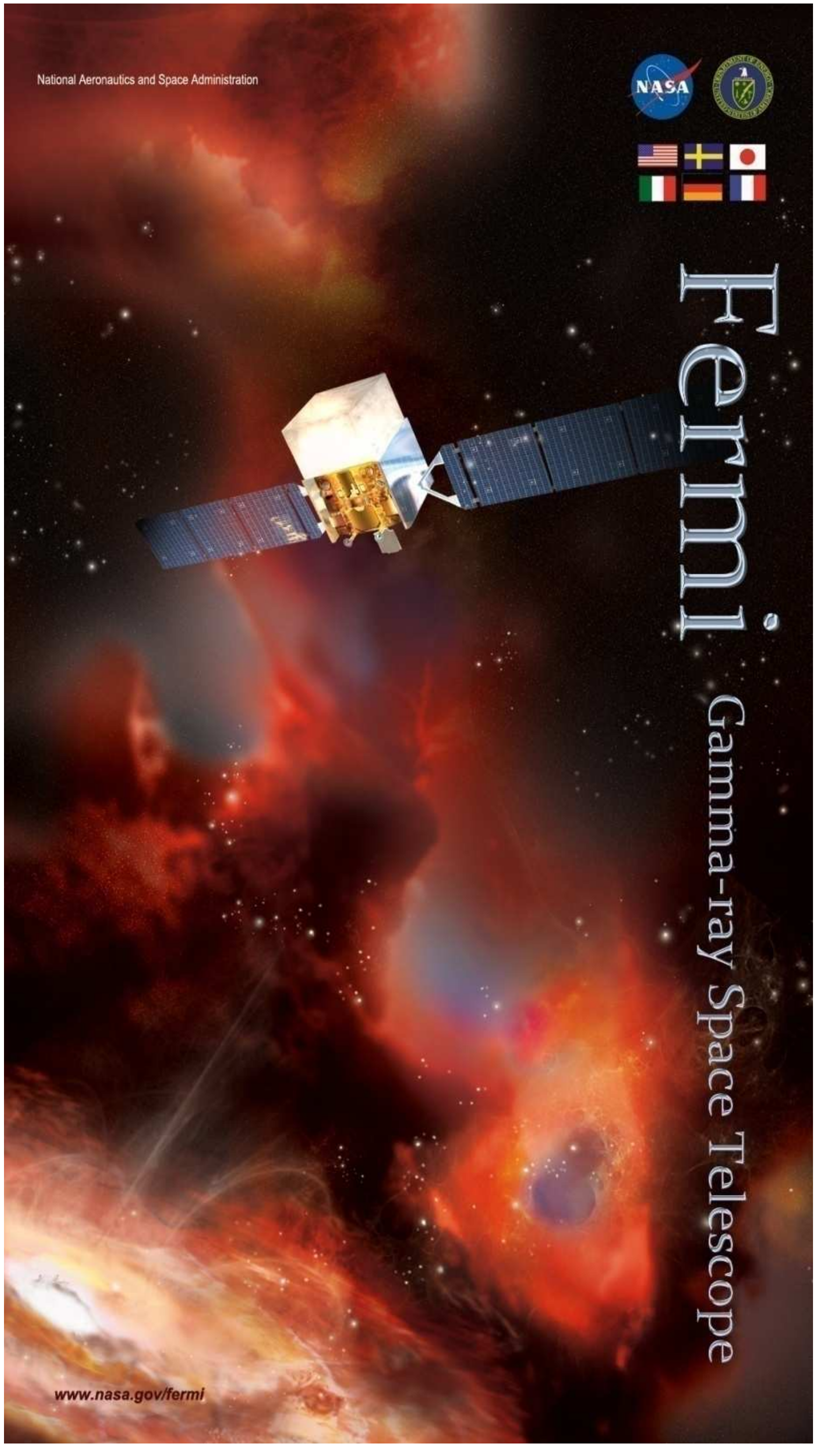

Astroparticle physics with Fermi gamma-ray AGN laboratories

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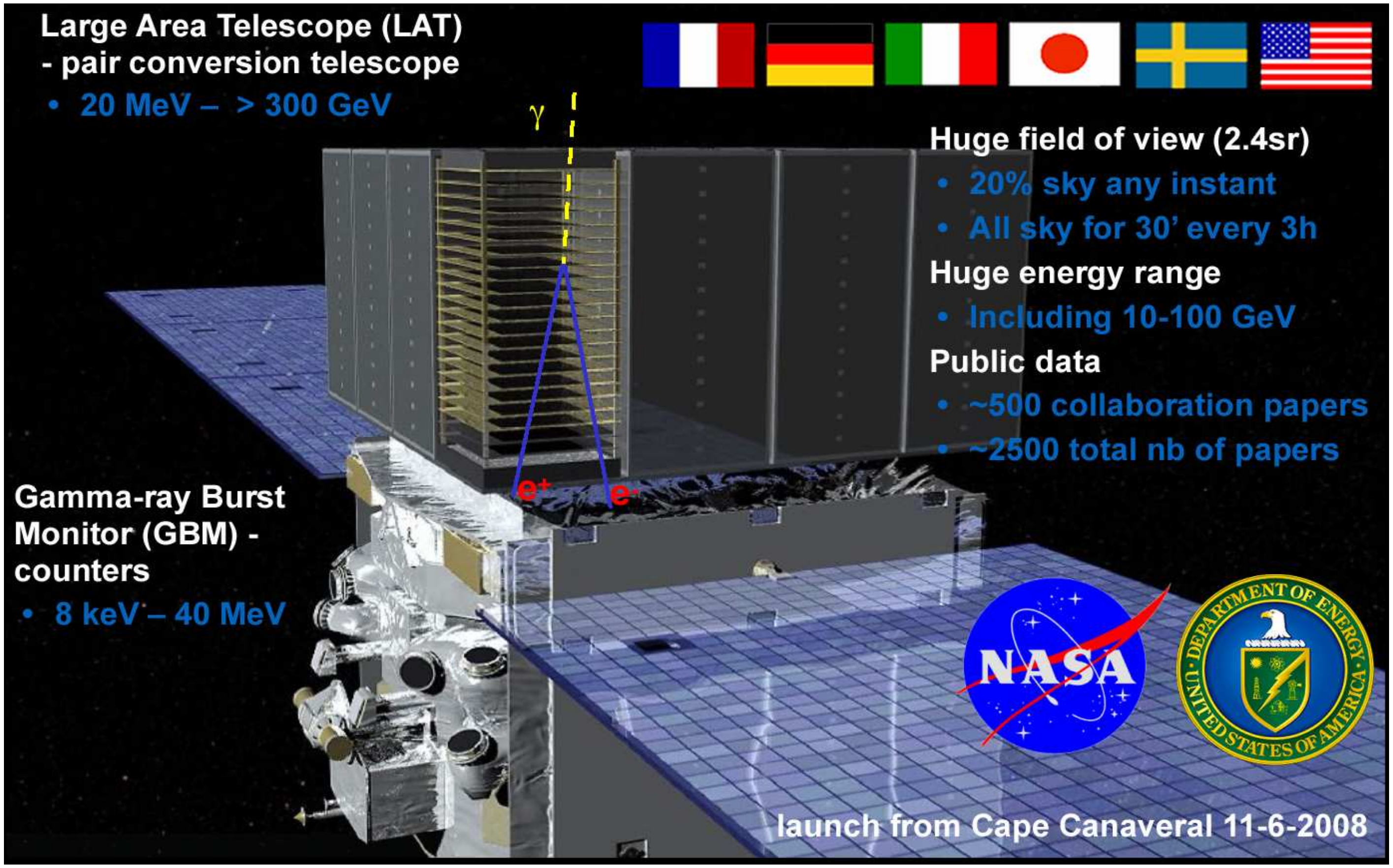
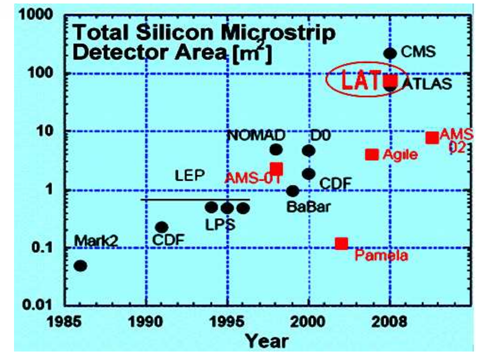
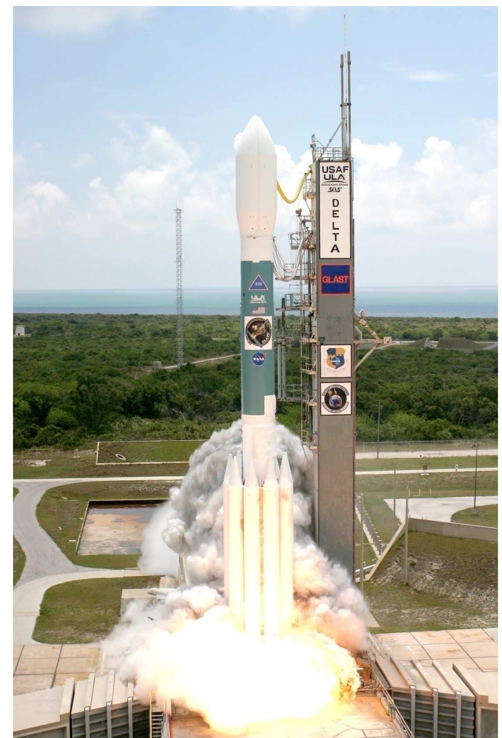
SSDC SPACE SCIENCE DATA CENTER asi agenzia spaziale italiana
INFN Istituto Nazionale di Fisica Nucleare

XLVII International Symposium on Multiparticle Dynamics - ISMD 2017
Sept. 11-15, 2017
Tlaxcala City, Mexico

Fermi Gamma-ray Space Telescope







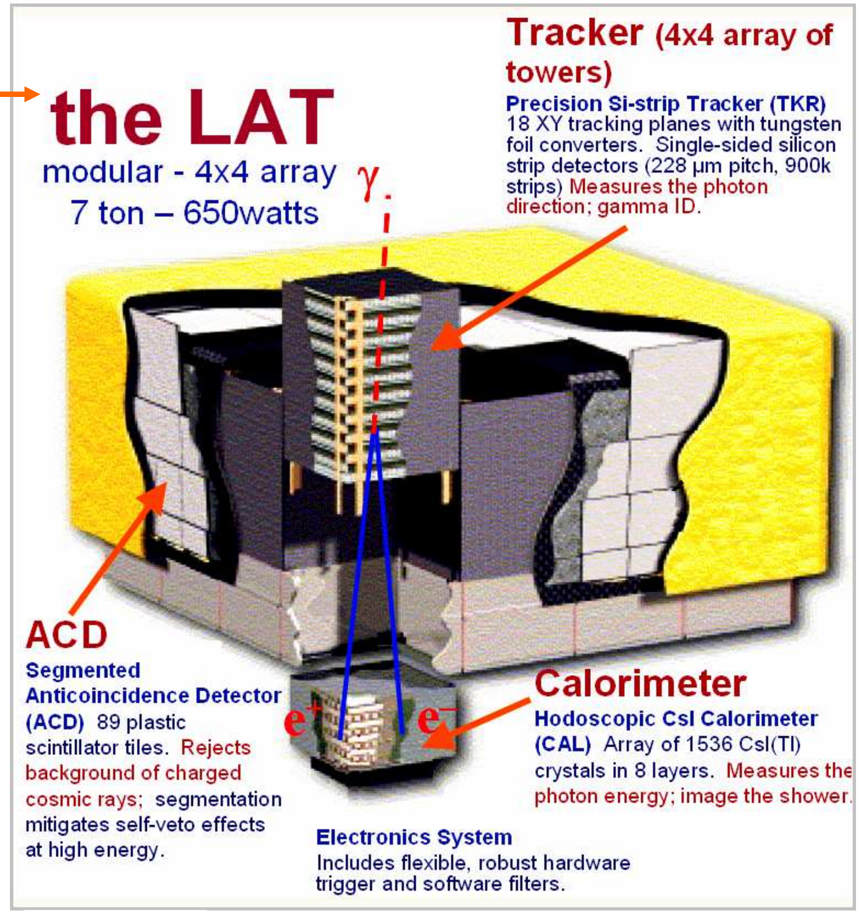
❑ Launched 11 june 2008, Delta II Rocket, circular orbit, 565km altitude, 25.6 deg inclination. **Operations.** Primary mode: all-sky survey with scan of the entire sky for 30min every 3 hours. Autonomous Repoint Request (ARR). Target of Opportunity (ToO). Huge field of view (2.4sr).

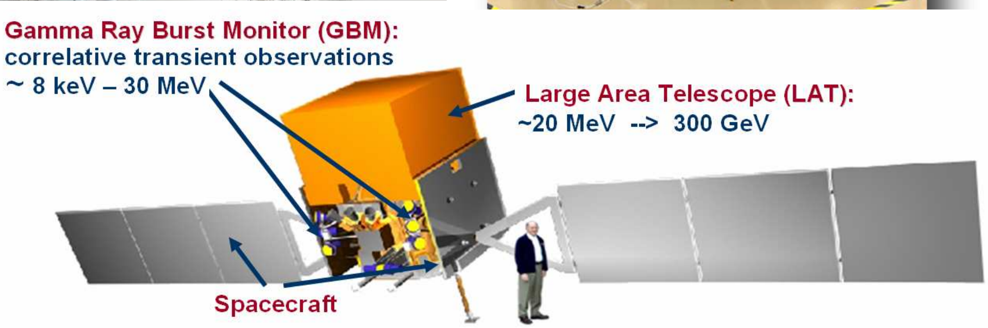
Fermi Gamma-ray Space Telescope

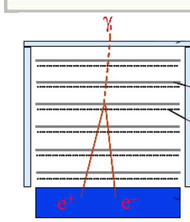
Fermi (formerly GLAST): two Instruments

The Large Area Telescope (LAT)
20 MeV - 300 GeV
>2.5 sr FoV

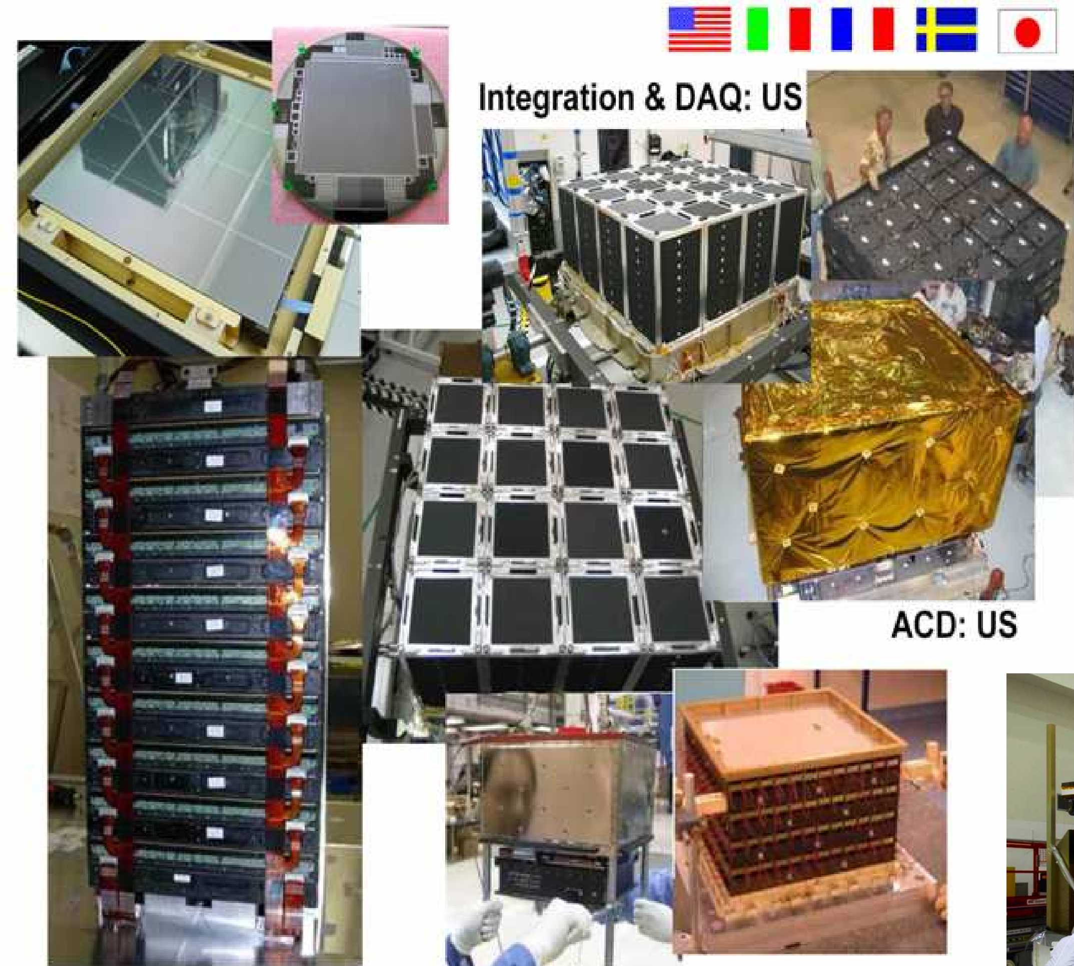
The Burst Monitor (GBM)
8 keV – 40 MeV
9.5 sr FoV







LAT construction: an international effort

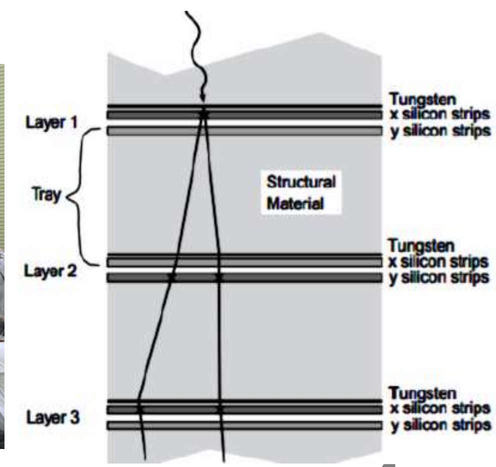


Tracker: US, Italy, Japan

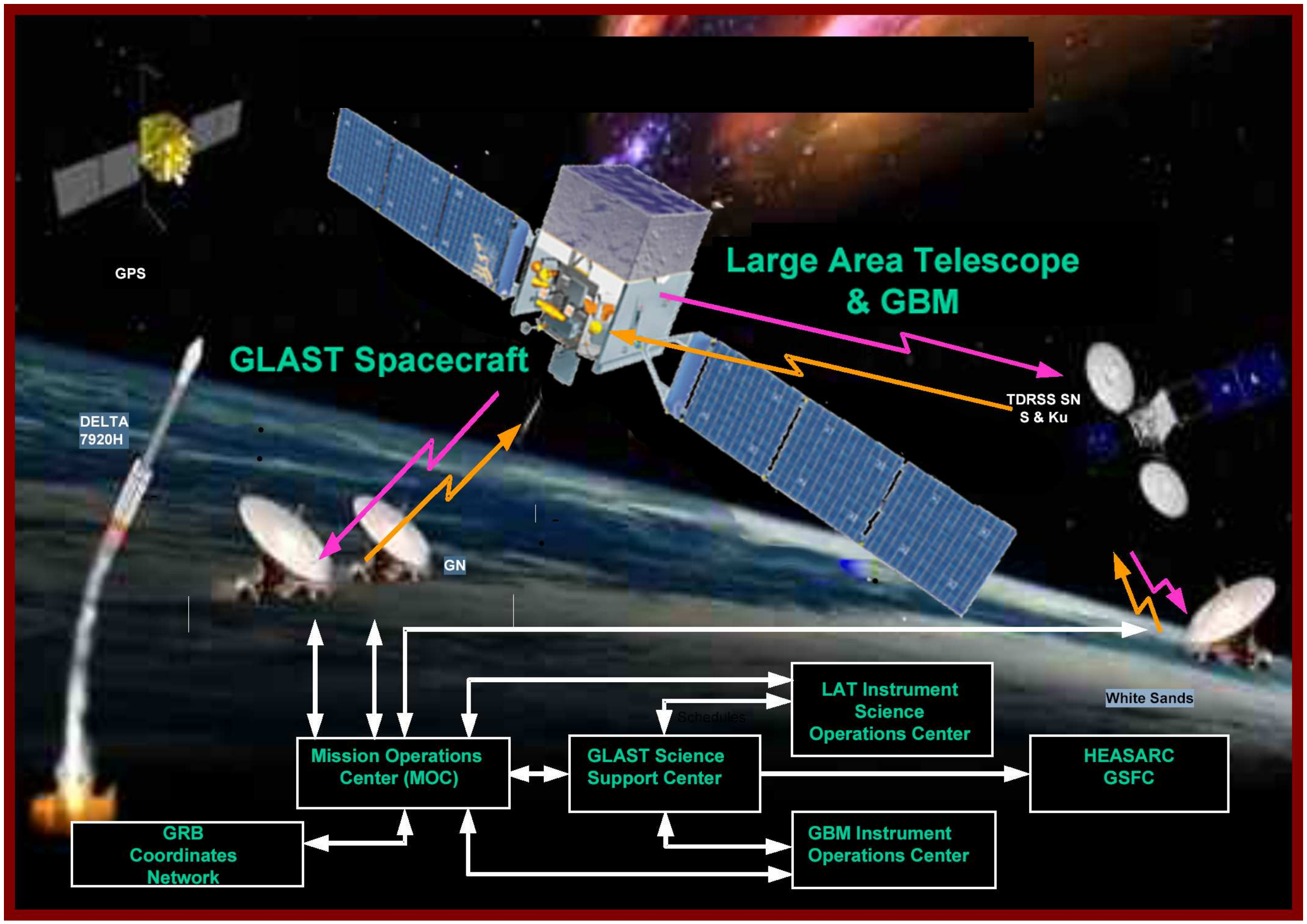
Calorimeter: US, France, Sweden

TRACKER details:

- 16 tower modules: 37×37cm² active cross section/layer
- 83 m² of Si
- 11500 Single Strip Detectors, ~ 1M channels, strip-pitch: 228µm
- 18 *xy* layers per tower 19 “tray” structures, 12 with 3% X_0 W on top, 4 with 18% X_0 W on bottom, 3 with no converter foils. Every tray is rotated by 90° with the previous one: W foils followed by. *x,y* plane of detectors, 2mm gap between *x* and *y* oriented detect.
- Trays stack and align at their corners
- Electronics on sides of trays: minimize gap between towers



Fermi mission elements



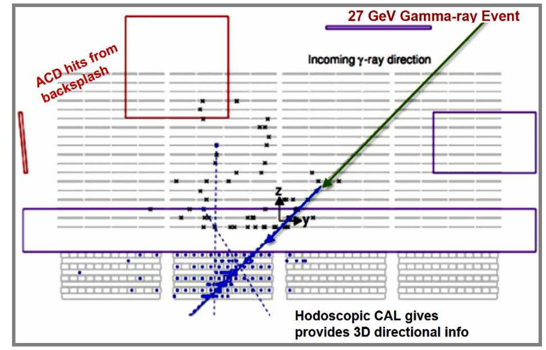
Two Line Element Set (TLE):

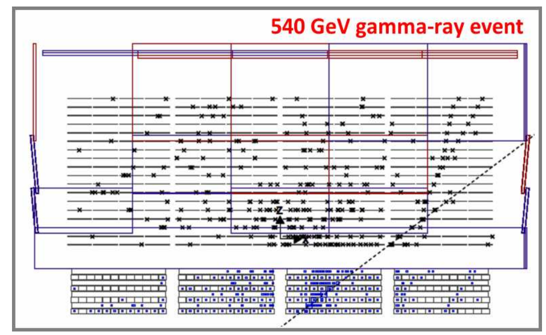
```
1 33053U 08029A   16294.12124780  .00000847  00000-0  32490-4 0  9991
2 33053  25.5822 197.2658 0012617  27.1381 332.9812 15.10735159460978
```

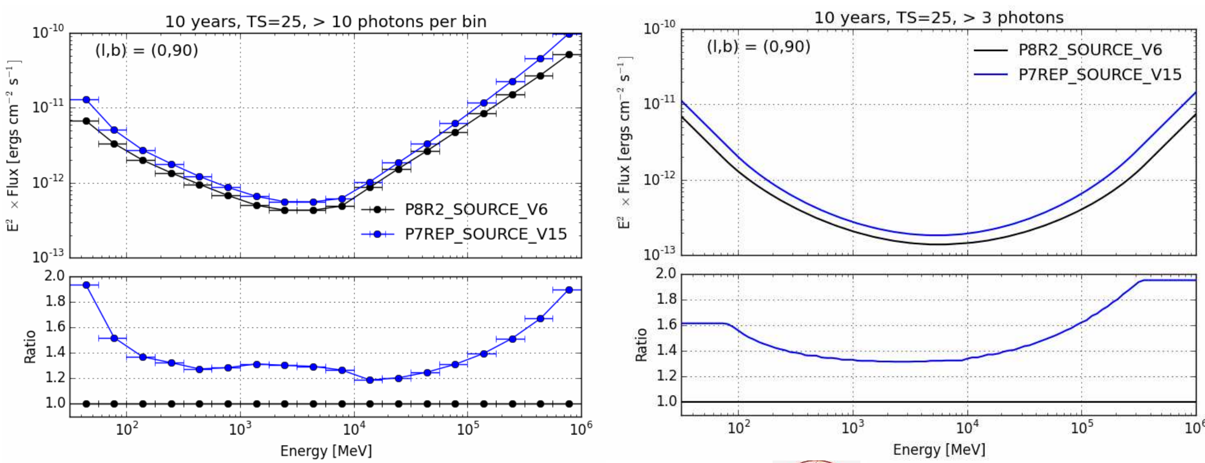
- ❑ **Launch: 11 june 2008,** 12:05 pm EDT: Launch from Cape Canaveral with a **Delta II (Heavy) Rocket**
- ❑ Circular orbit, 565km altitude, 25.6 deg inclination.
- ❑ **Operations**
  - Primary mode: sky survey: scan entire sky every 3h
  - Autonomous Repoint Request (ARR)
  - Target of Opportunity (ToO)
- ❑ on-board GPS (<300 ns, < 20m)
- ❑ Data Transmission: Ku-band via TDRSS 40 Mbps × 10-12/day
- ❑ Propulsion system for deorbiting and collision avoidance

Pass 8 event-level analysis and data reprocessing

- ❑ Pass 8 results in a long-term effort aimed at a comprehensive revision of the entire LAT event-level analysis.
  - Simulation, reconstruction, background rejection, analysis methods.
  - Incorporating the experience of the prime phase of the mission.
- ❑ Pass 8 extends the energy reach, maximizing the S/N and reducing the systematic uncertainties.
- ❑ Larger energy range, higher acceptance at all energies, better resolution (narrower PSF at mid-to-high energies with reduced tails), larger field of view (more off-axis effective area), comparable energy dispersion.
- ❑ Combination of larger acceptance and better PSF at high energy provide a 20-40% increase in sensitivity for a given observing time.
- ❑ Pass 8 performance and reprocessed data publicly released June 2015.

