Review

Cherenkov telescope array group @ICRR

Ievgen Vovk on behalf of the group members

ICRR young researchers' workshop
online, 12.11.2020

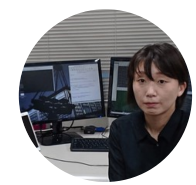
Outline

- *About the group*
- *CTA project*
- *MAGIC telescope*
- *Science with CTA and MAGIC*
- *What do we do @ ICRR*

Group

Meet the CTA group!

1 professor



3 associate professors

4 assistant professors

6 researchers

4 engineers

4 PhD students

6 master students

1 secretary

We are at the 3rd floor of ICRR building,
rooms ~300-330

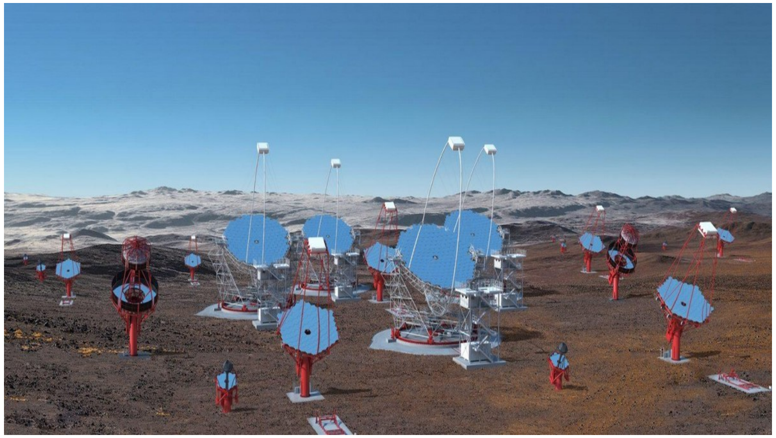
Cherenkov Telescope Array project

The largest Cherenkov observatory every built

~1500 scientists and engineers
~200 institutes
31 countries

→ Large international effort

Southern site (Chile)



Layout: 4 large-sized telescopes
25 medium-sized telescopes
70 small-sized telescopes

Northern site (Canary Islands)

Layout: 4 large-sized telescopes
15 medium-sized telescopes

Extremely rich scientific outcome is expected

Large Sized Telescope (CTA / LST)

Stereoscopic system of 4 IACTs, constructed at La Palma, Spain

Part of CTA/North array

Telescopes: four D=23m
Site: La Palma (Canary Islands)
Energy range: 20 GeV – above 3 TeV
Field of view: 4.3 deg

LST 1

- Oct. 2018: inauguration
- Dec. 2018: first light
- Nov. 2019: first γ-ray source
- present: in commissioning

LST 2-4 are under way…
expected by 2023

5 MSTs are also to be built in phase “A”

Big contribution of Japan and ICRR group

MAGIC telescope system

Stereoscopic system of 2 IACTs, located at La Palma, Spain

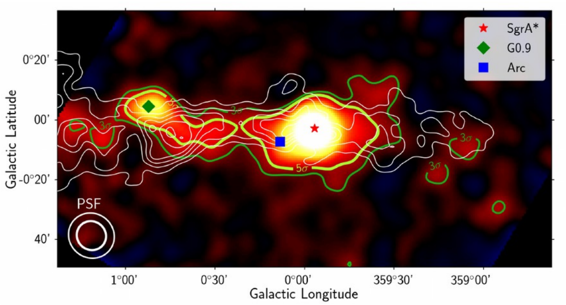
Telescopes: two D=17m
Site: La Palma (Canary Islands)
Energy range: 30 GeV – above 50 TeV
Resolution: 0.07º-0.14º (0.1-1 TeV)
Sensitivity: 0.6% Crab units (integral)
Field of view: 3.5 deg

Observes all kinds of sources:
AGNs, GRBs, gamma-ray binaries, pulsars and **pulsar wind nebulae** etc.

Recent improvements:
- at lower energies: new trigger system (SumTrigger-II);
- at higher energies: new observational strategy (Very Large Zenith angles).

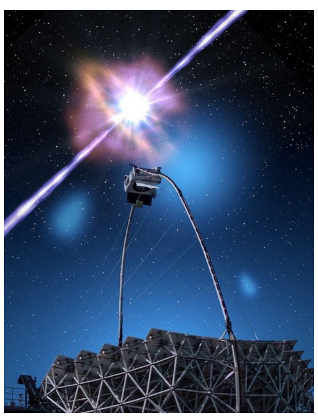
Science with CTA and MAGIC

Galactic center studies



A&A, 642, A190 (2020)

TeV emission from GRB 190114C

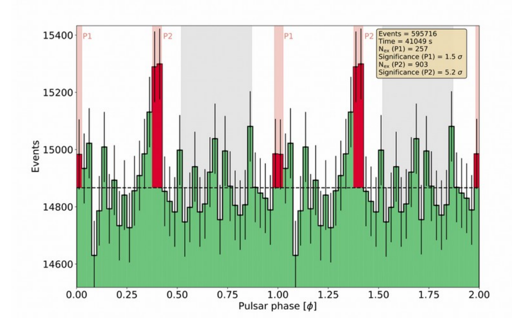


https://magic.mpp.mpg.de/index.php?id=257
Nature 575, p. 455–458 (2019)

We're doing diverse science:

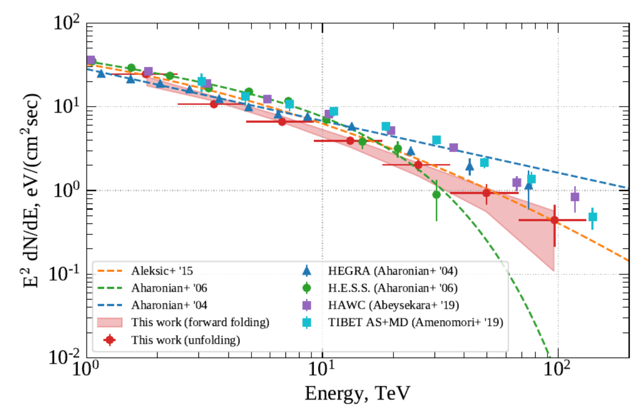
- Galactic center studies
- GRB observations
- pulsar observations
- γ-ray binaries
- IGMF studies
- new observational techniques
- … and more!

