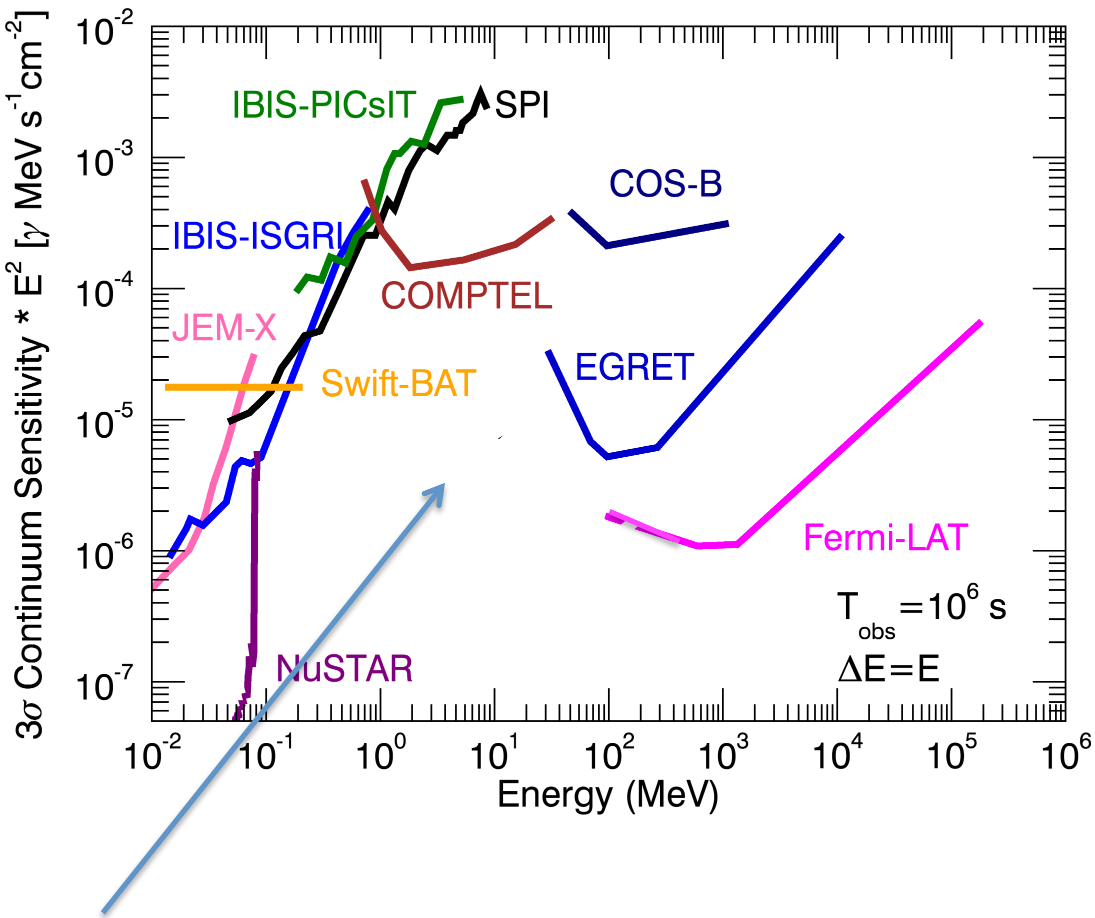
ComPair

ComPair and future perspectives in MeV Gamma-ray astronomy

- Why MeV range?
- What science is there? – thanks to Marco Tavani for excellent coverage of the science objectives
- Instrument concept – ComPair
- Future improvement – AMEGO
- More dreams…

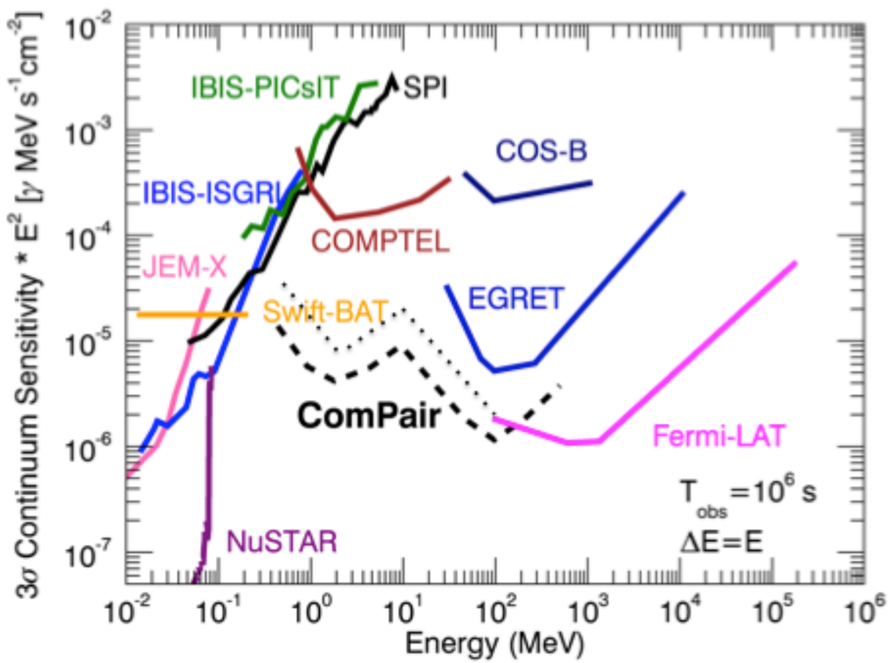
Alexander Moiseev
CRESST/NASA/GSFC and University of Maryland, College Park,
on behalf of the ComPair science team (NASA/GSFC, NRL, UCSC, WashU and Clemson U)

Why do we want to look in the MeV Range?



Guaranteed discovery space!

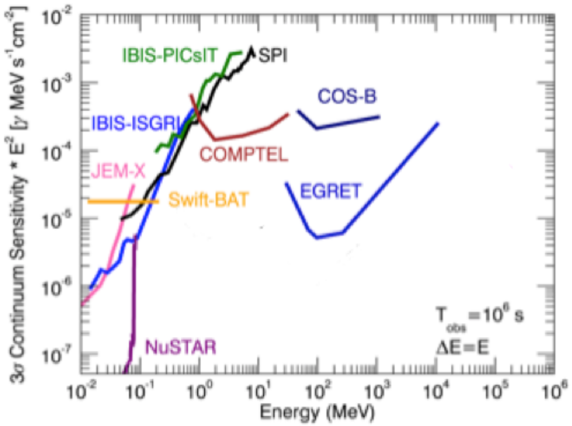
Science Driver for ComPair – Guaranteed discovery space

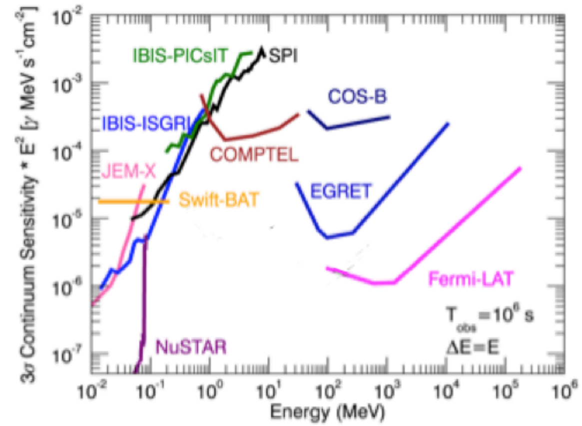


MeV: the least explored region of the electromagnetic spectrum

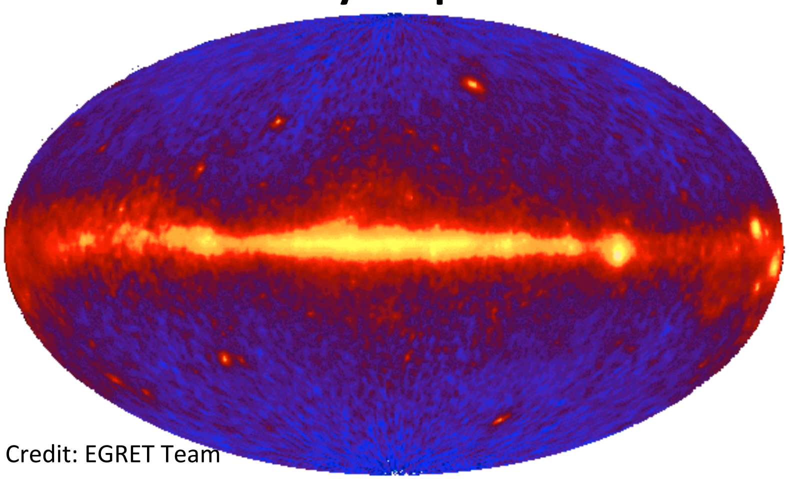
- ***ComPair will provide a huge leap in sensitivity and breakthrough science capability***
- ***ComPair will continue Fermi LAT exploration of gamma-ray sky at lower energy in "impossible" energy range, heavily basing on its heritage***

