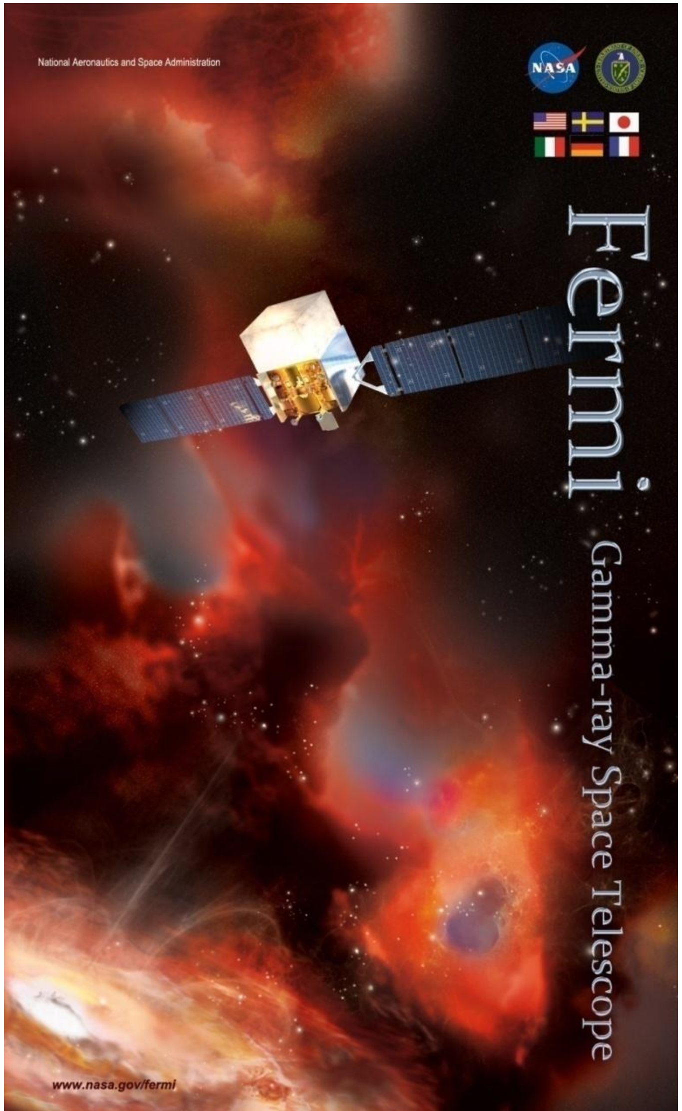

The extragalactic γ-ray sky as observed by *Fermi*. What have we learned? New discoveries and open questions

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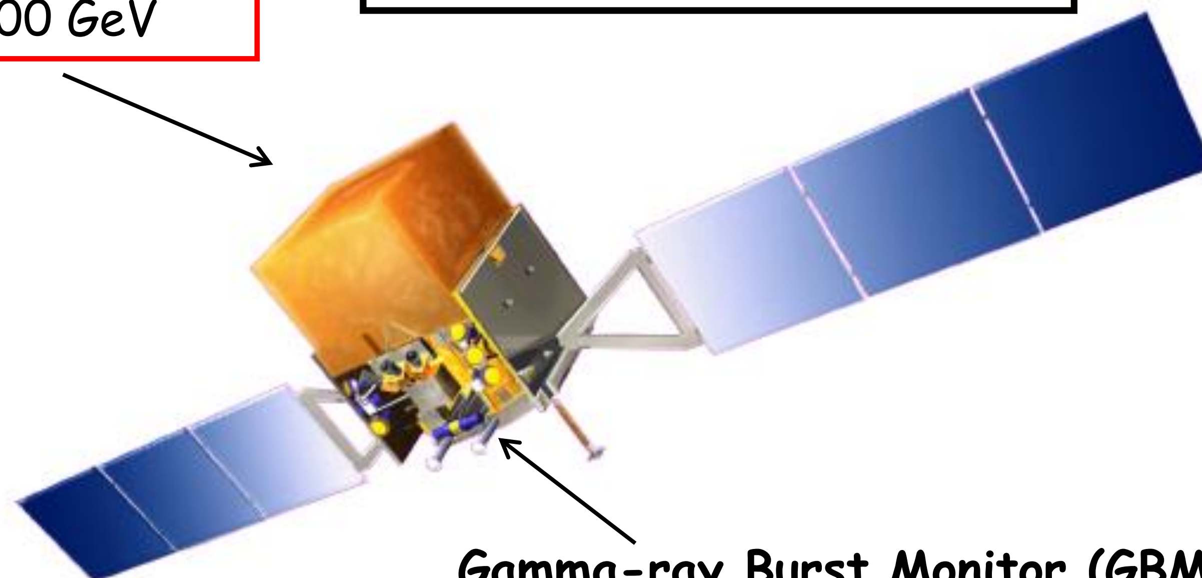
+ many others…