LST1 detection of Crab Pulsar



https://www.cta-observatory.org/lst1-detects-vhe-emission-from-crab-pulsar/

100 TeV emission from Crab Nebula



A&A 635, A158 (2020)

CTA / LST
construction & commissioning

LST activities: camera

Goal: record nanosecond signals from air showers with high efficiency

Quick facts:

- 1855 pixels in 265 modules
- 42% peak QE
- 4.3 deg FoV
- 10 KHz data acquisition rate

https://www.cta-observatory.org/project/technology/lst/

Our group activities

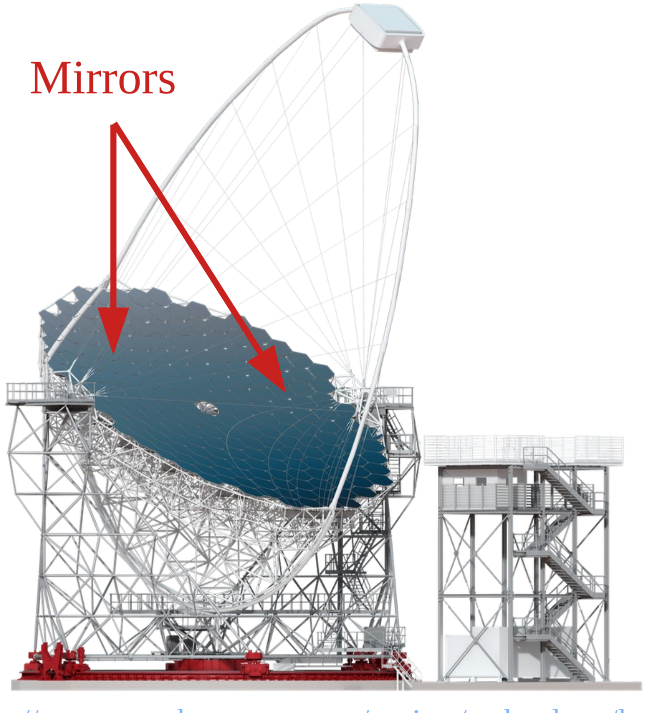
- big contribution to camera construction
- daily check to monitor PMT camera condition.
- automatic detection of anomalous events
- calibration of the camera pixels signals
- refinement of the MC description

LST activities: active mirror control

Goal: focus light onto the camera + compensate structure deformations

Quick facts:

- 198 mirrors in 16 groups
- ~400 actuators (wireless connection)
- ~200 CMOS cameras
- dedicated PSF camera



https://www.cta-observatory.org/project/technology/lst/

Our group activities

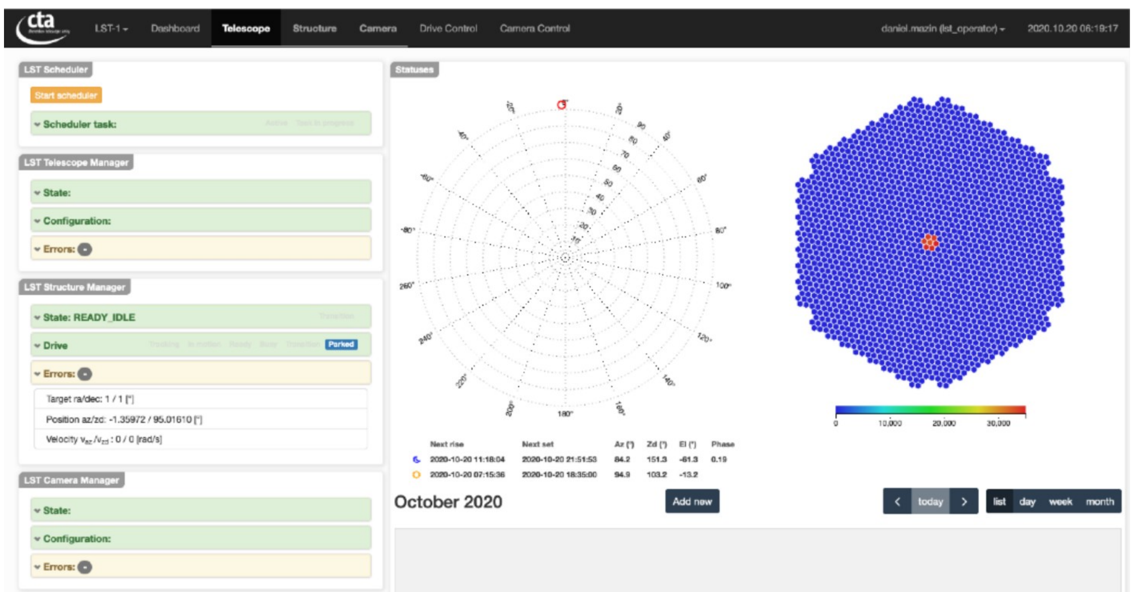
- we are the main responsible for AMC
- development of the mirrors and AMC hardware
- software control and automatization
- monitoring and logging
- remote and on-site maintenance
- fine-tuning for optimal performance

LST activities: telescope control

Goal: record nanosecond signals from air showers with high efficiency

Quick facts:

- aimed at remote operation
- central control server
- web-based interface
- multi-level access protection



Our group activities

- are one of the developers of the telescope control software
- camera control integration
- AMC control integration
- central monitoring database

