The extragalactic γ–ray sky

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Italian Space Agency - ASDC

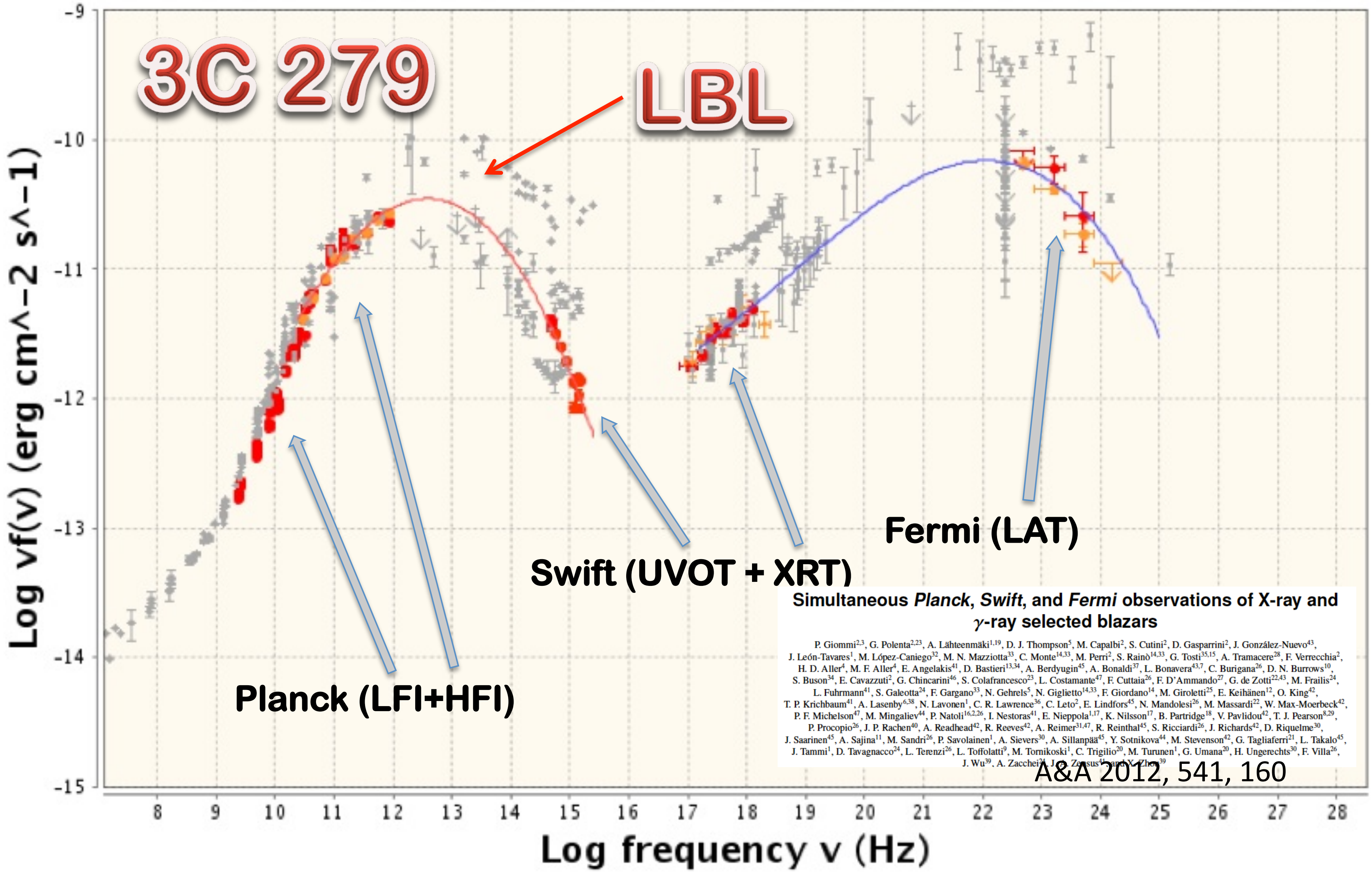
Three approaches:

- Gamma-ray observational data
  from space and ground observatories:
  e.g. Fermi, AGILE, Cherenkov Telescopes

- Monte Carlo simulations of blazar surveys

- New multi-frequency selected large samples of
  ϒ-ray/VHE emitting blazars

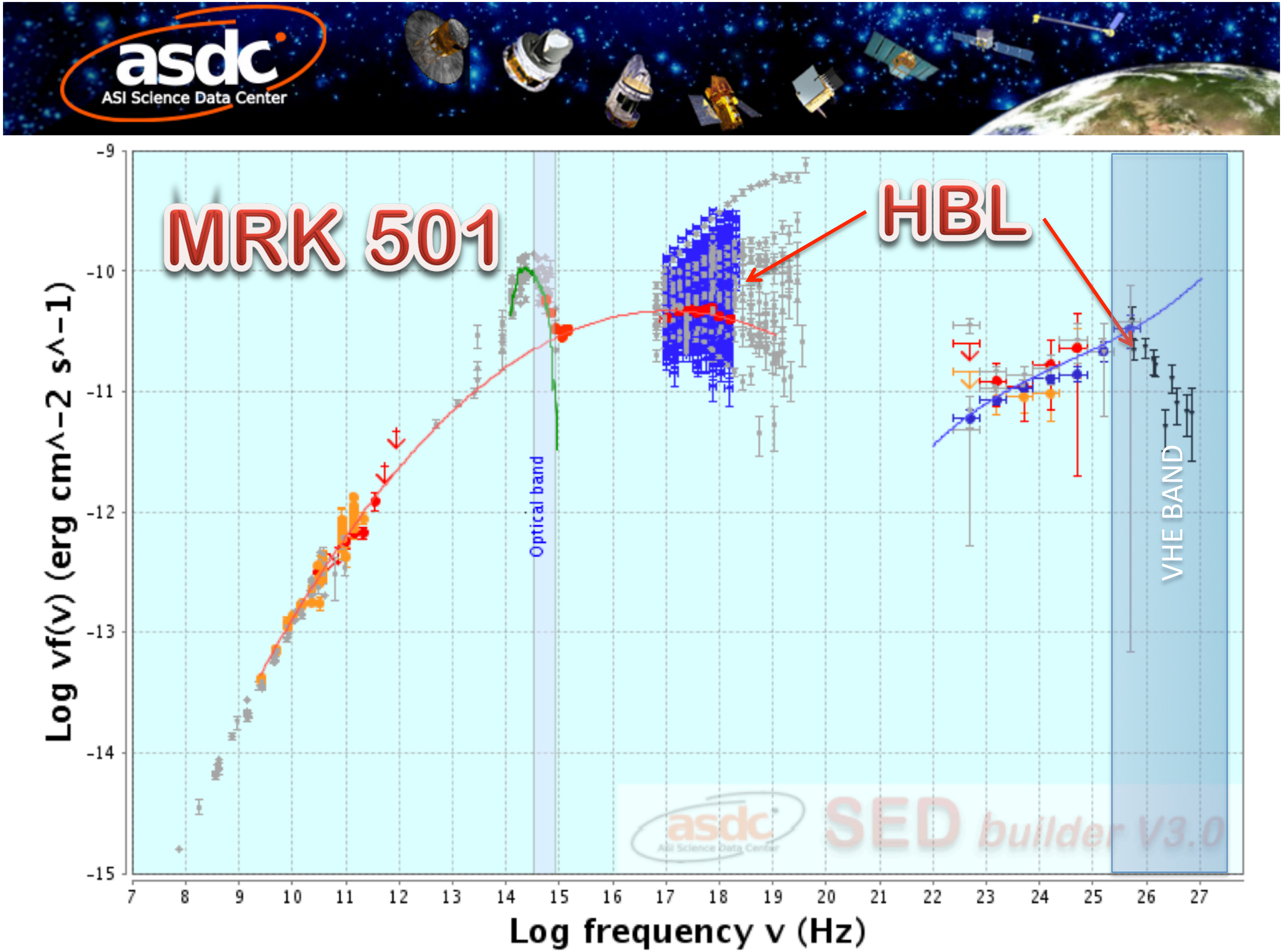
…but first:
a few slides about blazars



Simultaneous *Planck*, *Swift*, and *Fermi* observations of X-ray and γ-ray selected blazars

P. Giommi[2,3], G. Polenta[2,23], A. Lähteenmäki[1,19], D. J. Thompson[5], M. Capalbi[2], S. Cutini[2], D. Gasparrini[2], J. González-Nuevo[43], J. León-Tavares[1], M. López-Caniego[32], M. N. Mazziotta[33], C. Monte[14,33], M. Perri[2], S. Rainò[14,33], G. Tosti[35,15], A. Tramacere[28], F. Verrecchia[2], H. D. Aller[4], M. F. Aller[4], E. Angelakis[41], D. Bastieri[13,34], A. Berdyugin[45], A. Bonaldi[37], L. Bonavera[43,7], C. Burigana[26], D. N. Burrows[10], S. Buson[34], E. Cavazzuti[2], G. Chincarini[46], S. Colafrancesco[23], L. Costamante[47], F. Cuttaia[26], F. D'Ammando[27], G. de Zotti[22,43], M. Frailis[24], L. Fuhrmann[41], S. Galeotta[24], F. Gargano[33], N. Gehrels[5], N. Giglietto[14,33], F. Giordano[14], M. Giroletti[25], E. Keihänen[12], O. King[42], T. P. Krichbaum[41], A. Lasenby[6,38], N. Lavonen[1], C. R. Lawrence[36], C. Leto[2], E. Lindfors[45], N. Mandolesi[26], M. Massardi[22], W. Max-Moerbeck[42], P. F. Michelson[47], M. Mingaliev[44], P. Natoli[16,2,26], I. Nestoras[41], E. Nieppola[1,17], K. Nilsson[17], B. Partridge[18], V. Pavlidou[42], T. J. Pearson[8,29], P. Procopio[26], J. P. Rachen[40], A. Readhead[42], R. Reeves[42], A. Reimer[31,47], R. Reinthal[45], S. Ricciardi[26], J. Richards[42], D. Riquelme[30], J. Saarinen[45], A. Sajina[11], M. Sandri[26], P. Savolainen[1], A. Sievers[30], A. Sillanpää[45], Y. Sotnikova[44], M. Stevenson[42], G. Tagliaferri[21], L. Takalo[45], J. Tammi[1], D. Tavagnacco[24], L. Terenzi[26], L. Toffolatti[9], M. Tornikoski[1], C. Trigilio[20], M. Turunen[1], G. Umana[20], H. Ungerechts[30], F. Villa[26], J. Wu[39], A. Zacchei[24], J. A. Zensus[41], and X. Zhou[39]

A&A 2012, 541, 160


asdc
ASI Science Data Center
MRK 501
HBL
Optical band
VHE BAND
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
-9
-10
-11
-12
-13
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-15
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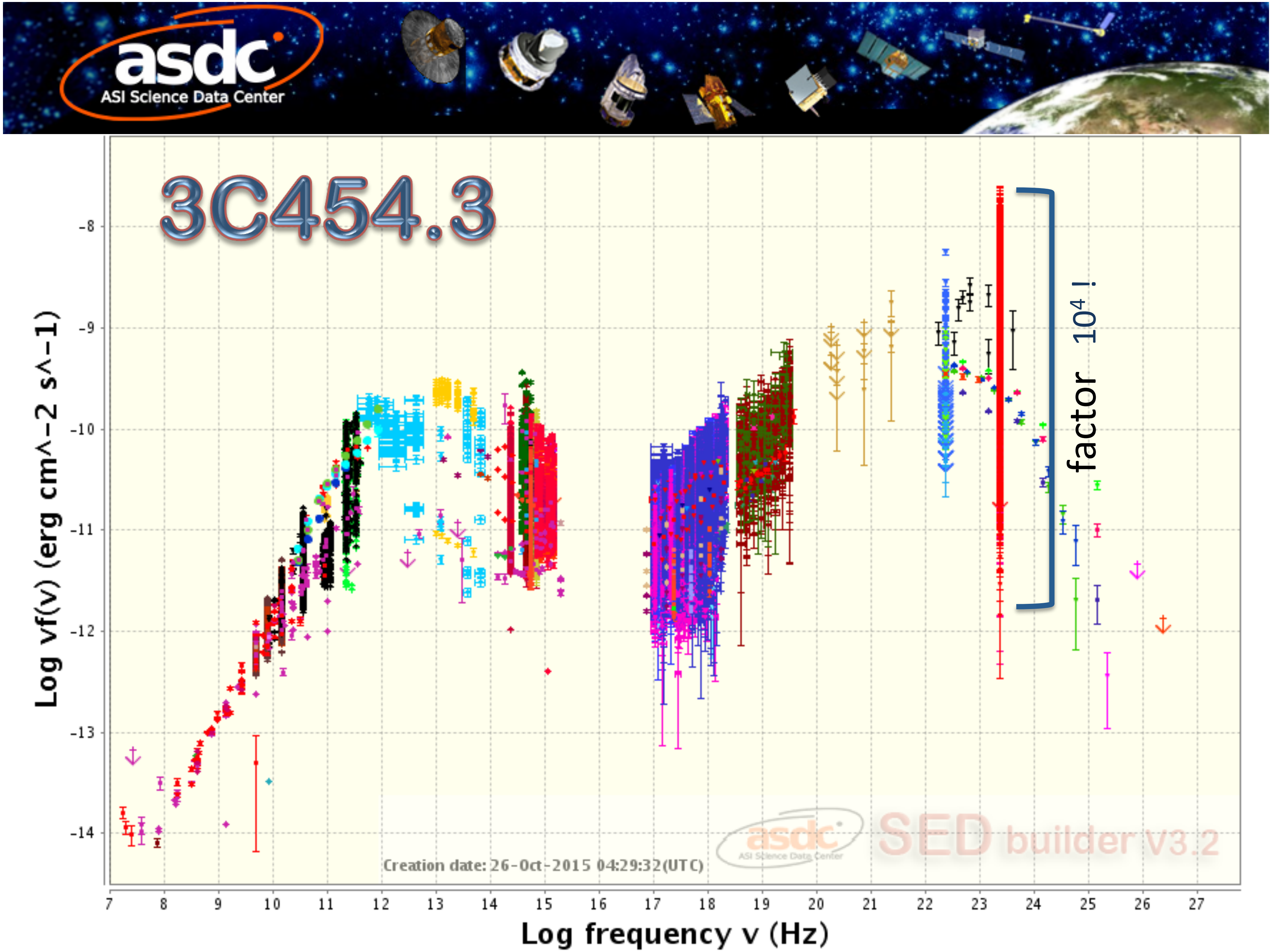
SED builder V3.0



ASI Science Data Center
3C454.3
factor 10^4 !
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
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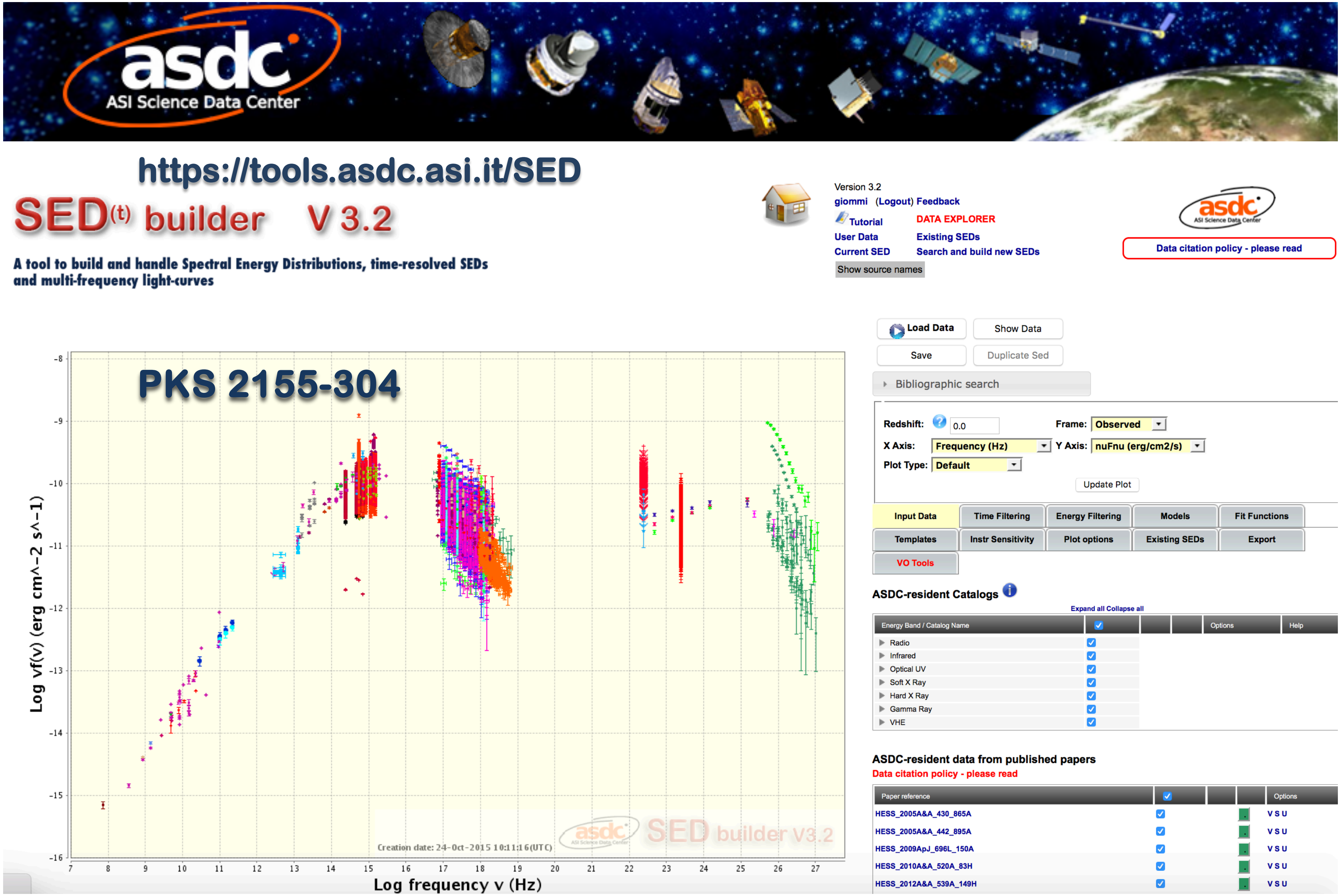
SED builder V3.2