The Fermi Gamma-ray Space Telescope

Large Area Telescope (LAT)
20% of the sky at any instant
from 20 MeV to >300 GeV

***Fermi*-LAT Collaboration:**
~400 Scientific Members



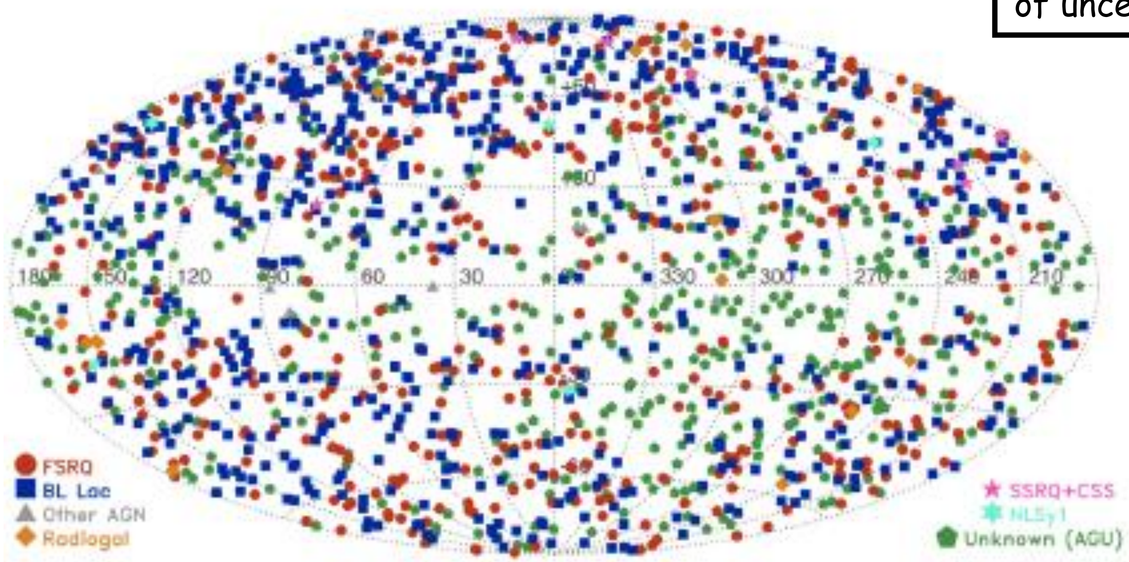
Gamma-ray Burst Monitor (GBM)
entire unocculted sky
transients from 8 keV to 40 MeV

Launched from Cape Canaveral Air Station on 2008 June 11
nearly circular orbit at 565 km, 25.6°. Orbital period of ~95 minutes.

The Third LAT AGN Catalogue (3LAC)

Ackermann et al. 2015, apJ, 810, 14

BCU = Blazar candidates of uncertain type



48 months of LAT data

- 1591 (1444) sources with TS>25, |b|>10° (71% more than in 2LAC)
- 182 low-latitude AGN (24 FSRQ, 30 BL Lacs, 125 BCU, 3 non-blazar AGN)