LST activities: IT and data analysis

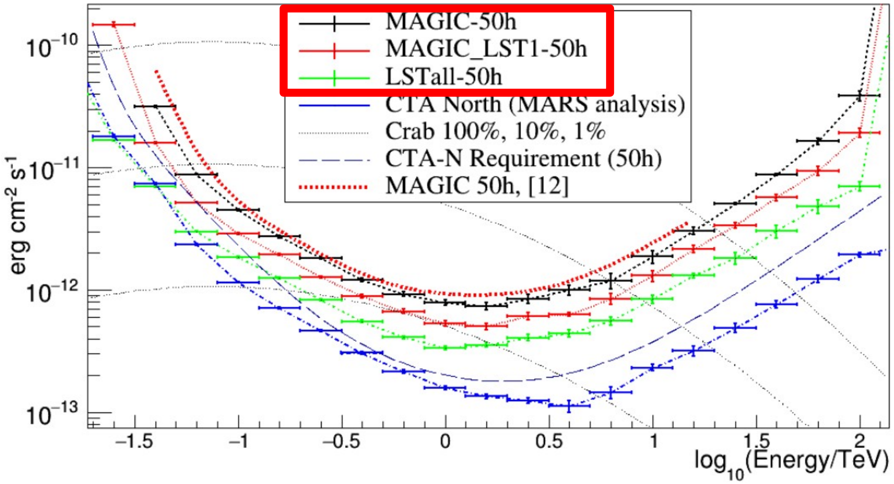
Goal: ensure smooth LST operation / data acquisition / processing

In our hands:
- ~2000 cores
- ~3 PTb of storage
- NVIDIA V100 GPU x 2
- dedicated "telescope" servers
- energy storage

Our group in IT
- we are the main responsible for onsite IT center
- cluster management
- backups
- access control
- remote and on-site maintenance

Our group in analysis
- analysis of performed observations
- joint analysis with MAGIC
- Monte Carlo refinement
- response functions generation
- advanced analysis using Convolutional Neural Networks (CNNs)

MAGIC+LST: sensitivity improvement!



Di Pierro et al. arXiv:1907.07508

Personal research of CTA group members

Leading science with CTA/LST and beyond

Koji Noda
Associate professor

About

- PhD in ICRR (Cherenkov telescope obs. in Hawaii)
  Earth-skimming tau neutrino from a GRB (upper limit)
- LHC forward experiment (CERN), which reduces systematic in UHECR
  PD in Nagoya and INFN, sometimes in CERN
- MAGIC & CTA (Gamma-ray telescopes in Spain) since 2013
  PD in MPP Munich and IFAE in Barcelona. Sources (co-)analyzed:
  - Mrk501 flares (2011, **2013**, 2014): corr. author of 2013 paper
  - **Neutrino alerts follow-ups** (Tracks, HESEs, NGC1068)
  - **GRB 190114C "the first (long) VHE GRB"**
    main analyzer of the discovery paper, published in Nature
  - **GRB 160821B "hint from a short GRB with kilonova"**
    main analyzer and editor of a (delayed) submitted paper

Present

working mostly on the commissioning of LST1, followed by the construction of LST2-4, as:

1) coordinator of **optics**
2) deputy coord. of **telescope control**
3) responsible for the **power** system ("main engineer")
4) **pointing correction** ("consultant")
5) **IT** (rather "partial")

Future

After LSTs will be in operation, particularly interested in:

- understanding of **more long/short GRBs** by VHE gammas, in particular with (late) **prompt emission**
- multi-messenger obs. of short GRBs / NS mergers with **VHE gammas and GW (including KAGRA)**
- multi-messenger obs. / understanding of **neutrino emissions, with source ID with gammas**
  - possible connection with GRB? (LL GRBs, choked,,,)
  - gamma-friendly (steady) sources? (e.g. starburst gal.)
  - (more from neutrino side? better ang. reso., stat,,,)

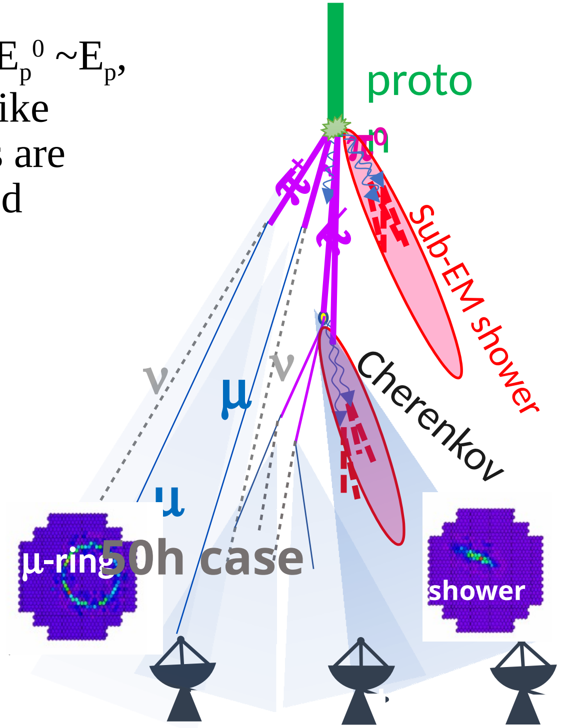
Influence of the uncertainty in the hadronic interaction on the CTA sensitivity estimation

Michiko Ohishi
Assistant professor

- g-rays make up just a tiny part (<1%) of the triggered events
- g-ray sensitivity of an IACT system is mostly determined by the capability of the background (CR proton + electrons) rejection

