VHE extragalactic results and perspectives from ground based instruments

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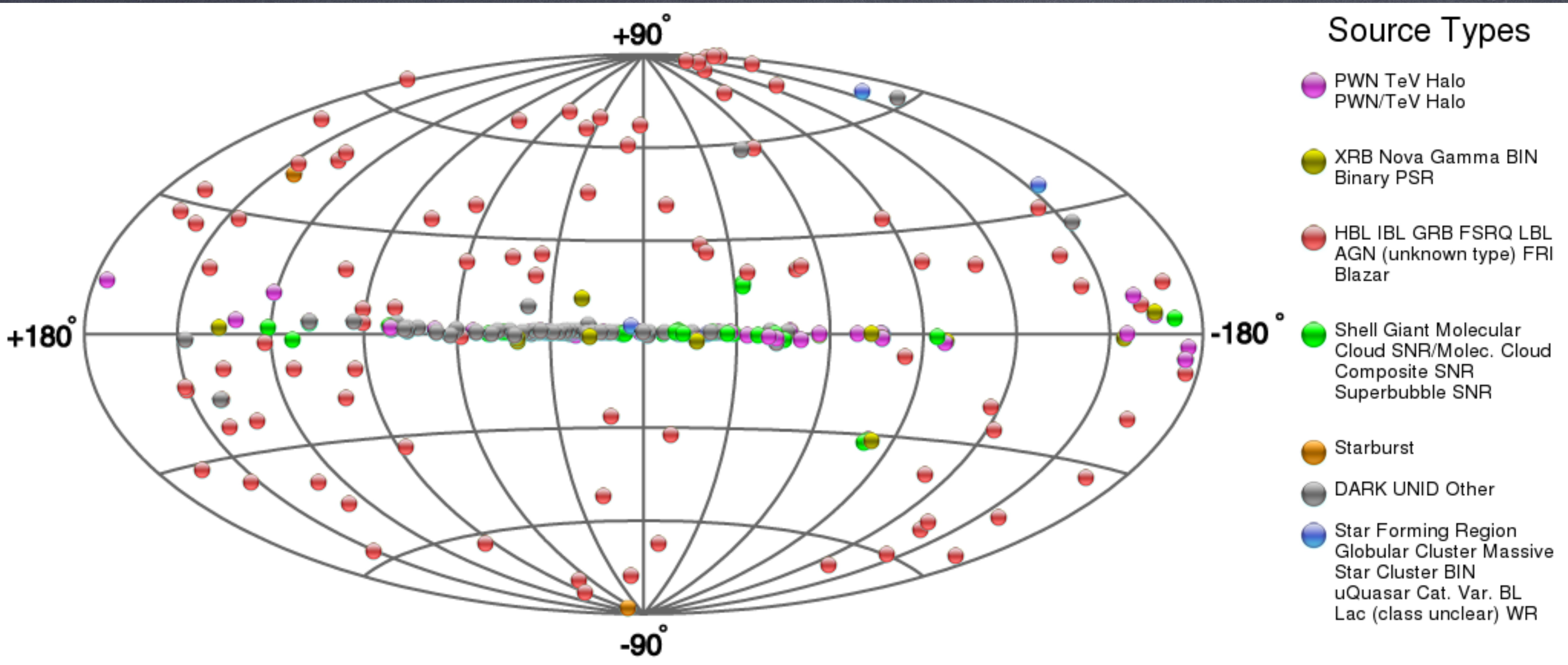


EGAL sources= 90 (+GRBs)

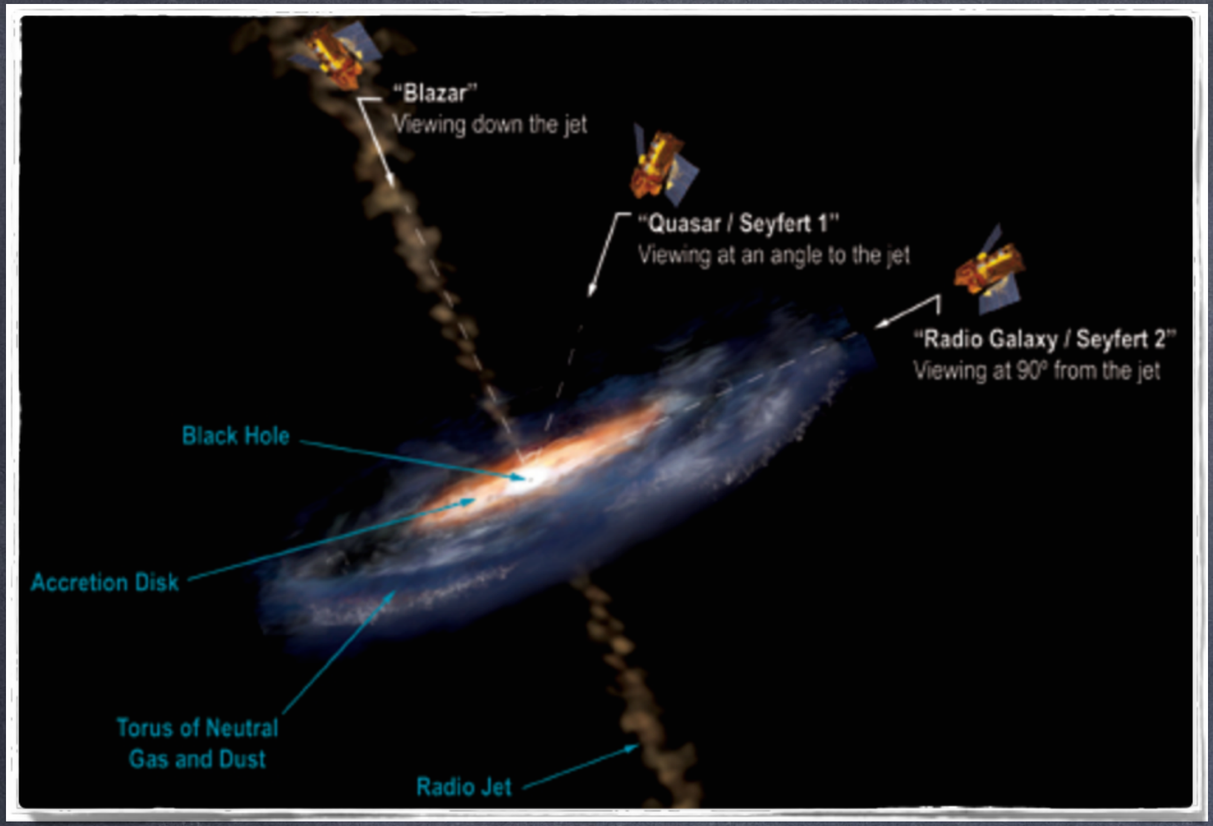
Blazars = 84

Radio galaxies ~ 4

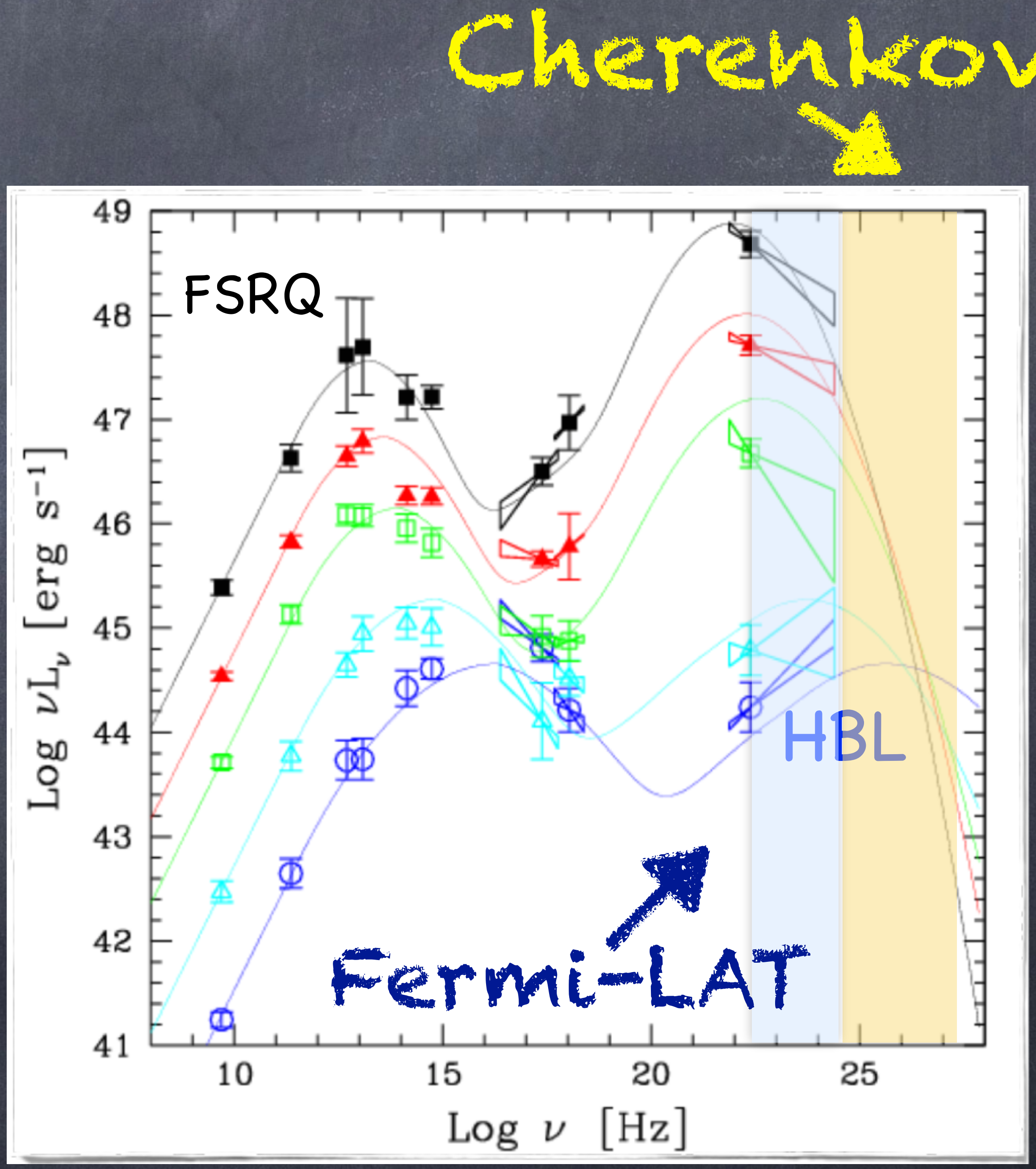
Starbursts = 2

Credits: TeVCat

Blazars

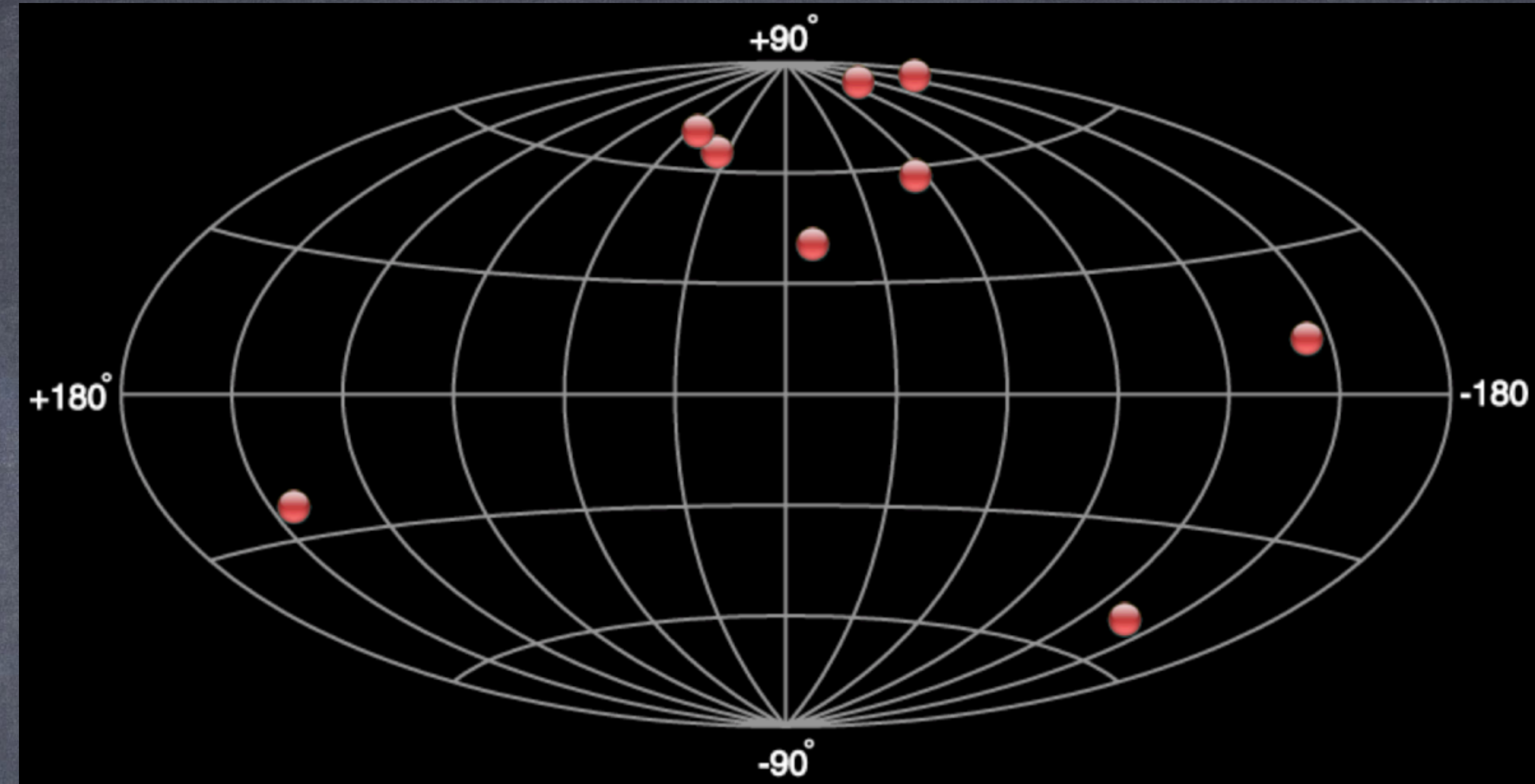


- Blazars can be classified as:
  - Flat Spectrum Radio Quasars (FSRQs)
  - BL Lac objects:
    - Low frequency peaking (LBL)
    - Intermediate frequency peaking (IBL)
    - High frequency peaking (HBL)
    - Extreme HBL (EHBL)



Fossati et al. 1998

FSRQs



Select All Unselect All Plot Selected Plot All Plot UnSelected Filter Selected Clear Filters

Reg Exp: OK

Name	RA	Dec	Type	Date	Dist	Catalog
			FSRQ			...
S3 0218+35	02 21 05.5	+35 56 14	FSRQ	2014.07	z = 0.954	Default Catalog
PKS 0346-27	03 48 38	-27 49 14	FSRQ		z = 0.991	Newly Announced
PKS 0736+017	07 39 17.0	+01 36 12	FSRQ	2016.07	z = 0.18941	Default Catalog
TON 0599	11 59 31.8	+29 14 44	FSRQ	2017.12	z = 0.7247	Newly Announced
4C +21.35	12 24 54.4	+21 22 46	FSRQ	2010.06	z = 0.432	Default Catalog
3C 279	12 56 11.1	-05 47 22	FSRQ	2008.06	z = 0.5362	Default Catalog
B2 1420+32	14 22 30.38	+32 23 10.44	FSRQ	2020.01	z = 0.682	Default Catalog
PKS 1441+25	14 43 56.9	+25 01 44	FSRQ	2015.04	z = 0.939	Default Catalog
PKS 1510-089	15 12 52.2	-09 06 21.6	FSRQ	2010.03	z = 0.361	Default Catalog

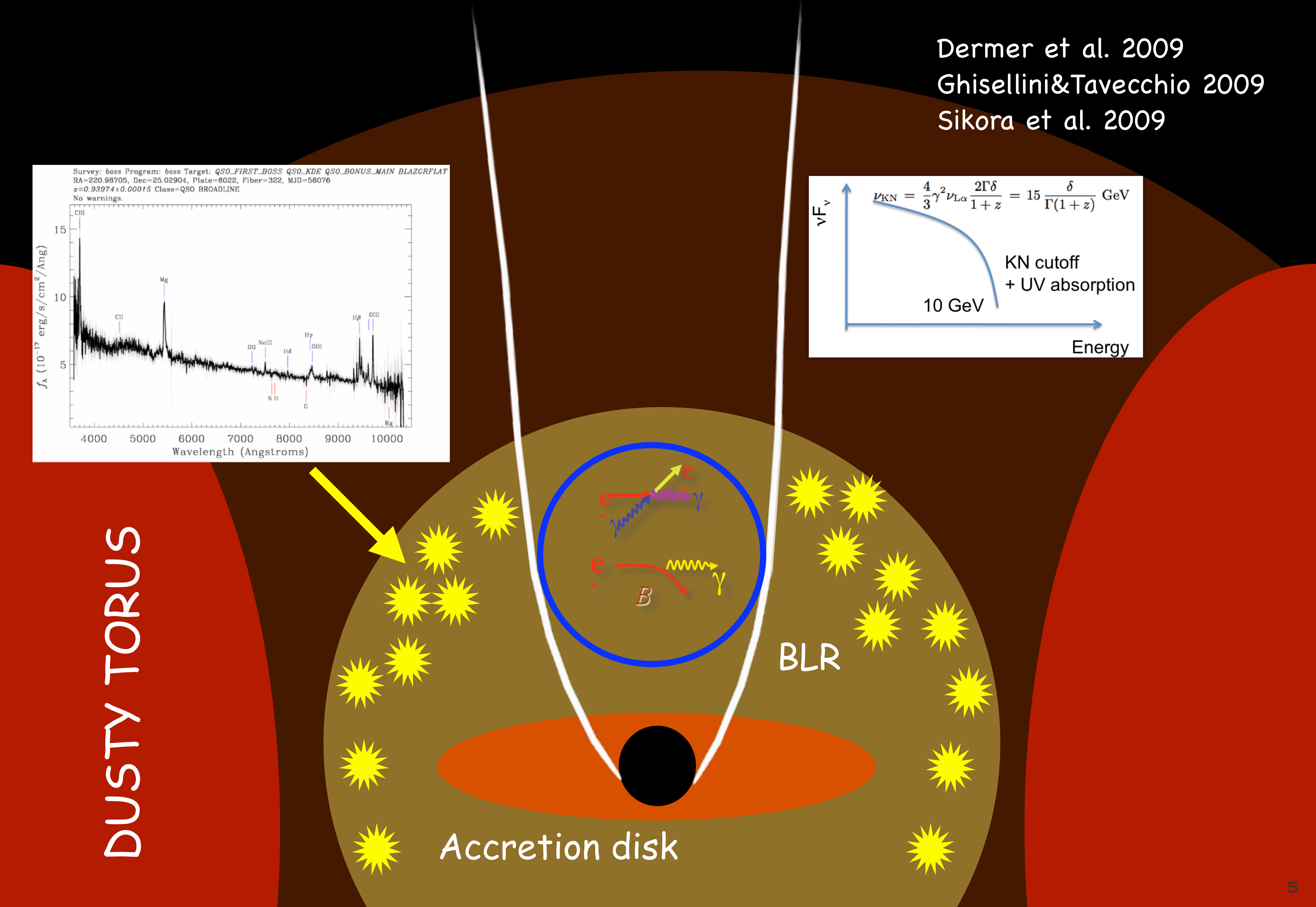
1-9

- Intrinsic absorption (BLR, Torus)
- Higher redshifts than BL Lac objects
- Lower energies, reaching maximum ~400 GeV

