Construction and Early Science of the LST Array

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What is the LST?

LST = Large-Sized Telescope

- Community driven scientific collaboration aiming to build 4 Large Size Telescopes (LST) in La Palma and up to 4 LSTs in Chile

2005

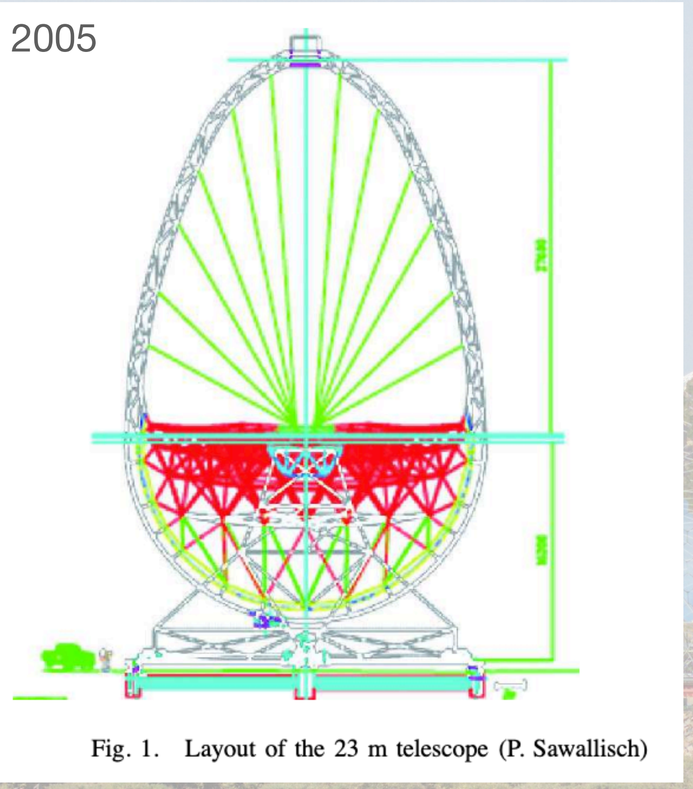
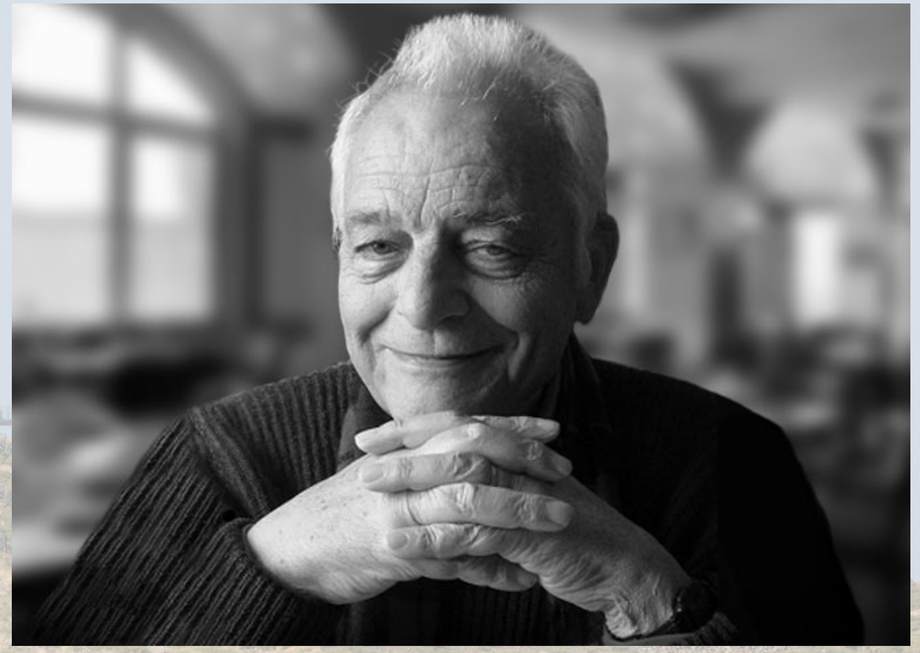


Fig. 1. Layout of the 23 m telescope (P. Sawallisch)

2018: Inauguration of the LST-1 in La Palma

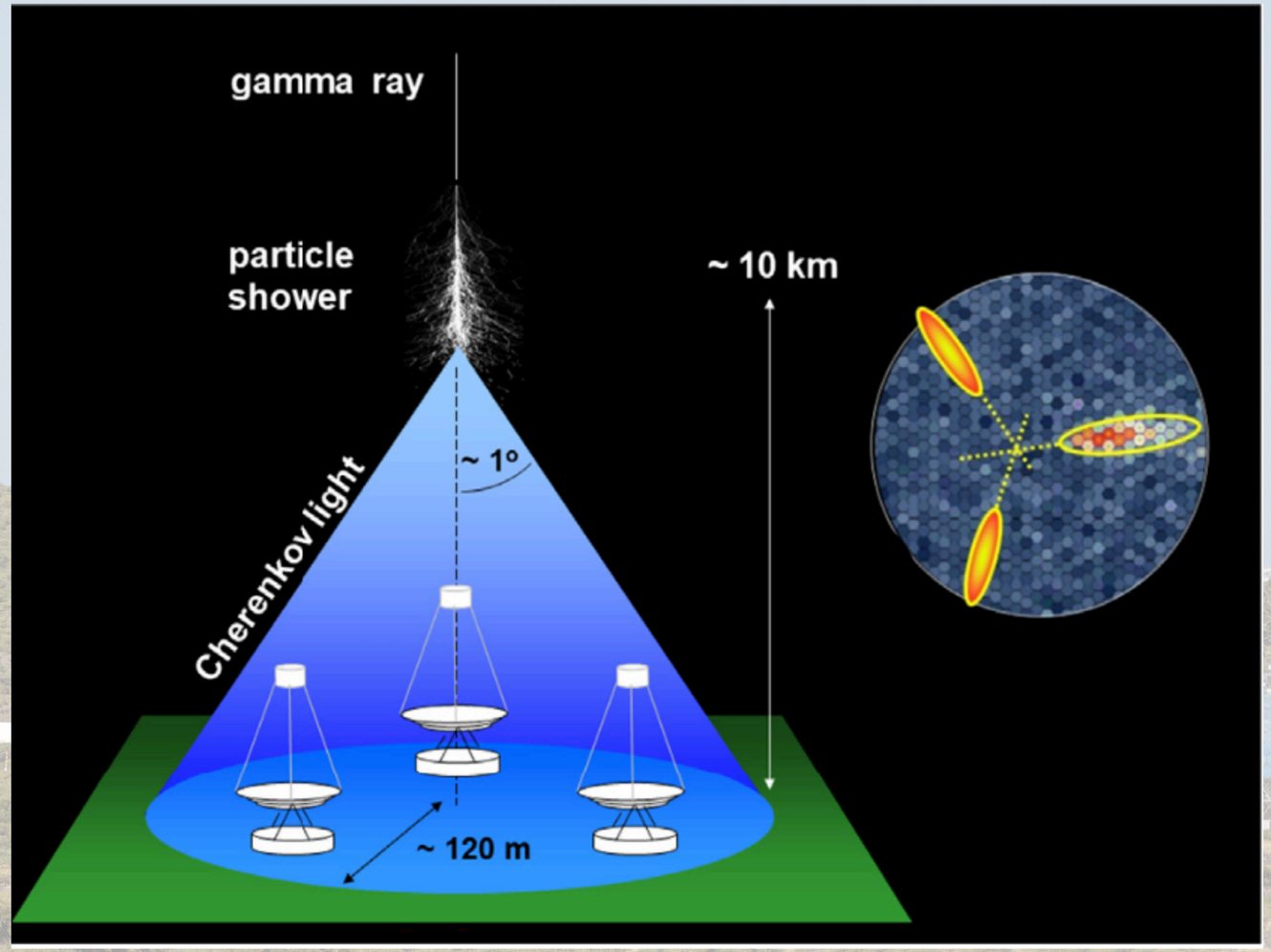


Eckart Lorenz (1938 - 2014): Farther of LST

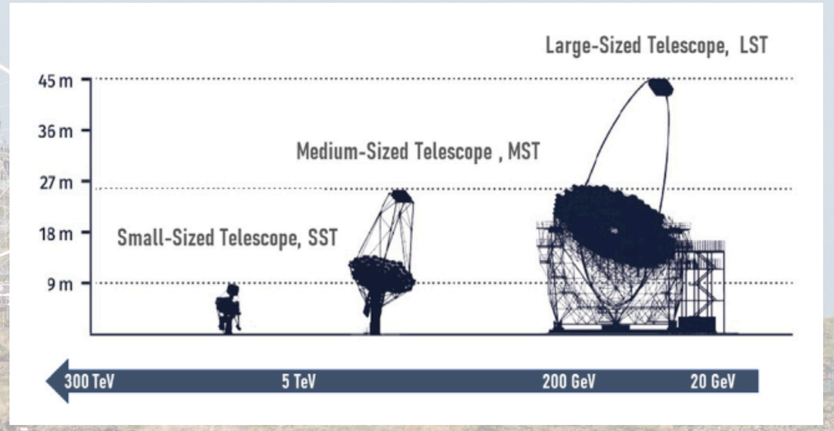


How does it work?

