AMEGO

All-sky Medium Energy Gamma-ray Observatory

A Discovery mission for the MeV gamma-ray band

R. Caputo (UMD/NASA/GSFC)

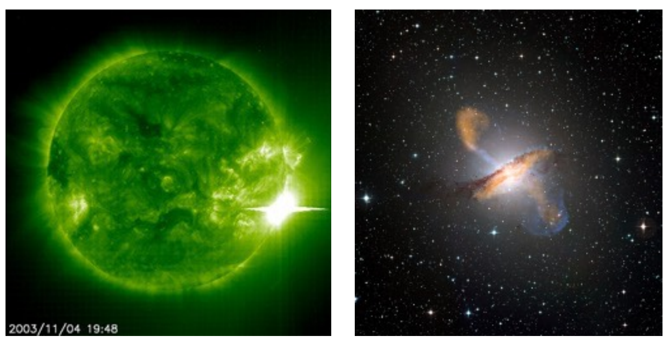
8 June 2017

Fermi Summer School, Lewes, DE

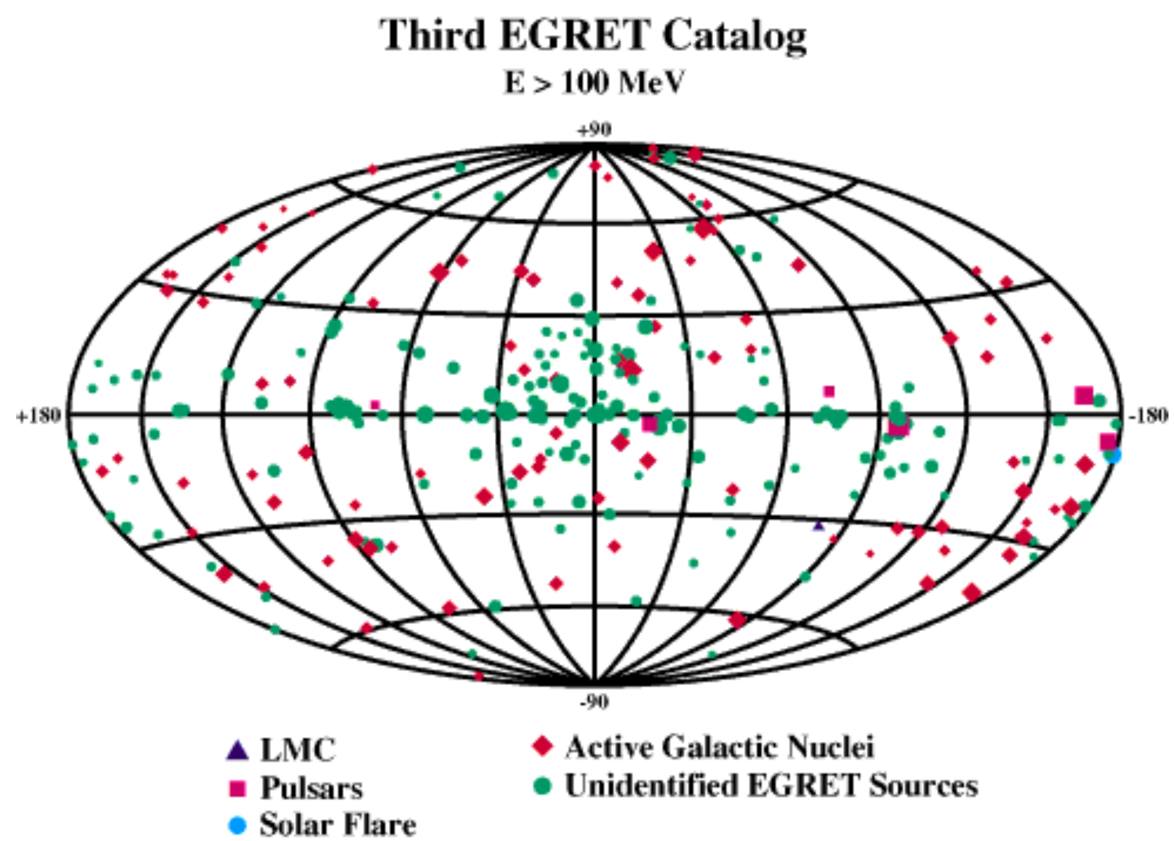
The Gamma-ray Sky circa 1991…

γ-ray Sky dynamic,

diverse



but many unknown (unidentified)



A new instrument:

higher energies,
better angular resolution,
better point source sensitivity

=

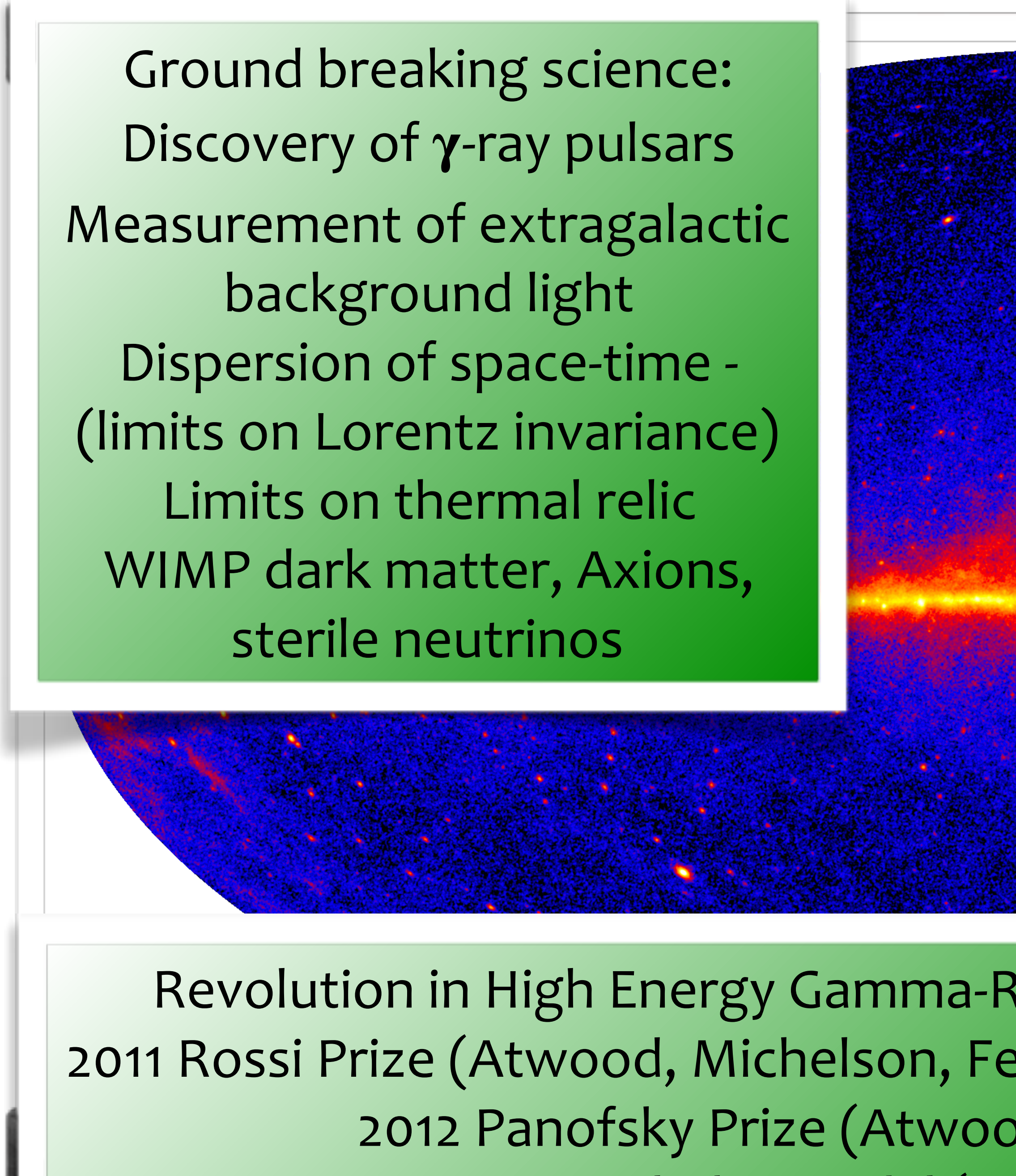
Fermi Gamma Ray Space Telescope (formerly GLAST)

The γ-ray Universe as seen by

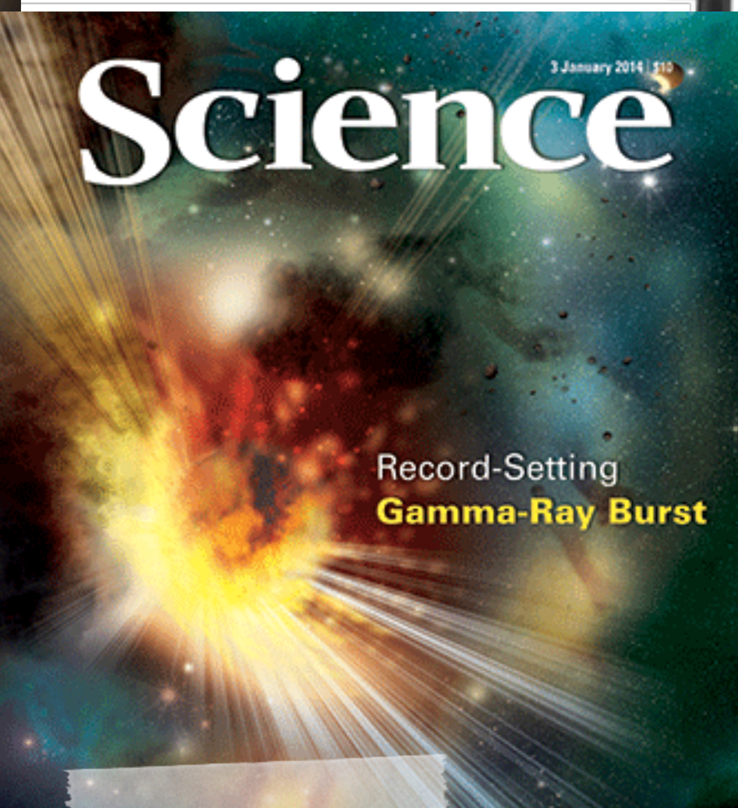
EGRET

Fermi-LAT

circa 2000…



Ground breaking science:
Discovery of γ-ray pulsars
Measurement of extragalactic background light
Dispersion of space-time - (limits on Lorentz invariance)
Limits on thermal relic WIMP dark matter, Axions, sterile neutrinos



Revolution in High Energy Gamma-Ray Physics:
2011 Rossi Prize (Atwood, Michelson, Fermi-LAT team)
2012 Panofsky Prize (Atwood)
2014 Manne Siegbahn Medal (Atwood)

The MeV Band

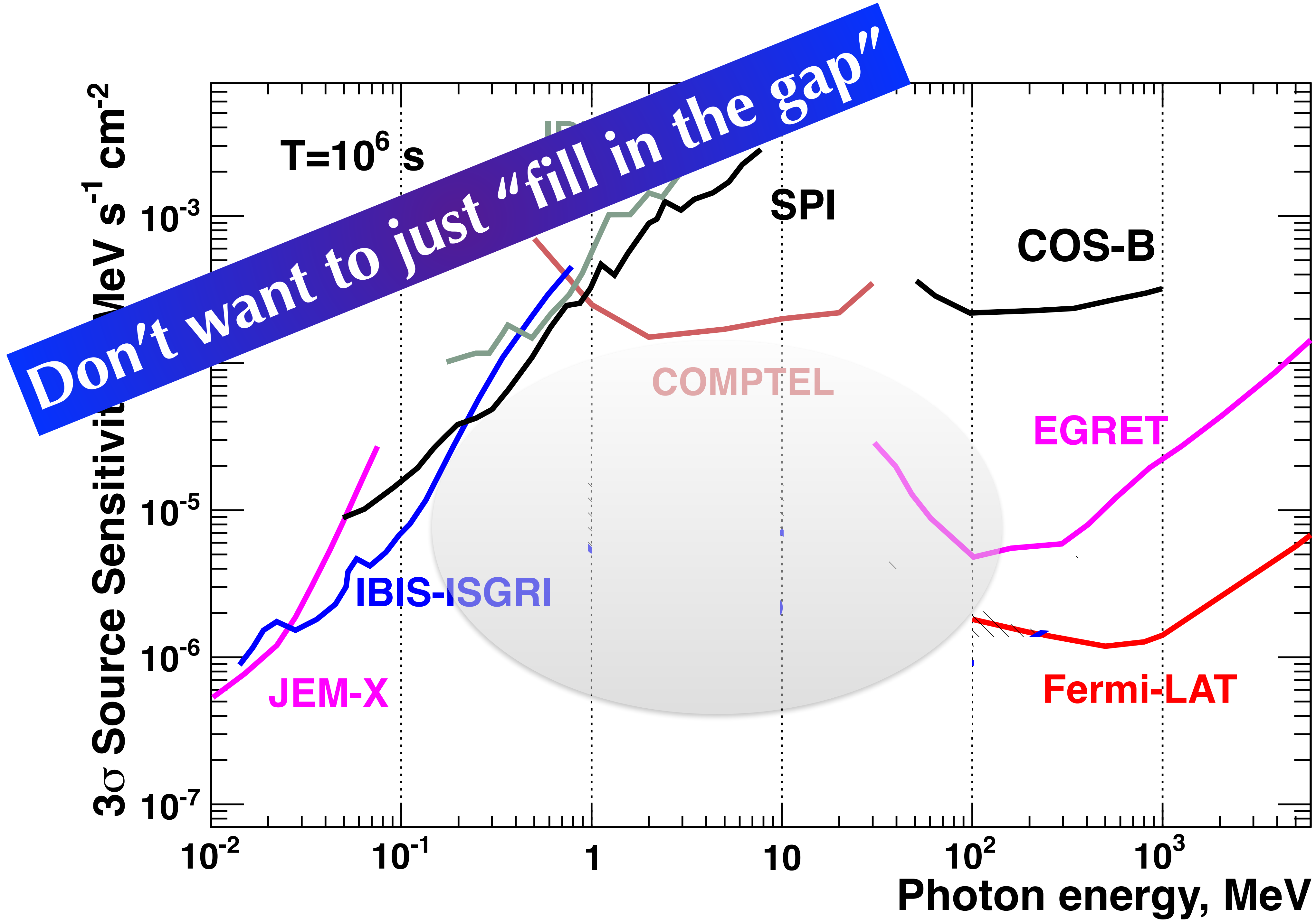
Deeper view: below 100 MeV

COMPTEL: 1 keV-30 MeV

Credit: COMPTEL Collaboration

What lies beyond?

Guaranteed Discovery Space



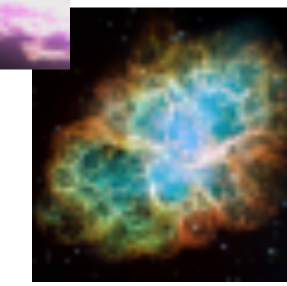
What will we find in this region of the spectrum??

What can you do with MeV data?

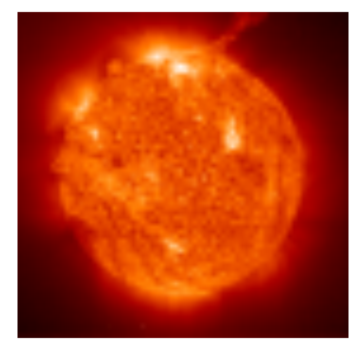
We want you…
to tell us what you think would be interesting for your work!

