

Satellite-based Calibration of the TAIGA-HiSCORE Cerenkov Array by the LIDAR on-board CALIPSO.

Andrea Porelli for The TAIGA Collaboration

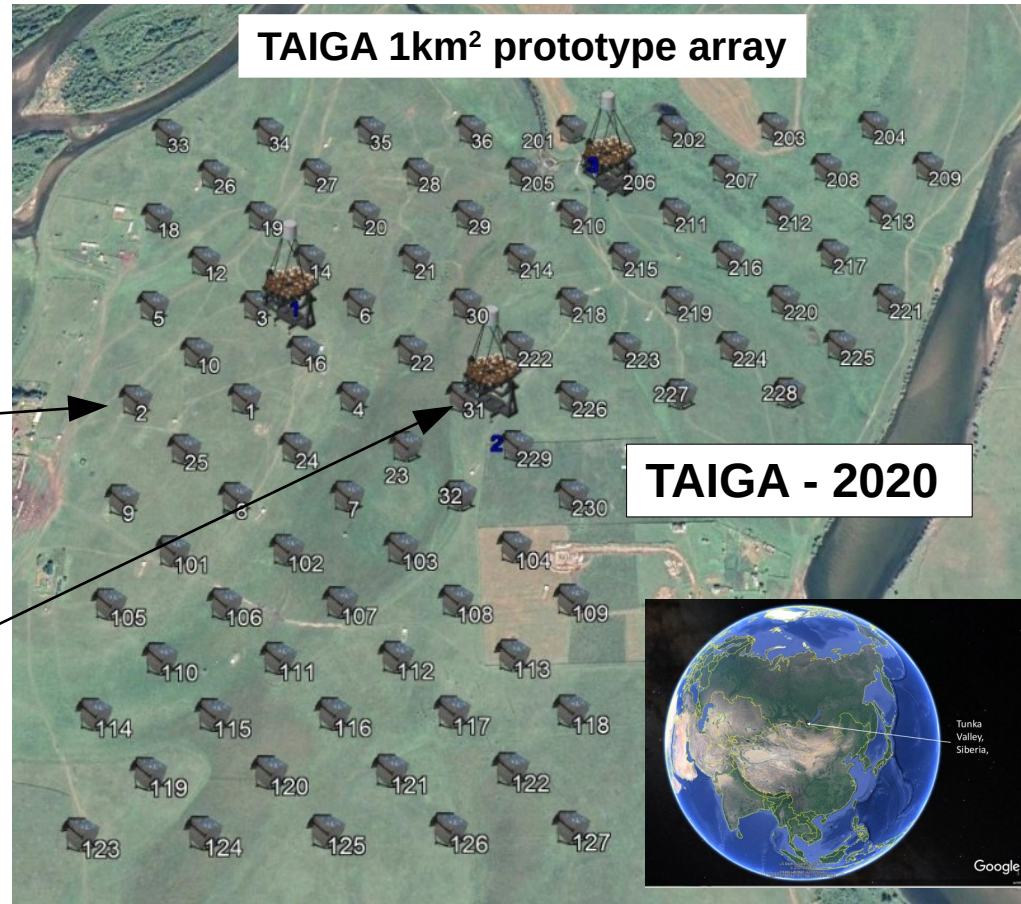
ICRC 2021, Berlin, 12-23 July 2021



TAIGA Observatory

Hybrid detection concept for Gamma Astronomy above 30TeV and Cosmic Ray Physics above 100TeV

- 1) **TAIGA-HiSCORE**: integrating Air Cherenkov timing array – 120 stations
- 2) **TAIGA-IACT**: 2 telescopes operating
Telescope 3 in construction
- 3) **TAIGA-Muon**: 240m² sparse surface and underground particle detectors



More info: [TAIGA overview talk - N.Budnev](#)

TAIGA-HiSCORE

EAS reconstruction: angular resolution and pointing precision

HiSCORE inside TAIGA: provide accurate EAS core and direction reconstruction. The required 0.1° angular resolution and an absolute pointing of 0.1° are achieved thanks to:

- A precise time calibration of unknown station time offsets (*Hybrid array calibration**)
- A sub-nsec relative time synchronization between the array stations

