Gamma-ray Blazars at the Dawn of the Universe

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on behalf of the *Fermi*-LAT collaboration

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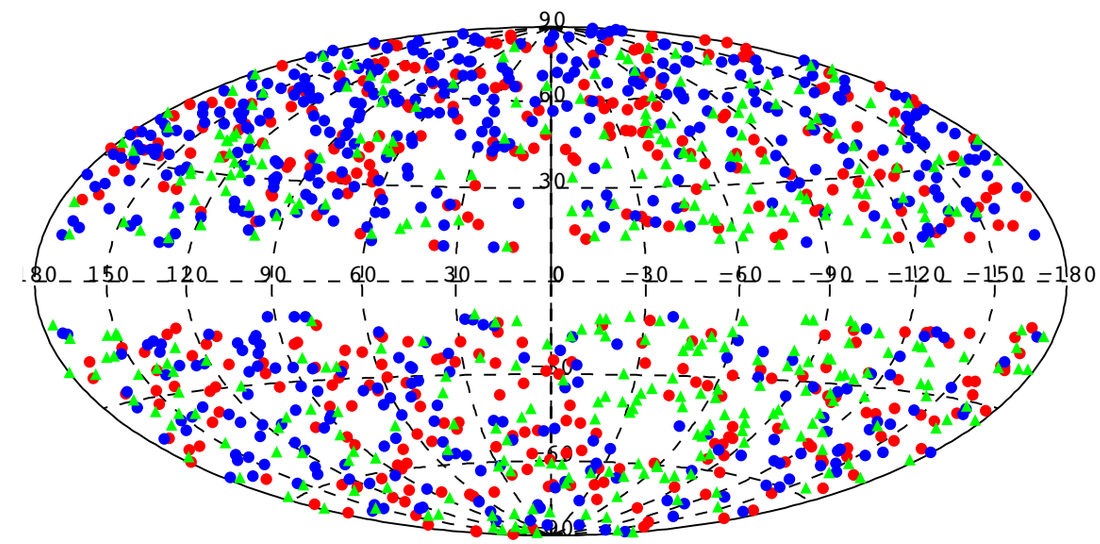
Blazars

