ComPair

A Wide-Aperture Discovery Mission for the MeV Band

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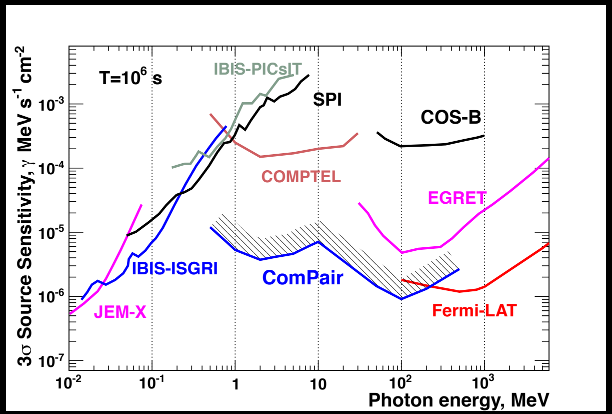
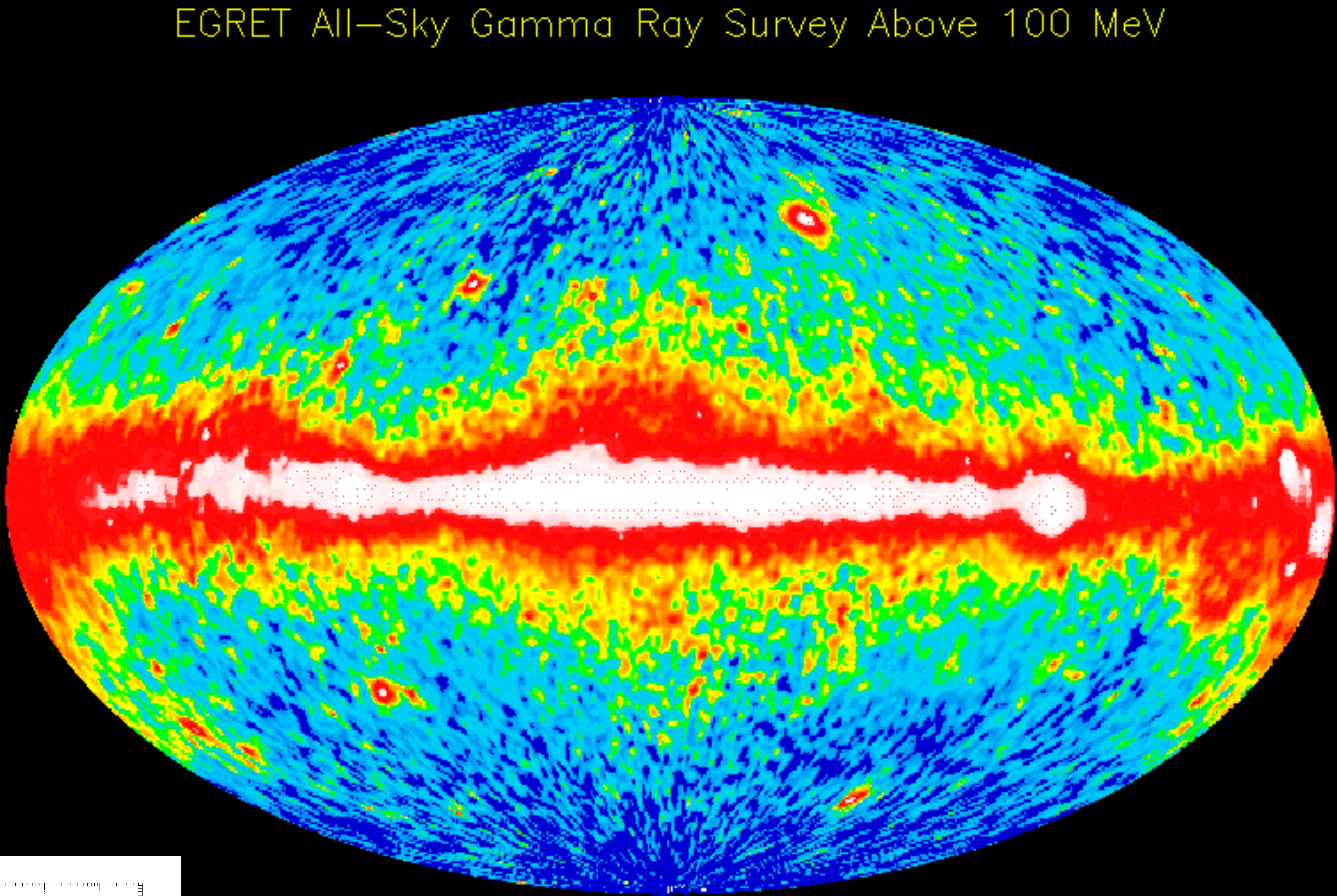
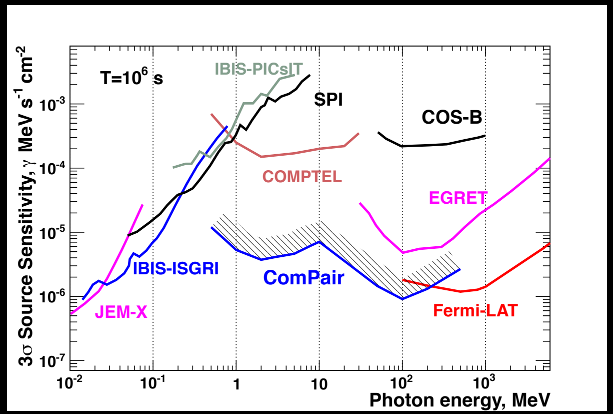
Macros 2016, Penn. State

Why do we want to look in the MeV range?

