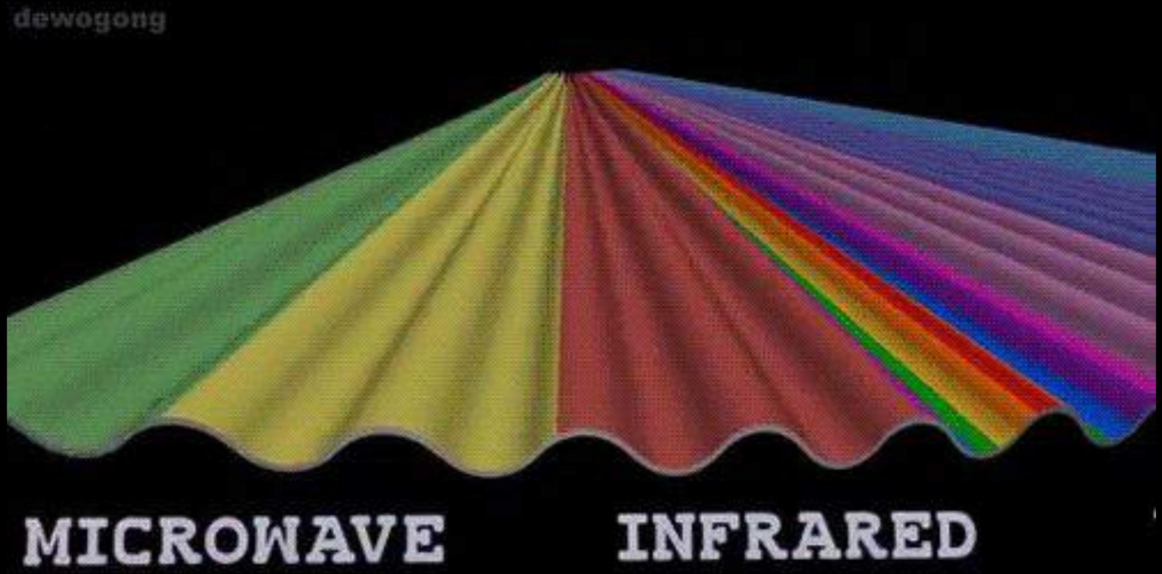
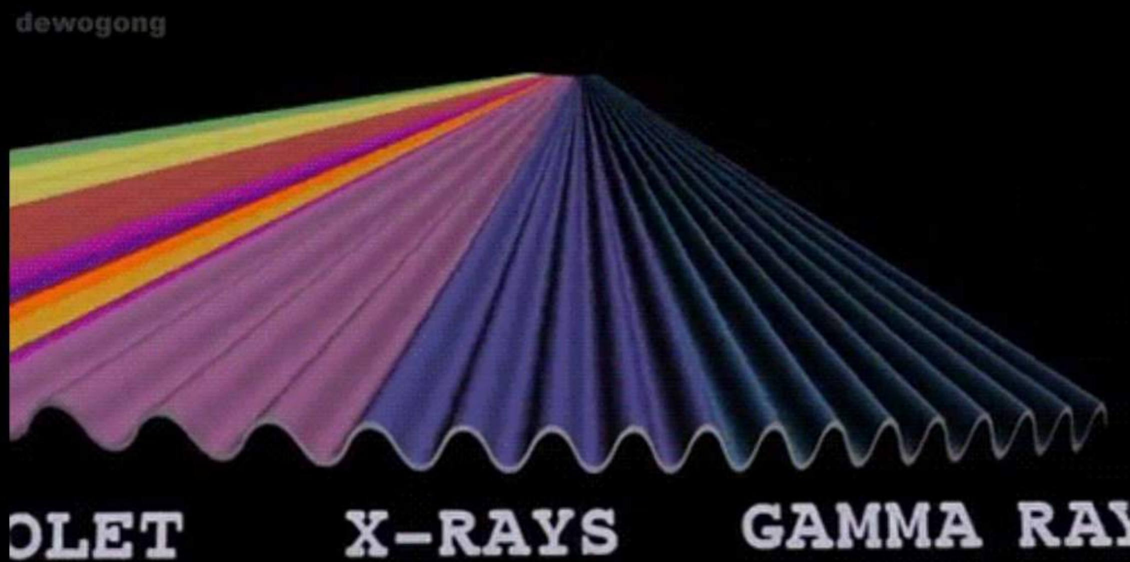
Fermi Gamma-ray Telescope: Hands-on Activity

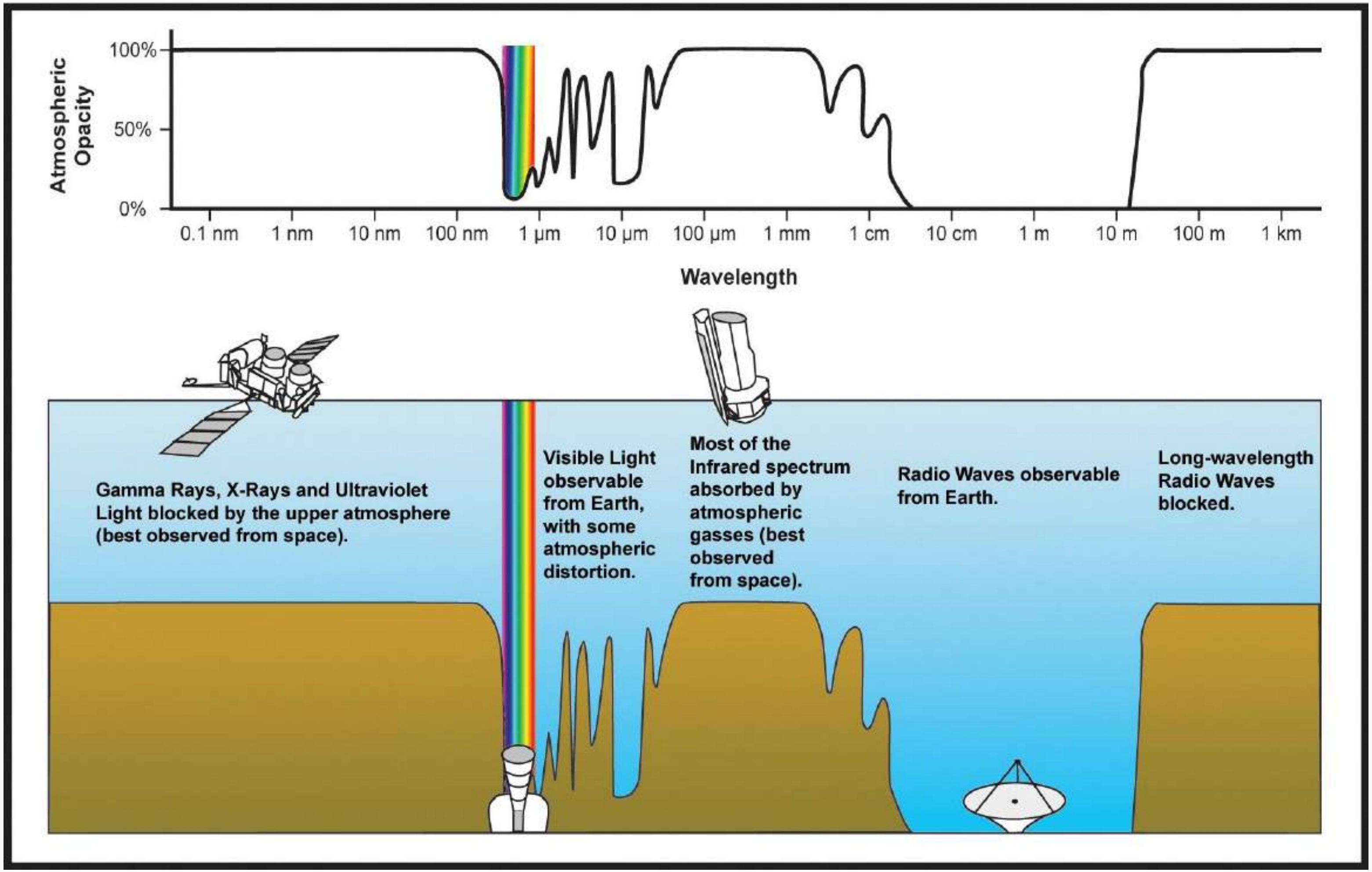
Fabio Cafardo • Rodrigo Nemmen

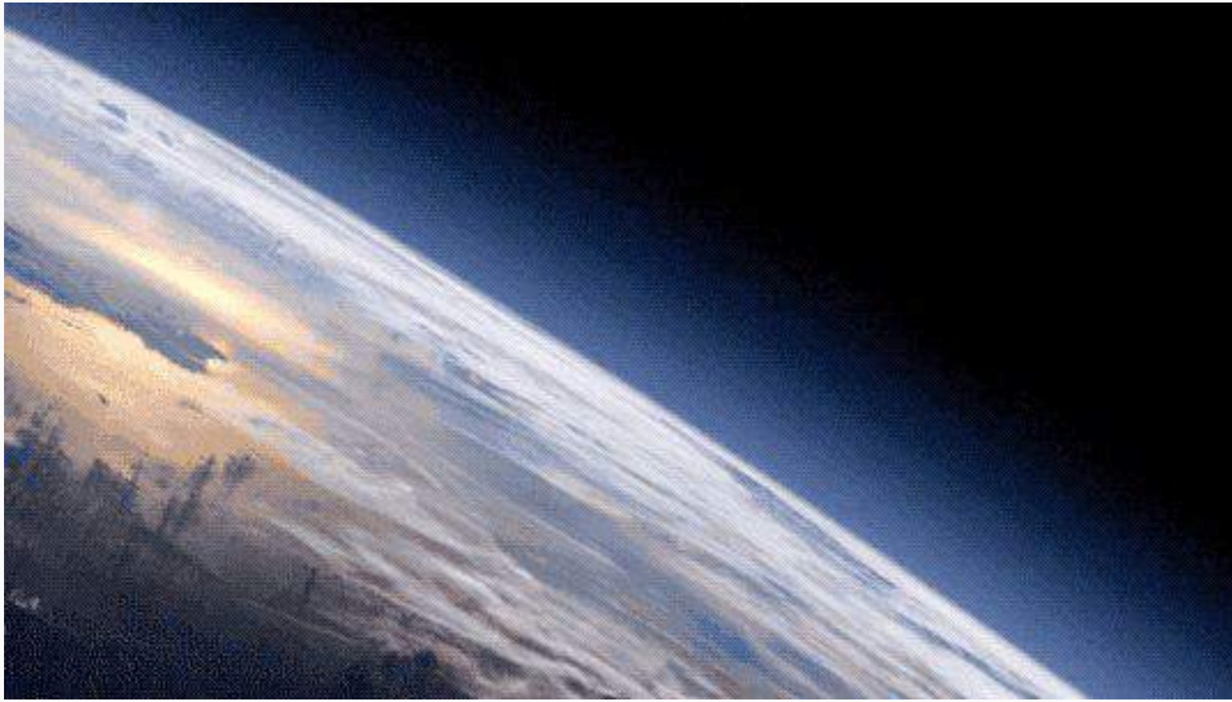
black hole group iag usp

School on High Energy Astrophysics - August 12th, 2019


dewogong
MICROWAVE
INFRARED


dewogong
OLET
X-RAYS
GAMMA RAY


Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.