Schematic diagram of a hadronic shower

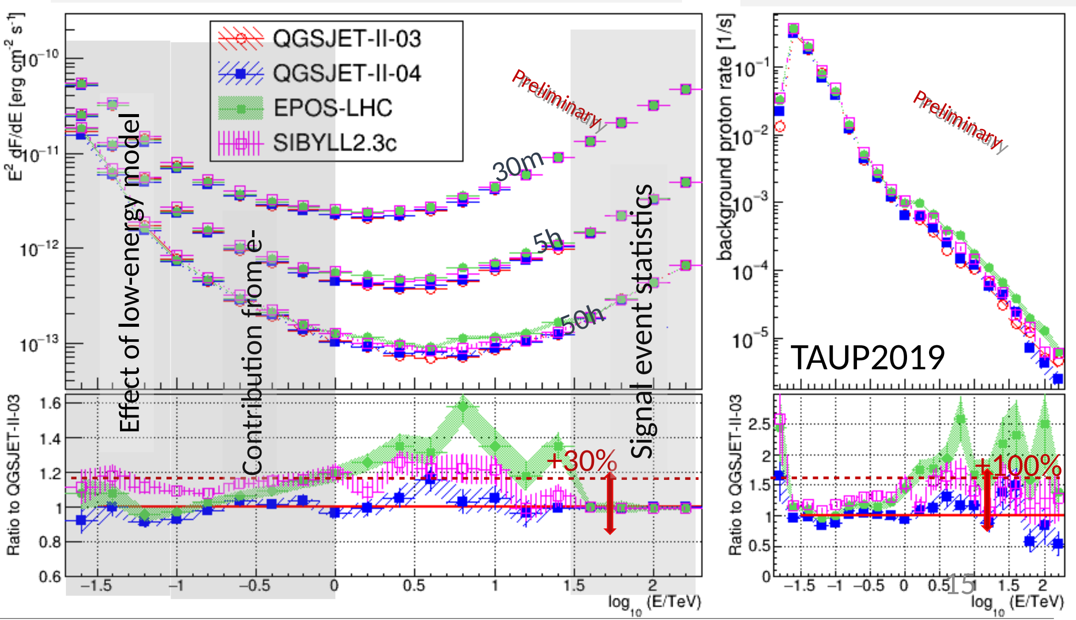
In case $E_p^0 \sim E_p$, very g-like showers are produced



*Simulated camera images from Mitchell+ (2019)

- Proton simulations are required in the γ-ray sensitivity estimation of CTA
- Difference of the hadronic interaction descriptions in the current models (QGSJET-II, EPOS-LHC, SIBYLL2.3c) brings the differences up to ~30% in the g-ray sensitivity and ~100% in the background rate

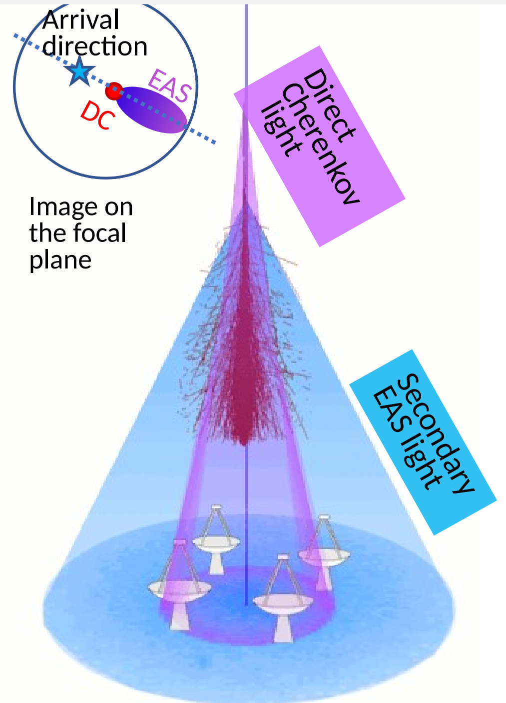
Differential sensitivity (South-site, Full array) **Background rate(p+e-)**



CR chemical composition measurement

Michiko Ohishi
Assistant professor

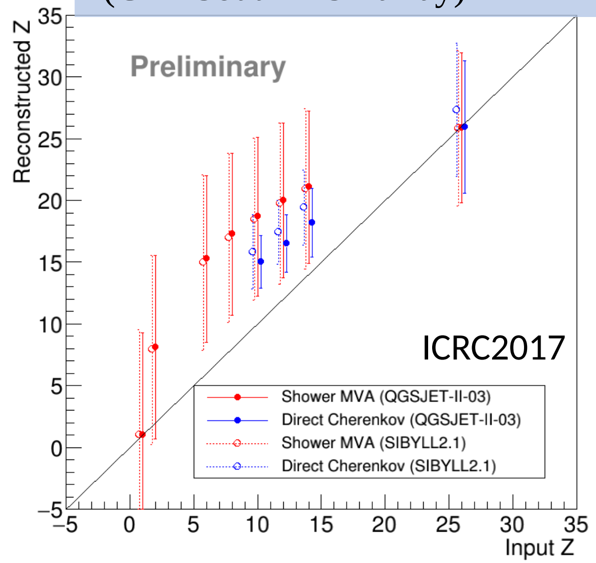
Schematic diagram of principle of the cosmic-ray composition measurement



Direct Cherenkov ☰ Z (charge)
EAS ☰ Energy, arrival direction, core position, and A (mass number)

- IACTs can estimate the primary nuclei type by
  - Direct Cherenkov light (Z: charge)
  - Air shower shape parameters (A: mass number)
- Energies and arrival directions are determined by air shower parameters (as we do in the gamma-ray observation)
- **Direct Cherenkov** : free from uncertainty in the hadronic interaction, but small effective area and upper limit in energy
- **EAS parameters**: large effective area, no energy limit, but affected from the uncertainty in the hadronic interaction

Charge resolution obtained from DC and EAS info. (CTA South MST array)

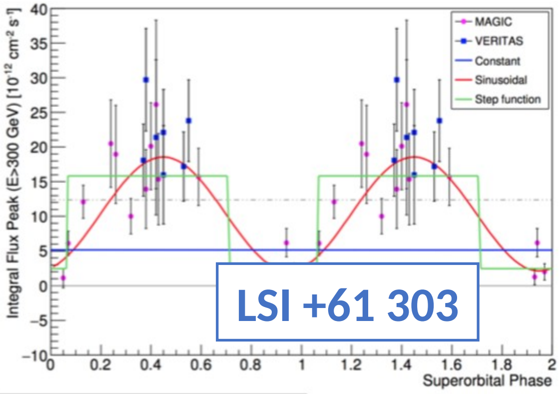


	Direct Cherenkov		Shower MVA	
	QGS	SIB	QGS	SIB
Fe	5.38	5.41	6.05	6.30
Si	2.77	3.02	6.16	6.50
Mg	2.33	2.59	6.24	6.54
Ne	2.14	2.99	6.44	6.55
O	-	-	6.55	6.84
C	-	-	6.74	7.08
He	-	-	7.41	7.66
H	-	-	8.30	8.53