What Fermi LAT has done: High-energy gamma-ray sky map after 8 years of operation





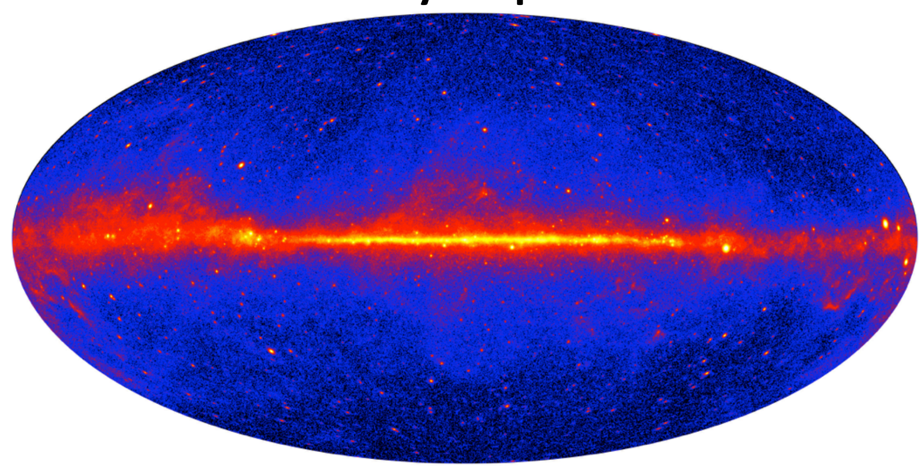
EGRET All-Sky Map Above 100 MeV



Credit: EGRET Team

~200 Sources Detected

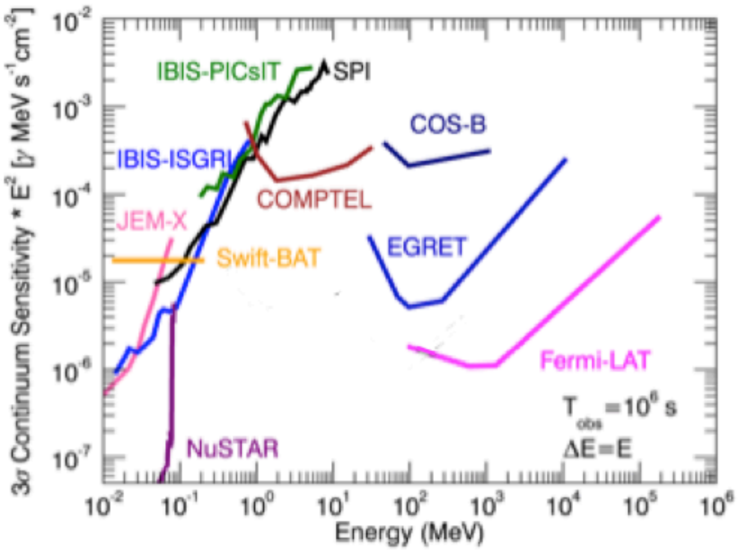
***Fermi*-LAT All-Sky Map Above 1 GeV**

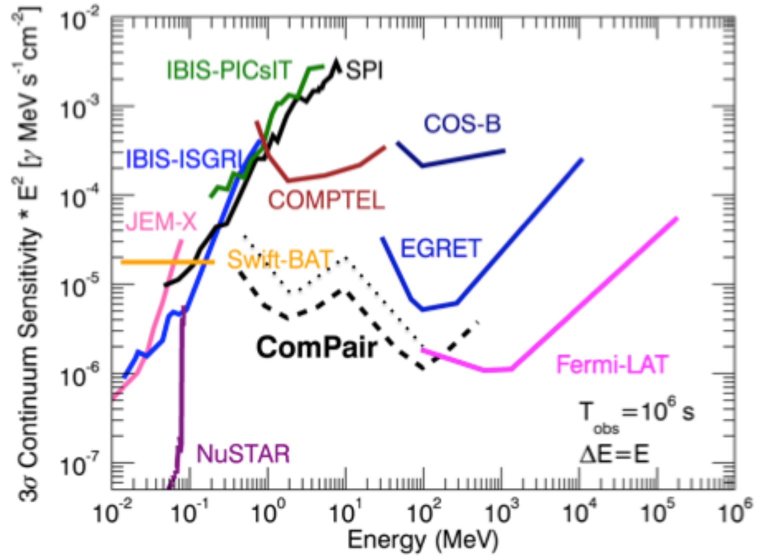


Credit: NASA/DOE/Fermi LAT Collaboration

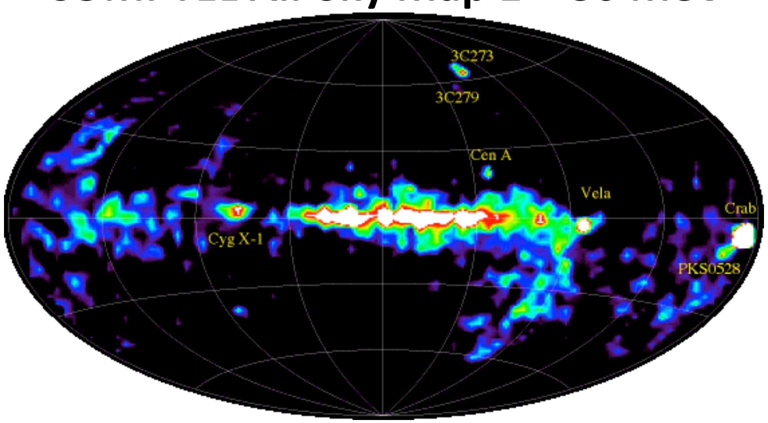
~3000 Sources Detected

What we can expect from ComPair:





COMPTEL All-Sky Map 1 - 30 MeV



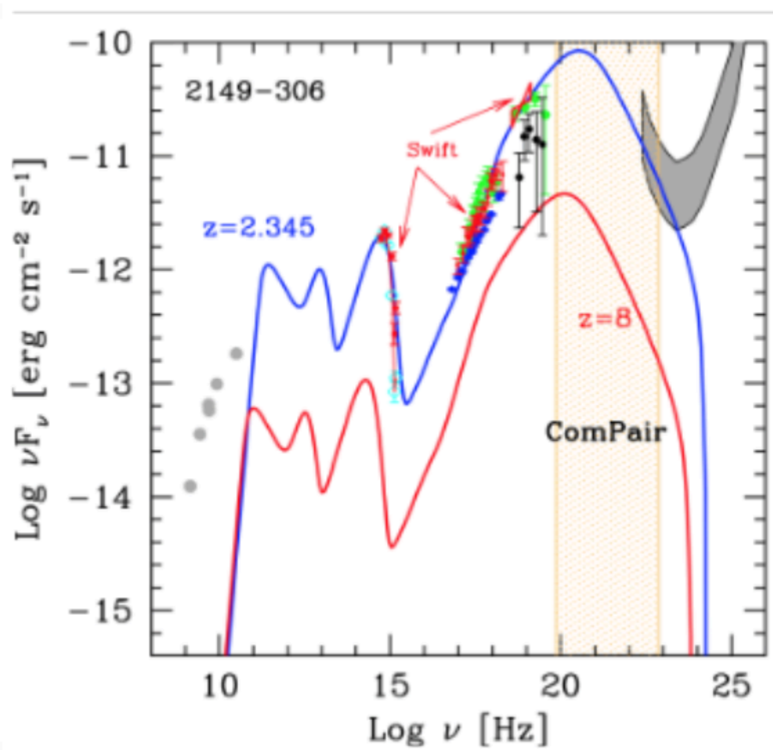
Credit: COMPTEL Collaboration

Tens of Sources Detected

Science Objectives: Extreme Astrophysics

- Understanding how the Universe works requires observing astrophysical sources at the wavelength of **peak power output**.
  - Peak power is crucial for establishing source energetics.
  - *Fermi*-LAT, NuSTAR, and *Swift* BAT have uncovered source classes with peak energy output in the poorly explored MeV band.
  - ComPair science objectives focus on cases of extreme astrophysics:
    - High matter densities
    - Strong magnetic fields
    - Powerful jets.

A critical energy band - Spectral features such as breaks, turnovers, cutoffs, and temporal behavior, which are critical to discriminate between competing physical models, occur within the MeV energy range.

