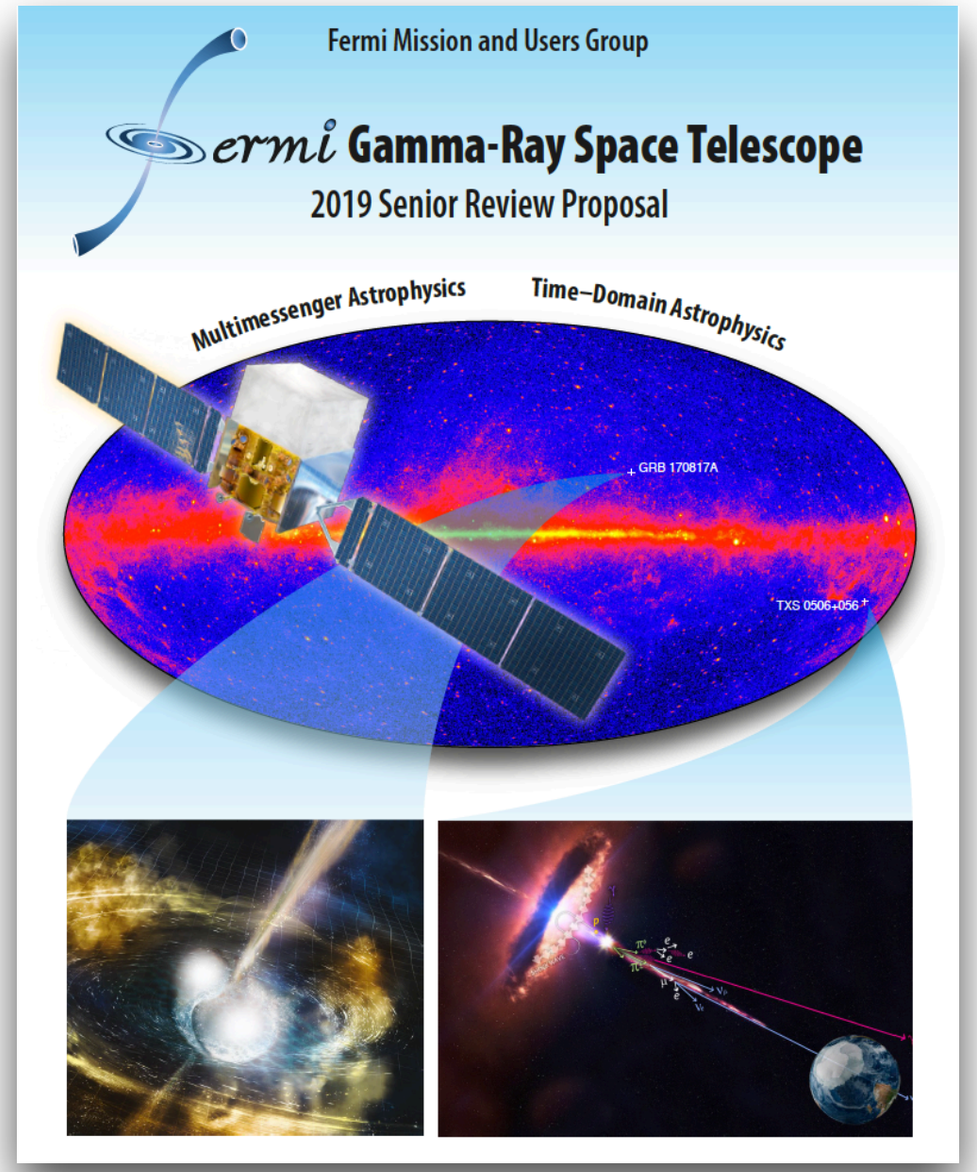
LUCA LATRONICO, INFN TORINO

INFN LNF WEBINAR
30 APRIL 2020

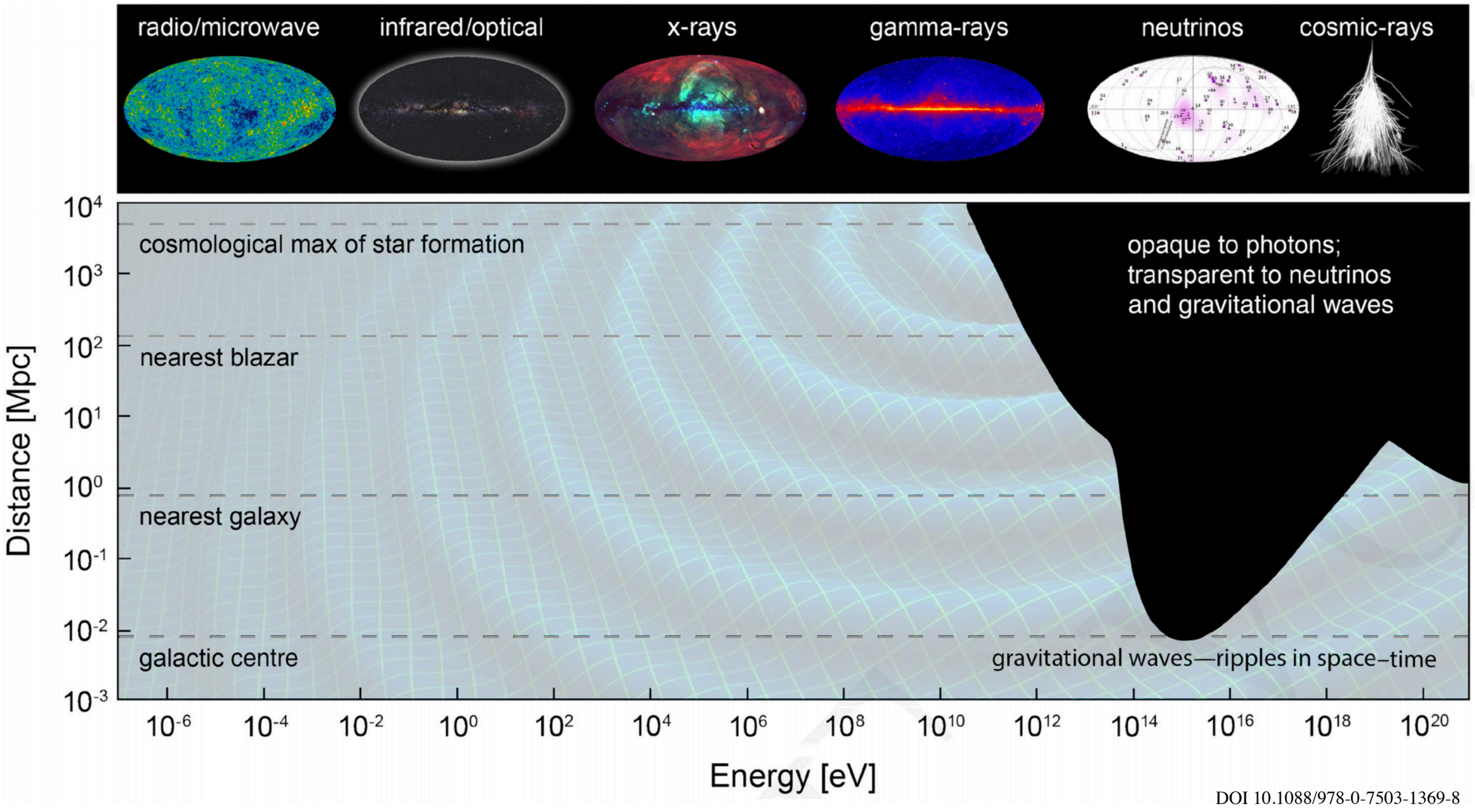
FERMI AND MULTI-MESSENGER OBSERVATIONS

1 – BIRTH OF MULTI MESSENGER ASTRONOMY



FERMI AND MULTIMESSENGER OBSERVATIONS

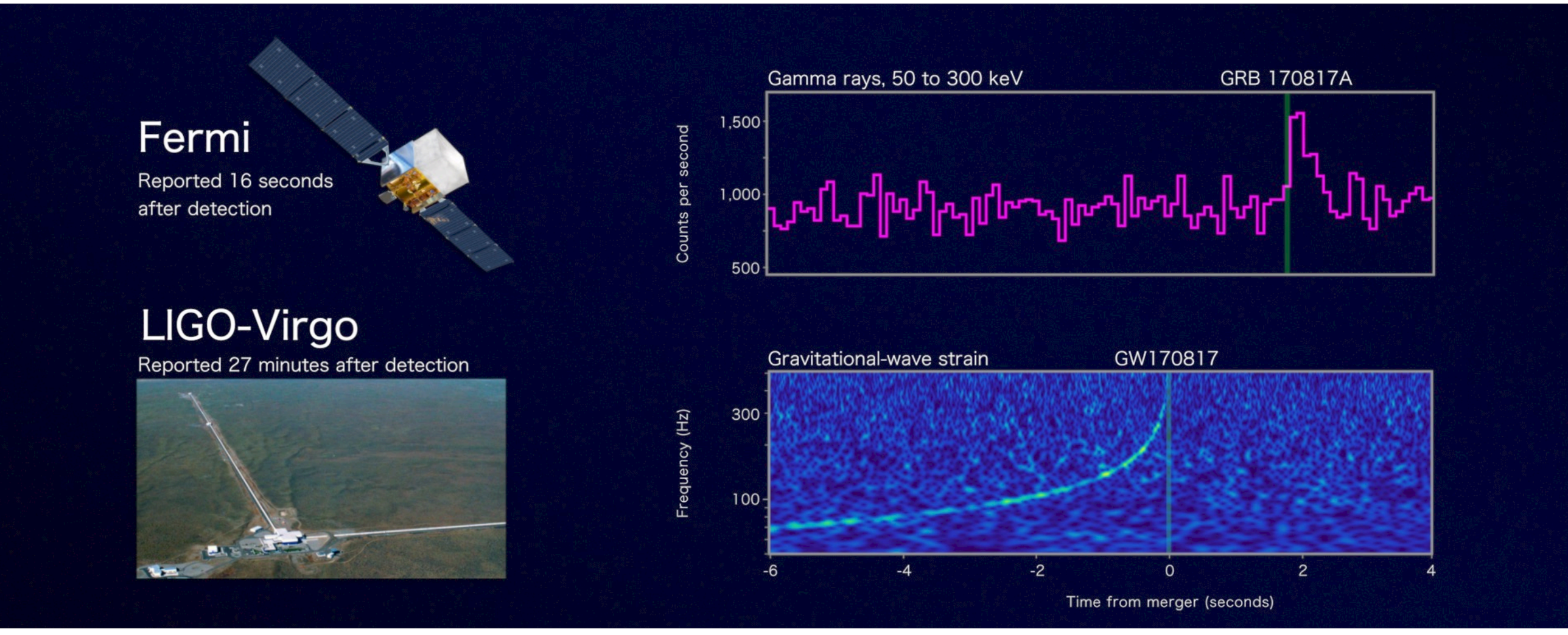
MESSENGERS



DOI 10.1088/978-0-7503-1369-8

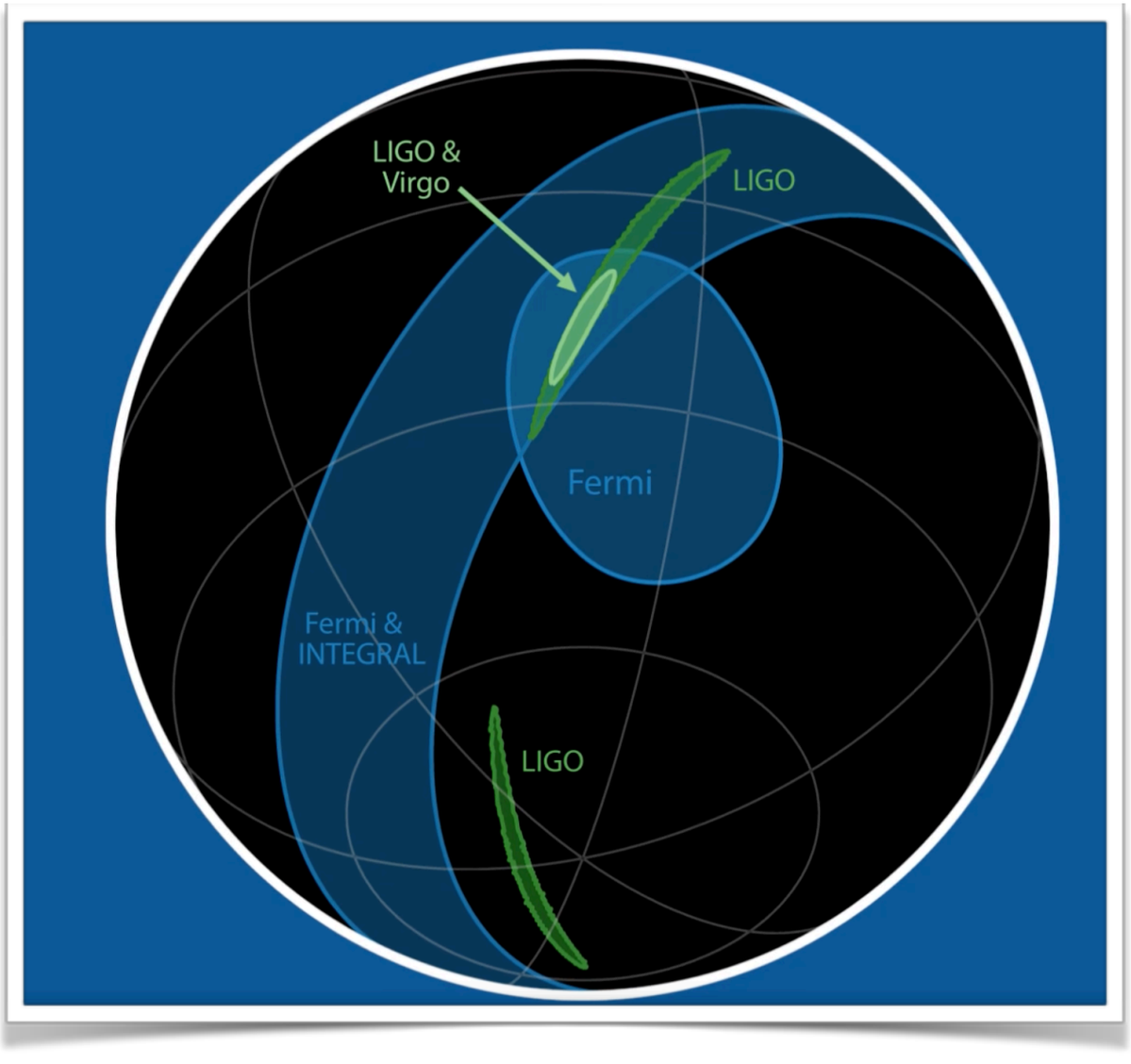
FERMI AND MULTIMESSENGER OBSERVATIONS

17 AUGUST 2017 – WAKE UP!

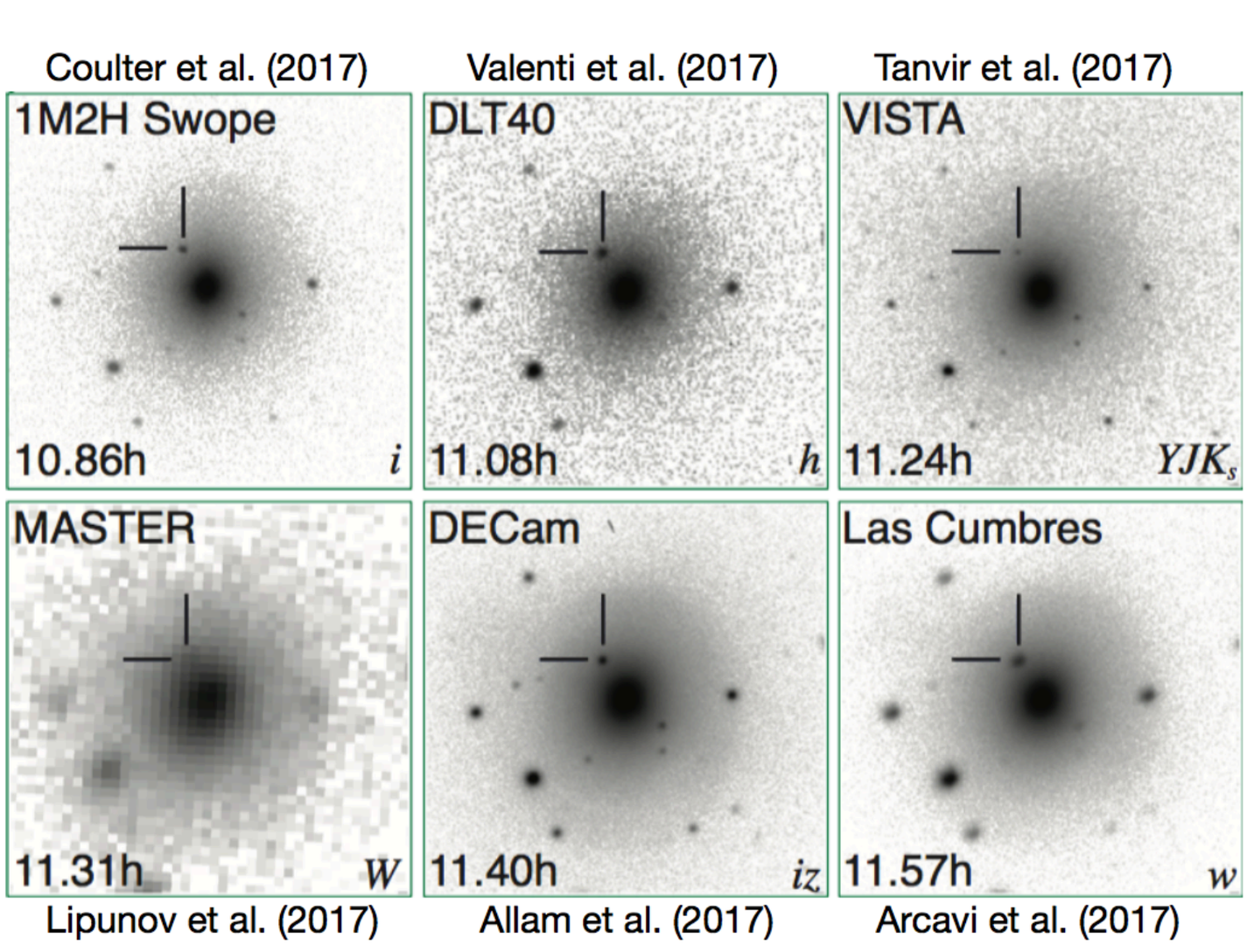


https://www.nasa.gov/centers/marshall/news/news/2017/fermi-gamma-ray-burst-monitor-wakes-the-world-to-smashing-neutron-stars.html

