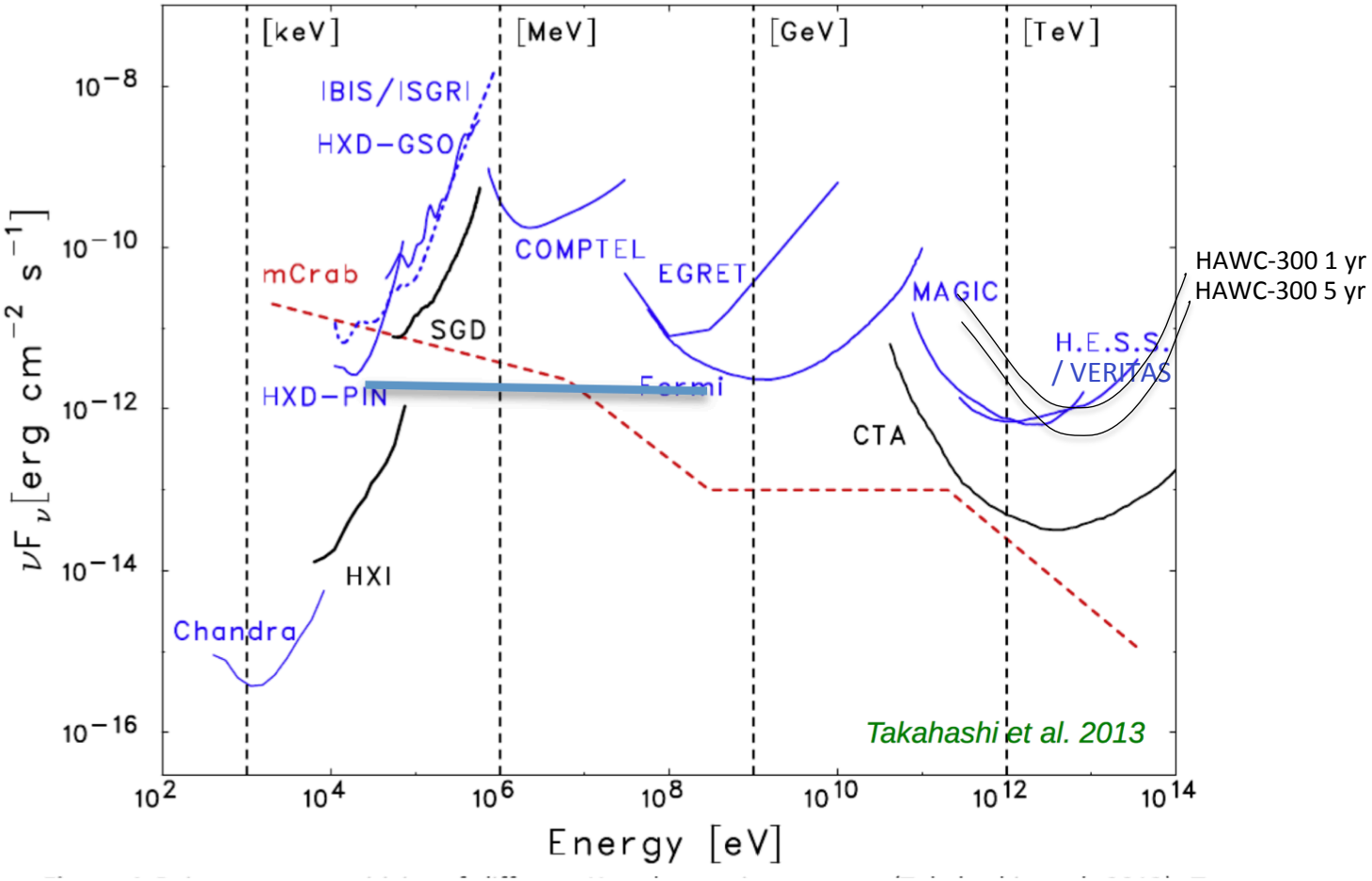
Future Directions in Space-based Gamma-ray Detection

Liz Hays

Fermi Summer School 2015

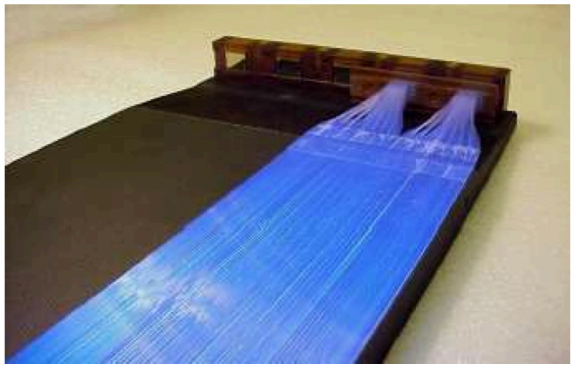
X-ray to Gamma-ray Instrument Sensitivity



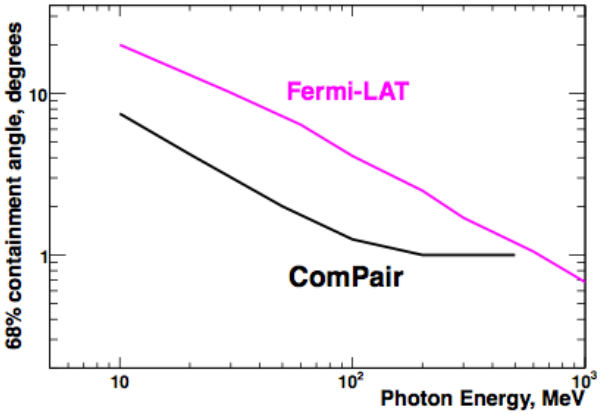
Beyond Fermi

- More GeV photons, please!
  - Scale up LAT – difficult
    - But ground tels nearing 10 GeV
  - Increase geometry factor
    - Use scintillating fibers, for example, APT concept
- Improve angular resolution
  - Reduce passive material in tracking detector, e.g. ComPair
  - Also aids sensitivity in separation from interstellar emission