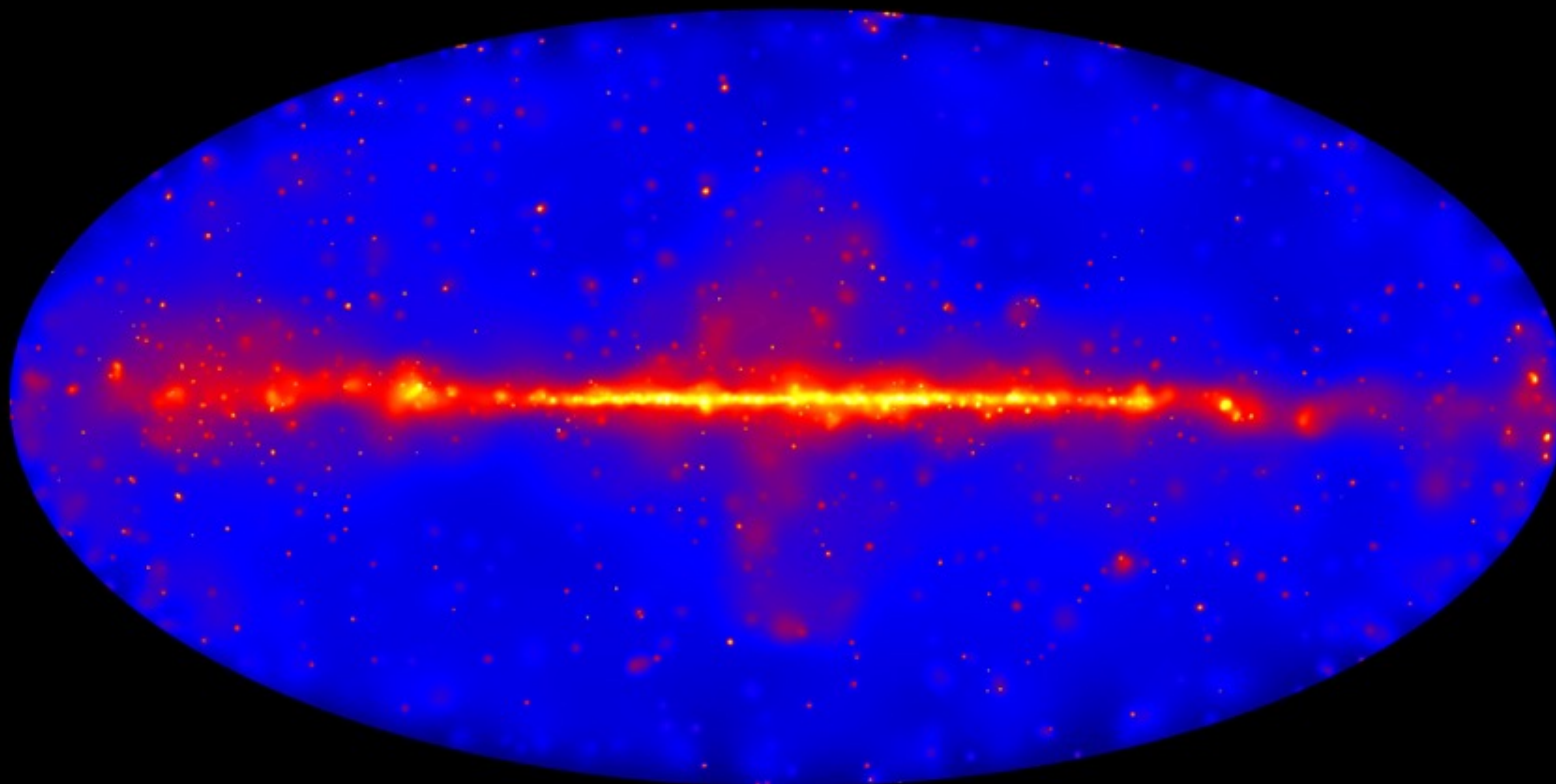


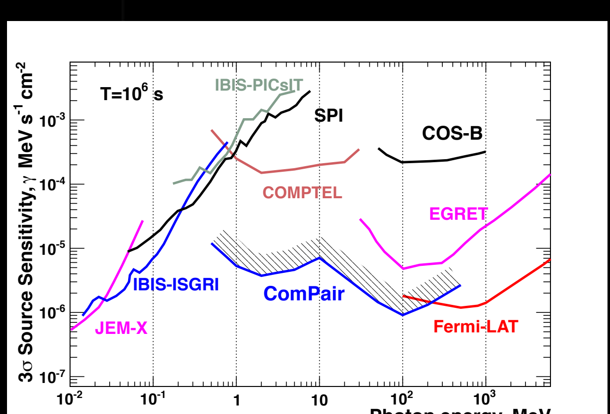




~200 Sources Detected

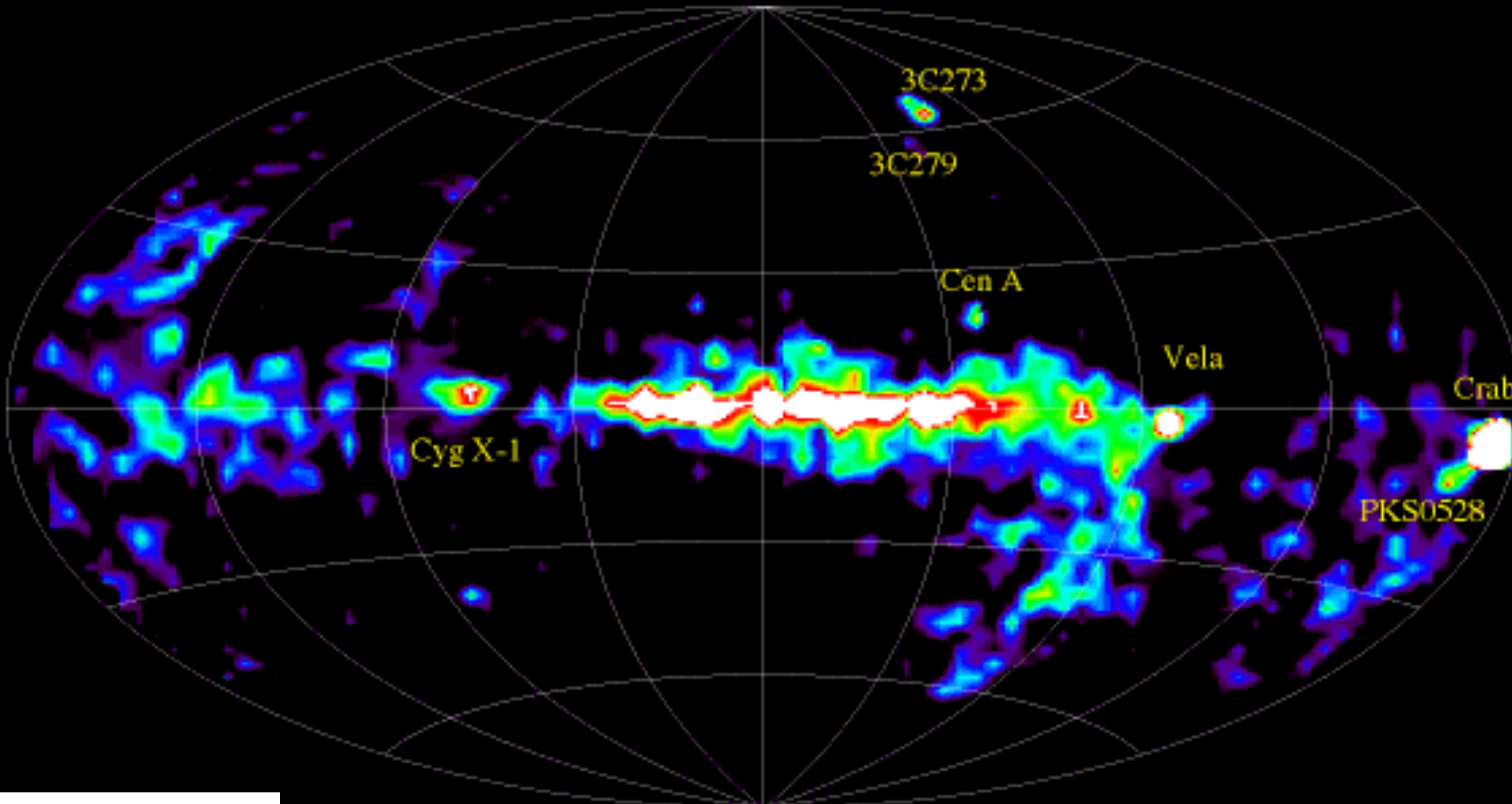
Fermi-LAT >1GeV Sky Map

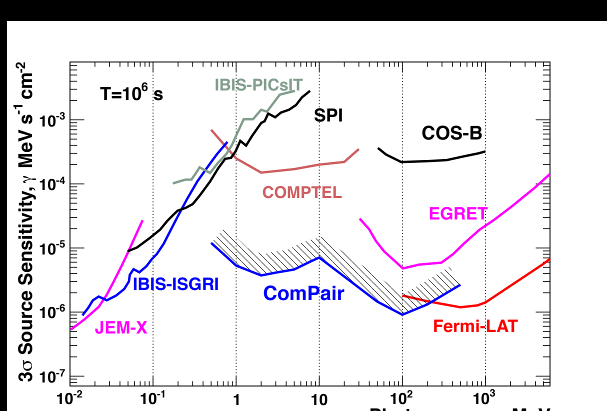




>3000 Sources Detected

COMPTEL All-sky Map

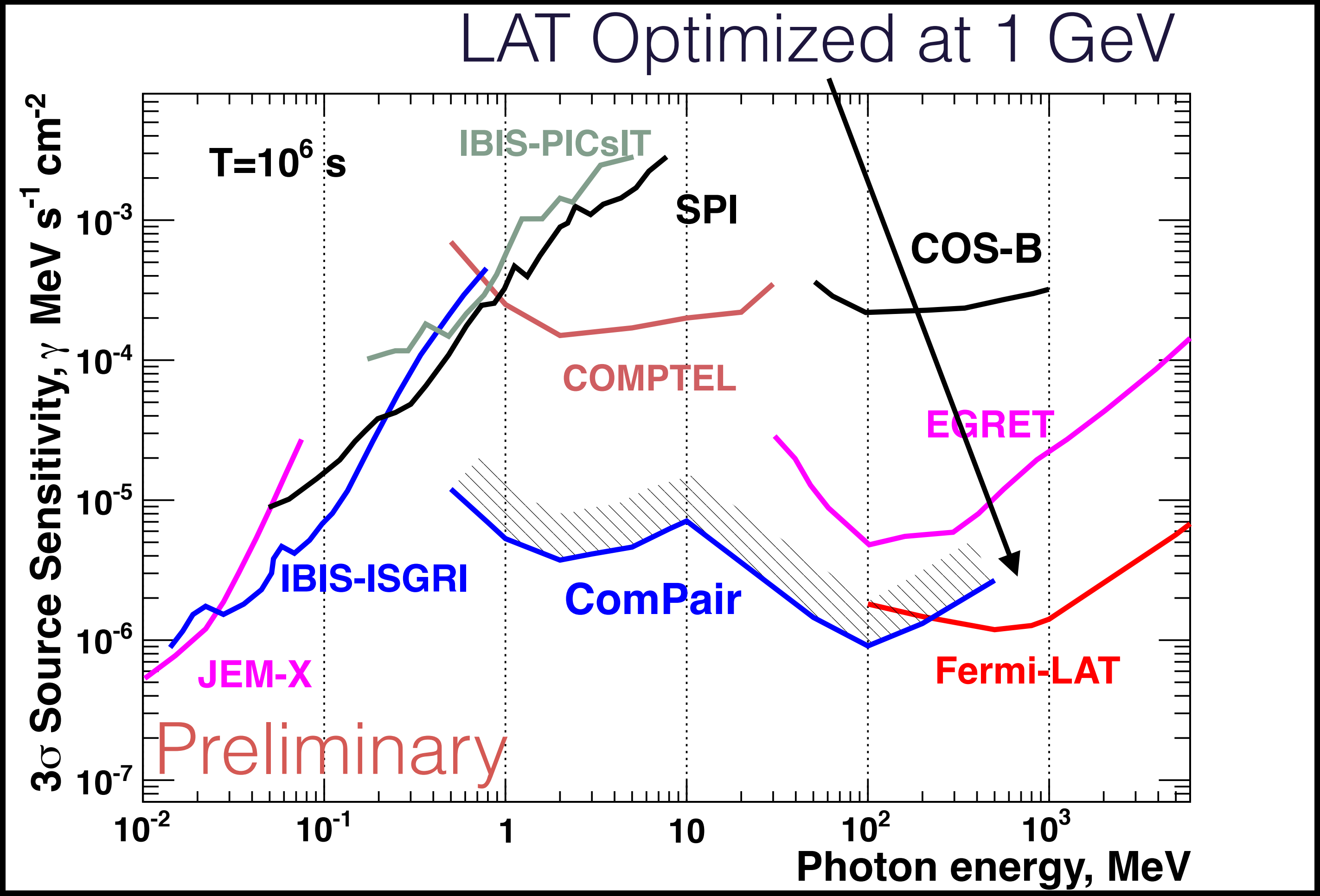




Tens of Sources Detected

Science Driver: Guaranteed Discovery Space

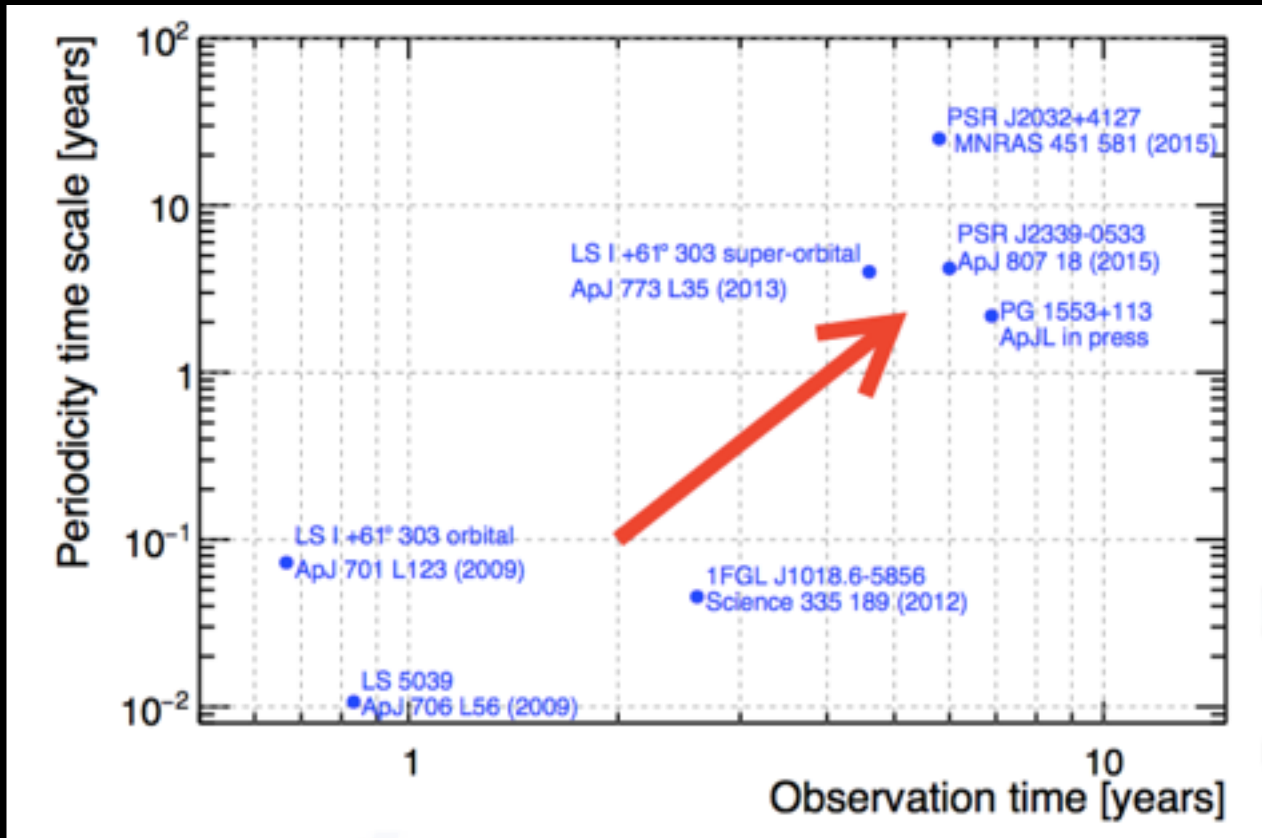
- We have not looked deep into the MeV range: here be dragons.
- Discovery space
- Key piece to the high-energy view of the Universe



Continuum Sensitivity for instruments in/near the MeV Band

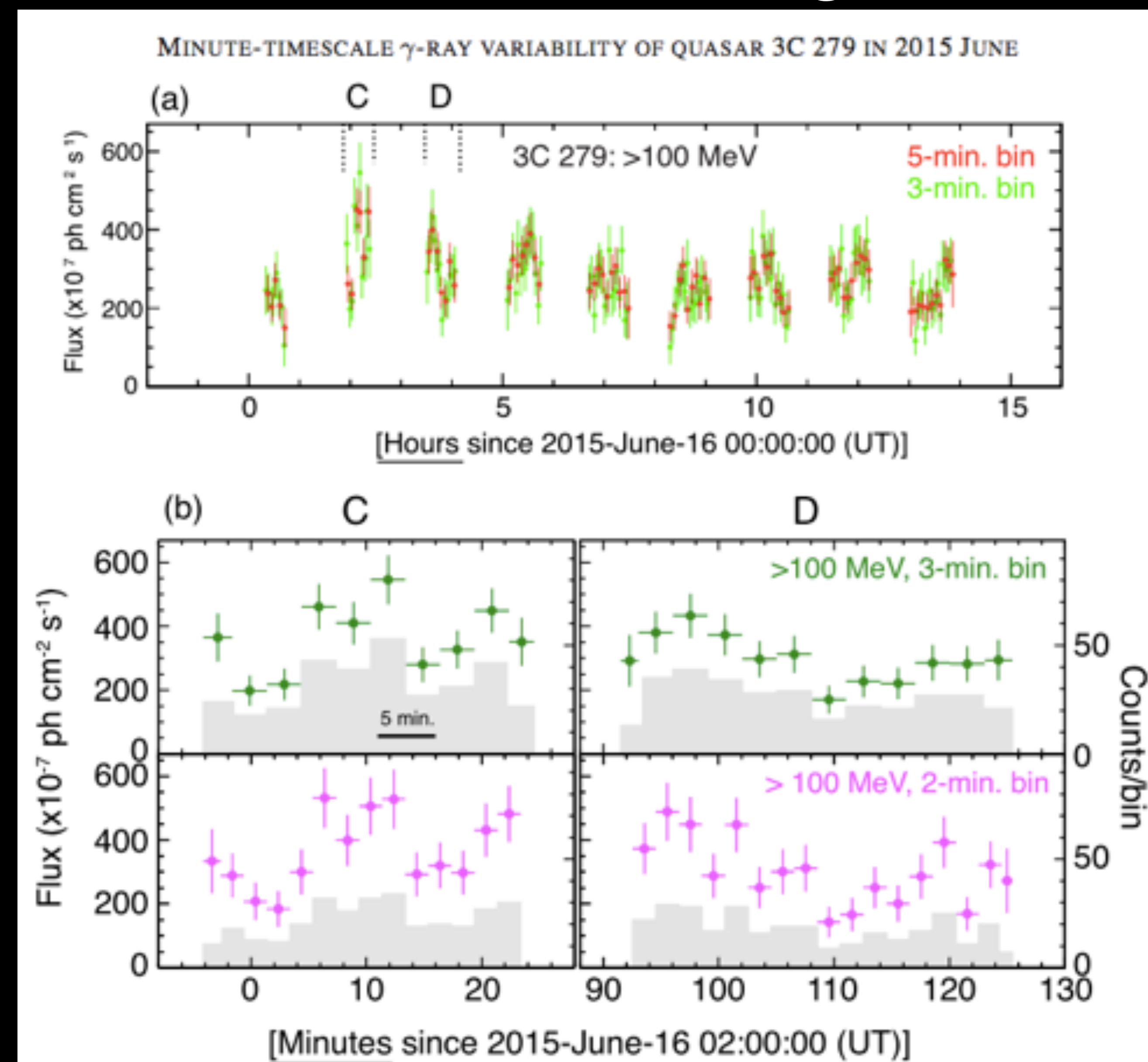
Science Objectives: Extreme Astrophysics

- 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*, NuSTAR, and Swift BAT have uncovered source classes with peak energy output int he poorly explored MeV band
    - ComPair science objectives focus on cases of extreme astrophysics
        - High matter densities
        - Strong magnetic fields
        - Powerful Jets
- Spectral features occurring in this energy range - breaks, turnovers, and cutoffs - and their temporal behavior are crucial to discriminate between competing physical models.



Need for long time baselines is clear.

