Selected MAGIC Highlights

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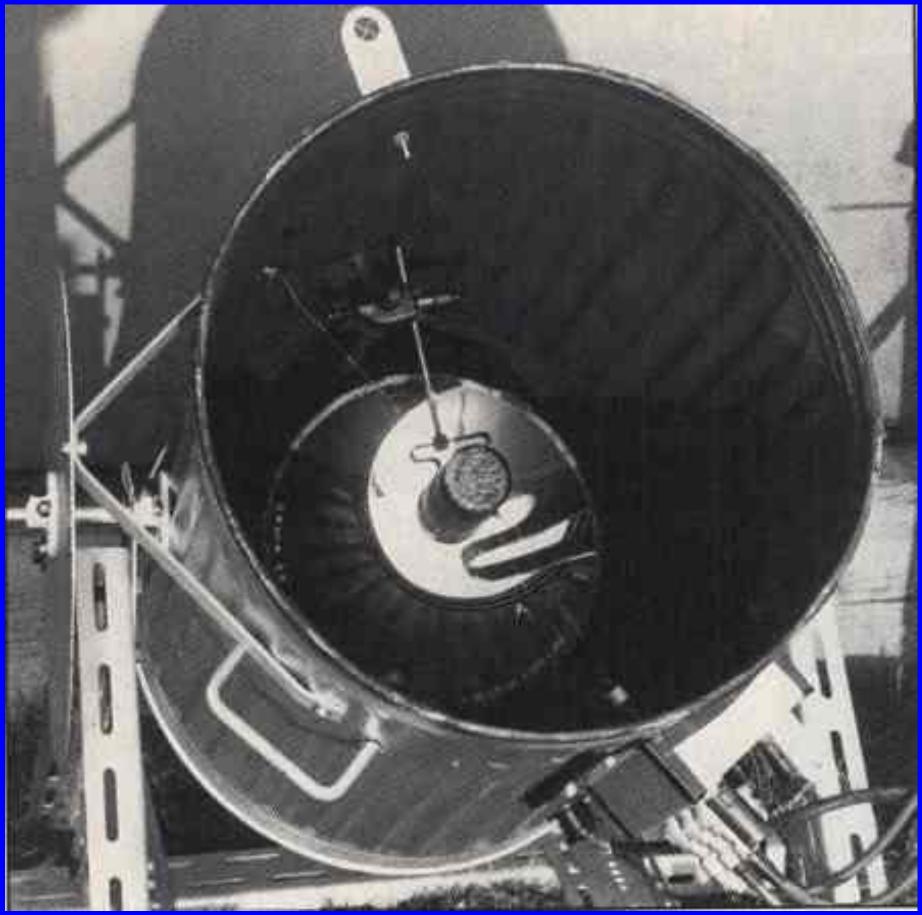
The Very Beginning of the Air Cherenkov Technique



1953

By using a dust bin, a 60 cm diameter mirror in it and a PMT in its focus Galbraith and Jelly had discovered the Cherenkov light pulses from the extensive air showers.

The Pioneer: all life-long trying really hard, until succeeding in 1988

THE ASTROPHYSICAL JOURNAL, Vol. 154, November 1968

A SEARCH FOR DISCRETE SOURCES OF COSMIC GAMMA RAYS OF ENERGIES NEAR 2×10^{12} eV

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AND

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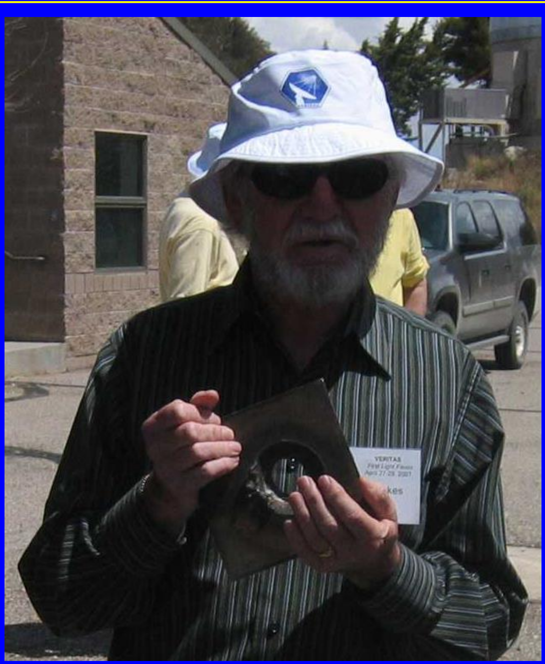
Mount Hopkins Observatory, Smithsonian Astrophysical Observatory, Tubac, Arizona
Received September 3, 1968

ABSTRACT

By use of the atmospheric Čerenkov nightsky technique, a study has been made of the cosmic-ray air-shower distribution from the direction of thirteen astronomical objects. These include the Crab Nebula, M87, M82, quasi-stellar objects, X-ray sources, and recently exploded supernovae. An anisotropy in the direction of a source would indicate the emission of gamma rays of energy 2×10^{12} eV. No statistically significant effects were recorded. Upper limits of 3–30 $\times 10^{-11}$ gamma ray cm^{-2} sec^{-1} were deduced for the individual sources.

Trevor and his 10m Ø Whipple telescope team gave birth to γ-ray astrophysics: 9σ from Crab Nebula in 1988 !

Photo: VERITAS inauguration, 2007



„If a telescope can within a few s evaporate a solid piece of steel, it can also measure gamma rays“ ;-)

Beginning of MAGIC

- Since from the beginning and until recently it was a common belief that the threshold of a Cherenkov telescope

$$E_{thr} \sim 1\sqrt{/A_{mirror}} = 1/D \qquad (1)$$

(still one can find this in some review papers)

- In 1990's we knew that an Imaging Air Cherenkov Telescope (IACT) of a rfelector of $\sim 10\ m^2$ area, with a camera based on pixel size of $\sim 0.25^\circ$, will operate above a threshold energy of ~ 1 TeV

- Let us assume we plan to lower that threshold by 20 times, going down to ~50 GeV

Beginning of MAGIC

- The formula (1) suggests that one needs a telescope with a

$$A_{mirror} \sim (20)^2 = 400$$

times larger mirror area, than the one operating at ~1 TeV,

$$\text{i.e. } 400 \times 10\ m^2 = 4000\ m^2$$

for measuring at a threshold ≥ 50 GeV

- Many researchers believed that for a single dish telescopes that's too big, the only seeming solution is to move towards huge mirror area solar power plants, comprising (2000 – 10000) m^2 distributed mirrors

Beginning of MAGIC

- In mid 1994 we understood that the below relation is **simply wrong** for an imaging telescope.

$$~~E_{thr} \sim 1\sqrt{}/A_{mirror}~~ = 1/D \qquad (1)$$

The correct relation is

$$E_{thr} \sim 1/A_{mirror} = 1/D^2$$

So increase of the 10 m^2 mirror area by 20 times, i.e. an IACT with ~200m^2 reflector area, one can operate at a threshold of ≥ 50 GeV

MAGIC & threshold of an IACT

- This is related to the fact, that the deduction of the Formula(1) is based on the **wrong believe** that the fluctuations o the Light of the Night Sky (LoNS) define the threshold of an IACT
- One needs at least ~100 photo electrons (ph.e.) for speaking about a meaningful image. This condition is much stringent than the one requested by the formiula (1).
- After that we started looking for a telescope with possibly $A_{mirror} \geq 200\ m^2$. Soon found the 17 m Ø solar energy telescope of German DLR in Lampoldhausen near Stuttgart, which served as the prototype for MAGIC

Beginning of MAGIC

- In fall 1994 we performed a feasibility study for a telescope with E_{thr}~40 GeV
- One thing became clear: there was a very strong background at several tens of GeV → Multiple telescopes were needed for suppressing it
- Because of political/financial reasons we started with the stand-alone MAGIC-I, deciding to go for the 2nd (and possibly more) telescopes in future

The Main Telescopes of the *"Roque de los Muchachos"* European Northern Observatory



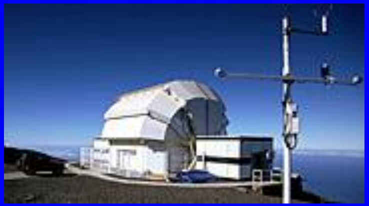


ORM is located on the Canary island of La Palma, at a height of 2200-2400 m a.s.l.





