MAGIC

Major
Atmospheric
Gamma
Imaging
Cherenkov telescopes

TAUP

Turin,September 16, 2015

Latest MAGIC discoveries pushing redshift boundaries in VHE AstroPhysics

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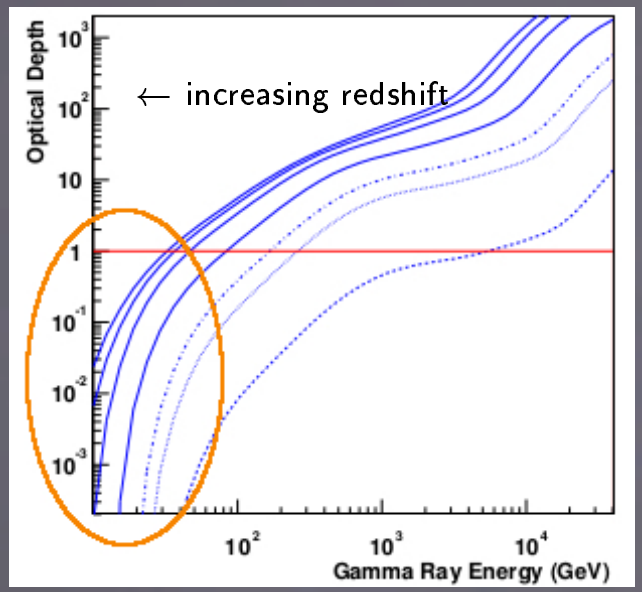
on behalf of MAGIC and FERMI-LAT collaborations

The Gamma Ray Horizon...



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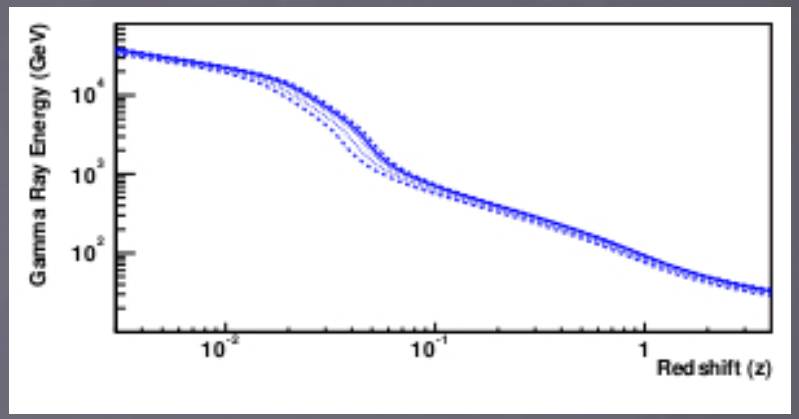

predicted

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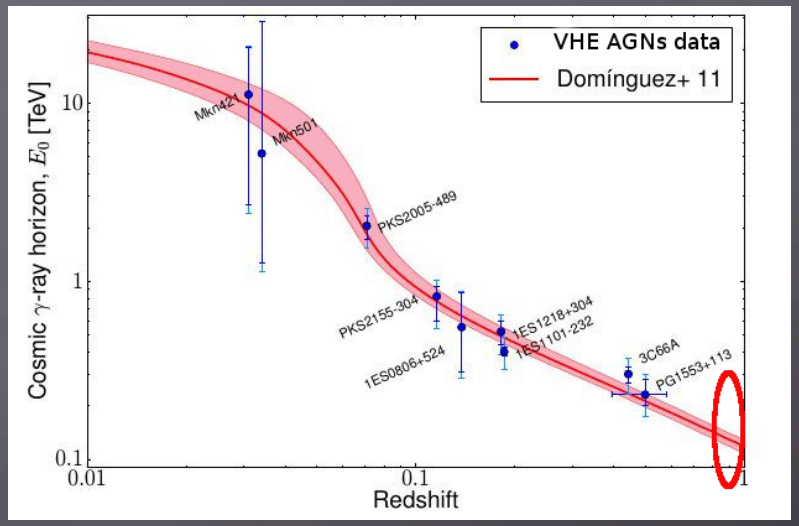
detected