- 467 FSRQ
- 632 BL Lacs
- *460 BCU (~50% new 3LAC sources)*
- 32 non-blazar AGN

Fermi Gamma-ray Space Telescope

Not only classical blazars in the 3LAC

Table 5. Non-blazar objects and misaligned AGN

Name	3FGL	2FGL	1FGL	Type	Photon index	Notes
NGC 1218	J0308.6+0408*	···	J0308.3+0403*	FRI	2.07±0.11	
IC 310	J0316.6+4119*	J0316.6+4119	···	FRI/BLL	1.90±0.14	Neronov et al. (2010)
NGC 1275	J0319.8+4130*	J0319.8+4130*	J0319.7+4130*	FRI	2.07±0.01	Abdo et al. (2009c); Kataoka et al. (2010)
1H 0323+342	J0325.2+3410*	J0324.8+3408*	J0325.0+3403*	NLSy1	2.44±0.12	
4C +39.12	J0334.2+3915*	···	···	FRI/BLL?	2.11±0.17	Giovannini et al. (2001)
TXS 0348+013	J0351.1+0128*	···	···	SSRQ	2.43±0.18	
3C 111	J0418.5+3813	···	J0419.0+3811	FRII	2.79±0.08	Abdo et al. (2010e); Kataoka et al. (2011); Grandi et al. (2012)
Pictor A	J0519.2−4542*	···	···	FRII	2.49±0.18	Brown & Adams (2012); Kataoka et al. (2011)
PKS 0625−35	J0627.0−3529*	J0627.1−3528*	J0627.3−3530*	FRI/BLL	1.87±0.06	
4C +52.17	J0733.5+5153	···	···	AGN	1.74±0.16	Part of a duplicate association. Most probable counterpart is a BCU III.
NGC 2484	J0758.7+3747*	···	···	FRI	2.16±0.16	quasar SDSS J075825.87+374628.7 is 0.8' away
4C +39.23B	J0824.9+3916	···	···	CSS	2.44±0.10	
3C 207	J0840.8+1315*	J0840.7+1310	J0840.8+1310	SSRQ	2.47±0.09	
SBS 0846+513	J0849.9+5108*	···	···	NLSy1	2.28±0.04	
3C 221	J0934.1+3933	···	···	SSRQ	2.28±0.12	
PMN J0948+0022	J0948.8+0021*	J0948.8+0020*	J0949.0+0021*	NLSy1	2.32±0.05	
PMN J1118-0413	J1118.2-0411*	···	···	AGN	2.56±0.08	
B2 1126+37	J1129.0+3705	···	···	AGN	2.08±0.13	Part of a duplicate association. Most probable counterpart is a BLL.
3C 264	J1145.1+1935*	···	···	FRI	1.98±0.20	
PKS 1203+04	J1205.4+0412	···	···	SSRQ	2.64±0.16	Part of a duplicate association. The other counterpart is a FSRQ.
M 87	J1230.9+1224*	J1230.8+1224*	J1230.8+1223*	FRI	2.04±0.07	Abdo et al. (2009d)
3C 275.1	J1244.1+1615	···	···	SSRQ	2.43±0.17	
GB 1310+487	J1312.7+4828*	J1312.8+4828*	J1312.4+4827*	AGN	2.04±0.03	
Cen A Core	J1325.4−4301*	J1325.6−4300	J1325.6−4300	FRI	2.70±0.03	radio core
Cen A Lobes	J1324.0−4330e	J1324.0−4330e	J1322.0−4515	FRI	2.53±0.05	giant lobes detected (Abdo et al. 2010b)
3C 286	J1330.5+3023*	···	···	SSRQ/CSS	2.60±0.16	
Cen B	J1346.6−6027	J1346.6−6027	···	FRI	2.32±0.01	Katsuta et al. (2013)
Circinus	J1413.2−6518	···	···	Seyfert	2.43±0.10	Hayashida et al. (2013)
3C 303	J1442.6+5156*	···	···	FRII	1.92±0.18	
PKS 1502+036	J1505.1+0326*	J1505.1+0324*	J1505.0+0328*	NLSy1	2.61±0.05	
TXS 1613−251	J1617.3−2519	J1617.6−2526c	···	AGN	2.59±0.10	Part of a duplicate association. Most probable counterpart is a BCU II.
PKS 1617−235	J1621.1−2331*	J1620.5−2320c	···	AGN	2.50±0.23	
NGC 6251	J1630.6+8232*	J1629.4+8236	J1635.4+8228*	FRI	2.22±0.08	
3C 380	J1829.6+4844*	J1829.7+4846*	J1829.8+4845*	SSRQ/CSS	2.37±0.04	
PKS 2004−447	J2007.8−4429*	J2007.9−4430*	J2007.9−4430*	NLSy1	2.47±0.09	

