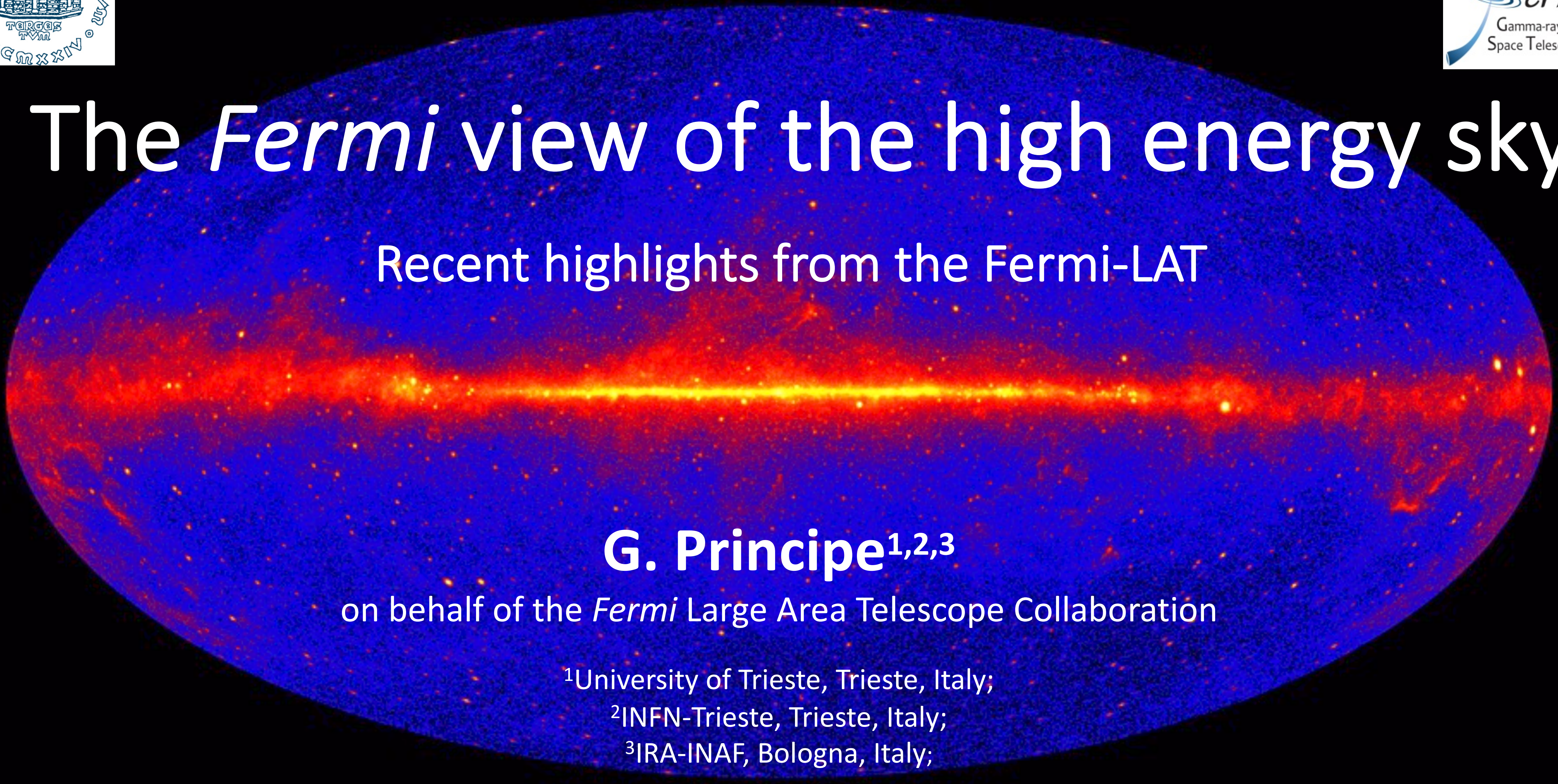


The *Fermi* view of the high energy sky

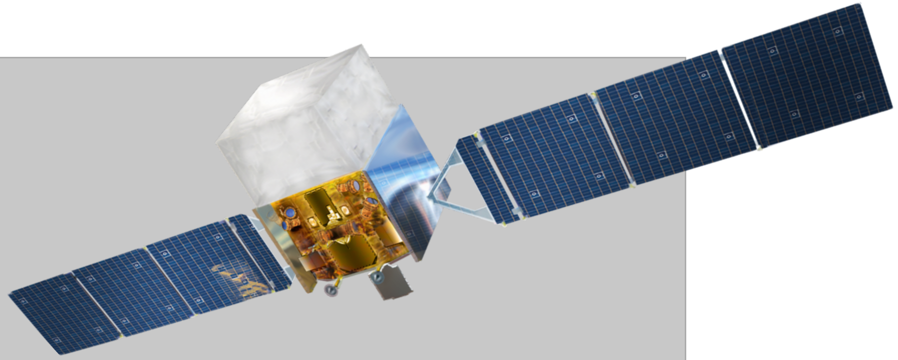
Recent highlights from the Fermi-LAT

G. Principe[1,2,3]

on behalf of the *Fermi* Large Area Telescope Collaboration

[1]University of Trieste, Trieste, Italy;
[2]INFN-Trieste, Trieste, Italy;
[3]IRA-INAF, Bologna, Italy;

Content



1. Introduction on *Fermi*-LAT

2. *Fermi*-LAT Sky and sources

3. Transient sources – from longer to shorter
   - blazar variability (and neutrino connection)
   - Solar flares
   - Magnetars
   - Gamma-Ray Bursts
   - Pulsar

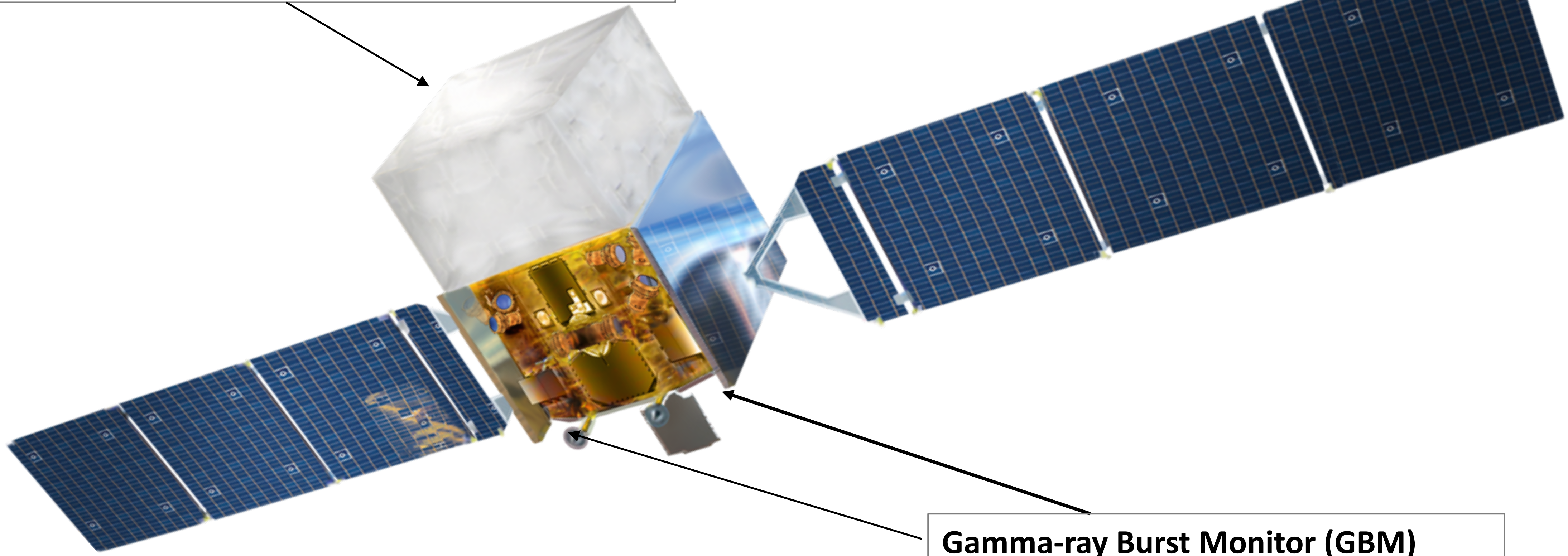
4. Towards higher energies (nFHL catalogs)

5. Outlook

Introduction on *Fermi*

Launched by NASA on 2008 June 11, from Cape Canaveral, Florida. Science mission started in August 2008.

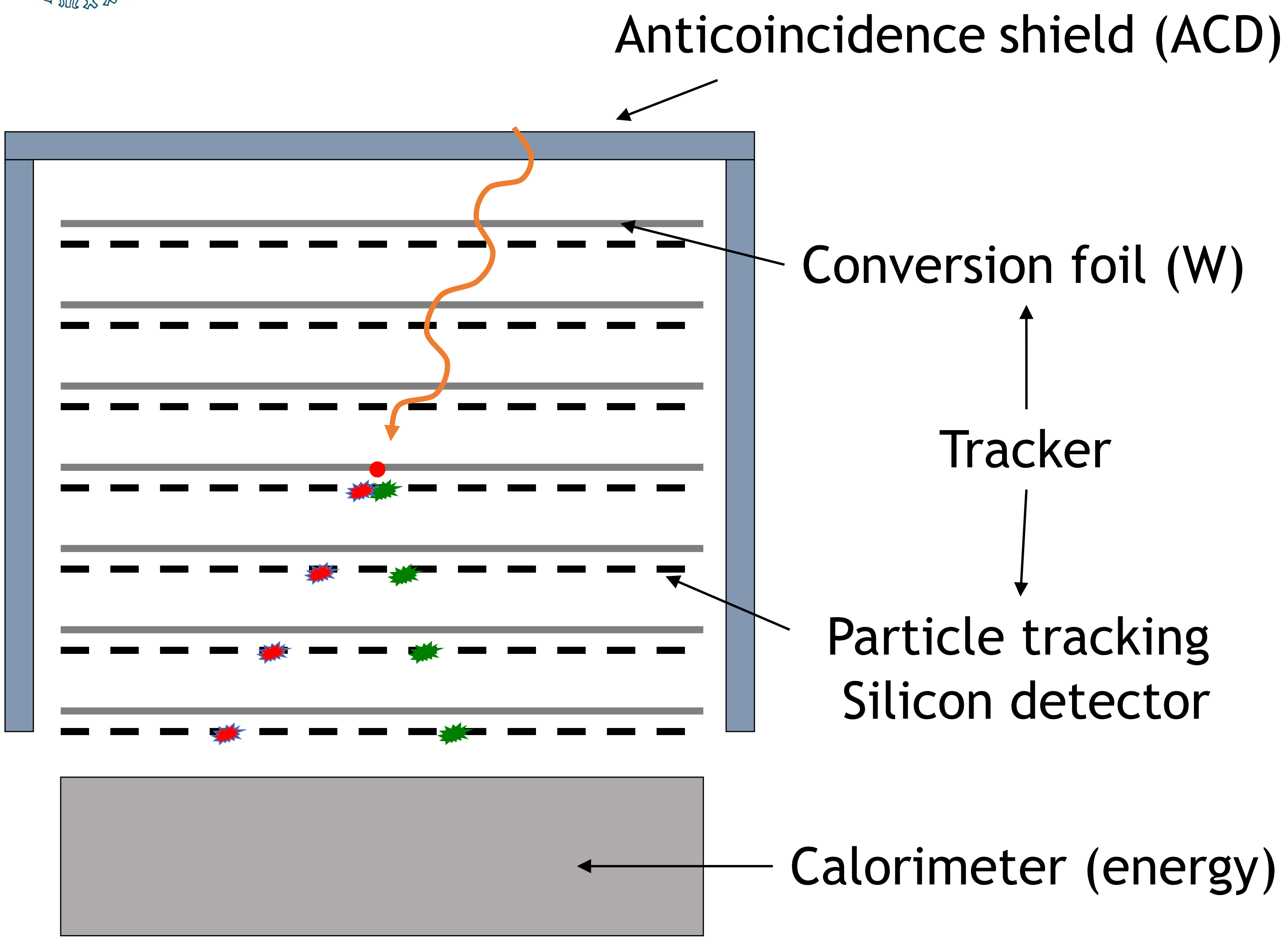
Large Area Telescope (LAT)
Observes more than 20% of the sky at any instant, views entire sky every 3 hrs 20 MeV - >300 GeV.



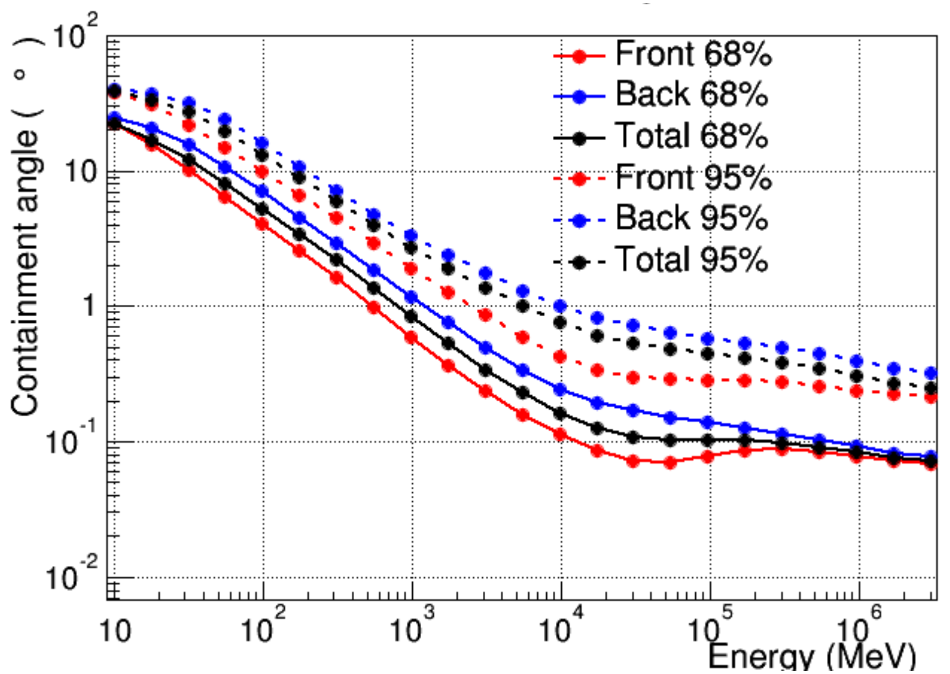
Gamma-ray Burst Monitor (GBM)
Observes entire unocculted sky.
Detects transients from 8 keV - 40 MeV

International collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

The *Fermi* Large Area Telescope



Energy range	20 MeV - over 300 GeV
Effective Area	~1 m^2 (E > 1 GeV)
Point spread function (PSF)	0.8° @ 1 GeV
Field of view	2.4 sr (~20% of the sky)
Orbital period	91 minutes
Altitude	565 km



Fermi-LAT performances

Fermi in DATA (up to July 18th 2022):

- 77500 orbits since launch
- >5000 days of science mission (2008 Aug. 4)
- **LAT has 98.7% uptime for Science mission**

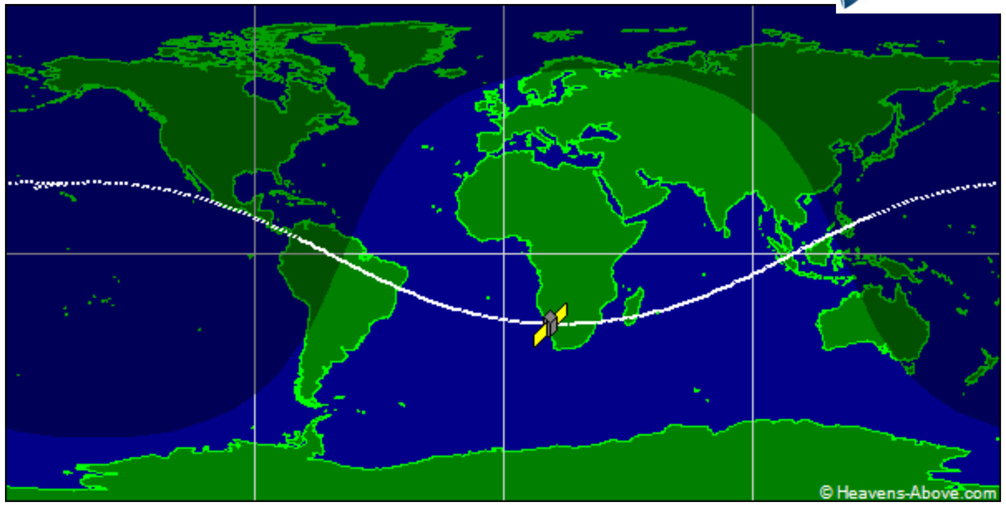
Event counts

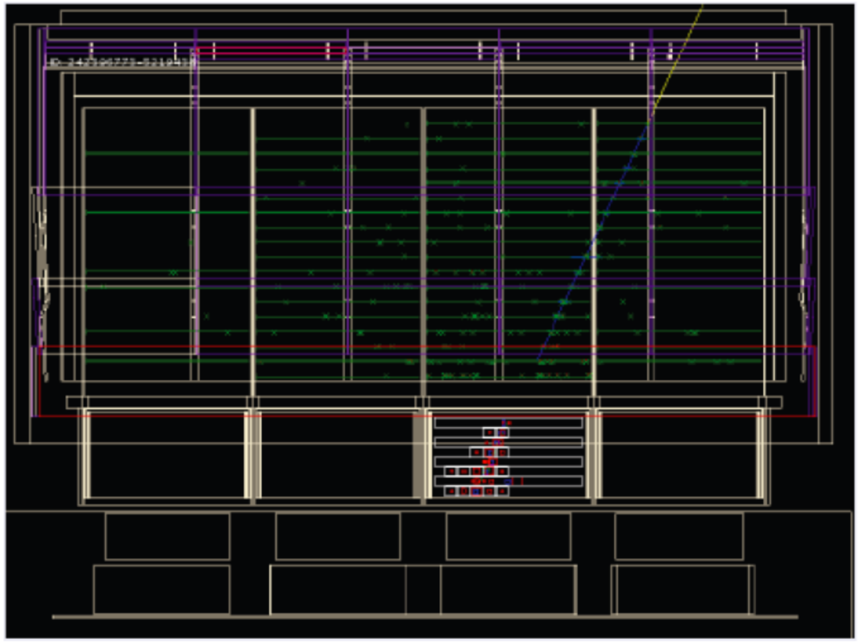
- 8 billion triggers on the LAT
- 170 billion events downlinked
- **1.5 billion LAT events publicly available at the FSSC!** (reached on Feb 28)
- 4 photons/second (including Earth limb)

Analysis:

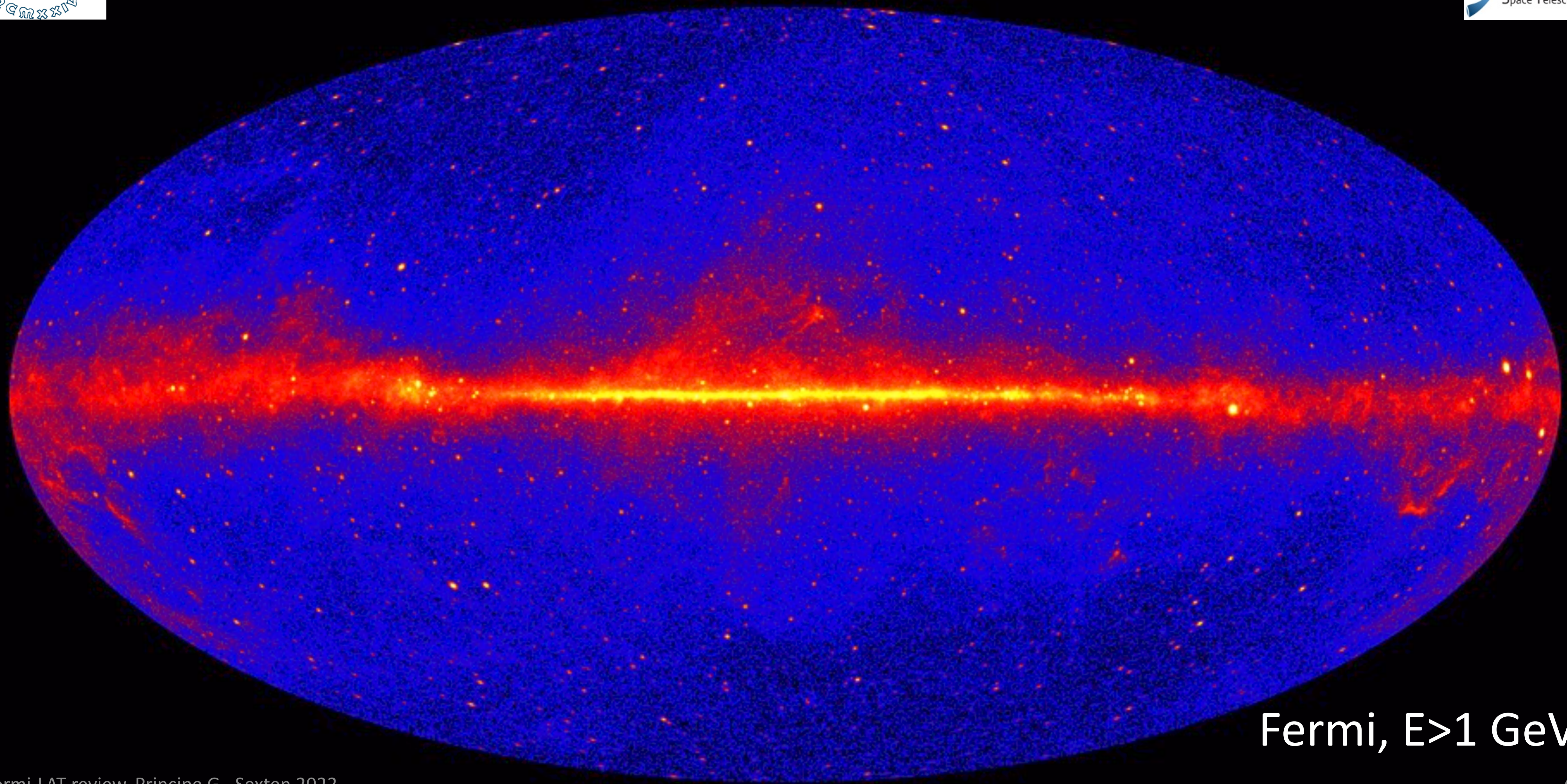
- *Analysis tools (Fermitools, Fermipy) publicly available!*

Fermi-LAT performance after 10 years of operation [Ajello et al., 2021]



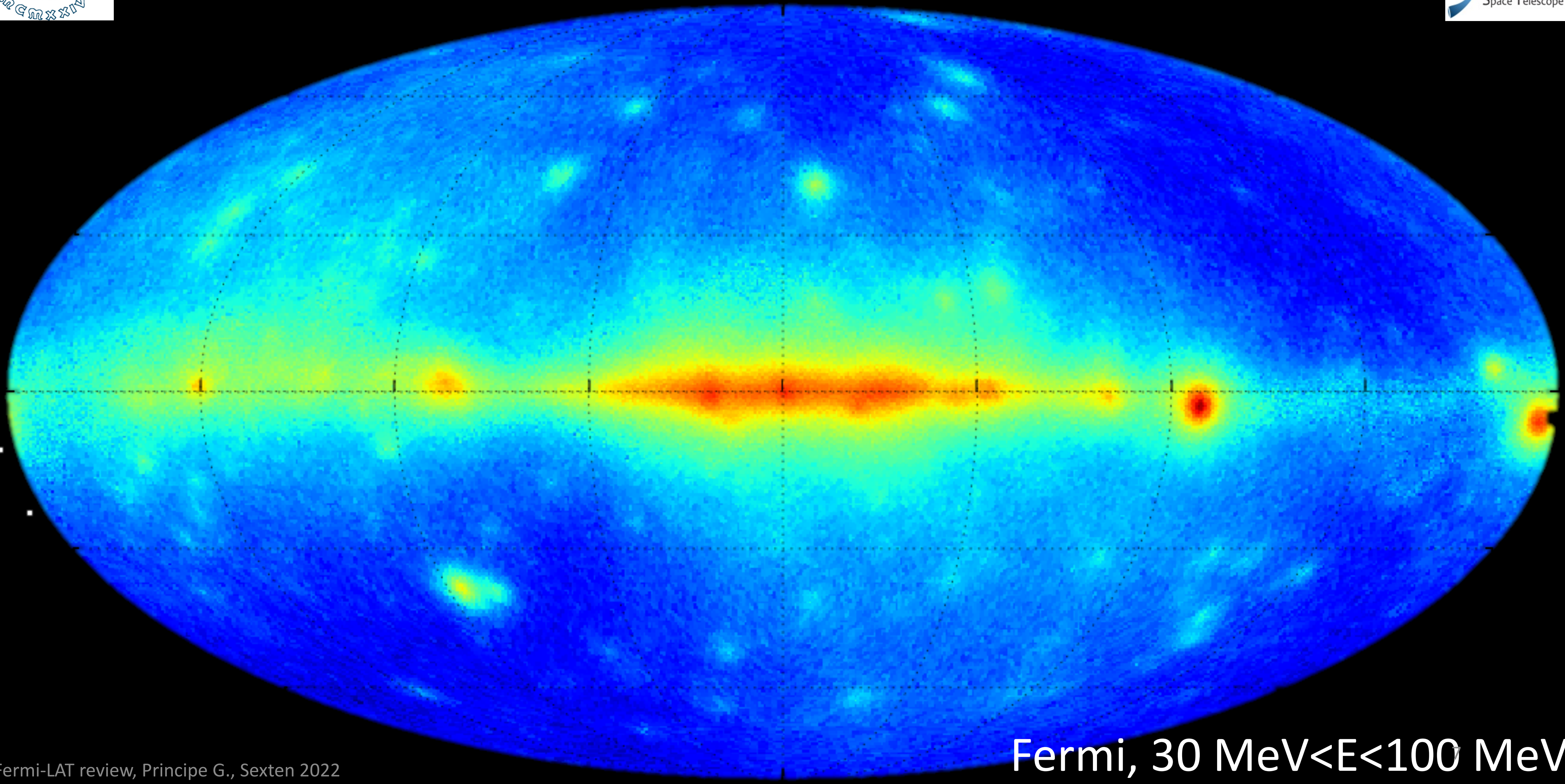


How is the sky seen by *Fermi*?



