Highlights of HE Gamma Ray Astronomy and Future Prospects

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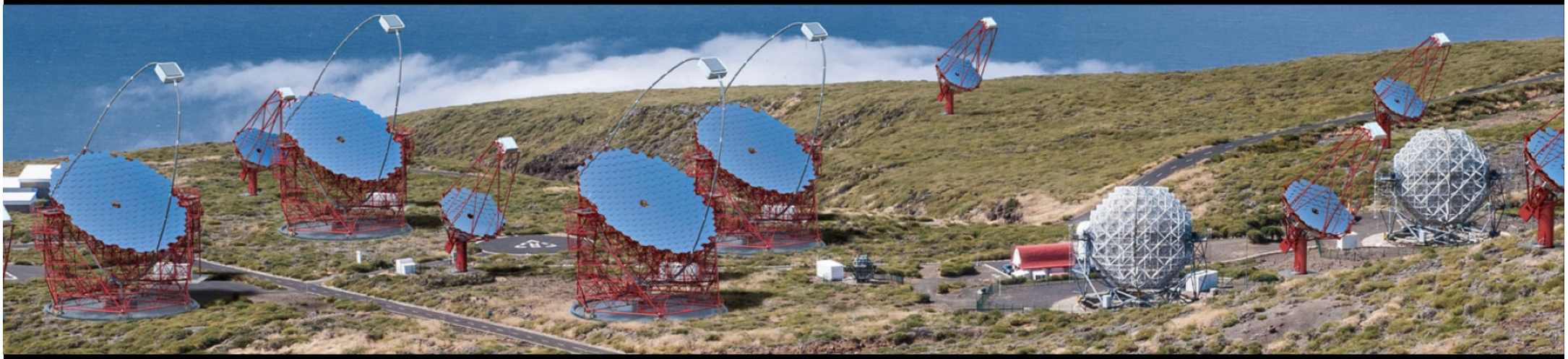
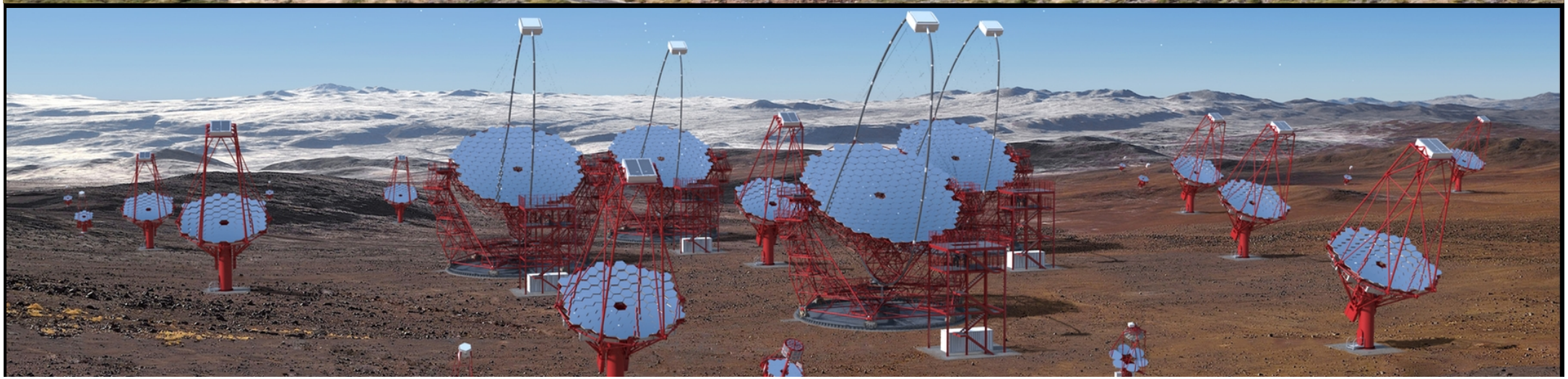
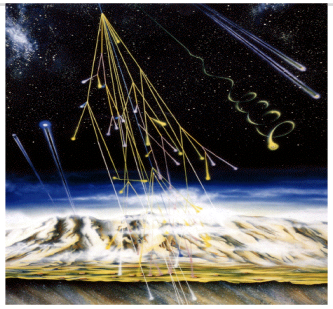
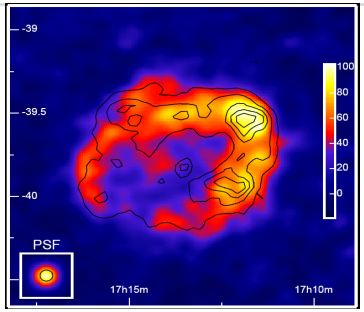
ICRR, The University of Tokyo
Max Planck Institute for Physics





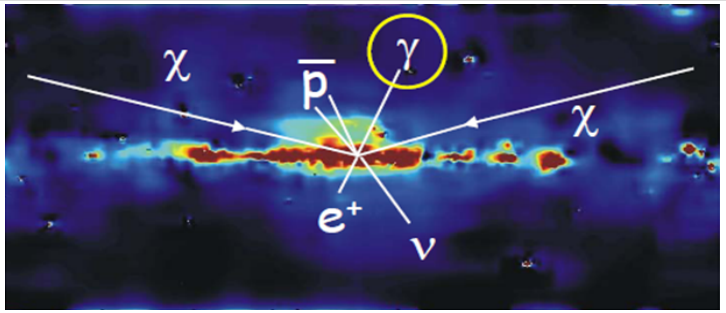
Science of HE Gamma-Ray astronomy is very wide
Energy Frontier in Astrophysics





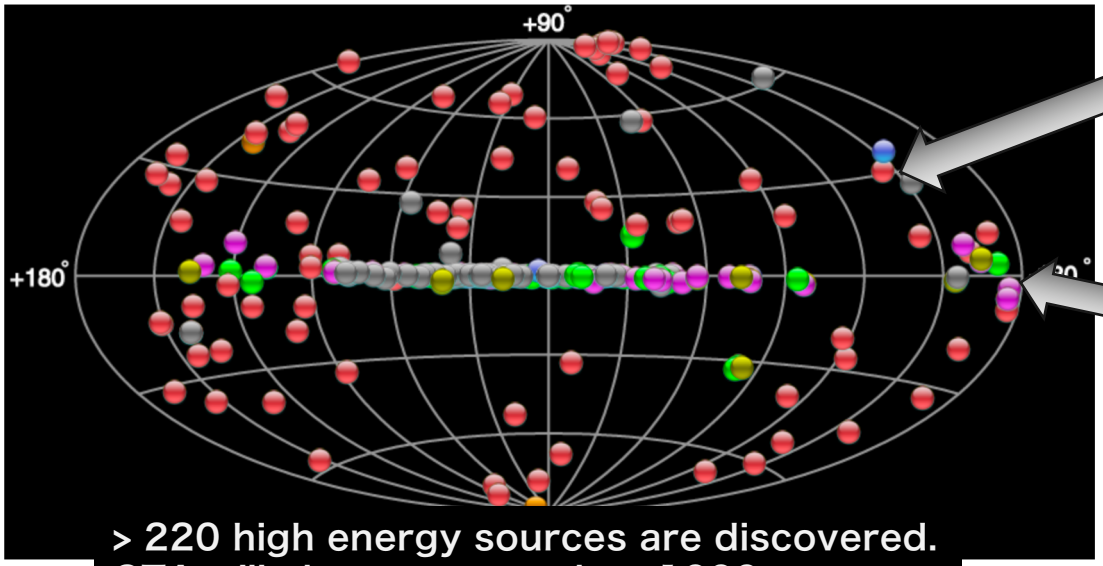
Cosmic Ray Origin

Super Massive Black Holes



Dark Matter Search (Discovery)

- Origin of Cosmic Rays (Big accelerators)
- Black Hole and S.M.B.H.
- Dark Matter Search



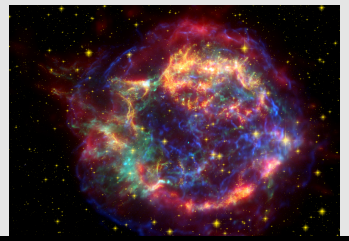
> 220 high energy sources are discovered.
CTA will observe more than 1000 sources.

