MAGIC and CTA LST

Koji Noda (ICRR, U. Tokyo)
for MAGIC Collaboration and CTA consortium

18-20 Feb 2019
VHEPA 2019 @ ICRR

Outline

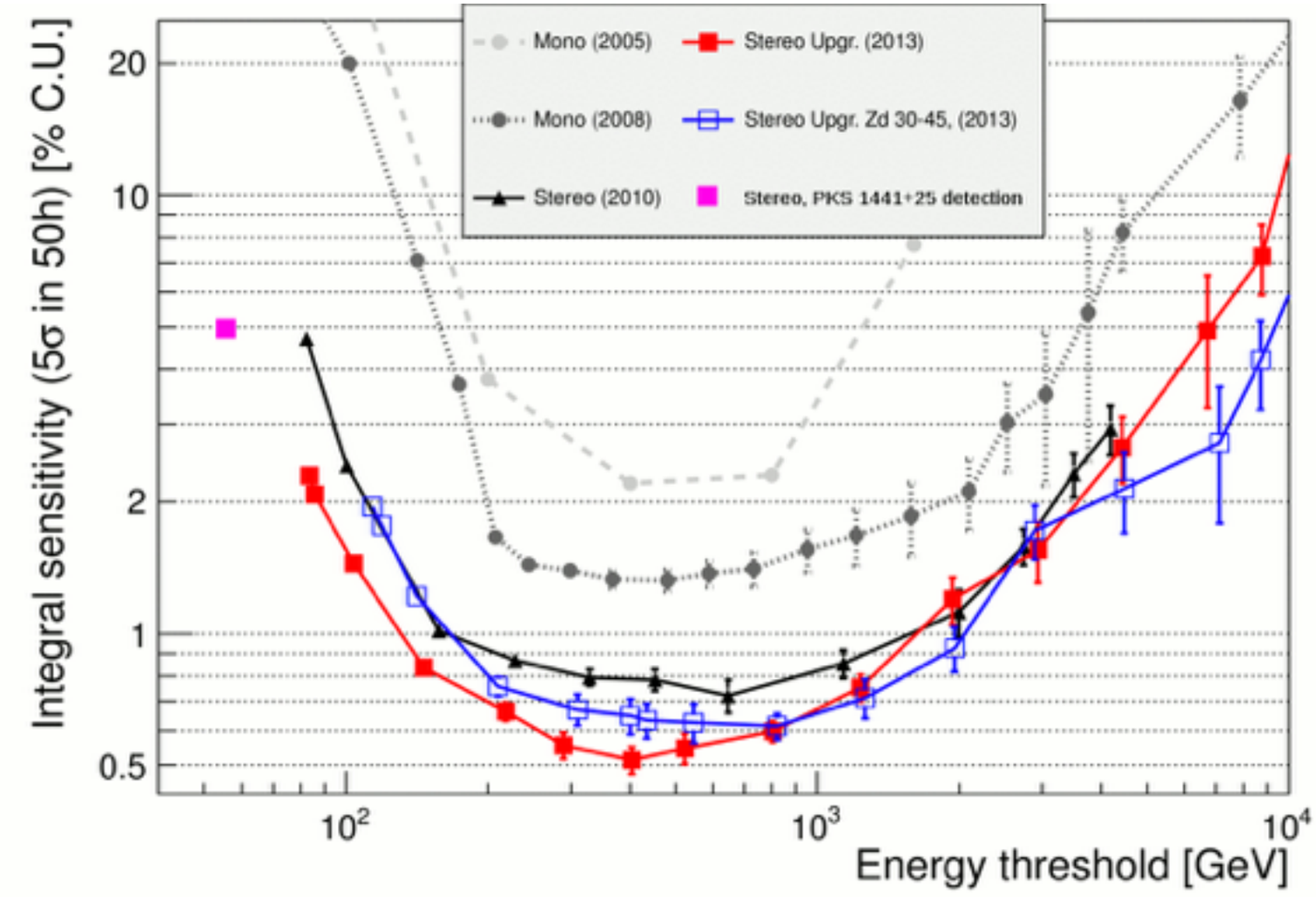
- MAGIC science
  - Galactic
  - Extragalactic
  - Fundamental physics
  - Transients
- CTA status
  - Overview
  - Large Sized Telescopes (LSTs)
  - LST1 status
- Summary

MAGIC

- The MAGIC Collaboration: ~170 collaborators in 10 countries.
- Stereo system of two Imaging Atmospheric Cherenkov Telescopes (IACTs). MAGIC-I since 2004, and MAGIC-II since 2009.
- Upgraded to homogenise the system. Stable operation since 2013.
- 17 m diameter, Eth ~= 70 GeV (analysis), lower with sum trigger
- Light weight => fast movement to catch transients (20 s / 180º)

Performance since 2013

- Trigger threshold down to ~50 GeV (low zenith)
- Analysis threshold down to 70 GeV.
- Energy resolution 15%-23% below 10 TeV
- Angular resolution <0.07° above 300 GeV
- Sensitivity 0.6% Crab Nebula flux in 50 hours



More special efforts to **maximise the duty cycle**

- Correction for atm. transmission with LIDAR (operational since 2013, method available since 2015)
- Systematic observations under moon (Astropart.Phys. **94** (2017) 29)

MAGIC

Major Atmospheric

Gamma Imaging

Cerenkov Telescopes

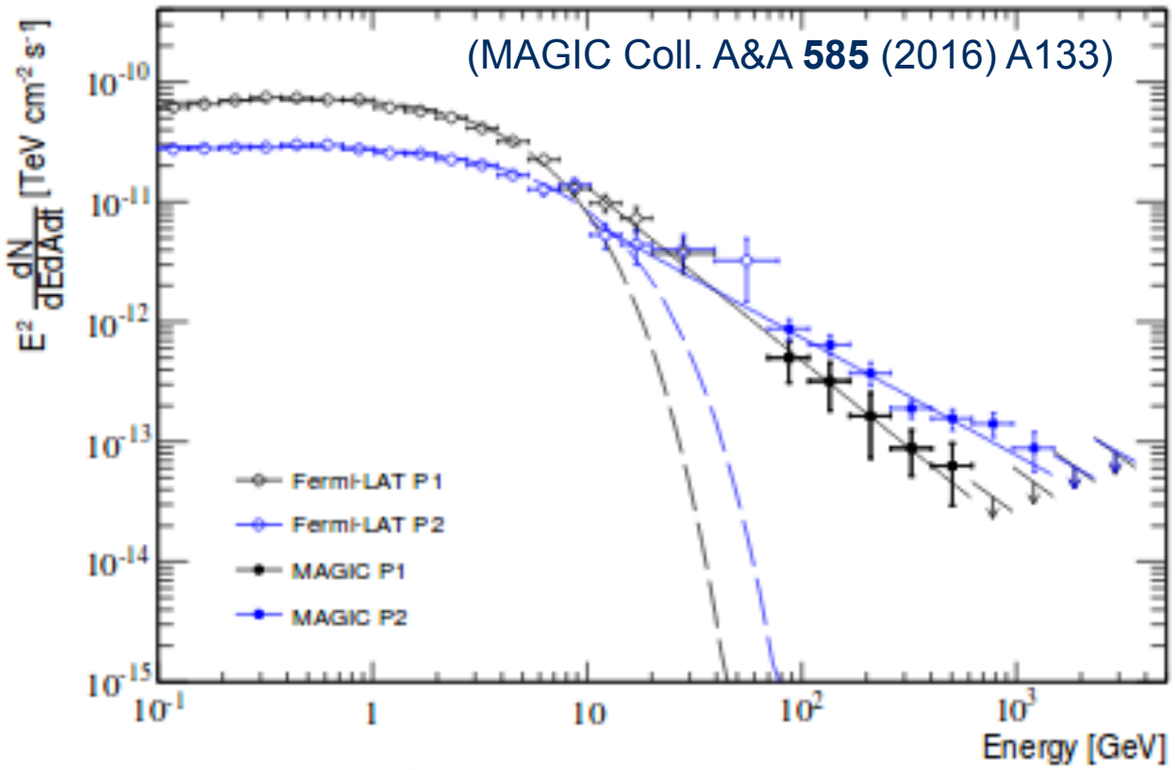
MAGIC science highlights

(roughly, from closer to further, and to unknown)

Galactic: pulsars

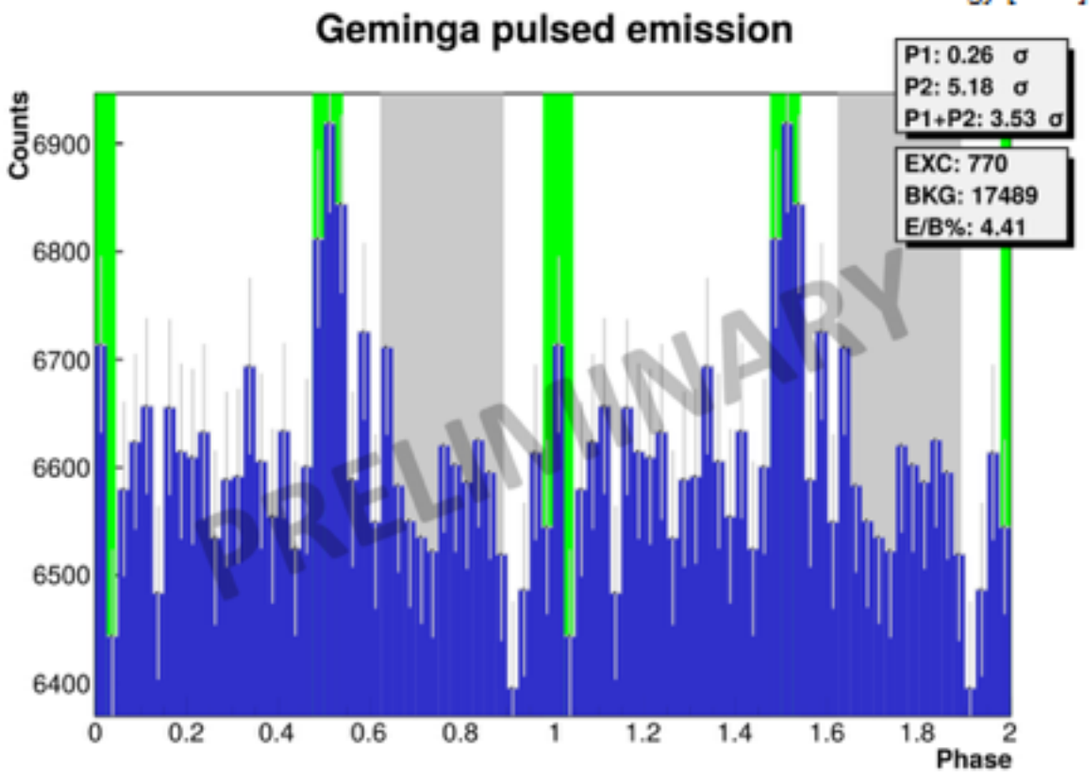
Crab pulsar

- MAGIC discovery > 25 GeV
  (Science **322** (2008) 1221)
  - VERITAS detects > 100 GeV (2011)
- Extended the spectra up to 400 GeV and measured P1/2 spectra separately (A&A **540** (2012) 69)
- **MAGIC discovery of emission up to TeV** (A&A **585** (2016) A133)

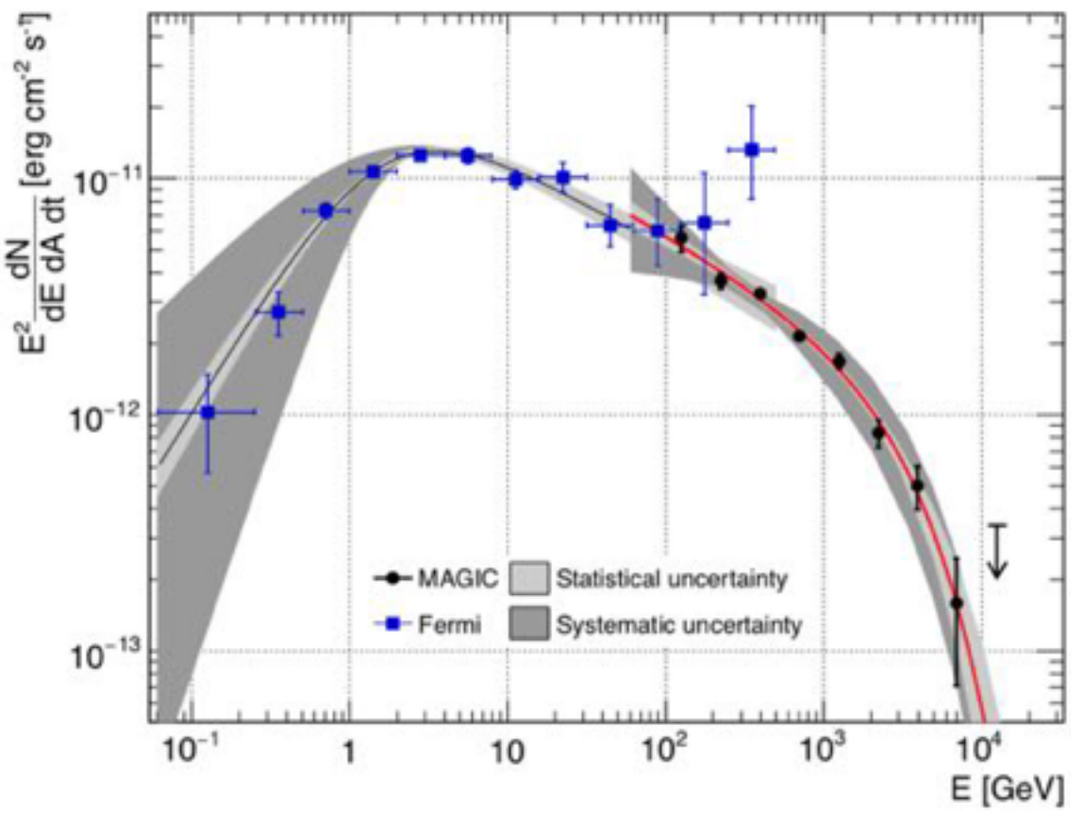


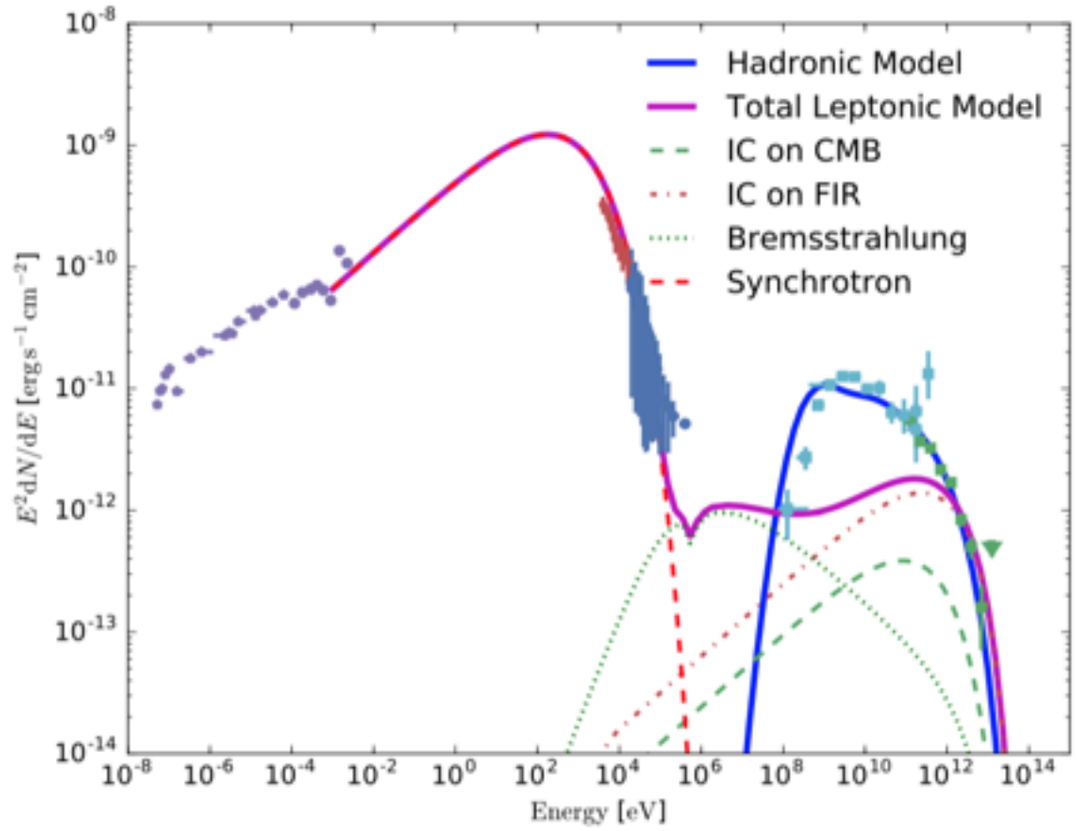
Geminga pulsar

- MAGIC discovery of P2 > 5 sigma from 30 hr obs. with sum trigger
- Became the 3rd known pulsar in VHE gamma