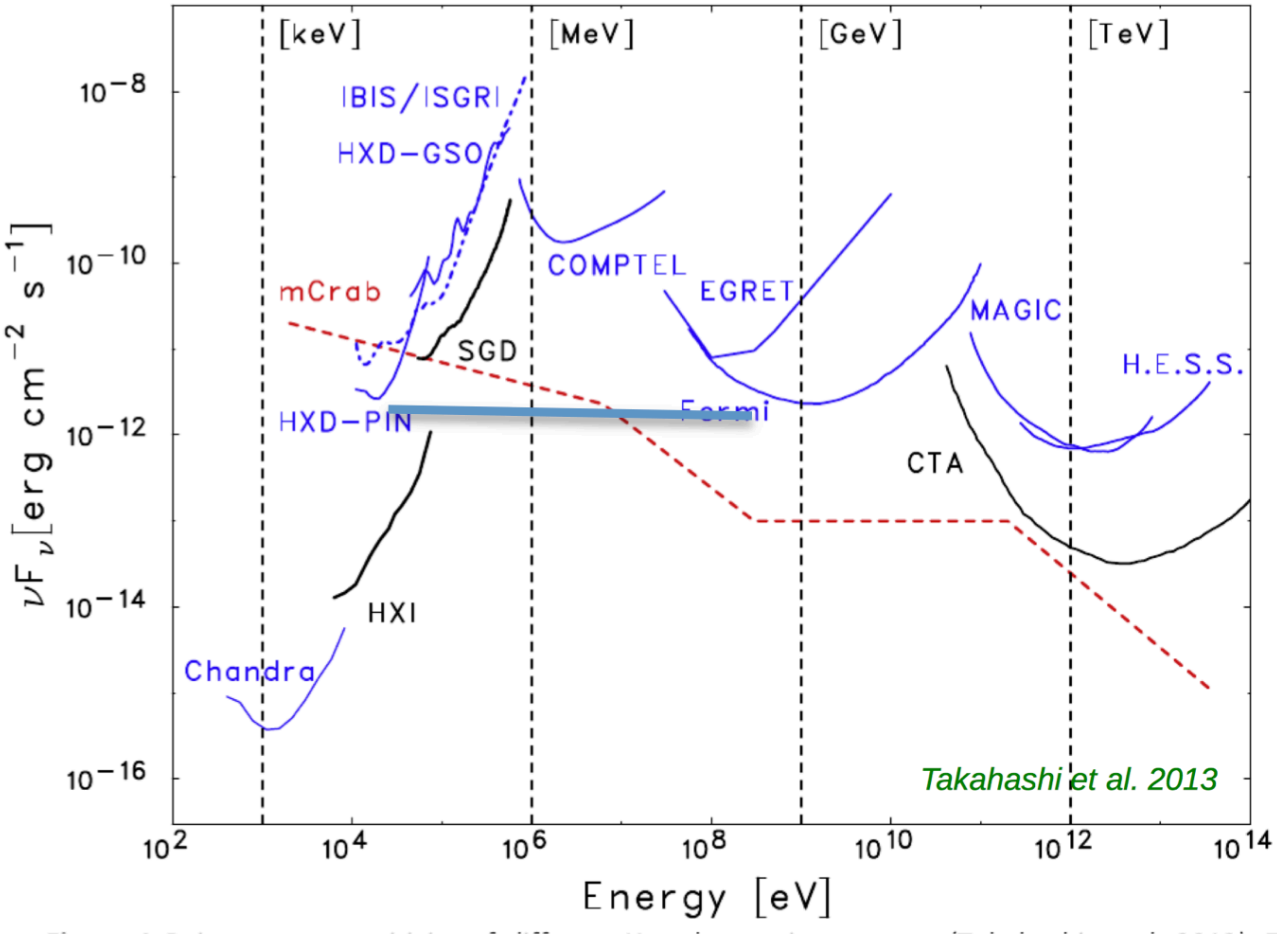
APT Scintillating fiber layer



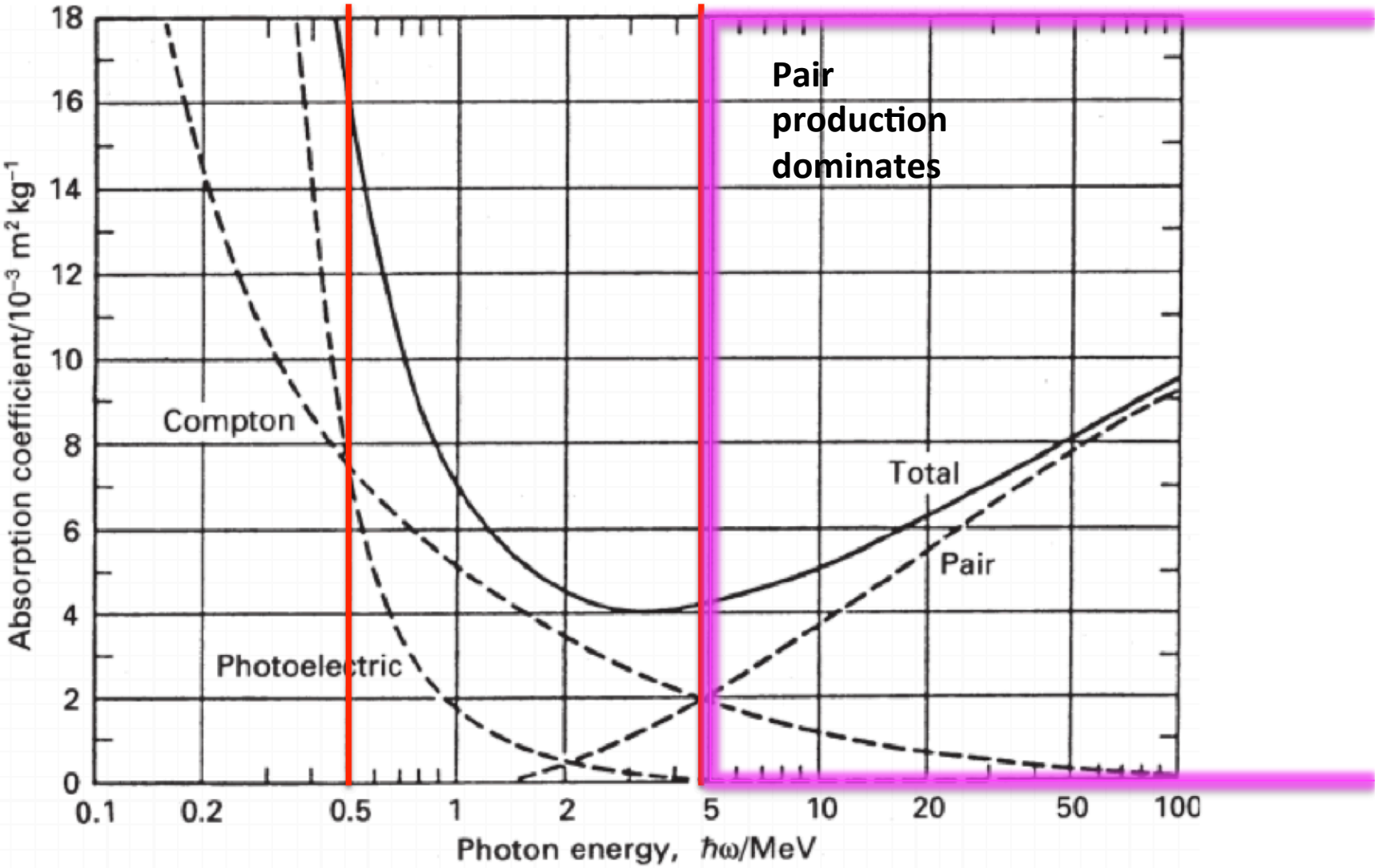
Angular resolution for ComPair (double-sided Si)



X-ray to gamma Instrument Sensitivity



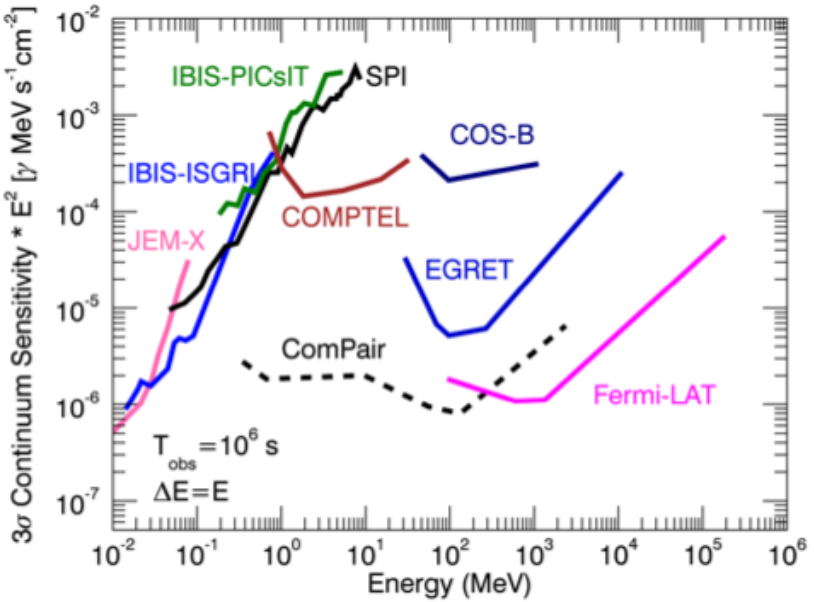
Energy loss of Photons in Matter



Extending below LAT energies

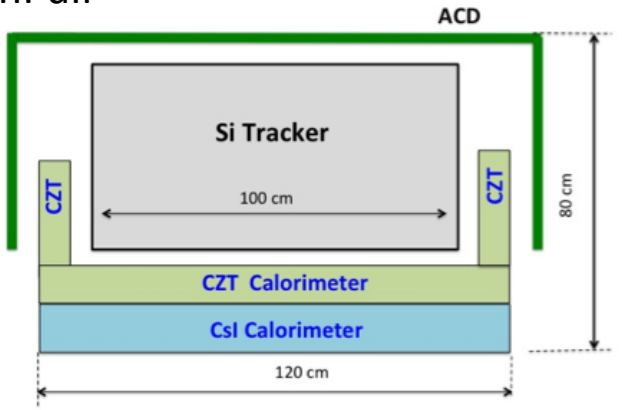
Pair + Compton telescopes

- Wide field of view
- Broad energy range
- Good angular resolution
- For example, ComPair, AstroGAM



Minimize passive material.
Good electron tracking.
Good imaging calorimetry for Compton mode.
Have to optimize design for two (or more) signatures