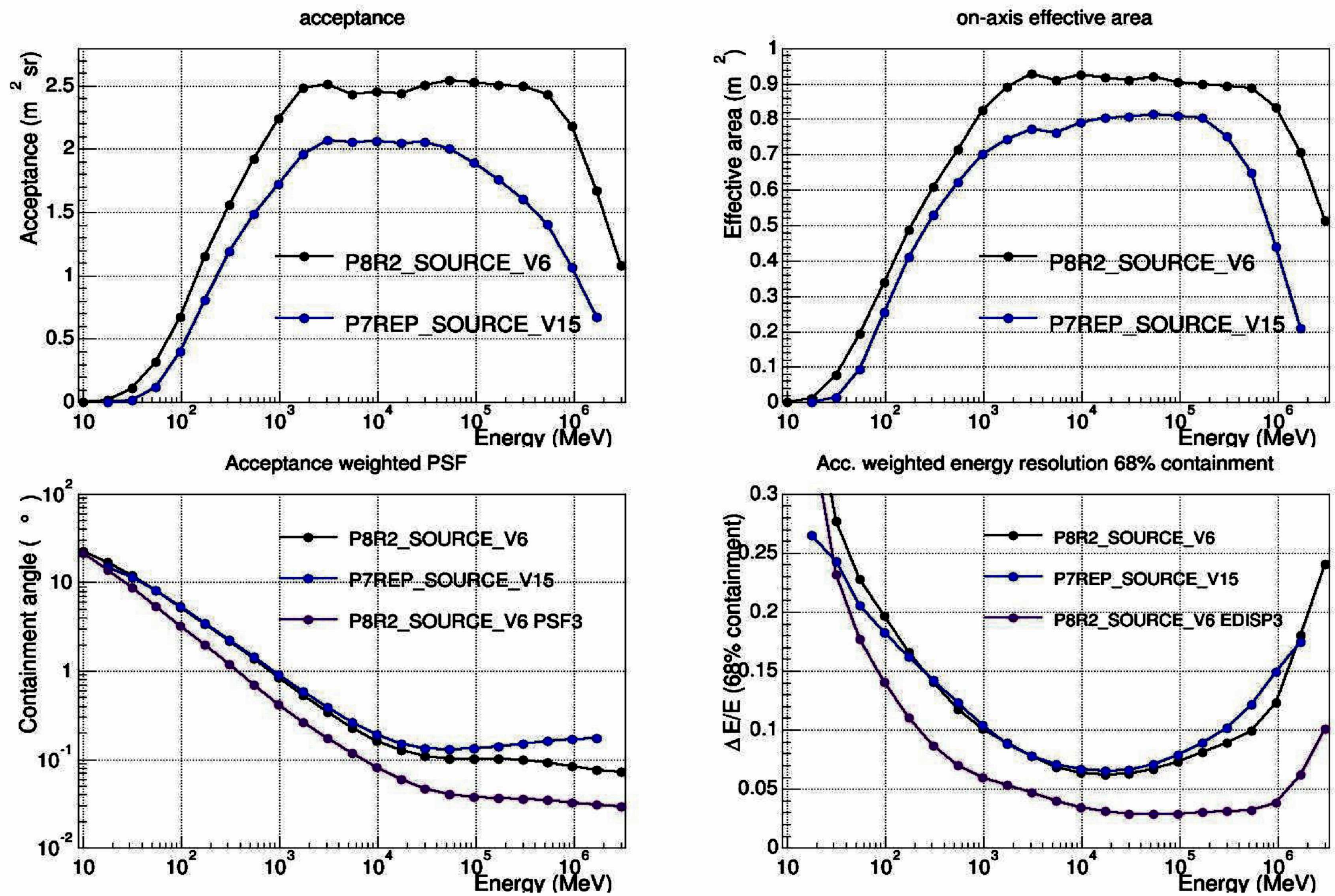




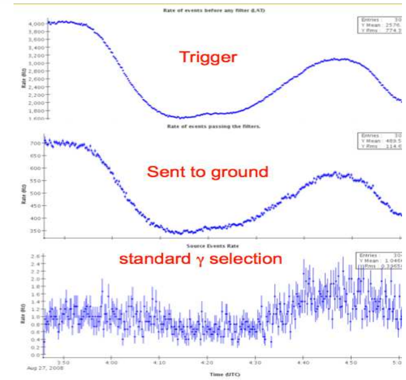


Pass 8 (P8R2_V6) versus Pass 7REP comparison of the differential sensitivity (left) and broadband sensitivity (right) at the north Galactic pole for a 10-year observation in survey mode.

LAT Pass 8 performances



LAT status and metrics



The LAT telescope is in a good status with stable performance.
On 2017 April 12: the 1,000,000,000th LAT gamma-ray photon is delivered to the NASA-Goddard Fermi Science Support Center (FSSC) archive of the LAT public data.

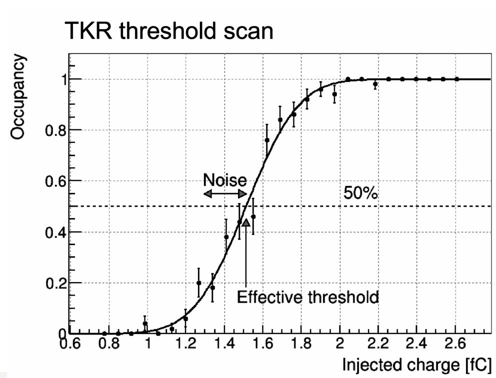
- ❑ 73 square meters of active silicon, 900k channels (comparable to the ATLAS Silicon tracker).
- ❑ ~2% noisy chans in 5 yrs.
- ❑ Similar stability in ACD and CAL.
- ❑ ~1% CAL aging in 2 yrs.
- ❑ ~hours/year spent in calibrations.

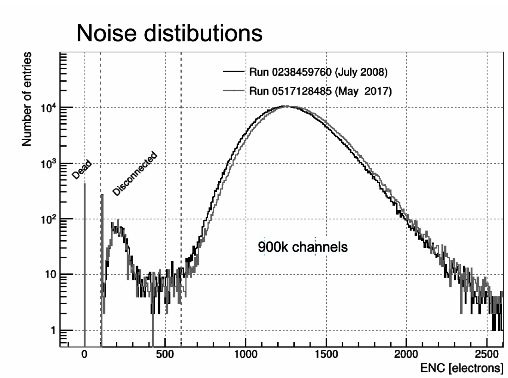
- ❑ Average input rate at detectors: ~2500Hz
- ❑ Downlink rate (sent to ground): ~450Hz
- ❑ Gamma-ray event rates (after event selection): ~Hz
- ❑ Large fraction of the events sent to ground are background.

- ❑ 51030 orbits since launch
- ❑ 50,000th orbit since launch was on 2017 July 4
- ❑ 3329 days since 2008 August 4
- ❑ LAT has 99% uptime (=(LPA run time + SAA time)/elapsed time) for the mission.

Event counts:

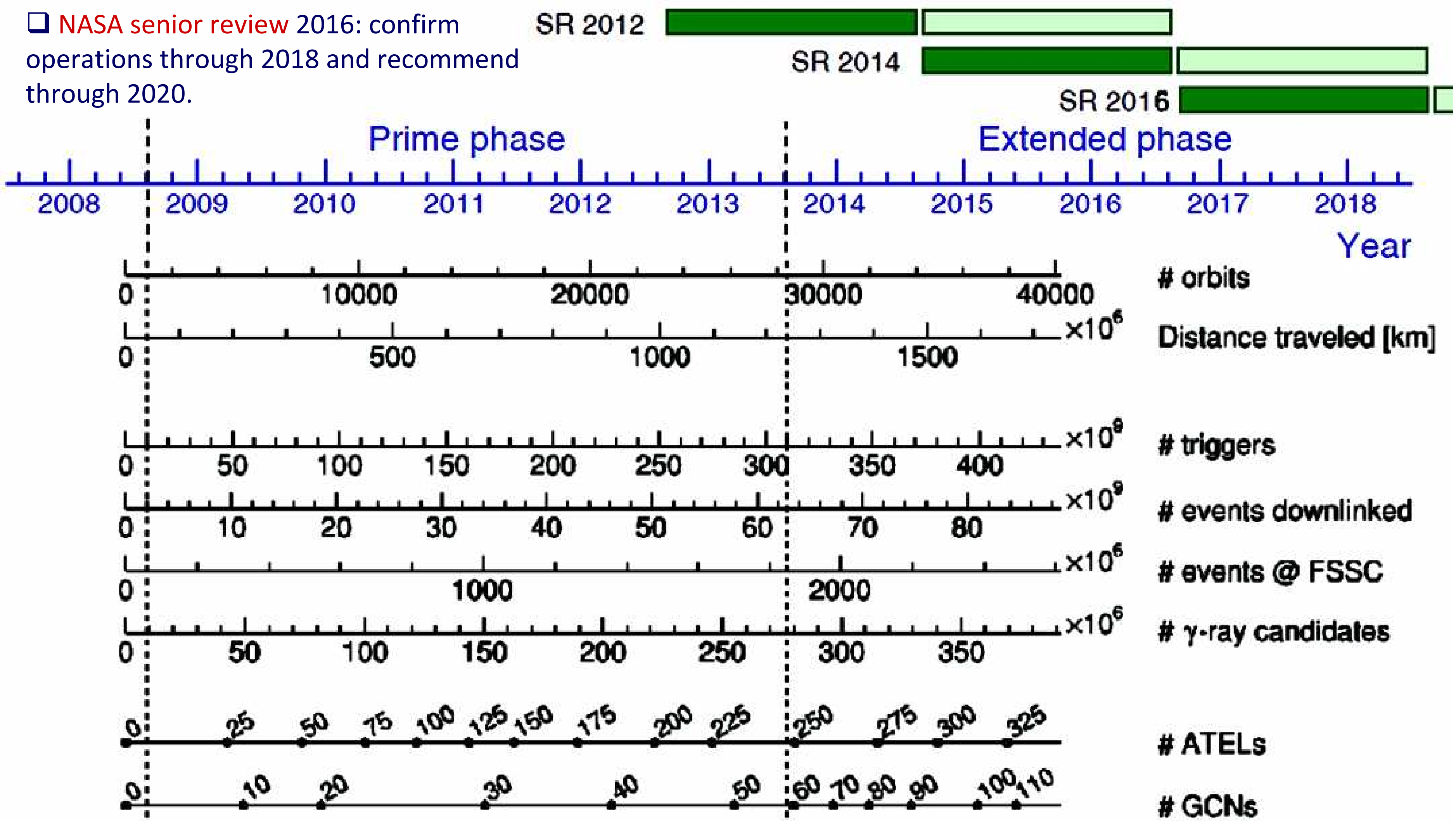
- ❑ 550 billion triggers on the LAT
- ❑ 110.3 billion events downlinked.
- ❑ 2.763 billion LAT events available at the FSSC.
- ❑ 1.045 billion source photons available at the FSSC.





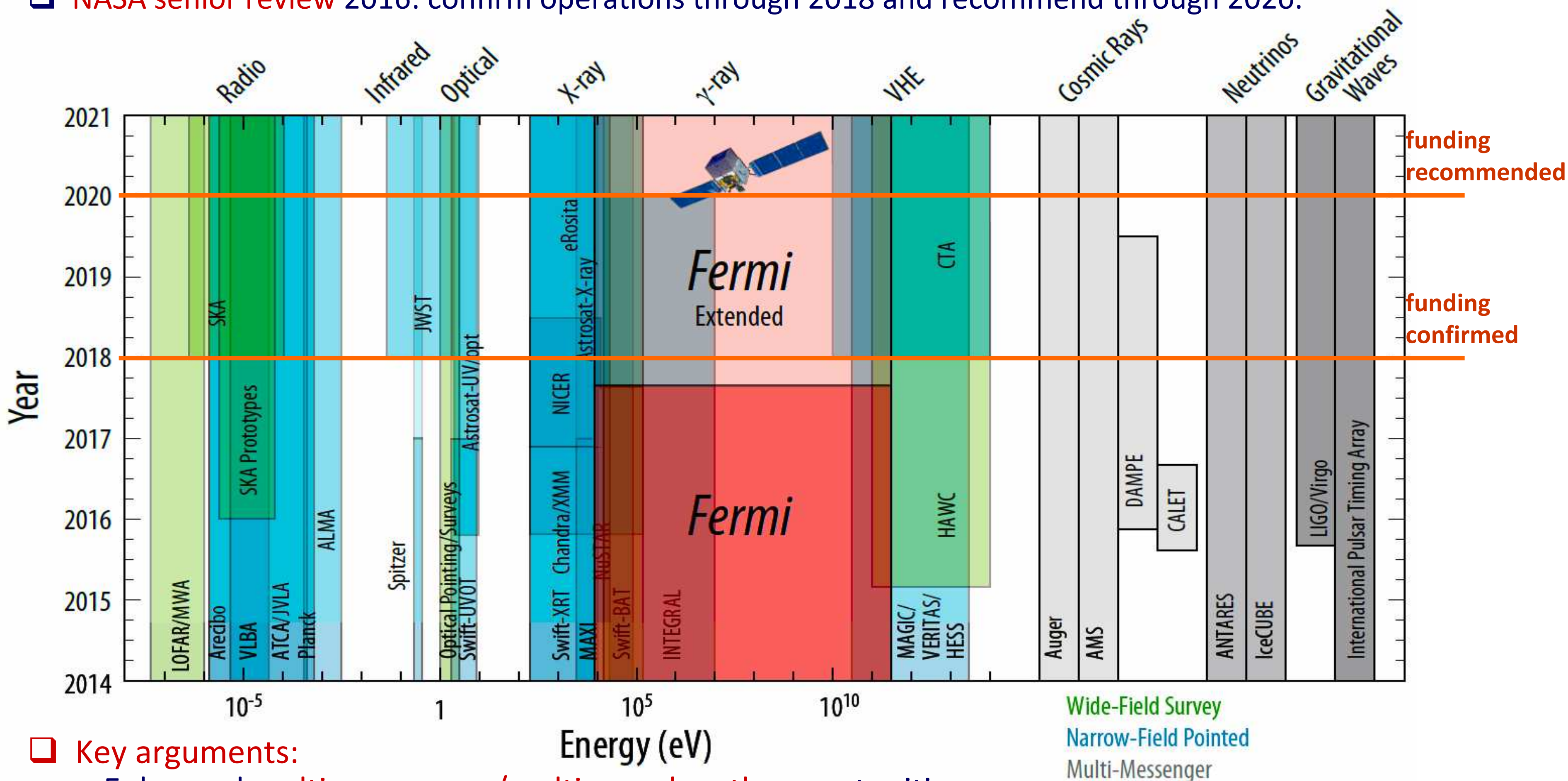
Extended phase and mission timeline

- NASA senior review 2016: confirm operations through 2018 and recommend through 2020.



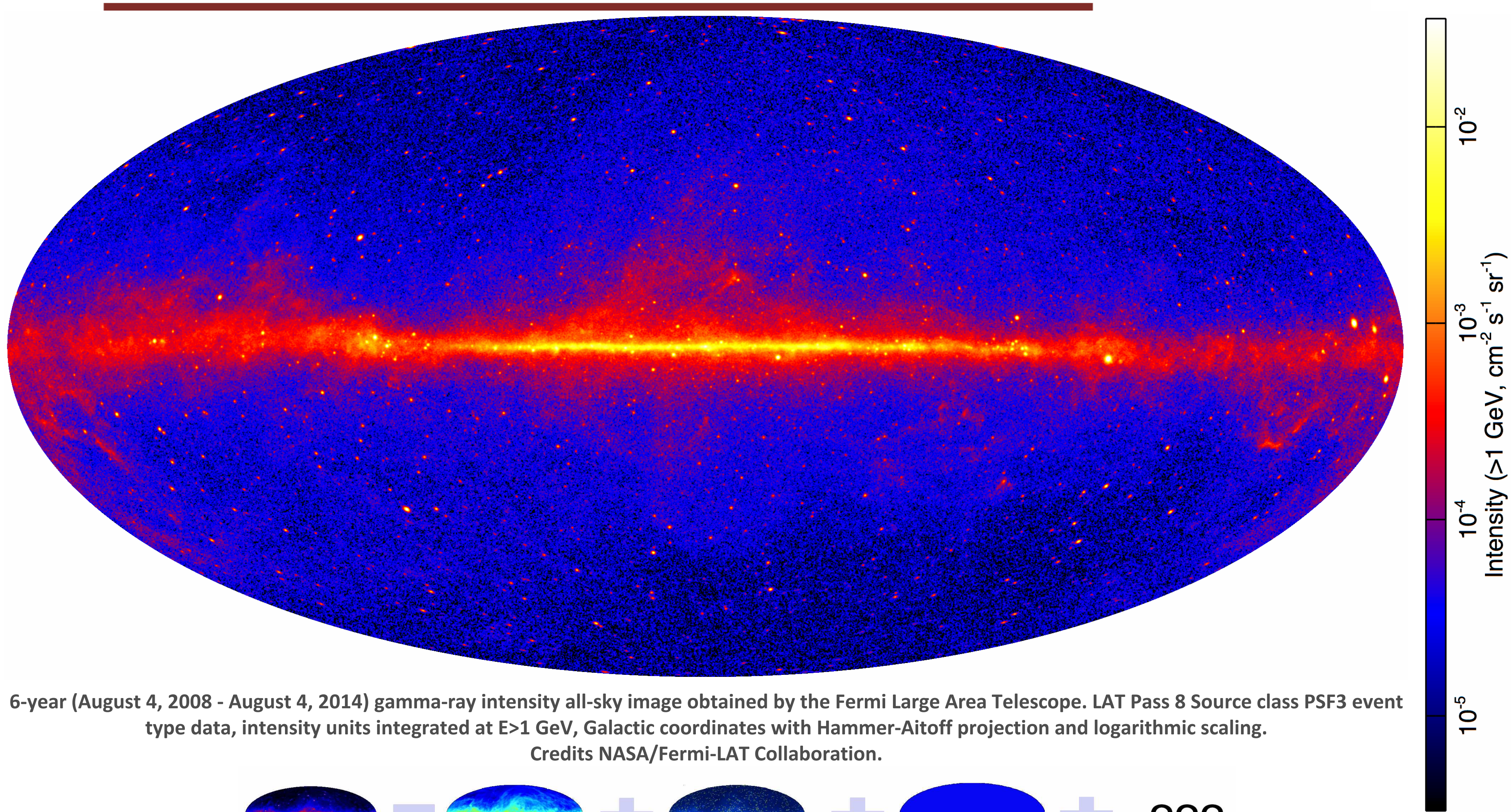
Astropart. phys./astrophys. operating context

- NASA senior review 2016: confirm operations through 2018 and recommend through 2020.

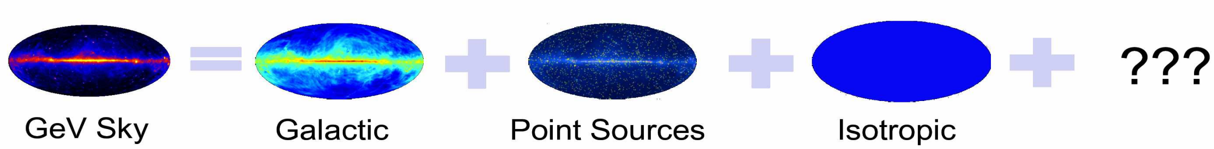


- Key arguments:
  - Enhanced multi-messenger/multi-wavelength opportunities.
  - Fermi unique all-sky monitor in a broad energy range (unique survey at MeV-GeV photon energies).

Unveiling the HE (GeV) gamma-ray sky

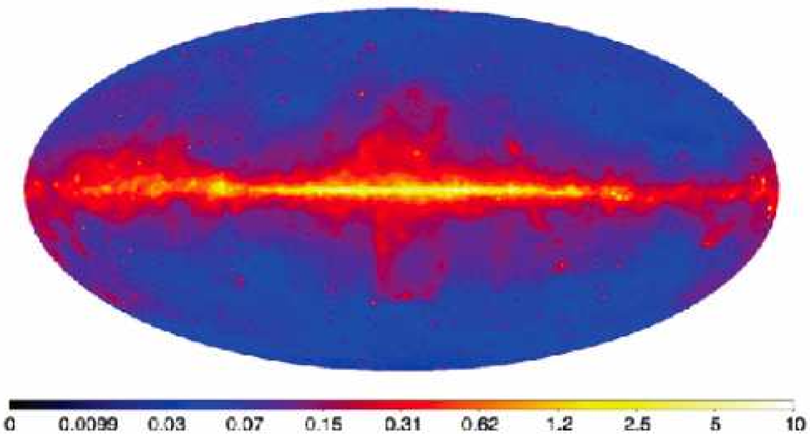


6-year (August 4, 2008 - August 4, 2014) gamma-ray intensity all-sky image obtained by the Fermi Large Area Telescope. LAT Pass 8 Source class PSF3 event type data, intensity units integrated at E>1 GeV, Galactic coordinates with Hammer-Aitoff projection and logarithmic scaling.
Credits NASA/Fermi-LAT Collaboration.

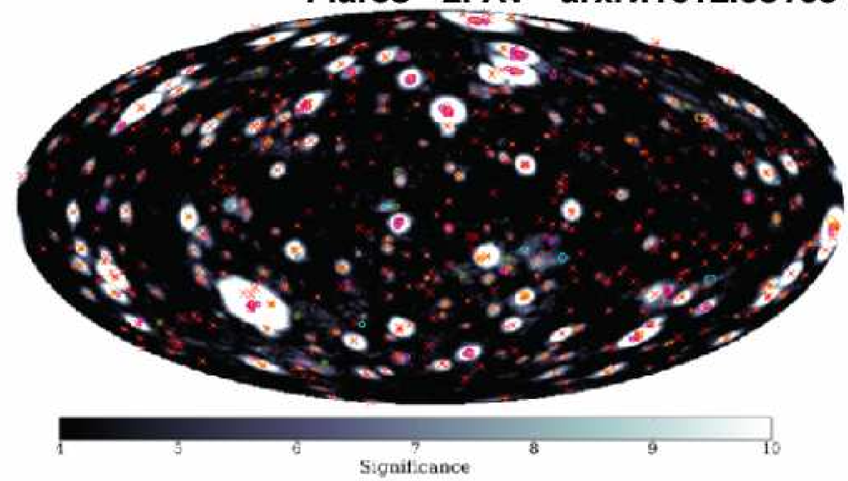


Different gamma-ray Fermi skies

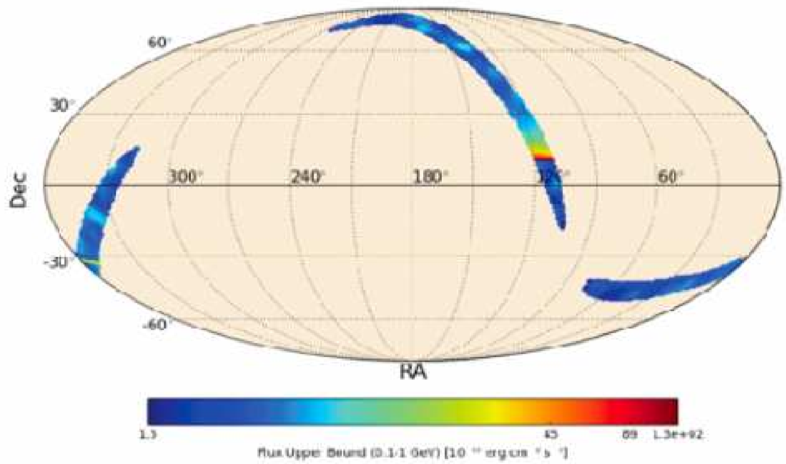
High Energy - 3FHL - arxiv.1702.00644



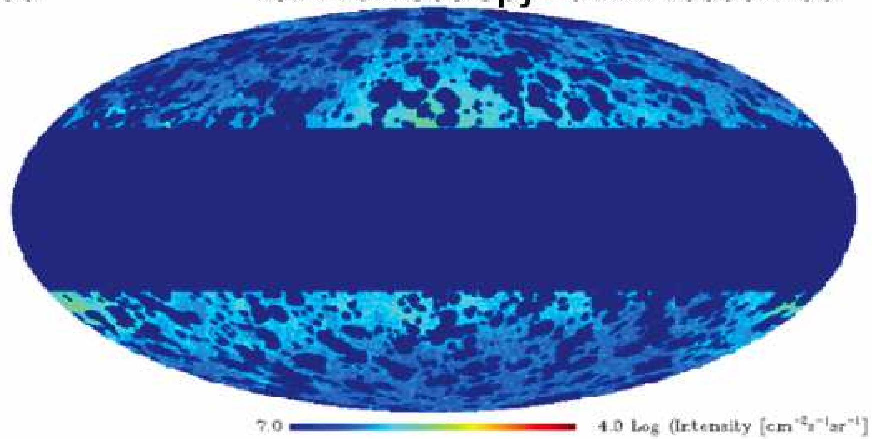
Flares - 2FAV - arxiv.1612.03165



GW170104 EM counterpart searches - arxiv.1706.00199



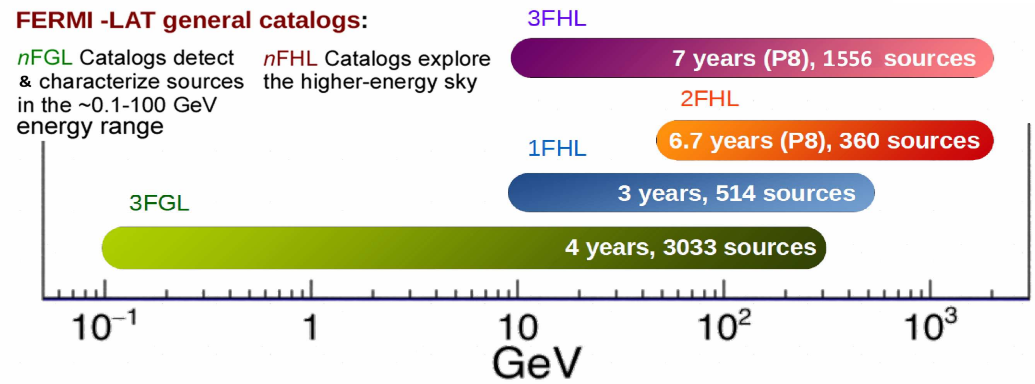
IGRB anisotropy - arxiv.160807289



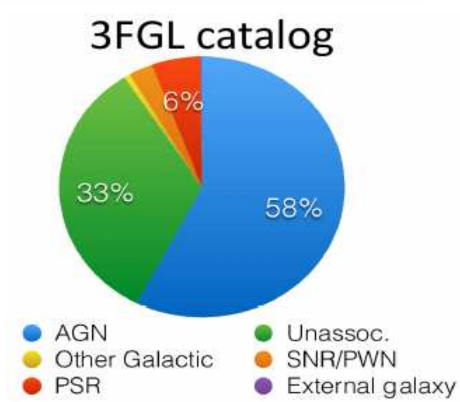
LAT gamma-ray source catalogs

❑ The general nFGL and nFHL catalogs are analyses over successively deeper data sets, and also represent successive analysis refinements, from event classification on up.