LOCALIZATION IN THE SKY

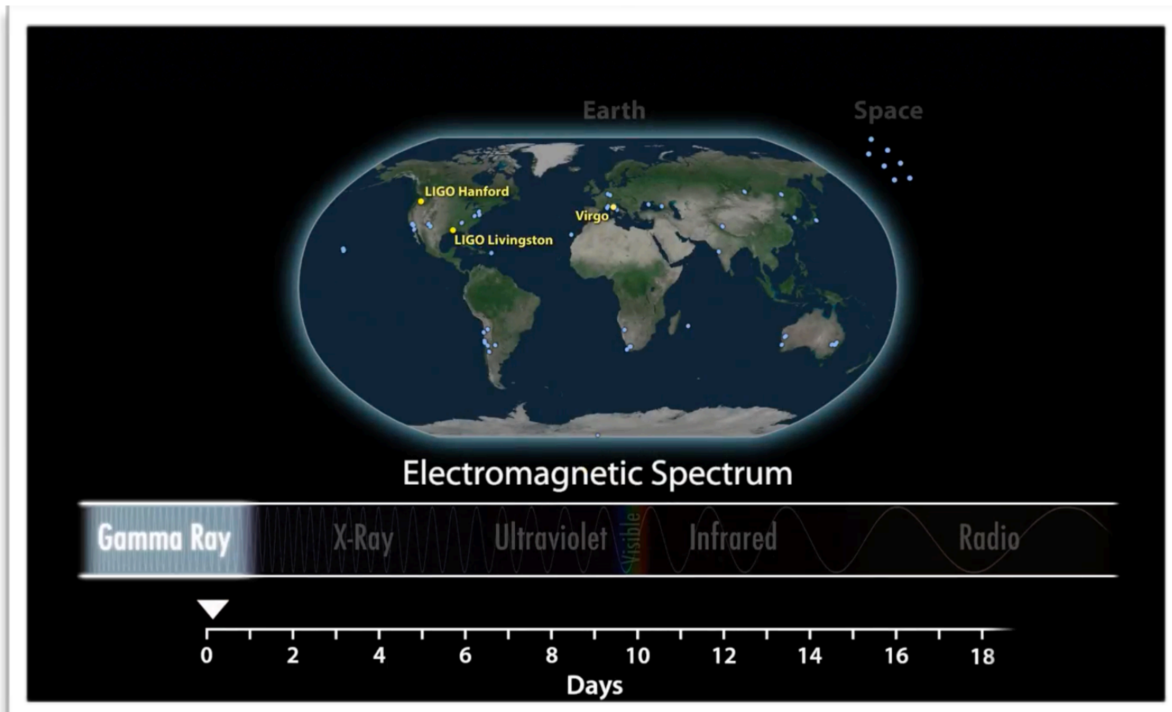


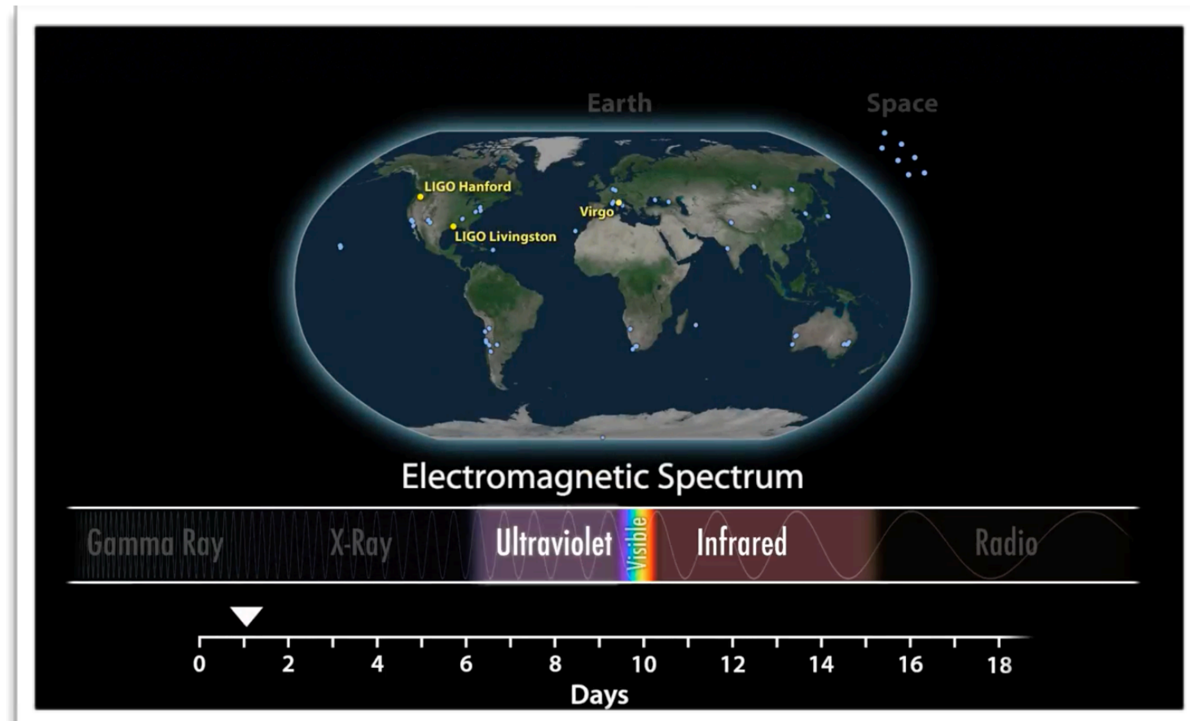
HOST GALAXY IDENTIFICATION VIA OPTICAL OBSERVATIONS

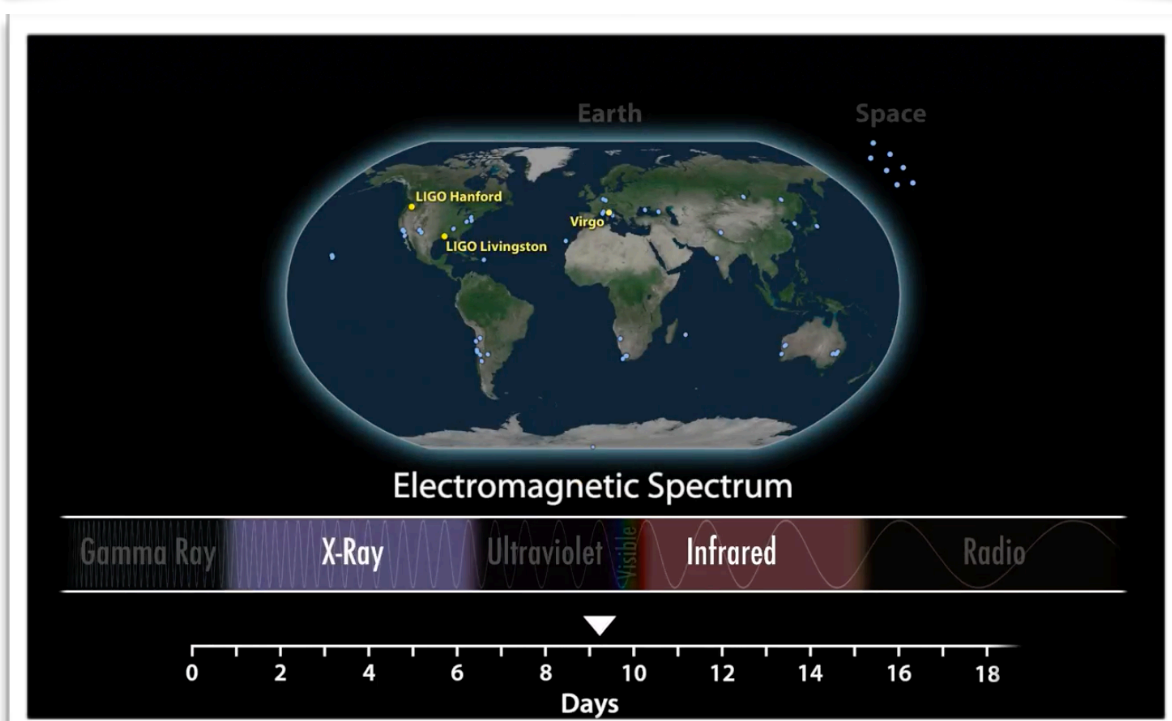


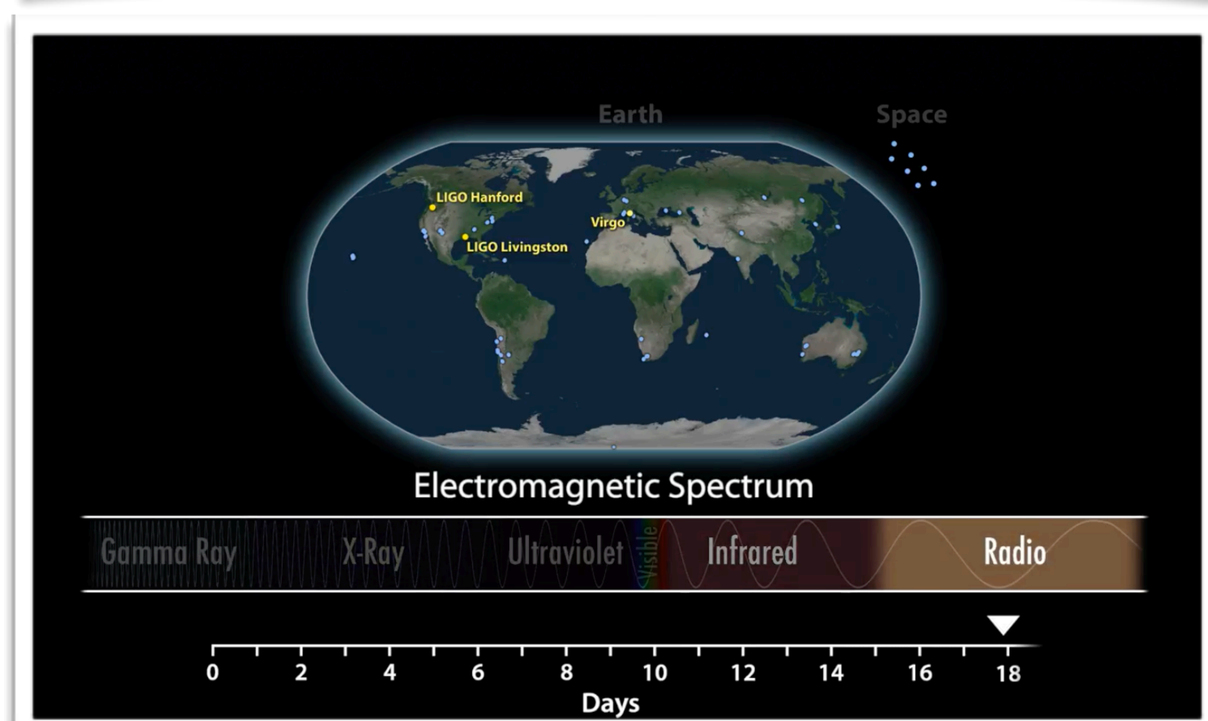
NGC 4993, S0 galaxy @ D = 41 Mpc, z = 0.00968 (Hjorth et al. 2017)

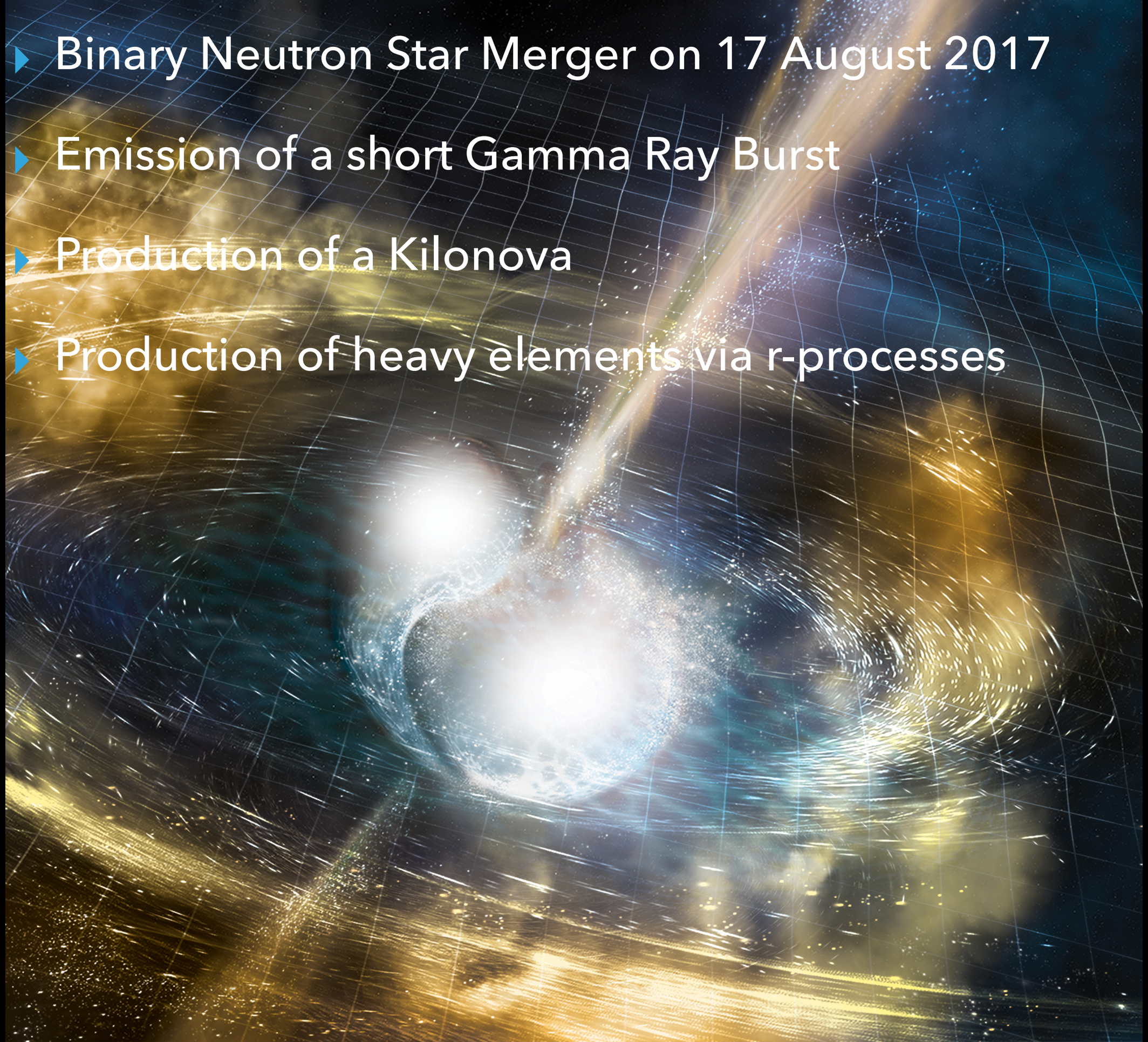
MULTIFREQUENCY OBSERVATIONS



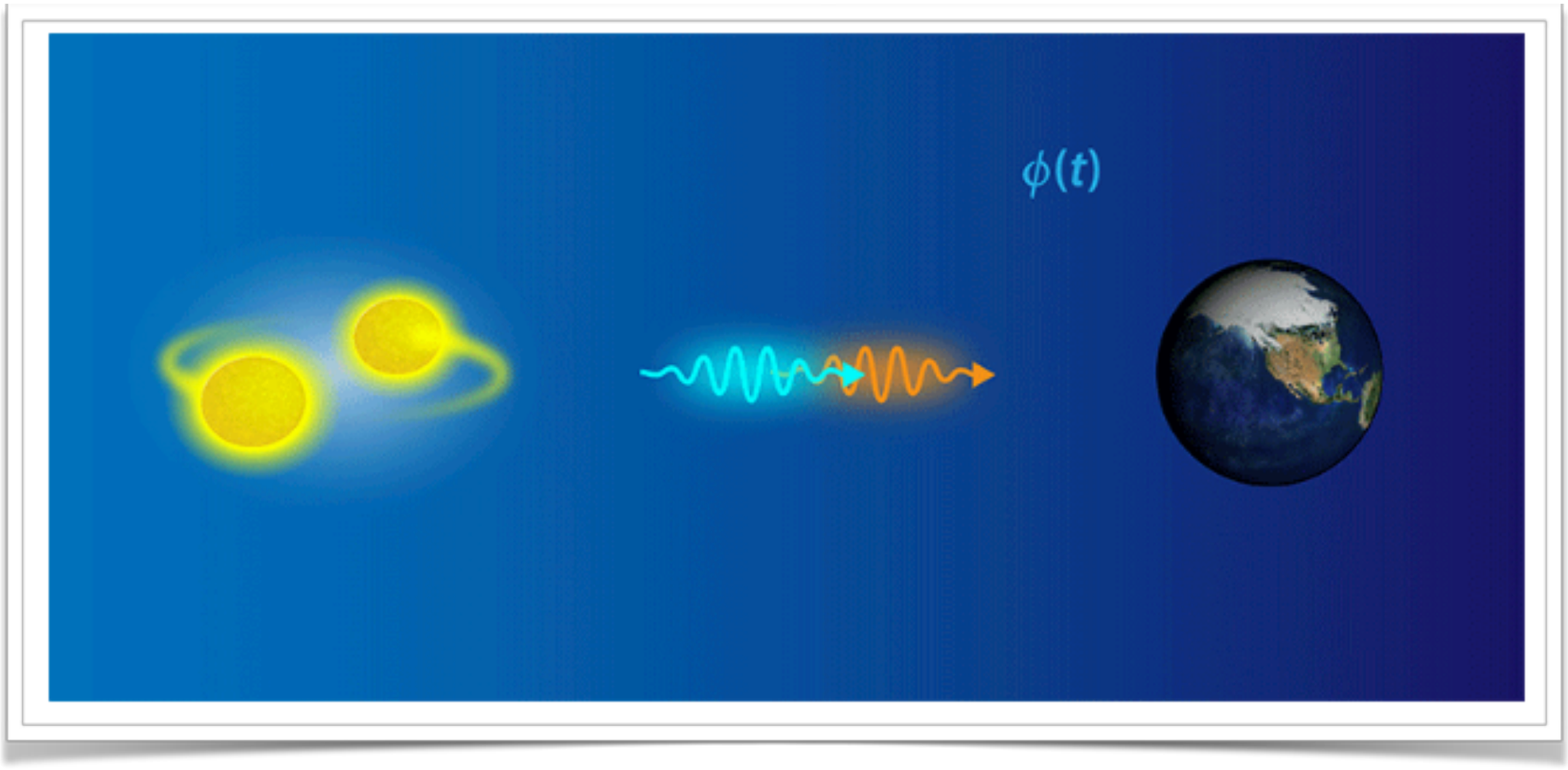







Binary Neutron Star Merger on 17 August 2017
Emission of a short Gamma Ray Burst
Production of a Kilonova
Production of heavy elements via r-processes

