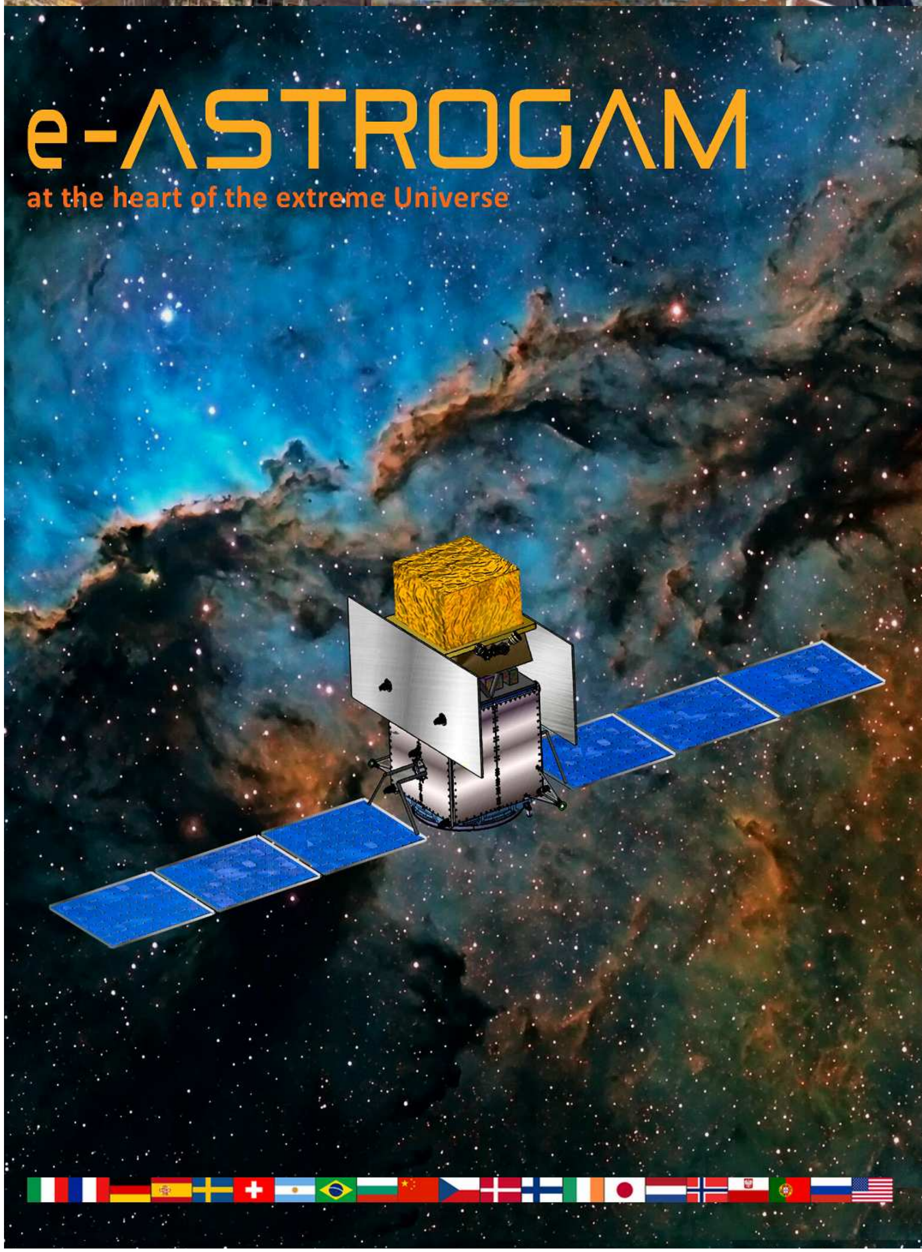

Observing blazars with eASTROGAM

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Based on White Book draft contributions and other contributions by: G. Ghisellini, F. Tavecchio, T. Sbarrato, S. Kauffman, O. Tibolla, S. Ciprini, C. Pittori, F. Verrecchia, L. Foschini, Chi C. Cheung, S. Buson, D. Gasparrini, S. Cutini, P. Giommi.

2nd e-ASTROGAM Workshop, joint to AMEGO Workshop: towards a White Book on MeV Gamma-ray Astrophysics
13-14 October 2017, Munich, Germany

MeV Active Galactic Nuclei (AGN) and Blazars

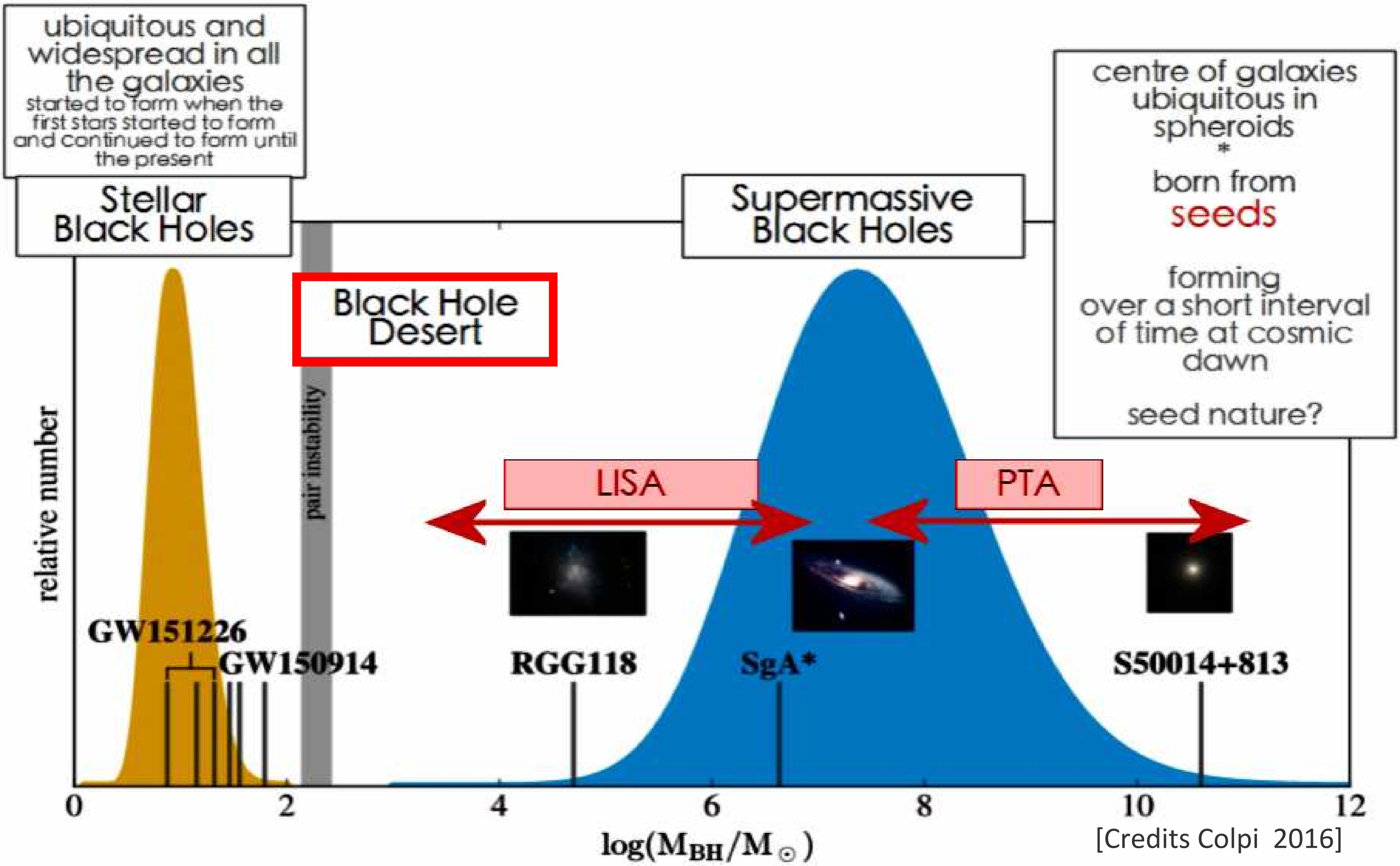
BEACONS/BEAMS OF THE UNIVERSE (e-ASTROGAM → of the EARLY Universe !)

- 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.

e-ASTROGAM will see
1) the most heavy SMBHs;
2) the most high redshift
(z=5,6,7 & beyond) SMBHs;
3) the primordial high-z jets, beaming and accretion in the Universe.

- AGN as (potential) multi-messenger astroparticle physics 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.

BHs: two flavors, Stellar/Supermassive BHs



[Credits Colpi 2016]

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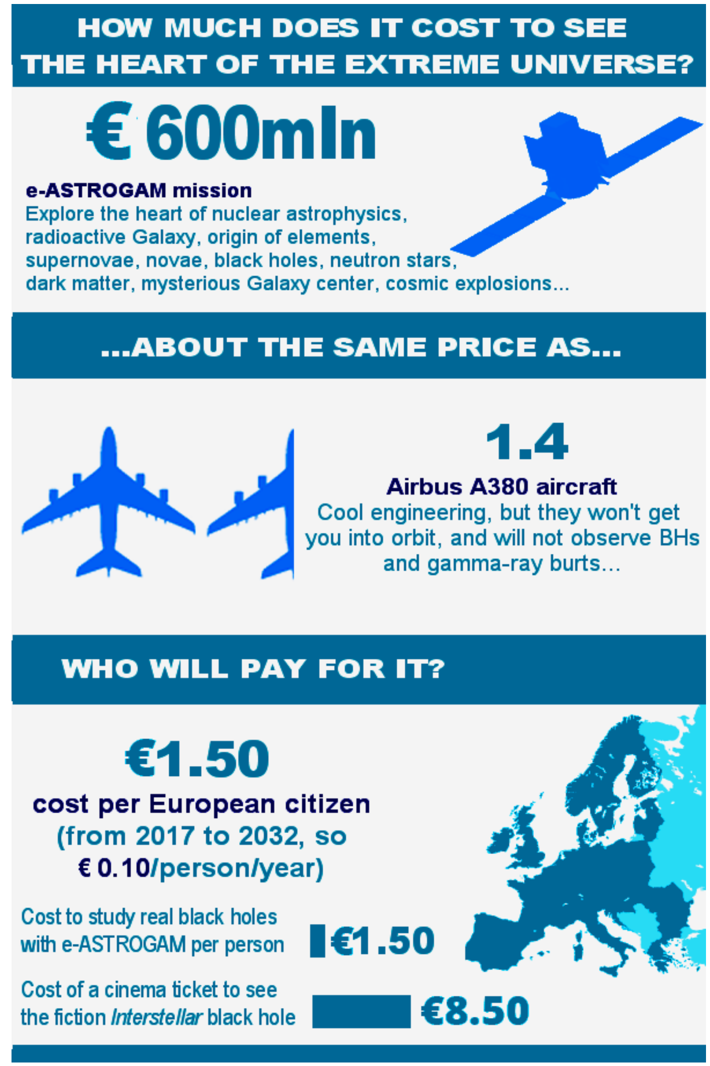
e-ASTROGAM: heavy-SMBHs/accretion/jets at high-z

- ❑ Black hole topic has an increasing media-hype (competition with exo-planets) because of aLIGO/aVIRGO gravitational wave burst detections, the Nobel 2017 in physics, and recent movies (Interstellar, more sci-fi fictions/movies).

- ❑ X-ray mission (like the ESA XMM-Newton and the future ATHENA) points to black holes as one of the main science (and large-public communication) topic. These missions catch also thermal and obscured objects driven by BHs, example non-jetted radio-quiet AGN).

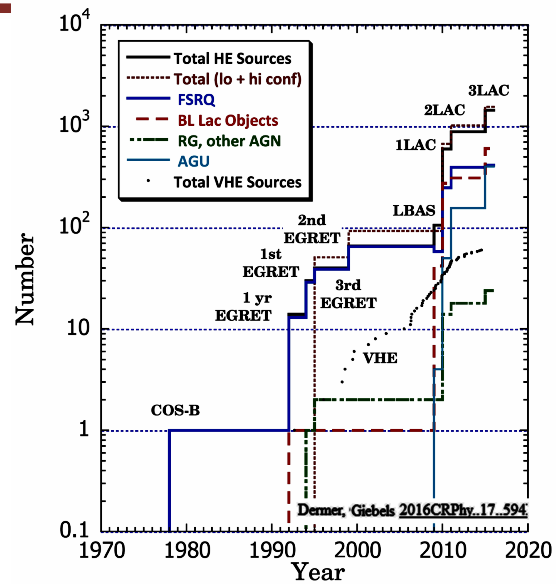
- ❑ e-ASTROGAM, generally speaking, can be announced also a black-hole, blazar, telescope, looking back to z=6 and z=7 (so cosmic ages, well linked to ESA's Cosmic Vision).
  → we can see the richest BHs (wrt to X-ray missions), because our SMBHs have relativistic jets, relativistic beaming (i.e. Special Relativity macroscopic effects, so large refereeing to Einstein, prime pop culture scientists entering in e-ASTROGAM community & large-pulic narration).

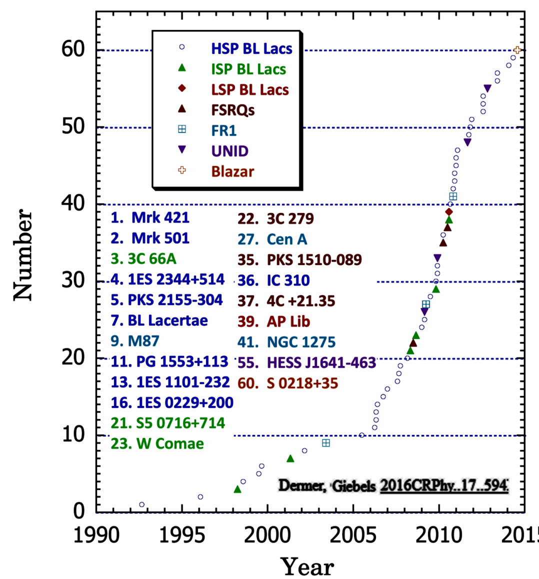
- ❑ Some relevant questions for e-ASTROGAM:
  - How many blazars of the two kinds (Flat Spectrum Radio Quasars and BL Lac objects) can be detected?
    (sensitivity: ~1.7e-10 for 100 ks; 1e-11 for one year)
  - How many in the e-ASTROGAM survey ?
  - How many new blazars (wrt to Fermi) are foreseen ?