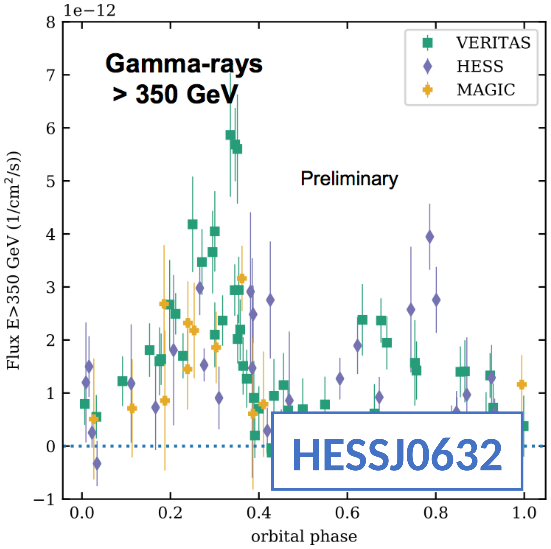
Transient sources / gamma-ray binaries and beyond

Daniela Hadasch
Project assistant professor

- **Questions of interest**
  - What is the nature of the compact object in gamma-ray binaries?
  - What are the emission mechanisms in transient objects?
  - Experiments: MAGIC telescopes & Fermi-Large Area Telescope
- **Latest results:**
  - Finding superorbital modulation in LS I +61 303 at GeV and TeV energies
  - Deep study of HESS J0632+057 with H.E.S.S., MAGIC & VERITAS analyzing 15 years of TeV & 10 years of X-ray data
- **Service duties:**
  - Galactic Convener within the MAGIC collaboration
  - IT management of the CTA computing cluster on La Palma



MAGIC Coll., 2016, A&A, 591, A76

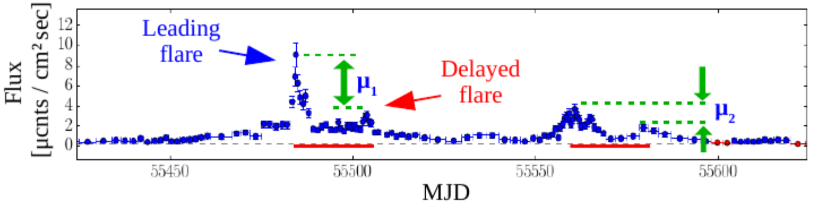


IGMF, microlensing and AGN

Ievgen Vovk
Assistant professor

- **Research topics**
  - Intergalactic Magnetic Field
  - Gravitational microlensing in γ rays
  - AGN physics
  - Large zenith angle observations

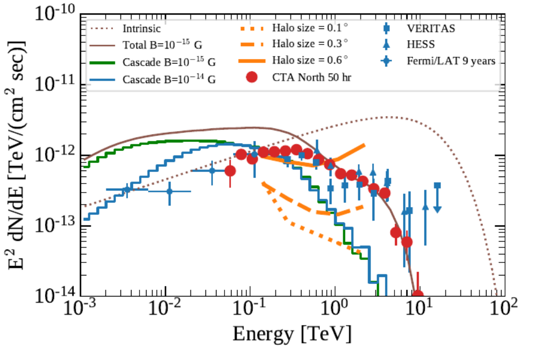
Microlensing in PKS 1830-211



Neronov, Vovk, Malyshev, Nature Physics, 11, 664 (2015)

- **Latest results:**
  - Detection of Crab Nebula 100 TeV emission with MAGIC
  - Observations of the diffuse emission of the Galactic Center
  - CTA sensitivity to IGMF detection
  - Detection of the highest-energy-ever γ rays from GRB (190114C)

1ES 0229+200 + IGMF simulation for CTA



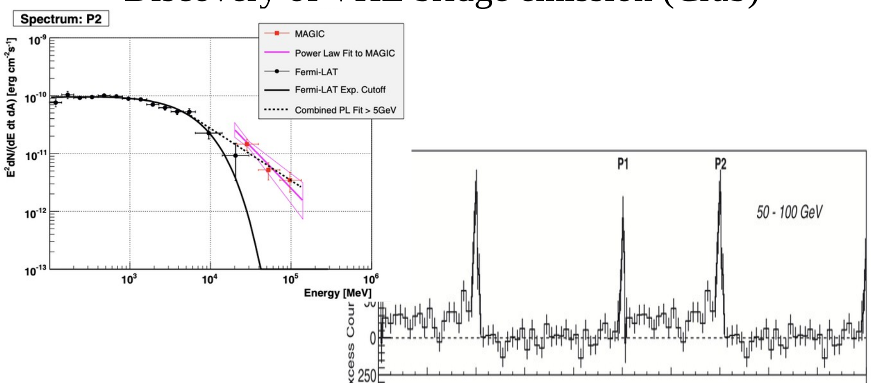
CTA Consortium, submitted (arXiv:2010.01349)

- **Service duties:**
  - AMC developement for CTA / LST
  - Control software development for CTA / LST
  - La Palma CTA computing cluster management (consultant)

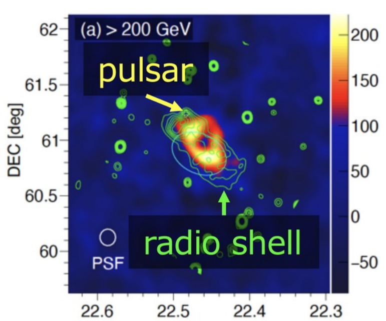
Pulsars and galactic objects / LST Camera