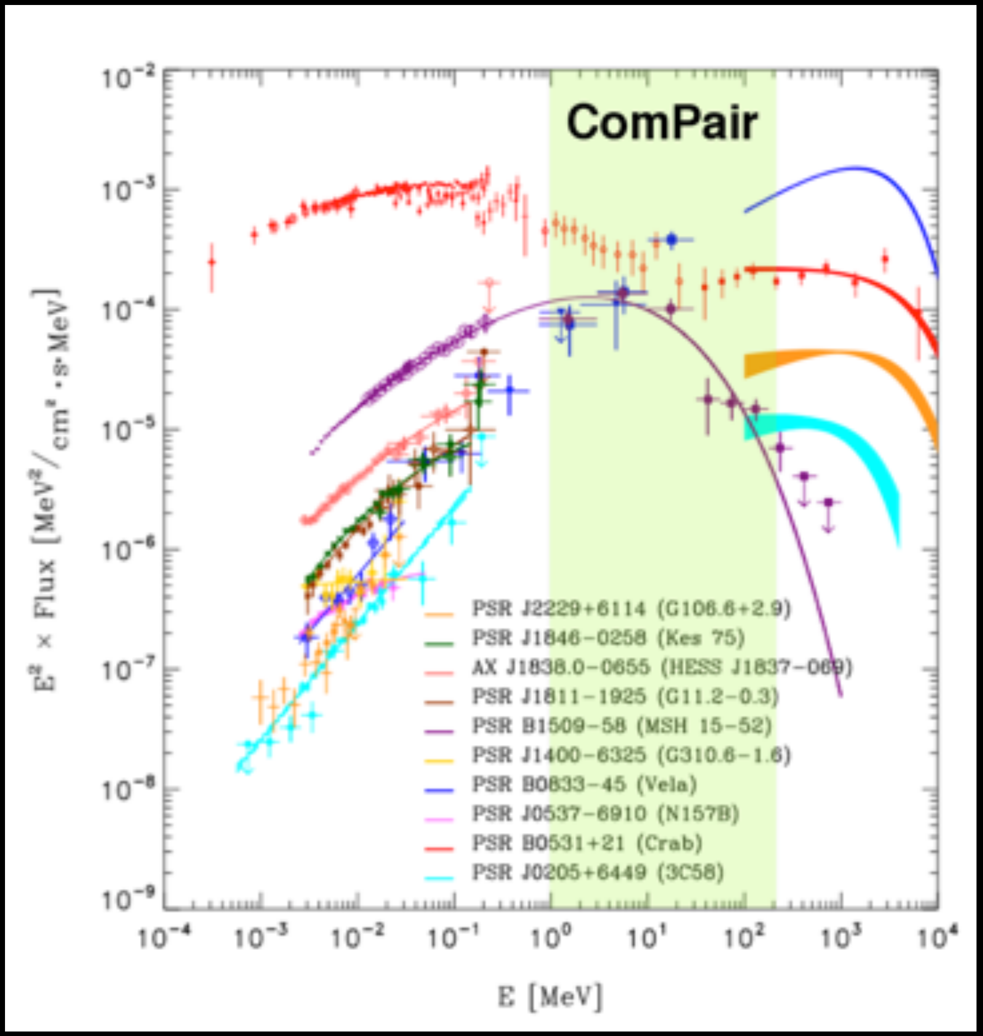
Need for all-sky monitoring is clear.

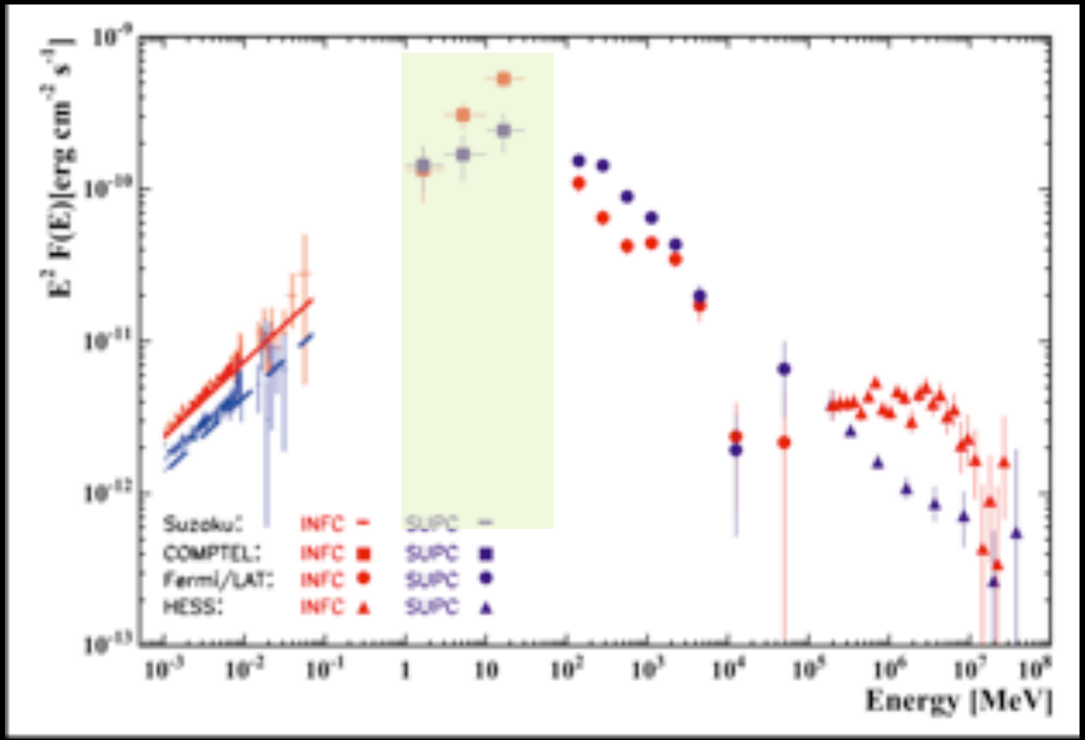


Science Objectives: Extreme Physics of Compact Objects

- Compact objects with key energy features in the MeV range include
  - **Magnetars** - strongest magnetic fields in the Universe
  - **Pulsars** - neutron stars represent the highest matter densities possible before collapse to a black hole

Selected pulsars
(N.B. ~170 gamma-ray puslars known)



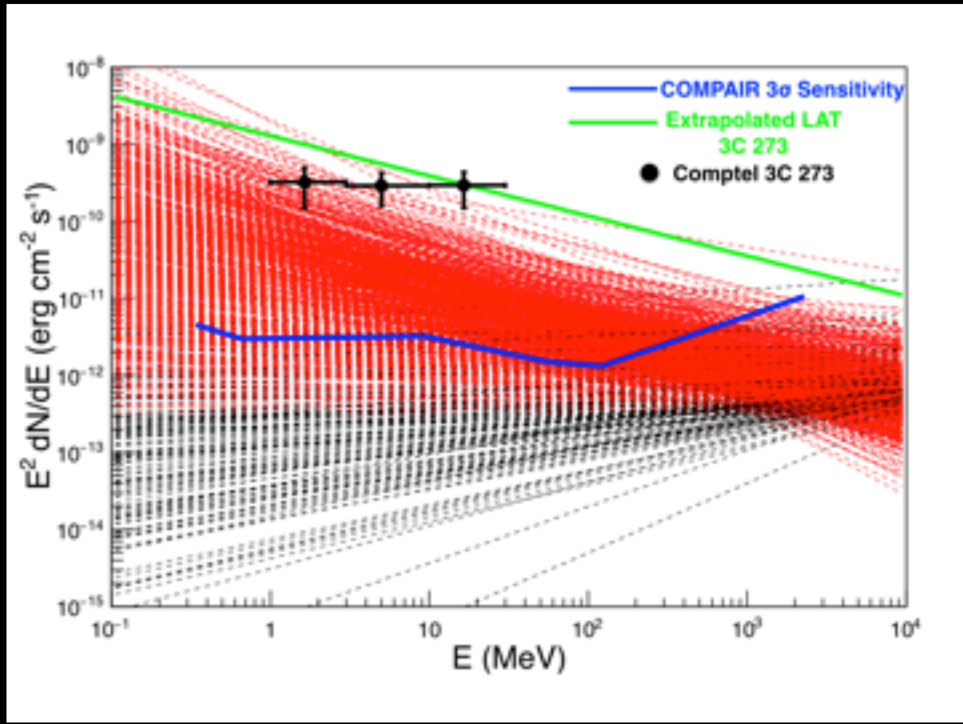


High mass x-ray binary LS 5039 at inferior and superior conjunction.

Science Objectives: Discovery Space

- Instruments covering the 1-100 MeV range have been limited in sensitivity, e.g. COMPTEL/OSSE on CGRO, Integral SPI
    - N.B. Fermi-GBM occultation studies are primarily < 1 MeV
- About 1/3 of Fermi-LAT sources remain unidentified.
- ComPair will provide the missing view between high-energy gamma-ray and X-ray regimes, helping to identify and study those objects.

More than 1/3 of Fermi-LAT catalog sources peak below the Fermi-LAT band.

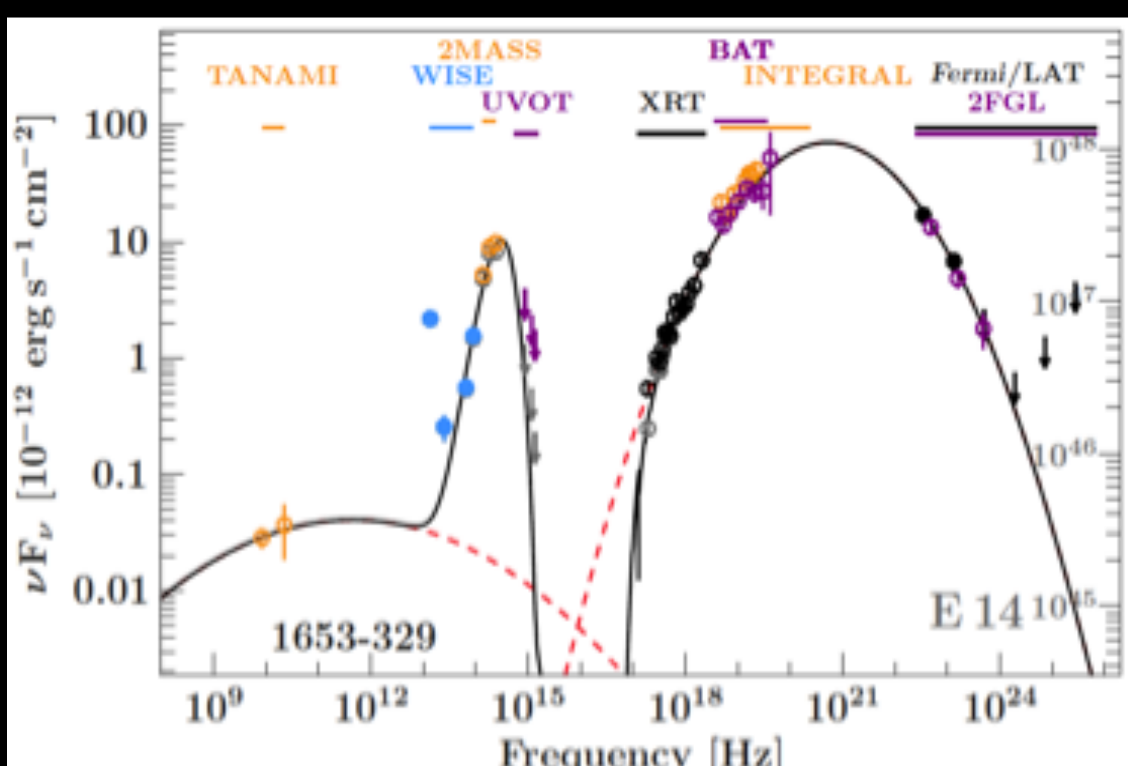


Below 200 MeV ComPair will dramatically improve sensitivity and will open a new window in the spectrum leading to the discovery of new sources and new source classes.

