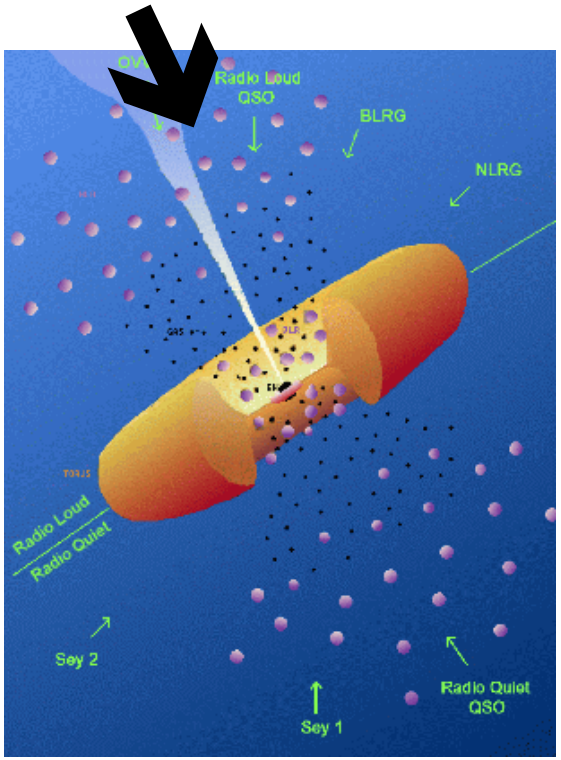
A multi-wavelength and multi-messenger view of blazars

Paolo Giommi
ASI-ASDC



AGN : Two main categories

1. *Dominated by (mostly) thermal emission from accretion disk -*

   Radio quiet AGN (>~90 %)

(normal QSO powered by accretion onto a SM black hole)

1. *Dominated by Non-Thermal radiation –*

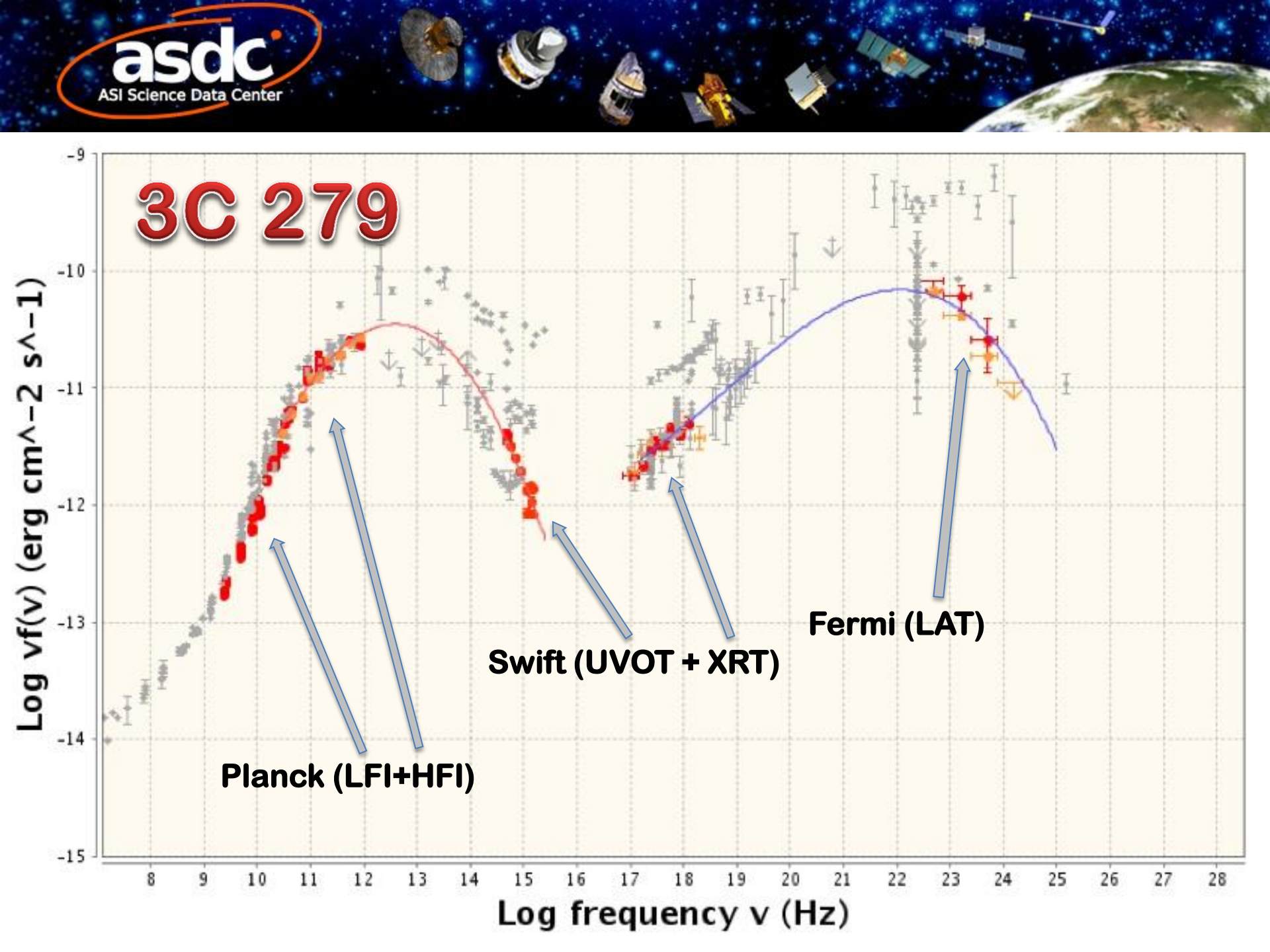
   Jet dominated AGN (< 10%)

When $\Theta < \theta_{blazar}$ ⟹ **Blazar**

As of today, about 3,561 blazars are known (Bzcat, edition 5., Massaro et al. 2015).

This number is increasing rapidly but it remains a small percentage of the over one million AGN known

..and the ~one billion stars/galaxies known


asdc
ASI Science Data Center
3C 279
Planck (LFI+HFI)
Swift (UVOT + XRT)
Fermi (LAT)
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
-9
-10
-11
-12
-13
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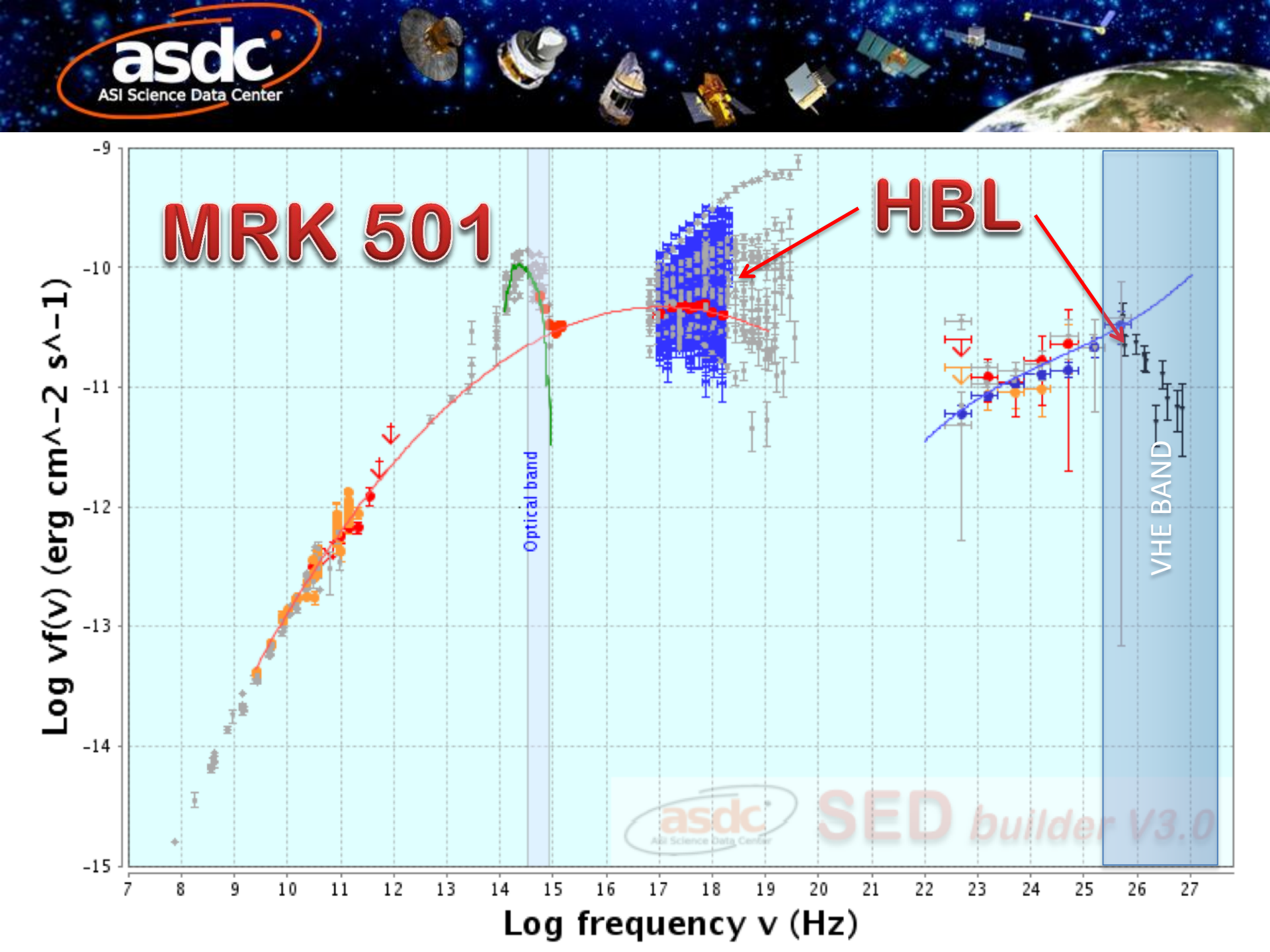
asdc
ASI Science Data Center
MRK 501
HBL
Optical band
VHE BAND
asdc SED builder V3.0
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
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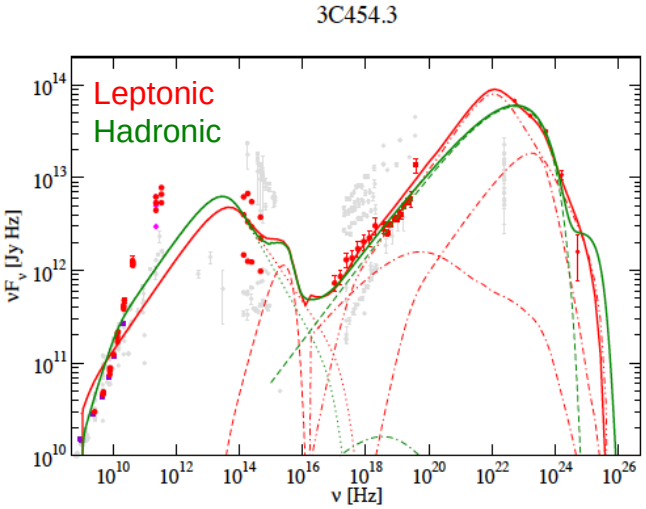
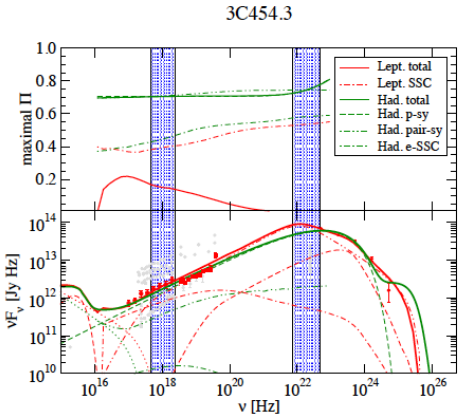
Leptonic or hadronic emission??

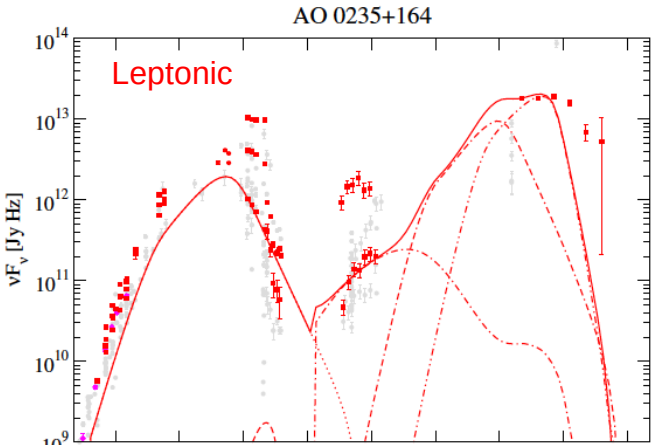
Most blazar spectra well fit by leptonic models

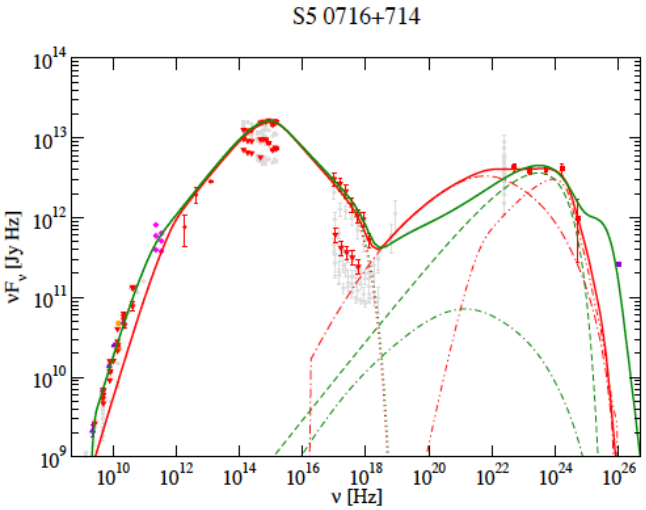
Optical/X-ray polarization can decide

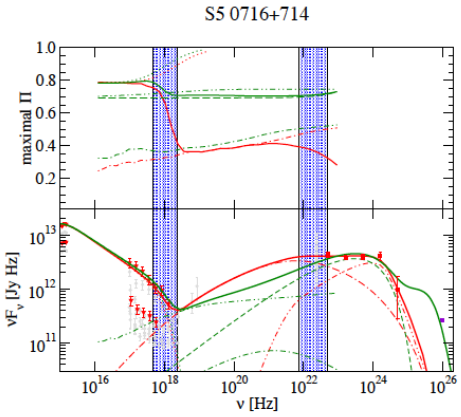
But a few are better fit by hadronic models

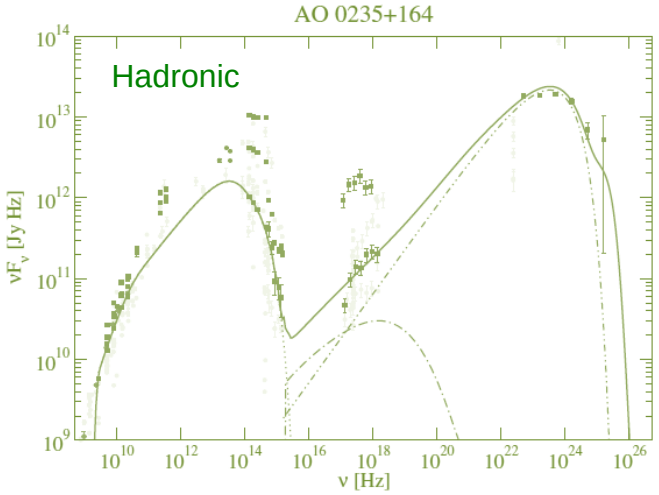




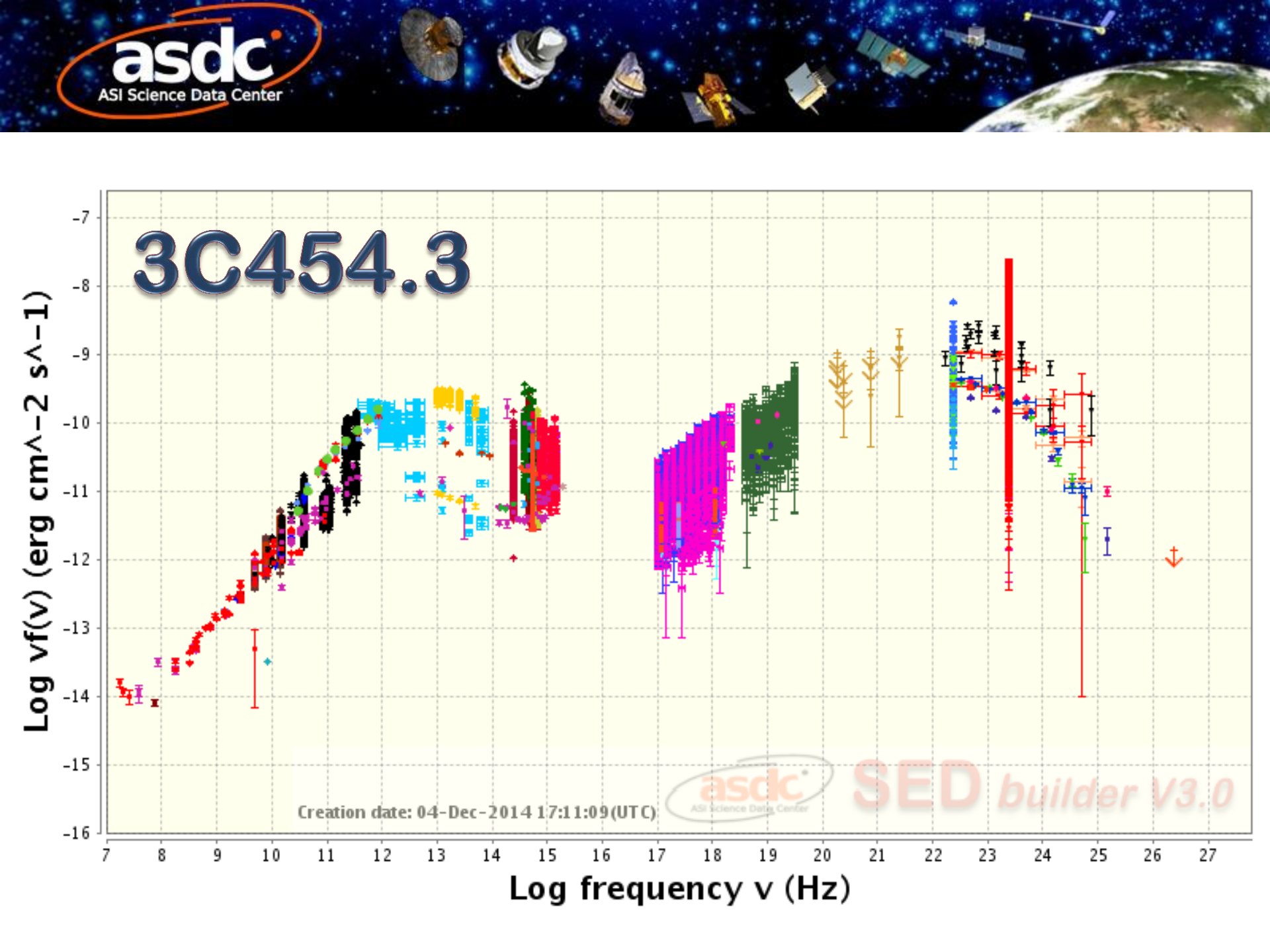








Bottcher et al. 2013


asdc
ASI Science Data Center
3C454.3
Log vf(v) (erg cm^-2 s^-1)
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
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Log frequency v (Hz)
Creation date: 04-Dec-2014 17:11:09(UTC)
asdc
ASI Science Data Center
SED builder V3.0