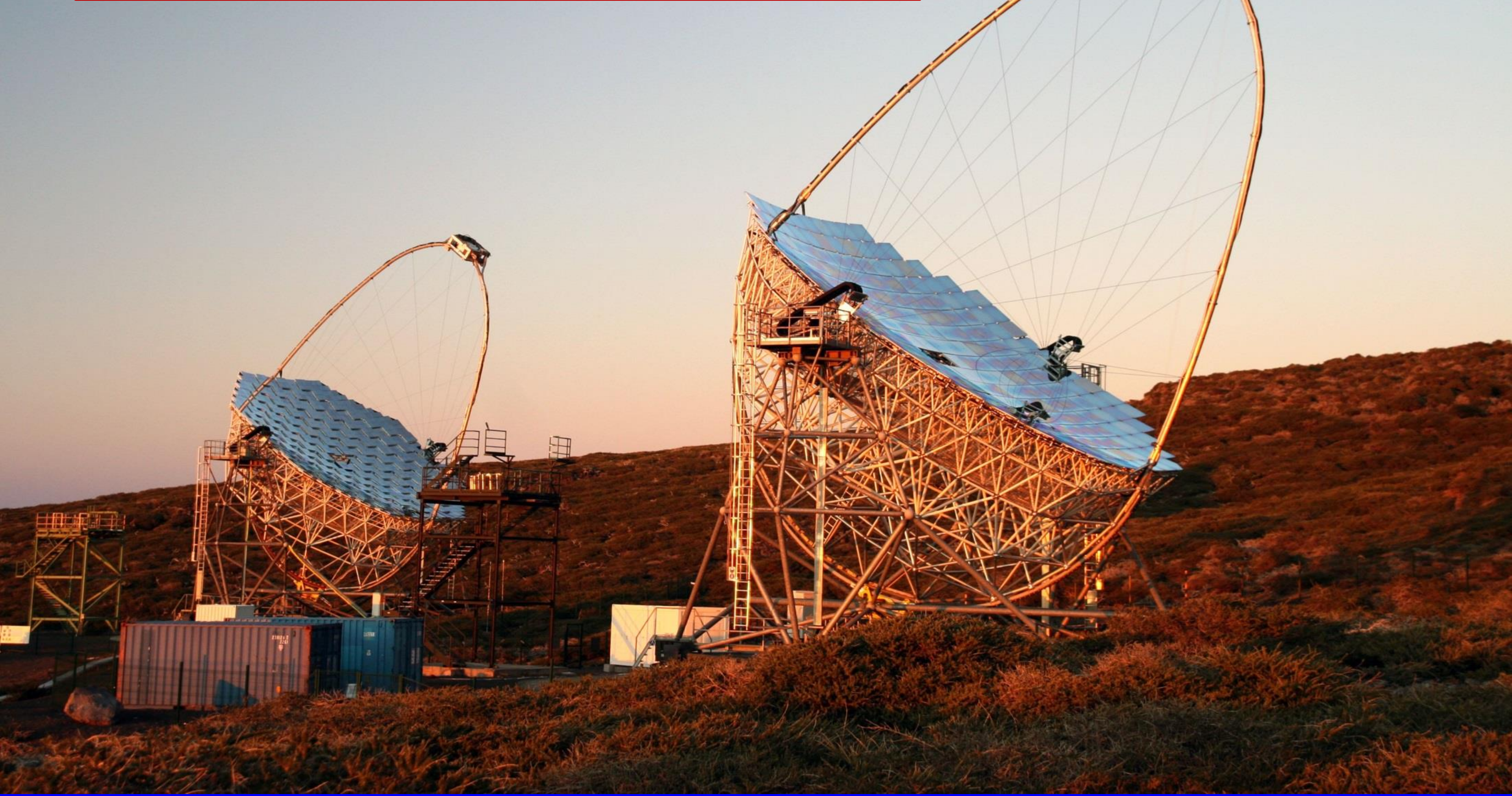





~170 Collaborating Astro-Physicists, 12 Countries

Armenia	Yerevan Physics Institute, IcraNet Armenia
Brazil	CBPF, Rio de Janeiro
Bulgaria	Sofia, Bulgaria
Croatia	Consortium (Zagreb, +…)
Finland	Consortium (Tuorla, +…)
Germany	DESY Zeuthen, U. Dortmund, MPI Munich, U. Würzburg
Japan	Consortium (Kyoto, Tokyo, +…)
Italy	INFN & U. Padova, INFN Pisa & U. Siena, INFN Como/Milano Bicocca, INFN Udine/Trieste & U. Udine, INAF (Consortium: Rome, Milan, +…)
Poland	Lodz U.
Spain	U. Barcelona, UAB Barcelona, IEEC-CSIC Barcelona, IFAE Barcelona, IAA Granada, IAC Tenerife, U. Complutense Madrid, CIEMAT Madrid
Switzerland	ETH Zurich
India	Saha Inst. Nucl. Physics, Kolkata

MAGIC: the **pioneering instrument** for γ-ray astrophysics for E ≥ 50 & ≥ 30 GeV

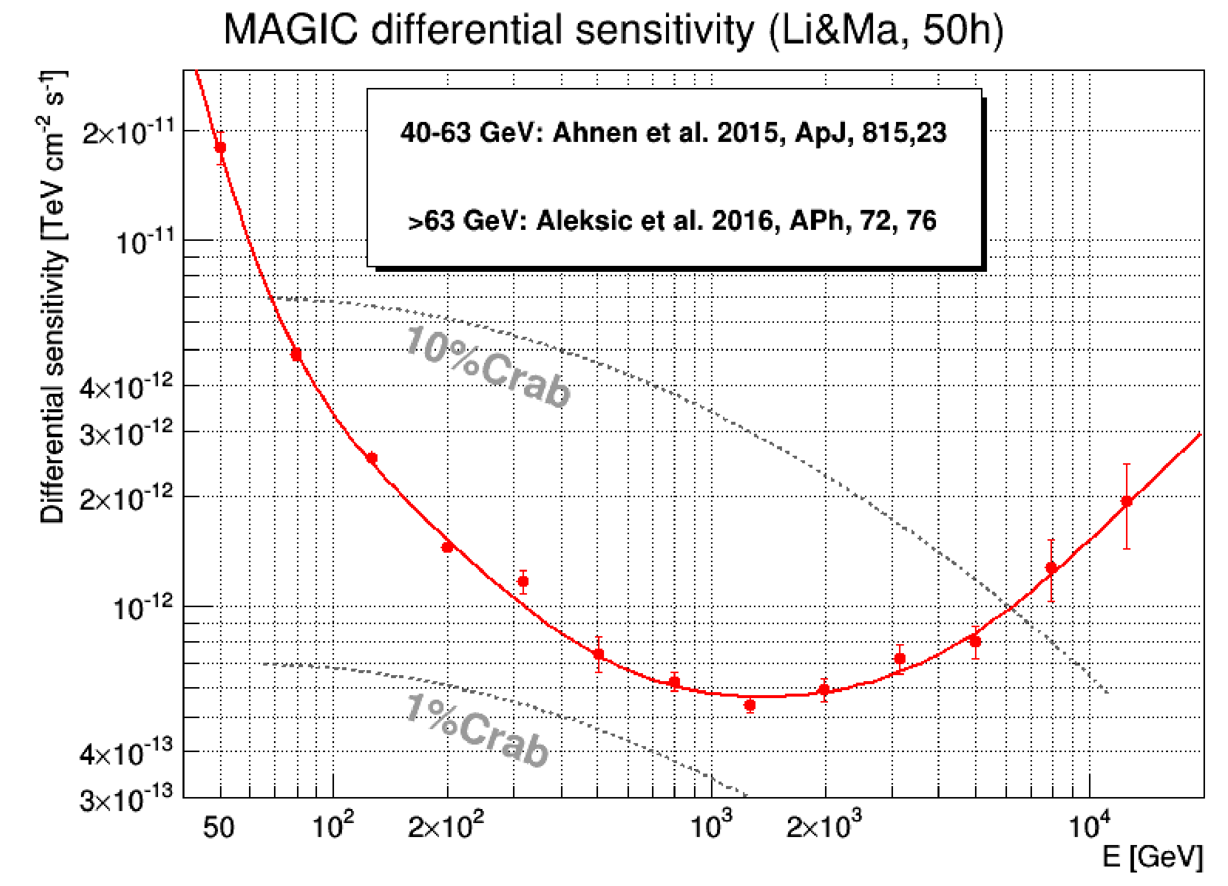


System of 2 MAGICs: the main parameters

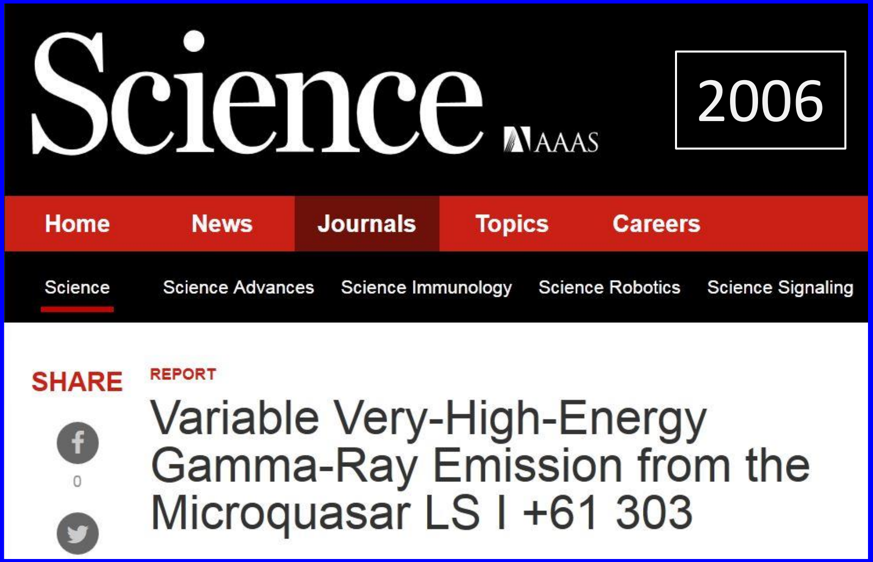
- Energy threshold (trigger): ~ 50 GeV
- Energy threshold in "*Sum-Trigger*" modus: 30 - 35 GeV
- Energy resolution: 15 % - 23 % for E ≤ 10 TeV
- Angular resolution: 0.07° for E ≥ 300 GeV;   0.05° @ 1 TeV
- Sensitivity: source with 6/1000 of Crab Nebula 5σ in 50h
- Light-weight construction, only ~ 70 T
- Fast re-positioning to any coordinates in the sky: 25s/180°
- Opto-electric design optimized to provide ~ 2.5ns FWHM pulses
- Data digitized by using DRS4 chips operated at 1.67 GigaSample/s
- Producing ~ 1 TB data per observation night per telescope