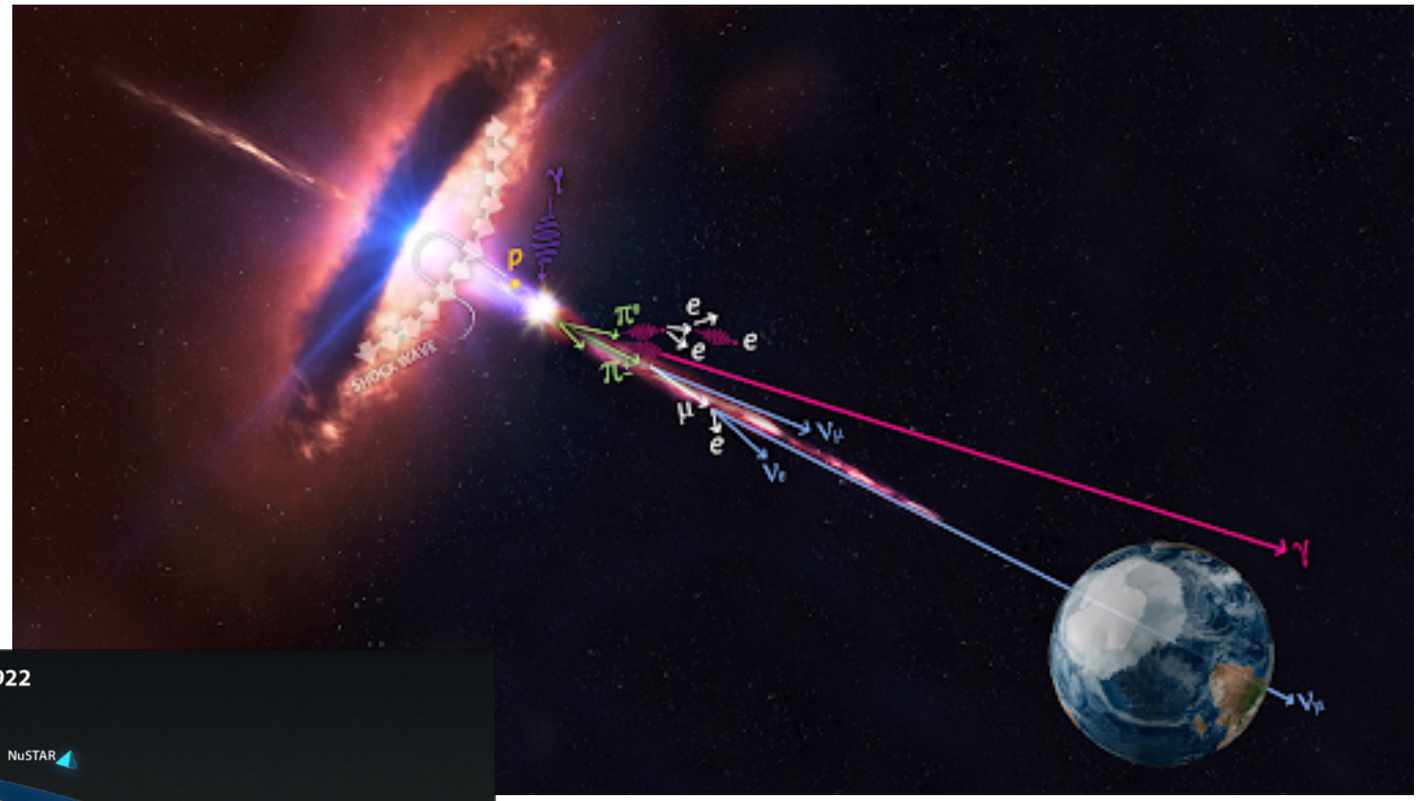
FUNDAMENTAL PHYSICS IMPLICATIONS

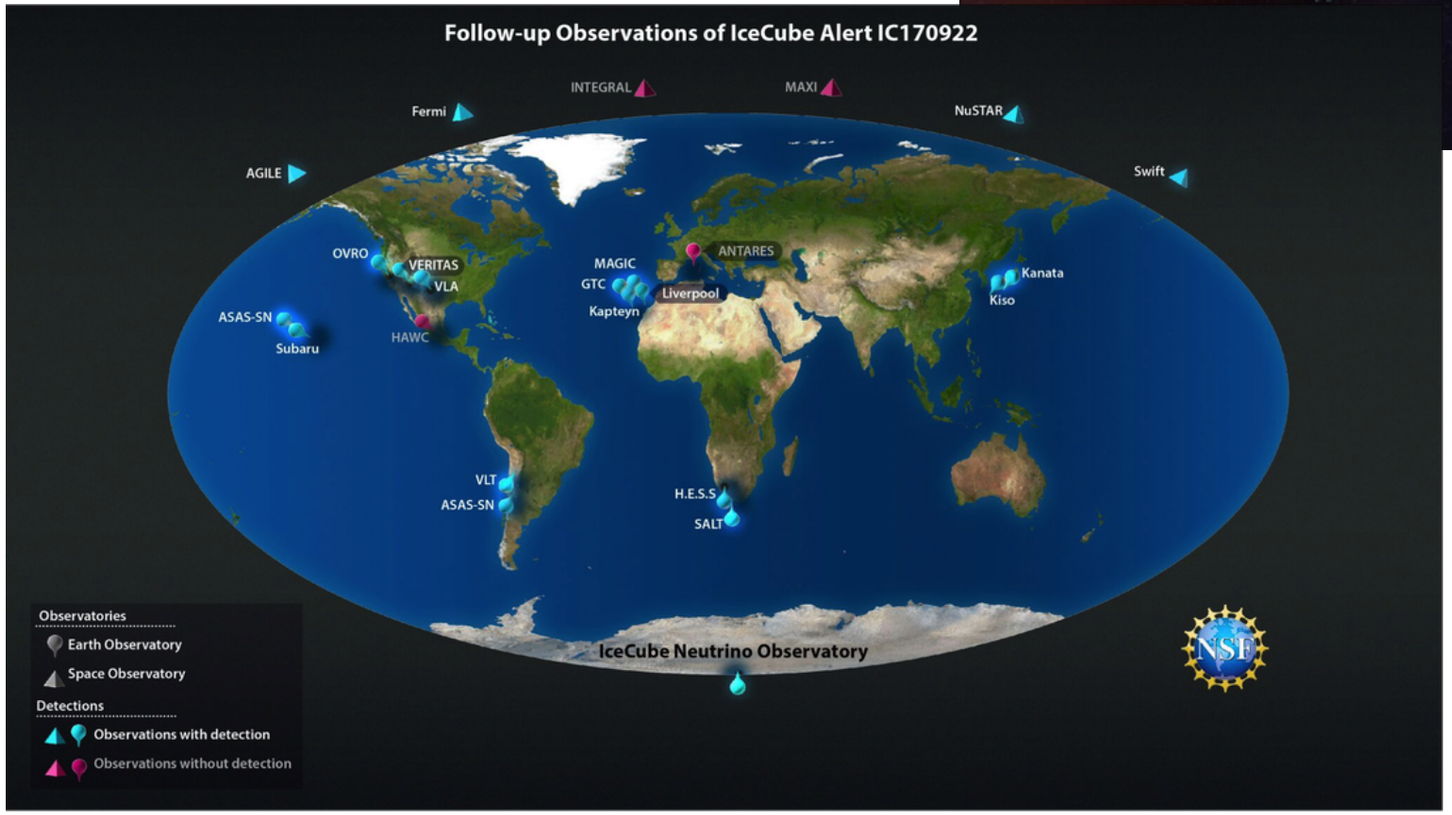


- GW and photons speed = c with ~1/10^{15} error (2s/130Mly)
  - Lorentz Invariance and Equivalence Principle verified (ApJL 848:L13, 2017)
  - limits to alternative cosmology other than GR + cosmological constant (https://physics.aps.org/articles/v10/134)

FERMI AND MULTIMESSENGER OBSERVATIONS

19 SEPTEMBER 2017





https://www.nasa.gov/press-release/nasa-s-fermi-traces-source-of-cosmic-neutrino-to-monster-black-hole

REMARKS

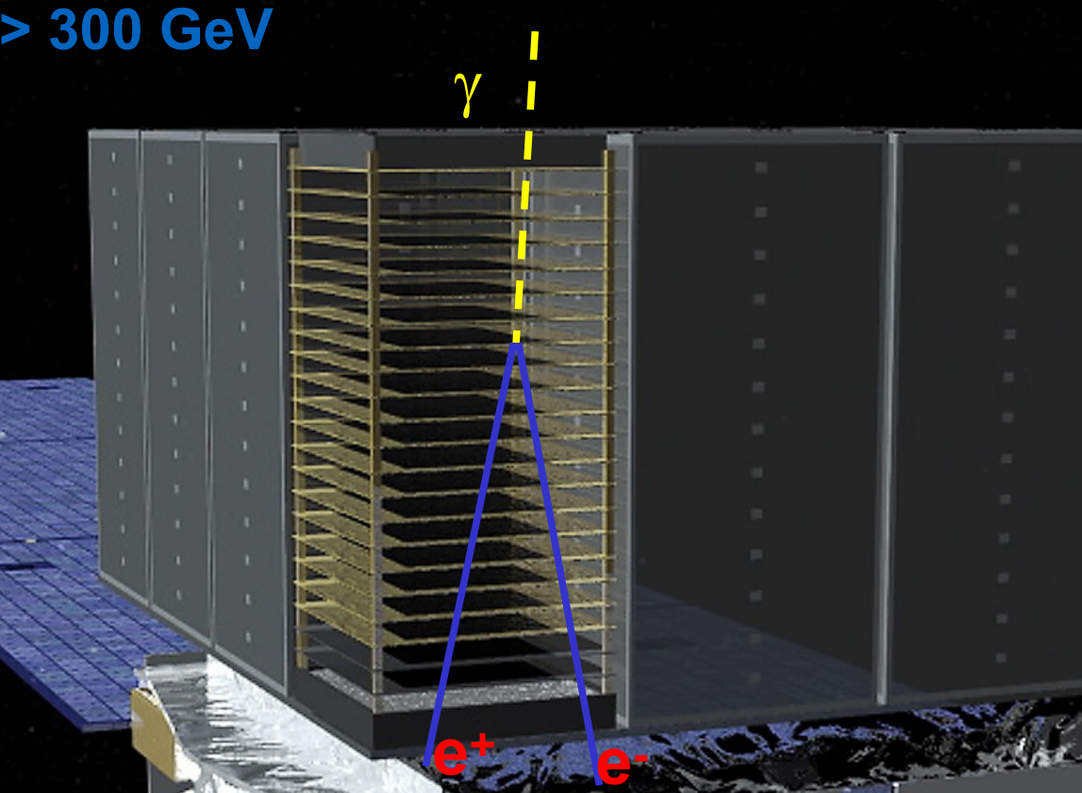
- Observatories
  - complex systems, decades long operations
- Multiple experimental techniques and operating environments
  - multi-decades R&D programs
- Complementary communities
  - Particle physics, Astrophysics, Cosmology
- Open questions
  - what are the sources of Cosmic Rays ? how are they accelerated ?
  - what is the nature of Dark Matter ?

2 – THE FERMI OBSERVATORY

The Fermi Observatory

Large Area Telescope (LAT) - pair conversion telescope

- 20 MeV – > 300 GeV



Huge field of view (2.4sr)

- 20% sky any instant
- All sky for 30’ every 3h

Huge energy range

- Including 10-100 GeV

Public data

- ~400 collaboration papers
- ~2400 total nb of papers

Gamma Burst Monitor (GBM) - counters

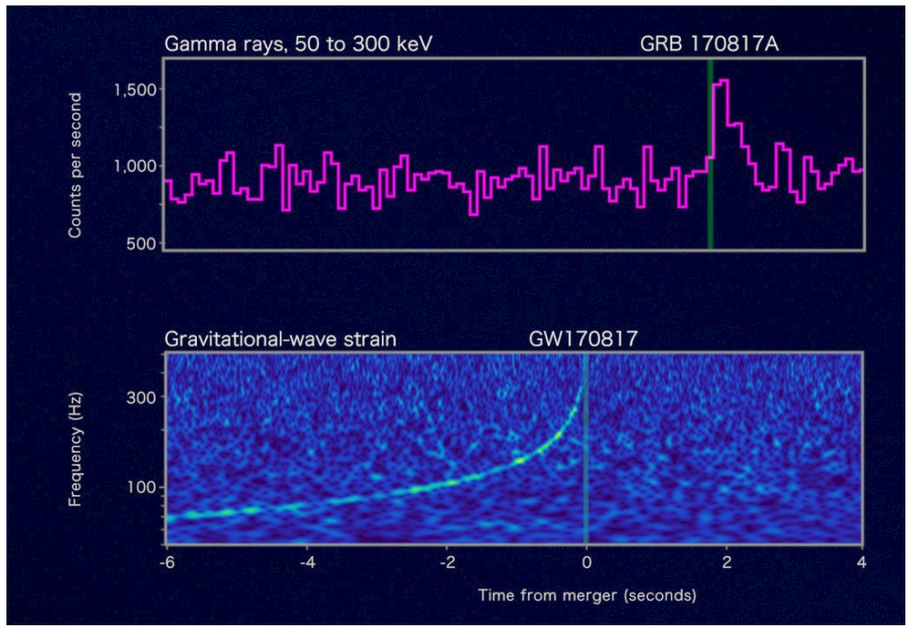
- 8 keV – 40 MeV

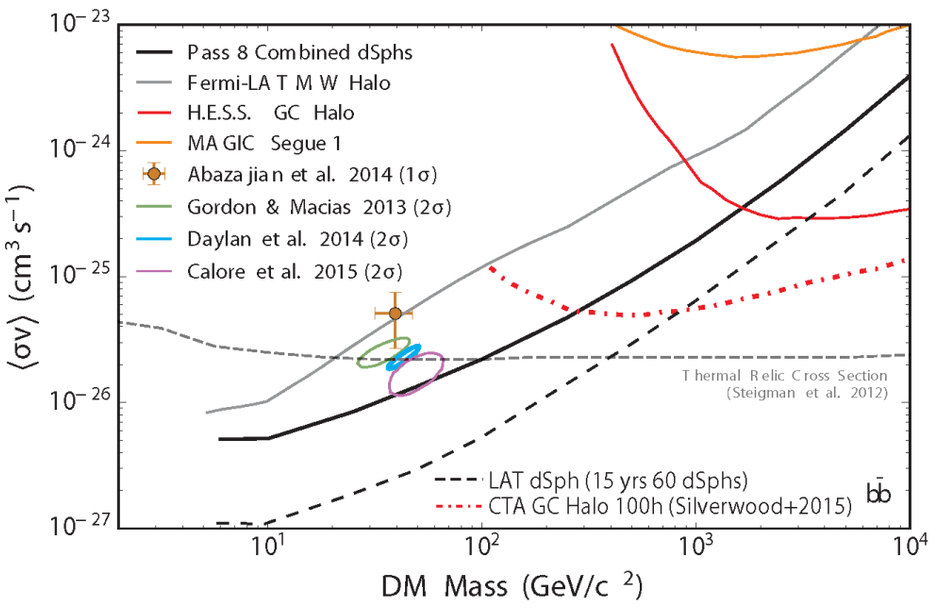
launch from KSC 11-6-2008

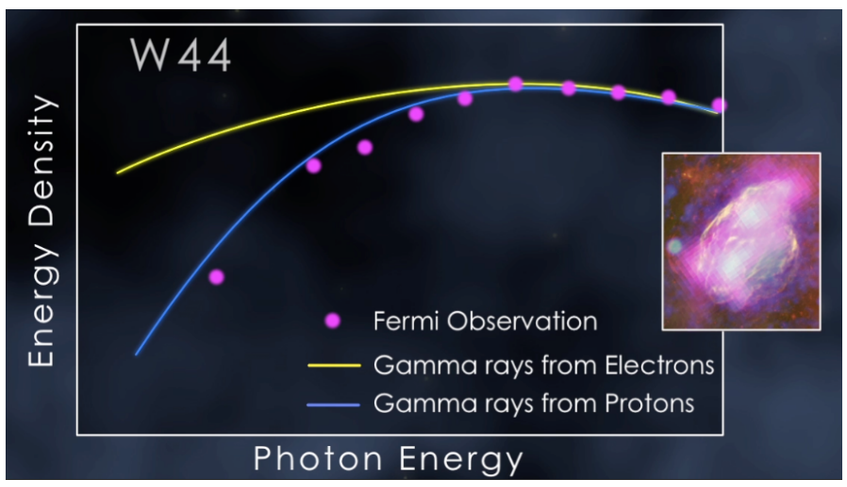
SCIENCE – TOP HIGHLIGHTS

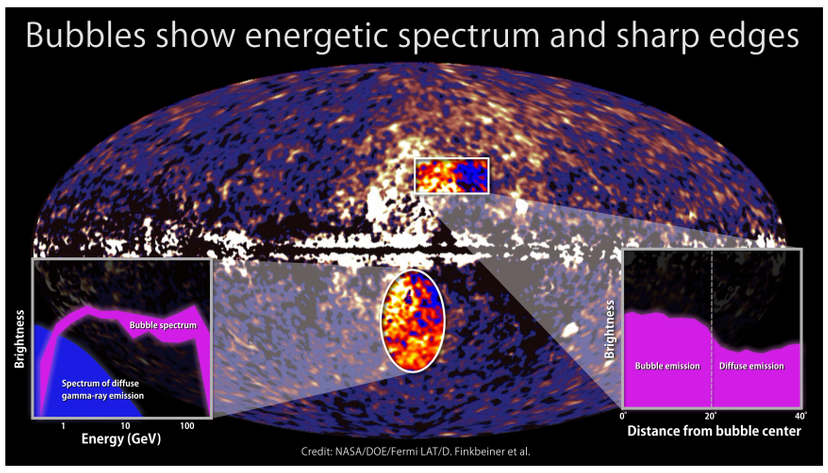
- Deep, high resolution, new view of the gamma-ray sky
  - sources and diffuse emission
- Cosmic rays origin and acceleration
  - unexpectedly energetic galactic electrons
  - evidence of proton acceleration in supernovae
  - Fermi bubbles
- Birth of Multimessenger astrophysicsGravitational Waves (GW)
  - with Gravitational Waves: first detection of electromagnetic emission after binary neutron star mergers
  - with Neutrinos: first association of extreme energy neutrino with gamma-ray flaring galaxy
- Dark Matter
  - most stringent limits on generic particle candidate (WIMP)

SCIENCE HIGHLIGHTS GALLERY





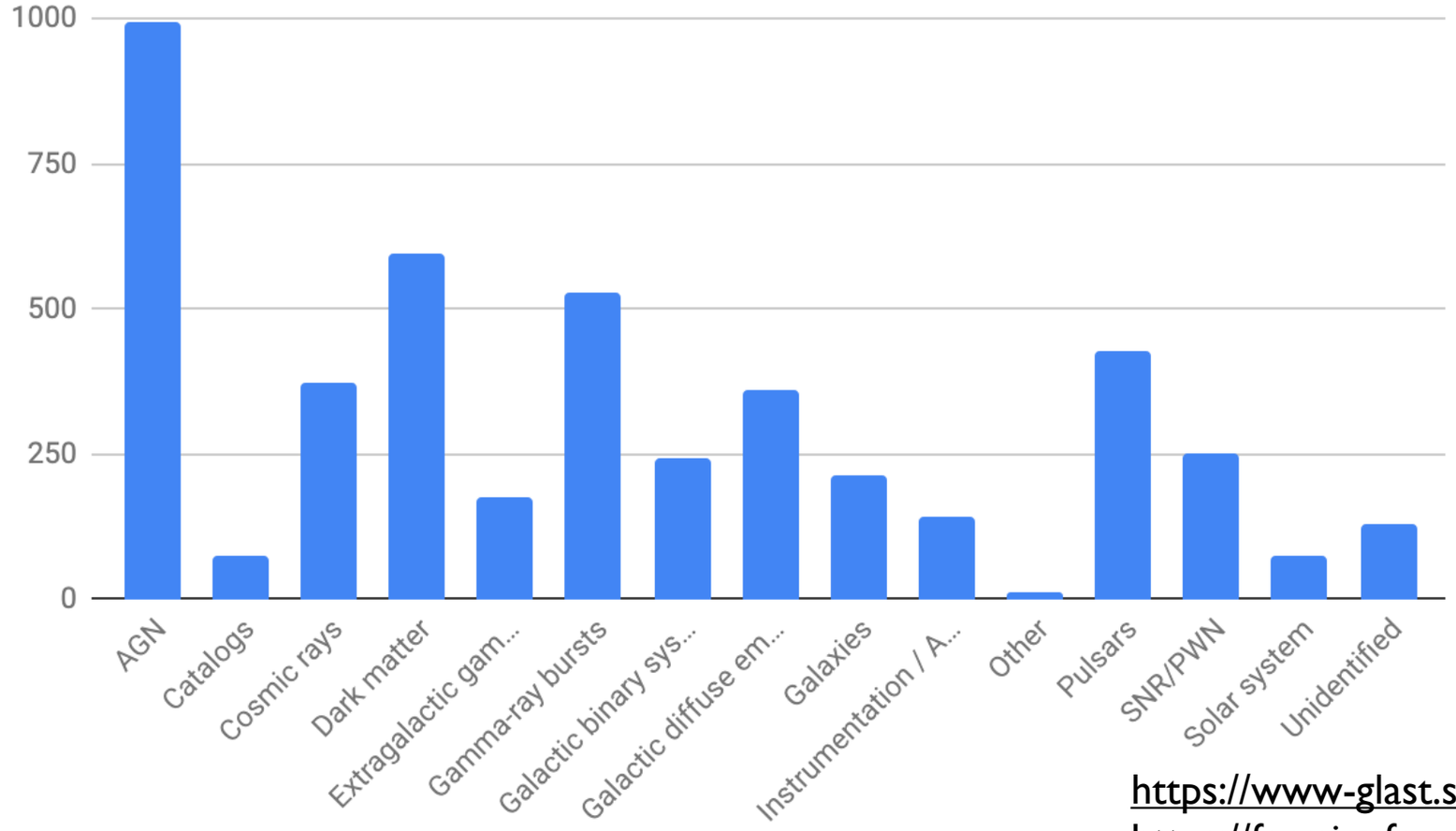




https://www-glast.stanford.edu/cgi-bin/pubpub

Science highlights

- **Fermi data - 4photons/sec**
  - **3.13B public photons, 1.19B source-class photons**
- **Fermi products - 1 LAT paper/week**
  - **3438 papers, 129667 citations, 563 LAT papers**



https://www-glast.stanford.edu/cgi-bin/pubpub
https://fermi.gsfc.nasa.gov/cgi-bin/bibliography_fermi