Galactic: SNR CasA





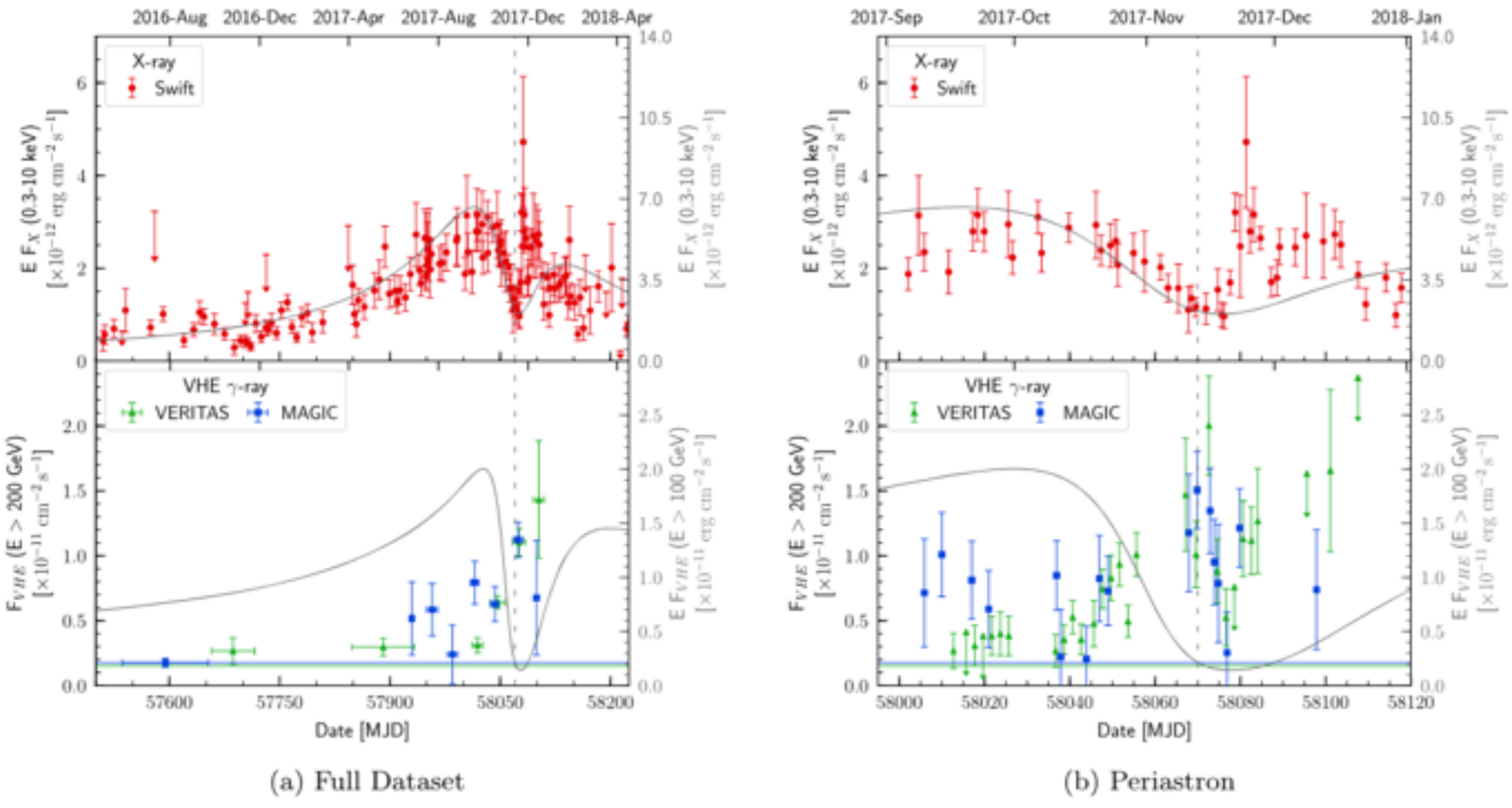
M. Ahnen et al. (MAGIC Coll.), MNRAS, **472** (2017) 3

- SNRs as PeV CR accelerators "PeVatron". CasA is one of the best candidates: young (~300 yr) & good MWL data to limit the models
- ~158 hr of MAGIC obs, 3/4 of which is taken under moon
- MAGIC spectrum shows a cut-off at a few TeV
- If hadronic (and unless significant diffusion), **CasA is not a PeVatron**

Galactic: binaries

PSR J2032+4107

New binary in TeV range discovered through joint campaign of MAGIC & VERITAS
ApJL, 867 (2018) L19



(a) Full Dataset (b) Periastron

HESS J0632+057

Joined effort of H.E.S.S., MAGIC & VERITAS to publish last paper on this source with current generation of Cherenkov telescopes

LS I +61 303

20 hrs of data taken in 2018 within campaign with VERITAS and optical telescope Liverpool on La Palma

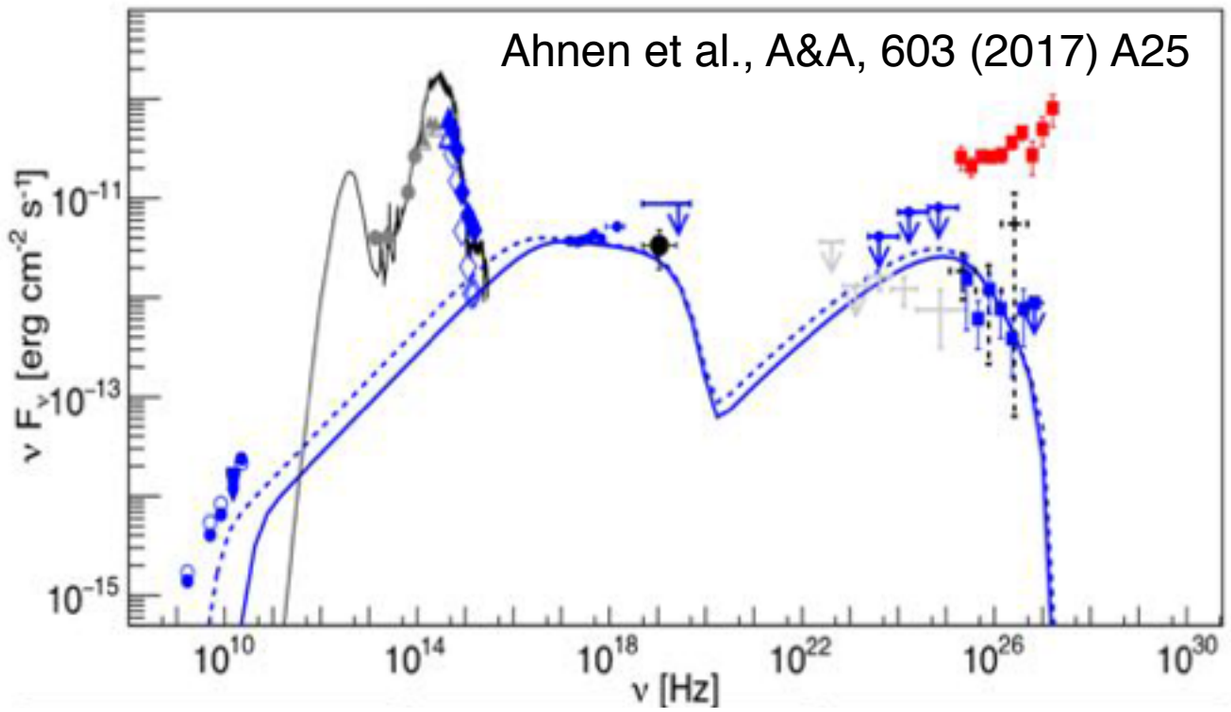
Others (CygX-1, V404 Cygni, SS433/W50,,,)

Extragalactic: Nearby AGNs

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

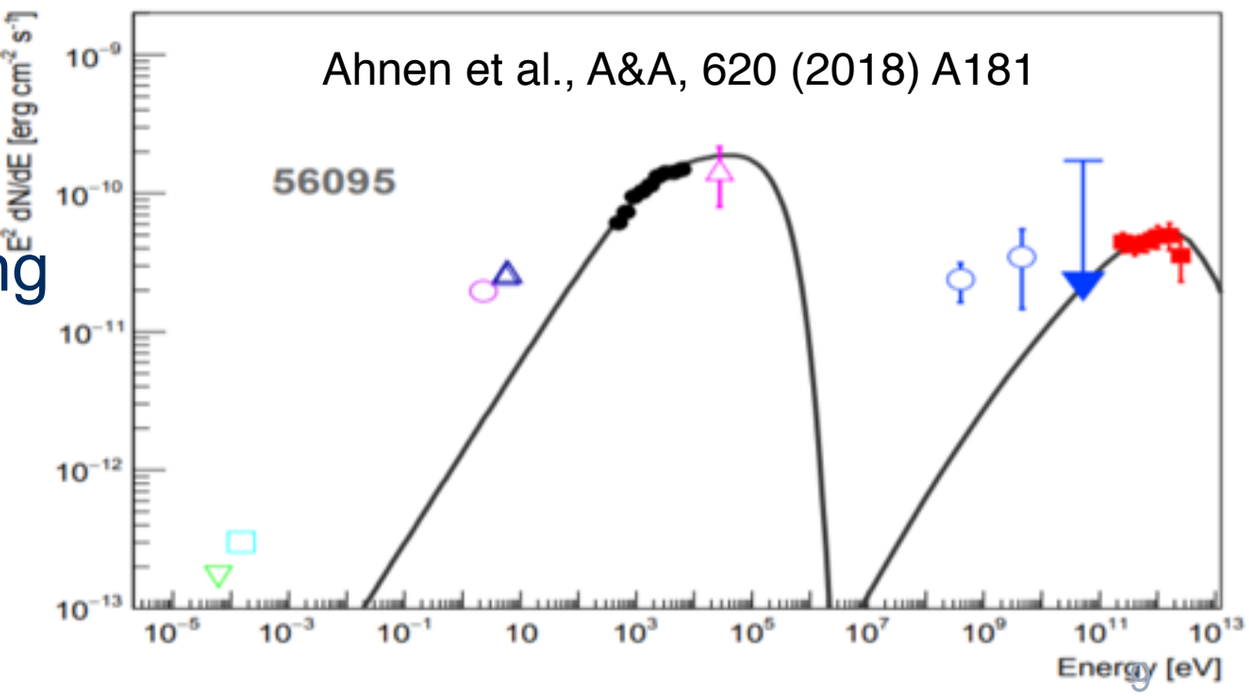
NGC1275 / IC310

- z = 0.017, 0.019
- MW studies of extremely fast variability in IC310 in 2014 =>
- NGC1275 also has day-scale variability in 2016-2017 data (A&A **617** (2018) A91)



Mrk421 / 501

- Well known HBL at z ~= 0.03
- Yearly monitoring campaigns
- Mrk501 2012: hard spectrum do not change with states, behaving as an extreme HBL
- 'Bump' in Mrk501 flare in 2014?



M87, NGC1068,,, stay tuned

Extragalactic: distant AGN

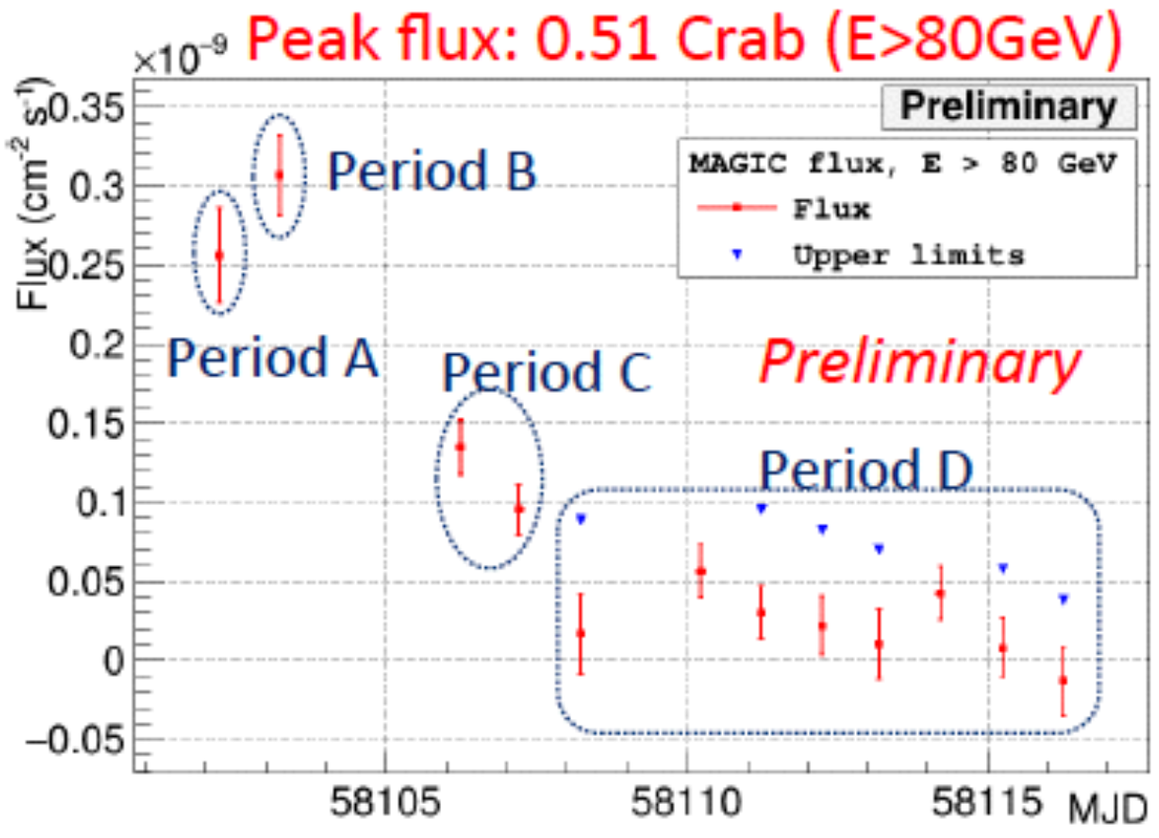
- Lowest possible energy threshold in VHE range less EBL, distant sources

- The farthest record so far: **B0218+35** flare detected 11.5 days after Fermi-LAT, which is well interpreted as a gravitational lensing
(Ahnen et al., A&A 595 (2016) A98)

- Recent news: **TON0599** as the 3rd farthest VHE source
(ATel #11061, Dec 2017)

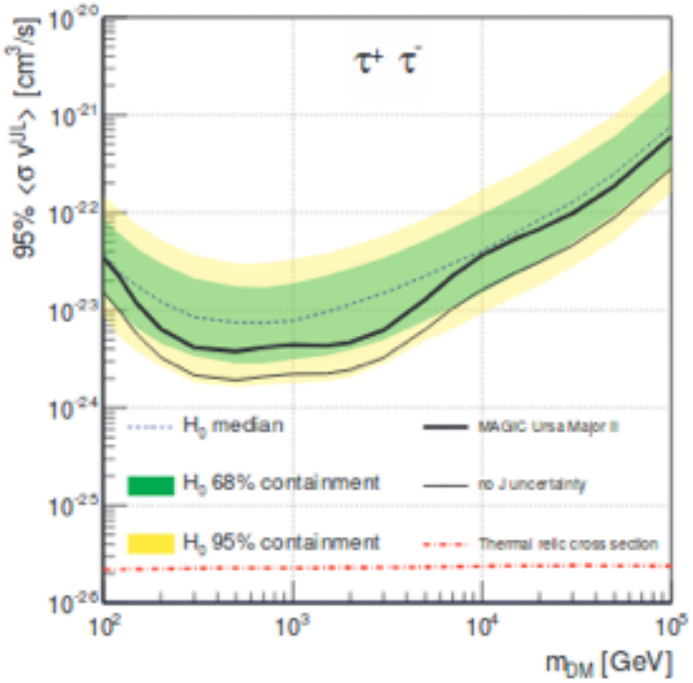
<u>Expanding the VHE horizon</u>

Blazar	Redshift	Discover	Year
B0218+35	**0.944**	**MAGIC**	2014
PKS 1441+25	**0.939**	**MAGIC**	2015
TON 599	0.725	**MAGIC**	2017
PKS 1424+240	>0.6	VERITAS	2009
3C 279	0.536	**MAGIC**	2006
1ES 0033+113	0.467	**MAGIC**	2016
PKS 1222+216 (4C +21.35)	0.432	**MAGIC**	2010

