EXPERIMENTS OTHER THAN ICECUBE

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IceCube Bootcamp

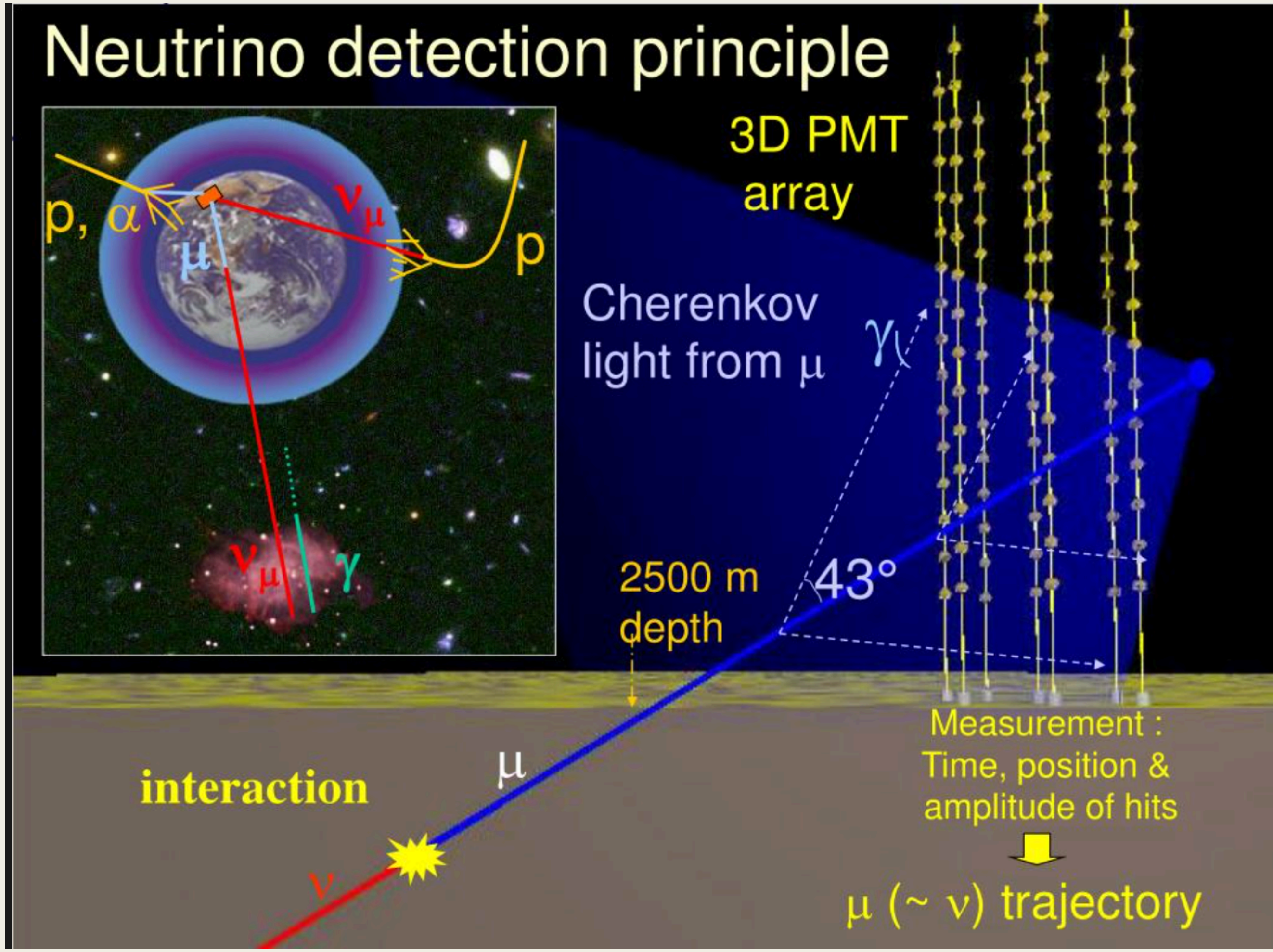
18th June 2020

Outline

- High energy Neutrino Detectors
- Low energy (compared to HE) neutrino detectors
- Electromagnetic radiation (Gamma ray photons) using Fermi
- Gamma ray measurements using Cherenkov telescopes (next talk)

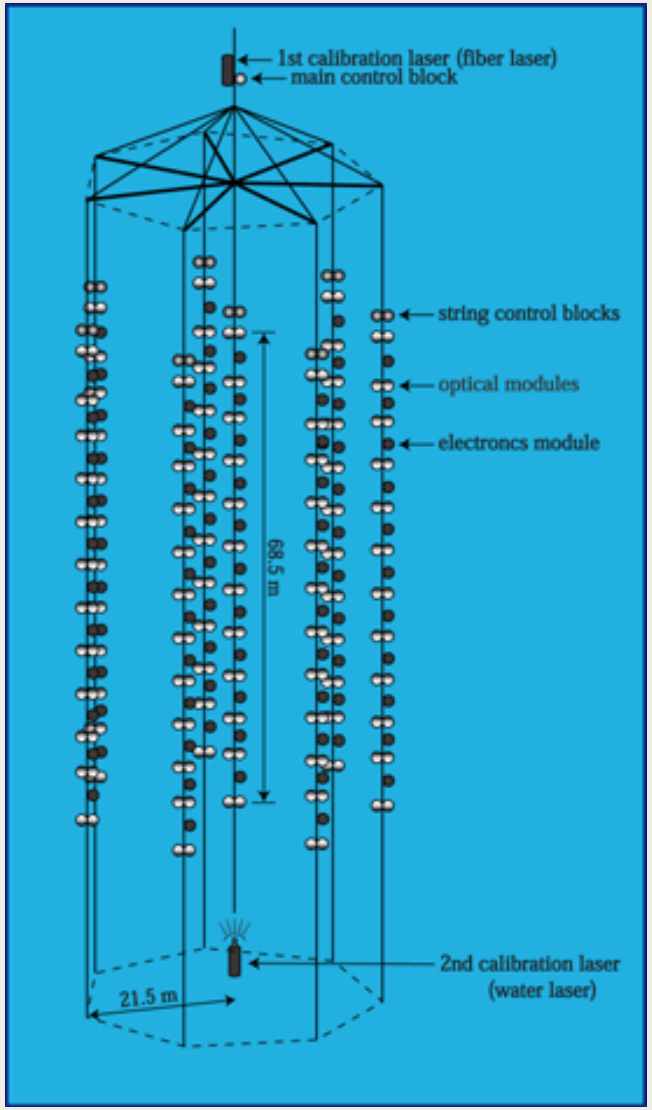
ANTARES

- The ANTARES Collaboration is operating since 2008 a large area water Cherenkov detector in the deep Mediterranean Sea, optimised for the detection of muons from high-energy astrophysical neutrinos.
- ANTARES is composed of 12 lines of about 350m each, covering a surface area of 0.1 km² : a first step toward the network of kilometric scale detectors KM3NeT which will be a combination of low energy and high energy arrays (ORCA and ARCA).



