

ICRC 2019 Highlights

Gamma-rays



ICRC2019

36th International Cosmic Ray Conference - Madison, WI, USA

THE ASTROPARTICLE PHYSICS CONFERENCE

Ekrem Oğuzhan Angüner
CPPM, 16.09.2019

Outline

- **Most interesting!**
- **Very High Energy γ -ray Astronomy**
- **Very High Energy γ -ray Experiments**
- **Scientific Results**

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)

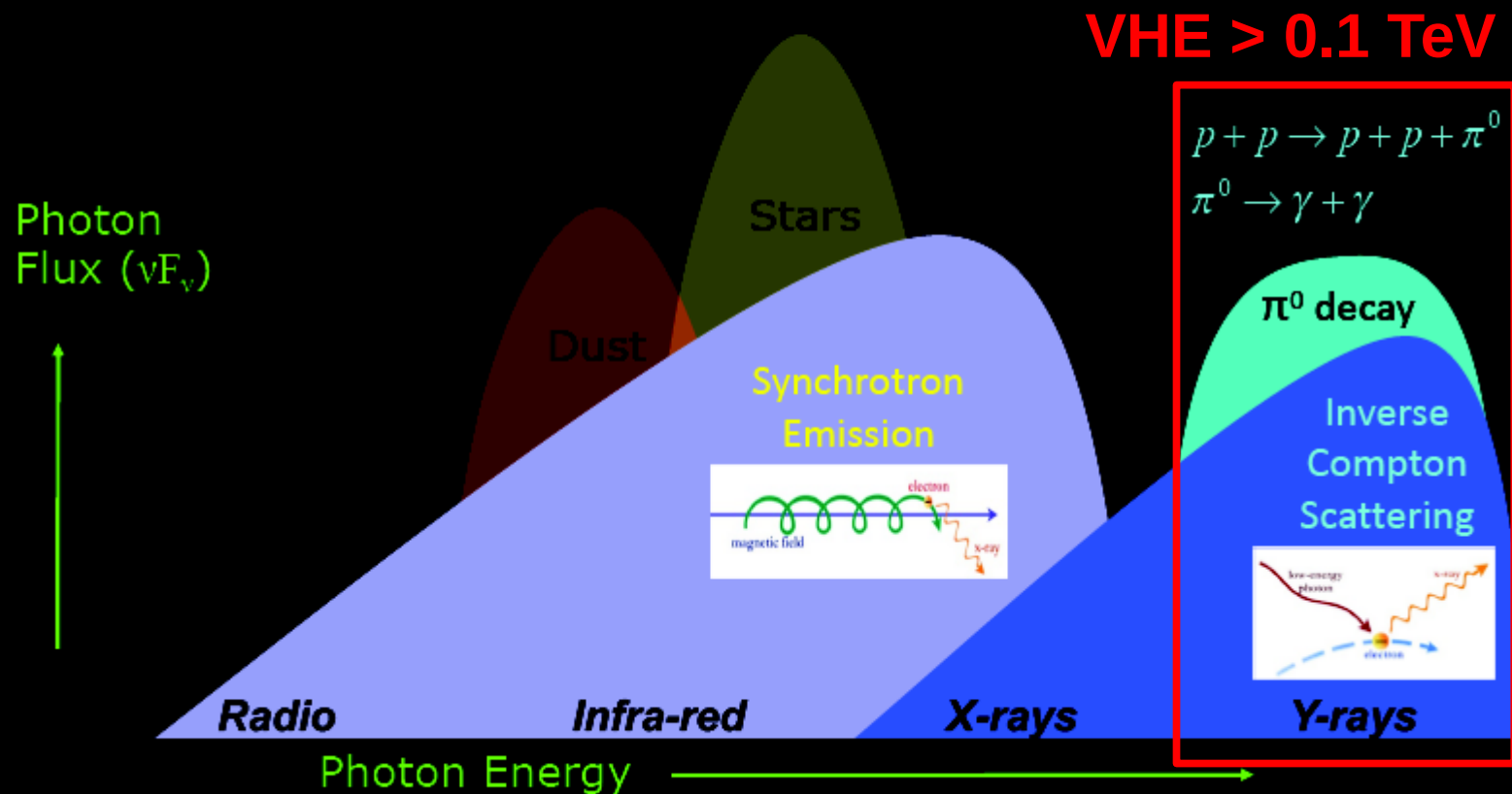
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

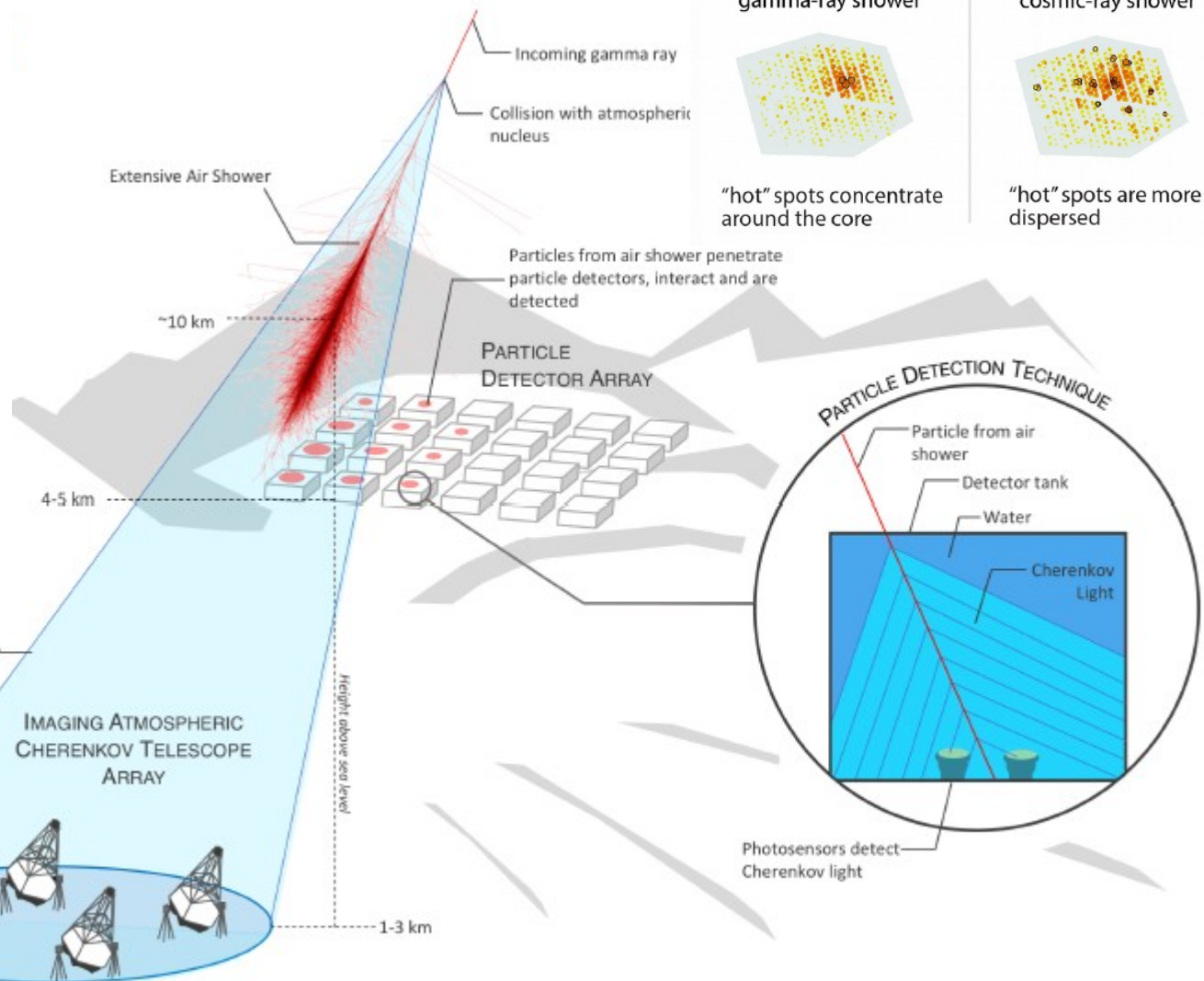
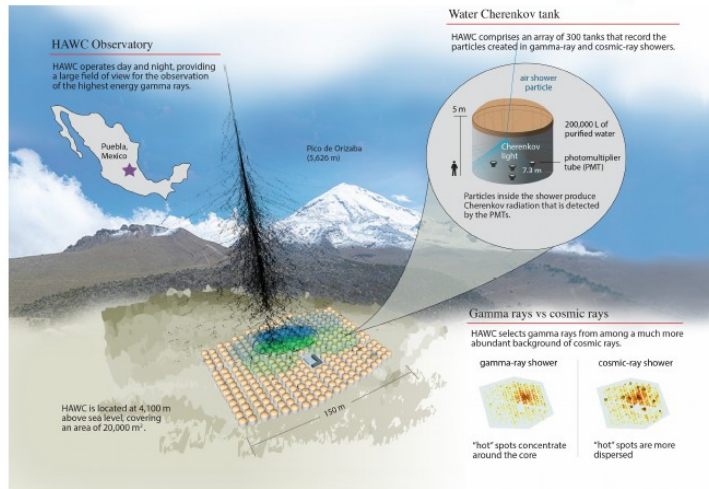


The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al., GCN 23693, Selsing et al., GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 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 >300 GeV. 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.