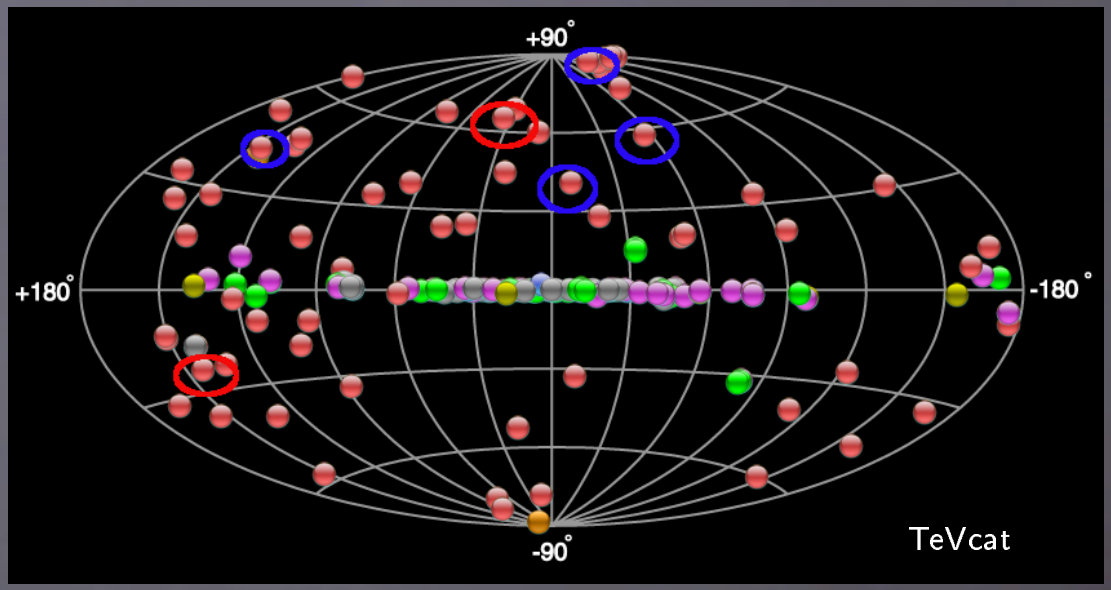
- Beyond the Gamma Ray Horizon, the Universe becomes opaque to VHE γ-ray radiation due to the interaction with Extragalactic Background Light
- for any given γ-ray energy, the Gamma Ray Horizon is defined as the source redshift for which the optical depth is $\tau(E,z) = 1$
- $\tau(E,z) = \int_0^z dz' \frac{dl}{dz'} \int_0^2 dx \frac{x}{2} \int_{\frac{2m^2c^4}{Ex(1+z')}}^{\infty} d\epsilon \cdot n(\epsilon, z') \cdot \sigma\left[2xE\epsilon(1+z')^2\right]$; $n(\epsilon, z')$ is the spectral density at z

* O. Blanch, M. Martinez, (2005)a, APh, 23, 588
** A. Domínguez et al., (2013) ApJ 770 77

and the Very High Energy sky

- more than 60 extragalactic sources detected at VHE ($E \gtrsim 100\,GeV$), the farthest being PKS 1424 + 240, at $z > 0.6$ ... but wait!! not anymore!

- FSRQs are the most luminous and distant γ ray sources
- only 5 (maybe 6) VHE sources are Flat Spectrum Radio Quasars
- 4 (5?) of them were discovered by MAGIC



source	redshift	discovered by	year
3C 279	0.536	MAGIC	2006
PKS 1510 - 089	0.361	H. E. S. S.	2009
PKS 1222 + 216	0.432	MAGIC	2010
S4 0954 + 65 *	0.368	MAGIC	2015
QSO B0218 + 357	0.944	MAGIC	2014
PKS 1441 + 25	0.939	MAGIC	2015

* classification under debate

redshift ~ 1 ! $\Rightarrow$

Flat Spectrum Radio Quasars at VHE

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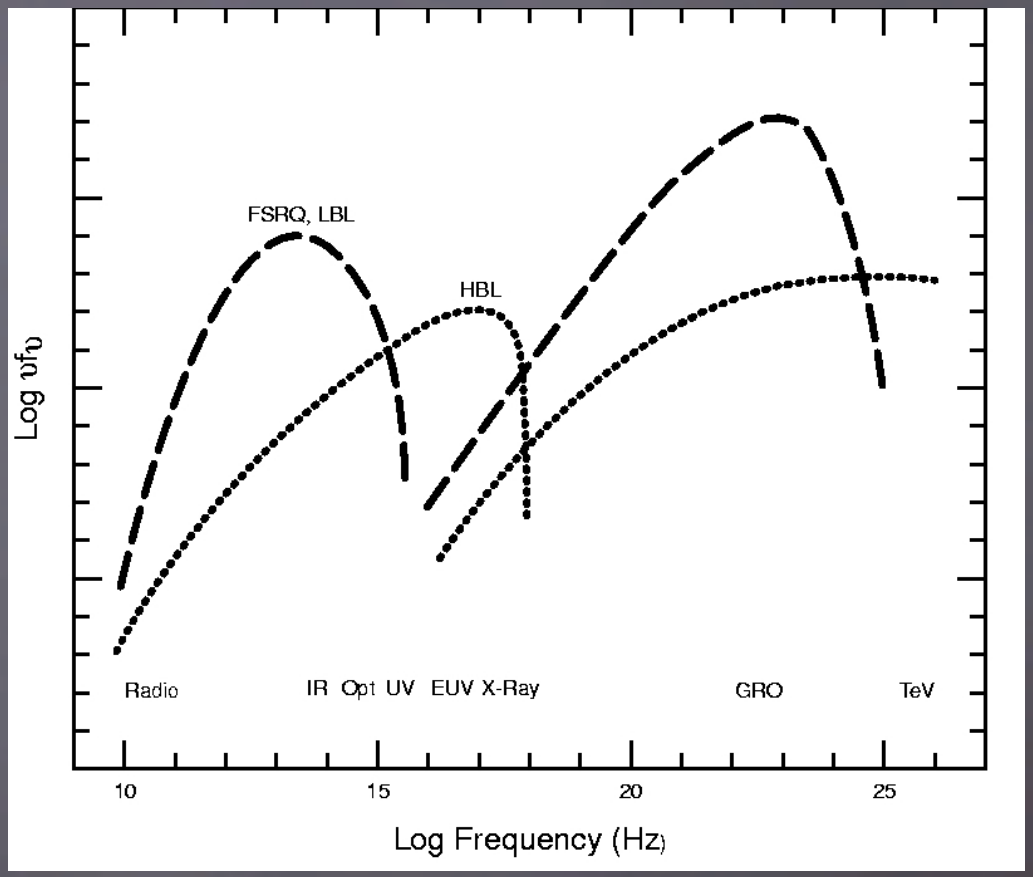
- Why only 5 (or 6) FSRQs detected in VHE?
  - Low synchrotron peak frequency
  - Intrinsic absorption
  - High redshift (typically)
- They can be mostly detected during flaring/spectral hardening states
- VHE help us to constrain the location of the emitting region
- Usually explained in the "far dissipation" external Compton scenario



* R. M. Sambruna, PhD thesis (1994)

VHE γ rays from the Universe's middle age: PKS 1441 +25 and QSO B0218 +357 discoveries by 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

Tweet 9 Recommend 22

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.

Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; ***Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration***
*on **28 Jul 2014; 14:20 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

Tweet 19 Recommend 109

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from S3 0218+357 (RA=02h21m05.5s, DEC=+35d56m14s, J2000.0). The object was observed with the MAGIC telescopes for a total of 3.5 hours from 2014/07/23 to 2014/07/26. The preliminary analysis of these data resulted in the detection of S3 0218+357 with a statistical significance of more than 5 standard deviations. From the preliminary analysis, we estimate the VHE flux of this detection to be about 15% of the flux from the Crab Nebula in the energy range 100-200 GeV. S3 0218+357 is a gravitationally lensed blazar located at the redshift of 0.944+/-0.002 (Cohen et al., 2003, ApJ, 583, 67). Fermi-LAT observations during the flaring state of S3 0218+357 in 2012 revealed a series of flares with their counterparts after 11.46+/-0.16 days delay, interpreted as due to the gravitational lensing effect (Cheung et al. 2014, ApJ, 782, L14). On 2014 July 13 and 14 Fermi-LAT detected another flaring episode (ATel #6316). Due to the full-moon time, the MAGIC telescopes were not operational and could not observe S3 0218+357 after the original alert. However, observations scheduled at the expected time of arrival of the gravitationally lensed component led to the first significant detection of a gravitationally lensed blazar and the most distant source detected at VHE with Cherenkov telescopes to date. MAGIC observations on S3 0218+357 will continue during the next days and multiwavelength observations are encouraged. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and J. Sitarek (jsitarek@ifae.es). 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 astrophysics in the energy range from 50 GeV to greater than 50 TeV.

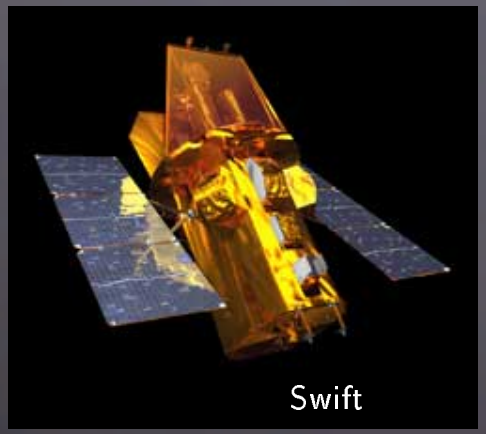
the MAGIC telescopes

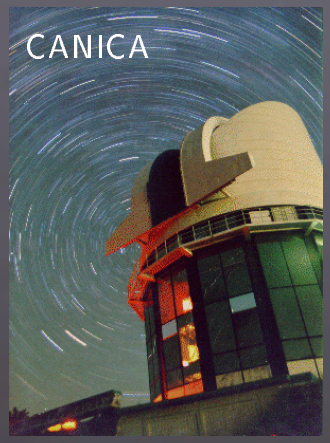
- Two 17m diameter Imaging Atmospheric Cherenkov telescopes
- Energy range from 50 GeV to >10 TeV
- Sensitivity above 300 GeV is $\sim$ 0.6% of the Crab nebula flux (for 50 hs)
- Devoted to the investigation of particle acceleration in the most violent cosmic environments
- Investigating the origin of Galactic cosmic rays and the nature of dark matter *. Observing the gamma-ray emission from sources at cosmological distances, we measure the intensity and evolution of the extra-galactic background radiation, and perform tests of Lorentz Invariance.

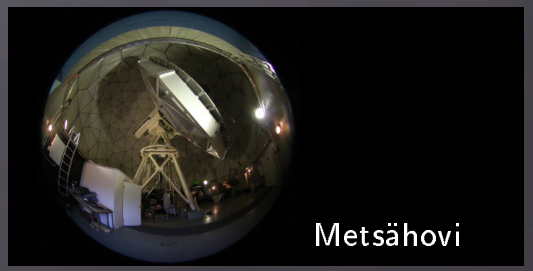
* see Paola Giammaria's talk, "Latest results on searches of Dark Matter signature in Galactic and extragalactic selected targets by the MAGIC telescopes"

Multi Wave Length observations with:

- Fermi-LAT $\rightarrow$ HE γ ray $(100\,MeV < HE < 100\,GeV)$
- NuSTAR $\rightarrow$ Hard X-ray
- Swift-XRT $\rightarrow$ X-ray
- Swift-UVOT $\rightarrow$ optical-UV
- KVA and Hans-Haffner $\rightarrow$ Optical R-band
- CANICA $\rightarrow$ Near Infrared
- Metsähovi $\rightarrow$ Radio