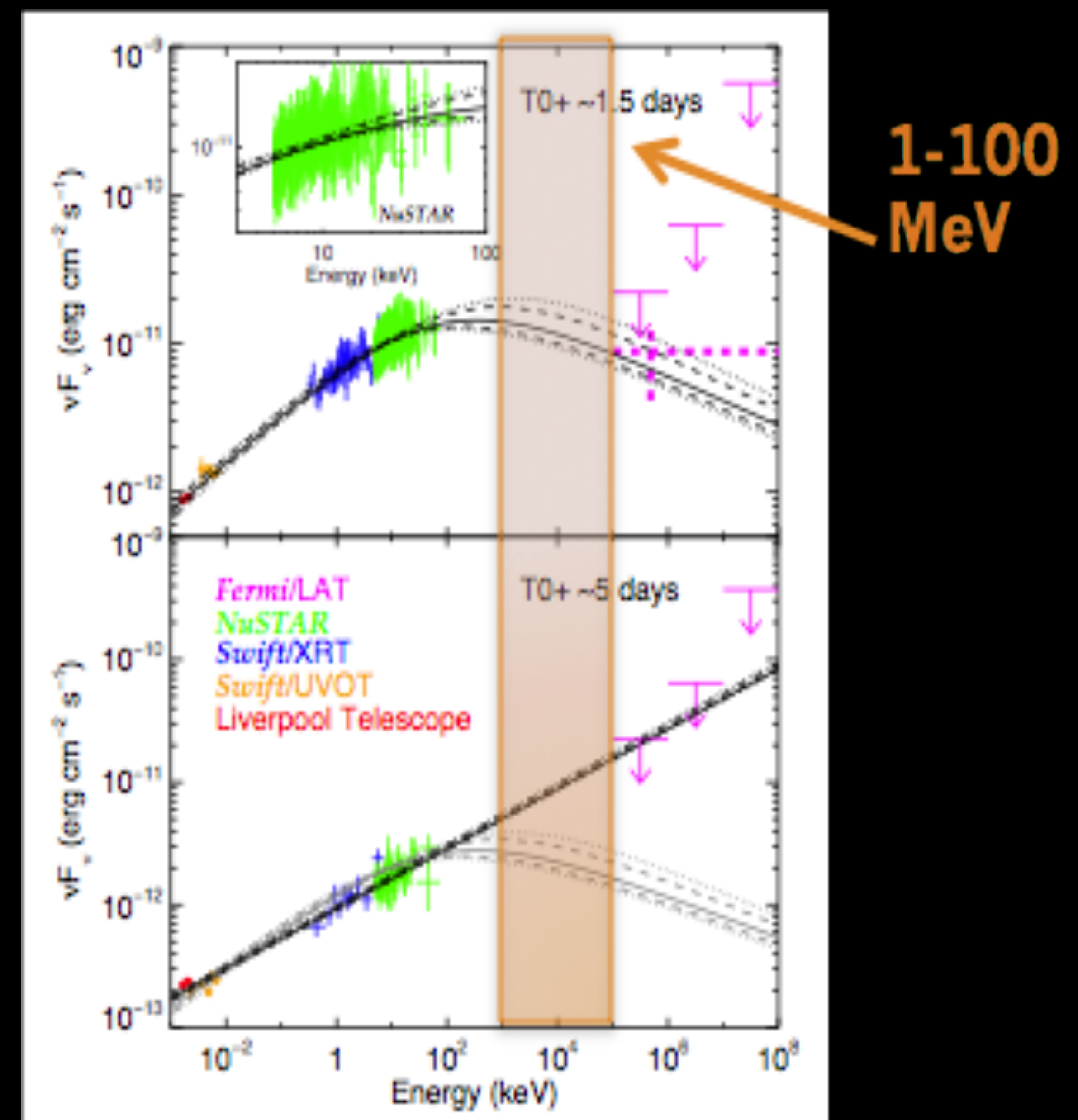
Science Objectives: Ubiquity of Jets

- Jets are powerful accelerators, but we do not yet understand their emission mechanisms
- Measurement of SEDs at interesting times with sufficient sensitivity is vital for physical models of their radiation processes

GRB 130427A



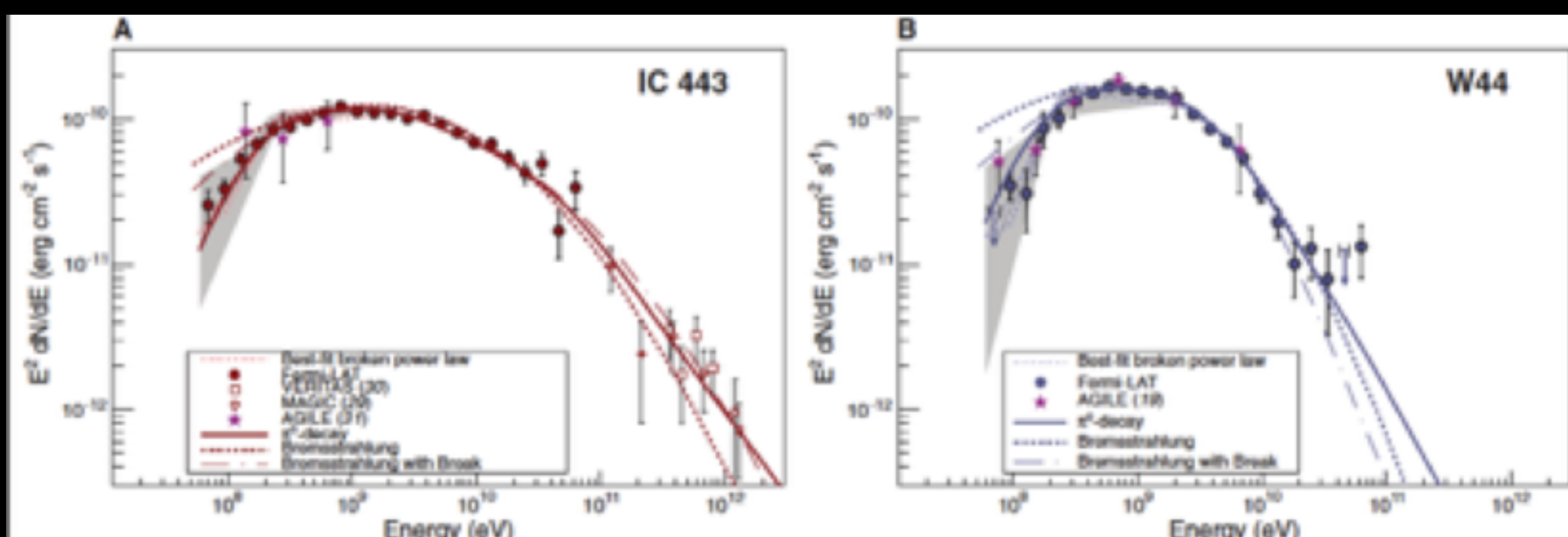
J1653-329, a candidate PeV neutrino emitter
Krauss et al. 2014



Kouveliotou et al. 2013

Examples of additional science with continuum instruments

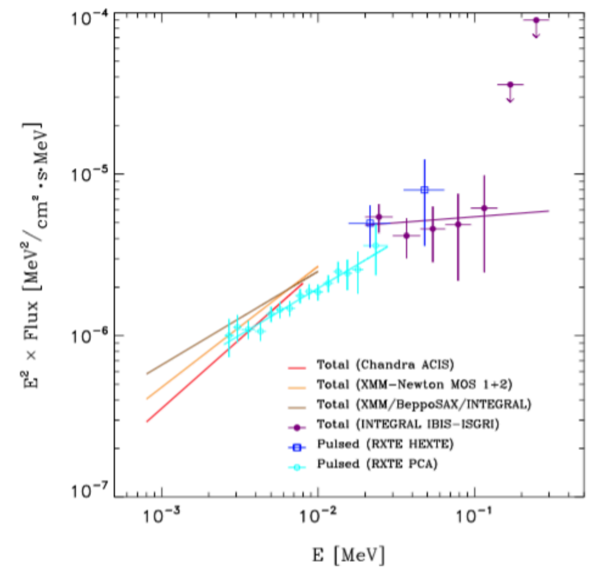
- Galactic Accelerators - Fermi has measured the pion bump in 2 SNRs and detected dozens
    - Detecting pion bump in all GeV SNR key to understanding particle acceleration in the Galaxy
- Dark Matter - new ideas on WIMP dark matter annihilation (dark photon mediators) lead to predictions of continuum gamma-ray signals in the 10-50 MeV band



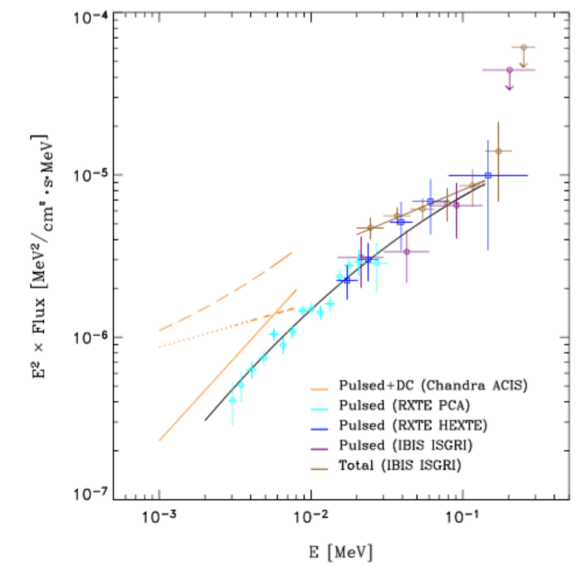
Pulsars in ComPair

- Soft gamma-ray pulsars peak in the MeV band, e.g. PSR B1509-58, PSR J1617-5055… (e.g., review by Kuiper & Hermsen 2015, MNRAS)
- Sub-100 MeV spectral components
  - For example, pair synchrotron component in energetic MSPs such as PSR B1937+21 and PSR B1821-24 (Harding and Kalapatharakos 2015)

