

CTA Large Size Telescopes

Status, Plans, and First Results



MPP Project Review, December 2021

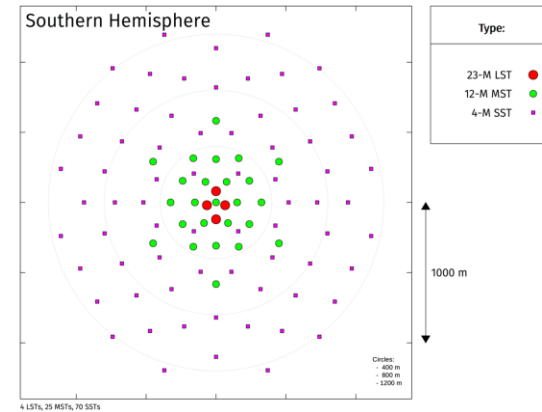
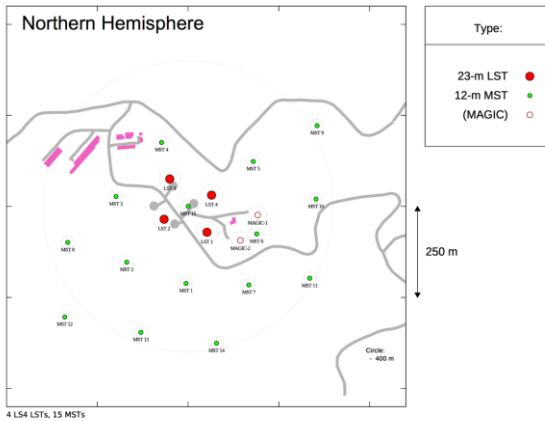
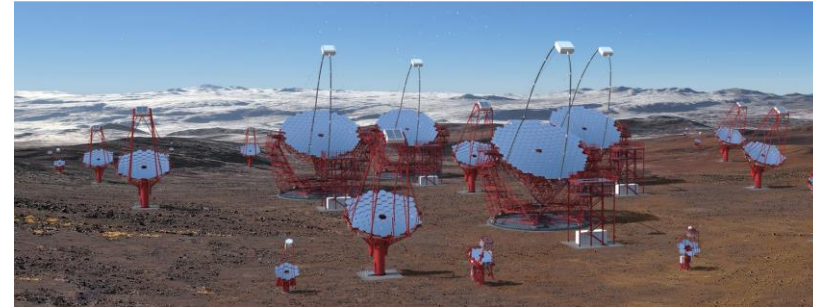


MAX-PLANCK-INSTITUT
FÜR PHYSIK



Martin Will
on behalf of the LST-CTA group

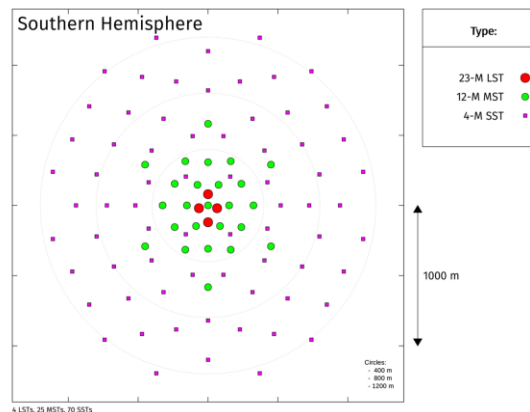
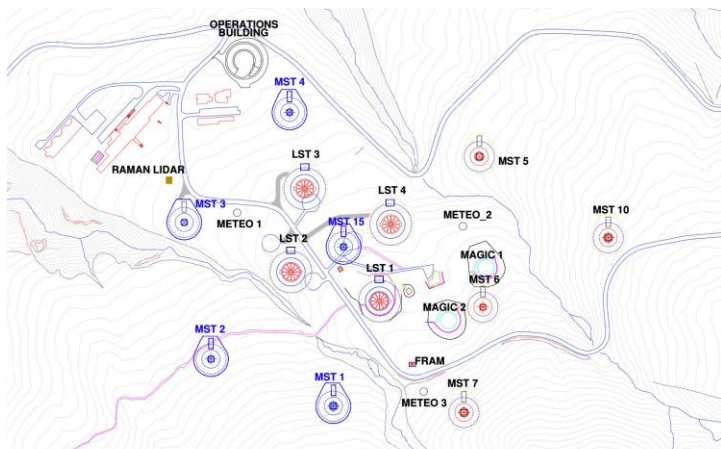
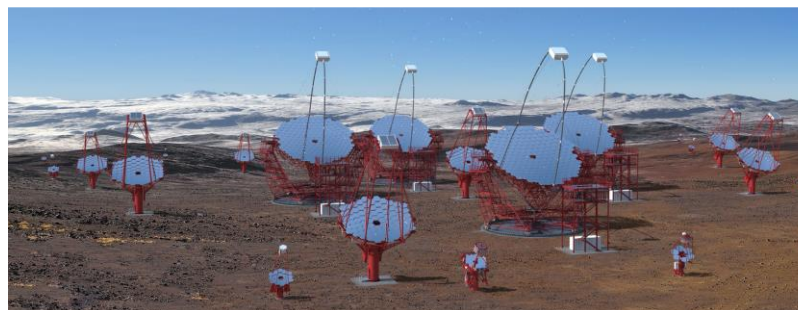
Cherenkov Telescope Array



- Northern site (baseline)
 - ▶ ORM, La Palma
 - ▶ 20 GeV to 20 TeV
 - ▶ **4 LST**, 15 MST

- Southern site (baseline)
 - ▶ Paranal, Chile
 - ▶ 20 GeV to 300 TeV
 - ▶ **4 LST**, 25 MST, 70 SST

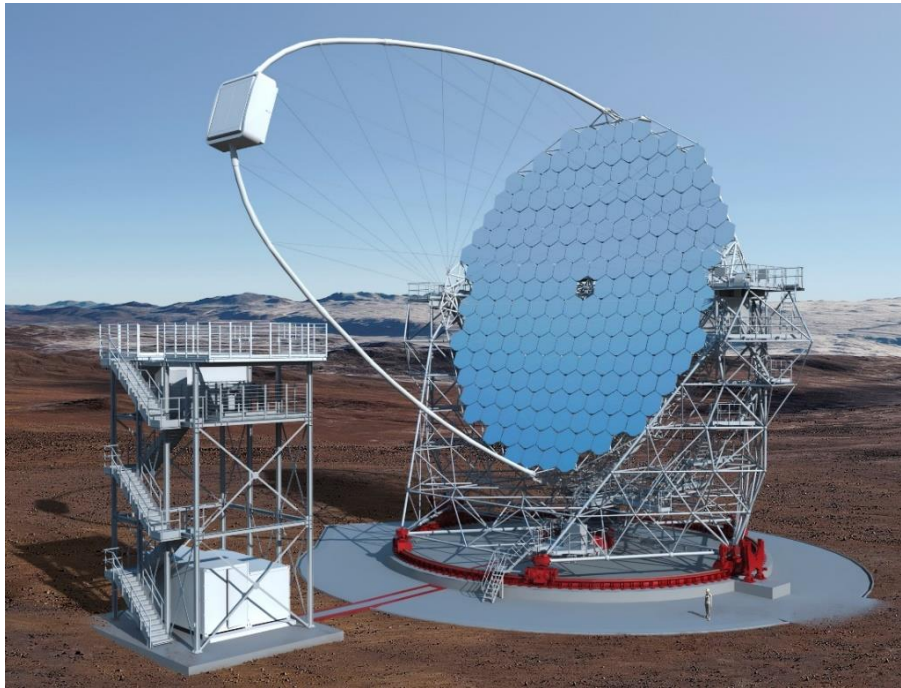
Cherenkov Telescope Array



- Northern site (Alpha)
 - ▶ LST 1–4 + MST 1 ongoing
 - ▶ MST 2 to 5 tender open now
 - ▶ MST 6 to 9 tender in 2022

- Southern site (baseline)
 - ▶ Paranal, Chile
 - ▶ 20 GeV to 300 TeV
 - ▶ **4 LST**, 25 MST, 70 SST

Large Size Telescope (LST)



- Energy range: 20–150 GeV (3 TeV)
- Camera: 1855 PMTs, FoV 4.5°
- Focal length: 28 m
- Parabolic mirror: 23 m, 400 m²
- Pointing precision: < 14 arcsec

- Tubular CFRP / steel structure
 - ▶ Total moving weight: ~100 tons
 - ▶ Repositioning speed: 10 deg/s
 - ▶ Repositioning to any point: < 30 s



LST Collaboration



- 11 Countries
- > 40 Institutions
- ~ 350 members (scientists, engineers, technicians, ...)