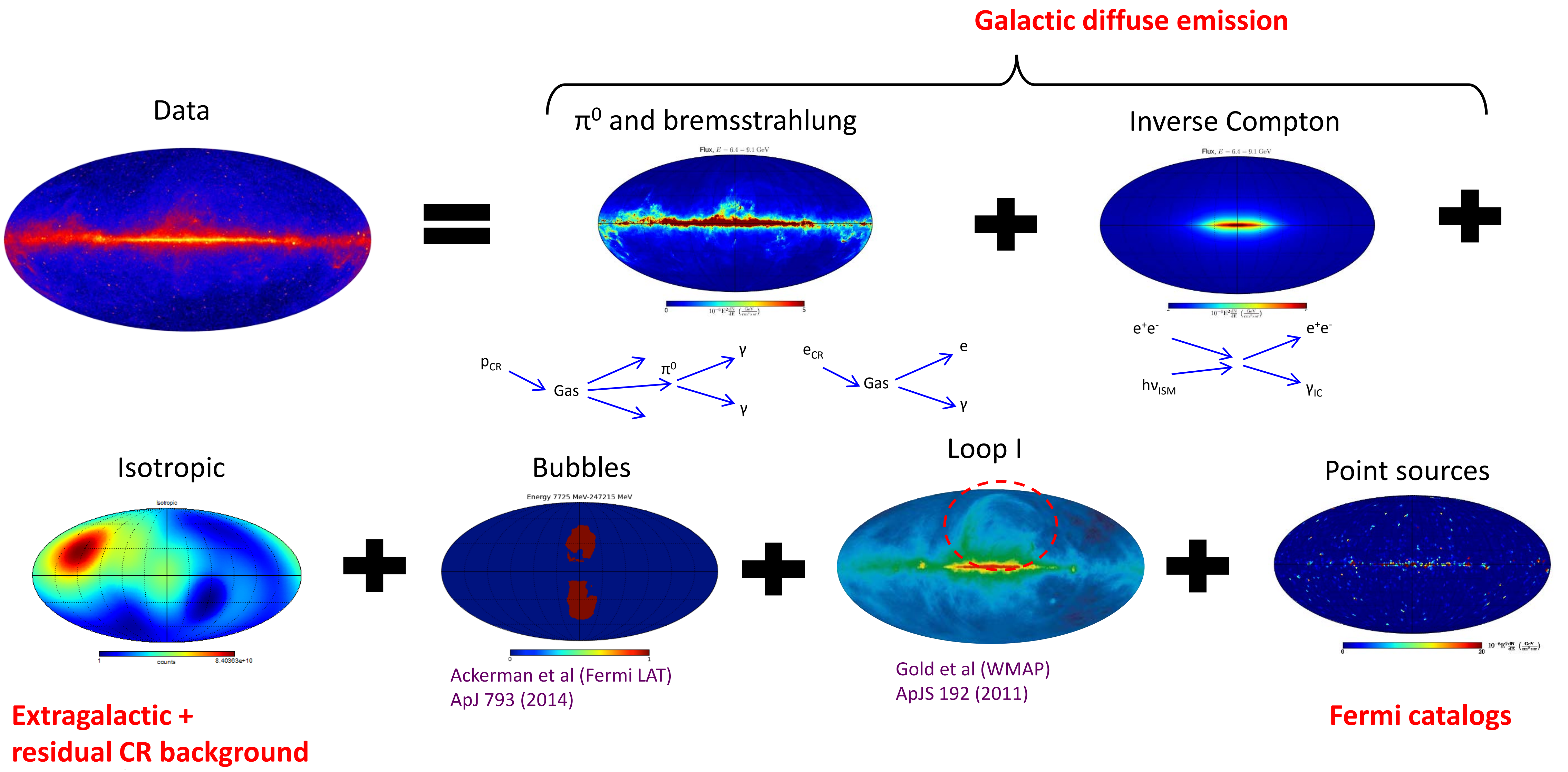
Fermi, E>1 GeV

How is the sky seen by *Fermi* at E<100 MeV?



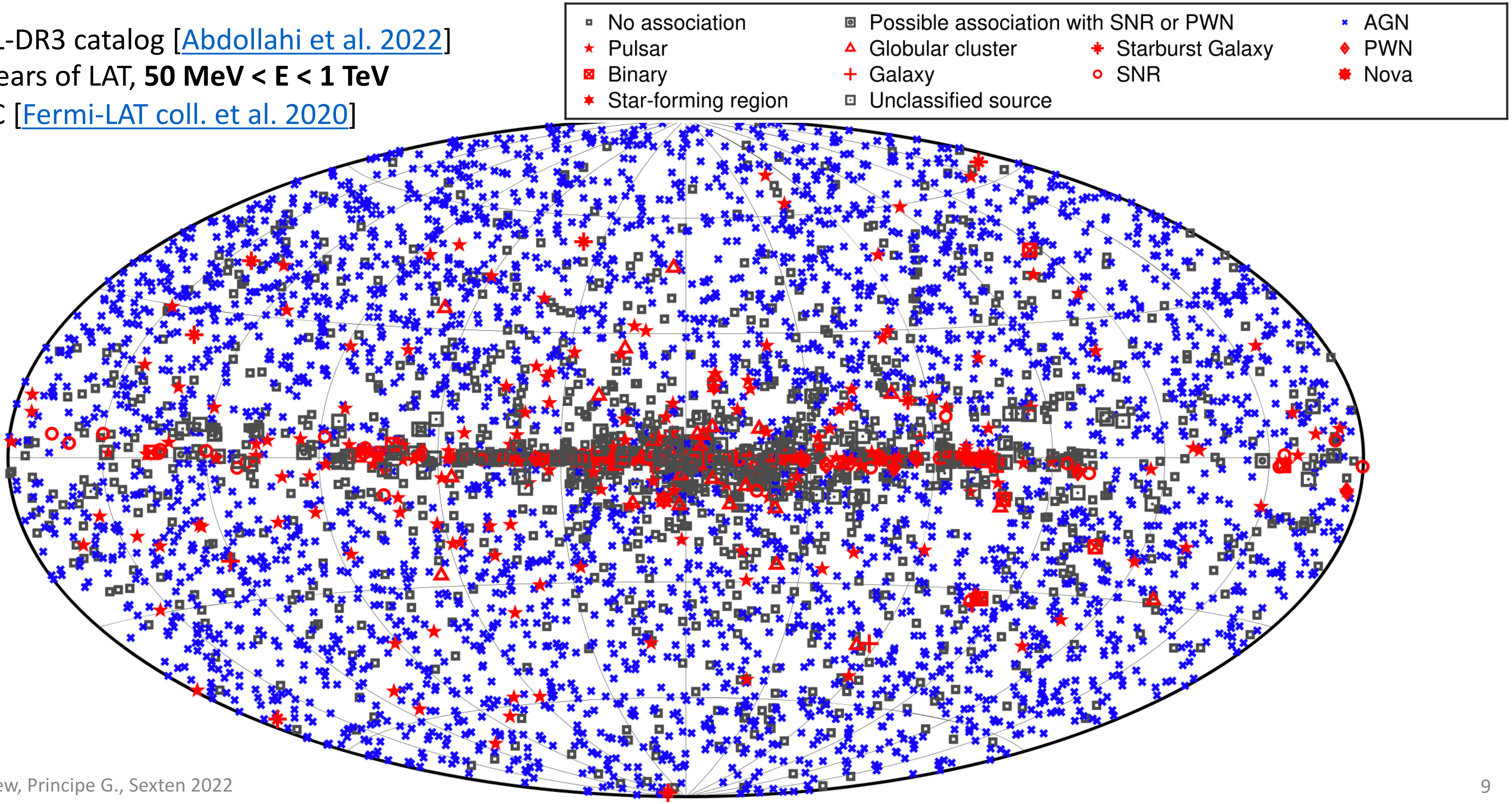
Fermi-LAT review, Principe G., Sexten 2022

The *Fermi*-LAT sky components



More than 6500 sources detected in first 12 years

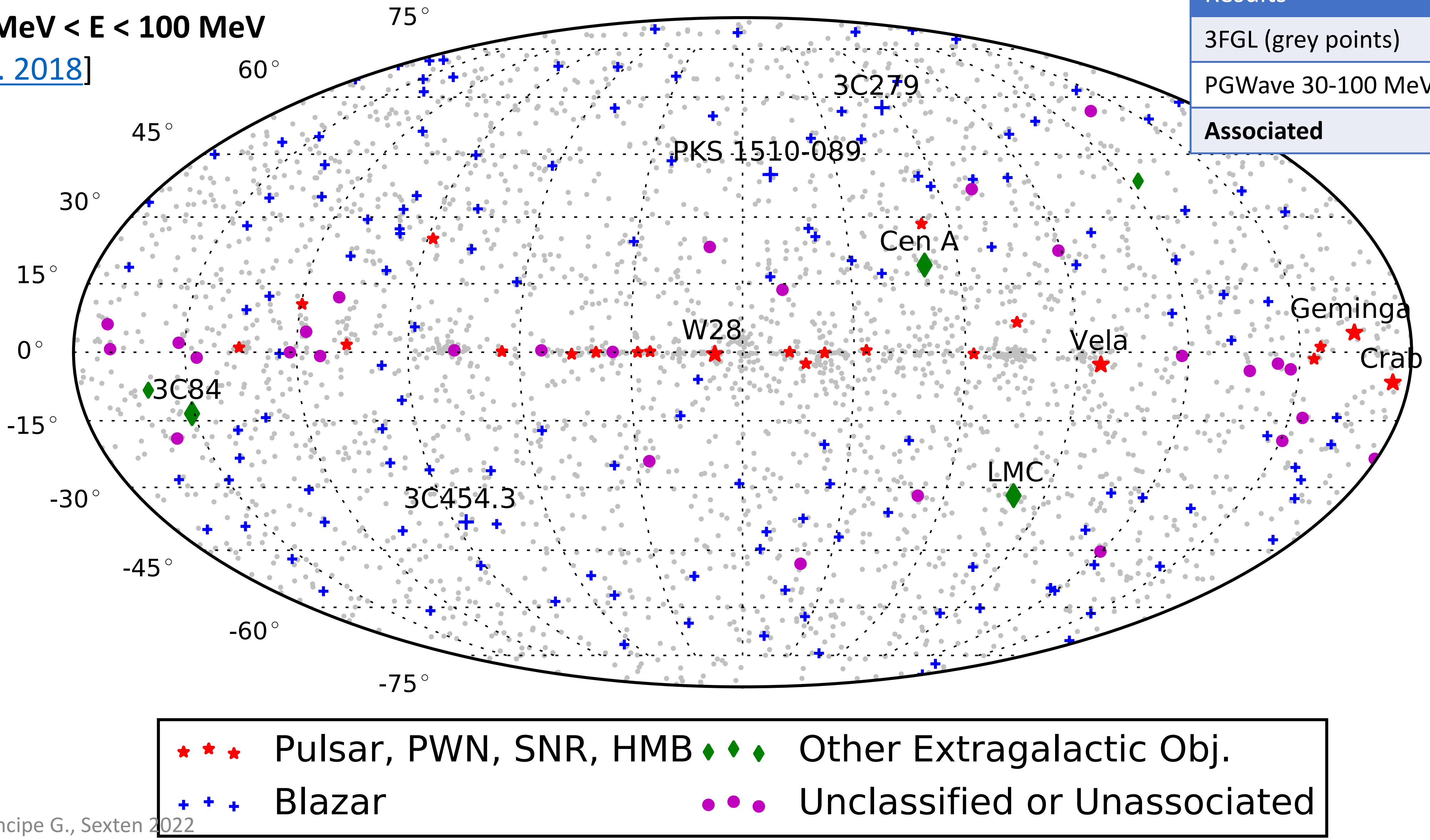
4FGL-DR3 catalog [Abdollahi et al. 2022]
12 years of LAT, **50 MeV < E < 1 TeV**
4LAC [Fermi-LAT coll. et al. 2020]



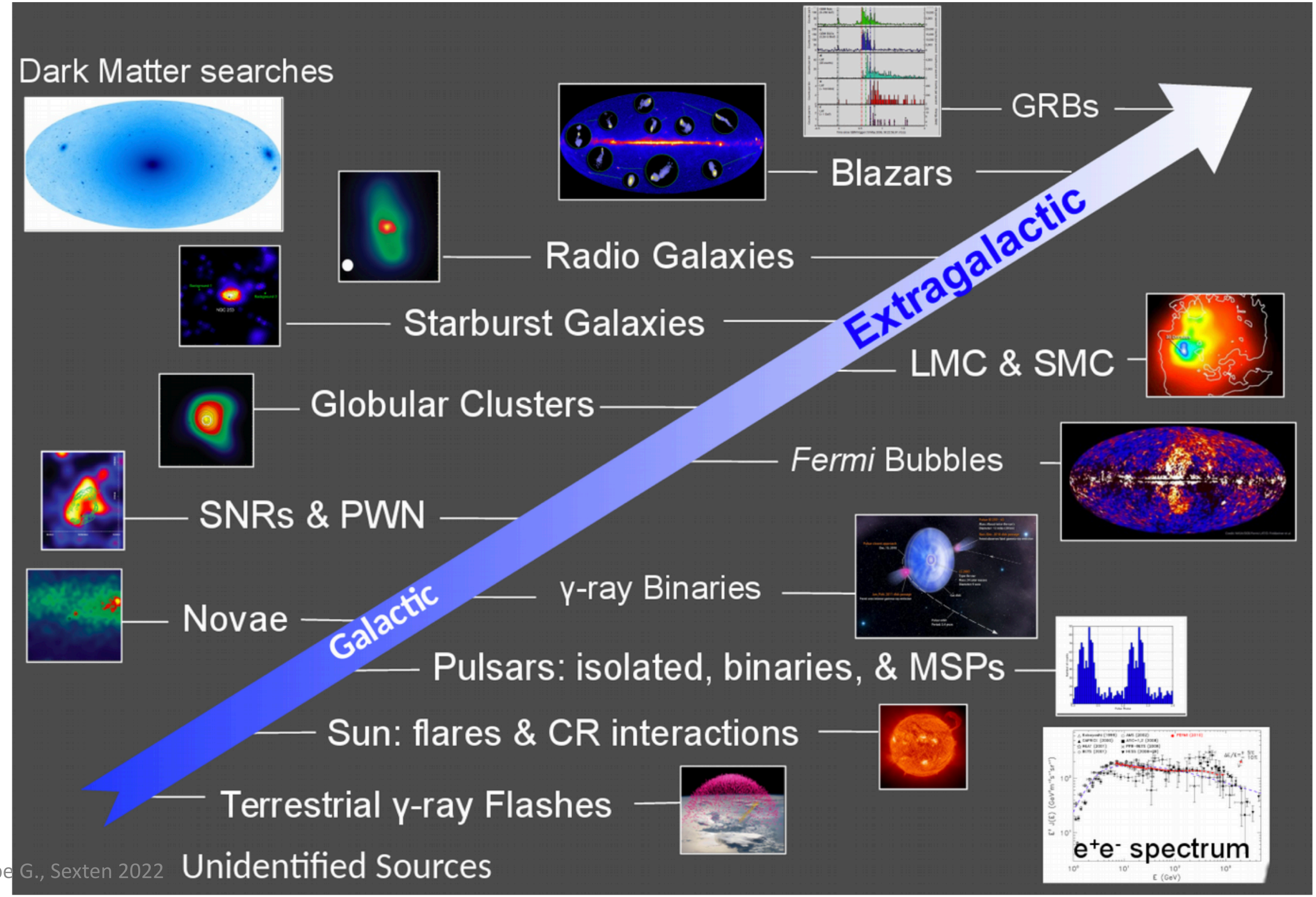
~200 sources found below 100 MeV

1FLE catalog,
8.7 years, **30 MeV < E < 100 MeV**
[Principe et al. 2018]

Results	Sources
3FGL (grey points)	3034
PGWave 30-100 MeV	198
Associated	**187**

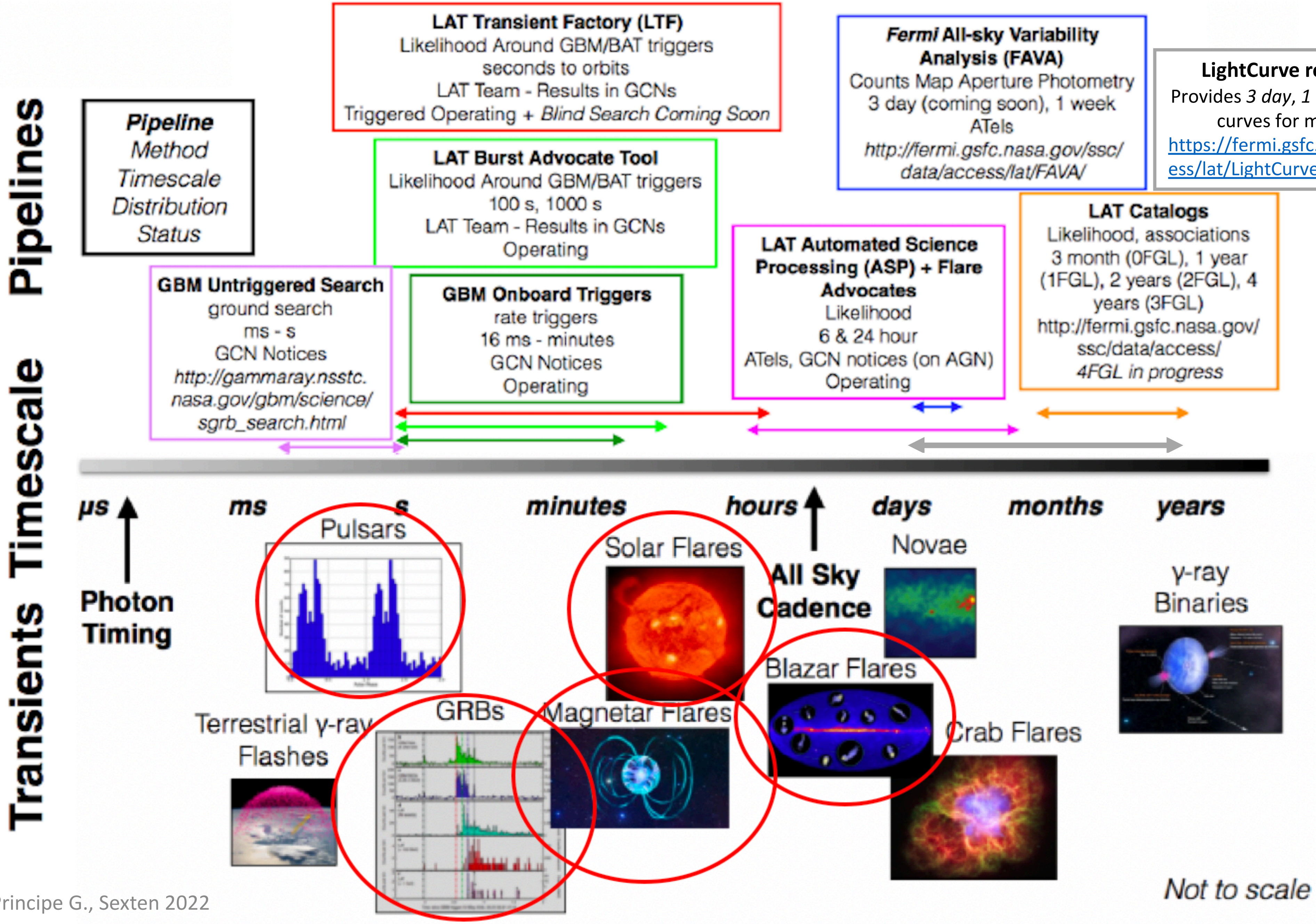


Fermi-LAT sources

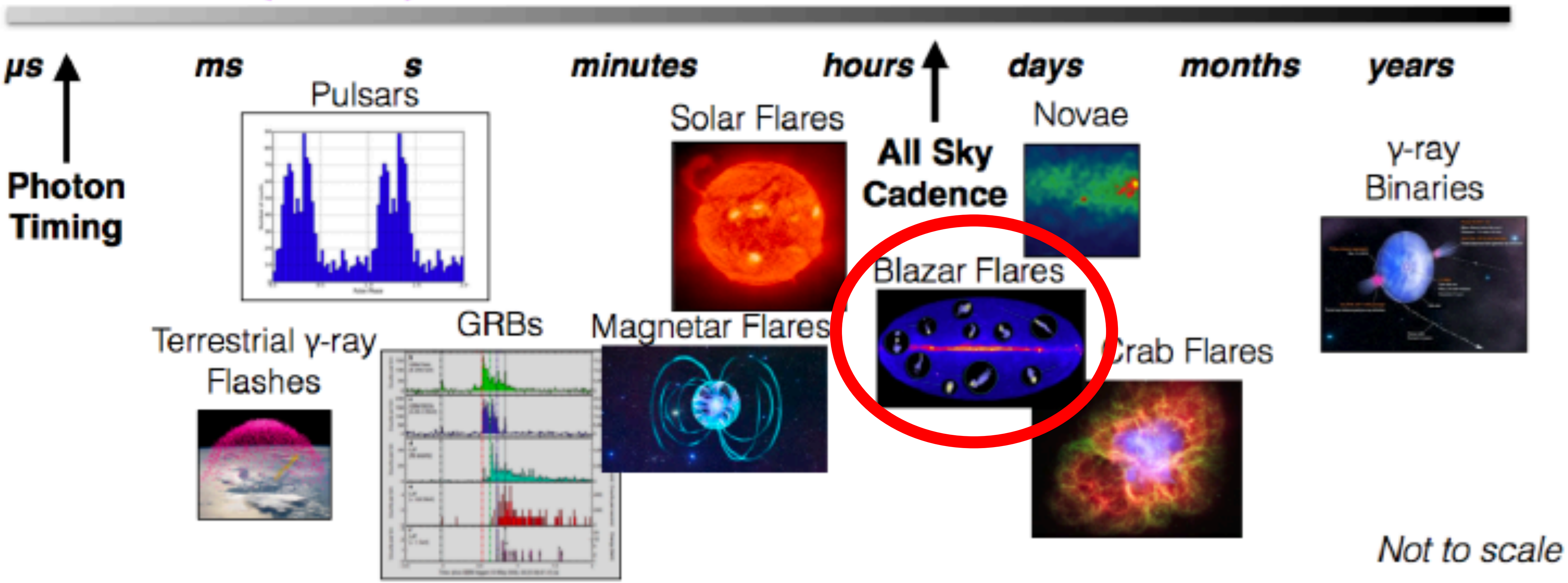


Fermi transient searches

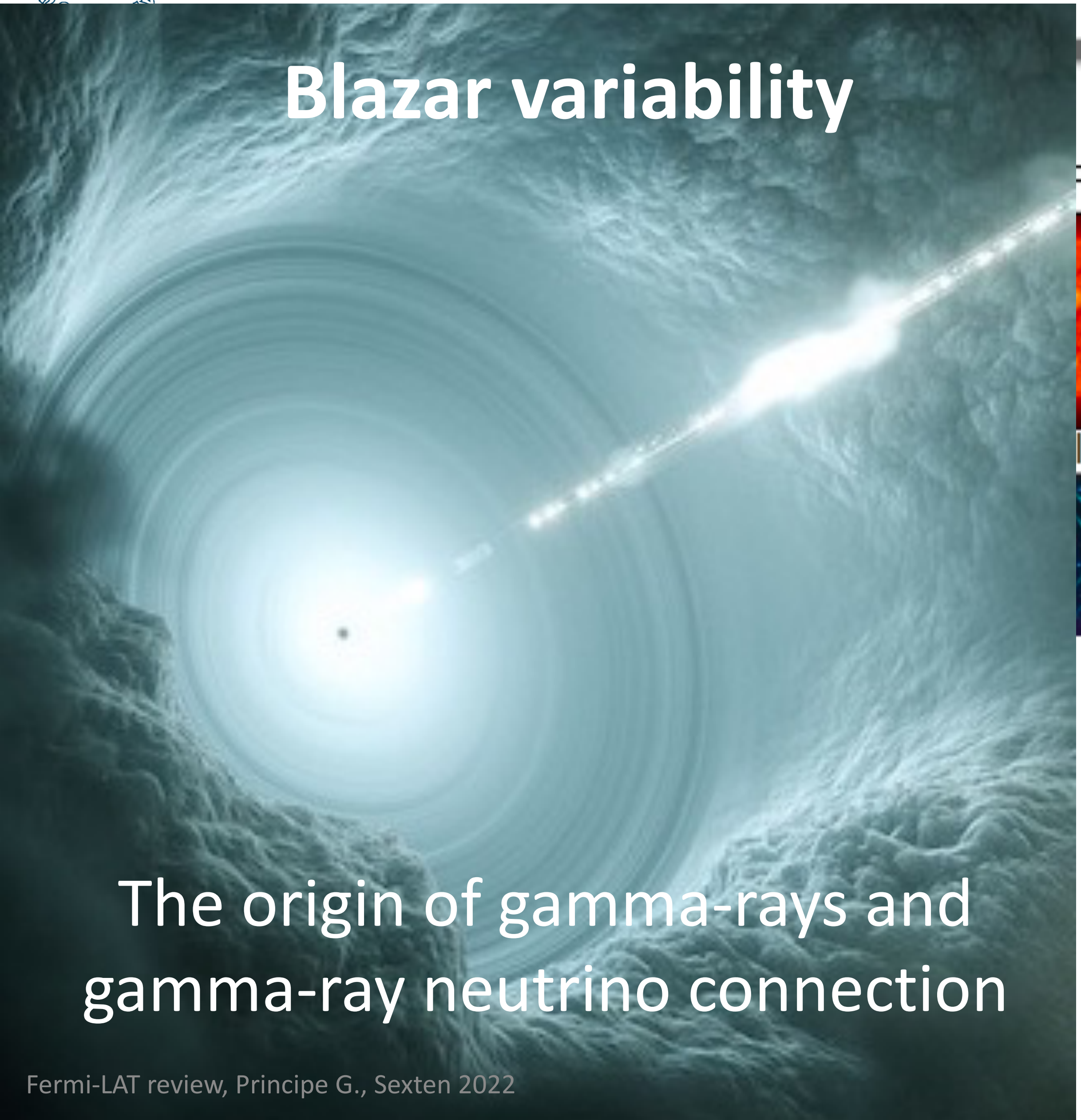
LightCurve repository (NEW!!)
Provides *3 day*, *1 week* and *1 month* light curves for many 4FGL sources
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/about.html