Credits: TeVCat

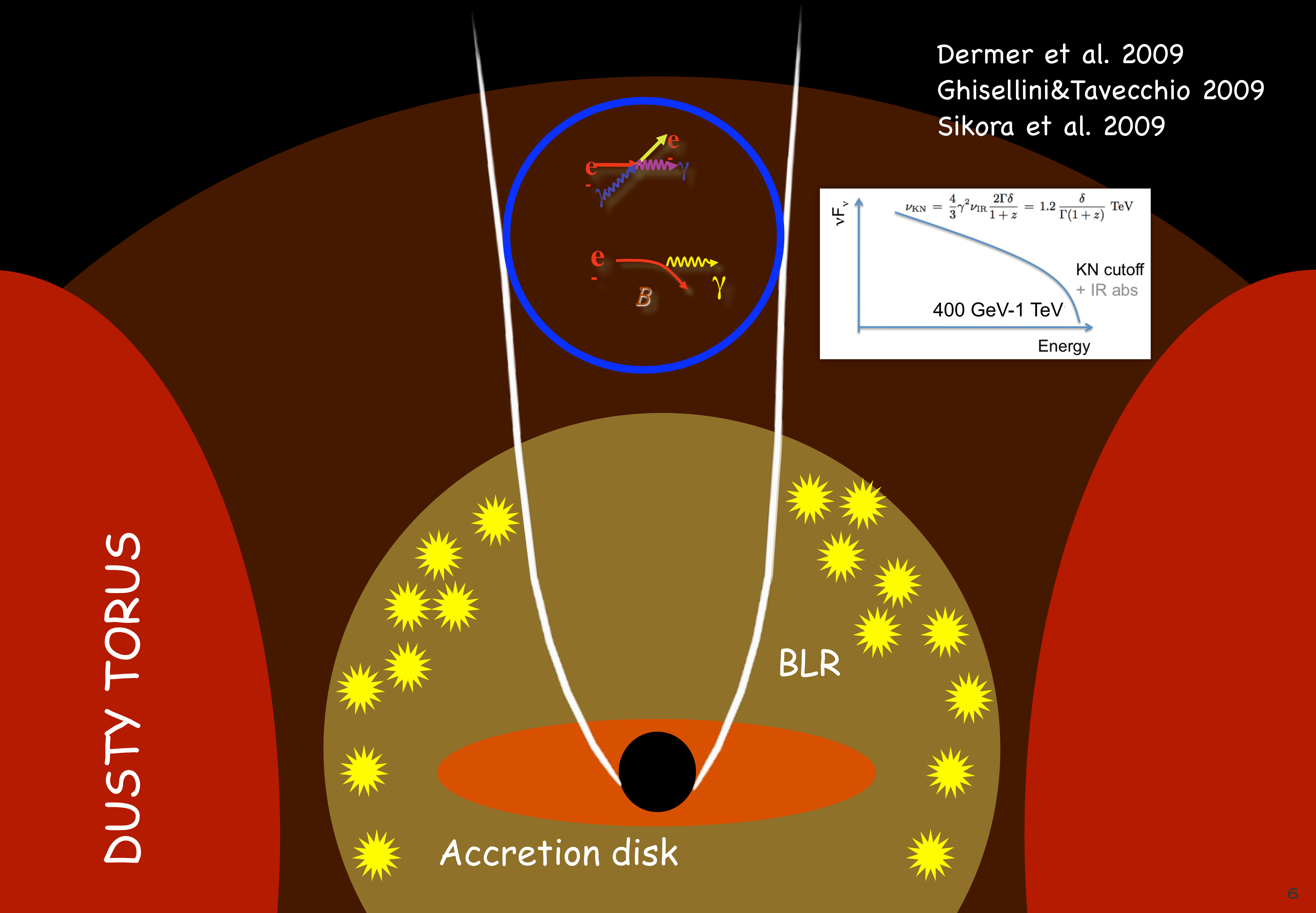
FSRQs: the "canonical" scenario

Dermer et al. 2009
Ghisellini&Tavecchio 2009
Sikora et al. 2009



FSRQs: the "far dissipation" scenario

Dermer et al. 2009
Ghisellini&Tavecchio 2009
Sikora et al. 2009



CTA will allow us…

- To lower the energy threshold together with the improved sensitivity, which will help us to increase the FSRQ VHE family
- The improved sensitivity will allow us hopefully to extend the VHE spectrum from FSRQs, to test the absorption due to the torus.

Torus absorption

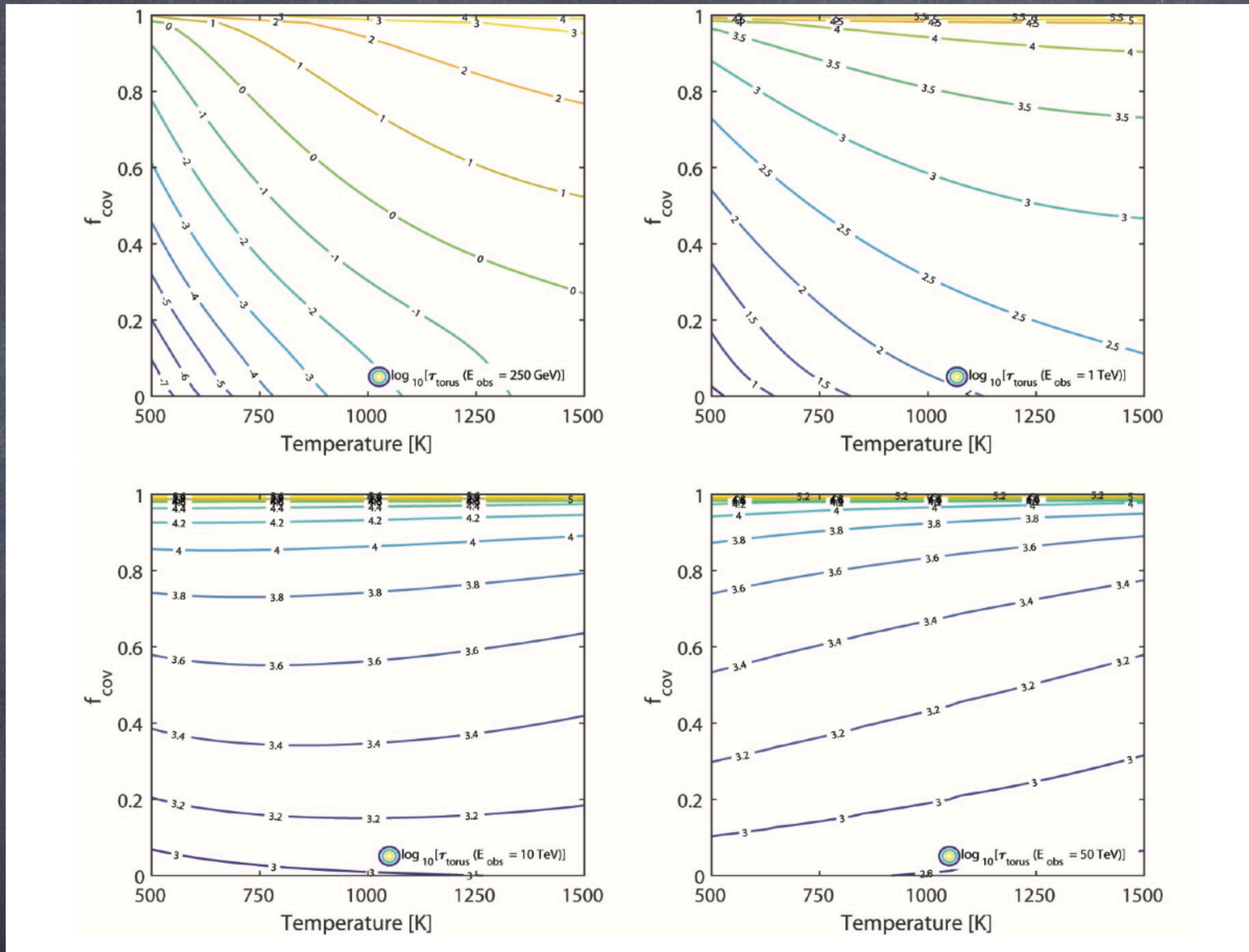


Figure 4. Torus optical depth contour lines as a function of the temperature and of f_{cov}. The behavior of the contour lines changes as the energy increases. The different panels correspond to different choices of the energy of the emitted hard photons.

VHE observations will allow us to constrain the temperature of the torus and the covering factor

Galanti et al. 2020, MNRAS, 495, 3463

Torus absorption

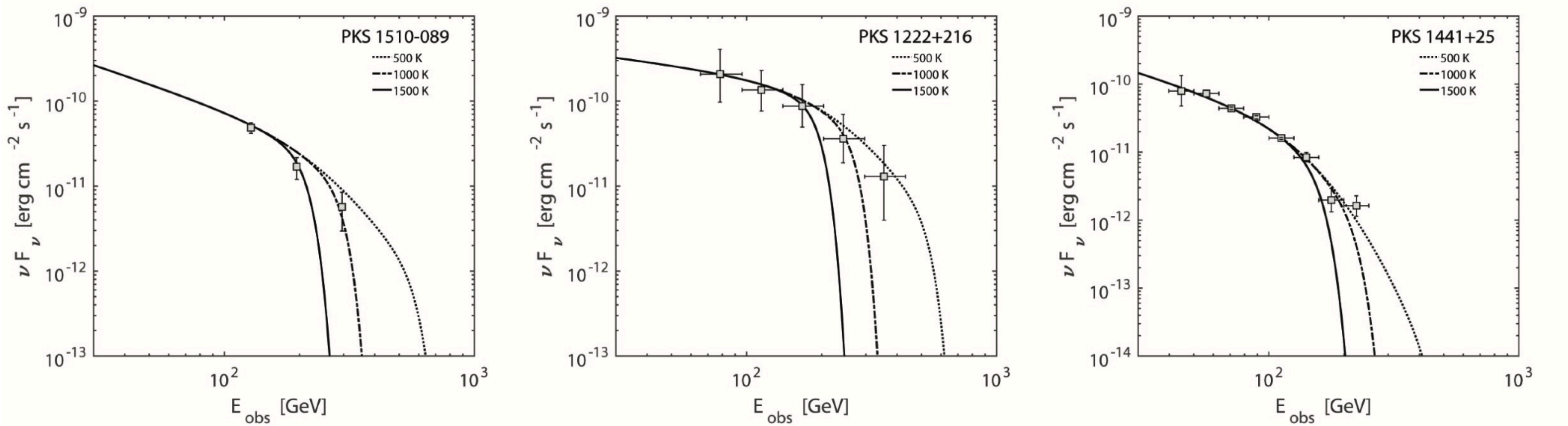
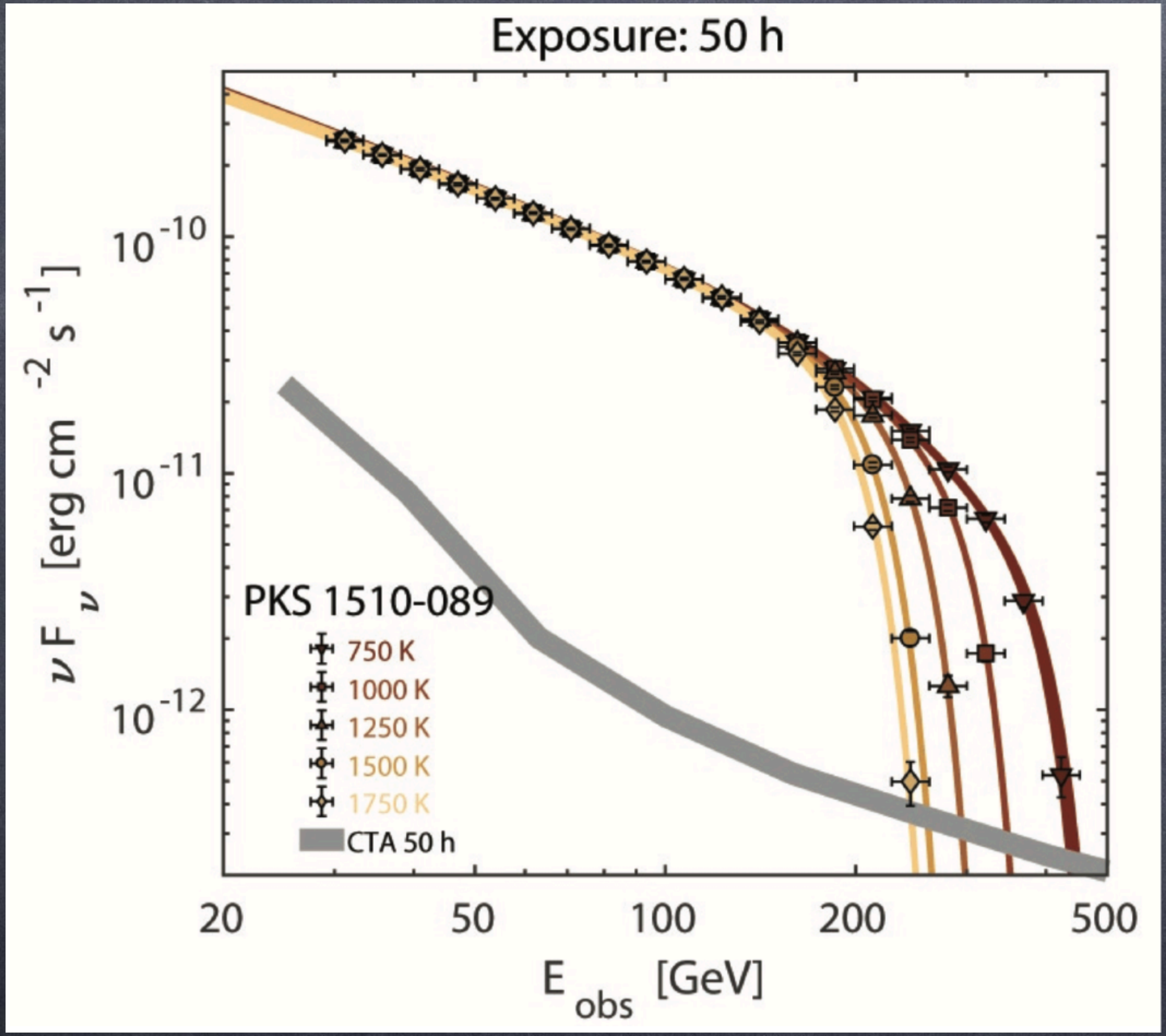


Figure 6. SED of PKS 1510-089 (left panel), PKS 1222+216 (central panel) and PKS 1441+25 (right panel). We take a fixed $f_{\rm cov} = 0.6$. The dotted black line corresponds to a torus model with $T = 500\,{\rm K}$, the dotted-dashed black line is referred to $T = 1000\,{\rm K}$ and the solid black line to $T = 1500\,{\rm K}$. The data points are all from MAGIC: Ahnen et al. (2017) for PKS 1510-089, Aleksić et al. (2011) for PKS 1222+216 and Ahnen et al. (2015) for PKS 1441+25.

Galanti et al. 2020, MNRAS, 495, 3463

Torus absorption



10 Galanti et al. 2020, MNRAS, 495, 3463

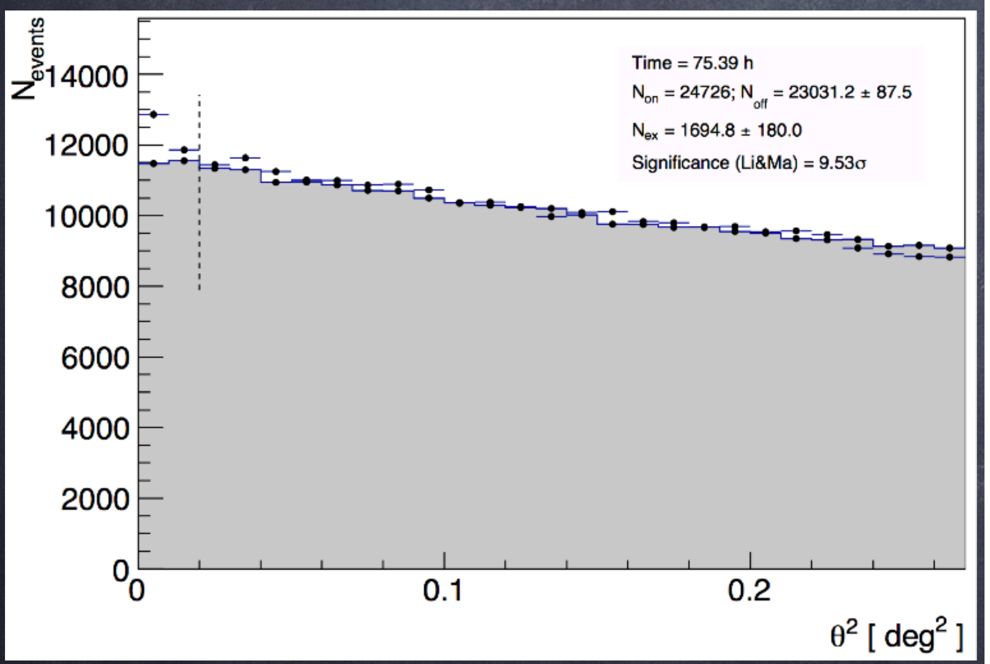
CTA will allow us...

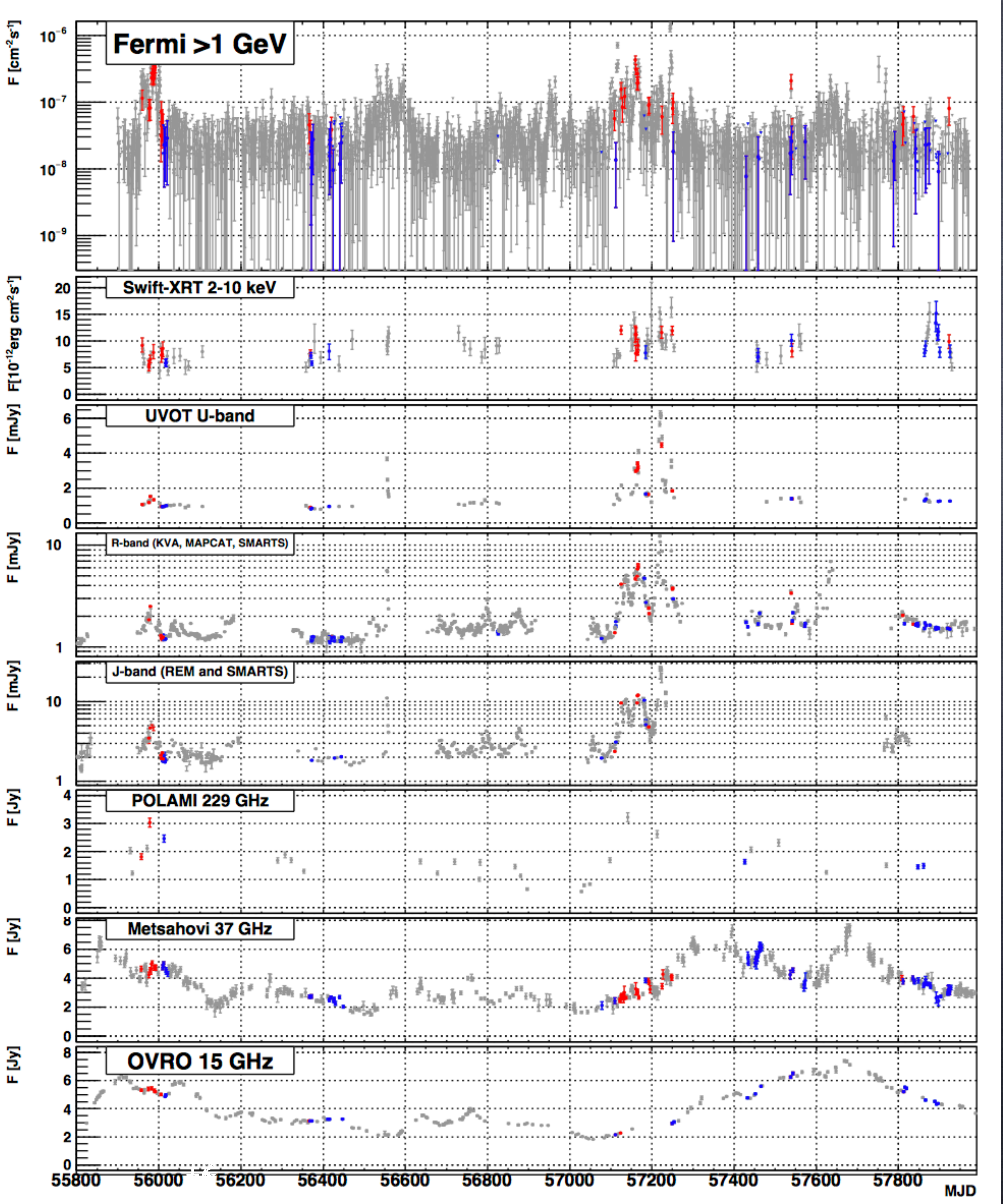
- To lower the energy threshold together with the improved sensitivity, which will help us to increase the FSRQ VHE family

- The improved sensitivity will allow us hopefully to extend the VHE spectrum from FSRQs, to test the absorption due to the torus.