- CTA-LST Group at MPP

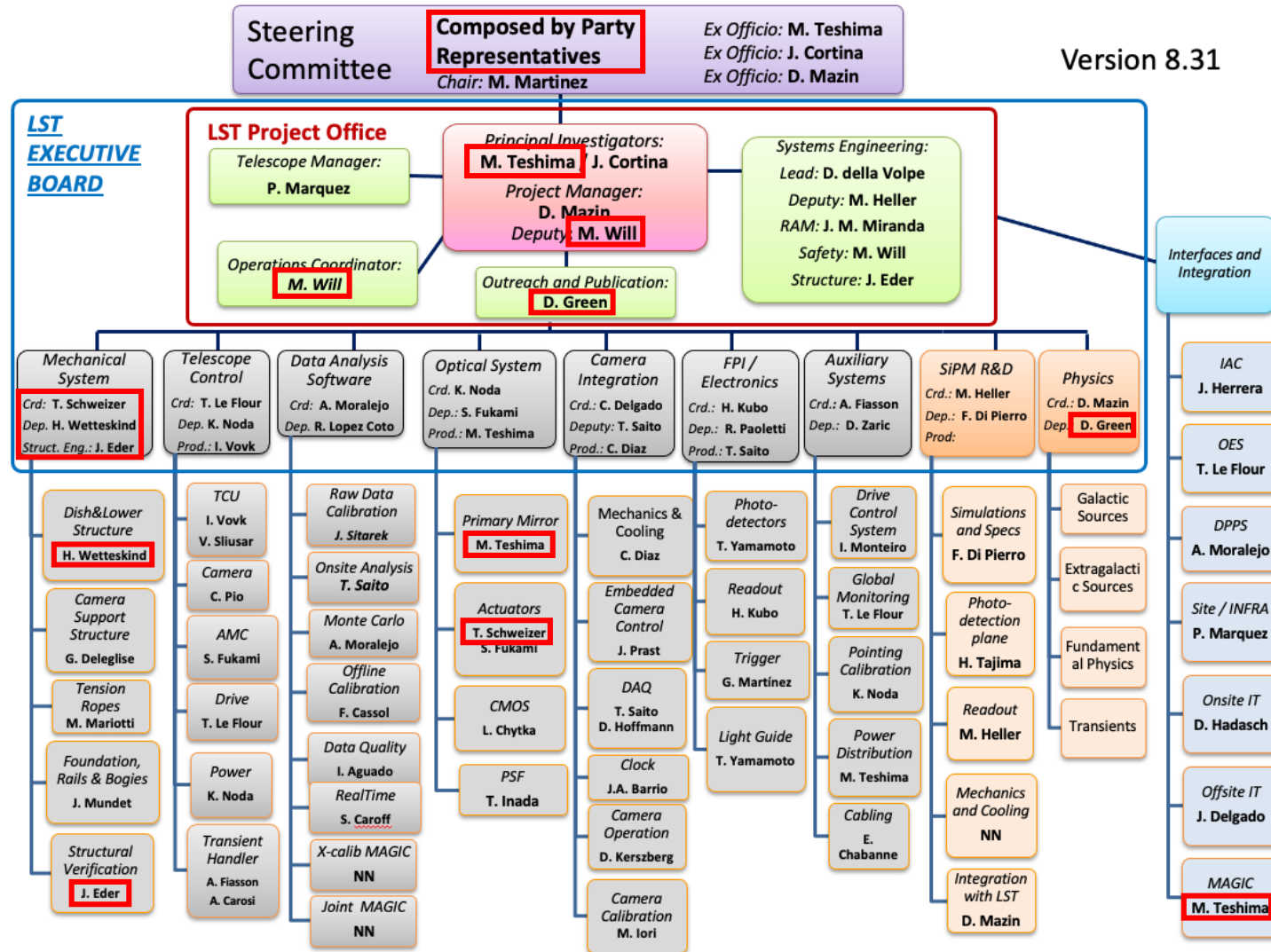
M. Teshima, T. Schweizer, M. Will, D. Green, A. Berti,
G. Pirola, J. Green, L. Heckmann, E. Jobst, Y. Ohtani (Guest from ICRR)

- Big thanks to the MPP construction, electronics, and the workshop!
H. Wetteskind, Ch. Jablonski, R. Stadler, T. Dettlaff, J. Schlammer, S. Horn, ...

- LST Common Fund Administration at MPP

M. Will, D. Werner, A. Fleischer, J. Wimmel

LST Organigram



- Added Physics Board
- Added MAGIC+LST
- Strengthened Systems Engineering

CDR Closure / Acceptance

- Critical Design Review
 - ▶ Review of LST design by CTAO and external panel in October 2019
 - ▶ Passed in 2020 by solving several major comments
 - ▶ Closure of CDR delayed to 2022 due to last minute changes in trigger architecture by CTAO, requires bigger change in Event Builder.

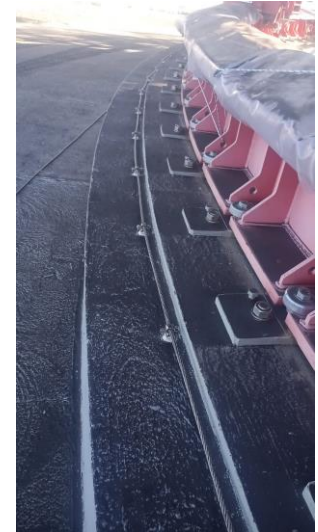
- Acceptance of LST-1 by CTAO
 - ▶ Solve open software and hardware non-conformities
 - ▶ Finish documentation, conformity reports, manuals
 - ▶ Start delayed to Q3 2022
 - ▶ Train CTAO personnel in operations and maintenance

PHASE		CONSEQUENCES on LST-1					
Name	No.	Operated by	Operation cost by	LST-1 Ownership	Liabilities & Risk	Maintenance by	
						Preventive	Corrective
CDR close-out	0A	n/a	n/a	n/a	n/a	n/a	n/a
LST internal commissioning	0B	LST	LST	LST	LST	LST	LST
Engineering Testing Phase	1	LST	LST	LST	LST	LST	LST
Integration Testing Phase	2	LST/CTAO	SHARED?	LST	LST	LST	LST
System performance testing	3	LST/CTAO	SHARED?	LST	LST	LST	LST
Warranty period operation	4	LST/CTAO	SHARED?	CTAO	CTAO	CTAO	LST
Normal Operation	n/a	CTAO	CTAO	CTAO	CTAO	CTAO	CTAO

time ↓

Volcano

- Volcano eruption on Cumbre Vieja started September 19
 - ▶ Longest lasting eruption in recorded history
 - ▶ Massive damage (houses, plantations, tourism, ...)
 - ▶ Severe travel restrictions due to frequent airport closures
- Impact on LST (20 km from volcano)
 - ▶ Telescope operations stopped, sensitive areas covered
 - ▶ Frequent cleanup of ash (abrasive, paramagnetic)
 - ▶ Restart once volcano stops and site is inspected and cleaned
 - ▶ New bending model due to seismic activity