asdc ASI Science Data Center

SED(t) builder [V2.1]

a VO-compliant ASDC tool

Version 2.1.6

giommi (Logout) Feedback

Tutorial DATA EXPLORER

User Data Existing SEDs

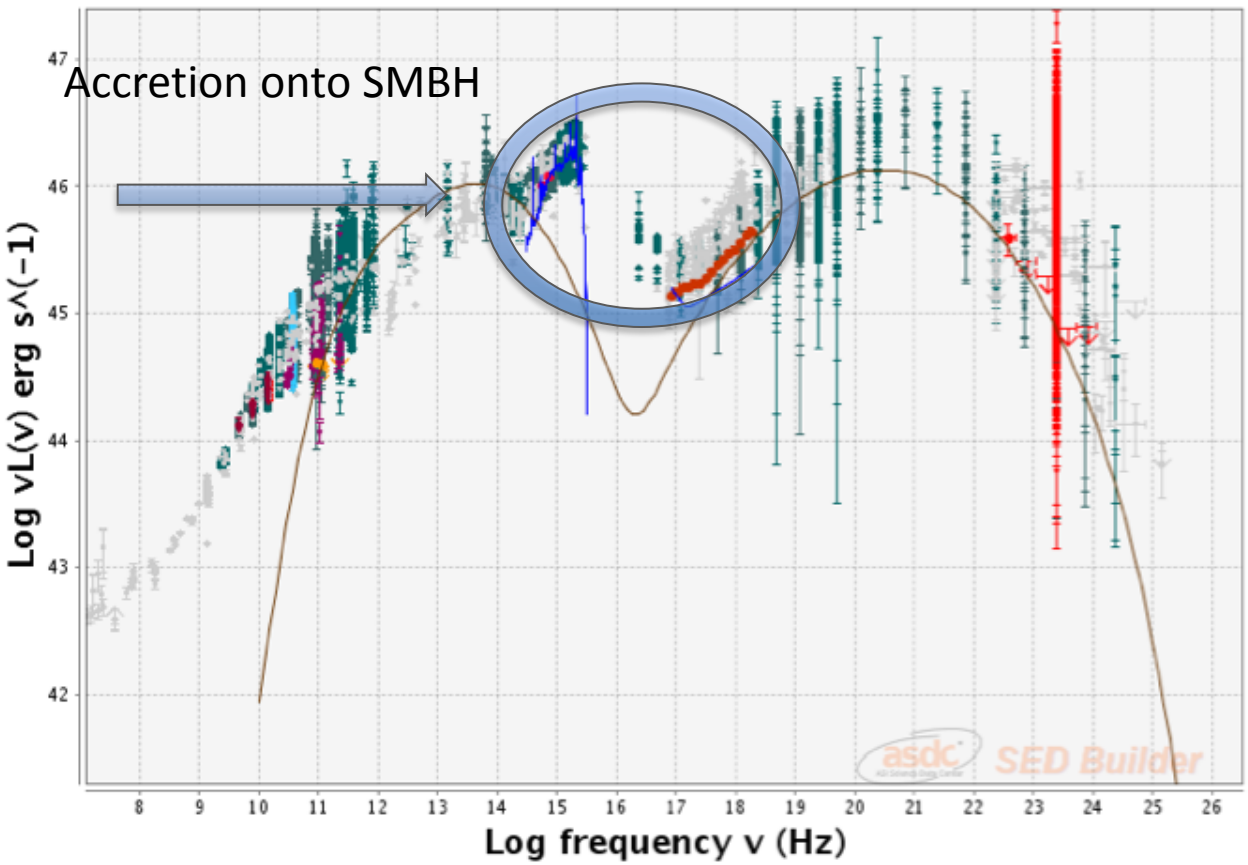
Current SED Search and build new SEDs

Edit SED properties

Load Data | Show Data | Save | Duplicate Sed

3C273 Ra=187.27750 deg Dec=2.05240 deg (NH=1.7E20 cm^-2)

Accretion onto SMBH



Redshift: 0.158 Frame: Observed

X Axis: Frequency (Hz) Y Axis: nuLnu (erg/s)

Update Plot

Input Data | Models | Fit Functions

Templates | Instr Sensitivity | Plot options

Existing SEDs | Export | Vo Tools

Caution.This is a Beta Version.

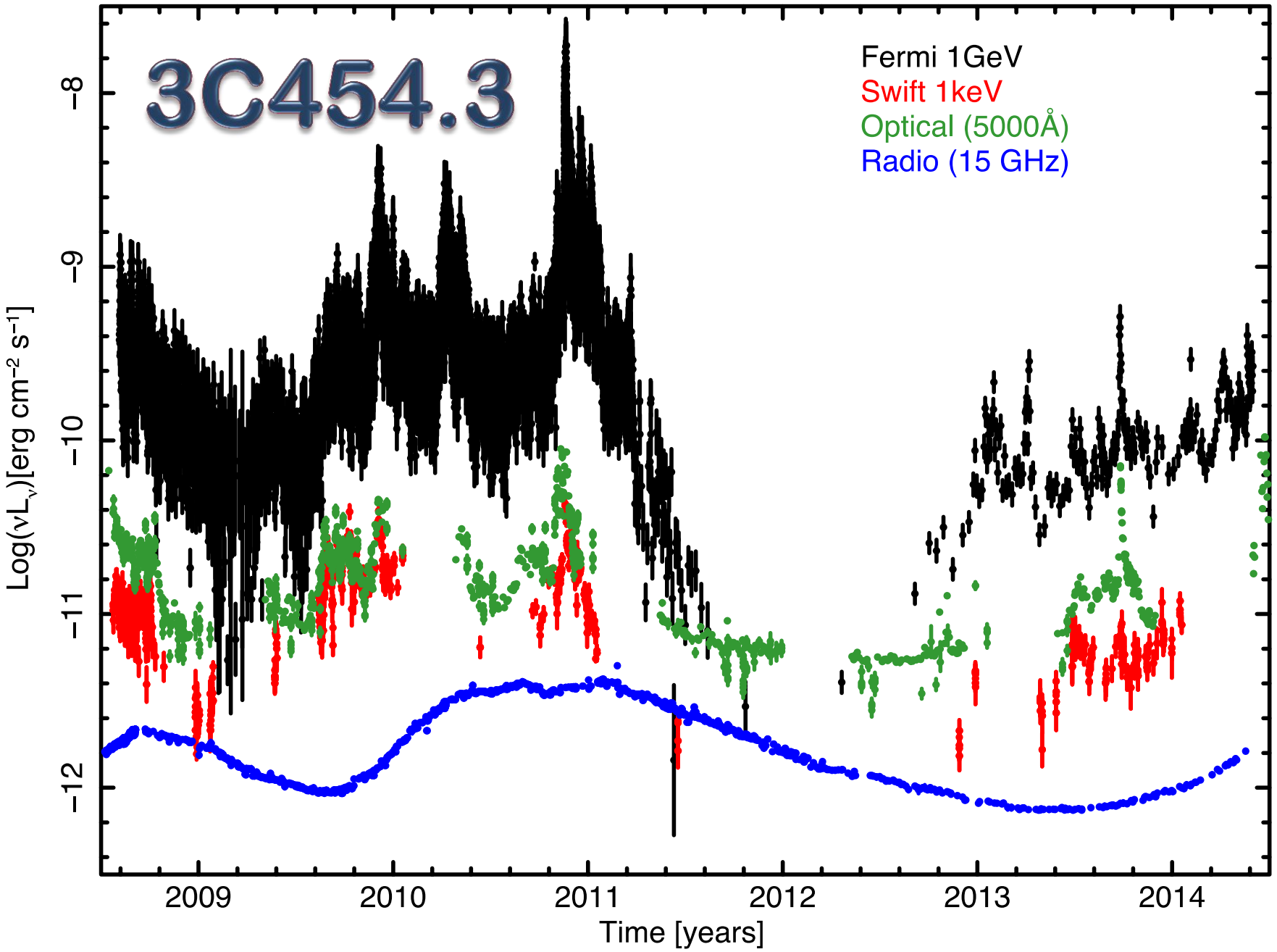
Launch TOPCAT | Launch IRIS

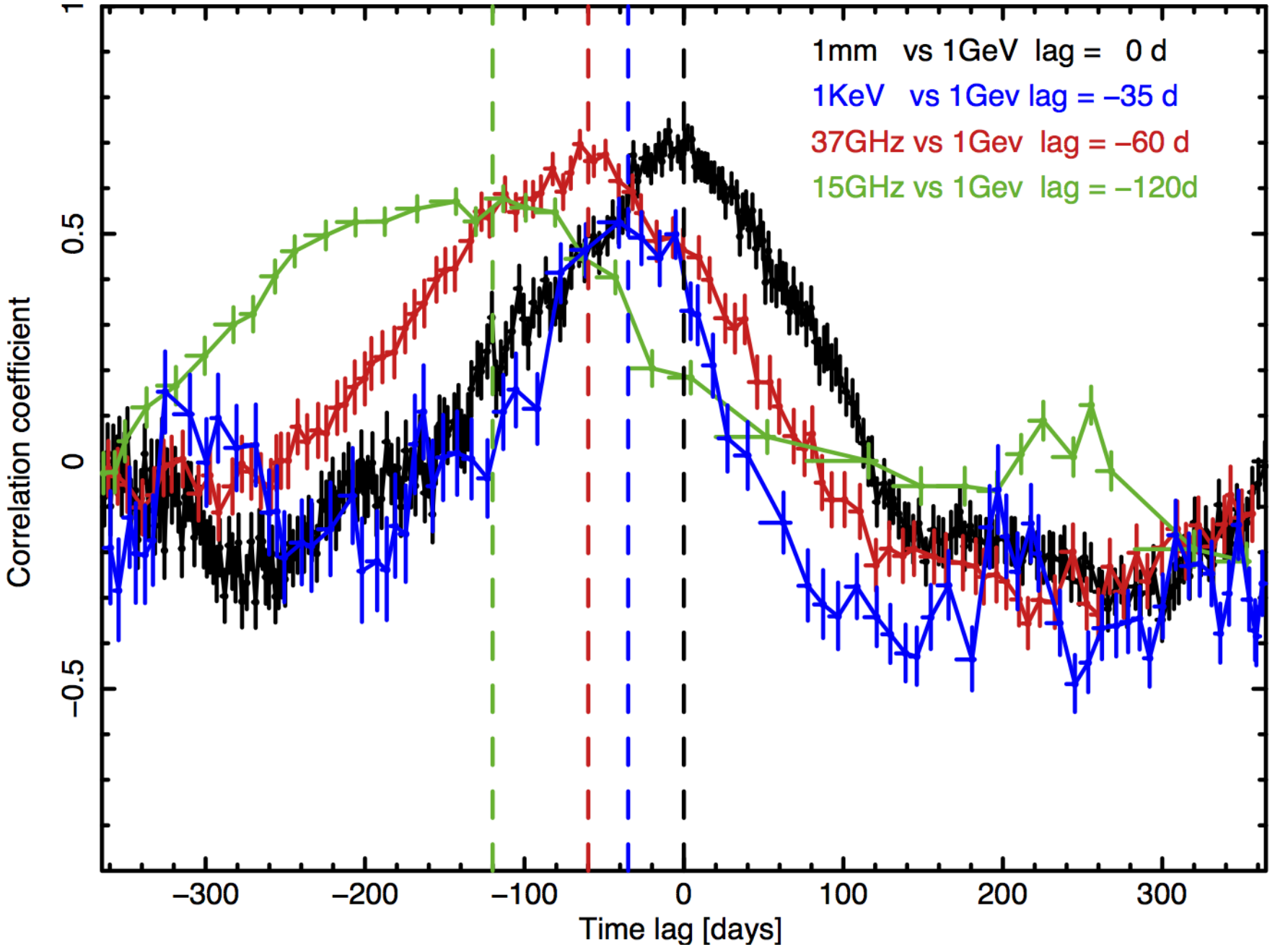
Broadcast Type: SED 3D

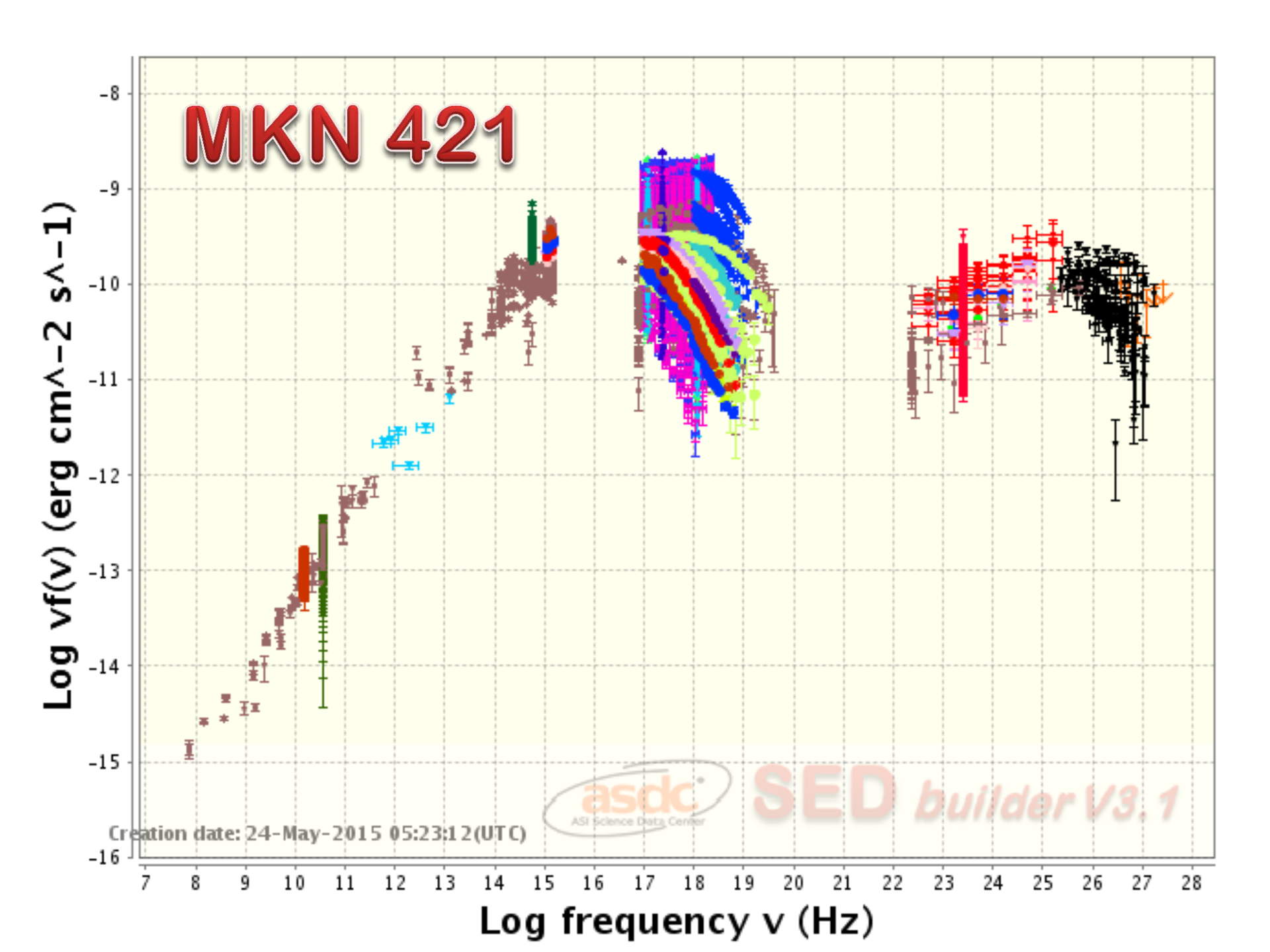
Register | Unregister Registered: Yes

Registered Clients

- Hub (meta+) (subs+)
- topcat (meta+) (subs+) Broadcast


3C454.3
Fermi 1GeV
Swift 1keV
Optical (5000Å)
Radio (15 GHz)
Log(νL_ν)[erg cm^-2 s^-1]
−8
−9
−10
−11
−12
2009
2010
2011
2012
2013
2014
Time [years]


1mm vs 1GeV lag = 0 d
1KeV vs 1Gev lag = –35 d
37GHz vs 1Gev lag = –60 d
15GHz vs 1Gev lag = –120d
Correlation coefficient
1
0.5
0
–0.5
–300
–200
–100
0
100
200
300
Time lag [days]