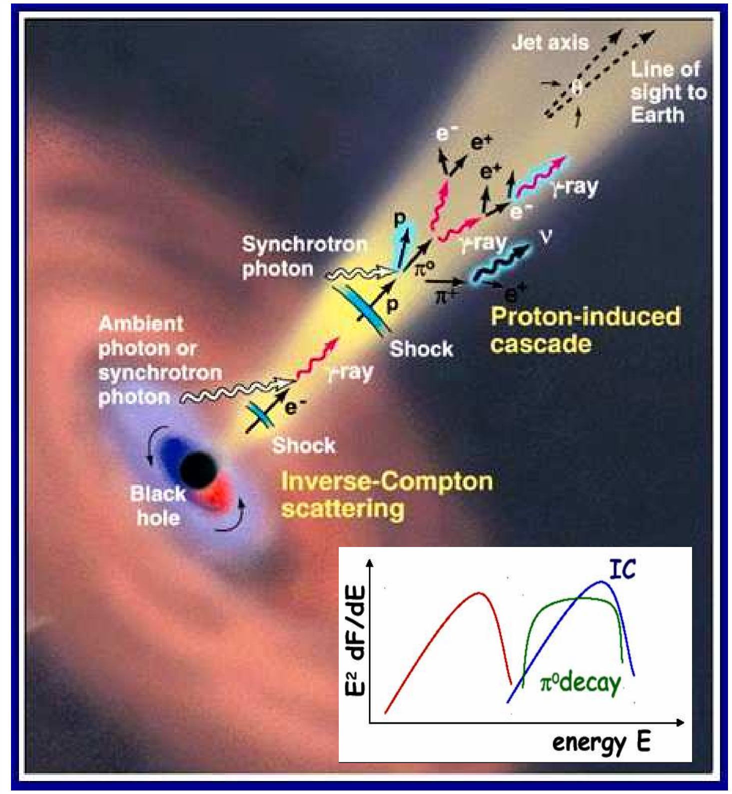


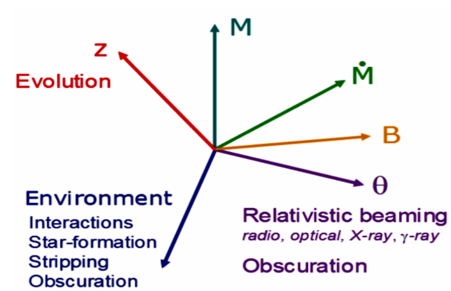
Rich laboratories for MW-astrophysics and MM-physics

- ❑ 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.







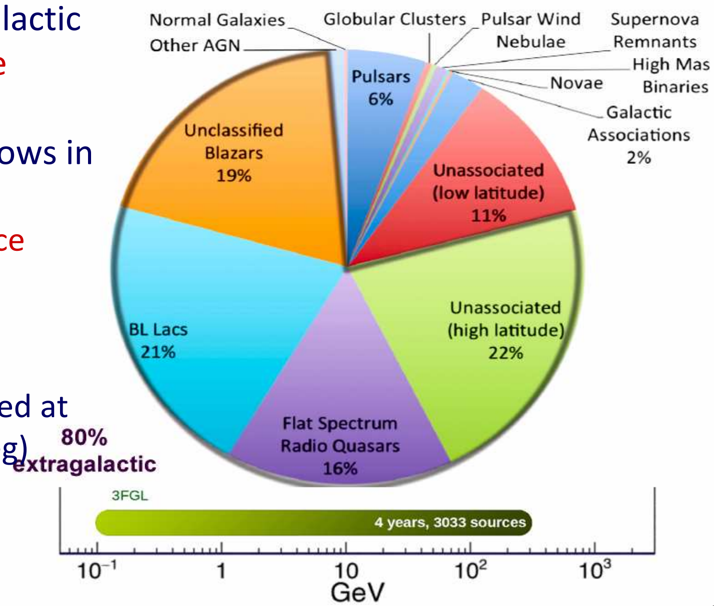


Fermi as a blazar telescope → e-ASTROGAM too

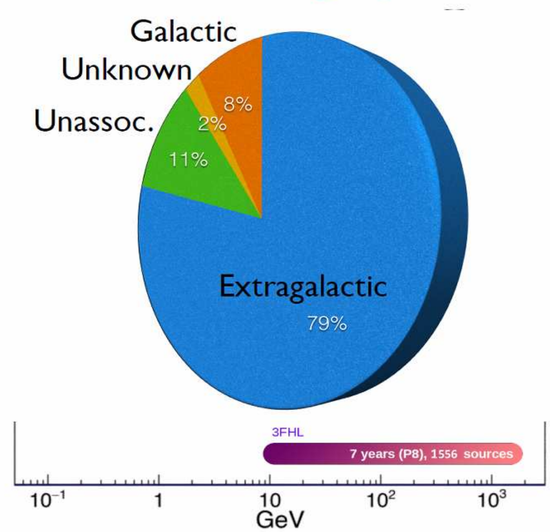
- ❑ Active Galactic Nuclei (AGN) and blazars in particular (they represents the extragalactic sky), dominated the gamma-ray source counts in Fermi LAT general catalogs.
- ❑ The 3rd LAT AGN catalog (3LAC) follows in the footsteps of the 3FGL catalog.
- ❑ Association of e.m. astrophysical source counterparts (radio/optical/IR/X-ray) is generally the strongest statement that we can make.
- ❑ 3LAC 1591 AGNs (mostly blazars) located at high Galactic latitudes (b<-10deg, b>10deg)

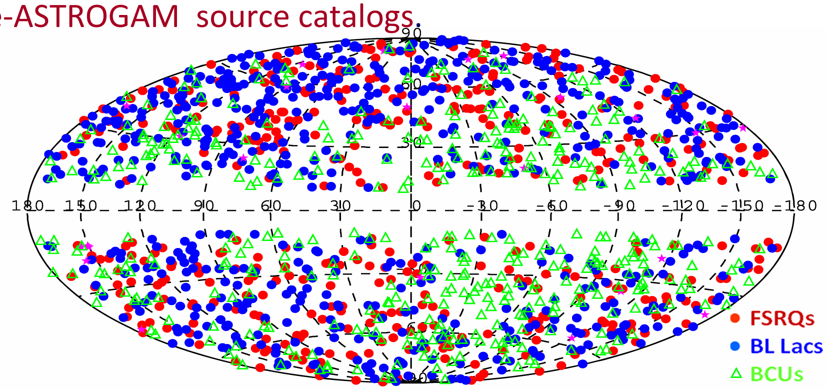
→ Fermi general (nFGL) catalogs and AGN/blazar (nLAC) catalogs activities are very relevant for the future e-ASTROGAM source catalogs.

3FGL demographics



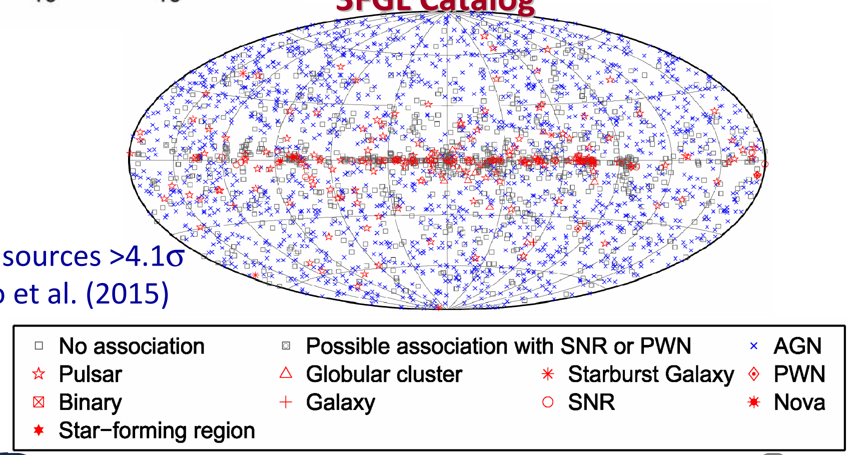
3FHL demographics





Ackermann et al. 2015, ApJ, 810, 14

3FGL Catalog



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

e-ASTROGAM WB contribution 1

The most massive high redshift and jetted black holes in the universe

(G. Ghisellini, F. Tavecchio, T. Sbarrato, S. Kauffman, O. Tibolla)

❑ Flat Spectrum Radio Quasars (FSRQ) at high redshift (z>4 up to z=6,7) are the most persistent powerful hard X–ray sources in the Universe.
→ 1) Optimal targets both to study the physics of jets and of accretion along the cosmic history.
→ 2) Probes to shed light on the far Universe.

❑ Electromagnetic output of high–z powerful FSRQs peaks just in the band of e-ASTROGAM → e–ASTROGAM can discover several of new sources of this kind.

❑ Estimations of BH mass, the accretion rate and the jet power for each blazar source detected.

❑ Relativistic collimated jet angle 1/LorentFactor so each detected source corresponds to other 2*(LorentFactor^2) sources pointing elsewhere. Evaluate how the number density of massive BH with jets behave as a function of BH mass.

❑ New detected FSRQs → refine current ideas of the relation between the jet and the accretion rate (Blandford–Znajek mechanism or other theories ?

❑ e-ROSITA (heritage and refined catalogs at the end of '20s) + e-ASTROGAM synergy.

The short message

❑e-ASTROGAM in MeV band looks at energetic, relativistic, beamed EARLY UNIVERSE, (z=6, z=7 and further).

❑ Optimal fit of the ESA's Cosmic Vision.

❑ It looks at the most heavy supermassive black holes (SMBH) in the Universe.

❑ It looks at the highest redshift SMBHs in MeV band (not observable with Fermi or other missions).

❑ Looks at the most energetic, relativistic, primordial (high-z) JETS of the Universe.

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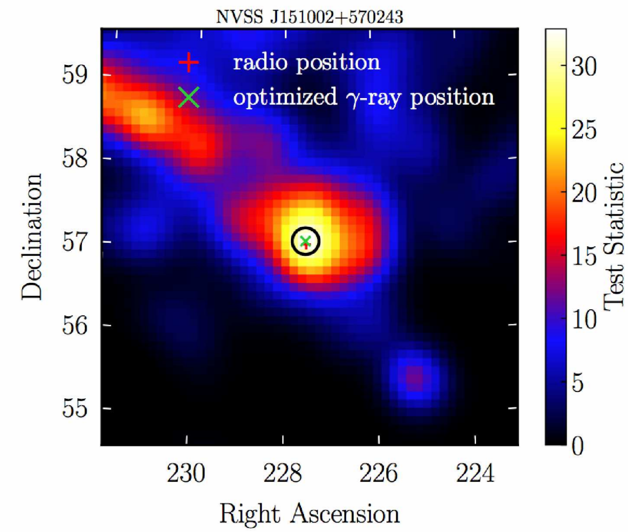
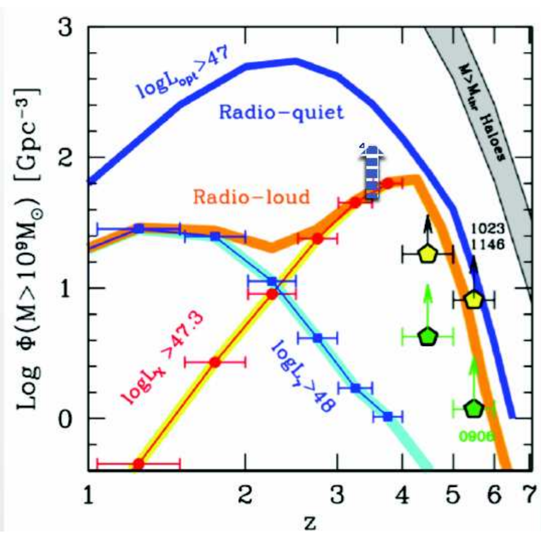
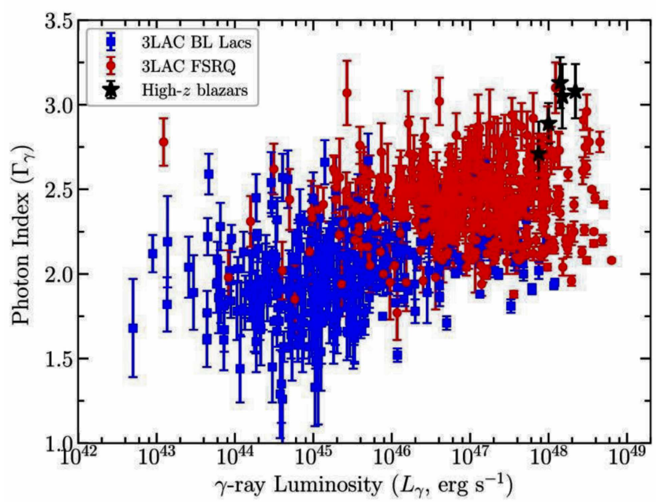
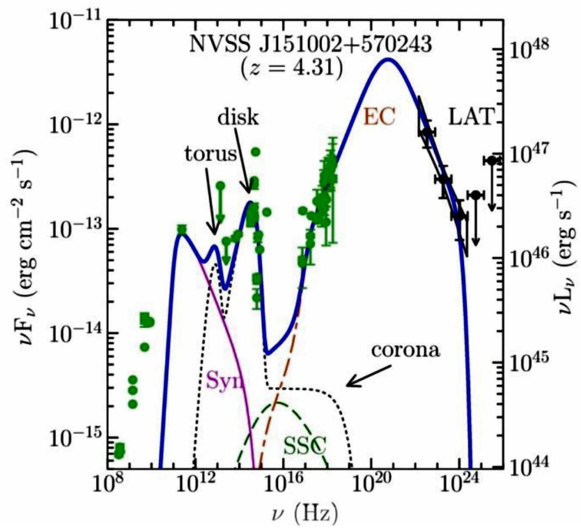
Example: Fermi GeV blazars at z=3 and 4

❑ 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.







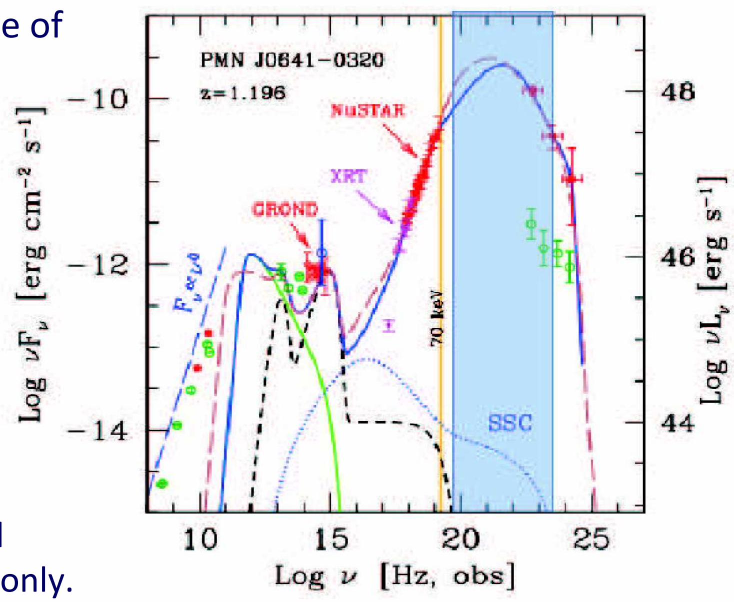


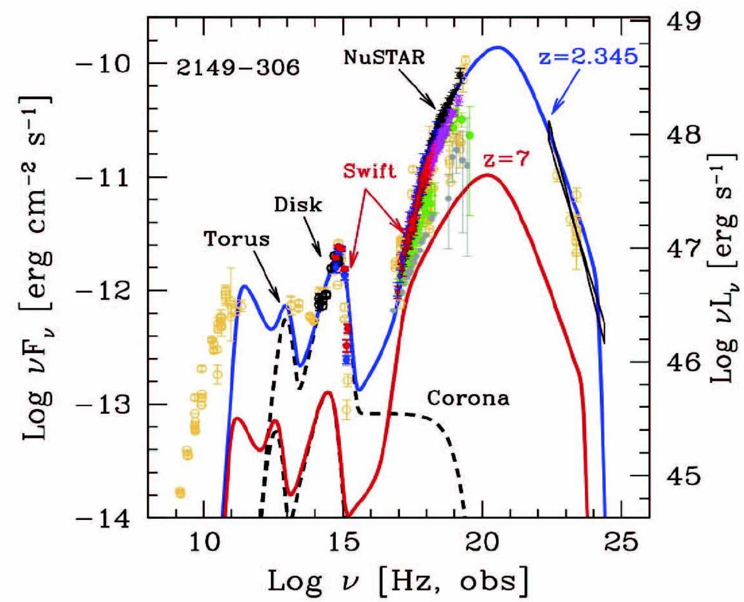
e-ASTROGAM WB contribution 2

MeV Blazars: the key to study the evolution of blazar at high-redshift

(S. Kaufmann, O. Tibolla, S. Ciprini, G. Ghisellini, F. Tavecchio, C. Pittori, F. Verrecchia)

- Blazars with a high luminosity at MeV energies (MeV-Blazars) are of the class of the most luminous blazars.
- 1st COMPTEL catalog and subsequent re-analysis evidenced for MeV emission of several blazars both in the lower (< 3 MeV) and upper (> 3 MeV) COMPTEL energy bands.
- At high luminosities and redshift, the accretion disc is expected to become visible in FSRQs, which could be a physical sequence of the Compton dominance.
- Understanding cause of violent and luminous outbursts.
- Problem of the external-jet photon field (BLR or Torus) of seed photons for Inverse Compton scattering.
- Models galore! They can be constrained with detailed MeV data only.





