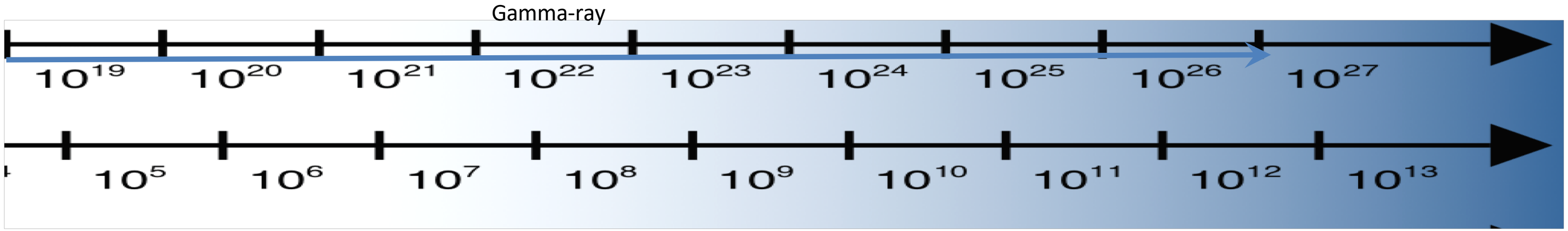
Gamma-rays From Space: Where next?

Julie McEnery (NASA/GSFC)

Gamma-ray Astrophysics

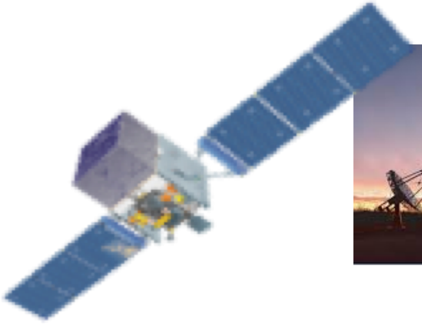
Freq (Hz)
Energy (ev)

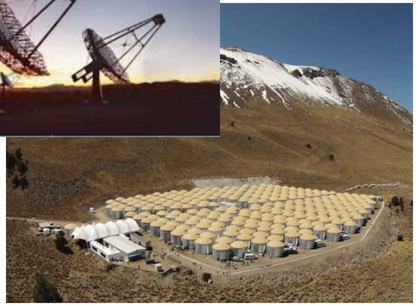


Medium Energy gamma-rays (aka MeV)

High Energy gamma-rays (aka GeV)

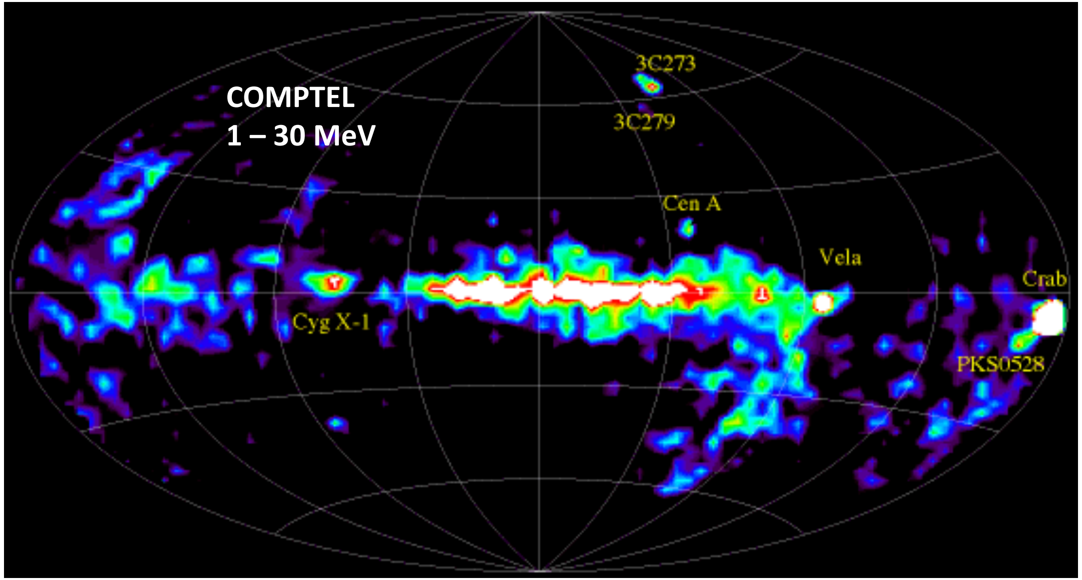
Very High Energy (VHE) gamma-rays (aka TeV)





The MeV Gamma-ray Sky

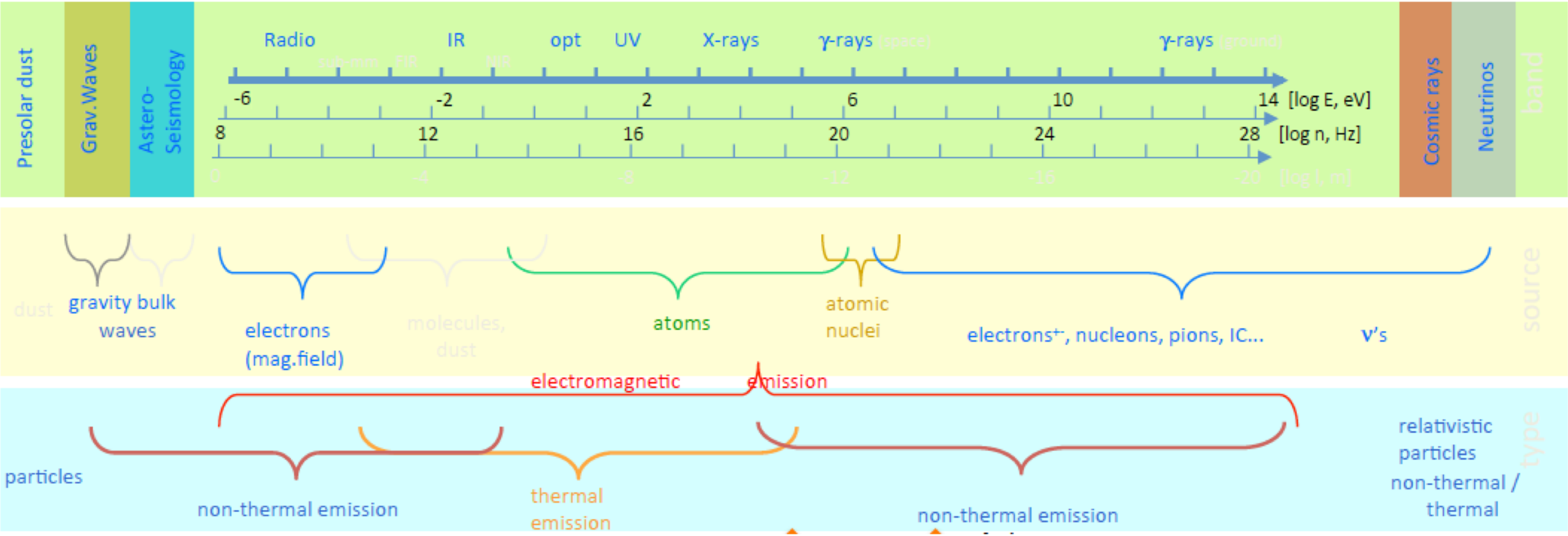
32+ steady sources and 31 GRBs (Schoenfelder et al. 2000)



?

