The Fermi experiment status and results:
14 years of discoveries with Fermi Large Area Telescope

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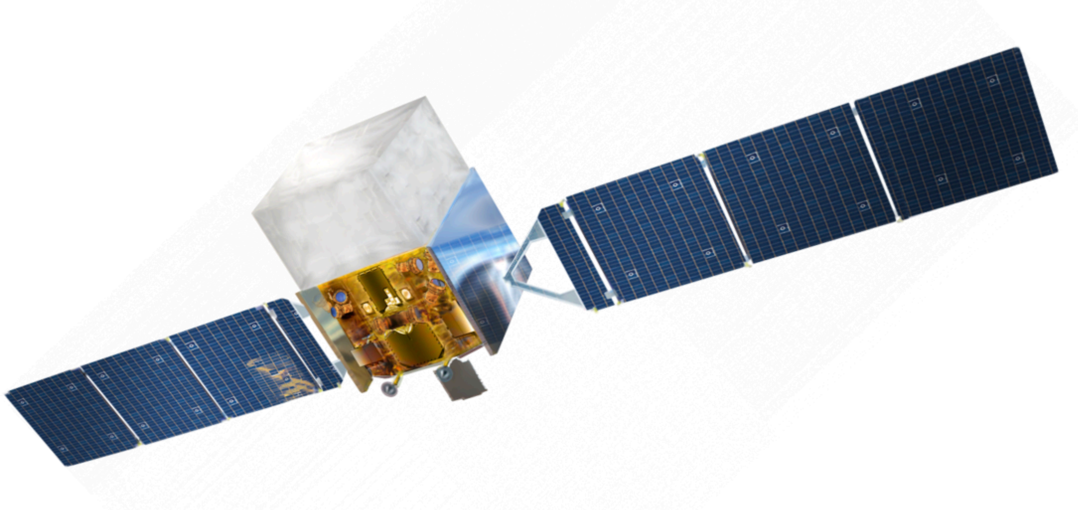
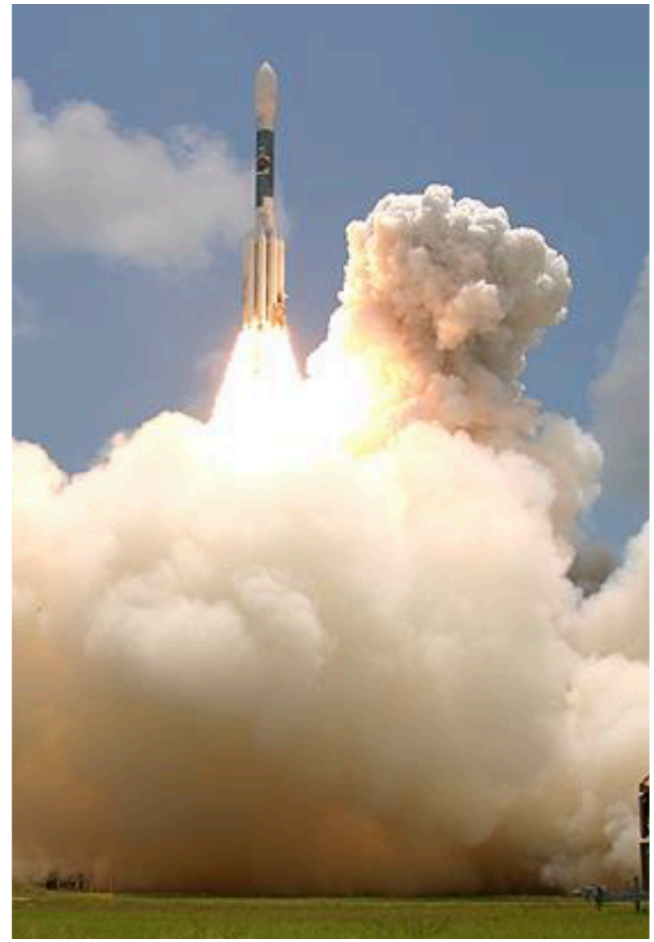
On behalf of the *Fermi* LAT Collaboration

Fermi Gamma-ray Space Telescope

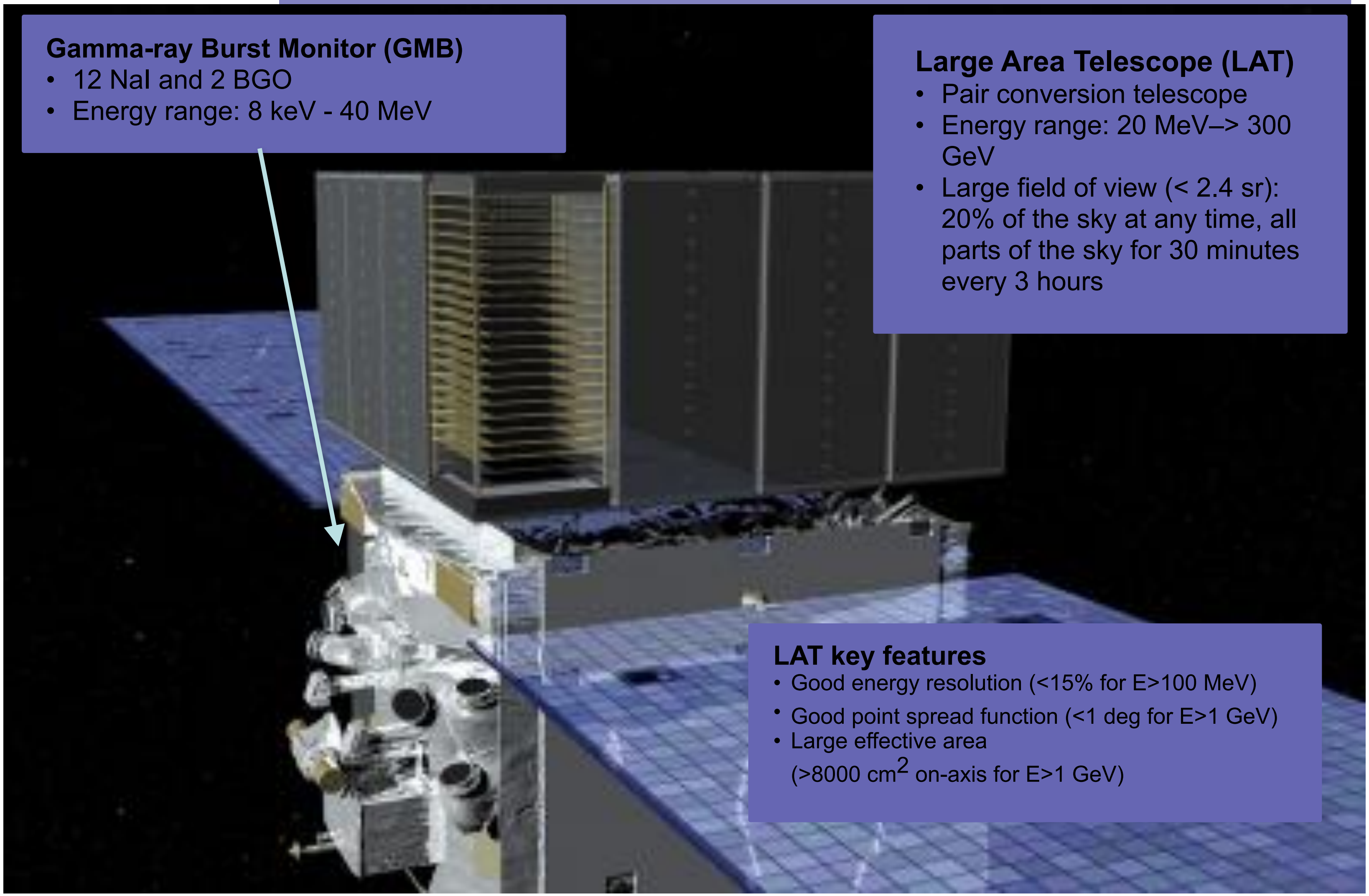
Launched by NASA on 2008 June 11, from Cape Canaveral, Florida. Science mission started on August 2008.



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



Fermi Gamma-ray Space Telescope



Gamma-ray Burst Monitor (GMB)
- 12 NaI and 2 BGO
- Energy range: 8 keV - 40 MeV

Large Area Telescope (LAT)
- Pair conversion telescope
- Energy range: 20 MeV–> 300 GeV
- Large field of view (< 2.4 sr): 20% of the sky at any time, all parts of the sky for 30 minutes every 3 hours

LAT key features
- Good energy resolution (<15% for E>100 MeV)
- Good point spread function (<1 deg for E>1 GeV)
- Large effective area (>8000 cm^2 on-axis for E>1 GeV)

Atwood, W. B 2009ApJ...697.1071A

Fermi in numbers

Fermi-LAT in data

- 77805 orbits since launch
- 5187 days of science mission (2008 Aug. 4)
- LAT has 99.8% runtime

Event counts

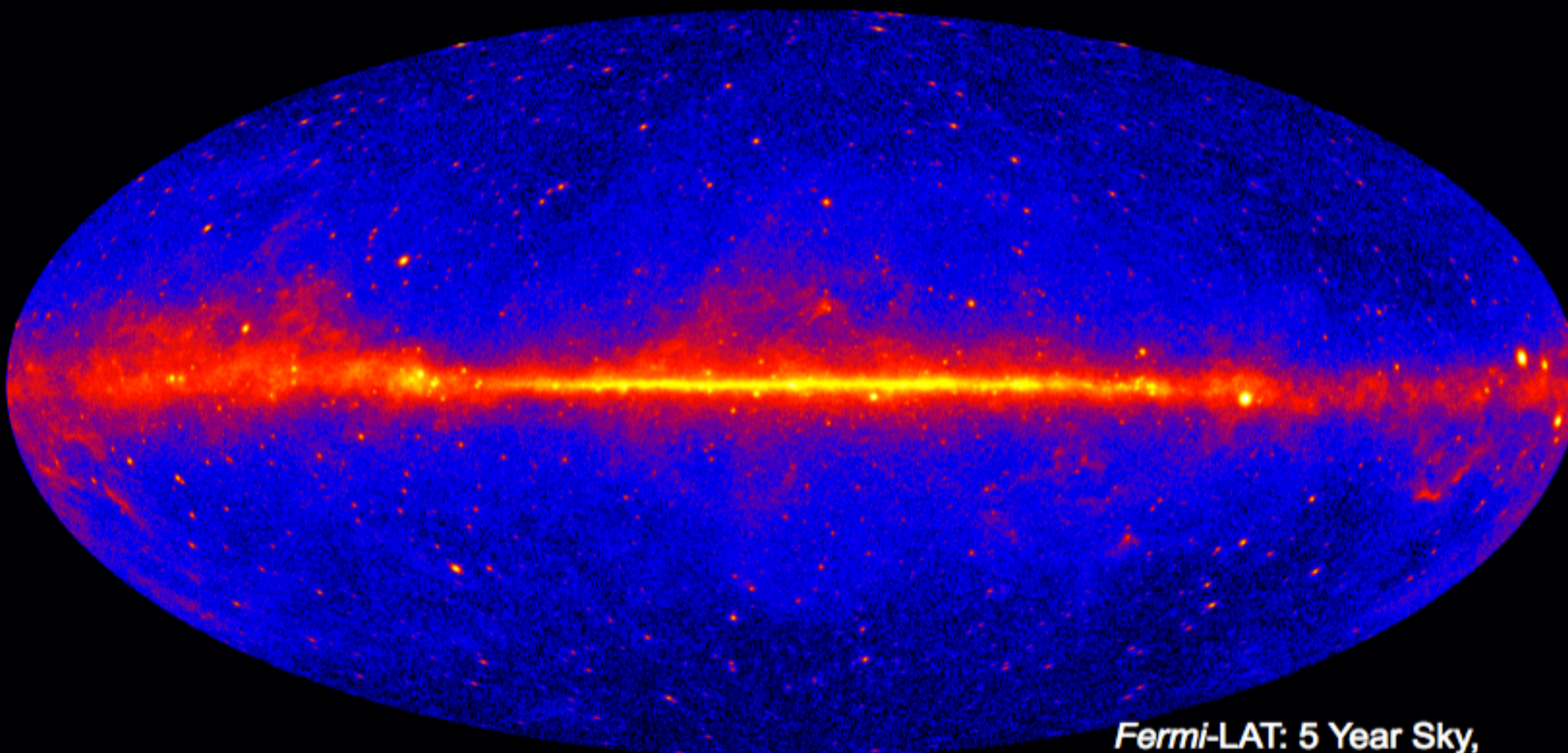
- ~ 8 billion triggers on the LAT
- ~ 170 billion events downlinked
- ~ 4 billion LAT events available at the FSSC

Short notice publications (LAT and GBM):