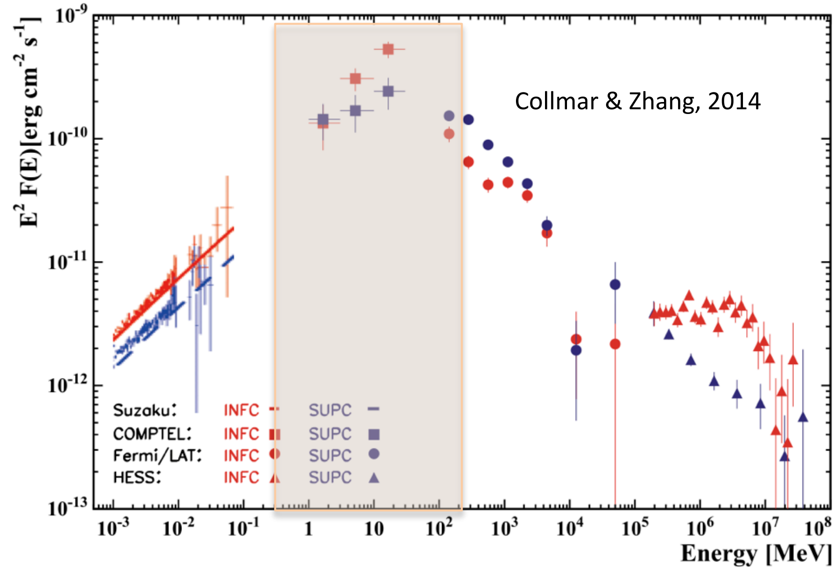


MeV Blazars

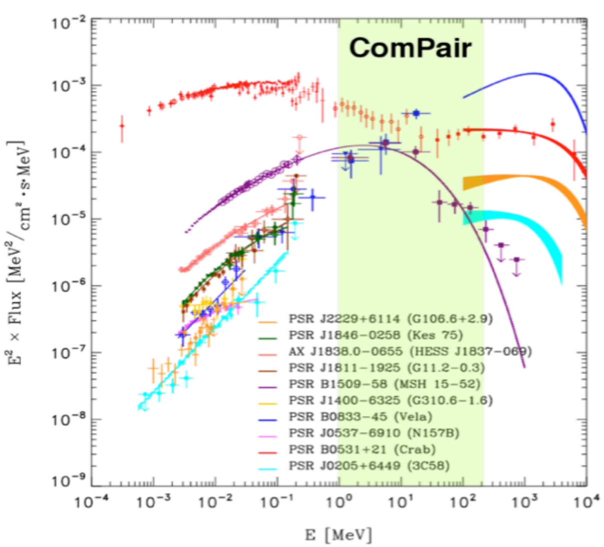
- Among the most powerful persistent sources in the Universe
- Large jet power, easily larger than accretion luminosity
- Host massive black holes, near 10^9 solar masses or more
- Detected up to high redshift
- Evolution of MeV blazars is stronger than any other source class – i.e. maximum density might be very early on
- **ComPair will detect >500 MeV blazars**
  - **~100 at z>3**

Science Example: Extreme Physics of Compact Objects

- Compact objects with key energy features in the MeV range include:
  - **Magnetars** - strongest magnetic fields in the Universe (note that they don't peak in the MeV).
  - **Pulsars** - neutron stars represent the highest matter densities possible before collapse to a black hole.

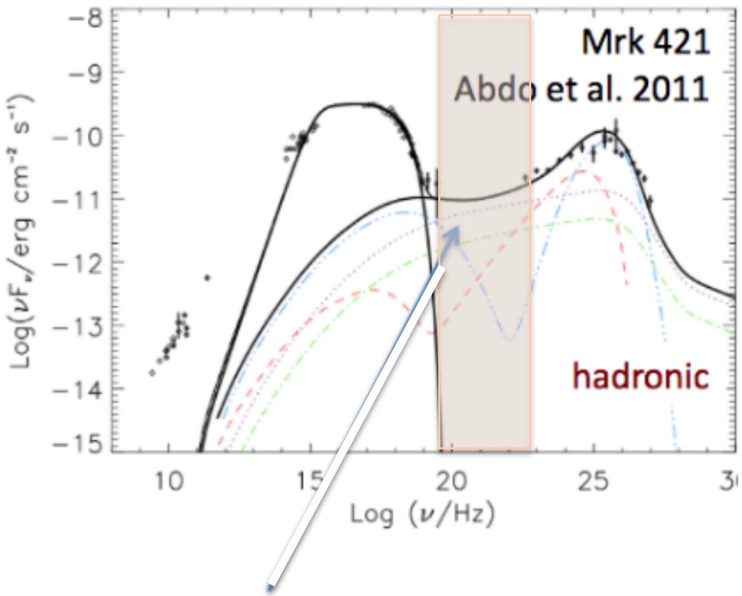


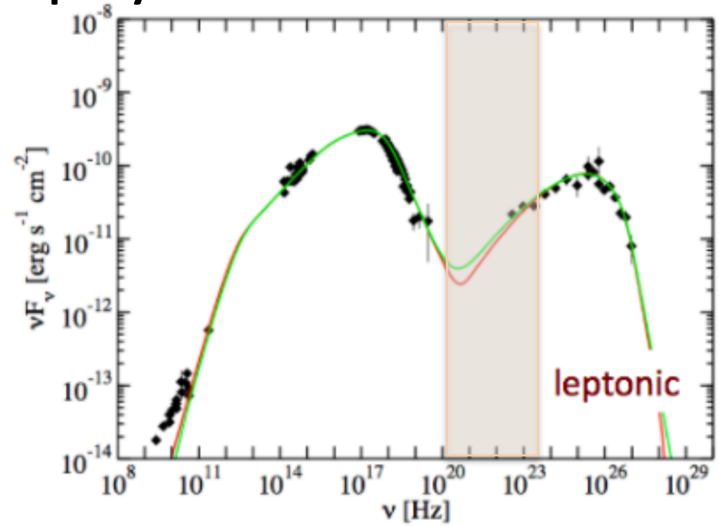
High mass X-ray Binary LS 5039 at superior and inferior conjunction.

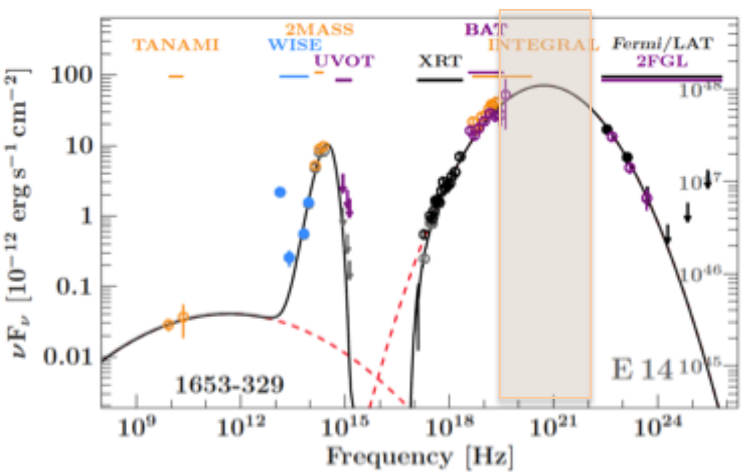


Selected Pulsars (200 gamma-ray pulsars are known).

MeV Blazars/observations and Multimessenger Astrophysics



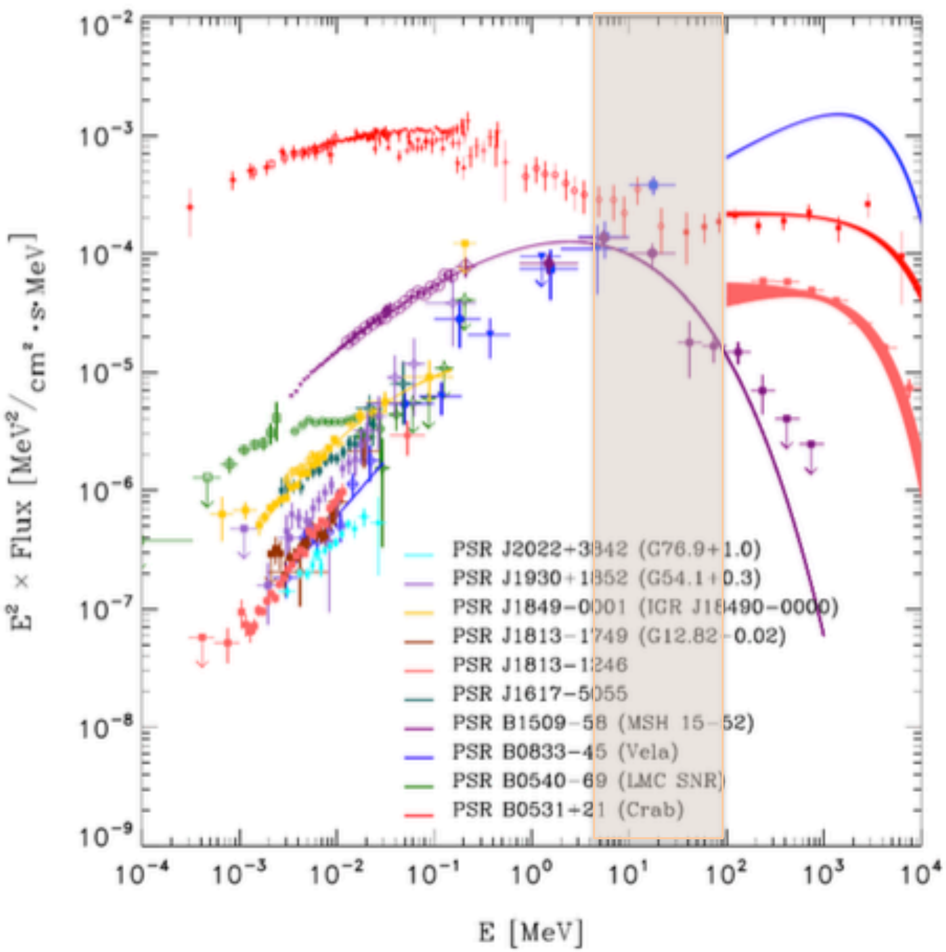




J1653-329 a candidate PeV neutrino emitter (Krauss et al 2014)

