Highlights of MAGIC

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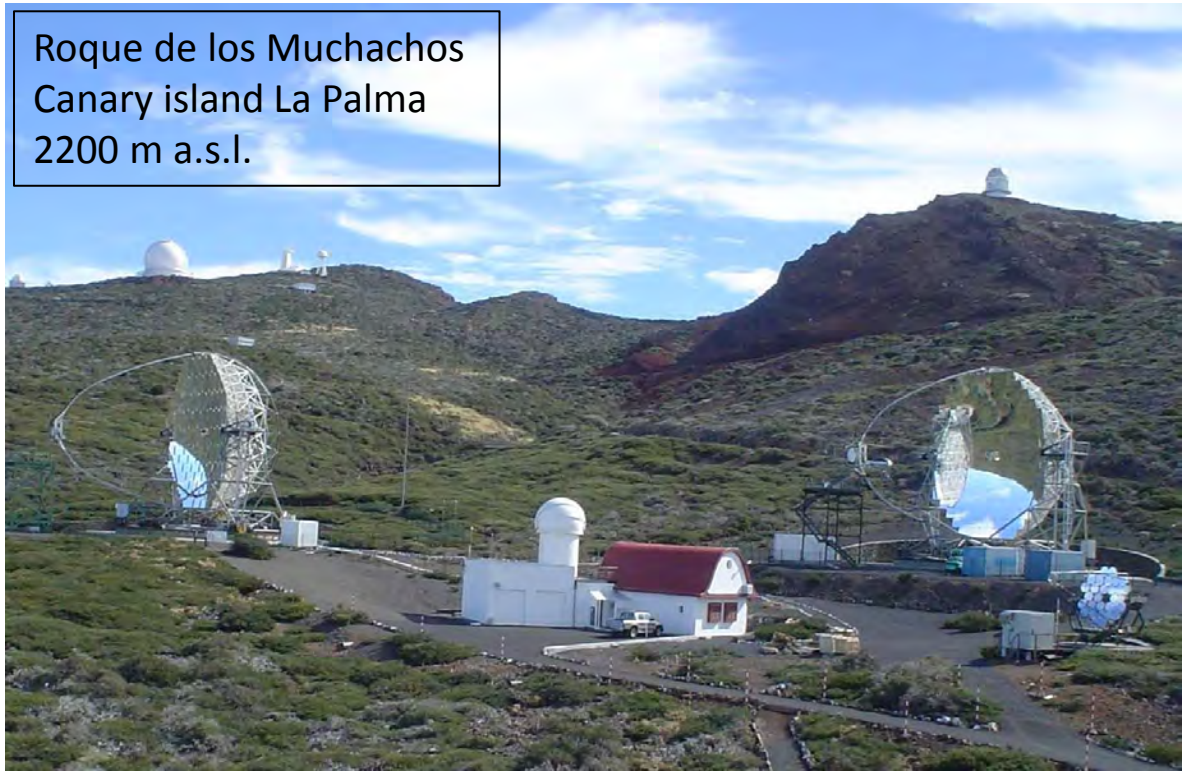
Munich, Germany
On Behalf of the MAGIC Collaboration

The MAGIC Telescopes

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

~160 astro-physicists from 10 countries



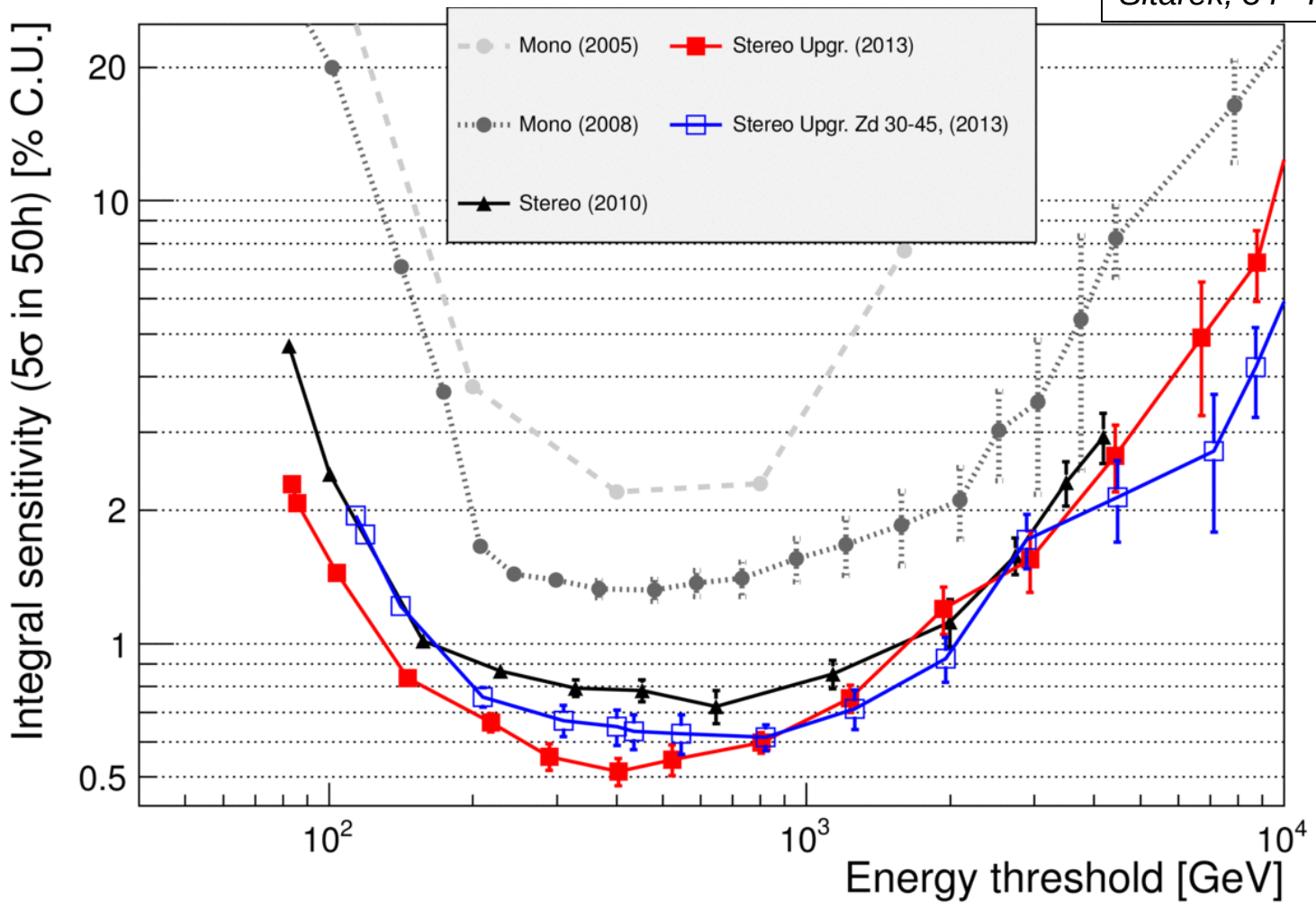
Collaboration member countries: Bulgaria, Croatia, Finland, Germany, India, Italy, Japan, Poland, Spain, Switzerland

- 2 x 236 m^2 mirror, F = 17m
- M1 - M2 distance: 85m
- $E_{thresh.}$ (std. trigger): ~ 50 GeV
- $E_{thresh.}$ *Sum-Trigger:* ~35 GeV
- $\Delta E/E$: (15-20) %
- $\Delta\theta$: (0.05-0.1)°
- Sensitivity: ~ 0.6% Crab/50h
- Light-weight, only ~70 T
- Re-positioning: ~180°/25s
- Analog signal transmission by using 162m optical fibres
- ~2.5ns FWHM pulses
- Digitization: 1.64 GS/s DRS4
- ~ 1 TB/(telescope & night)

Evolution of MAGIC sensitivity with time

4-fold improvement in sensitivity over the history of MAGIC

Sitarek, 34th ICRC, GA11



1st time IACT publication included **LIDAR** corrections: measurement of Mrk-501 flare

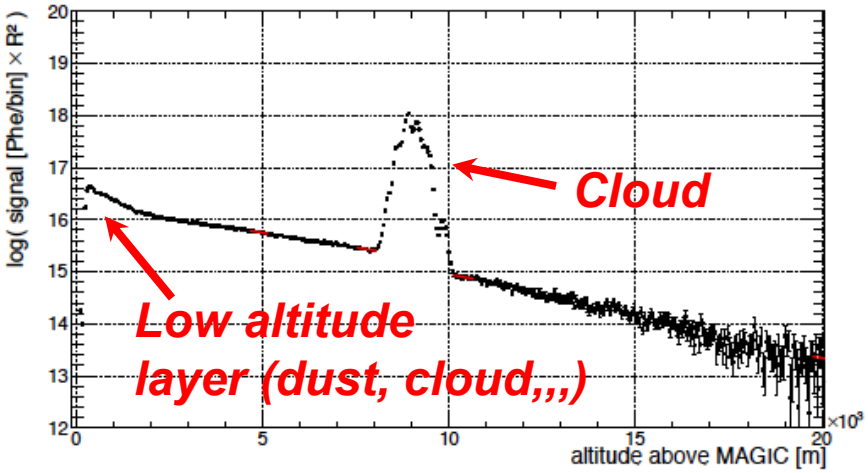
- Recovered 10 hours of crucial data from flaring activity of Mrk501 *Noda, 34th ICRC*