MKN 421
Log vf(v) (erg cm^-2 s^-1)
-8
-9
-10
-11
-12
-13
-14
-15
-16
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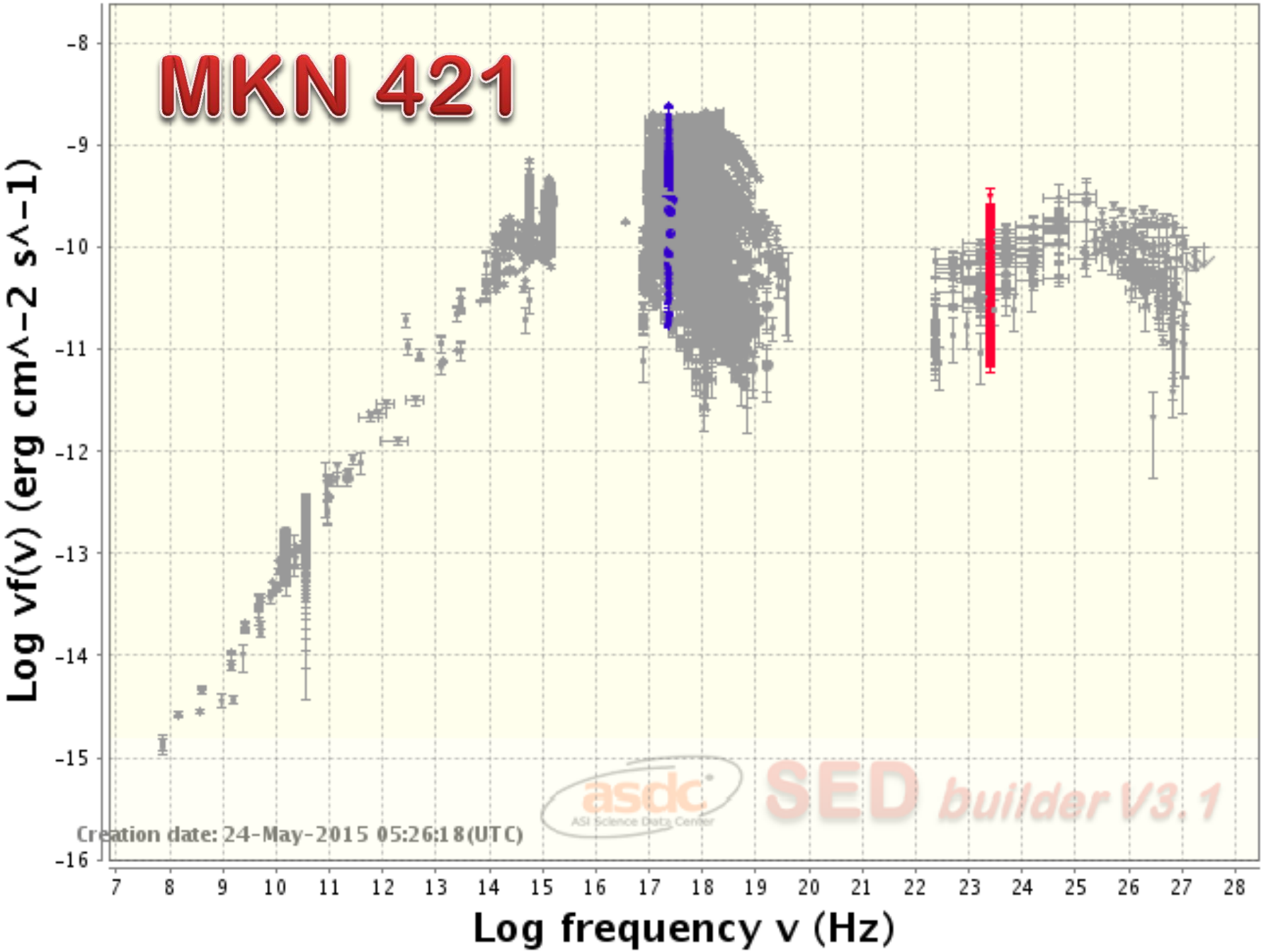
Log frequency v (Hz)
asdc
ASI Science Data Center
SED builder V3.1
Creation date: 24-May-2015 05:23:12(UTC)


MKN 421
Log vf(v) (erg cm^-2 s^-1)
-8
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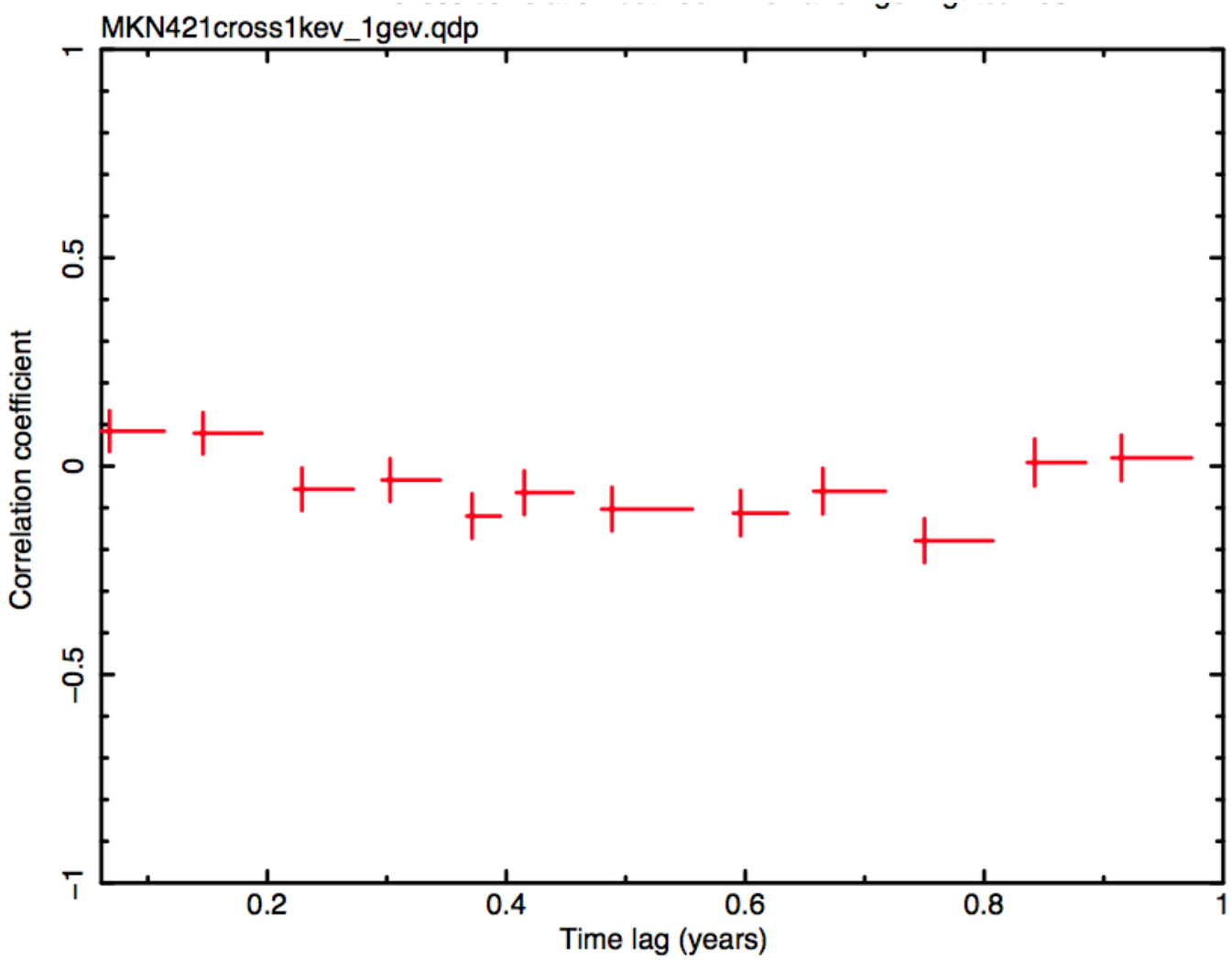
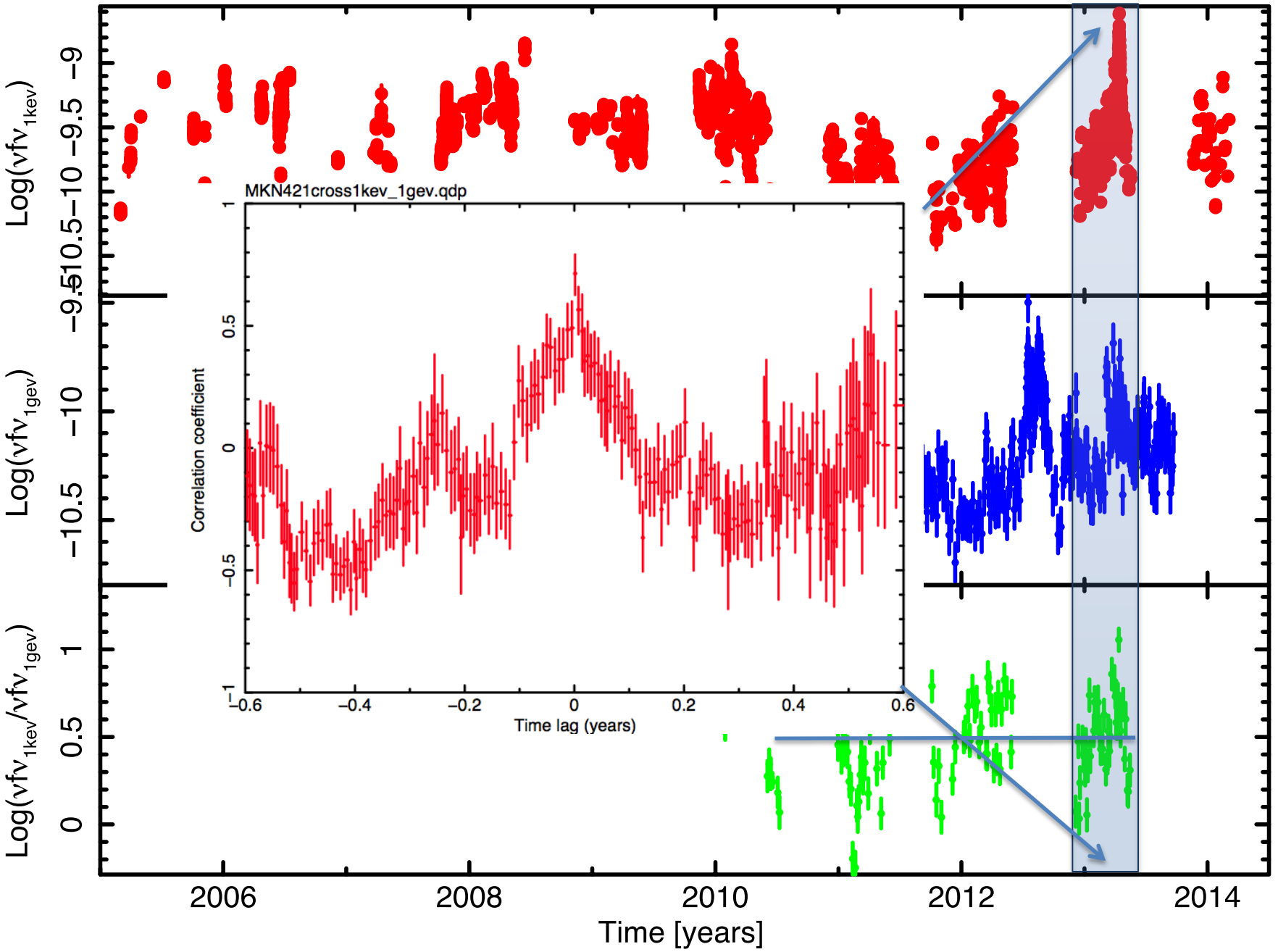
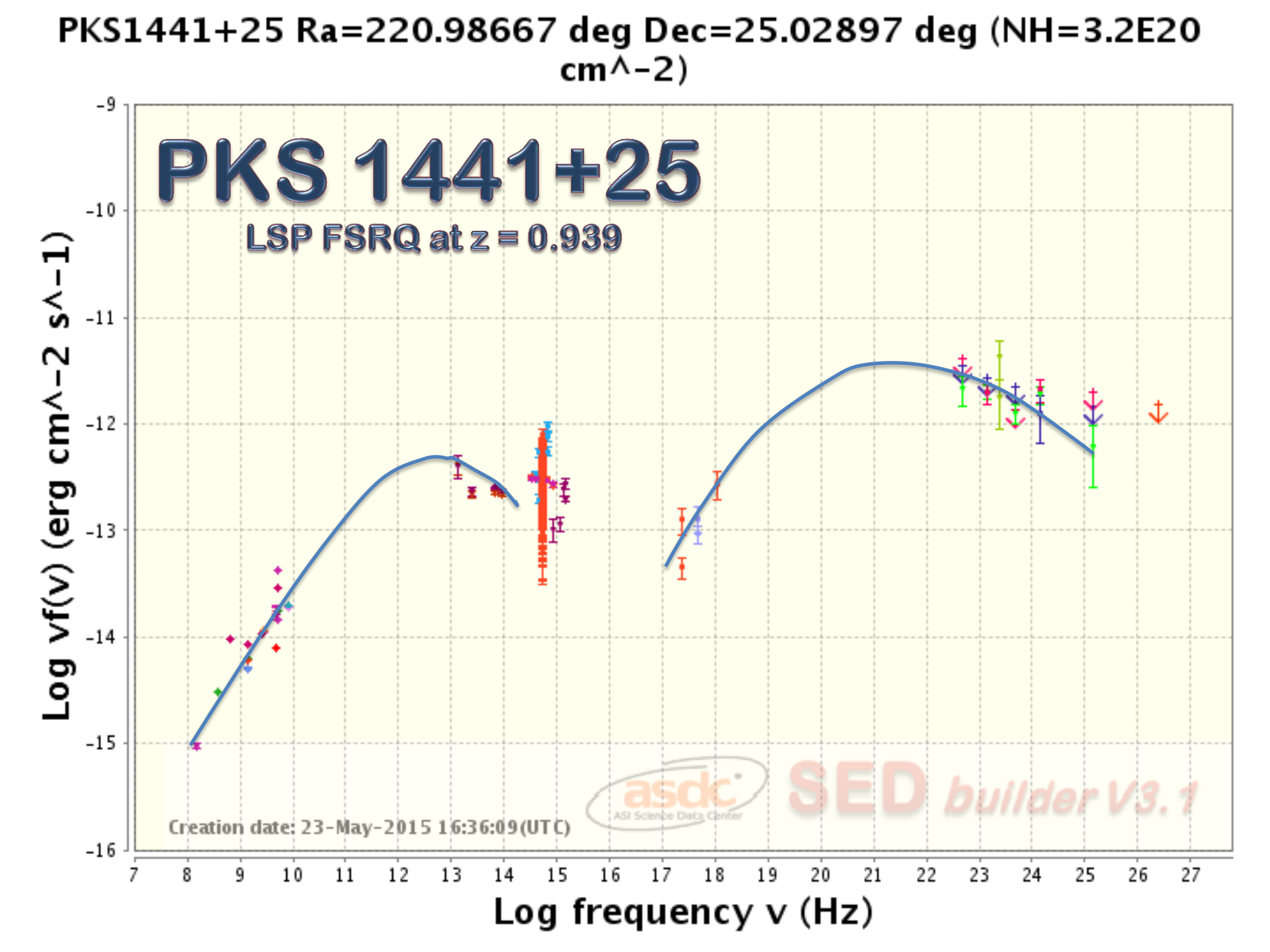
28
Log frequency v (Hz)
Creation date: 24-May-2015 05:26:18(UTC)
asdc
ASI Science Data Center
SED builder V3.1

Cross correlation between 1keV and 1 GeV
Period 2008.5 – 2013.5



MKN 421


Log(νfν1kev)
−9
−9.5
−10
−10.5
Log(νfν1gev)
−10.5
−10
−9.5
Log(νfν1kev/νfν1gev)
1
0.5
0
2006
2008
2010
2012
2014
Time [years]
MKN421cross1kev_1gev.qdp
Correlation coefficient
1
0.5
0
−0.5
−1
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
Time lag (years)


