

AGN Variability with CTAO.

D.A. Sanchez, LAPP,CNRS

AGNs variability in Gamma and MWL



Seyfert, NGC 5548, bright core with artefact from the observations

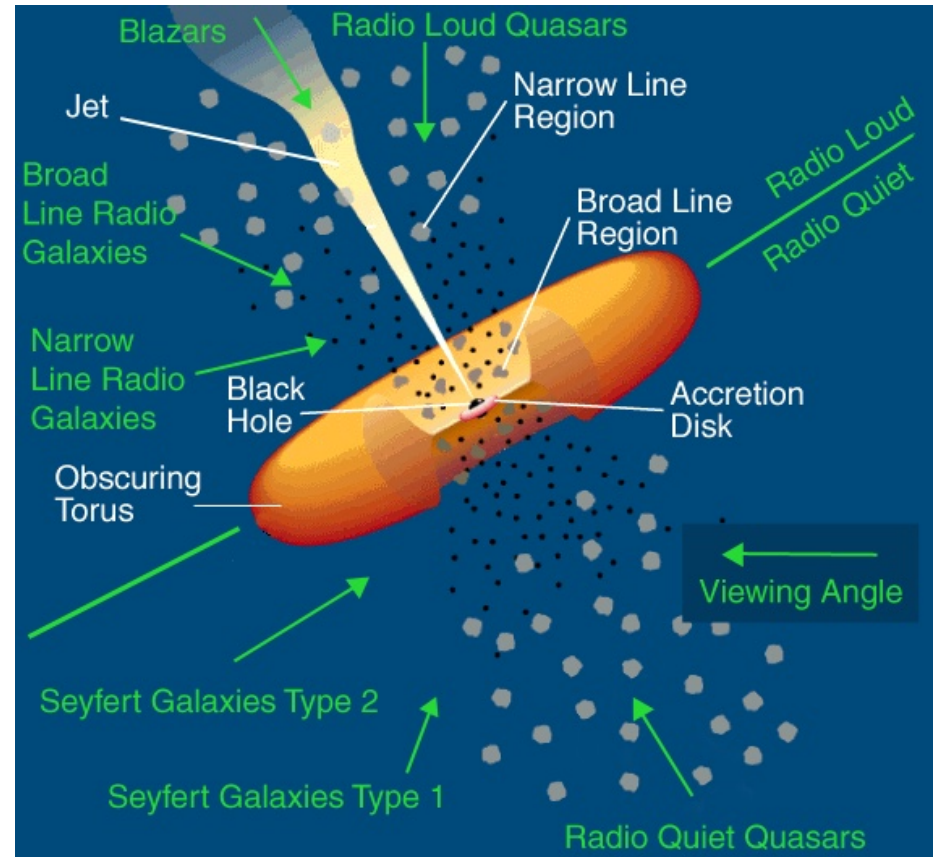


Non-active galaxy, NGC 3370. Core is less luminous

Supermassive black holes (SMBHs) at galaxy centers accreting matter.

Unified model: Radio-quiet (Seyferts, quasars) vs. radio-loud (blazars, radio galaxies).

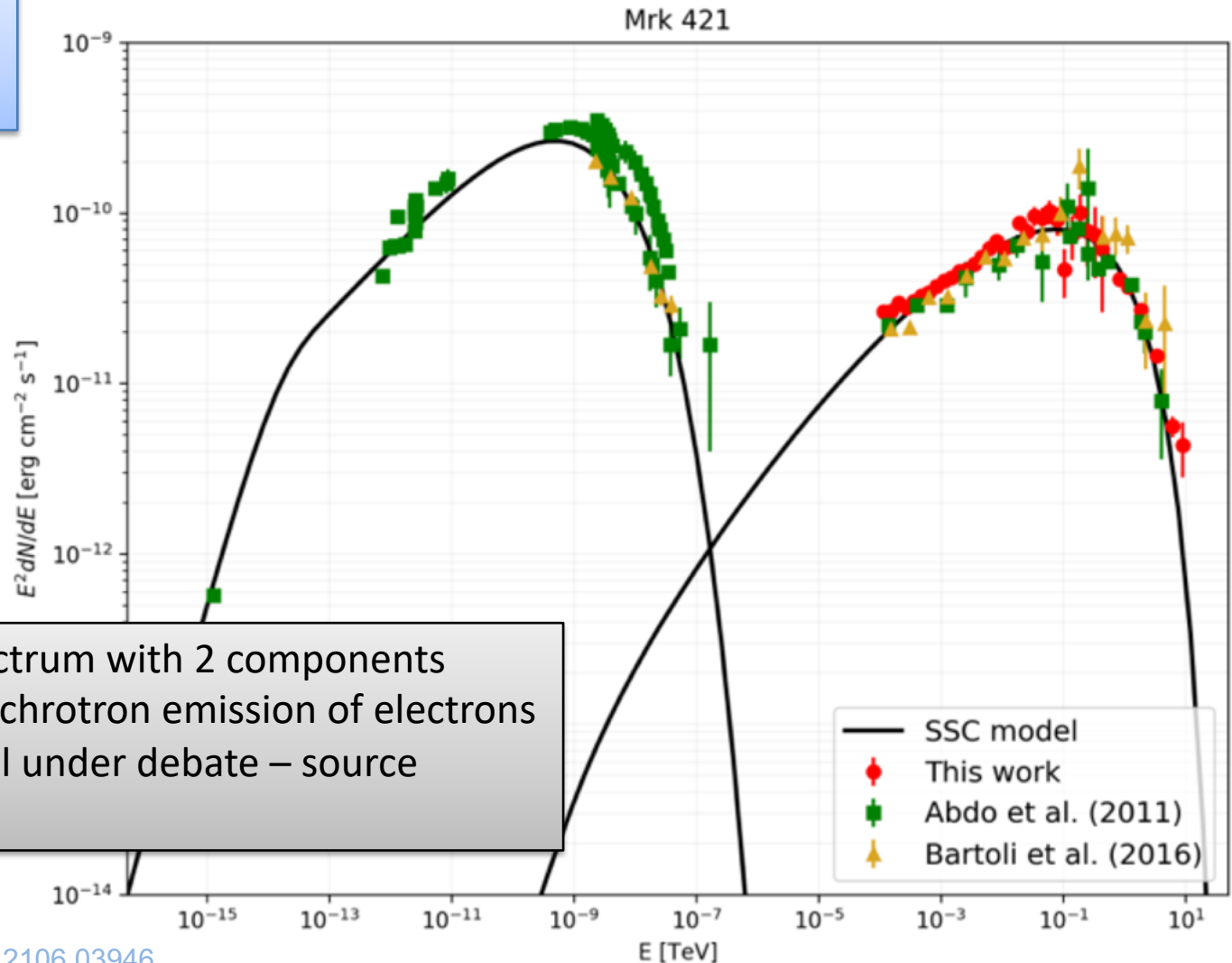
Blazars (jet aligned with Earth) are prime targets for TeV observations.



Urry & Padovani, (1995)

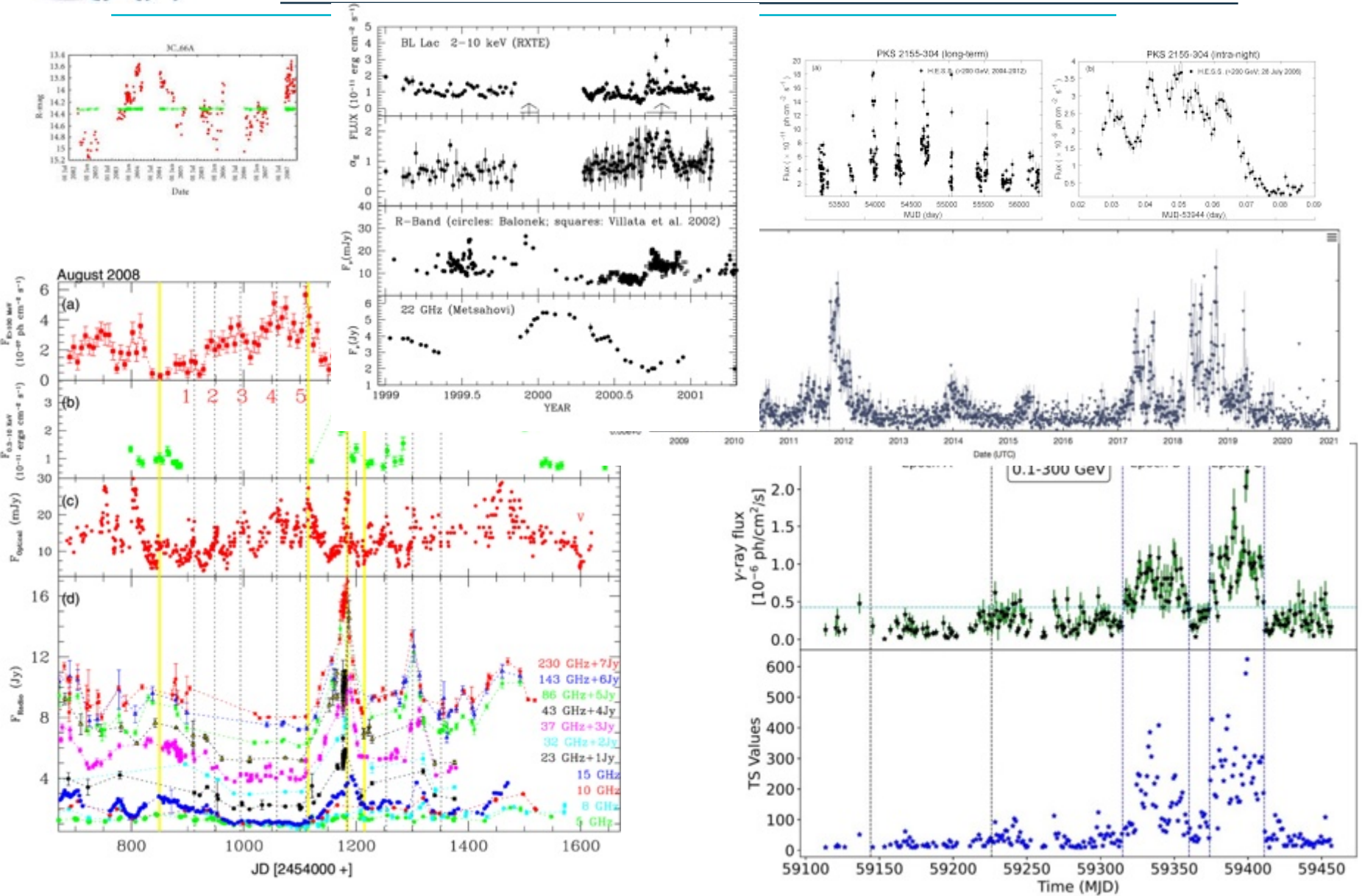
Mrk 421

- HBL
- $z=0.031$



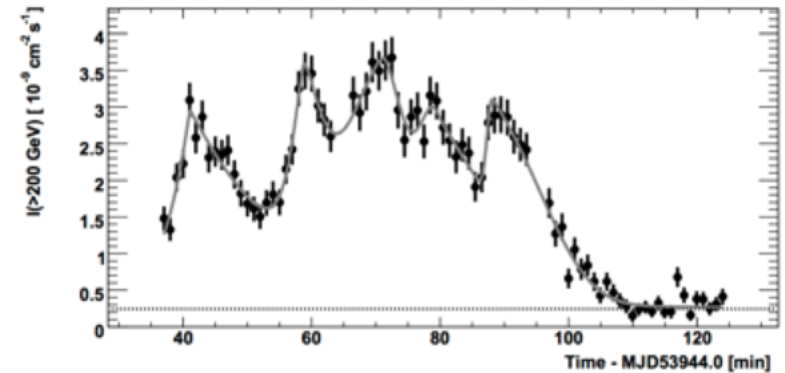
- Non-thermal spectrum with 2 components
- Low energy = Synchrotron emission of electrons
- High energy is still under debate – source dependent

MAGIC collaboration, 2106.03946



Measuring and characterising variability:

- Flux ϕ as a function of time with associated error σ
- S is the variance



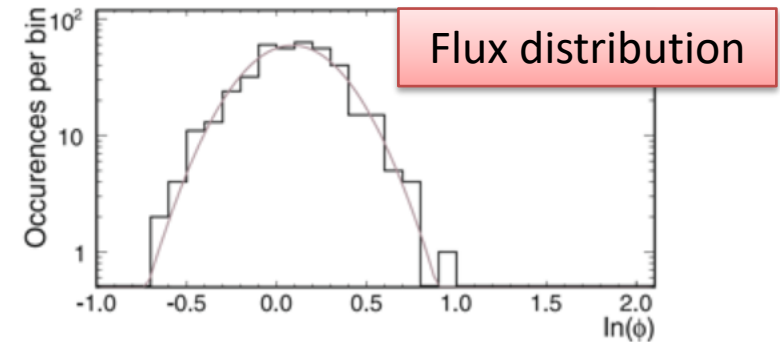
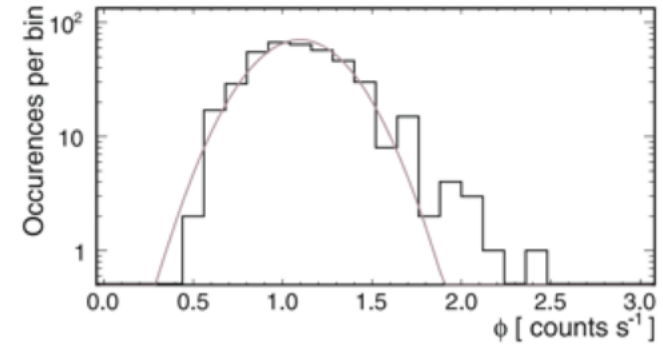
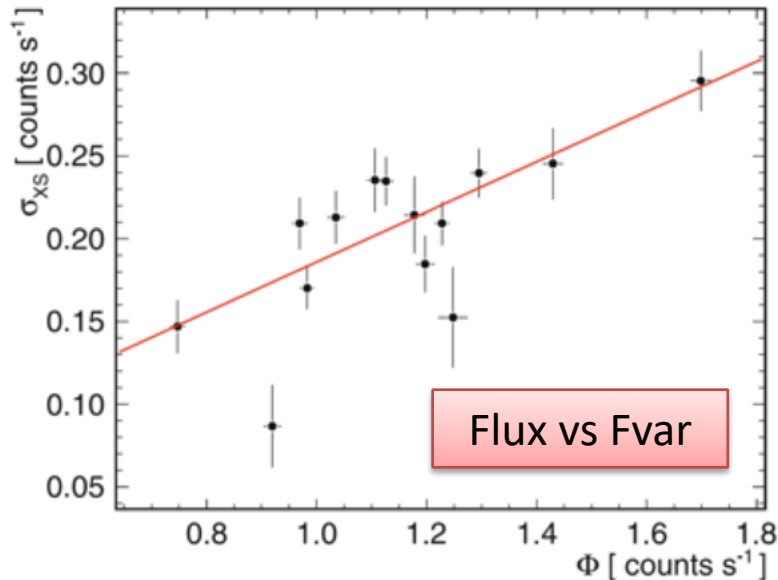
- Fit with a constant function + χ^2
- Lomb-Scargle periodogram Lomb 1976; Scargle 1982
- Fvar : Normalised excess variance Vaughan et al. 2003
- Power Spectra Density

$$F_{\text{var}} = \frac{\sqrt{S^2 - \overline{\sigma_{\text{err}}^2}}}{\overline{\Phi}}$$

AGN variability: Log-normality

Log-Normality seems common in Blazars

Lognormal variability in BL Lacertae B. Giebels and B. Degrange

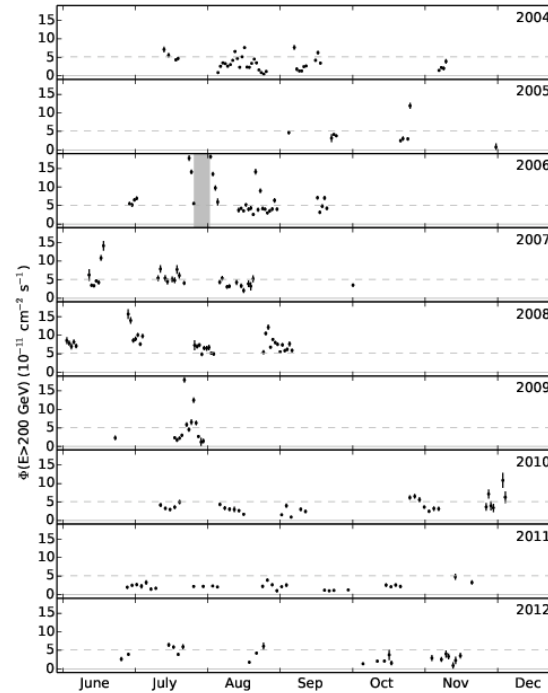


Seen in other type of sources.

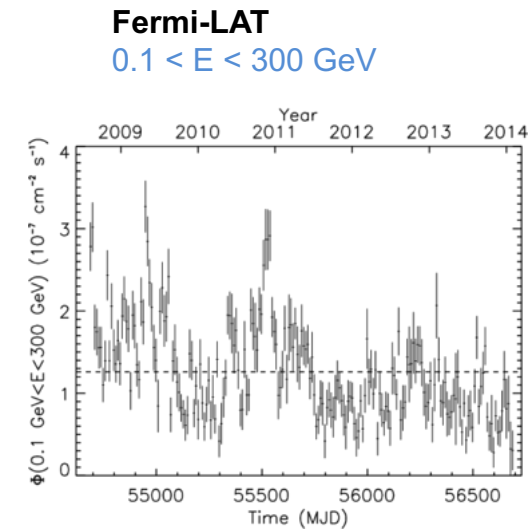
- Link Jet-Accretion disk
- Mini jets in jet

PKS 2155-304

- HBL
- $z=0.116$
- Southern source
- Classical « 2 bump » SED



H.E.S.S.
 $E > 200 \text{ GeV}$



First detection at TeV:

Chadwick, P.M. et al., Astroparticle Physics 11 p145-148 (1999)

Bright source in gamma

Variability studies and modeling of the blazar PKS 2155-304 in the light of a decade of multi-wavelength observations J. Chevalier et al.

The case of PKS 2155-304

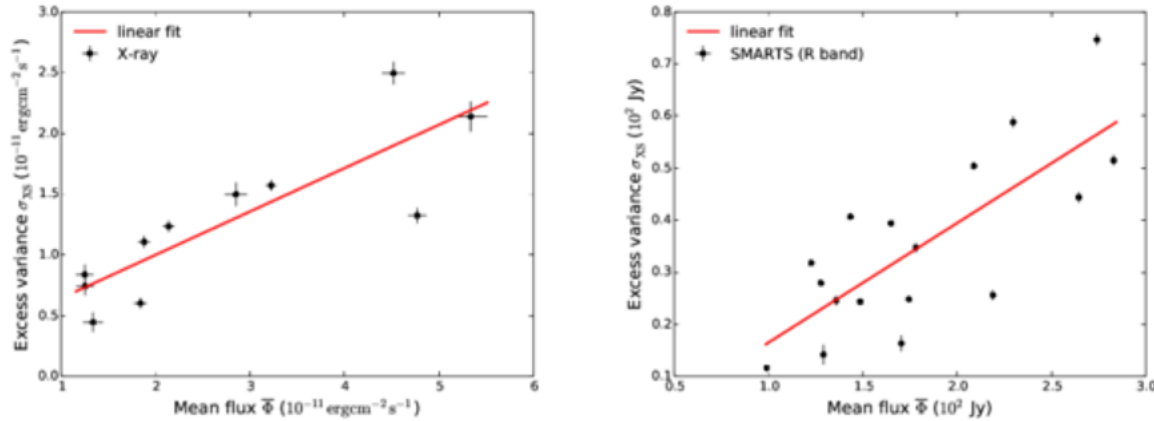


Figure 4. Excess variance σ_{XS} as a function of the mean flux Φ in X-ray and in the SMARTS R band. The red line is the result of a linear fit to the data.