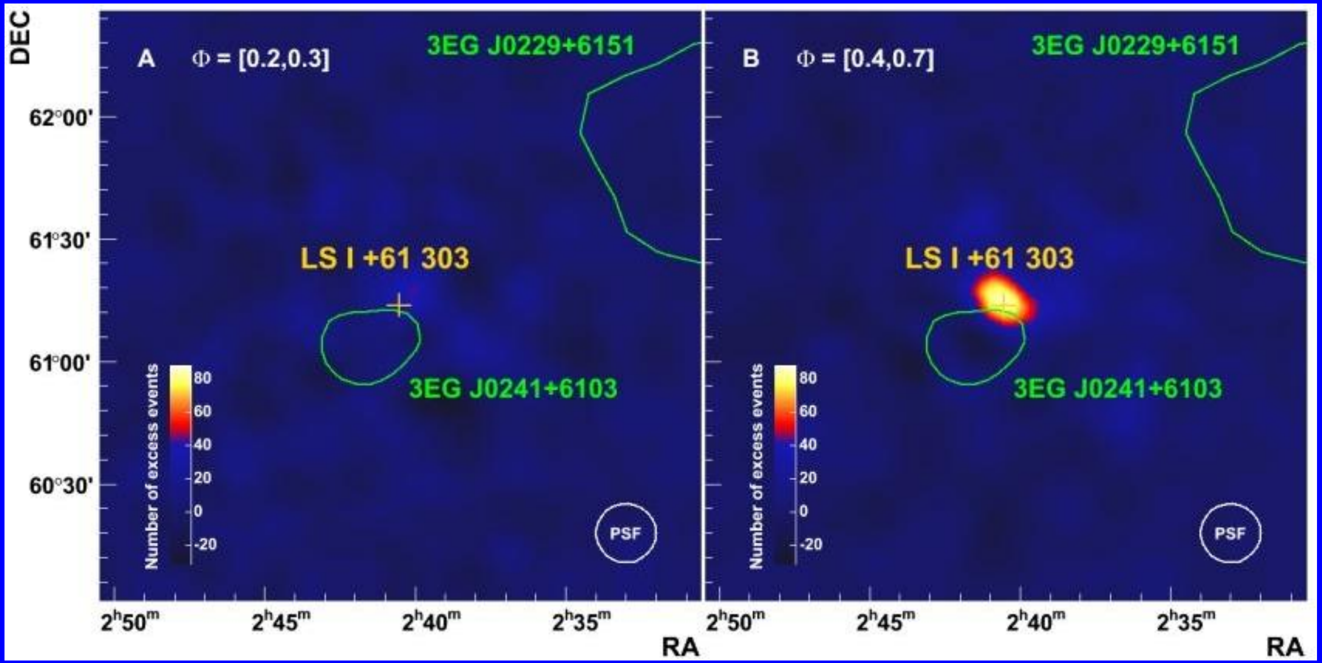
Current Sensitivity of MAGIC

~60 mCrab in 50h for $E_{\gamma} \geq 400$ GeV



2005 Started to "warm-up"





Quasar 3C-279; red shift = 0.536

Science AAAS

Very-High-Energy Gamma Rays from a Distant Quasar: How Transparent Is the Universe?
The MAGIC Collaboration, *et al.*
Science **320**, 1752 (2008);
DOI: 10.1126/science.1157087

Observation of Pulsed γ-Rays Above 25 GeV from the Crab Pulsar with MAGIC

The MAGIC Collaboration*

One fundamental question about pulsars concerns the mechanism of their pulsed electromagnetic emission. Measuring the high-end region of a pulsar's spectrum would shed light on this question. By developing a new electronic trigger, we lowered the threshold of the Major Atmospheric γ-ray Imaging Cherenkov (MAGIC) telescope to 25 giga–electron volts. In this configuration, we detected pulsed γ-rays from the Crab pulsar that were greater than 25 giga–electron volts, revealing a relatively high cutoff energy in the phase-averaged spectrum. This indicates that the emission occurs far out in the magnetosphere, hence excluding the polar-cap scenario as a possible explanation of our measurement. The high cutoff energy also challenges the slot-gap scenario.

It is generally accepted that the primary radiation mechanism in pulsar magnetospheres is synchrotron-curvature radiation. This occurs when relativistic electrons are trapped along the magnetic field lines in the extremely strong field of the pulsar. Secondary mechanisms include ordinary synchrotron and inverse Compton scattering. It is not known whether the emission of electromagnetic radiation takes place closer to the neutron star (NS) [the polar-cap scenario (*1–3*)] or farther out in the magnetosphere [the slot-gap (*4–6*) or outer-gap (*7–9*) scenario (Fig. 1)]. The high end of the γ-ray spectrum differs substantially between the near and the far case. Moreover, current models of the slot gap (*6*) and the outer gap (*8*, *9*) differ in their predicted γ-ray spectra, even though both gaps extend over similar regions in the magnetosphere. Therefore, detection of γ-rays above 10 GeV would allow one to discriminate between different pulsar emission models.

At gamma-ray energies (E) of ~1 GeV, some pulsars such as the Crab (PSR B0531+21) are among the brightest γ-ray sources in the sky. The Energetic γ-ray Experiment Telescope (EGRET) detector, aboard the Compton γ-ray Observatory (CGRO), measured the γ-ray spectra of different pulsars only up to $E \approx 5$ GeV because of its small detector area (~0.1 m^2) and the steeply falling γ-ray fluxes at higher energies. At $E > 60$ GeV, Cherenkov telescopes (*10*) are the most sensitive instruments because of their large detection areas of $\geq 10^4$ m^2. But, in spite of several attempts, no pulsar has yet been detected at such energies (*11–16*). This suggests a spectral cutoff; that is, that the pulsar's emission drops off sharply, between a few giga–electron volts and a few tens of giga–electron volts.

The Crab pulsar is one of the best candidates for studying such a cutoff. Its spectrum has been measured by EGRET (*17*) up to $E \approx 5$ GeV without a clear cutoff being seen. Earlier observations with the 17-m-diameter Major Atmospheric γ-ray Imaging Cherenkov (MAGIC) (*18*) telescope (Canary Island of La Palma, 2200 m above sea level) revealed a hint of pulsed emission at the 2.9 standard deviation (σ) level above 60 GeV (*19*, *20*). To verify this result, we developed and installed a new trigger system that lowered the threshold of MAGIC from ~50 GeV to 25 GeV [supporting online material (SOM) text] (*21*).

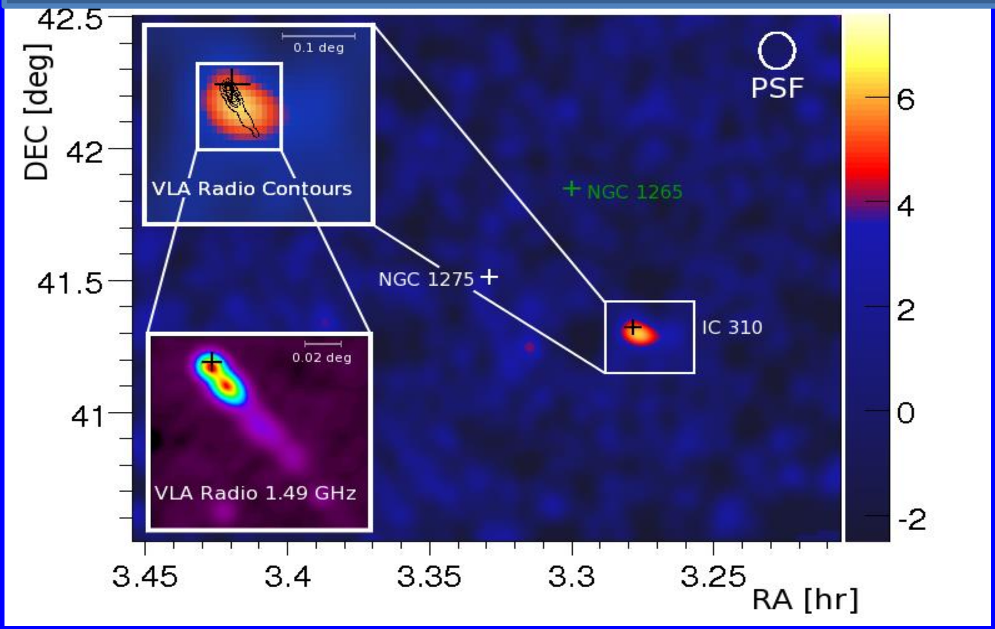
We observed the Crab pulsar between October 2007 and February 2008, obtained 22.3 hours of good-quality data, and detected pulsed emission above 25 GeV. The pulsed signal (Fig. 2) has an

*The full list of authors and affiliations is presented at the end of this paper.

www.sciencemag.org **SCIENCE** VOL 322 21 NOVEMBER 2008 **1221**

IC 310: Unexpected Discovery in the Perseus Cluster of Galaxies

IC 310: detected ≥ 30GeV by *Fermi*/LAT (Neronov et al. 2010) & ≥ 260GeV by MAGIC (Aleksic et al. 2010)

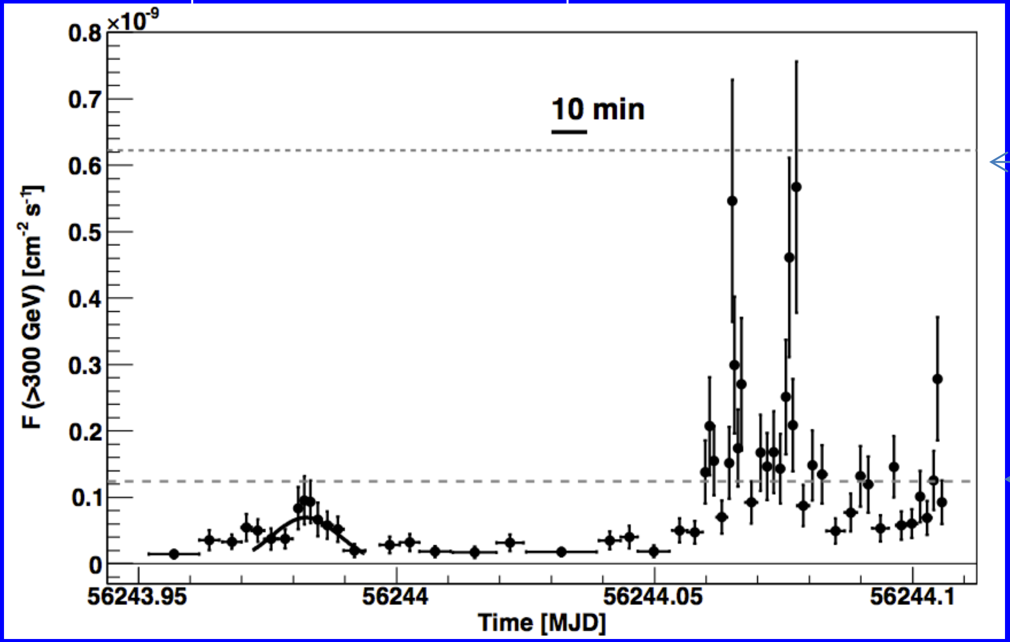


- Flux and spectral variability in X-ray
- Day-scale variability in VHE, no spectral variability
- Hard spectrum in HE and VHE → 2^{nd} hump ≥ 1TeV
- Original head-tail classification not supported
- VLBI reports parsec-scale blazar-like structures; $\theta \leq 38°$
- ➢ MWL campaign in Nov. 2012 to Feb 2013