730 ATels of flaring source activity

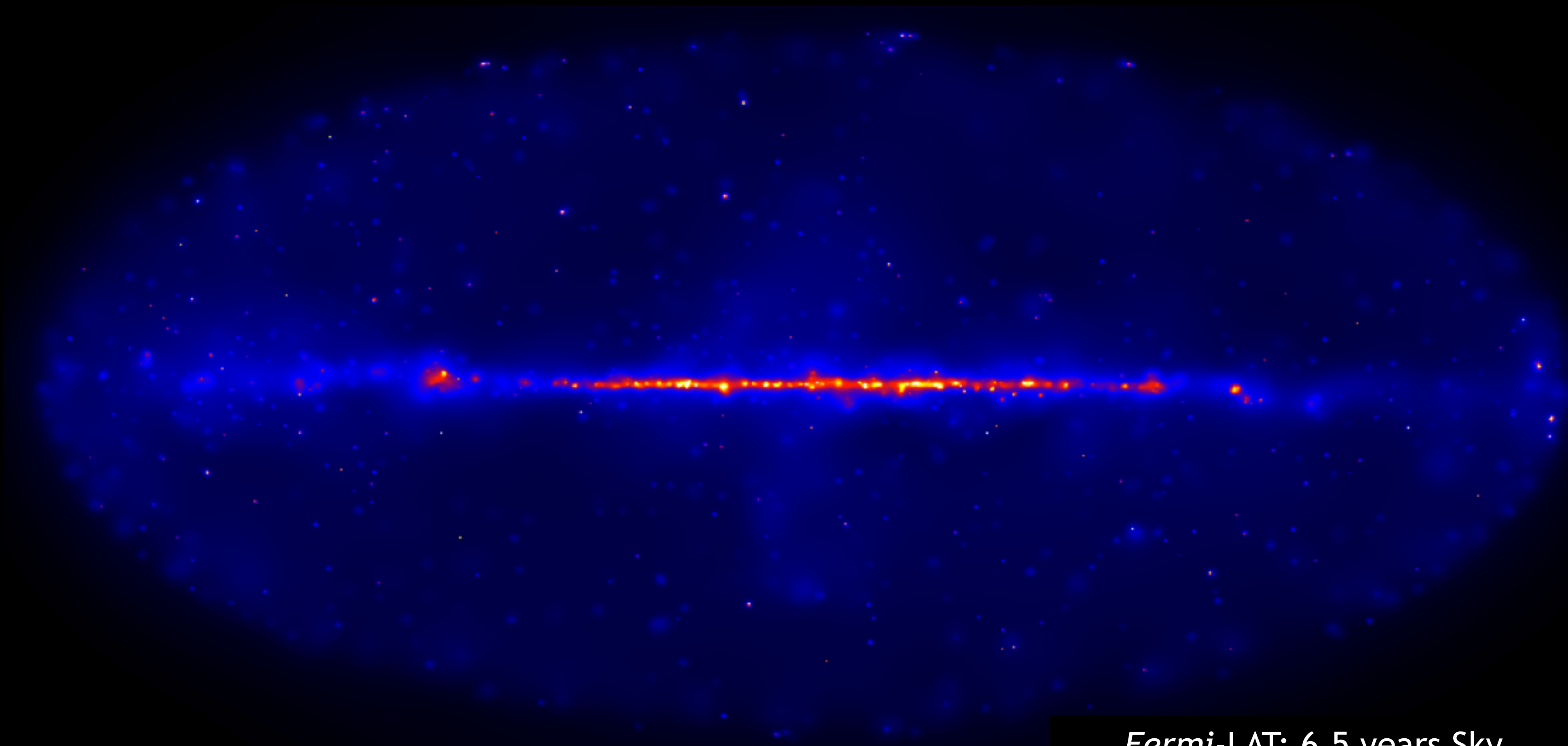
2205 GCN circular on GRB and others

γ-ray Sky



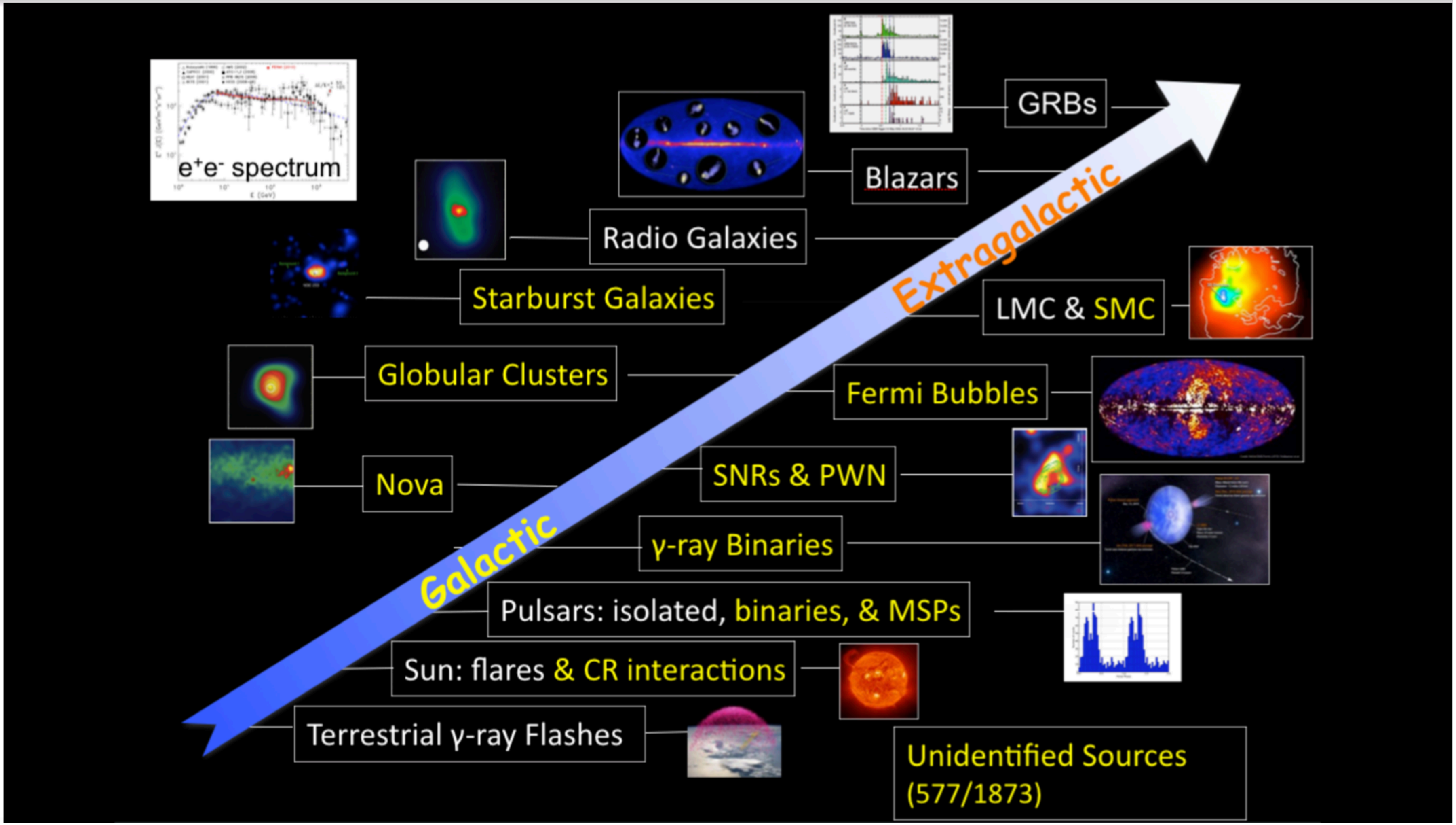
Fermi-LAT: 5 Year Sky,
Front-converting events > 1 GeV

γ-ray Sky

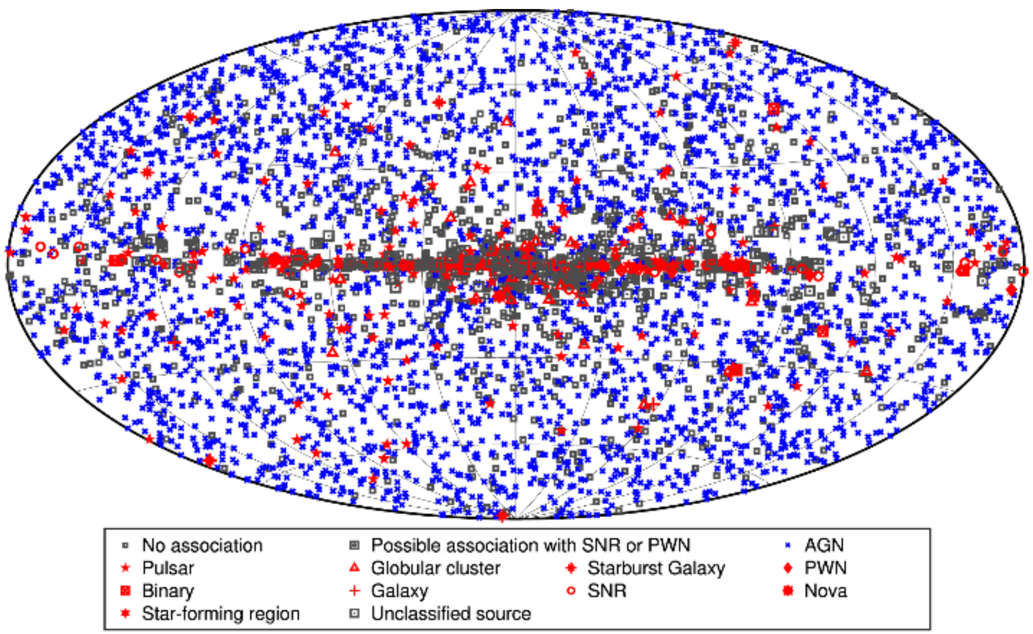


Fermi-LAT: 6.5 years Sky
Energy > 50GeV

Fermi-LAT science menù



4th Fermi-LAT Source Catalog



4FGL-DR3 catalog contains 6659 gamma-ray sources [1]
12 years of LAT
50 MeV < E < 1 TeV

Fermi-LAT catalog included source not seen before in gamma-ray:

non-AGN galaxies[3], globular clusters[8], high-mass binaries[2], novae[6]

Some source classes are more populated than expected:

milliseconds pulsars[5], radio quite pulsars and high redshift AGNs

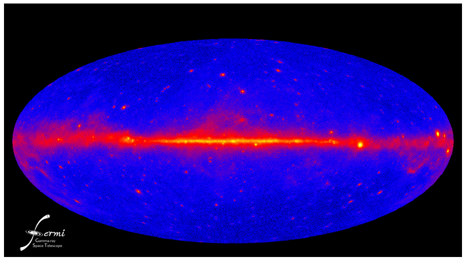
~30% of sources are still unassociated:

new type of gamma-ray emitters?

[1] Abdollahi et al. 2022ApJS...260...53A; [8]Abdo A. 2009Sci...325..845A
[2]Ackermann, M. 2012Sci...335..189F [3]Abdo A. A. 2010Sci...328..725A,
[5] Abdo A. A. 2009Sci...325..848A,[6]Ackermann, M. 2014Sci...345..554A,

Fermi-LAT and time domain astronomy

gamma-ray sky



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Blazar variability

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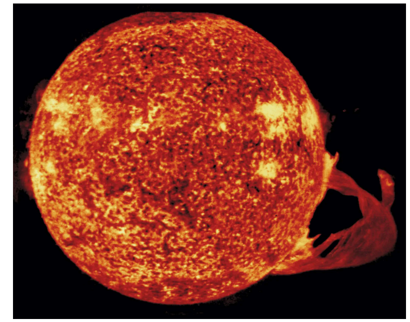
Solar flare



Flow of the talk

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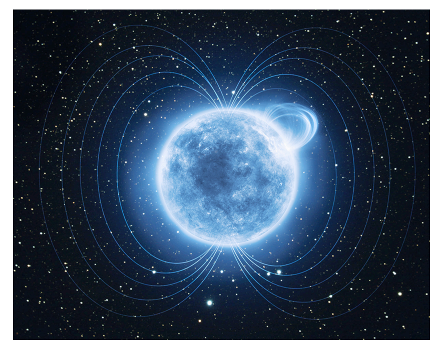
Magnetar and FRB



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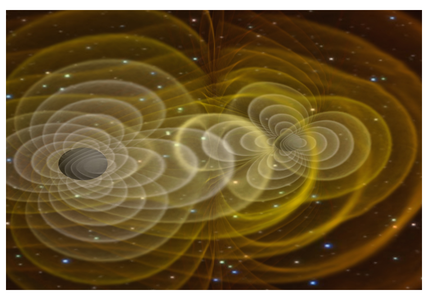
multimessenger astronomy and sources follow-up



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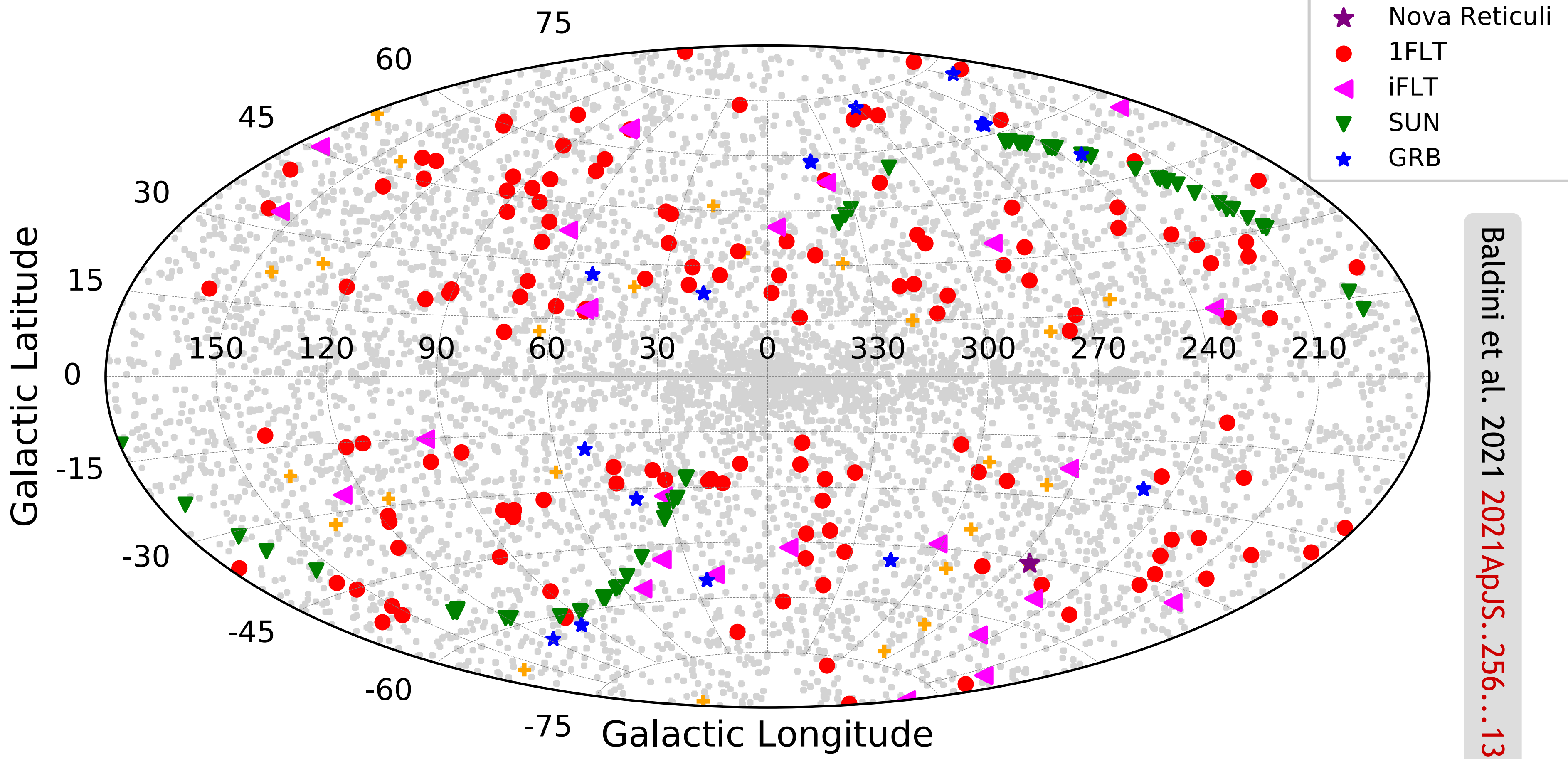
..looking forward

