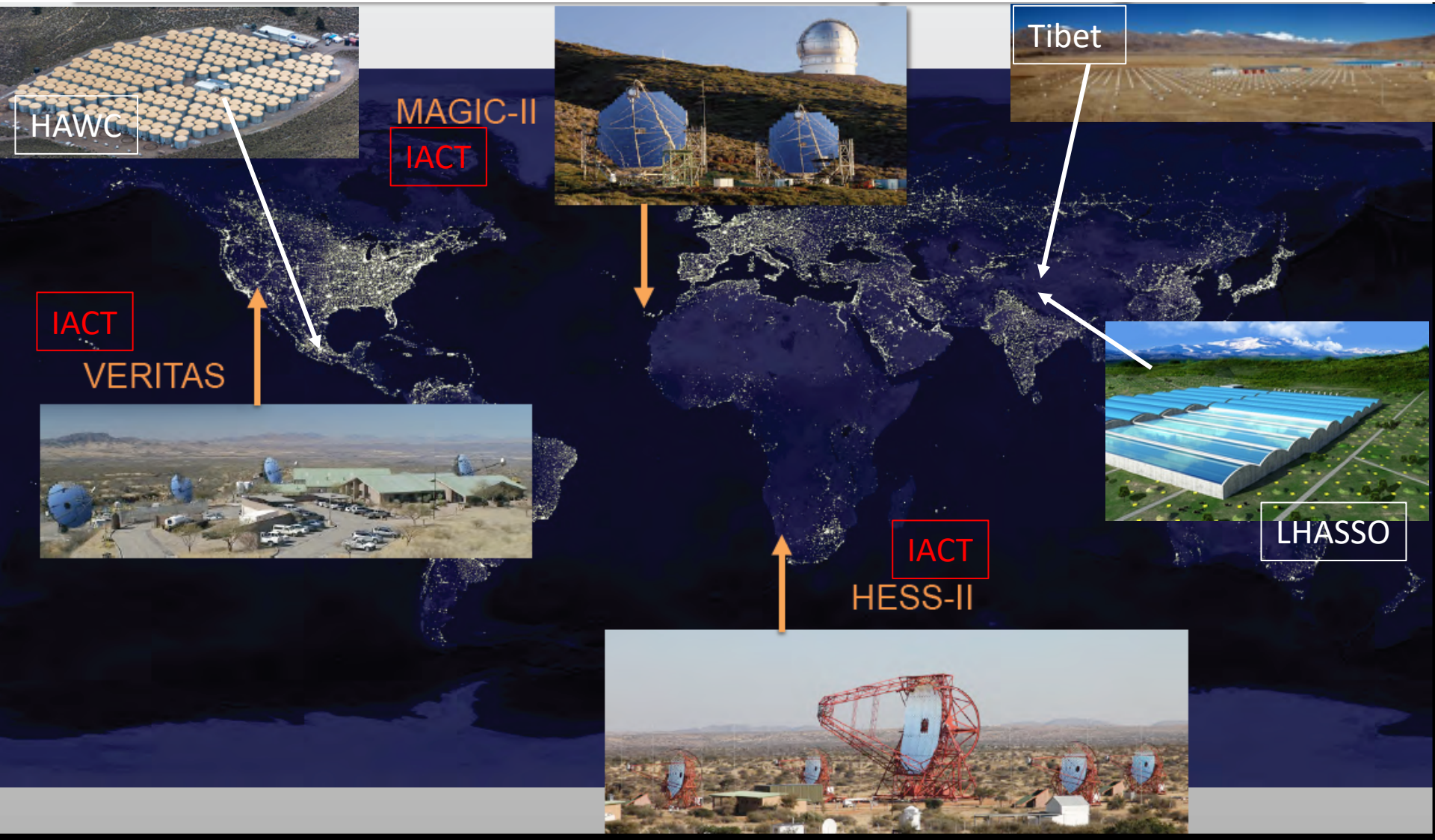
Status of CTA/LST

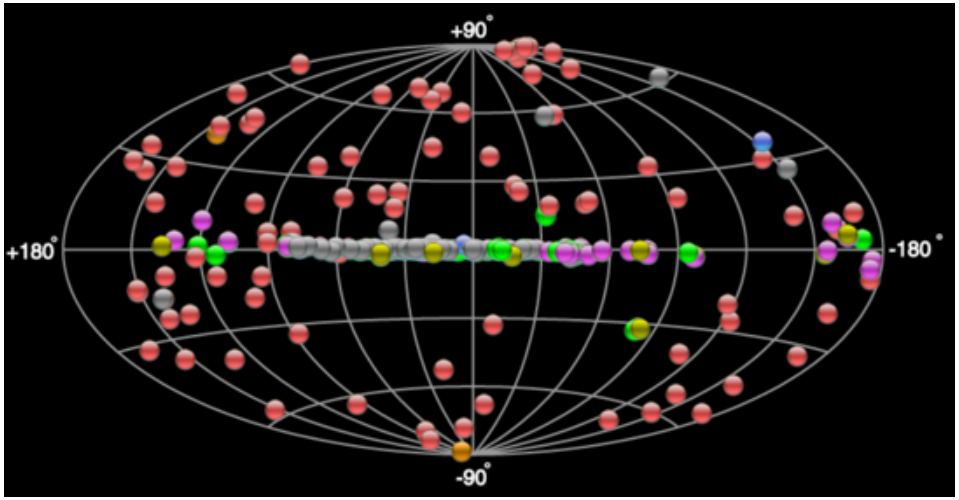
Takayuki Saito (ICRR)
On behalf of CTA-Japan Consortium

Dec/3rd/2020　Extreme Universe viewed in VHE gamma rays 2020 @ zoom

VHE Gamma-ray Observatory



VHE Gamma-ray Observations



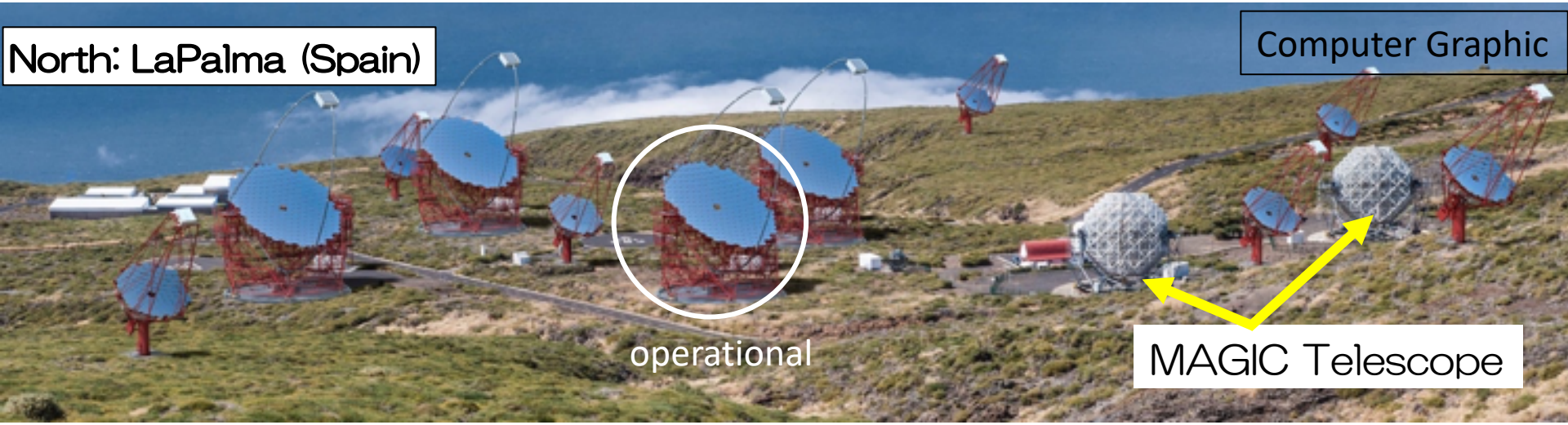
http://tevcat.uchicago.edu/

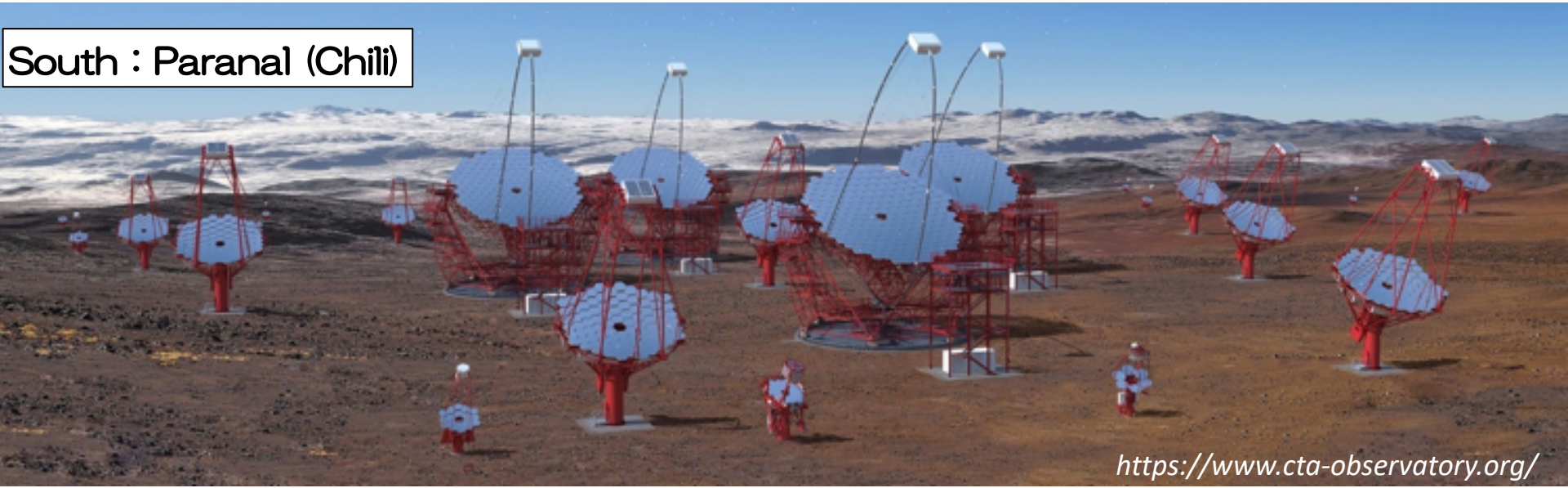
Only ~200 sources are known so far.

	type	Number
Galactic		**~130**
	SNR Shell	27
	Pulsar	4
	PWN	31
	Binary	11
	Cluster	4
	UnID	59
Extra Galactic		**~80**
	Blazar	73
	FR-I	4
	Starburst Gal.	2
	GRB	3

