MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Highlights with MAGIC @ Very High Energies

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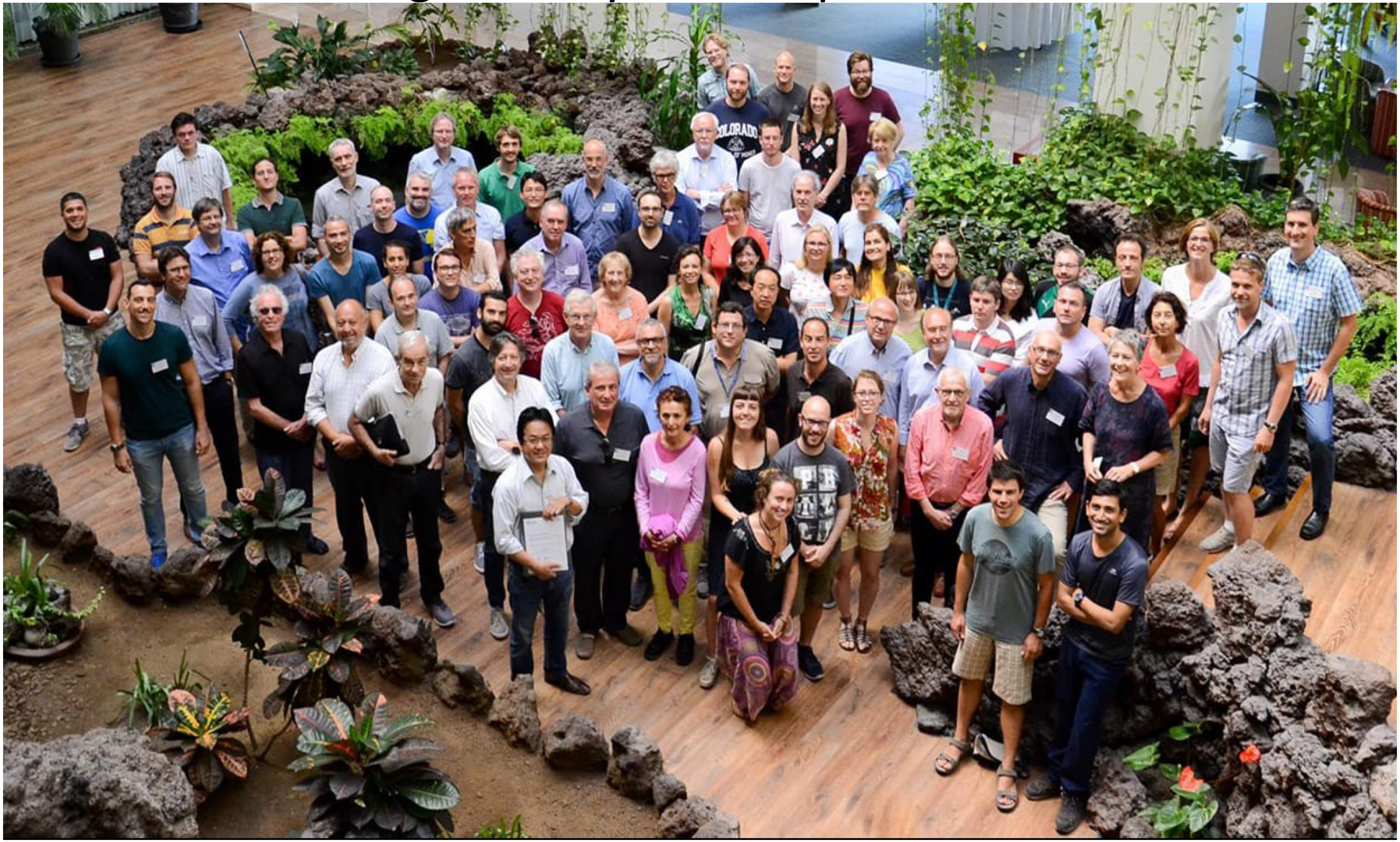
The MAGIC project for VHE gamma-ray astrophysics at E ~ 25 GeV - 30 TeV