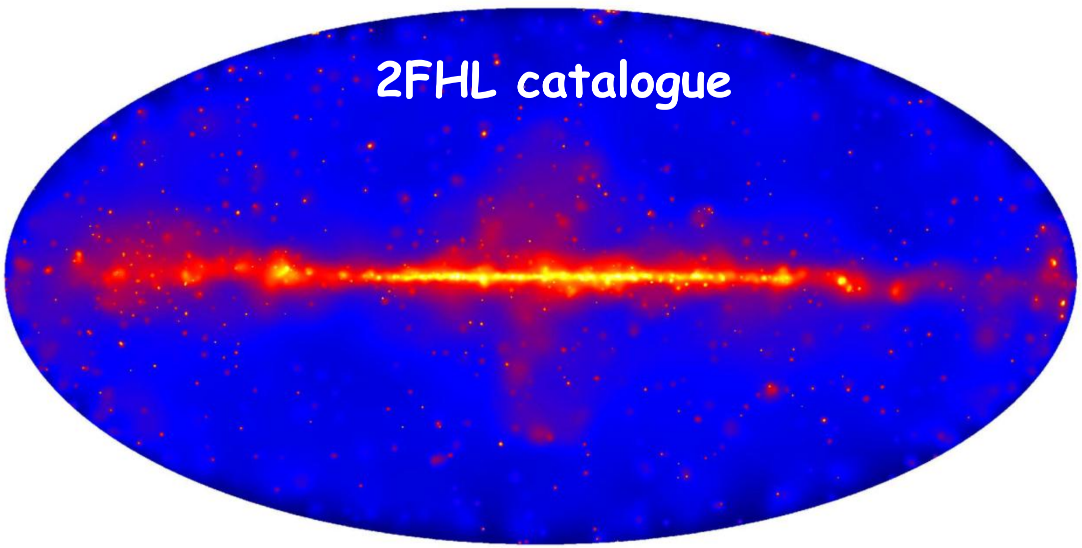
9 (12) FR I / 3 FR II

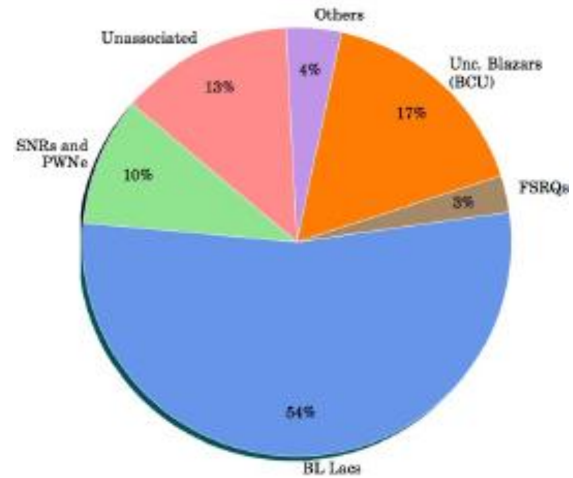
1 Seyfert
1 CSS (?)
7 SSRQ
5 NLSy1

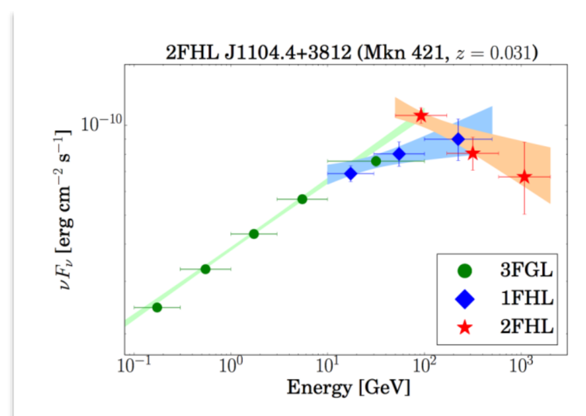
+ NLSy1 FBQS J1644+2619 (D'Ammando et al. 2015, MNRAS, 452, 520) and CSO PKS 1718-649 (Migliori et al. 2016, ApJ, 821, L31)

First all-sky census between 50 GeV and 2 TeV

- It finds 360 sources, with 61000 photons collected in 80 months using Pass 8 data
- The 2FHL catalogue contains 282 sources not detected by the IACTs
- The 2FHL catalogue contains 57 sources not included in the 3FGL and 48 never detected in γ-rays

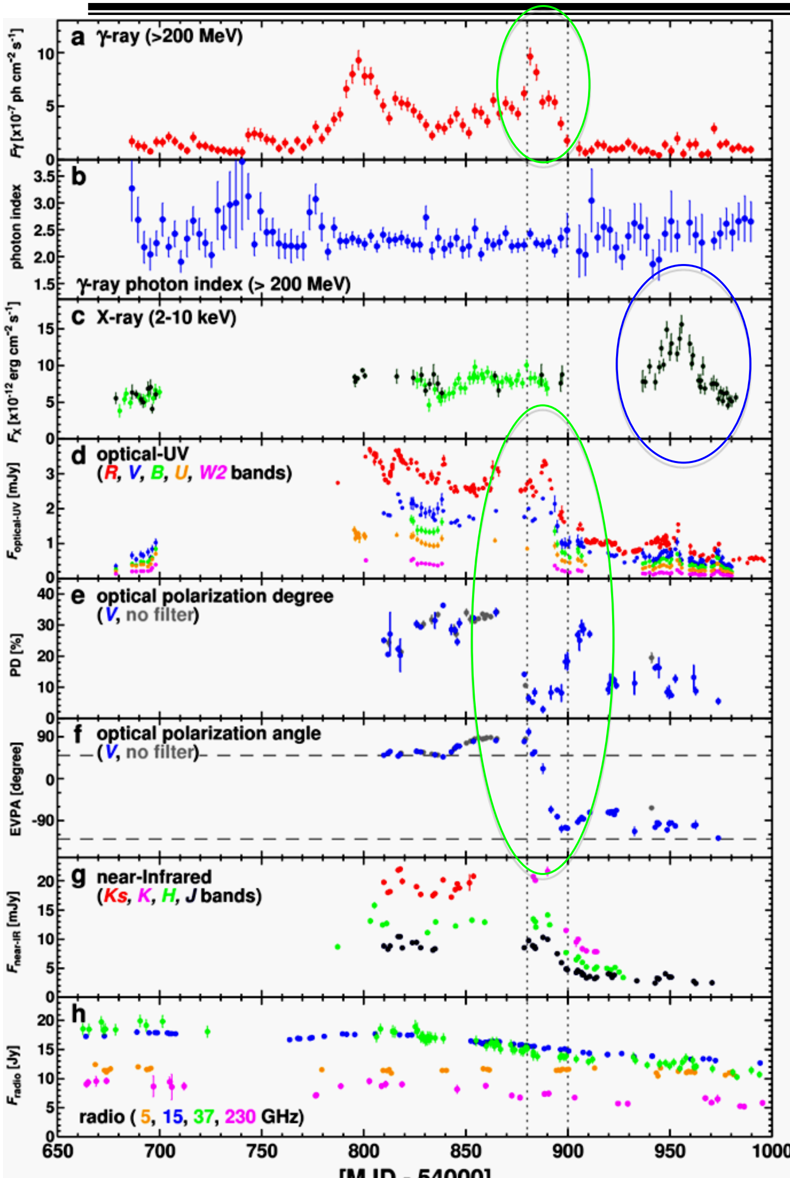






Ackermann et al. 2016, ApJS, 222, 5

Rotation of polarization angle during a γ-ray flare



- double-peak structure in γ-rays for 3C 279 during 2008-2009 with factor ~ 10 variations