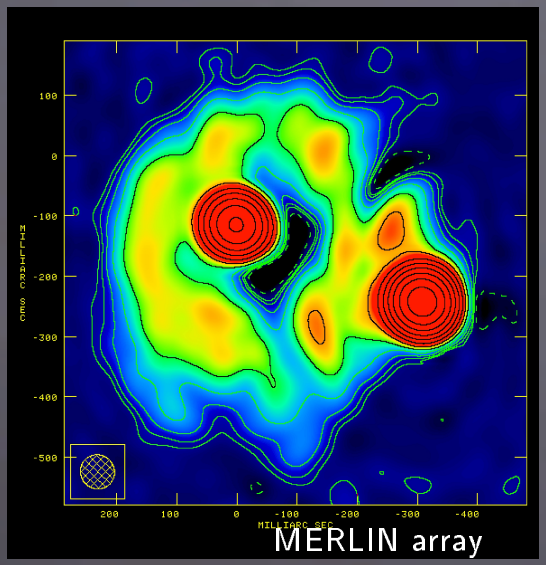




QSO B0218 + 357 (a. k. a. S30218 + 35)

J. Becerra, D. Dominis, E. Lindfors, M. Manganaro, D. Mazin, M. Nievas, A. Stamerra, I. Vovk and S. Buson

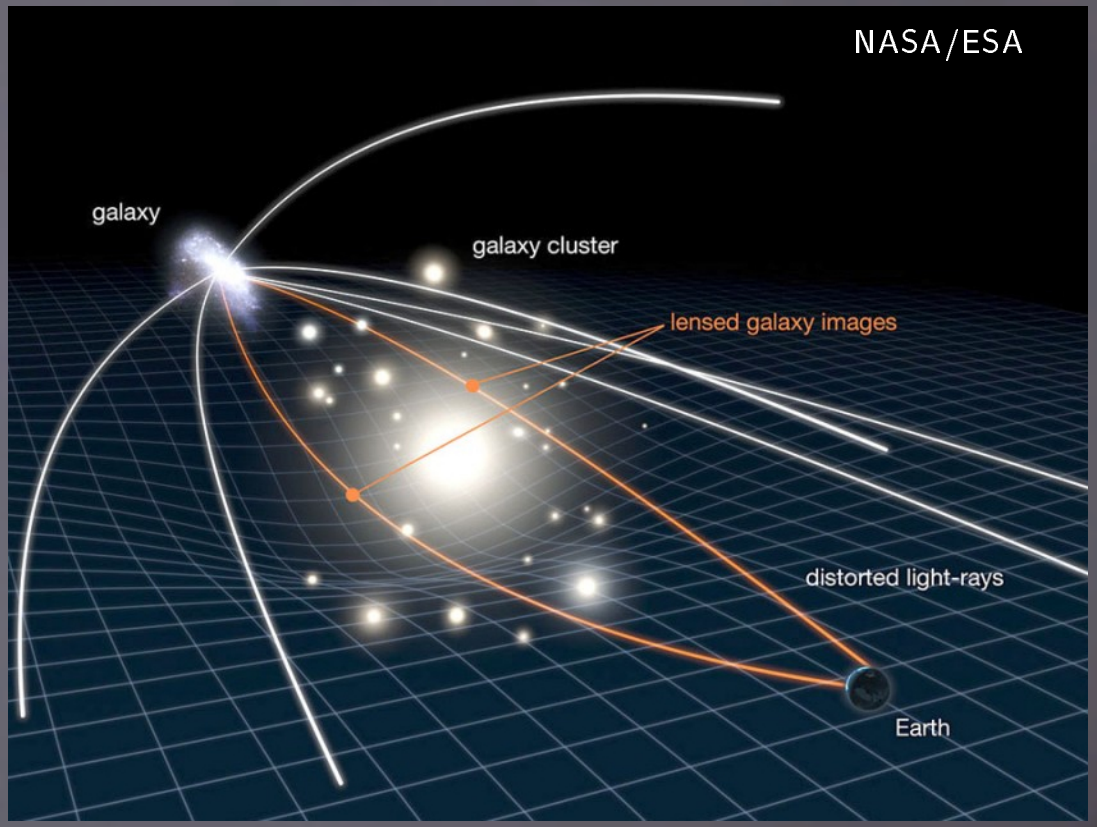
- First gravitationally lensed blazar at VHE! -

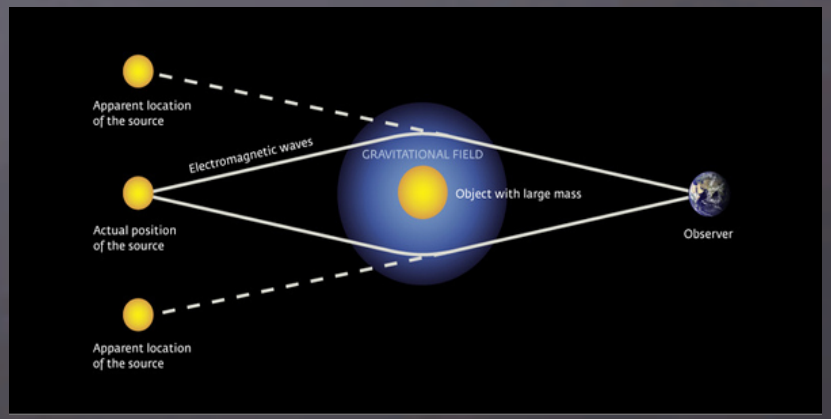


- The farthest source ever detected in VHE
- Redshift: 0.944 ± 0.002
- Lens: [PBK93] B0218 + 357G (probably spiral) at z=0.68
- In radio double image and Einstein's ring is visible
- Separation of images: ~ 0.335 arc sec

Gravitational lensing

- If there is a substantial mass (e.g. a galaxy or a cluster) between the source and the observer the light path will be bent.
- For strong lensing: one can get Einstein's ring (most pronounced for perfect alignment) and/or multiple images with different magnification and timing
- Gravitational lensing is achromatic, but geometry effects can mimic wavelength dependence