Masahiro Teshima: Ground-Based Very High
Energy Gamma Astrophysics with MAGIC

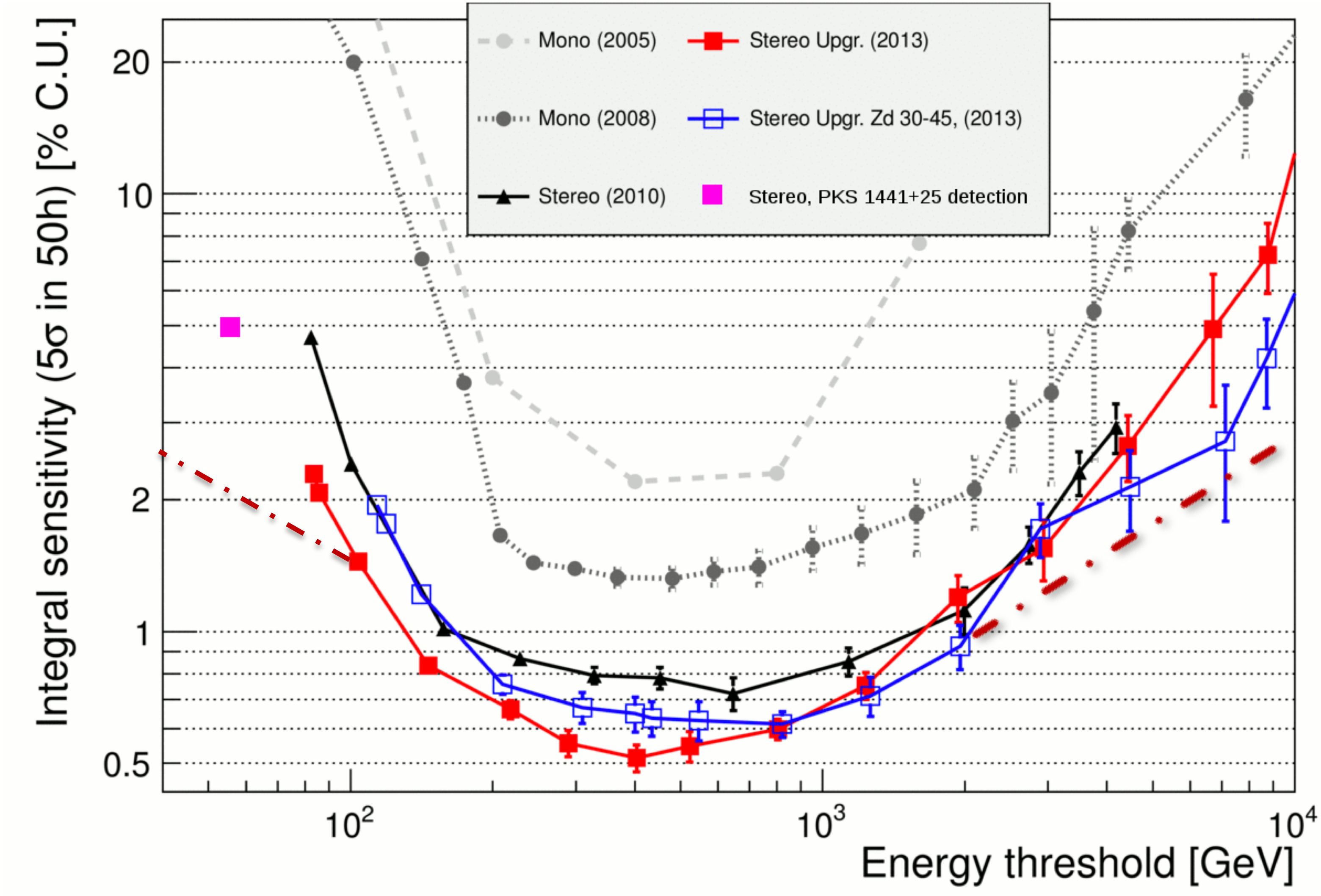
~170 Astro-Physicists From 11 Countries

Armenia	ICRANet and Alikhanian Broth. Nat. Lab.
Bulgaria	Sofia nuclear Physics Institute
Croatia	Consortium (Zagreb, +…)
Finland	Consortium (Tuorla, +…)
Germany	DESY Zeuthen, U. Dortmund, MPI Munich, U. Würzburg
Japan	Consortium (Kyoto, +…)
Italy	INFN & U. Padova, INFN Pisa & U. Siena, INFN Como/Milano Bicocca, INFN Udine/Trieste & U. Udine, INAF (Consortium: Rome, +…)
Poland	U. Lodz
Spain	U. Barcelona, UAB Barcelona, IEEC-CSIC Barcelona, IFAE Barcelona, IAA Granada, IAC Tenerife, U. Complutense Madrid, CIEMAT Madrid
Switzerland	ETH Zurich