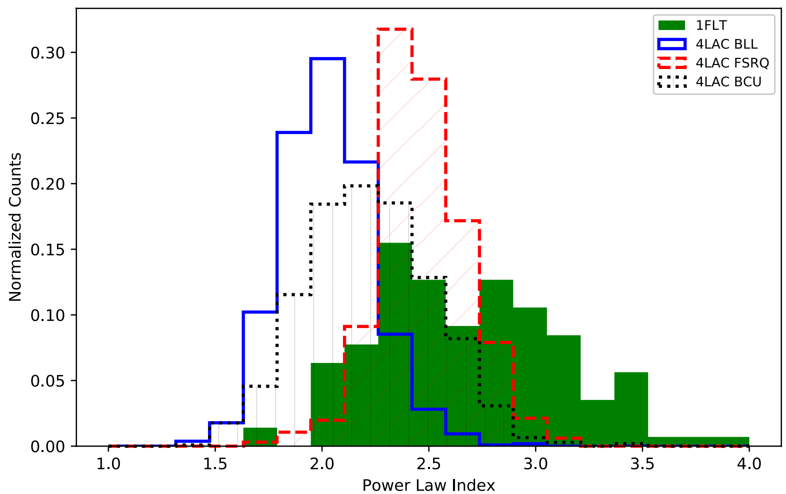
1FLT Catalog of Long-Term Transient Sources

142 new transient source in monthly time scale (not in 4FGL-DR2)

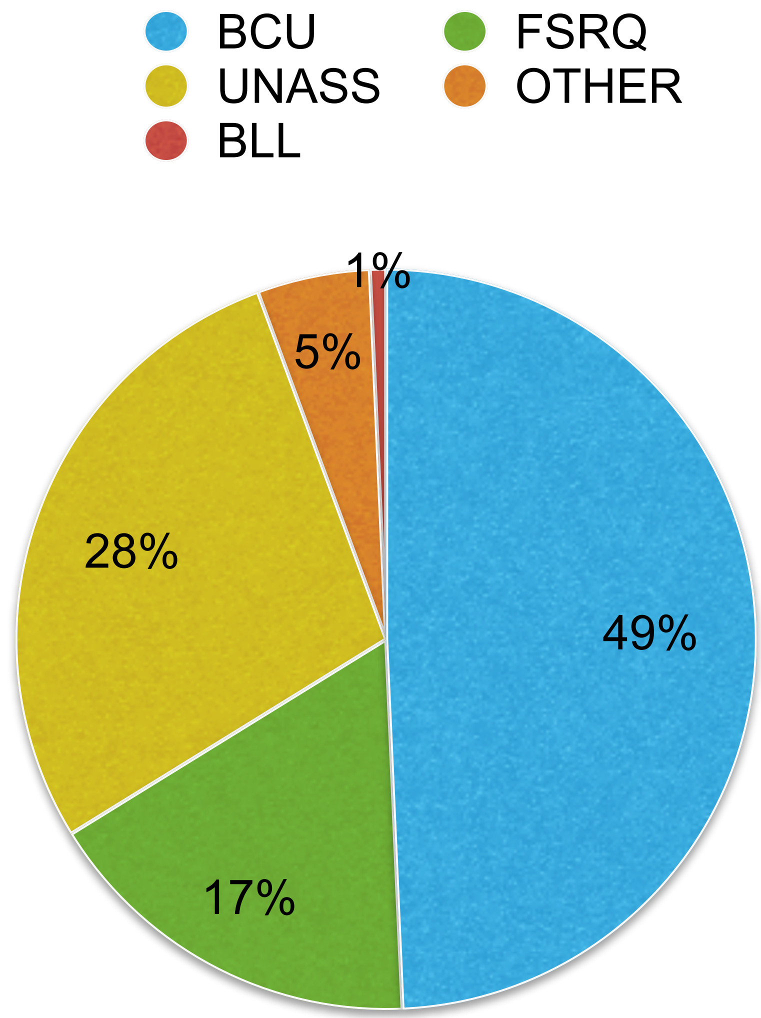


Baldini et al. 2021 2021ApJS..256...13B

1FLT Catalog of Long-Term Transient Sources



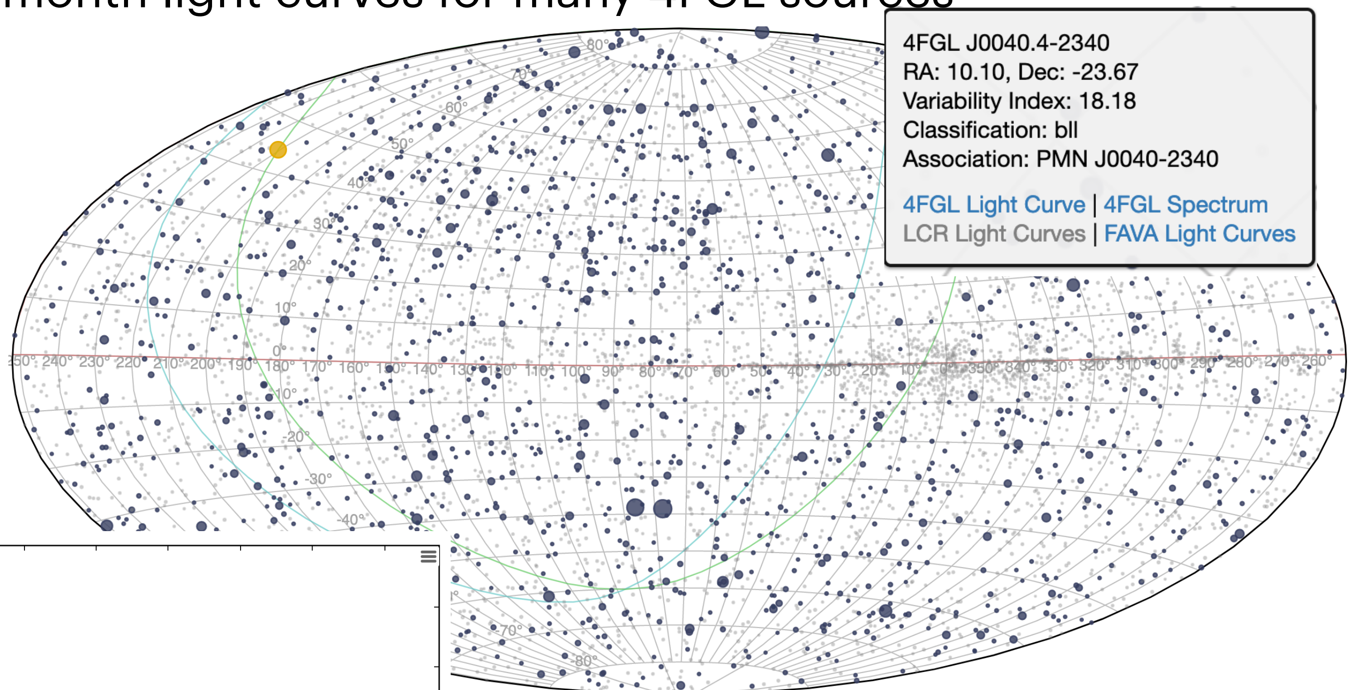
The 1FLT distribution extends to softer Γ values compared to 4LAC, with a median value of 2.7 compared to 2.2 of 4LAC (2.5 if we consider only 4LAC FSRQs.)

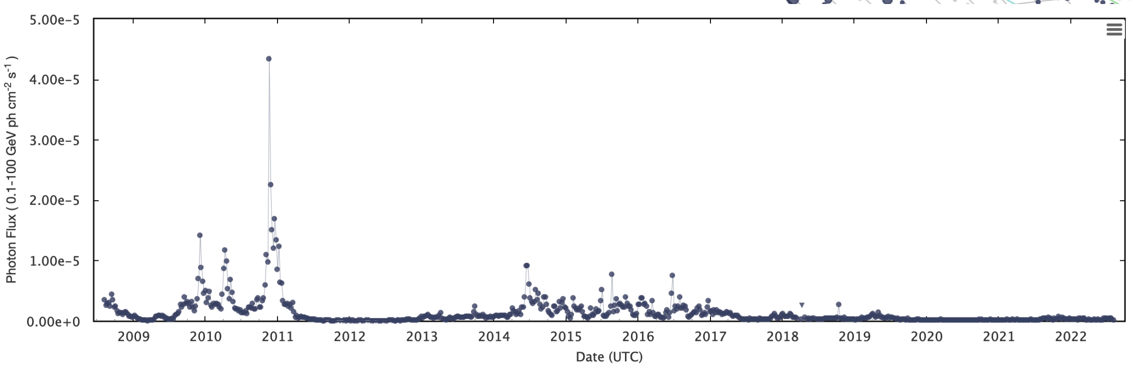


Fermi light curve repository online!

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
- Energy flux and photon flux
- Light curves derived from Maximum likelihood analysis





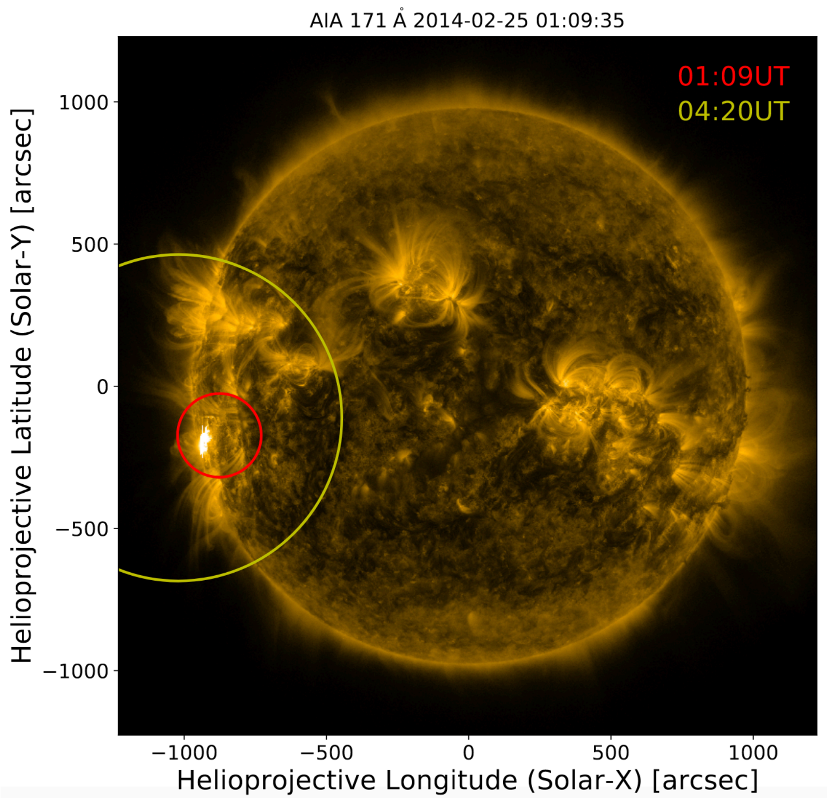
First Solar Flare Catalog

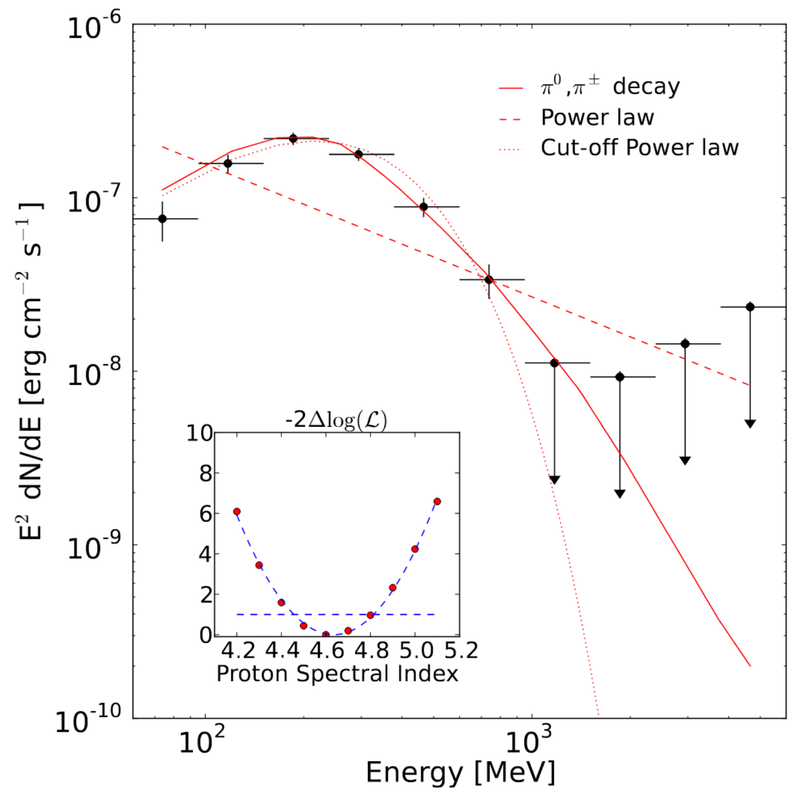
45 Fermi-LAT solar flares (*FLSF;* E > 60 MeV)