- High energy gamma rays are only produced by *non-thermal* processes.
 - Inverse Compton Scattering (for electrons) – **Leptonic** Model
 - Neutral pion decay (for protons) – **Hadronic** Model



The HAWC Observatory



Not to scale

The High Energy Stereoscopic System (H.E.S.S.)

Imaging Atmospheric Cherenkov Telescope Array in Namibia

- Sensitive to gamma-ray energies from ~30 GeV to 100 TeV
- Regular observation time ~1000h/year (astronomical darkness)



Phase I (2002)

- 4x 12m telescopes
- 960 PMTs/camera
- 5 degree field of view (FoV)
- Energy threshold ~100 GeV
- Angular resolution ~0.1deg

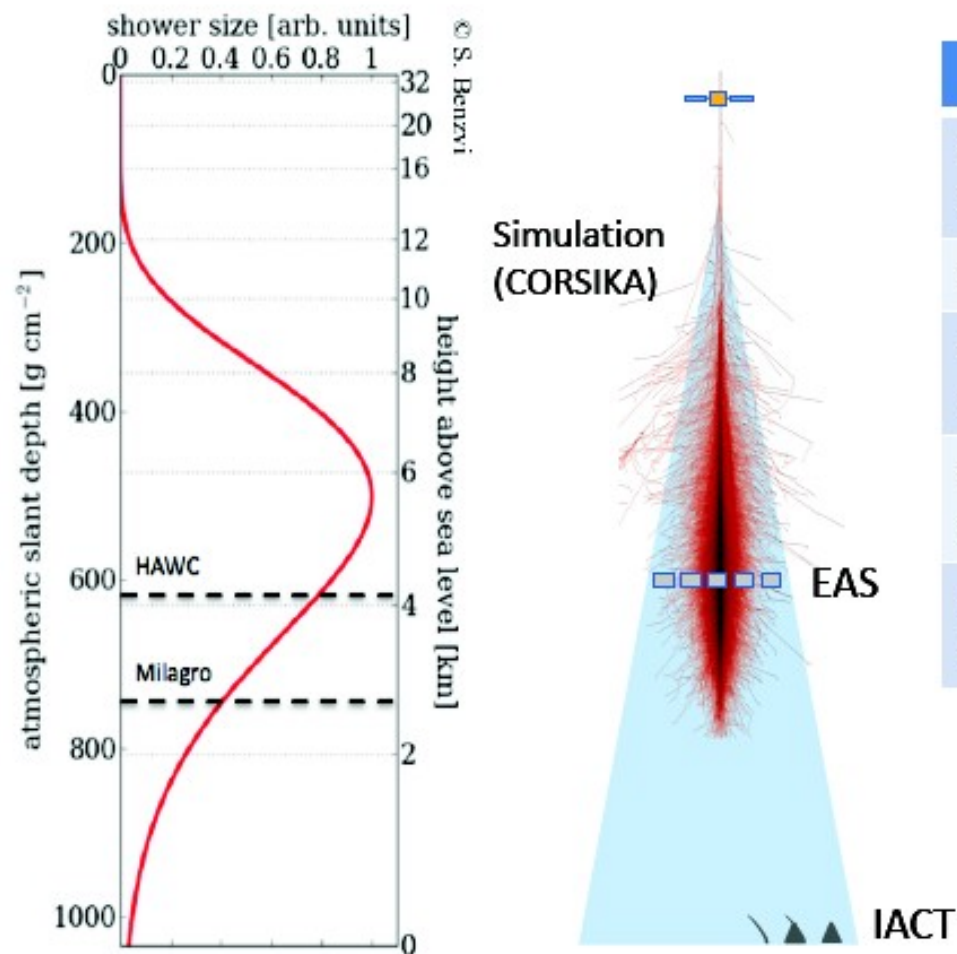
Phase II (2012)

- Additional 28m telescope (CT5) with 2048 PMTs
- 3.2 degree FoV
- Energy threshold ~30 GeV
- Angular resolution 0.1-0.4 deg

Heike Prokoph · H.E.S.S. Highlights · ICRC 2019, Madison, WI · July 2019 · 2

Shower image, 100 GeV, image adapted from: P. Zech, J. Knapp, "CORONA Shower Images", 2003, <https://www.zeruthen.desy.de/~knapp/fs/showerimages.html>

EAS v. IACT



	EAS Array	IACT
Field of View (FOV)	$\sim 90^\circ$ ($\sim 2 \text{ sr}$)	$\sim 5^\circ$ ($\sim 4 \text{ msr}$)
Duty Factor	$\sim 100\%$	$\sim 10\%$
Angular Resolution	$1^\circ - 0.2^\circ$	$0.1^\circ - 0.06^\circ$
Energy Range	500 GeV - 100 TeV	50 GeV – 50 TeV
Energy Resolution	50% - 30%	20% - 8%

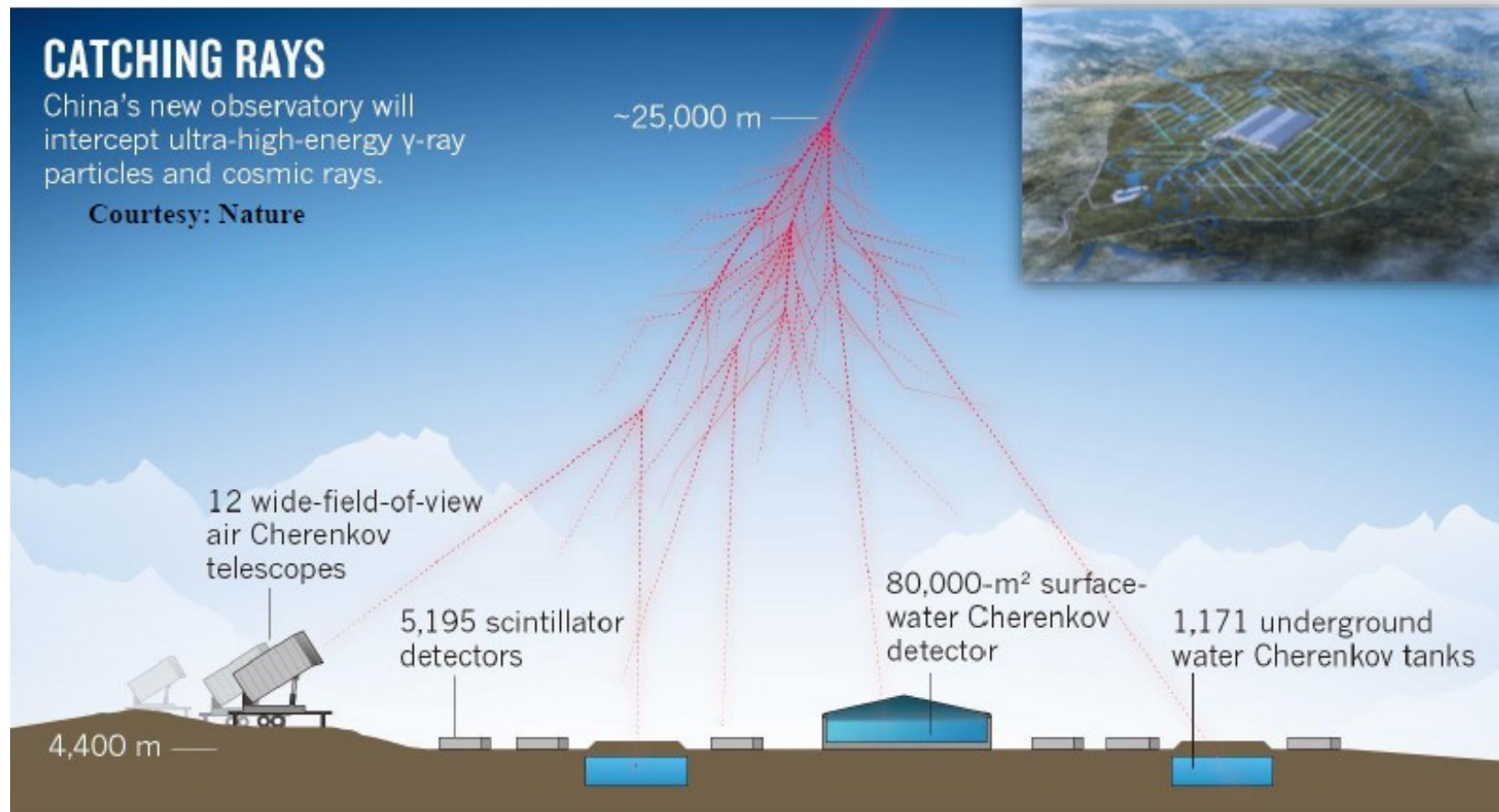
EAS – Altitude Matters
Higher = Lower Energy