asdc
ASI Science Data Center
https://tools.asdc.asi.it/SED
SED(t) builder V 3.2
A tool to build and handle Spectral Energy Distributions, time-resolved SEDs and multi-frequency light-curves
Version 3.2
giommi (Logout) Feedback
Tutorial
DATA EXPLORER
User Data
Existing SEDs
Current SED
Search and build new SEDs
Show source names
Data citation policy - please read
PKS 2155-304
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
Creation date: 24-Oct-2015 10:11:16(UTC)
SED builder V3.2
Load Data
Show Data
Save
Duplicate Sed
Bibliographic search
Redshift: 0.0
Frame: Observed
X Axis: Frequency (Hz)
Y Axis: nuFnu (erg/cm2/s)
Plot Type: Default
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Input Data
Time Filtering
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Models
Fit Functions
Templates
Instr Sensitivity
Plot options
Existing SEDs
Export
VO Tools
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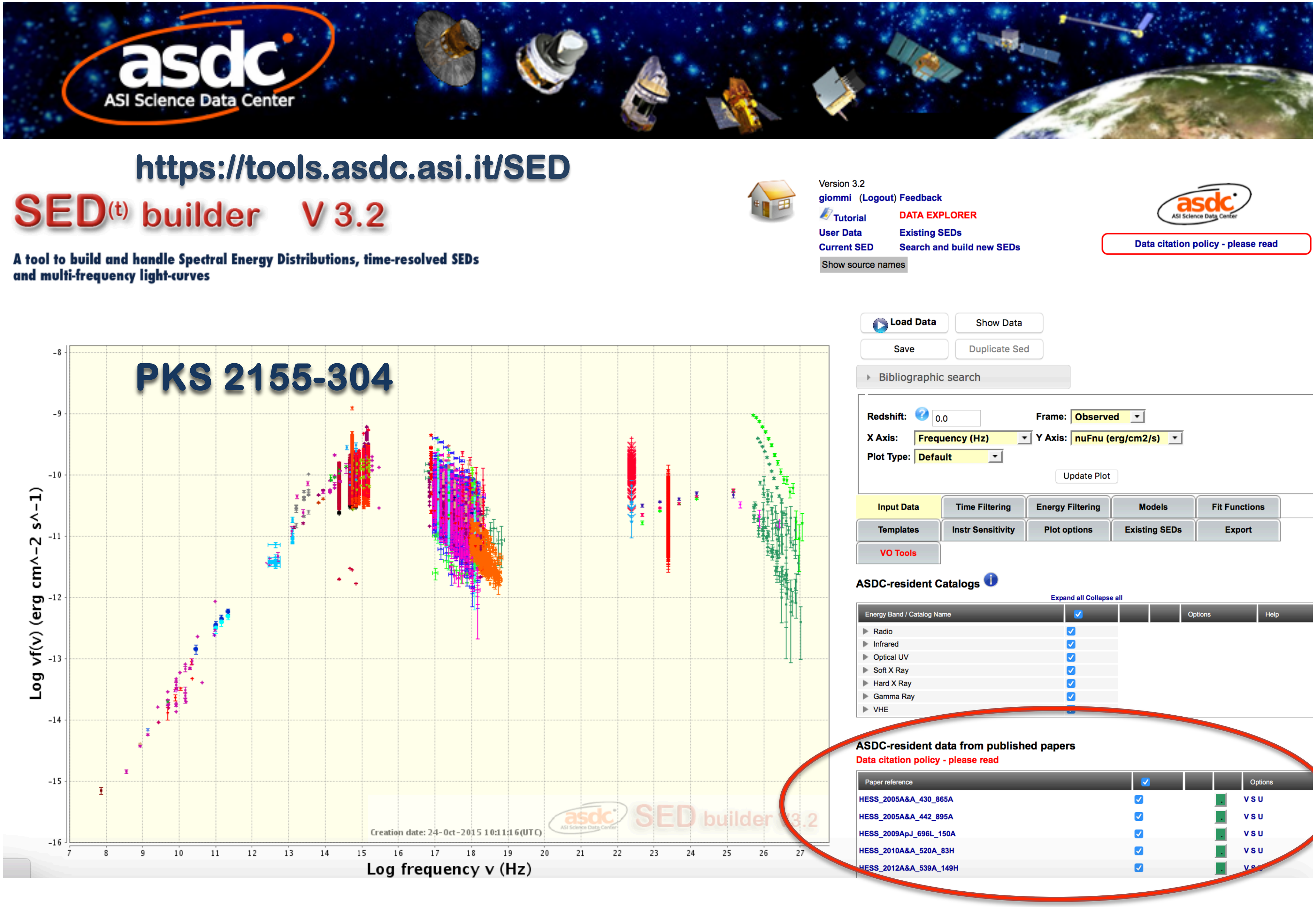
Expand all Collapse all
Energy Band / Catalog Name
Options
Help
Radio
Infrared
Optical UV
Soft X Ray
Hard X Ray
Gamma Ray
VHE
ASDC-resident data from published papers
Data citation policy - please read
Paper reference
Options
HESS_2005A&A_430_865A
HESS_2005A&A_442_895A
HESS_2009ApJ_696L_150A
HESS_2010A&A_520A_83H
HESS_2012A&A_539A_149H
V S U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Update Plot
Input Data
Time Filtering
Energy Filtering
Models
Fit Functions
Templates
Instr Sensitivity
Plot options
Existing SEDs
Export
VO Tools
ASDC-resident Catalogs
Expand all Collapse all
Energy Band / Catalog Name
Options
Help
Radio
Infrared
Optical UV
Soft X Ray
Hard X Ray
Gamma Ray
VHE
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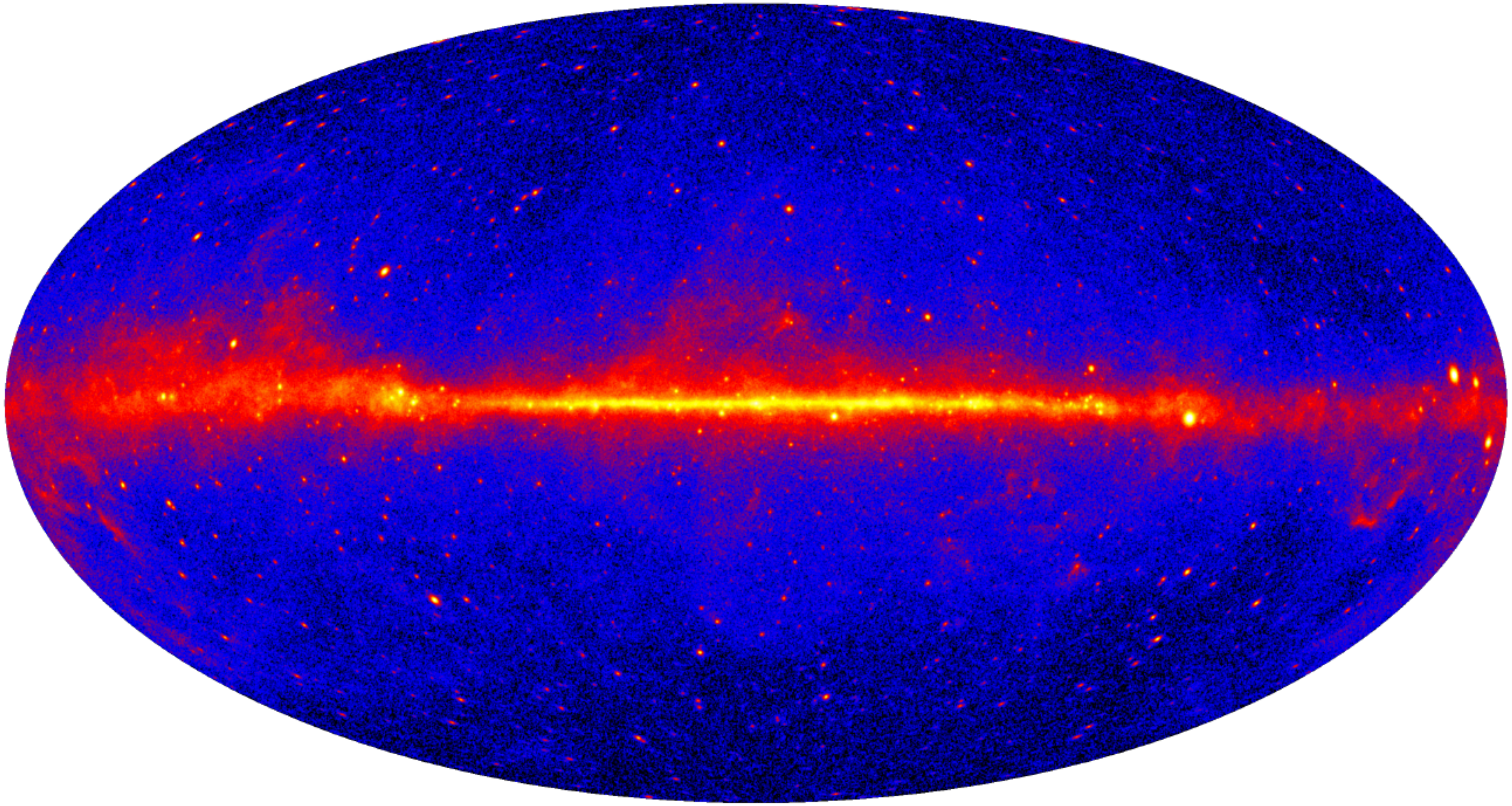
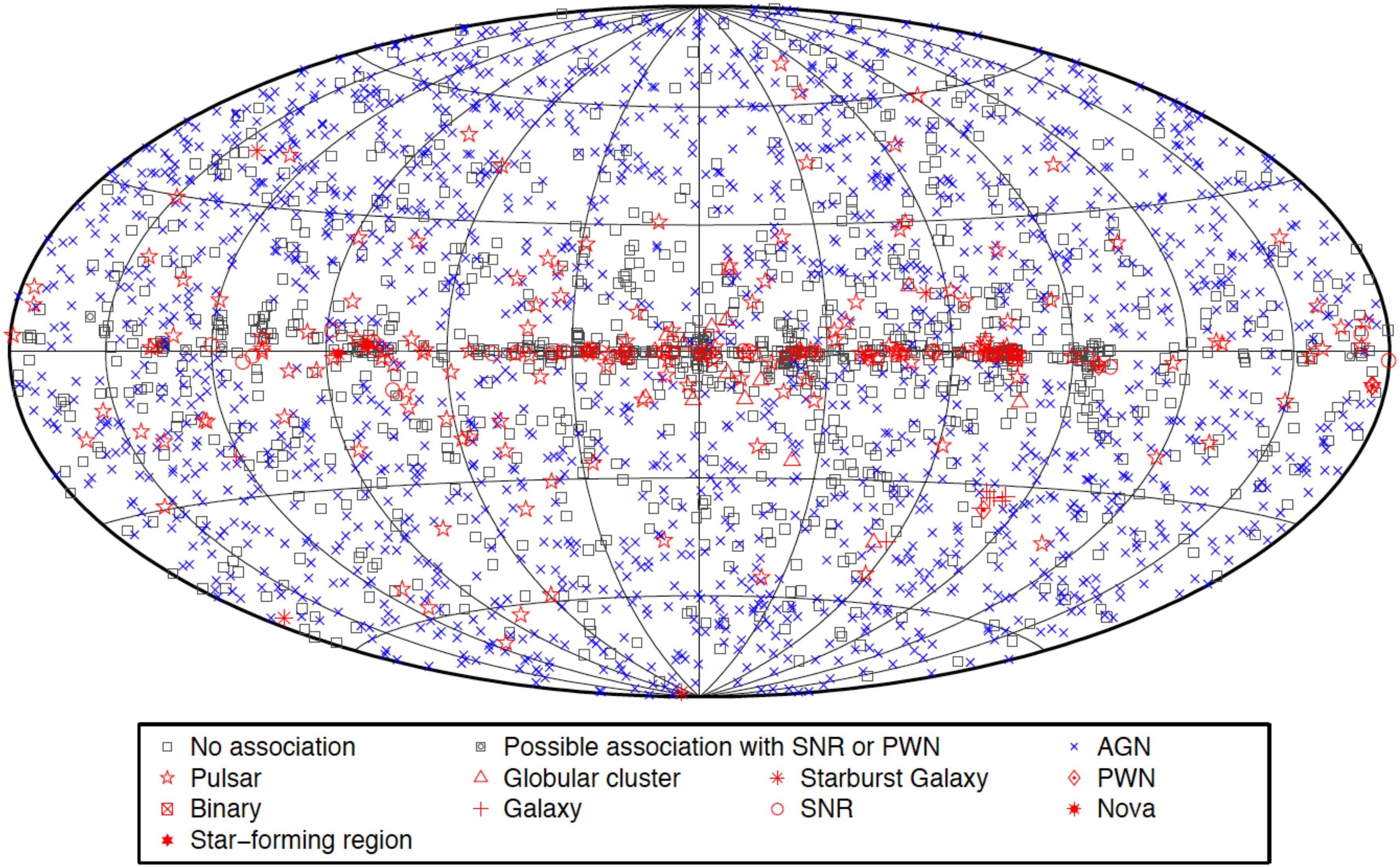
HESS_2010A&A_520A_83H
HESS_2012A&A_539A_149H
V S U

The 100 MeV-100 GeV sky seen by Fermi



Fermi 3FGL catalog: Ackermann et al. 2015, ApJ 810, 14, arXiv:1501.06054

4 years of PASS 7 data: 3033 sources

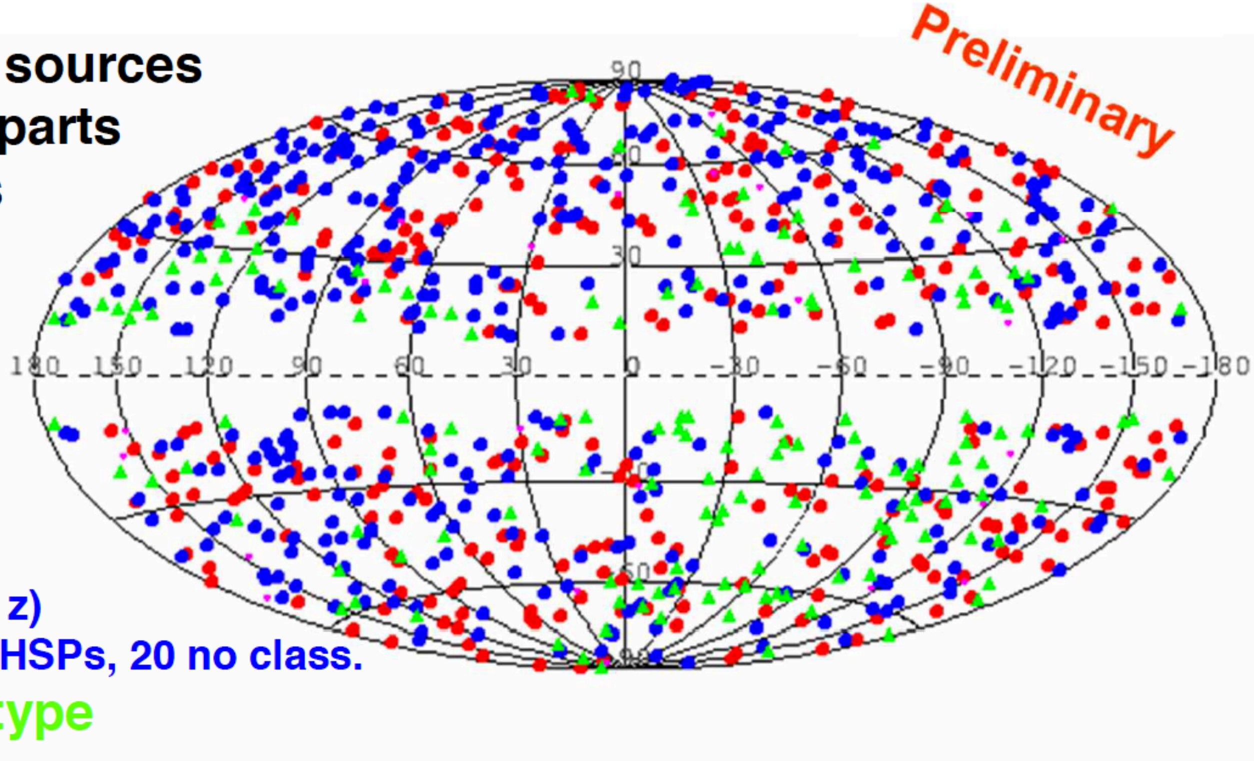


The Third LAT AGN catalog (3LAC)

- **48 month data set**

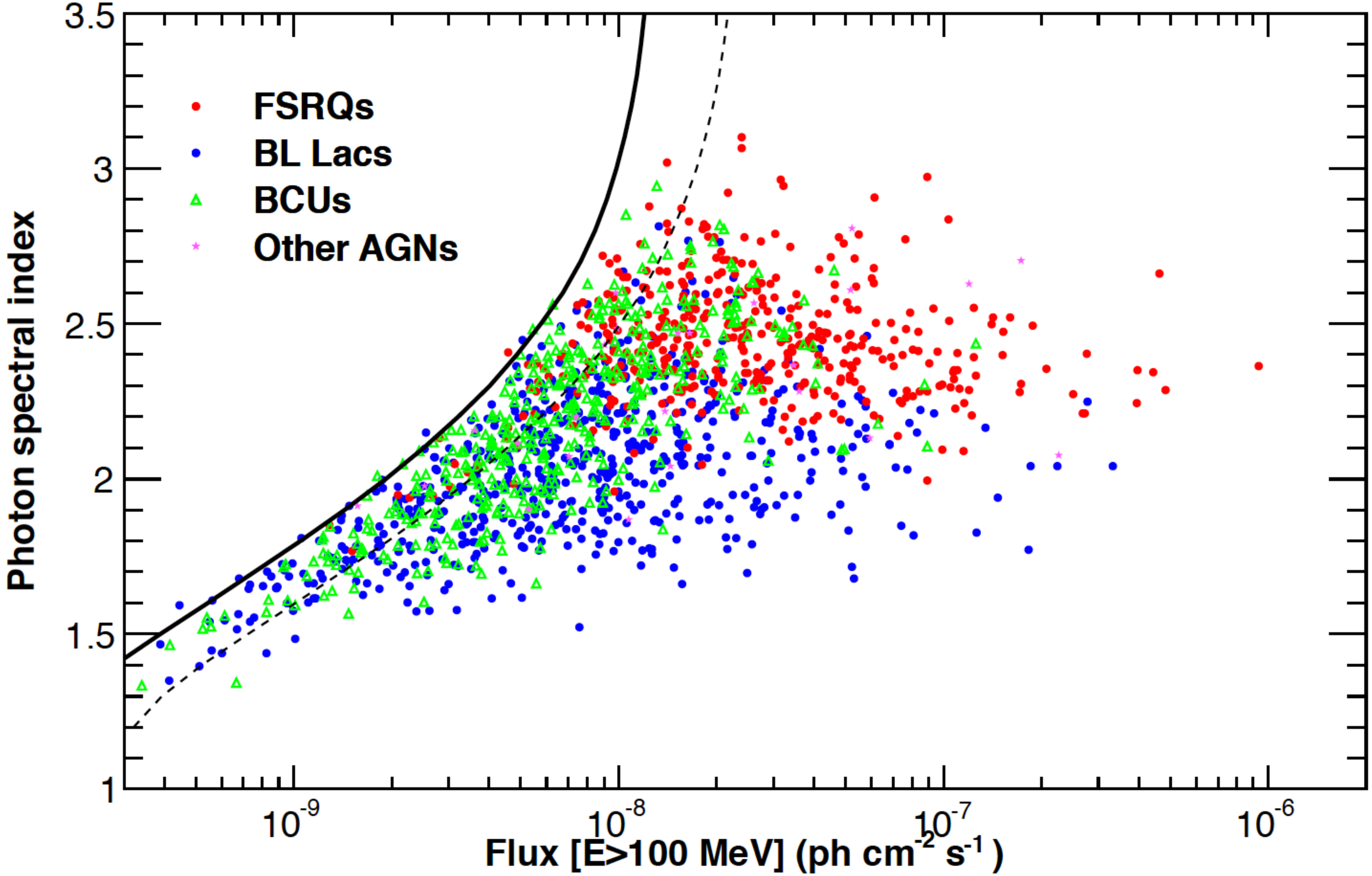
Ackermann M. et al., arXiv:1501.06054

- **2192 TS>25, |b|>10° sources**
- **3LAC: 1591 counterparts**
  1563 sources
- **1444 AGNs in *Clean Sample* (no dup., no flags)**



- **Census :**
  - **415 FSRQs**
  - **602 BLLacs**
    (~50% with measured z)
    162 LSP, 178 ISP, 272 HSPs, 20 no class.
  - **413 of unknown type**
  - **23 other AGNs**

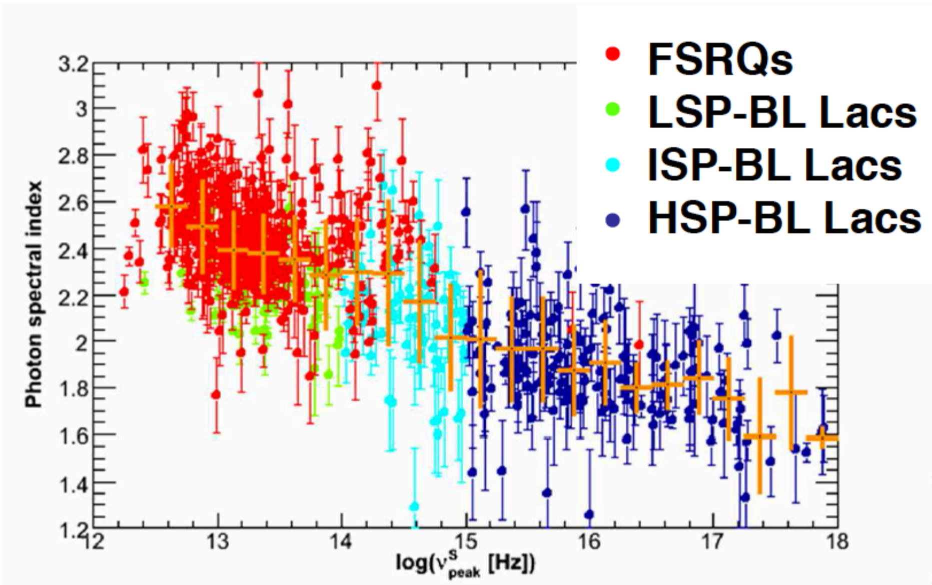
Differences between Northern and Southern Hemispheres:
40% of BL Lacs in Southern Hemisphere



FSRQs
BL Lacs
BCUs
Other AGNs
Photon spectral index
Flux [E>100 MeV] (ph cm^{-2} s^{-1})
3.5
3
2.5
2
1.5
1
10^{-9}
10^{-8}
10^{-7}
10^{-6}

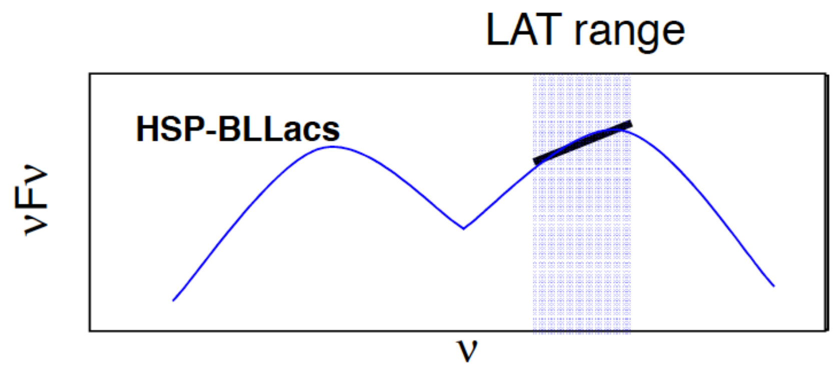
Spectral photon index vs ν_{peak}

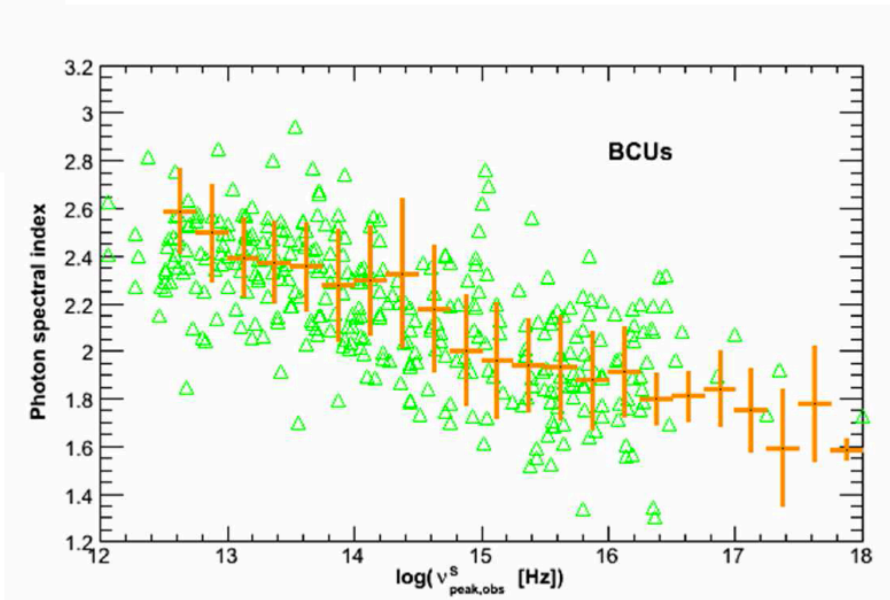
Preliminary



- Correlation between spectral hardness and ν_{peak} confirmed

- Same implies to BCUs





Fermi 2FHL

The Fermi-LAT view of the Very High Energy Sky

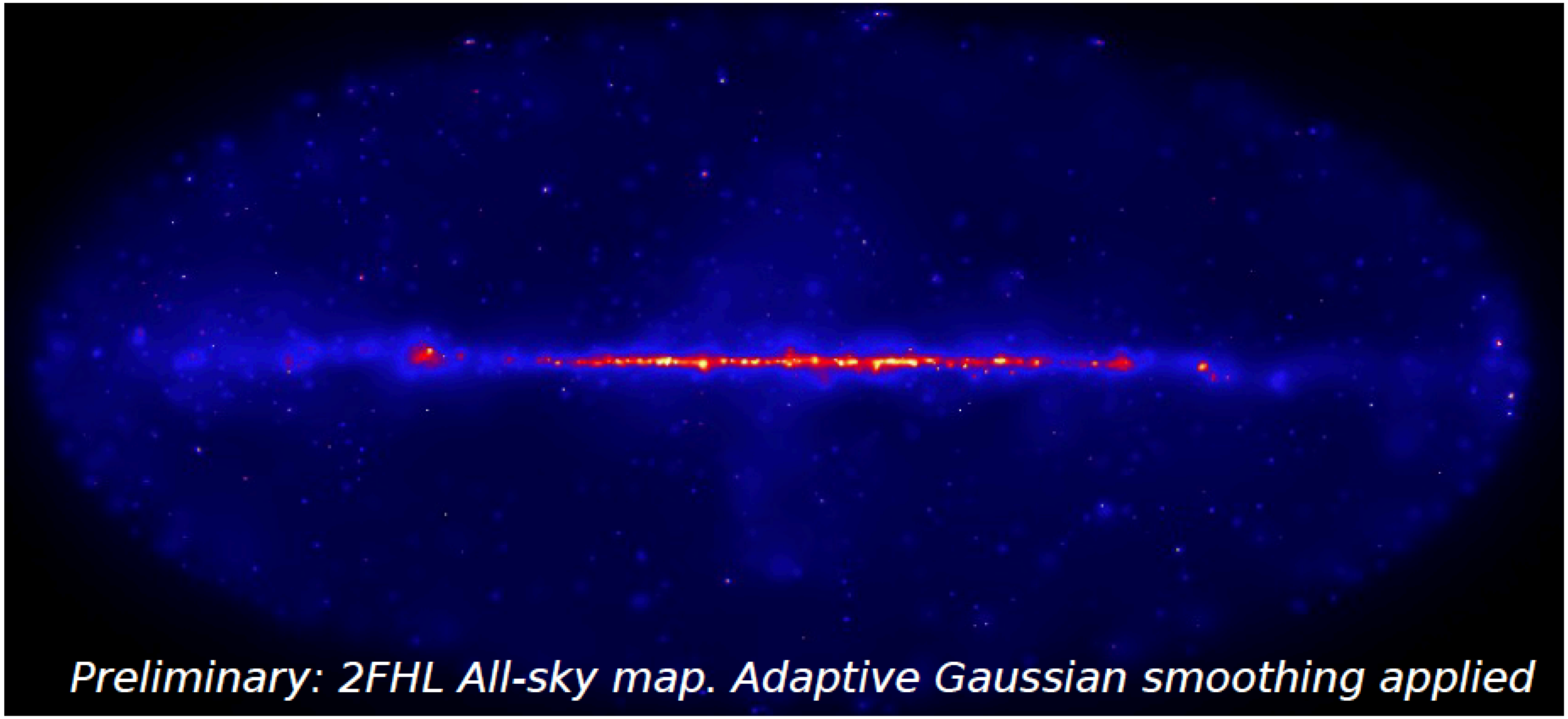
Ackermann et al. 2015, submitted. arXiv:1508.04449