PKS1441+25 Ra=220.98667 deg Dec=25.02897 deg (NH=3.2E20 cm^-2)
PKS 1441+25
LSP FSRQ at z = 0.939
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
-9
-10
-11
-12
-13
-14
-15
-16
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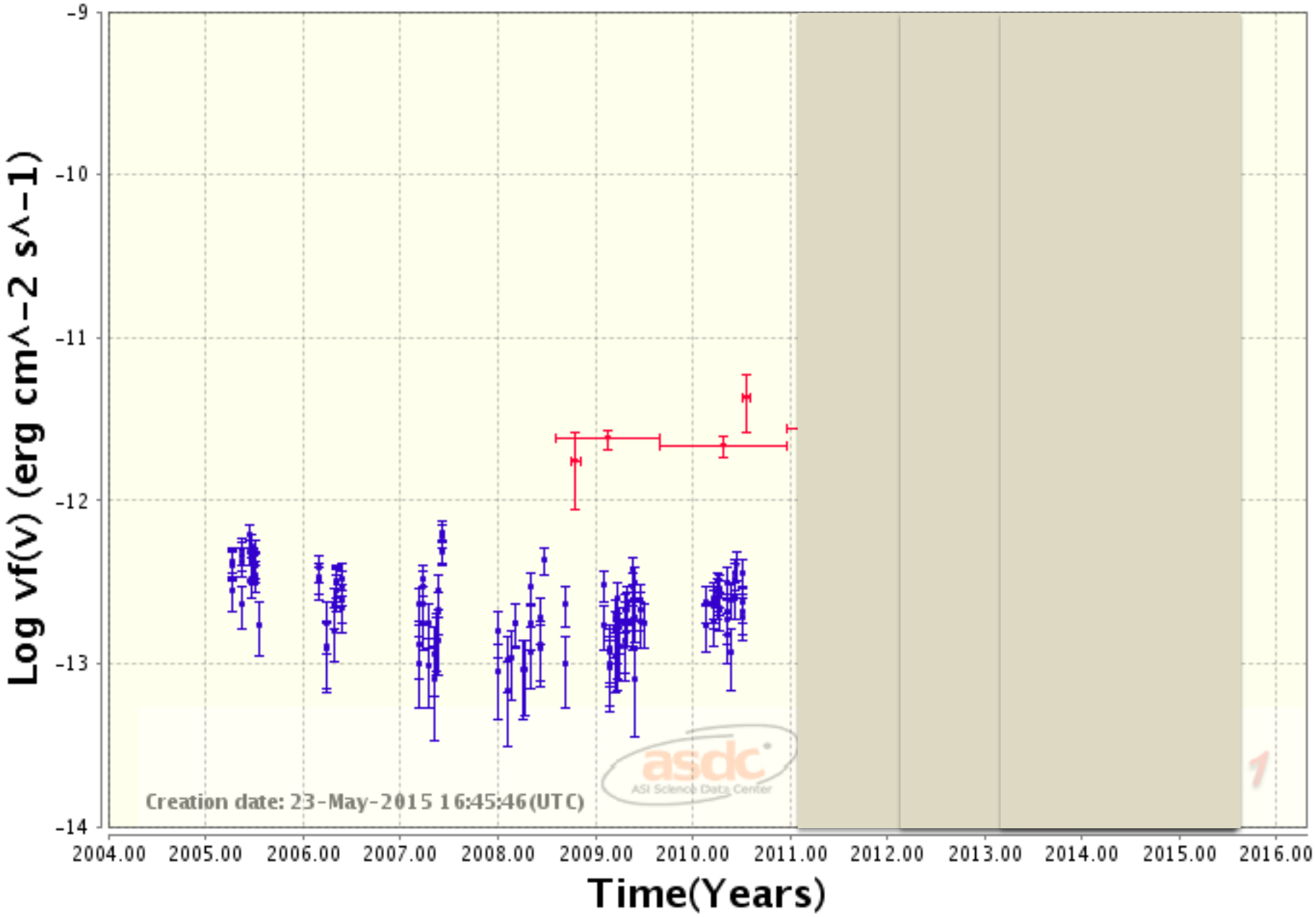
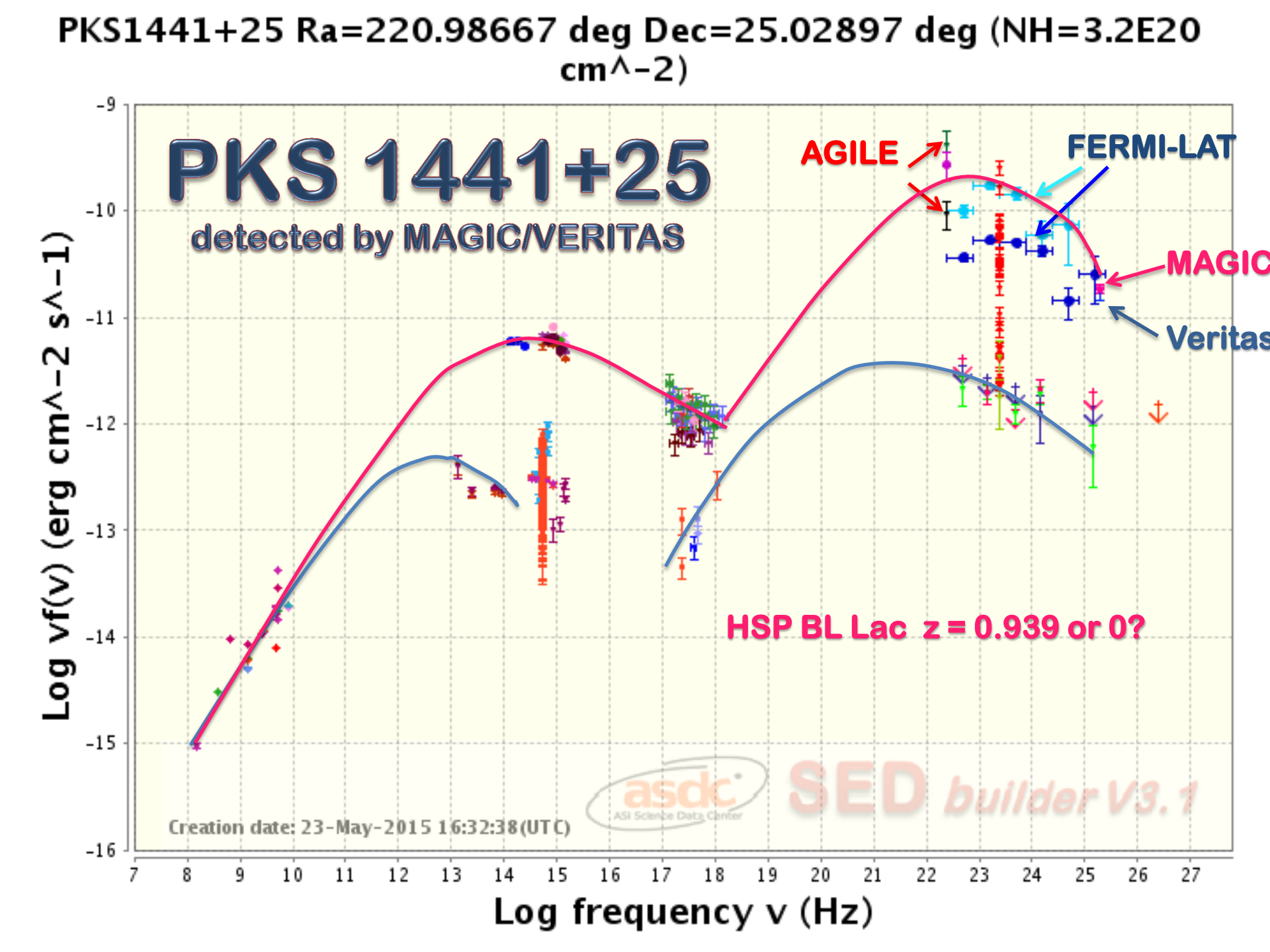
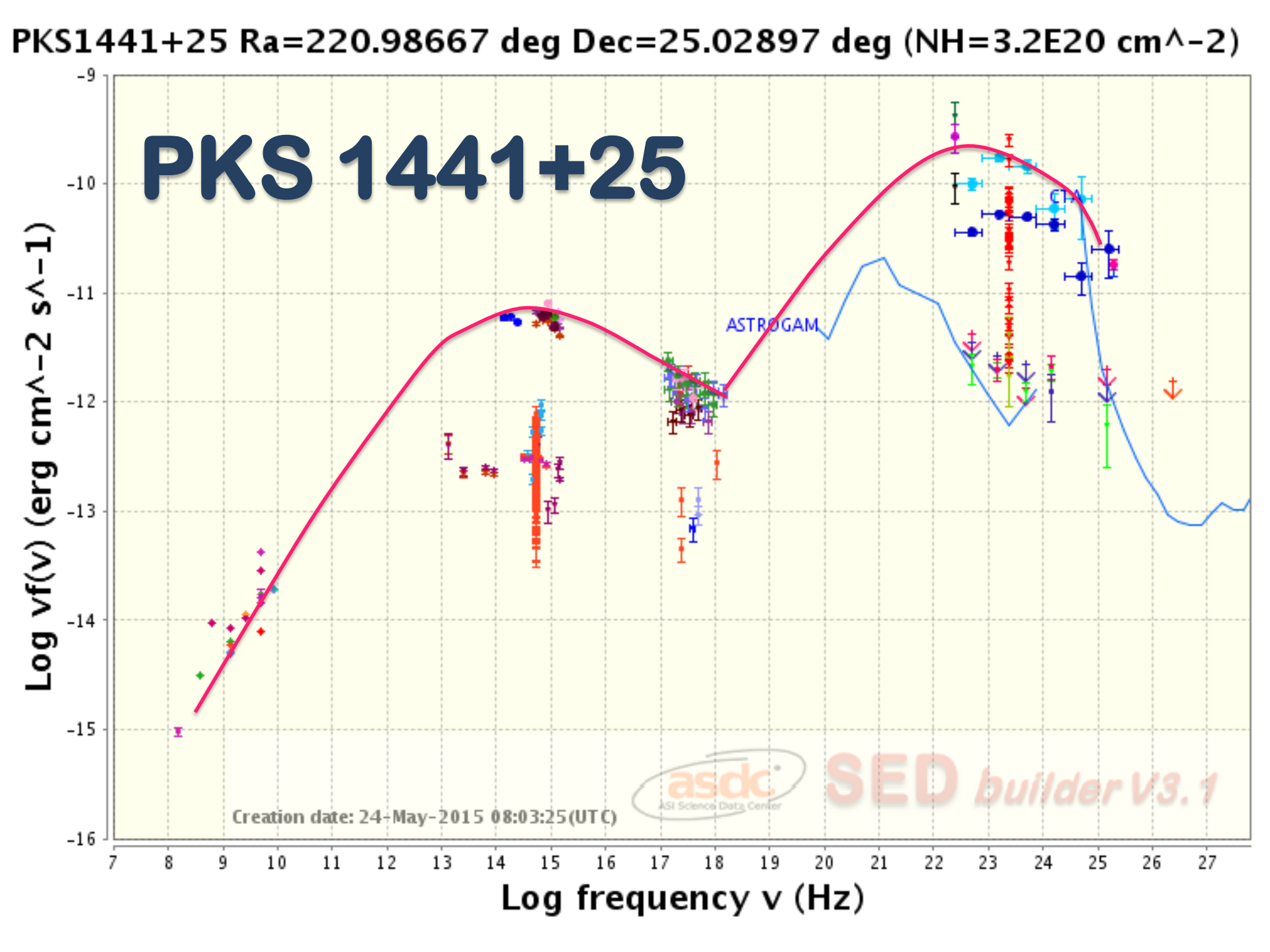
Creation date: 23-May-2015 16:36:09(UTC)
asdc
ASI Science Data Center
SED builder V3.1


PKS1441+25 Ra=220.98667 deg Dec=25.02897 deg (NH=3.2E20 cm^-2)
Log vf(v) (erg cm^-2 s^-1)
-9
-10
-11
-12
-13
-14
2004.00
2005.00
2006.00
2007.00
2008.00
2009.00
2010.00
2011.00
2012.00
2013.00
2014.00
2015.00
2016.00
Time(Years)
Creation date: 23-May-2015 16:45:46(UTC)
asdc
ASI Science Data Center


PKS1441+25 Ra=220.98667 deg Dec=25.02897 deg (NH=3.2E20 cm^-2)
PKS 1441+25
detected by MAGIC/VERITAS
AGILE
FERMI-LAT
MAGIC
Veritas
HSP BL Lac z = 0.939 or 0?
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
Creation date: 23-May-2015 16:32:38(UTC)
asdc
ASI Science Data Center
SED builder V3.1


PKS1441+25 Ra=220.98667 deg Dec=25.02897 deg (NH=3.2E20 cm^-2)
PKS 1441+25
ASTROGAM
CTA
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
Creation date: 24-May-2015 08:03:25(UTC)
asdc
ASI Science Data Center
SED builder V3.1

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

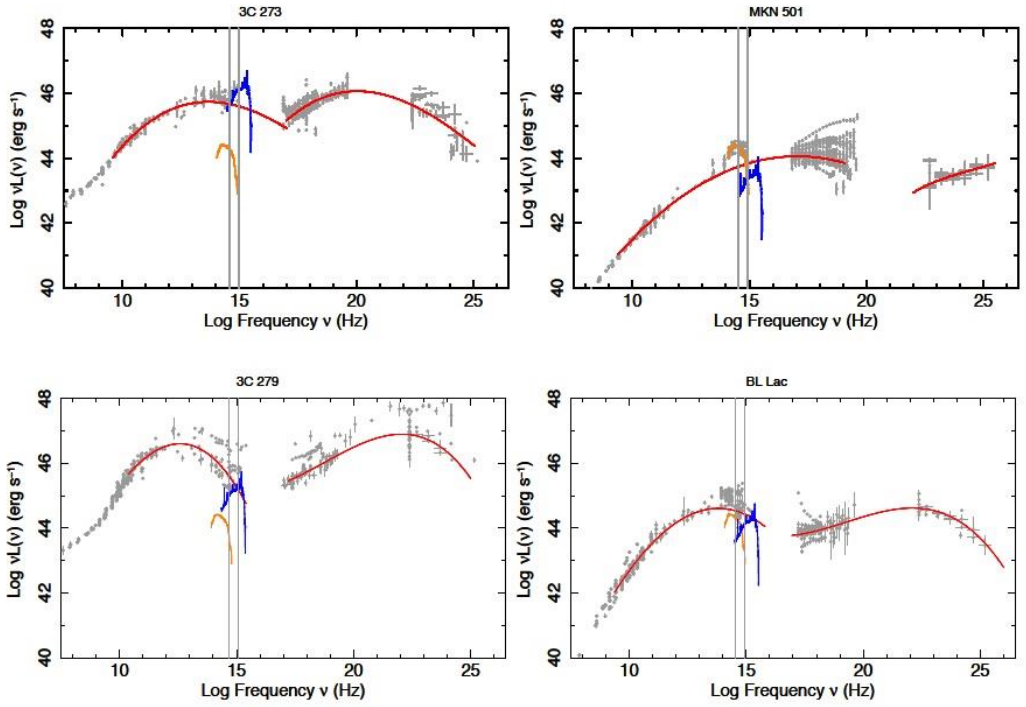
MNRAS, 2012, 420, 2899

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



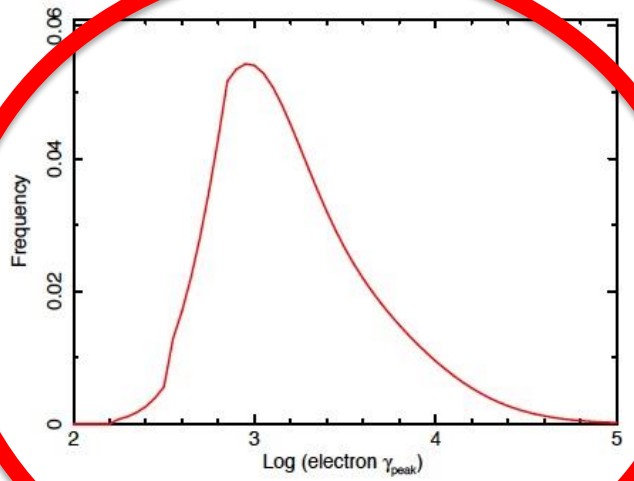


Figure 4. The distribution of the Lorentz factors of the electrons radiating at the peak of the synchrotron SED used for the simulation which also assumes a magnetic field of B=0.15 Gauss and a gaussian distribution of Doppler factors with ⟨δ⟩=15.

Fermi 2FHL

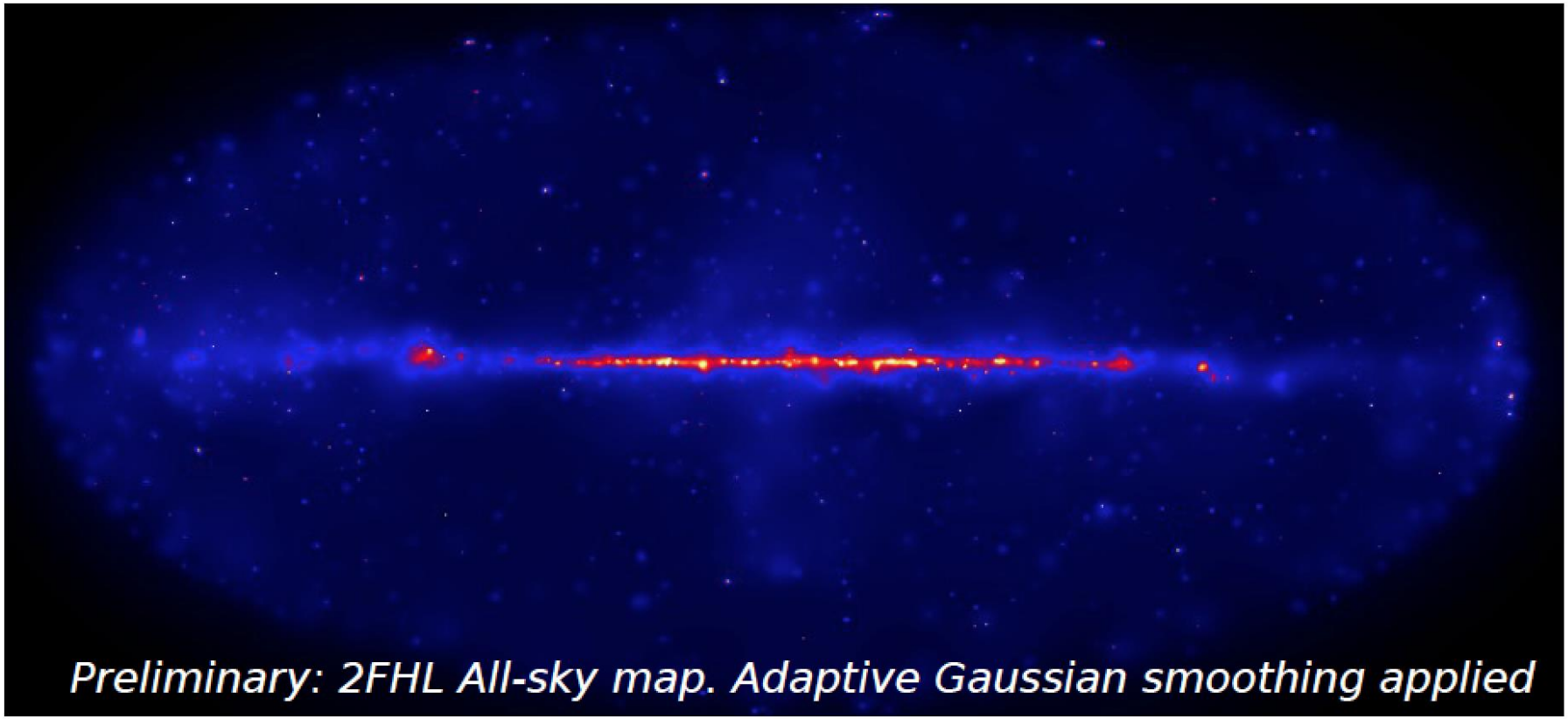
The Fermi-LAT view of the Very High Energy Sky