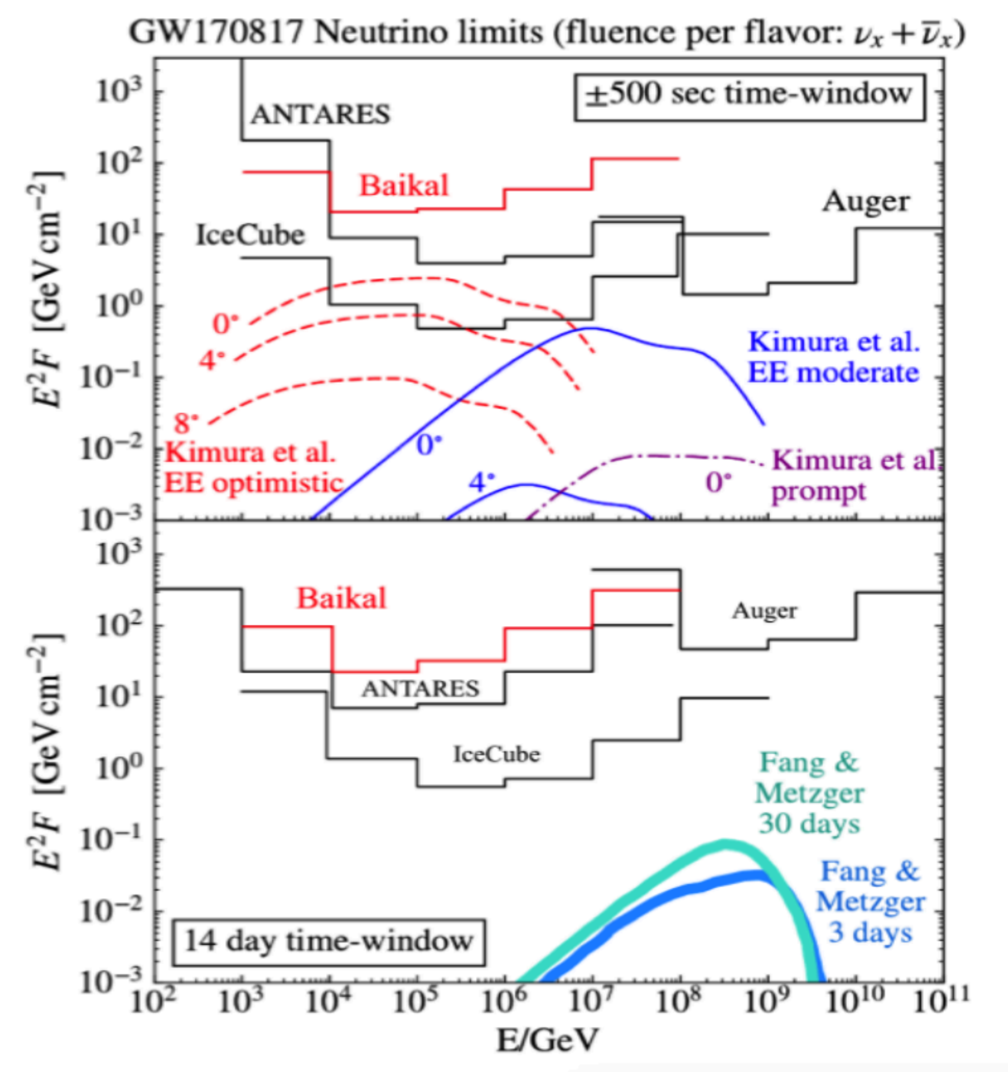
Baikal Neutrino Observatory

- The design of the neutrino telescope is an array of photomultiplier tubes detecting Cherenkov radiation generated by secondary muons and particle cascades which are produced in neutrino interactions in the water.
- It was constructed to study high-energy muon and neutrino fluxes and search for new types of elernentary particles: magnetic monopoles, WIMPs - massive particles which can be considered as candidates to "dark" matter, and others.
- https://inr.ru/eng/ebgnt.html



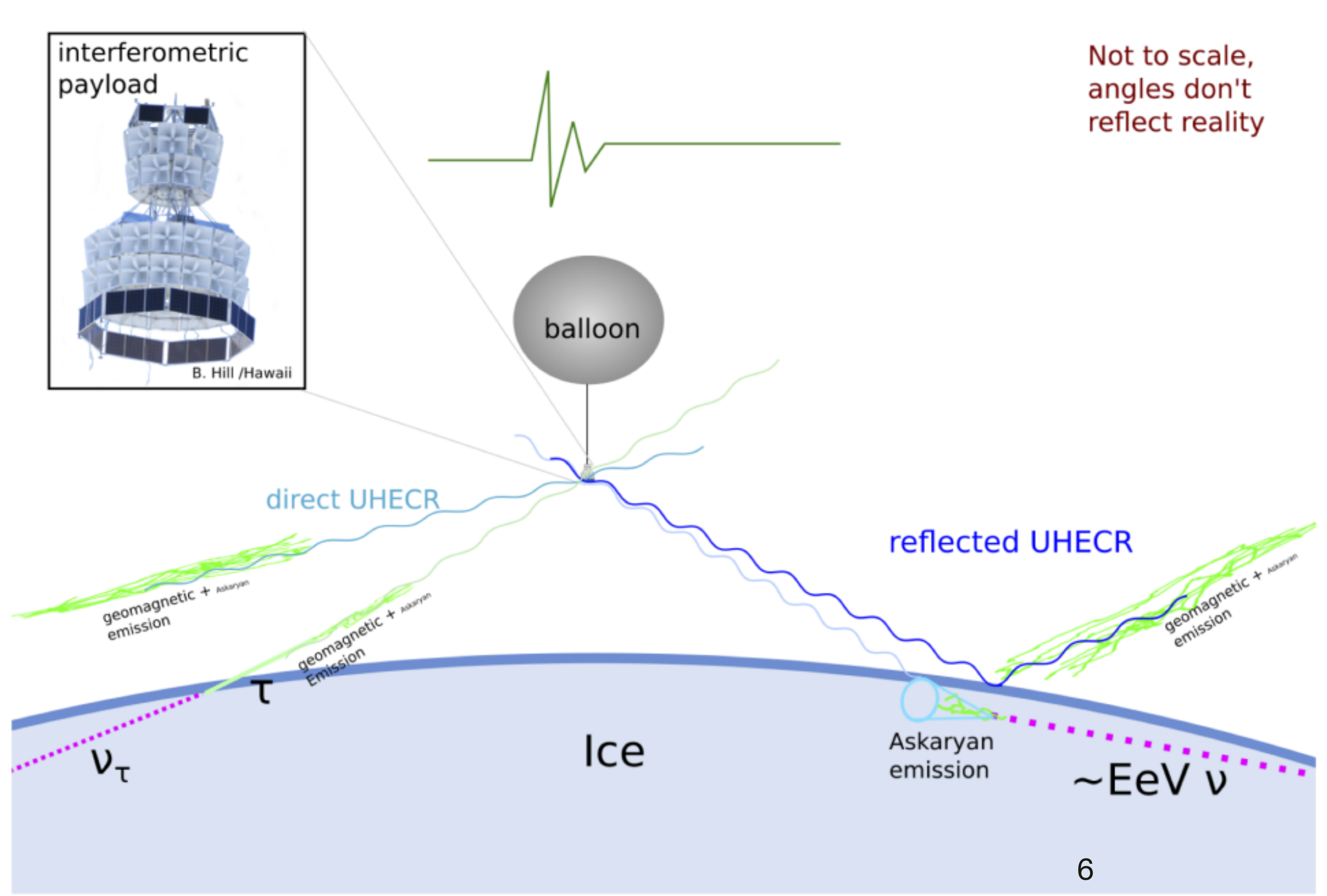
Baikal Neutrino Observatory

- “The alert system of the Baikal-GVD detector under construction will allow for a fast, on-line reconstruction of neutrino events recorded by the Baikal-GVD telescope and - if predefined conditions are satisfied - for the formation of an alert message to other communities.”
- Upper limits at 90% C.L. on the fluence of neutrinos associated with GW170817 for prompt and delayed emission time.
- “The Baikal-GVD design allows to search for HE neutrinos at the early phases of array construction. The GVD developed alert system for multi-messenger studies is in progress”