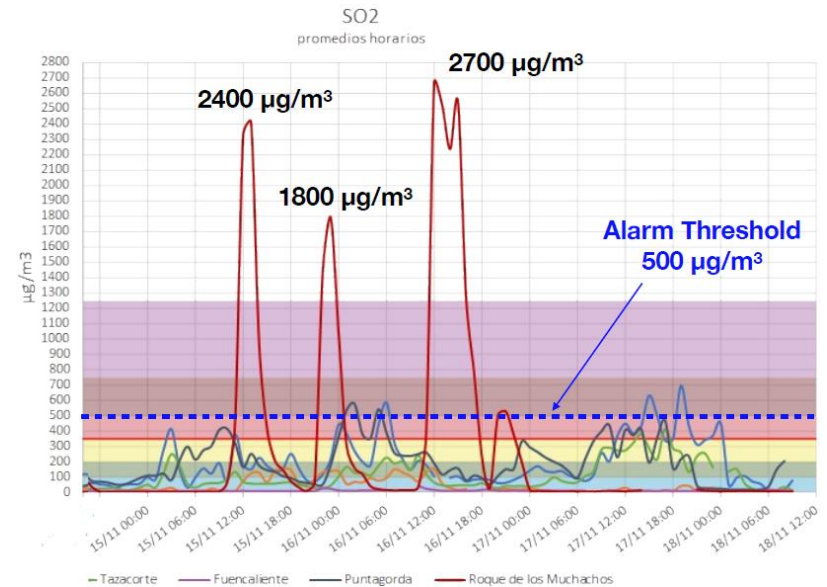
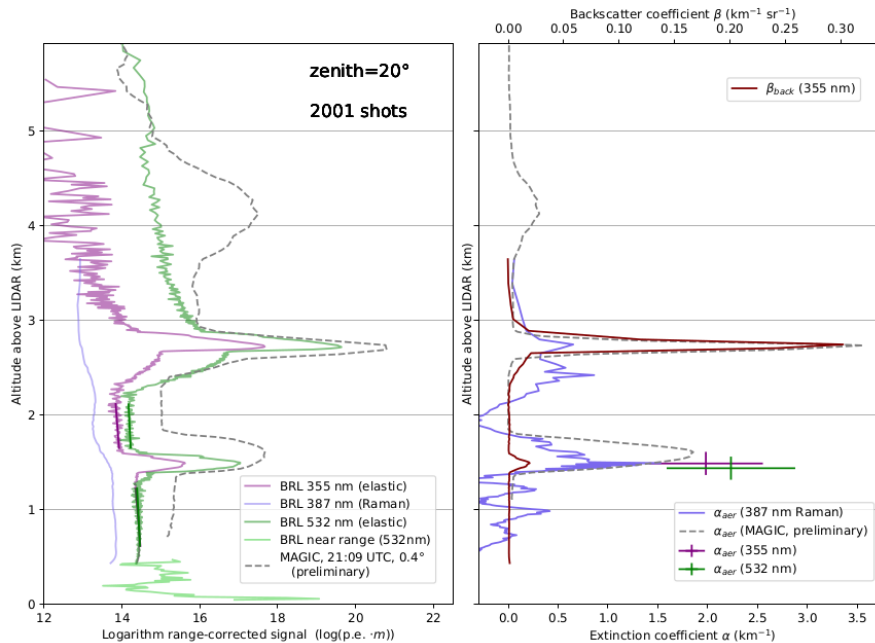


Volcano

- Atmospheric / geologic / seismic measurements
 - ▶ 3 LIDARs at ORM measuring aerosol data: MAGIC + 2 CTA Raman LIDAR pathfinders with clear detection of volcanic ash layer
 - ▶ New sensors to measure concentration of SO₂: hazardous for people, possible H₂SO₄ with water



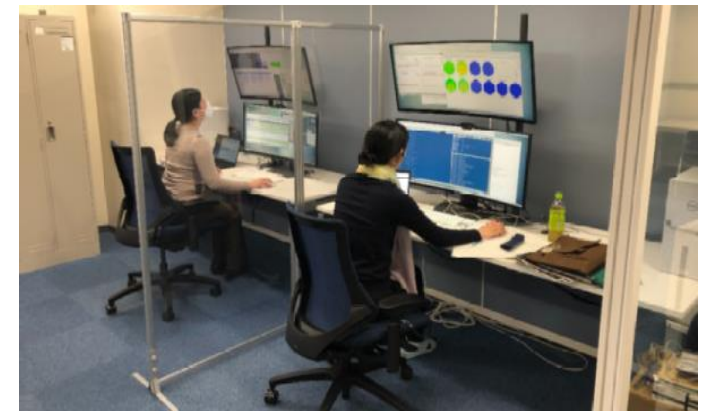
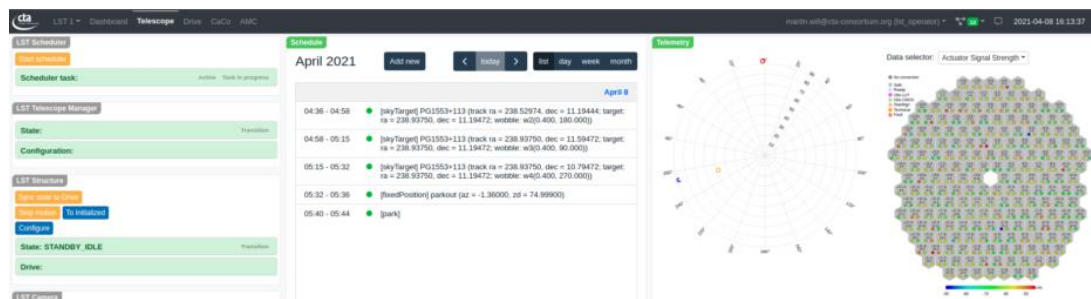
Michele Fiori



- Camera
 - ▶ **Solved most remaining issues**
 - ▶ New camera shutter works well
 - ▶ Some software issues remain
 - ▶ Trigger calibrations not complete
- Optics
 - ▶ **Non-conformity: detached mirror on Feb 25 during storm, singular failure in production**
 - ▶ Control software almost finished
 - ▶ Online mirror adjustment mode still pending, hopefully in 2022
 - ▶ Not at nominal PSF (< 25 mm), but achievable
- Mechanics
 - ▶ **Protections against icefall and solar radiation installed**
 - ▶ Park-in/park-out issues solved
 - ▶ Lightning protection to be finalized
- Other
 - ▶ Pointing precision ~ 21 arcsec, needs some improvement
 - ▶ Central control working well, still under development
 - ▶ **Transient Alert System online**