No significant advances in this energy band in ~20 years

Nuclear processes and the MeV Band

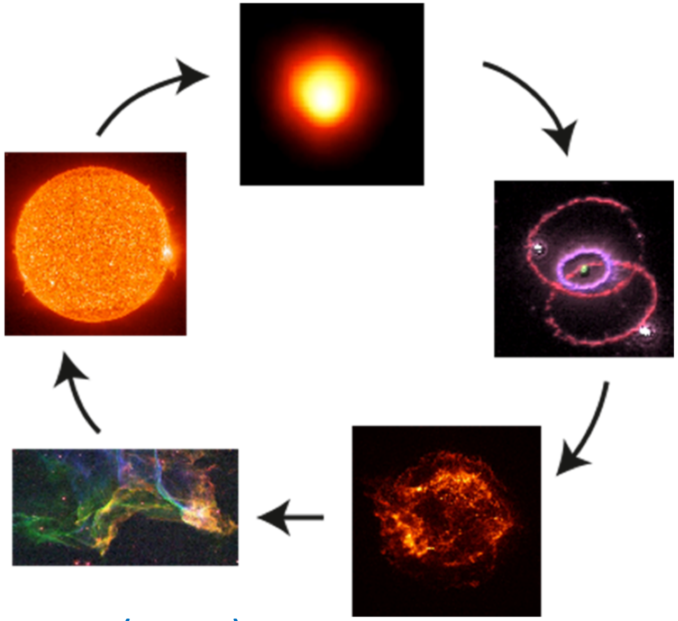


- The MeV Band is special
- Nuclear processes (i.e. atomic nuclei de/excitation) only accessible at observation energies of 0.05 to 16 MeV

Gamma-ray Spectroscopy

Nuclear lines explore Galactic chemical evolution and sites of explosive element synthesis (SNe)

- Electron-positron annihilation radiation
  - $e^+ + e^- \rightarrow 2\gamma$ (0.511 MeV)
- Nucleosynthesis
  - Giants, CCSNe (^{26}Al)
  - Supernovae (^{56}Ni, ^{57}Ni, ^{44}Ti)
  - ISM (^{26}Al, ^{60}Fe)
- Cosmic-ray induced lines



56Ni: 158 keV 812 keV (6 d)
56Co: 847 keV, 1238 keV (77 d)
57Co: 122 keV (270 d)

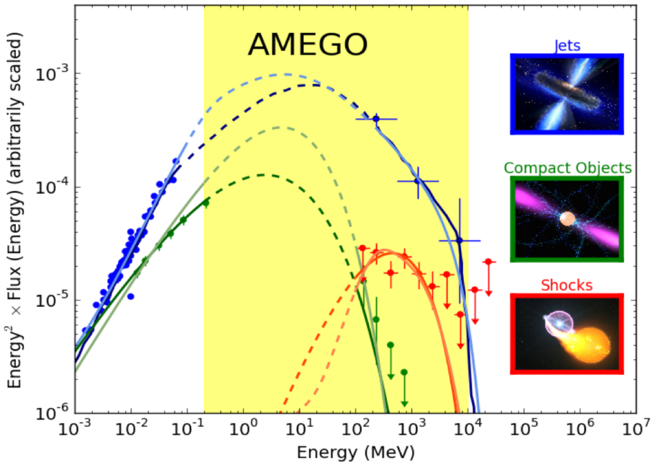
44Ti: 1.157 MeV (78 yr)
26Al: 1.809 MeV (0.7 Myr)
60Fe: 1.173, 1.332 MeV (2.6 Myr)

Medium Energy Gamma-ray Astrophysics

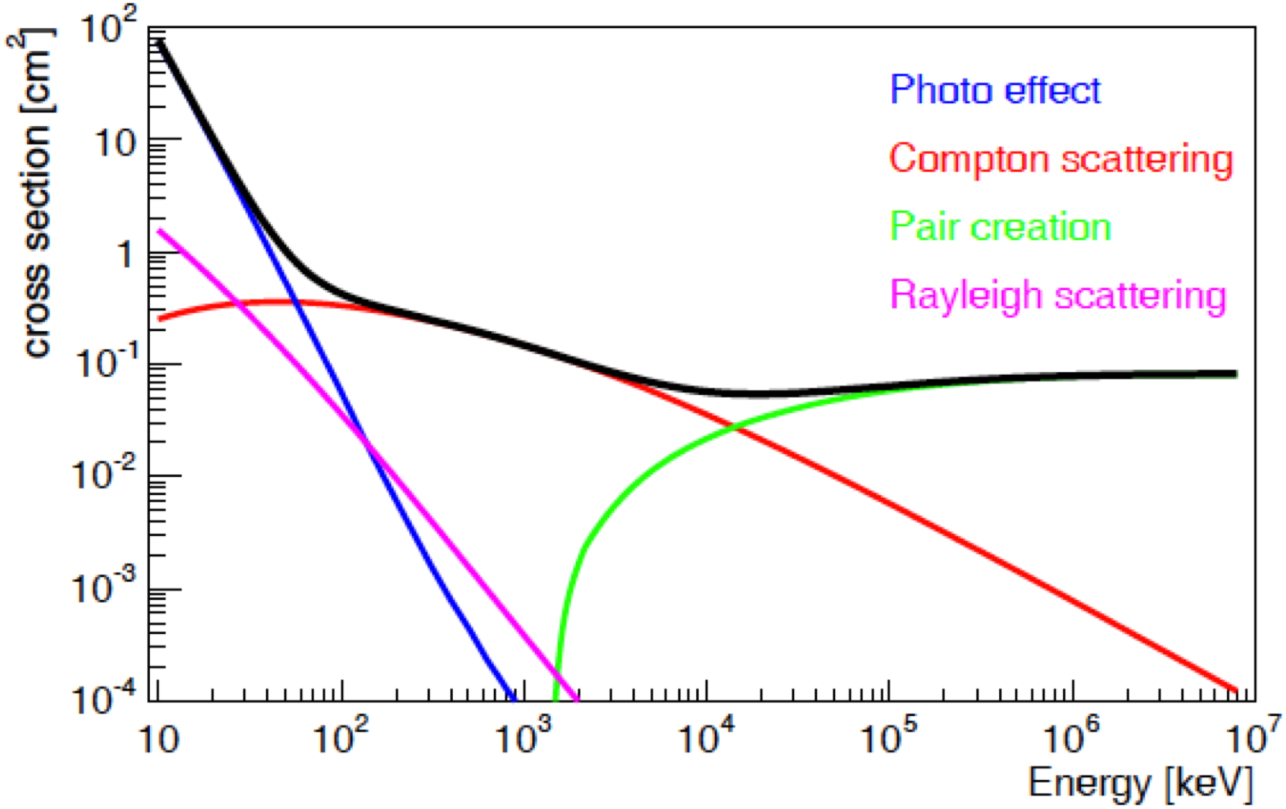
- Understanding how the Universe works requires observing astrophysical sources at the wavelength of **peak** power output **crucial for source energetics**
- Fermi, NuSTAR, and Swift BAT have uncovered source classes with peak energy output in the poorly explored MeV band