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

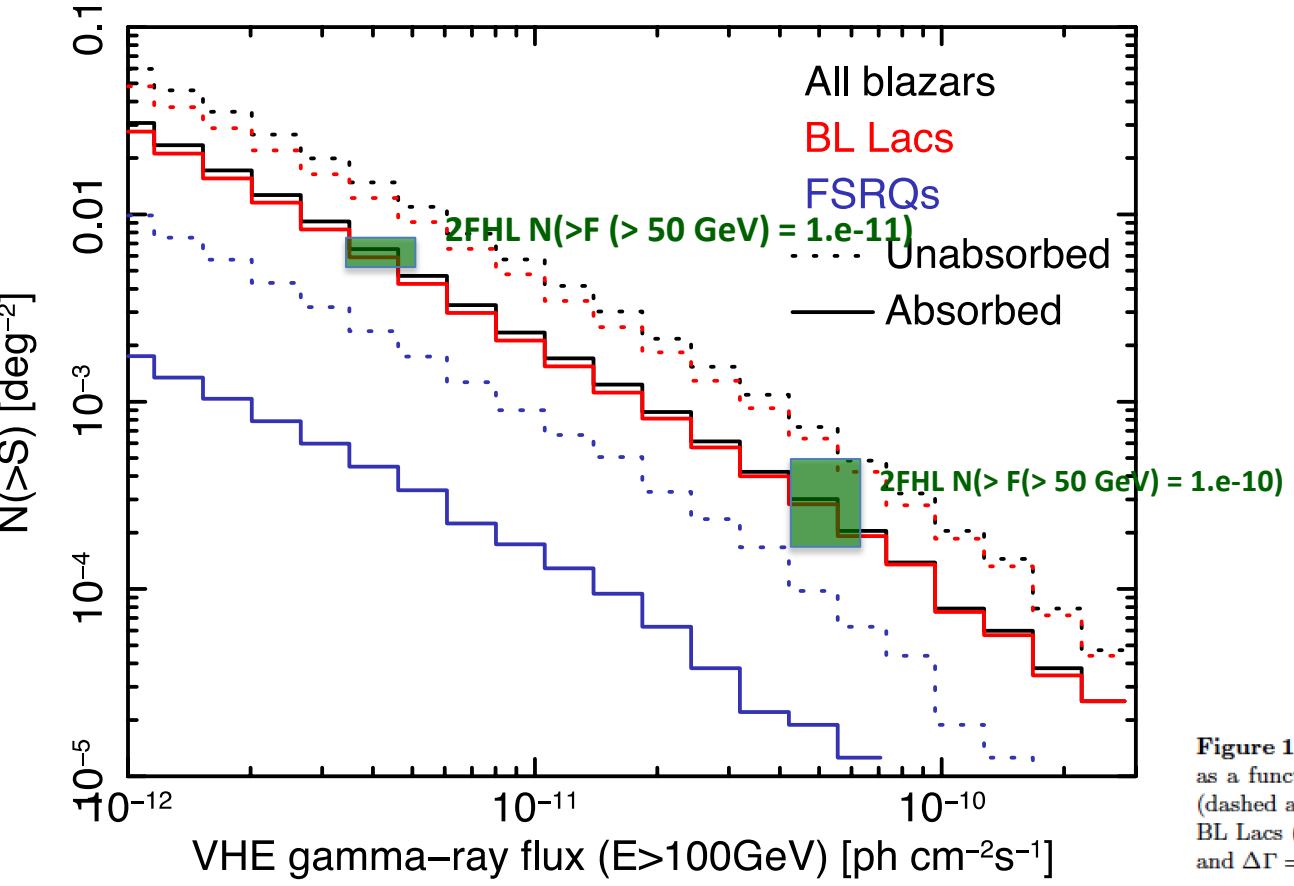
about 1 photon every deg^2



Preliminary: 2FHL All-sky map. Adaptive Gaussian smoothing applied

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

P. Padovani[1,2⋆], P. Giommi[3,4,5]
[1]*European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[2]*Associated to INAF - Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*
[3]*ASI Science Data Center, via del Politecnico s.n.c., I-00133 Roma Italy*
[4]*ICRANet-Rio, CBPF, Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro, Brazil*
[5]*Associated to INAF - Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy*



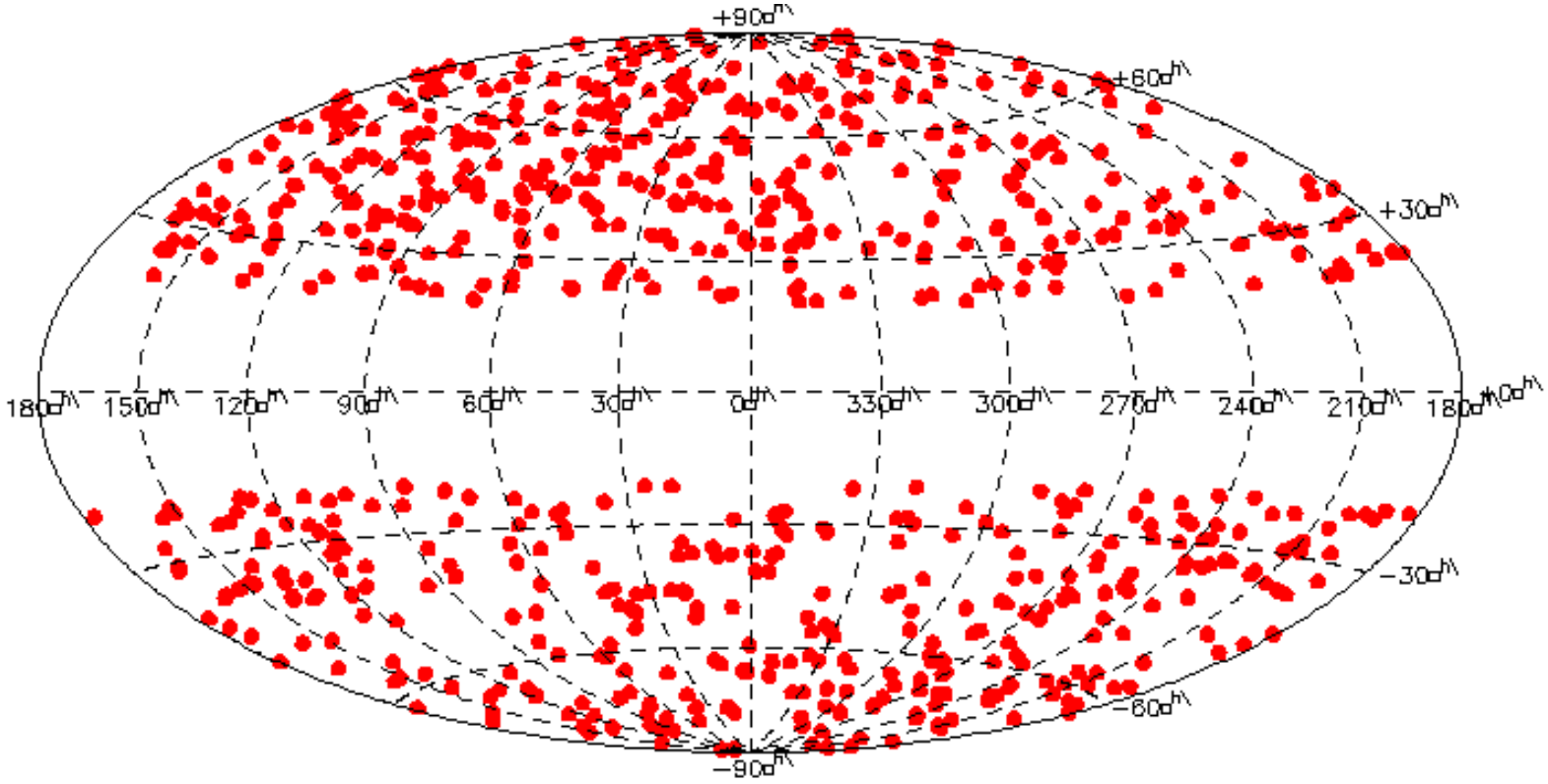
MNRAS 2015, 446L, 41
arXiv 1410.0497

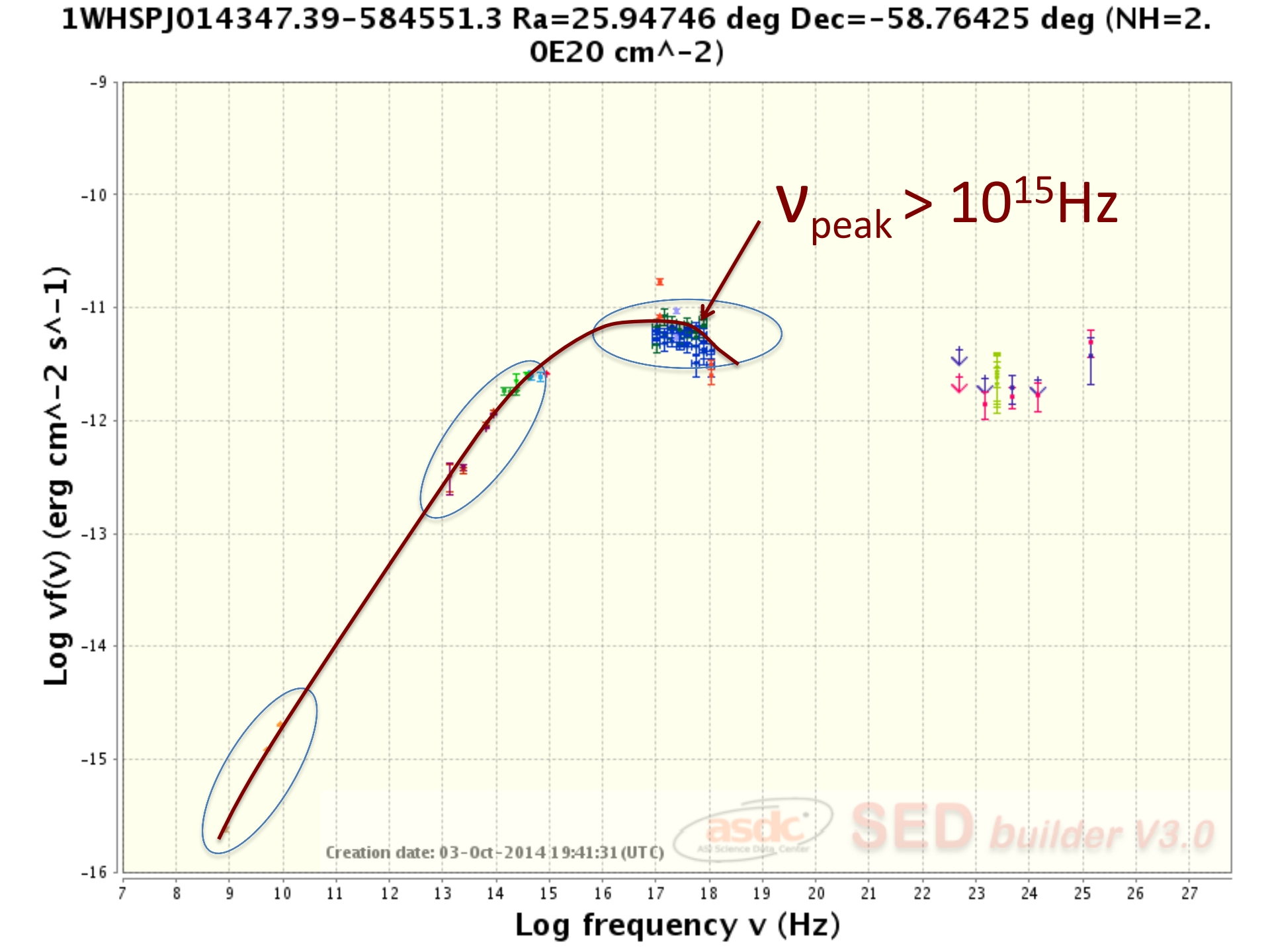
Figure 1. The predicted integral number counts at $E \geqslant 100$ GeV as a function of photon flux with and without EBL absorption (dashed and solid lines respectively) for all blazars (black lines), BL Lacs (red lines), and FSRQs (blue lines) ($E_{\rm break} = 100$ GeV and $\Delta\Gamma = 1$).

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, in press
arXiv:1504.02801




1WHSPJ014347.39-584551.3 Ra=25.94746 deg Dec=-58.76425 deg (NH=2.0E20 cm^-2)
$\nu_{peak} > 10^{15}$Hz
Log vf(v) (erg cm^-2 s^-1)
Log frequency v (Hz)
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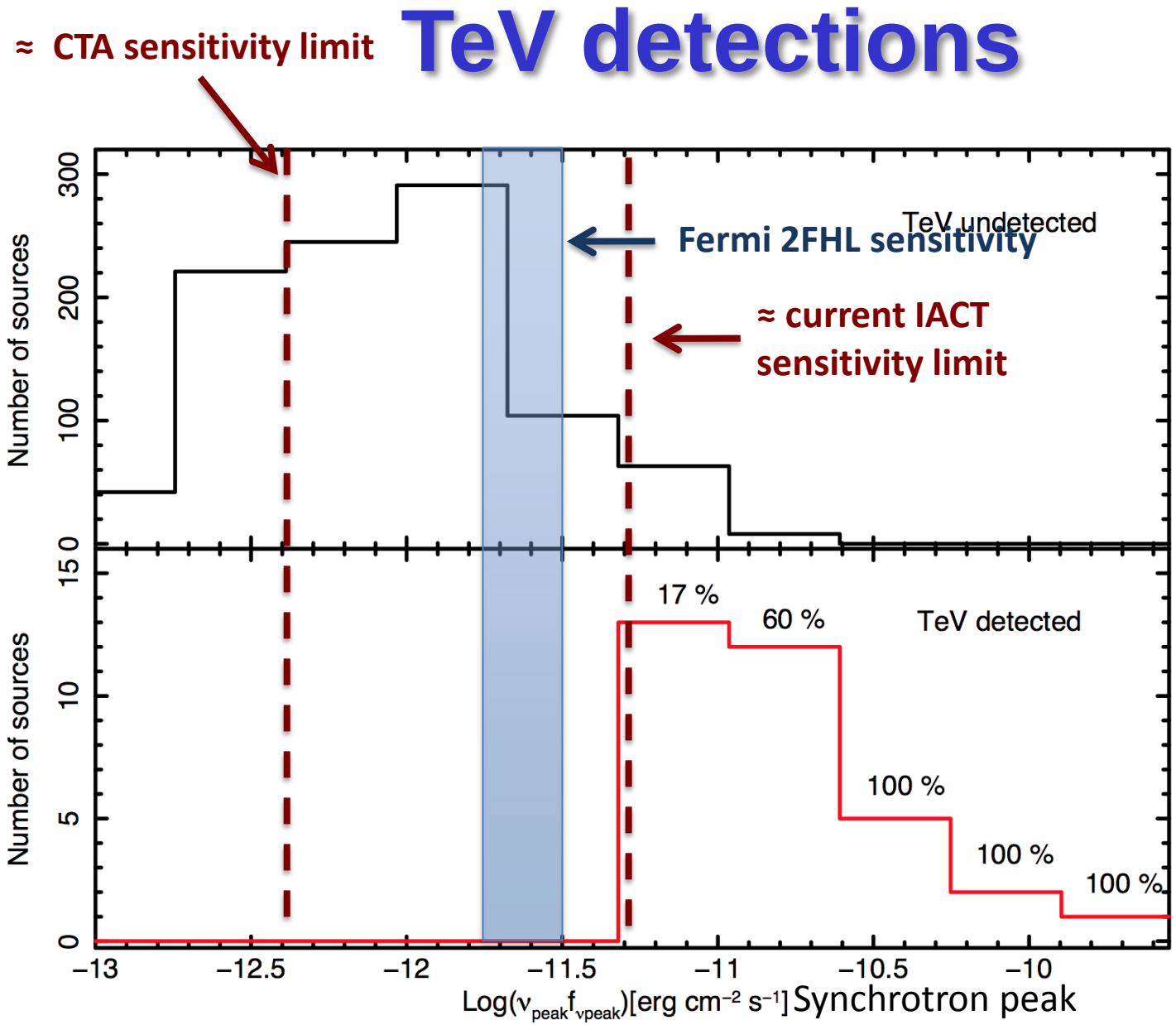
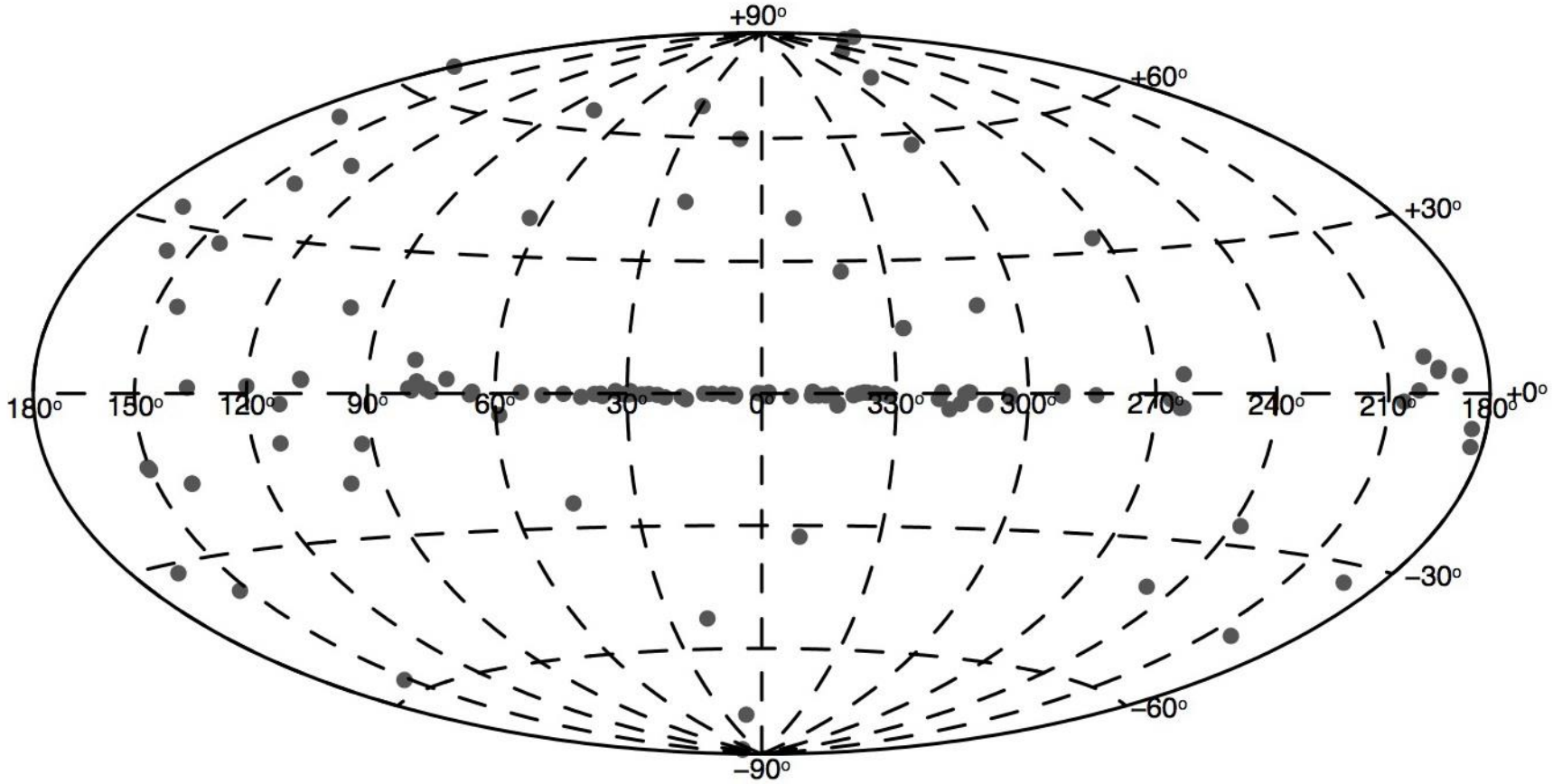
Creation date: 03-Oct-2014 19:41:31 (UTC)
asdc
SED builder V3.0