Science Objectives

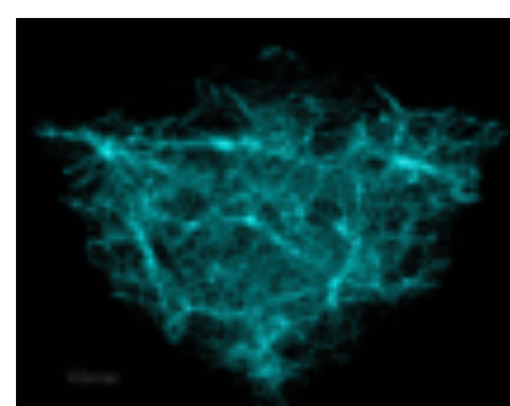
Extreme Astrophysics



How do we resolve the physics of astrophysical objects that have extreme densities, gravity, acceleration and/or magnetic fields?



How do extreme phenomena impact the evolution of the universe?



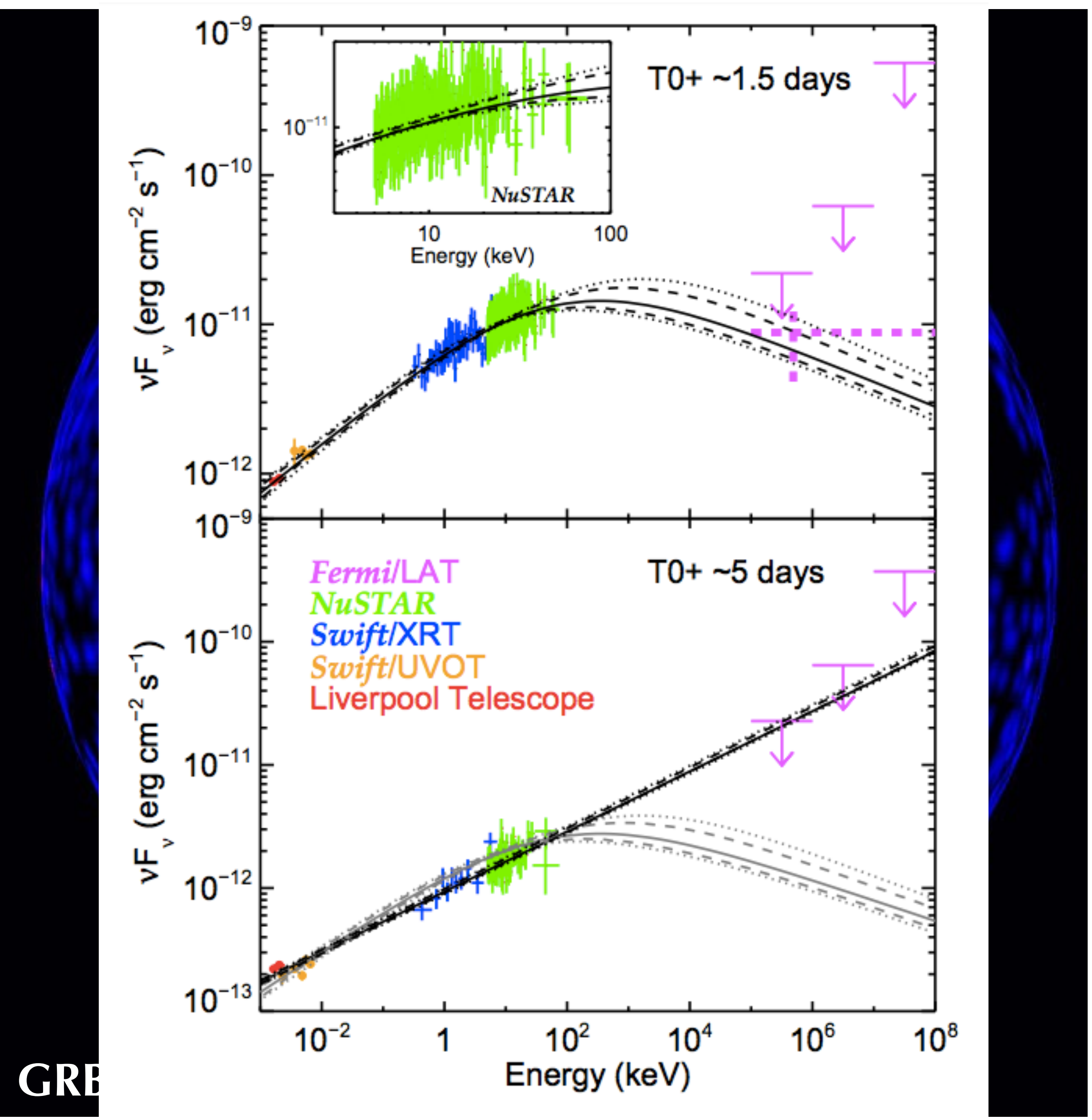
Fundamental nature and evolution of the large population of supermassive black holes and highly-magnetized neutron stars

Astrophysical Jets

Compact Objects

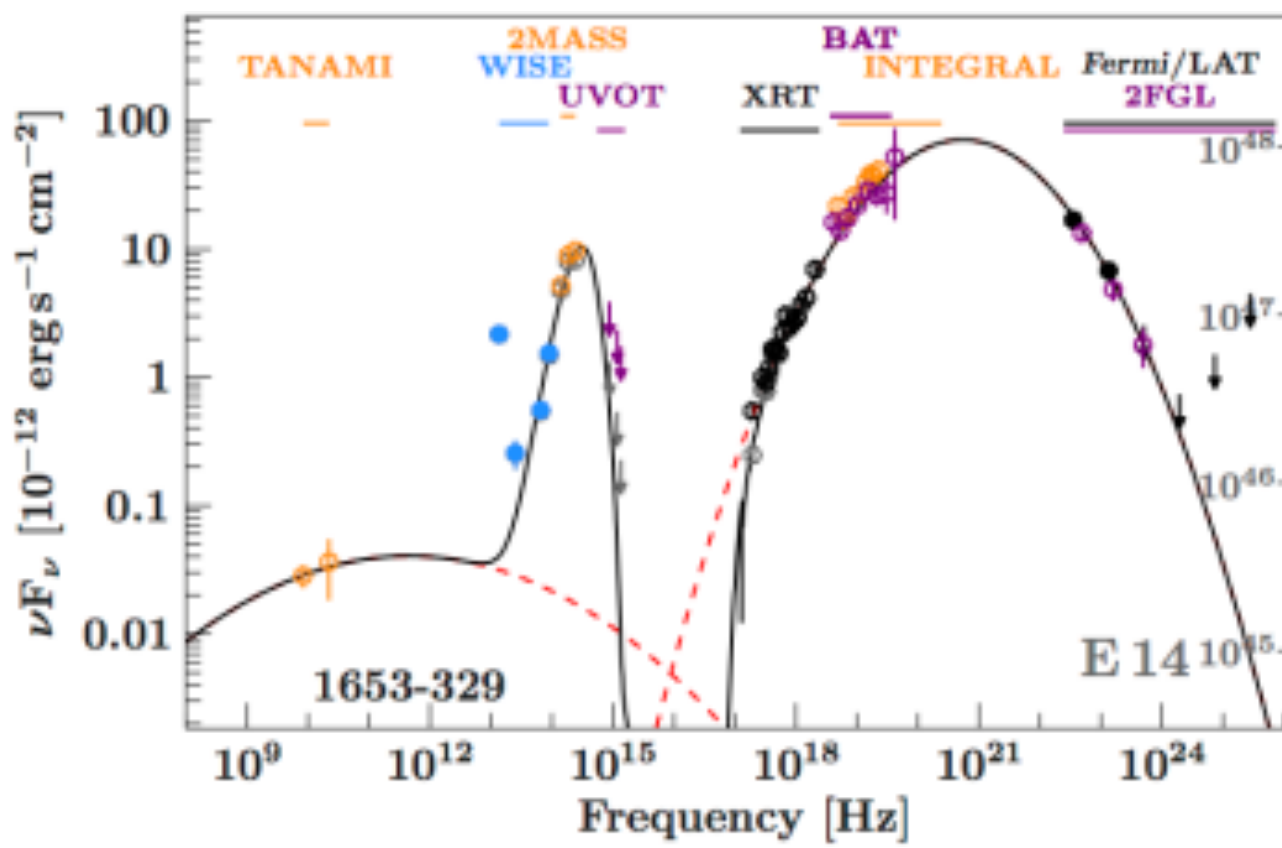
Gamma-ray Bursts

- Jet mission mechanism
  - full spectral energy distribution vital



NASA/DOE/Fermi LAT Collaboration

Kouveliotou et. al, 2013

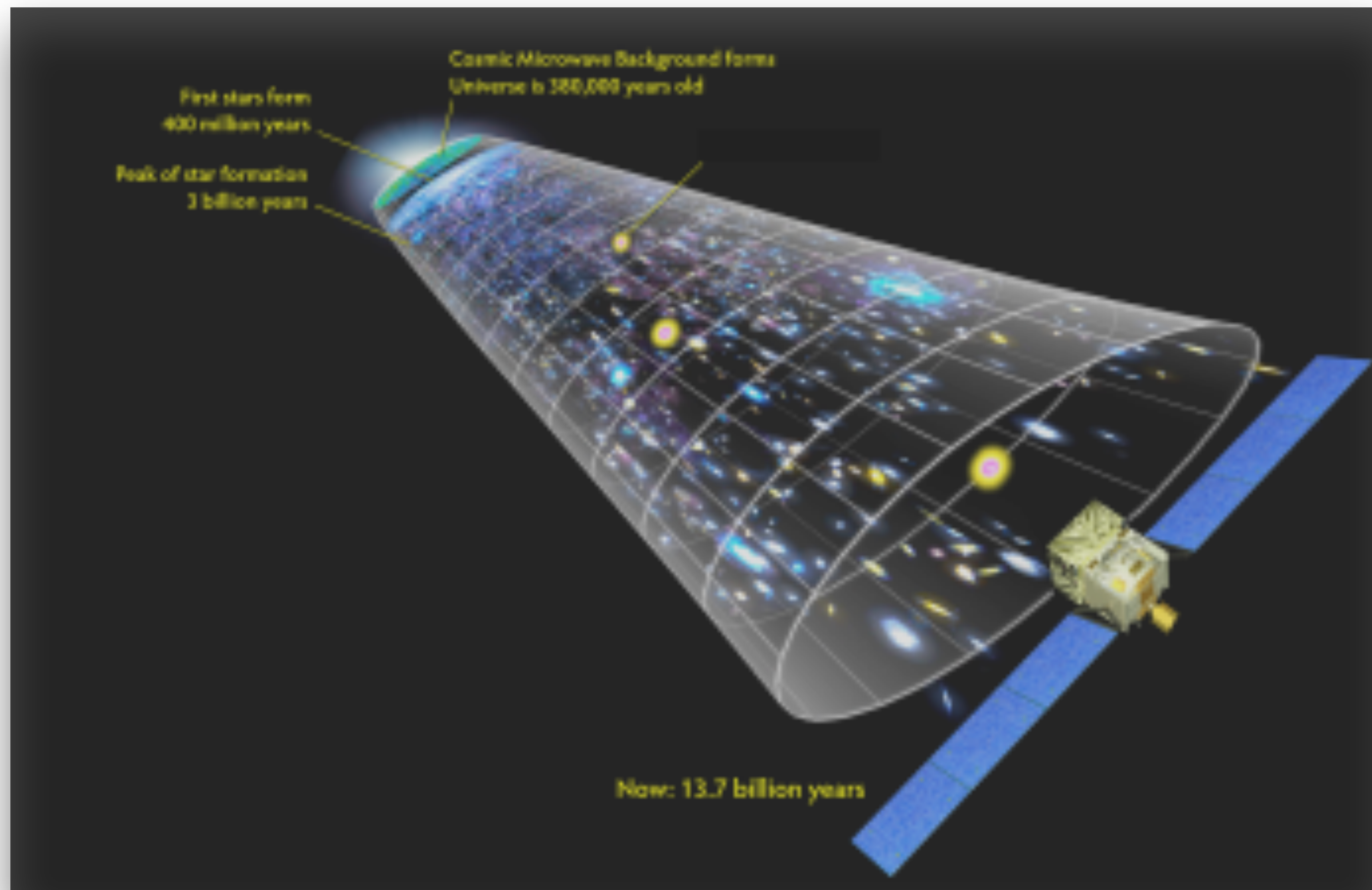


Krauss et. al 2014

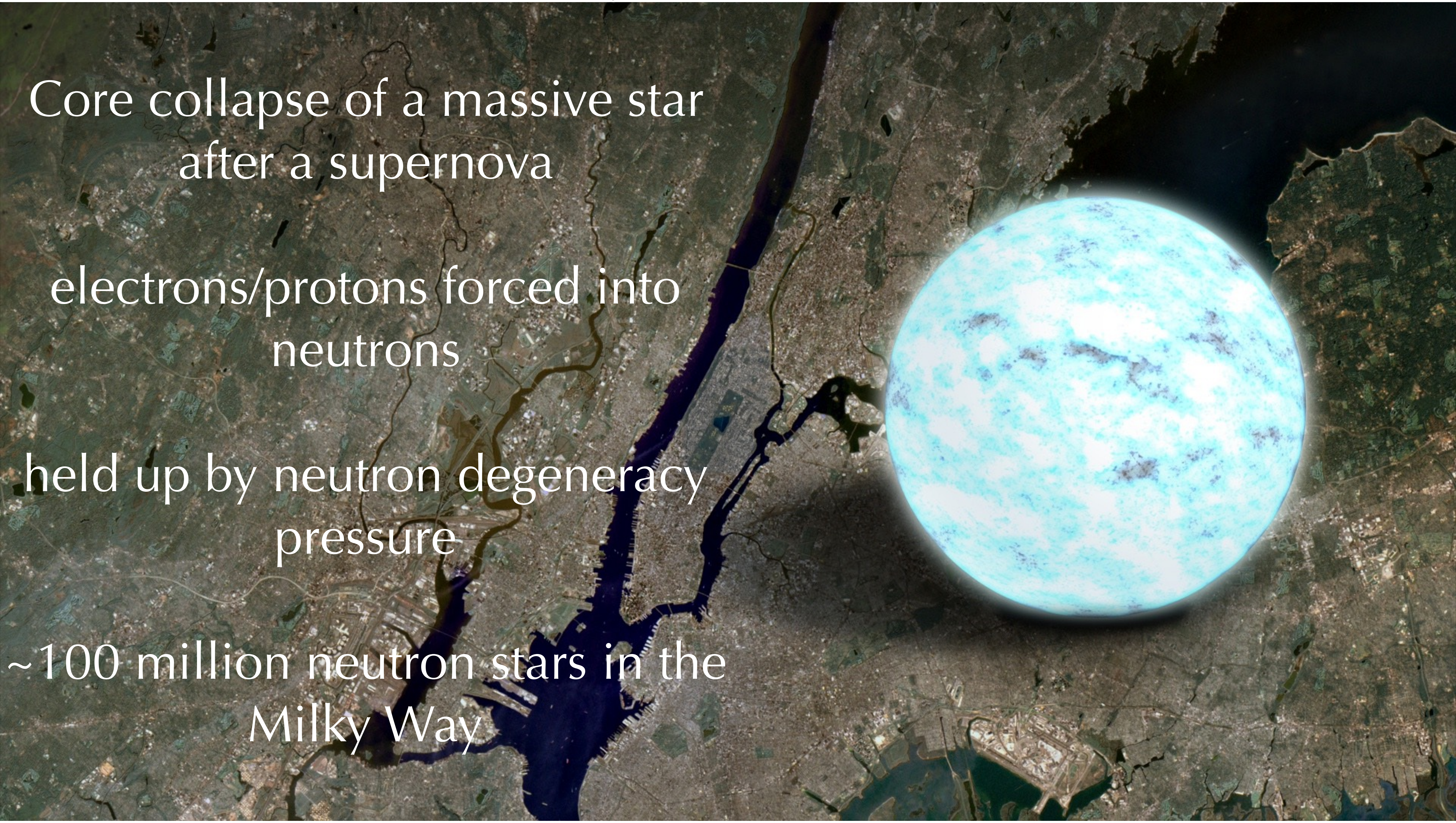
J 1653-329,
a candidate PeV neutrino emitter