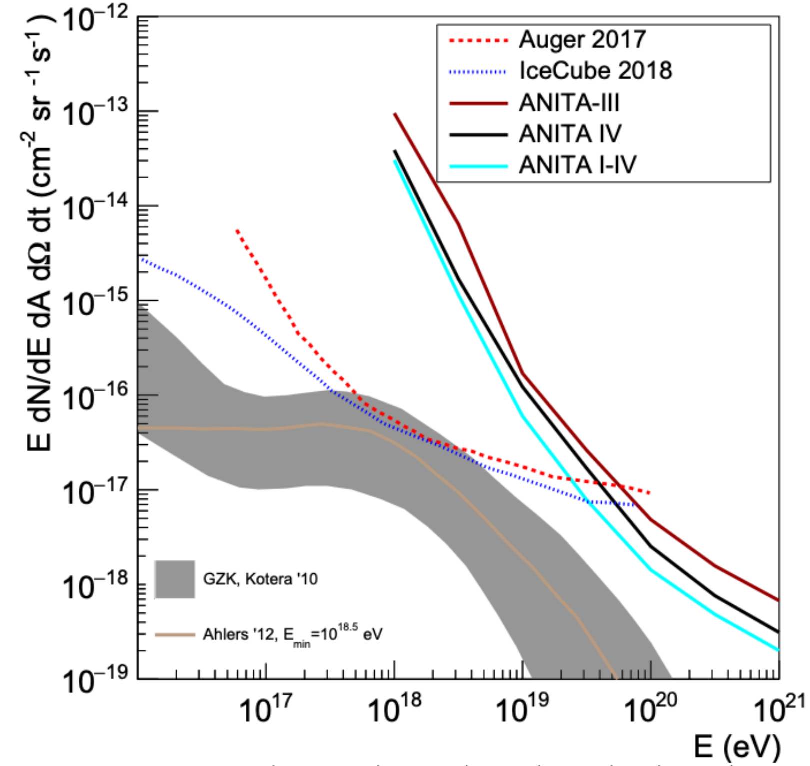


https://arxiv.org/pdf/1908.05450.pdf

- The ANITA instrument is a radio telescope to detect ultra-high energy cosmic-ray neutrinos from a scientific balloon flying over the continent of Antarctica.
- The ANITA instrument detects these ultra-high energy neutrinos by use of the Askaryan effect which predicts the production of a coherent radio emission from the cascade of particles produced in a high-energy particle interaction.



- ANITA-IV limit on the all flavor diffuse UHE neutrino flux and a combined limit from ANITA I-IV made using the ANITA-IV limit and the published ANITA-I, II, and III limits.
- The most recent UHE neutrino limits from the Auger and IceCube experiments, and two cosmogenic neutrino models are also displayed.
- The table lists the ANITA-IV effective area as a function of neutrino energy used to make the limit, not including analysis efficiency.

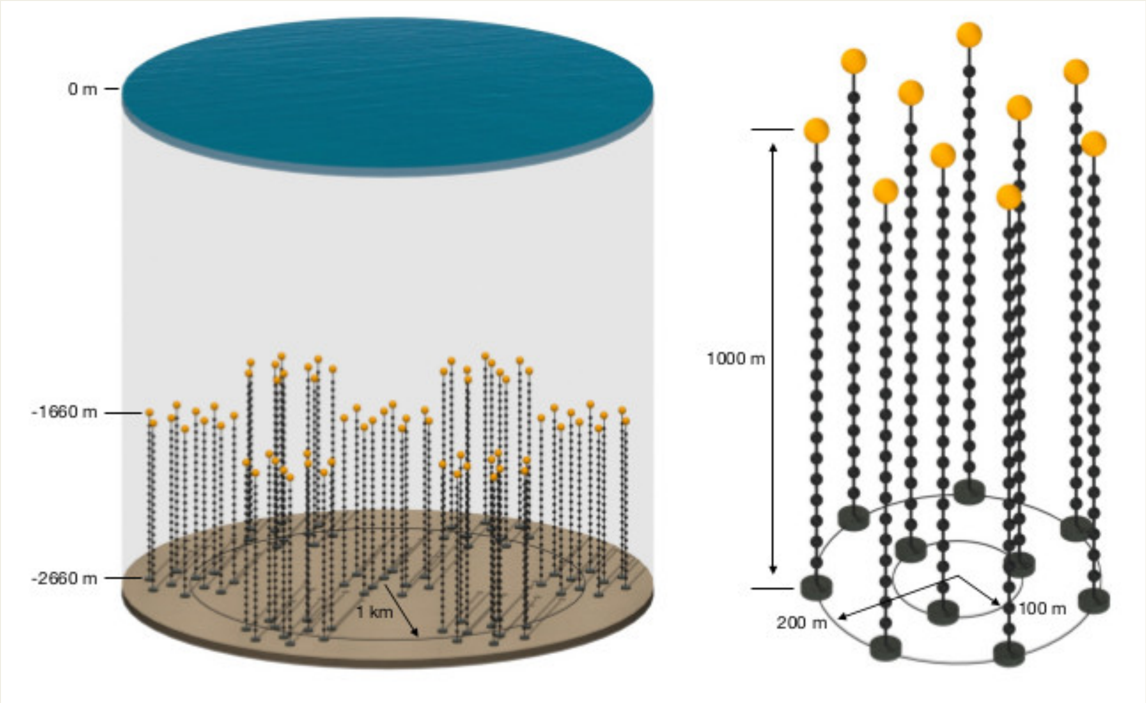


$\log_{10}(E(eV))$	18	18.5	19	19.5	20	20.5	21
A ($km^2 \cdot sr$)	0.0032	0.033	0.43	3.1	21	68	167

https://arxiv.org/pdf/1902.04005.pdf

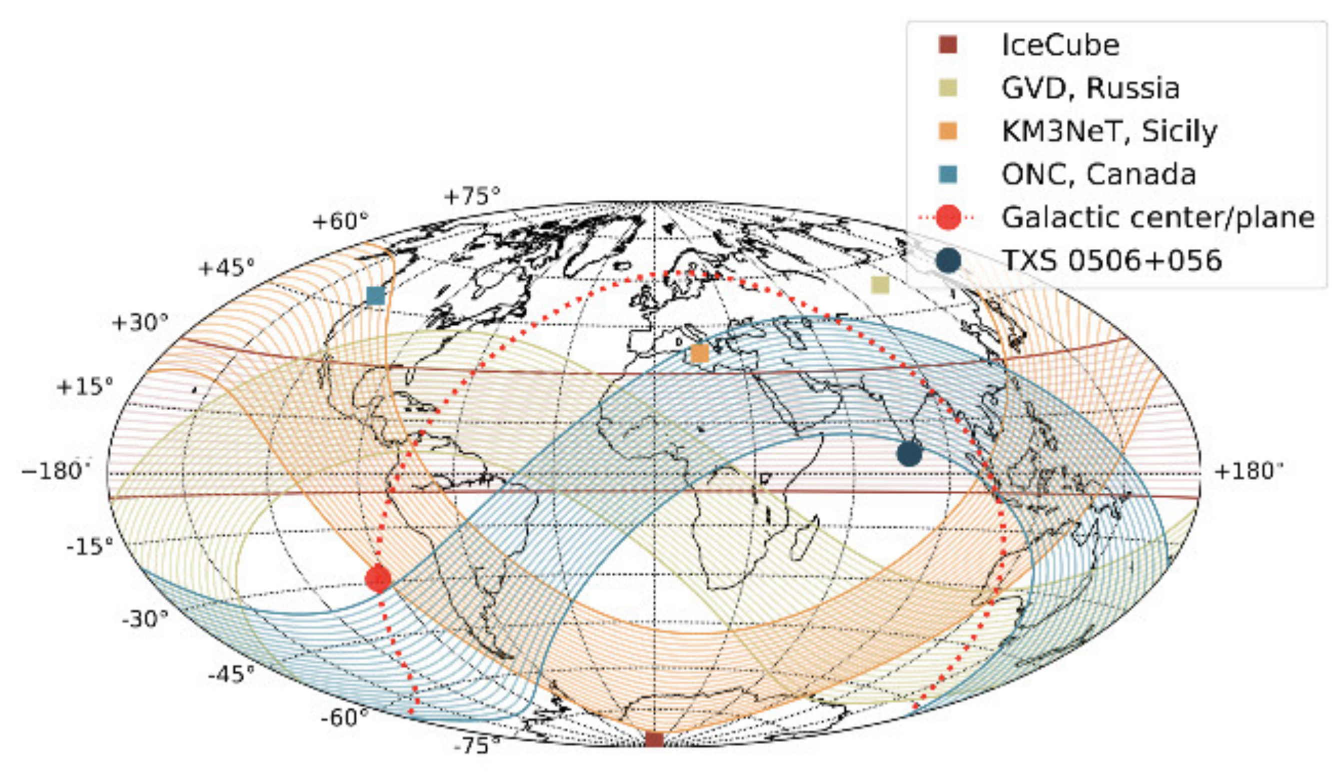
PONE

- The Pacific Ocean Neutrino Explorer (P-ONE) is a new initiative which aims to redevelop ocean-based neutrino telescopes by harnessing one of the largest comprehensive ocean observing infrastructures in the world, Ocean Networks Canada (ONC).
- **Design of the proposed final stage of instrumentation of the Pacific Ocean Neutrino Experiment consisting of seven segments optimized for energies above 50 TeV (left) and the design of an individual segment that is planned to be installed in a four weeks sea operation in 2023/24 as Pacific Ocean Neutrino Explorer standalone detector. (Credit: TUM)**



Why a telescope's observable horizon is limited?