Radiogalaxy IC 310

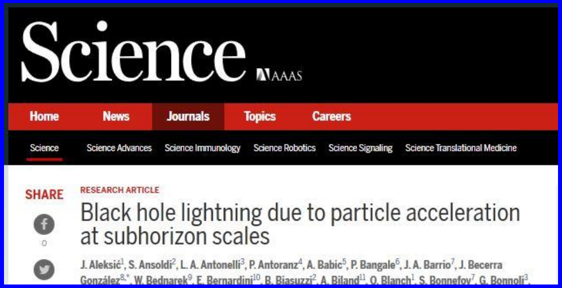
Aleksic et al., SCIENCE

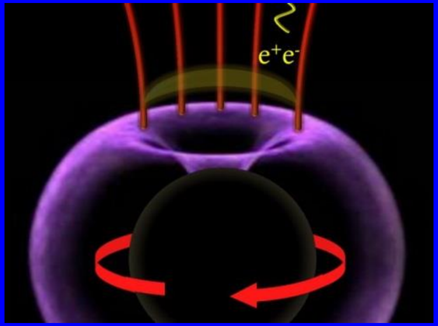
Nov.12, 2012



5 crabs

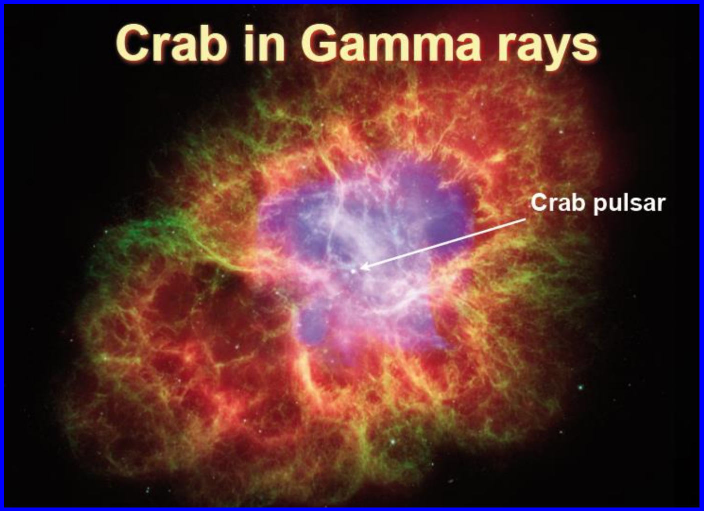
1 crab

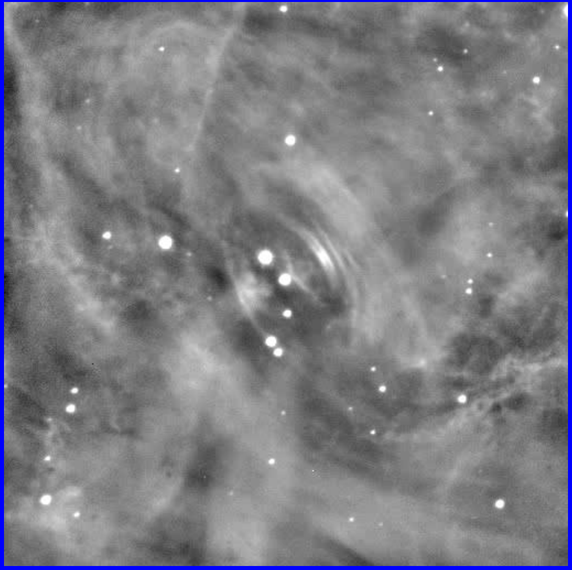




- Light curve with 1-minute bins shows extreme variability; unusual for a radio galaxy
- Still, spectral shape in the VHE remains constant
- No curvature in spectrum from 60 GeV – 10 TeV
- Difficult to explain with current (standard) theoretical scenarios

Crab nebula & its pulsar





Aliu et al. (MAGIC collab.)
Science 322 (2008) 1221
First detection of emission above 25GeV for a pulsar

Aliu et al. (VERITAS collab.)
Science 334 (2011) 69-72
First detection of emission above 100GeV

Aleksic et al (MAGIC collab.), Ap J, 742 (2011) 43,
First spectrum 25-100GeV

Aleksic et al (MAGIC collab.), A& A, 540 (2012) A69
First spectrum 50-400GeV

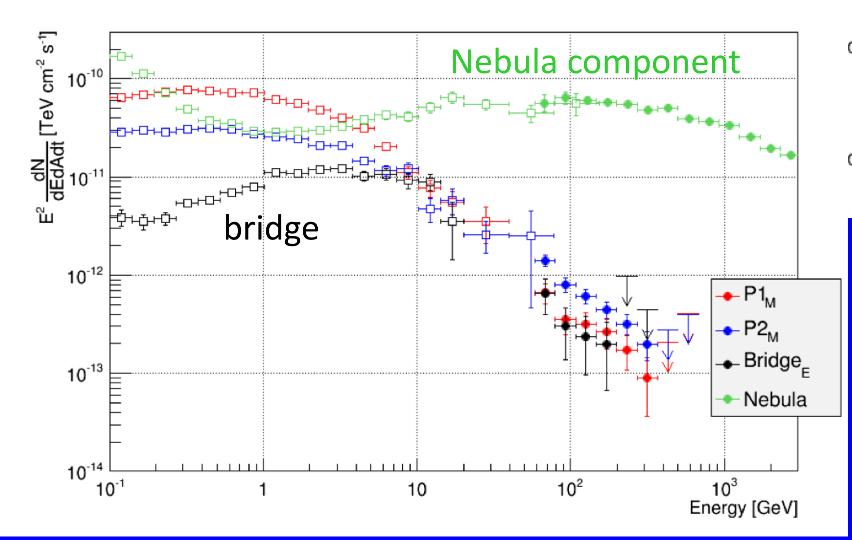
Aleksic et al (MAGIC collab.),
A&A, 565, L12 (2014)
Discovery of Bridge Emission

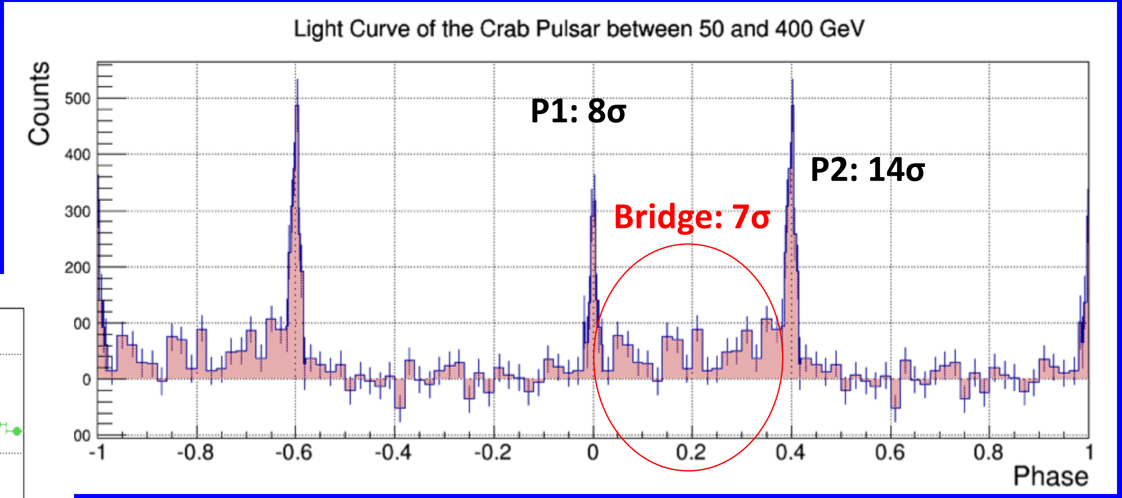
Aleksic et al (MAGIC collab.)
A&A 585 (2016)
***TeraelectronVolts pulsed gammas from Crab* pulsar**

MAGIC finds the bridge emission & very narrow pulses

J. Aleksic, et al., arXiv:1402.4219

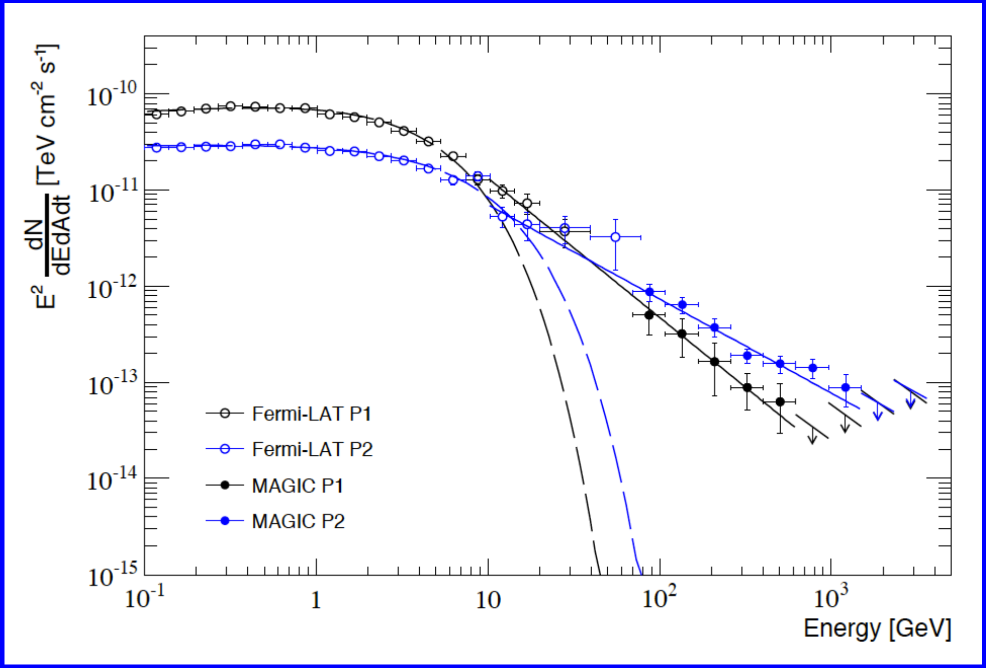
Fermi bridge emission becomes strong above few GeV