Jets from AGN: Blazars

- Class whose peak power output ~1MeV
    - most luminous
    - harbor most massive black holes
    - persistent gamma-ray sources



Compact Objects: Neutron Stars



Core collapse of a massive star after a supernova

electrons/protons forced into neutrons

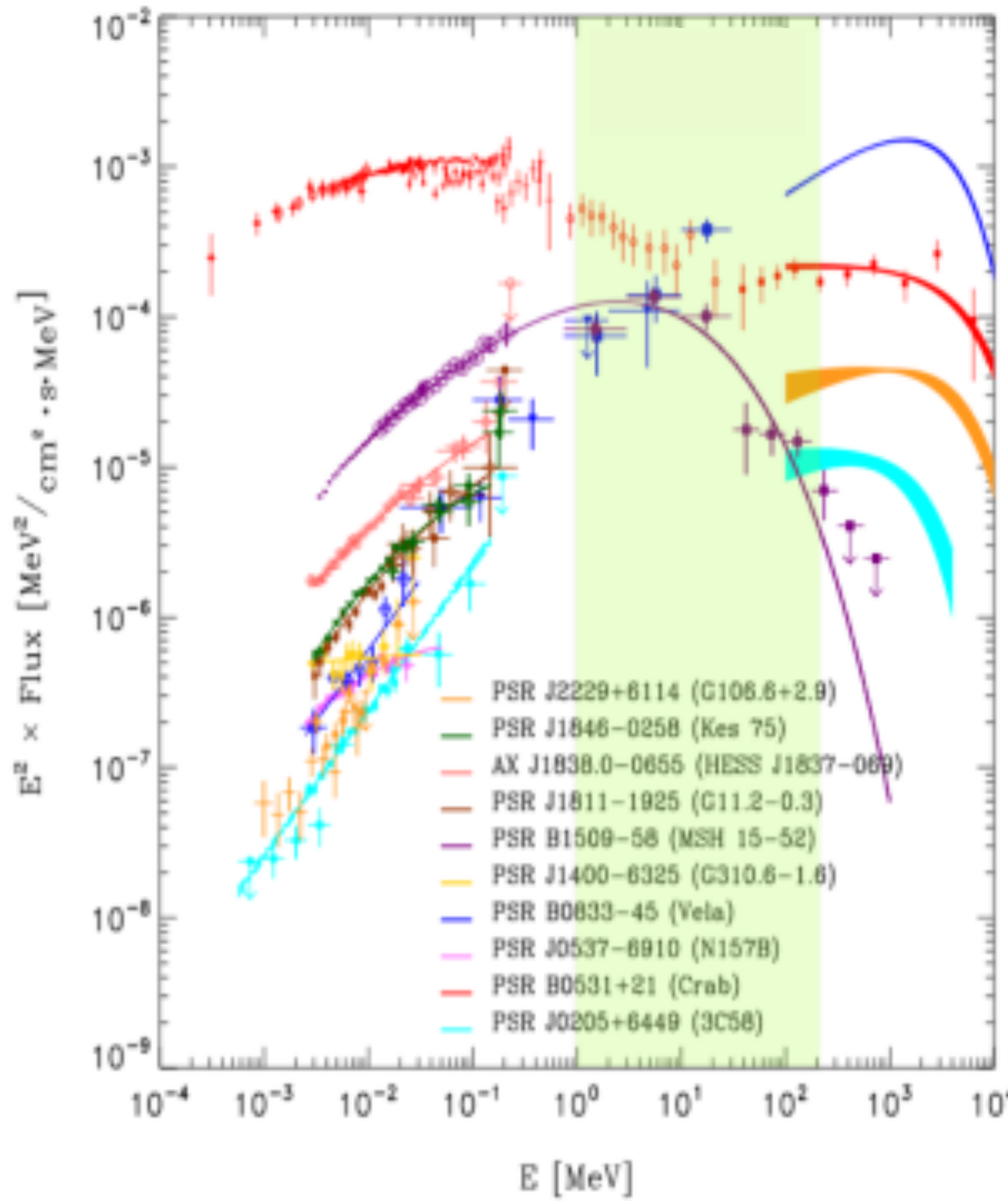
held up by neutron degeneracy pressure

~100 million neutron stars in the Milky Way

Neutron Stars

Magnetars - the strongest magnetic fields in the Universe

Pulsars - rapidly rotating (~ms to s) over 200 known gamma-ray pulsars



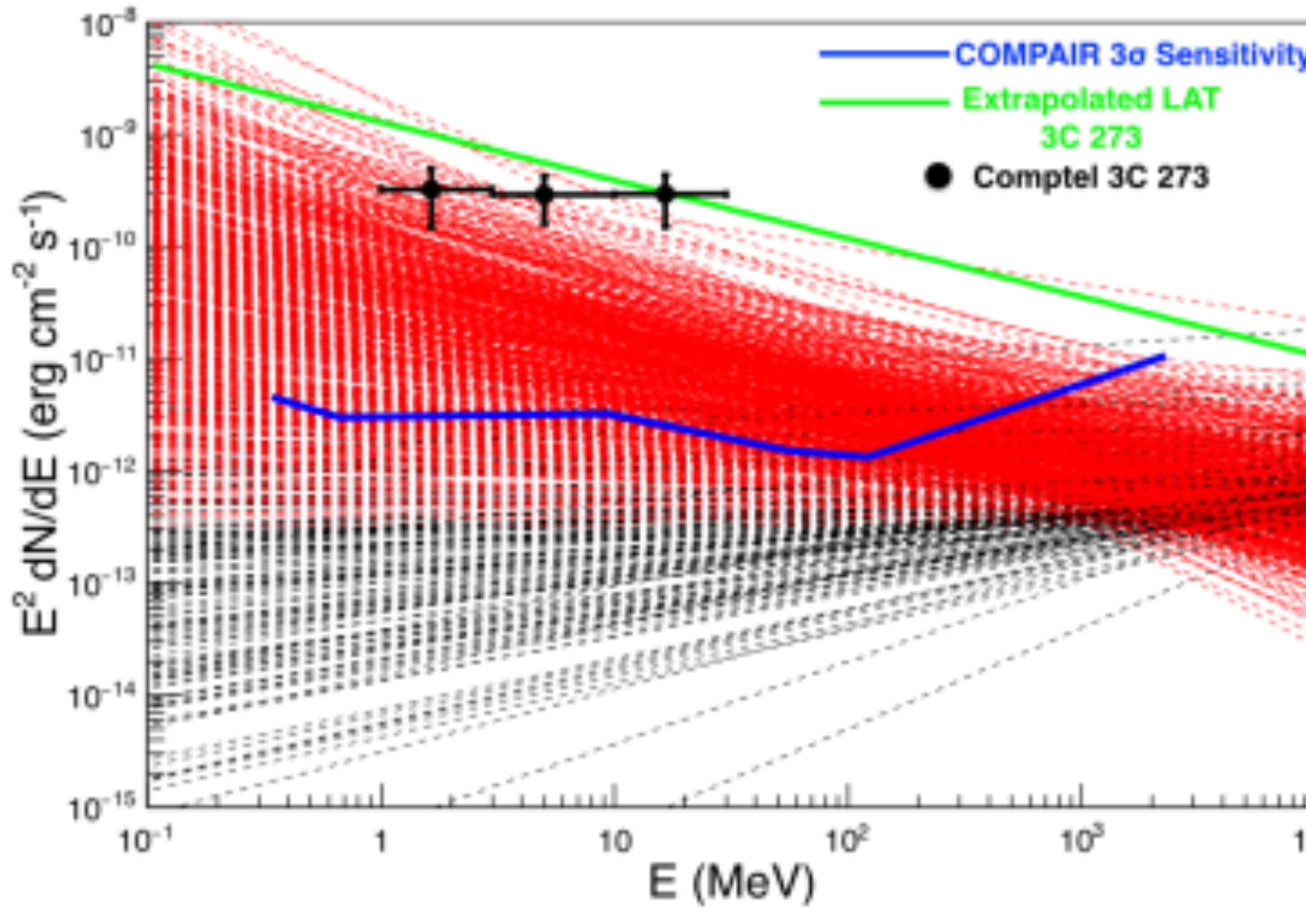
New types of astrophysical object have peak power output in the MeV band and how do they work?

New Sources!

New Physics!

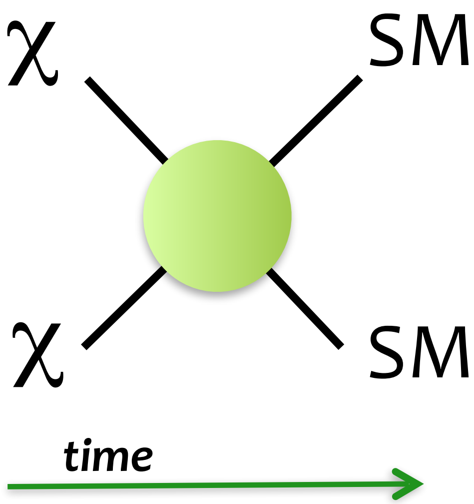
Discovery Space

- 1/3 of Fermi-LAT sources are unidentified (>1000)
    - Bridge between high-energy gamma-ray regime and X-ray regime
- Below 200 MeV: discovery of many new sources and source classes



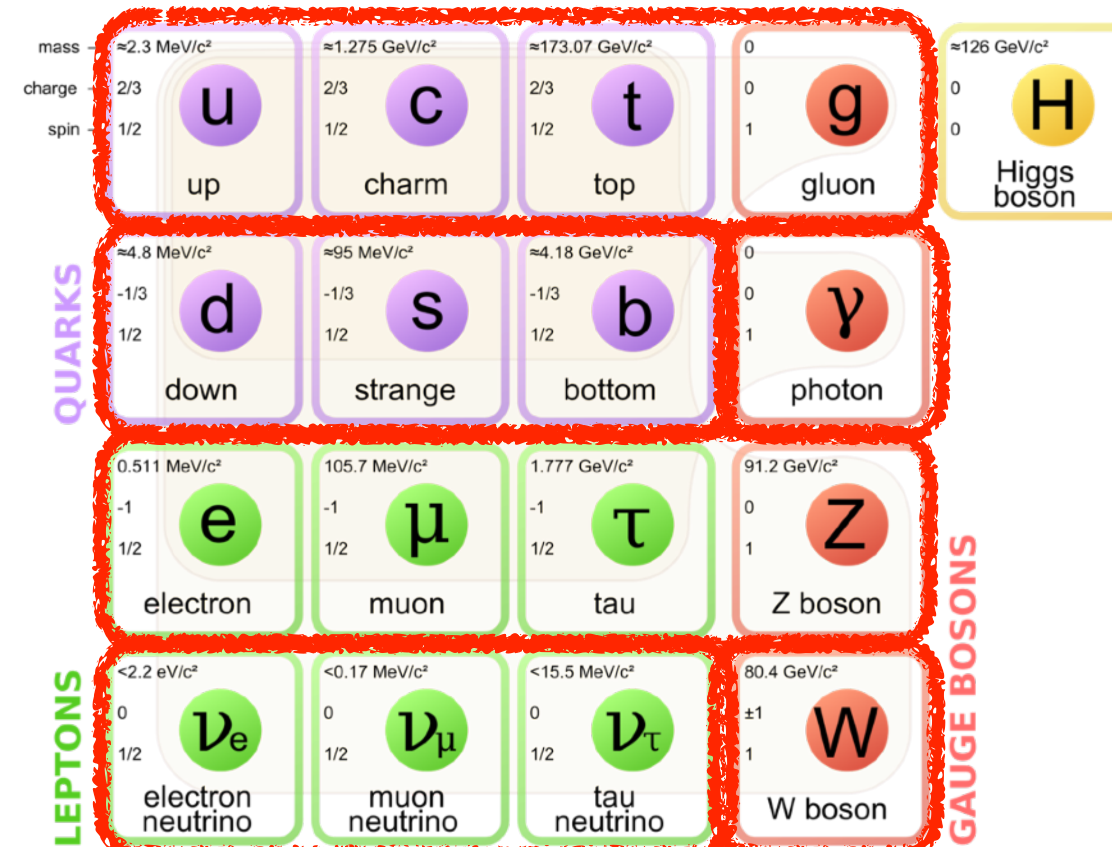
>50% of Fermi-LAT sources peak at energies below LAT sensitivity

Detecting Dark Matter



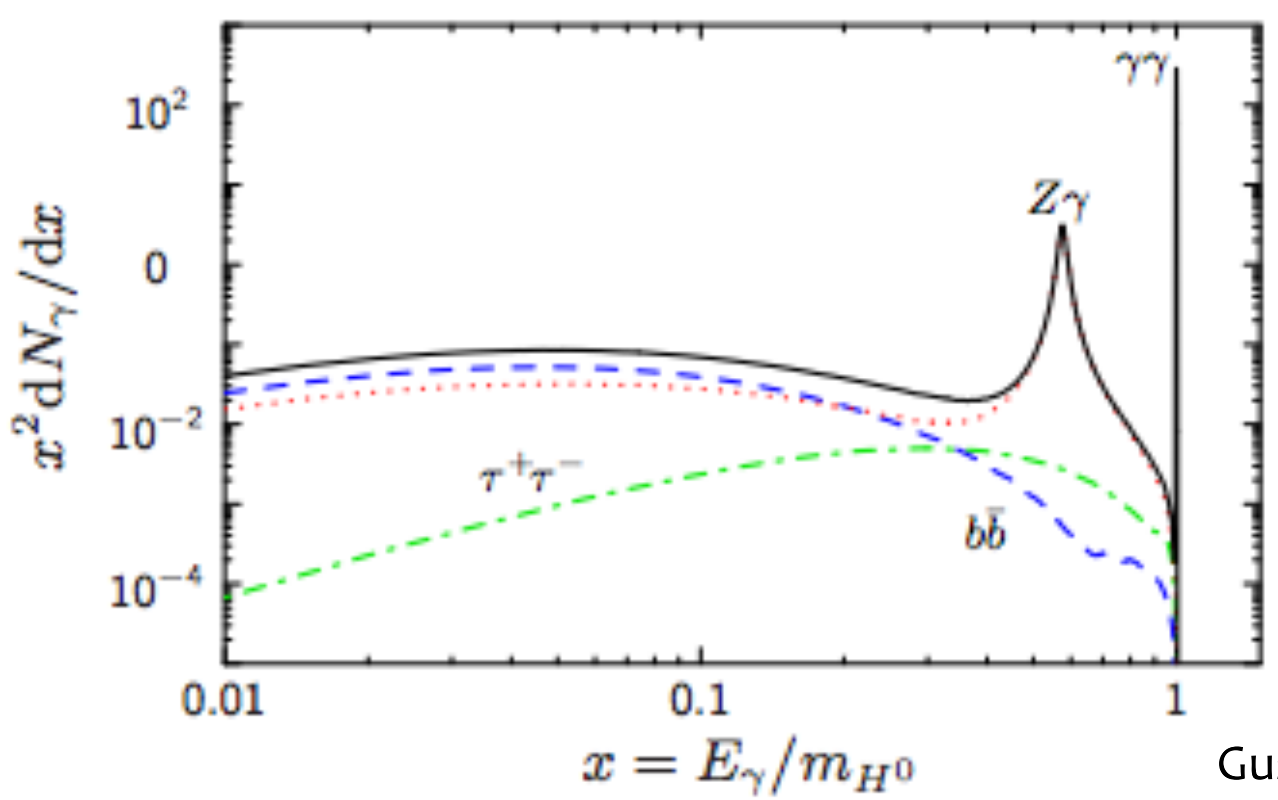
Indirect Detection

SM:



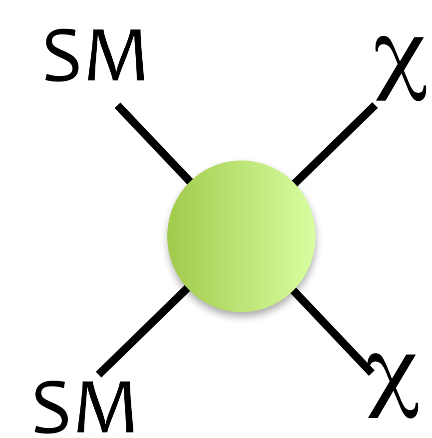
information about mass, point back to source

eventually can get to photons

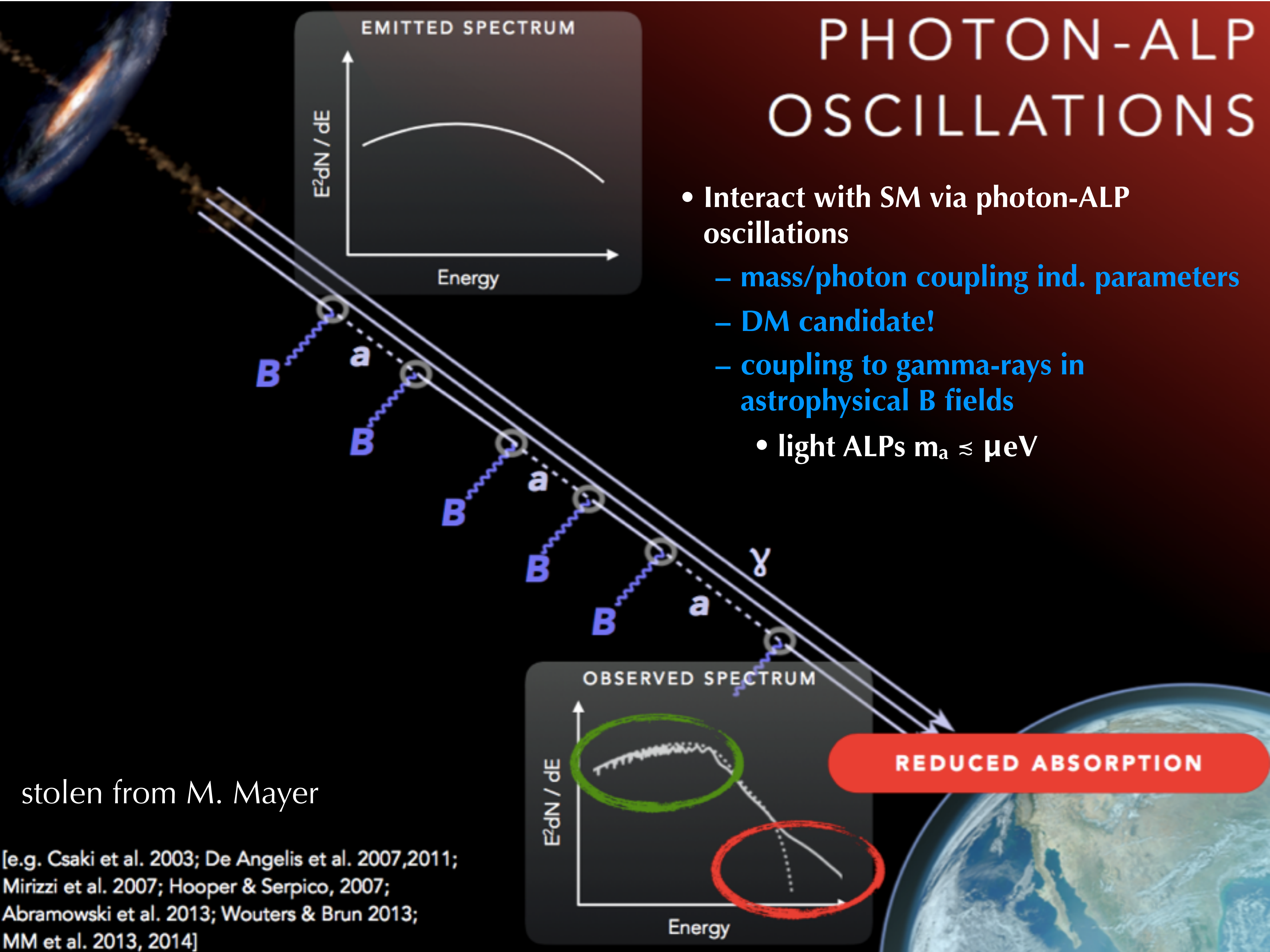


Gustafsson et al.
PRL 99.041301

Collider



PHOTON-ALP OSCILLATIONS



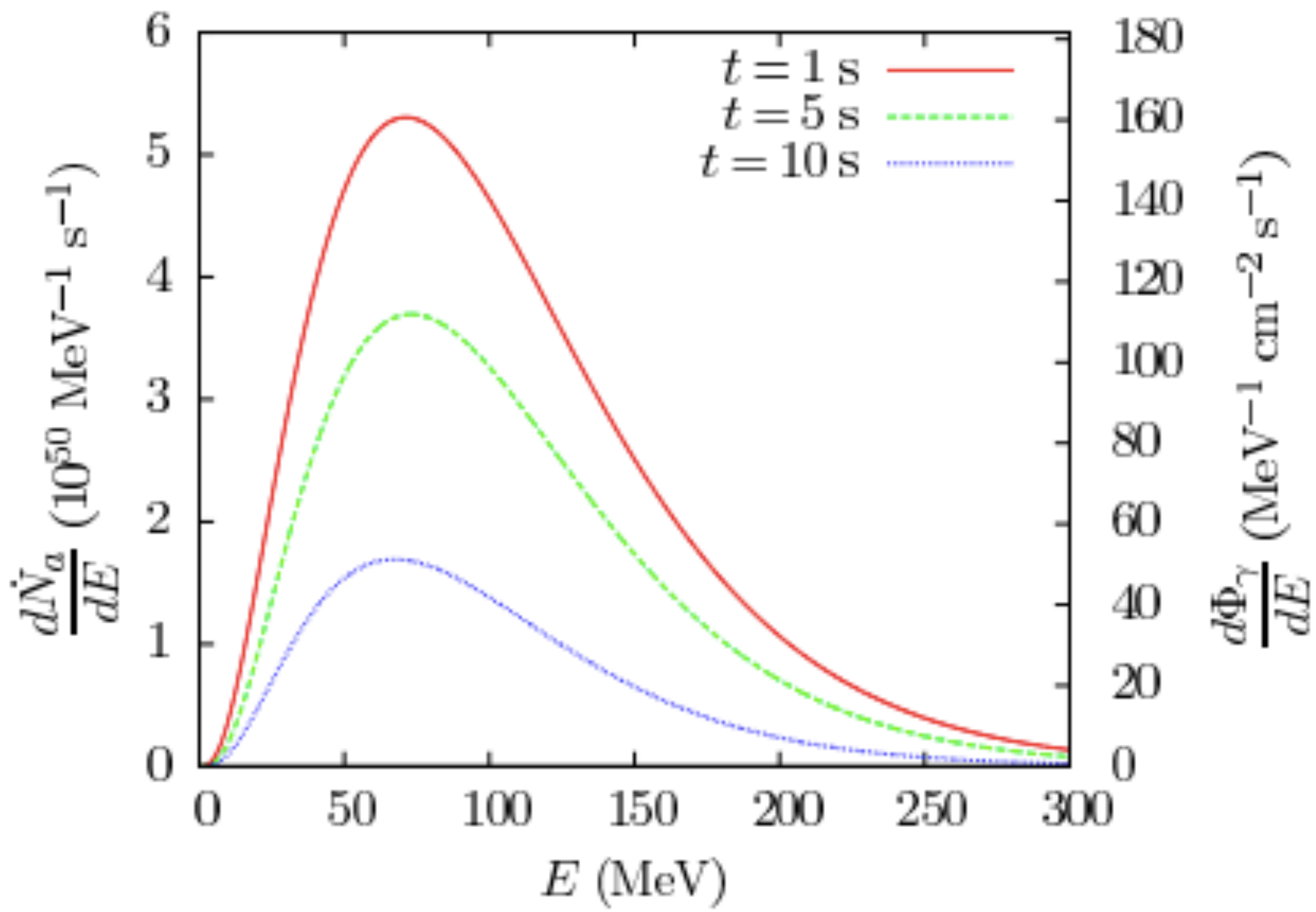
- Interact with SM via photon-ALP oscillations
  - mass/photon coupling ind. parameters
  - DM candidate!
  - coupling to gamma-rays in astrophysical B fields
    - light ALPs $m_a \lesssim \mu eV$

stolen from M. Mayer

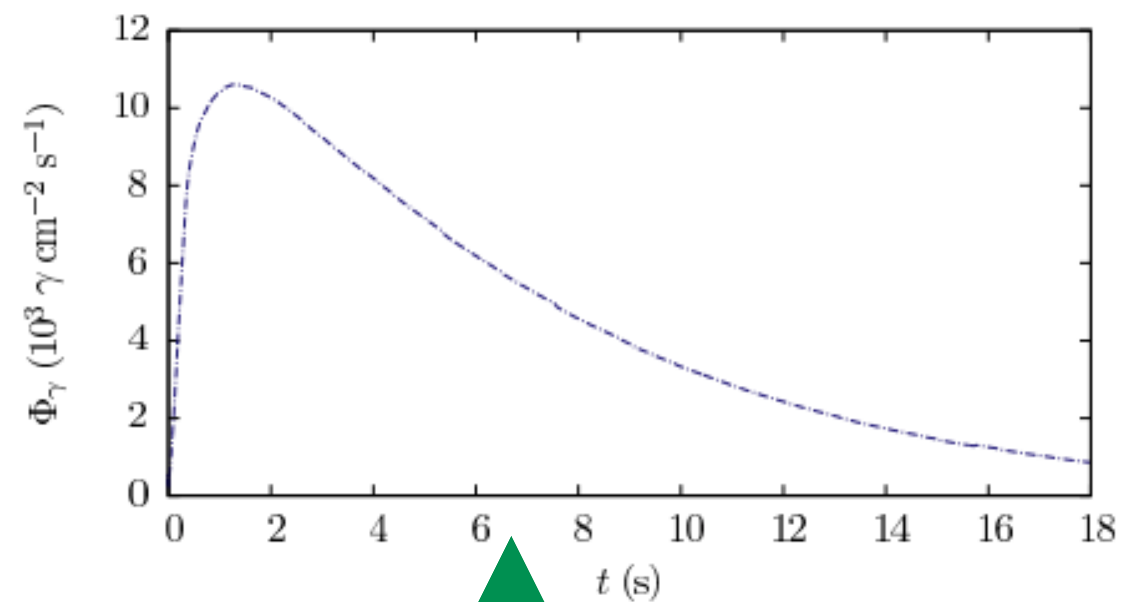
[e.g. Csaki et al. 2003; De Angelis et al. 2007,2011; Mirizzi et al. 2007; Hooper & Serpico, 2007; Abramowski et al. 2013; Wouters & Brun 2013; MM et al. 2013, 2014]

MeV Dark Matter: Axions

- **Axions in neutron stars (hep-ph/0505090)**
  - **emission process for axions with mass up to a few MeV**
  - **production in Gamma Ray Bursts**



ALP (m_a~10^{-11} eV)
with $g_{a\gamma} = 10^{-10}$ GeV^{-1}
18 M_{sol} progenitor



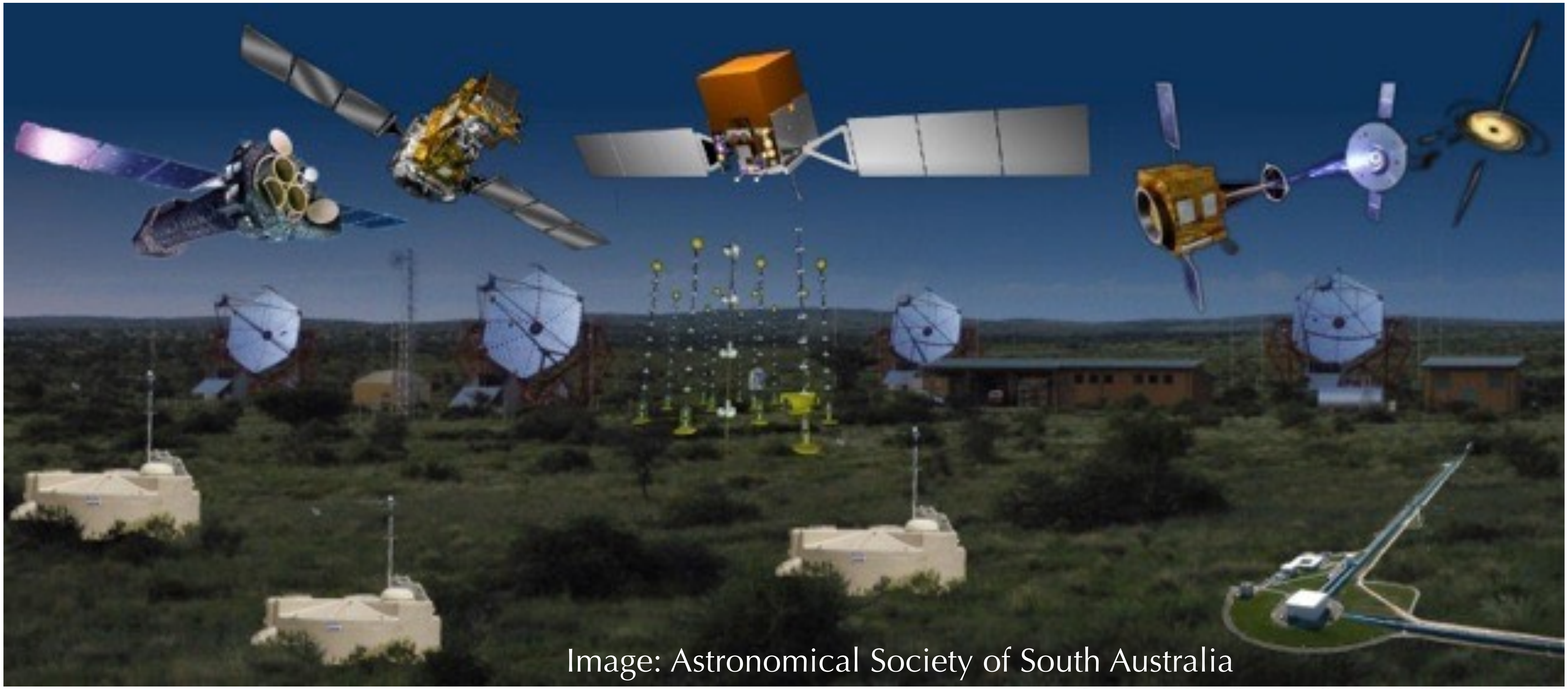
timing of
photons between
(25-100 MeV)
with $g_{a\gamma} = 10^{-10}$ GeV^{-1}
18 M_{sol} progenitor