Low energy data

Gamma-ray data

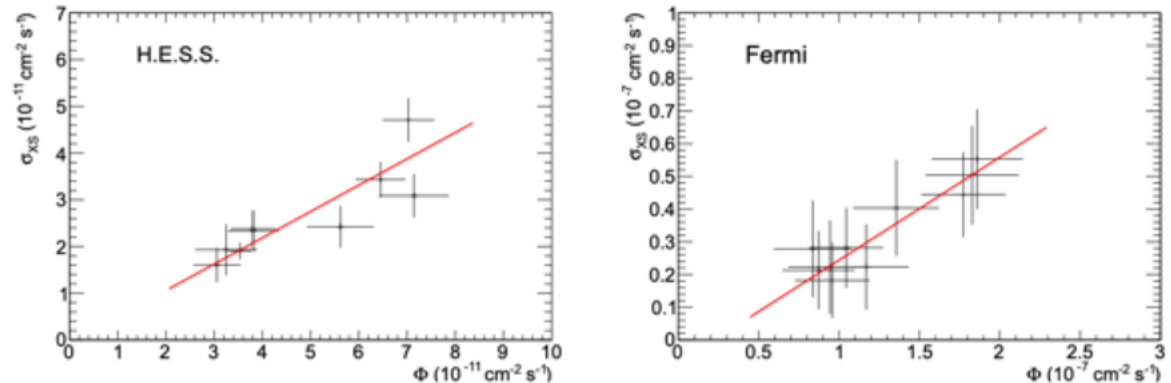


Fig. 3: Scatter plot of the excess RMS and the average flux for the H.E.S.S. (left) and *Fermi* LAT (right) data. Each flux and excess rms values are computed using at least 20 adjacent light curve points. A linear fit is shown in red.

The H.E.S.S. Collaboration: γ -ray long-term variability of PKS 2155-304

AGN variability: RMS-Energy relation

$$F_{\text{var}} = \frac{\sqrt{S^2 - \sigma_{\text{err}}^2}}{\bar{\Phi}}$$

Fun Fact : this was one of the first discussion I had with Berrie

Unveiling the X-ray/TeV engine in Mkn 421
Berrie Giebels, G. Dubus and Bruno Khelifi

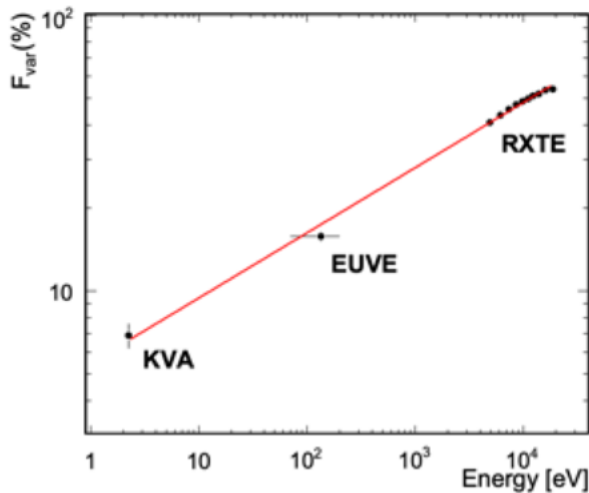


Fig. 6. Fractional rms as a function of observed energy, for the RXTE and KVA data from this campaign. Also a EUVE measurement is shown as an open circle, from a MWL campaign on Mkn 421 (Takahashi et al. 2000) in 1998. The data are well described by a power law with a slope $\propto E^{1/4}$.

VHE γ -ray emission of PKS 2155–304: spectral and temporal variability HESS Collaboration

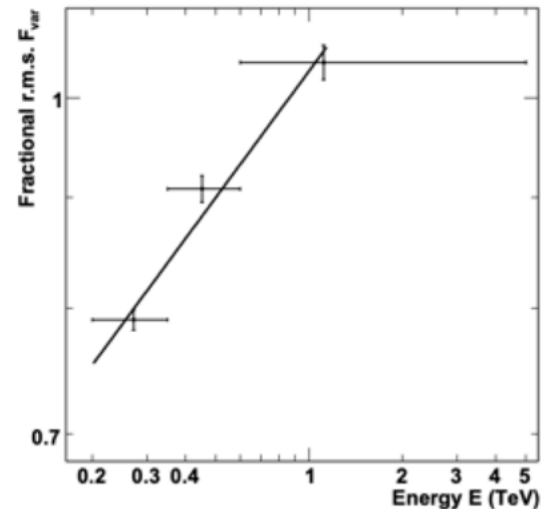
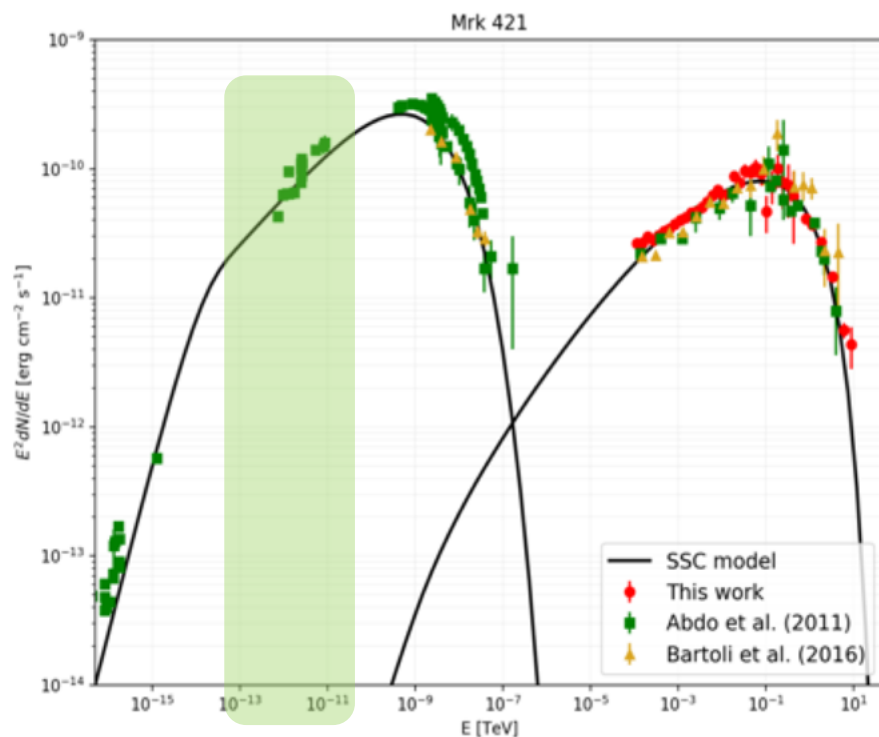


Fig. 9. Fractional r.m.s. F_{var} versus energy for the observation period MJD 53944–53947. The points are the mean value of the energy in the range represented by the horizontal bars. The line is the result of a power law fit where the errors on F_{var} and on the mean energy are taken into account, yielding $F_{\text{var}}(E) \propto E^{0.19 \pm 0.01}$.

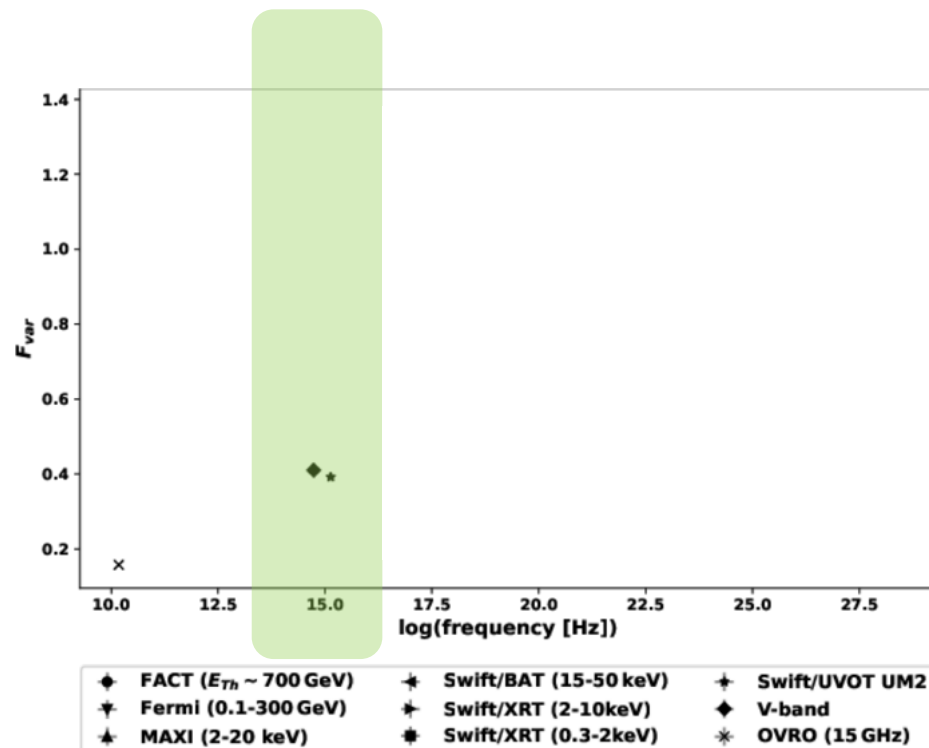
Can this be extended to other energy ranges?

Optical range (Smarts, ATOM, etc.):
monitoring, temporal gaps (Earth rotation), sensitivity

Time-Averaged flux



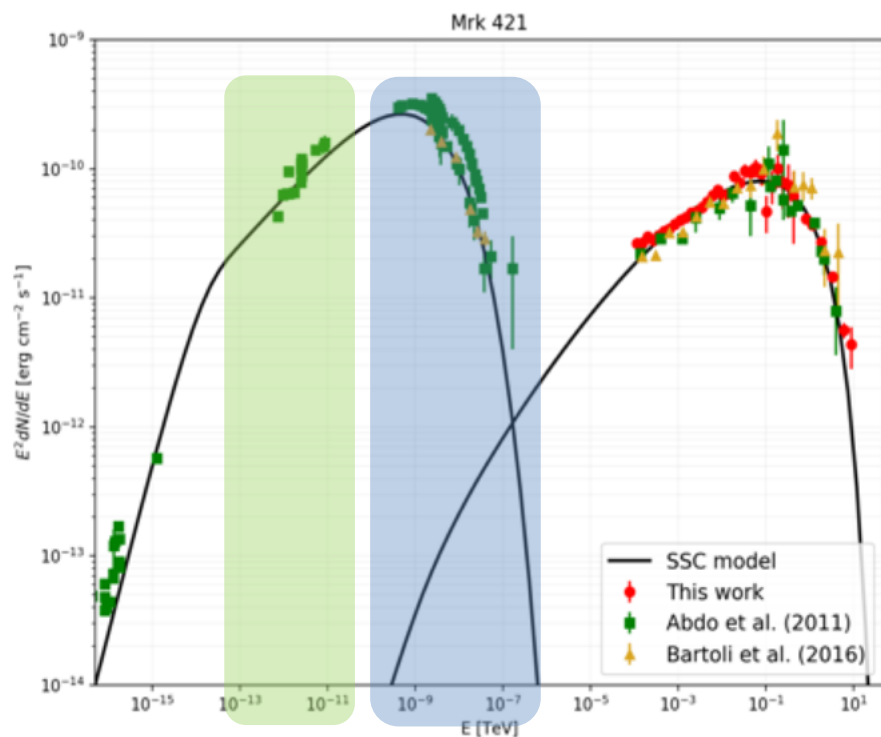
Variability



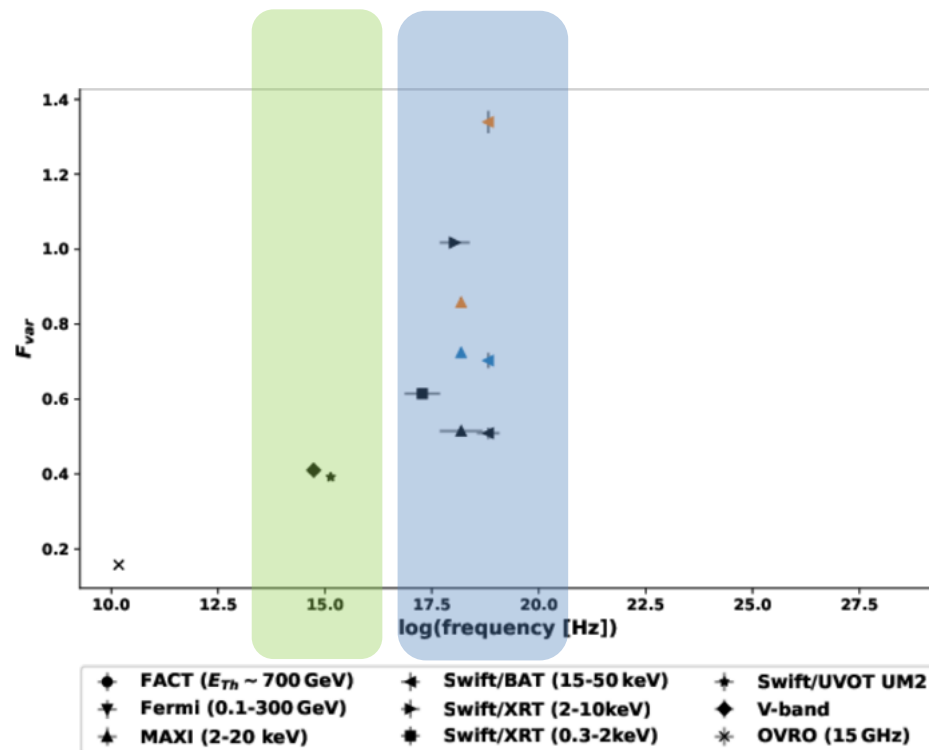
A. Arbet-Engels et al., 2101.10651

Rayons X (Swift-XRT, Nustar, etc):
Almost no monitoring, large gaps, good sensitivity

Time-Averaged flux



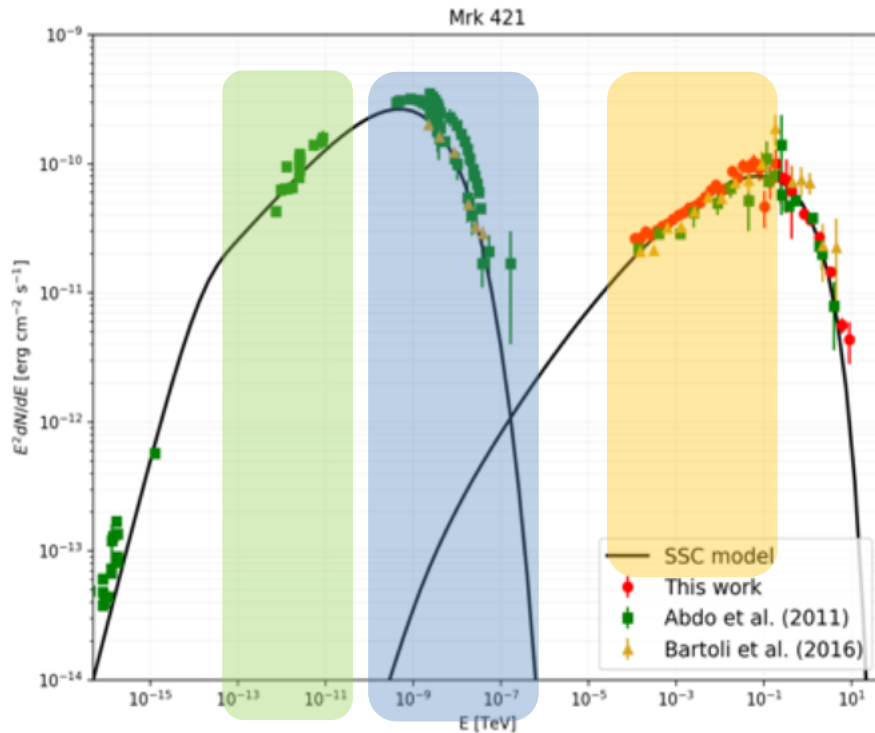
Variability



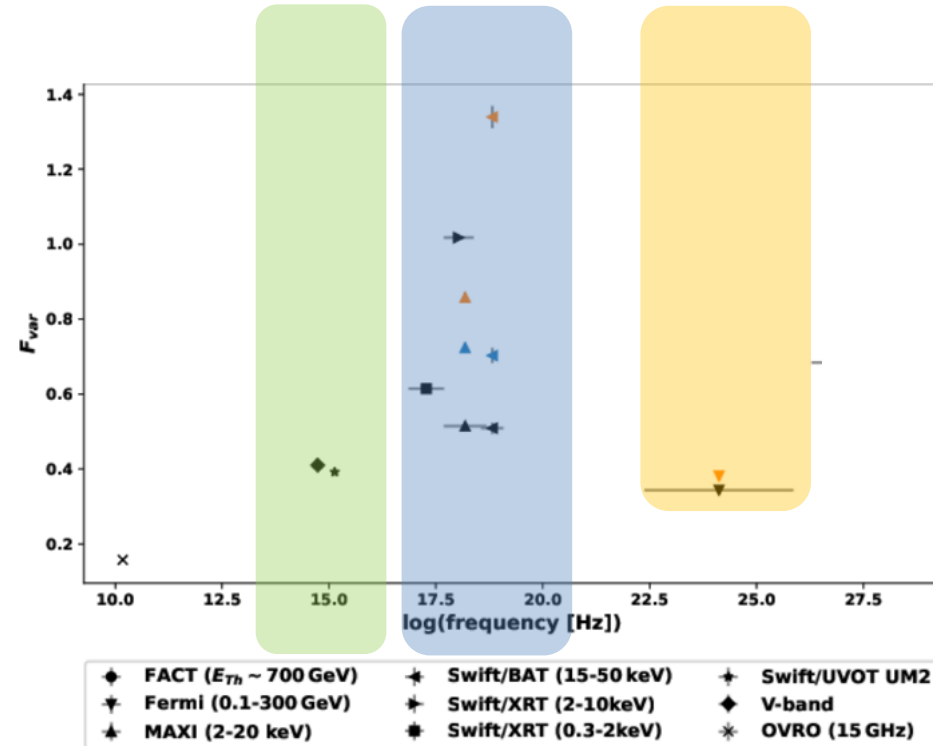
A. Arbet-Engels et al., 2101.10651

High-energy (Fermi-LAT):
high duty-cycle , monitoring, no gap

Time-Averaged flux



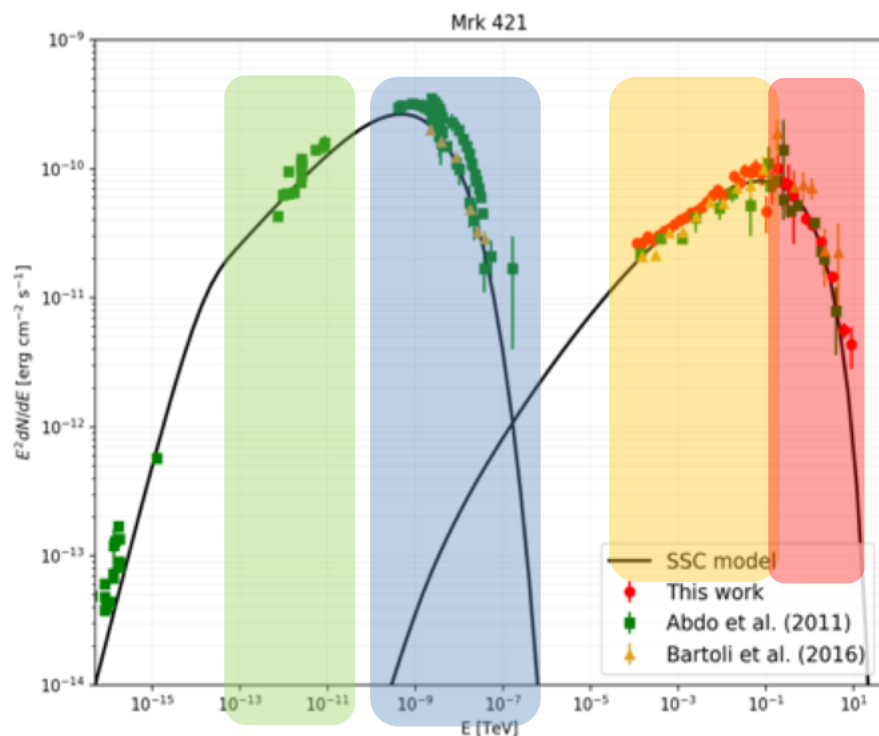
Variability



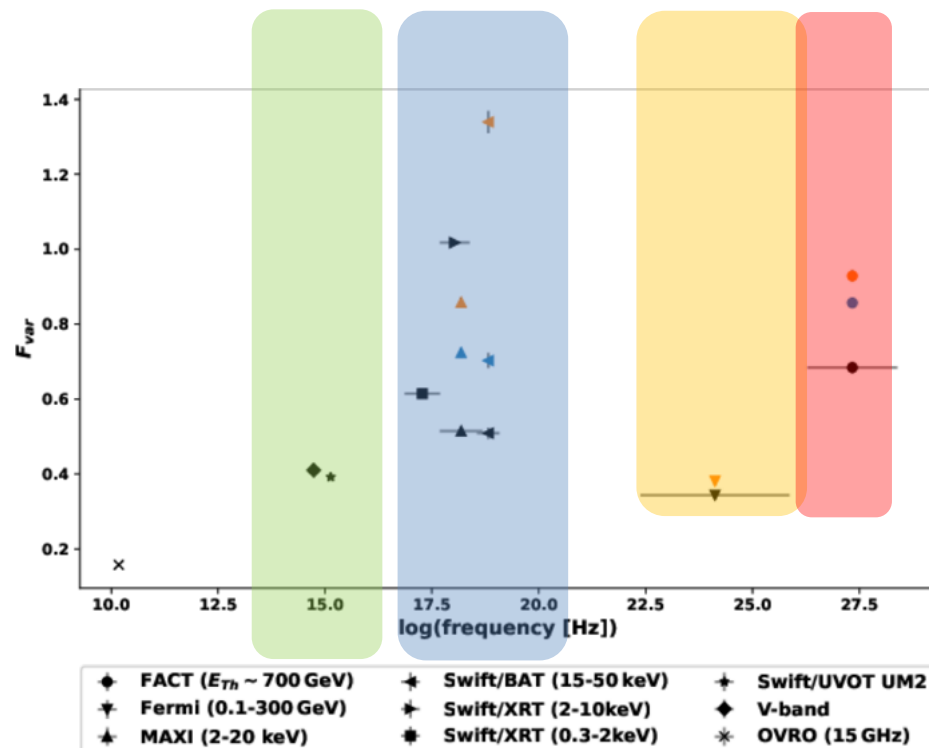
A. Arbet-Engels et al., 2101.10651

Very high-energy (H.E.S.S., MAGIC, Veritas):
low « duty-cycle », almost no monitoring, large gaps

