MAGIC detection of very-high-energy gamma-ray emission from the z = 0.94 blazar PKS 1441+25

Miguel Nievas Rosillo

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L. Pacciani, J. McEnery, A. Domínguez, R. Ojha, D. Thompson,
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On behalf of the MAGIC and Fermi-LAT collaborations
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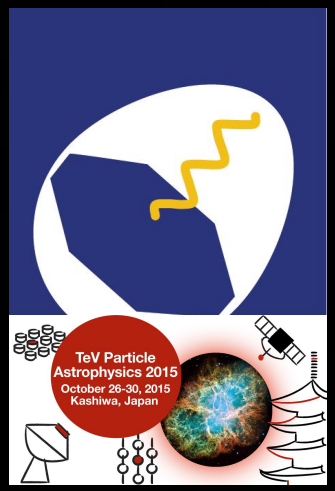
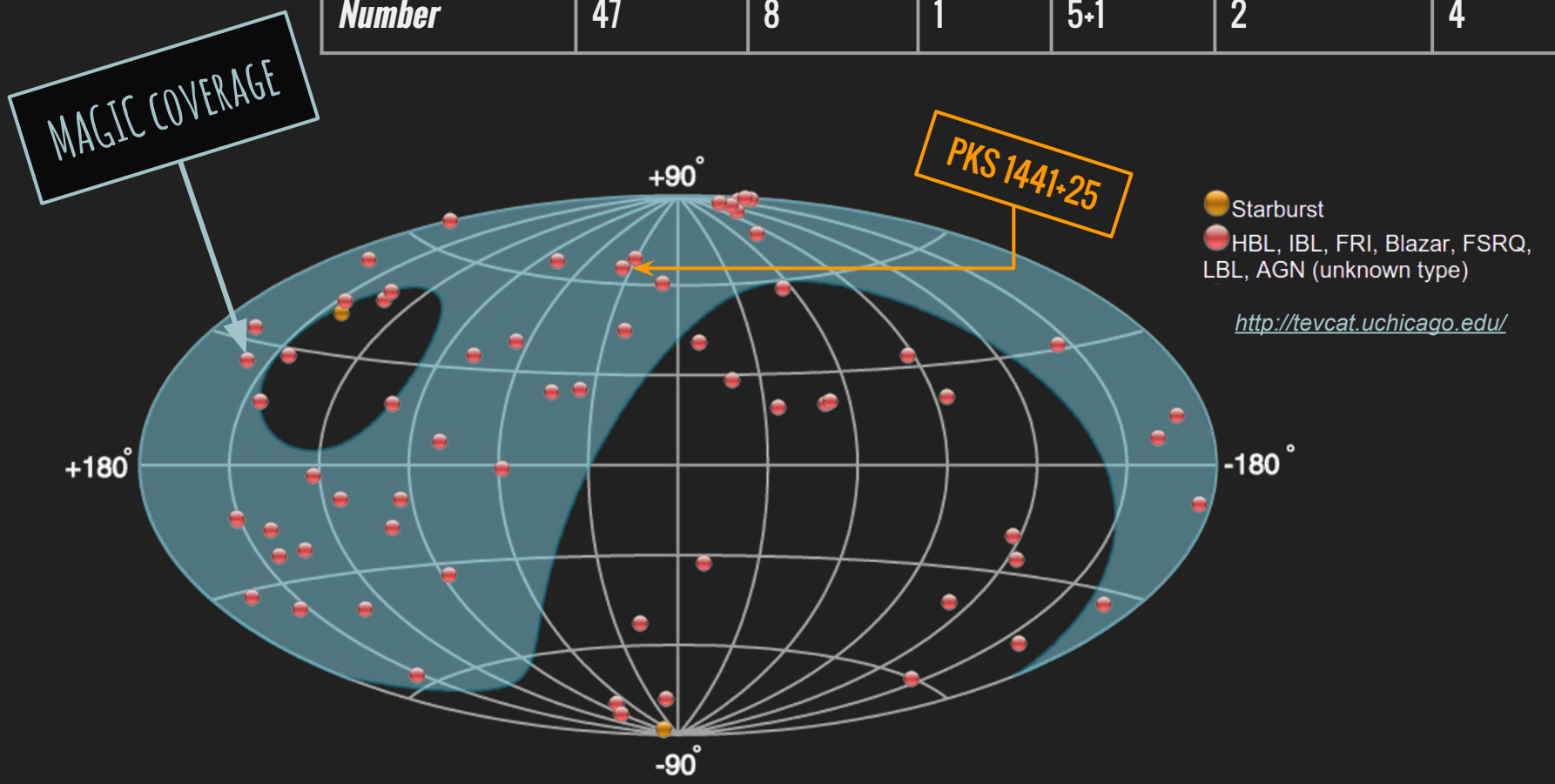


The very high energy gamma-ray sky

2015/10/13	HBL	IBL	LBL	FSRQ	Starburst	FRI
Number	47	8	1	5+1	2	4



- 68 extragalactic sources detected at very high-energy gamma-rays (VHE, E>100 GeV)
- 5+1 FSRQ at high redshifts, 0.36 < z < 0.94

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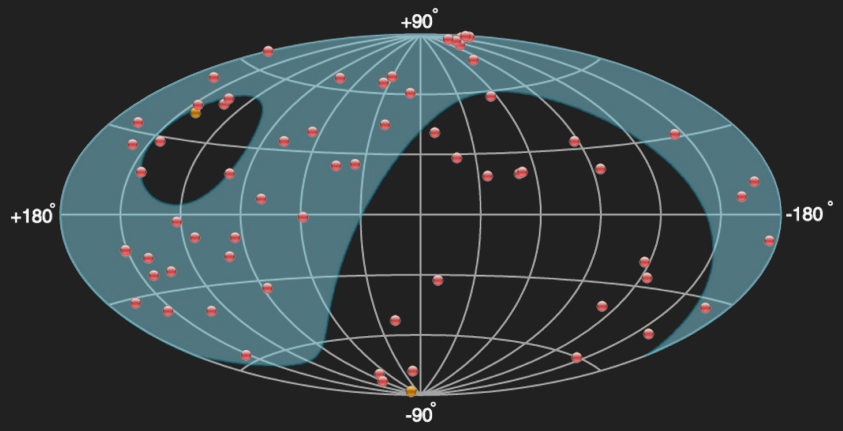


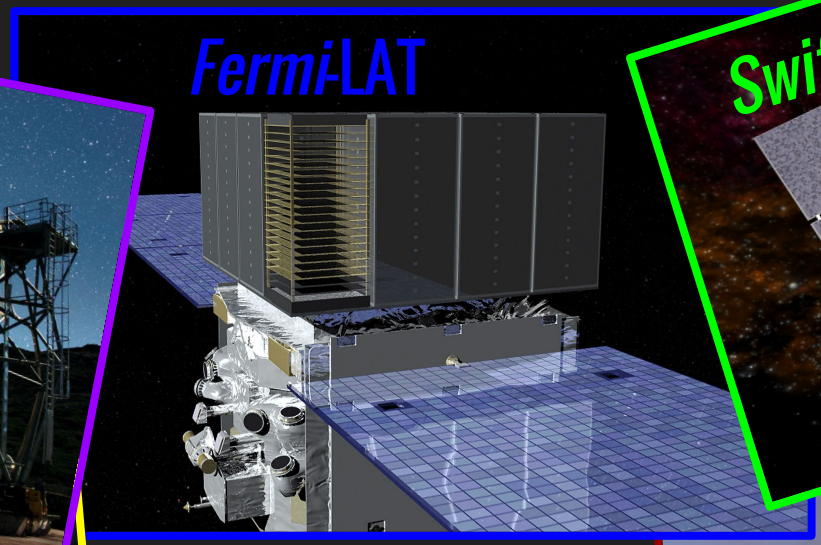
Source	z	Discoverer	Year
3C 279	0.5362	MAGIC	2006
PKS 1510-089	0.361	HESS	2009
PKS 1222+216	0.432	MAGIC	2010
B0218+367	0.944	MAGIC	2014
S4 0954+65	0.368	MAGIC	2015
PKS 1441+25	0.939	MAGIC	2015

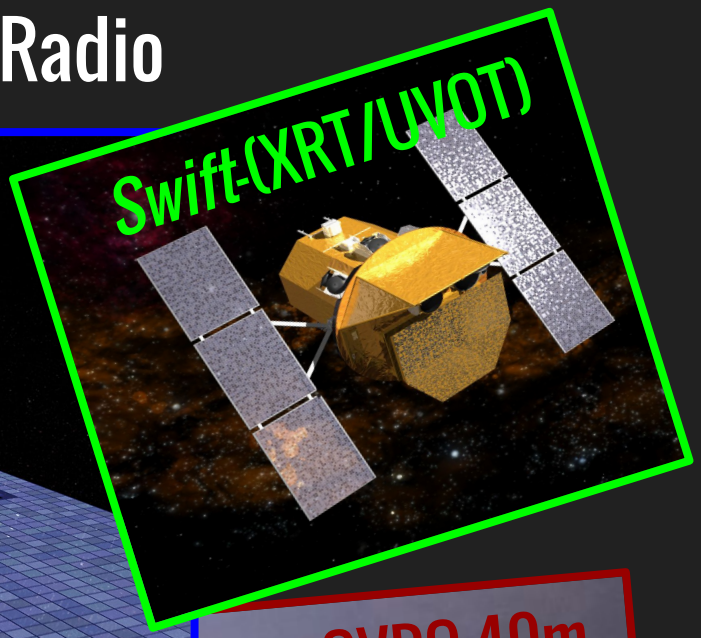
1st grav. lensed blazar in VHE - See D. Domini's talk.

