Flat spectrum radio quasars at very high energy gamma-rays: the new detection of PKS 1441+25

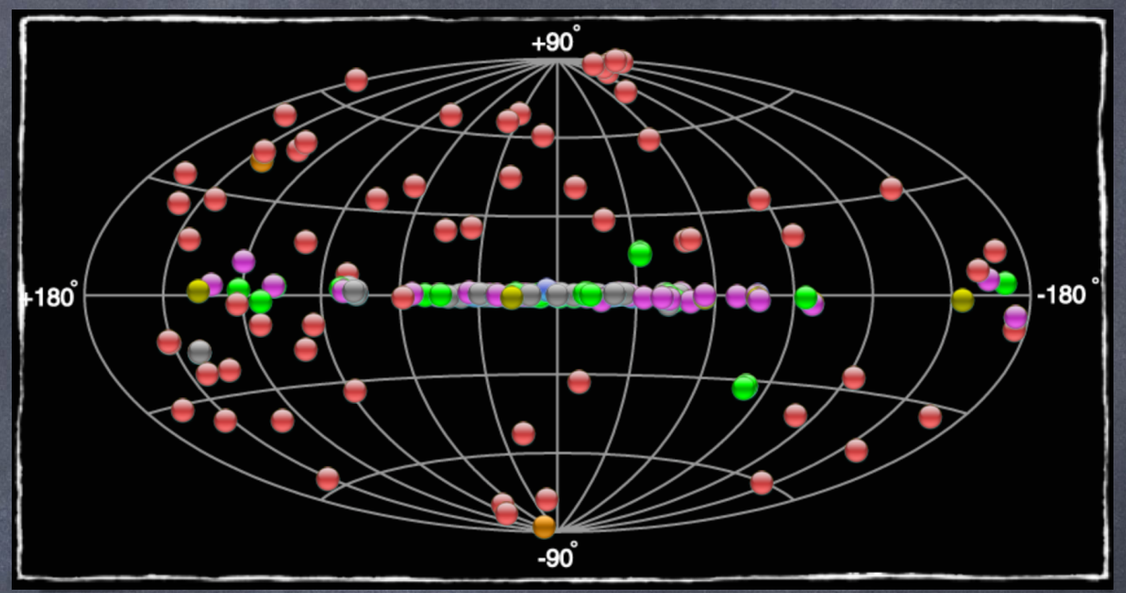
Josefa Becerra González
on behalf of MAGIC and Fermi-LAT collaborations
NASA Goddard Space Flight Center
University of Maryland
Instituto de Astrofísica de Canarias
josefa.becerra@nasa.gov

co-Is: M. Nievas, M. Manganaro, F. Tavecchio, E. Linfors, A. Moralejo, L. Pacciani

MWL Collaborators: G. De Caneva, A. Dominguez, V. Fallah Ramazani, T. Hovatta, S. Jorstad, A. Lähteenmäki, A. Marscher, J. McEnery, R. Ojha, K. Satalecka, J. Sitarek, D. Thompson, M. Tornikoski +

The very high energy gamma-ray sky

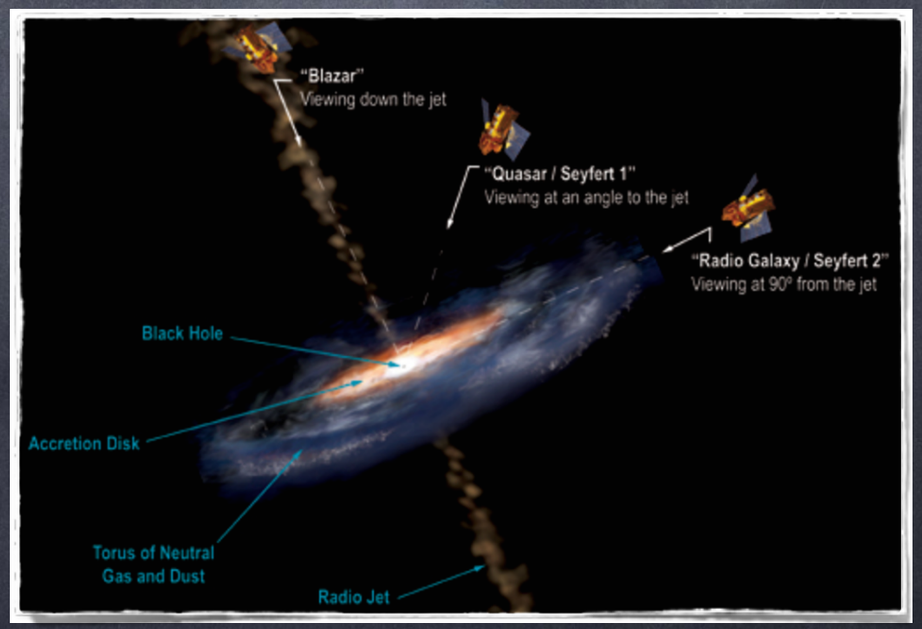
- To date ~60 extragalactic sources (mainly blazars) are known at very high energy gamma-rays (VHE, E>100 GeV) band
- Only 5 of them are flat spectrum radio quasars (FSRQs)
- They are the most distant VHE sources
  —> allow us to constrain the extragalactic background light (EBL) absorption



TeVcat

Source	*Redshift*	*Discoverer*	*Year*
3C 279	0.5362	MAGIC	2006
PKS 1510-089	0.361	HESS	2009
PKS 1222+216	0.432	MAGIC	2010
S3 0218+35	**0.944**	MAGIC	**2014**
S4 0954+65*	0.368	MAGIC	**2015**
PKS 1441+25	**0.939**	MAGIC	**2015**

* classification under debate



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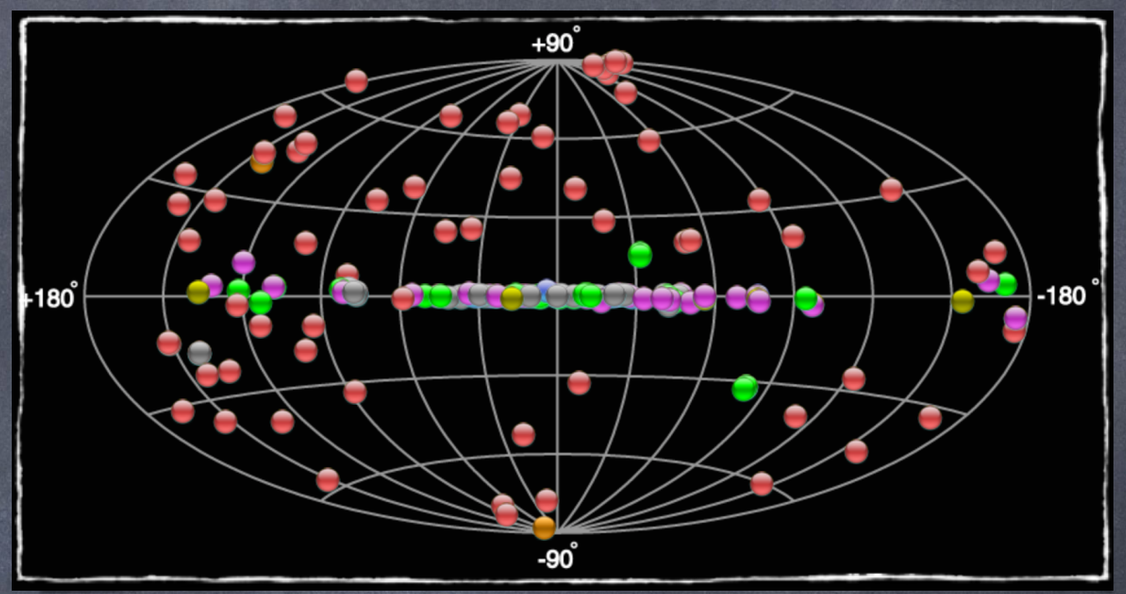