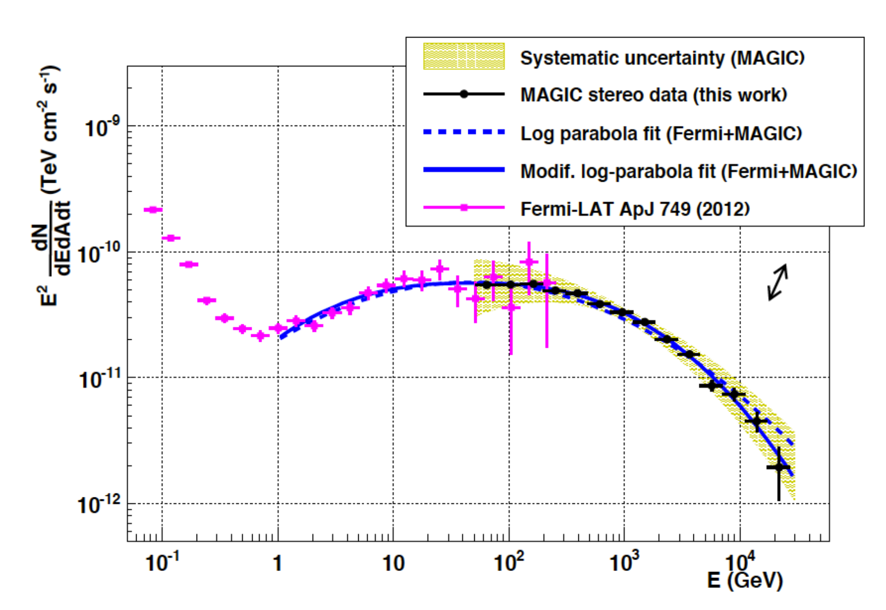
- bridge hints on toroidal bending of magnetic lines near LC
- This result set a quest for precision Crab pulsar theories

MAGIC established the Crab pulsar as the most compact accelerator of TeV γ rays



- Discovered pulsed emission from Crab pectrum extending ≥ 1.2 TeV
- Again, challenging emission models
- MAGIC-Fermi fit shows IC emission 10 GeV to ≥ 1 TeV
- Emission from the vicinity of LC (r ~ 1600 km)

MAGIC & Crab Nebula

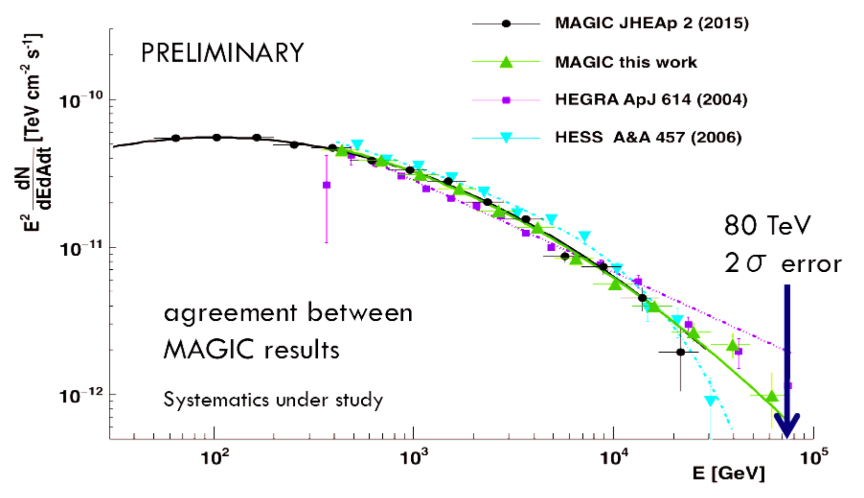


Aleksic et al. (MAGIC) JHEAP, 5, 2015

- Crab Nebula spectrum from 60 GeV till 30 TeV
- Together with Fermi LAT precision definition of the IC peak

Large zenith angle observations θ ≤ 70° for exploring the E range ~80 TeV

With a novel calibration it seems soon we can improve this result



Is Cas A a PeVatron candidate ?

- Sincle long SNRs considered as the promising source of CRs up to the “Knee”.
- But no evidence (yet) of particle acceleration up to 1015 eV!

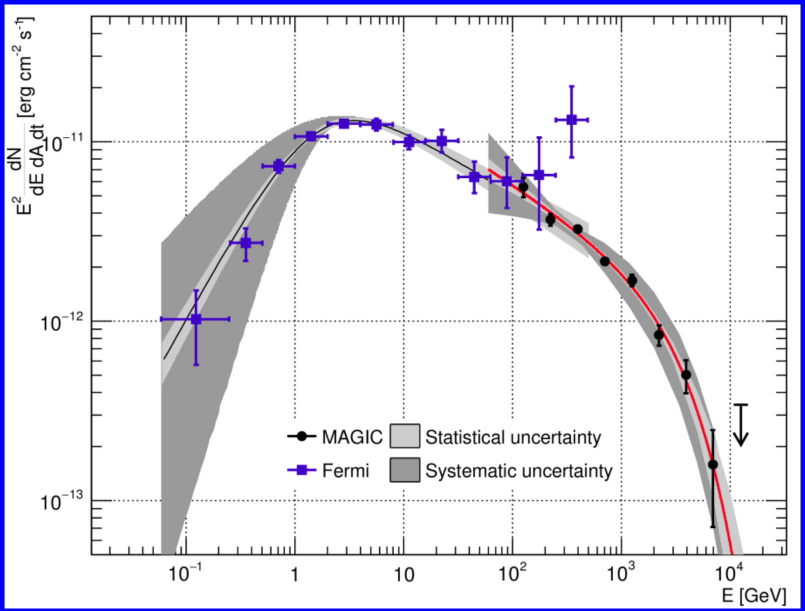
Cassiopeia A (Cas A)

- Bright and point-like in GeV/TeV (Fermi, HEGRA, VERITAS and MAGIC)
- TeV emission most likely of hadronic origin

Guberman et al, ICRC 2017

MAGIC observations

- 160h of data (2014 and 2016), mostly moon
- SED measured up to ~8 TeV
- Exponential cut-off (EPWL) fit preferred over pure power-law (PWL) at 4.6σ
- Cut-off at ~ 3.5 TeV
- Even if TeV due solely to hadrons, Cas A cannot be a PeVatron at present time.



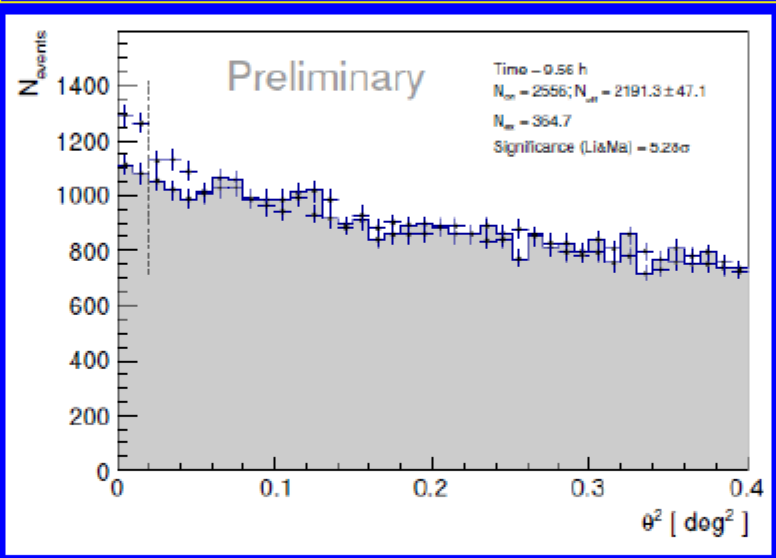
New discoveries

Sitarek et al, ICRC 2017

Almost 50 HBLs known in VHE γ-rays, but only a handful of IBLs, LBL, and FSRQ

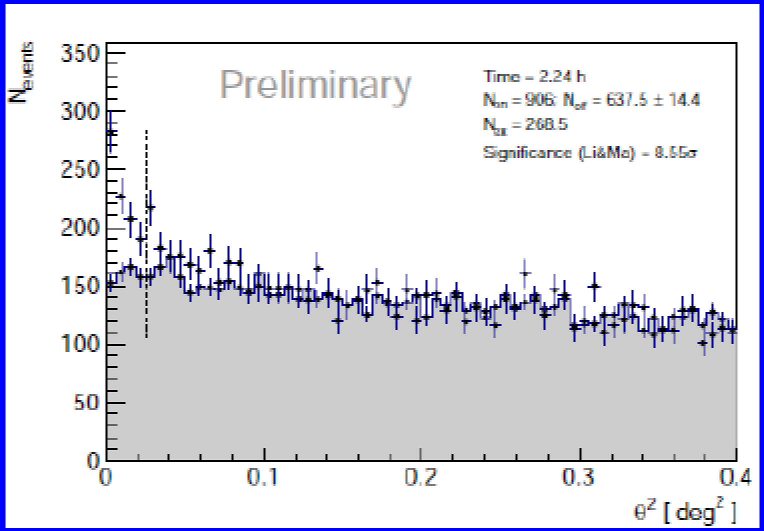
S2 0109+22

IBL at z > 0.35
Detected during high state in July 2015



OT 081

LBL at z = 0.322
Detected during enhanced state in Optical, X-ray and GeV in 2016