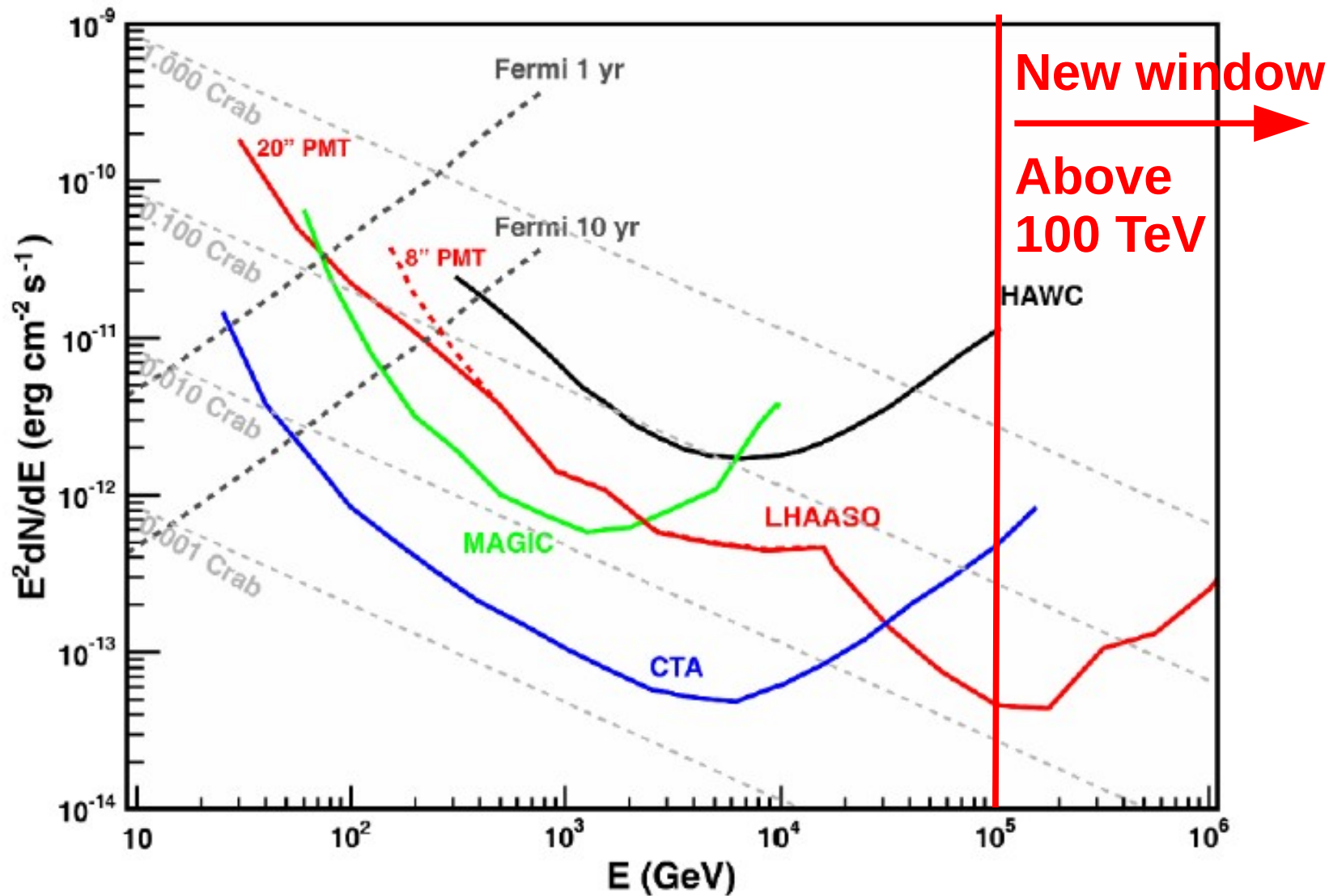
Hybrid Detection of EASs by LHAASO

CATCHING RAYS

China's new observatory will intercept ultra-high-energy γ -ray particles and cosmic rays.

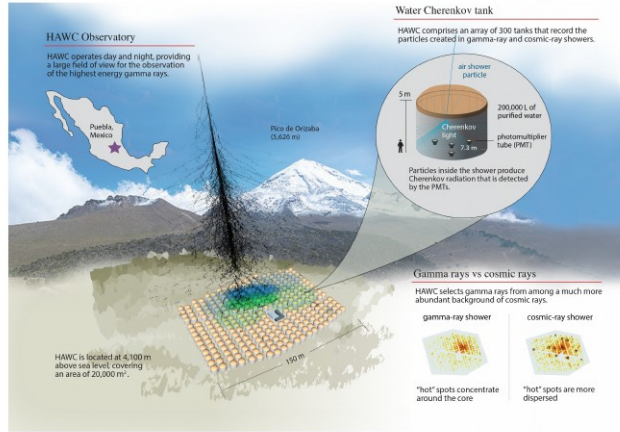
Courtesy: Nature





Scientific News from EAS arrays

The HAWC Observatory



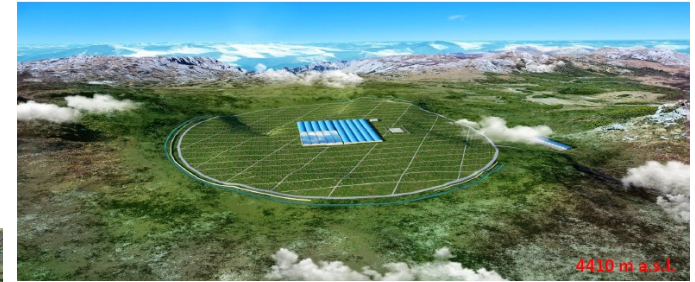
29-July-2019

F. Salesa Greus (IFJ-PAN) - HAWC

LHAASO

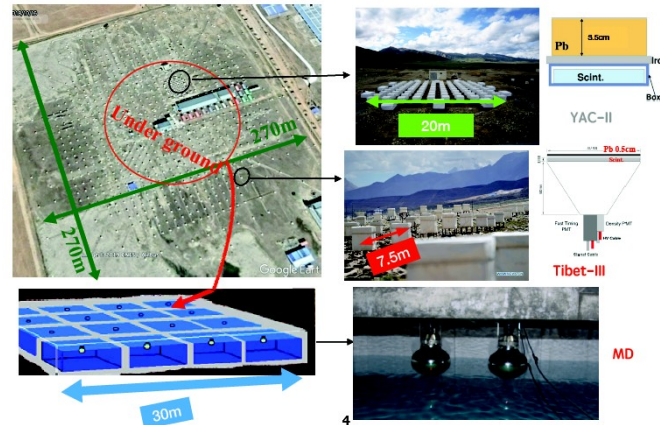
Large High Altitude Air Shower Observatory

- Total budget: ¥1,200 M



The Tibet ASy experiment

At Yangbajing, Tibet, China (90.522°E, 30.102°N, 4300m a.s.l.)