Science Highlights - 8 years catalog

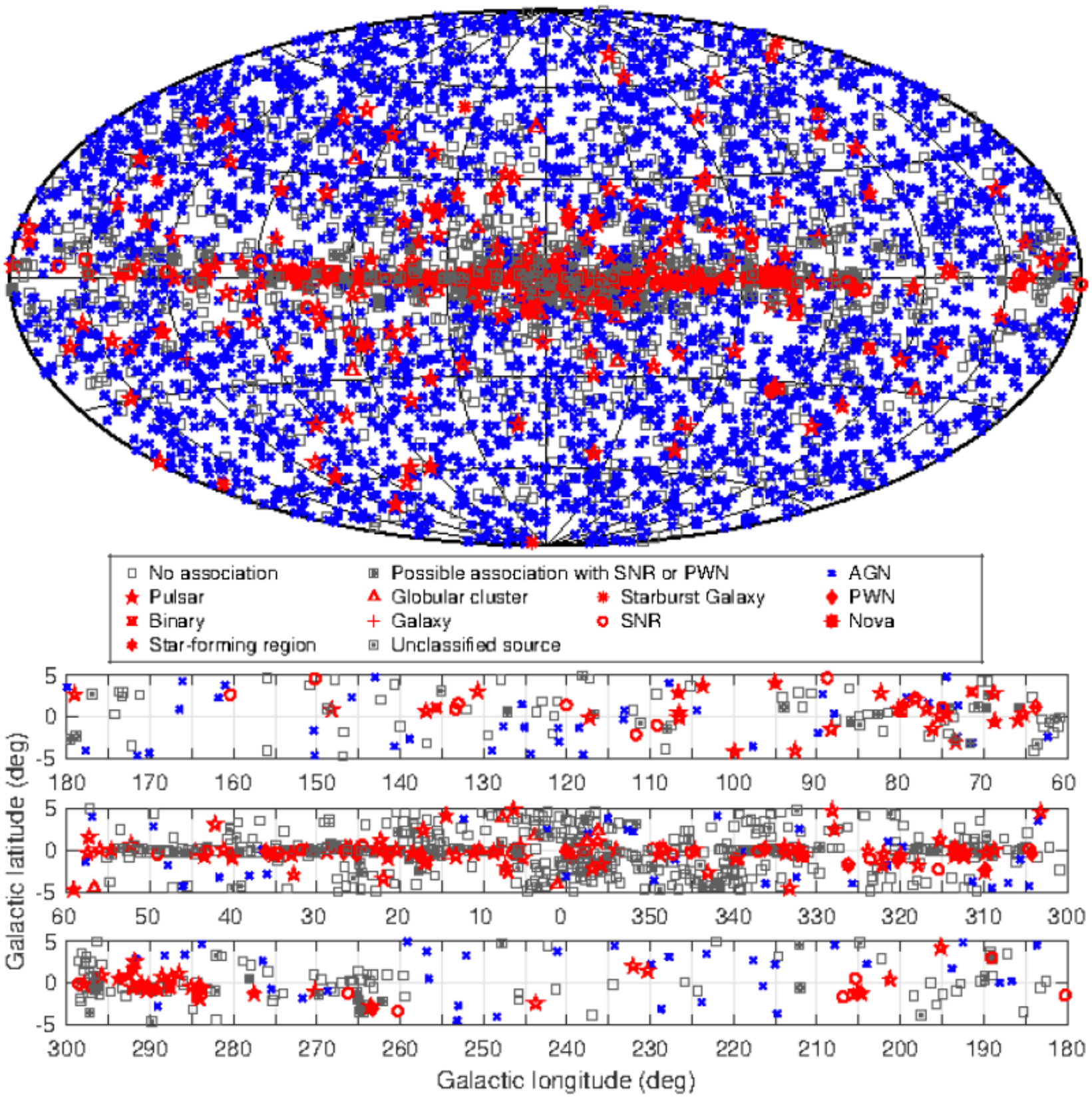


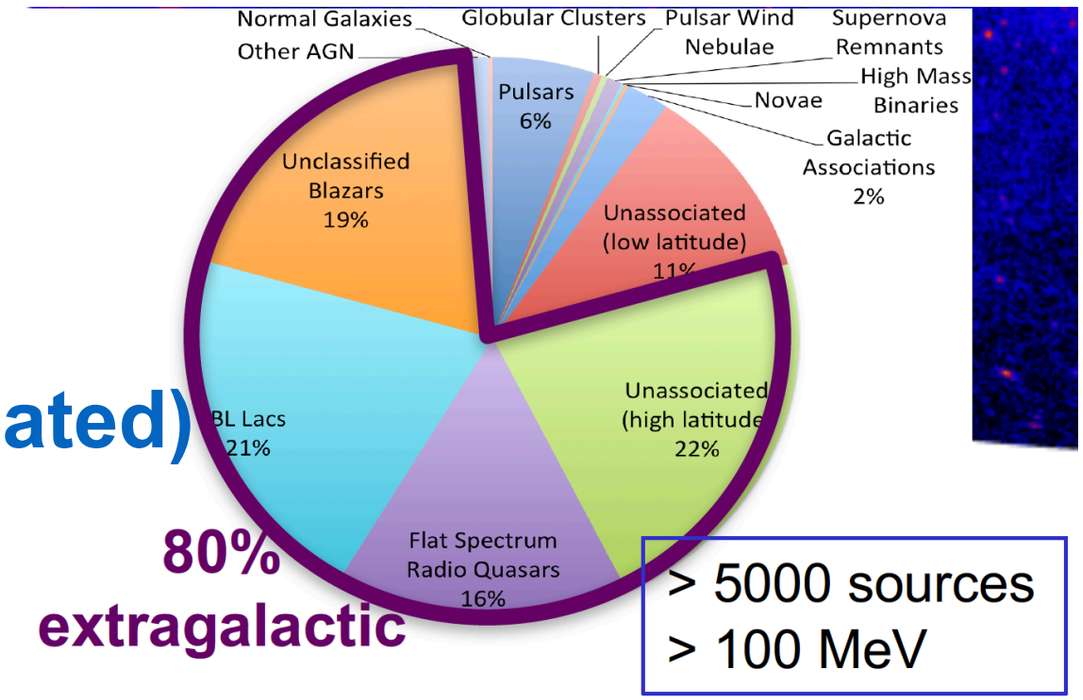
Figure 2. Full sky map (top) and blow-up of the Galactic plane split into three longitude bands (bottom) showing sources by source class (see Table 7, no distinction is made between associations and identifications). All AGN classes are plotted with the same blue symbol for simplicity. Other associations to a well-defined class are plotted in red. Unassociated sources and sources associated to counterparts of unknown nature are plotted in black.

https://arxiv.org/abs/1902.10045

4th LAT Catalog

- ***Ultimate*** **effort - beyond 5 years catalog legal obligation**
  - **8 years of data, latest Pass8 IRFs, improved diffuse emission model, updated multi-wavelength catalogs, search for spatial extension, multiple spectral models**

- ***Known*** **findings**
  - **~30% unidentified sources**
  - **>60% (of total) / >80% (of associated) are blazars**
  - **multiple classes**



2020, ApJS, 247, 33

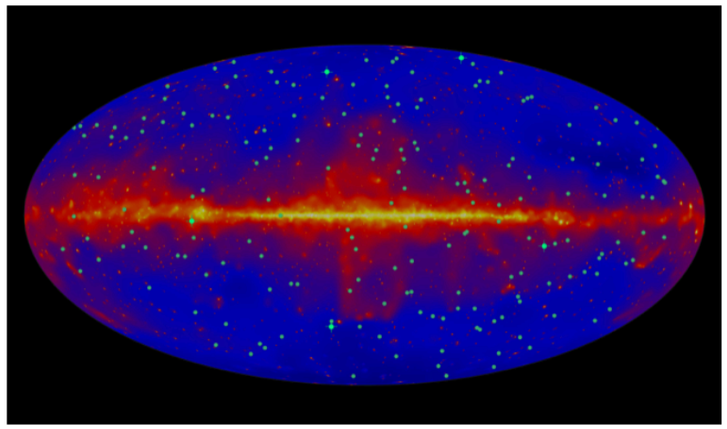
Science Highlights - GRB Catalog

Comunicazione

- Ufficio Comunicazione
- Comunicati stampa
- News
- Newsletter
- Rassegna Stampa
- Mostre e Installazioni
- Eventi
- Approfondimenti
- Infografiche e poster
- Brochure
- Editoria
- Asimmetrie
- Immagini
- Video
- Social network

13 GIUGNO 2019

LAMPI GAMMA: ECCO IL CATALOGO DEI PIÙ ENERGETICI OSSERVATI DA FERMI



186 lampi gamma di alta energia registrati dal telescopio satellitare per raggi gamma Fermi in dieci anni di osservazione: sono questi i protagonisti del catalogo pubblicato oggi, 13 giugno, su The Astrophysical Journal. Questi lampi gamma, anche noti come Gamma Ray Burst (GRB), sono stati rivelati dal Large Area Telescope (LAT), strumento di Fermi progettato e realizzato con un contributo decisivo dell'Italia, grazie all'Agenzia Spaziale Italiana ASI, all'Istituto Nazionale di Fisica Nucleare INFN e l'Istituto Nazionale di Astrofisica INAF.

"Ogni Gamma Ray Burst è in qualche modo unico. È solo quando siamo in grado di studiarne tanti, come abbiamo fatto in questo catalogo, che iniziamo a comprenderne le caratteristiche comuni," racconta Elisabetta Bissaldi, ricercatrice dell'INFN e del Politecnico di Bari. "Il primo catalogo LAT, pubblicato nel 2013, comprendeva solo 35 GRB. Grazie a un netto miglioramento delle tecniche di analisi dati, abbiamo identificato un numero di GRB cinque volte maggiore in questo nuovo catalogo, imparando così a conoscere meglio i meccanismi fisici all'opera. Ad esempio, abbiamo confermato che l'emissione di raggi gamma ad alta energia dura più a lungo rispetto all'emissione a bassa energia e che la succede," conclude Bissaldi.

Il catalogo che fornisce nuove indicazioni su origine ed evoluzione dei lampi gamma è il frutto del lavoro di 120 scienziate e scienziati della collaborazione Fermi coordinati da Bissaldi, da Magnus Axelsson dell'Università di Stoccolma e dagli italiani Nicola Omodei e Giacomo Vianello dell'Università di Stanford.

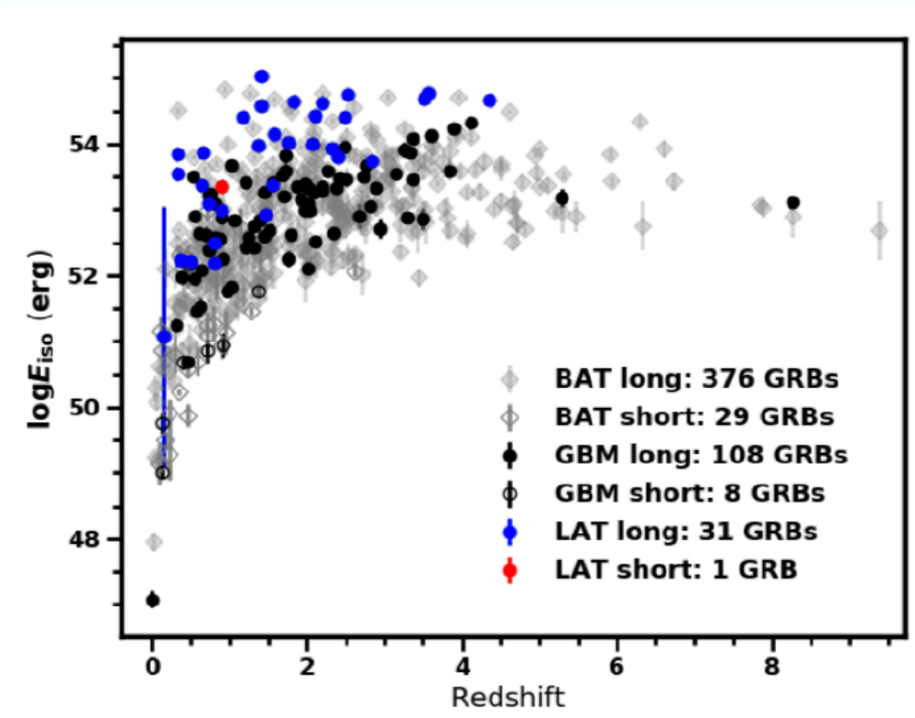
La maggior parte dei lampi gamma nasce quando alcuni tipi di stelle massive esauriscono il proprio combustibile e collassano generando buchi neri. Altri invece hanno origine dalla collisione di due stelle di neutroni, oggetti densissimi residuo di esplosioni stellari. Sia il collasso di una stella sia la collisione di due stelle di neutroni danno, infatti, origine a jet relativistici di particelle che si muovono a una velocità prossima a quella della luce. Quando le particelle all'interno dei jet si scontrano tra di loro o interagiscono con l'ambiente intorno alle stelle, nascono i raggi gamma che sono poi rivelati da Fermi grazie ai suoi strumenti principali: il LAT e il GBM.

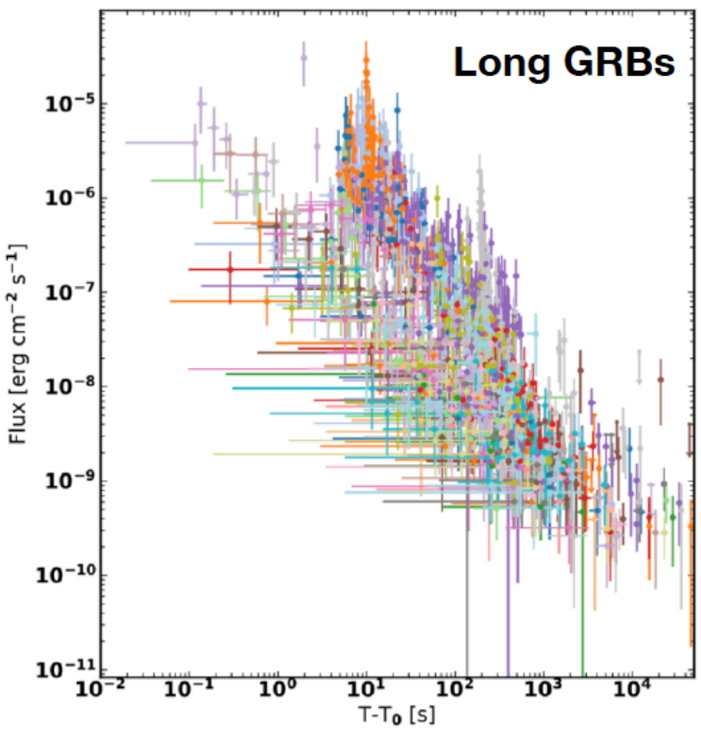
A Decade of Gamma-Ray Bursts Observed by Fermi-LAT: The Second GRB Catalog
Ajello, M. (Fermi LAT Collaboration) et al. 2019, ApJ, 878, 52 Hide links
doi: 10.3847/1538-4357/ab1d4e
arXiv: 1906.11403 INSPIRE

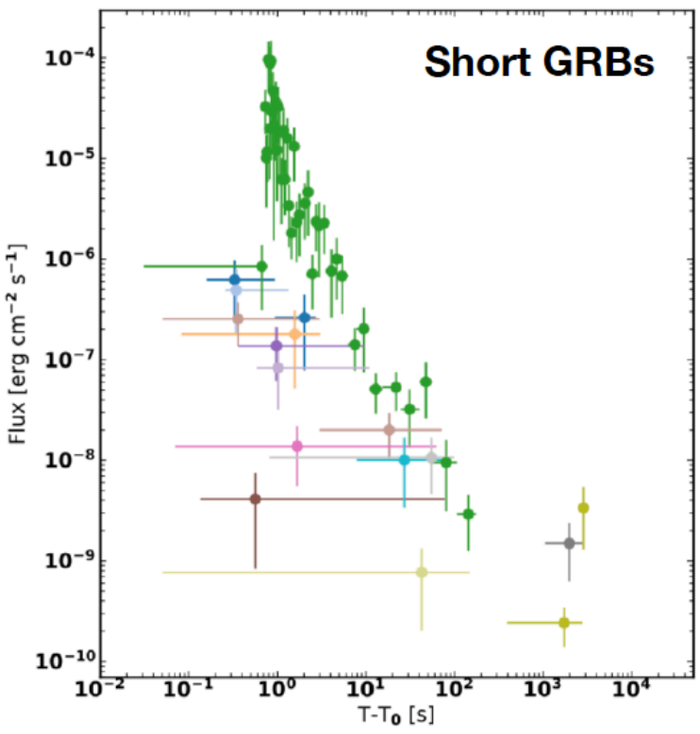
Fermi GRBs

- GBM has detected ~2650 GRBs in 11 years
  - ~240 GRBs/yr (40 short/yr)
- LAT has detected ~200 GRBs in 11 years
  - ~18 GRBs/yr (1.7 short/yr)
  - closest and/or most energetic events

- Common features in High Energy GRB emission
  - delayed onset (GeV relative to keV)
  - extra components (thermal, extra power laws)
  - extended emission - GeV afterglows







Ajello et al. 2019, ApJ, 878, 52

Operational Context

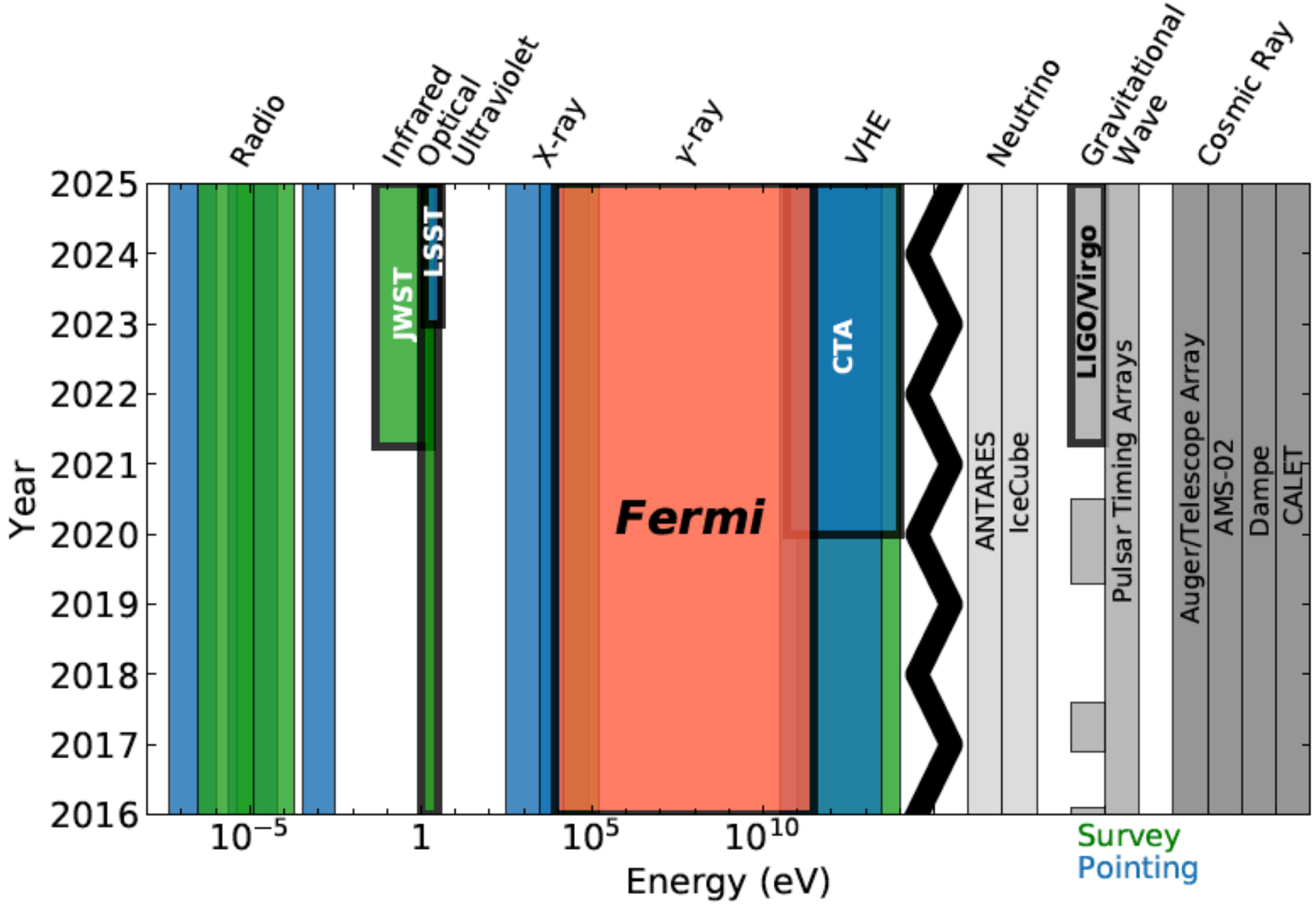
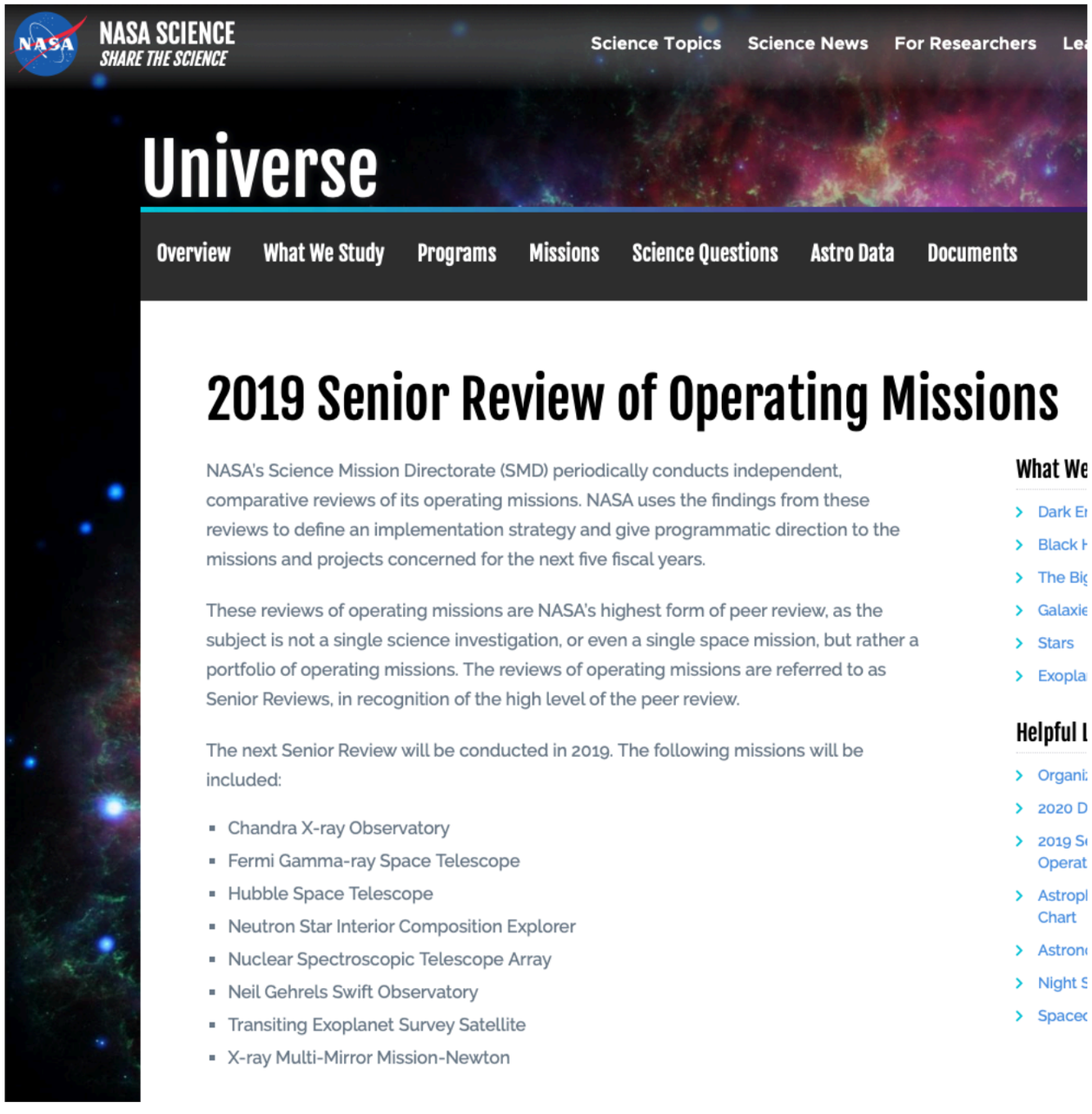


Figure 7: *Fermi* fills a unique part of the electromagnetic spectrum, especially vital in the coming years as new or enhanced facilities (bold outlined) come online presenting new opportunities in cooperation with *Fermi*.