India	Kolkata

Photo from the last June, from “A+M” conference celebrating the 15-years of operation of MAGIC

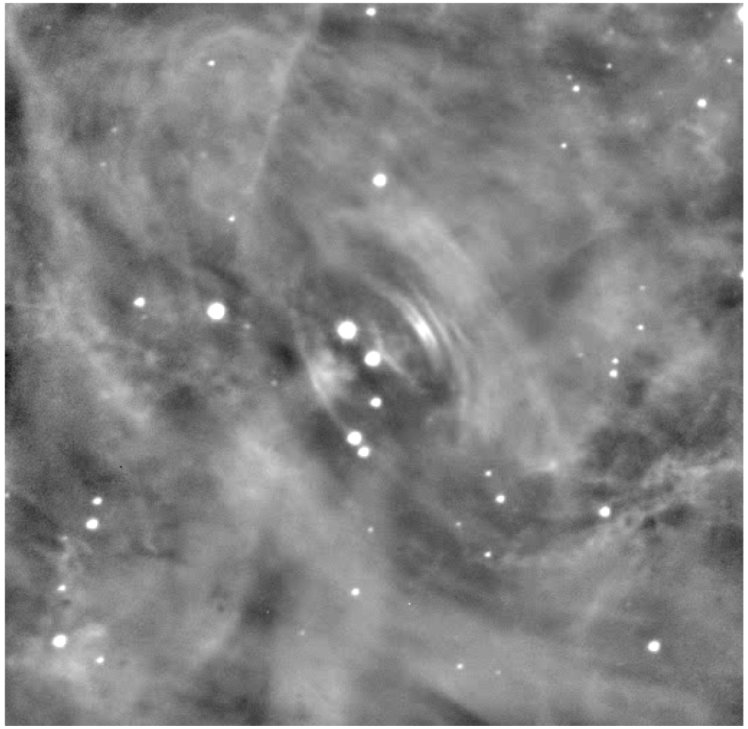


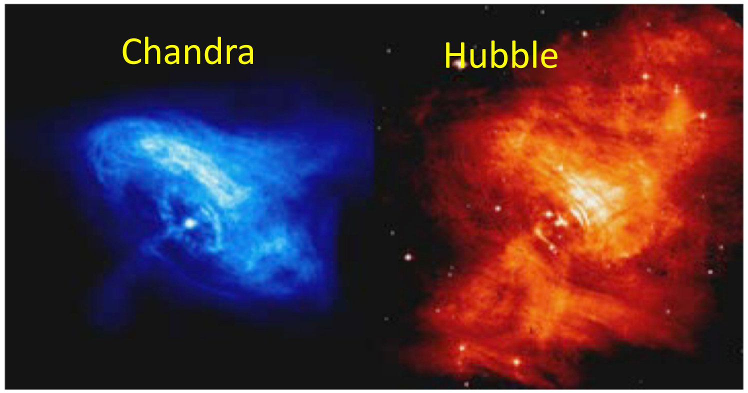
Significant Improvements of Sensitivity at Lowest and Highest Energies due to SumT-II & VLZA Observations



Razmik Mirzoyan: Ground-Based Very High
Energy Gamma Astrophysics with MAGIC

The Crab pulsar & MAGIC





Aliu et al. (MAGIC collab.)
Science 322 (2008) 1221
1st detection of VHE $\gamma \geq$ 25GeV

Aleksic et al (MAGIC collab.),
ApJ, 742 (2011) 43,
1st spectrum 25-100GeV

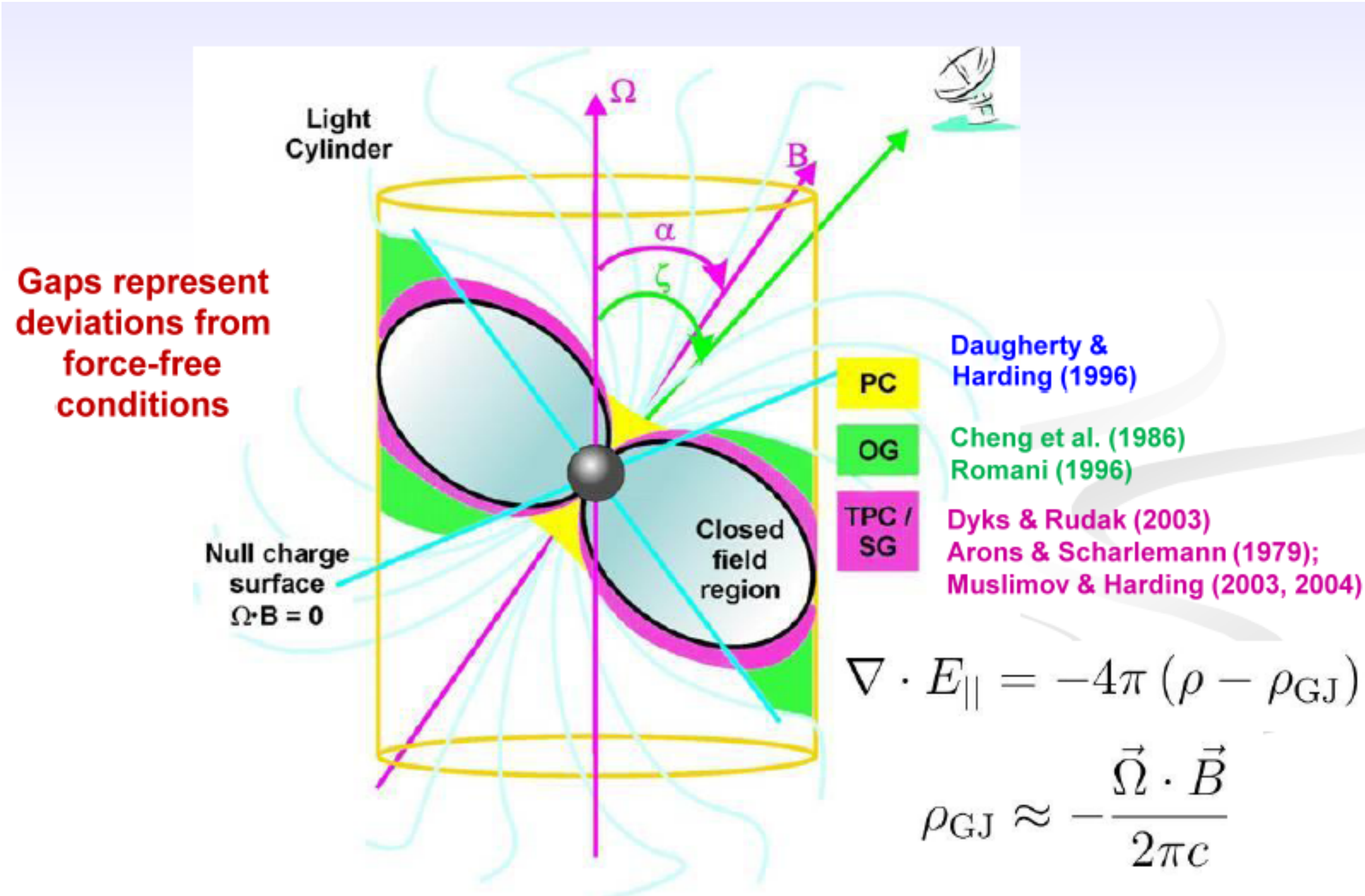
Aliu et al. (VERITAS collab.)
Science 334 (2011) 69-72
1st detection of γs 120-250 GeV