Klepser


Jordanagoodman

Movie available at:
http://fermi.sonoma.edu/multimedia/360degrees2.mp4

fermi.sonoma.edu/multimedia

fermi.sonoma.edu/multimedia

Data

Events files
- reconstructed direction
- reconstructed energy
- moment of the detection
- quality parameters

The photon database currently holds 3,245,299,693 events

All this data is public!
(as well as the analysis software)

Spacecraft files
- position
- orientation
- 30-second intervals

Movie available at:
https://svs.gsfc.nasa.gov/vis/a010000/a010400/a010407/index.html

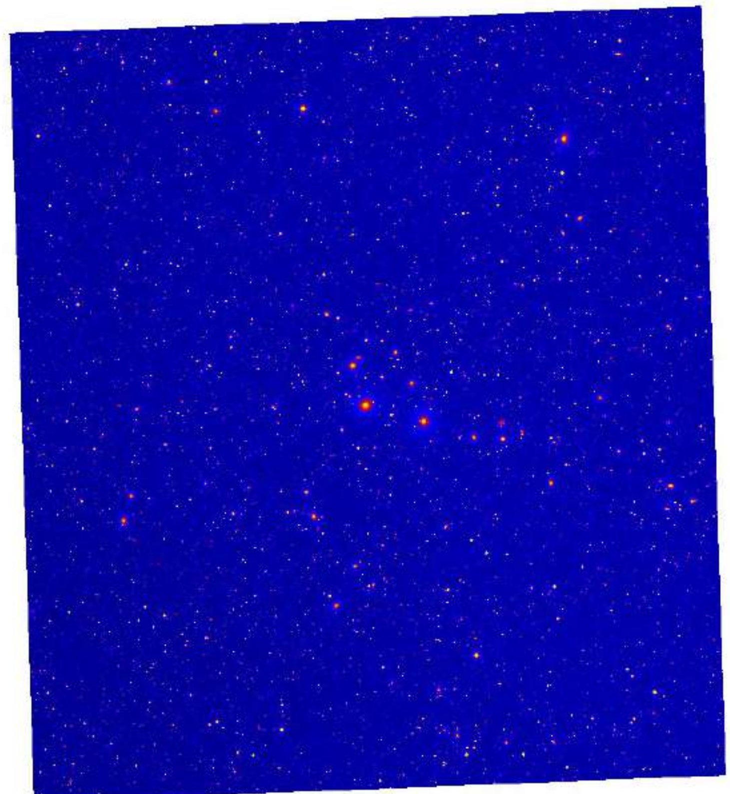
NASA/DOE/Fermi LAT Collaboration

Movie available at:
https://www.youtube.com/watch?v=0RExg9Wzp5s

NASA/Goddard Space Flight Center Conceptual Image Lab

One example: NGC 1275

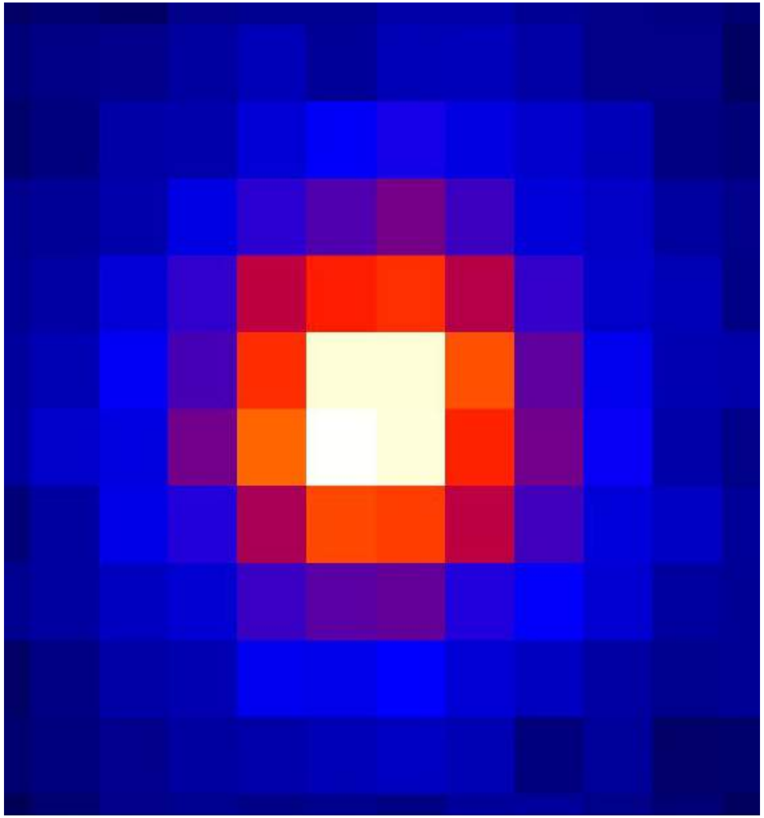
6450Å
Telescope Palomar
48-inch Schmidt



1°
(~1.2 Mpc)

One example: NGC 1275

100 MeV - 300 GeV
Fermi-LAT

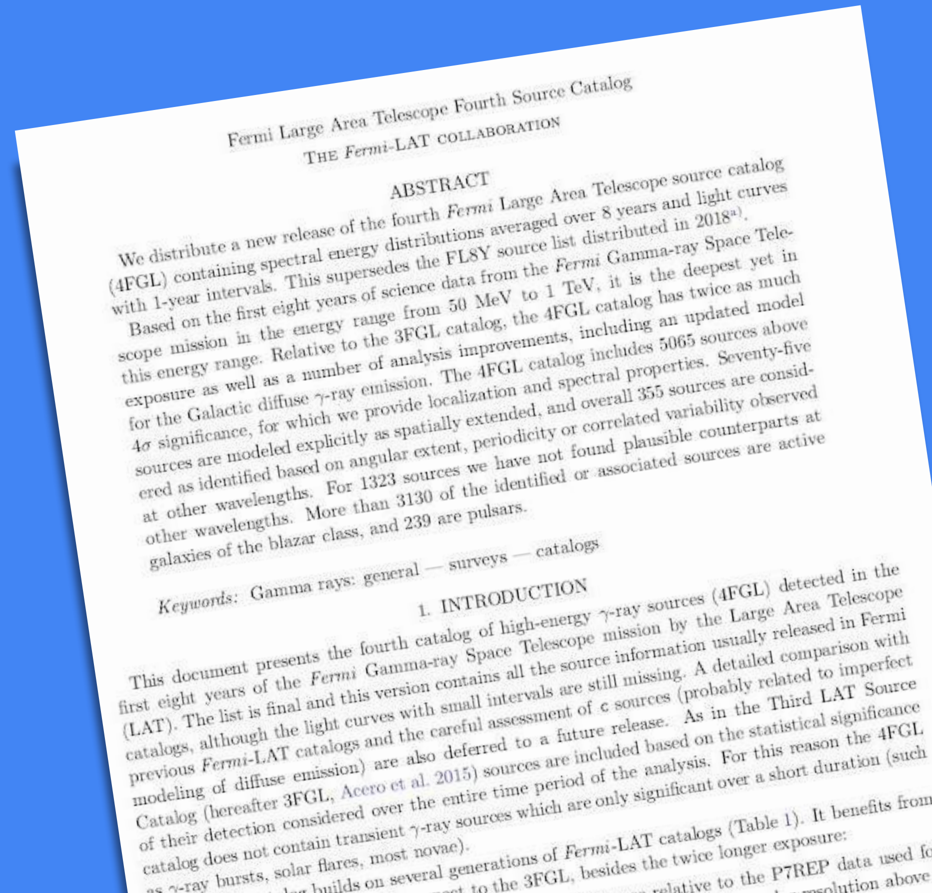


Fermi Large Area Telescope Fourth Source Catalog (4FGL)

8 years of data

5065 sources

energy range
50 MeV - 1 TeV



Fermi Large Area Telescope Fourth Source Catalog

The *Fermi*-LAT collaboration

ABSTRACT

We distribute a new release of the fourth *Fermi* Large Area Telescope source catalog (4FGL) containing spectral energy distributions averaged over 8 years and light curves with 1-year intervals. This supersedes the FL8Y source list distributed in 2018[a)]. Based on the first eight years of science data from the *Fermi* Gamma-ray Space Telescope mission in the energy range from 50 MeV to 1 TeV, it is the deepest yet in this energy range. Relative to the 3FGL catalog, the 4FGL catalog has twice as much exposure as well as a number of analysis improvements, including an updated model for the Galactic diffuse γ-ray emission. The 4FGL catalog includes 5065 sources above 4σ significance, for which we provide localization and spectral properties. Seventy-five sources are modeled explicitly as spatially extended, and overall 355 sources are considered as identified based on angular extent, periodicity or correlated variability observed at other wavelengths. For 1323 sources we have not found plausible counterparts at other wavelengths. More than 3130 of the identified or associated sources are active galaxies of the blazar class, and 239 are pulsars.

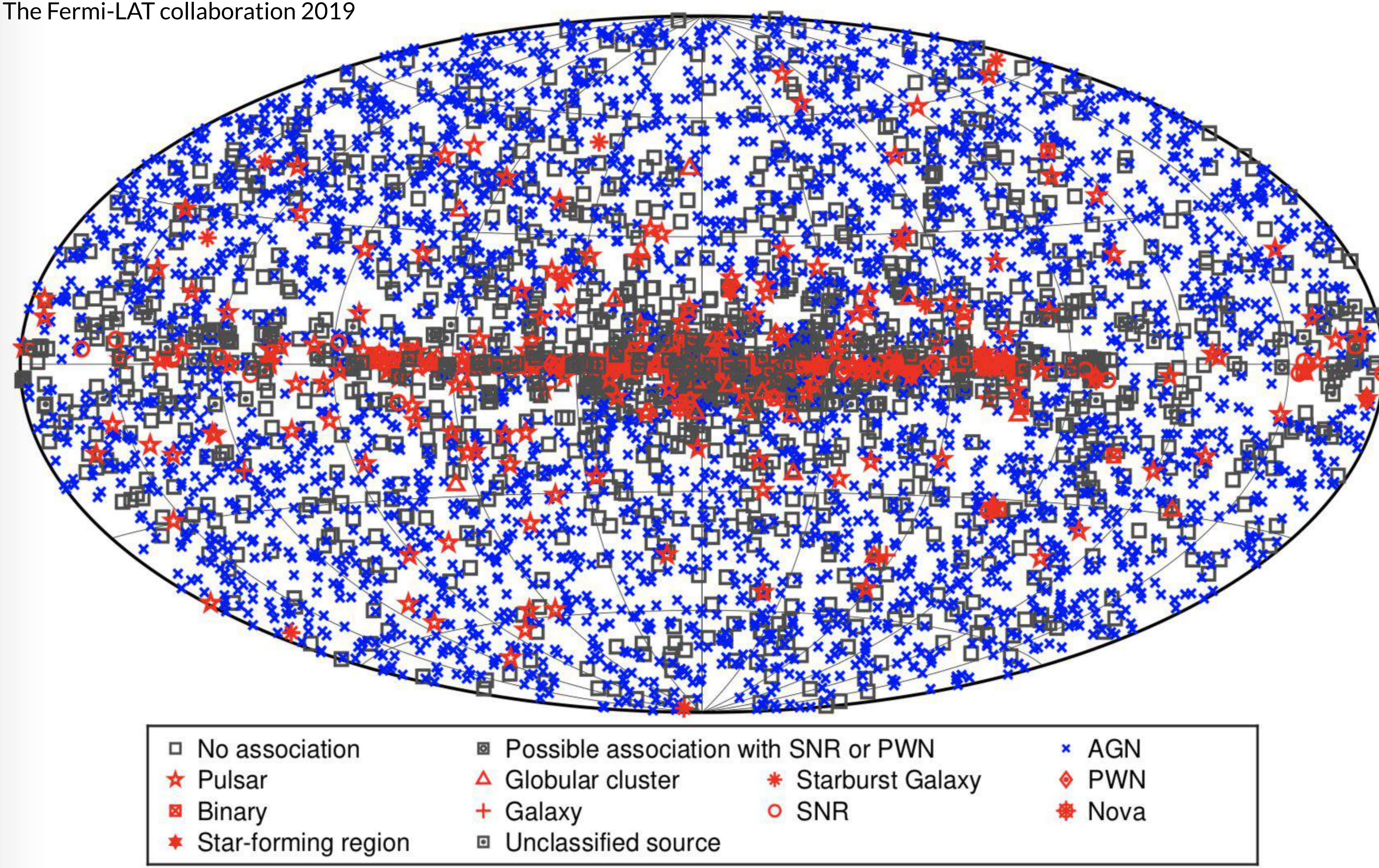
Keywords: Gamma rays: general — surveys — catalogs