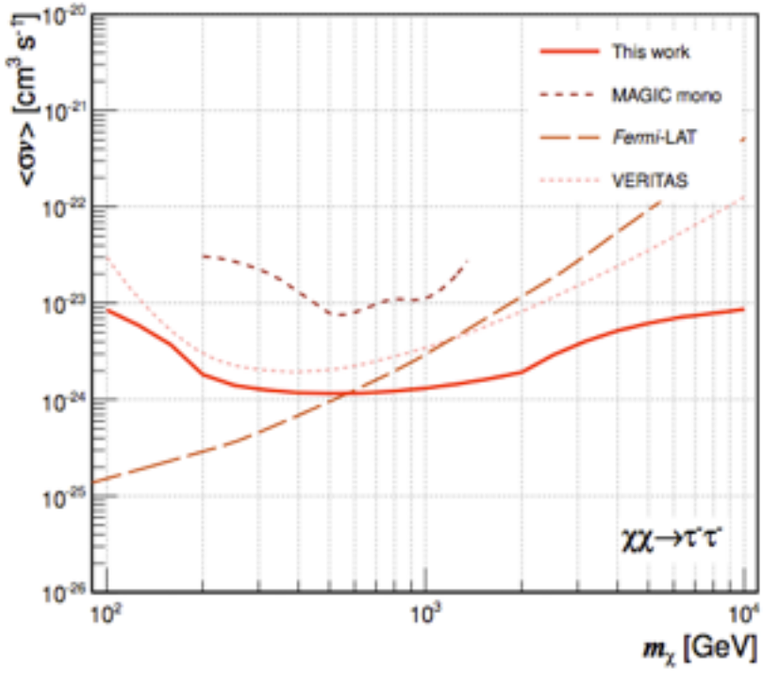


Fundamental physics

- Dark Matter search for annihilation signal
  - Galactic Dwarf
    Segue I
    Ursa Major II
    etc.
  - Galactic Center

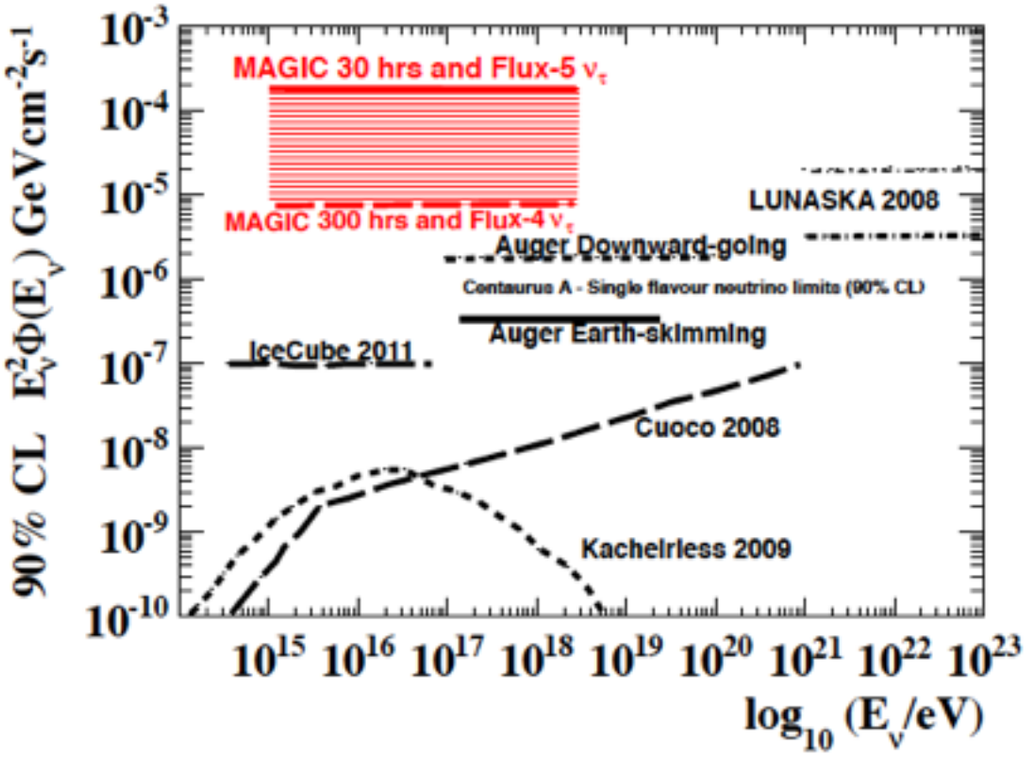


Aleksic et al. JCAP 03 (2018) 009



Ahnen et al. JCAP 02 (2014) 008

- Tau neutrinos
  Limits on flux (1 PeV - 3 EeV)
  (Astropart.Phys. 102 (2018) 77)
  - Observation for 31.5 hr directing to the sea



Transients

- Transients: new physics working group
- Strong relation with multi-messenger astronomy, as mostly triggered by other instruments
- multi-wavelength: Radio, optical, keV, MeV,,,
  - **GRB**
  - FRB
    (ULs on the repeating FRB 121102 (MAGIC Coll.,MNRAS **481** (2018) 2479))
  - Novae, etc.
- multi-messenger:
  Real time events were / will be automatically followed up
  - **IceCube/ANTARES HE neutrinos**
  - LIGO/Virgo gravitational waves
    (First IACT followup of GW151226. More to follow in the coming O3)

Transients / multi-messenger: *blazar TXS0506+056 (z=0.3365)*

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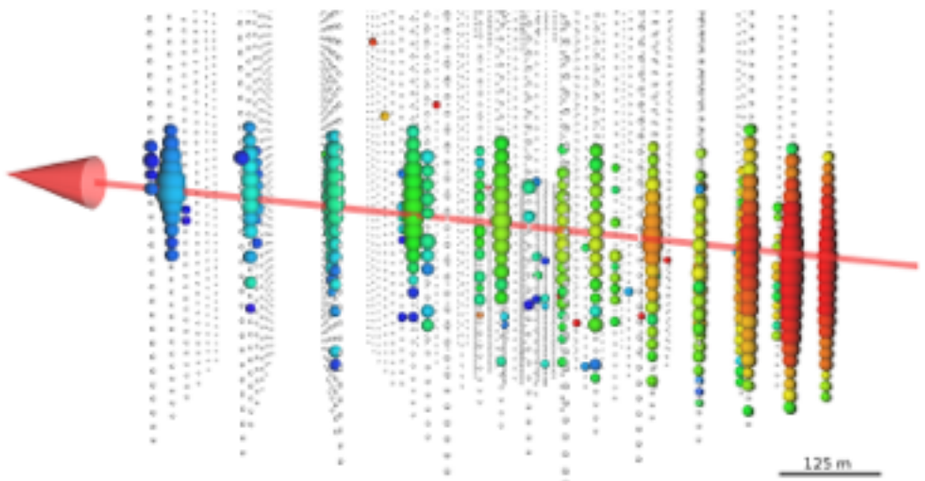
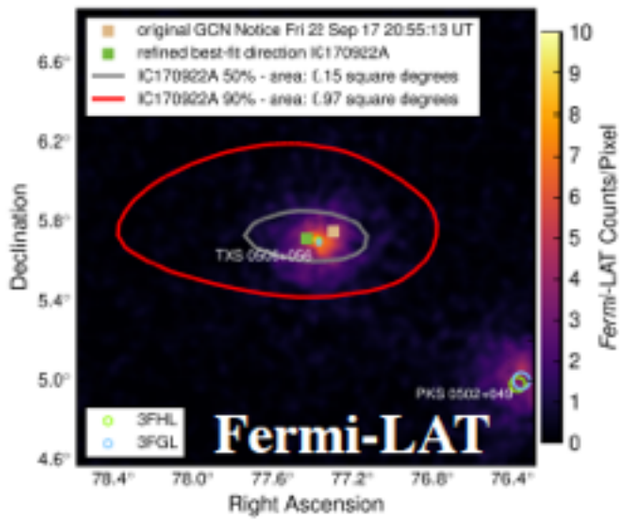
Gamma Imaging
Cerenkov Telescopes

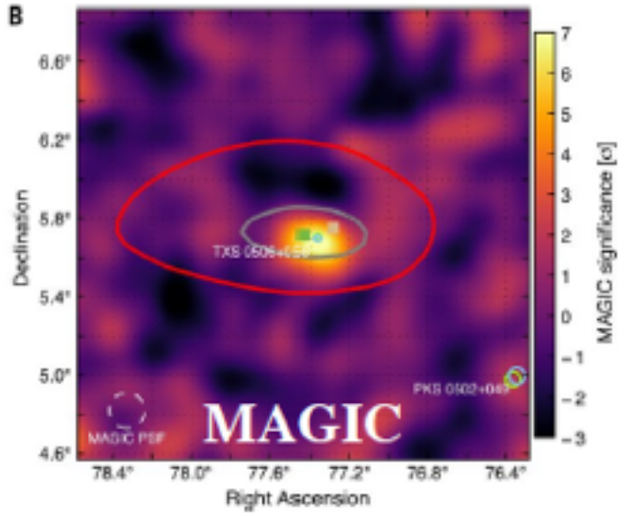
- flare coincident with IceCube event IC-170922A: highlight in 2018



P(astrophysical) ~56.5%

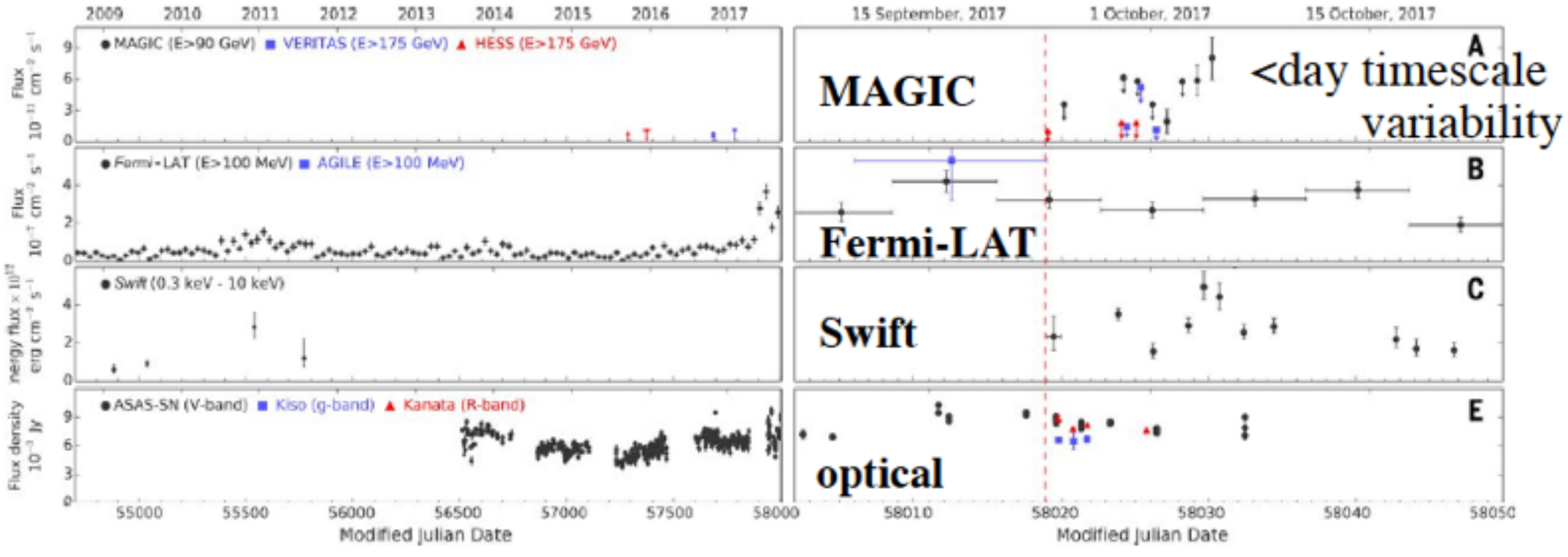
E_ν~290 TeV (183 TeV - 4.3 PeV 90% CL)





significance of association ~3σ

possible source of possible astrophysical high-energy neutrino



Science **361** (2018) eaat1378

TXS0506: MWL modeling

(MAGIC Coll., ApJ **863** (2018) L10)

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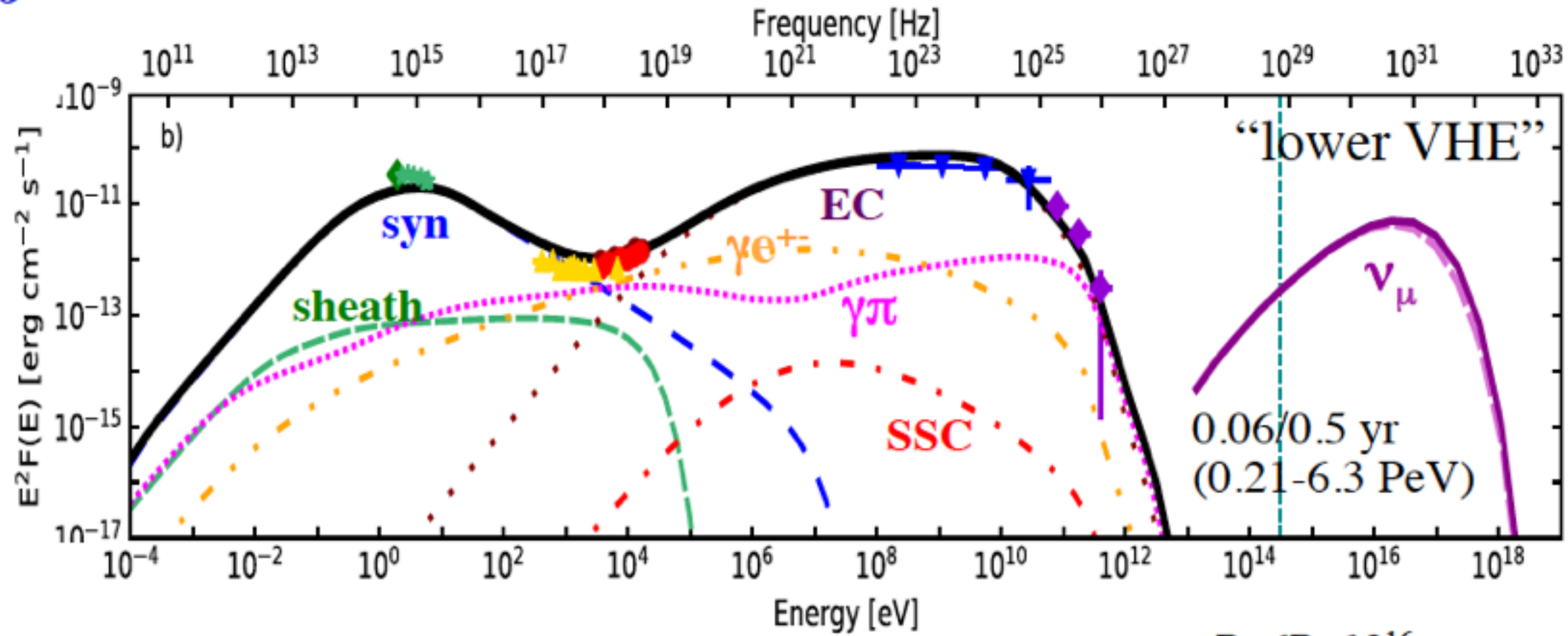
Gamma Imaging
Cerenkov Telescopes

jet-sheath model for electroweak emission



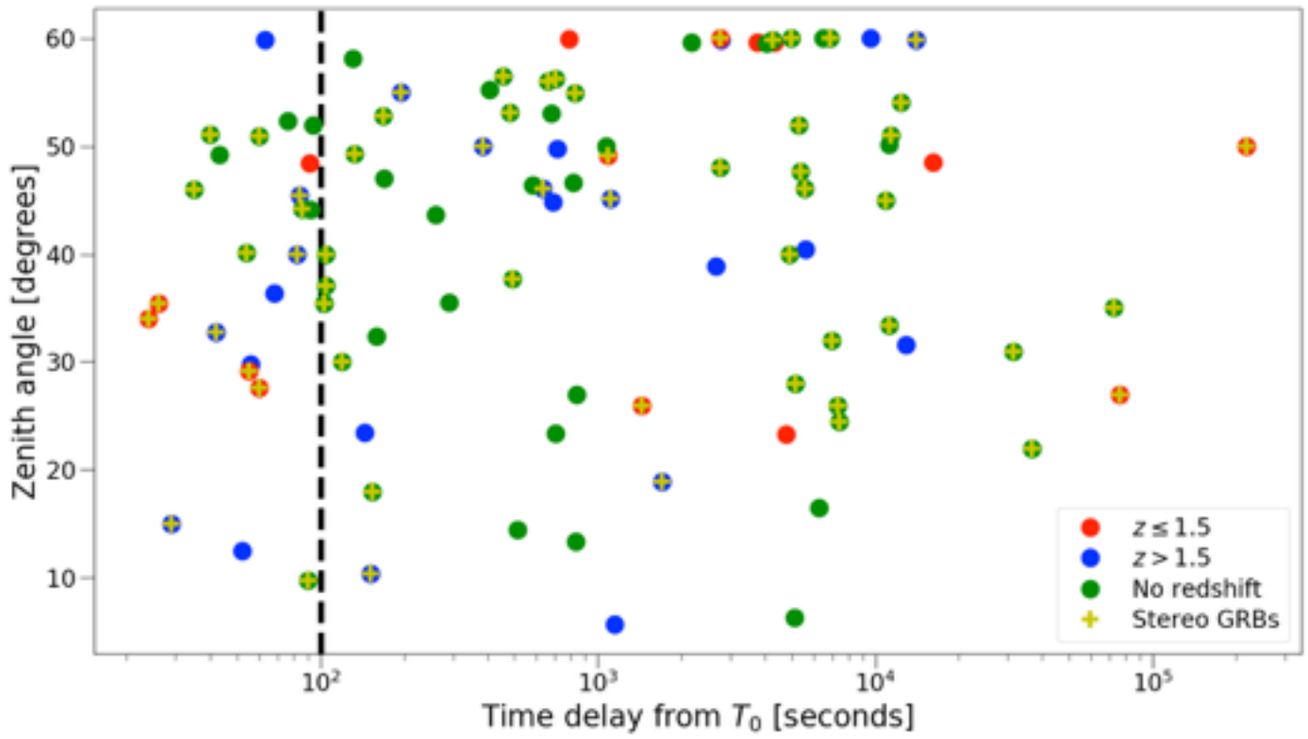
- large no. of parameters but reasonably constrained
- SED predominantly leptonic, γ-rays EC (not SSC)
- photopion+photopair cascade subdominant
  but non-negligible in X (+VHE)
  -> crucial constraint on proton population
- photopion efficiency $f_{p\gamma}(E_p \sim 6\ \mathrm{PeV}) \sim 10^{-4}$
  -> $\tau_{\gamma\gamma}(E_\gamma \sim 12\ \mathrm{GeV}) \sim 0.1$ -> $\tau_{\gamma\gamma}(E_\gamma \sim 100\ \mathrm{GeV}) \sim 1$
  consistent with observed GeV-TeV break