- FSRQ VHE studies are highly biased toward flaring states, CTA should allow us to observe them outside extreme flaring episodes

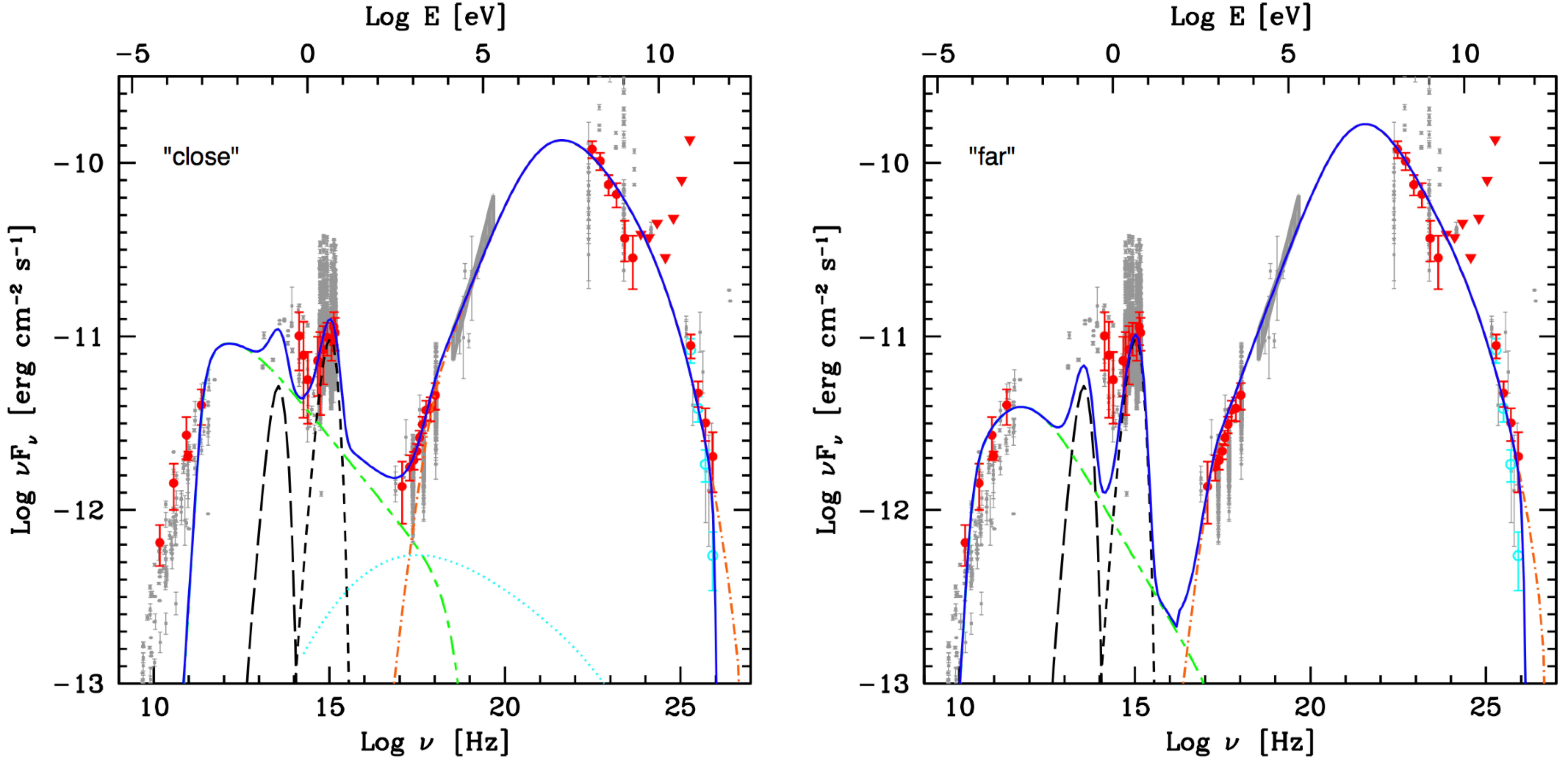
PKS 1510-089





MAGIC coll. 2018, A&A, 619, A159

PKS 1510-089 persistent emission

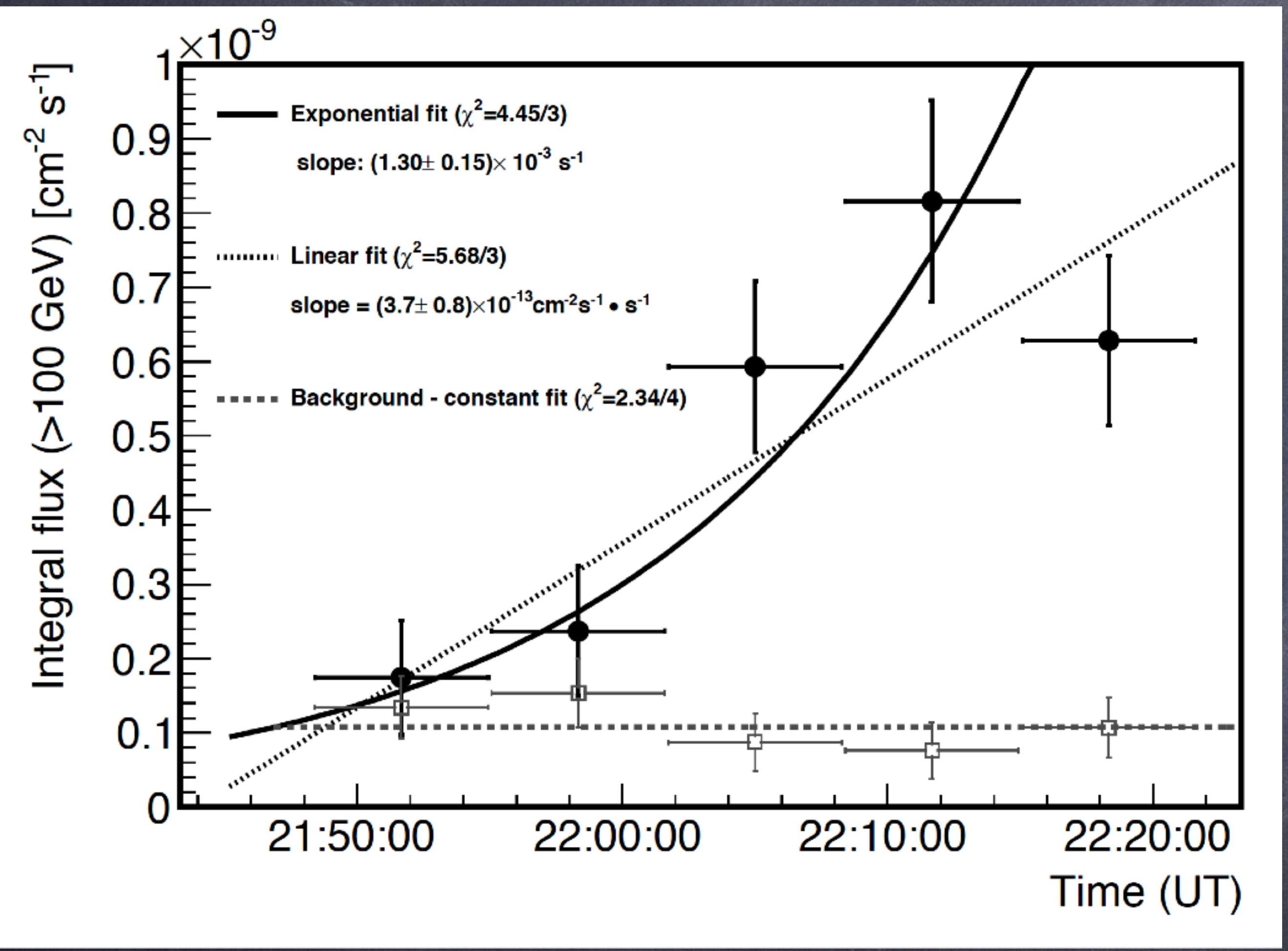


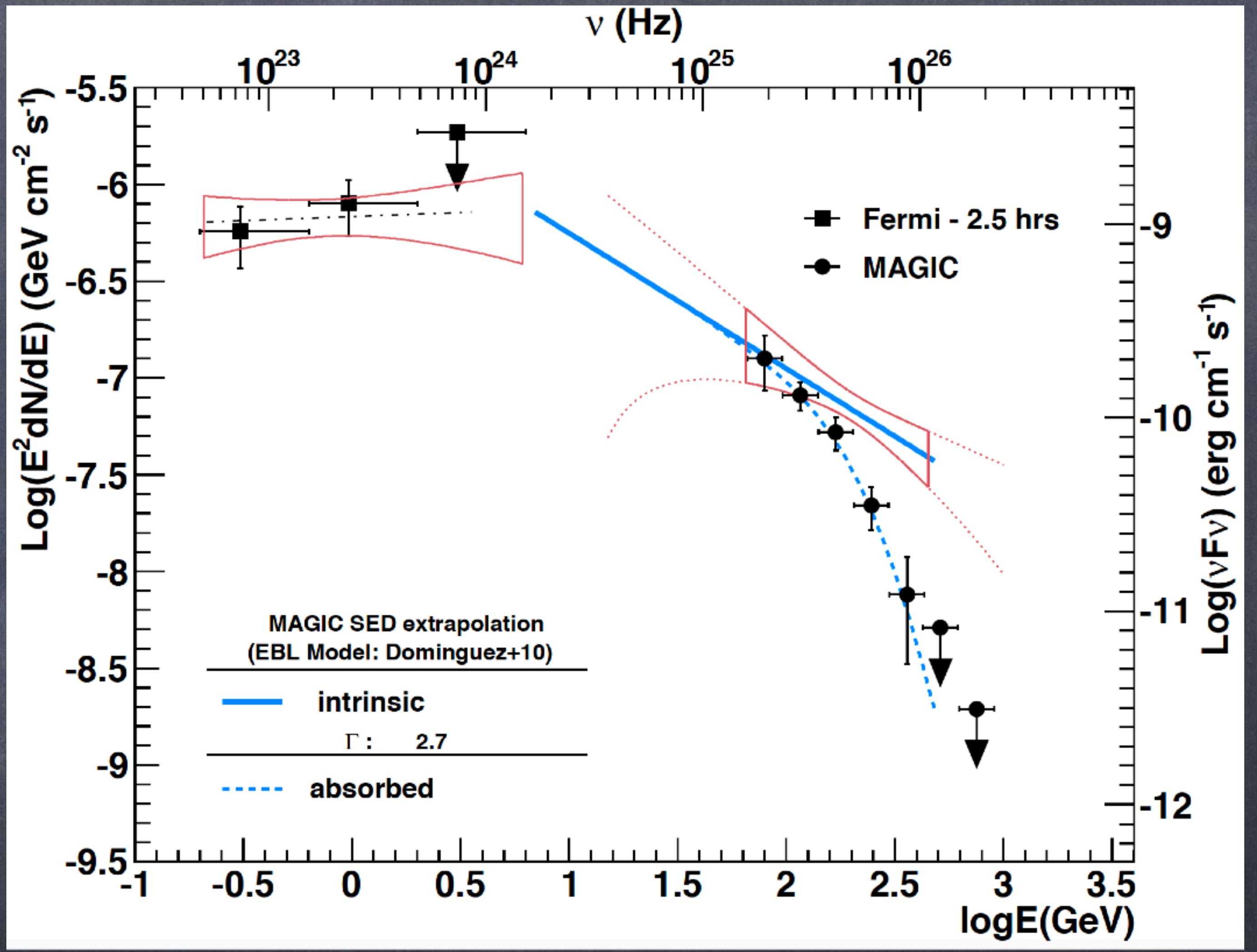
MAGIC coll. 2018, A&A, 619, A159

Jet structure

- Some multi-wavelength light curves points to the need of structure jets, showing more complex behaviours than expected from simple one-zone emitting regions, including also fast variability