Extragalactic Sources

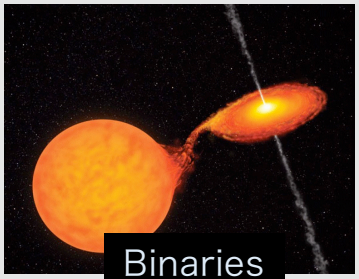
Active Galactic Nuclei

Gamma Ray Bursts

Galactic Sources

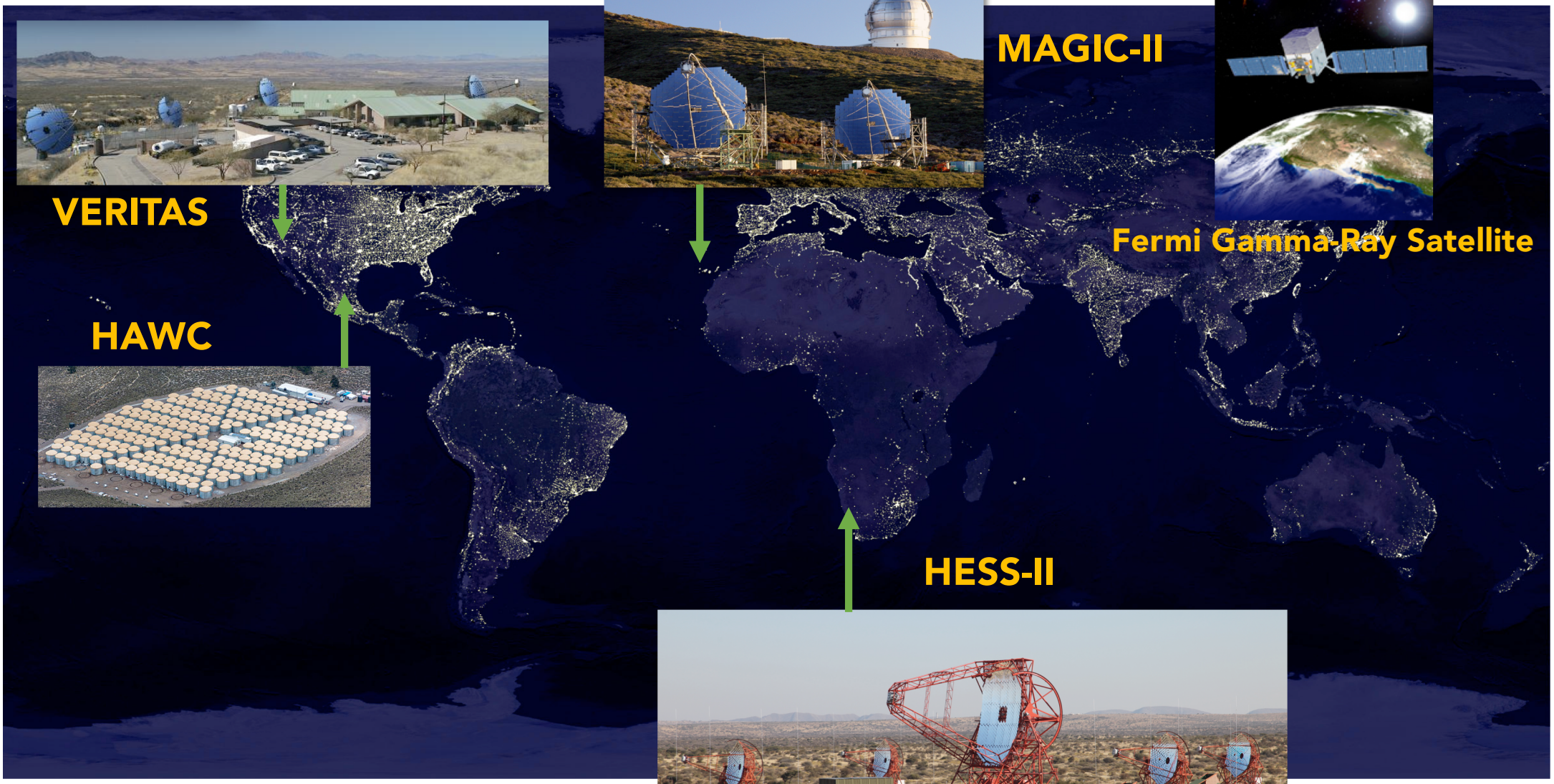


Super Nova Remnants

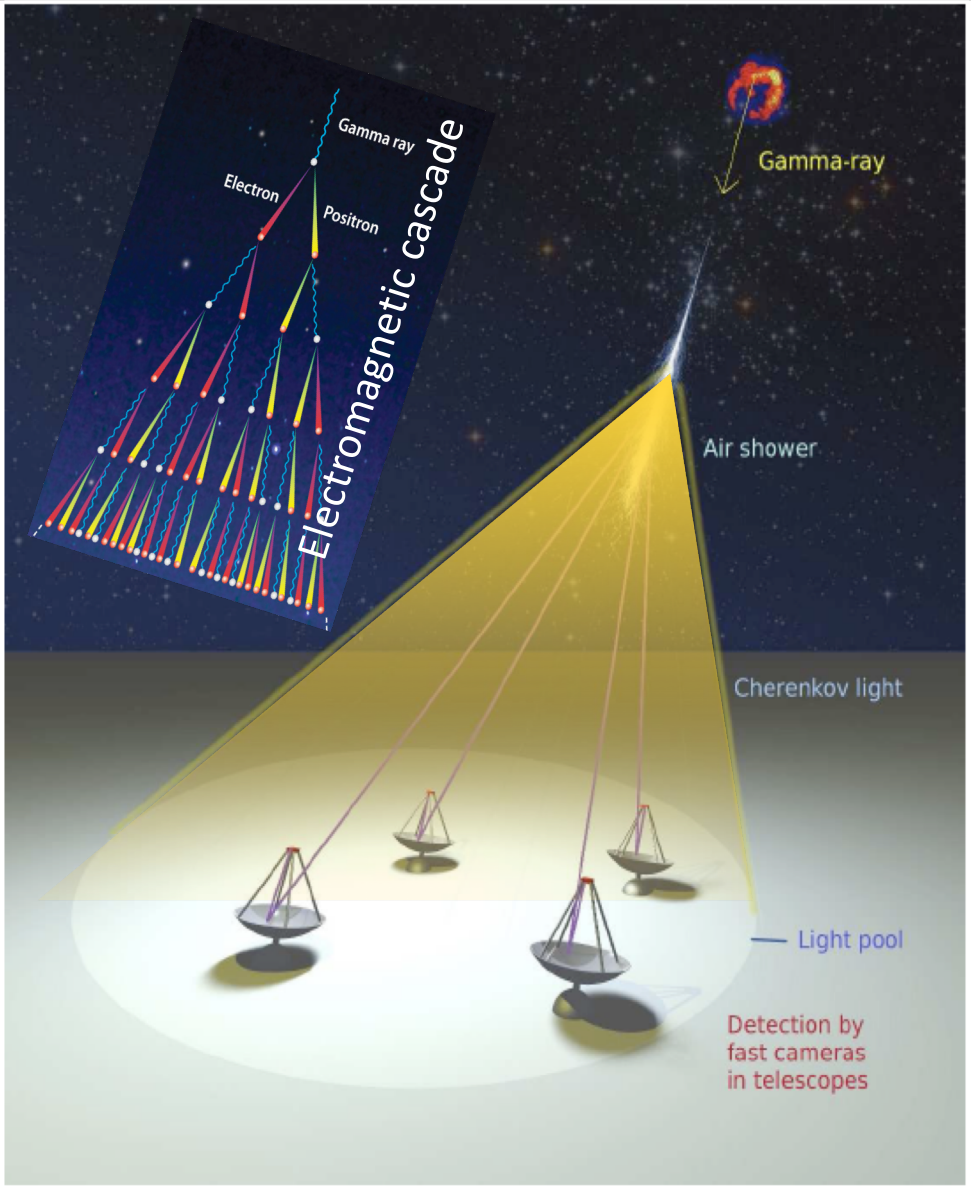


Binaries

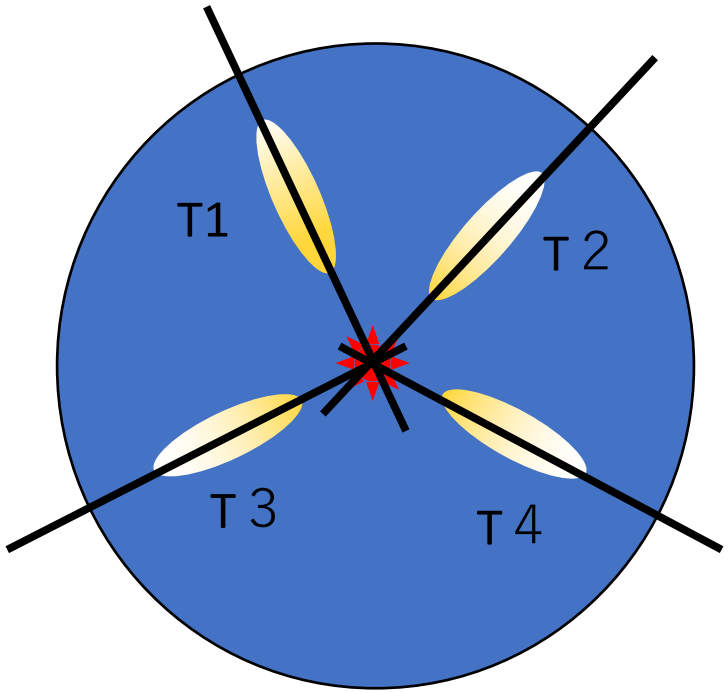
HE/VHE Gamma-Ray detectors



Imaging Cherenkov Technique
it is established in 1989 by T. Weeks

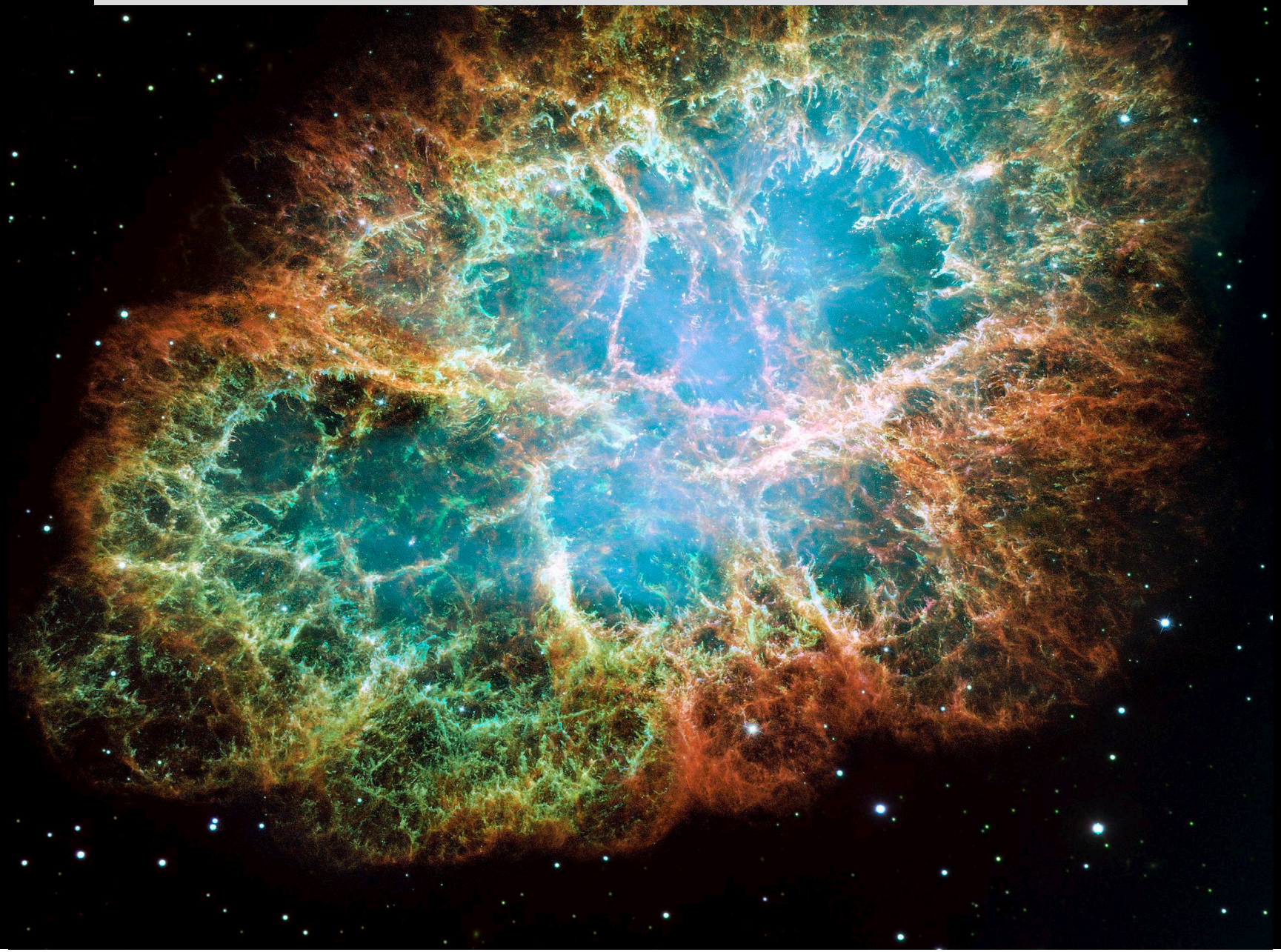


# of Photons: 50photons/m² at 1TeV

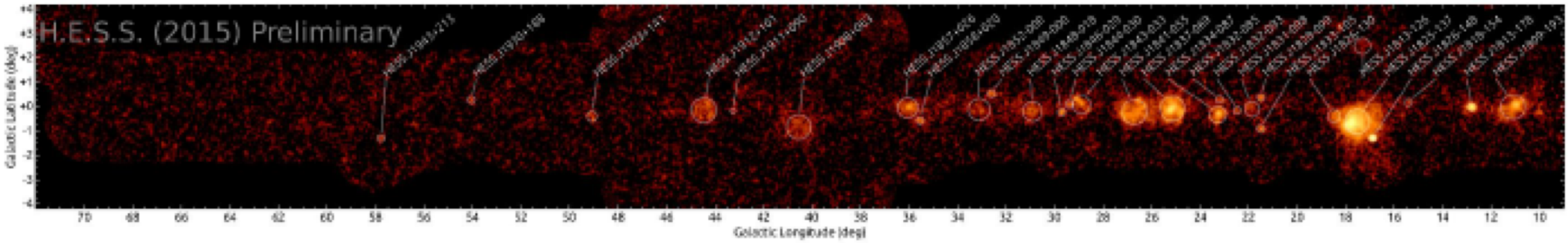


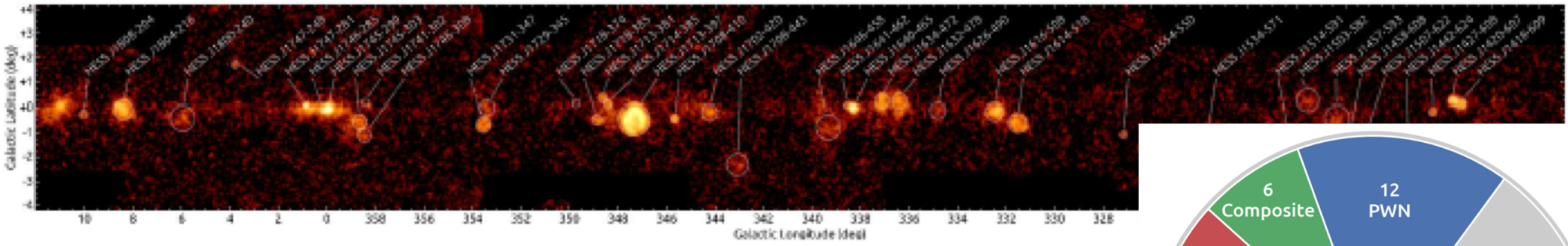

MAGICMovie

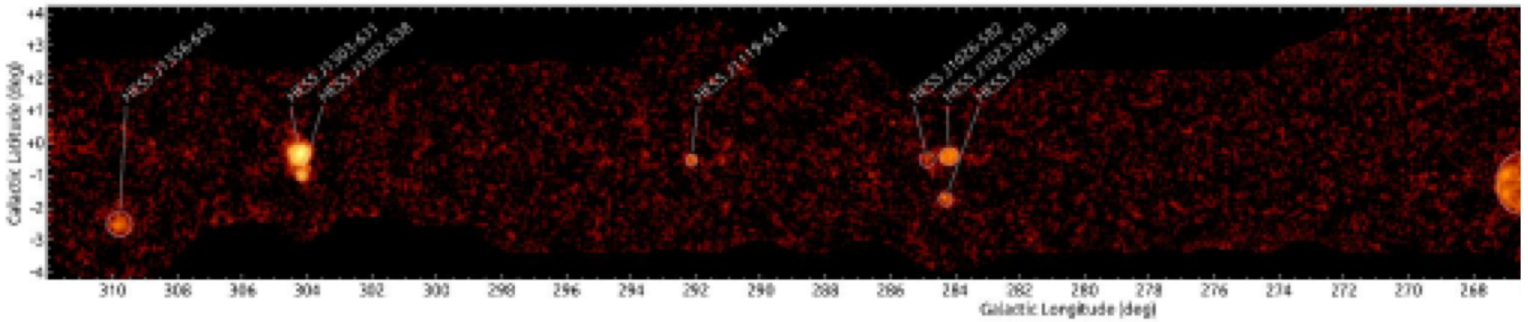
Galactic Sources

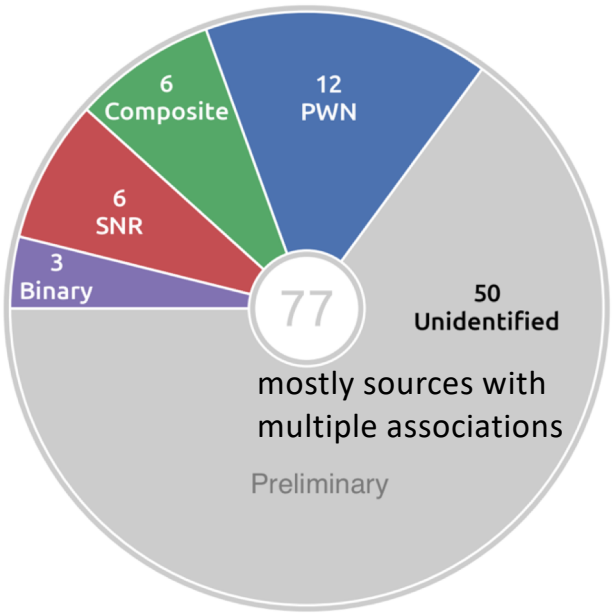


HESS Galactic Plane Survey 2015

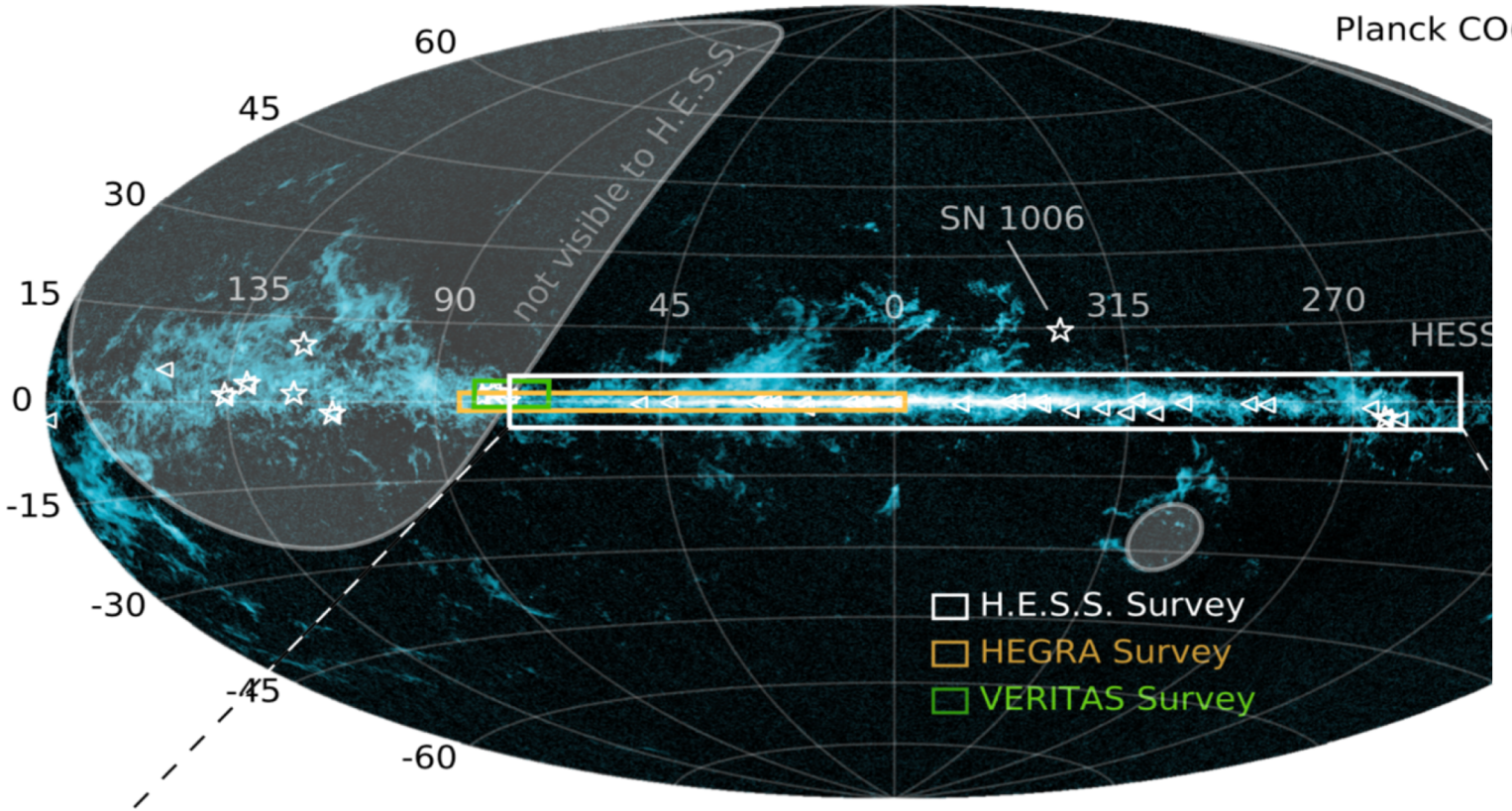


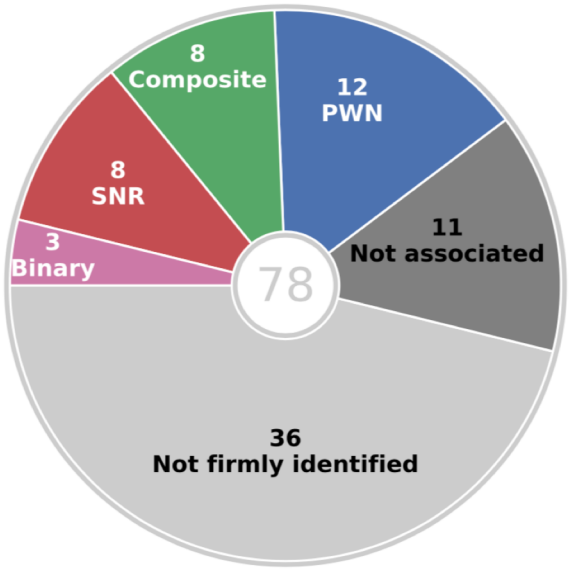


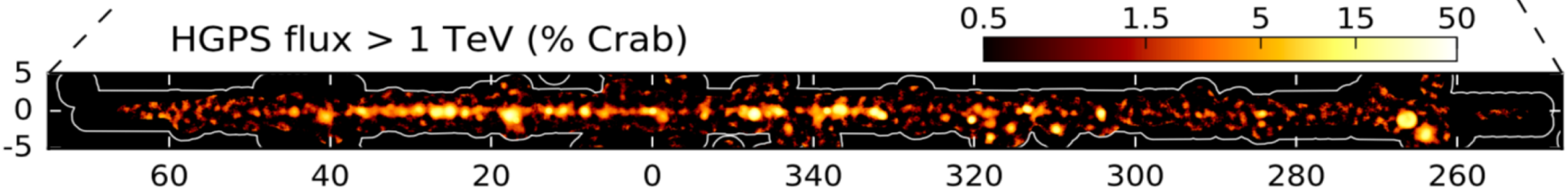


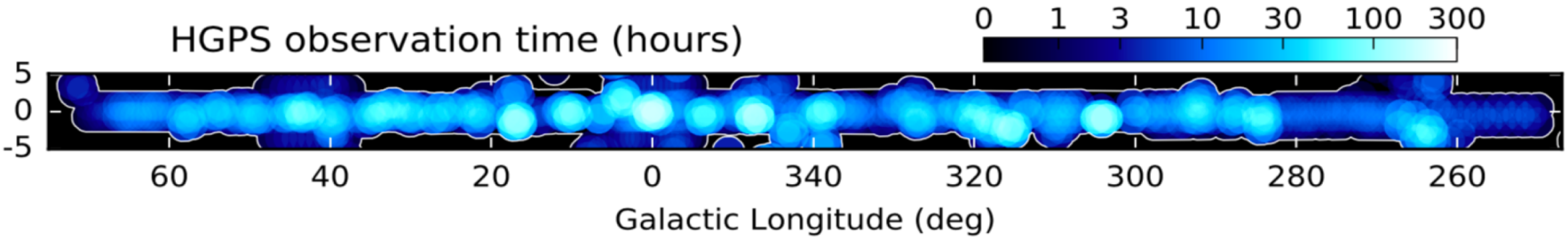


HESS Galactic Plane Survey 2018

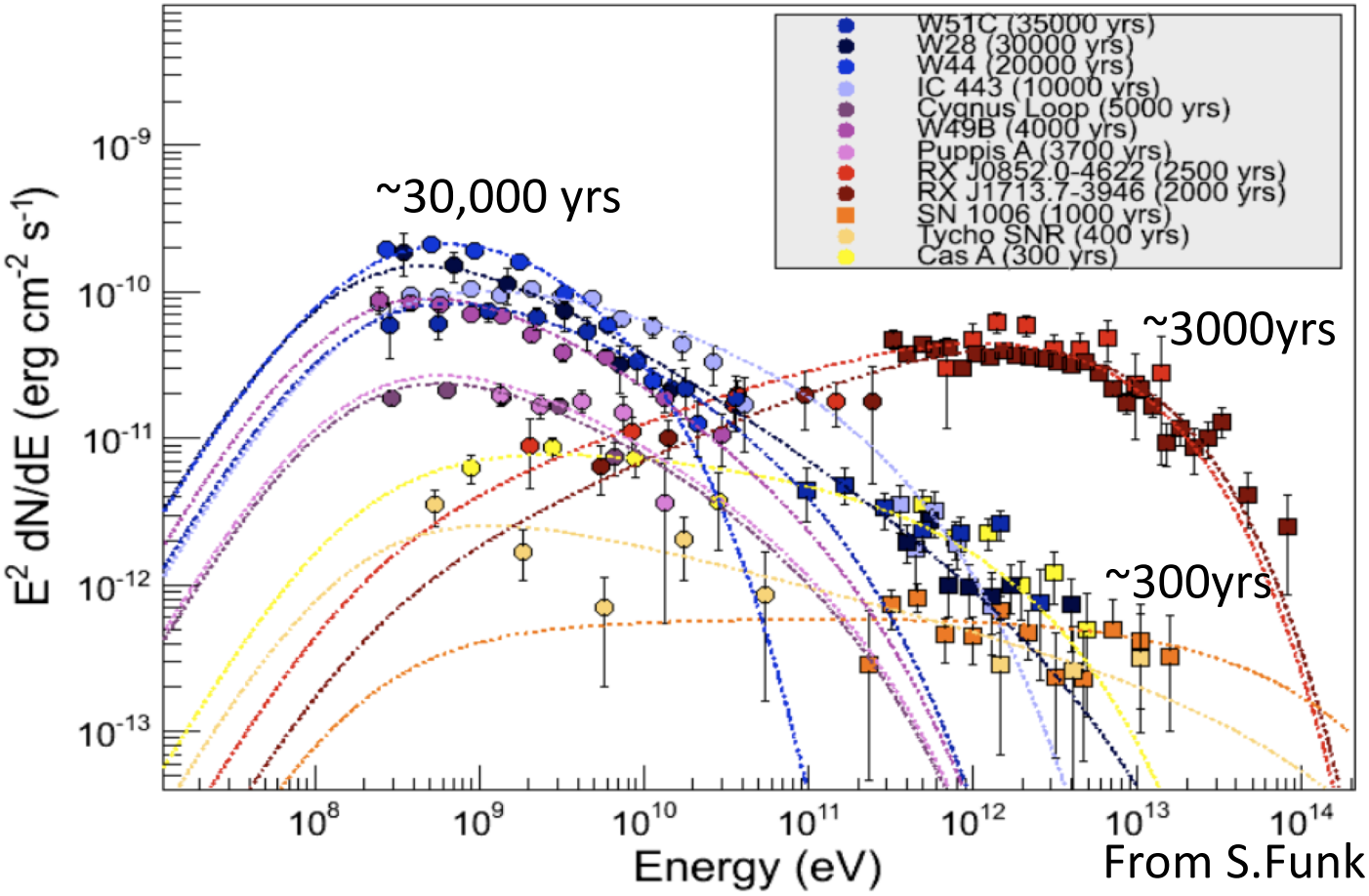


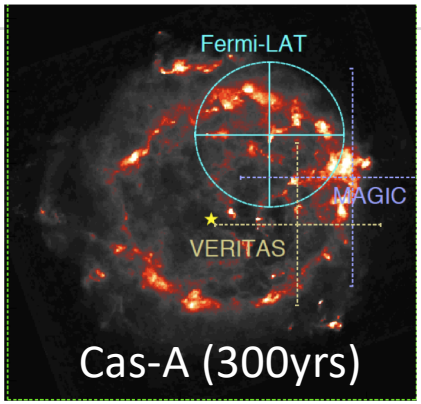


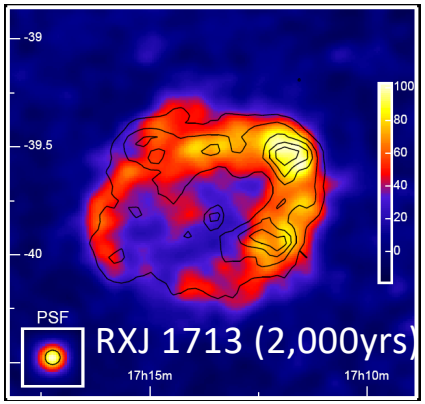


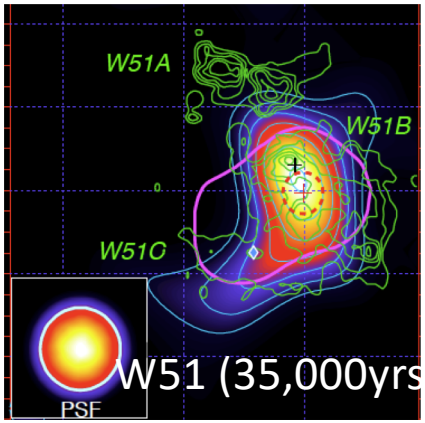


Shell Type Super Nova Remnants
are identified as cosmic ray sources









- We need 200-300 SNRs to explain the energetics of galactic cosmic rays
- What is the maximum attainable energy with SNRs

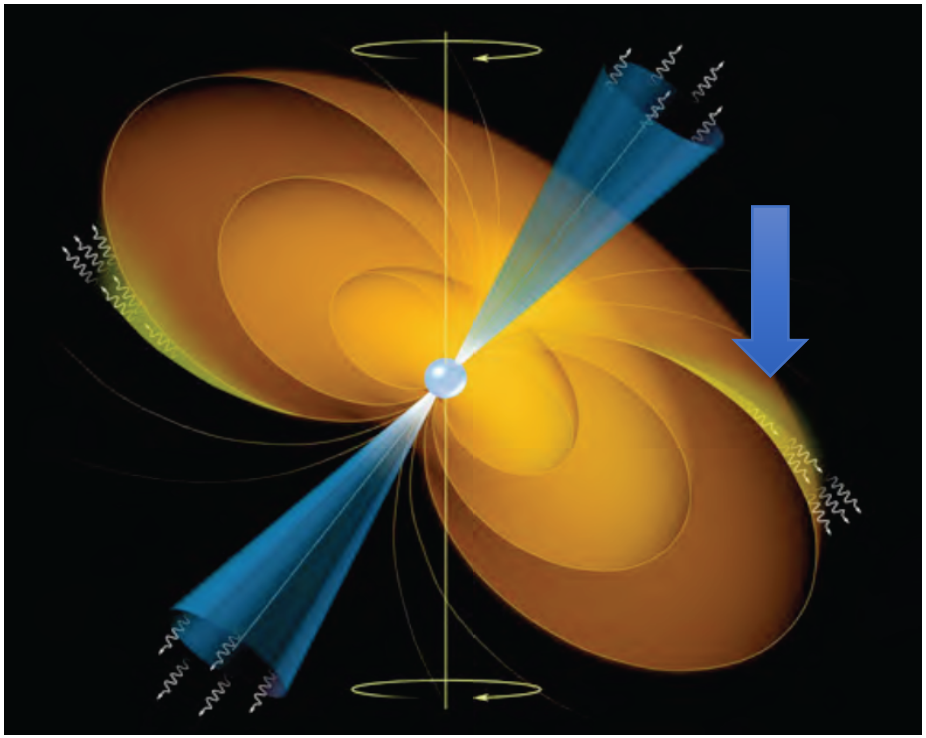
Crab Pulsar observation with MAGIC in 2008

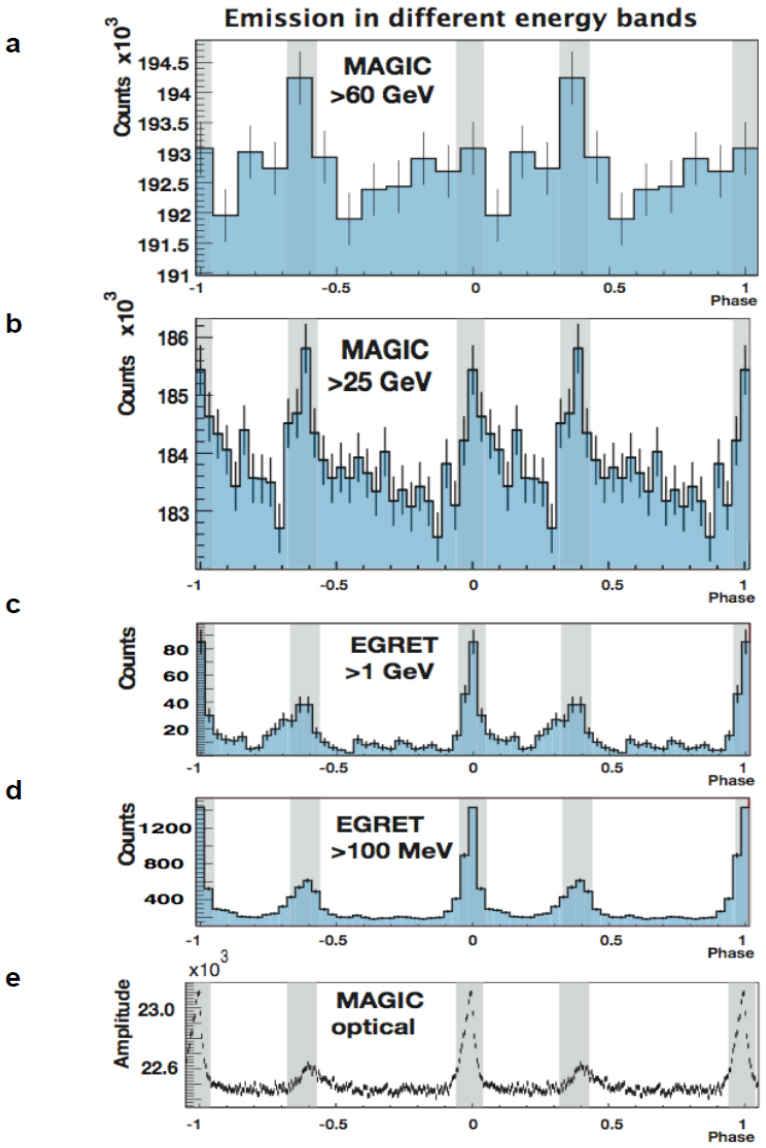
MAGIC result: Published in Science in 2008

Measuring the spectrum around cutoff
or at high energies is important to distinguish
the emission model

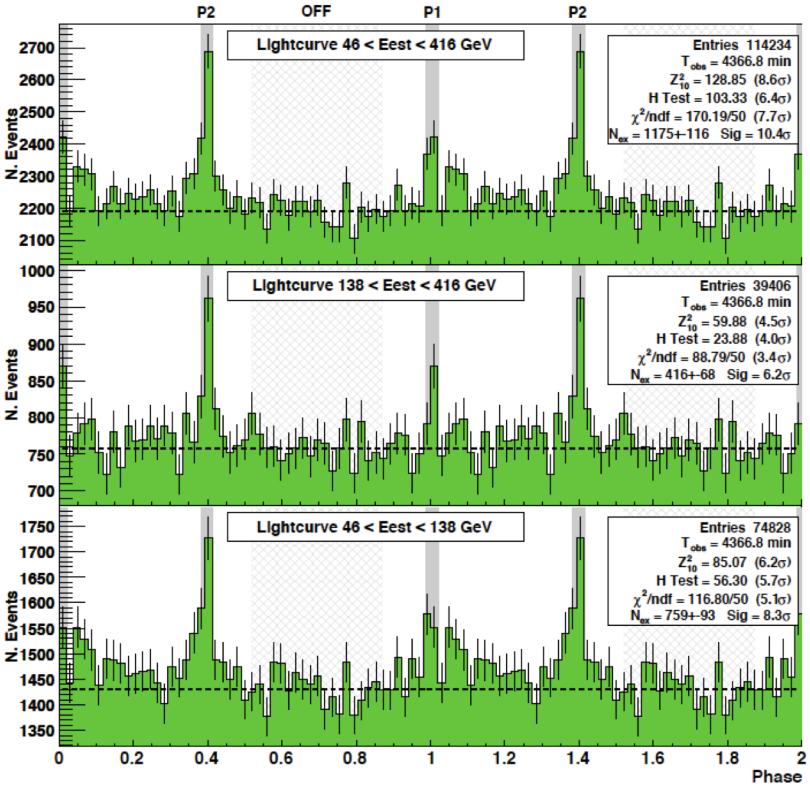
Polar cap: double exponent

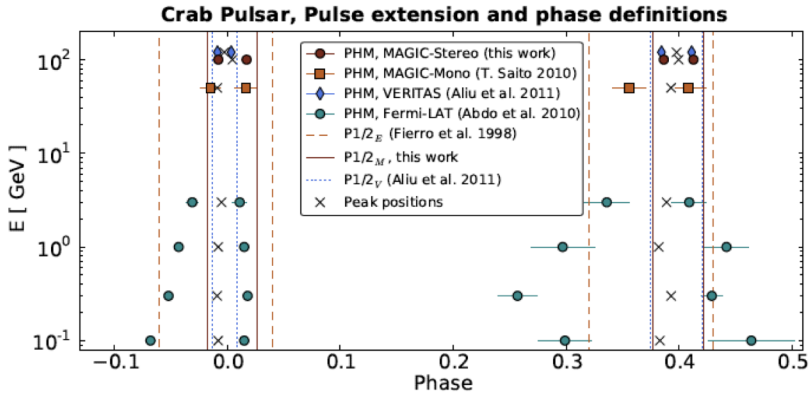
Outer gap: simple exponent

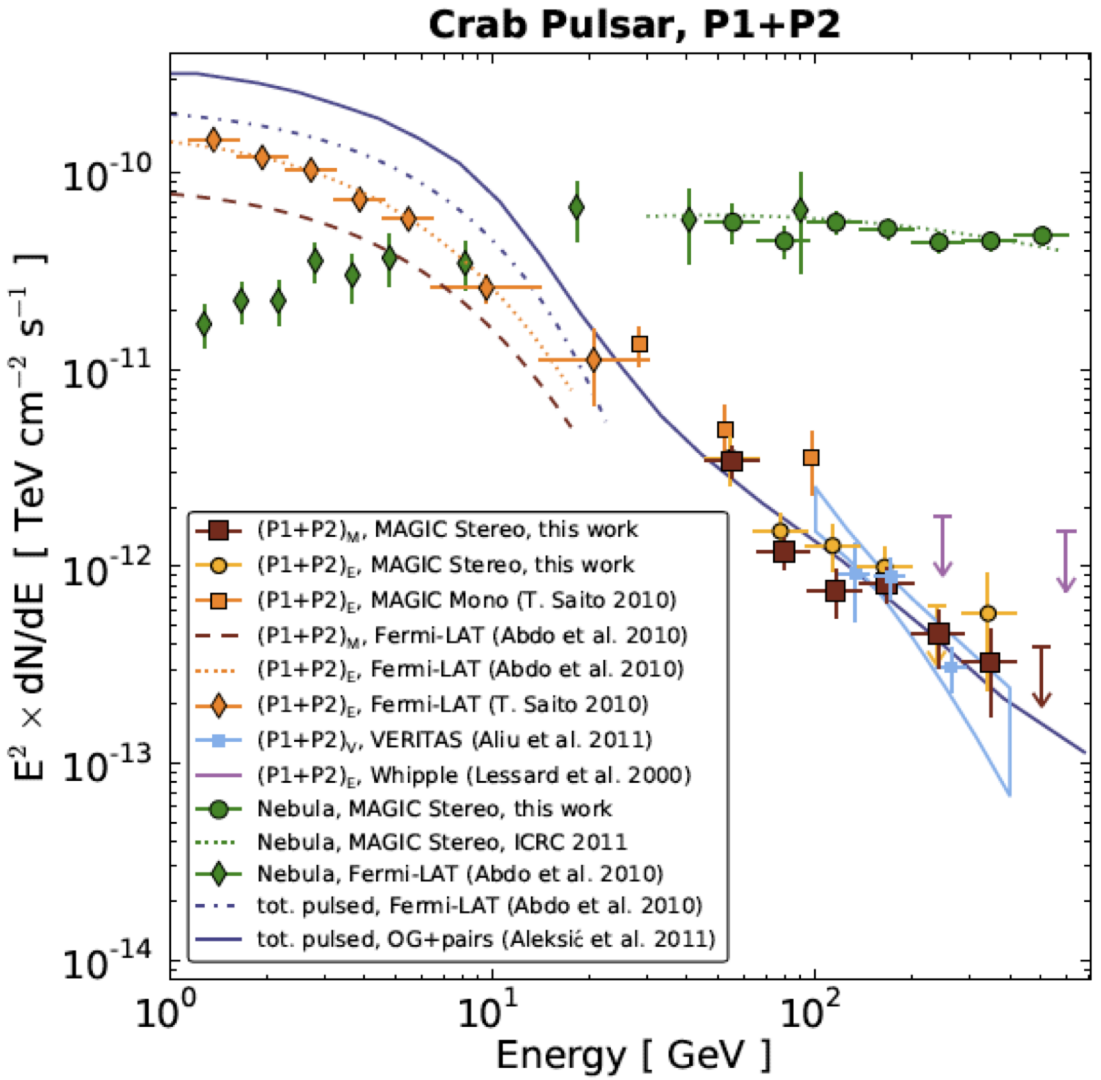




Crab Pulsar with MAGIC Stereo

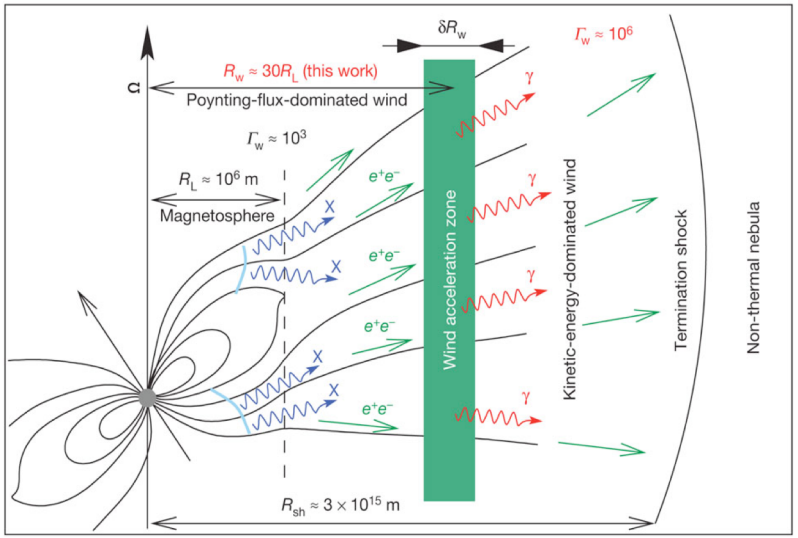


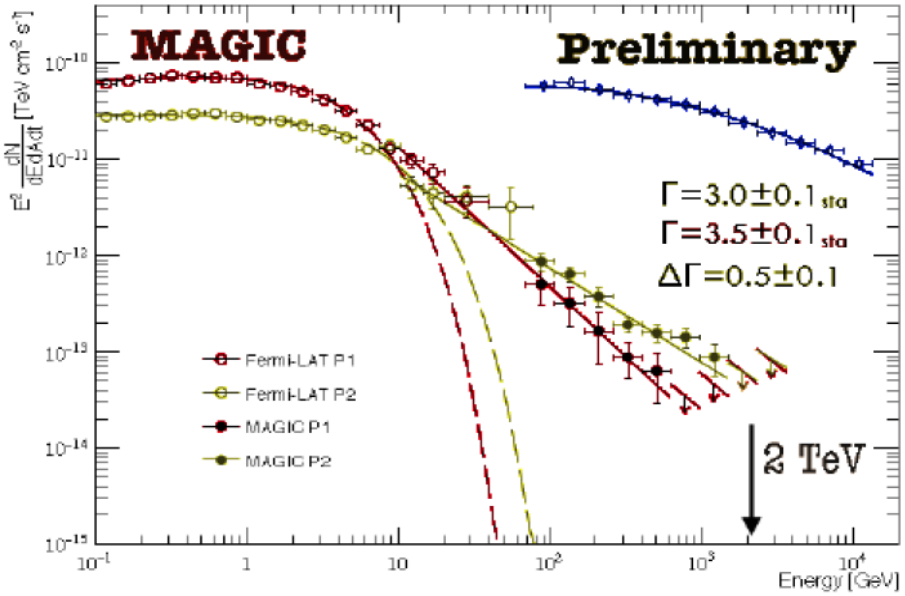




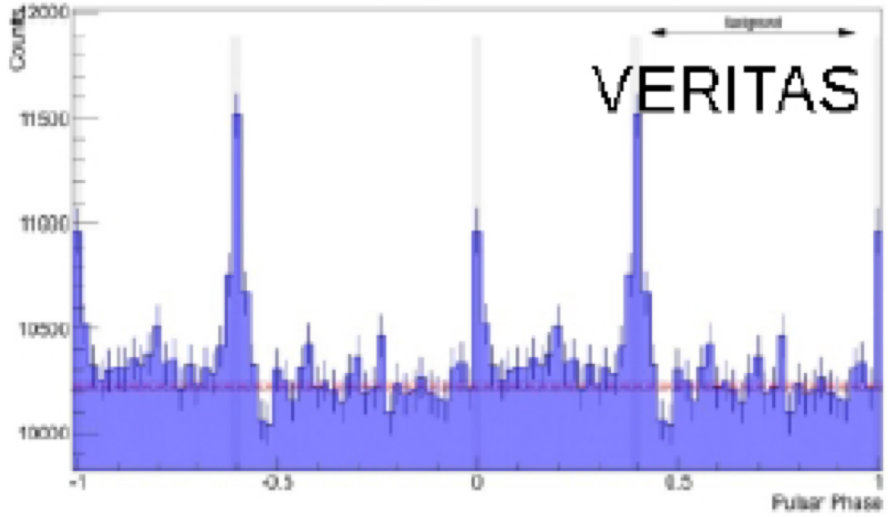
- Cascading model: Hirotani et al.
- Pulsar Wind model: Aharonian et al.