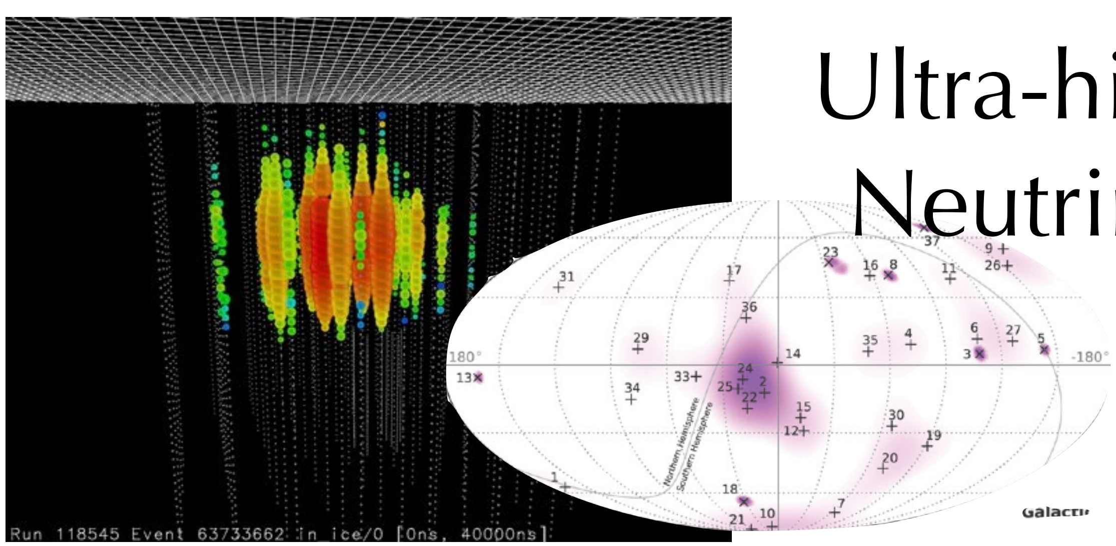
Electromagnetic counterparts of neutrino and gravitational wave sources

Neutrino EM Counterparts

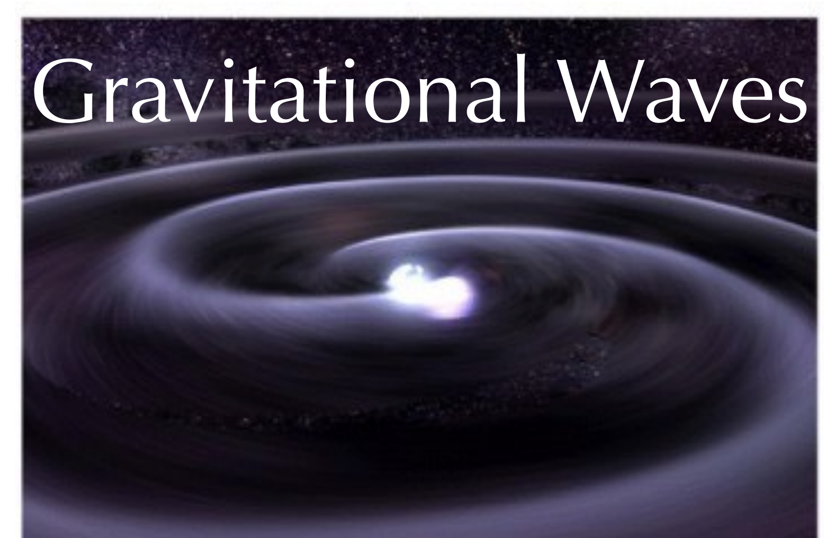
GW EM Counterparts

Multi-messenger Astrophysics





Ultra-high Energy Neutrino events



How do we answer these questions?

Science Requirements

Goal	Energy Range	Spatial Resolution	Time Resolution	Sensitivity	FoV
Jets	~ 0.5 MeV to GeVs	~ 1 deg	< msec	10^{-10} erg/cm^2/s	Large
Compact Objects	~ 0.2 MeV to GeVs	~ 1 deg	< msec	10^{-10} erg/cm^2/s	Large
New Sources	~ 1MeV to GeVs	~ 1 deg	< msec	10^{-10} erg/cm^2/s	Large

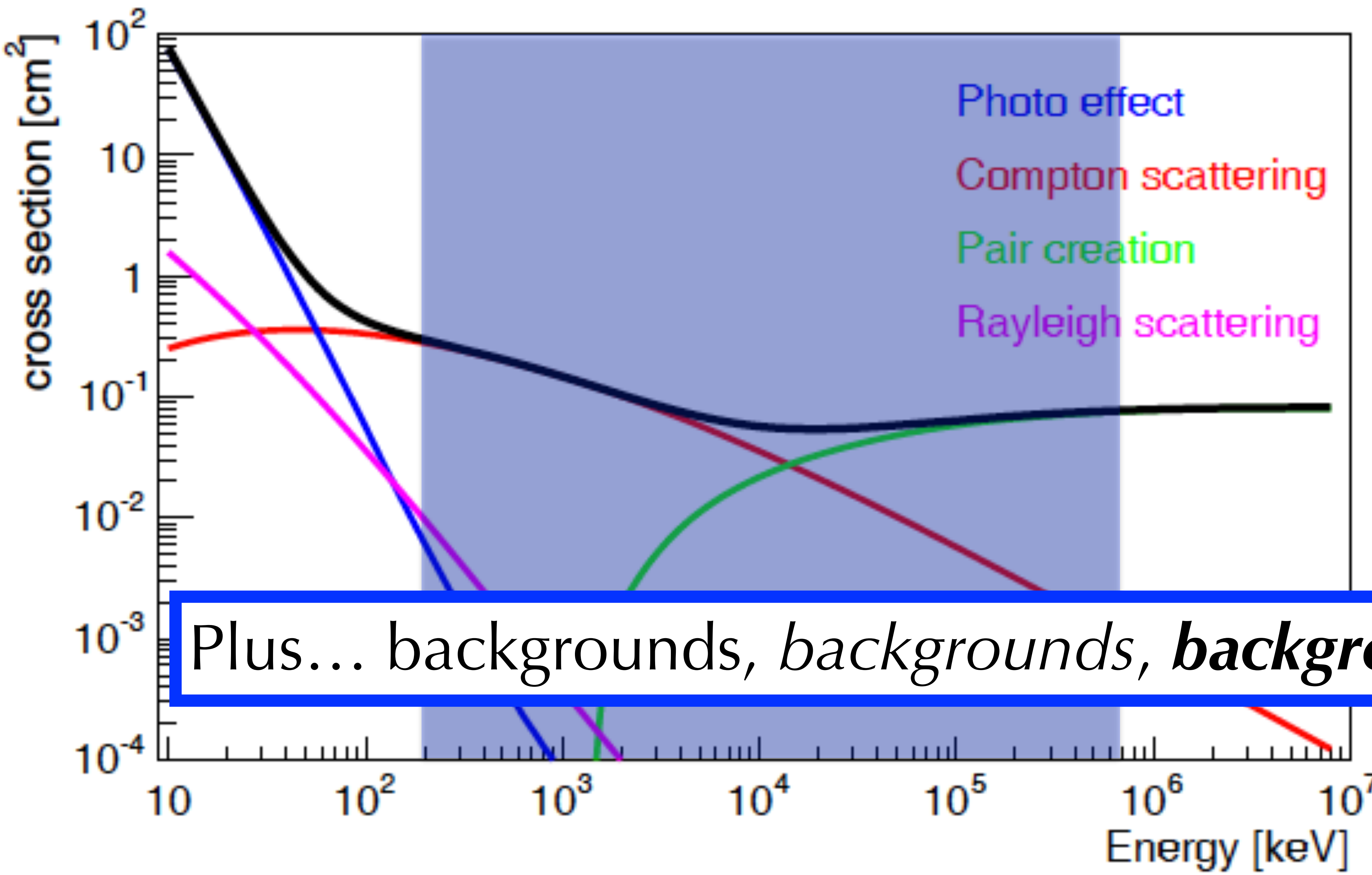
large field-of-view instrument with good angular and energy resolution,
optimized for continuum sensitivity and time domain science

Goals

An instrument that satisfies the following:

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

Challenges



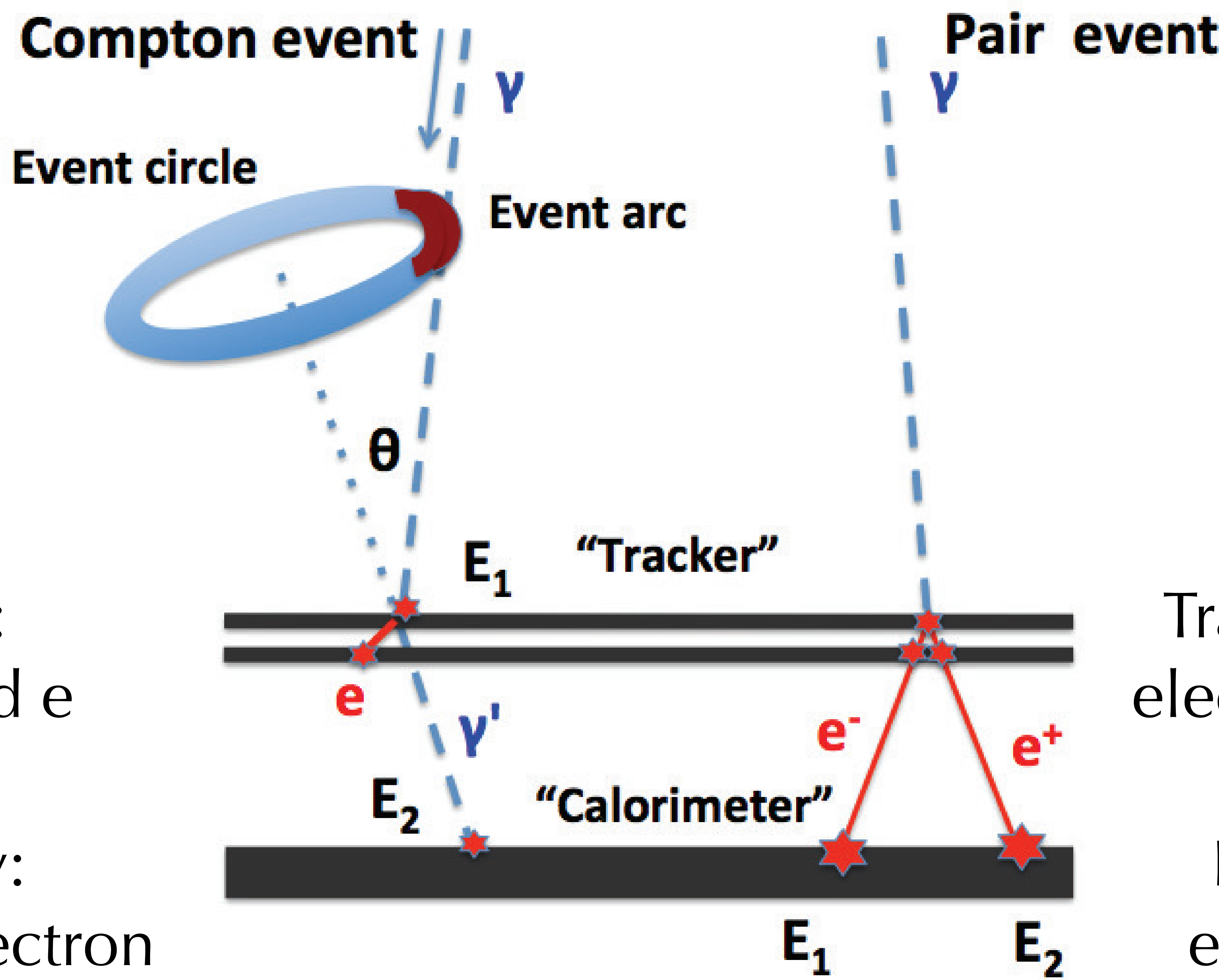
Plus… backgrounds, *backgrounds*, ***backgrounds***

Between 0.1 and 100 MeV, gamma-rays interact via two different physical processes
To fill the "MeV Gap" need to consider both Compton Scattering and Pair Production