FSRQ PKS 1222+21



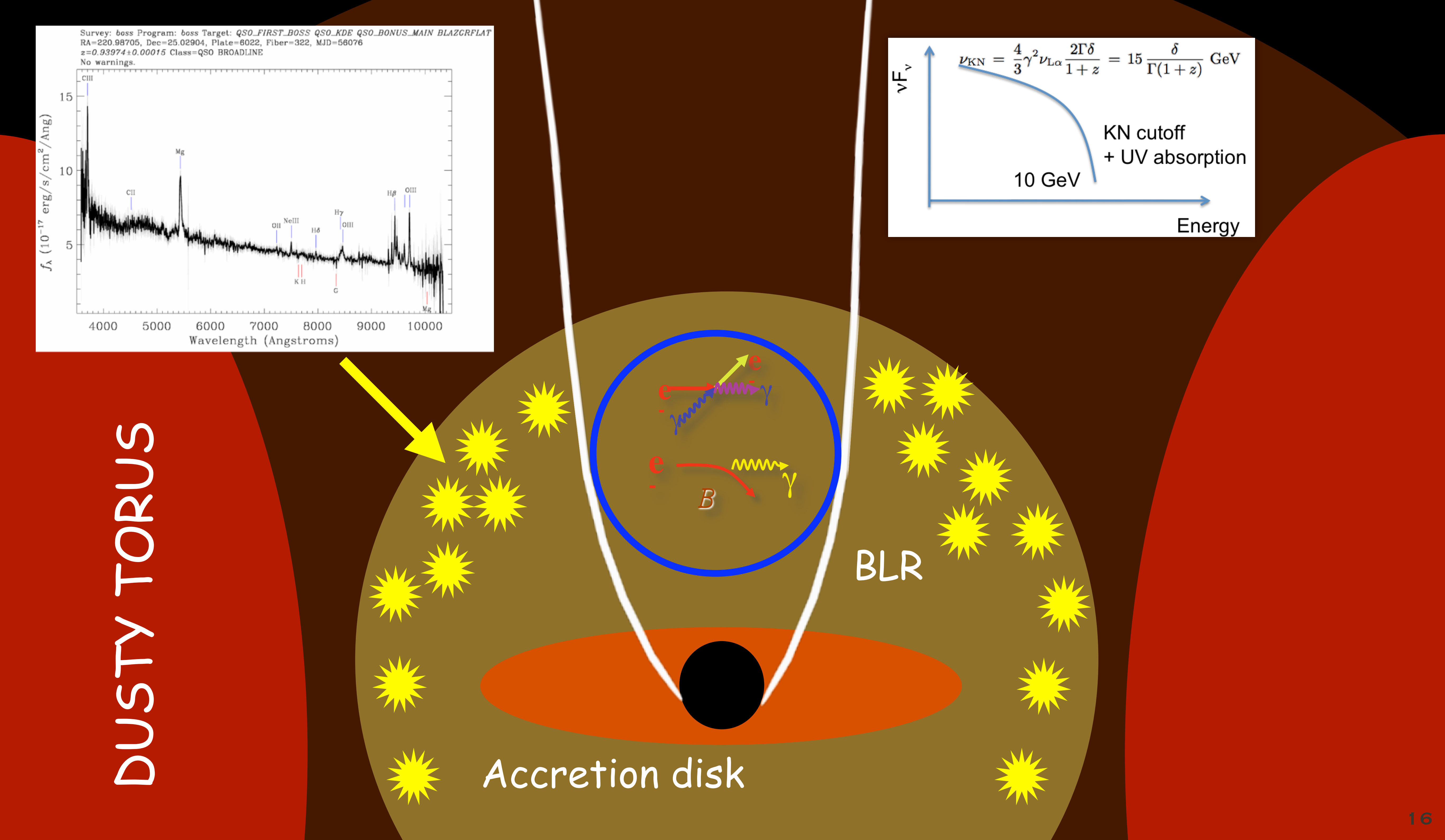


- Fast variability: 9 min doubling time
- No VHE intrinsic spectral absorption

MAGIC Coll. et al. 2011, ApJL, 730, L8

FSRQs: the “canonical” scenario

Dermer et al. 2009
Ghisellini&Tavecchio 2009
Sikora et al. 2009



FSRQs: the "far dissipation" scenario

Dermer et al. 2009
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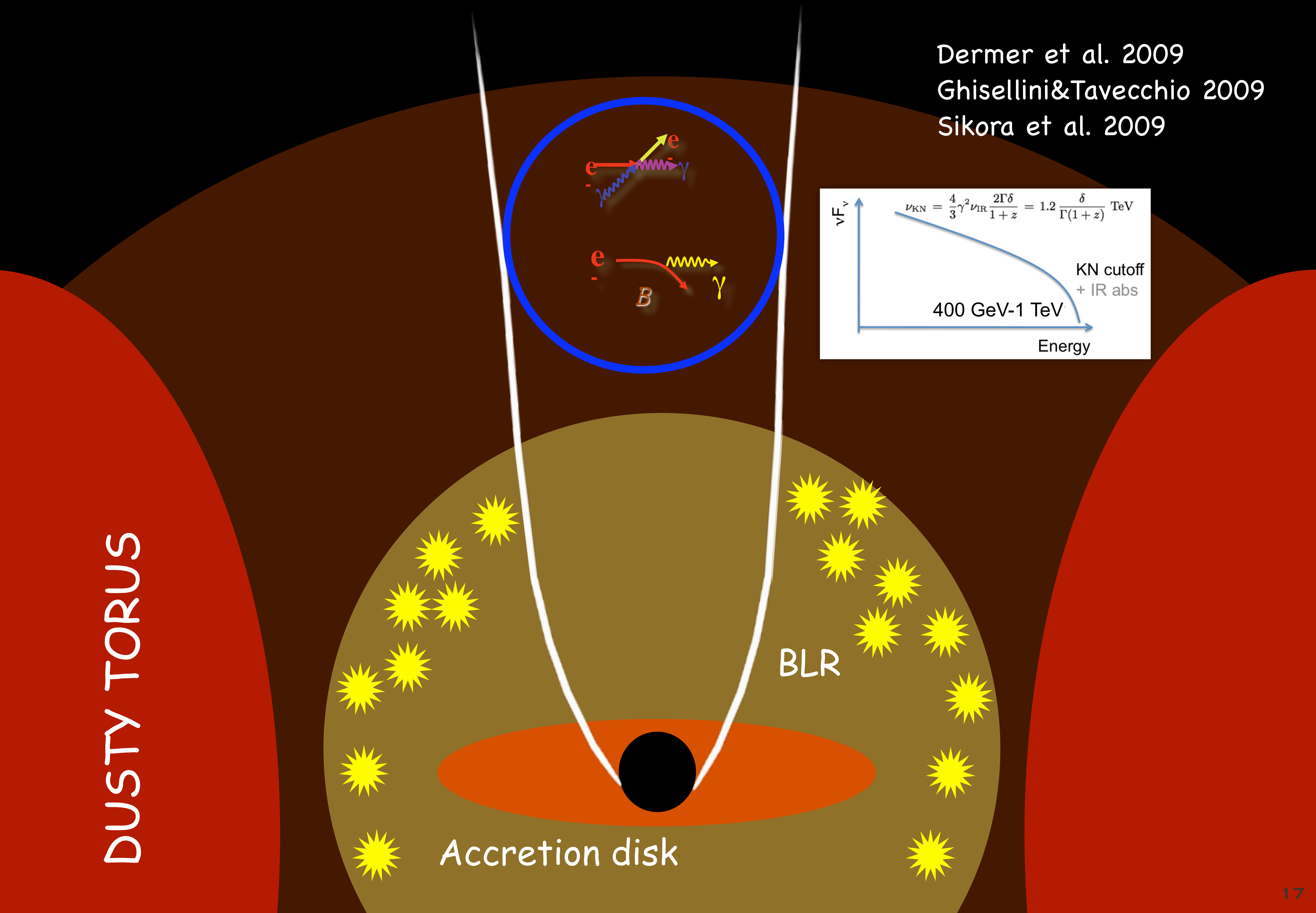
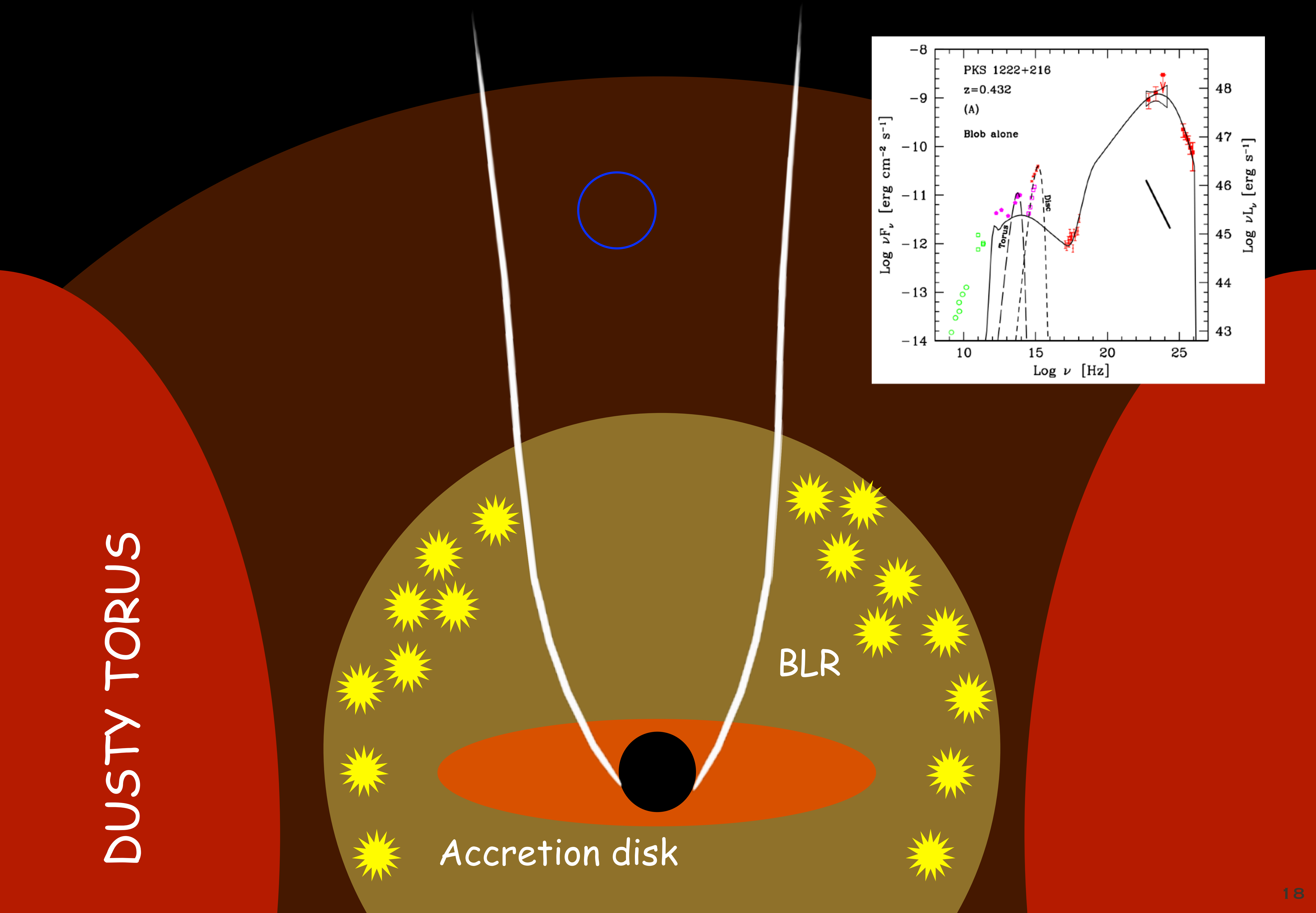
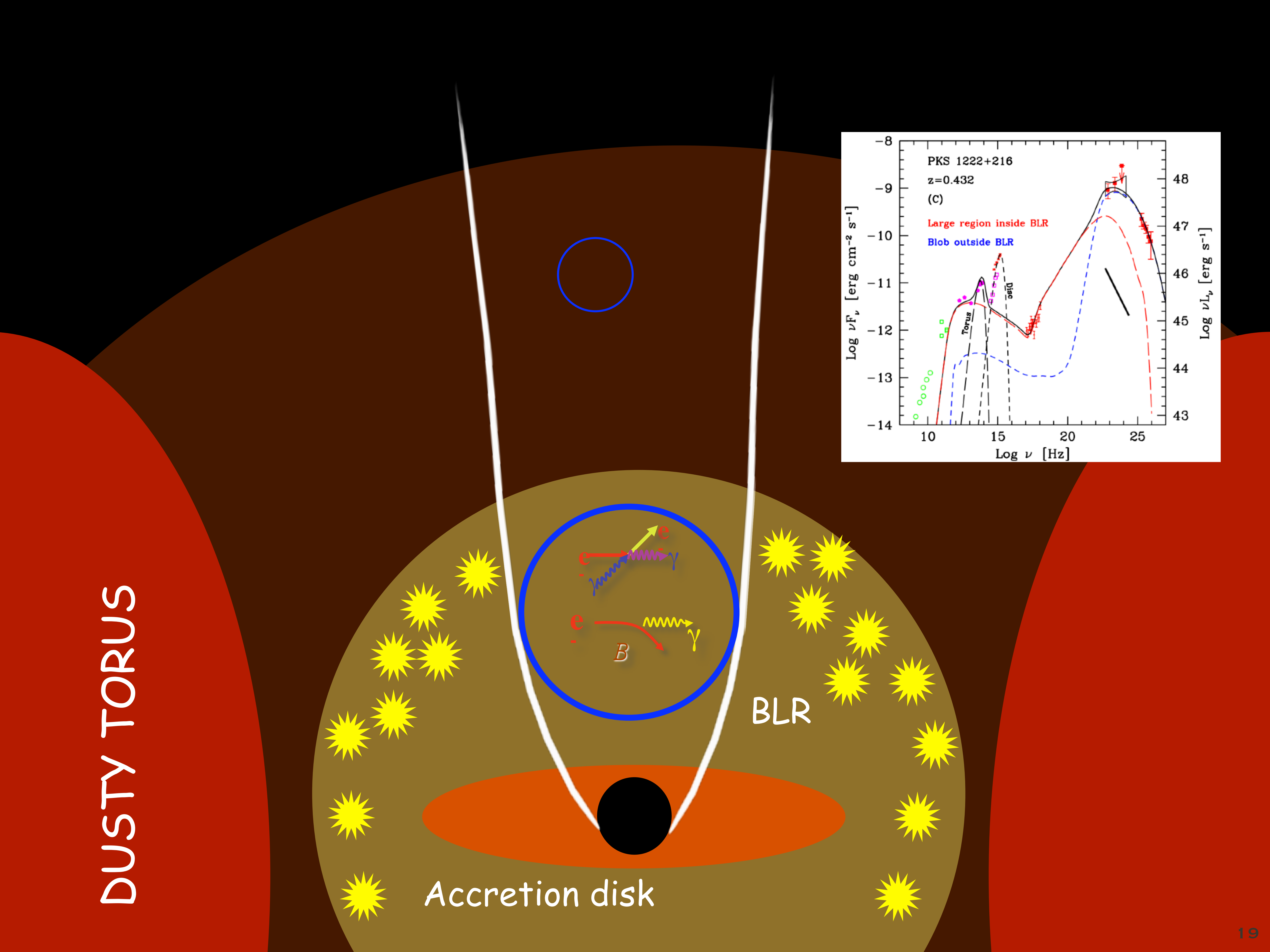
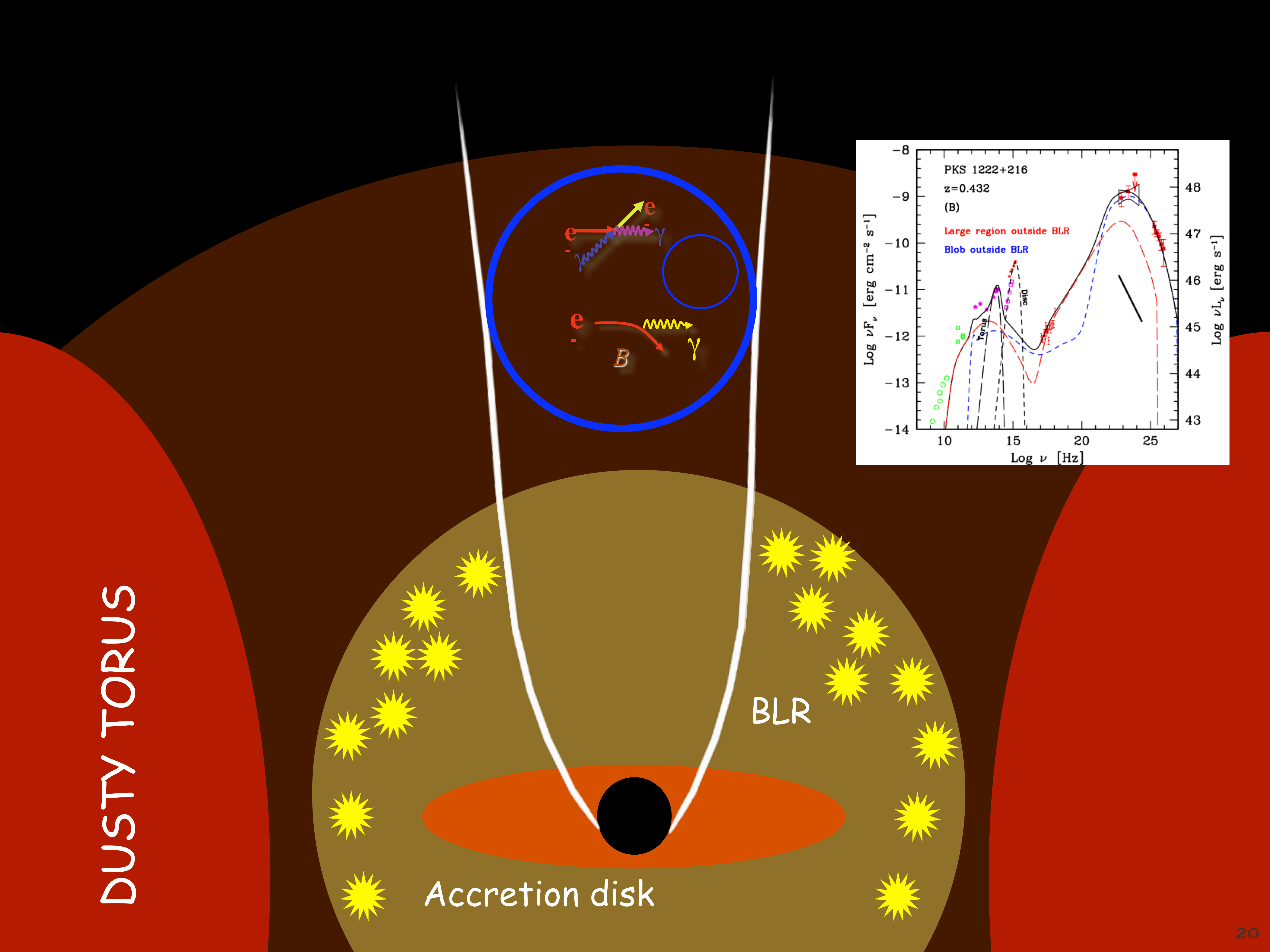



DUSTY TORUS
BLR
Accretion disk
PKS 1222+216
z=0.432
(A)
Blob alone
Torus
Disc
Log νF_ν [erg cm⁻² s⁻¹]
Log νL_ν [erg s⁻¹]
Log ν [Hz]
−8
−9
−10
−11
−12
−13
−14
10
15
20
25
43
44
45
46
47
48

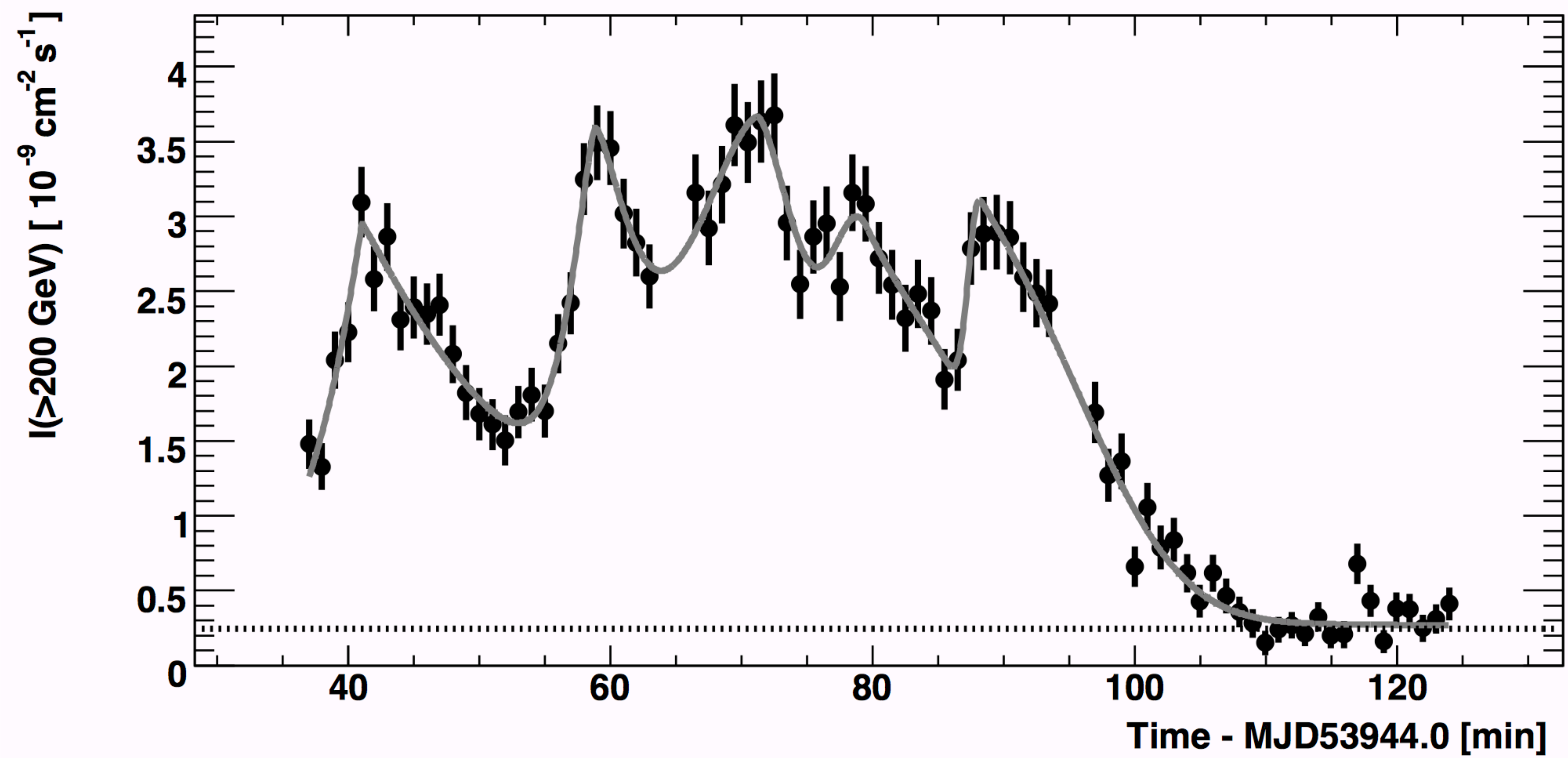


DUSTY TORUS
BLR
Accretion disk
e
γ
B
PKS 1222+216
z=0.432
(C)
Large region inside BLR
Blob outside BLR
Torus
Disc
Log ν [Hz]
Log νF_ν [erg cm^-2 s^-1]
Log νL_ν [erg s^-1]



e
e
γ
e
γ
B
PKS 1222+216
z=0.432
(B)
Large region outside BLR
Blob outside BLR
Torus
Disc
Log νF_ν [erg cm⁻² s⁻¹]
Log νL_ν [erg s⁻¹]
Log ν [Hz]
BLR
DUSTY TORUS
Accretion disk

Extreme variability PKS 2155-304



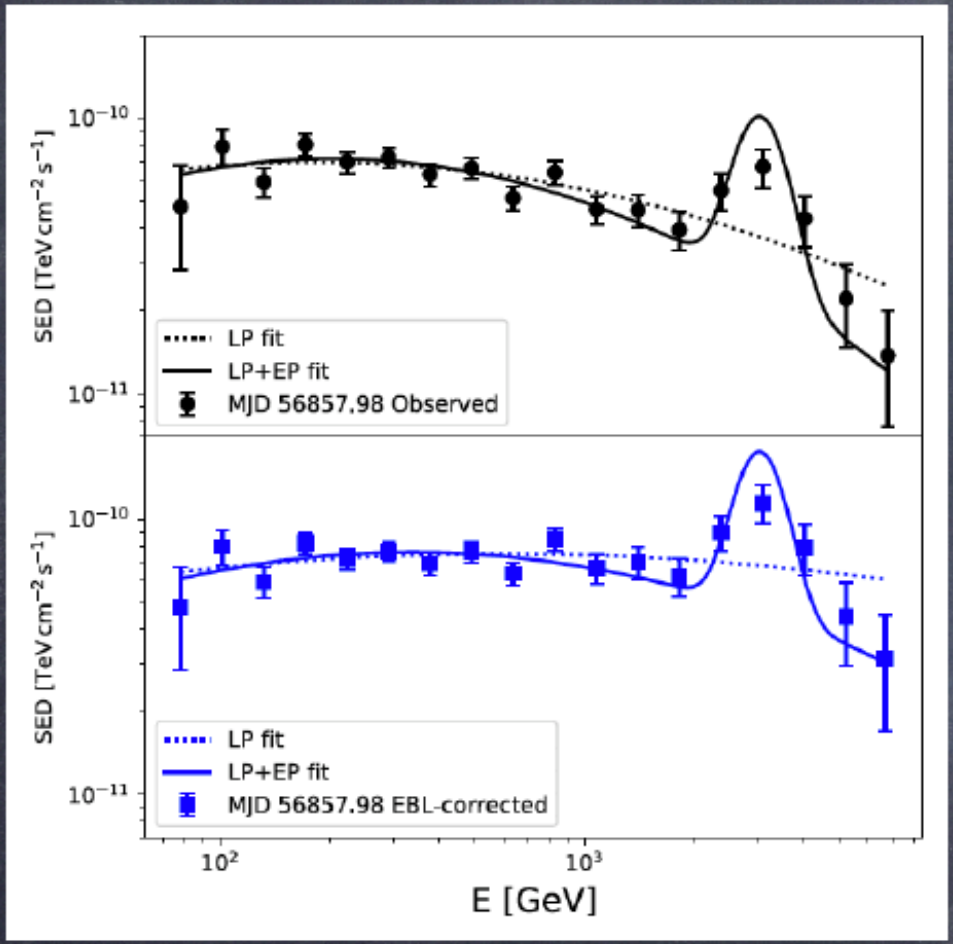
 HESS coll. 2007, ApJ, 664, L71

Jet structure

- Some multi-wavelength light curves points to the need of structure jets, showing more complex behaviours than expected from simple one-zone emitting regions, including also fast variability
- First hint of an spectral narrow feature in the VHE band from Mrk 501
- CTA will bring better resolution and MWL campaigns will be key