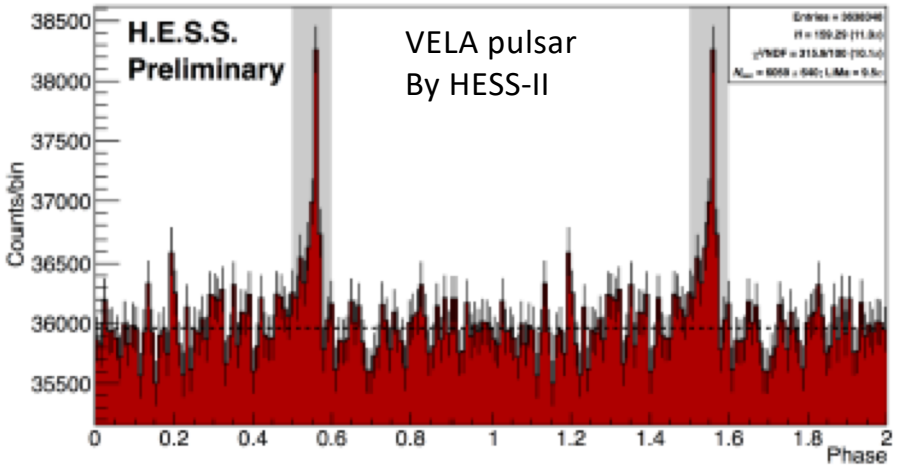
Crab Pulsar & VELA Pulsar





VERITAS Crab Pulsar

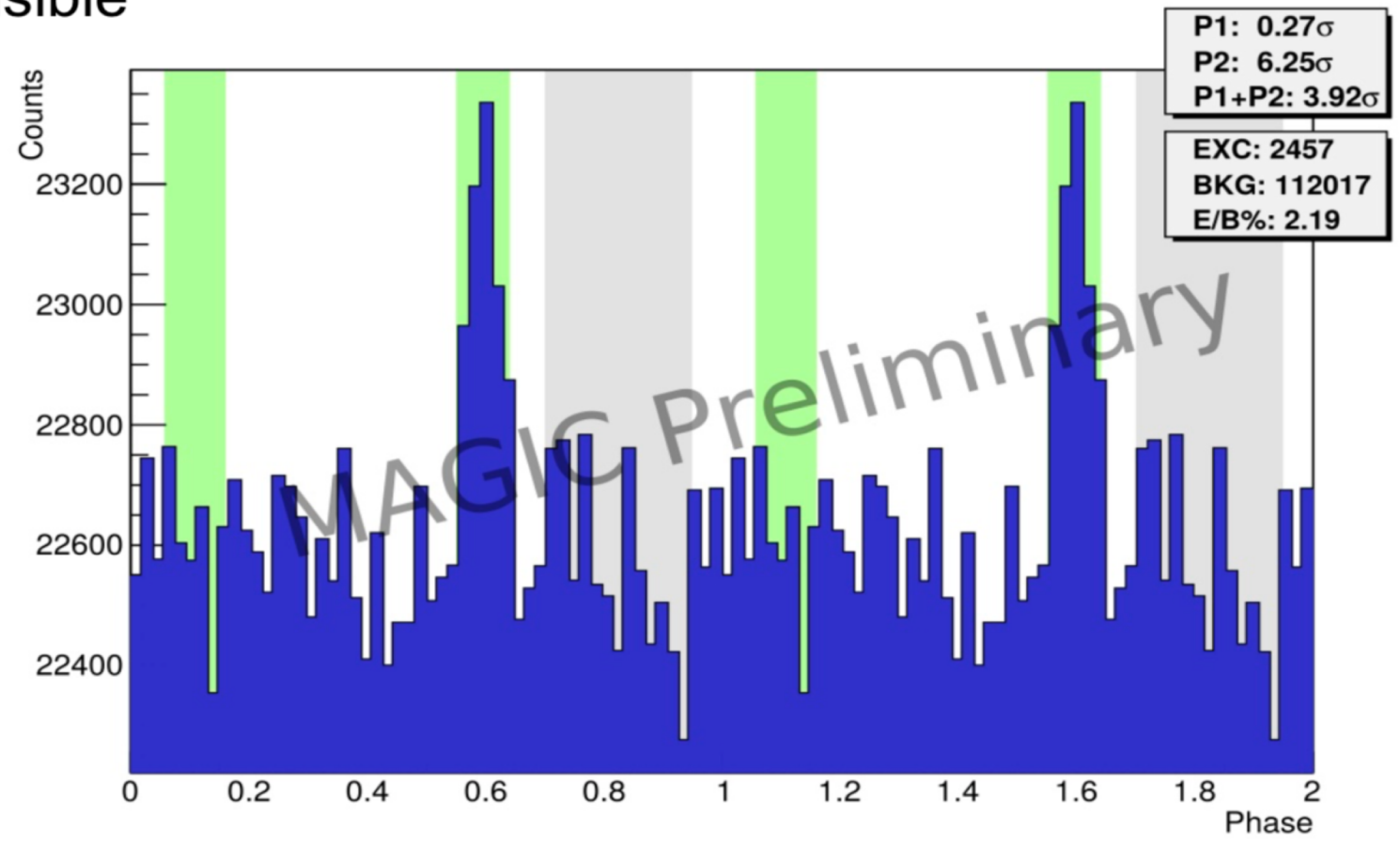




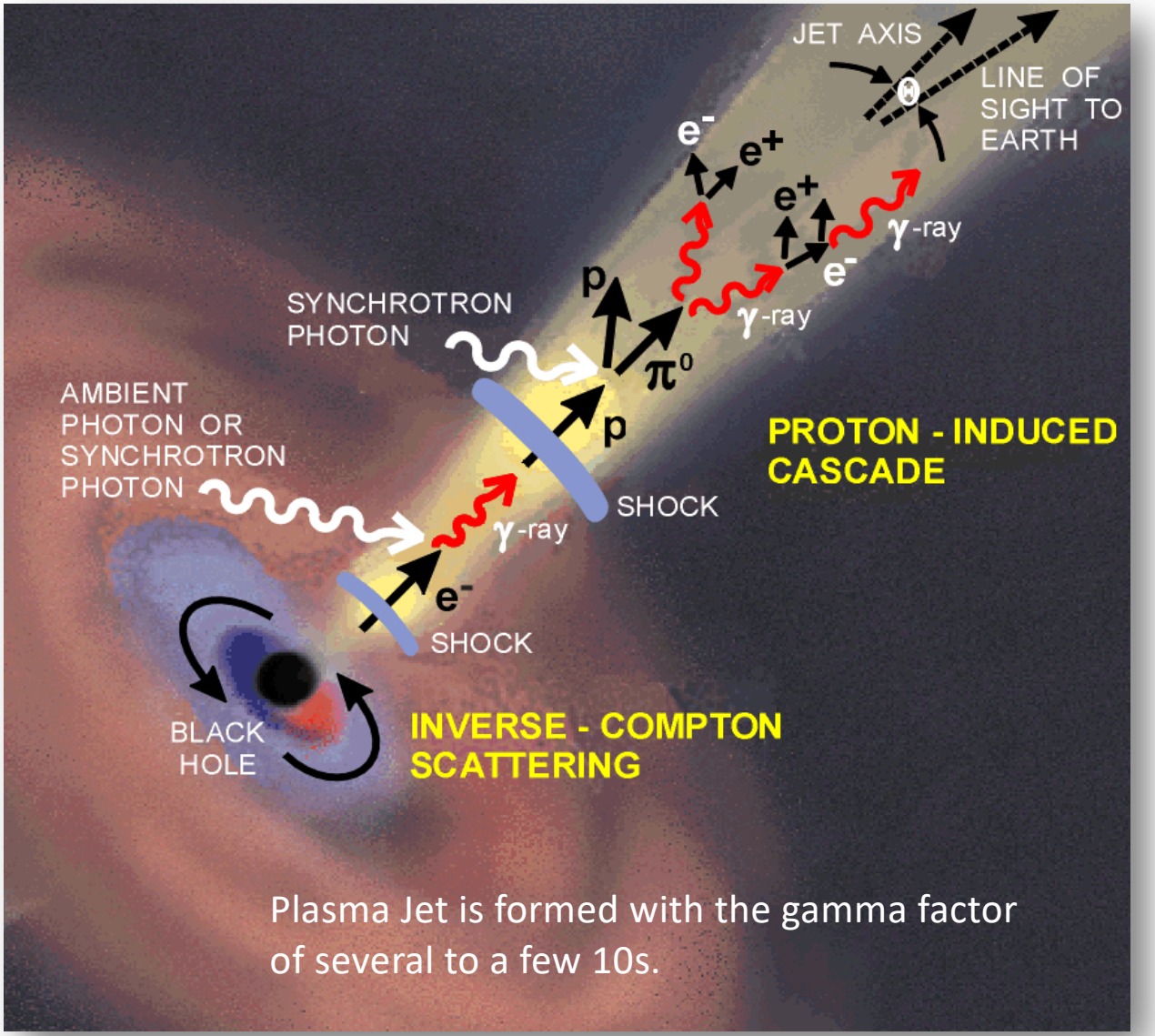
MAGIC Geminga Light curve

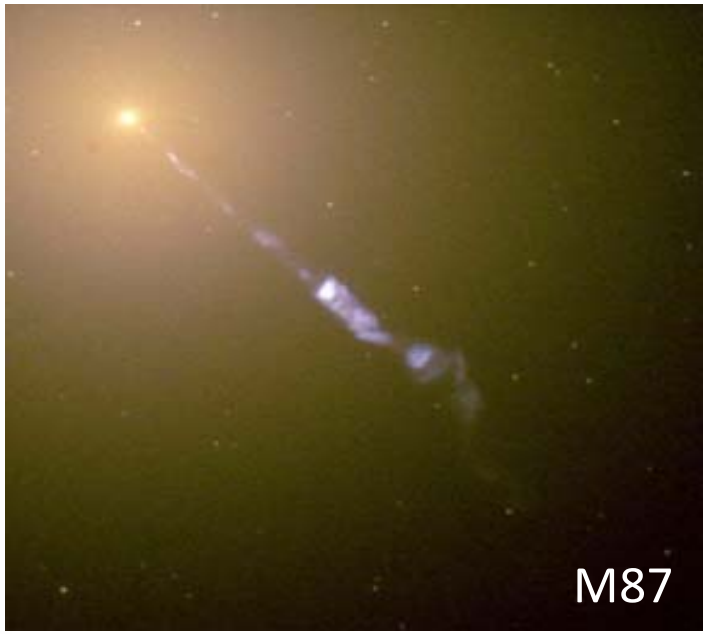
- P2 detected at **6σ** level
  - E range: 20 – 80 GeV
  - Pulse width similar to the one seen by Fermi-LAT
- P1 not visible

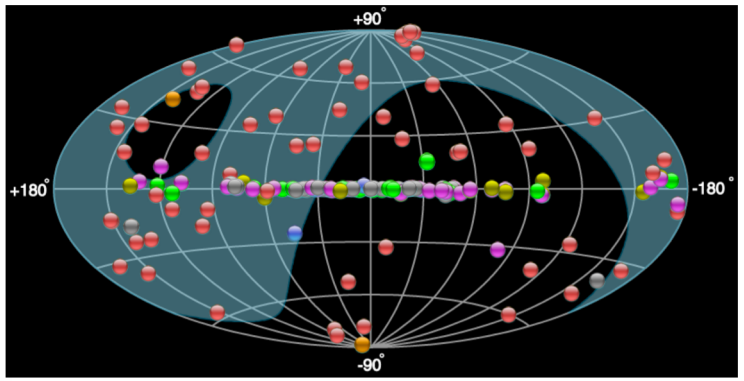
80hrs of observation in 2016-2018



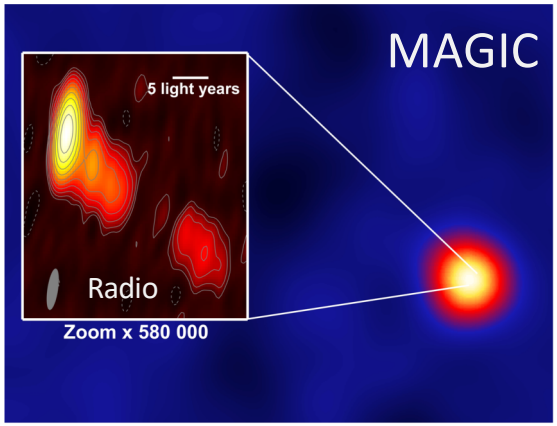
Supermassive Blackholes ~ 10^8 $M_\odot$
Good Particle Accelerators







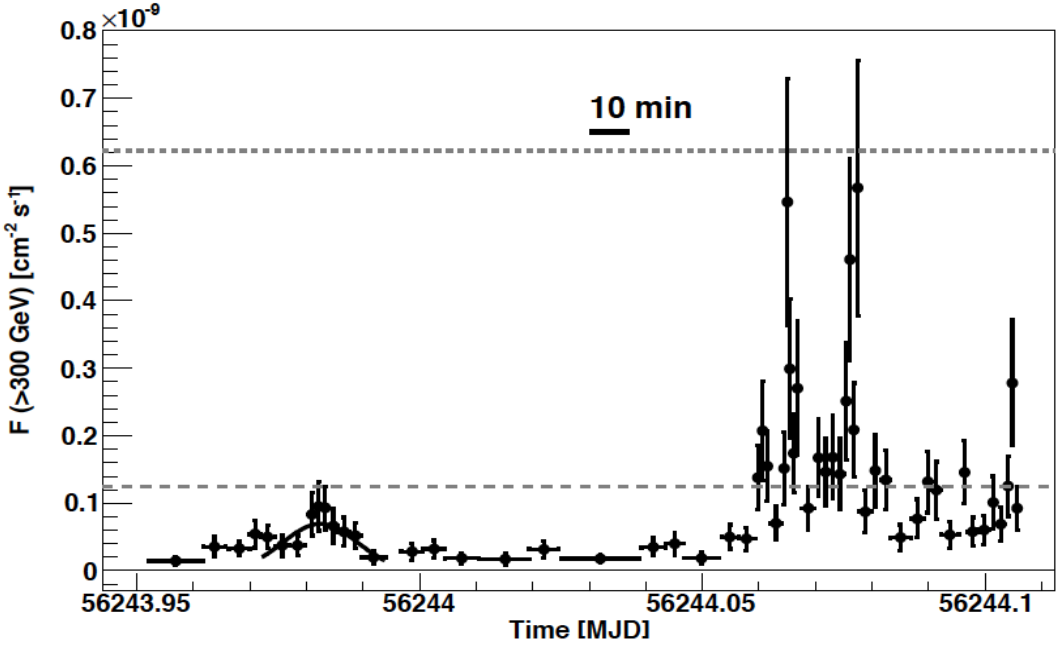
IC310 Radio Galaxy / Blazar
MAGIC Observation published in Science



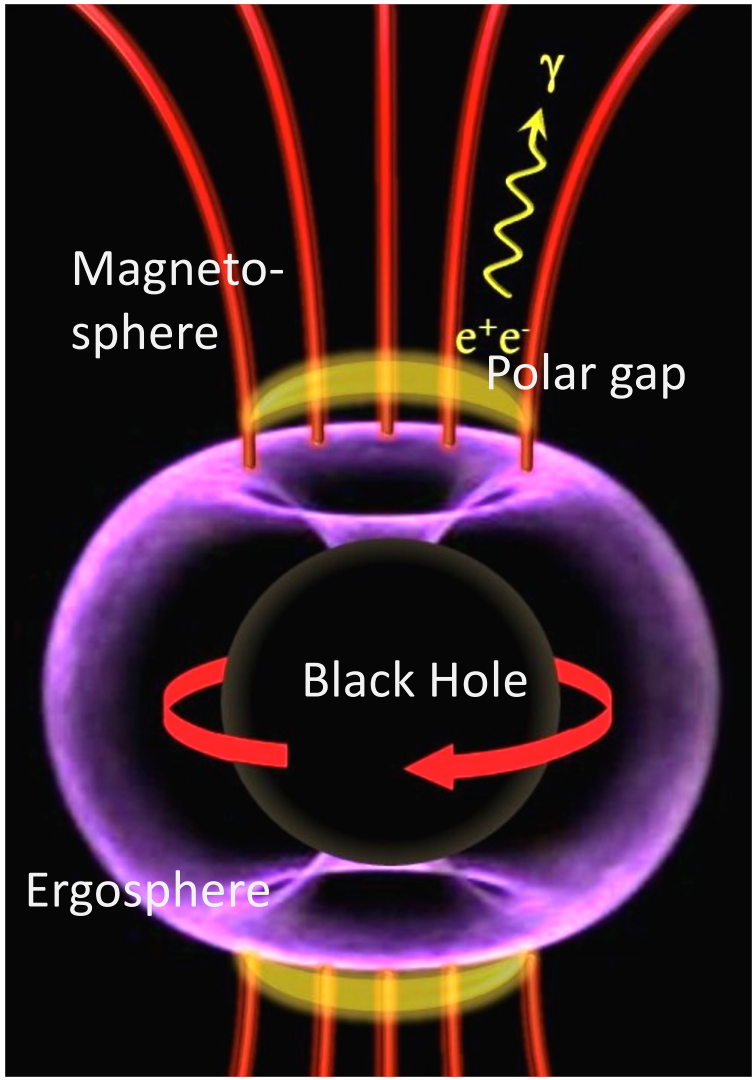
- Nov.12 2012 MAGIC obs.
- Flare ~ 100 x Low State
- Time variation ~ 1 min

- B.H. mass 3 x $10^8 M_\odot$
  - Crossing Time ~ 25mins
  - Γ-factor of jet ~ 5

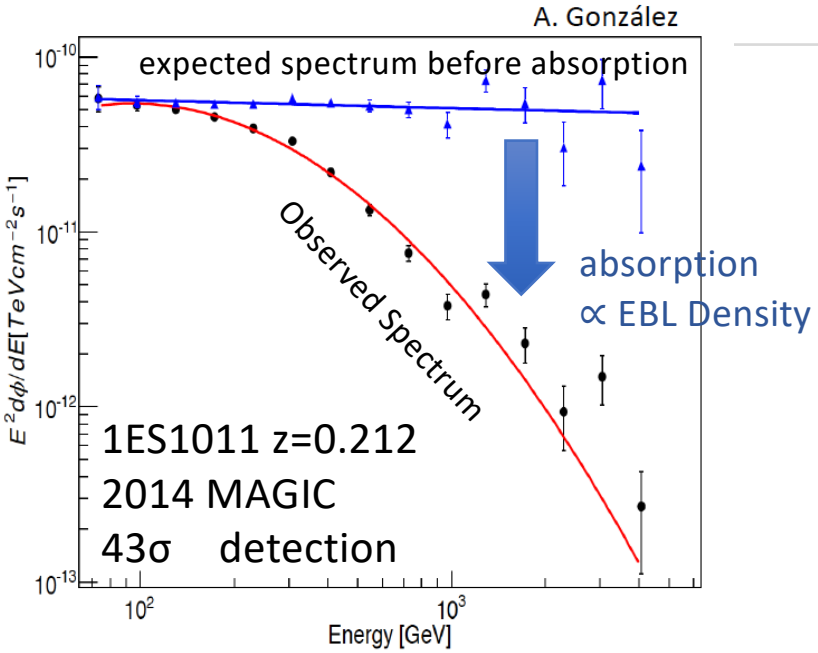
IC310 Light curve

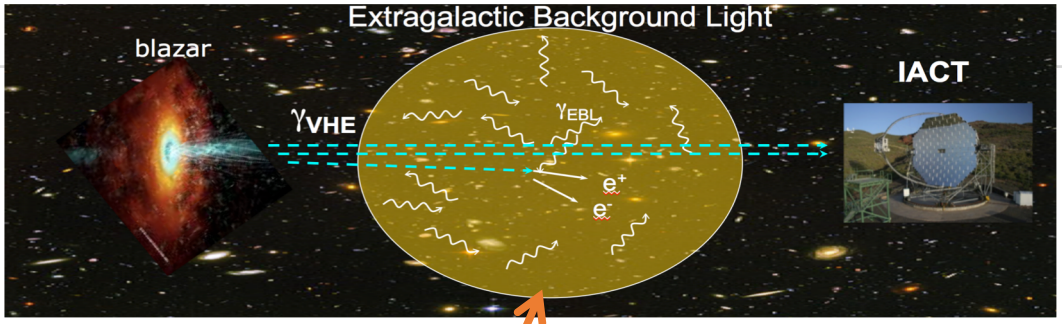


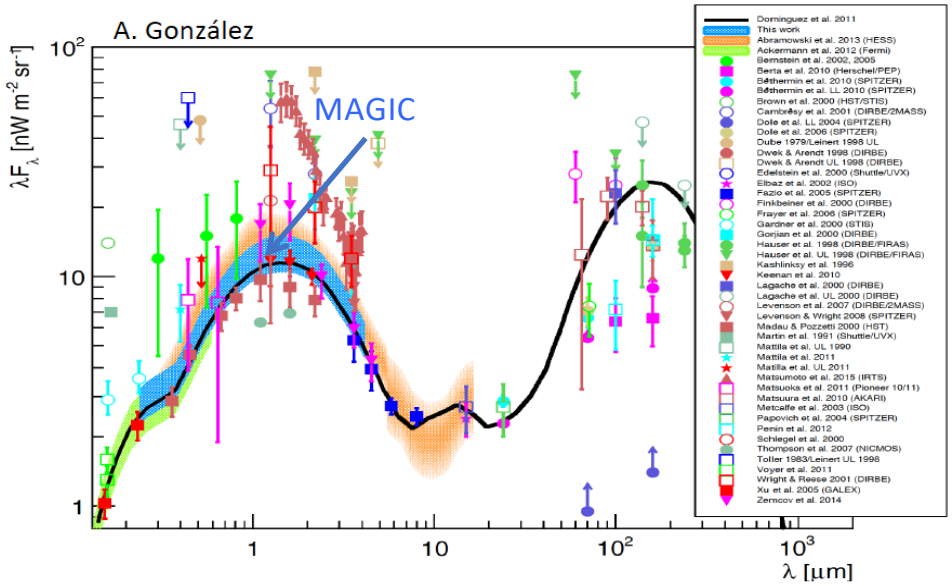
Possible Model



Study of Extragalactic Background Light
1ES1011 observed with MAGIC in 2014







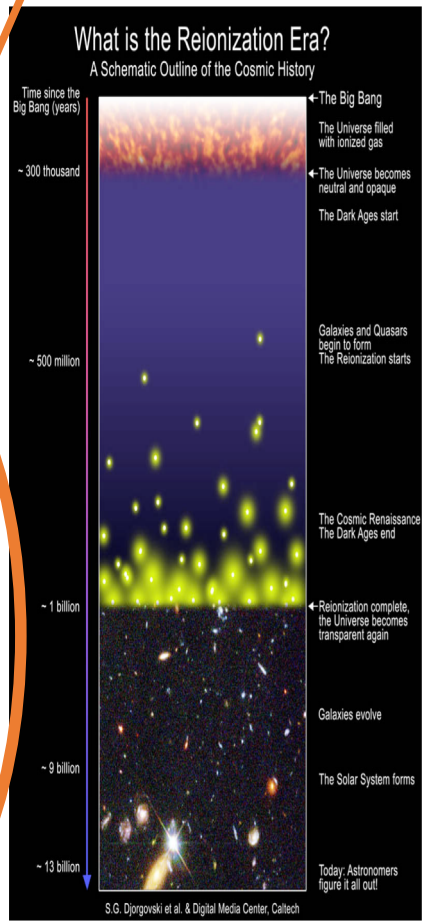
z ~ 1000, WMAP

z = 15~30, First star Pop-III

z = 6~15, Reionization

z = 3,Galaxies

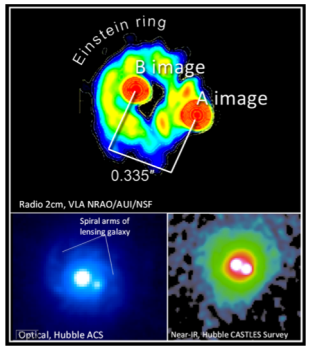
z = 0, Present

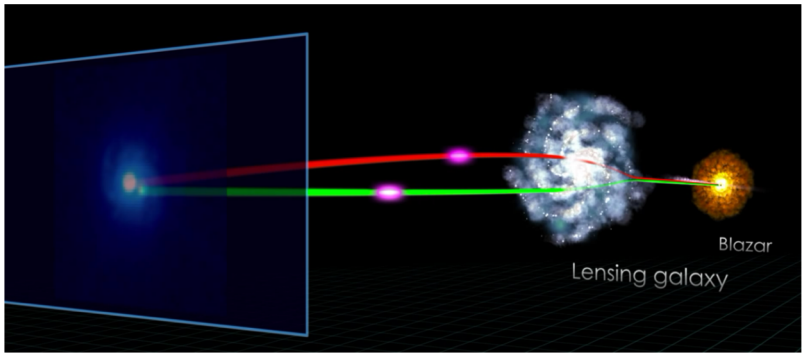


Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

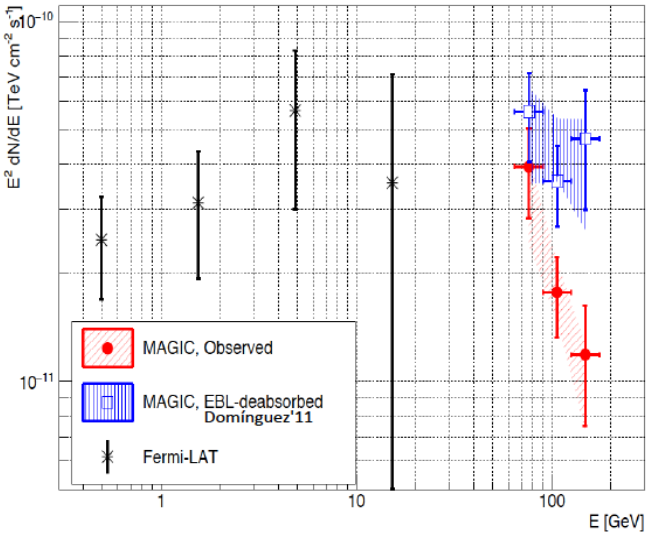
FSRQ S3 0218+357 z =0.944

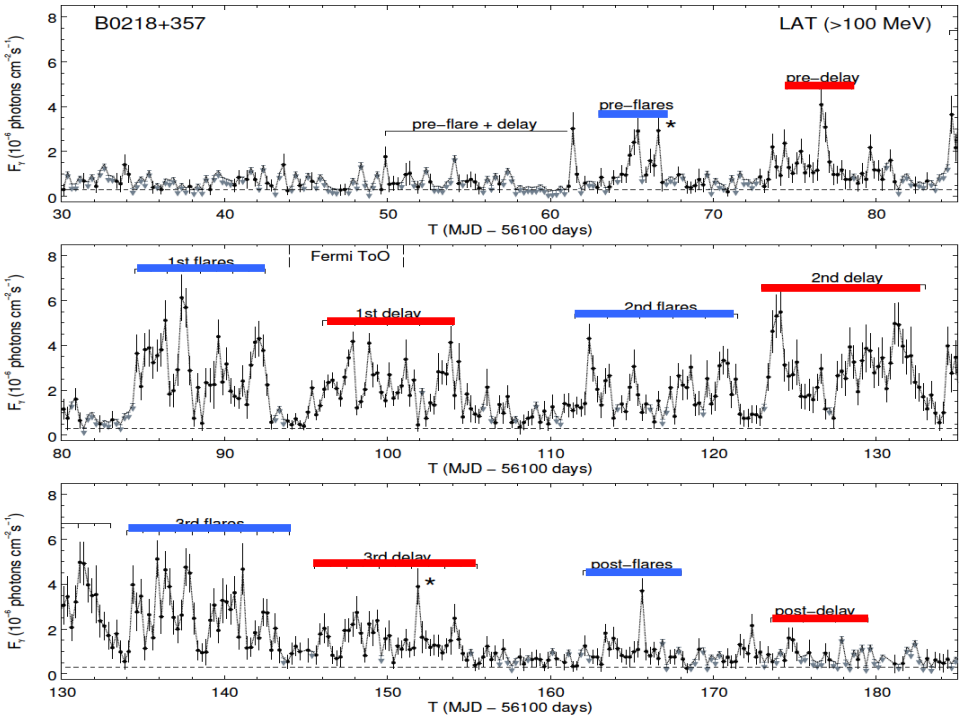
ATel #6349; *Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration*
on 28 Jul 2014; 14:20 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

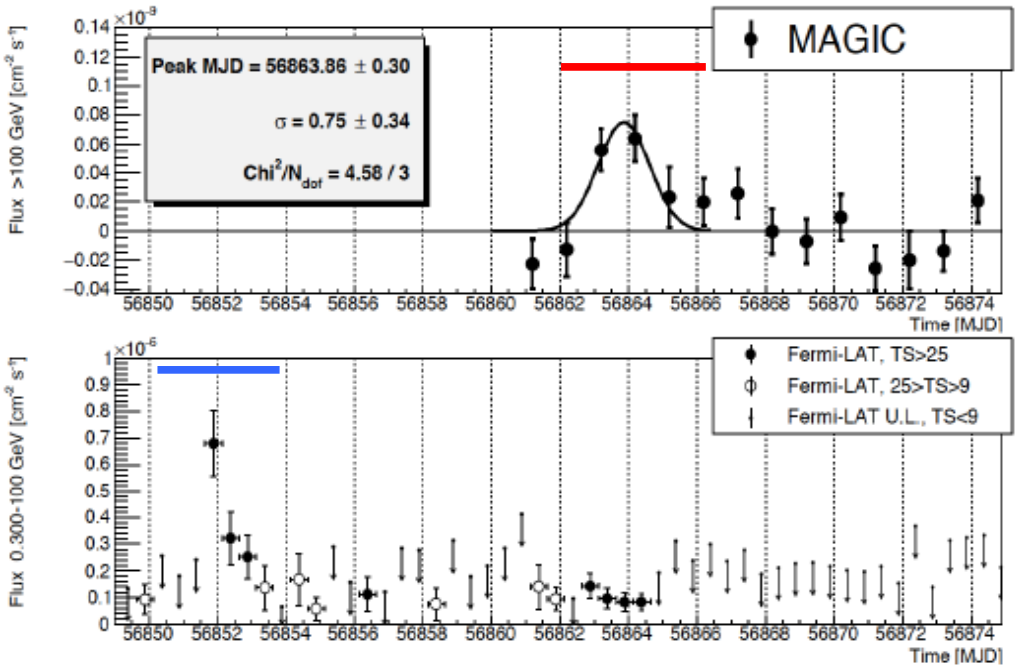




J. Sitarek, from B0218 MAGIC paper draft








Gamma Ray Bursts

MAGIC Observed GRB190114C with 50 sigma above 300GeV, Source distance z = 0.42

[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)

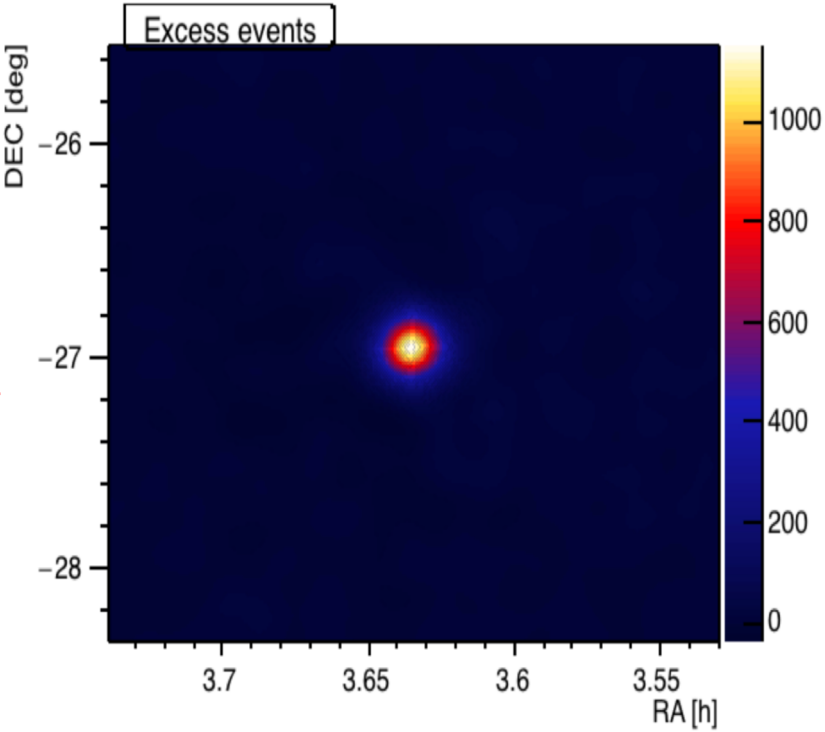
Related
12395 GRB 190114C: Search for high-energy neutrinos with IceCube
12390 First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