Compton/Pair Production Boundary

Track:
scattered e

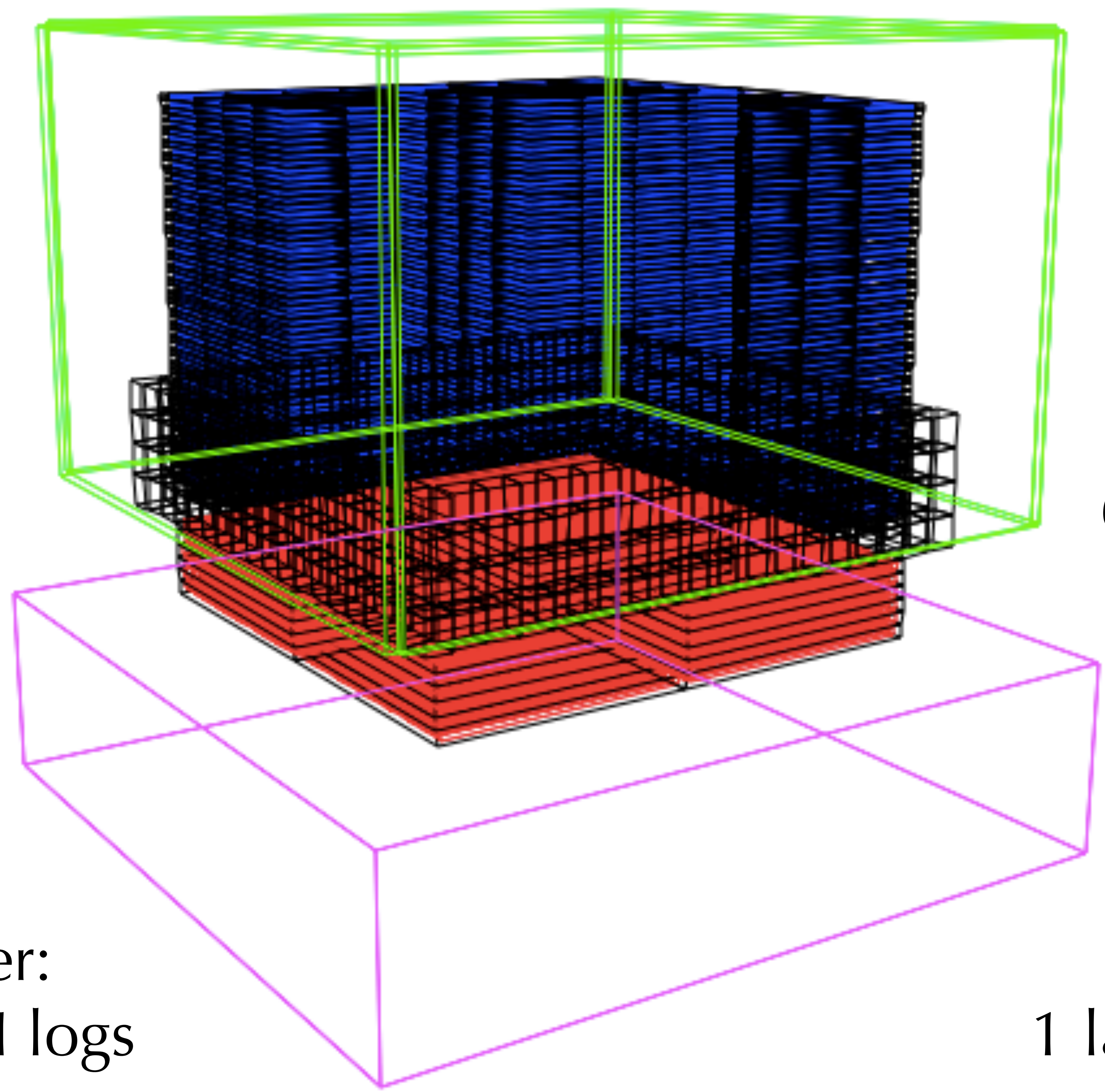
Energy:
photon, electron



Tracks:
electrons

Energy:
electrons

AMEGO Instrument



ACD:
charged particle
veto

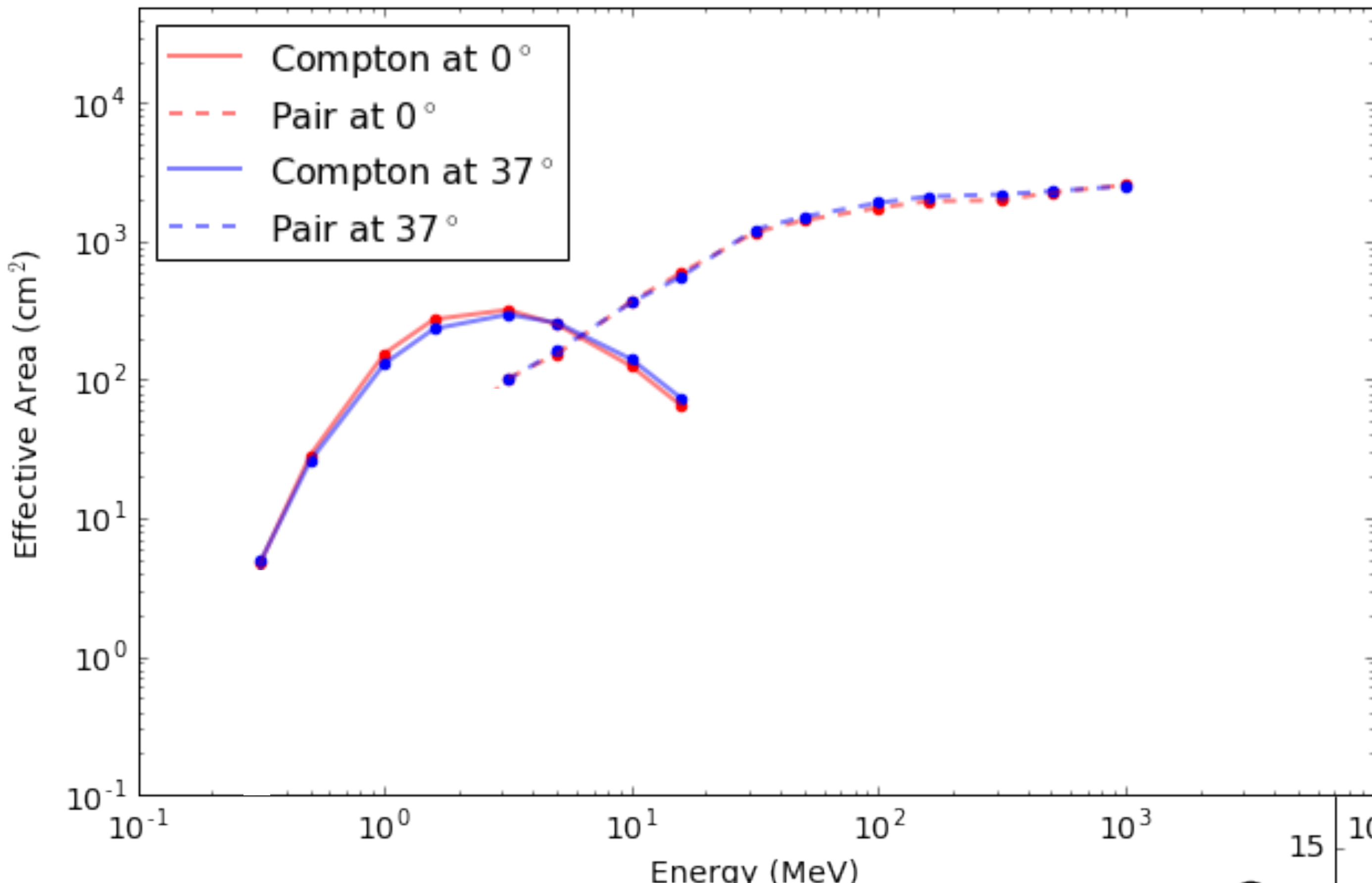
Tracker:
60 layers of DSSD
spaced by 1 cm

Calorimeter:
6 layers of CsI logs
1.5x1.5x38 cm

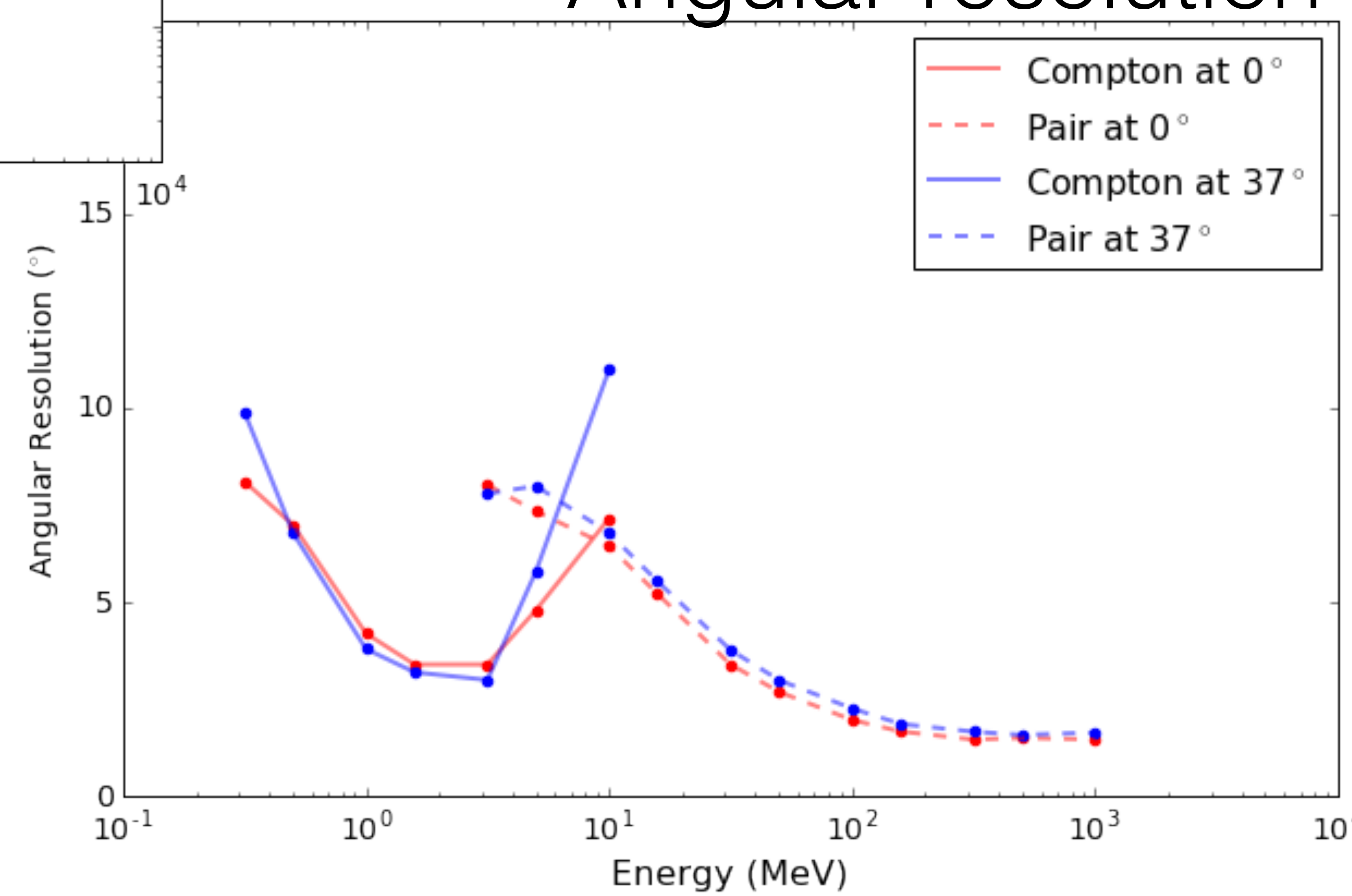
Calorimeter:
1 layer of CZT logs
+ side CZT logs