Cherenkov Telescope Array

31 countries,
>1500 scientists

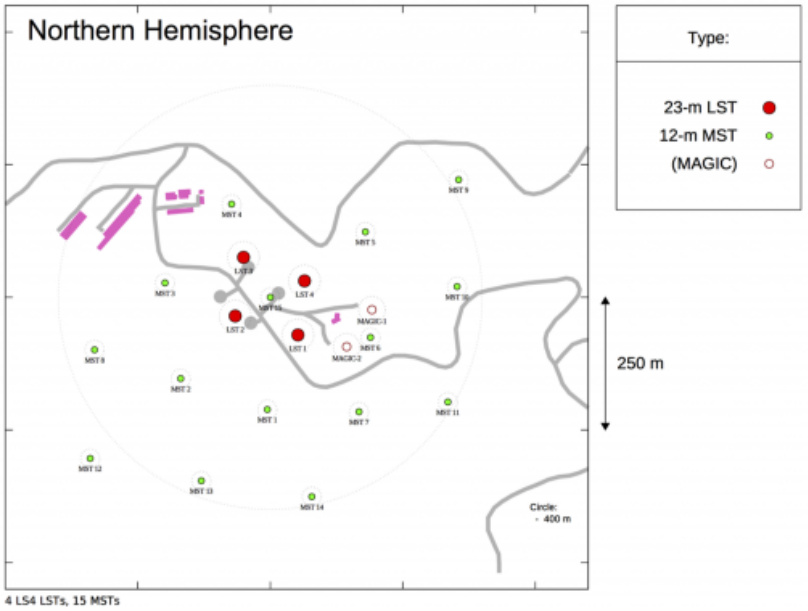




https://www.cta-observatory.org/

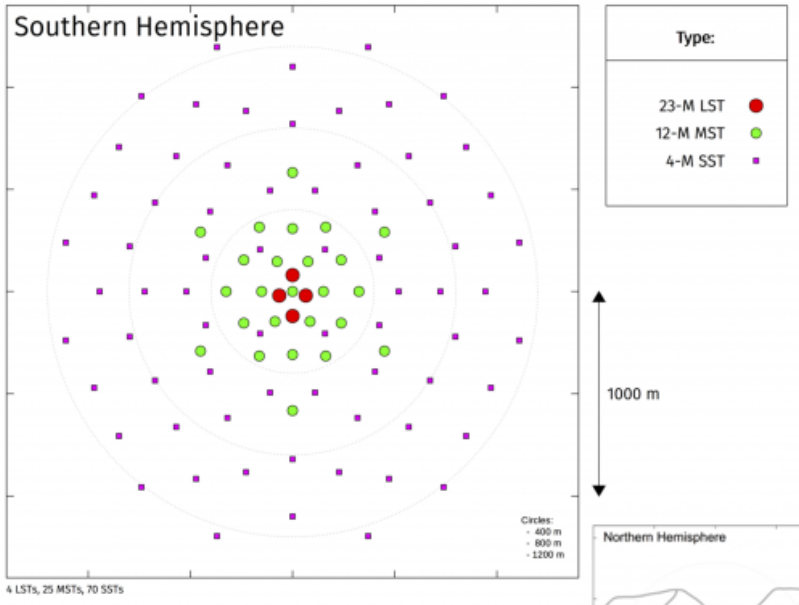
Array Configurations

North: LaPalma (Spain)



- 4 LSTs
- 15 MSTs

South : Paranal (Chili)



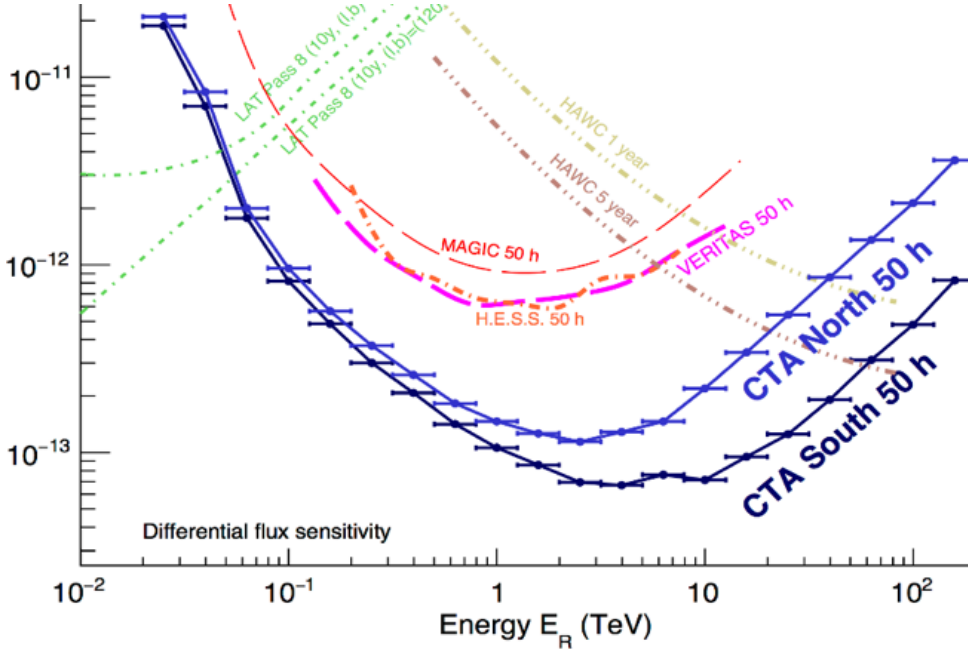
- 4 LSTs
- 25 MSTs
- 70 SST

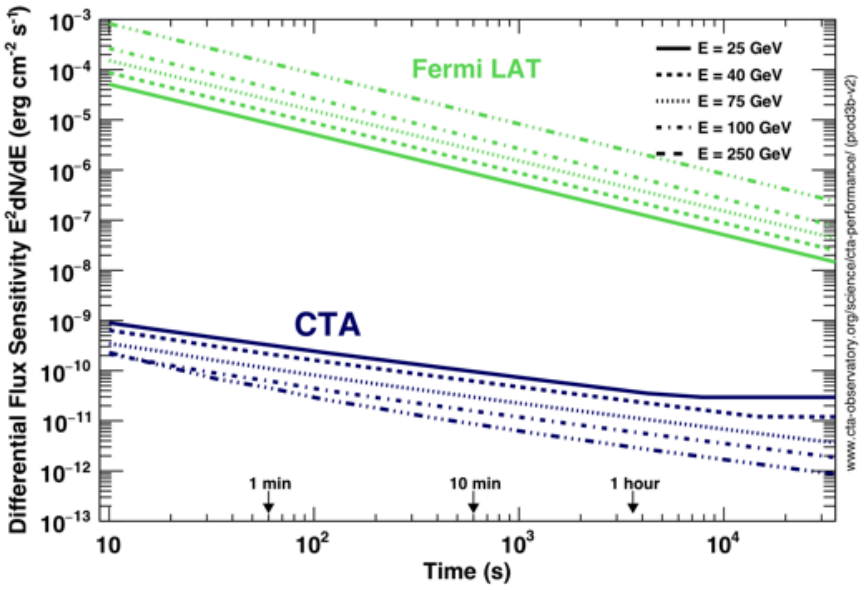
LST: 23mϕ
20 GeV – 3 TeV
FOV=4.5°

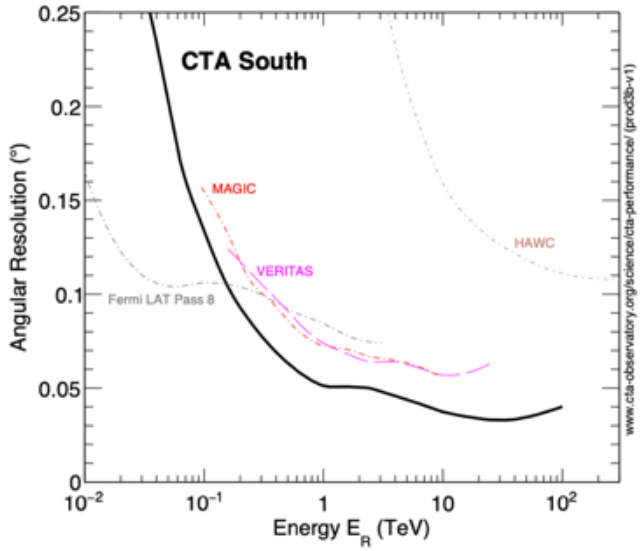
MST: 12mϕ
80 GeV – 50 TeV
FOV=~8°

SST: 4mϕ
1 TeV – 300 TeV
FOV=9° – 10°

CTA Sensitivity







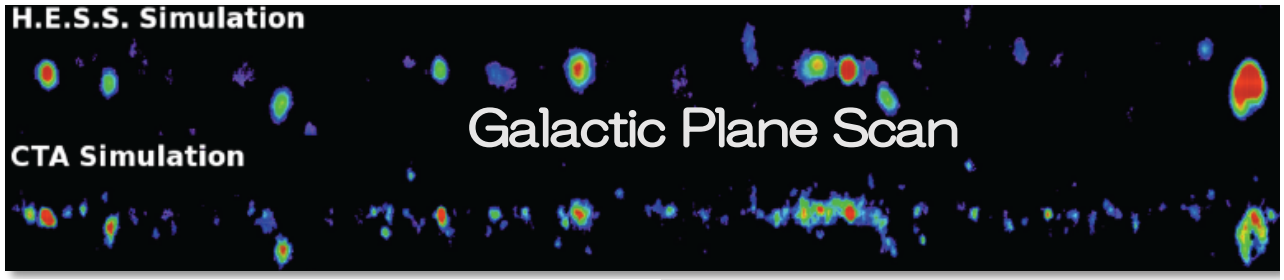
- Wide Energy Coverage from 20 GeV to > 300 TeV
- 1 order higher sensitivity
- 3 (2) arcmin angular resolution > 1 (10) TeV,

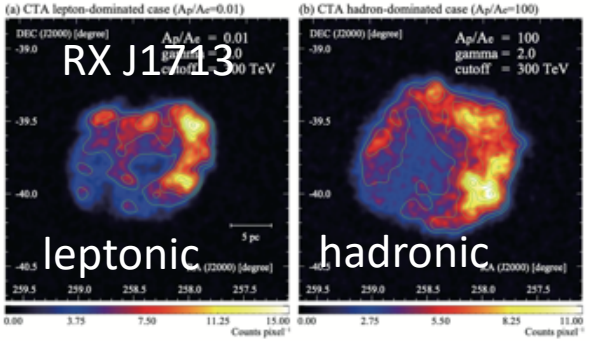
- **4-5 orders of magnitude higher sensitivity than Fermi-LAT for transient sources below 100 GeV**

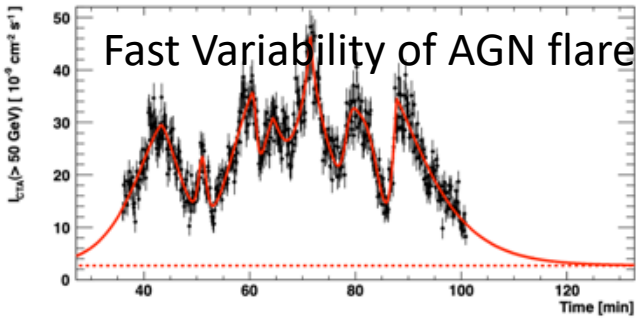
- **Detection of >1000 sources are expected**
- **Redshift up to 4 are reachable (GRB)**

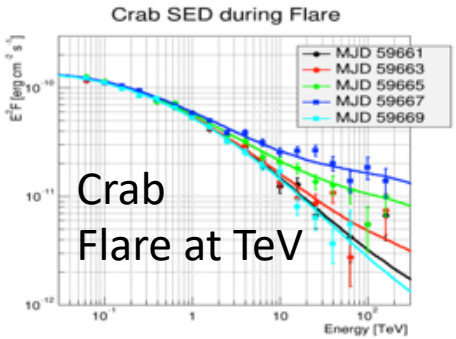
Science with CTA

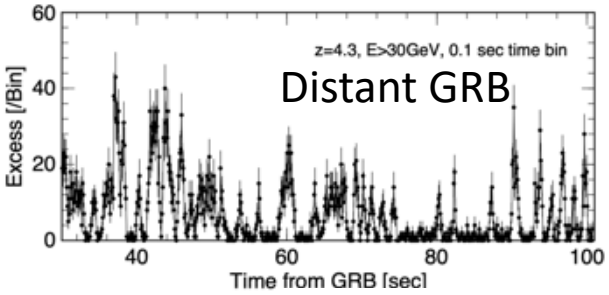
1. Understanding the origin of Cosmic Rays and their acceleration mechanism
2. Study of the physics in the vicinity of Black Hole and Neutron star
3. Contribution to the fundamental physics and cosmology using TeV photons