❑ There are also class-specific catalogs (AGNs, pulsars, GRBs, SNRs, transients, spatially extended sources, TGFs, solar flares, etc.).



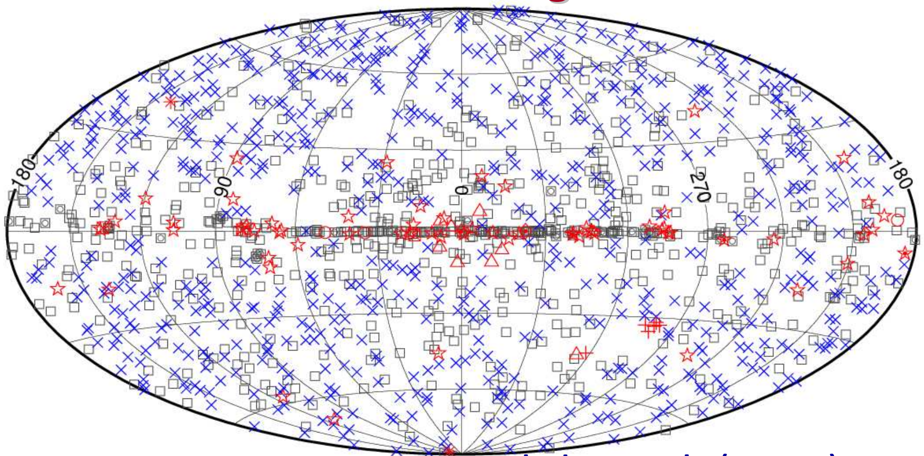
Catalog	Energy Range (GeV)	Data Interval (months)	Sources	Event Selection	Release Date
0FGL	**0.2-100**	**3**	**205**	**P6V1 DIFFUSE**	**Feb.2009**
1FGL	**0.1-100**	**11**	**1451**	**P6V3 DIFFUSE**	**Feb.2010**
2FGL	**0.1-100**	**24**	**1873**	**P7V6 SOURCE**	**Aug.2011**
1FHL	**10-500**	**36**	**511**	**P7V6 CLEAN**	**Jun.2013**
3FGL	**0.1-300**	**48**	**3033**	**P7V15 SOURCE**	**Jan.2015**
2FHL	**50-2000**	**6.7 years**	**360**	**P8R2 SOURCE**	**Aug.2015**
3FHL	**10-2000**	**7 years**	**1556**	**P8R2V6 SOURCE**	**Feb.2017**



3FGL Catalog
- 4 years, P7REP
- Front/Back handled separately (different isotropic and Earth limb).
- Energy range 100 MeV - 300 GeV.
- 3033 sources (2192 at |b|>10°) >4.1 s (Acero et. al 2015).
- Blazars and pulsars dominate and 1/3 fraction of unassociated sources.

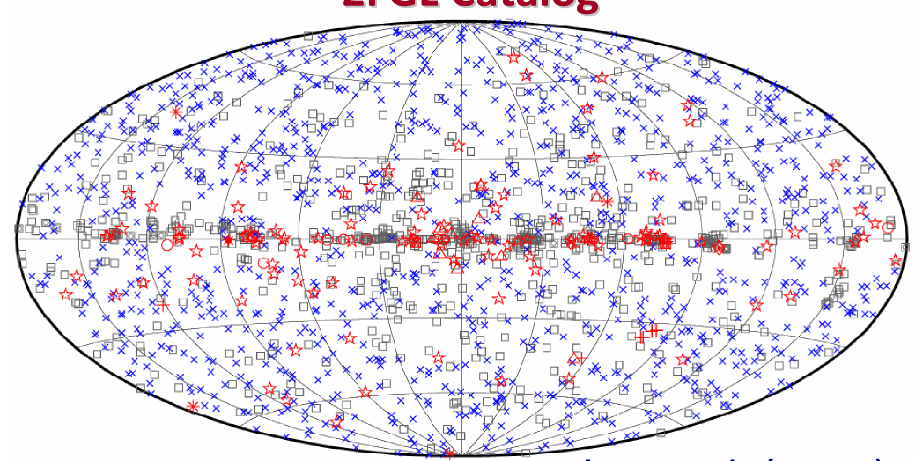
LAT gamma-ray source catalogs

1FGL Catalog



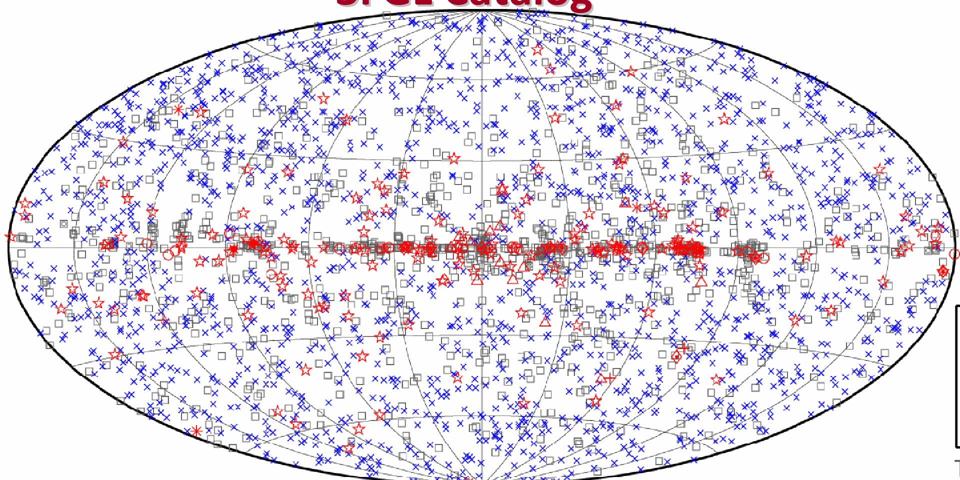
1451 sources >4.1σ   Abdo et al. (2009)

2FGL Catalog



1873 sources >4.1σ   Nolan et al. (2012)

3FGL Catalog



3033 sources >4.1σ   Acero et al. (2015)

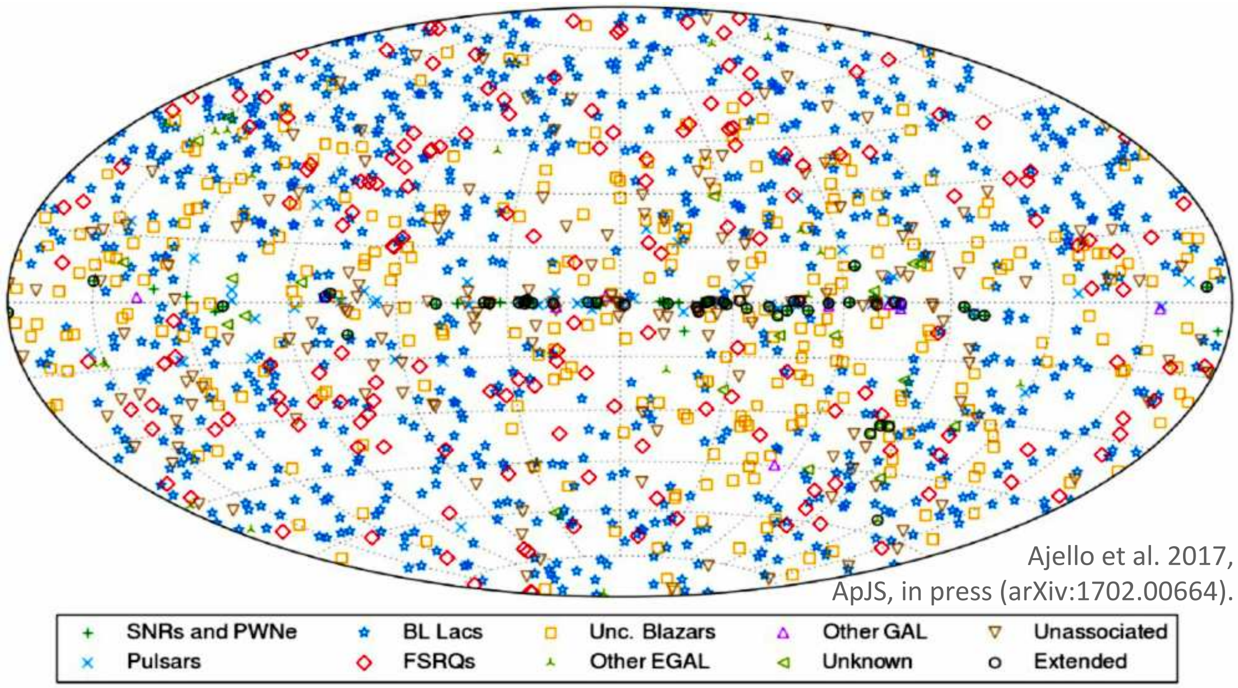
LAT nFGL catalogs:

- **To know what the LAT has detected**
- **Approach for finding new gamma-ray source classes**
- **Population studies**
- **Systematic analysis of the sky**
- **Standard model-fitting LAT source analysis → the catalog is initial guess for detailed study of any source**

No association	Possible association with SNR or PWN		AGN
Pulsar	Globular cluster	Starburst Galaxy	PWN
Binary	Galaxy	SNR	Nova
Star−forming region			

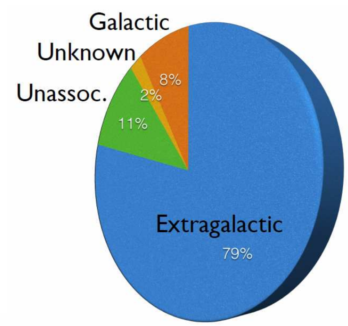
Test statistics TS>25 corresponds to a significance >4.1σ evaluated from the chi^2 distribution (4 degrees of freedom position, spectral parameters, Mattox et al. 1996).

The latest production: the 3FHL catalog



Ajello et al. 2017, ApJS, in press (arXiv:1702.00664).

- The recent 3FHL Catalog contains 1556 sources detected in the 10 GeV - 2 TeV energy range in the first 7 years of integrated Fermi LAT survey.
- 79% of 3FHL sources are extragalactic, ~8% are Galactic (>50 pulsars), and ~13% are unassociated.
- The 3FHL catalog is well suited for joint studies with ground-based Cherenkov tel. (HESS, MAGIC, VERITAS, HAWC, ...CTA).



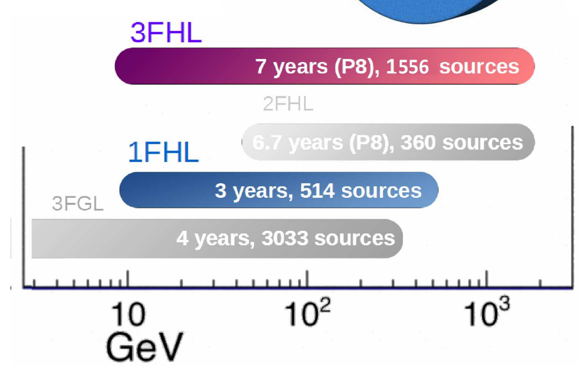
Comparison Summary	1FHL (3 years+Pass7)	3FHL (7 years+Pass8)
Number of sources	514	1556
Number of extended sources	18	48
Flux above 10 GeV (ph/cm2/s)	1.29 (0.87, 2.74) x 10^-10	5.03 (3.22, 10.33) x 10^-11
Spectral Index	2.36 (2.01, 2.90)	2.47 (2.13, 2.93)
Positional Uncertainty (deg)	0.079 (0.054, 0.097)	0.038 (0.028, 0.049)
Significance	6.17 (4.71, 9.37)	7.04 (5.18, 10.88)

X 3.0 more sources

X 2.7 more extended sources

x 2.6 deeper in flux

x 2.1 better location accuracy



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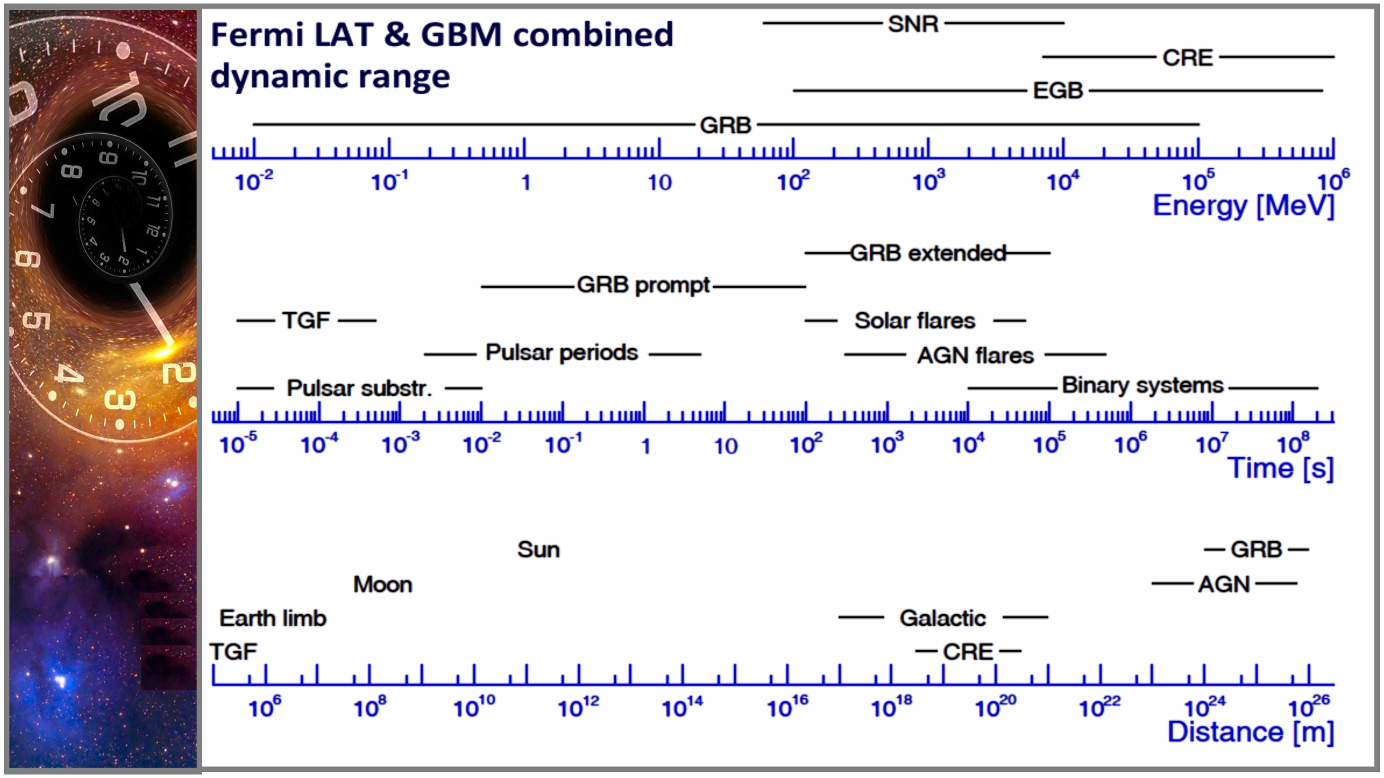
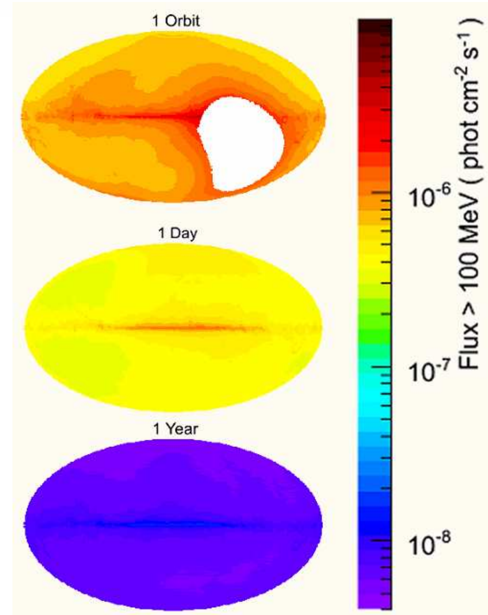
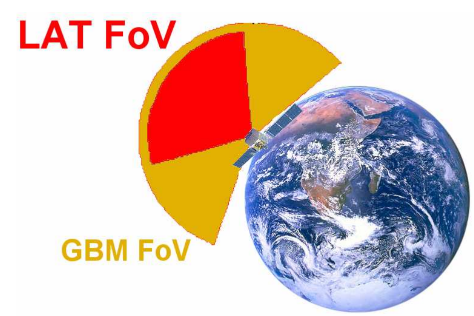
Fermi: all-sky survey & time-domain monitor



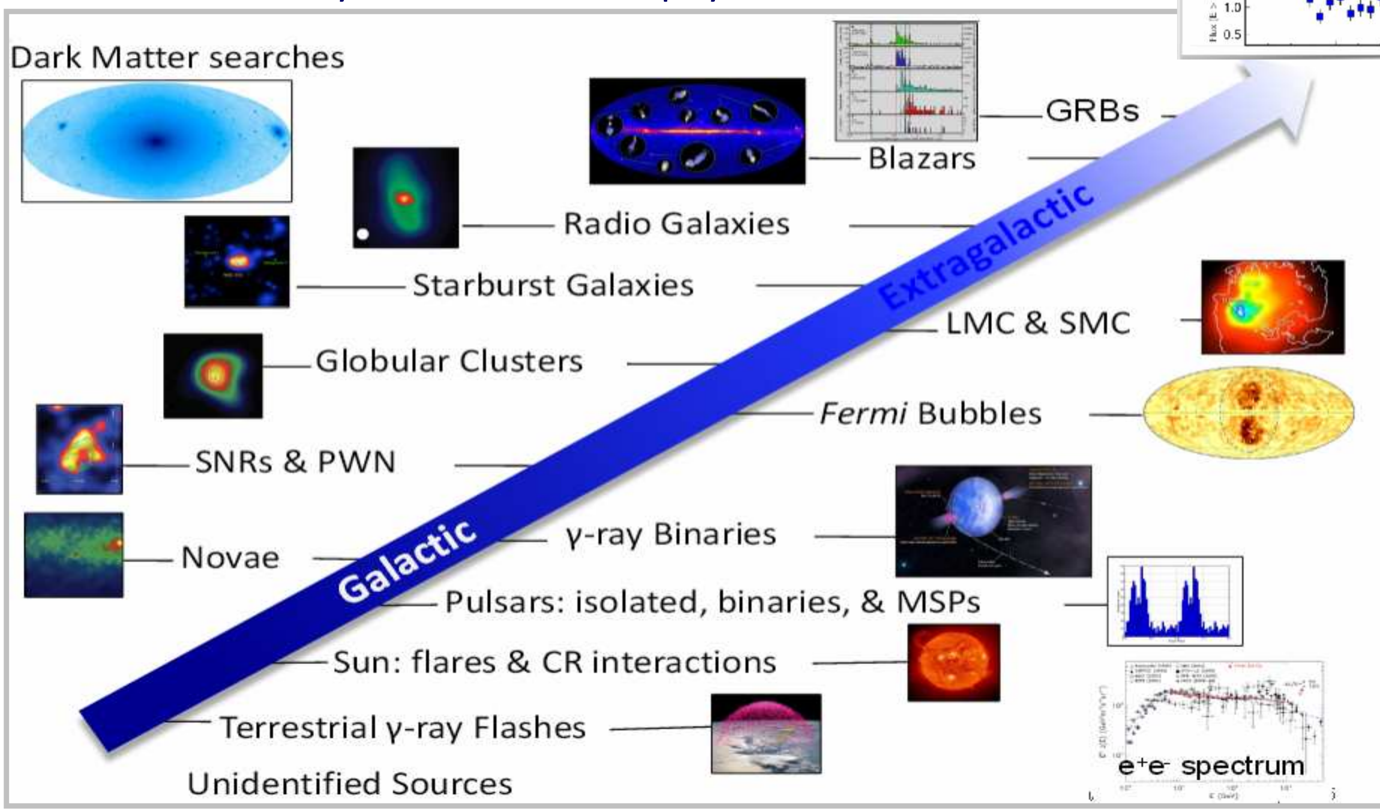


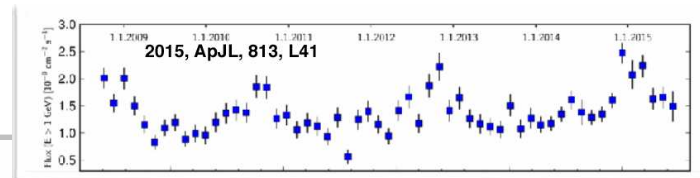


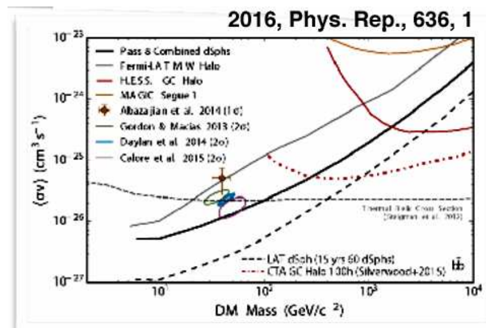
- The Fermi LAT has a wide field of view >20% of the sky (>2.5 sr)
  → Excellent to "catch" GRBs, AGN/blazars flares, glitches, galactic source transients, novae, SNs, solar flares, terrestrial gamma-ray flasjes, search for neutrino and gravitational waves electromagnetic counterparts, and to monitor the variable gamma-ray sources in general.
- Survey mode: the LAT observes entire sky every 2 orbits (~3 hours). Each sky point ~30min exposure.
  → Fermi LAT is an all-sky hunter and surveyor for high-energy transients and flares and all-sky monitor for variability of the restless/violent high-energy sky.

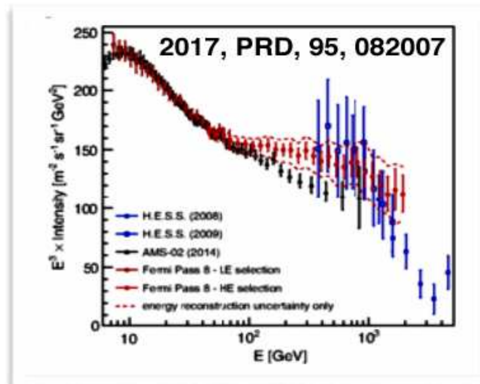
Fermi: all-sky survey & time-domain monitor

Fermi: unique ALL-SKY + ALL-TIMES mission for the HE cosmic laboratory and natural astrophysical accelerators.