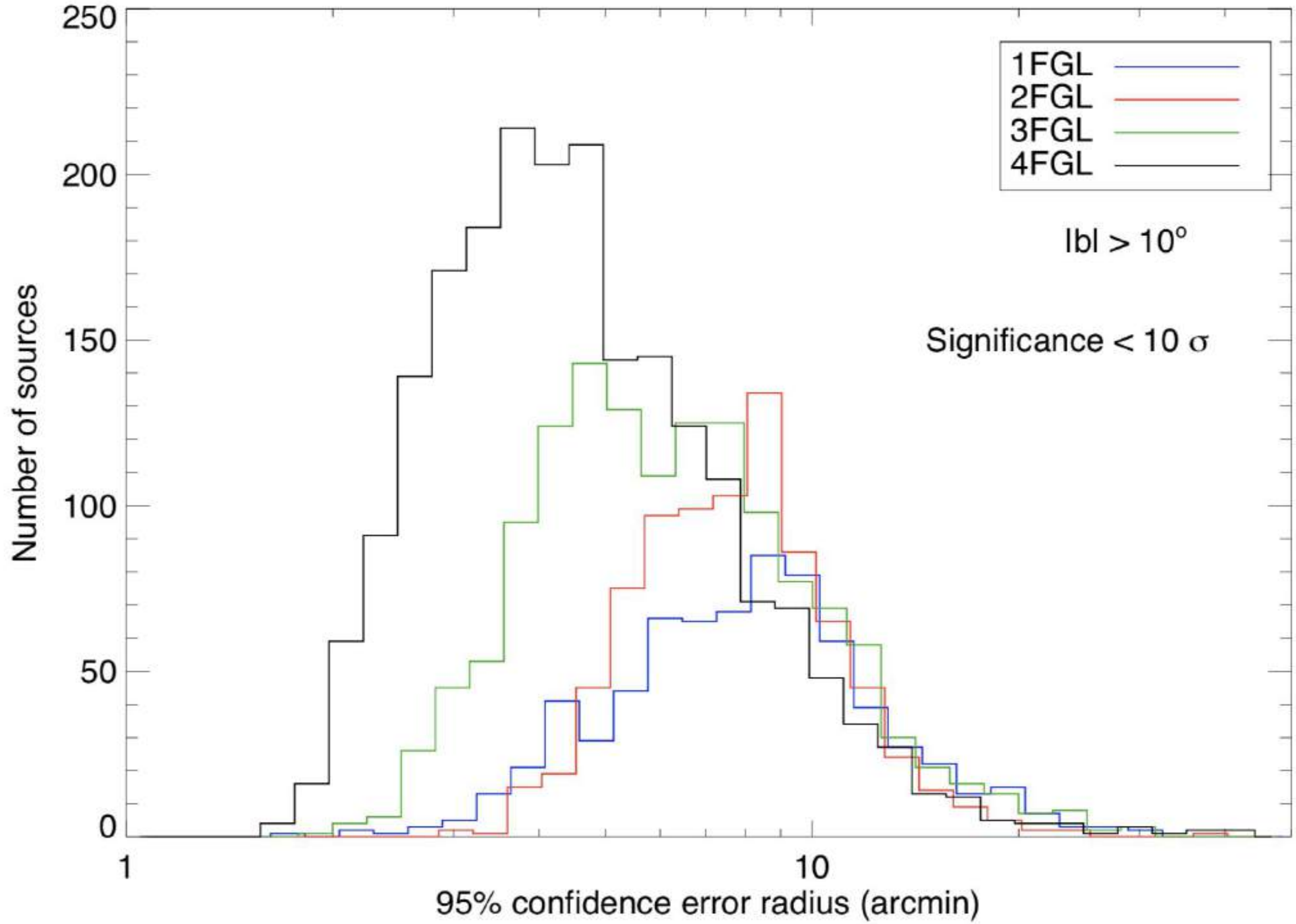
1. INTRODUCTION

This document presents the fourth catalog of high-energy γ-ray sources (4FGL) detected in the first eight years of the *Fermi* Gamma-ray Space Telescope mission by the Large Area Telescope (LAT). The list is final and this version contains all the source information usually released in Fermi catalogs, although the light curves with small intervals are still missing. A detailed comparison with previous *Fermi*-LAT catalogs and the careful assessment of c sources (probably related to imperfect modeling of diffuse emission) are also deferred to a future release. As in the Third LAT Source Catalog (hereafter 3FGL, Acero et al. 2015) sources are included based on the statistical significance of their detection considered over the entire time period of the analysis. For this reason the 4FGL catalog does not contain transient γ-ray sources which are only significant over a short duration (such as γ-ray bursts, solar flares, most novae).

... catalog builds on several generations of *Fermi*-LAT catalogs (Table 1). It benefits from ...

The Fermi-LAT collaboration 2019





The Fermi-LAT collaboration 2019

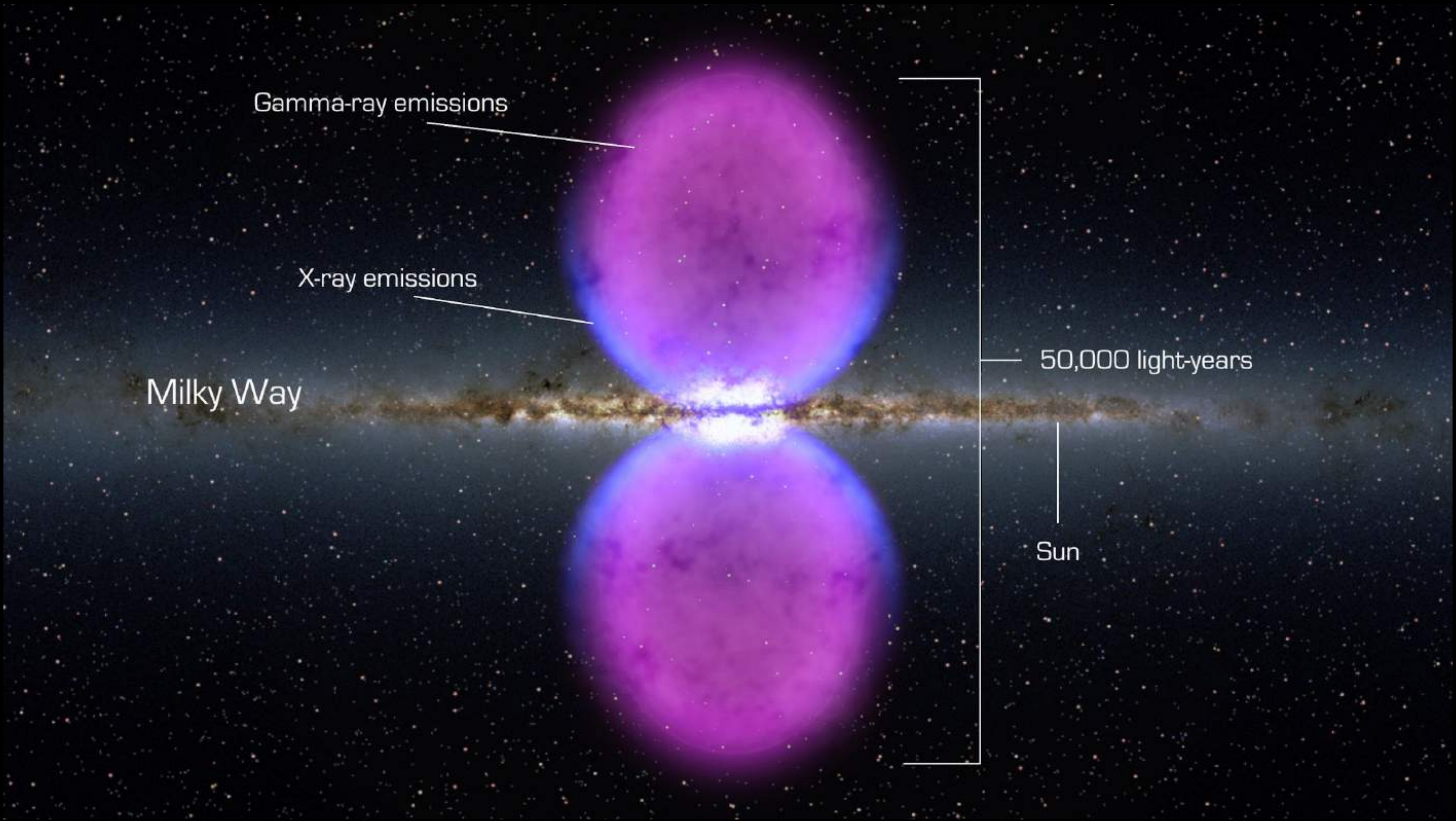
Some of Fermi’s most interesting results