From longer to shorter

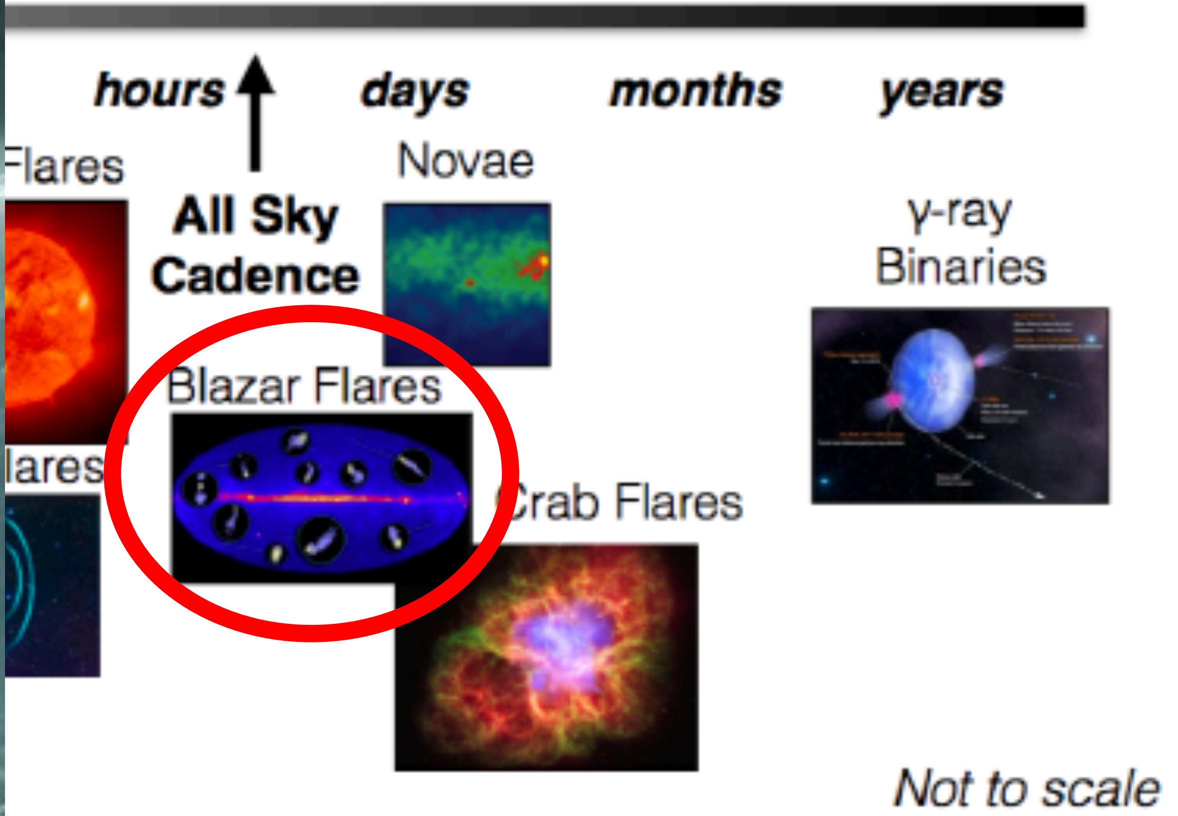


From longer to shorter



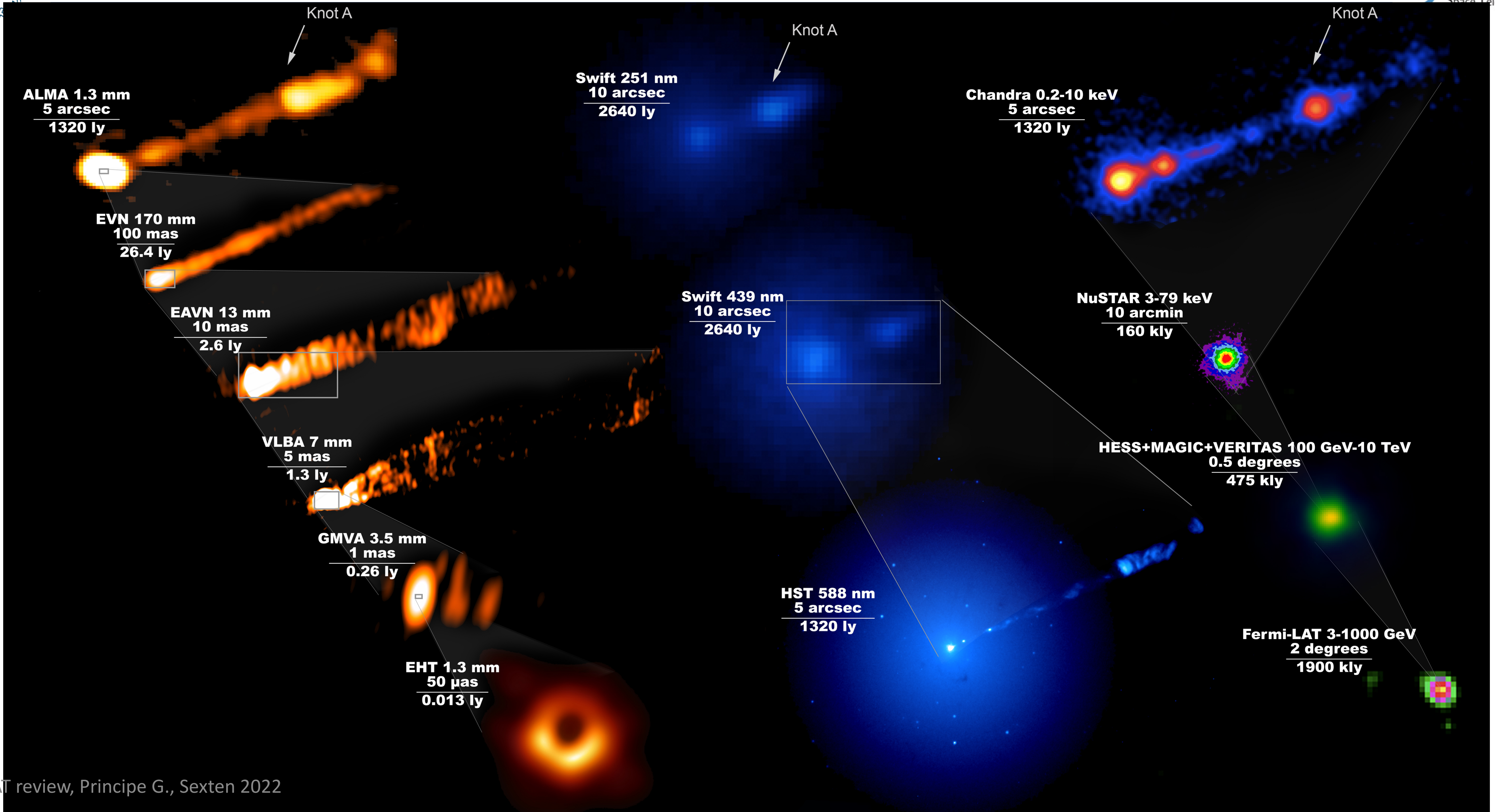
Blazar variability

The origin of gamma-rays and gamma-ray neutrino connection



14

EHT-MWL: unveiling the origin of the gamma-ray emission



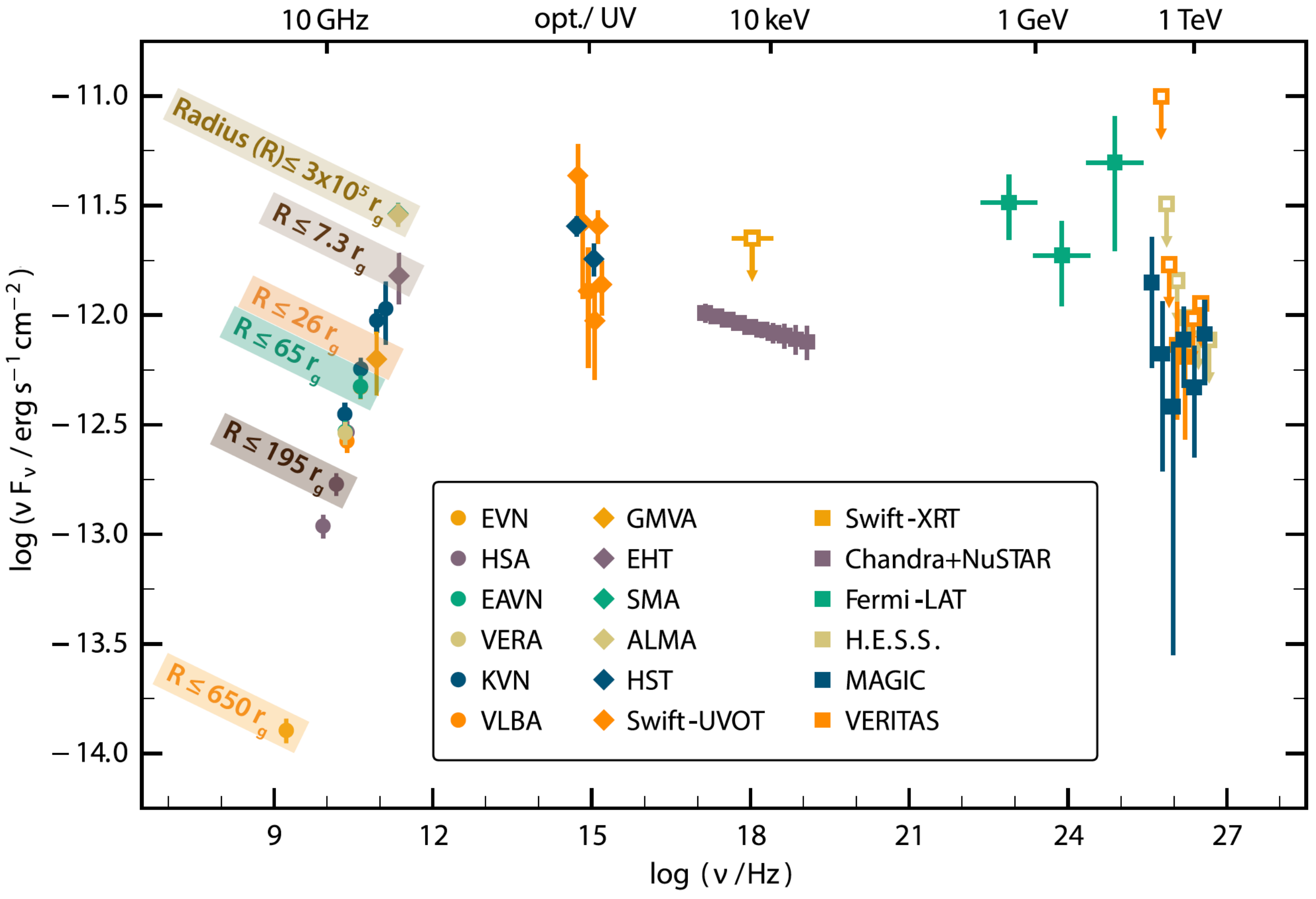
EHT-MWL: unveiling the origin of the gamma-ray emission

Most extensive, quasi simultaneous broadband spectrum of M87 yet taken covering more than 17 decades in frequency

Results:

- M87 core was in a relatively low state, but clearly still dominating over the nearest knot HST-1
- M87's complex, broadband spectral energy distribution cannot be modeled by a single zone
- **It is not yet clear where the VHE γ-rays originate, but we can robustly rule out that they coincide with the EHT region for leptonic processes**.

[EHT-MWL science working group et al. 2021]



- Hardening from optical to X-rays
- Fairly large Compton dominance
- Hard for simple SSC models!

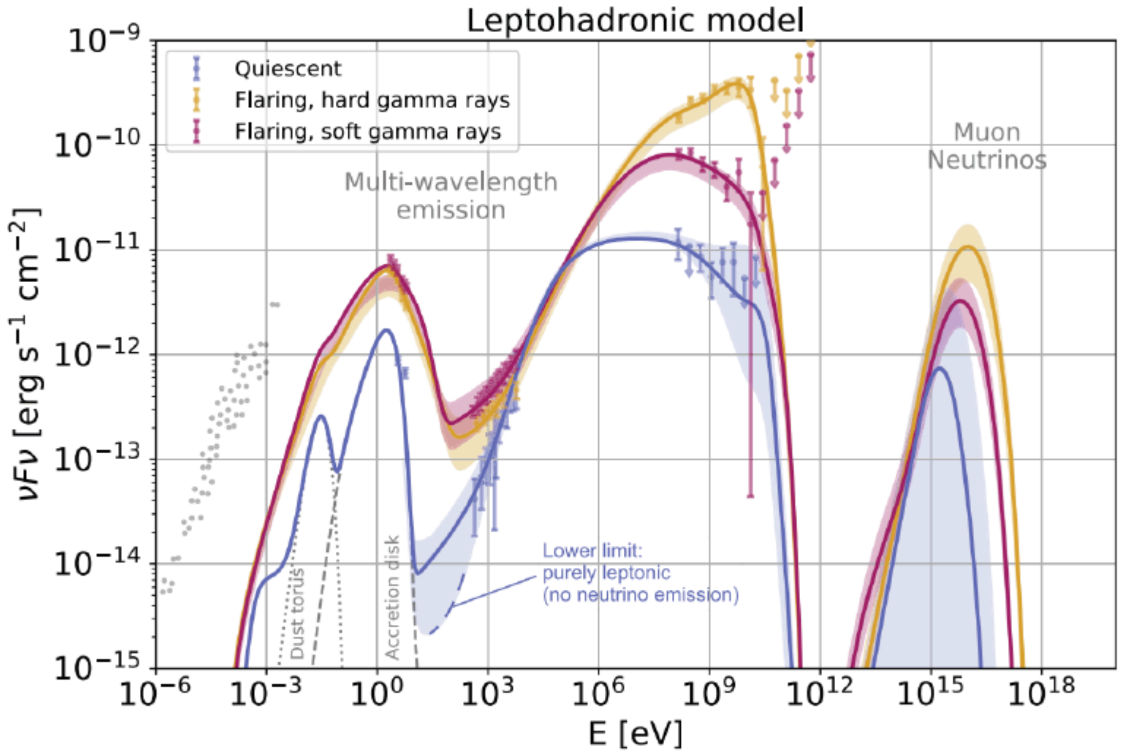
Neutrino – gamma ray connection

Association of neutrino with flaring blazar TXS0506+056 sparked interest to identify further counterparts.

So far, no other counterpart has been unambiguously identified.

One source of interest: PKS 1502+106; bright FSRQ located at redshift z = 1.84

[IceCube Coll. et al. 2018; Garrappa et al. 2019; Rodrigues et al. 2021]



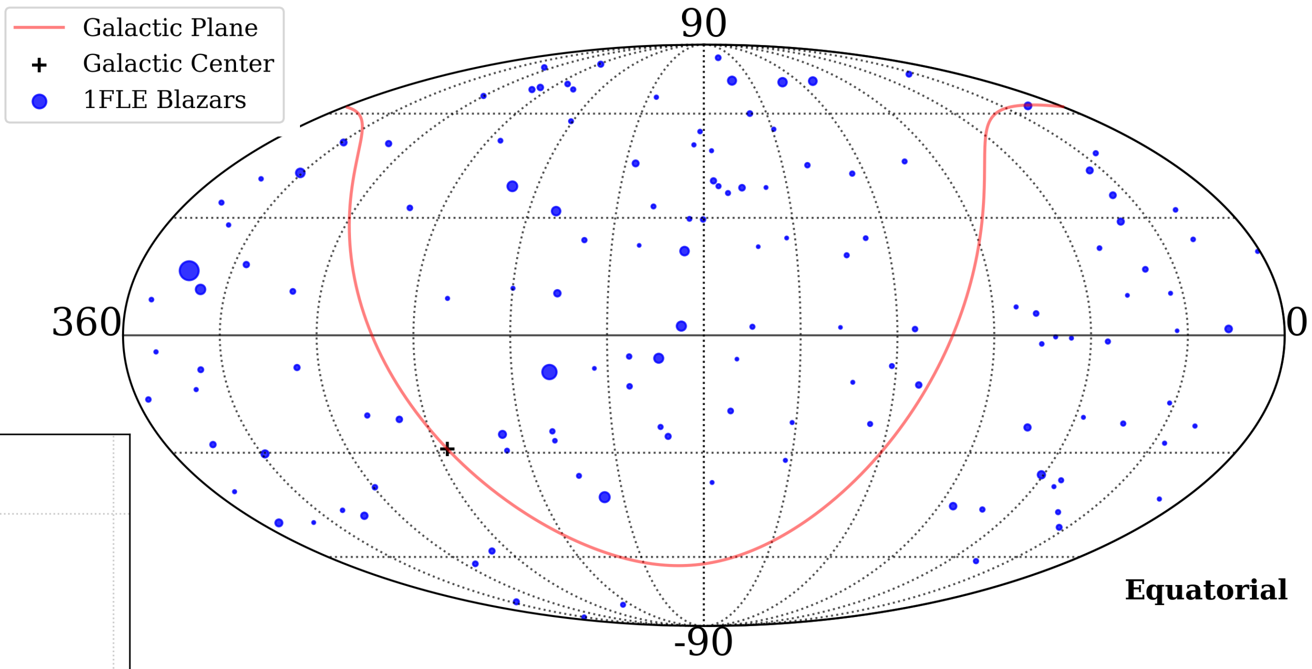
Neutrino Source Candidates

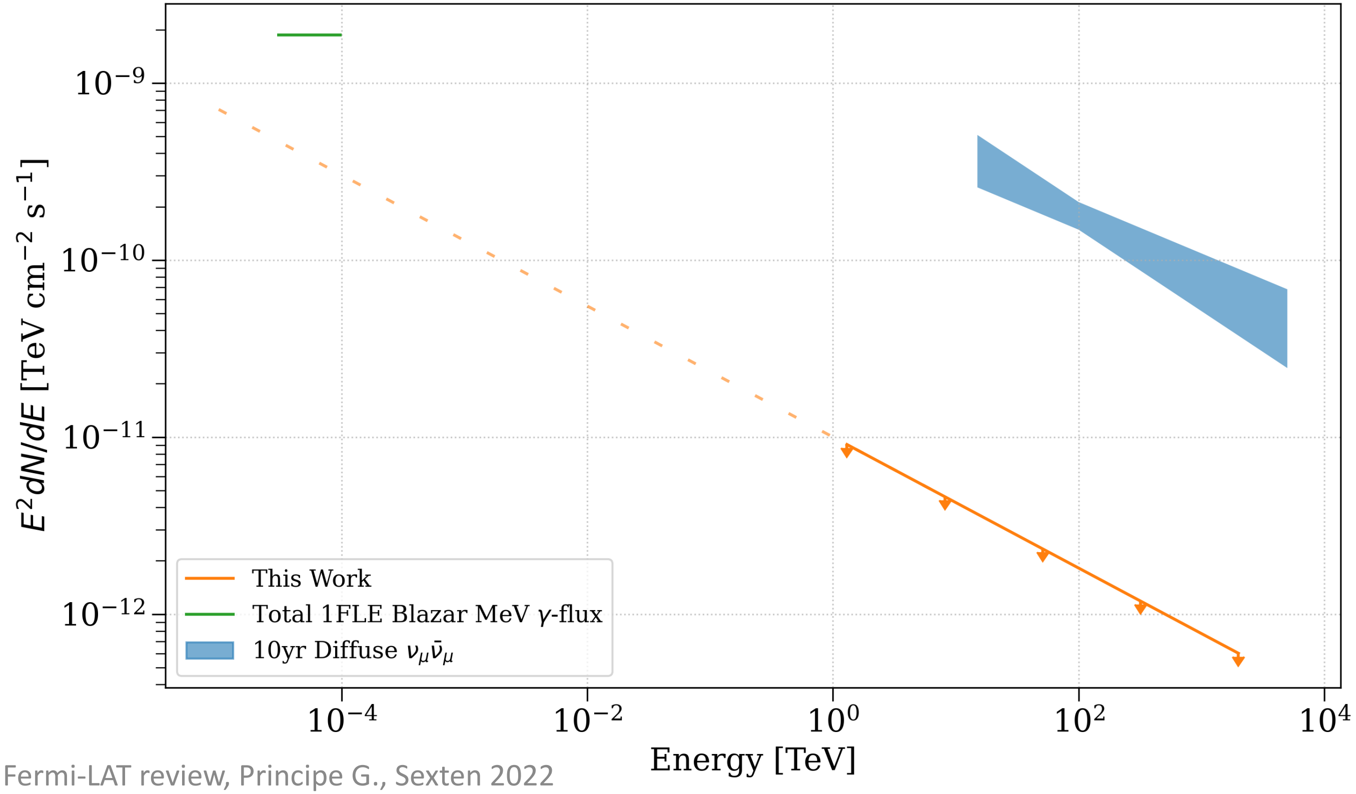
Source Name	4FGL Name	Class	Redshift	T_0 (MJD)	T_w (days)	p_γ	$T_{\gamma,\nu}$ (MJD)	L_γ (erg s^{-1})
Single High-energy Neutrinos								
MG3 J225517+2409	J2255.2+2411	BL Lac	1.37[a]	55,355.49	⋯	0.04	[55,346.73, 55,403.54]	1.3×10^{47}
GB6 J1040+0617	J1040.5+0617	BL Lac	0.73[b]	57,000.14311	⋯	0.17	[56,997.67, 57,055.08]	4.6×10^{46}
1RXS J125847.7–044746	J1258.7–0452	BL Lac	0.586[c]	57,291.90119	⋯	⋯	⋯	2.9×10^{45}
GB6 J0244+1320	J0244.7+1316	BCU[d]	⋯	57,695.38	⋯	⋯	⋯	⋯
TXS 0506+056	J0509.4+0542	BL Lac[e]	0.336[f]	58,018.87	⋯	0.009	[58,016.57, 58,019.94]	2.2×10^{46}
AT20G J175841–161703	J1758.7–1621	BCU	⋯	58,535.35	⋯	0.39	[58,304.43, 58,633.01]	⋯
PKS 1502+106	J1504.4+1029	FSRQ	1.839	58,694.8685	⋯	0.75	[58,603.54, 58,695.14]	4.7×10^{48}

Garrappa et al. 2019

Search for neutrino from the 1FLE blazars with IceCube

1FLE catalog (8.7 years)
30 MeV < E < 100 MeV
134 blazars
[Principe et al. 2018]





UL from the stacking analysis are 1.0% of the diffuse flux measurement [IceCube Coll. et al., 2022]

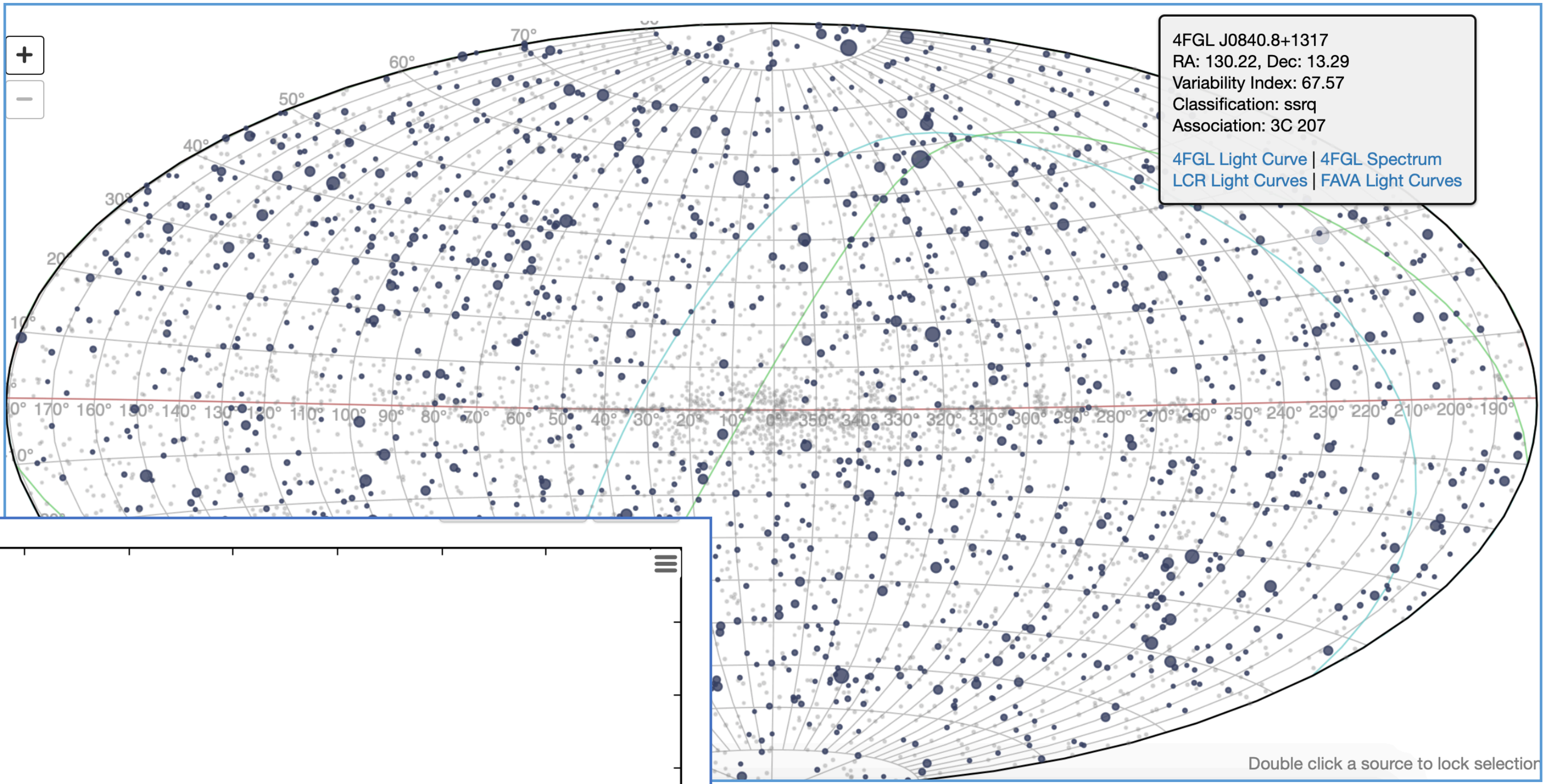
Fermi light curve repository online!!

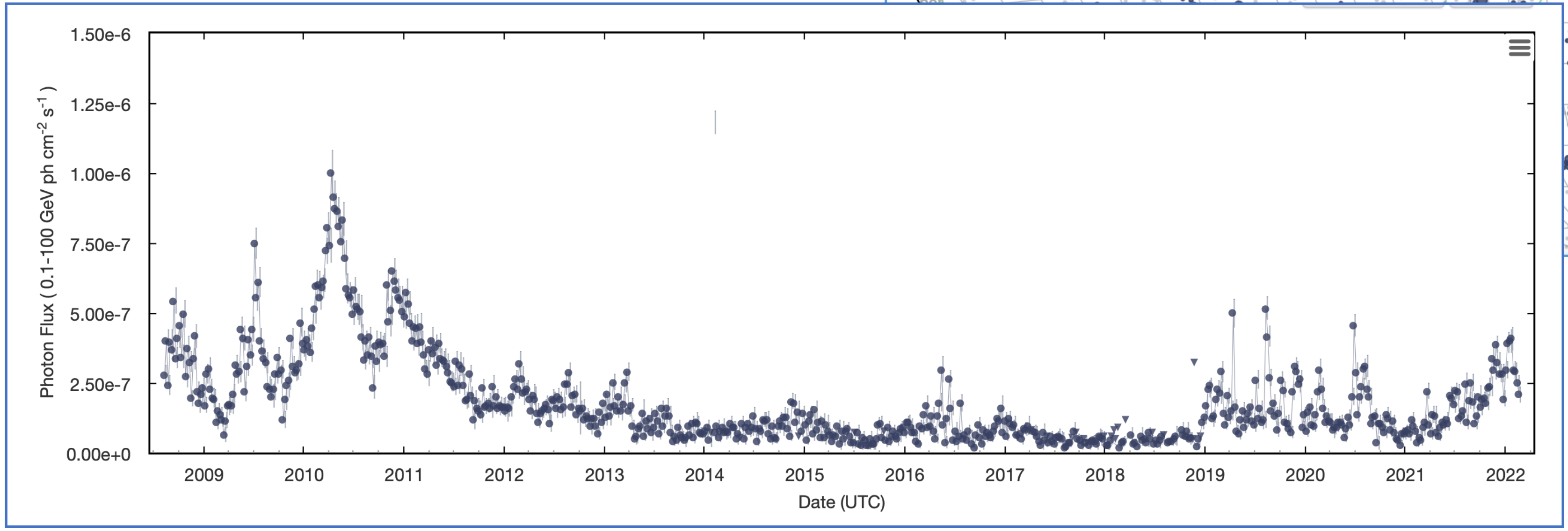
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/about.html

- Provides *3 day*, *1 week* and *1 month* light curves for many 4FGL sources

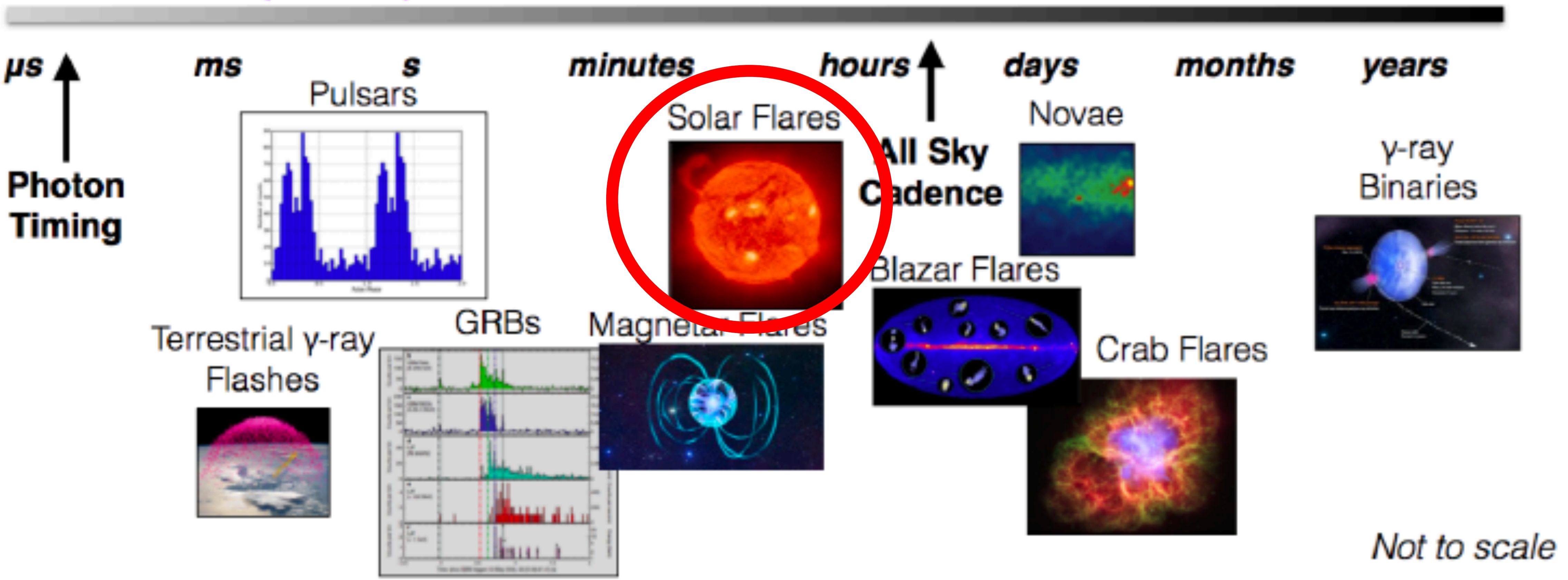
- Light curves derived from full likelihood fit