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 the Bridge Emission

Aleksic et al (MAGIC collab.),
A&A, 585 (2016)
Spectrum up to ~2 TeV pulsed γs

Cartoon of a pulsar



$$\nabla \cdot E_{||} = -4\pi \left(\rho - \rho_{\mathrm{GJ}} \right)$$

$$\rho_{\mathrm{GJ}} \approx -\frac{\vec{\Omega} \cdot \vec{B}}{2\pi c}$$

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

The MAGIC Collaboration*

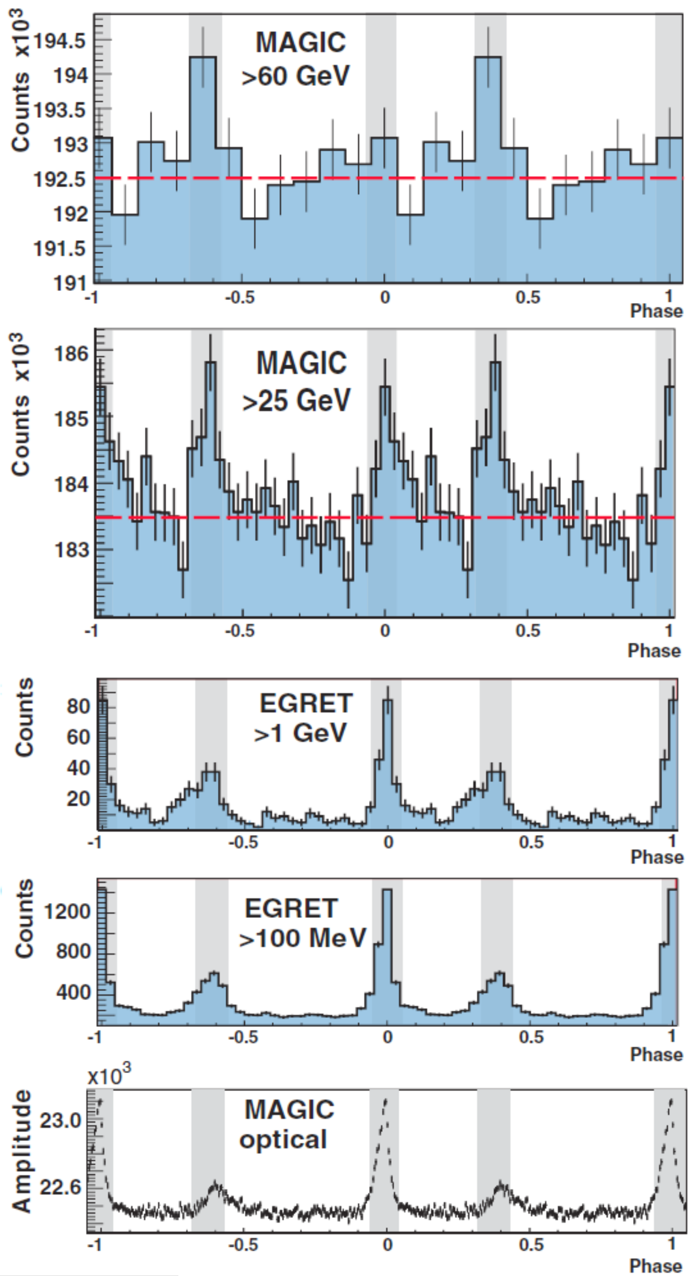
→ Polar cap model excluded

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

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

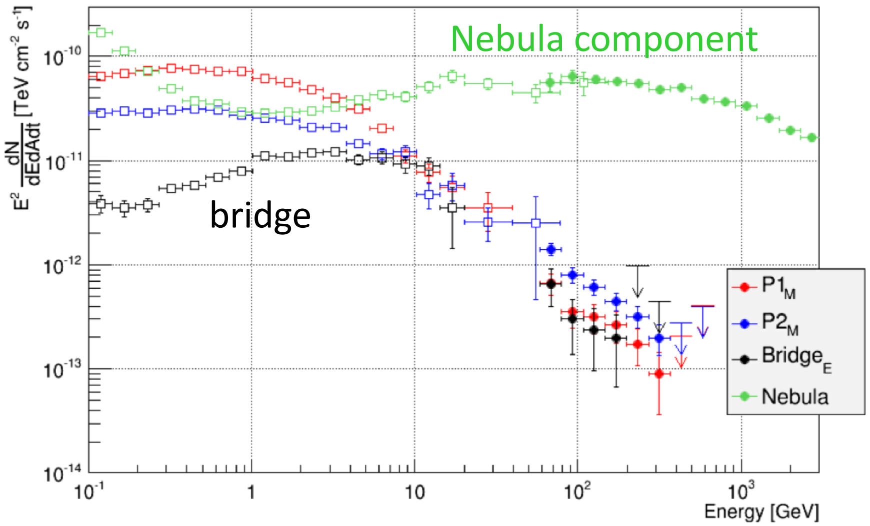


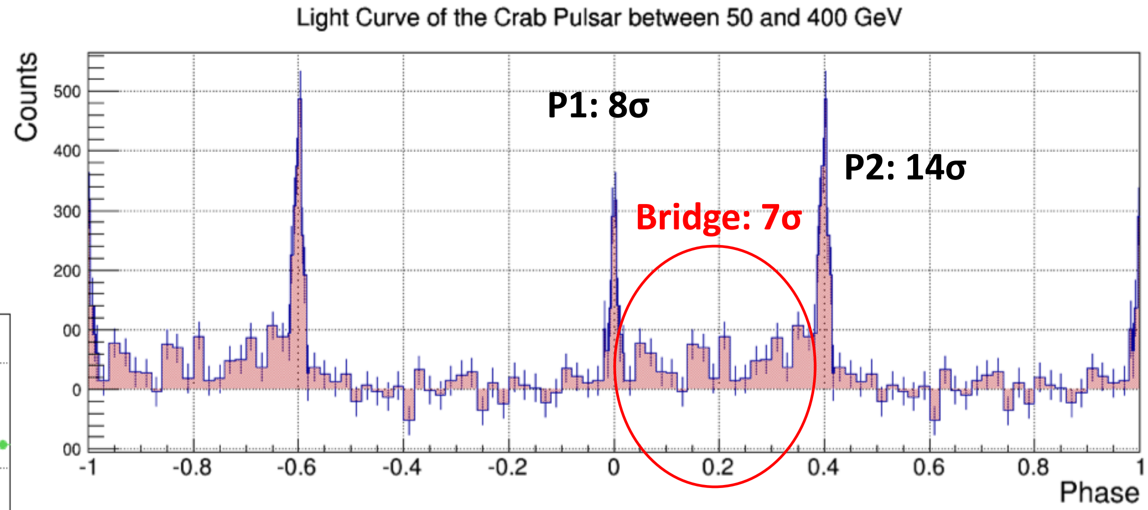
21 NOVEMBER 2008 VOL 322 SCIENCE

MAGIC discovery of the bridge emission & very narrow pulses

Aleksic et l, A&A 565, L12 (2014)

Fermi bridge emission becomes strong above few GeV



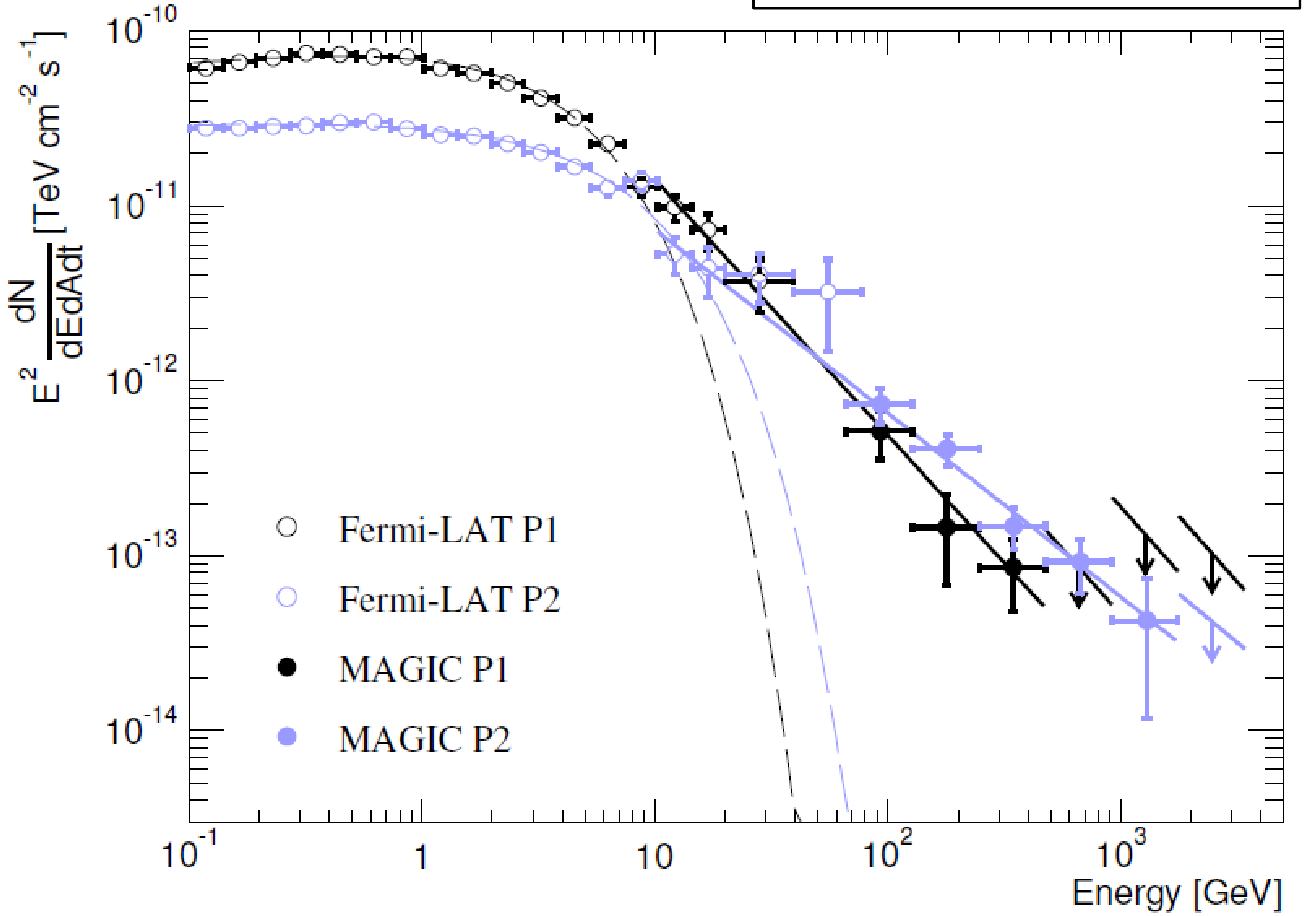


- bridge hints on toroidal bending of magnetic lines near LC
- qualitative description of Crab pulsar emission belongs to the past; need models which can be tested against precision experimental data

Spectral Energy Distribution defies current models

No cut-off observed, we just run out of statistics at highest energies

Aleksic et al, A&A, 585 (2016)



The VHE tail is well fitted by a simple power-law for both P1 and P2

Spectral indices:
P1: 3.4 ± 0.4 ±0.3
P2: 3.1 ±0.2 ± 0.3

Spectra extend:
P1: up to ~ 0.9 TeV
P2: up to ~ 1.7 TeV

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Geminga pulsar

- Unlike Crab pulsar, it is radio-quiet
- ~ 340 kyr old

(Crab pulsar is 1 kyr old)