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e-ASTROGAM WB contribution 2

MeV Blazars: the key to study the evolution of blazar at high-redshift

(S. Kaufmann, O. Tibolla, S. Ciprini, G. Ghisellini, F. Tavecchio, C. Pittori, F. Verrecchia)

❑ Cosmological/redshift evolution of blazars. Even z=7 blazars are expected to be discovered.

❑ Detailed modeling of the leptonic Inverse Compton-dominated (or hadron processes) component of the spectral energy distribution is needed to identify the underlying physical properties of gamma-ray loud/dominated emission of blazars.

❑ Understand the possible emergence of multi-component and multi-process gamma-ray signatures (different-seed leptonic IC or hadronic processes or other) with detailed spectral/temporal MeV data.

❑ e-ROSITA (heritage and refined catalogs at the end of '20s) + e-ASTROGAM synergy here.

❑ ATHENA + e-ASTROGAM synergy here.

❑ Based on Fermi LAT photon index distribution of GeV detected blazars, more than 450 blazars expected to be detected with e-ASTROGAM (conservative).

The short message

❑ **e-ASTROGAM in MeV band looks at most luminous gamma-ray beams in the early Universe. Cosmological evolution of blazars/AGN.**

❑ **High-z → accretion disc become visible in FSRQs.**

❑ **Detailed modeling constraints of dominating leptonic Inverse Compton (or hadronic processes) component of the SED. Understand origin of the huge outbursts.**

❑ **Understand underlying physical properties, disentangle multi-components and multi-processes.**

❑ **e-ROSITA heritage + ATHENA + e-ASTROGAM synergy.**

❑ **> 450 blazars expected (conservative).**

e-ASTROGAM WB contribution 3

Narrow-Line Seyfert 1 galaxies: high accretion rates and low black hole masses

(S. Kaufmann, O. Tibolla, L. Foschini)

❑ Radio-loud Narrow-Line Seyfert 1 (NLSy1) galaxies new class of gamma-ray AGN: relatively low black hole masses (10^6-10^8 Msun) but near-Eddington accretion rates and with powerful relativistic jets.

❑ MeV peaked spectral emission of NLSy1 has to be studied in more detail.

❑ The SED is rather complex and need to understand the different contributions of the SSC and EC in the gamma-ray MeV-GeV band.

❑ Ongoing discussion about comparable characteristics to X-ray binaries.

❑ Importance of simultaneous X-ray and MeV gamma-ray observations during high-variability states.

❑Possible detection below 100 MeV of the, unbeamed, parent population.

❑e-ROSITA heritage + e-ASTROGAM synergy and SKA + e-ASTROGAM synergy here.

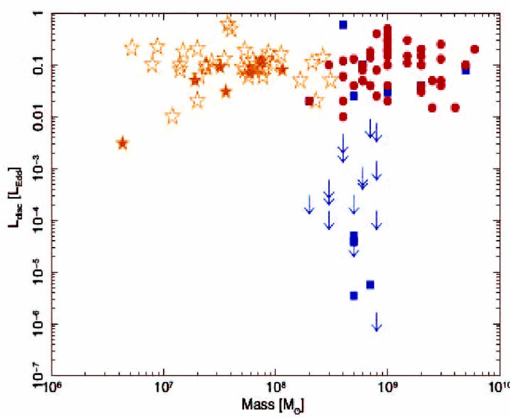
❑Expect a few dozens of MeV peaked NLSy1 galaxies to be detected by e-ASTROGAM.

The short message

❑ New class gamma.ray AGN: NLSy1 with high accretion rate & smaller BH masses and complex SED and jet physics → MeV data very useful .

❑ Possibility to detect for first time MeV emission from NLSy1 parent population.

❑ e-ROSITA heritage + SKA + e-ASTROGAM synergy.



Accretion disk luminosity in Eddington units versus the mass of the central black hole

orange stars radio-loud NLSy1

red circles FSRQs

arrows BL Lac objects.

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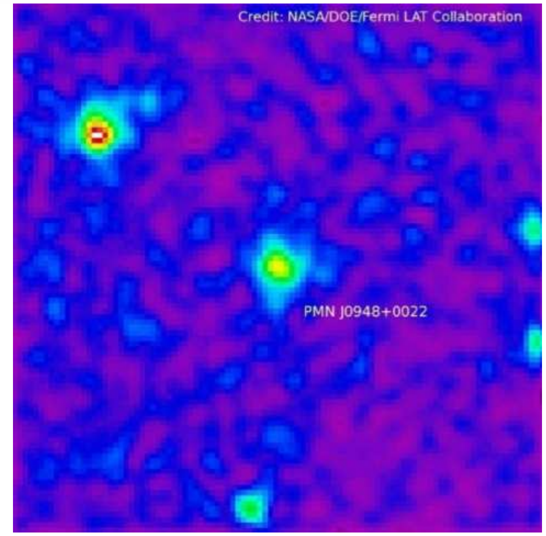
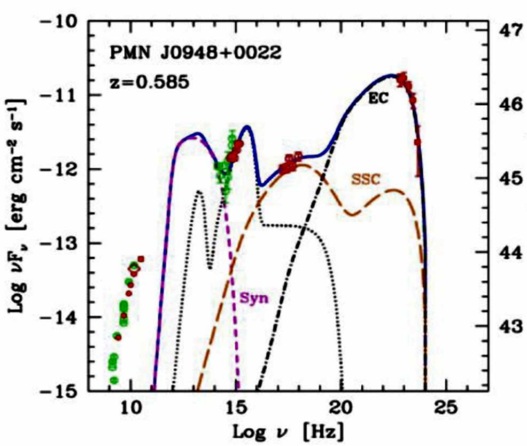
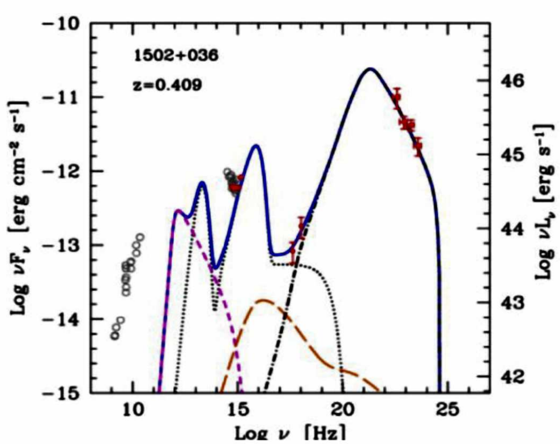
Example: Fermi GeV NLSy1 galaxies

- ❑ 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.

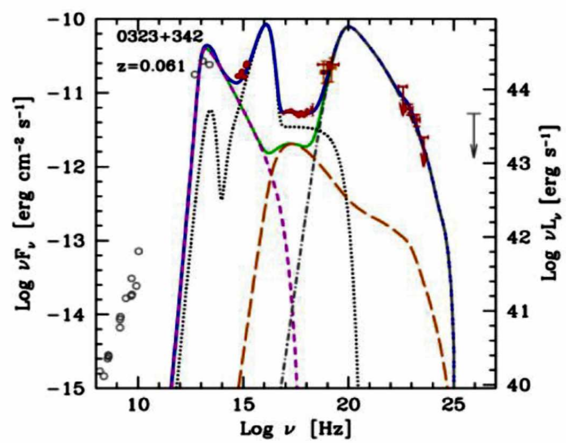




Foschini et al. 2012, 2014



Abdo et al. 2009



D'Ammando et al. 2012

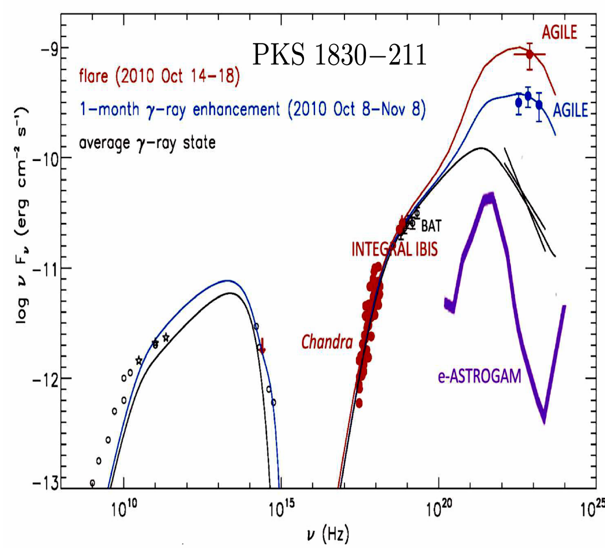
e-ASTROGAM WB contribution 4

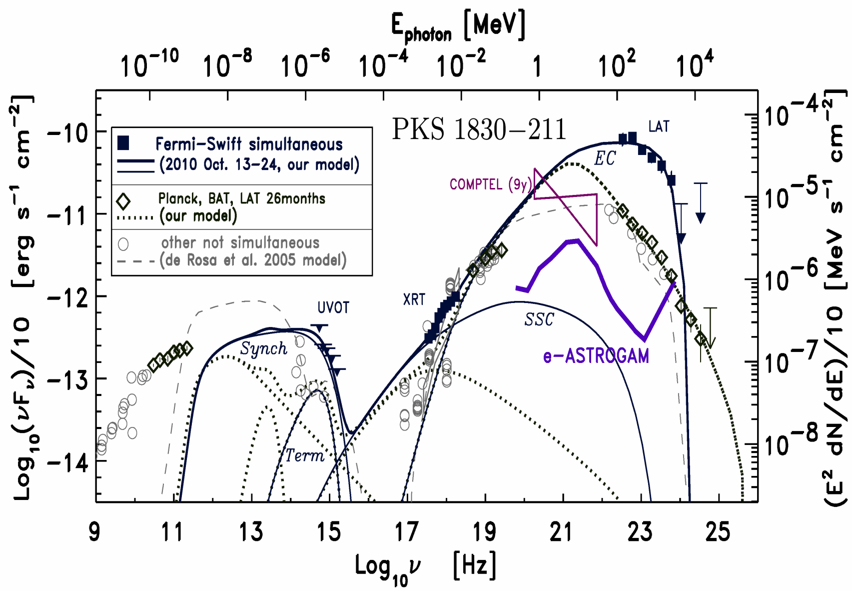
Gravitationally lensed MeV blazars

(S. Ciprini, C. Pittori, Chi C. Cheung, S. Buson, F. Verrecchia, D. Gasparrini, S. Cutini)

- ❑ Example of strong (but complicated) gravitational lensing is the powerful, MeV-peaked FSRQ, PKS 1830-211 (z=2.507, routinely detected in GeV gamma-ray band by AGILE and Fermi). Already detected by COMPTEL too.
- ❑Other lensed GeV blazar detected by Fermi, and recently by MAGIC, is S3 0218+35 (lens B0218+357, z=0.6847): it is the smallest-separation lens known. First independent gamma-ray delay measurement by Fermi LAT.
- ❑ In the MeV regime (i.e., before/around/after the gamma-ray FSRQ emission peak the largest excursion for flares and variability patterns is expected, enriching statistics in delayed events of these & newly discovered lensed MeV blazars.

❑ Data and analyses by Fermi, AGILE, INTEGRAL on this PKS 1830-211 lensed blazar → future fruitful confluence in e-ASTROGAM of scientists and knowledge from these current missions.





e-ASTROGAM WB contribution 4

Gravitationally lensed MeV blazars

(S. Ciprini, C. Pittori, Chi C. Cheung, S. Buson, F. Verrecchia, D. Gasparrini, S. Cutini)

❑ Evidence for micro/milli-lensing effects in strong lensed quasars increasing (variability in the images flux ratio).

❑ Independent MeV delay measurements from strong macro-lensing and derivation of futher measurements of projected size of the gamma-ray jet emission regions disentangling micro-lensing timing features.

❑ EUCLID heritage + LSST + ALMA + SKA + e-ASTROGAM synergy here.

❑ Special multi-messenger physics laboratories:
1) neutrino signal magnification for lensed hadronic MeV blazars.
2) Neutrino quantum interference and oscillations.
3) Differential arrival times of messenger particles (consequences for new physics unexplored topic).
4) Speculative theories of gamma-ray lensed blazars helping ALPs evidence and signals.

The short message

❑ Discover many MeV lensed blazar wrt to Fermi GeV lensed blazars (higher z, luminosity and variability at around the MeV peak).

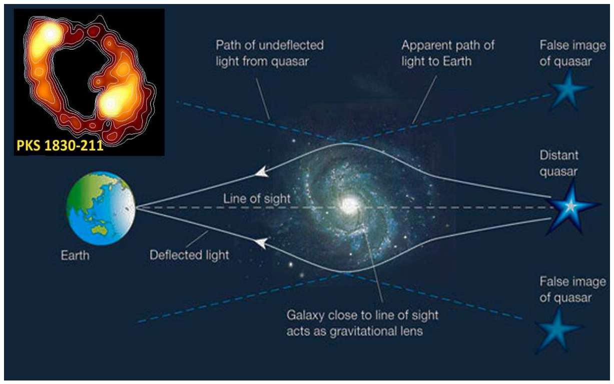
❑ Independent MeV delay measurements (strong macro-lensing) + micro/milli-lensing effects (importnant tool for >10^4 factor in resolving emission regions, and possible DM halos structure).