Time-Averaged flux



Variability

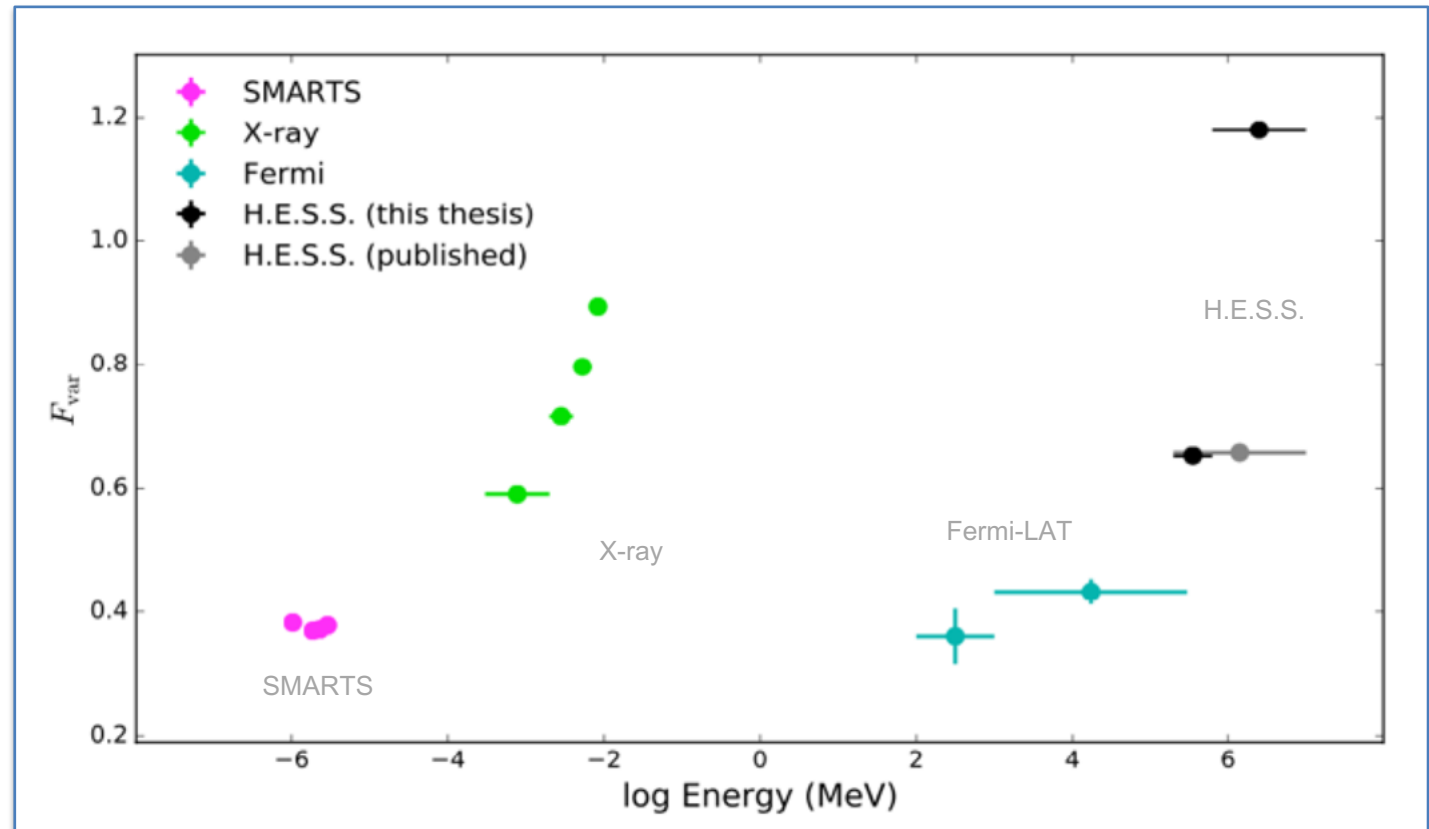


A. Arbet-Engels et al., 2101.10651

Variability energy Distribution: VED

Bimodal structure : Interpretation as a close link
optical – GeV
X-ray - TeV

J. Chevalier, PhD



AGN variability: Quasi-Periodicity

PG 1553+113 First detection in Gamma-Ray (*Fermi*-LAT)

- Triggers a lot of work
- Not yet in TeV

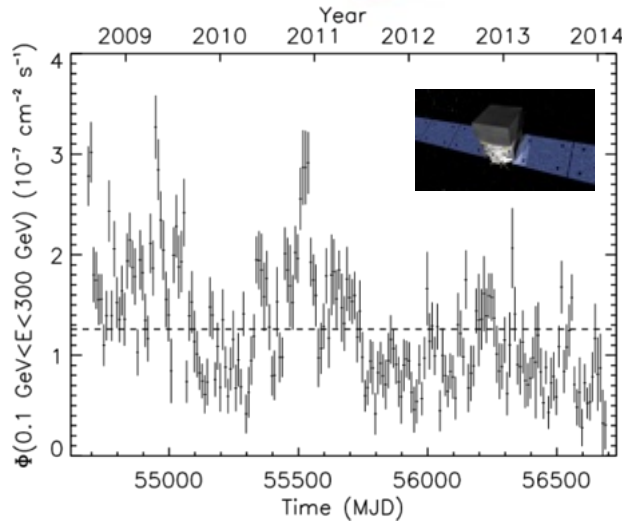
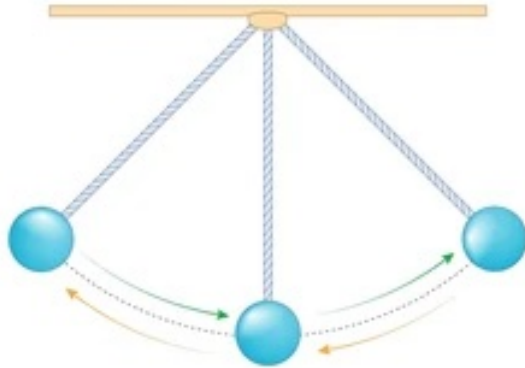
Can we even see Periodicity in TeV?



Possible explanations

- Jet precession
- Accretion disk processes
- Interaction with another compact object

PENDULUM



PKS 2155–304

PKS 2155–304 ~1.7 years *Zhang et al., 2017*

3C 66A ~1.0–1.5 years *Raiteri et al., 2023*

PG 1553+113 ~2.2 years *Ackermann et al., 2015*

OJ 287 ~12 years *Valtonen et al., 2016*

BL Lacertae ~1.2–1.5 years *Sandrinelli et al., 2016*

PKS 0537–441 ~0.7–1.0 years *Prokhorov & Moraghan, 2017*

4C +21.35 ~1.0 years *Tanaka et al., 2022*

AGN variability: PSD

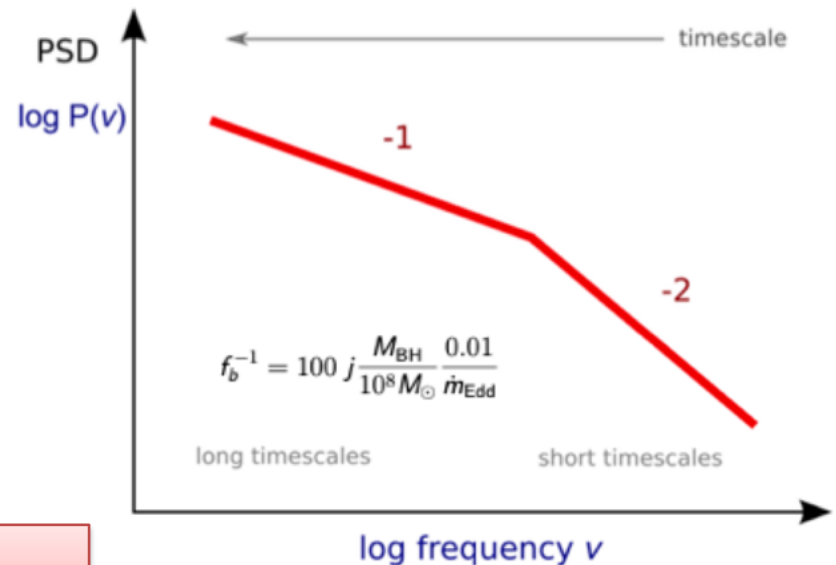
$$\text{PSD}(\nu) = \nu^{-\beta}$$

A broken power-law PSD => characteristic timescale (t_b)

Long time scale ($>1\text{d}$), HE and VHE data shows a
 $B = 1$ for pink or flicker noise

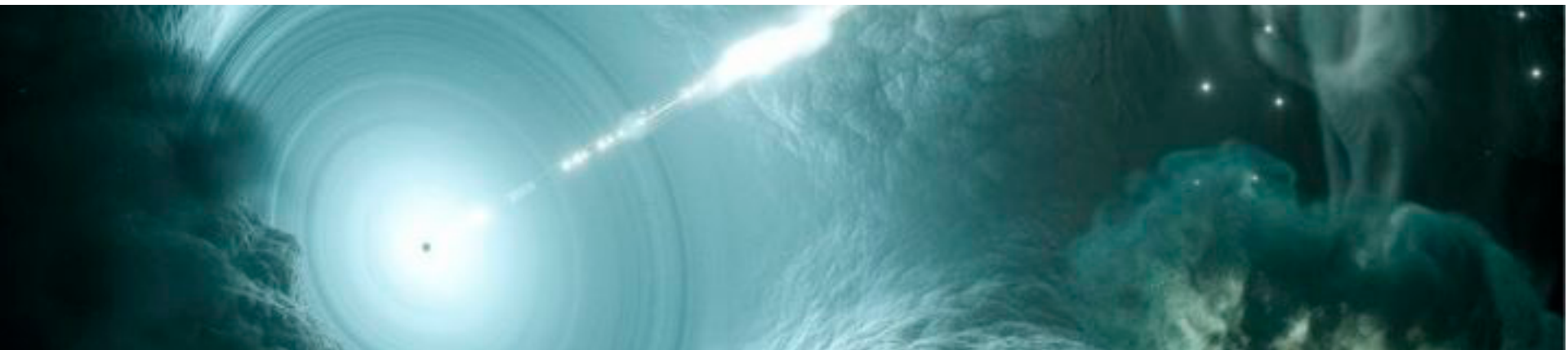
For PKS 2155-204

- Red noise during the 2026 outburst
- Pink on longer time scale



Break linked to accretion

McHardy et al. (2006), radio-quiet Seyfert AGNs



High variability in Gamma-ray

- But difficult observations

Astrophysical interests:

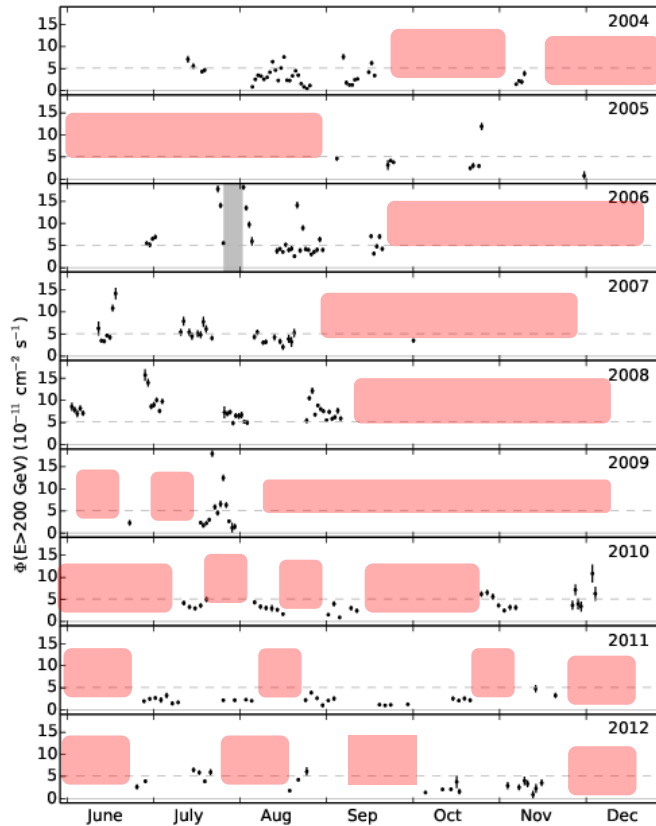
- Non-thermal Universe : High energy particles
- Acceleration process (shock, reconnection)
- Cosmic rays ? Neutrino emission ?

Cosmological interests:

- Extragalactic background (EBL), LiV

High variability in Gamma-ray

- But difficult observations

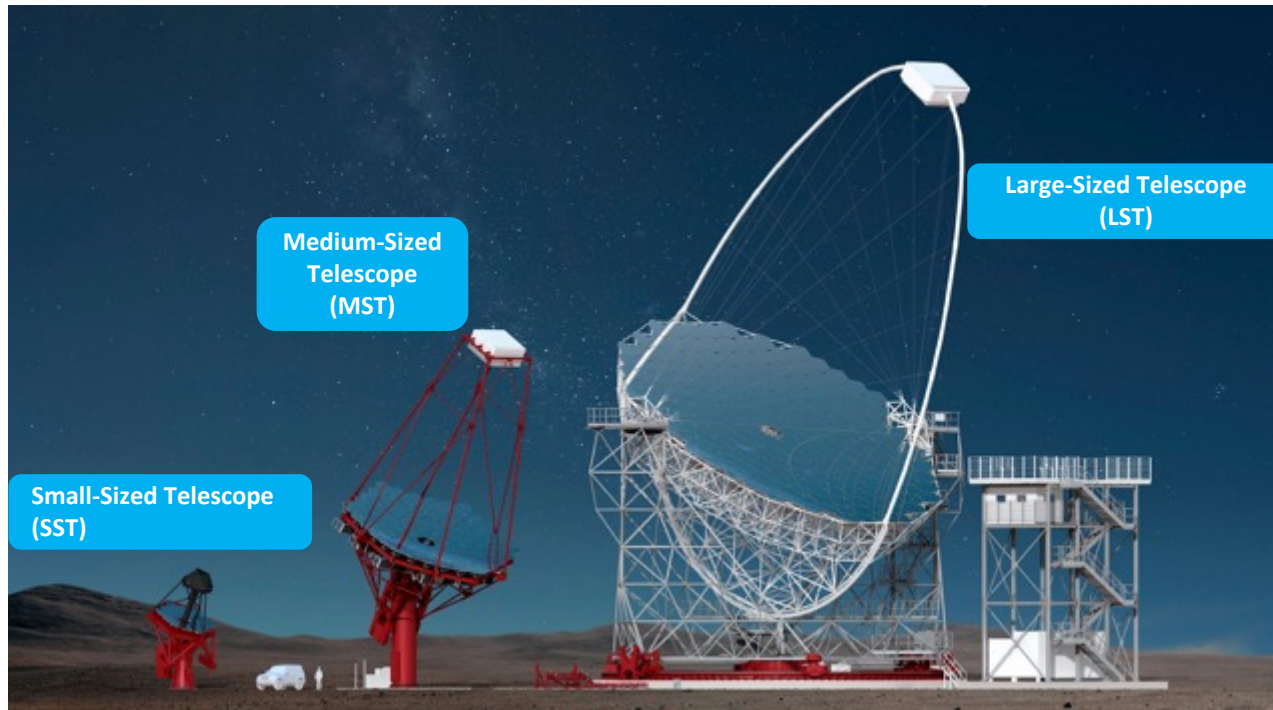


Observations can be prevented by :

- Weather
- Moon
- Earth rotation

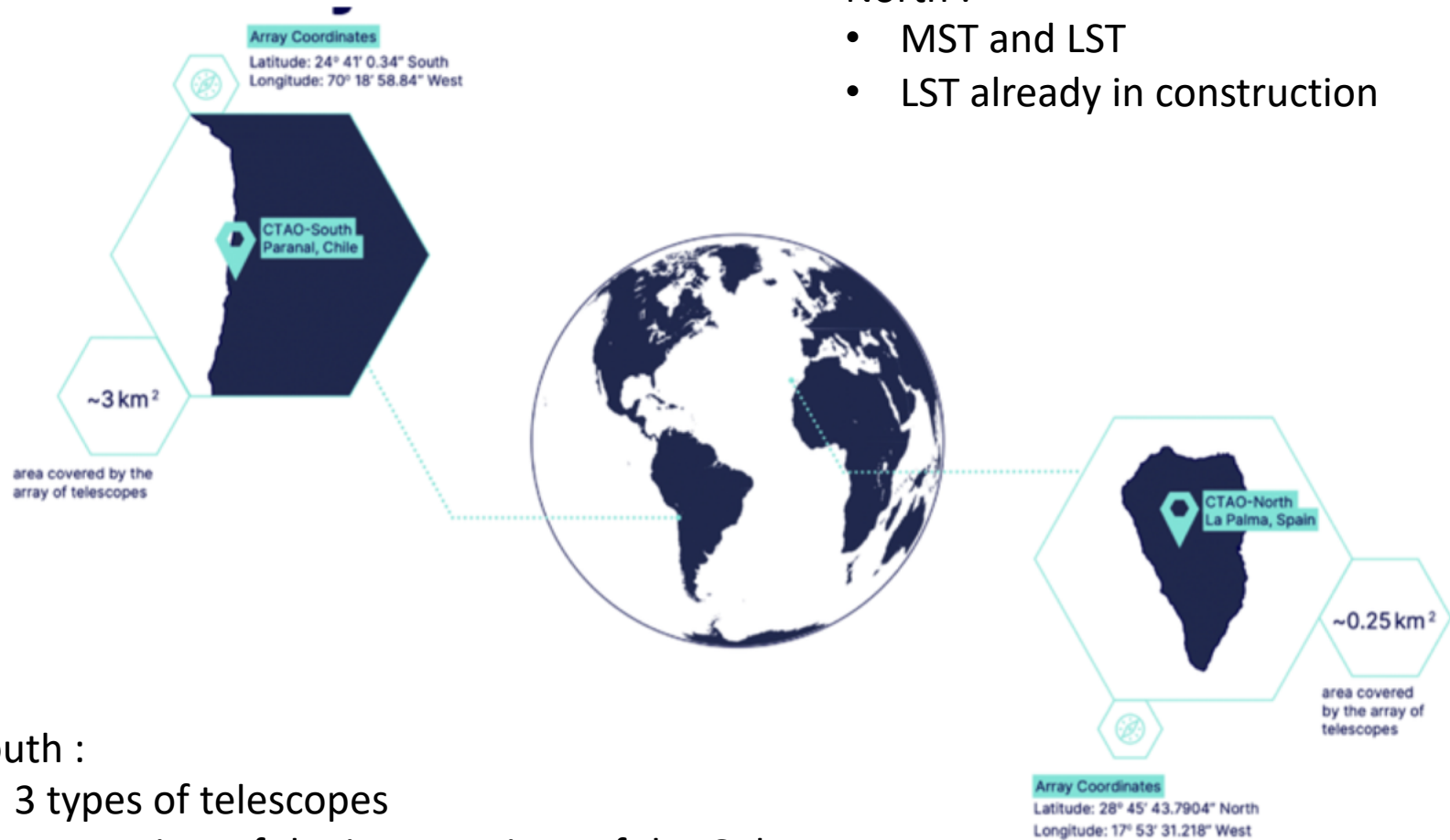
Windowing effects and Binning effects are challenging

