An Introduction to…

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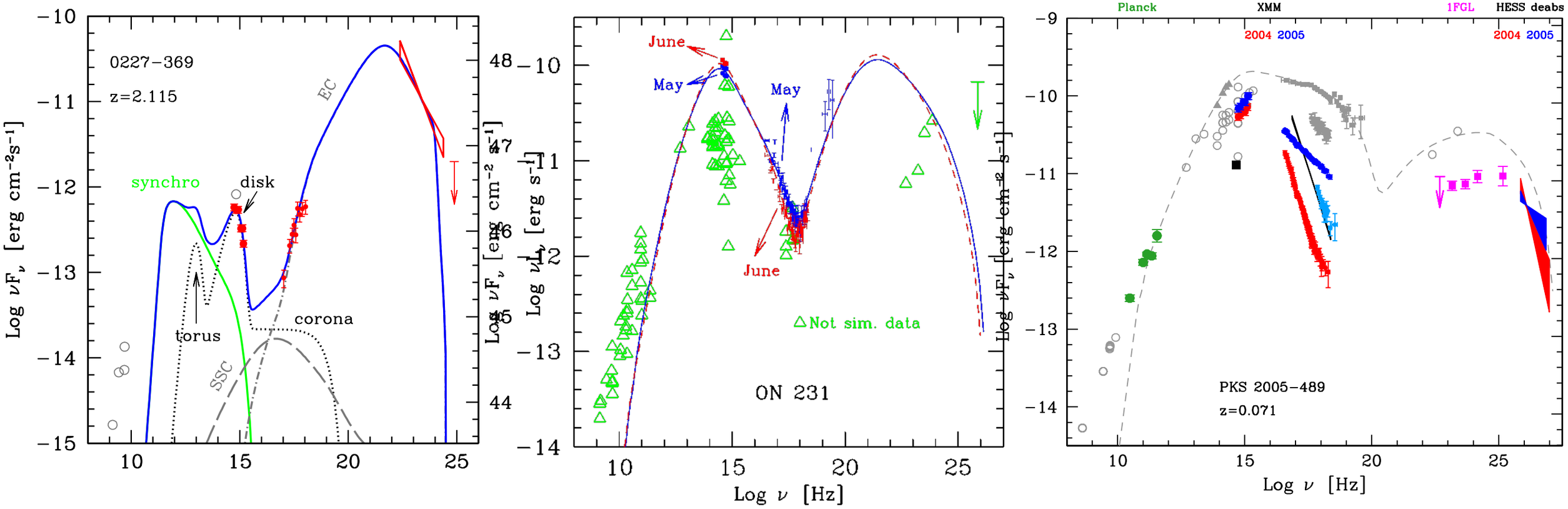
What are they ?
Who are they ?
How many are they ?
Which behaviour ?
Why are they important ?
Where to find them ?

Blazars' SED Sequence

$\alpha_x < 1$ α_x ~1 V-shape $\alpha_x > 1$



FSRQ / LBL IBL HBL

From Low to High-energy peaked Blazars

Giommi & Padovani 1994,1995

What are they: Definitions

Extreme BL Lacs are the highest-peak version of HBL

They come in TWO TYPES:

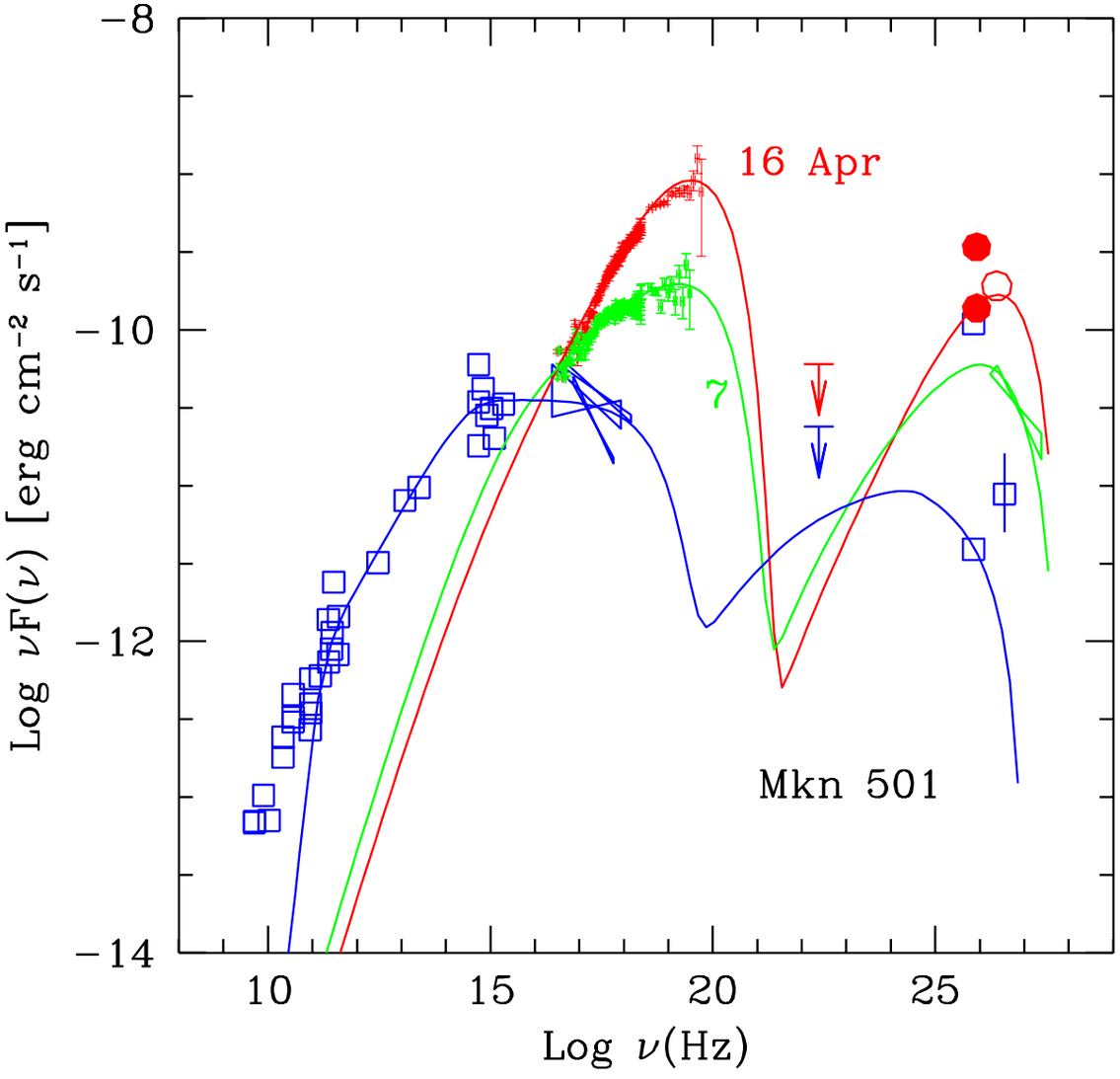
1) Extreme Synchrotron: $\nu_{\rm peak} > 1\ {\rm keV}$ $\Gamma_{\rm X} < 2$

2) Extreme Compton: $\nu_{\rm peak} > 1\ {\rm TeV}$ $\Gamma_{\rm VHE} < 2$

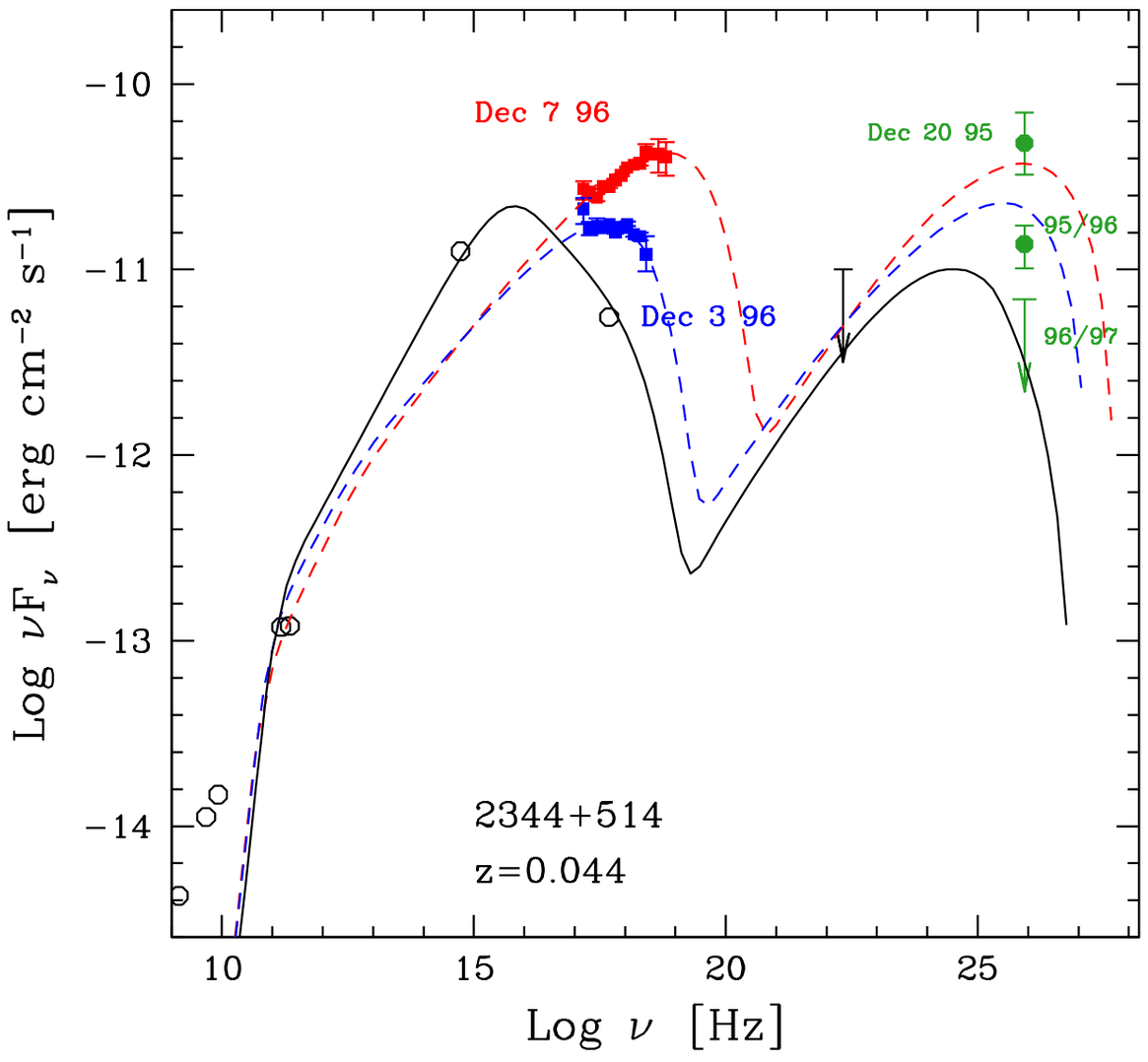
keV-peaked BLLac (KBL) & TeV-peaked BL Lac (TBL) ?

It all started in ~1997…

with BeppoSAX

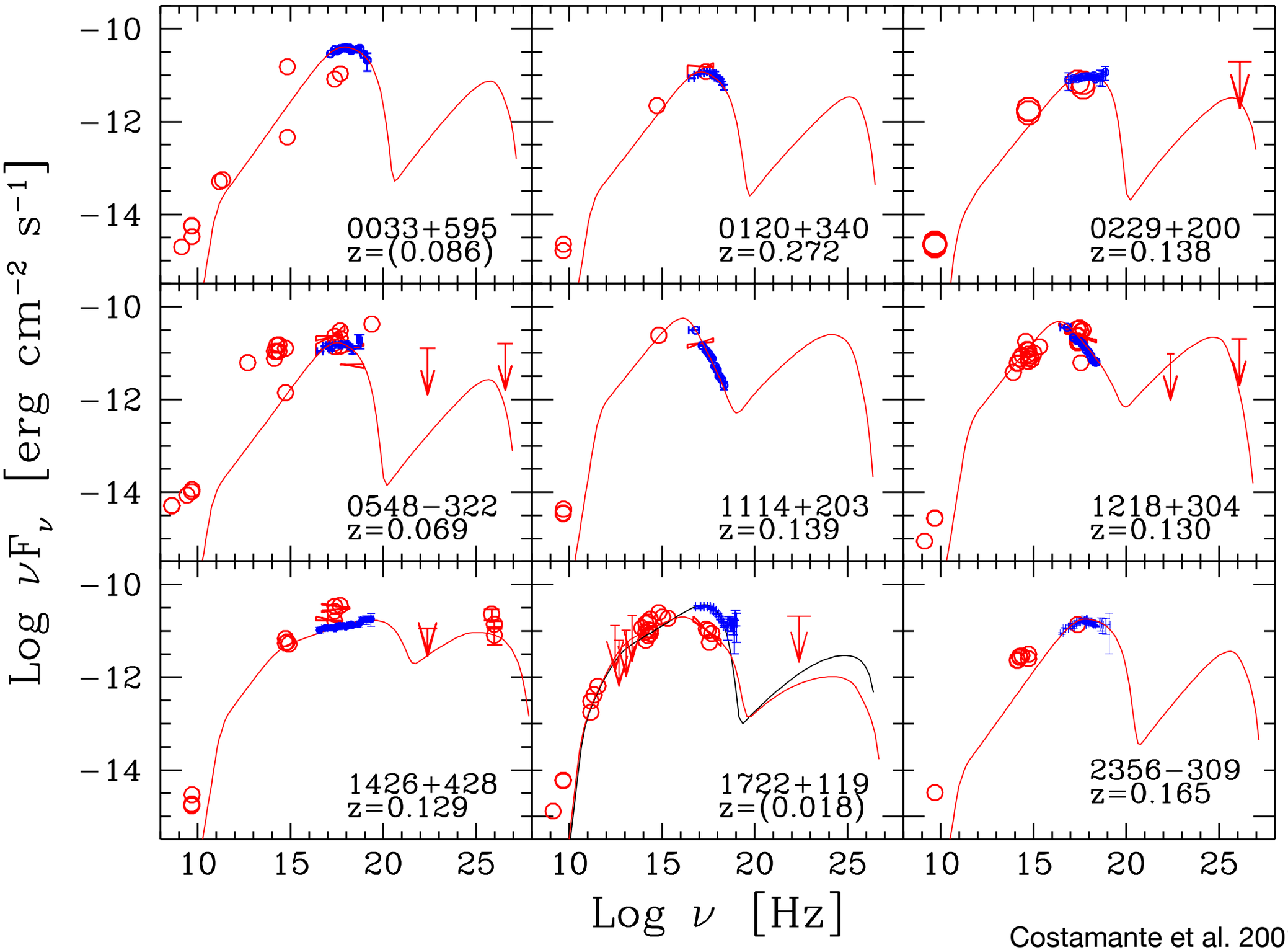


Pian et al. 1998



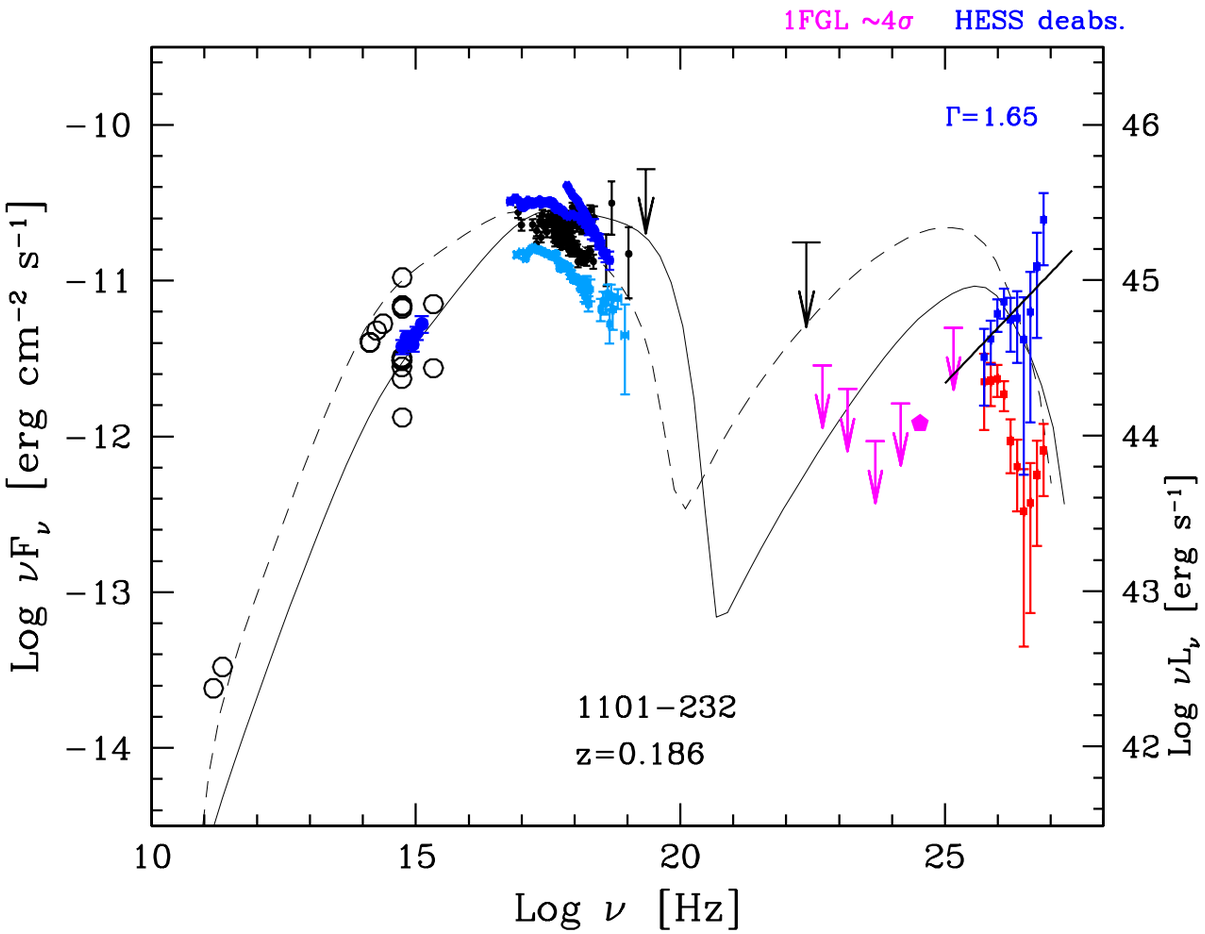
Giommi et al. 2000
Ghisellini et al. 2000

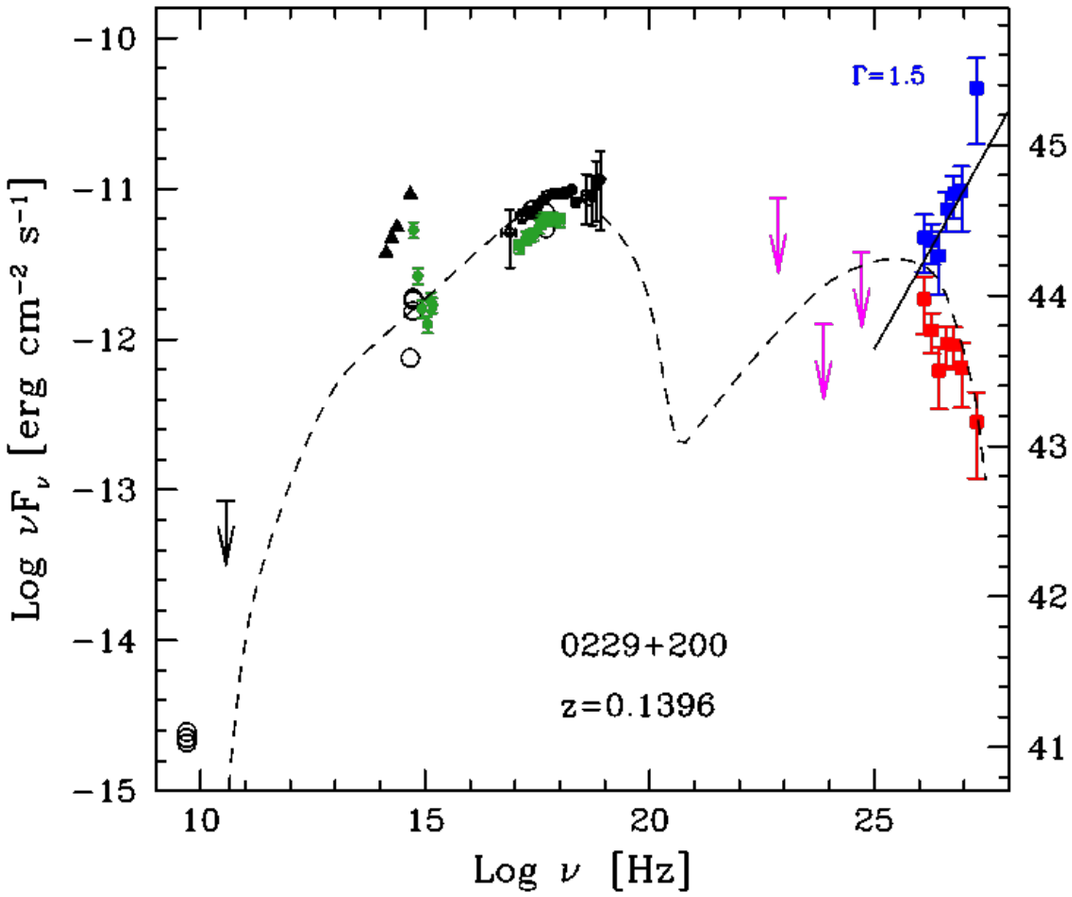
Ghisellini hunting: $\alpha_{RX} < 0.6$ & $F_X > 1E\text{-}11$



Costamante et al. 2001, 2002

Extreme Compton BL Lacs





Intrinsic $\Gamma_{VHE} < 2$ (typically 1.5-1.7), with any EBL intensity (even lowest one).

⇒ Compton peak ≥ 3-10 TeV

Who are they ?

So far:

Name	z	$\Gamma_{intr.}$	Energy TeV
1ES 0229+200	0.140	1.5 ± 0.2	0.6–12
1ES 0347−121	0.188	1.8 ± 0.2	0.25–3
1ES 0414+009	0.287	1.9 ± 0.3	0.15–2
PKS 0548−322	0.069	2.0 ± 0.3	0.3–4
RGB J0710+591	0.125	1.8 ± 0.2	0.3–4
1ES 1101−232	0.186	1.7 ± 0.2	0.2–4
1ES 1218+304	0.182	1.9 ± 0.1	0.2–4
H 2356−309	0.165	1.95 ± 0.2	0.2–2
$1ES\,1741+196$	0.084	1.9 ± 0.3	Magic
		2.4 ± 0.7	Veritas
$1ES\,1727+502$	0.0554	1.8 ± 0.3	Veritas moonlight
		2.3 ± 0.5	Magic

EBL-deabsorption with:
Franceschini et al. 2008
Dominguez et al. 2011

Mkn 501 nearly: a case by itself… (see later)

How many are they ?

TeVCAT (December 2018): *49 HBL* *-12 no or uncertain z*
- 4 no data

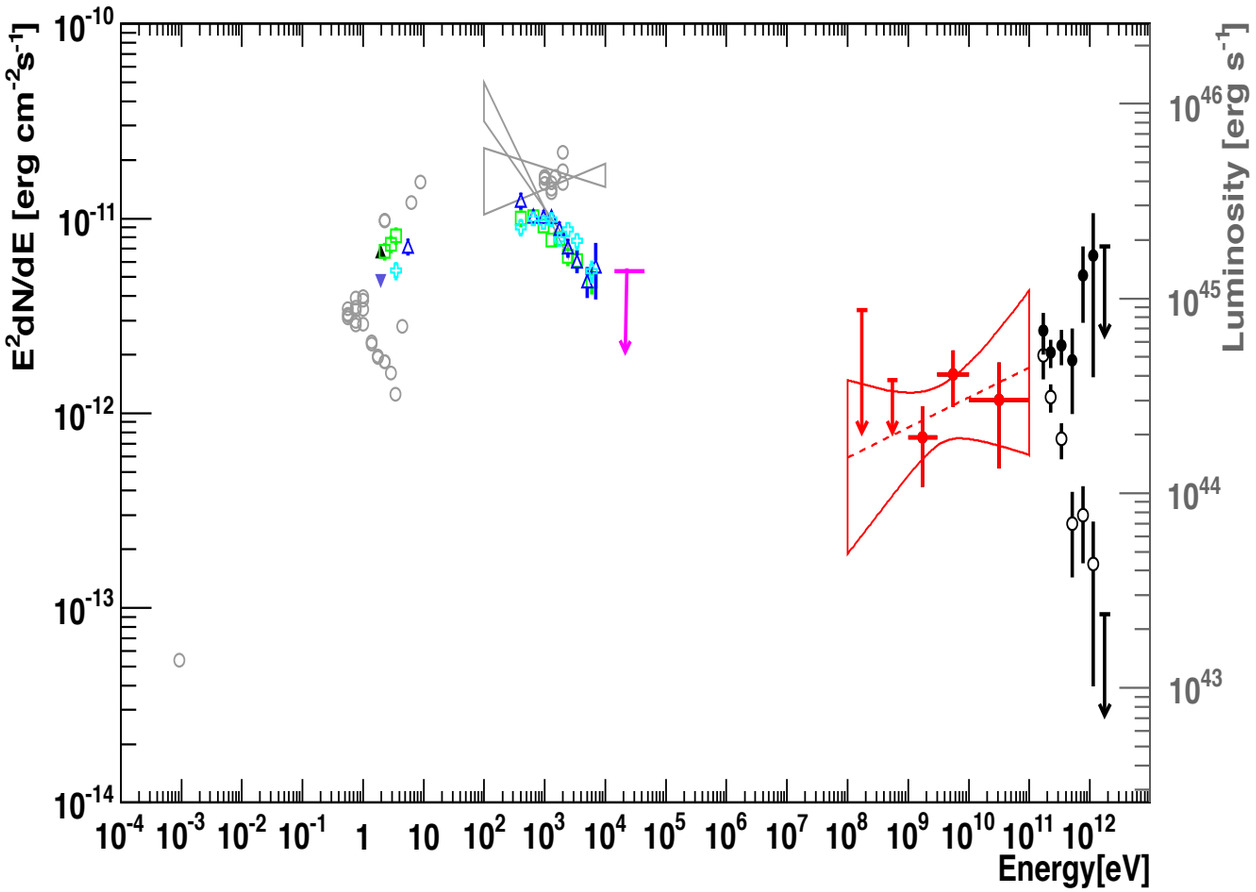
VHE spectral sample: 33 HBL Hard-TeV spectra: 8 (+2)
Soft-TeV spectra: 22

Extreme-C are (8/33) ~ 1/4 of all HBL

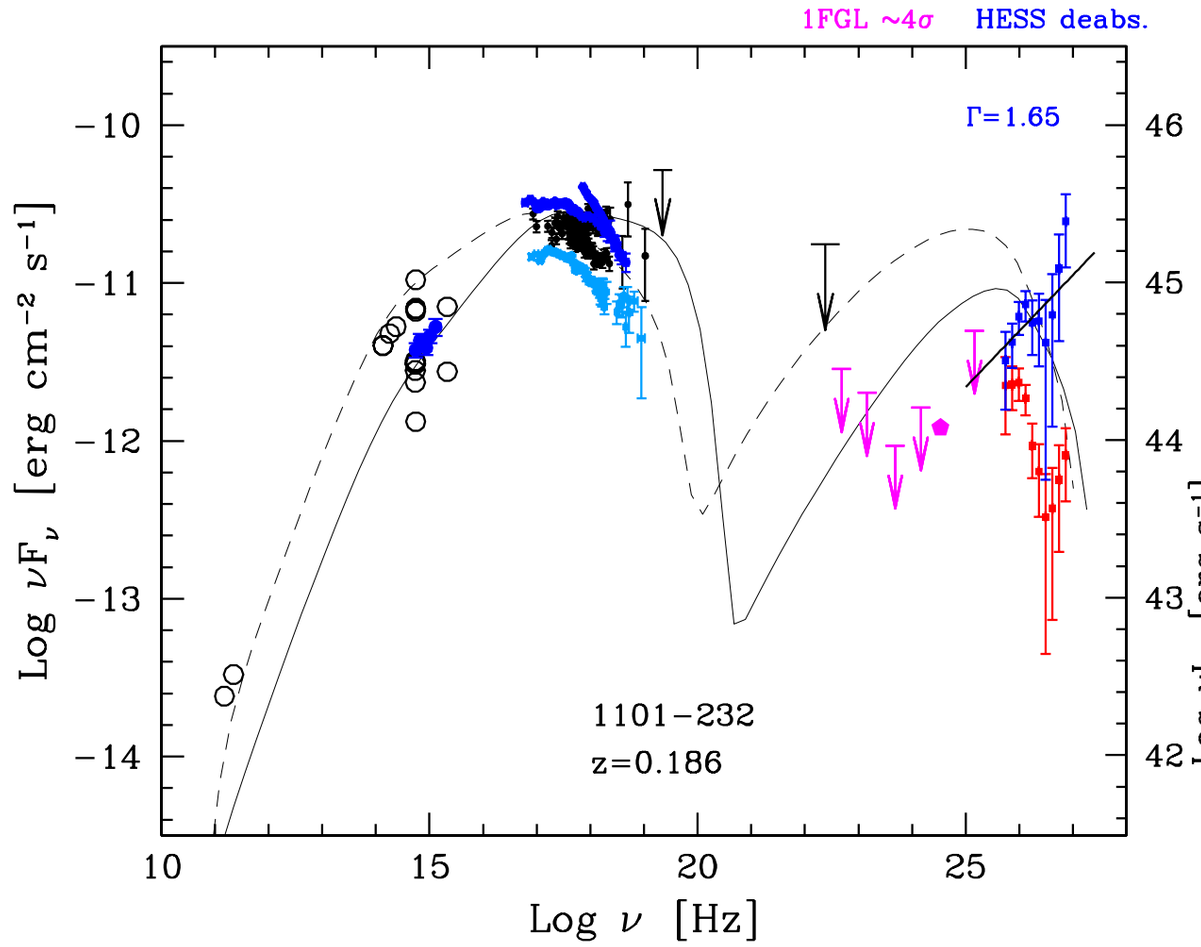
Extreme-S are > 15 ~ to be completed (Swift)
(12/44) ~ 1/4 of SAX HBL

Relation between the two types ?