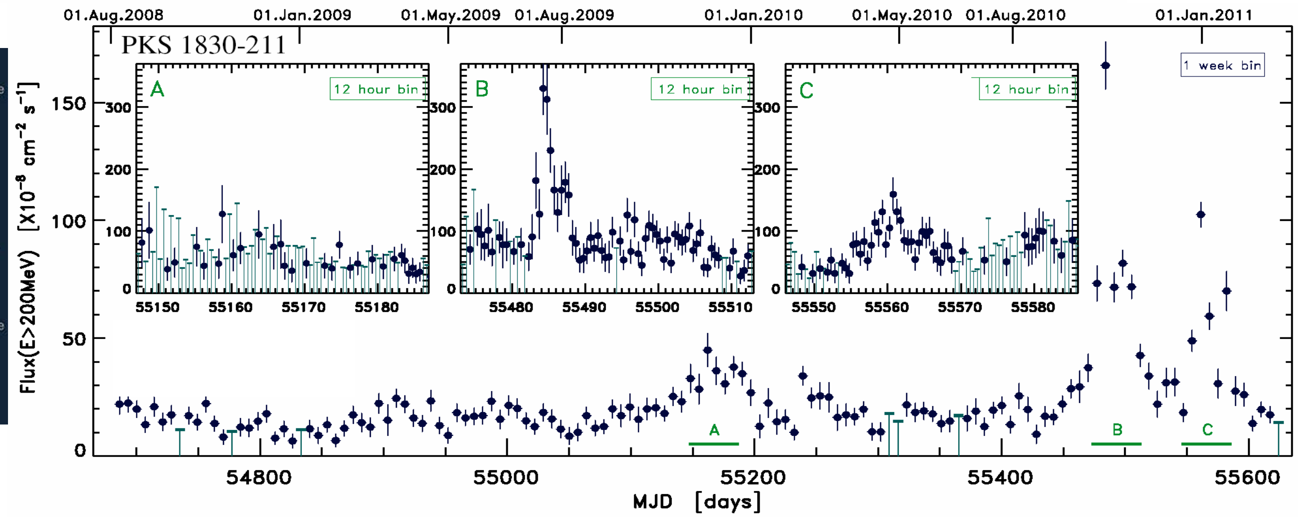
❑ Higher statistics for macrolensing delayed events and timining microlensing due to higher MeV variability.

❑ Powerful/extensive EUCLID + LSST + ALMA + SKA + e-ASTROGAM synergy expected here. Heritage of Fermi+AGILE+INTEGRAL.

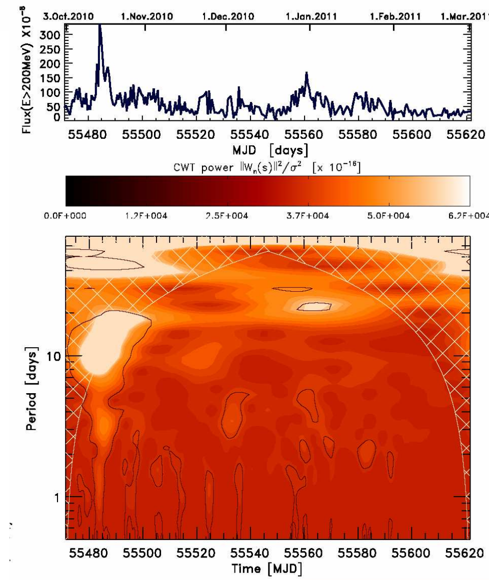
❑ Special multi-messenger physics laboratories (neutrino signal magnification, quantum interference and oscillations, differential multi-messenger arrival times and delays, MeV lens helping in ALPs signal detection.

Example: Fermi GeV view of PKS 1830-211





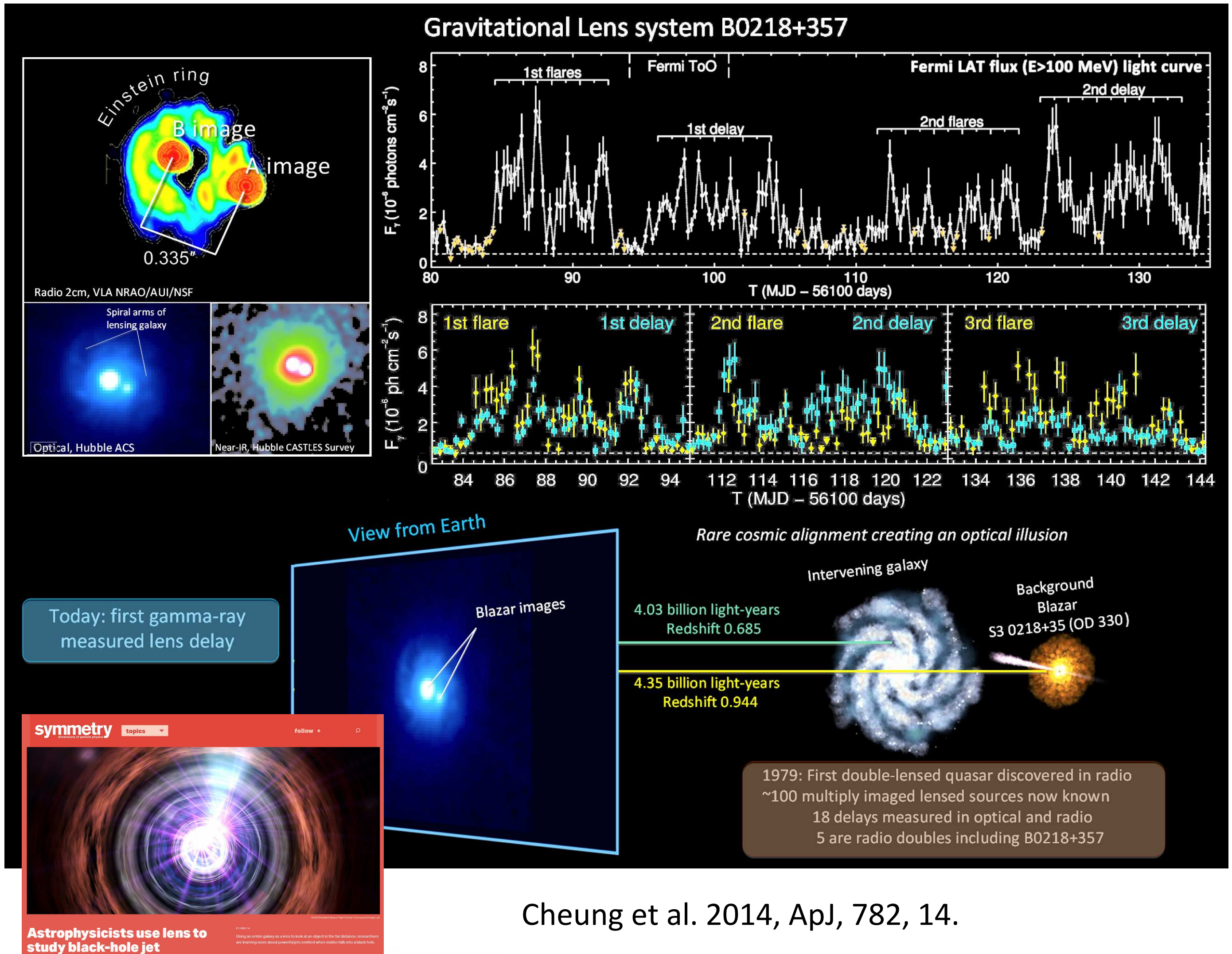
- Intense gamma-ray outburst from the blazar PKS 1830-211 (z =2.507) in October 2010, followed by high activity and other flares.
- A gravitationally lensed, highly dust-absorbed and reddened (by our Galaxy) flat spectrum radio quasar, peaked at MeV energy band.
- Analysis of 3-year Fermi LAT observations 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).



Example: Fermi GeV view of 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.

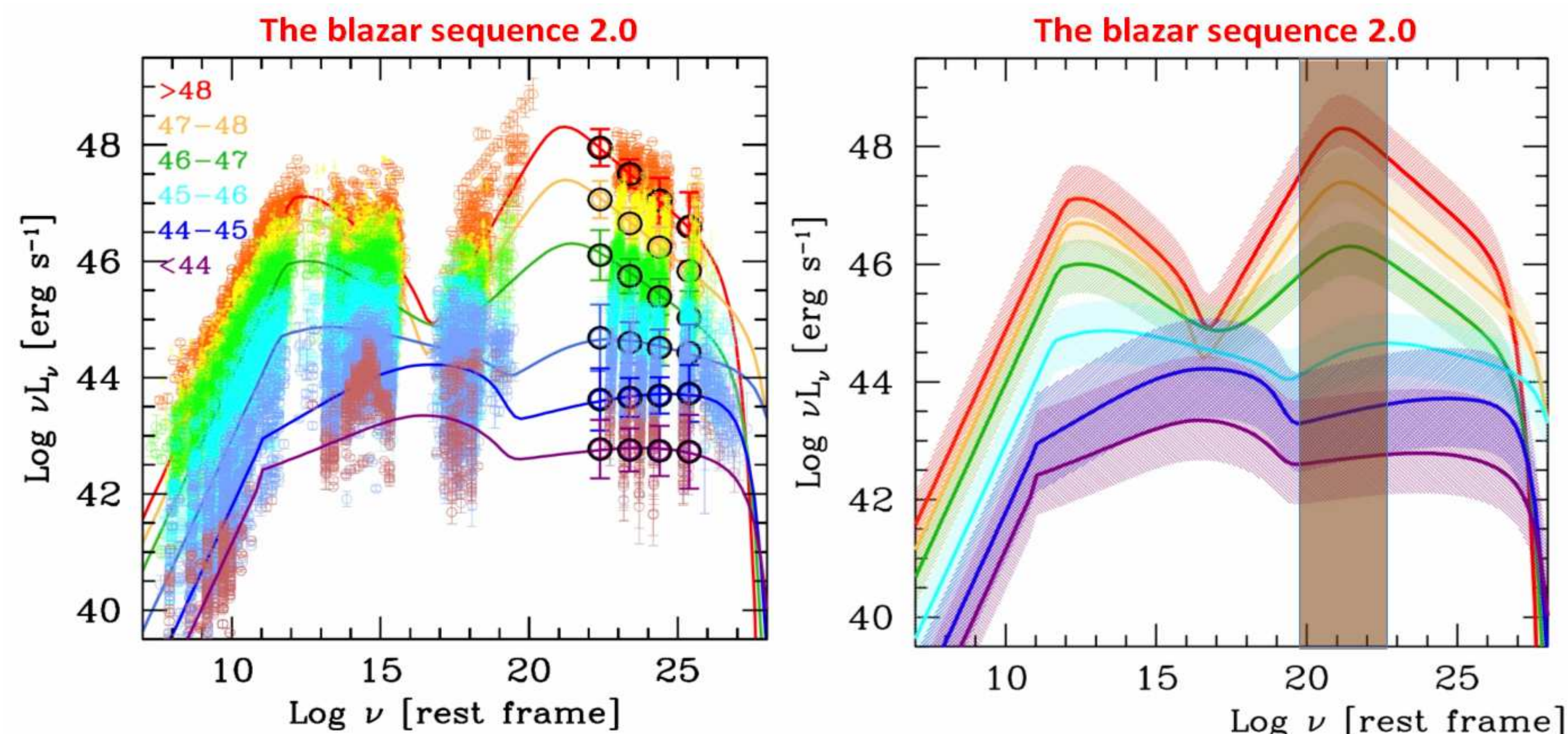


Cheung et al. 2014, ApJ, 782, 14.

A sequence in astrophysical parameters

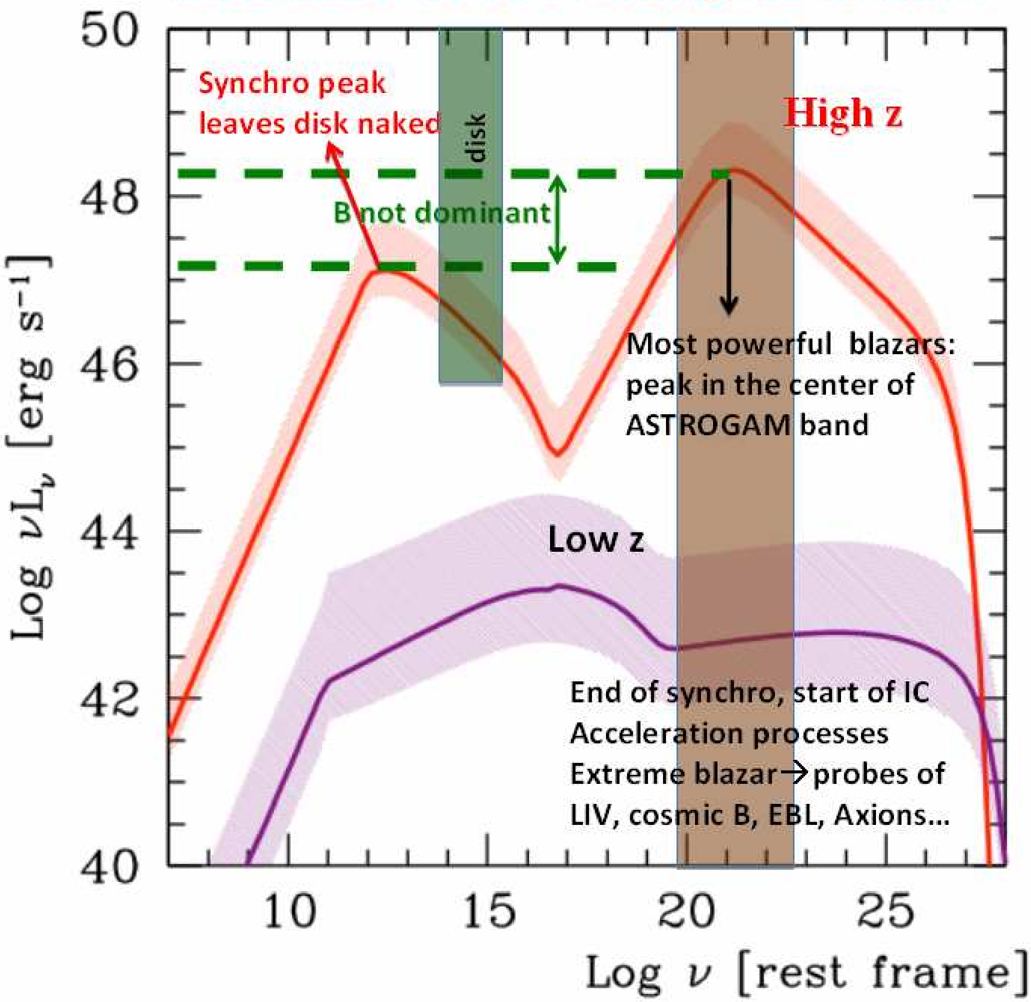
- ❑ The blazar sequence diagram 2.0 (Ghisellini, Tavecchio, Maraschi et al. works). A phenomenological observed SED sequence depending from physical parameters (a sort of tentative HR-diagram for blazars) .
- ❑ Blazars come in two flavours: BL Lac (lineless) and FSRQs (with broad emission lines).
- ❑ They form a sequence, the stronger the redder. Very weak BL Lacs may have their synchrotron peaking above 100 keV. Very strong FSRQs have their SED peaking at ~1 MeV.

→ At both extremes of the sequence we find optimal e-ASTROGAM targets



A sequence in astrophysical parameters

At both extremes we find strong MeV emission:

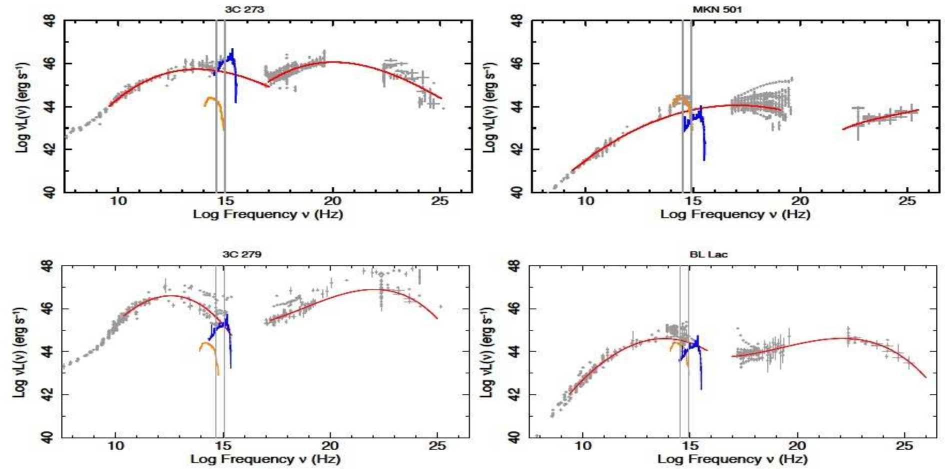


- ❑ Synchrotron peak (in mm/IR) leaves disk naked.
- ❑ High-redshift blazars.
- ❑ Most powerful blazars: the emission peak is in the center of e-ASTROGAM band.
- ❑ Complex spectral energy region: end of synchrotron, start of IC, different acceleration processes.
- ❑ Extreme blazars are probes of LIV, cosmic magnetic fields, EBL, Axions...