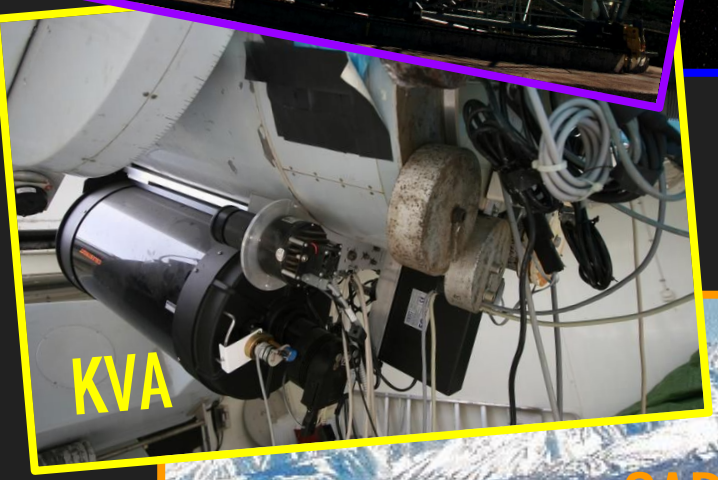
Classification under debate.

- 68 extragalactic sources detected at very high-energy gamma-rays (VHE, E>100 GeV)
- 5+1 FSRQ at high redshifts, 0.36 < z < 0.94

PKS 1441+25. From VHE Gamma-rays to Radio







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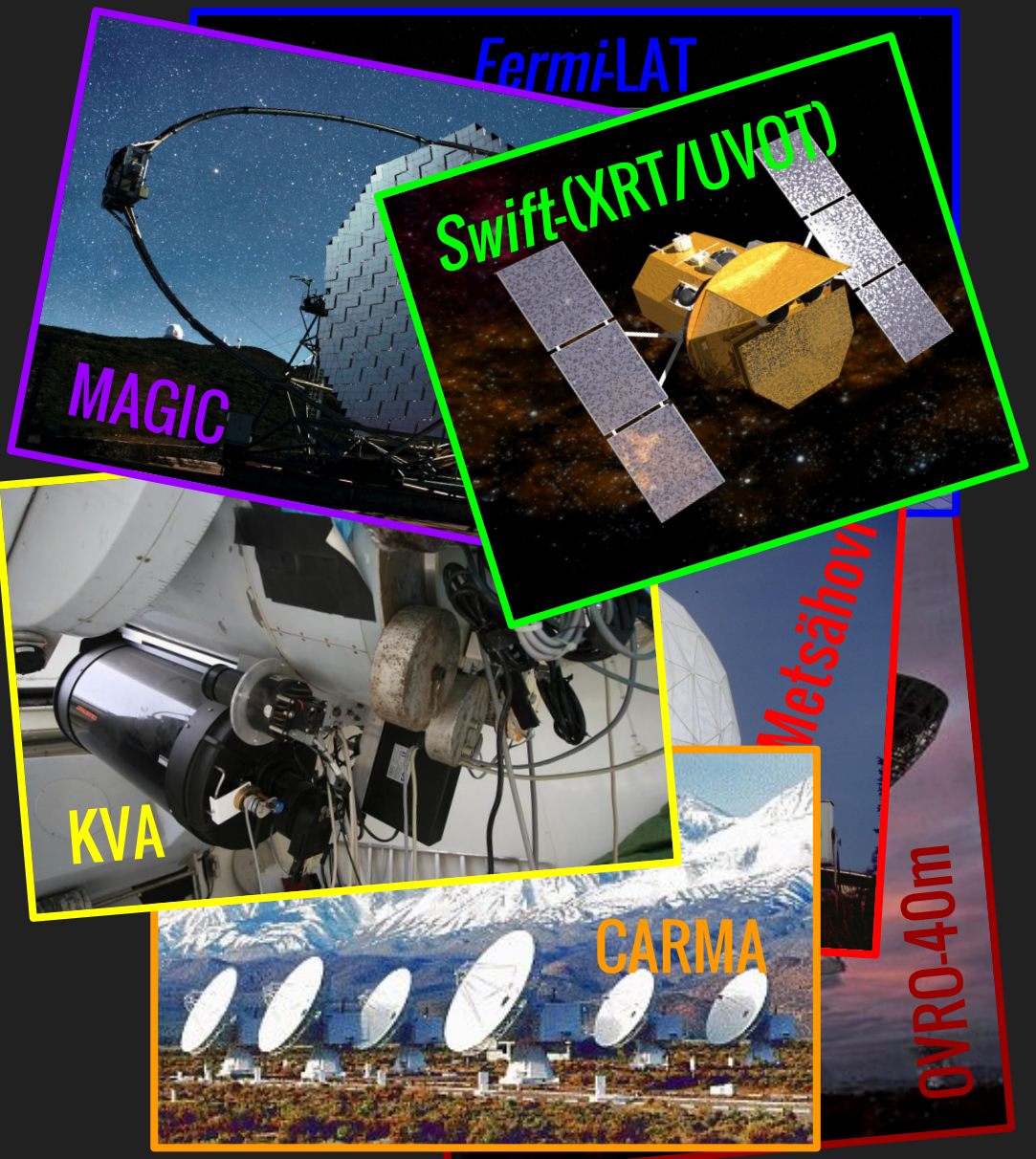


Source details

- **Classification**: FSRQ (Abdo et al. 2010a; Nolan et al. 2012; Ackermann et al. 2013).
- **Redshift**:
  - $z = 0.9397 \pm 0.0003_{stat}$ (SDSS)

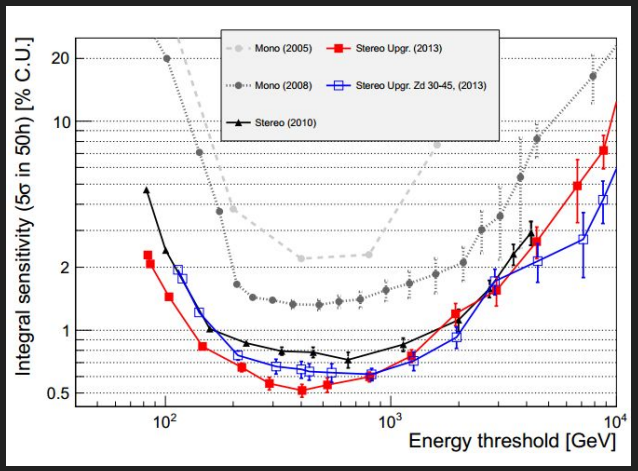
Instruments

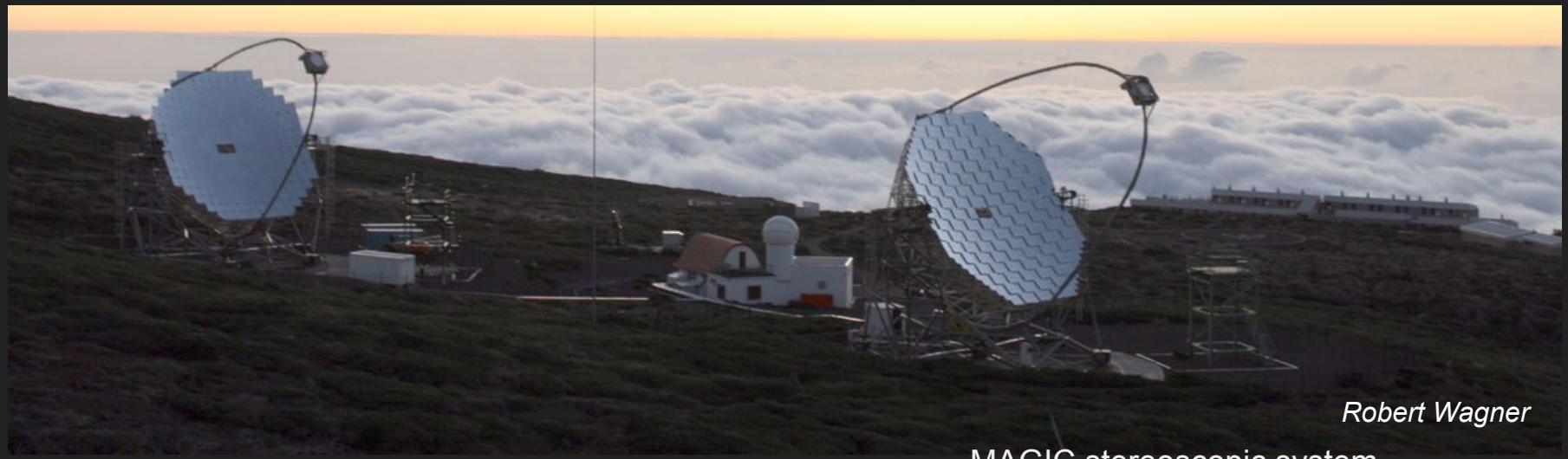
- **MAGIC** (VHE gamma-ray): E> 50 GeV
- ***Fermi*-LAT** (HE gamma-ray) : 0.1<E<300 GeV
- **NuSTAR** (Hard X-ray): 3<E<79 keV
- ***Swift*-XRT** (X-rays)
- ***Swift*-UVOT** (UV/optical)
- **KVA** (optical-R)
- **Hans-Haffner-Telescope** (optical-R)
- **CANICA** (IR: J, H, and K_S bands)
- **CARMA** (Radio. *27-270 GHz*)
- **Metsähovi** (Radio, *2-150 GHz*)
- **OVRO-40m** (Radio, *15 GHz*)