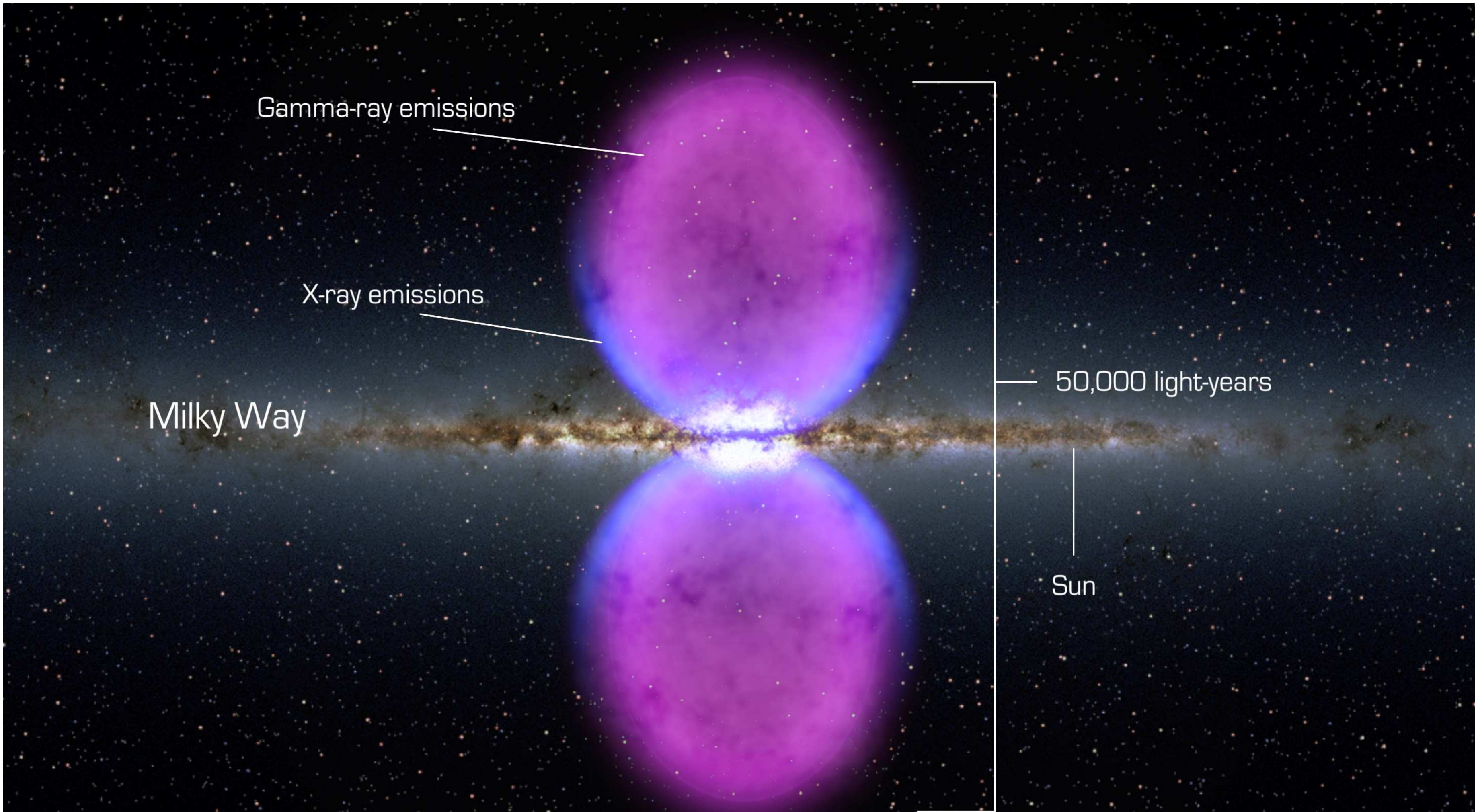






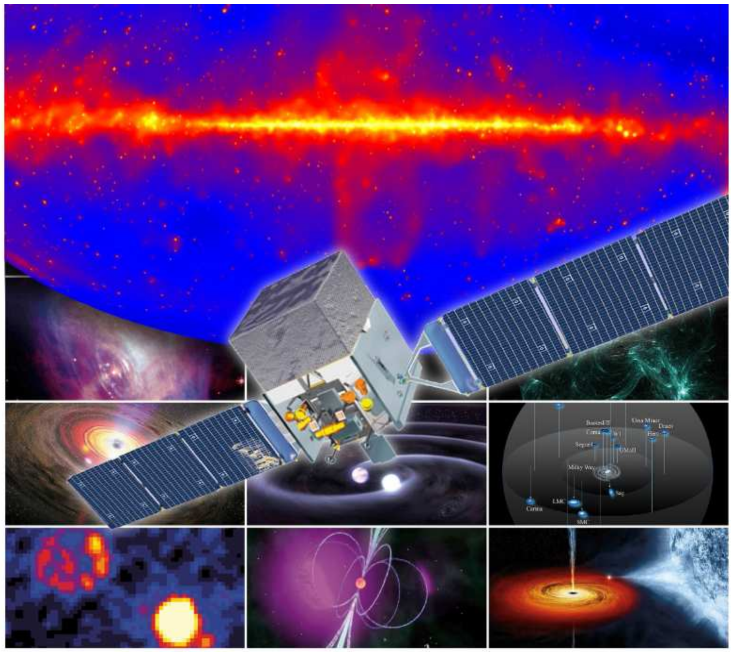
SURVEY → uniformity, serendipity, variability, transients, cross-corr, cross-match.

One example only: the Fermi bubbles of our Galaxy



These bubbles may indicate past energetic activity in the center of our Galaxy.

Fermi gamma-ray sources and science menu

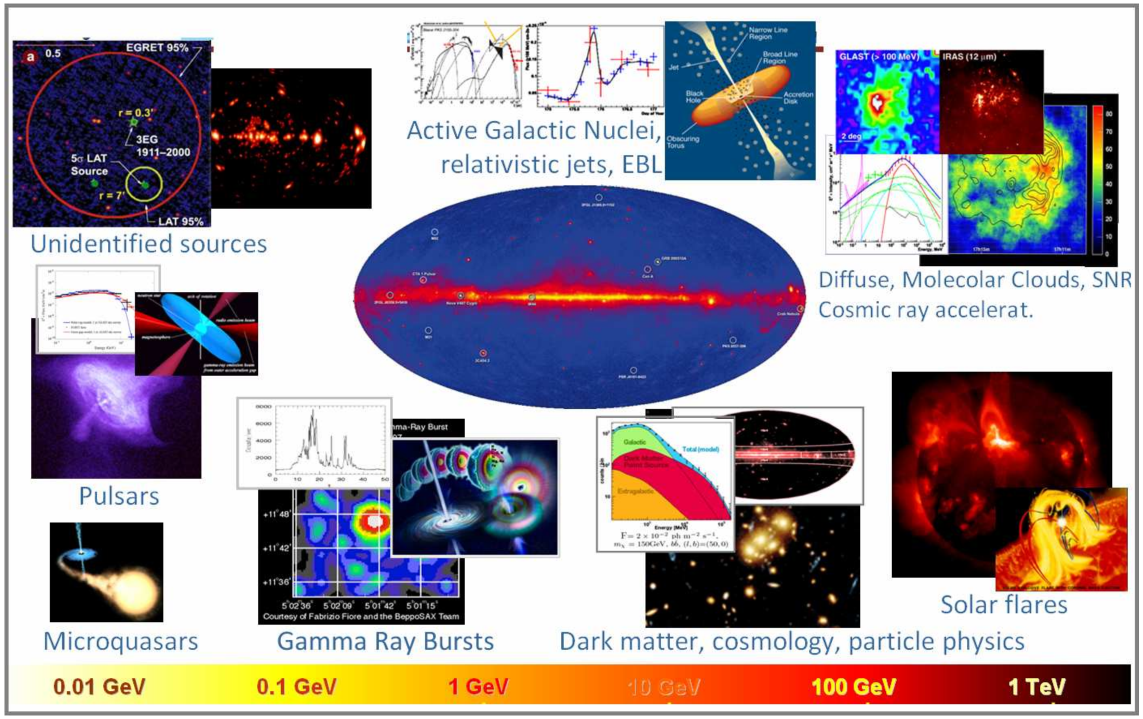


Examples of recent HE (>10GeV) scientific topics:

- ❑ Hard sources catalogs
- 3FHL, arxiv.1702.00664, in press to ApJS
- ❑ Extended sources
- 2017, ApJ, 843, 139
- ❑ Resolving the Galactic Center
- 2016, ApJ, 819, 44; - 2017, ApJ, 840, 43; arxiv. 1705.00009 (subm. to ApJ).
- ❑ Diffuse emission and CR propagation
- 2017, PRL 119, 031101

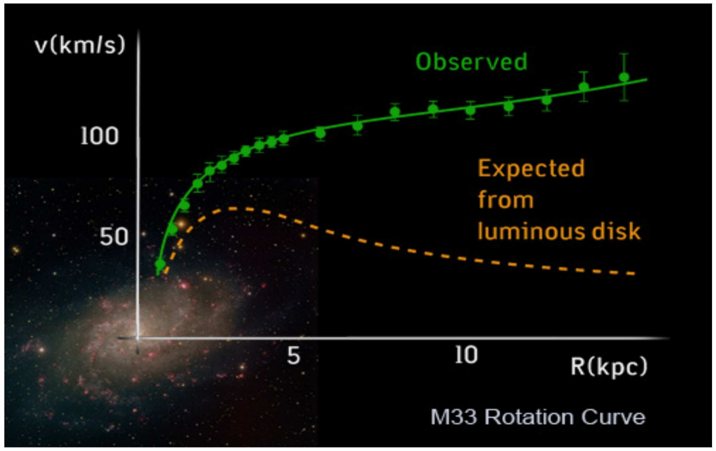
NASA Senior Review 2016 themes:

- ❑ Messengers (gammas, electrons, and MM/MW astroph.).
- ❑ Time (millisecond transients to multi-year variability/modulations)
- ❑ Dark Matter (WIMPs and axion candidates)
- ❑ Particle Astrophysics (CR acceleration sites and mechanisms).

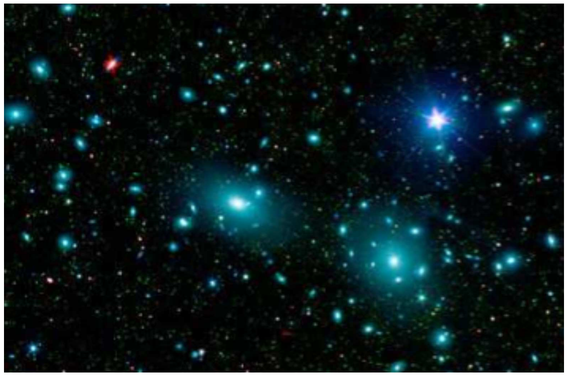


Evidence for Dark Matter

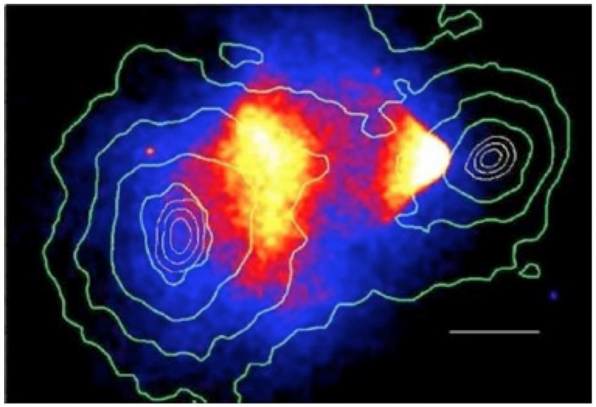
All the evidence for Dark Matter is astrophysical.

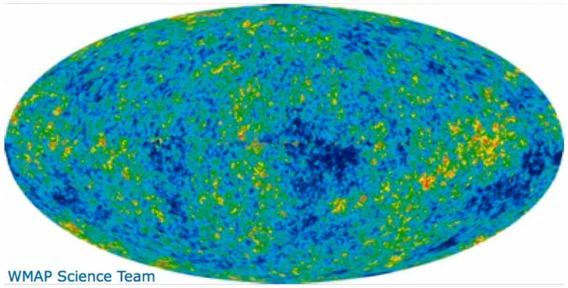


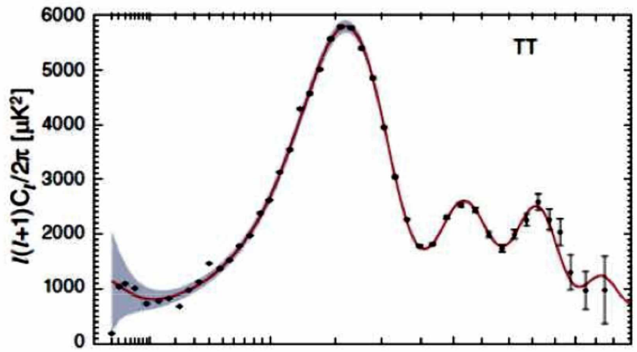
- ❑ Comprises majority of mass in Galaxies. Missing mass on Galaxy Cluster scale. Zwicky (1937)



- ❑ Large halos around Galaxies. Rotation Curves. Rubin+(1980).



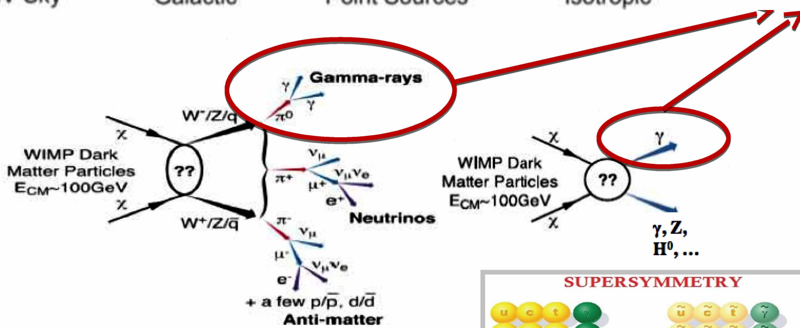


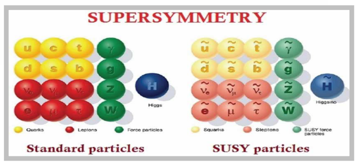


- ❑ Almost collisionless Bullet Cluster. Clowe+(2006)

- ❑ Non-Baryonic Big-Bang Nucleosynthesis. CMB Acoustic Oscillations. WMAP(2010), Planck(2015).

Fermi DM indirect search: inner Milky Way Galaxy



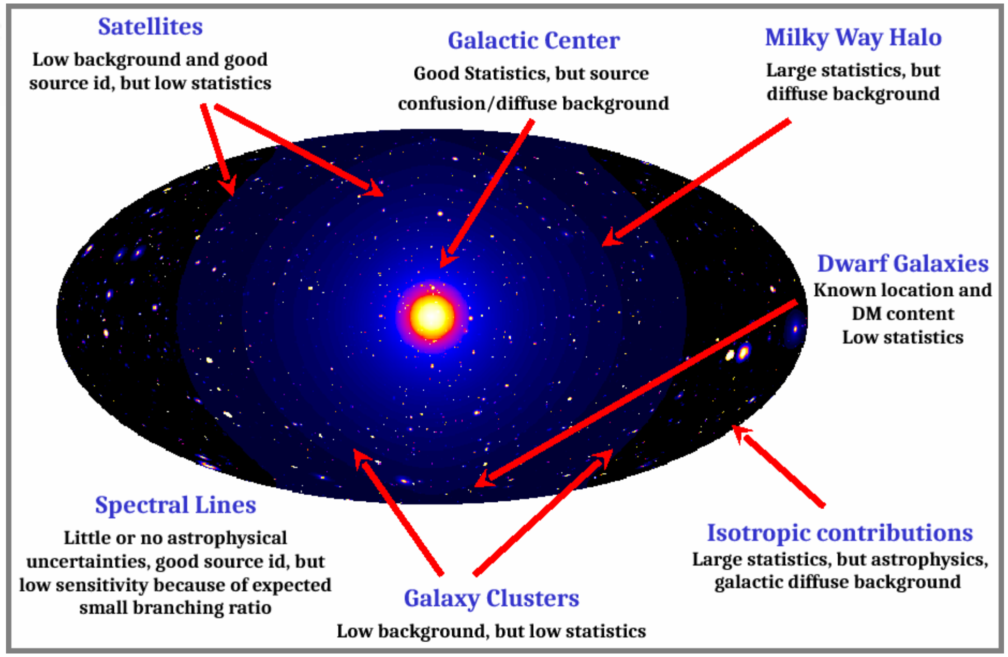


Our (Milky way) inner Galaxy:

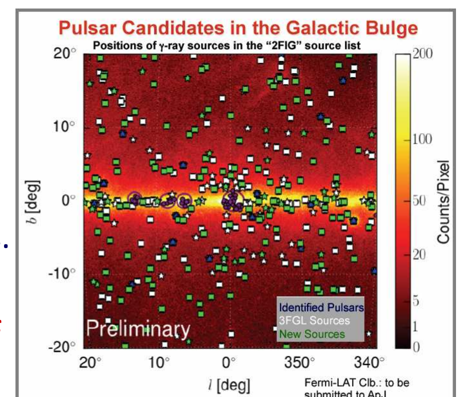
- ❑ Likely the brightest dark matter source in the gamma-ray sky, but embedded in large and complicated backgrounds (resolved/unresolved sources, diffuse).
- ❑ Several independent studies find a spatially extended GeV excesses above the expected diffuse background
  - The excess and its spatial extension are robust
  - Spherically symmetric, spectrum consistent with DM
  - The excess spectrum strongly dependent on emission model

The excess at the Galactic Center could be due to dark matter or unresolved sources (e.g. a new population of millisecond pulsars, MSPs, in the inner galaxy, diffuse emission from CR inhomog.).

- ❑ DM best fit cross section is in mild tension with other limits.



- ❑ Dedicated source analysis tracking the MSPs in the GC: pulsar candidate selection criteria trained on identified pulsars and number density compatible with expectations.
- ❑→ GC excess can be attributed to a popul. of unresolved MPSs.



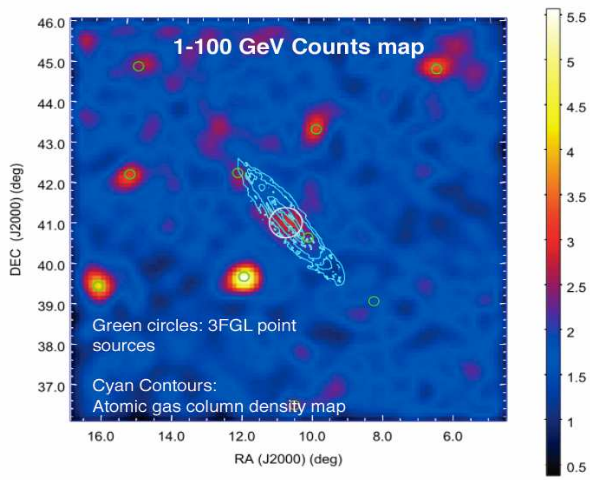
Fermi DM indirect search: Andromeda galaxy

❑ Andromeda (M 31) galaxy: gamma-ray emission comes primarily from inner 5kiloparsec region.
❑ Not correlated with interstellar gas and star formation regions.
❑ Galactic disk not detected.

❑ Interpretation I: Interstellar Emission (related to gas from pion decay: low gas content in GC could be compensated for by high cosmic ray density, far far from typical accelerators like star forming regions; related to IC scattering IC would need twice the luminosity from IC than from pion decay).

❑Interpretation II: Unresolved Source Populations (short-lived massive stars SNR or normal pulsars; old stellar populations like low-mass X-ray binaries and MSPs).

❑Interpretation III: Dark matter →



Ackermann et. al., (2017) ApJ Volume 836, issue 2, Number 2
https://arxiv.org/abs/1702.08602


Feb. 21, 2017

NASA's Fermi Finds Possible Dark Matter Ties in Andromeda Galaxy

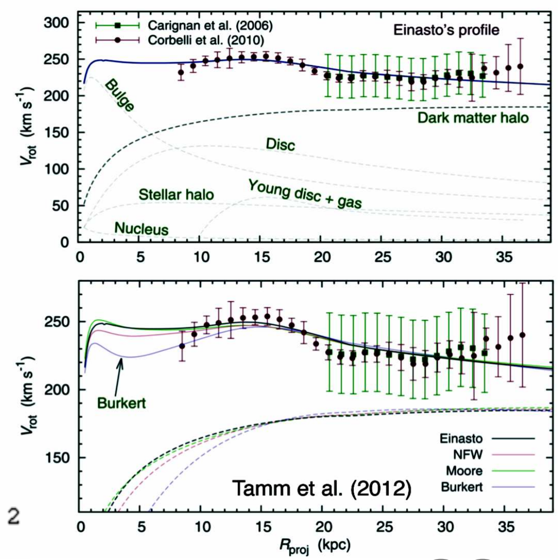
NASA's Fermi Gamma-ray Space Telescope has found a signal at the center of the neight
could indicate the presence of the mysterious stuff known as dark matter. The gamma-ray
Fermi at the center of our own Milky Way galaxy.

Consistent with DM from GCE?

J-factors:
Milky Way: 2×10^{22} GeV^2/cm^5
M31: 8×10^{18} GeV^2/cm^5 (±20%)

- Observed flux from M31 5x higher than expected value

- However, uncertainties on J-factor of M31 and on GCE flux (follow-up in progress…)

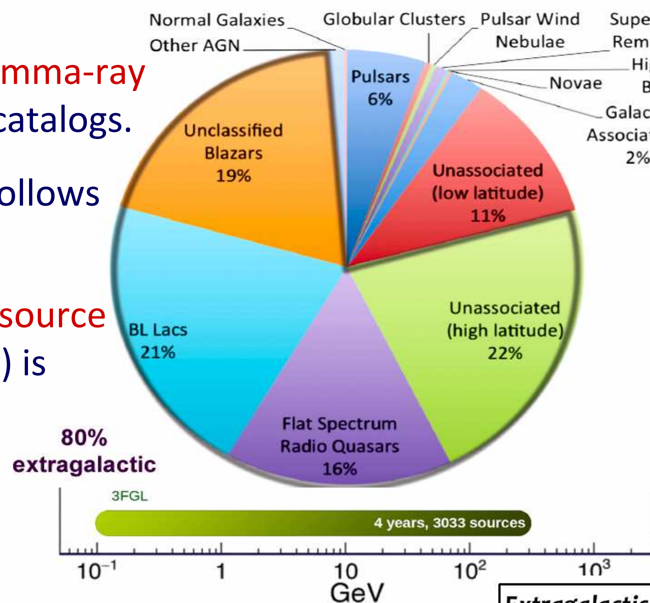


Ackermann et. al., (2017) ApJ Volume 836, issue 2, Number 2
https://arxiv.org/abs/1702.08602

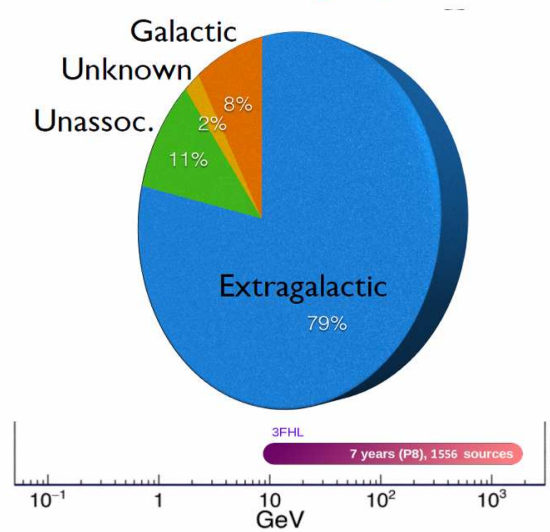
Fermi as an AGN/blazar telescope

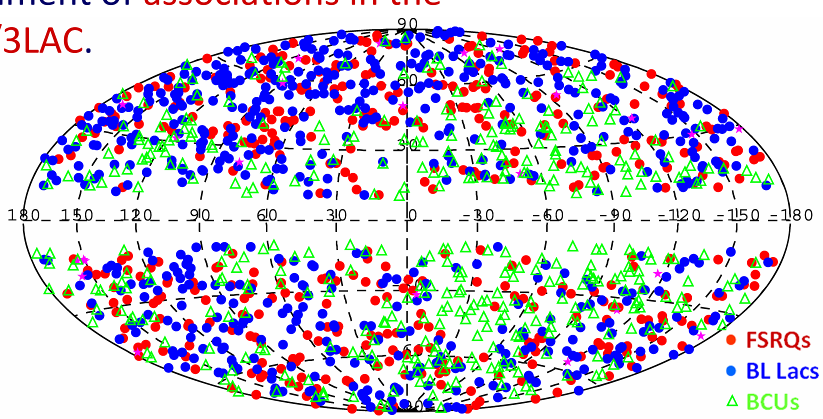
- ❑ Active Galactic Nuclei (AGN) and blazars in particular (they represents the extragalactic sky), dominated the gamma-ray source counts in Fermi LAT general catalogs.
- ❑ The 3rd LAT AGN catalog (3LAC) follows in the footsteps of the 3FGL catalog.
- ❑ Association of e.m. astrophysical source counterparts (radio/optical/IR/X-ray) is generally the strongest statement that we can make: two quantitative methods, Bayesian method (BM) Likelihood ratio method (LRM), for assignment of associations in the 3FGL/3LAC.