Count Map

Approximately 6 years of P8 data (50 GeV – 2 TeV)

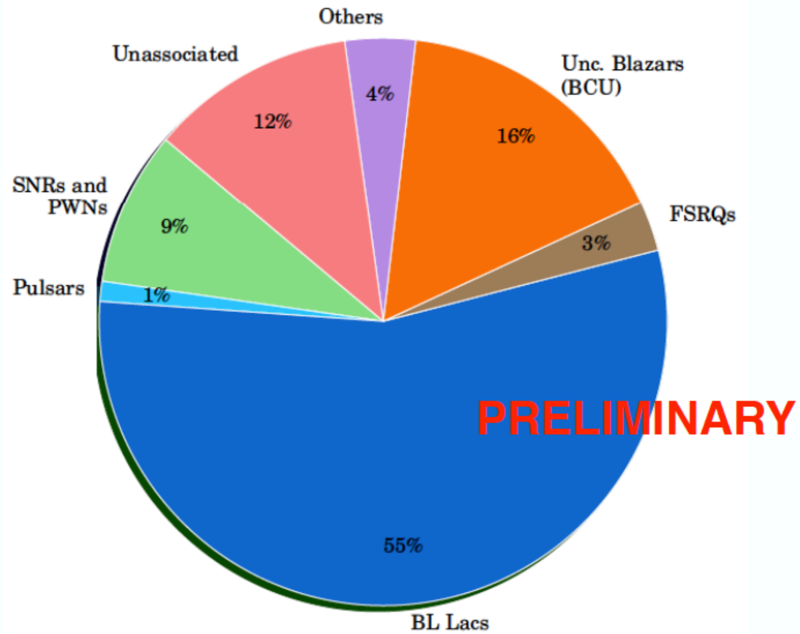
51,000 photons E > 50 GeV
18,000 photons E > 100 GeV
2,000 photons E > 500 GeV

about 1 photon every deg^2



2FHL CATALOG

- Energy Range: 50-2000 GeV using IRFs: P8R2_SOURCE_V6
- ~80 months of data
- ~360 sources
- only 25% already detected by ACTs (TeVCat)
- 206 detected in 1FHL
- 234 detected in 3FGL (4 years, up to 300 GeV)
- ~100 sources not in 1FHL and ~250 not in TeVCat



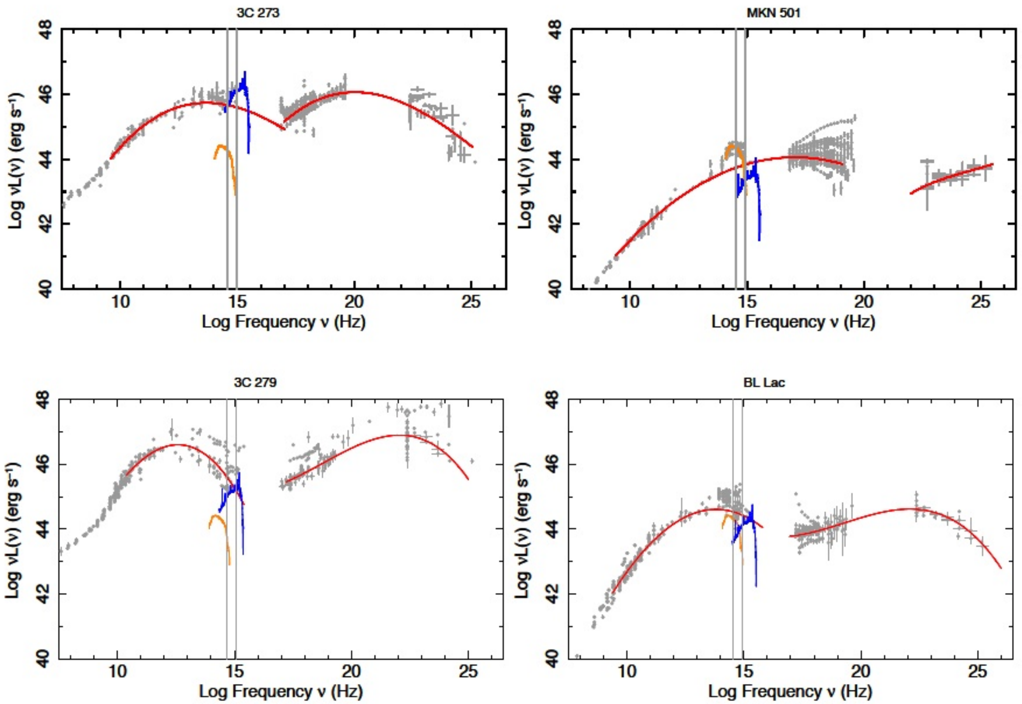
Monte Carlo Simulations of blazars surveys

A simplified view of blazars: clearing the fog around long-standing selection effects

MNRAS, 2012, 420, 2899

P. Giommi[1⋆], P. Padovani[2], G. Polenta[1,3], S. Turriziani[1], V. D'Elia[1,3], S. Piranomonte[3]
[1]*ASI Science Data Center, c/o ESRIN, via G. Galilei, 00044 Frascati, Italy*
[2]*European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[3]*INAF-Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*

Monte Carlo survey simulations



Occam's razor approach

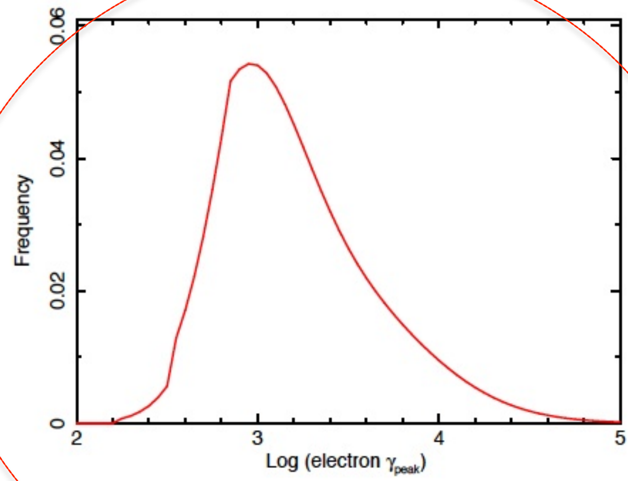


Figure 4. The distribution of the Lorentz factors of the electrons radiating at the peak of the synchrotron SED used for the simulation, which also assumes a magnetic field of B=0.15 Gauss and a gaussian distribution of Doppler factors with $\langle\delta\rangle$=15.

A simplified view of blazars: clearing the fog around long-standing selection effects

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Monte Carlo survey simulations

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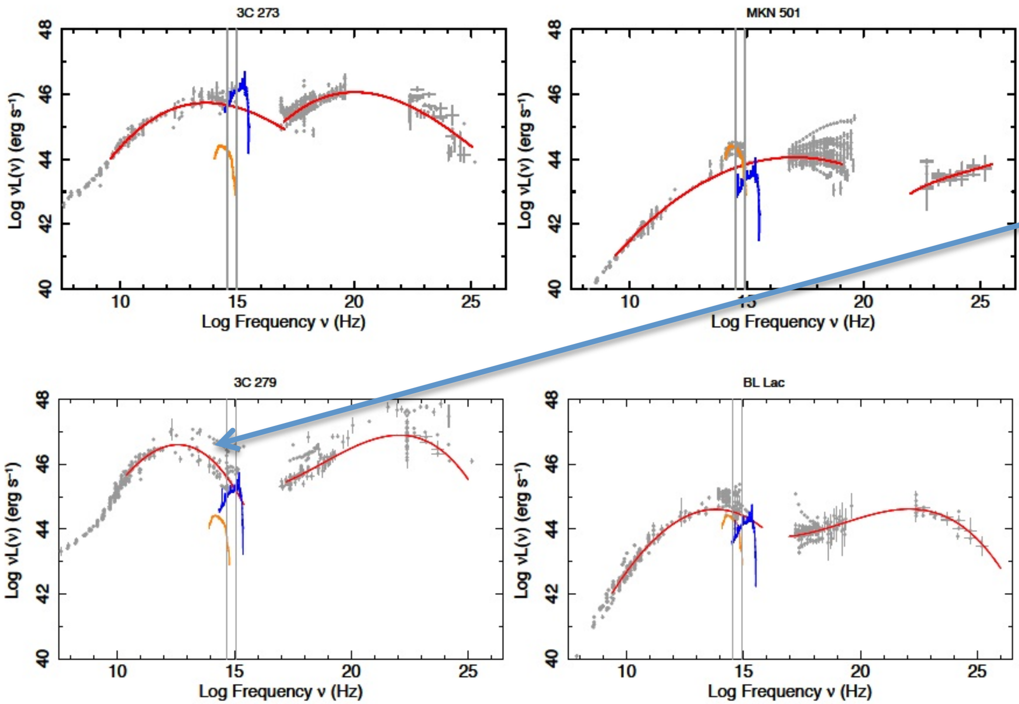

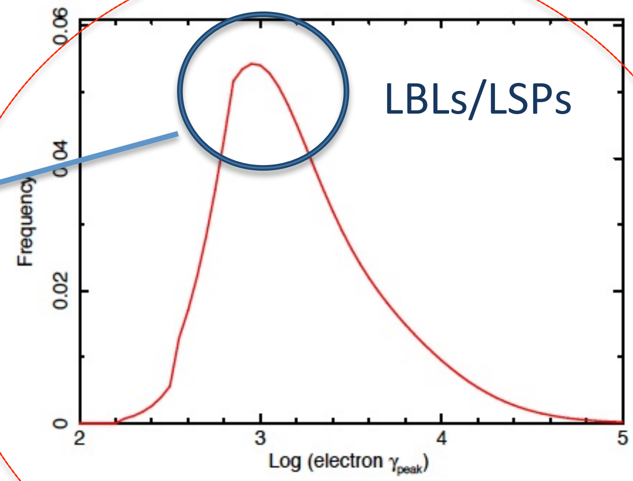

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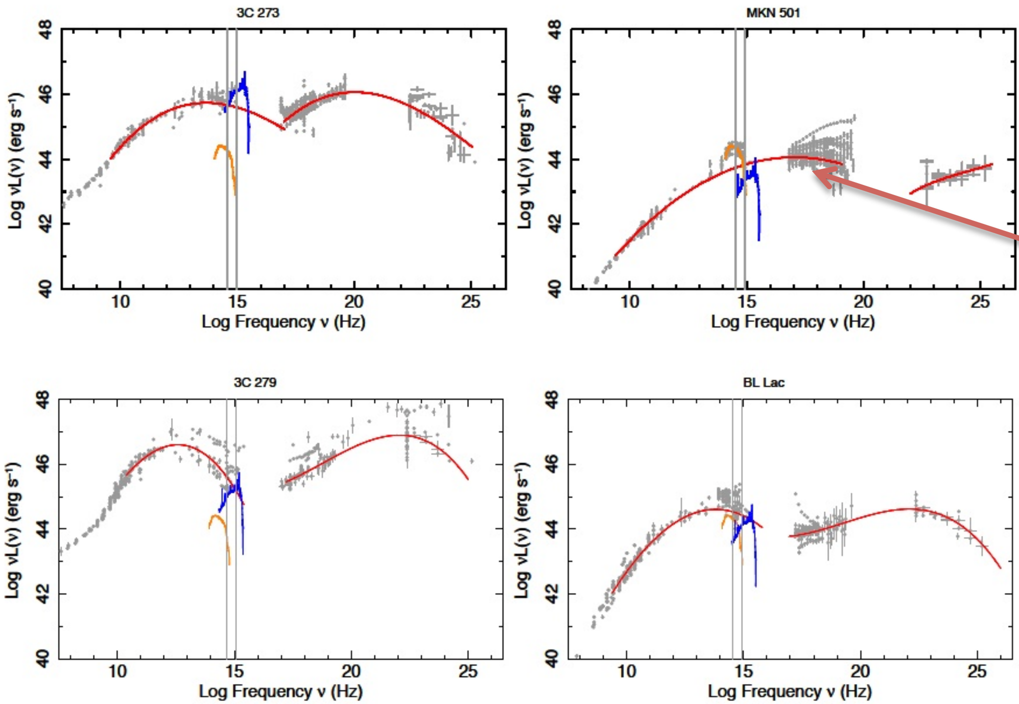

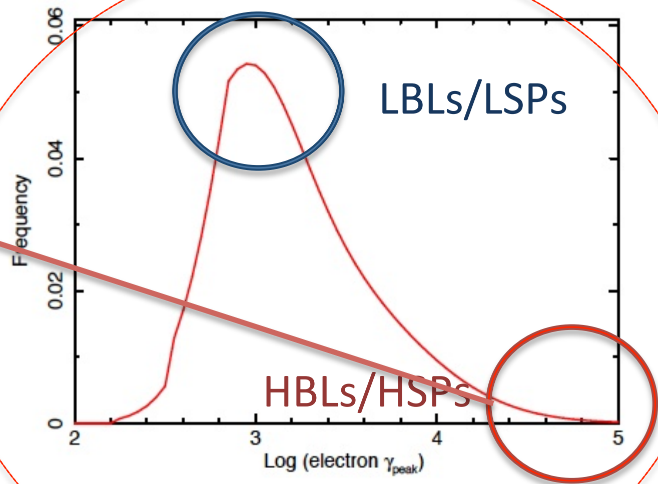

Figure 4. The distribution of the Lorentz factors of the electrons radiating at the peak of the synchrotron SED used for the simulation, which also assumes a magnetic field of B=0.15 Gauss and a gaussian distribution of Doppler factors with $\langle\delta\rangle$=15.

Some results

- Properties of high flux density radio- and X-ray-selected blazar samples are reproduced:
  - ✓ BL Lac & FSRQ fractions
  - ✓ evolutionary properties ($\langle V/V_m \rangle$)
  - ✓ redshift distributions
  - ✓ ν_{peak} distributions
  - ✓ fraction of BL Lacs without redshift determination
- Results are *stable* to minor changes (e.g., evolution and LF, $\langle \delta \rangle$)

Paper II

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **431,** 1914–1922 (2013) doi:10.1093/mnras/stt305
Advance Access publication 2013 March 14

A simplified view of blazars: the γ-ray case

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γ-ray (*Fermi*) band

ABSTRACT

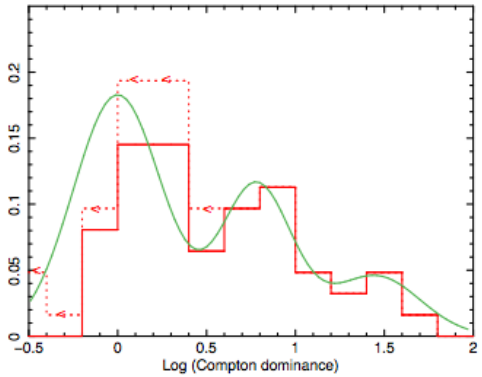
We have recently proposed a new simplified scenario where blazars are classified as flat spectrum radio quasars (FSRQs) or BL Lacs according to the prescriptions of unified schemes, and to a varying combination of Doppler-boosted radiation from the jet, emission from the accretion disc, the broad line region and light from the host galaxy. Here we extend our approach, previously applied to radio and X-ray surveys, to the γ-ray band and, through detailed Monte Carlo simulations, compare our predictions to *Fermi*-Large Area Telescope (LAT) survey data. Our simulations are in remarkable agreement with the overall observational results, including the percentages of BL Lacs and FSRQs, the fraction of redshift-less objects and the redshift, synchrotron peak and γ-ray spectral index distributions. The strength and large scatter of the oft-debated observed γ-ray–radio flux density correlation are also reproduced. In addition, we predict that almost 3/4 of *Fermi*-LAT BL Lacs, and basically all of those without redshift determination, are actually FSRQs with their emission lines swamped by the non-thermal continuum and as such should be considered. Finally, several of the currently unassociated high Galactic latitude *Fermi* sources are expected to be radio-faint blazars displaying a pure elliptical galaxy optical spectrum.

Key words: radiation mechanisms: non-thermal – BL Lacertae objects: general – quasars: emission lines – gamma-rays: galaxies – radio continuum: galaxies.

Predictions for ϒ-ray emission

Giommi et al. 2013
MNRAS, 431, 1914

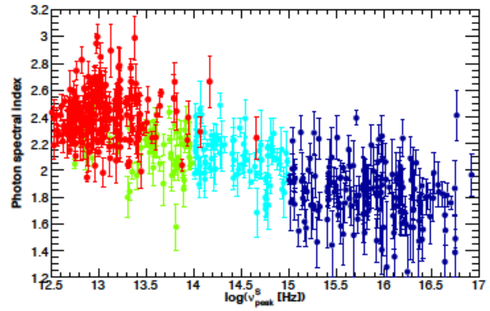
Radio luminosity + ν_{peak} +



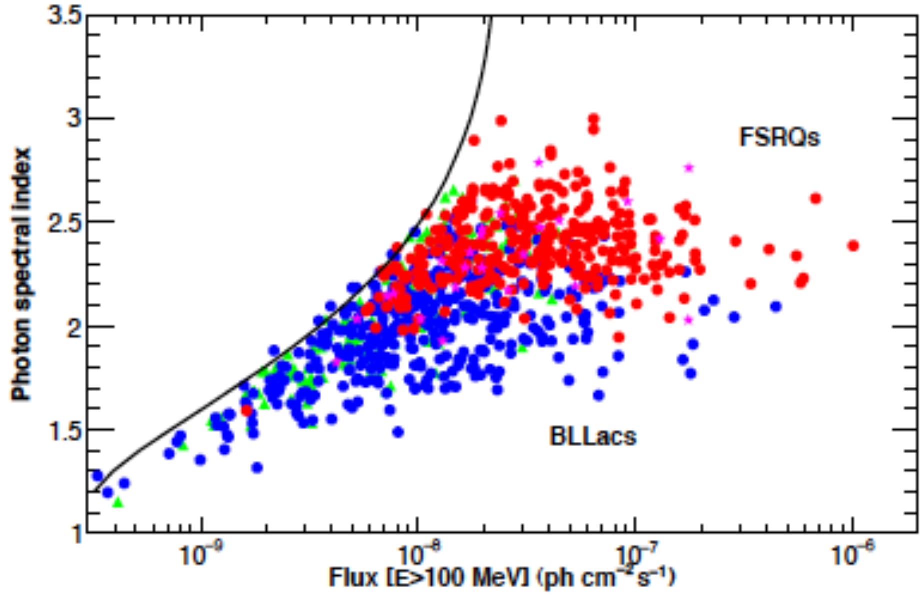
ϒ-ray luminosity

$\Gamma_{(0.1\text{-}100\ GeV)}$ from observed correlation between

ν_{peak} and $\Gamma_{(0.1\text{-}100\ GeV)}$

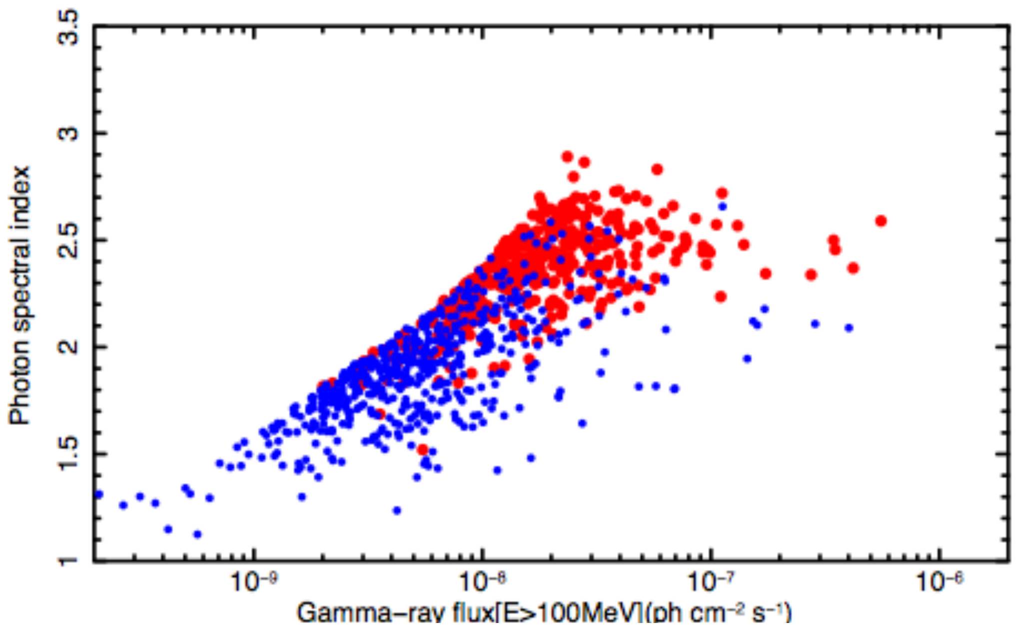


No dependence of L_{radio}/L_{γ} on *luminosity or redshift*



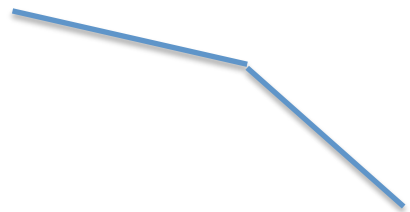
Ackermann et al. 2012
(Fermi 2LAC clean sample)

Simplified view
Simulation



From GeV to VHE emission

Power law spectrum with a break at E= 200 GeV



$$\Gamma_{(100\ \mathrm{GeV}-10\mathrm{TeV})} = \begin{cases} \Gamma_{(0.1-100\ \mathrm{GeV})} & \text{if } E < 200\ \mathrm{GeV} \\ \Gamma_{(0.1-100\ \mathrm{GeV})} + 0.5 & \text{if } E > 200\ \mathrm{GeV} \end{cases}$$

A simplified view of blazars: the very high energy γ-ray vision

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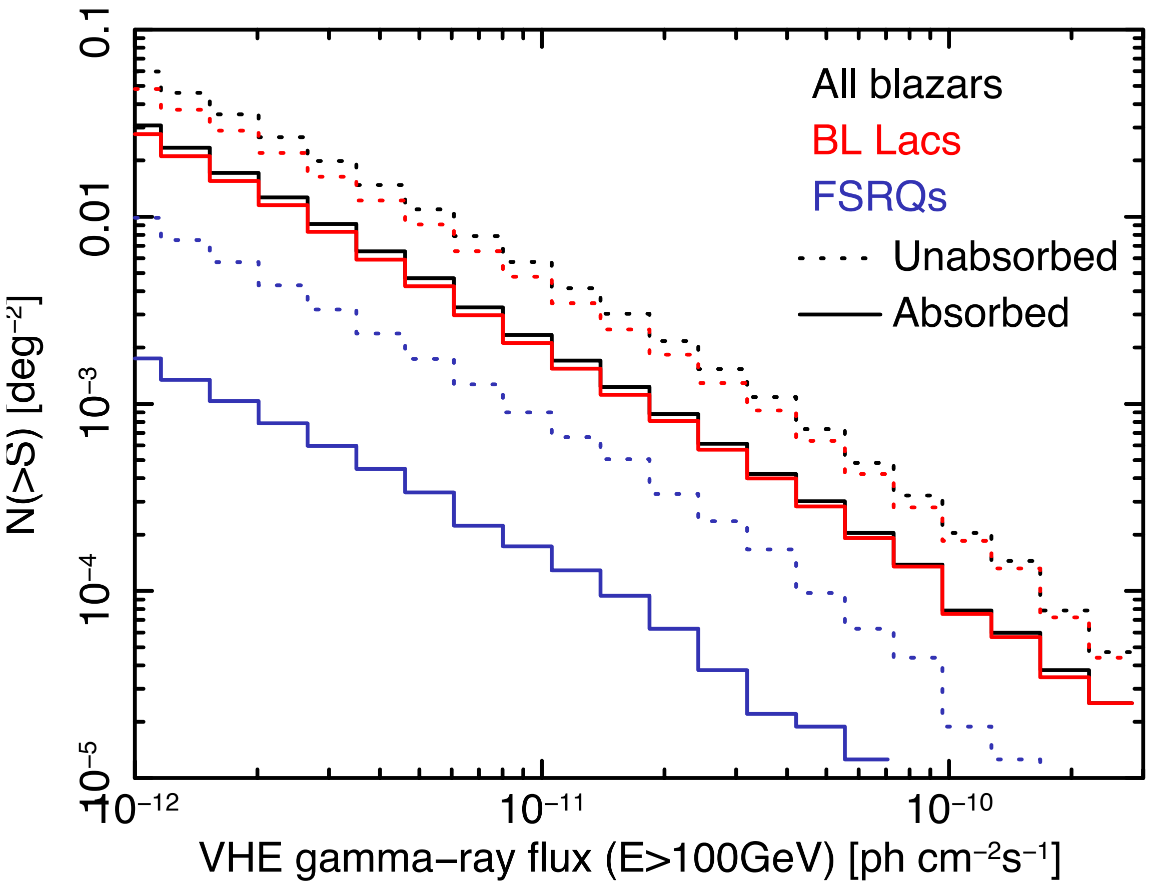

MNRAS 2015, 446L, 41
arXiv 1410.0497

Figure 1. The predicted integral number counts at $E \geqslant 100$ GeV as a function of photon flux with and without EBL absorption (dashed and solid lines respectively) for all blazars (black lines), BL Lacs (red lines), and FSRQs (blue lines) ($E_{\rm break} = 100$ GeV and $\Delta\Gamma = 1$).