- Facilitates, e.g., search for gamma-ray flare counterparts of neutrino events

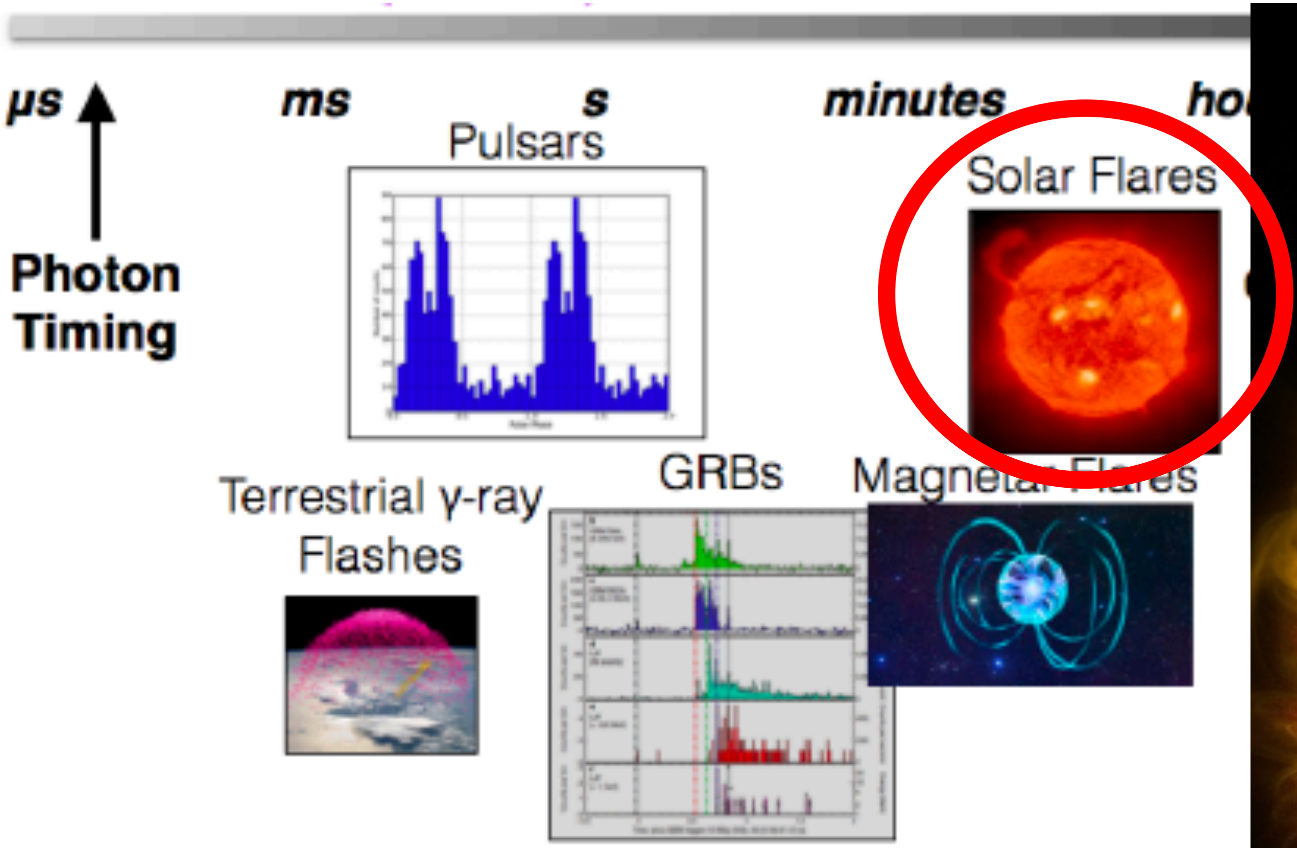


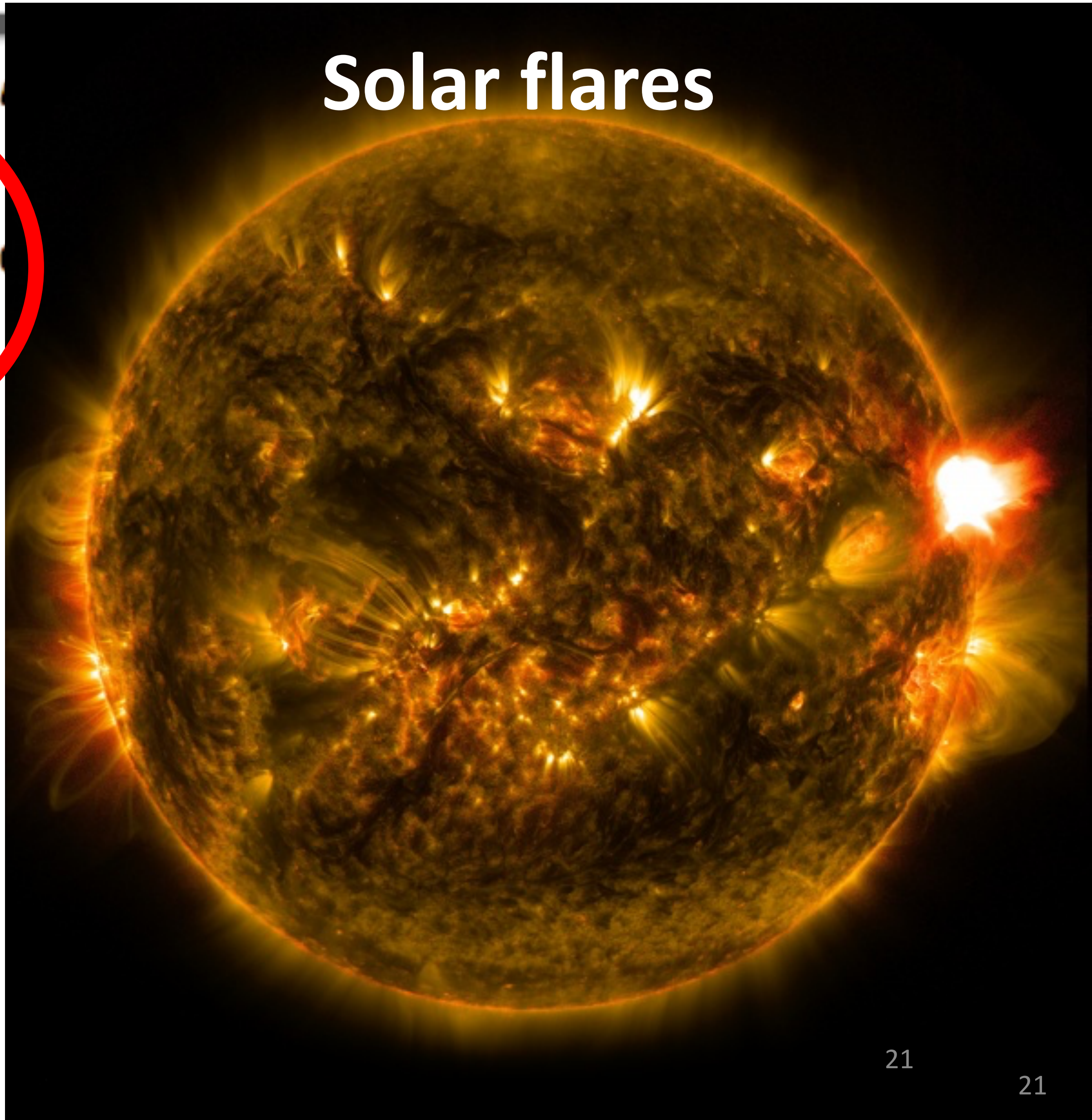


From longer to shorter



From longer to shorter



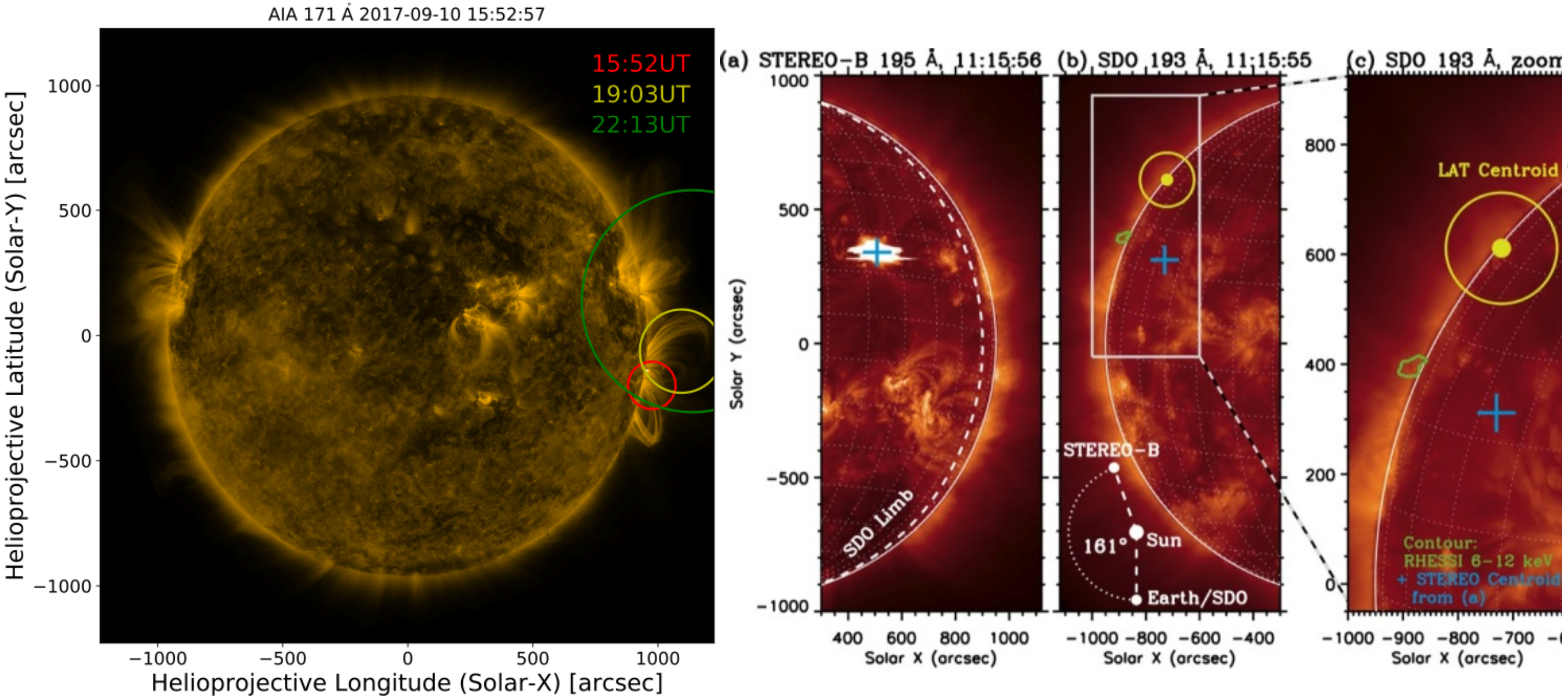


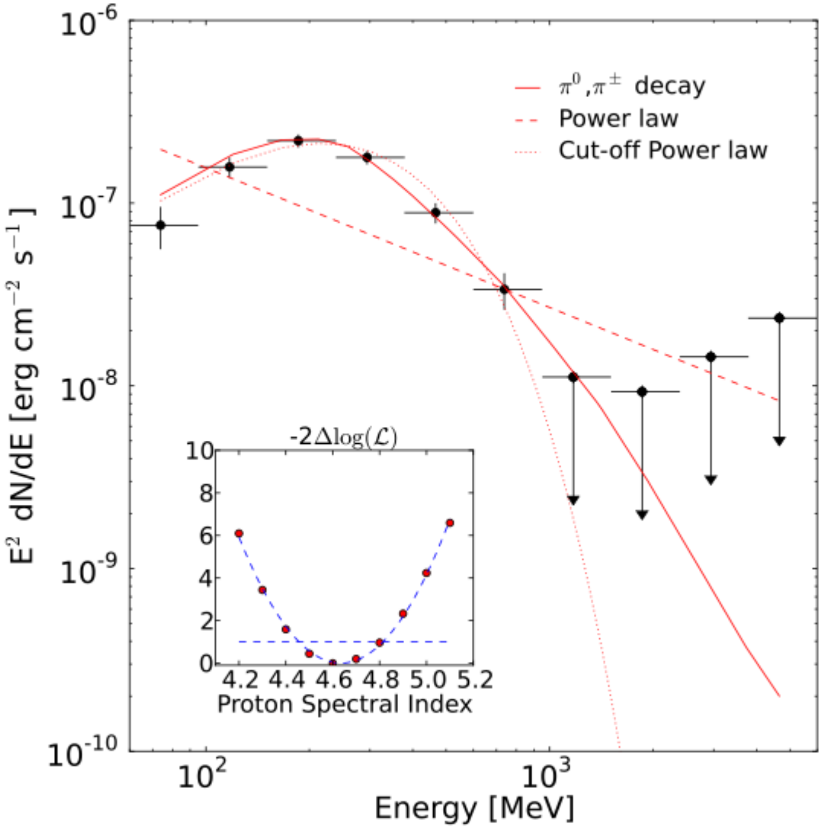
First solar flare catalog

45 *Fermi*-LAT solar flares (FLSFs), <u>3 from *behind the limb* </u>[[Ajello et al. 2021](#)]

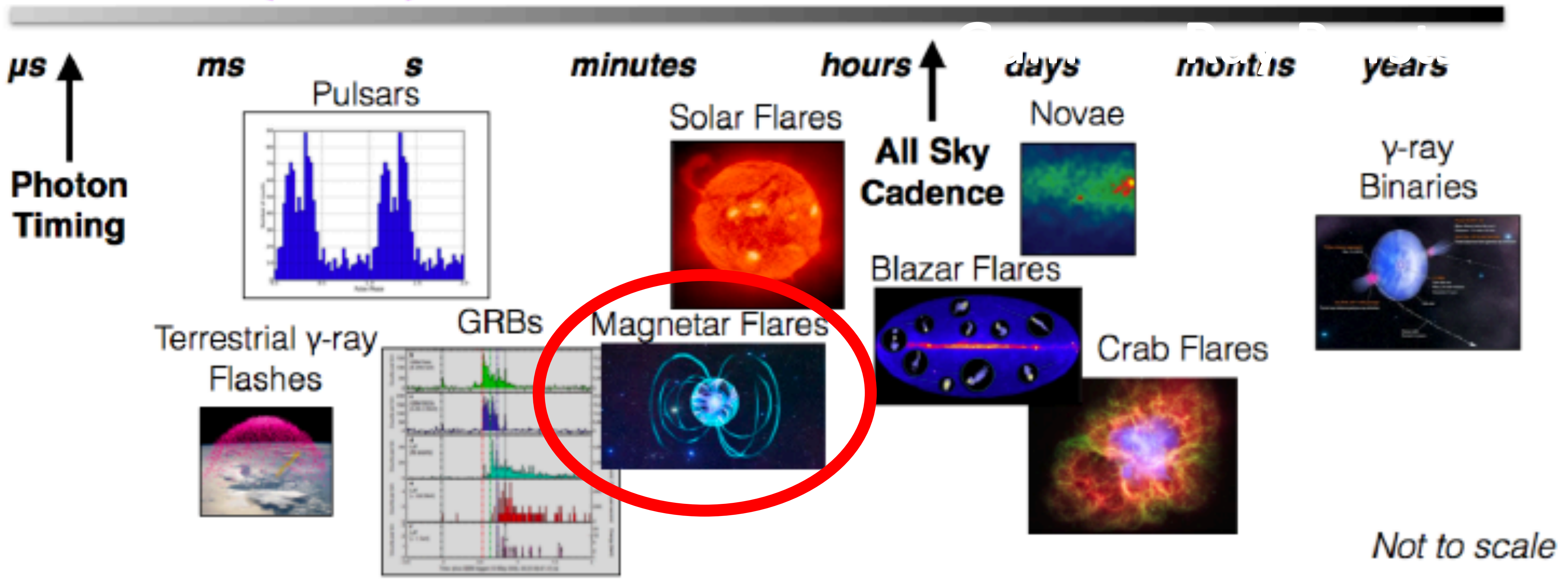
Obs. 30 MeV - 10 GeV over the years 2010-2018 (Solar cycle 24)

The impulsive solar flares are dominated by electron emission, a fair fraction have accelerated protons and ions ->Gamma-ray emission due to pion decay.

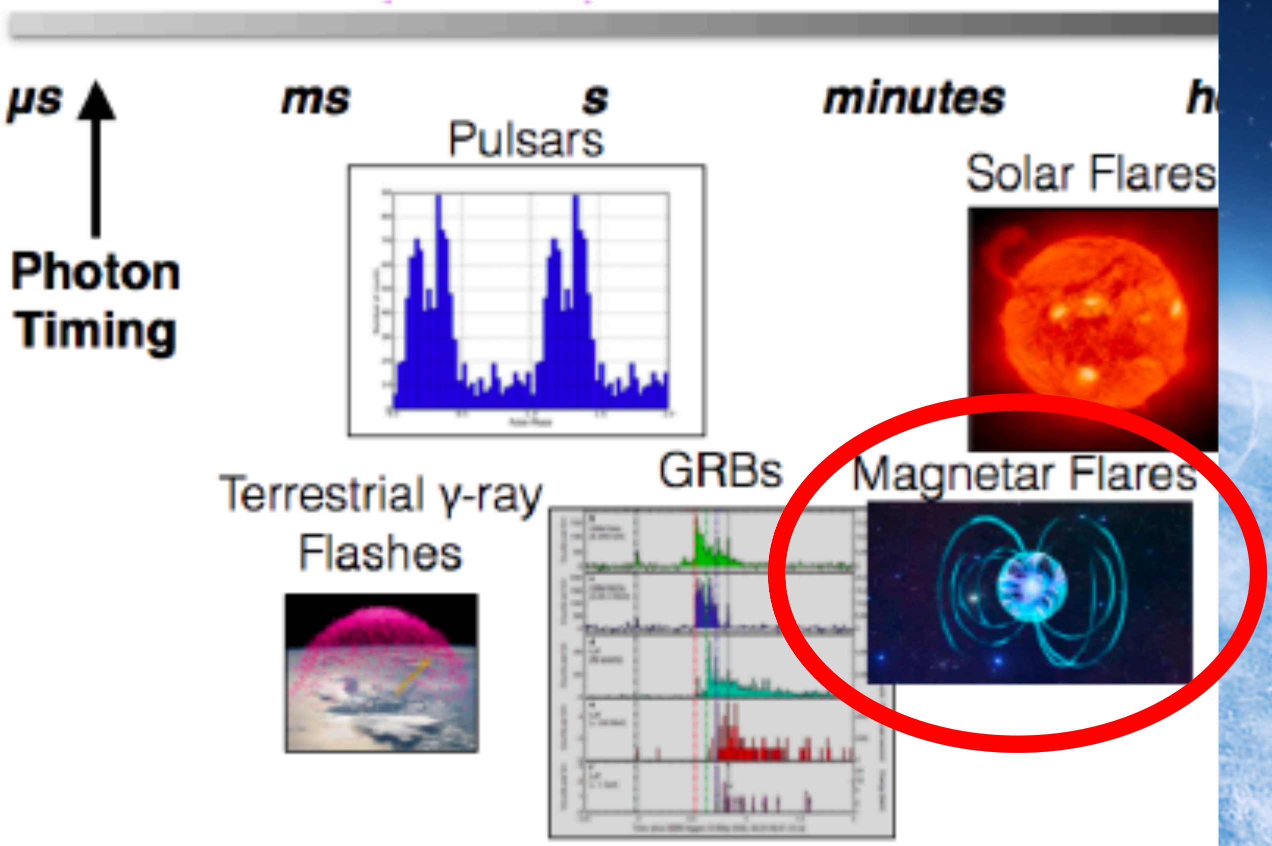


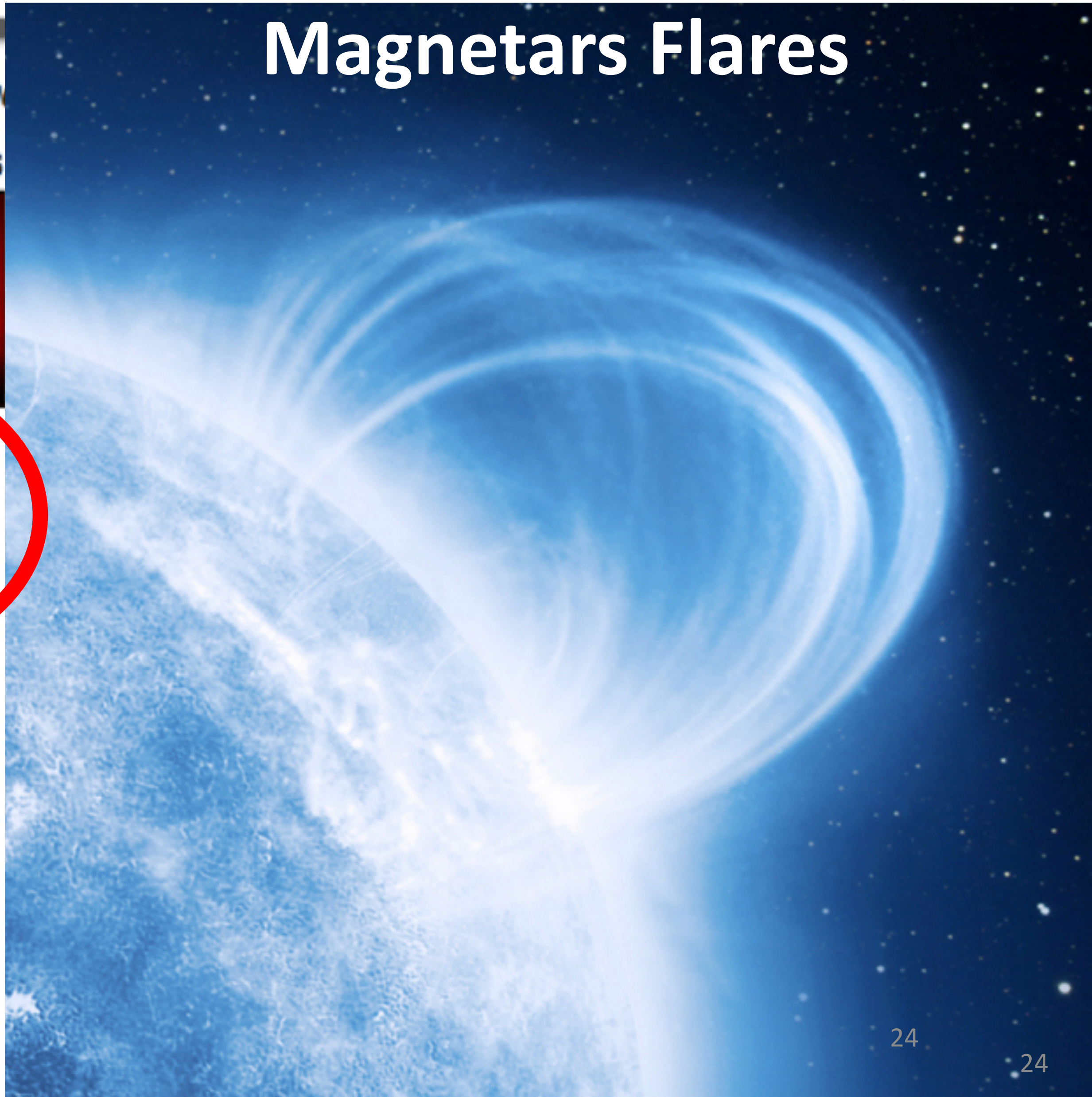


From longer to shorter



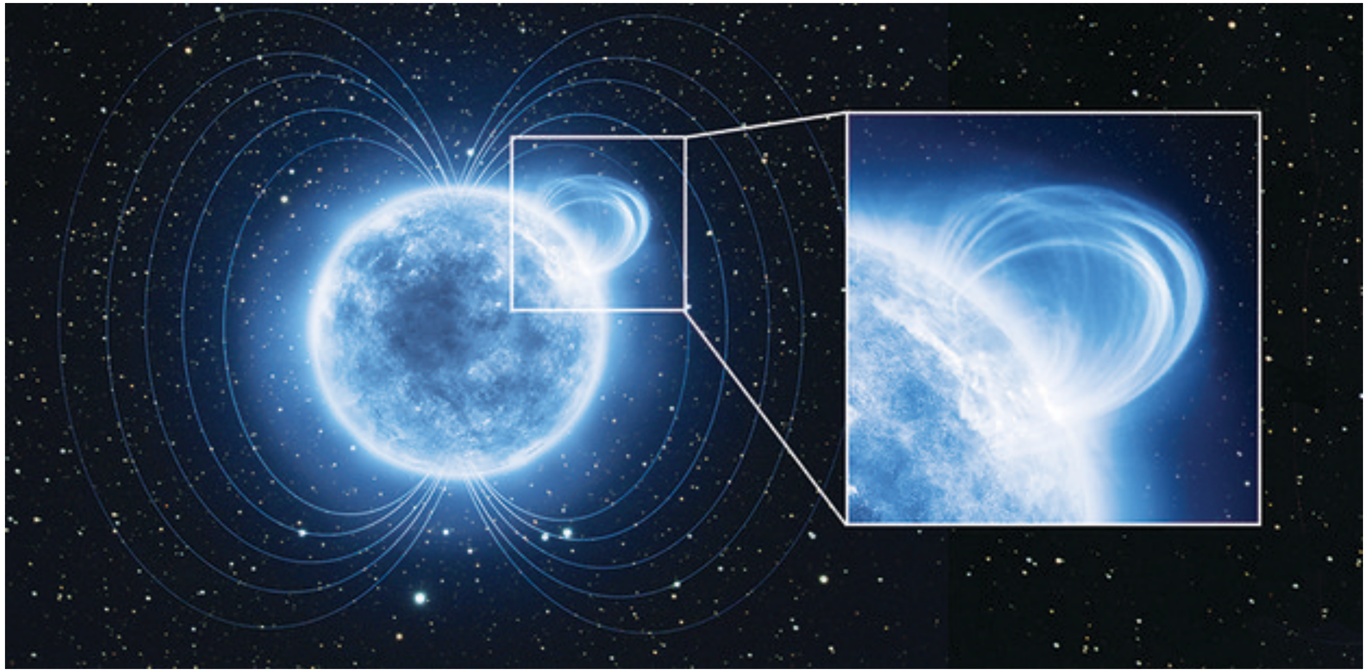
From longer to shorter

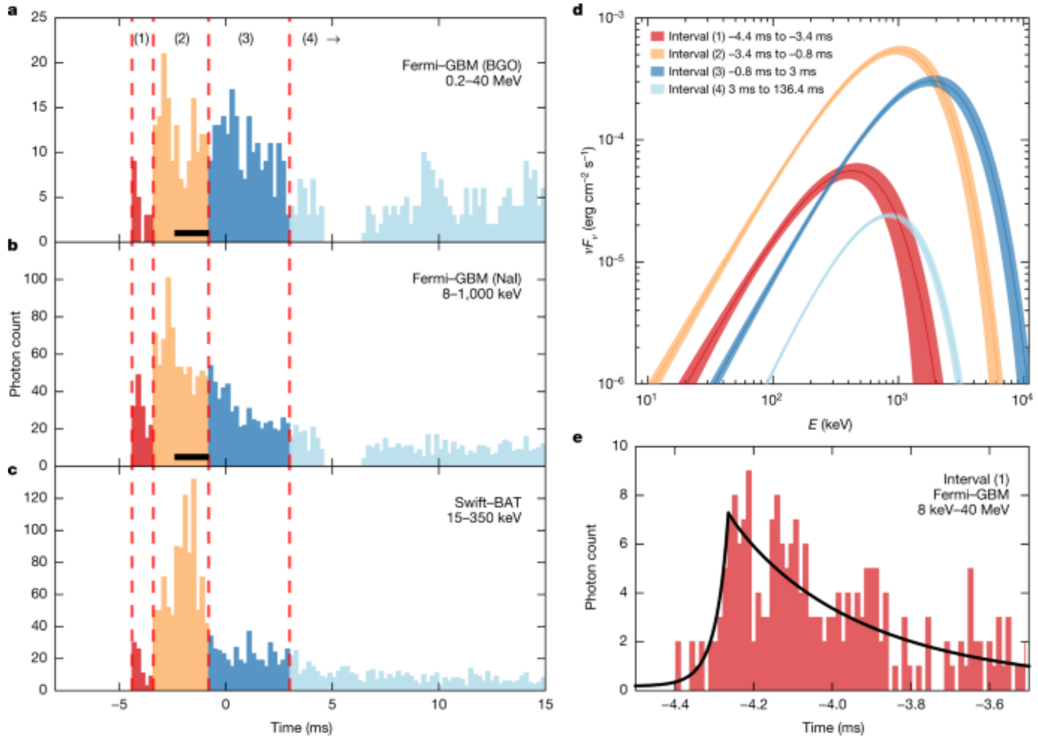




Magnetar Giant Flares (MGF)