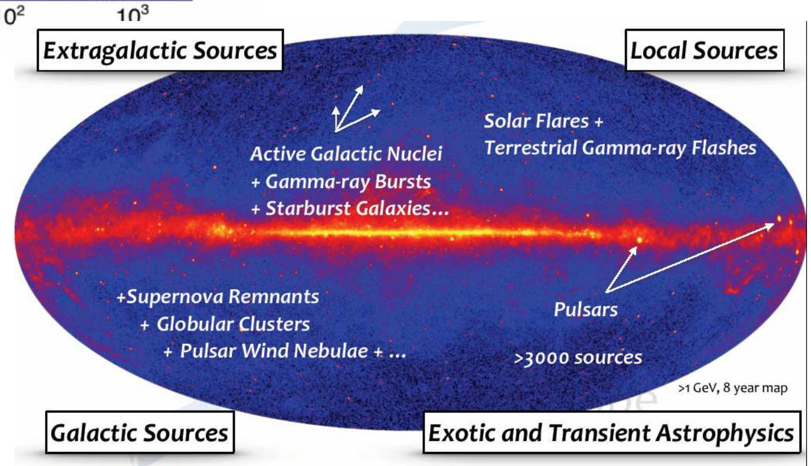
3FGL demographics



3FHL demographics







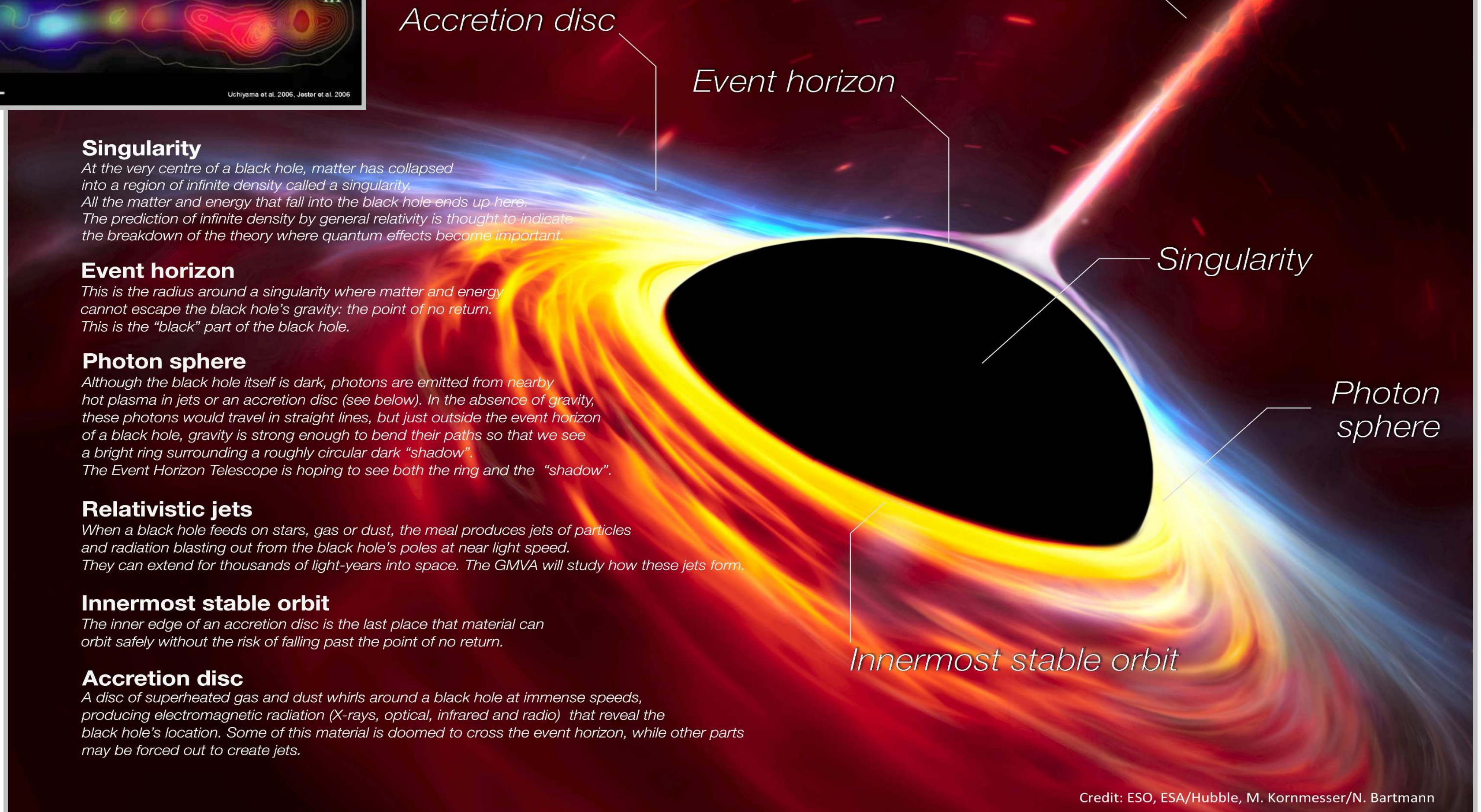
Active Galactic Nuclei (AGN)

BEACONS/BEAMS OF THE UNIVERSE

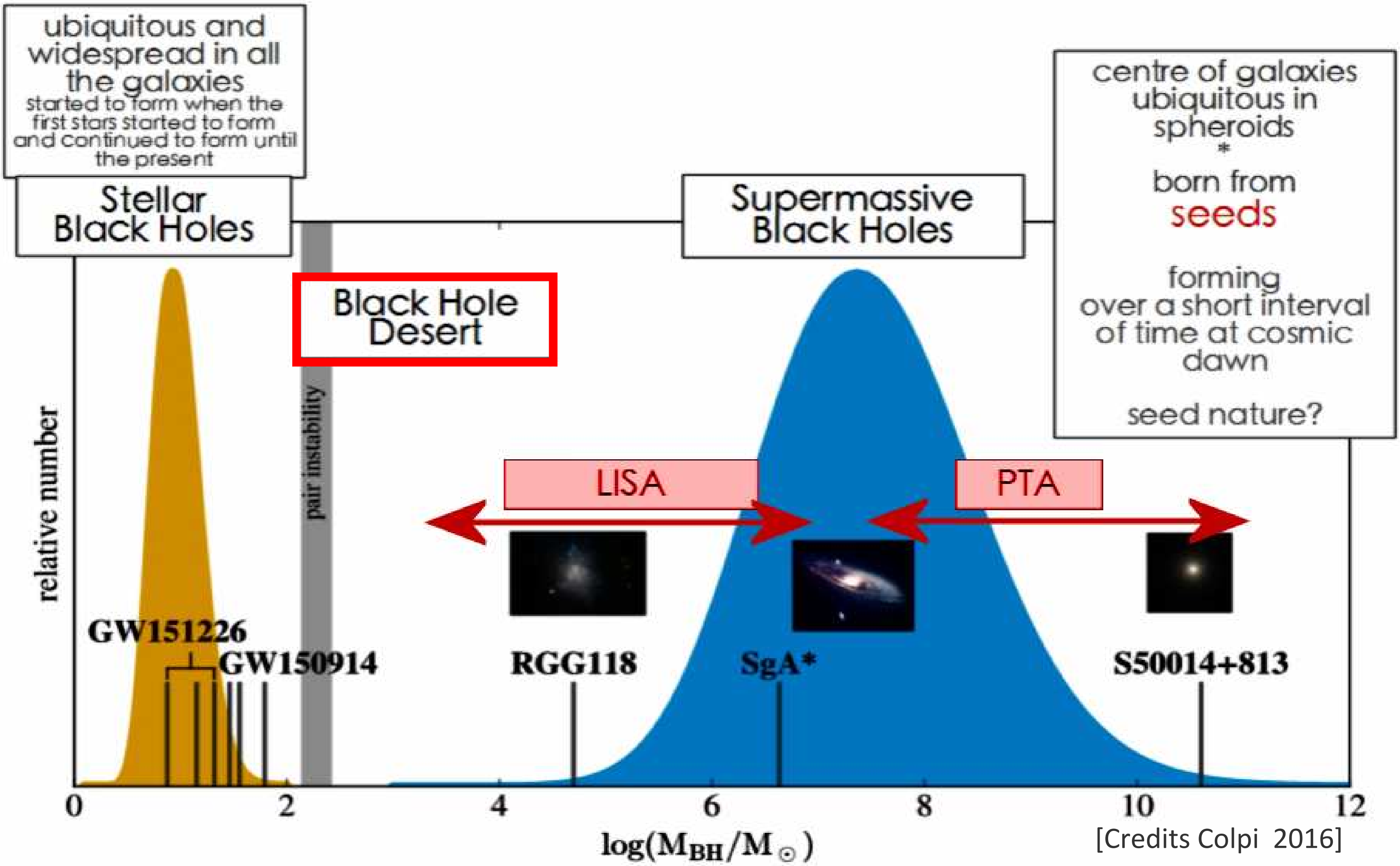
- The great power in the AGN (quasars and blazars are subfamilies) is driven by accreting matter onto a super-massive black hole (SMBH).
- Part of this accretion energy fuel a relativistic jet (particles and energy). In blazars the jet dominated the observed energy output and it points toward our line of sight. Macroscopic Special Relativity effects in action (for example the relativistic beaming).
- **AGN as astrophysical sources:** still controversial topics are, for example, emission region location and radiative processes, nature and physics of their relativistic jets, accretion, variability mechanisms, particles composition and acceleration mechanisms, disk-jet connection, object populations and cosmological evolution.

- **AGN as (potential) multi-messenger astroparticle sources**: cosmic PeV-energy neutrinos, UHE cosmic rays, axion-like supersymmetric particles (ALPs), intense very-low frequency gravitational waves.
- Phenomenology includes MeV/GeV/TeV gamma-ray radiation, rapid, irregular and strong photon flux variability on very different time scales and at all the energy bands (radio to gamma rays), a high degree of optical/radio polarization, a compact unresolved radio core.

Active Galactic Nuclei (AGN)

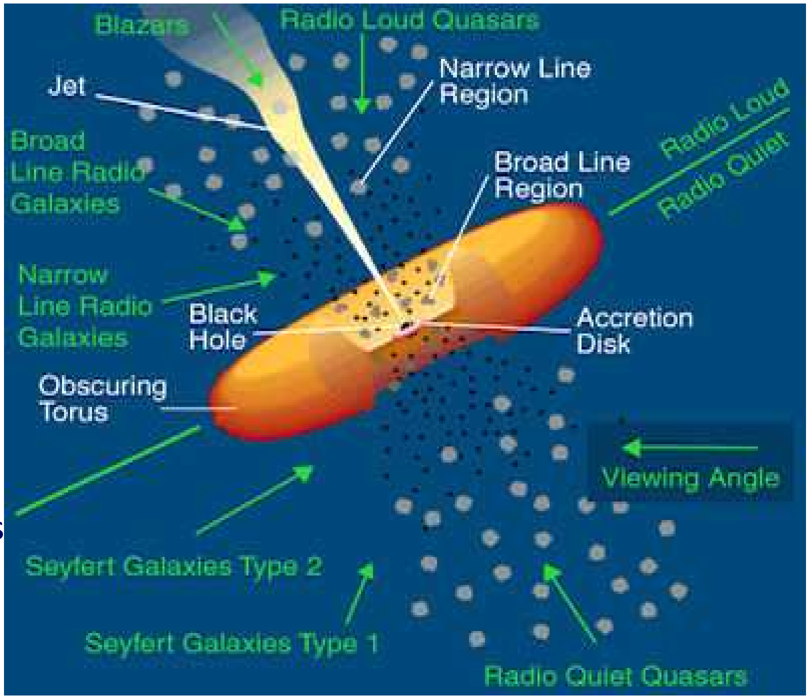


BHs: two flavors, Stellar/Supermassive BHs



[Credits Colpi 2016]

An AGN primer



- ❑ Almost all galaxies contain a massive black hole.
- ❑ 99% of them are (not-completely) silent (e.g. our Galaxy)
- ❑ 1% is active (mostly radio-quiet AGNs): accretion onto a central, supermassive black hole (SMBH). Accretion disks produce optical/UV/X-ray emission via various thermal processes.
- ❑ 0.1% is radio loud: jets (mostly visible in the radio). Highly collimated relativistic outflows (beams). Lorentz factor about 10-30.
- ❑ Compact radio core, flat/inverted spectrum, relatively high radio/optical polarization.
- ❑ Extreme variability at all frequencies (gamma-rays too), large brightness temps, superluminal motion at VLBI scales.
- ❑ Unified models: orientation with observer line-of-sight determines source properties, e.g., radio galaxy vs blazar.
- ❑ Other factors: accretion rate, SMBH mass and spin, host galaxy…

❑ **FSRQs:** bright broad emission lines, sometimes a "blue bump" (accretion disc), multi-temperature disk emission, broad lines in opt-UV, non-thermal components peak in IR and hard X-ray/MeV regime, high luminosity ($L \sim 10^{48}$ erg s^{-1}) and redshift $z \geq 1$. **BL Lacs**: weak (EW<5 Å) emission lines, little or no evidence of disk or emission lines in Opt-UV, non-thermal peaks in UV/soft X-rays & GeV, lower luminosity ($L \sim 10^{45}$ erg $^{s-1}$) and $z < 0.5$

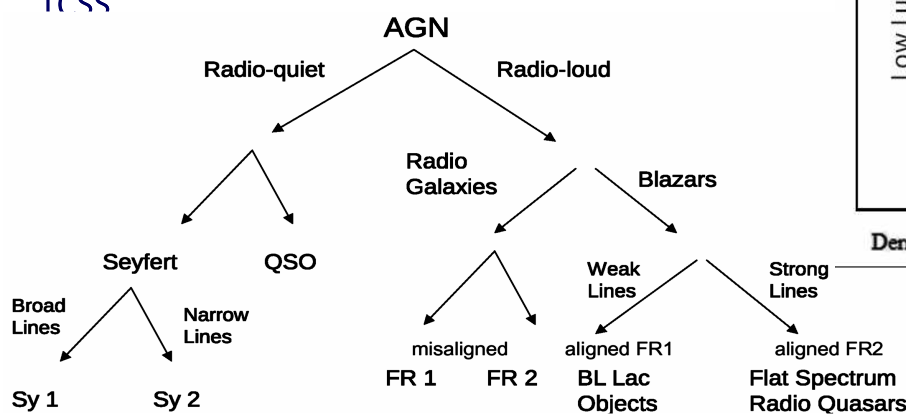
❑ Intense emission in MeV-GeV gamma-ray energies: it dominates the bolometric radiative power output. Powerful gamma-ray FSRQs are also optimal probes to explore the distant Universe at cosmological scales.

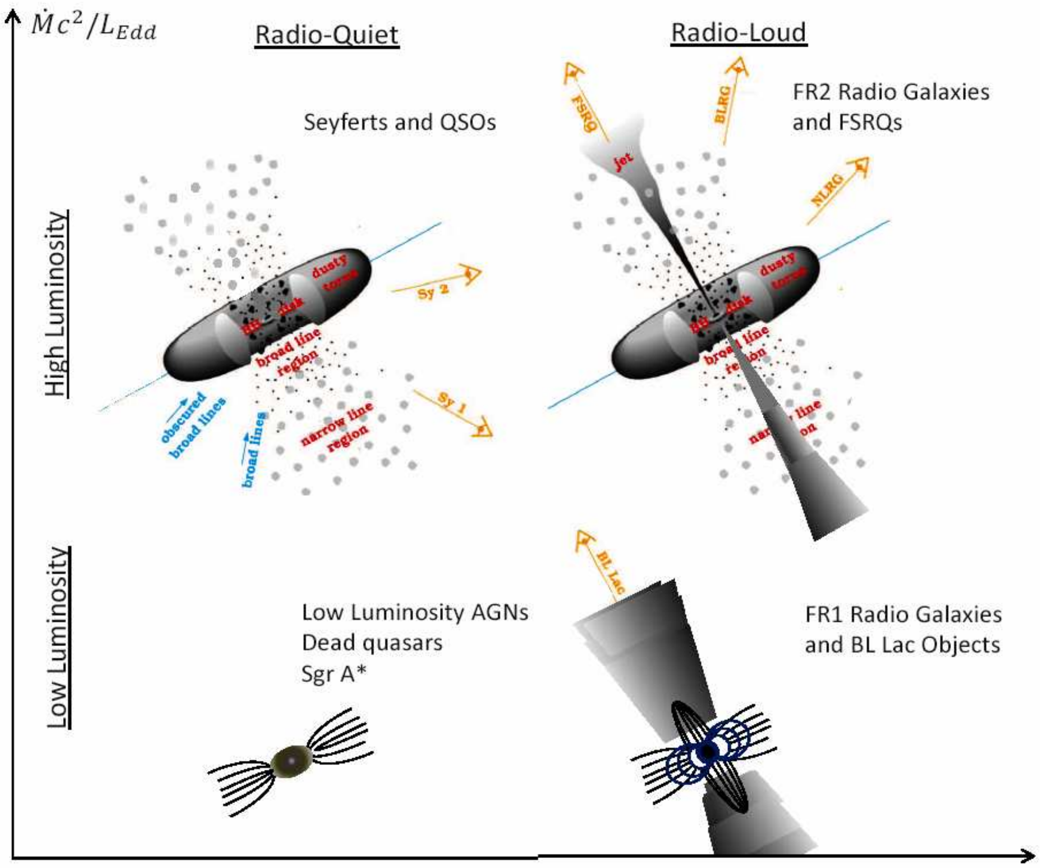
❑ A couple of recent reviews: 1) Padovani et al. 2017, *"Active galactic nuclei: what's in a name?",* Astron. and Astroph. Rev., 25, 2, (91pp) (arXiv:1707.07134) ; 2) Dermer & Giebels 2016, *"Active galactic nuclei at gamma-ray energies*", Comptes Rendus Physique, 17, 594 (arXiv:1602.06592v1).

An AGN primer

- ❑ Quasars (radio-quiet or radio-loud quasars)
- ❑ BL Lacertae Objects
- ❑ Radio Galaxies (broad or narrow line radio galaxies, BLRG, NLRG and Fanaroff-Riley type I or II)
- ❑ Seyfert Galaxies (type 1 – 2 and Narrow-Line Seyfert-1 galaxies, NLSy1)
- ❑ Low-Luminosity AGN (Ionization Nuclear Emission-Line Region, LINER Galaxies, and “Regular” spirals like Sgr A*).

❑ All AGN types are able to emit gamma-ray photons ?
Not only classical blazars in the Fermi 3FGL catalog: 9(12) radiogal. FR-I, 3 FR-II, 7 SSRQ, 5 NLSy1, 1 Sey, 1CSS



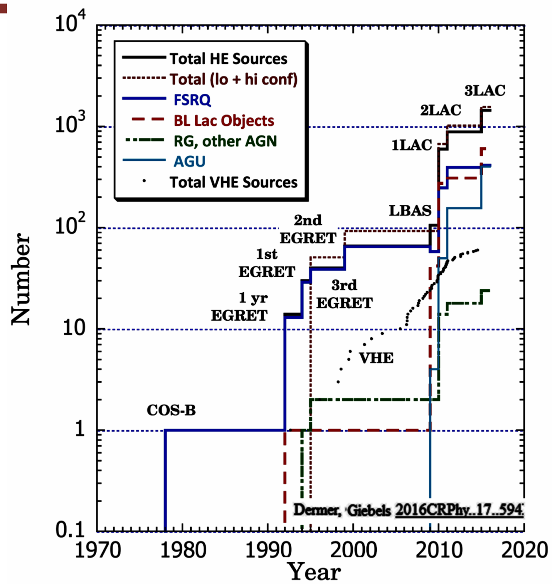


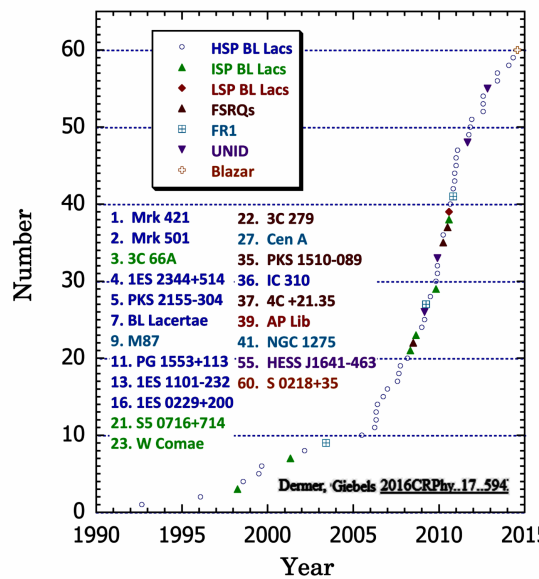
Dermer, Giebels 2016CRPhy..17..594

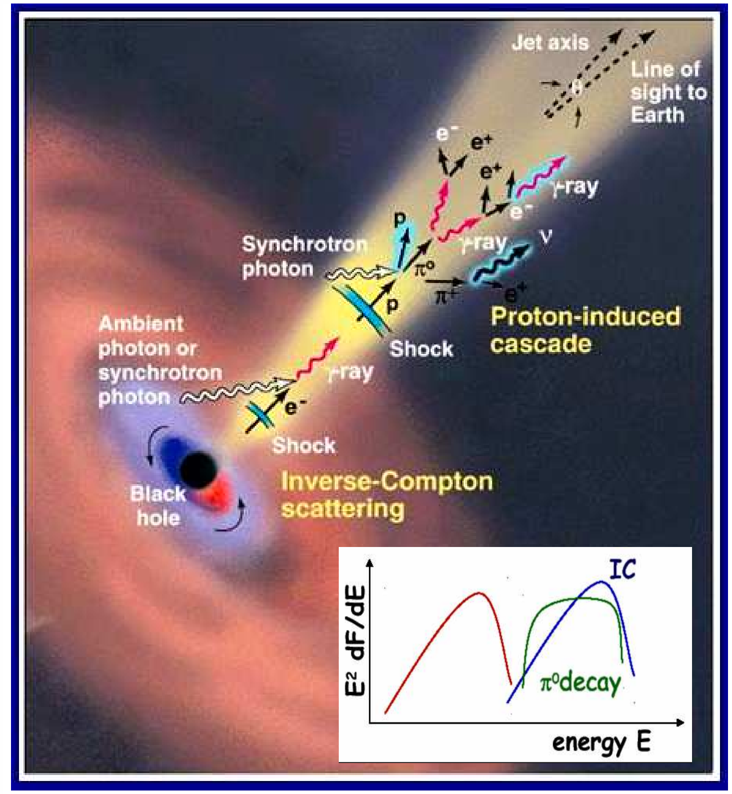
❑ The jet power dominates over the accretion power by a factor of 10 and is somewhat larger than entire gravitational power (Ghisellini et al., 2014, Nature, 515, 376).

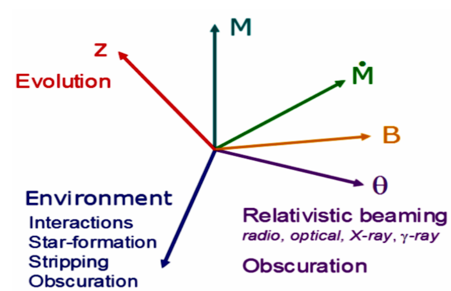
An AGN primer

- ❑Emission mechanisms (especially for high energy component)
  - -- Leptonic (IC of synchrotron or external photons) vs hadronic ($\pi^0 \rightarrow \gamma\gamma$, proton synchrotron). Hadronic models foresee the emission of HE neutrinos.
- ❑Emission location
  - -- Single zone for all wavebands (completely constraining for simplest leptonic models)
  - -- Opacity effects and energy-dependent photospheres
- ❑Particle acceleration mechanisms
  - -- Shocks, Blandford-Znajek
- ❑Jet composition
  - -- Poynting flux, leptonic, ions
- ❑Jet confinement
  - -- External pressure, magnetic stresses
- ❑ Accretion disk-black hole-jet connection
- ❑ Blazars as probes of the extragalactic background light (EBL)
- ❑ Effect of blazar emission on host galaxies and galaxy clusters.



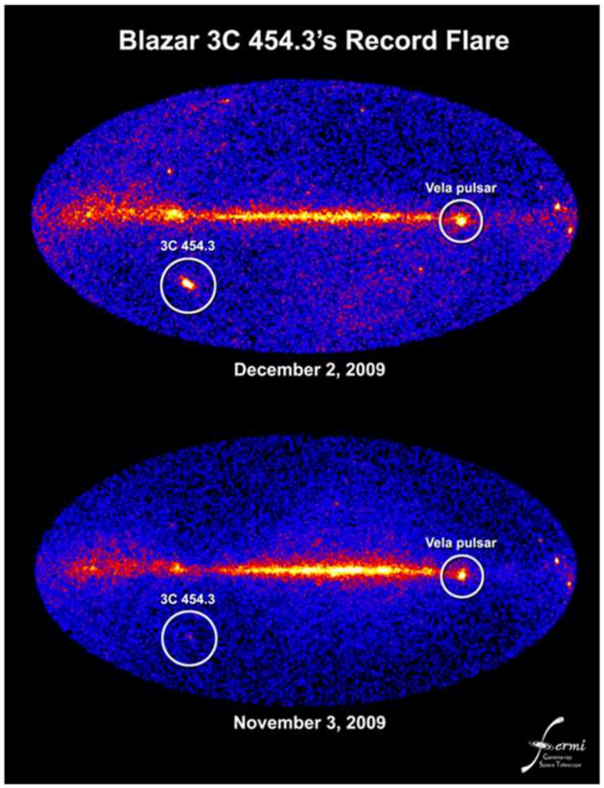


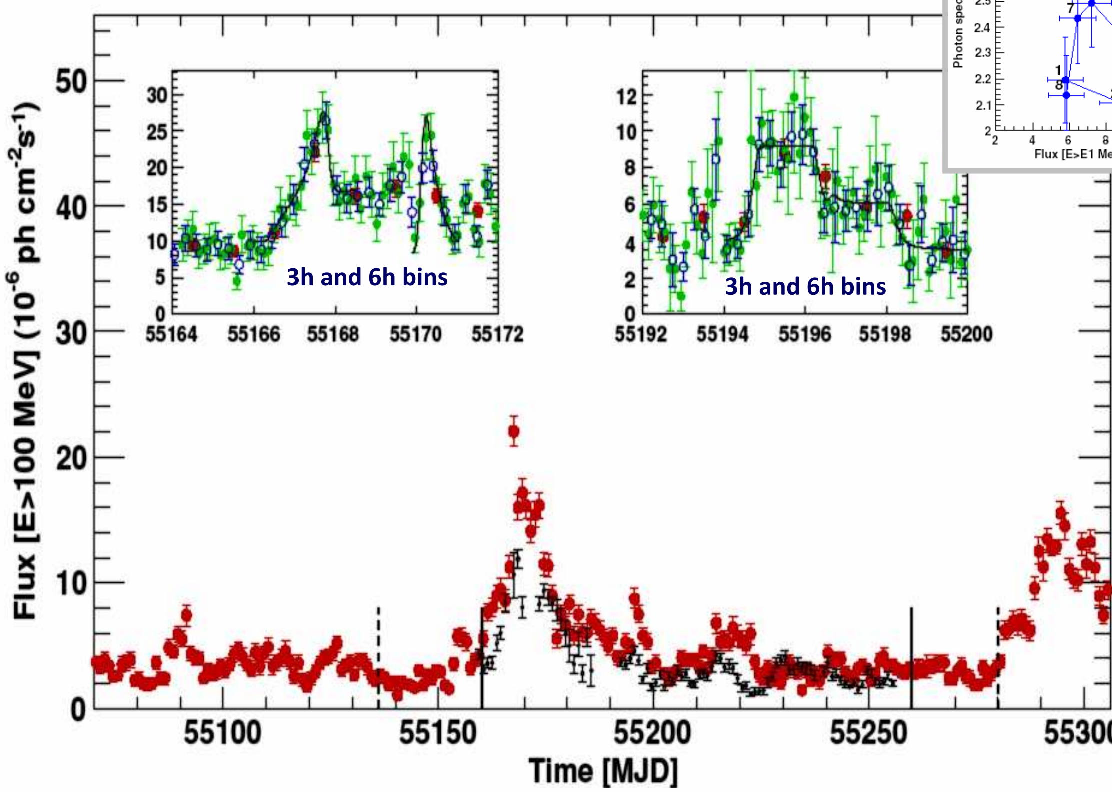




Big GeV outbursts: the case of 3C 454.3

- Correlated spectral-temporal properties of 3C 454.3 during two very strong flaring episodes studied (it was the brightest object in the gamma-ray sky during the peak).