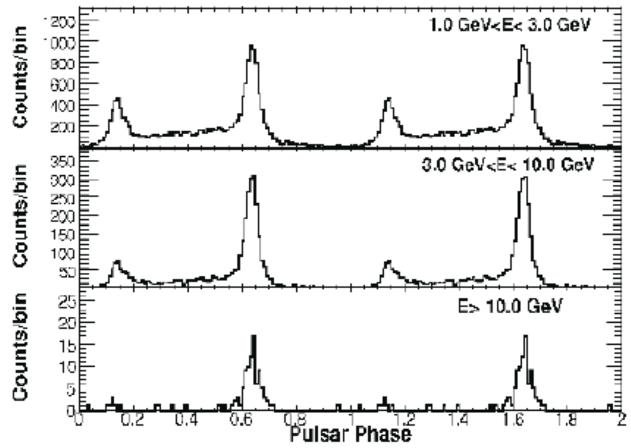
- Nearby 150 pc

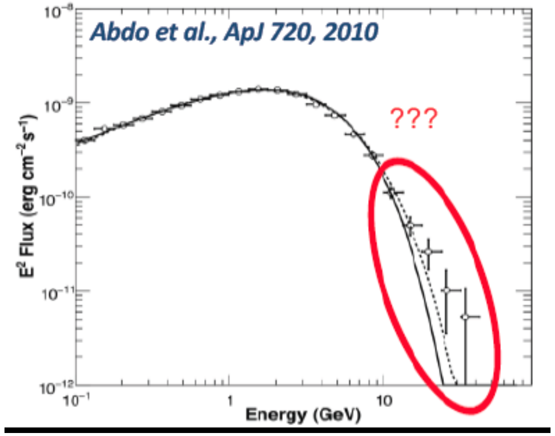
(Crab is at ~ 2000 pc)

- $\dot{E} \sim 3 \cdot 10^{34}$ erg /s

(for Crab pulsar $\dot{E} \sim 5 \cdot 10^{38}$ erg/s)

- Fermi LAT saw pulsations ≥ 10 GeV
- Fermi spectrum seems to deviate from exponential cut-off





Discovery of Geminga pulsar at E ≥ 30 GeV by MAGIC
One of the Sum-T-2 new results:

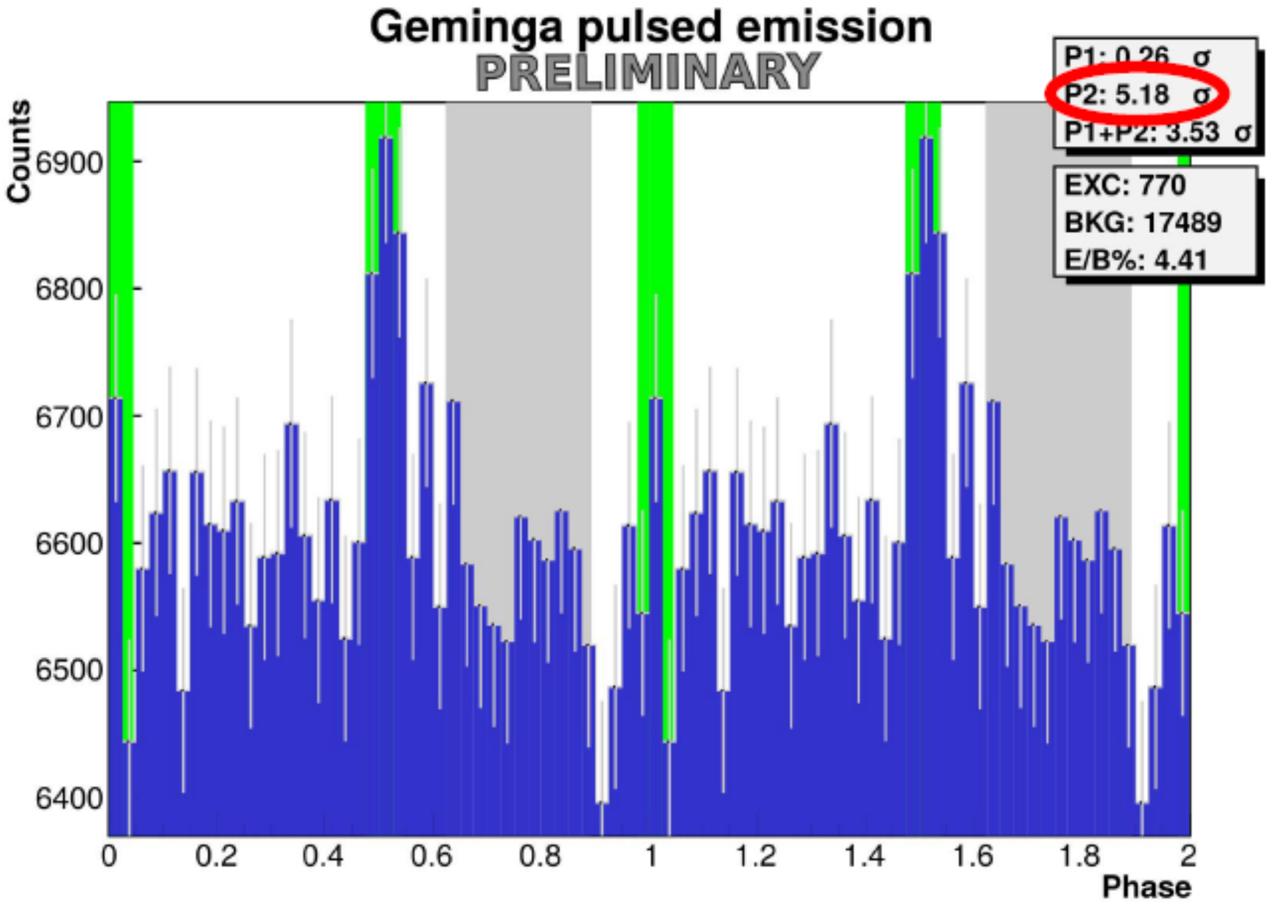
Studying if the spectrum at higher energies follows a power law

Geminga phaseogram
(~30h)