Takayuki Saito
Assistant professor

- Studying pulsars with MAGIC
  - Discovery of the extention of spectrum after a break (Crab)
  - Discovery of VHE bridge emission (Crab)

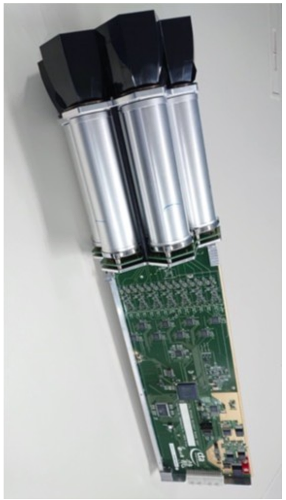


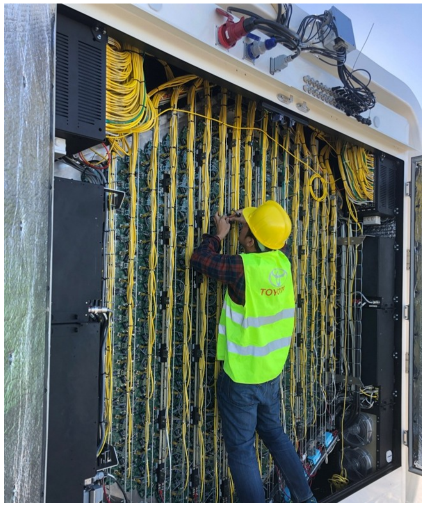
- Recently Studying SNR G106 region (around the Boomerang pulsar) with MAGIC



Possible Pavatron Candidates

- Deputy coordinator of LST Camera
  - Developping and producing the PMT modules.
  - Quality Control
  - Integration to the camera
  - Comissioning
    - ✓ PMT HV tuning
    - ✓ Trigger tuning
    - ✓ DAQ tests
    - ✓ Current and cooling
    - ✓ etc





Galactic center with MAGIC

Tomohiro Inada
Researcher

Gamma-ray flux from DM annihilation

$$\frac{dN_\gamma}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\sum_i Br_i \frac{dN_\gamma^i}{dE} \times J(\Delta\Omega)$$

"J-factor" depends on astrophysical conditions.

- DM density distribution
- ΔΩ of the instrument
- Distance to the source

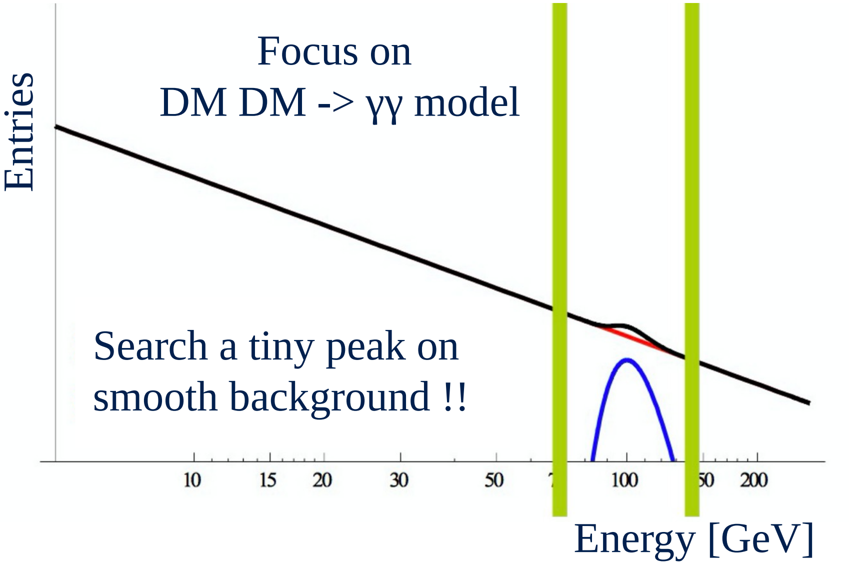
Particle models

- DM DM -> γγ (this study)
- Br : Branching ratio 100% (assumption)
- Line emission search

$$\frac{dN_\gamma}{dE} = 2\delta(E - m_{DM})$$

We want to know :

- σv : annihilation cross-section ∝ flux
  - as a function of dark matter mass m_{DM}
- Constrain theoretical models