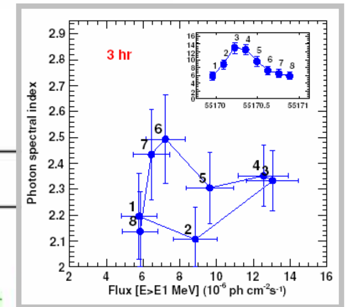
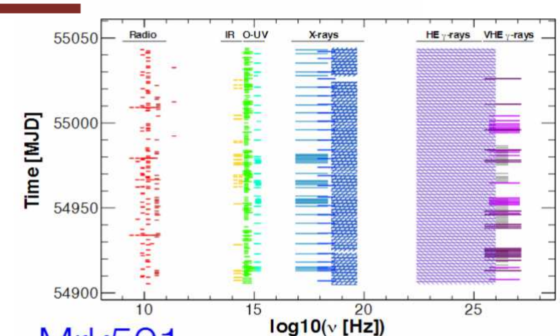


Figure 1. Light curve of the flux of 3C 454.3 in the 100 MeV–200 GeV band (red) between MJD 55,070–55,307 (2009 August 27–2010 April 21). The solid (dashed) lines mark the period over which the PSD (CWT) analysis has been conducted. The light curve of the 2008 July–August flare, shifted by 511 d, is shown for comparison (black). The insets show blow-ups of the two periods when the largest relative flux increases took place. The red, blue, and green data points in the insets correspond to daily, 6 hr, and 3 hr averaged fluxes, respectively. The fit results discussed in the text are displayed as solid curves.

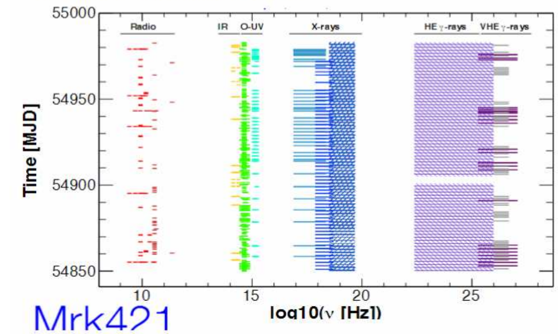
(Ackermann et al. 2010, ApJ, 721, 1383; Abdo et al. 2011, ApJ, 733, L26)

Excellent blazar beams: Mkn 421 and Mkn 501

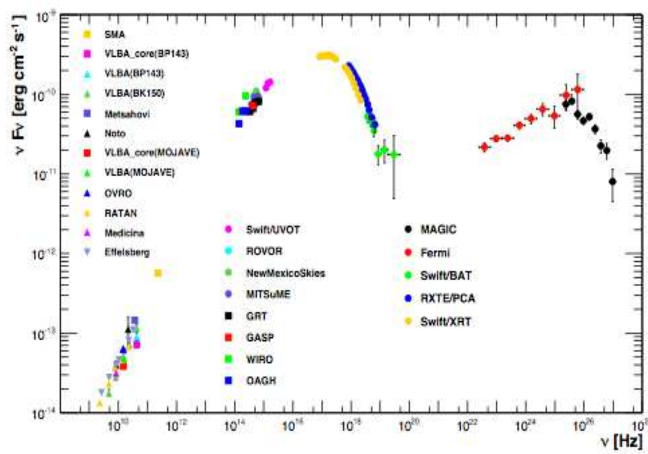
- ❑ Test bench for blazar physics and multi-frequency astrophysics:
Mrk 421 and Mrk 501 optimal "blazar probes".
  - Bright blazars, among the 1st detected in X-rays, VHE (TeV) gamma-ray instruments
  - Easy to detect with IACTs, Fermi, and X-rays, optical, radio instruments in short times
  - Relatively easy to characterize the entire SED in every "time-frame" of their variability.
  - Nearby blazars (z~0.03; ~140 Mpc). Imaging with VLBA possible down to scales of <0.01-0.1 pc (<100-1000 r_grav).
  - Minimal effect from EBL (among VHE blazars) (not well known, systematics for VHE blazars).
  - No strong BLR effects (another unknown, composition/shape).
- ❑ Deepest temporal and energy coverage of any TeV object
- ❑ Large complexity in the temporal evolution of the broadband (radio to TeV gamma-rays) SED.
- ❑ Lack of coherent picture when trying to explain all observations (papers often focus on the main trend, or some special/unusual features, rather than trying to explain all the observations).

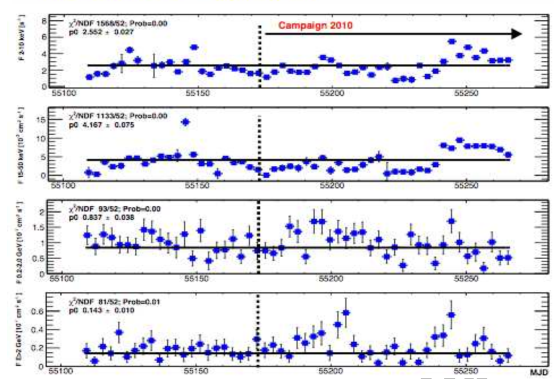


Mrk501
Abdo et al., 2011, ApJ, 727, 129



Mrk421
Abdo et al., 2011, ApJ, 736, 131





Blazar Mkn 421 and 30 EeV CR

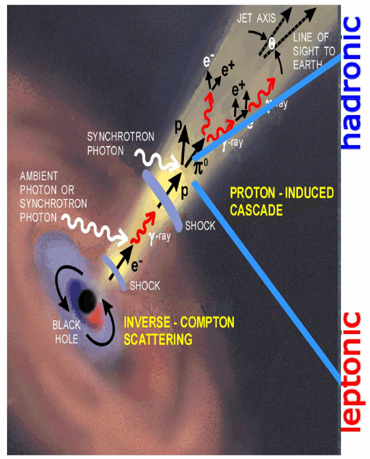
❑ Mrk 421 as possible source of PeV neutrinos and 30 EeV CR.

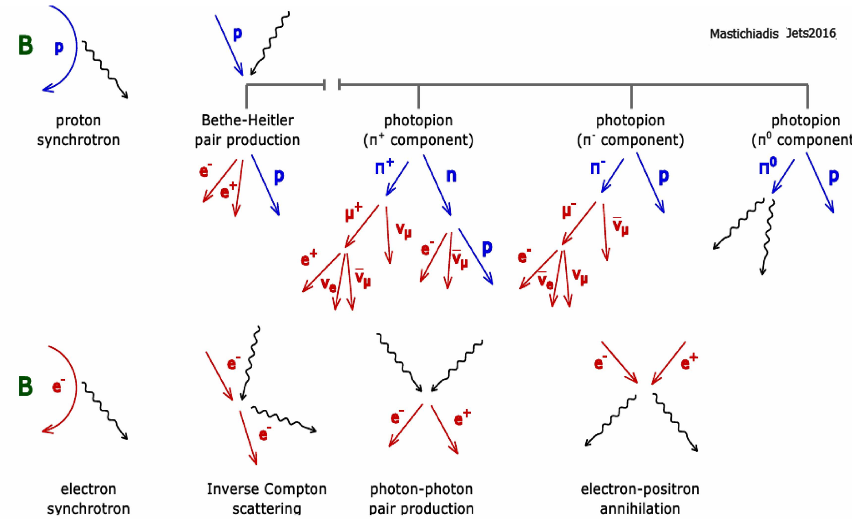
❑ Current theoretical/numerical one-zone time-dependent hadronic models (with secondary injection photopion + Bethe-Heitler) (Mastichiadis et al. 2016)

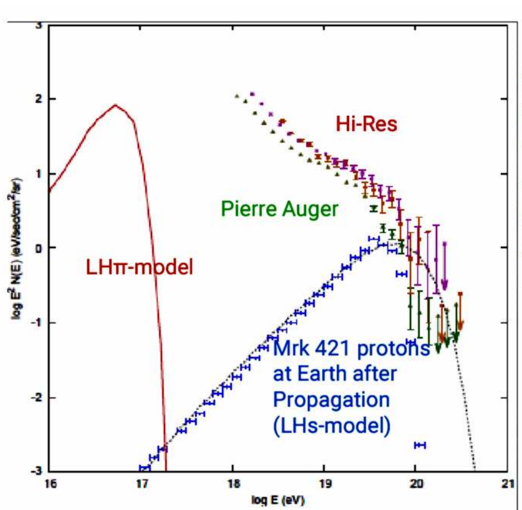
❑Two brands of hadronic models for AGN multifrequency e.m. emission:

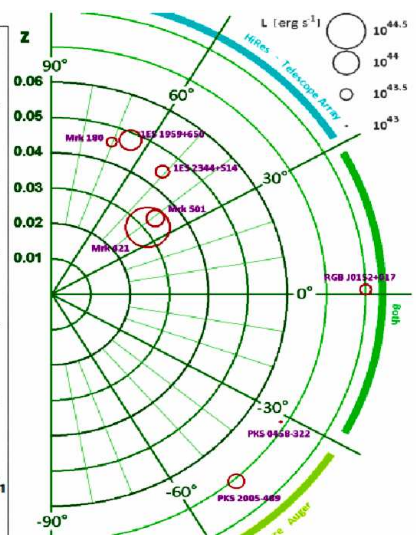
• gamma-rays from photopion + EM cascade,

• gamma-rays from proton synchrotron.

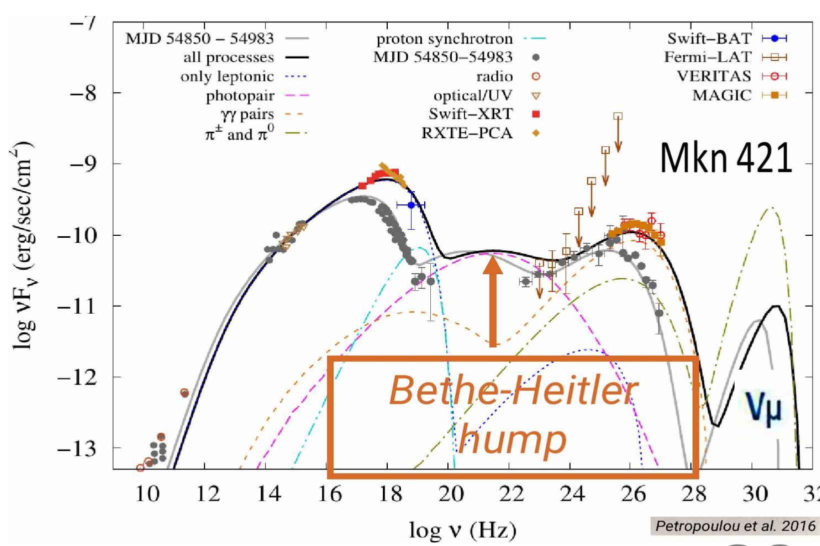




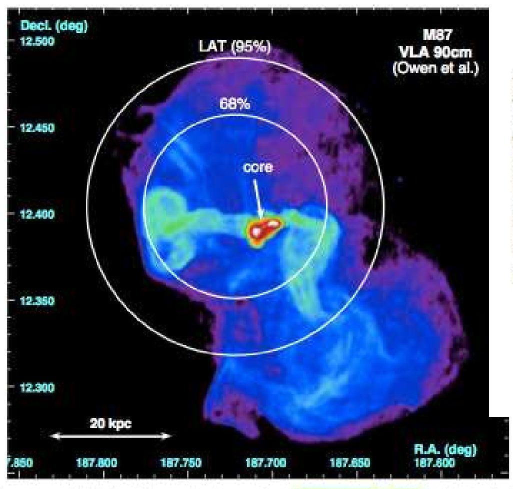


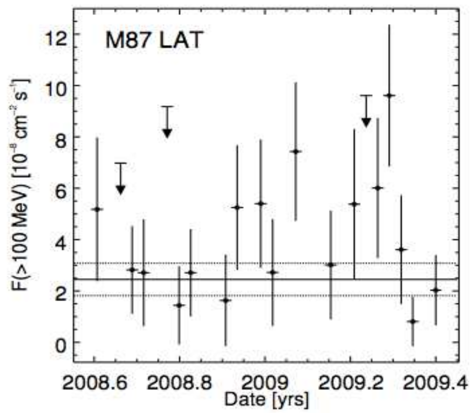


Mastichiadis (Jets2016)



GeV-TeV connection





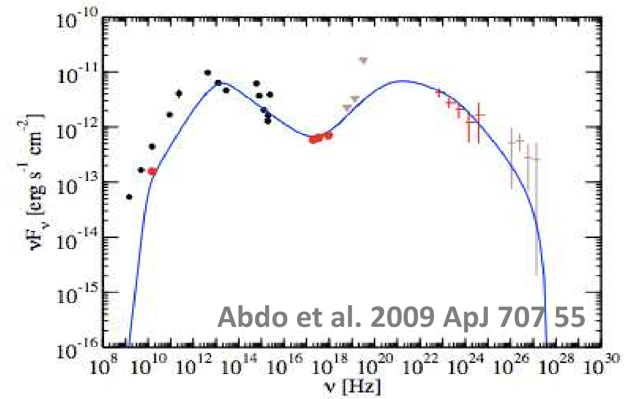
The case of M 87

❒Single SSC with a viewing angle > 10 deg. Bulk lorenz factor ~ 3

❒ Such SSC model also reproduce well the broad band SED of Per A (NGC 1275) and Cen A.

❑ No significant variability in the MeV/GeV regime

❑ Gamma-ray emission appears to be correlated to the compact radio core.

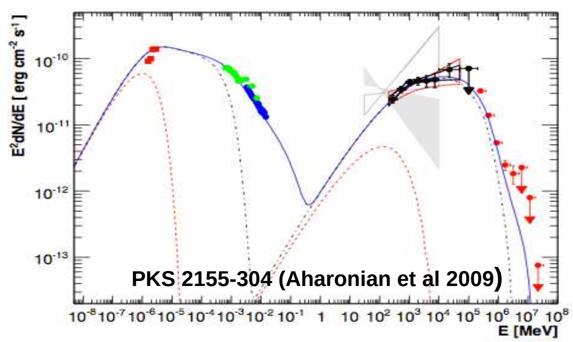


Abdo et al. 2009 ApJ 707 55

The case of PKS 2155-304:

❑ one of few cases with SED modeled with one-zone leptonic SSC

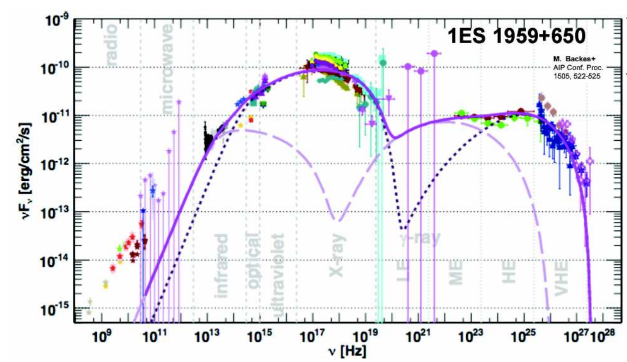
❑Indication of a correlation between optical and VHE. Anticorrelation between X-ray fluxes and LAT spectral indices.



PKS 2155-304 (Aharonian et al 2009)

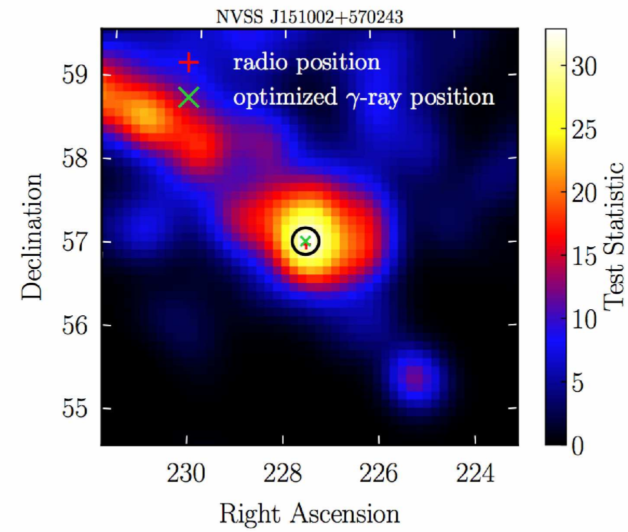
The case of 1ES 1959+650:

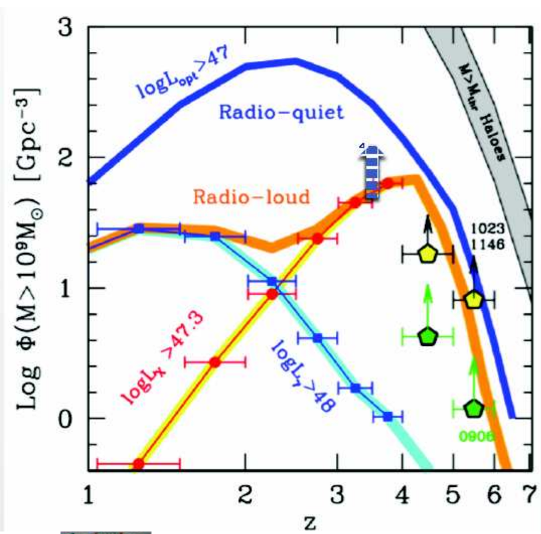
❑a "standard" blazar (no EBL, no hard TeV...), a High Synchrotron Peaked source with an hadronic VHE bump? Leptonic multi-zones emission? Challenging the one zone leptonic model: Flat VHE spectrum

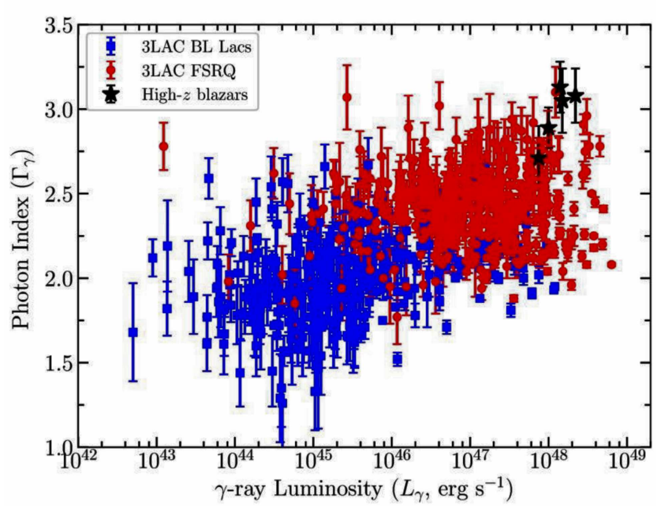


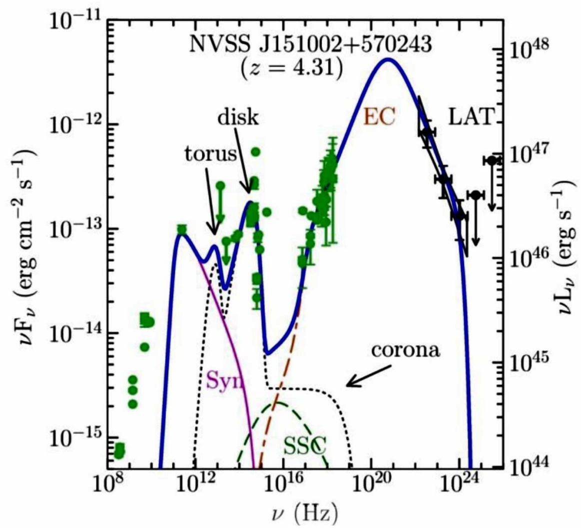
Gamma-ray blazars within the first 2 billion years

- ❑ 5 new gamma-ray emitting blazars at redshift higher than z = 3.1 have been detected by Fermi-LAT using 92 months of Pass 8 data.
- ❑ The farthest is at z = 4.31! (Ackermann et al. 2017, ApJL, 837, L5)
- ❑ These are placed within the first two billion years sinc ethe Big Bang. → cosmological beams/probes.
- ❑ Fermi LAT found two of the newly detected MeV blazars to host >10^9 M_sun SMBH.
- ❑This has increased the space density of billion solar mass black holes in radio-loud sources to 70 Gpc^-3, compared to ~50 Gpc^-3 known earlier.
- ❑ This implies that the radioloud phase may be a key ingredient for a quick SMBH growth in the early Universe.

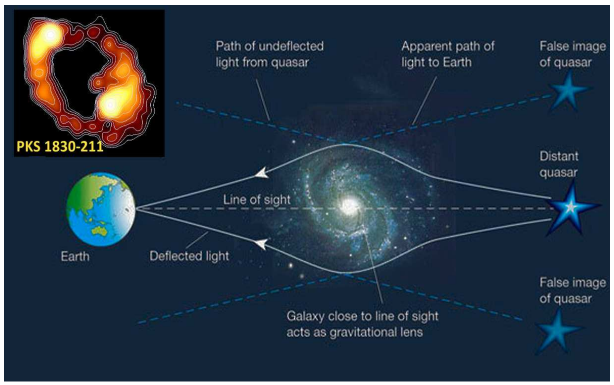


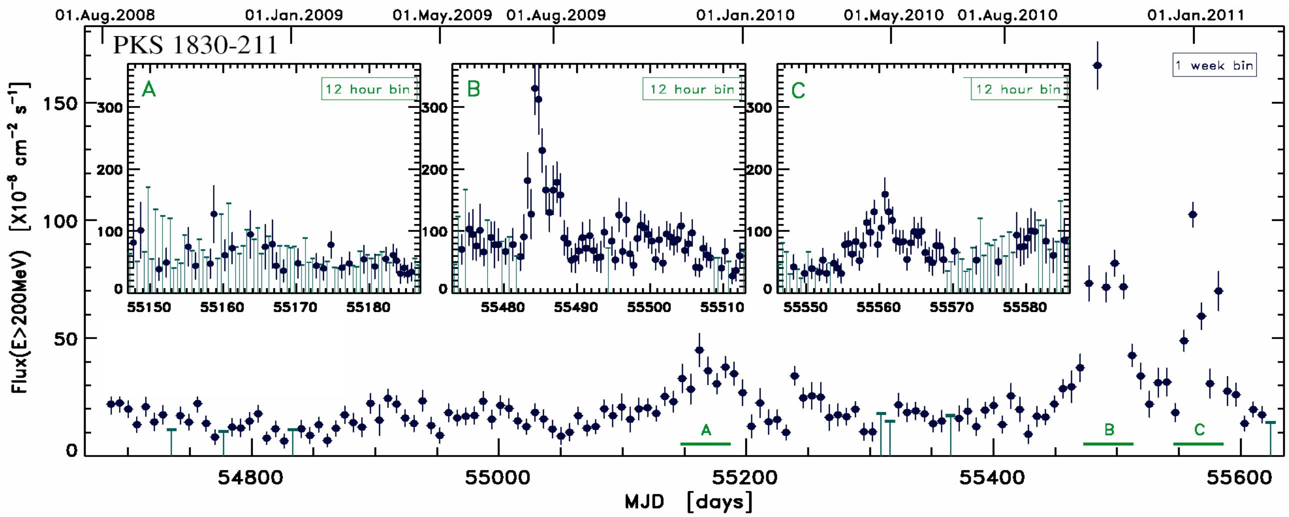




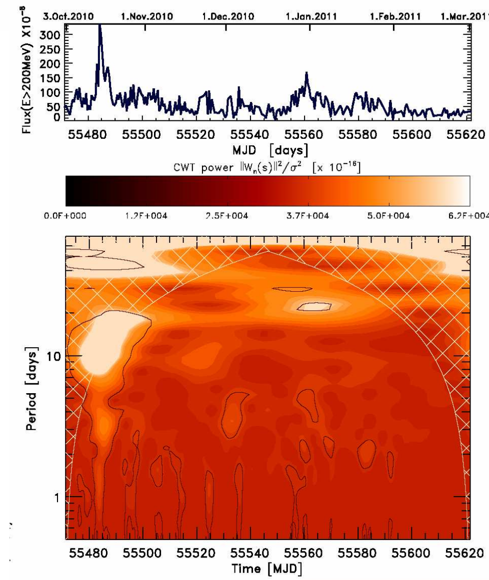


Gravitationally lensed blazar: PKS 1830-211





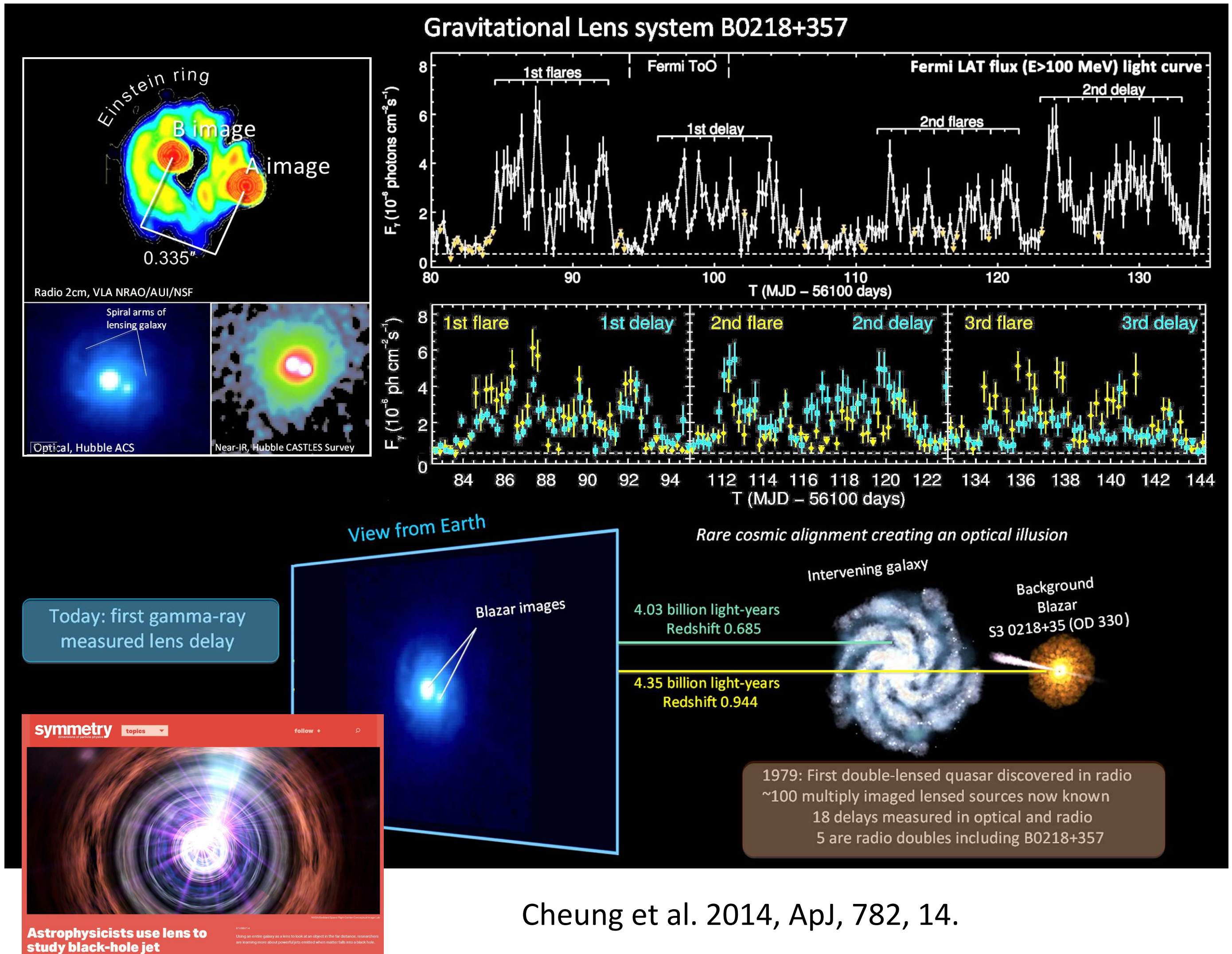
- ❑ Intense gamma-ray outburst from the blazar PKS 1830-211 (z =2.507) in October 2010, followed by high activity and other flares.
- ❑ A gravitationally lensed, highly dust-absorbed and reddened (by our Galaxy) flat spectrum radio quasar, peaked at MeV energy band.
- ❑ Analysis of 3-year Fermi LAT observations and simultaneous Swift data.
- ❑ No evident sign of echo gamma-ray flares caused by the lens.
- ❑ External-Compton (where seeds photons are from dusty torus) can fit the collected SED data. X-rays data are very similar to what was seen by Chandra in 2005 while gamma-rays are flaring → X-rays can origin from a different region or radiation mechanism. (Abdo et al. 2015, ApJ, 799, 143).