Angular resolution and pointing precision verification

- Angular resolution: experimentally verified using the *Chessboard**
- Pointing accuracy: usually used detected gamma point sources - no sources detected so far with HiSCORE. Need for alternative methods

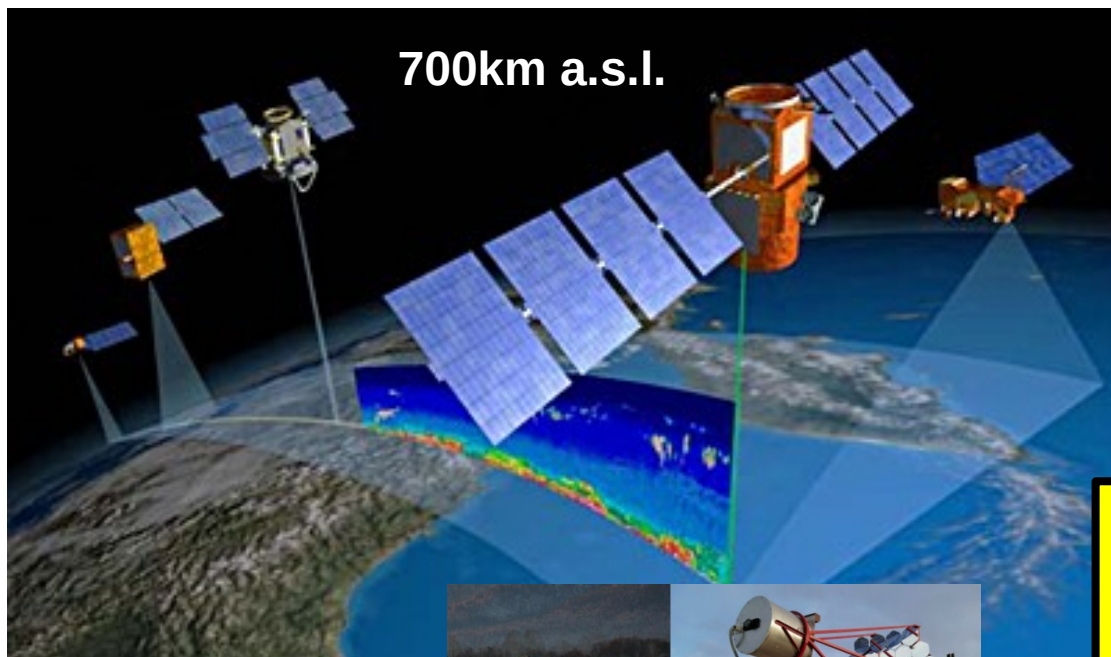
First detection of space-based LIDARs: CATS on the International Space Station (ISS)

- 11 detections with TAIGA-HiSCORE between 2015-17
- Unique tool for array calibration and performance verification (absolute pointing)
- Other detected LIDARs: **CALISPO**, CloudSat2

**from more details, see [HiSCORE: 5yrs analysis - A.Porelli, ICRC21](#)*

CALIPSO

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation



"The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite provides new insight into the role that clouds and atmospheric aerosols (airborne particles) play in regulating Earth's weather, climate, and air quality."
<https://www-calipso.larc.nasa.gov/>



Signal seen by TAIGA:
20Hz rate
532nm laser
110mJ/pulse (x100 ISS/CATS)
20ns pulse width