QSO B0218 + 357, MAGIC results

- On July 13/14 Fermi saw a flare not as strong as in 2012, but with a much harder spectrum (slope 1.4 – 1.6 and a 94 GeV photon)
- MAGIC couldn't observe the original flare because of the full moon period, but got ready for the delayed emission
- The two nights around the time of the expected delayed emission lead to a detection with 5.7σ significance

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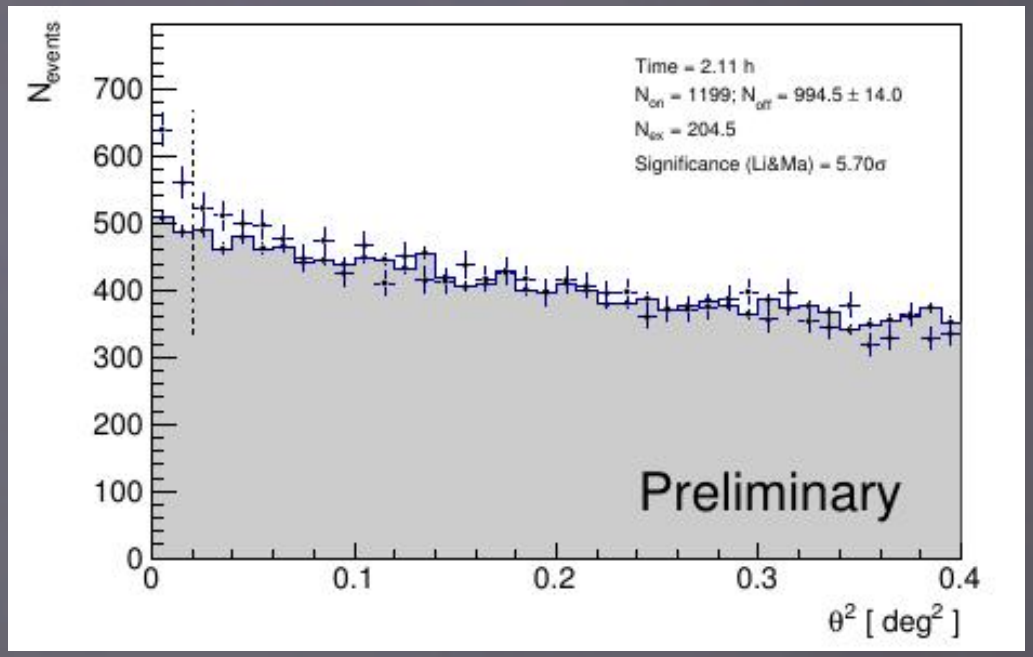


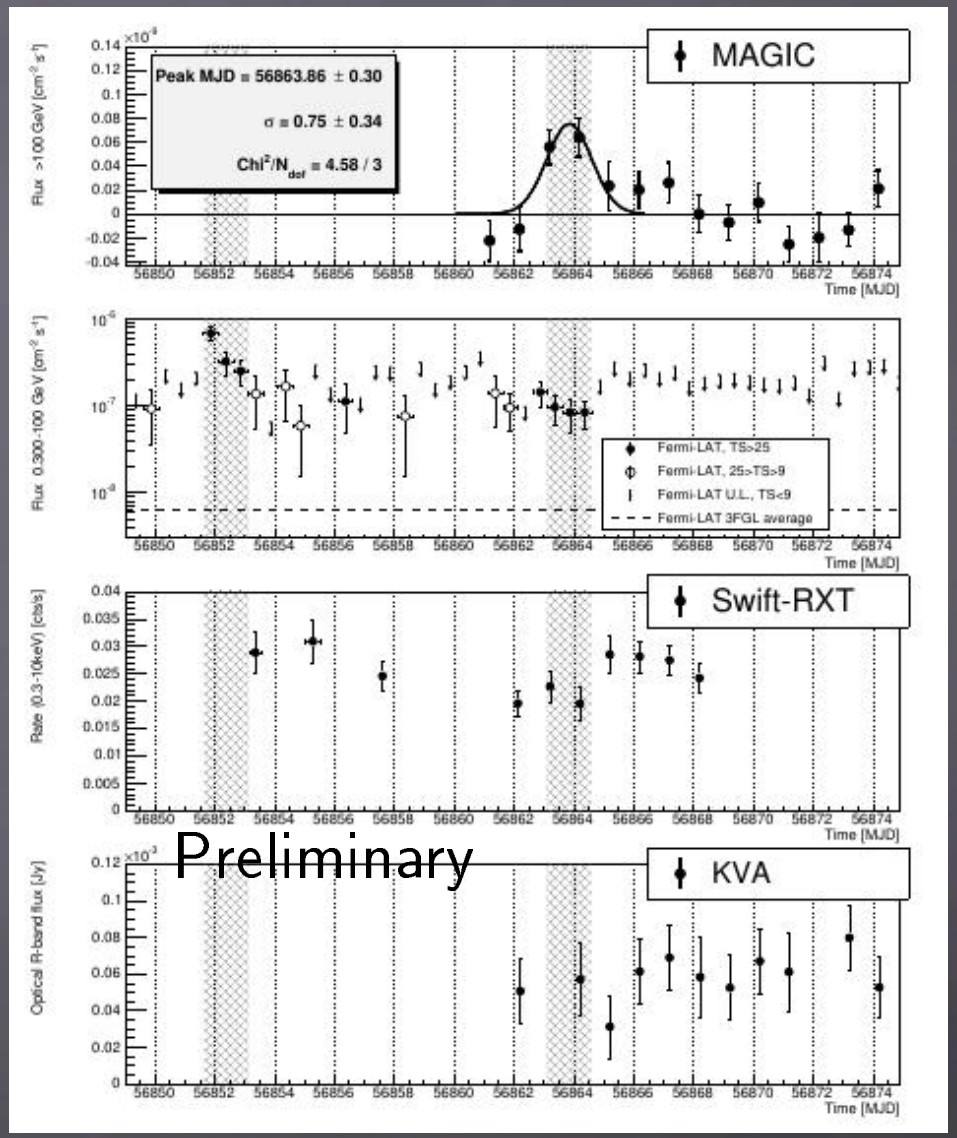
→ expanding VHE sky from z= 0.5-0.6 to 0.94 !