- Magnetars: strongly magnetized neutron stars with magnetic fields of **$10^{13\text{-}15}$ G** and periods of **0.1-10 s**
- Can show rare **outbursts** (flare and pulsating tail) in X-rays and soft gamma-rays with luminosities around $10^{44\text{-}47}$ erg s^{-1}
- Likely caused by *crustquakes induced by high magnetic fields*



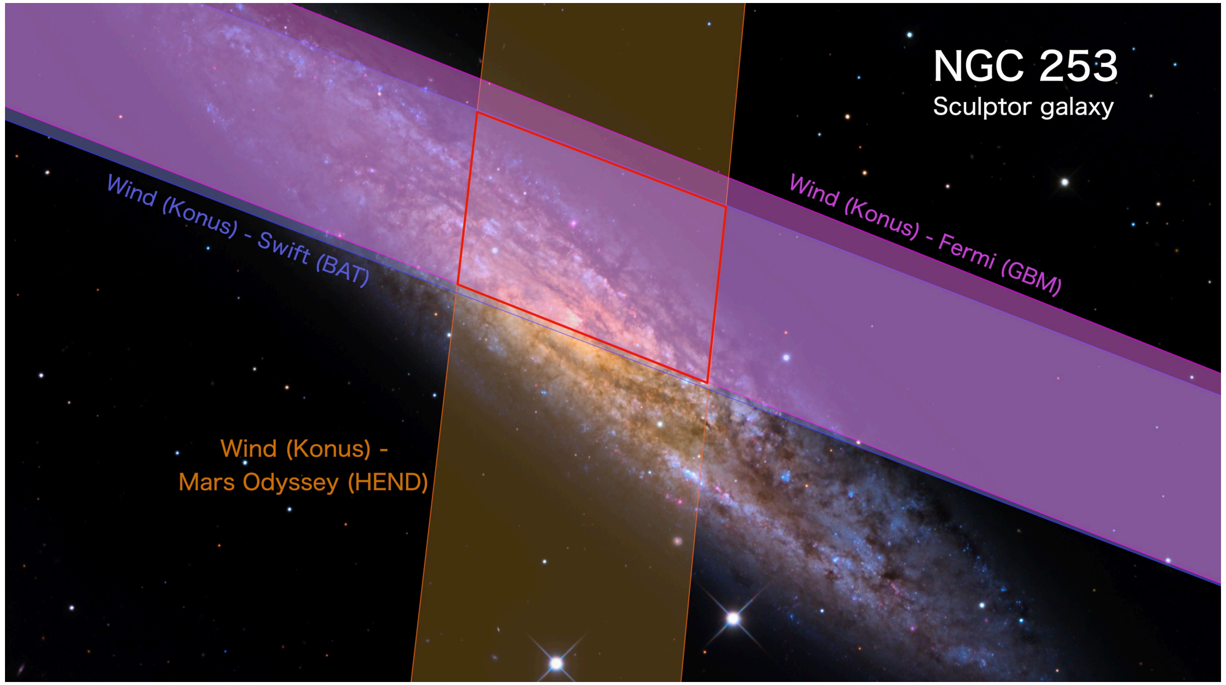


Magnetar Giant Flares (MGF)

GRB 200415A

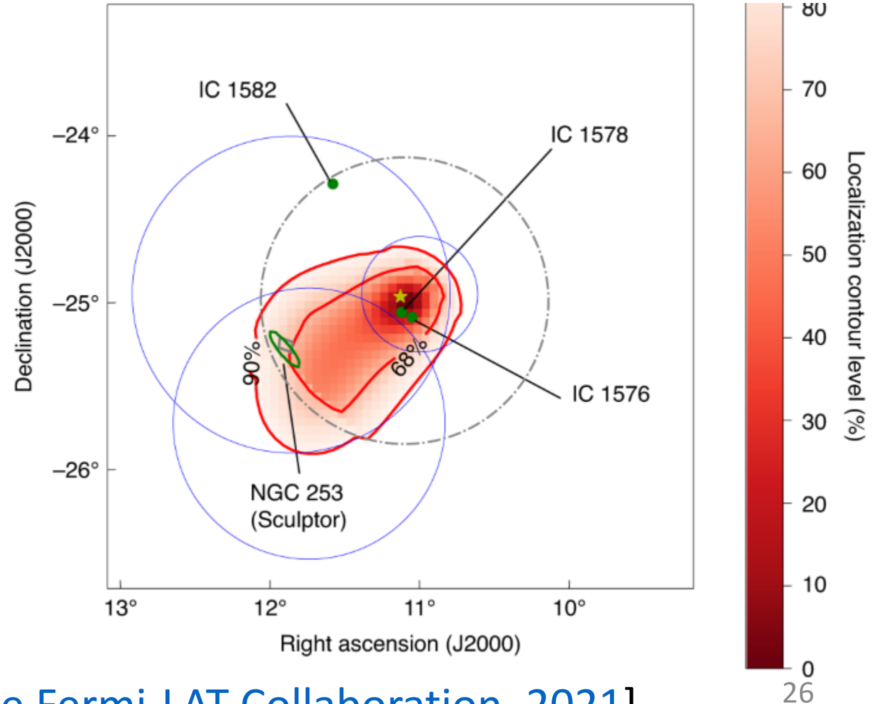
April 15th 2020, GBM triggered at 08:48:05.56 UTC [Roberts et al. Nature, 2021]

Burst most likely originated in star-forming Sculptor Galaxy, $D_L \approx 3.5$ Mpc [Svinkin et al. Nature, 2021]



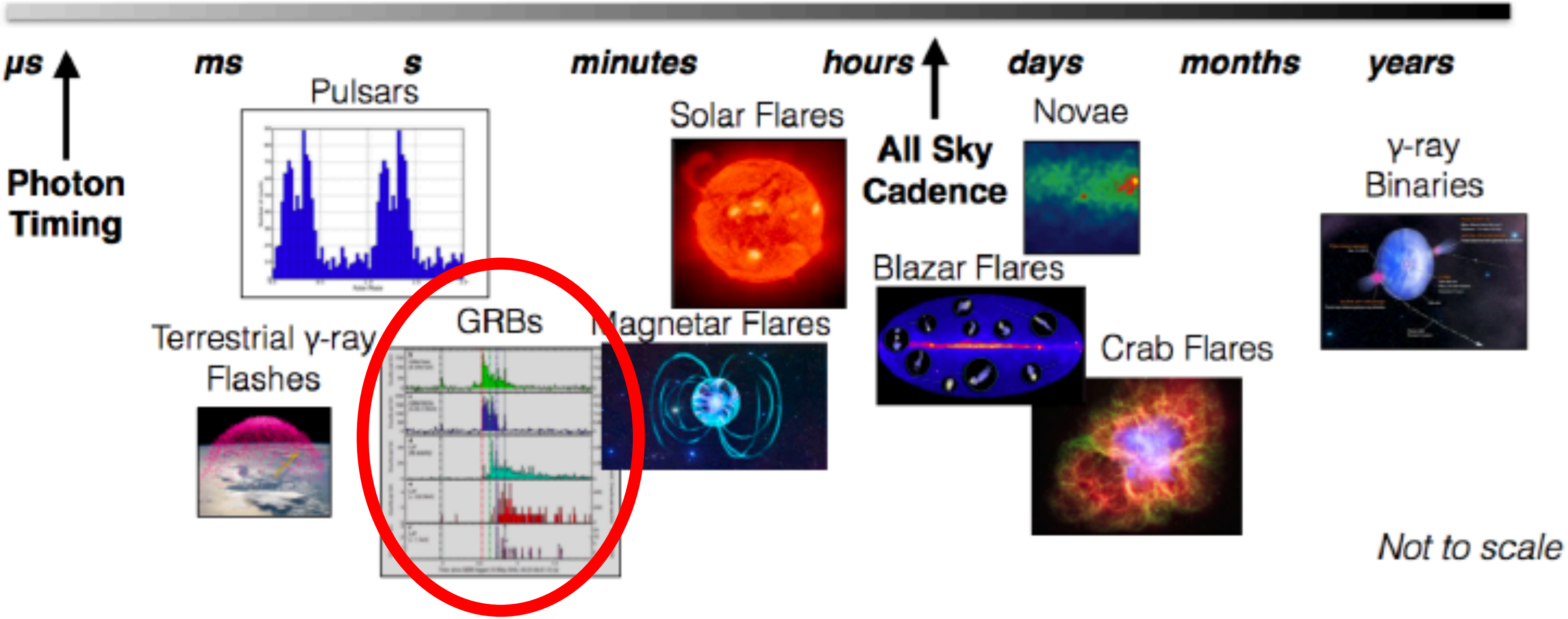
Time since T_0 (s)	Energy (MeV)	Distance to NGC 253 (°)	Assoc. Prob.
19.18	480	0.3	0.990
180.22	1300	0.5	0.988
284.05	1700	0.9	0.999

LAT detected 3 photons (TS=29)
- NGC 253 (Sculptur gal.) at 72% localization CL
- Probability of chance coincidence: < 2.9 x 10^{-3}
- Long delay of first photon after T0 atypical for sGRB

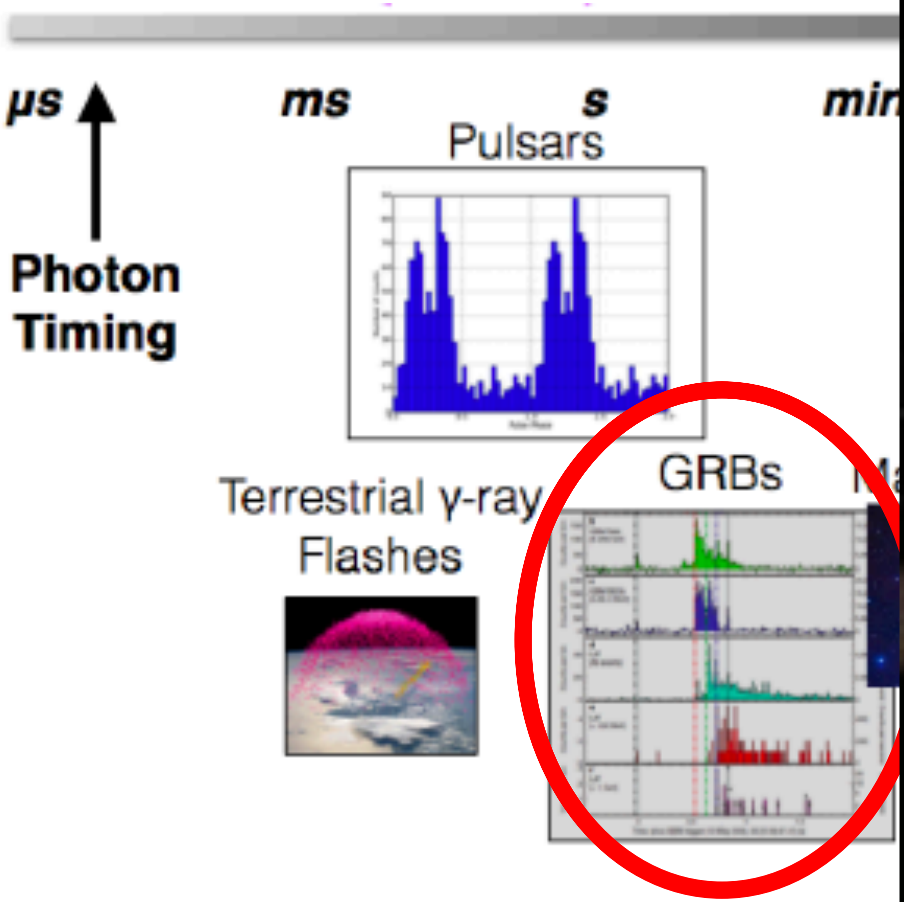


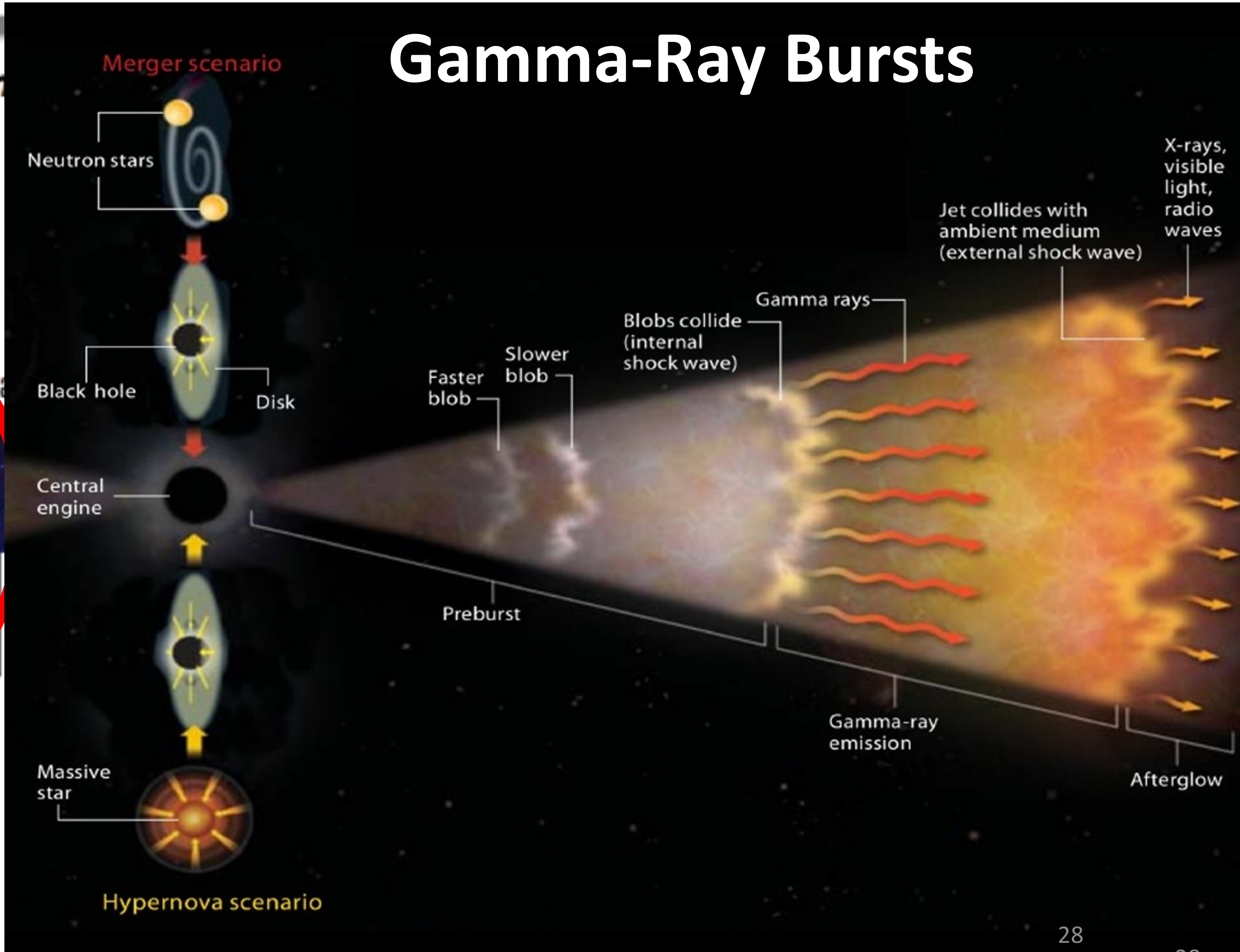
[The Fermi-LAT Collaboration, 2021]

From longer to shorter

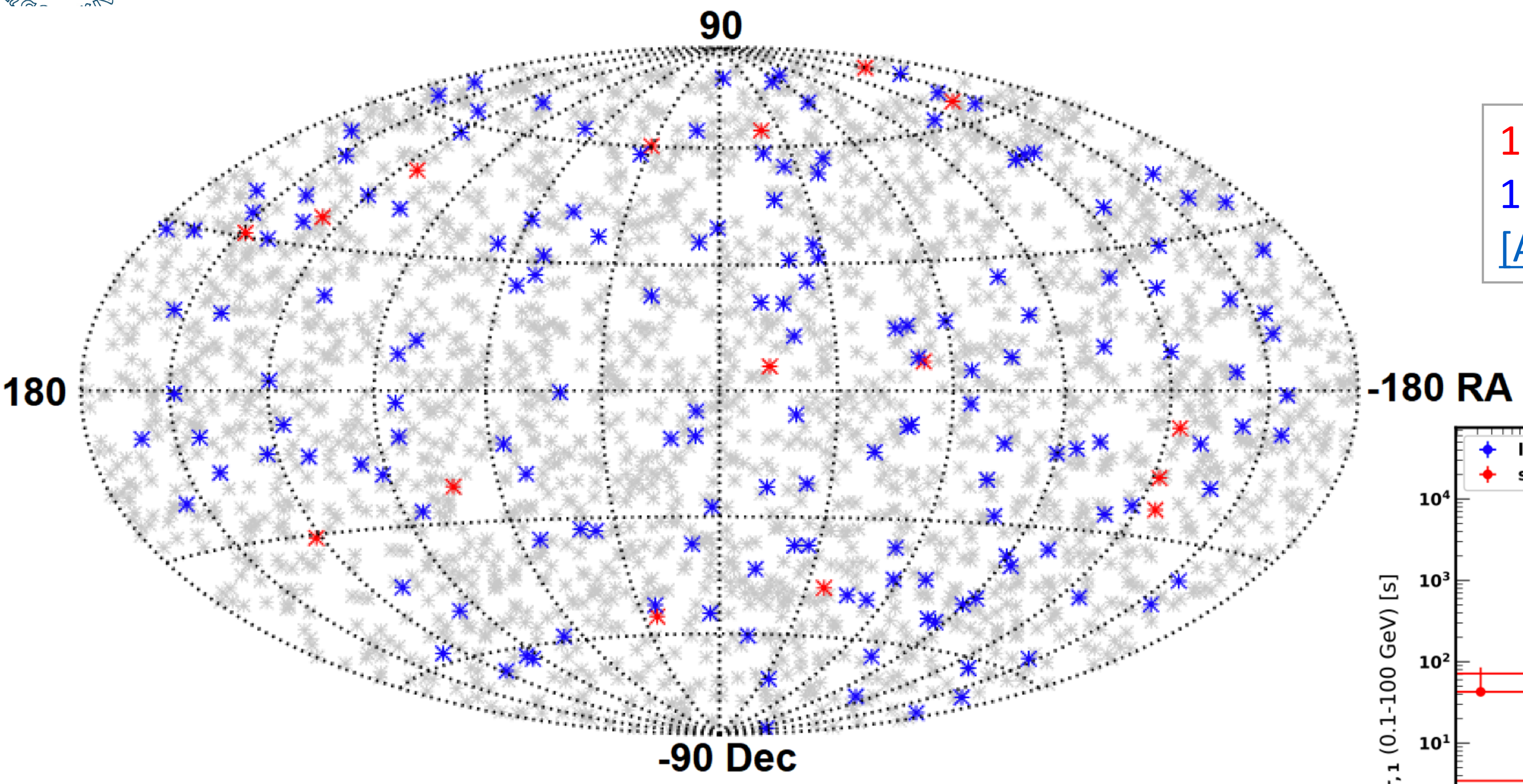


From longer to shorter

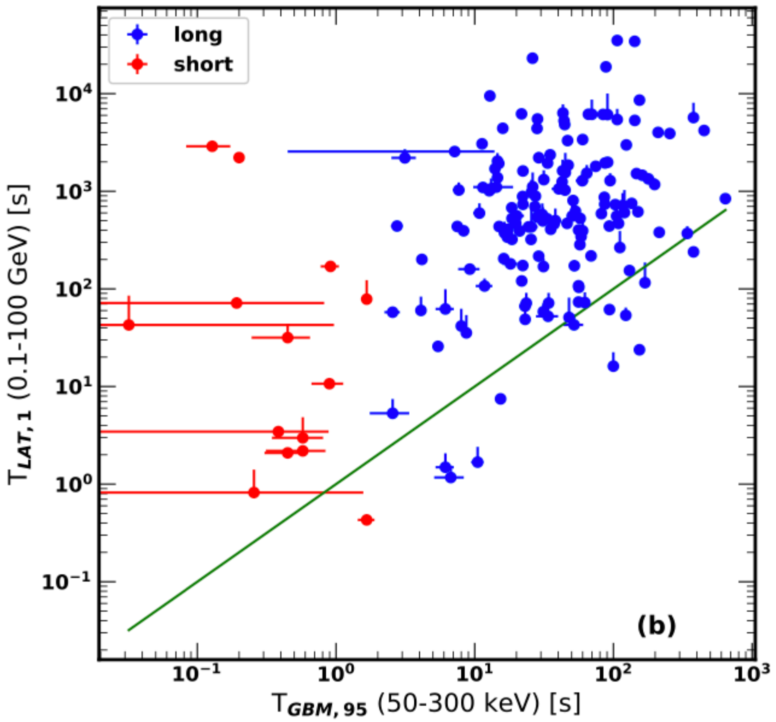




Second Gamma-Ray Burst (GRB) catalog released

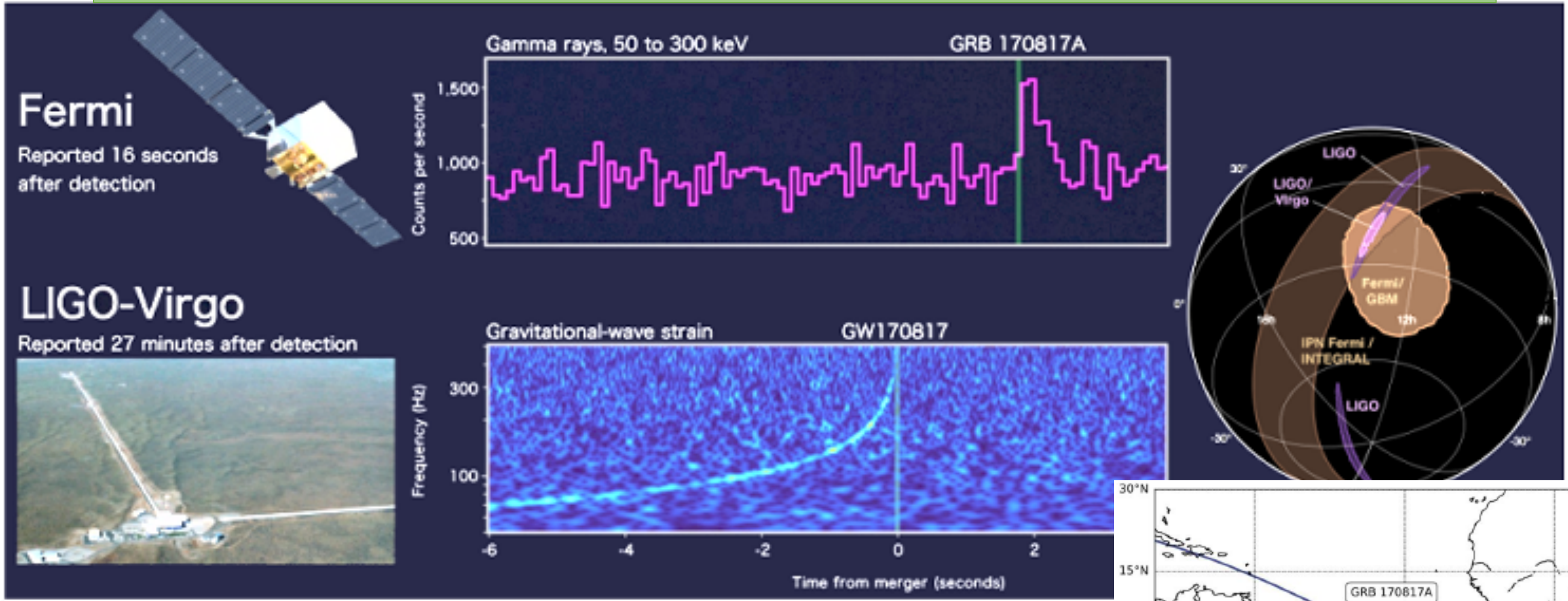


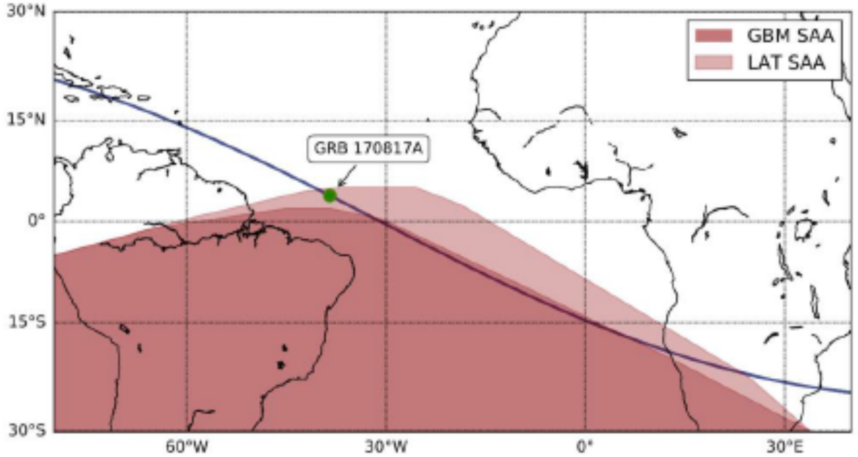
17 short (<2s) GRBs
169 long (>2s) GRBs
[Ajello et al. 2019]



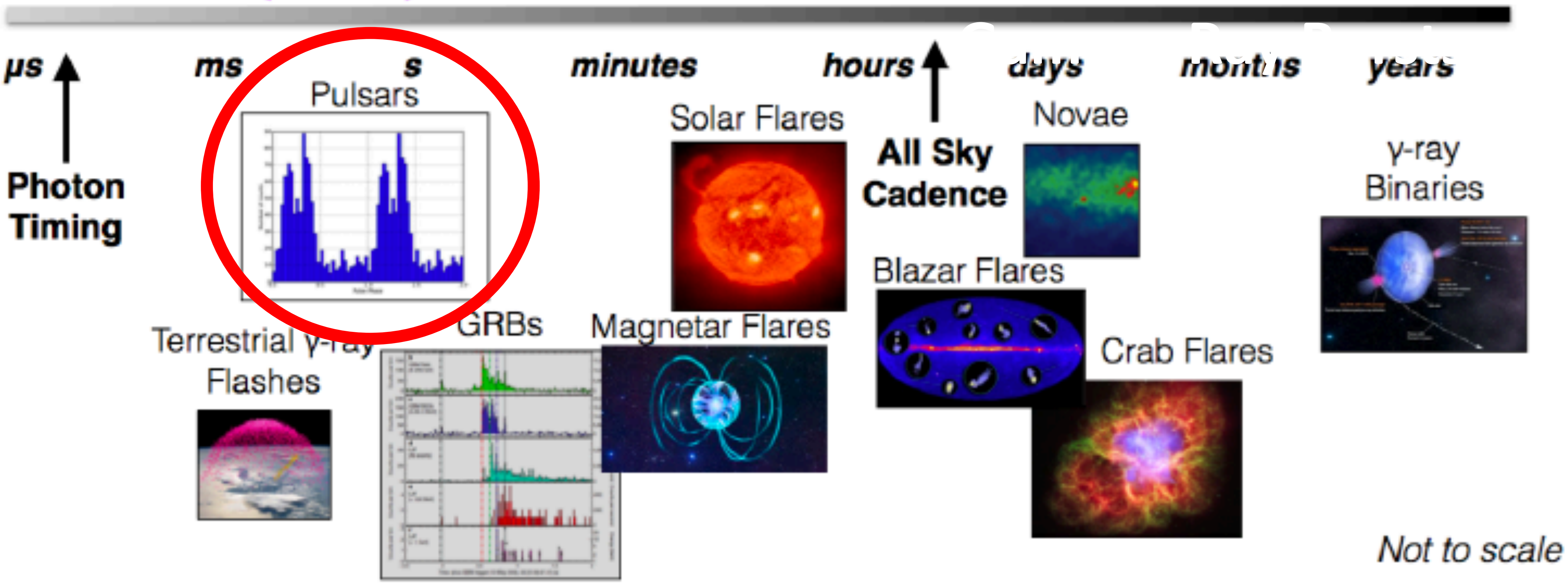
GRB170817: a unique GRB!