—> ***3 from behind the limb***

—>All but three of the flares in FLSF the catalog are associated with CMEs

Emission due to decay of pions (π0, π±) produced by > 300 MeV protons





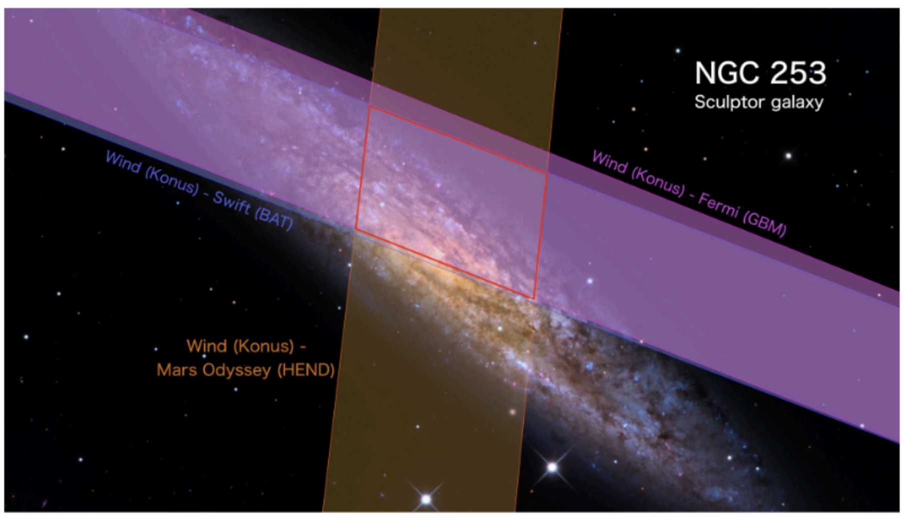
Ajello et al. 2021 2021ApJS..252...13A

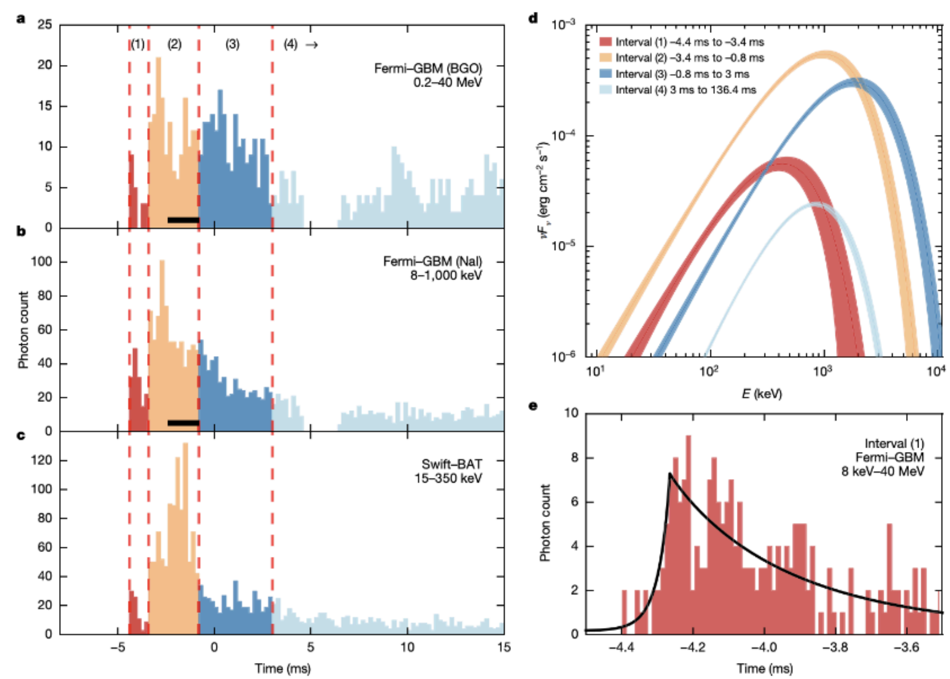
Magnetar Giant Flares

GRB 200415A

Transient on April 15th 2020

- GBM triggered at 08:48:05.56 UTC
- Localized with 20 square arcmin precision through interplanetary Network of gamma-ray detectors
- Burst most likely originated in star forming Sculptor Galaxy, DL~ 3.5 Mpc





Roberts et al. 2021 2021Natur.589..207R

Svinkin et al. 2021, 2021Nature.589..211S

Magnetar Giant Flares

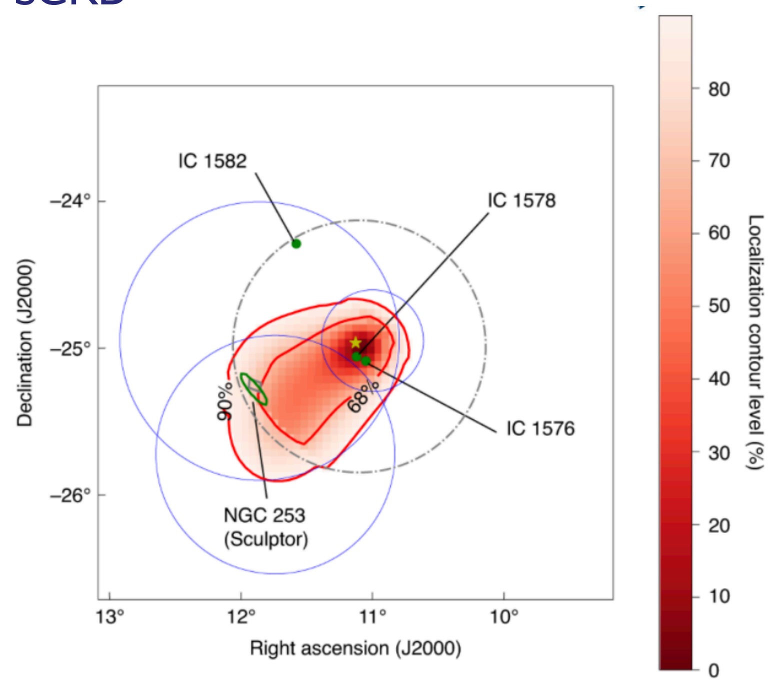
GRB 200415A

LAT detected 3 photons

Maximum test statistic TS=29

- NGC 253 (Sculptur gal.) at 72% localization CL
- Probability of chance coincidence: < 2.9 x 10-3
- Long delay of first photon to T0 atypical for sGRB

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

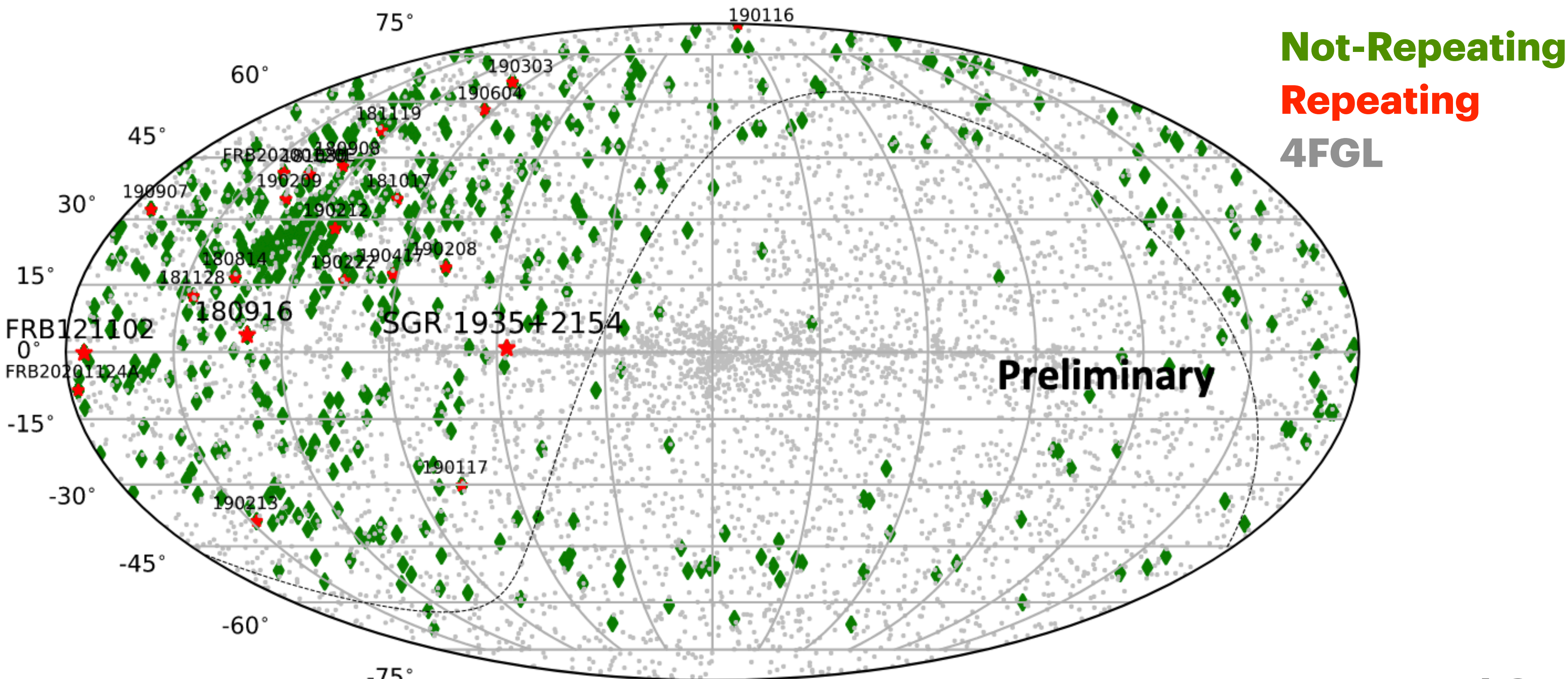


Ajello et al. 2021 2021NatAst...5585F

Magnetars and FRB connection?

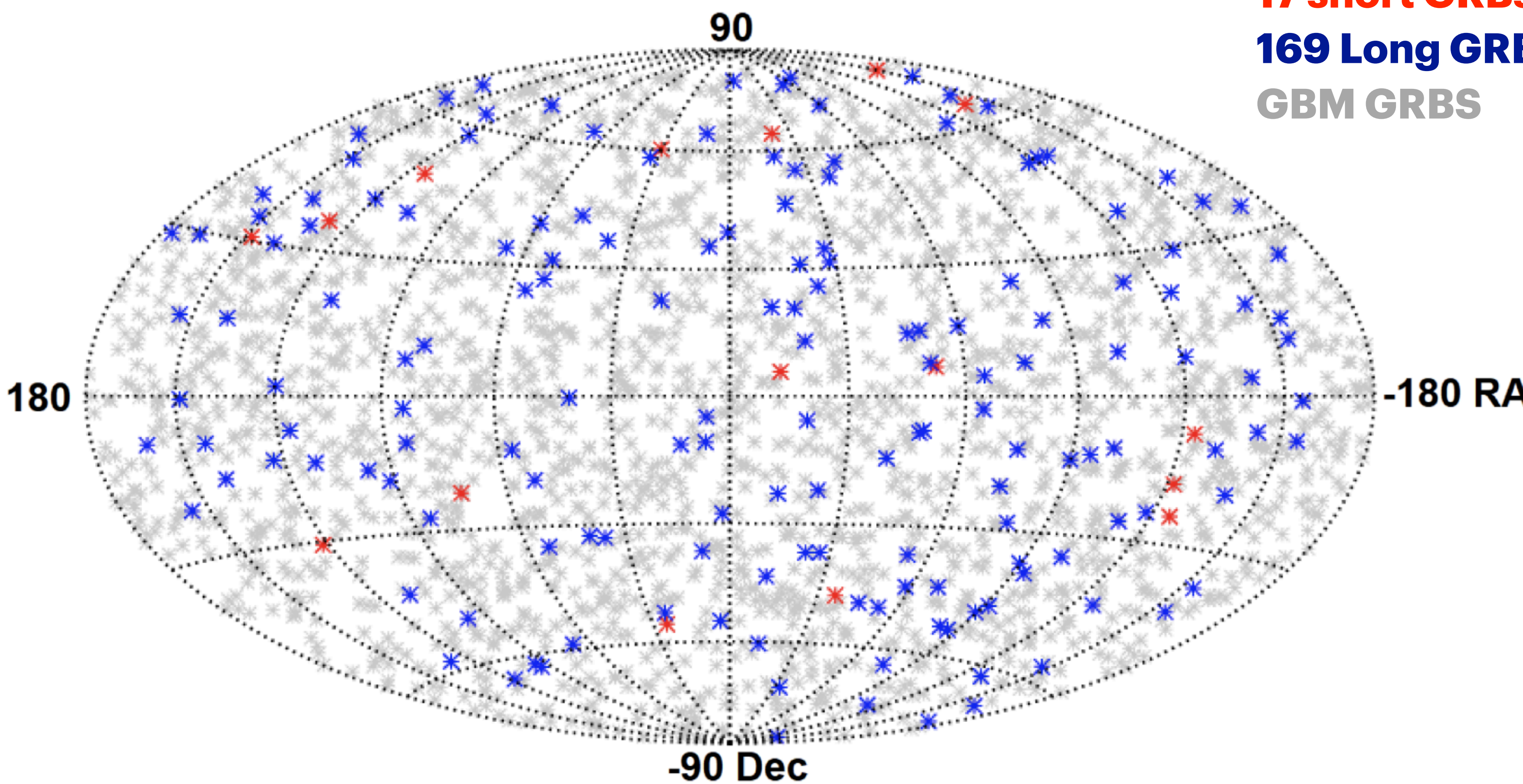
The recent LAT detection of GeV emission from a magnetar flare in the sculptor galaxy motivated the search for gamma-rays from FRBs

—>We are performing the largest and deepest systematic search for gamma-ray emission from all the reported repeating and not-repeating FRB with 12 years of Fermi-LAT data