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

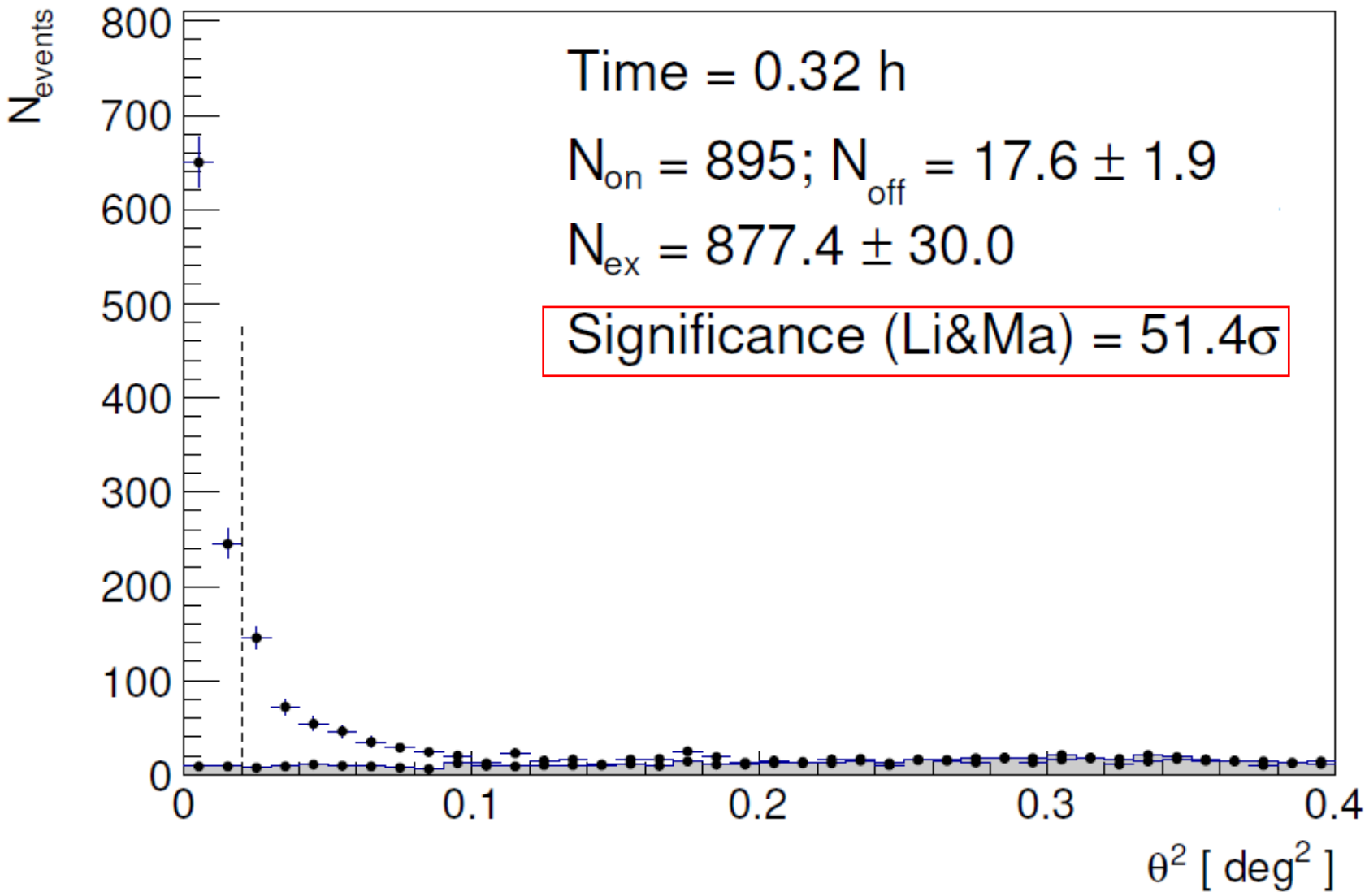
Referred to by ATel #: 12395

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.

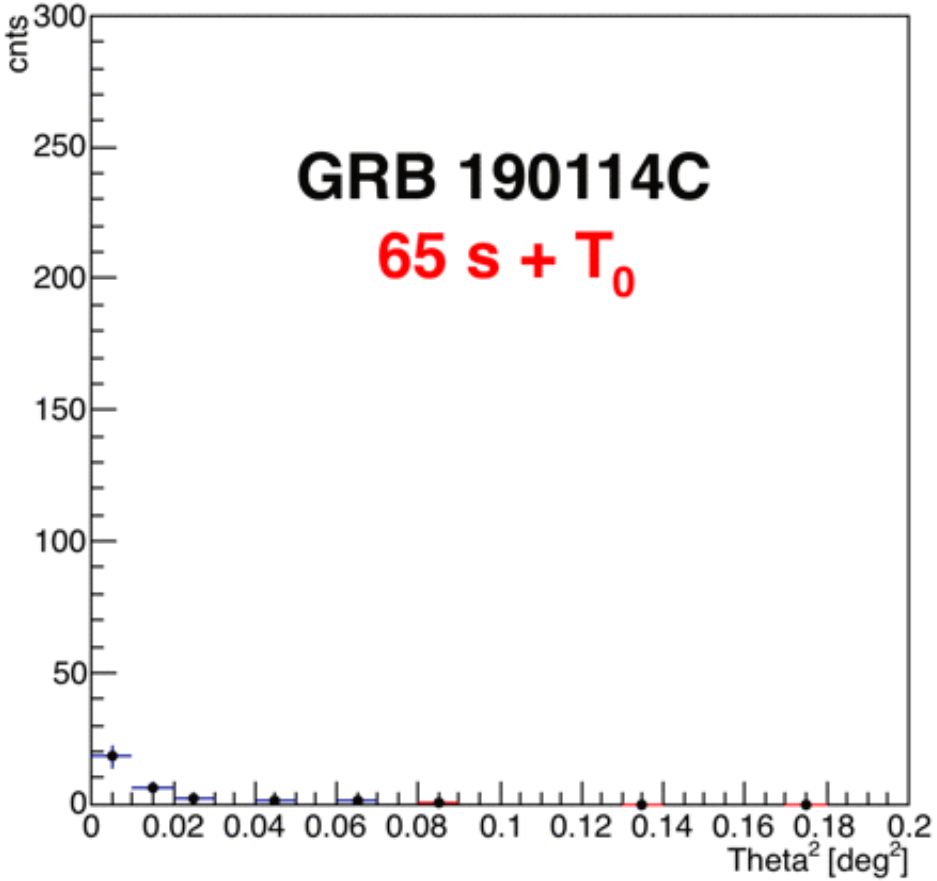


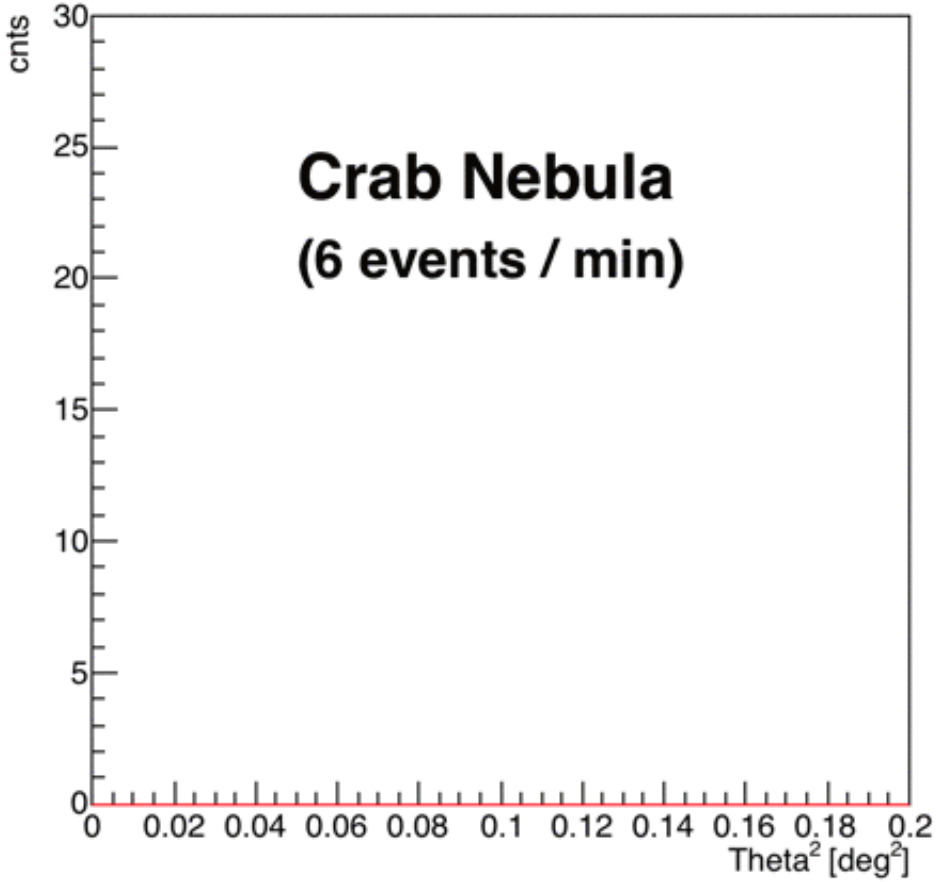
The most intense, purest signal in VHE gamma-ray astrophysics: GRB190114C detection by MAGIC at E ≥ 200 GeV



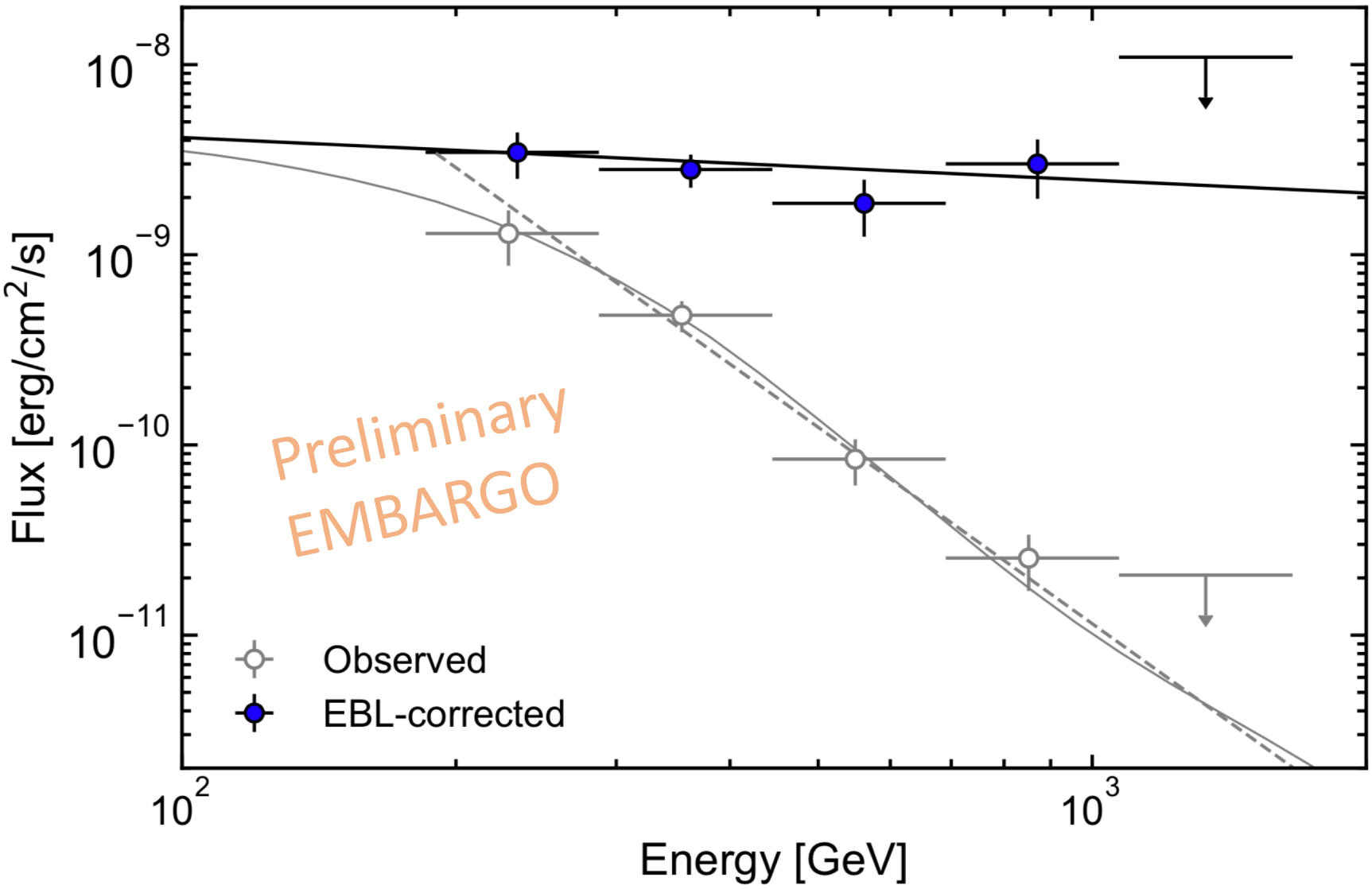
Gamma-rate from GRB190114C & Crab Nebula by MAGIC for the first ~100 s after start of data taking

Please note the Y-axes scale difference of x 10 for the GRB190114C

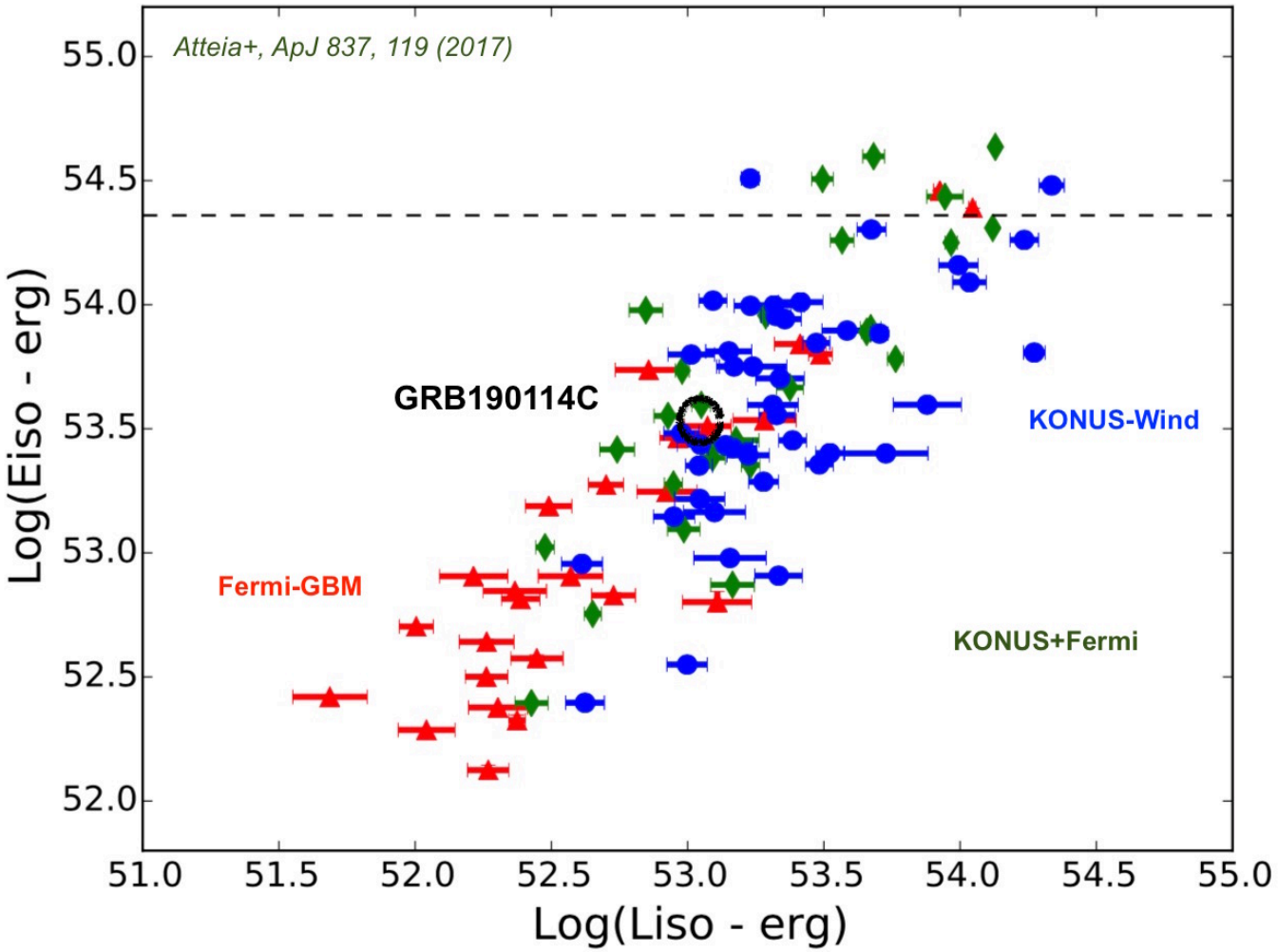




Observed and EBL corrected Energy Spectra GRB 190114C by MAGIC



GRB 190114C compared to other long GRBs it is not too special



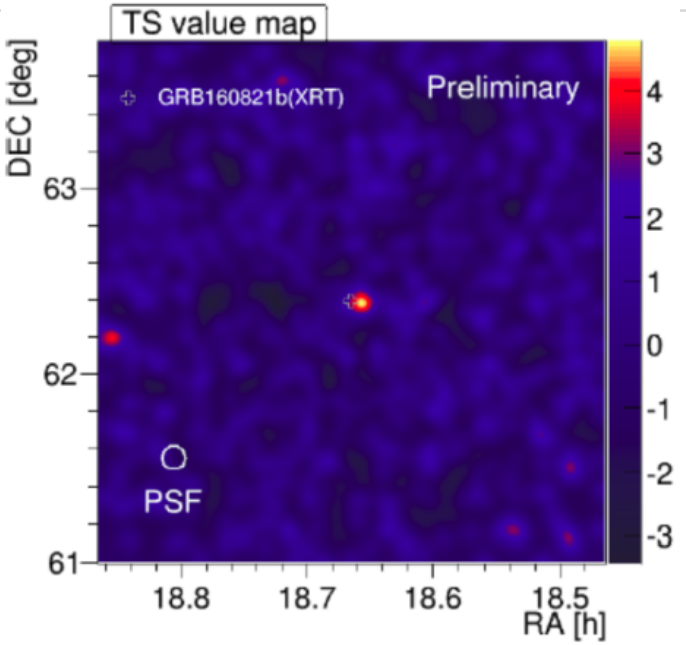
MAGIC Hint From GRB 160821B at ICRC2017

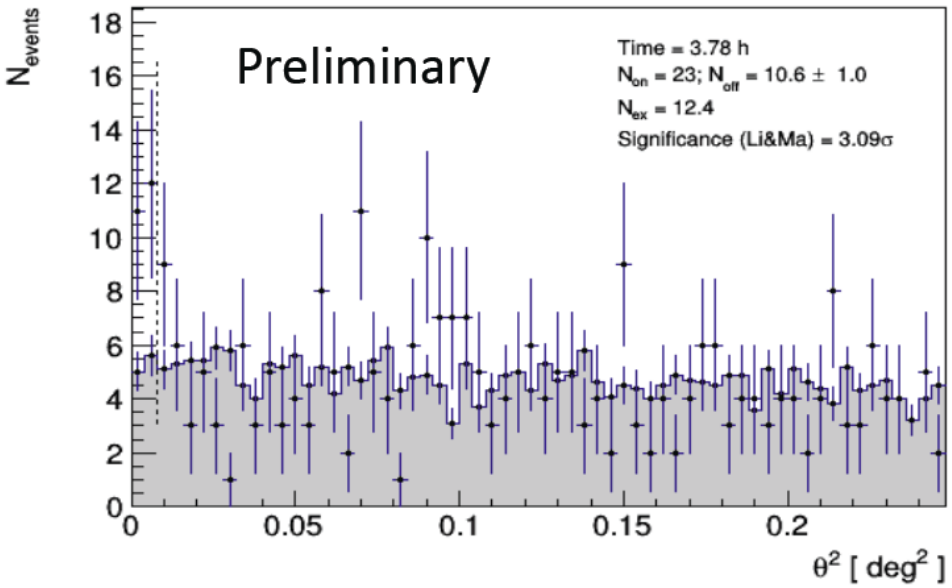
MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

- **Short GRB** (T90 ~= 0.5 s) at **z = 0.16**, triggered by Swift-BAT
- Swift-XRT: t < 300 s extended emission + steep decay, t < 30 ks plateau?
- No LAT detection. HST: **hint of a kilonova?**
- **MAGIC: 24 s - 4 hr**. Bright moon

  (3-9 x dark LoNS)
- **3.1 sigma (post-trial)**

  hint at E ≥ 600-800 GeV



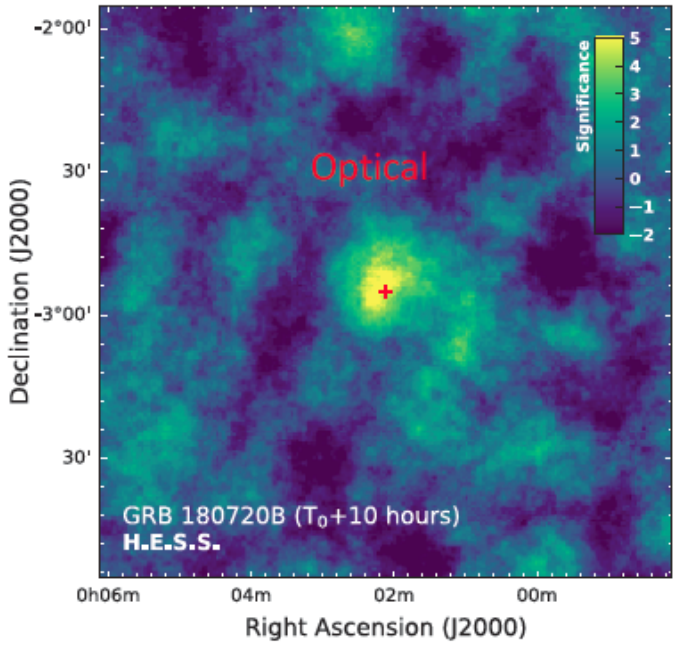


~5 months after MAGIC GRB Detection
At CTA Symposium in Bologna on 8th of May 2019
H.E.S.S. Reported on GRB 180721B

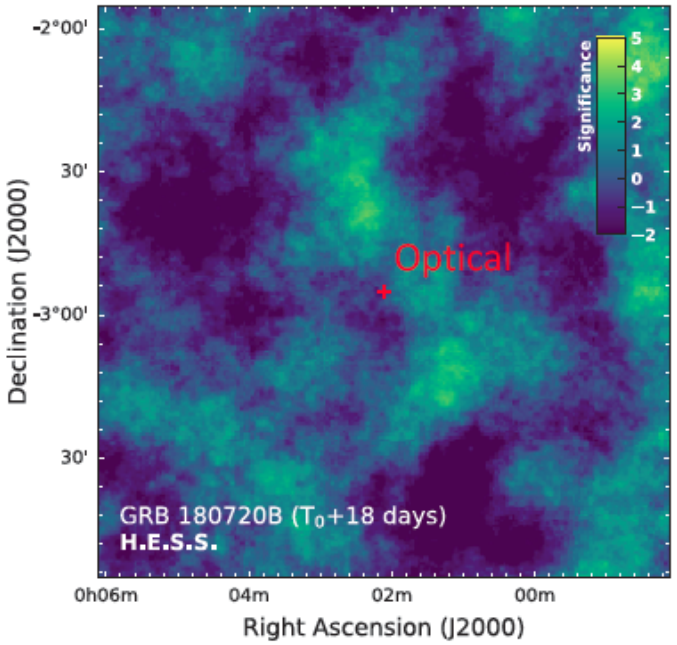
The GRB180720B detection

- 10 hours after the Swift trigger
- Redshift z = 0.653 (ESO-VLT/X-shooter)

Quentin Piel ICRC2019



2 hours taken between 25° and 40° zenith angle

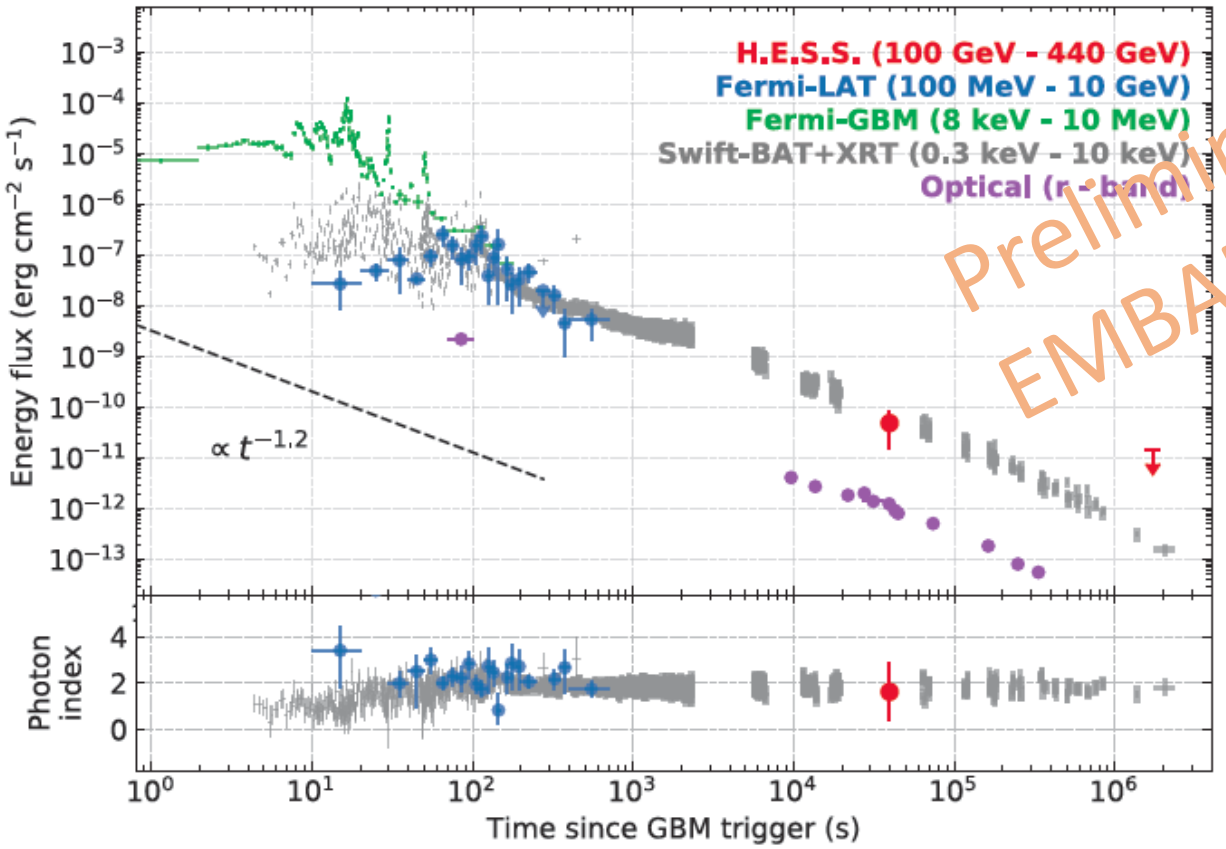


Between 18 days and 25 days after the burst

H.E.S.S. Detection of Afterglow From GRB180720B

The GRB180720B detection

- Fermi-LAT detection up to 700 s after trigger wit a photon index close to -2.0.
- Coincident optical and X-ray temporal decay
- H.E.S.S. detection until 440 GeV and same level as X-ray domain



H.E.S.S. Detection of Afterglow From GRB190829A

GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.