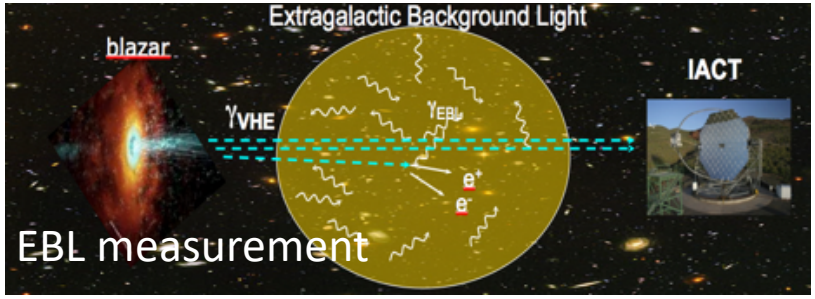


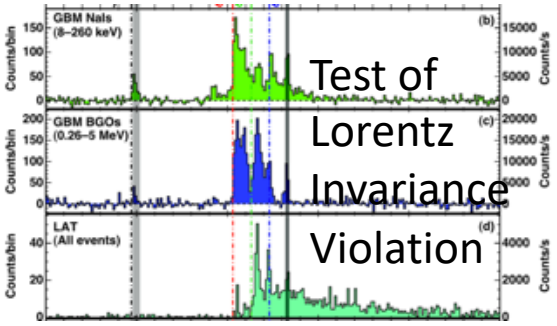


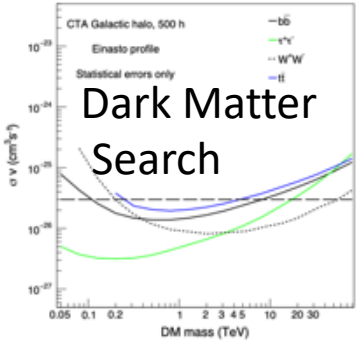




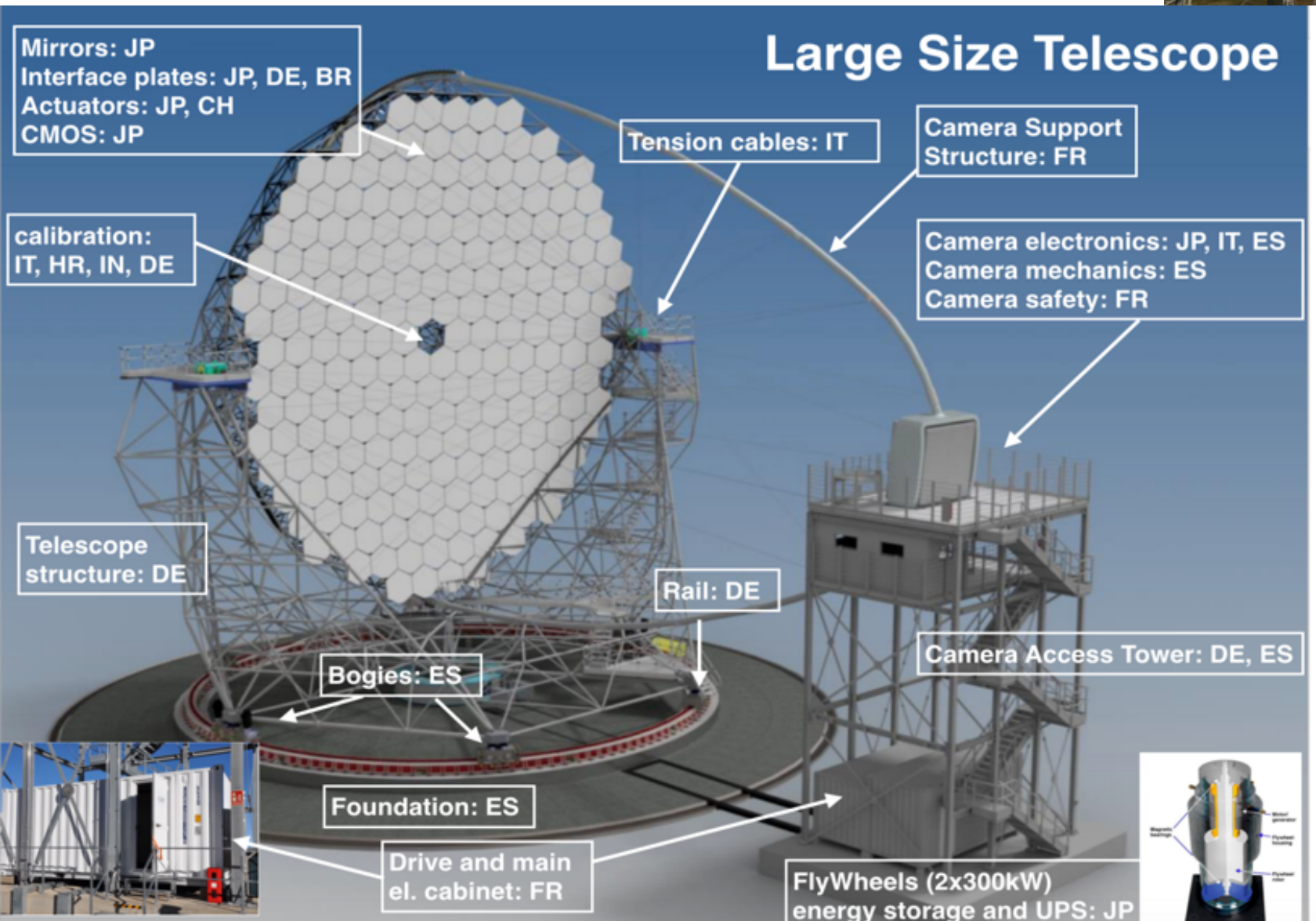


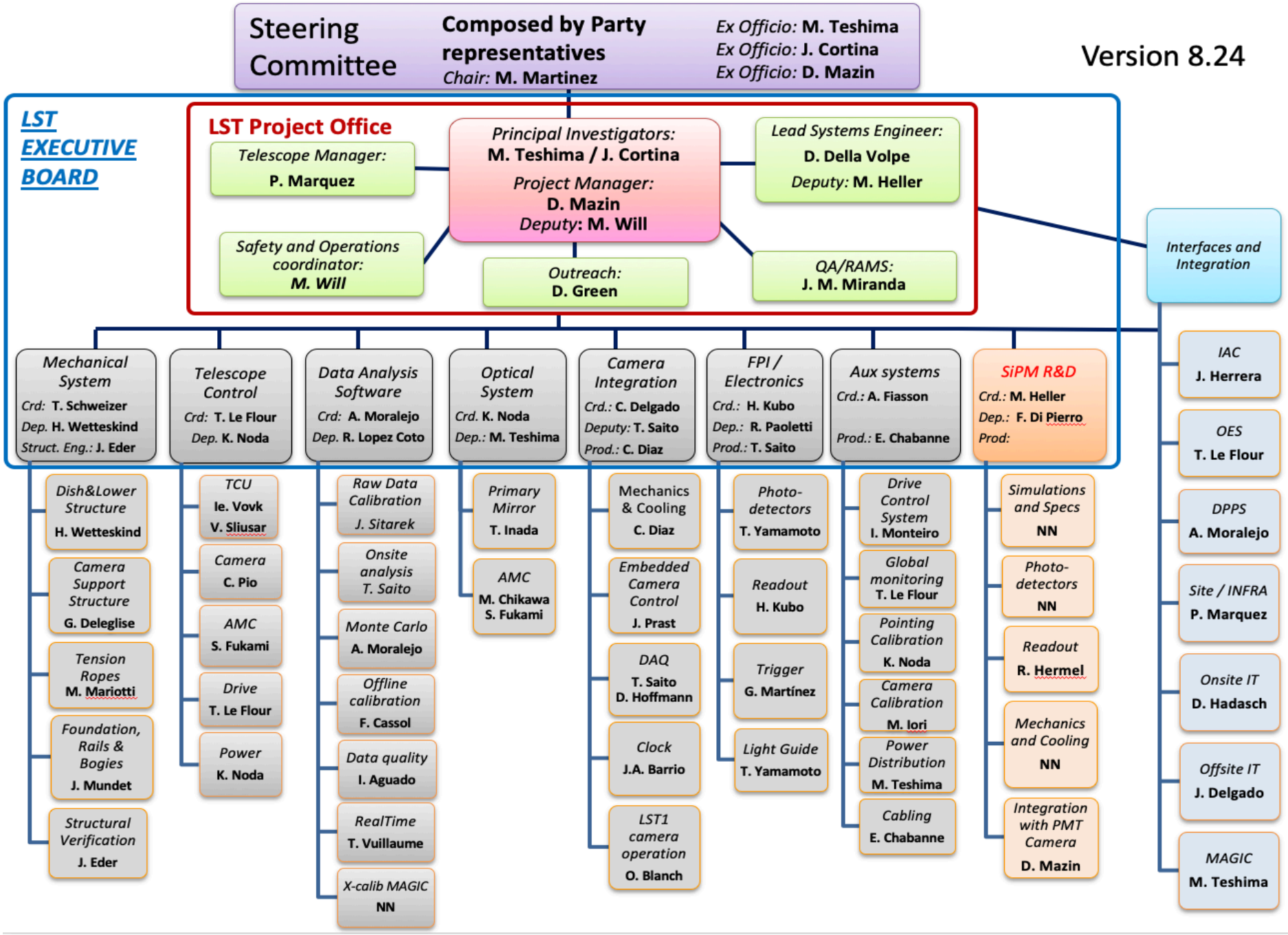






Large Size Telescope




Steering Committee
Composed by Party representatives
Chair: M. Martinez
Ex Officio: M. Teshima
Ex Officio: J. Cortina
Ex Officio: D. Mazin
Version 8.24
LST EXECUTIVE BOARD
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Telescope Manager: P. Marquez
Principal Investigators: M. Teshima / J. Cortina
Project Manager: D. Mazin
Deputy: M. Will
Lead Systems Engineer: D. Della Volpe
Deputy: M. Heller
Safety and Operations coordinator: M. Will
Outreach: D. Green
QA/RAMS: J. M. Miranda
Interfaces and Integration
Mechanical System
Crd: T. Schweizer
Dep. H. Wetteskind
Struct. Eng.: J. Eder
Telescope Control
Crd: T. Le Flour
Dep. K. Noda
Data Analysis Software
Crd: A. Moralejo
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Prod:
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T. Vuillaume
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NN
Primary Mirror
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S. Fukami
Mechanics & Cooling
C. Diaz
Embedded Camera Control
J. Prast
DAQ
T. Saito
D. Hoffmann
Clock
J.A. Barrio
LST1 camera operation
O. Blanch
Photo-detectors
T. Yamamoto
Readout
H. Kubo
Trigger
G. Martínez
Light Guide
T. Yamamoto
Drive Control System
I. Monteiro
Global monitoring
T. Le Flour
Pointing Calibration
K. Noda
Camera Calibration
M. Iori
Power Distribution
M. Teshima
Cabling
E. Chabanne
Simulations and Specs
NN
Photo-detectors
NN
Readout
R. Hermel
Mechanics and Cooling
NN
Integration with PMT Camera
D. Mazin

LST: Drive

4 MJ is “stored” as a rotation energy of a flying cylinder.
It can be converted to electricity fast and efficiently.

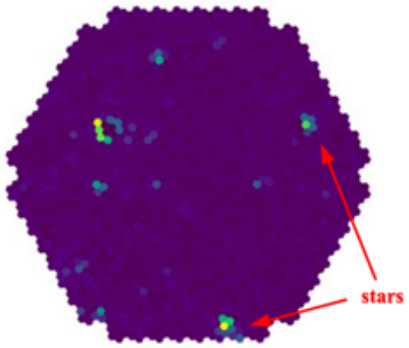
Each LST is quiped with 2 FW.