UNCLEAR
(all combinations)



HESS-LAT Coll. 2012

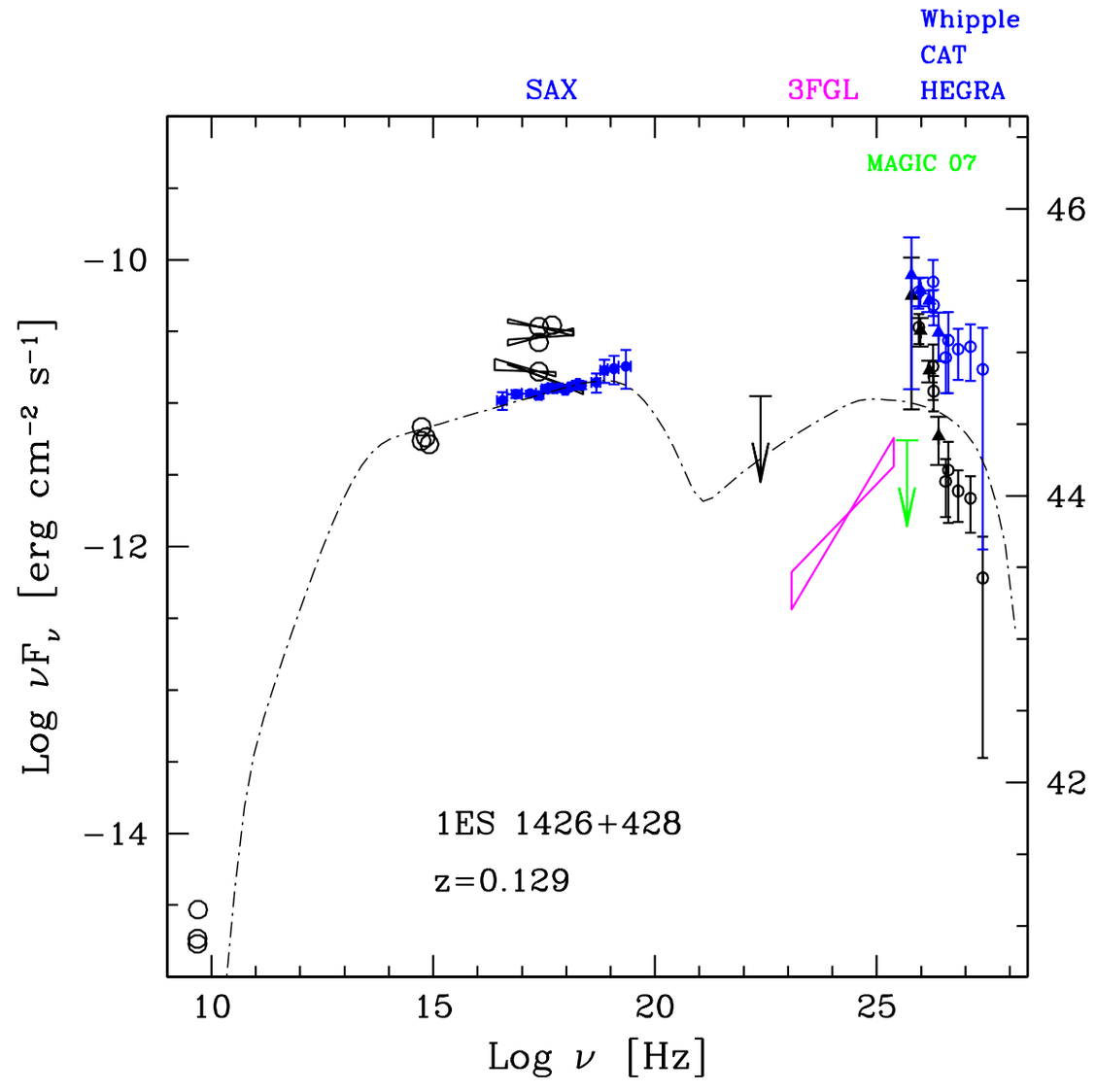


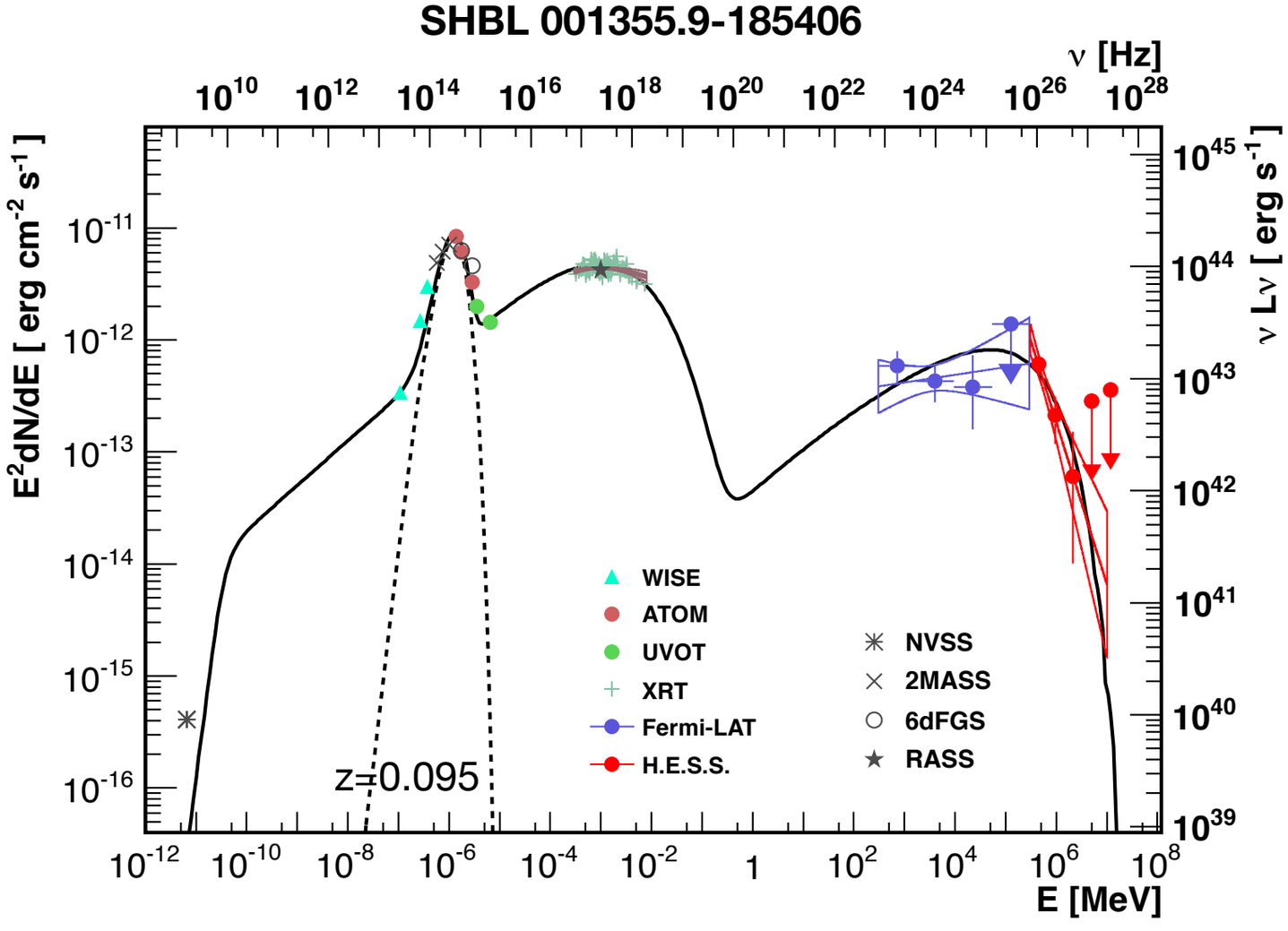
Costamante 2013

Extreme C, not S

Relation between the two types ?

UNCLEAR
(all combinations)



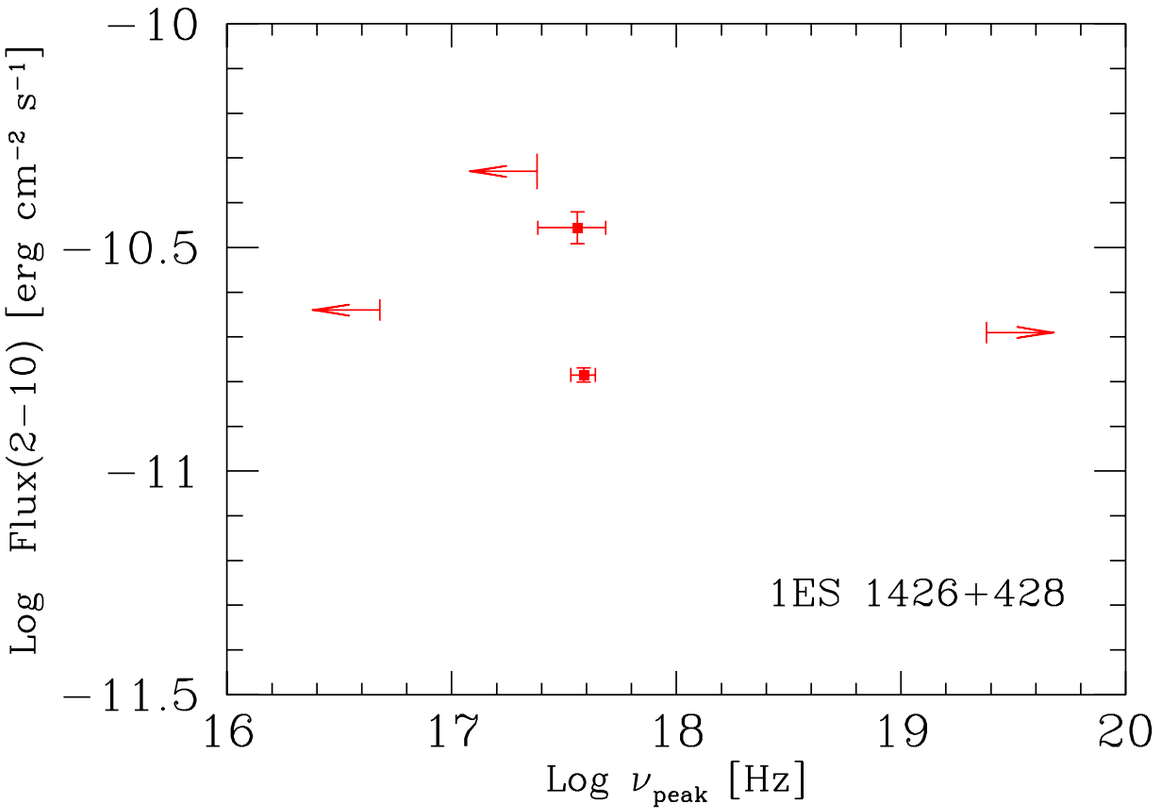


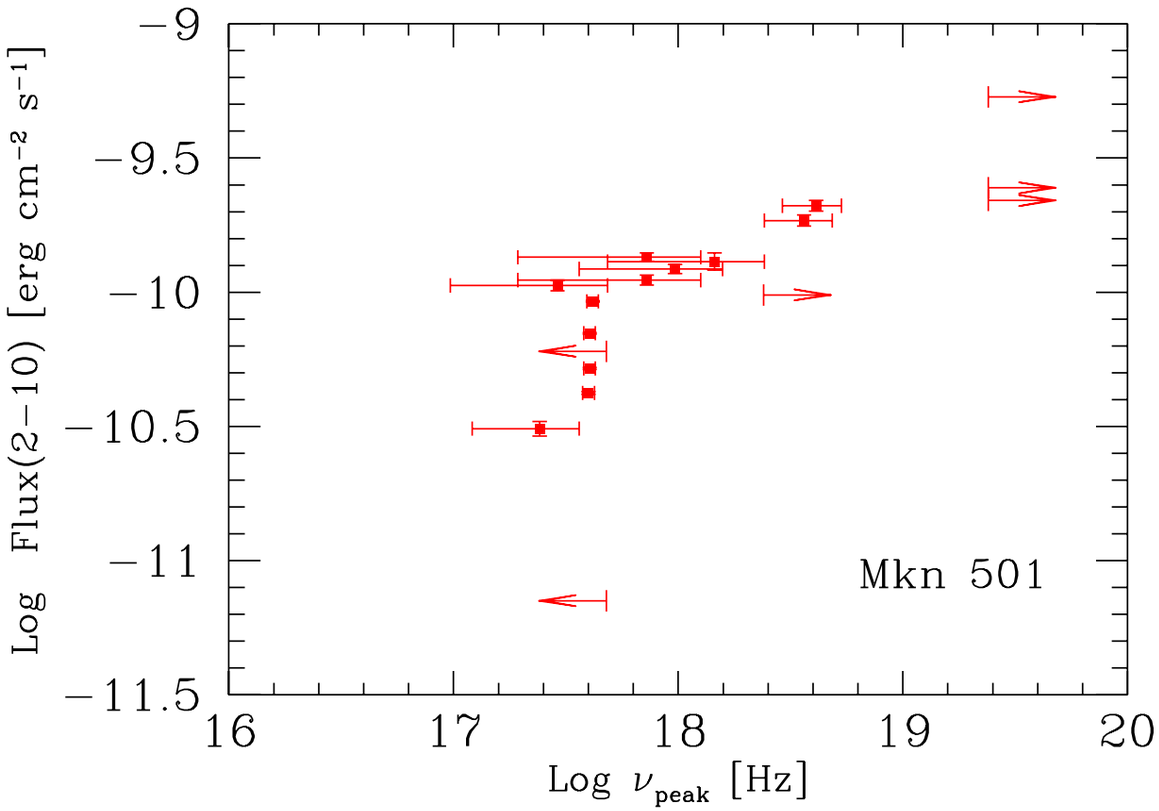
HESS Coll. 2013

Extreme S, not C

Variability ?