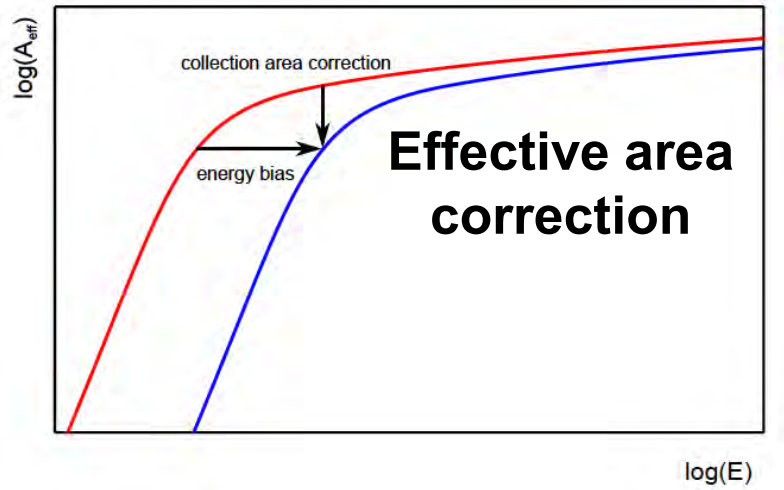
μ-LIDAR used to CORRECT and RECOVER data taken under adverse weather conditions

- **Effective area and energy corrected event-by-event basis**

LIDAR, next to MAGIC

Example: LIDAR response





Flat spectrum radio quasars with MAGIC

Becerra, 34th ICRC, GA04

- Only 5 (6) FSRQs so far detected in VHE, 5 (4) discovered by MAGIC
- More complex than BL Lacs, strong broad-line region can absorb γ's.
  Can be used for probing the emitting region within the jet
- Extensive MWL campaigns crucial to understand emission mechanisms and λ correlations: *OVRO, Fermi-LAT, Swift, Steward, Perkins, KVA, Carma, Metsahovi*

Source	Redshift	Discovery	Year
3C 279	0.5362	MAGIC	2006
PKS1510-089	0.361	H.E.S.S.	2009
PKS 1222+216 (4C + 21.35)	0.432	MAGIC	2010
B 0218+357	0.944	MAGIC	2014
PKS 1441+25	0.939	MAGIC	2015
S4 0954+65* (class. debate)	>0.368	MAGIC	2015

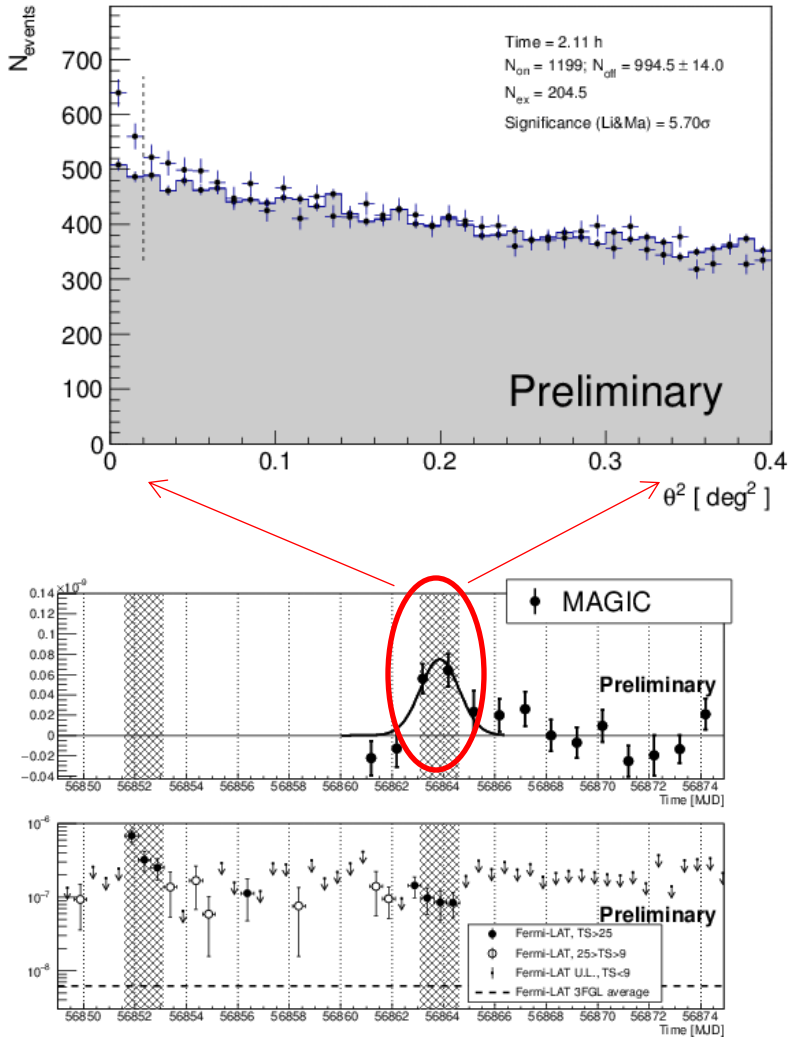
Breaking the red shift barrier, B0218+357: Gravitationally μ-lensed blazar @ z=0.944!

MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

Sitarek, 34th ICRC, GA08

- In 2012 *Fermi-LAT observed ~11.5d delay between the direct & lensed components*
- Next GeV flare by *Fermi-LAT in July 2014*
- Observations with MAGIC performed during the 2nd flare: detection of sub-TeV lensed emission → much more prominent emission than by Fermi
- VHE emission from z~1 is strongly attenuated above ~100 GeV
- GeV + sub-TeV observations can put constraints on the EBL models at z ≤ 0.94 → impact on cosmology models

μ-lensing evolution in time can allow one to strongly constrain size of the source



γ signal from the further half of the Universe: the FSRQ PKS 1441 @ z = 0.939 !

MAGIC
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MacOS: Dashboard Widget

The Astronomer's Telegram

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

- **25 σ signal**
- **$E_{threshold}$ ≥ 45 GeV**

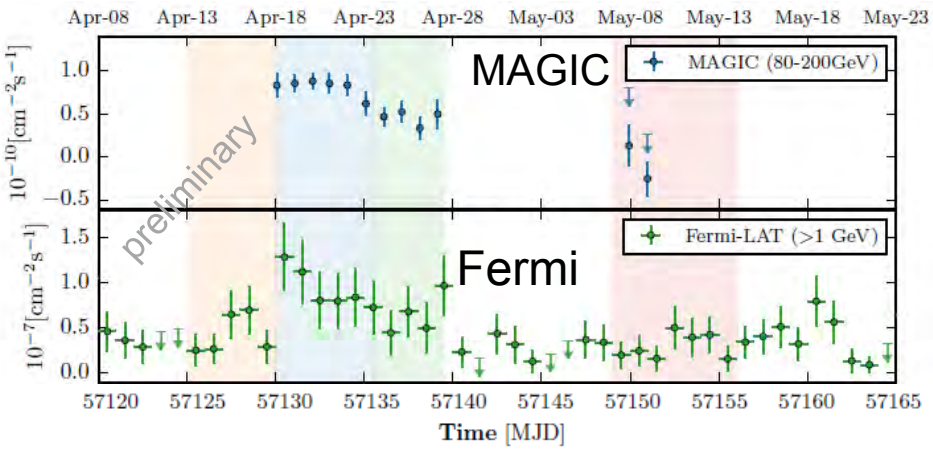
Related

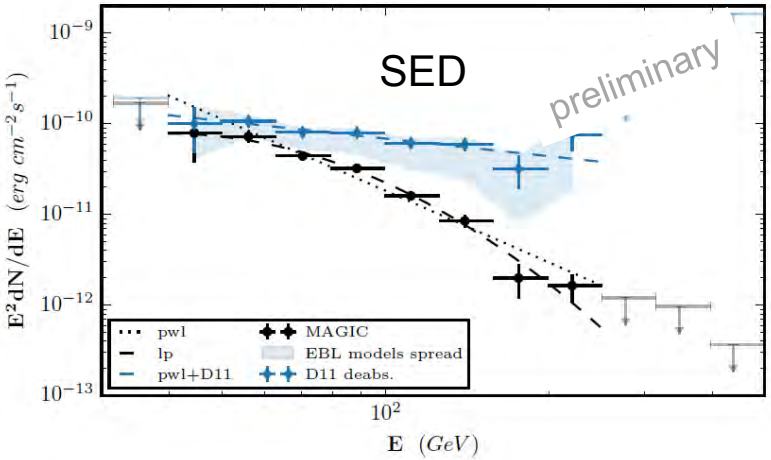
7459 A Giant NIR flare of the FRQS PKS1441+25