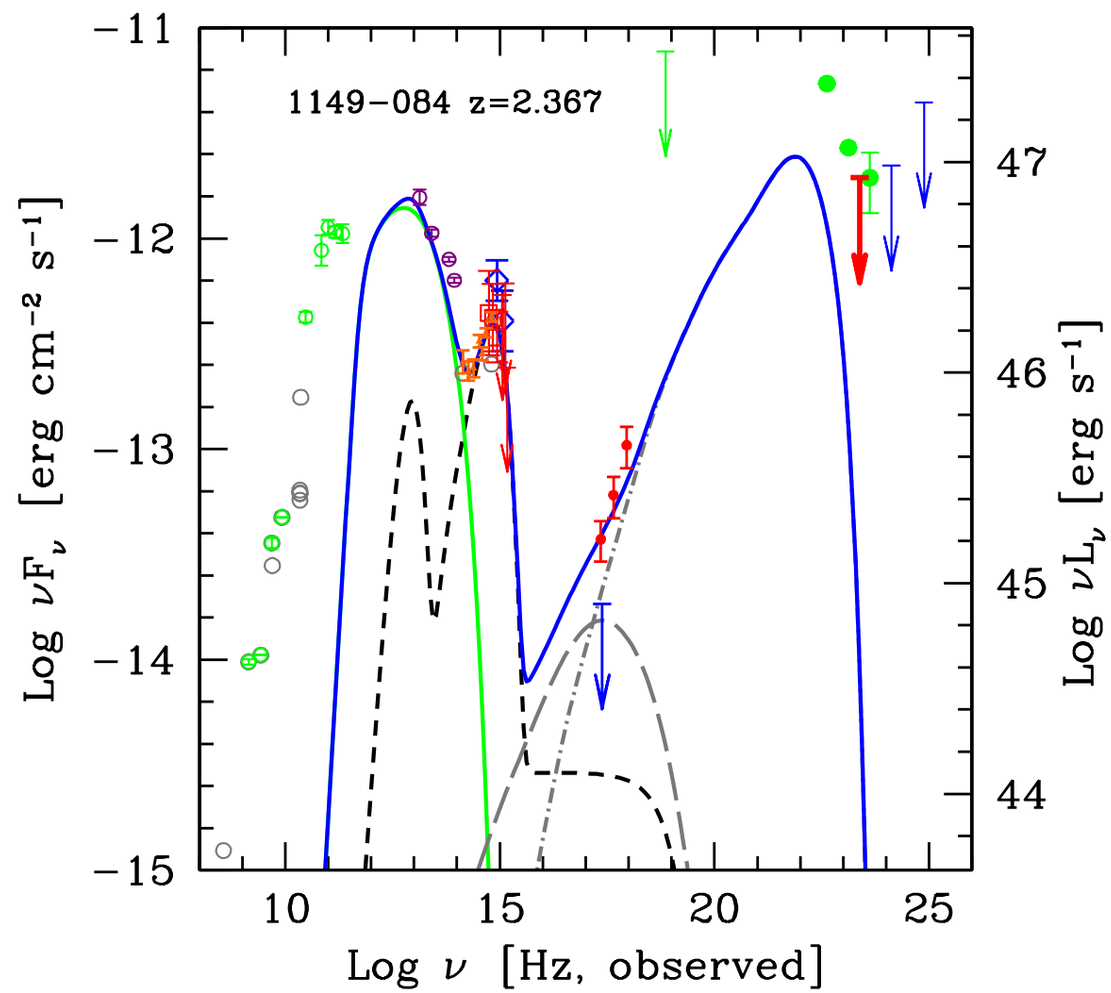
- AGN with the relativistic jet aligned close to the line of sight ($\theta_V < 1/\Gamma$)
- Emitted radiation is predominantly non-thermal, variable, polarized, and relativistically boosted
- Dominates high energy extra-galactic sky
- Due to relativistic beaming, they are observable even at high redshift ($z > 2$)
- Classified as FSRQ & BL Lacs



Ackermann+, 2015, ApJ, 810, 14

High Redshift Blazars

- Most powerful FSRQs
- Host ~$10^9 M_\odot$ black holes
- Synchrotron peak lies in IR whereas IC hump peaks at MeV energy range
- Shift in high energy peak causes them to be more luminous at hard X-rays than the γ-ray band
- In the latest LAT catalog (i.e., 3FGL), the farthest known γ-ray emitter has z=3.1