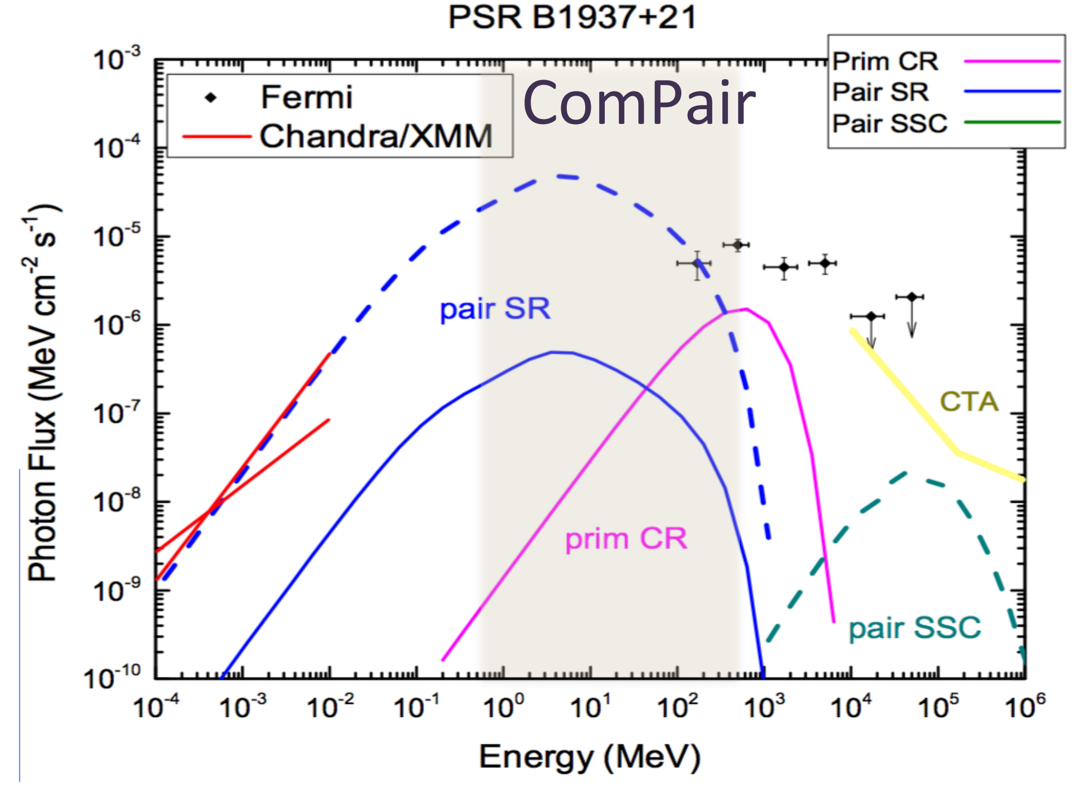
PSR J1617-5055



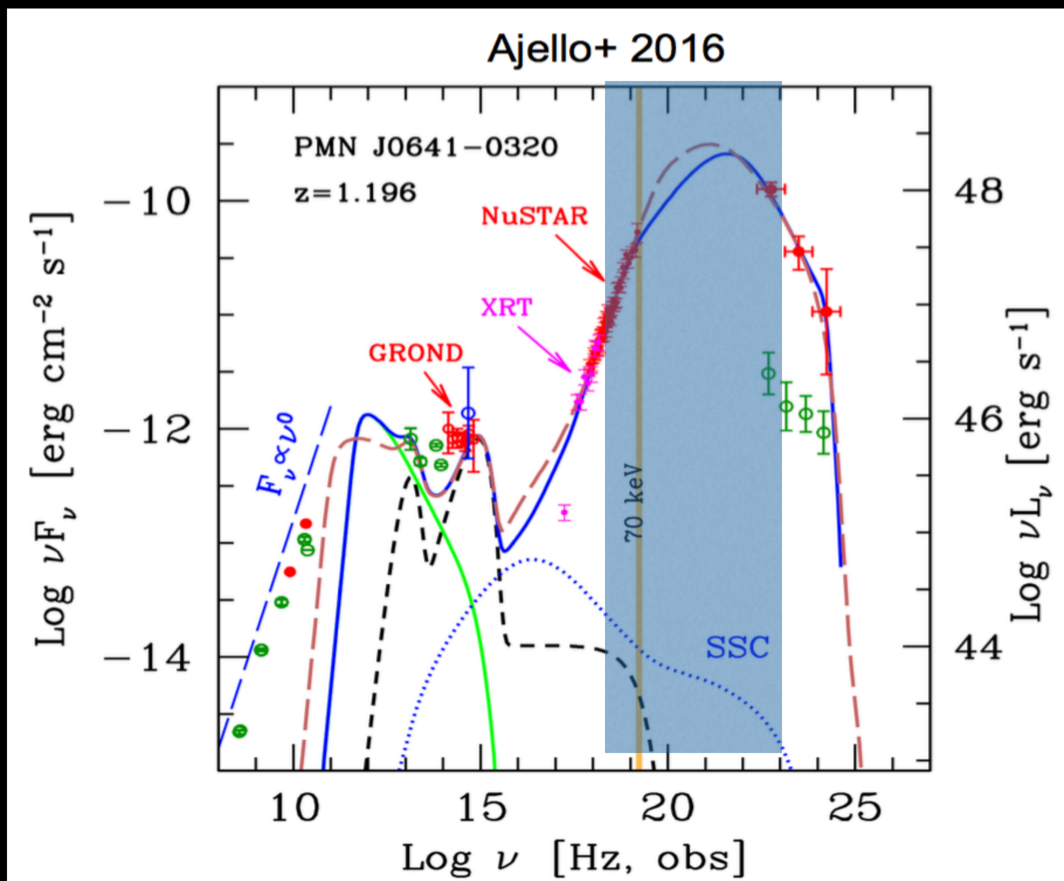
PSR J1811-1925



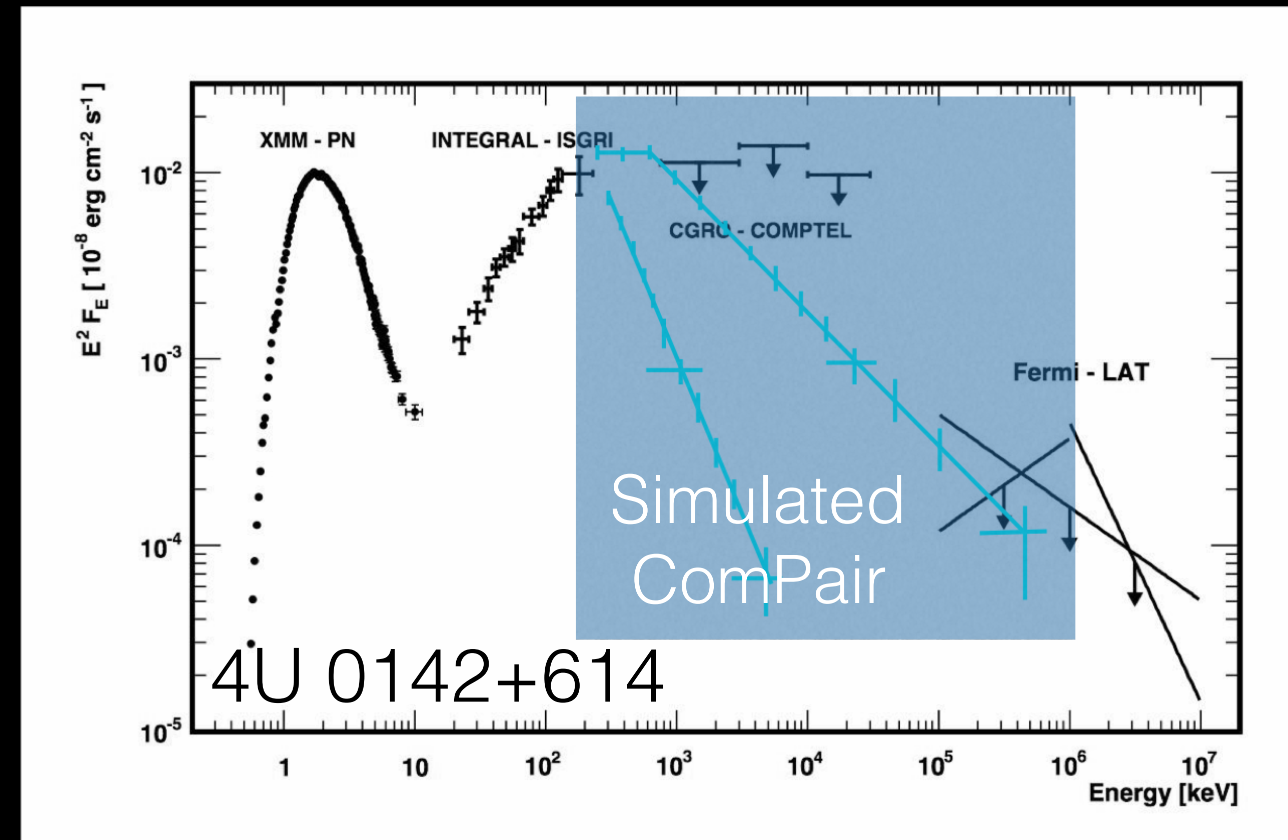
PSR B1937+21



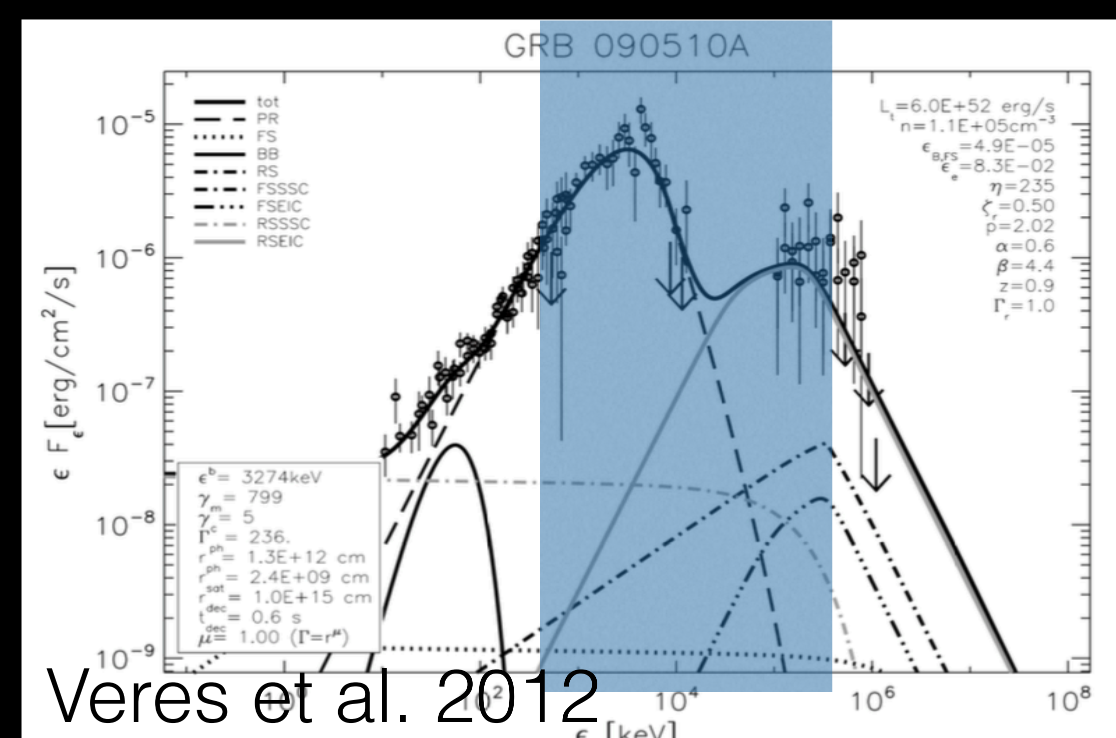
Extremely massive black holes at z>3



Probe sites of strong magnetic fields



Measure peak power and multiple emission components of relativistic jets.



Many more examples of the need for an MeV survey.

Science Requirements

Goal	Energy Range	Spatial Resolution	Time Resolution	Sensitivity	FoV
Jets	~ 0.5-100 MeV	~ 1 deg	< msec	10^{-10} erg/cm2/s	Large
Compact Objects	~ 0.1-100 MeV	~ 1 deg	< msec	10^{-10} erg/cm2/s	Large
New Sources	~ 1-100 MeV	~ 1 deg	< msec	10^{-10} erg/cm2/s	Large

Hence, we focus on a large field-of-view instrument with good angular and energy resolution, optimized for continuum sensitivity and time domain science.

- Not really a new idea. Which is a good thing…

Focus on Continuum Flux Sensitivity

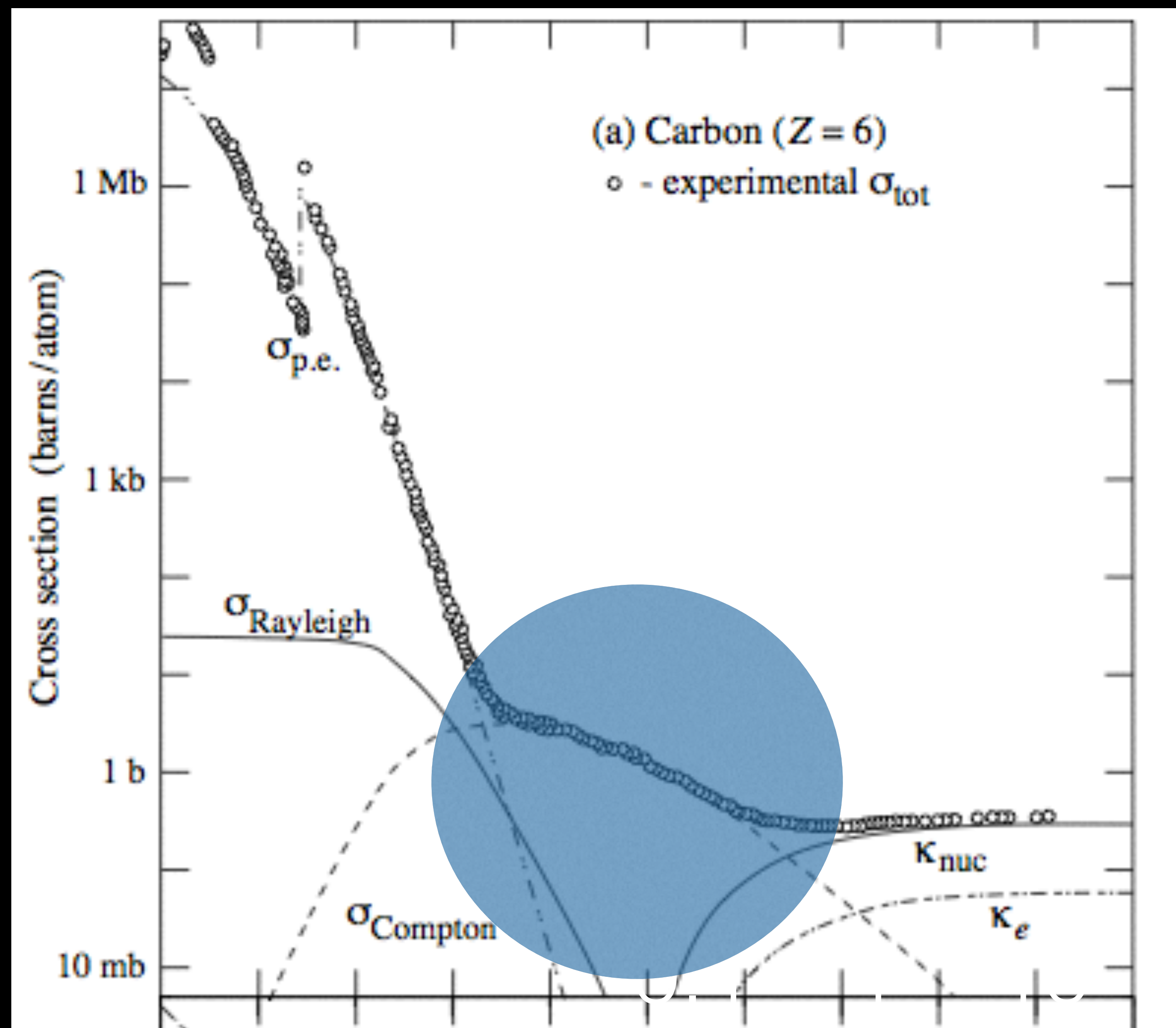
- ComPair is a new instrument in name but not in heritage. Concept is built on on mature technology and extensive prior instrument development and optimization
  - Maximal use of Fermi LAT hardware heritage and lessons learned
  - Modification of a mature, well studied mission concept (MEGA)
  - Most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

Goals

- Wide-field - monitor the whole gamma-ray sky
- Energy range 200 keV –> 500 MeV
- Sensitivity ~10-50 times better than COMPTEL at ~ 1 MeV
- Angular resolution 3-5 times better than Fermi LAT at 20-100 MeV

What are the challenges?

Challenges for MeV Energy Regime

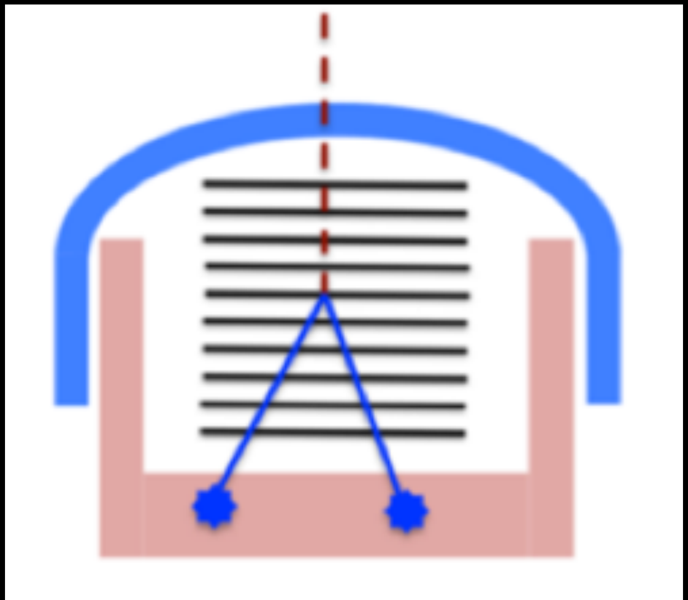


MeV

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

How are we going to do this?