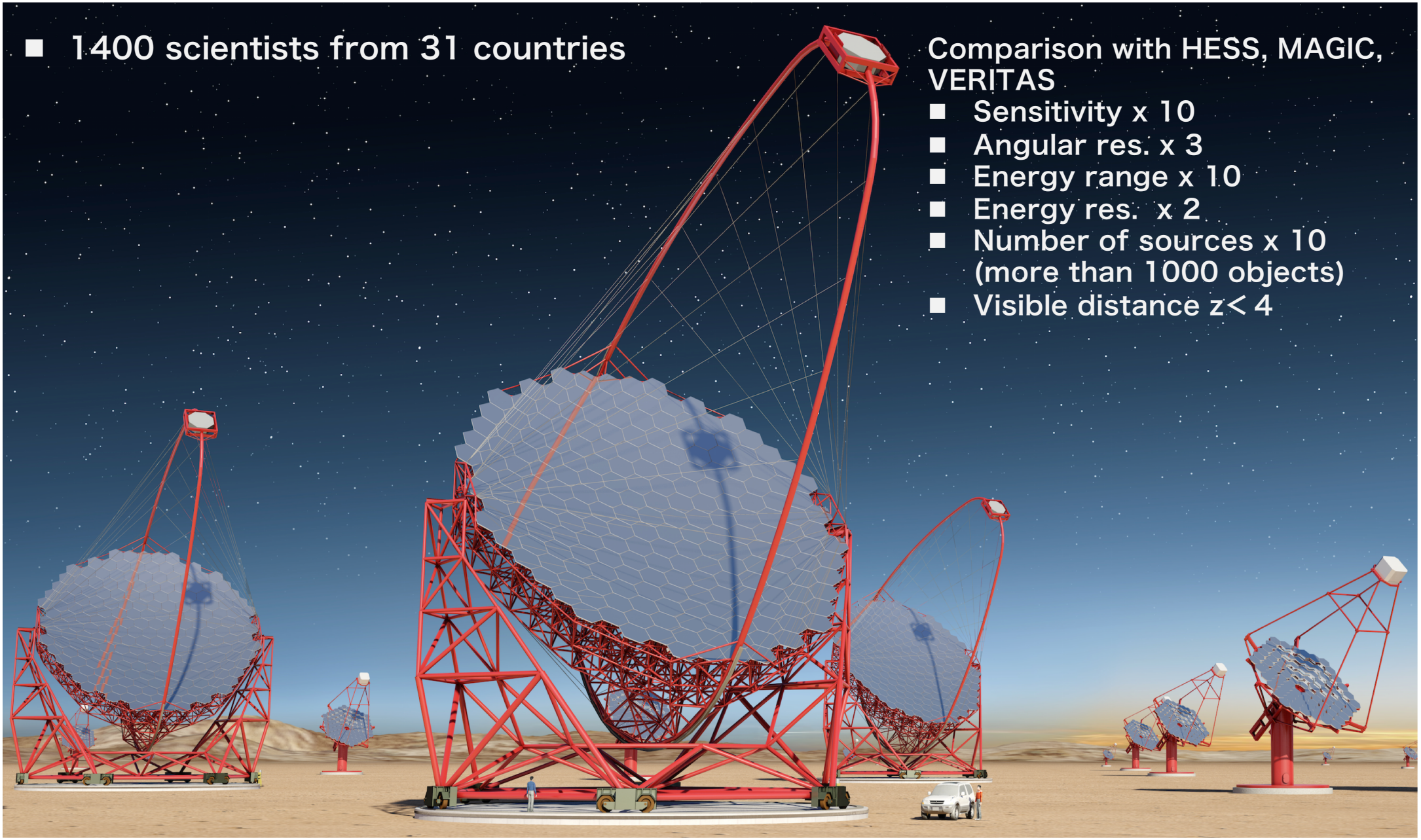
ATel #13052; *M. de Naurois (H. E.S. S. Collaboration)*
on 30 Aug 2019; 07:12 UT
Credential Certification: Fabian SchÃÂ¼ssler (fabian.schussler@cea.fr)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Tweet

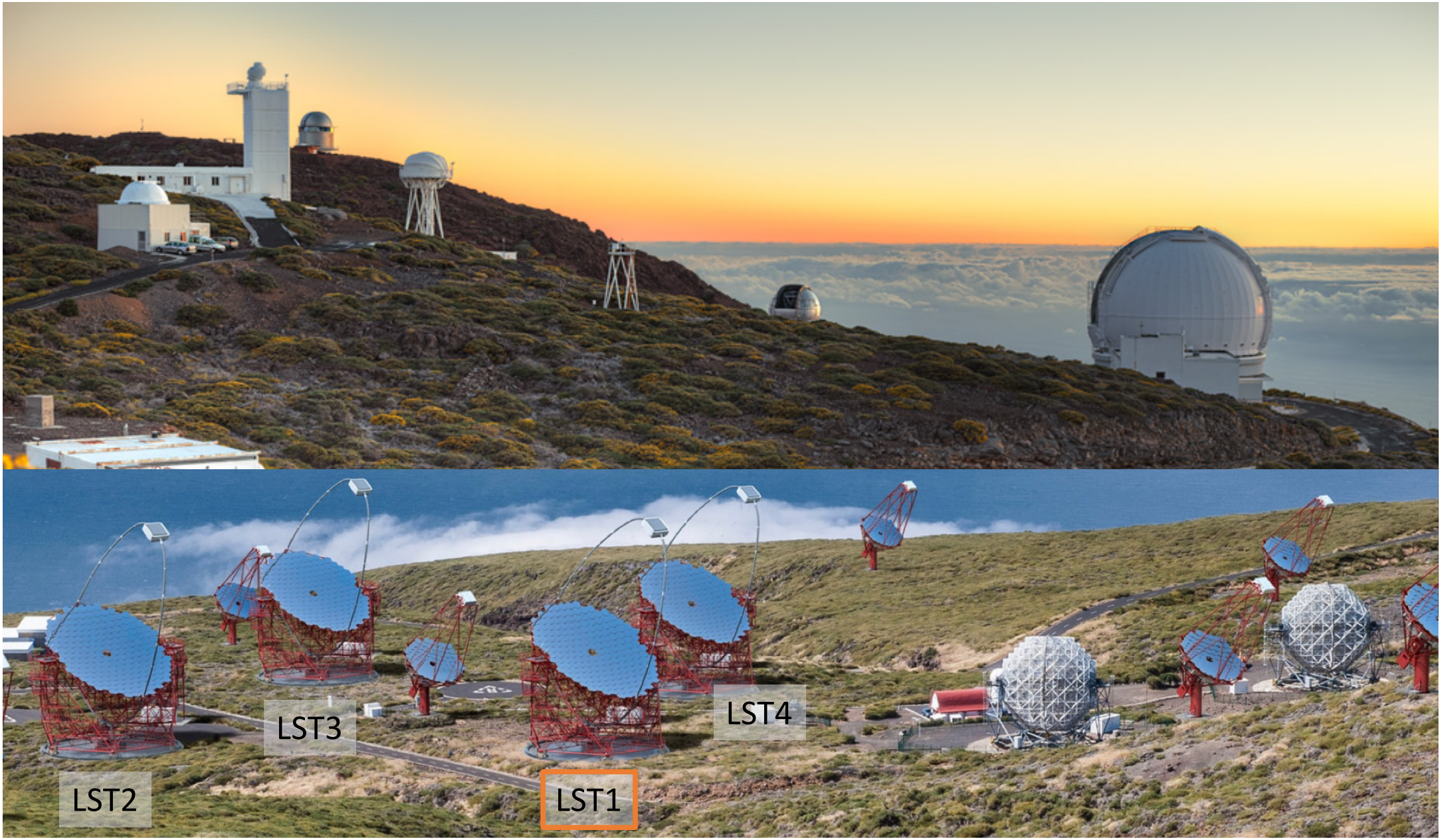
The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552). At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date. H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A. Further analyses of the data are on-going and further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths. H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

Constructing CTA
Big International Project



CTA North

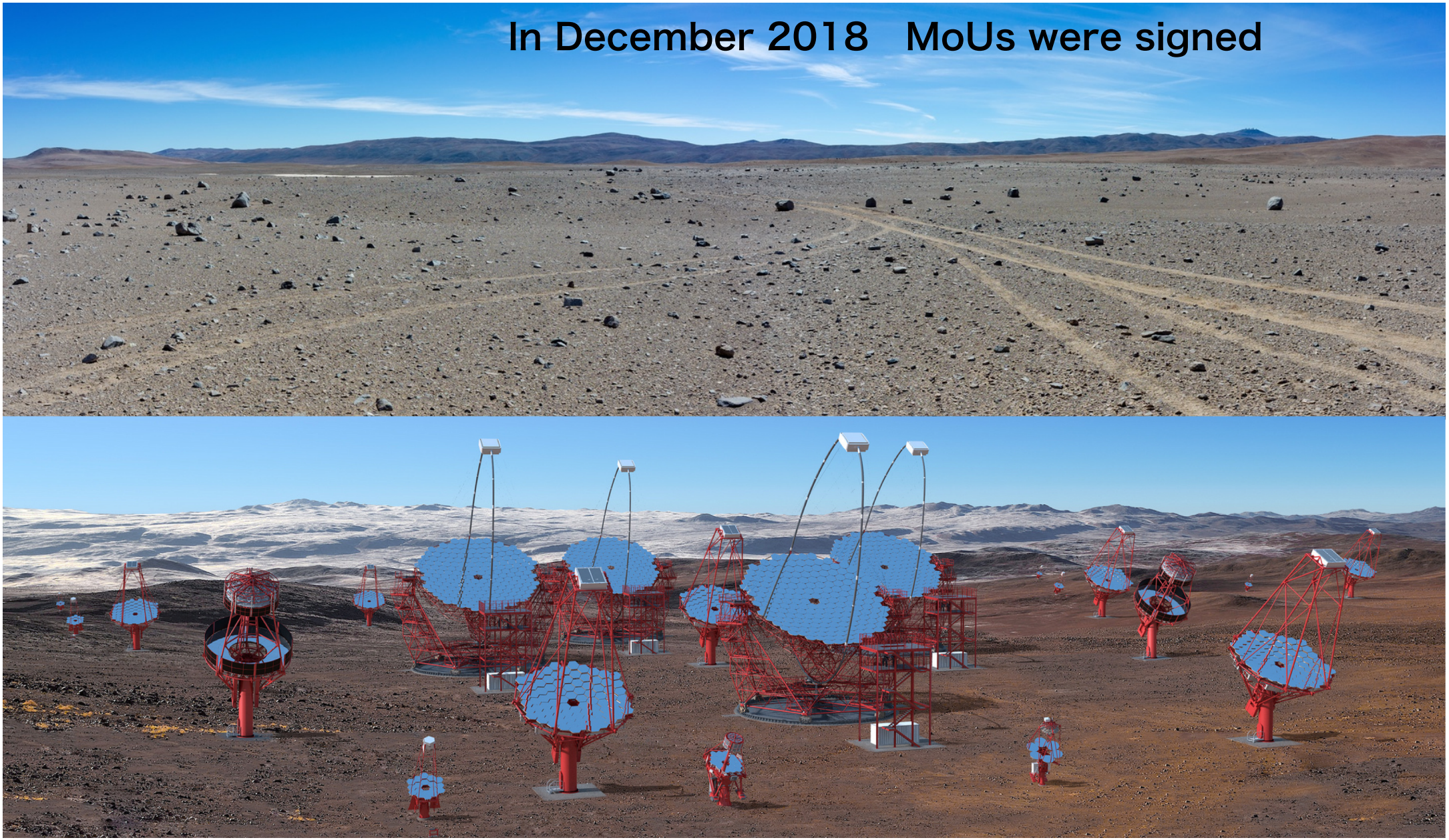
Observatorio del Roque de los Muchachos



cherenkov telescope array

CTA South

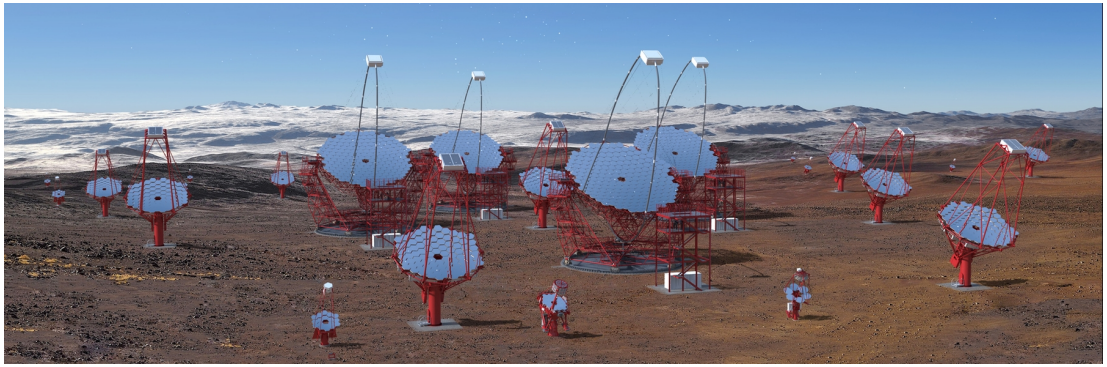
ESO site Chile Paranal

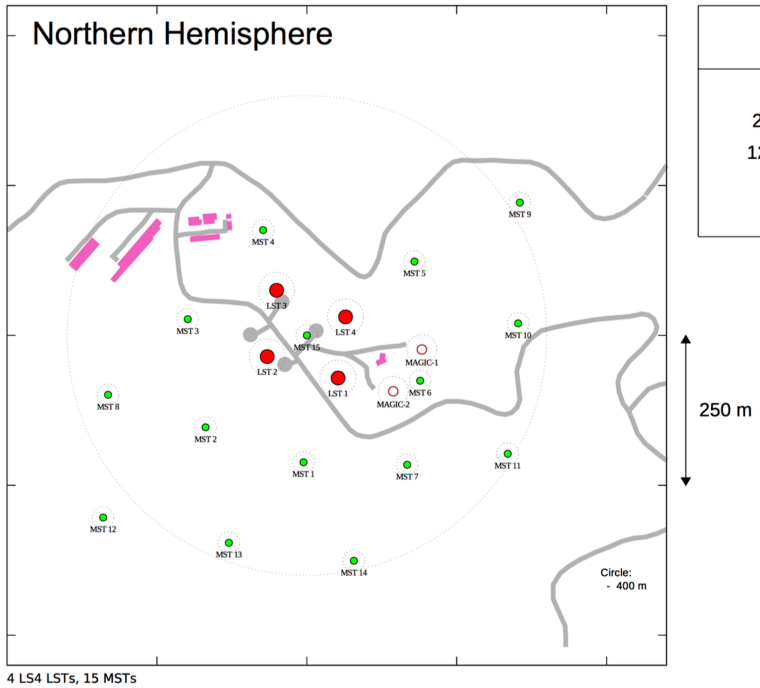


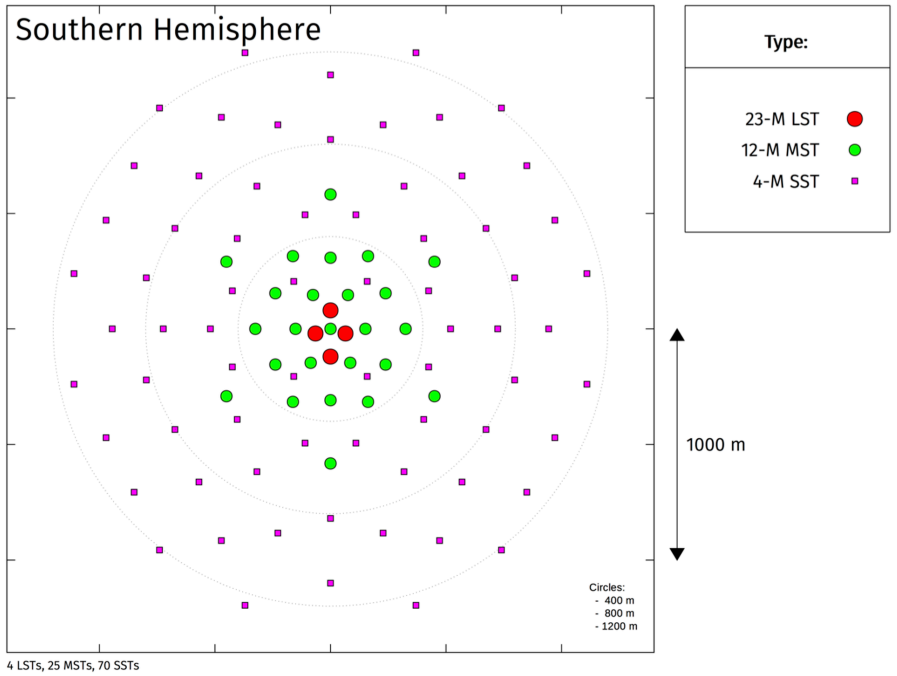
Two sites for all sky observatory

Roque de los Muchachos Observatory
La Palma, Spain

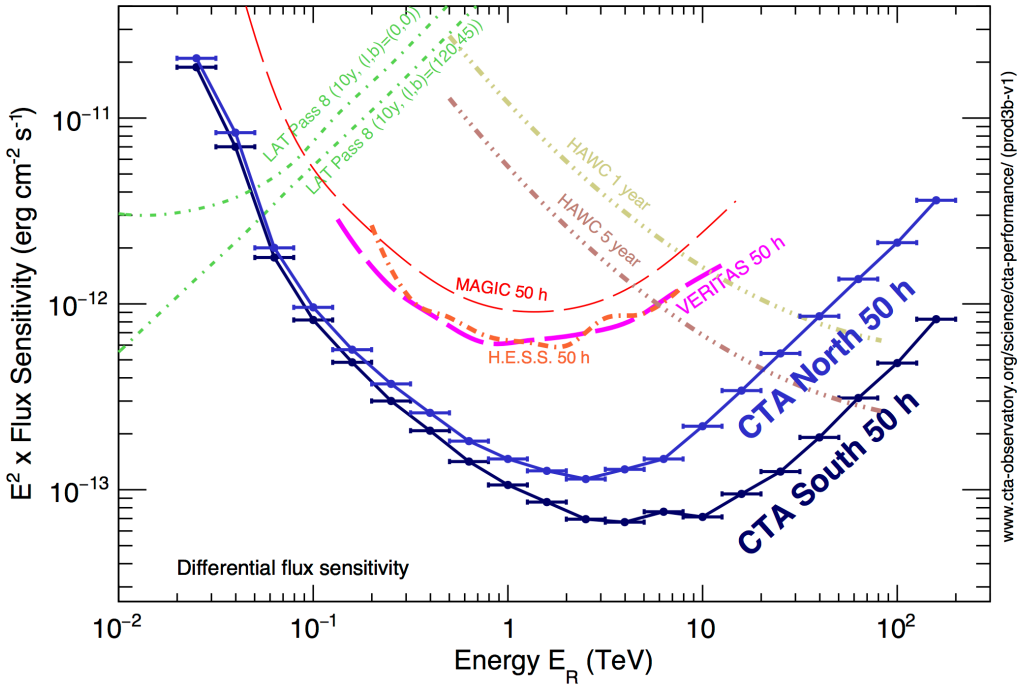
Paranal, Chile

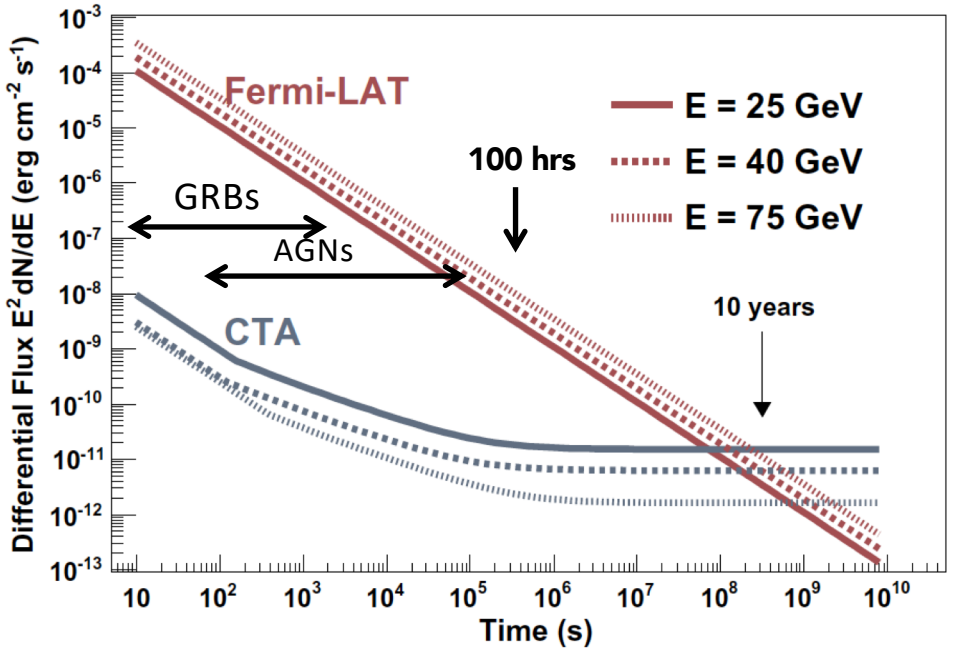






Sensitivity x10, Angular Resolution x2 Energy Range 20GeV~200TeV





- CTA-LST array contributes to the sensitivity in low energies
- >20GeV Threshold Energy
- Distant AGNs are observable up to z=2, and GRBs up to z=4
- X10000 sensitivity for GRBs and AGN flares than Fermi
- First observation of GRBs from ground

CTA-LST Project: big International Effort

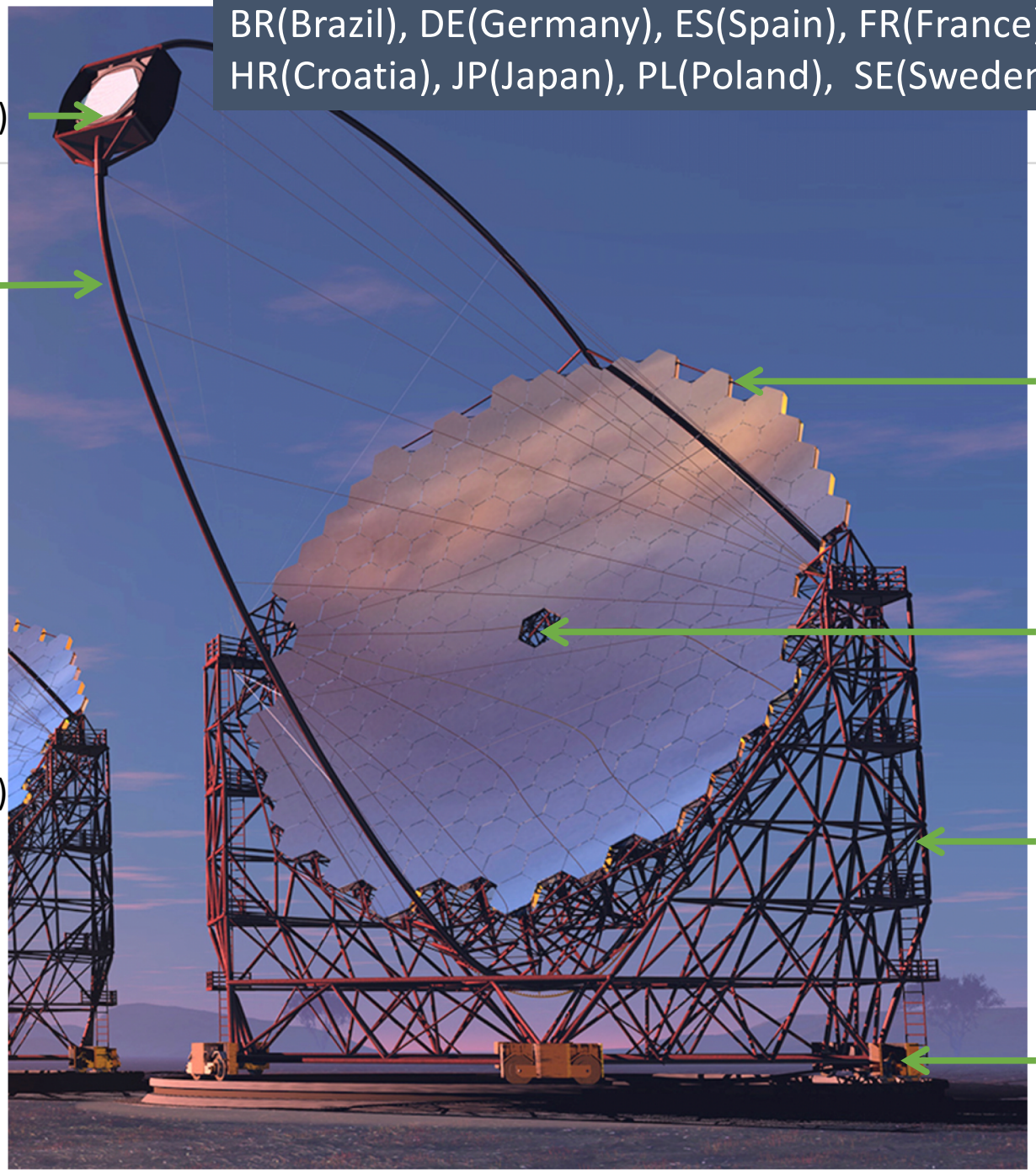
BR(Brazil), DE(Germany), ES(Spain), FR(France), IN(India), IT(Italy), HR(Croatia), JP(Japan), PL(Poland), SE(Sweden)

Focal Plane Instr.
Electronics (JP/IT/ES/FR)
Camera body (ES)

Camera Supporting Structure (FR/IT)

Camera Access Tower (ES/DE)

Flywheel, UPS (JP)
Computers, network (JP)
INFRA (ES)



Mirror (JP)
Interface Plate(JP/BR)
Actuator (JP)
CMOS-Cam (JP)

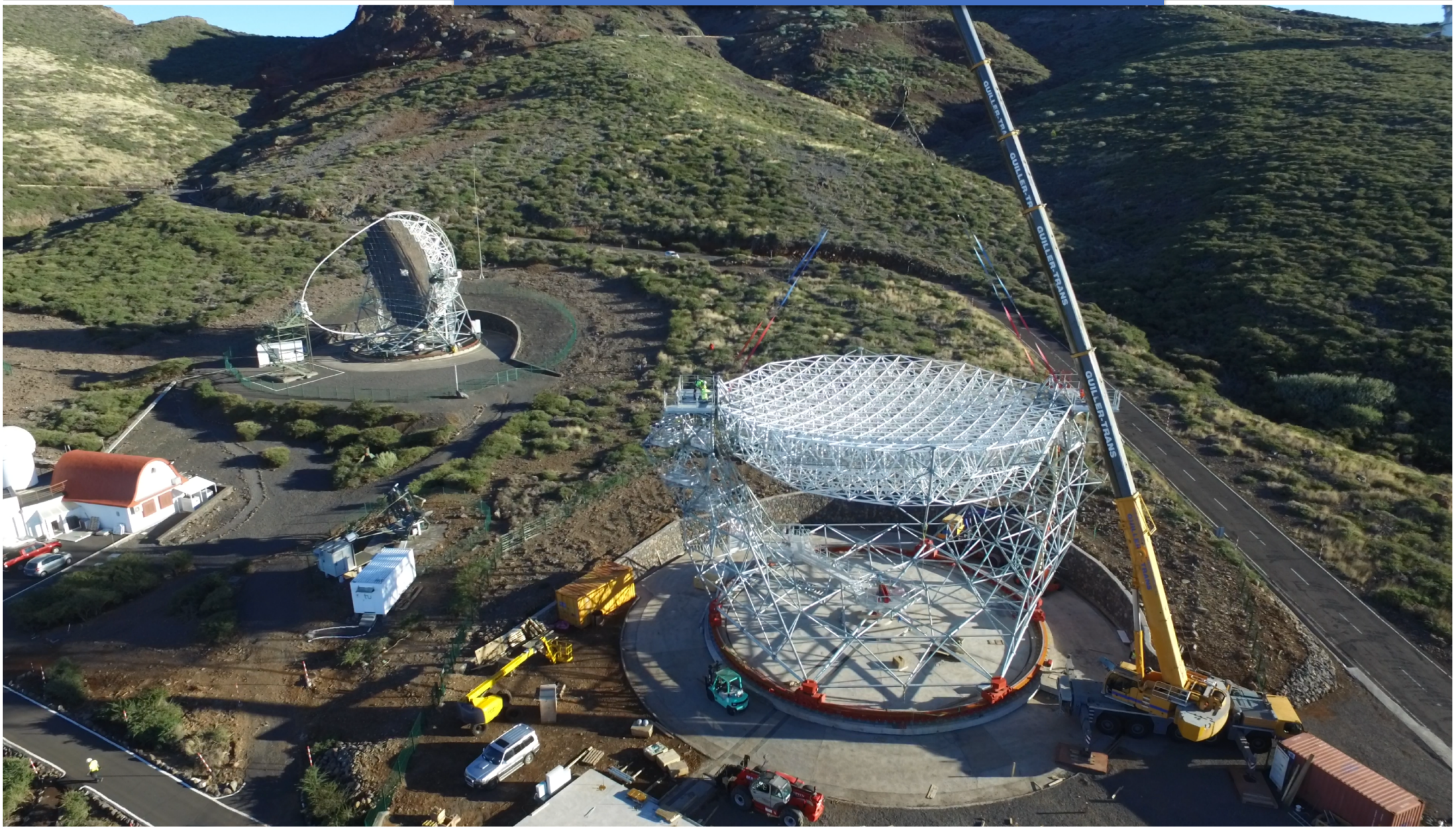
Star Guider (**HR**/JP/SE)
Calibration Box (IN/IT)
Cabling (DE/FR)

Structure (DE/ES)
Access Tower (DE/ES)