Some of Fermi's most interesting results

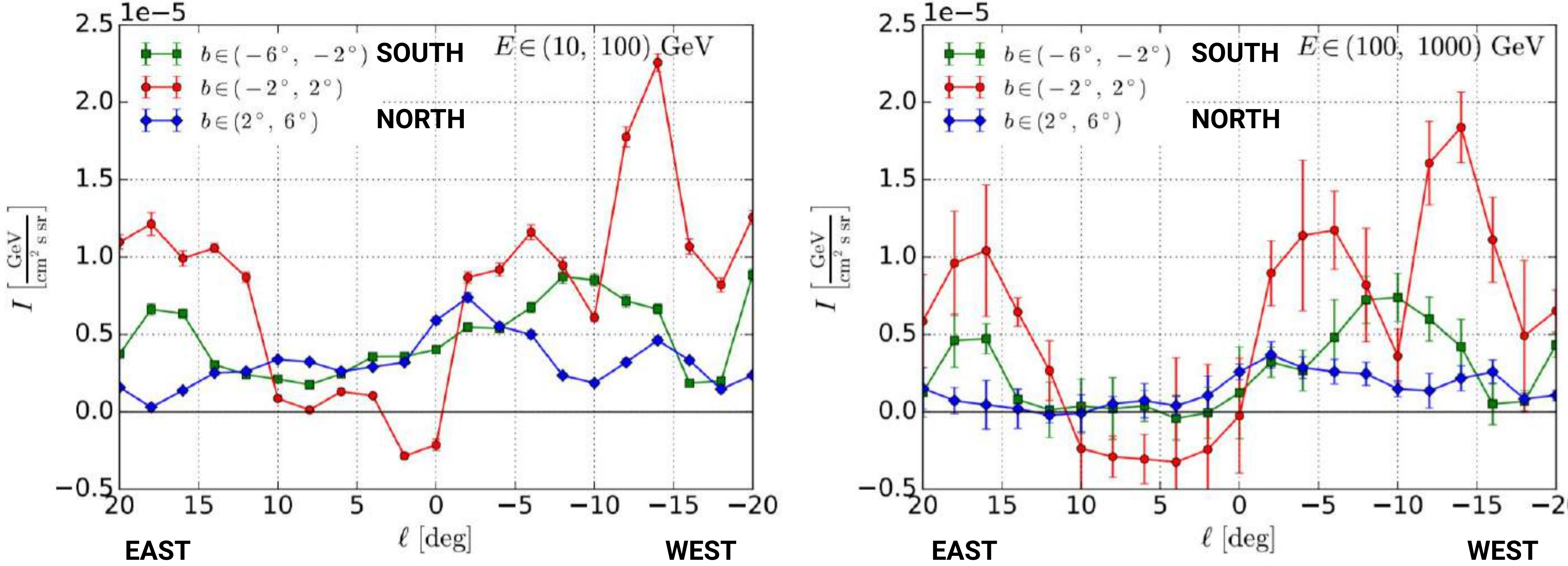
Fermi Bubbles

Movie available at:
https://www.youtube.com/watch?v=i0eomCnIBUc

NASA/DOE/Fermi LAT/D. Finkbeiner et al 2010

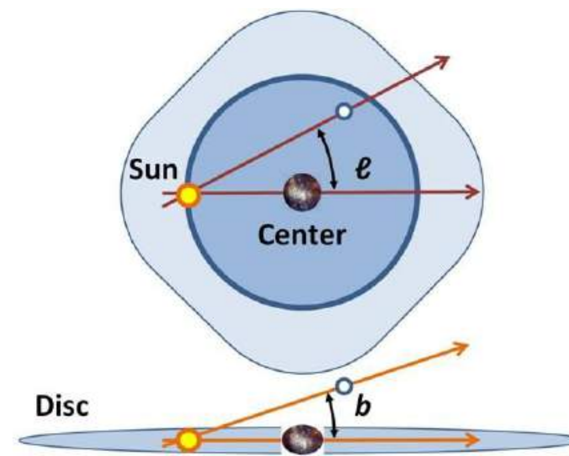


fermi.gsfc.nasa.gov/fermi10/brackets



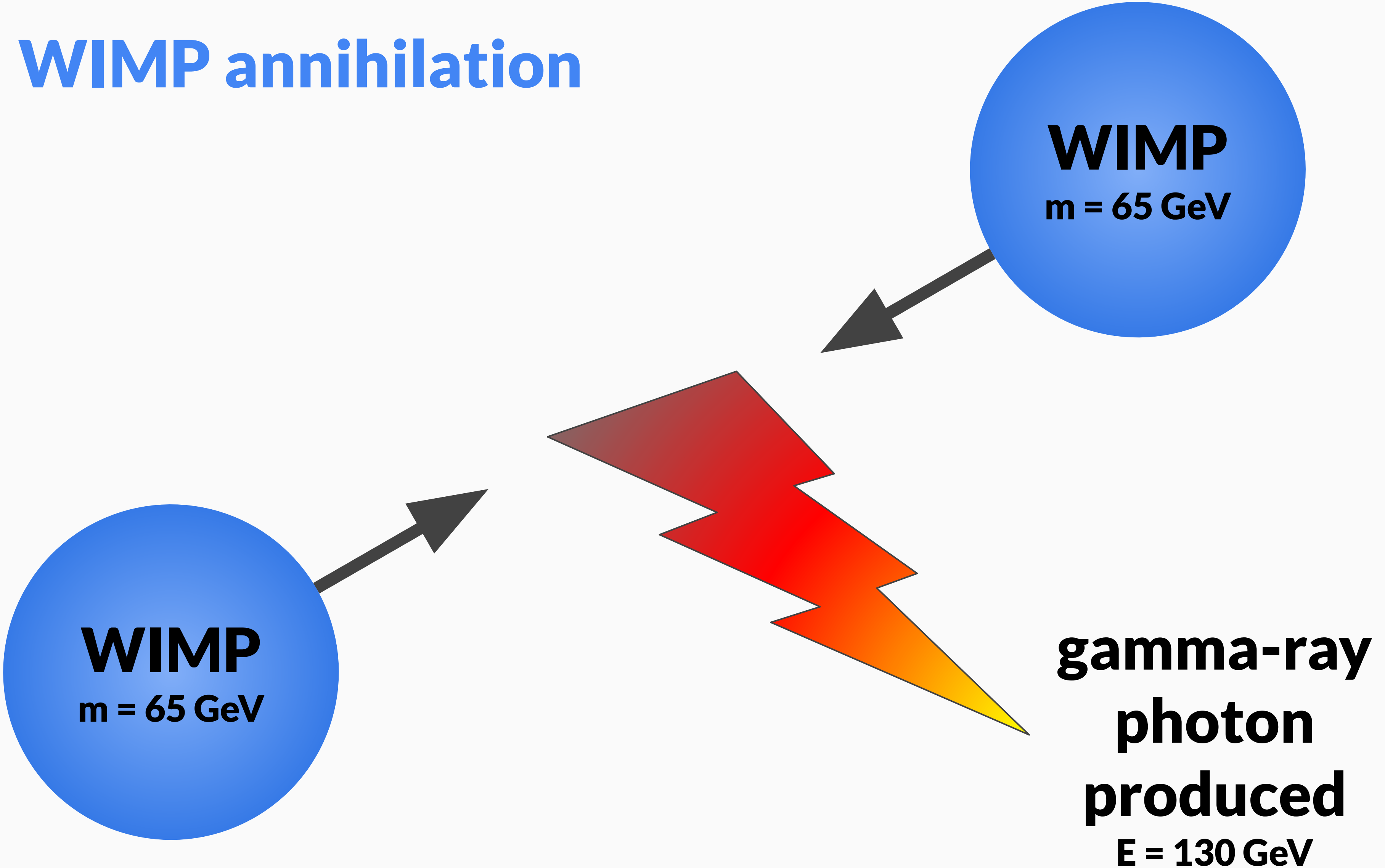
Herold & Malyshev 2019

The shift of the emission to the West disfavors models where the Fermi Bubbles were created by SgrA*

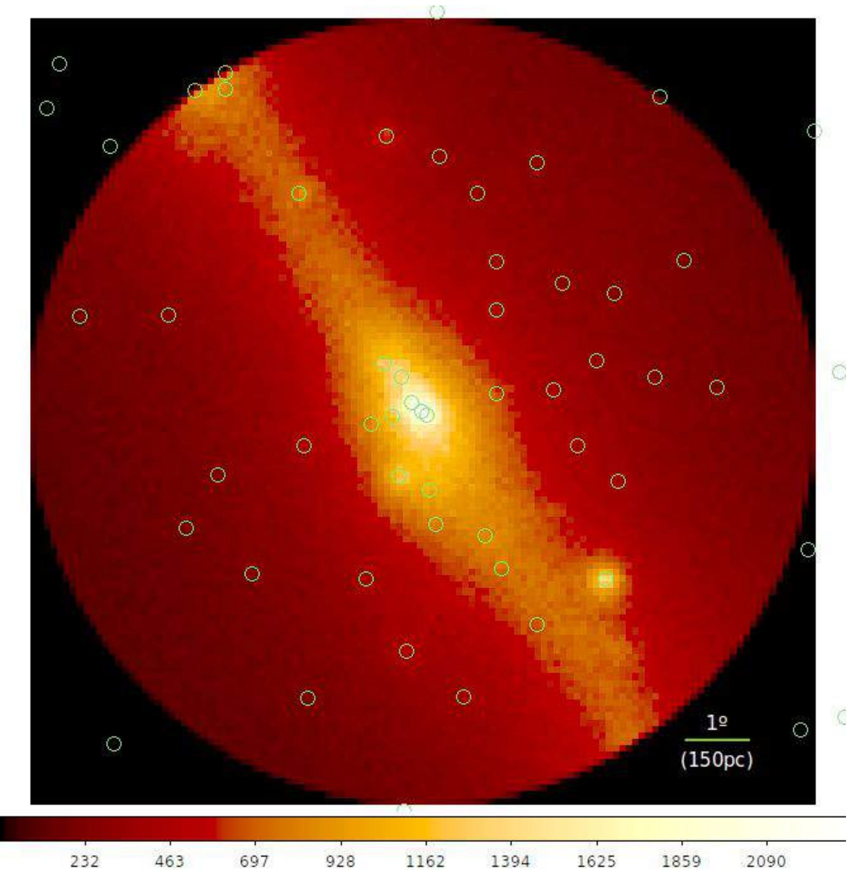


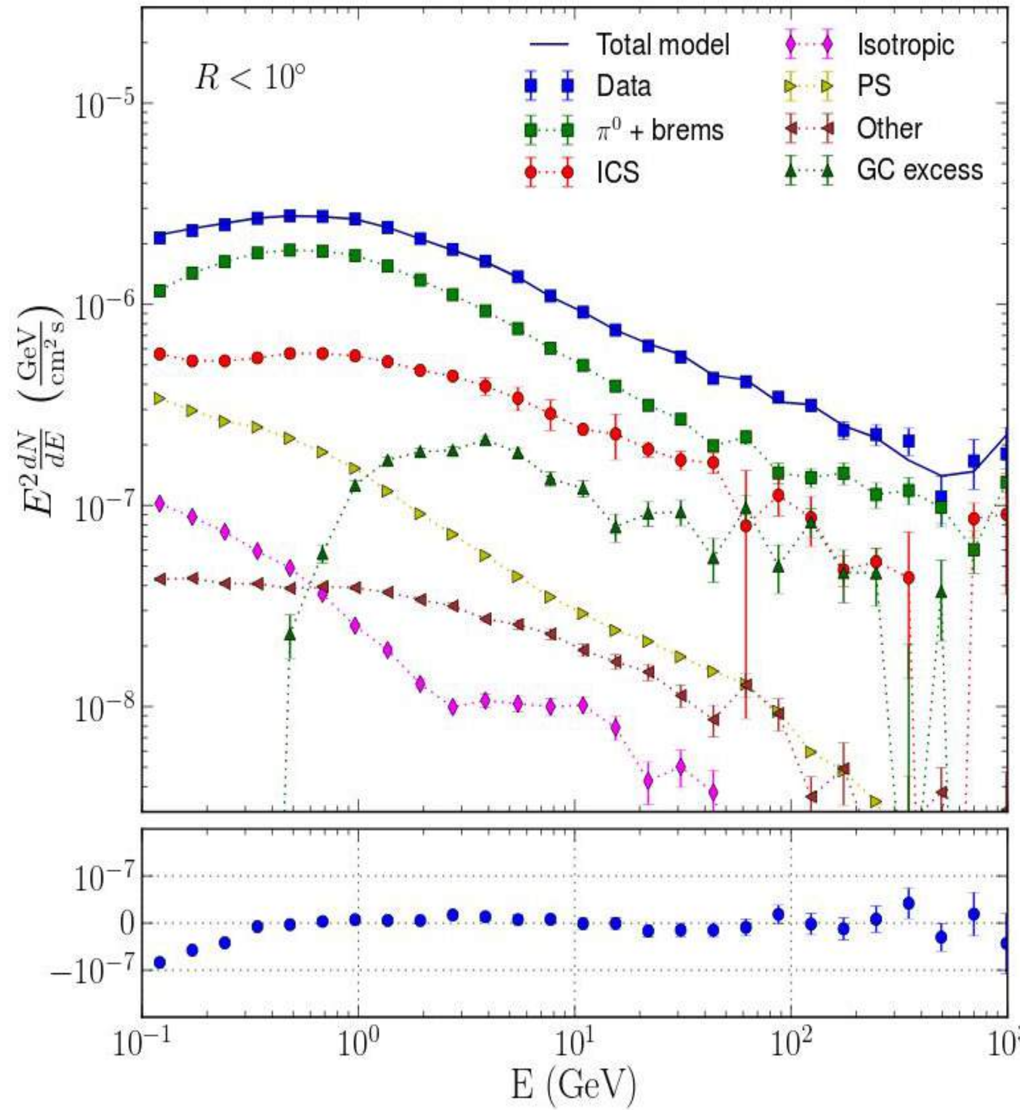
Some of Fermi's most interesting results

The search for Dark Matter


WIMP annihilation
WIMP
m = 65 GeV
WIMP
m = 65 GeV
gamma-ray
photon
produced
E = 130 GeV

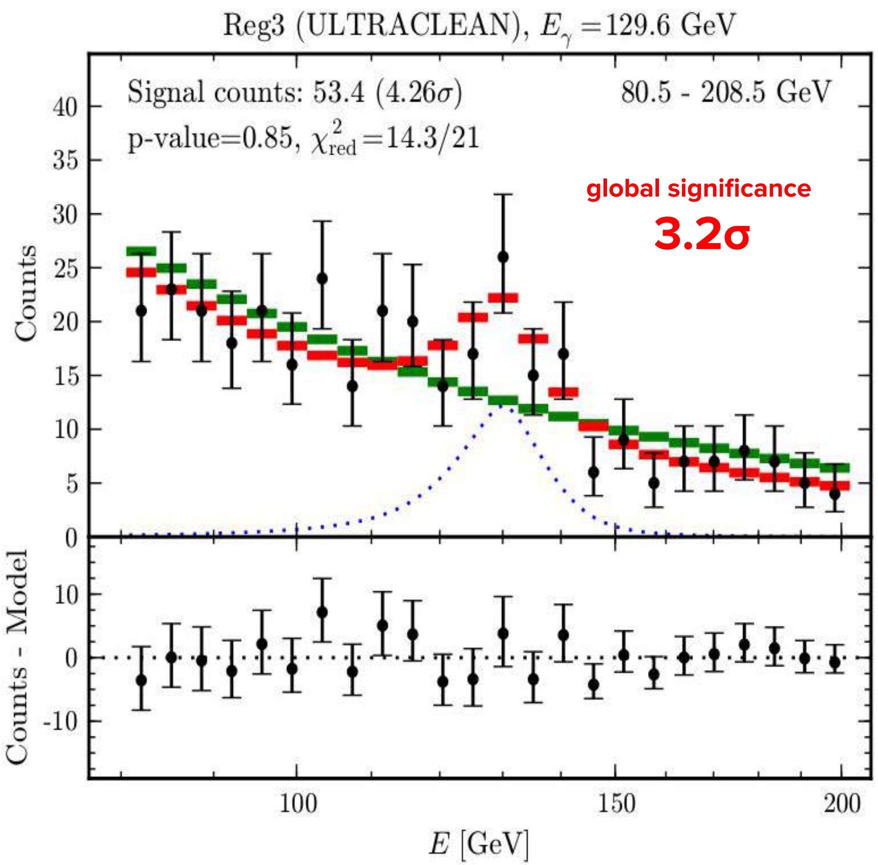
Dark Matter in the Galactic Center?