A simplified view of blazars: the very high energy γ-ray vision

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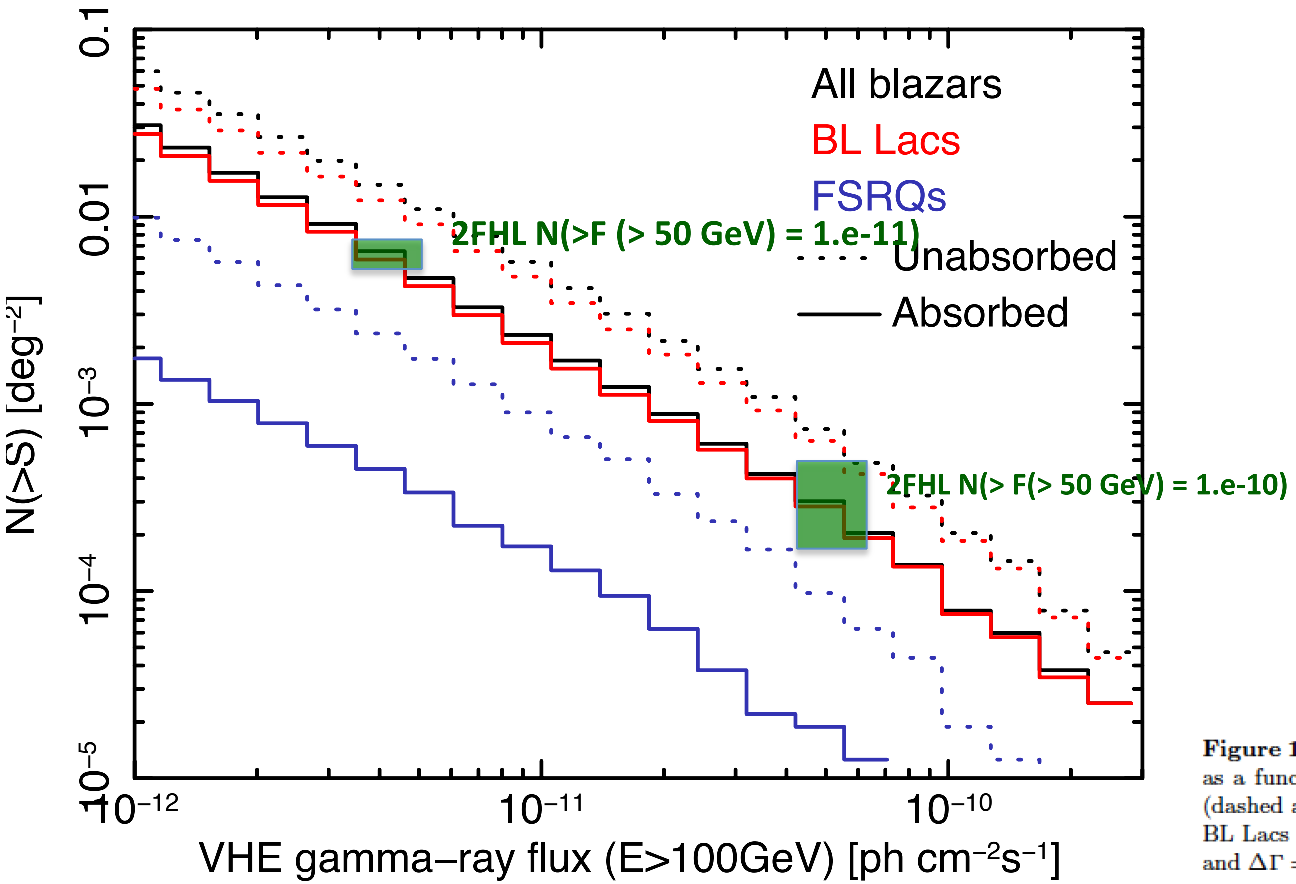

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Padovani & Giommi 2014, MNRAS, 446,L41

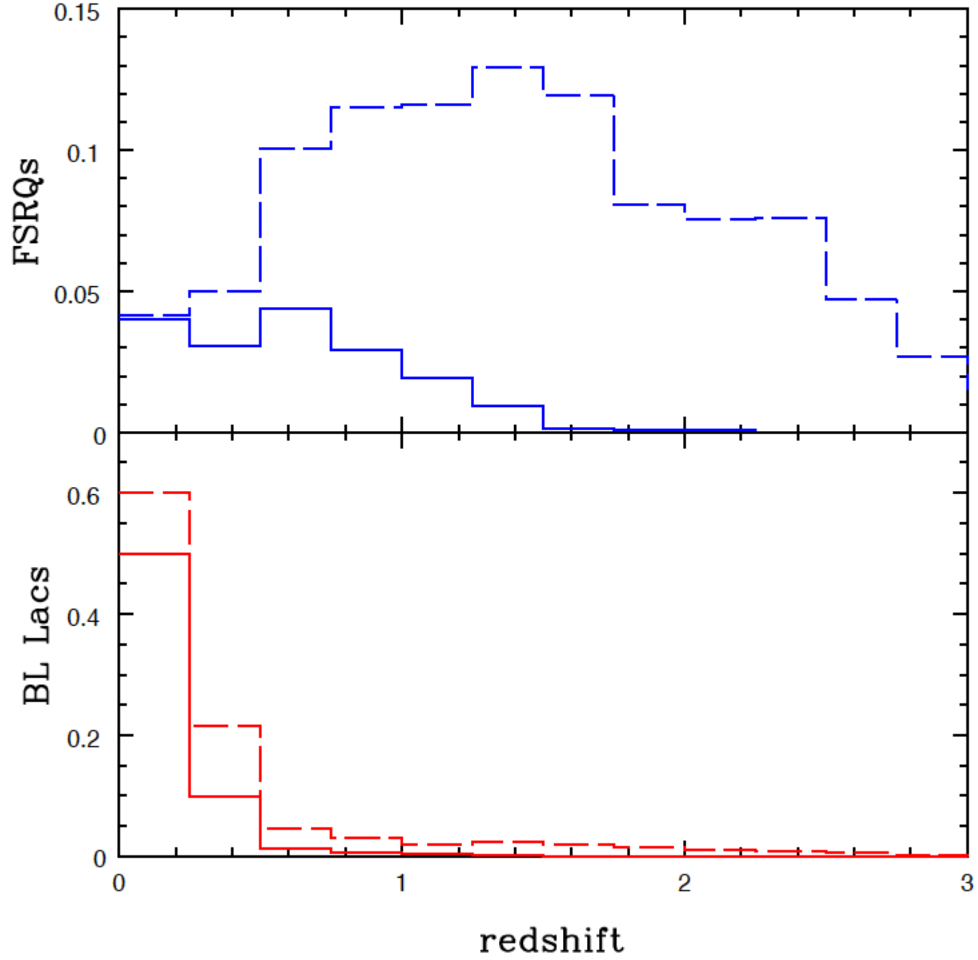

Figure 2. The predicted normalised redshift distributions for FSRQs (top panel) and BL Lacs (lower panel) before (dashed lines) and after (solid lines) applying the EBL absorption correction ($F(> 100\ \mathrm{GeV}) \geqslant 2.5 \times 10^{-12}$ photon cm^{-2} s^{-1}, $E_{\mathrm{break}} = 100$ GeV and $\Delta\Gamma = 1$).

A simplified view of blazars: contribution to the X-ray and γ-ray extragalactic backgrounds

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[2] *Associated to INAF - Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy*
[3] *European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
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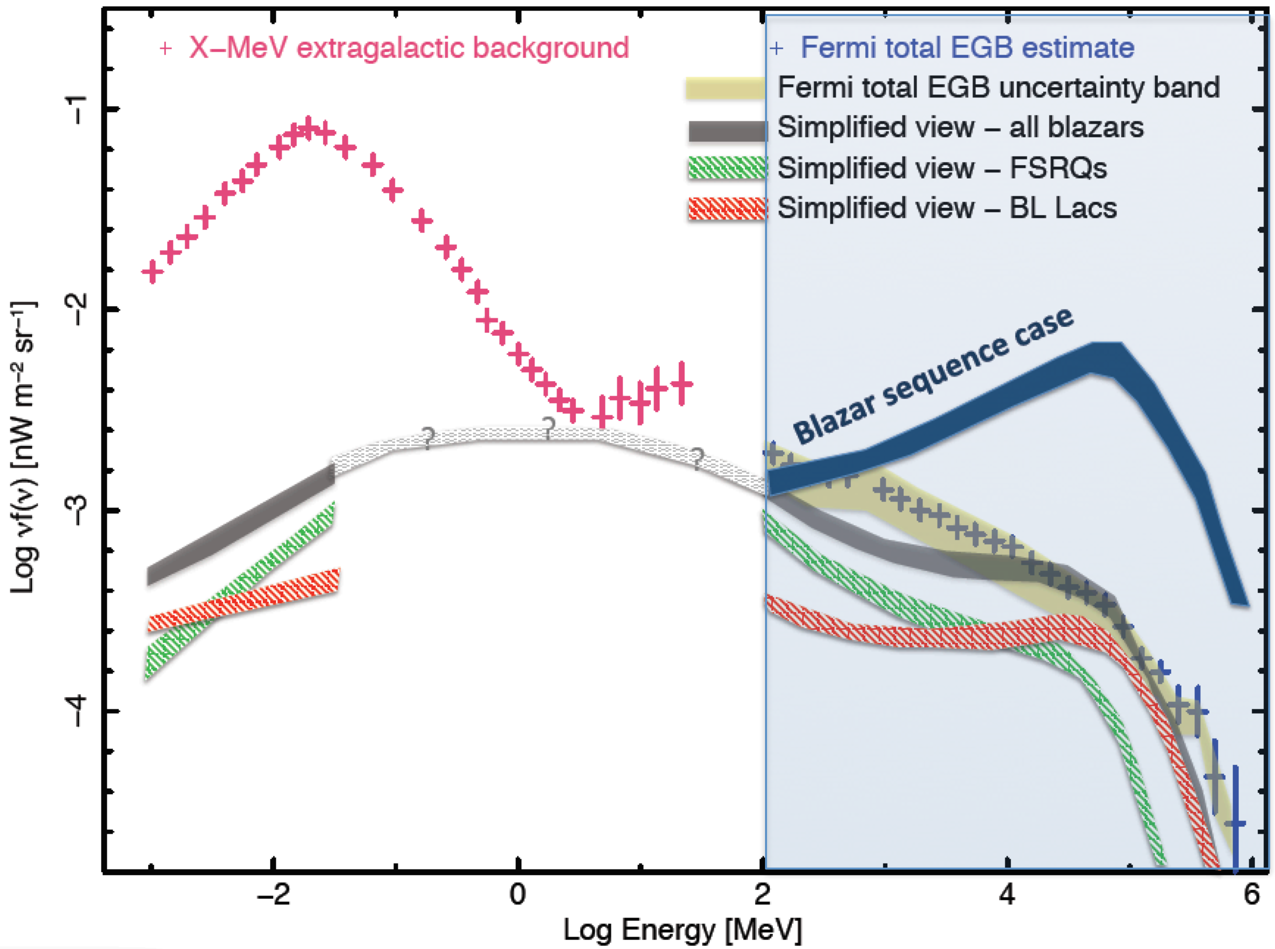
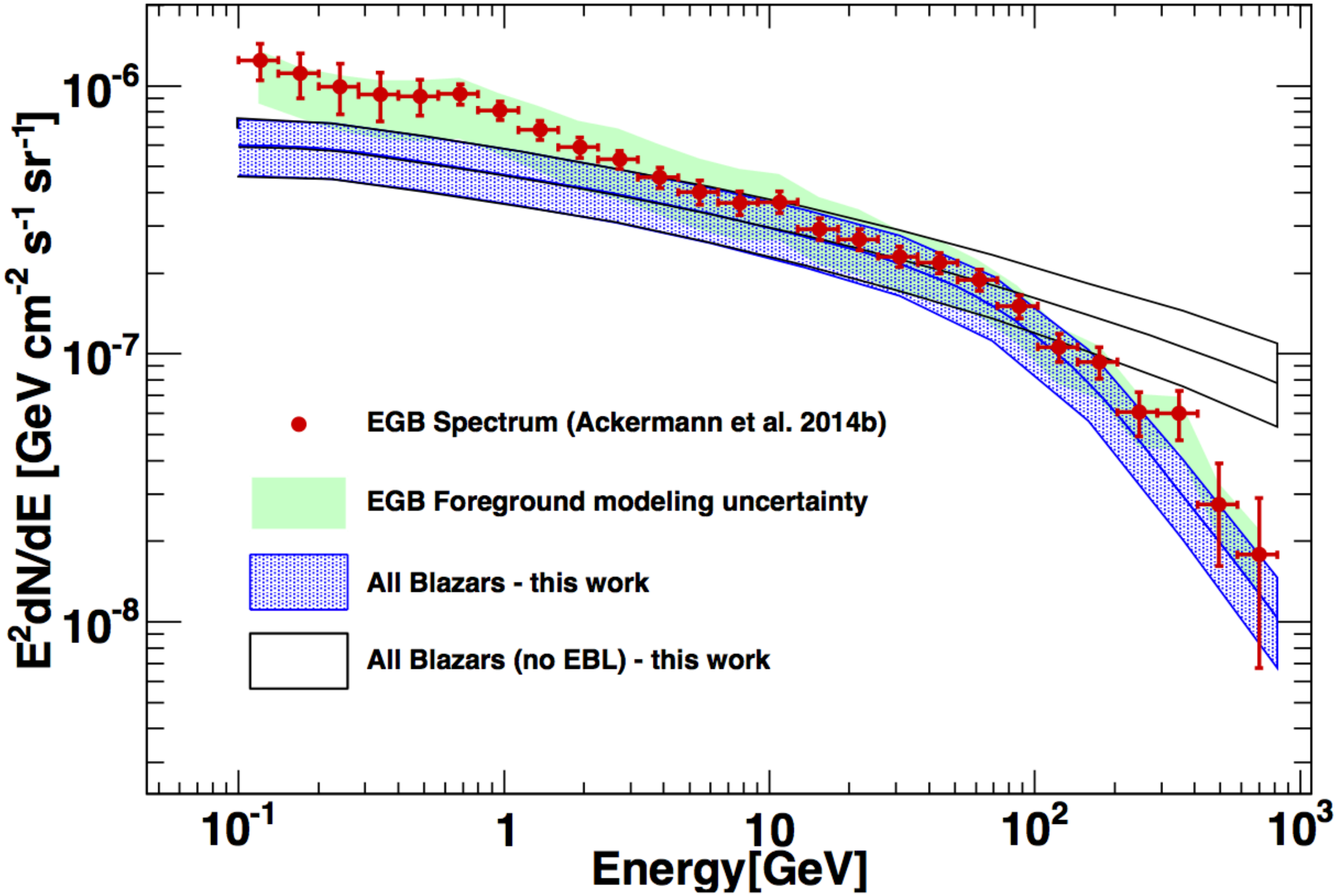


2015, MNRAS 450, 2404
arXiv:1504.01978

The Origin of the Extragalactic Gamma-Ray Background and Implications for Dark-Matter Annihilation

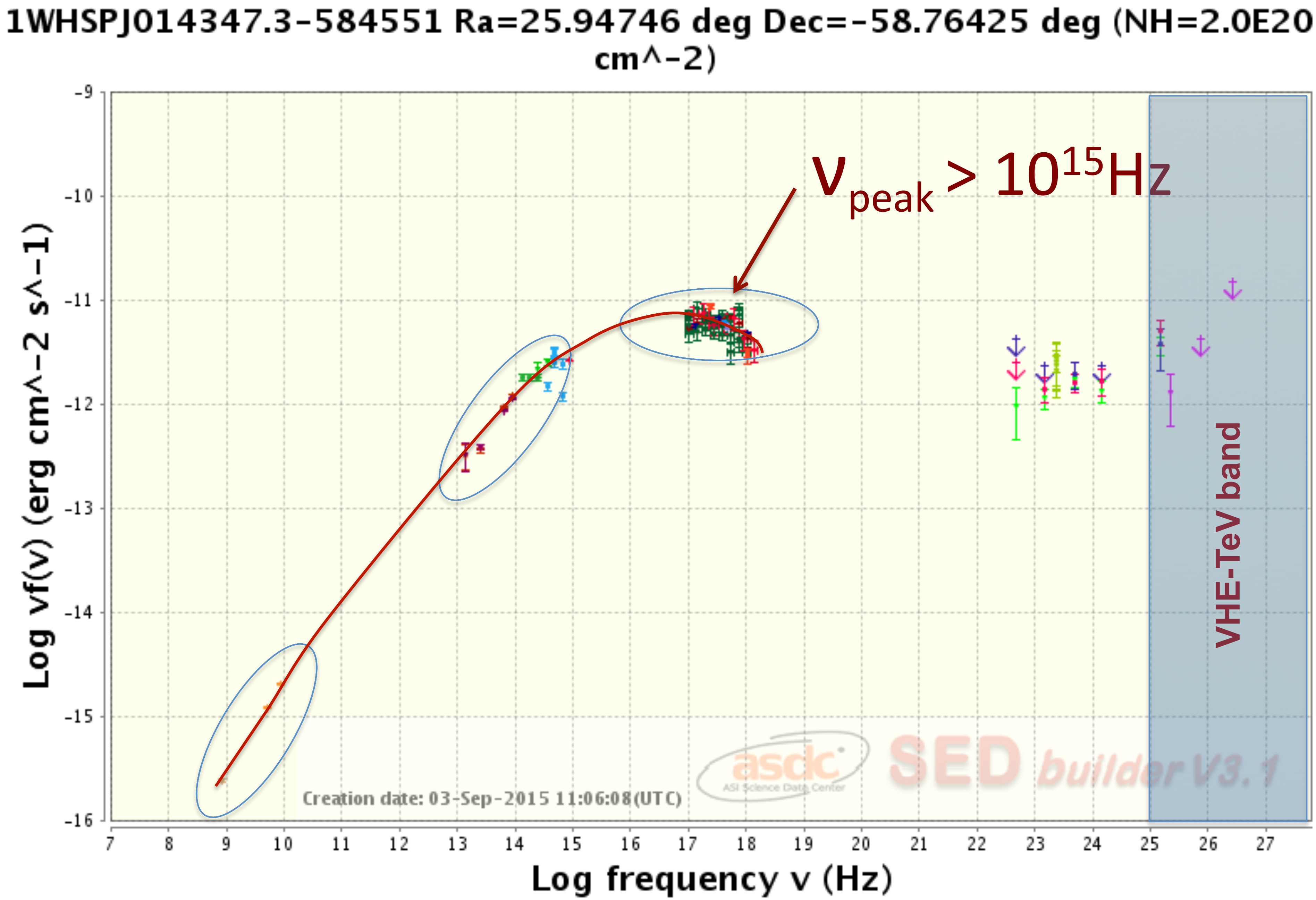
M. Ajello[1], D. Gasparrini[2,3], M. Sánchez-Conde[4,5,6], G. Zaharijas[7,8,9] M. Gustafsson[10,11], J. Cohen-Tanugi[12], C. D. Dermer[13], Y. Inoue[14], D. Hartmann[1], M. Ackermann[15], K. Bechtol[16], A. Franckowiak[4], A. Reimer[17], R. W. Romani[4], A. W. Strong[18]