TeV detections

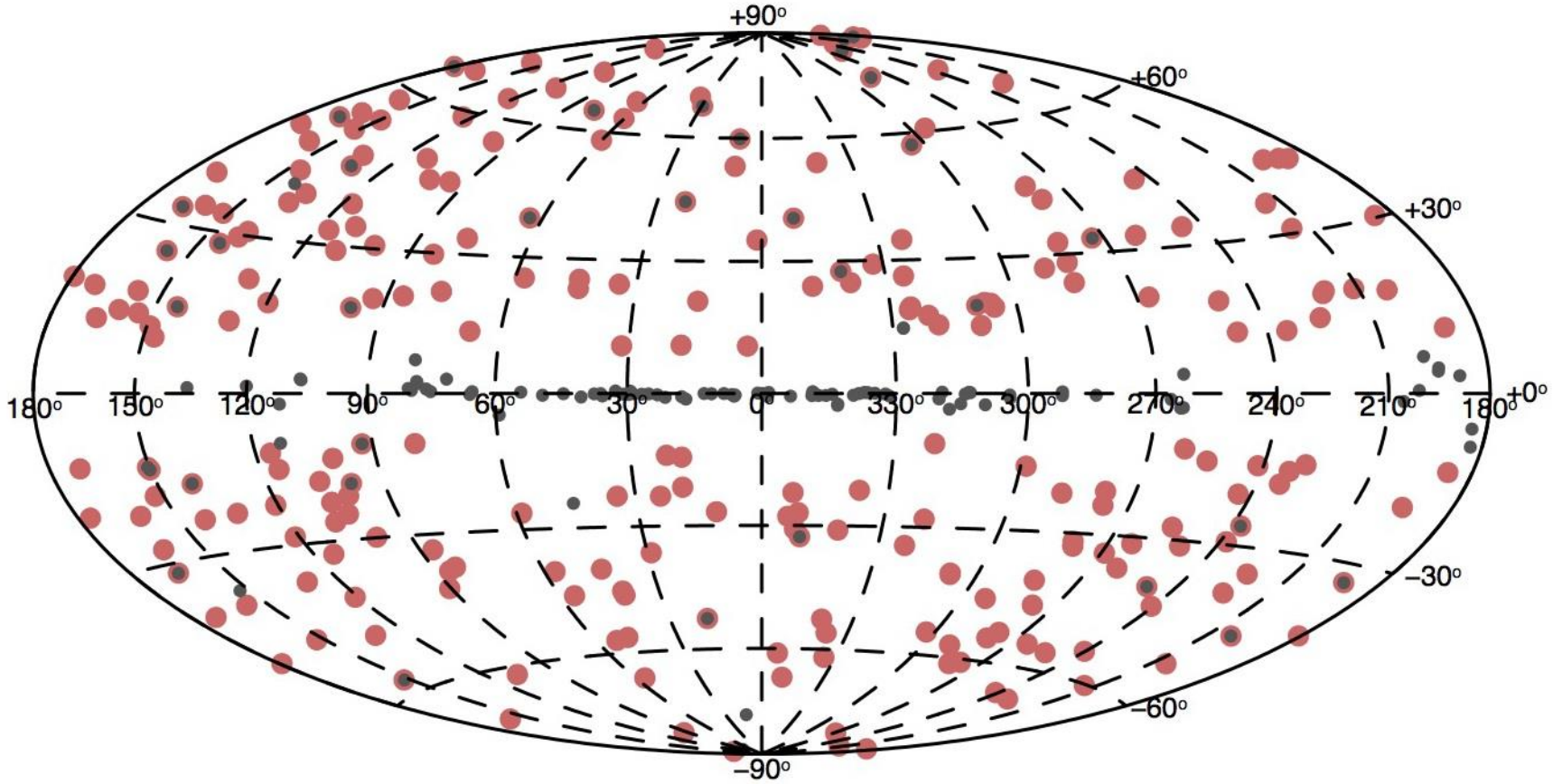


The VHE sky (IACTs)



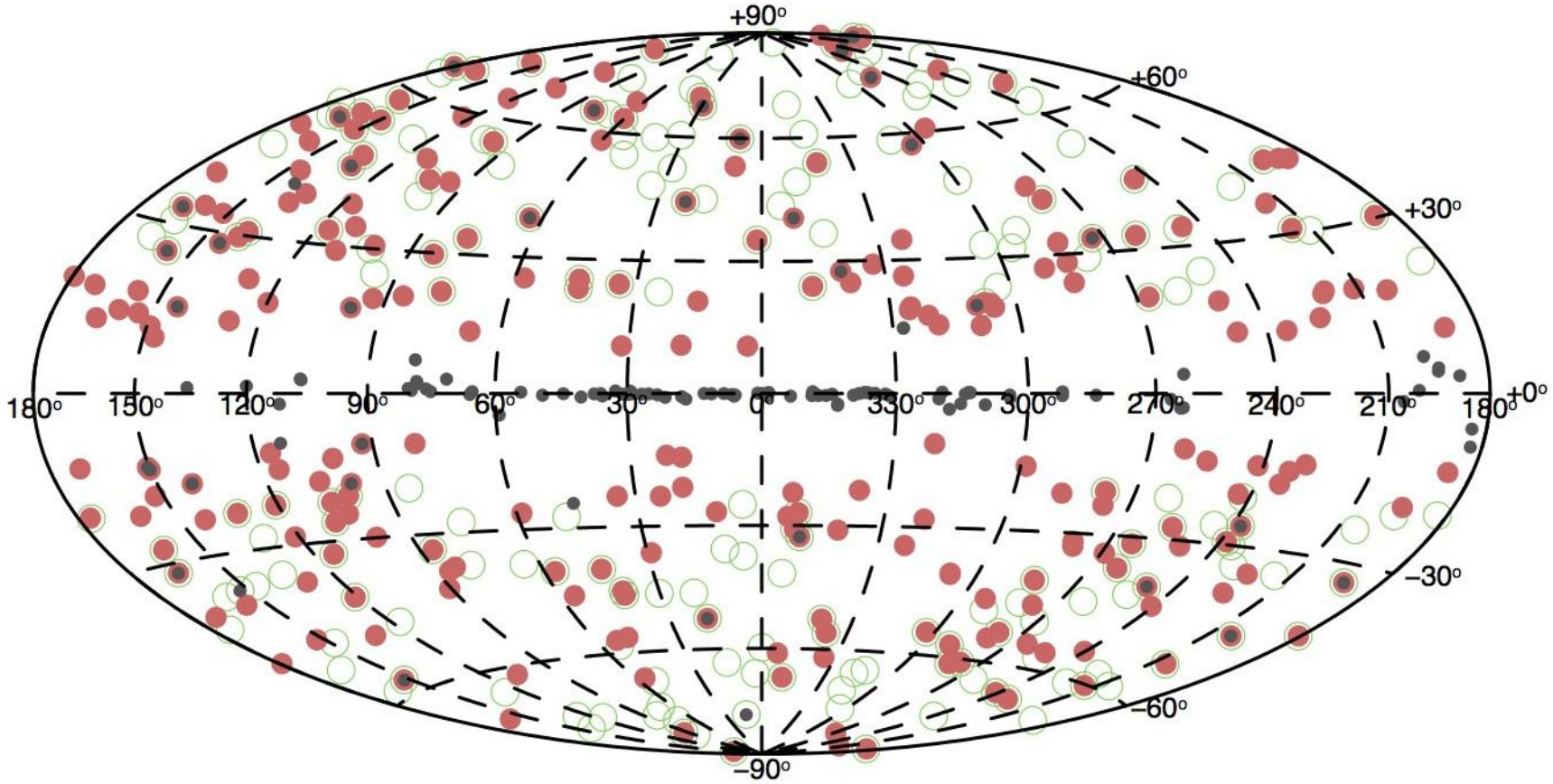
The VHE sky (IACTs+Fermi 2FHL)

PRELIMINARY



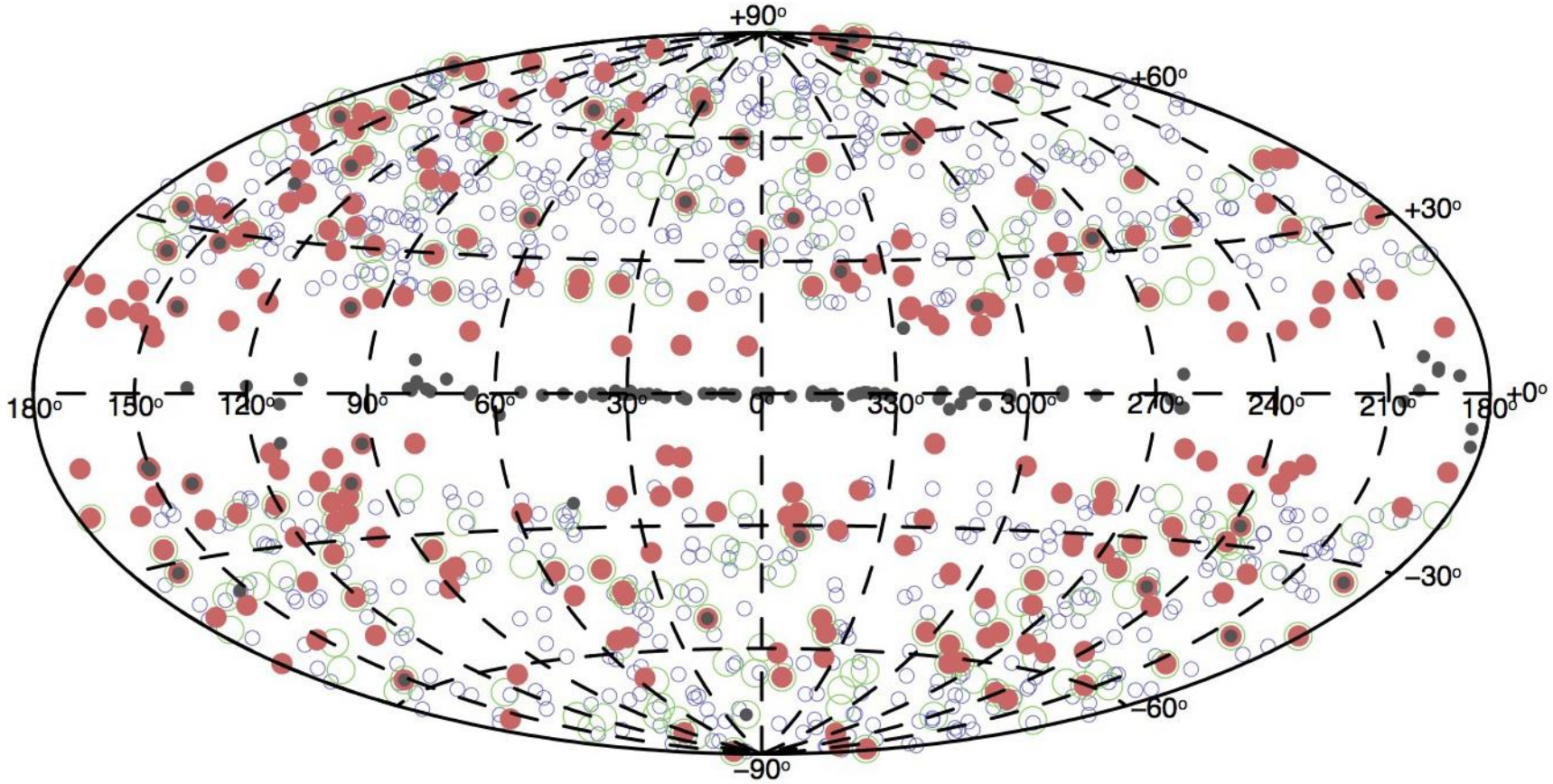
The VHE sky (IACTs+Fermi 2FHL+1WHSP-bright)

PRELIMINARY



The VHE sky (IACTs+Fermi 2FHL+1WHSP-bright-faint)

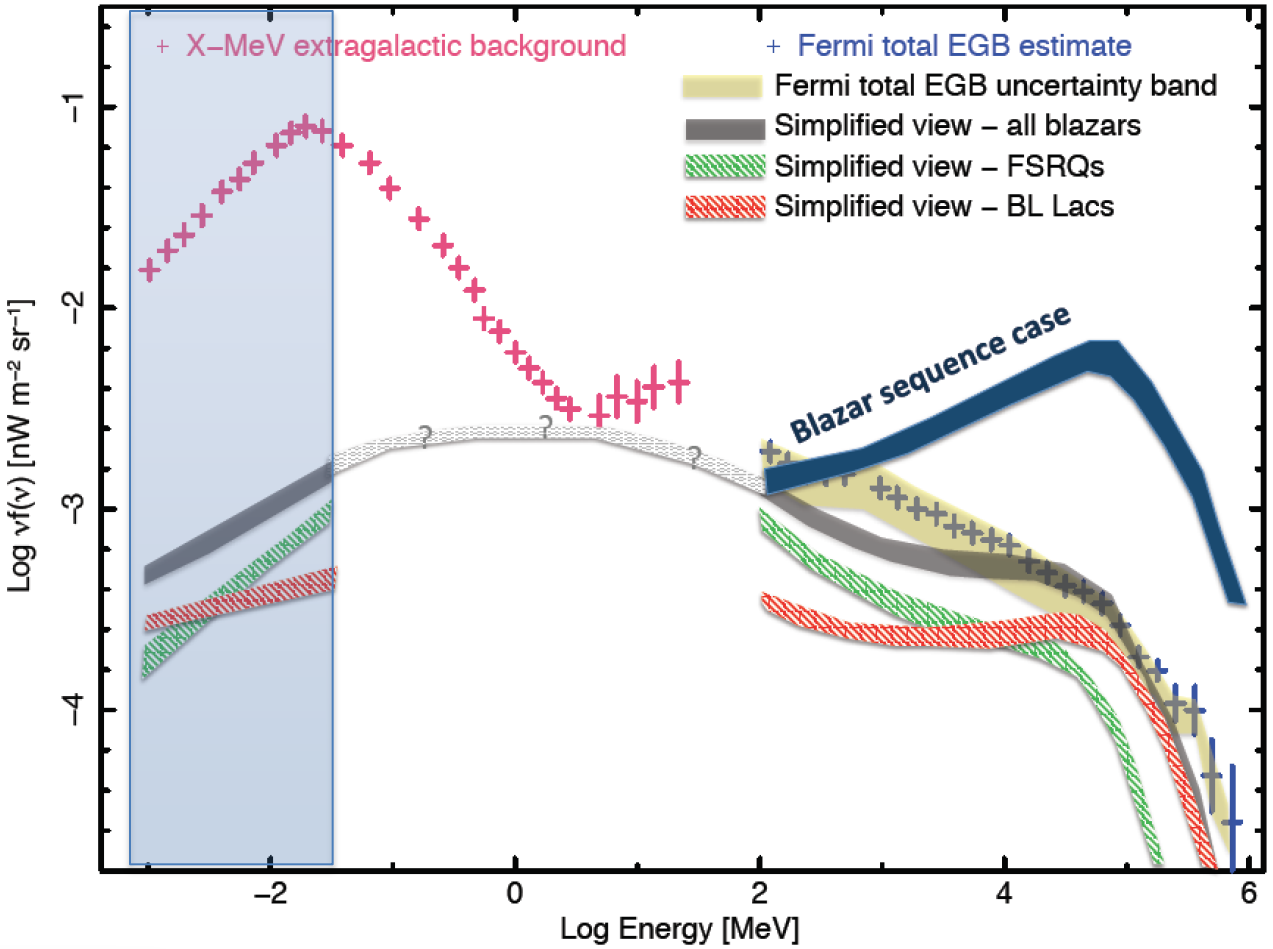
PRELIMINARY



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

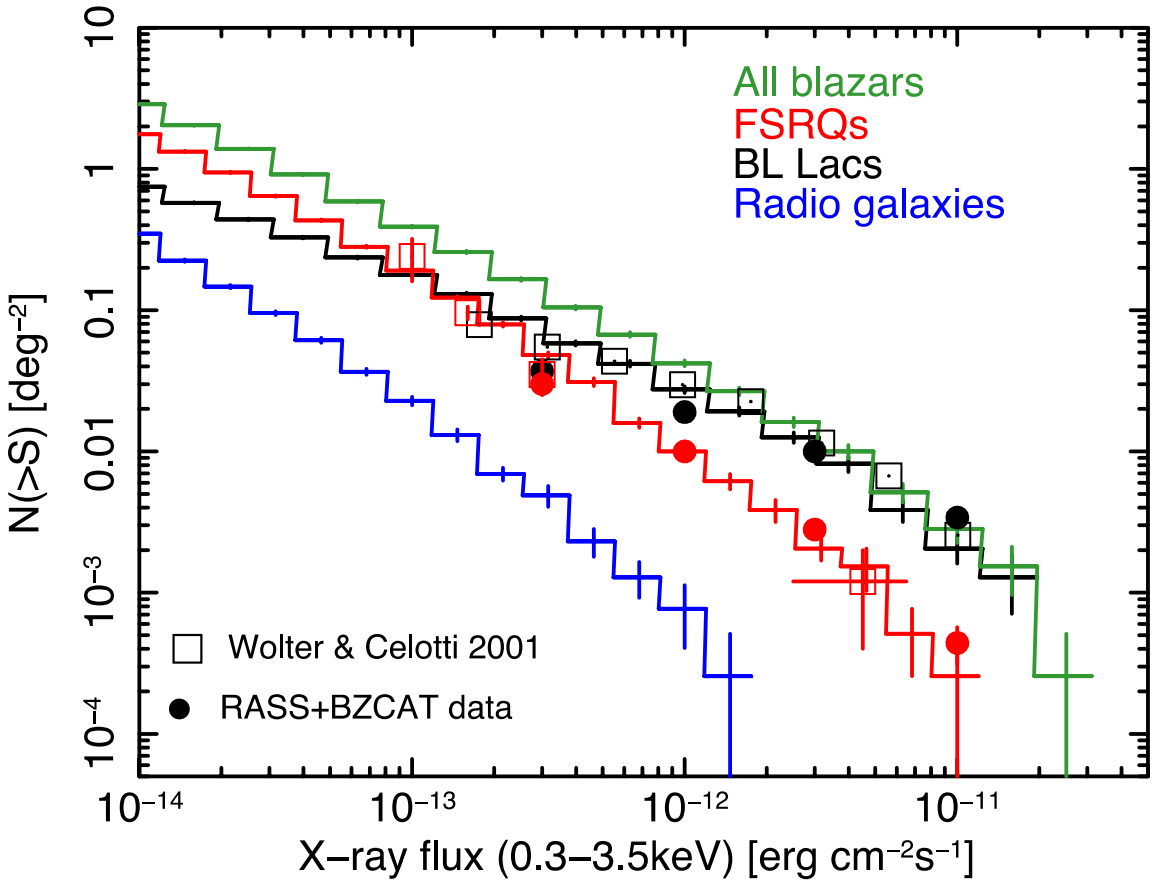
MNRAS 2015, 450, 2404
arXiv:1504.01978

P. Giommi[1,2⋆], P. Padovani[3,4]
[1] *ASI Science Data Center, via del Politecnico s.n.c., I-00133 Roma Italy*
[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*
[4] *Associated to INAF - Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*