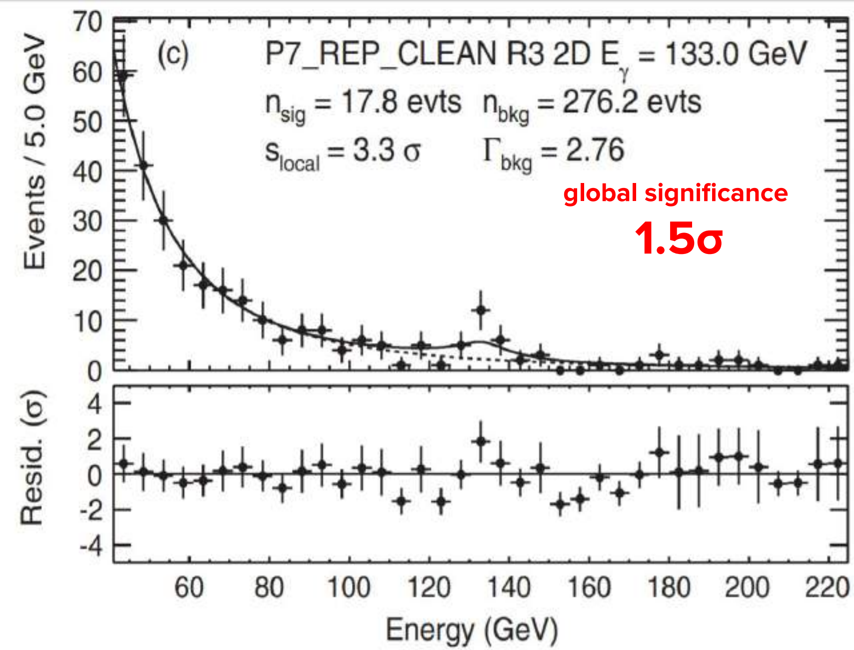
Ackermann et al 2017

Dark Matter in the Galactic Center?



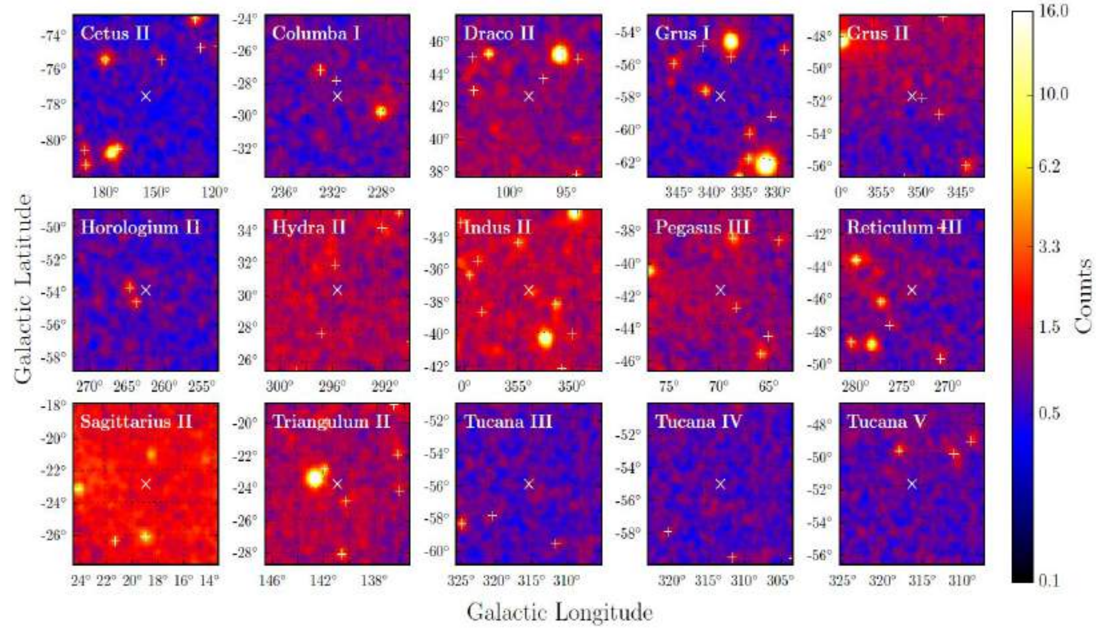
Weniger 2012

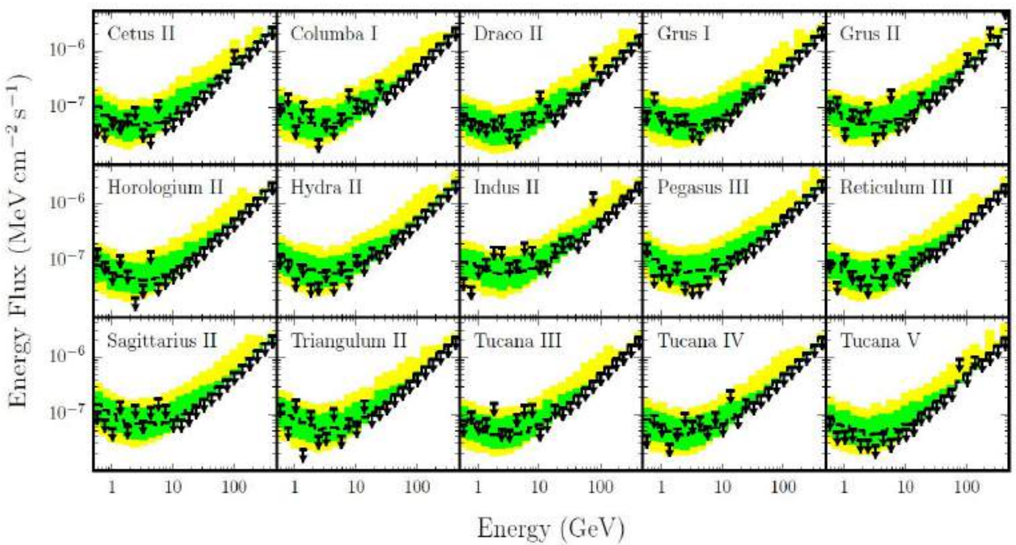
significance reduced in more recent studies



Ackermann 2013

Dark Matter in Dwarf Spheroidal Galaxies?





Searching for dark matter annihilation in recently discovered milky way satellites with Fermi-LAT

Albert et al. 2016

Some of Fermi’s most interesting results

Neutron stars collision and Gravitational Waves

PRL 119, 161101 (2017) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.*[*]

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

On August 17, 2017 at 12:41:04 UTC the Advanced LIGO and Advanced Virgo gravitational-wave detectors made their first observation of a binary neutron star inspiral. The signal, GW170817, was detected with a combined signal-to-noise ratio of 32.4 and a false-alarm-rate estimate of less than one per 8.0×10^4 years. We infer the component masses of the binary to be between 0.86 and 2.26 $M_\odot$, in agreement with masses of known neutron stars. Restricting the component spins to the range inferred in binary neutron stars, we find the component masses to be in the range 1.17–1.60 $M_\odot$, with the total mass of the system $2.74^{+0.04}_{-0.01} M_\odot$. The source was localized within a sky region of 28 deg^2 (90% prob... had a luminosity distance of 40^{+8}_{-14} Mpc, the closest and most precisely localized gravitational-... yet. The association with the γ-ray burst GRB 170817A, detected by Fermi-GBM 1.7... coalescence, corroborates the hypothesis of a neutron star merger and provides the first direct... link between these mergers and short γ-ray bursts. Subsequent identification of transient... across the electromagnetic spectrum in the same location further supports the interpretation o... a neutron star merger. This unprecedented joint gravitational and electromagnetic observ... insight into astrophysics, dense matter, gravitation, and cosmology.

DOI: 10.1103/PhysRevLett.119.161101

I. INTRODUCTION

On August 17, 2017, the LIGO-Virgo detector network observed a gravitational-wave signal from the inspiral of two low-mass compact objects consistent with a binary neutron star (BNS) merger. This discovery comes four decades after Hulse and Taylor discovered the first neutron star binary, PSR B1913+16 [1]. Observations of PSR B1913+16 found that its orbit was losing energy due to the emission of gravitational waves, providing the first indirect evidence of their existence [2]. As the orbit of a BNS system shrinks, the gravitational-wave luminosity increases, accelerating the inspiral. This process has long been predicted to produce a gravitational-wave signal observable by ground-based detectors [3–6] in the final minutes before the stars collide [7].

Since the Hulse-Taylor discovery, radio pulsar surveys have found several more BNS systems in our galaxy [8]. Understanding the orbital dynamics of these systems inspired detailed theoretical predictions for gravitational-wave signals from compact binaries [9–13]. Models of the ... binaries, informed by the known ...

will observe between one BN... hundreds per year [14–21]. Th... includes three Fabry-Perot-M... measure spacetime strain ind... waves as a varying phase ... propagating in perpendicu... LIGO detectors (Hanford, ... and the Advanced Virgo d...

Advanced LIGO's fir... September 12, 2015, to... 49 days of simultaneous ... While two confirmed bi... were discovered [24–2... candidates had compone... a 90% credible upper lir... of BNS mergers [27]... Letter contain 90% of ... otherwise). This meas... of astrophysical predi... $\sim$10 000 Gpc^{-3} yr^{-1}...

The second observ... November 30, 2016...

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20

https://doi.org/10.3847/2041-8213/aa91c9

Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT

(See the end matter for the full list of authors.)