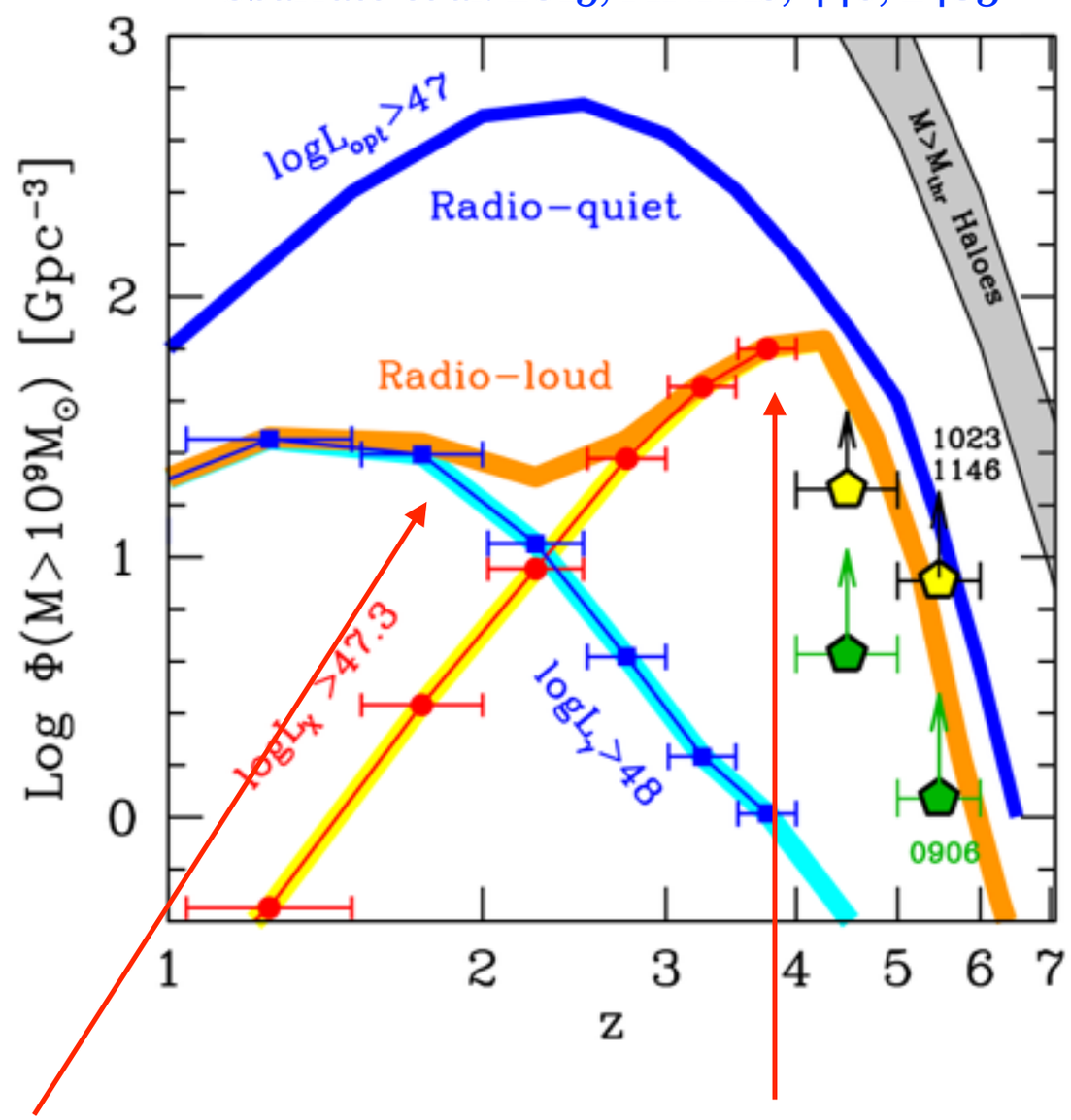


Ghisellini+, 2013, MNRAS, 428, 1449

Motivation

- Our primary target is to study the general physical properties of high redshift MeV blazars
- Their contribution to the cosmic MeV background, & finally BH mass evolution at high redshift (e.g., Volonteri+, 2011, MNRAS, 416, 216)