- **Isolated X-ray flare**

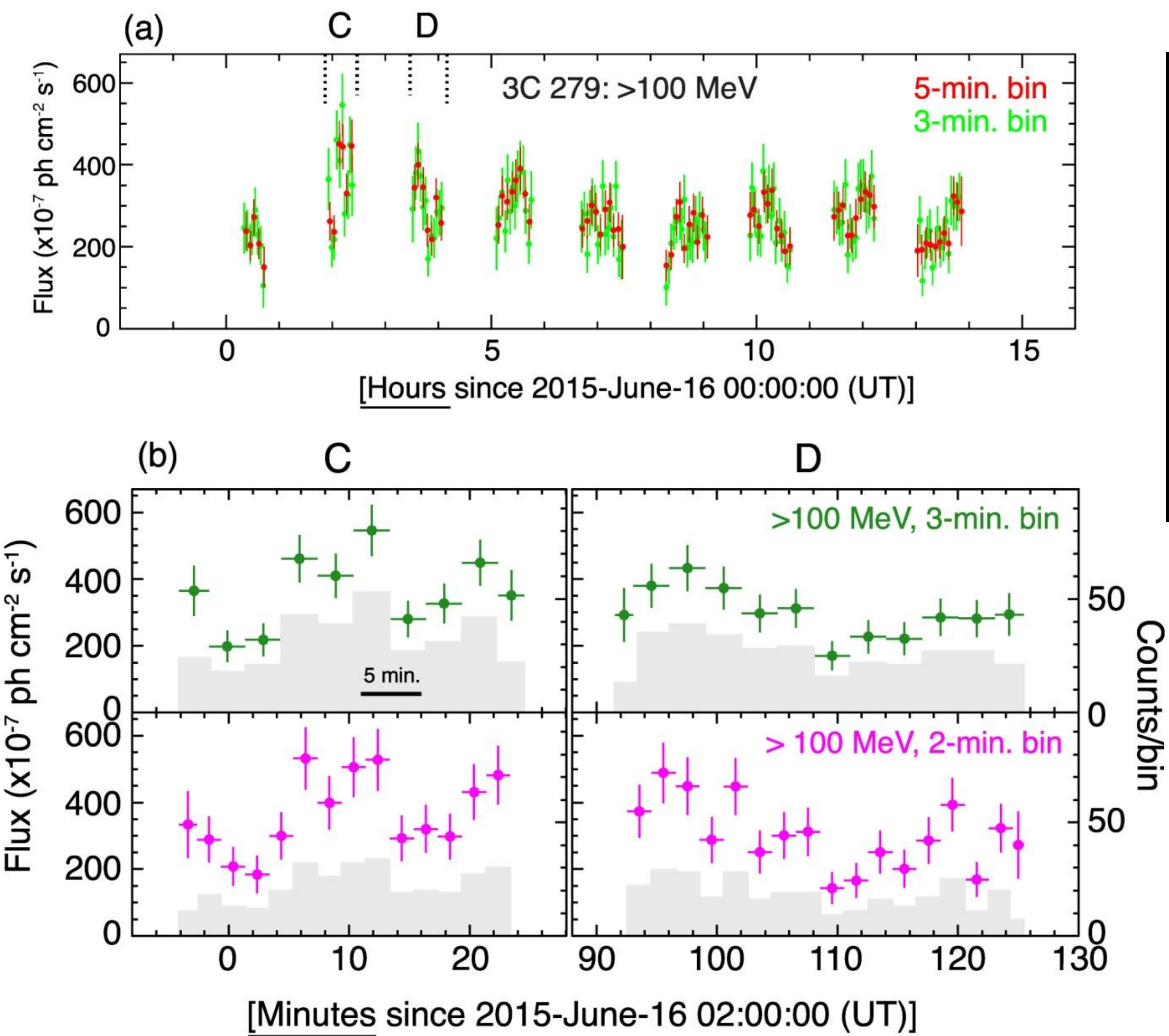
- **2nd gamma-ray flare simultaneous to a** ***drastic change of the optical polarization angle in about 20 days*** **suggesting a non-axisymmetric structure of the jet**

- **No new jet component ejected at the time of the γ-ray flare**

Possible scenarios:
- helical magnetic field model
- bend jet model
- "flow-through" (jet wobbling) scenario

Abdo et al. 2010, Nature, 463, 919

Minute time-scale variability at HE in 3C 279



Flux reached values of 5×10^{-5} ph cm^{-2} s^{-1} , with minute-scale variability.

This variability implies a very compact emitting region inside the BLR with very high Lorentz factor ($\Gamma \sim 50$) and very low jet magnatization.