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



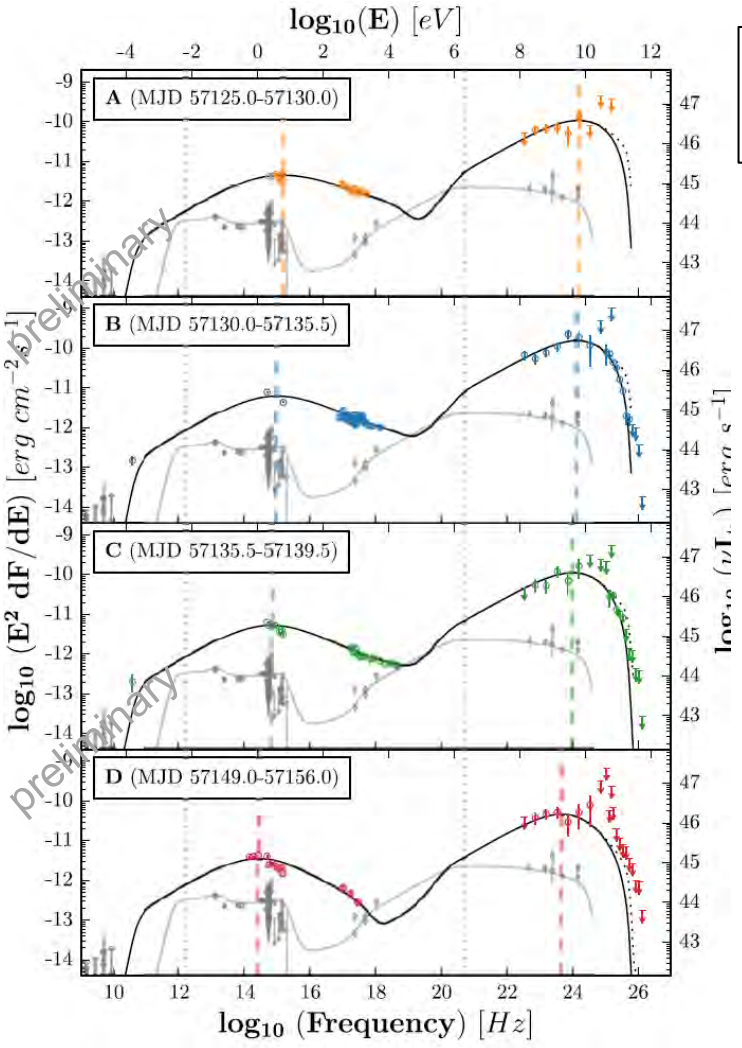


γ signal from the further half of the Universe: the FSRQ PKS 1441 @ z = 0.939 !

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Becerra, 34th ICRC, GA04

MAGIC +MWL SED

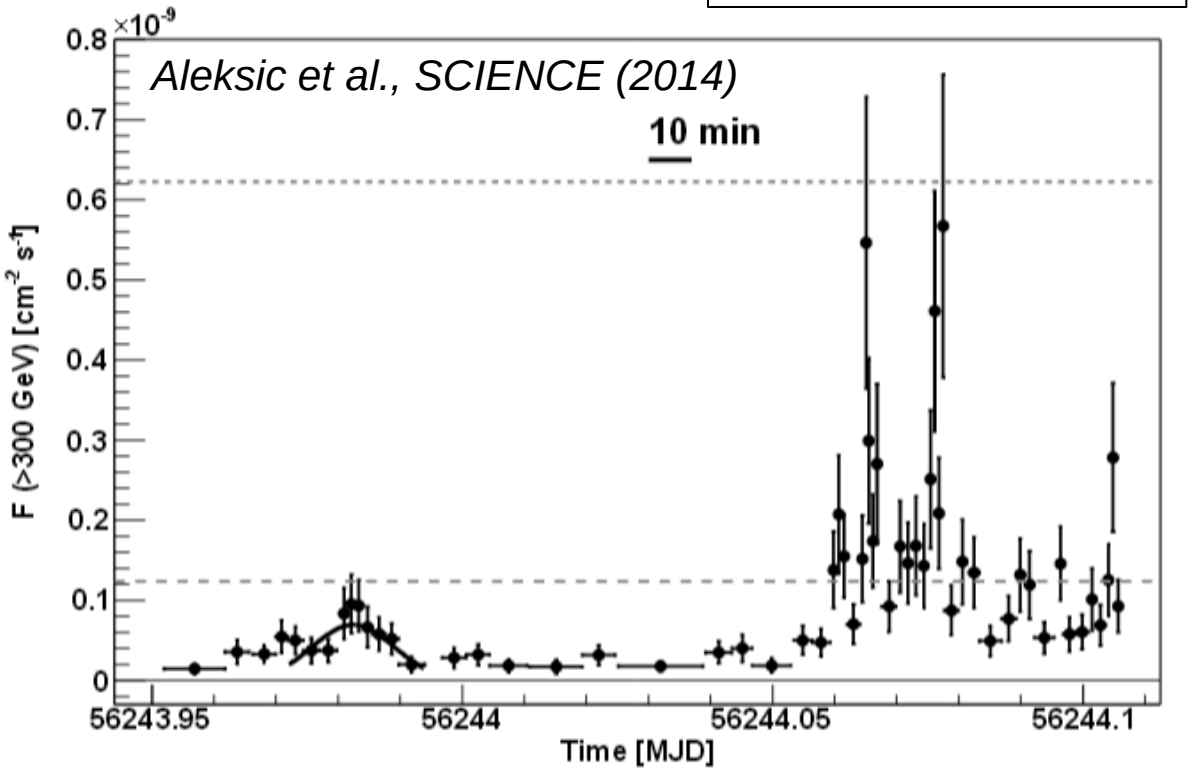


Black Hole Lightning from IC 310

- Variable X-ray & γ-ray flux *Aleksic et al, (2014) A&A*
- pc scale structure in radio VLBI images
- Blazar like (not a head-tail radio galaxy), but the viewing angle $10° \leq \theta \leq 20°$
- Because not a blazar, no strong Doppler boost

Glawion, 34th ICRC, GA07

- MWL campaign in 2012 – 2013
- Bright, variable TeV flare detected Nov 12/13, 2012
- Flux doubling time: < 4.8 min
- Hard, simple power-law spectrum up to 10 TeV

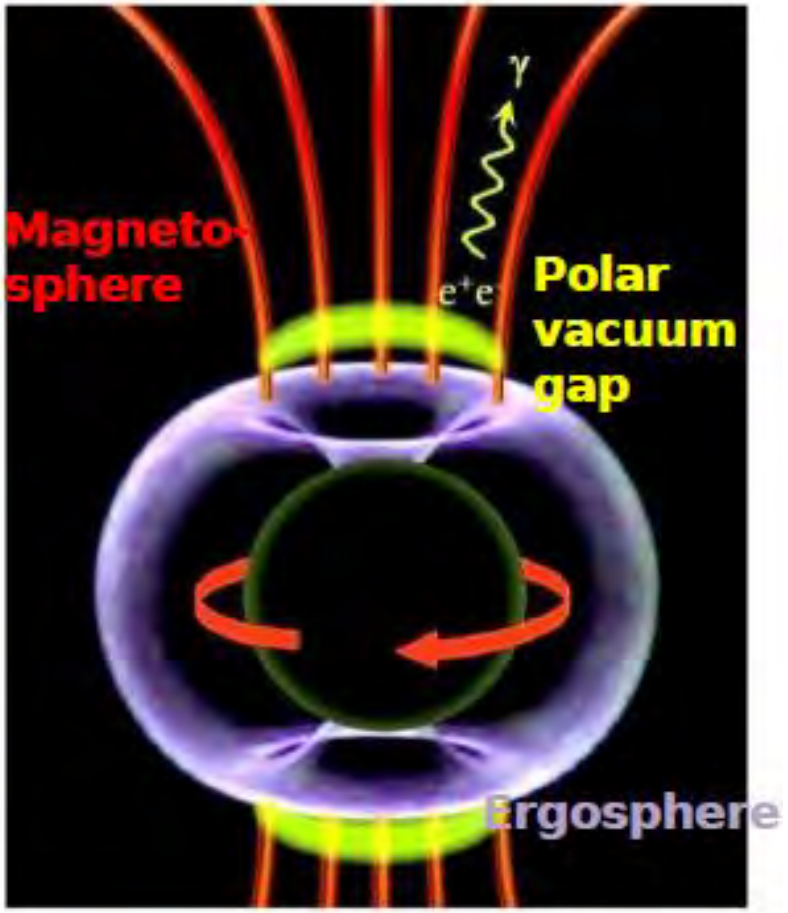


Black Hole Lightning from IC 310

Glawion, 34th ICRC, GA07

Aleksic et al., SCIENCE (2014)

- Emission region constrained to $< 0.2\delta R_G$ from variability
- Huge optical depth for $\gamma\gamma$ pair production due to small Doppler boost → inconsistent with shock-in-jet model
- Magnetospheric model similar to pulsar models
  (e.g. Levinson & Rieger, 2011)
- Acceleration of particles close to black hole in vacuum gaps
- hard γ-ray spectrum due to electromagnetic cascading