Another view: instrumental selection effects

- ❑ Other interpretation: Monte Carlo survey simulations and Occam's razor approach (Giommi, Padovani et al. works). Possible bias due to flux-limited and incompleteness (energy-dependent psf and sensitivity, unknown redshifts, etc.) of high-energy (X-ray, gamma-ray) surveys.

→ e-ASTROGAM survey of the MeV sky where powerful blazars are expected to peak is crucial).



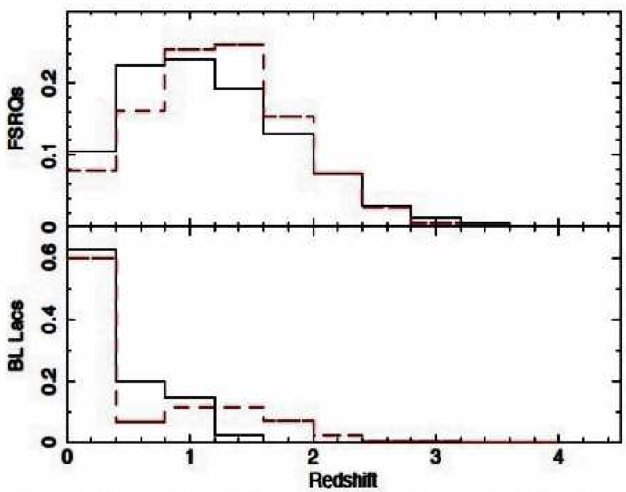


Figure 6. Top panel: the redshift distribution of the WMAP5 FSRQs (solid histogram) compared to that of FSRQs in a simulation of a radio survey (dashed histogram). Bottom panel: the redshift distribution of the WMAP5 BL Lacs (solid histogram) compared to that of BL Lacs in a simulation of a radio survey (dashed histogram)

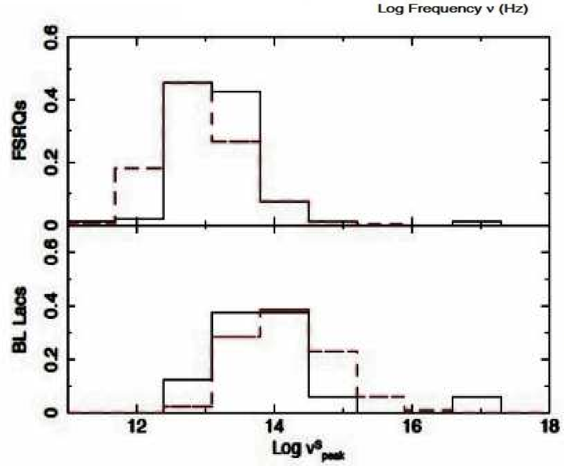


Figure 8. Top panel: the $\nu^{S}_{\rm peak}$ distribution of radio selected FSRQs taken from the work of Giommi et al. (2011) (solid

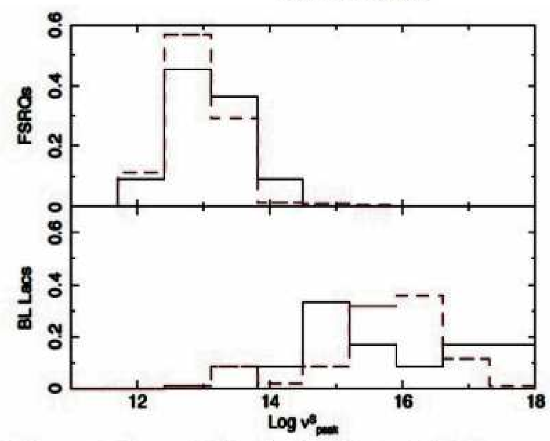
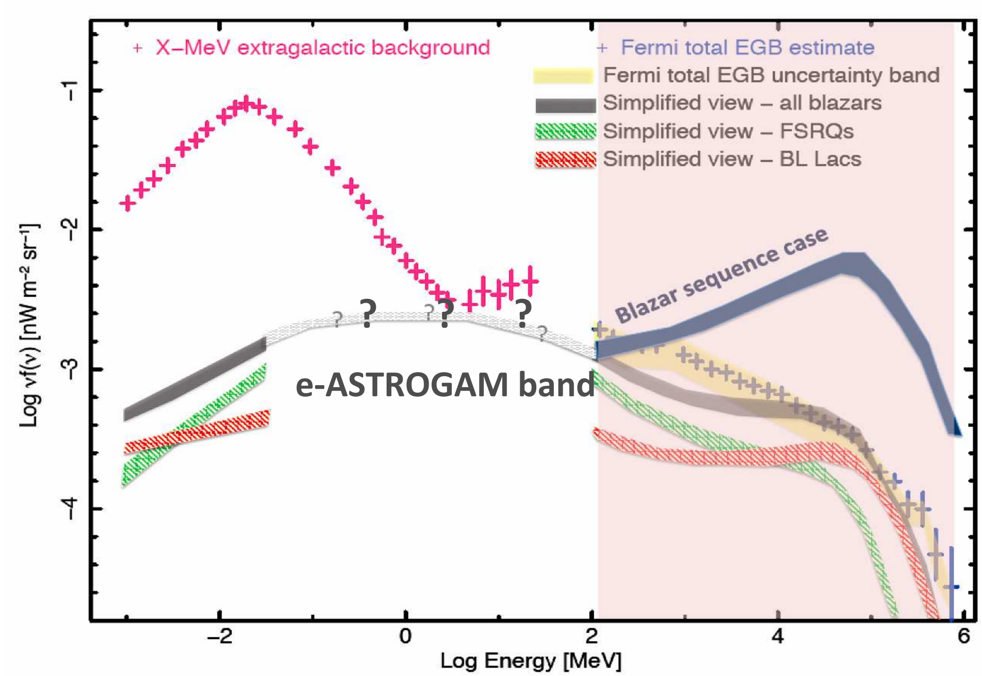
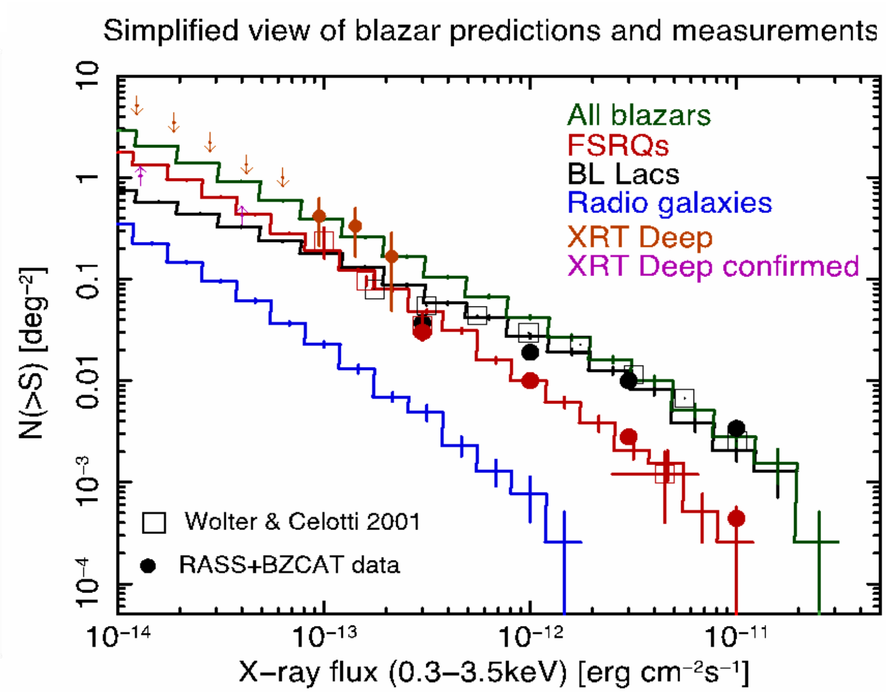


Figure 10. Top panel: the $\nu^{S}_{\rm peak}$ distribution of the X-ray selected FSRQs in Giommi et al. (2011) (solid histogram) compared to that of FSRQs in a simulation of an X-ray survey

Another view: instrumental selection effects

❑ The different synchrotron peak energy distributions in BL Lacs and FSRQs is not due to cooling or other physical reason, but to selection effects.





❑ A simulated source is classified as FSRQ, BL Lac or radio galaxy on the basis of the balance of Thermal, Blue-bump/broad-lines, non-thermal/jet radiation and host galaxy in the optical band (3800-8000 Å in the observer frame).

$$B = \int_{S_{min}}^{S_{max}} S \, \frac{dN}{dS} \, dS$$

❑ **FSRQ** if the rest-frame EW (Non-thermal + Blue bump) of any line in the optical band is > 5 Å

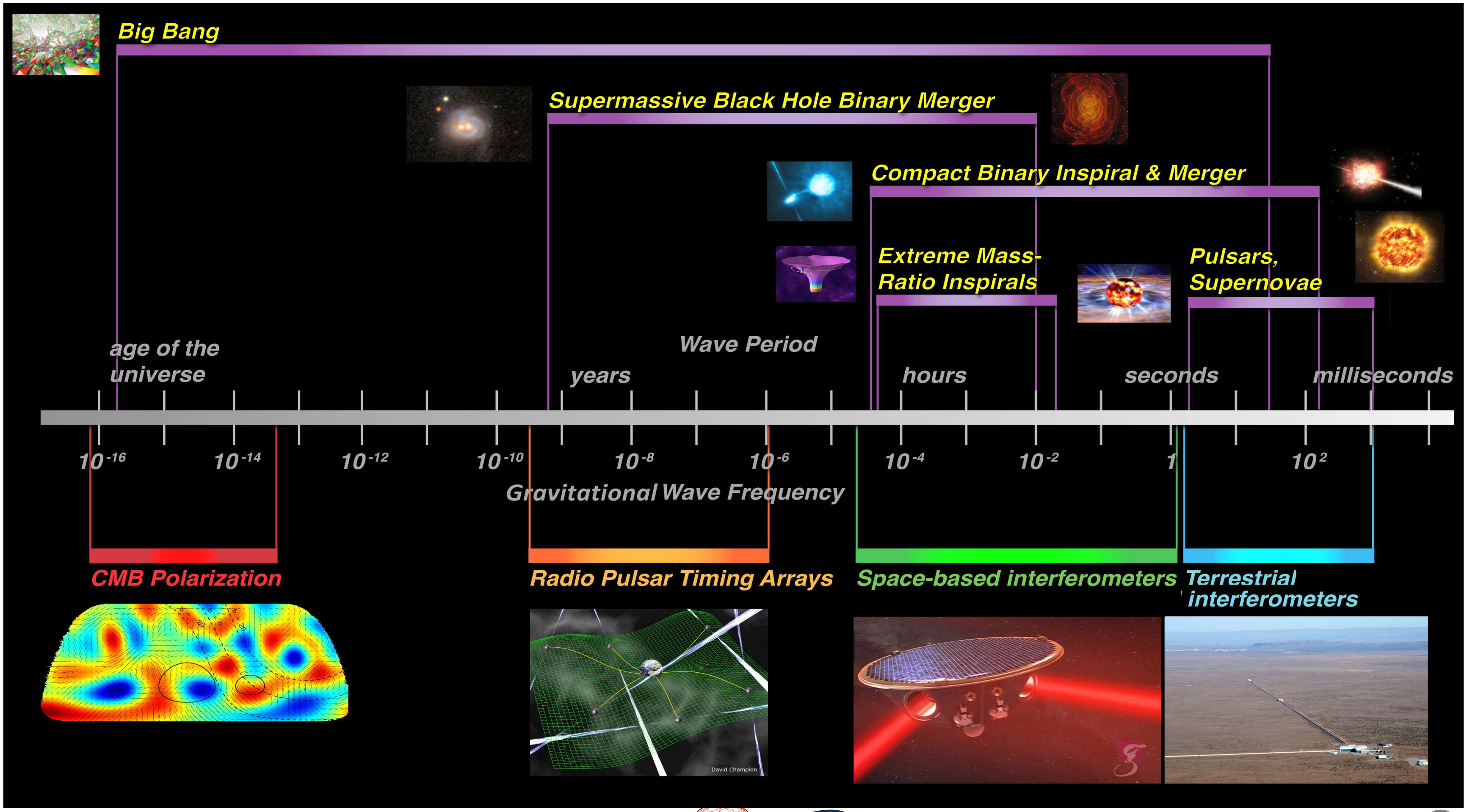
❑ **BL-Lac** if the observed EW (Non-thermal + Blue bump) of any line in the optical band (observer frame) is < 5 Å

❑ **Radio Galaxy** if only absorption features form the host galaxy are in the optiacal band and Ca H&K break > 0.4

❑ Redshift of BL Lacs is assumed to be ***not measurable*** if the EW of the brightest line in the optical band is < 2 Å.