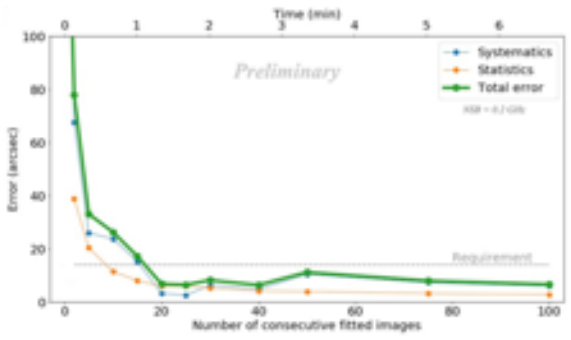
- ❑ Alt-Azimuth mount
- ❑ Steering 10t structure

- ❑ **180 degree rotation within 20 sec.**
- ❑ **This fast rotation requires a fast energy supply. “Flywheel” technology was adopted.**

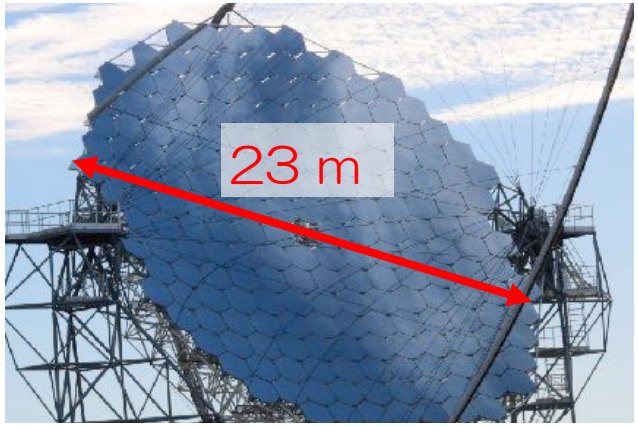
LST1 Drive Status

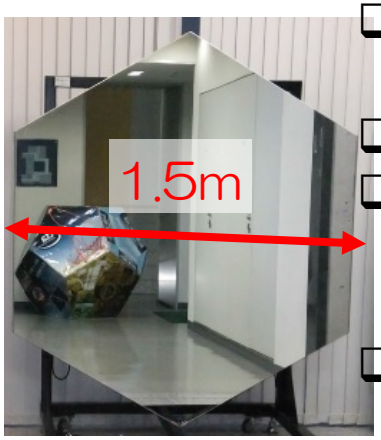
- Tracking accuracy is 2 arcmin。
- Offline correction using star images makes it 10 arcsec.
- Fast rotation has been tested.
- (but not ready to react on the GRB alert yet.)



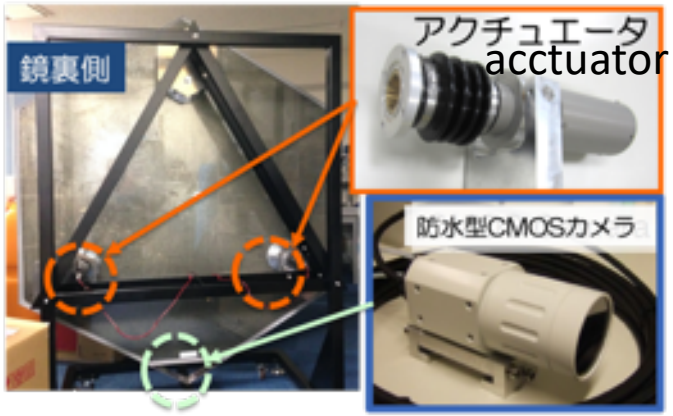


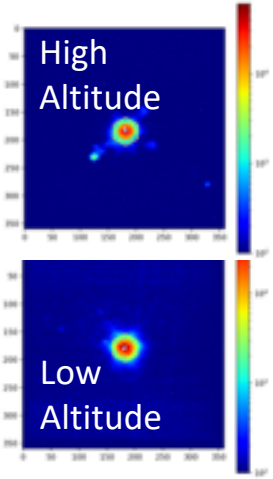
LST: Mirror





- Parabolic reflector with 23 m diameter.
- Consists of 198 hexagonal facet
- Each facet is equipped with two actuators. The orientation can be controlled with them.
- Each facet also has a CMOS camera. It can be used to correct orientation in real time.

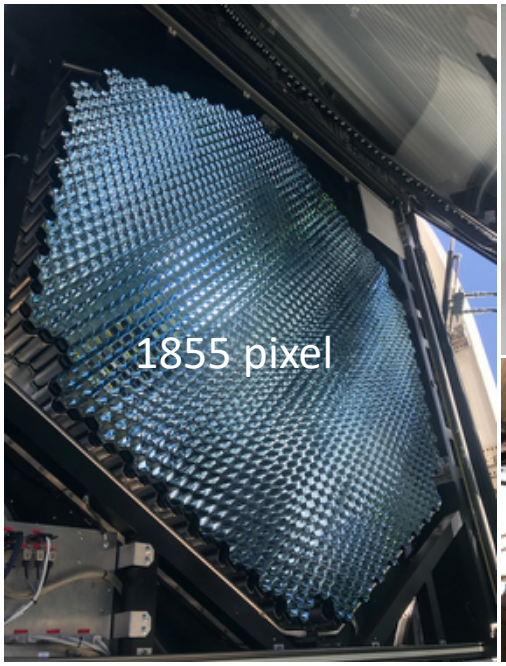


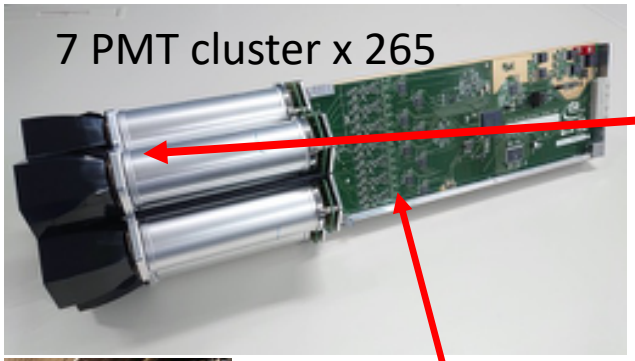


LST1 Mirror Status

- Alignment control is done with LUT
- PSF is smaller than 1 pixel (0.1deg)
  - 0.055deg (80%) @ high altitude
  - 0.066deg (80%) @ low altitude
- Automatic control using CMOS camera image is under commissioning.

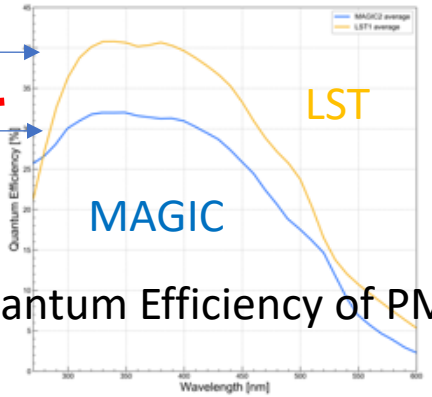
LST: Camera

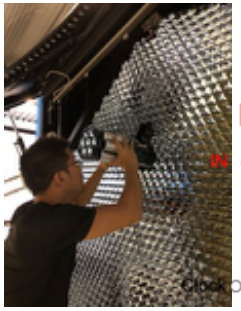


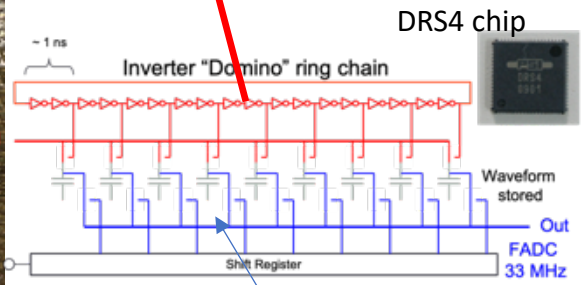


40%

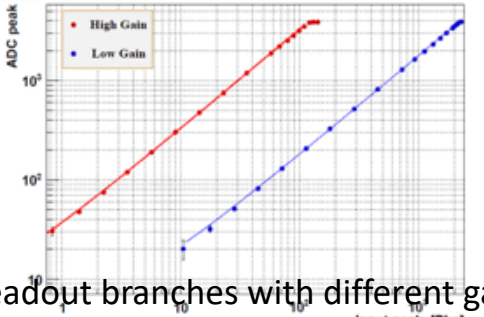
30%



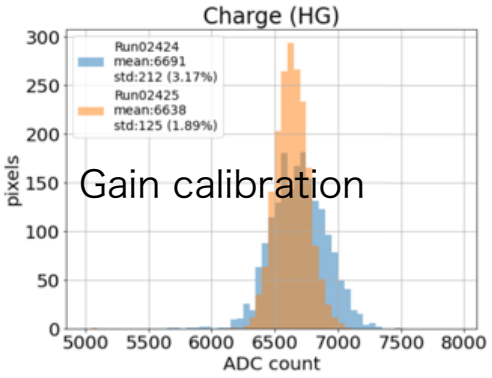




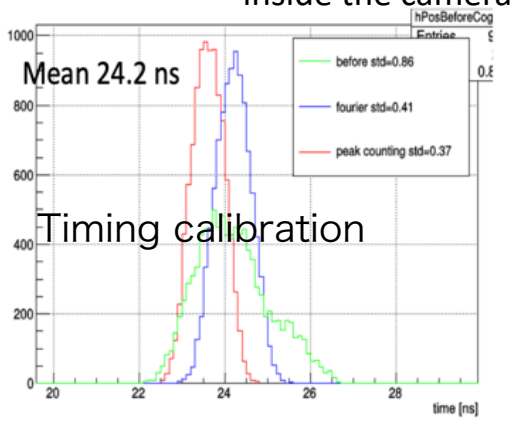
Digitize the signal waveform inside the camera.