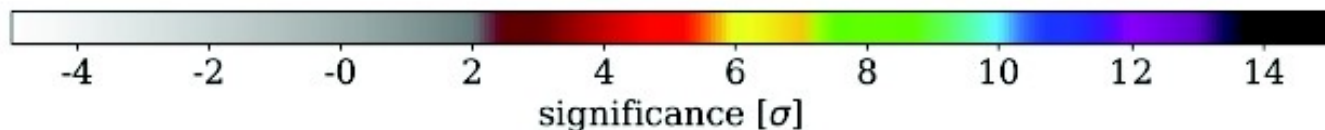


HAWC Sky Map with 1346 Days

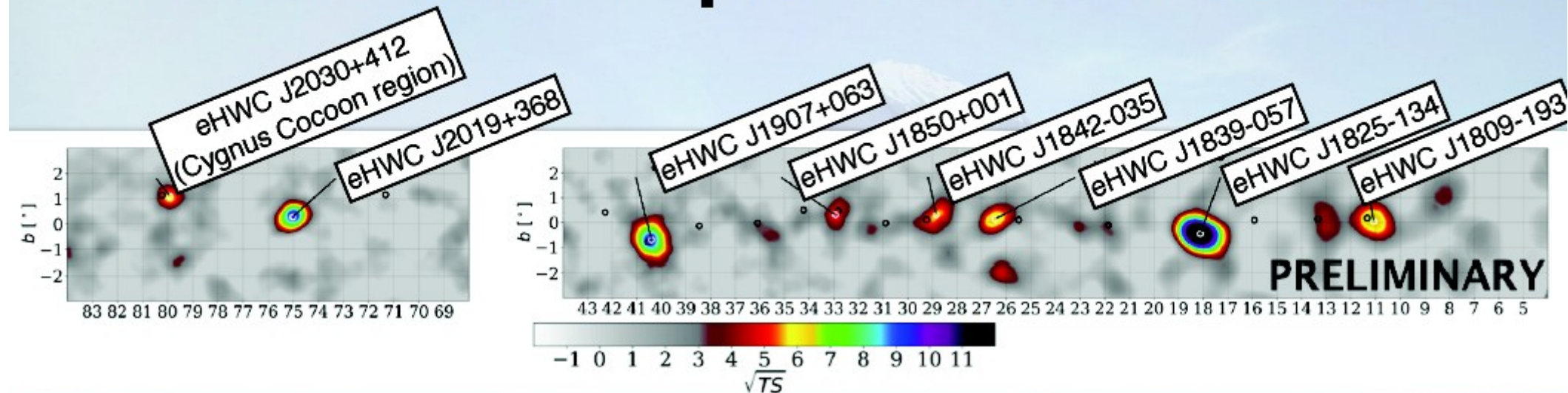


BRAND NEW

New reconstruction improvements coming soon

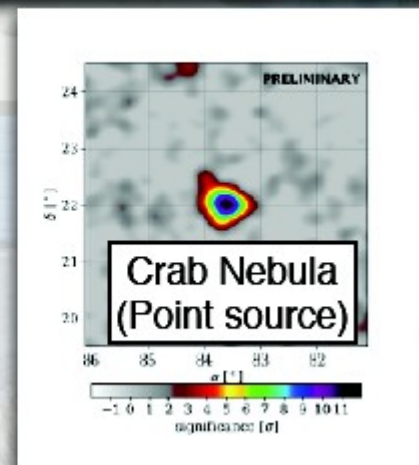


Inner Galactic plane above 56 TeV

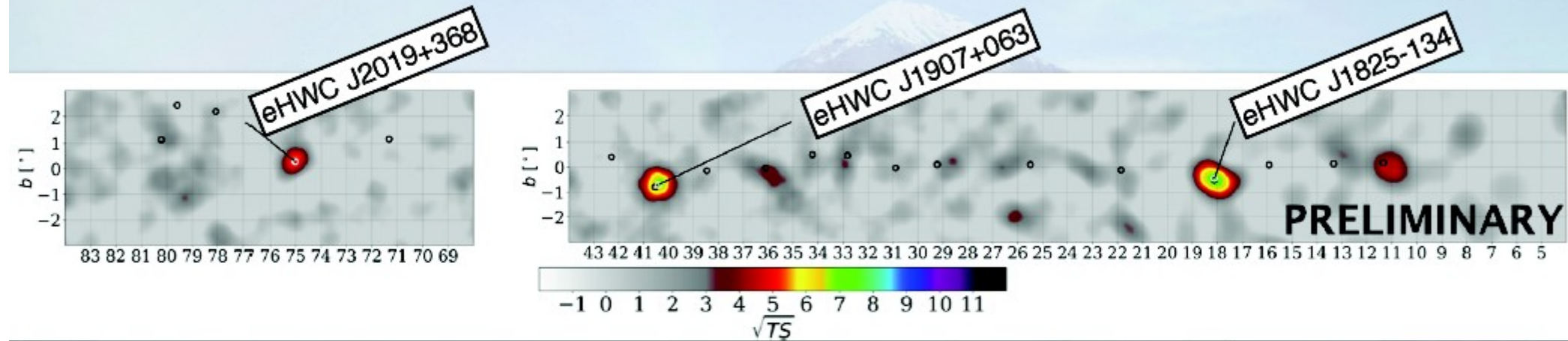


- 1038 days of data
- Map assumes 0.5 degree disk as the spatial morphology
- All sources in the Galactic plane remain extended above 56 TeV

→
Crab Nebula

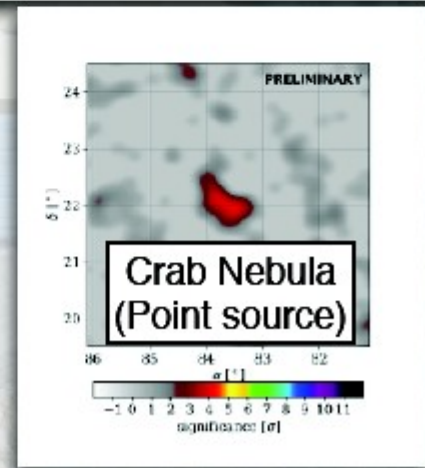


Inner Galactic plane above 100 TeV

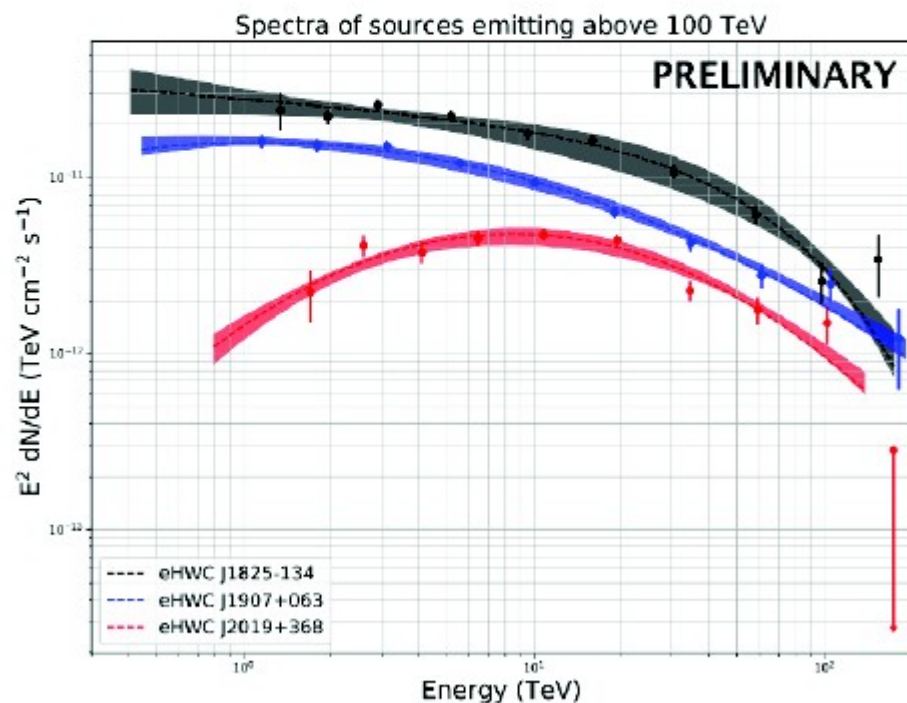


- 1038 days of data
- Map assumes 0.5 degree disk as the spatial morphology
- All sources in the Galactic plane remain extended above 100 TeV