- Do AGN jets accelerate protons to extremely high energies?
  - Producing PeV neutrinos, UHECR and high energy gamma-rays
  - MeV range is crucial

Soft Gamma-ray Pulsars



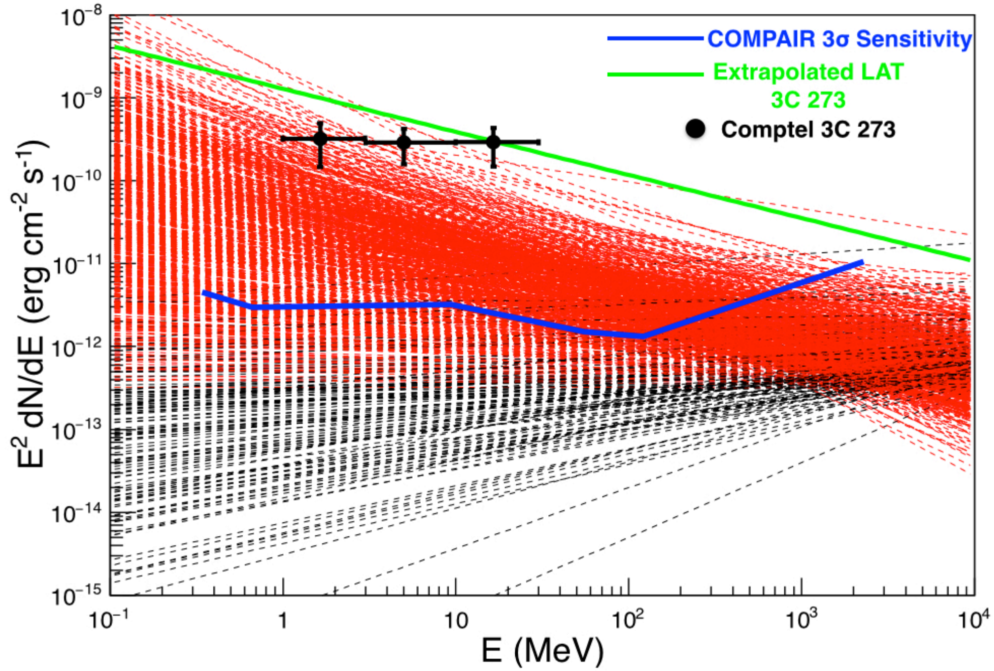
- Pulsars seen in hard X-ray but not by Fermi-LAT, peak lies in MeV band
- 11 MeV pulsars known
  - Extremely energetic E_{dot} > 10^{36} erg
- **Possible "hidden" population of energetic soft gamma emitting pulsars**

Discovery Space

- Previous instruments covering the 1-100 MeV range were COMPTEL/ OSSE on CGRO and Integral SPI; Fermi-LAT is not well optimized below 100 MeV

- **~⅓ of Fermi-LAT sources remain unidentified !**
    - ComPair will provide a bridge between high- energy gamma-ray and X-ray regimes, helping to identify and understand these objects

- Below 200 MeV, ComPair will dramatically improve sensitivity and open a new window in the EM spectrum leading to the discovery of many new sources and source classes

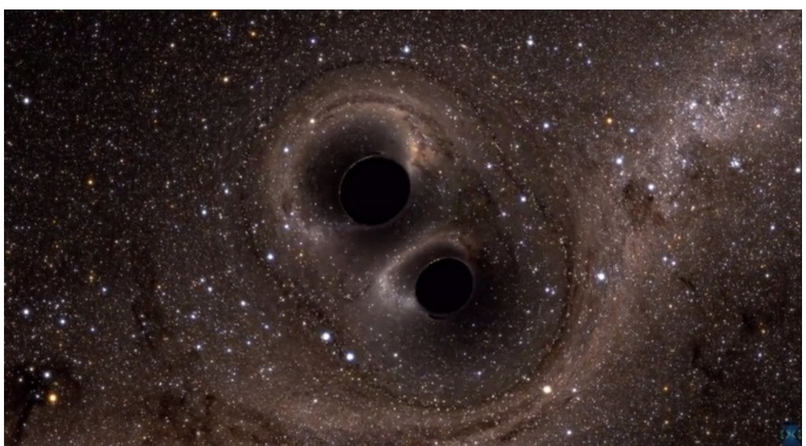


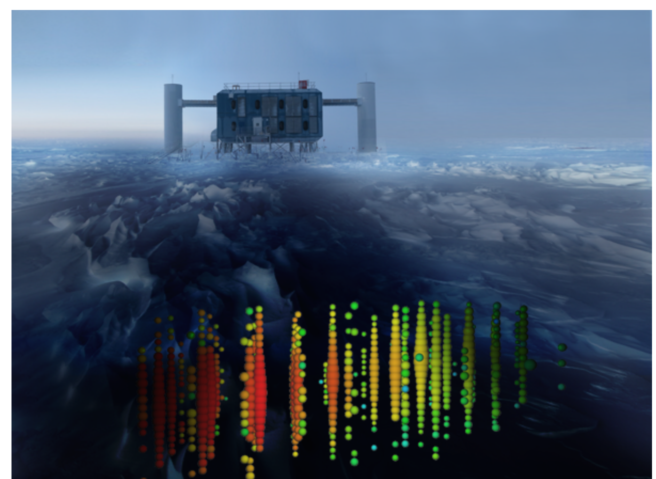
>50% of Fermi-LAT catalog sources have a peak below the Fermi-LAT band.

ComPair

New Astronomy: Gravitational Waves and Neutrinos

- Multimessenger Astrophysics – studying the Universe using high energy neutrinos and gravitational waves
  - Neutrinos are produced only only in regions with extreme particle acceleration
  - (Detectable) Gravitational waves are produced in regions with enormous energy release
  - Gamma-ray observatories are the most natural path to connecting this “new astronomy” to known astrophysical objects





Courtesy of Julie McEnery

Mission Goals

- Field-of-view: wide-field - monitor the whole gamma-ray sky.
- Energy Range: 200 keV → 500 MeV
- Sensitivity: At least 10 times better than COMPTEL at ~1 MeV
- Angular Resolution: 3 - 5 times better than *Fermi*-LAT at 20 - 100 MeV

Why Wide-Field Survey?

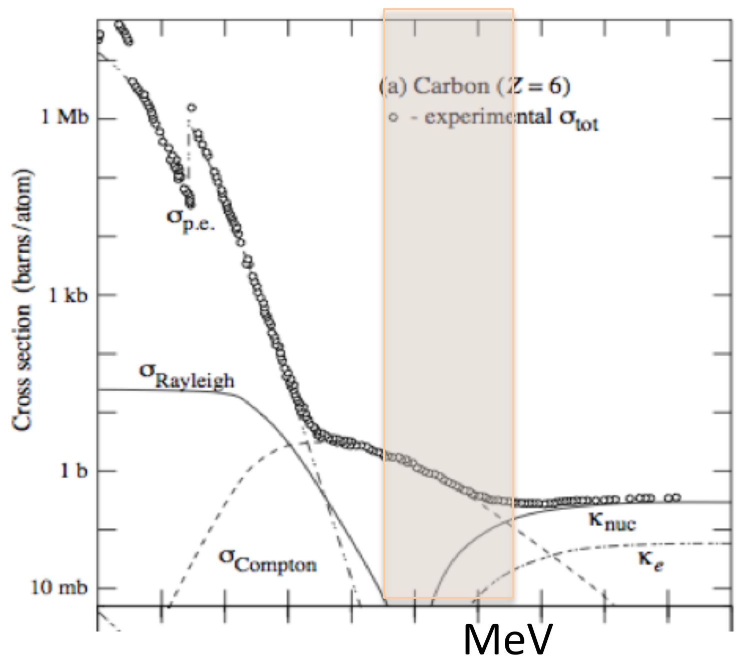
- Need a long-baseline to detect pulsars.
- Need to determine when 'interesting things happen' (glitches, state changes, …)
- Need to watch for transient phenomenon.
- Need to search for the unknown.

Concept and Approach

- Focus on Continuum Flux Sensitivity
- ComPair is a new instrument in name but not in heritage. Concept is built on mature technology and extensive prior instrument development and optimization.
  - **Maximal use of *Fermi*-LAT hardware heritage and lessons learned.**
  - **Modification of a mature, well studied mission concept (MEGA)**
  - **Most technically straightforward approach for this energy range**.
- Addresses compelling science questions and allows a broad science discovery capability.