Extreme-S synchrotron peak

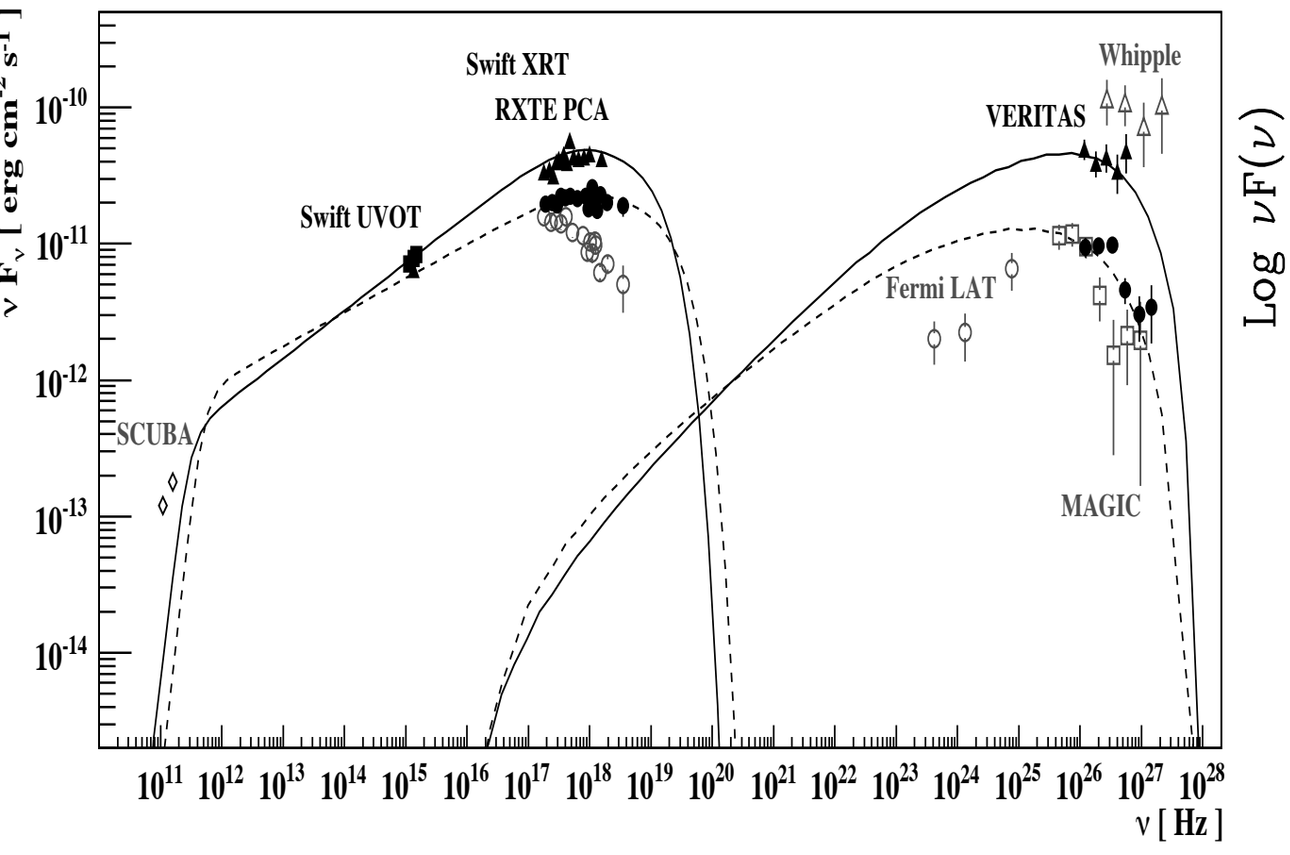




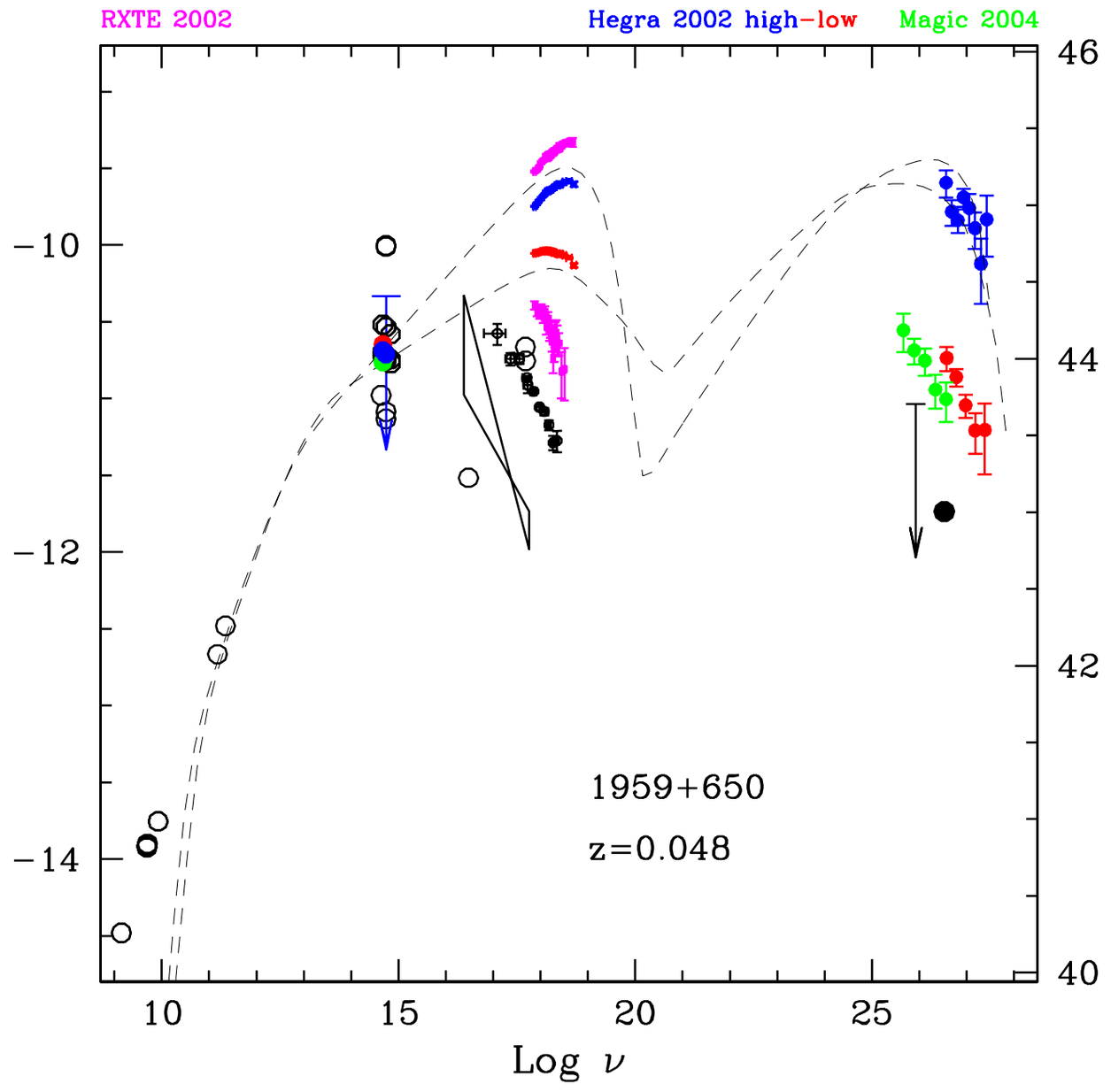
LC et al. 2002

When flaring, extreme-S remain Soft-TeV

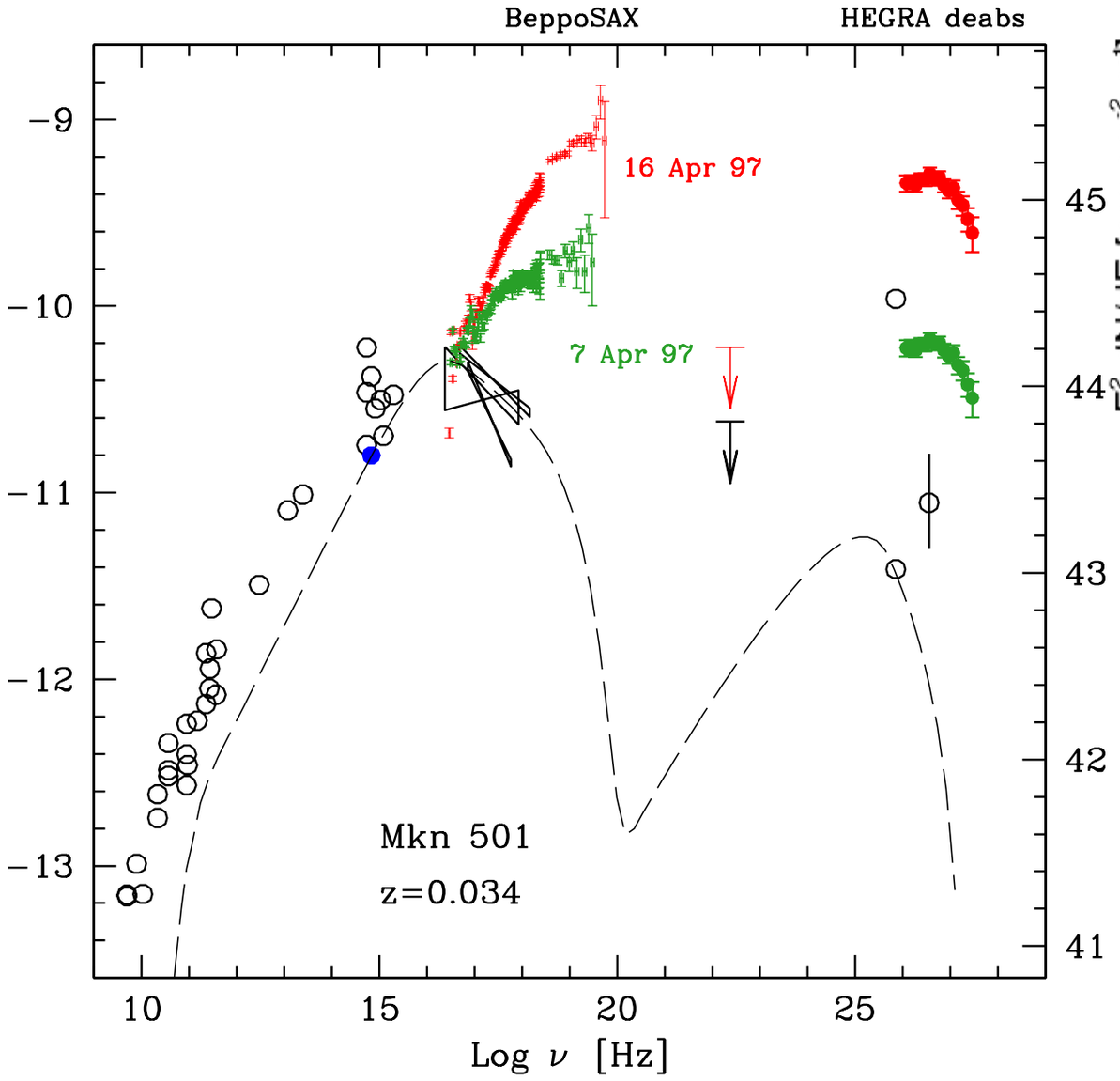
1ES 2344+514



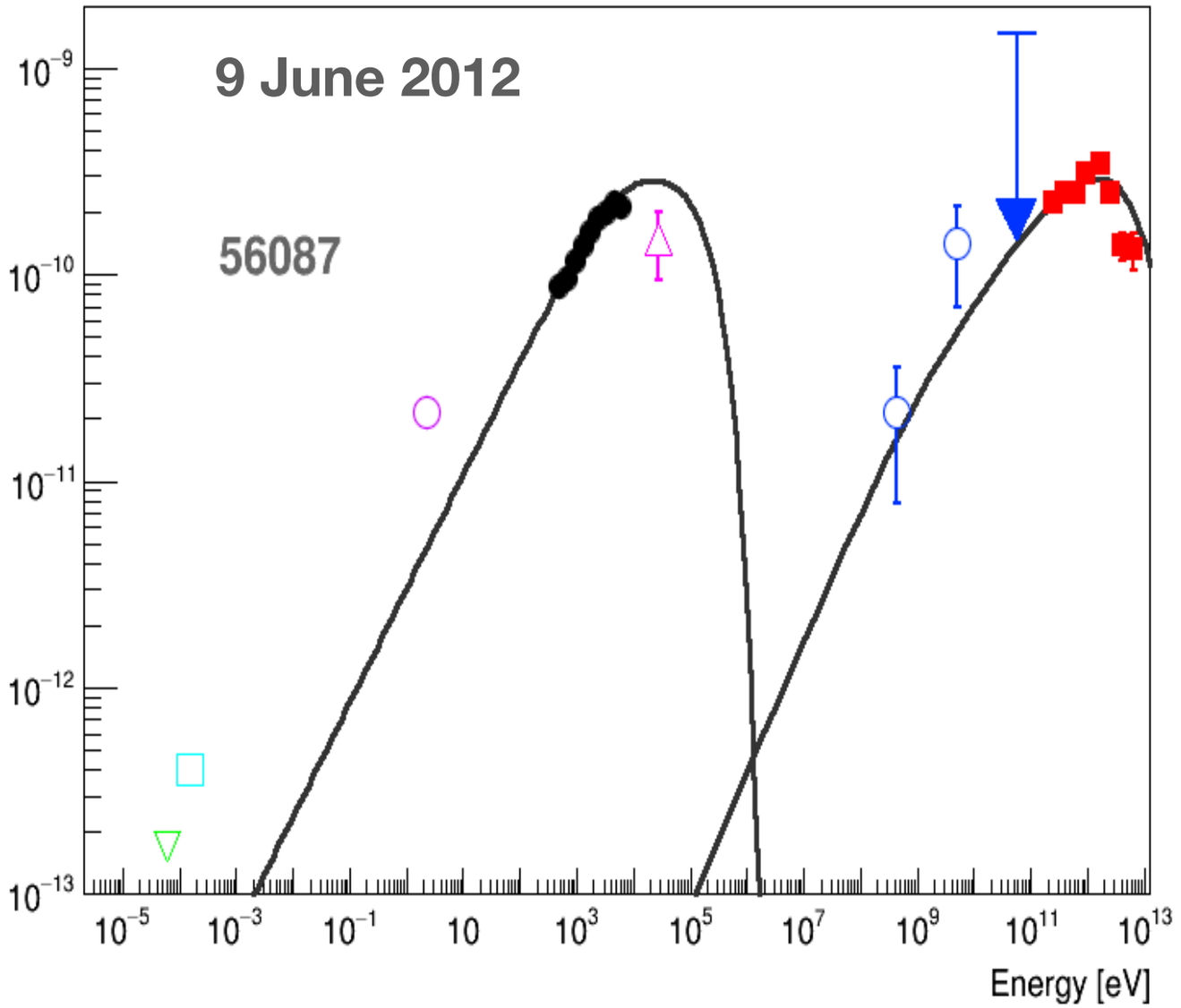
e.g. Veritas Coll. 2013



Mkn 501: 1997 ≃ 2012

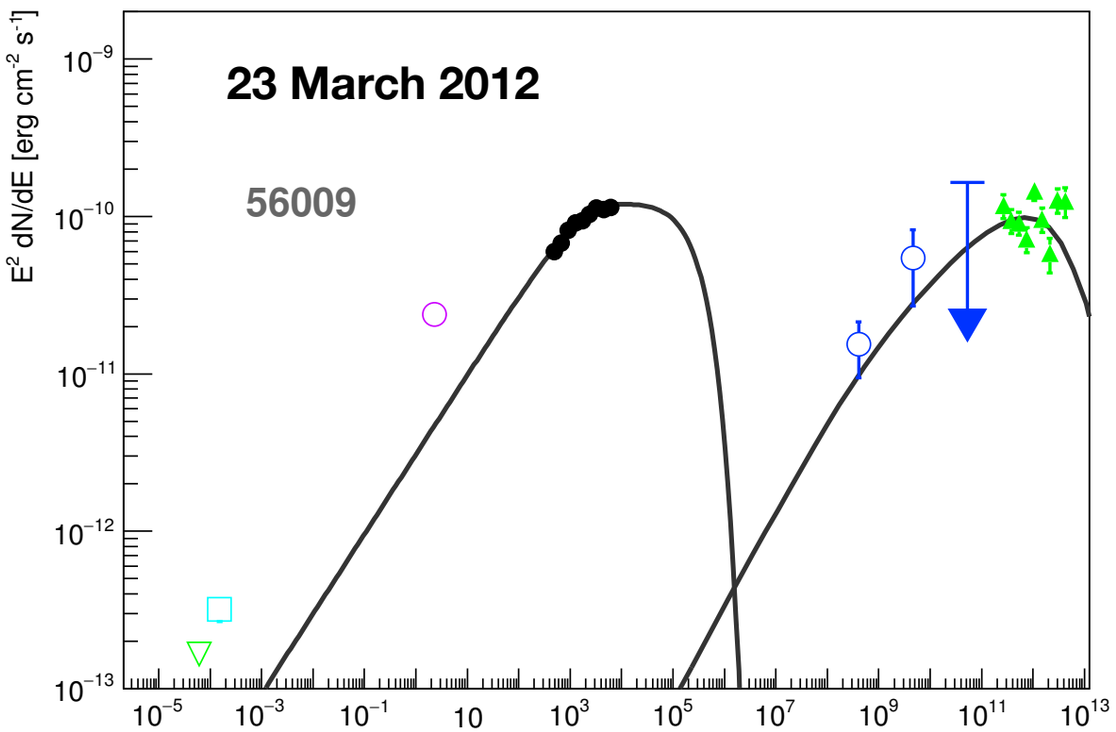


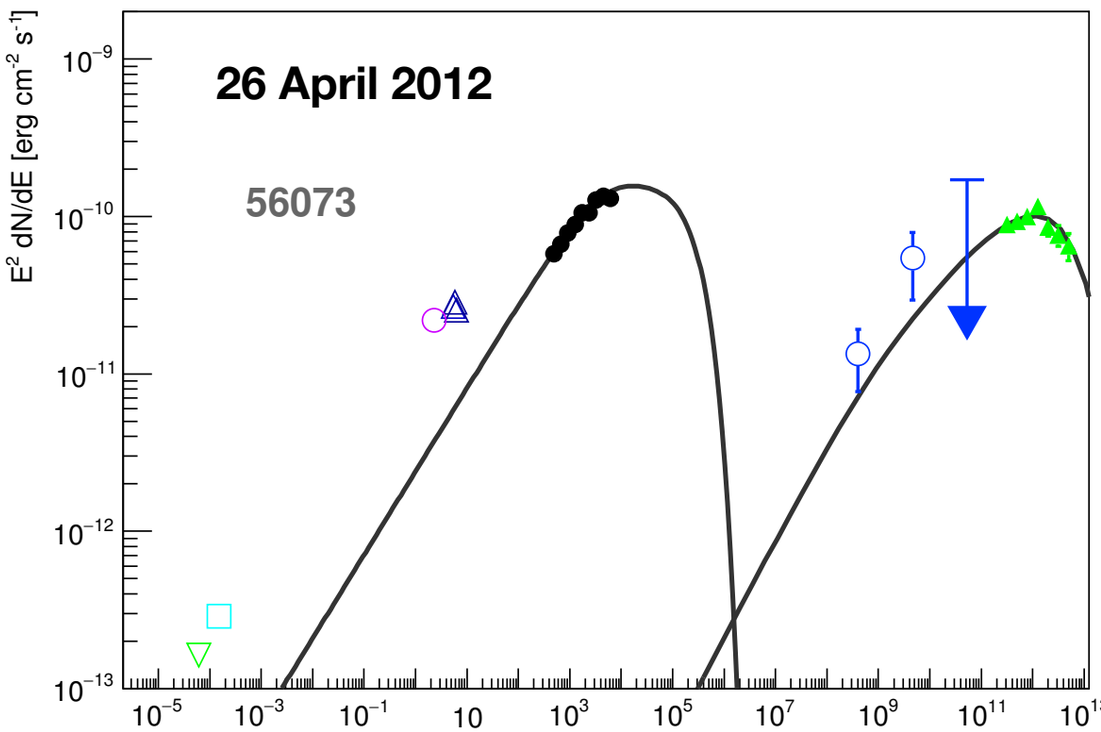
Pian et al. 1998
HEGRA Coll. 1999

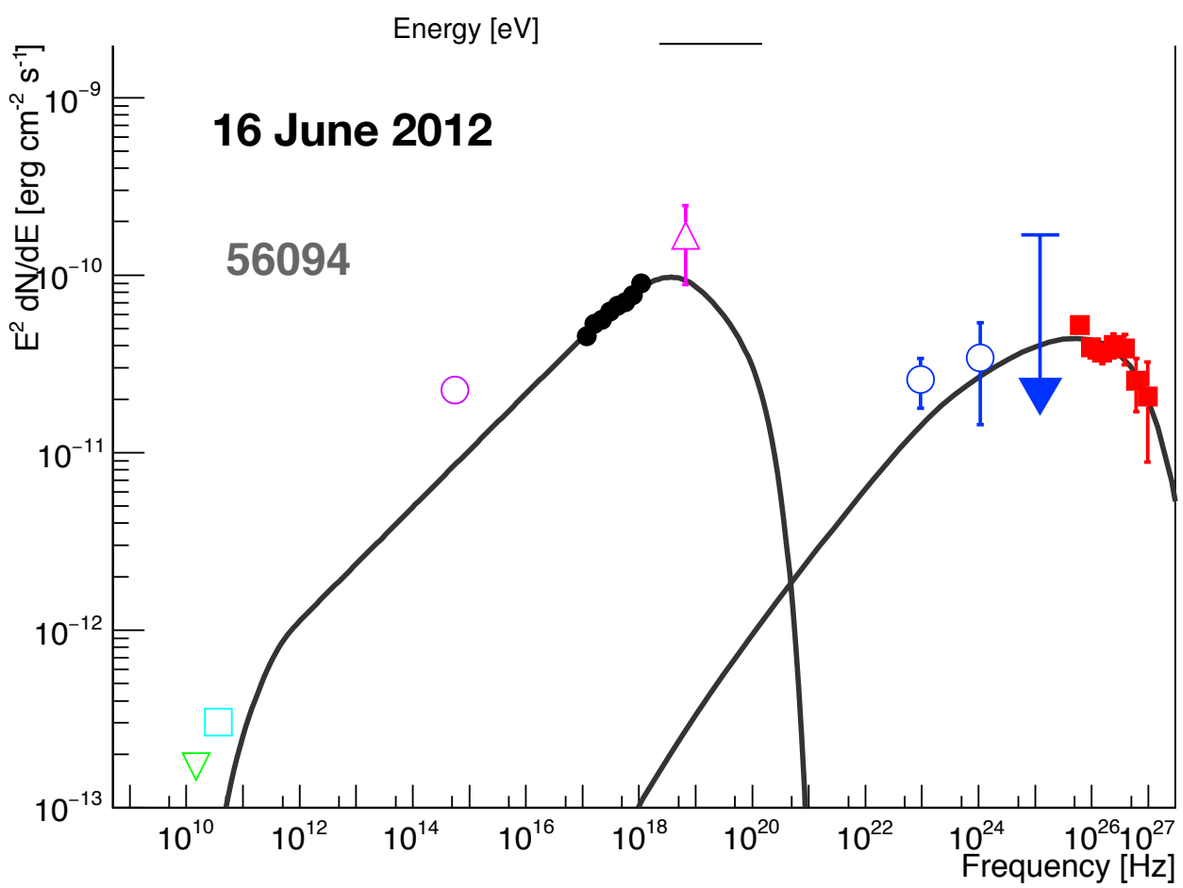


Ahnen et al. 2018,
Magic data

Extreme-S for long time (1426-like)

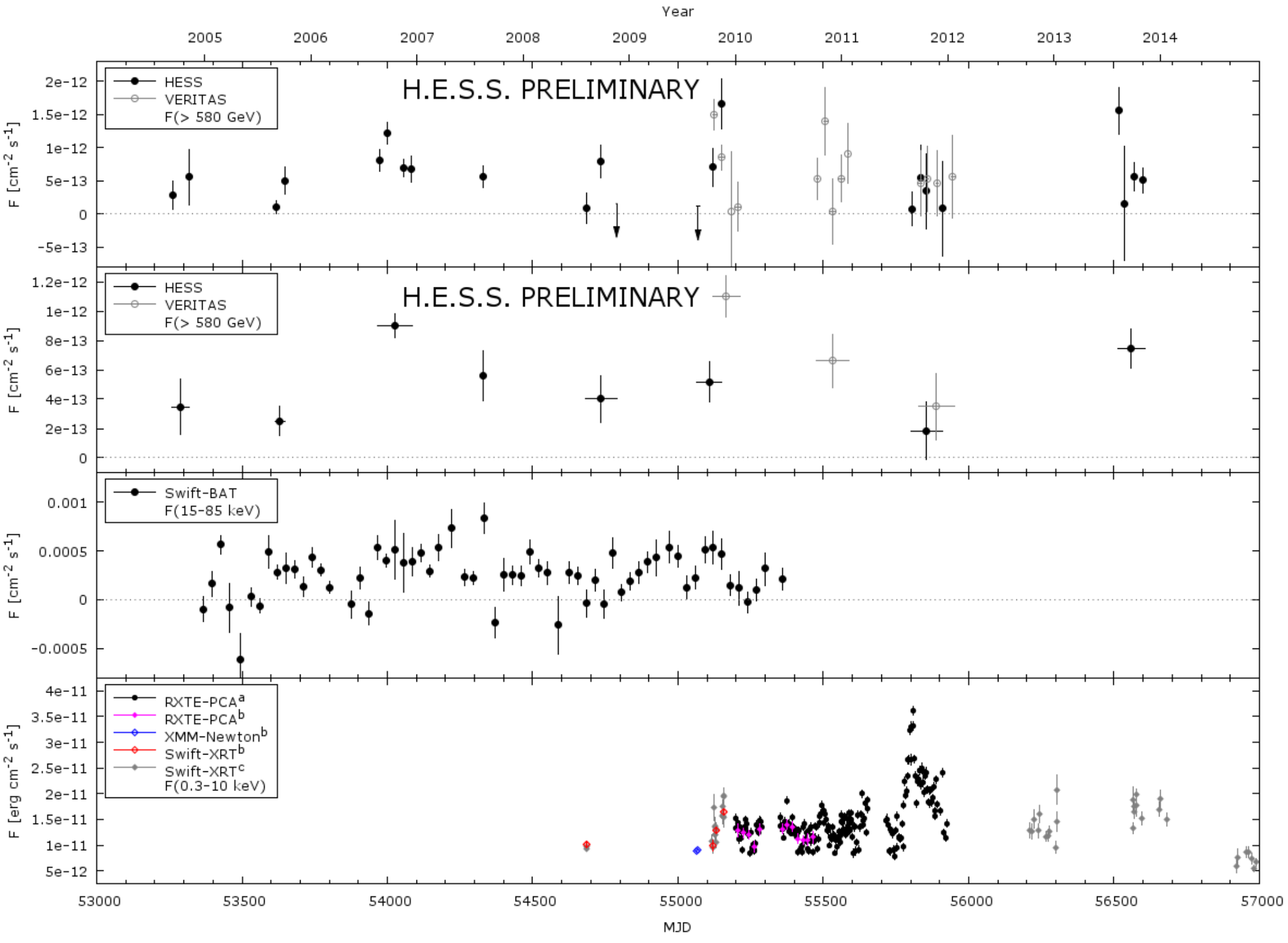






Ahnen et al. 2018
see Paneque talk

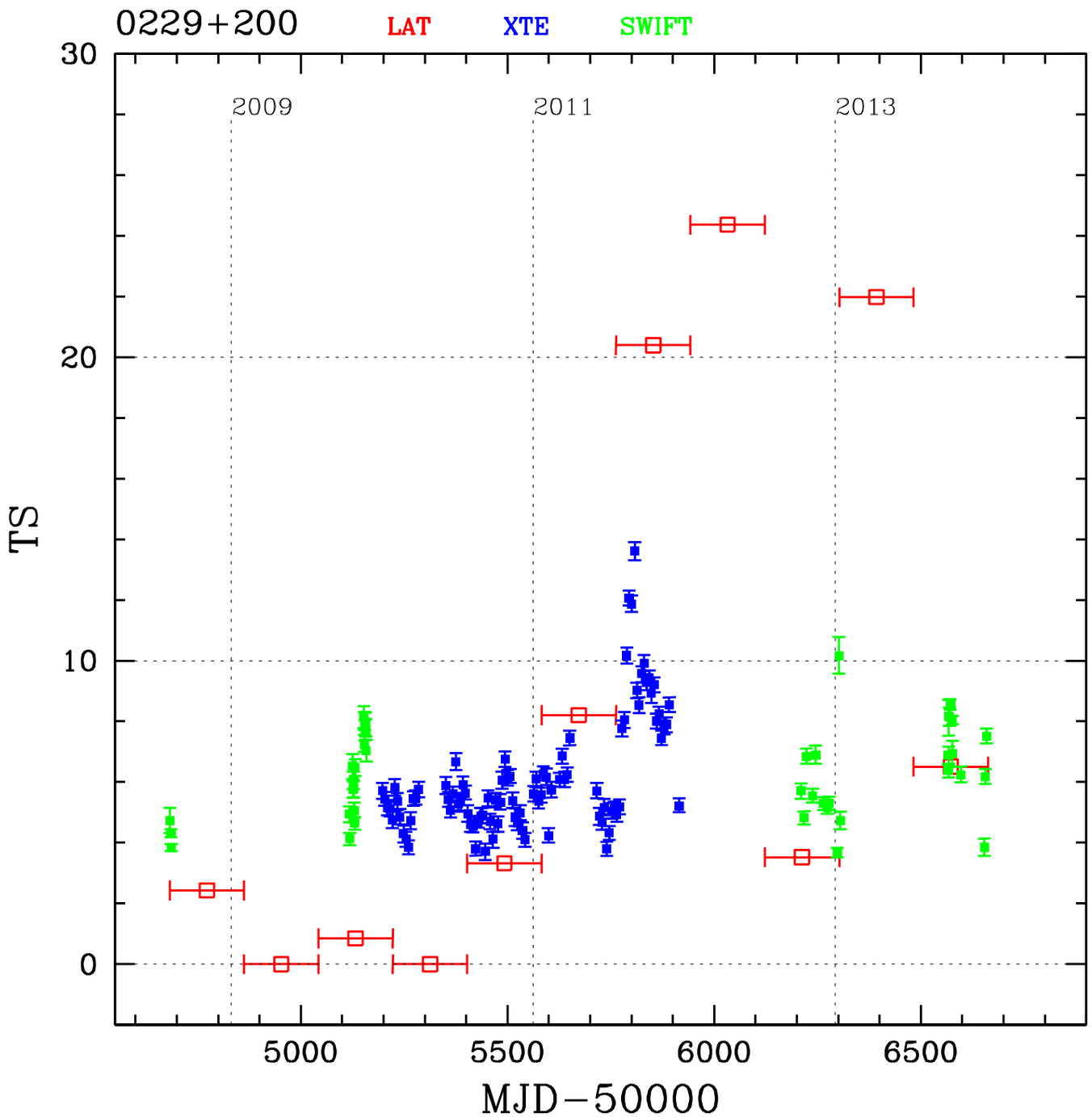
1ES 0229+200 Lightcurve



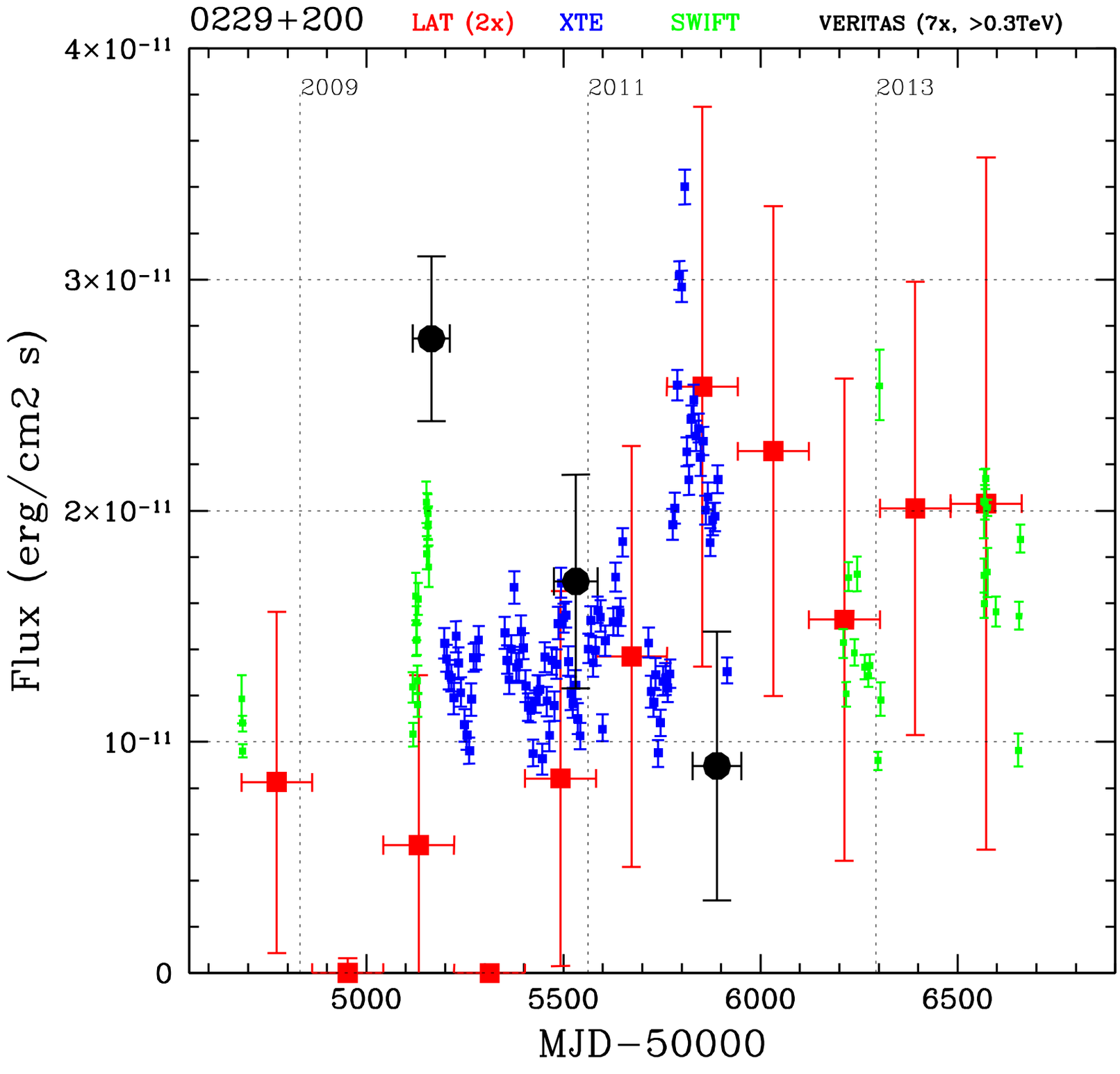
Cologna et al. 2015, ICRC

1ES 0229+200 Fermi-LAT detection only after 2011

TS
LAT 1-300 GeV

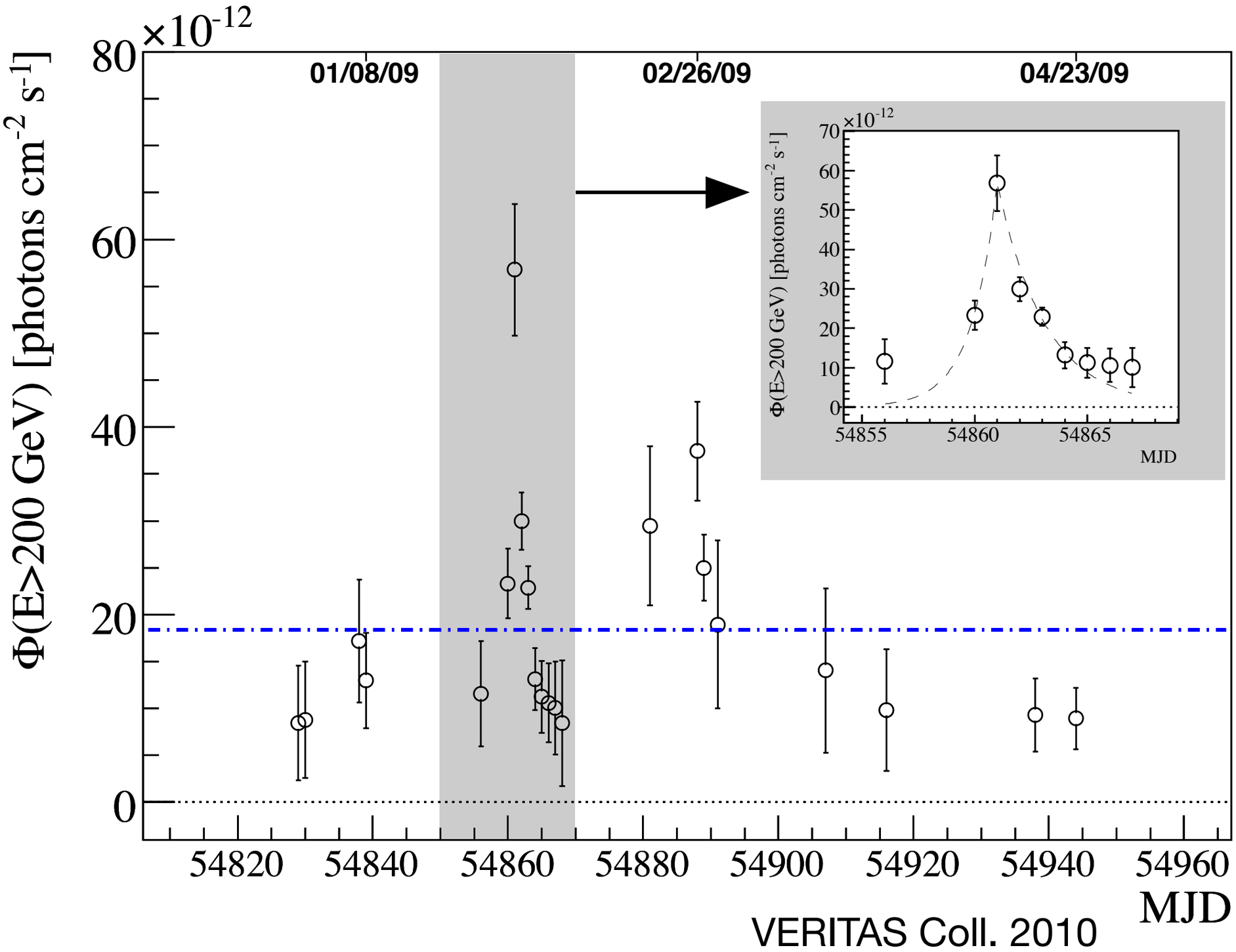


LC, Boheme Meeting 2014



LC, Boheme Meeting 2014
Veritas Coll. 2014

1ES 1218+304: Fast Day-timescale variability at VHE



Why they are important:

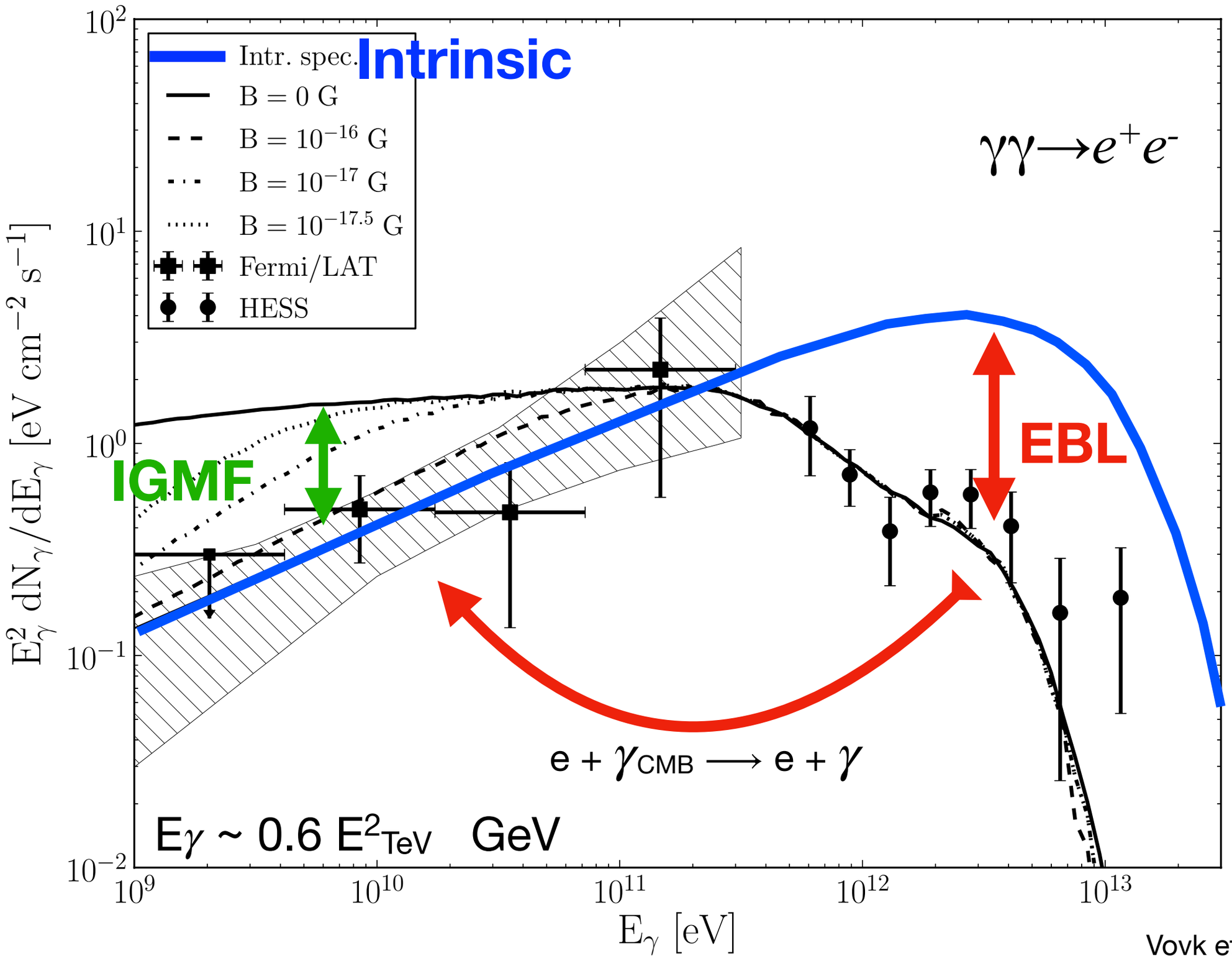
1) TeV beamers: cosmological probes for EBL and IGMF

2) Neutrino / UHECR sources ?