Second Gamma Ray Burst Catalog

10 years of data
17 short GRBs
169 Long GRBs
GBM GRBS

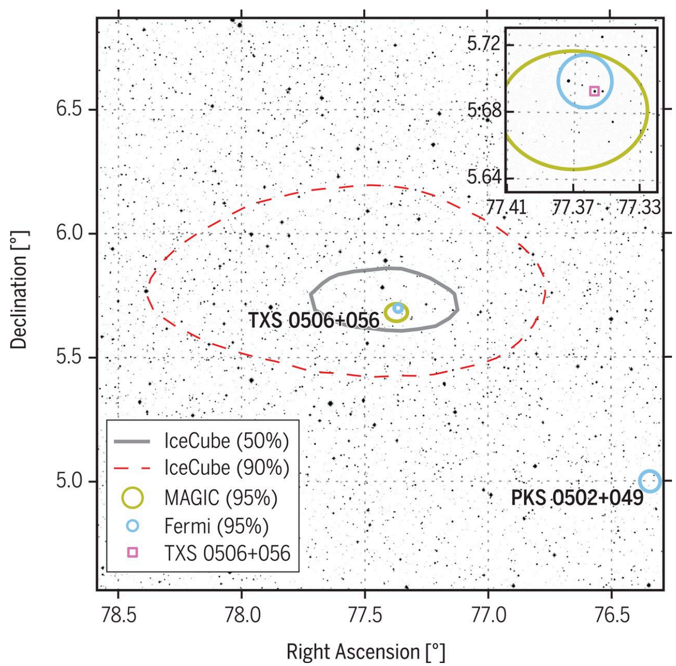


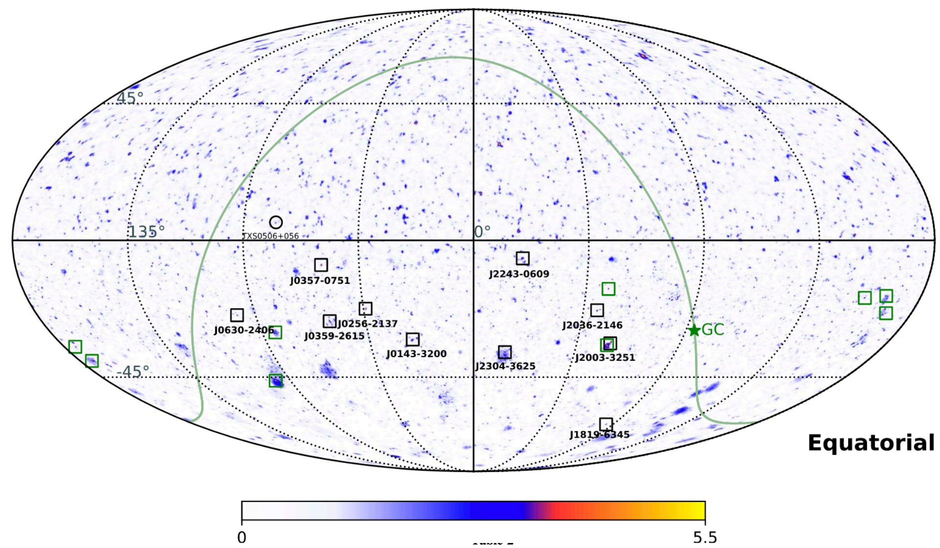
Ajello et al. 2019 2019ApJ...878...52A

Neutrino - gamma ray connection

Association of neutrino with flaring blazar TXS 0506+056 sparked interest to identify further counterparts

- So far, no other counterpart has been unambiguously identified—> however 10 IceCube neutrino's hotspots located in the southern sky are likely originated from blazars





List of PeVatron blazars/Neutrino Hotspot Associations Found by This Work

IceCube Hotspots				Blazar Associations		
	α_{hs}[°]	δ_{hs}[°]	L	5BZCat	z	Separation[°]
IC J2243−0540	340.75	−5.68	4.012	5BZB J2243−0609	0.30[c]	0.47
IC J0359−0746	59.85	−7.78	5.565	5BZQ J0357−0751	1.05	0.42
IC J0256−2146	44.12	−21.78	4.873	5BZQ J0256−2137	1.47	0.17
IC J2037−2216	309.38	−22.27	4.664	,5BZQ J2036−2146	2.299	0.51
IC J0630−2353	97.56	−23.89	4.420	5BZB J0630−2406[a],[b]	>1.238[d]	0.28
IC J0359−2551	59.94	−25.86	4.356	55BZB J0359−2615[a]	1.47[e]	0.40
IC J0145−3154	26.28	−31.91	4.937	55BZU J0143−3200[a]	0.375	0.42
IC J2001−3314	300.41	−33.24	4.905	5BZQ J2003−3251	3.773	0.53
IC J2304−3614	346.03	−36.24	4.025	5BZQ J2304−3625	0.962	0.24
IC J1818−6315	274.50	−63.26	4.030	5BZU J1819−6345	0.063	0.53

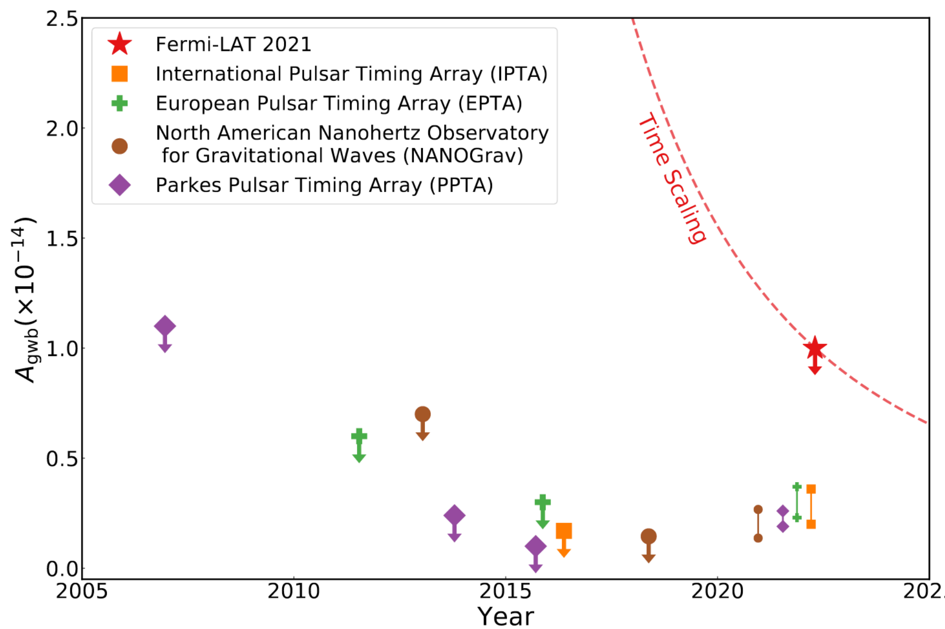
IceCube Coll. et al. 2018, 2018Sci...361.1378I; Garrappa et al. 2019, 2022icrc.confE.956G ; Buson et al 2022; 2022ApJ...933L..43B

Gamma-ray pulsar timing array (PTA)

Coalescing supermassive black holes in the centers of merging galaxies fill the universe with low-frequency gravitational waves (@nanohertz)

Searches for this background utilize pulsar timing arrays.
—>We use 12.5 years and 35 brightest MSP of Fermi Large Area Telescope data form a gamma-ray pulsar timing array.

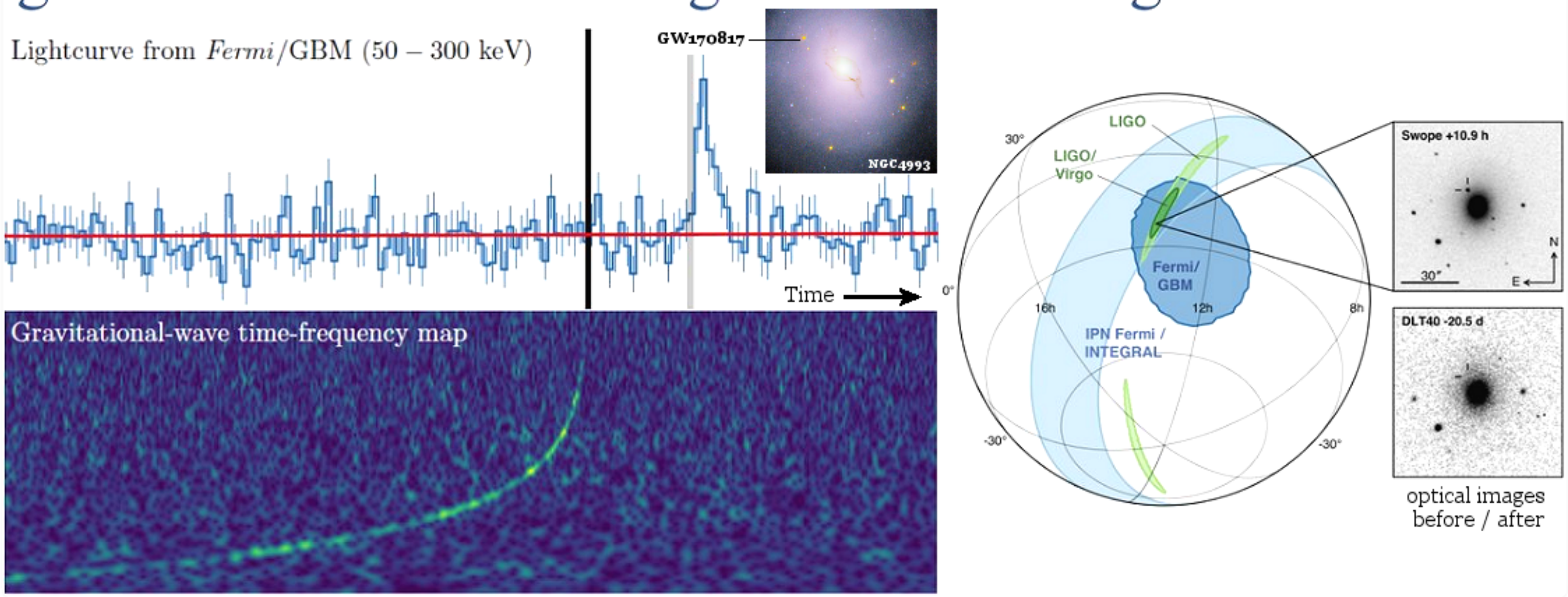
This provides an independent method to search for signals detected by radio PTAs; unlike the radio PTAs, it is free from the effects of the ionized interstellar medium.



Ajello et al. 2019; 2022Sci...376..521F

Gravitational wave follow-up

LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars



Fermi plays a fundamental rule in the follow-up of GW—> huge FoV and good localization

Abbott et al. 2017; 2017ApJ...848L..12A
Abbott et al. 2017; 2017ApJ...848L..13A

Gravitational wave follow-up

The new GW observing run is approaching; O4 will start at the end of the year

Promising previsions for Fermi in O4

GW+ GRBs conservative approach

Model	$\mathcal{R}(0)$	GW	GW+EM (prompt)							
			Swift/BAT		Fermi/GBM		INTEGRAL/IBIS		SVOM/ECLAIRs	
			uniform	structured	uniform	structured	uniform	structured	uniform	structured
	$Gpc^{-3}yr^{-1}$	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}
A1	31	1	0.0006 (0.0023)	0.014-0.020	0.003 (0.013)	0.070-0.11	0.0001 (0.0004)	0.0024-0.0035	0.0005 (0.0019)	0.013-0.017
A3	258	5	0.003 (0.01)	0.07-0.10	0.017 (0.068)	0.35-0.54	0.0005 (0.002)	0.01-0.02	0.002 (0.01)	0.06-0.08
A7	765	13	0.008 (0.031)	0.18-0.26	0.045 (0.18)	0.91-1.42	0.001 (0.005)	0.031-0.046	0.006 (0.025)	0.17-0.22

GW+ GRBs more optimistic approach

Model	$\mathcal{R}(0)$	GW	GW+EM (prompt)							
			Swift/BAT		Fermi/GBM		INTEGRAL/IBIS		SVOM/ECLAIRs	
			uniform	structured	uniform	structured	uniform	structured	uniform	structured
	$Gpc^{-3}yr^{-1}$	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}	yr^{-1}
A1	31	5	0.002 (0.01)	0.05-0.08	0.014 (0.06)	0.27-0.46	0.0005 (0.002)	0.009-0.014	0.002 (0.008)	0.05-0.07
A3	258	22	0.01 (0.04)	0.24-0.37	0.06 (0.26)	1.17-2.00	0.002 (0.008)	0.04-0.06	0.009 (0.04)	0.22-0.32
A7	765	61	0.03 (0.12)	0.67-1.05	0.18 (0.74)	3.28-5.65	0.006 (0.02)	0.11-0.18	0.02 (0.10)	0.63-0.90

Patricelli et al. 2022; 2022MNRAS.513.4159P

Summary and Conclusions

- Fermi's first 14 years have produced numerous scientific discoveries that have revolutionized our understanding of the gamma-ray universe

- 2022 Senior Review Panel had conveyed a highly favorable review of Fermi

—>The Fermi mission has been approved for another period of extended operations!

- Fermi-LAT and GBM are working without major problems:
  —>Fermi had his first hardware failure on March 16, 2018, however the observatory has so much flexibility that this glitch has only minor impact on science operations

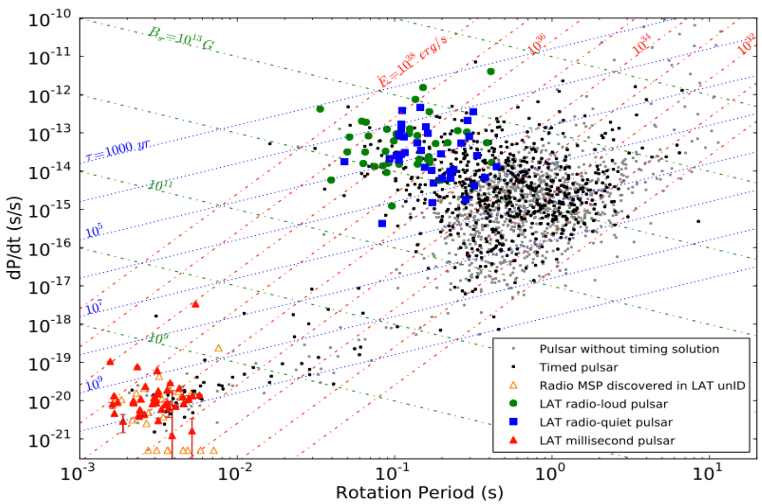
- Fermi observations remain indispensable for multi-messenger counterpart searches
  —>O4 observing run is approaching

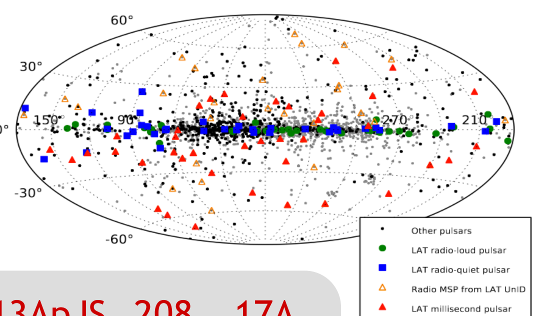
..... much more is waiting to be discovered!