Hint of a narrow VHE spectral feature

Likelihood Ratio Test



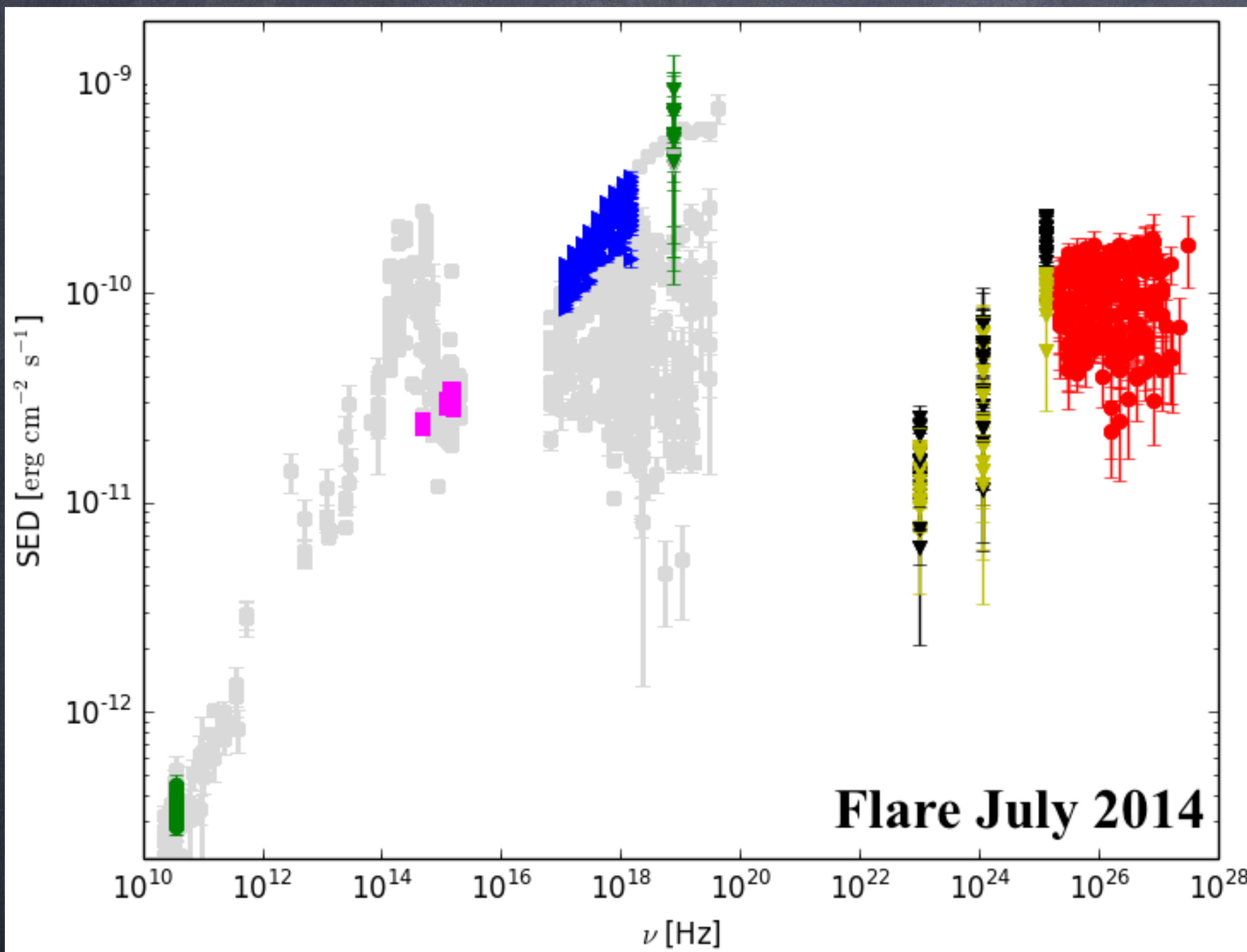
2014 July 19-20
(MJD 56857.98)

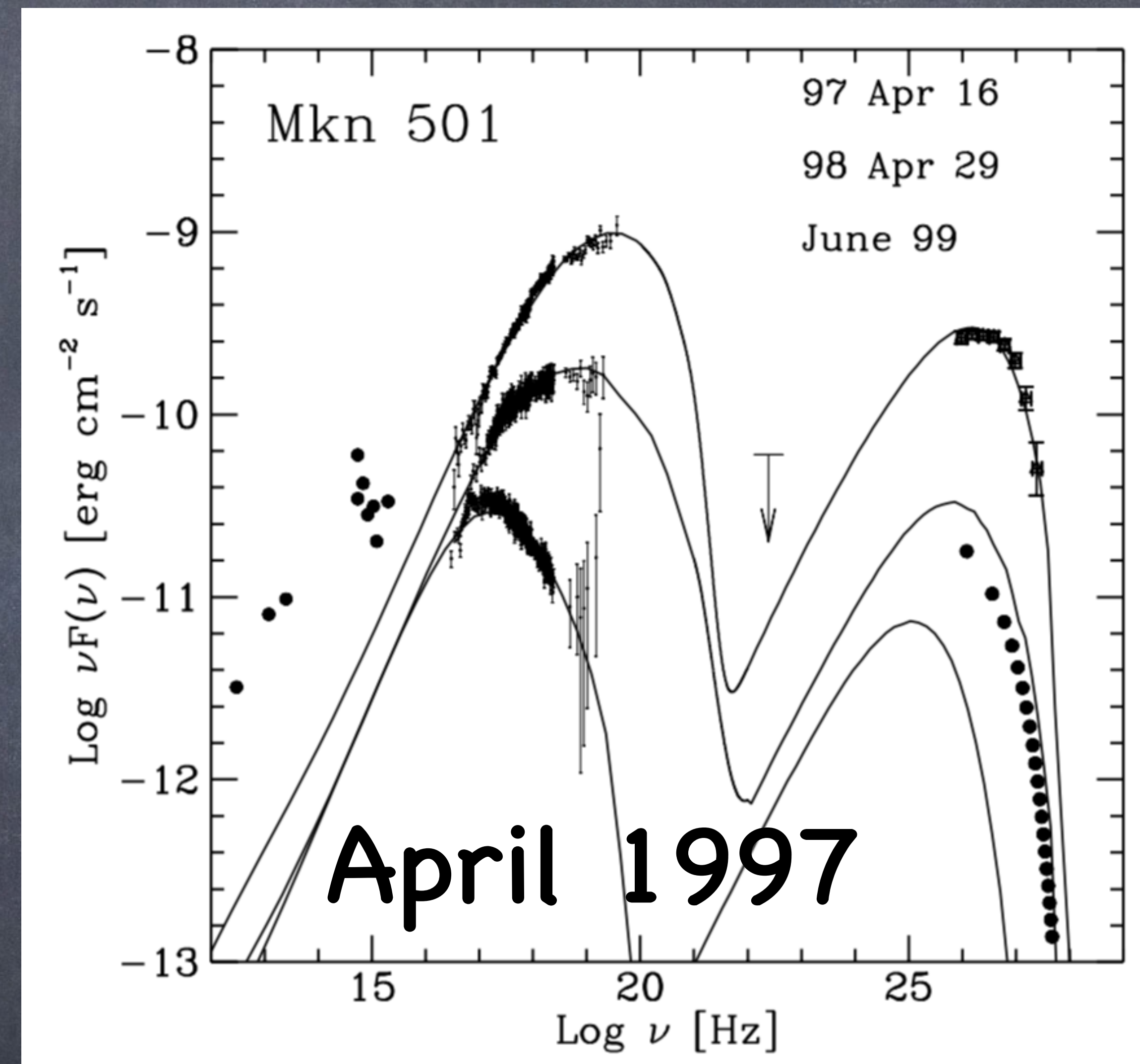
	Fit	$f_0 \cdot 10^{10}$ [TeV^{-1}cm^{-2}s^{-1}]	Γ	b	$K \cdot 10^5$ [TeV^{-1}cm^{-2}s^{-1}]	β	Ep [TeV]	χ^2/df	LRT
Observed	LP	2.56 ± 0.09	-2.16 ± 0.03	0.08 ± 0.02	-	-	-	39.8/19	
Observed	LP+EP	2.54 ± 0.10	-2.26 ± 0.04	0.14 ± 0.03	7.7 ± 1.7	9.1 ± 3.2	3.04 ± 0.10	13.5/16	4.5σ
EBL-corr	LP	3.00 ± 0.11	-1.99 ± 0.03	0.04 ± 0.02	-	-	-	35.4/19	
EBL-corr	LP+EP	2.99 ± 0.11	-2.08 ± 0.04	0.10 ± 0.03	13.0 ± 3.0	10.0 ± 3.6	3.03 ± 0.10	14.6/16	3.9σ

MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86

[redacted]

MWL SED overview





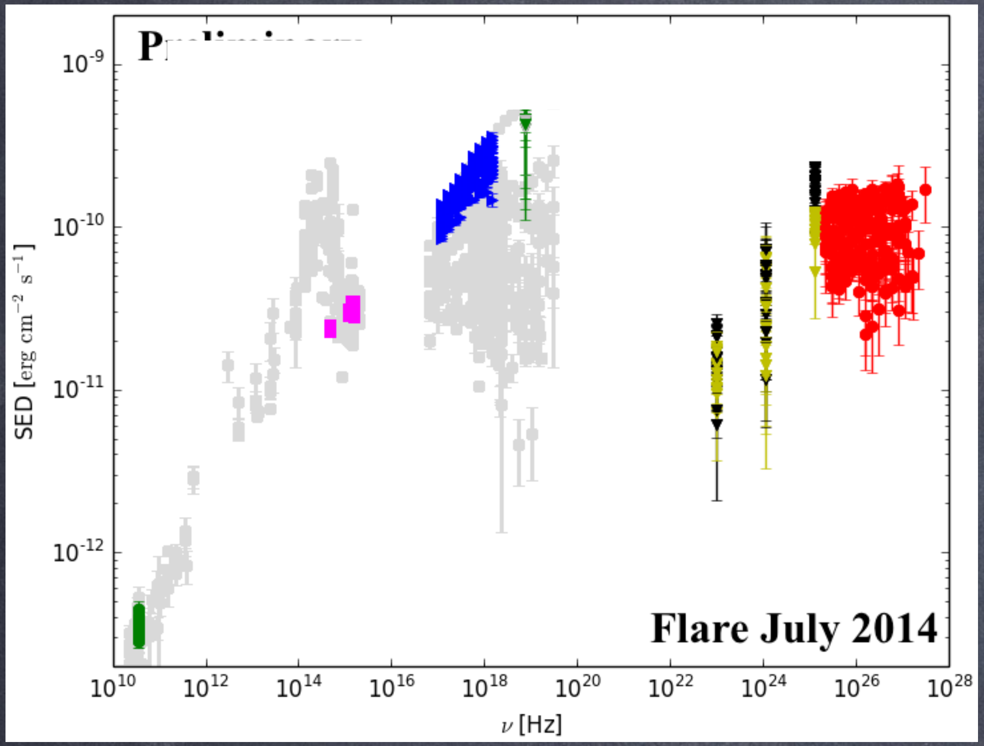
Tavecchio et al. (2001)
ApJ 554, 725

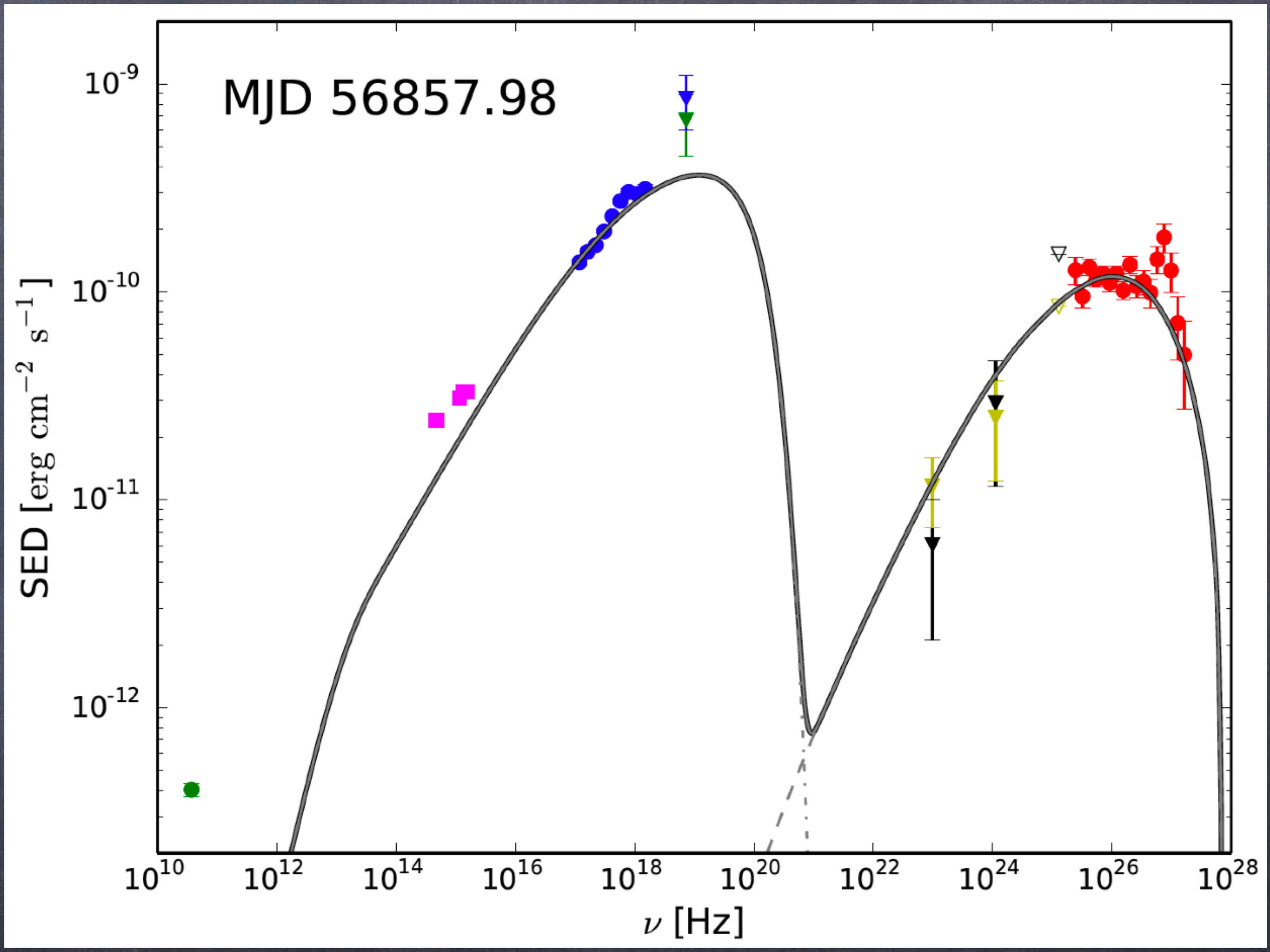
X-ray flux comparable

TeV more variable in 1997

[redacted]

MWL SED overview





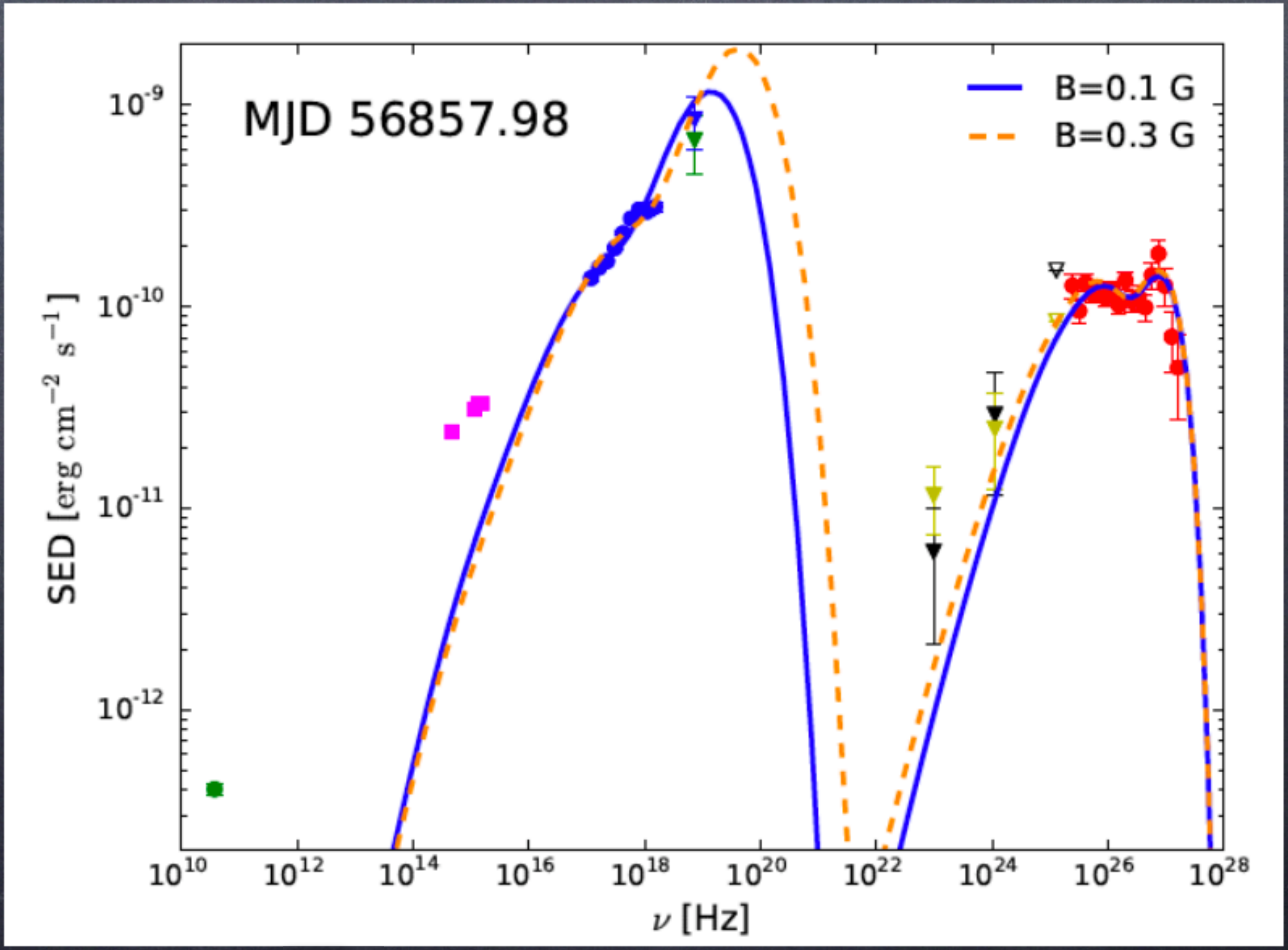
MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86

[redacted]

Theoretical interpretation

a) Pile up in the energy electron distribution due to stochastic acceleration

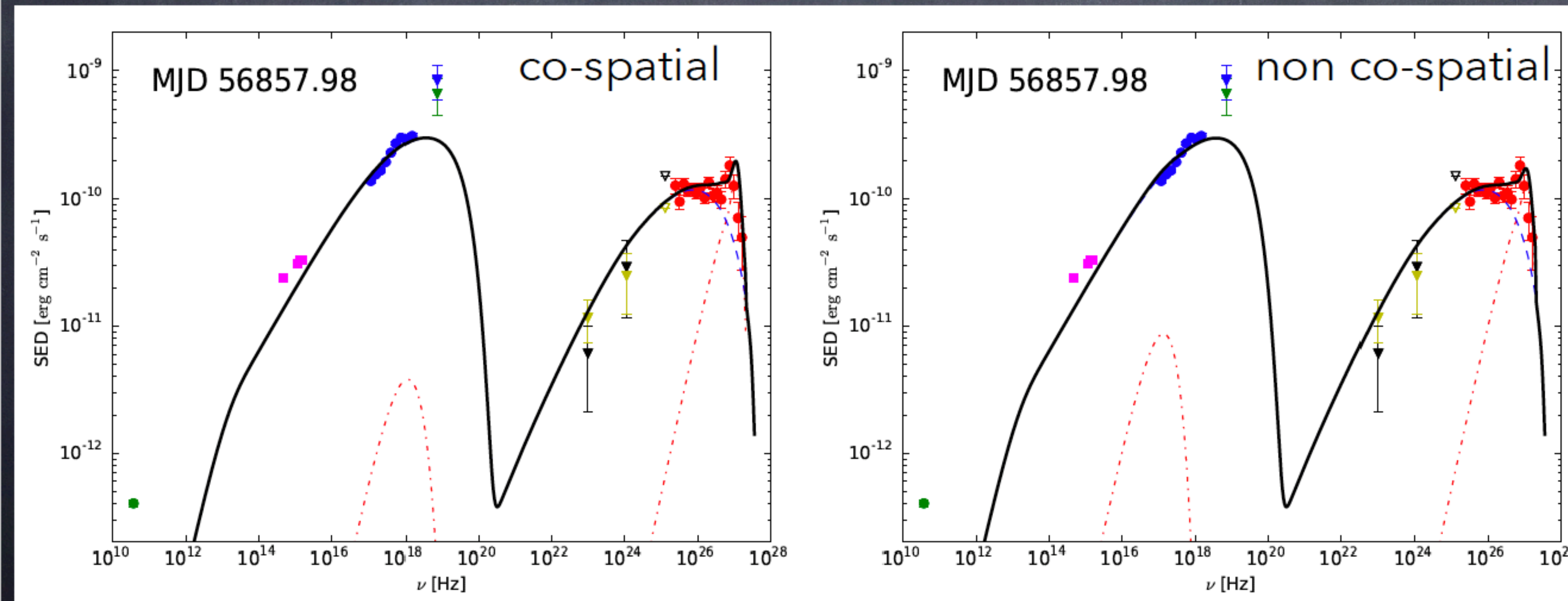
JetSeT open code



MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86 [redacted]