Extensive MWL campaigns on Mrk421 and Mrk501

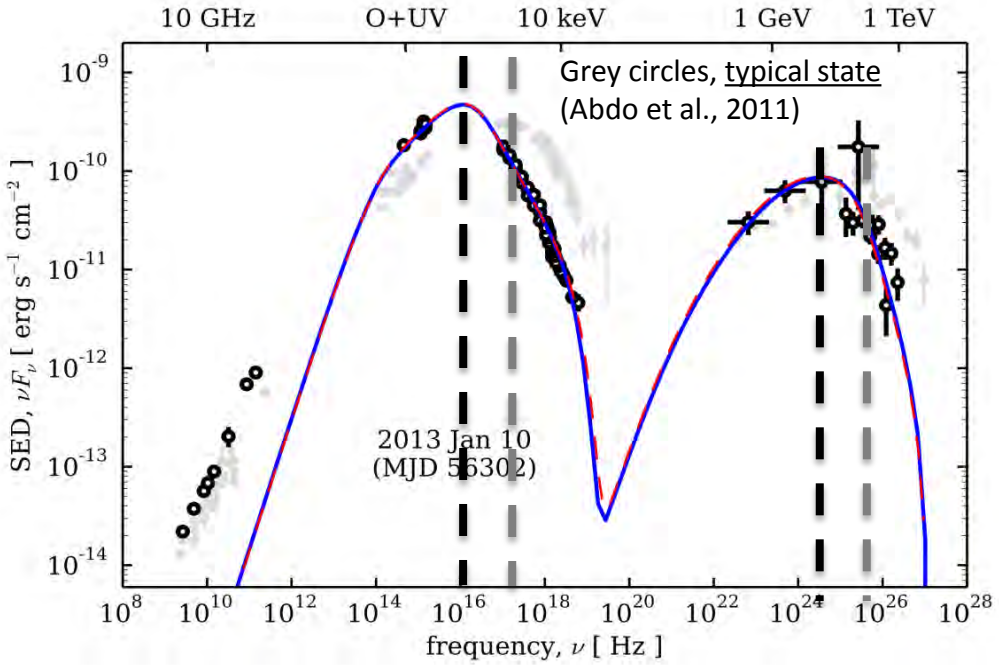
"easiest" blazars:

→ nearby, bright in all energy bands and no broad line region effects

- More than 25 instruments participate, from radio to VHE
  → Regular observations by **MAGIC and VERITAS**
- Monitoring regardless of activity, also in "low states"

Low activity in blazars is as interesting as fares, but can only be studied in the brightest sources

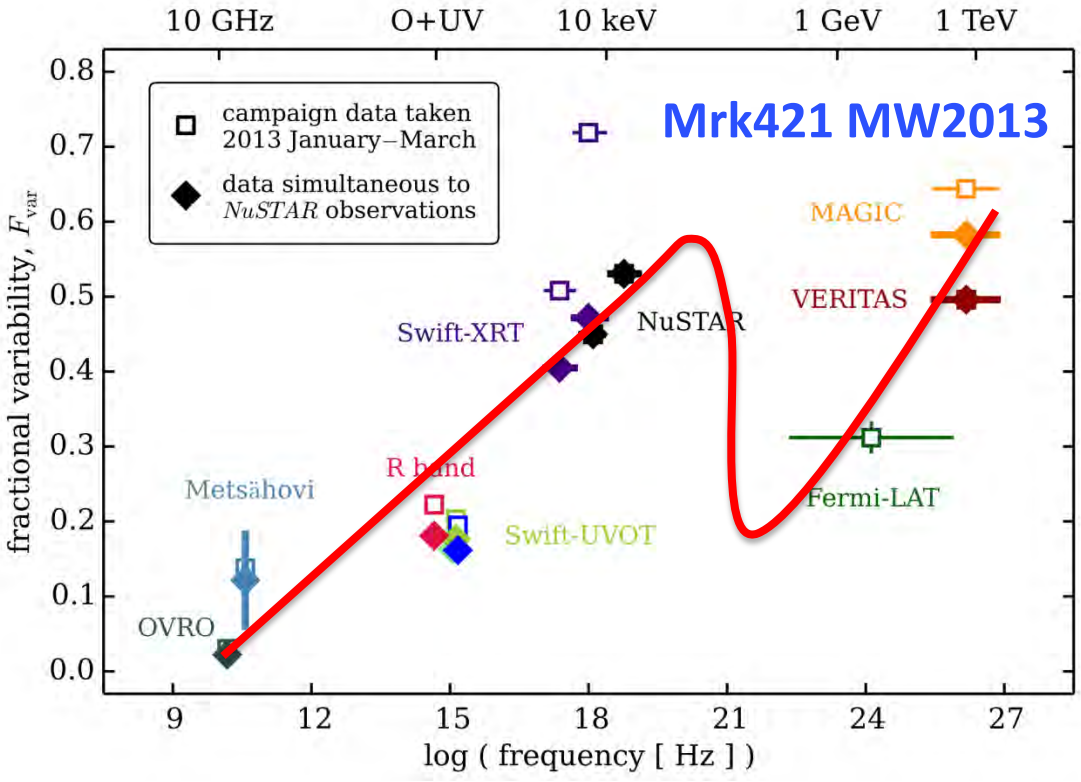
SED of Mrk421 in January 10, 2013 (First MWL campaign that included NuSTAR)



Synchrotron and IC peak shifted to ~ 10 times lower energies

→ **Never seen before for any blazar**
→ ***"HBL moving towards IBL"***
→ **Low activity softened the X-ray and VHE spectra, but did not show spectral cutoffs**

Fractional variability vs energy band



Double-bump structure in F_{var} vs E (related to the two SED bumps)

→ **F_{var} increases with E for each bump**

→ *Largest variability in the highest energy electrons*

Similar variability pattern observed in **2009** (LOW activity, ***Aleksic et al., 2015, A&A 575***) and **2010** (HIGH activity, **Aleksic et al., 2015 *A&A* 578)**

→ **intrinsic characteristic of Mrk421, in both high and low states**

In Mrk501, the variability at VHE is higher than that at X-rays.

→**Different from what is observed in Mrk421**

→ Details about variability in Mrk501:

Aleksic et al, 2015, A&A 573; Doert & Paneque, 2013 (arXiv:1307.8344) and Furniss et al, subm. ApJ

Hughes, 34th ICRC, GA 07

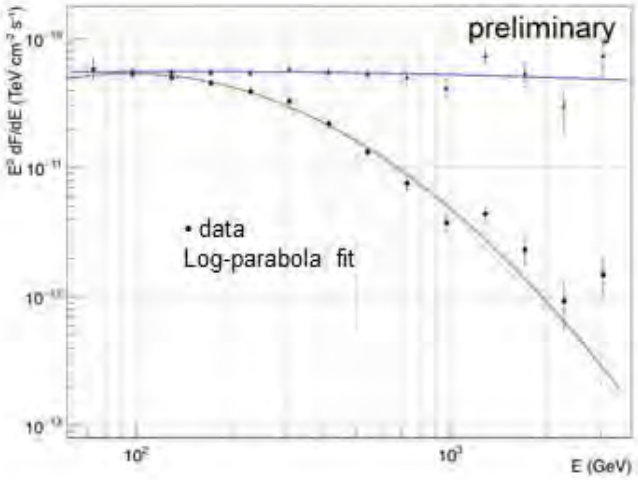
Noda, 34th ICRC, GA12

1ES 1011+496 February 2014 flare

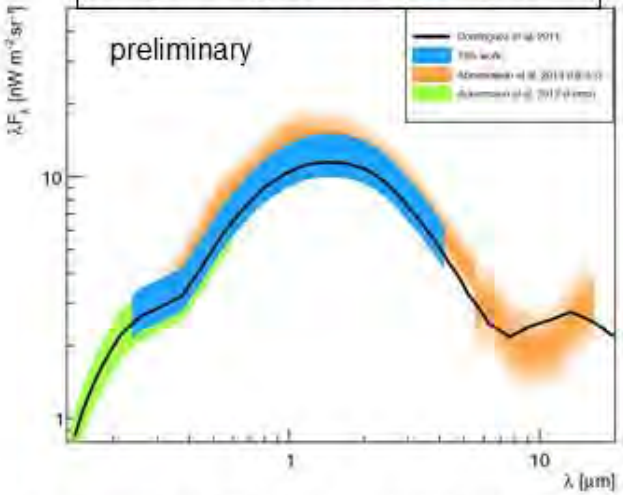
Bangale, 34th ICRC, GA18

HBL at z = 0.212, first detected at VHE by MAGIC in 2007

- In 2014, 12 hours of good data, Feb 6th – March 7th, alert issued by VERITAS
- Spectral points up to optical depth $\tau \approx 4$
- Observed spectrum cannot be well fitted by any concave function
- → clear imprint of EBL absorption at the 4.6-σ level, using (conservatively) a log-parabola as intrinsic spectral model



EBL density constraint from MAGIC observations of 1ES 1011 flare, using Dominguez'11 EBL template



- Consistent with previous measurements based on VHE observations
- No hint of propagation anomalies