3) New physics probes ?

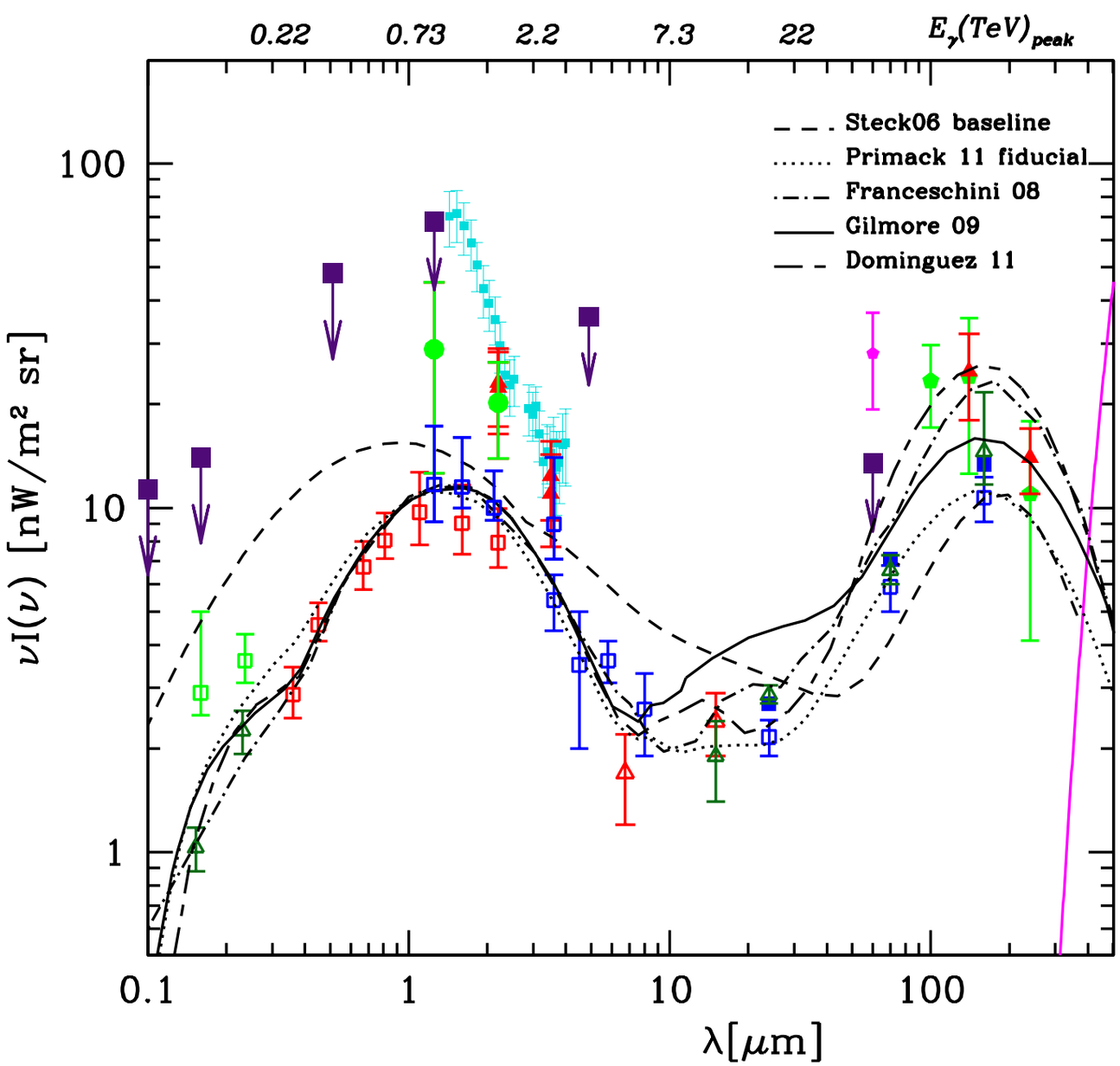
4) Challenge for Blazars emission models:
   what origin for the observed gamma-rays ?

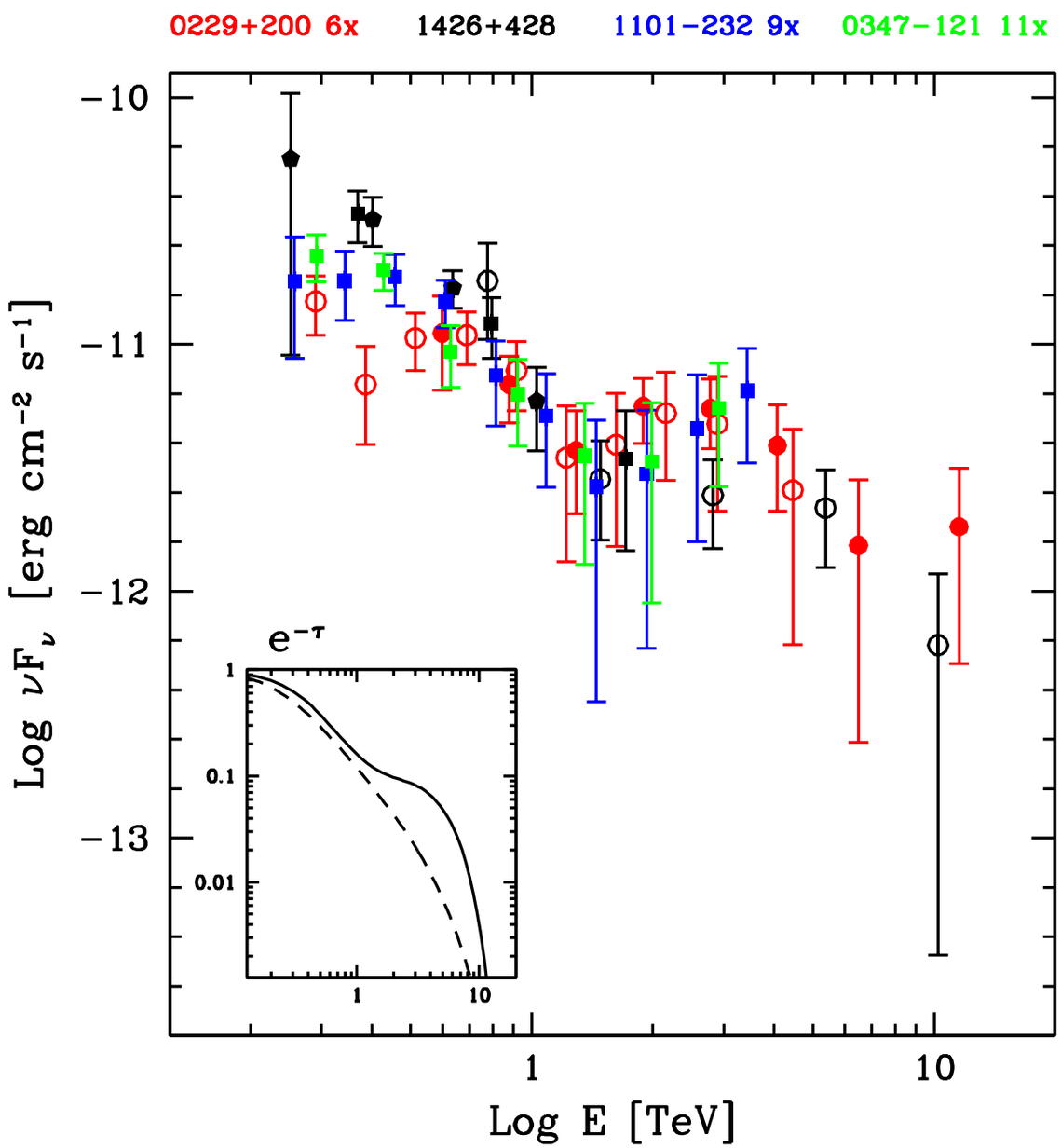
Cosmological probes



Vovk et al. 2012

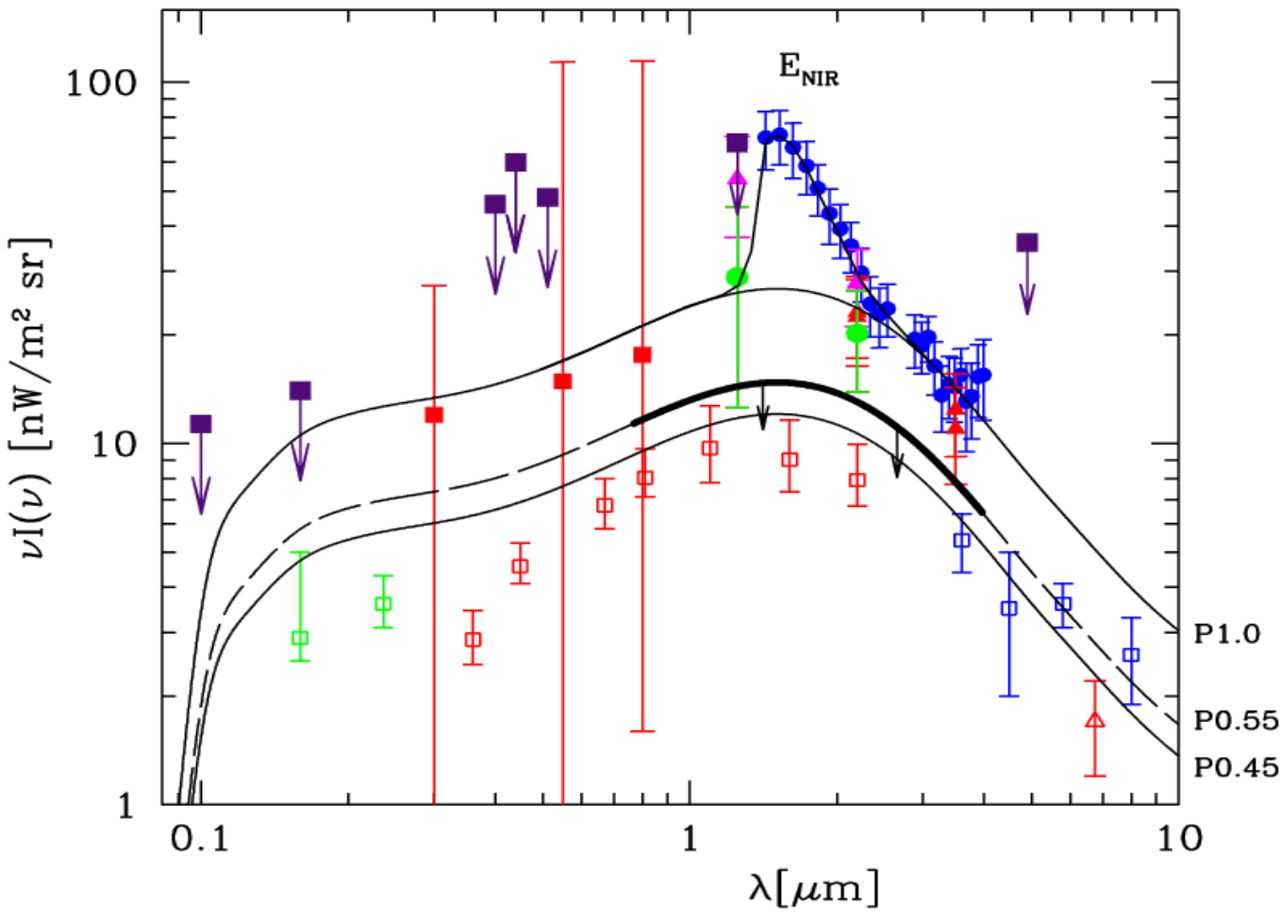
SED of Extragalactic Background Light



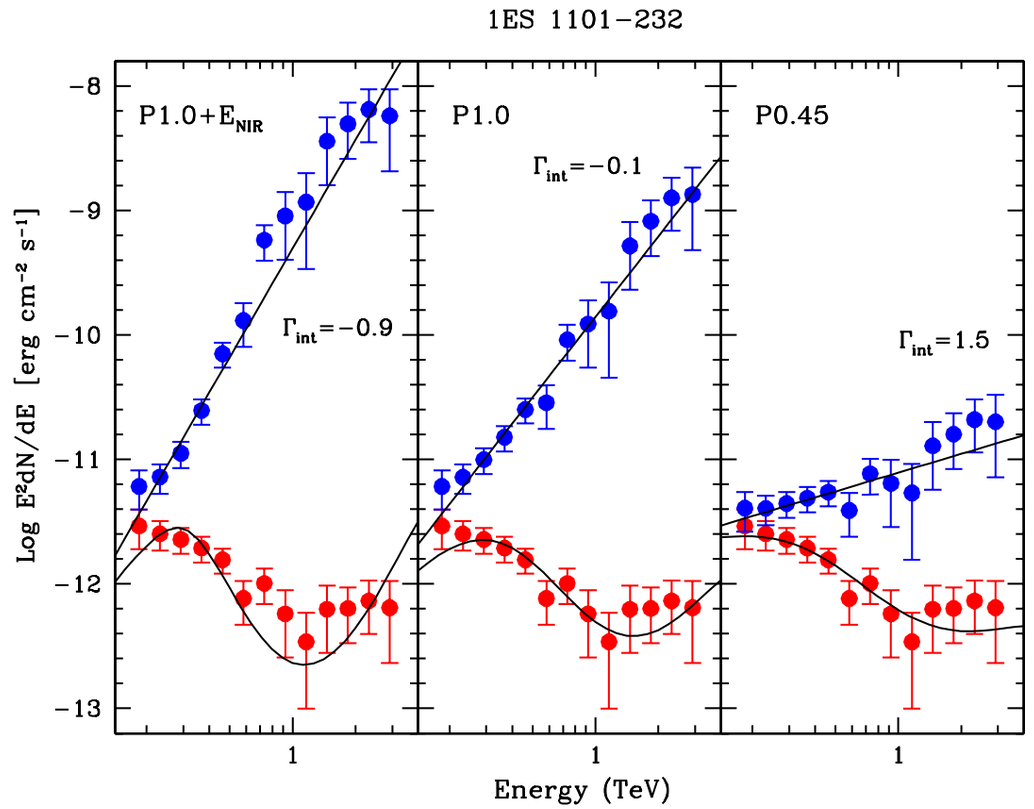


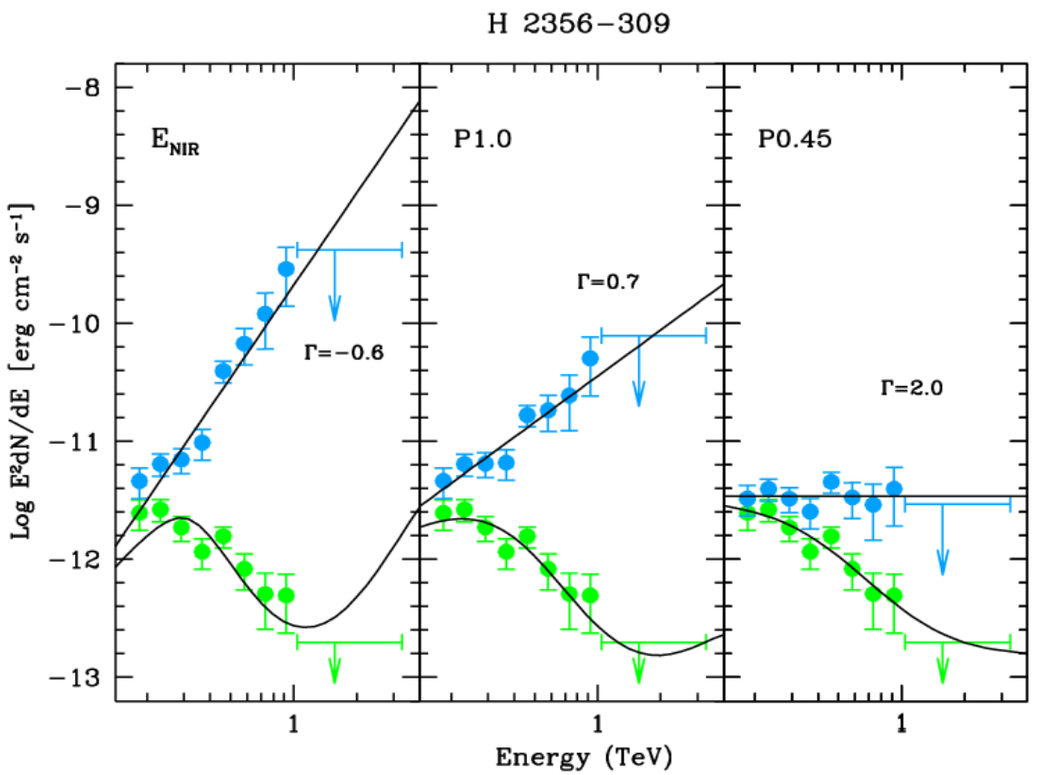
see e.g Costamante 2013

Breakthrough in 2006

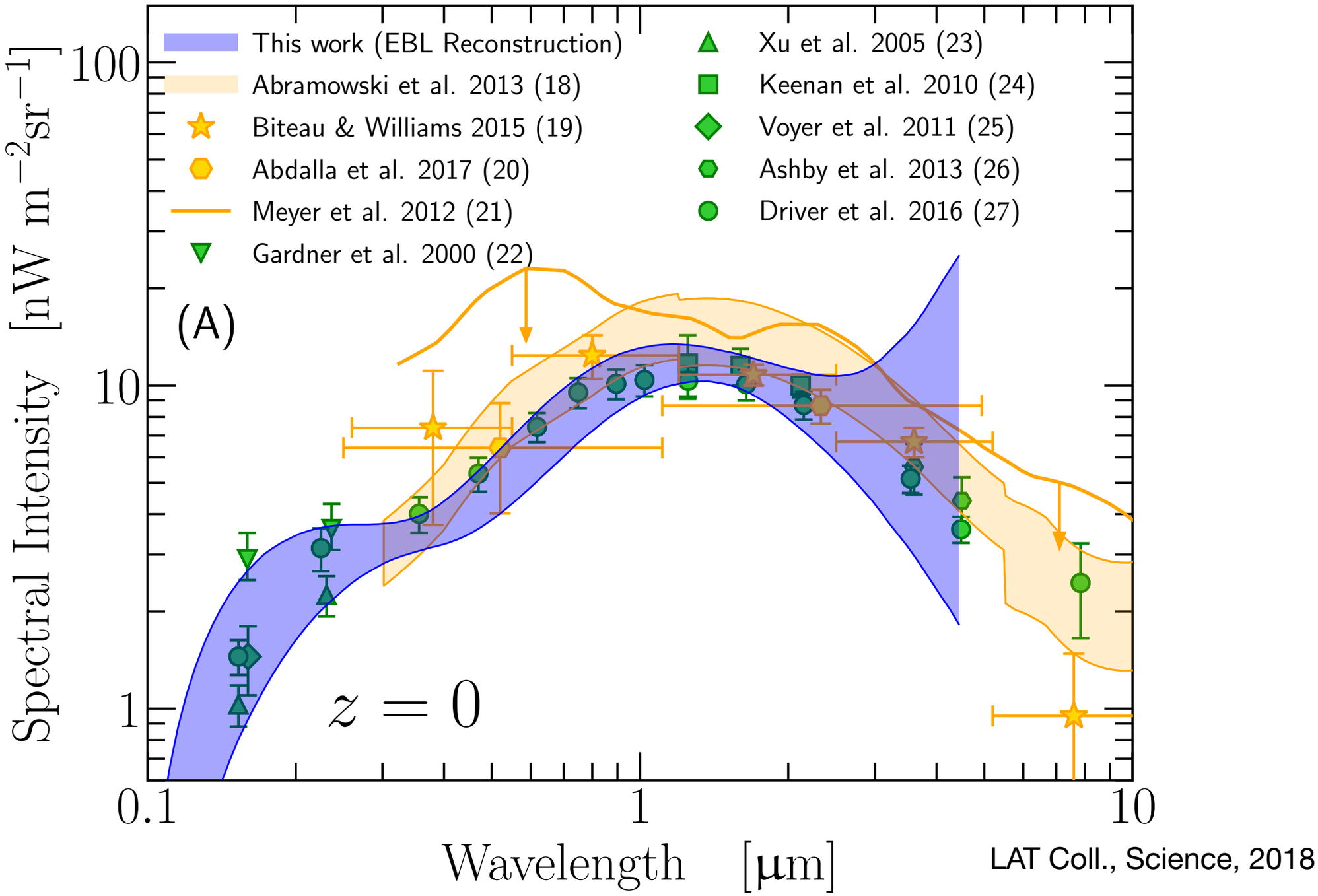


HESS Coll. Nature 2006





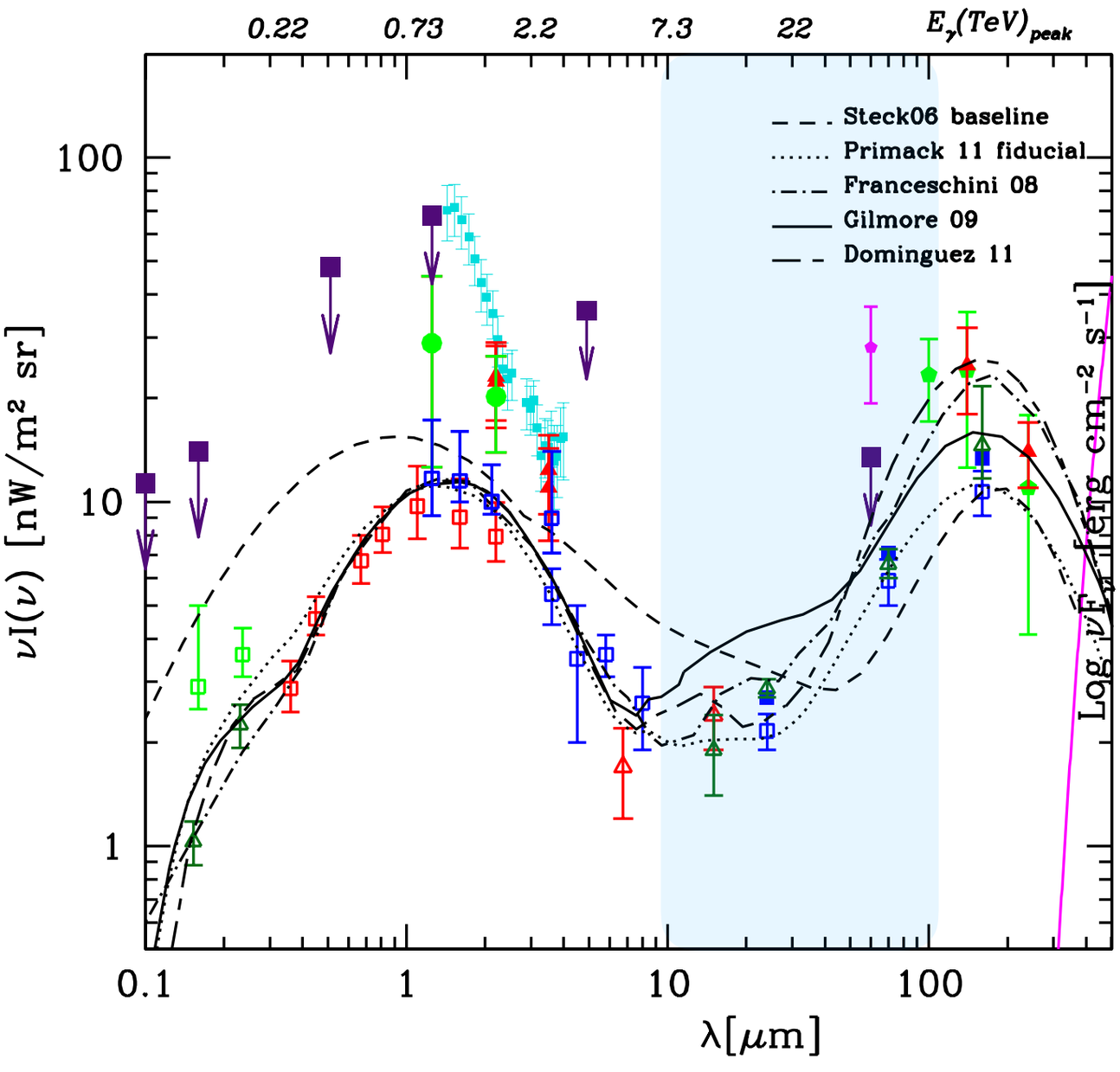
Strong limits **Fermi-LAT + VHE**

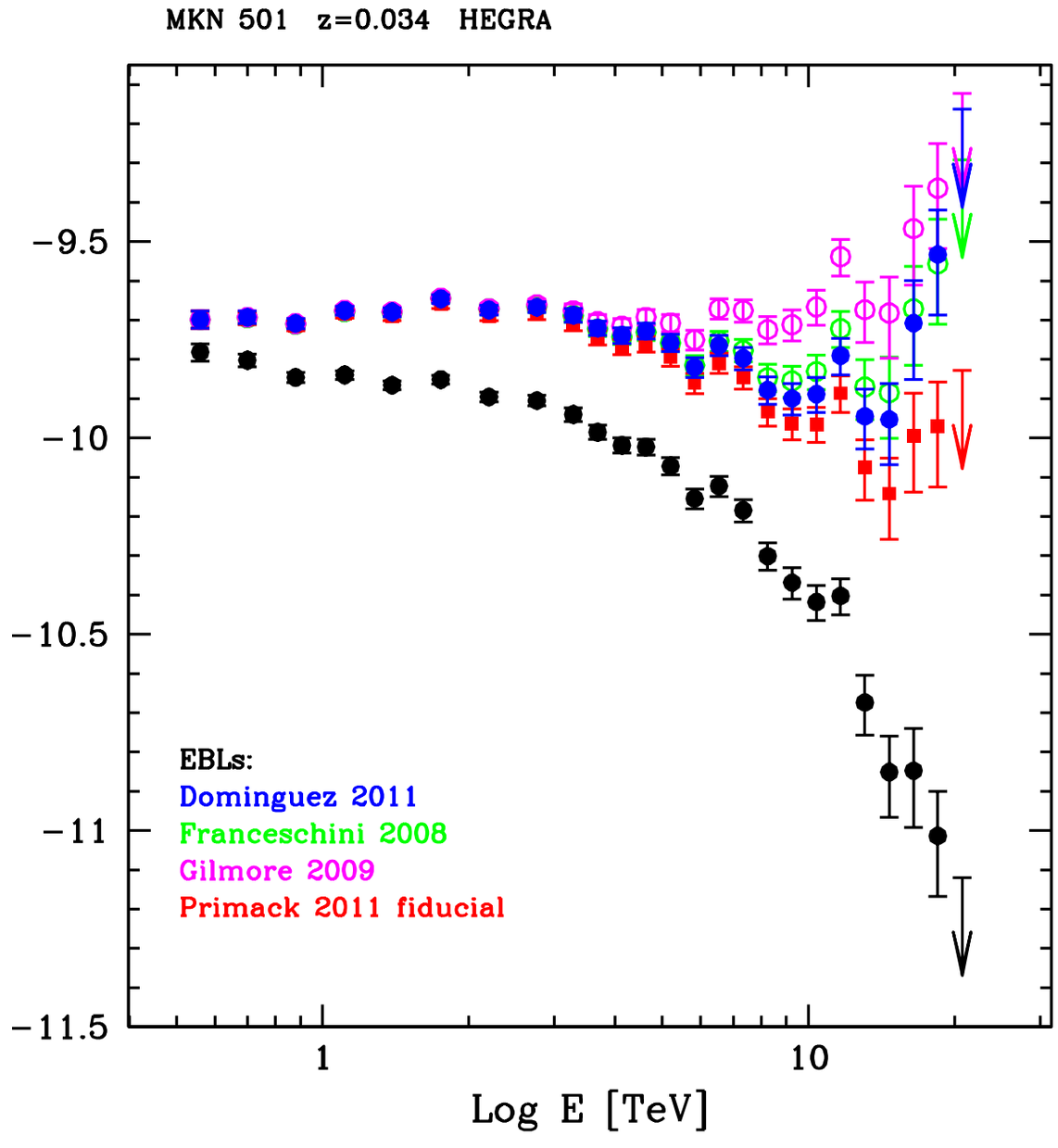


LAT Coll., Science, 2018

Extreme-C probe CIRB above 10 μm

Spectra > 10 TeV, possible problems ?