IACT = Imaging Atmospheric Cherenkov Telescopes



- Duration of Cherenkov flash: 1-several nanoseconds
- Need fine pixelized and fast O(Gsps) cameras
- Stereoscopic reconstruction largely improves energy and spatial resolution

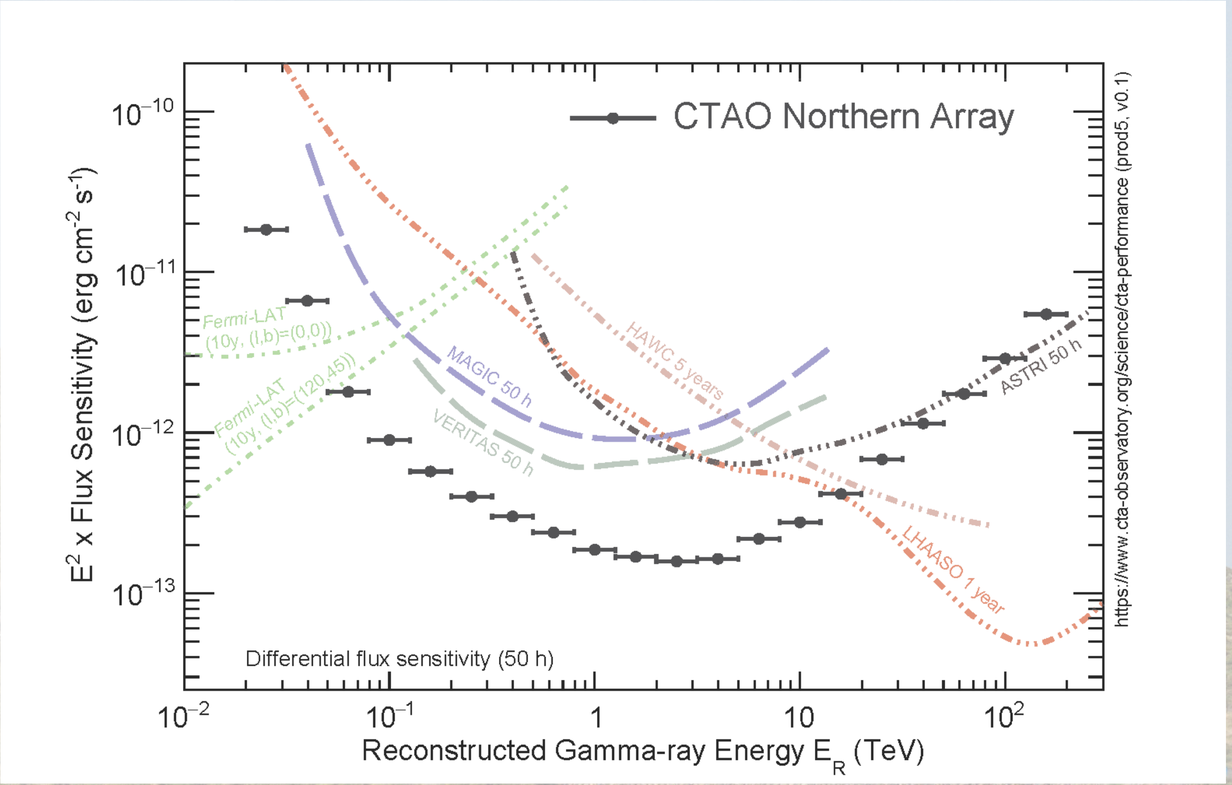


What do we want to achieve?