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

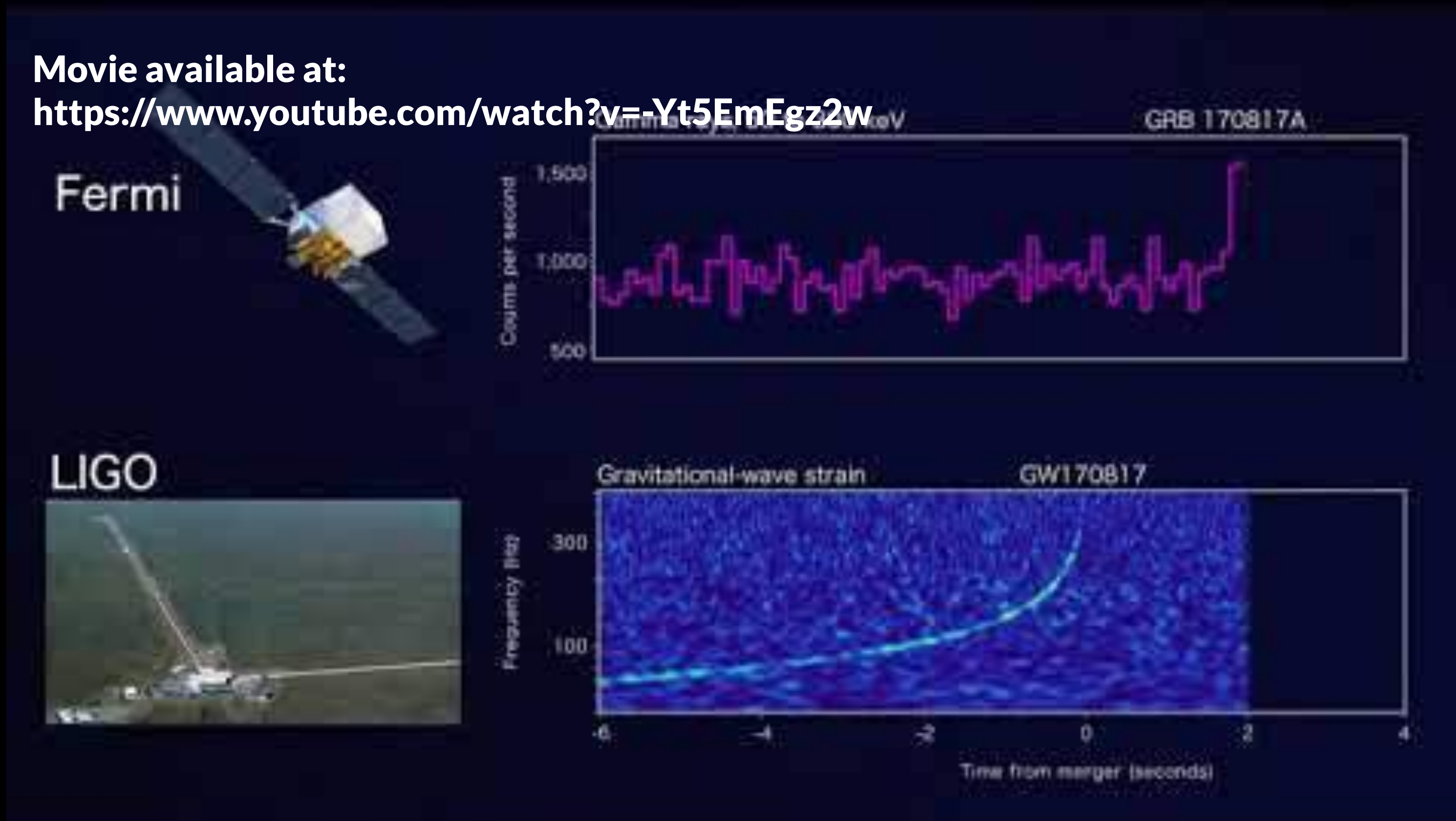
Abstract

On 2017 August 17 a binary neutron star coalescence candidate (later designated GW170817) with merger time 12:41:04 UTC was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. The *Fermi* Gamma-ray Burst Monitor independently detected a gamma-ray burst (GRB 170817A) with a time delay of $\sim$1.7 s with respect to the merger time. From the gravitational-wave signal, the source was initially localized to a sky region of 31 deg^2 at a luminosity distance of 40^{+8}_{-8} Mpc and with component masses consistent with neutron stars. The component masses were later measured to be in the range 0.86 to 2.26 $M_\odot$. An extensive observing campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient (SSS17a, now with the IAU identification of AT 2017gfo) in NGC 4993 (at $\sim$40 Mpc) less than 11 hours after the merger by the One-Meter, Two Hemisphere (1M2H) team using the 1 m Swope Telescope. The optical transient was independently detected by multiple teams within an hour. Subsequent observations targeted the object and its environment. Early ultraviolet observations revealed a blue transient that faded within 48 hours. Optical and infrared observations showed a redward evolution over $\sim$10 days. Following early non-detections, X-ray and radio emission were discovered at the transient's position $\sim$9 and $\sim$16 days, respectively, after the merger. Both the X-ray and radio emission ... arise from a physical process that is distinct from the ...

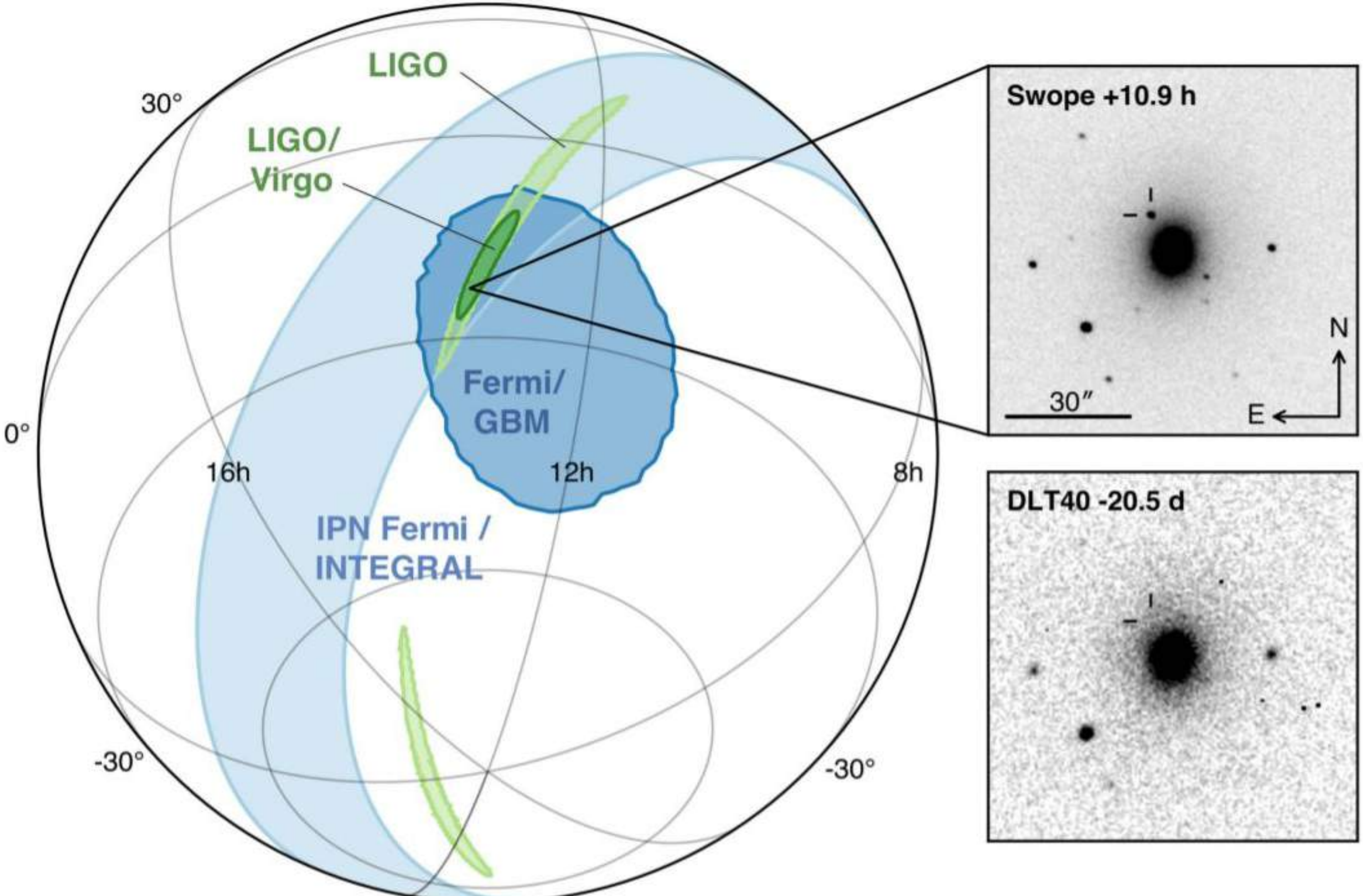
Movie available at:
https://www.youtube.com/watch?time_continue=13&v=x_Akn8fUBeQ

NASA's Goddard Space Flight Center/CI Lab

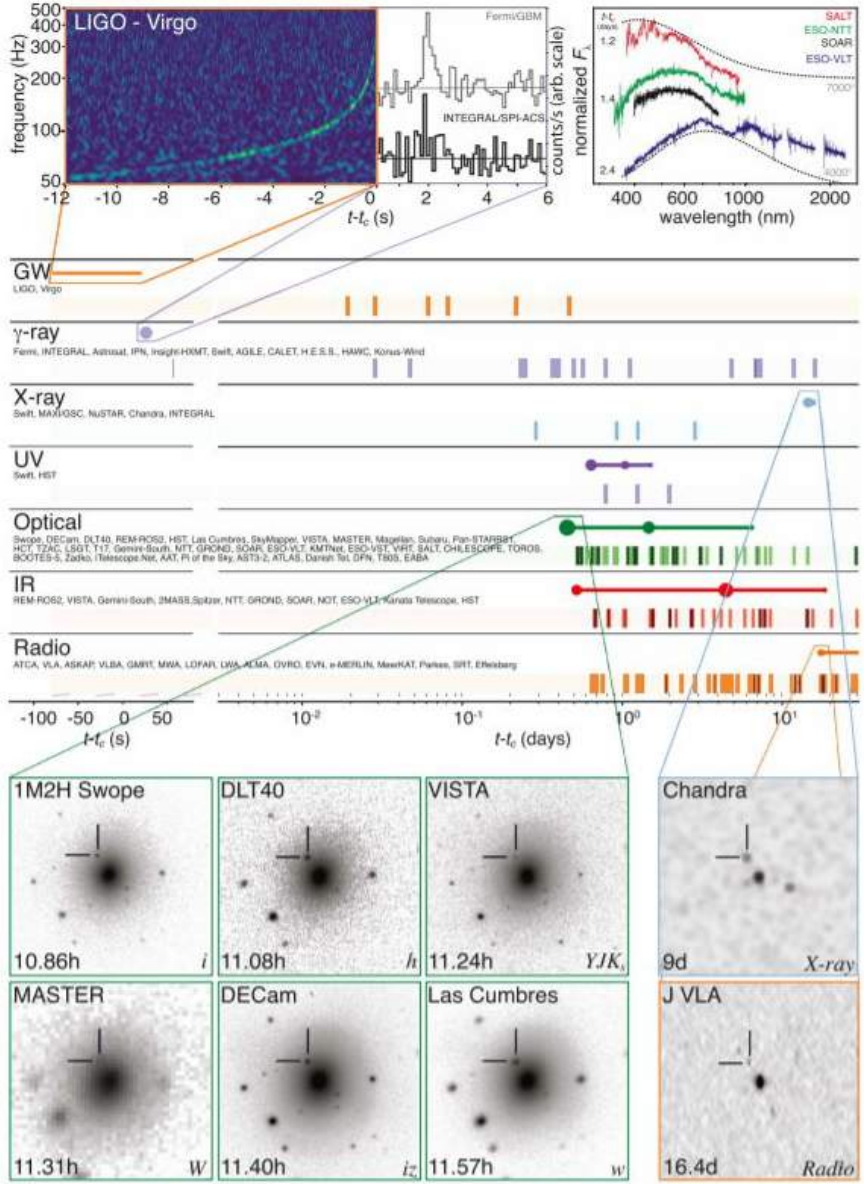
Movie available at:
https://www.youtube.com/watch?v=-Yt5EmEgz2w