Cherenkov Telescope Array (CTA)



	SST	MST	LST
Effective mirror area	8m ²	88 m ²	370 m²
Energy range	1 TeV - 300 TeV	80 GeV - 50 TeV	20 GeV - 3 TeV
Exclusive energy range	5 TeV - 300 TeV	150 GeV - 5 TeV	20 GeV - 150 GeV
#Telescopes North	0	9	4
#Telescopes South	37 (*+5)	14	0 (*+2)
Photo-sensors	SiPM	PMT	PMT

* LST funded with Italian PNNR



North :

- MST and LST
- LST already in construction

South :

- 3 types of telescopes
- Better view of the inner regions of the Galaxy

Finally approved January 7th 2025

New ERIC Council and committees;

Increased funding,

Solidify agreements with host countries

International recognition and visibility

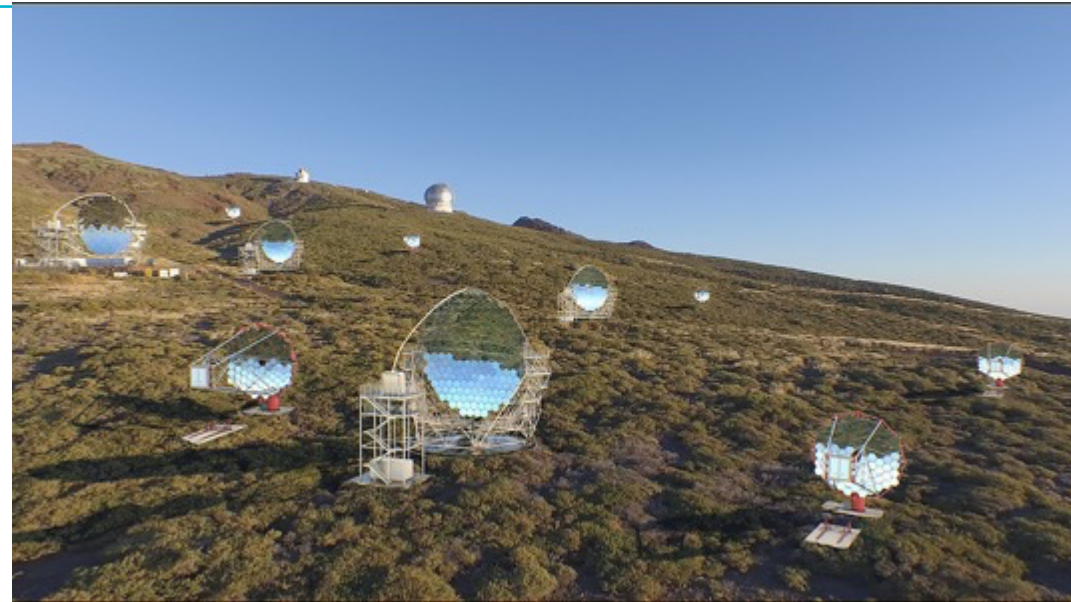
Accept telescopes



Transfer from gGmbH to ERIC

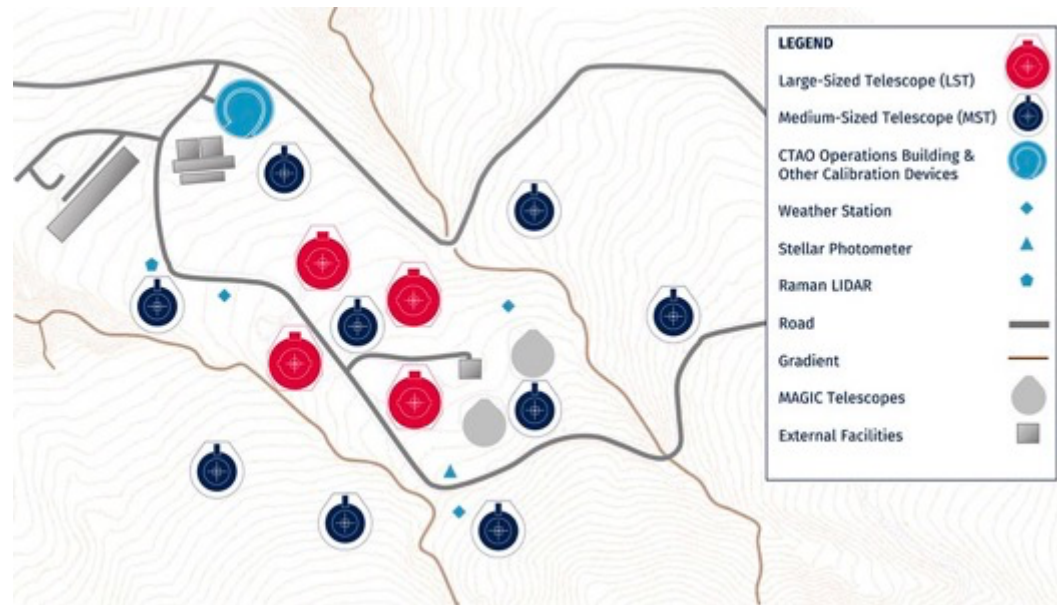


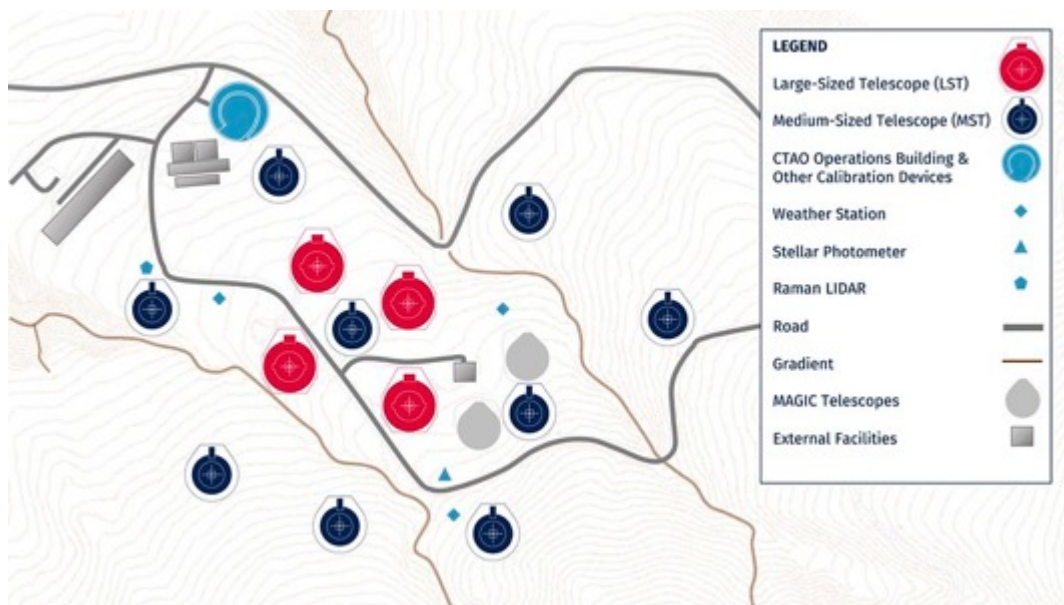
1st ERIC Council Meeting



Located at Observatorio
Roque de los Muchachos (ORM),
Spain

- 4 LSTs+ 9 MSTs



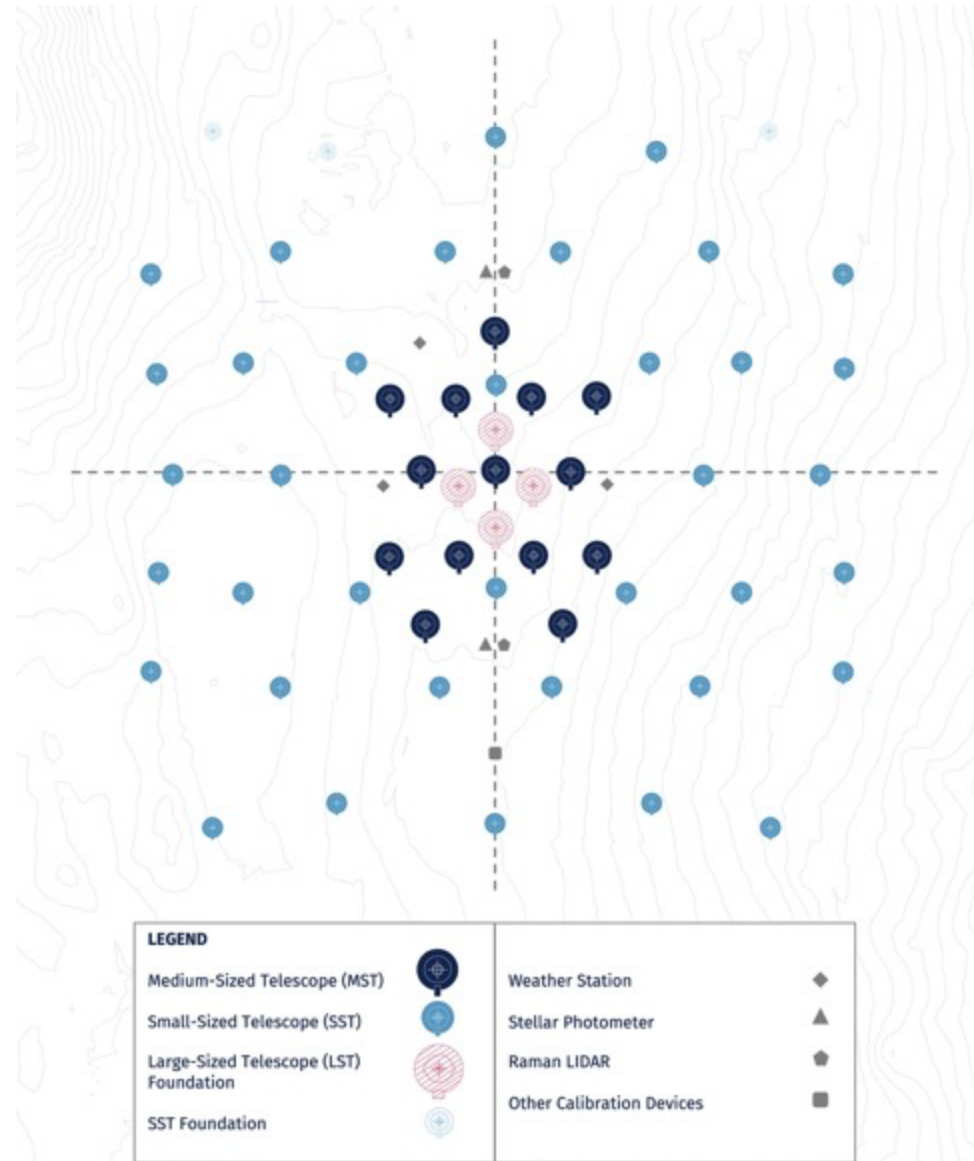
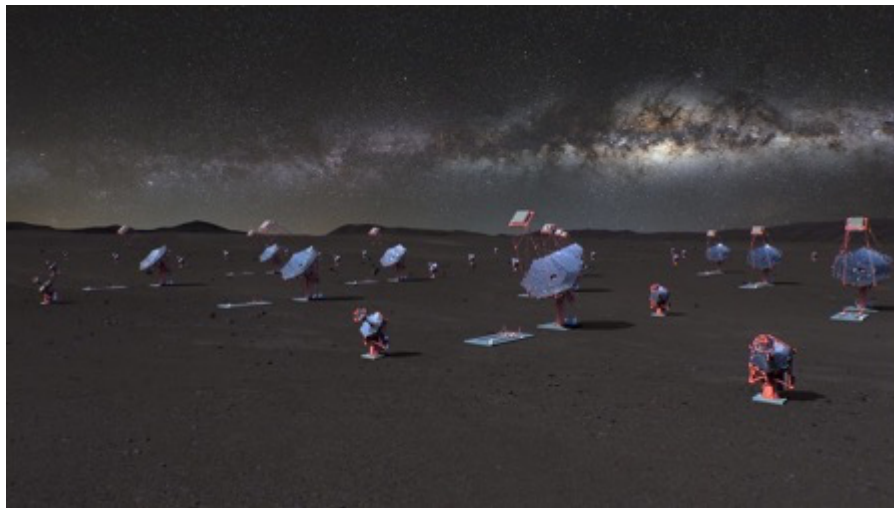


4 LST to be finished
next year



Located at Atacama Desert, Chile

- 14 MSTs + 37 SSTs + 2 LSTs



Road under construction

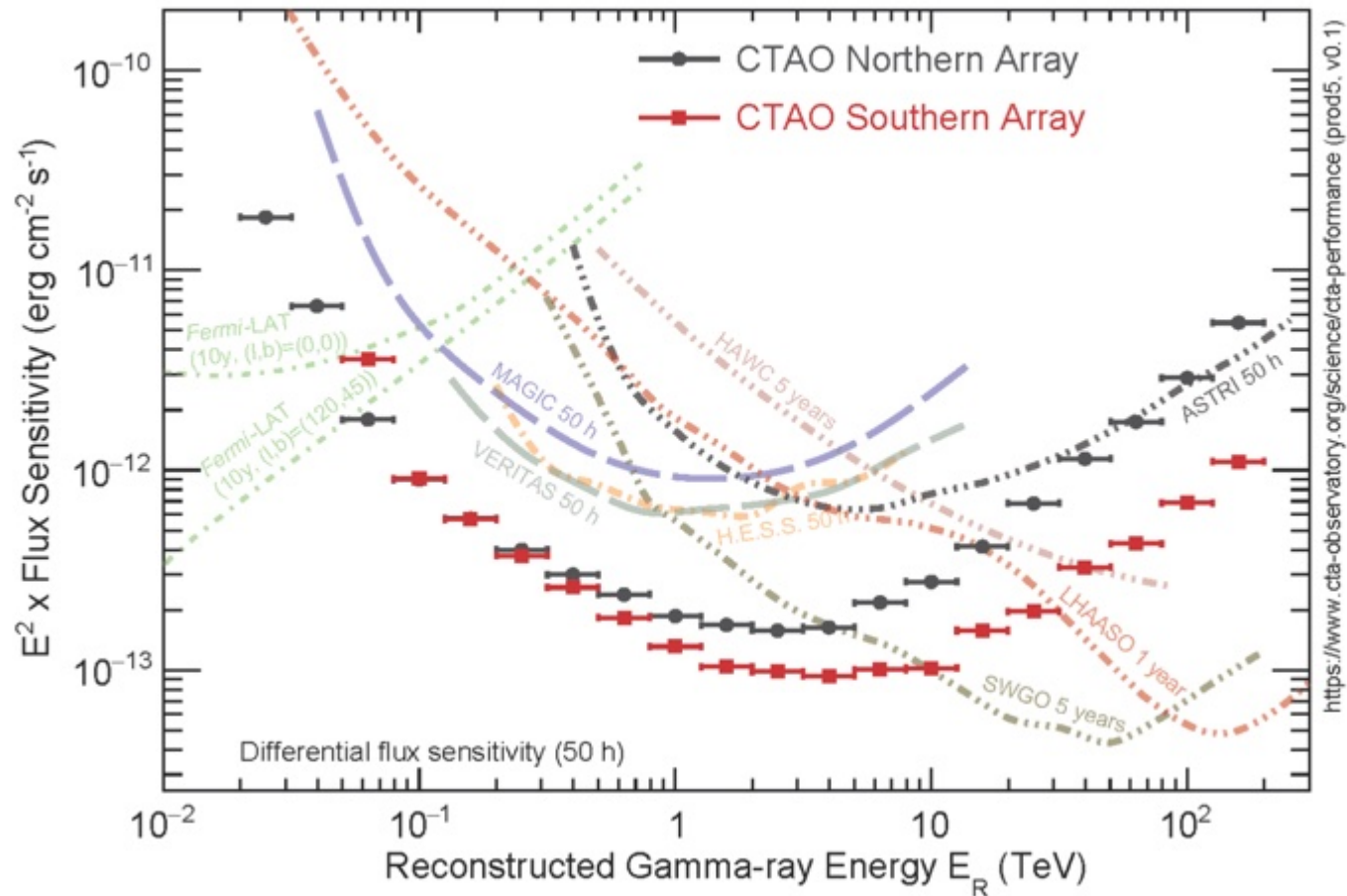


Announcement

Contract signed for construction of CTAO-South roads and telescope foundations

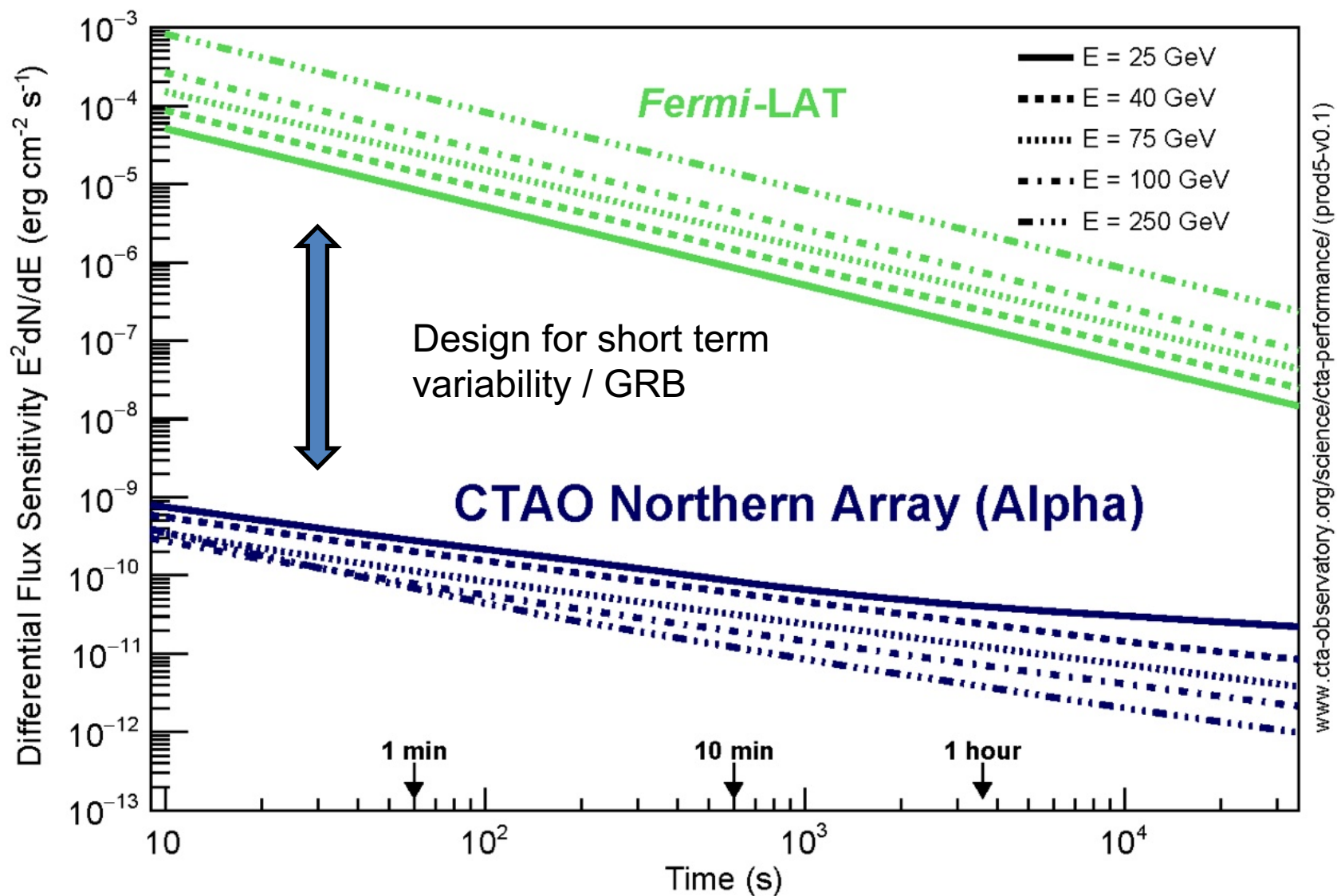
3 July 2025





North site devoted to low energy

South site more sensible at high energy



Long term variability

- Monitoring of AGNs

Short term variability

- Reply to Alert
- Real Time Analysis

What can we do :

- Explore duty cycle
- Periodicity studies
- PSD
- LiV
- Etc...