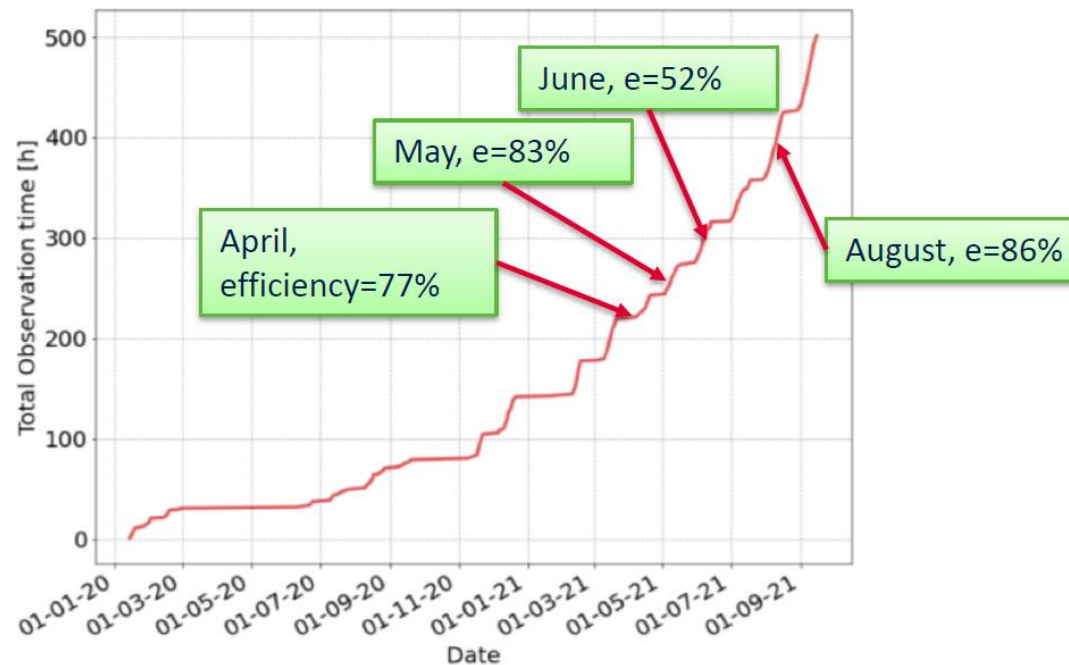
COVID Impact (Good Part)

- Software development increased a lot
- Commissioning of automatic systems
 - ▶ Locking systems (azimuth, elevation, camera)
 - ▶ Park-out, park-in procedures
 - ▶ Strong involvement of MPP team
- Improvement of remote control
 - ▶ Browser-based telescope control
 - ▶ IR webcams
 - ▶ Various control rooms
 - ▶ Semi-remote operations in 2021



Data Taking

- More than 500 hours taken since January 2020
 - ▶ Test-free week once per month to stress the system
 - ▶ Goal (CTA requirement) is $> 95\%$ availability
 - ▶ Not yet at 95%, summer was spent chasing bugs and then we got a volcano



We can use this data for some first results...

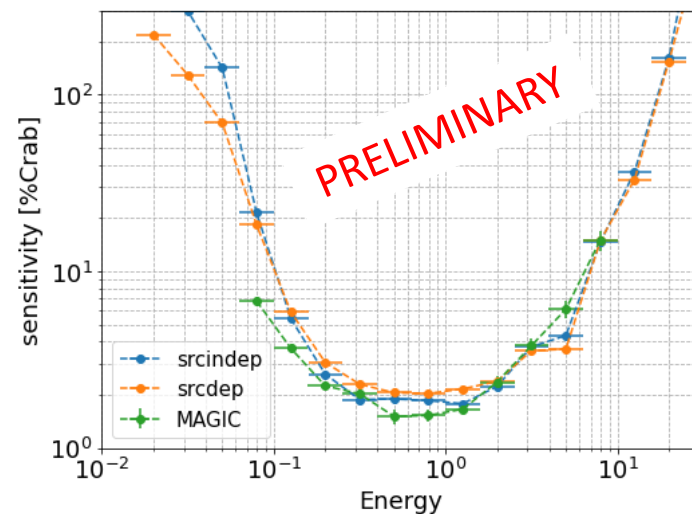
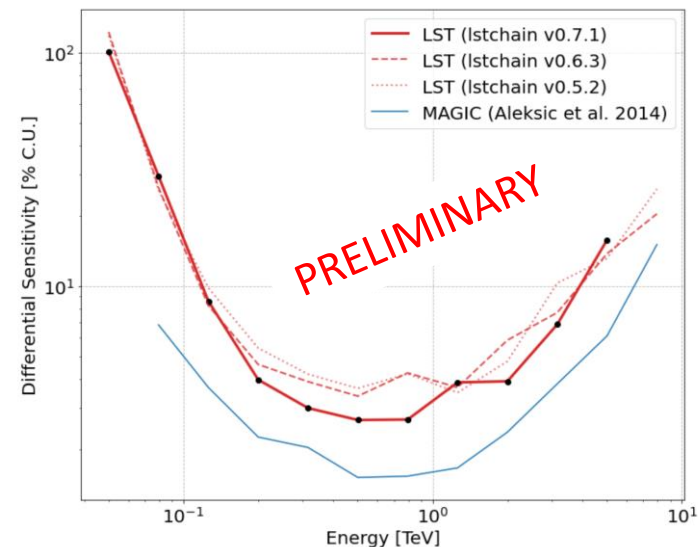
Results: Sensitivity

■ Evolution of sensitivity

- ▶ 30 hours from Nov 2020 to Mar 2021
- ▶ Wobble mode (standard observations)
- ▶ With absolute image cleaning (8,4) plus interleaved pedestals and time constraints
- ▶ Steady improvement with continued analysis software development

■ Source-dependent analysis

- ▶ Improvement for point-like sources, known position used in reconstruction
- ▶ Better sensitivity and energy resolution below 80 GeV (important for LST)



Results: BL Lac

- ATel submitted on 13th July 2021
 - ▶ CTA's first "published result" on extragalactic AGN outburst
 - ▶ Demonstrating LSTs capabilities for quick analysis and validation of transient results

Detection of very-high-energy gamma-ray emission from BL Lac with the LST-1

ATel #14783; **Juan Cortina for the CTA LST collaboration**
on 13 Jul 2021; 21:03 UT

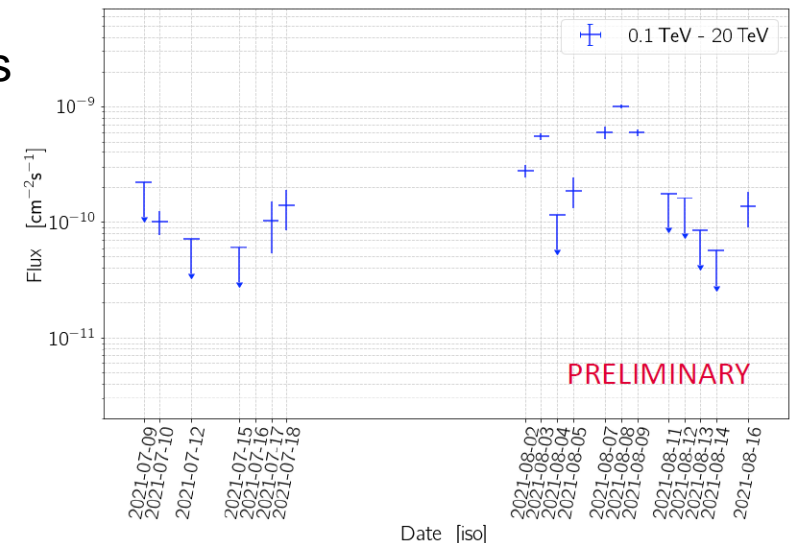
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