Fermi renewed status of CERN recognized experiment through 2022

NASA Senior Review

- 2019 Proposal well received
- SR panel and NASA HQ confirmed funds through 2022 and invite Fermi at next 2022 SR

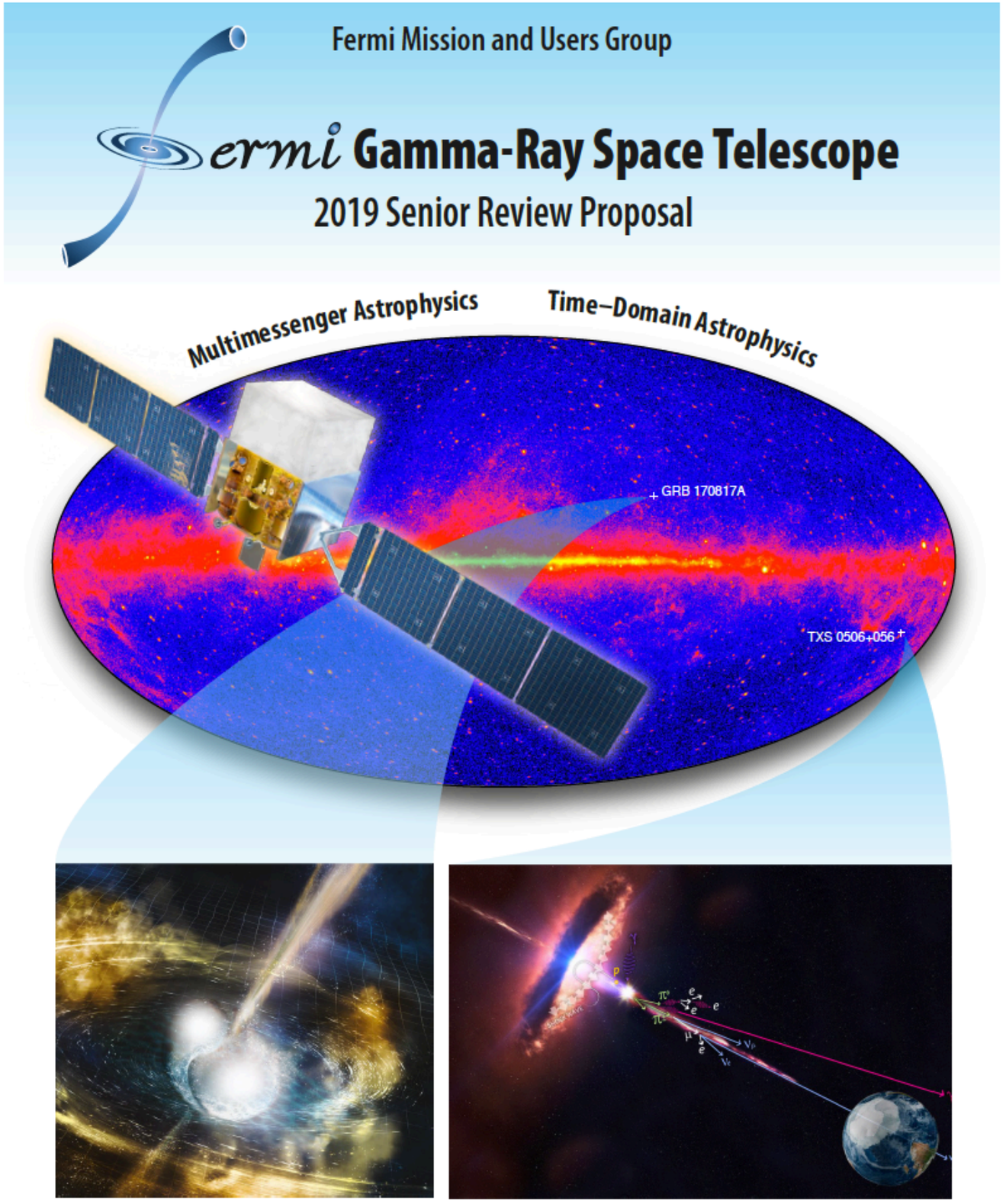


https://science.nasa.gov/astrophysics/2019-senior-review-operating-missions

Fermi 2019 SR Proposal

Focus on multi-messenger and time-domain astrophysics after

- **first observation of BNS gravitational merge in gamma-rays**
- **first association of flaring AGN with high energy neutrino**

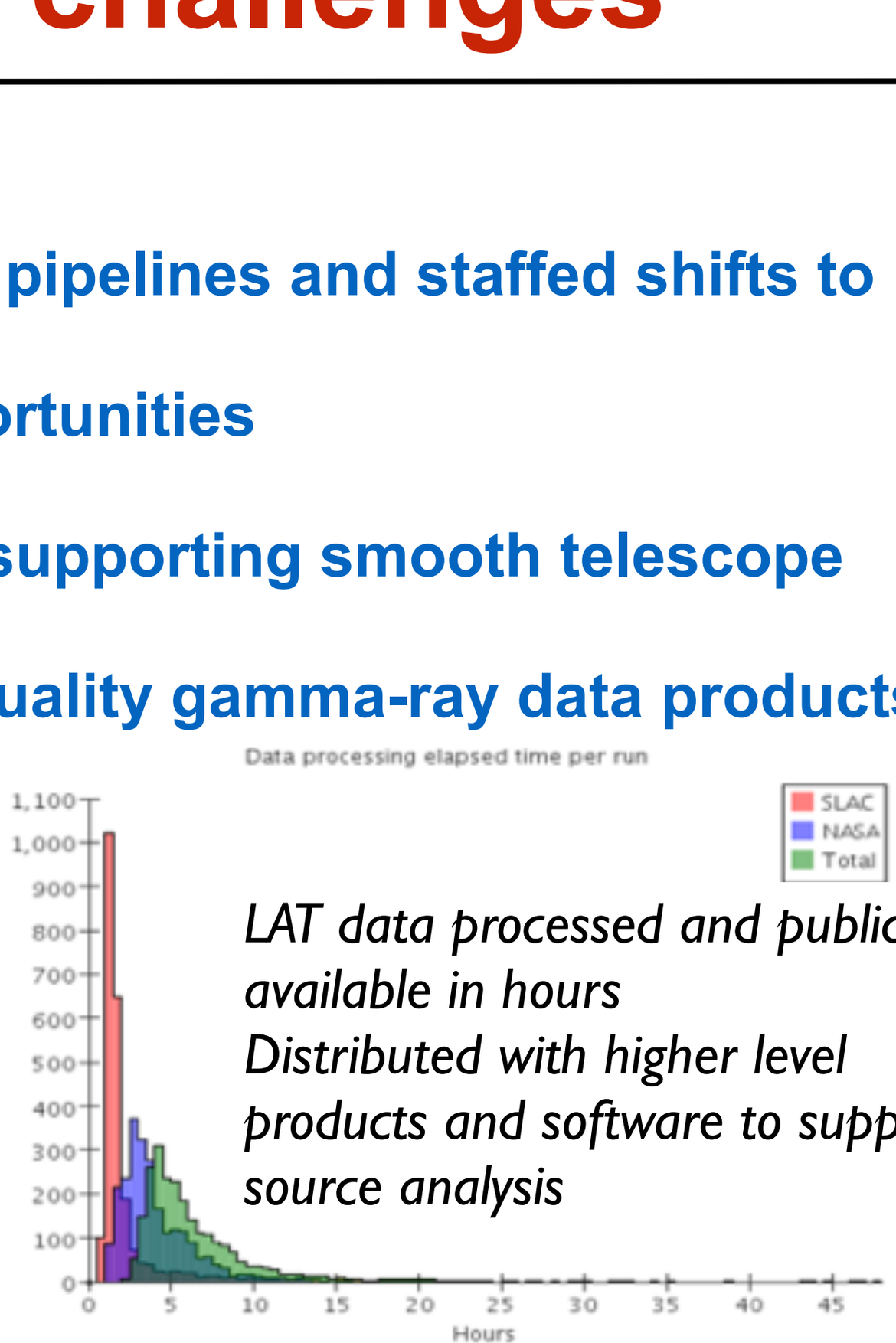


Mission status

- **Observatory running smoothly**
  - **one solar array drive damaged in March 2018, since then oriented at fixed position**
  - **modified rocking profile to recover exposure uniformity**
- **All LAT subsystems working with no degradation**
  - **CAL light output reduced by ~6% since launch, as expected from irradiation**
  - **TKR has only 0.07% strips masked**

Upcoming challenges

- **Open data and alert systems**
  - **LAT collaboration prepared pipelines and staffed shifts to cover multi-messenger opportunities**
  - **LAT committed to continue supporting smooth telescope operations and serve high quality gamma-ray data products to the community**



LAT data processed and publicly available in hours
Distributed with higher level products and software to support source analysis

https://fermi.gsfc.nasa.gov/ssc/data/access/

Data

- Data Policy
- **Data Access**
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

Currently Available Data Products

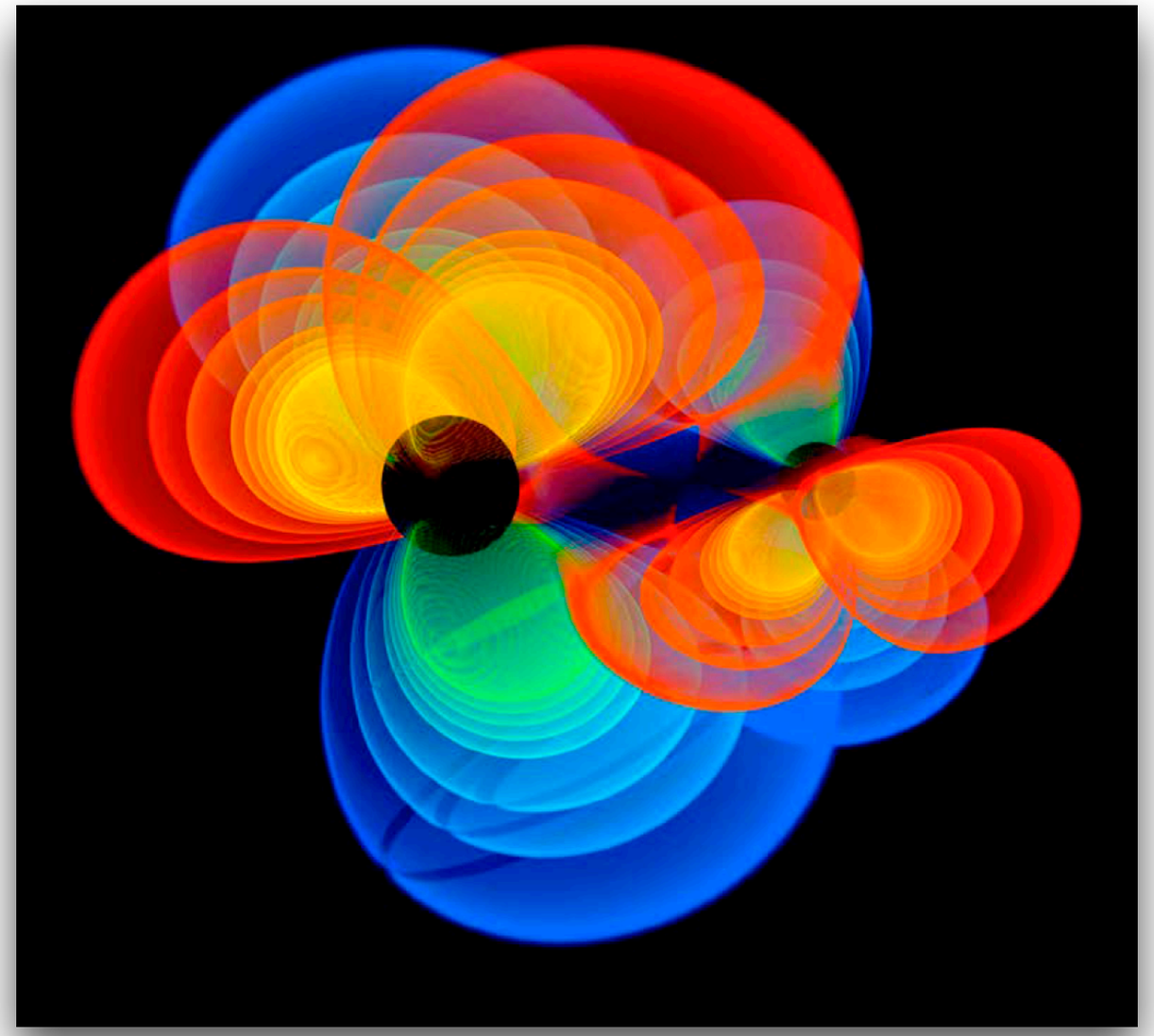
The Fermi data released to the scientific community is governed by the data policy. The released instrument data for the GBM, along with LAT source lists, can be accessed through the Browse interface specific to Fermi. LAT photon data can be accessed through the LAT data server.

The FITS files can also be downloaded from the Fermi FTP site. The file version number is the 'xx' in the characters before the extension in each filename; you should keep track of the version numbers of files you analyze since the instrument teams may update them.

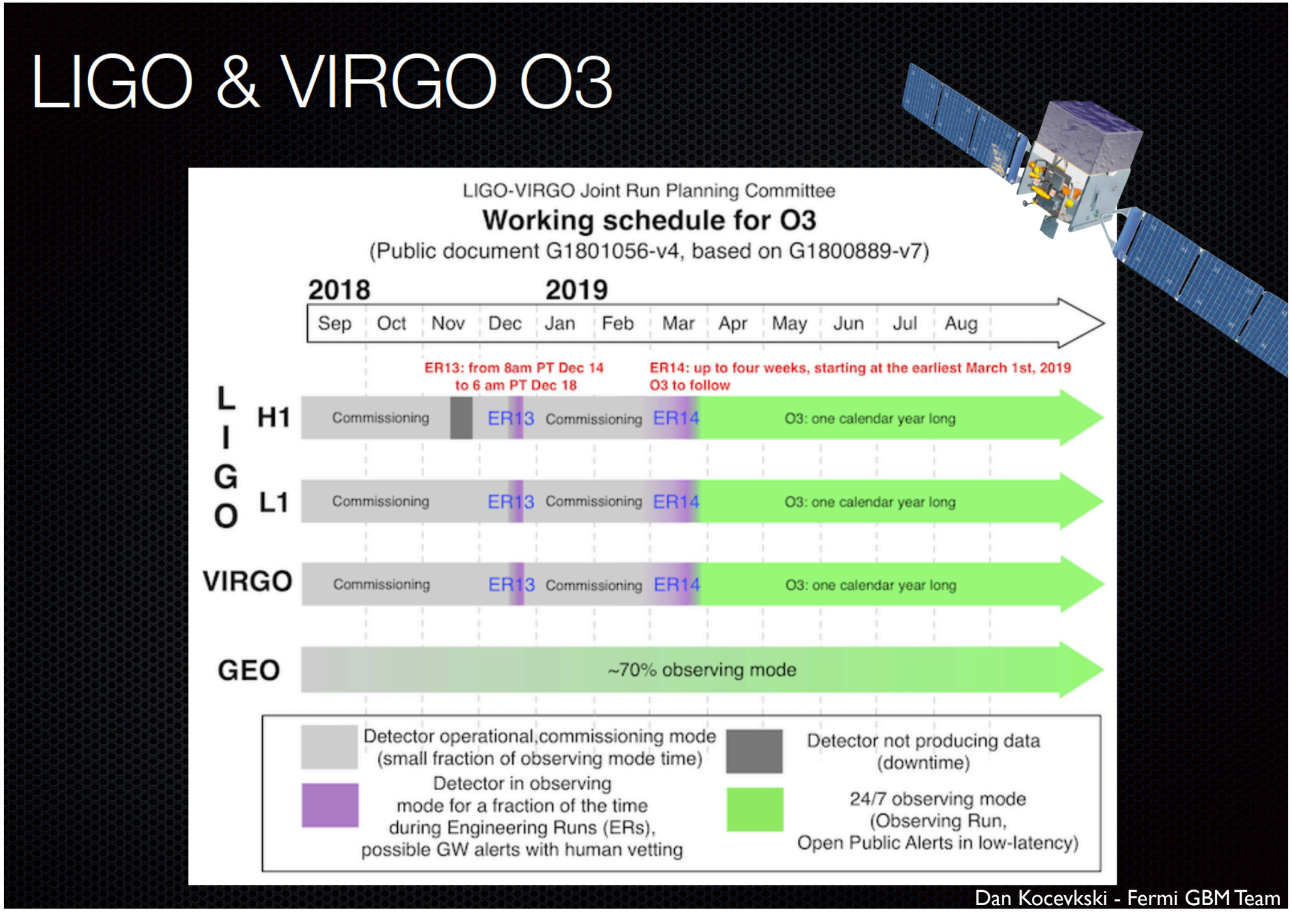
Note that the LAT and GBM data are accompanied by caveats about their use.