Back-up slides

Pulsars population

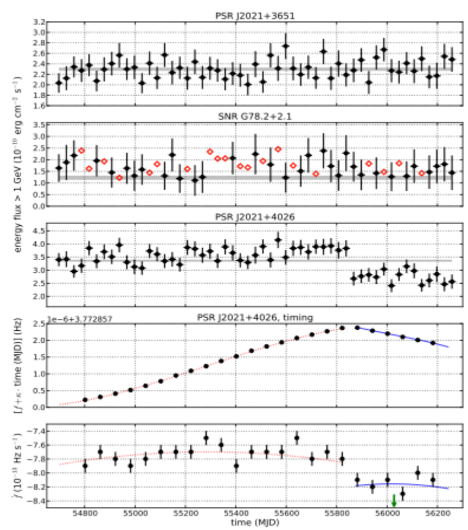
Family portrait



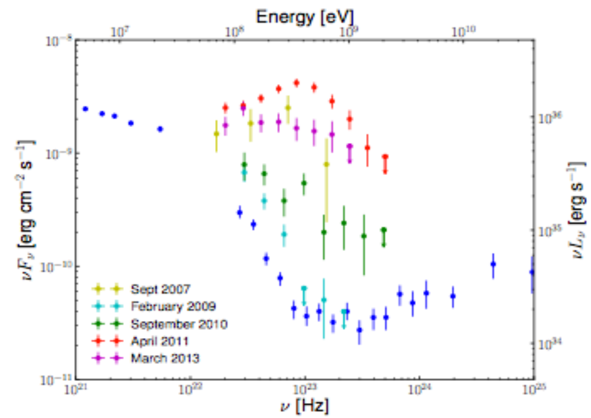


Before Fermi only 7 pulsars, now 147 with 2nd pulsars catalog [1]
Emission region location: outer-gap model preferred respect to the polar-gap[2]
Pulsars, considered the must stable sources were discovered to be variable![3,4]

PSR J2021+4026 in the Gamma Cygni region:
the first variable gamma-ray pulsar[3]



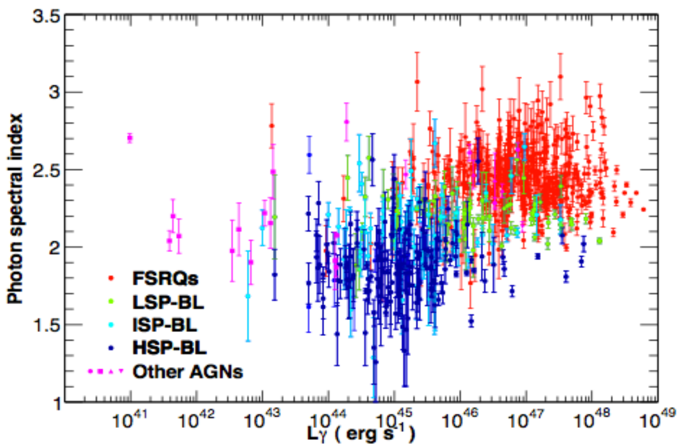
Crab flare related to the nebulae[4]

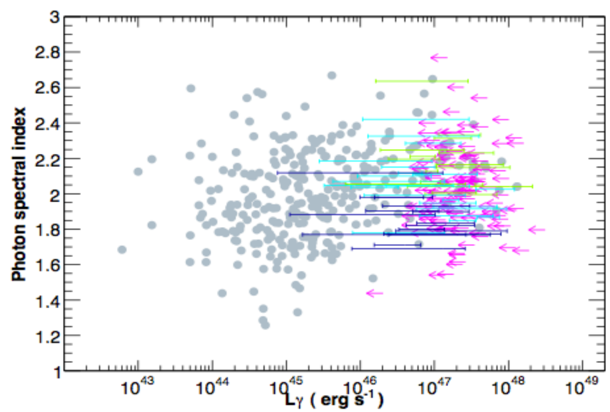


[1] Abdo A. A, 2013ApJS..208…17A
[2] Abdo A.A 2009ApJ...696.1084A
[3] Allafort, A. 2013ApJ...777L...2A
[4] Abdo A. A. 2011Sci...331..739A

Active Galaxy Nucleus population and evolution

The 75% of the gamma-ray sources are aligned AGN: blazars (BL Lacs + FSRQ)[1]
MW follow-ups provide z for many Fermi blazars introducing the LL a population of high redshift BL Lacs were found[1,2]

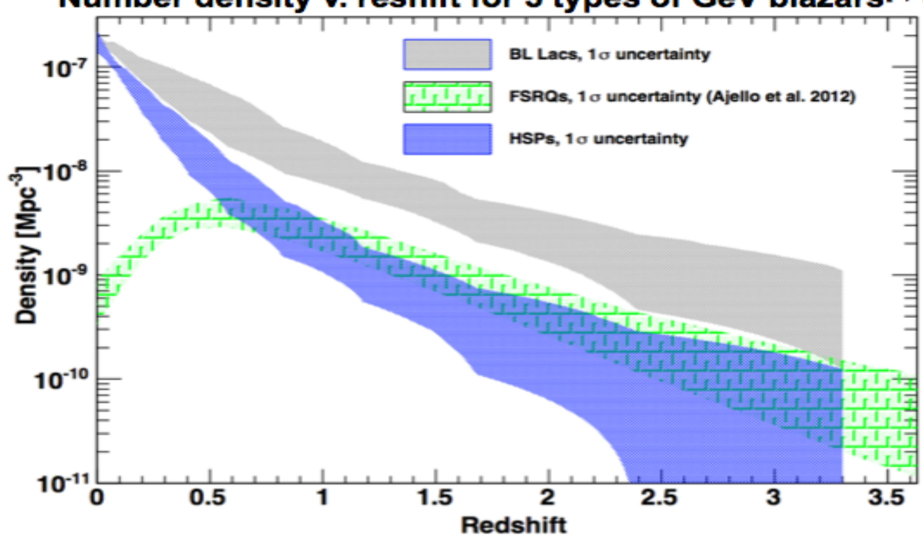




Many gamma-ray blazars in the early universe, but still unclear how to form so many supermassive BH so early

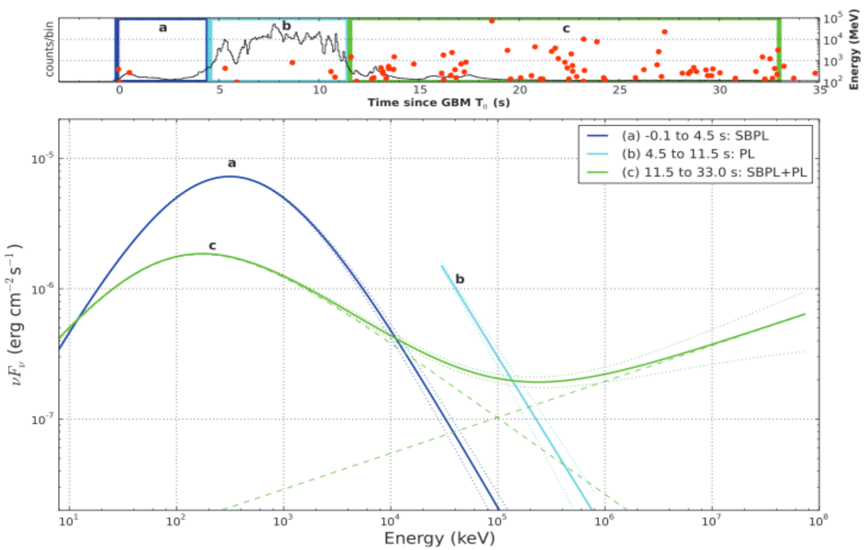
Population studies show that the high syn peaked BL Lacs could be the evolution of FSRQ that cleans up the surrunding[3]

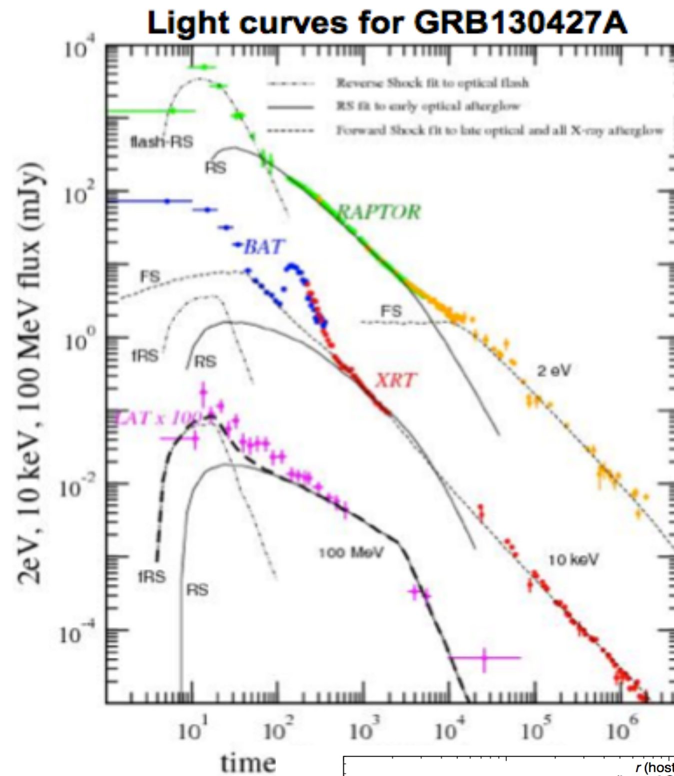
Number density v. reshift for 3 types of GeV blazars[1,2]



[1]Ackermann M. 2015arXiv150106054A
[2] Shaw M. 2013ApJ...764..135S
[3] Ajello, M. 2014ApJ...780...73A

GRB 130427A: a nearby monster

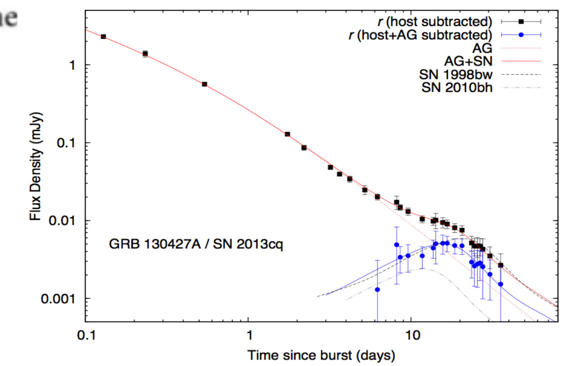




[1] Ackermann, M. 2014Sci...343...42A
[2] D. Xu 2013ApJ...776...98X
[3] Maselli, A. 2014Sci...343...48M

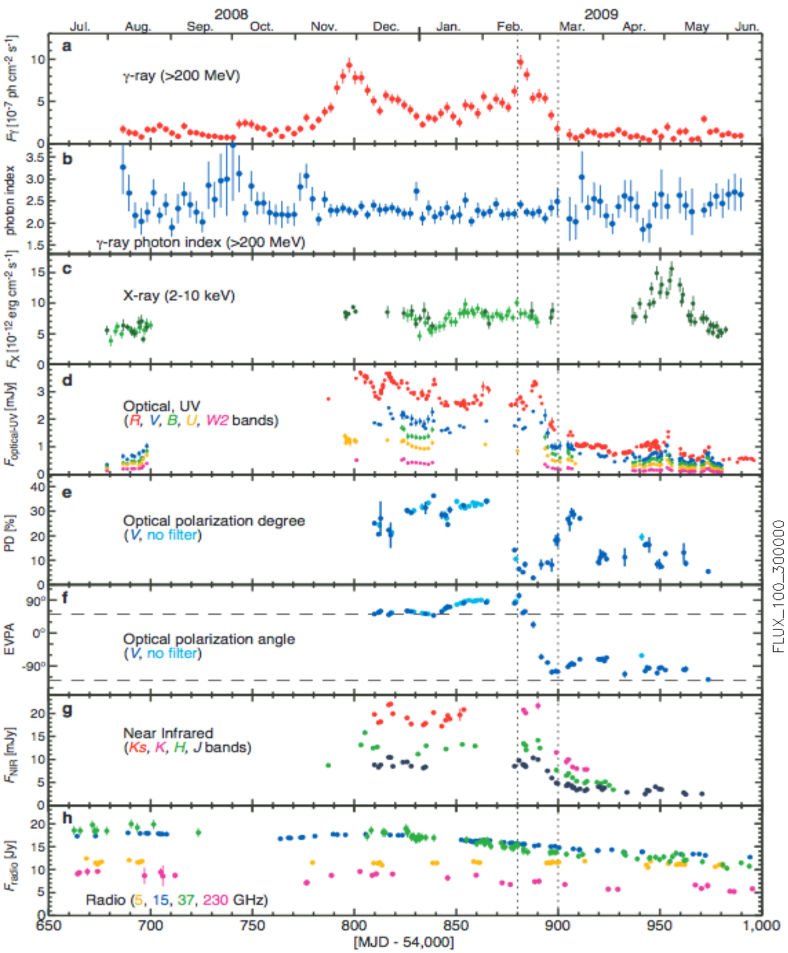
Record breaking:

Highest γ-ray fluence (prompt) > 10^{-3}erg/cm^2[1]
Highest γ-ray photons detected 95GeV[1]
Longest live γ-ray emission (prompt+afterglow)[1]
First Fermi-LAT γ-ray GRB with super novae detection:
GRB 130427A/SN 2013cq connection[2]
2th brightest optical flash ever observed[3]
Prompt emission described as Self Synchrotron Compton[1]