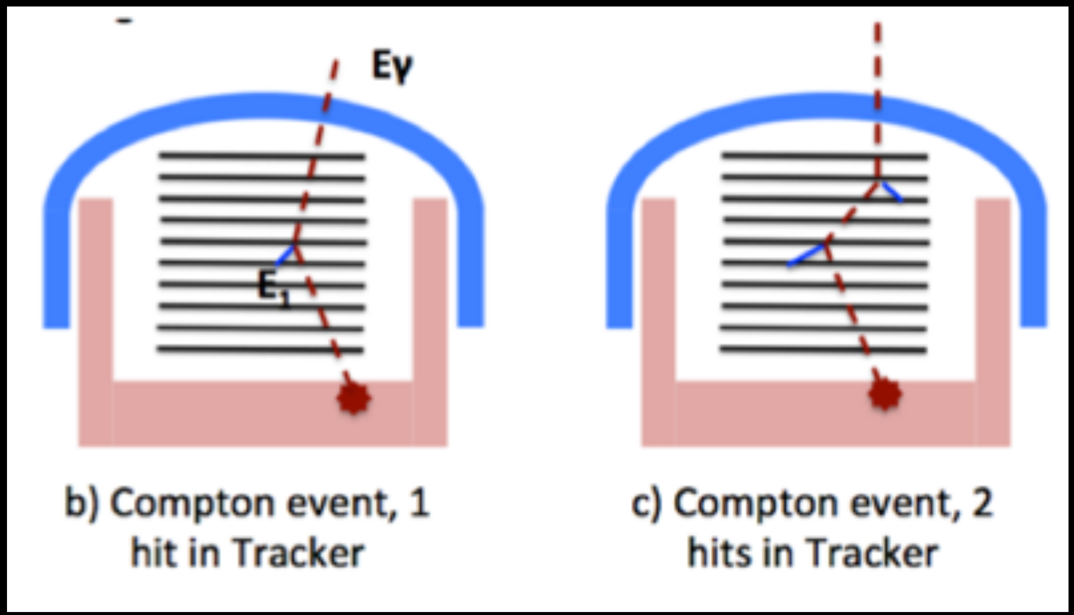
Detection of Pair-production Events



Photon converts to pair (e-/e+) in multi-layer Si-strip tracker (no additional conversion material).

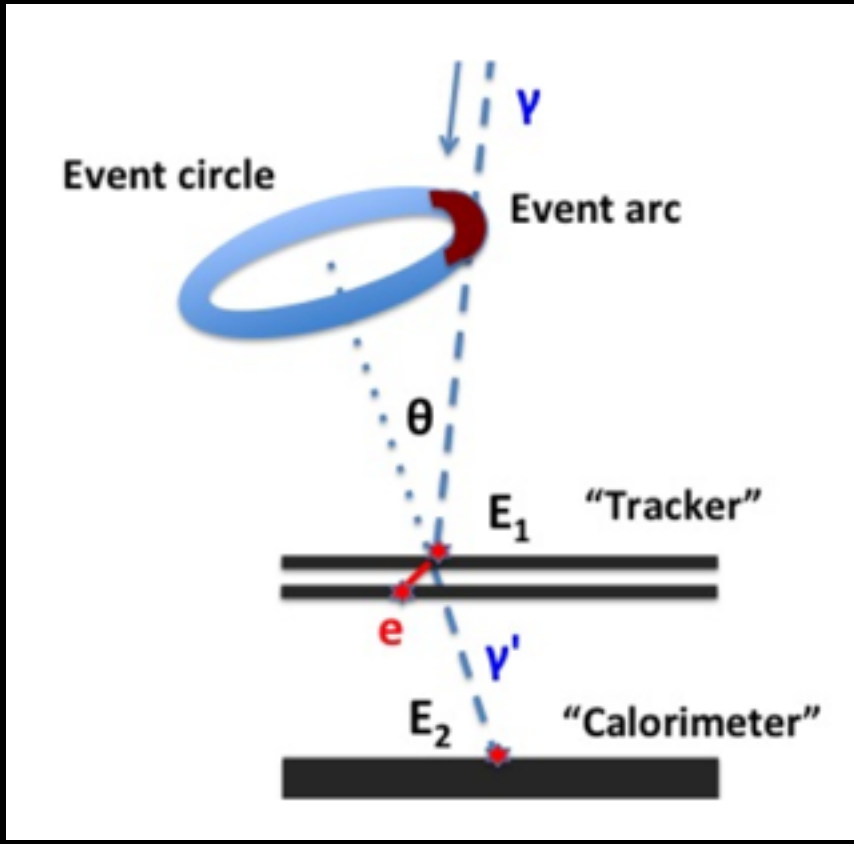
- **Trigger** on signals in 2 consecutive Si-strip layers in coincidence with energy deposit in the calorimeter
- **Photon direction** is determined by measuring the position of the pair components as they pass through the Si-strip layers and calorimeter.
- **Photon energy** is determined by evaluating energy deposited in the Si-strips and in the calorimeter.

Detection of Compton-scattered events

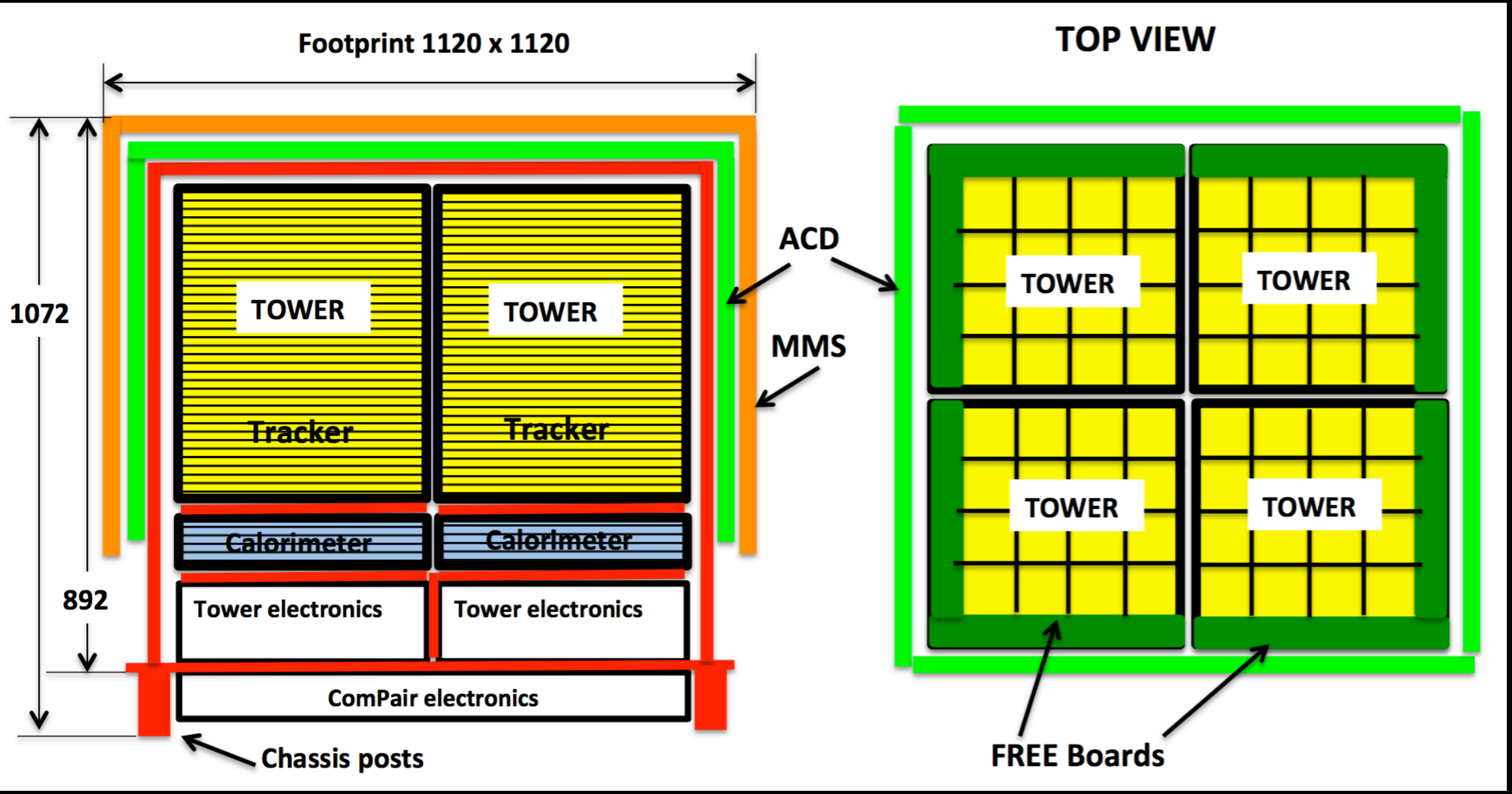


Photon scatters in Si-strip detector, creating low-energy electron. Scattered photon can be absorbed in the calorimeter.

- **Trigger** on signal in Si-strip detector in coincidence with energy deposit in the calorimeter.
- **Photon direction**, constrained to a circle or arc on the sky, is determined by position and energy measurements of electron and absorbed photon.
- **Photon energy** is determined by evaluating energy deposited in the Si-strips and in the calorimeter.
- Measurement of additional scattering enhances reconstruction and background rejection, but occurs less frequently.



Instrument Layout



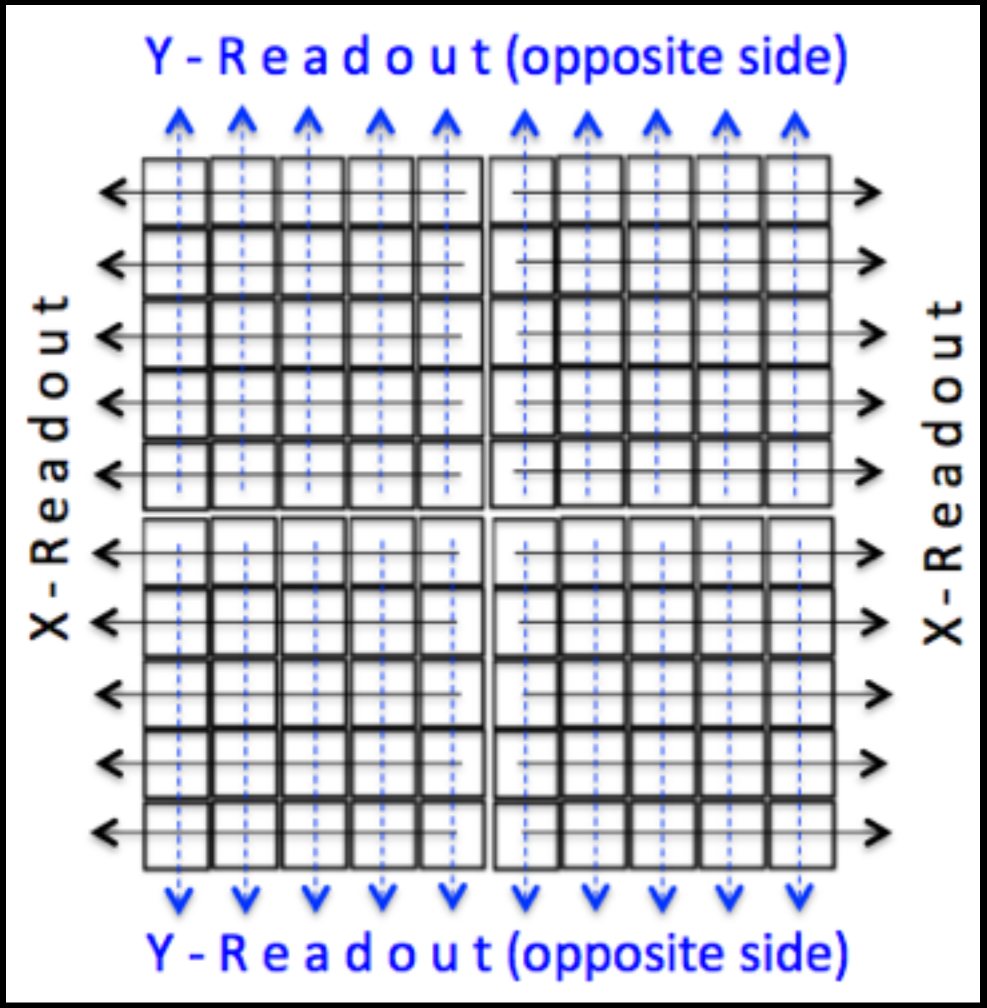
- Key differences from LAT for low-energy pair performance and Compton event detection
  - Remove Tungsten layers in the tracker
  - Use double-sided Silicon strip detectors in the tracker
  - Improve spatial resolution in the CsI calorimeter

ComPair Tracker

Provides incident photon interaction position (Compton or pair production) and tracking for secondary charged particles