PG 1553+113: Periodicity Study

MAGIC
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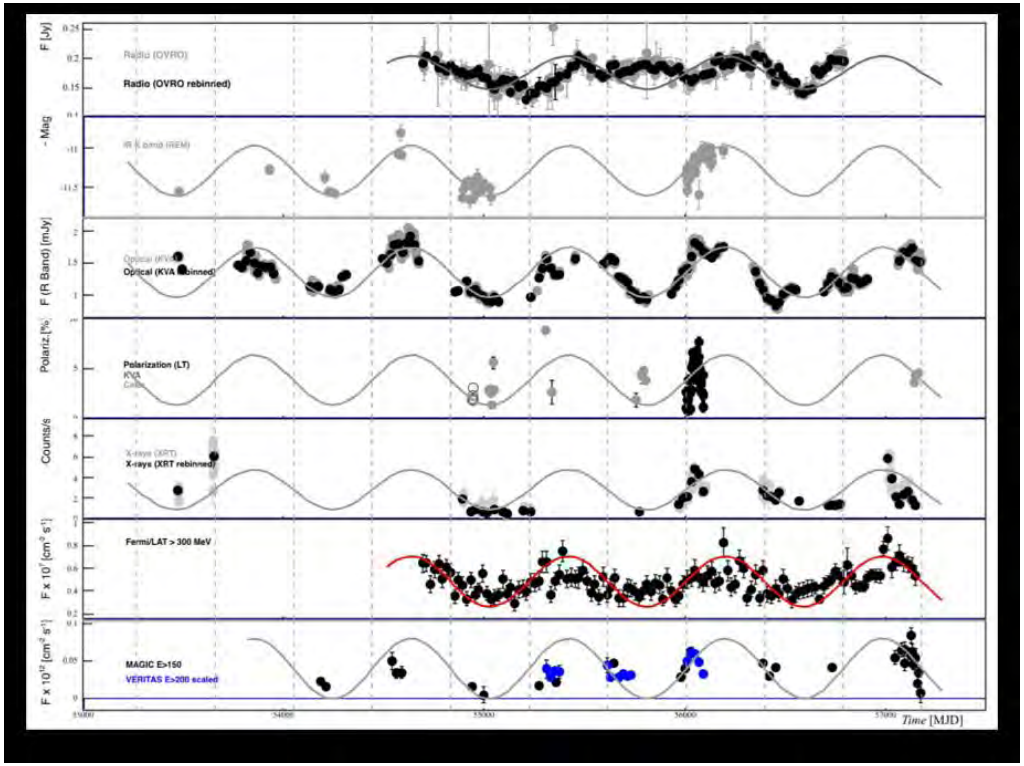
Prandini, 34th ICRC

- Yearly-periodicity hint may point to a SMBH binary system, possibly in a merging state
- MAGIC performing a MWL monitoring program on PG1553+113
- Evaluating

– Time lags → emitting region

– SED → emission processes

- Constraints on the process at the base of periodic modulation
- Prospect for future experiments for GW from SMBH coalescence (eLISA)

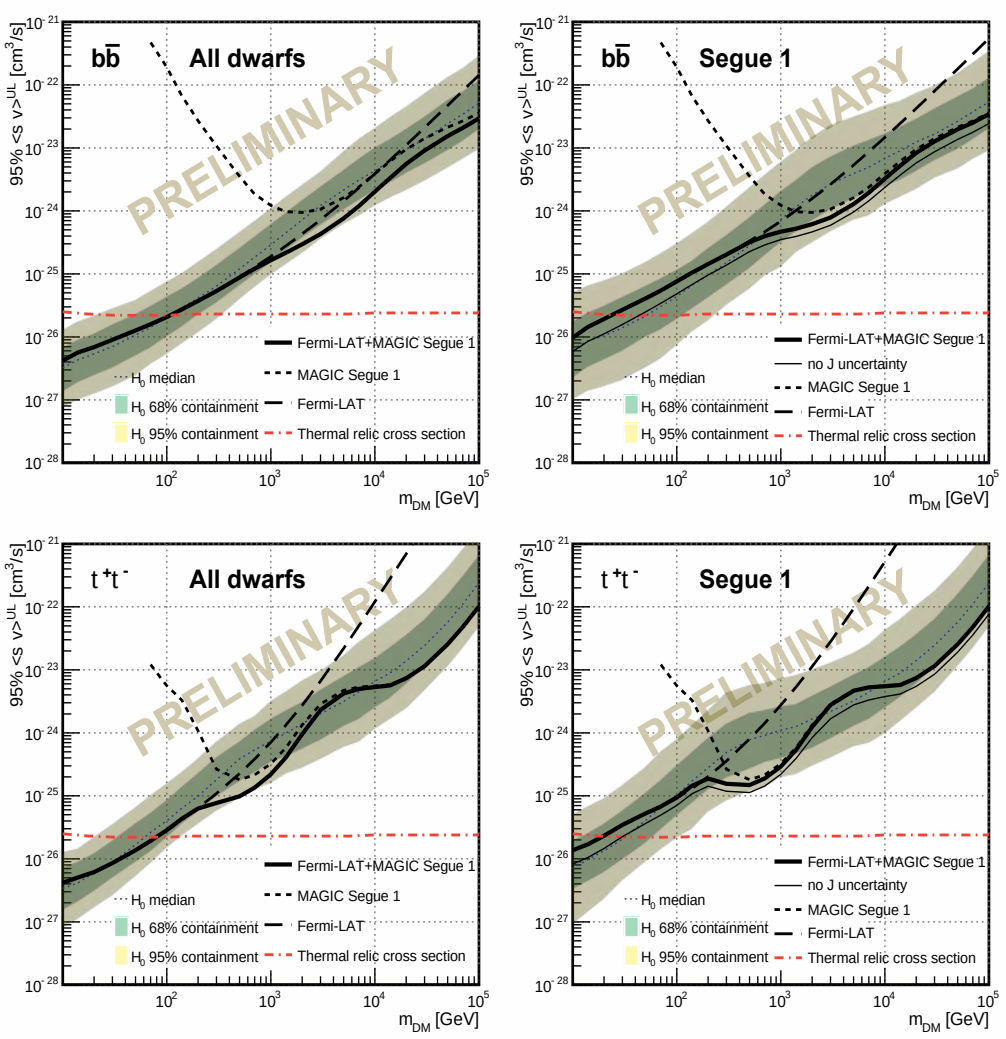


MWL light curve superimposed by a periodic function of a period T=783 days
(from Fermi/LAT public data)

Dark Matter: MAGIC/Fermi-LAT combined results

Rico, 34th ICRC, 3DM & NU

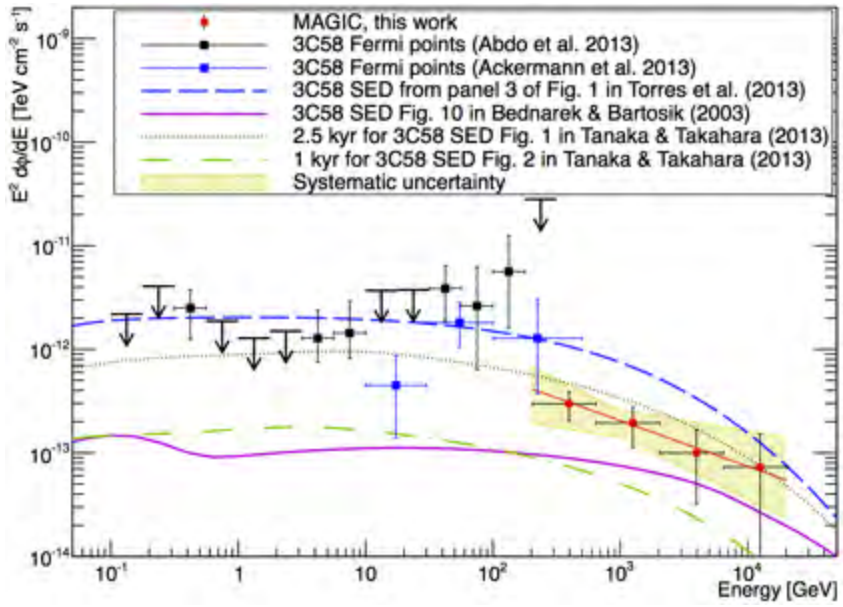
- Combined MAGIC-Fermi-LAT DM searches, using published results:
  - Fermi-LAT: 15 dwarfs, 6 years, pass 8
  - MAGIC: Segue 1 stereo, 158 hours
- ❖ Coherent analysis in:
  - Statistical treatment
  - J-factor and uncertainty
- ❖ Most constraining limits from dwarfs in the mass range from 10 GeV to 100 TeV
- ❖ Generic approach -> ultimate goal: merge ALL results from dwarfs (incl. HESS, VERITAS, neutrino…)