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

Simplified view of blazar predictions and measurements

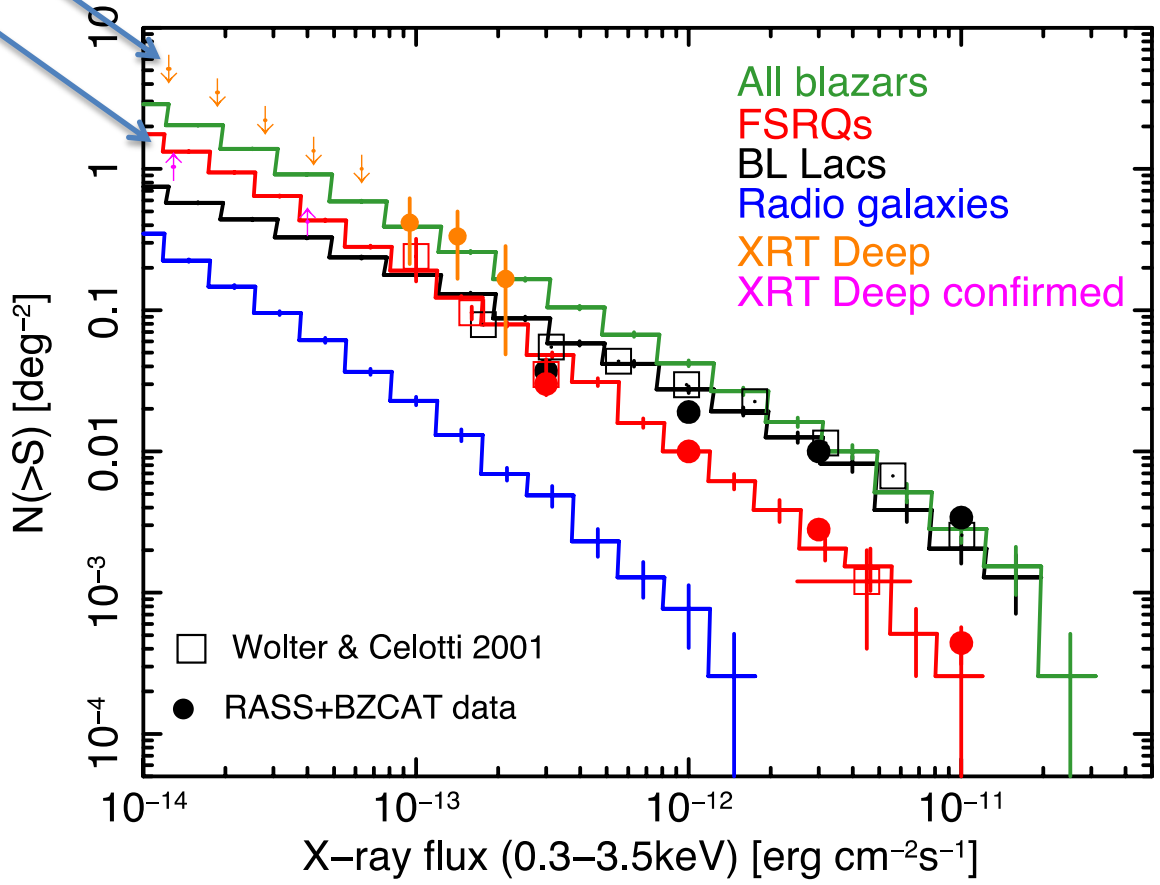


MNRAS 2015, 446L, 41
arXiv 1410.0497

Fraga, Turriziani, Giommi,
2015 in preparation

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

Simplified view of blazar predictions and measurements



MNRAS 2015, 446L, 41
arXiv 1410.0497

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

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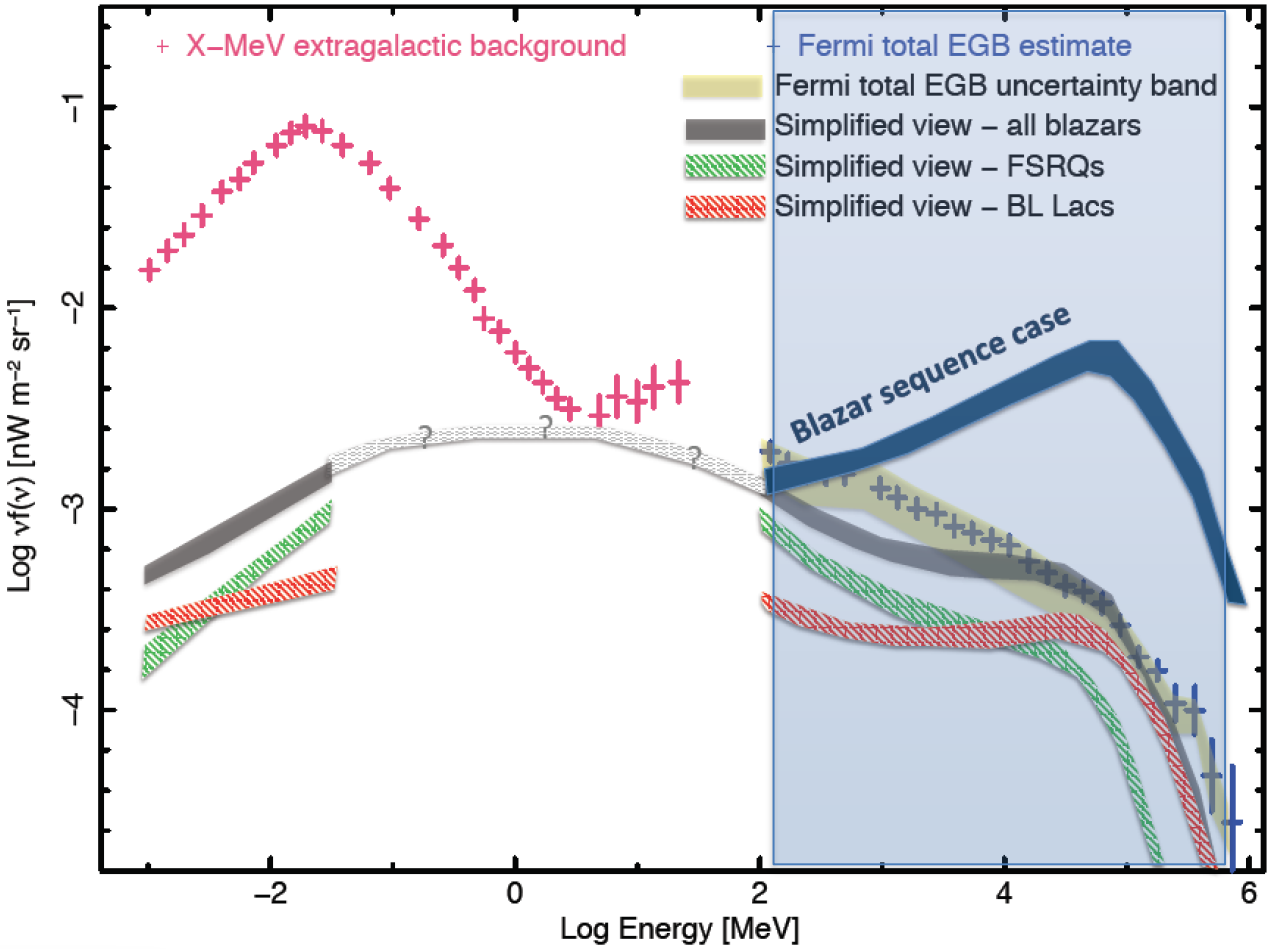
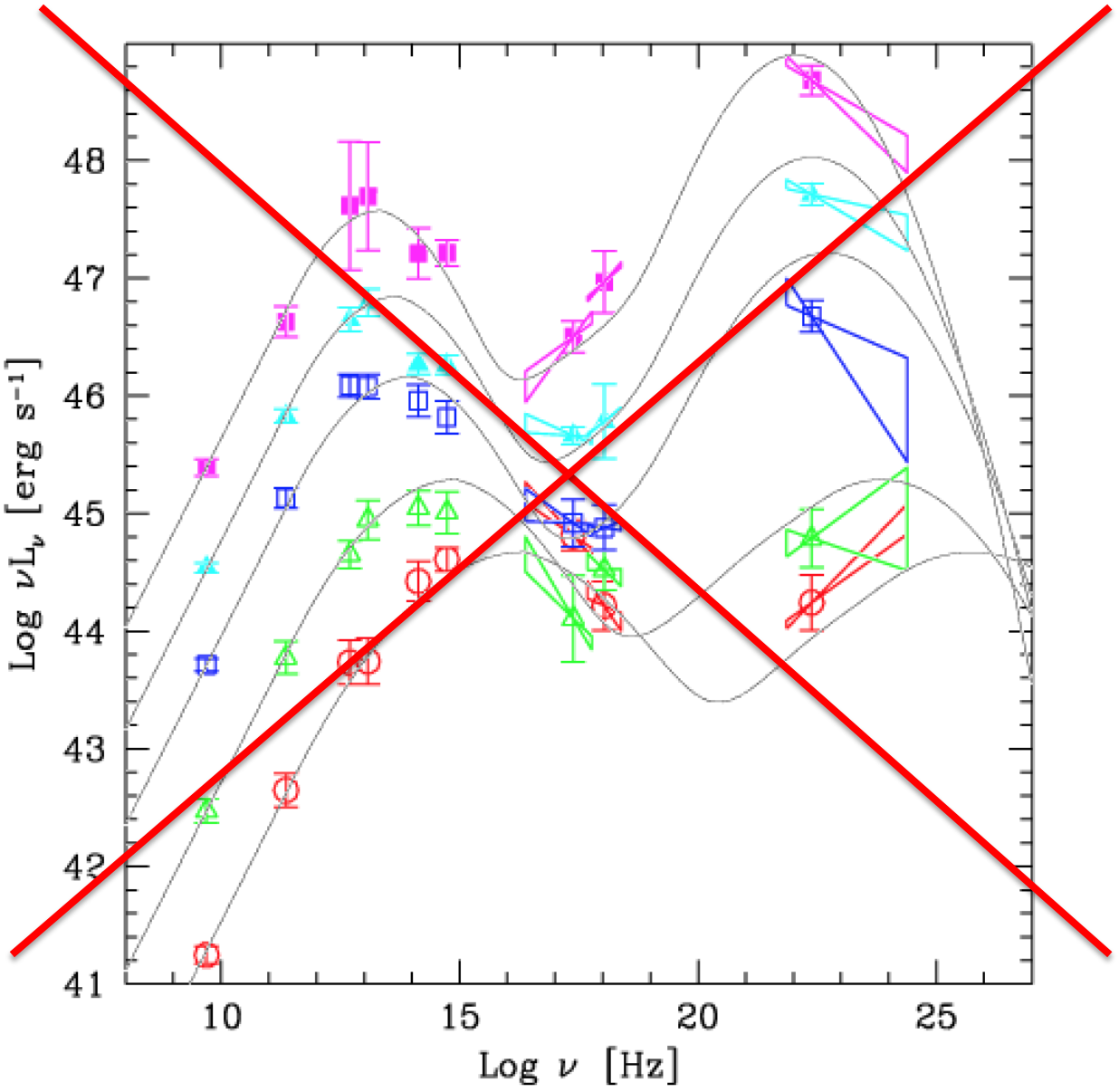
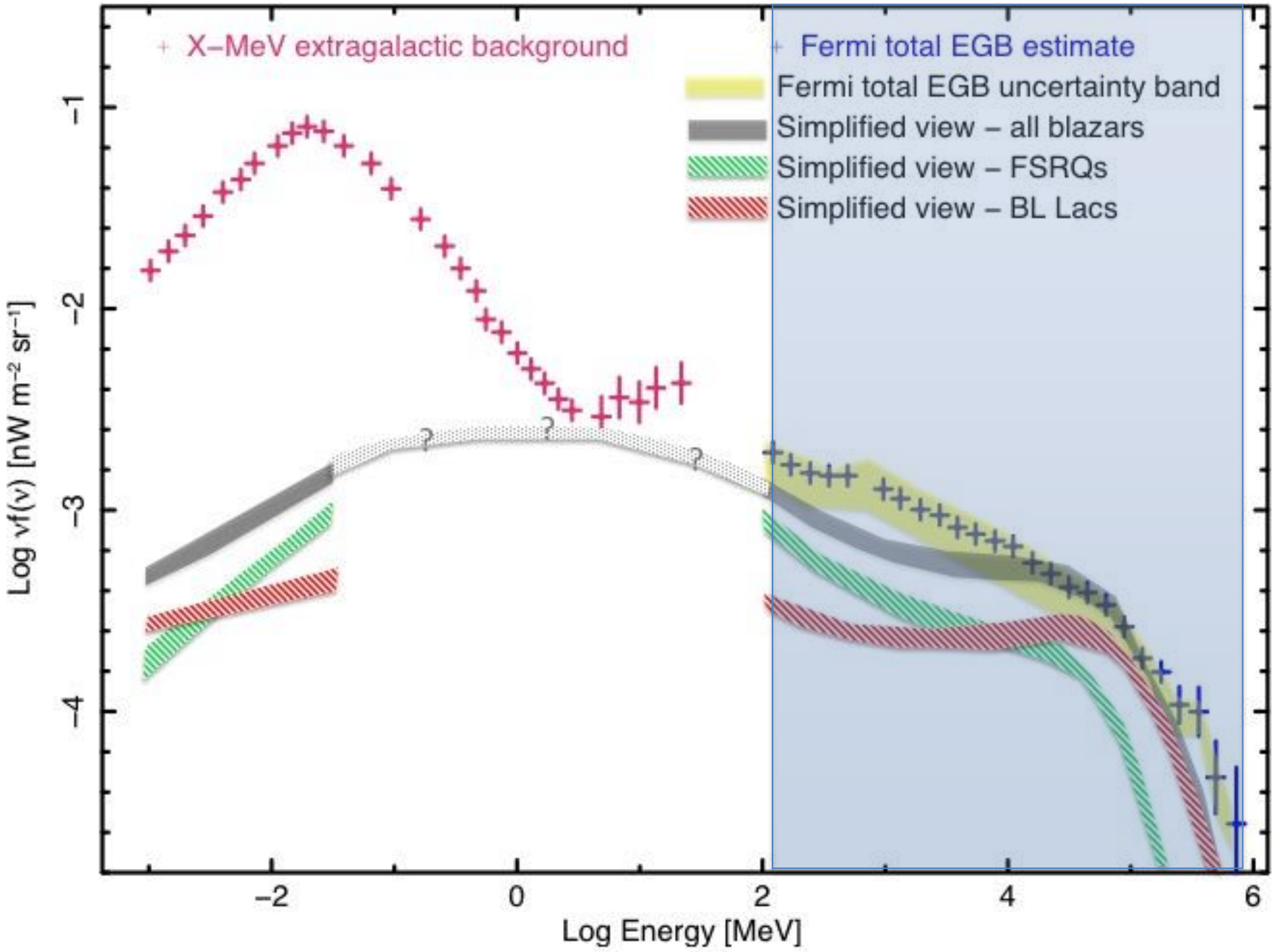
[3] *European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[4] *Associated to INAF - Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*