2 readout branches with different gain.
0.2 – 3000 p.e./pixel could be measured



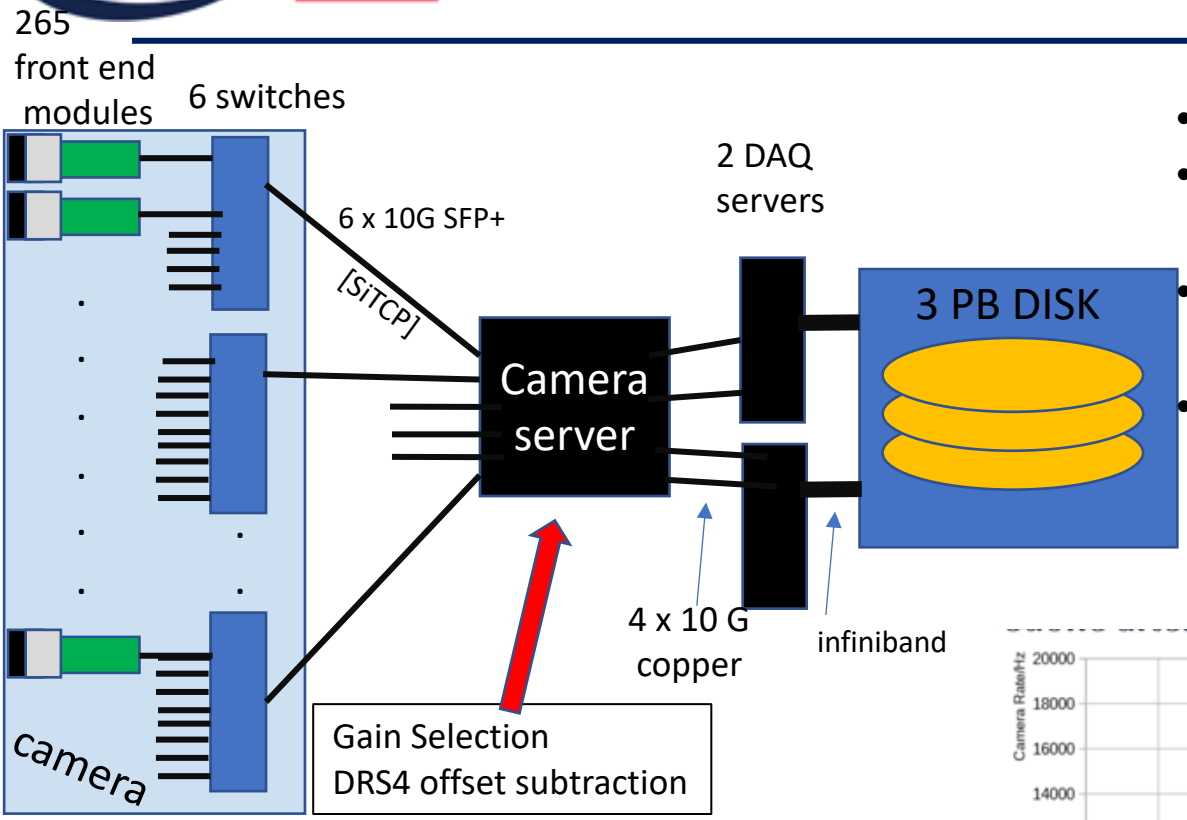
Bad pixels (443, 825) were excluded from calculation of mean and std. dev.



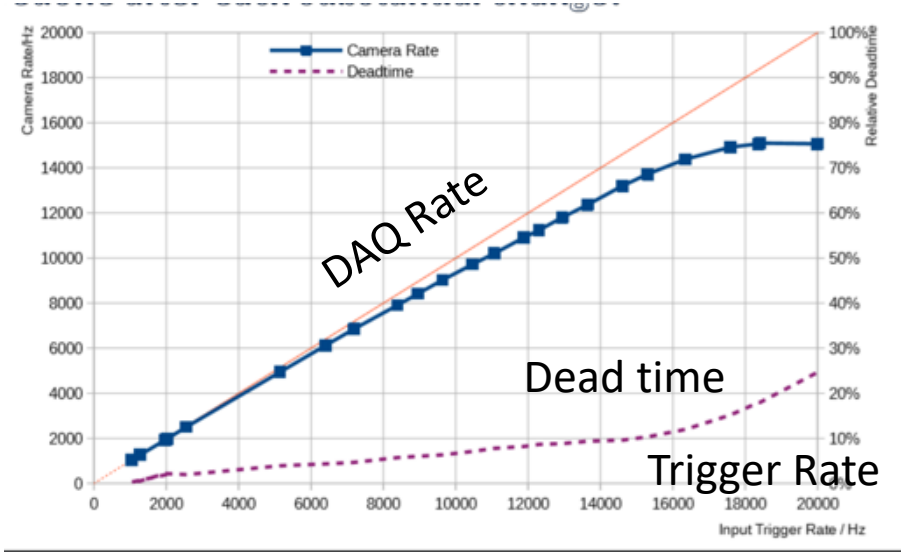
LST1 Camera Status:

- PMT Gain calibrated within 2% precision
- Pixel timing calibrated within 0.4 ns precision
- All 1855 pixels are wokring without a problem

LST: DAQ



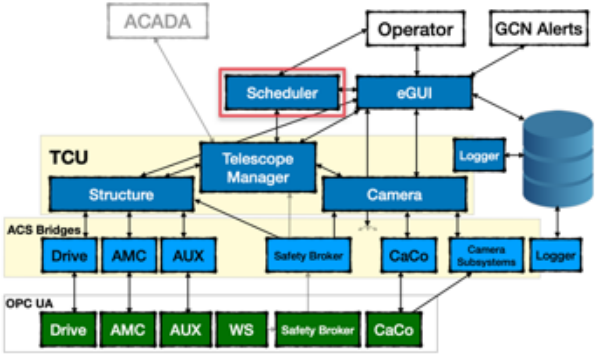
- 1 event = 356 k byte.
- Hardware limit of DAQ bandwidth is 60 Gbit /sec = 7.5 GB/sec.
- Hardware limit of Trigger rate is ~21 kHz
- Requirement
  - 7.5 % dead time at 10 kHz trigger rate
  - 15 kHz DAQ should be. possible

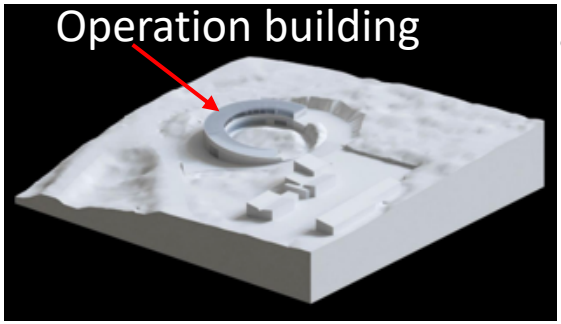


LST1 DAQ Status:

- Requirement has been fulfilled
- Data taking is possible even at 20 kHz trigger rate.

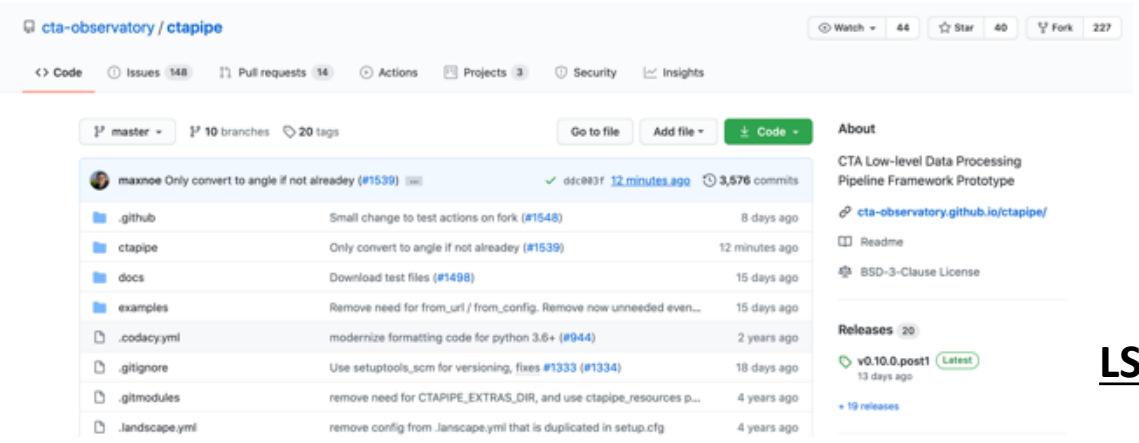
LST: Control and Data Storage





- Tentative IT center is setup next LST1 in a container. Telescope control severs and computing servers are there.
- Total 2000 Cores, 16TB RAMS.
- 3 PB data storage disk
- Array control uses the ALMA Control Software (ACS).
- Data are temporarily stored in the local 3 PiB disk, but will be transferred to PIC/INFN-CNAF
- Operation building is being designed. It will be built in the observatory.

LST: Analysis



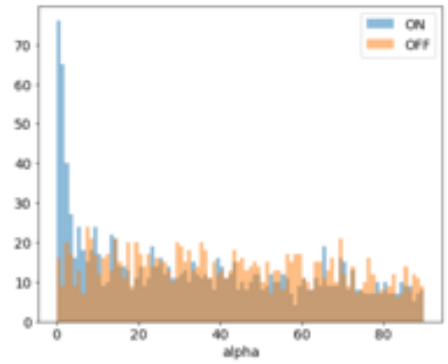
Compare alpha distributions of ON and OFF (only for real data)

In [35]:
```
if datatype == 0:
    # gammaness cut
    data_dl2_off_gamma = data_dl2_off[data_dl2_off['gammaness'] > 0.95]

    # plot alpha distribution
    fig = plt.figure(figsize=(7.5,6))

    plt.hist(data_dl2_gamma['alpha'],     bins=90, range=[0,90], alpha = 0.5, label='ON')
    plt.hist(data_dl2_off_gamma['alpha'], bins=90, range=[0,90], alpha = 0.5, label='OFF')
    plt.xlabel('alpha')
    plt.legend()

    plt.show()
```

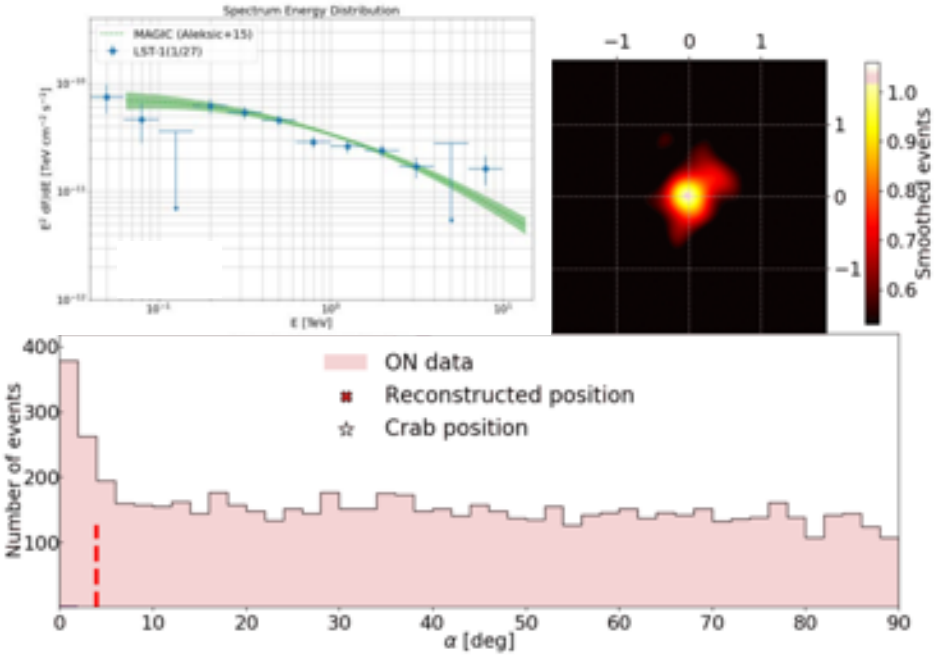


- Python based software "*ctapipe*"
- Currently managed in github

LST1 Analysys Status:

- LST1 specific software package called "*lstchain*" based on *ctapipe* has been developed. (Single telescope analysis)
- Process from the raw data until the gamma-like event list is ready.
- Higher level analysis tool (spectrum/skymap/light curves) are not yet standardized.