January 2017
February 2017

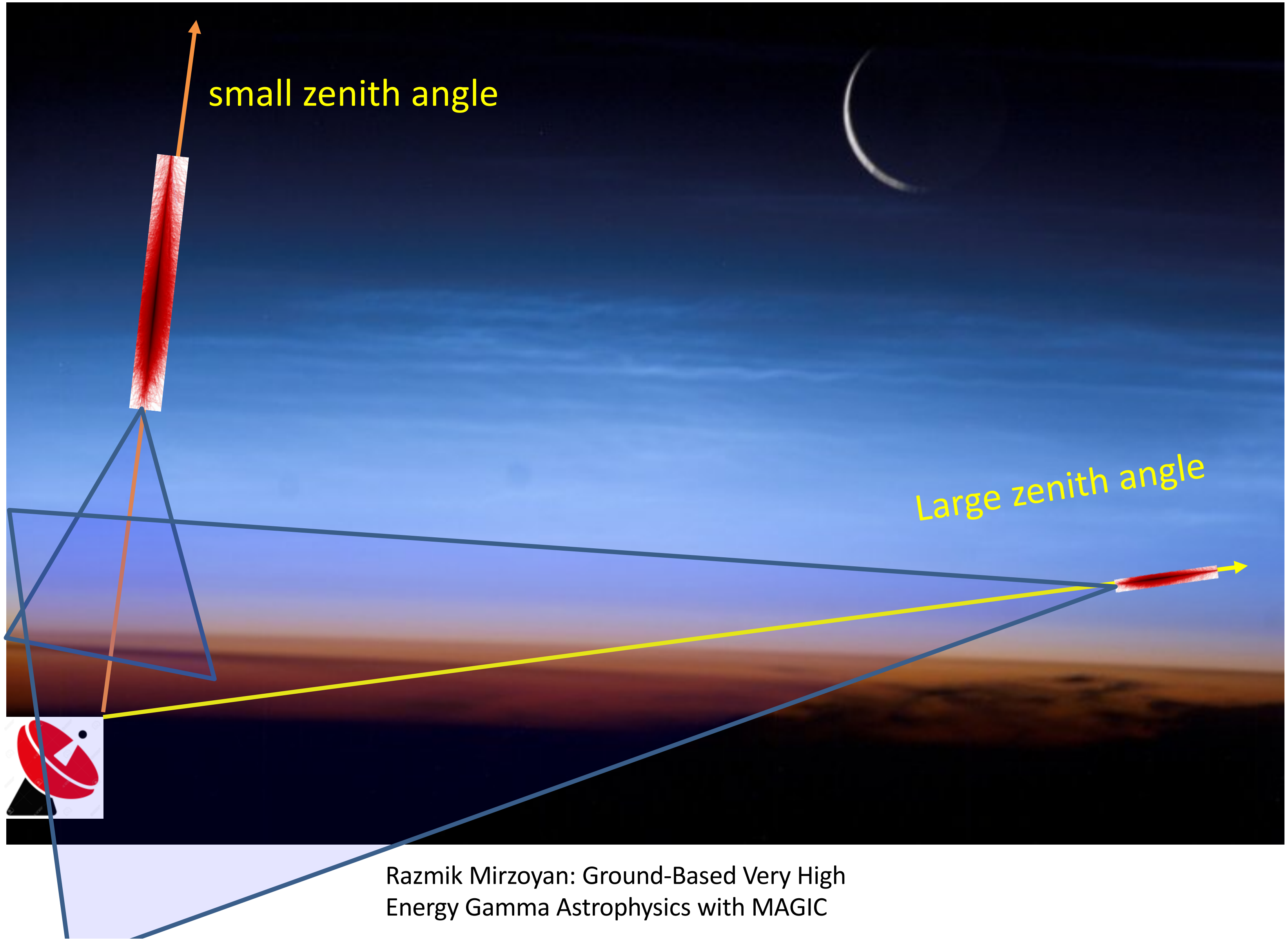
Ephemeris derived from Fermi/LAT data with robust procedure

Cuts from MC efficiency (flute-style)



25/06/2018 G. Ceribella

Cartoon on longer path length in atmosphere for an EAS @ large zenith angle observations



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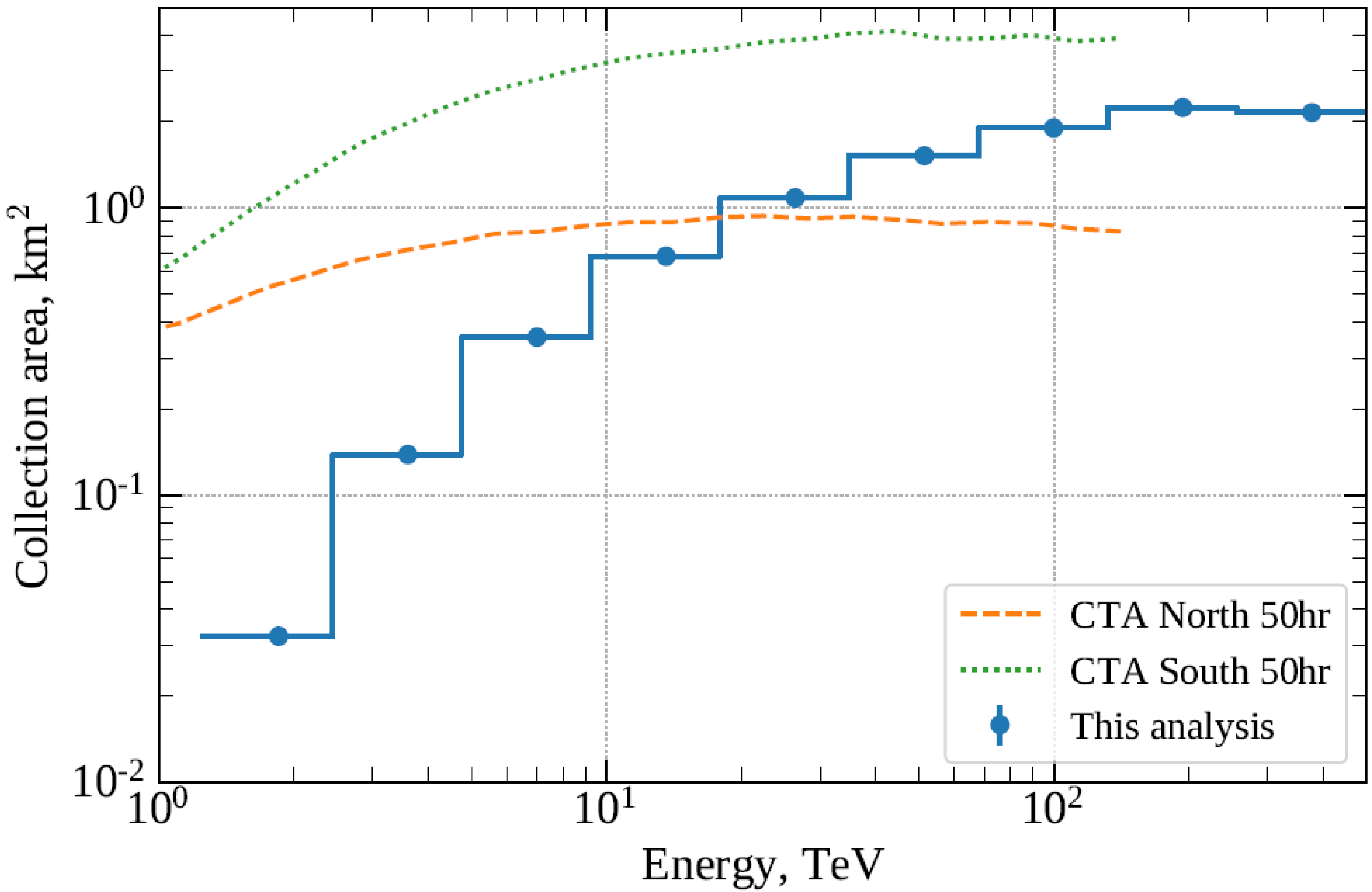
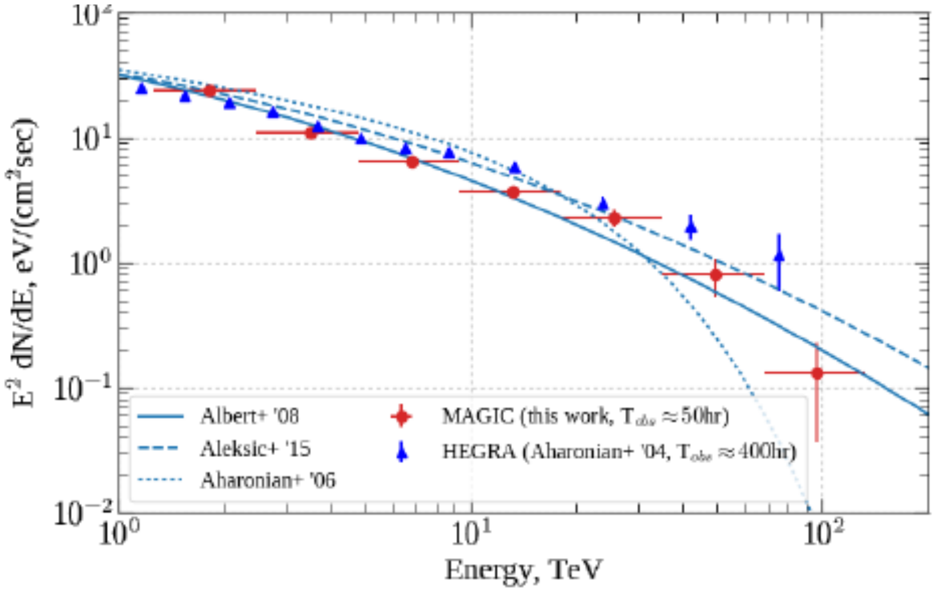
Observations close to horizon dramatically increase the effective collection area of air showers