Study universe through very high energy gamma rays

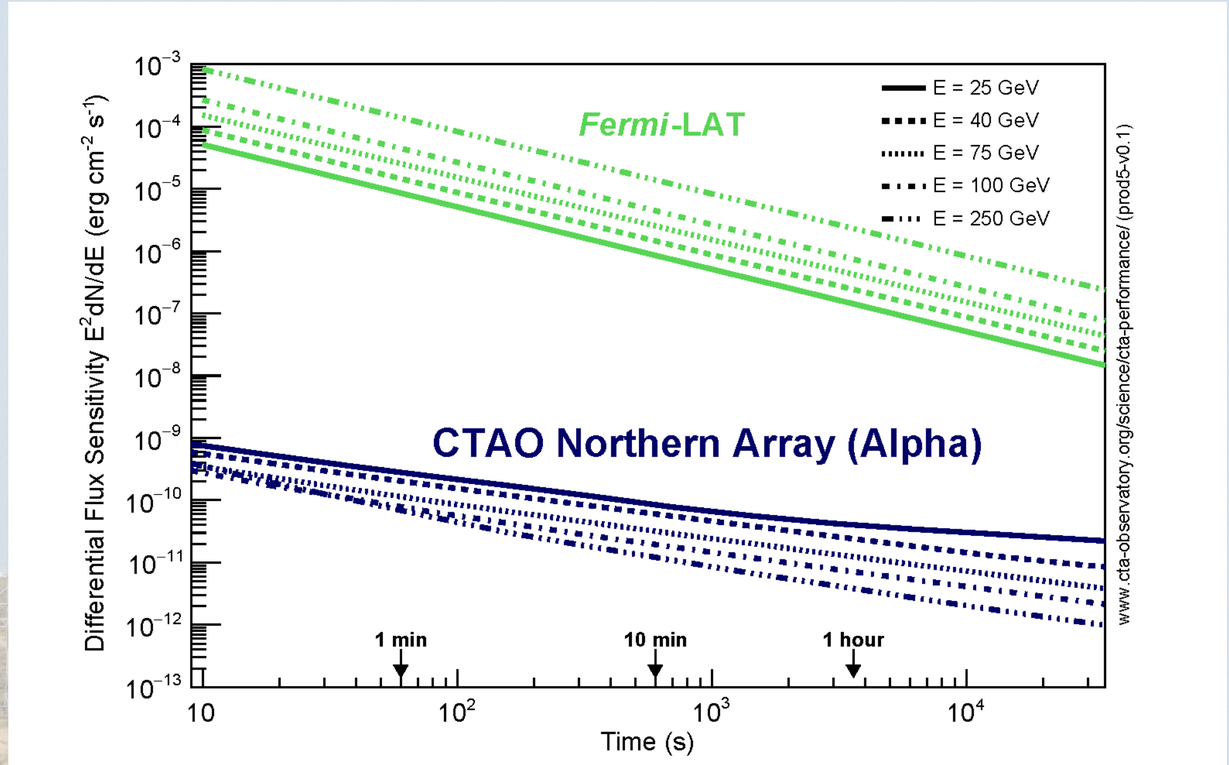
- Flux sensitivity

An order of magnitude boost compared to the current instruments



- Sensitivity vs time

Five (5) orders of magnitude boost compared to satellites

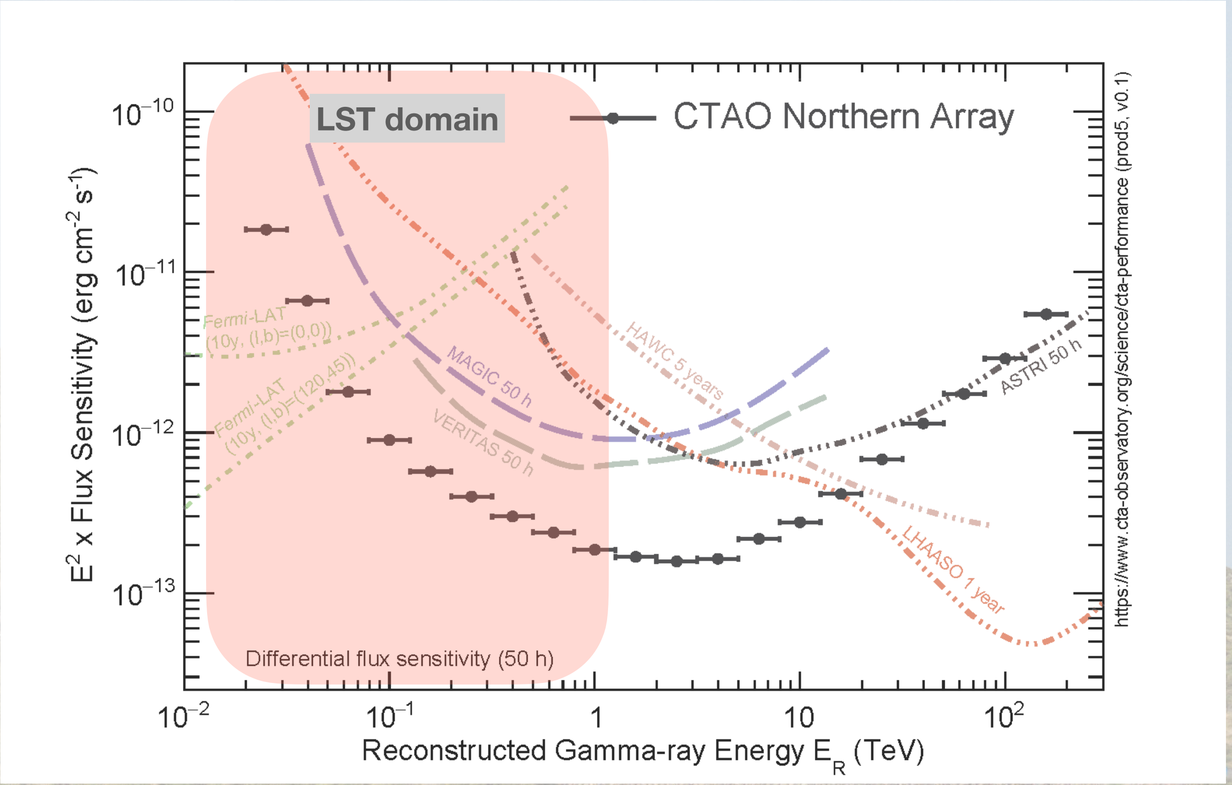


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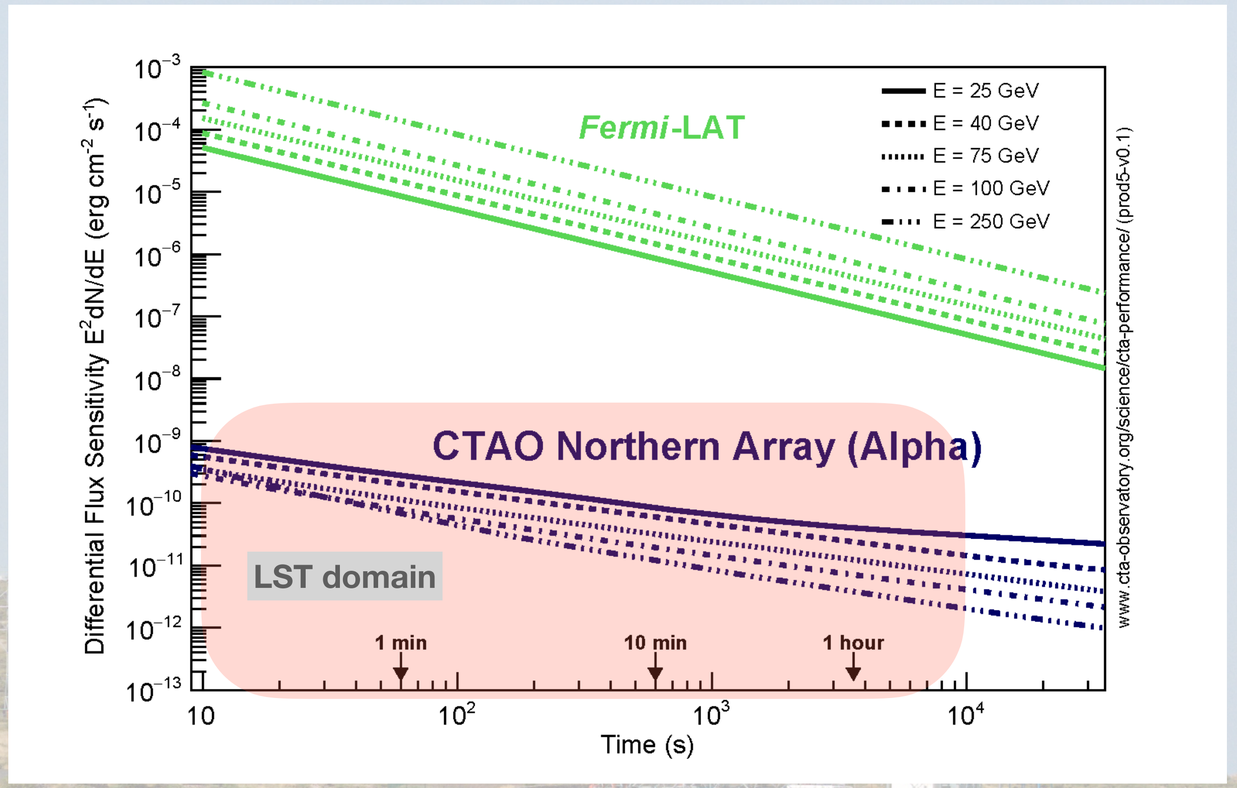
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- Sensitivity vs time

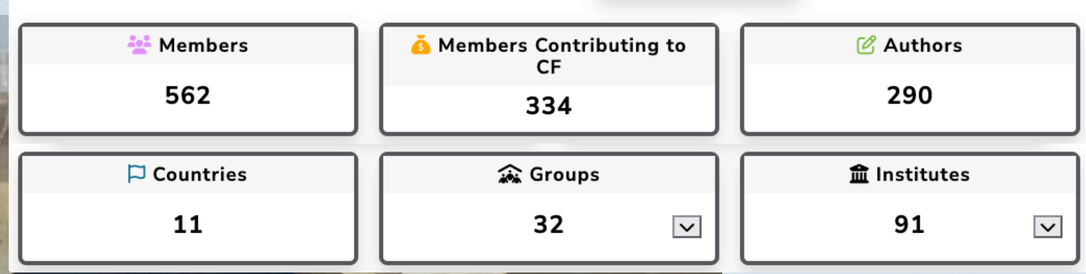
Five (5) orders of magnitude boost compared to satellites



CTAO LST collaboration

Who are we?







Where did we start?

Let’s start at the LST1 inauguration in 2018



LST2-4: production phase of LSTs

Almost exact copy of LST1 but

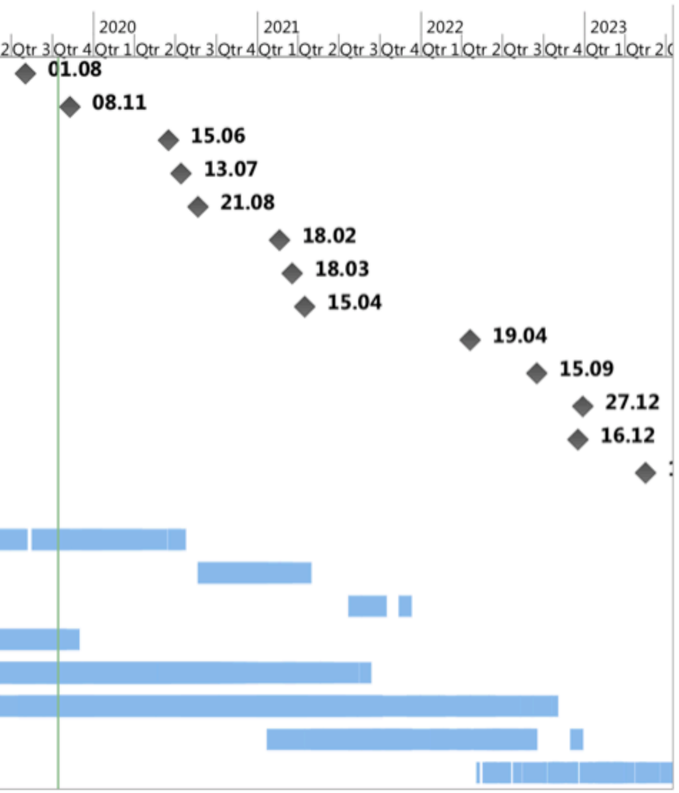
- Improved mirror actuators. Series E. Production organized by Max-Planck for physics (MPP)
- AMC boxes. Improvements by MPP of the original Japanese design
- Photosensors: move to 7 stage instead of 8 stage to have a narrower pulse. Japan
- Readout boards: some minor improvements. V5 -> V7. Japan
- Telescope mechanics. Keep all but move production responsibility from Germany (MPP) to Spain (IAC)
- Camera mechanics and part of the electronics. Move from production in institutes (LST1) to industry (LST2-4)
- Due to changes of responsibility, industrialization and several years between LST1 and LST2-4 production: **major challenge!**
- + COVID19, several geopolitical crises and volcano Tajogaite in La Palma in 2021

LST milestones

We were very ambitious!

Schedule from 2019

	Task Name	Duration	Start	Finish
1	Sign Contract for Short Project	0 days	01.08.19	01.08.19
2	Basic project ready for submission	0 days	08.11.19	08.11.19
3	All Permissions granted	0 days	15.06.20	15.06.20
4	Sign civil work contract	0 days	13.07.20	13.07.20
5	Civil Works start	0 days	21.08.20	21.08.20
6	LST2 construction starts	0 days	18.02.21	18.02.21
7	LST3 construction starts	0 days	18.03.21	18.03.21
8	LST4 construction starts	0 days	15.04.21	15.04.21
9	LST2 construction completed	0 days	19.04.22	19.04.22
10	LST3 construction completed	0 days	15.09.22	15.09.22
11	LST4 construction completed	0 days	27.12.22	27.12.22
12	LST2 ready for acceptance	0 days	16.12.22	16.12.22
13	LST3 ready for acceptance	0 days	16.05.23	16.05.23
14	LST4 ready for acceptance	0 days	25.08.23	25.08.23
15	**Project and Permissions LST2-4**	**788 days**	**18.07.17**	**23.07.20**
44	**Civil Works**	**180 days**	**21.08.20**	**29.04.21**
49	**Removal of LST1 assembly platform**	**100 days**	**23.07.21**	**09.12.21**
53	**Optics**	**935 days?**	**02.05.16**	**29.11.19**
58	**Mechanics**	**865 days**	**21.05.18**	**10.09.21**
190	**Camera**	**1697 days**	**02.05.16**	**01.11.22**
236	**Installation**	**503 days**	**22.01.21**	**27.12.22**
264	**AIV (commissioning)**	**343 days**	**04.05.22**	**25.08.23**



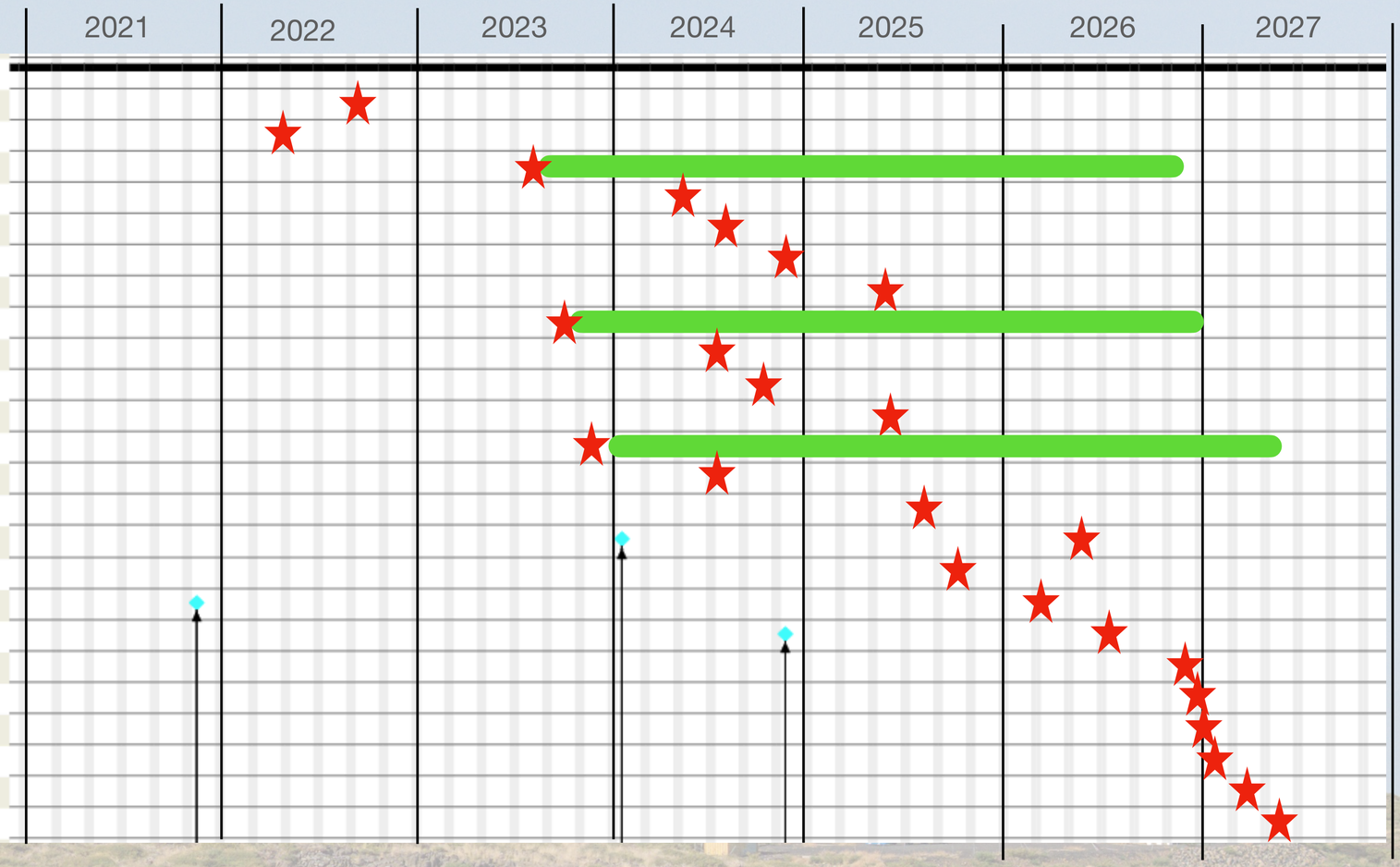
- LST 2-4 construction finished by 2022
- LST 2-4 commissioning finished by 2023