- LAT Photon and Extended Data
  - LAT Data Server (updated with P8R3 data 26-Nov-2018)
  - LAT Low-Energy (LLE) Data (Browse table)
  - Products available on the FTP Site (current processing version of the data).
    - Weekly Photon Files
    - Weekly Spacecraft Files
    - Mission Long Spacecraft File
    - Weekly 1-second Spacecraft Files
    - Filtered Weekly Photon Files with Diffuse Response Columns
  - Previous processing versions available on the FTP site
    - Pass 8 (P8R2) Weekly Files
    - Pass 7 (V6d) Weekly files
    - Pass 7 (V6) Weekly files
    - Pass 6 (V11) Weekly files
    - Pass 6 (V3) Weekly files
  - ASDC data server (external)
- LAT catalogs and associated products (high-level products only)
  - LAT Point Source Catalog
    - LAT 8-year Point Source Catalog (4FGL)
    - Preliminary LAT 8-year Source List (FL8Y)
    - LAT 4-year Point Source Catalog (3FGL)
    - LAT 2-year Point Source Catalog (2FGL)
    - LAT 1-year Point Source Catalog (1FGL)
    - LAT 3-month Bright Source List (0FGL)

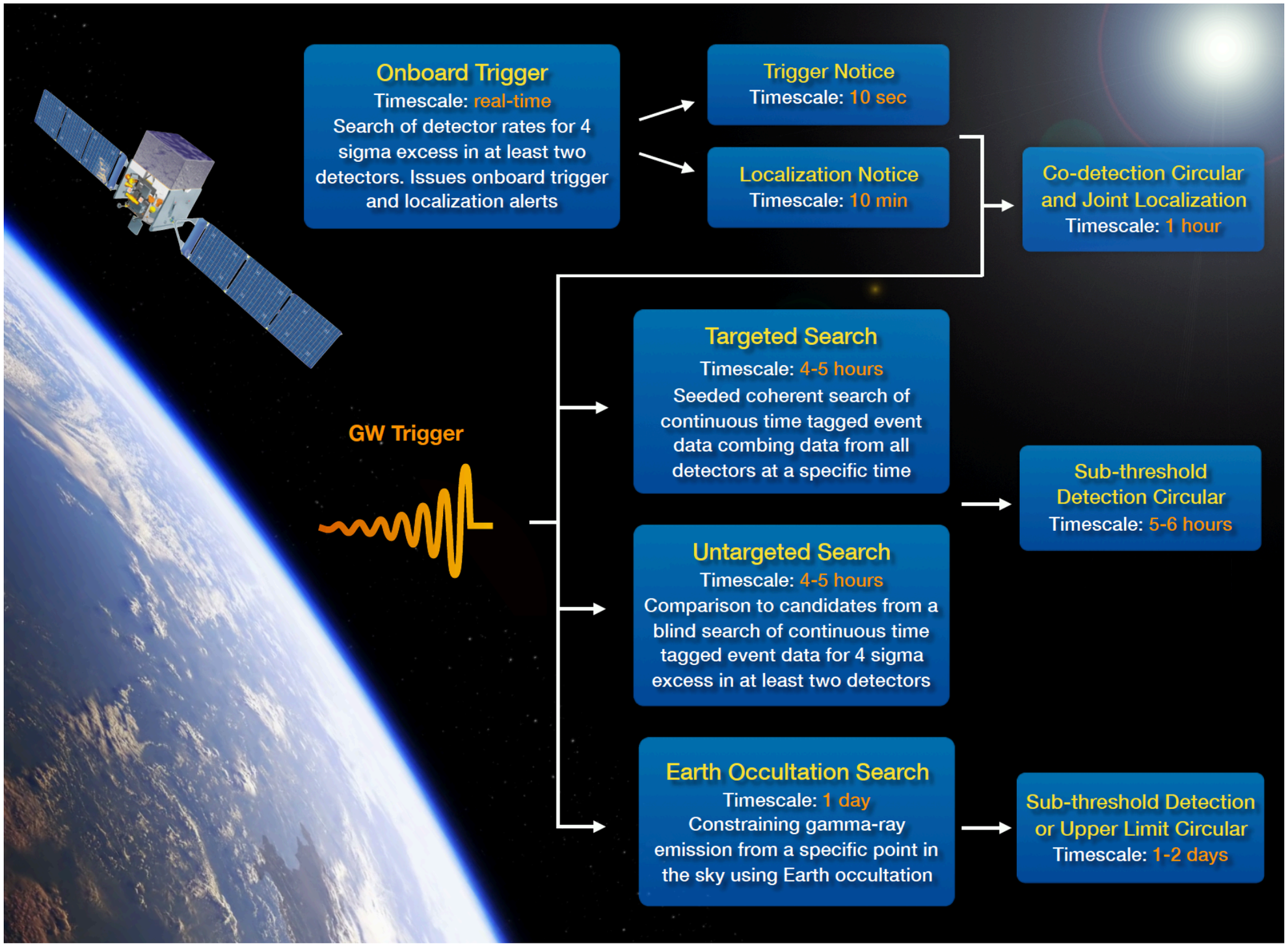
3 – MULTIMESSENGER ASTRONOMY – STATUS AND PROSPECTS



LVC OPERATIONS

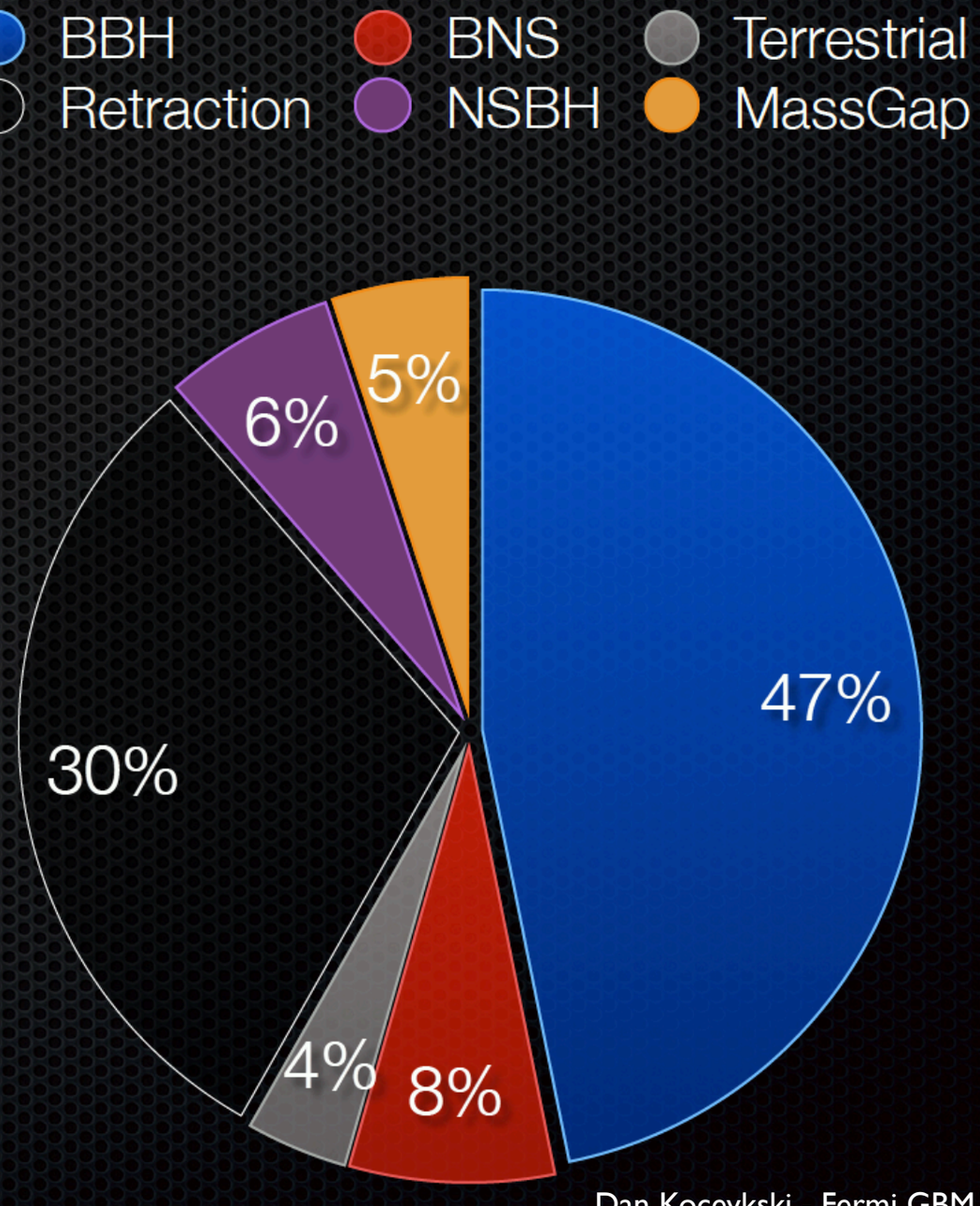


FERMI GBM OPERATIONS



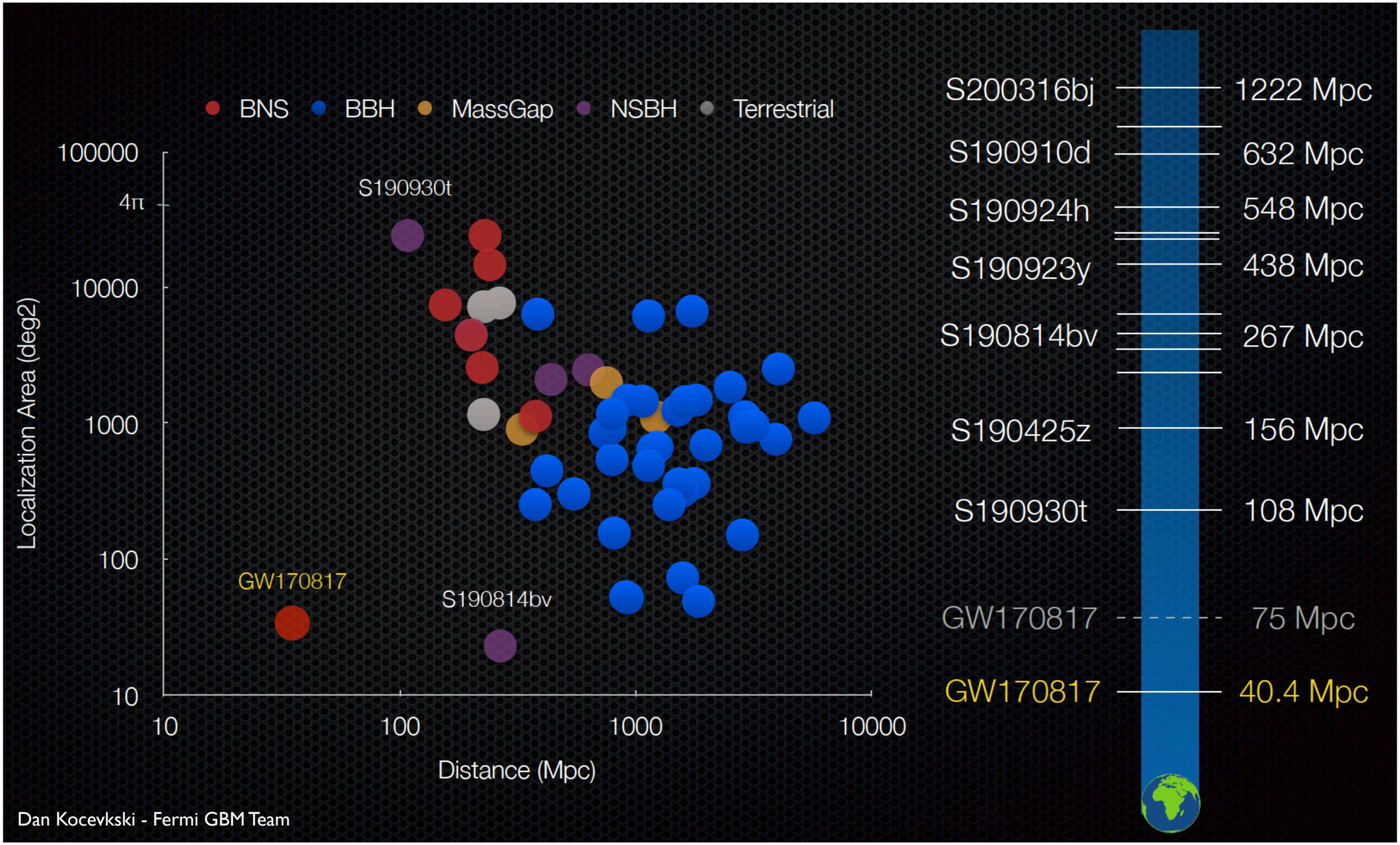
GW OBSERVATIONS

- LVC issued 80 public detection alerts via GCN since April 5th, 2018
  - 37 BBH
  - 6 BNS
  - 5 NSBH
  - 4 MassGap
  - 3 Terrestrial?
  - 24 Retractions
- Ferm was in SAA for 9 of 55 un-retracted triggers, or roughly 16% of the time



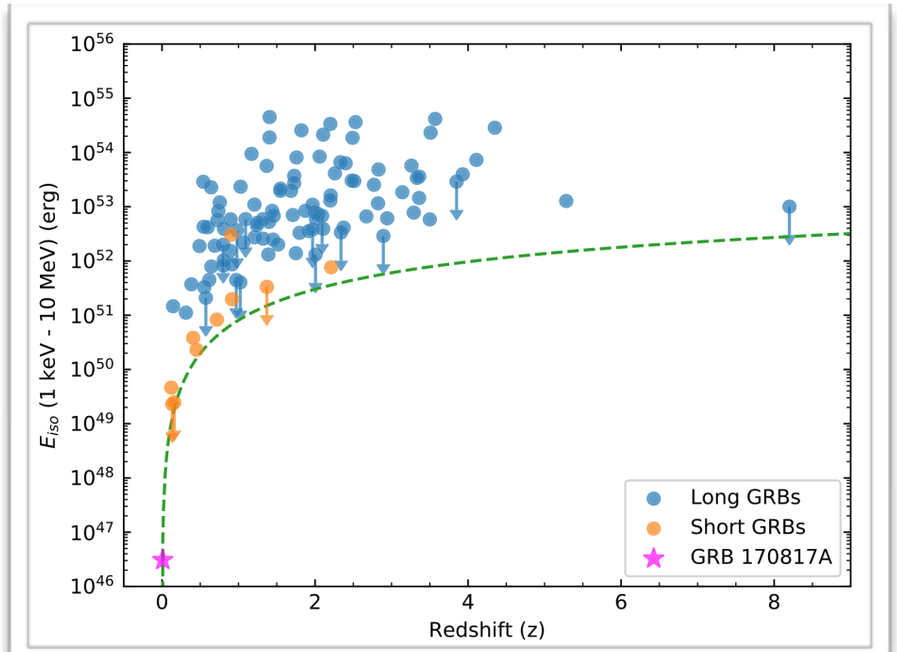
FERMI AND MULTIMESSENGER OBSERVATIONS

GW OBSERVATIONS

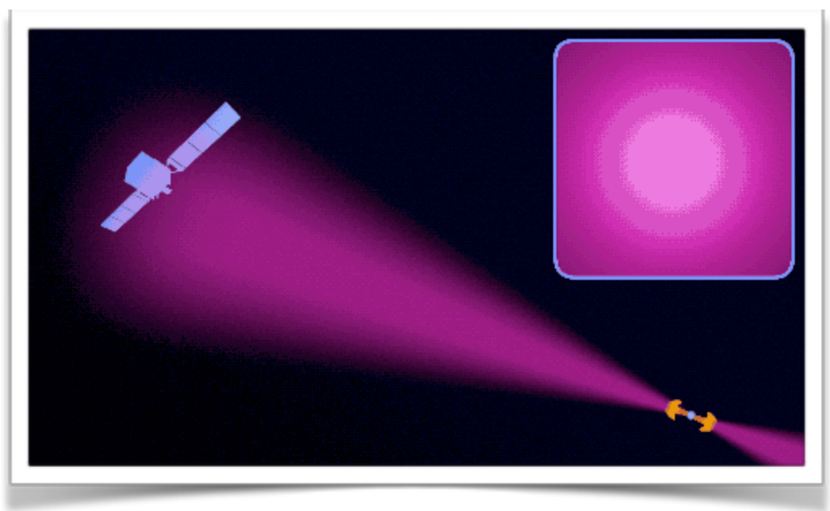


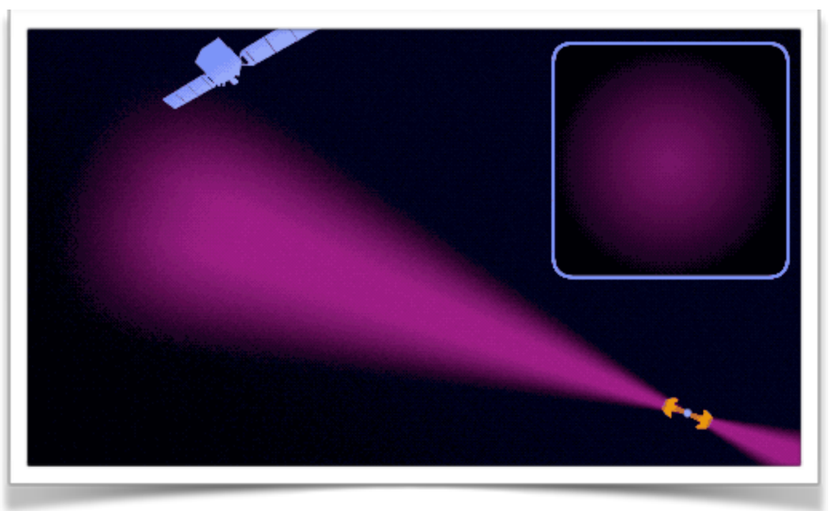
GRB170817 – A SPECIAL EVENT?

- ~10^4 dimmer than ordinary GRBs
- Circumstantial evidence of a jet seen off axis
- long term multi-wavelength observations and jet modeling to assess this picture



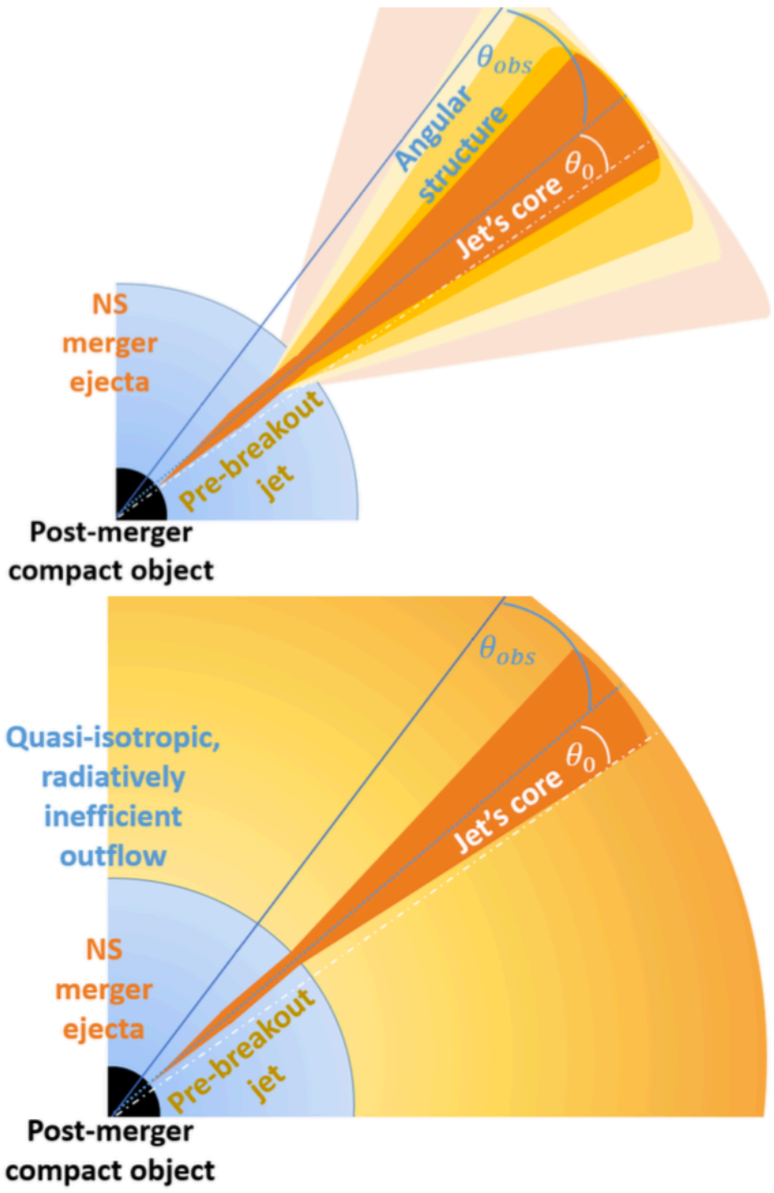
Abbott et al, 2017, arXiv:1710.05834





GRB170817 EMISSION MODELS

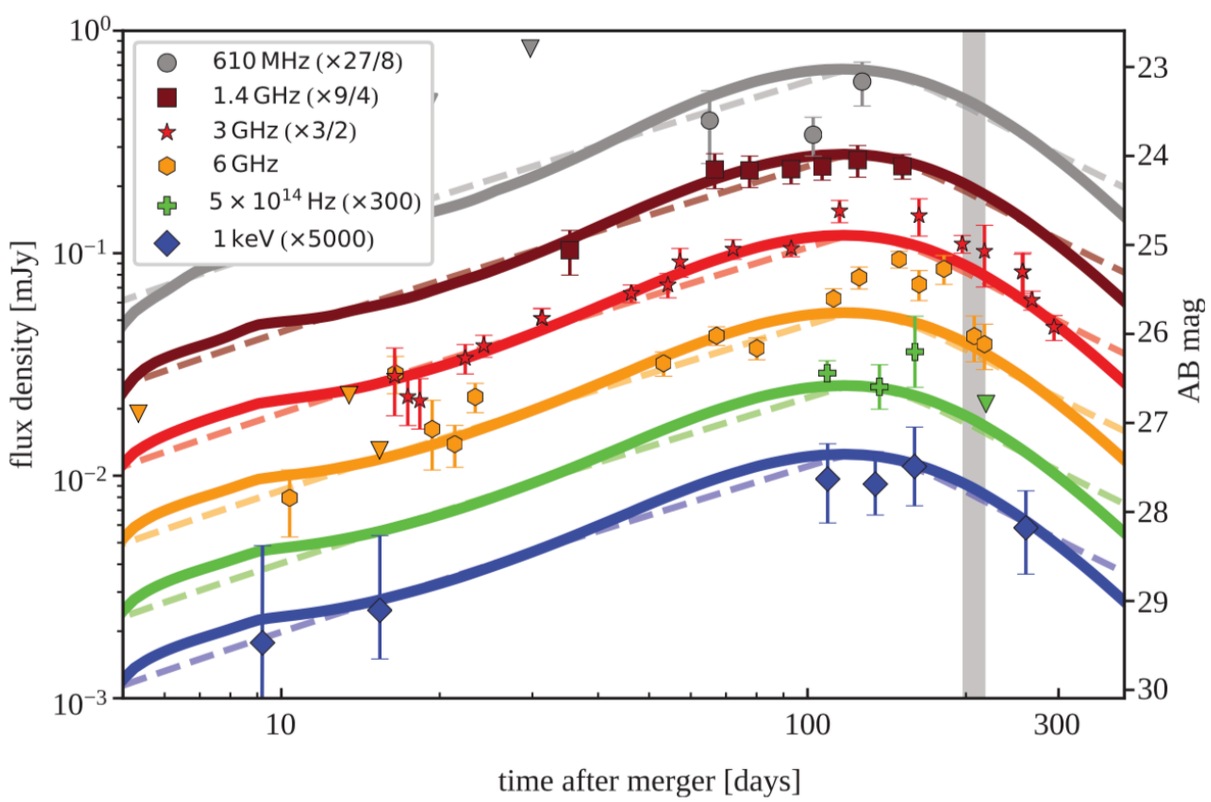
- Top: **structured jet**
  - jet with core luminosity (power-law / gaussian) breaks the ejecta
  - observer sees dimmer / less energetic emission
- Bottom: **choked cocoon**
  - jet with radiatively inefficient outflow