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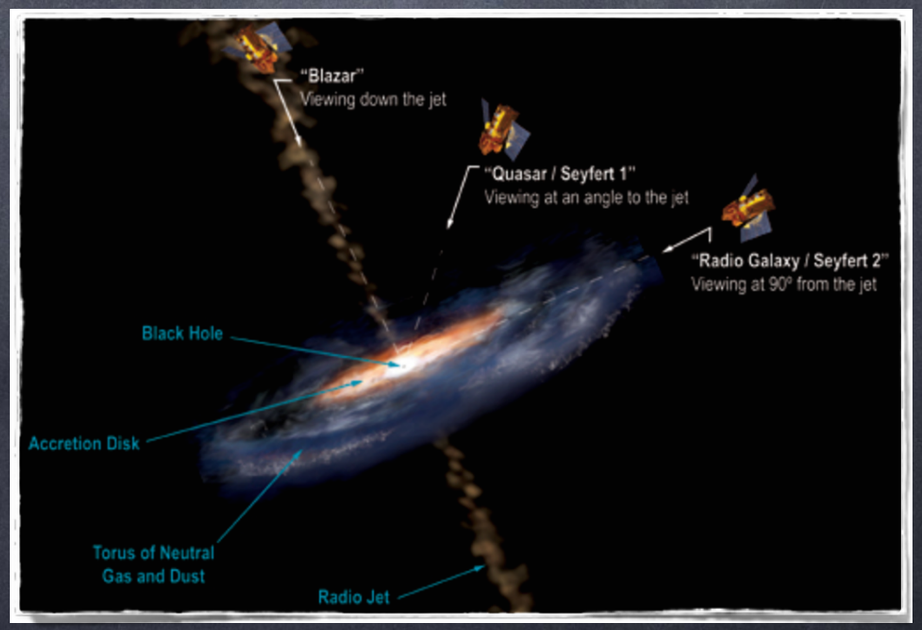

http://www.nasa.gov/feature/goddard/nasas-fermi-satellite-kicks-off-a-blazar-detecting-bonanza

Ahnen et al. 2015, 815, L23 TODAY!!

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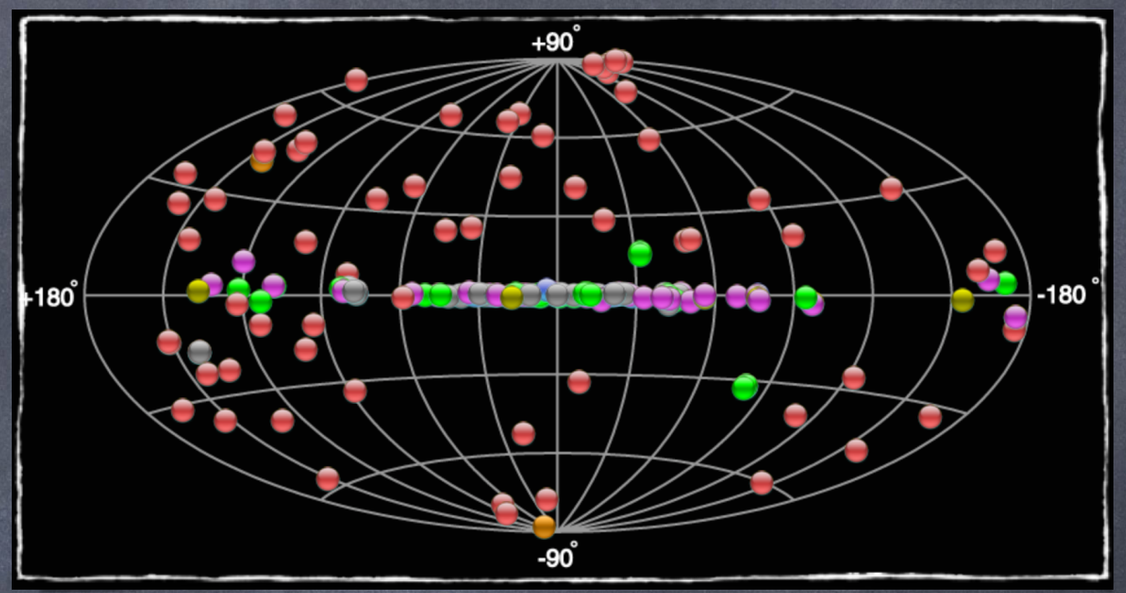

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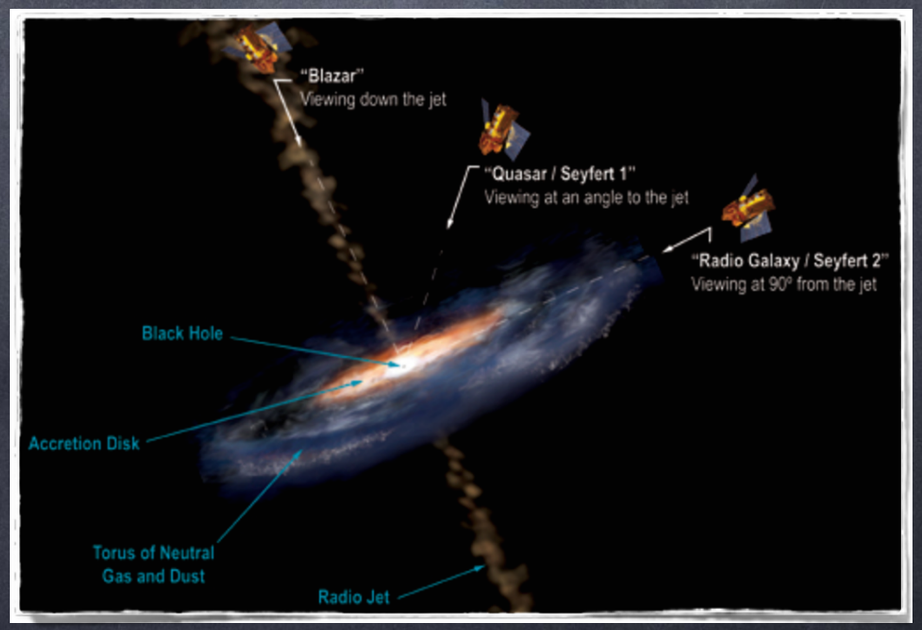