Hayashida et al. 2016, ApJL, in press

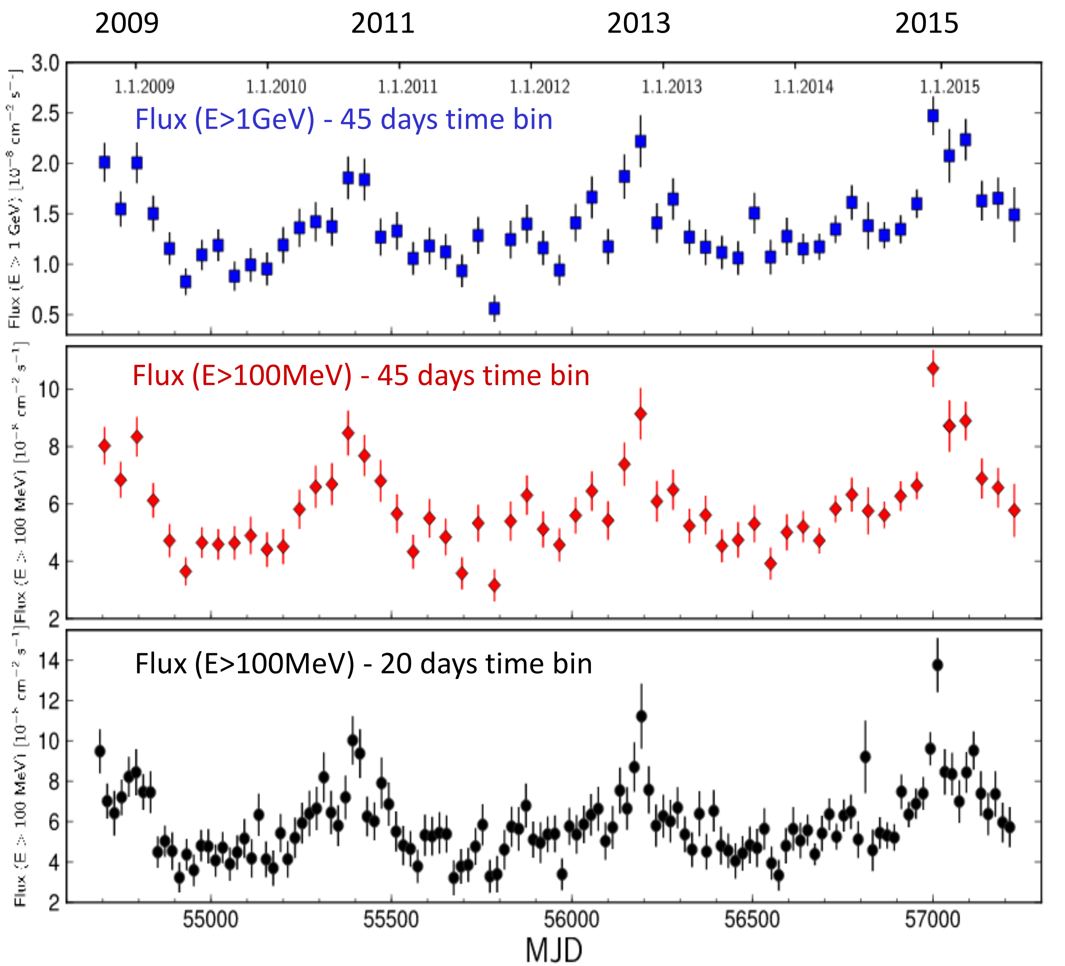
Quasi-periodicity of PG 1553+113 in γ-rays

A long-term oscillating trend is visually evident from the LAT γ-ray light curves of PG 1553+113.

An apparent quasi-periodicity seems to be present in γ-rays.

Possible interpretations are:

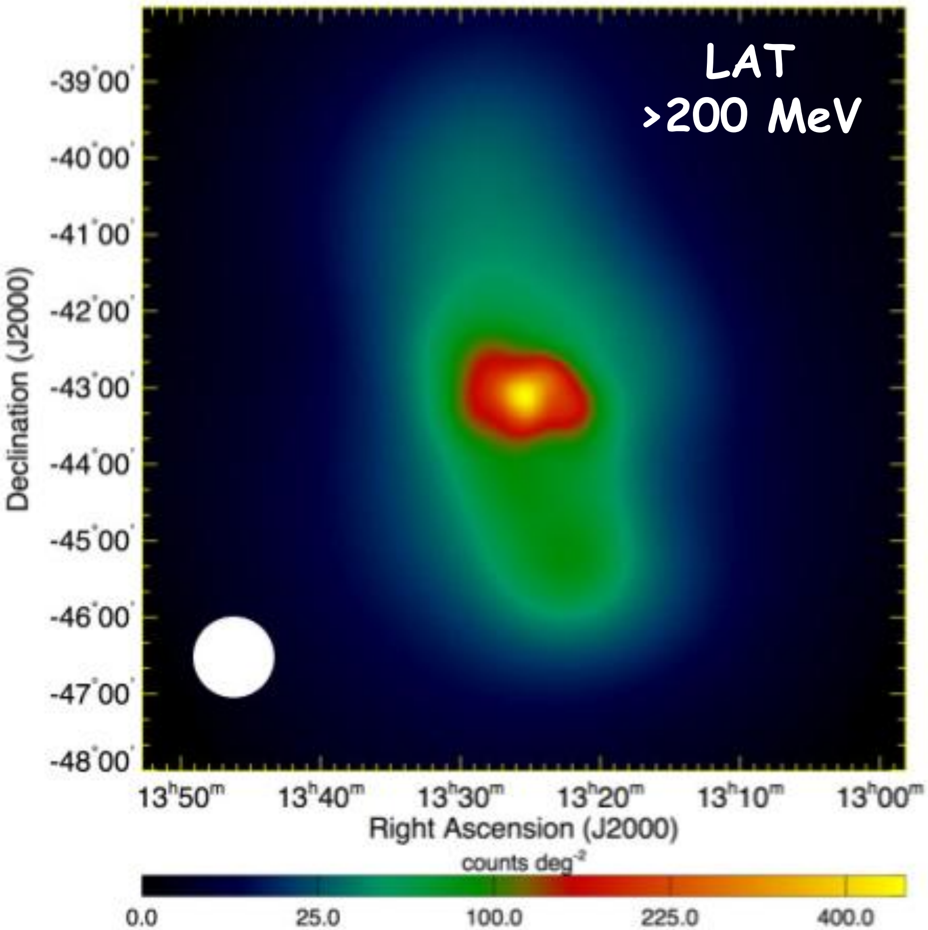
- SMBH binary system
- QPO from helical path or flow instabilities
- jet precession