Beniamini et al, 2018, arXiv:1808.04831

GRB170817 – MULTIFREQUENCY OBSERVATIONS

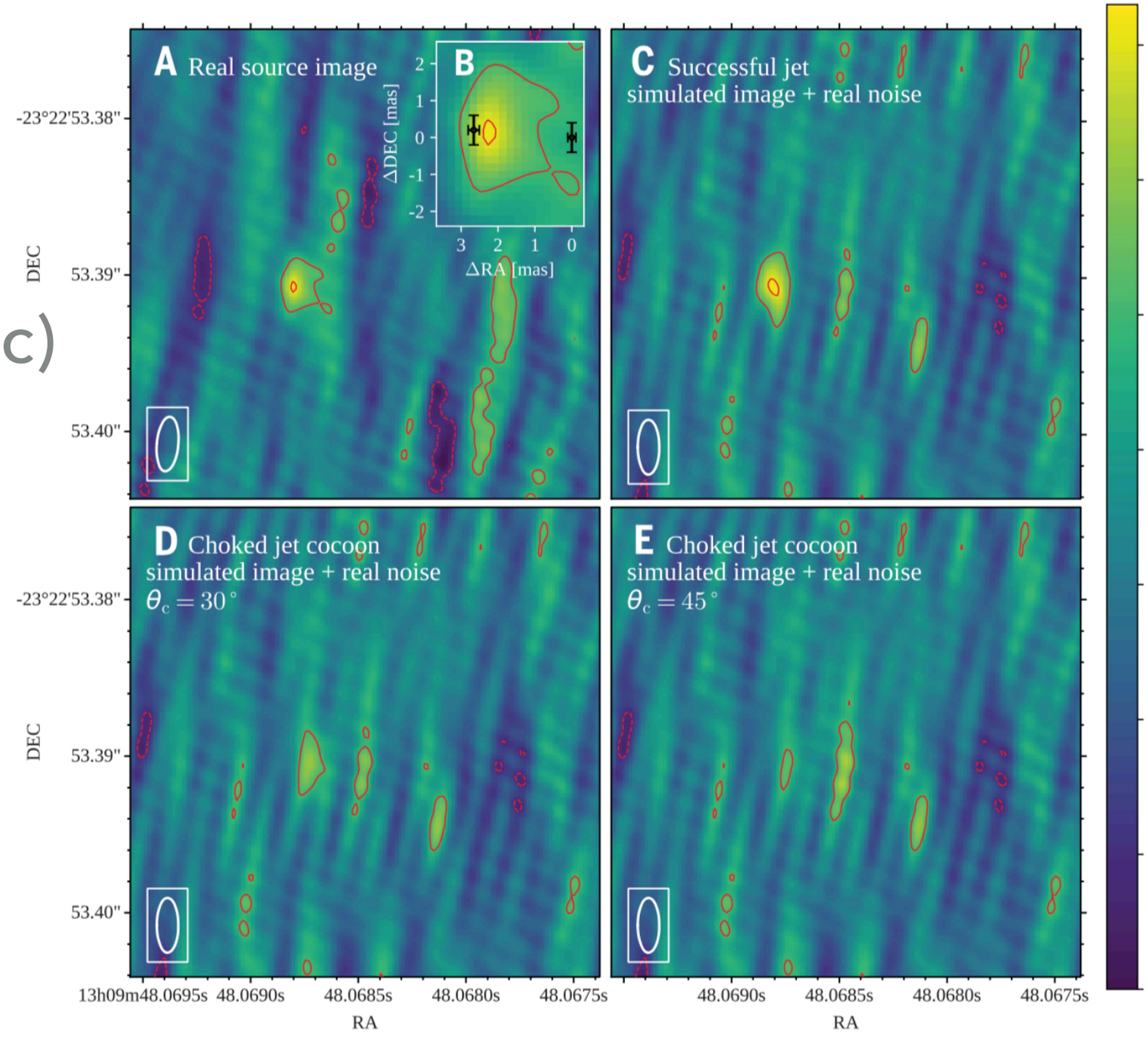
- Long-term observations of the multifrequency emission confirm non thermal emission
- Flux information compatible with a structured jet (solid lines) as well as with a choked cocoon (dashed)



Ghirlanda et al, 2019, Science 363, 968-971

GRB170817 – RADIO VLBI OBSERVATIONS – IMAGING

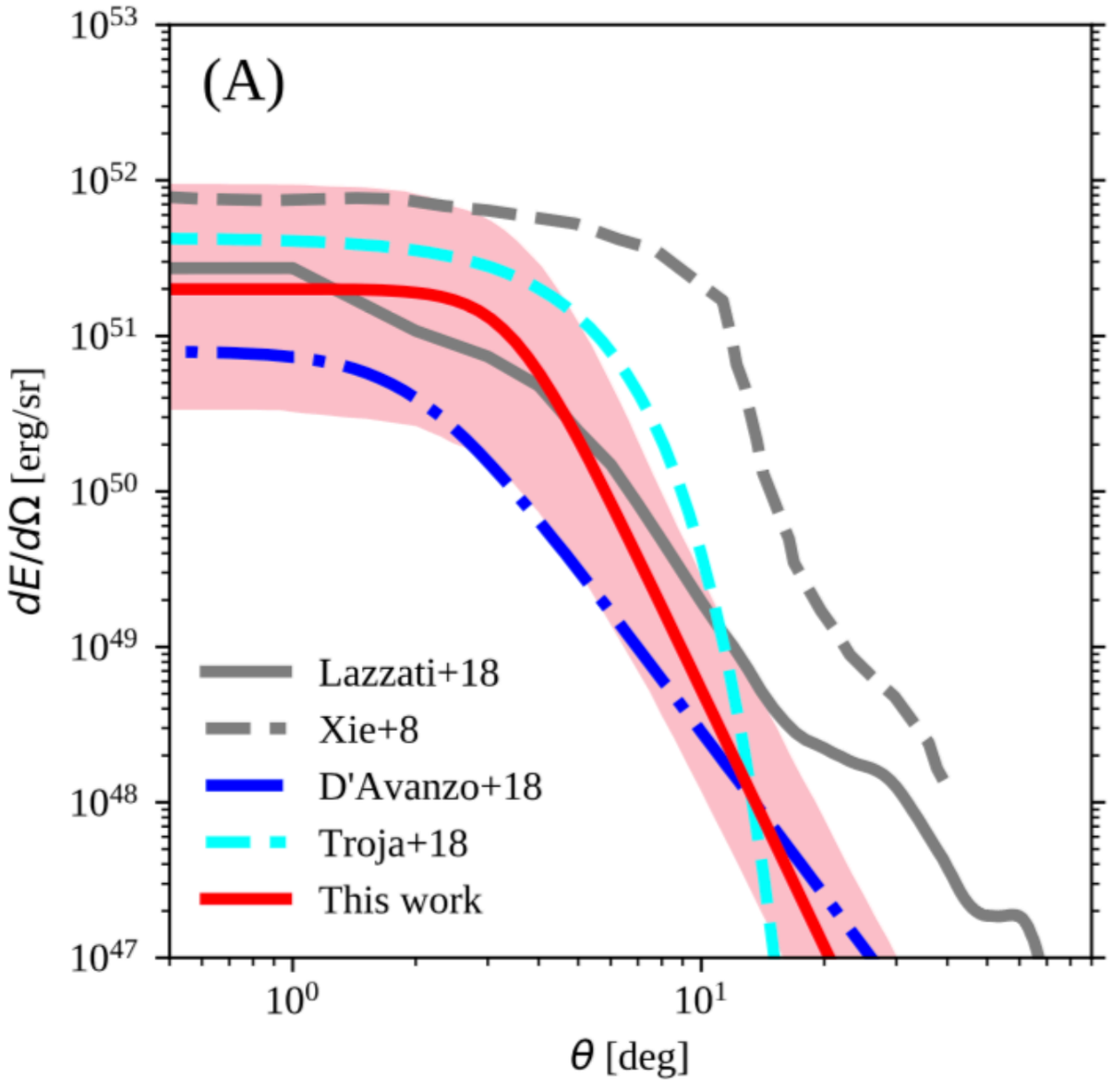
- Structured jet preferred to chocked cocoon
  - **compact** (<~2marcsec)
  - peaked brightness



Ghirlanda et al, 2019, Science 363, 968-971

GRB170817 – RADIO VLBI OBSERVATIONS – JET MODEL

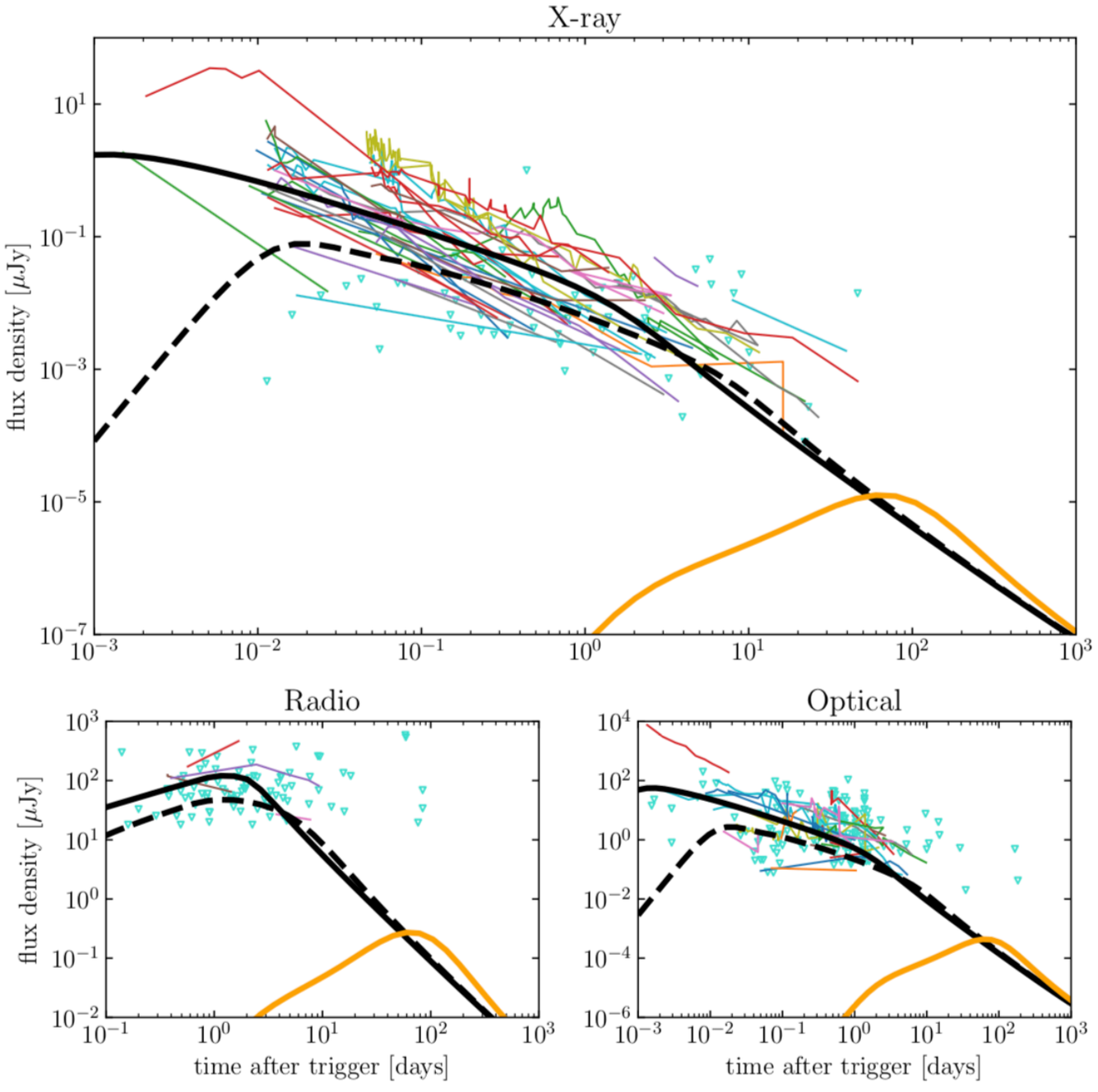
- Structured jet preferred to chocked cocoon
  - compact (<~2marcsec)
  - **peaked brightness**



Ghirlanda et al, 2019, Science 363, 968-971

A UNIVERSAL SHORT-GRB JET STRUCTURE ?

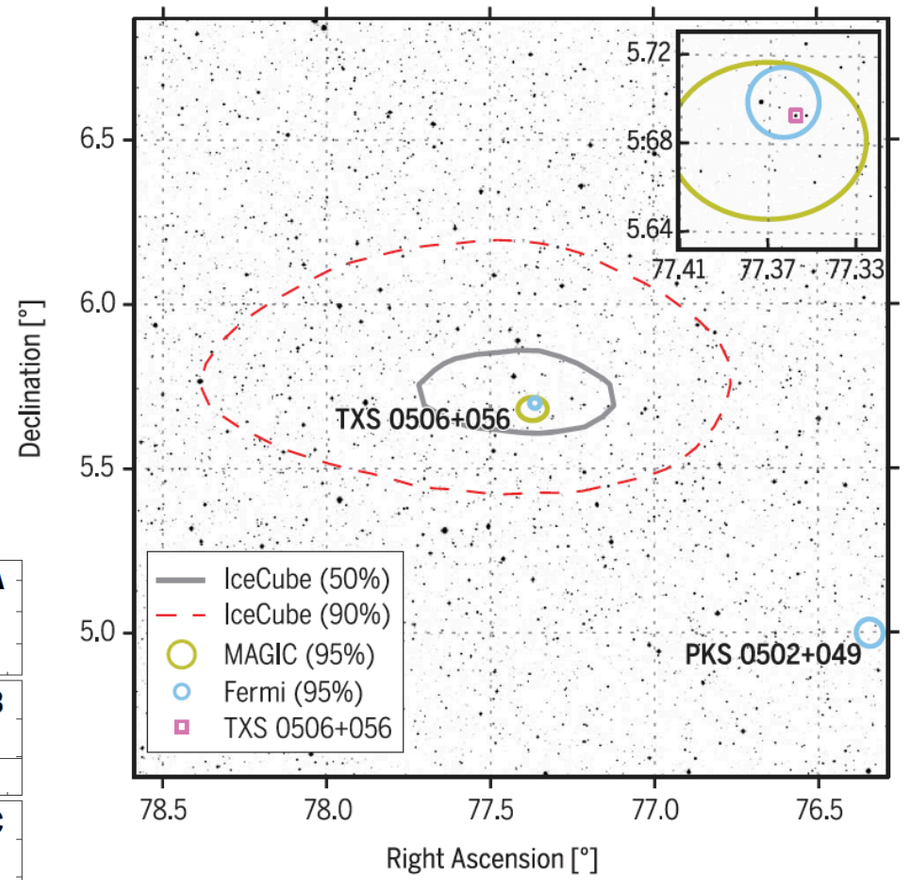
- sGRBs afterglows: archival data for ordinary GRBs with a GRB170817-like structured jet seen on-axis (black lines) or off-axis (orange line)
- diversity of sGRB afterglows attributed to external properties

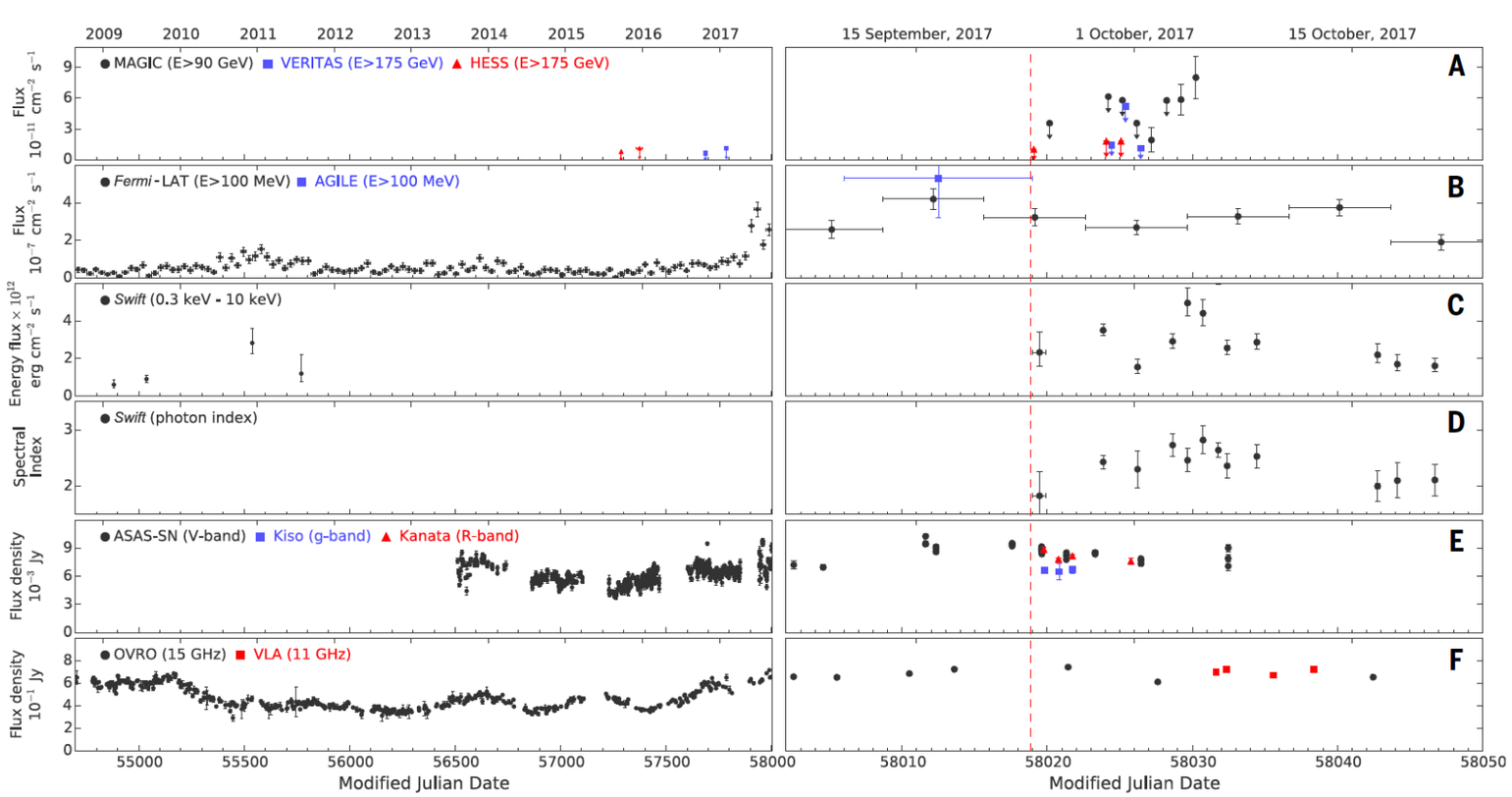


Salafia et al, 2019, MNRAS, arxiv 1905.01190

NEUTRINO SOURCES ?