$R = dR = 10^{16}$ cm
$B = 2.6$ G
$\Gamma_j = 22$, $\Gamma_s = 2.2$
$\theta_v = 0.8°$ ($\delta_j = 40$)
$E'_{pmax} = 10^{16}$ eV
$L_e = 1.6 \times 10^{42}$ erg/s
$L_p = 3 \times 10^{45}$ erg/s(?)
($L_B = 1.2 \times 10^{45}$ erg/s)

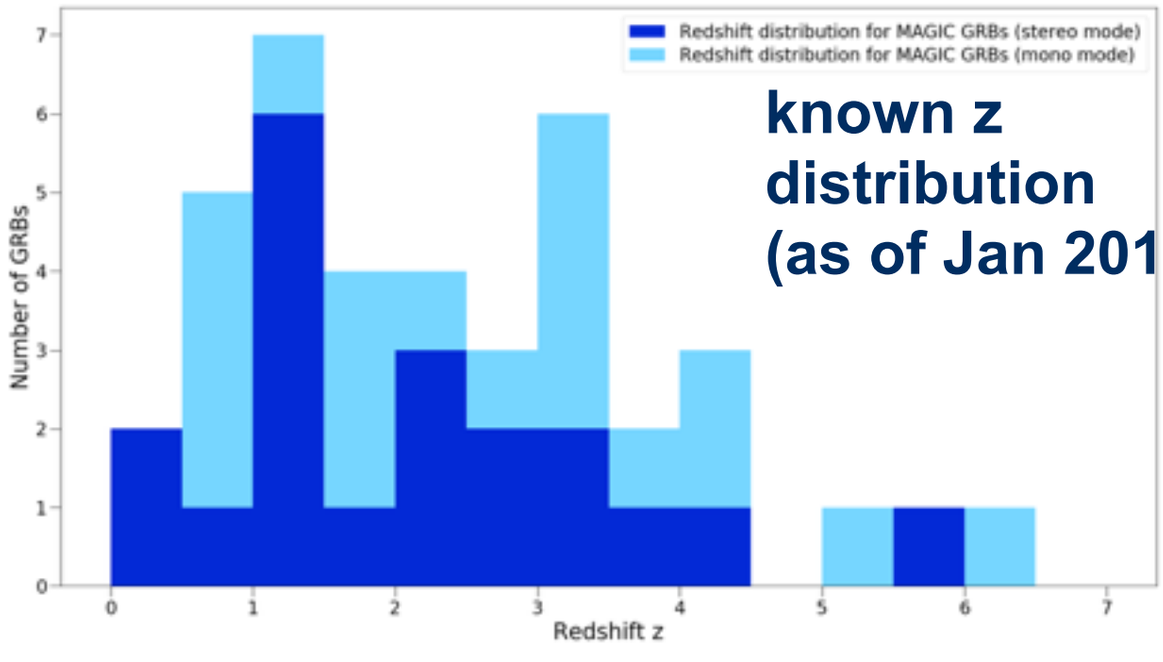
Inoue+

GRBs

- 107 GRBs observed since 2005 (not all analysed)
  - 25 with delay <100 s
  - out of which 16 stereo
  - out of which 5 known z <1.5
- Fastest: **24 s** of **160821B**, whose z known to be **0.16** (closest in MAGIC GRBs)
  - the second fastest is 26 s, but z = 1.3 (131030A)
  - the second closest z = 0.37 is 160623A, but delay ~7e4 s
- 3 more <100 s && z<1.5
  - z = 1.16 (130701A)
  - z = 1.32 (141220A)
  - **z = 0.42 (190114C!)**



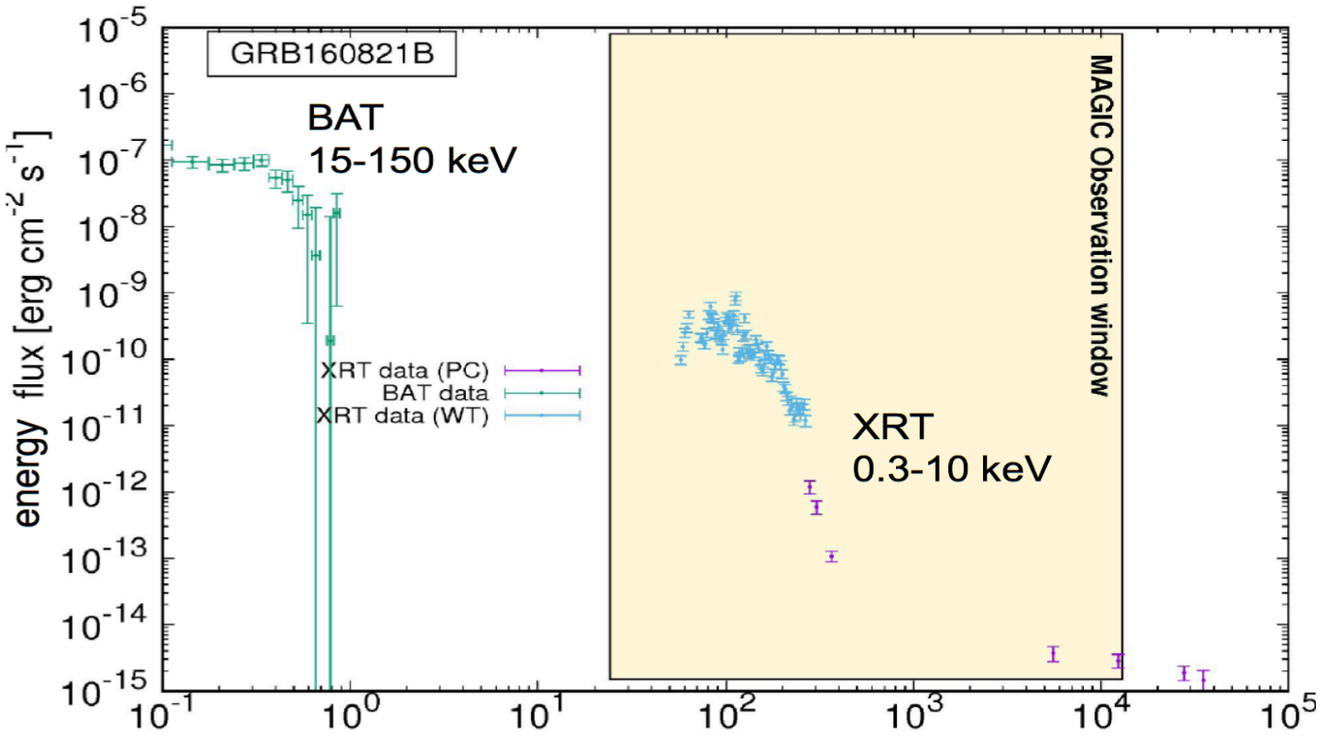
Delay vs. Zenith angle (as of Jan 2018)

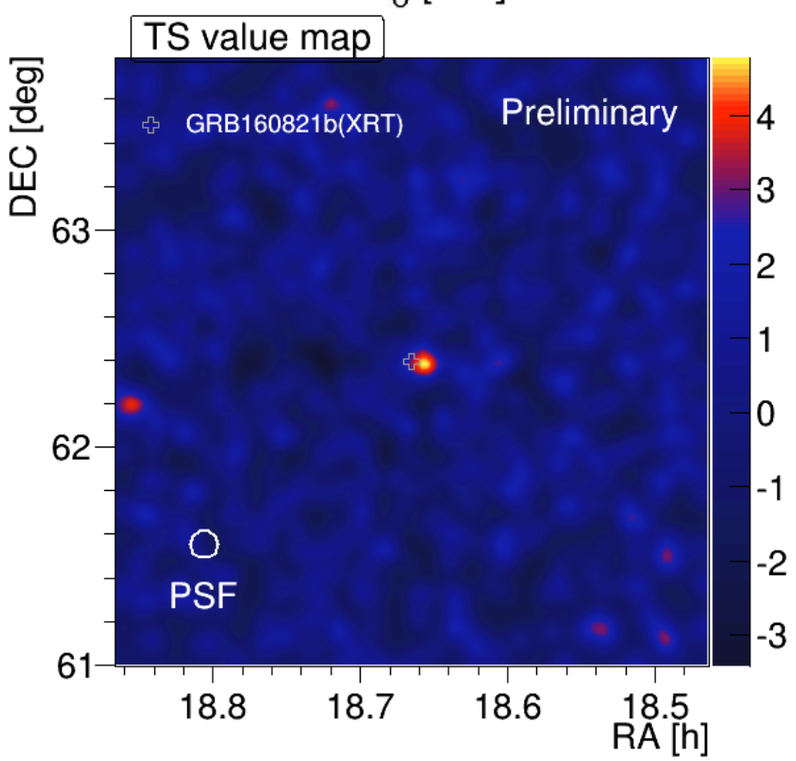


known z distribution (as of Jan 2018)

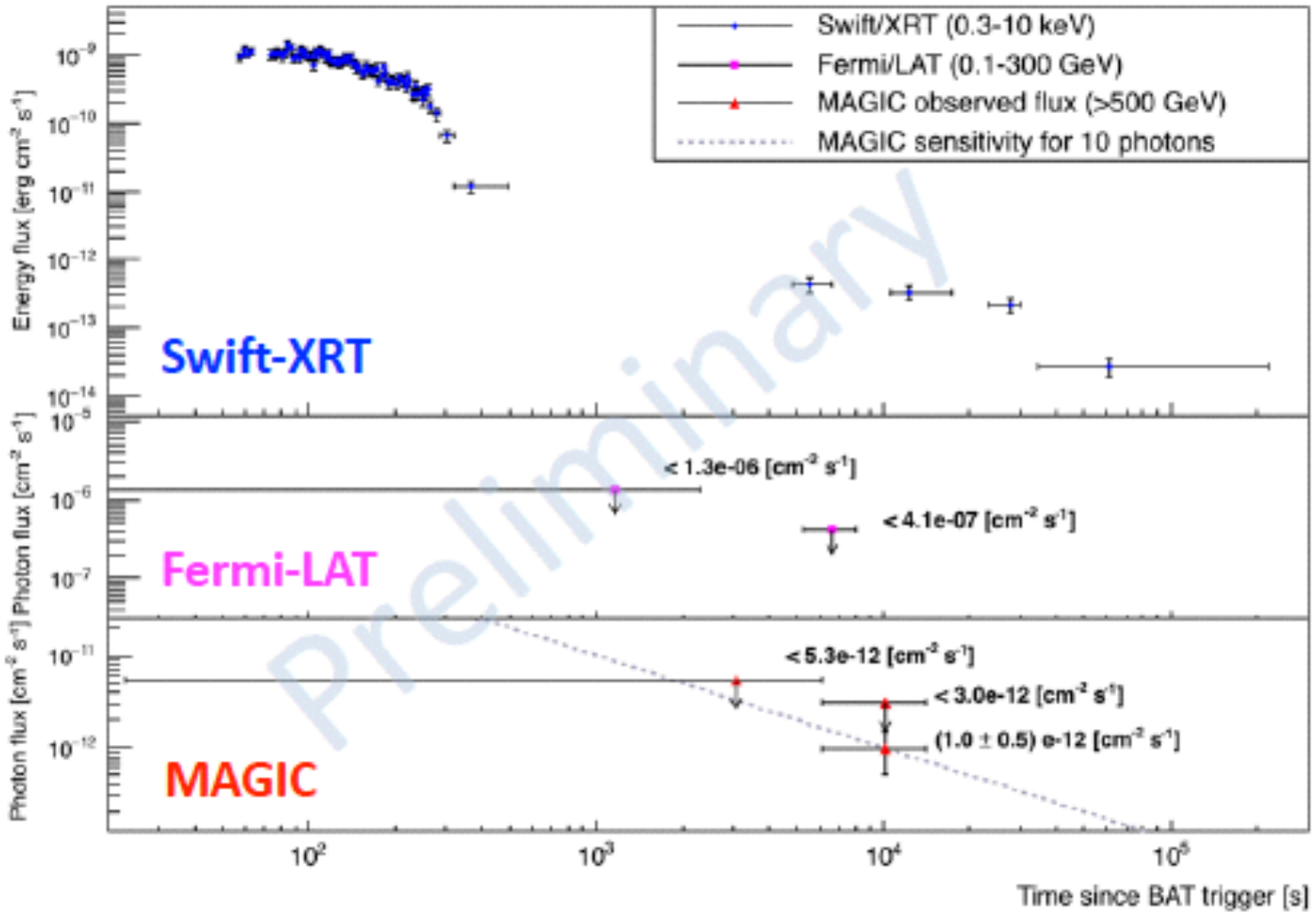
GRB 160821B

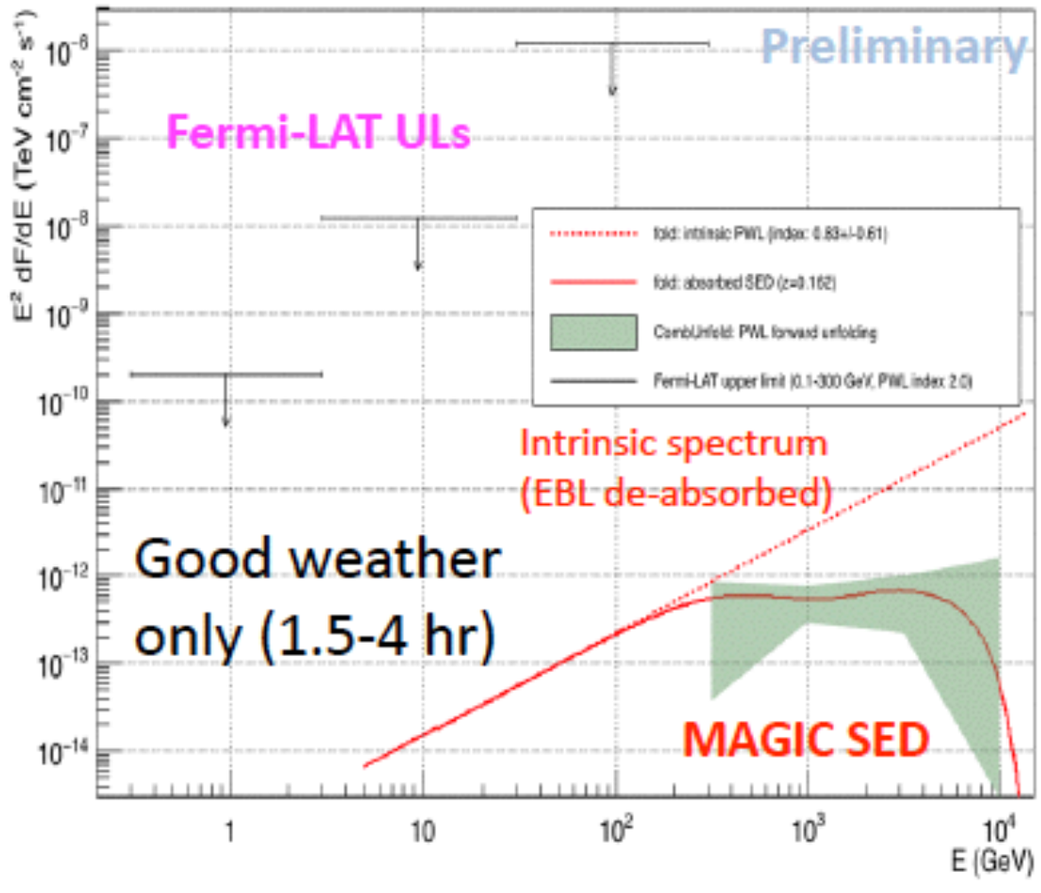
- Triggered by Swift-BAT
  T90 ~0.5 s **Short GRB**
- Swift-XRT:
  t < 300 s extended emission + steep decay, t < 30 ks plateau?
- MAGIC covered this period
  24 s - 4 hr (14.4 ks)
  - Bright moon, adverse weather
  - >4 (pre-trial), 3.1 sigma (post-trial) **hint of detection** in >600-800 GeV
  - No candidate source around
  - No detection ~1 yr later (not steady)
- No detection by Fermi-LAT.
  Kilonova hint by HST (Tanvir+, in prep)
  Optical: NOT, WHT (z=0.16), GTC, MASTER, UVOT. Radio: VLA, AMI