Galactic center with MAGIC

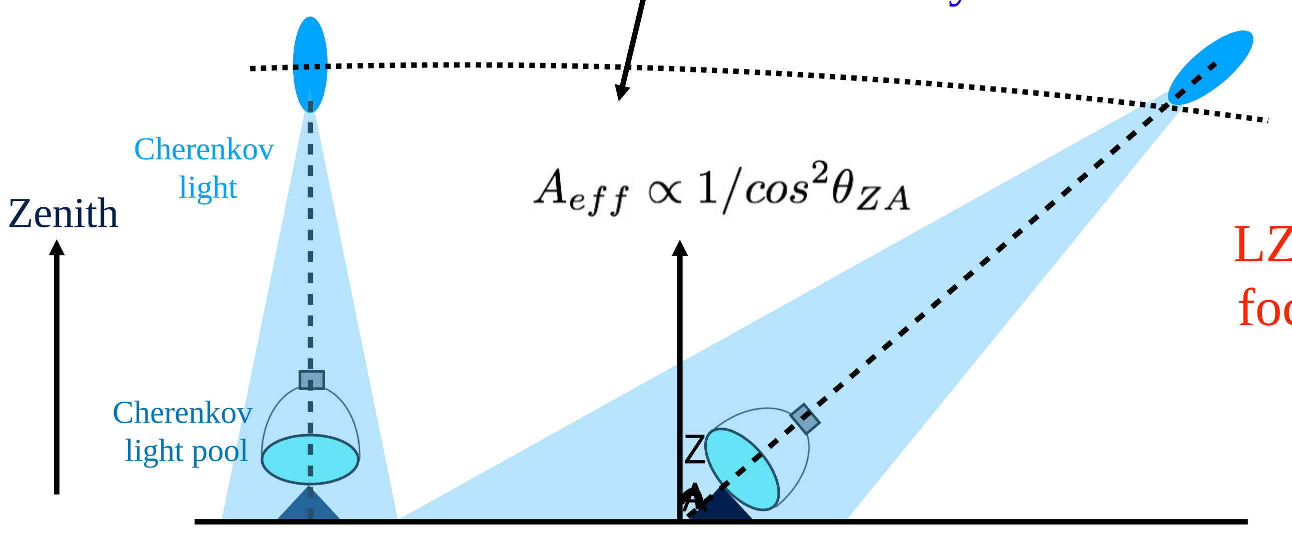
Tomohiro Inada
Researcher

The Galactic Centre with MAGIC

- Zenith angle : 58 - 70 [deg]
  - Large zenith angle observation, LZA

Merit and demerit

- Increase the γ-ray detectable area
  - (× 2-10)
  - Get larger statistics in higher energies
- Increase the energy threshold
- Increase systematics from atmosphere



$$A_{eff} \propto 1/cos^2\theta_{ZA}$$

Vertical observations

Large Zenith angle observations (MAGIC)

LZA is good way to focus on TeV-scale dark matter

Stay tuned!!

Image analysis techniques for extended gamma-ray emission

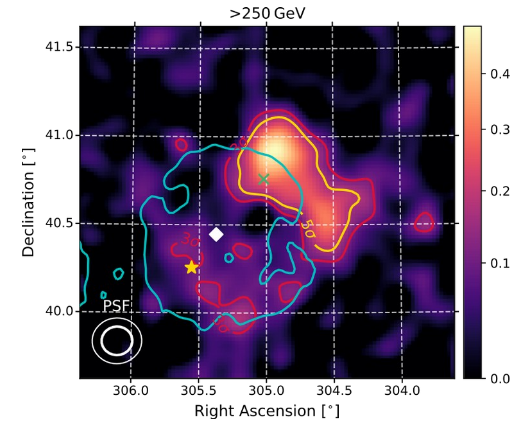
Marcel Strzys
Researcher (ICRR fellow)

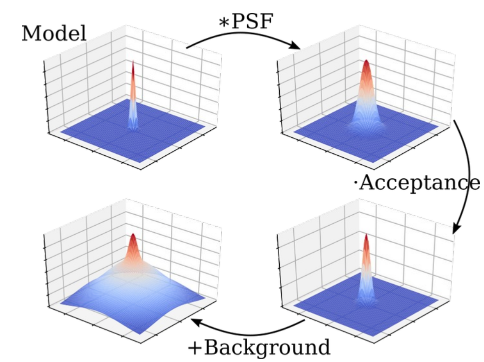
Research interests
- How do CR escape their acceleration site?
- How can we better disentangle different source components?

Latest results
- Study of gamma-ray emission around the γ Cygni SNR (hints for CR escape)
- Observations of the diffuse emission of the Galactic Centre (with I. Vovk)
- Development of a spatial likelihood analysis for MAGIC

Service duties
- Member of the MAGIC software board
- La Palma CTA/LST computing cluster admininstration (together with D. Hadasch and I. Vovk)

HE γ-ray emission from the γ Cygni SNR with MAGIC [arXiv:2010.15854]

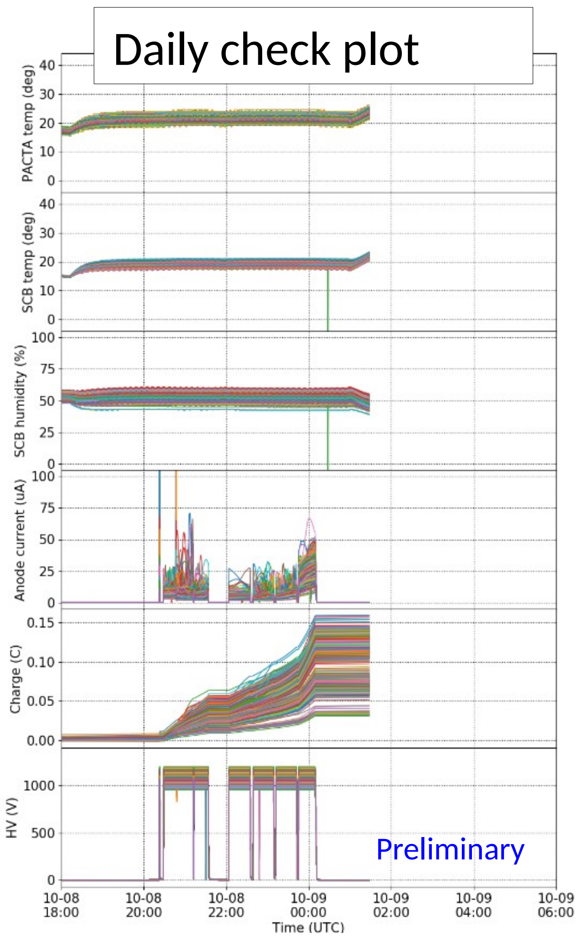


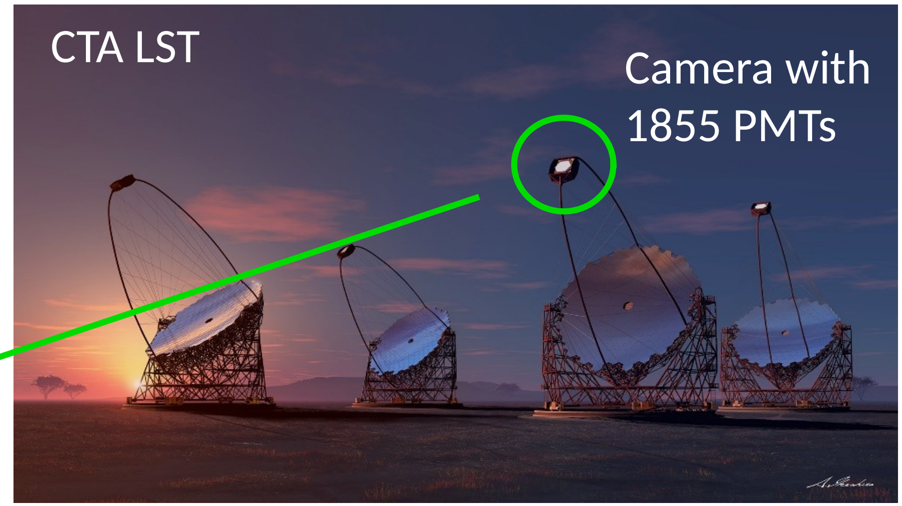


Principle of the Spatial likelihood technique used in MAGIC A&A 619, A7 (2018)

Daily check of PMT camera module

Ryuji Takeishi
Researcher





- We are establishing daily check program to monitor PMT camera condition.
- If PMT parameters such as high voltage and anode current shows strange feature, it is recorded on a day-by-day basis.