ComPair



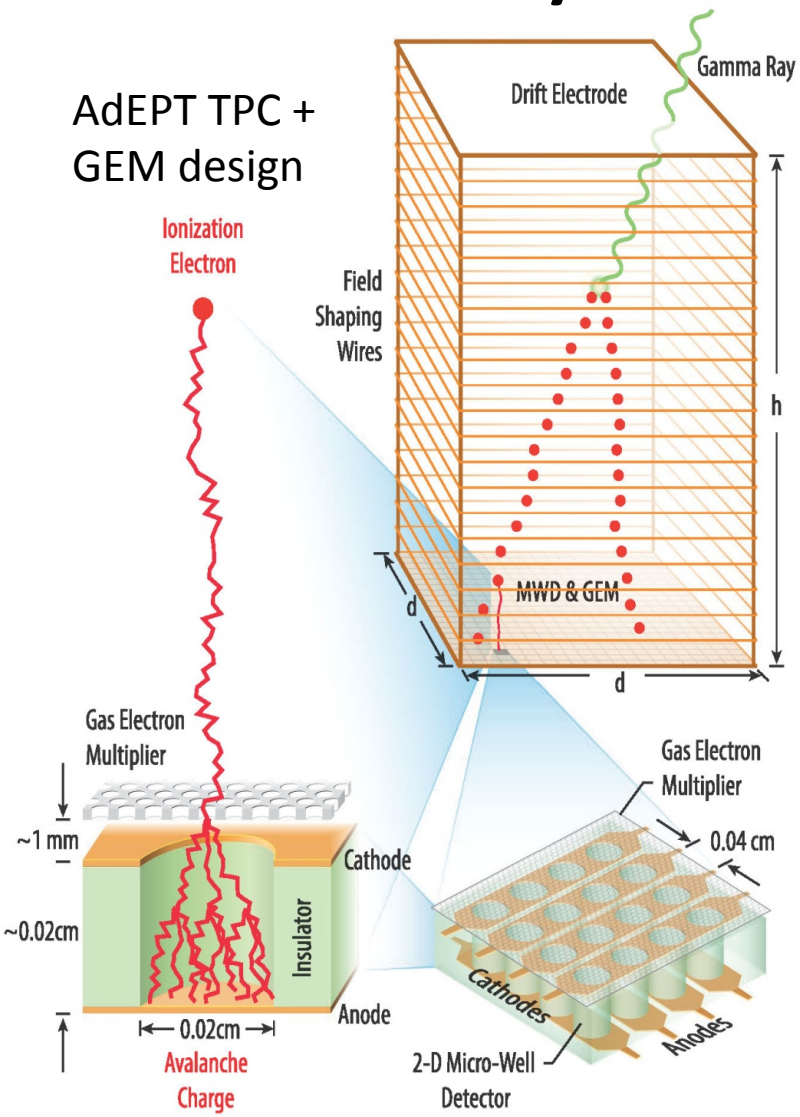
Gamma-Ray Pair Polarimetry

Requires excellent spatial resolution for tracking e-/e+

Time Projection Chambers

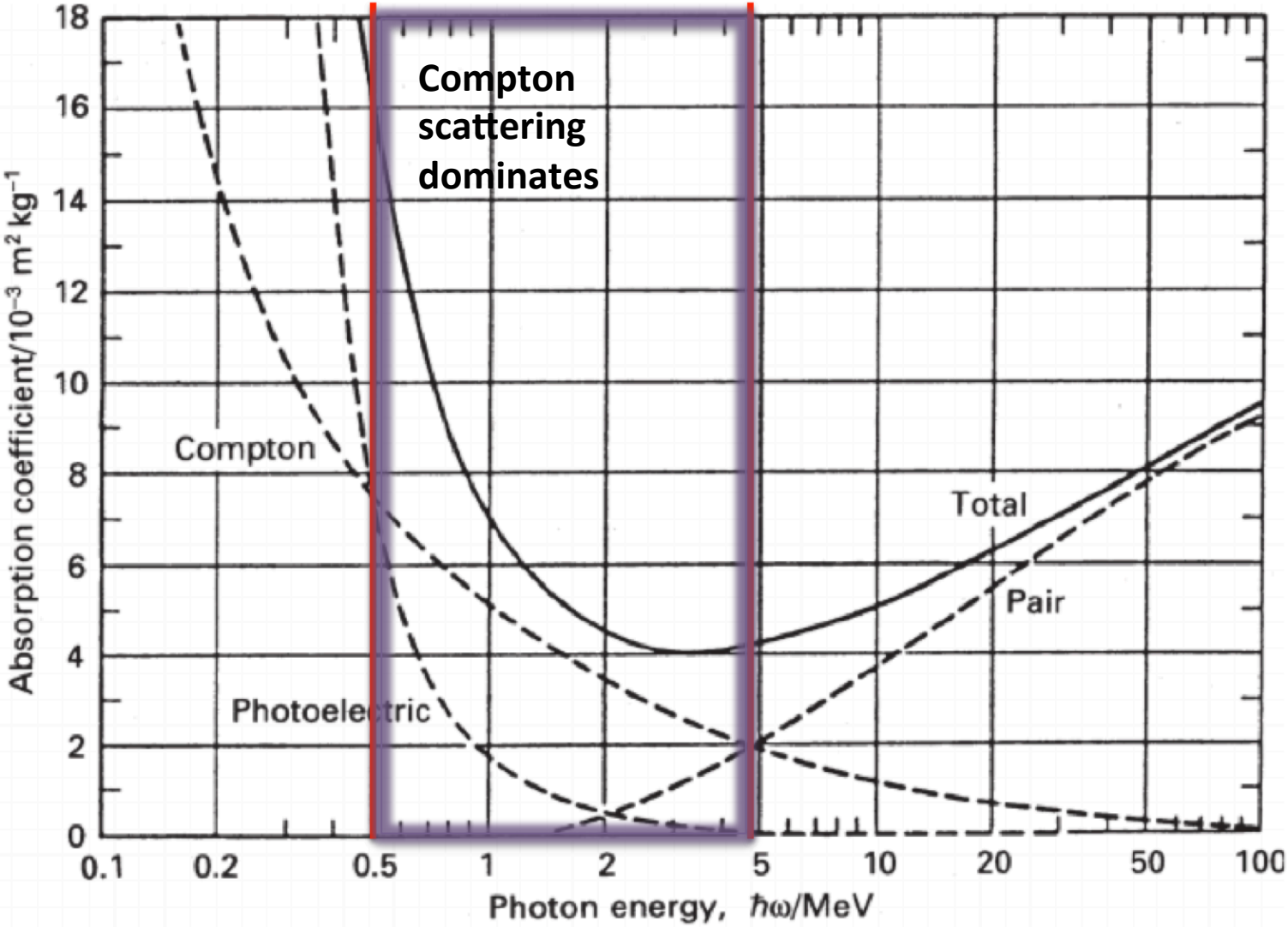
- High angular resolution
- Good polarization capability
- For example, AdEPT, HARPO, LArGO

Some polarization capability in solid state detectors.