Lightcurve and SED

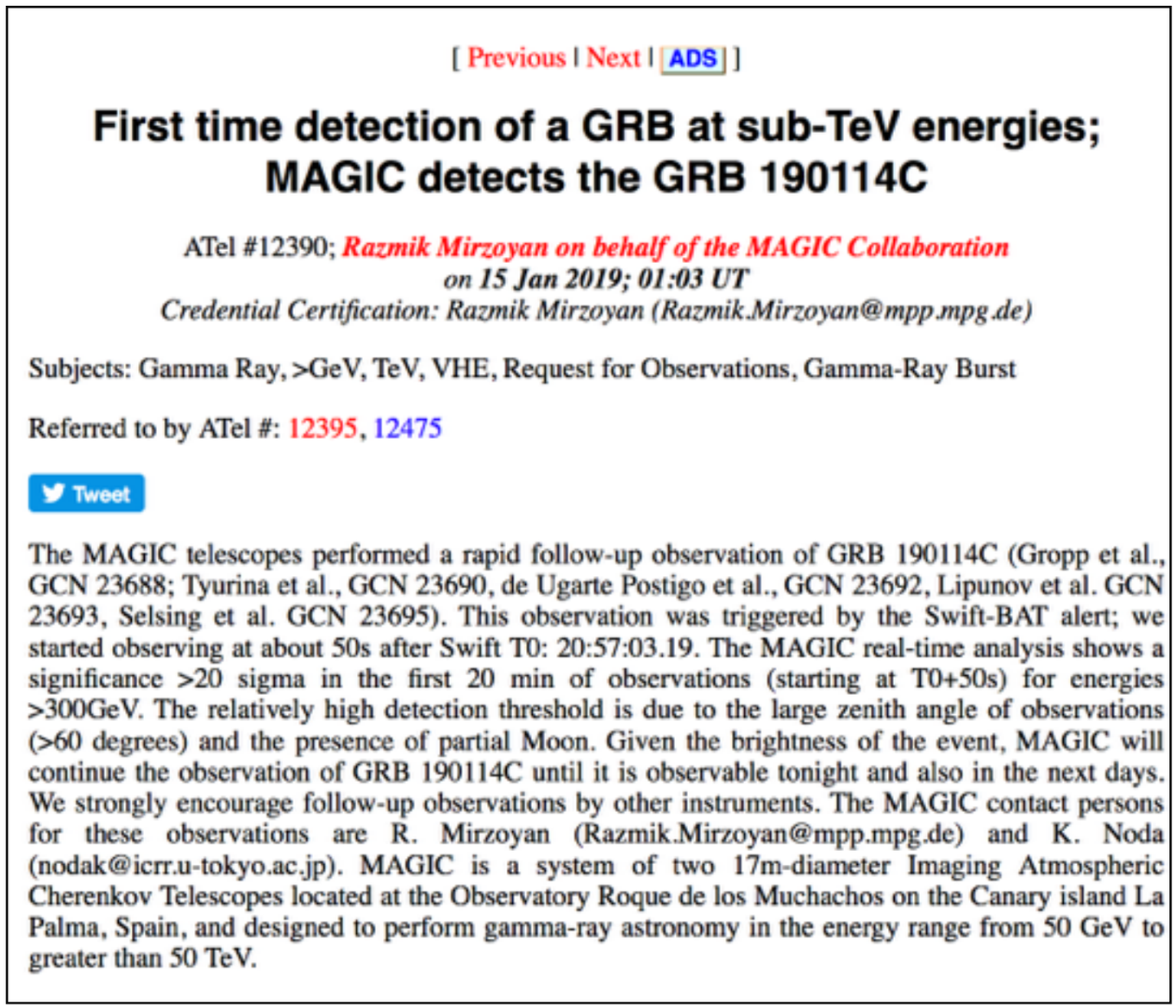




- MAGIC and LAT points are compatible with a relatively flat LC, coinciding with a possible X-ray shallow decay
- EBL de-absorbed intrinsic spectrum is still acceptable but hard.
- Modelling ongoing by Inoue et al.

GRB 190114C: First IACT GRB

- Long GRB with T90 = 361 s triggered by Swift-BAT "very bright" "half 130427A"
- The 3rd closest (z=0.42) in MAGIC GRBs
- Not the fastest (~50 s) but within the prompt phase
- Zenith angle from 55 deg (mostly >60 deg)
- Under moon (again!)
- **First clear detection of a GRB in VHE regime**
  - ">20 sigma in the first 20 min for >300 GeV"...
  - I was the on-call burst advocate, and I am analysing the data
- Big efforts ongoing. Stay tuned!



[Previous | Next | ADS]

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

Tweet

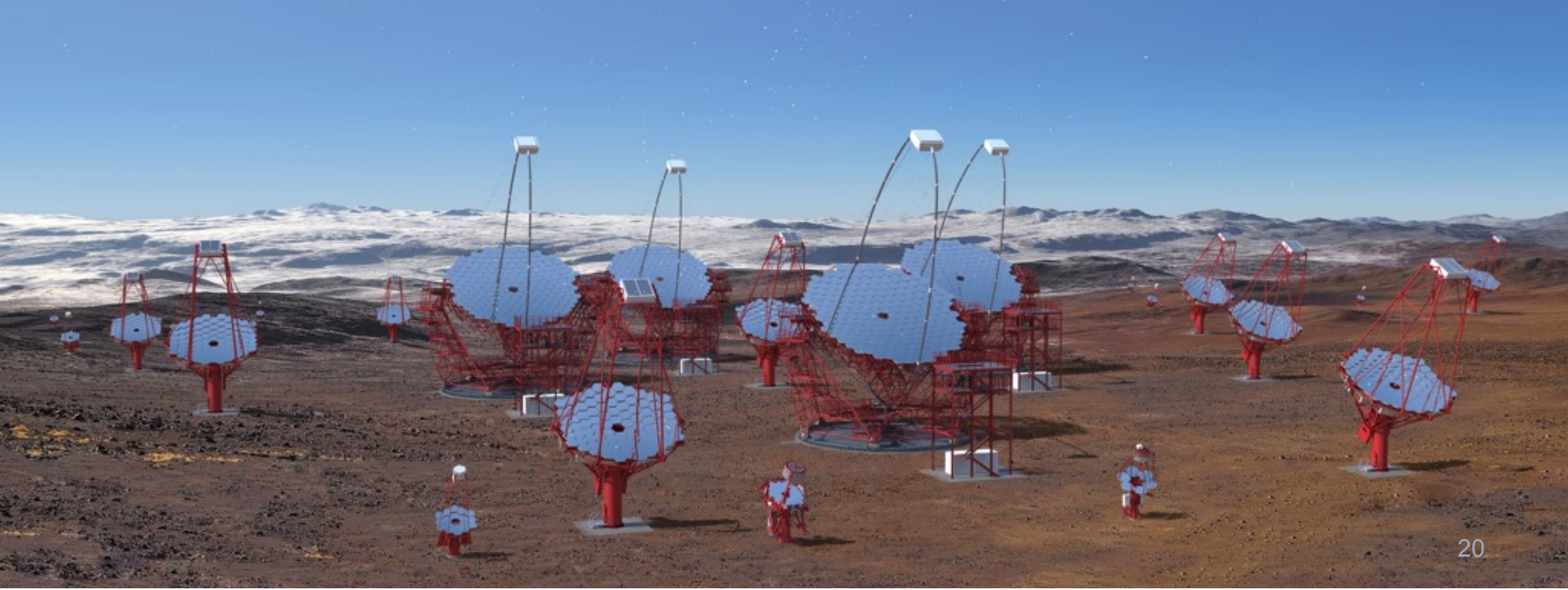
The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about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

ATel #12390 (and also GCN #23701)

CTA LST

Cherenkov Telescope Array

- 1451 members from 203 institutes in 31 countries
- Two observatory sites (in the northern and southern hemispheres)
- >100 IACTs in total, 3 sizes of telescopes
- x~10 higher sensitivity, x~10 wider energy range
  x~2 angular resolution



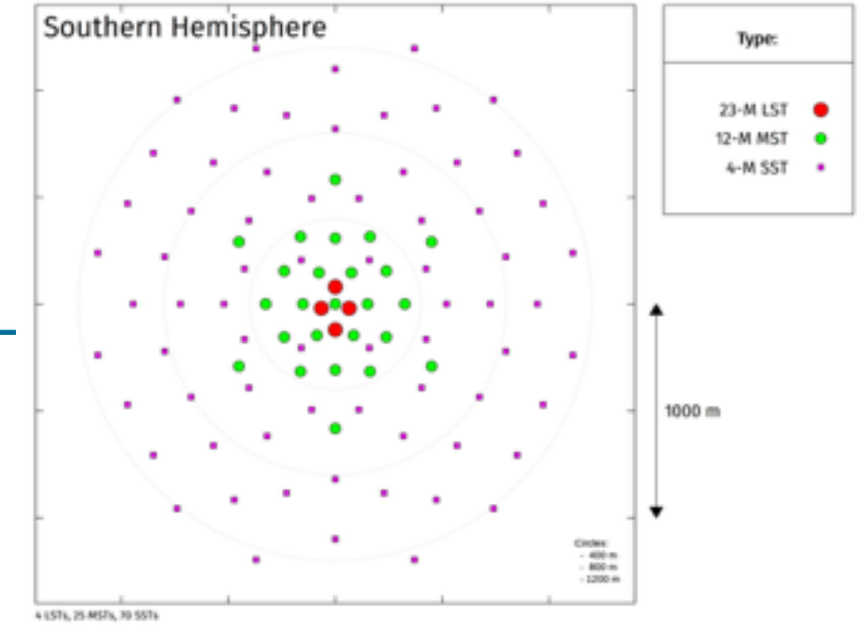
CTA sites

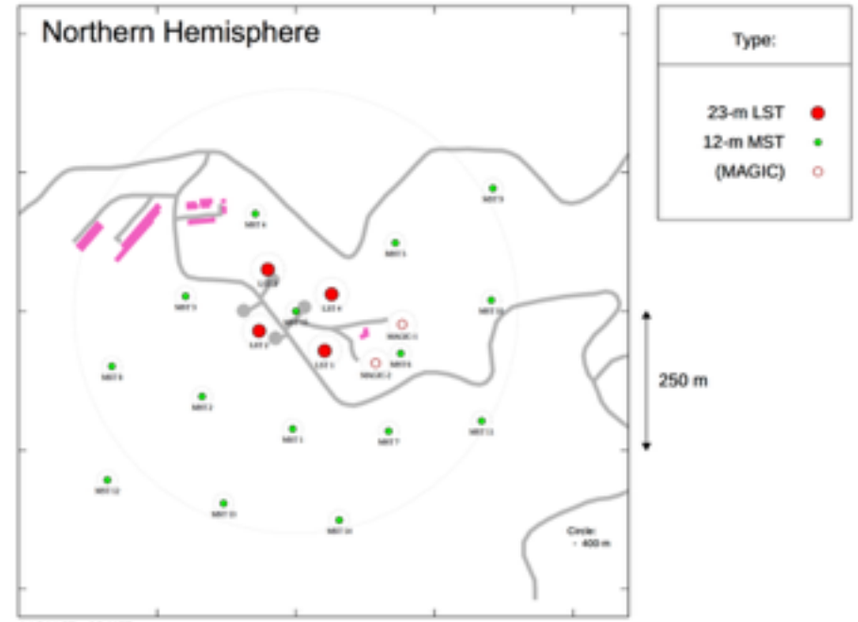
- North site
  Observatorio del Roque de los Muchachos
  La Palma Island, Canaries, Spain
  2200 m a.s.l.
  <u>Same as MAGIC</u>
- South site
  <10 km from the ESO Paranal Observatory in Atacama, Chile
  (host agreement signed)

- Headquarter in Bologna, Italy (partially in Heidelberg, Germany)
- Science Data Management Centre in DESY Zeuthen, Germany

Telescopes

- **Large Sized Telescopes**: 4 (N), 4 (S)
  23 m in diameter, FoV 4.3 deg,
  20 GeV - >150 GeV
- Medium Sized Telescopes: 15 (N), 25 (S)
  11.5 m in diameter, FoV 7.5-7.7 deg,
  <150 GeV - >5 TeV
- Small Sized Telescopes: 0 (N), 70 (S)
  covered by Akira
  4.0-4.2 m, FoV 8.3 - 10.5 deg,
  <5 TeV - 300 TeV





LST

23 m Φ, FoV 4.3 deg, mirror effective area 370 m^2, Focal length 28 m, 0.11 deg / pixel, 1855 pixels, moving weight ~110 t, fast slewing 180 deg / 20 sec

Mechanics

Optics

Foundation

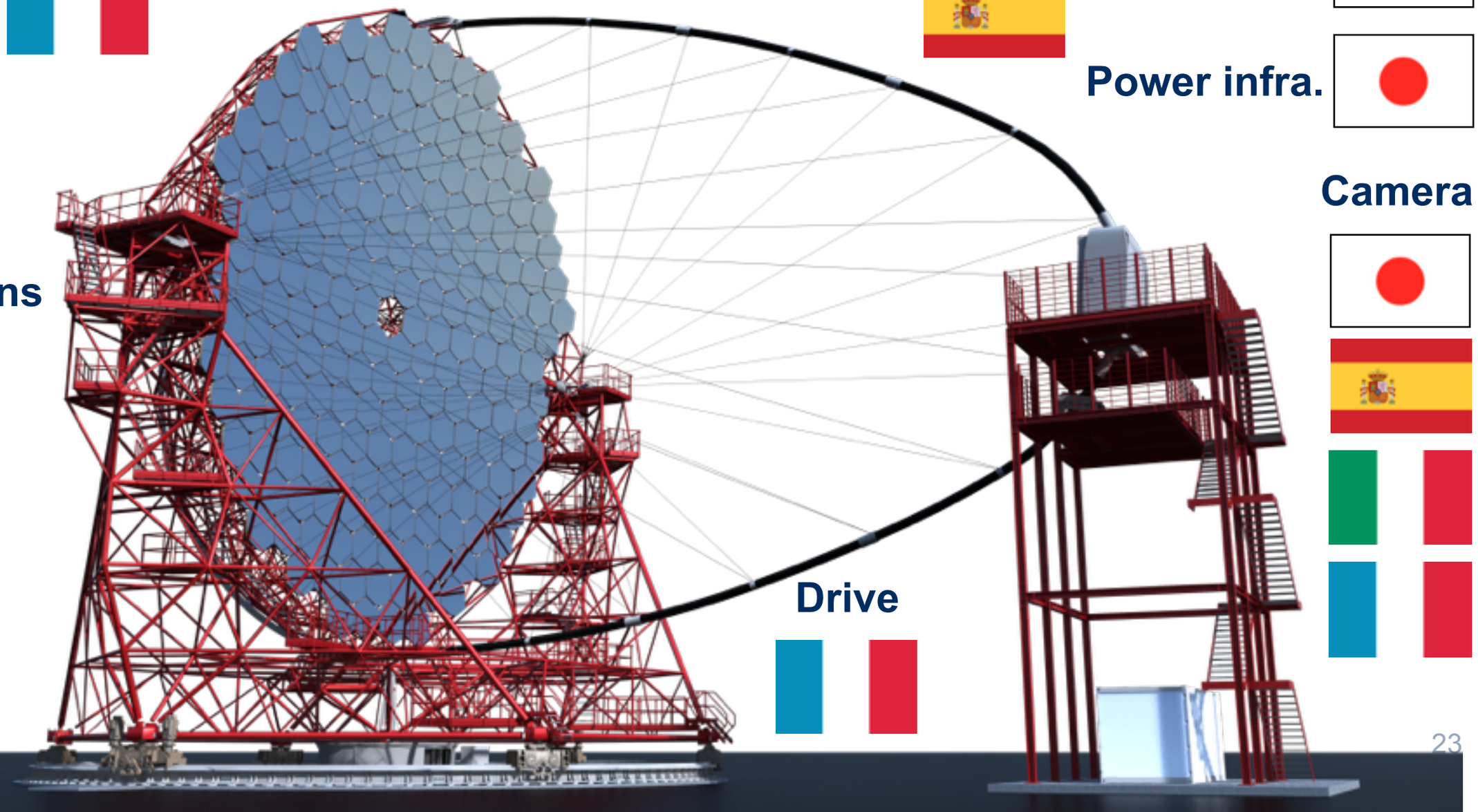
IT infra.