2015, ApJL 800L, 27, arXiv:1501.050301



New large samples of high-energy synchrotron peaked blazars

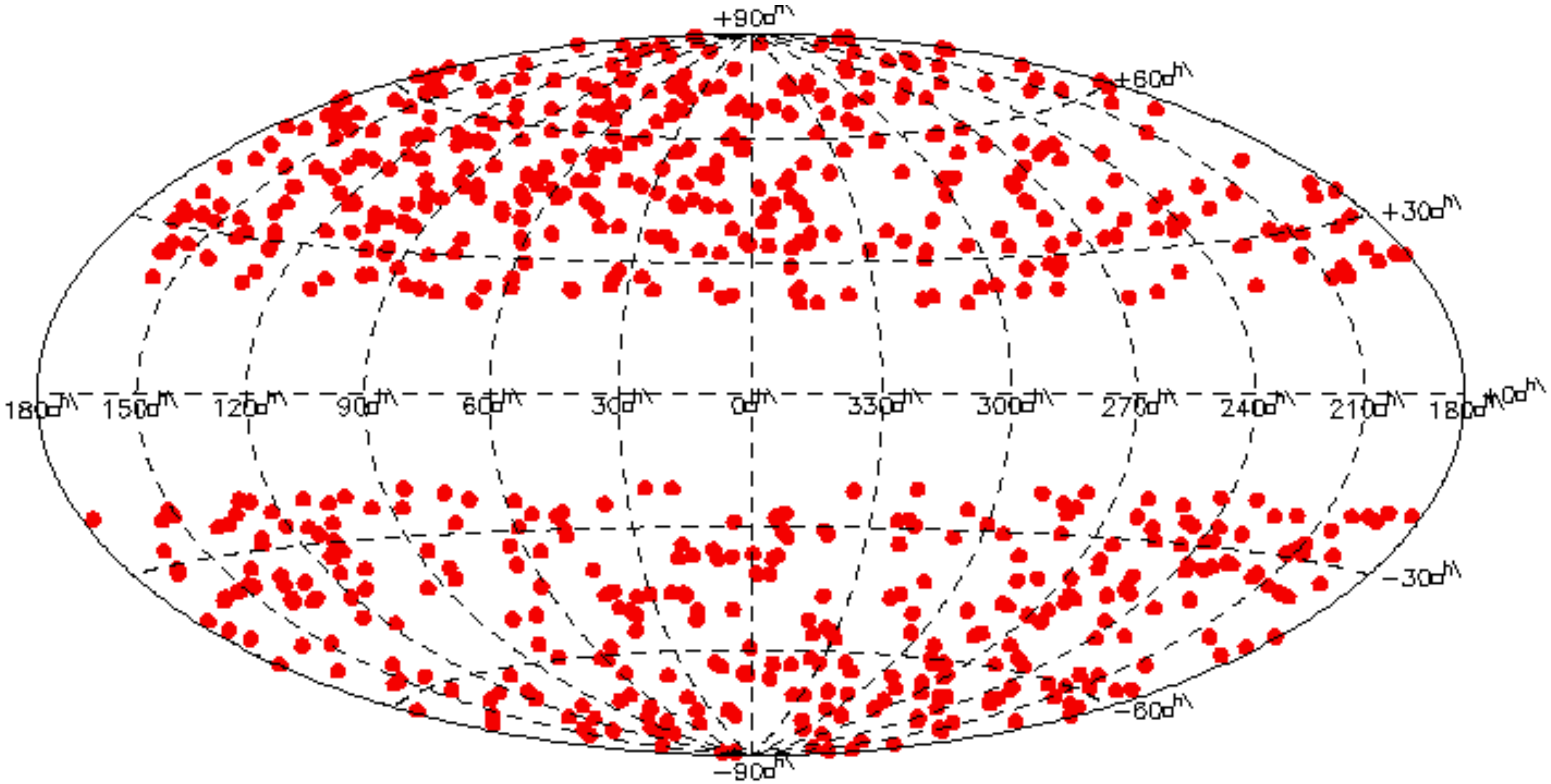
-The most powerful and energetic particle accelerators known and likely VHE emitters -


1WHSPJ014347.3-584551 Ra=25.94746 deg Dec=-58.76425 deg (NH=2.0E20 cm^-2)
$\nu_{peak} > 10^{15}$Hz
VHE-TeV band
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
Creation date: 03-Sep-2015 11:06:08(UTC)
asdc
ASI Science Data Center
SED builder V3.1

1WHSP: an IR-based sample of ~1,000 VHE γ-ray blazar candidates

B. Arsioli[1,2], B. Fraga[1,2], P. Giommi[3], P. Padovani[4,5], and M. Marrese[3]

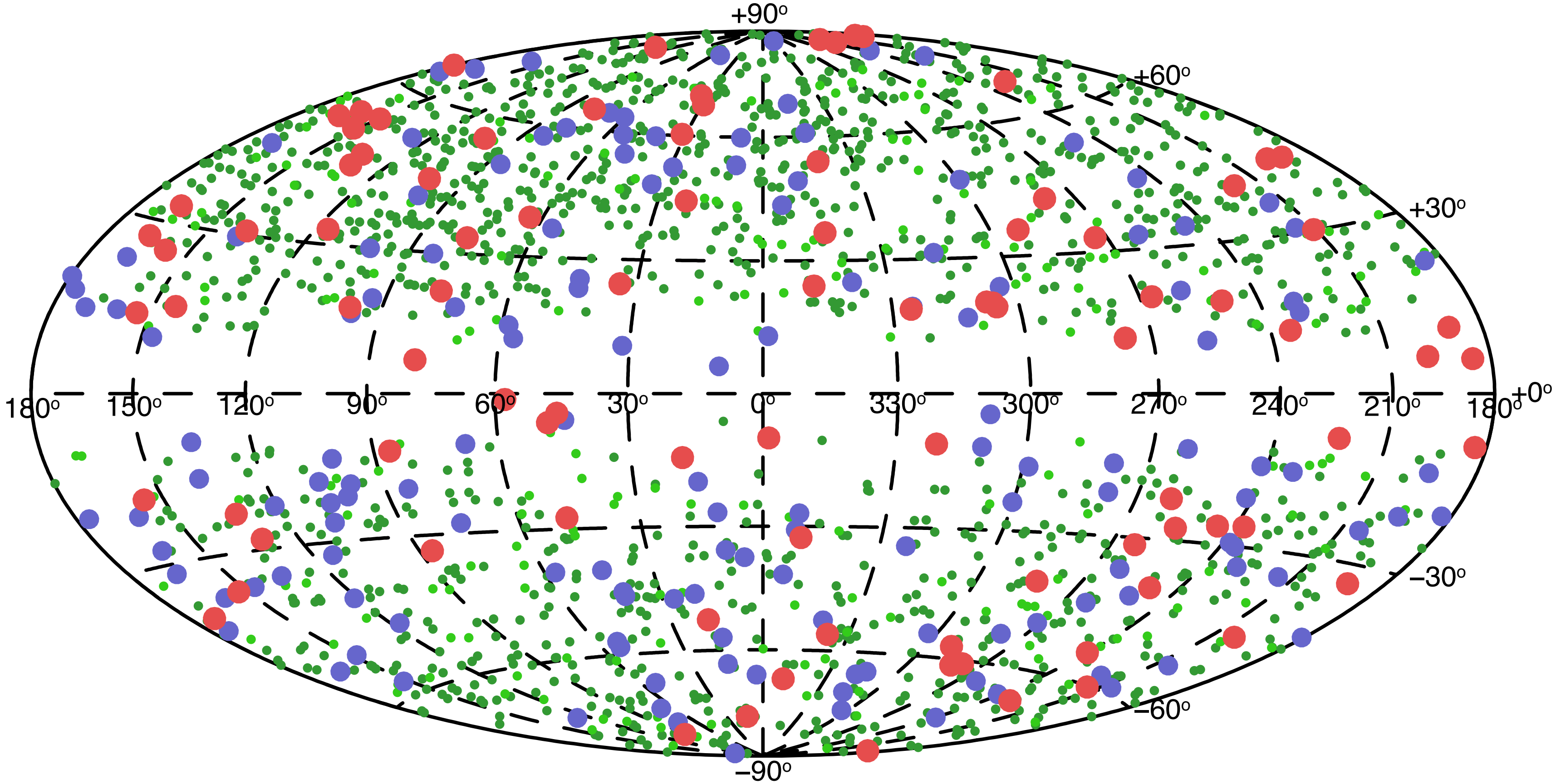
A&A 2015, A&A, 2015, 579, 34
DOI: 10.1051/0004-6361/201424148



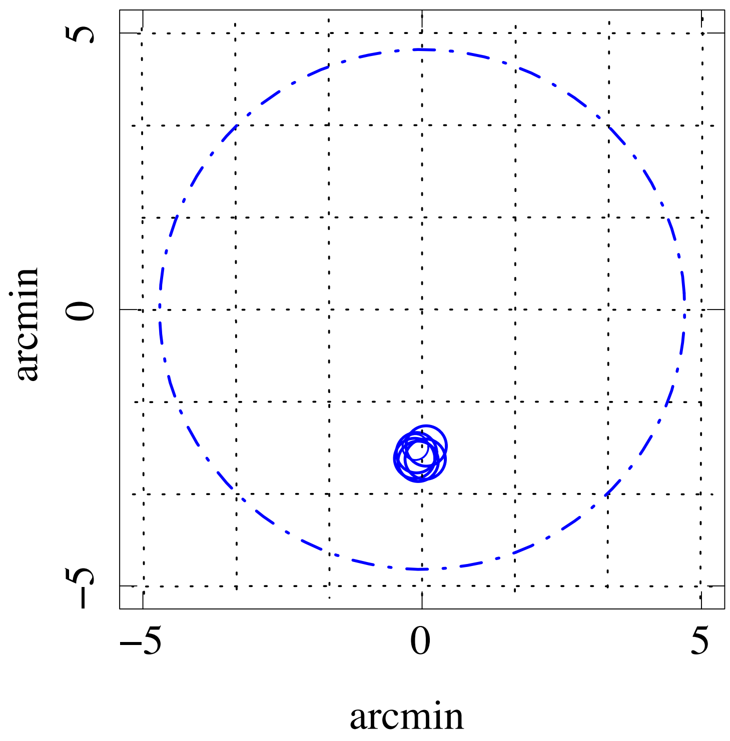
asdc
ASI Science Data Center

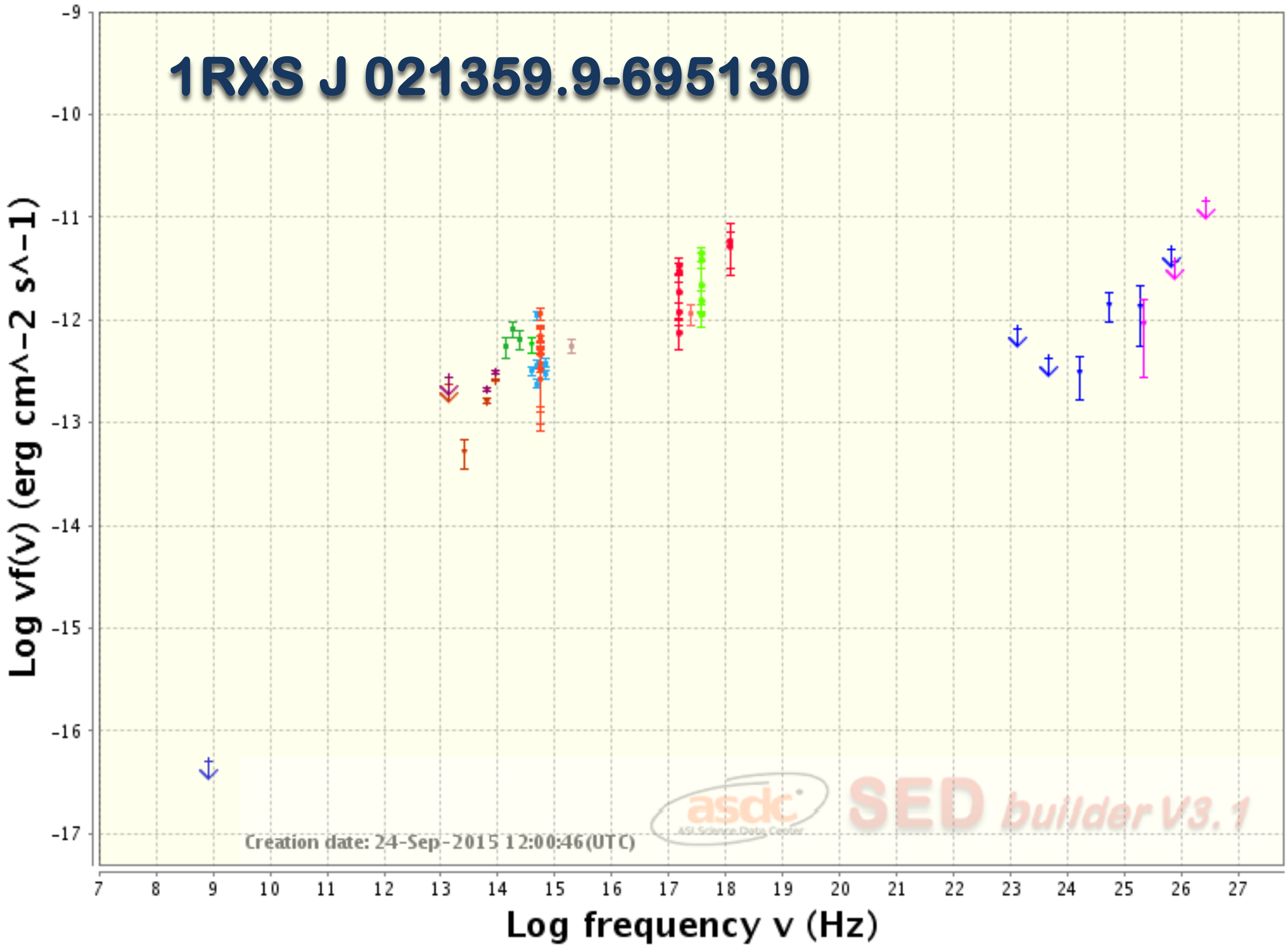
2WHSP ~1,690 objects

Y-L. Chang, B. Arsioli, P. Giommi, P. Padovani, 2015 in preparation

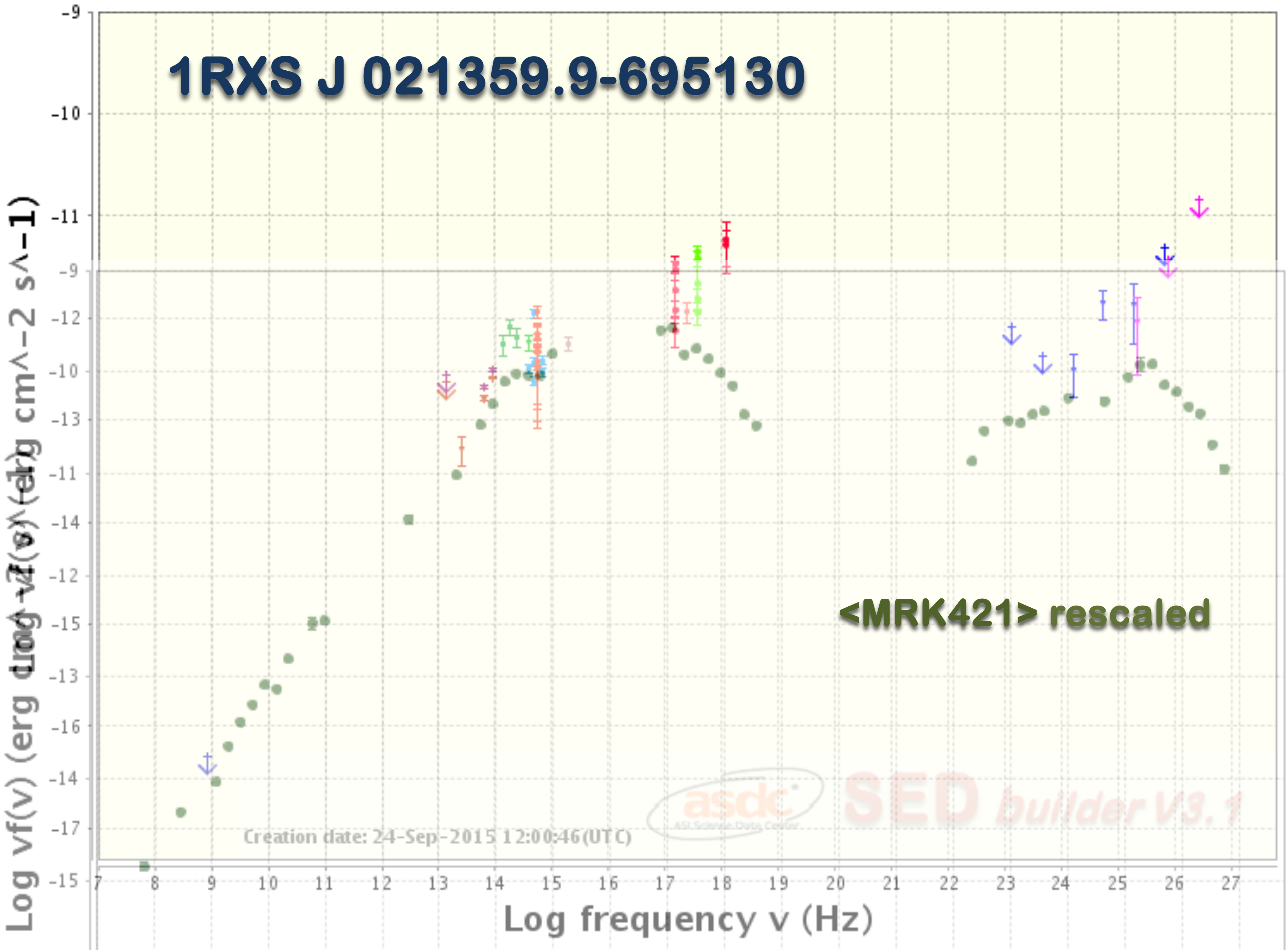


2FHL J0213.9-6949





1RXS J 021359.9-695130
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
Creation date: 24-Sep-2015 12:00:46(UTC)
asdc
SED builder V3.1


1RXS J 021359.9-695130
<MRK421> rescaled
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
Creation date: 24-Sep-2015 12:00:46(UTC)
SED builder V3.1

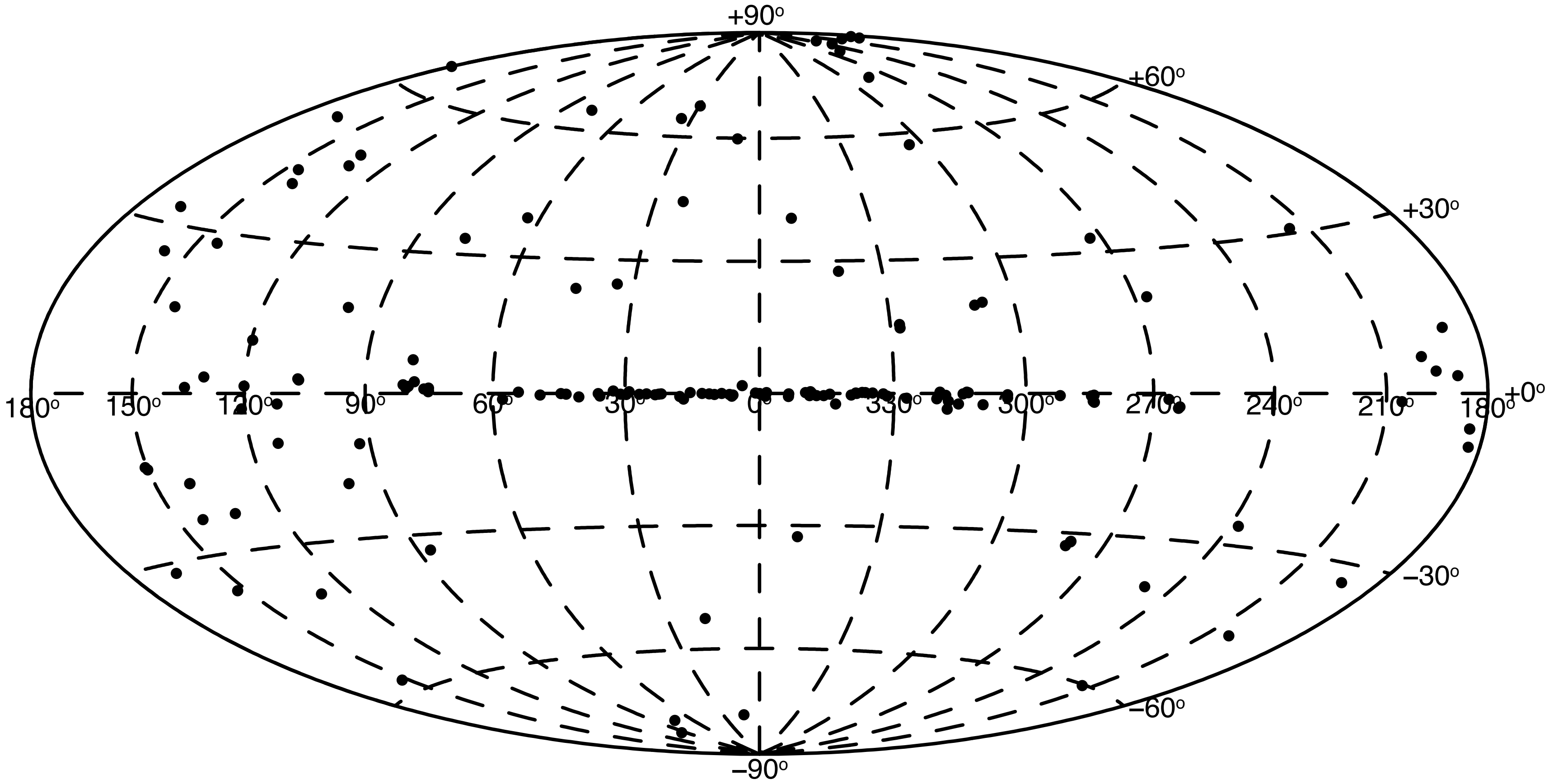
The very high energy (VHE)

(E > 50 GeV)

sky

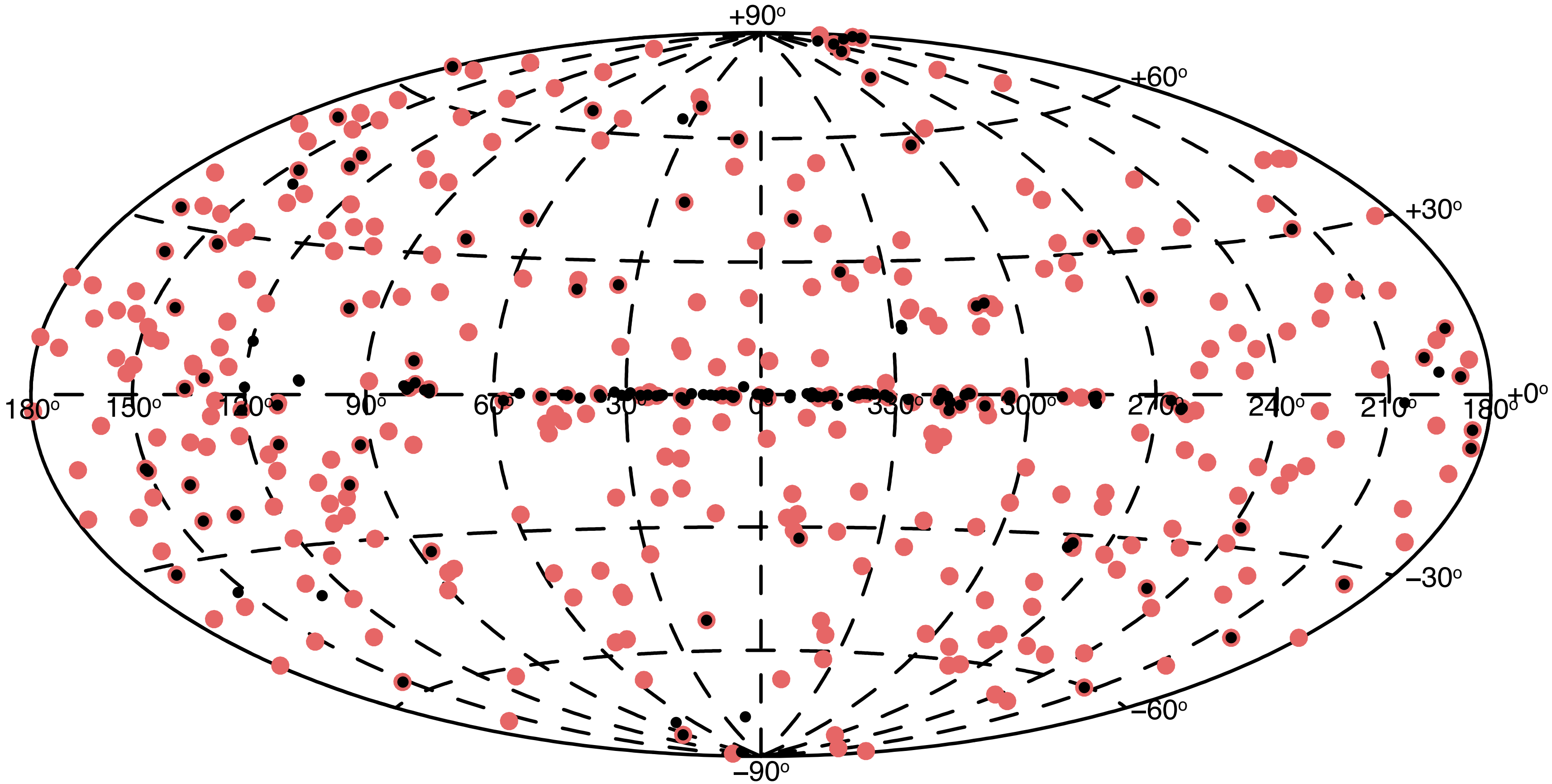
The VHE sky (IACTs)

F > ~ 10 mC.U.