A critical energy band –

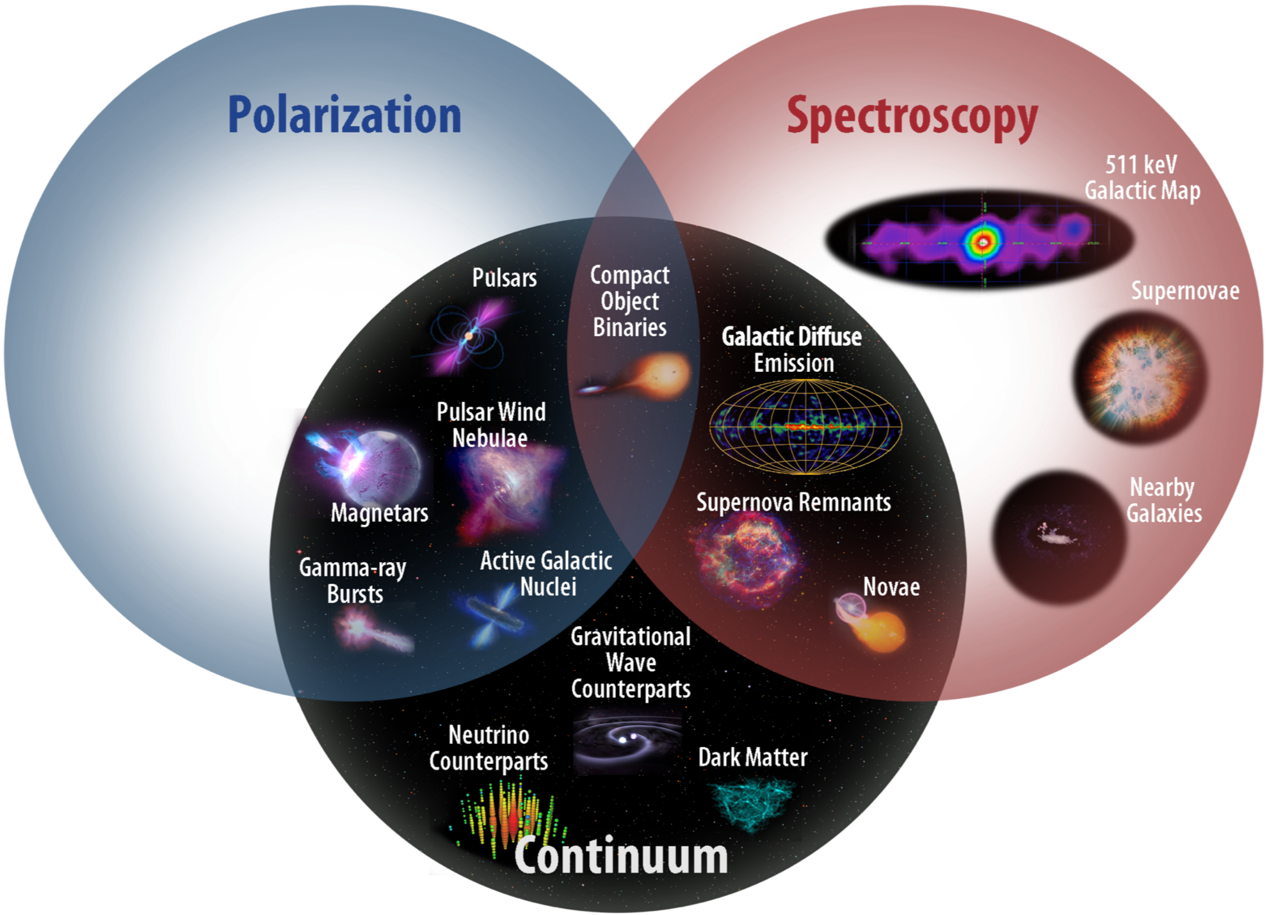
- Transition between the thermal and non-thermal Universe
- Only part of the EM spectrum where it is possible to directly observe nuclear processes (atomic nuclei de/excitations)
- Covers positron annihilation line (511 keV)
- Large population of known sources with peak power output in the MeV range
  - Crucial for source energetics



Detecting MeV Gamma-rays



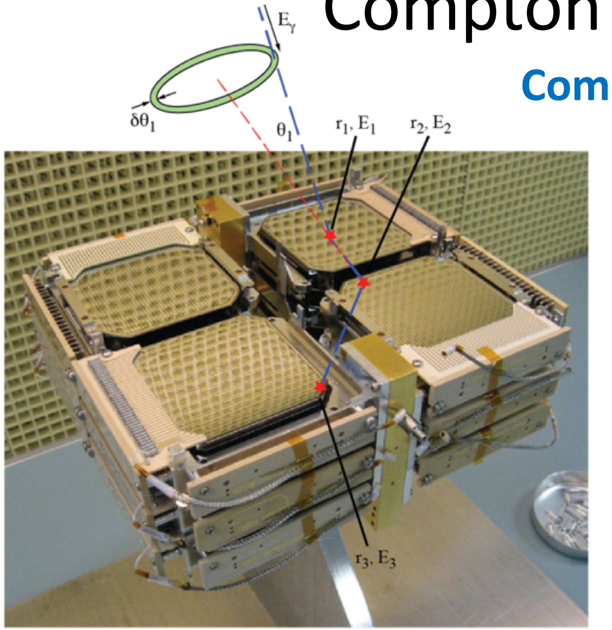
- To fill the “MeV Gap” need to consider both Compton Scattering and Pair Production



Polarization
Spectroscopy
511 keV
Galactic Map
Supernovae
Nearby
Galaxies
Pulsars
Compact
Object
Binaries
Galactic Diffuse
Emission
Pulsar Wind
Nebulae
Magnetars
Supernova Remnants
Gamma-ray
Bursts
Active Galactic
Nuclei
Novae
Gravitational
Wave
Counterparts
Neutrino
Counterparts
Dark Matter
Continuum

Compton Spectrometer and Imager (COSI)

Compton regime – focus on polarization and spectroscopy



- Ge strip detectors
- 0.2-5 MeV
- Instantaneous FOV (25% sky)
- Energy resolution of 0.2-1% (FWHM)

- Balloon launch from New Zealand for mid-latitude flight and Galactic Center coverage
- Angular resolution = 5.1 deg (FWHM) at 0.511 MeV
- COSI-X strips are half as wide

The COSI/COSI-X Collaboration:

S.E. Boggs (PI), A. Lowell, J. Roberts *(UCSD and UC Berkeley/SSL)*

C. Kierans, C. Sleator, J.A. Tomsick, A. Zoglauer *(UC Berkeley/SSL)*

C. Tindall, M. Amman *(LBNL)*

T. Brandt , A. Smale (GSFC)

P. Jean, P. von Ballmoos *(IRAP, France)*

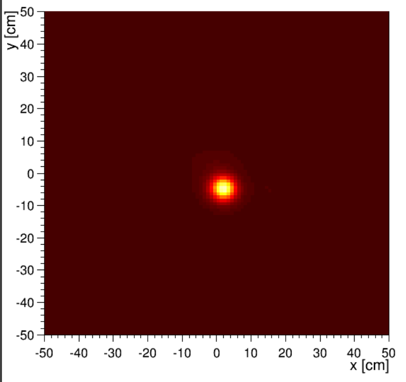
E. Wulf, E. Grove, B. Phlips (NRL)

Dieter Hartmann (Clemson University)

J.-L. Chiu, H.-K. Chang, C.-Y. Yang, C.-H. Tseng, C.-Y. Chu, Y.-C. Chang *(NTHU, Taiwan)*

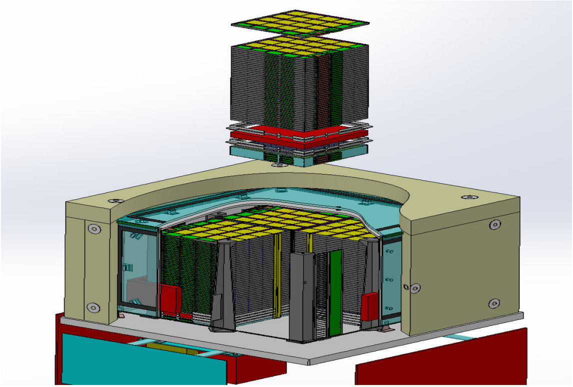
C.-H. Lin (AS, Taiwan), Y.-H. Chang , Y. Chou *(NCU, Taiwan)*

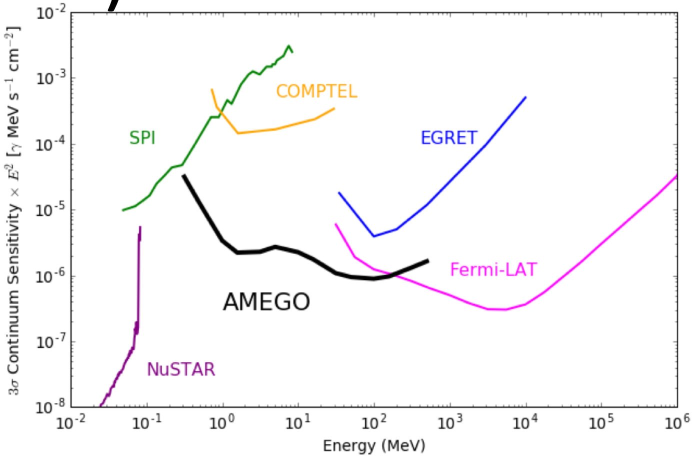
COSI US is supported through grants by NASA



Calibration image of a 662 keV ^{137}Cs source ~56 cm above the instrument.