AGN/norm.galaxies SMBH binaries and GWs

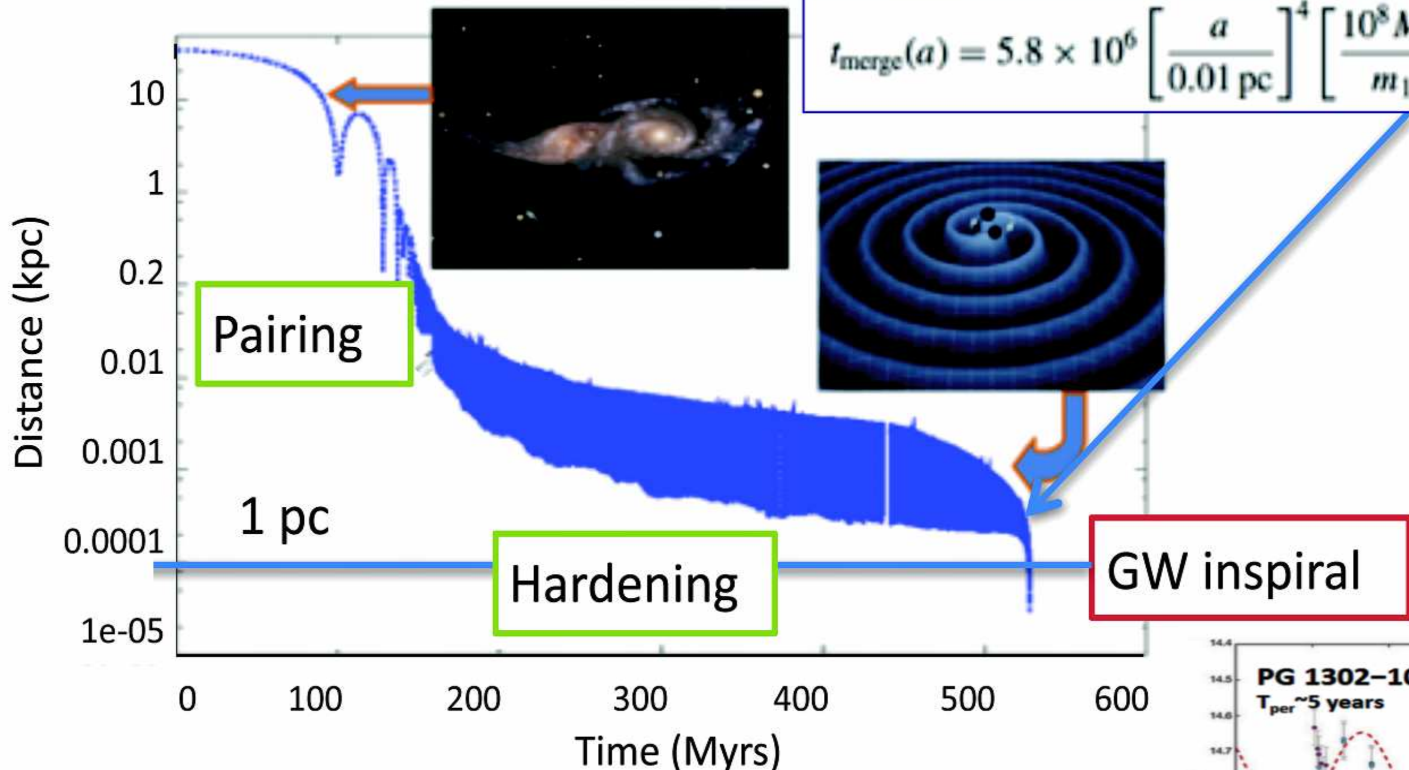
Instruments capable of detecting gravitational waves (GWs) and their sources in the next years: ground-based interferometers like aLIGO (discovered them), aVIRGO, KAGRA, Geo600, etc.; the Pulsar Timing Arrays (PTAs), the Square Kilometer Array (SKA); the LISA space mission, the 3rd gen. Einstein GW Telescope.

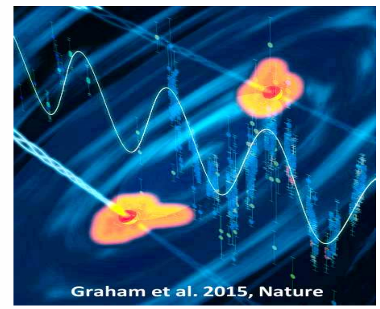


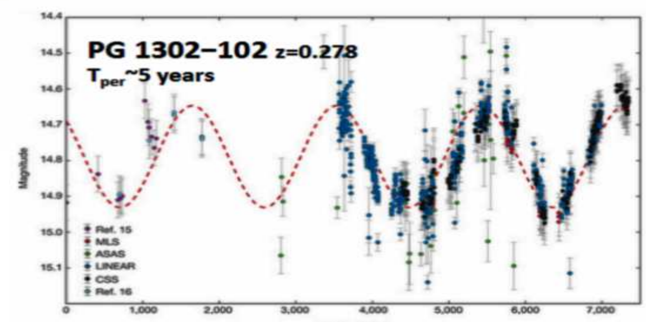
Supermassive BHs pairs/binaries

❑ 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.

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



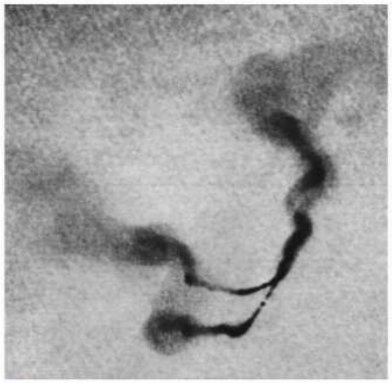




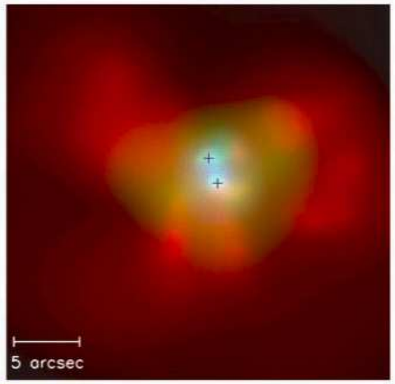
Graham et al. 2015, Nature 518
Binary SHBH 0.01 parsec (2X10^4 AU) separation

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

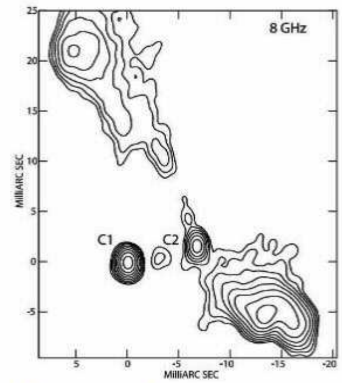
SMBHs pairs/binaries evidence



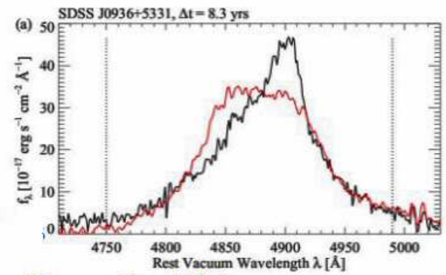
Dual jets (3C 75, a~7kpc)
[Owen+ 1985]



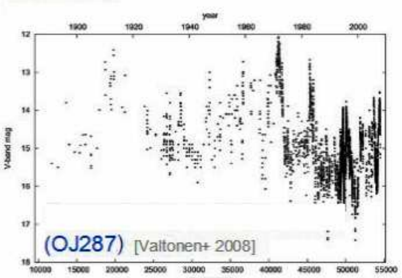
Dual X-ray sources
(NGC 6240, a ~ 1.5 kpc) [Komossa+ 2003]

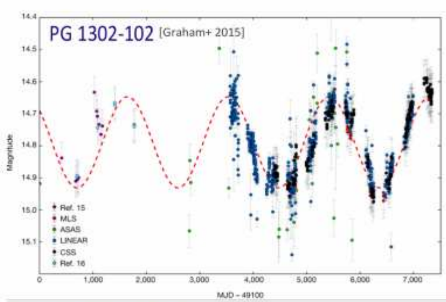


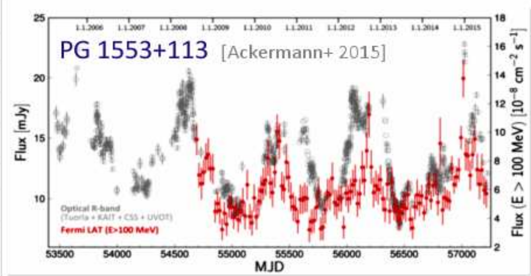
Binary radio sources
(0402+379, a ~ 7pc) [Owen+ 1985]

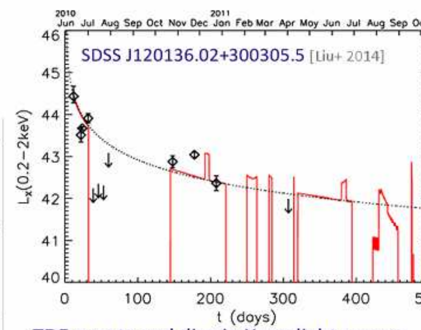


Kinematic shift in
multi-epoch observations
[Liu+ 2013]







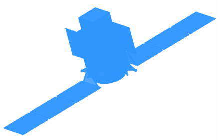


TDE events and dips in X-ray light curves

Quasi periodicity in light curves (still controversial topic)

❑ 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.

Conclusions



- 4 (+1 EGB) WB contributions for blazars/AGNs with e-ASTROGAM.
- Mostly astrophysical science topics, but room for astro-particle (multi-messenger/particle important) science.
- More speculative contributions with exotic fundamental or multi-messenger physics would be possible in principle if needed.
- AGN/blazars (i.e. jetted and Gargantua black holes) are one of the main science menu for the Fermi LAT and therefore for e-ASTROGAM.
- Important message: e-ASTROGAM unique mission to probe high-redshift (z=6, z=7 and beyond?) accreting and jetted SMBHs of the young Universe.
- Important message: MeV blazars are optimal multi-frequency photon beams, multi-messenger/particle beams from the distant universe. We can profiting with e-ASTROGAM of rapidly growing survey and multi-messenger instruments (e.g. large scale neutrino and EHE cosmic ray detectors, exotic GW signals for current and eLISA interferometers from exotic physics in SMBHs ambient, e-ROSITA heritage, ATHENA, LSST, GAIA and Euclid heritages, ALMA, SKA, CTA).
- High-variability (also huge outburst) in MeV gamma rays → more opportunities for the next multi-mission/frequency and time-domain astrophysics.

MeV blazars discovered/seen by e-ASTROGAM are crucial in 3M-science: Multi-time domain, Multi-wavelength, Multi-messenger.

MeV blazars discovered/seen by e-ASTROGAM allow us to see:
1) the most heavy SMBHs;
2) the most high redshift (z=5,6,7 & beyond) SMBHs;
3) the primoridal high-z jets and accretion processes in the Universe.

Backup slides

The 3rd LAT AGN catalog (3LAC)

The 3LAC follows in the footsteps of the 3FGL (blazars dominates).
[Ackermann et al. 2015, ApJ, 810, 14]

- ❑ Association of source counterparts 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.

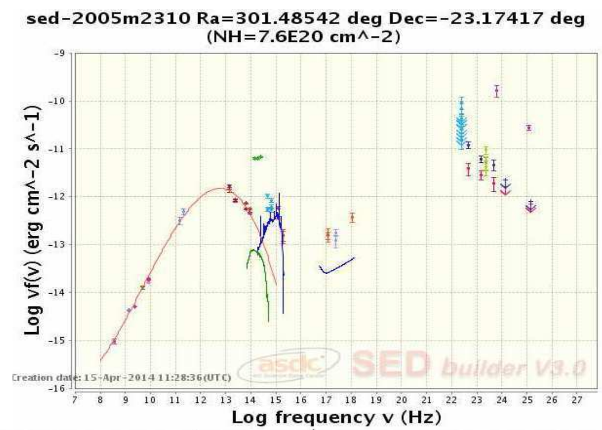
- ❑ The source counterpart association is like calibrated cross correlation between source catalogs and surveys (covering the entire sky or complemnetary, ex: NVSS/SUMSS/PMN/ATCA20/RASS), providing quantitative probabilities of association and to controlled false positive association rate (1,2,3FGL/1,2,3LAC catalogs we adopted P > 0.8 threshold in one of the two methods).

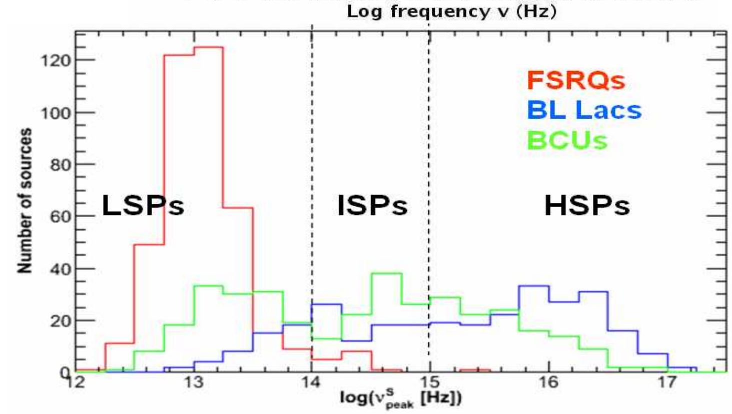
- ❑ 3LAC: LRM specific for this catalog. Association probability > 0.8 in one of the 2 methods: 71% BM & LRM, 379 only BM, 62 only LRM, false-positive rate < 2%.

- ❑ 3LAC: 2 classification schemes for the associated AGN:
1) optical spectrum-based (strength of broad lines, FSRQs, BL Lacs, BCUs aka Blazar Candidates of Unknown type);
2) Spectral Energy Distribution (SED) based (Low-,Intermediate-, High-Synchrotron-Peaked AGN/blazars LSPs, ISPs, HSPs). Algorithm-/manually-controlled fit.

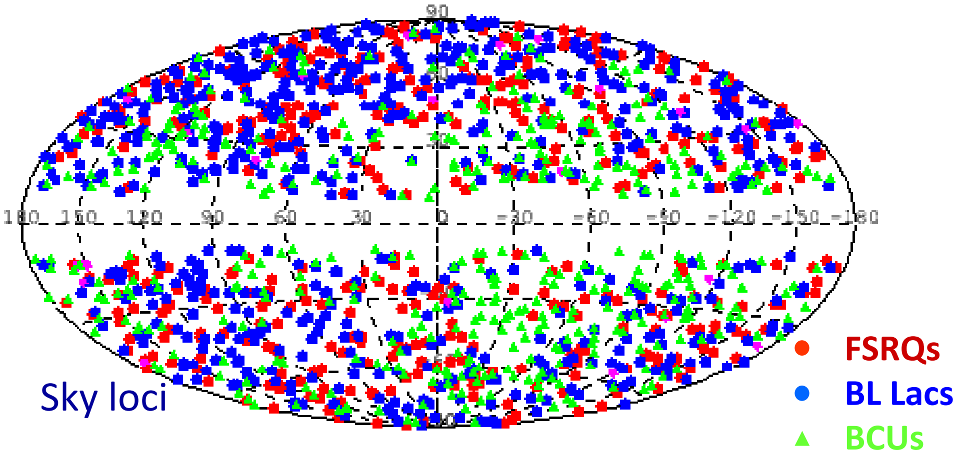
- ❑ Identification: strong term, based on correlated variability or spatial extent (in the 3FGL: 25 extended sources, 232 identified sources, 132 of which were pulsars, the other are mostly blazar with correlated multifrequency variability).

Catalogs used for 3LAC source association:
Véron-Cetty & Véron; BZCAT; VLBA Calibrator list; CRATES; CGRaBs; TeVCat; ATCA 20-GHz survey; WISE gamma-ray blazar candidates; 1WHSP; NRAO VLA Sky Survey; Sydney University Mongolo Sky Survey; ROSAT All Sky Survey Bright and Faint Source Catalogs.