The VHE sky (IACTs+Fermi 2FHL)

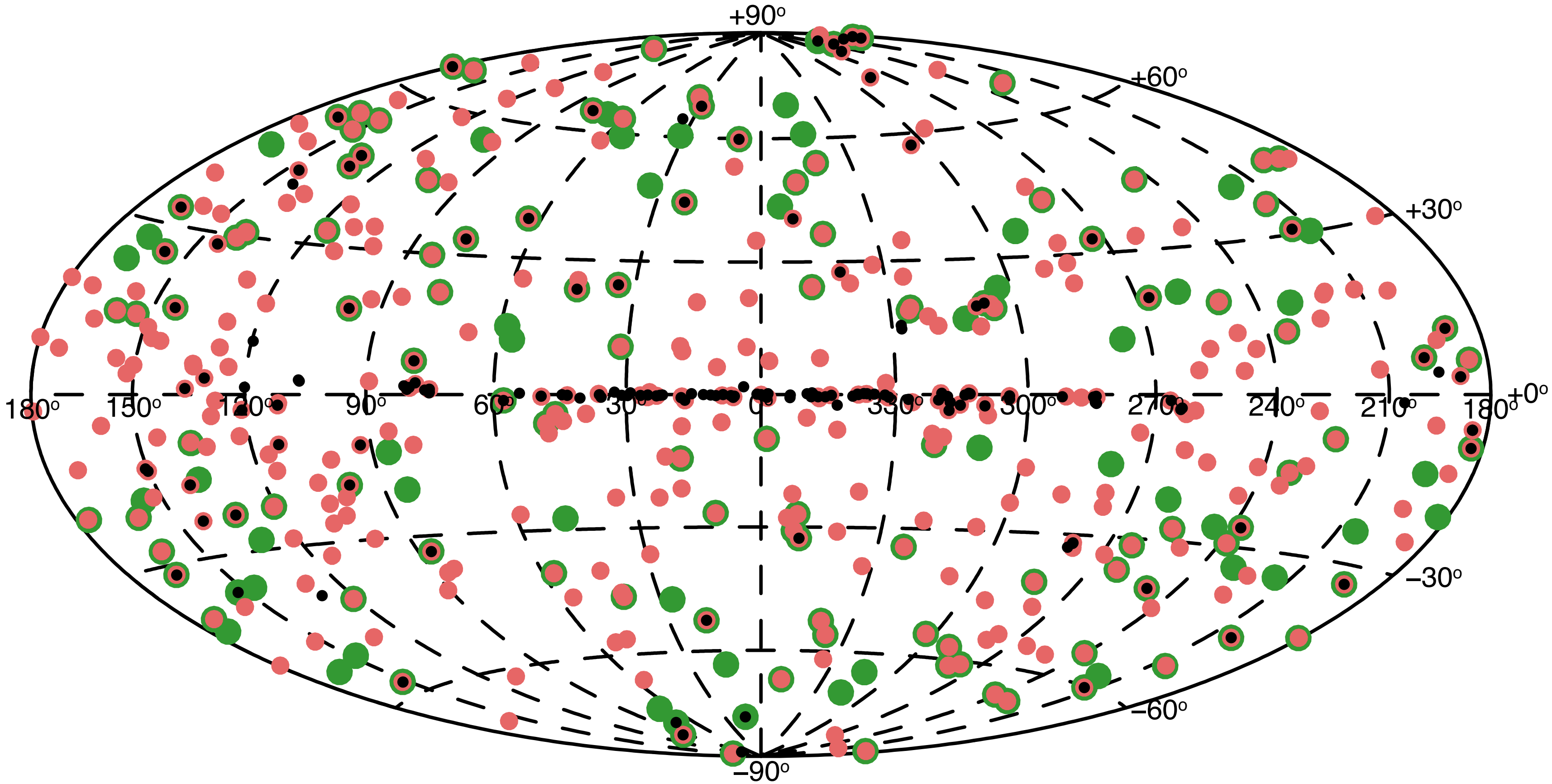
F > ~ 10 mC.U. F > ~ 10 mC.U.



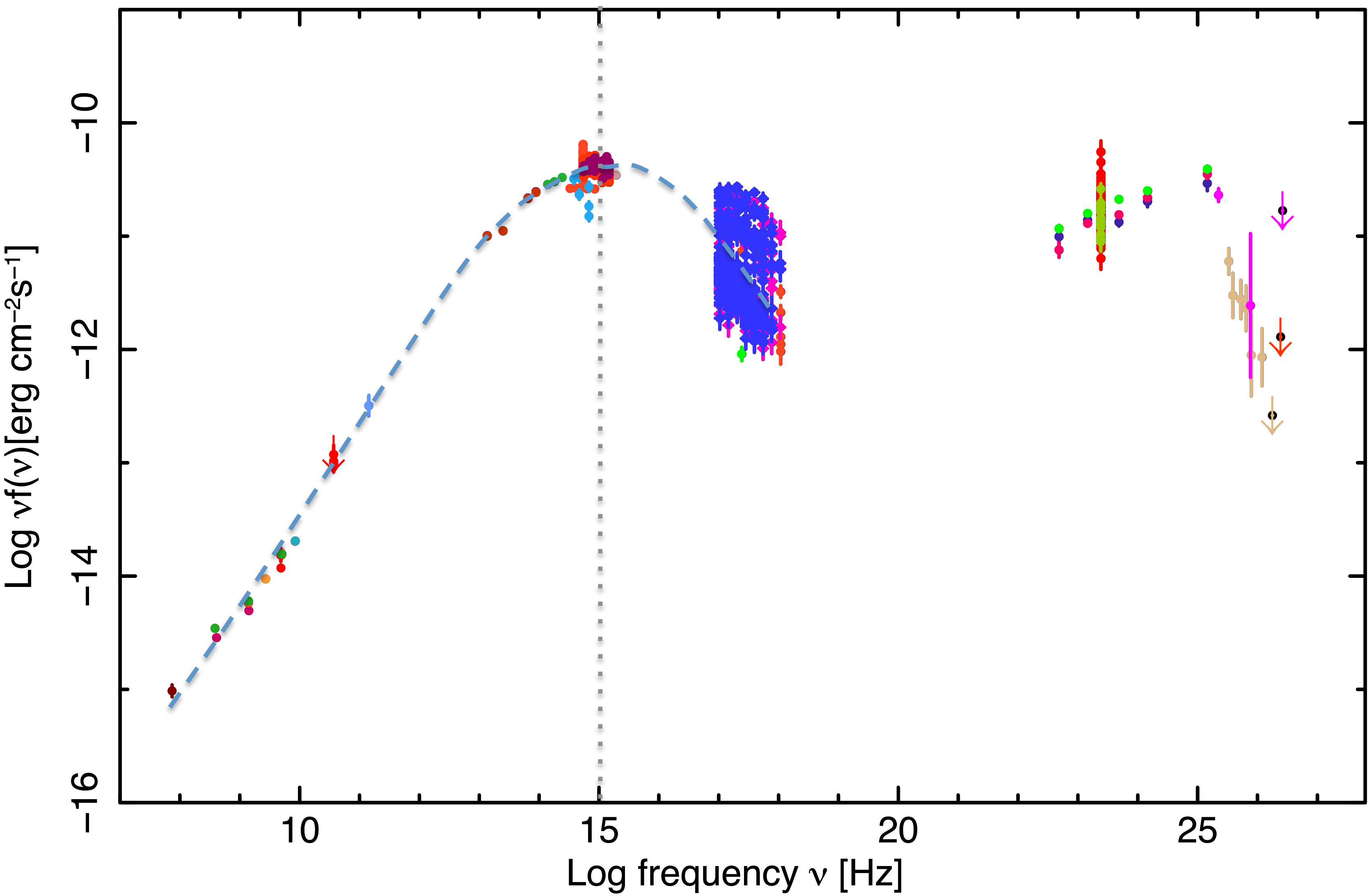
The VHE sky (IACTs+Fermi 2FHL+2WHSP bright)

F > ~ 10 mC.U.   F > ~ 10 mC.U   F > ~ 10 mC.U

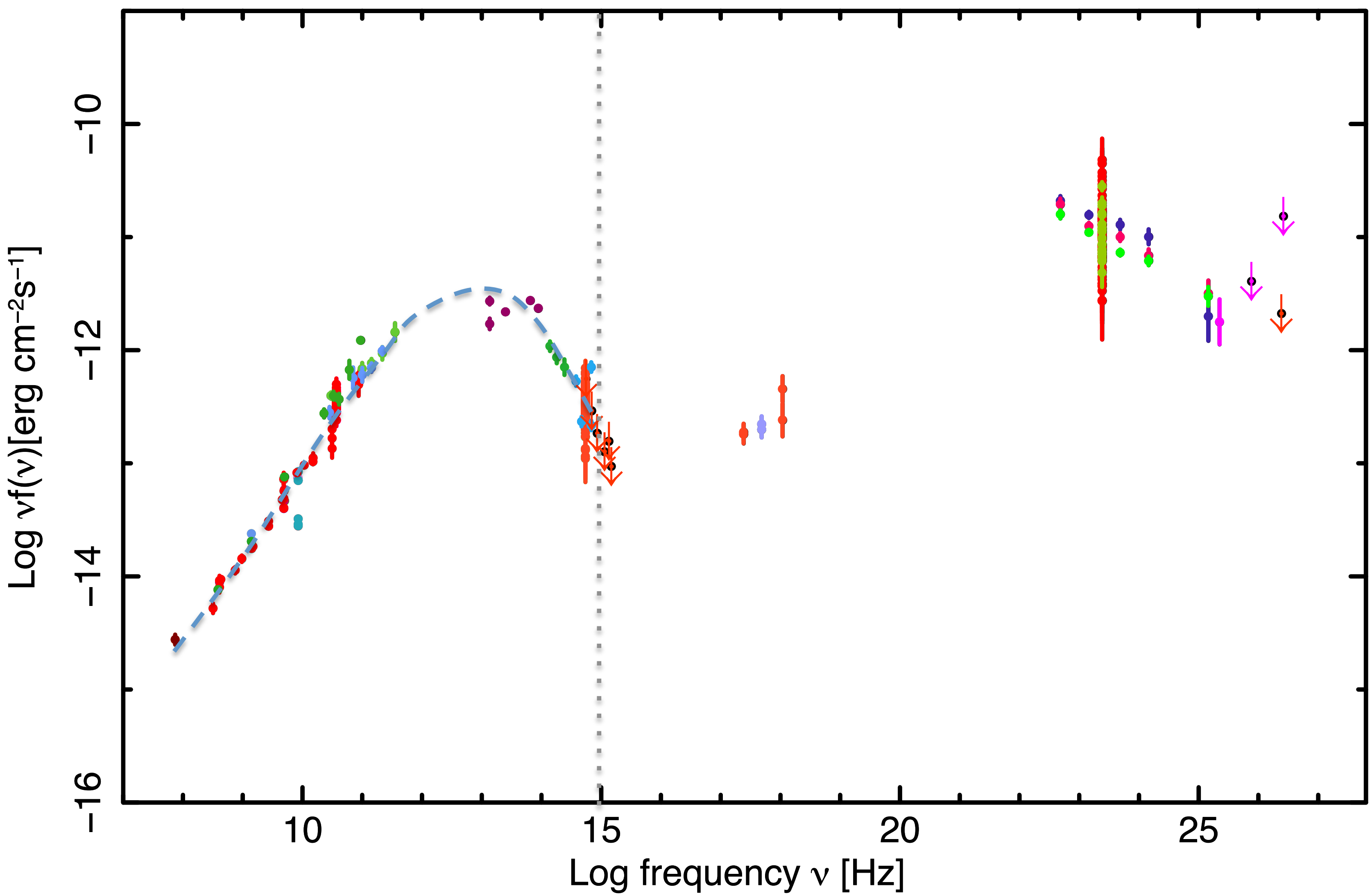
PRELIMINARY



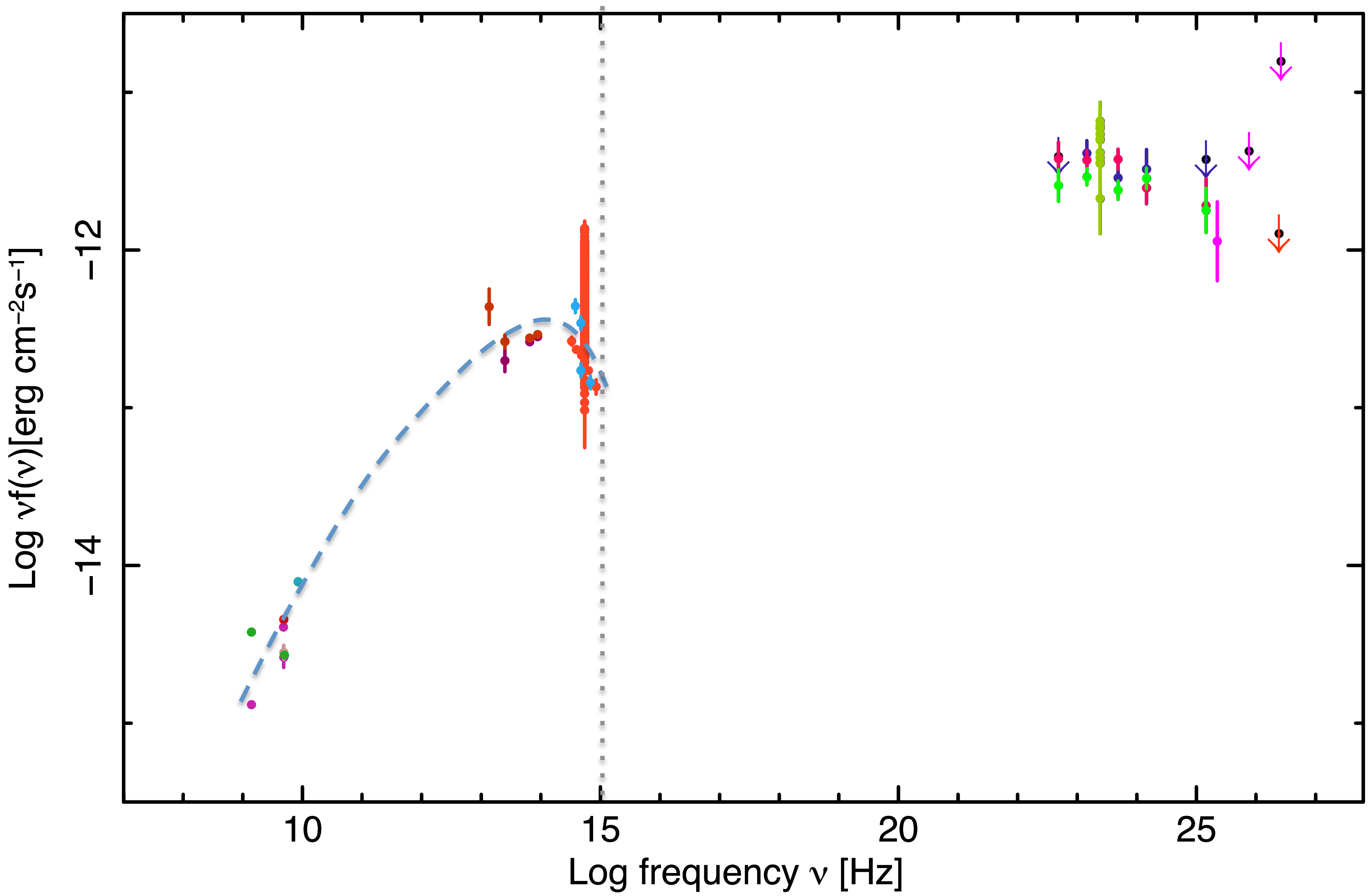
5BZB J1427+2348: an example of Blazar in 2FHL and in the 2WHSP sample



5BZU J0221+3556: an example of Blazar in 2FHL but not in the 2WHSP sample



5BZQ J0043+3426: an example of Blazar in 2FHL but not in the 2WHSP sample



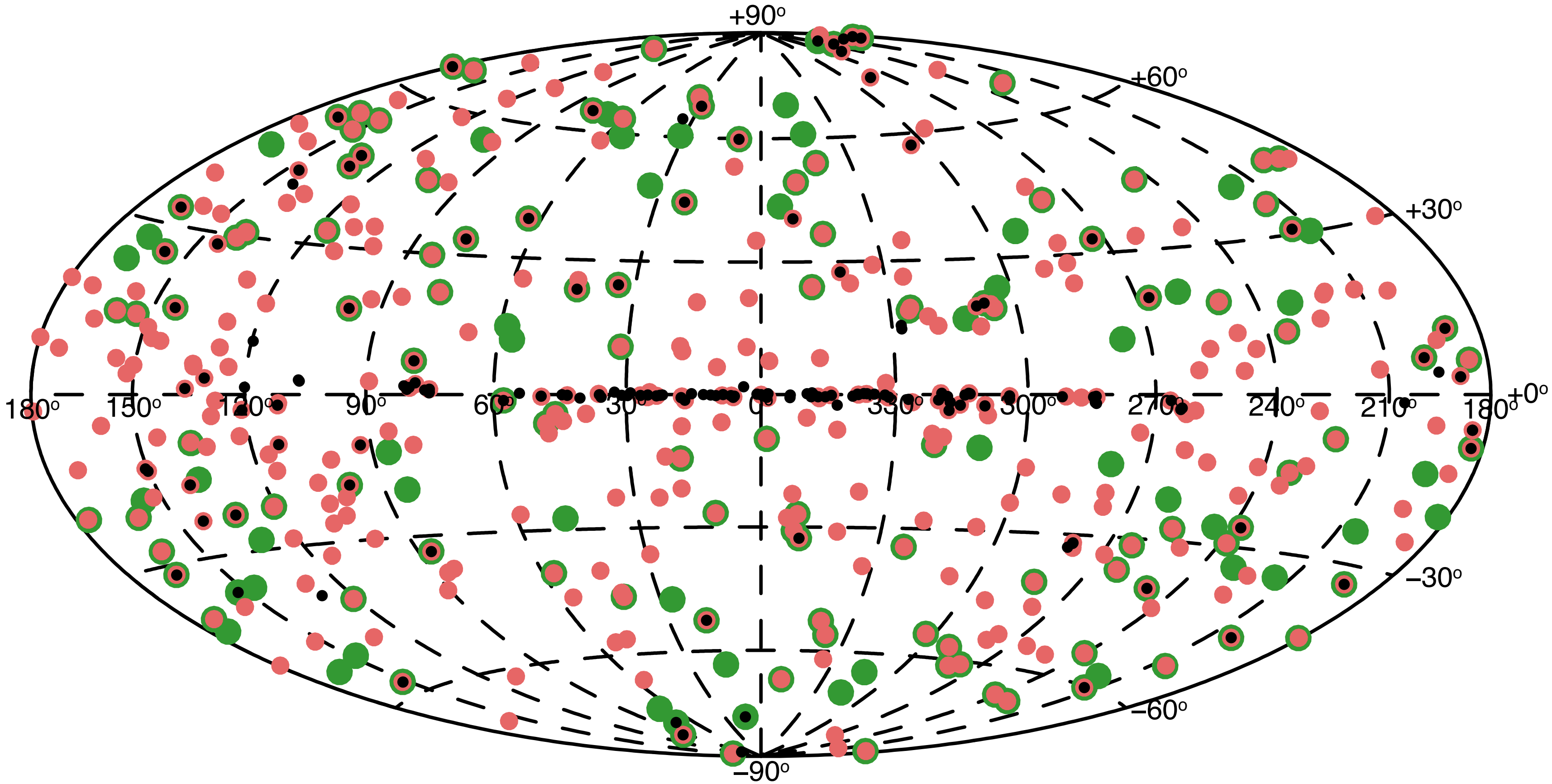
About 1/3 of the Fermi 2FHL blazars have $\nu_{peak} < 10^{15}$Hz

(not in 2WHSP)

The VHE sky (IACTs+Fermi 2FHL+2WHSP bright)