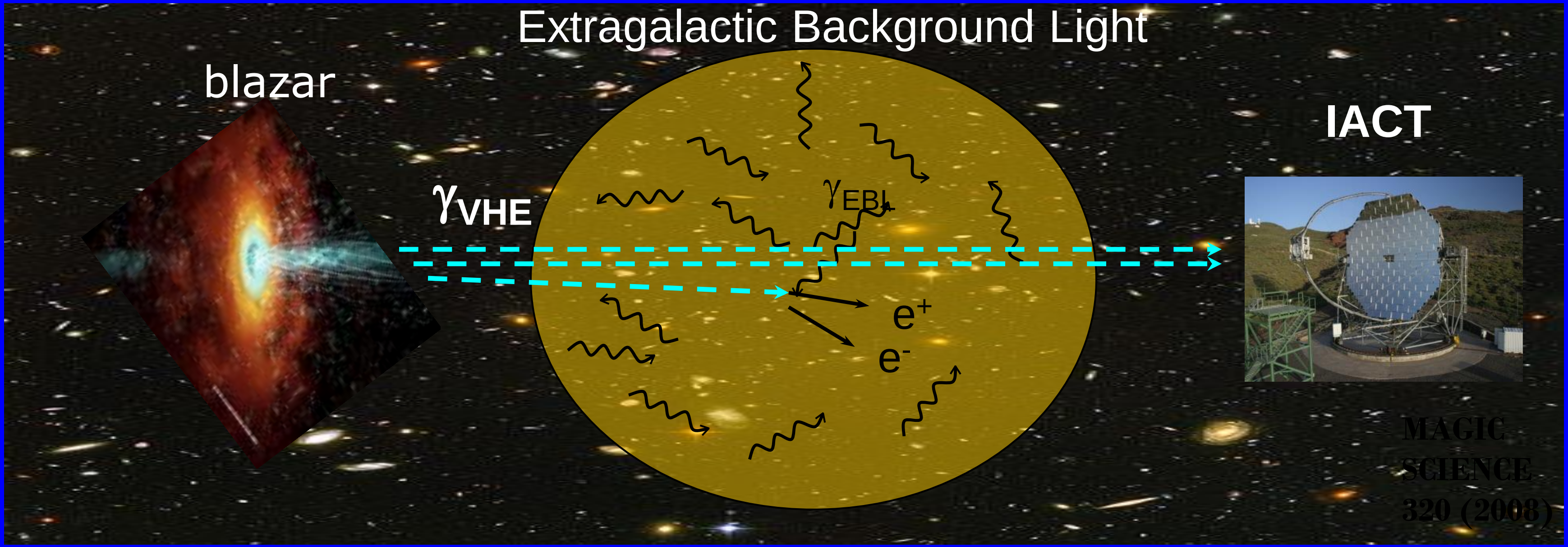
Flat Spectrum Radio Quasars

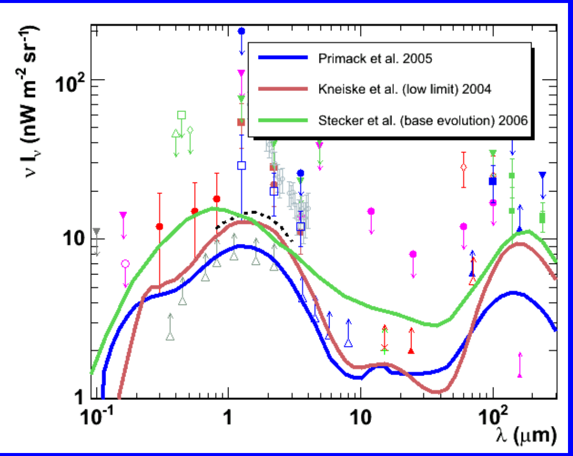
- The most luminous sources: γ-ray emitting AGN class
  - -the VLBA jets with high Doppler factors, “knots” in the jet
  - -optical spectrum shows broad emission lines
  - -SED: low synchrotron peak frequencies (infrared)

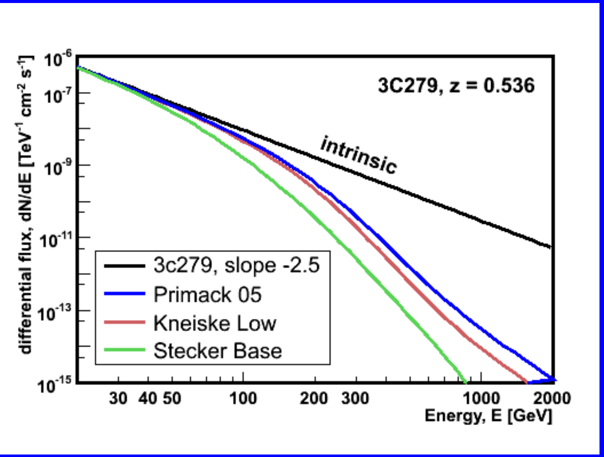
In VHE (>100GeV) gamma-rays 7(?) known, 6-MAGIC:

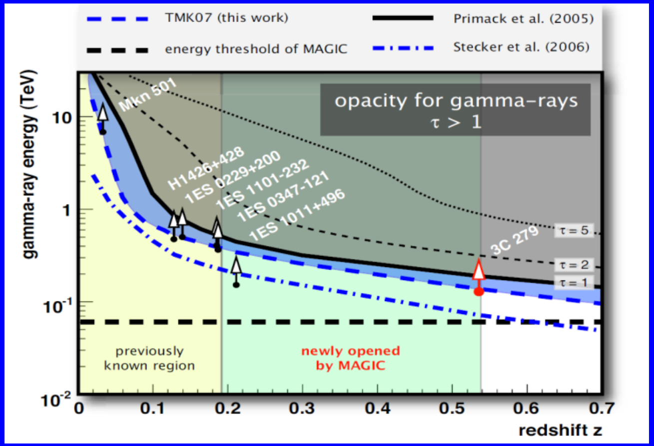
- 3C279 (MAGIC in Feb 2006 and Jan 2007, single night detections, MAGIC in Feb 2014 detection of weak signal
- PKS1510-089 (H.E.S.S. in March-Apr 2009, MAGIC in Feb-Apr 2012, March-June 2013 no VHE variability)
- PKS1222+216 (MAGIC single night in June 2010, VERITAS and MAGIC several nights in Feb 2014)
- PKS1441+25 and B0218+357
- S4 0954+65 and BL Lac disputed classifications

Gamma Ray Absorption by EBL





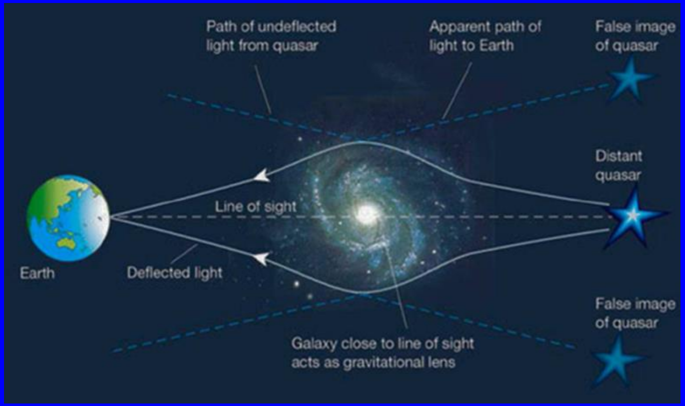


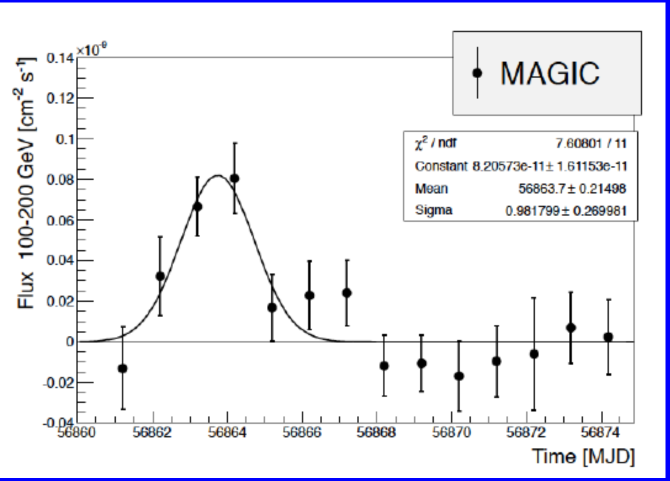


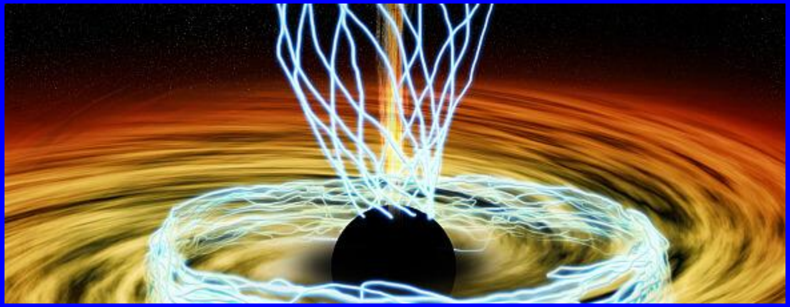
Discovery of Gravitationally Lensed Blazar S3 0218+357 residing at the red shift 0.944

- In 2012 Fermi observed high state, with many overlapping flares
- Fermi claimed 11.46 ± 0.16 days delay for the lensed component
- On July 13/14 2014 Fermi again observed a high state
- Magic started observing 2 days before the predicted delayed signal and kept on-going till 5th of August

Ahnen, et al, A&A 2016







Discovery of FSRQ PKS-1441 +25

[Previous | Next | ADS]

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

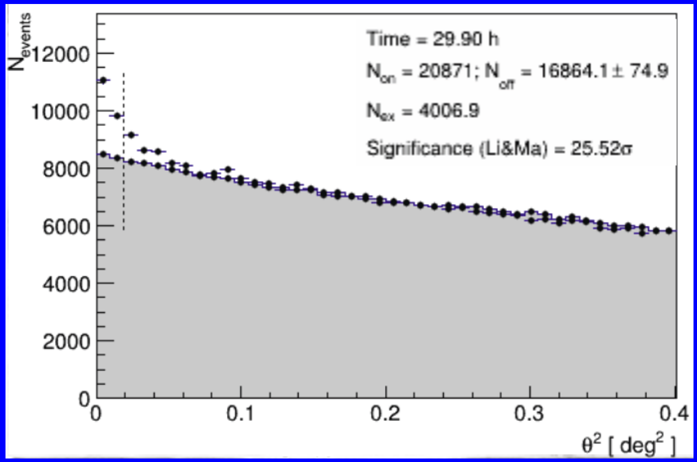
The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the FSRQ PKS 1441+25 (RA=14h43m56.9s DEC=+25d01m44s), located at redshift z=0.939 (Shaw et al. 2012, ApJ, 748, 49). The object was observed with the MAGIC telescopes for ~2 hours during the night 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.