All Sky Medium Energy Gamma-ray Observatory (AMEGO)

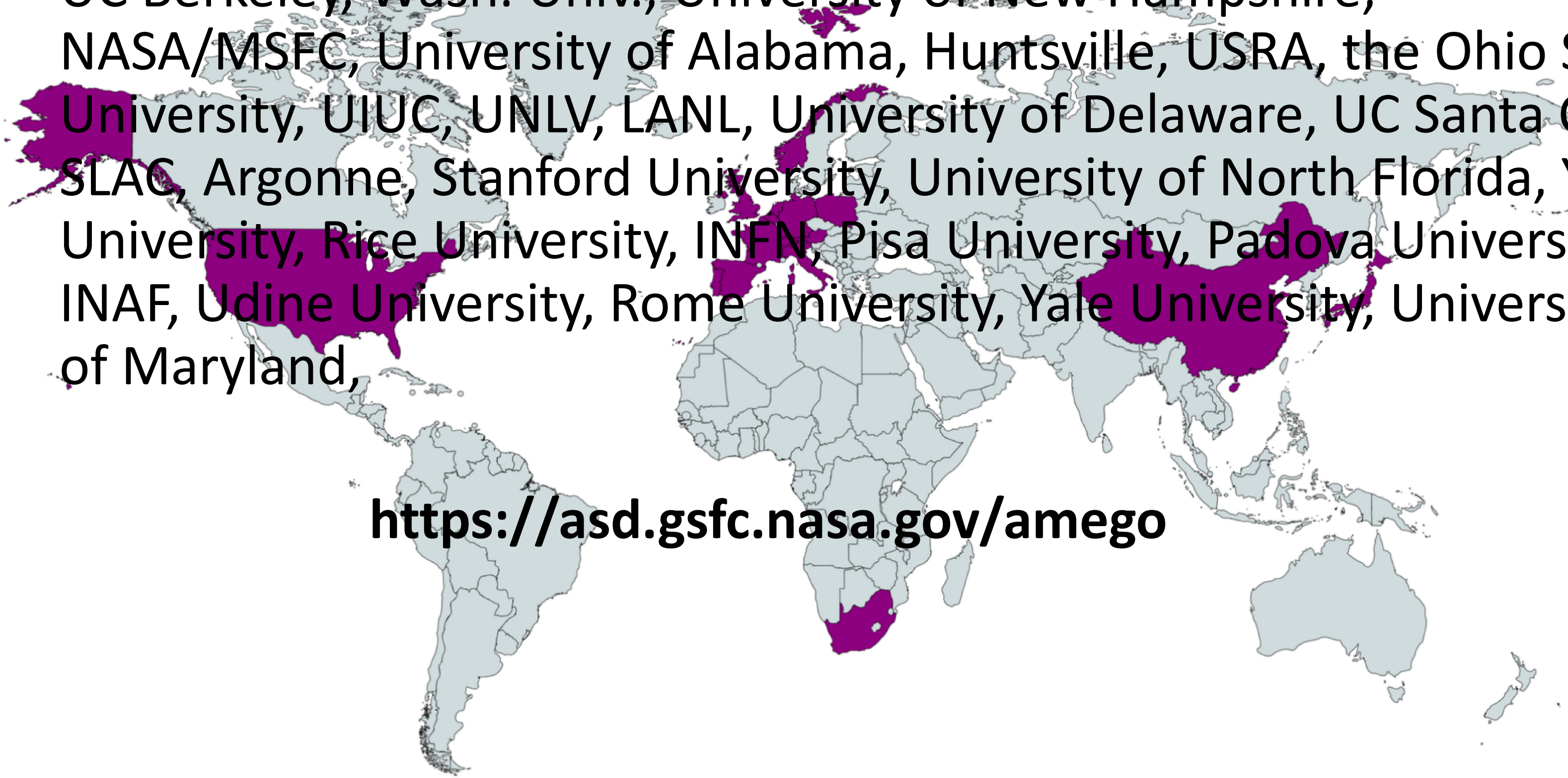




- Energy range: 200 keV – >10 GeV; <2% energy resolution below 5 MeV
- Angular resolution: 3^o (1 MeV), 10^o (10 MeV), 1.5^o (100 MeV)
- Field of View: ~2.5 sr
- Survey mode, view 80% of the sky per orbit – Explore the time domain!
- Sensitivity to polarization and nuclear lines

AMEGO Collaboration

- NASA/GSFC, George Wash. Univ., Clemson Univ., Naval Research Lab, UC Berkeley, Wash. Univ., University of New Hampshire, NASA/MSFC, University of Alabama, Huntsville, USRA, the Ohio State University, UIUC, UNLV, LANL, University of Delaware, UC Santa Cruz, SLAC, Argonne, Stanford University, University of North Florida, Yale University, Rice University, INFN, Pisa University, Padova University, INAF, Udine University, Rome University, Yale University, University of Maryland,



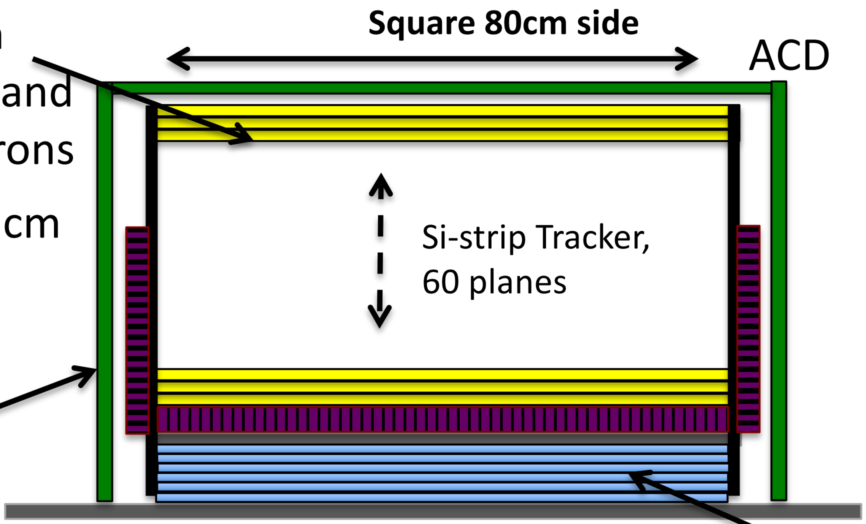
https://asd.gsfc.nasa.gov/amego

All-sky Medium Energy Gamma-ray Observatory (AMEGO)

Tracker

Incoming photon undergoes pair production or Compton scattering. Measure energy and track of electrons and positrons

- 60 layer DSSD, spaced 1 cm
- Strip pitch 0.5mm



CZT Calorimeter

Measure location and energy of Compton scattered photons

- Layer of 0.6x0.6 x 2cm bar CZT

CsI Calorimeter

Extend upper energy range

- 6 planes of 1.5cm x 1.5 cm bars

AMEGO Science

Understanding Extreme Environments

Astrophysical Jets

Understand the formation, evolution, and acceleration mechanisms in astrophysical jets

Compact Objects

Identify the physical processes in the extreme conditions around compact objects

Dark Matter

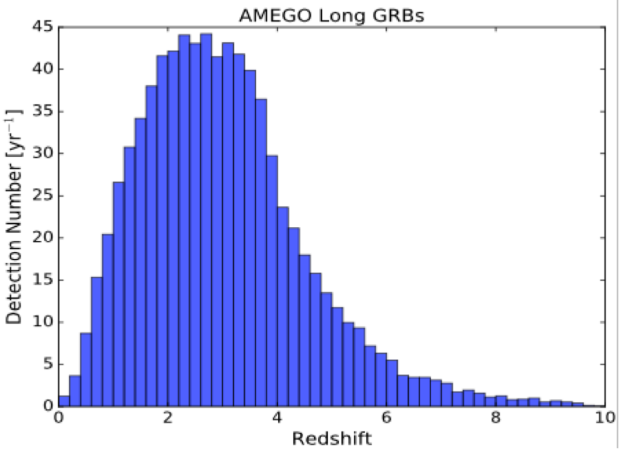
Test models that predict dark matter signals in the MeV band