Theoretical interpretation

b) Structured jet: two-zone SSC model

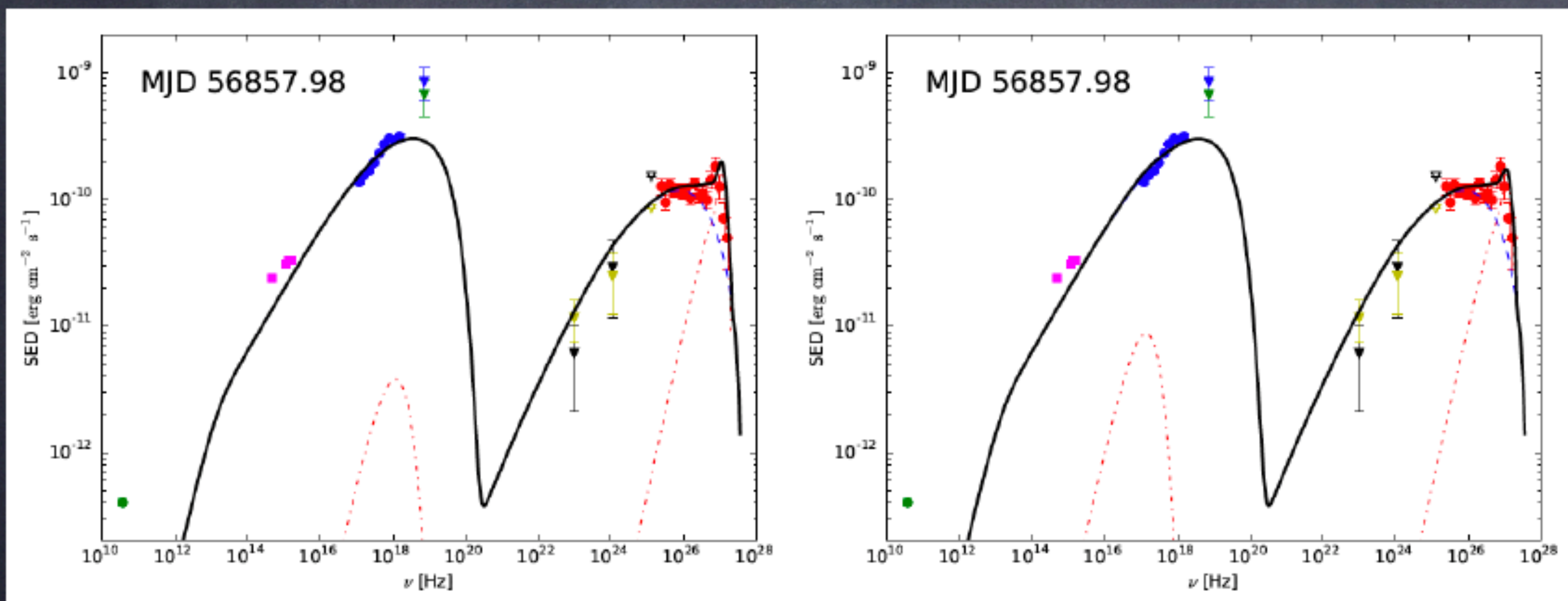


MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86

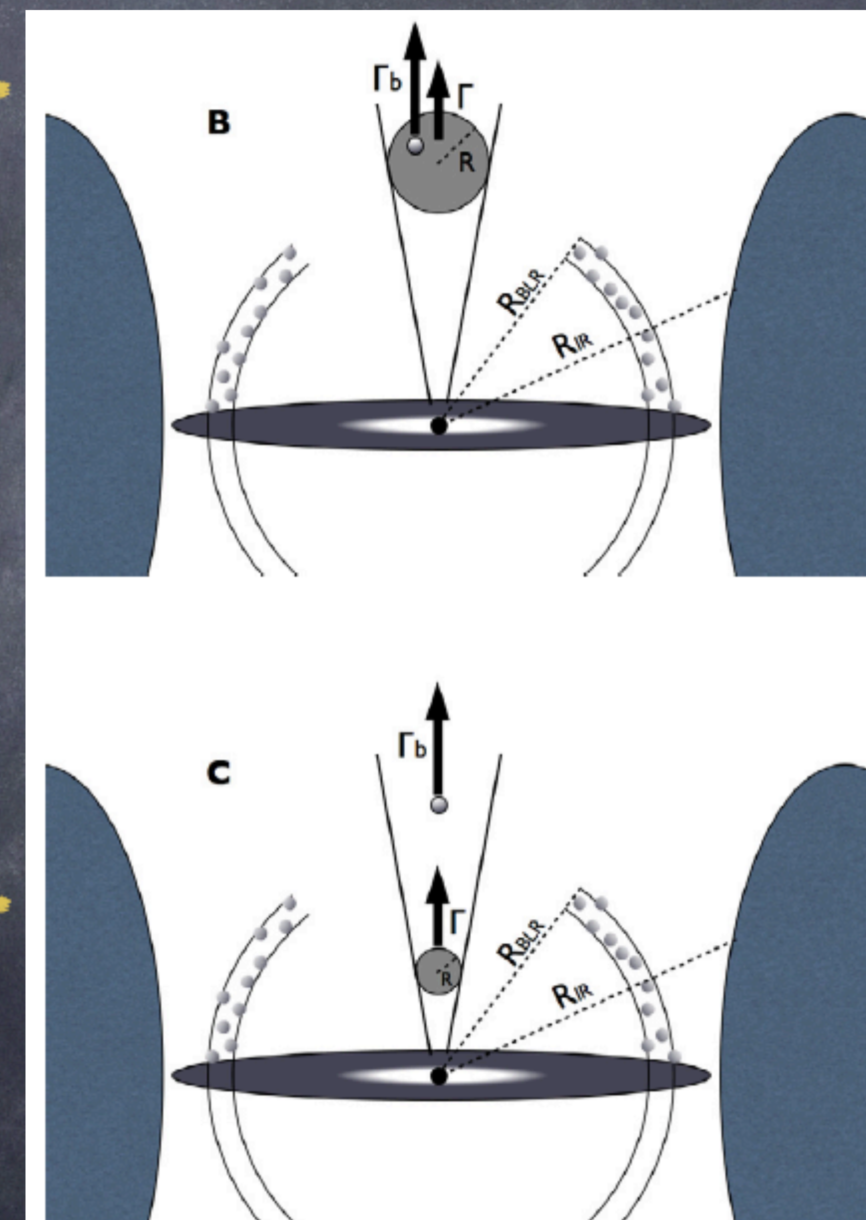
[redacted]

Theoretical interpretation

b) Structured jet: two-zone SSC model



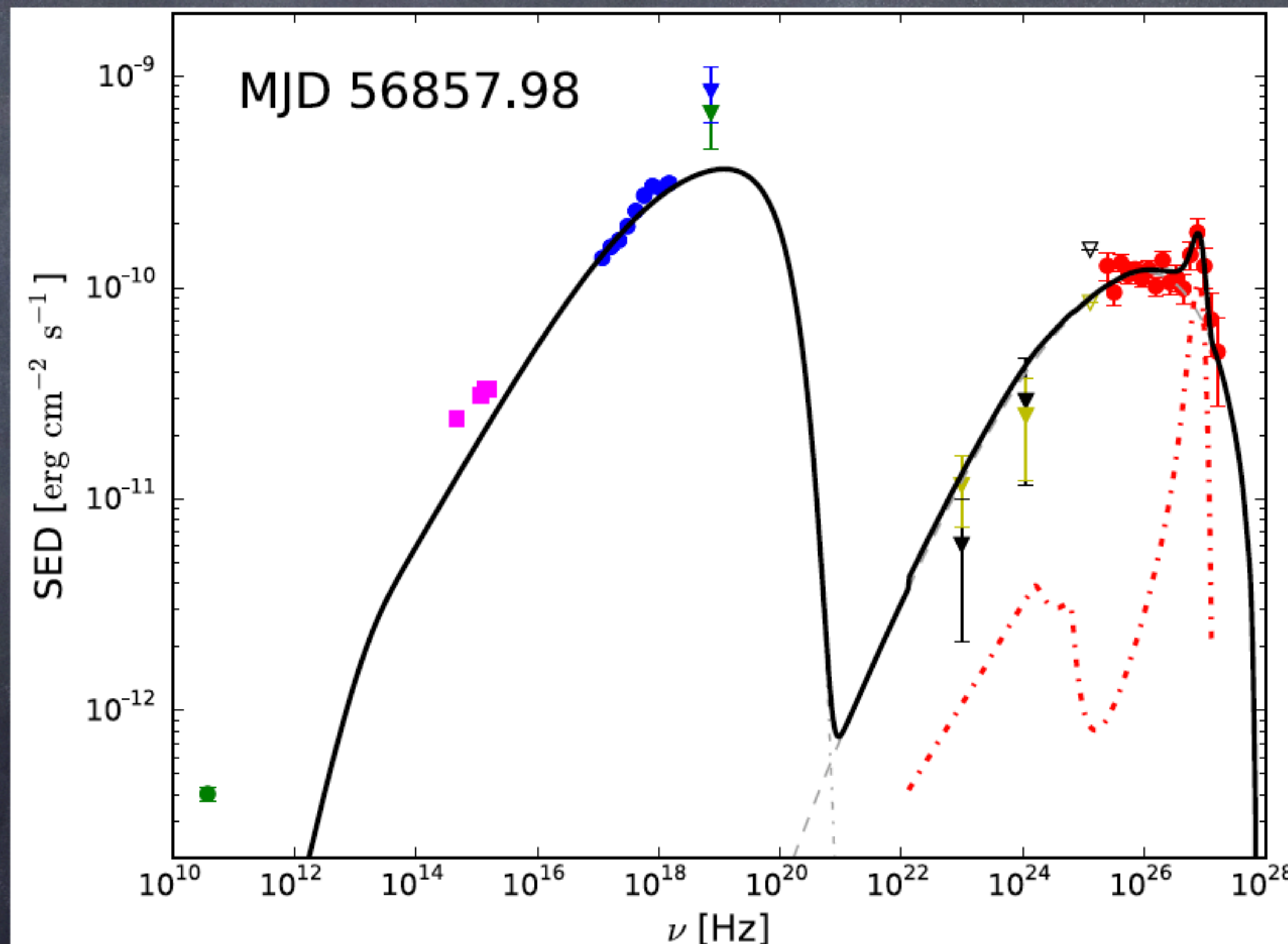
MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86



Tavecchio, JBG et al., 2011, A&A, 534, A86

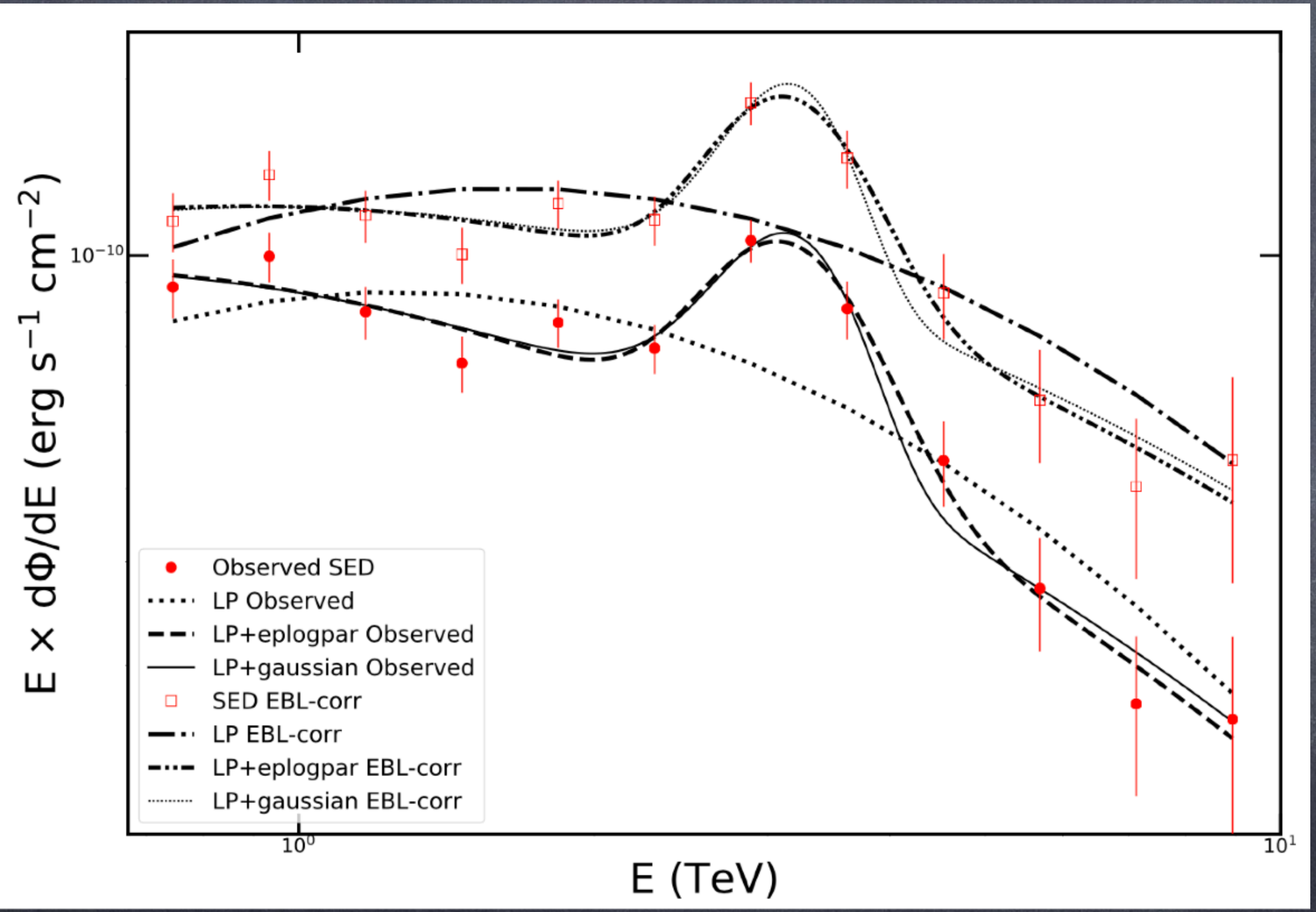
Theoretical interpretation

c) Magnetospheric vacuum gap model + one-zone SSC



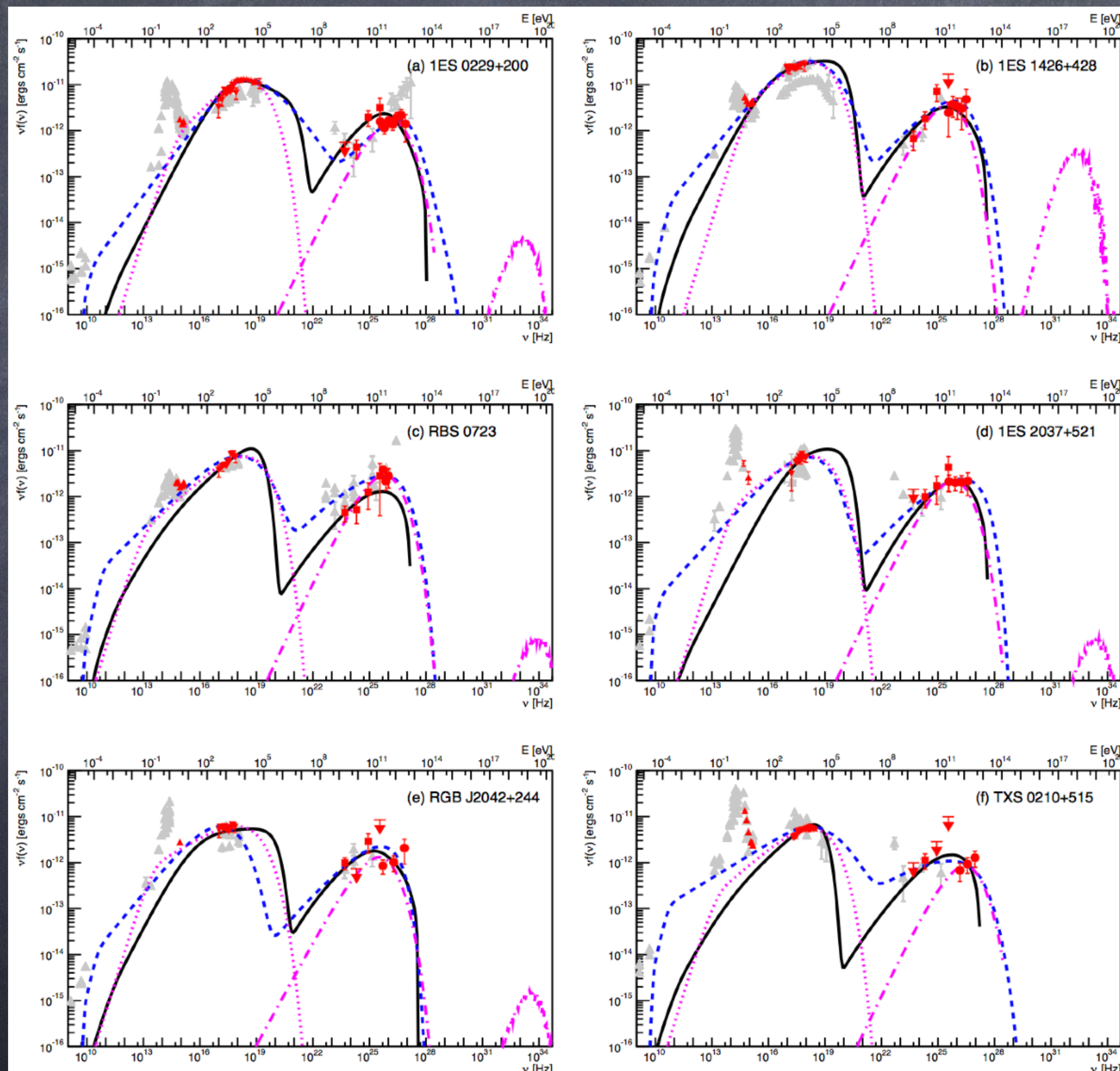
MAGIC Coll. (JBG, DP) 2020, A&A, 637, A86
Wendel, JBG et al. 2021, A&A, 646, A115 [redacted]

ASTRI-MiniArray simulations



Saturni et al. 2022, JHEAp, 35, 91

Extreme blazars



MAGIC coll. 2020, ApJS, 247, id.16

Extreme blazars

HAWC and LHAASO could help to point to them, although they are weak targets —> from long term integrations? HAWC starting to detect AGNs beyond Mrk 501 and Mrk 421

Source	Redshift	"Pass 4" TS	"Pass 5" TS
M87	0,004	13,2	29,6
1ES1215+303	0,130	12,8	43,8
VER J0521+211	0,108	10,3	18,2