Short time scales

Important constraints on:

- Doppler factor
- Particle acceleration, cooling processes

Preparatory work:

- How many flares

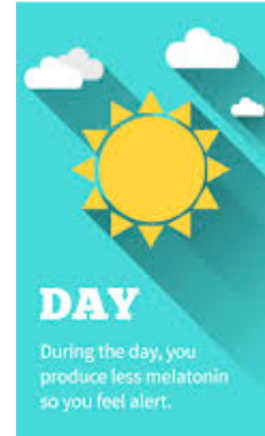
Flares definition ($F_\gamma = 5.10e-7 \text{cm}^{-2}\text{s}^{-1}$)

- 845 in FSRQs (~70 per year)
- 369 in BL Lacs (~30 per year)

~100 flares per year.

During the day :

- How to be alerted?
- Selection of Alert?
- Continue or stop observation



J.Otero & J. Becerra





Send a ToO to observe an alert



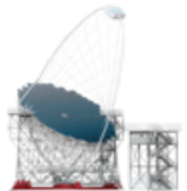
What can you see?



Gammapy simulations of light-curve and spectra based on theoretical model

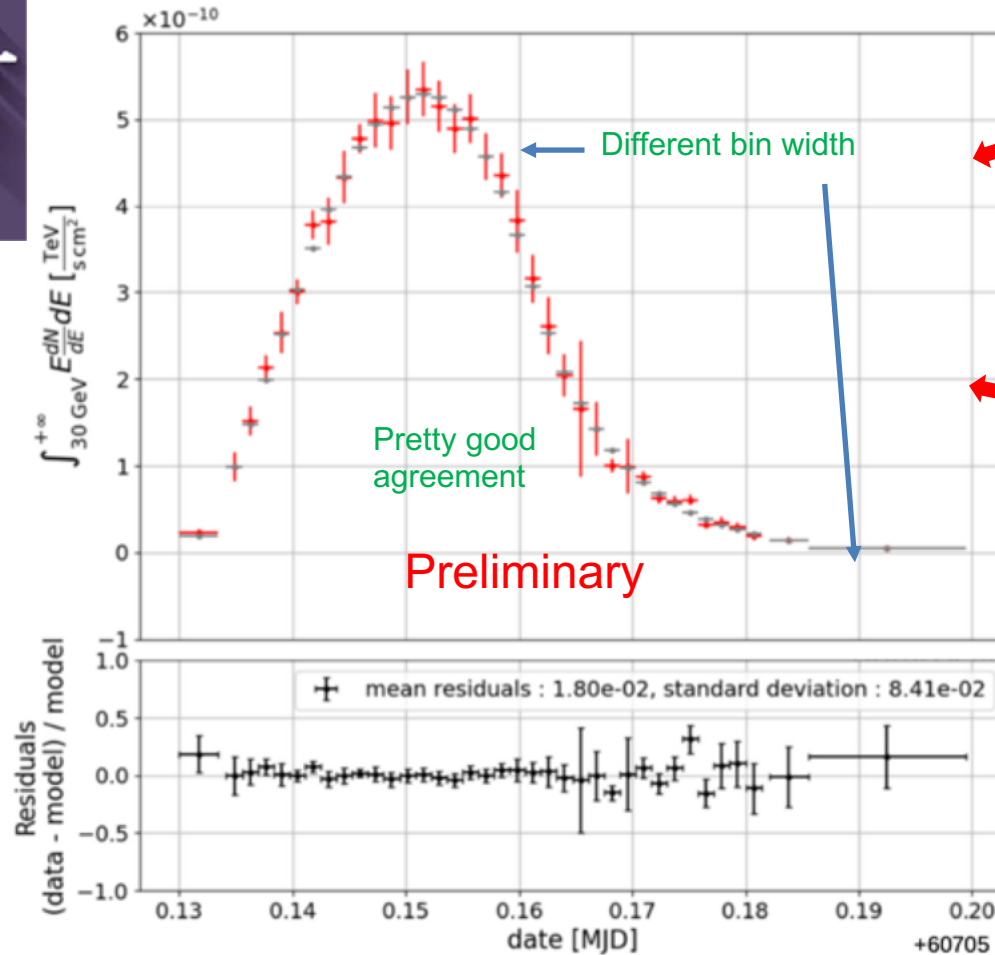


Include realistic observing conditions,
i.e. visibility and tracking

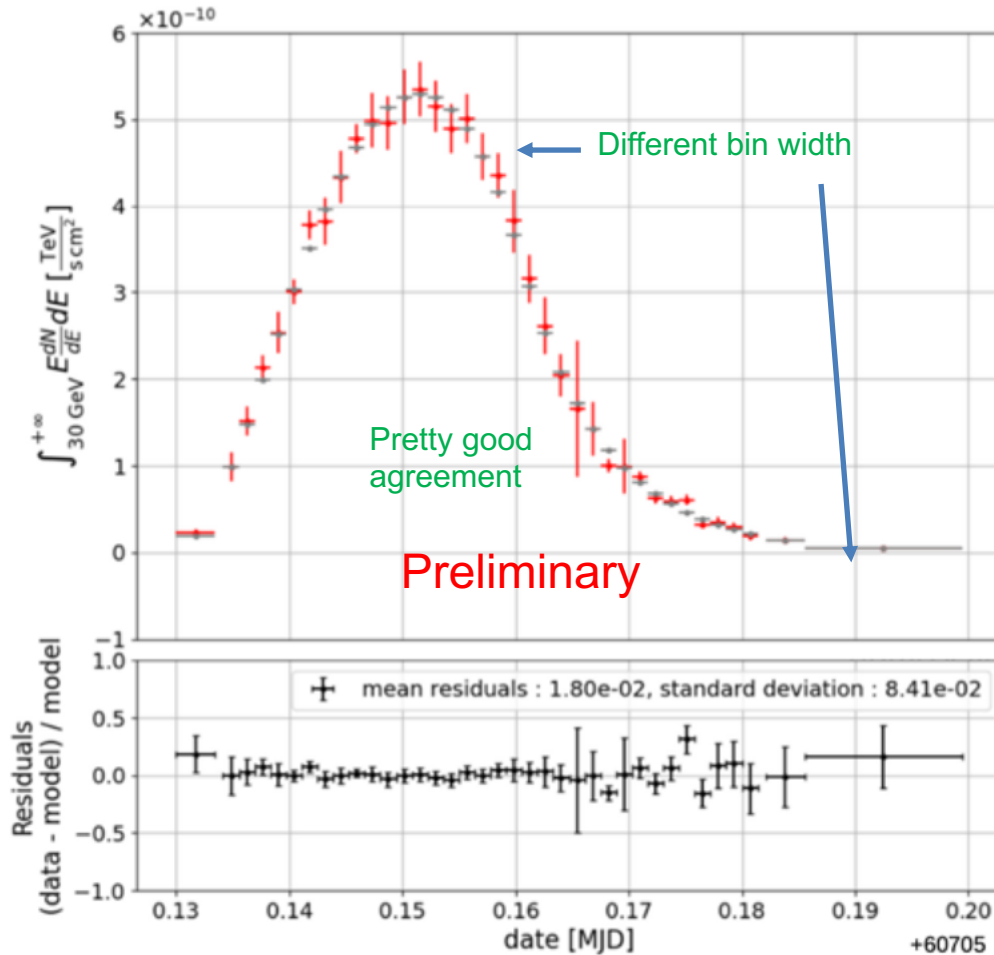


Short time scale

CTA allow Flux to be reconstructed with a PL fit EBL absorbed



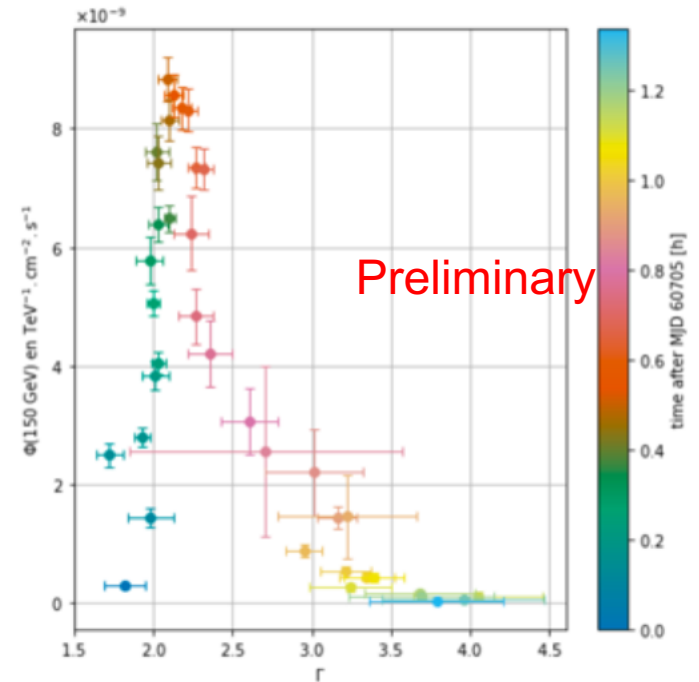
Reconstructed flux between 30 GeV - 30 TeV



Reconstructed flux between 30 GeV - 30 TeV

Short time scale

CTA allow Flux to be reconstructed with a PL fit EBL absorbed

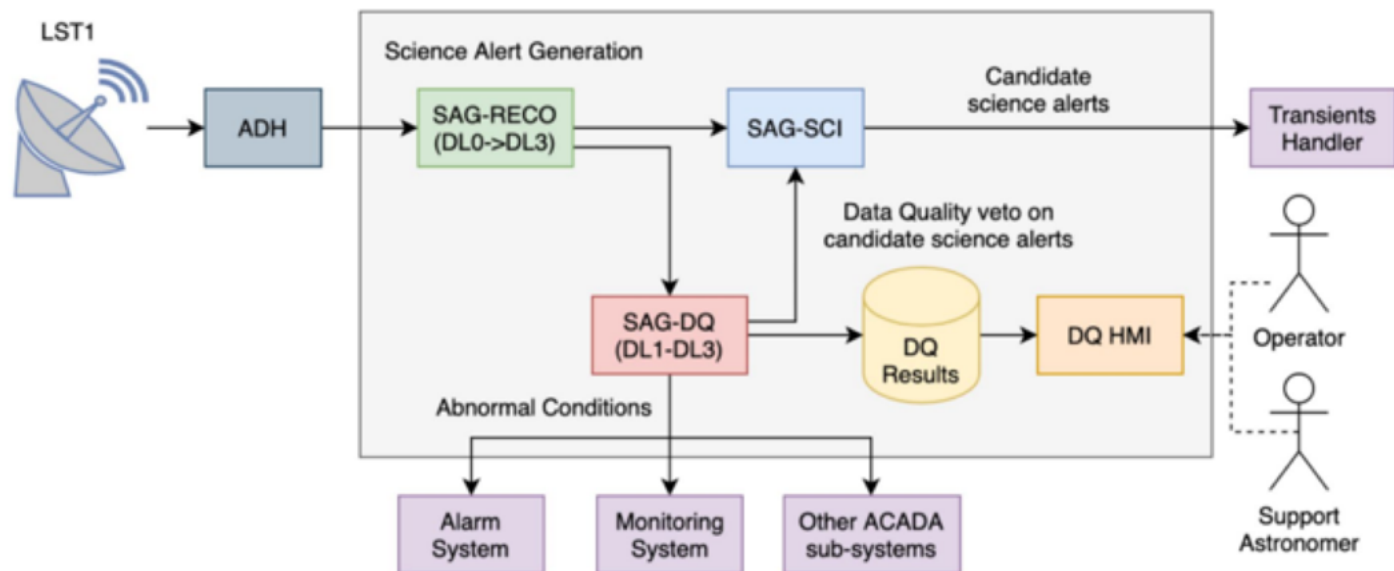


Sensitivity also spectral fit

How to react to a Flare during the night or the day after?

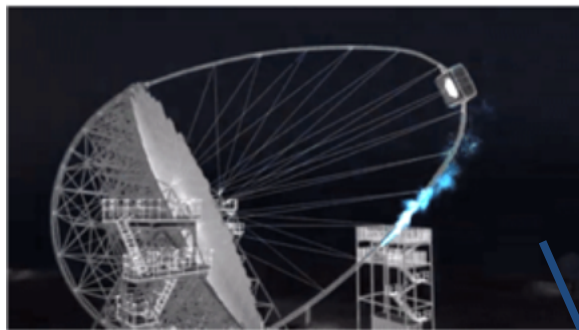


- (1) Handling telescope trigger rates of tens of kHz;
- (2) Being capable of issuing candidate science alerts with a maximum **latency of 20s** after the data becomes available.



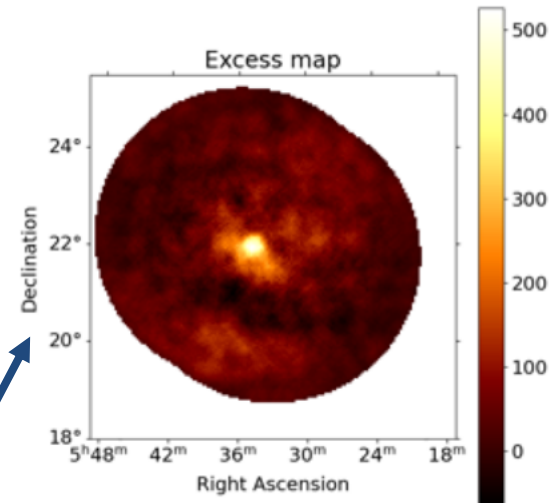
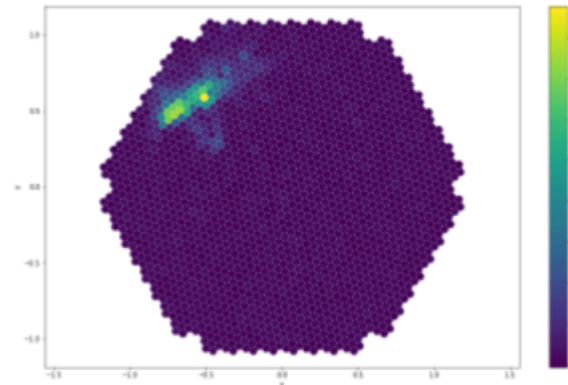
LST-1 RTA is a SAGE-Reco prototype

- Aim is to provide real time feedback on the telescope observation (for transient and variable source observations)
 - DL0/R1/**R0** (1855 pixels raw data) -> DL3 (gamma-like, energy, direction)
 - Current performances with the LST



input stream **~3 GB/s**
output data **~20 kB/s**
current speed **~0.75 GB/s/CPU**
DL3 available in **~50 secs**

image 3397, id = 5172882, type = 1,
Signal mean = 5.24393272399023 pe, min = -1.293764352798462, max = 174.82127380371094, id = 54.8300397872948



Weeks, Months, Years time scales

Key science project of CTA :

Long-term monitoring program of AGN

1500 hours of data to be taken during 10 years

Weekly observation of sources during the visibility period



CTA consortium 2019

Power Spectrum Density (PSD)
follows :

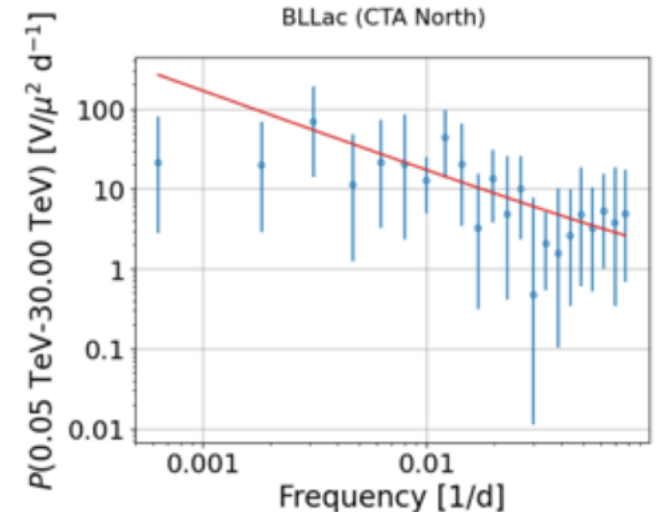
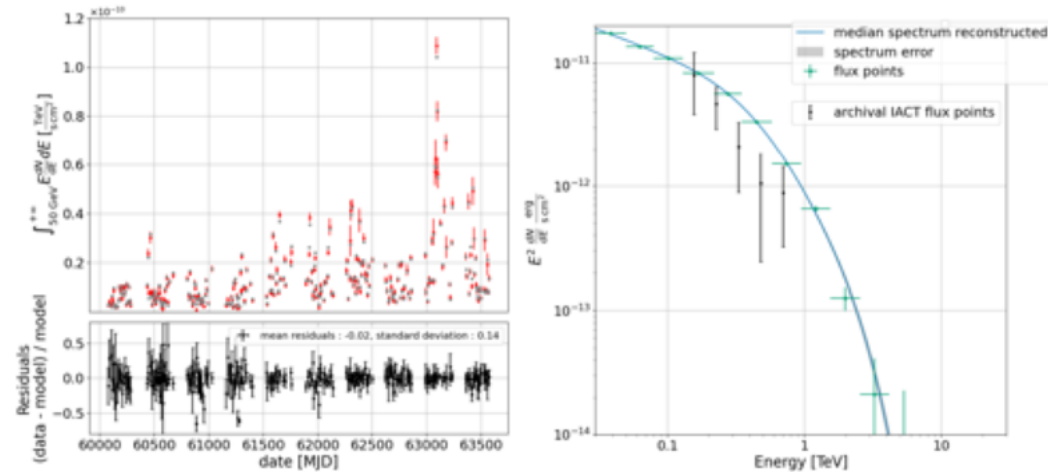
- red noise
- red noise + pink noise after break

Aim is to reconstruct PSD indices and
breaks

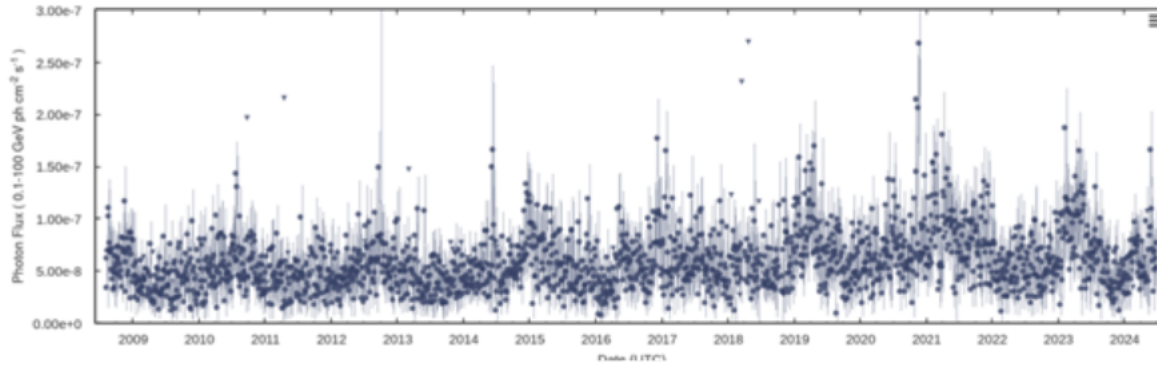
20 years of data simulated

Good reconstruction of PL PSD
Break is investigated

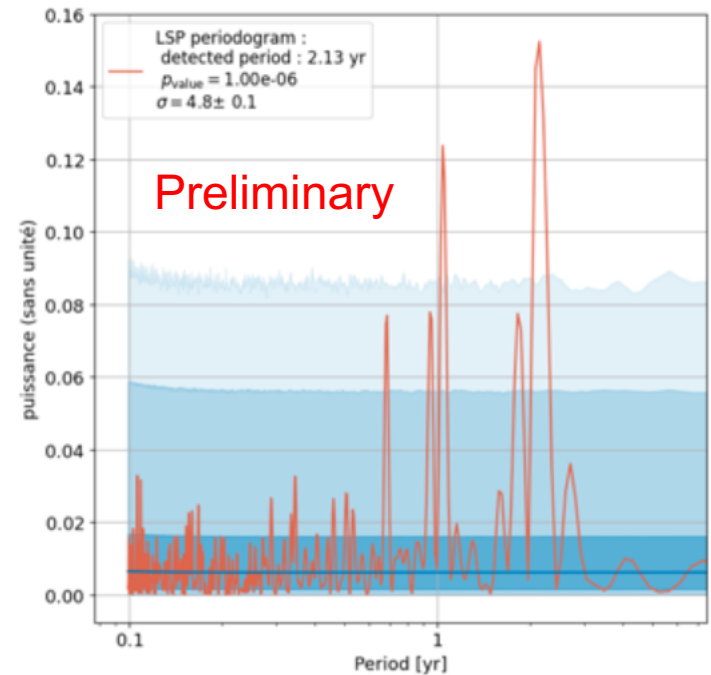
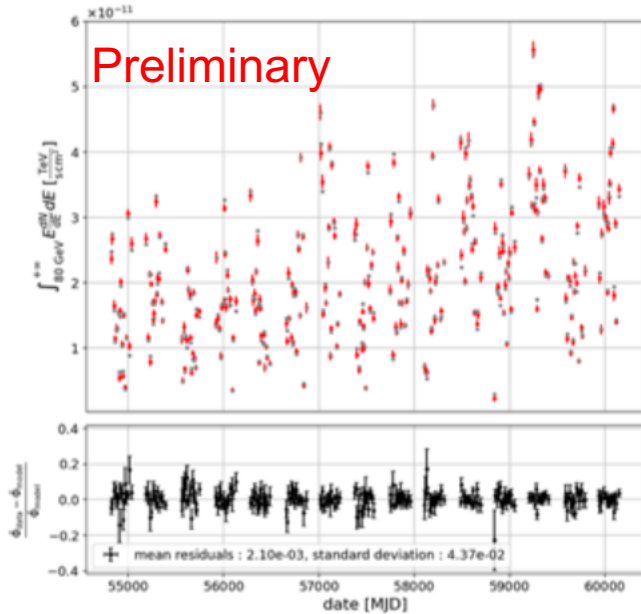
G. Grolleron, Gamma 2024
G. Grolleron, PhD Thesis