Power infra.

Camera

Calibrations

Drive



LST Collaboration >200 people, 10 countries

Version 7.10

Steering Committee:
DE: **T. Schweizer** | *ES:* **M. Martinez (chair)** | *FR:* **J.-P. Lees** | *JP:* **H. Kubo** | *IT:* **N. Giglietto** | *IAC:* **M. Vazquez Acosta** | *Ex Officio:* **M. Teshima** | *Ex Officio:* **J. Cortina** | *Ex Officio:* **D. Mazin**

LST EXECUTIVE BOARD

LST Project Office

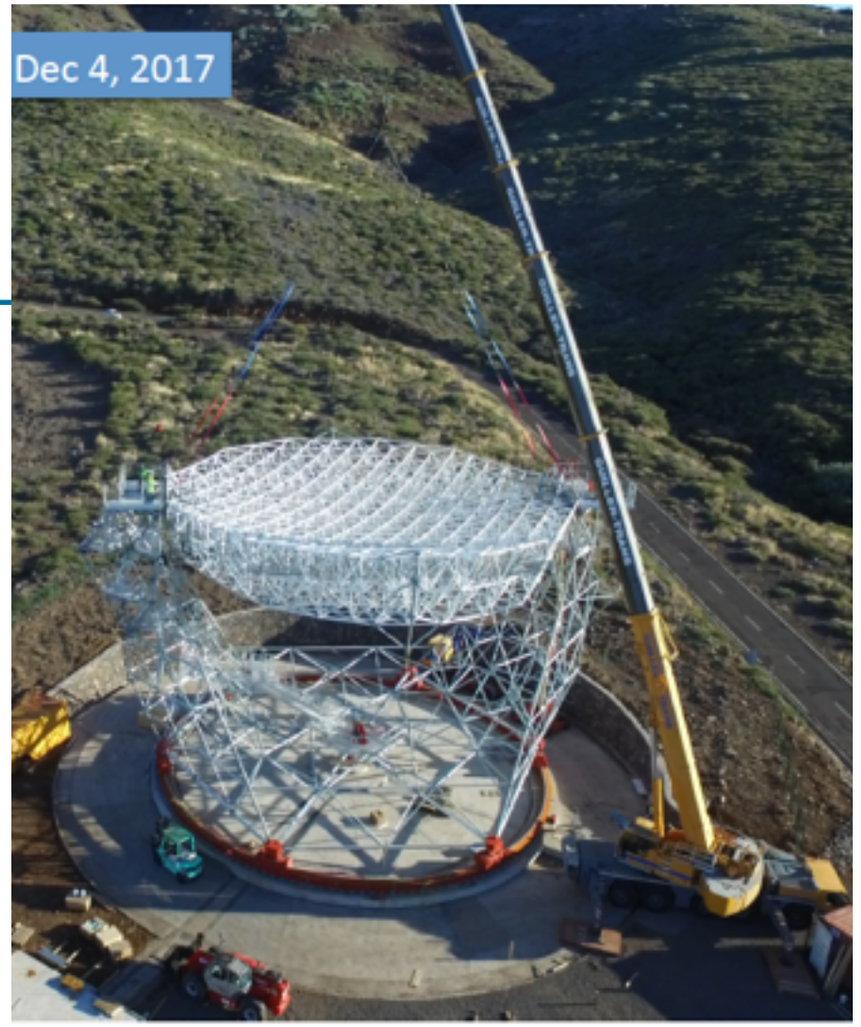
- *QA/RAMS:* **J. M. Miranda**
- *Systems Engineer:* **O. Ballester**
- *Telescope Manager:* **P. Marquez**
- *Principal Investigators:* **M. Teshima / J. Cortina**
- *Project Manager:* **D. Mazin**, Deputy: **NN**

prototype only

- *Site / INFRA* — Crd.: **J. Cortina**, Dep. **J. Herrera**
  - *Geological survey*
  - *Concrete foundation*
  - *Power / Network*
- *Data Analysis Software* — Crd.: **A. Moralejo**, Dep. **R. Lopez Coto**
  - *MonteCarlo*
  - *Data manage-ment*
  - *Data analysis*
- *Mechanical System* — Crd: **T. Schweizer**, Dep. **H. Wetteskind**, Struct. Eng.: **J. Eder**
  - *Dish&Lower Structure* — **H. Wetteskind**
  - *Camera Support Structure* — **G. Deleglise**
  - *Foundation, Rails & Bogies* — **J. Mundet**
  - *Structural Verification* — **J. Eder**
- *Optical System* — Crd. **K. Noda**, Dep.: **M. Teshima**
  - *Primary Mirror* — **T. Inada**
  - *AMC* — **M. Chikawa**, **S. Fukami**
- *Camera Integration* — Crd.: **O. Blanch**, Deputy: **C. Delgado**, Prod.: **C. Diaz**
  - *Mechanics & Cooling* — **C. Diaz**
  - *Slow Control* — **J. Prast**
  - *DAQ* — **T. Saito**, **D. Hoffmann**
- *FPI / Electronics* — Crd.: **H. Kubo**, Dep.: **R. Paoletti**, Prod.: **T. Saito**
  - *Photo-detectors* — **T. Yamamoto**
  - *Readout* — **H. Kubo**
  - *Trigger* — **G. Martínez**
  - *Light Guide* — **A. Okumura**
- *Auxiliary systems* — Crd.: **A. Fiasson**, Prod.: **E. Chabanne**
  - *Drive Control System* — **I. Monteiro**
  - *Global monitoring* — **T. Le Flour**
  - *Pointing Calibration* — **K. Noda**
  - *Camera Calibration* — **P. Majumdar**
  - *Power Distribution* — **M. Teshima**
- *R&D – Cam. SiPM* — Crd.: **R. Rando**, Prod: **S.Rosier-Lees**
  - *Photo-detectors* — **G. Ambrosi**
  - *Readout* — **R. Hermel**
  - *Integration with PMT Camera* — **D. Mazin**
- *Interfaces and Integration*
  - *ACTL* — **T. Le Flour**, **K. Noda**
  - *Data* — **NN**
  - *Site / INFRA* — **J. Cortina**
  - *Common Test Facilities* — **M. Doro**
  - *MAGIC* — **O. Blanch**

Mechanics, optics (a movie later)

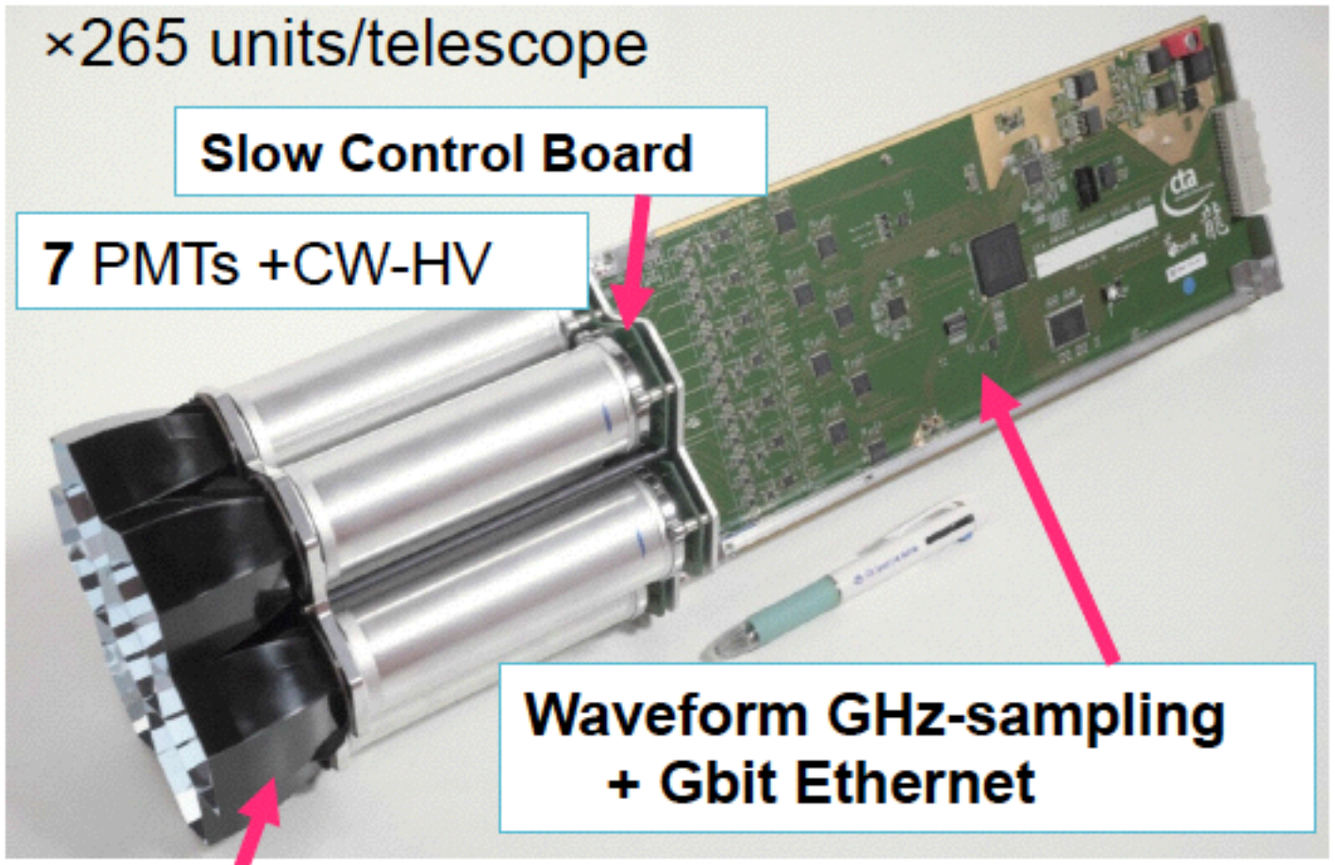
After the long delay of the construction permission



April 26 April 28 May 4 May 10 May 15 2018

Aug 11 2018

Camera assembly



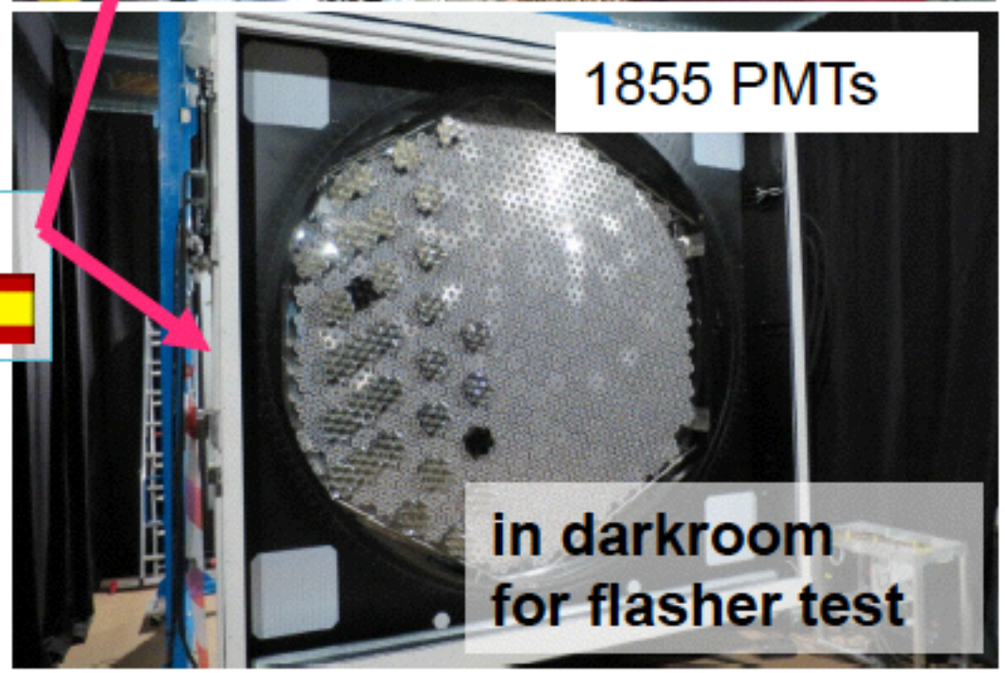
Light Guide

The design was changed from ESR reflective film to direct coating to plastic cone. Mass production was done in Q2 2018.

Integration & Test

@IFAE(Barcelona) in Apr. to Jul.

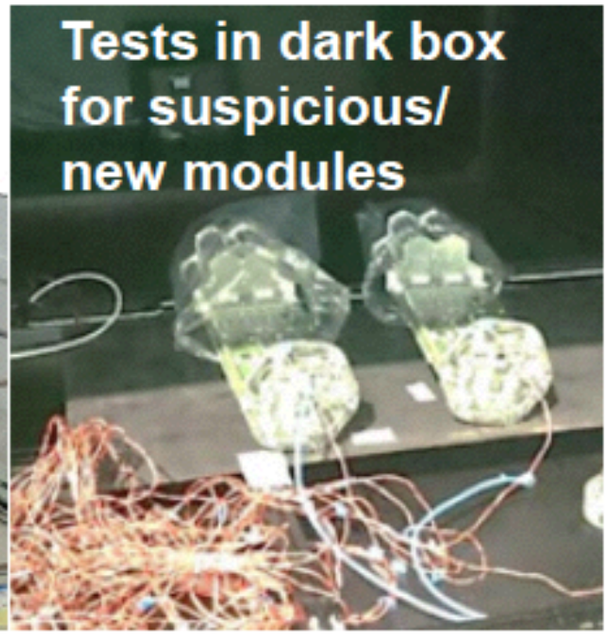
Camera body

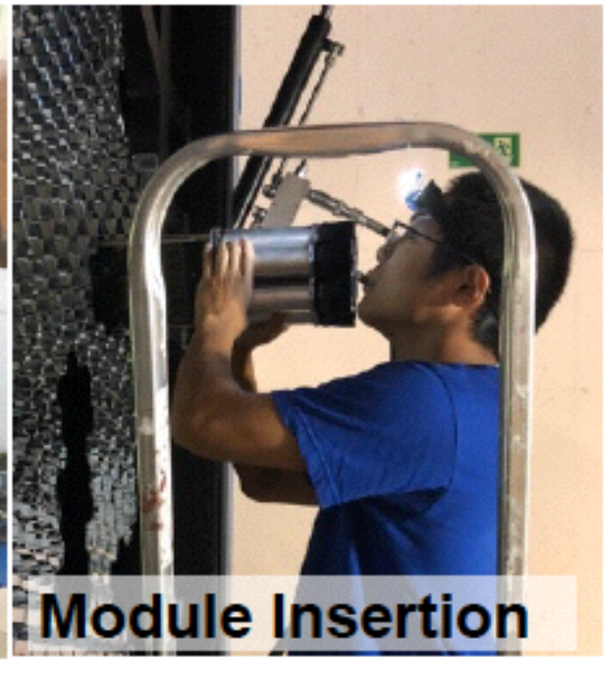


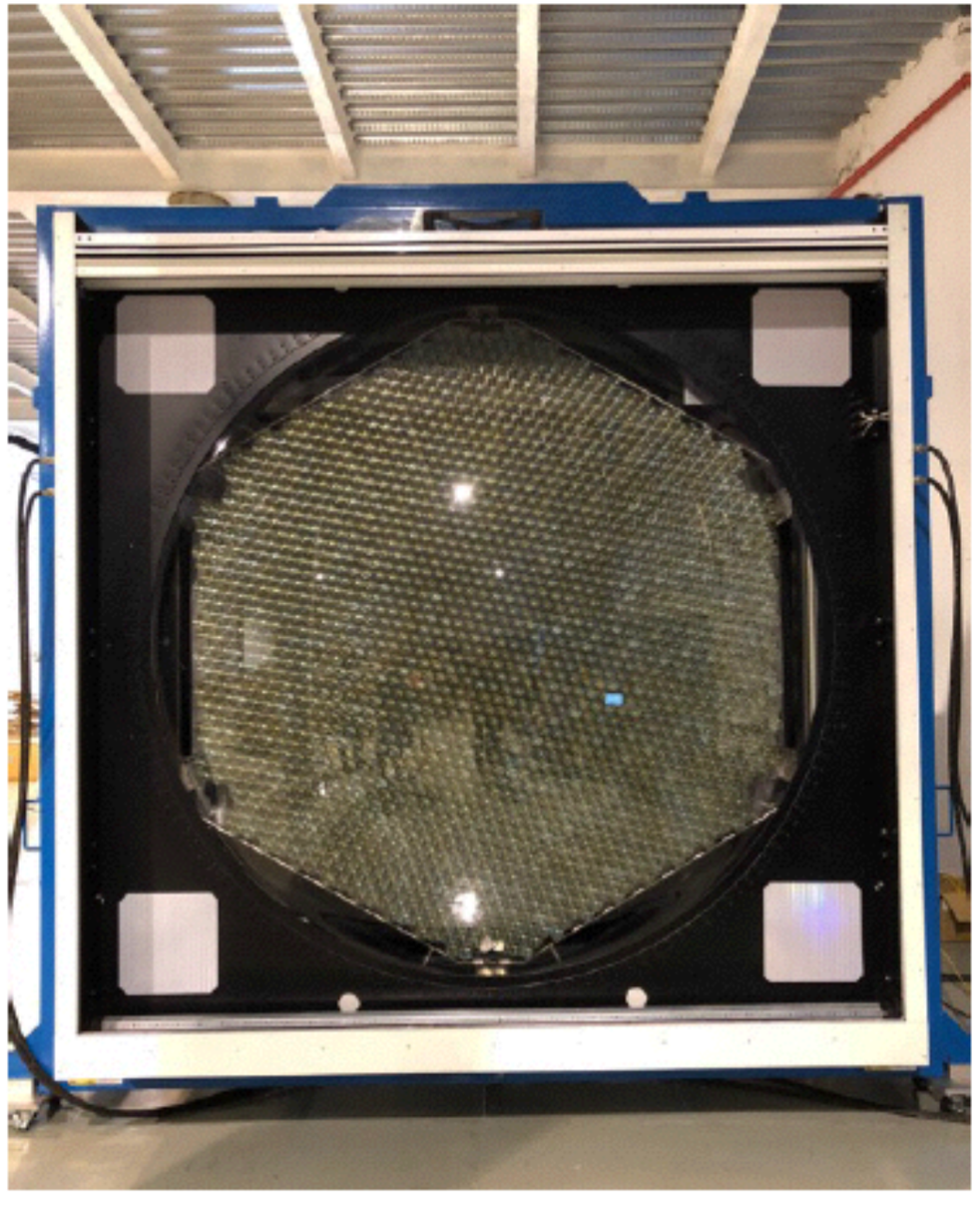
After tests, PMT-modules were removed from the body for shipping to La Palma.