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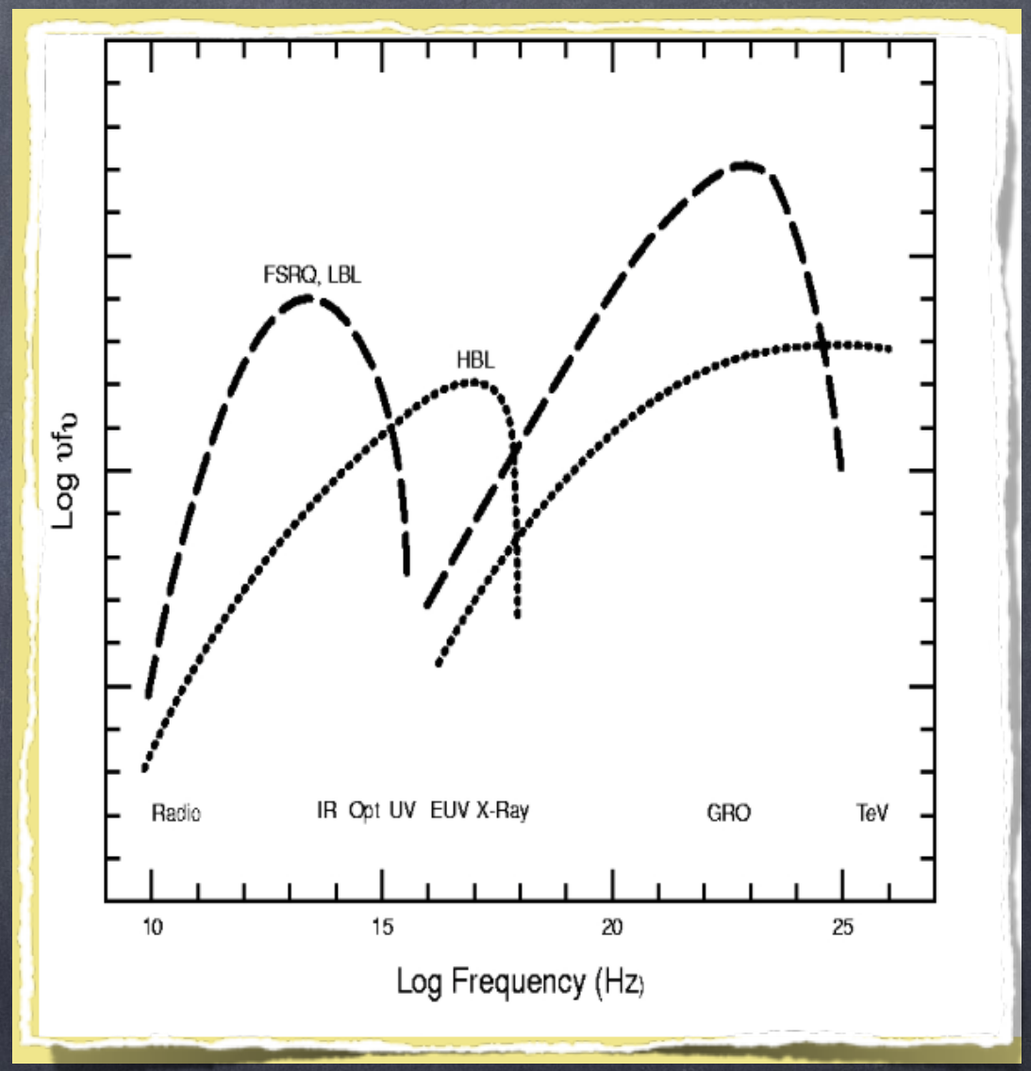
FSRQs at VHE

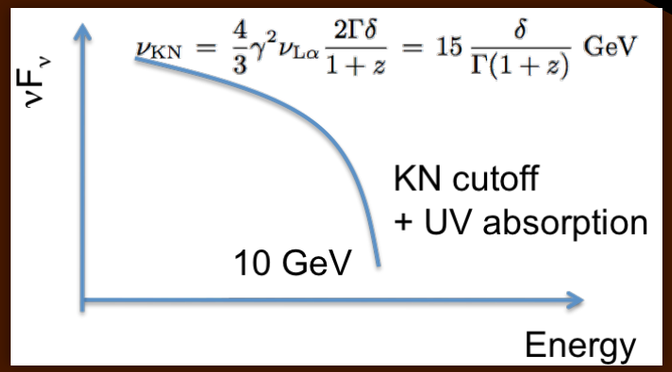
- Why only 5 FSRQs detected in VHE?
  - Low synchrotron peak frequency
  - Intrinsic absorption
  - High redshift (typically)
- They can be mostly detected during flaring/spectral hardening states
- VHE help us to constrain the location of the emitting region
- Typically explained in the "far dissipation" external Compton scenario



Sambruna R. M

FSRQs: the "canonical" scenario

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



DUSTY TORUS

BLR

Accretion disk

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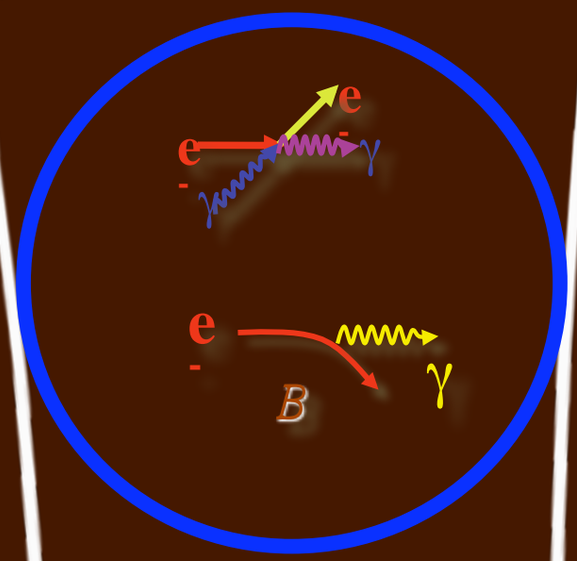