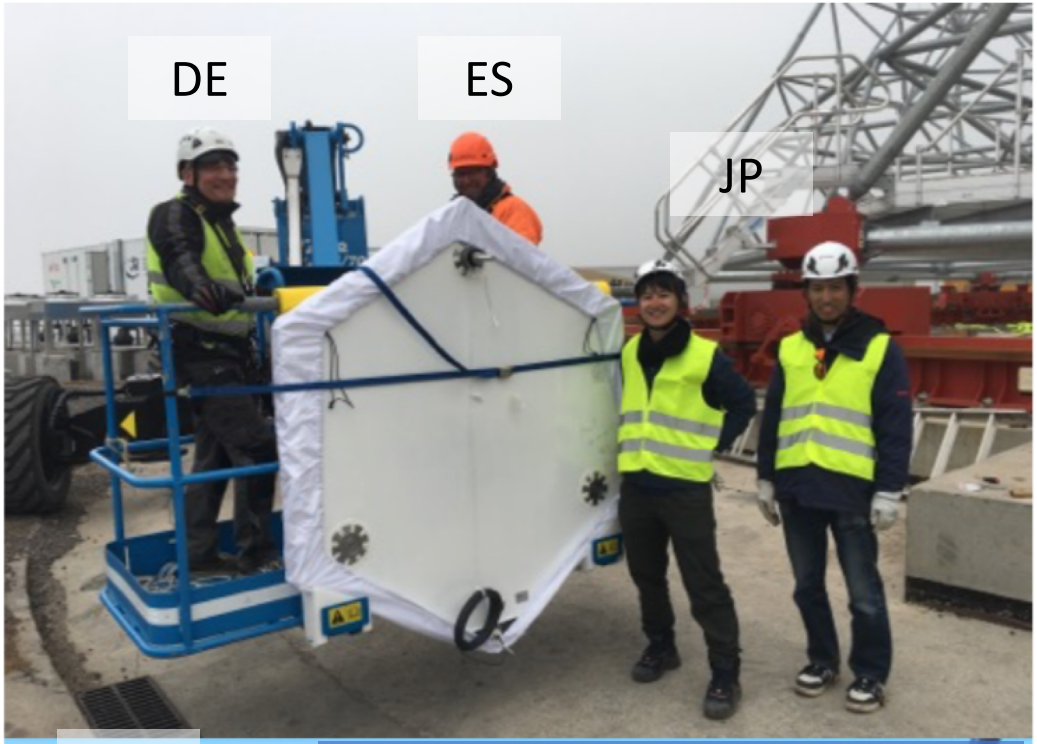
Drive (ES/FR/DE)
Bogie (ES/DE/IT)
Rail (ES/DE)
Foundation (ES)

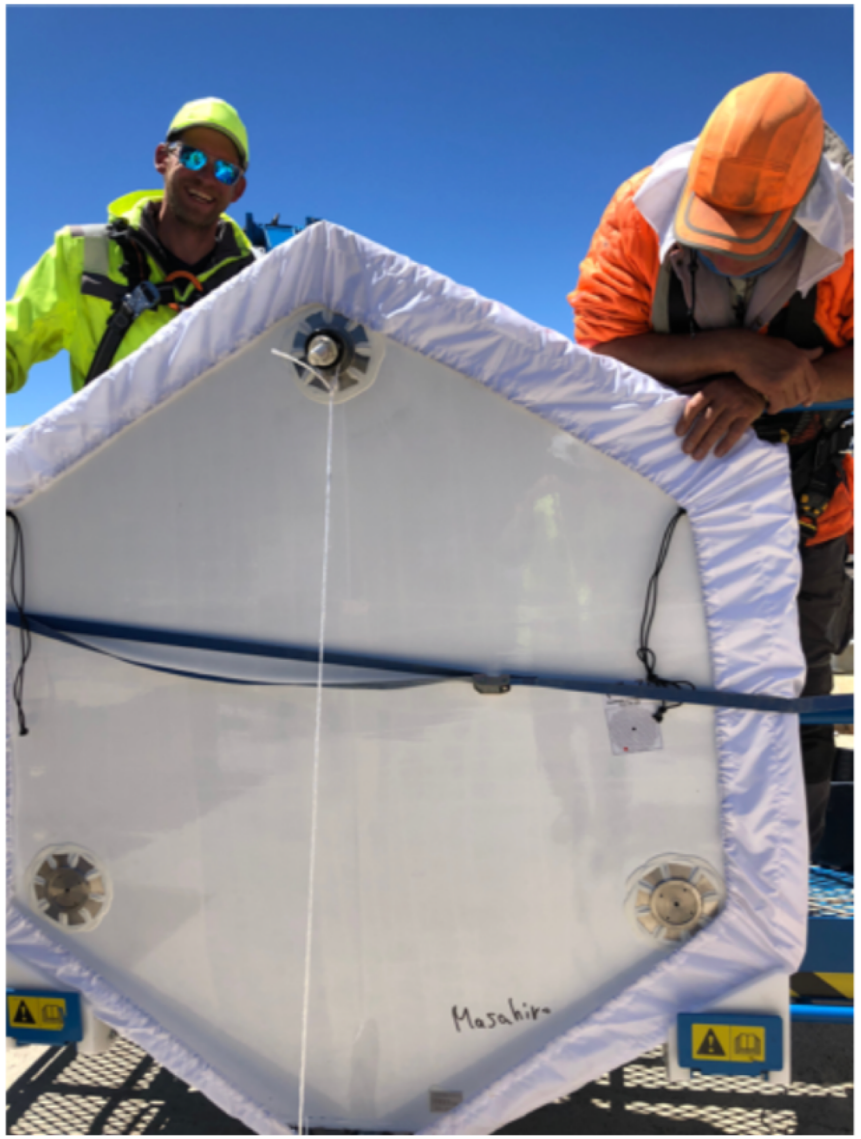
LST1: Mirror dish installation

Dish installed on the understructure, Dec 4, 2017



LST1: Mirror installation

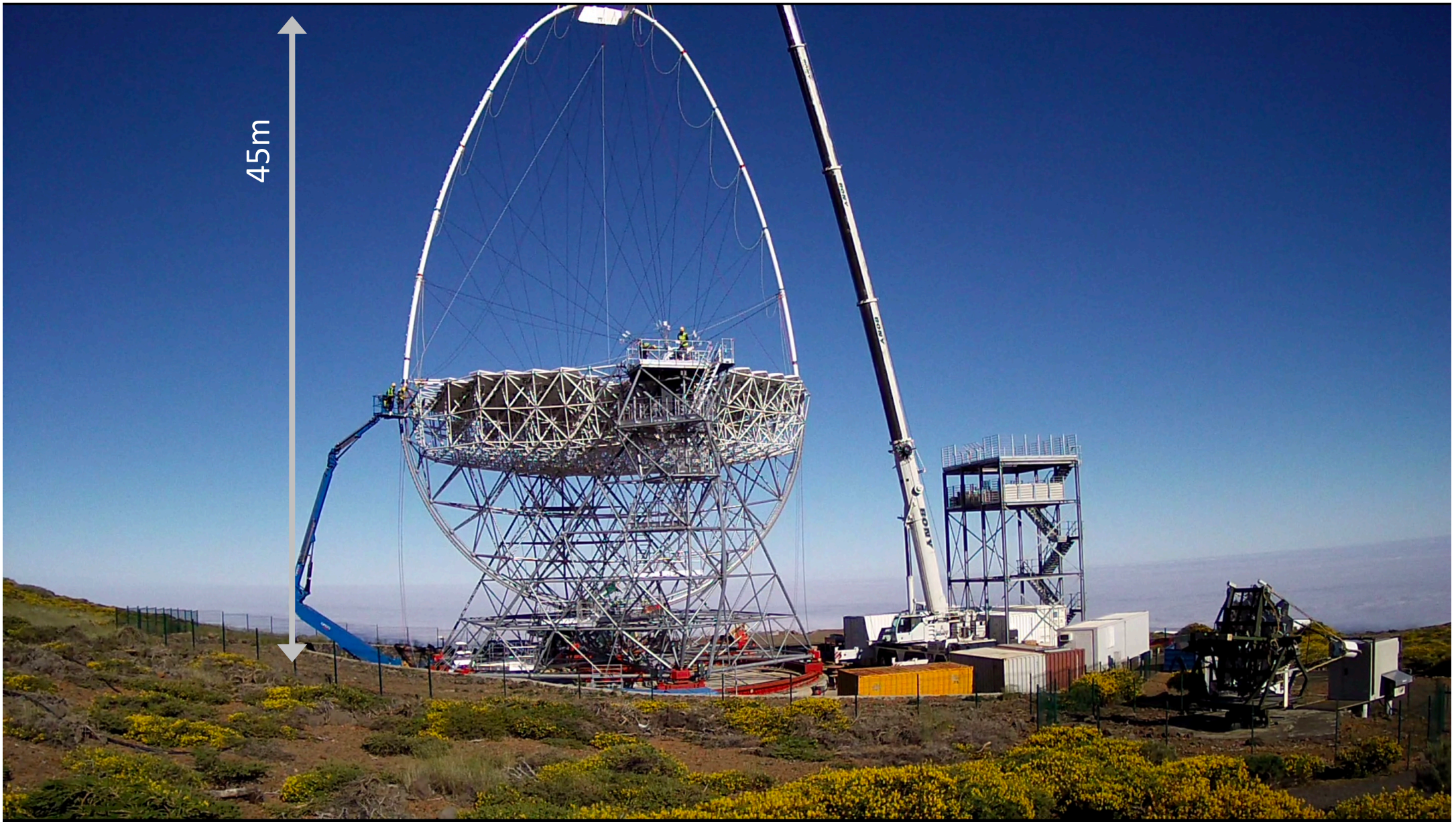




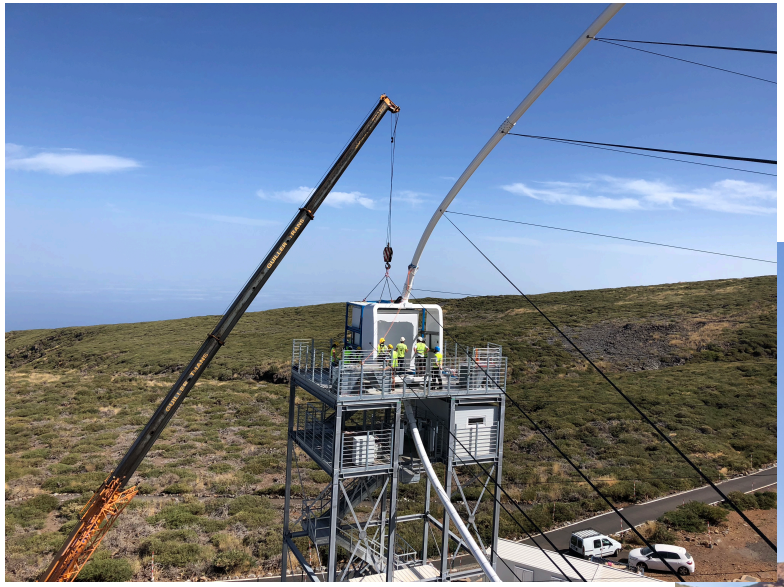
There is 'Martin' mirror as well ;)

cherenkov telescope array

LST1: CSS installation
22 June 2018



LST1: Camera rolled in 25 Sep 2018

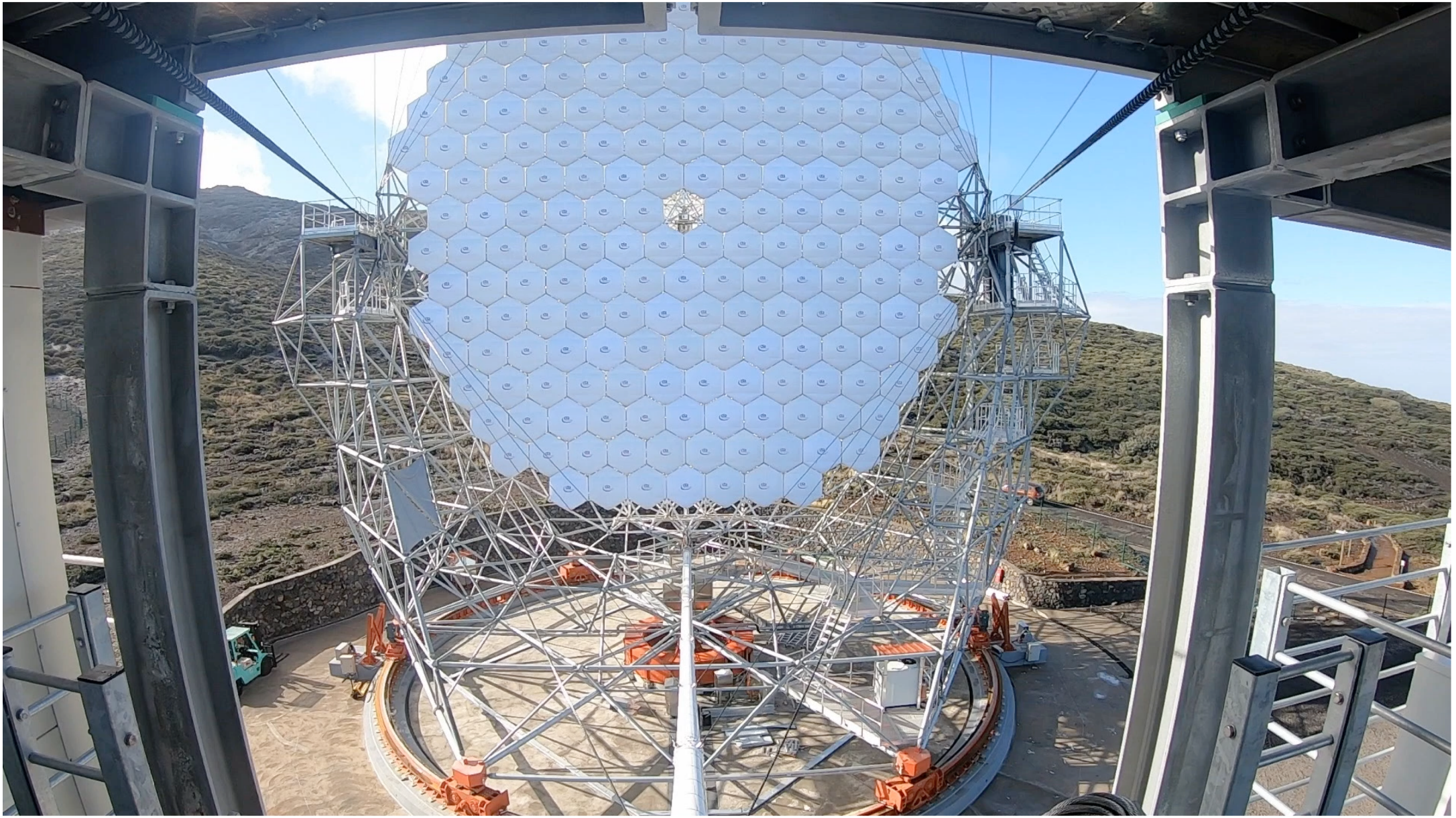


LST1 Inaugurated on 10 October 2018

In Feb 2019 LST1 is awarded with 21st Cent. Technology 2019

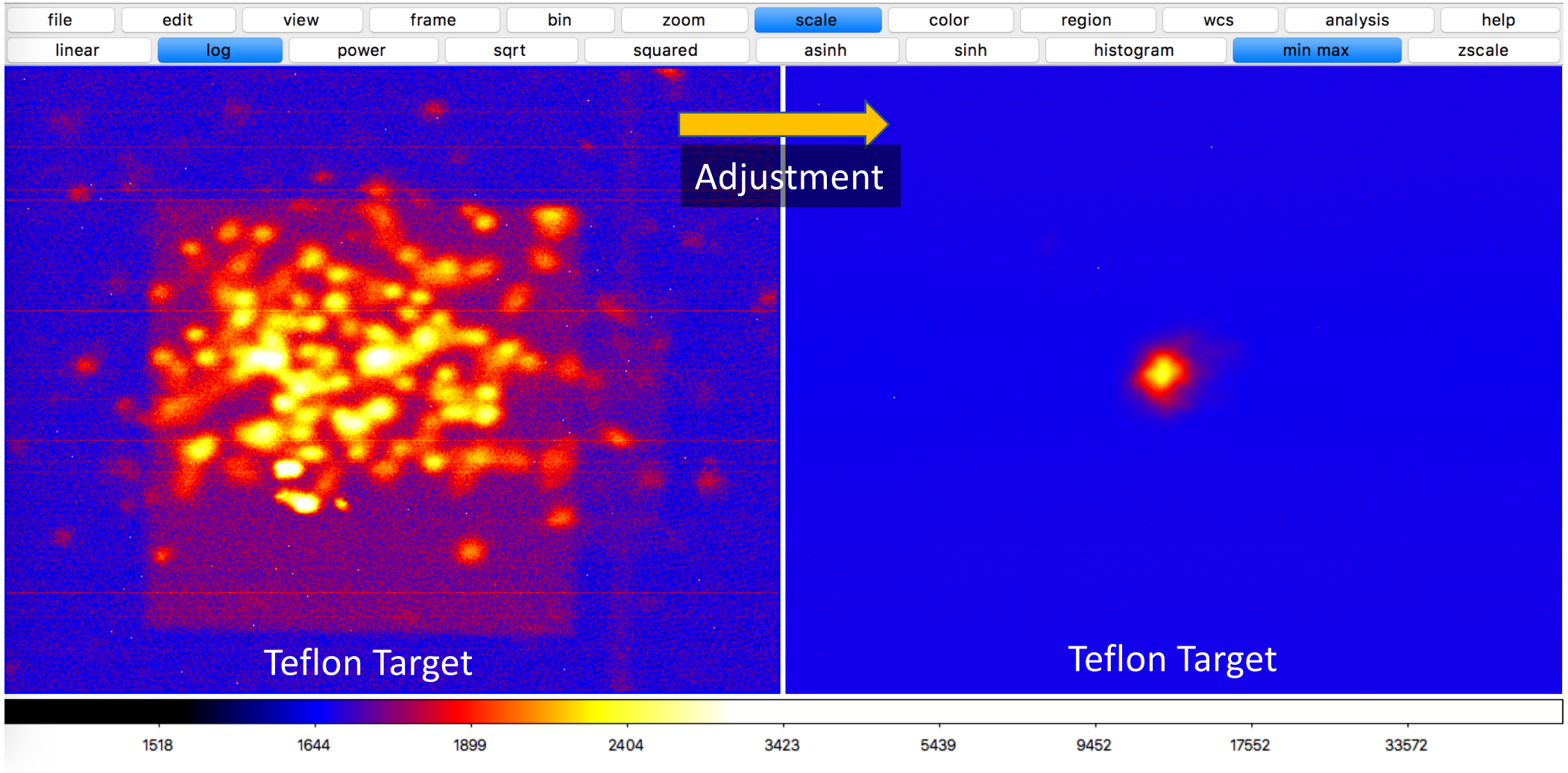
cherenkov telescope array

Fast Rotation of LST1 for GRB observations (April 2019)

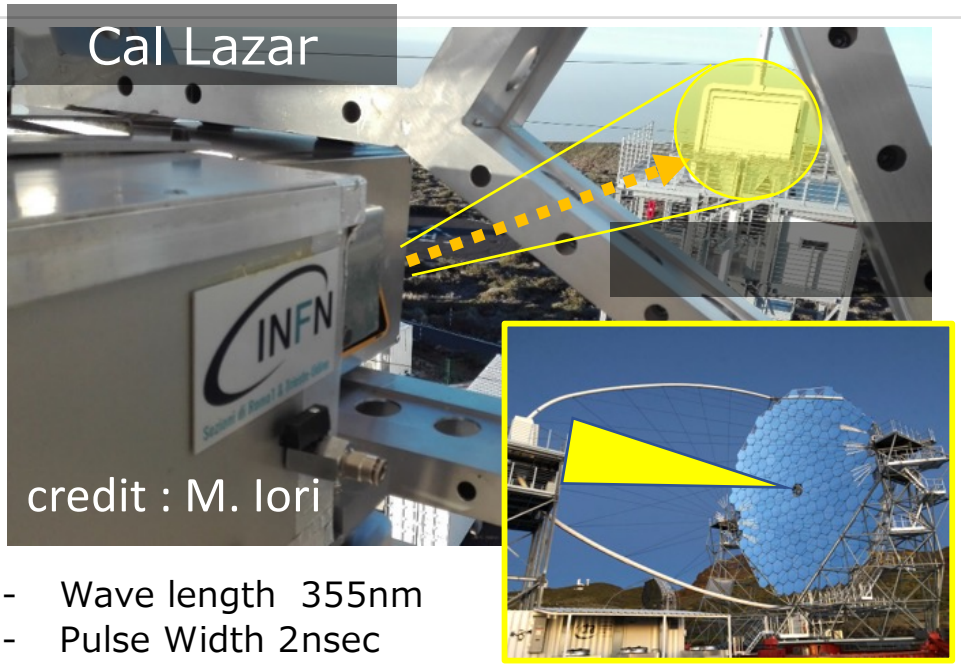


Active Mirror Control and PSF (Image of Arcturus) May 2019

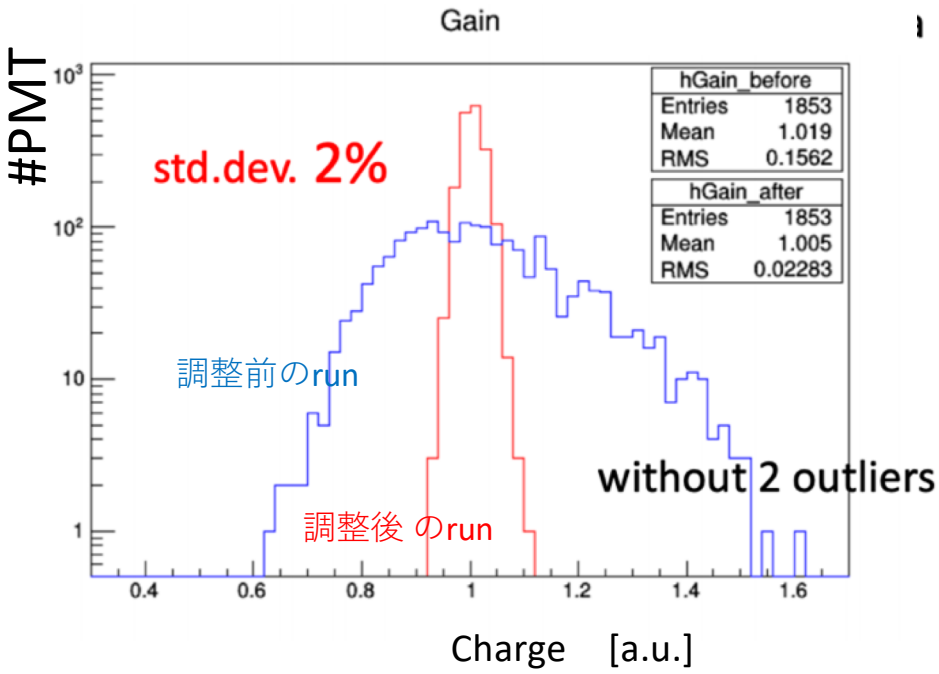
PSF < 0.1 degrees in diameter ➔ D80 =0.05 degrees reached



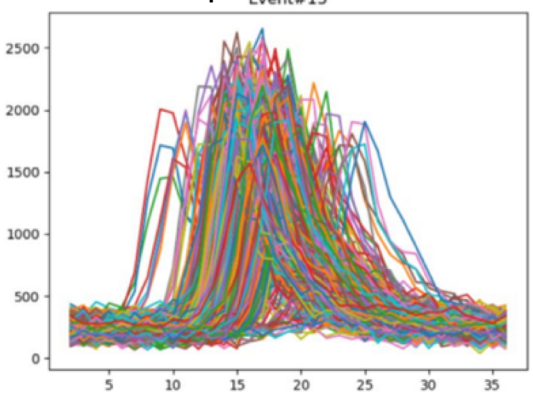
PMT gain calibration



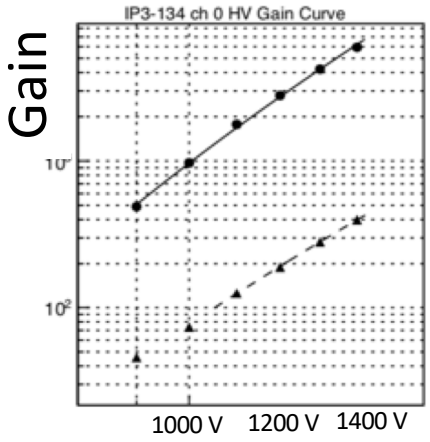
- Wave length 355nm
- Pulse Width 2nsec
- Lazar Stability 1%
- Uniformity <2%



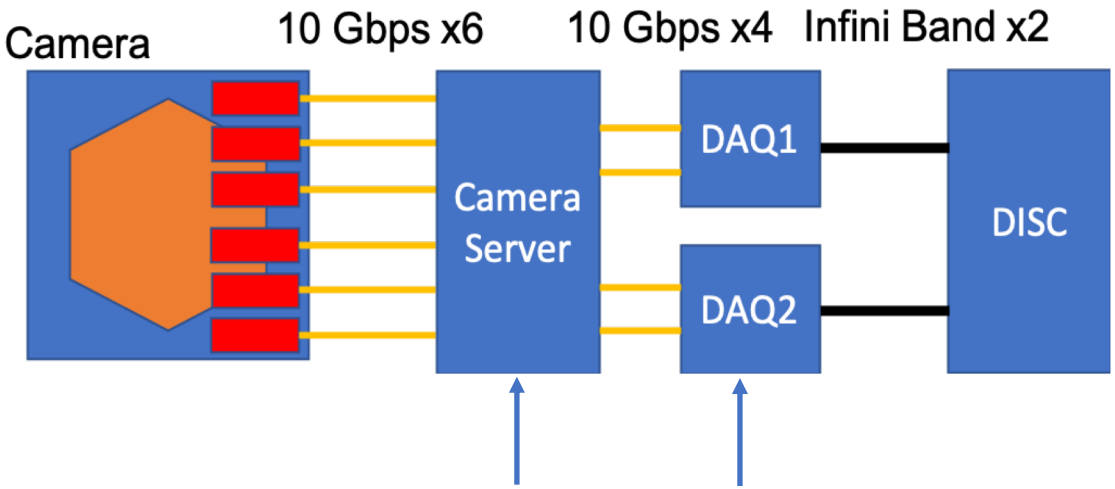
Pulse shapes before calib.