Search of periodicity at TeV energies



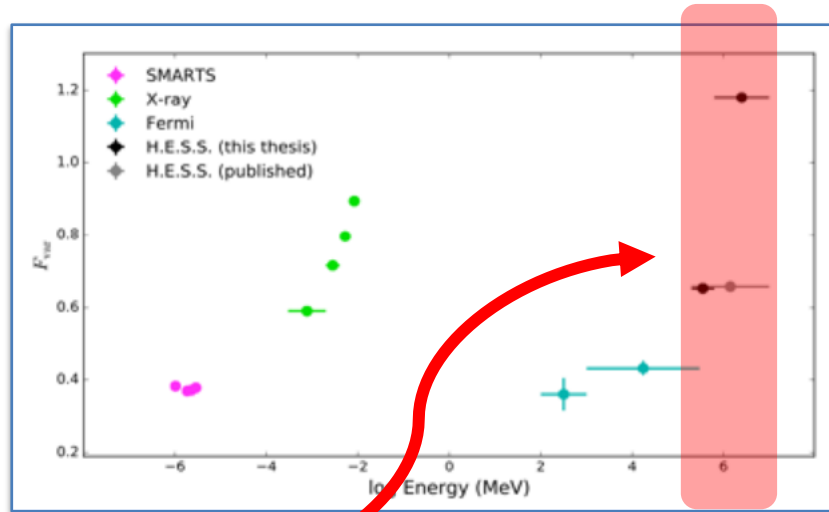
Fermi LAT light curve
can be extrapolated



15 years of observation
30 min / week

G. Grolleron, Gamma 2024
G. Grolleron, PhD Thesis

But



Fvar vs E for PKS 2155-304

Higher Stochastic variability in TeV might blur the periodicity

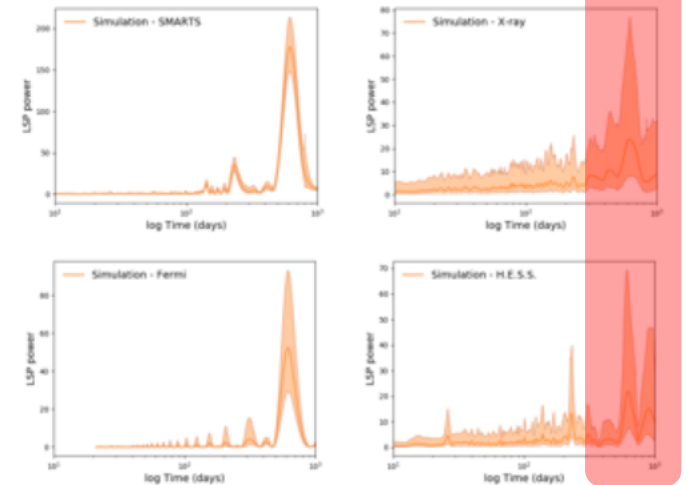
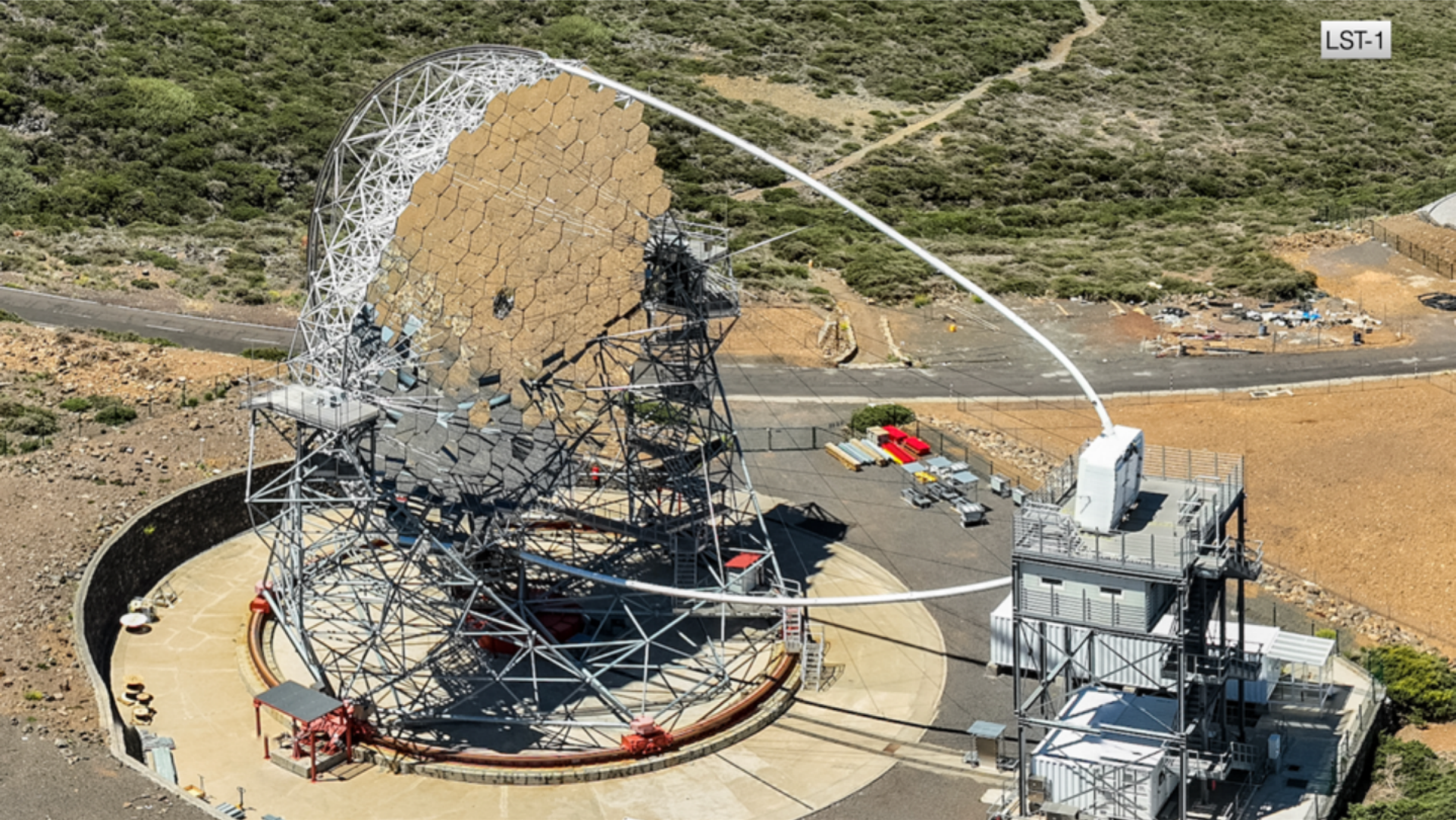
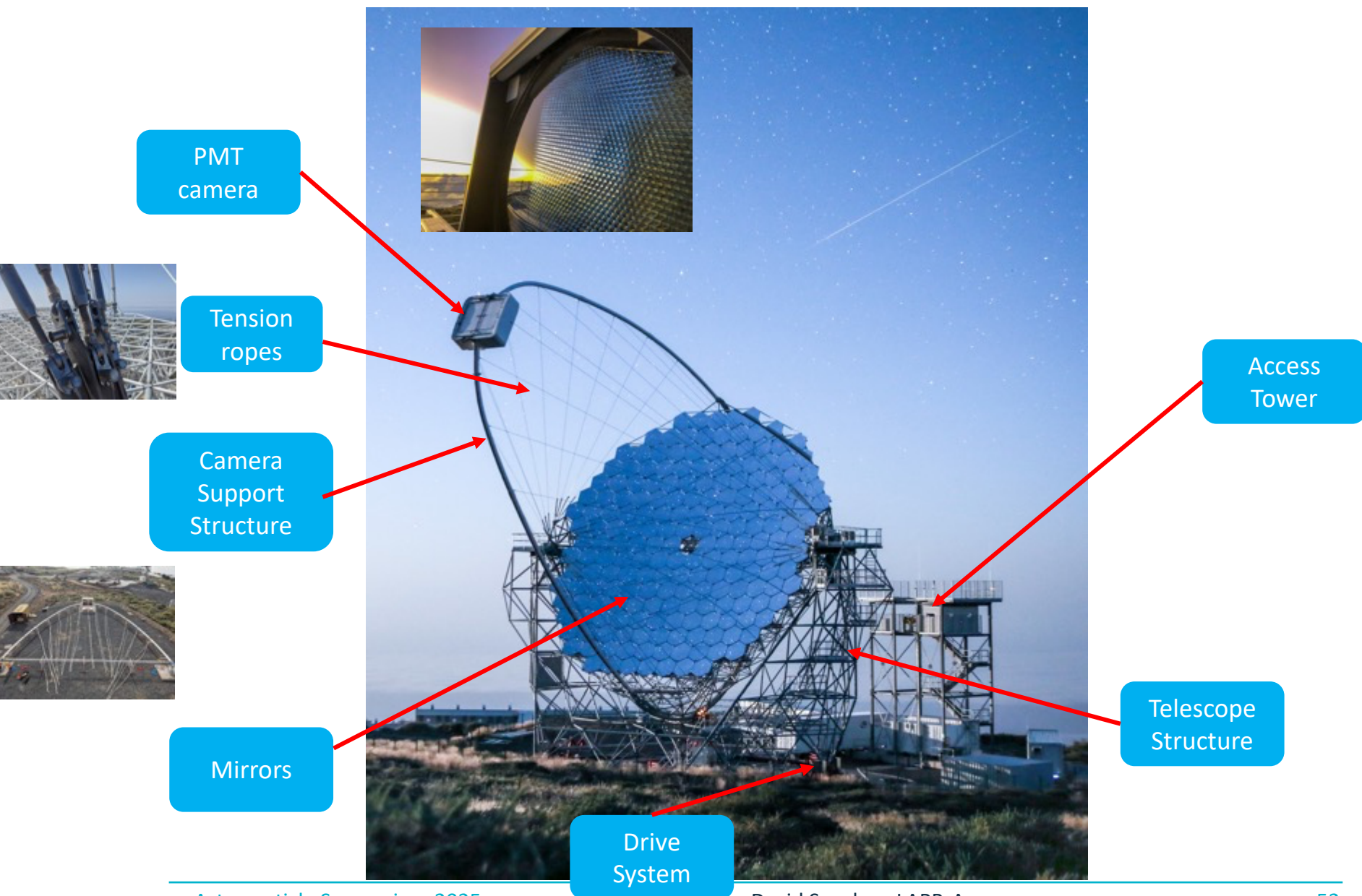


Figure 9. LSP of the simulated light curves with a periodicity of 600 days injected in the Doppler factor for the optical R, X-ray, Fermi-LAT and H.E.S.S. bands (from top to bottom).

Variability studies and modeling of the blazar PKS 2155-304 in the light of a decade of multi-wavelength observations J. Chevalier et al.

The first telescope of CTAO



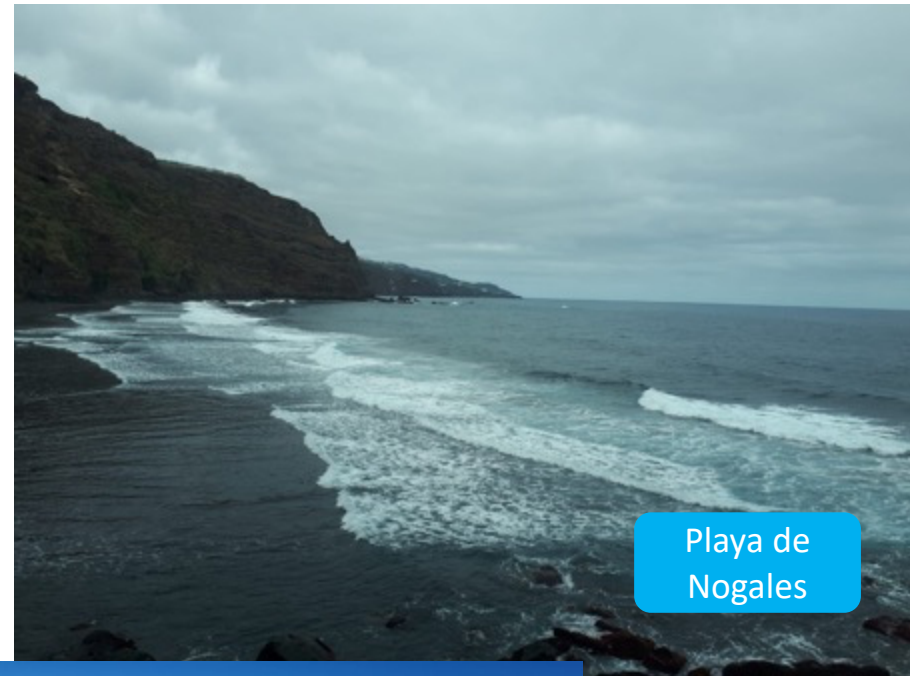


Beautiful landscape and more...

But..



Mercadillo
Puntagorda



Playa de
Nogales



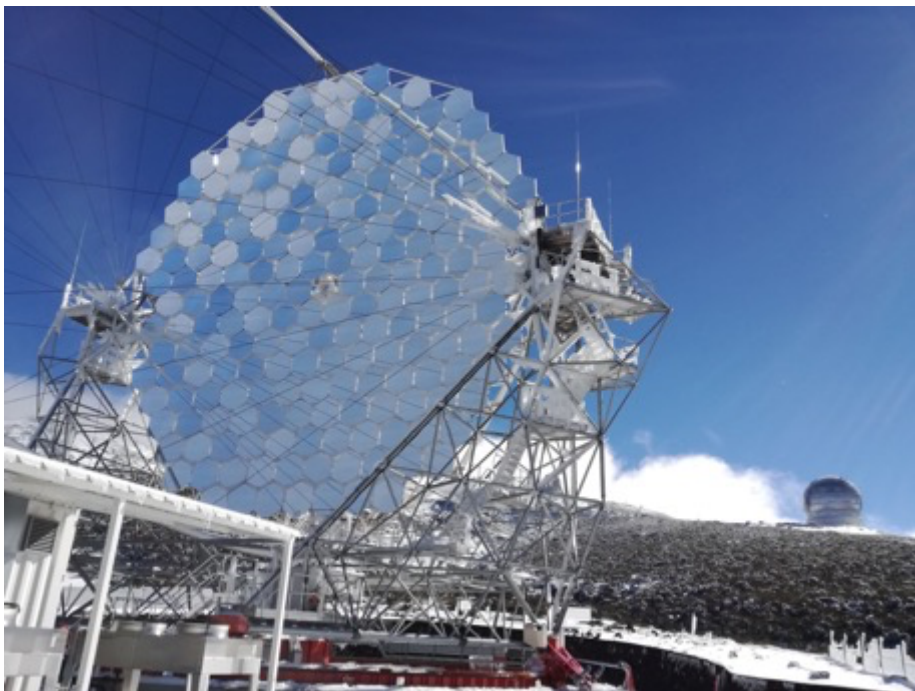
Roque de los
Muchachos



19/09/21 Volcano Cubre Viela

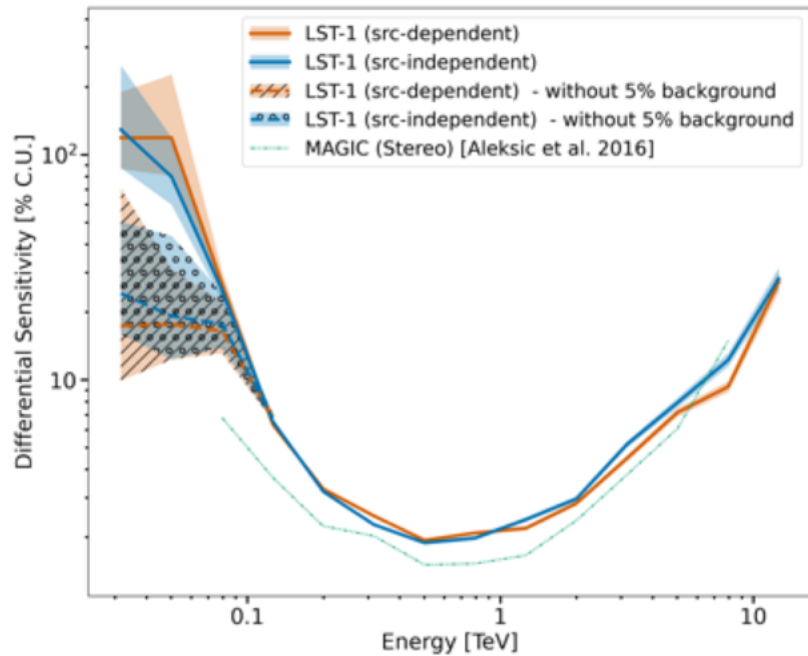
Stop operation for ~ 6 month

Storm during LST-1 construction



Central
pin

Crab Nebula is our standard candle



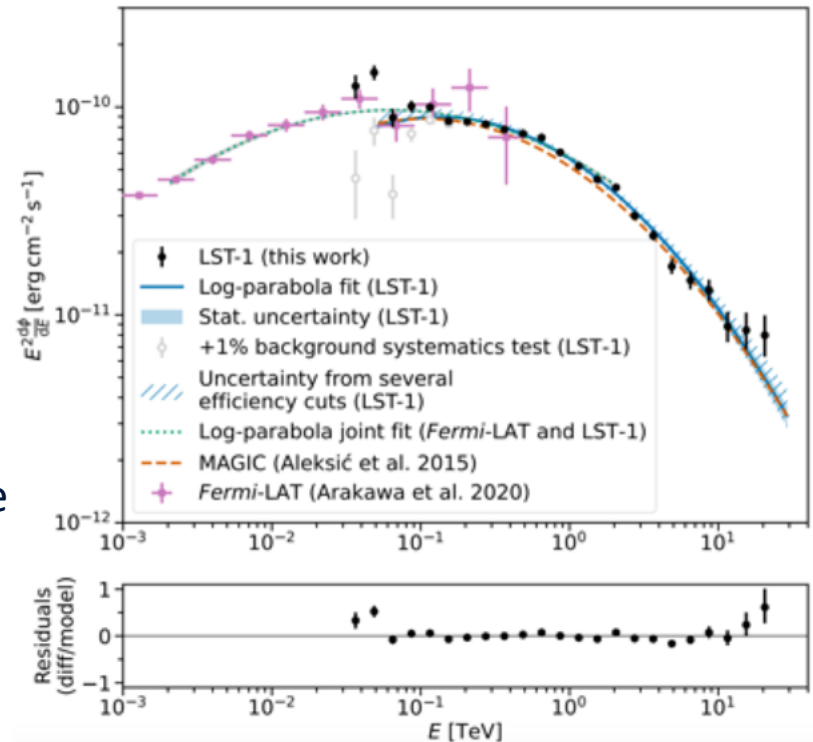
Roughly 1.5x less sensitive than MAGIC
Stereoscopic Telescopes