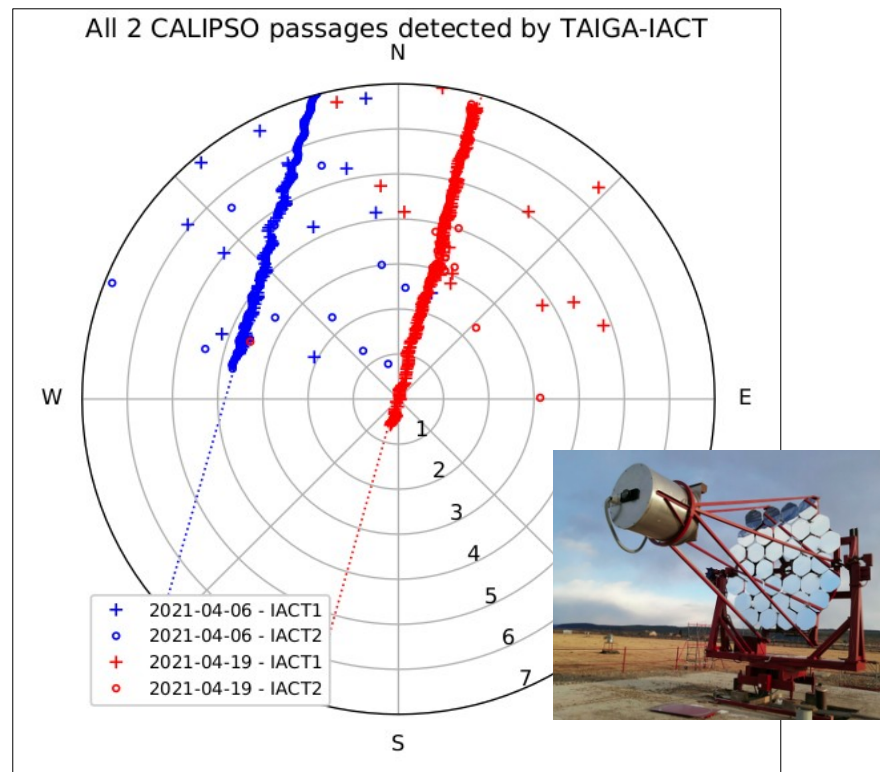
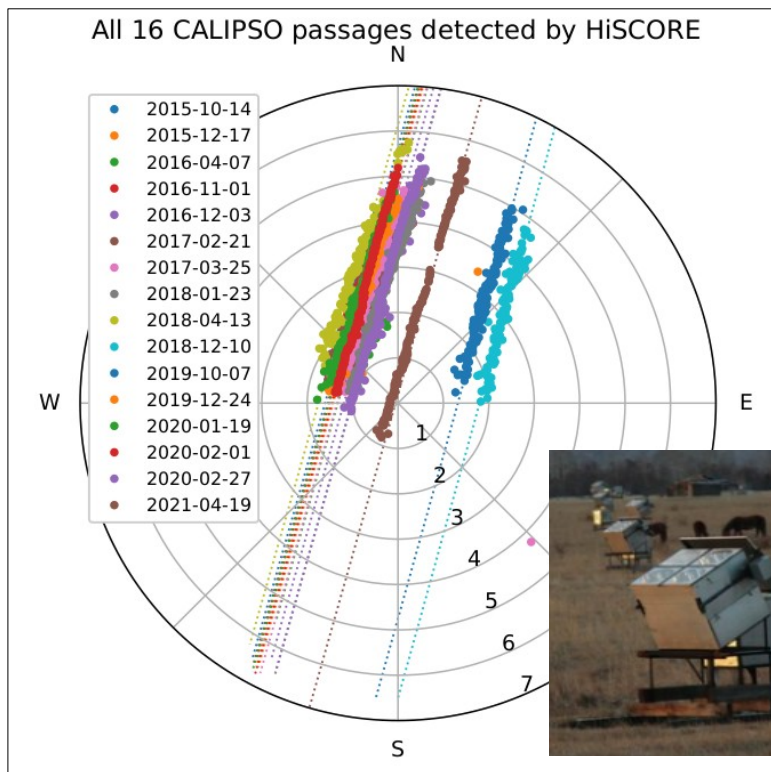
See also talk [HiSCORE fast transient](#) - A. Panov

CALIPSO detection with TAIGA Observatory

- **HiSCORE: 16 passages seen between 2015-2021 (archival analysis)**
- **IAC: 2 passages seen with both TAIGA-IACs in April 2021 (targeted observation)**

CALIPSO

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation



*Satellite track prediction obtained with sgp4 propagator and public TLEs

See also talk [HiSCORE fast transient - A. Panov](#)