Performance Plots

Effective Area



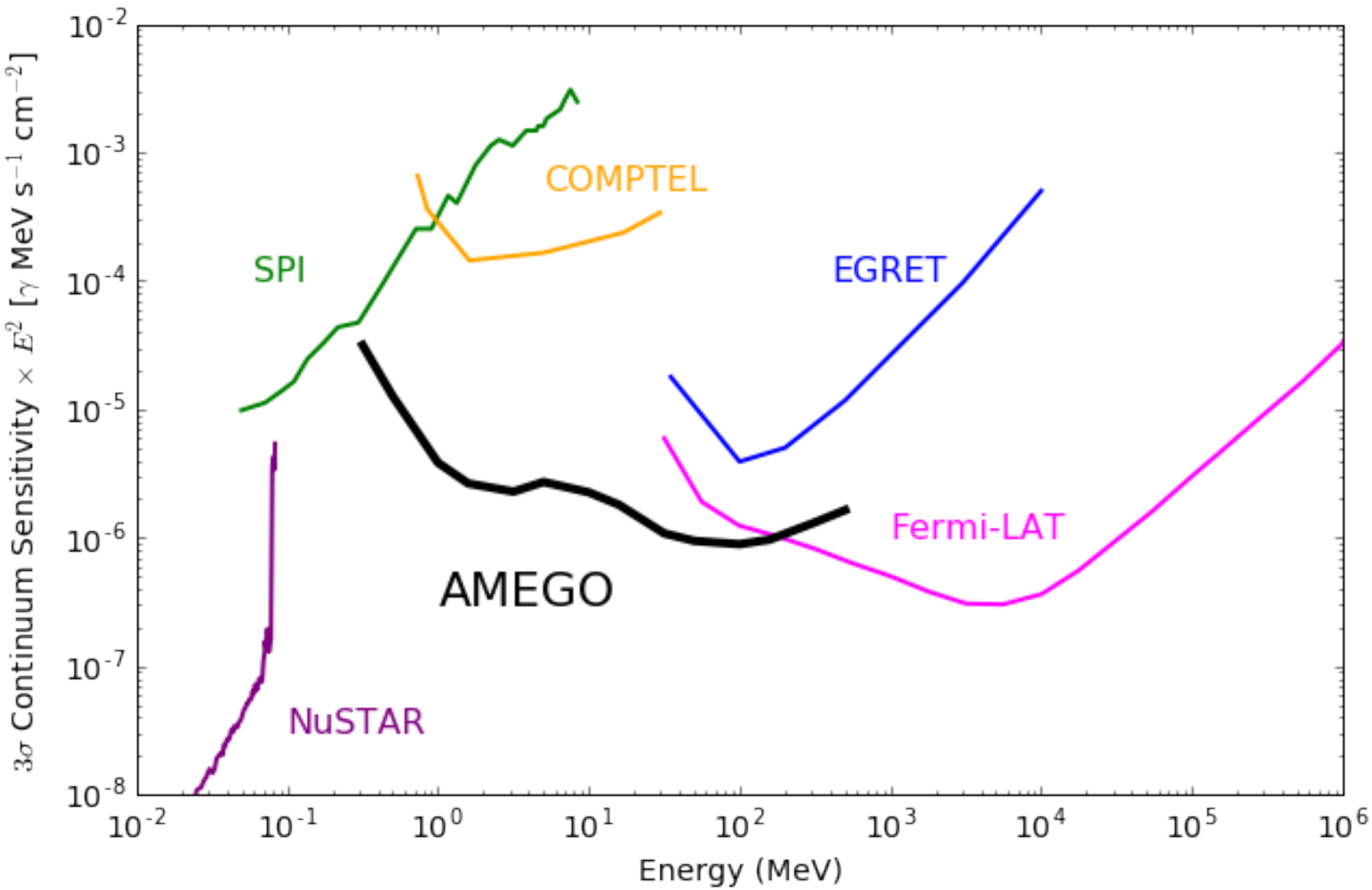
Angular resolution



Simulation in MEGAlib

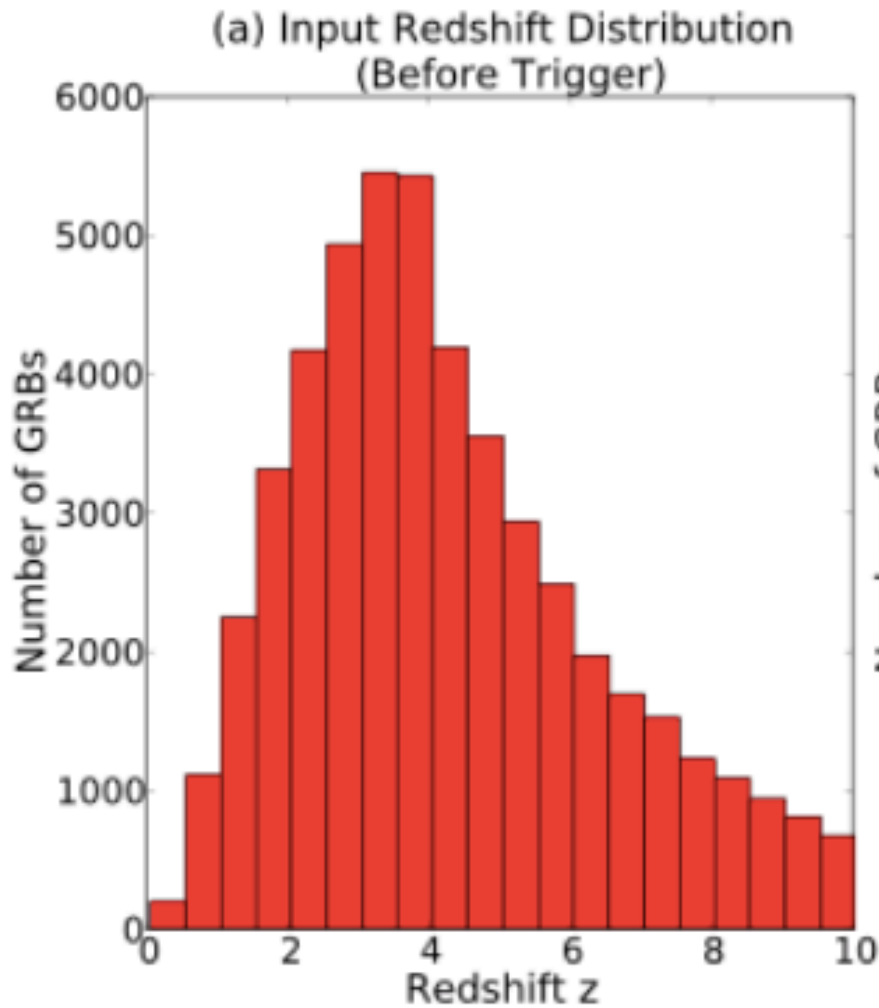
http://megalibtoolkit.com

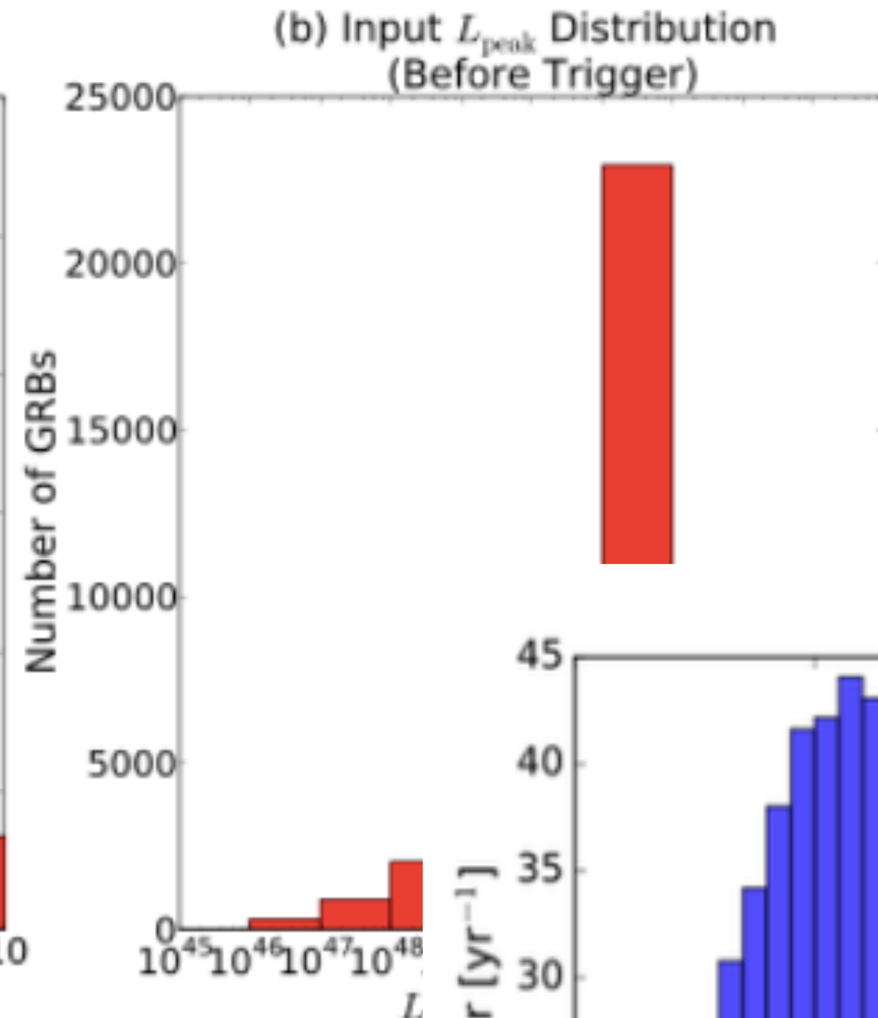
Performance Plots

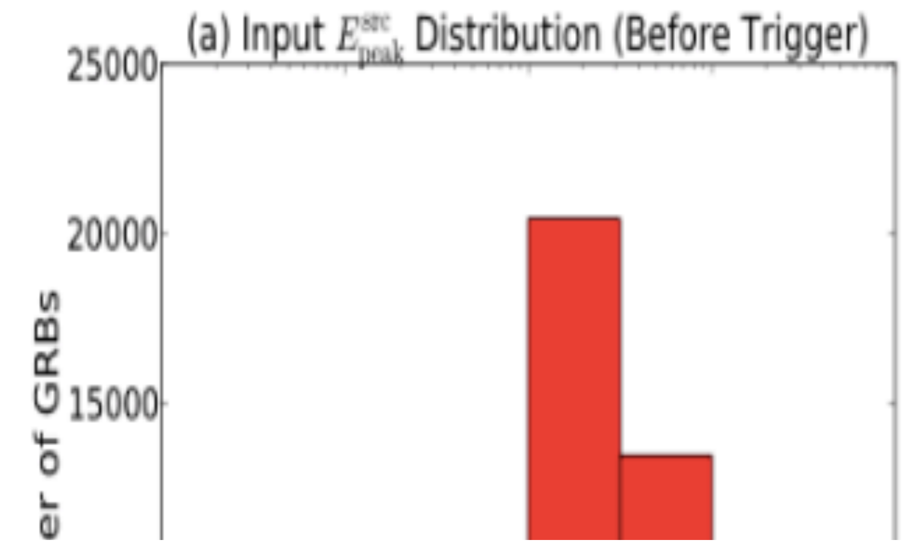


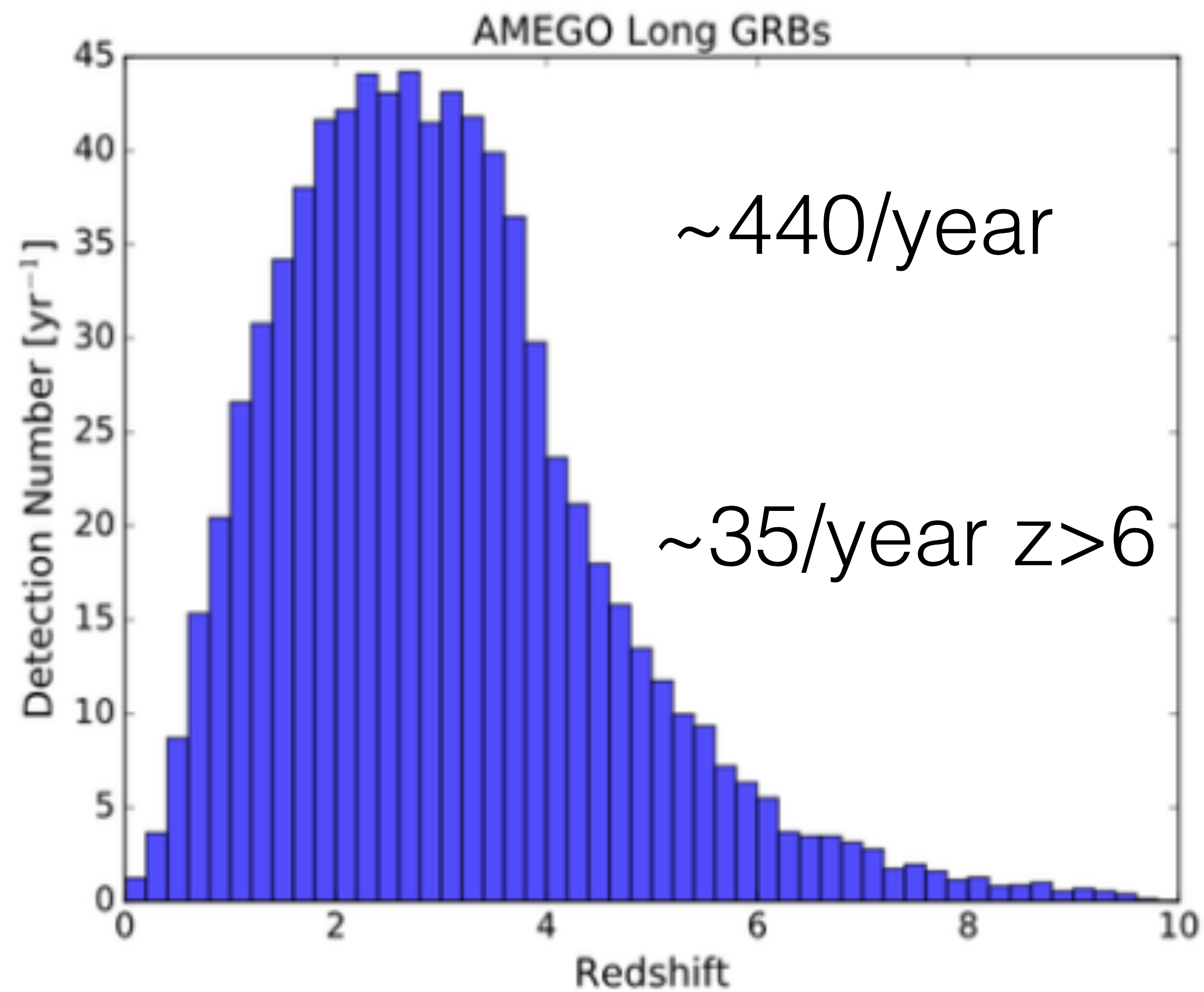
What we can do with this…

GRBs… what about them?





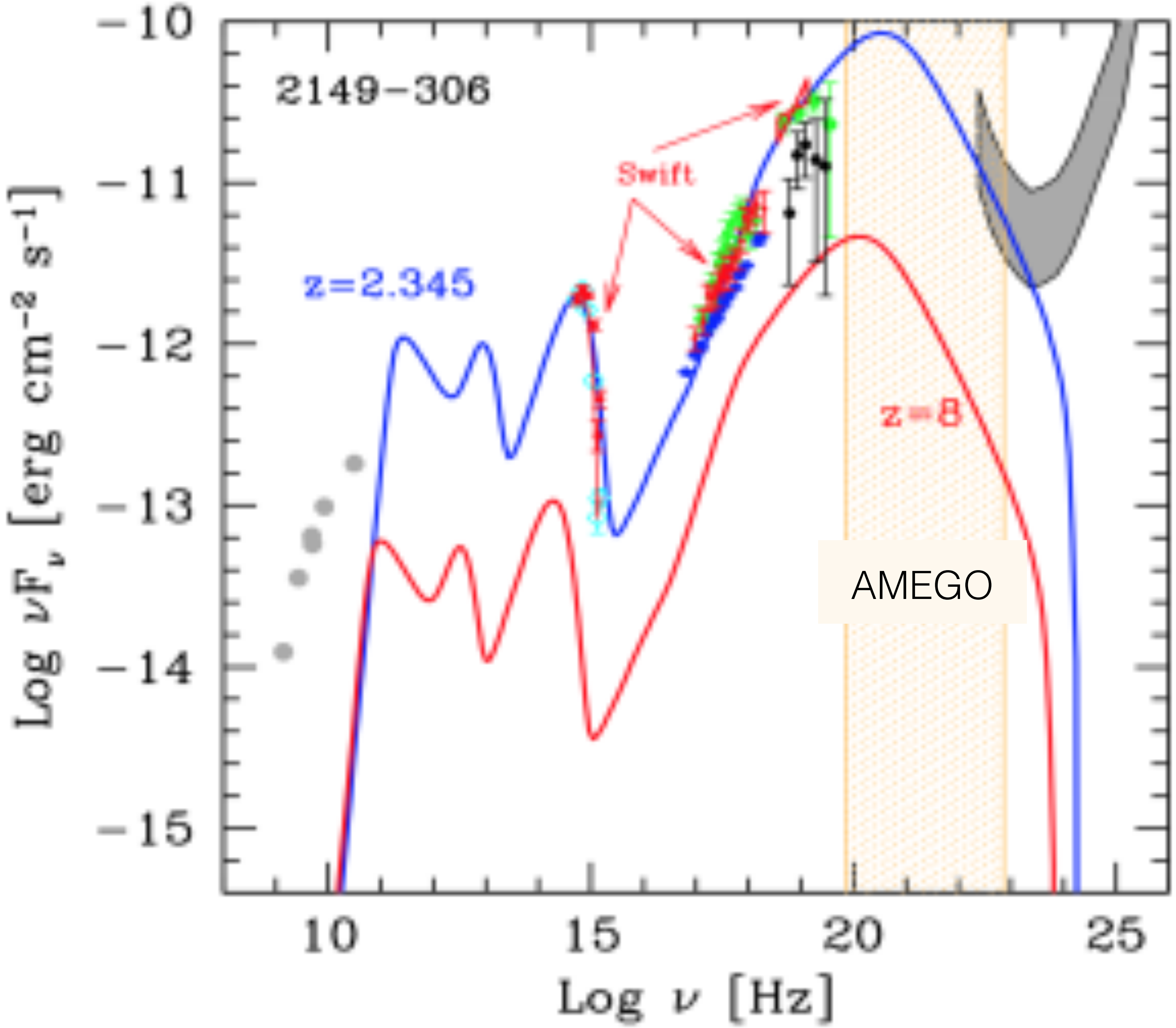




~4500 intrinsic long GRBs…

* sensitivity * FOV

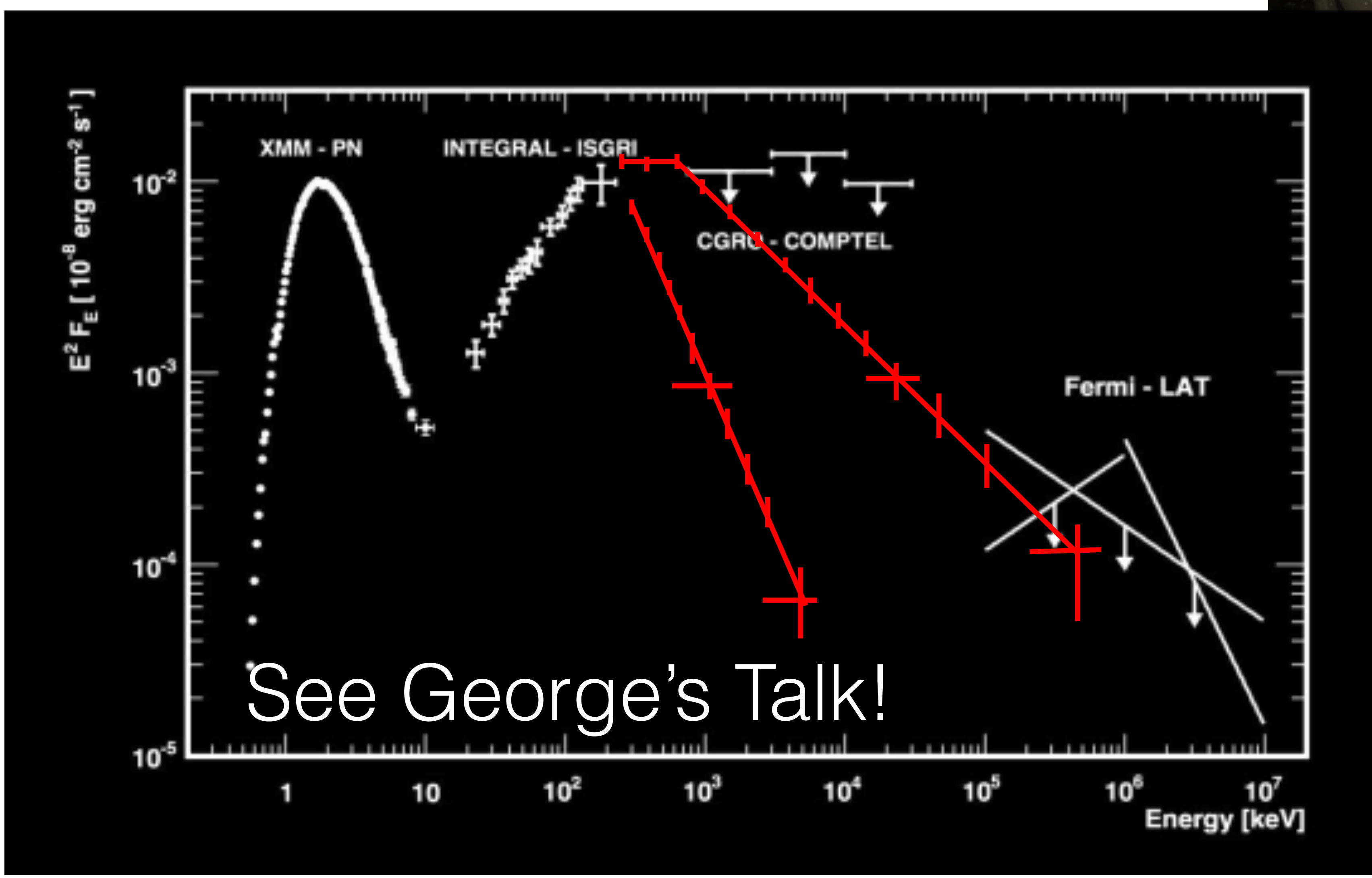
And about those MeV blazers?