Related

- 7459 A Giant NIR flare of the FRQS PKS1441+25
- 7433 Very-high-energy gamma-ray emission from PKS 1441+25 detected with VERITAS
- 7429 ASAS-SN Detection of an Optical Brightening in FSRQ PKS 1441+25
- 7417 High Optical Polarization Detected in PKS 1441+25
- 7416 Discovery of Very High Energy Gamma-Ray Emission from the distant FSRQ PKS 1441+25 with the MAGIC telescopes
- 7402 Optical, X-, Gamma-ray flare of the FSRQ PKS 1441+25
- 6923 Optical Activity of the Flaring Gamma-ray Blazar PKS 1441+25
- 6895 NIR Photometry of the FRQS PKD1441+25
- 6878 Fermi LAT Detection of a Bright GeV Flare from the FSRQ PKS 1441+25

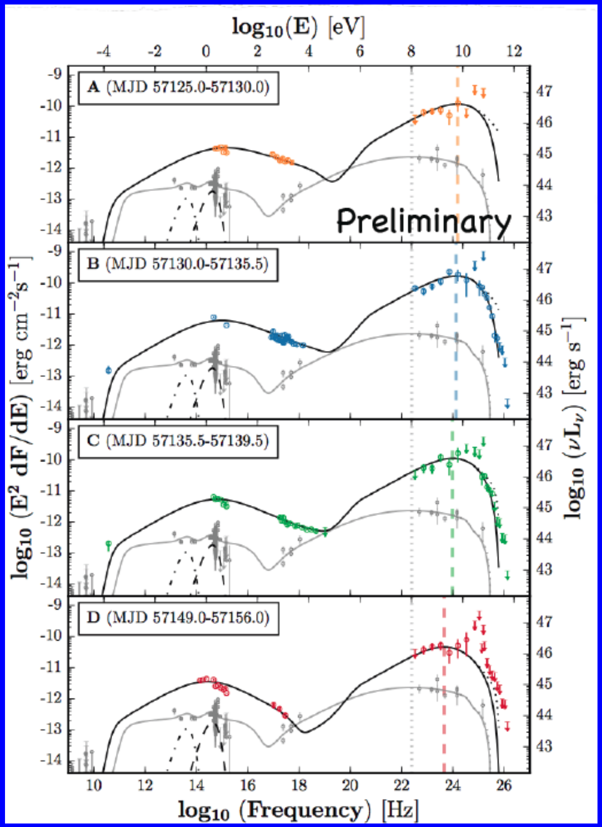
- Along with S3 0218 +357, z = 0.944, this is the most distant VHE source: **z = 0.939**
- Started observing on April 17th after alert from Fermi, for 10 days
- In a couple of days, also VERITAS started observations

25 σ, > 4000 γ events
Spectrum measured in
40 – 250 GeV energy range

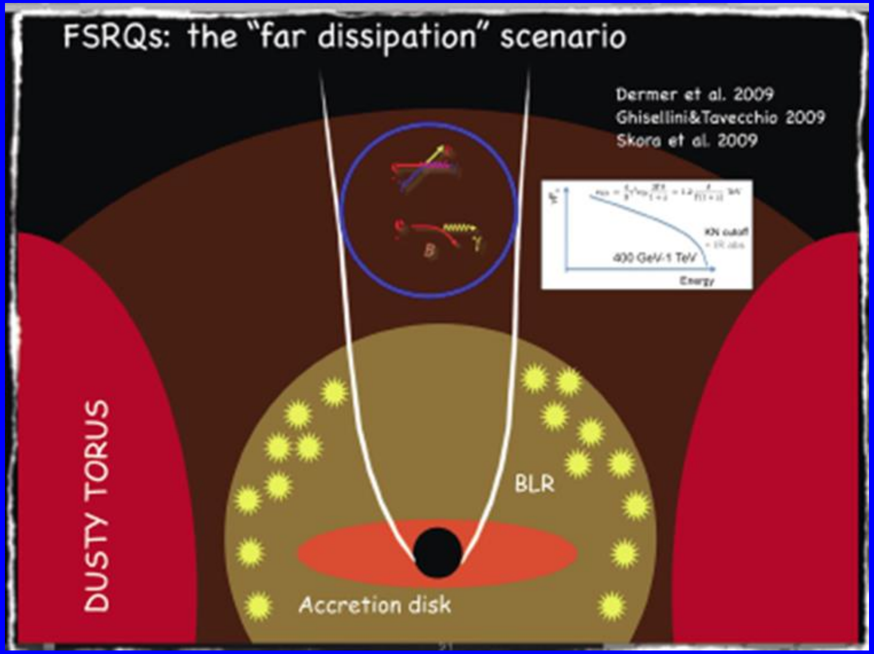


Ahnen et al, ApJ L., 2015

SED PKS-1441 +25



Lack of absorption features in the measured HE - VHE γ-ray spectra allows one to constrain the location of emitting region to be far from the center

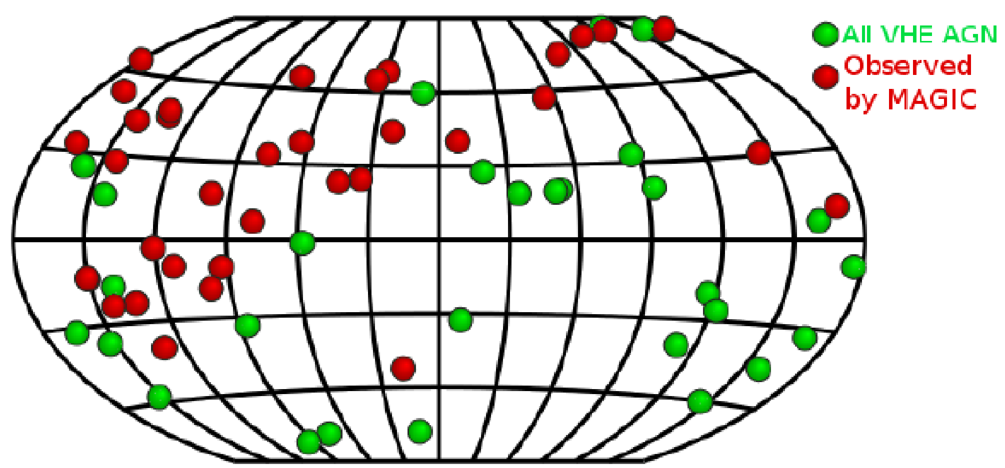


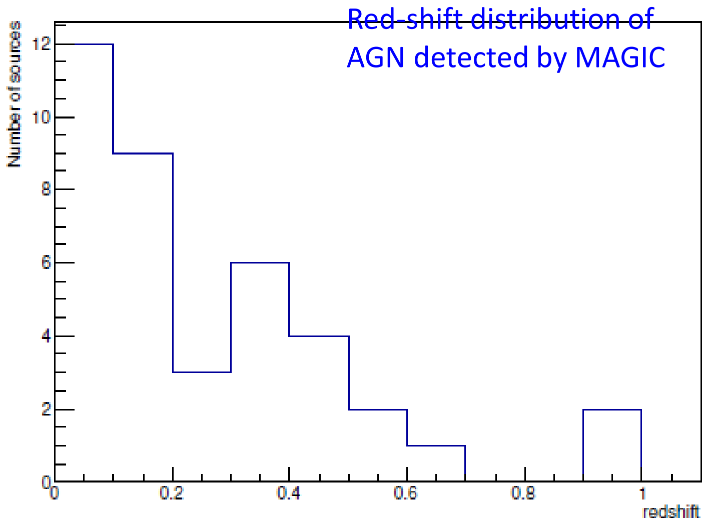
- In the 1st time it allowed us to check the EBL models till the red shift z ~1

External Compton scenario

The "MAGIC" Sky

MAGIC discovered and co-discovered 37 sources of VHE γ-rays, mostly of extragalactic origin