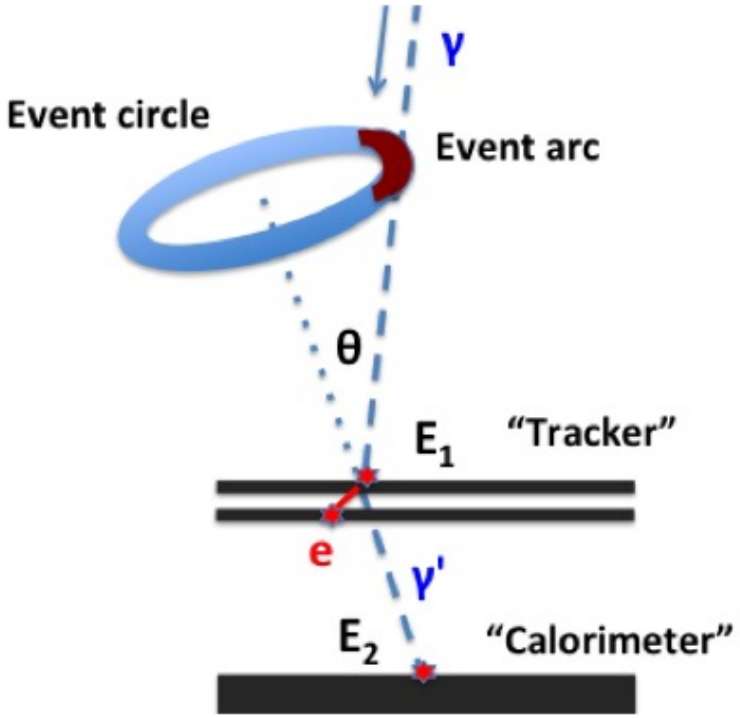


Hunter 2014

Energy loss of Photons in Matter



Compton Imaging

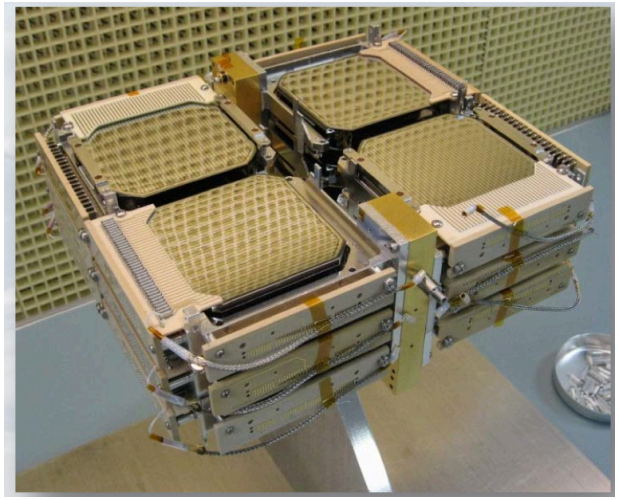


Soft-gamma-ray Telescopes

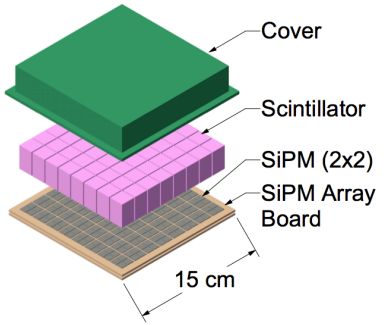
Compton Telescopes

- Gamma-ray spectroscopy
  - Nuclear line emission is an important driver
    - Optimize for very good energy resolution
  - Wide field of view
  - Some polarization capability
  - For example, previously COMPTEL on CGRO, some recent concepts: COSI (germanium detectors), ASCOT (liquid scintillator with SiPMs)