Razmik Mirzoyan: Ground-Based Very High Energy Gamma Astrophysics with MAGIC

Comparison with HEGRA Crab spectrum: due to VLZA observations collected similar statistics in ~ 8-times shorter time with MAGIC

The spectrum below is a result of IACT observations extended into the zenith angle range 70° - 80°, i.e. almost to the horizon



Older MAGIC spectrum suggests:
alpha = 2.47 + 0.24*log10(4/1) ~ 2.61
beta = 0.24

CombUnfold:
f_0 = (6.88 +/- 0.45) x 10-13 1/(cm*sec*TeV)
alpha = -2.78 +/- 0.11
beta = -0.20 +/- 0.17

Fold:
f_0 ~ 7.0 x 10-13 1/(cm*sec*TeV)
alpha ~ 2.59
beta ~ 0.30

This technique shall allow us to chase the galactic PeVatrons

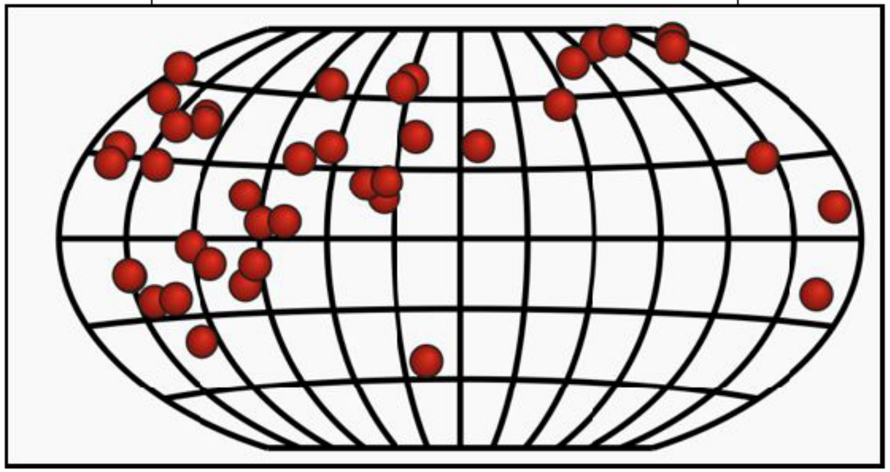
MAGIC extragalactic sky

Our science case

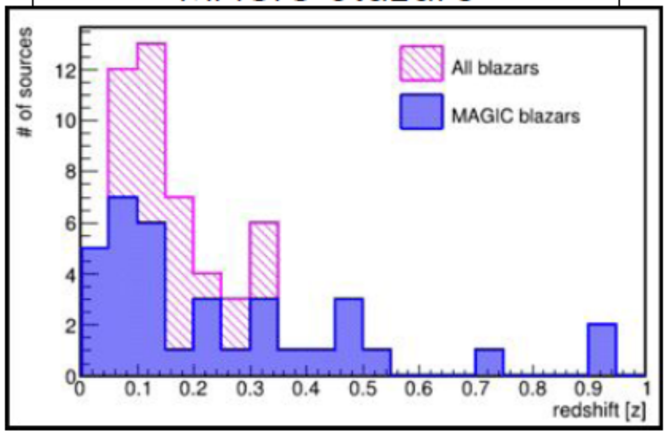
- **Characterization of extragalactic TeV emitters**
  - *Blazars*: BL Lac objects and Flat Spectrum Radio Quasars
  - *Radio galaxies*
  - *Seyfert galaxies*
- **Cosmology and fundamental physics**
  - EBL
  - IGMF
  - LIV

MAGIC is leading the high-z, TeV blazar science case

41 MAGIC-detected AGNs



redshift distribution of MAGIC blazars



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) γ-rays 8 (?) known, 6-from MAGIC:

3C 279 (z=0.536): 2006 (by MAGIC)
PKS1510 (z=0.361): 2009 (by H.E.S.S), 2012 (by MAGIC)
PKS1222+216 (z=0.432): 2010 (by MAGIC)
B0218+357 (z=0.954): 2014 (by MAGIC)
PKS1441+25 (z=0.939): 2015 (by MAGIC), 2015 (by VERITAS)
S4 0954+65 (disputed classification, redshift ?): 2015 (by MAGIC)
PKS0736+017 (z=0.189): 2016 (by H.E.S.S.)
TON 0599 (z=0.725): 2017 (by MAGIC), 2017 (by VERITAS)

MAGIC Transients Program

- Gamma-Ray Bursts
- Gravitational wave follow-up
- Neutrino ToO
- Fast Radio Bursts
- Novae, etc

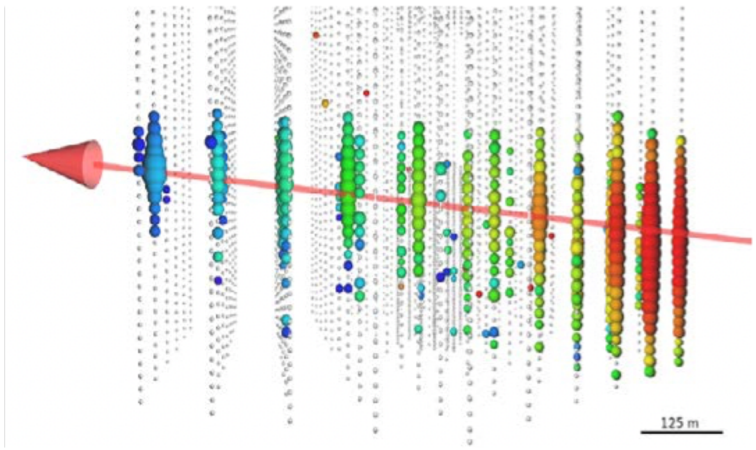
MAGIC is using an Automatic Alert System

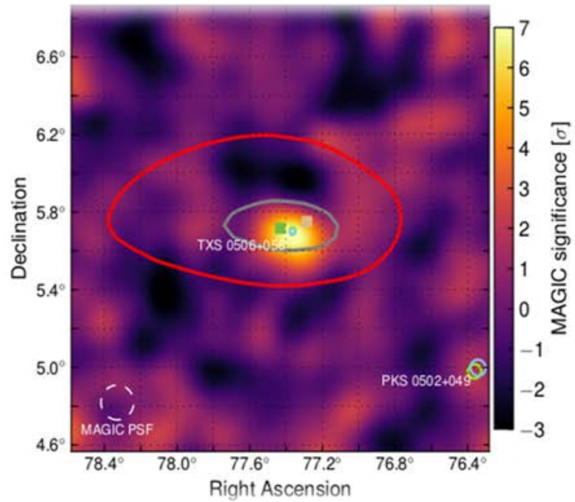
- Automatic re-positioning within 25s to anywhere in the sky (closing the running files, measuring the pedestal, calibrating with laser, downloading and readjusting the individual mirror positions,…
- Multi-Messenger: adapted to neutrino and GW alerts