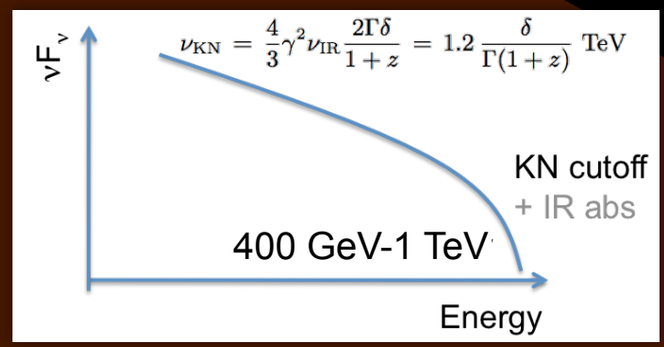

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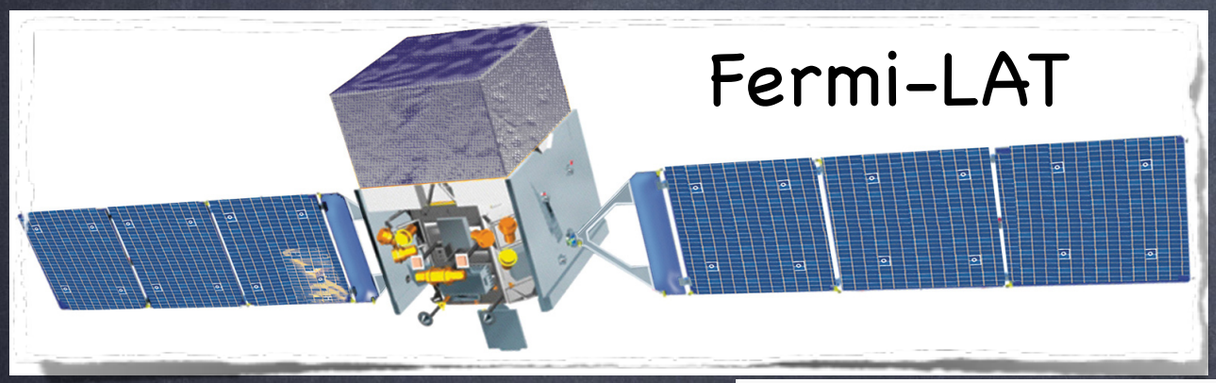
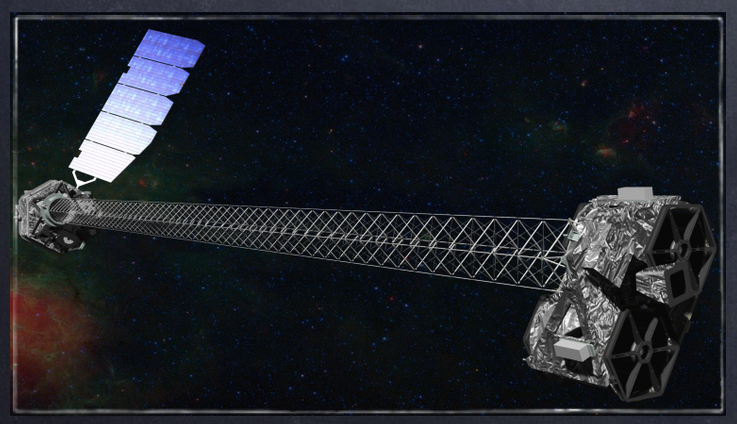
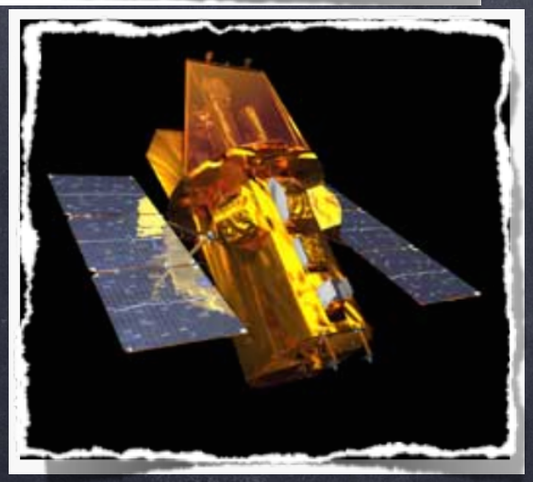
Instruments:

- MAGIC:
  - Air Cherenkov technique
  - Stereoscopic system of two 17 m telescopes
  - Located in Canary Islands
  - Energy Threshold ~50 GeV
- MWL instruments:
  - Fermi-LAT: High energy gamma-rays (E>100 MeV)
  - X-rays: Swift-XRT, NuSTAR
  - Optical-UV: KVA (R-band), Swift-UVOT
  - Radio: Metsähovi
- Fermi+MAGIC: 100 MeV to ~400 GeV (FSRQs) —> probe intrinsic absorption







Discovery of Very High Energy Gamma-Ray Emission from the distant FSRQ PKS 1441+25 with the MAGIC telescopes

ATel #7416; *R. Mirzoyan (Max-Planck-Institute for Physics)*
on 20 Apr 2015; 02:09 UT
Credential Certification: Masahiro Teshima (mteshima@mppmu.mpg.de)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Referred to by ATel #: 7417, 7433, 7459

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the FSRQ PKS 1441+25 (RA=14h43m56.9s DEC=+25d01m44s), located at redshift z=0.939 (Shaw et al. 2012, ApJ, 748, 49). The object was observed with the MAGIC telescopes for ~2 hours during the night 2015 April 17/18, and for ~4 hours during 18/19. A preliminary analysis of the data yields a detection with a statistical significance of more than 6 standard deviations for the night of April 17/18, and more than 11 standard deviations for 18/19. This is the first time a significant signal at VHE gamma rays has been seen from PKS 1441+25. The flux above 80 GeV is estimated to be about 8e-11 cm^-2 s^-1 (16% of Crab Nebula flux). PKS 1441+25 has entered an exceptionally high state at optical, X-, and Gamma-ray frequencies (ATel #7402), which triggered the MAGIC observations. The Swift Follow-up observation from April 18/19 revealed that the high state in X-rays is continuing: http://www.swift.psu.edu/monitoring/source.php?source=PKS1441+25 MAGIC observations on PKS1441+25 will continue during the following nights, and multiwavelength observations are encouraged. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and E. Lindfors (elilin@utu.fi). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Canary island of La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