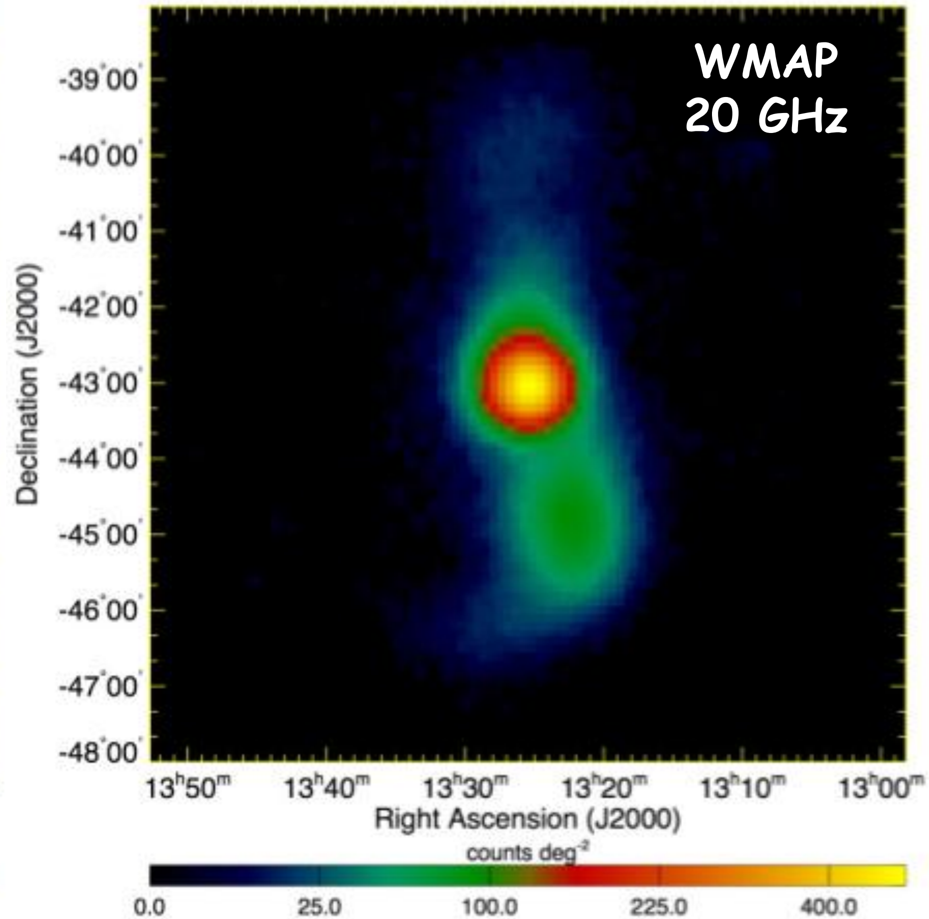


Ackermann et al. 2015, ApJ, 813, L41

First γ-ray Imaging of Cen A Giant Lobes

Over ½ of the total >100 MeV observed LAT flux in the lobes due to IC of CMB (and EBL)

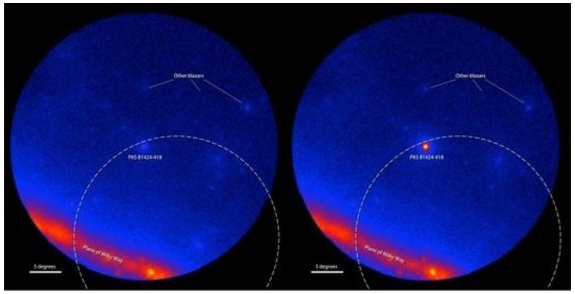




Background & point sources subtracted

Abdo et al. 2010, Science, 328, 725

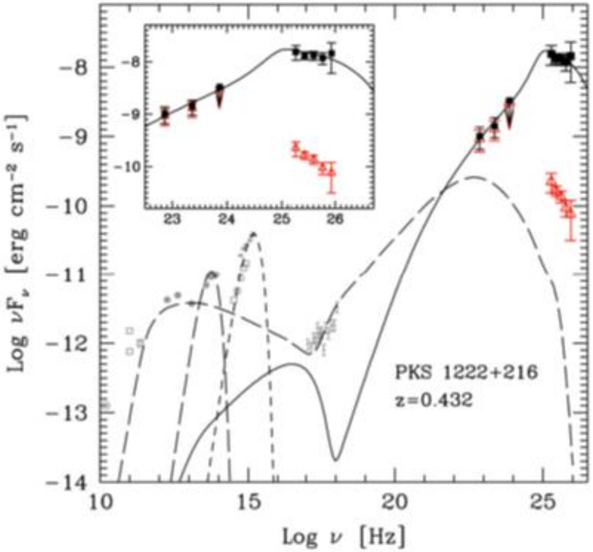
Multimessenger Astrophysics with *Fermi*