* J. Sitarek et al., ICRC proceedings (2015)
M. L. Ahnen et al., in preparation

QSO B0218 + 357, MAGIC results *

Multi Wave length LC

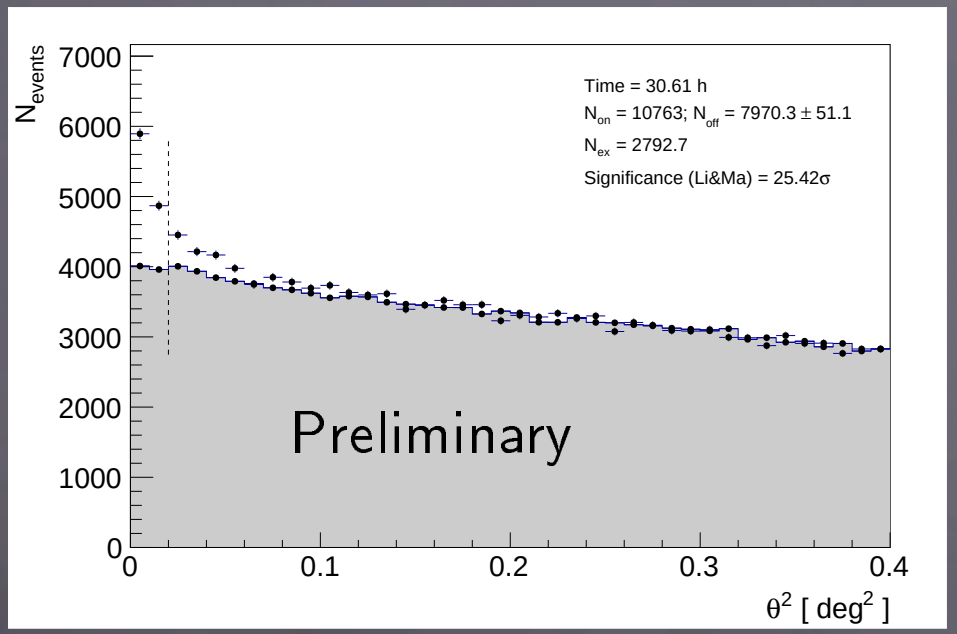
- MAGIC saw a single 2 day long flare at the expected time of arrival
- Being prepared for a flare we also have VHE observations before it
- Follow up observations were done for 2 weeks, but no further flares were observed
- No increase during the second component of the flare in x-rays and optical range



* J. Sitarek et al., ICRC proceedings (2015)
M. L. Ahnen et al., in preparation

PKS 1441 + 25: MAGIC results

J. Becerra, E. Lindfors, M. Manganaro, D. Mazin, M. Nievas, E. Prandini, J. Sitarek, A. Stamerra, F. Tavecchio



- in April 2015, an increased multiwavelength emission and an outburst seen by Fermi in GeV range, triggered MAGIC observations
- MAGIC detects the source with 25 σ between 40 GeV and 250 GeV