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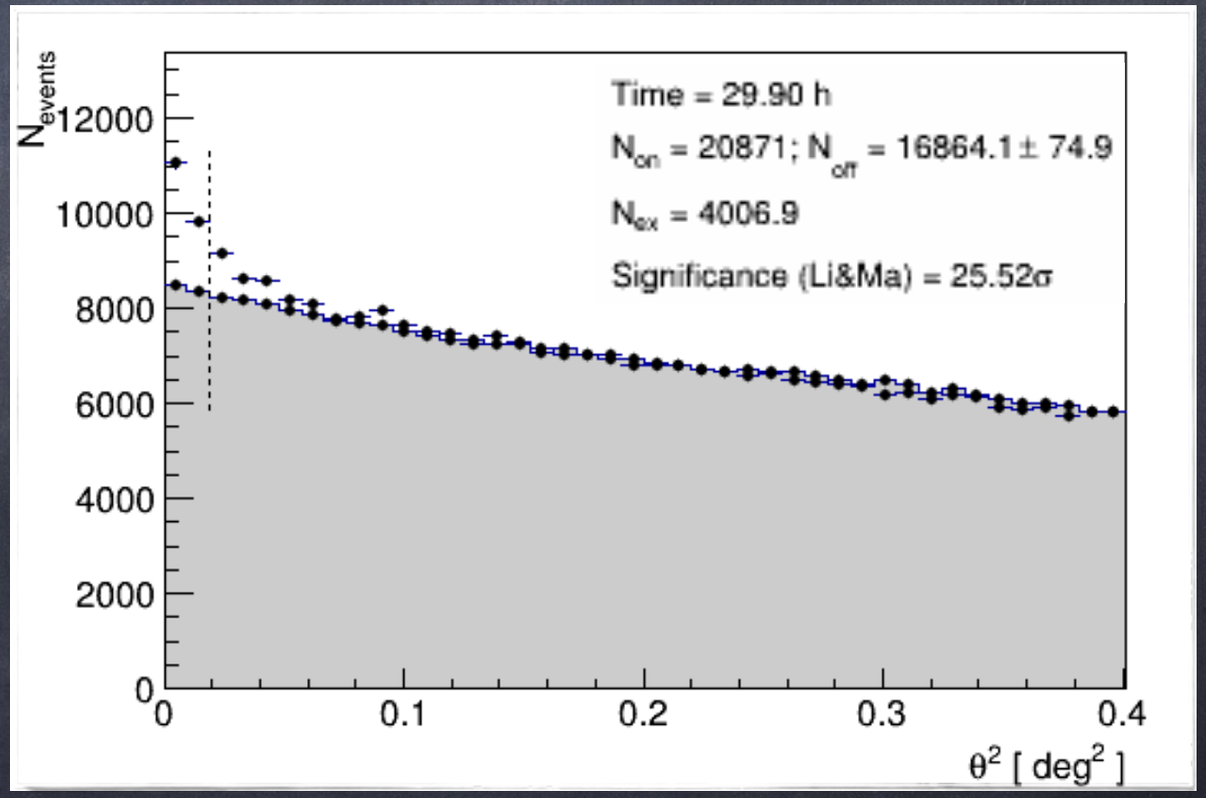
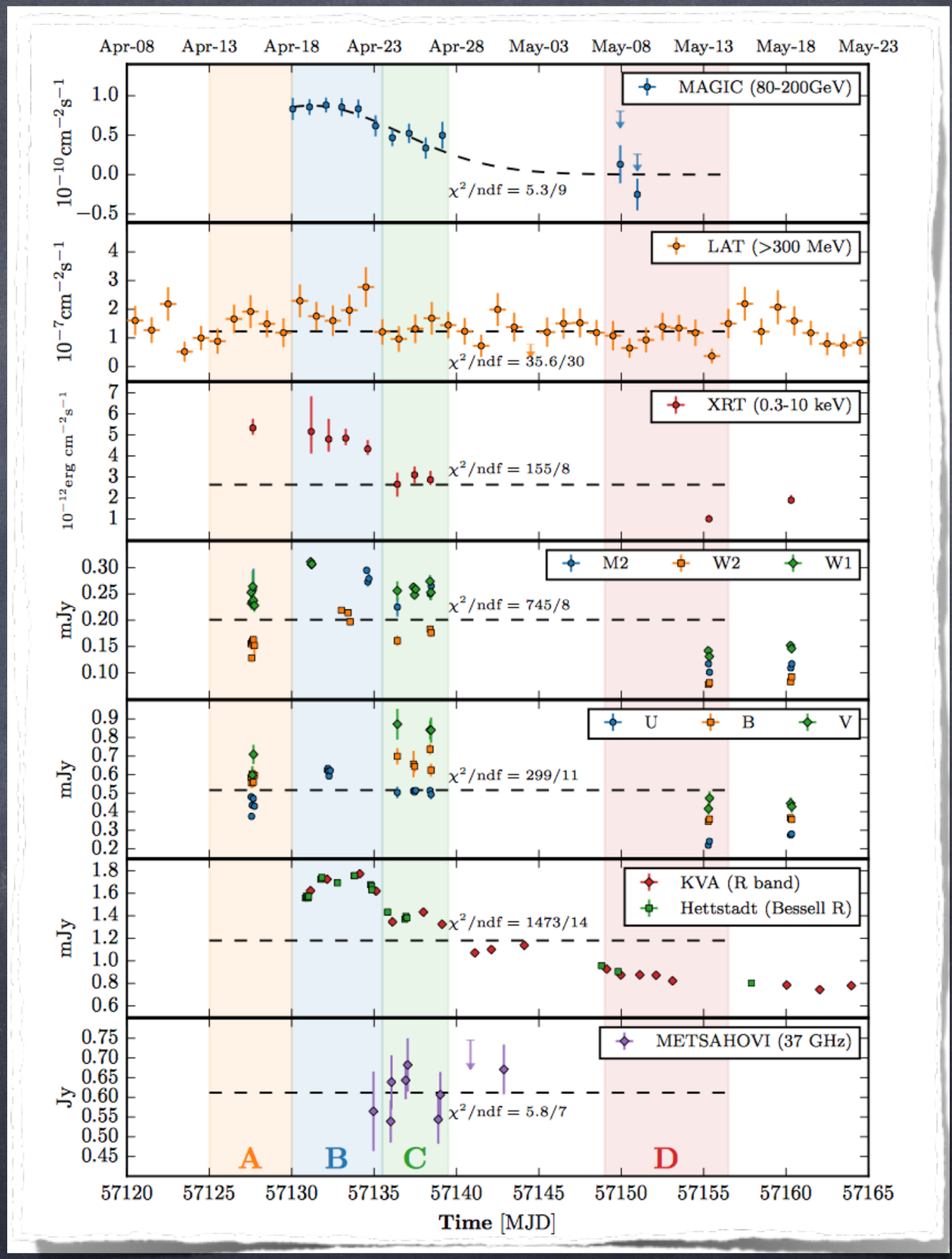
- It is the most distant (together with S3 0218+357) VHE source, located at z=0.94
- Observations started on Apr 17-18 2015 after a high state alert from Fermi-LAT (E>10GeV), optical and X-Rays.
- Detection during 10 days of consecutive observations: 4010 +/- 160 gamma-ray like events



PKS 1441+25

- Two flux states can be distinguished during the flare
- Halving time scale ~6 days
- No signal was detected in May (after Moon break)