Gain vs HV relation

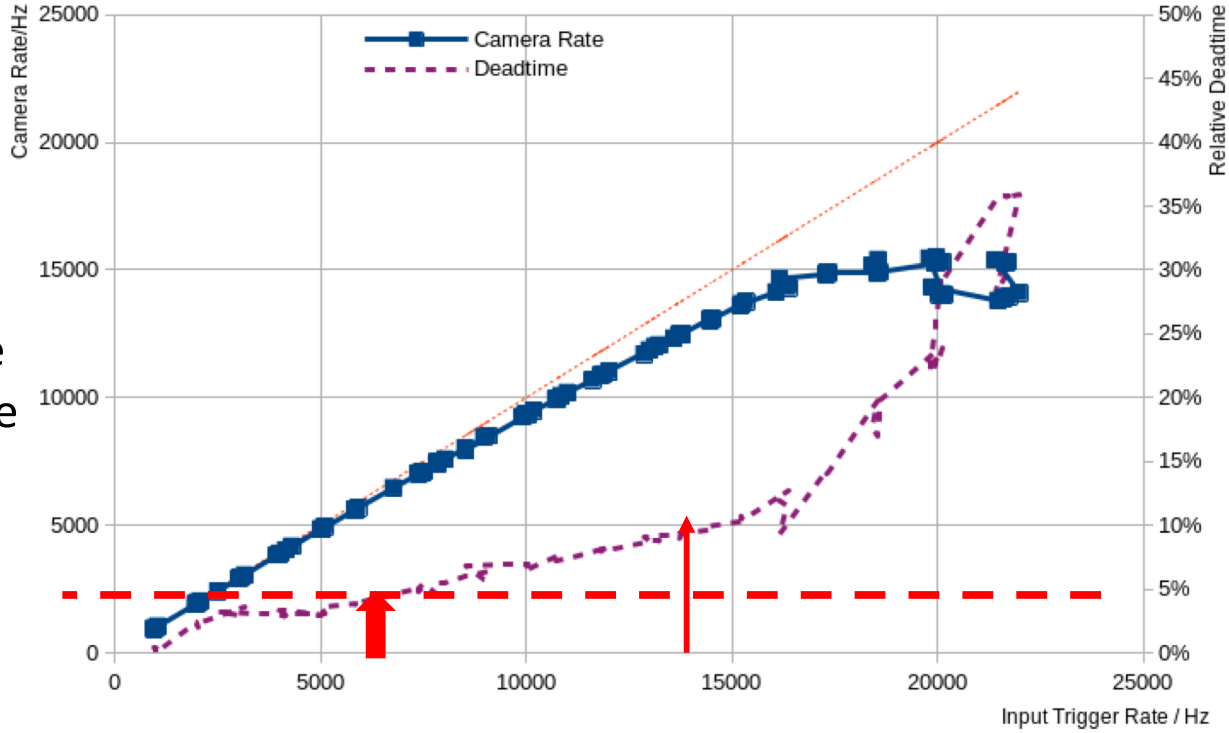


LST-DAQ System



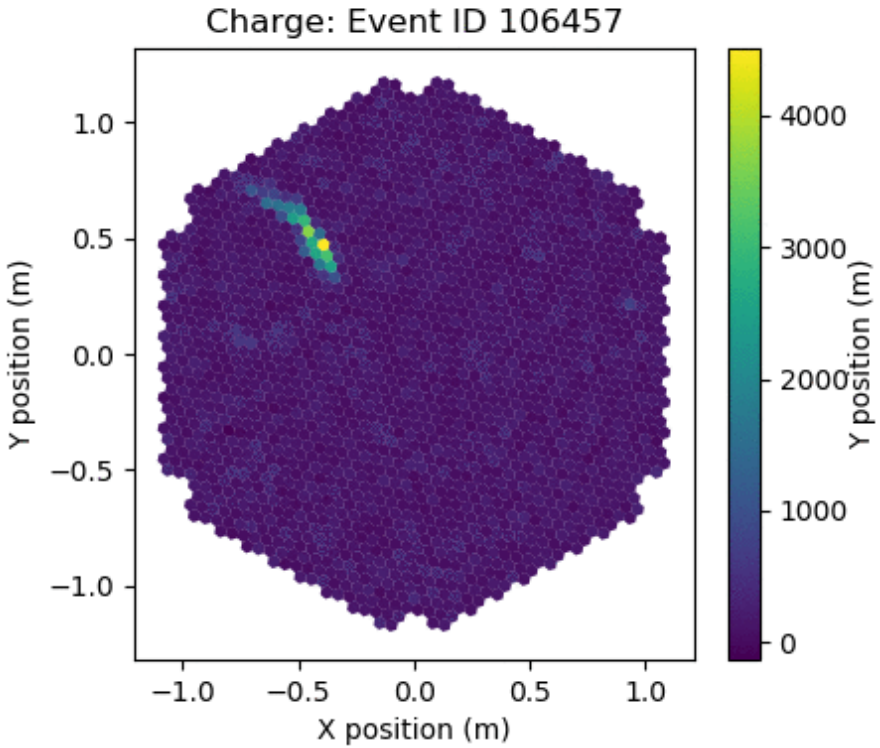
- ❑ Raw data = 356 kBytes /events = 2.85 Mbit
- ❑ Limit of data transfer: 60 Gbits/sec
- ❑ Trigger rate can be up to ~20 kHz
- ❑ Deadtime 7.5 usec / events

Select Low gain or High gain ch, and reduce data volume

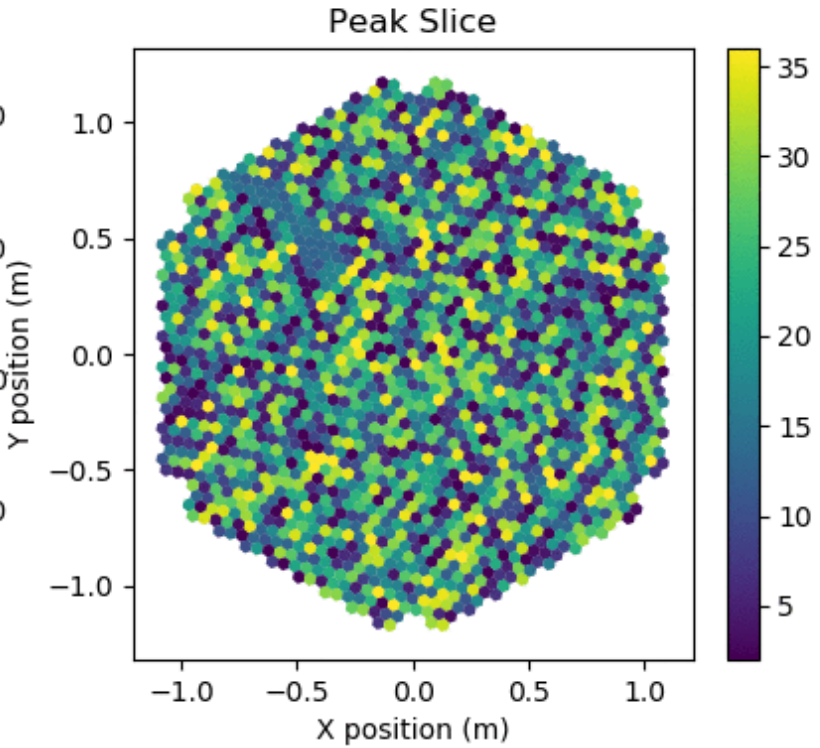


- At 7.5 kHz trigger rate 5% deadtime
- At 15 kHz trigger rate 10% deadtime

Test Observation August 2019
Trigger is not optimized yet

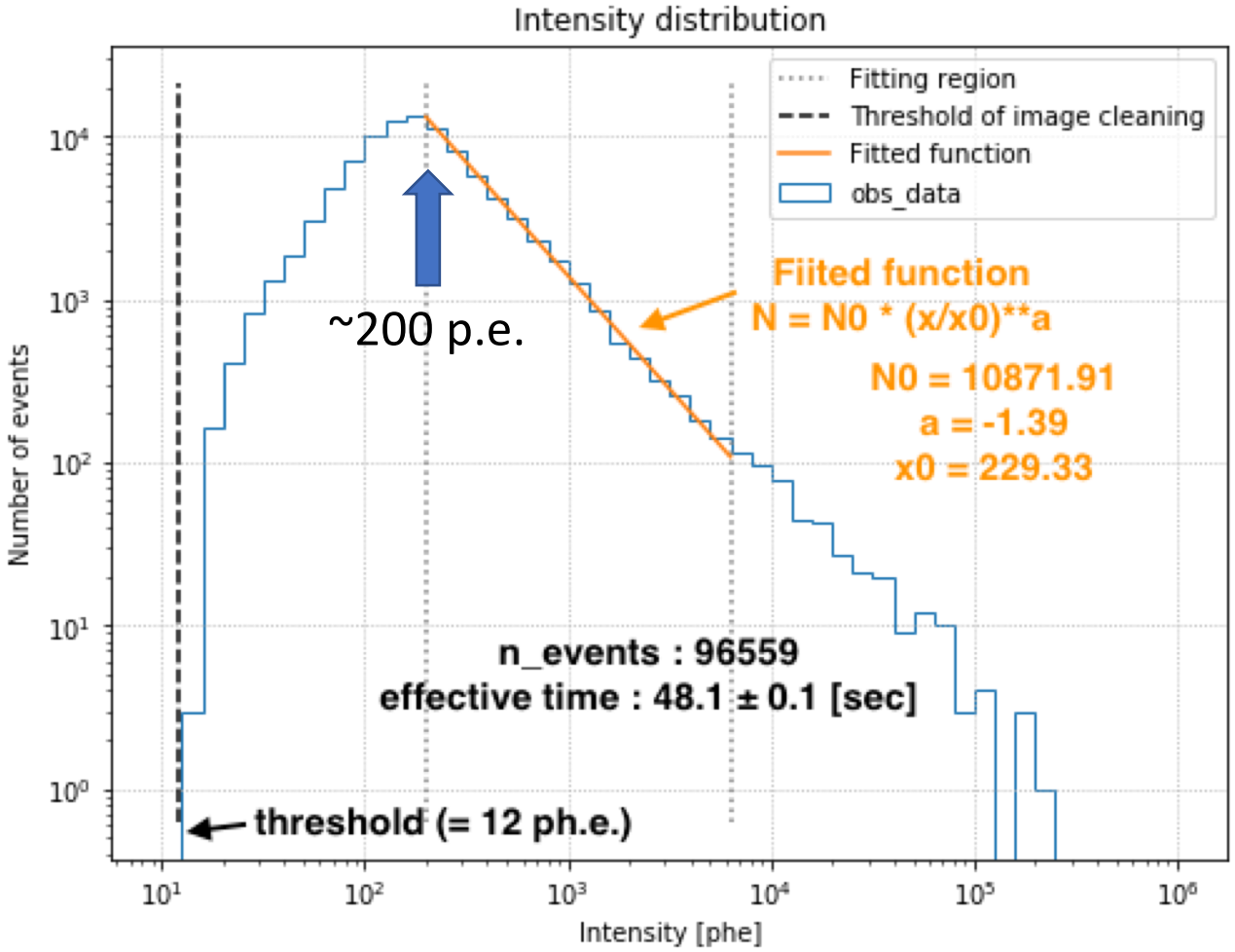


電荷



タイミング

Test observation
Trigger is not optimized yet



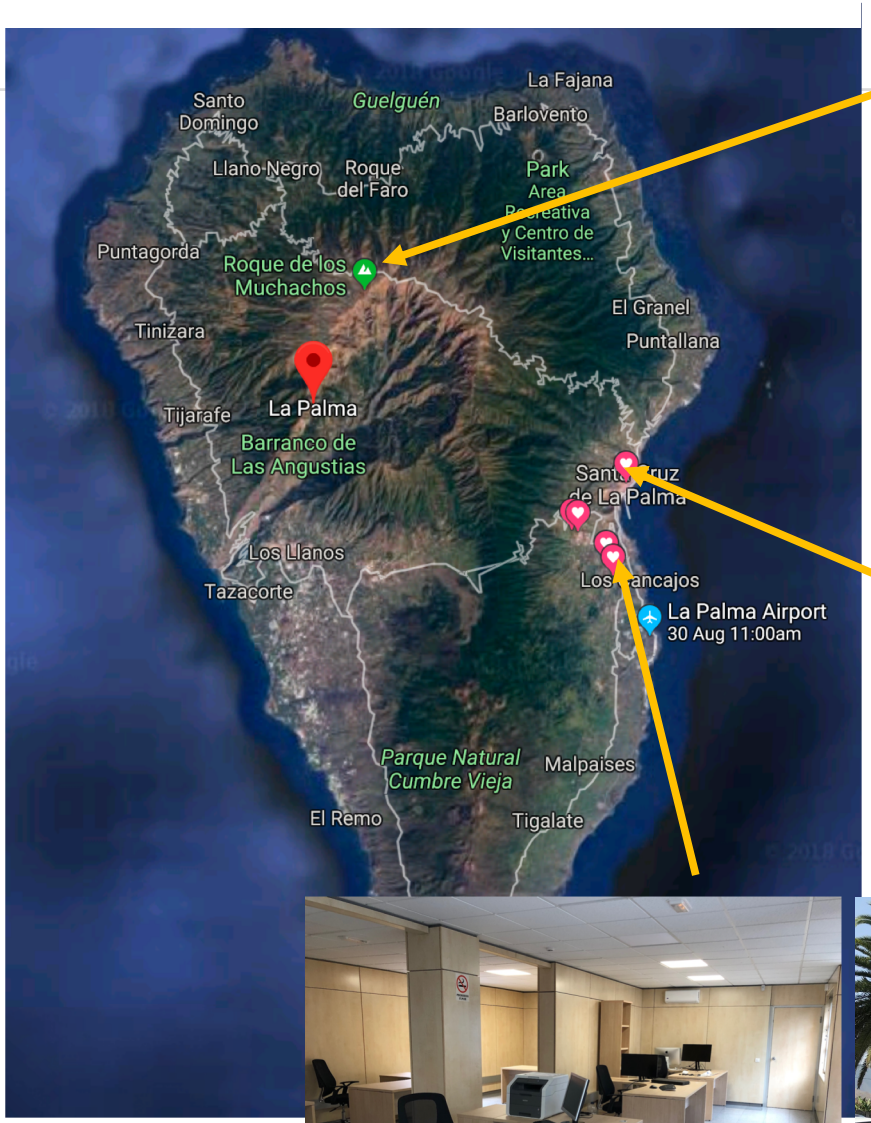
Run # : 1321
Event rate : 1837 Hz
Pedestal: 50Hz

Size(p.e.)(Med) : 200 p.e. ➔
Eth for gamma: 60 GeV

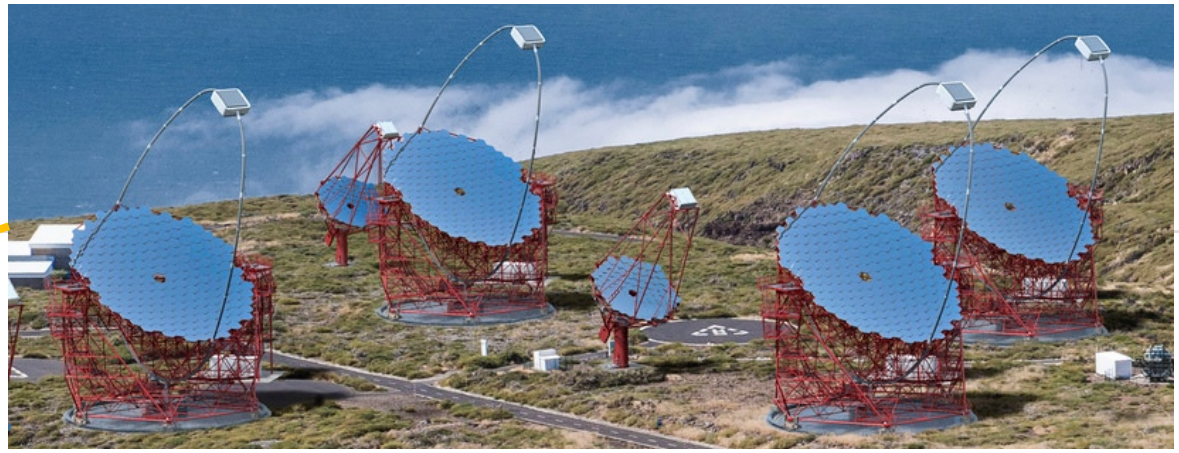
dlog N/dlogSize ∝ E^-1.39
Acceptance ∝ E^0.25 (from M.C.)

dlogN/dlogE ∝ E^-1.65
➔ Consistent with P + He spectrum

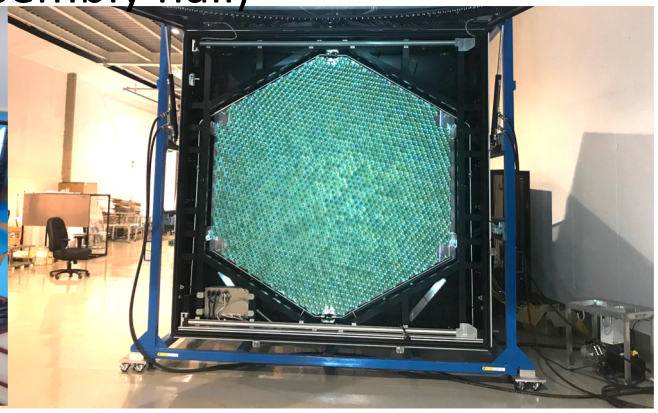
Working Environments



ORM



MIRCA (Storage and Assembly hall)



CALP(カナリー高エネルギー宇宙物理観測研究施設2019年4月)

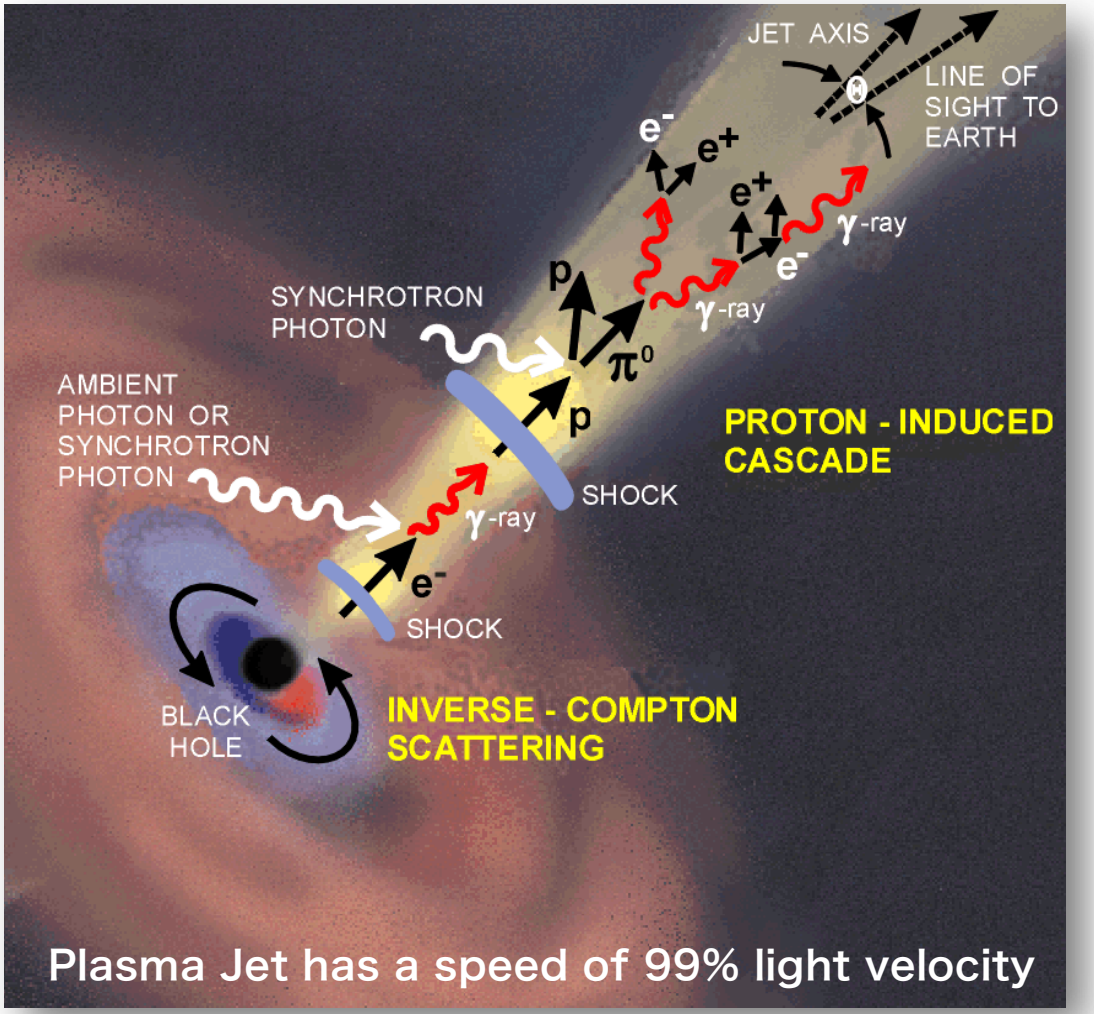
Read this document!!

211 pages, >500 authors

It will invite you to support this project, and then to work on that!!

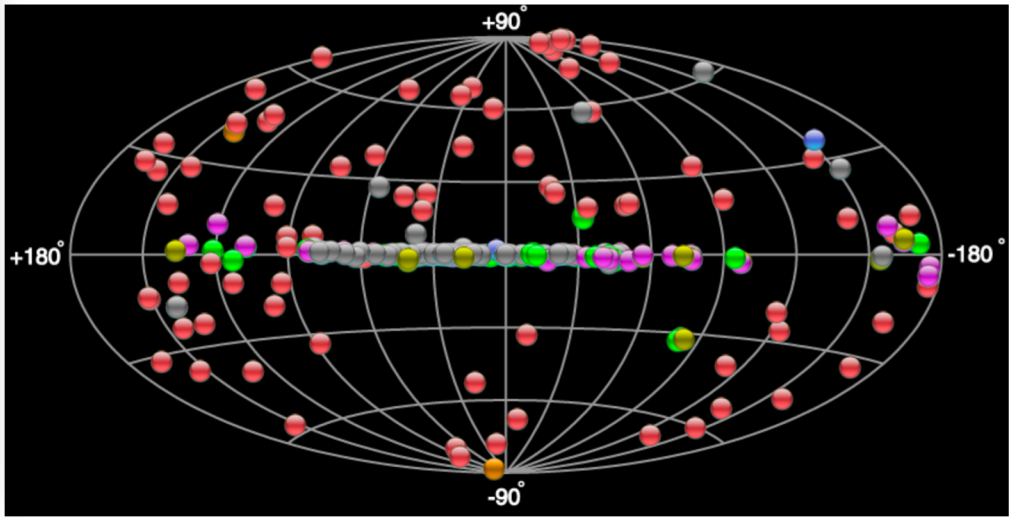
arXiv:1709.07997

Super Massive Black Holes ~10^8 $M_\odot$
Candidates Sources for >10^{18}eV Cosmic Rays



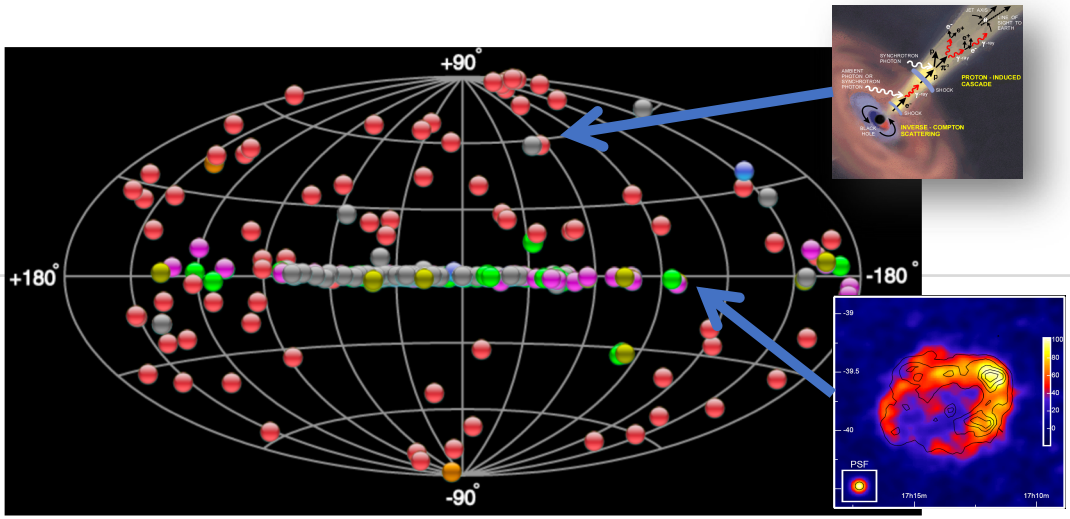
- What is the Maximum Energy?
- Can reach to 10^{20}eV?
- Energy source is accretion disk or rotation energy of Black Hole?
- Explore Black Hole sub Horizon

Red closed circles are Super Massive Black Holes observed MAGIC, HESS, and VERITAS



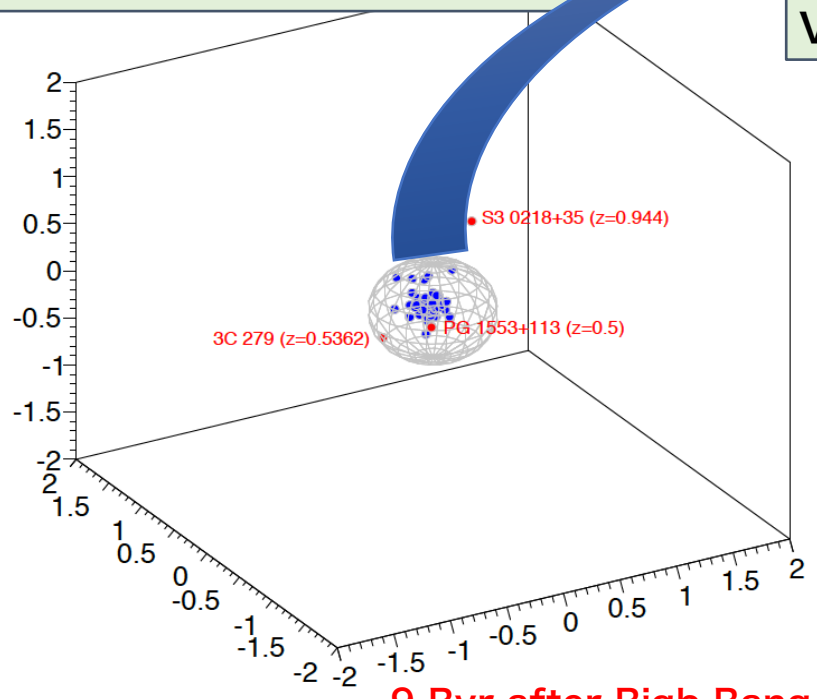
cherenkov telescope array

CTA: Ultimate Survey Machine



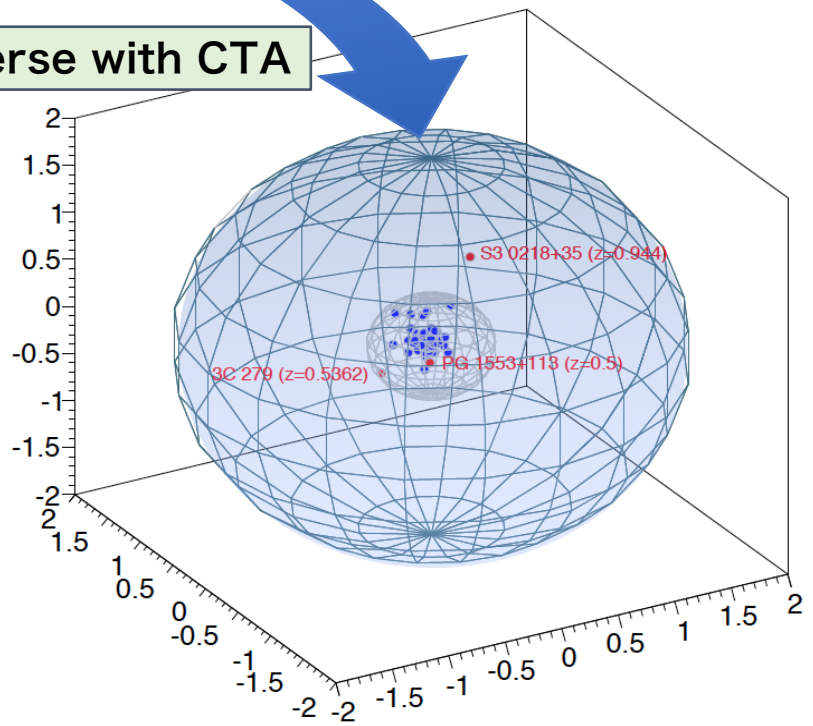
～200 VHE gamma ray sources have been discovered

Observed Universe at V.H.E.



9 Byr after Bigb Bang

Visible Universe with CTA



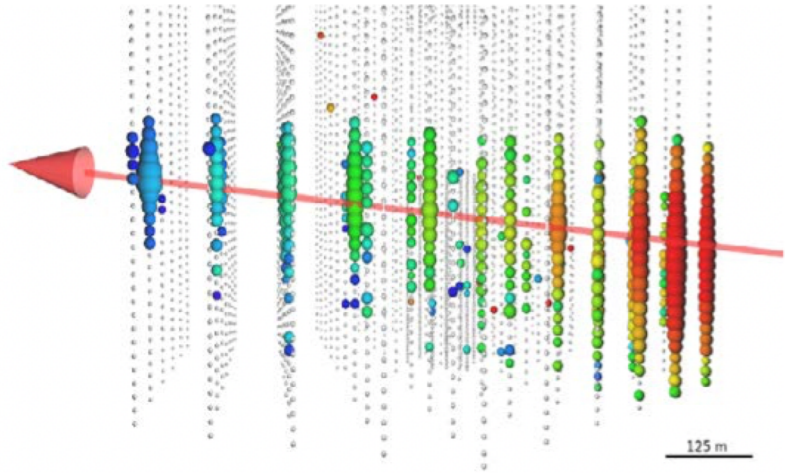
Early Universe
1.6Byr after Big Bang

IC170922A / TXS 0506+056

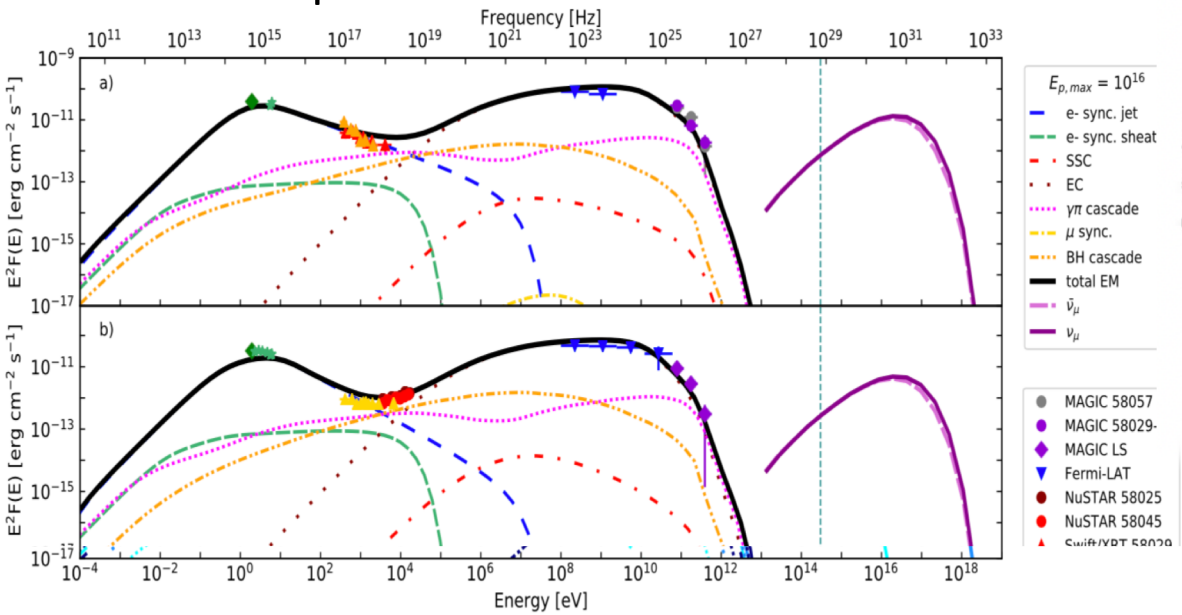
Neutrino from photo-pion process?