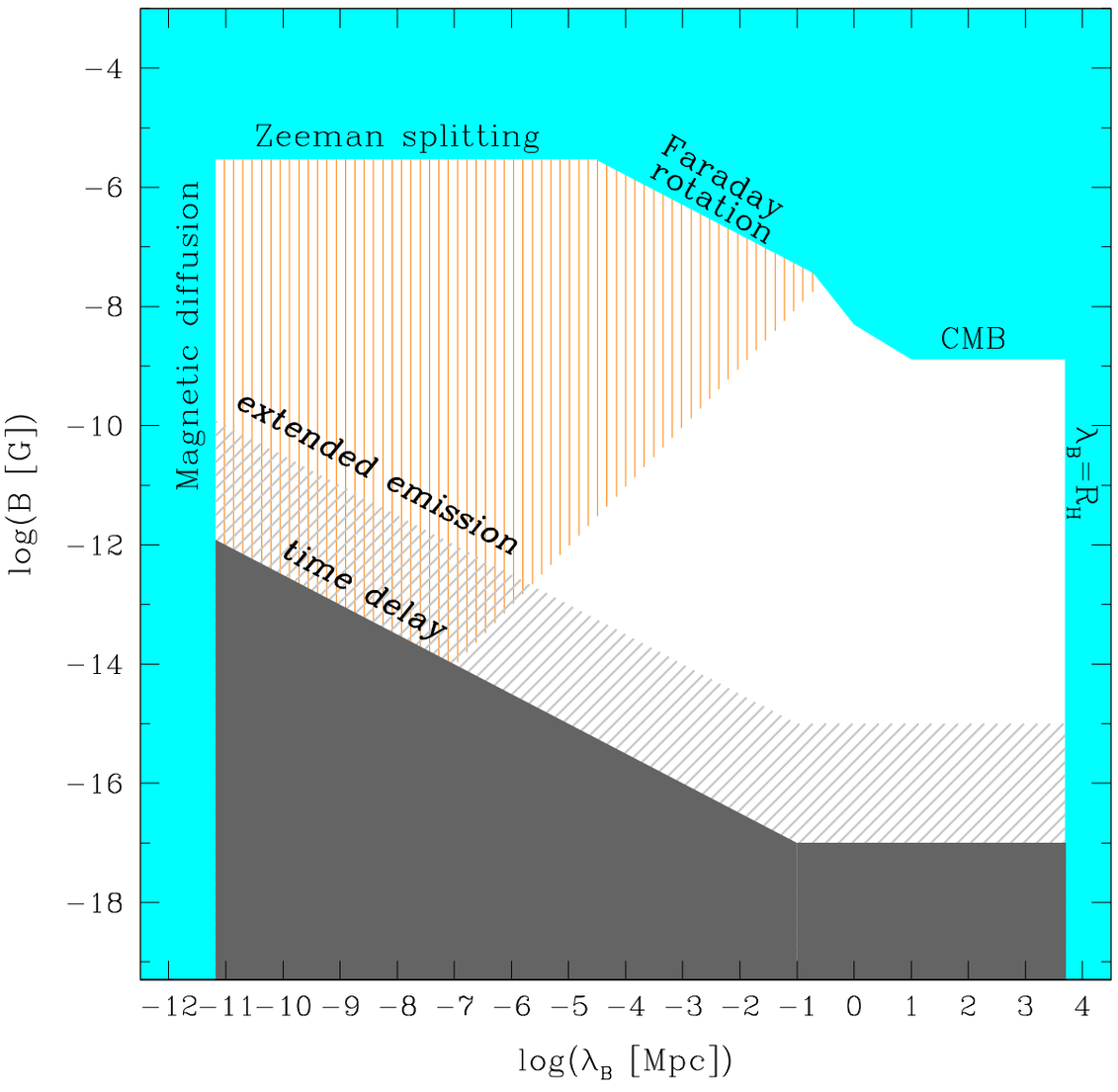


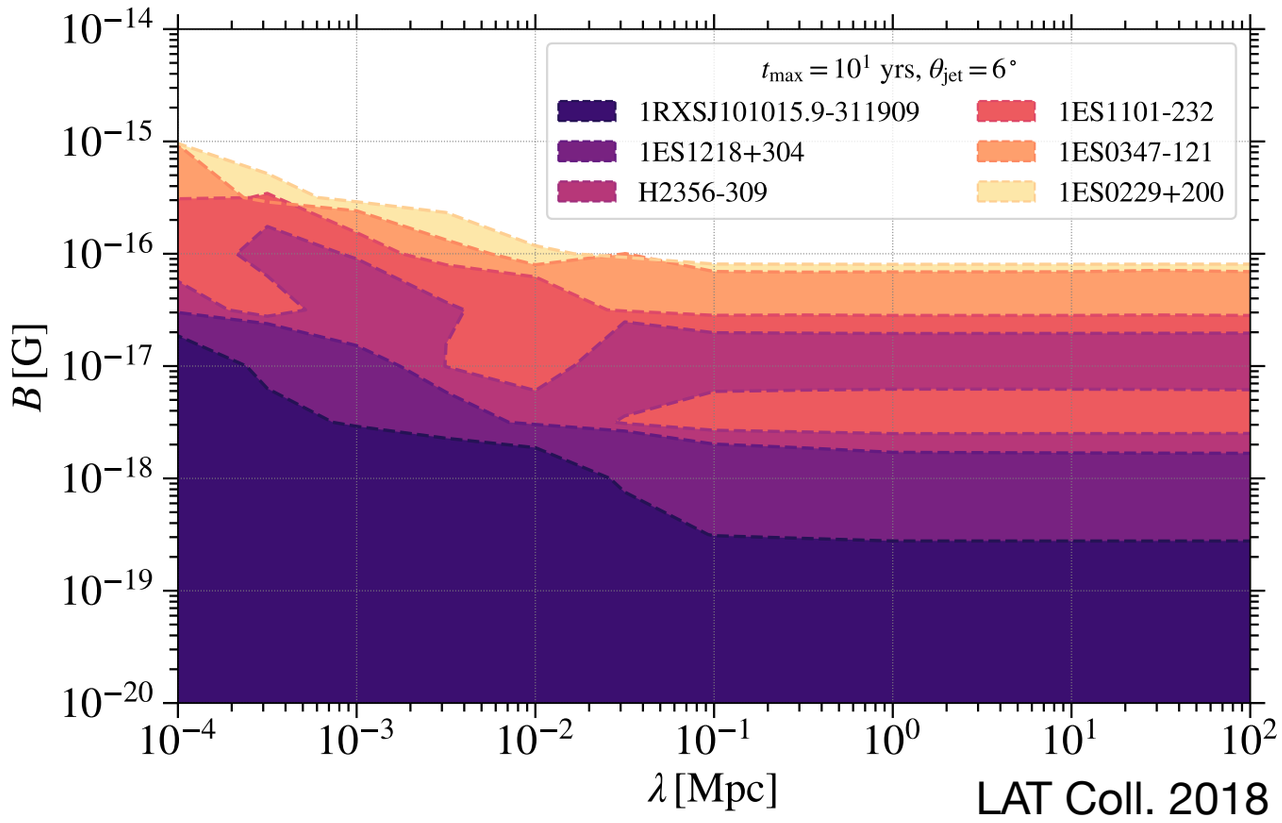


e.g. Costamante 2013

IGMF lower limits

B> 10^{-16} - 10^{-17} G

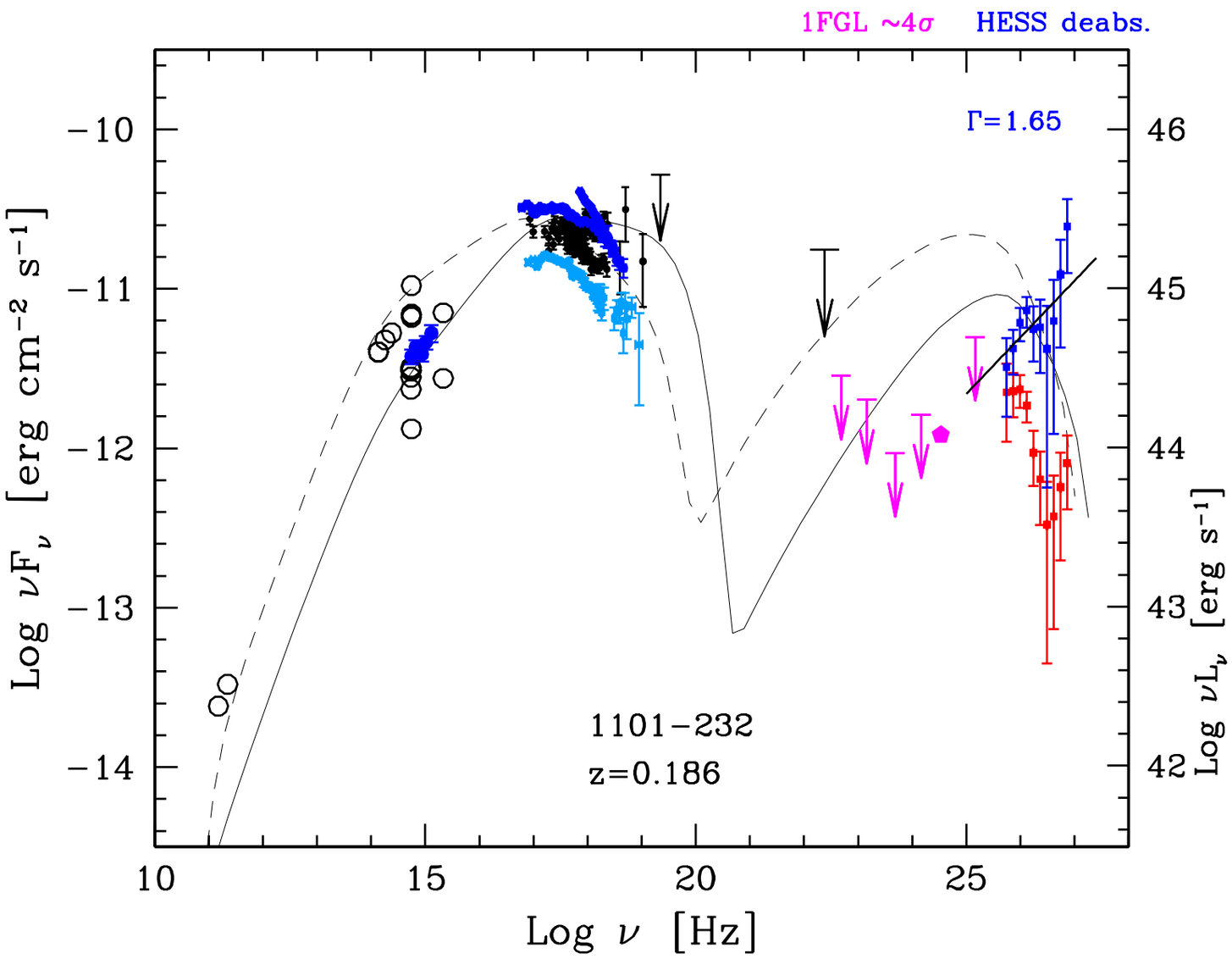




LAT Coll. 2018

Neronov & Vovk 2010
Tavecchio et al 2010
Taylor et al. 2011
Vovk et al. 2012 etc

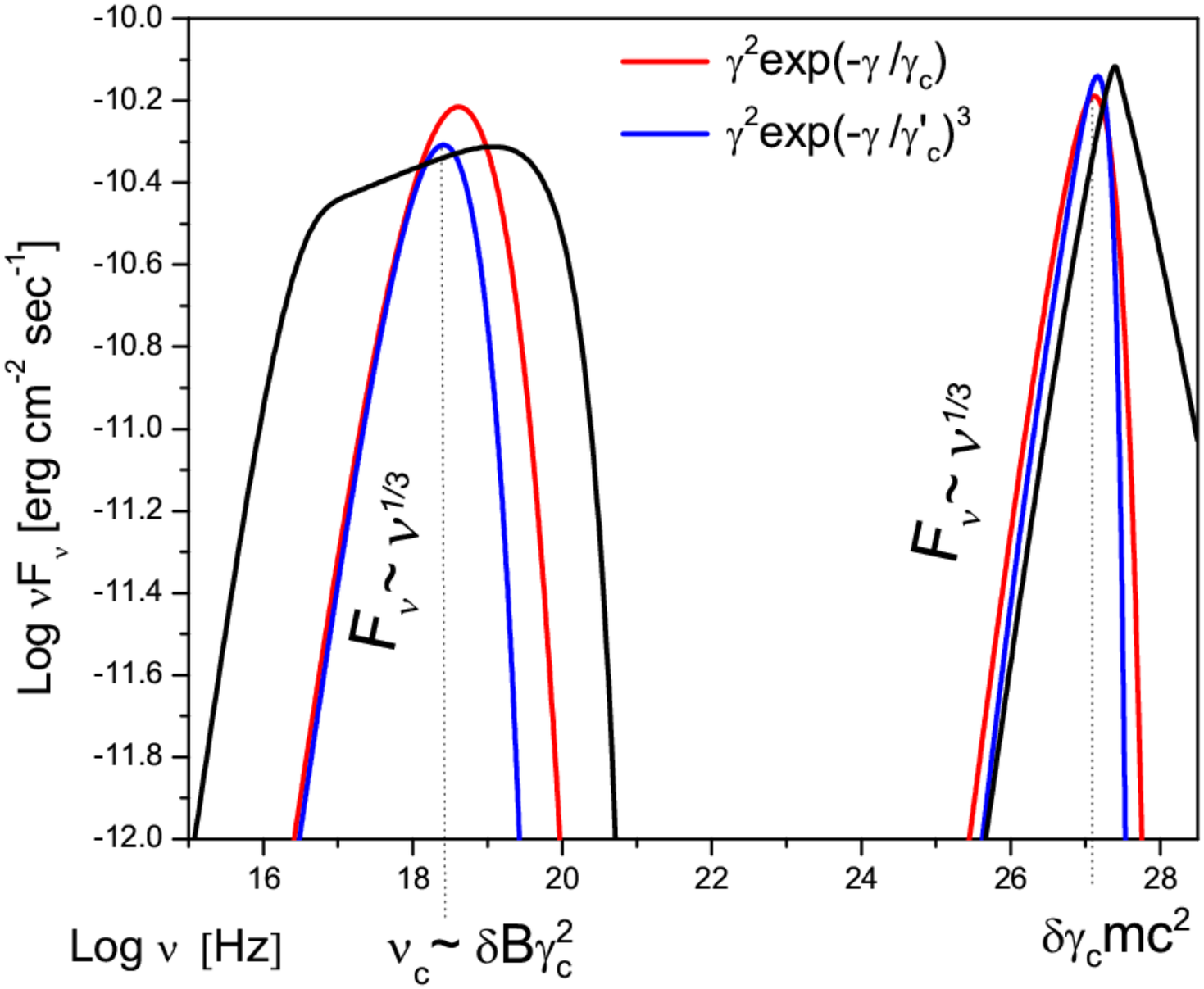
Emission mechanism:
problems for one-zone SSC



Efficient Cooling + KN effects tend to steepen spectrum at VHE-TeV

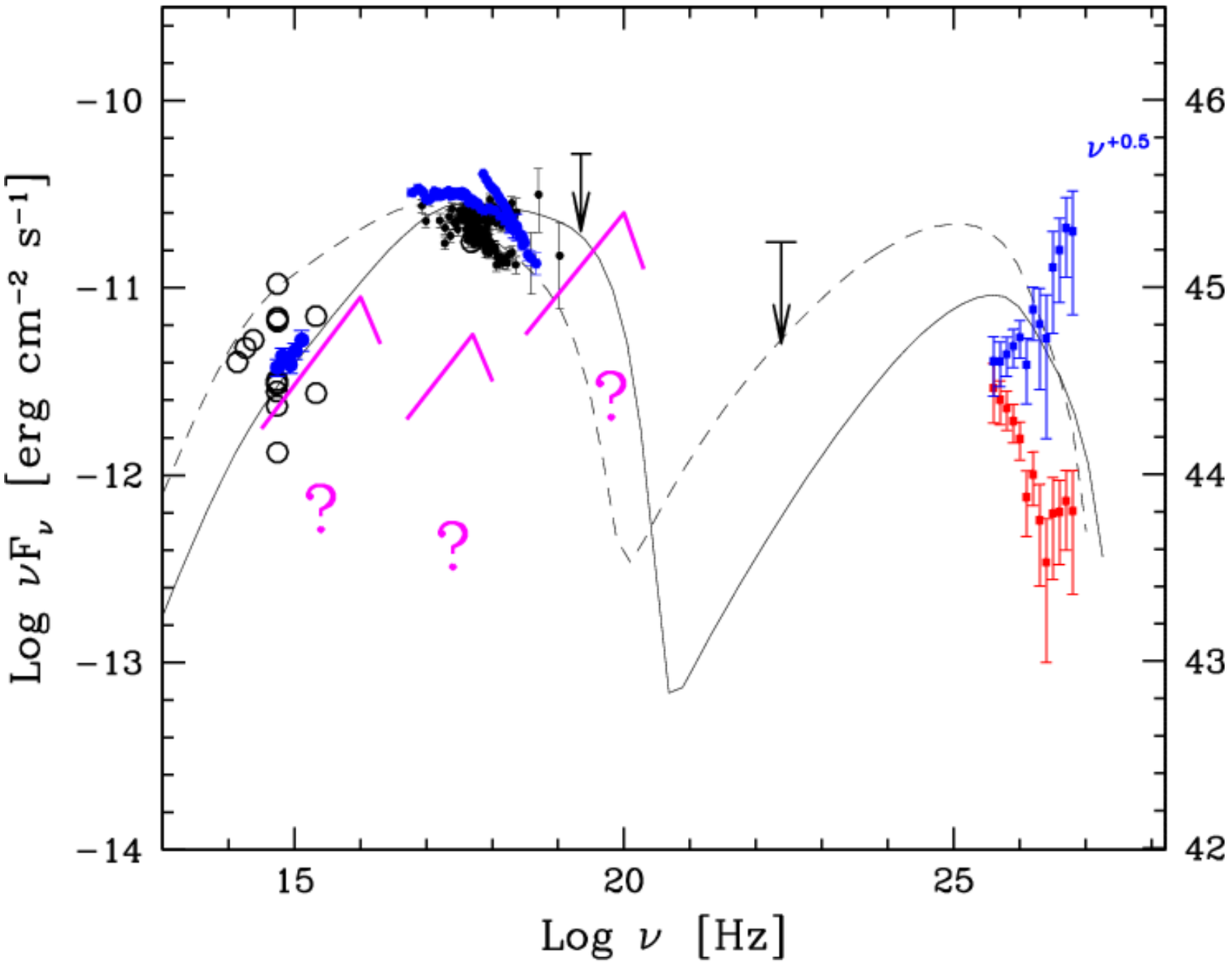
Hard distributions and SSC ?

comprehensive discussion in Lefa et al 2011



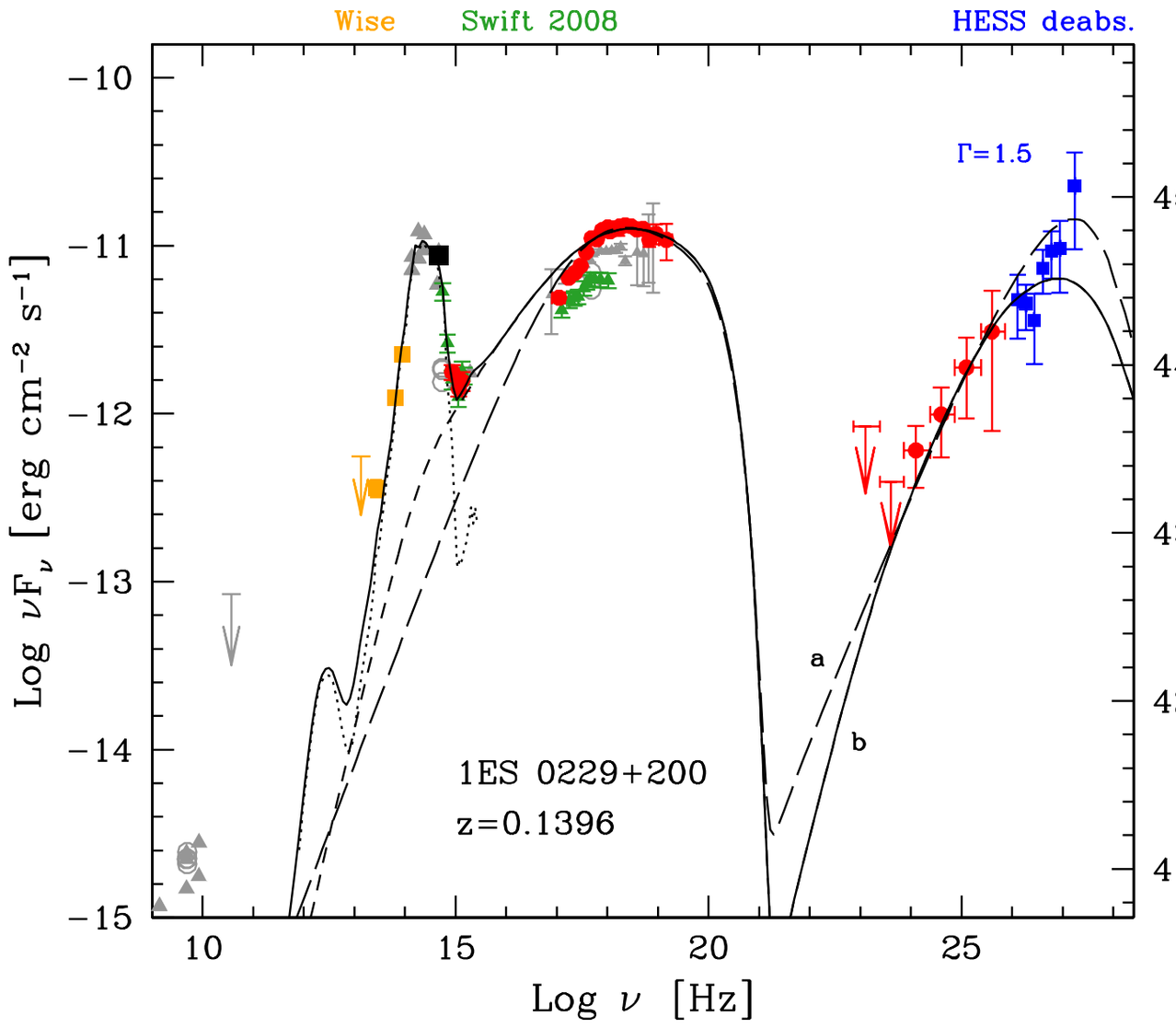
- Low-energy cutoff at high energies (Katarzynski 2007)
- Maxwellian distribution (Henri et al 2002)

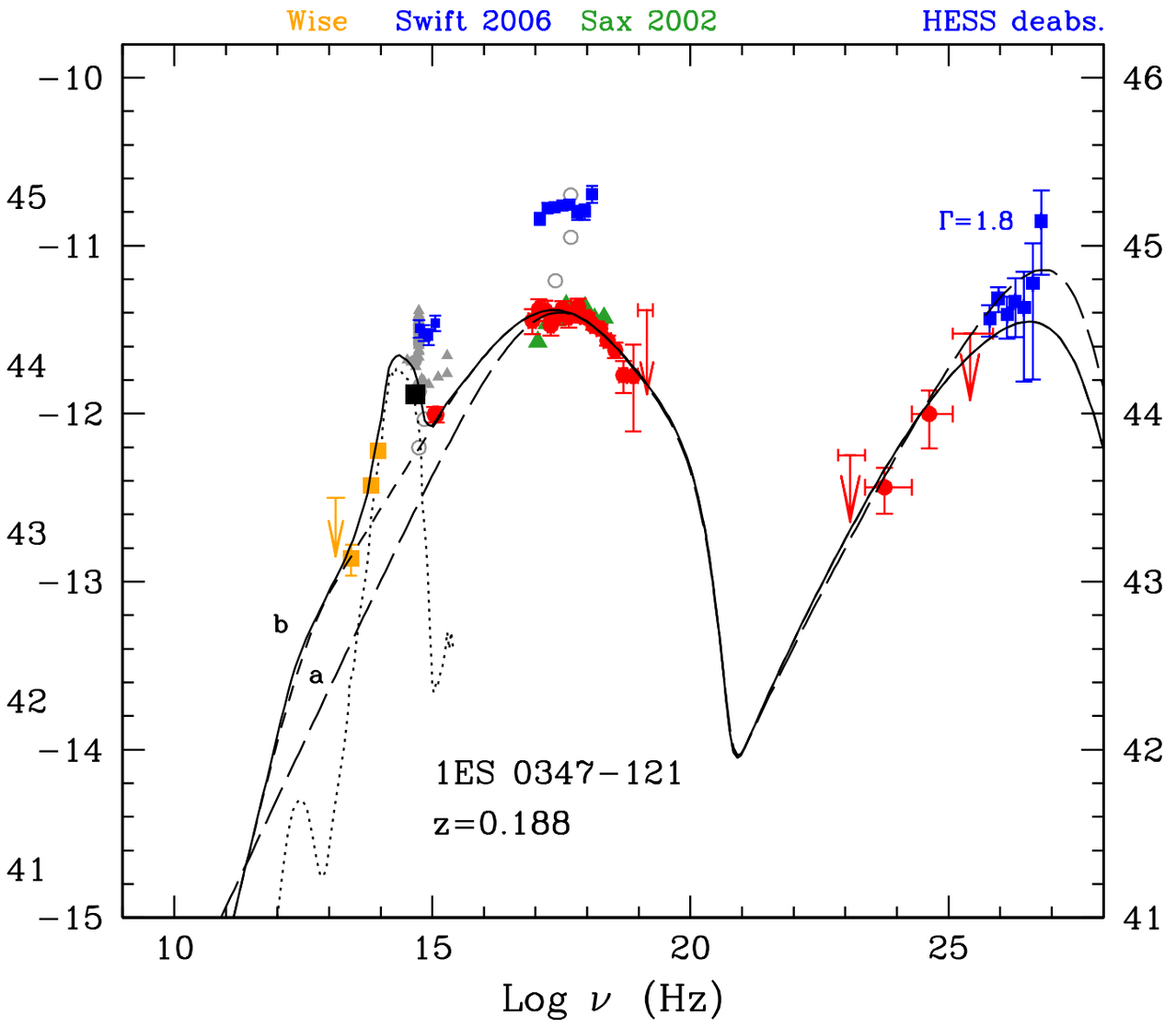
Where is synchrotron emission of these TeV electrons ?