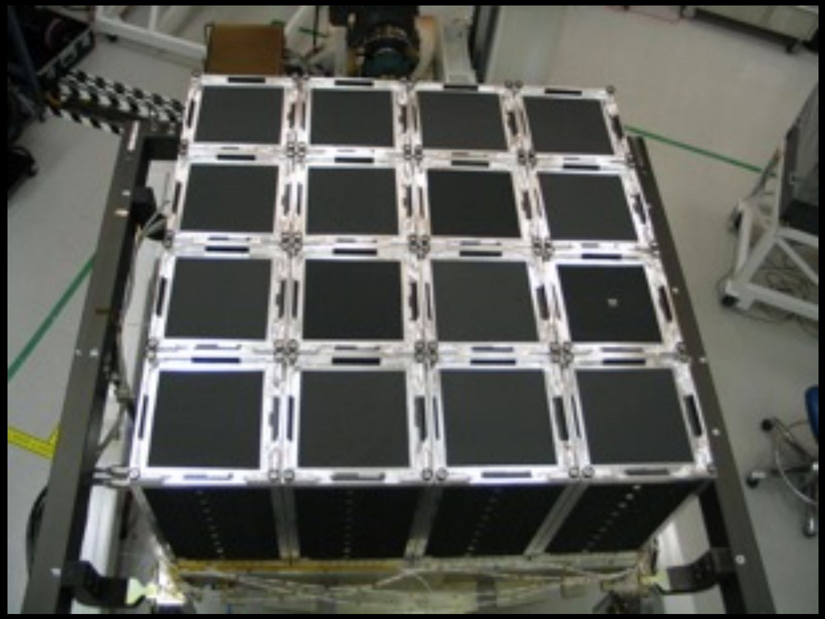
- Stack of 40 double-sided Si-strip planes
  - 1 cm spacing
  - Analog readout from each strip
- Each plane divided into 4 sections
  - 4 x 4 daisy-chained array of 9.5 cm x 9.5 cm DSSD with thickness of 0.5 mm and strip pitch of 0.5 mm
  - X- and Y-strips on opposite sides of DSSD
- Number of FEE channels: 3 x 10^5

Tracker Layer
Top View



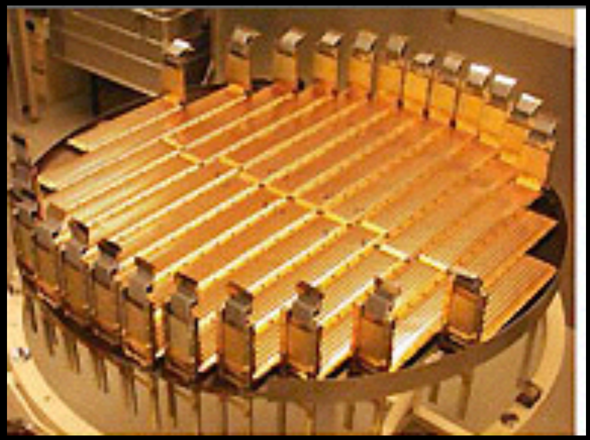
Heritage

- Si-strip detectors are widely used in particle physics. Practically all complex detectors on accelerators use Si-strip detectors: CERN, FermiLab, SLAC, etc.
- Extensive space flight heritage: Fermi-LAT, AGILE, PAMELA, AMS
- Options available for electronic components with space flight certification: IdEAS, products used in Swift, CREAM, AMS, PAMELA, Astro-H, etc.
- Scale of the detector: 50 m2 of double-sided Si (Fermi-LAT has ~80 m2 of single-sided Si)
- ComPair team includes UCSC, Si-tracker subsystem lead for Fermi-LAT



Fermi LAT

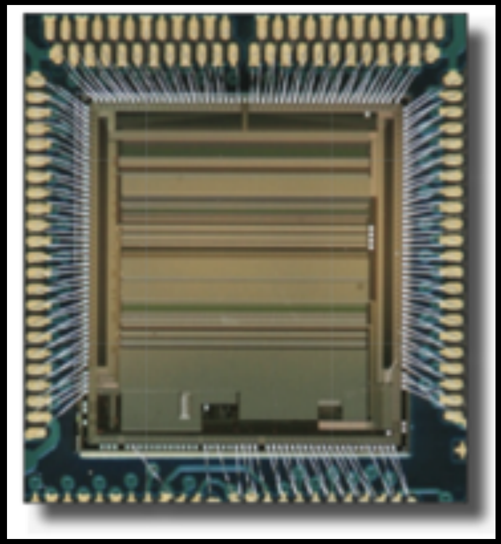
PAMELA



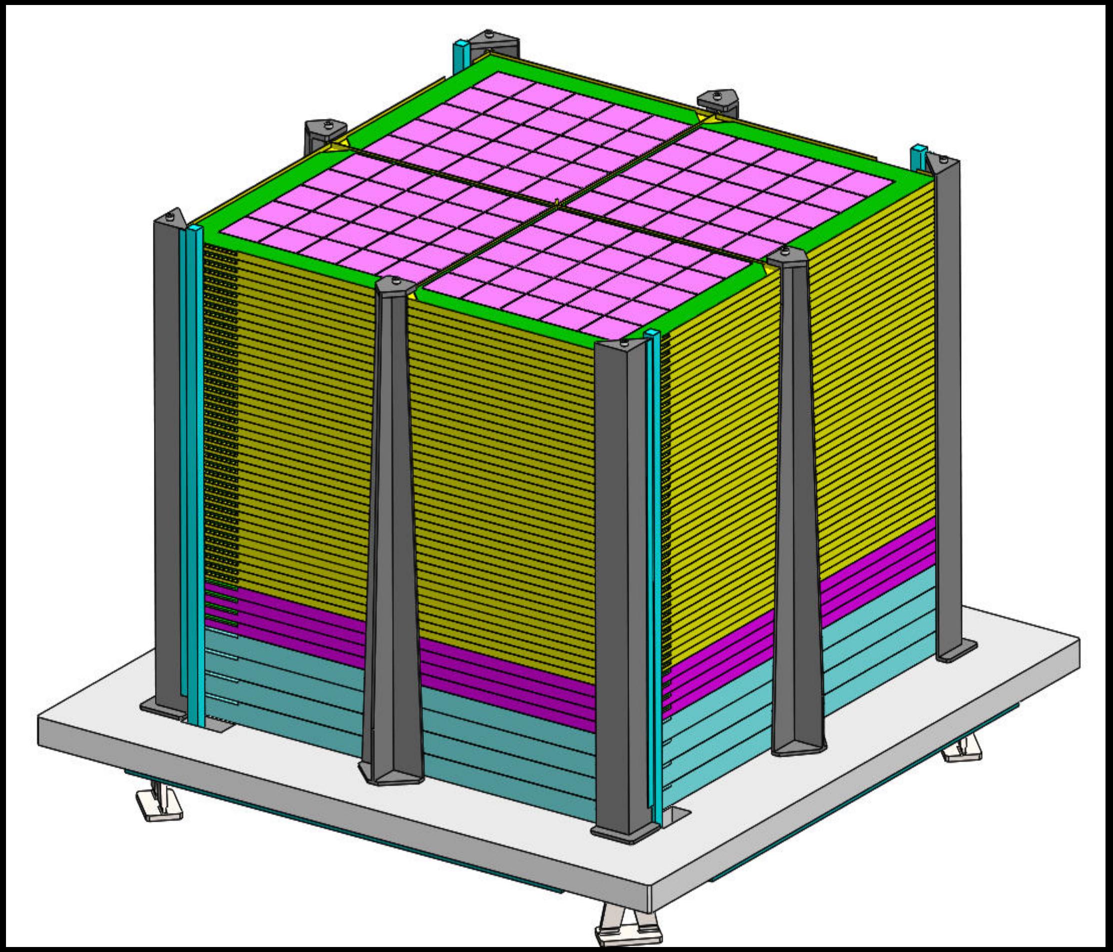
AMS-02

Calorimeter Heritage

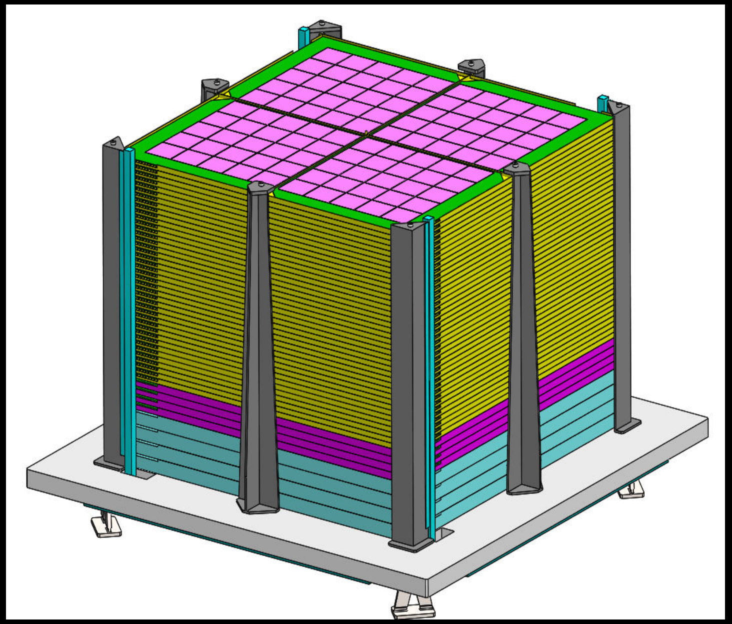
- CsI calorimeter: widely used in particle physics and astrophysics. Successfully used in Fermi LAT with very similar design. ComPair team includes NRL, Calorimeter subsystem lead for Fermi-LAT
  - Mechanical design uses LAT heritage
  - Lowest TRL item is readout electronics for SiPMs