IC170922A / TXS 0506+056

UHECR Sources / Neutrinos may come from distant sources

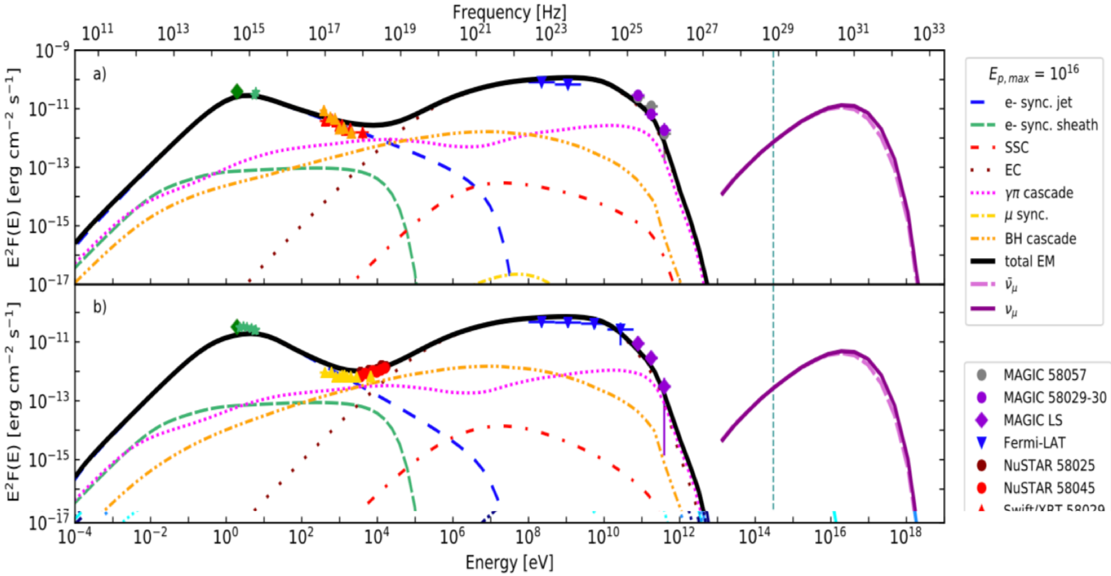
Ice Cube Observation (~300TeV)

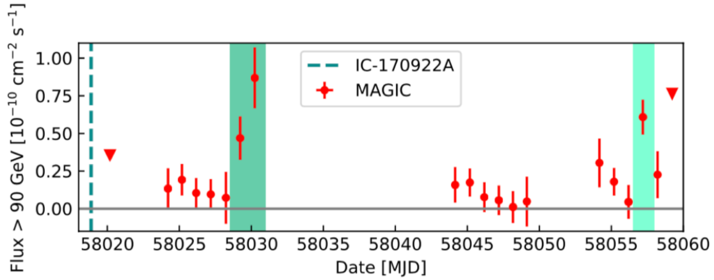


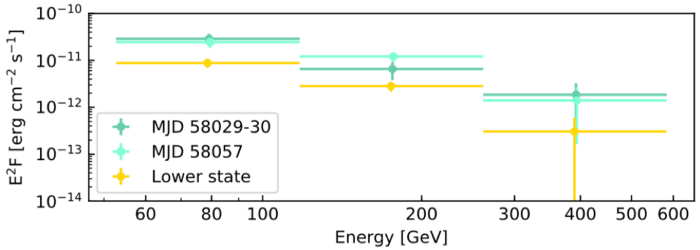


MAGIC (>100GeV)

Lepto-Hadronic Scenario







GTC Observation z = 0.3365
S. Paiano et. al 2018

MAGIC Observed GRB190114C with >20 sigma above 300GeV
z=0.42, usual bright GRB

[Previous | Next]

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

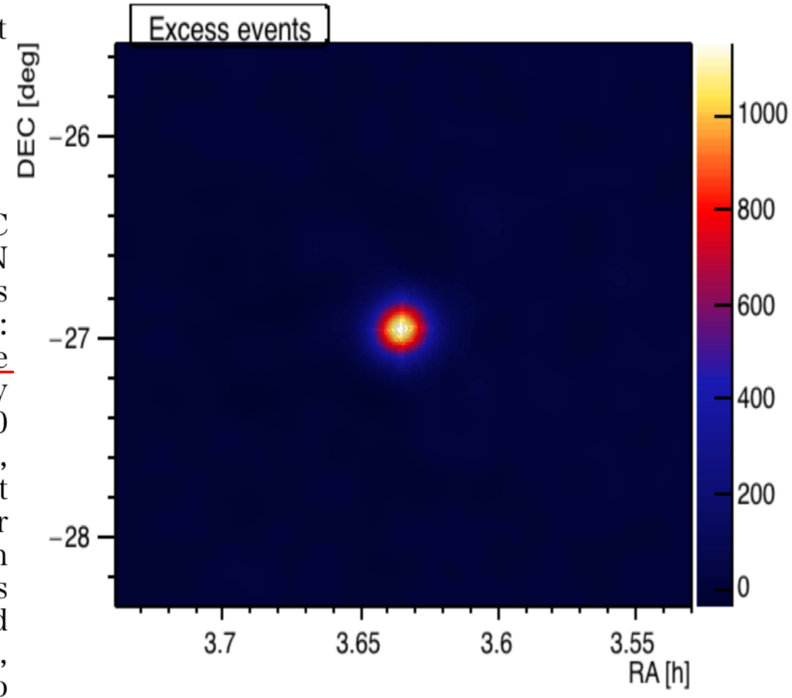
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

Related	
12395	GRB 190114C: Search for high-energy neutrinos with IceCube
12390	First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C



MAGIC is fully in for Multi-Messenger Observations

MAGIC is an excellent IACT for transient physics

- **GRB**: On January 14th 2019 we measured a giant signal from the GRB 190114C
- **Neutrino** follow-up: HESEs & TXS 0506+056 detection, exciting prospects for multi-messenger modelling, papers are scheduled
- **FRB**: optical and VHE signals explored at the shortest time scales

The 23m LST1 of CTA was inaugurated on October 10, 2018, at ORM

Summary

- The MAGIC experiment is in its historical best condition
- We are planning to operate MAGICs at least till 2022
- We are in the best, most productive phase of our science productivity
- At very low energies (~ 20-30 GeV) and at very high energies (≥ 100 TeV) we got a serious boost (a 2nd wind) in sensitivity due to Sum-T-2 and VLZA observations
- We are continuing exciting studies with peak sensitivity and hoping for new 1st class results
- The last outstanding discovery of MAGIC is the emission of γ-rays from the GRB 190114C, shown on the next page