Referred to by ATel #: 14820, 14826, 14839

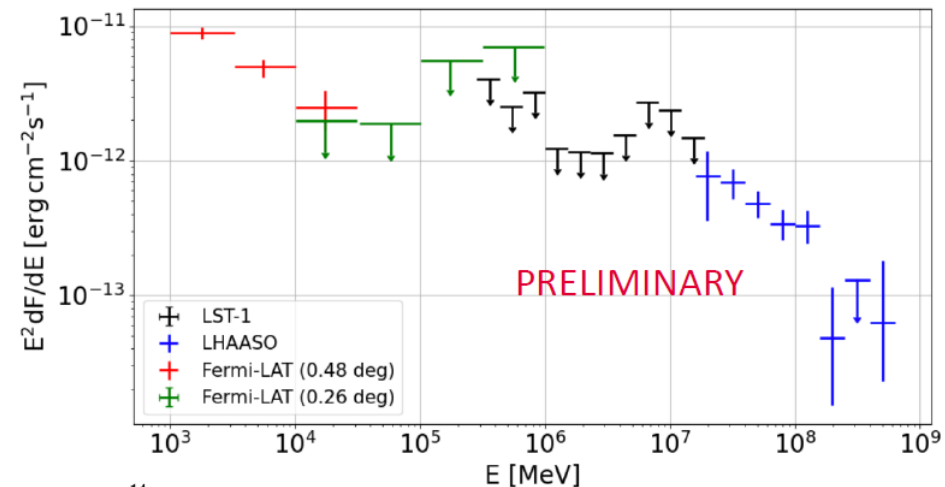
- Flare on Aug 8, 2021
 - ▶ Bright flare allowed application and comparison of different analysis methods
 - ▶ Analysis performed using source-dep., source-indep., and likelihood analysis
- Collected data from July/August allowed to calculate long-term and intra-night light curves

BL Lac light curve from 2021 LST data



Results: LHAASO J2108

- Discovery by LHAASO Collaboration (Nature, 2021)
 - ▶ Detected photons above $E > 100$ TeV
 - ▶ Makes it a possible candidate for PeV cosmic ray acceleration (PeVatron)
 - ▶ Power-law spectrum between 20 and 500 TeV
 - ▶ No obvious known source nearby
- LST observations
 - ▶ Effective time after quality cuts ~ 55 hours
 - ▶ No significant detection
 - ▶ Upper limits derived
 - ▶ Analysis will be updated using the latest software improvements
- MoU with LHAASO to get alerts for potential PeVatrons



Results: Nova RS Oph

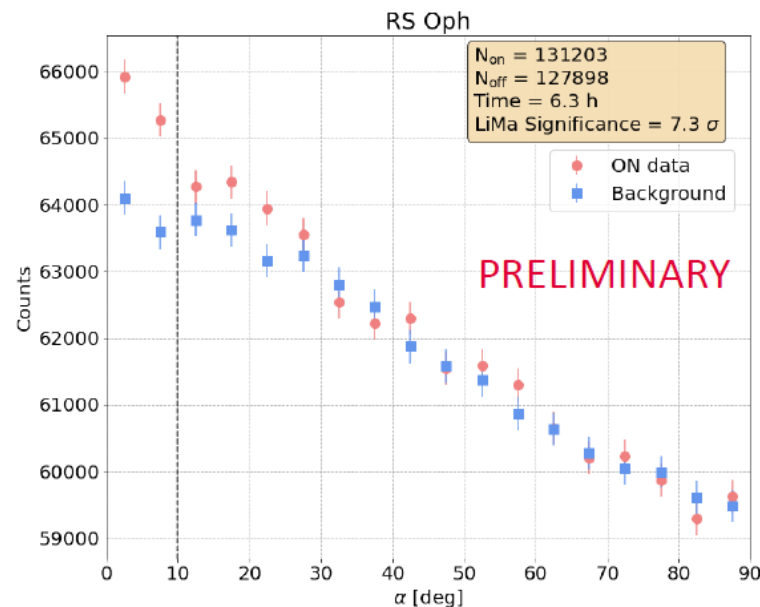
■ RS Oph

- ▶ Symbiotic binary of white dwarf and red giant, 1.6 kpc distance
- ▶ Recurrent nova: outbursts 1958, 1967, 1985, 2006, 2021
- ▶ ATel by Fermi (20210809) and H.E.S.S. (20210810)

■ LST Observations

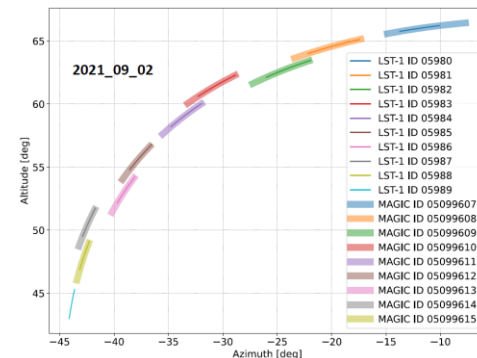
- ▶ Three non-consecutive nights, total of ~6.3 h analyzed
- ▶ Clear detection using standard cuts
- ▶ Working on deriving spectrum using latest analysis developments

■ LST able to follow up galactic transients with competitive analysis results

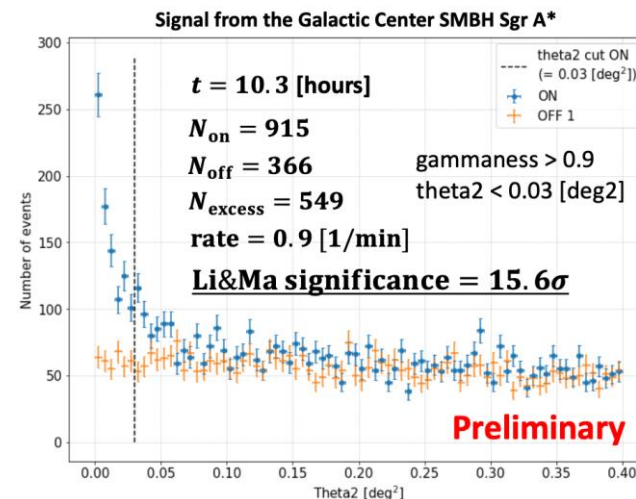


LST + MAGIC Data Analysis

- Majority of LST observations in coincidence with MAGIC for cross-calibration and commissioning
- Development of analysis framework based on CTA tools to analyze MAGIC and LST1 data
 - ▶ Validation of combined analysis pipeline using Crab Nebula data taken last winter
 - ▶ Sensitivity approaching expectations
 - ▶ SED offset from the reference due to Data/MC or analysis discrepancies
- Combined analysis applied to other sources, Galactic Center clearly detected



Y. Ohtani, G. Pirola,
D. Green, E. Jobst,
L. Heckmann



Intensity Interferometry

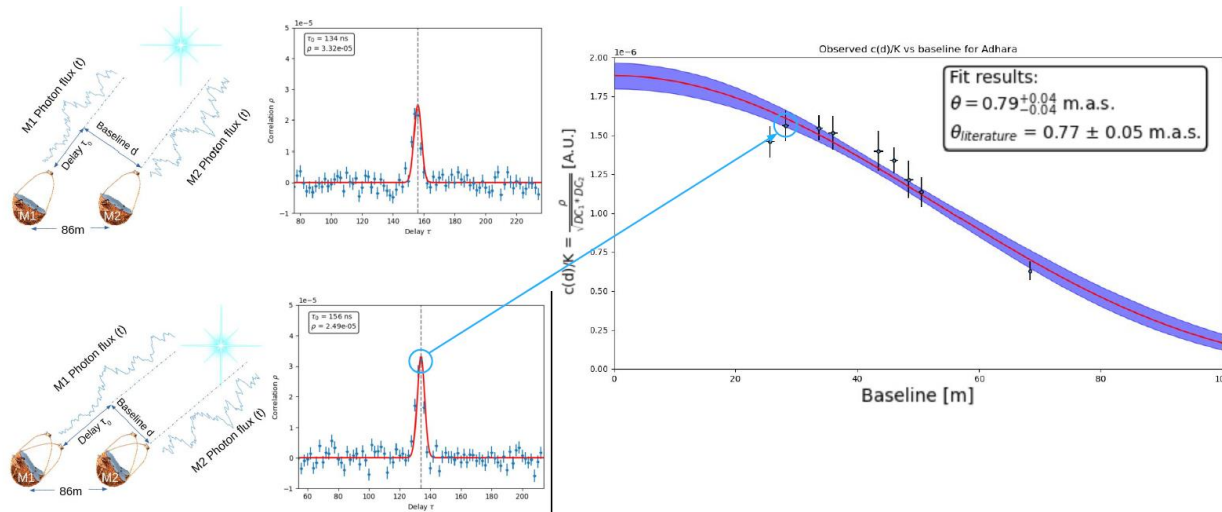
T. Schweizer
D. Fink

■ Preparing for LST1

- ▶ MAGIC correlator can digitize and correlate four input channels
- ▶ Optical fibers between LST1 and MAGIC in place
- ▶ Install filter holder for LST1
- ▶ Transmission board to send signal via optical fiber produced and characterized at MPP