LST1recent observations



Crab Nebula, Nov 2019

- First Gamma ray signal

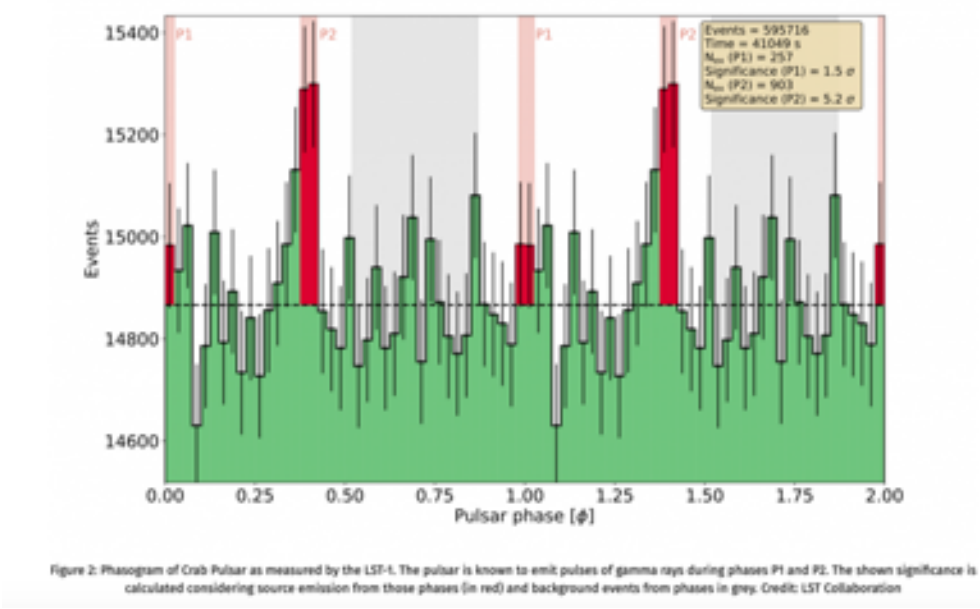
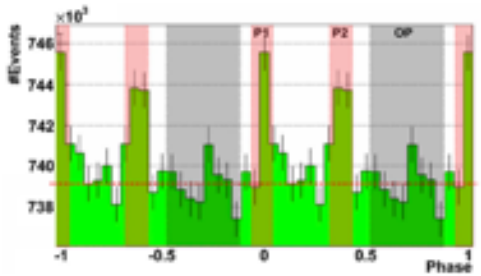


Figure 2: Phasogram of Crab Pulsar as measured by the LST-1. The pulsar is known to emit pulses of gamma rays during phases P1 and P2. The shown significance is calculated considering source emission from those phases (in red) and background events from phases in grey. Credit: LST Collaboration

Crab pulsr, Jan-Feb 2020

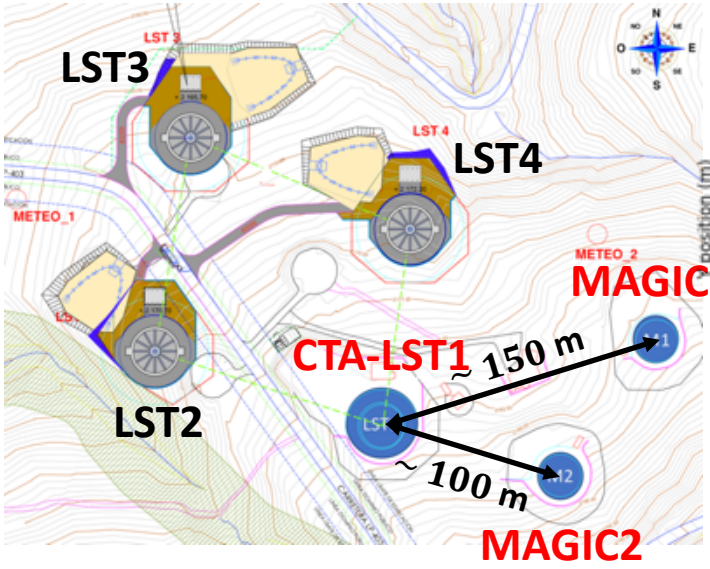
- Prove the low energy threshold
- But P2 is higher. We can even lower the threshold

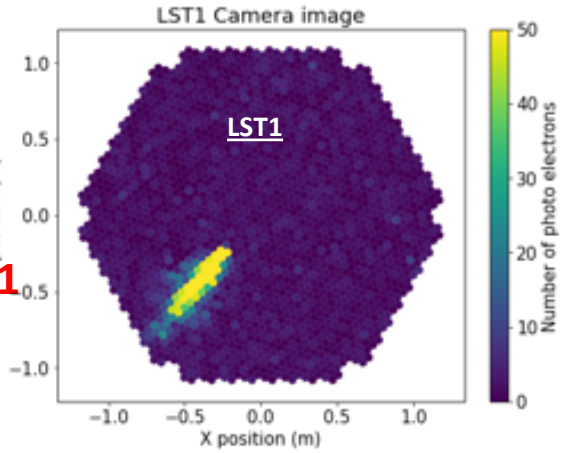
- **Several famous Blazers were also observed and detected without a problem**. Spectral analysis etc is on-going.

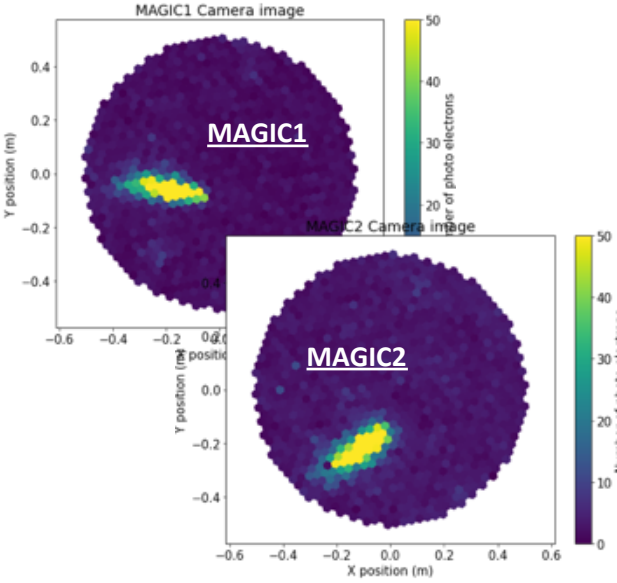


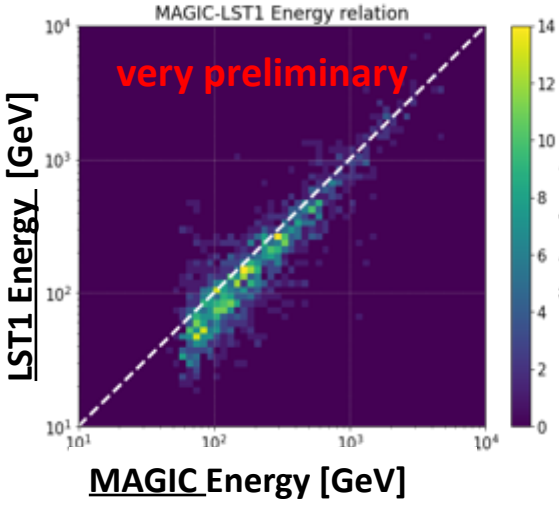
MAGIC >25 GeV

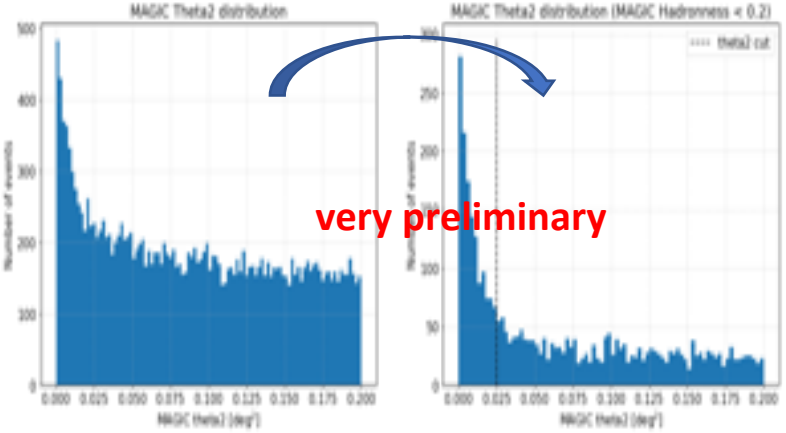
Co-observation with MAGIC











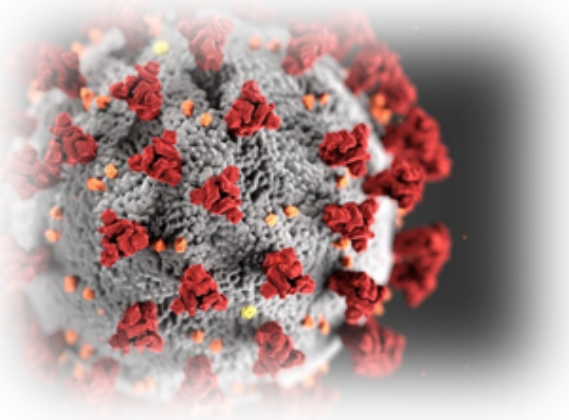
Coincidence with MAGIC

- Cross Calibration
- Higher sensitivity

LST Theta2 plot

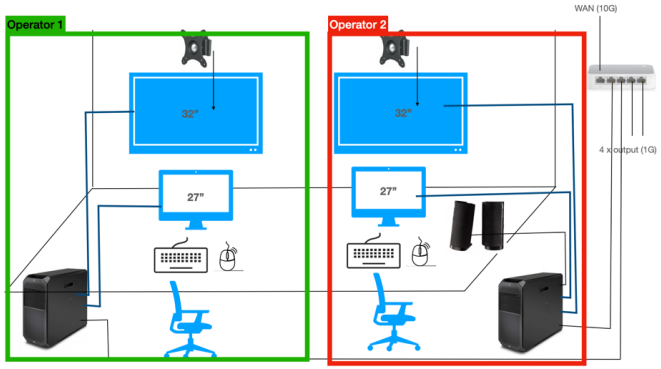
LST Theta2 + MAGIC event selection

COVID 19 on LST1

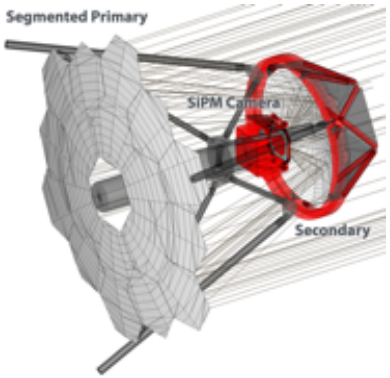


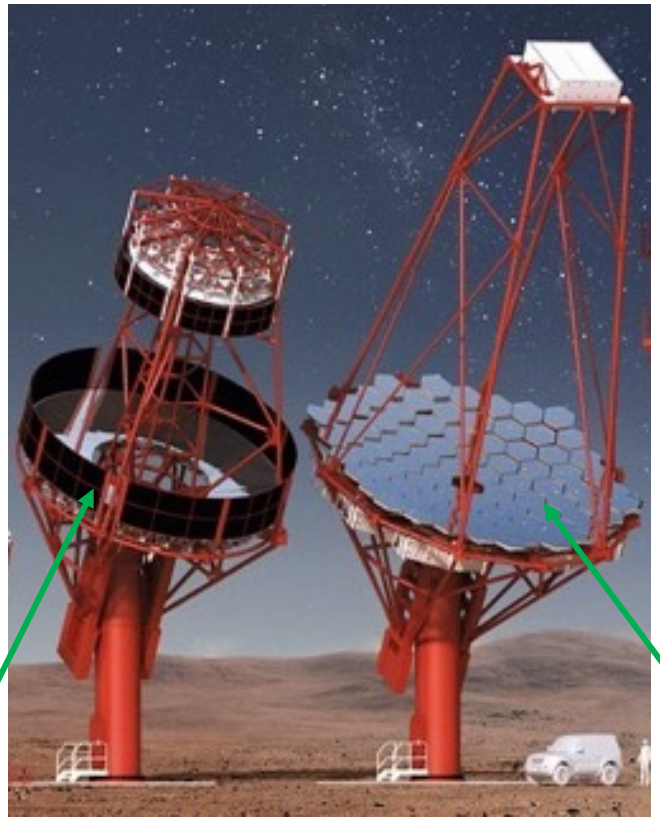
- Shutdown of the telescope from mid March 2020.
- Slowly restarted operation from June 2020
  - with reduced number of shifters (shared with MAGIC shift)
  - with special measure agaist the virus

- Moving toward remote operation.
  - Test remote operation is planned next week.