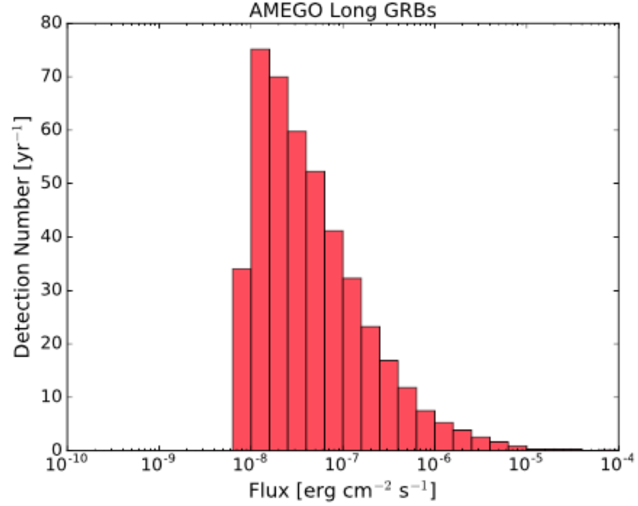
MeV Spectroscopy

Measure the properties of element formation in dynamic systems

AMEGO and GRB

- 440 long GRB/year (determined using method of Lien et al 2014)
  - 19.2/year with z>6
  - All with localization
- Polarization! - 20% MDP for brightest 1% of AMEGO GRB
  - AMEGO observations will probe the GRB emission mechanism and jet composition
- ~80 short GRB/year (by scaling short/long ratio from GBM)
  - Important implications for gravitational wave counterpart searches





GW170817/GRB170817A

- The only known prompt counterpart to a GW event is in the gamma-ray band
  - First x-ray observations were upper limits, optical is expected to have a time delay before switching on
  - (but should we wary of over interpreting a single event)

Gamma-ray Counterparts to GW events

- Current Facilities

Instrument	Energy range	GRB/year	localization
Fermi-GBM	8 keV – 40 MeV	240 (trig)	5-15 deg
Swift-BAT	15 keV – 150 keV	90	arcmin
Fermi-LAT	50 MeV – 300 GeV	10	~<0.5 deg
Insight-HMXT	200 keV – 5 MeV		5-15 deg
INTEGRAL-IBIS	15 keV – 10 MeV	2-5	arcmin

- Selected Proposed Future Facilities

Instrument	Energy range	GRB/year	localization
AMEGO*	200 keV – 10 GeV	500	0.5-2 deg
TAP/TAO	10 keV – 1 MeV	240	5-15 deg
SVOM-eclairs	4 keV – 120 keV	80	arcmin

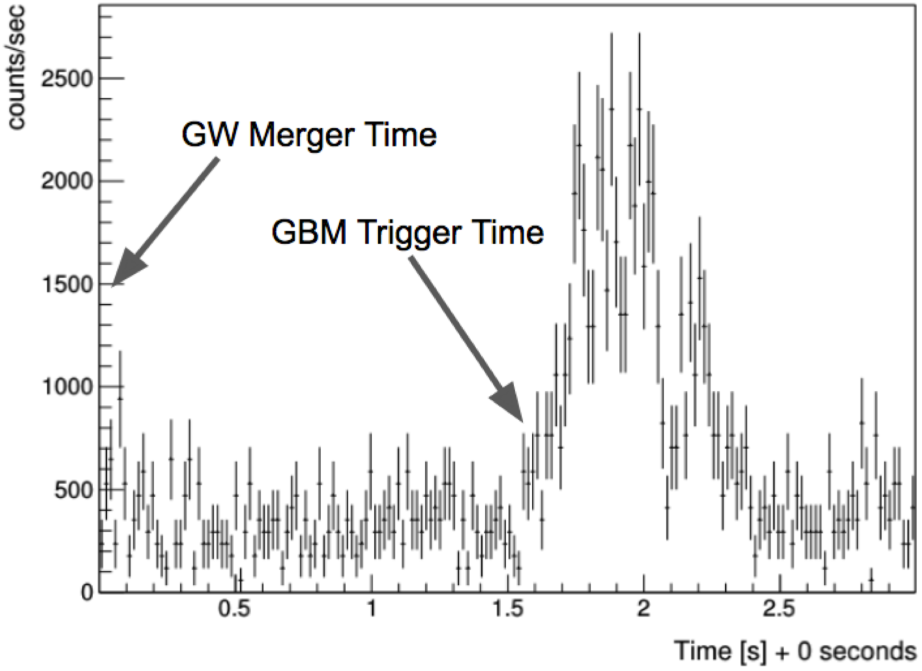
* Very similar to eAstroGAM proposed to M5

GRB 170817A

GRB 170817 is the EM counterpart to GW 170817 at 43 Mpc

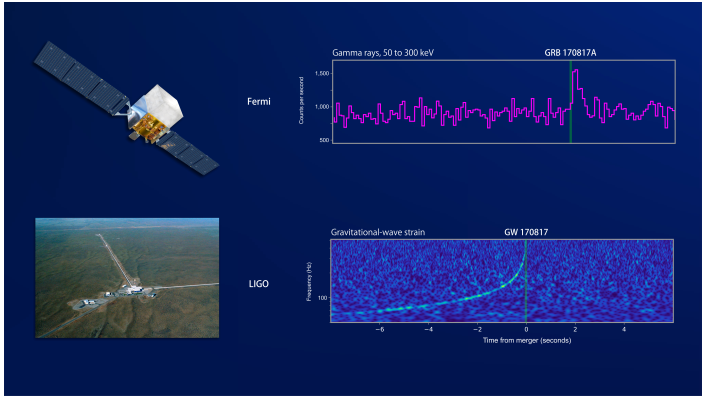
With AMEGO:

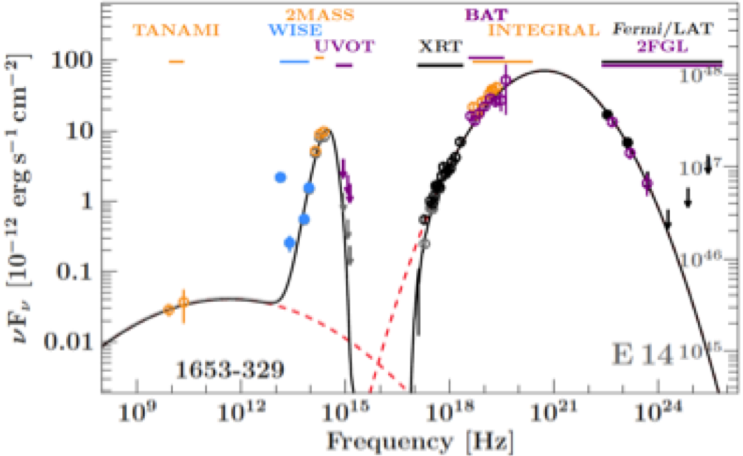
- Detectable out to at least 130 Mpc
- Few deg localization (with very preliminary analysis)
- ~20% probability being within the FoV