■ MAGIC+LST1

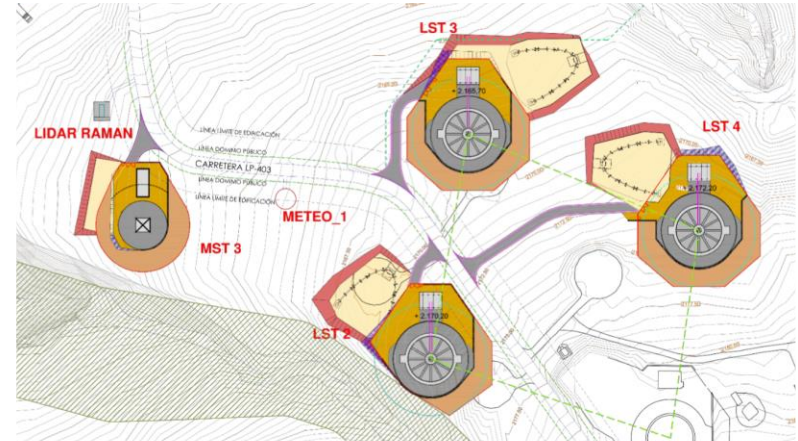
- ▶ 2 additional baselines at larger distances: Improve model fit accuracy, resolution, sensitivity
- ▶ Improved S/N: allows to observe dimmer stars and darkening
- ▶ Each baseline samples different projections: Binary systems, oblateness of fast rotators



Schedule LST 2-4

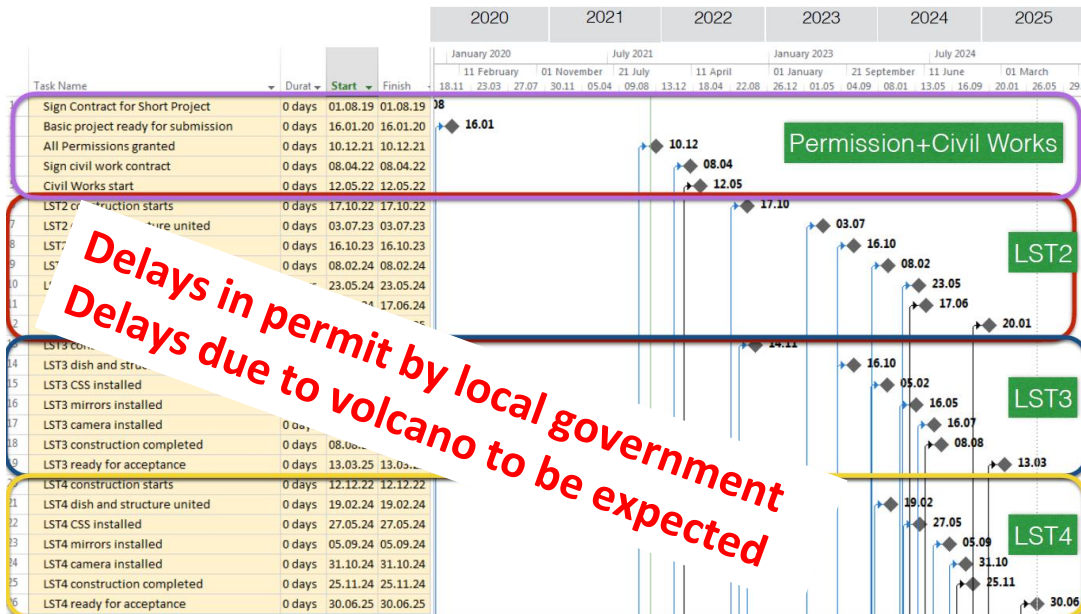
MPP Hardware Contributions

- ▶ 3 Central pins
- ▶ 3 Azimuth + Elevation cable chains
- ▶ 3 Elevation drives
- ▶ 3 Camera locking systems
- ▶ 3 Access tower platform drive systems
- ▶ 3 x 400 mirror actuators



More MPP contributions

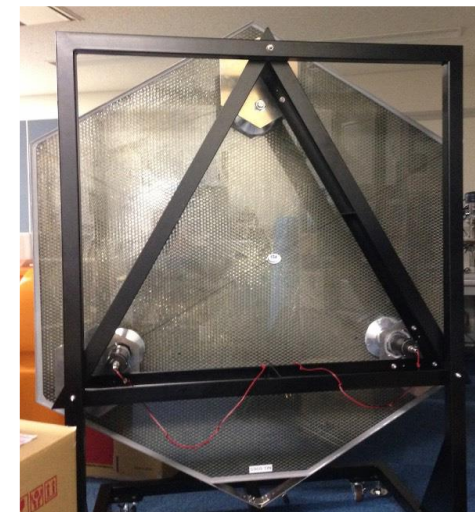
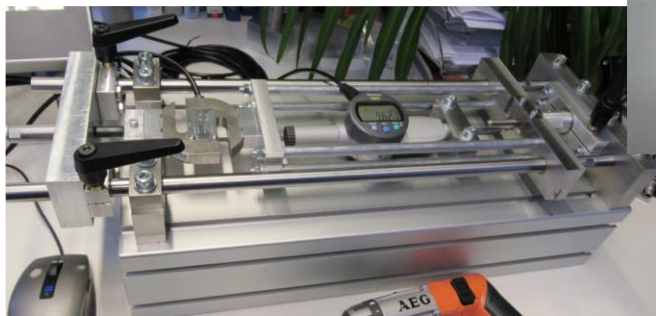
- ▶ Project leadership
 - Principle Investigator
 - Mechanics Coordination
 - Operations, Commissioning, Outreach, Physics Board
 - Common Fund Admin.
- ▶ Systems Engineering
 - Safety, Req. & Verification
- ▶ LST+MAGIC Data Analysis



Mirror Control LST 2-4

T. Schweizer
H. Wetteskind
Ch. Jablonski

- Production of 1400 actuators
 - ▶ Tender won by Diener Precision Machining AG
 - ▶ Precision machining for medical devices and tools, automatic production lines, very economic and high quality
 - ▶ Some mechanical and electronics parts by MPP
 - ▶ Prototypes in Dec 2021, full production in 2022
- Preparation
 - ▶ Choice of cardan joint bearing and ball bearing to minimize mechanical play in actuator assembly
 - ▶ Quality control setup for spindle production