PKS 1441+25. VHE observations with MAGIC

- MAGIC I operating since 2004, MAGIC II since 2009.
- 17m diameter, 1039 PMTs cameras and a 3.5deg FOV.
- Performance after the major upgrade of 2011-2012:
  - ✓ Energy threshold of ~50GeV. Lower in pulsar analysis.
  - ✓ Sensitivity ~ 0.66% Crab units in 50h @ E>220GeV.
  - ✓ Energy resolution of 16% @ E~220GeV.
  - ✓ Angular resolution < 0.07° @ E>220GeV.
- Collaboration of ~ 200 members from 10 countries.

J. Aleksić et al. (2015)





MAGIC stereoscopic system.
Roque de los Muchachos, 2200m a.s.l.
La Palma, Spain

PKS 1441+25. VHE observations with MAGIC

Optical, X-, Gamma-ray flare of the FSRQ PKS 1441+25

ATel #7402; *Luigi Pacciani (INAF-IAPS)*
on 16 Apr 2015; 12:08 UT
Credential Certification: Luigi Pacciani (luigi.pacciani@iaps.inaf.it)

Subjects: Optical, Ultra-Violet, X-ray, Gamma Ray, >GeV, Blazar

Referred to by ATel #: 7416, 7417, 7429, 7433

We detected a gamma-ray flare from the FSRQ PKS 1441+25 (z=0.939), triggering on FERMI-LAT data at E > 10 GeV with TS ~44, from 2015-03-21 to 2015-04-15, following the prescription of Pacciani et al. 2014, ApJ, 790, 45. The gamma-ray flux was (38+/-3)E-8 ph cm^-2 s^-1, photon index 1.93+/-0.07, TS ~ 760 (E>0.1 GeV), to be compared with the catalog flux of 1.3E-8 ph cm^-2 s^-1 reported in the 3rd Fermi-LAT point-source catalog. The FERMI-LAT revealed gamma-ray emission up to 33 GeV. The source has been detected in high gamma-ray state also on January 2015 (ATEL#6878). The Swift Follow-up revealed the source in high state in optical and X-ray. The preliminary Swift-UVOT photometry on 2015-04-15 is:

V = 16.79 +/- 0.06

B = 17.01 +/- 0.03

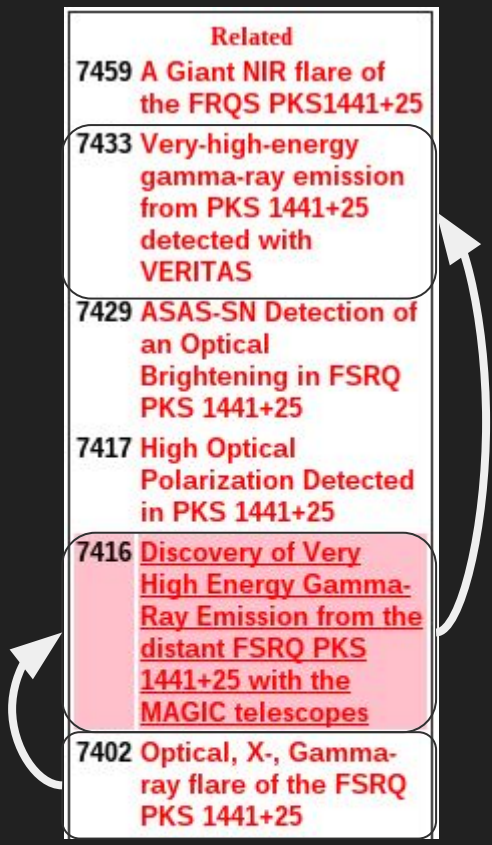
U = 16.21 +/- 0.02

UVW1 = 16.36 +/- 0.03

UVM2 > 18.4

UVW2 = 16.59 +/- 0.03 which is ~4 times brighter then the optical flux on 2015 January 5th and 28th (swift obsid 00040618005, 00040618003, see also ATEL#6895, ATEL#6923). Magnitudes are in the UVOT photometric system (Poole et al. 2008, MNRAS, 383, 627) and have not been corrected for Galactic extinction. We verified the optical photometry using SDSS J144357.93+250051.0 as a reference. The simultaneous Swift-XRT observation gives a counting rate of 0.109+/-0.006 cps (to be compared with 0.045+/-0.004 cps of the brightest state on 28th January 2015, Swift obsid 00040618005) and an unabsorbed flux of (5.3+/-0.5)E-12 erg cm^-2 s^-1 (0.3-10 keV). We encourage further multi-wavelength observations. We thank the Swift team and Swift Observatory Duty Scientist for rapidly scheduling our observations.

- Observations started on Apr 17-18 2015 after a high state alert from *Fermi*-LAT (E>10GeV), optical and X-Rays.



PKS 1441+25. VHE observations with MAGIC

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

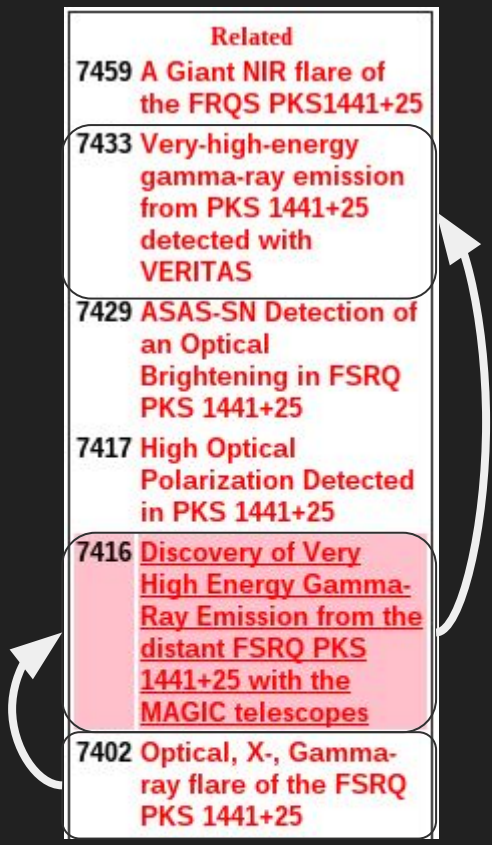
ATel #7416; *R. Mirzoyan (Max-Planck-Institute for Physics)*
on 20 Apr 2015; 02:09 UT
Credential Certification: Masahiro Teshima (mteshima@mppmu.mpg.de)

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.

- Observations started on Apr 17-18 2015 after a high state alert from *Fermi*-LAT (E>10GeV), optical and X-Rays.
- MAGIC detected the source with 6σ on Apr 17-18 (2h) and on Apr 18-19 (4h) again, with more than 11σ.



- VERITAS observations were triggered by MAGIC results. VHE signal was confirmed with >5σ during the night of April 21, 2015