→
Crab Nebula

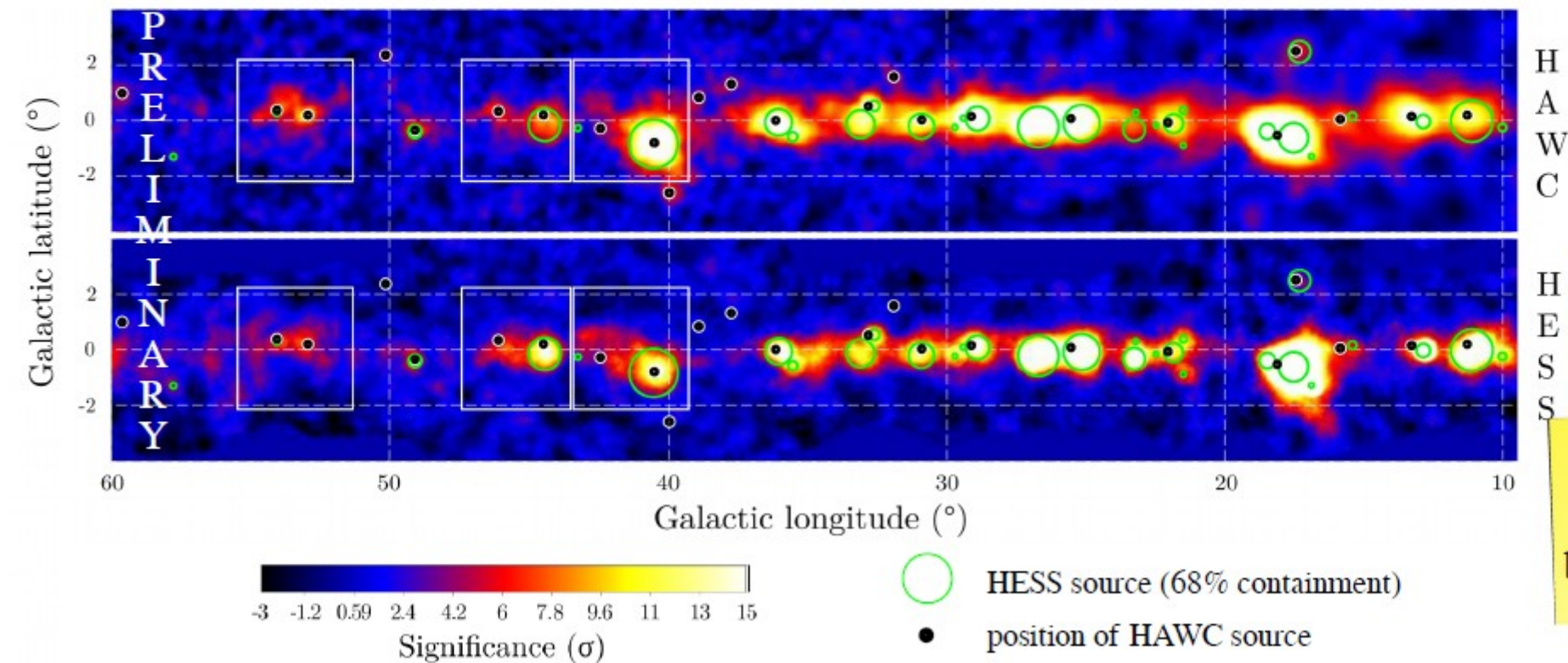


Spectra of the 3 sources that emit above 100 TeV



- Spectra of the three highest-energy sources are different
- Roughly the same flux at 100 TeV
 - Possibly selection bias due to HAWC's sensitivity
- More talks on highest-energy HAWC photons and implications:
 - J. Linnemann, 14:00 on July 30, GAI9
 - H. Martinez-Huerta, 17:00 on July 31, GAI11

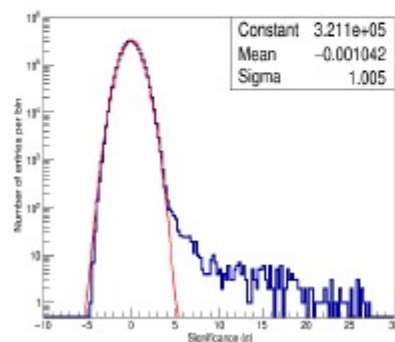
HAWC and HESS galactic plane maps > 1TeV