Different MSTs





Schwarzshild Couder MST

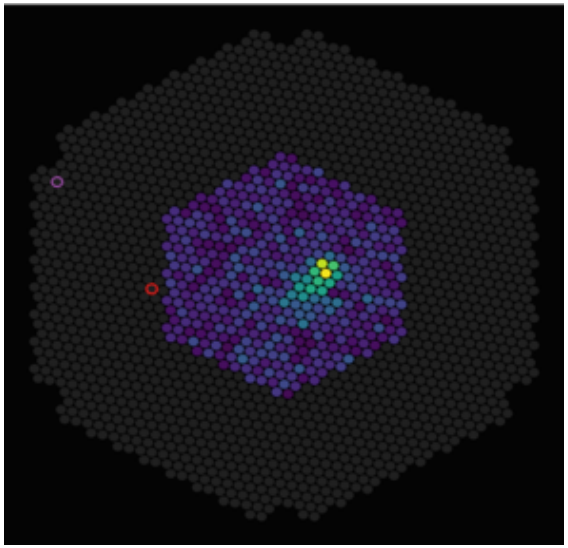
SiPM Camera

Devis-Cotton MST

Nectar Cam

Flash Cam

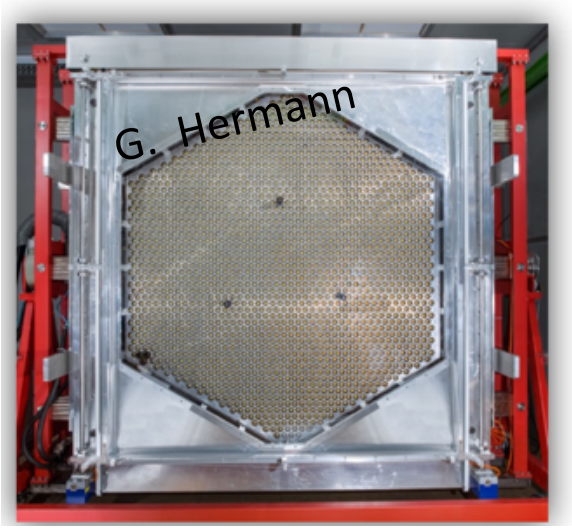
NectarCam-MST



NectarCam-MST

- Similar to LST Cam. (Same Number of pixels but wider FoV (8 deg).
- Backplane, Trigger interface board, DAQ program are the same as LST.
- Well tested in the lab and in the Berlin prototype tel.

FlashCam-MST

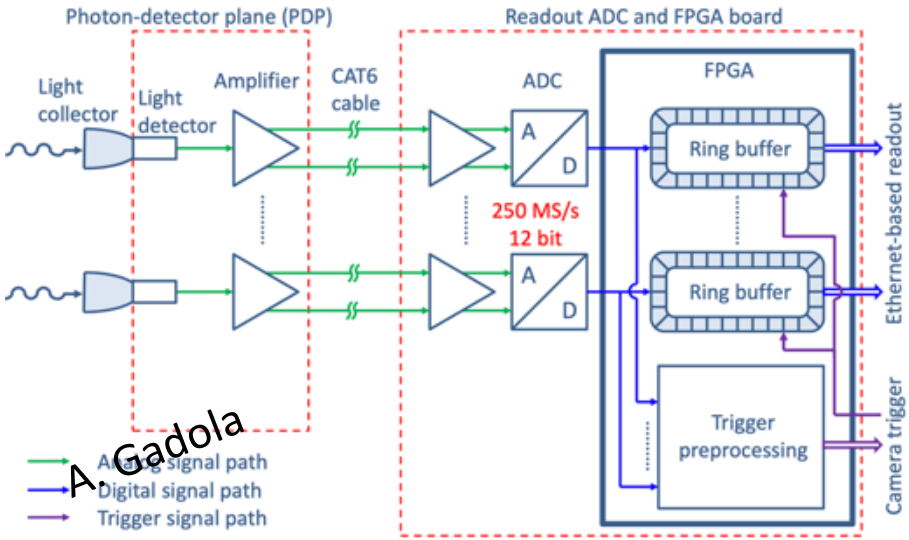


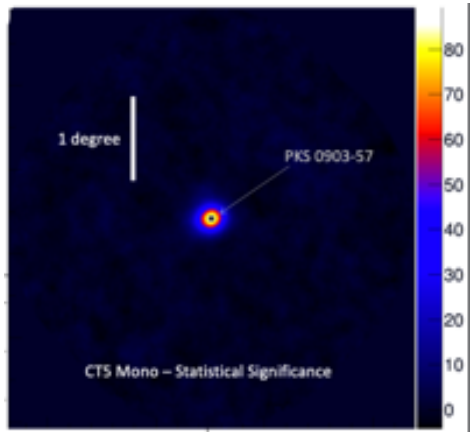
FlashCam for MST:
- 1758 pixels
- 7.7 deg FoV
- 3 m x 3 m wide
- < 2000 kg

- Fully digital on-board signal processing
- Deadtime-free up to > 30 000 events/sec
- Large dynamic range 0.2 .... > 3000 p.e.
- Low power consumption of < 4.5 kW (verified)

The same camera was mounted on the HESS II telescope one year ago.

One year of routine operation was a very useful experience.





- 98.7% availability.
- Very good consistency with simulations.
- Very stable

Ready to be implemented in CTA.

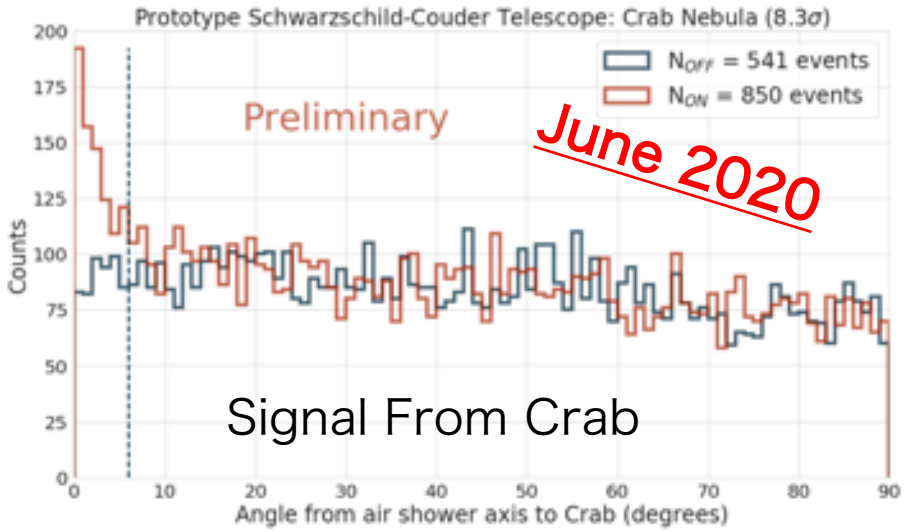
Schwarzshild Couder MST

Optics:

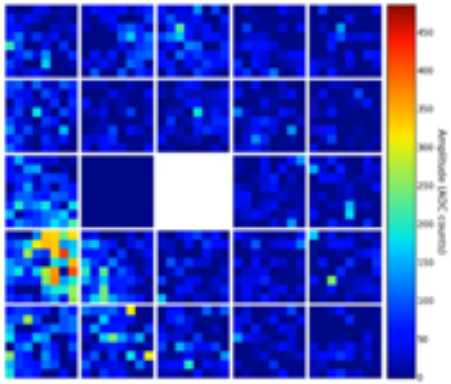
- Primary (D～9.7m)
- Secondary (D～5.4m)

Camera:

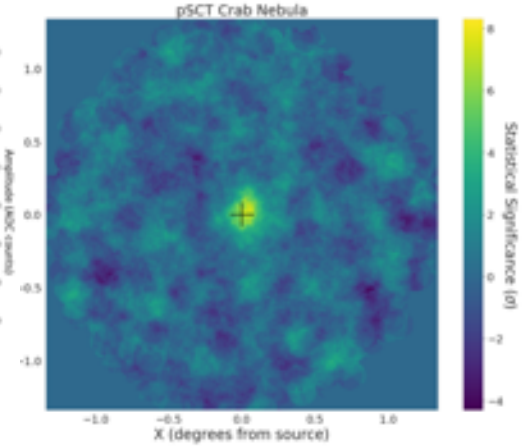
- FoV 8 deg
- SiPM～11k pixel



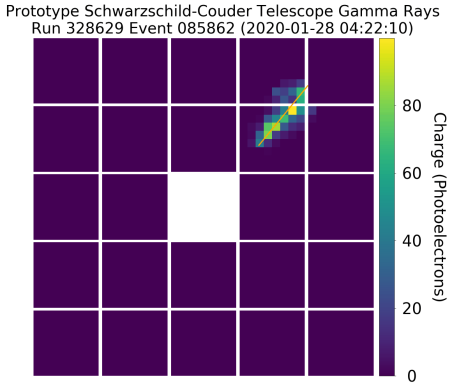
SiPM Camera



Cherenkov Image



Crab Nebula skymap



Gamma-ray Event

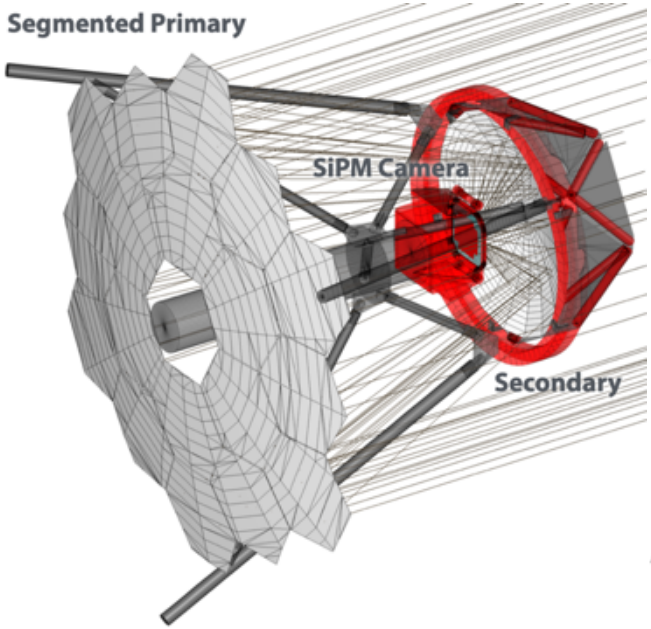
SST

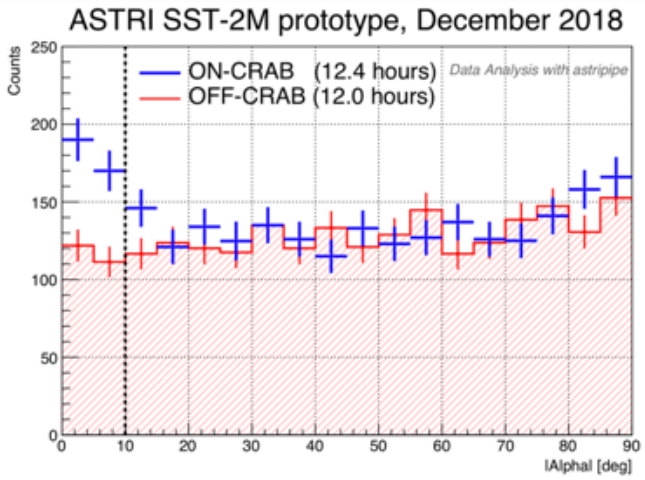
Compact High-Energy Camera (CHEC)

Credit: Christian Föhr (MPIK)

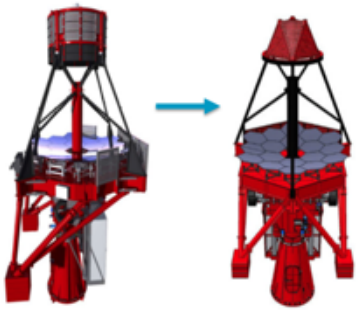
Performance is proven.