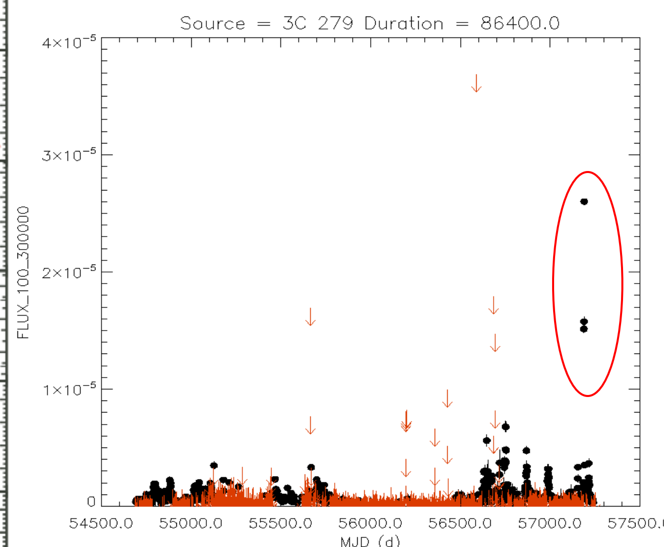
3C 279: one of the most famous

History of flux in various band and optical polarization during the 2009 flare



Strong gamma-ray flare in Feb. 2009 with associated a drammatic change of the polarization angle:

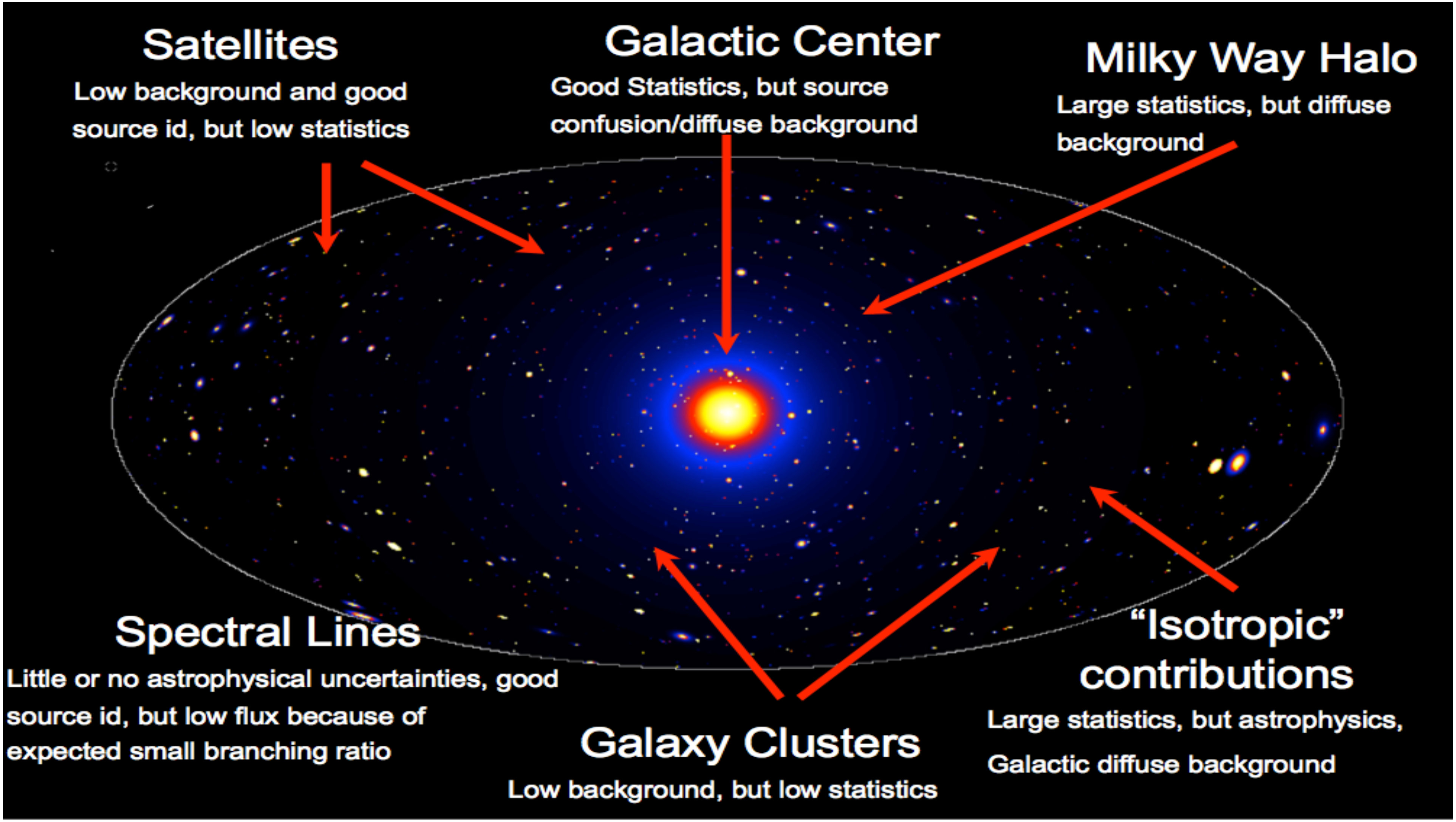
- ➔co-spatiality of the optical and gamma-ray emission zone
- ➔highly ordered jet magnetic field
- ➔emission region distant from the BH
- ➔Possibility of a bend jet scenario



NEWS: Record flux in 14 June 2015 since 1991
The brighter object in the sky for few hours[2]

[1] Abdo, A.,A.2010Natur.463.919A
[2] Cutini, S. 2015ATel.7633....1C

LAT target of DM search



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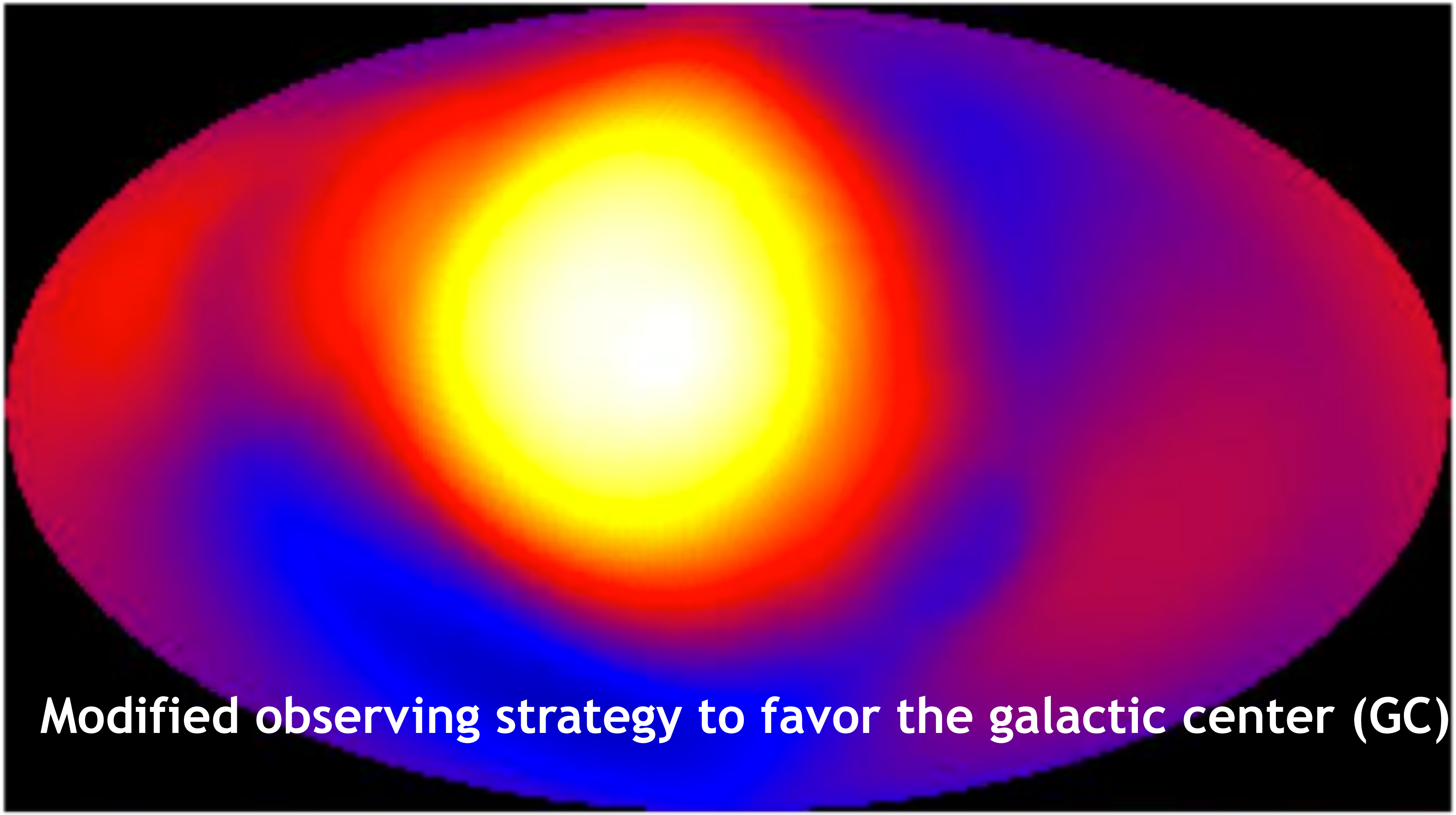
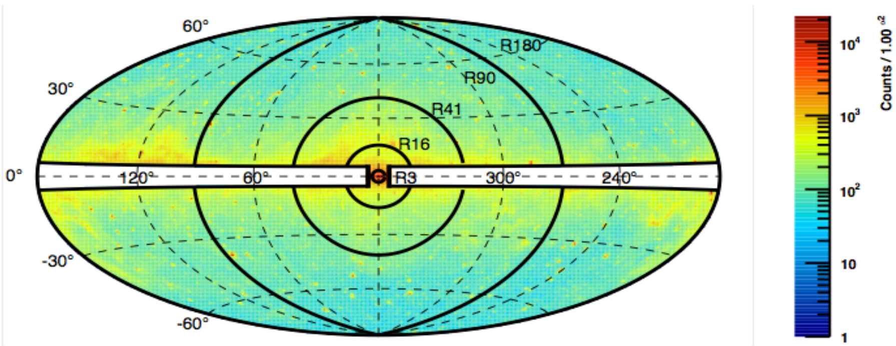
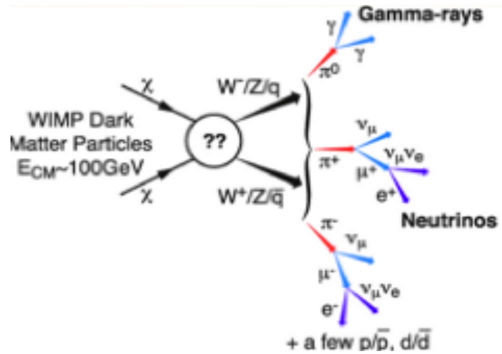


Search for spectral line: 133 GeV case

Weakly Iteracting Massive Particles (WIMP) are a promising dark matter candidate
Indirect DM search: WIMP annihilation

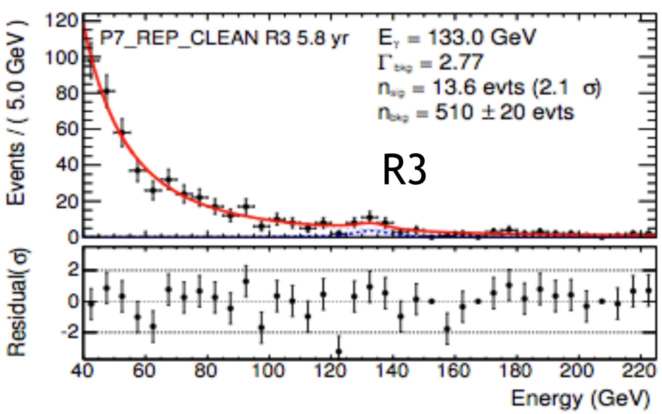
Definition of the ROI centered in the GC

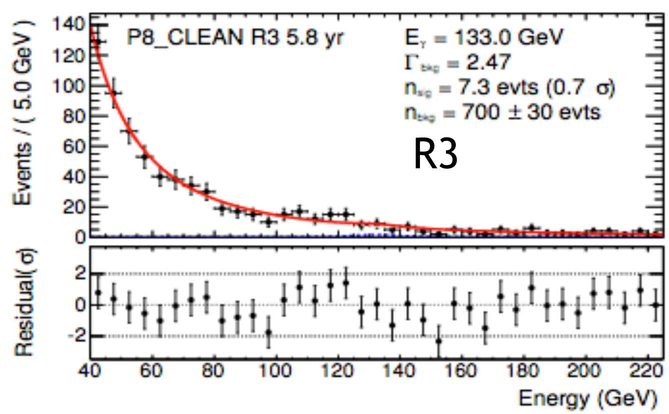




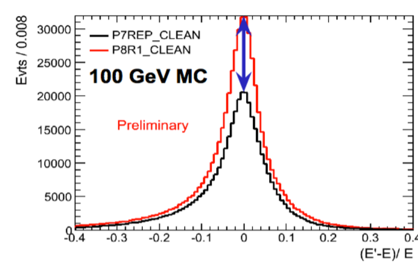
[1] Ackermann, M. 2013PhRvD..88h2002A
[2] Ackermann, M. 2015PhRvD..91l2002A
[3] Weniger C. 2012JCAP...08..007W

No globally spectral lines is detected with P7rep $\sigma<2$[1], even smaller significance with P8[2]
Too narrow feature in 133 GeV is seen with P7rep (previously reported in [3])