2015, MNRAS in press
arXiv:1504.01978

Blazar sequence

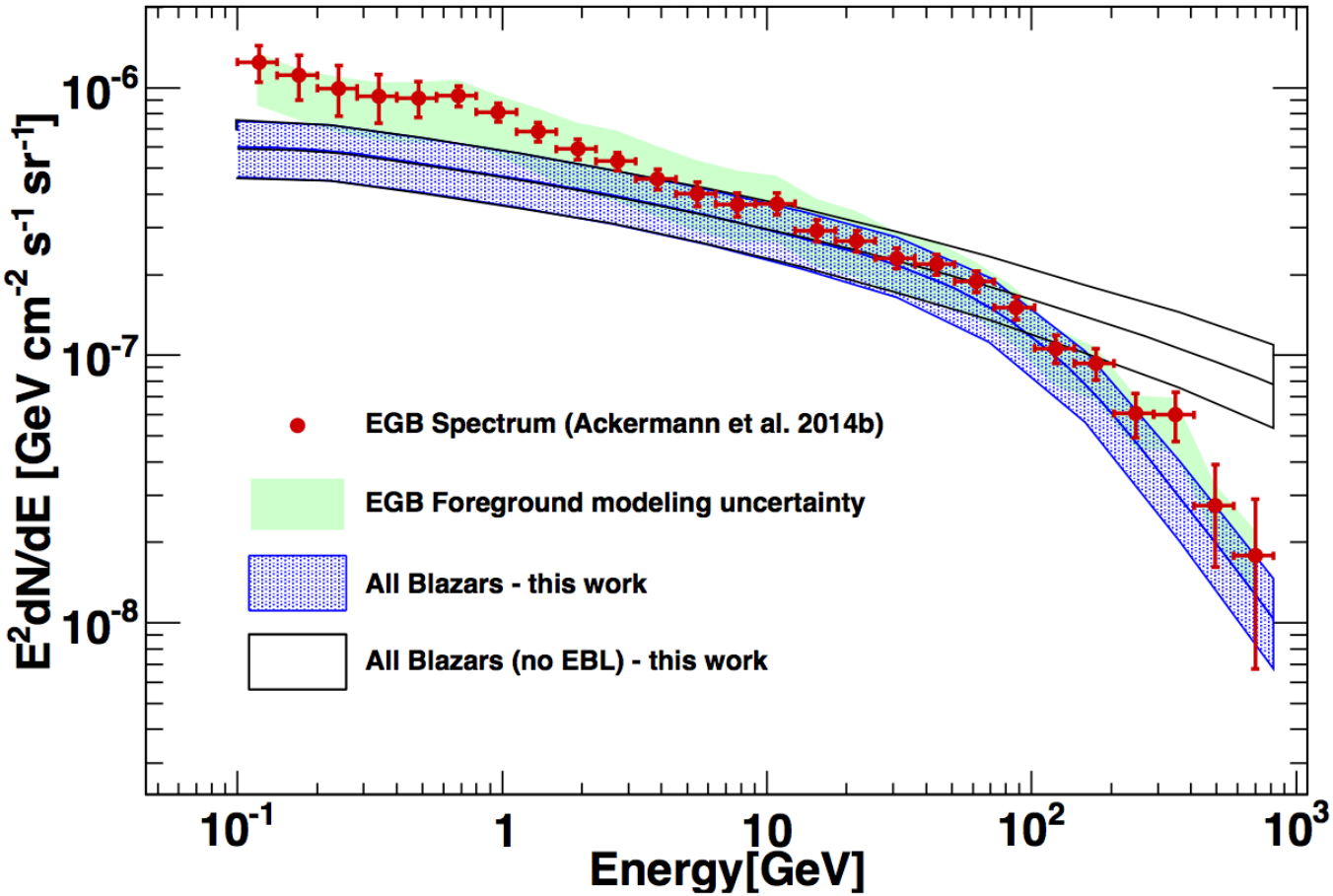



X–MeV extragalactic background
Fermi total EGB estimate
Fermi total EGB uncertainty band
Simplified view – all blazars
Simplified view – FSRQs
Simplified view – BL Lacs
Log νf(ν) [nW m⁻² sr⁻¹]
−1
−2
−3
−4
−2
0
2
4
6
Log Energy [MeV]

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 in press, arXiv:1501.050301



Blazar multi-messenger astrophysics?

Are both BL Lacs and pulsar wind nebulae the astrophysical counterparts of IceCube neutrino events?

P. Padovani[1] and E. Resconi[2⋆]
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ArXiv 1406.0376V2

TANAMI Blazars in the IceCube PeV Neutrino Fields

F. Krauß[1|2], M. Kadler[2], K. Mannheim[2], R. Schulz[1|2], J. Trüstedt[1|2], J. Wilms[1], R. Ojha[3|4|5], E. Ros[6|7|8], G. Anton[9], W. Baumgartner[3], T. Beuchert[1|2], J. Blanchard[10], C. Bürkel[1|2], B. Carpenter[5], T. Eberl[9], P.G. Edwards[11], D. Eisenacher[2], D. Elsässer[2], K. Fehn[9], U. Fritsch[9], N. Gehrels[3], C. Gräfe[1|2], C. Großberger[12], H. Hase[13], S. Horiuchi[14], C. James[9], A. Kappes[2], U. Katz[9], A. Kreikenbohm[1|2], I. Kreykenbohm[1], M. Langejahn[1|2], K. Leiter[1|2], E. Litzinger[1|2], J.E.J. Lovell[15], C. Müller[1|2], C. Phillips[11], C. Plötz[13], J. Quick[16], T. Steinbring[1|2], J. Stevens[11], D. J. Thompson[3], and A.K. Tzioumis[11]

ArXiv 1406.0645V1


MKN 421
IceCube neutrino
ID 9
Log vf(v) (erg cm^-2 s^-1)
Log energy (eV)
Creation date: 25-Jun-2014 10:19:09(UTC)
asdc
SED builder V3.0

Our most probable counterparts

IceCube ID	Counterpart(s)	Class	Catalogue(s)
9	MKN 421	BL Lac (HSP)	TeVCat/WHSP
	1ES 1011+496	BL Lac (HSP)	TeVCat/WHSP
10	H 2356−309	BL Lac (HSP)	TeVCat/WHSP
14	HESS J1809−193	PWN	TeVCat
17	PG 1553+113	BL Lac (HSP)	TeVCat/WHSP
19	1RXS J054357.3−553206	BL Lac (HSP)	WHSP
20	SUMSS J014347−584550	BL Lac (HSP)	WHSP
22	1H 1914−194	BL Lac (HSP)	WHSP
27	PMN J0816−1311	BL Lac (HSP)	WHSP
33	MGRO J1908+06	PWN	TeVCat

9 IceCube events, 10 counterparts: 8 BL Lacs and 2 PWN (no starburst or radio galaxy)

$\sim$ 700 catalogued sources → 115 “positional” matches → 10 “positional” & “energetic” matches

A simplified view of blazars: the neutrino background

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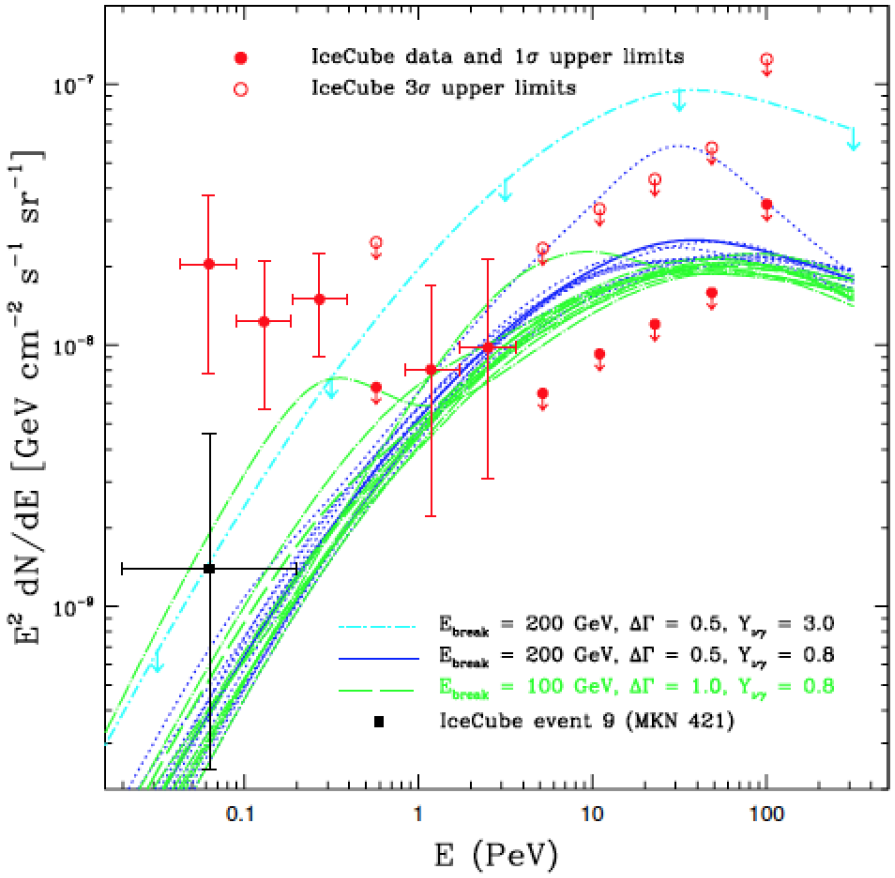
[6]*Technische Universität München, Physik-Department, James-Frank-Str. 1, D-85748 Garching bei München, Germany*



MNRAS, submitted

$$E_\nu F(E_\nu) = \frac{Y_\nu}{\int_{x_{\min}}^{\infty} \frac{dx}{x} \; [illegible]} \frac{F_\gamma(>10\ \mathrm{GeV})}{} \left(\frac{E_\nu}{E_{\nu,p}}\right)^{-s+1} \exp\left(-\frac{E_\nu}{E_{\nu,p}}\right). \quad (5)$$

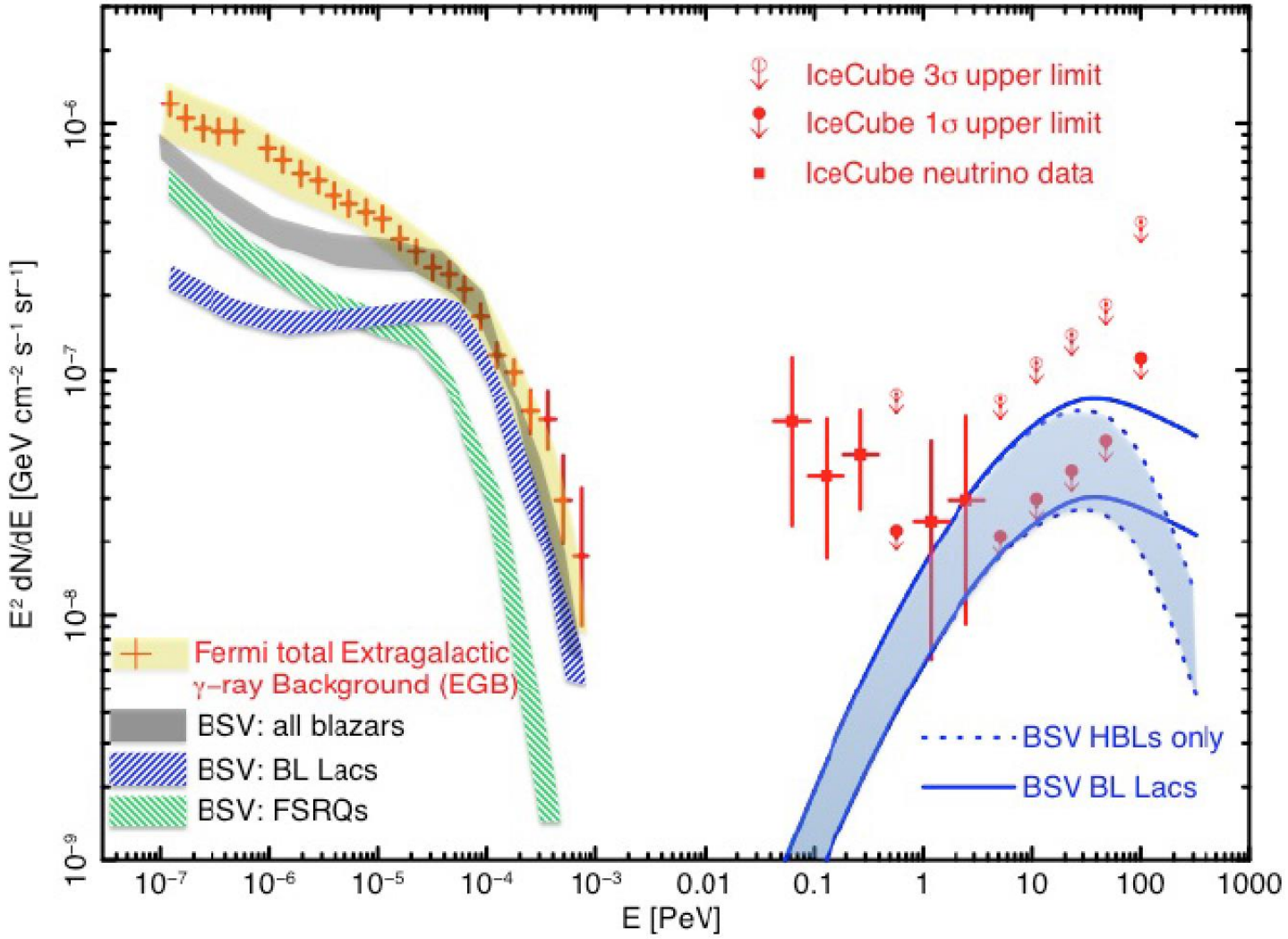


Figure 5. The electromagnetic and neutrino extragalactic backgrounds predicted by our simulations in the energy range 100 MeV – 300 PeV. The left side of the plot ($E < 1$ TeV)

Blazars and UHECRs

The origin of UHECRs, particles with energy > 1.x10^{18} eV, is still one of the mysteries of astroparticle physics

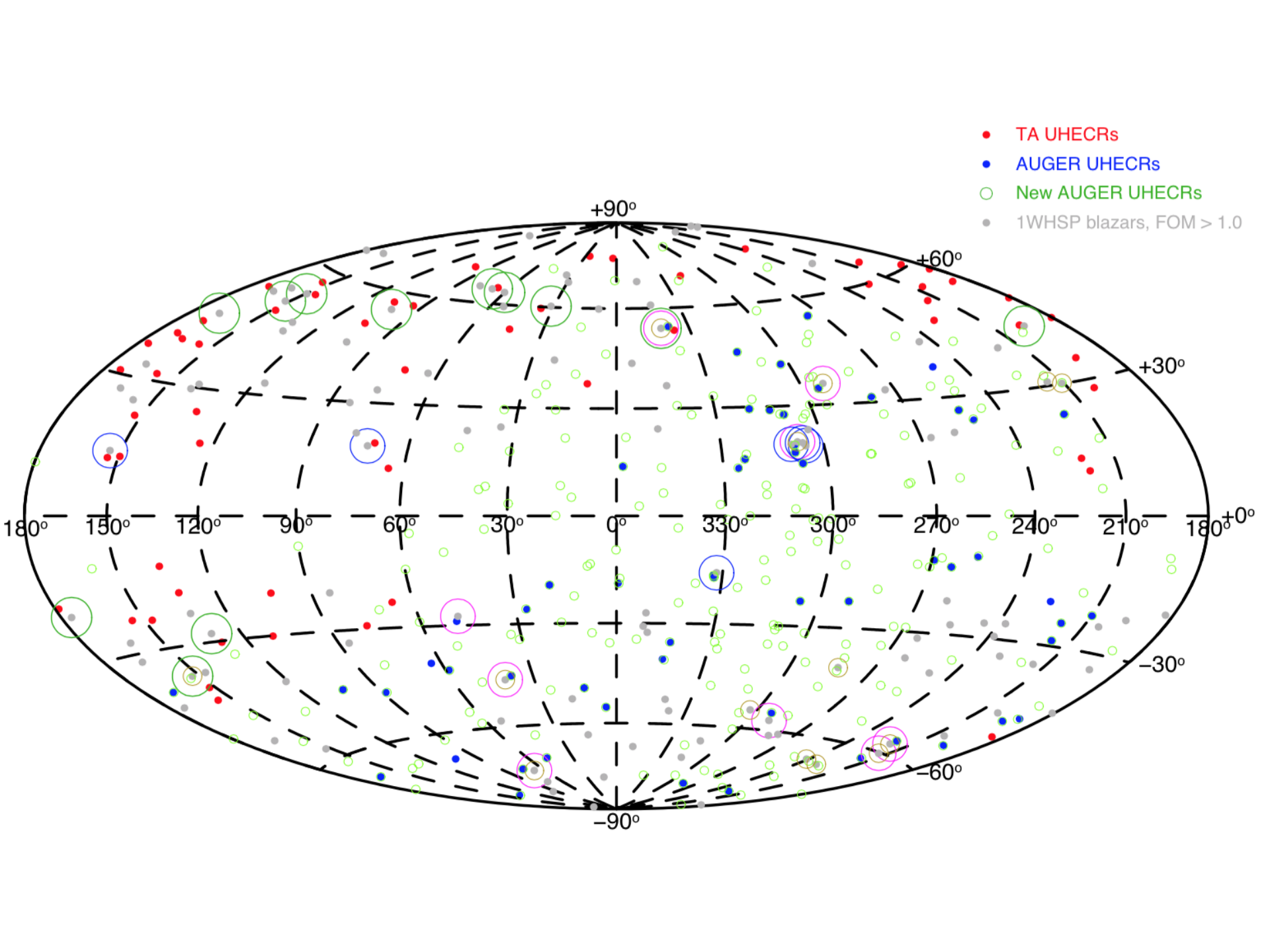
Abbasi et al. 2014, arXiv:1404.5890

AGN, BL Lacs, particularly TEV BL Lacs (HSPs), have been suggested as possible sources of UHECR

e.g. Tyniakov, Tkachev, 2001, arXiv:astro-ph/010247, Abbasi et al. 2008, arXiv:0804.0382,
Abreu et al. 2010 arXiv:1009.1855,
Zhang, Zhao, and Cao 2014,dx.doi.org/10.4236/ijaa.2014.43046

1WHSP is the largest and most complete sample of HSP blazars, that is the extragalactic sources known to accelerate particles to the highest energies.

(Giommi, Arsioli and Padovani work in progress)
We cross-matched the sky positions of the brighter sources in the 1WHSP sample (FOM > 1 : 110 objects) with those of TA and AUGER UHECR (E> 5. x10^{19} eV) at b > |20| deg.


TA UHECRs
AUGER UHECRs
New AUGER UHECRs
1WHSP blazars, FOM > 1.0
+90°
+60°
+30°
+0°
−30°
−60°
−90°
180°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
180°

But.....

The new set of 231 AUGER UHECR (published two months ago) does not confirm the strong statistical association between HSPs and UHECR… work is on-going.


Energy and time domain
Astronomy
With
Archival Data
3C 454.3