Sensitive to both, pair-production and Compton events

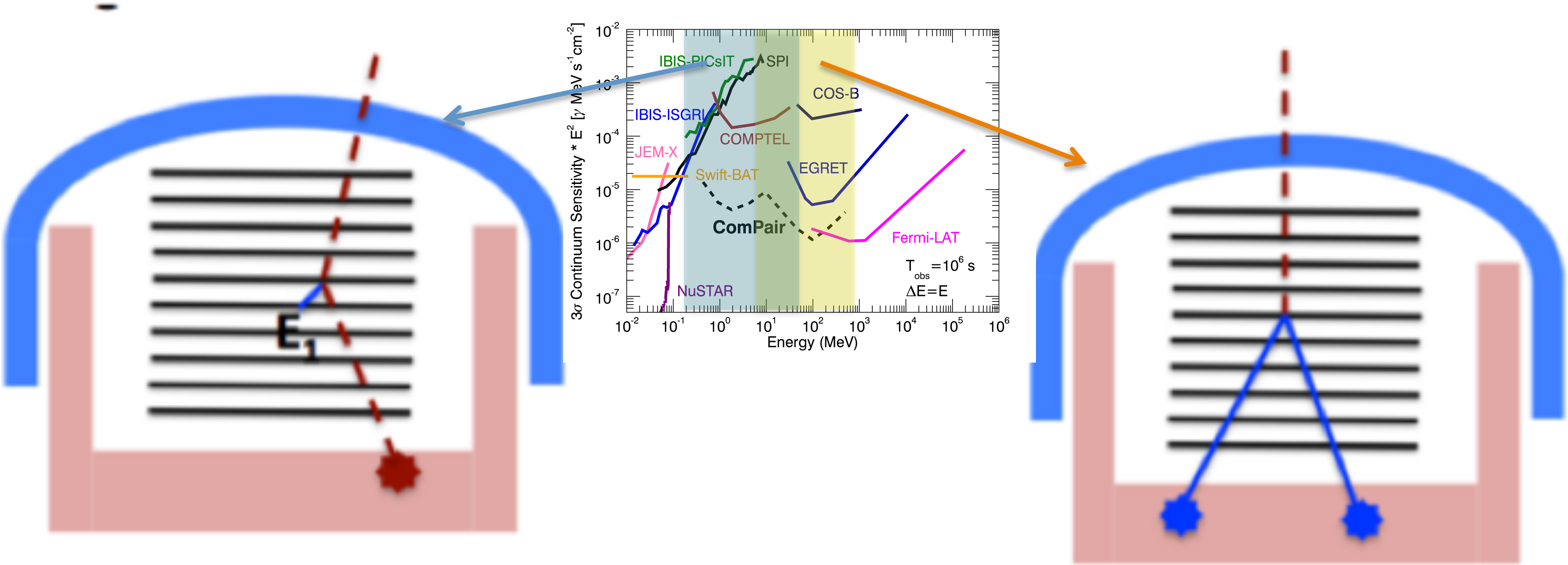
From ~0.1 - 100 MeV two photon interaction processes compete: Compton scattering and pair production cross sections intersect at ~10 MeV



Challenge and advantage at the same time: identification of the process (pair-production or Compton) and applying appropriate analysis improves the quality of the results and enables cross-check in overlapping energy range (assessment of systematic errors)

Event detection in ComPair

In the ComPair energy range, gamma-rays interact with matter via two different processes: Compton Scattering at low energies and pair production at higher energies

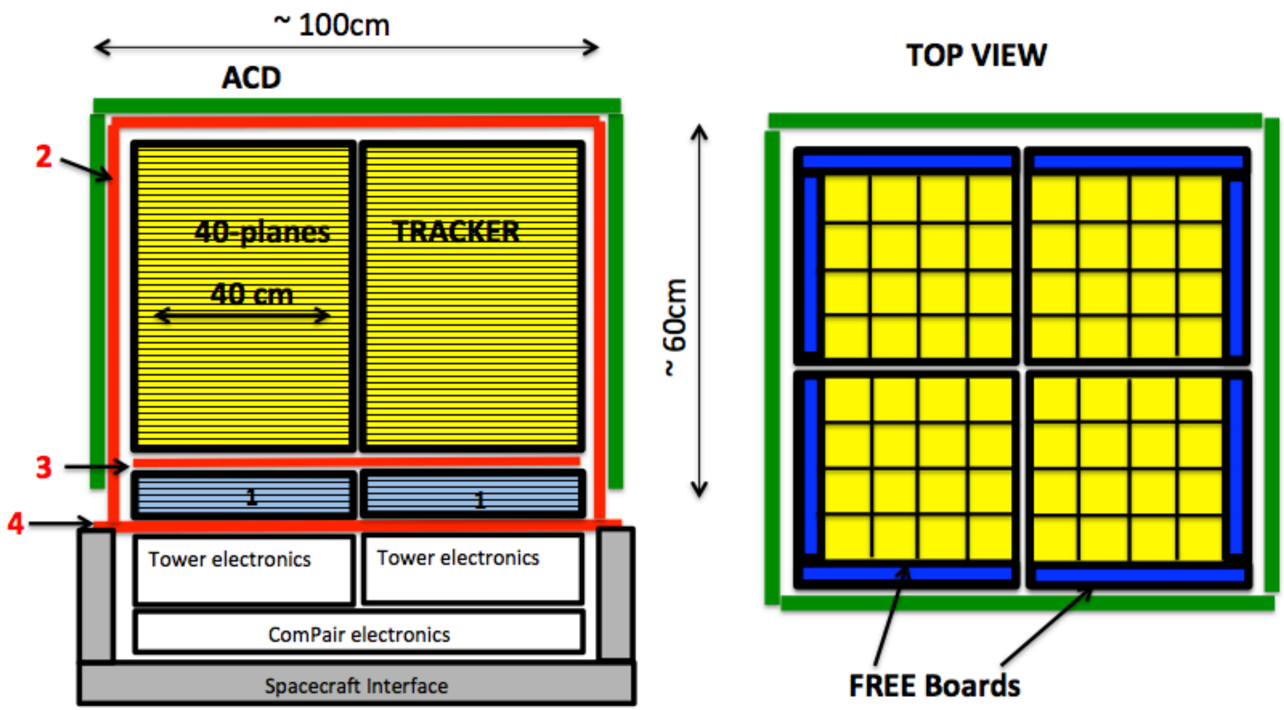


Compton event

Pair production event

- What do we need to measure?
  - Compton event – measure electron track and energy, and scattered gamma-ray position and energy
  - Pair event – measure electron tracks and energy

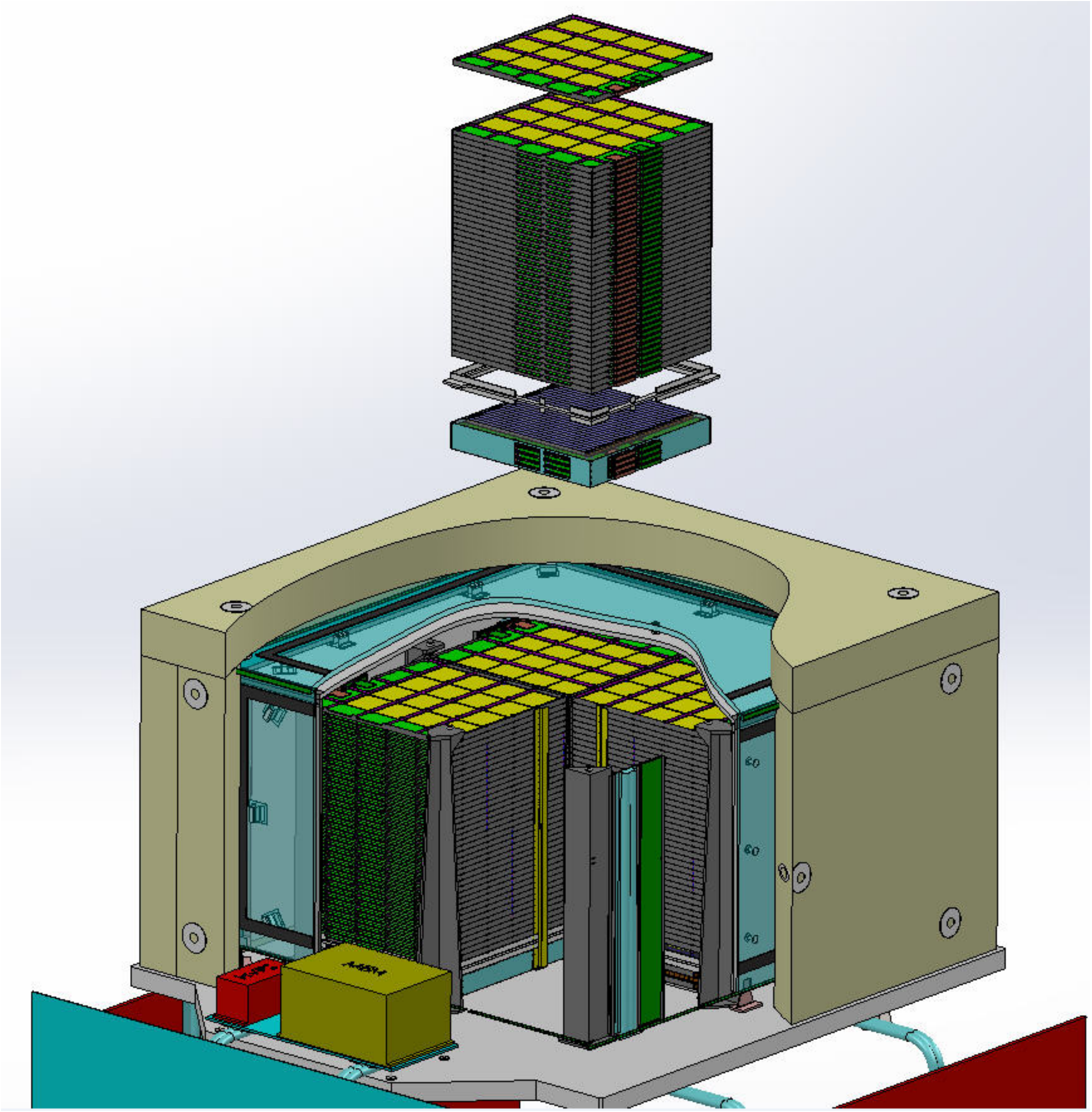
ComPair – our reality for MIDEX 2016.