Ahnen et al. 2015, 815, L23



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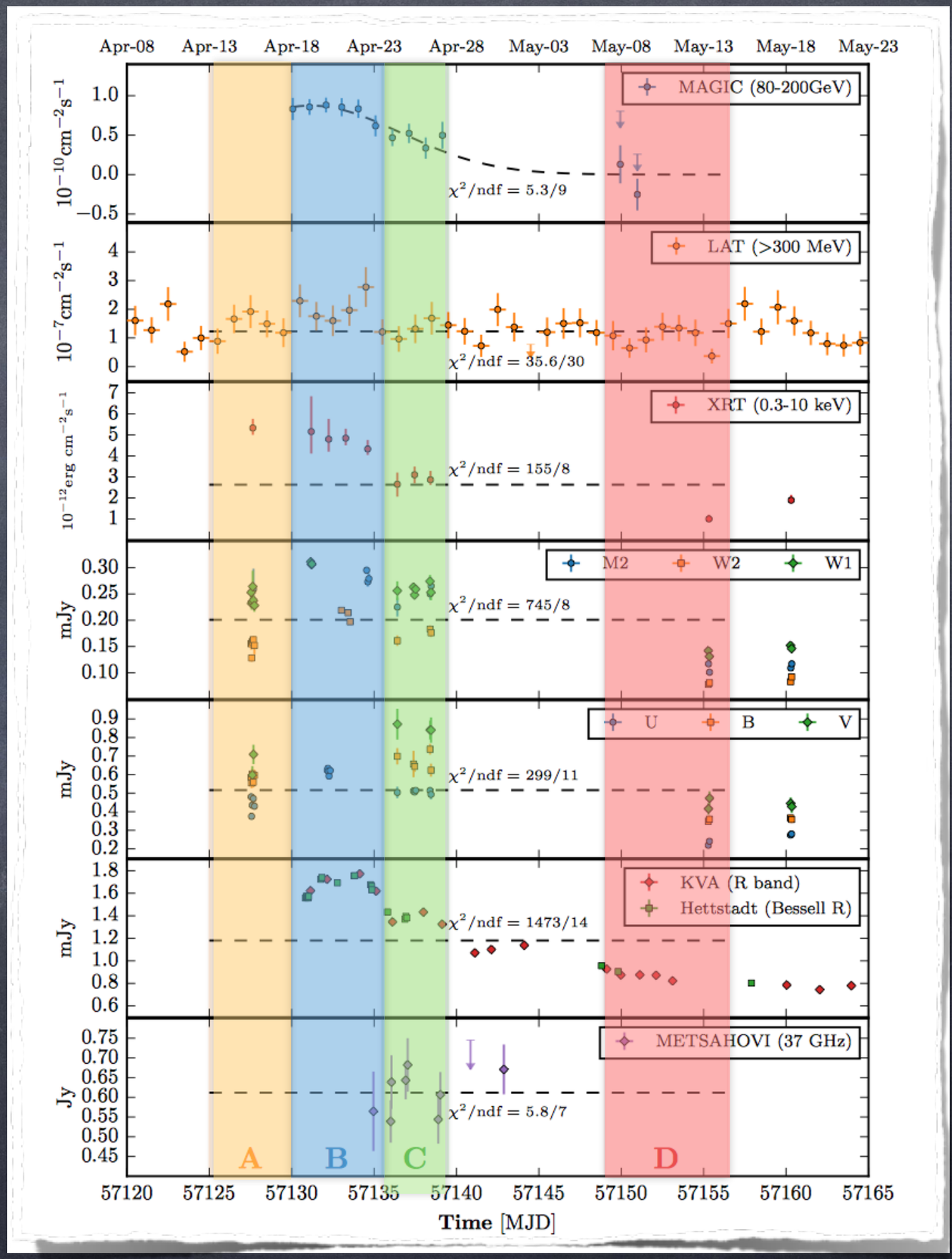

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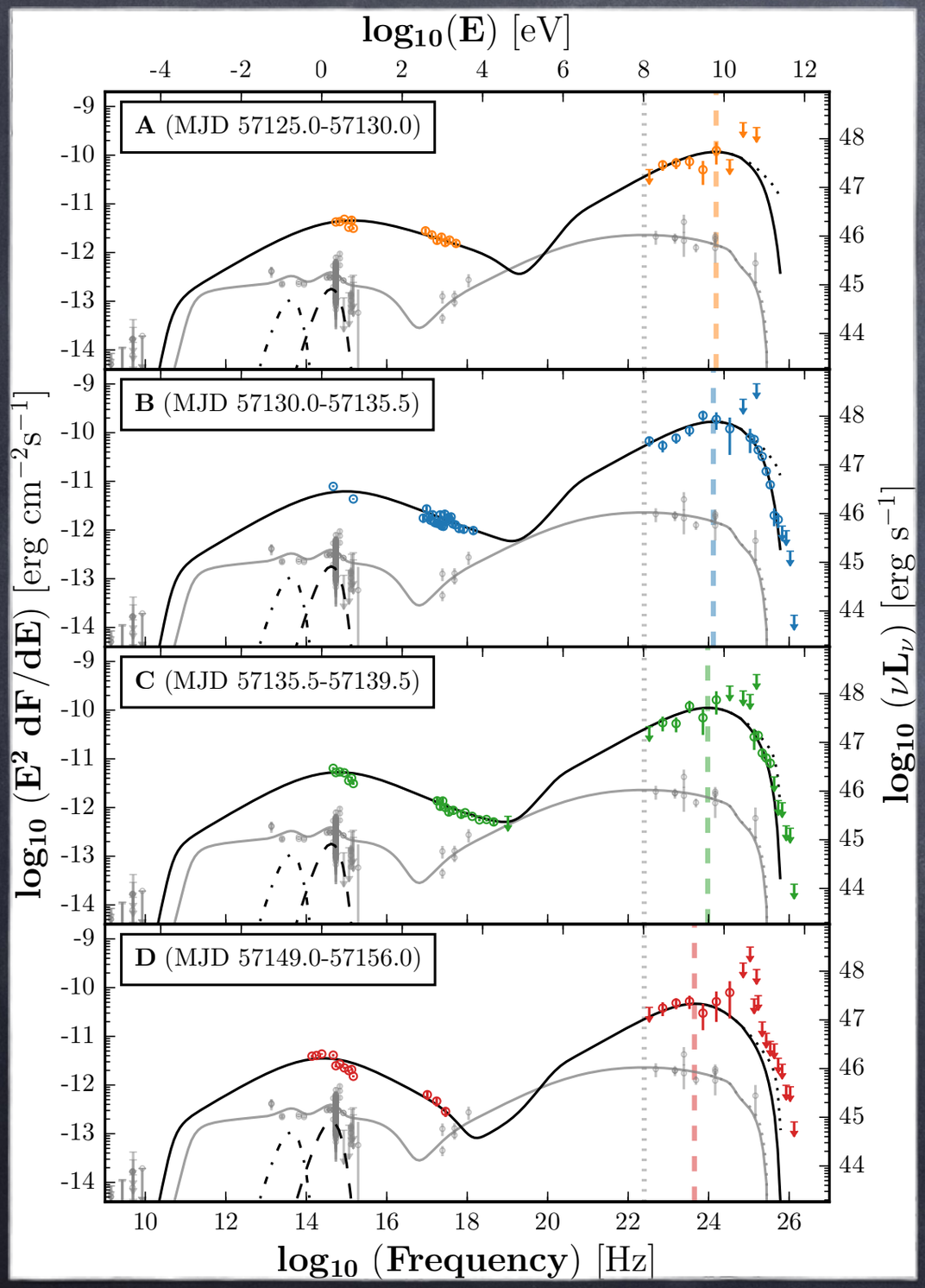
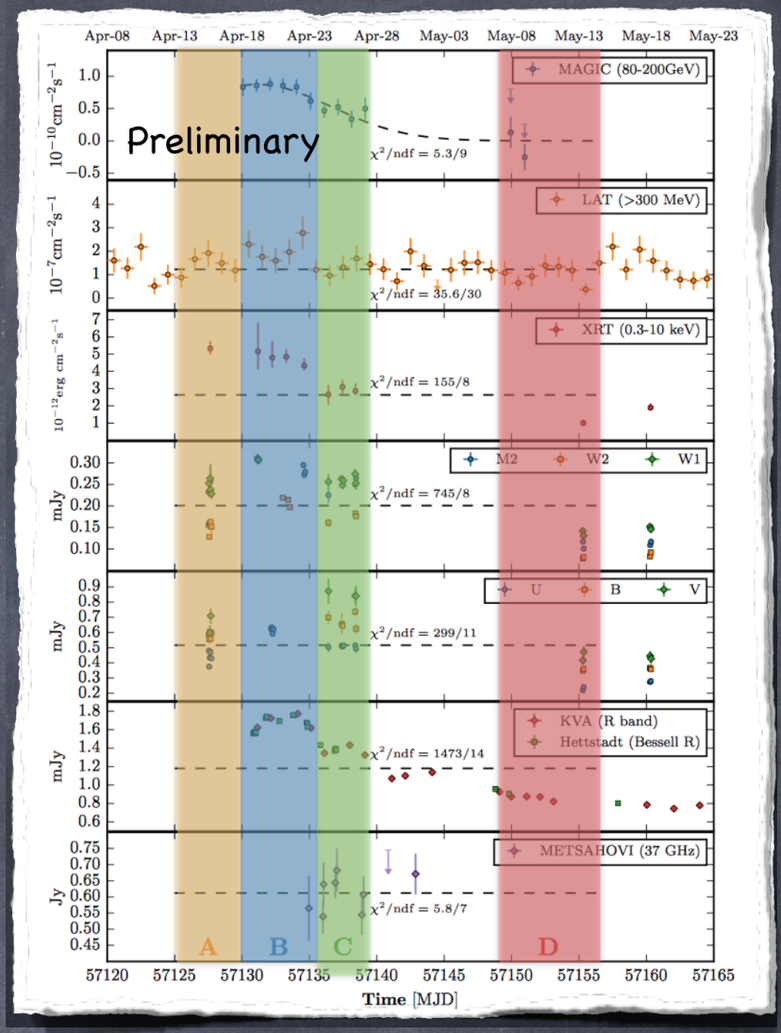