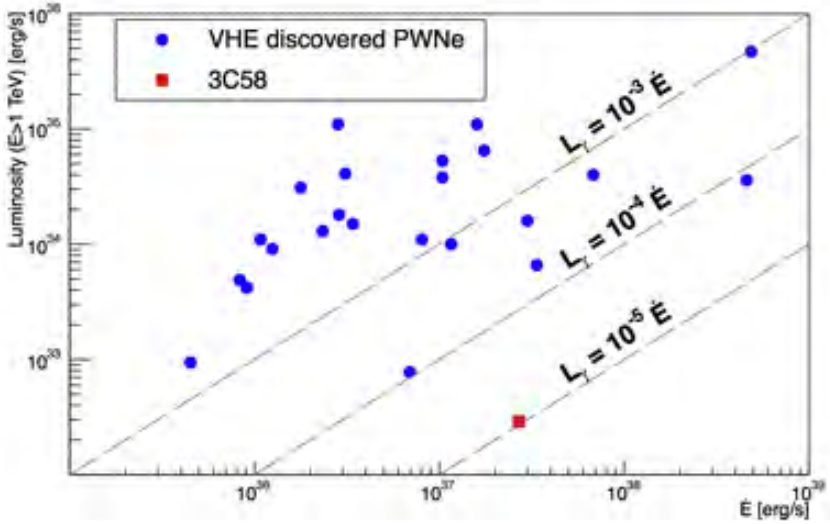


Discovery of 3C58

- Powered by high spin down pulsar PSR J0205+6449, $\dot{E} = 2.7 \cdot 10^{37}$ erg·s^{-1}
  ~2 kpc (~2 % of Crab pulsar, similar morphology)
- TeV emission discovered in 100h of observations (0.65 % CU)
- Least luminous PWN at TeV (association with SNR highly unlikely)
- Magnetic field drawn from models is far from equipartition and low for a young PWN

Lopez-Coto, 34th ICRC, GA07

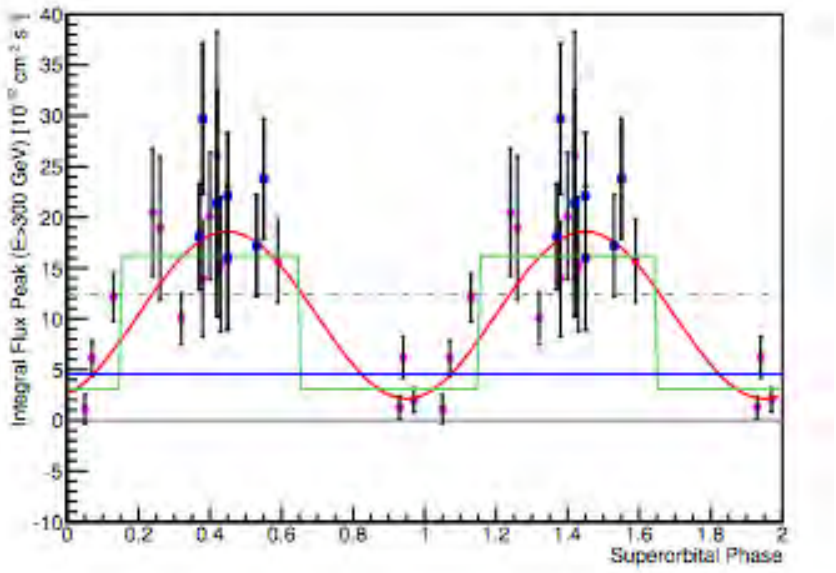




Proving Super-orbital modulation in LSI +61 303

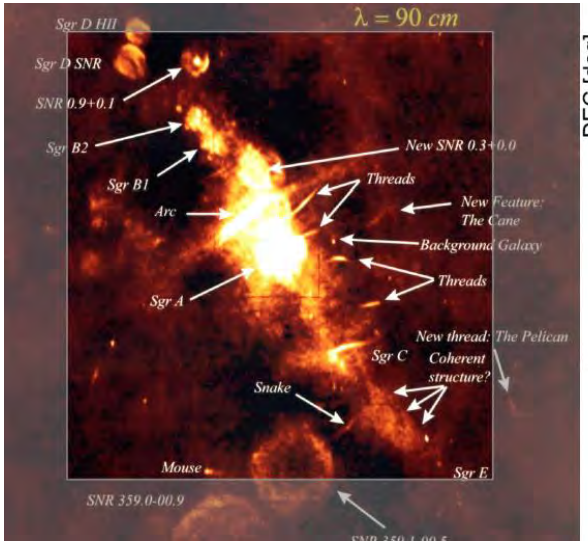
Fernandez-Barral, 34th ICRC, GA09

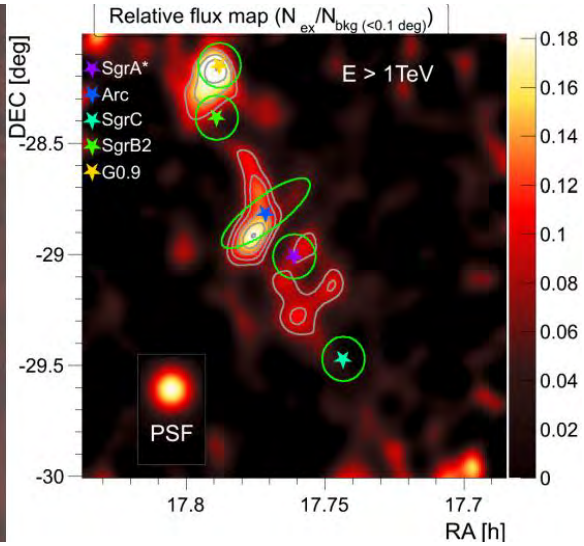
- Compact object + Be star
- Orbital period: (26.496 +/- 0.0028 days)
- Super-orbital period: (1667 +/- 8) day
- Probability for the flux being fluctuation is extremely small: 4.5×10^{-12}; constant flux is excluded
- TeV flux compatibility with the radio super-orbital period is on ~8 % level (assuming a sinusoidal signal).



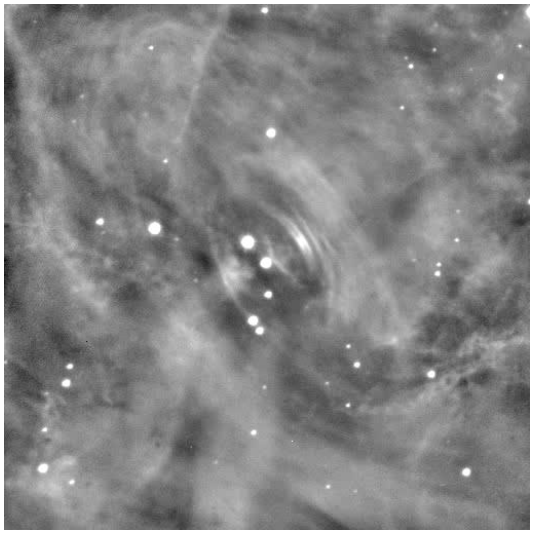
Arc near the Galactic Centre

Fruck, 34th ICRC, GA14





- MAGIC observed the Galactic centre under large zenith angle range of 58°-70°
- Observed good correlation between 90cm radio image and the TeV skymap
- Radio arc seem to have a TeV counterpart



Crab pulsar: recent history

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

Aliu et al. (VERITAS collab.)
Science 334 (2011)
First detection of emission above 120-250 GeV

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

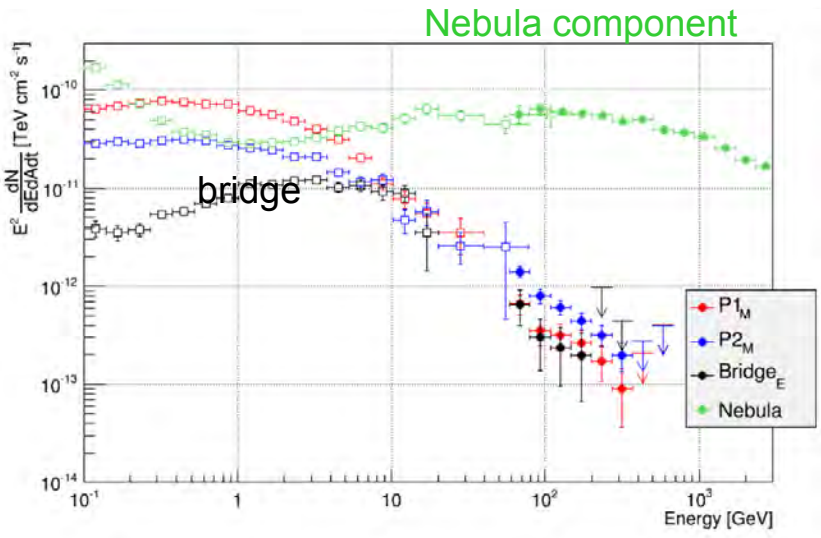
Aleksic et al (MAGIC collab.), A&A, 540 (2012)
First spectrum 50-400 GeV