1 – CsI Calorimeter
2 – ACD supporting frame

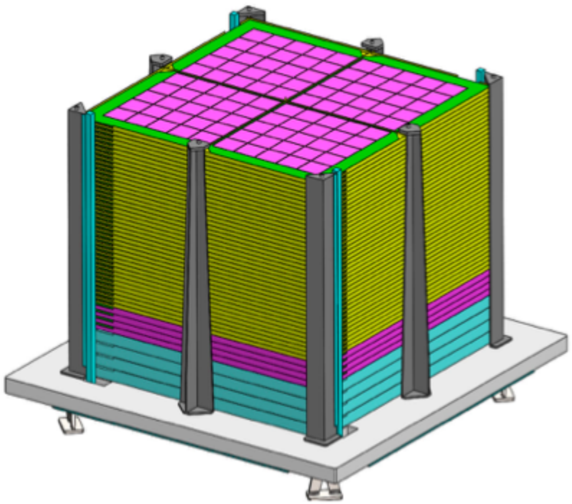
3 – Tracker – CsI mechanical Interface
4 – ComPair chassis

- **40-plane 0.8m x 0.8m double-side Si-strip tracker. 4 towers**
- **4-plane 3.2X thick log CsI calorimeter**
- **5-panel plastic scintillator ACD with WLS+SiPM strip readout**



ComPair Instrument Summary

Energy Range	1 - 200 MeV (200 keV - 500 MeV)
Effective Area	100 - 200 cm^2 < 10 MeV, 200 - 1200 cm^2 > 10 MeV
Angular Resolution	~7° at 10 MeV, ~1° at 100 MeV
Energy Resolution	2 - 5 % < 20 MeV, ~12 % at 100 MeV
Solid Angle	~3 sr
Dimensions	1 m x 1 m x 0.7 m (sensitive volume)
Mass	<1000 kg (science payload)
Power	<1000 w (science payload)



Instrument and System Design Studies have been completed: Viable MIDEX Mission.

From MIDEX to Probe

Motivation: perform comprehensive exploration of sub-MeV – hundreds MeV energy range, outperforming ComPair to include the unique capabilities in:

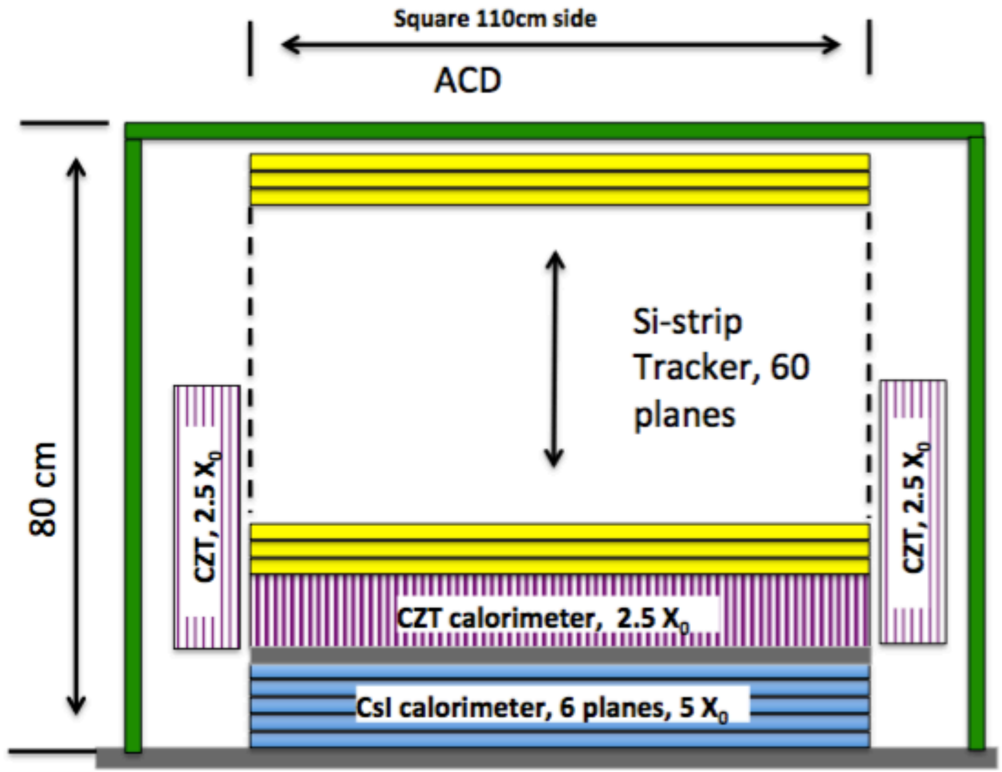
- **Search for and study of new sources and their localization and identification with high sensitivity, accuracy and confidence; perform dedicated study of Galactic Center morphology with better than 0.1 degree resolution**
- **Enabling nuclear astrophysics: study of nuclear gamma-ray lines with high energy resolution, map 511 keV gamma-ray emission from Galactic Center with high energy and angular resolution**
- **Conducting measurement of gamma-radiation polarization in energy range from a fraction of MeV to a few tens of MeV**

	ComPair	**AMEGO (Expected)**
Energy Range	1 - 200 MeV (200 keV - 500 MeV)	200 keV – 500 MeV (100 keV – >5 GeV)
Effective Area, cm^2	20-50 cm^2 < 10 MeV, ~500 cm^2 at 200 MeV	50-200 cm^2 < 1 MeV, 1,500 cm^2 at 500 MeV
Angular Resolution	~12^0 at 10 MeV, ~2^0 at 100 MeV	1^0 at 1 MeV, 10^0 at 10 MeV, 1^0 a 100 MeV
Energy resolution	5% at 1 MeV, 10-15% at 100 MeV	1% at < 1 MeV, 1-2% at 5 MeV, 10% at 500 MeV

AMEGO

- **Now we have a better idea about the cost. The first vision of AMEGO can be close to the original ComPair, but with more attention to the new science: nuclear line spectrometry and polarimetry**

- **We already realized that the use of GLAST and other flown instruments heritage is extremely helpful to go through the proposing procedure, so we suggest to follow the ComPair path to use well-developed technology**



ComPair

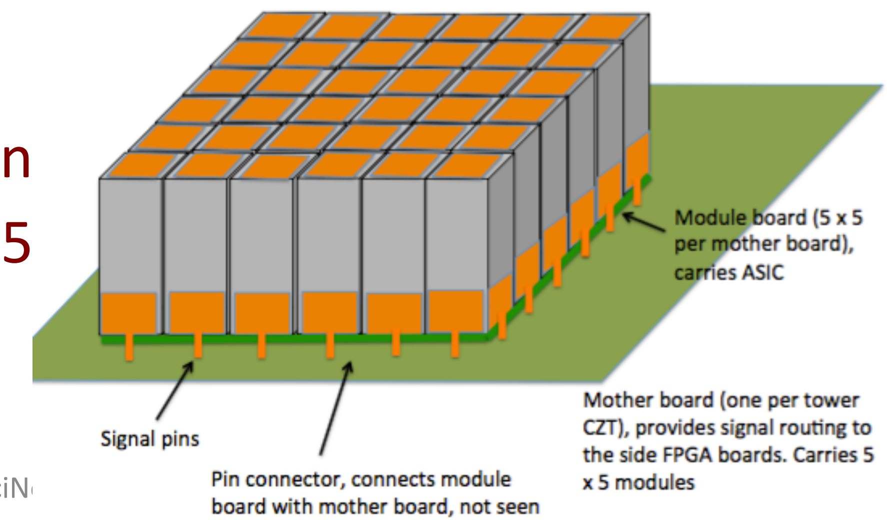
Tracker:

- 4 towers. Each is a stack of 60 double-sided (orthogonal X & Y) 0.5mm thick Si-strip detector planes, spaced by 1cm, strip pitch 0.25mm. No additional passive converter!
- Each plane of the tower is made of 5 x 5 double-side Si-strip detectors, 9.5 by 9.5 cm each, with daisy-chained strips in each direction and readout from the sides. Remark: 5 daisy-chained TBC. More would be better
- Analog signal readout from strips to provide energy measurement
- Segment design to be taken from ComPair development

CZT CALORIMETER

- Positioned under the bottom and at all 4 sides of the Tracker
- Drift-bar approach is used (Bolotnikov et al, Brookhaven NL)
- Segmented calorimeter. 1 segment is made of 6x6 CZT bars, 8x8 mm area (segment area 5cm x 5cm) and 4cm long, to create 4cm thick calorimeter (2.5 X_0)
- 100 segments are put together to make a 10x10 tower tray
- Expected energy resolution is <1% at 662 keV, 2-3% at 5 MeV
- Expected position resolution <0.5mm at <1 MeV, 2-3mm at 5 MeV

Single segment



Energy resolution for CZT drift bar detector

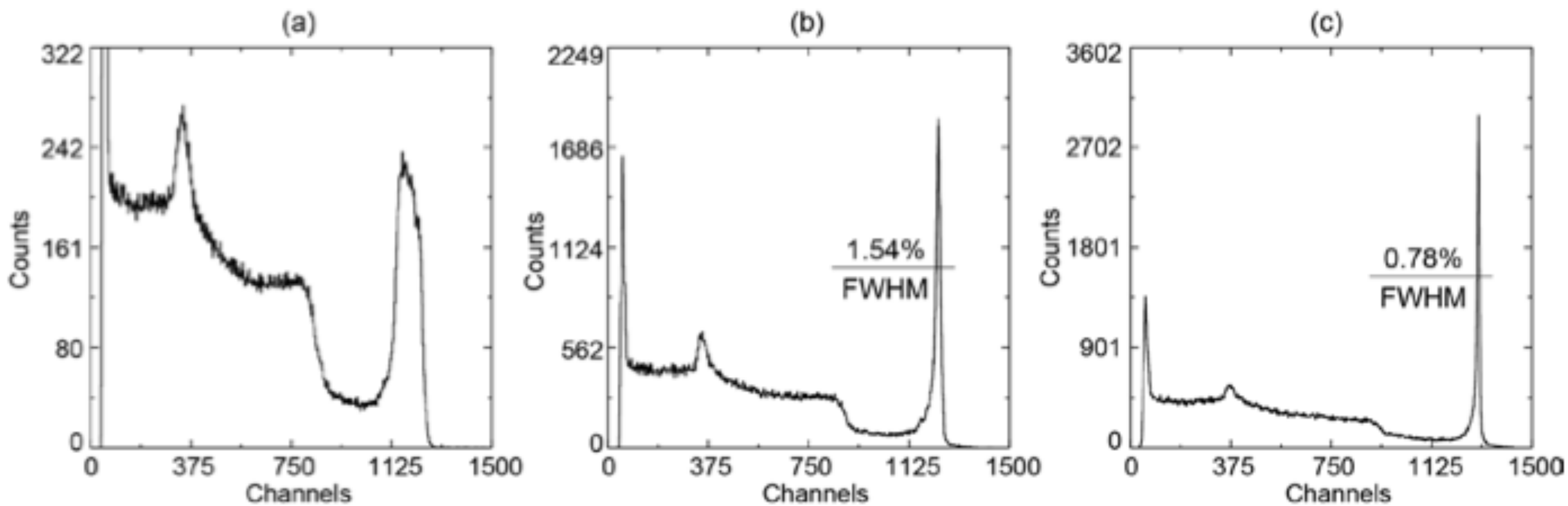


Fig. 2. Pulse-height spectra measured for a (7x7x25) mm^3 HP-EDG detector: (a) Raw spectra, (b) after correction for drift time (or interaction depth), and (c) after 3D correction.

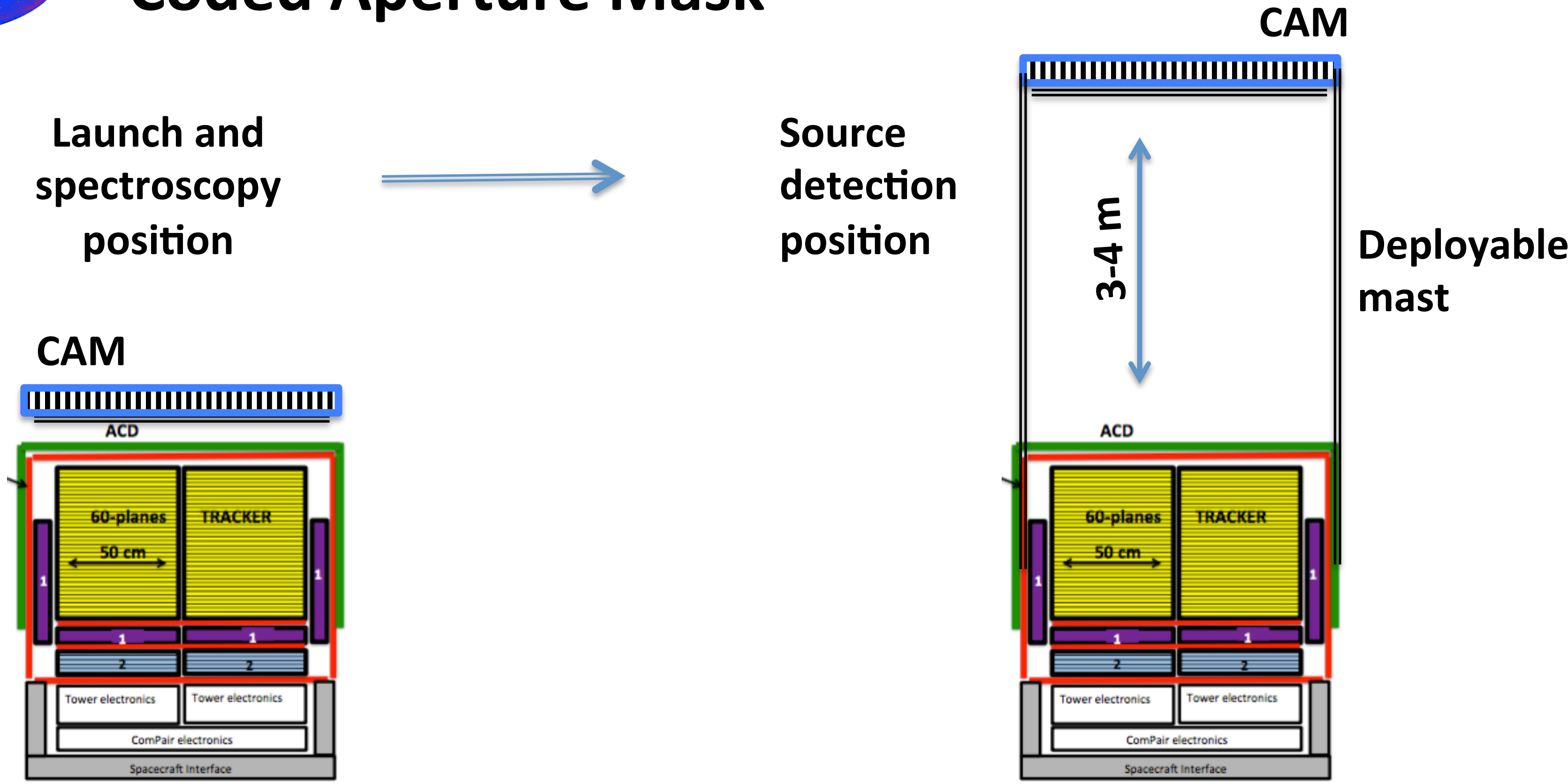
Courtesy of A. Bolotnikov

CsI CALORIMETER

- The CsI(Tl) calorimeter design is similar to that of Fermi-LAT and ComPair.
- Consists of 6 planes of 1.5cm x 1.5cm cross section 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 calorimeter is ~5 X_0