"Far dissipation" external Compton scenario



Period	γ_{min}	$\gamma_b(10^4)$	$\gamma_{max}(10^6)$	n_2	B (G)	K (10^3 cm^{-3})	$\nu_{IC}[Hz]$	CD
A	80	1.0	1.0	3.55	0.15	2.80	24.2	24
B	80	1.0	1.0	3.70	0.15	4.00	24.1	25
C	50	0.8	1.0	3.75	0.17	3.35	24.0	21
D	50	0.5	0.2	3.90	0.23	2.00	23.6	13
Archival	20	10^{-2}	3×10^{-2}	3.05	0.35	70	22.4	7

Doppler factor =15

Ahnen et al. 2015, 815, L23

See video at:

https://youtu.be/AJh7fq7tYfg

Credits: NASA

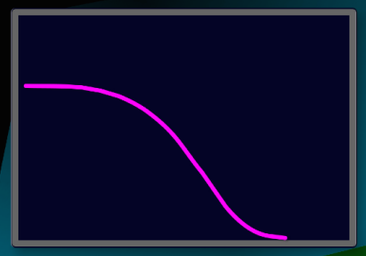
Cosmic Microwave Background forms
Universe is 380,000 years old

First stars form
400 million years

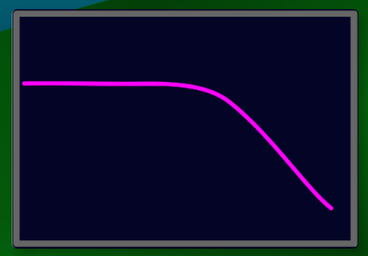
Peak of star formation
3 billion years

Blazar

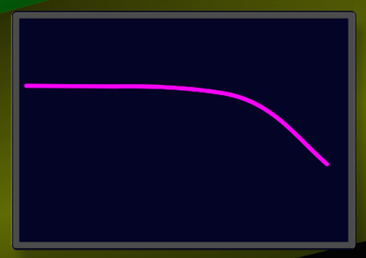
Gamma-ray attenuation



4.1 to 8.6 billion years



8.6 to 11.2 billion years



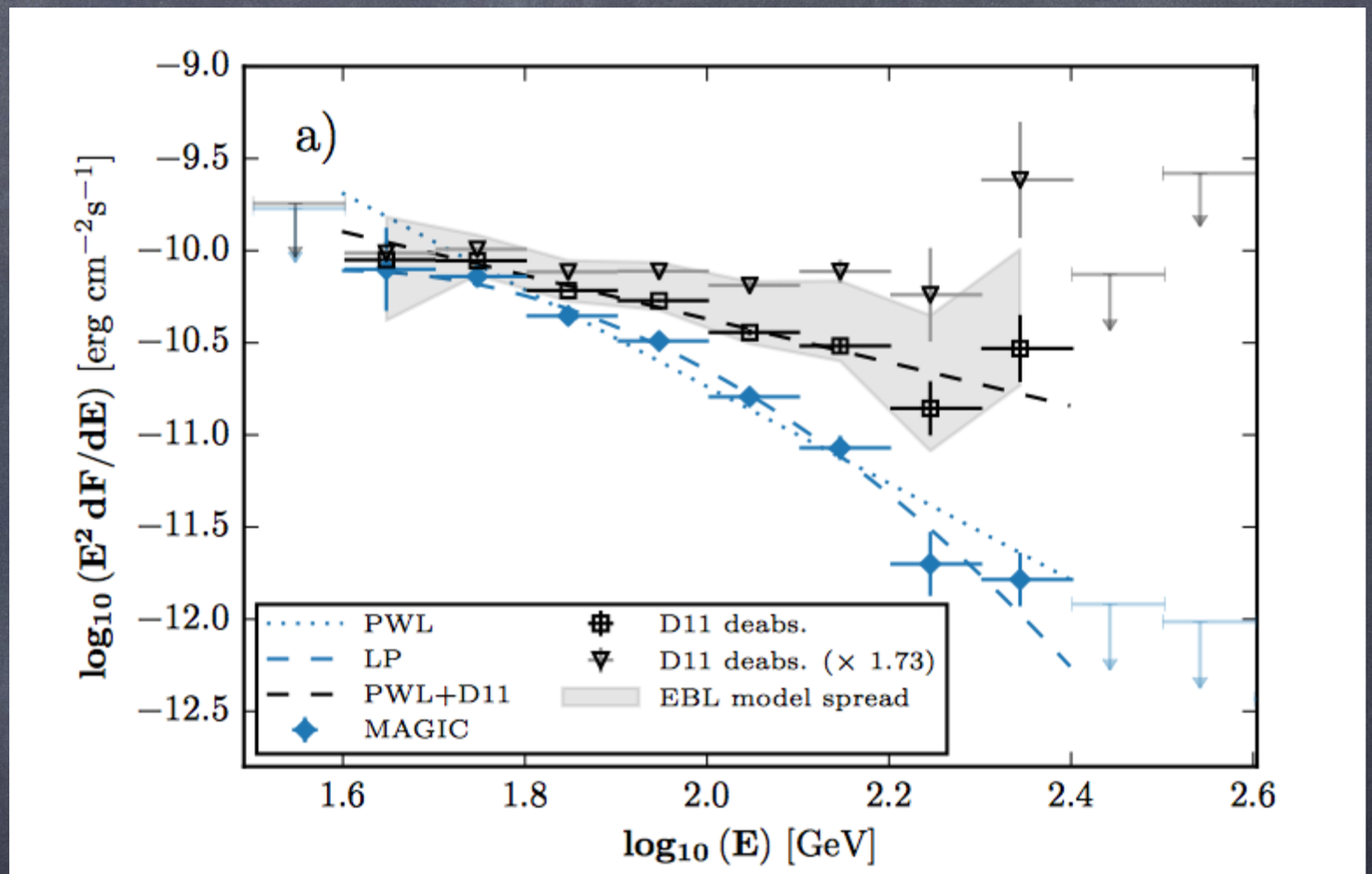
11.2 to 13.7 billion years

Now: 13.8 billion years

Credits: NASA

Probing the EBL models with PKS 1441+25

- Spectrum measured in the energy range 40 to 250 GeV
- For the first time extragalactic background light (EBL) models are tested at z=0.94 in the VHE regime.
- VHE spectrum compatible with current generation of EBL models: Dominguez +11, Franceschini+08, Gilmore+12, Scully+14

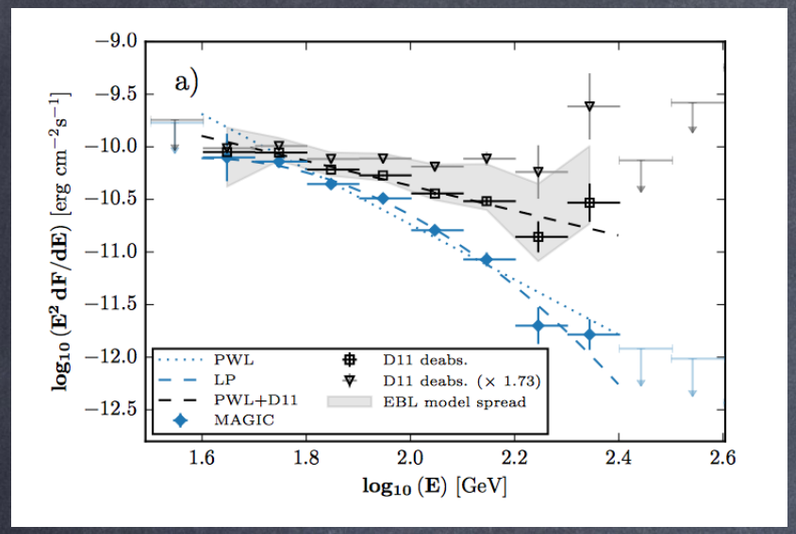


Observed: LRT LogP vs power-law=4.2 sigma

EBL corrected: Compatible power-law

Γ=3.18 ± 0.15stat ± 0.18sys

Probing the EBL models with PKS 1441+25



- Likelihood Ratio Test (e.g. Ackermann et al. 2012, Abramowski et. 2013)
- Different intrinsic spectral shape tested: power-law, logparabola and power-law with cut off.
- Different EBL models
- Maximum optical depth scaling factor ($\alpha\tau$) from models assuming a power-law as intrinsic spectrum: $\alpha \leq 1.7$
- Maximum scaling factor from EBL measurements (Scully et al 2014): $\alpha \leq 3.4$
- Compatible with previous measurements from Fermi: $\alpha = 1.3 \pm 0.4$ ($0.5 < z < 1.6$)

UPPER LIMITS AT 95 % CONFIDENCE LEVEL ON THE RELATIVE EBL OPACITY α