LST-1 Camera

Integration and Tests at La Palma in Aug. to Sep.







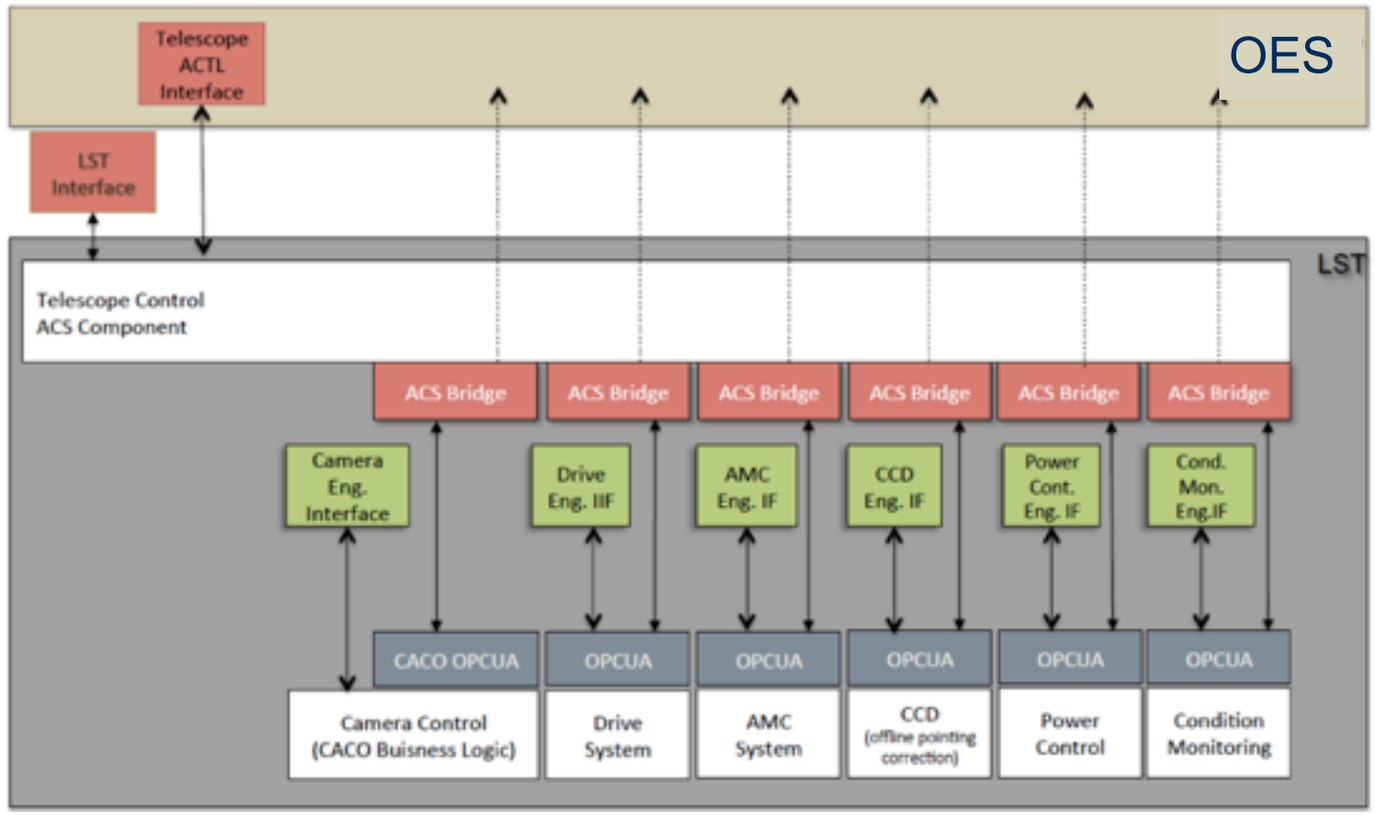
Finally perfect camera completed!

In collaboration with Spanish and French groups

Software (Slow control, analysis,,,)

Slow Control

- Subsystems OPCUA to communicate with higher
- Telescope Control Unit to control the subsystems and to talk to Observation Execution System (OES), in ALMA Common Software (ACS), based on CORBA



DAQ, on-/off-line analyses

- LST has the high data rate => 3 GB / s in total from the north site
- Significant data reduction (~1/10) required, for the fast calibration and reconstruction, and the data transfer to outside the island

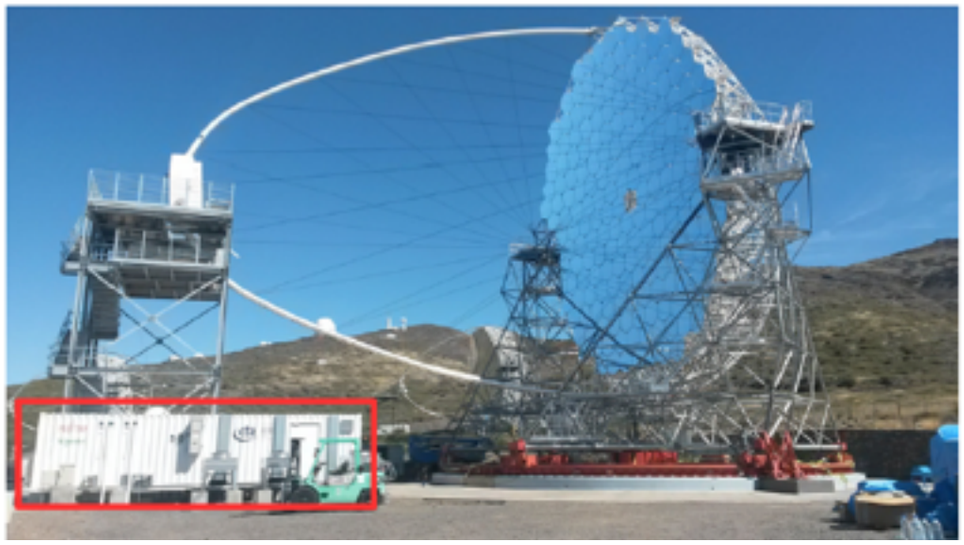
Compliant with the whole CTA array concept

We need a high computing power on site

IT & power infra (by Japan)

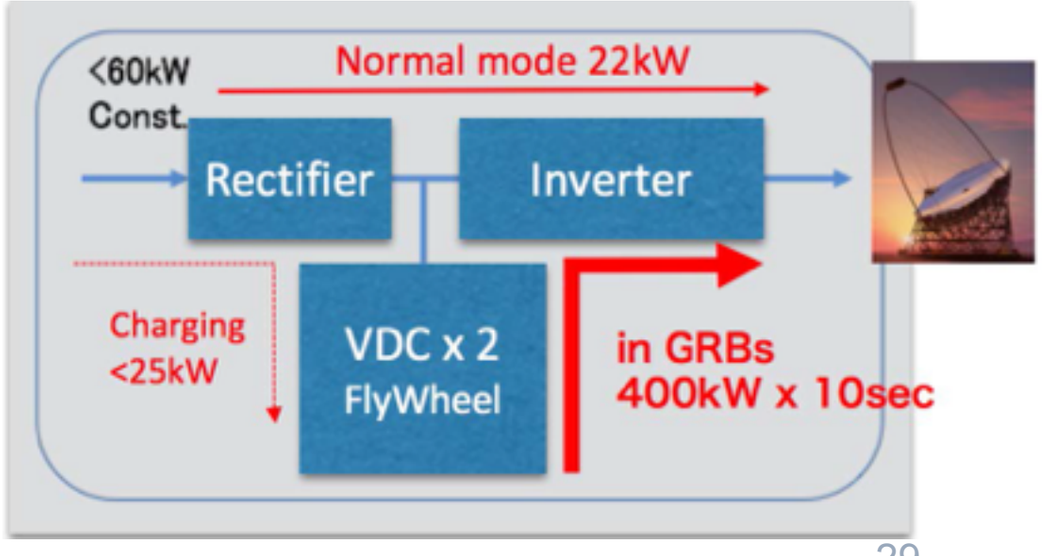
Onsite data center for North site (not only for LST)

- Infrastructure & components provided by Fujitsu
  - Infiniband & Ethernet network configurations
  - 2000 CPU cores
  - 3.4 PB of disk space
  - Nexus 9508 Router
  - Lustre file system
  - SLURM batch system



Power supply system for the LST fast rotation Each LST has a special UPS

Instead of batteries, the system has two flywheels to store the energy



LST-1 construction movie

LST1 Inauguration

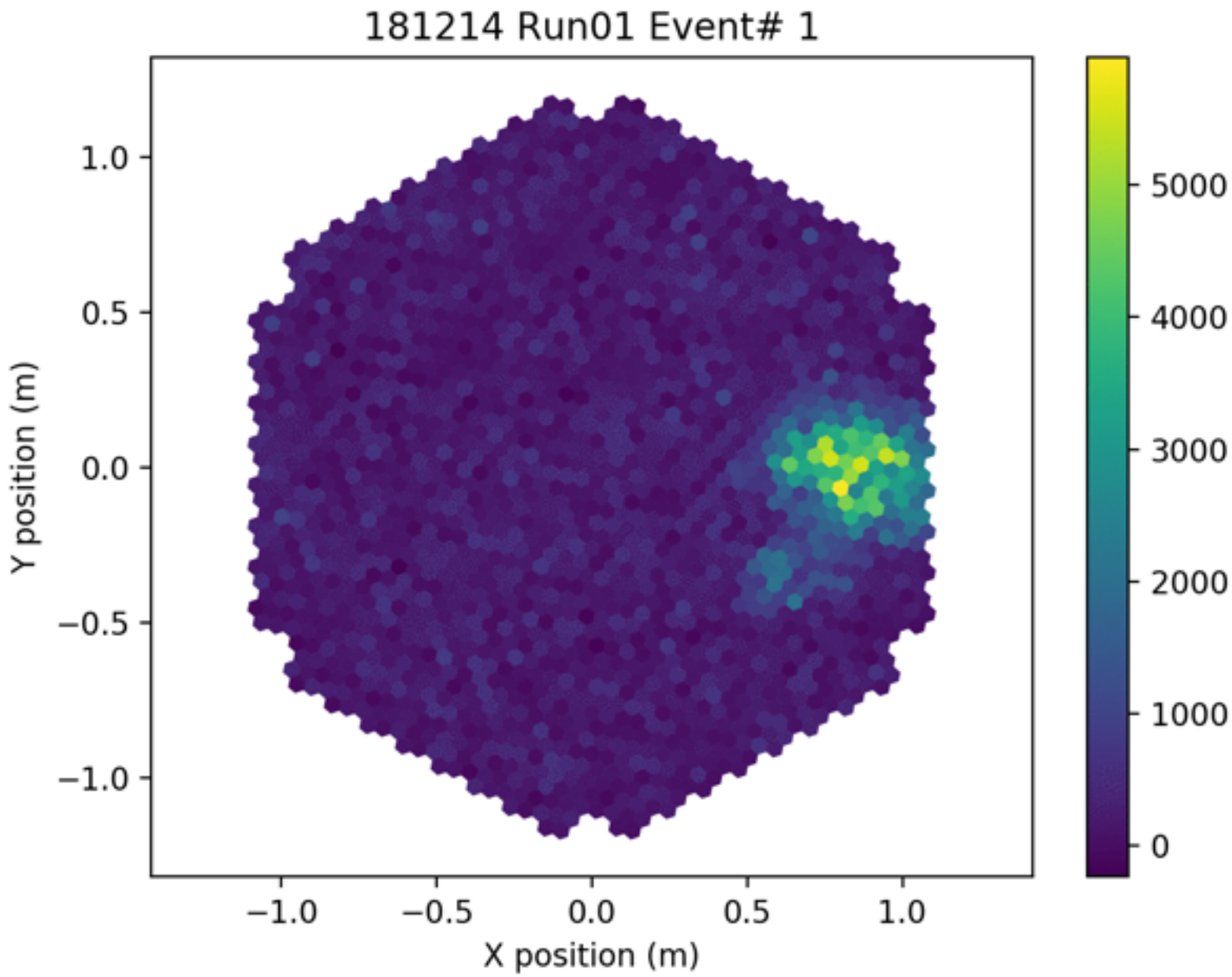
- 10 Oct 2018
- Press release from ICRR, U. Tokyo
- Followed by news articles

Director ICRR, U. Tokyo
Prof. Takaaki Kajita

CTAO director
Prof. Federico Ferrini
Vice president U.Tokyo
Prof. Masashi Haneda
Minister of Science in Spain
Pedro Duque
LST PI
Prof. Masahiro Teshima

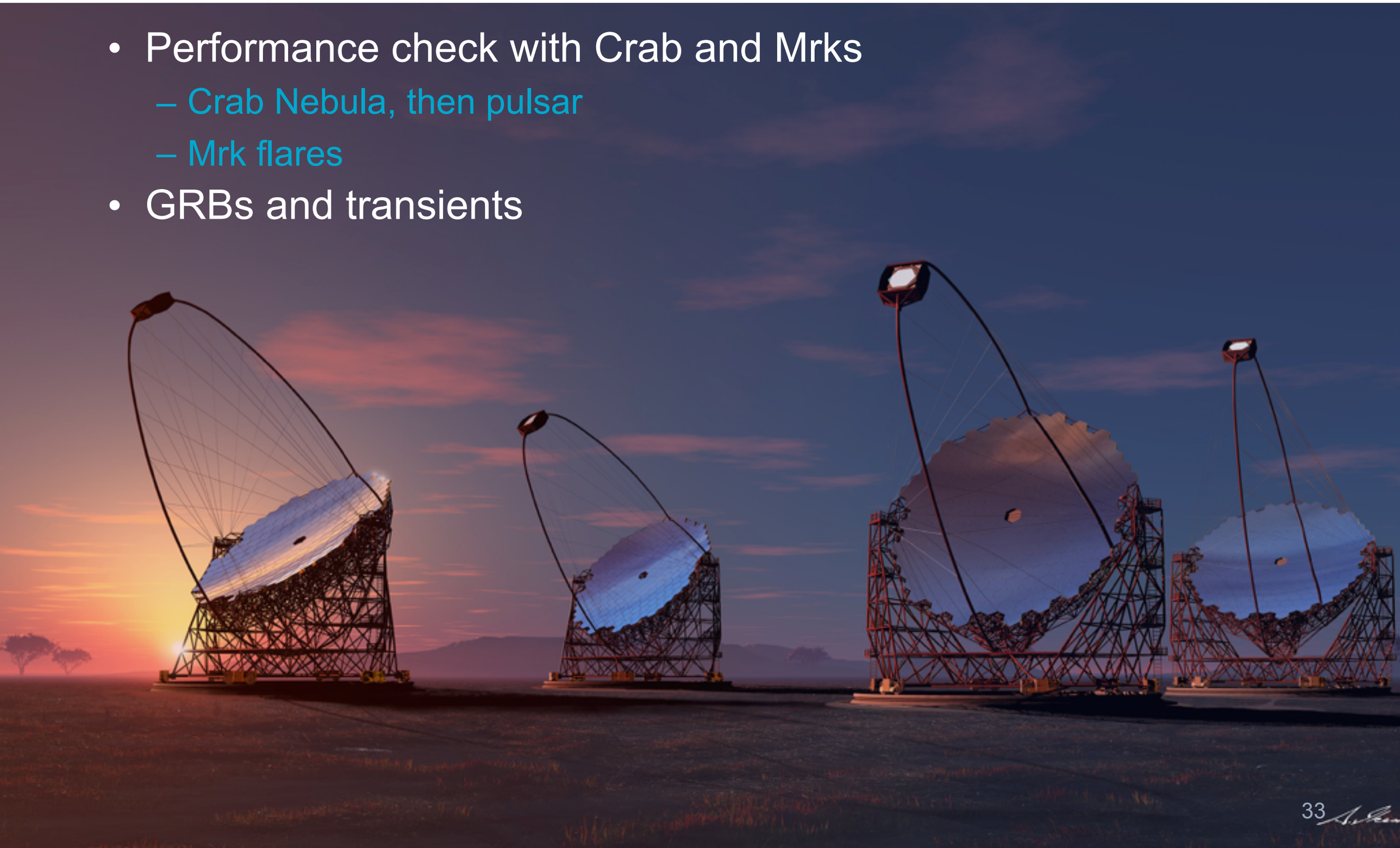
Status after it

- First shower images in media before Xmas
  - Mirrors not yet adjusted!
- Another set of shower images taken in Feb
- Commissioning phase until April-May
- Stable operation expected after the comm. phase