Sbarrato et al. 2015, MNRAS, 446, 2483



LAT FSRQs, Ajello+12

MeV blazars, Ajello+09

Sample selection

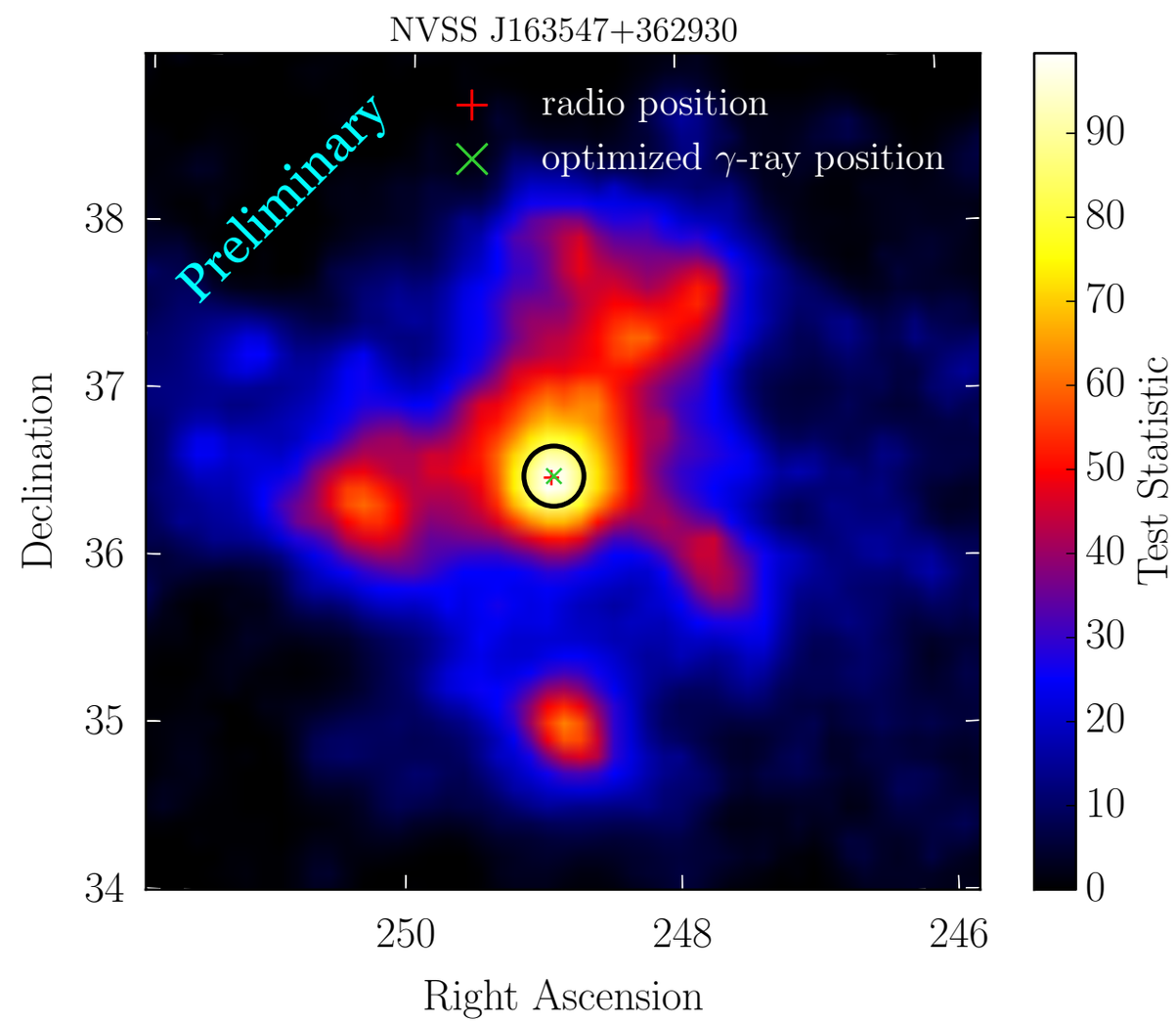
- We start with Million Quasar Catalog, ~1.4 million quasars, updated on March 2, 2016
- First filter of redshift is applied and only z>3.1 sources are retained
- Second filter of radio-loudness is used & only radio-loud objects (RL>10) are considered
- This left ~1000 sources and we analyze LAT data for all of them

Data analysis

- Standard LAT data analysis procedure was adopted with a couple of the modifications
- Pass 8 dataset with all the four PSFs considered independently
- Energy range: 60 MeV to 300 GeV
- Component wise data analysis for the four PSFs
- Joint fitting for all the four components using ‘summed likelihood’ tool included in pylikelihood library
- TS maps were generated to identify unmodeled objects

Results: MW Association

- A total of 5 γ-ray emitters with TS>25 are found
- Likelihood ratio association method (as in 3LAC) is also adopted & the results are confirmed
- These objects have IR colors similar to WISE FSRQs (lie on or close to the WISE blazar strip, e.g., D'Abrusco+, 2012, ApJ, 748, 68)