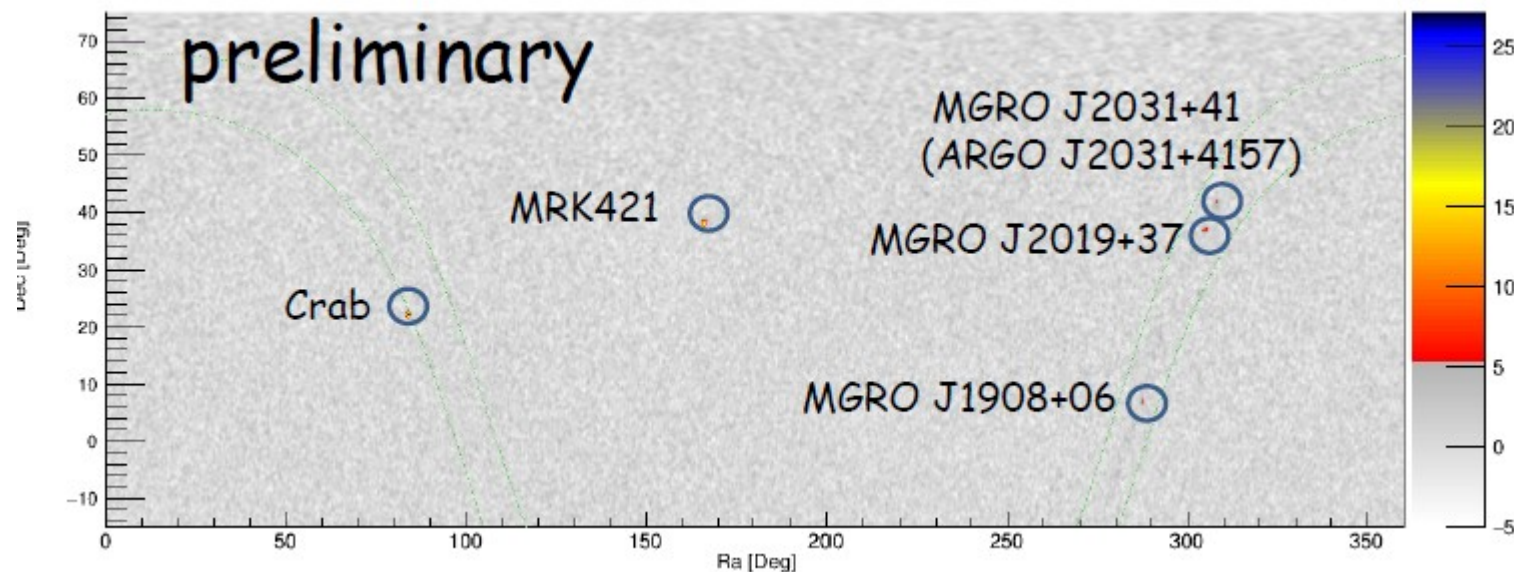
0.4°
correlation
radius

Field of
view
background

WCDA#1 Sky Map



- Data up to 2019-06-30
- Live time: 57 days
- Crab: 27σ



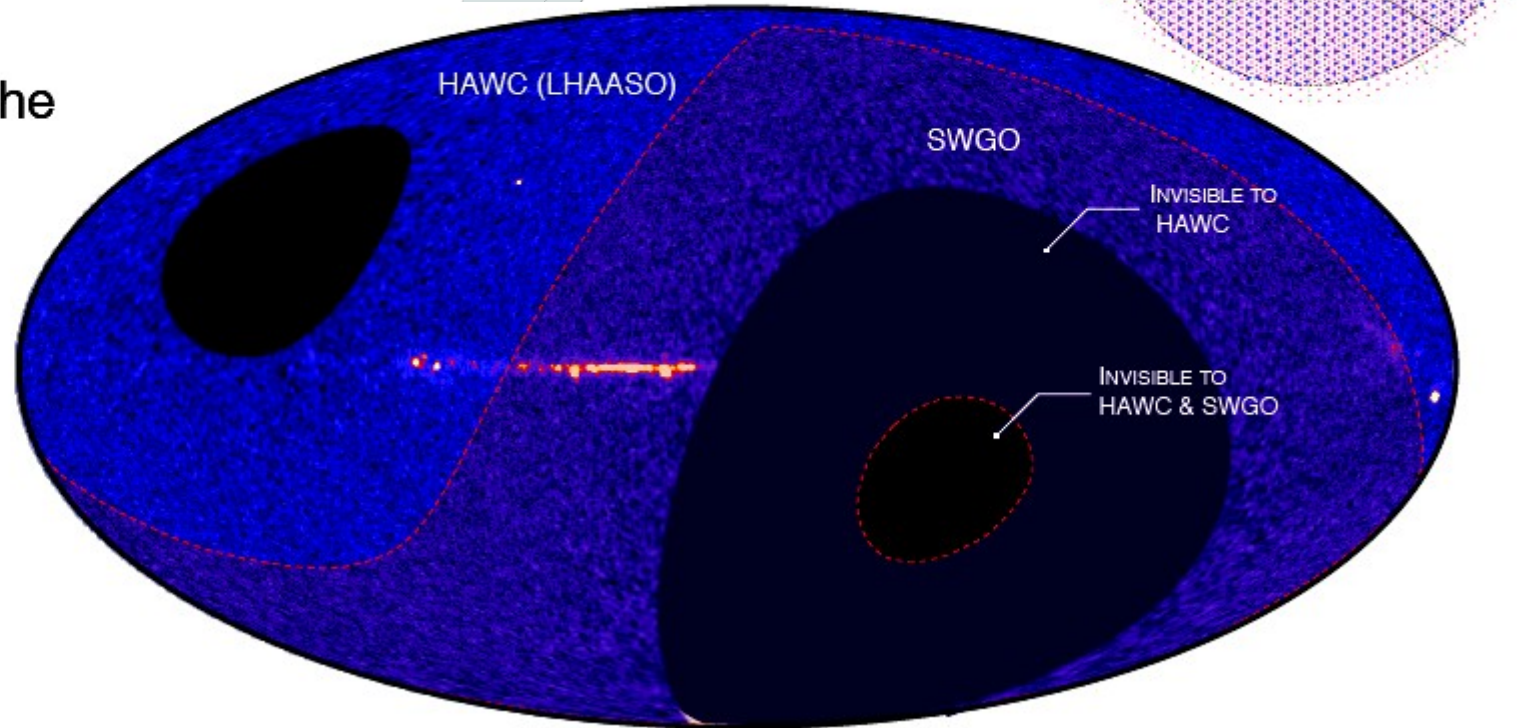
Surveying the southern sky

- The northern sky is surveyed by HAWC and LHAASO
- We propose a next-generation facility in the southern hemisphere

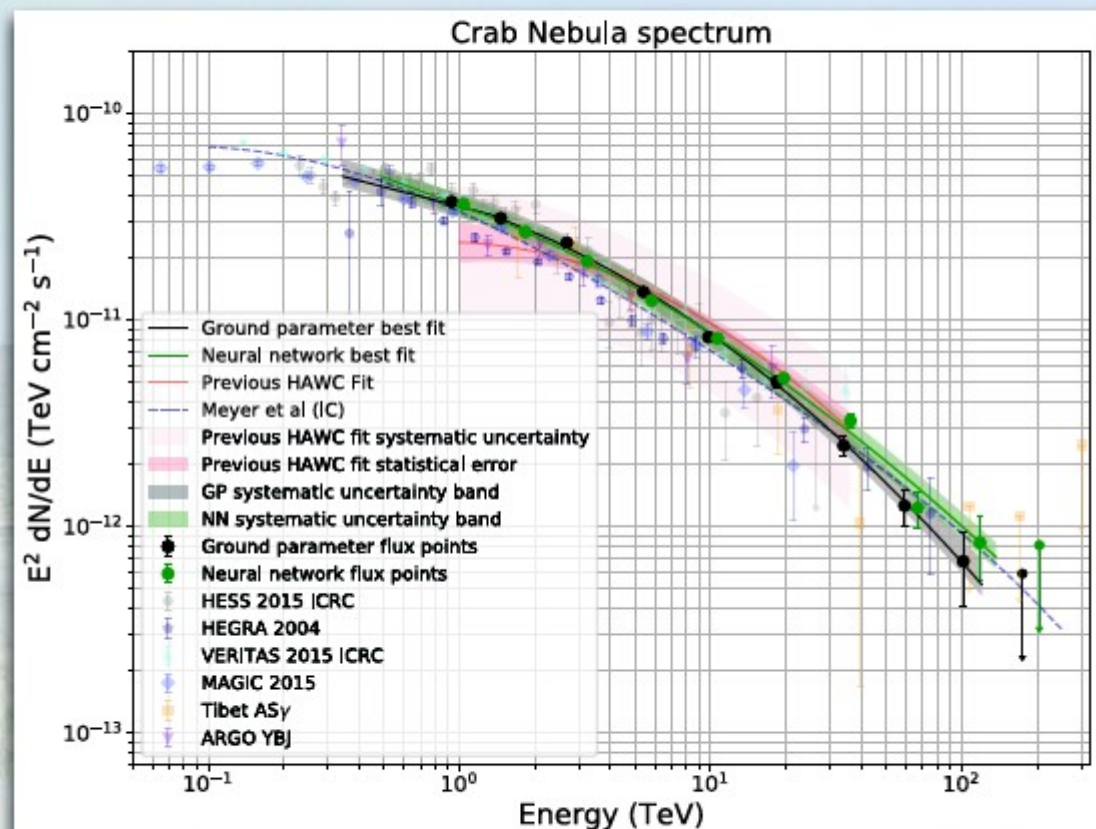


The Southern Wide field-of-view Gamma-ray Observatory

Harm Schoorlemmer for the SWGO collaboration



Crab spectra



<https://arxiv.org/abs/1905.12518>

Accepted by ApJ

- 837 day dataset
- Two independent energy estimation methods agree within statistical uncertainties
- Agree well with IACTs in energy range with overlapping sensitivity

Tibet Air Shower Array

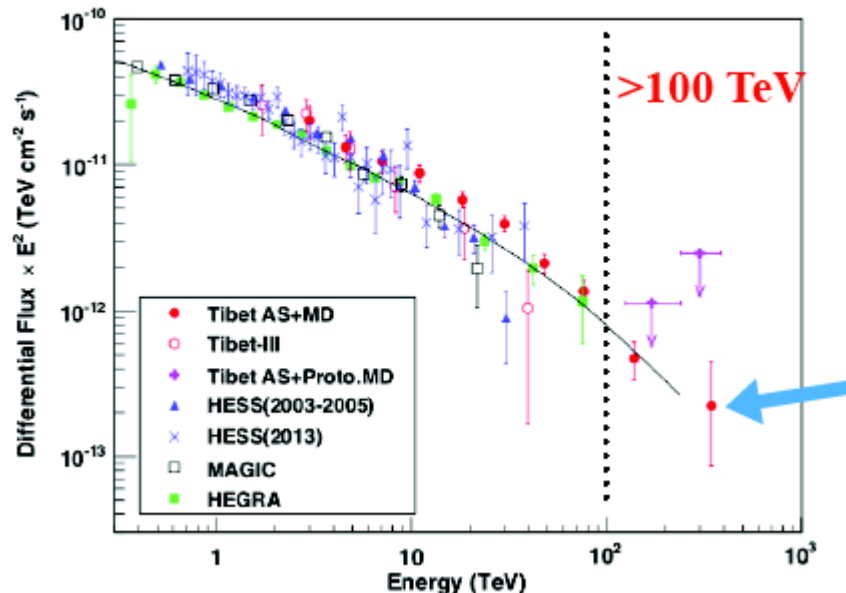
Number of events
(integral)

Crab

Relative number
of muons > 100 TeV

$E_{\text{Rec}}(\text{TeV})$	after muon cut	
	$N_{\text{ON}} / \langle N_{\text{OFF}} \rangle$	σ
>10.0	1691 / 1031	18.3
>15.8	915 / 472.7	17.5
>25.1	417 / 159.1	16.4
>39.8	169 / 46.9	13.2
>63.1	69 / 14.6	9.8
>100	24 / 5.5	5.6
>251	4 / 0.8	2.4

Differential energy spectrum



$$\left(R_{\mu} = \frac{\text{observed } \Sigma N_{\mu}}{\text{cut value of } \Sigma N_{\mu}} \right)$$

➤ First Detection of sub-PeV γ

➤ Highest-energy photon ~ 450 TeV (See poster: PS1-75)

Scientific News from IACTs

The High Energy Stereoscopic System (H.E.S.S.)