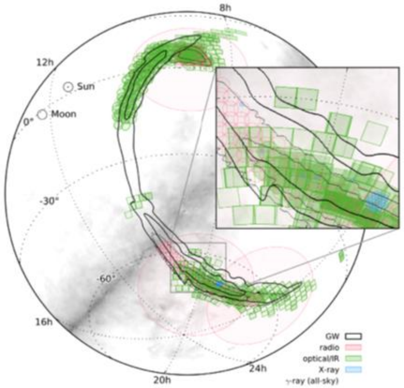
Kadler et al. 2016, Nature Physics

Coincidence of a high-fluence outburst from the FSRQ PKS 1424-418 with a PeV-energy neutrino event observed by IceCube .

Axion-like particles would evade pair production in broad line region of FSRQ (e.g. short time variability observed at VHE for 4C +21.35)



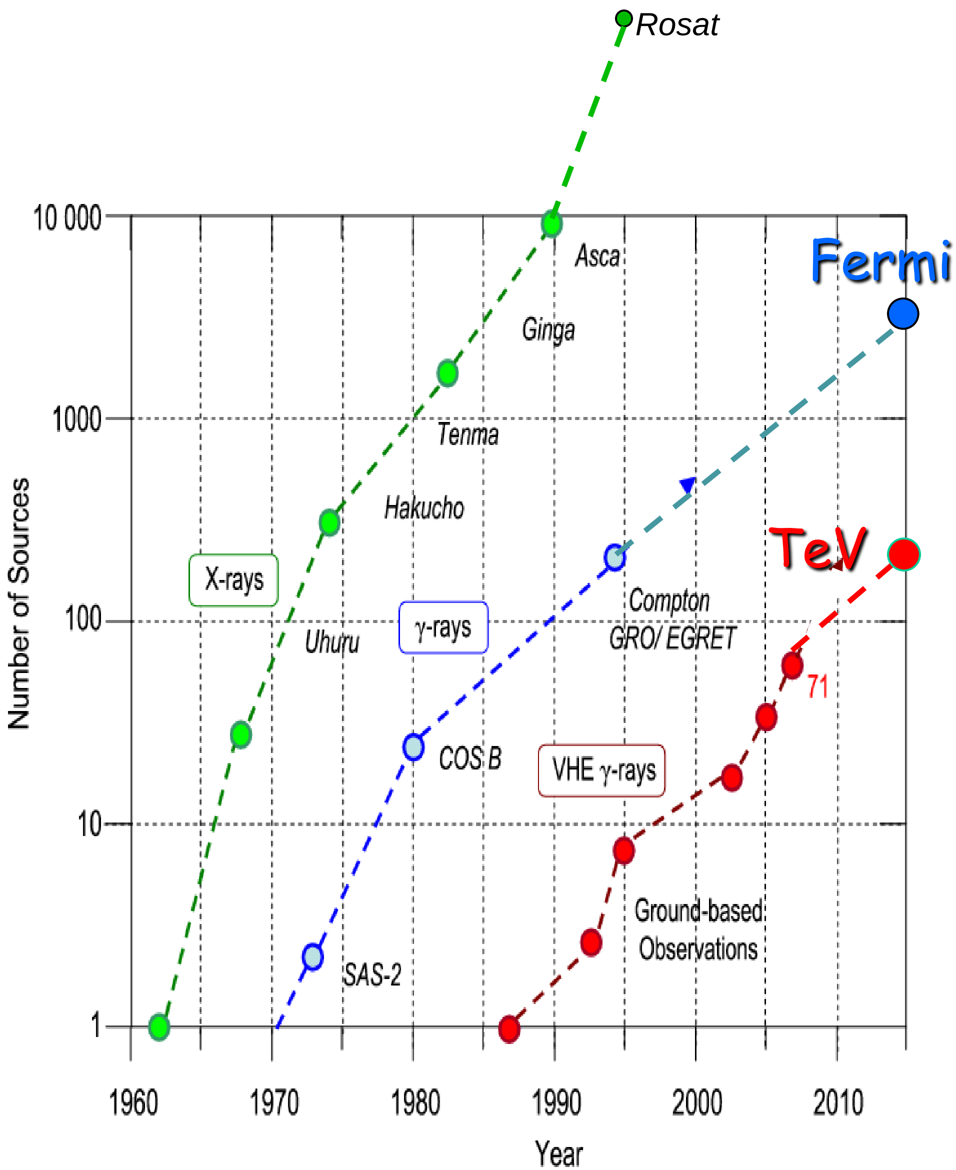
Tavecchio et al. 2012, PhRvD, 86, 5036



The LIGO localization arc for the event GW150914 became observable by Fermi LAT ~4000 s after the GW event, and an upper limit on different time-scales was obtained.

Abbott et al. 2016

The future of the γ-ray astronomy



γ-ray astronomy is a relatively young science and only in the last years we started to detect a significant number of sources at HE and VHE

Credits: Gabriele Ghisellini