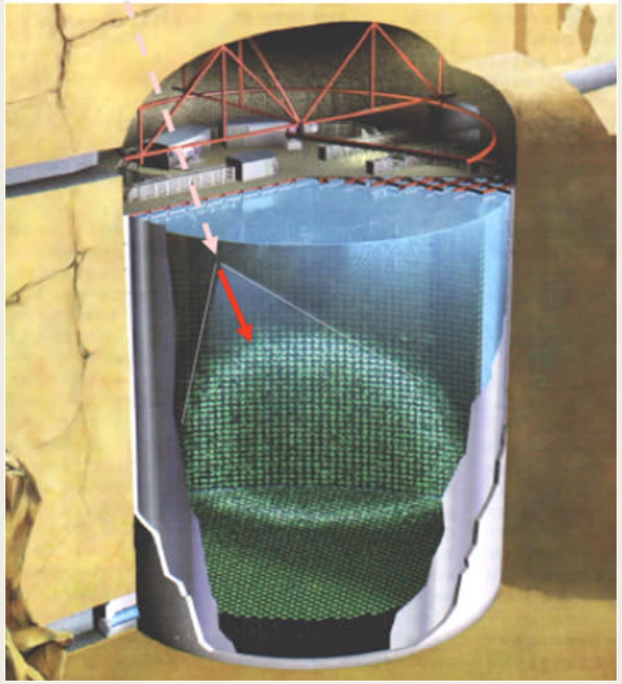
- Upgoing vs downgoing tracks and separating it from atmospheric neutrinos.
- Cross Section of neutrinos depending on the energy of the neutrino



- http://www.pacific-neutrino.org/p-one/

Other neutrino detectors

Super-Kamiokande

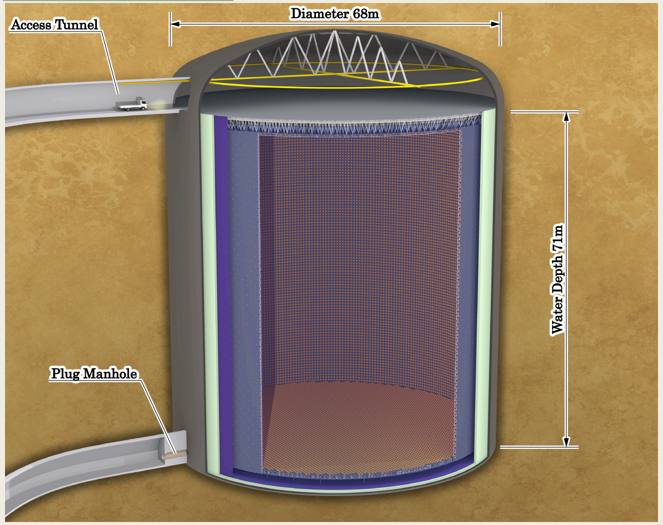


- 50, 000 tons of ultra pure water
- 13,000 photomultipliers
- Located 1 km underground in Kamioka-mine, Japan

- Latest updates:
- GADZOOKS project : dissolving Gd in Super-K water for effective neutron tagging

On June 27, 2015, the Super-Kamiokande Collaboration approved the SK-Gd project which will enhance neutrino detectability by dissolving gadolinium in the Super-K water.

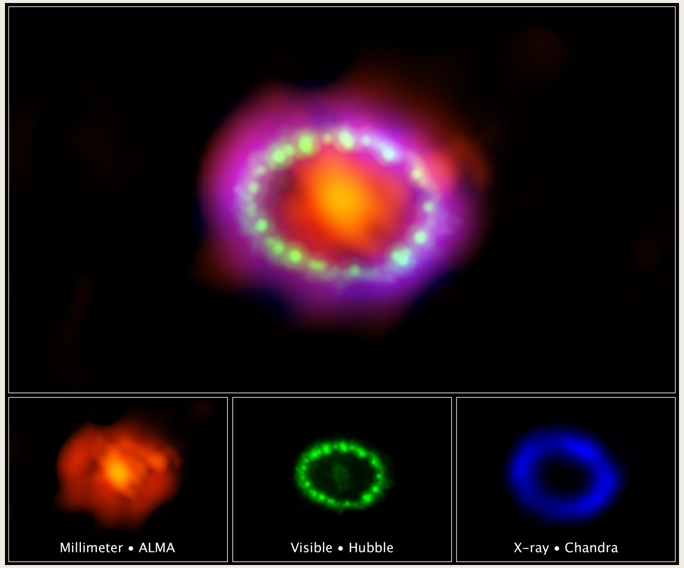
Hyper-K



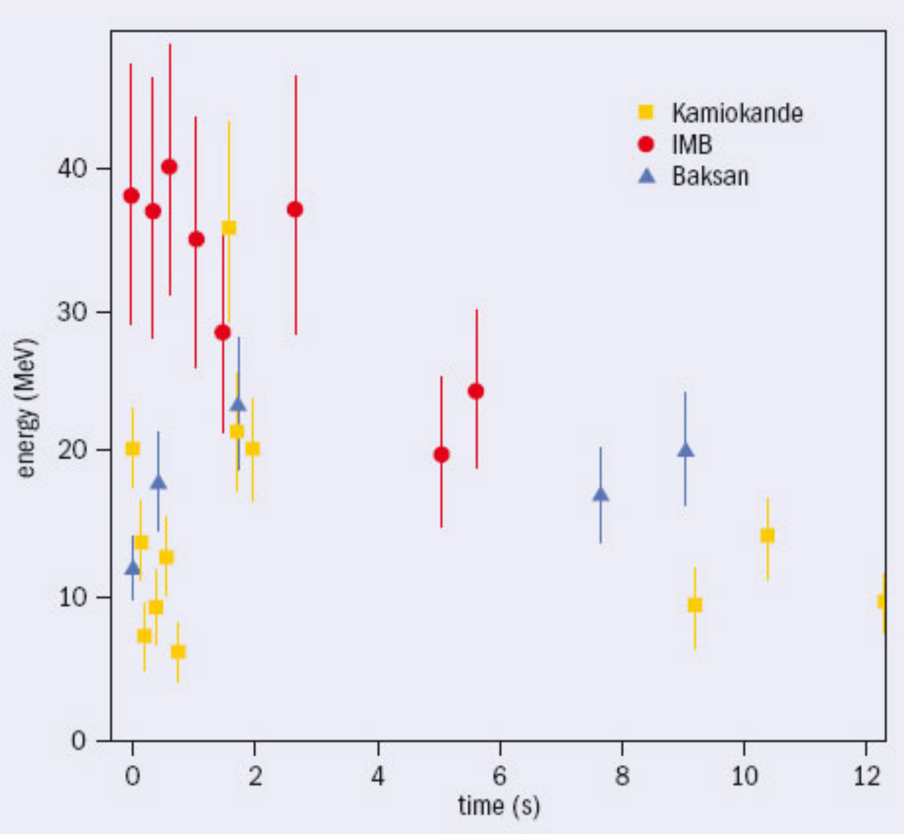
- Order of magnitude bigger than Super-Kamiokande (SK), with the optimal design consisting of two half megaton tanks equiped with ultra high sensitivity photosensors.

https://www.hyperk.org/

SN1987A



- On 23 February 1987 at 0735 (UT), when the Kamiokande detector was ready to detect solar neutrinos, it observed neutrinos from SN1987A.
- The progenitor of the supernova was a blue giant in the Large Magellanic Cloud, 170,000 light years away.
- “After whizzing through space for 166,000 years still hours ahead of the light front, the neutrinos from SN 1987A swept over the earth—and were detected.”