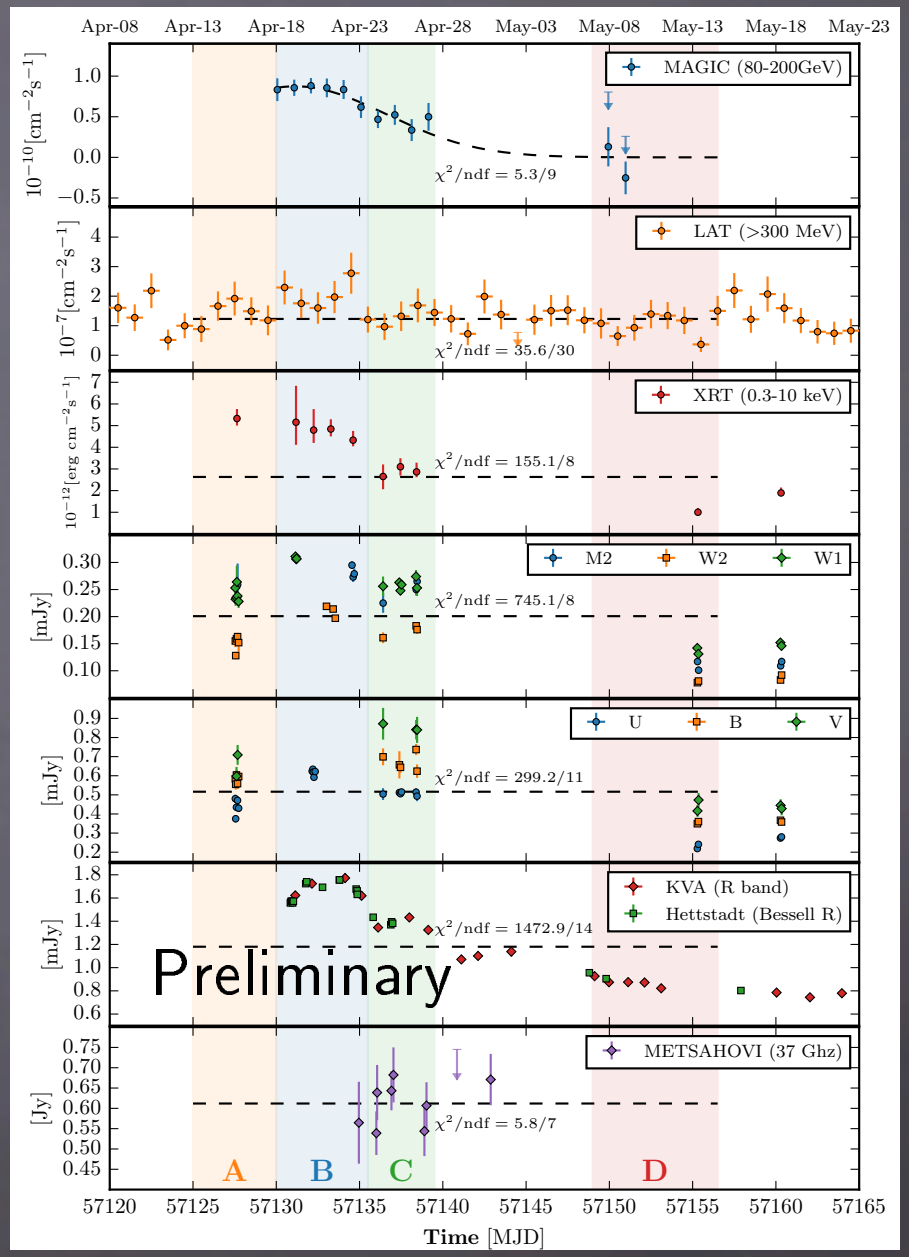
Redshift: 0.93974 ± 0.00015

* M. L. Ahnen et al, submitted to ApJL

PKS 1441 + 25: MAGIC results

Multi Wave Length LC

- 4 different states of the source
- The average flux in the high state B is significantly larger than the one in C
- Similar pattern in X-rays, optical and HE
- No hint of intra-night variability detected