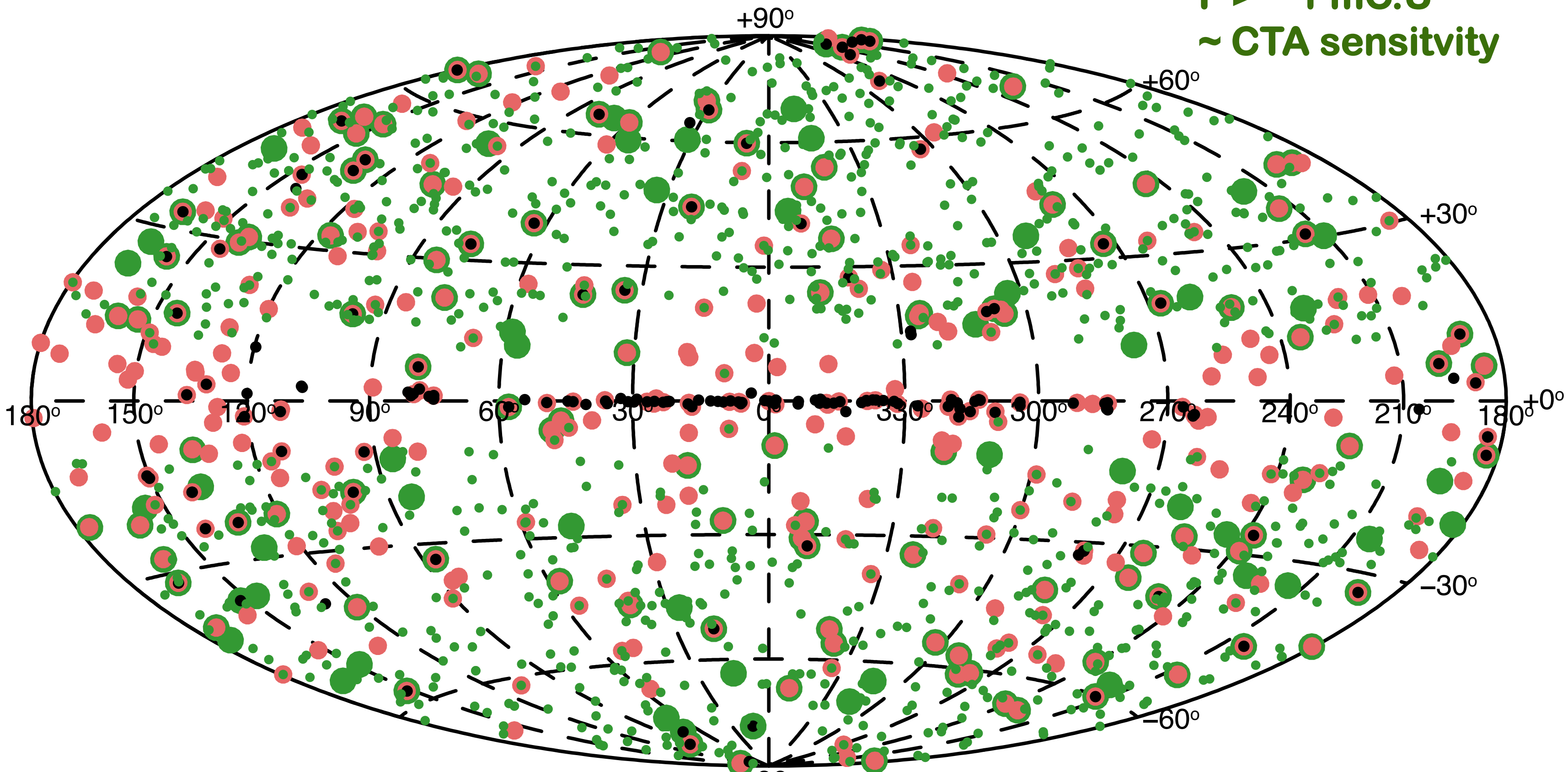
F > ~ 10 mC.U. **F > ~ 10 mC.U** **F > ~ 10 mC.U**

PRELIMINARY



The VHE sky (IACTs+Fermi 2FHL+2WHSP bright + faint)

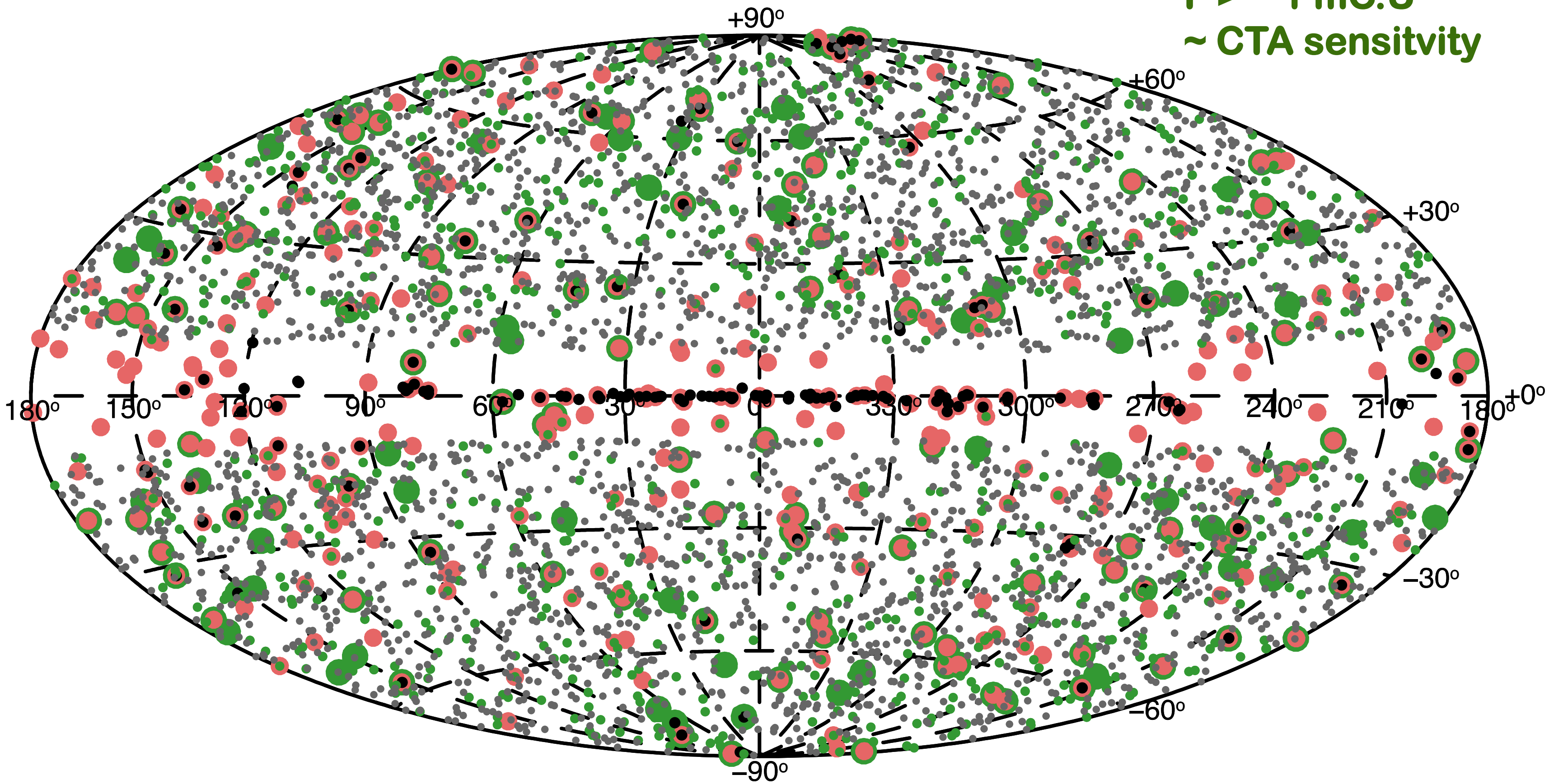
PRELIMINARY



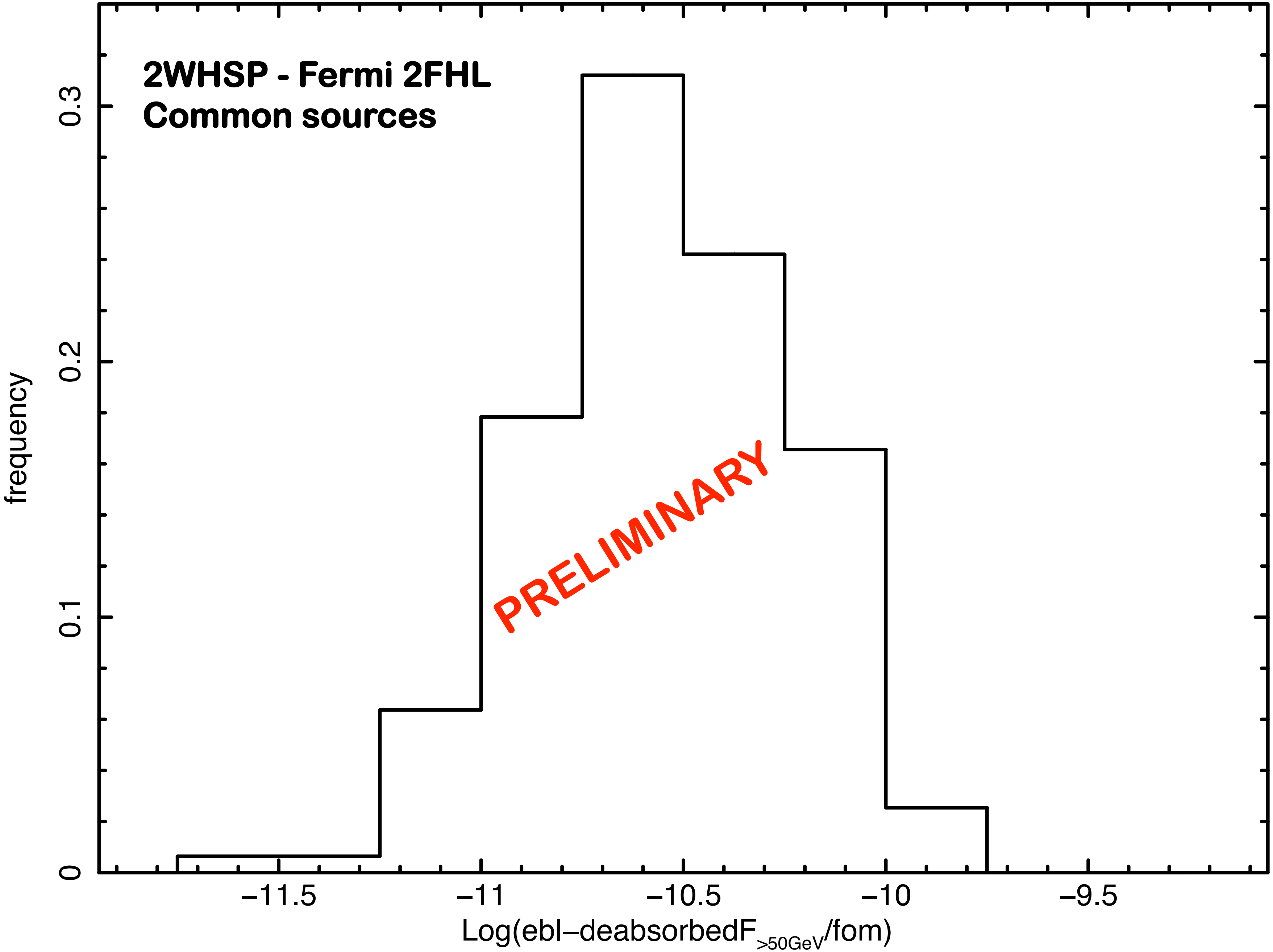
The VHE sky (IACTs+Fermi 2FHL+2WHSP bright + faint)

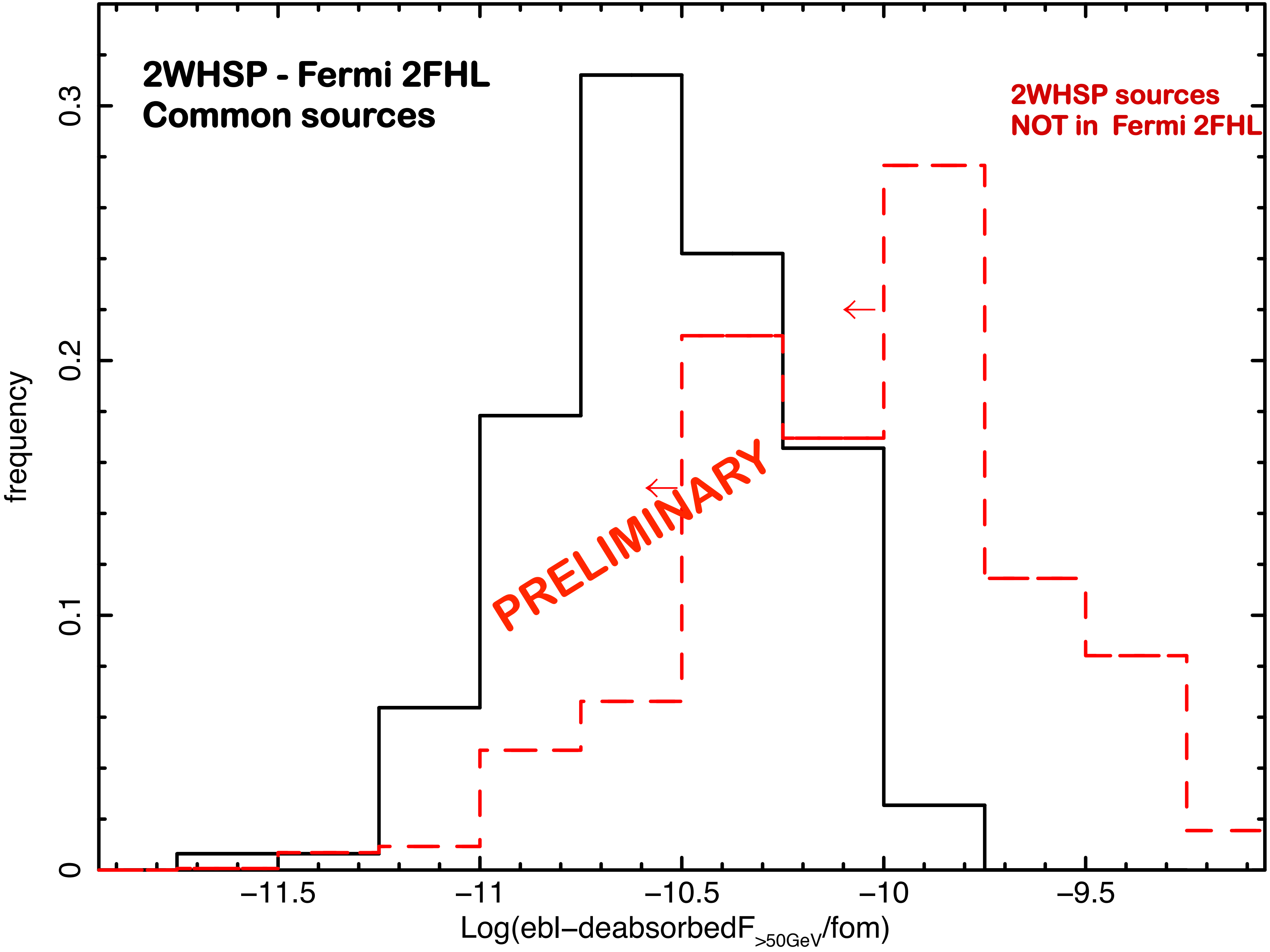
PRELIMINARY

F > ~ 1 mC.U
~ CTA sensitvity

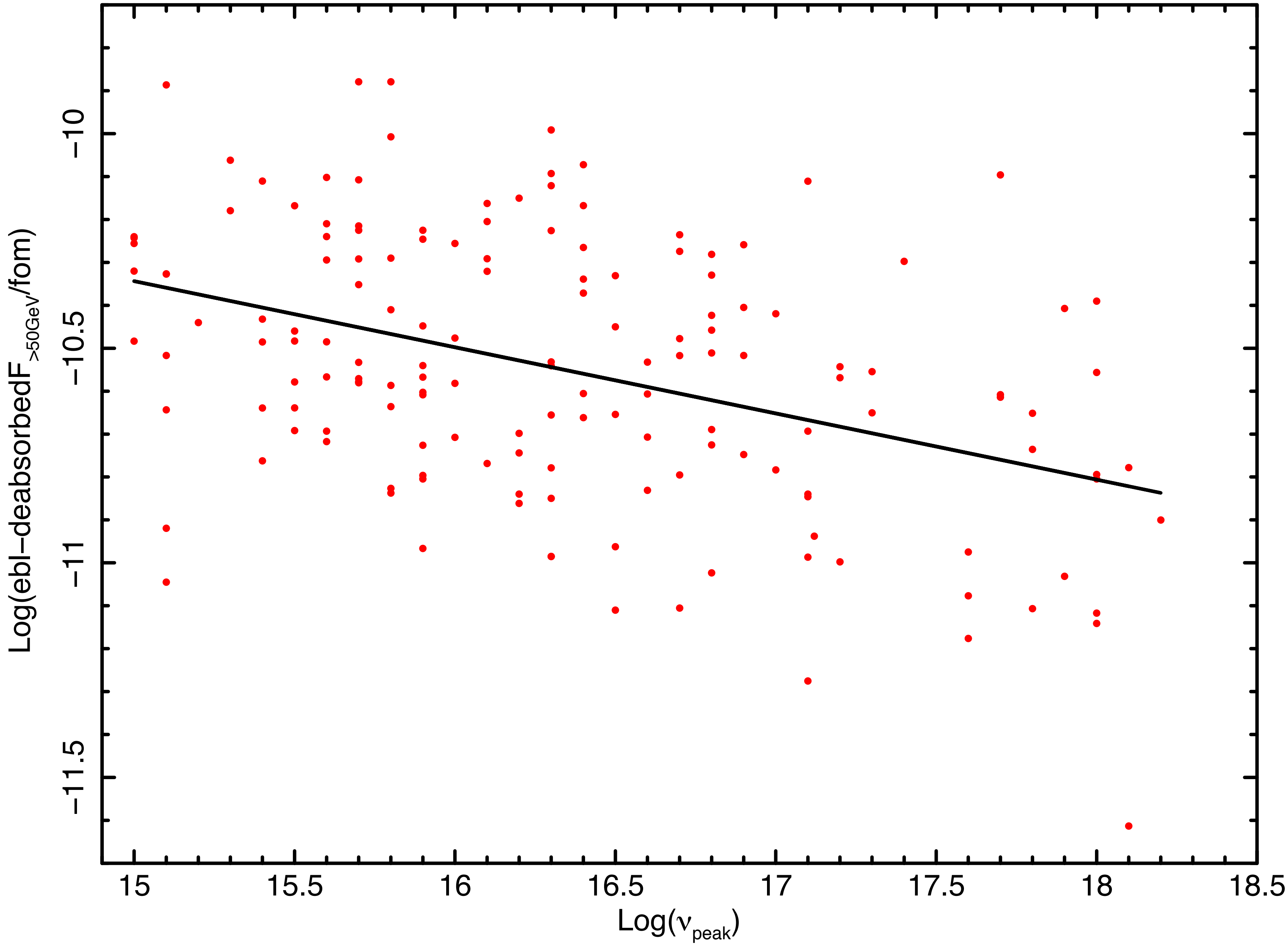


IBLs+LBLs from simulations

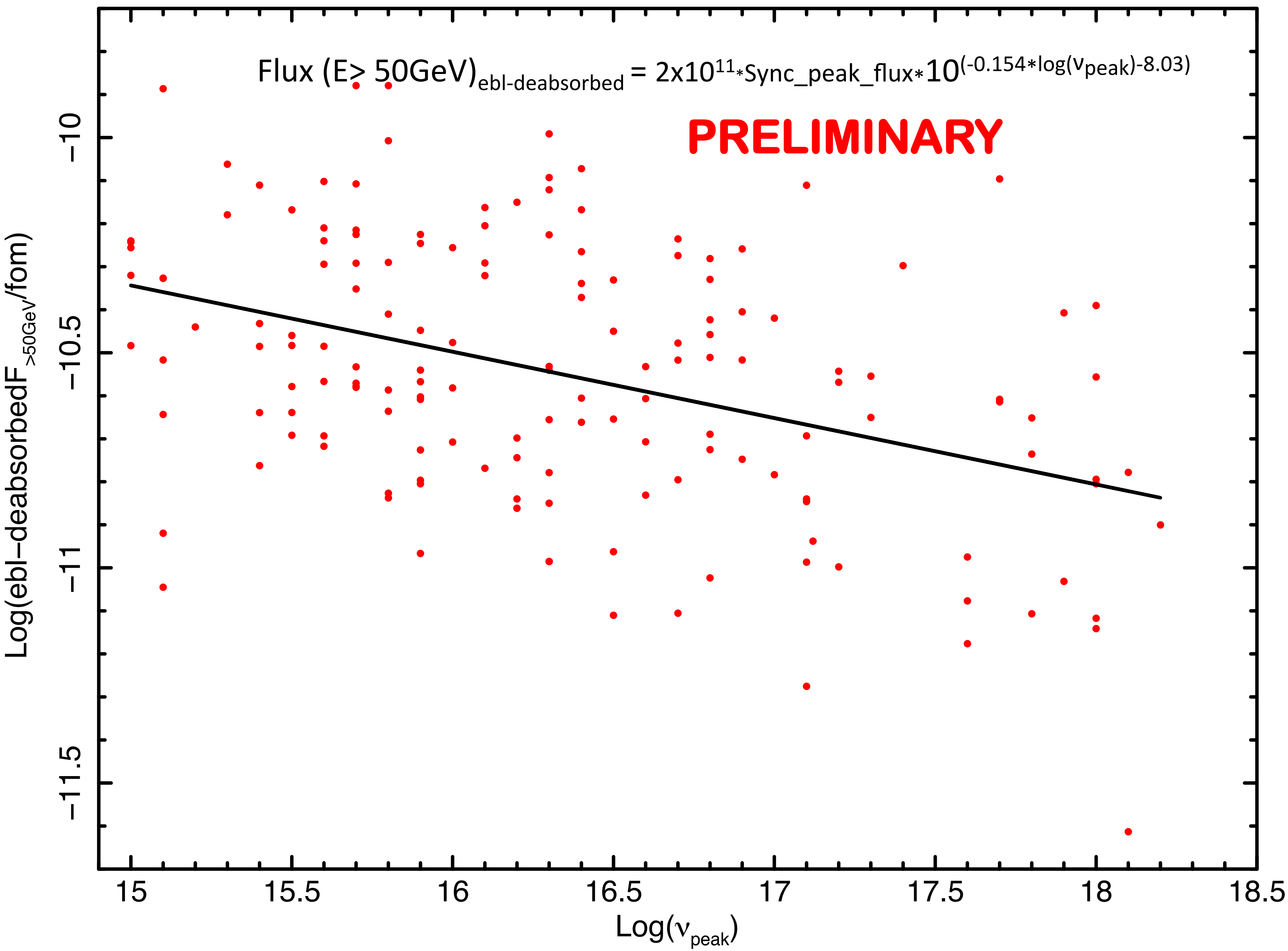

2WHSP - Fermi 2FHL
Common sources
PRELIMINARY
frequency
0
0.1
0.2
0.3
−11.5
−11
−10.5
−10
−9.5
Log(ebl−deabsorbedF>50GeV/fom)