Still improving the design.





Alpha-plot of the ASTRI-Horn observation of the Crab Nebula performed in December 2018. Observations were performed pointing toward the Crab Nebula for 12.4 hours (blue crosses) and then pointing to another field without any gamma source for another 12 hours in order to evaluate the background (red crosses). Comparing the excess of counts in the direction of the Crab Nebula versus the background clearly shows the detection of the Crab Nebula.



total rotating structure 18597 kg
total telescope 24719 kg

total rotating structure 15390 kg
total telescope 17464 kg

CTA Phase I and the enhancement in CTA CB and BP

COST Book 2020		CTA Construction	CTA Enhancement
Northern Array	Number of LSTs	4	0
	Number of MSTs	5	10
Southern Array	Number of LSTs	0	4
	Number of MSTs	15	10
	Number of SSTs	50	20
Total		74	44

Business Plan 2016

Site	Telescope	Baseline Number	Threshold Scenario	Priorities Beyond Threshold
CTA-South	LST	4		4
	MST	25	15	
	SST	70	50	
CTA-North	LST	4	4	
	MST	15	5	+5

LST Timeline

- 2021-2023
  - Deployment of 3 more LSTs, and 5 MSTs in CTA North
  - Study the Advanced Design and Prototyping, and create budgets for LST South
- 2024-
  - Operation of CTA North will start
  - Construction of LST South (by Switzerland, Japan, Italy-INAF, Germany-MPP,,,)

<table>
<tr><th></th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th></tr>
<tr><td rowspan="2">LST North</td><td colspan="4">Comissioning and Operation of LST1</td><td colspan="5" rowspan="2">CTA North starts the operation with 4 LSTs and 5 MSTs</td></tr>
<tr><td>CDR</td><td colspan="3">Deployment of LST2-4</td></tr>
<tr><td>MST North</td><td colspan="2">Design and Finance</td><td colspan="2">Construction of 5MSTs</td></tr>
</table>

<table>
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<tr><td>LST South</td><td></td><td colspan="3">Advanced Design and Proto / Finance / CDR</td><td colspan="3">Construction of 4LSTs</td><td colspan="2">Operation</td></tr>
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<table>
<tr><th></th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th></tr>
<tr><td rowspan="2">Organization</td><td colspan="3">CTAO gGmbH</td><td colspan="6"></td></tr>
<tr><td></td><td colspan="8">CTAO ERIC (European Research Infrastructure Consortium)</td></tr>
</table>

<table>
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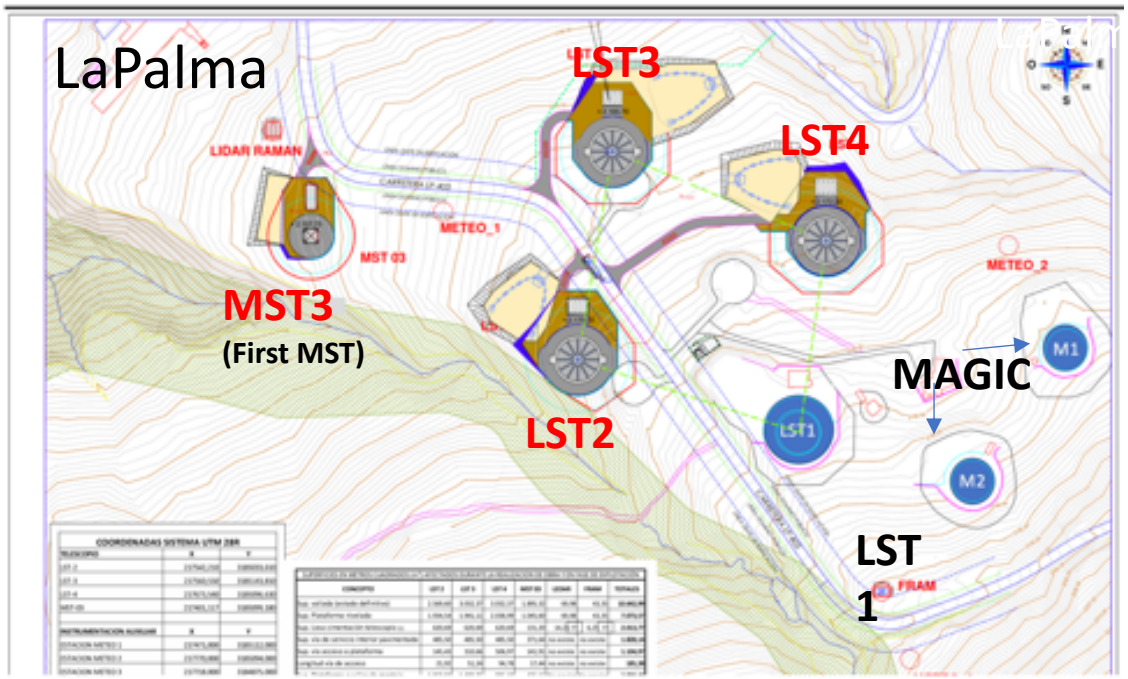
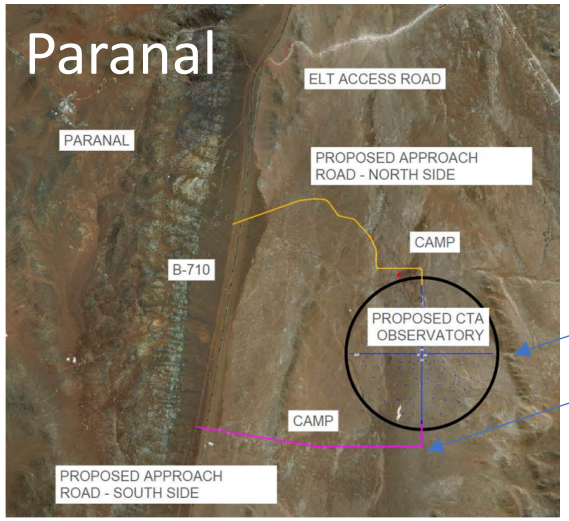
<tr><td rowspan="2">CTA South</td><td colspan="2" rowspan="2">Design and Finance</td><td rowspan="2">INFRA</td><td colspan="3">Construction and Deplyment of 15 MSTs</td><td colspan="3">Operation of 15 MSTs</td></tr>
<tr><td colspan="3">Construction and Deployment of 50 SSTs</td><td colspan="3">Operation of 50 SSTs</td></tr>
</table>

CTA North/South construction 2021



❑ CTA-North

- The location of LST2,3,4 and MST3 has been decided.
- Paths of power lines and trigger exchange optical fibers have been decided.
- Foundation contstruction will start.
- Mirrors facets are already in LaPalma
- PMT modules are in Tenerife, and their performace need to be tested there.



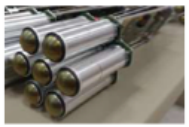
Location of CTA-South

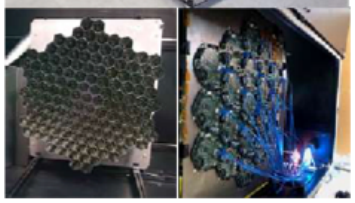
❑ CTA-South

- As soon as ERIC (European Research Infrastructure Consortium) has been established, the construction of infrastructure will start.

This access road will be constructed first.

LST2-4 construction





- Basically the copy of LST1

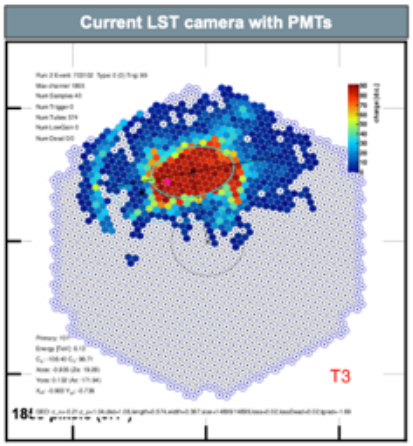
- Budget is OK
- Most of the elements are procured

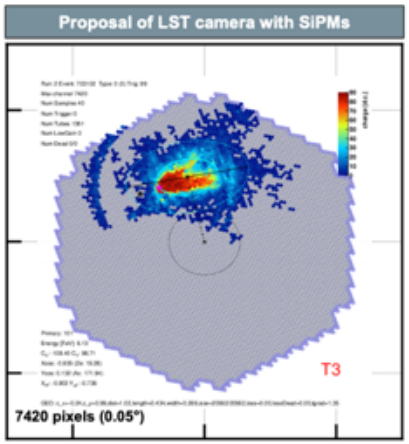
- Construction permission (including enviromental assessment) on the site has been given.

- Some tests (e.g. quality control of the PMT modules) were delayed due to COVID, but no major impact on the overall schedule (so far).

Study for future upgrade of LST

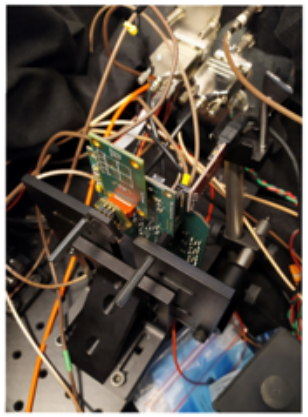
The camera





- Finer pixel may improve the sensitivity.
- SiPM may have better performance than the conventional PMTs.
- CNN technique may improve the analysis than the conventional parametrization analysis.

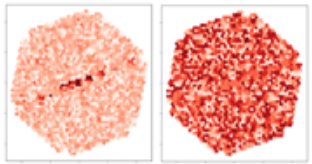
MUSIC ASIC



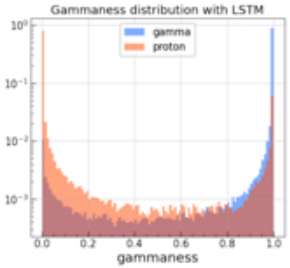
D. Gascon, at al. «MUSIC: An 8 channel readout ASIC for SiPM arrays», ICC-UB

Images

p.e. image, arrival_time

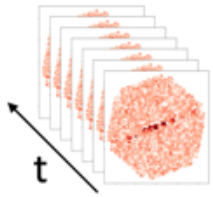


Straightforward adaptation of CNN from other fields



Waveform

Calibrated waveform



Sensitive for CR features

Studies on these topics are on-going intensively.

(This camera may be used in LST-South?)

Summary

- LST adopted several **new technologies**. Most of them are already working well. LST1 is operating successfully.
- MSTs, SSTs are also almost **ready to be deployed** in the arrays
- Construction of **LST2-4 and MST3** will start in 2021 in CTA-North.
- ”Phase I” will be completed in 2023 in CTA-North, and in 2025 in CTA-South, followed by further enhancement.
- The upgrade beyond the plan is already being studied.

Backup