Gamma-ray (GRB170817) and gravitational waves (GW180817) from merging neutron stars: the first multimessenger (EM-GW waves) event!

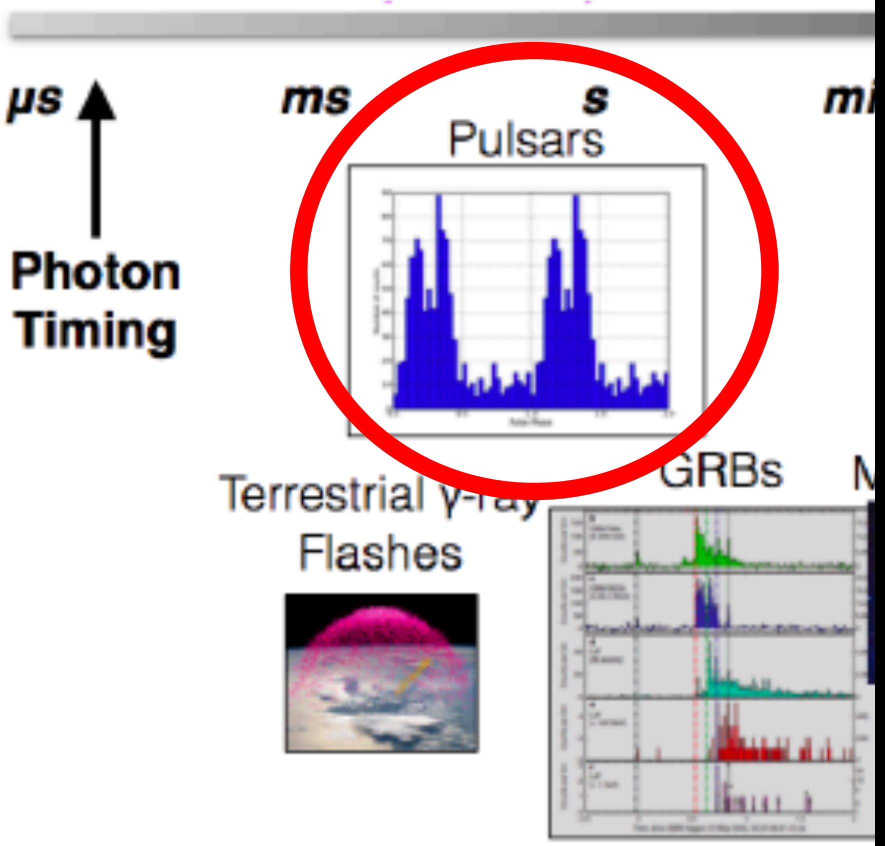


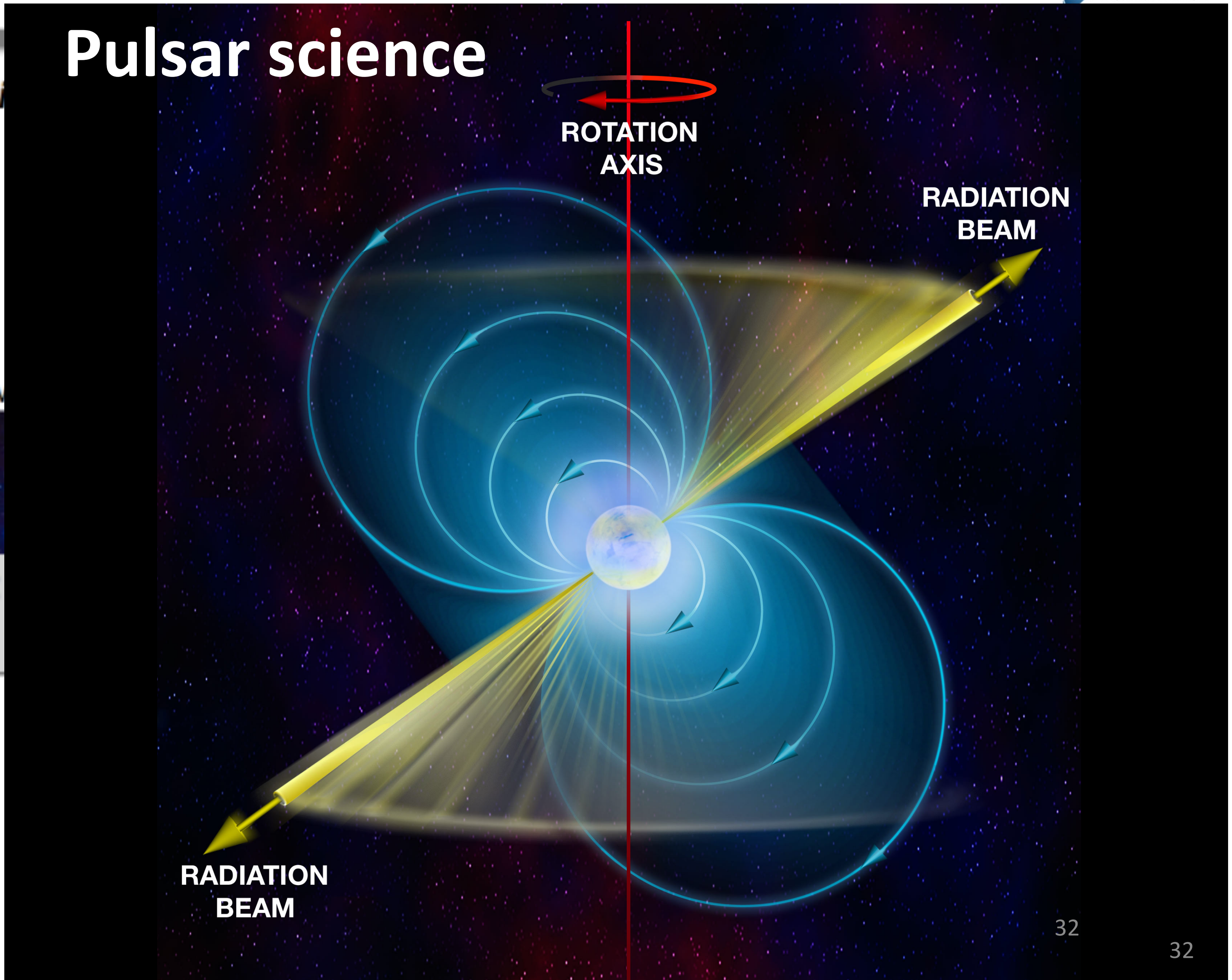


From longer to shorter



From longer to shorter

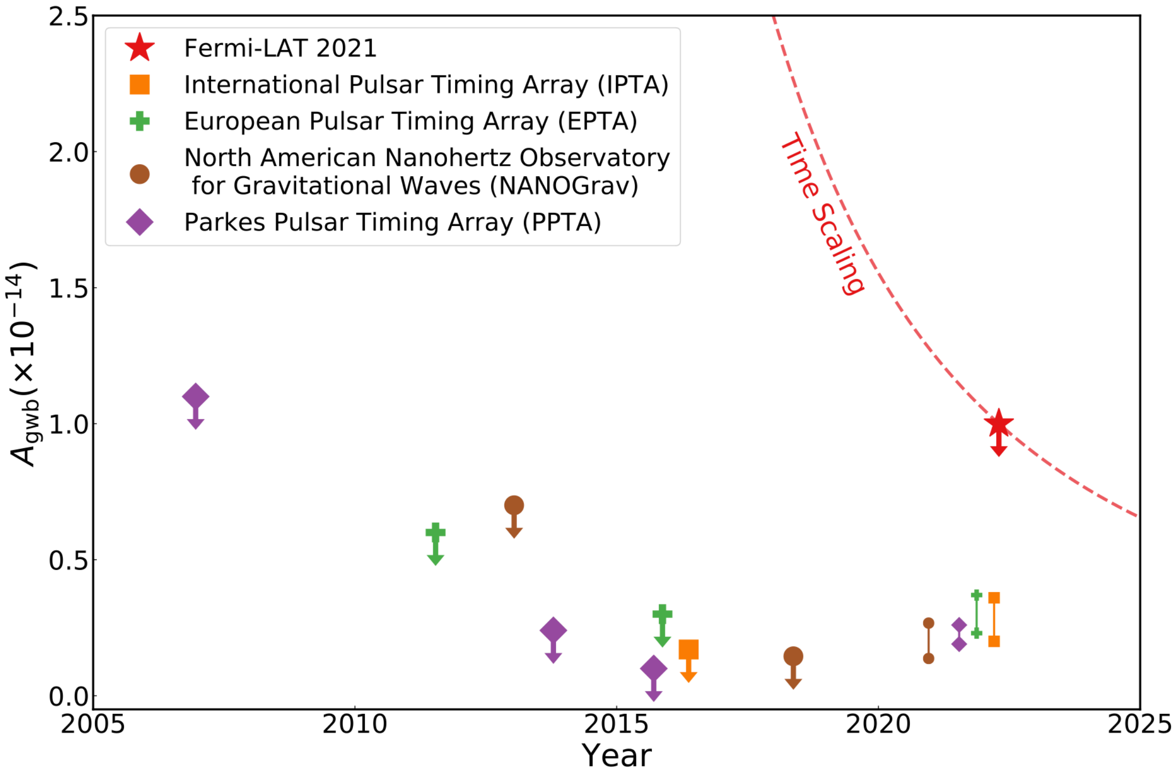




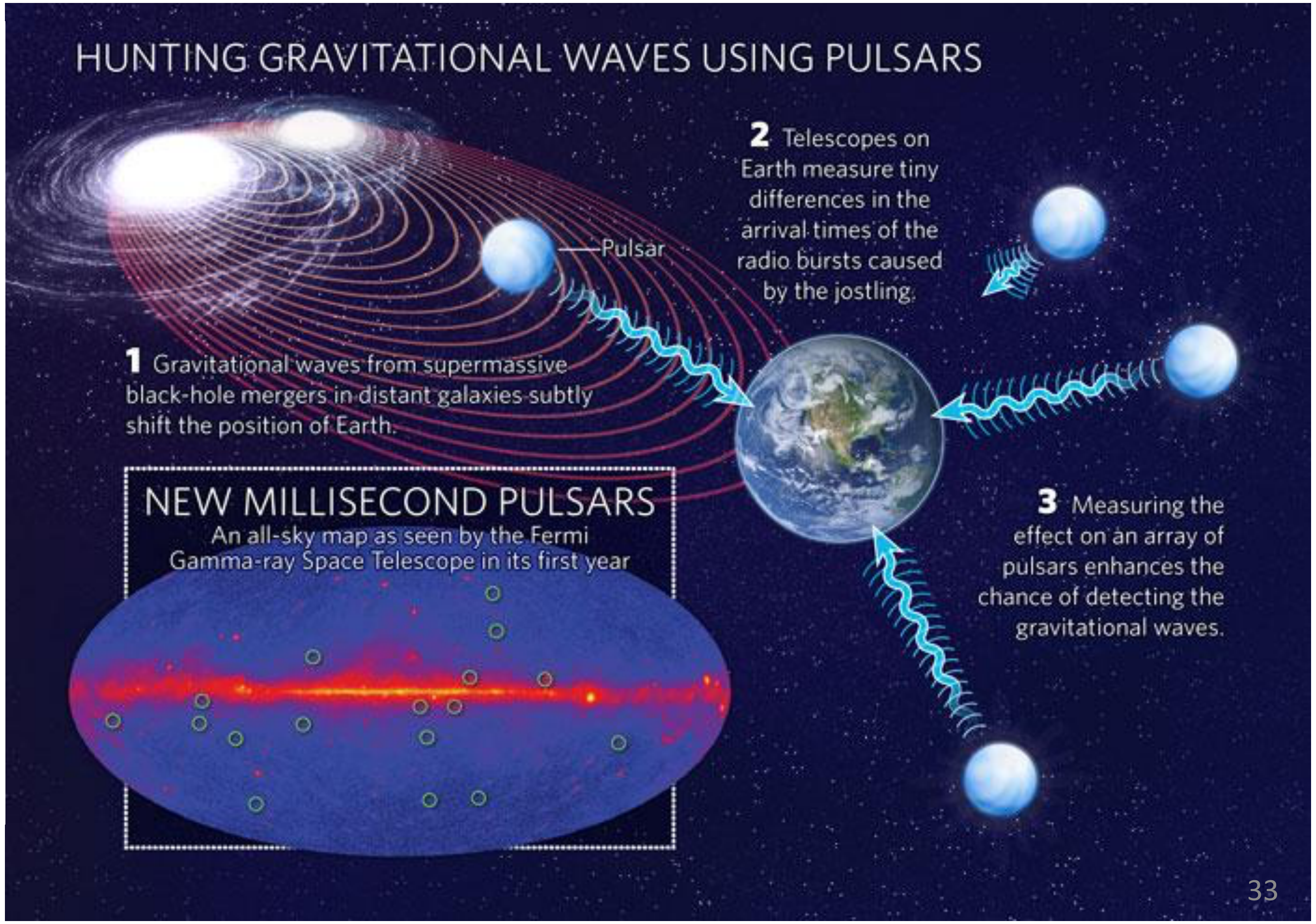
Outlook – Pulsar Timing Array

Gravitational wave search at very low frequencies (5-500 nHz, from), merging of supermassive black hole (SMBH) binaries may be deteceted through pulsar timing.

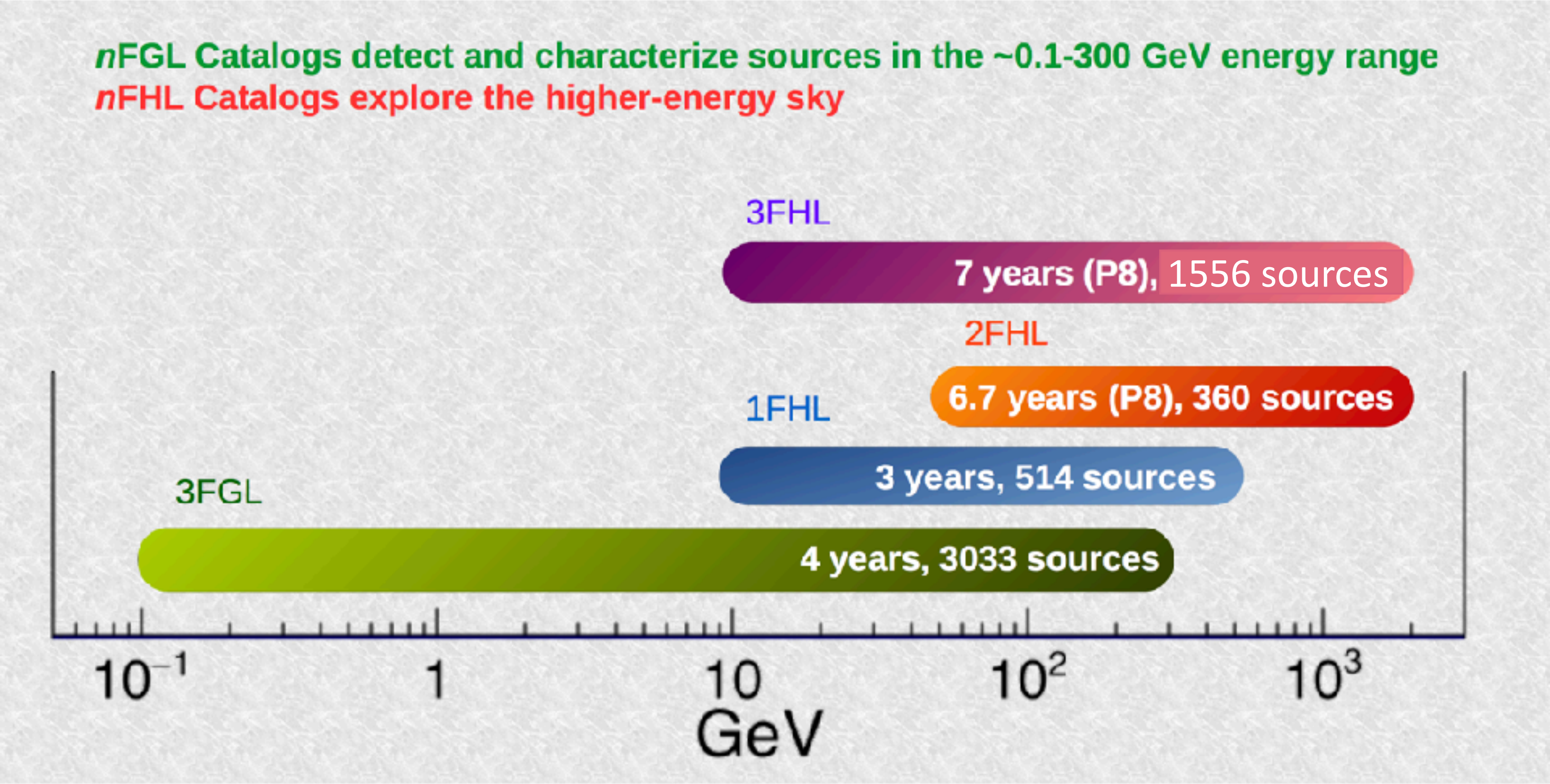
Gravitational waves can be detected by monitoring the times of arrival of the steady pulses from each pulsar, which arrive earlier or later than expected due to the spacetime perturbations.



[Fermi-LAT coll. et al., 2022]

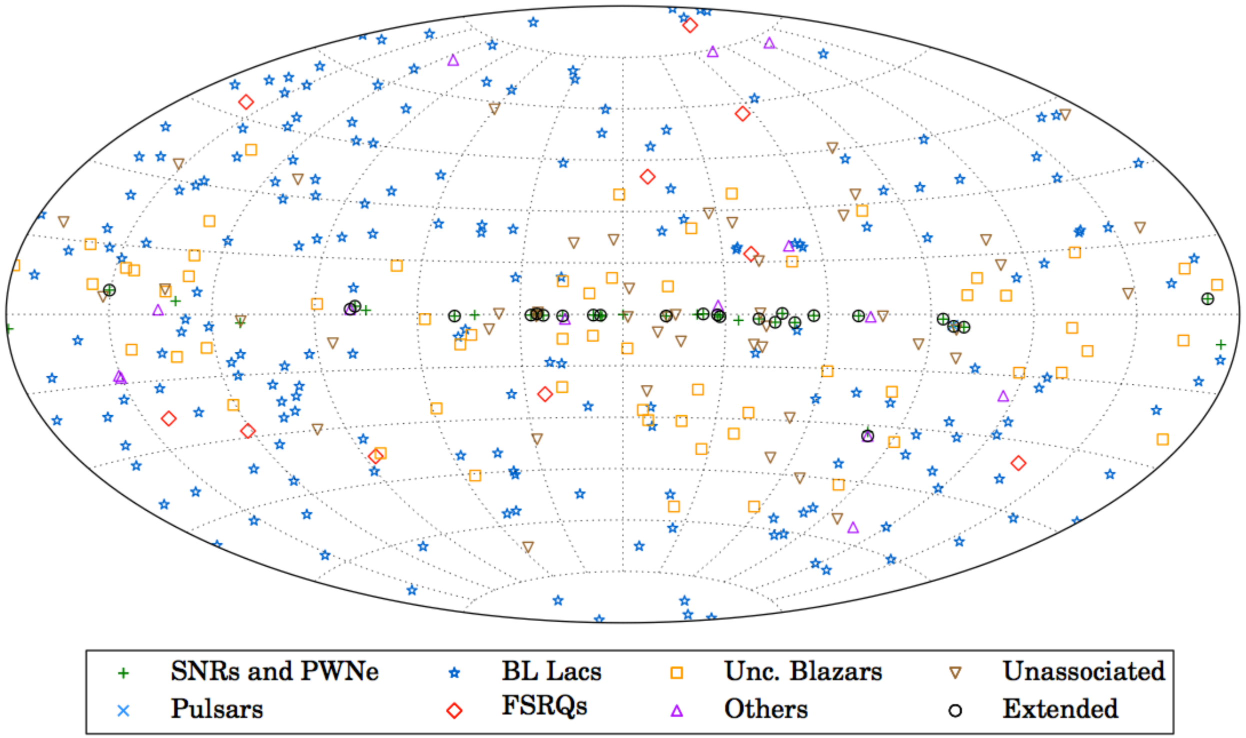


Towards higher energies: FHL catalogs

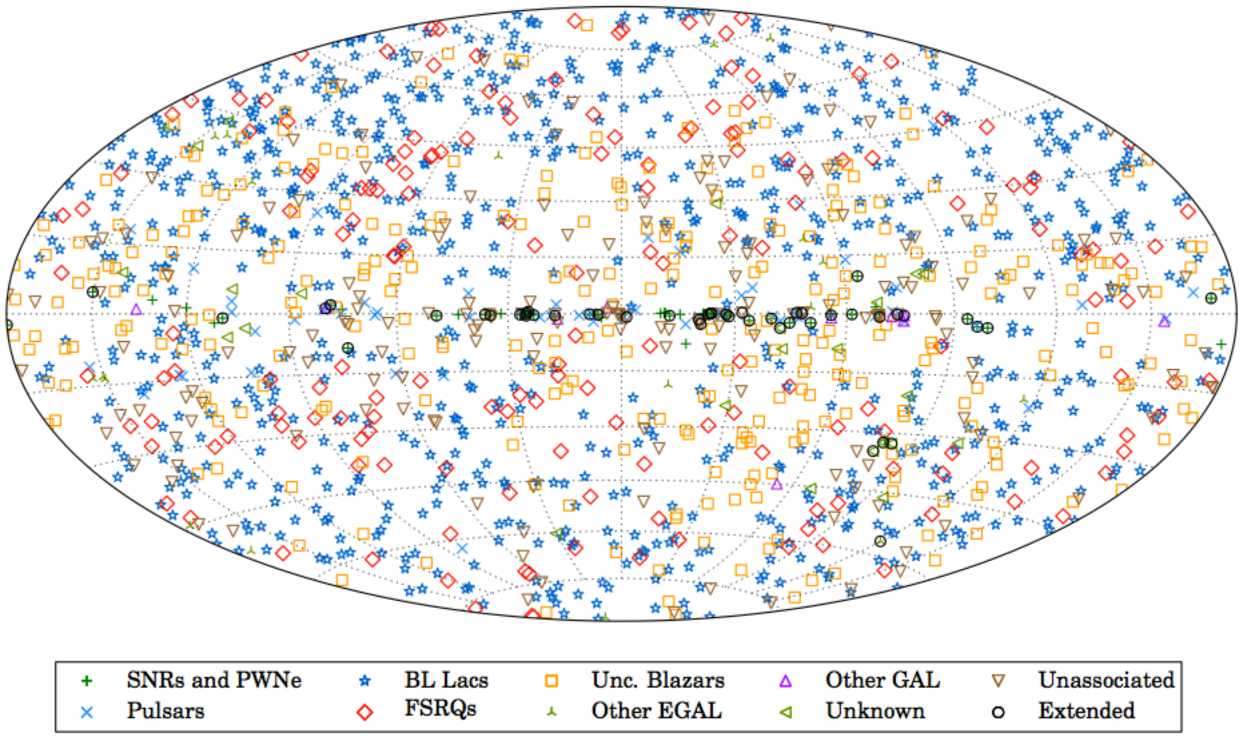


2FHL and 3FHL catalogs

2FHL (E>50 GeV, 6.7 years)



3FHL (E>10 GeV, 7 years)



2FHL (514 sources)

- >80% extragalactic, remaining are Galactic and unassociated

[Ackermann et al, 2015]

3FHL (1556 sources)

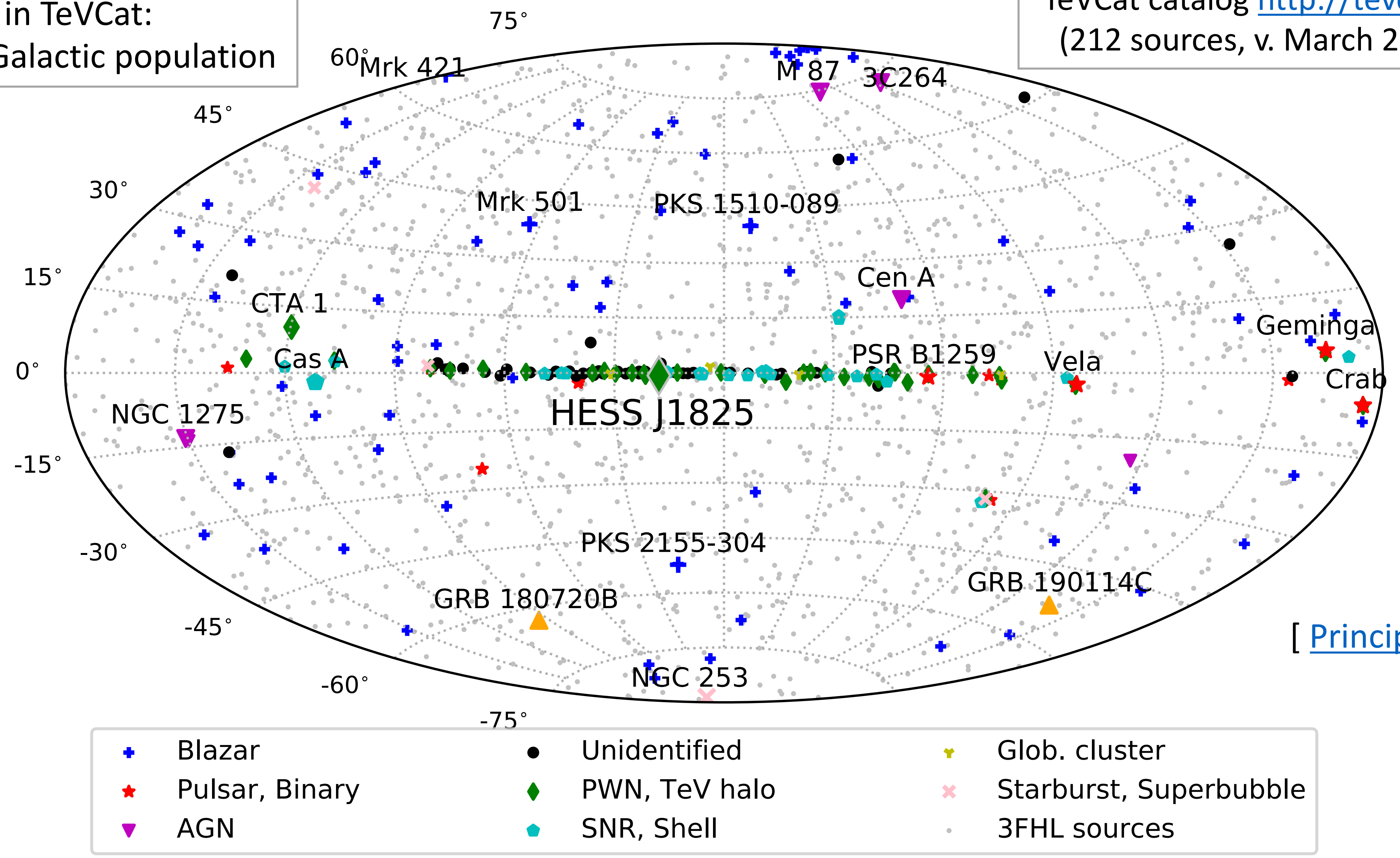
- 79% extragalactic, 8% Galactic, 13% unassociated
- 48 extended sources (FGES paper,)