LST milestones

Delayed but delivered!

Schedule from today

LST2-LST4-Schedule	02/05/16	07/03/28
All permits granted	19/10/22	19/10/22
Civil works start	13/04/22	13/04/22
LST4 construction starts	11/09/23	11/09/23
LST4 dish and structure united	06/05/24	06/05/24
LST4 CSS installed	01/07/24	01/07/24
LST4 mirrors installed	03/12/24	03/12/24
LST4 camera installed	21/05/25	21/05/25
LST3 construction starts	09/10/23	09/10/23
LST3 dish and structure united	17/06/24	17/06/24
LST3 CSS installed	26/09/24	26/09/24
LST3 mirrors installed	14/05/25	14/05/25
LST2 construction starts	06/11/23	06/11/23
LST2 dish and structure united	13/08/24	13/08/24
LST2 CSS installed	14/07/25	14/07/25
LST3 camera installed	11/05/26	11/05/26
LST2 mirrors installed	15/09/25	15/09/25
LST4 Dirve Validated	09/02/26	09/02/26
LST2 camera installed	15/06/26	15/06/26
LST4 Ready For Commissioning	02/11/26	02/11/26
LST3 Drive validated	30/11/26	30/11/26
LST3 ready for Commissioning	16/12/26	16/12/26
Civil works finish	11/01/27	11/01/27
LST2 drive validated	22/03/27	22/03/27
LST2 ready for Commissioning	07/04/27	07/04/27



LST route 2018 - 2026

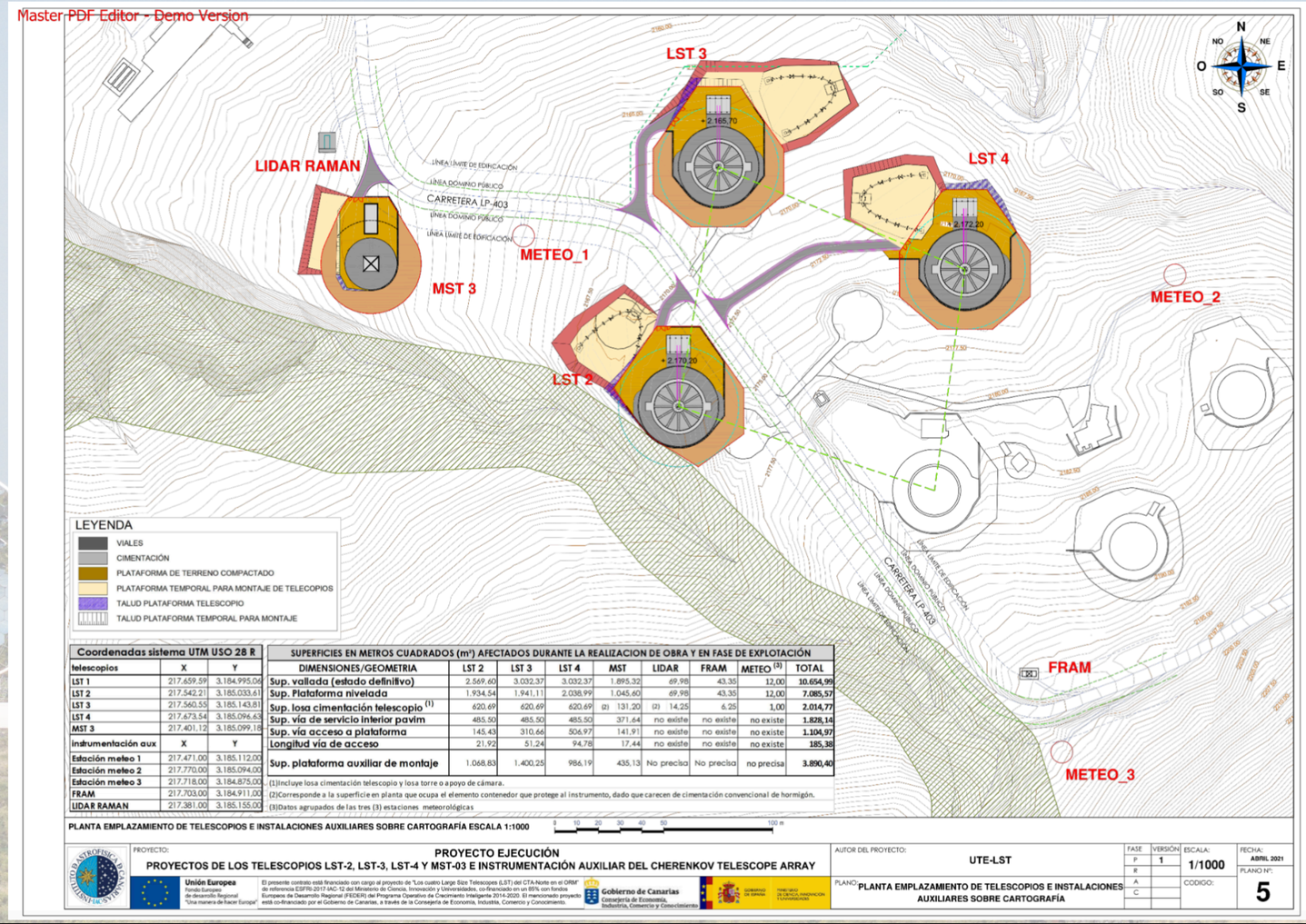
We kept focus on LSTs!





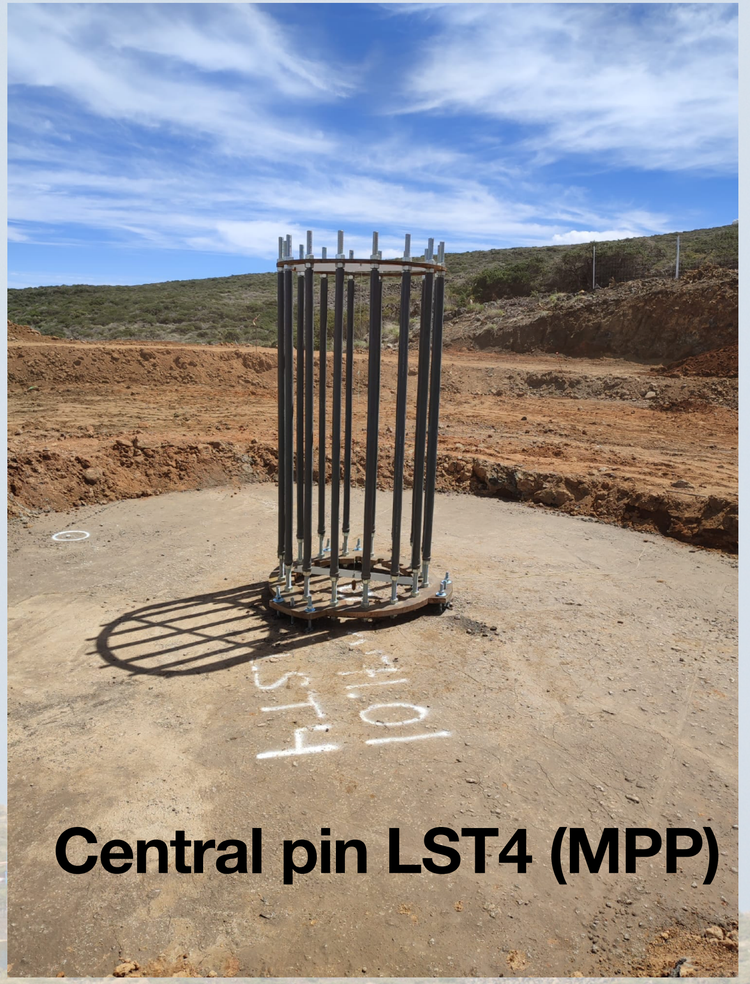
LST civil works in La Palma

Huge work done by the IAC: planning, permissions, execution



LST civil works in La Palma





Central pin LST4 (MPP)