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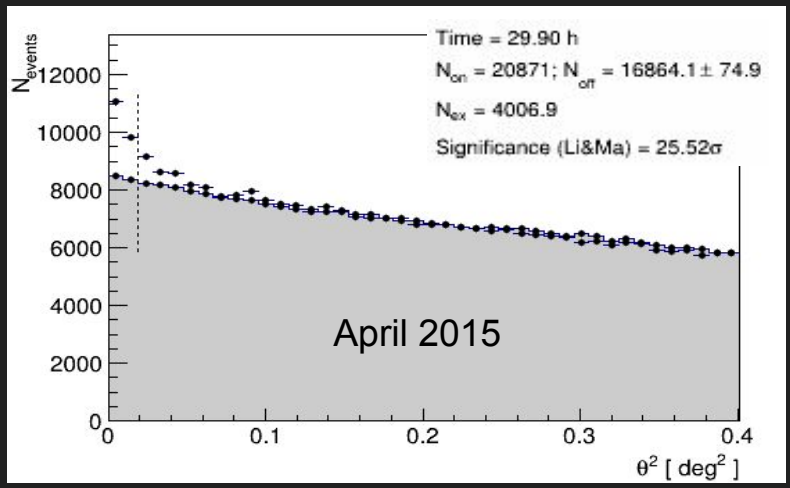
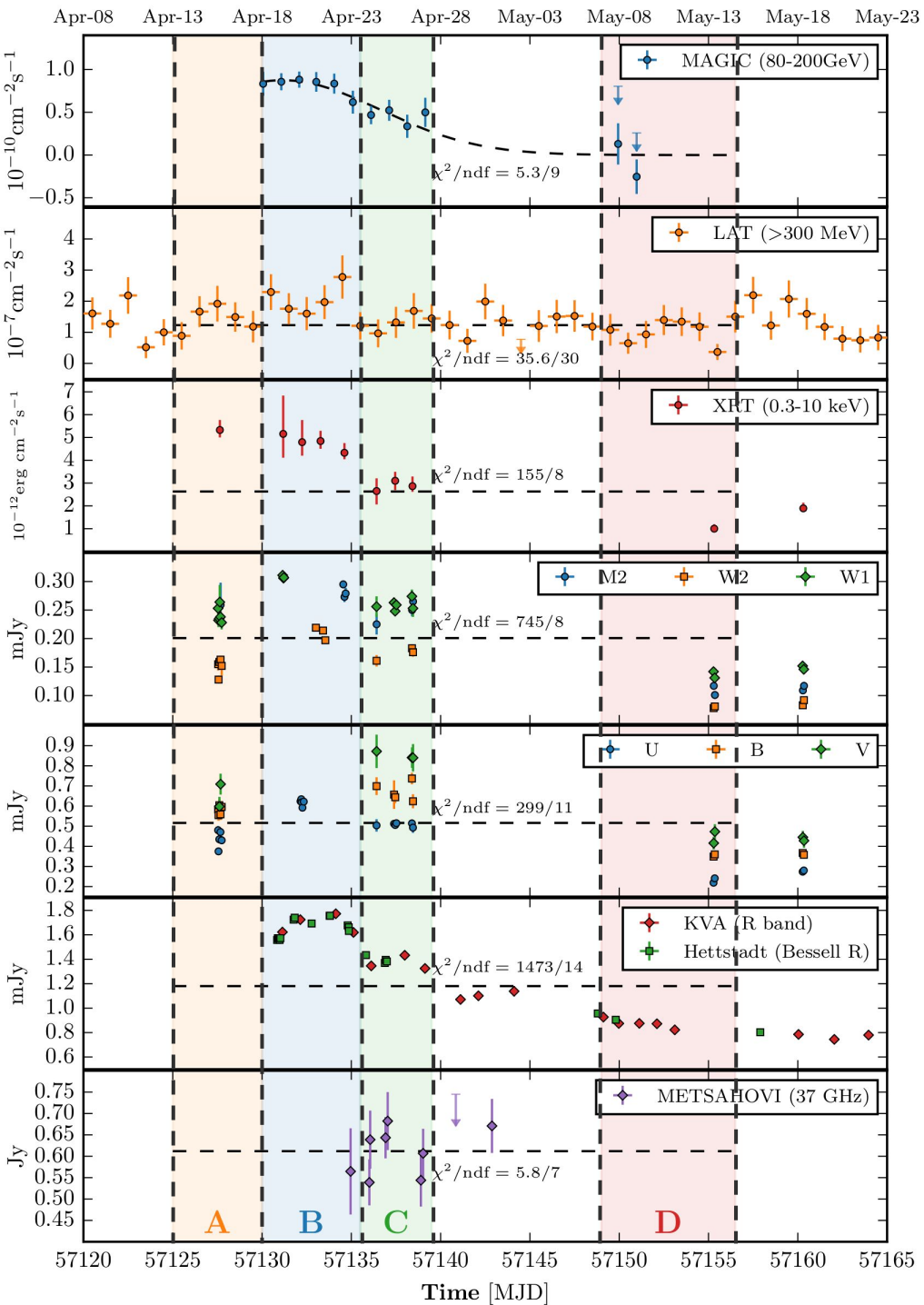


- After 10 days of continuous monitoring (30h), the significance >25σ (4010 ± 160 gamma-ray like events).
- No signal was detected in May (after the Moon break).

Multi-wavelength flux evolution.

- No-variability hypotheses discarded:
  - B+C+D: χ^2/ndf = 52.5/11, P=2.2e-9
  - B+C: χ^2/ndf = 26.0/9, P=2.1e-3.
- Halving flux time (Gaussian):
  - 6.4 ± 1.9 d (VHE)
  - 7.6 ± 1.7 d (X-rays)
- Mean flux ratios among periods (F_B/F_C):
  - VHE: 1.80 ± 0.27
  - HE: 1.40 ± 0.29
  - X-rays: 1.58 ± 0.17
- No intra-night variability detected (VHE).

Ahnen et al. (2015, subm. to ApJL)



Emission models for FSRQs

Ingredients:

- ➢ External radiation field (thermal radiation of the dusty torus / reprocessed disk radiation).
- ➢ IC Scattering with relativistic e- in the jet. *Softening expected at ~ GeV (KN cutoff).*
- ➢ Spherical emission region with radius R ~ jet cross-section and bulk Lorentz factor Γ. Cases:
  - A. Inside BLR
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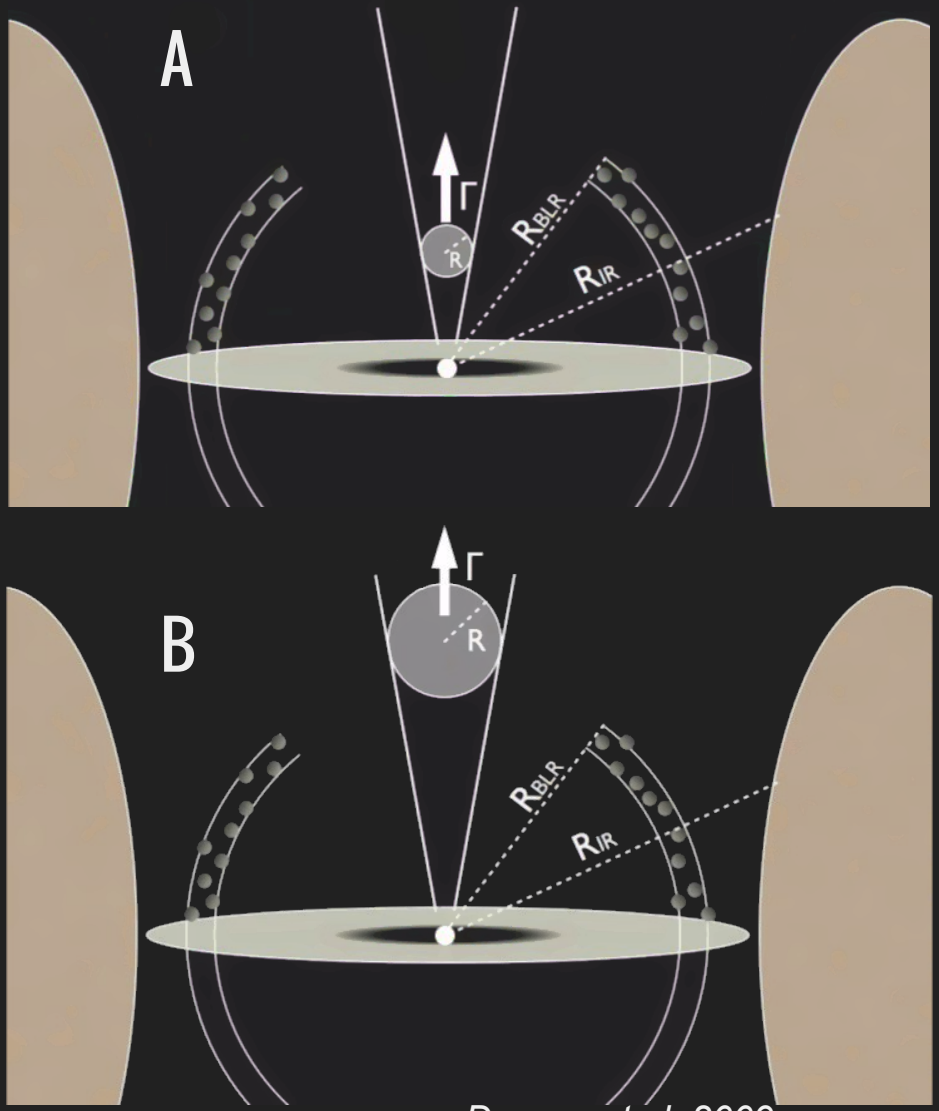

std one-zone model

Dermer et al. 2009
Ghisellini&Tavecchio 2009
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Case A:

- Gamma-rays interact with UV photons from the BLR → strong absorption at ~ GeV

Case B:

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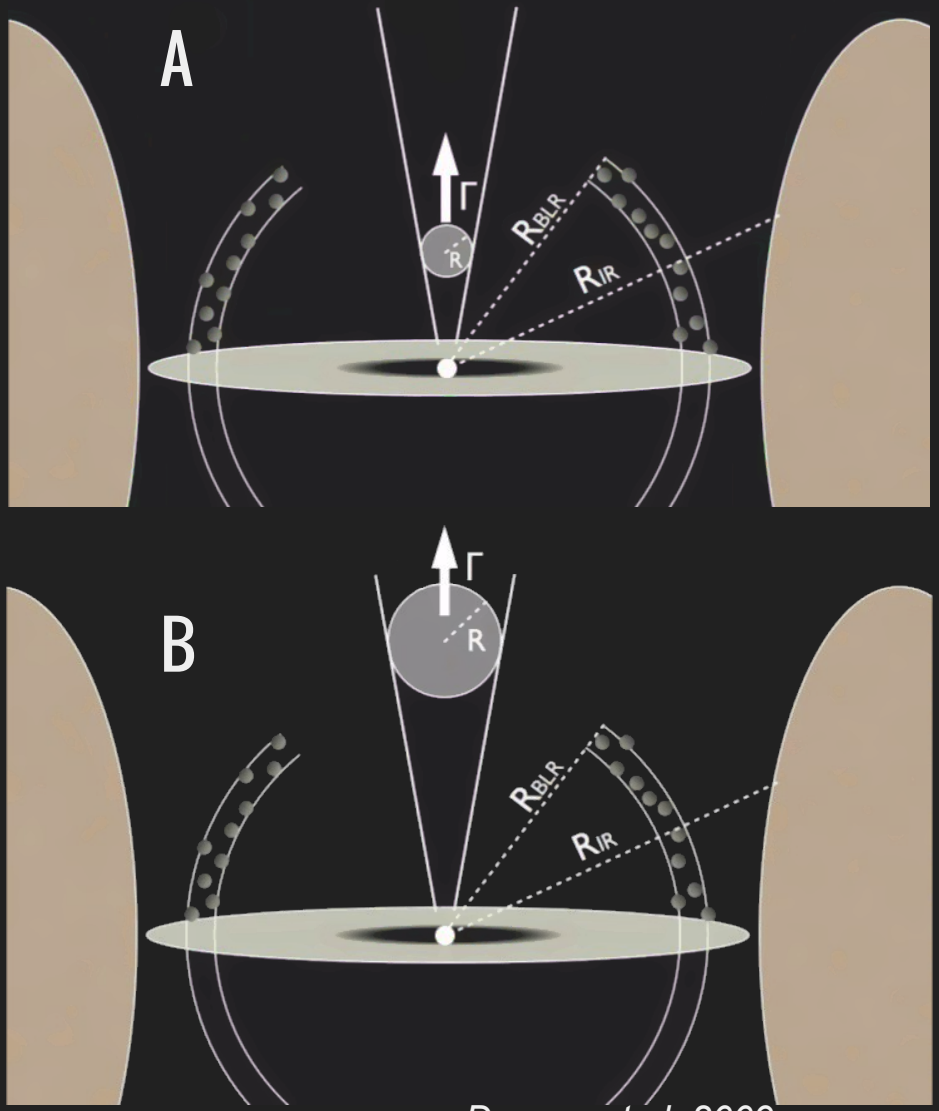

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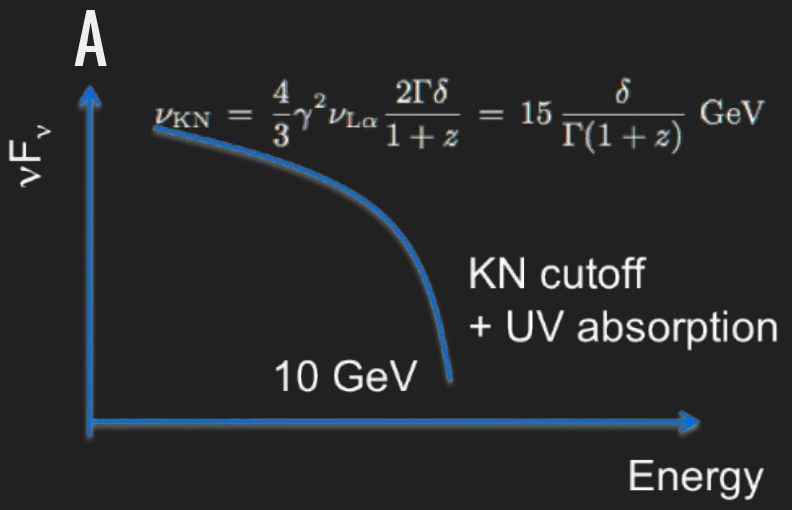

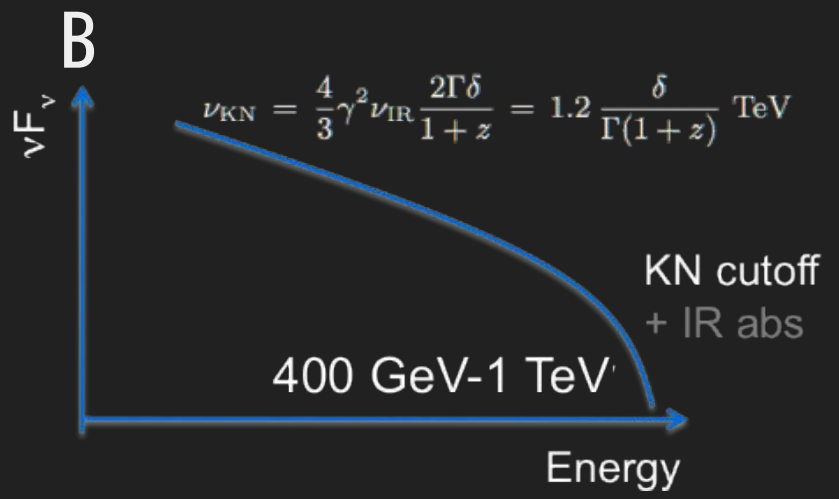

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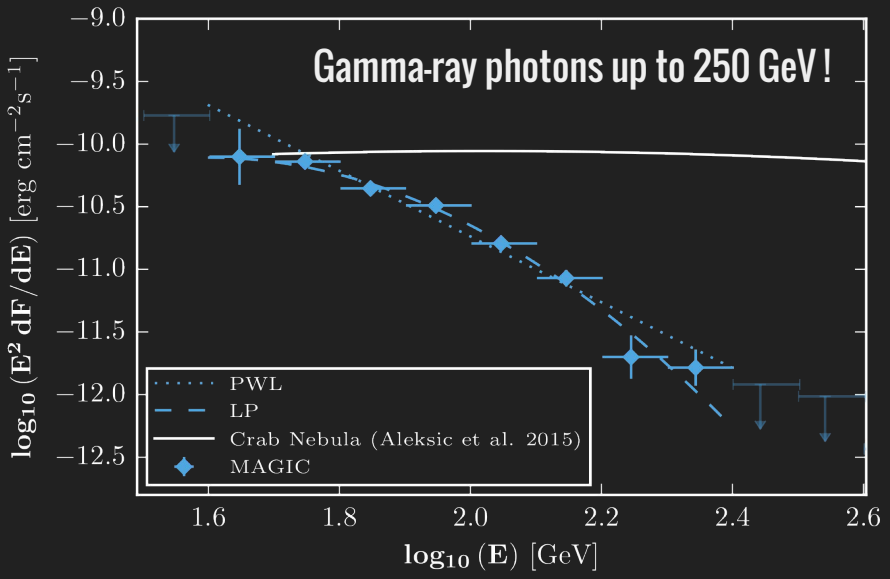