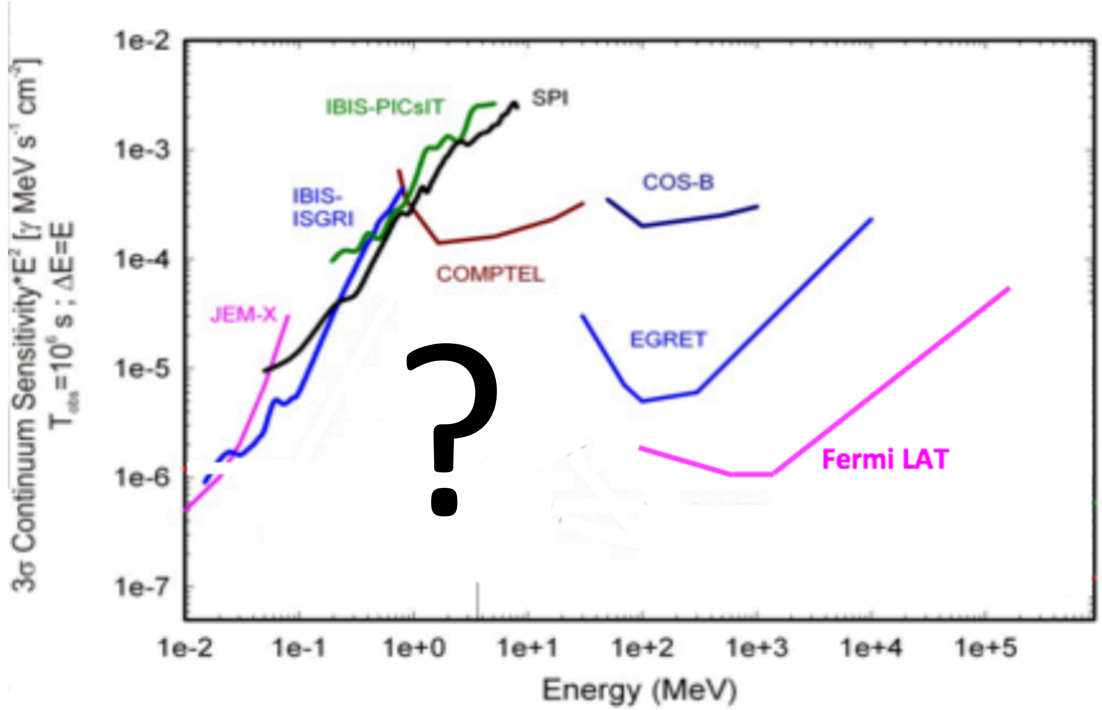
A bit of dreaming….. to happen

Coded Aperture Mask



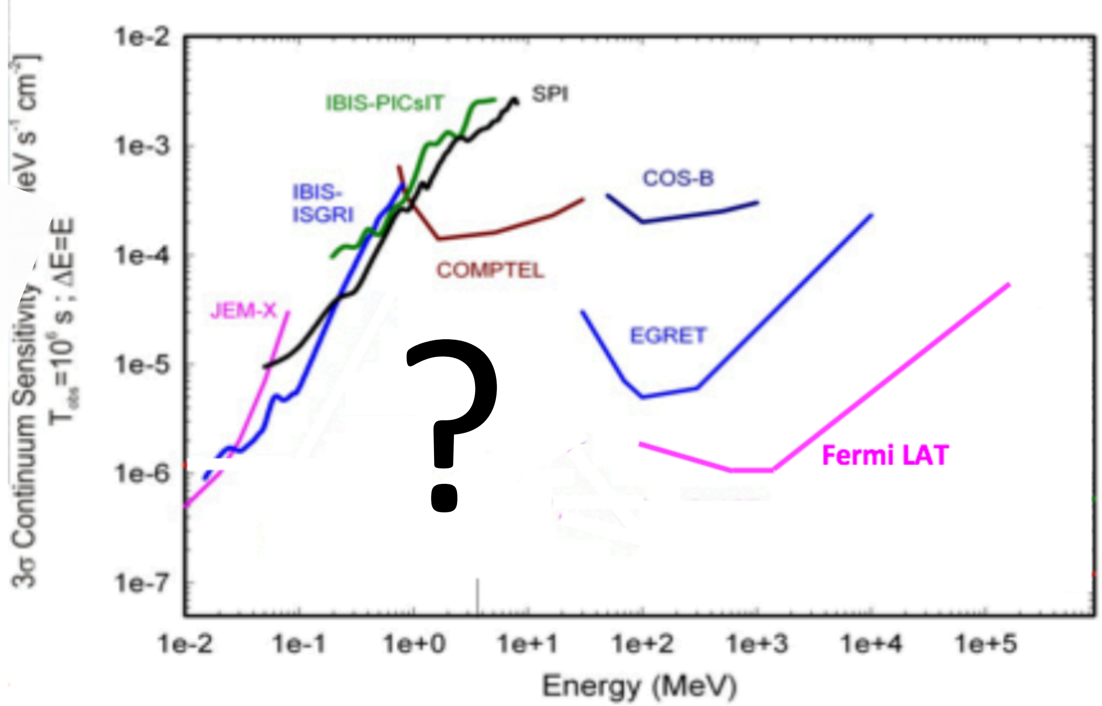
- CAM can be set at different distance from AMEGO
- Takes away small solid angle not to be in conflict with scanning observations – source localization with pointing mode
- If set close to AMEGO, works as a collimator for mapping
- Galactic Center observations with PSF < 1'

ComPair



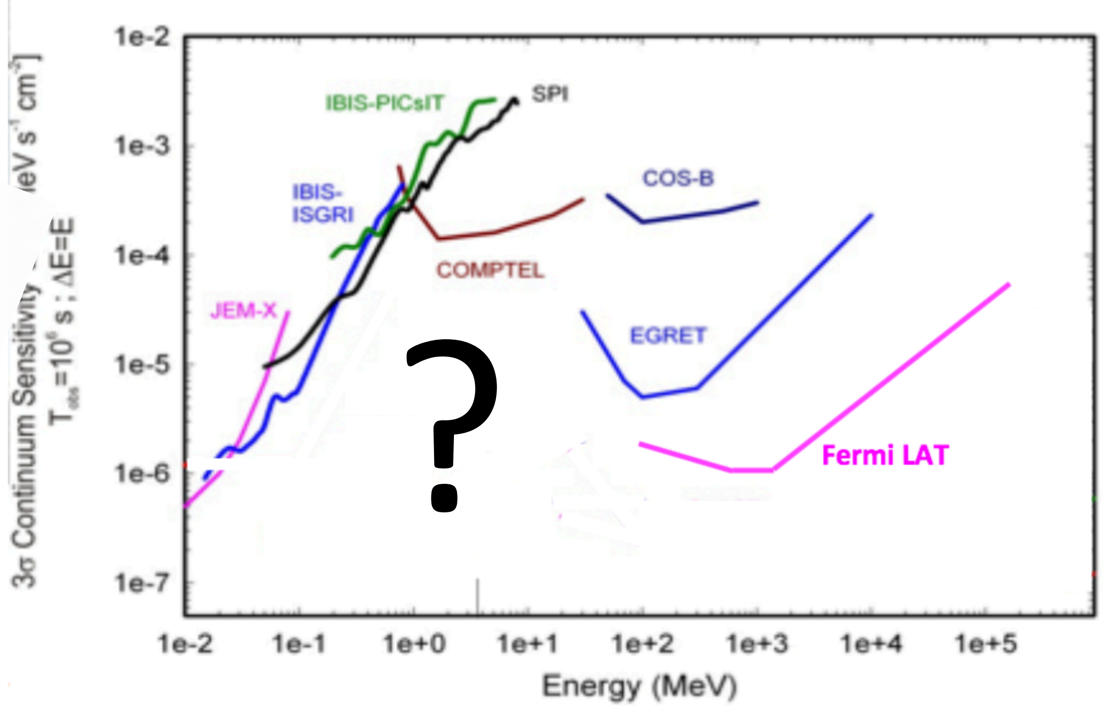
COMPTEL

ComPair



COMPTEL

ComPair

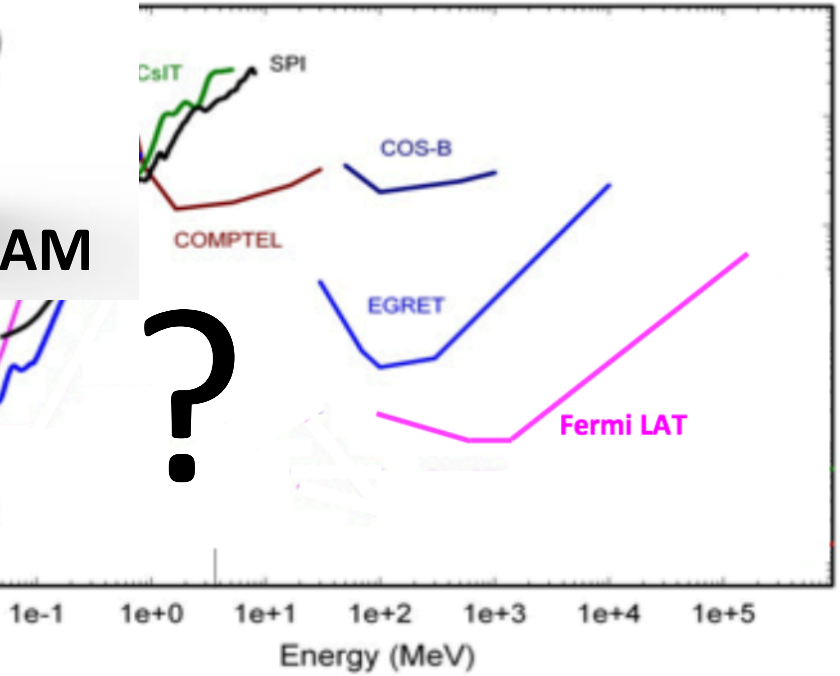


COMPTEL

AMEGO

ComPair

AMEGO- CAM



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COMPTEL

AMEGO