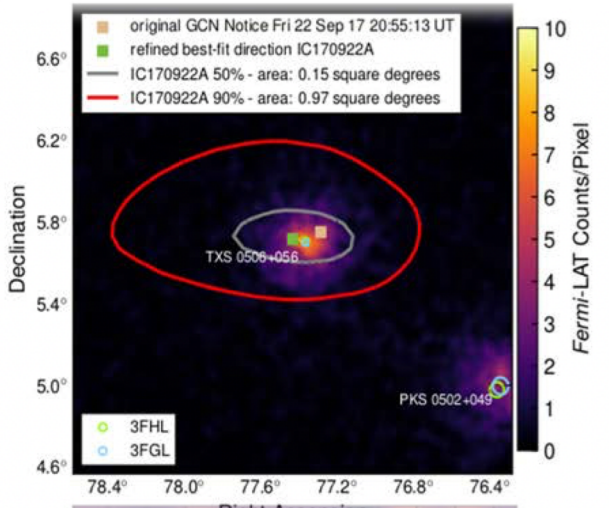
➔ UHECR Sources (>10^{18}eV)

Ice Cube Observation (~300TeV)

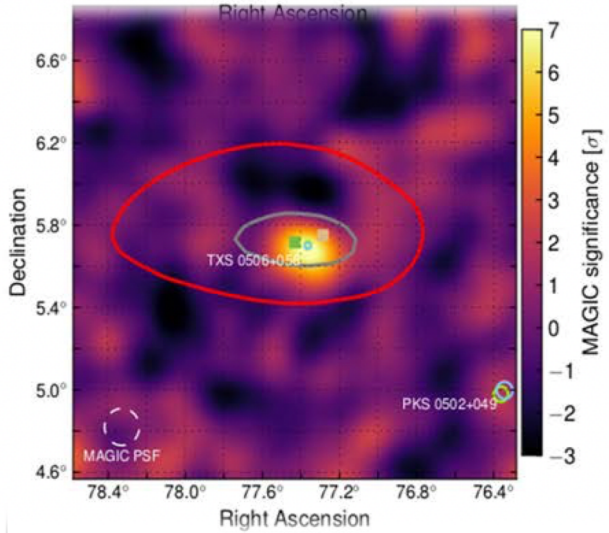


Lepto-Hadronic Scenario





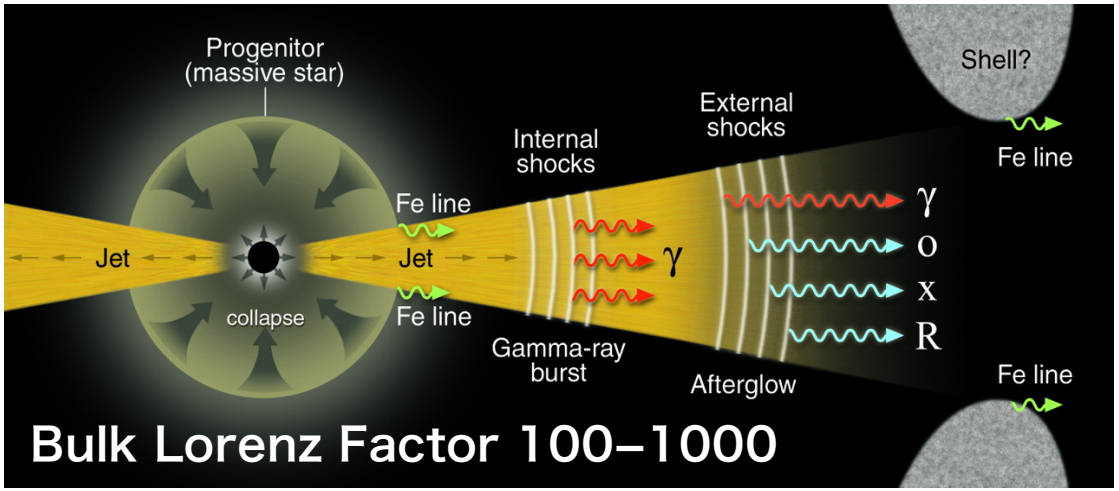
Fermi LAT
(>100 MeV)

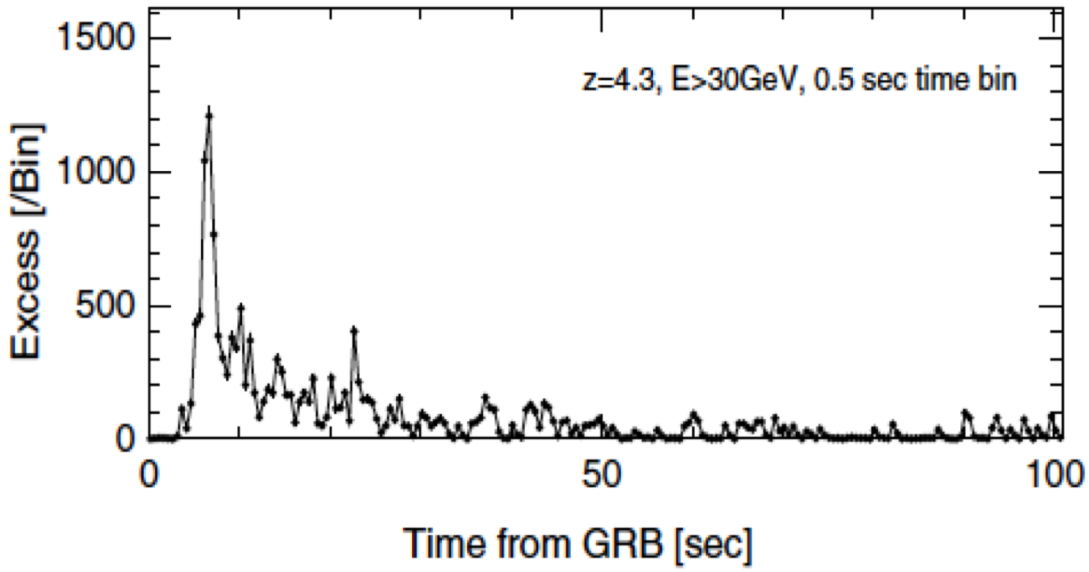


MAGIC
(>100GeV)

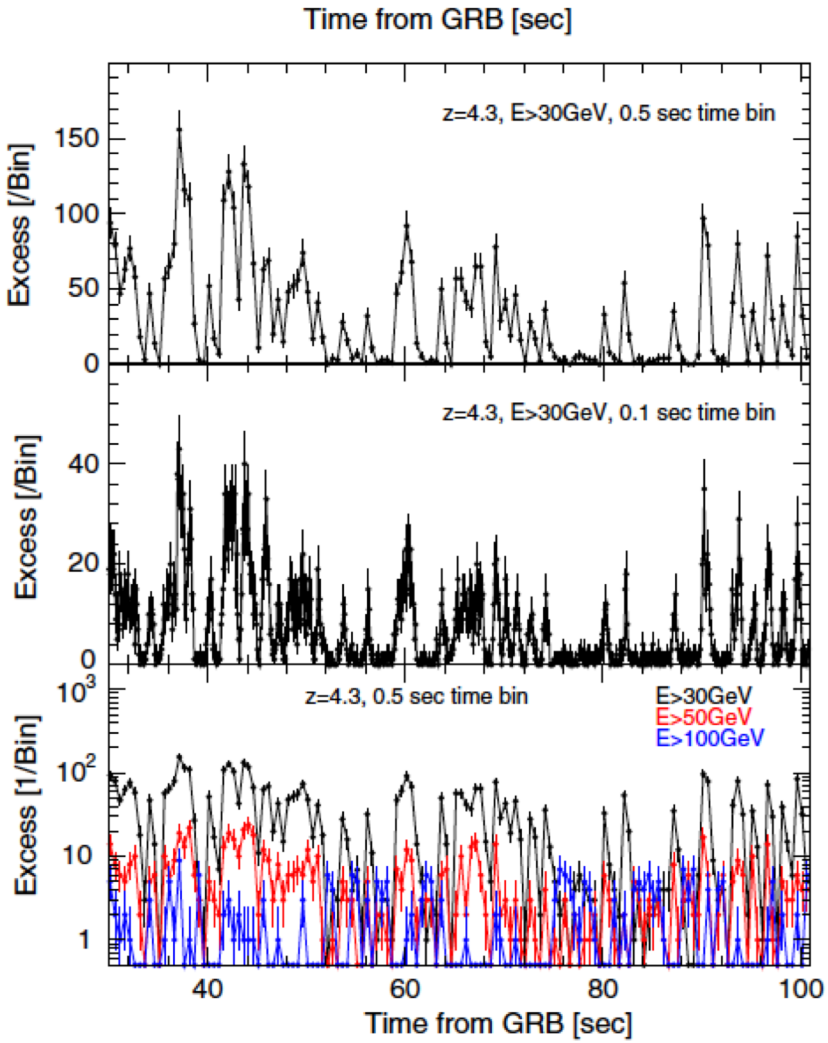
GTC Observation z = 0.3365
S. Paiano et. al 2018

GRBs: good targets for CTA-LSTs
Study the newborn baby black holes





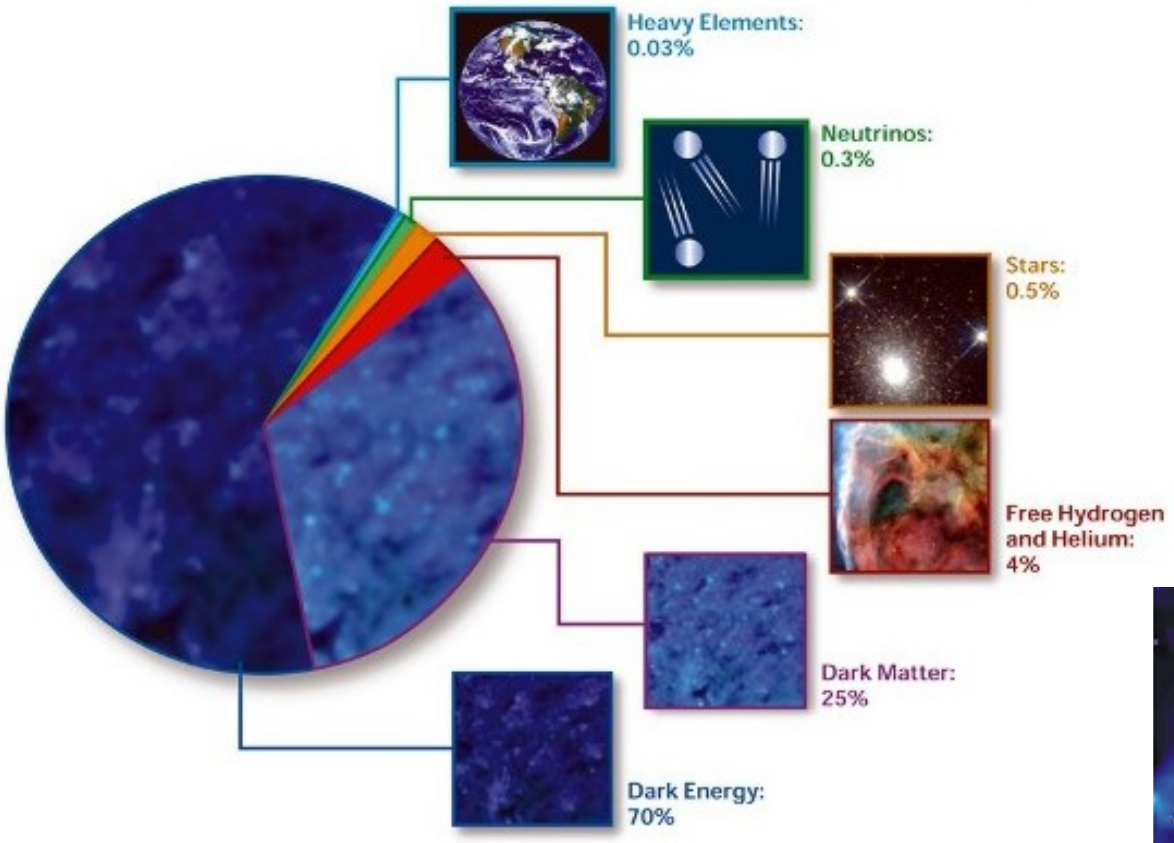
CTA Simulation
(Template GRB080916C)



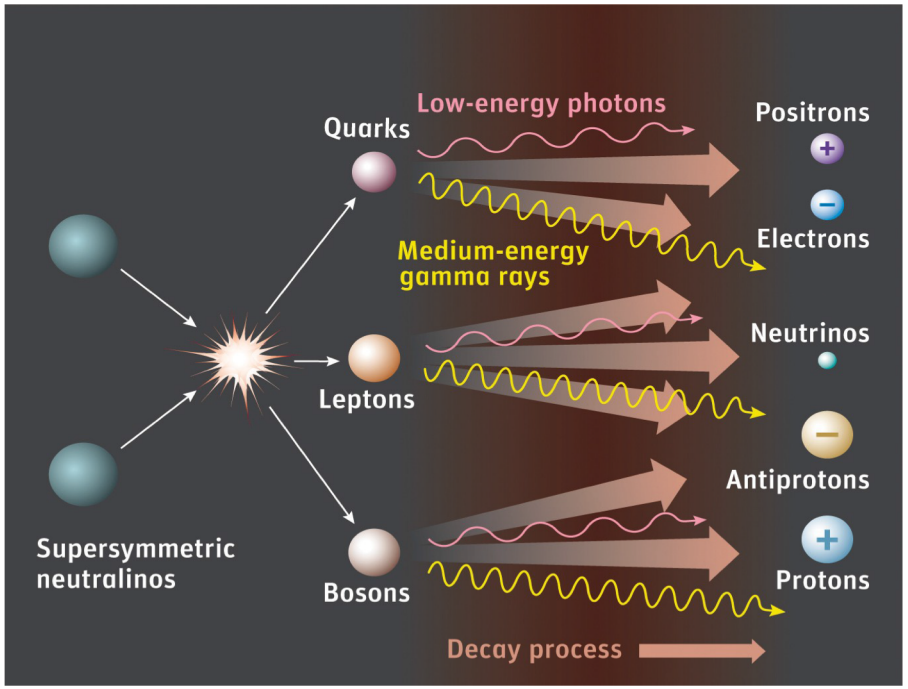
Dark Matter Search

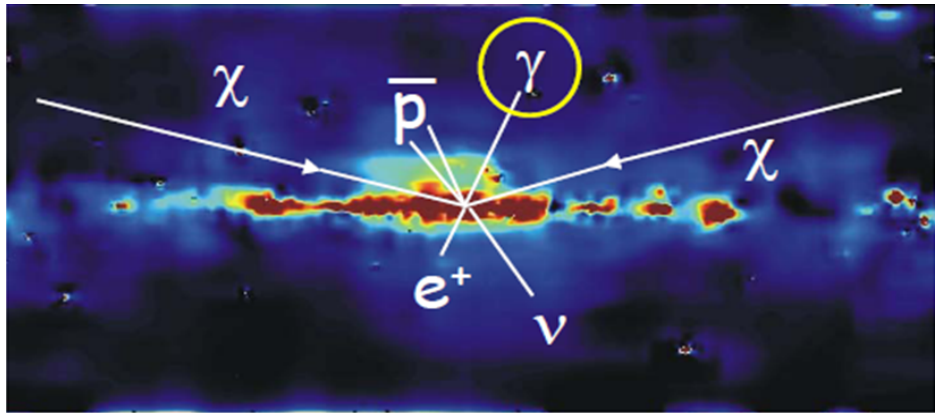
Mass Scale M_χ: 100GeV - 10TeV

Surprisingly Physicists, Astronomers and Professors do not know well the Universe!!



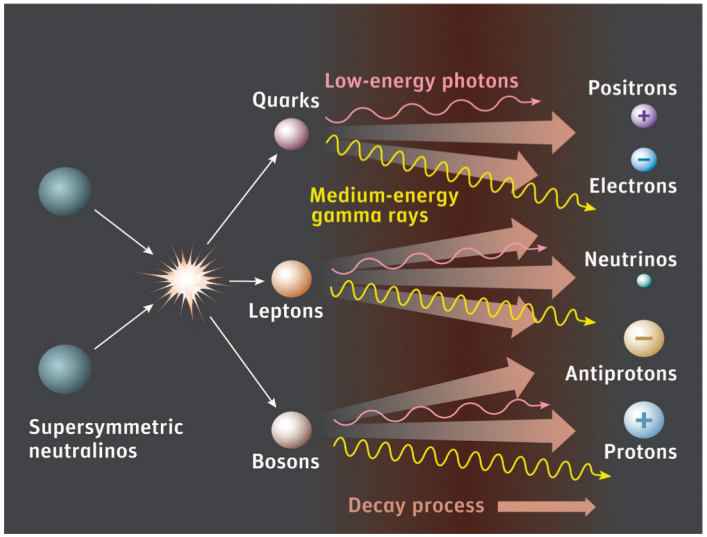
Known Matter	~ 5%
Dark Matter	~25%
Dark Energy	~70%





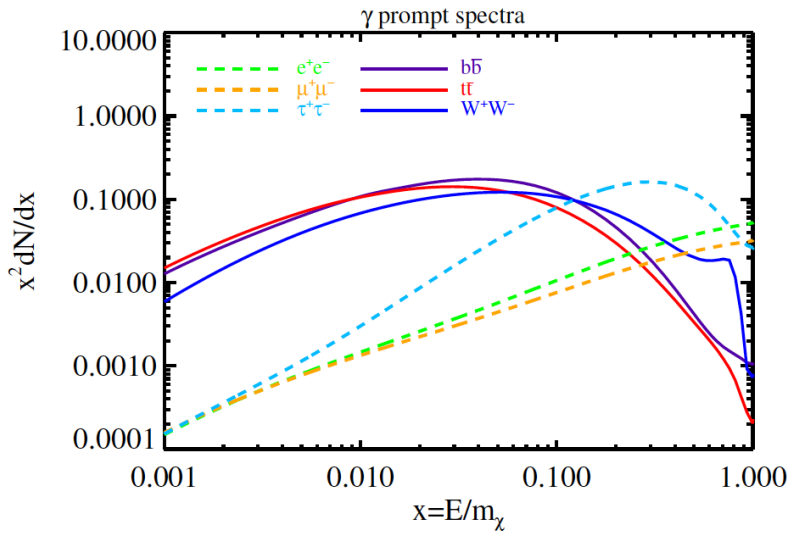
Dark Matter Search

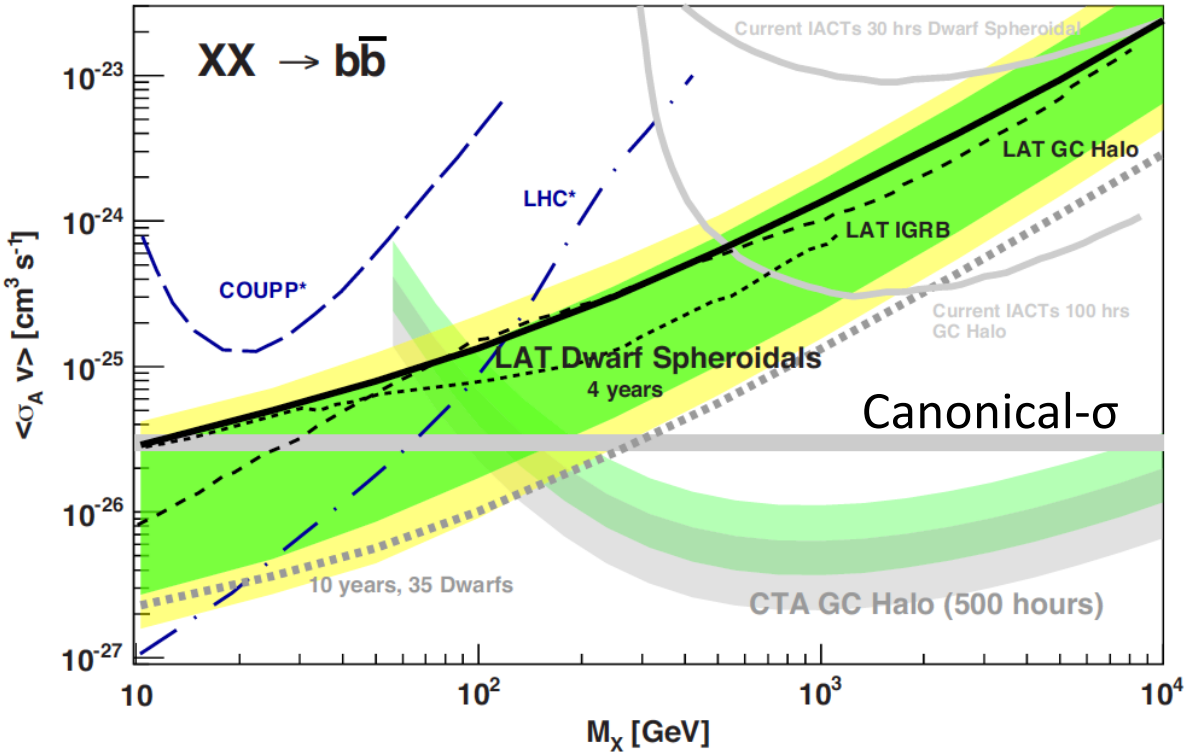
Sensitive M_χ: 200GeV - 10TeV



$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \underbrace{\frac{<\sigma_{ann} v>}{2m^2_{WIMP}} \sum_f \frac{dN^f_\gamma}{dE_\gamma} B_f}_{\text{'Particle Physics'}} \times \underbrace{\int_{\Delta\Omega} d\Omega' \int_{los} \rho^2 dl(r,\theta')}_{\text{'Astrophysics' or } J(E)}$$

Particle Physics Astrophysics





Gamma rays from Annihilation produce the bump around 1/10 -1/20 Mχ ➔ 20GeV-1TeV domain

CTA gives the stringent upper limit.
Stefan Funk 2015

Summary

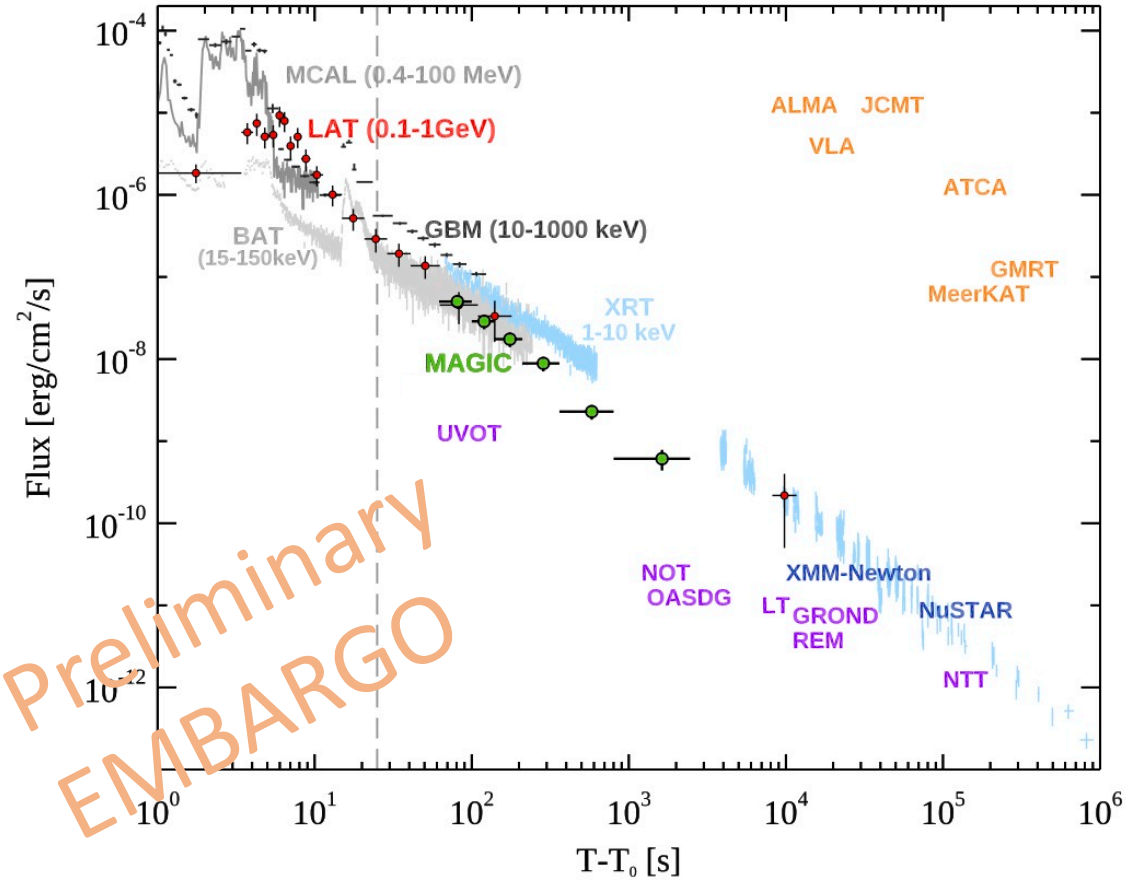
- The new window to observe the Universe,
  - "High-Energy Gamma Ray Astronomy"
  - Energy Frontier in the Electro-Magnetic window
    - Four GRBs are recently reported by MAGIC and HESS
    - MAGIC one is quite prominent.
    - Dark Matter (increase our knowledge on the Universe from 5% to 30%)
  - **MWL and MM observation** with GW and PeV/subPeV Neutrino!!

- **CTA is under construction**
  - The new generation gamma ray observatory CTA with all our experiences and new technologies
  - In three years CTA-LST North will start the operation and offer the world best sensitivity for H.E. Gamma Observation


cta
cherenkov
telescope
array

Multi-wavelength light curves of GRB190114C measured > 20 space-born and ground-based instruments

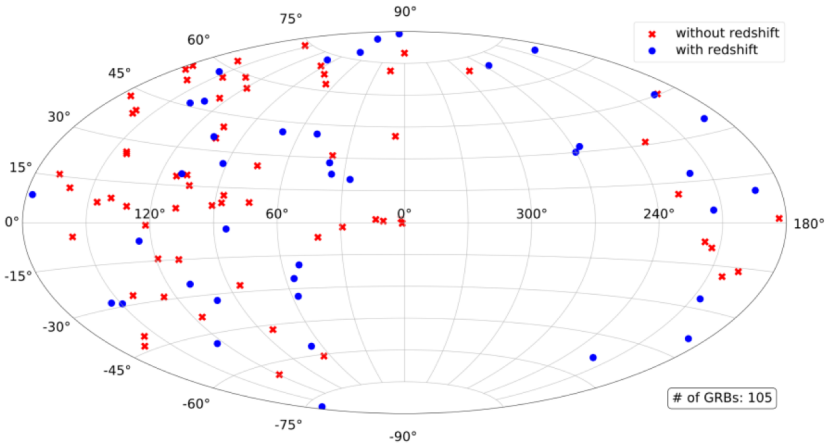
- MAGIC detected the afterglow phase of the GRB
- A significant share of GRB energy is emitted in the TeV energy range



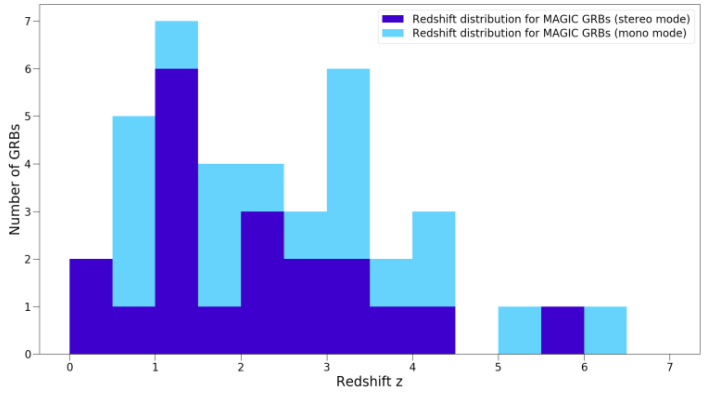
GRB follow-ups

- Since 2005 we observed 105 GRBs
- On average 8-10 GRB/year
- Afterglow observations since 2013
- 24 with < 100 s delay & stereo,

  4 out of which with z < 1.5

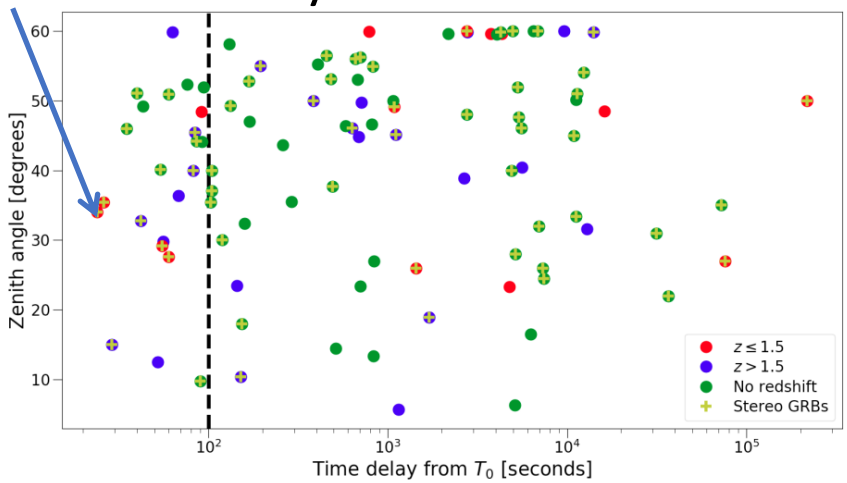


Red-shift distribution



GRB 160821B

Delay versus observation angle

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