- Goal: Detect >500 Blazers to z~6-8

Compact Objects: Magnetars

Neutron Stars with
Extreme Magnetic Fields

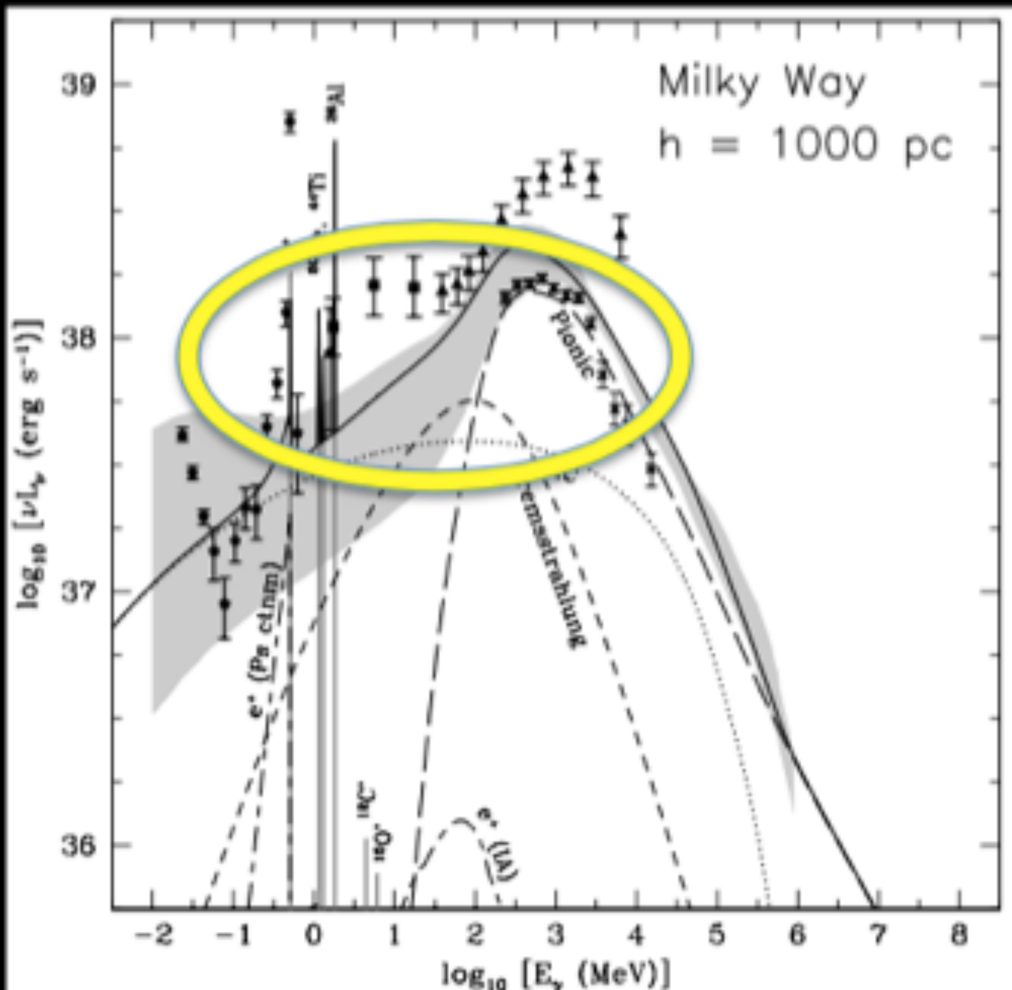


Strong magnetic fields,
rotation period(1-10 s)
<30 known

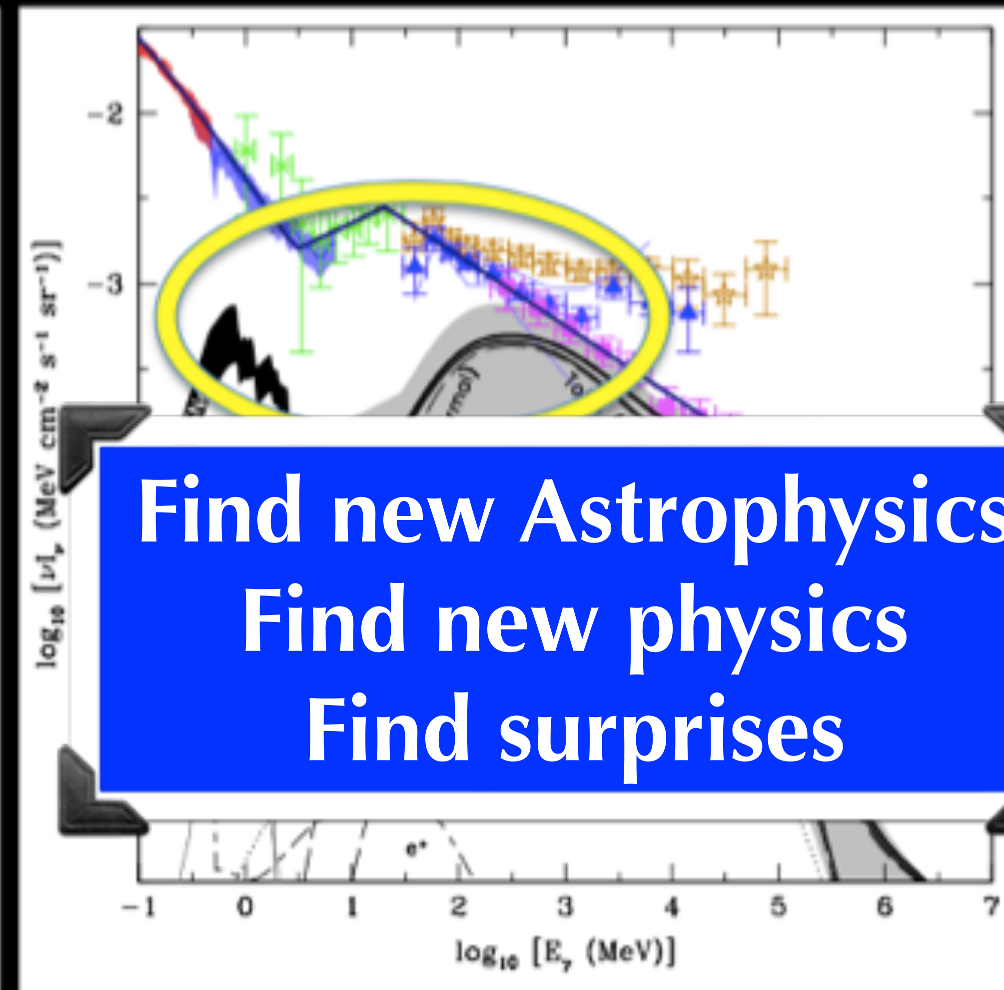
Soft Gamma-ray repeaters
Anomalous x-ray pulsars

MeV Messes are Holding Back Progress

MeV Excess: Galactic



MeV Excess: Cosmic



Find new Astrophysics
Find new physics
Find surprises

Lacki, Horiuchi, Beacom 2014

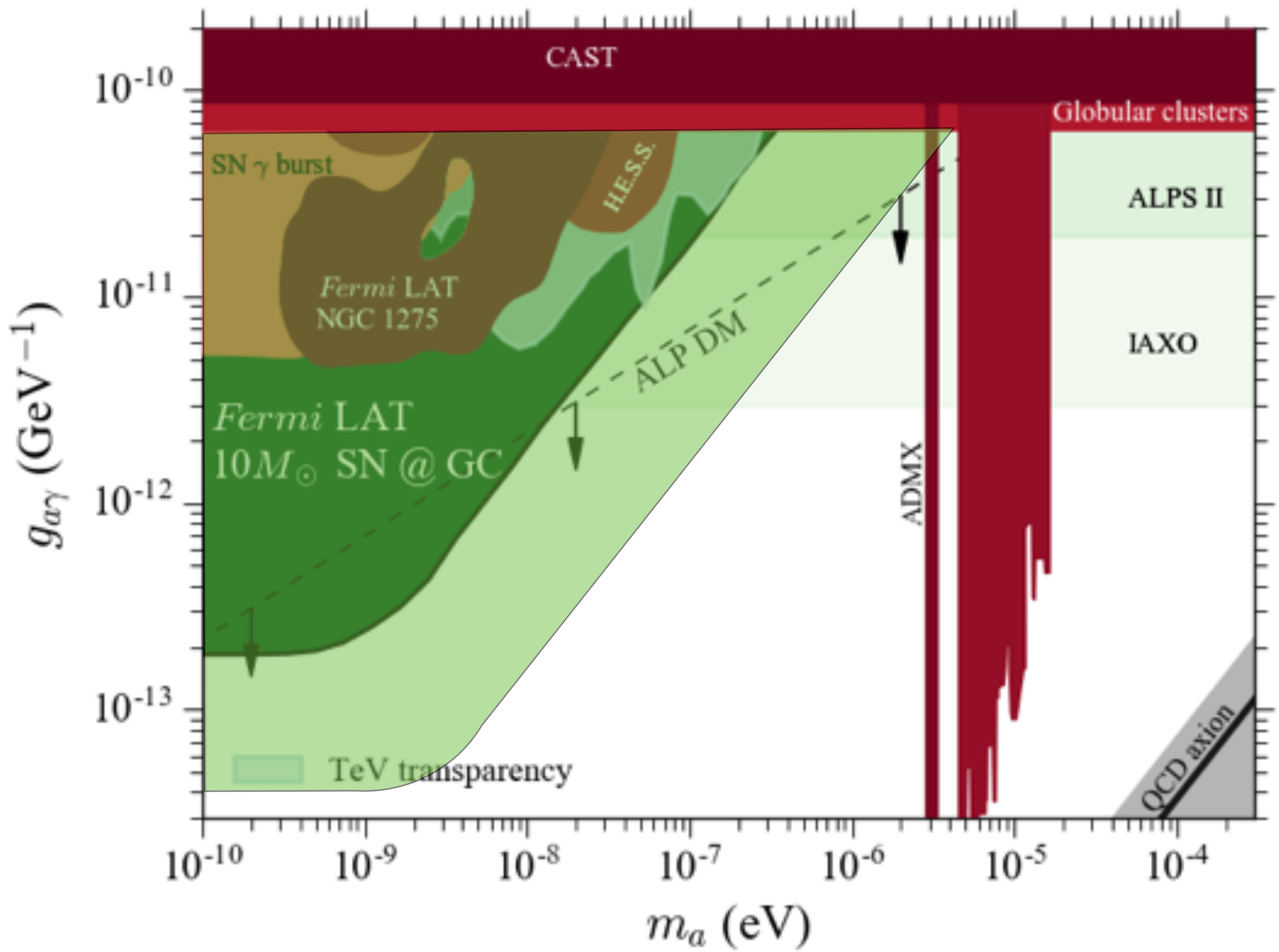
See also Strong, Moskalenko, Reimer 2004 (x2)

Also: 511 keV excess unsolved, Type Ia supernovae not understood, MeV sky never properly studied

New MeV missions are essential and urgent

MeV Dark Matter: Axions

- **Axions produced in supernovae (arXiv:1410.3747)**
  - **core collapse supernova (SN1987A)**



Limited by PSF @<100 MeV

These are just some of the topics we're actively working on…

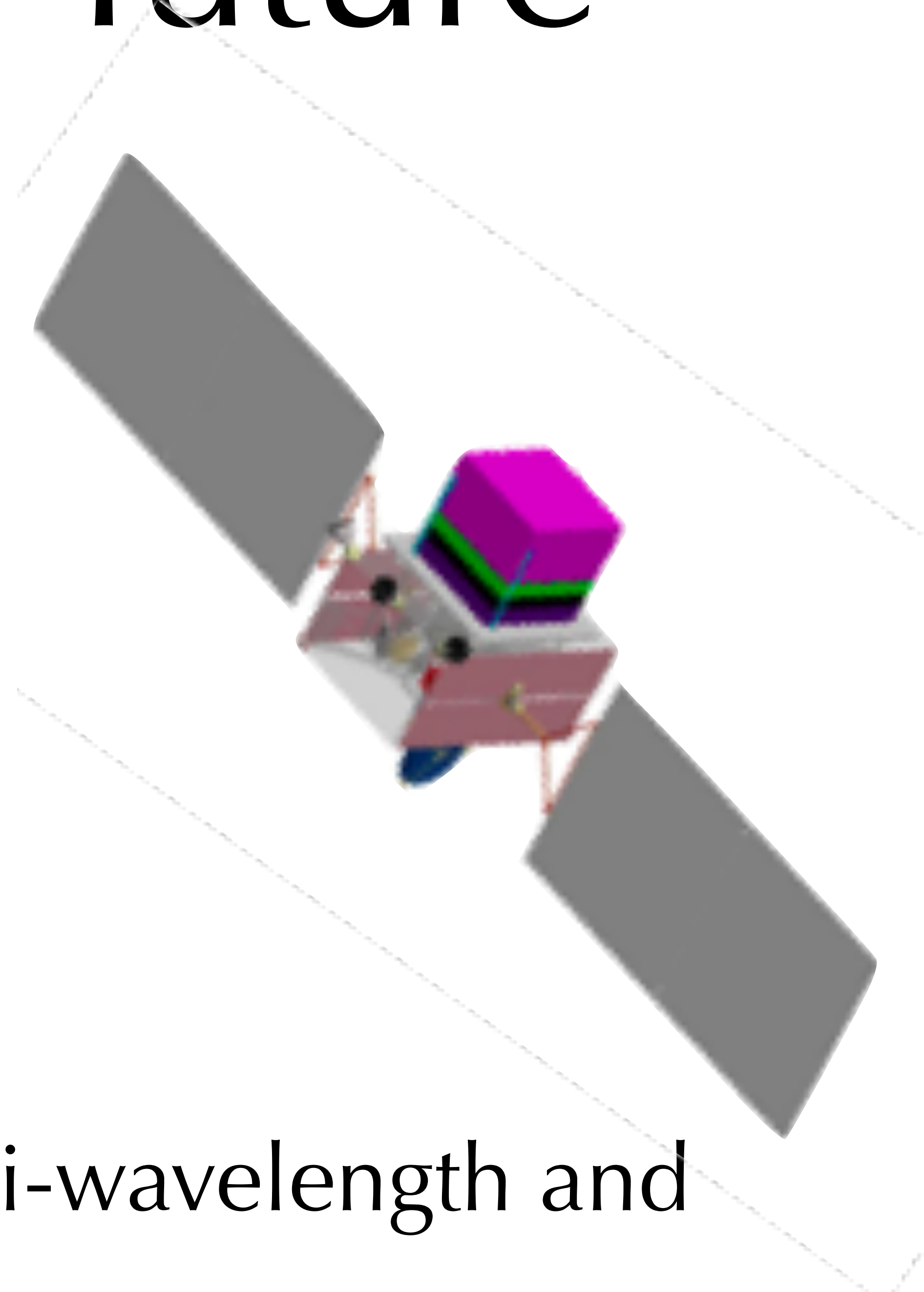
There's also polarization, SN1a, nuclear lines… and much much more

Current Mission Status

- NASA probe scale mission
  - Funded for to develop a prototype detector for beam tests and balloon flight
- What we would like…
  - Interest for you/your advisor we'd like you to get involved…

https://asd.gsfc.nasa.gov/amego/index.html

The Gamma-ray future



- Critical for understanding the most highly energetic universe
    - all-sky instrument with continuum sensitivity
- Guaranteed new discovery space
- Uniquely able to participate in multi-wavelength and multi-messenger astronomy
    - synergies with GW/Neutrino/ground gamma-ray instruments, current/future space missions… etc.


Questions?