[Ajello et al. 2017]

TeV gamma-ray sources

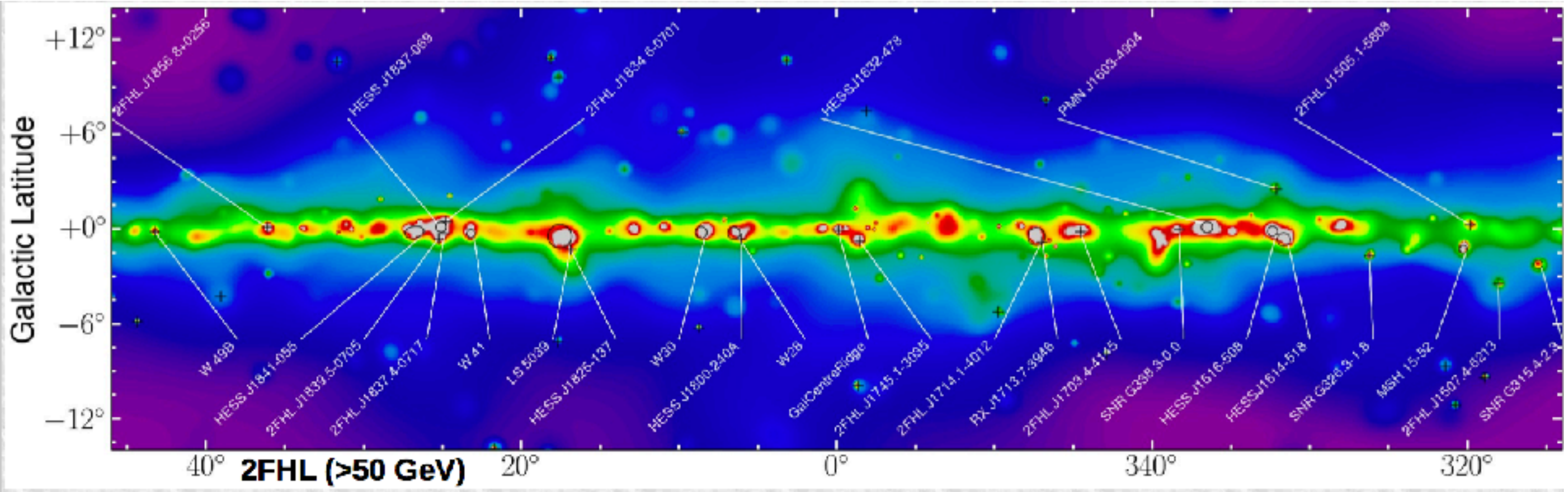
35 PWN in TeVCat:
the biggest TeV Galactic population

TeVCat catalog http://tevcat.uchicago.edu
(212 sources, v. March 2019, now >250)

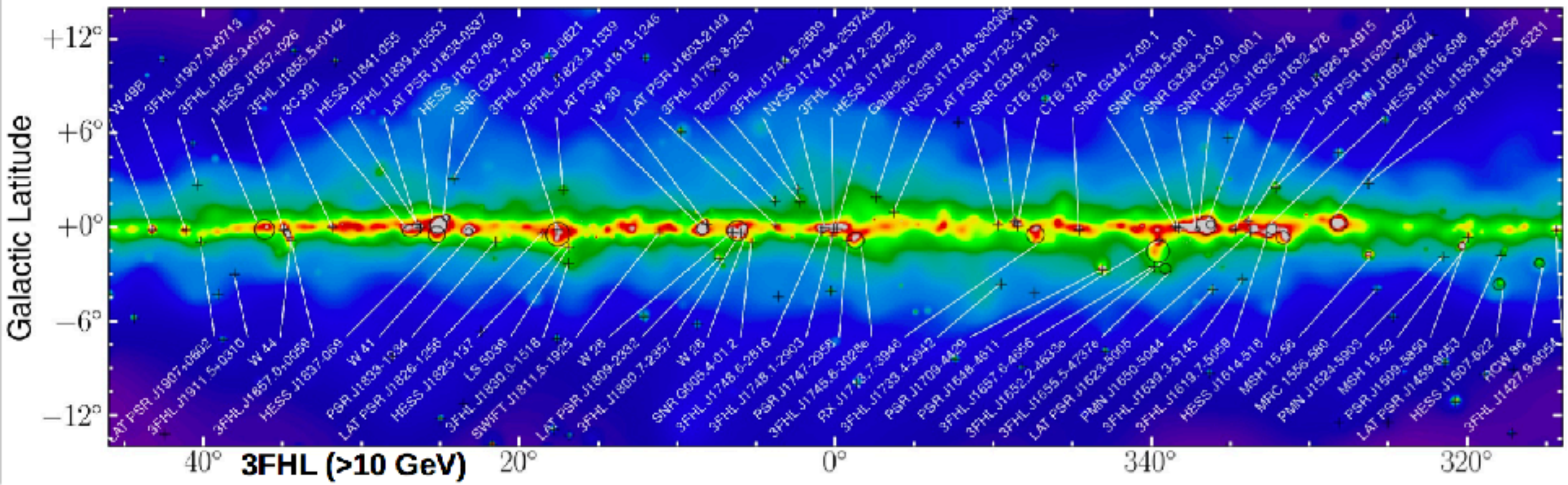


[Principe et al., 2020]

The nFHL Galactic Plane

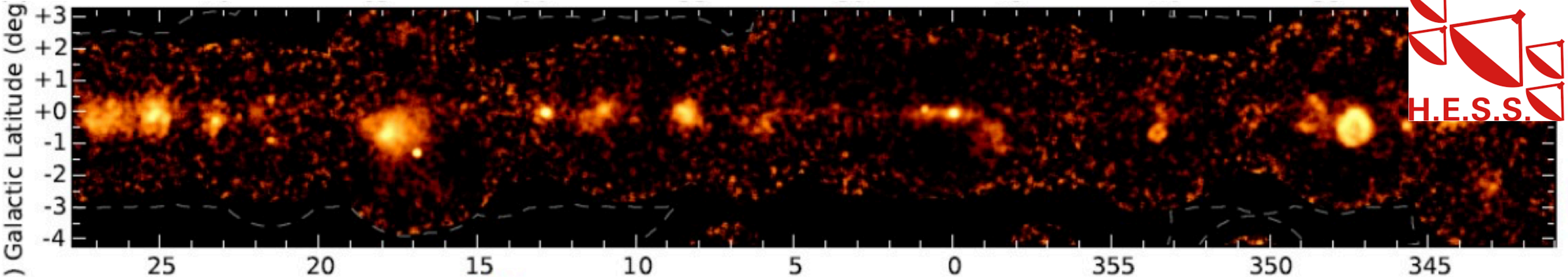


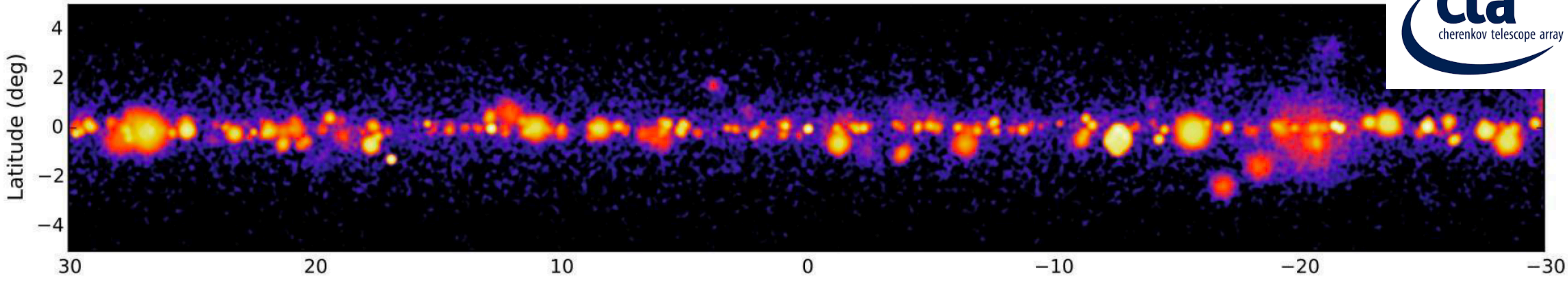
[Ackermann et al, 2015]



[Ajello et al. 2017]

TeV Galactic plane



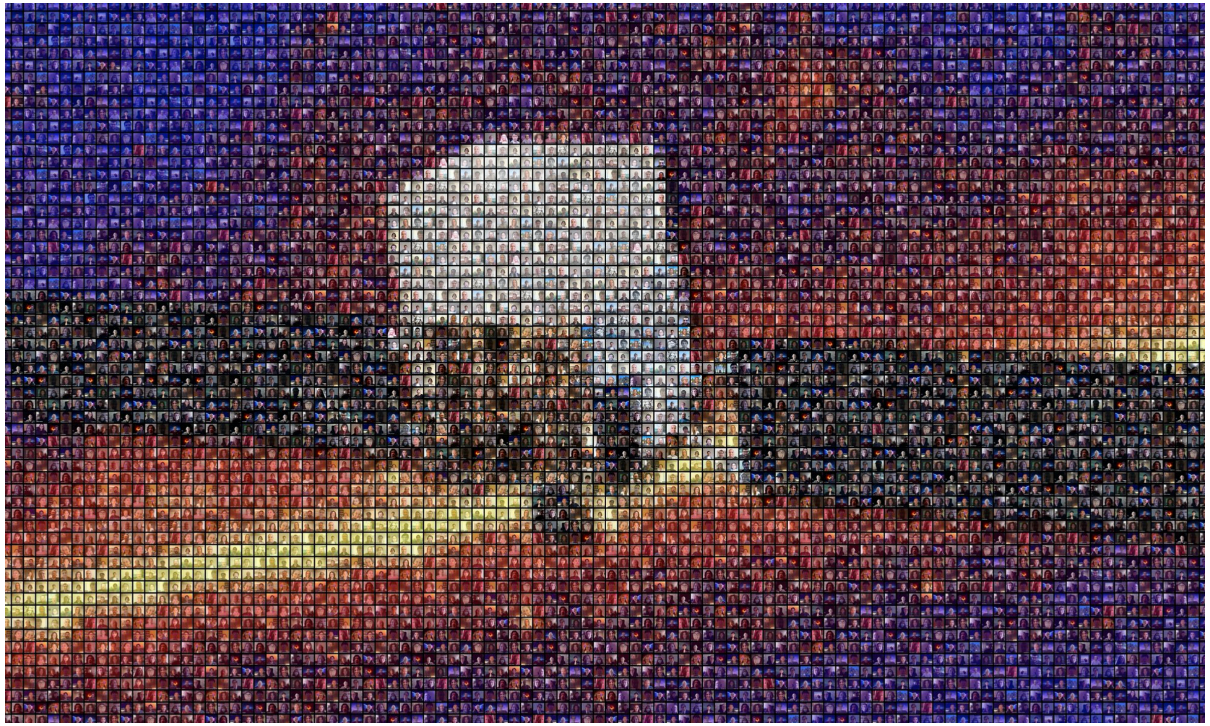


[H.E.S.S. Coll., 2018]
[CTA Consortium, 2019]

Summary and conclusion

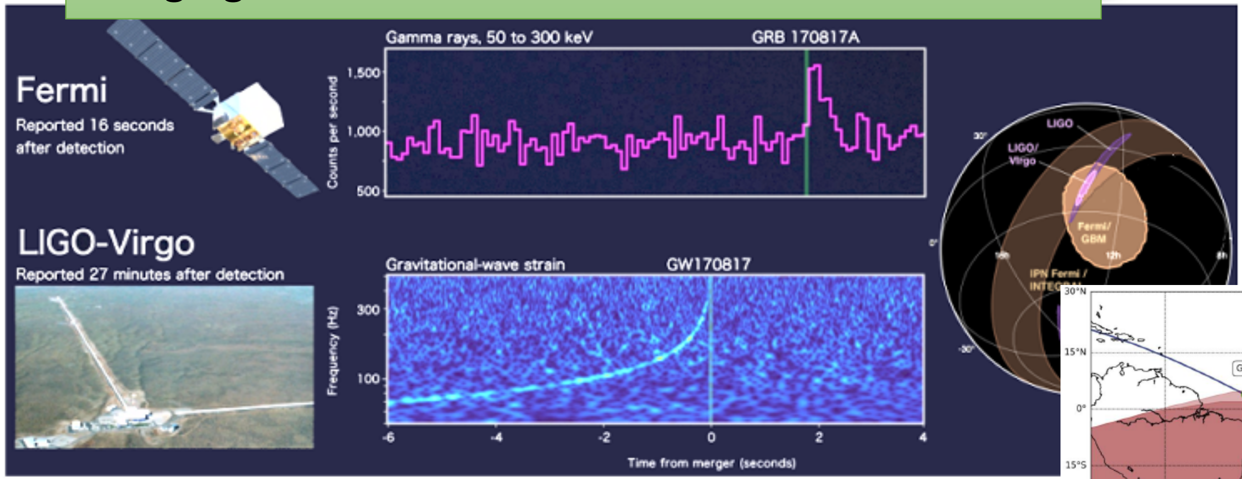
- *Fermi* LAT is working without major problems and continues to deliver exciting science results
- After almost 14 years of data taking, discovery of (new) transient phenomena are particularly exciting
- 2020 marked the year of the detection of a magnetar giant flare at GeV energies
- Recently published the search for GW *with the Fermi* gamma-ray pulsar timing array
- *While Fermi* results remain indispensable for ongoing multi-messenger counterpart searches, they provide also the basis for future gamma-ray observations!

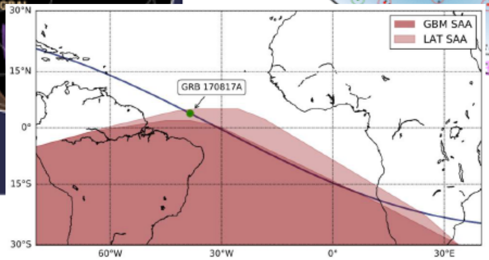
Thanks for your attention!



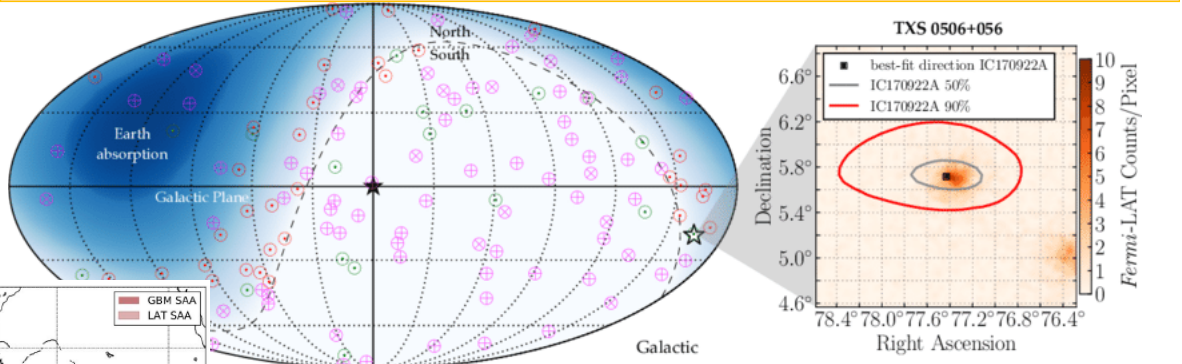
Backup slides

Gamma-ray and gravitational waves from a merging neutron stars

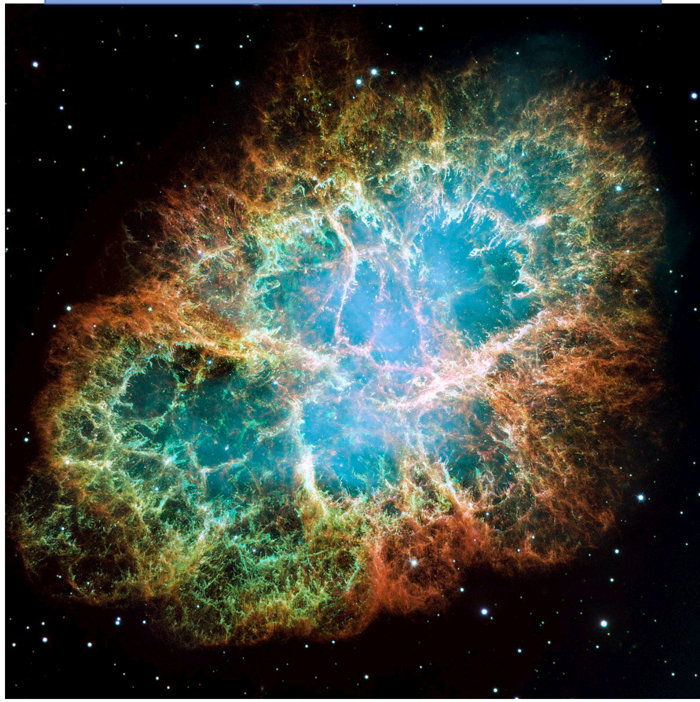




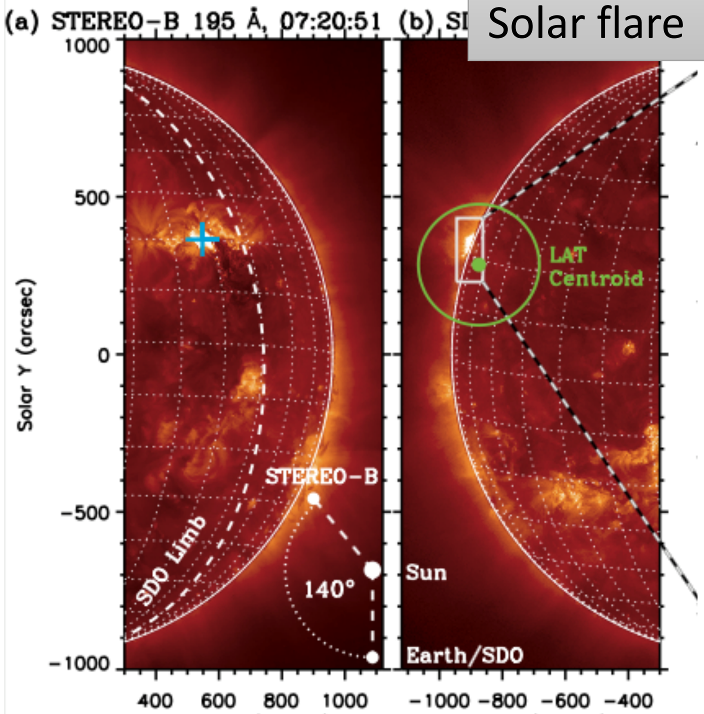
Gamma-ray and neutrino from a flaring blazar



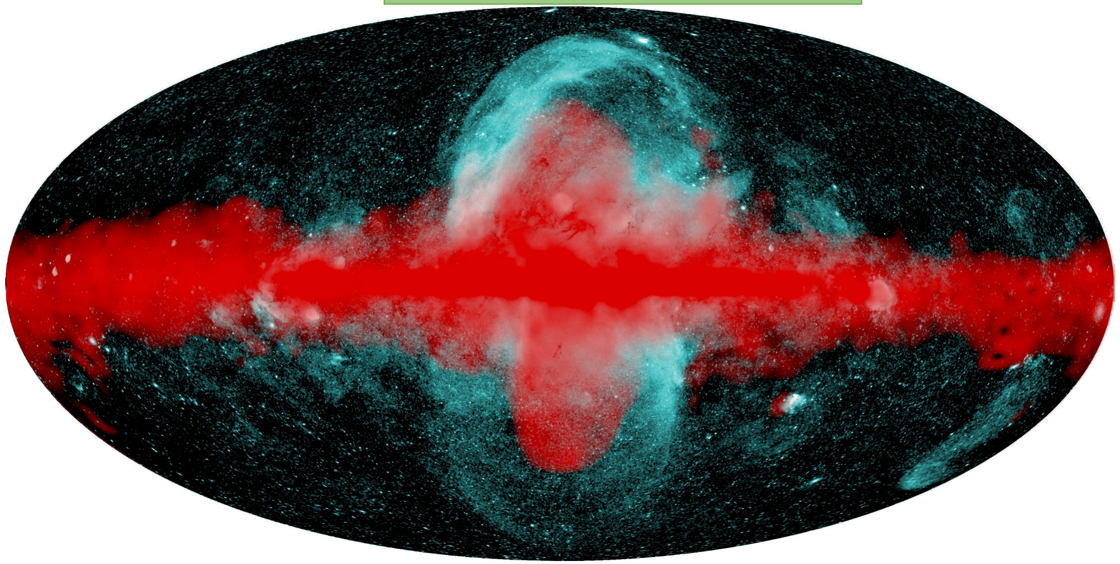
Crab nebula flares



Solar flare

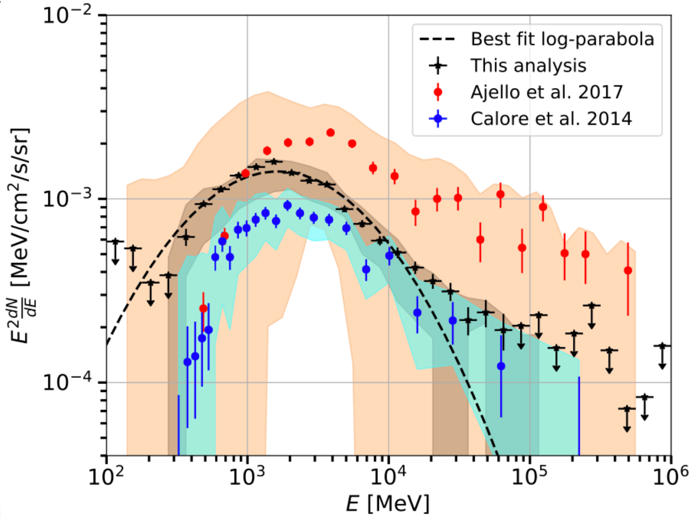


Fermi-LAT bubble



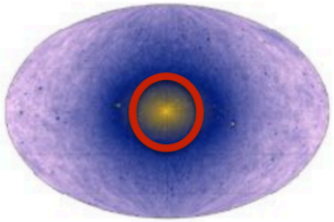
Fermi Dark Matter

[Di Mauro 2021]