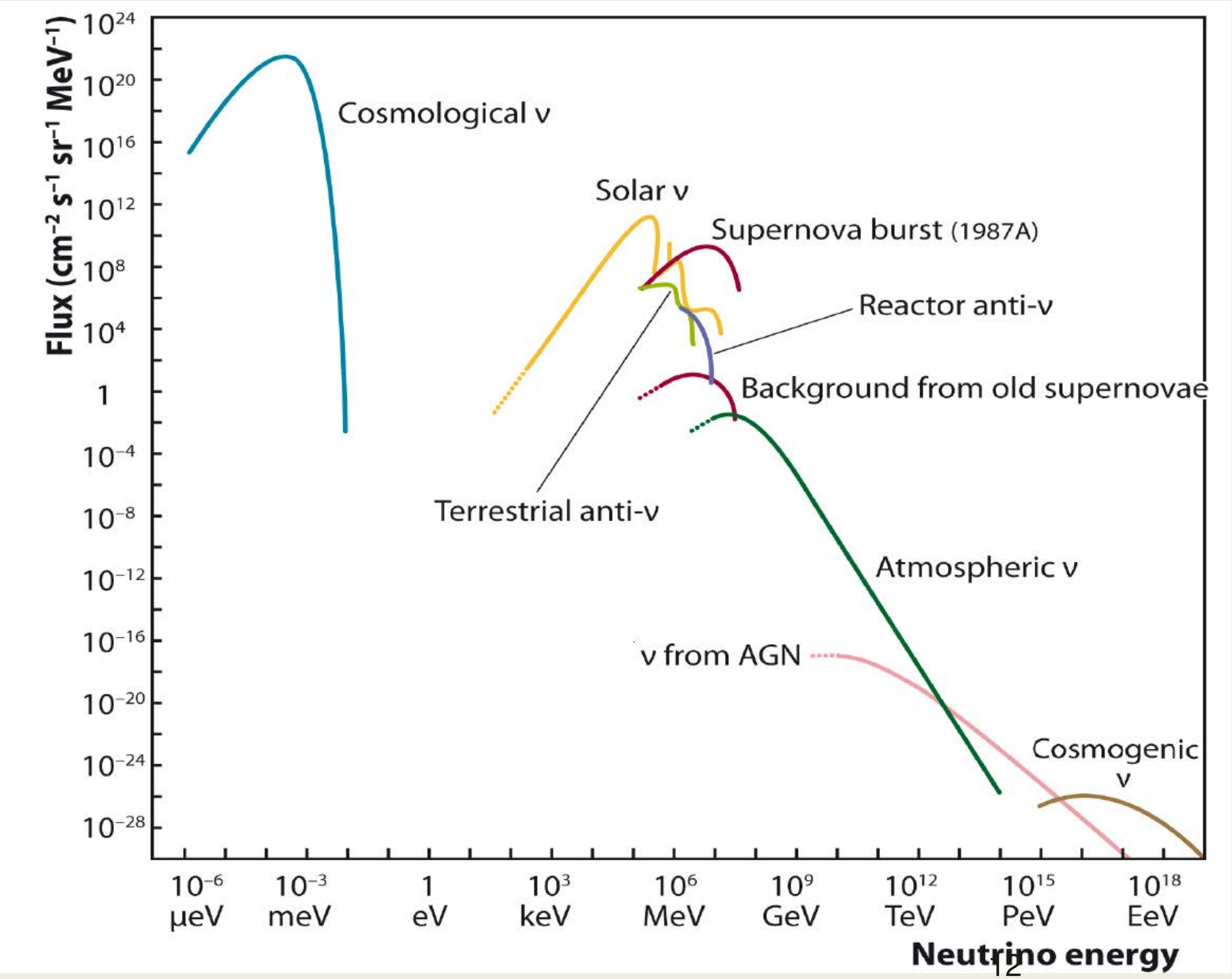


SN1987A neutrino events observed by Kamiokande, IMB and Baksan showed that the neutrino burst lasted about 13 s.

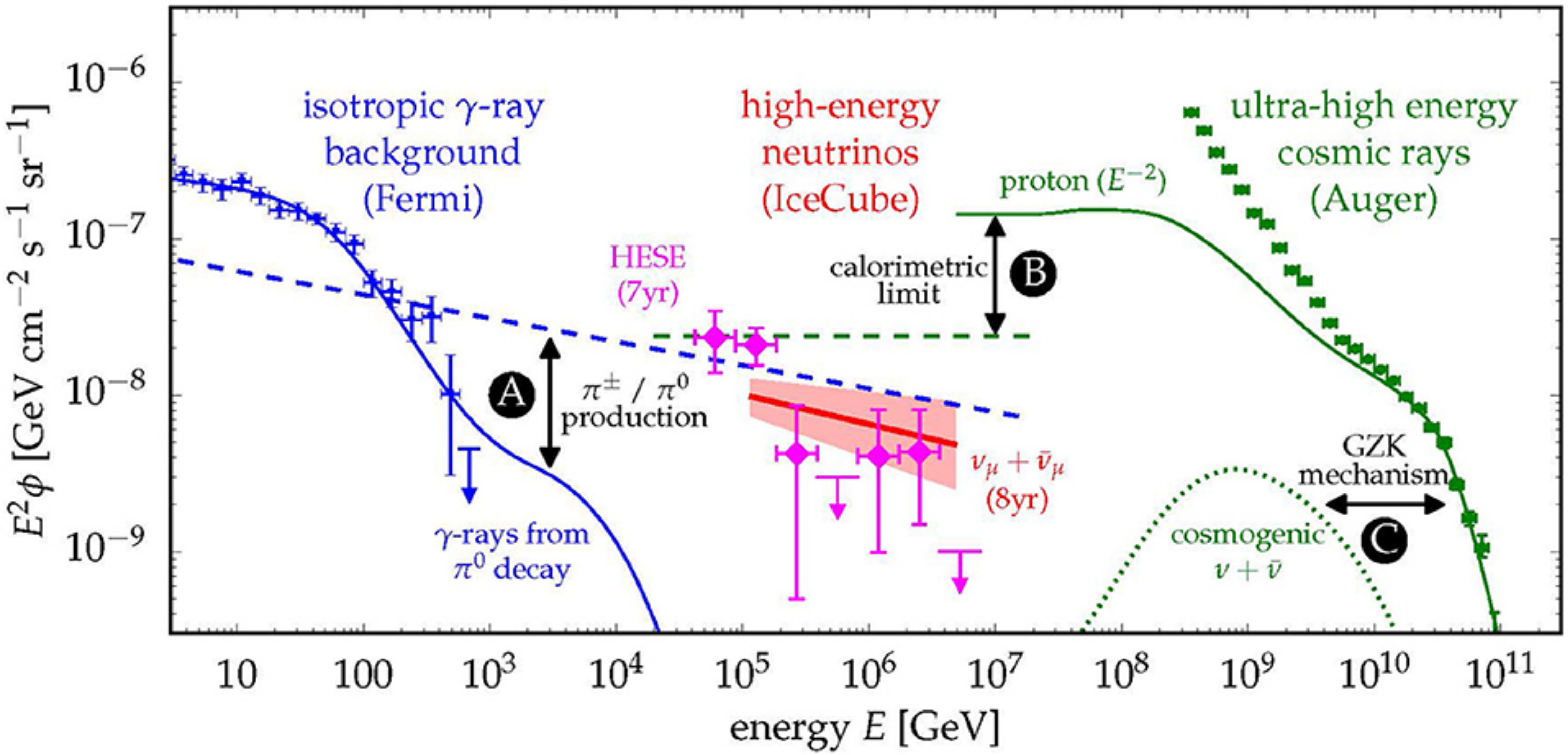
Measured and expected fluxes of natural and reactor neutrinos