Expected soon from LST1

- Performance check with Crab and Mrks
  - Crab Nebula, then pulsar
  - Mrk flares
- GRBs and transients

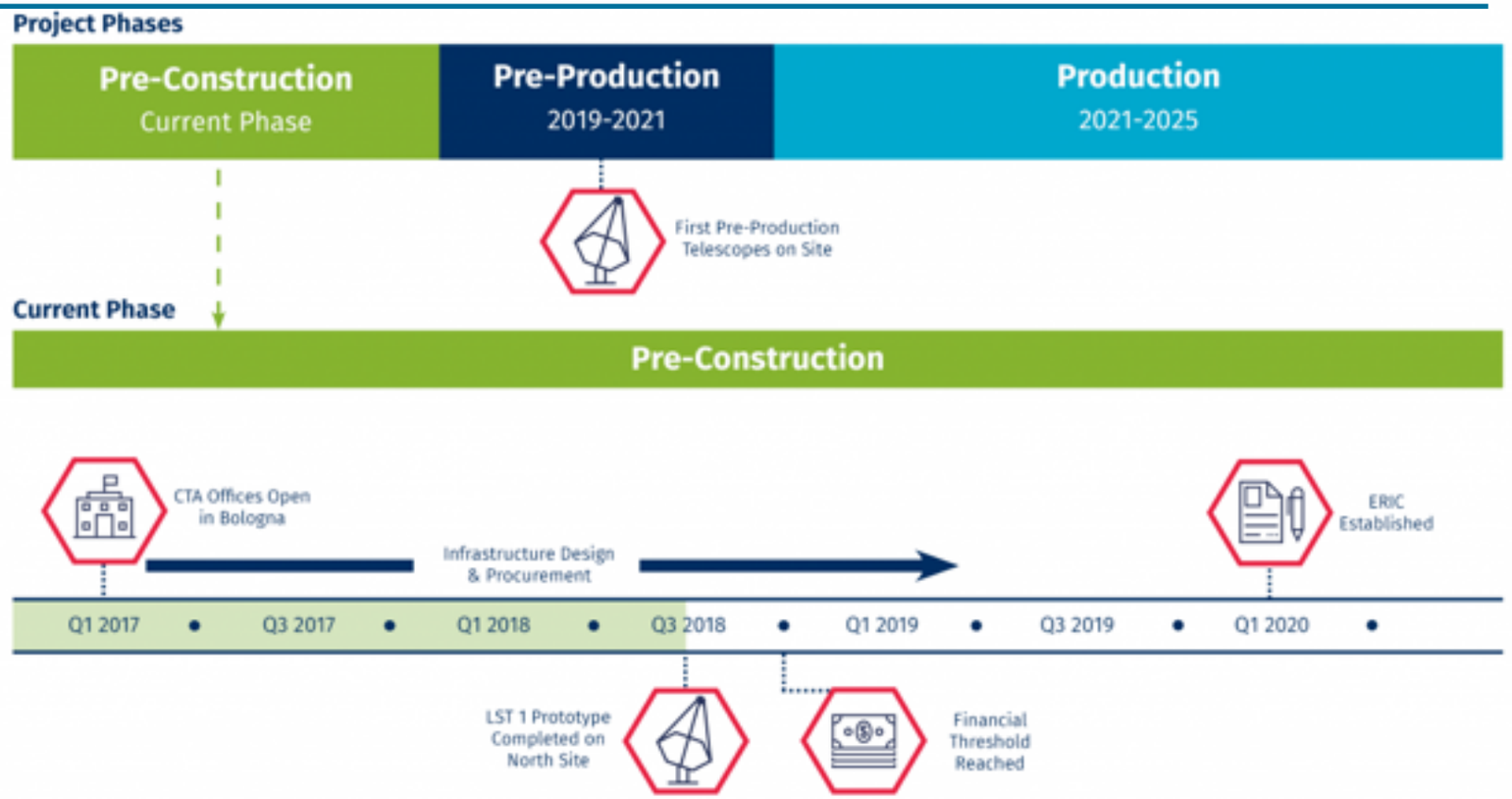


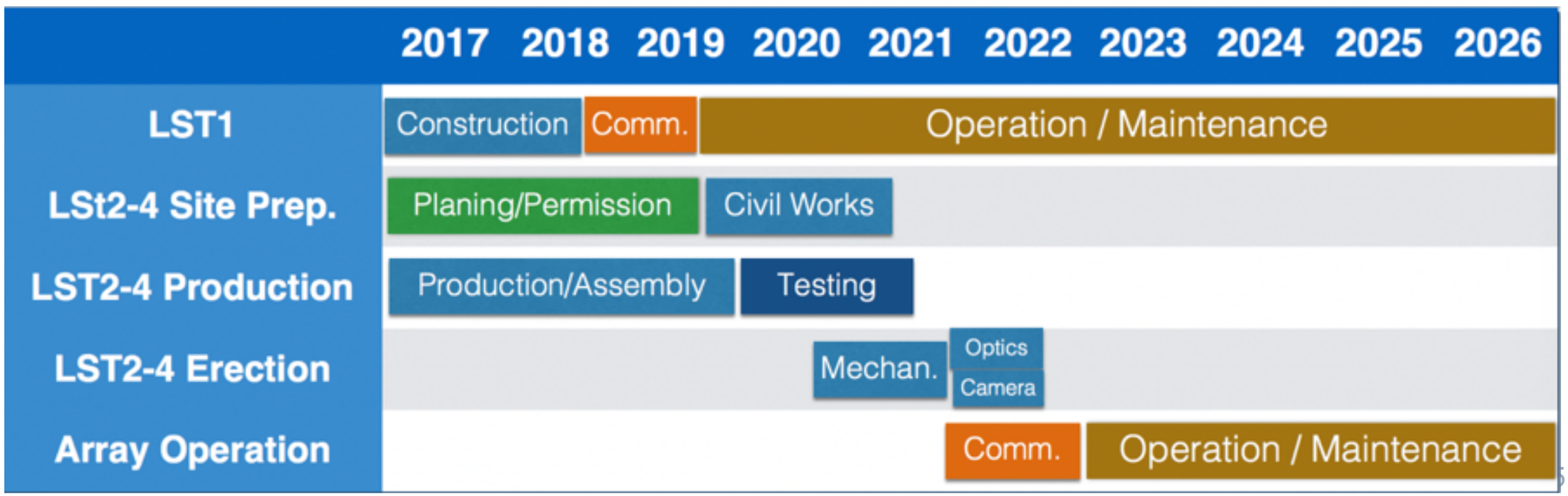
CTA expected physics

- "Science with the Cherenkov Telescope Array" (arXiv:1709.07997)
- Open Observatory – proposal driven
- 9 Key Science Projects (KSPs) + DM
  - **Dark Matter**: N 100 h / yr (dSph), S 200 h / yr (GC, etc.)
  - **Transients**: N 400 h / yr, S 400 h / yr
  - **Active Galactic Nuclei**: N 320 h / yr (LST), S 200 h / yr
  - Extragalactic survey: N 600 h, S 400 h in total
  - Clusters of Galaxies: N 300 h in total
  - Galactic Plane Survey: N 600 h, S 1000 h in total
  - Star Forming Systems: N 500 h, S 340 h in total
  - Galactic Center: S 500 h in total
  - Large Magellanic Cloud Survey: S 300 h in total
  - Cosmic Ray PeVatrons: S 300 h in total
  - others (CR nuclei, CR electron, optical interferometry,,,)

Timeline

- From CTA project
- From LST PI
  - Preparations for LST2-4 ongoing





MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

cta
cherenkov
telescope
array

Summary

Summary

- MAGIC: experiencing more fruitful years than ever before
  - Galactic: pulsar, SNR, binaries,,,
  - Extragalactic: variable nearby AGN, distant AGN,,,
  - Fundamental physics: DM, tau neutrinos,,,
  - Transients: neutrino blazar, GRB,,,
- CTA LST: soon to come with a better performance
  - CTA in a good shape as a project
  - LST1: commissioning going on
  - LST2-4: construction will start in 1-2 years
  - north site: MSTs will follow
  - south site: host agreement signed. Plans to start infrastructure development are ongoing

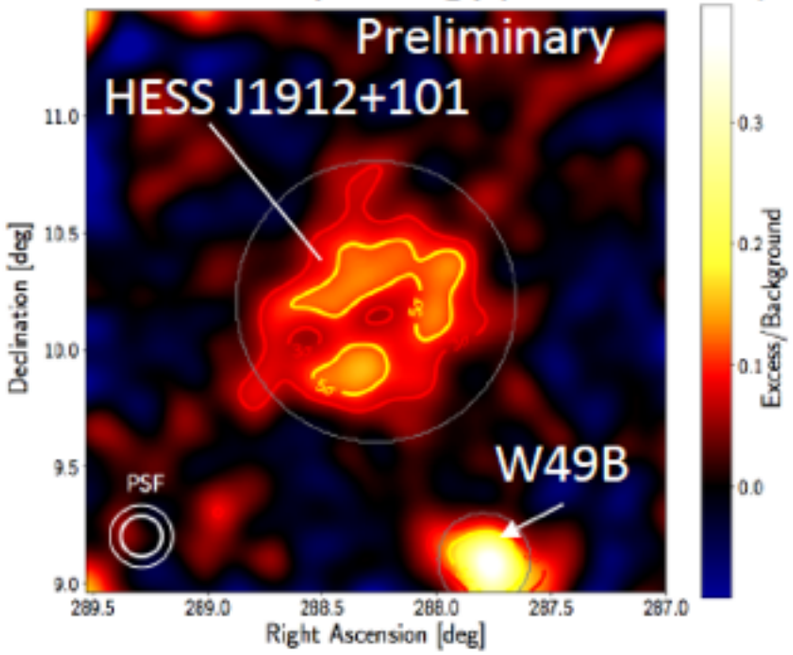
Backups

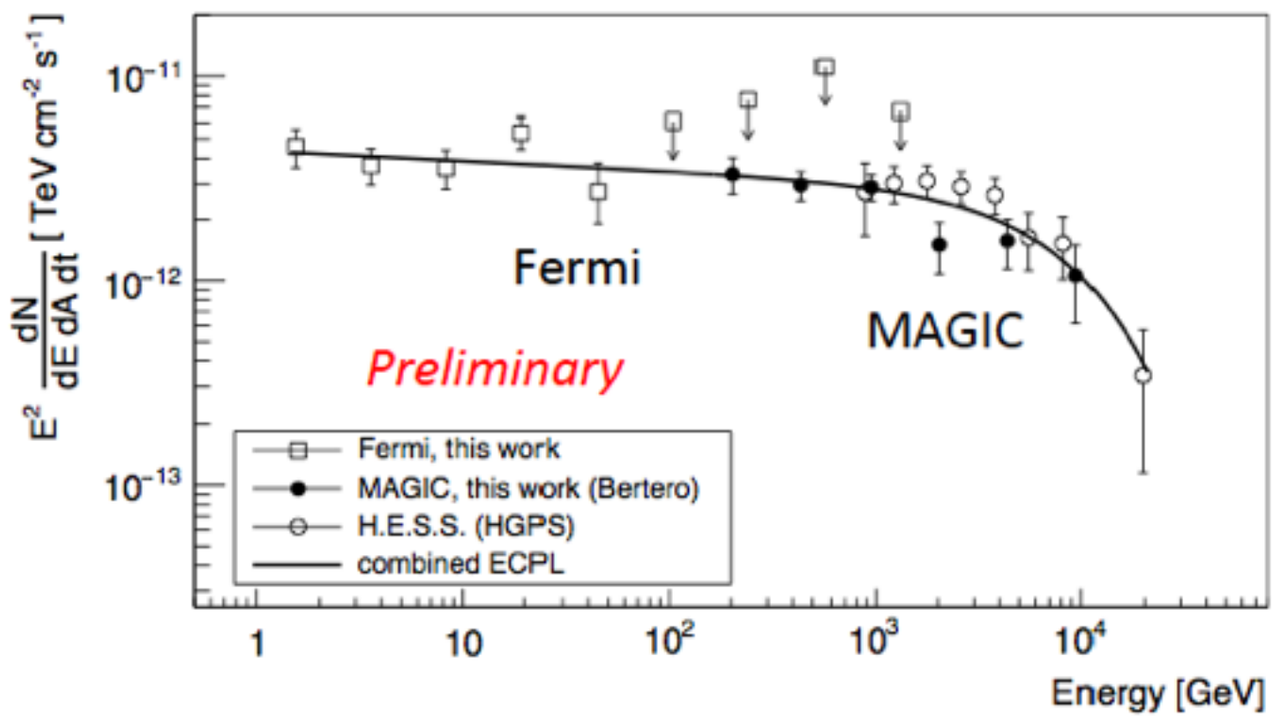
Galactic: SNR HESS J1912

HESS J1912+101

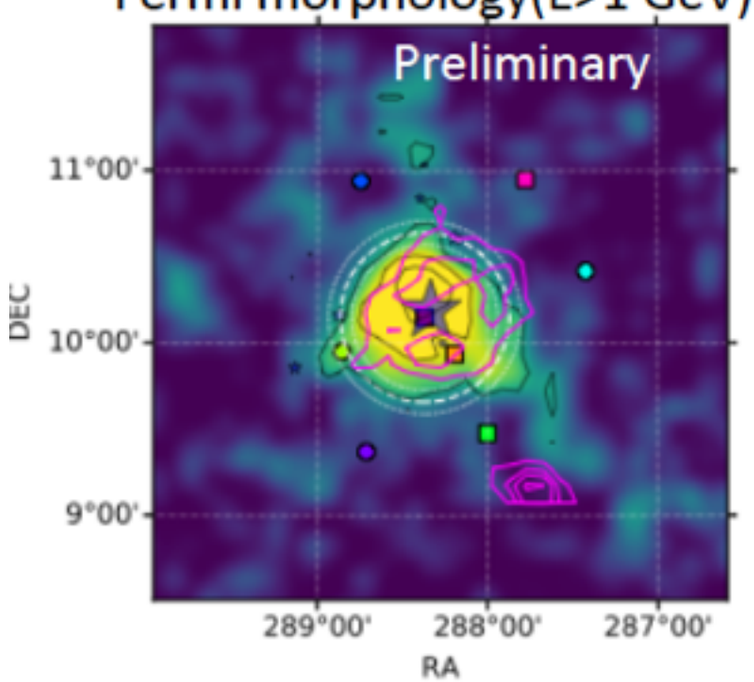
- unID discovered by H.E.S.S Galactic Plane Survey
- shell-like structure -> labeled “SNR candidate”

MAGIC morphology(E>200 GeV)





Fermi morphology(E>1 GeV)



- Extended emission in the GeV energy range as well as the TeV energy range. Fermi-LAT and MAGIC show consistent results both morphologically and spectrally.
- MAGIC morphology (>200 GeV) prefers a shell-like structure, but Fermi morphology (>1 GeV) prefers the gaussian-like structure.
- Energy spectrum in gamma-ray range (1 GeV – 10 TeV) do not have any contradiction with DSA if the gamma-ray emission is dominated by hadronic process.

presented at 8th Fermi symposium 2018 Nagayoshi+