EBL model	Shape	$\alpha_{\rm best}^{\rm nominal}$	$\alpha_{\rm w/syst}^{\rm UL}$	Param. (best fit) p_0	p_1	p_2	p_3	P − value
PWL	No EBL	-	-	**−11.9**	−4.6			< 0.01
PWL	F08	$1.09^{+0.36}_{-0.31}$	1.72	**−11.6**	−3.1			0.50
PWL	D11	$1.09^{+0.37}_{-0.32}$	1.73	**−11.5**	−3.1			0.47
PWL	G12	$0.99^{+0.33}_{-0.28}$	1.55	**−11.4**	−2.7			0.51
PWL	S14 (max)	$1.09^{+0.37}_{-0.32}$	1.73	**−11.5**	−3.1			0.47
PWL	S14 (min)	$2.20^{+0.70}_{-0.61}$	3.41	**−11.4**	−2.7			0.54
LP	No EBL	-	-	**−11.9**	−4.7	3.2		0.39
LP	F08	$0.35^{+1.06}_{-1.58}$	1.69	**−11.8**	−4.2	2.2		0.40
LP	D11	$0.18^{+1.20}_{-1.42}$	1.68	**−11.8**	−4.4	2.7		0.39
LP	G12	$0.37^{+0.92}_{-1.63}$	1.53	**−11.7**	−3.9	2.0		0.40
LP	S14 (max)	$0.18^{+1.20}_{-1.42}$	1.68	**−11.8**	−4.4	2.7		0.39
LP	S14 (min)	$1.64^{+1.25}_{-3.56}$	3.40	**−11.5**	−3.2	0.83		0.42
PWLsc	No EBL	-	-	**−6.2**	1.4	−0.41	0.48	0.27
PWLsc	F08	$0.22^{+1.20}_{-3.21}$	1.70	**−7.4**	0.46	−0.13	0.47	0.27
PWLsc	D11	$0.15^{+1.23}_{-3.14}$	1.68	**−2.7**	2.7	−1.9	0.34	0.27
PWLsc	G12	$0.37^{+0.92}_{-3.36}$	1.54	**−1.4**	2.6	−3.0	0.27	0.27
PWLsc	S14 (max)	$0.15^{+1.23}_{-3.14}$	1.68	**−2.7**	2.7	−1.9	0.34	0.27
PWLsc	S14 (min)	$1.75^{+1.15}_{-4.74}$	3.40	**−2.4**	0.39	−5.8	0.17	0.29

References. — F08: Franceschini et al. (2008), D11: Domínguez et al. (2011), G12: Gilmore et al. (2012), S14: Scully et al. (2014).

NOTE.—**The normalization factor 10^{p_0} is given in erg cm^{-2} s^{-1} units.**

Take home message

- New discovery of PKS 1441+21 at z=0.94 in the VHE band (energy threshold of ~40 GeV!). Compatible with state-of-the-art EBL models
- PKS 1441+25 shows an extreme shift of the SED peaks
- Detection of the FSRQs 3C 279, PKS 1222+21 and PKS 1510-089 during moderate HE gamma-ray activity during 2013-2014 observation campaign
- The only common MWL feature on 3C 279, PKS 1222+21 and PKS 1510-089 during the VHE detection epochs is the ejection of a new VLBA component
- No hints of intrinsic absorption features compatible with the absorption within the broad line region have been found so far in VHE FSRQs —> favor "far dissipation" scenario

Thanks! :)