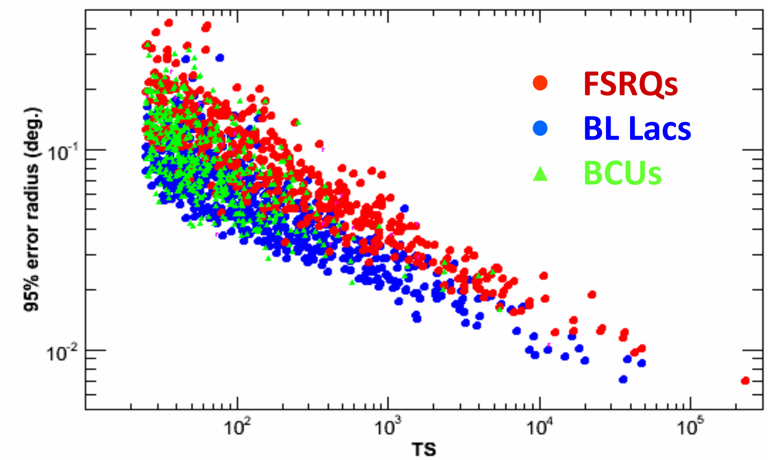




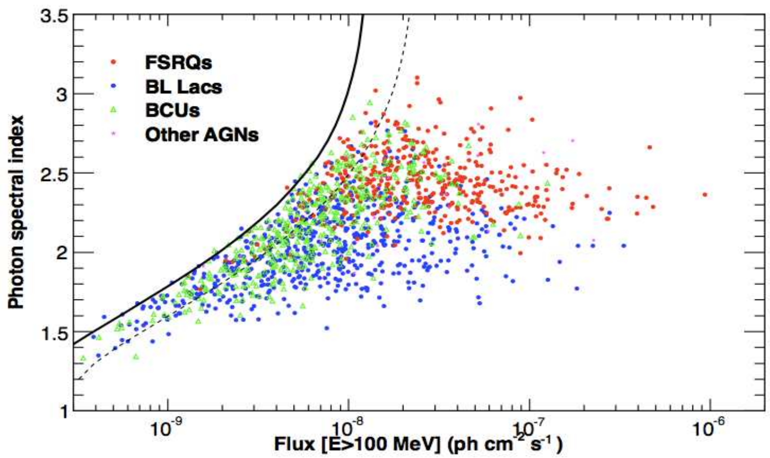
3LAC sample properties



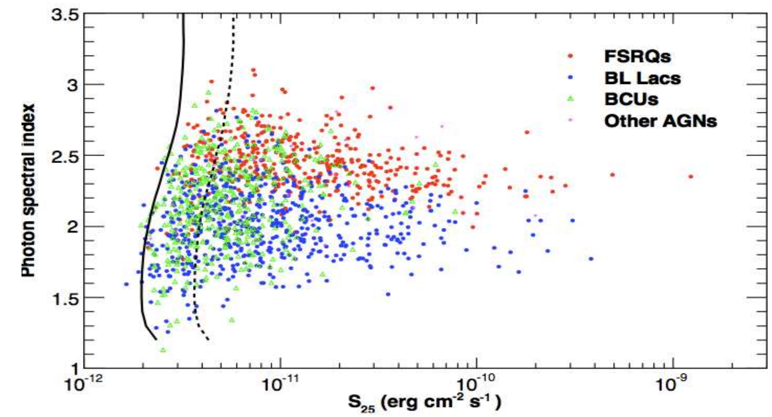
Sky loci



95% position error radii vs TS (detection significances)



Spectral photon index vs integrated (E>100MeV) gamma-ray flux



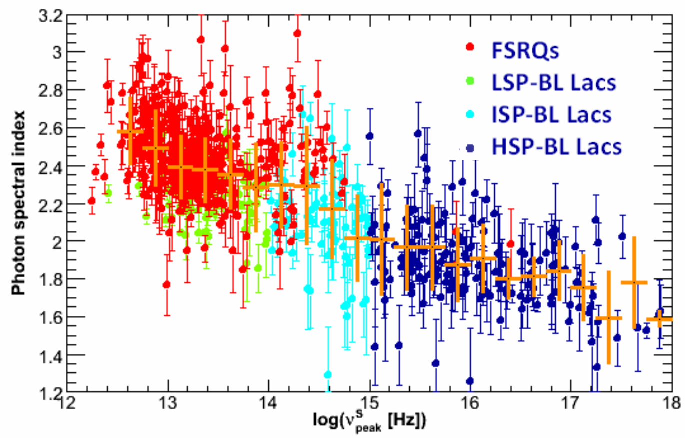
Spectral photon index vs gamma-ray (100 MeV - 100 GeV) energy flux (less biased by the ph.index).

Flat Spectrum Radio Quasars (FSRQs), BL Lacertae objects (BL Lacs), blazar candidates of unknown type (BCUs)

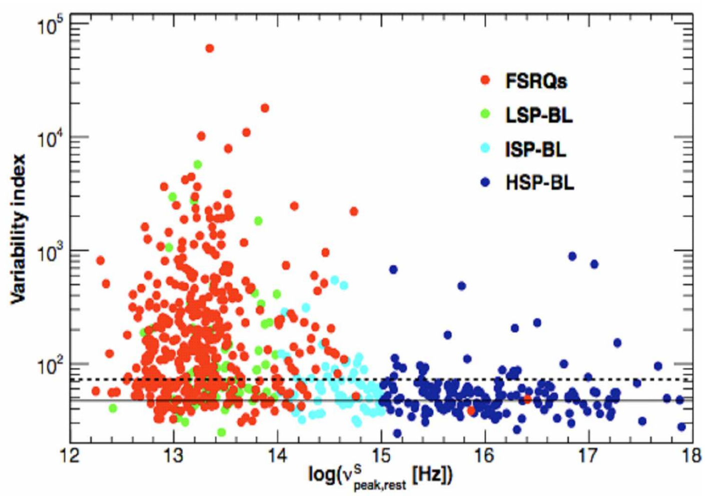
3LAC sample properties

❑Radiogalaxies/misaligned AGN in 3LAC (12 FRI, 3 FRII, 8 SSRQ/CSS).

Name	3FGL	Type	Photon indeL	
NGC 1218	J0308.6+0408*	FRI	2.07±0.11	-0403*
IC 310	J0316.6+4119*	FRI/BLL	1.90±0.14	
NGC 1275	J0319.8+4130*	FRI	2.07±0.01	-4130*
1H 0323+342	J0325.2+3410*	NLSy1	2.44±0.12	-3403*
4C +39.12	J0334.2+3915*	FRI/BLL?	2.11±0.17	
TXS 0348+013	J0351.1+0128*	SSRQ	2.43±0.18	
3C 111	J0418.5+3813	FRII	2.79±0.08	-3811
Pictor A	J0519.2−4542*	FRII	2.49±0.18	
PKS 0625−35	J0627.0−3529*	FRI/BLL	1.87±0.06	-3530*
4C +52.17	J0733.5+5153	AGN	1.74±0.16	
NGC 2484	J0758.7+3747*	FRI	2.16±0.16	
4C +39.23B	J0824.9+3916	CSS	2.44±0.10	
3C 207	J0840.8+1315*	SSRQ	2.47±0.09	-1310
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*	NLSy1	2.32±0.05	-0021*
PMN J1118-0413	J1118.2-0411*	AGN	2.56±0.08	
B2 1126+37	J1129.0+3705	AGN	2.08±0.13	
3C 264	J1145.1+1935*	FRI	1.98±0.20	
PKS 1203+04	J1205.4+0412	SSRQ	2.64±0.16	
M 87	J1230.9+1224*	FRI	2.04±0.07	-1223*
3C 275.1	J1244.1+1615	SSRQ	2.43±0.17	
GB 1310+487	J1312.7+4828*	AGN	2.04±0.03	-4827*
Cen A Core	J1325.4−4301*	FRI	2.70±0.03	-4300
Cen A Lobes	J1324.0−4330e	FRI	2.53±0.05	-4515
3C 286	J1330.5+3023*	SSRQ/CSS	2.60±0.16	
Cen B	J1346.6−6027	FRI	2.32±0.01	
Circinus	J1413.2−6518	Seyfert	2.43±0.10	
3C 303	J1442.6+5156*	FRII	1.92±0.18	
PKS 1502+036	J1505.1+0326*	NLSy1	2.61±0.05	-0328*
TXS 1613−251	J1617.3−2519	AGN	2.59±0.10	
PKS 1617−235	J1621.1−2331*	AGN	2.50±0.23	
NGC 6251	J1630.6+8232*	FRI	2.22±0.08	-8228*
3C 380	J1829.6+4844*	SSRQ/CSS	2.37±0.04	-4845*
PKS 2004−447	J2007.8−4429*	NLSy1	2.47±0.09	-4430*



Correlation between gamma-ray spectral hardness and synchrotron peak frequency confirmed (also for BCUs).



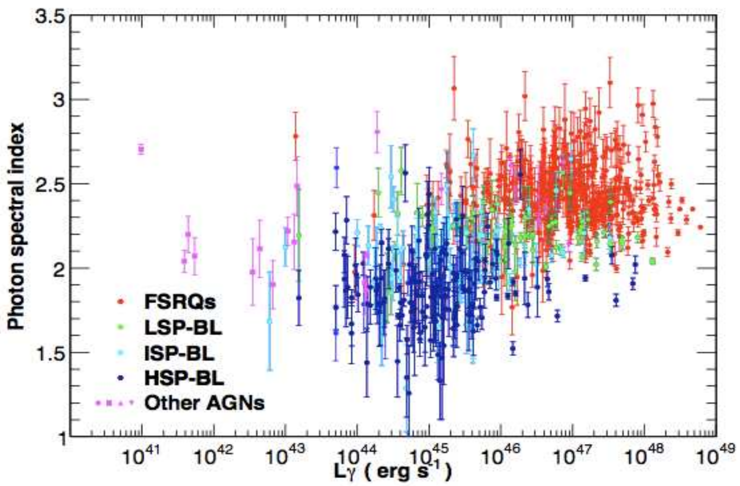
Fractions of sources showing significant gamma-ray variability

FSRQS: 69%

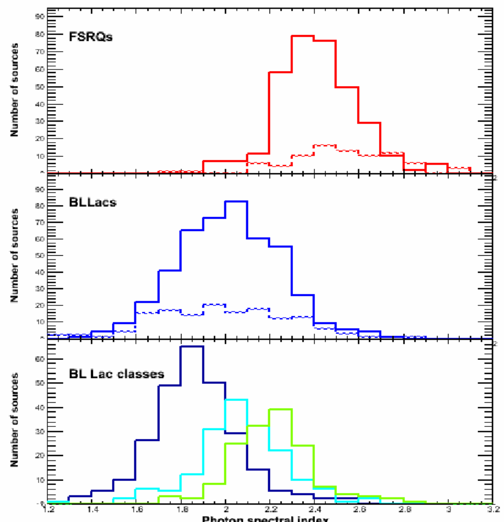
BL Lacs 23 %

(39%, 23%, 15%) for (LSP, ISP,HSP).

3LAC sample properties

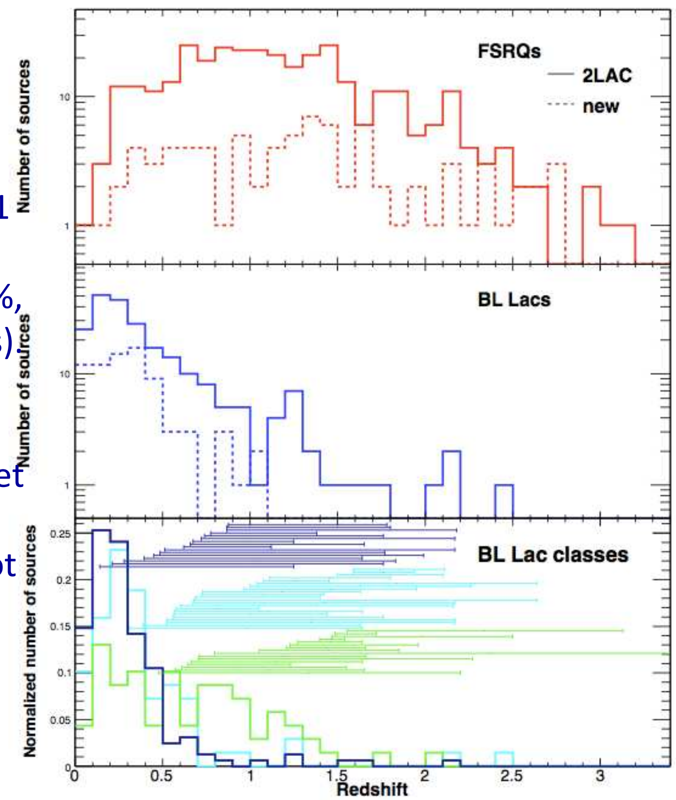


Spectral photon index vs gamma-ray power (luminosity).



Redshifts

- Slightly higher z for new FSRQs relative to 2LAC ones <z>=1.33 vs. 1.17.
- Maximum redshift still z=3.1
- 295/604 BL Lacs have no measured redshifts (55%, 61%, 40%) for (LSPs, ISPs and HSPs).
- Narrower z distribution for BL Lacs in 3LAC than 2LAC.
- 134 constraints from Shaw et al. (2013).
- Redshift limits for BLLacs not compatible with measured redshifts: measured redshifts are biased low.



Photon spectral indexes

- Little overlap between FSRQs and BL Lacs
- New FSRQs slightly softer than 2LAC ones: (<Γ>=2.53 vs. 2.41), and not so for BL Lacs
- BCUs' index distribution straddling the two classes and extending beyond 2.5

Gamma-ray blazar luminosity functions: a rise in HSP density corresponds to a drop-off in that of FSRQs. Are HSPs an accretion-starved end state of an earlier merger-driven, gas-rich phase (FSRQs)?

3rd Fermi LAT AGN catalog (3LAC)

- The LAT FGL catalog analysis procedure has been applied, with successive refinements, several times. More LAT catalogs are in development and a number of class-specific catalogs also exist.
- Uniform, systematic analysis has a number of useful objectives.
- 3FGL has 3033 sources.
- 3LAC has 1773 AGN (1591 located at high (|b|>10°) Galactic latitudes). 71% increase over the 2LAC (increased exposure and the use of improved counterpart catalogs). 2% are non-blazar associated sources.
- 3LAC is a significant improvement over the 2LAC also in term of analysis method and data quality.
- Significant increase of non-blazar AGN population (3 new FRI, 2 new FRII, 4 new SSRQ).
- Main properties reported in 1LAC and 2LAC are confirmed.
- The next 4LAC will use >8 years of data and will make use of Pass 8 data and will constitute another notable step forward and reference AGN/blazar catalog for e-ASTROGAM.