Multimessenger Astrophysics

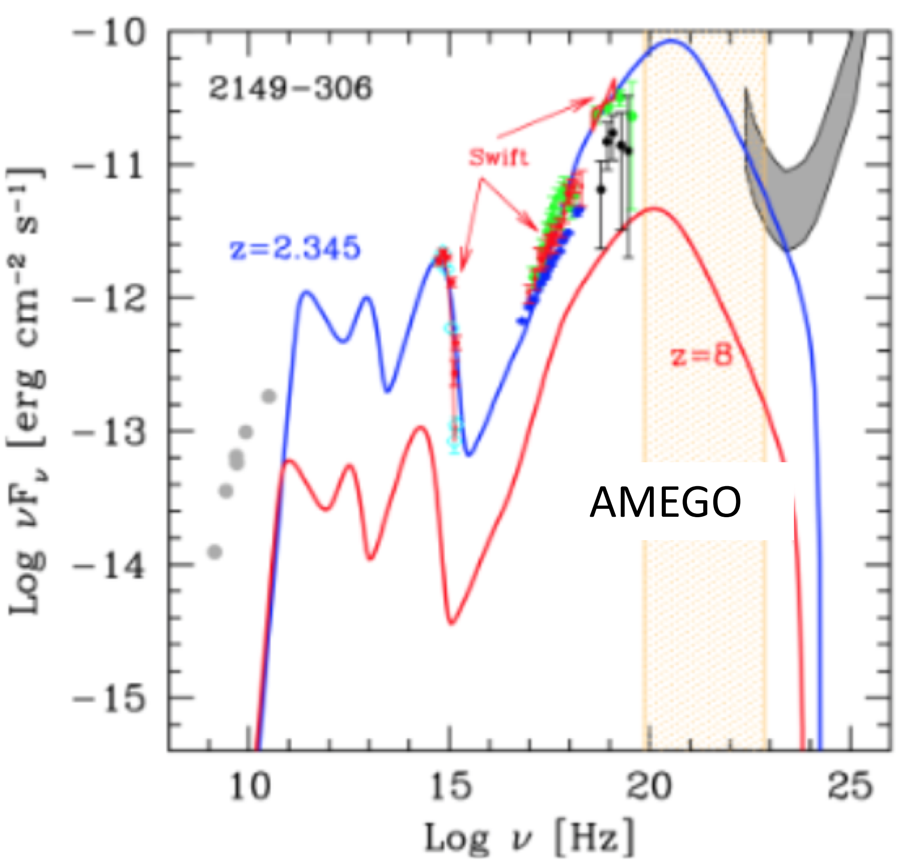
- GRB and GW sources: AMEGO will detect ~80 sGRB/year with ~degree localization - significantly more than any currently operating GRB detector
- Do AGN jets accelerate protons to extremely high energies?
  - Producing PeV neutrinos, UHECR and high energy gamma-rays
  - MeV range is crucial





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
  - AMEGO will detect >500 MeV blazars
  - ~100 at z>3



- Amc
  pers
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- Larg
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- Host
  10^9 s
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[Previous | Next | ADS]

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

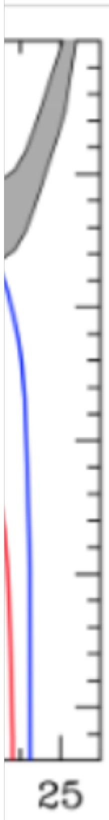
Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831, 10833, 10838, 10840, 10844, 10845, 10861, 10890, 10942, 11419, 11430

We searched for Fermi-LAT sources inside the extremely high-energy (EHE) IceCube-170922A neutrino event error region (https://gcn.gsfc.nasa.gov/gcn3/21916.gcn3, see also ATels 10773, 10787) with all-sky survey data from the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope. We found that one Fermi-LAT source, TXS 0506+056 (3FGL J0509.4+0541 and also included in the 3FHL catalog, Ajello et al., arXiv:1702.00664, as 3FHL J0509.4+0542), is located inside the IceCube error region. The FAVA (Fermi All-sky Variability Analysis) light curve at energies above 800 MeV shows a flaring state recently (https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/SourceReport.php?week=477&flare=27). Indeed, the LAT 0.1--300 GeV flux during 2018 September 15 to 27 was (3.6+/-0.5)E-7 photons cm-2 s-1 (errors are statistical only), increased by a factor of ~6 compared to the 3FGL flux, with nearly the same power-law index of 2.0+/-0.1. We strongly encourage multiwavelength observations of this source. We also encourage optical spectroscopy for this source, because the redshift is still unknown. According to NED, the R-band magnitude is reported as 15.1 (Healey et al. 2008, ApJS 175, 97). Radio observations show that this blazar has had increasing flux during the past year: http://www.astro.caltech.edu/ovroblazars/data.php?page=data_query, http://www.physics.purdue.edu/astro/MOJAVE

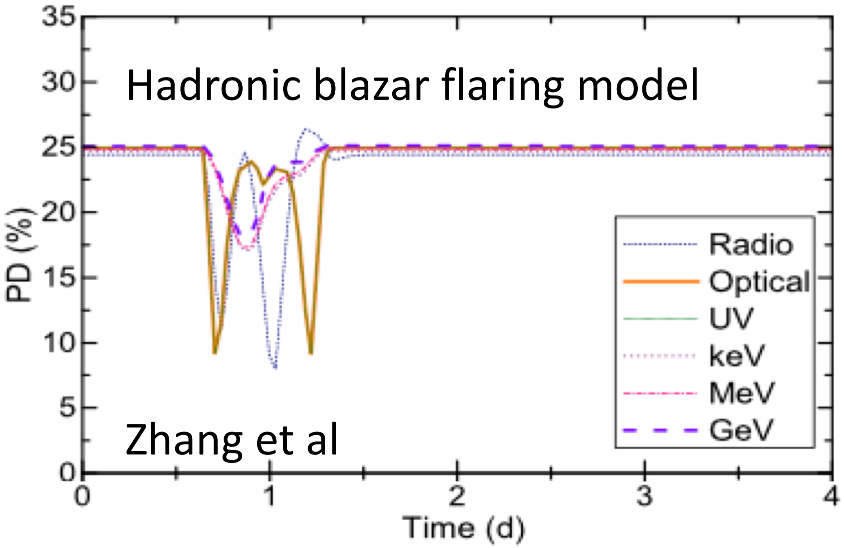
Related

- 11430 Optical polarimetry of TXS 0506+056 (possible counterpart of IceCube-170922A)
- 11419 Fermi-LAT detection of enhanced gamma-ray activity and hard spectrum of TXS 0506+056, located inside the IceCube-170922A error region
- 10942 IceCube-171106A: Swift observations
- 10890 Subaru/FOCAS Optical Spectroscopy for a possible IceCube-170922A counterpart TXS 0506+056
- 10861 VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event
- 10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
- 10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
- 10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)
- 10838 MAXI/GSC observations of IceCube-170922A and TXS 0506+056
- 10833 VERITAS follow-up observations of IceCube neutrino event 170922A
- 10831 Optical photometry of TX0506+056
- 10830 SALT-HRS observation of the blazar TXS 0506+056 associated with IceCube-170922A
- 10817 First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A
- 10802 HAWC gamma ray data prior to IceCube-170922A

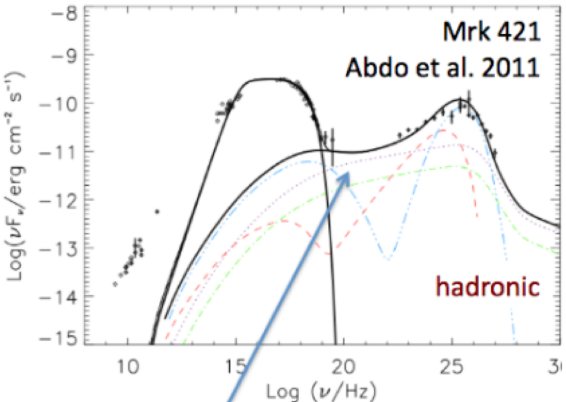


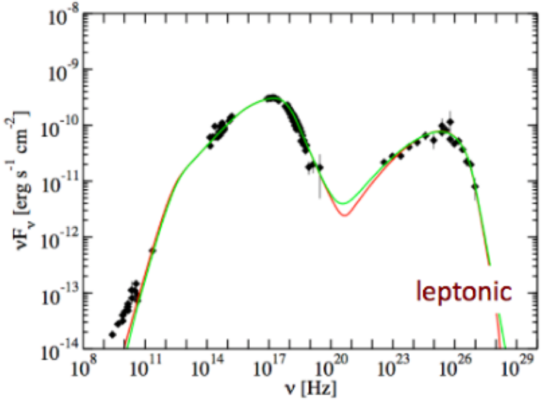
Relativistic Jets in AGN

- Do AGN jets accelerate protons to extremely high energies?
  - Producing PeV neutrinos, UHECR and high energy gamma-rays
  - Simultaneous observations of optical and MeV flux and polarization during blazar flares can test hadronic acceleration models