Joining the Dish and the Lower Structure



Installation of the Camera Support Structure



Installation of the Camera Support Structure

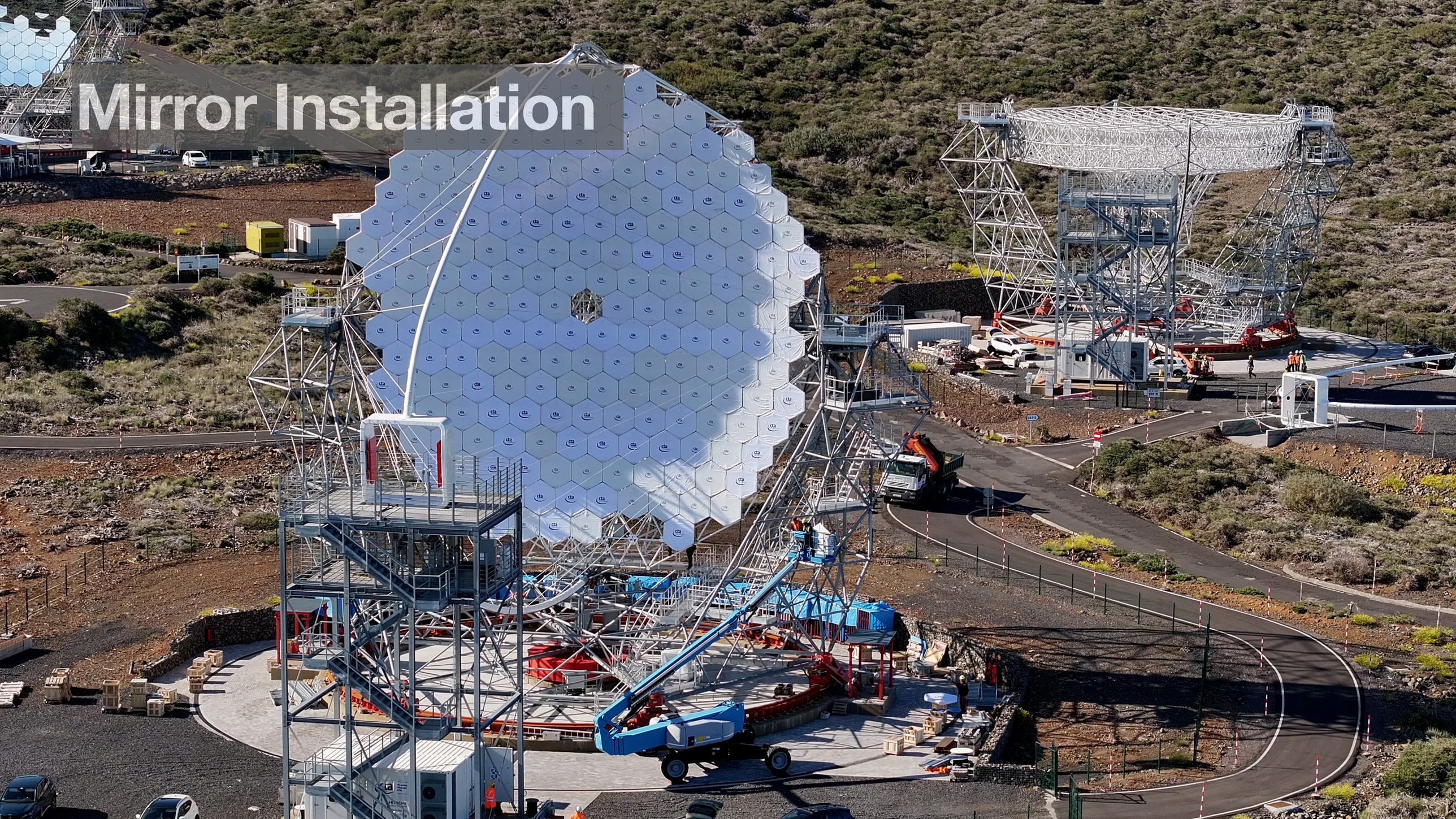


Installation of the Camera Support Structure



Mirror Installation




Mirror Installation

Camera Installation



Drive tests



LST route 2018 - 2026

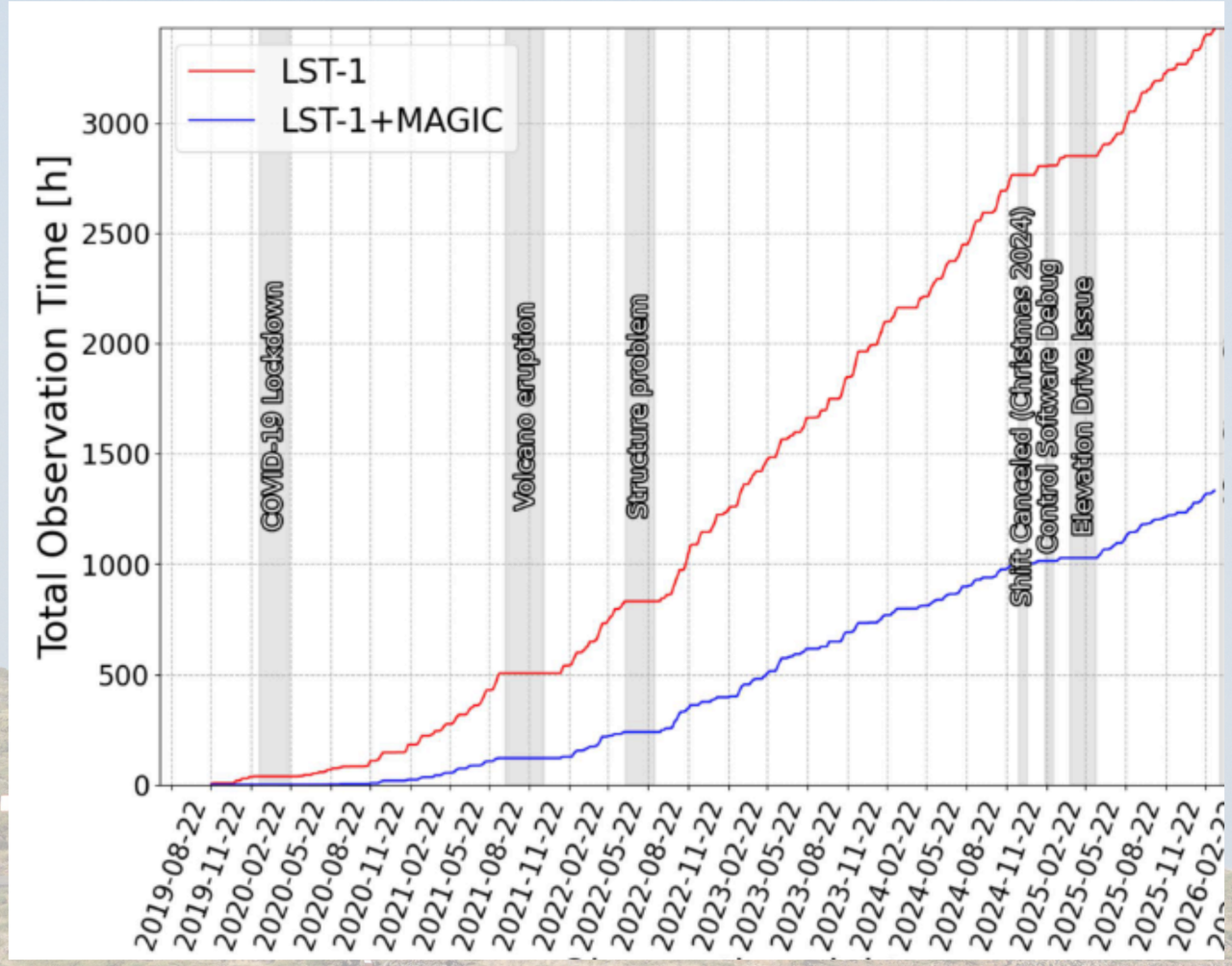
LST sub-array inauguration October 15, 2026



LST commissioning

Taking data on a regular basis since beginning of 2020

- Some interruptions due to
  - COVID19
  - Volcano
  - Missing shifters
  - Control software debugging
  - Technical issues



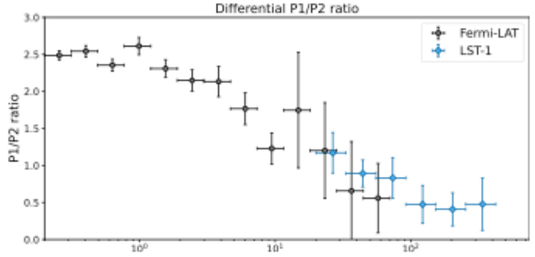
LST physics highlights

The standard candle: Crab Pulsar

LST-1 observations of the Crab PSR

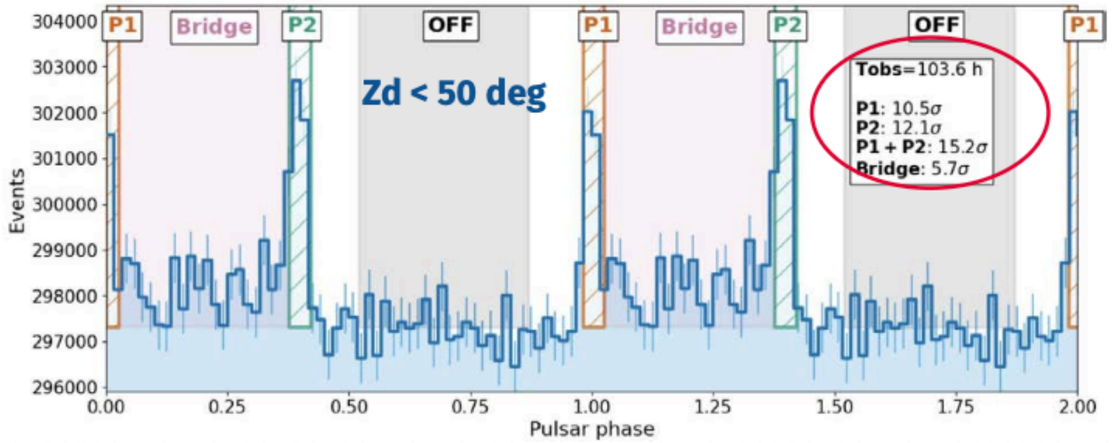
- LST-1 commissioning obs. (Sep. 2020 - Jan. 2023)
- Time after quality cuts: ~103h for Zd < 50deg