NuSTAR-Swift observations

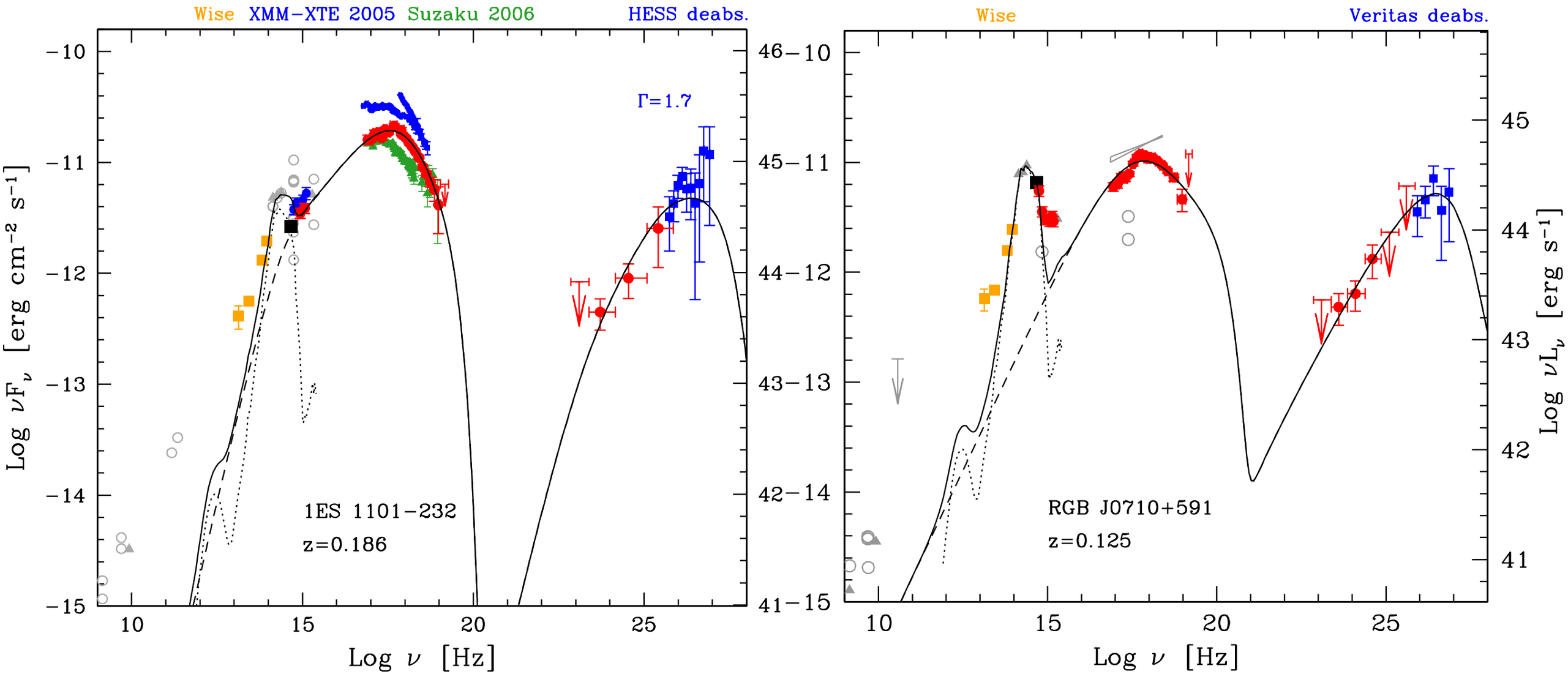
2013-2016 observations, Fermi-LAT data 4Y: 2013-2017 Pass8





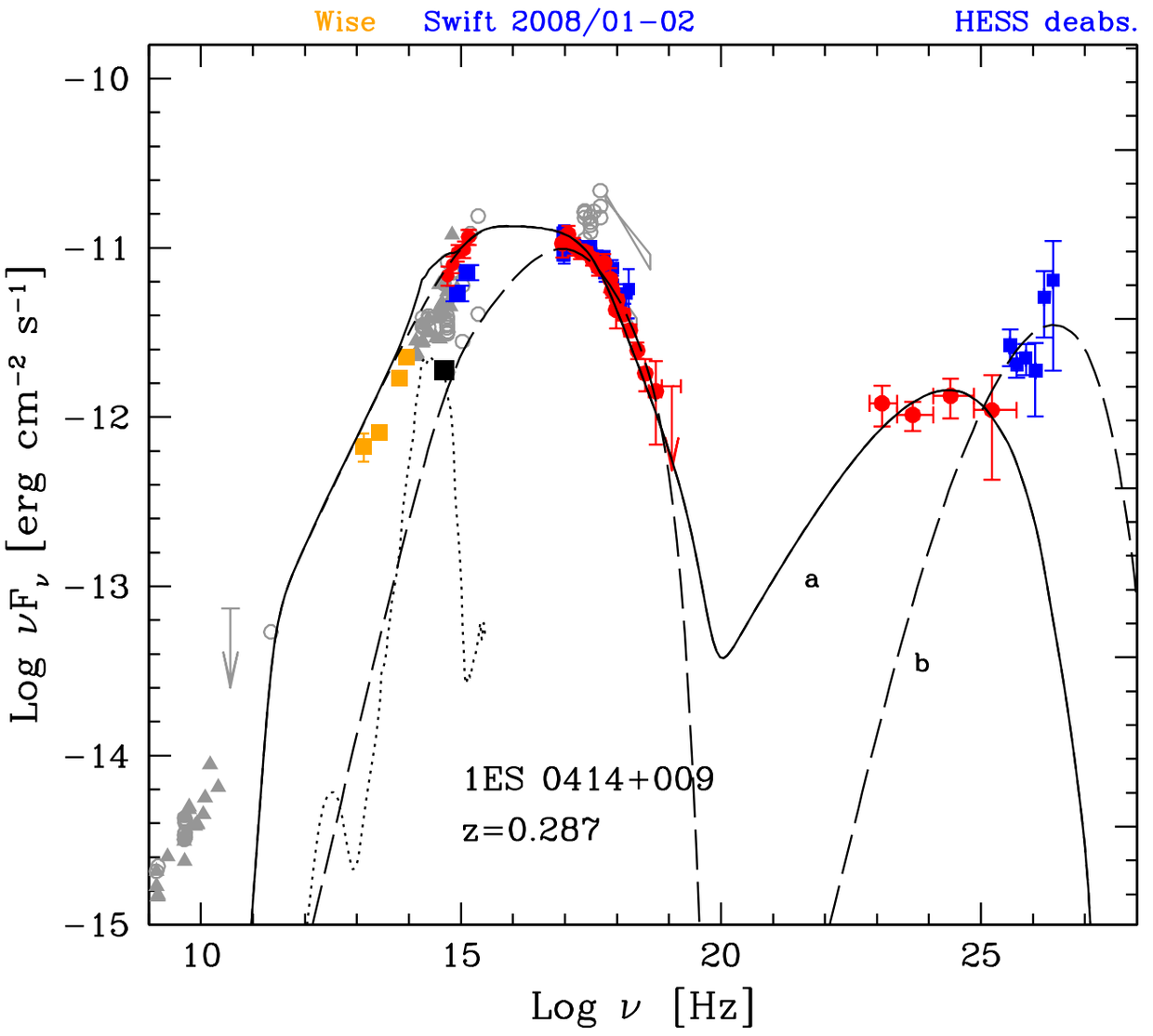
Costamante et al. 2018

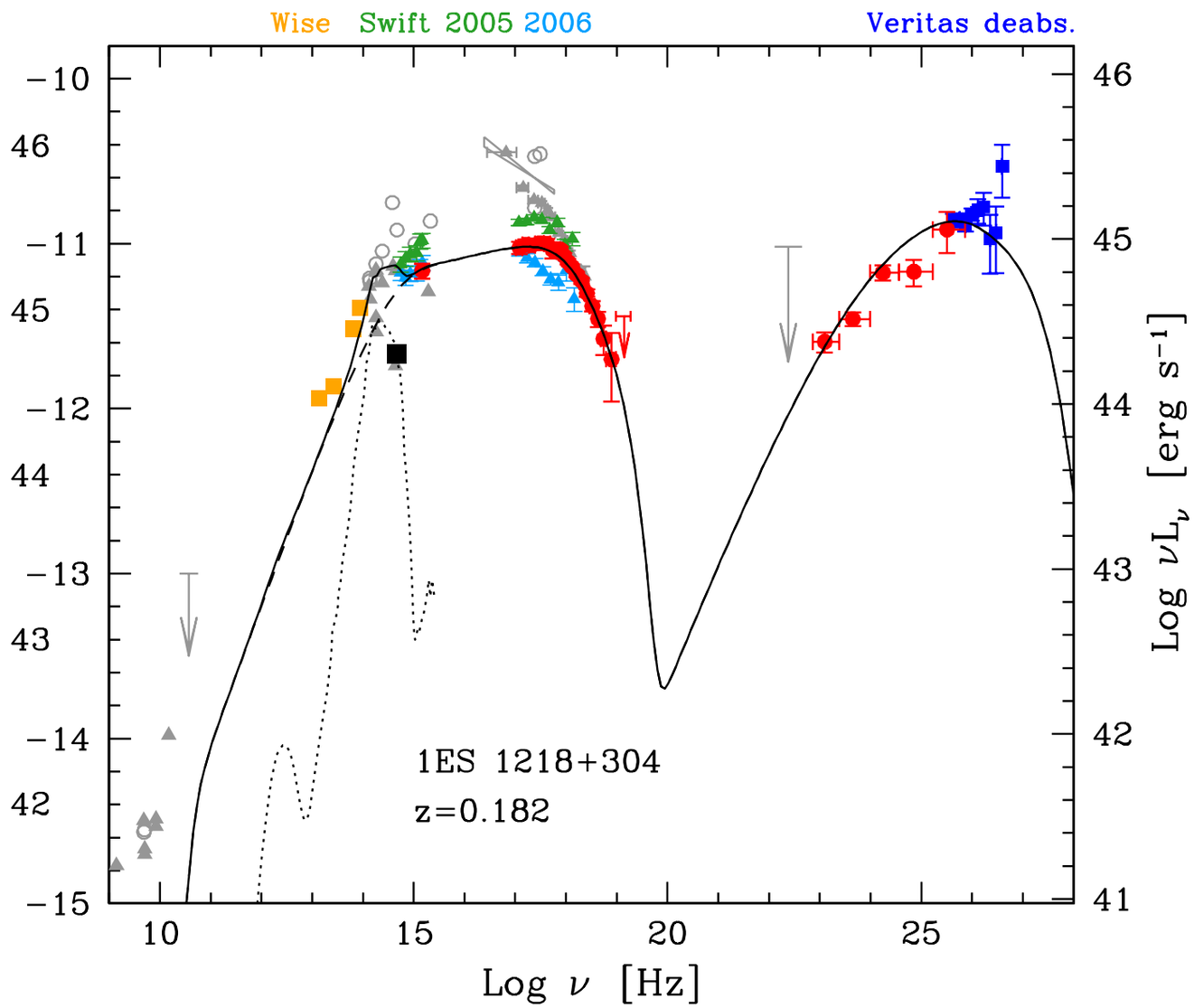
NuSTAR-Swift observations



Costamante et al. 2018

NuSTAR-Swift observations





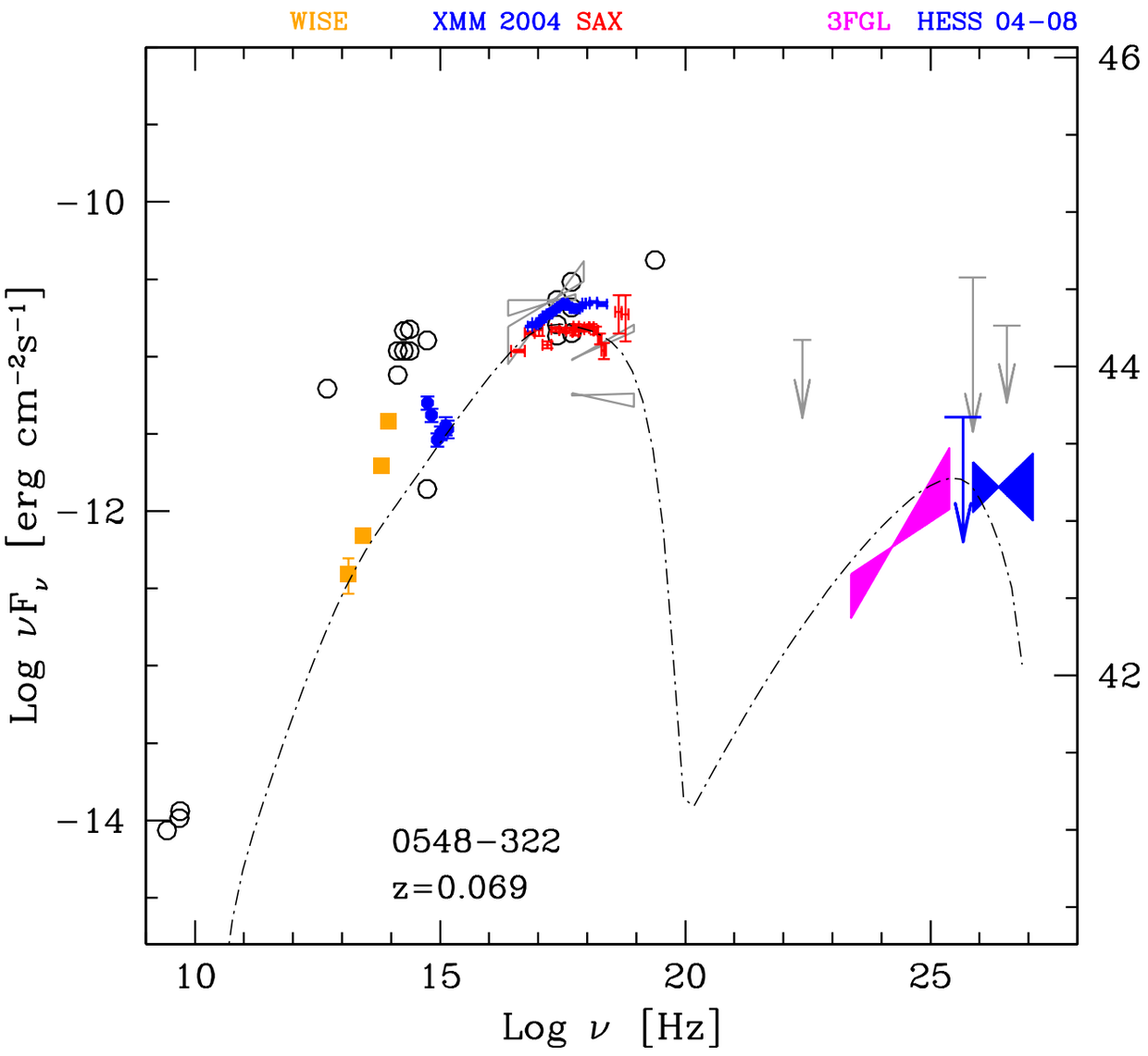
Costamante et al. 2018

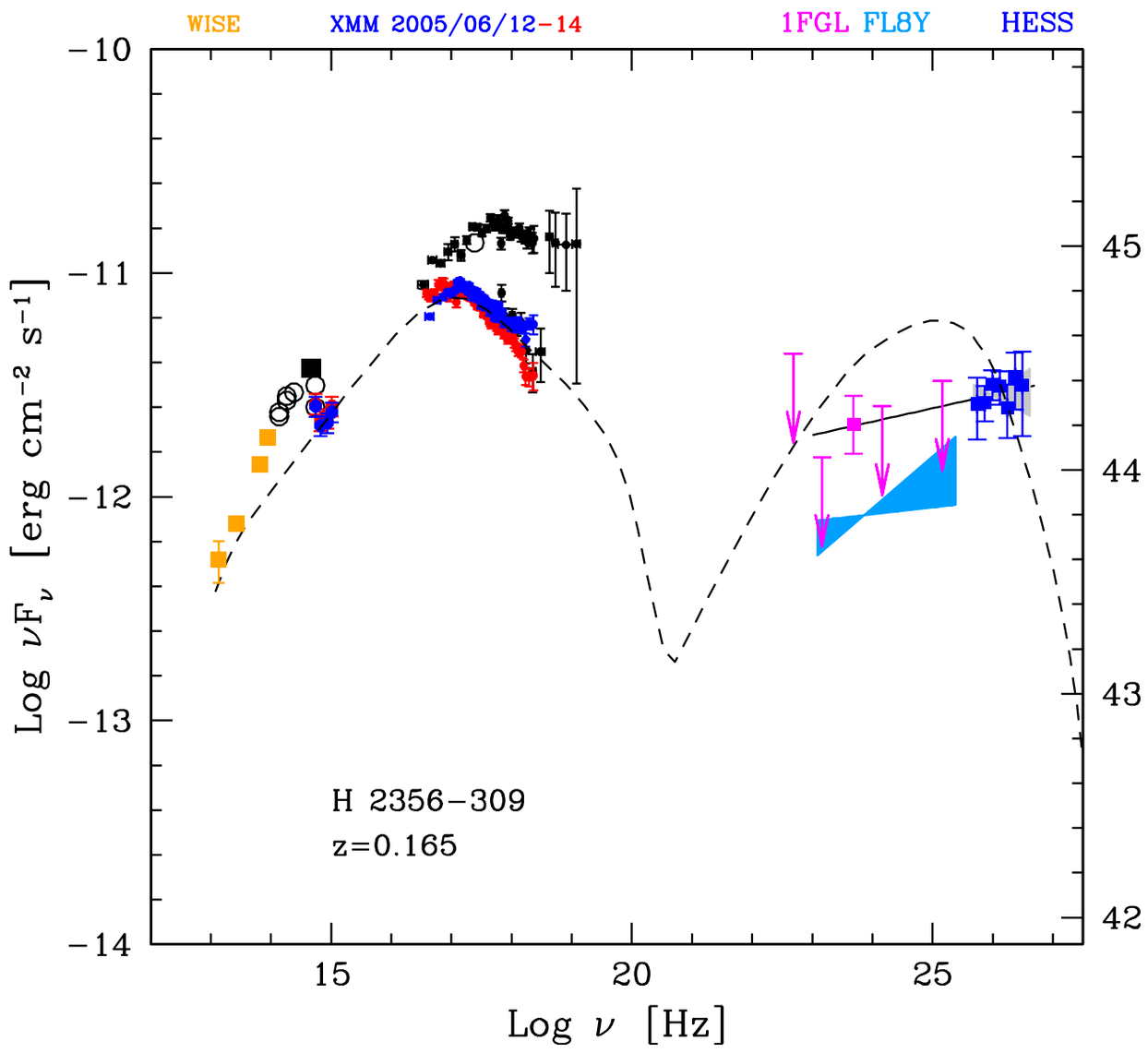
Source [1]	γ_0 [2]	n_0 [3]	γ_1 [4]	γ_b [5]	γ_2 [6]	n_1 [7]	n_2 [8]	B [9]	K [10]	R [11]	δ [12]	U_e/U_B [13]
1ES 0229+200 a	-	-	100	1.1×10^6	2×10^7	1.4	3.35	0.002	6	0.8	50	1.7×10^5
1ES 0229+200 b	-	-	2×10^4	1.5×10^6	2×10^7	2.0	3.4	0.002	10^3	2.1	50	2.0×10^4
1ES 0347-121 a	-	-	100	7.5×10^5	1.8×10^7	1.7	3.8	0.0015	1.2×10^2	1.2	60	1.5×10^5
1ES 0347-121 b	-	-	3×10^3	7.5×10^5	1.8×10^7	2.0	3.8	0.0015	8×10^2	2.5	60	3.4×10^4
1ES 0414+009 a	10	1.7	1×10^4	10^5	10^6	3.0	4.6	0.3	8×10^6	2.1	20	0.5
1ES 0414+009 b	-	-	3×10^4	5×10^5	3×10^6	2.0	4.3	0.0025	1.6×10^2	6.5	60	9.3×10^2
RGB J0710+591	-	-	100	6×10^5	10^7	1.7	3.8	0.011	1.2×10^2	0.92	30	2.7×10^3
1ES 1101-232 a	-	-	3.5×10^4	1.1×10^6	6×10^6	2.2	4.75	0.0035	7.0×10^3	2.5	60	2.4×10^3
1ES 1101-232 b	-	-	1.5×10^4	9.5×10^5	4×10^6	2.2	4.75	0.005	2.4×10^3	3.8	50	6.0×10^2
1ES 1218+304	100	1.3	3×10^4	10^6	4×10^6	2.85	4.2	0.0035	1.2×10^7	3.5	50	4.5×10^3

Costamante et al. 2018, models by Tavecchio

SSC can work but: 1) dropping one zone (no fit below UV)
2) strongly out of equipartition (E-3 to E-6)
3) extremely low radiative efficiency

SEDs of the last two:

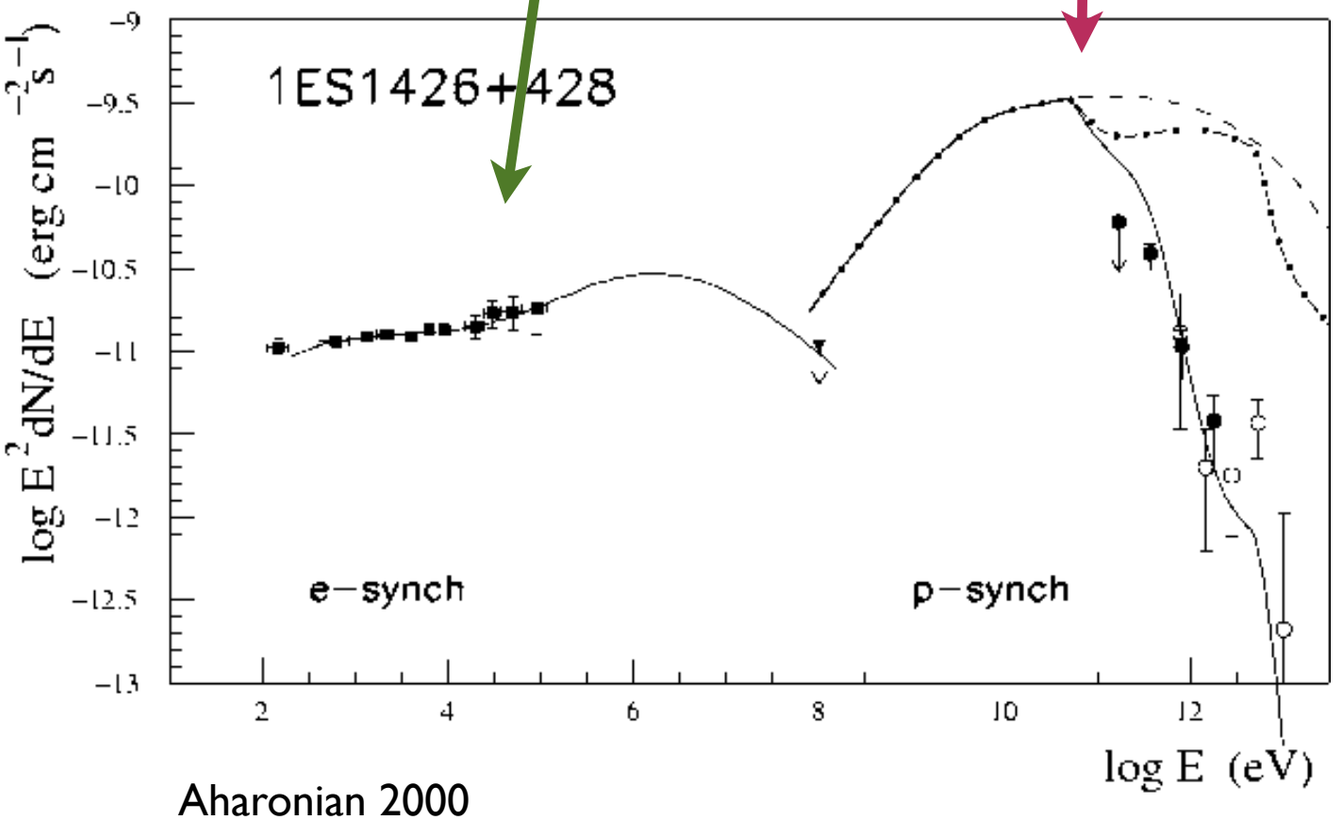




Alternatives ?
proton-synchrotron scenarios

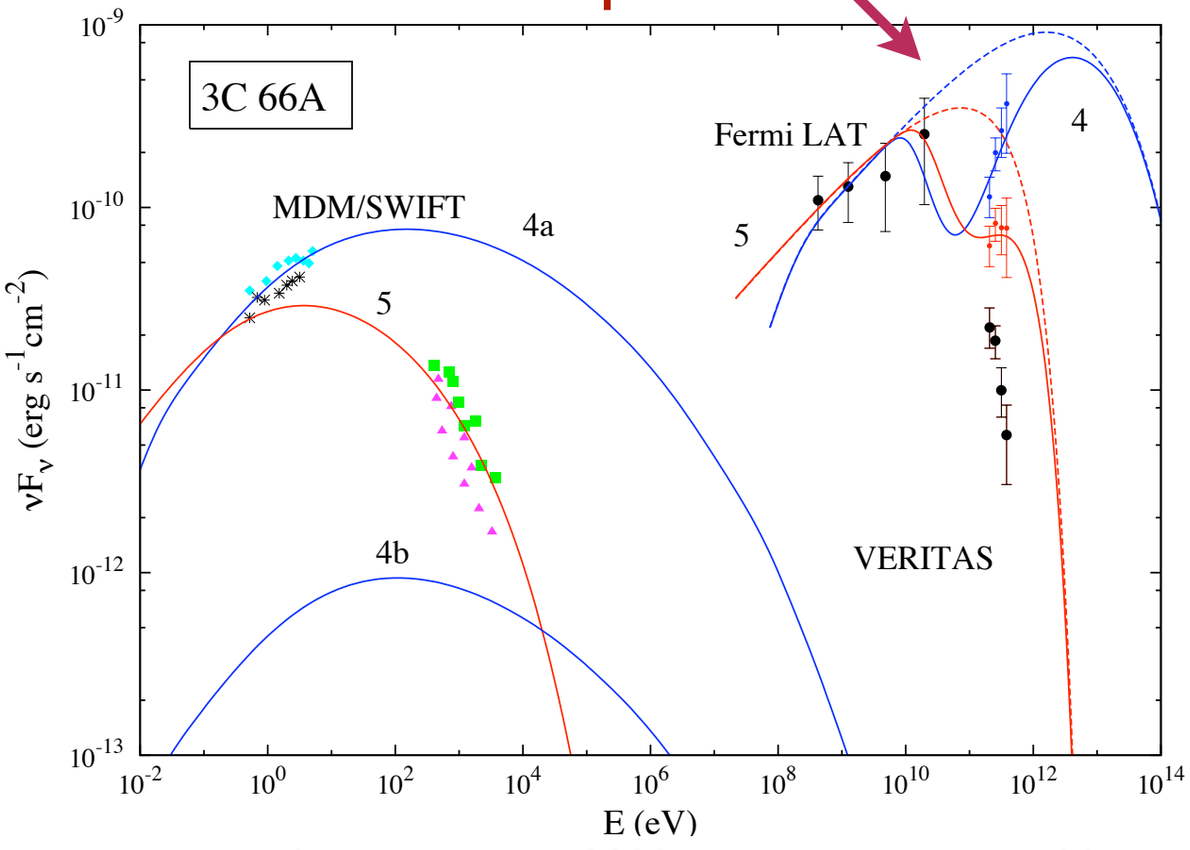
secondary electrons

primary protons



Aharonian 2000

gamma-gamma absorption

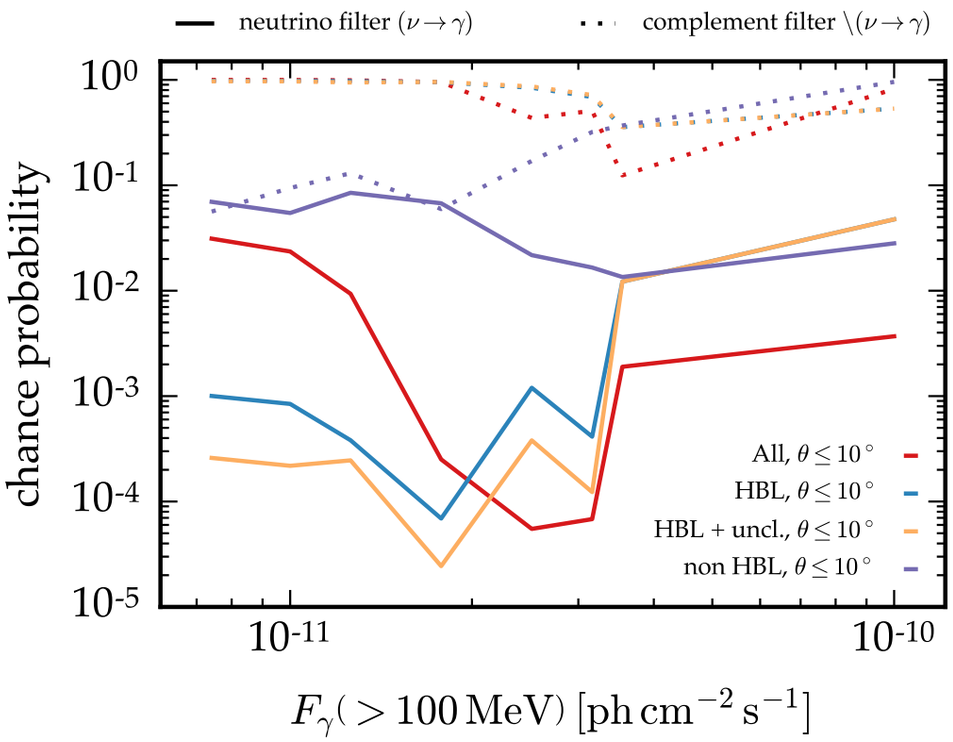


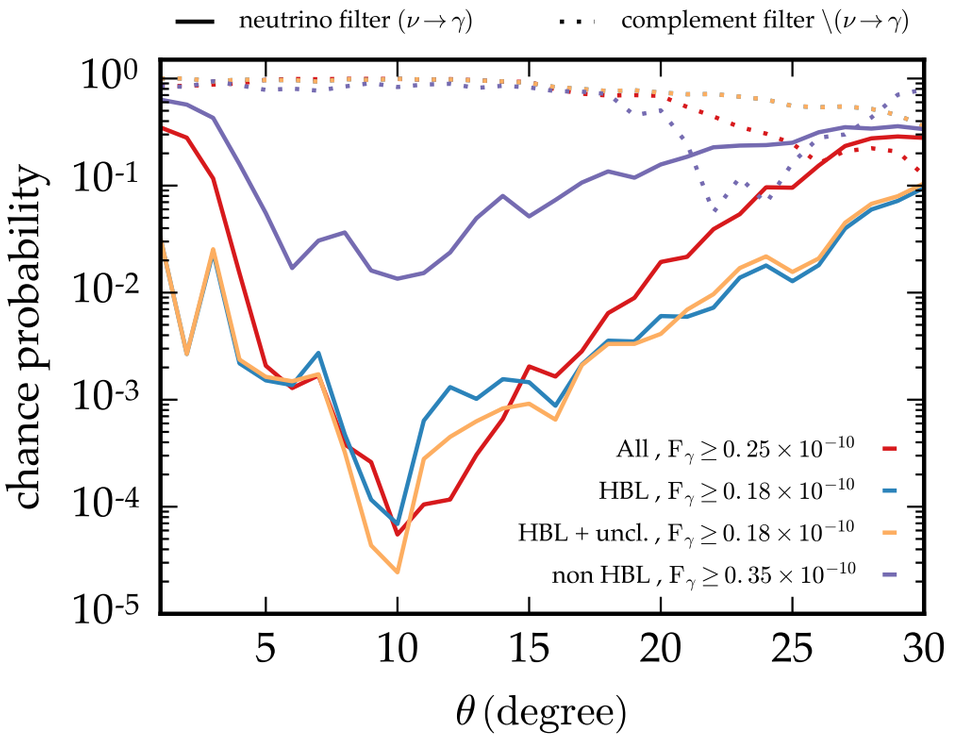
Aharonian et al. 2008, Zacharopulou et al. 2011

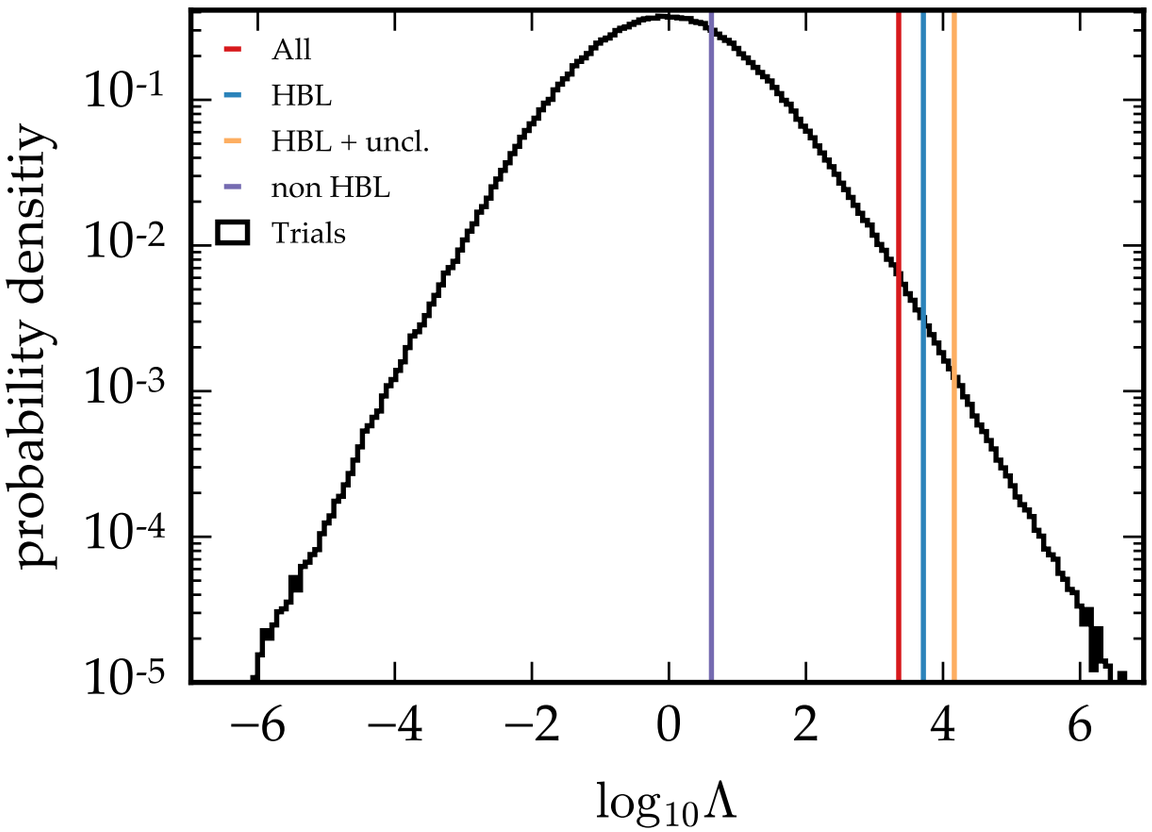
Photo-pion problem: for broad-band spectra, high U_{rad} absorbs VHE gammas…

But see Petropoulou et al. 2016

…but HBL give most of the signal for UHECR - blazar correlation in Icecube Neutrinos Fields





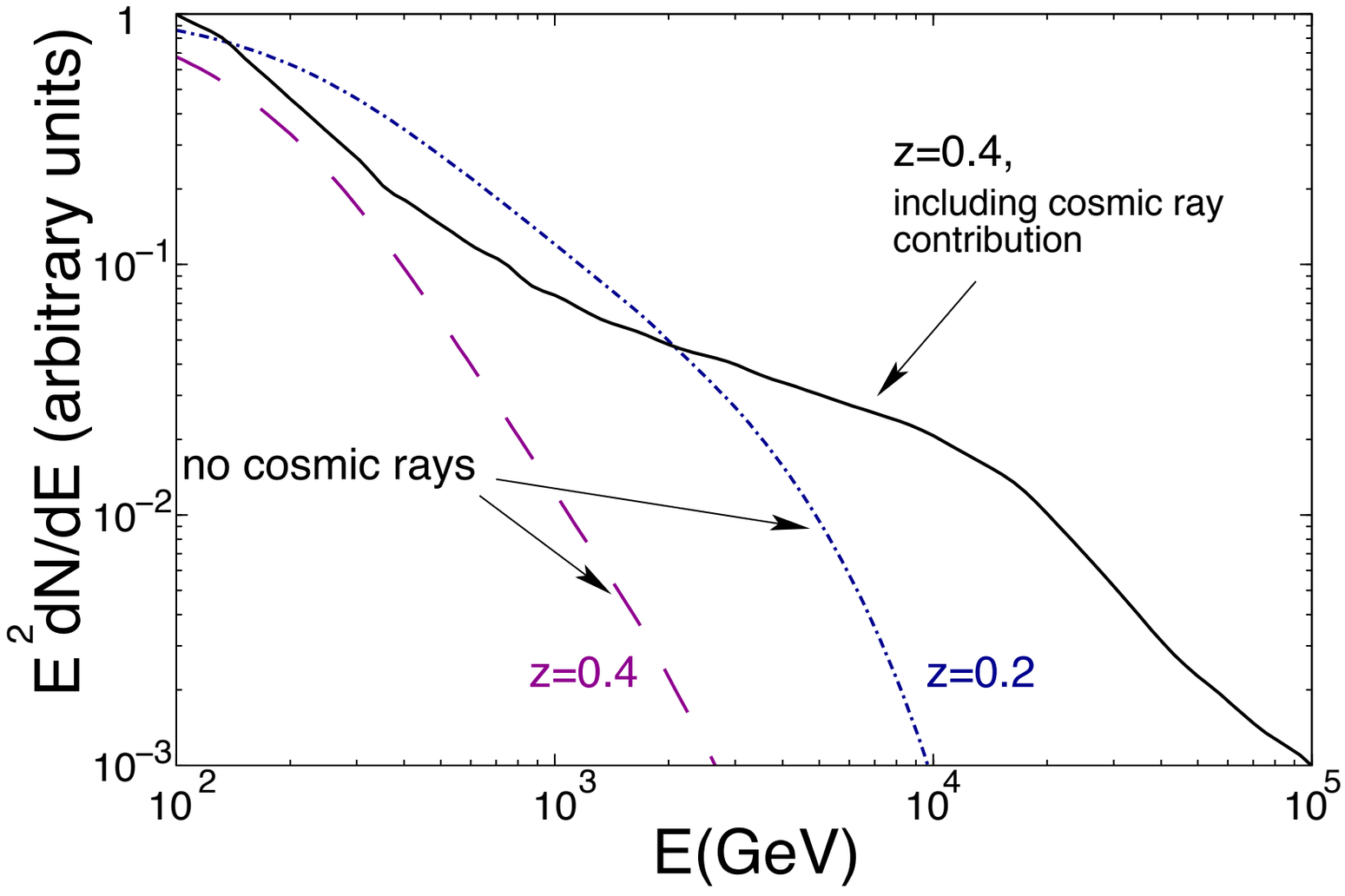


Resconi et al. 2016

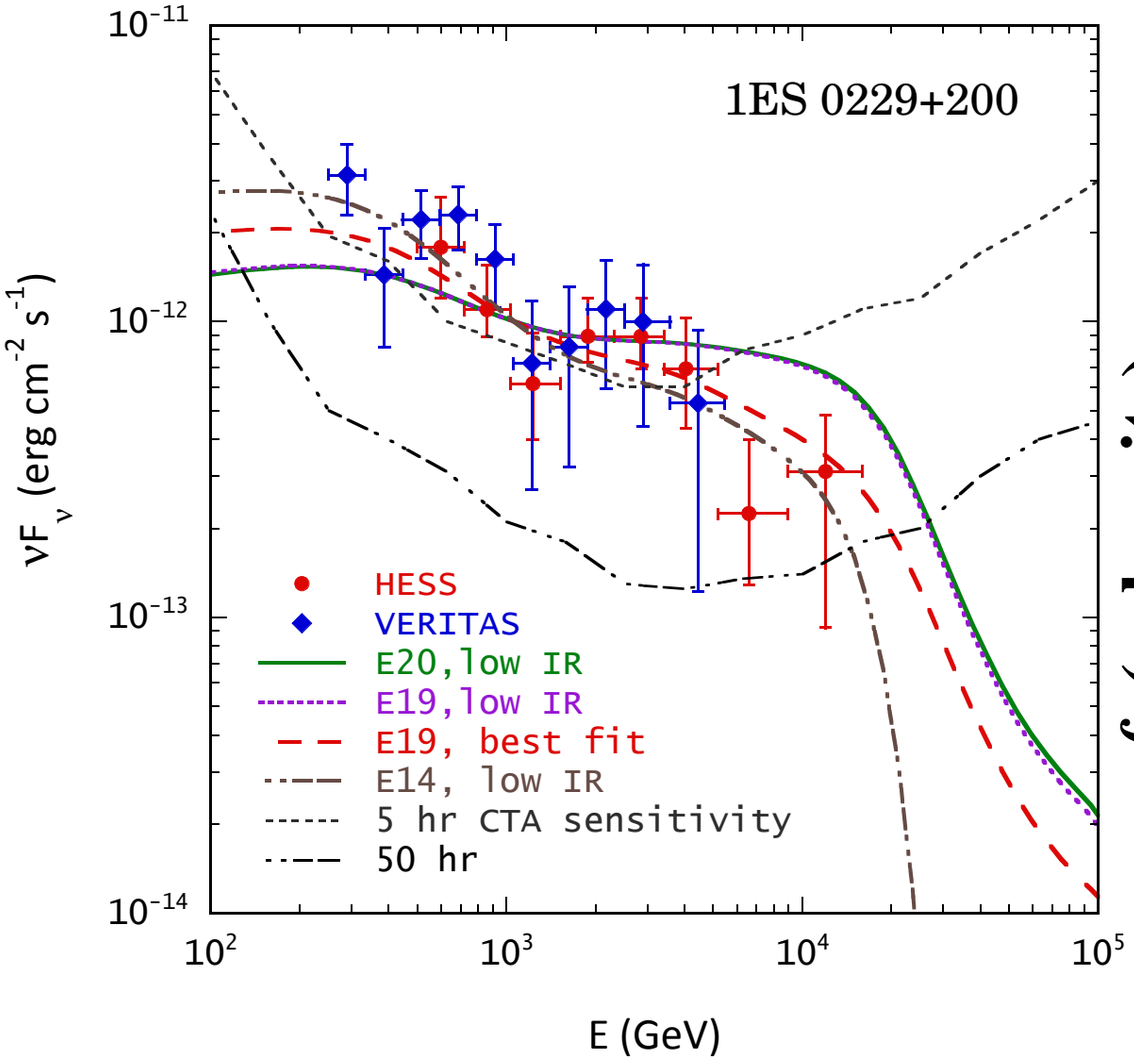
Secondary emission ? e.g. from UHE-protons

$$p + \gamma_{\mathrm{CMB}} \rightarrow p + e^{+} + e^{-} \longrightarrow \text{cascade}$$

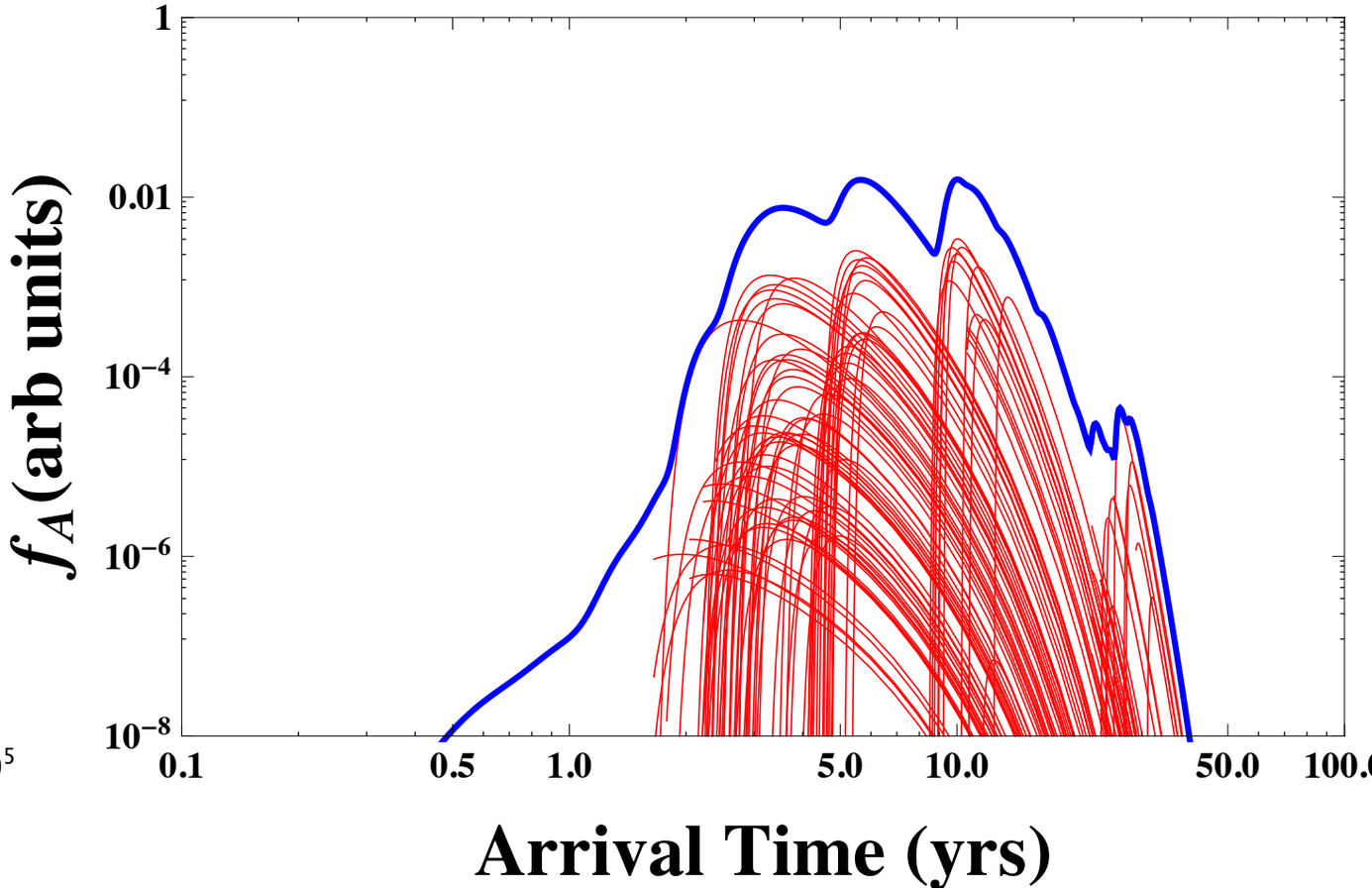
$\longrightarrow$ deposition of gamma-rays closer to us



Prosekin et al, Kusenko et al.,
Murase et al., Aharonian et al,



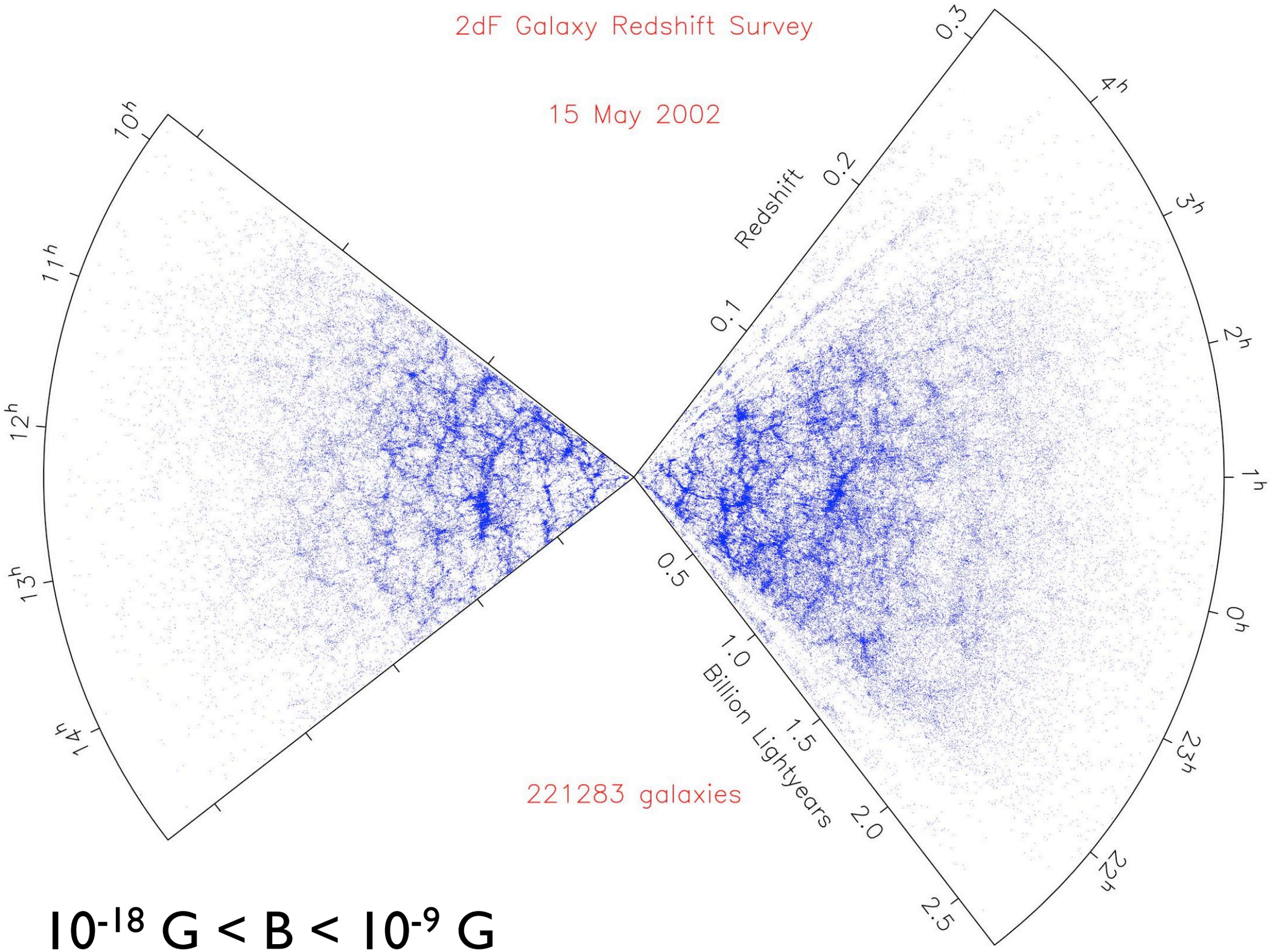
Murase et al. 2011



Prosekin et al. 2012

But: No strict X-TeV correlation
No fast variations (washed out)

Main problem: Large Scale Structure IGMF



10^{-18} G < B < 10^{-9} G

Where to find them

Warning:

Extremeness is established ONLY through direct measure of X-ray and VHE spectra !

$$\Gamma_{\mathrm{X}} \leq 2$$

$$\Gamma_{\mathrm{TeV}} \leq 2$$

Where to find them

Sedentary Survey sample (Giommi et al. 1999-2005)

150 BL Lacs, candidate Extreme-S

1. $|b| > 20°$;
2. $f_x / f_r \geq 3 \times 10^{-10}$ erg cm^{-2} s^{-1} Jy^{-1};
3. $\alpha_{ro} > 0.2$;
4. $f_r \geq 3.5$ mJy;
5. RASSBSC count rate ≥0.1 cts/s;
6. $V \leq 21$;

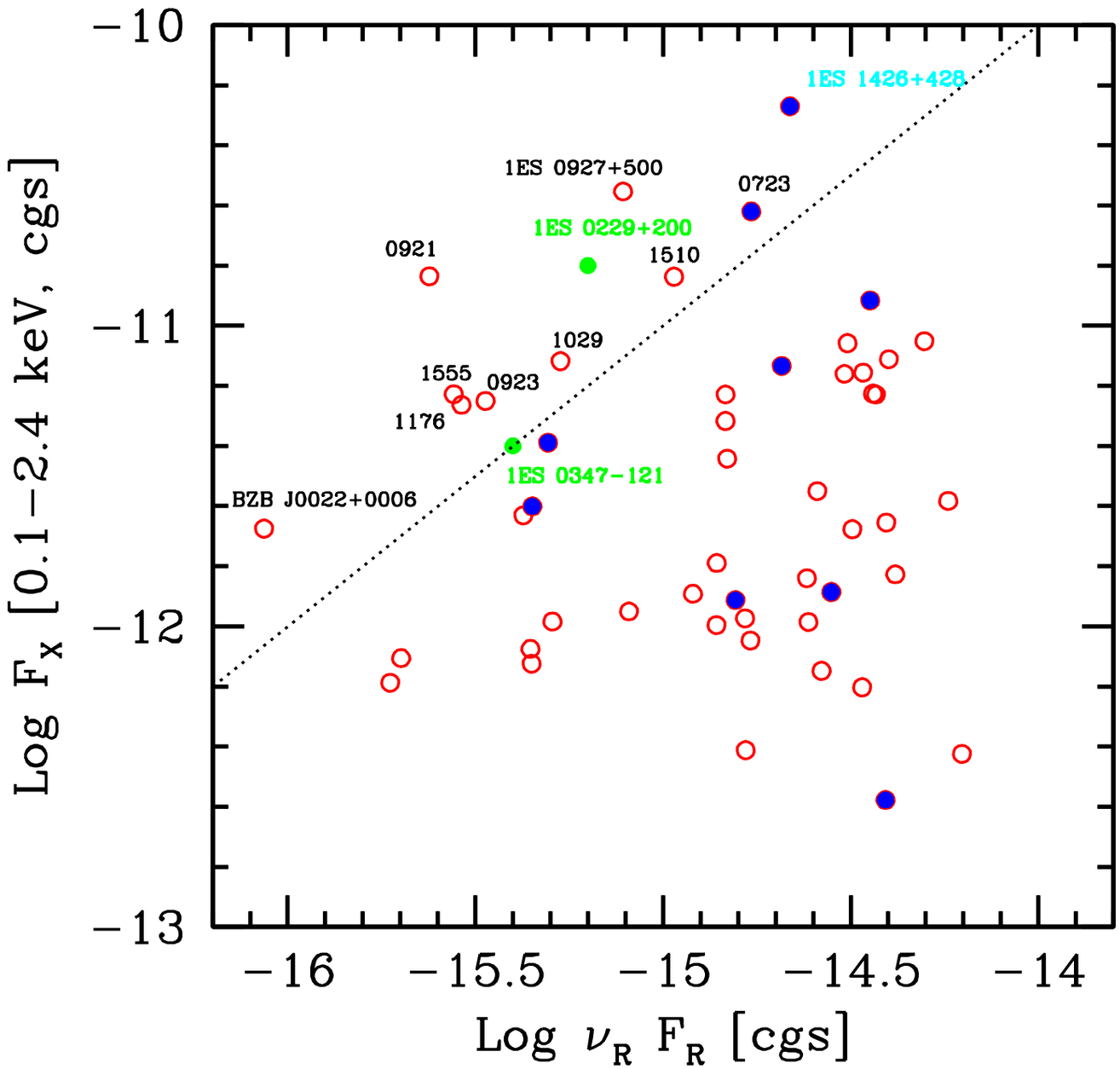
$\alpha_{XR} < 0.6$

Where to find them

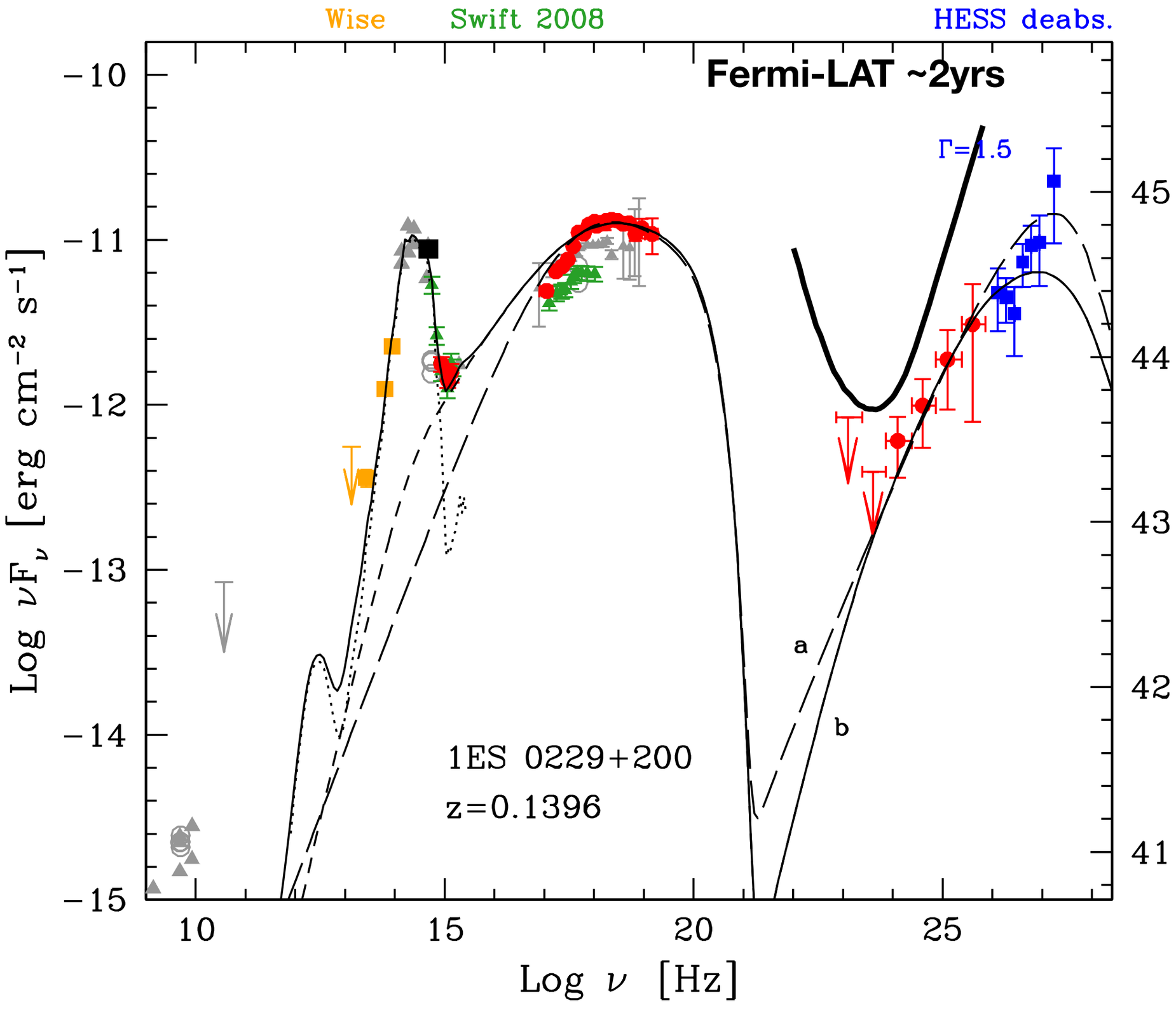
Not simply TeV BL Lacs, but *TeV-peaked* BL Lacs !