COSI detectors



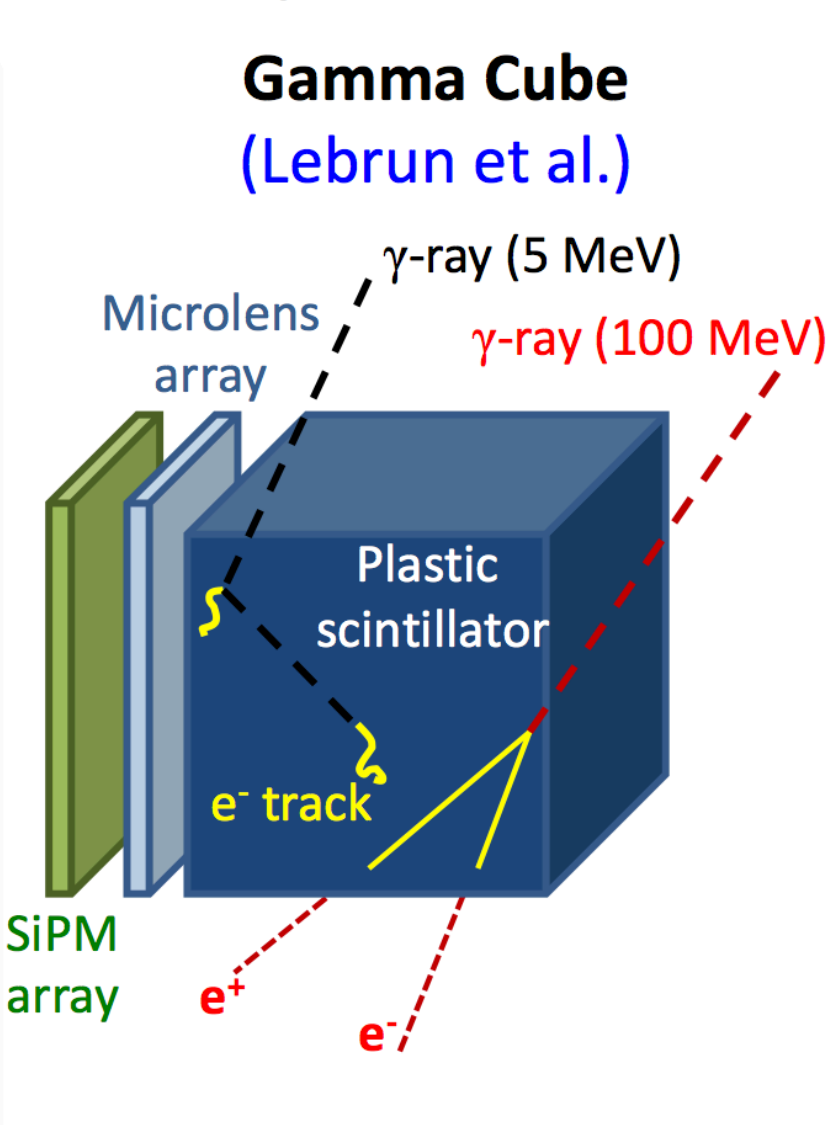
ASCOT detector layer concept



Novel Concepts: 3D Scintillation Tracker

Image ionization traces in plastic scintillator from charged particles – Compton or pair interactions.

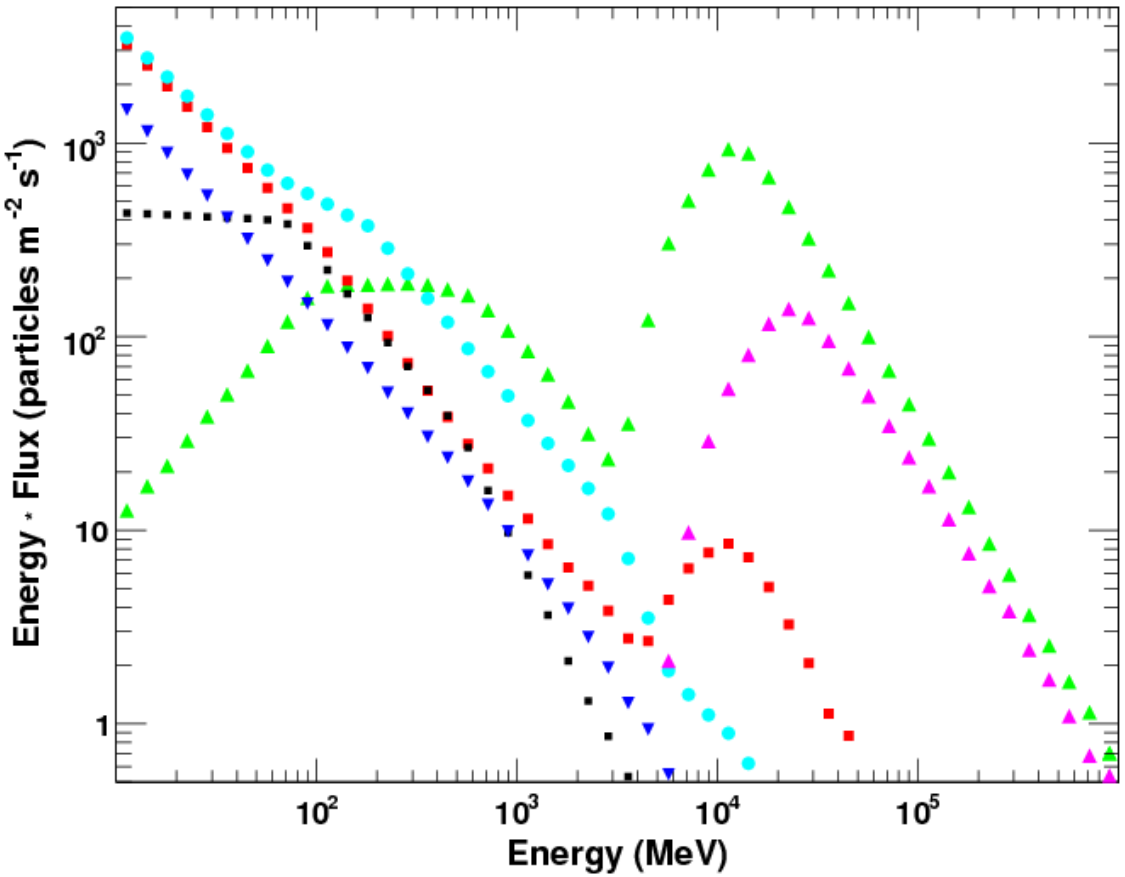
Don't need full absorption.