- The energy range from keV to several GeV is the domain of underground detectors.
- The region from tens of GeV to about 100 PeV, with its much smaller fluxes, is addressed by Cherenkov light detectors underwater and in ice.
- The highest energies are only accessible with huge detector volumes and methods
- Must Read:

  https://arxiv.org/pdf/1207.4952.pdf



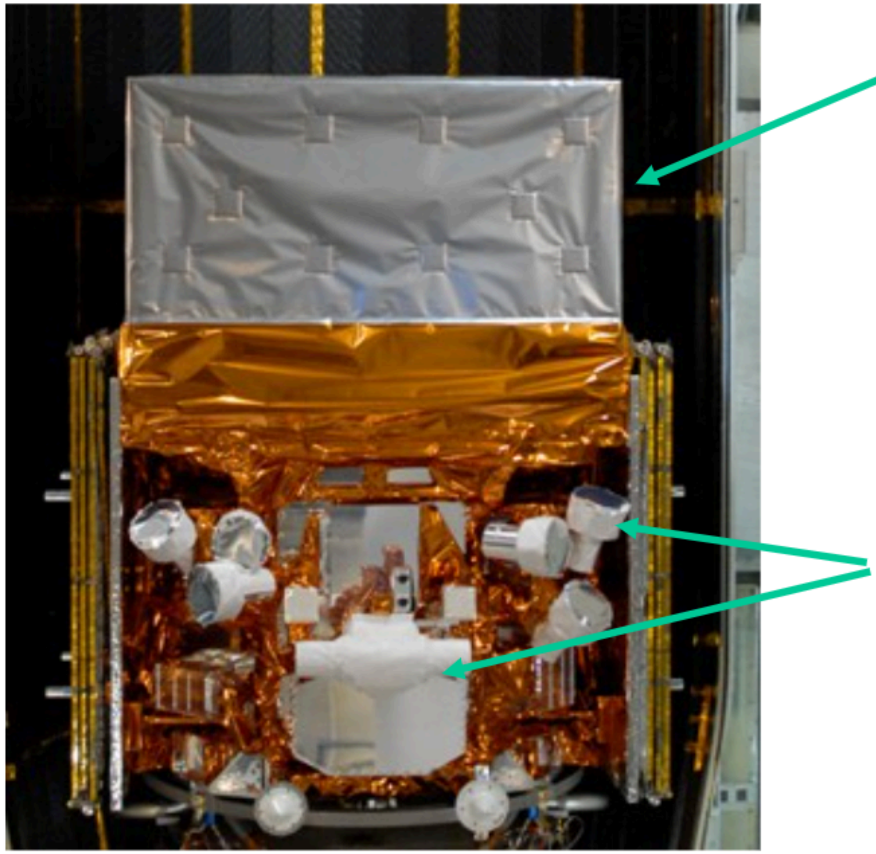
Moving away from neutrinos….



FERMI

- Originally known as the Gamma-Ray Large Area Space Telescope (GLAST).
- The two instruments on board the Fermi telescope are:
- The Gamma-ray Burst Monitor (GBM)
- The Large Area Telescope (LAT)

FERMI



Large Area Telescope (LAT):

- 20 MeV - >300 GeV
- 2.4 sr FoV (scans entire sky every ~3hrs)

Gamma-ray Burst Monitor (GBM)

- 8 keV - 40 MeV
- views entire unocculted sky

Launched on June 11, 2008

FERMI GBM

- Perform a periodic survey of the complete visible sky and provide burst triggers and locations.
- The observing field of view of the GBM is 9.5 steradians with a gamma ray burst location accuracy of 3" and a timing accuracy of 2 s