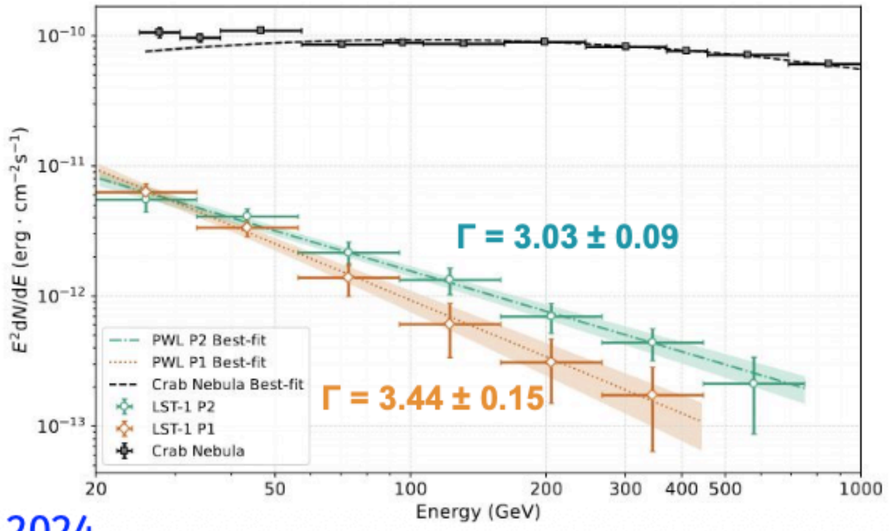
- **Peak location does not change** with increasing energy (20 - 700 GeV)
- **P1 width dropping** until ~10 GeV, **P2 width decrease > 2 GeV**
- **P1/P2 declines up to 100 GeV**, remains constant (P1/P2 ~0.5) at > 100 GeV



P1 + P2 detected at >15σ in 100h

Similar to MAGIC Sumtrigger-II but with only one telescope!





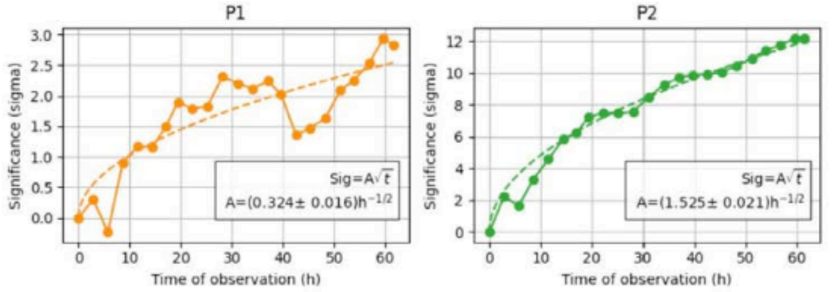
Abe et al. 2024

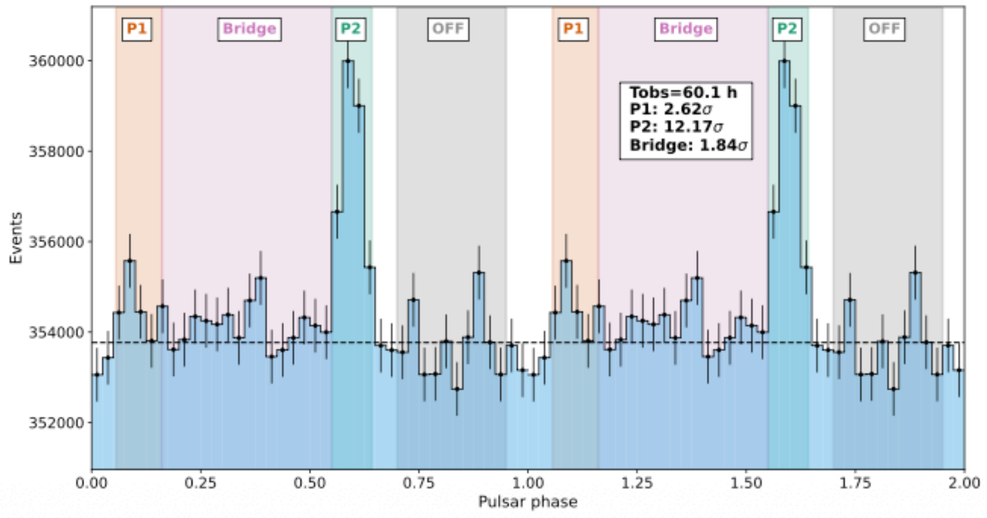
LST physics highlights

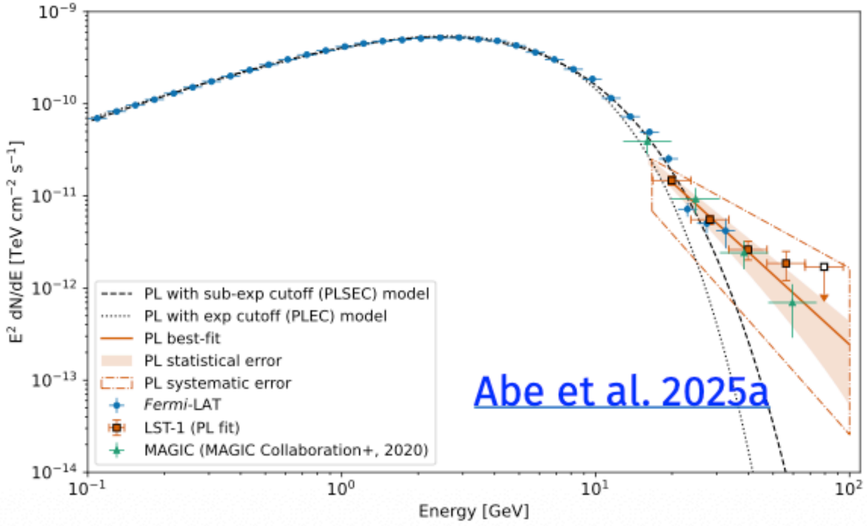
Geminga Pulsar

LST-1 observations of the Geminga PSR

- Making use of ~60h (after quality cuts) for Zd < 50deg
- Demonstrates **LST-1 capabilities for PSR studies**:
  P2 at > 12σ in 60h (compare to MAGIC: 6.3σ in 80h)
- **P1 undetected** (2.6σ hint => 200h for a 5-σ signal)
- **No E-dependent evolution**





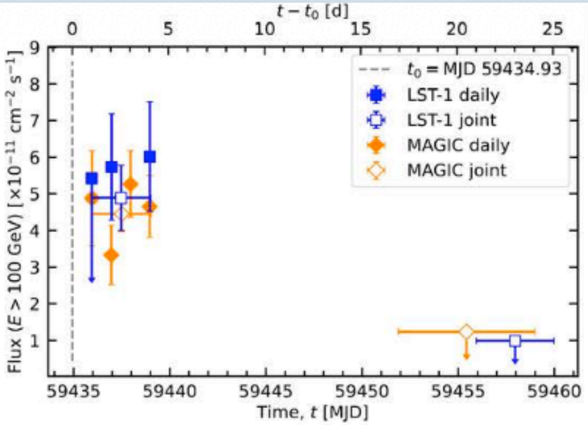


LST physics highlights

Nova

Nova RS Ophiuchi

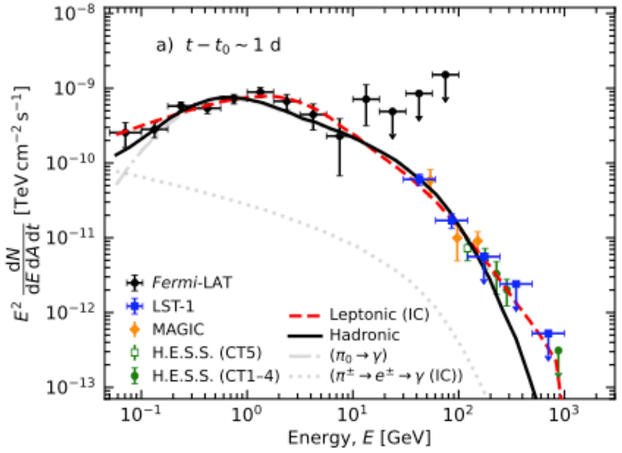
- Symbiotic binary: white dwarf + red giant star, d~2.45 kpc, with recurrent nova outbursts (~15 yr)
- **First nova ever detected at VHE gamma rays**
- Gamma-ray emission modeling: **hadronic** scenario favoured
- Retrieve **spectra of injected particles** (using LST-1, MAGIC, H.E.S.S. and LAT)
- Excellent perspectives for future novae (e.g. **T CrB**)





Credit: David A.Hardy/ www.astroart.org & PPARC.