Imaging Atmospheric Cherenkov Telescope Array in Namibia

- Sensitive to gamma-ray energies from ~ 30 GeV to 100 TeV
- Regular observation time ~ 1000 h/year (astronomical darkness)



Phase I (2002)

- 4x 12m telescopes
- 960 PMTs/camera
- 5 degree field of view (FoV)
- Energy threshold ~ 100 GeV
- Angular resolution ~ 0.1 deg

Phase II (2012)

- Additional 28m telescope (CT5) with 2048 PMTs
- 3.2 degree FoV
- Energy threshold ~ 30 GeV
- Angular resolution 0.1-0.4 deg



About VERITAS

Four 12 m Imaging Atmospheric Cherenkov Telescopes (IACTs)

Effective energy range: 85 GeV – >30 TeV (“VHE band”)

Field of view = 3.5° ; angular resolution = 0.08° @ 1 TeV

1% Crab Nebula in < 25 hr



MAGIC telescopes

- System of two Imaging Atmospheric Cherenkov Telescopes
- Observing the very high energy gamma-ray sky
- Dish diameter 17m
- Located at La Palma, Canary islands
- 2200 m a.s.l



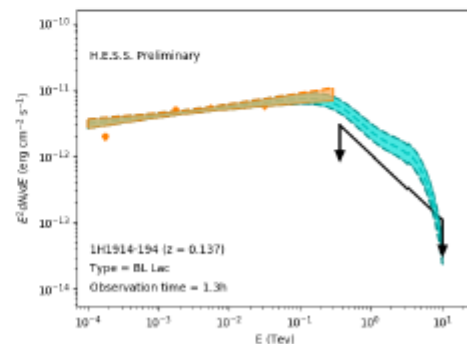
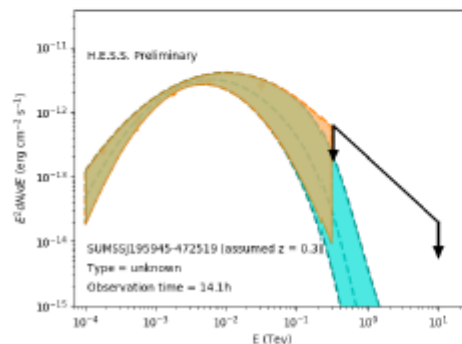
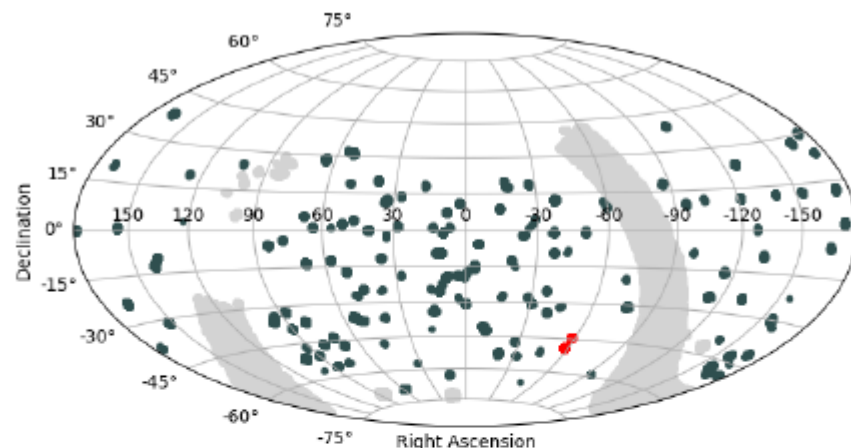
H.E.S.S.-I Legacy Data Sets

Galactic Plane Scan

- Release of >2500 hours of observations of the Galactic Plane by H.E.S.S. (2004 – 2013)
 - A&A special issue (2018)

Extragalactic „Survey“

- Planned release of >2500 hours of H.E.S.S. extragalactic observations (2004 – 2013) covering about 6% of the sky
 - Systematic search for variability
 - Comparison with known Fermi-LAT sources
- Further investigations on long-term variability and deep exposure data sets (>100h)



Taverner
al. (GA11a)

Search for primordial black holes



H.E.S.S.-I Precision Measurements

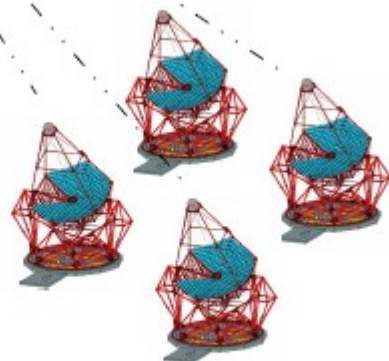
- Improved reconstruction using run-wise simulations (ICRC2017)
 - Taking into account source-specific observation and instrument conditions



Array-wise
Tracking, source position, atmosphere

Telescope-wise
Trigger settings, live-time

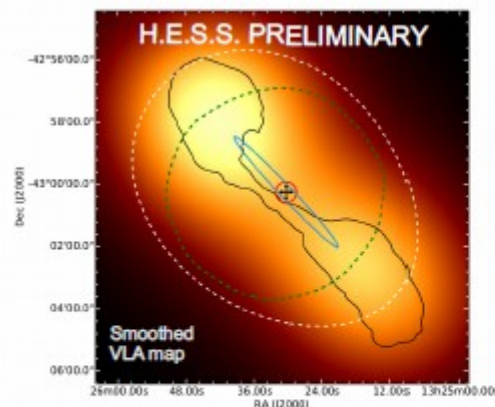
Pixel-wise
Broken pixels, gain, NSB



M. de Naurois
et al. (GAI5e)

VHE extension measurements by H.E.S.S.

- Crab Nebula extension**
→ accepted by Nature Astronomy (2019)
- Centaurus A extension (nearby radio galaxy)**
 - 13.1sigma detection in 202 hours live-time
 - VHE morphology analysis favors elliptical shape

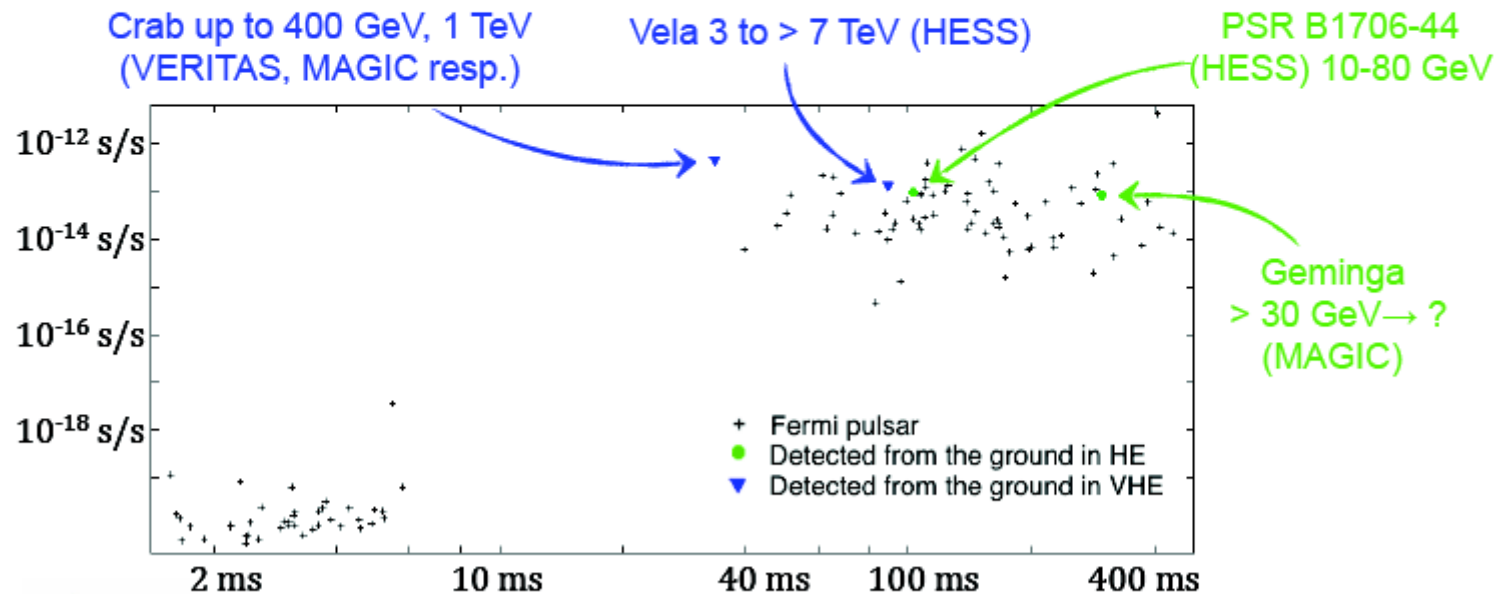


- Gaussian width of semi-major axis (blue contours): $0.044^\circ \pm 0.012^\circ$ (2.8 kpc)
- Point-Like in the transverse direction
- Aligned with radio jets