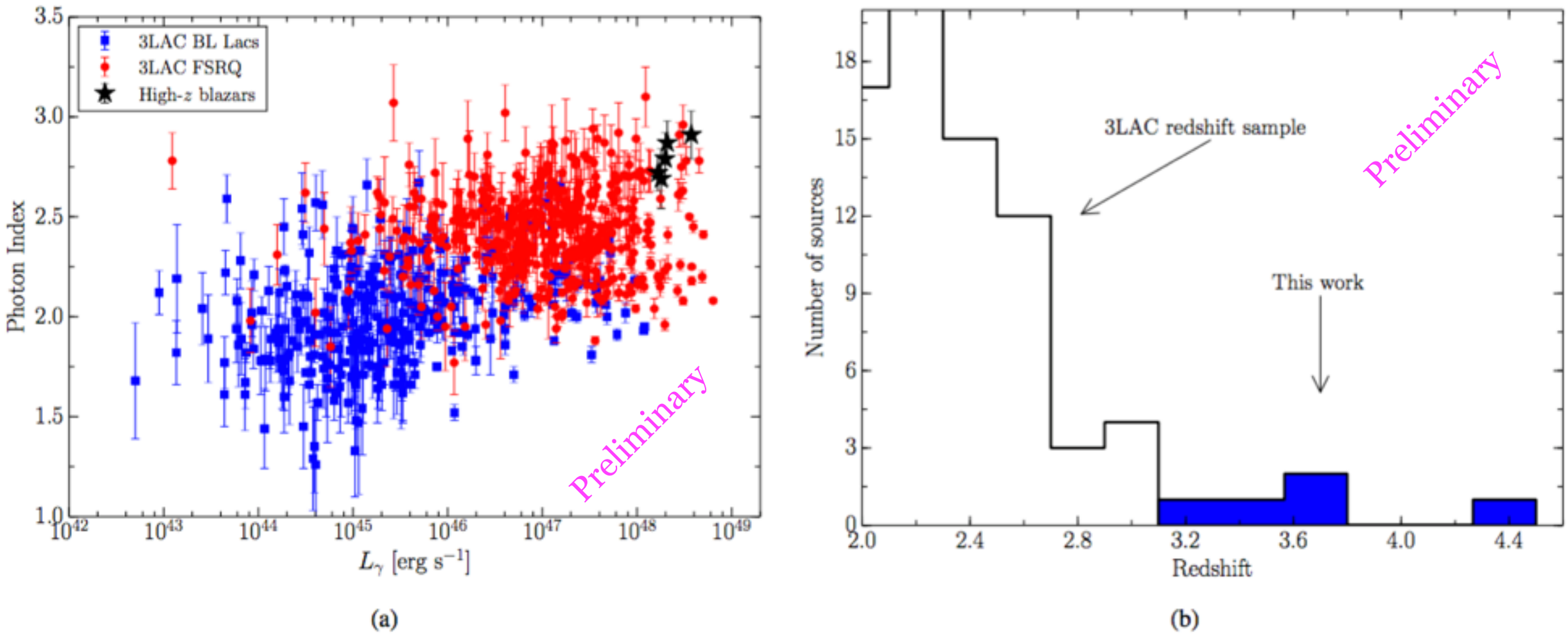
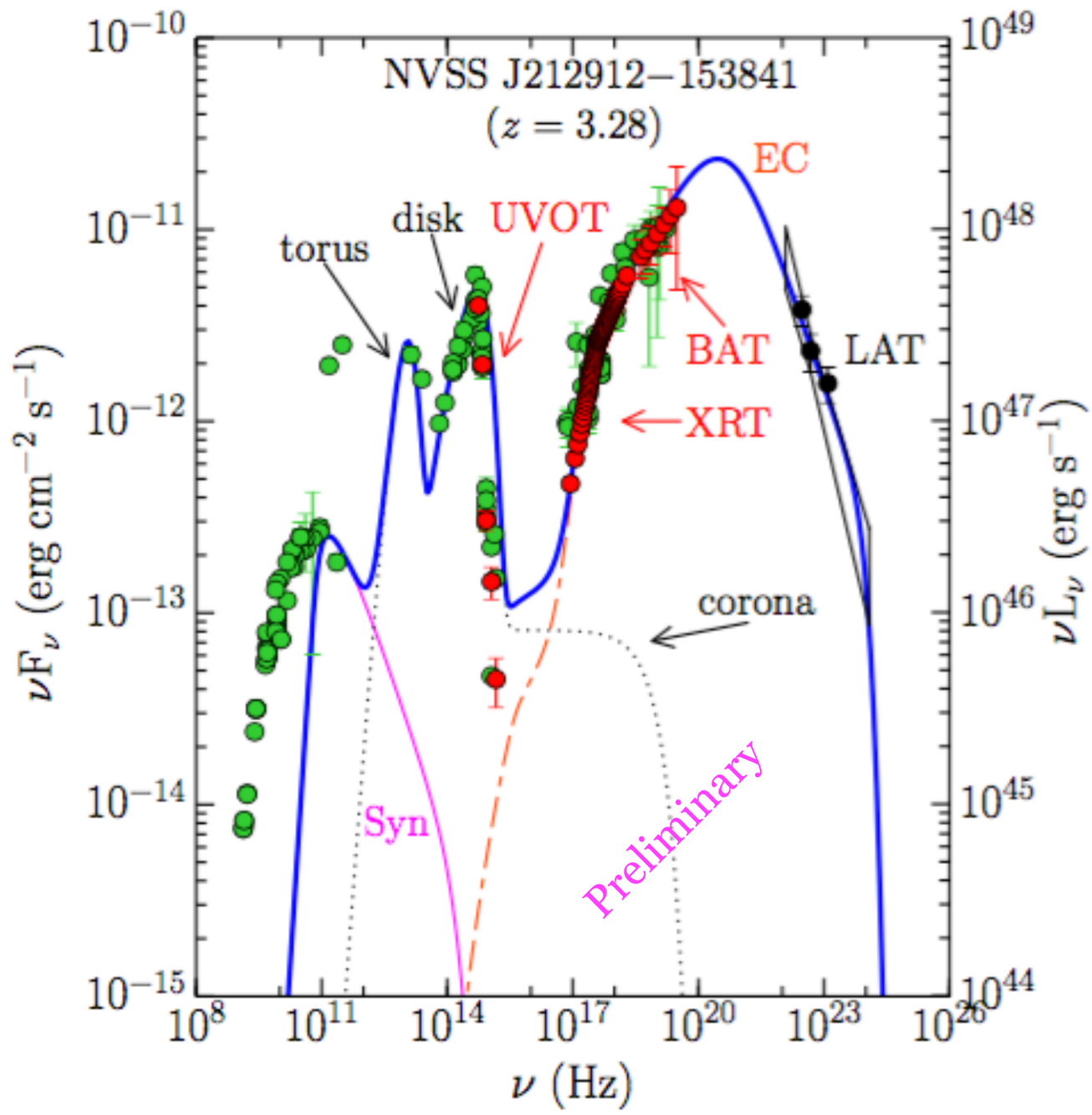


Figure 2. Comparison of new γ-ray detected high-z blazars with 3LAC objects in, left: γ-ray luminosity vs. photon index plane, and right: the redshift histogram.

Results: MW Properties

- SED modeling done for all objects that have multi-wavelength data available
- Modeling confirms these objects to have all the characteristics of powerful FSRQs, e.g., a hard X-ray spectrum, large Compton dominance, etc.



Results: BH Mass

- We found two objects to host more than a billion solar mass black holes, following the optical spectroscopic approach
- The space density of the currently known billion solar mass black holes ~50 Gpc^{-3} (Sbarrato+, 2015, MNRAS, 446, 2483)
- Our work has increased it to ~70 Gpc^{-3}.
- This indicates that the radio-loud phase may be a key ingredient for quick black hole growth in the early Universe

Summary

- A systematic search of the high redshift γ-ray emitting blazars has led to the detection of 5 new sources
- Available MW observations indicates their similarity with the known powerful high redshift FSRQs
- To increase the sample size further, the best approaches are
  - lowering the energy threshold of the LAT
  - use *NuSTAR*
- However, the optimal instrument would be a sensitive all sky MeV telescope, e.g., ComPair

!!Thank you!!