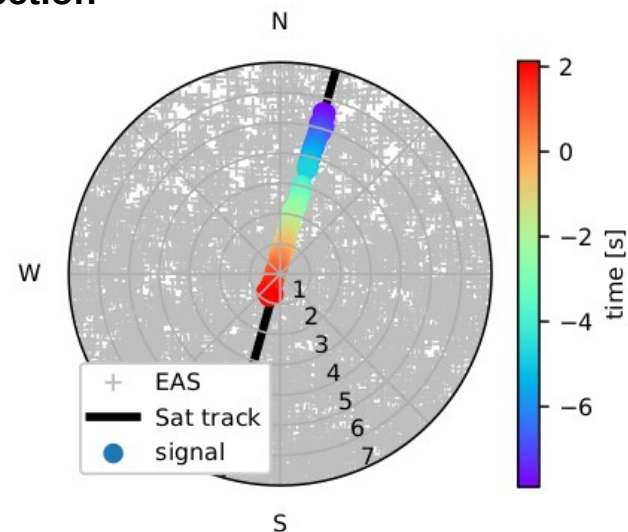
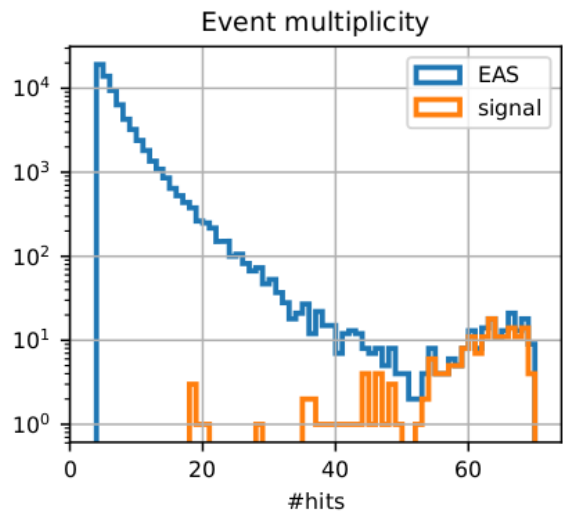
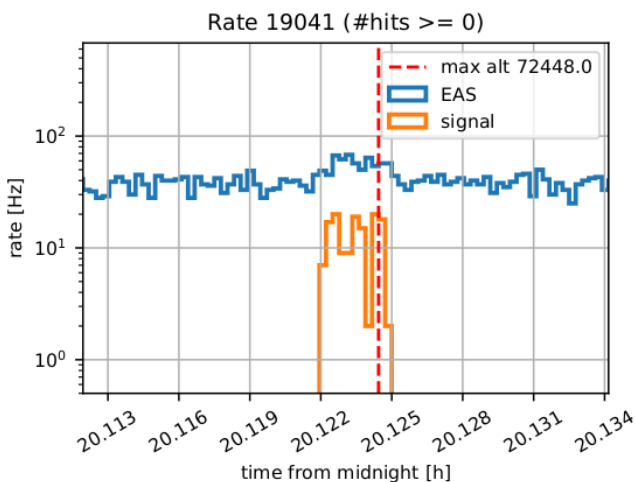
CALIPSO detection with TAIGA Observatory

- HiSCORE: 16 passages seen between 2015-2021 (archival analysis)
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CALIPSO and TAIGA-HiSCORE

Detection and verification

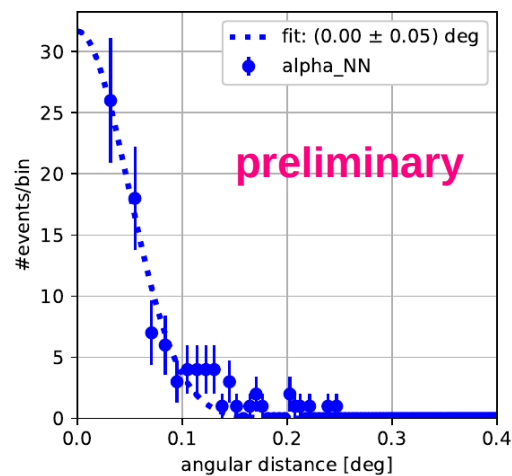
Passage: 19.04.21 – soft event selection