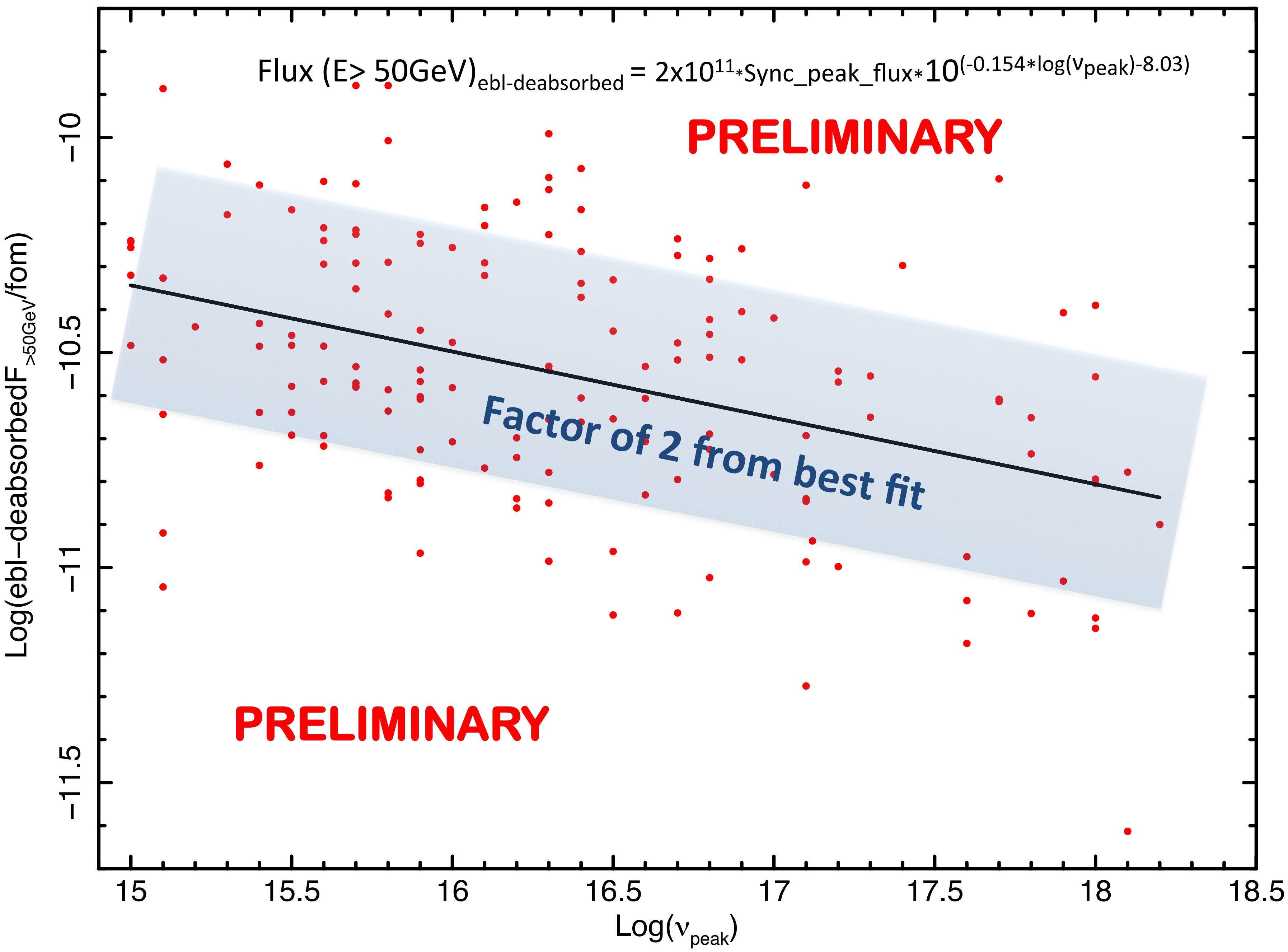
2WHSP - Fermi 2FHL
Common sources
2WHSP sources
NOT in Fermi 2FHL
PRELIMINARY
frequency
0
0.1
0.2
0.3
−11.5
−11
−10.5
−10
−9.5
Log(ebl−deabsorbedF>50GeV/fom)



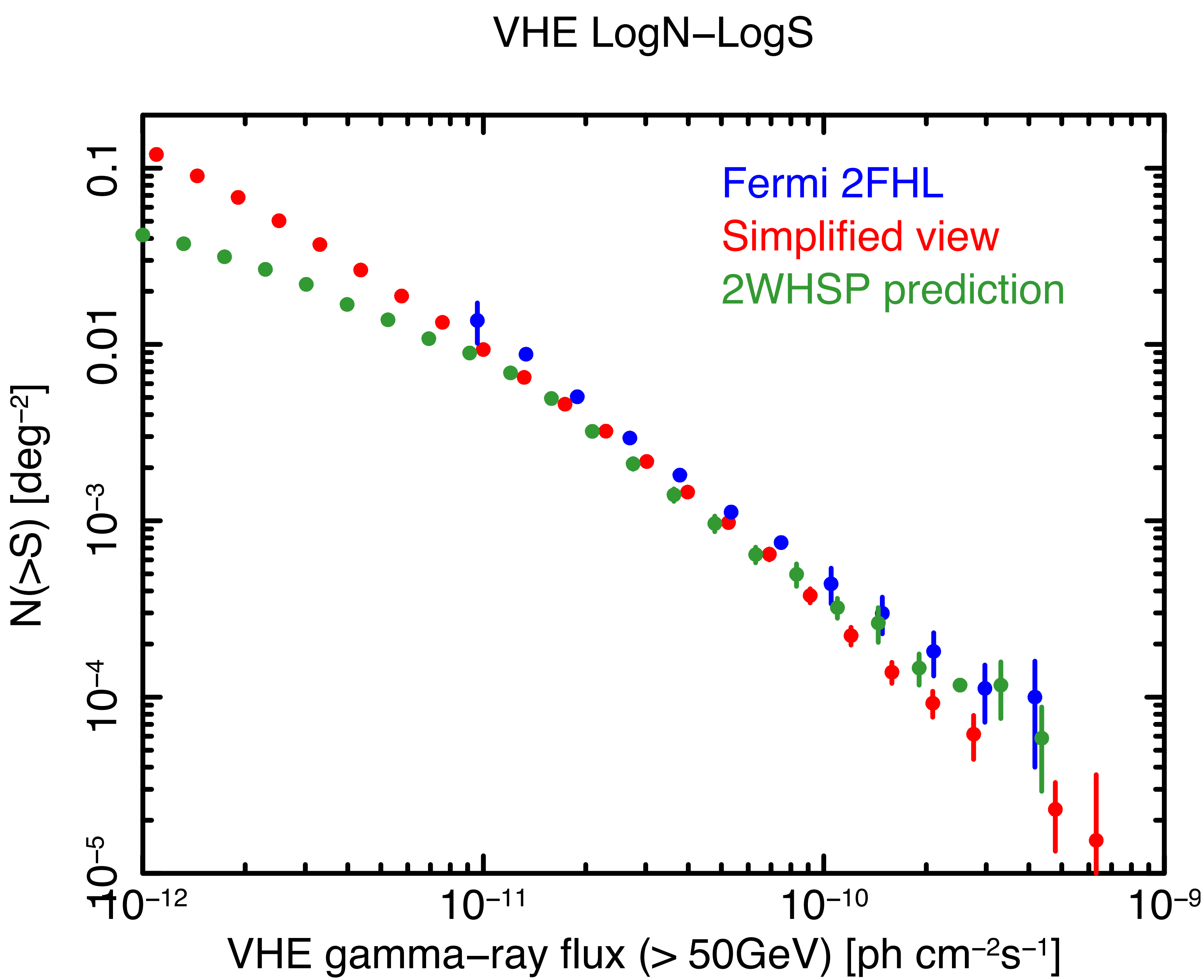
Log(ebl−deabsorbedF>50GeV/fom)
−10
−10.5
−11
−11.5
15
15.5
16
16.5
17
17.5
18
18.5
Log(νpeak)



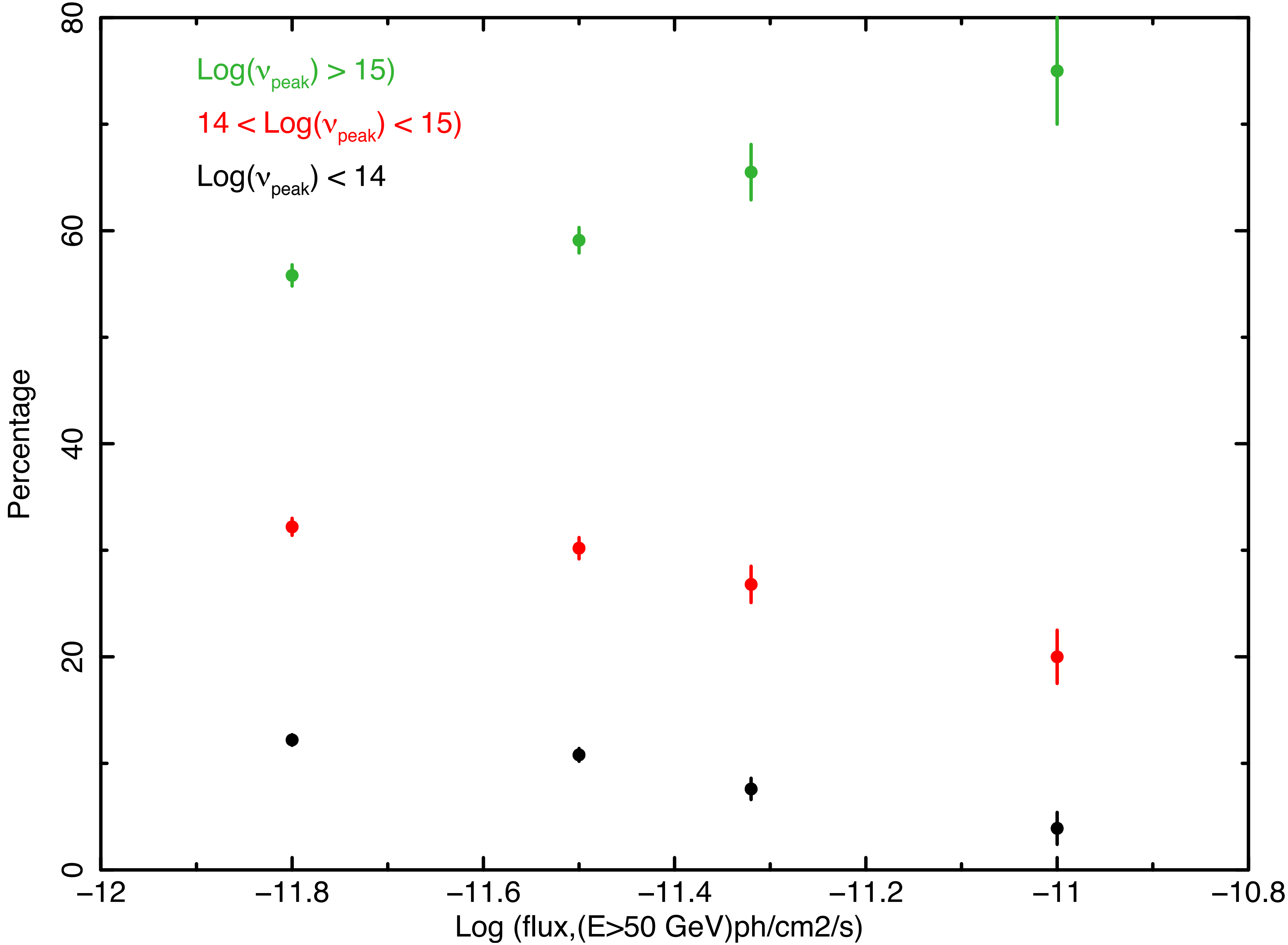
Flux (E> 50GeV)ebl-deabsorbed = 2x10^11*Sync_peak_flux*10^(-0.154*log(νpeak)-8.03)
PRELIMINARY
Log(ebl−deabsorbedF>50GeV/fom)
−10
−10.5
−11
−11.5
15
15.5
16
16.5
17
17.5
18
18.5
Log(νpeak)



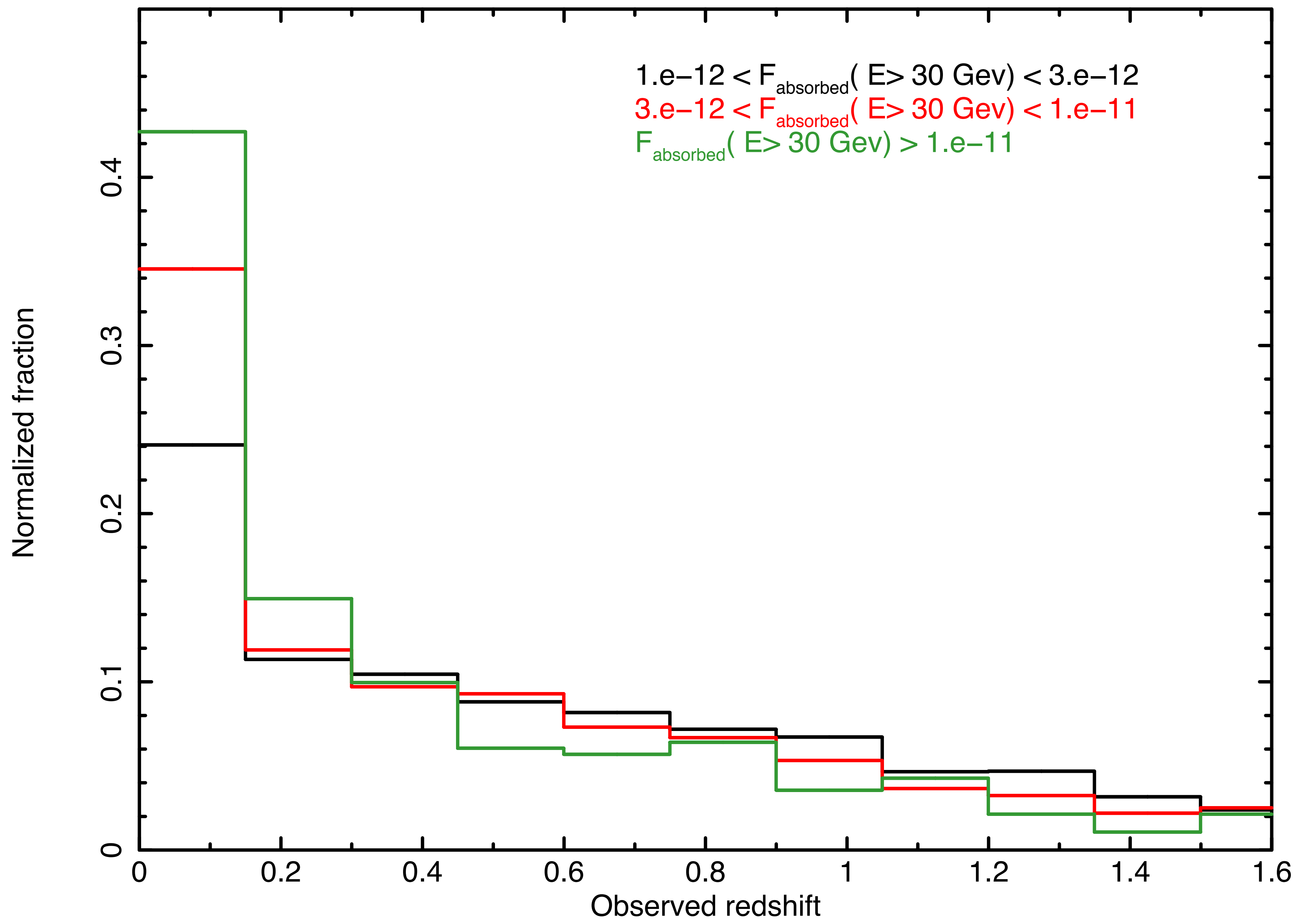
Flux (E> 50GeV)ebl-deabsorbed = 2x10^11*Sync_peak_flux*10^(-0.154*log(νpeak)-8.03)
PRELIMINARY
Factor of 2 from best fit
PRELIMINARY
Log(ebl−deabsorbedF>50GeV/fom)
−10
−10.5
−11
−11.5
15
15.5
16
16.5
17
17.5
18
18.5
Log(νpeak)



VHE LogN–LogS
Fermi 2FHL
Simplified view
2WHSP prediction
0.1
0.01
10^{-3}
10^{-4}
10^{-5}
N(>S) [deg^{-2}]
10^{-12}
10^{-11}
10^{-10}
10^{-9}
VHE gamma–ray flux (> 50GeV) [ph cm^{-2}s^{-1}]



Log(ν_peak) > 15)
14 < Log(ν_peak) < 15)
Log(ν_peak) < 14
Percentage
0
20
40
60
80
−12
−11.8
−11.6
−11.4
−11.2
−11
−10.8
Log (flux,(E>50 GeV)ph/cm2/s)



1.e−12 < F$_{absorbed}$(E> 30 Gev) < 3.e−12
3.e−12 < F$_{absorbed}$(E> 30 Gev) < 1.e−11
F$_{absorbed}$(E> 30 Gev) > 1.e−11
Normalized fraction
Observed redshift
0
0.1
0.2
0.3
0.4
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

The cumulative neutrino emission from BL

A simplified view of blazars: the neutrino background

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MNRAS, 2015, 452, 1877

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arXiv:1506.09135v1 [astro-ph.HE] 30 Jun 2015

ABSTRACT
Blazars have been suggested as possible neutrino sources long before the recent IceCube discovery of high-energy neutrinos. We re-examine this possibility within a new framework built upon the *blazar simplified view* and a self-consistent modelling of neutrino emission from individual sources. The former is a recently proposed paradigm that explains the diverse statistical properties of blazars adopting minimal assumptions on blazars' physical and geometrical properties. This view, tested through detailed Monte Carlo simulations, reproduces the main features of radio, X-ray, and γ-ray blazar surveys and also the extragalactic γ-ray background at energies $\gtrsim$ 10 GeV. Here we add a hadronic component for neutrino production and estimate the neutrino emission from BL Lacs as a class, "calibrated" by fitting the spectral energy distributions of a preselected sample of BL Lac objects and their (putative) neutrino spectra. Unlike all previous papers on this topic, the neutrino background is then derived by summing up at a given energy the fluxes of each BL Lac in the simulation, all characterised by their own redshift, synchrotron peak energy, γ-ray flux, etc. Our main result is that BL Lacs as a class can explain the neutrino background seen by IceCube above $\sim$ 0.5 PeV while they only contribute $\sim$ 10% at lower energies, leaving room to some other population(s)/physical mechanism. However, one cannot also exclude the possibility that individual BL Lacs still make a contribution at the $\approx$ 20% level to the IceCube low-energy events. Our scenario makes specific predictions testable in the next few years.

Key words: neutrinos — radiation mechanisms: non-thermal — BL Lacertae objects: general — gamma-rays: galaxies

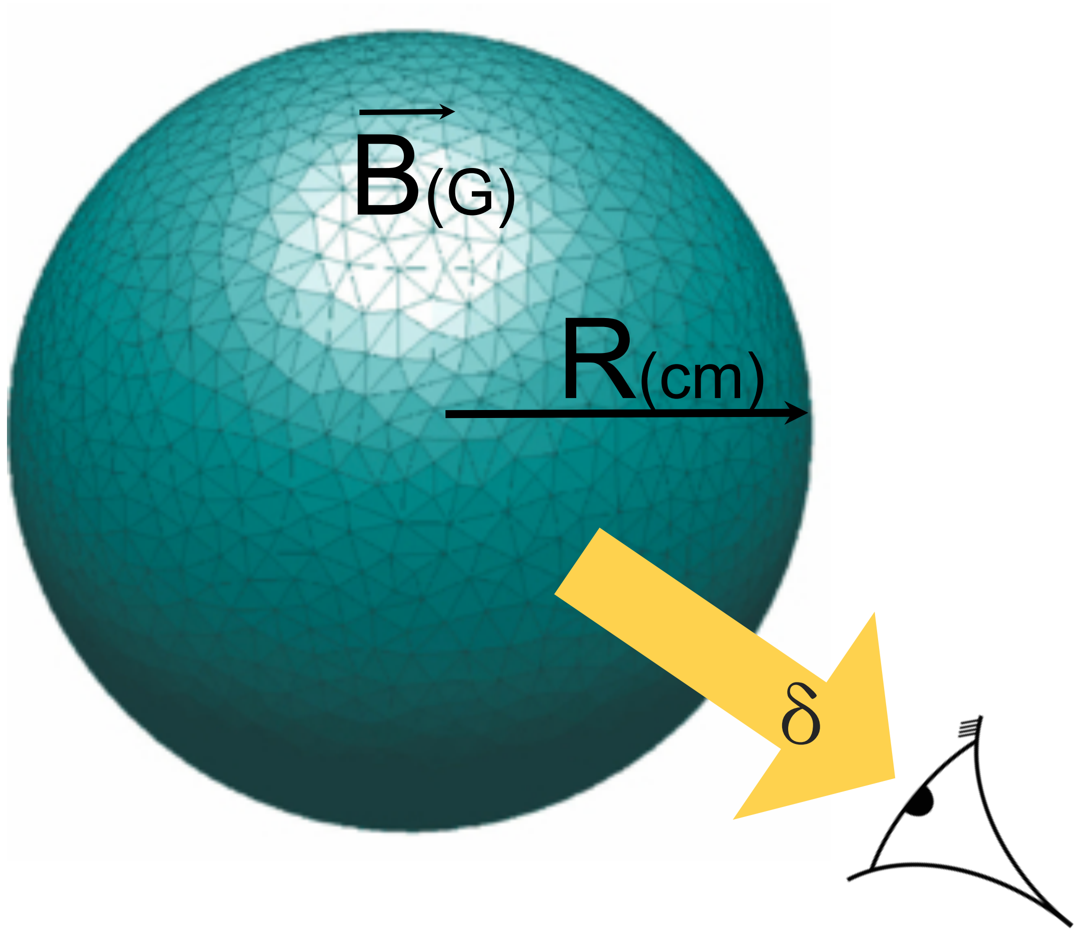
1 INTRODUCTION

Blazars are a class of Active Galactic Nuclei (AGN), which host a jet oriented at a small angle with respect to the line of sight. Highly relativistic particles moving within the jet and in a magnetic field emit non-thermal radiation (Blandford & Rees 1978; Urry & Padovani 1995). This is at variance with most other AGN whose energy is mainly thermal and produced through accretion and rapid variability, and strong emission over the entire electromagnetic spectrum. The two main blazar subclasses, namely BL Lacertae objects (BL Lacs) and flat-spectrum radio quasars (FSRQ), differ mostly in their optical spectra, with the latter displaying strong, broad emission lines and the former instead being characterised by optical spectra showing at most weak emission lines, sometimes exhibiting absorption features, and in many cases being completely featureless.

Theoretical modelling

Input:

- electrons and protons accelerated by some mechanism
- injected isotropically in the blob, constant rate
- interaction with magnetic field, production of secondaries



Theoretical modelling

Output: five stable particle populations

- protons lose energy by:
  - ✓ synchrotron radiation, Bethe-Heitler (*pe*) pair production ($p+\gamma \rightarrow e^{+} + e^{-}$), photopion interaction
- electrons lose energy by:
  - ✓ synchrotron radiation, inverse Compton scattering
- photons: gain and lose energy in various ways
- neutrons: escape
- neutrinos: escape

Interplay of the processes described by a set of time-dependent kinetic equations, solved by a numerical code.

Neutrino spectra

$= L_\nu / L_\gamma$

$$E_\nu F(E_\nu) \propto Y_{\nu\gamma} E_\nu^{1-s} \exp(-E_\nu / E_0) F\gamma(>10 GeV)$$

$$E_0 \cong \frac{17.5 PeV}{(1+z)^2} \left(\frac{\delta}{10}\right)^2 \left(\frac{\nu_{synch,peak}}{10^{16} Hz}\right)^{-1}$$

Plus: γ-ray luminosity function, evolution, source class, etc.

The big picture