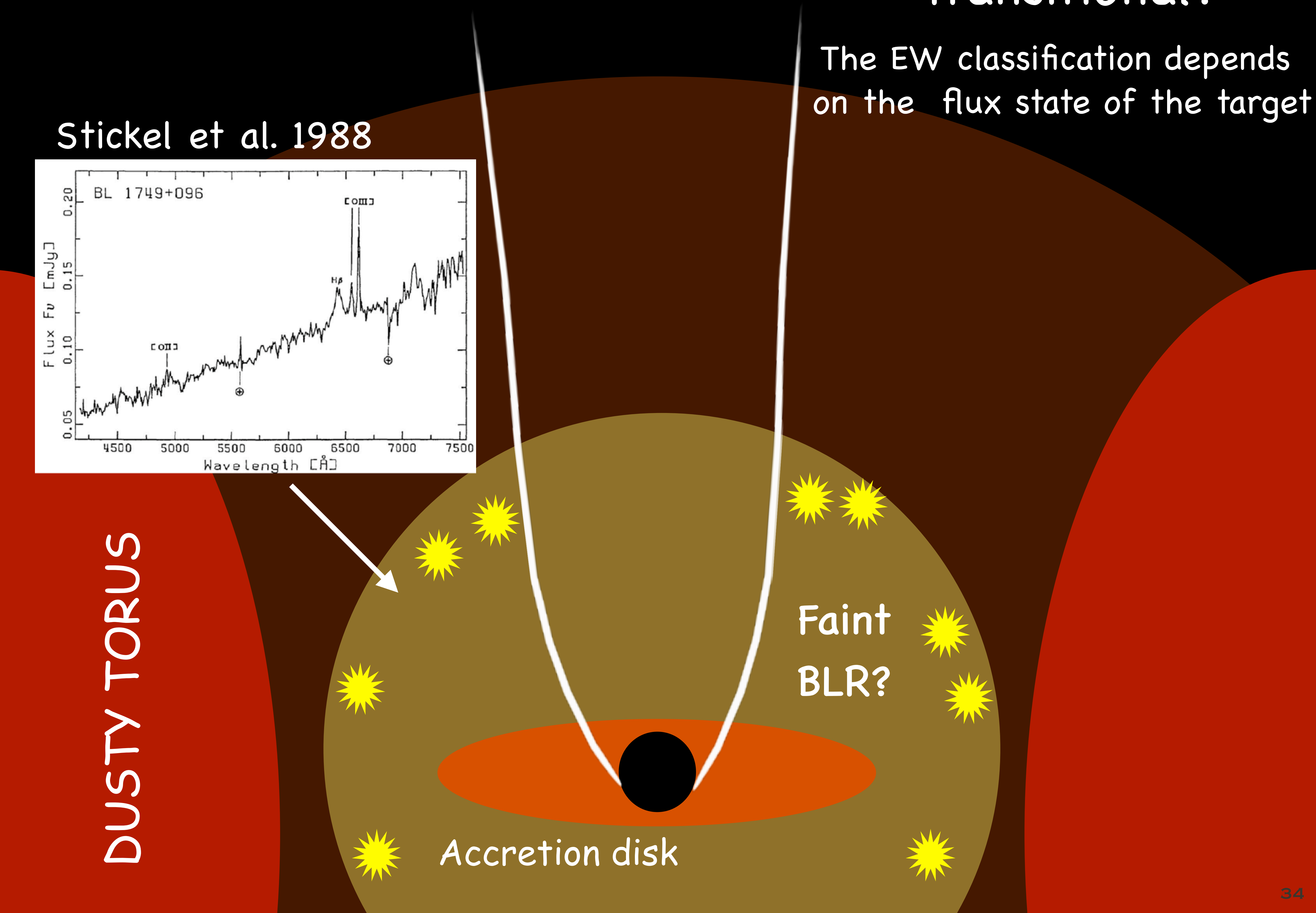
Goodman et al. Gamma 2022

Transitional blazars

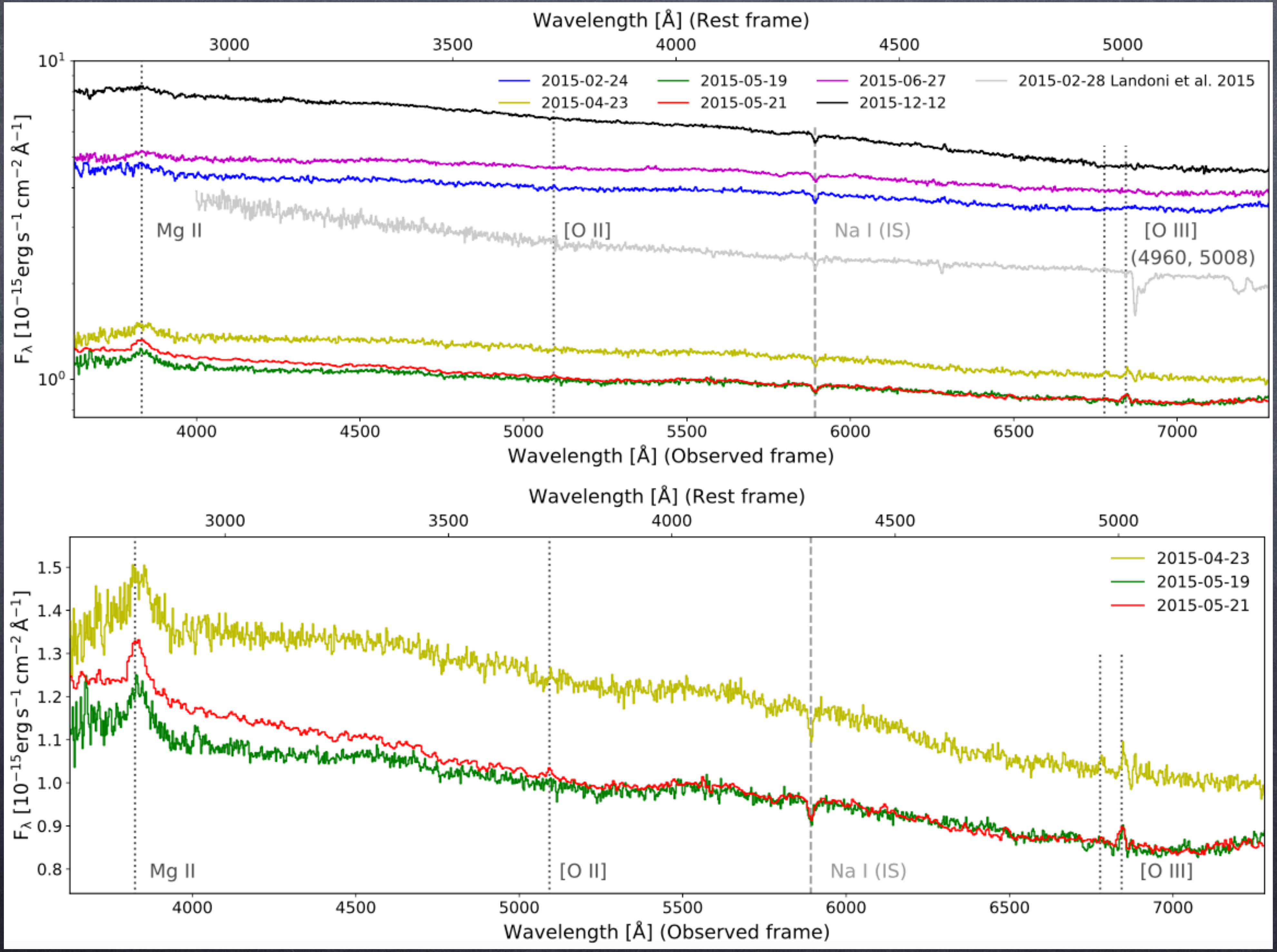
- S4 0954+65 (z=0.367)
- OT081 (z=0.322)
- Optical+VHE observations would allow to constrain the AGN structure
- CTA will allow us to enlarge the sample of transitional VHE blazars

Transitional?

The EW classification depends on the flux state of the target

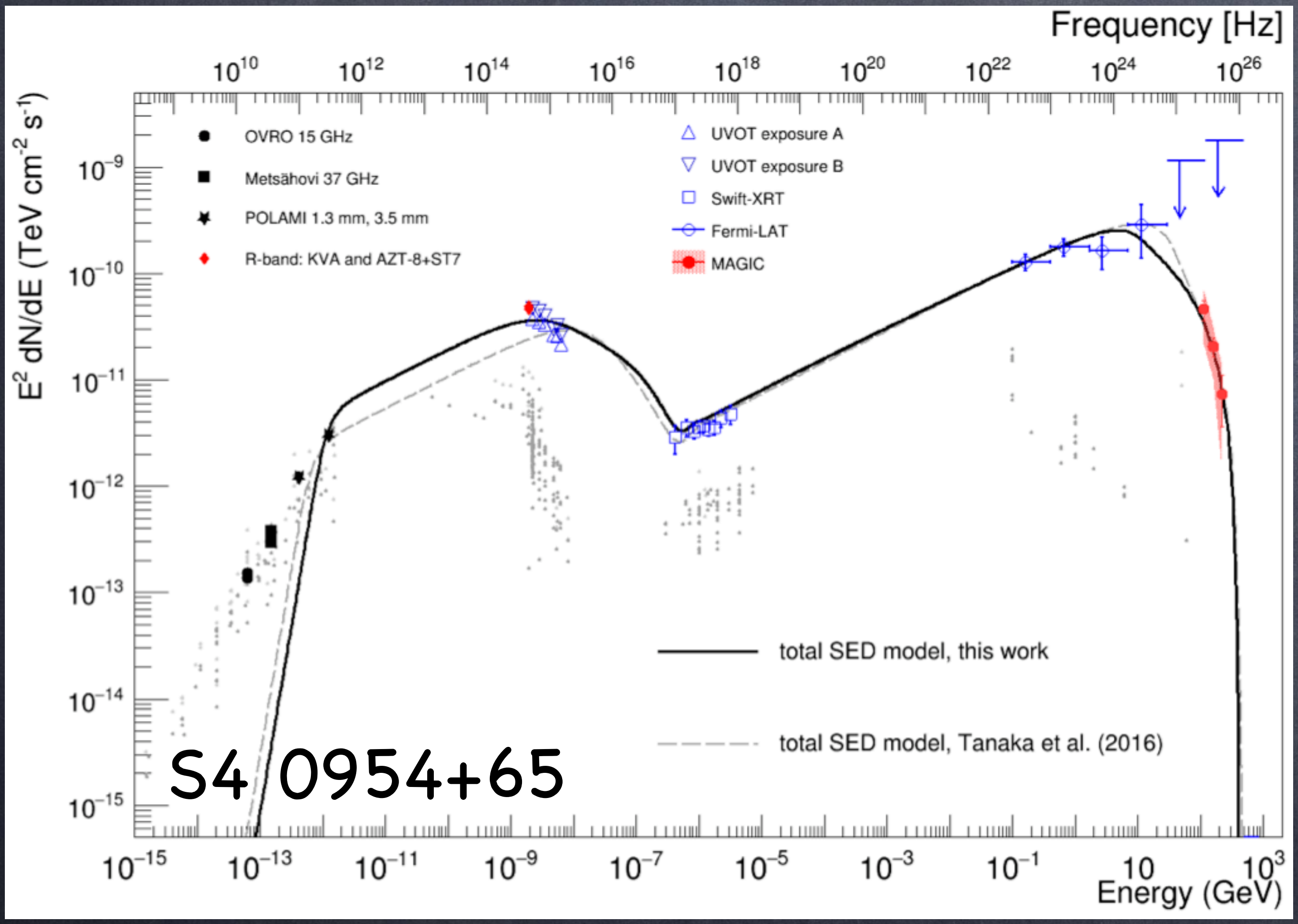


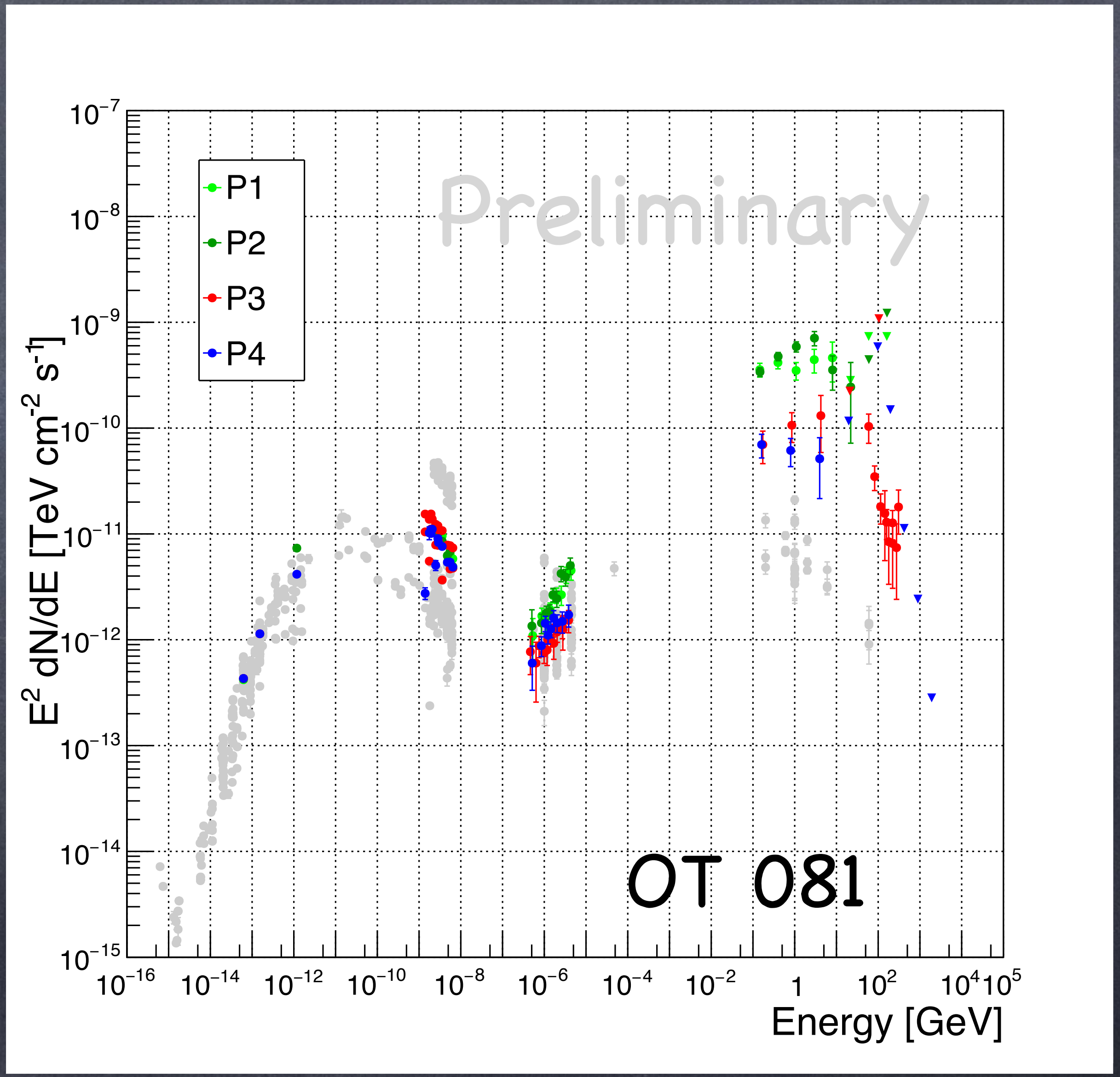
Optical spectroscopic follow up
S4 0954+65



 JBG et al. 2021, MNRAS, 504, 5258

Transitional blazars MWL SEDs





MAGIC coll. 2018, A&A, 617, A30

MAGIC+HESS work in progress

Most distant blazars

- FSRQ
- z=0.99

Enhanced HE and VHE gamma-ray activity from the FSRQ PKS 0346-27

ATel #15020; *S. Wagner (U. Heidelberg, Germany), for the H. E.S. S. collaboration and B. Rani (KASI, S. Korea), on behalf of the Fermi Large Area Telescope Collaboration*
*on **6 Nov 2021; 18:38 UT***
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

Subjects: Gamma Ray, >GeV, VHE, AGN, Blazar, Quasar

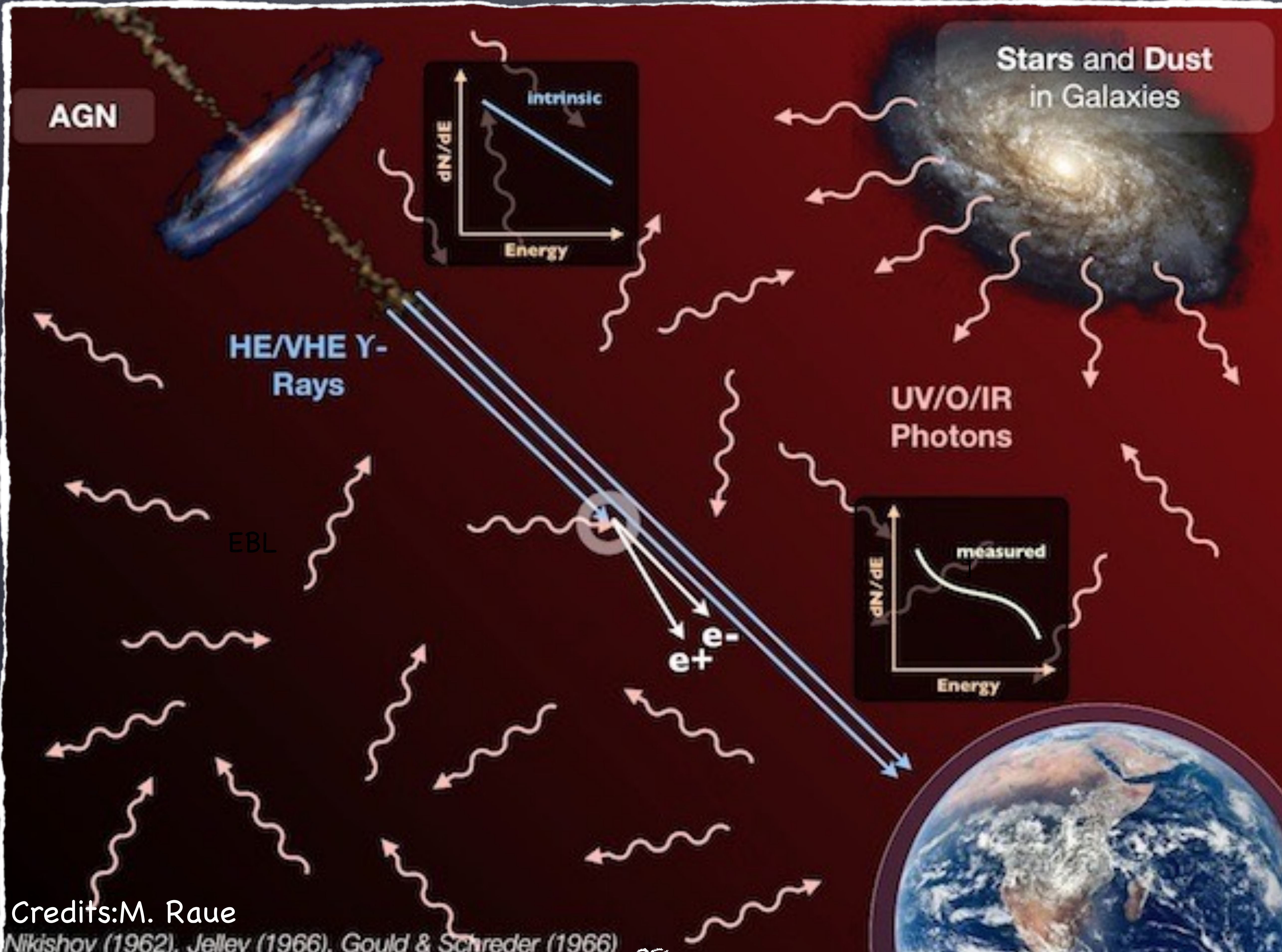
Referred to by ATel #: 15092

Tweet

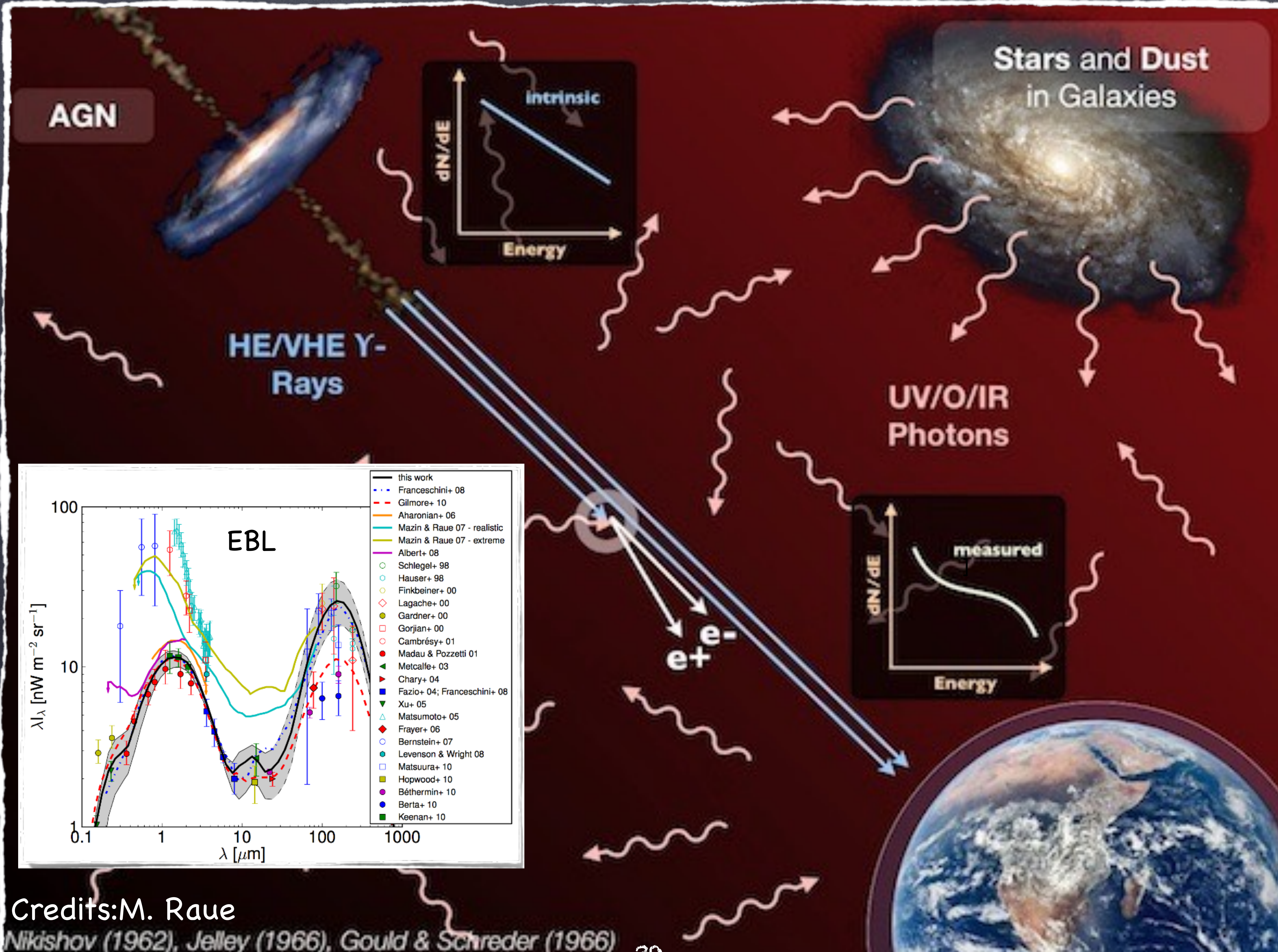
The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed enhanced gamma-ray activity from a source positionally consistent with the flat-spectrum radio quasar PKS 0346-27, also known as 4FGL J0348.5-2749 (The Fermi-LAT collaboration 2020, ApJS, 247, 33), with coordinates RA=03h 48m 38s, Dec=-27d 49' 14" (J2000; Beasley et al. 2002 ApJS, 141, 13), and a reported redshift of z=0.991 (White et al. 1988 ApJ, 327, 561).