Excellent plane wave reconstruction from next-neighbour events comparison

- Satellite motion not taken into account
- Preliminary upper limit estimation

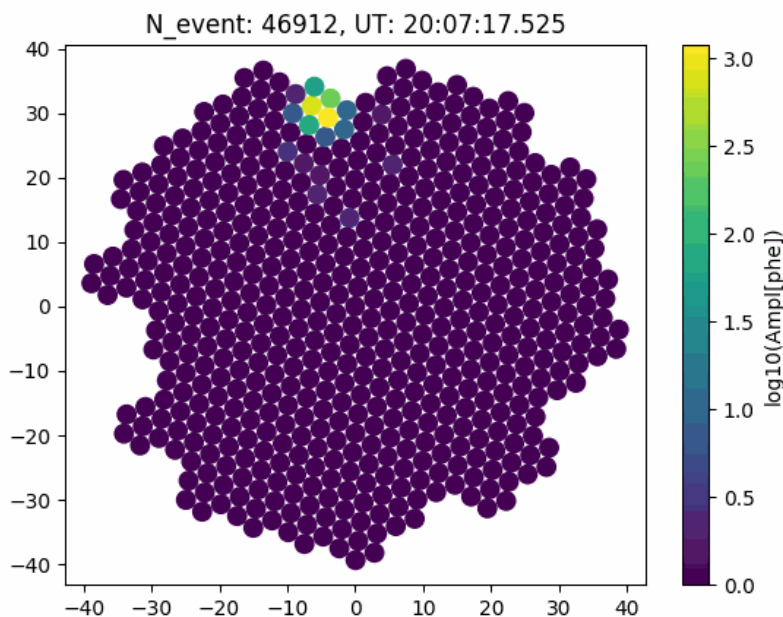
$$\alpha_{68\%} = \frac{\vec{dir}_i \cdot \vec{dir}_{i-1}}{\sqrt{2}} \leq 0.05^\circ$$



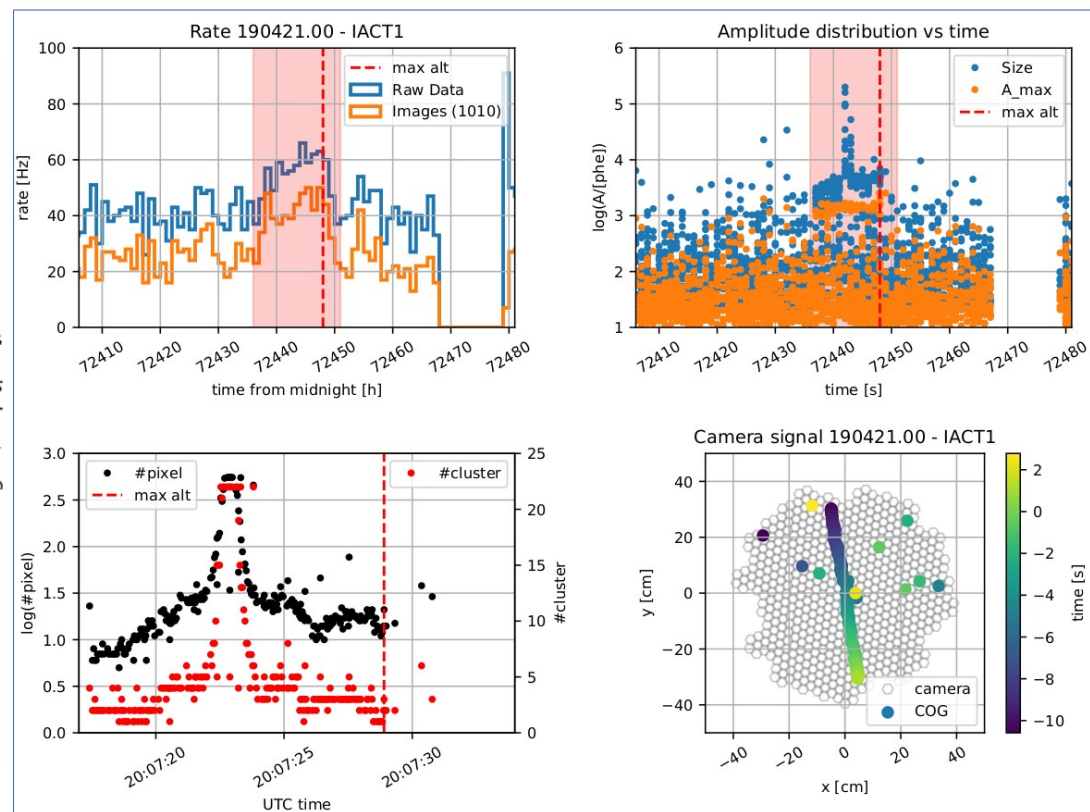
CALIPSO and TAIGA-IACT

Passage: 19.04.21 - IACT#1

Detection and verification



Credit: E.Gress (ISU, Irkutsk)