Consistent with single telescope performance vs
Stereoscopic system

Measure Crab Nebula down to 30 GeV

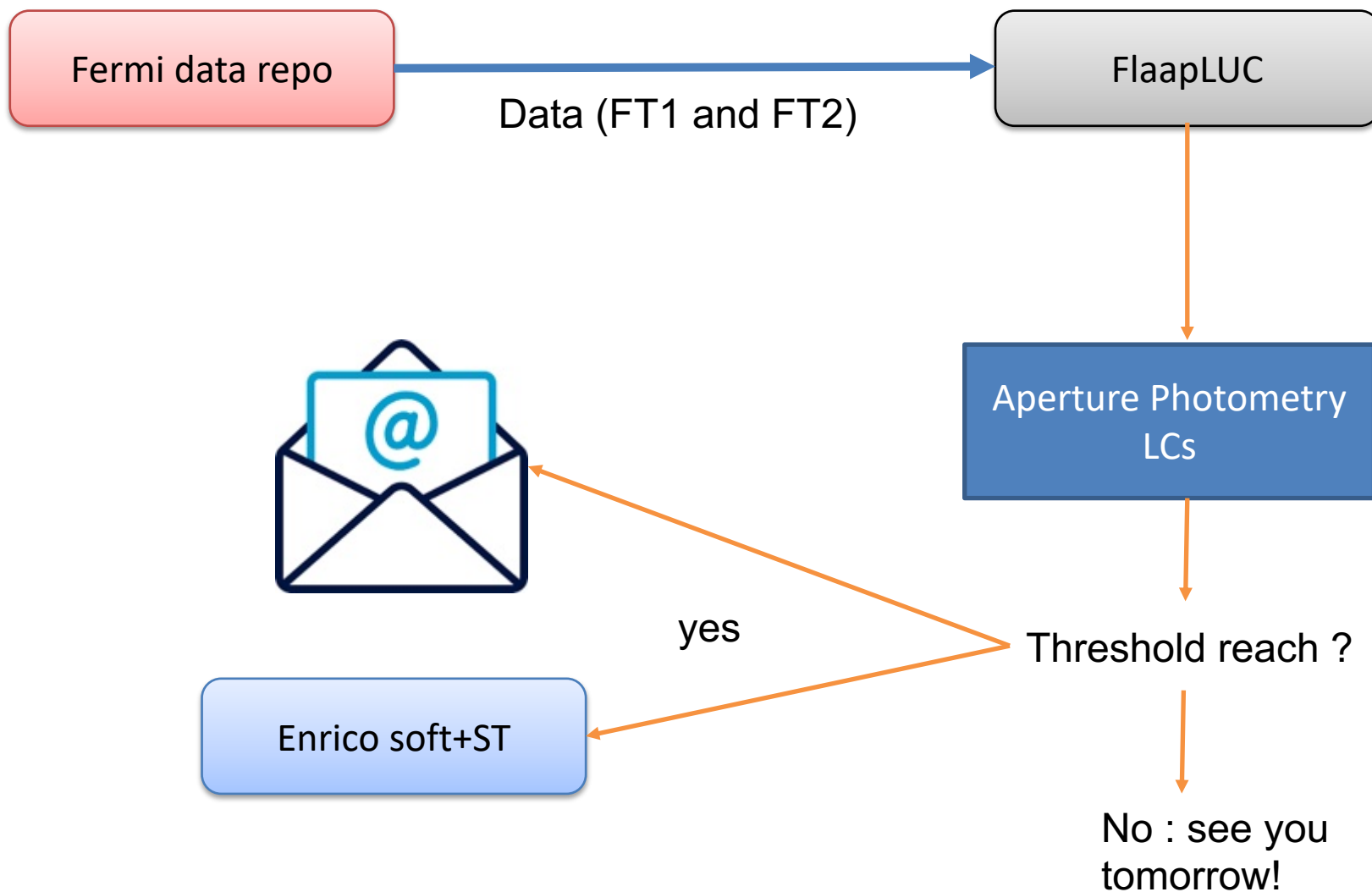
Systematics from background begin to dominate
below 50 GeV

Abe, H., et al.: ApJ, 956:80 (2023)



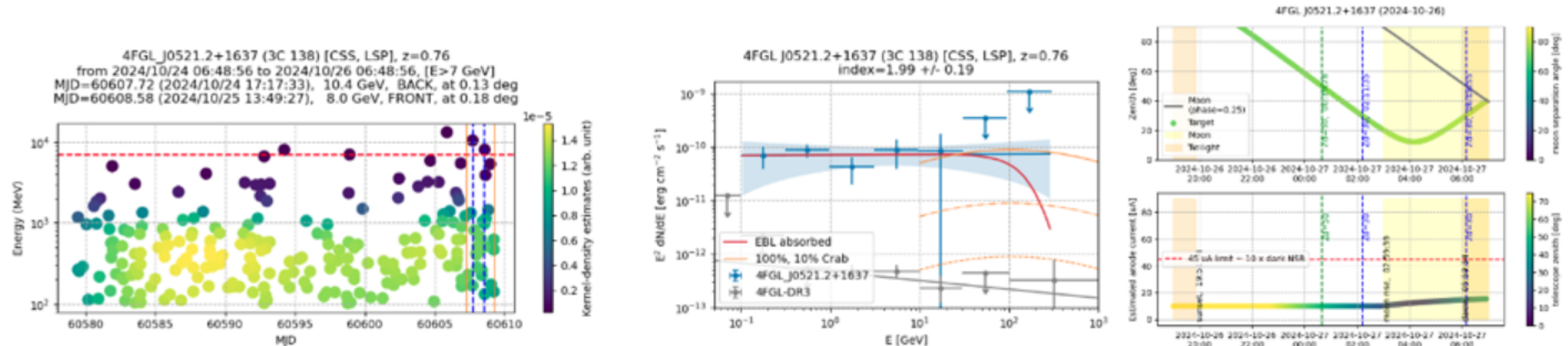
LST-1 ToO program

FlaapLUC: a pipeline for the generation of prompt alerts on transient Fermi-LAT γ -ray sources <https://arxiv.org/abs/1709.04065>



Analysis is made every 2 hours using weekly data

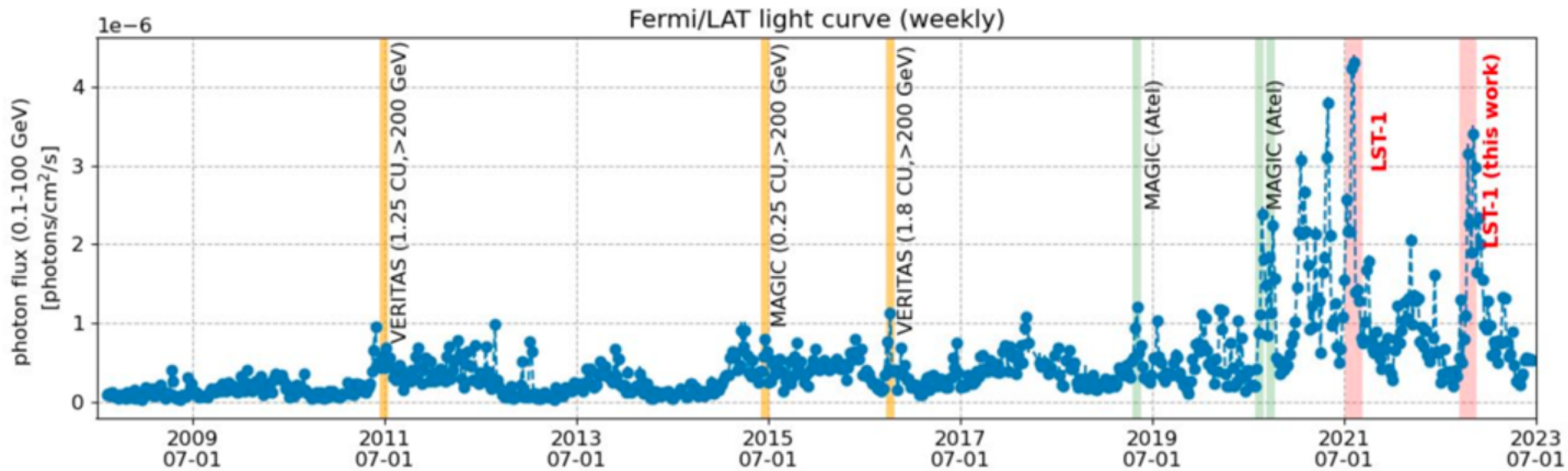
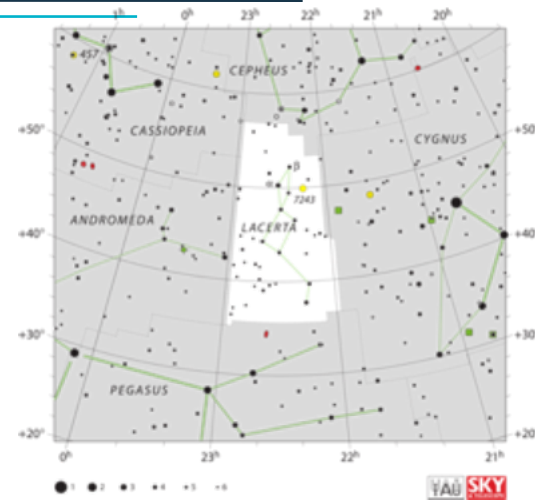
- Search for >2 HE photons (>7 GeV) within 2 days from all 4LAC sources
- then perform quick Fermi analysis
- Blind search (>10 GeV, $|b|>10$)



LST-1 ToO Results

BL Lac: IBL, $z = 0.069$

Variable in the HE range



→ Two major flares in 2021 and 2022, brightest emission ever observed from BL Lac in VHE.

First ATel by LST/CTAO

[Previous | Next | ADS]

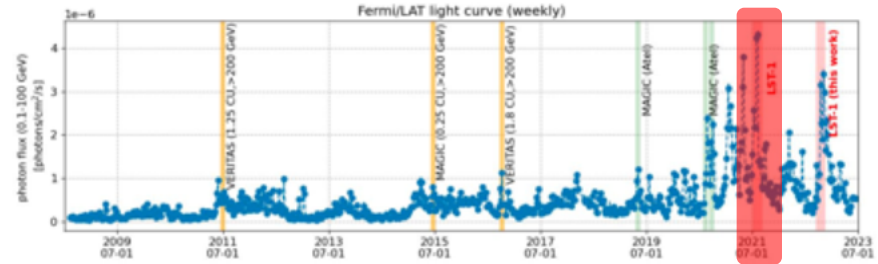
Detection of very-high-energy gamma-ray emission from BL Lac with the LST-1

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

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

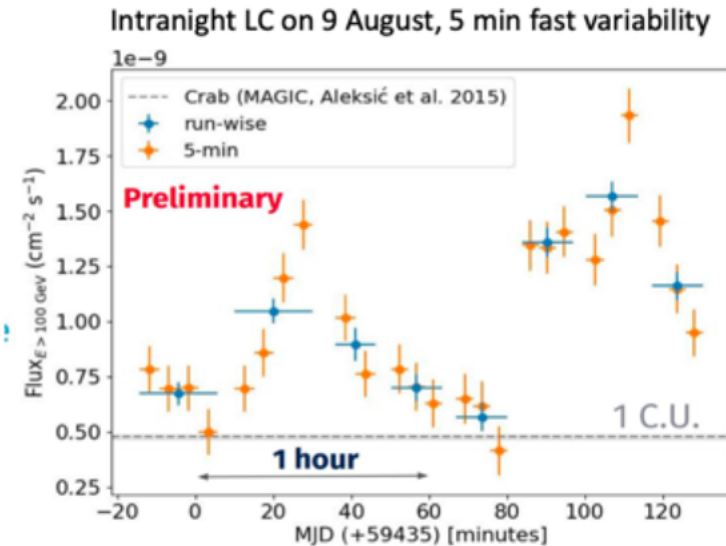
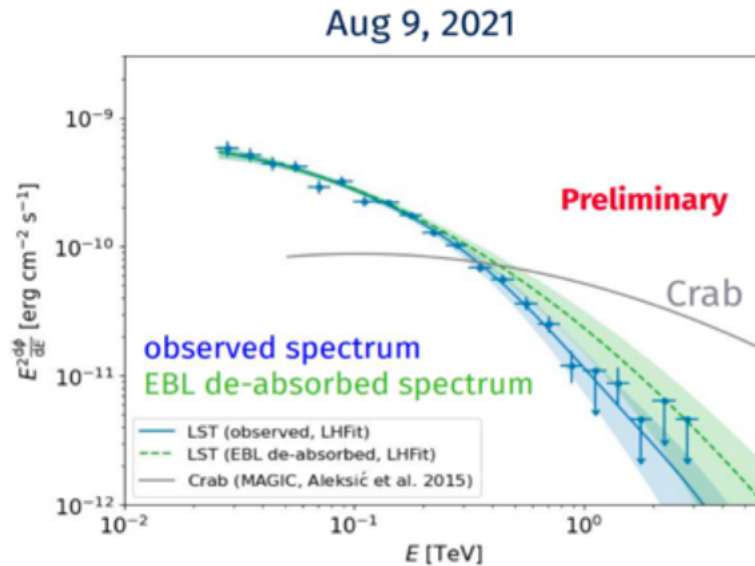
Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

Referred to by ATel #: 14820, 14826, 14839

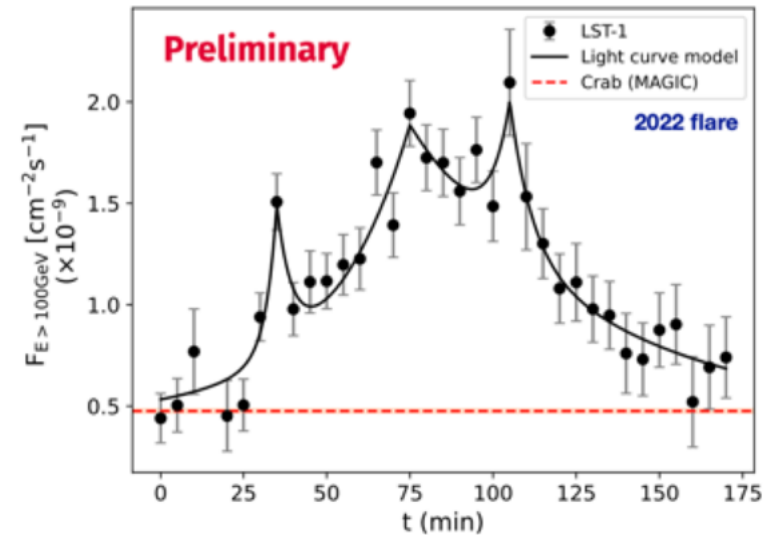
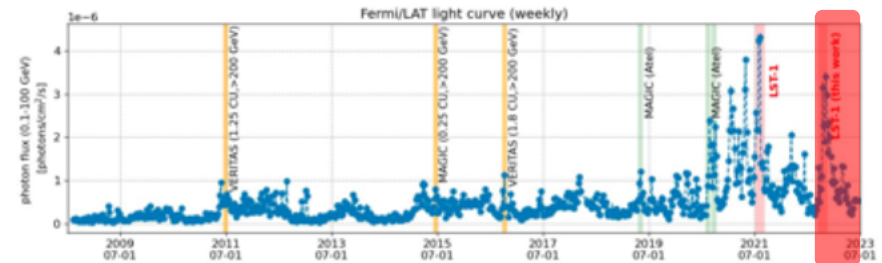
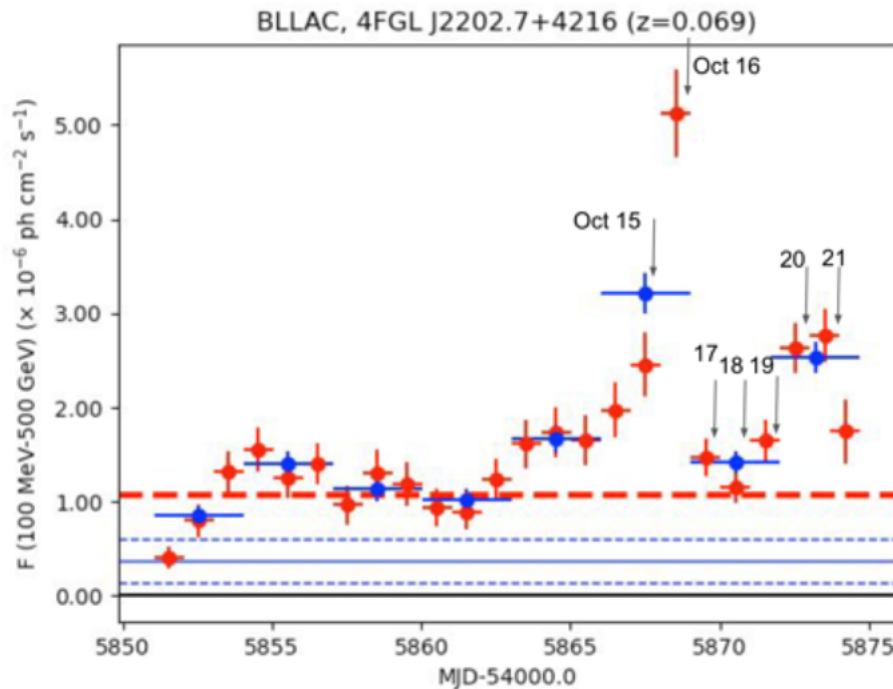


- Spectrum observed > 25 GeV
- August 9, about 3-5 Crab
- Unit at 30-100 GeV
- Very fast variability (<5min)

2021 flare (adapted from S. Nozaki's presentation at ICRC2023)



The first ToO triggered with FlaapLuC was on BL Lac

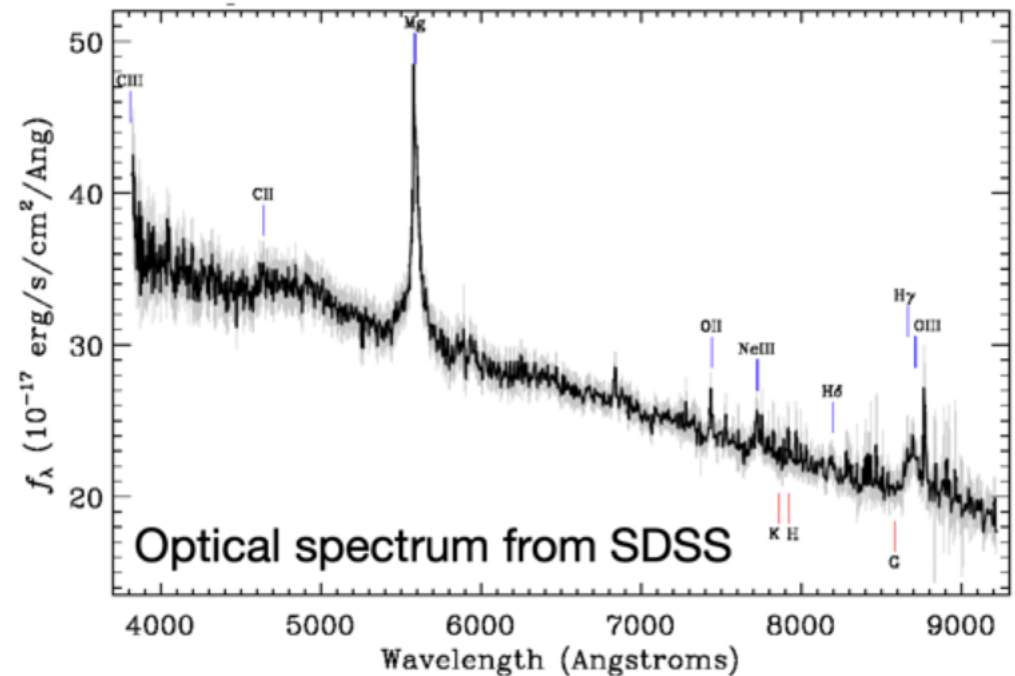


CTAO-LST project (in prep.)