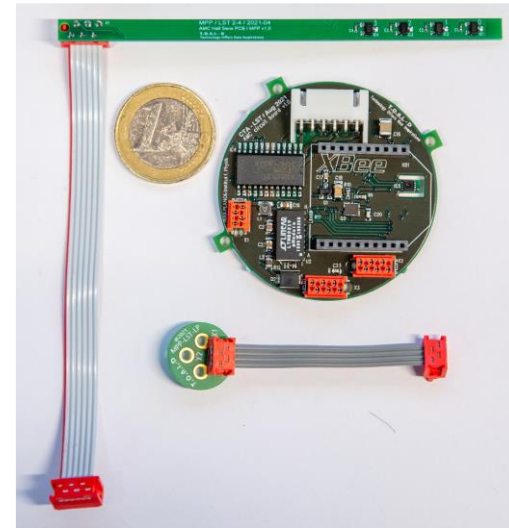
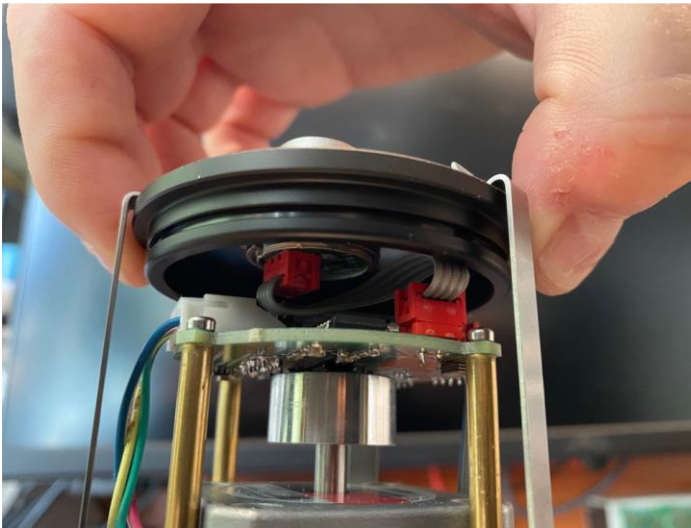
Sinter brass bearing

Ball bearing

Spring bearing

Mirror Control LST 2-4

- Actuator electronics production
 - ▶ Redesign of PCB (routing), change of connector (damage protection)
 - ▶ 1400 electronics boards produced in-house, ready to be shipped to the company for assembly
 - ▶ All XBees scanned for MAC address, connected with actuator serial numbers in database



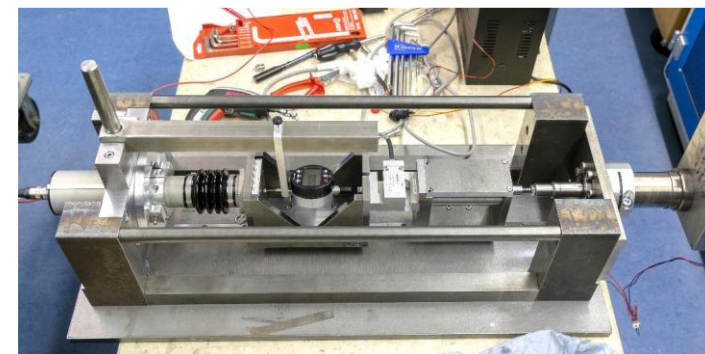
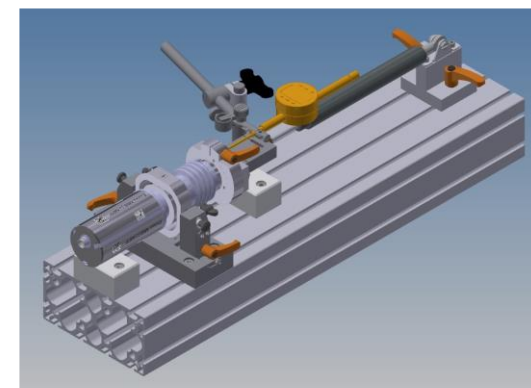
**Big thanks to Electronics Production department
for producing 1400 parts in very short time!**

Mirror Control LST 2–4

- Quality checks for prototypes in Dec 2021
 - ▶ Weight
 - ▶ Water immersion test
 - ▶ Functional test
 - ▶ Read temperature and humidity
 - ▶ Run-in test: 100 full movements with load while measuring the current and position
 - ▶ Mechanical play measurement
 - ▶ Survival test: Maximum static load 1500N push and pull (severe storm case)
 - ▶ Mechanical play measurement (repeat)
- Decision on quality control at Diener depending on quality of prototype



T. Schweizer
H. Wetteskind
Ch. Jablonski
T. Dettlaff
A. Berti
M. Will

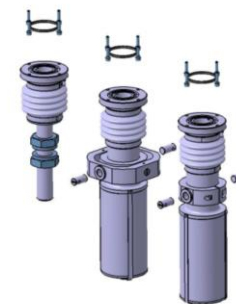


Big thanks to University Tübingen for providing mechanical play test setup!

Mirror Control LST 2-4

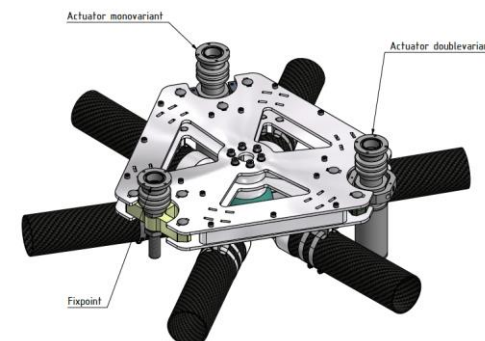
■ Production schedule

- ▶ 3 x 200 actuator / fix point sets + 100 spare sets + replacement parts
- ▶ MPP contributions (motors, electronics, ...) sent to Diener, full production of elements started already
- ▶ Test stands to be delivered to Diener in 2022 after tests of prototypes and decision on quality control
- ▶ Fix point production started at University Hamburg, well in time, some elements still to be purchased



■ Delivery to La Palma in 2022 / 2023 possible

- ▶ Integration with mirror interface plates before installation on structure
- ▶ Probably slowed down due to overall delay in construction



Central Pins LST 2-4

Ch. Jablonski

- Production of 3 central pins
 - ▶ Production finished and already shipped to La Palma
 - ▶ Ready for installation as soon as civil works can start



Cable Chains LST 2–4

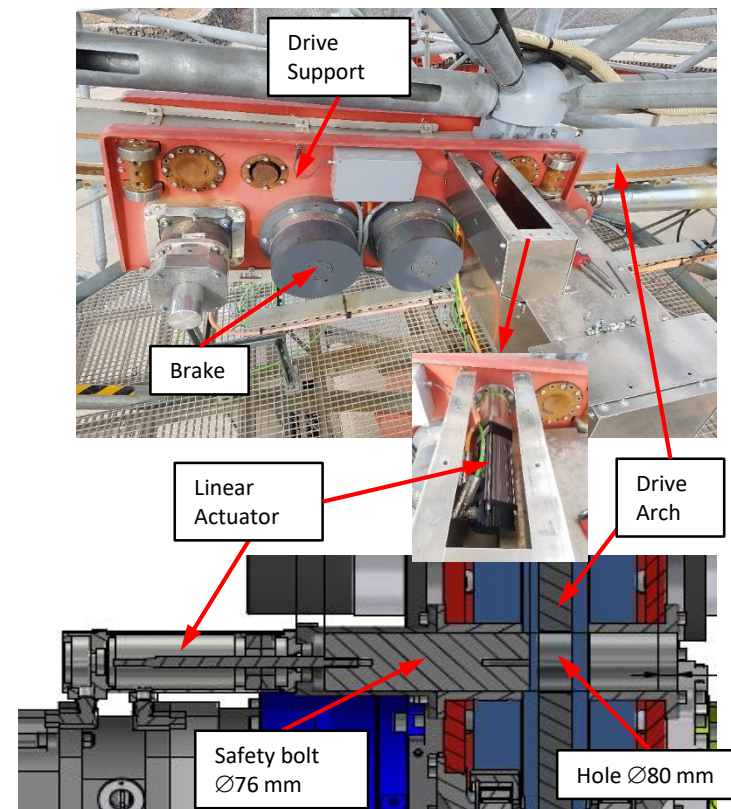
- Azimuth cable chain
 - ▶ 3 cable carousels produced, packed and currently on their way to La Palma
 - ▶ Production of frame and cover in-house
- Elevation Cable Chain
 - ▶ Asking for offers, standard item
 - ▶ Cable overlengths still to be defined
- Parts for cable ducts ordered, will be delivered by next year