- TXS 0506+056 and IceCube 170922A association inferred from positional coincidence and concurrent high energy flare

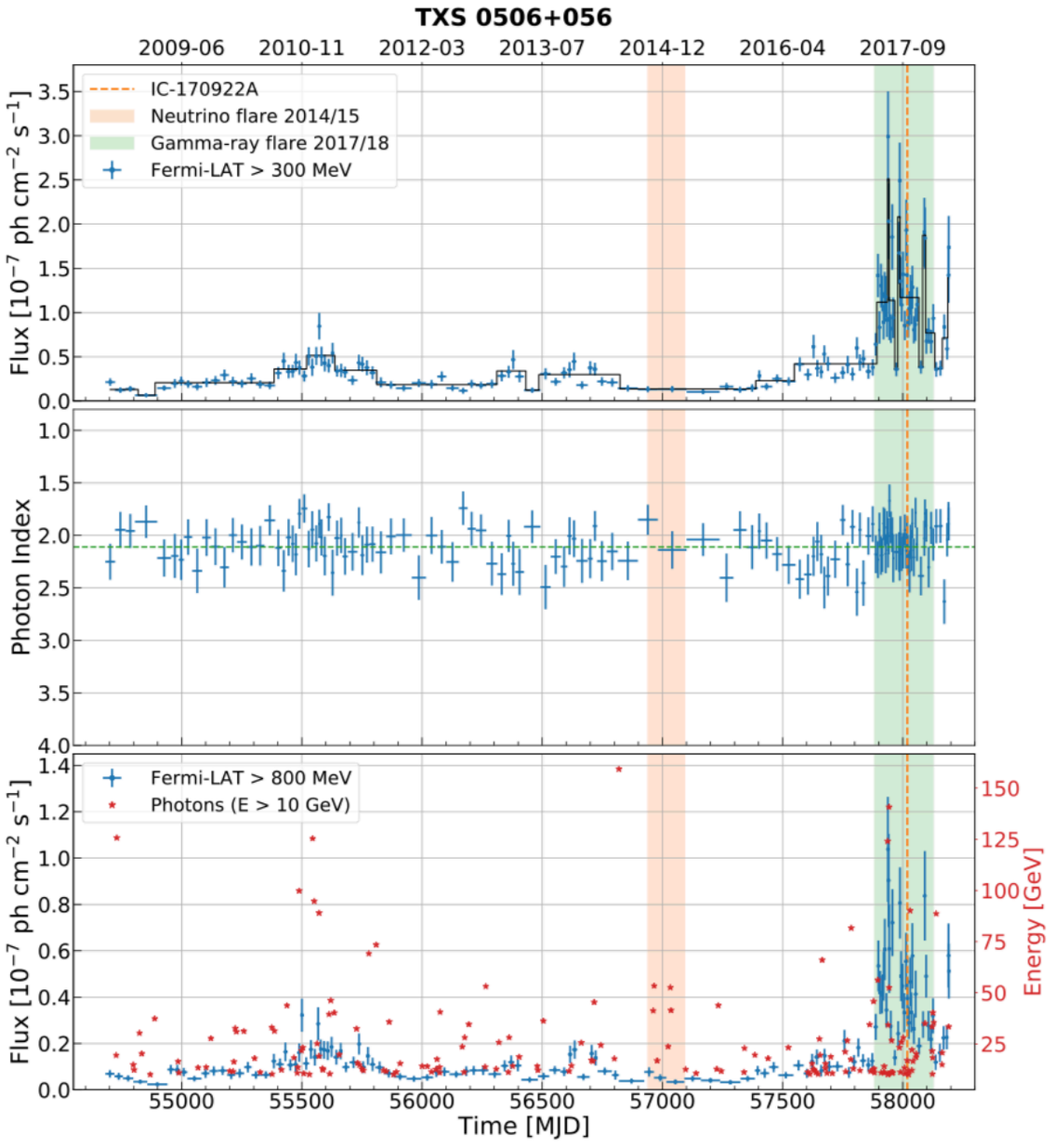




IceCube, Fermi, MAGIC et al, Science 361 (6398), eaat1378

NEUTRINO SOURCES ?

- Absence of gamma-ray emission with archival neutrino flare 2014/2015

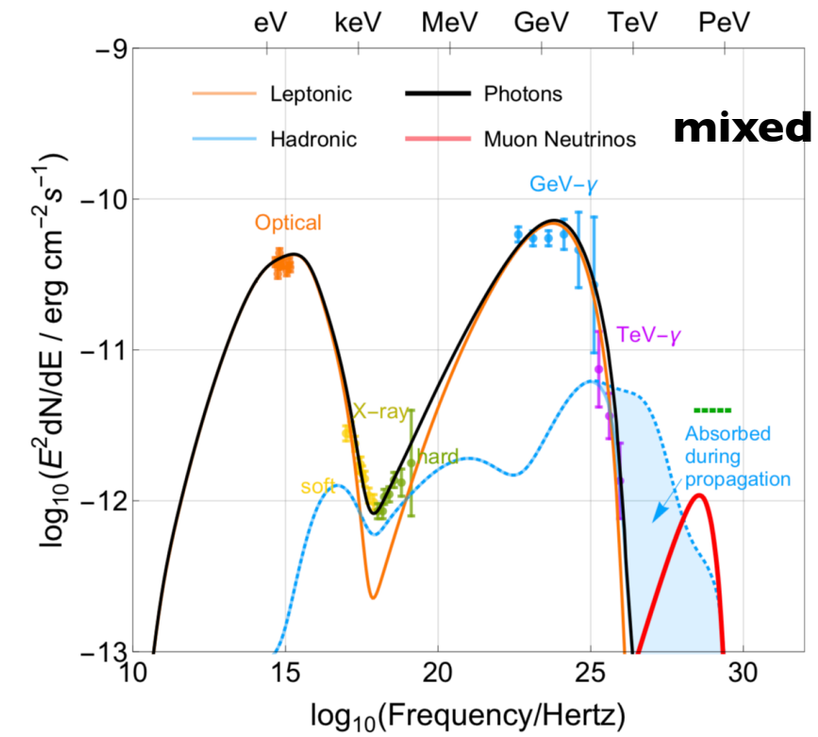


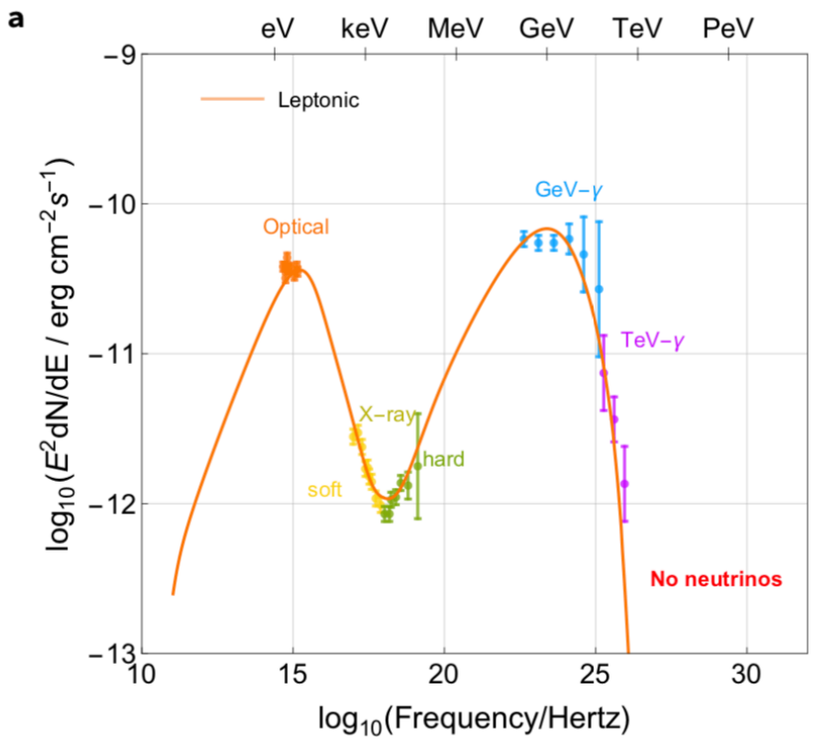
Garrappa et al, 2019, ApJ 880 103

FERMI AND MULTIMESSENGER OBSERVATIONS

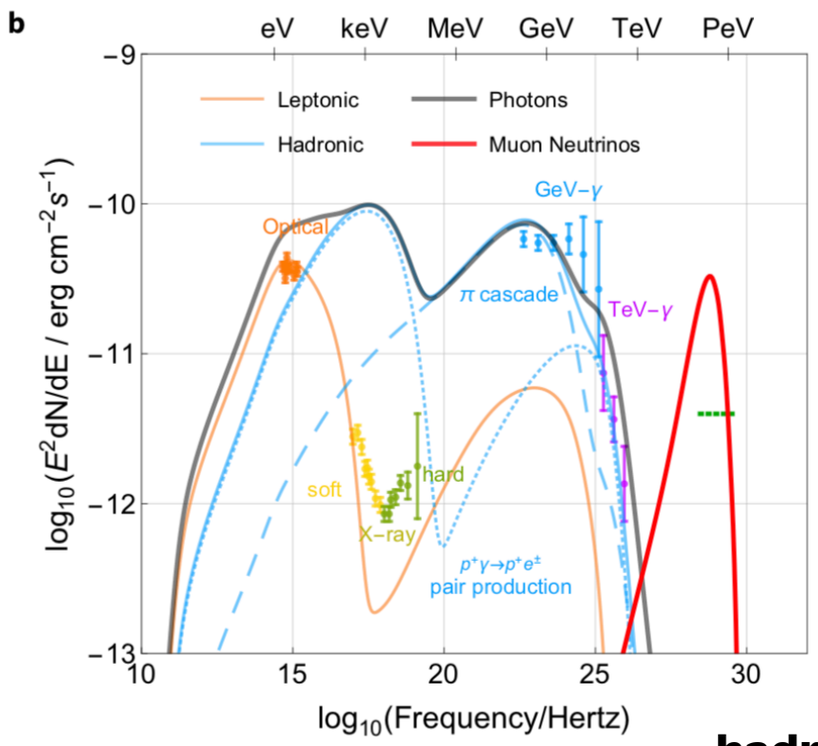
NEUTRINO SOURCES ?

- Difficulties in reproducing photon and neutrino measured fluxes with simple models





leptonic



hadronic

Gao et al, 2018, Nature Astronomy, arxiv 1807.04275

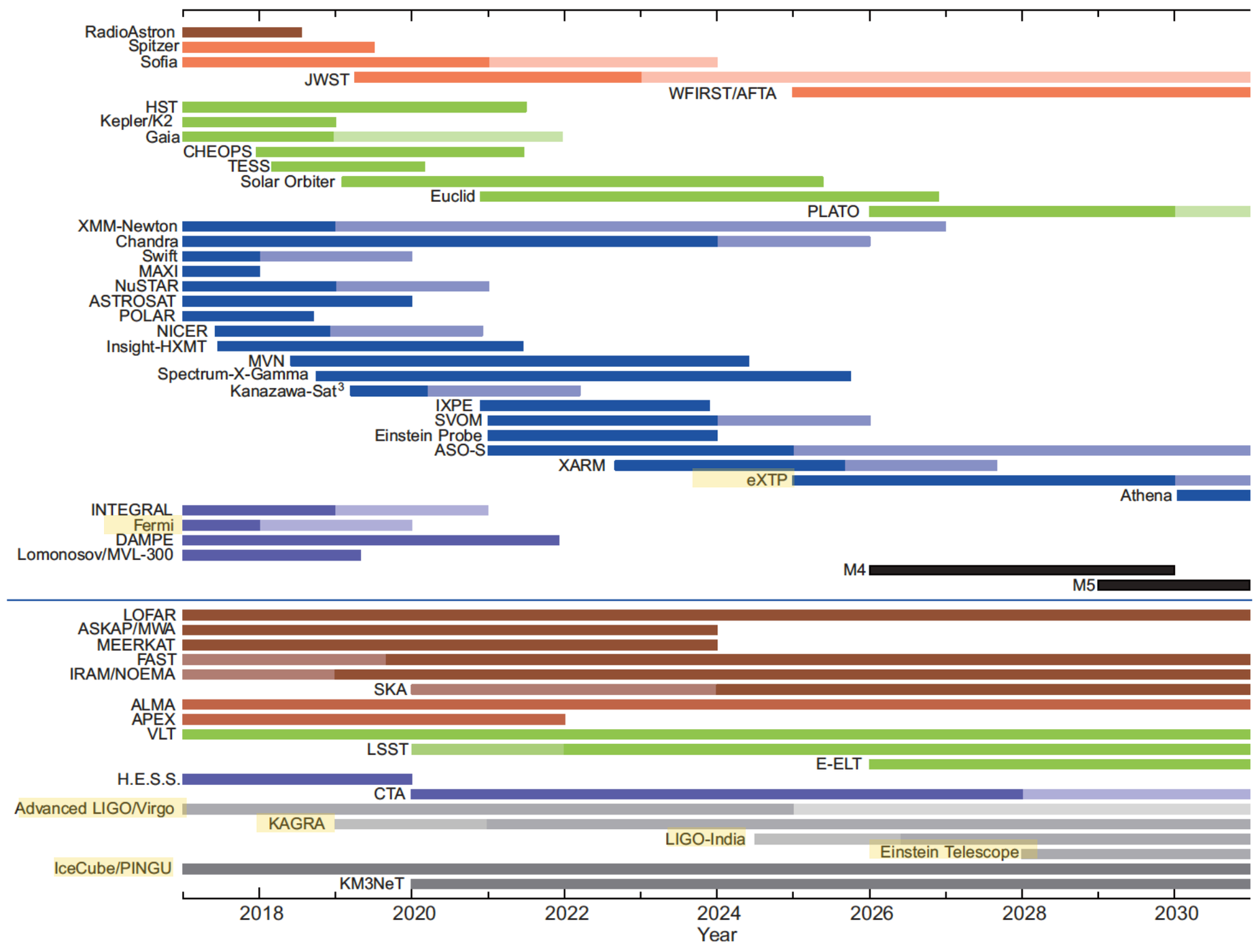
4 – PROSPECTS

FERMI AND MULTIMESSENGER OBSERVATIONS

OBSERVATORIES

Space

Ground



Dark - funded
Light - lifetime

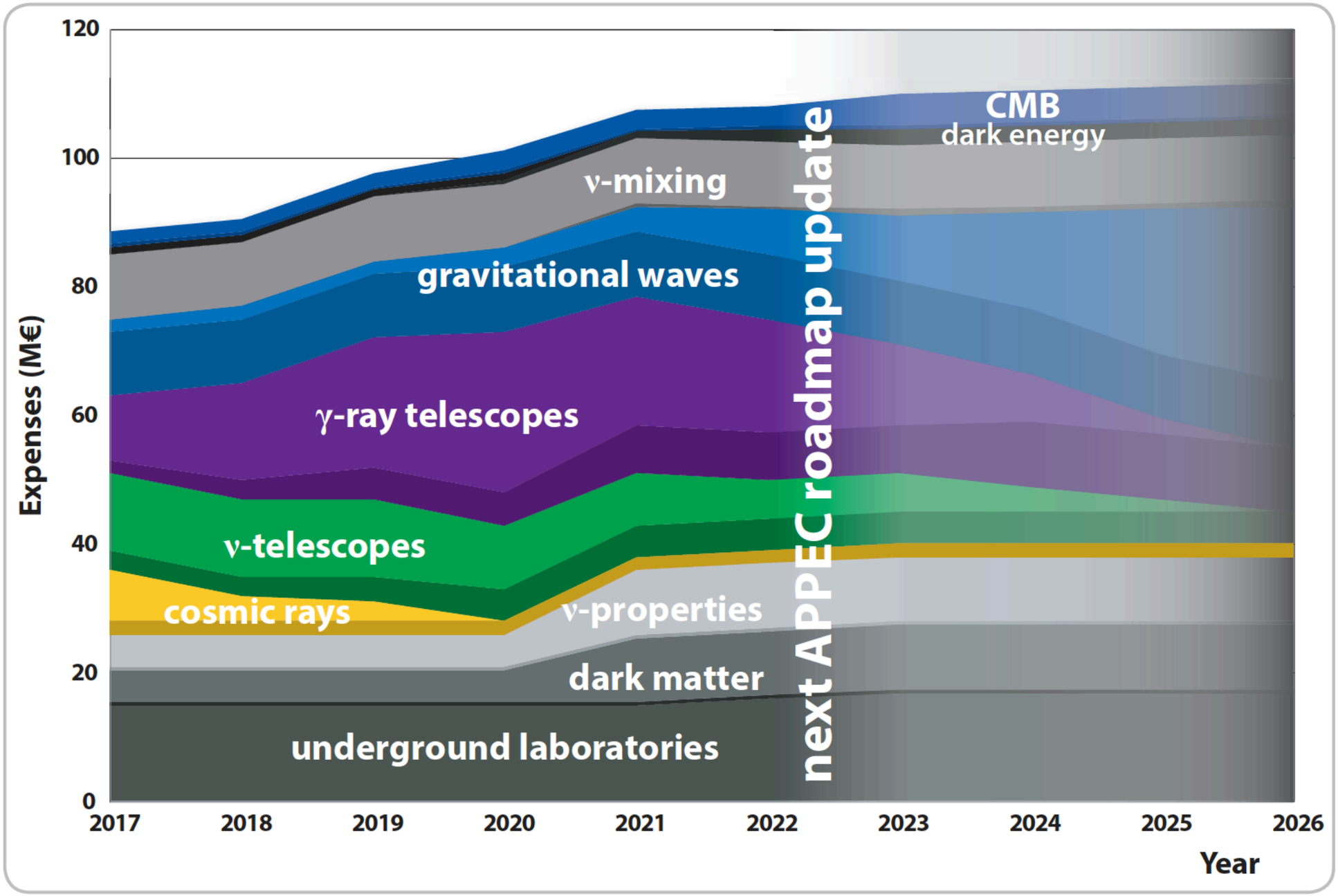
Red - radio
Green - OIR
Blue - X
Purple - gamma
Grey - GW nu

Survey - large FOV

eXTP Observatory Science - doi 10.1007/s11433-017-9186-1

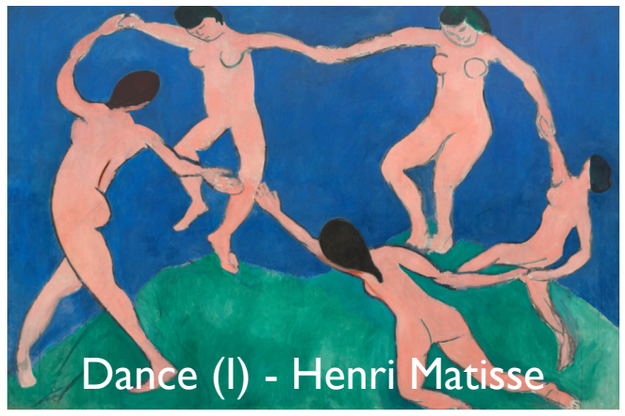
FERMI AND MULTIMESSENGER OBSERVATIONS

FUNDS



APPEC strategy book

CONCLUDING REMARKS


Dance (I) - Henri Matisse

- Observational multi-messenger astronomy starts in 2017
  - still only two concurrent observations of major events
- Progress comes from a new interdisciplinary community
  - data from many observatories must continue to flow
    - requires dedicated efforts and investments
  - complementary scientific backgrounds and cultures are key
    - to complete the broad picture from major events and non concurrent multi-messenger data