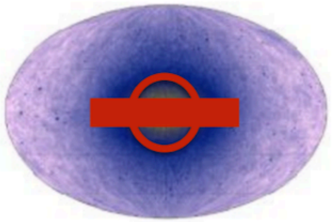


signal strength

GC



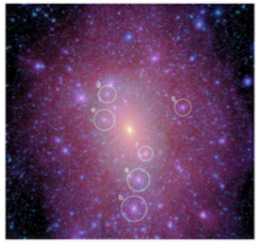
GC halo



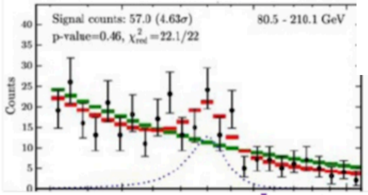
cumulative extragalactic signal

clusters of galaxies

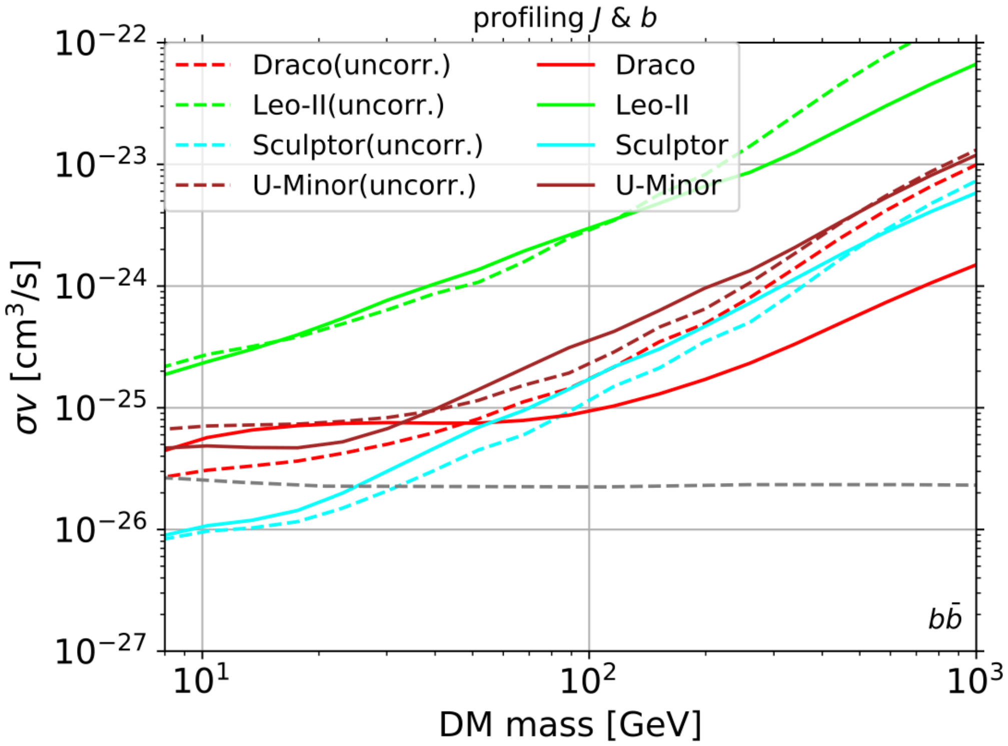
dwarf satellites



spectral line

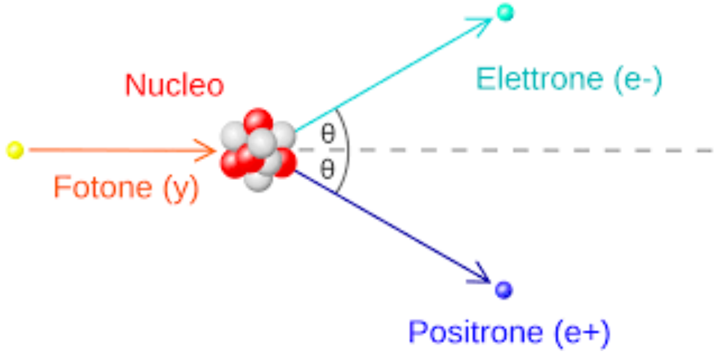


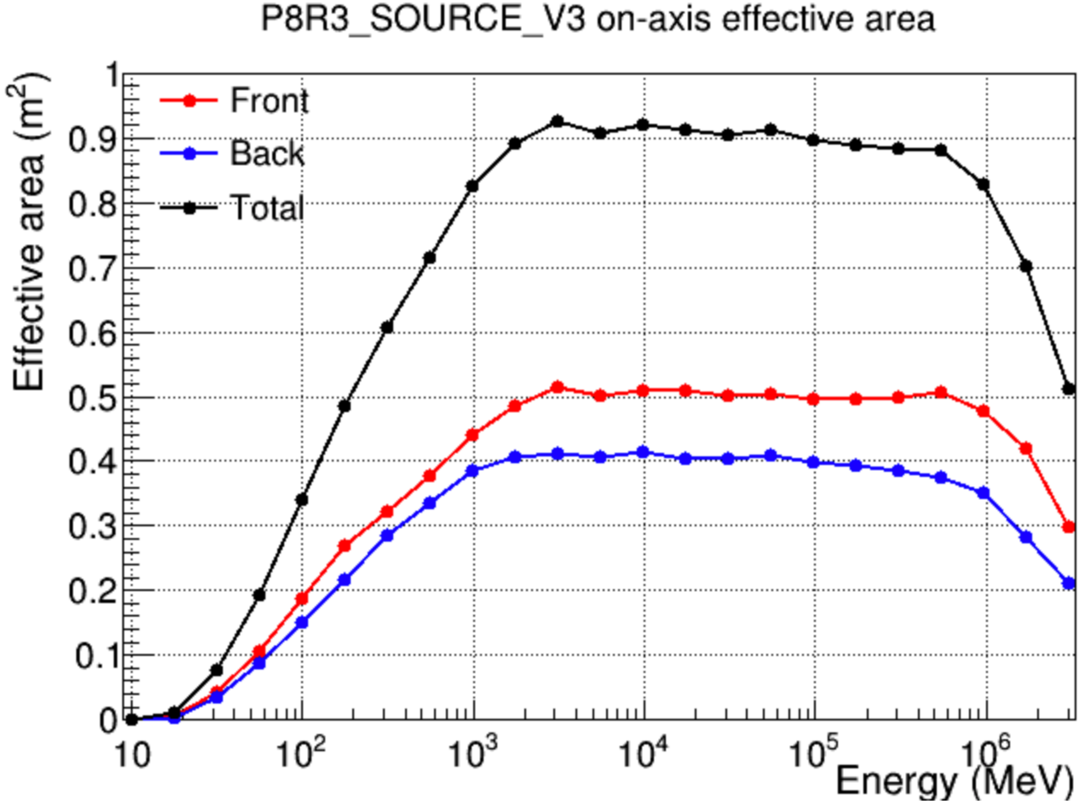
robustness

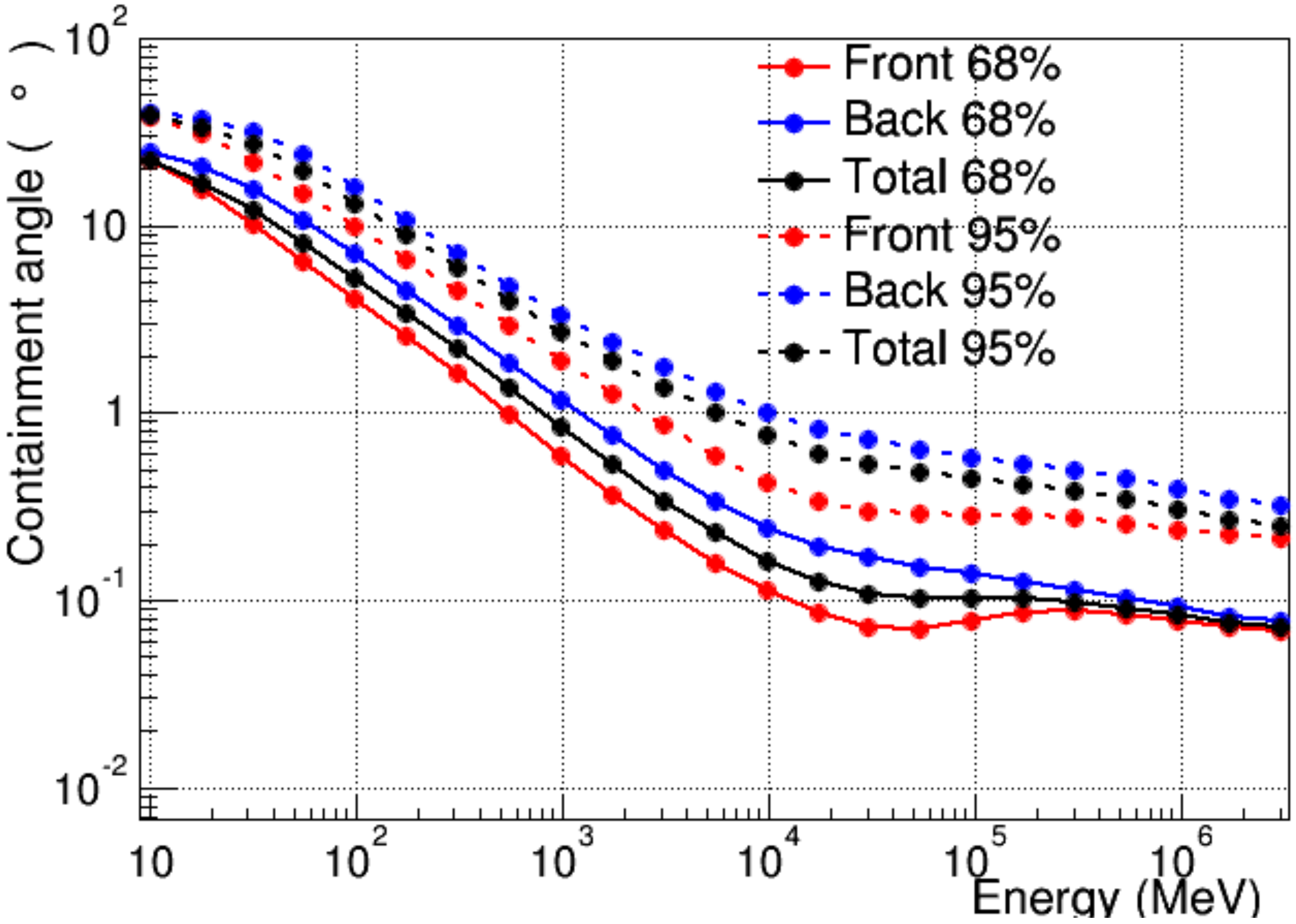


[Alvarez et al. 2020]

Fermi-LAT performances





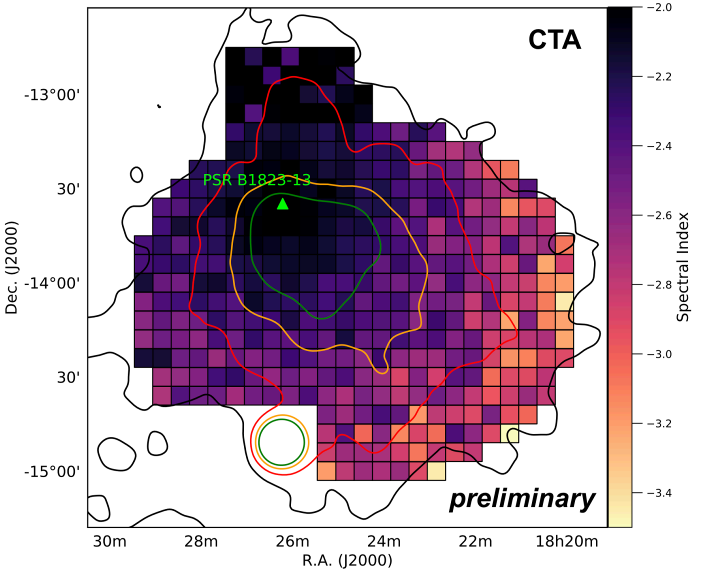


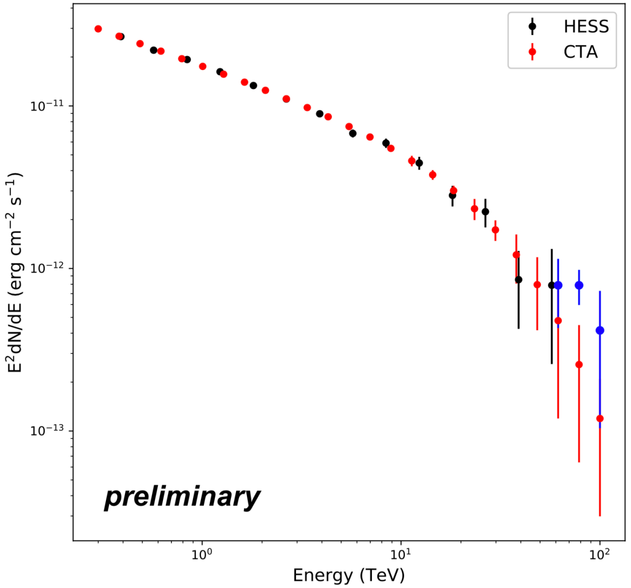
https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.html

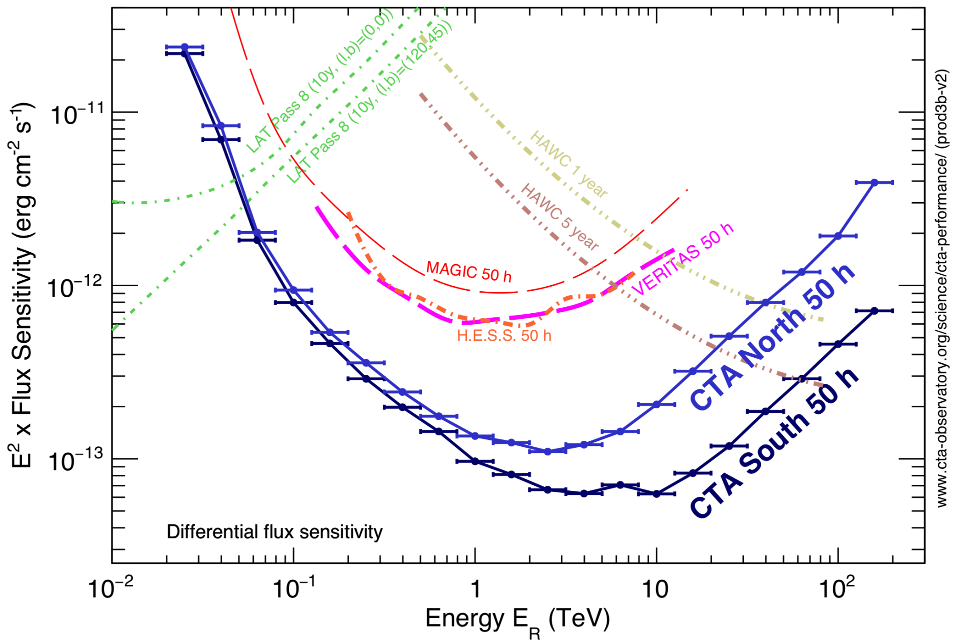
Future perspective – Toward CTA

CTA, as single observatory, will cover almost the entire energy range where the PWN HESS J1825-137 is detected at gamma rays (few GeV – hundreds TeV).
In particular it will help also to place strong constraints on a possible hadronic contribution to emission from PWN (currently assumed leptonic dominated).

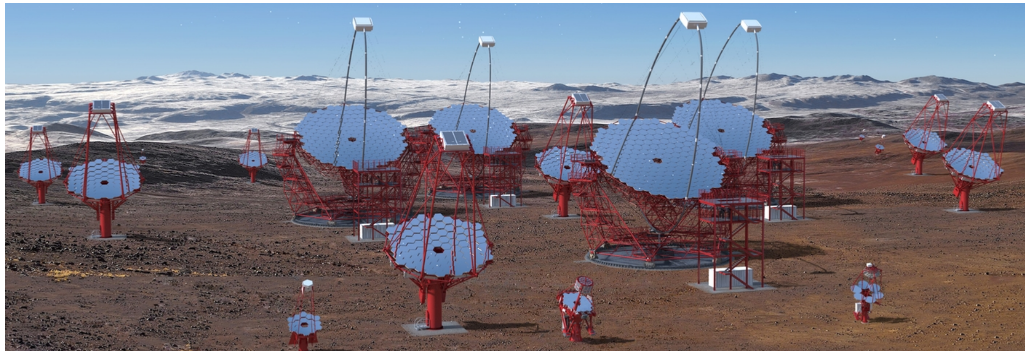
Mitchell, Principe et al. (Poster, 1st CTA Symposium 2019)







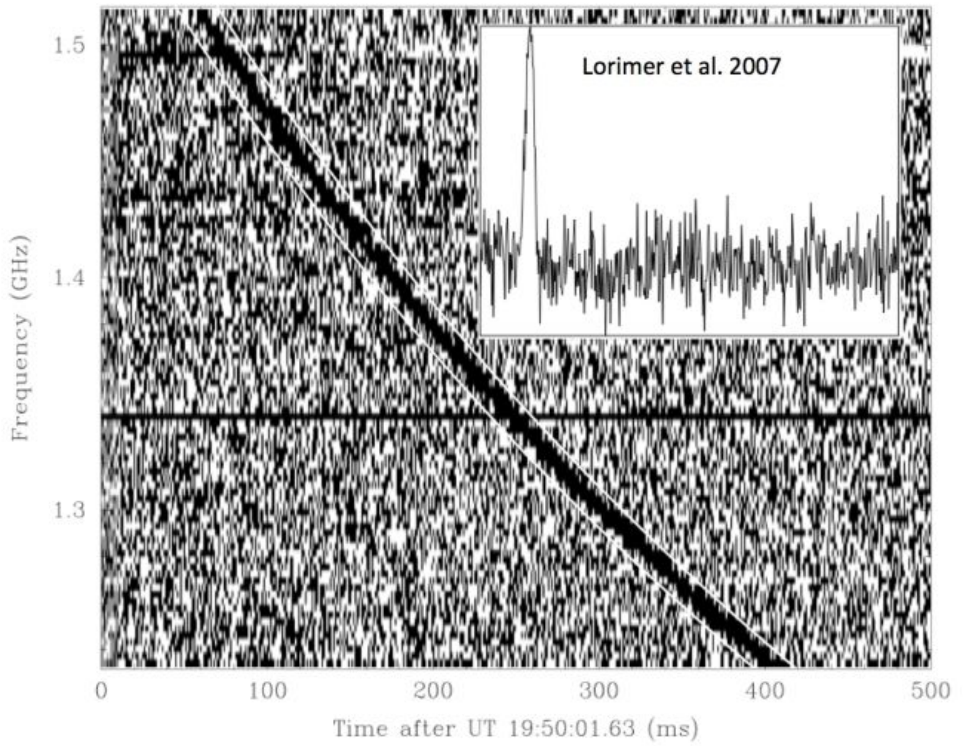
Credit: CTA Cons.

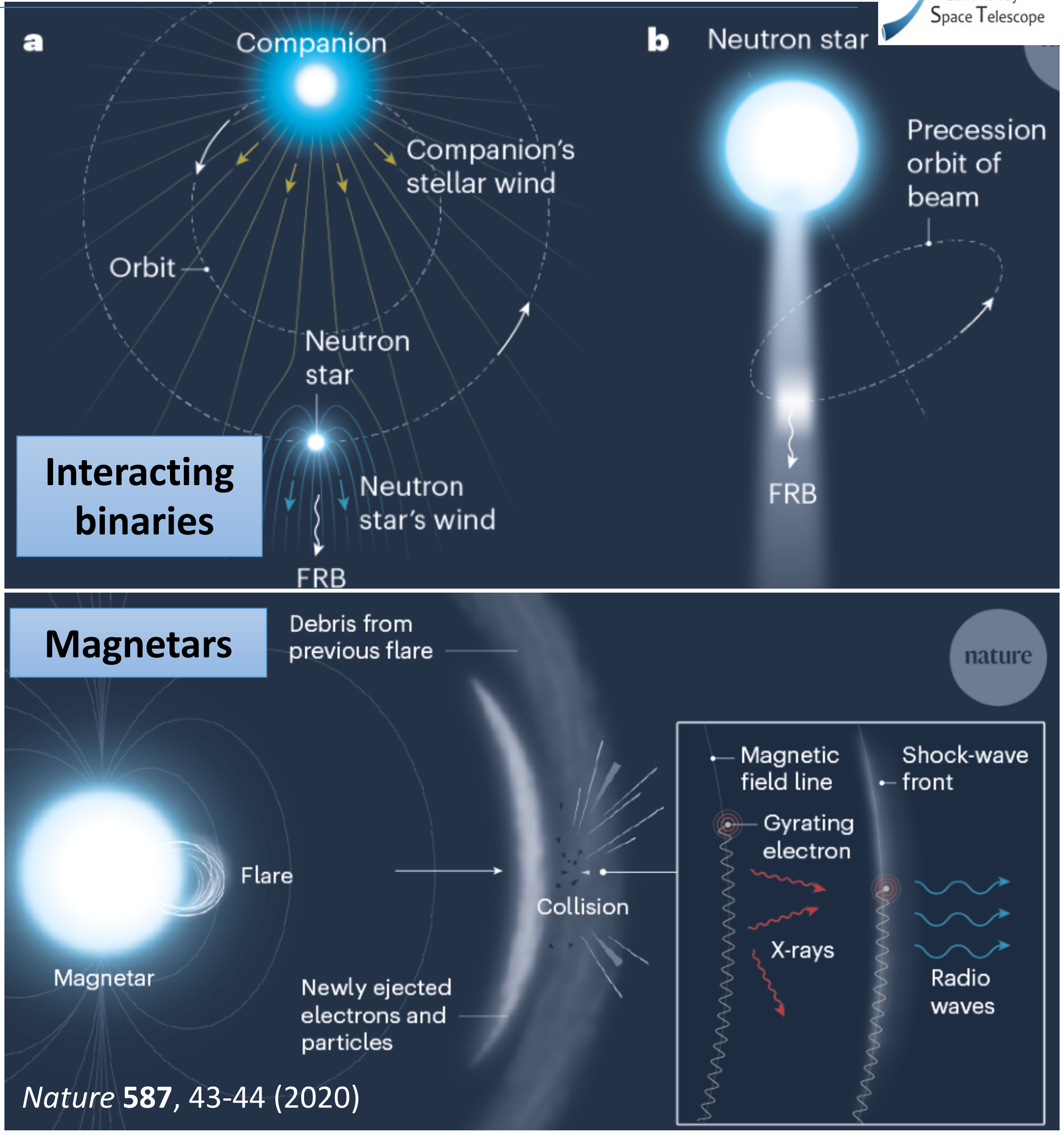


Magnetars and Fast Radio Burst (FRBs) connection??

Fast radio bursts (FRBs): are bright (Jy) and short-duration (few ms) radio pulses. Discovered just over a decade ago, FRBs are one of the newest astrophysical enigmas.

April 2020 for the first time, an FRB event was associated with Galactic magnetar giant flare (MGF) (SGR 1935+2154).

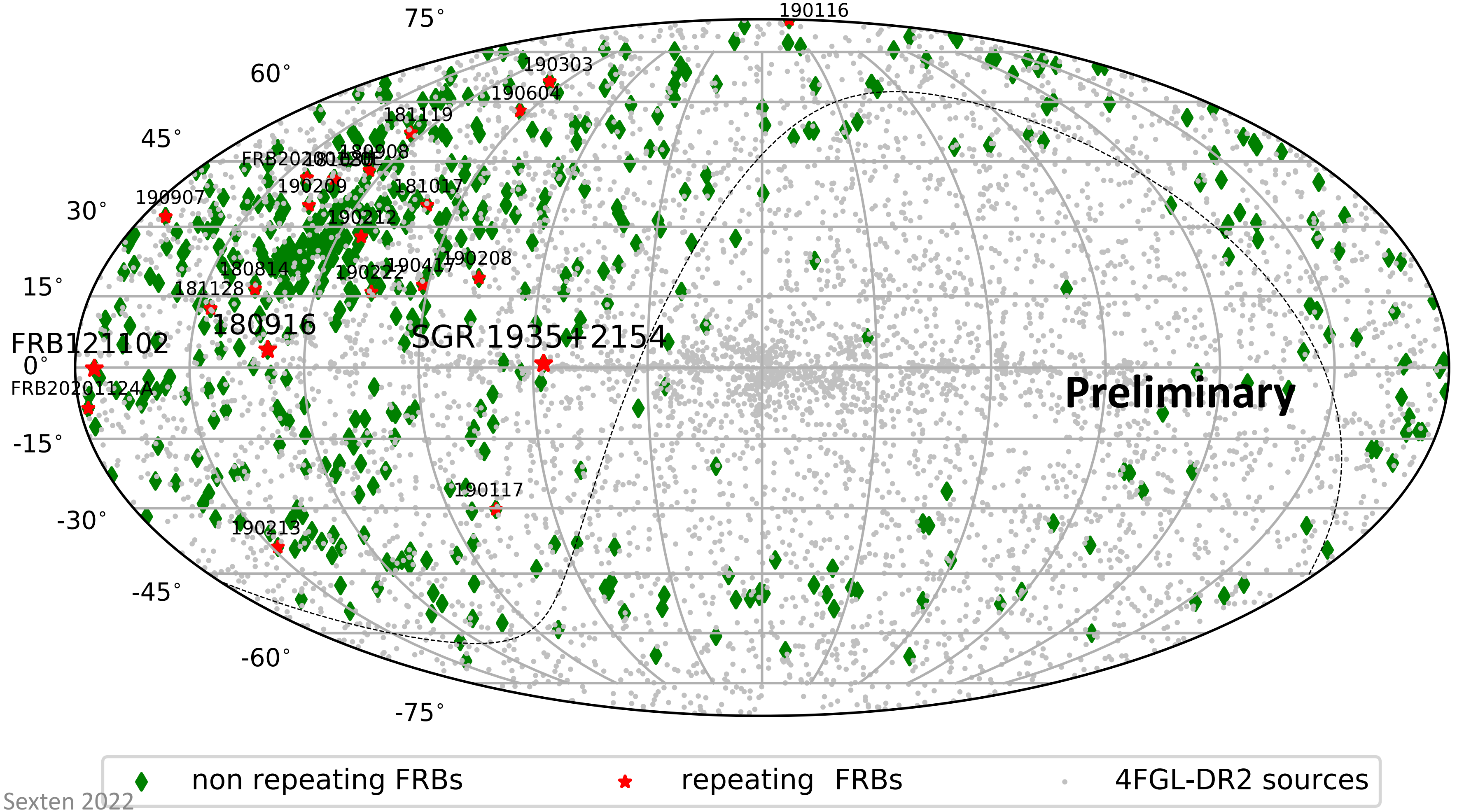




Nature **587**, 43-44 (2020)

Gamma-Ray / Fast Radio Burst connection?

Motivated by the detection of GeV emission from a magnetar flare (*Sculptor* galaxy), we are performing the largest and deepest systematic search for gamma-ray emission from all the reported repeating and non-repeating Fast Radio Burst (>1000 FRBs) using 12 years of *Fermi*-LAT data.



Preliminary results on the periodic FRB 180916

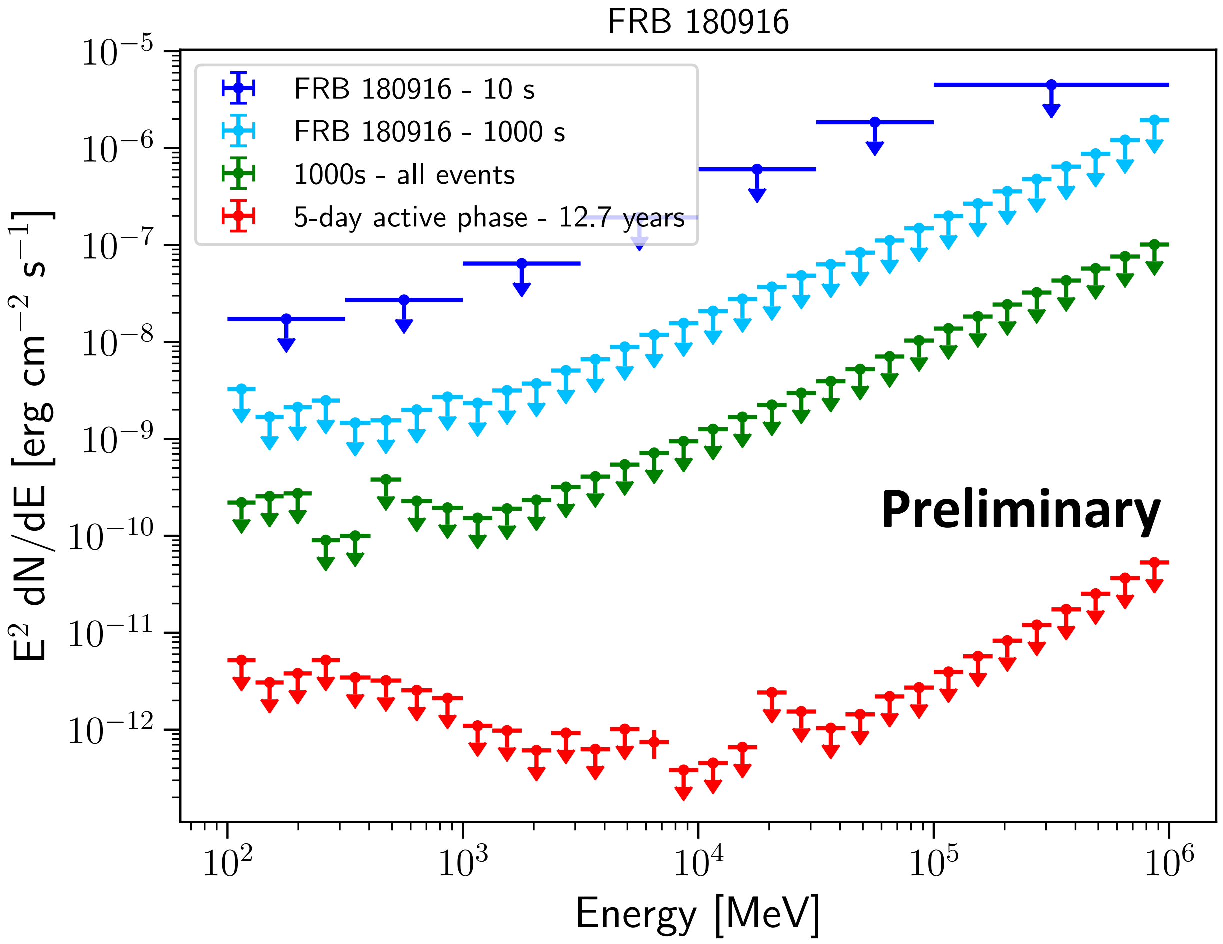
We search for high-energy emission from the periodic FRB 180916 (z=0.0337) with *Fermi*-LAT.

We provide the so-far most stringent upper limits on the gamma-ray emission from the FRB 180916 source during its 5.4-day active-phase window ($F_{\gamma\text{-ray}} < 2.3 \times 10^{-12}$ erg cm^{-2} s^{-1}, $L_{\gamma\text{-ray}} < 7.5 \times 10^{42}$ erg s^{-1}).

Our results provide crucial information on constraining the origin of FRBs and modelling their emission mechanisms.

Preliminary results in [Principe et al. 2021]

STAY TUNED!



Catalog of Long Transient Sources (10 years)

1FLT catalog on a monthly base [Baldini et al. 2021]: 142 transients (not in 4FGL-DR2) catalog.
102 AGN: 24 FSRQ; 1 with a BLLac; 70 BCU; 3 Radio Galaxies; 1 CSS radio source;
1 SSRQ; 2 other AGN. 40 unassociated.