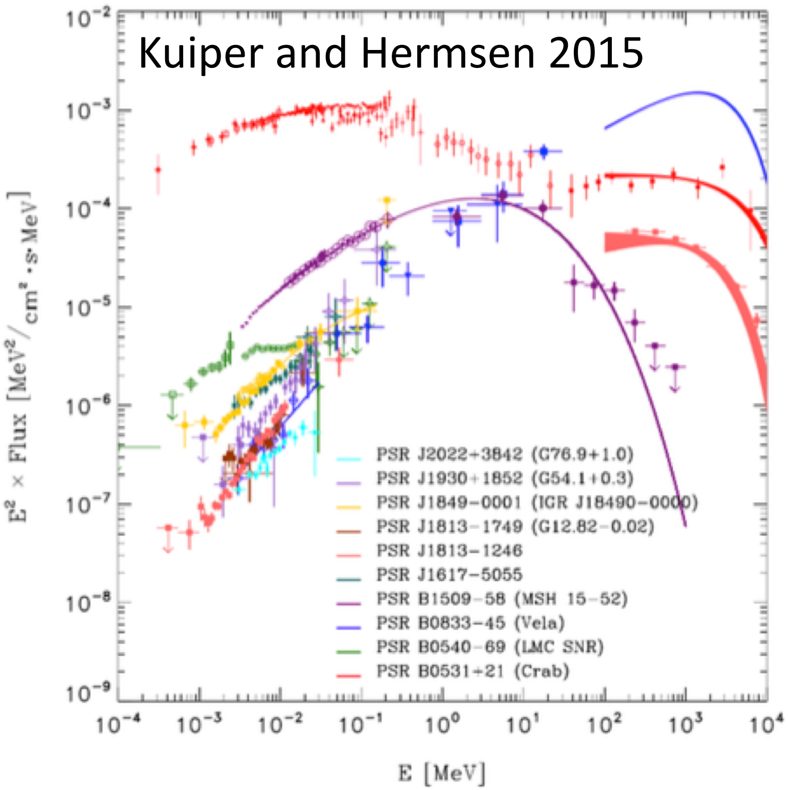


Quiescent: Hard X-rays/soft gammas: secondaries from pion production and proton synchrotron





MeV Pulsars



- Pulsars seen in hard X-ray but not by Fermi-LAT, peak lies in MeV band
- 11 MeV pulsars known
  - Extremely energetic Edot > 10^{36} erg
- Possible “hidden” population of energetic soft gamma emitting pulsars
- Emission might probe different part of the magnetosphere than GeV

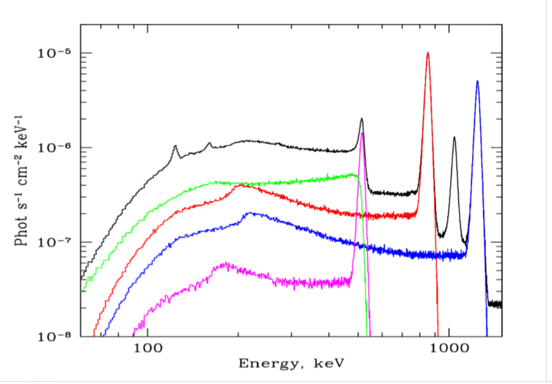
MeV Pulsar Puzzles: Who do most have single peaked lightcurves? Why most are radio quiet? where do their SEDs peak and why ?

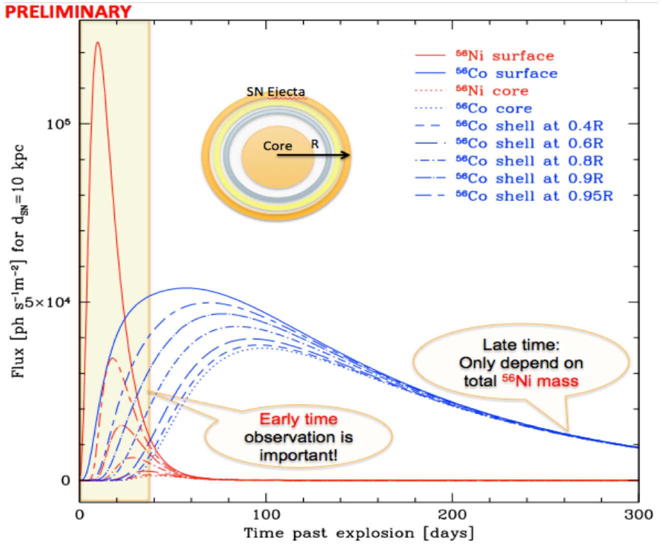
Thermonuclear Supernovae (SNIa)

- 77% of energy escapes in gamma-rays, observed for SN2014J

$$^{56}Ni \xrightarrow{\tau=8.8\,days} {}^{56}Co+\gamma$$
$$^{56}Co \xrightarrow{\tau=111.3\,days} {}^{56}Fe+\gamma$$

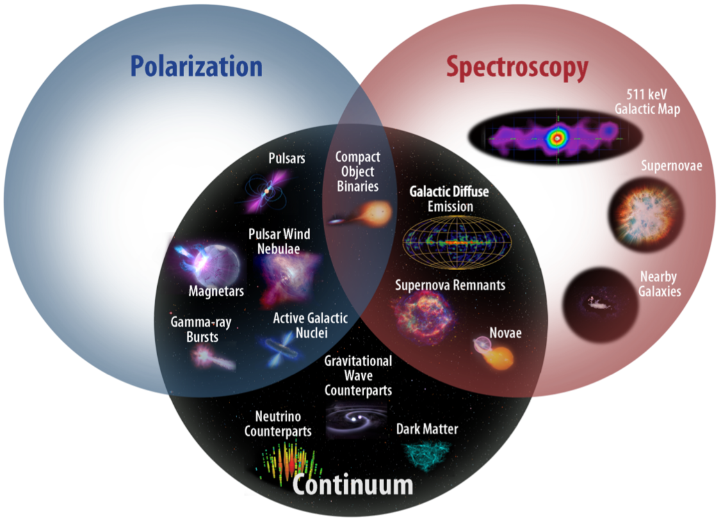
- Modeling gamma-ray emission (decay + Compton + absorption) much simpler than in optical band
- No obscuration – AMEGO can find SNIa in dusty starburst galaxies
- AMEGO will precisely measure 56Ni mass for nearby SNIa
- Lightcurve at early times sensitive to ^{56}Ni location, at late times depends only on ^{56}Ni mass.
- AMEGO will detect 2 SNIa/year out to a distance of 30 Mpc





AMEGO Plans and activities

- Prototyping/testing readout for CZT and daisy chained double-sided Si strip detectors
- Developing prototype instrument for beam tests and balloon flight in 2018/2019
- Engineering study of full instrument/mission concept (IDL/MDL)
  - Robust resources and cost estimate
- Developing and communicating AMEGO science case
- Plan to submit white papers to the upcoming decadal survey



AMEGO will provide three new gamma-ray science capabilities in the MeV band

- AMEGO, optimized for high flux sensitivity, broad energy range and a wide field of view will focus on astrophysical extremes
  - Astrophysical jets and multimessenger astrophysics
  - Compact objects (neutron stars and black holes)
  - Element formation in dynamic environments
  - Dark matter and new physics