VATA460 ASIC from IdEAS



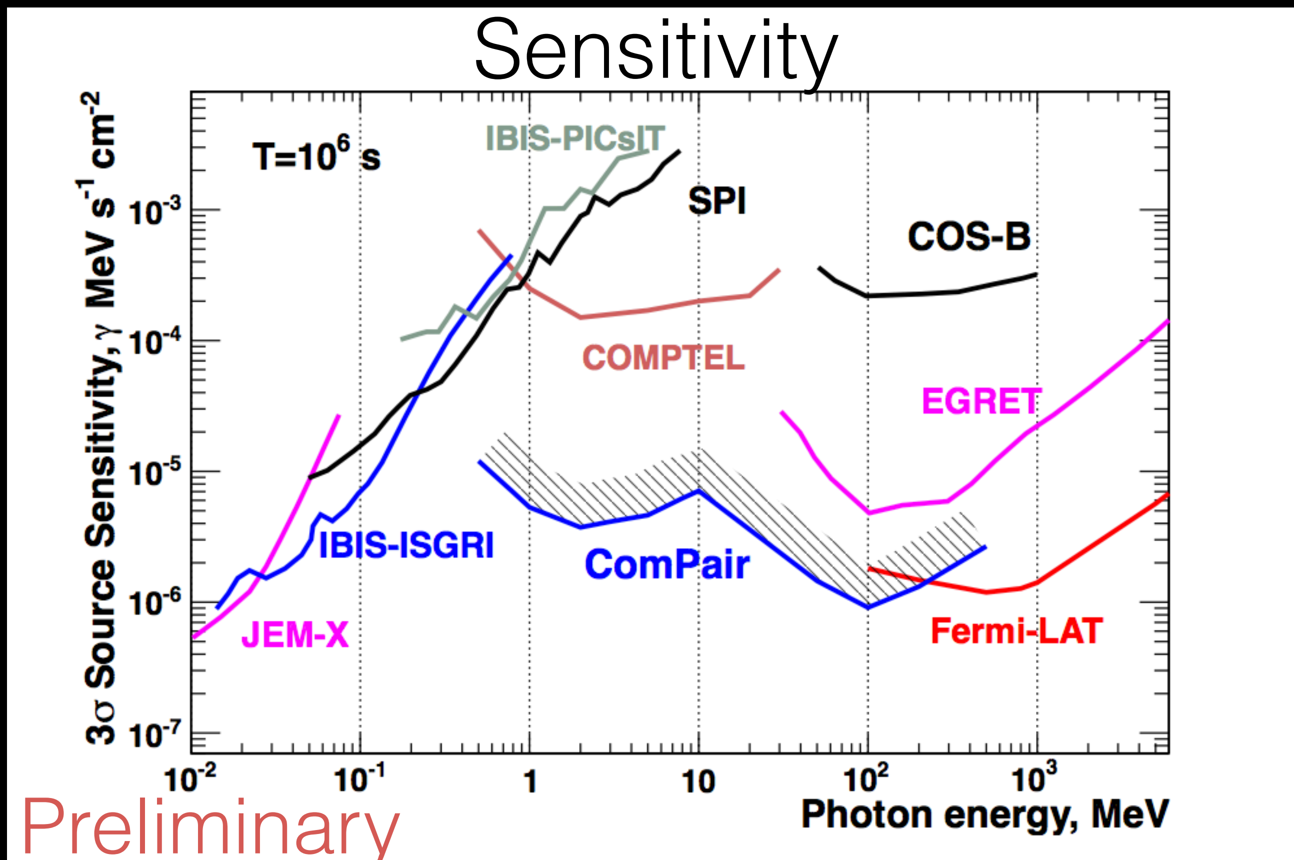
ComPair
Instrument Summary

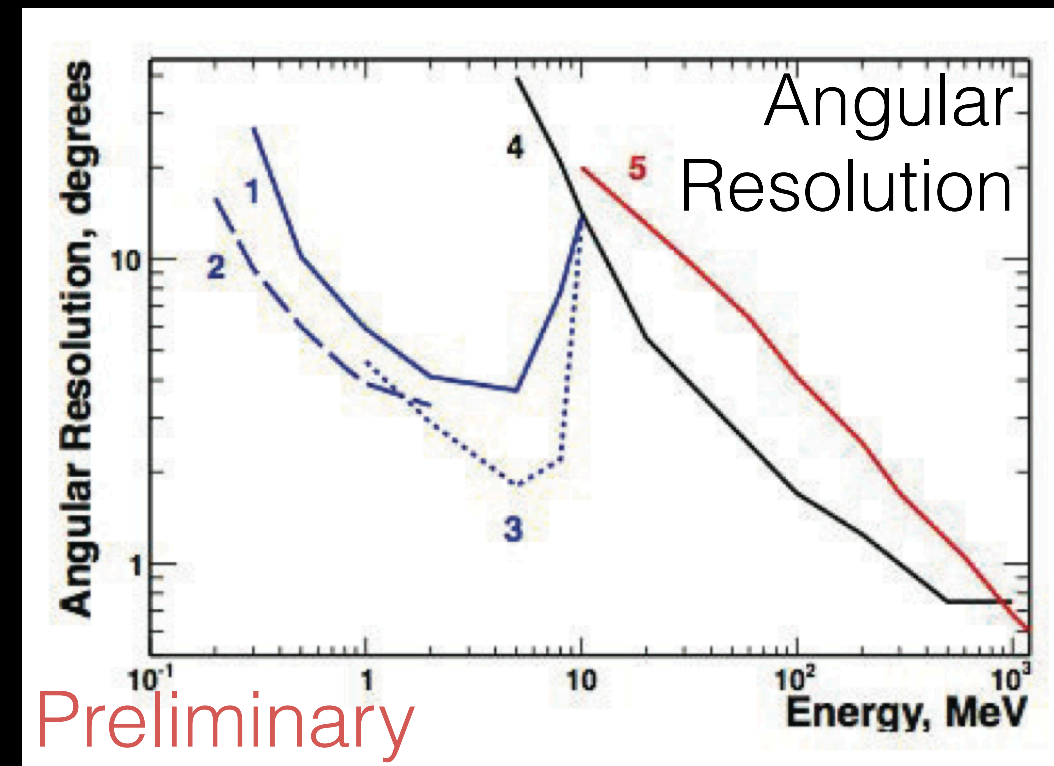


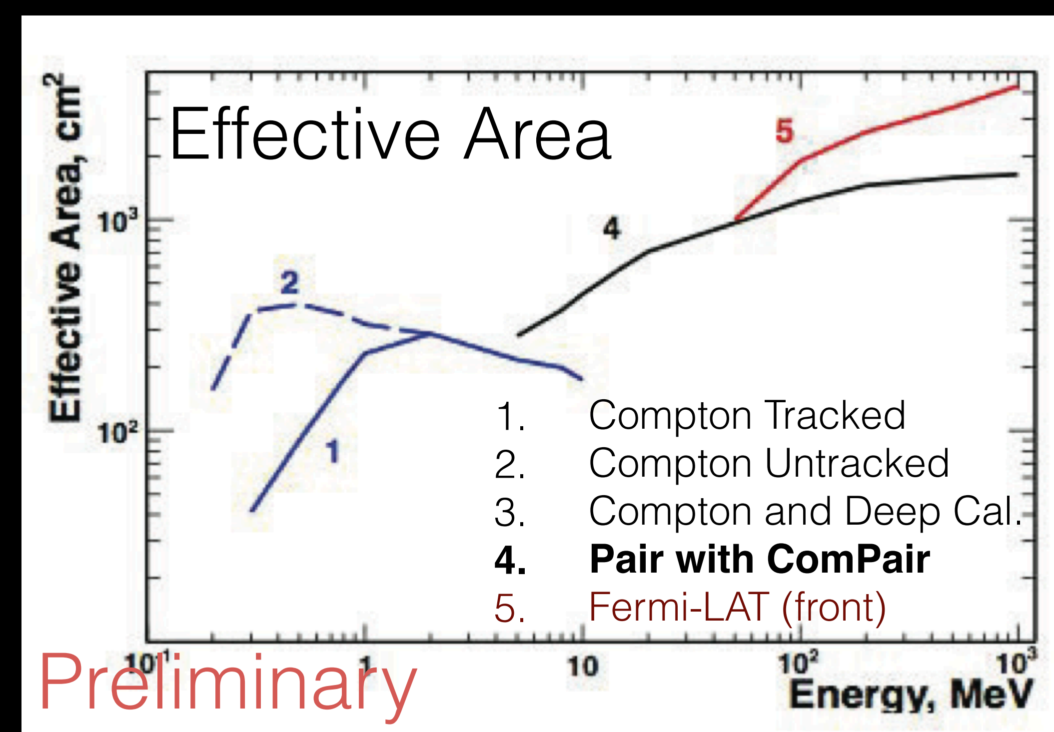
Energy Range	1 – 200 MeV (200 keV – 500 MeV)
Effective Area	100 – 200 cm^2 <10 MeV, 200-1200 cm^2 >10 MeV
Angular Resolution	~7° at 10 MeV, ~1° at 100 MeV
Energy Resolution	2-5% <20 MeV, ~12% at 100 MeV
Solid Angle	~3 sr
Dimensions	1 m x 1 m x 0.7 m (sensitive volume)
Mass	<1000 kg (science payload)
Power	<1000 W
Detector Depth	4.7 X0 (Tracker: 0.3 X0, CSI Calorimeter: 4.4 X0)

IDL and MDL Runs have been completed. Viable MIDEX mission.

Preliminary Instrument Performance







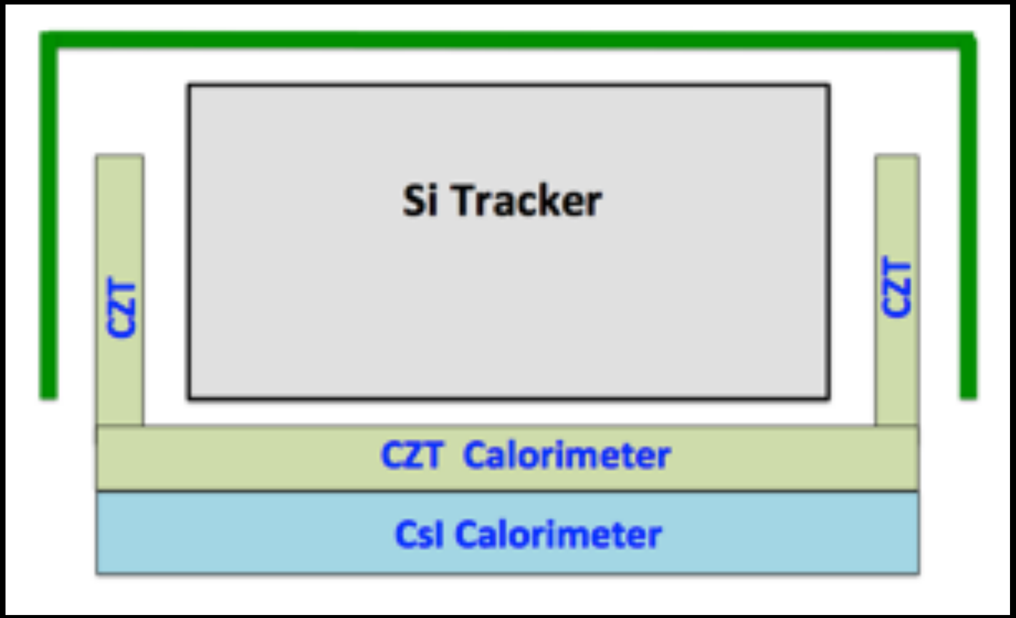
Simulated performance via MEGAlib and MGEANT.

See Moiseev et al. 2015 for more details.

Probe Concept: All-sky Medium Energy Gamma-ray Observatory (AMEGO)

ComPair is designed to be a medium-sized explorer optimized for one primary science capability. Additional resources would greatly enhance observatory performance and open up science capabilities.

- Improve performance for Compton events by adding a high resolution CZT calorimeter
  - Expand Energy Range
  - Deepen sensitivity in Compton regime
  - Increase energy resolution to allow **line spectroscopy**
  - Enhance performance for measuring **polarization**



Summary

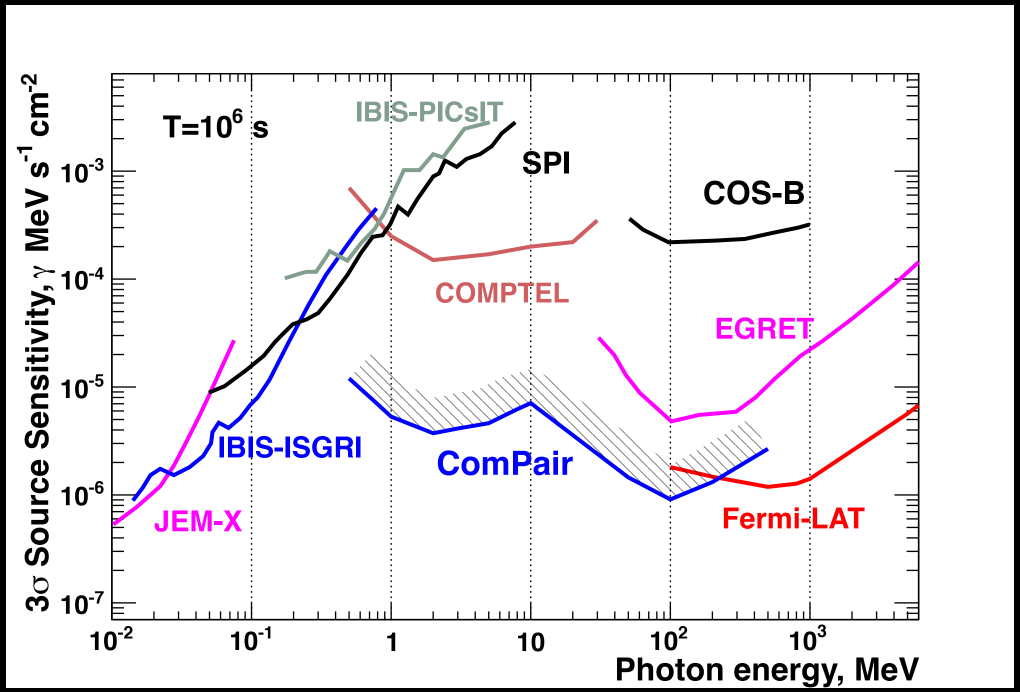
ComPair is a moderate and readily doable concept for a observatory that addresses extreme astrophysics and has a broad science reach in a poorly explored part of the spectrum

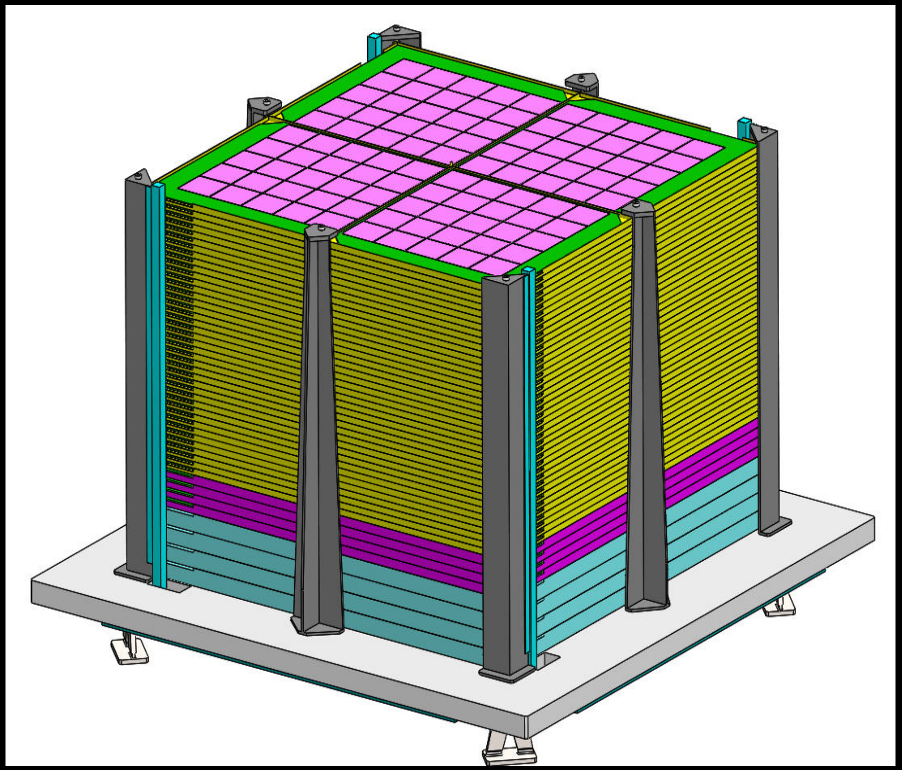
ComPair provides key capabilities for time domain astrophysics

ComPair

A Wide-Aperture Discovery Mission for the MeV Band

- Science focus: extreme astrophysics - high matter densities, strong magnetic fields, powerful jets
- Monitor the whole gamma-ray sky in the energy range 200 keV – > 500 MeV with sensitivity ~10 -50 times better than COMPTEL at ~1 MeV and improved angular resolution over Fermi LAT
- Optimized for continuum sensitivity and field of view but a probe concept will provide other ground-breaking capabilities, e.g. polarization, spectroscopy





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NEW