Gravitationally lensed blazar: S3 0218+35

- S3 0218+35 (lens B0218+357) discovered as a strong radio source in 1972.
- Revealed in 1990s as smallest-separation gravitational lens known.
- Brighter radio A image leads B image by 10.5±0.2days (1σ) by Biggs et al. (1999)

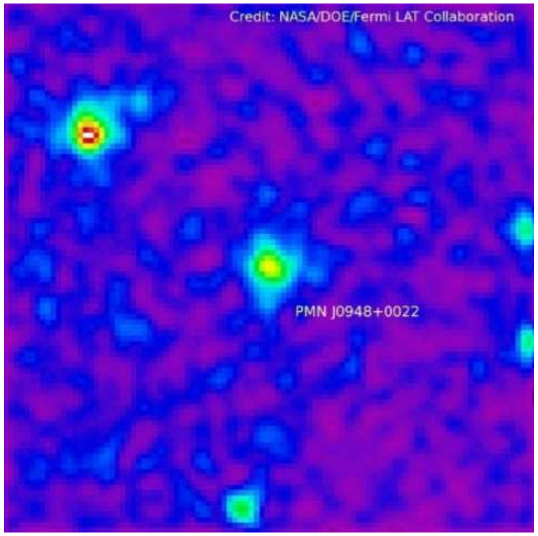
- Gamma rays detected by Fermi LAT since 2008.
- Fermi LAT made the first gamma-ray delay measurement for a gravitationally lensed system: 11.46±0.16 days (1σ).
- Possible probe of blazar jet structure through independent gamma-ray and radio delay measurements.
- Showcases LAT capability to obtain delay measurements for other gamma-ray gravitationally lensed systems.

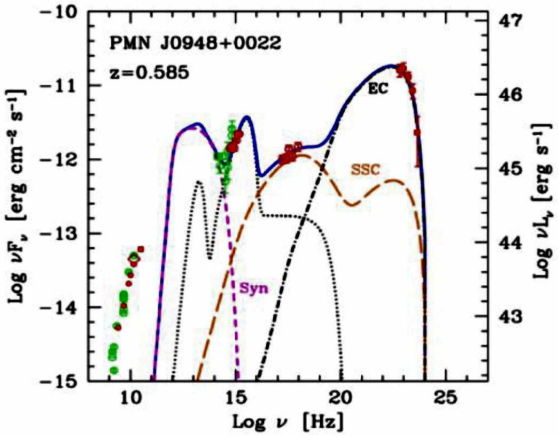


Cheung et al. 2014, ApJ, 782, 14.

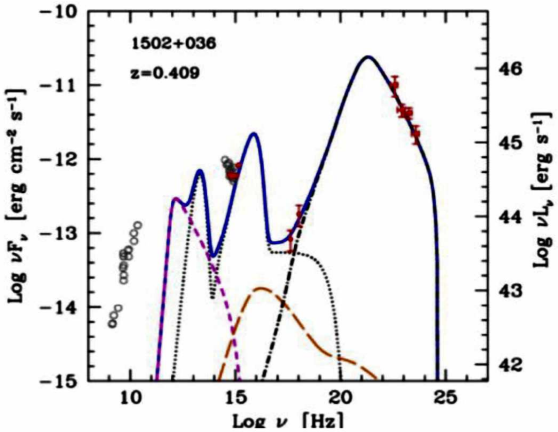
Gamma-ray narrow-line Seyfert 1 galaxies

- ❑ 5 NLSy1 were reported in the 3FGL/3LAC catalogs (Acero et al. 2015, namely 1H 0323+342, SBS 0846+513, PMN J0948+0022, PKS 1502+036, PKS 2004-447).
- ❑ New LAT detections with Pass 8 data (FBQS J1644+2619, B3 1441+476, NVSS J124634+023808).
- ❑ They have some blazar-like properties (for example at parsec scale a core-jet radio structure was observed).
- ❑ Seyfert galaxies in general have lower mass BHs (about 10^7Msun) and NLSy1s have high accretion rates → Eddington ratio is a key determinant of SED characteristics.

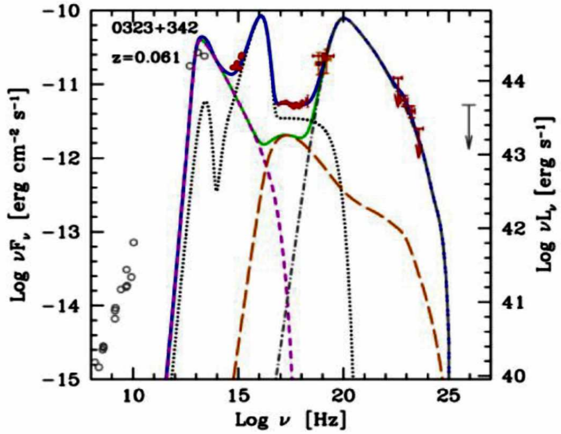




Foschini et al. 2012, 2014



Abdo et al. 2009

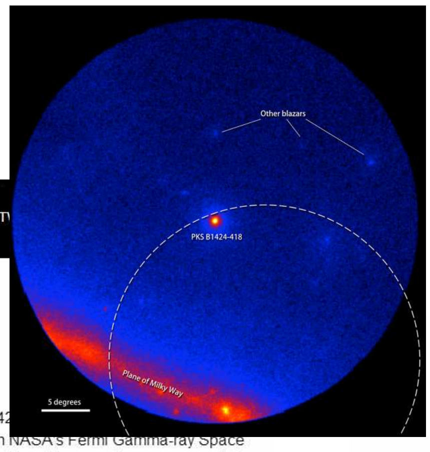


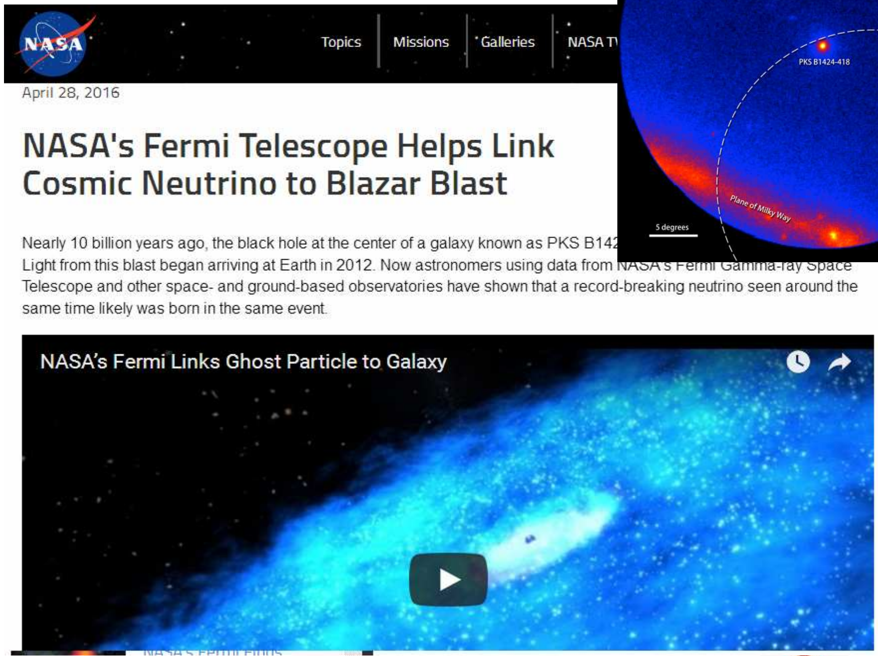
D'Ammando et al. 2012

Gamma-ray blazars and PeV neutrinos

- ❑ No convincing correlation in general. To be investigate with spatial-time constraints.
- ❑ Best (claimed) case of PKS 1424-41: a major outburst of this blazar occurred in temporal and positional coincidence with the PeV-energy neutrino event (IC 35) detected by IceCube.

(Kadler et al. 2016, Nature Phys., 12, 807).

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April 28, 2016

NASA's Fermi Telescope Helps Link Cosmic Neutrino to Blazar Blast

Nearly 10 billion years ago, the black hole at the center of a galaxy known as PKS B142... Light from this blast began arriving at Earth in 2012. Now astronomers using data from NASA's Fermi Gamma-ray Space Telescope and other space- and ground-based observatories have shown that a record-breaking neutrino seen around the same time likely was born in the same event.

NASA's Fermi Links Ghost Particle to Galaxy

ATel #9008;

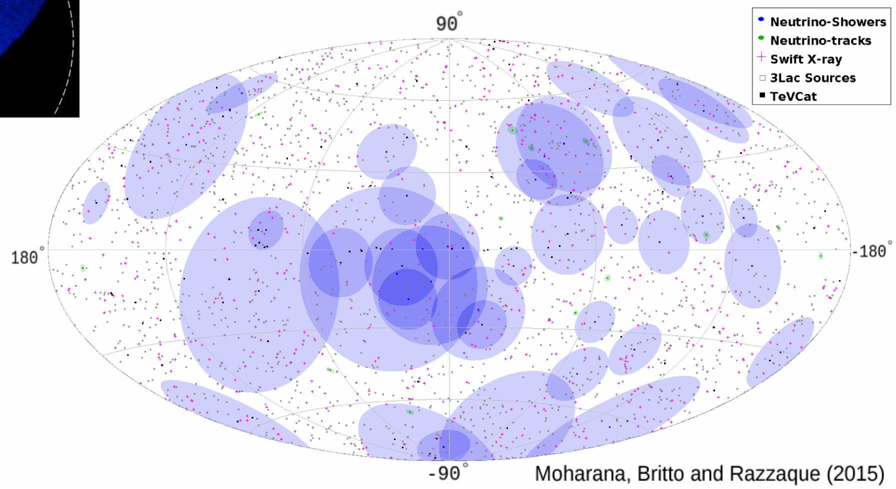
Fermi/LAT search for counterpart to the IceCube event 67093193 (run 127853)

28 Apr 2016; 22:34 UT

The 90% containment provided by IceCube, which is ~36 arcmin wide, contains no LAT source from the Fermi Point Source catalog (3FGL, Acero et al. 2015). The 5 closest sources are all blazars:

Source name	Distance	Association	Blazar Type
3FGL J1603.7+1106	108'	MG1 J160340+1106	BL Lac
3FGL J1608.6+1029	117'	4C +10.45	FSRQ
3FGL J1555.7+1111	147'	PG 1553+113	BL Lac
3FGL J1552.1+0852	153'	TXS 1549+089	BL Lac
3FGL J1546.0+0818	249'	1RXS J154604.6+081912	BL Lac

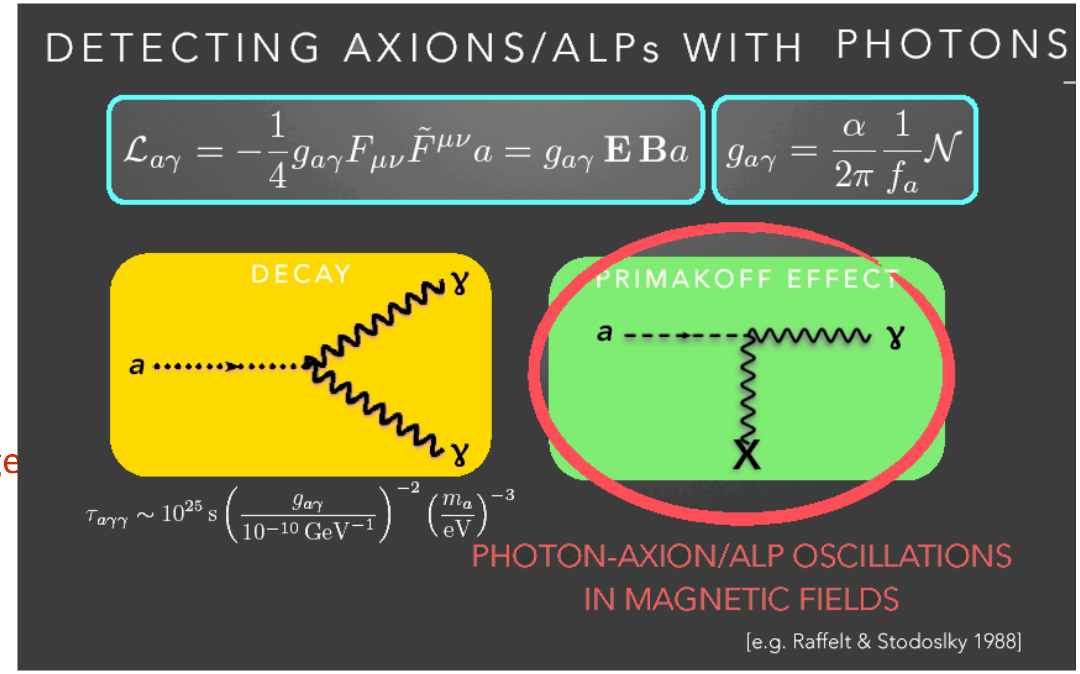
We note in particular that PG 1553+113 has been detected in high state on 2016-04-27 in the 0.3-10 keV band by the Swift X-ray Telescope (B. Kapanadze, ATel #8998), although we do not detect any significant change in flux above 100 MeV.

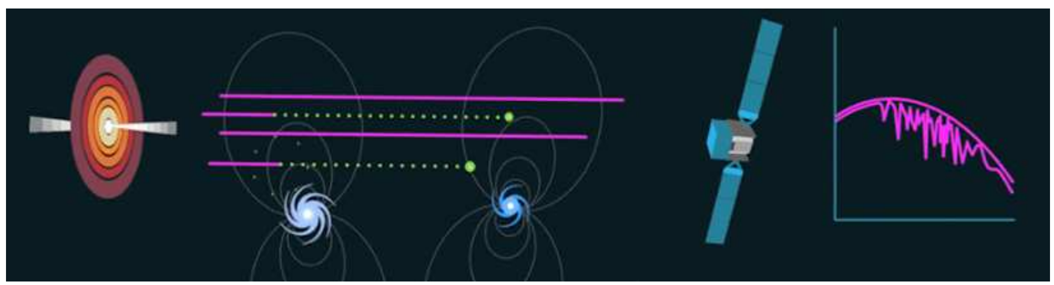


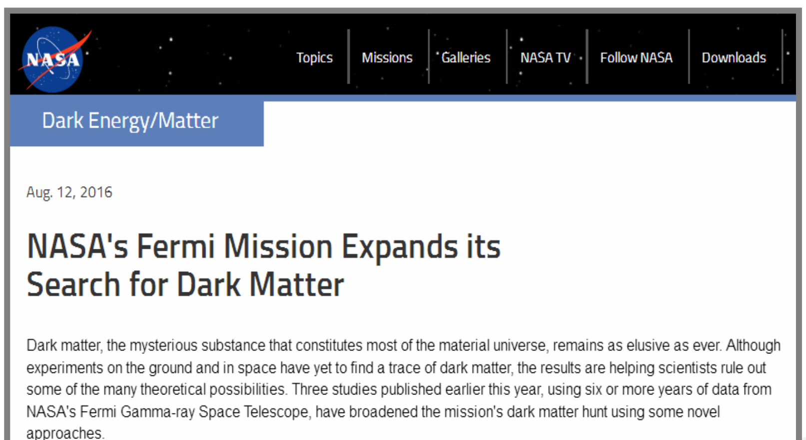
Moharana, Britto and Razzaque (2015)

Gamma-ray blazars and photon-ALPs mixing

- Dark matter might consist of hypothetical axion-like particles (ALPs).
- Intriguing aspect of ALPs is their ability to convert into gamma-rays and back again when they interact with strong magnetic fields. These conversions leave behind characteristic traces, like gaps or steps, in the spectrum of a bright gamma-ray source.
- No detection. Fermi LAT excluded a small range of axion-like particles that could have comprised about 4 percent of dark matter.
(Ajello et al. 2016, PhysRevLett 116 161101)



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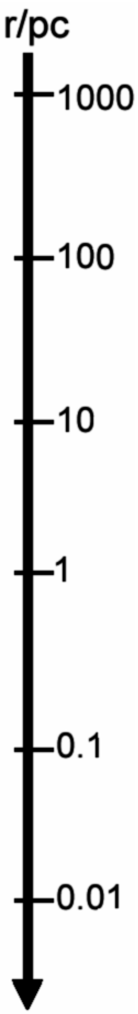
Dark Energy/Matter

Aug. 12, 2016

NASA's Fermi Mission Expands its Search for Dark Matter

Dark matter, the mysterious substance that constitutes most of the material universe, remains as elusive as ever. Although experiments on the ground and in space have yet to find a trace of dark matter, the results are helping scientists rule out some of the many theoretical possibilities. Three studies published earlier this year, using six or more years of data from NASA's Fermi Gamma-ray Space Telescope, have broadened the mission's dark matter hunt using some novel approaches.

Supermassive BHs pairs/binaries



Observational evidence for SMBH pairs and gravitationally bound binary systems:

❑ quasar pairs, AGN in clusters of galaxies

❑ pairs of active galaxies, interacting galaxies in early phase of interaction/merging (double-peaked narrow optical emission lines, if both galaxies have NLR)

❑ SMBH pairs in "single" galaxies and advanced mergers, kpc/100-pc scales
(ex.: two accreting SMBHs spatially resolved, often heavily obscured --> X-ray/radio observations)

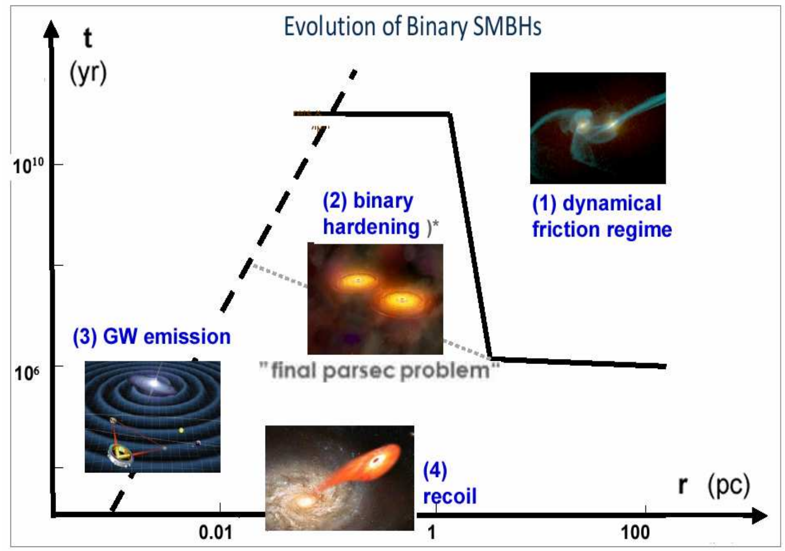
❑ spatially unresolved binary-SMBHs candidates
(1. pseudo/quasi/semi-periodic signals in radio/optical flux light curves; 2. pc-scale spatial radio-structures distorted/helical-patterns in jets; 3. double-peaked broad lines)

❑ a few post-merger candidates
(X-shaped radio sources, galaxies with central light deficits, double-double radio sources, recoiling SMBHs)

Nature Vol. 287 25 September 1980 307

Massive black hole binaries in active galactic nuclei

M. C. Begelman*, R. D. Blandford† & M. J. Rees‡



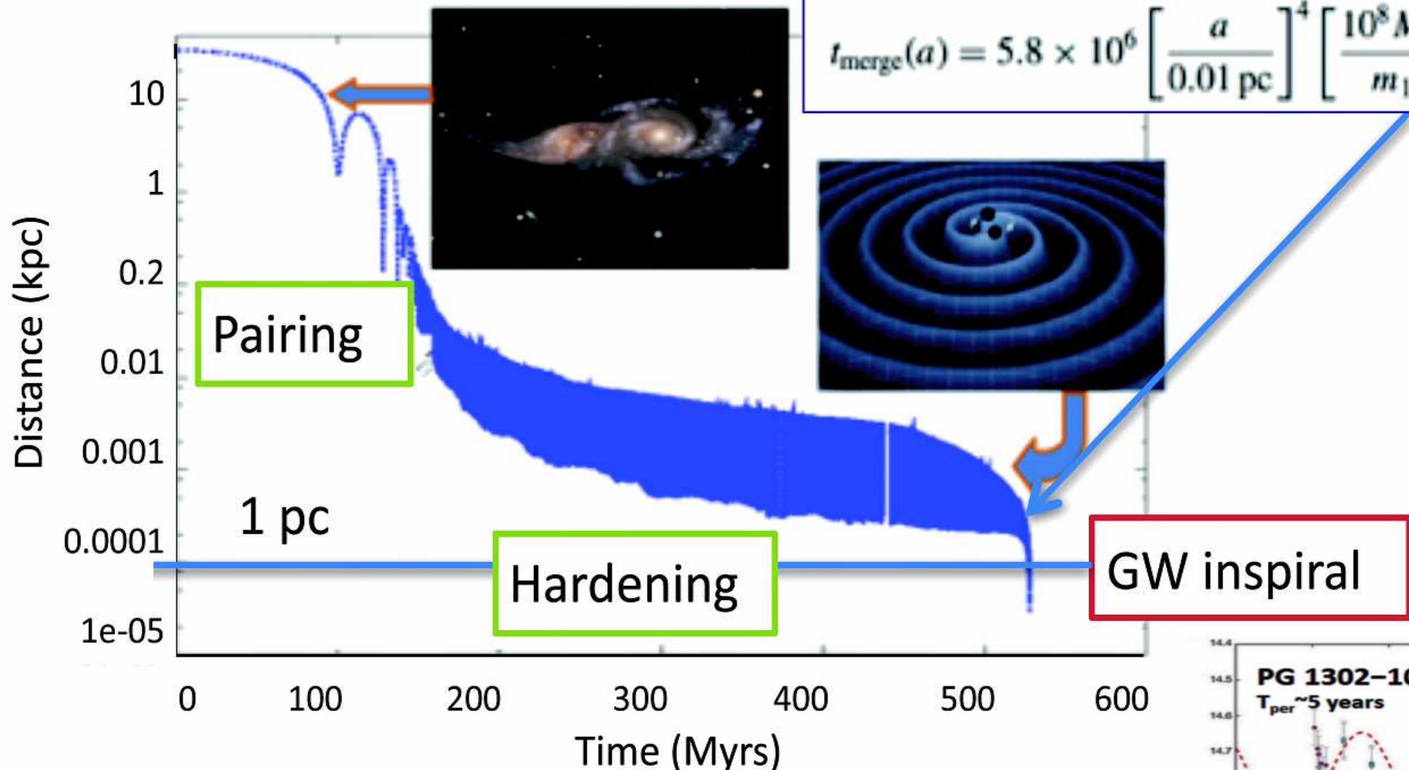
[Credits S. Komossa 2014] Komossa et al.

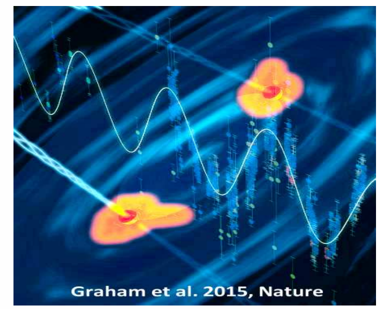
• Galaxy mergers. Sites of major BH growth & feedback processes.
• Coalescing binary SMBHs. Powerful emitters of GWs and e.m. radiation.
• GW recoil. SMBHs oscillate about galaxy cores or even escape.