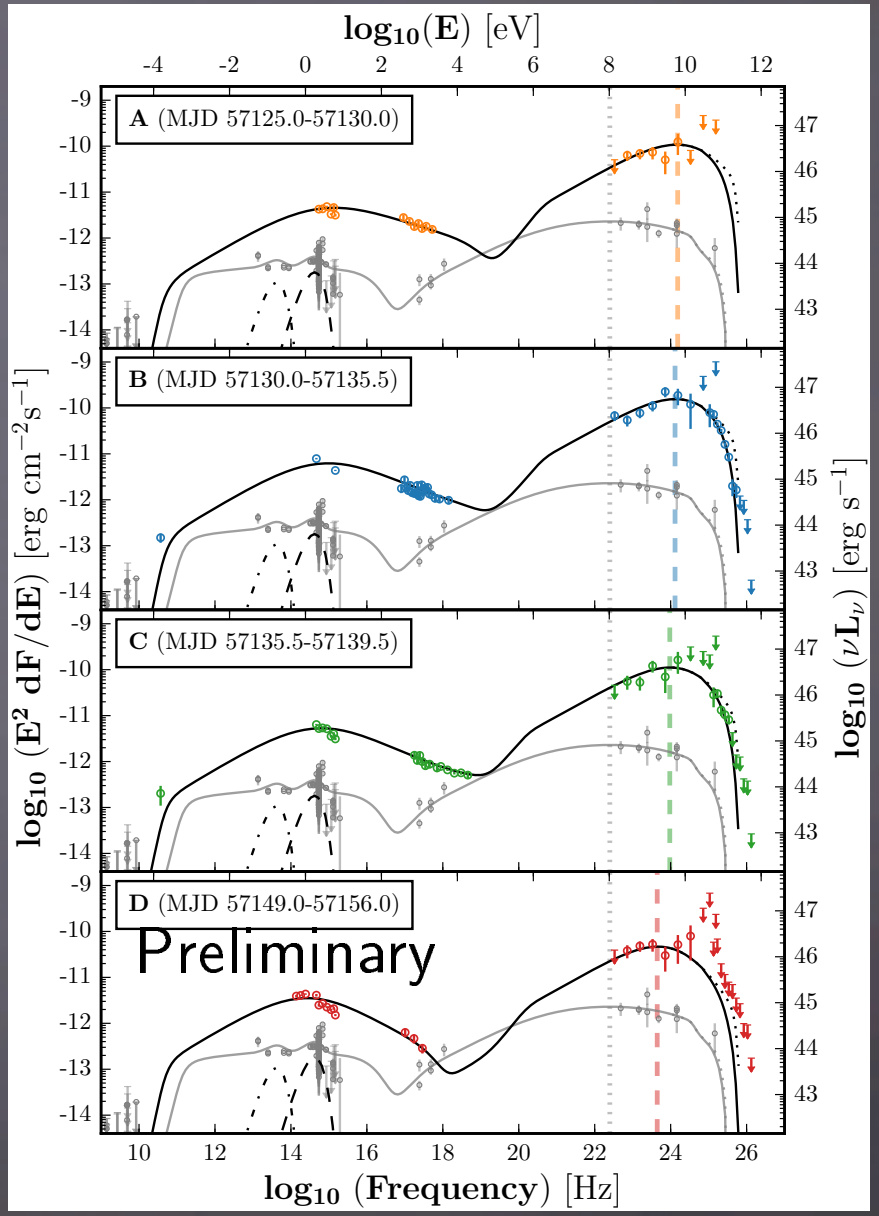


* M. L. Ahnen et al, submitted to ApJL

PKS 1441 + 25: MAGIC results

Broadband SED

- shift of synchrotron and IC peaks to higher energies
- significant variation of the X-ray and HE γ ray spectral indexes
- emitting region originating in the jet just outside the broad line region
- high degree of optical polarization-the emission may come from a compressed region in the jet, like an internal shock



* M. L. Ahnen et al, submitted to ApJL

PKS 1441 + 25: MAGIC results

EBL constraints

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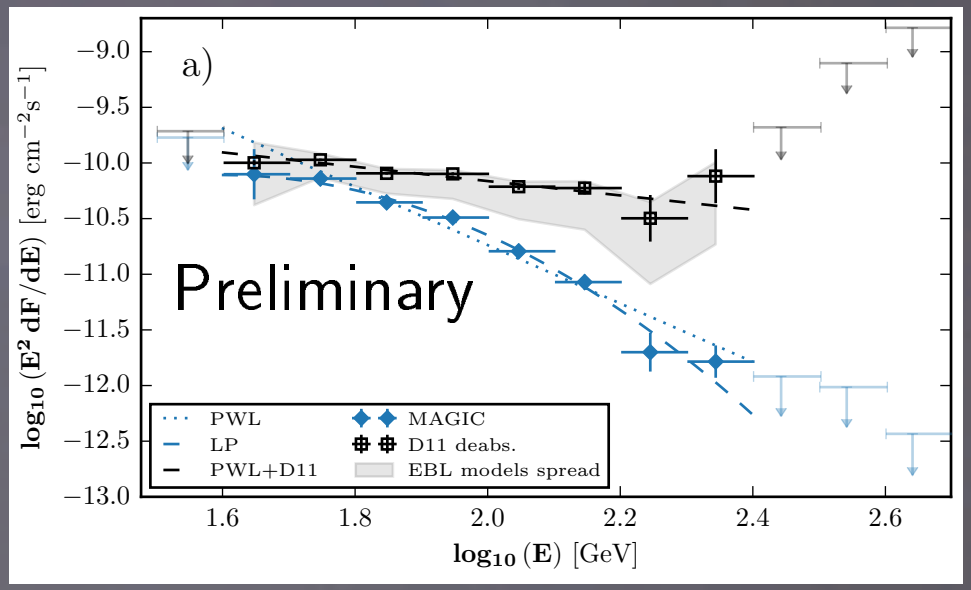
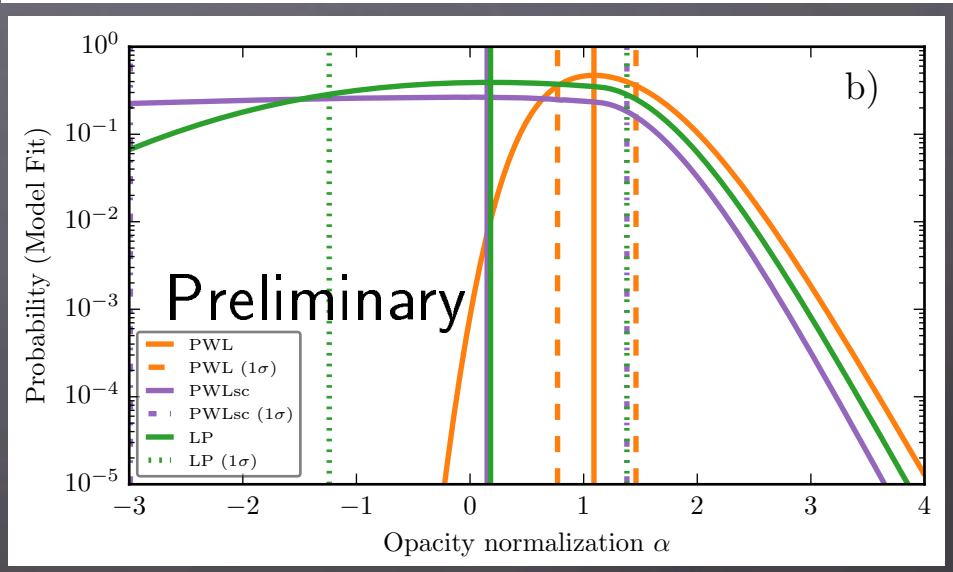
- probing EBL models at a distance never explored before in VHE
- measured spectrum is compatible with the present generation of EBL models
- robust upper limit on the relative EBL opacity α: < 1.73 for Dominguez 2011 model **
- EBL density constrained between 0.20 and 0.30μm





* M. L. Ahnen et al, submitted to ApJL
** A. Domínguez et al., (2011) MNRAS 410, 2556

Conclusions

- VHE emission detected for the first time from QSO B0218 + 357 and PKS 1441 + 25 by MAGIC
- With redshifts of 0.944 and 0.939 respectively they are the most distant sources ever observed in VHE
- Studying them allows us to understand more about blazars when the Universe was only half of its current age
- Constraints on the Extragalactic Background Light were given, and work is in progress