Parameter	Best-fit value on observation day		
	Day 1	Day 2	Day 4
Leptonic BPL model without systematics			
Slope 1, $\Gamma_{e,1}$	$0.0^{+0.8}_{-0.6}$	$-1.3^{+1.5}_{-0.5}$	$-1.4^{+0.6}_{-0.7}$
Slope 2, $\Gamma_{e,2}$	$-3.79^{+0.17}_{-0.18}$	$-3.57^{+0.11}_{-0.15}$	$-3.52^{+0.05}_{-0.06}$
$E_{b,e}$ [GeV]	14^{+3}_{-3}	17^{+8}_{-4}	22^{+9}_{-6}
$\chi^2/N_{d.o.f}$	12.9/15	24.9/21	24.9/15
χ^2_{red}	0.86	1.19	1.66
AIC_c	23.7	34.9	35.8
Hadronic ECPL model without systematics			
Slope, Γ_p	$-2.25^{+0.13}_{-0.13}$	$-2.49^{+0.07}_{-0.07}$	$-2.48^{+0.08}_{-0.08}$
$E_{c,p}$ [TeV]	$0.26^{+0.08}_{-0.08}$	$1.0^{+0.3}_{-0.3}$	$1.6^{+0.6}_{-0.6}$
$\chi^2/N_{d.o.f}$	21.5/16	24.9/22	26.5/16
χ^2_{red}	1.34	1.13	1.66
AIC_c	29.1	32.0	34.1



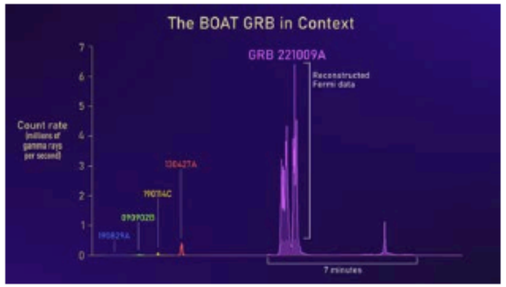
Abe et al. 2025b

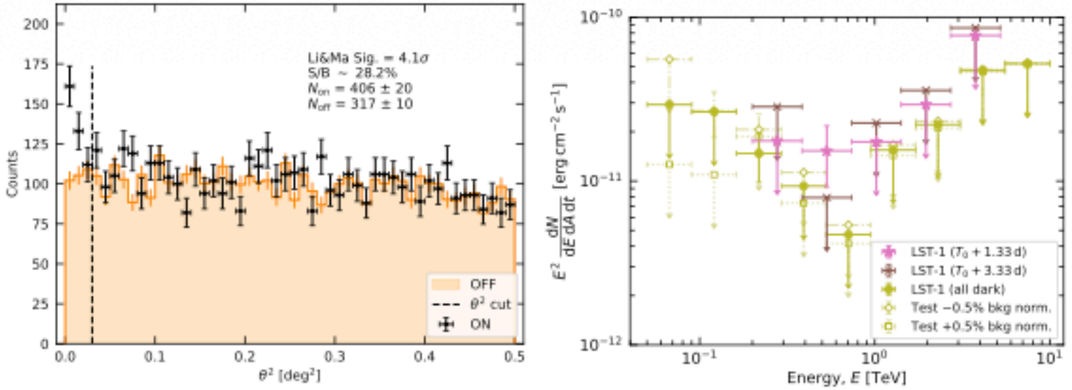
LST physics highlights

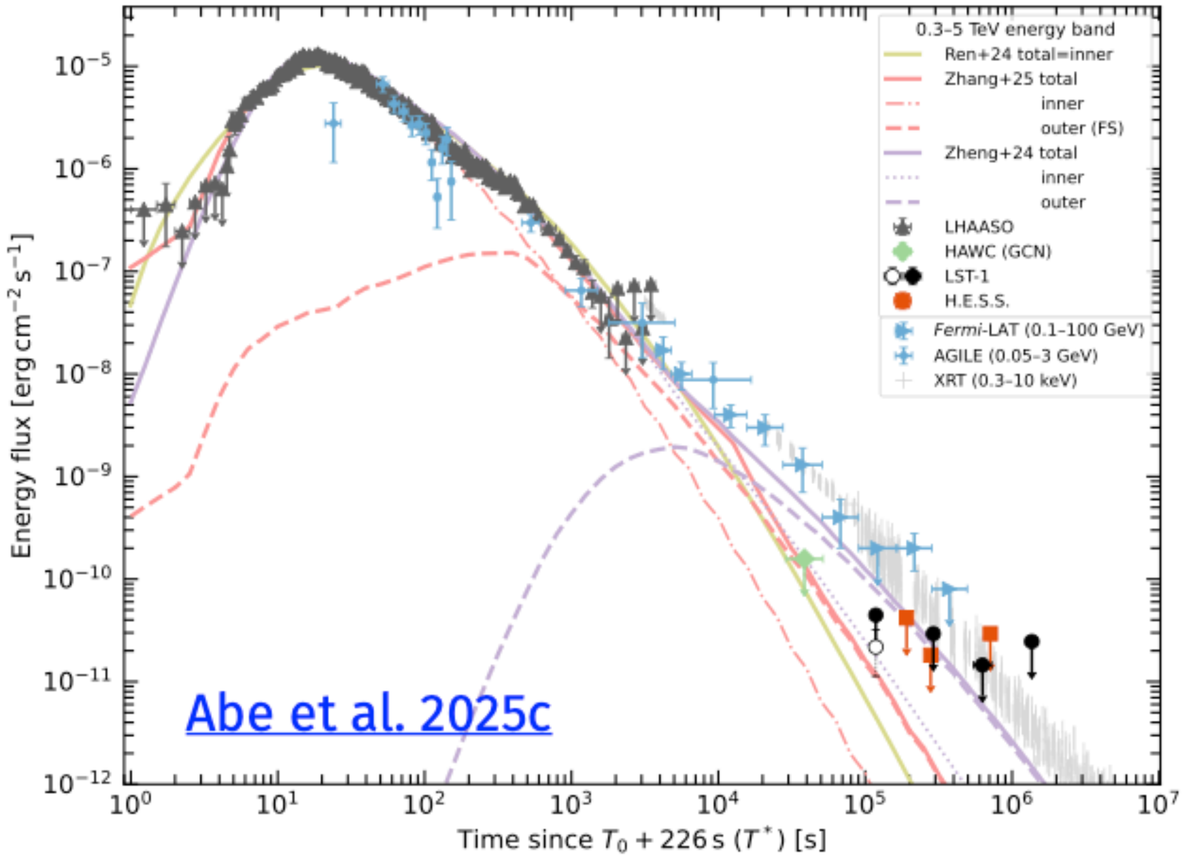
Gamma Ray Burst(s)

GRB221009A: “The Boat"

- The brightest of all time (“The BOAT") GRB, only **1 event expected every ~10^3 yr** (or even 10^4 yr, Burns+ 2023)
- Peak energy flux reaching **~ 10^5 Crab Units** (LHAASO 2023)
- GRB prompt phase during strong moonlight observation conditions (dedicated analysis needed)
- **LST-1** observations on Oct. 10 (T0 + 1.33 d): **4.1-σ**
- Bridges the HAWC and H.E.S.S. ULs, and provides constraints on structured (multi-component) jet models
  Ren+ 2024
  Zheng+ 2024