https://gcn.gsfc.nasa.gov/gcn3/27957.gcn3

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Monday, June 15th

bot APP 3:32 PM

SUBJECT: IceCube-200615A: Upper limits from Fermi-GBM Observations

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//////////////////////////////////////////////////////////////////////
TITLE:    GCN CIRCULAR
NUMBER:   27957
SUBJECT:  IceCube-200615A: Upper limits from Fermi-GBM Observations
DATE:     20/06/15 20:31:57 GMT
FROM:     Joshua Wood at MSFC/Fermi-GBM  <joshua.r.wood@nasa.gov>
J. Wood (NASA/MSFC) reports on behalf of the Fermi-GBM team:
For the IceCube high-energy neutrino candidate event IceCube-200615A
(GCN 27950), at the event time Fermi-GBM was observing the reported
neutrino location at:
RA: 142.95 (+1.18 -1.45 deg 90% PSF containment) J2000
Dec: 3.66 (+1.19 -1.06 deg 90% PSF containment) J2000
There was no Fermi-GBM onboard trigger around the event time of the
neutrino candidate. An automated, blind search for short gamma-ray
bursts below the onboard triggering threshold in Fermi-GBM also
identified no counterpart candidates. The GBM targeted search,
the most sensitive, coherent search for GRB-like signals,
was run from +/-30 s around the neutrino candidate time.
From this search, no significant signal was found related
to IceCube-200615A.
We set upper limits on impulsive gamma-ray emission. Using the
representative soft, normal, and hard GRB-like templates described in
arXiv:1612.02395, we set the following 3 sigma flux upper limits over
10-1000 keV (in units of 10^-7 erg/s/cm^2):
Timescale   Soft     Normal    Hard
------------------------------------------
0.128 s:    7.5      11.       26.
1.024 s:    1.8      2.9       6.4
8.192 s:    0.4      0.9       2.2
These results are preliminary.
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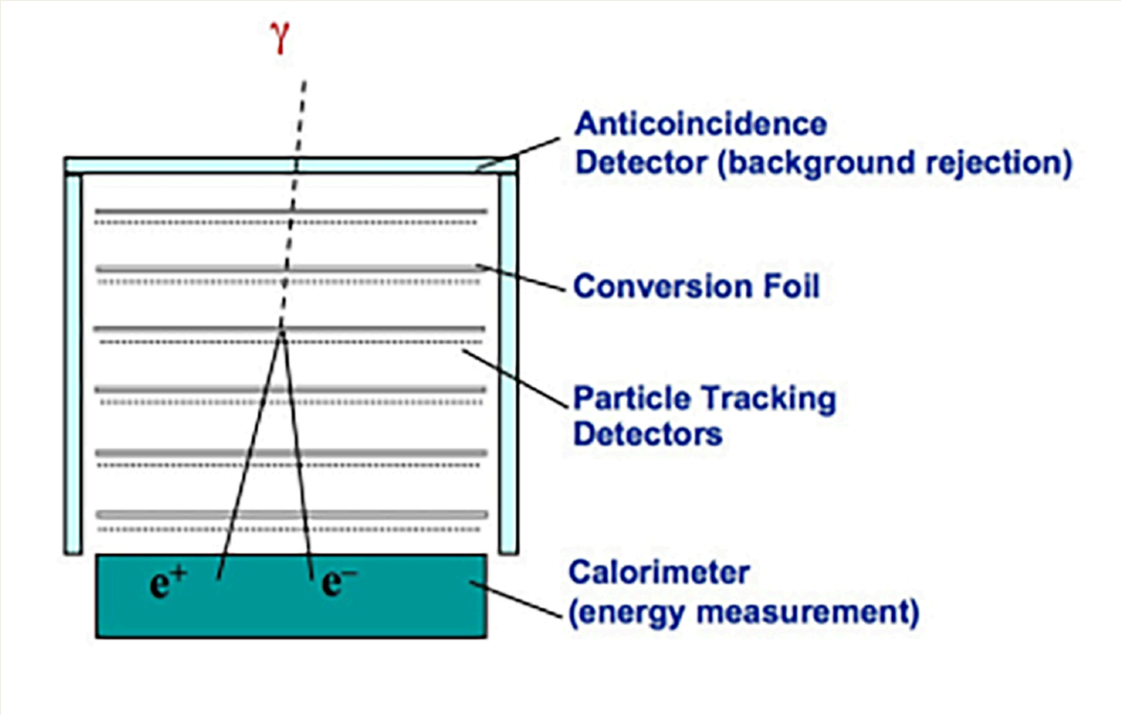
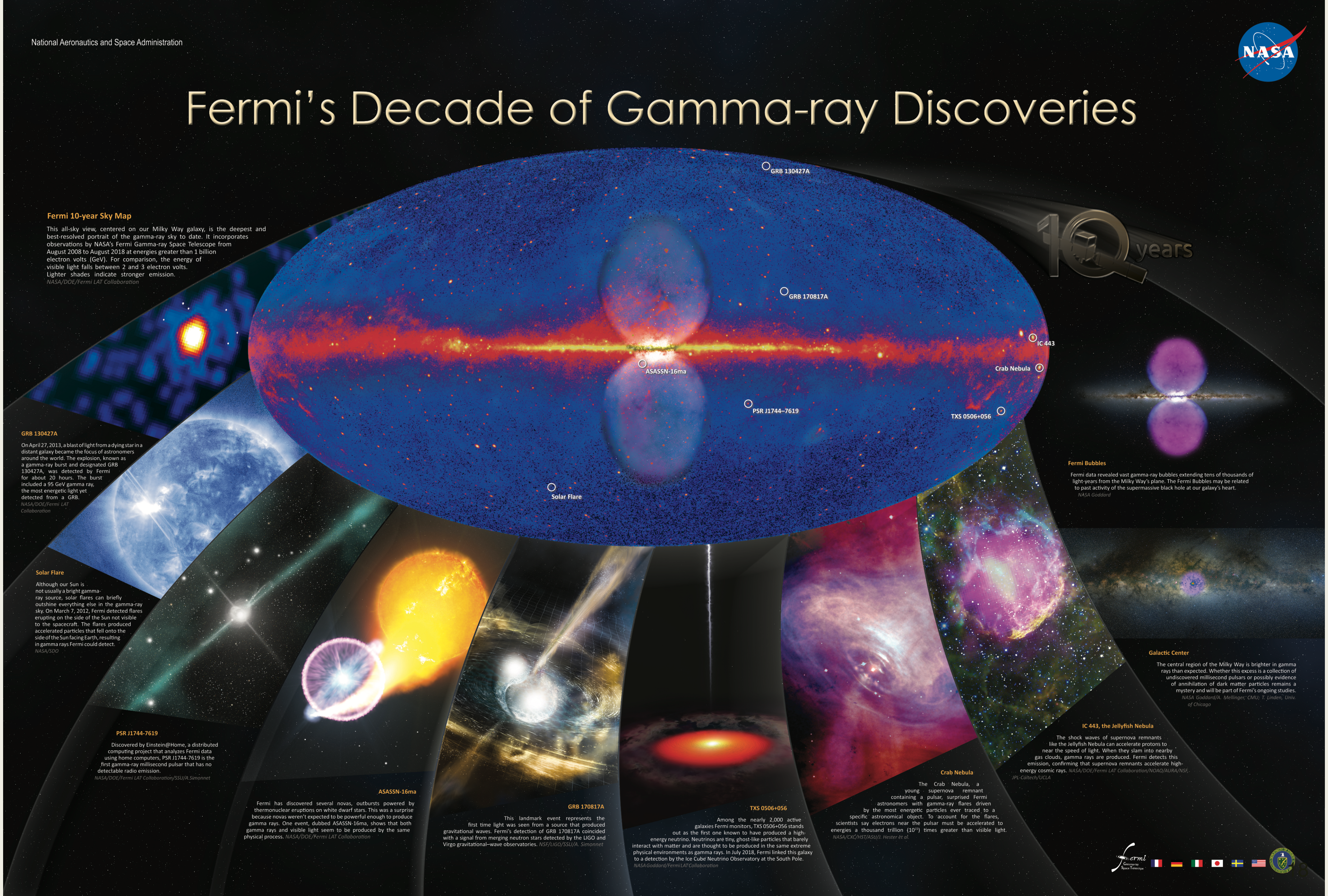
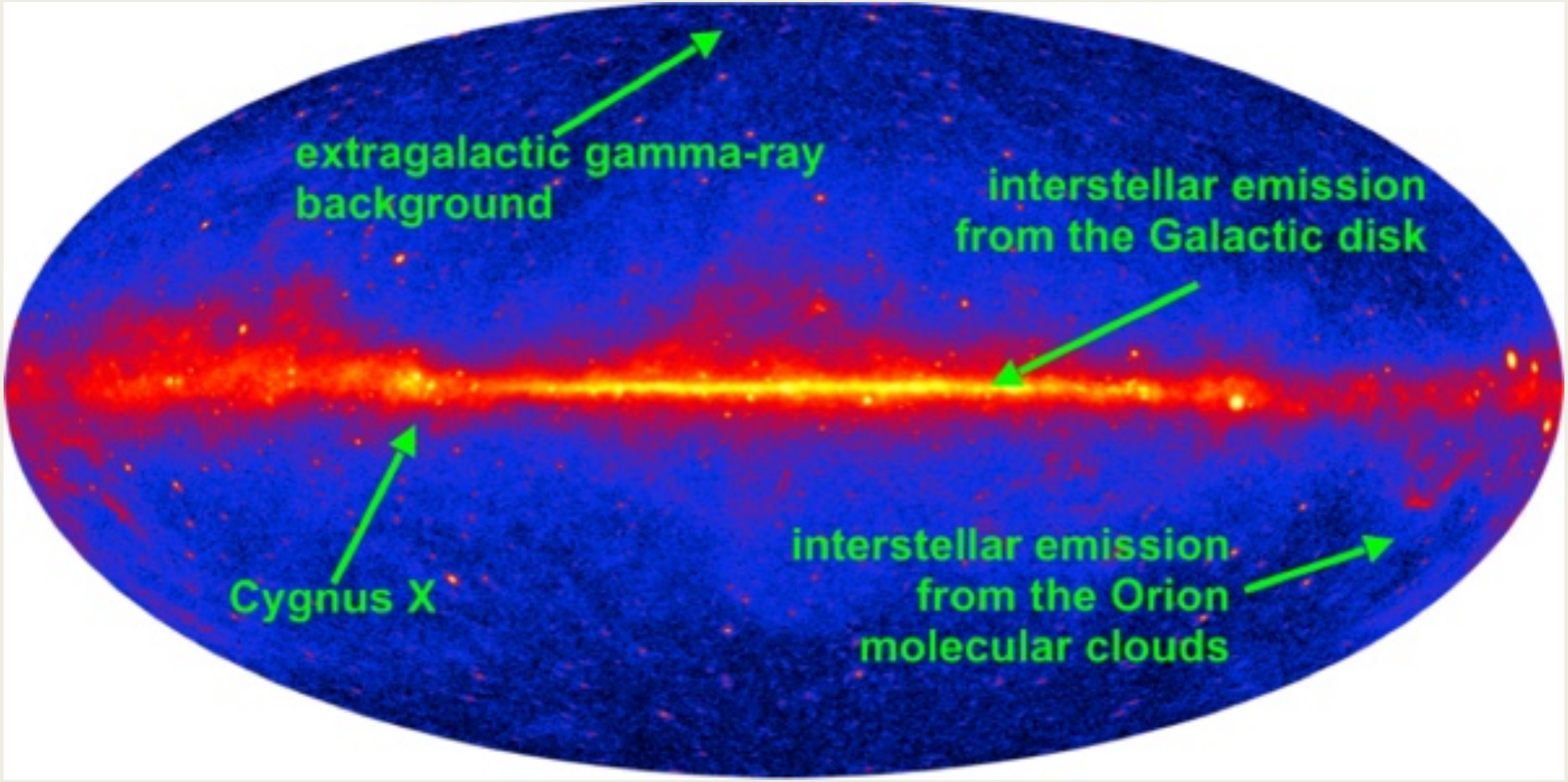
FERMI LAT

- The main aim of the LAT is the detection of incoming high energy gamma rays which cannot be refracted or focused using a lens or mirror like visible light.
- The gamma rays are detected using an electron positron pair production method akin to the one used in high-energy particle accelerators.
- Thin plastic anticoincidence detector causes the incoming gamma rays to pass freely but charged cosmic rays to cause a flash of light separating out the relatively rare gamma rays.
- To make use of the large FoV of the LAT, the Fermi spacecraft, orbits the earth in about 96 minutes with the LAT pointed upwards at all times to remove interference from earth.