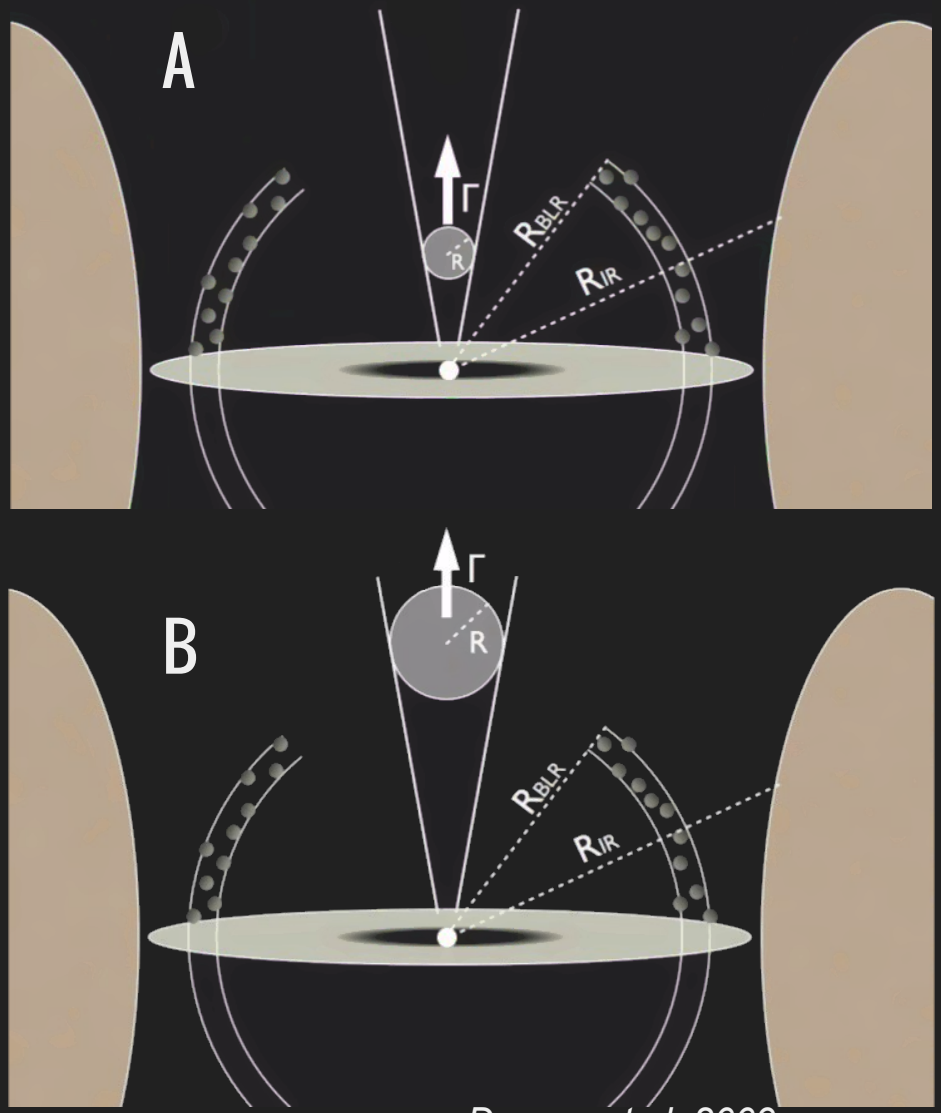

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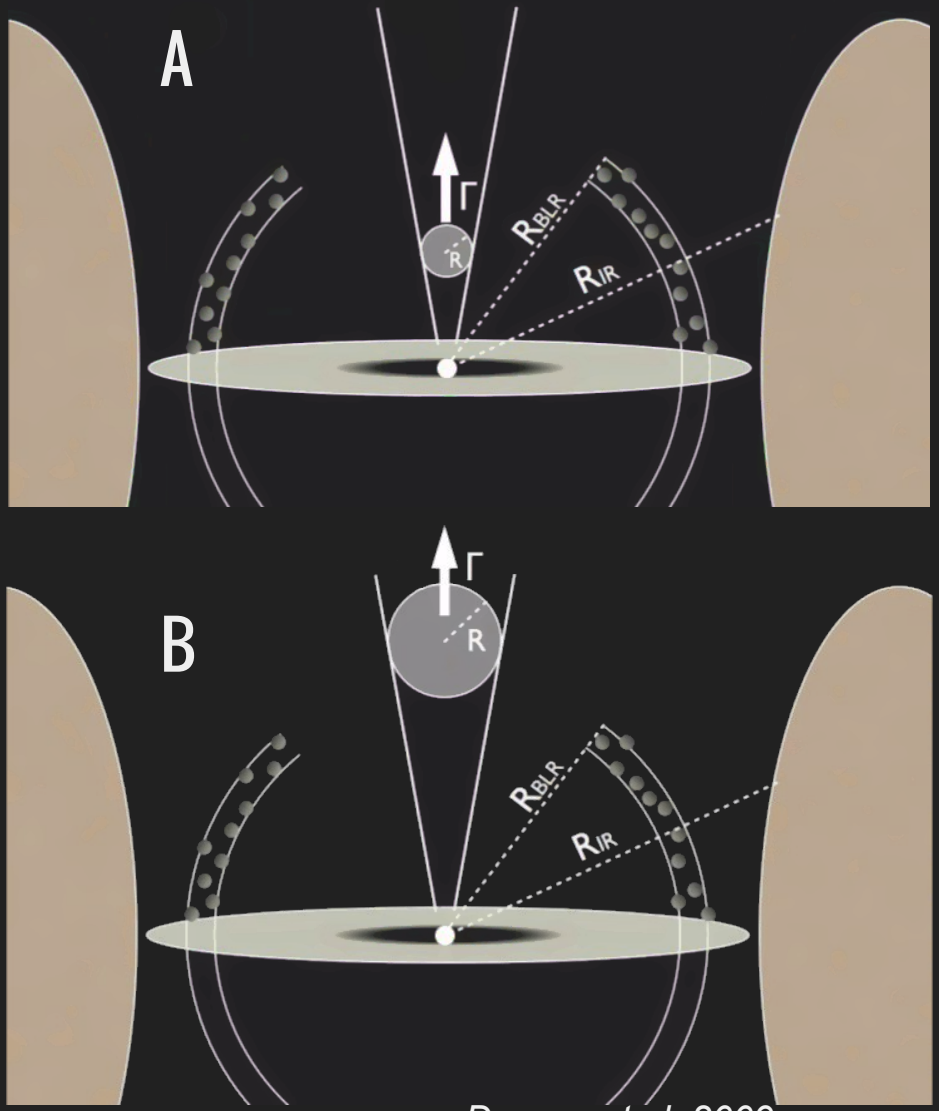

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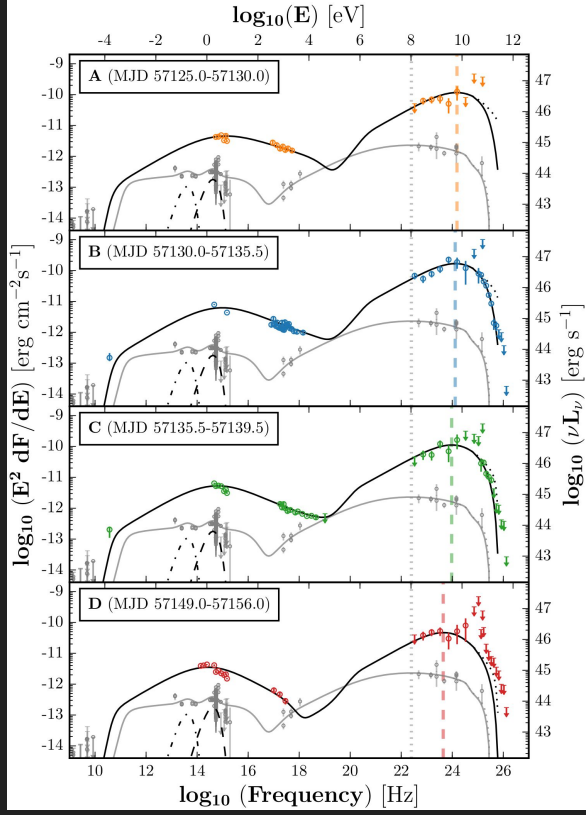
The 'far dissipation' scenario

Some parameters are kept fixed to standard values (Ghisellini & Tavecchio 2015):

- Γ =15 and δ = 20 → viewing angle of the jet θ_v = 2.7º.
- Aperture angle fixed to θ_v = 5.7º.
- Emission region located ~ BLR border. d=5×10^{17} cm→ R = 5×10^{16} cm
- n_1 fixed to standard value of 2

ν_{IC}: Inverse Compton peak frequency (log scale).
CD: Compton Dominance (ratio between IC peak and Sync. peak in the SED).



Ahnen et al. (2015, subm. to ApJL)

TABLE 1
INPUT PARAMETERS FOR THE EMISSION MODELS SHOWN IN FIG. 2

Period	MJD	$\gamma_{\rm min}$	$\gamma_{\rm b}(10^4)$	$\gamma_{\rm max}(10^6)$	n_2	B (G)	K (10^3 cm^{-3})	$\nu_{\rm IC}$[Hz]	CD
A	57125.0–57130.0	80	1.0	1.0	3.55	0.15	2.80	**24.2**	**24**
B	57130.0–57135.5	80	1.0	1.0	3.70	0.15	4.00	**24.1**	**25**
C	57135.5–57139.5	50	0.8	1.0	3.75	0.17	3.35	**24.0**	**21**
D	57149.0–57156.0	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**

The ‘far dissipation’ scenario

MWL SEDs for PKS 1441+25 for the four states of the source indicated in Fig. 1.

- **Solid line:** Observed spectrum.
- **Dotted line:** EBL-deabsorbed spectrum (Dominguez et al. (2011)
- **Dashed:** Disk emission.
- **Dash-dotted:** Torus emission.
- **Vertical lines:** Inverse Compton (IC) peaks

Grey: Archival data extracted from ASDC (http://tools.asdc.asi.it) are shown in grey.

The VHE spectral points are not corrected for EBL.