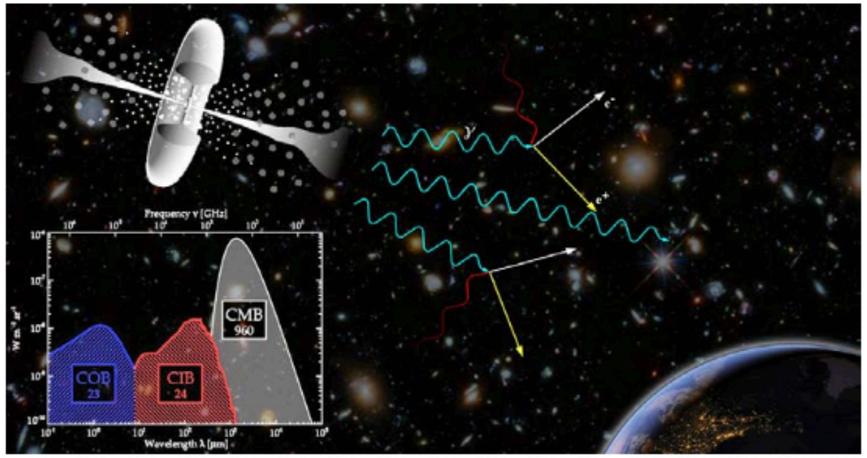


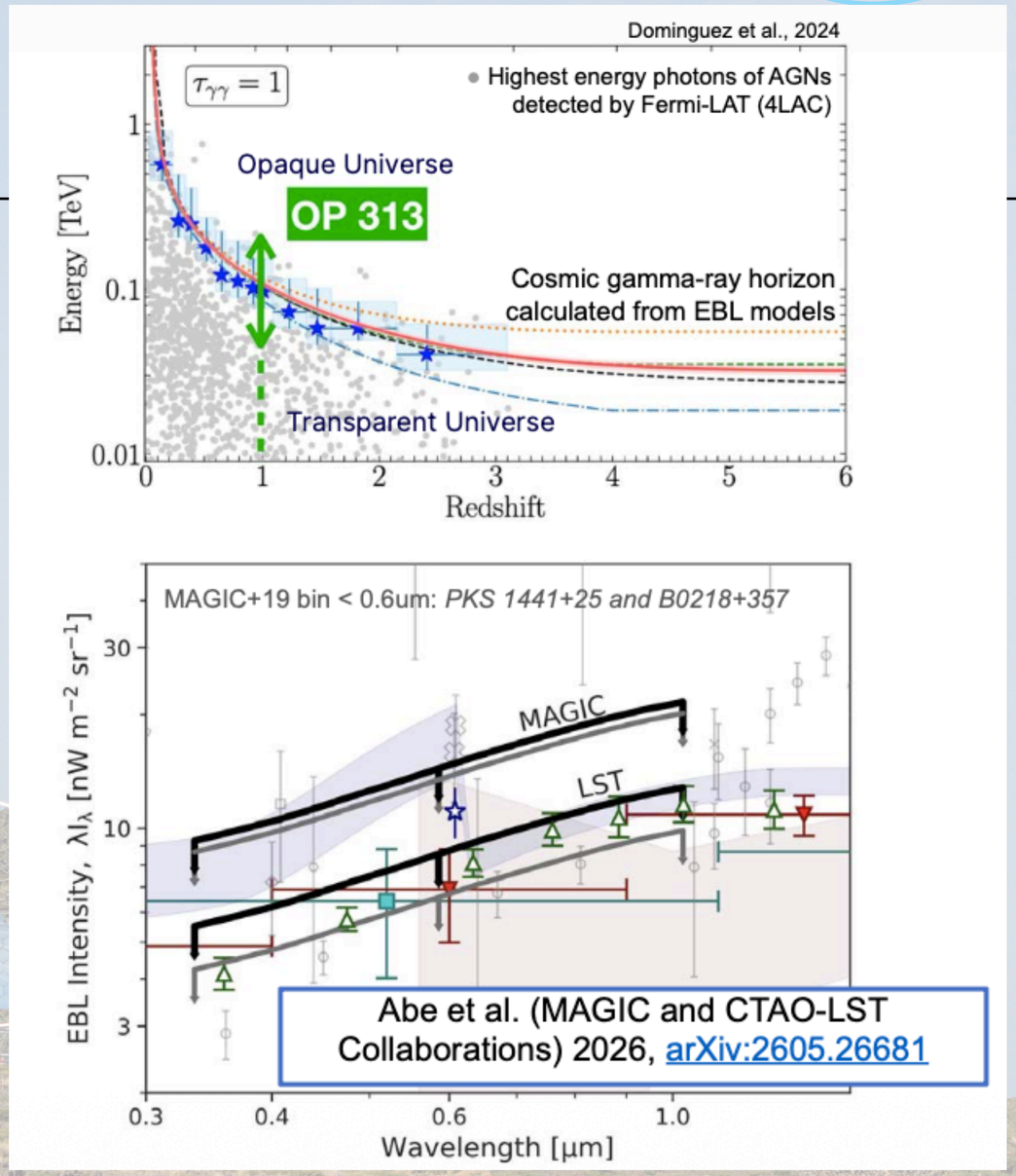
LST physics highlights

AGNs

OP 313: the farthest AGN @ VHEs

- **Most distant quasar ever detected in VHE** (z=0.9973) and second most distant VHE source after GRB 201216C
- Not detected in VHE before (despite several attempts)
- **Extensive MWL campaign** (radio, IR, optical, UV, γ-ray)

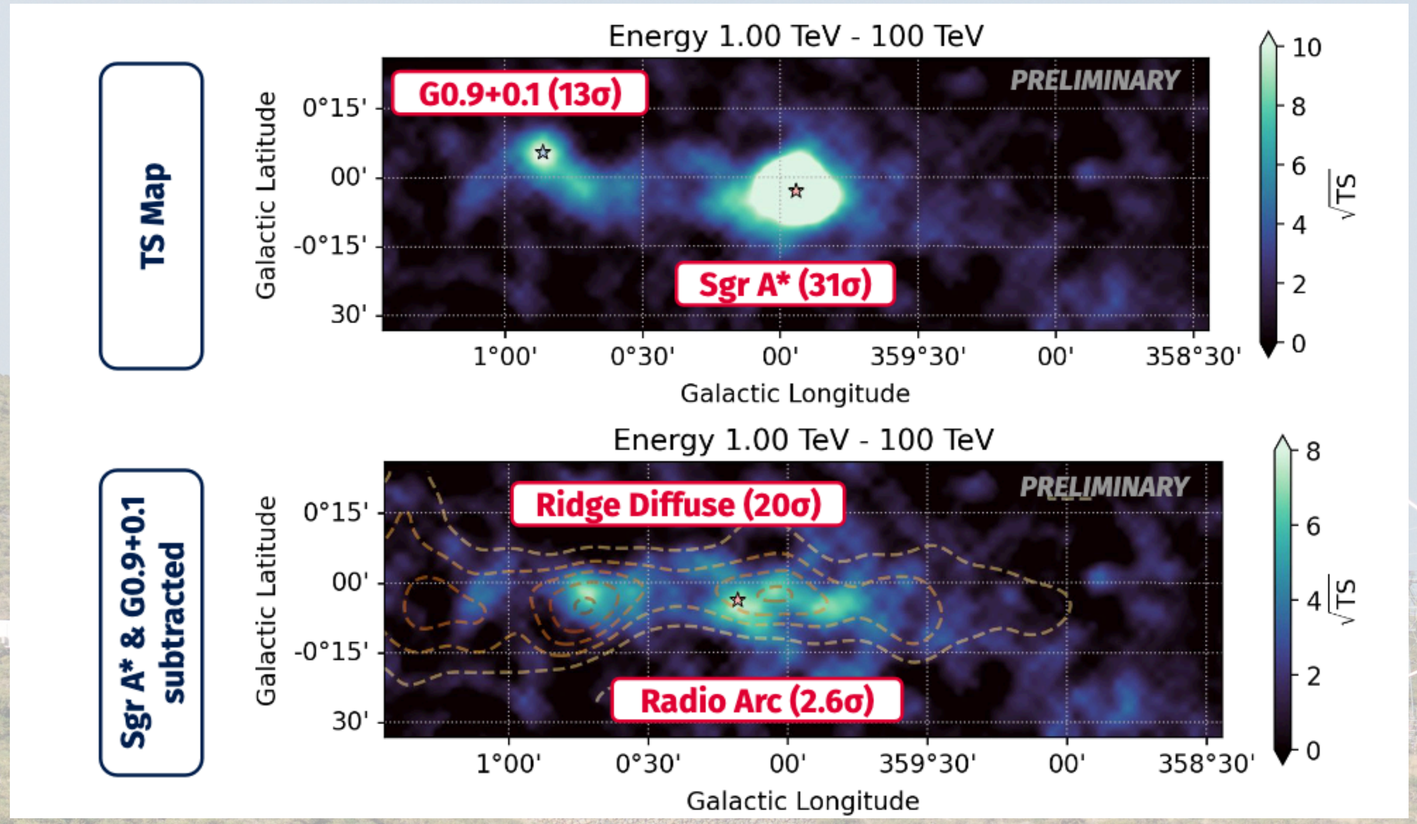


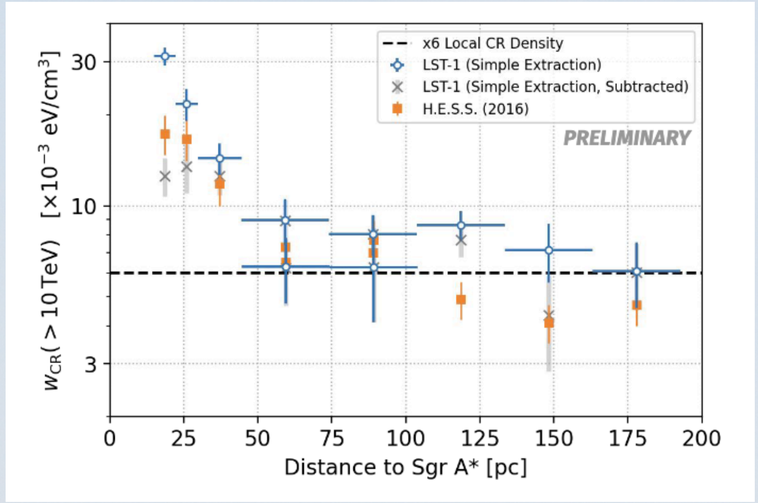


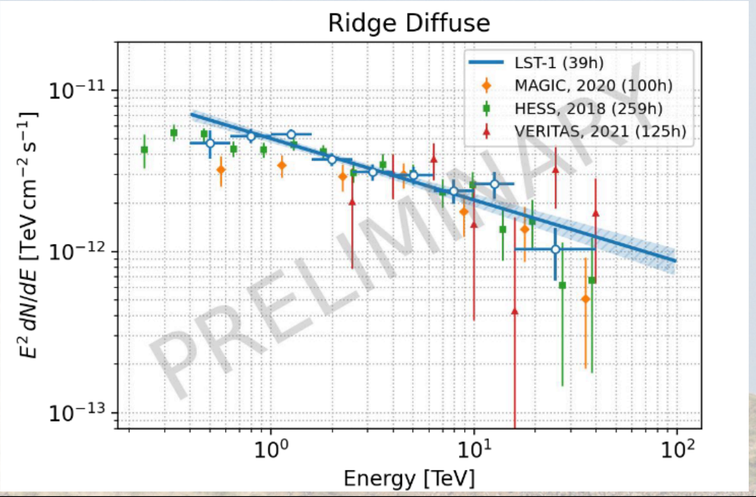
LST physics highlights

Galactic Center

- 39 hrs of good quality data with LST1in 2020/21



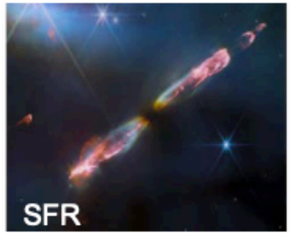


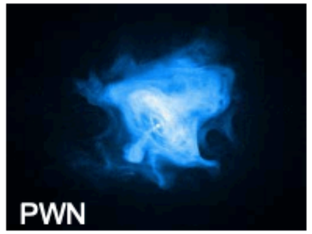


Future perspectives



Cosmic ray acceleration





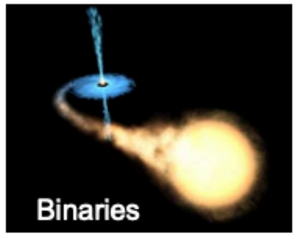




Proving extreme environments



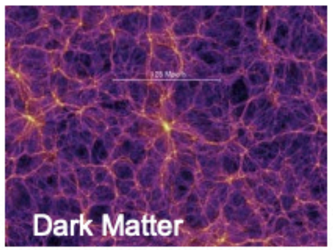


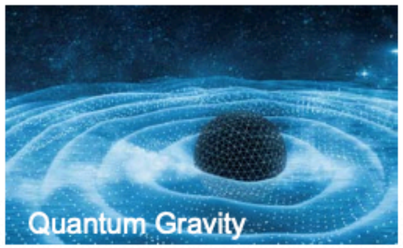


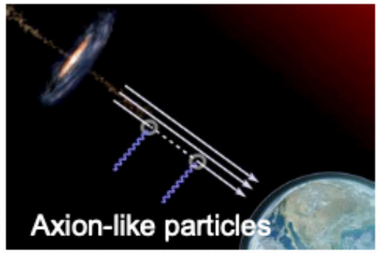




Physics frontiers







Adapted from López-Coto
RENATA meeting 2025

LST sub-array is here.
Let’s make great science together!