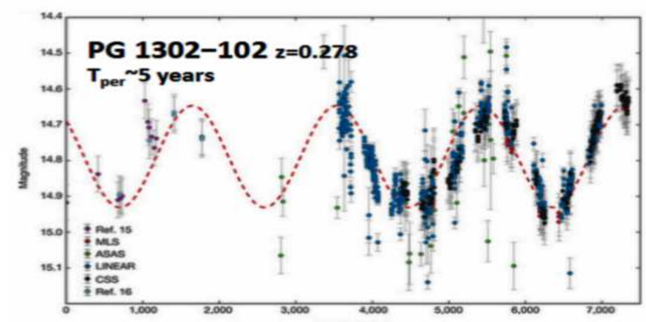
Supermassive BHs pairs/binaries

❑ Observational evidence is important to solve the theoretical "final parsec problem" in GR (solved by non spherical geometry). There is also the final 0.1 pc problem.

$$t_{merge}(a) = 5.8 \times 10^6 \left[\frac{a}{0.01\,\mathrm{pc}}\right]^4 \left[\frac{10^8 M_\odot}{m_1}\right]^3 \frac{m_1^2}{m_2(m_1+m_2)}\ \mathrm{yr}$$







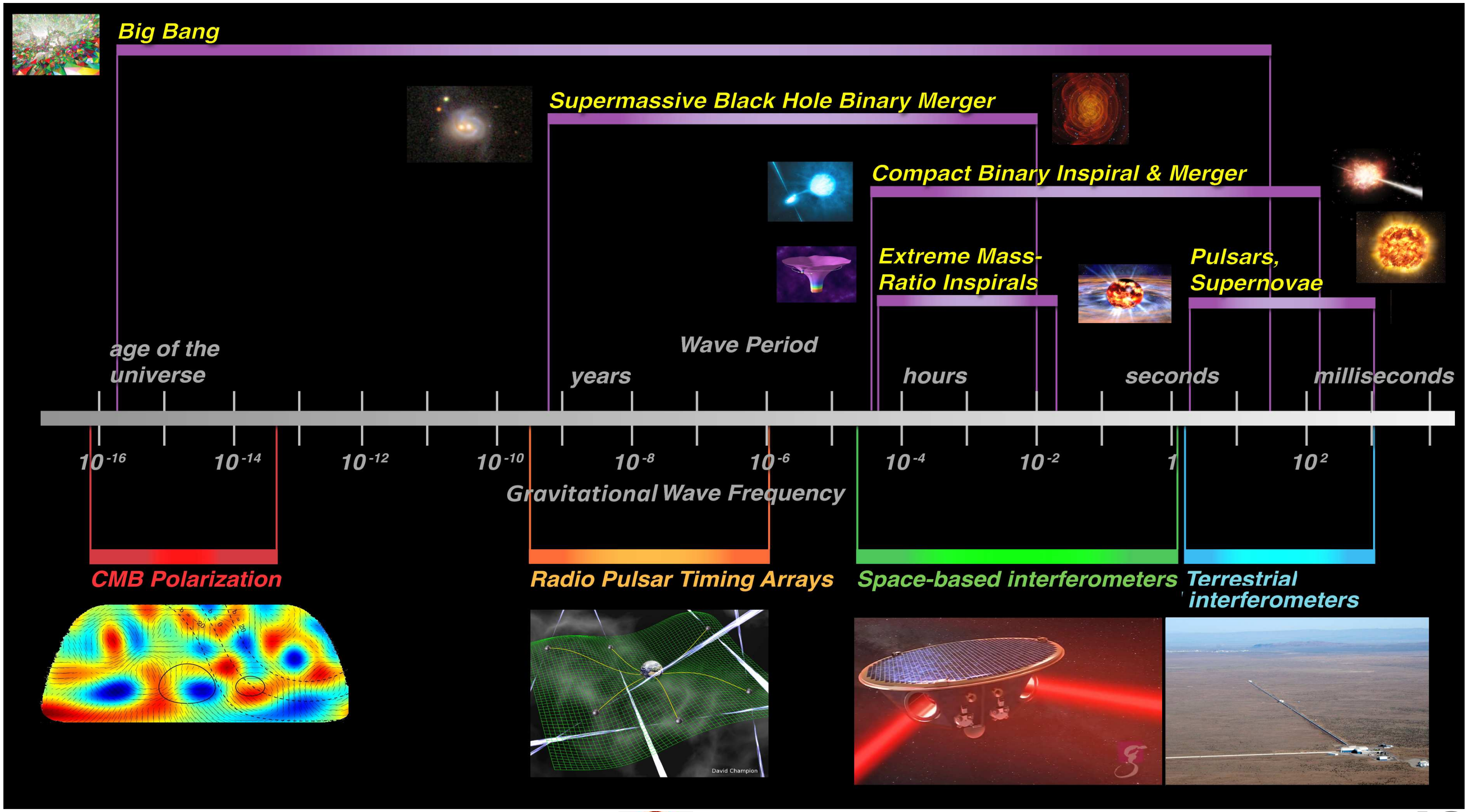
Timescale from two galaxy merger to their central SMBH merger in the range 10^8-10^9 years

Graham et al. 2015, Nature 518

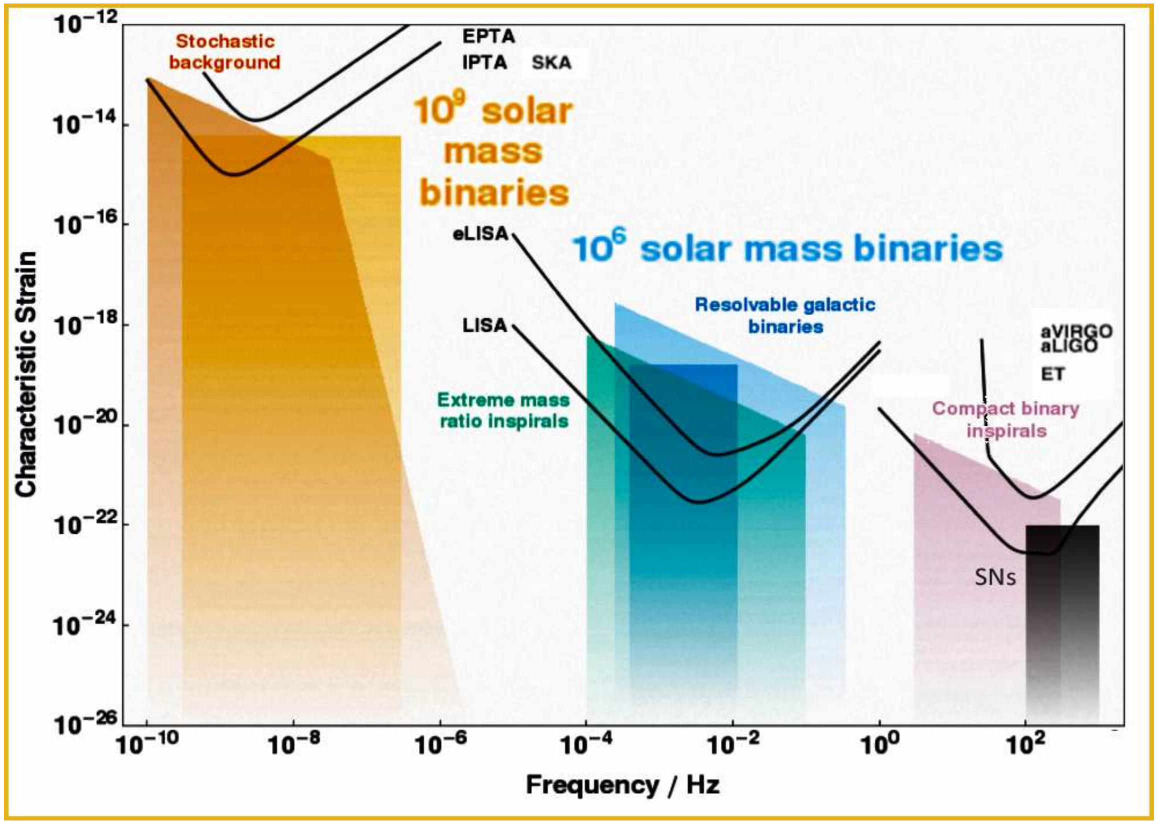
Binary SHBH 0.01 parsec (2X10^4 AU) separation

SMBH binaries and GWs

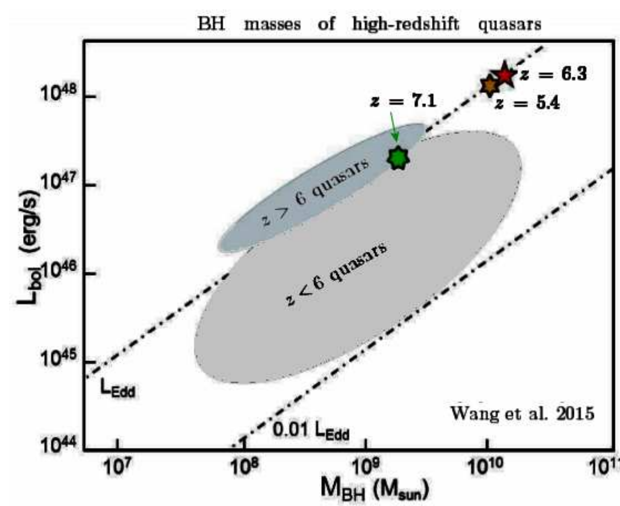
Instruments capable of detecting gravitational waves (GWs) and their sources in the next years: ground-based interferometers like aLIGO (discovered them), aVIRGO, KAGRA, Geo600, etc.; the Pulsar Timing Arrays (PTAs), the Square Kilometer Array (SKA); the LISA space mission, the 3rd gen. Einstein GW Telescope.



SMBH binaries and GWs

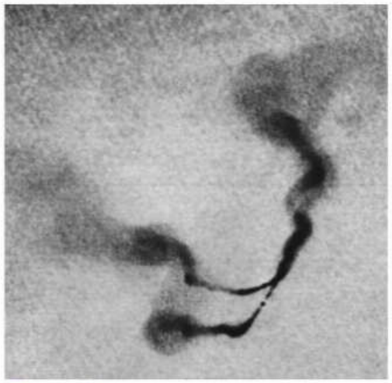


❑ Pulsar timing arrays (PTAs) started to place constraints on galaxy merger history from limits on the stochastic Gravitational Wave (GW) background.
❑ Coalescing binary SMBHs → loudest sources of very-low frequency (micro-Hz to nano-Hz) GWs in the universe. Subsequent GW recoil → implications (SMBHs oscillate/even escape).
❑ Importance of accretion, merging and stellar captures in growing black holes, and on the BH spin history.

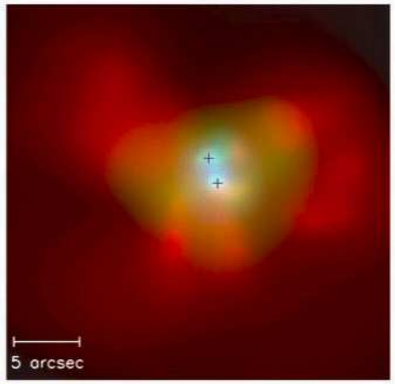


❑ Possibilities for future GW astronomy: new research window on structure formation and galaxy mergers, direct detection of coalescing binary SMBHs, high-precision measurements of SMBHs masses and spins, constraints on SMBHs formation and evolution.

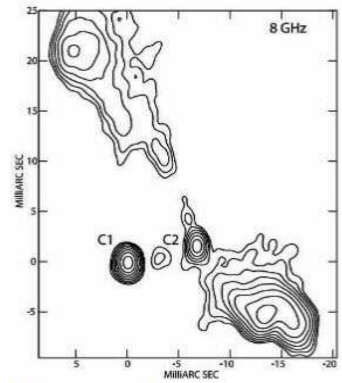
Observational evidence for SMBHs pairs/binaries



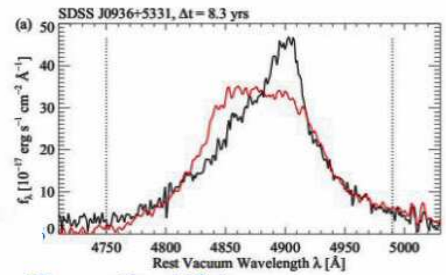
Dual jets (3C 75, a~7kpc)
[Owen+ 1985]



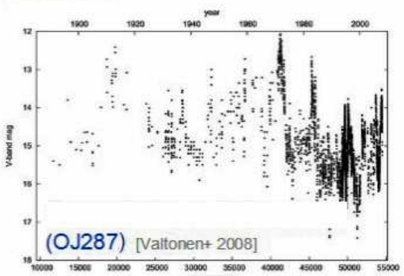
Dual X-ray sources
(NGC 6240, a ~ 1.5 kpc) [Komossa+ 2003]



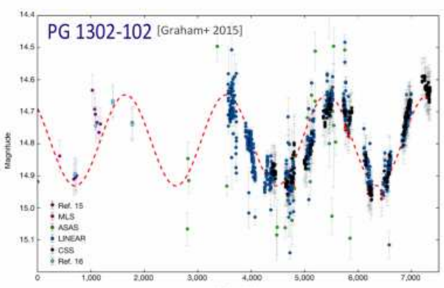
Binary radio sources
(0402+379, a ~ 7pc) [Owen+ 1985]

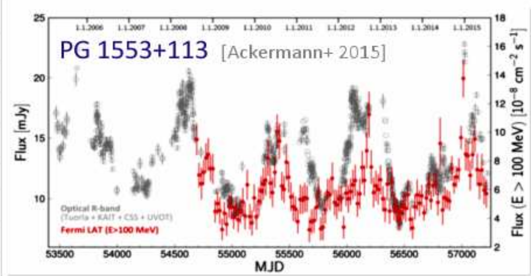


Kinematic shift in
multi-epoch observations
[Liu+ 2013]

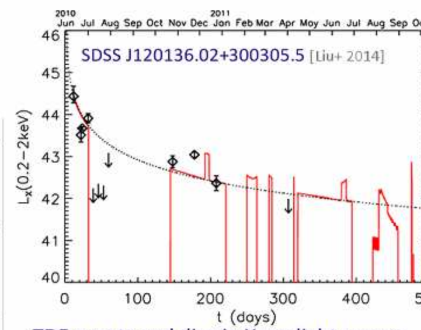


(OJ287) [Valtonen+ 2008]





Quasi periodicity in light curves (still controversial topic)



TDE events and dips in X-ray light curves

- ❑ Many binary SMBHs candidates but few non-controversial confirmations! Why so few ?

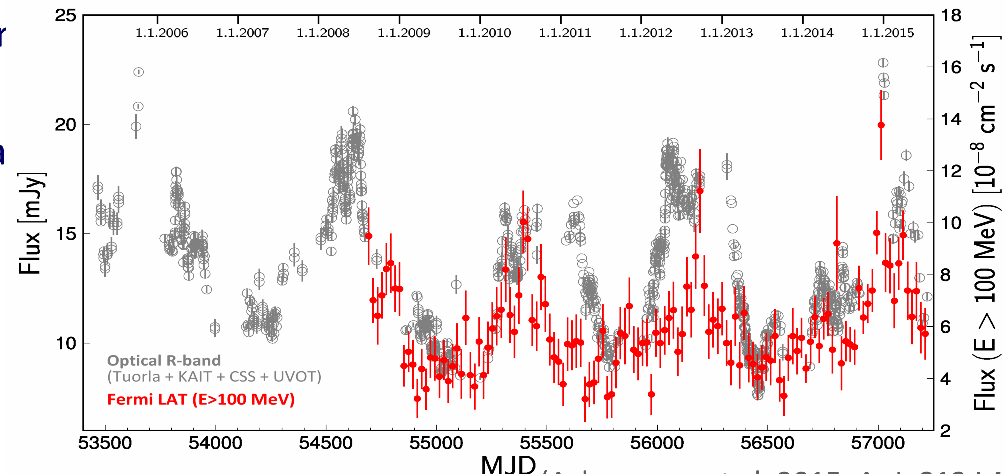
Large distances (difficult to resolve). Perhaps obscured. Need to distinguish other phenomena (in-jet knots, lensing, ...). In close pairs most current methods require at least one SMBH to be active (many may not be).

- ❑ Perhaps the greatest challenge is to identify the inactive binary SMBHs which might be the most abundant, but are also the most difficult to identify. Most binary SMBHs may form quiescently either in gas-poor or minor galaxy mergers without driving AGN activities.

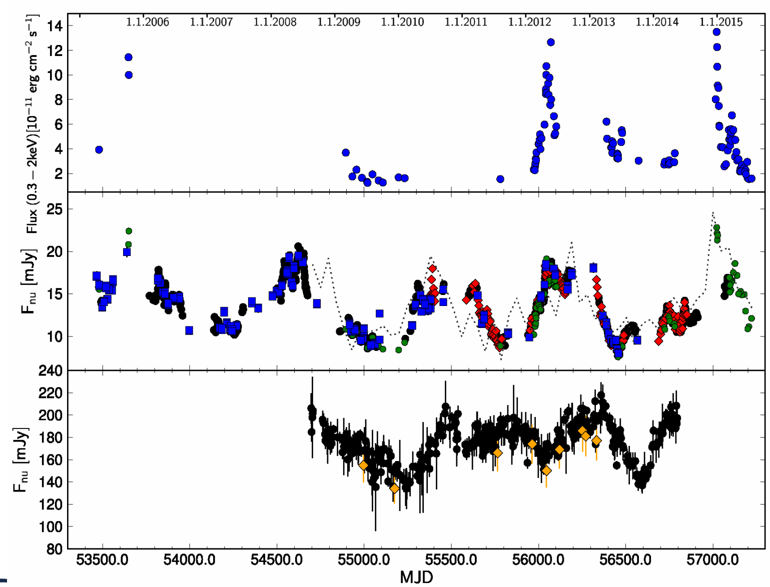
Gamma-ray blazar PG 1553+113

- Strong claims needs strong evidence (and bewar of systematics, red noise and personal biases).
- Multifrequency analysis found possible 2-yea regular modulation of the flux.
- Potential significant periodicity found (to be confirmed or not in next couple of years); long-term LAT data analysis + multifrequency long-term monitor data collection and analysis.
- Some hypotheses:

1) Pulsational accretion flow instabilities, approximating periodic behavior (ex. magnetically arrested and magnetically dominated accretion flows MDAFs);
2) Jet precession, jet rotation, or helical structure in the jet (geometrical models);
3) Mechanism similar low-frequency QPO from Galactic high-mass binaries (QPO Lense–Thirring precession);
4) Binary, gravitationally bound, SMBH system (total mass of 1.6X10^8 Msun, milliparsec separation, early inspiral gravitational-wave driven regime. Keplerian binary orbital motion --> periodic accretion perturbations or jet nutation.
(Ackermann et al. 2015, ApJ, 813 L41)



(Ackermann et al. 2015, ApJ, 813 L41)



Conclusions

❑ Fermi is the reference gamma-ray observatory providing a continuous all-sky spatial survey and time-domain monitoring of the restless variable/transient/seredipitous GeV Universe.

❑ 1G photons, thousands sources, importance of source catalogs, public database.

❑ Synergy with TeV observatories is strong.

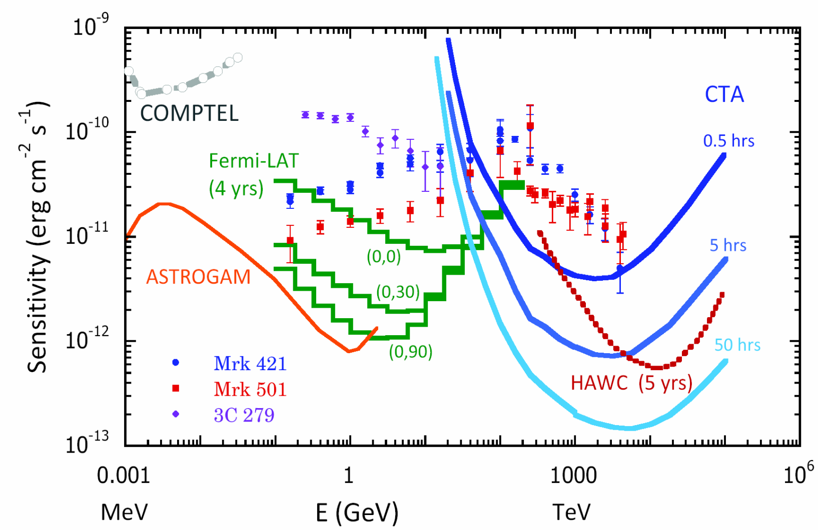
❑ Recent advances in DM searches (limits) and CR properties characterization.

❑ Remarkable time-domain and transient capability (for example follow-up of LIGO Gravitational Waves events).

❑ AGN/blazars are one of the main science menu for the Fermi LAT. They are multi-frequency photon beams and potentially multi-messenger/particle beams.

❑ Large community interested in the analysis (atroph./HE-phys.) of LAT data.

❑ Where to go next? Extending the Fermi mission and build a new space Compon-Telescope at lower energy (rather unexplored MeV gamma-ray Universe).

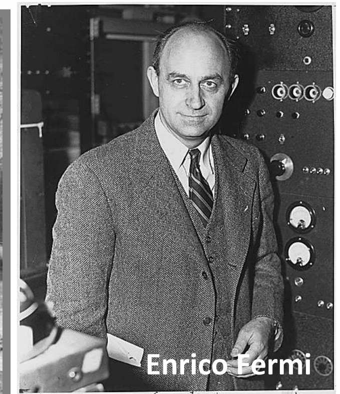


❑ M3Astroparticle-physics: Multi-time domain, Multi-wavelength, Multi-messenger.

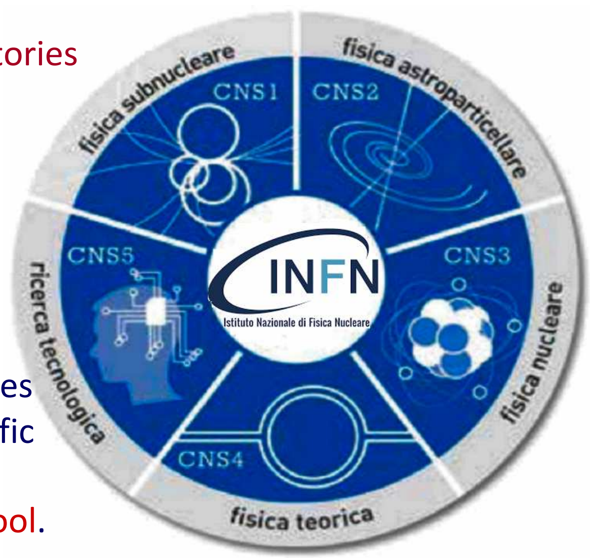
Backup slides

INFN

Istituto Nazionale di Fisica Nucleare (I.N.F.N.)

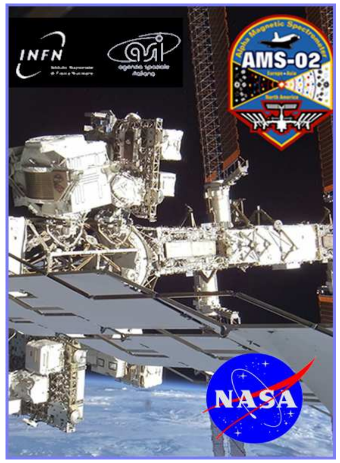


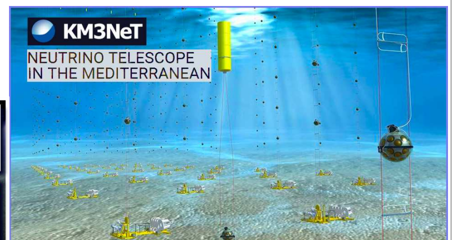
- ❑ Scientific institution for the study of the fundamental physics laws and the elementary components of the matter.
- ❑ Experimental and theoretical researches in nuclear, subnuclear, and astroparticle physics.
- ❑ Promotes innovation → transfer to industrial world the acquired knowledge and technology.
- ❑ INFN works with big international collaborations and is deeply present on the national territory: 20 INFN Sections, 6 linked Groups in 6 univ., 4 INFN National Laboratories (Catania, Frascati, Legnaro, Gran Sasso), 3 consortiums (EGO, CNAF, TIFPA).
- ❑ Activities developed in an international competition field and in collaboration with the academy (universities).
- ❑ Funded 8 Aug. 1951 by groups in four universities (Rome, Padua, Turin, Milan) to develop the scientific tradition started in '30s with experimental and theoretical researches of Enrico Fermi and his school.

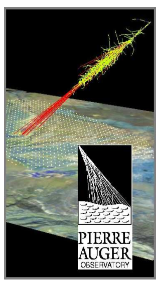


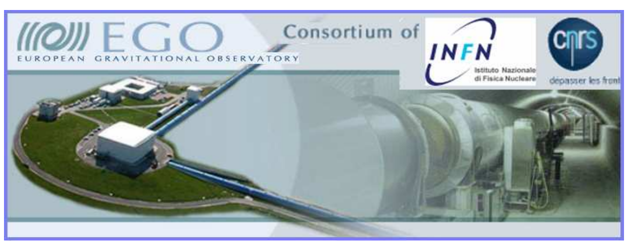
INFN and astro-multi-particle physics

- ❑ INFN is very active and competitive in experimental astroparticle physics (expl.):
  - The Laboratori Nazionali del Gran Sasso of INFN is the biggest underground laboratory.
  - Detectors on space satellites, space station balloons, to obtain access to the primary cosmic rays. Ground-based telescopes and arrays too (IACTs, EAS).
  - Undersea, under-ice, underground labs for neutrinos, direct DM detect, rare-processes…
  - EGO/Virgo interferometer detectors for gravitational waves. …and more.









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AUGER	LHAASO
BOREX	LIMADOU_
CRESST	LISA-PF
CTA	LSPE
CUORE	LVD
CUPID	MAGIA-ADV
DAMA	MAGIC
DAMPE	MOONLIGHT2
DARKSIDE	NEWS
ENUBET_2	NU_AT_FNAL
EUCLID	PVLAS
FERMI	QUAX
FISH	QUBIC
GAPS	SABRE
G-GRANSASSO-RD	SUPREMO
GERDA	T2K
HUMOR	VIRGO
ICARUS	WIZARD
JEM-EUSO-RD	XENON
JUNO	XPE
KM3