Elevation Drive LST 2-4

R. Stadler
H. Wetteskind

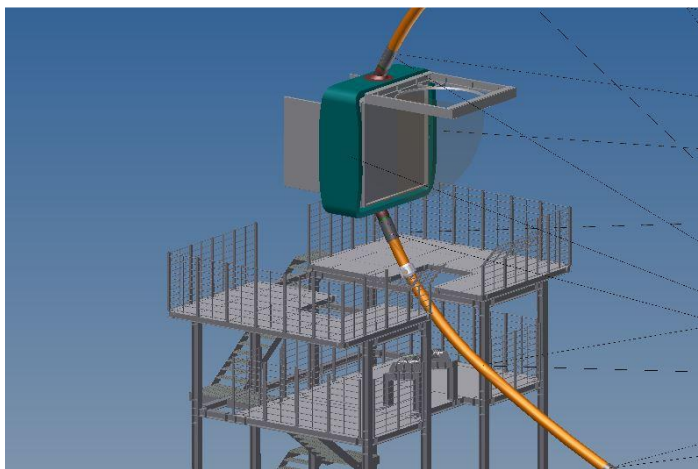
- Elevation drive parts purchased and produced in-house
- Drive support boxes finished this year
- To be delivered to La Palma in 2022, slowed down production and delivery to save storage in La Palma



Camera Tower LST 2-4

R. Stadler
J. Schlammer

- Platform drive
 - ▶ All parts purchased
 - ▶ One unit is finished and ready for shipping
 - ▶ Two units in production now
- To be delivered to La Palma in 2022, slowed down production and delivery to save storage in La Palma

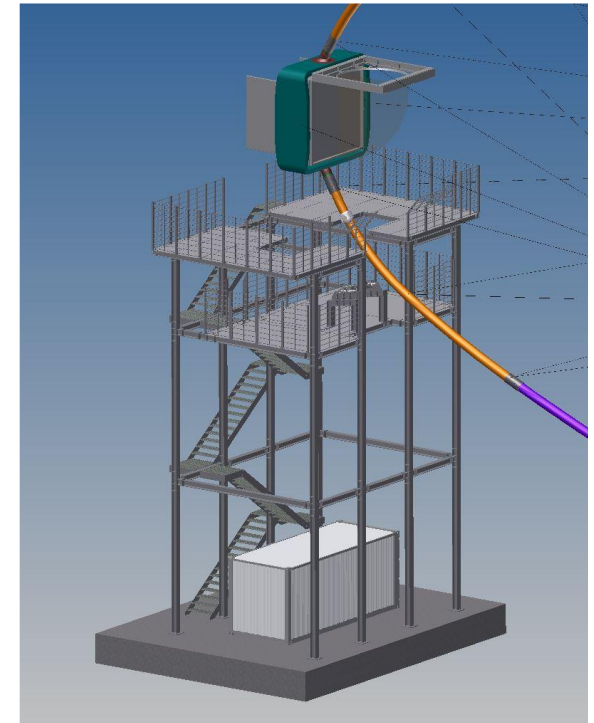


Production in Spain, design by MPP

Camera Locking LST 2–4

R. Stadler
H. Wetteskind

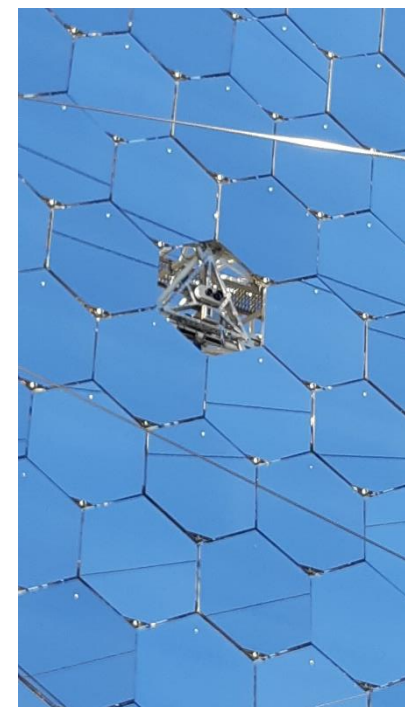
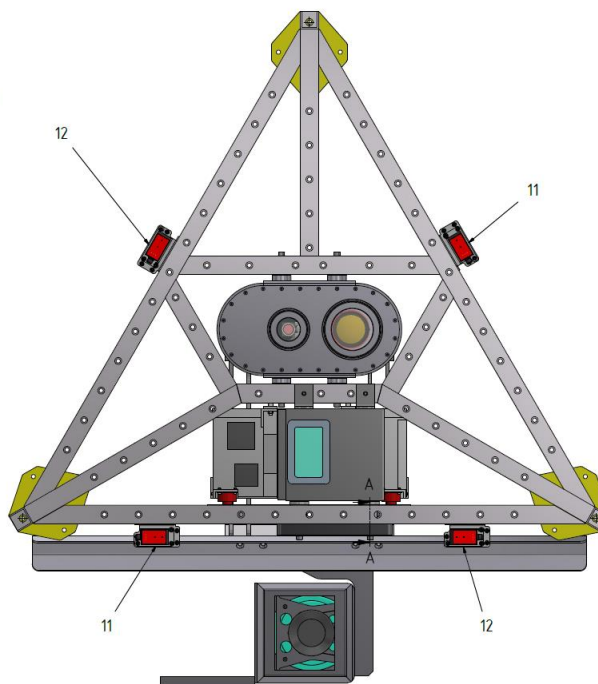
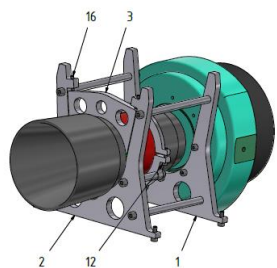
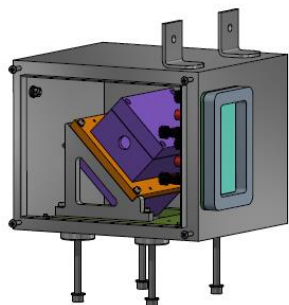
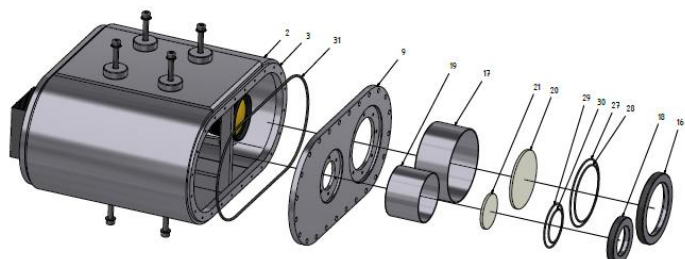
- Camera Locking
 - ▶ All components (springs and frames) purchased and delivered
 - ▶ Production (in-house) finished about 95%
 - ▶ Assembly of all 3 units to start in 2022
- To be delivered when needed to save storage in La Palma



Central Frames LST 2-4

R. Stadler
Ch. Jablonski
G. Obermüller

- Central Frame and Housings for Calibration Devices
 - ▶ Some redesign at MPP necessary
 - ▶ Schedule not yet decided, one of the last items to be installed during telescope construction
 - ▶ Production (possibly in-house) in 2022 or 2023



- Fine tune and finish commissioning of all subsystems despite pandemics and volcanic eruptions
- Continue work on stable operations to increase telescope availability
- Close CDR, prepare for acceptance review in 2022
- Civil works and assembly of LST2–4 delayed into 2022, production of parts and preparation of constructions progressing very well
- Meanwhile: Detect new sources, a couple of GRBs, pulsars, etc 😊