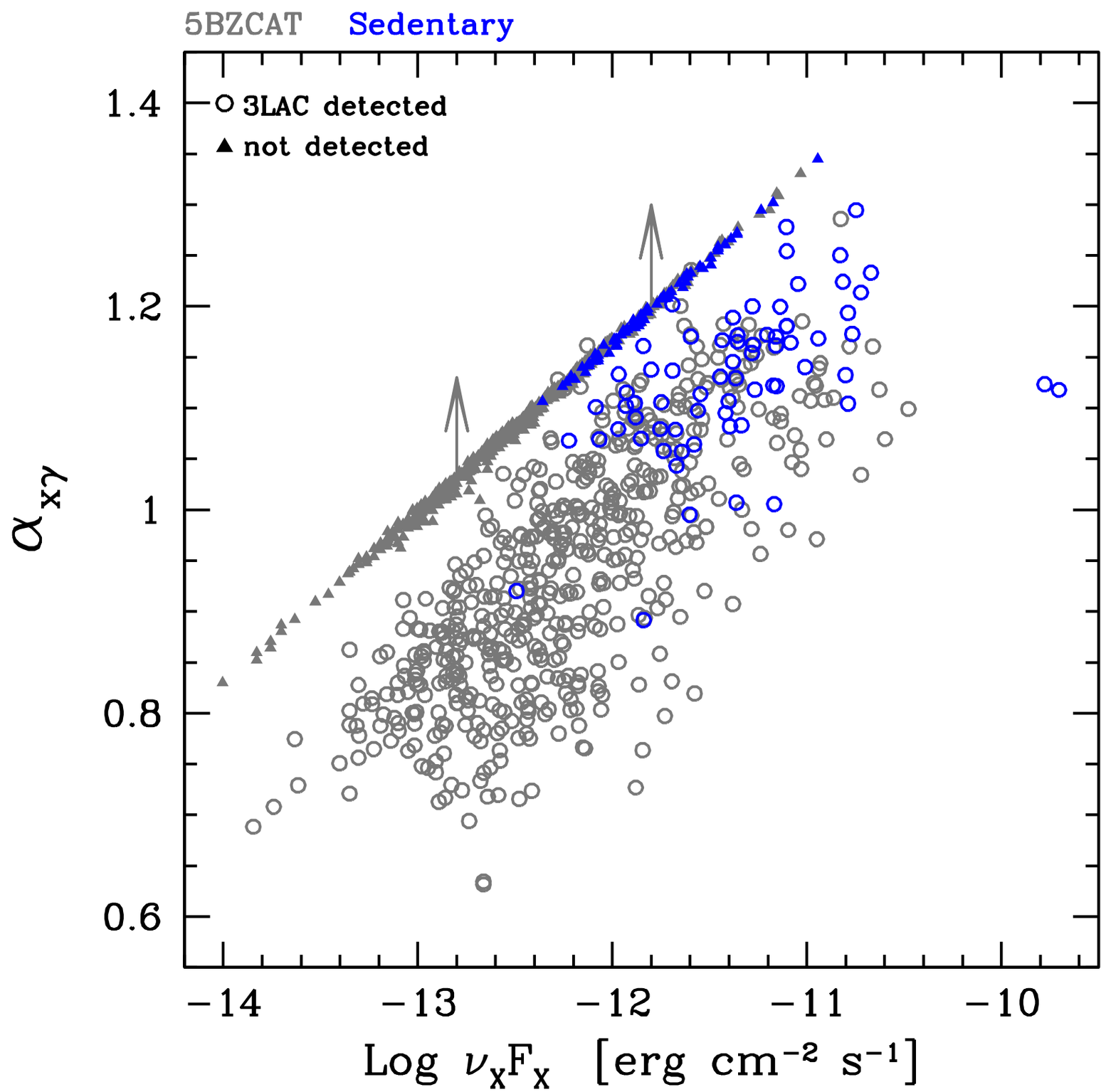
Bonnoli et al. 2015:

- $F_X/F_R > 10^4$
- Host galaxy dominance
- $z < 0.4$
- Plotkin sample

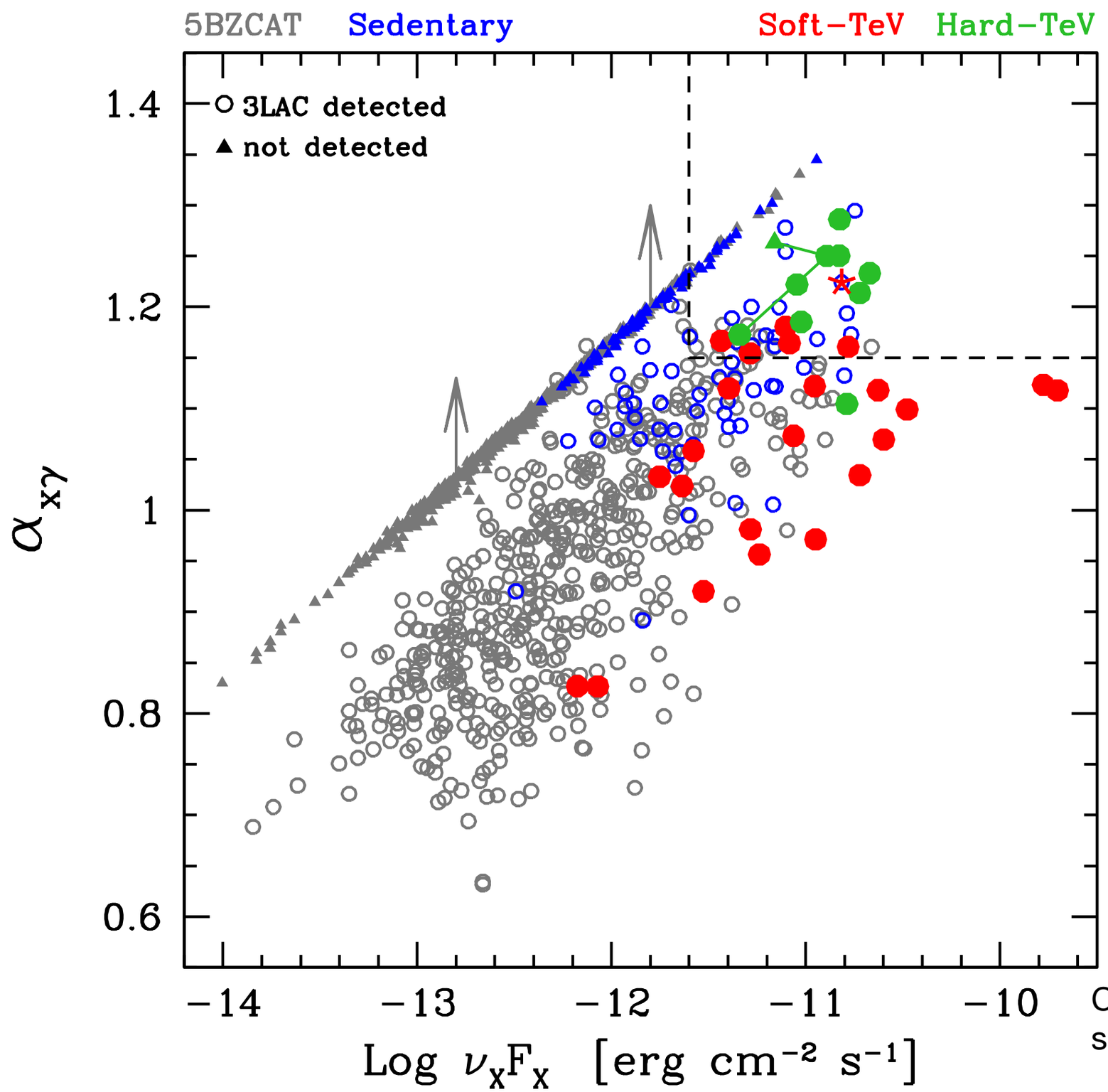


Better look at *Fermi-weak objects* !
not Fermi-bright HBL !




5BZCAT
Sedentary
3LAC detected
not detected
1.4
1.2
1
0.8
0.6
$\alpha_{x\gamma}$
−14
−13
−12
−11
−10
Log $\nu_X F_X$ [erg cm^{-2} s^{-1}]

Quadratisch. Praktisch. Gut !

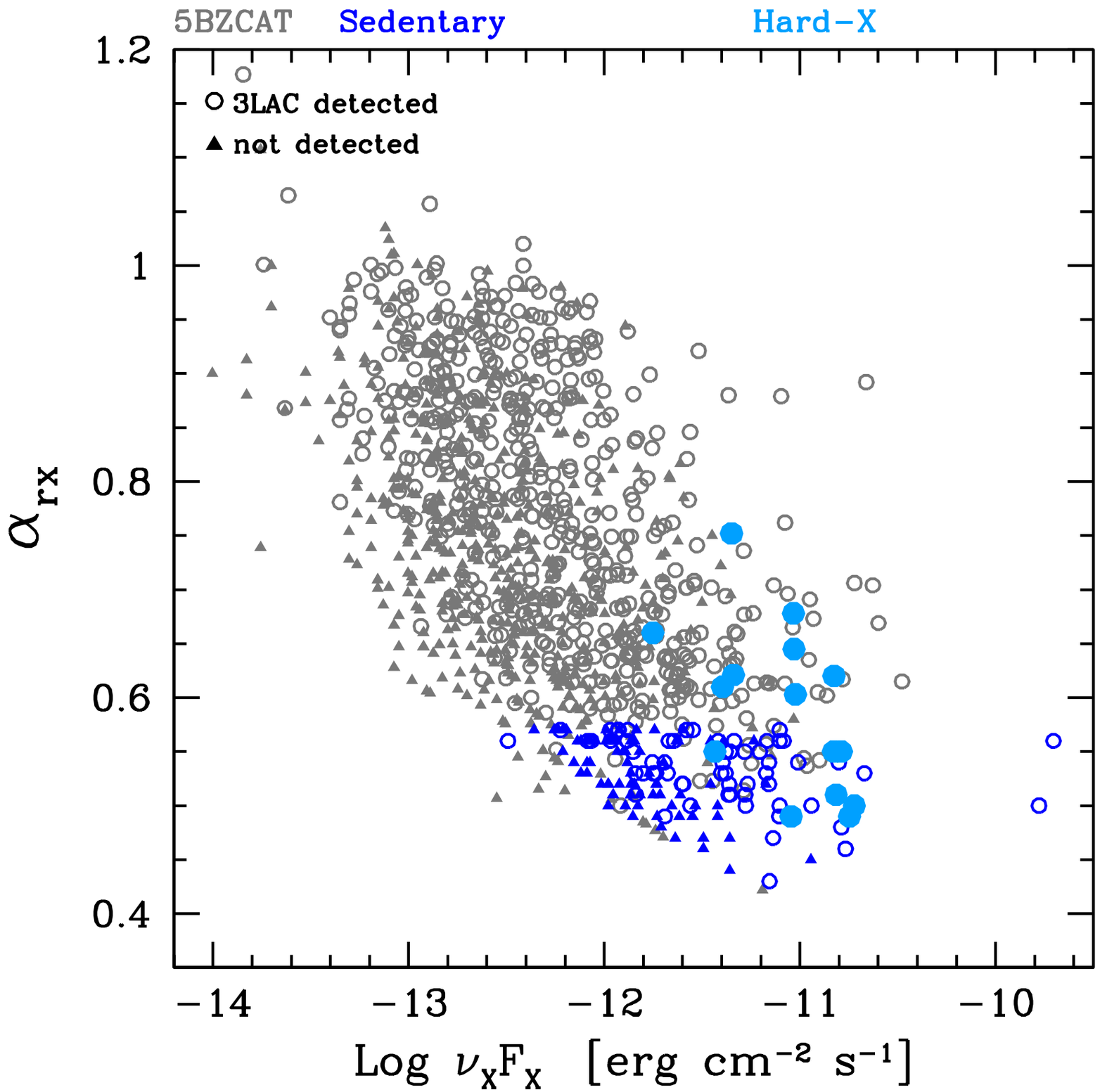


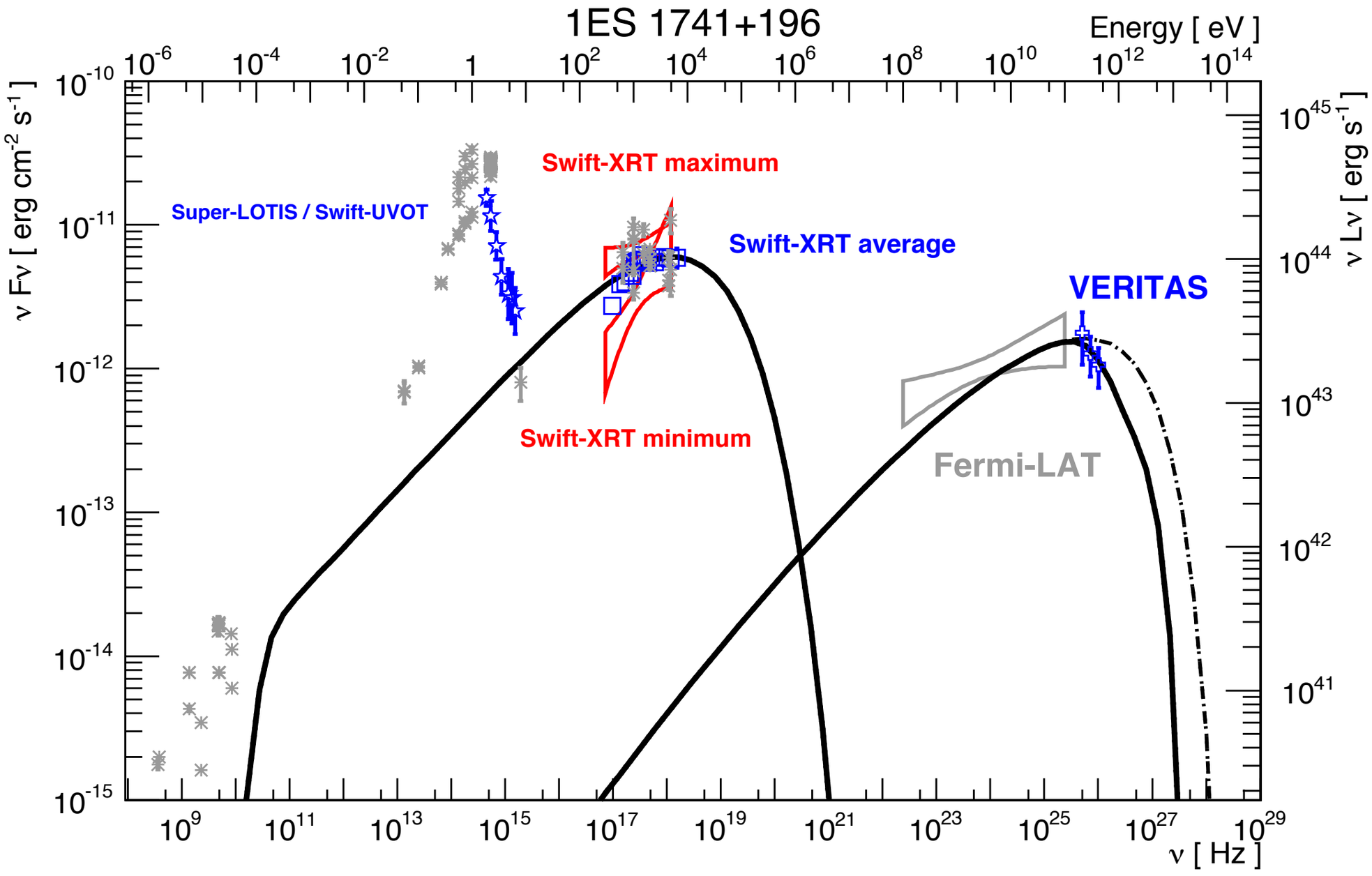
Costamante 2019, subm.
soon on arXiv !

Some **Conclusions**

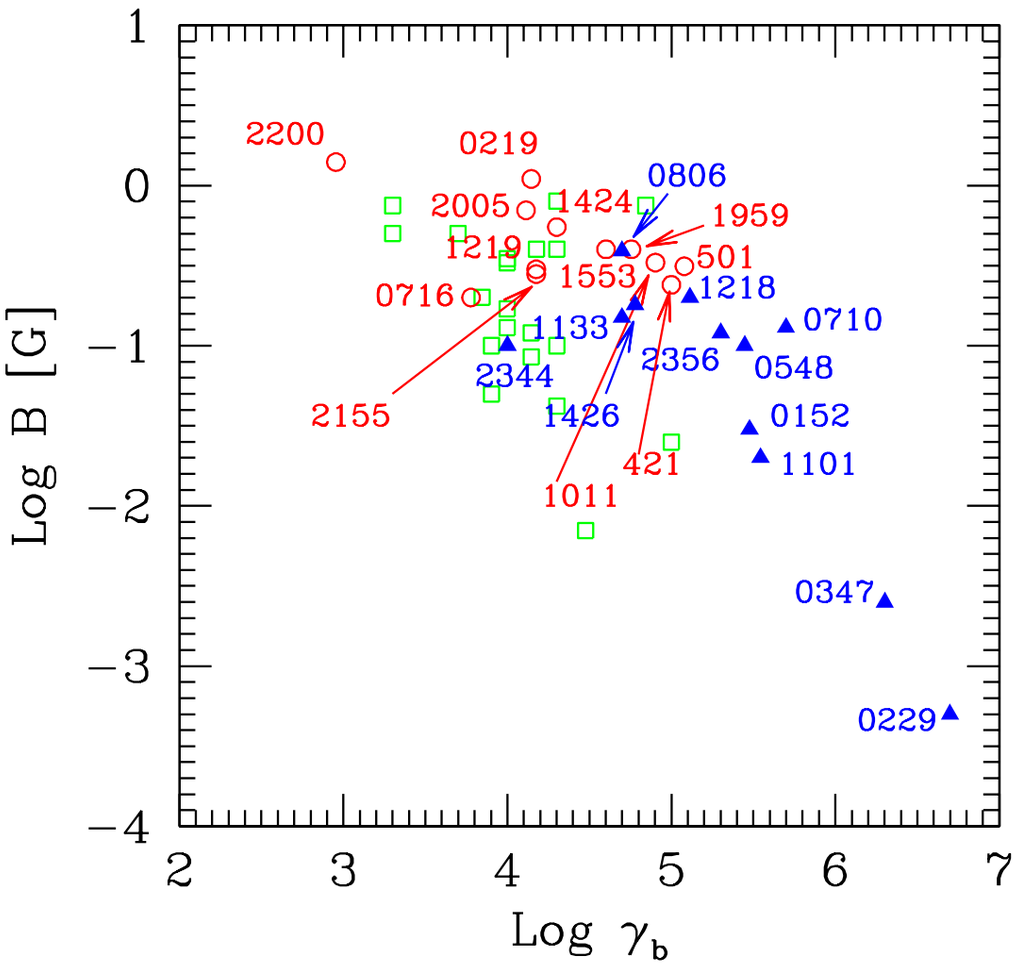
- Extreme BL Lacs are the most challenging and rewarding Blazars so far, at the crossroads of many different research fields.
- We do not know yet for sure the origin of their gamma-rays
- Need of unbiased sky surveys in TeV
- Answers with eRosita and CTA surveys (for the two types)
- But in the meantime: to Cherenkov Collaborations, please do dedicated observing programs and publish them !
- To all of us: lots of possible treasures in Swift database

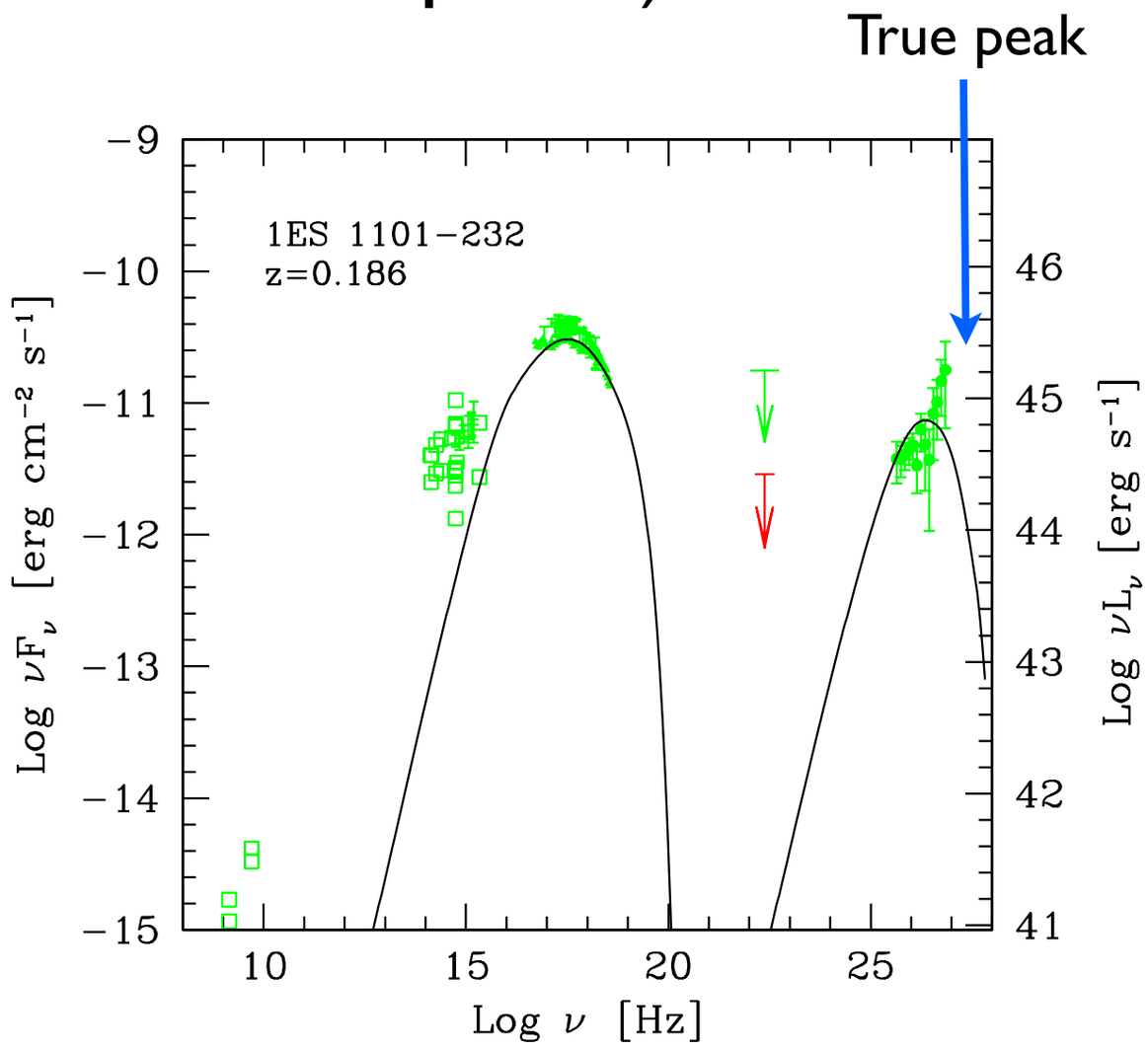
Back-up slides


5BZCAT
Sedentary
Hard−X
3LAC detected
not detected
1.2
1
0.8
0.6
0.4
α_{rx}
−14
−13
−12
−11
−10
Log $\nu_X F_X$ [erg cm^{-2} s^{-1}]


1ES 1741+196
Energy [eV]
10^-6
10^-4
10^-2
1
10^2
10^4
10^6
10^8
10^10
10^12
10^14
ν Fν [erg cm^-2 s^-1]
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
ν Lν [erg s^-1]
10^45
10^44
10^43
10^42
10^41
Super-LOTIS / Swift-UVOT
Swift-XRT maximum
Swift-XRT average
Swift-XRT minimum
VERITAS
Fermi-LAT
10^9
10^11
10^13
10^15
10^17
10^19
10^21
10^23
10^25
10^27
10^29
ν [Hz]

Not well fitted by standard SSC models, require extreme parameters and multi-zone (does not fit Opt-UV)





Tavecchio et al 2009