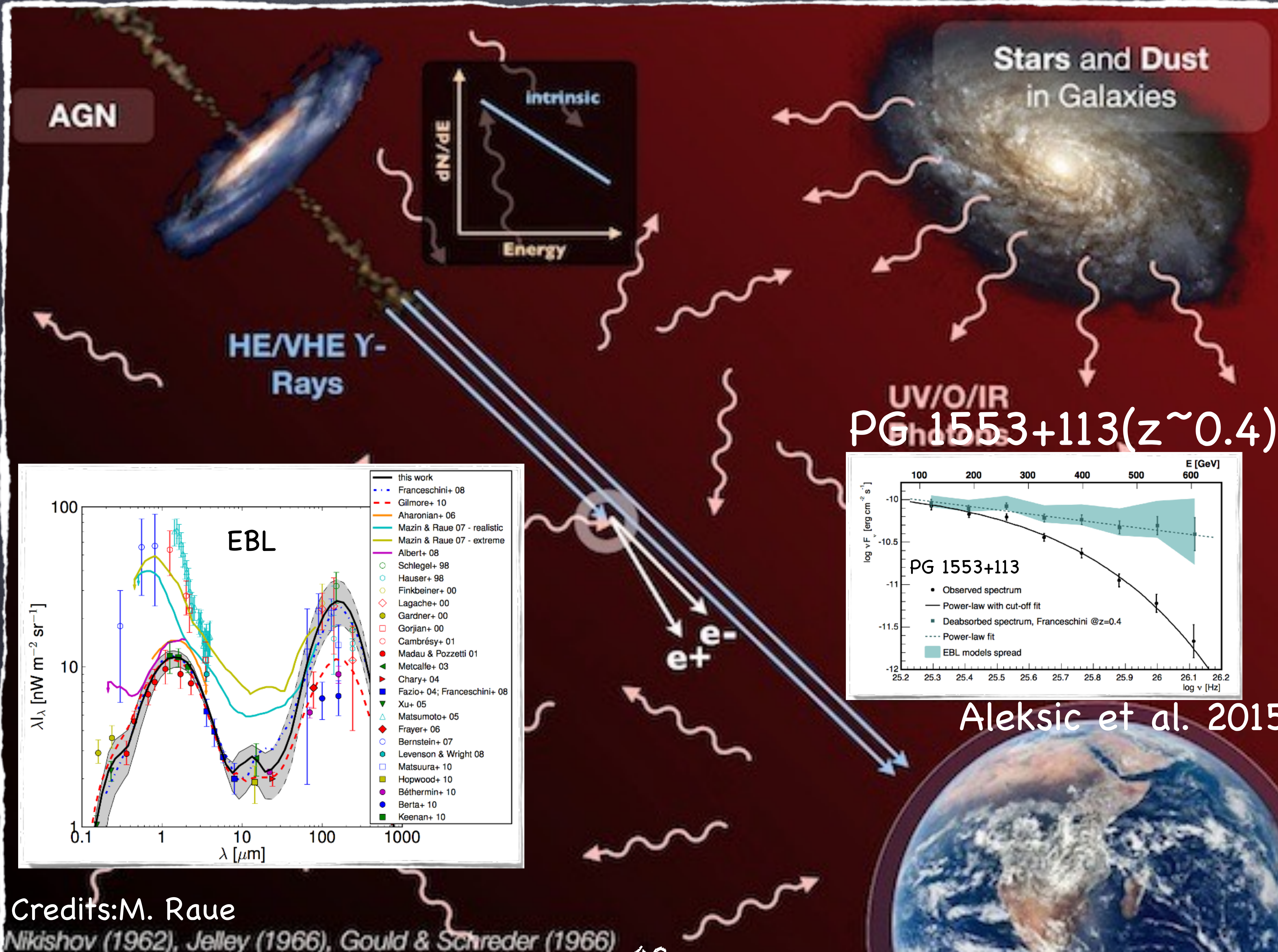
The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out observations of PKS 0346-27. On November 03 (MJD 59521.9), a two hour observation shows a >5 sigma excess in the very-high-energy gamma-ray band compatible with the direction of PKS 0346-27. Preliminary analysis shows a very soft power law (photon spectral index > 4). H.E.S.S. observations are ongoing.

Preliminary analysis of the data obtained with the Fermi/LAT instrument indicates that this source was in an elevated gamma-ray emission state on November 02, 2021, with a daily averaged gamma-ray flux (E>100MeV) of (1.8+/-0.2) X 10^-6 photons cm^-2 s^-1 (statistical uncertainty only). This corresponds to a flux increase of a factor of 200 relative to the average flux reported in the fourth Fermi-LAT catalog (4FGL). The corresponding photon index is 1.8+/-0.1, and is significantly smaller than the 4FGL value of 2.5+/-0.1. Previous enhanced gamma-ray activity in the source was detected on February 20, 2020 (ATel#13521).



AGN
intrinsic
dN/dE
Energy
Stars and Dust in Galaxies
HE/VHE γ-Rays
UV/O/IR Photons
EBL
e-
e+
measured
dN/dE
Energy
Credits:M. Raue
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)


AGN
intrinsic
dN/dE
Energy
Stars and Dust in Galaxies
HE/VHE γ-Rays
UV/O/IR Photons
e-
e+
measured
dN/dE
Energy
EBL
this work
Franceschini+ 08
Gilmore+ 10
Aharonian+ 06
Mazin & Raue 07 - realistic
Mazin & Raue 07 - extreme
Albert+ 08
Schlegel+ 98
Hauser+ 98
Finkbeiner+ 00
Lagache+ 00
Gardner+ 00
Gorjian+ 00
Cambrésy+ 01
Madau & Pozzetti 01
Metcalfe+ 03
Chary+ 04
Fazio+ 04; Franceschini+ 08
Xu+ 05
Matsumoto+ 05
Frayer+ 06
Bernstein+ 07
Levenson & Wright 08
Matsuura+ 10
Hopwood+ 10
Béthermin+ 10
Berta+ 10
Keenan+ 10
λI_λ [nW m^{-2} sr^{-1}]
λ [μm]
Credits:M. Raue
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)

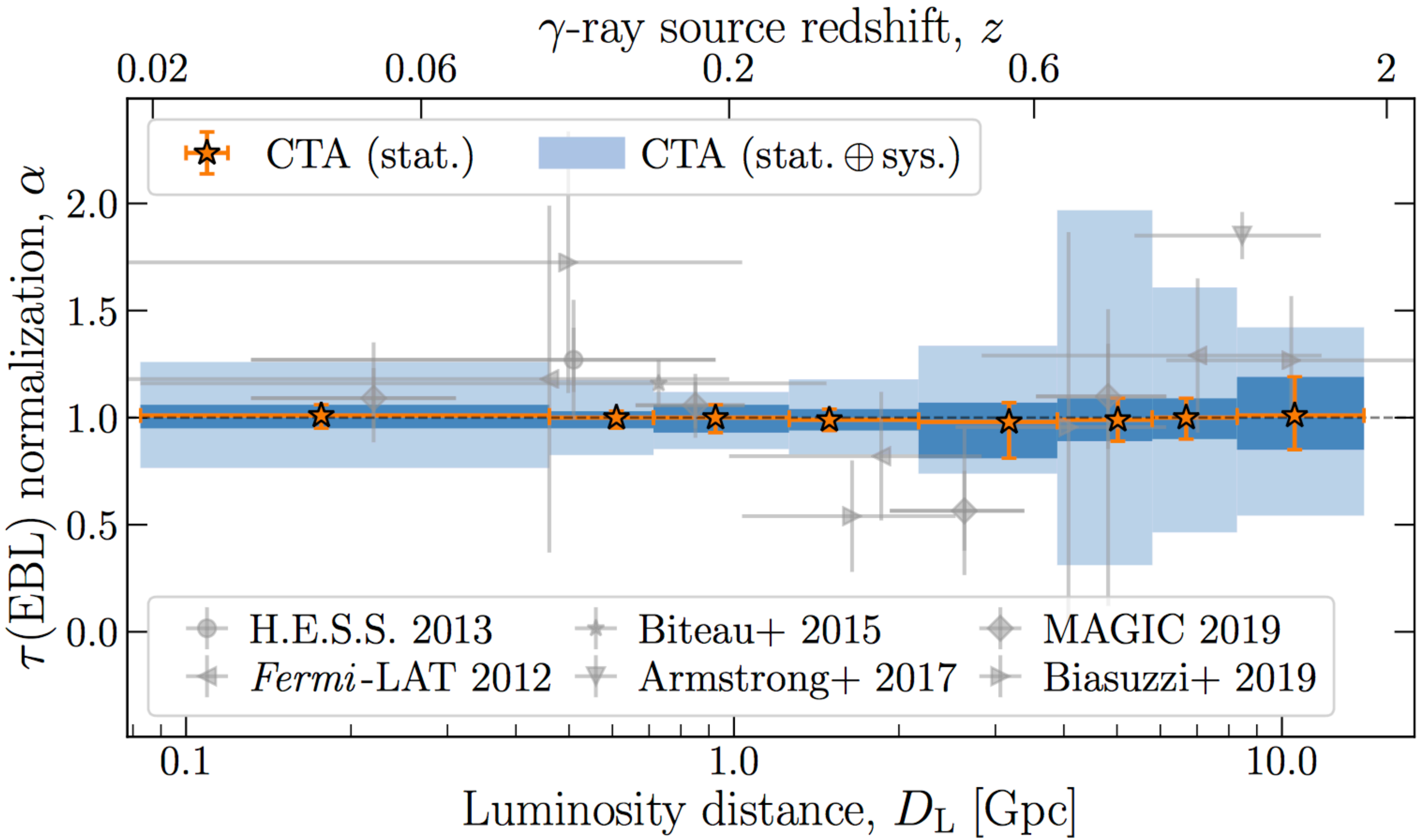


PG 1553+113(z~0.4)

Aleksic et al. 2015

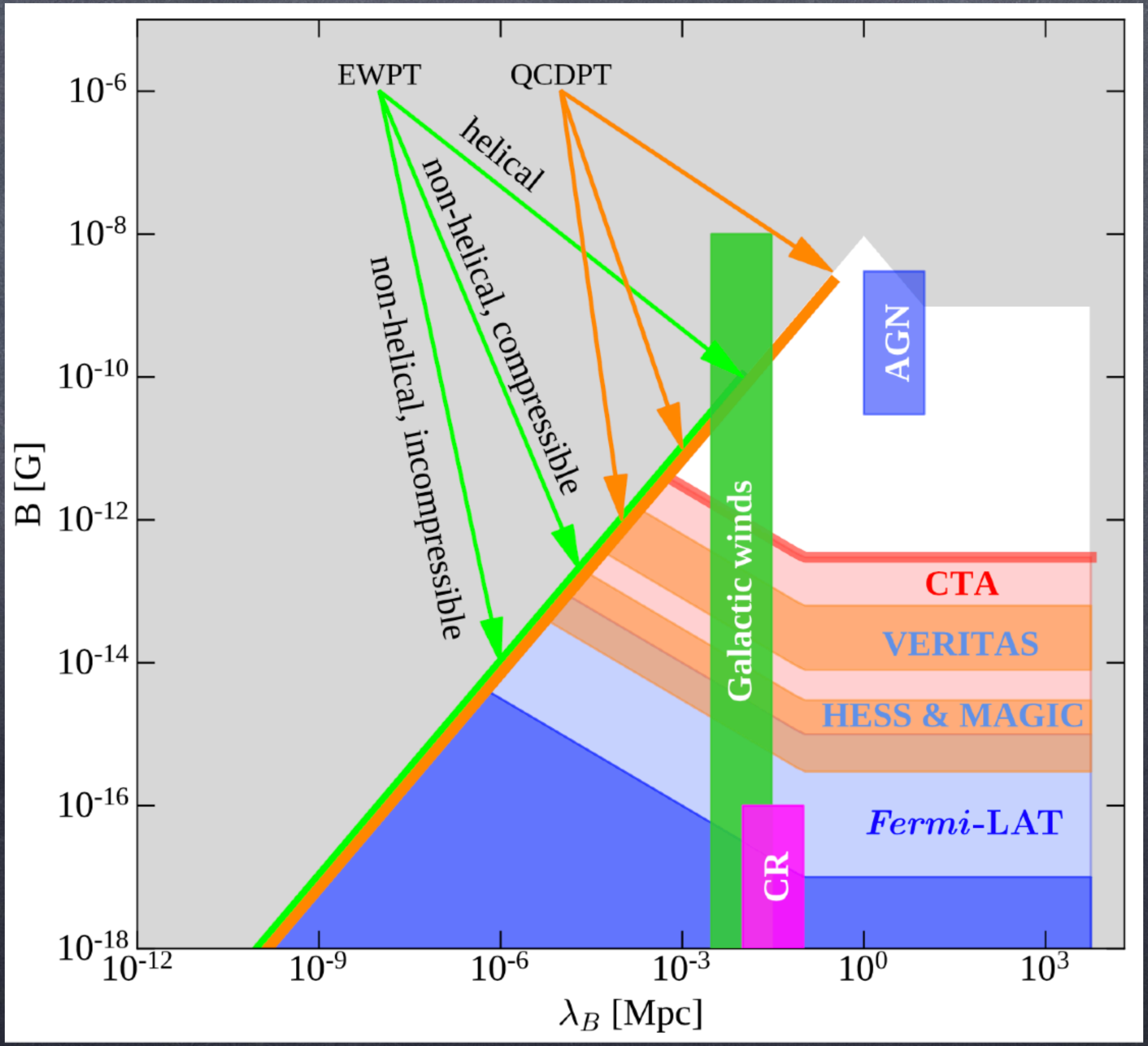
Credits:M. Raue

Nikishov (1962), Jelley (1966), Gould & Schreder (1966)



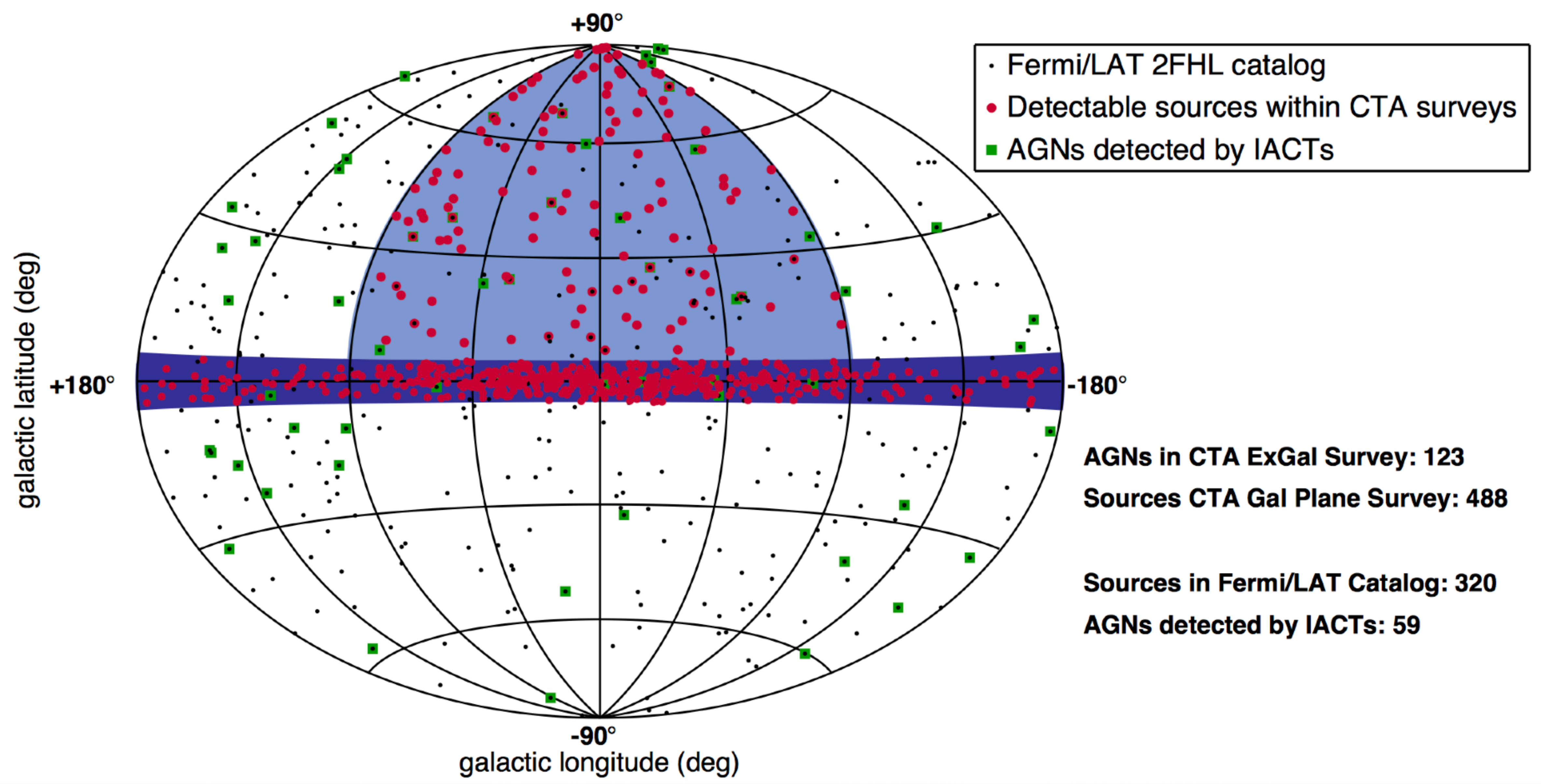
Abdalla et al. 2021, JCAP, id.048

Intergalactic Magnetic Field



Abdalla et al. 2021, JCAP, id.048

EGAL CTA survey



6 mCrab sensitivity

25% of the sky

Science with the Cherenkov Telescope Array; arXiv:1709.07997

Take home message

- The VHE extragalactic astronomy is nowadays strongly bias towards flaring episodes
- CTA will help us to explore the VHE sky not only with an improved sensitivity but also in an extended energy range which should allow to unveil/extend new population currently under represented
- MWL/Multi-messenger coordination is key to understand the physical processes behind