An aside on backgrounds

GeV Backgrounds

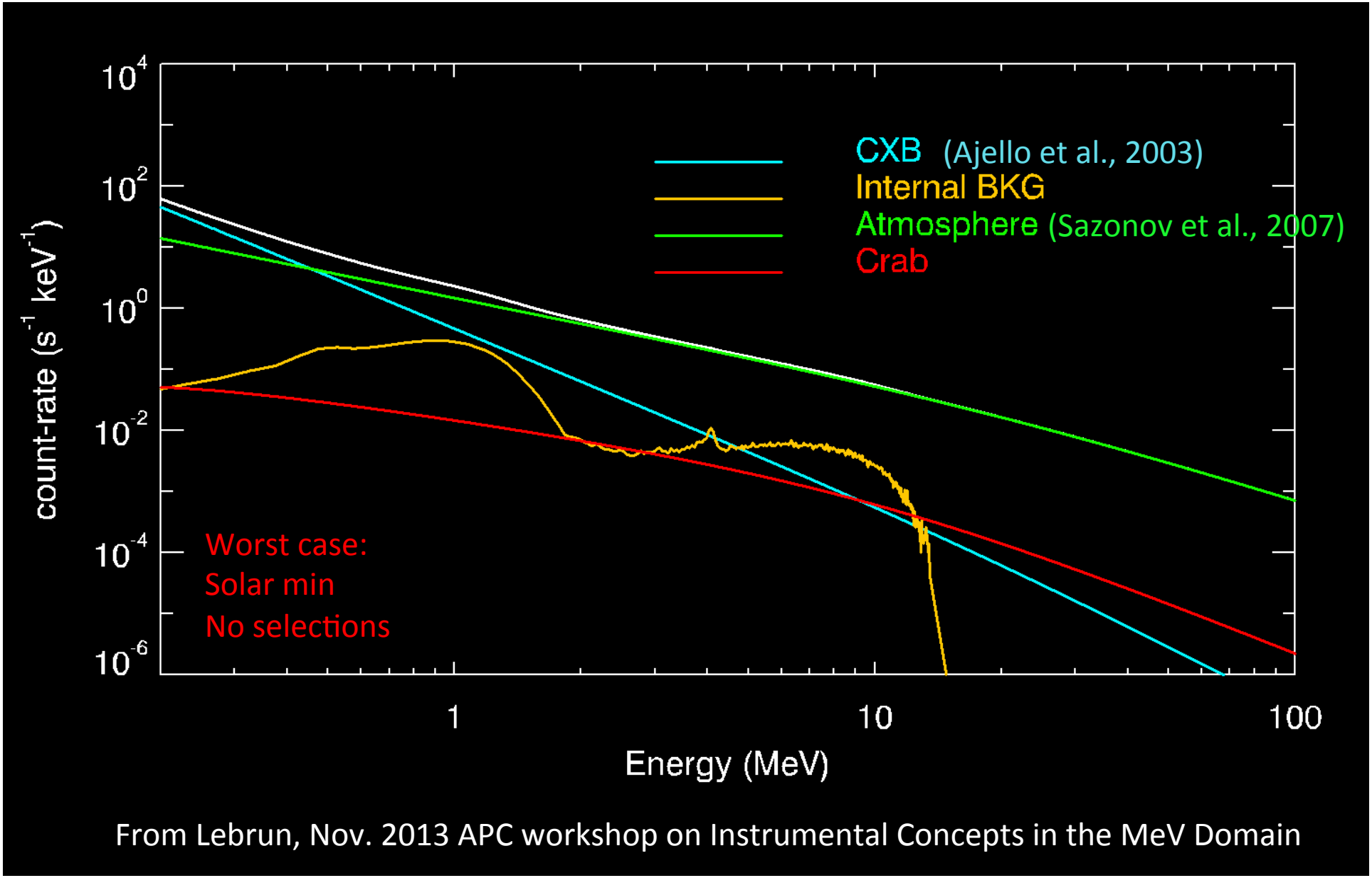
Dominated by charged particles.
Significant gamma-ray background from the Earth ~< 300 MeV.



Light blue = positrons
Red = electrons
Dark blue = Earth albedo gamma rays
Black = Earth albedo neutrons
Green = protons
Magenta = alphas

LAT Background Model: Atwood et al., 2009

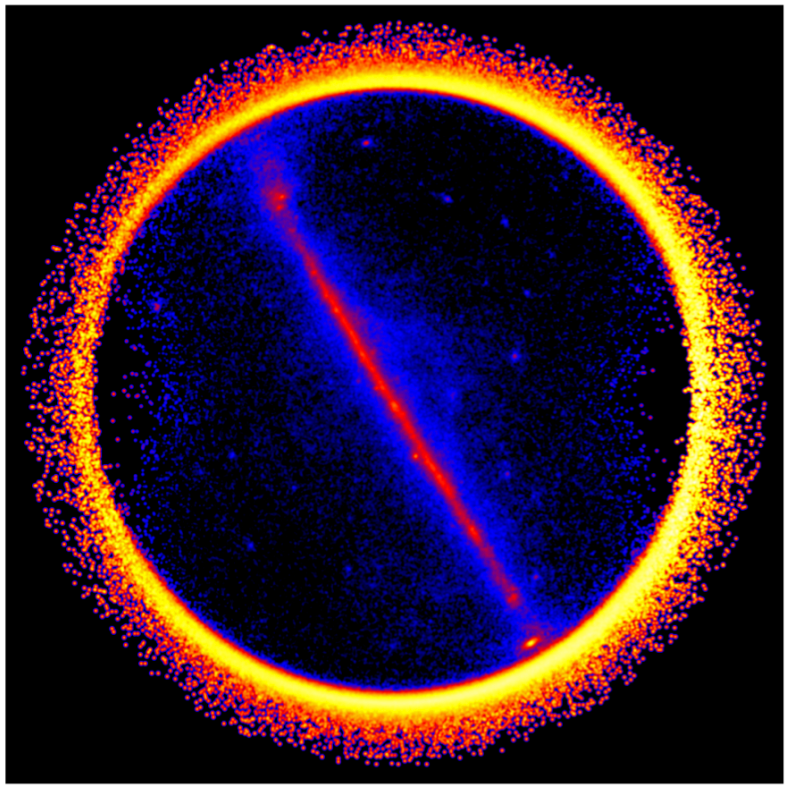
MeV Backgrounds



From Lebrun, Nov. 2013 APC workshop on Instrumental Concepts in the MeV Domain

The Earth at GeV energies

- **The horizon is by far the brightest gamma-ray source in the GeV energy range**
  - **From cosmic-ray interactions in the upper atmosphere**
- **The horizon has essentially a fixed angular distance from the zenith**
- **If you select times when the zenith happened to be near the Galactic center and *don't* make a zenith angle cut, you can compare the Galactic diffuse emission to the ~1000x brighter limb of the atmosphere**