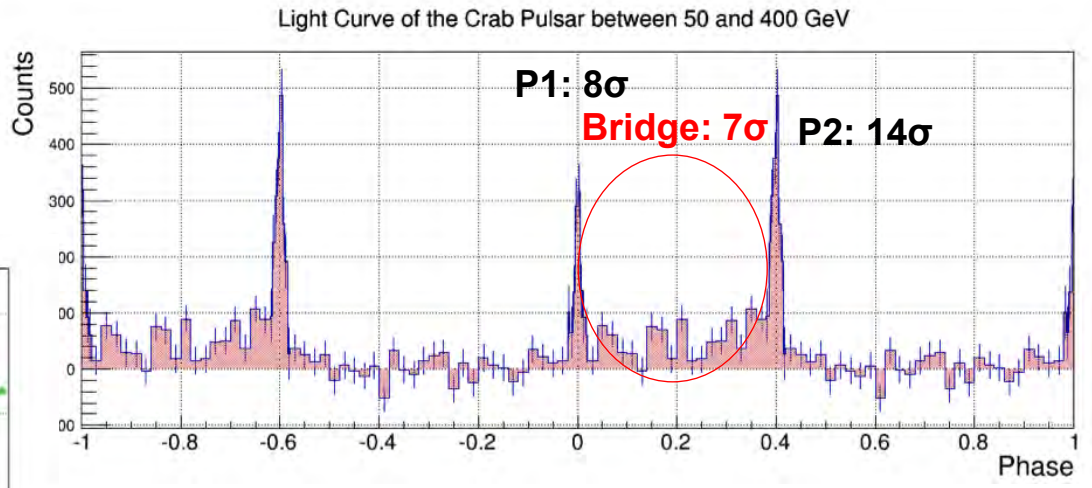
Aleksic et al (MAGIC collab.), A&A, 565, L12 (2014)
Bridge Emission ≥ 50 GeV

MAGIC discovers the bridge emission & very narrow pulses

Aleksic, et al, A&A 565 (2014)

Need models which can be tested against precision experimental data



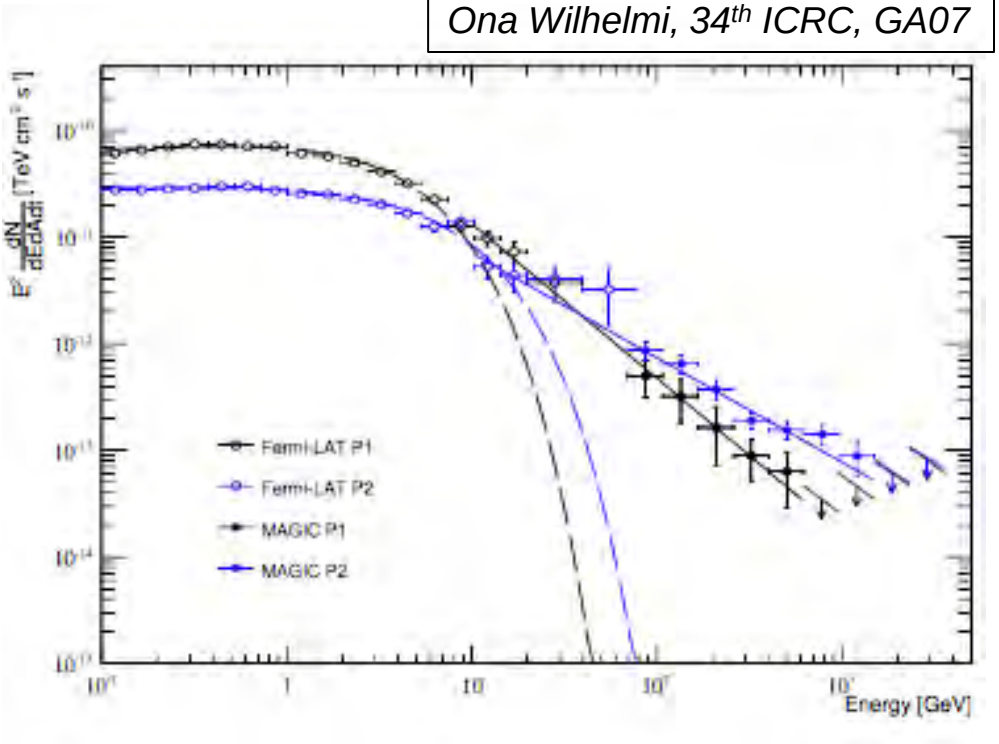


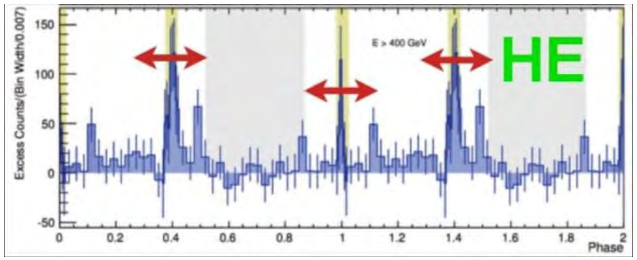
- Bridge hints on toroidal bending of magnetic lines near LC
- Qualitative description of Crab pulsar emission belongs to the past

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

Ona Wilhelmi, 34th ICRC, GA07

- Discovered pulsed emission from Crab, spectrum extending ≥ 1.2 TeV
- Challenging the emission models
- MAGIC-Fermi fit shows IC emission from ~10 GeV to ≥ 1 TeV
- Emission from the neighborhood of Light Cylinder (r ~1600km)
- TeV pulsation is used to put quadratic limits for Lorentz Invariance Violation (LIV): EQG2 > 4.4 x 10^{10} GeV: this is only factor 3 below current best limit from Fermi