The Astrophysical Journal Supplement Series, 218:23 (41pp), 2015 June doi:10.1088/0067-0049/218/2/23

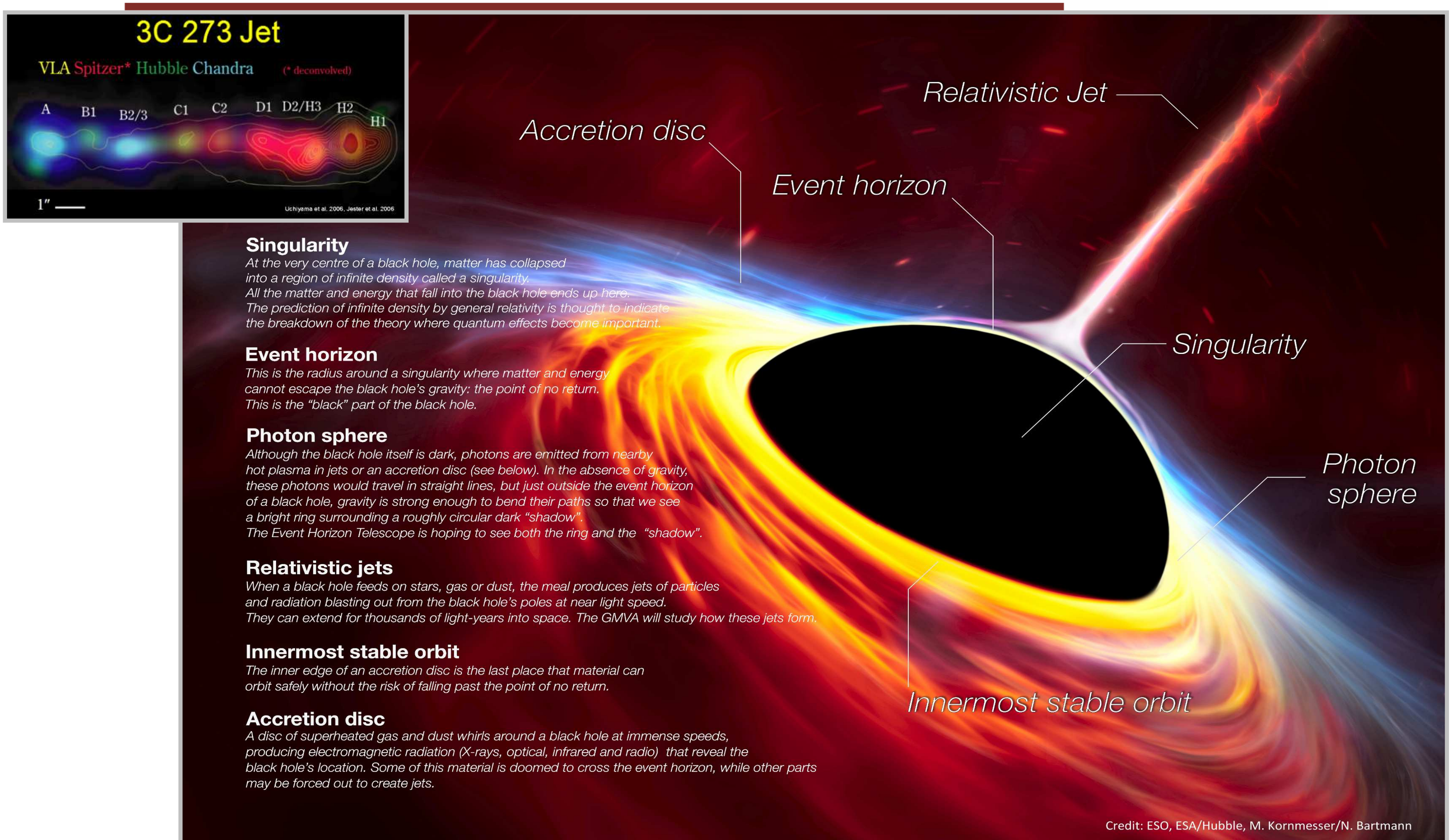
FERMI LARGE AREA TELESCOPE THIRD SOURCE CATALOG

The Astrophysical Journal, 810:14 (34pp), 2015 September 1 doi:10.1088/0004-637X/810/1/14

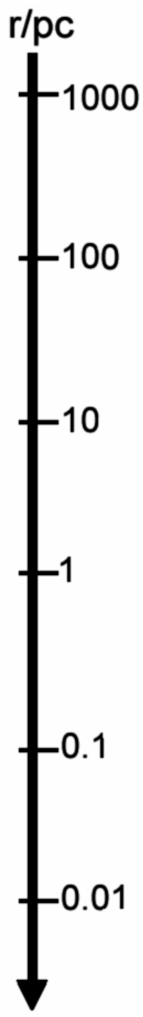
THE THIRD CATALOG OF ACTIVE GALACTIC NUCLEI DETECTED BY THE *FERMI* LARGE AREA TELESCOPE

stefano.ciprini@ssdc.asi.it - ASDC Rome

Active Galactic Nuclei (AGN) and Blazars



Supermassive BHs pairs/binaries evolution



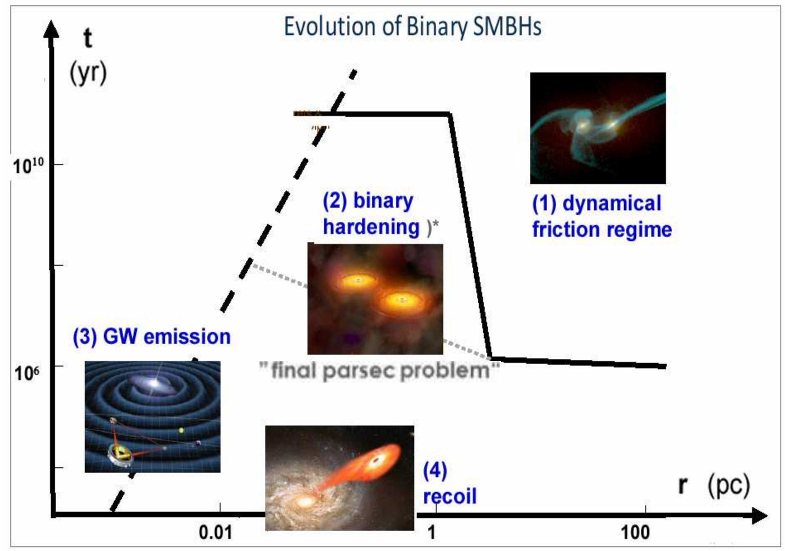
Observational evidence for SMBH pairs and gravitationally bound binary systems:

- ❑ 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‡

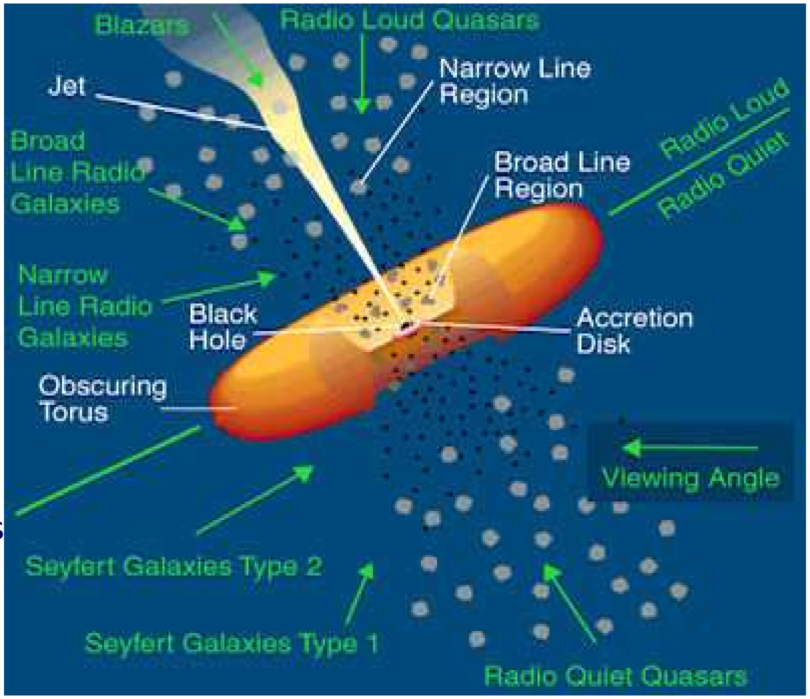


[Credits S. Komossa 2014] Komossa et al.

- 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.

Introduction: some AGN characteristics

- ❑ 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 ~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~10^{45} erg $^{s-1}$) and $z < 0.5$

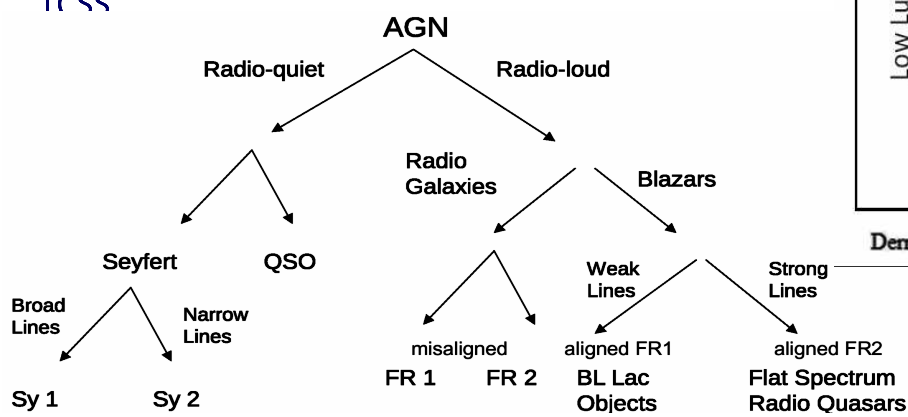
- ❑ Intense emission in MeV-GeV gamma-ray energies: it dominates the bolometric radiative power output. Powerful gamma-ray FSRQs are also optimal probes to explore the distant Universe at cosmological scales.

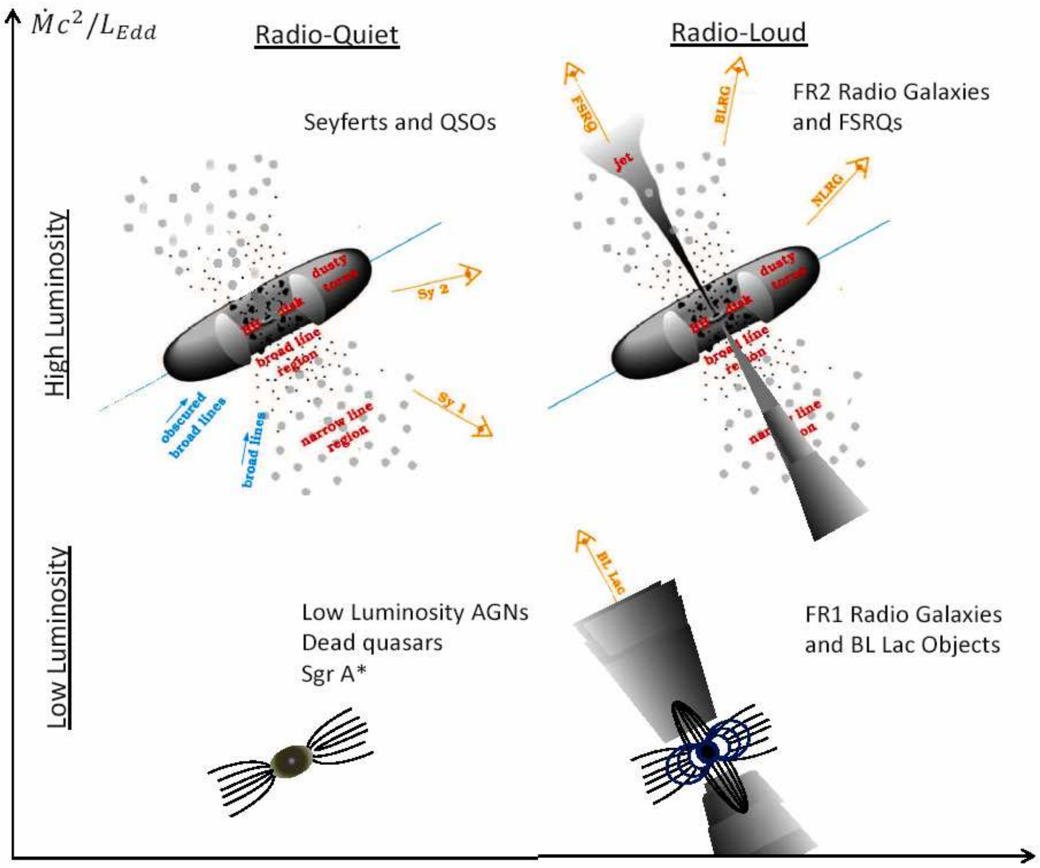
- ❑ A couple of recent reviews: 1) Padovani et al. 2017, *"Active galactic nuclei: what's in a name?",* Astron. and Astroph. Rev., 25, 2, (91pp) (arXiv:1707.07134) ; 2) Dermer & Giebels 2016, *"Active galactic nuclei at gamma-ray energies*", Comptes Rendus Physique, 17, 594 (arXiv:1602.06592v1).

Introduction: some AGN characteristics

- ❑ 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).

Introduction: some AGN characteristics

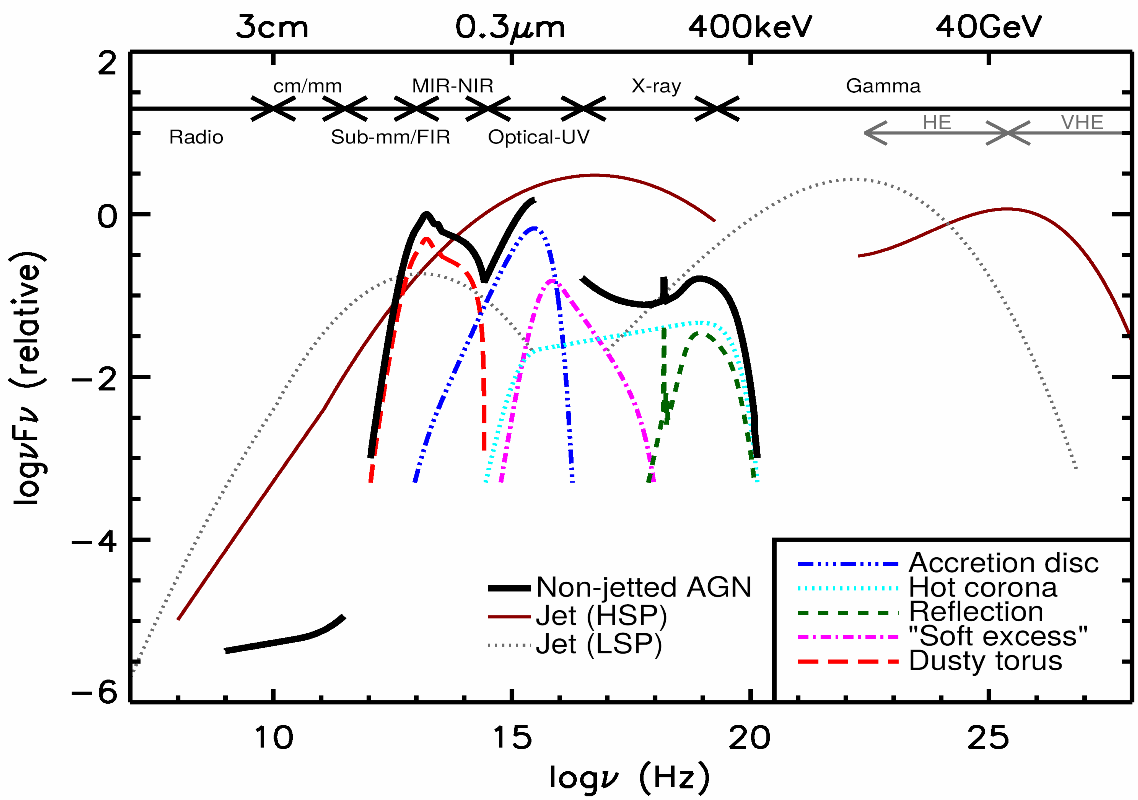


Fig. 1 A schematic representation of an AGN spectral energy distribution (SED), loosely based on the observed SEDs of non-jetted quasars (e.g. Elvis et al., 1994; Richards et al., 2006a). The black solid curve represents the total emission and the various coloured curves (shifted down for clarity) represent the individual components. The intrinsic shape of the SED in the mm-far infrared (FIR) regime is uncertain; however, it is widely believed to have a minimal contribution (to an overall galaxy SED) compared to star formation (SF), except in the most intrinsically luminous quasars and powerful jetted AGN. The primary emission from the AGN accretion disk peaks in the UV region. The jet SED is also shown for a high synchrotron peaked blazar (HSP, based on the SED of Mrk 421) and a low synchrotron peaked blazar (LSP, based on the SED of 3C 454.3; see Sect. 6.1). Adapted from Harrison (2014). Image credit: C. M. Harrison.