- **Event characterization:** Large image size (pixel saturation during close-by CALIPSO passage)
- **Direction reconstruction:** Image amplitude COG ($\text{Amp}_{\text{pix}} \geq 10\text{phe}$)
- **LIDAR signal can be used to verify IACTs tracking accuracy (pointing, camera rotation, etc.)**
Good agreement (preliminary) with standard TAIGA-IACT calibration

TAIGA-HiSCORE calibration

Absolute pointing and internal timing

Absolute LIDAR position available with limited accuracy

- SGP4 propagator + TLEs: unknown systematic uncertainties

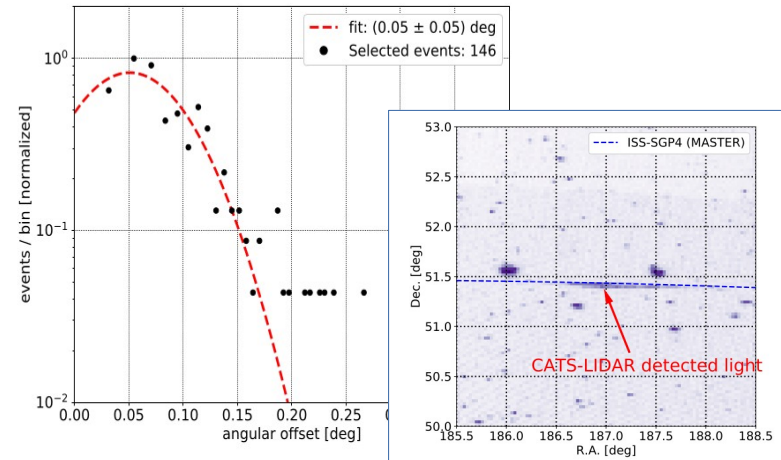
ISS/CATS - we used external localization by the on-site MASTER optical telescope. Obtained:

- HiSCORE pointing accuracy $\leq 0.1^\circ$
- Time calibration difference: rms ~ 1.5 ns

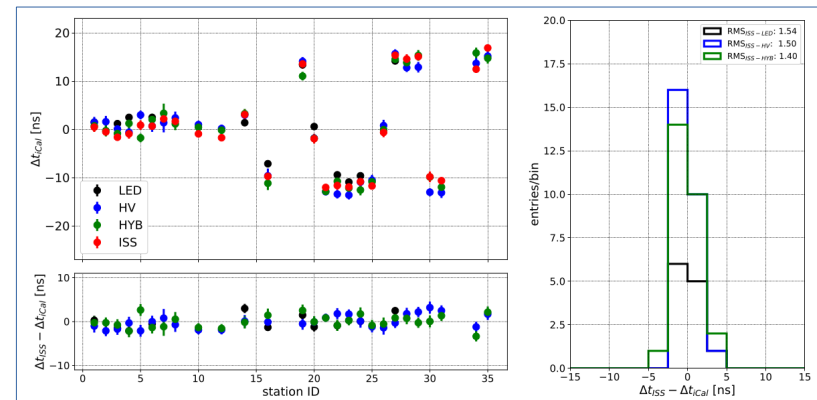
NEW IDEA: TAIGA-IACT for precise localization of CALIPOS LIDAR:

- Use as reference for HiSCORE pointing verification
- Perform time calibration of HiSCORE stations (LED-like calibration)
- *work in progress*

HiSCORE-MASTER pointing



Station time calibration with ISS/CATS



Summary

- **TAIGA established ground-based detection of satellite LIDARs**
 - CATS-ISS: 11 passages in 2015-2017 with HiSCORE (first ground-based satellite LIDAR detection)
 - CALISPO: 16 passages with HiSCORE (2015-2021) – 2 passages with IACT since 2021
- **Space LIDARs: a unique tool for**
 - detector calibration and verification (sub-nsec timing, angular resolution, absolute pointing)
 - Extraterrestrial light flashes
 - Atmospheric light propagation studies
- **CALISPO observation by other detectors**
 - VERITAS: multiple detections (Foote, G. *et al.*, 238th AAS meeting). Routine observation started
 - CTA-LST: observation started
 - Cross calibration between different experiments (e.g. Cosmic Rays ground arrays)

Thank you

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Backup slides