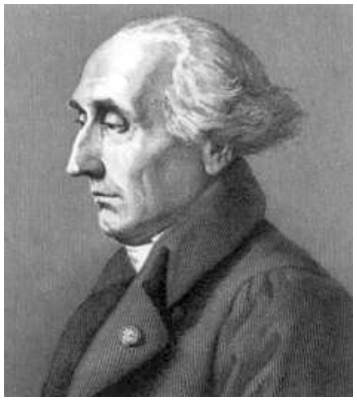
>300 MeV

From Seth's talk on Monday showing the Earth limb in comparison to the Milky Way

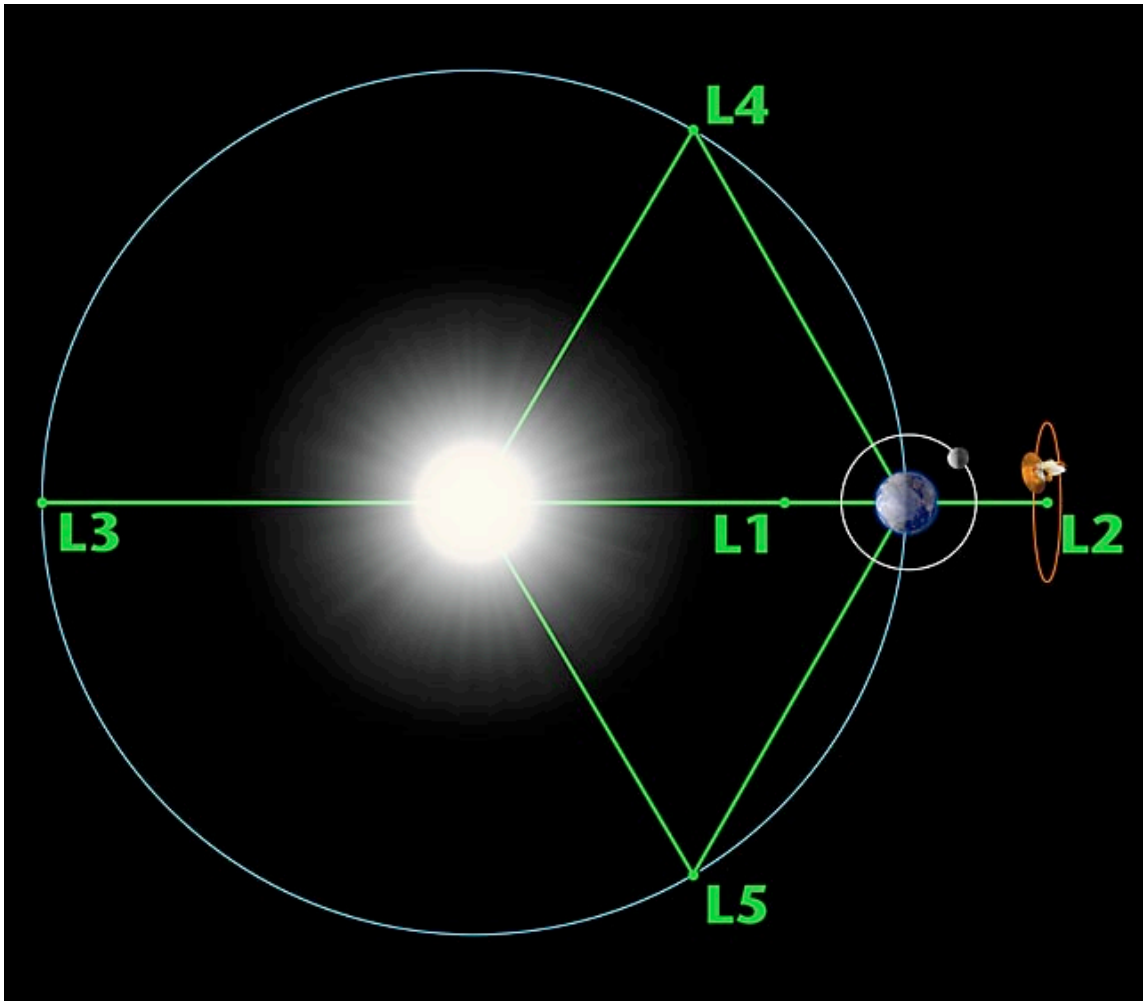
Minimizing Background

- Particle backgrounds from spacecraft
  - Choose materials wisely
  - Detailed mass models
  - Mount instrument away from spacecraft on a boom (e.g. ASCI concept)
- Gamma-ray background from Earth
  - Time of flight
  - Shielding
  - Directional rejection in analysis
  - Go to L2

What is L2?



Joseph-Louis Lagrange



The Lagrange Points are positions where the gravitational pull of two large masses equals the centripetal force required for a smaller mass to move with them. This mathematical problem, known as the "General Three-Body Problem" was considered by Lagrange in his prize winning paper (*Essai sur le Problème des Trois Corps*, 1772).

Mini-Summary on Backgrounds

- Resolution, resolution, resolution!
  - Tracking resolution – resolve pile up
  - Time resolution – avoid pile up
  - Angular resolution – limit confusion on the sky
  - Energy resolution – limit confusion in energy for lines

More Info on Future Space Concepts

- In the USA
  - Goddard Future Space Observatory Workshop: http://asd.gsfc.nasa.gov/conferences/future_gamma_obs/program/
  - Gamma Science Interest Group (part of the Physics of the Cosmos Program Analysis Group): http://pcos.gsfc.nasa.gov/sigs/gammasig.php
  - AAS High Energy Astrophysics Division Meeting: https://aas.org/meetings/high_energy_decadal
- In Europe
  - APC (Paris) Workshops
    - Instruments (Nov 2013): https://indico.in2p3.fr/event/8608/timetable/#all.detailed
    - Science (Jan 2013): https://indico.in2p3.fr/event/7243/timetable/#all.detailed
    - Report:
  - AstroMeV + Gamma Light -> First AstroGAM Workshop (Dec 2014): http://astrogam.iaps.inaf.it/Program_Astrogam.html

Summary

- Lots of future science (See previous lectures)
  - Important connections to ground-based telescopes and multimessenger observations
- Tried/true and newer (to space) technologies being explored
- Mission concepts exist optimized for a variety of gamma-ray energies and capabilities (imaging, continuum and line spectroscopy, polarimetry)