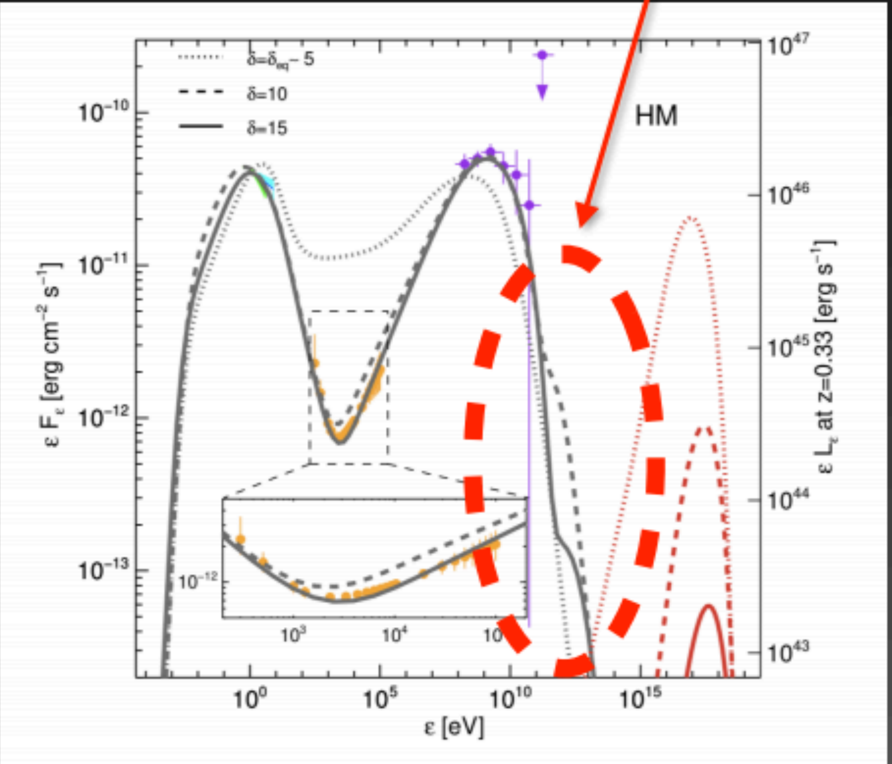


National Aeronautics and Space Administration
NASA
Fermi's Decade of Gamma-ray Discoveries
10 years
GRB 130427A
GRB 170817A
IC 443
Crab Nebula
ASASSN-16ma
PSR J1744–7619
TXS 0506+056
Solar Flare
Fermi 10-year Sky Map
This all-sky view, centered on our Milky Way galaxy, is the deepest and best-resolved portrait of the gamma-ray sky to date. It incorporates observations by NASA's Fermi Gamma-ray Space Telescope from August 2008 to August 2018 at energies greater than 1 billion electron volts (GeV). For comparison, the energy of visible light falls between 2 and 3 electron volts. Lighter shades indicate stronger emission. NASA/DOE/Fermi LAT Collaboration
GRB 130427A
On April 27, 2013, a blast of light from a dying star in a distant galaxy became the focus of astronomers around the world. The explosion, known as a gamma-ray burst and designated GRB 130427A, was detected by Fermi for about 20 hours. The burst included a 95 GeV gamma ray, the most energetic light yet detected from a GRB. NASA/DOE/Fermi LAT Collaboration
Solar Flare
Although our Sun is not usually a bright gamma-ray source, solar flares can briefly outshine everything else in the gamma-ray sky. On March 7, 2012, Fermi detected flares erupting on the side of the Sun not visible to the spacecraft. The flares produced accelerated particles that fell onto the side of the Sun facing Earth, resulting in gamma rays Fermi could detect. NASA/SDO
PSR J1744-7619
Discovered by Einstein@Home, a distributed computing project that analyzes Fermi data using home computers, PSR J1744-7619 is the first gamma-ray millisecond pulsar that has no detectable radio emission. NASA/DOE/Fermi LAT Collaboration/SSU/A.Simonnet
ASASSN-16ma
Fermi has discovered several novas, outbursts powered by thermonuclear eruptions on white dwarf stars. This was a surprise because novas weren't expected to be powerful enough to produce gamma rays. One event, dubbed ASASSN-16ma, shows that both gamma rays and visible light seem to be produced by the same physical process. NASA/DOE/Fermi LAT Collaboration
GRB 170817A
This landmark event represents the first time light was seen from a source that produced gravitational waves. Fermi's detection of GRB 170817A coincided with a signal from merging neutron stars detected by the LIGO and Virgo gravitational–wave observatories. NSF/LIGO/SSU/A. Simonnet
TXS 0506+056
Among the nearly 2,000 active galaxies Fermi monitors, TXS 0506+056 stands out as the first one known to have produced a high-energy neutrino. Neutrinos are tiny, ghost-like particles that barely interact with matter and are thought to be produced in the same extreme physical environments as gamma rays. In July 2018, Fermi linked this galaxy to a detection by the Ice Cube Neutrino Observatory at the South Pole. NASA Goddard/Fermi LAT Collaboration
Crab Nebula
The Crab Nebula, a young supernova remnant containing a pulsar, surprised Fermi astronomers with gamma-ray flares driven by the most energetic particles ever traced to a specific astronomical object. To account for the flares, scientists say electrons near the pulsar must be accelerated to energies a thousand trillion (10^{15}) times greater than visible light. NASA/CXC/HST/ASU/J. Hester et al.
IC 443, the Jellyfish Nebula
The shock waves of supernova remnants like the Jellyfish Nebula can accelerate protons to near the speed of light. When they slam into nearby gas clouds, gamma rays are produced. Fermi detects this emission, confirming that supernova remnants accelerate high-energy cosmic rays. NASA/DOE/Fermi LAT Collaboration/NOAO/AURA/NSF, JPL-Caltech/UCLA
Galactic Center
The central region of the Milky Way is brighter in gamma rays than expected. Whether this excess is a collection of undiscovered millisecond pulsars or possibly evidence of annihilation of dark matter particles remains a mystery and will be part of Fermi's ongoing studies. NASA Goddard/A. Mellinger, CMU; T. Linden, Univ. of Chicago
Fermi Bubbles
Fermi data revealed vast gamma-ray bubbles extending tens of thousands of light-years from the Milky Way's plane. The Fermi Bubbles may be related to past activity of the supermassive black hole at our galaxy's heart. NASA Goddard
Fermi Gamma-ray Space Telescope

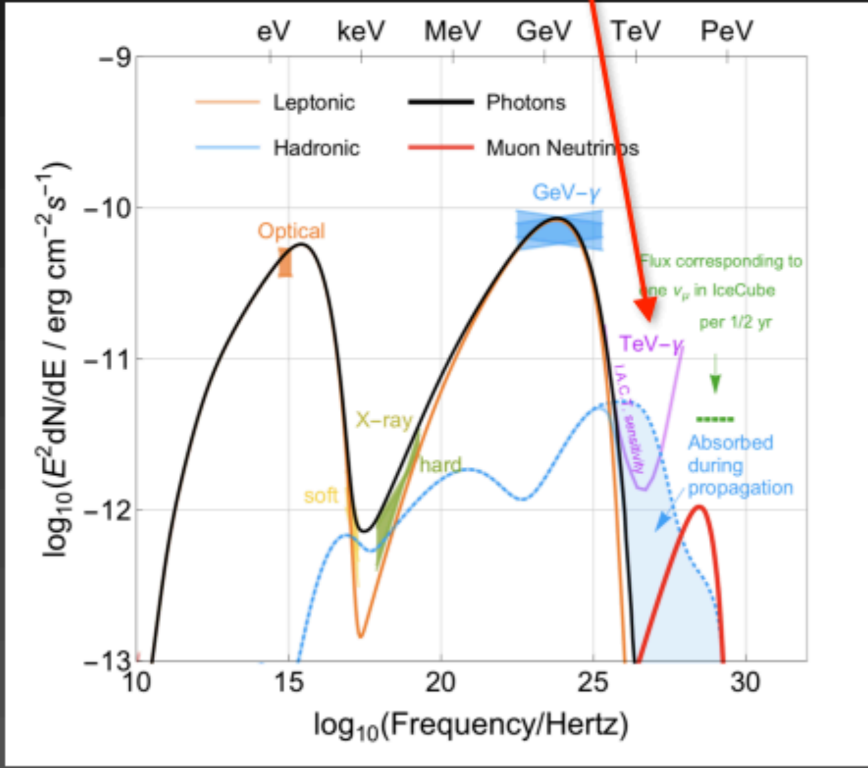

extragalactic gamma-ray
background
interstellar emission
from the Galactic disk
Cygnus X
interstellar emission
from the Orion
molecular clouds

Leptonic, *Hadronic*… ***Both***?

CTA can give insight on particle jet composition



Keivani et al. (2018)



Gao et al. (2018)

MOVING TOWARDS CTA…