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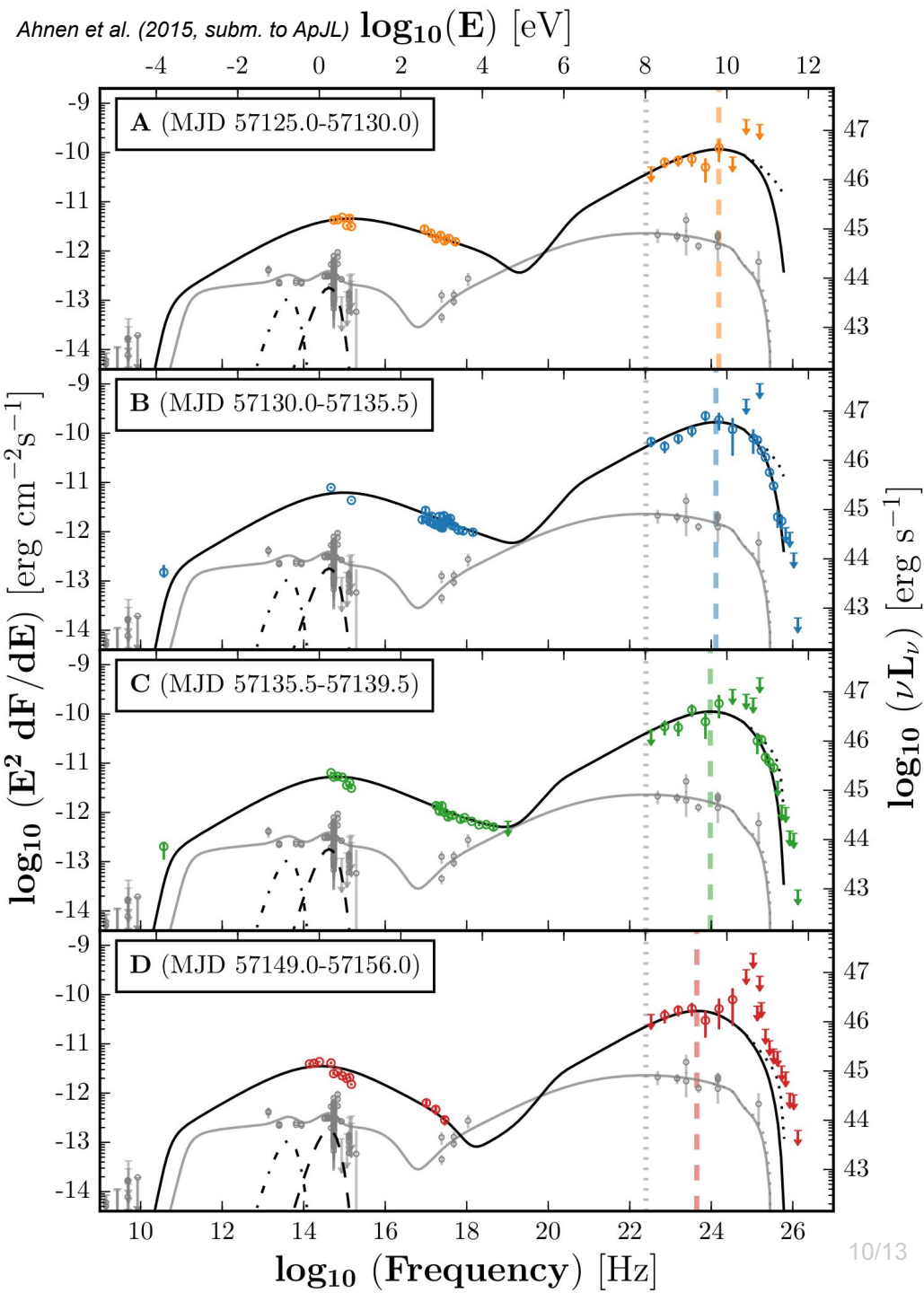
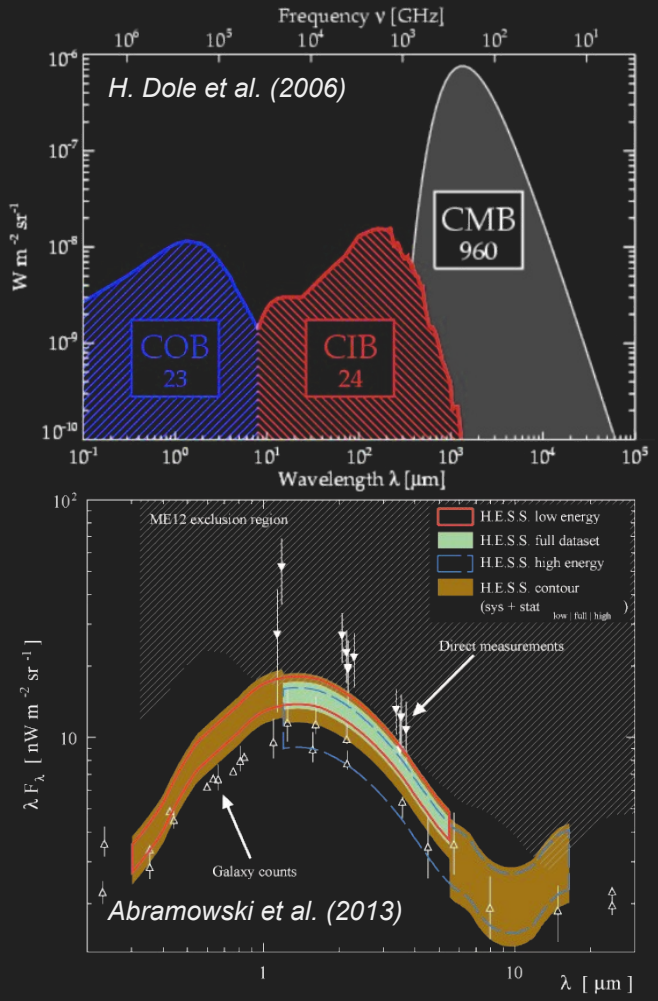
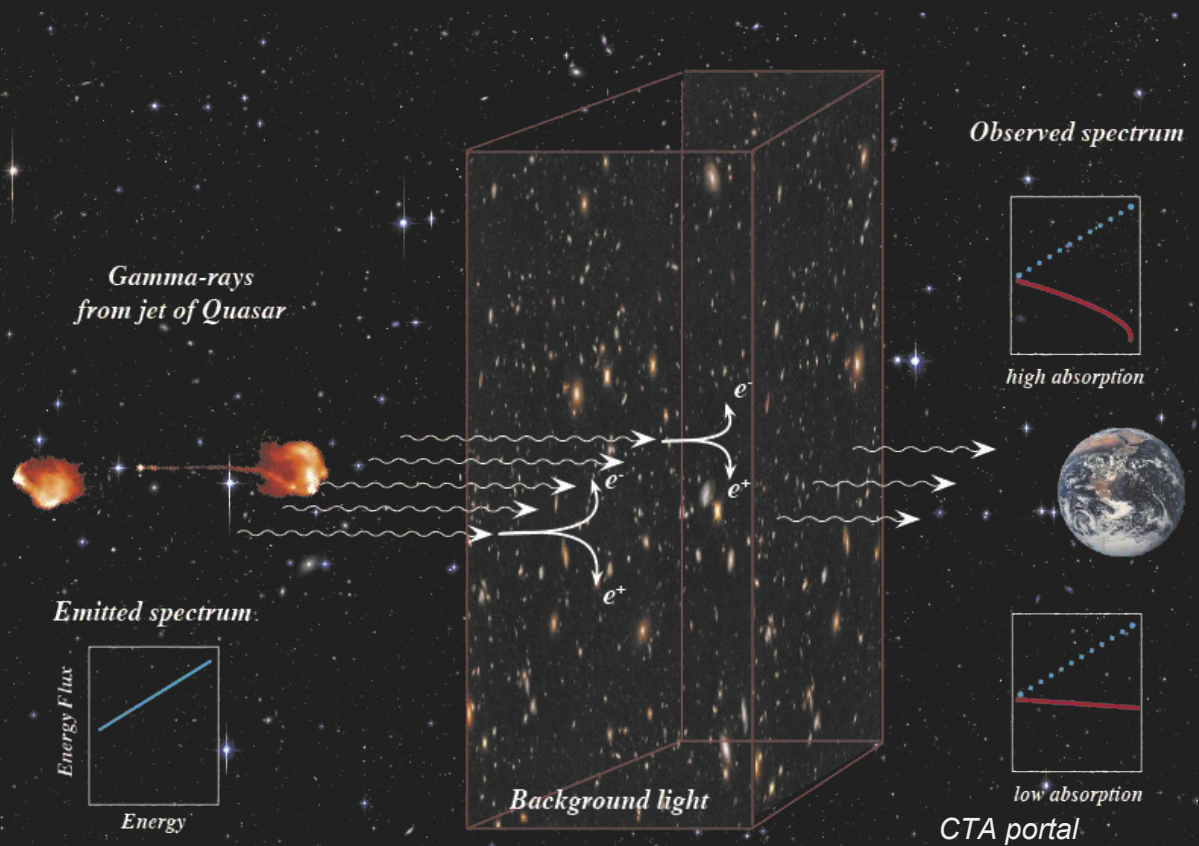