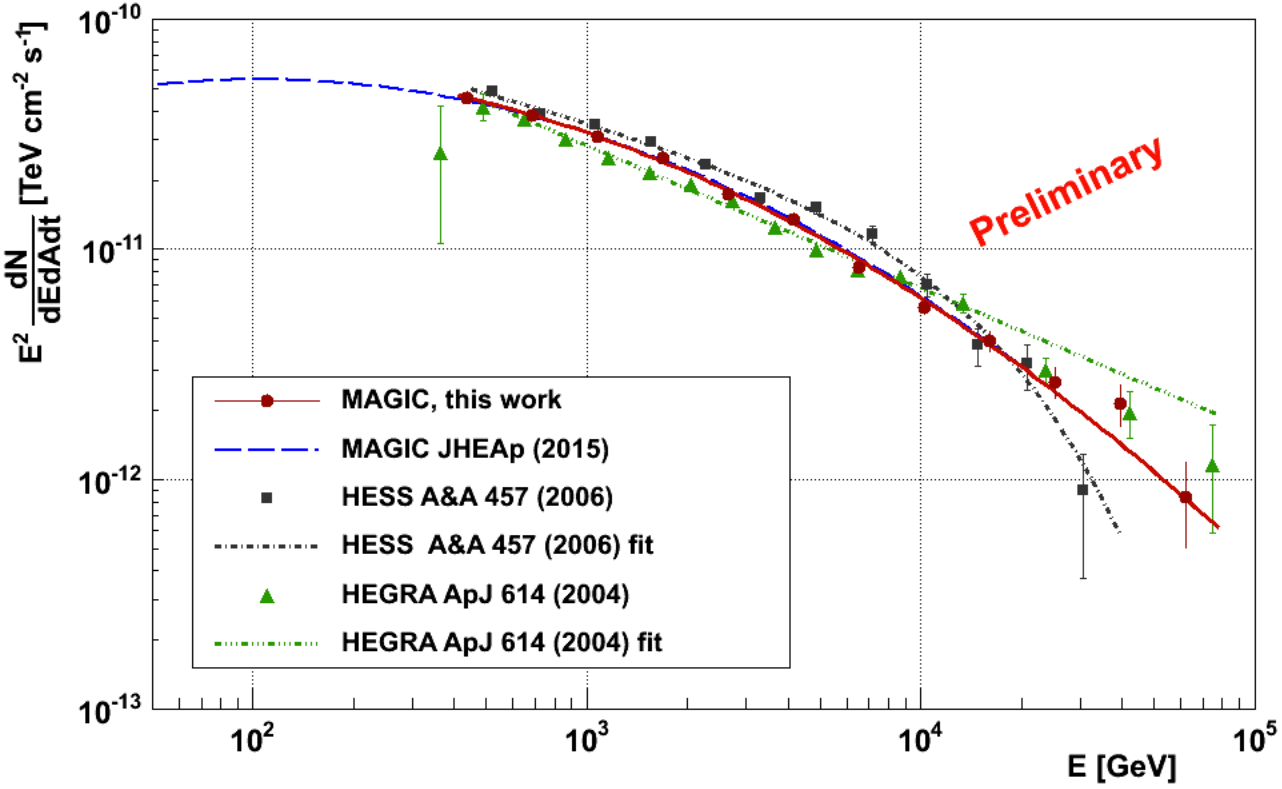




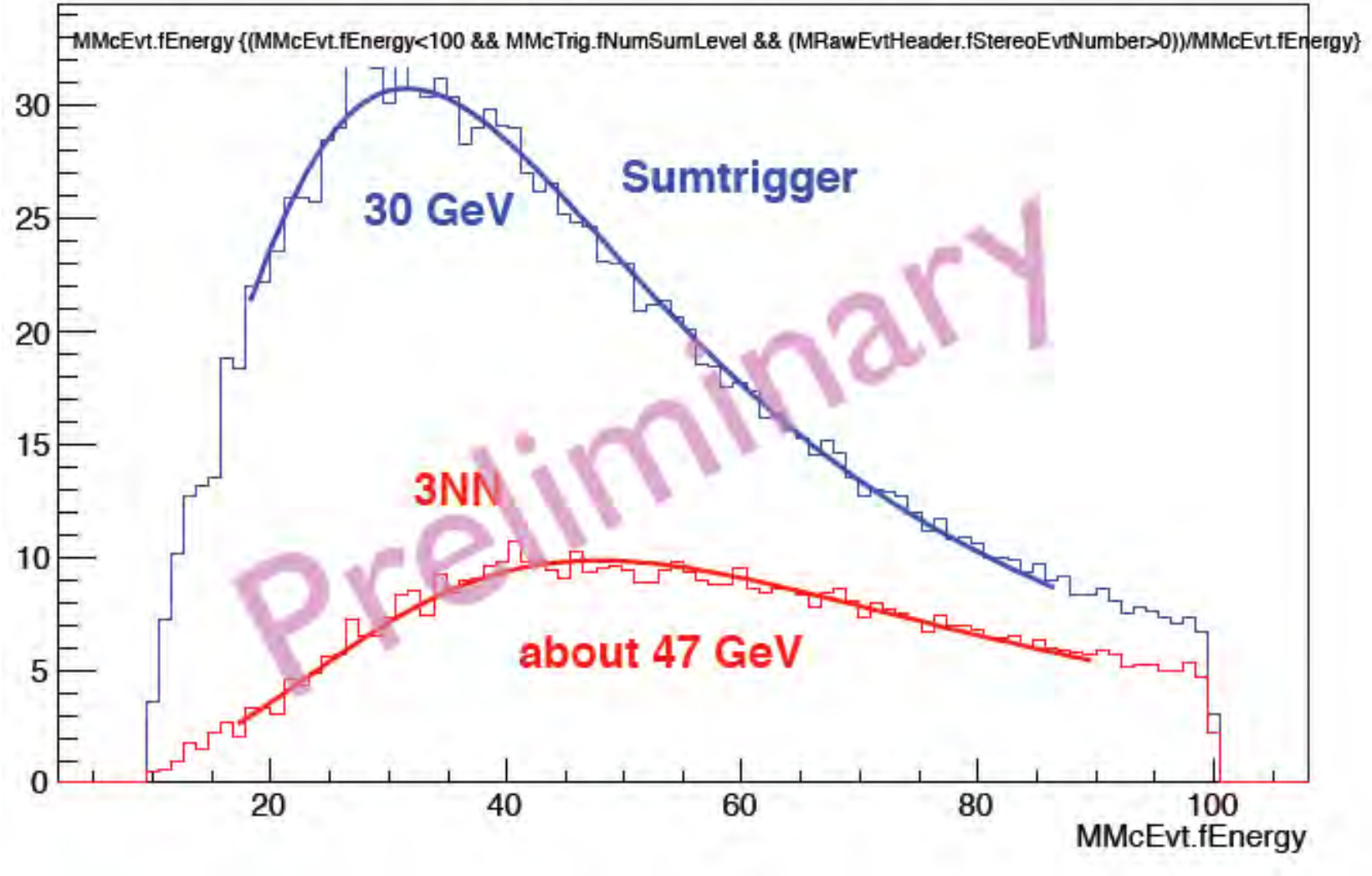
Crab Nebula Spectrum up to ~80 TeV

Zanin, 34th ICRC, GA03

- Investigating the SED of the Crab Nebula from ~50 GeV to ~80 TeV



MAGIC Stereo SUM-Trigger



Stereoscopic Topological (TOPO) Trigger

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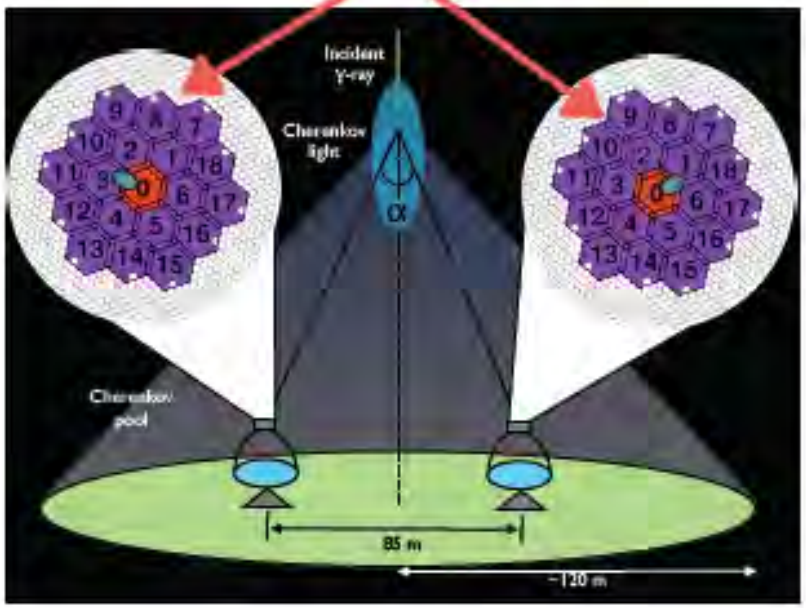
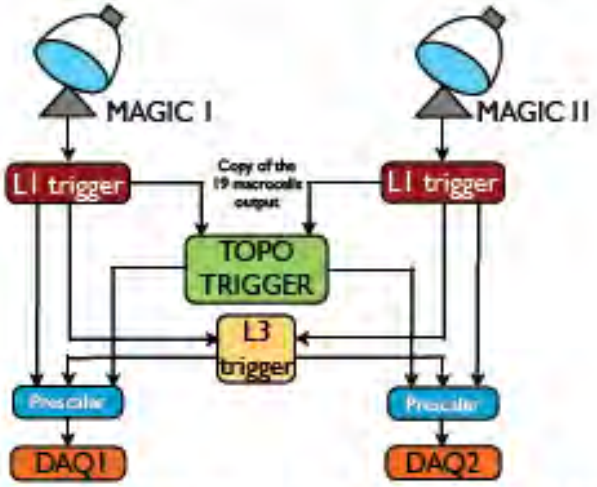
Idea: use individual trigger location in the two cameras for triangulation of the incoming Cherenkov light. If triangulation fails, veto the trigger online

MAGIC trigger is segmented into 19 macrocells



Triangulation of Cherenkov light produced by a γ-ray shower by the MAGIC telescopes. The angle α between the light arriving at the telescopes is maximum when the shower impact is between the two telescopes (α = 0.6º).



Schematic of the TOPO Trigger implementation in MAGIC: The trigger macrocell information (19 bits per telescope) is processed online and a veto signal is issued in case the result of the triangulation algorithm is negative.

Status: TOPO Trigger is implemented and is now in the commissioning phase. Monte Carlo simulations show that algorithm suppresses 90% accidental triggers and reduces *analysis* threshold by about 10% while increasing γ-ray collection area at low energies up to 60%

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26 Jul 2015; 12:49 UT

[Previous]

Discovery of Very High Energy Gamma-Ray Emission from the intermediate BL Lac S2 0109+22 with the MAGIC telescopes

ATel #7844; *Razmik Mirzoyan (Max-Planck-Institute for Physics, Munich), on behalf of the MAGIC collaboration*
on 26 Jul 2015; 12:48 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

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

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the BL Lac S2 0109+22 (RA: 01h12m05.8s Dec:+22d44m39s, J2000). The object was observed with the MAGIC telescopes for 5.3 hours from 2015/07/22 to 2015/07/25, following the high-flux state spotted in the high-energy (E>10 GeV) domain of the public Fermi/LAT data, according to the prescription of Pacciani et al. ApJ 790 (2014) 45. The preliminary analysis of the first three nights of MAGIC data showed an excess with a statistical significance of ~5 standard deviations. The VHE flux of this detection was estimated to be (1.6+/-0.7)e-11 ph/cm2/s above 100 GeV, about 3% of the flux from the Crab nebula. The daily flux shows a marked enhancement on the night of 25 July up to (9.7+/-1.5)e-11 ph/cm2/s, ~15% of the Crab flux at E>100 GeV, corresponding to an excess with >7 sigma statistical significance. S2 0109+22 is located at the red shift z=0.265 (from CGRaBS spectroscopy, Healey et al., ApJ 175 (2008) 97). It is classified as an intermediate-synchrotron peaked BL Lac object in the 2LAC (Ackermann et al. ApJ

Other AGN discoveries:

- RBS 0723, z=0.198, BL Lac
  (Carosi, 34th ICRC, 2GA)
- RX J1136.5+6737, z=0.1342, BL Lac
  (Hayashida, 34th ICRC, GA01)
- FSRQ S4 0954+65, z=0.368,
  (Becerra, 34th ICRC, GA04)

Conclusions

- The MAGIC telescopes are in their historically best shape, providing a best-ever high sensitivity (especially after the recent upgrade of the mirrors and their fine adjustment)
- With confidence we are looking forward for farther first-class science results for the next several years and for a fruitful cooperation with leading astronomy instruments