Find strange behavior automatically

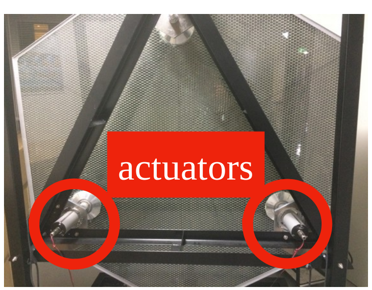
LST active mirror control & GRB observations

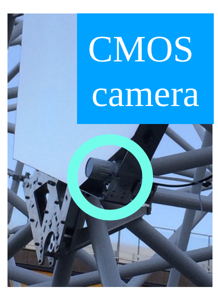
Satoshi Fukami
Researcher

1. Development of Active Mirror Control (AMC) system for LSTs

- LST mirrors suffer from deformation due to:
  - **gravity** depending on the angle
  - **weather condition** (temperature, wind, etc.)
- developed automatic mirror alignment system using actuators & CMOS cameras for individual mirrors
  - mode 1: prepare **look-up tables** of actuator lengths for different zenith angles
  - mode 2: monitor **a reference laser spot** with CMOS cameras to detect mirror deformation

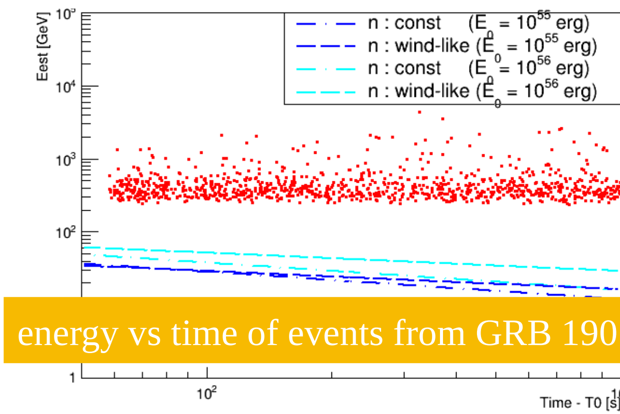
mode 1 is done for LST1 ! mode 2 ongoing!





2. Gamma ray bursts analysis with MAGIC

- observe gamma-ray bursts (GRBs) in the TeV band
  - restrict **models of the gamma-ray emission**
  - study acceleration mechanism of high energy particles, driving mechanism of the jets, etc.
- analyzed several GRBs and calculated upper limits (or **one detection**!) for them



energy vs time of events from GRB 190114C

3. data analysis of the LST prototype

- LST prototype (LST-1) started its observations
- analyzed Crab nebula and some other sources
- started developing analysis procedure

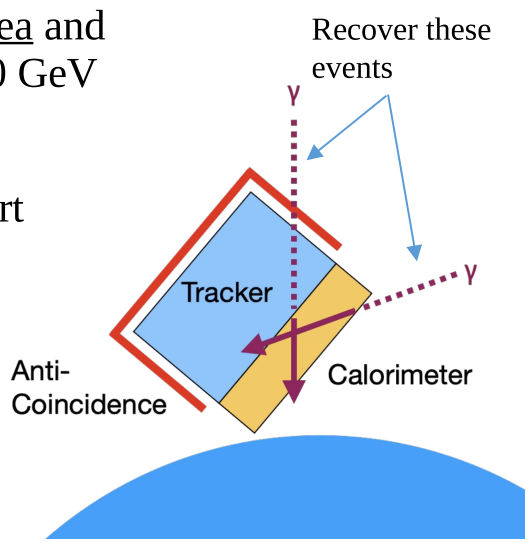
R/D for existing and future experiments

Mitsunari Takahashi
Researcher

New Event-level Analysis of Fermi-LAT

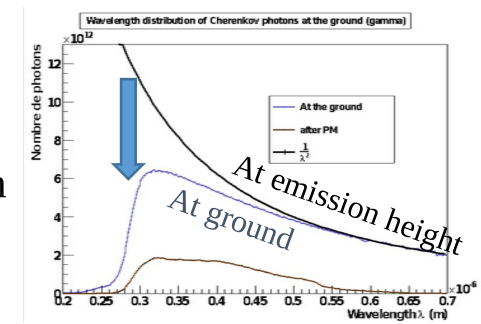
- Novel classes of gamma-like events only with Calorimeter and Anti-Coincidence information
  - cf. Standard classes need Tracker information

- Increase <u>effective area</u> and <u>field of view for</u> >20 GeV
- Useful for
  - GW-counterpart
  - GRB
  - Pulsar
  - Dark matter
- <u>ICRC2019</u>



Calibration of Atmospheric Absorption for IACT with Balloon

- Atmospheric absorption of Cherenkov light cannot be calibrated with muon



[Chalme-Calvet 2013]

- Gamma-ray energy estimation depends on our knowledge on atmosphere → Can we calibrate this?
- Launch UV-LEDs onboard balloon to Cherenkov emission height ~10 km
- Measure absorption by observing LEDs by IACT
- Now testing 308-nm UV-LED

Instead of epilogue

Thanks for listening!

Please feel free to pop by
and
Let's do more science together!