Extragalactic Background Light

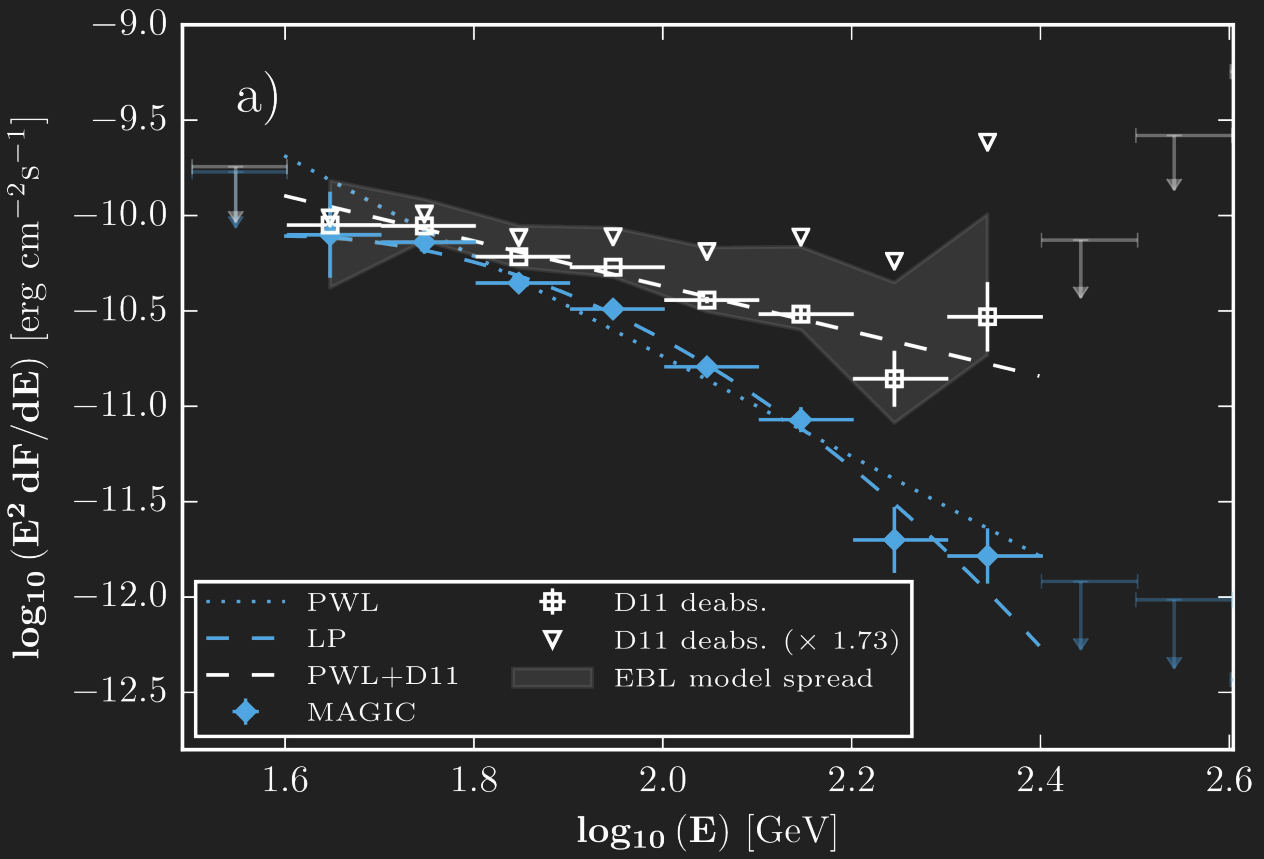




EBL: diffuse radiation (COB+CIB) which absorbs GeV-TeV radiation via pair e^+ e^- production.
Direct measurement, galaxy counts (lower limits), indirect measurements (IACT + Fermi, γ-rays absorption).

Extragalactic Background Light

Ahnen et al. (2015, subm. to ApJL)



Likelihood Ratio Test (LRT)

$\tau(z,E) = \alpha\, \tau_{model}$

EBL Models considered:

- Dominguez et al. (2011)
- Franceschini et al. (2008)
- Gilmore et al. (2012).
- Scully et al. (2014).

Spectral shapes tested:

- Power-law.
- Log-parabola.
- Power-law with sub/sup. exponential cutoff.

Worst case UL:

$\alpha_{F08} < 1.72$

$\alpha_{F08} = 1.3 \pm 0.4$ ($0.5 \le z \le 1.6$)
[*Ackermann et al. 2012*]

Pros: Strong signal, lack of fast variability (data stacking), high redshift (significant EBL suppression) ...
Cons: Soft spectrum (FSRQ - KN regime), possible cutoff at ~ 1 TeV (source/z=0.94 reference frame) . . . .

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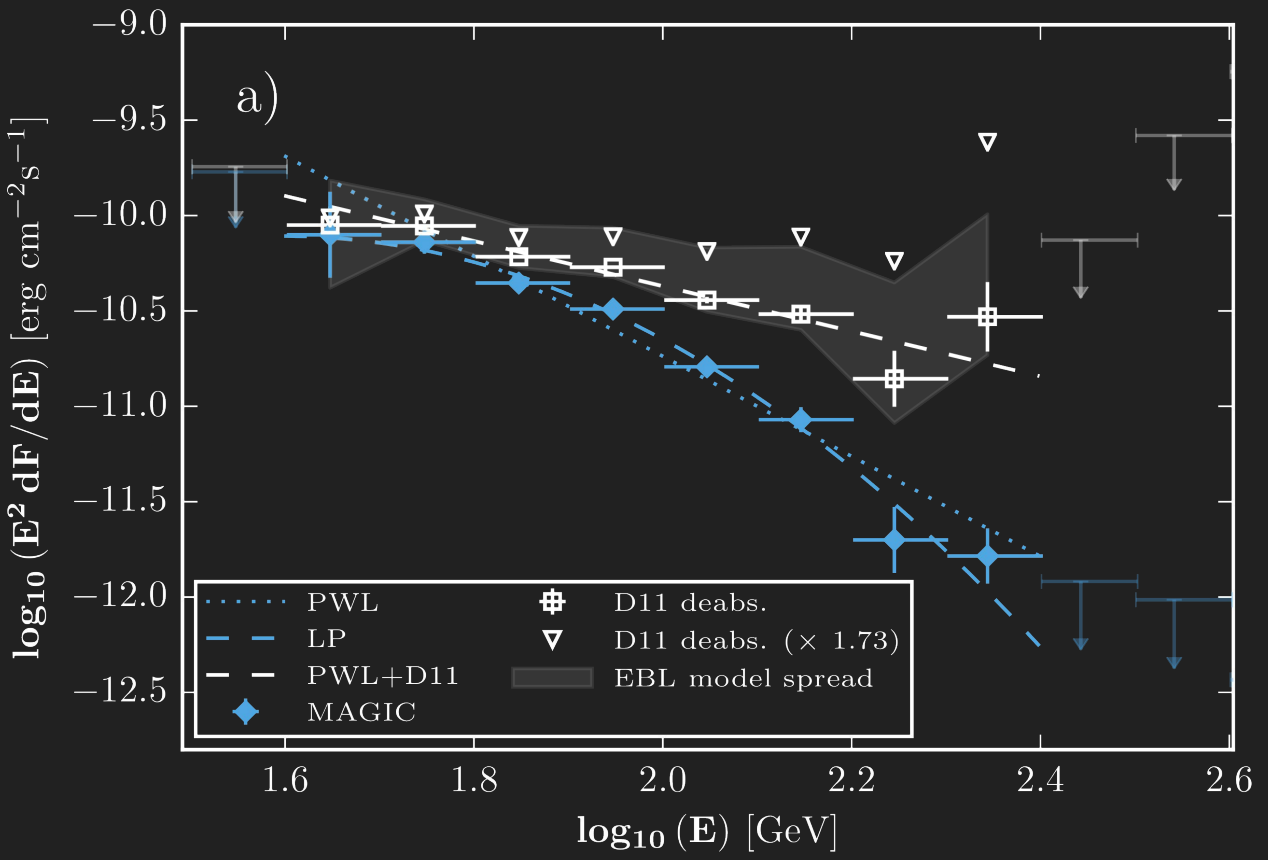

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Worst case UL:

$\alpha_{F08} < 1.72$

$\lambda f_{\lambda=0.45\mu m} < 7.3$ nW cm^{-2}sr^{-1}

Pros: Strong signal, lack of fast variability (data stacking), high redshift (significant EBL suppression) ...
Cons: Soft spectrum (FSRQ - KN regime), possible cutoff at ~ 1 TeV (source/z=0.94 reference frame) ... .

Conclusions

- MAGIC detected for the first time VHE emission from the z=0.940 blazar PKS 1441+25 during a MWL outburst in April 2015.
- Together with (QSO) B0218+357, it is the farthest VHE source detected.
- The MWL SED is modeled with an External Compton model.
  - The emitting region is constrained to be just outside the BLR by the absence of intrinsic absorption in the HE and VHE regimes.
  - Emitting region is partially embedded during the low state activity.
  - An evolution in the electron distribution and magnetic field is detected.
- First indirect probes of the EBL at z~1 with a VHE ground based instrument.
  - Measured VHE spectrum is fully consistent with the attenuation caused by the EBL.
  - Upper limits to the EBL density are derived by assuming state-of-the-art EBL models: $\tau(z,E) < 1.73\ \tau_{D11}$