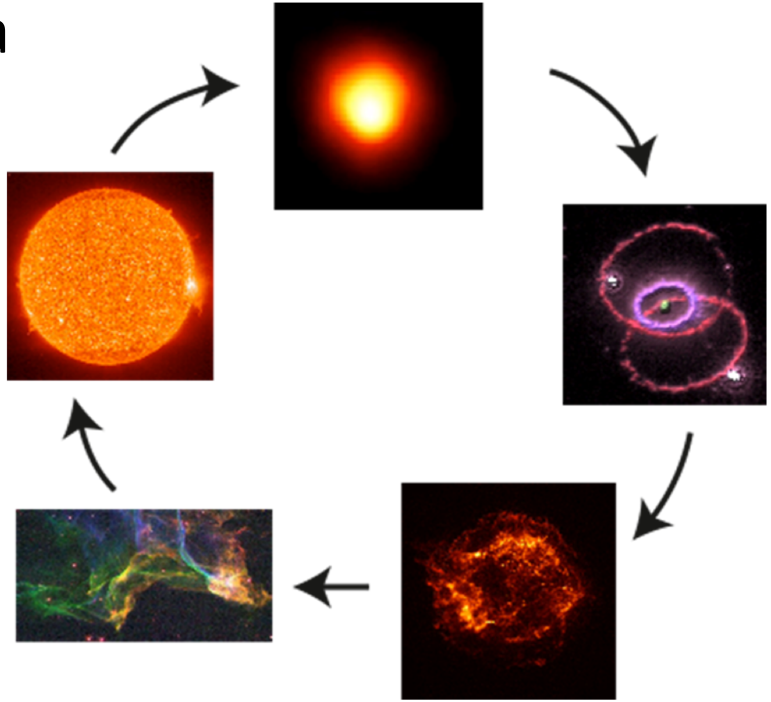
Dark matter Searches

- Unique sensitivity to the 511-keV line
  - Sensitivity to many classical positron sources: can constrain the contribution from nearby pulsars
- The MeV region is where the bulk of photons from WIMPs below 100 GeV is expected
- Axions, ALPs:
  - Sensitivity to photons emitted by SNe (Meyer et al. 2016)
  - Sensitivity to photon/ALP oscillations (Roncadelli et al. 2011; Hooper et al. 2009

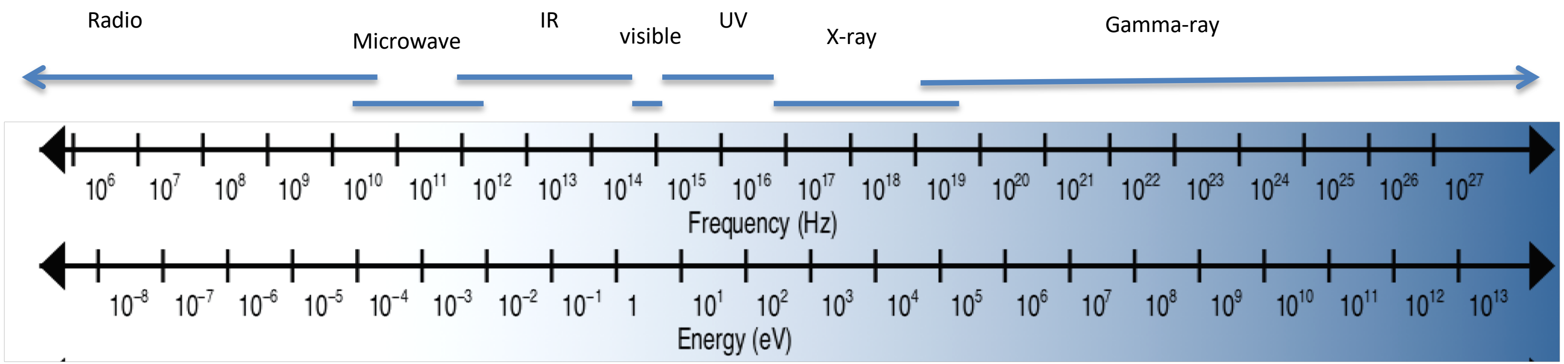
Gamma-ray Spectroscopy

Nuclear lines explore Galactic chemical evolution and sites of explosive element synthesis (SNe)

- Electron-positron annihilation ra
  - $e^+ + e^- \rightarrow 2\gamma$ (0.511 MeV)
- Nucleosynthesis
  - Giants, CCSNe (^{26}Al)
  - Supernovae (^{56}Ni, ^{57}Ni, ^{44}Ti)
  - ISM (^{26}Al, ^{60}Fe)
- Cosmic-ray induced lines
  - Sun
  - ISM

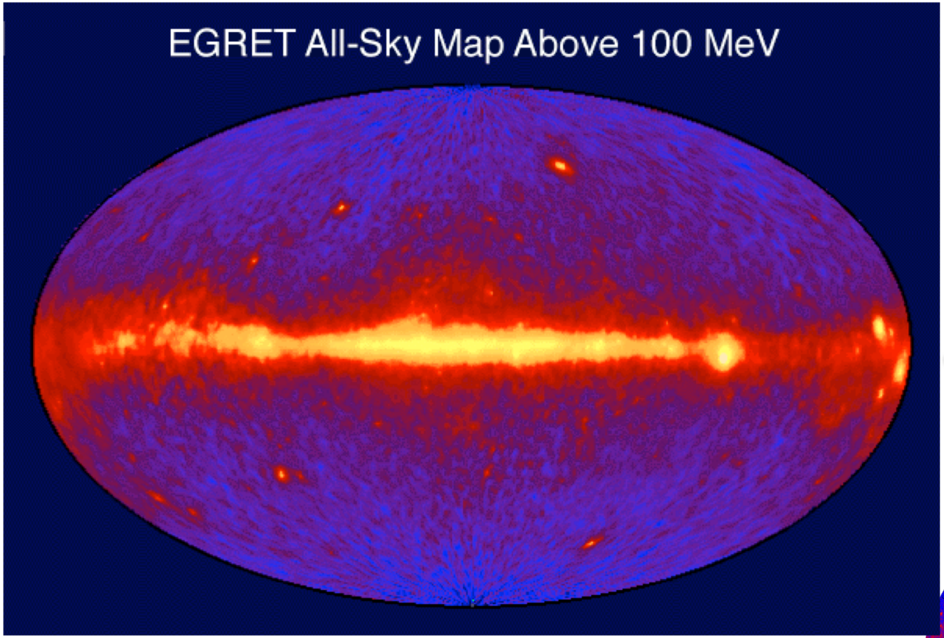


Gamma-ray Astrophysics

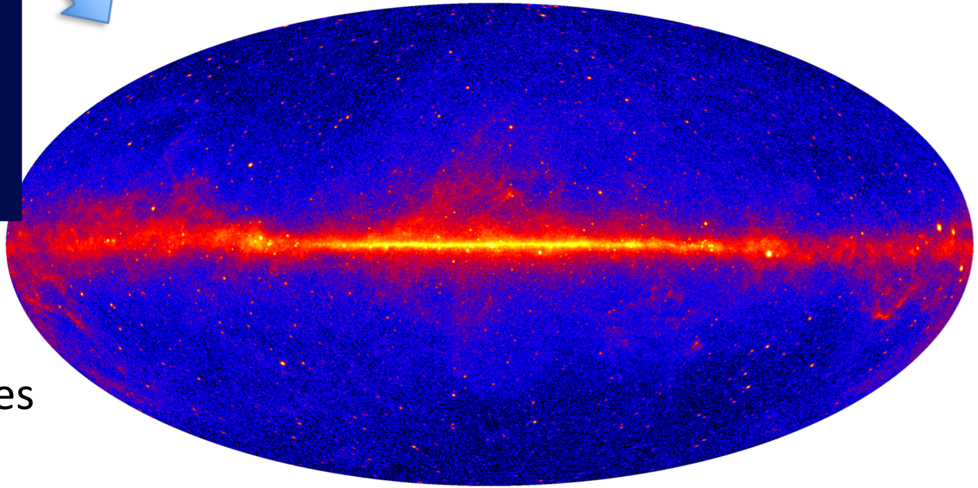


- High energy gamma-rays explore nature's accelerators - "Where the energetic things are"
  - natural connections to UHE cosmic-ray and neutrino astrophysics
- High energy photons often produced in a different physical process to the lower energy emission
  - Independent handle on the physical conditions.
- Huge Advances in the past decade

From EGRET to Fermi-LAT



~300 sources



~5000 sources