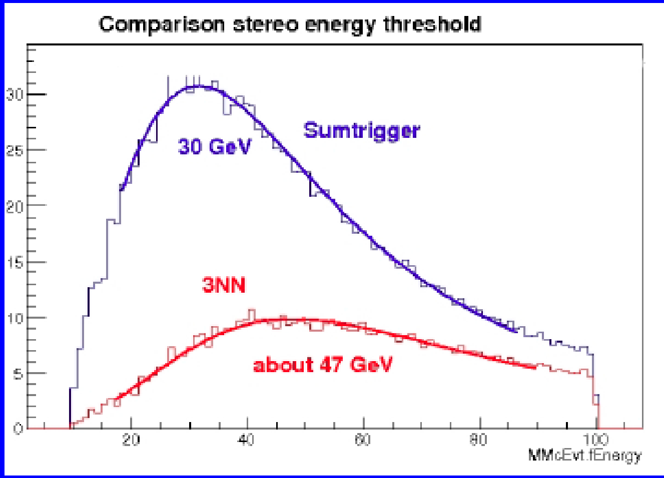


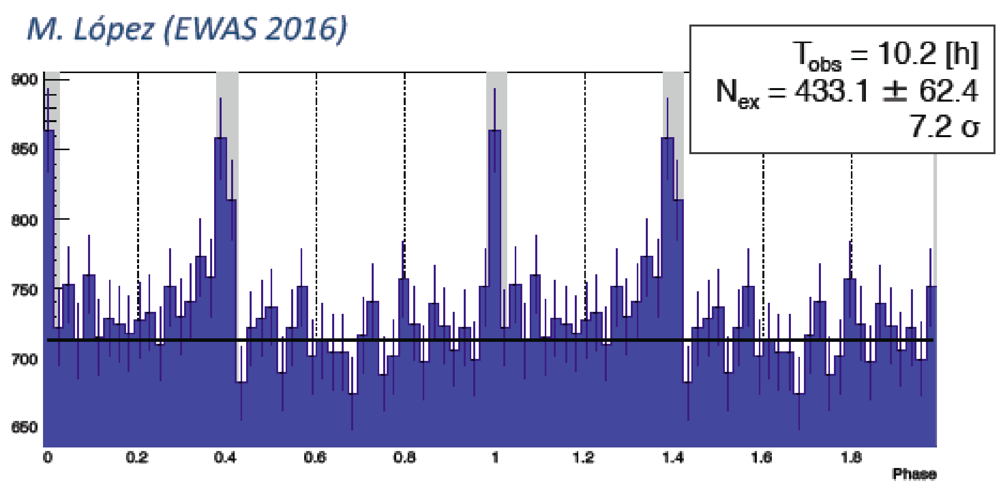
Novel "Stereo" SUM-Trigger

Lopez et al, ICRC 2017

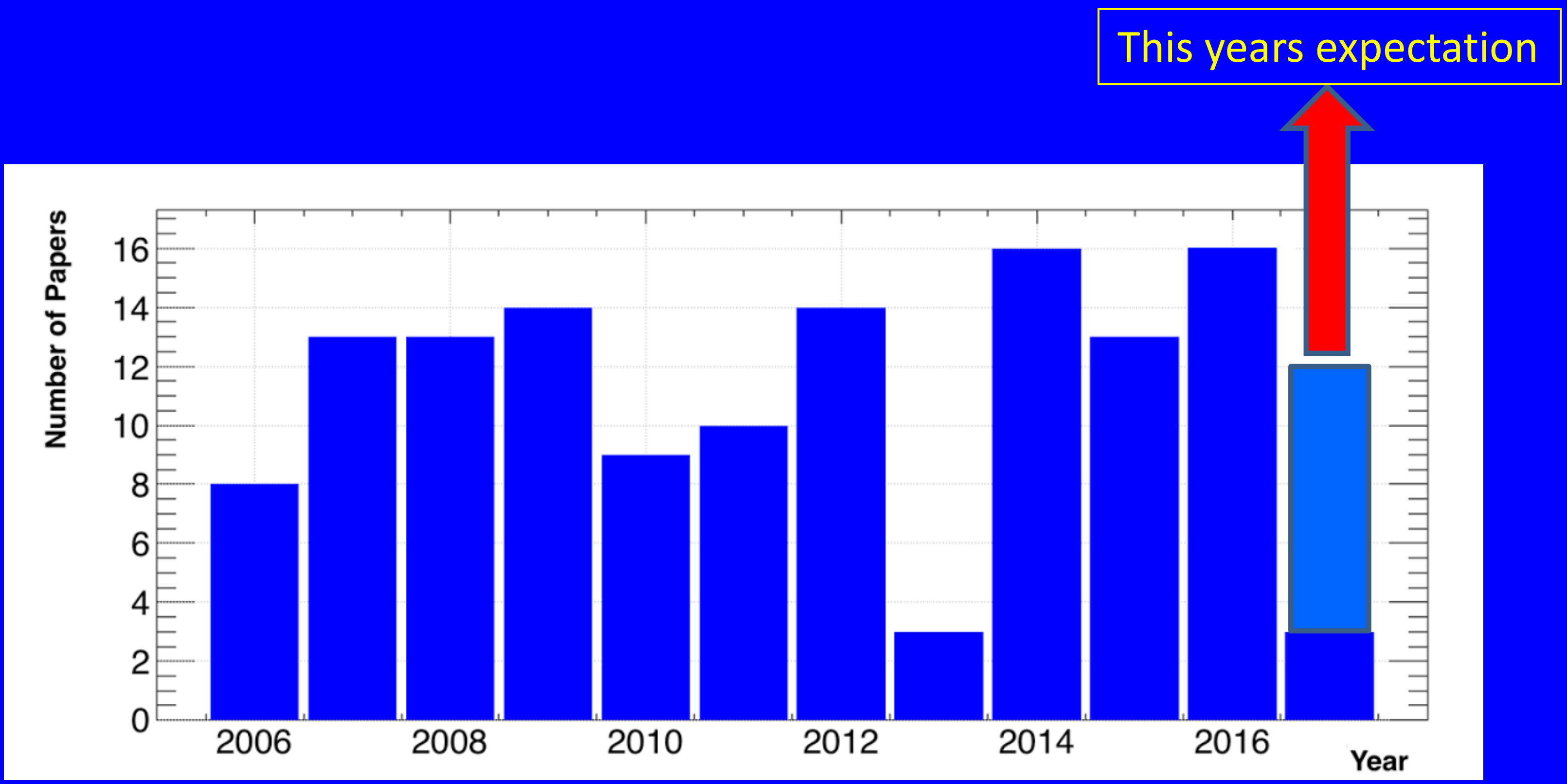
- New trigger system installed in MAGICs, reducing the energy threshold to ~ 30 GeV for improved performance for pulsars

- Test Crab pulsar data shows new trigger outperforms the standard one: Q ~ 2.3σ√t
- Interesting data may become available soon





MAGIC publication annual rates in peer-reviewed journals



VERITAS – MAGIC Common Studies

- Multiband variability studies and novel broadband SED modeling of Mrk 501 in 2009
MAGIC and VERITAS Collaborations (M.L. Ahnen *et al.*),
ePrint: arXiv:1612.09472

- A search for spectral hysteresis and energy dependent time lags from Xray and TeV gamma ray observations of Mrk 421
VERITAS and MAGIC Collaborations (A.U. Abeysekara, *et al.*),
Astrophys. J. 834 (2017) no.1, 2

- The 2009 multiwavelength campaign on Mrk 421: Variability and correlation studies
MAGIC and VERITAS Collaborations (J. Aleksić, *et al.*),
Astron. & Astrophys. 576 (2015) A126

- Multiwavelength observations of Mrk 501 in 2008
MAGIC and VERITAS Collaborations (J. Aleksić, *et al.*),
Astron. & Astrophys. 573 (2015) A50

VERITAS – MAGIC Common Studies

- The 2010 very high energy gamma ray flare \& 10 years of multiwavelength observations of M 87
H.E.S.S. and VERITAS Collaborations (A. Abramowski, *et al.*),
Astrophys. J. 746 (2012) 151

- Spectral Energy Distribution of Markarian 501: Quiescent State vs. Extreme Outburst
VERITAS and MAGIC Collaborations (V.A. Acciari, *et al.*),
Astrophys.J. 729 (2011) 2

- Insights Into the High Energy Gamma ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era
LAT and MAGIC and VERITAS Collaborations (A.A. Abdo, *et al.*),
Astrophys. J. 727 (2011) 129

Radio Imaging of the Very High Energy Gamma Ray Emission Region in the Central Engine of a Radio Galaxy
VERTIAS and H.E.S.S. and MAGIC Collaborations (V.A. Acciari, *et al.*).
Science 325 (2009) 444-448

VERITAS – MAGIC Common Studies

- Simultaneous Multi-wavelength Observations of Markarian 421 During Outburst

MAGIC and VERITAS Collaborations (V.A. Acciari, *et al.*),
Astrophys. J. 703 (2009) 169178

- The June 2008 flare of Markarian 421 from optical to TeV energies

AGILE and VERITAS Collaborations (V. Vittorini,
et al.),
Astrophys.J. 691 (2009) L13L19

- Very High-Energy Gamma-Ray Follow-Up Program Using Neutrino Triggers from IceCube

IceCube collaboration, Aartsen *et al.*; MAGIC collaboration, : *et al.*; VERITAS collaboration, : *et al.*
JINST 076, 0916, November 2016 (Submitted 2016/10/06)

- Work is on-going on VER J0521+211 (RGB J0521.8+211), 1es0229 (Extreme HBL, paper

under preparation with H.E.S.S., VERITAS and MAGIC), 1es1959+650 (big flare in 2016)
on blazar physics with Fermi, probably also PG1553, also on Lorentz Invariance Violation (many flares), Dark Matter using Dwarfs,…

MAGIC future

- Recently at the general meeting of the MAGIC collaboration in Split, Croatia, the Collaboration Board decided to prolong the MAGIC MoU and operate the telescopes for another 5 years

- I wish that my colleagues from VERITAS and H.E.S.S. will also continue measuring with their powerful instruments for at least 5 more years; these 3 instruments strongly contributed into the VHE γ-astrophysics and as we can see, they are still making strong contributions

In some 5 years hopefully the CTA telescopes will have a matching sensitivity compared to the current instruments; then we can reconsider the new situation

Summary

- MAGIC was inaugurated in 2003
- Commissioned in 2004 and started producing science data
- Currently MAGIC is in it's **historical most productive phase**
- Since 4 years operating with the **historical best sensitivity**
- Plan to operate the telescopes for at least another ~ 5 years
- Plan to celebrate the 15-years after inauguration of MAGIC next year in La Palma