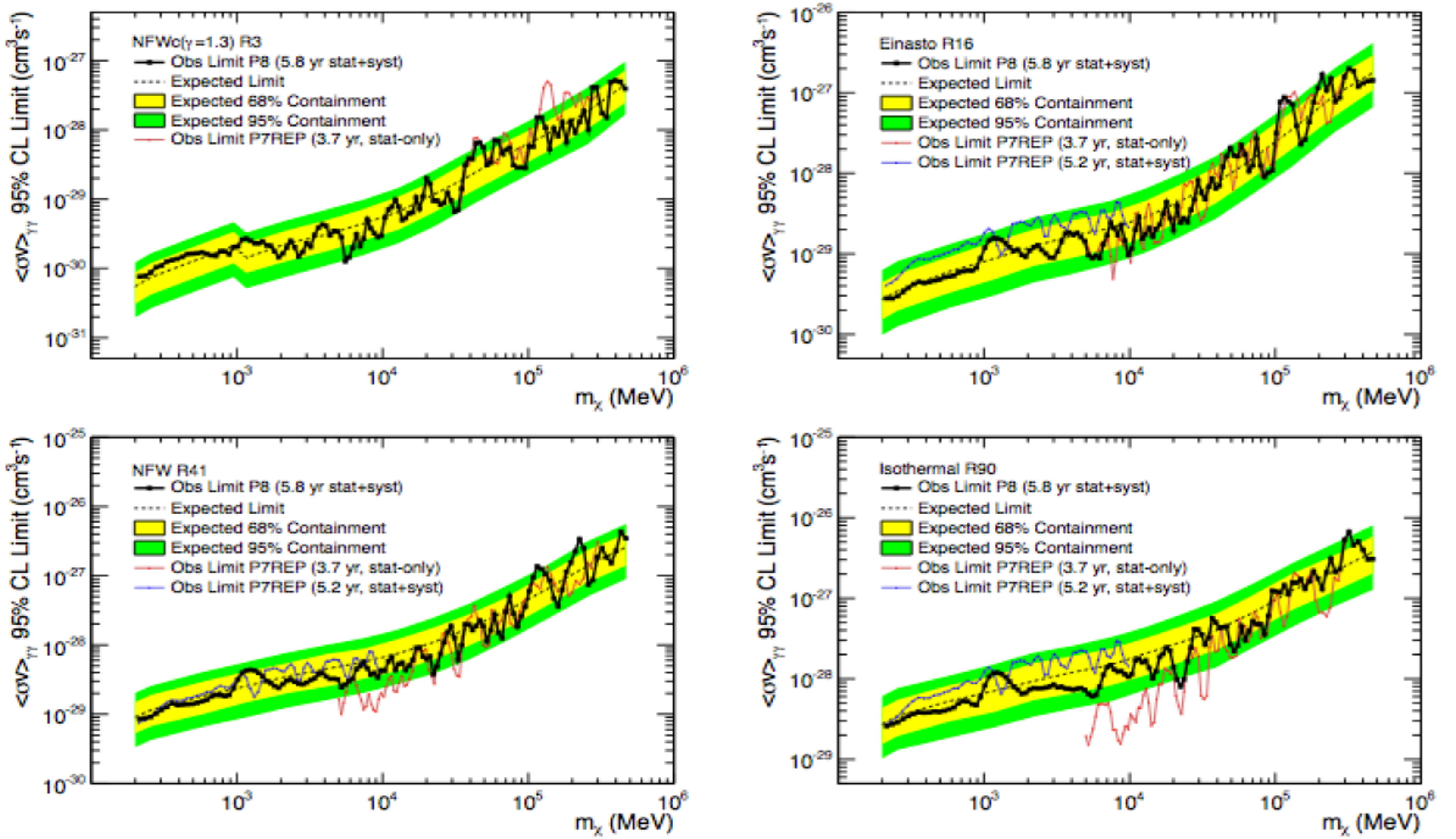


Strongly increasing the acceptance with pass8



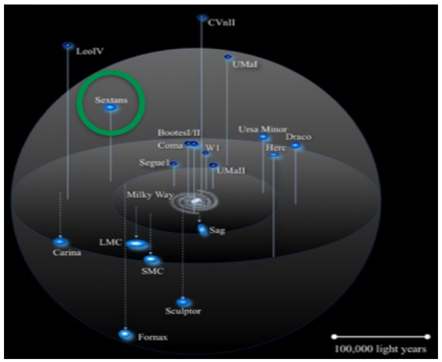
Search for spectral line

No globally significant lines found in each ROI



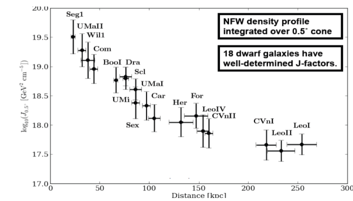
Dark matter annihilation the Milky Way: dwarf Spheriodal Galaxies

The stellar kinematic data indicate that the dwarf spheriodal satellite galaxies (dSphs) of the Milky way contain a substantial DM component - 25 dSphs close to us to 25-250 Kpc



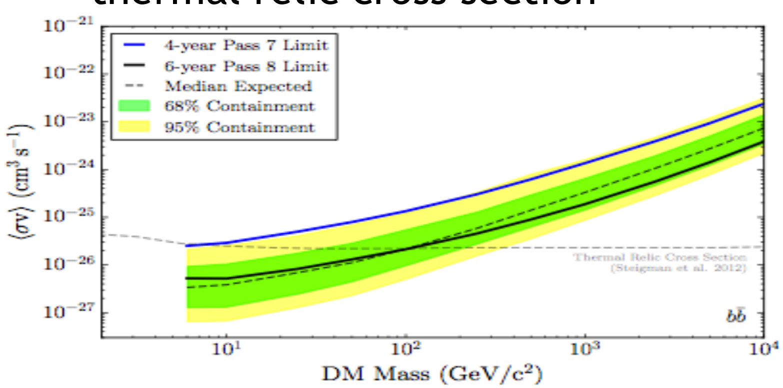
gamma-ray signals = particles properties x astrophysical properties

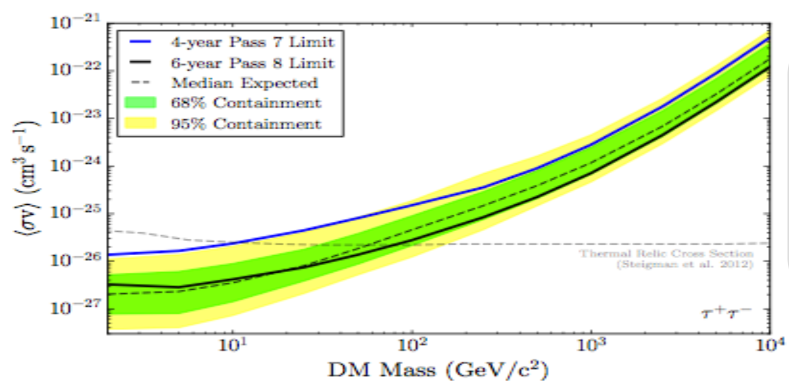
$$\phi_\gamma(E,\psi) = \frac{1}{4\pi}\frac{\langle\sigma_\chi v\rangle}{2m_\chi^2}N_\gamma(E)\times J(\psi)$$



Dwarf J-factors are determined **spectroscopically** from the stellar velocity dispesions ➔using the los velocity dispersion and assuming DM density profile (NFW) we can estimate the J-factor

Joint likelihood analysis in 15 dSphs : we constrain the dark matter annhilation cross section through the quark and τ-lepton channel for WIMP with m_χ < 100 GeV➔lies below the canonical thermal relic cross section

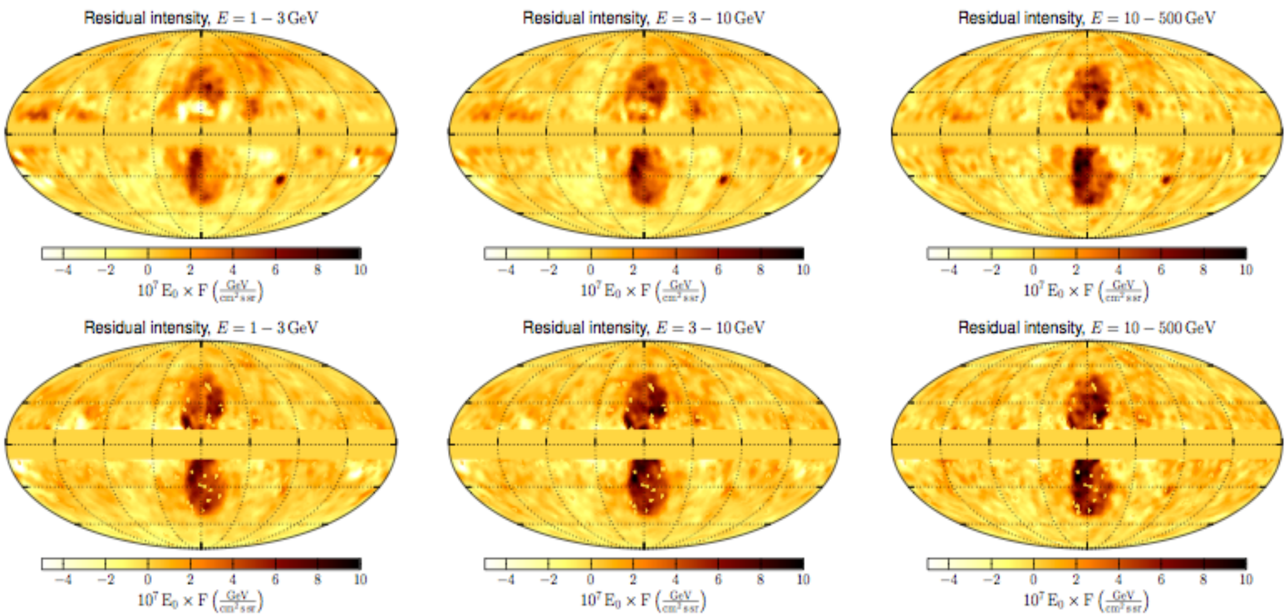


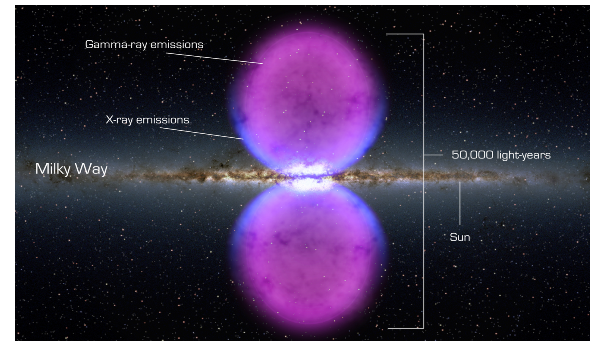


[1] Ackermann, M. 2014PhRvD..89d2001A
[2] Ackermann, M. 2011PhRvL.107x1302A
[3] Drlica-Wagner, A 2015ApJ...809L...4D

Fermi Bubbles

We detected an excess in the diffuse emission beween 1 GeV up to 50GeV [1*





Bubbles extend above and below the galactic plane of about 55°[2]

Fermi bubbles have the same morphology of the WMAP microwave haze ➔ **common origin**
The Fermi bubble structures were likely created by some large episode of energy injection in the GC, such as a past accretion event onto the central MBH, or a nuclear starburst in the last~10 Myr.

Evidence of substructures but no an evidence of a jet

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[2] Ackermann, M. 2014ApJ...793...64A

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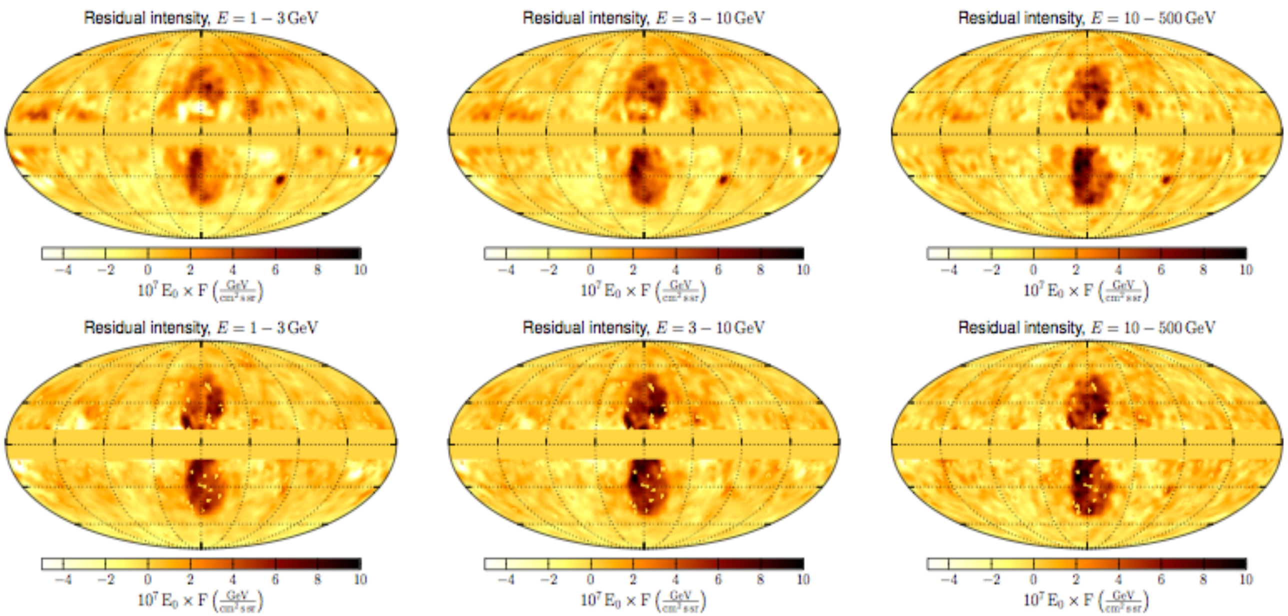

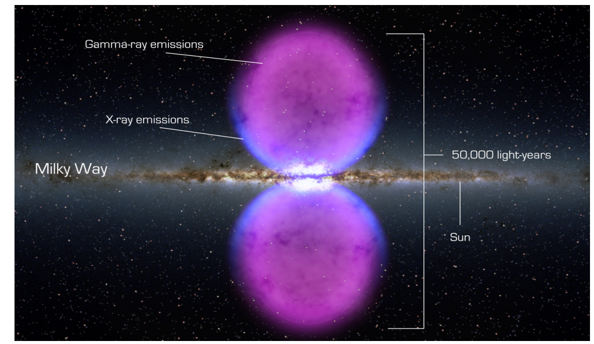

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