Pulsars detected in ground-based γ -ray telescopes

- 3 pulsars detected from the ground so far (the Crab, Vela and Geminga)
- We announce the detection of PSR B1706-44 in the 10-80 GeV range
- 2 in the HE (<100 GeV) range only: PSR B1706-44 and Geminga
- 2 in the HE and VHE range: the Crab and Vela



J2032+4127

Young, gamma-ray pulsar recently (2015) found to be in a long-period binary (approx. 50 years)

Periastron occurred in November 2017

VHE campaign coordinated to monitor periastron in 2017 (VERITAS & MAGIC)

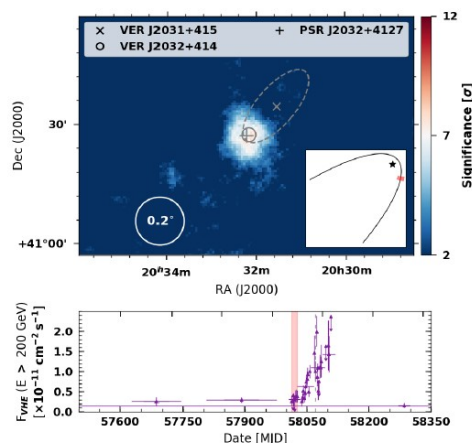
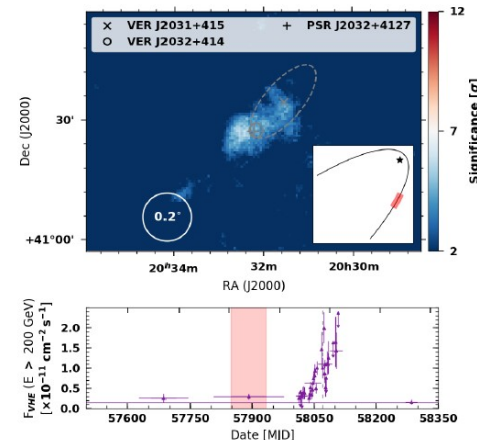
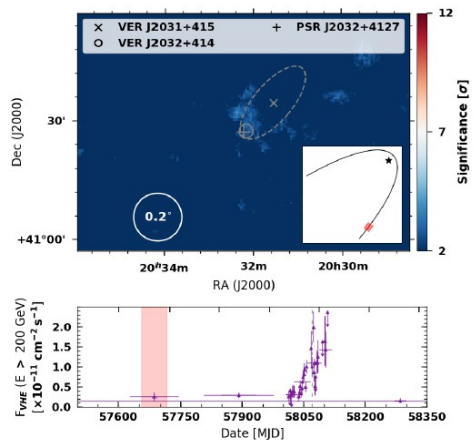
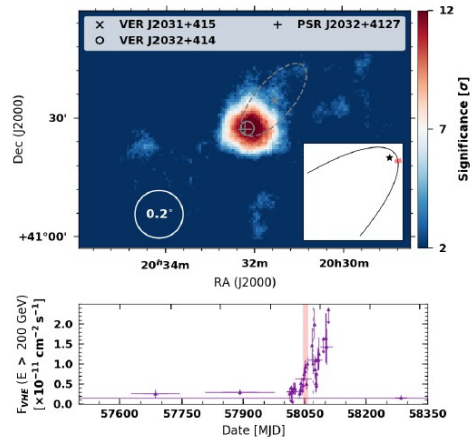
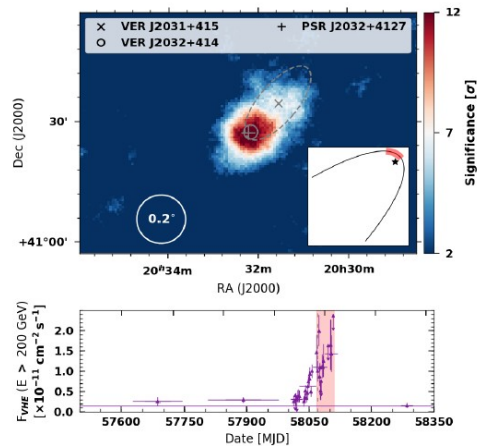
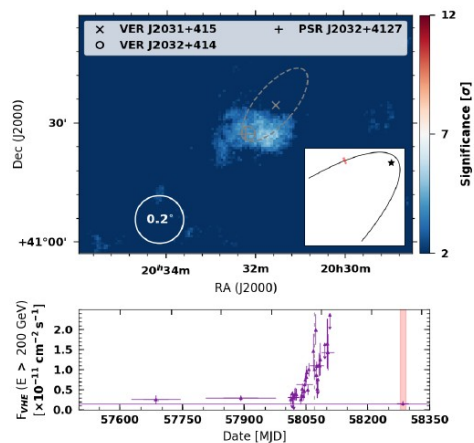
Recent Results from the VERITAS Galactic Science Program

Rising VHE flux seen beginning in September 2017

Associated with emergence of a new point source at pulsar location



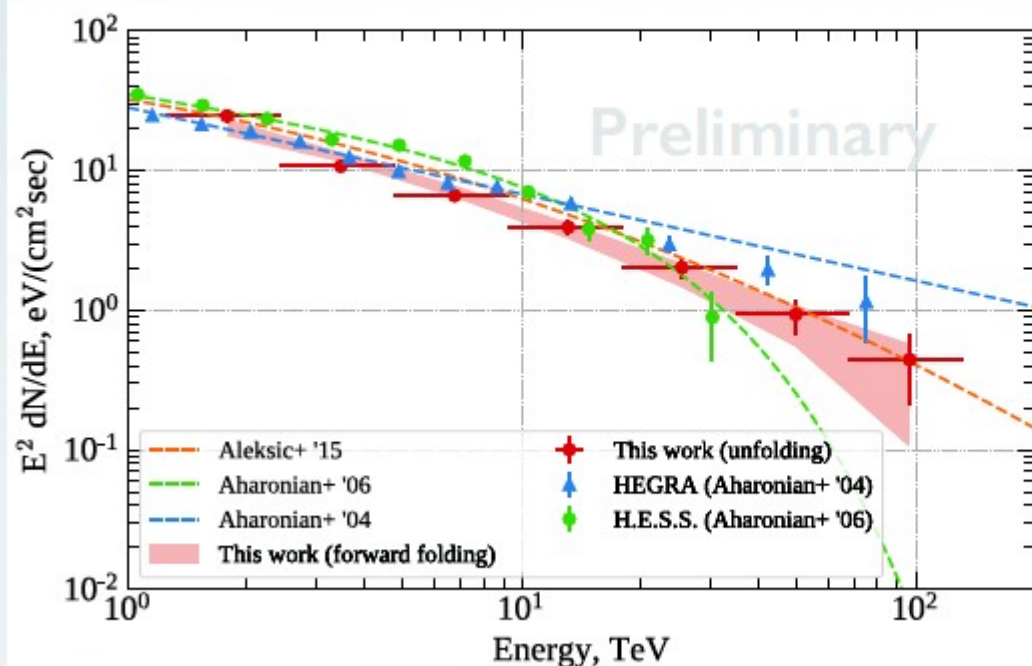
Confirmation of 2nd known gamma-ray binary with compact companion identified



THE CRAB NEBULA SPECTRUM AT ~ 100 TEV MEASURED WITH MAGIC UNDER VERY LARGE ZENITH ANGLES



Crab Nebula SED up to 100 TeV : **highest IACT measurement to date**



Energy estimation
(all compatible results)

- **LUTs** (standard approach - this work)
- random forest (**RF**) multivariate analysis
- neural network (**NN**) regression

Background suppression

- RF classification
- 90% γ -ray efficiency cuts

MAGIC Collection area improved ~ 20 times from low-zenith

Also 2 times better than CTA-North at low zenith

Summary

- **First detection of a GRB by MAGIC (>20 sigma)**
- **VHE gamma-ray map of the Galactic plane above 56 TeV and 100 TeV**
- **Crab Nebula spectrum up to 100 TeV (and above)**
- **Crab nebula – extended source (HESS)**
- **Confirmation of 2nd known gamma-ray binary by (VERITAS)**
- **Confirmation of first extended extragalactic source (HESS)**
- **Skymaps & news from exciting future experiments**

ICRC 2019 Highlights

Gamma-rays



ICRC2019

36th International Cosmic Ray Conference - Madison, WI, USA

THE ASTROPARTICLE PHYSICS CONFERENCE

Thank you...