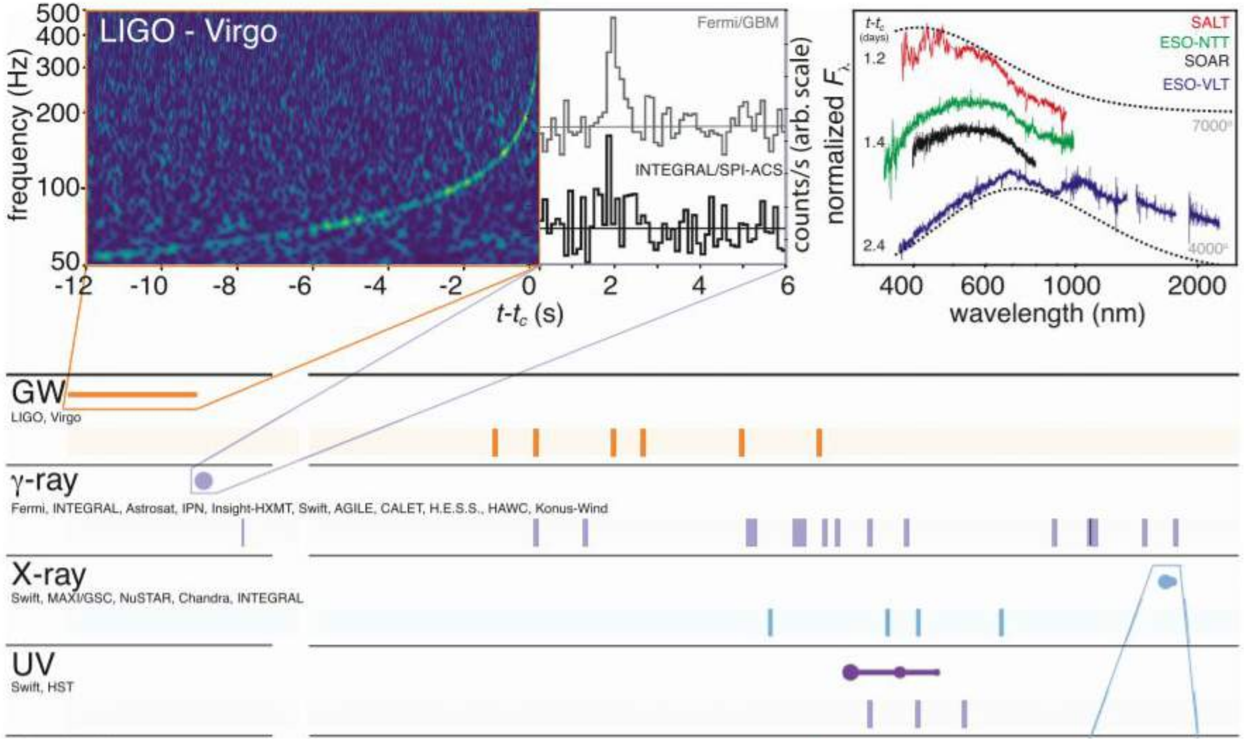
NASA GSFC & Caltech/MIT/LIGO Lab



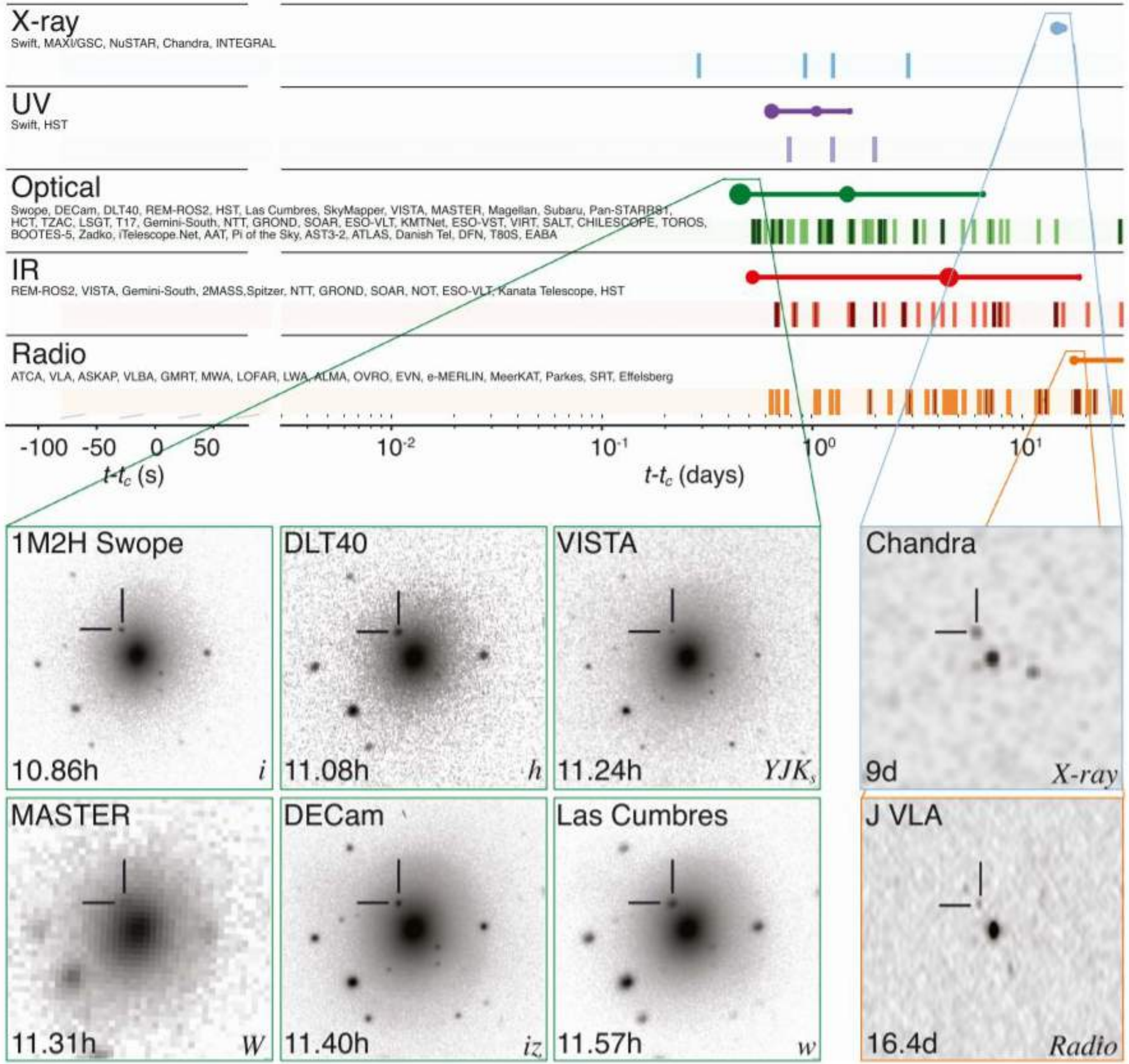
LIGO-Virgo Collaboration et al 2017



LIGO-Virgo Collaboration et al 2017



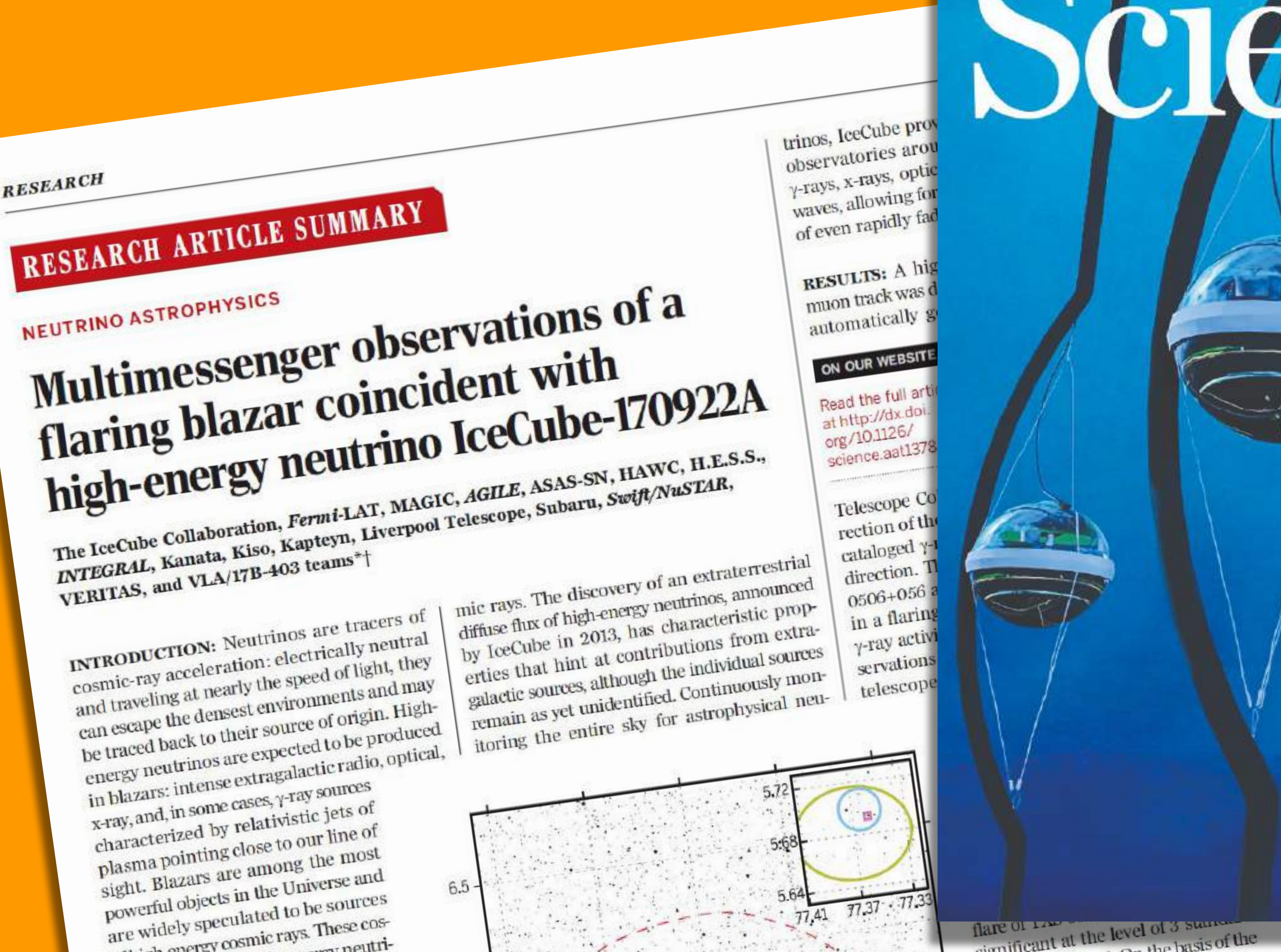
LIGO-Virgo Collaboration et al 2017



LIGO-Virgo Collaboration et al 2017

Some of Fermi’s most interesting results

Neutrino detection from a flaring blazar


RESEARCH

RESEARCH ARTICLE SUMMARY

NEUTRINO ASTROPHYSICS

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

INTRODUCTION: Neutrinos are tracers of cosmic-ray acceleration: electrically neutral and traveling at nearly the speed of light, they can escape the densest environments and may be traced back to their source of origin. High-energy neutrinos are expected to be produced in blazars: intense extragalactic radio, optical, x-ray, and, in some cases, γ-ray sources characterized by relativistic jets of plasma pointing close to our line of sight. Blazars are among the most powerful objects in the Universe and are widely speculated to be sources of high-energy cosmic rays. These cos-mic rays. The discovery of an extraterrestrial diffuse flux of high-energy neutrinos, announced by IceCube in 2013, has characteristic properties that hint at contributions from extragalactic sources, although the individual sources remain as yet unidentified. Continuously monitoring the entire sky for astrophysical neu-trinos, IceCube prov… observatories arou… γ-rays, x-rays, optic… waves, allowing for… of even rapidly fad…

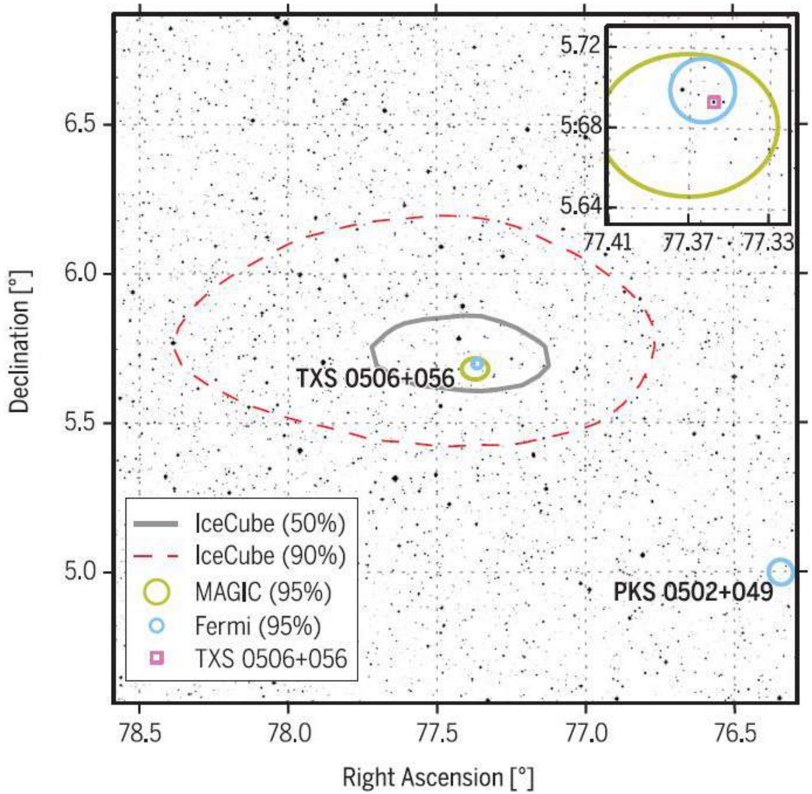
RESULTS: A hig… muon track was d… automatically g…

ON OUR WEBSITE

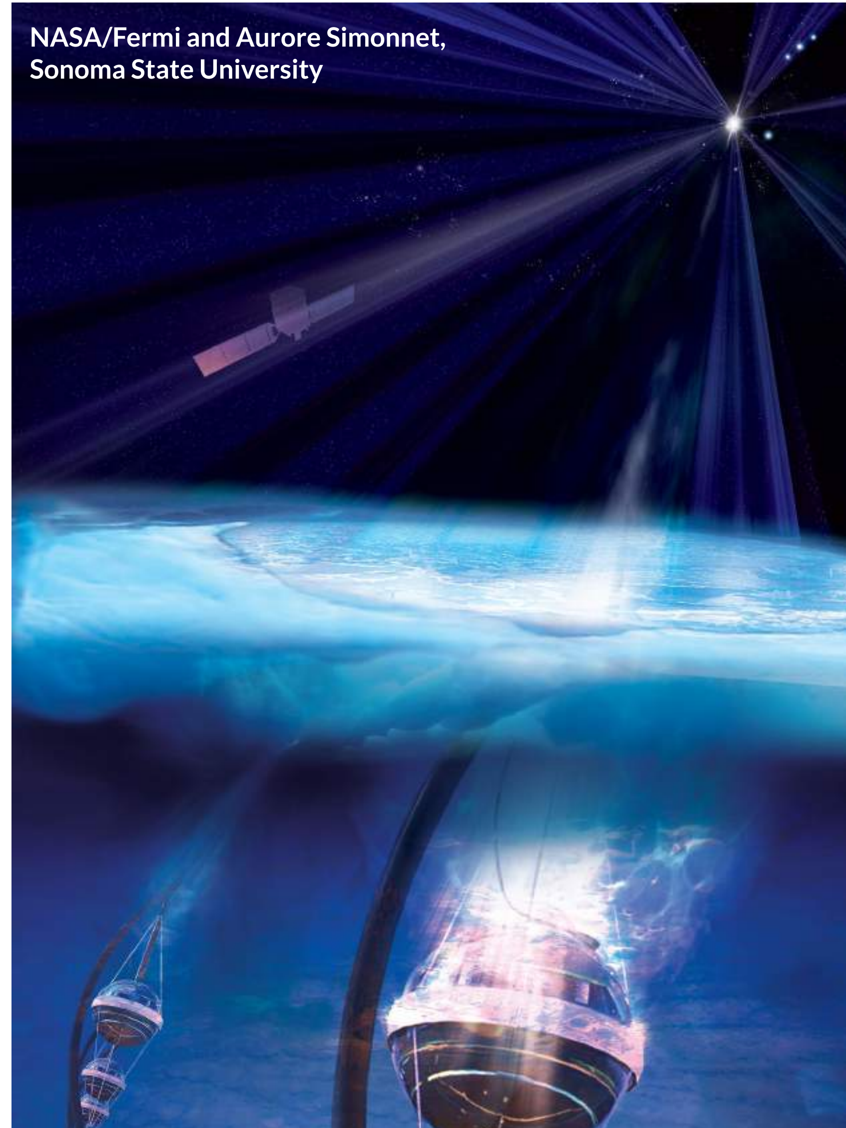
Read the full artic… at http://dx.doi. org/10.1126/ science.aat1378

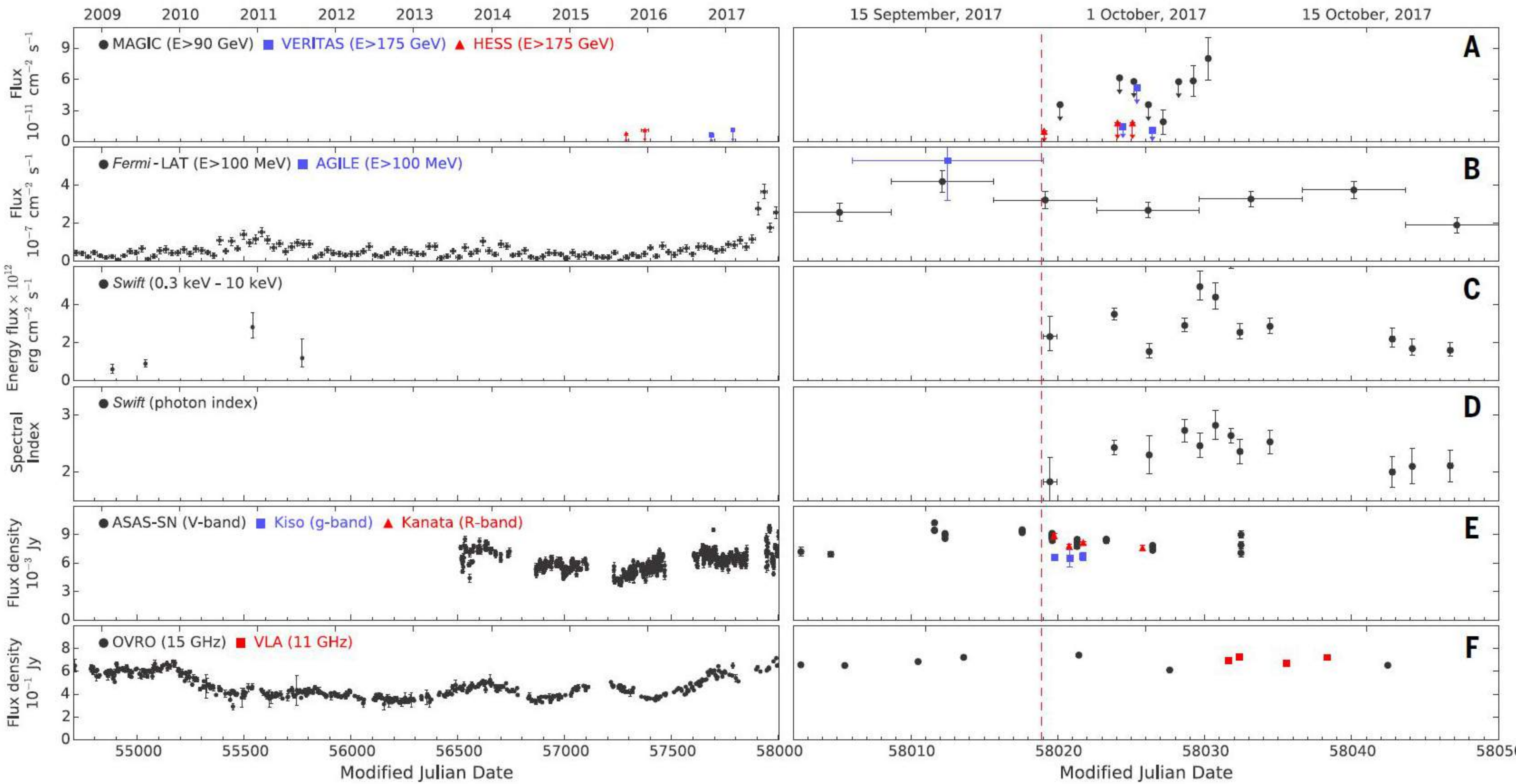
Telescope Co… rection of the… cataloged γ-r… direction. T… 0506+056 a… in a flaring… γ-ray activi… servations… telescope…

flare of TXS… significant at the level of 3 stand… On the basis of the



The IceCube Collaboration et al 2018





The IceCube Collaboration et al 2018

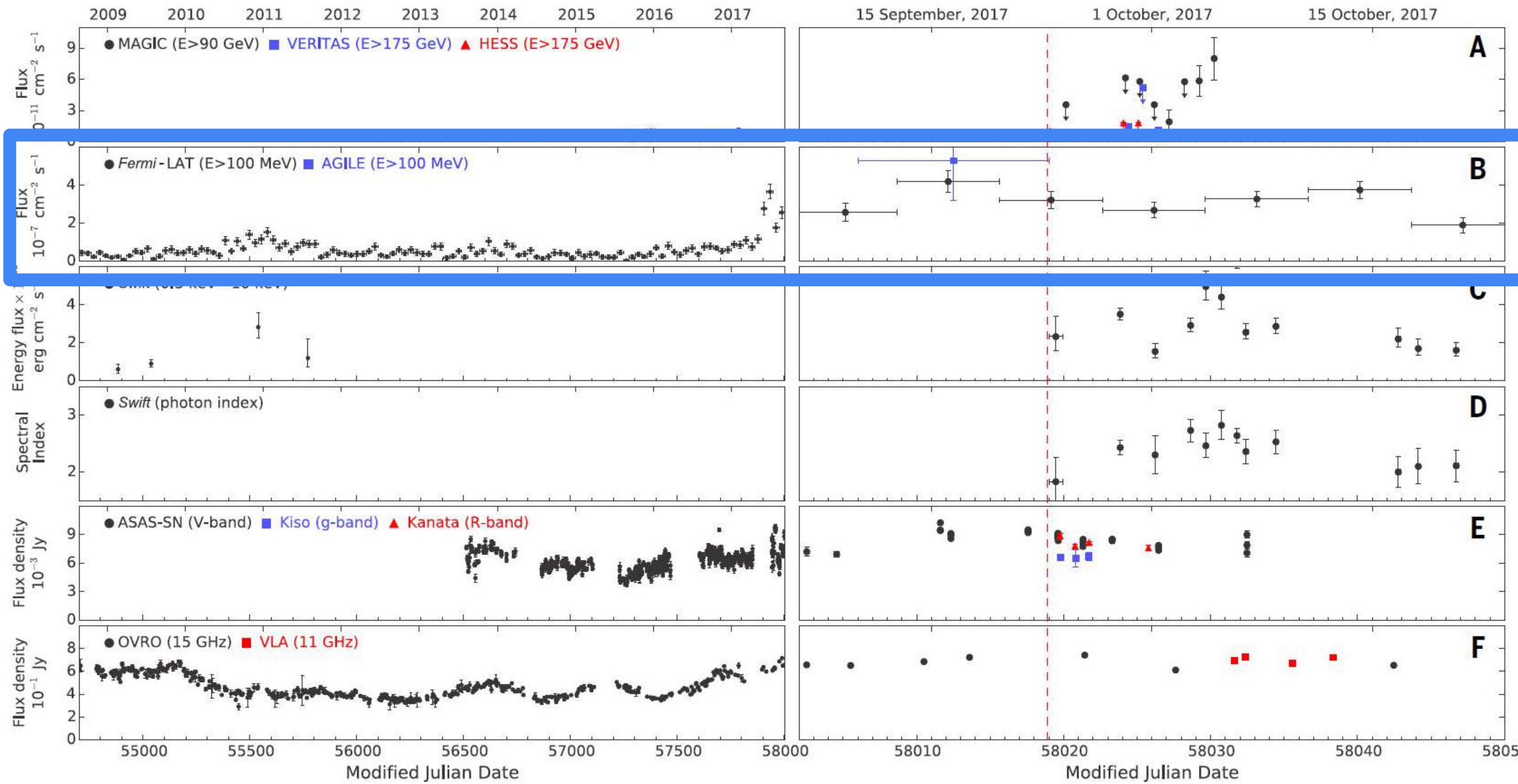
Preparing for our hands-on activity tomorrow

What will we do?

Analyze blazar TXS 0506+056 around the moment of neutrino IceCube-170922A detection using Fermi Space Telescope data.

We will:

- Model the region's gamma ray flux
- Obtain TXS 0506+056 gamma ray flux
- Construct an SED for this source
- Create a light curve



The IceCube Collaboration et al 2018

The tools

- Fermitools: https://fermi.gsfc.nasa.gov/ssc/data/analysis/
- Fermipy: https://fermipy.readthedocs.io/

This kind of analysis usually take something between 6 to 8 hours!

We don’t have this amount of time!

Solution: most of the steps are already preprocessed. The outputs are available with the material you downloaded.

Preparing to the tutorial

Go to:

https://github.com/black-hole-group/fermipy-tutorial

And follow the instructions.

To start the tutorial

1. For Mac/Windows users only: look for the Docker icon in your computer and click on it to open the application.

2. `cd` to the `fermi` directory which contains the lesson files and where we plan to run our analysis

3.
```
sudo docker run -it --rm -p 8888:8888 -v
$PWD:/workdir -w /workdir fermipy/fermipy:11-05-02
```

4. Copy and paste the address displayed in your web browser, and replace the string between `http://` and `:8888` with `localhost`

To start the tutorial

5. Browse to `fermipy-tutorial/blazar` and double click the file `BlazarNeutrino.ipynb`. This will open the Jupyter Notebook with the activity.

6. To run a cell with code, click on the cell and press:

Shift + Enter

I will also be running the tutorial on the screen and commenting on what is happening.