Similar flux as in 2021, intra-night variability

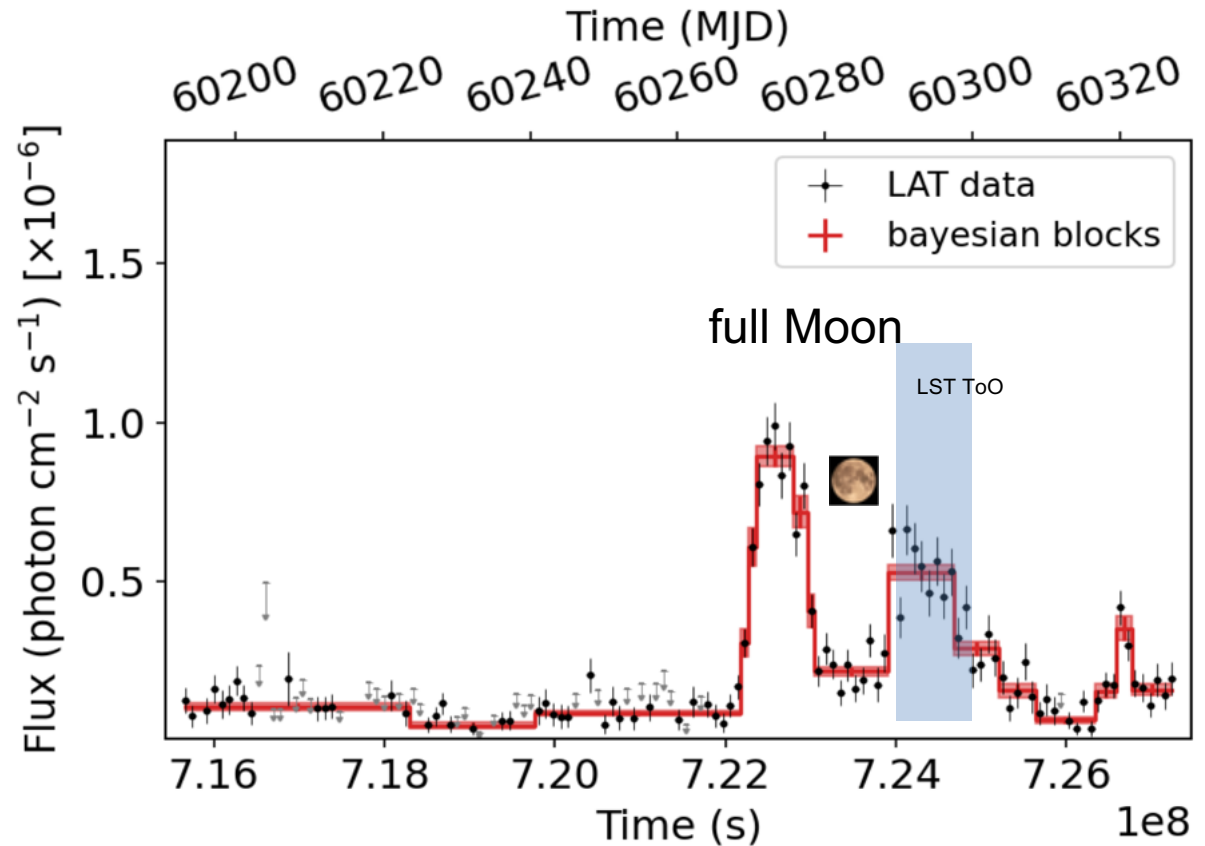
Quasar OP 313

- **Flat-spectrum radio quasar (FSRQ)**
- **Not detected at VHE** before
- Only 9 VHE FSRQs were known
- **$z = 0.9973$** (Schneider et al., 2010)
- **Strong attenuation at VHE** (>100 GeV) due to **EBL**
- **Possible internal absorption of its gamma-ray emission**



FlaapLuC aperture photometry Lightcurve of OP 313

Source was active before BUT during Moon break



- ATel
- Large press coverage
- Several presentations at different conferences

First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1

ATel #16381; Juan Cortina (CIEMAT) for the CTAD LST collaboration
on 15 Dec 2023; 14:31 UT
Credential: Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar, Quasar

% Post

The Large-Sized Telescope (LST-1) on La Palma has been monitoring the very distant Flat Spectrum Radio Quasar (FSRQ) OP 313 ($z=0.997$, Schneider et al. 2010, AJ, 139, 2360) since November 2023. Following the announcement of enhanced gamma-ray emission by Fermi-LAT (ATel #16354) and several optical facilities (ATel #16360) in early December, the Fermi-LAT emission of OP 313 has been closely monitored using the RaspLUC pipeline (Astronomy and Computing, Volume 22, p. 9-15, 2018). This monitoring revealed the detection of renewed activity in the high-energy (HE, $E>100$ MeV) band and so, Target of Opportunity observations with LST-1 were triggered on December 10th 2023. OP 313 was detected by LST-1 with a preliminary offline analysis using data from 2023/12/11 to 2023/12/14. It was detected with a significance greater than 5 sigma and an integrated flux, above 100 GeV, at 15% flux of the Crab Nebula. LST-1 observations on OP 313 will continue during the next few nights and therefore multi-wavelength observations are highly encouraged. LST-1 is a prototype of the Large-Sized Telescope for the Cherenkov Telescope Array Observatory, and is located on the Canary island of La Palma, Spain. The telescope design is optimized for observation of gamma rays in the range from 20 GeV to 3 TeV. The preliminary offline analysis has been performed by Daniel Morcuende (d.morcuende@iaa.es), Jorge Otero-Santos (joteros@iaa.es) and Selya Nozaki (snozaki@mpg.de). The LST-1 contact persons for these observations are Masahiro (m.mpg.de) and Juan Cortina (juan.cortina@ciemat.es).

16354	Optical follow-up of the gamma-ray flare of the blazar OP 313 with LST-1
16356	Fermi-LAT detection of renewed gamma-ray activity from the FSRQ OP 313, and enhanced gamma-ray activity from the FSRQ OP 313
16360	Preliminary results of the FSRQ OP 313
16361	POLARIMETRIC RESULTS OF THE FSRQ OP 313
16370	The Blazar TON 099 is now in a particularly bright state in the optical and near
16376	The FSRQ B2 1309+230: an unusual gently sloping spectrum after absorption maximum at 0.1-0.2 eV
16396	B2 1309+230 is dimming after the highest outburst state
16402	FSRQ B2 1309+230: Upper limits from a neutrino search with IceCube
16405	MM Phase of the Blazar B2 1309+230
16408	Fermi-LAT detection of enhanced gamma-ray activity from the FSRQ OP 313 (B2 1309+230)
16480	ATLAS photometry of B2 1309+230 shows continued brightening
16479	The FSRQ B2 1309+230: new

Accueil » Techno » Recherche

Le LST-1 détecte un quasar à plus de 100 Gigaélectronvolts

il y a 3 semaines Recherche, Techno



Le 15 décembre, une découverte majeure a été annoncée par la collaboration du **Large-Sized Telescope (LST)**. L'objet OP 313 (quasar) a été détecté à des énergies très élevées, une première pour le LST-1. Cette détection marque une étape importante dans l'étude des noyaux galactiques actifs (AGN) et des quasars à spectre plat (FSRQ).

La collaboration LST a annoncé la détection de la source OP 313 à des énergies très élevées avec le LST-1. Bien que l'OP 313 soit connu à des énergies plus faibles, il n'avait jamais été détecté au-dessus de 100 GeV. Cette détection fait de l'OP 313 l'AGN le plus éloigné jamais détecté par un télescope Cherenkov, démontrant ainsi les performances exceptionnelles du prototype LST pendant sa mise en service sur le site CTAD-Nord sur l'île de La Palma, en Espagne.

OP 313 est ce que l'on appelle un quasar à spectre plat ou FSRQ, un type d'AGN. Ce sont

Announcement

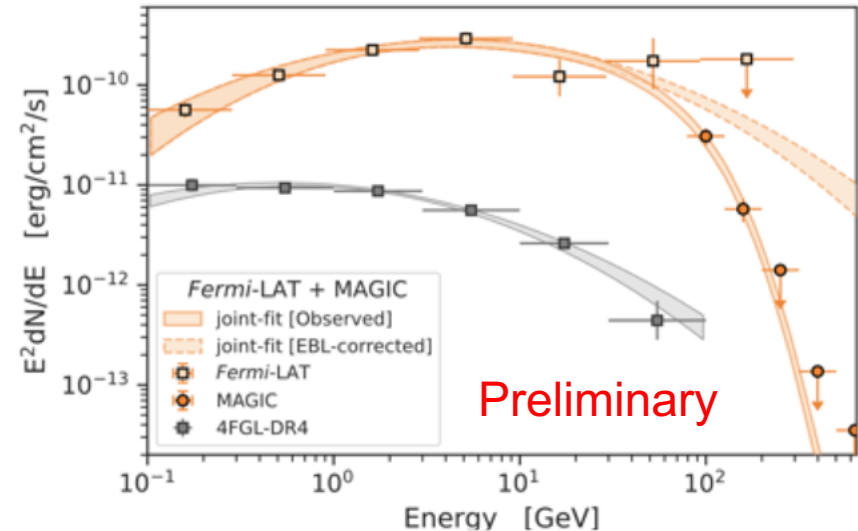
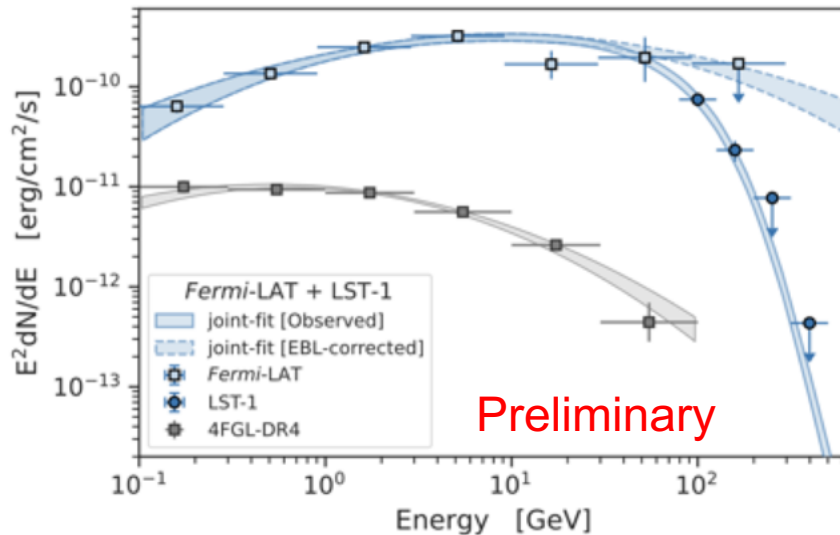
2023-December-06

LST-1 Discovers the Most Distant AGN at Very High Energies

La Palma, Spain -- On 15 December, the Large-Sized Telescope (LST) Collaboration announced through an *Astronomer's Telegram* (ATel) the detection of the source OP 313 at very high energies with the LST-1. Although OP 313 was known at lower energies, it had never been detected above 100 GeV, making this the LST-1's first scientific discovery. With these results, OP 313 becomes the most distant Active Galactic Nuclei (AGN) ever detected by a Cherenkov telescope, further showcasing the LST prototype's exceptional performance while it is being commissioned on the CTAD-North site on the island of La Palma, Spain.



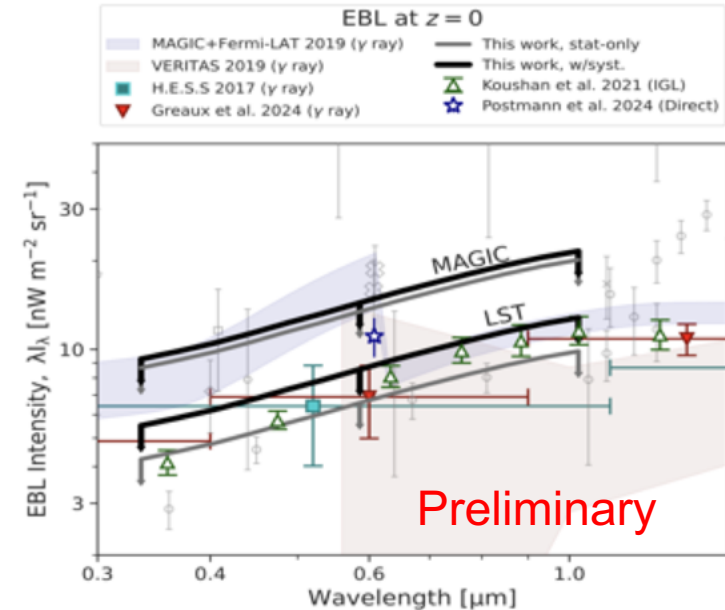
OP 313 is what is known as a Flat Spectrum Radio Quasar or FSRQ, a type of AGN. These are very luminous objects found in the centres of some galaxies, where a supermassive black hole devours material from its surroundings, creating powerful accretion disks and jets of light and relativistic particles.



Joint LST + *Fermi*-LAT and MAGIC + *Fermi*-LAT

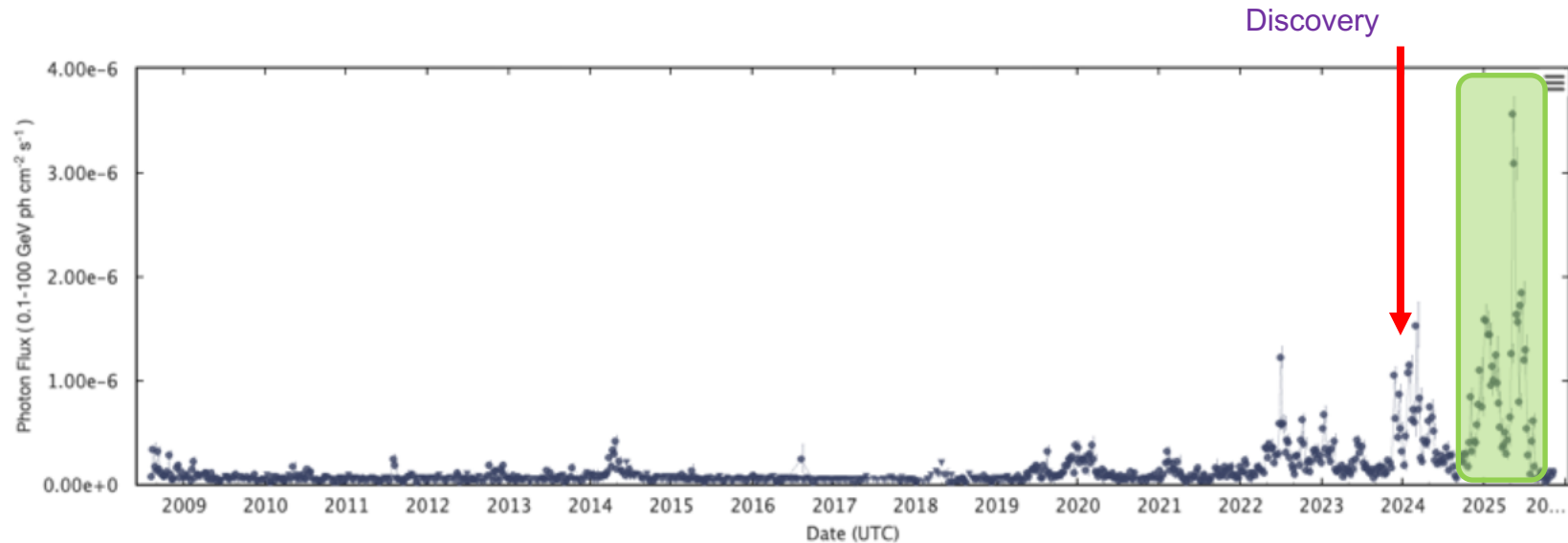
-> thanks to Gammapy and use work from Nieves Rosillo, M et al. 2025

Upper limits on EBL (Saldana-Lopez +21)

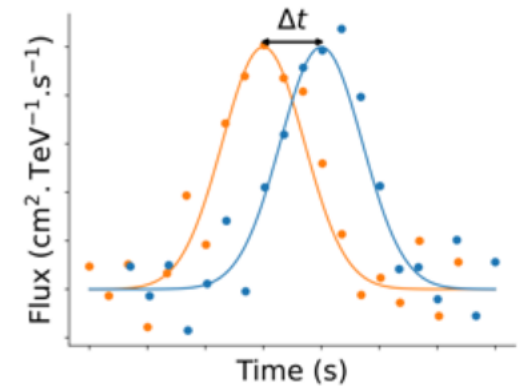
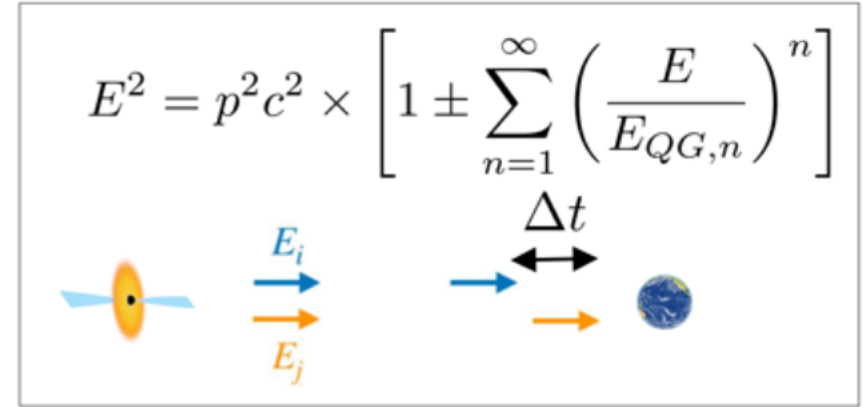
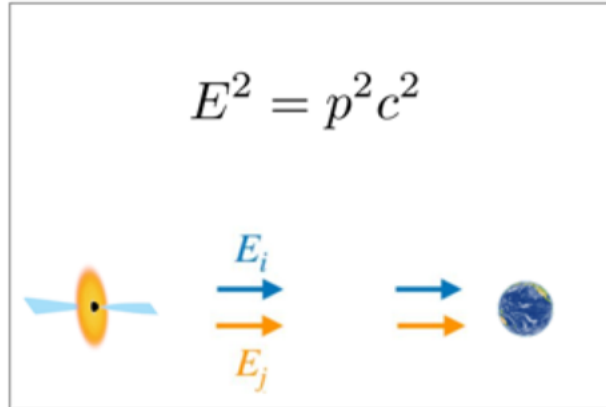


This is not the end.

The source was very active and we called it “Never ending ToO”



LiV studies with LST-1



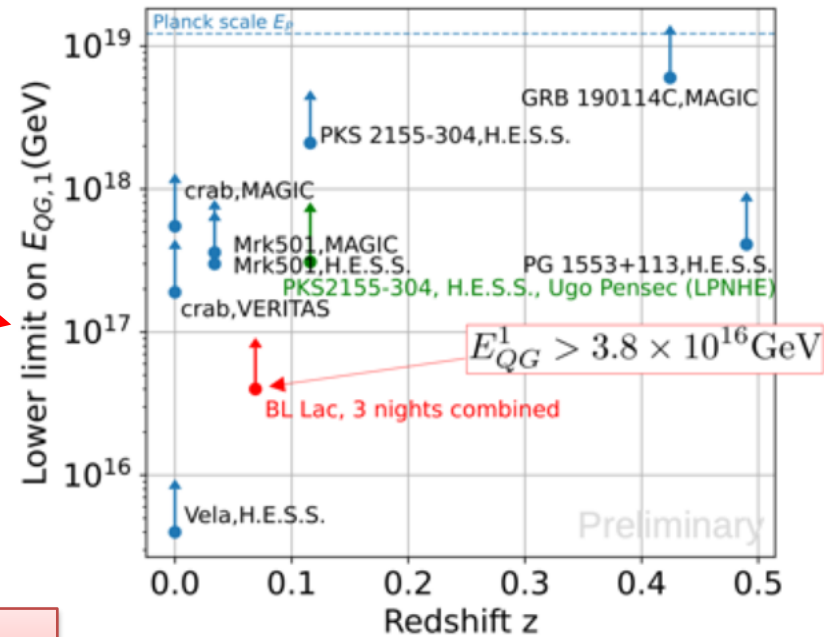
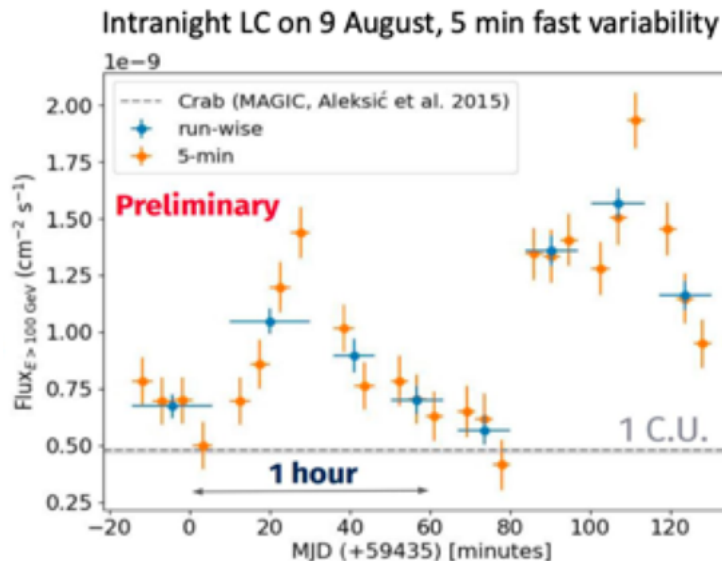
[Previous | Next | ADS]

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



Bolmont et al., 2022

No LiV detection but UL on QG energy scale

Cyand Plard (PhD, LAPP)

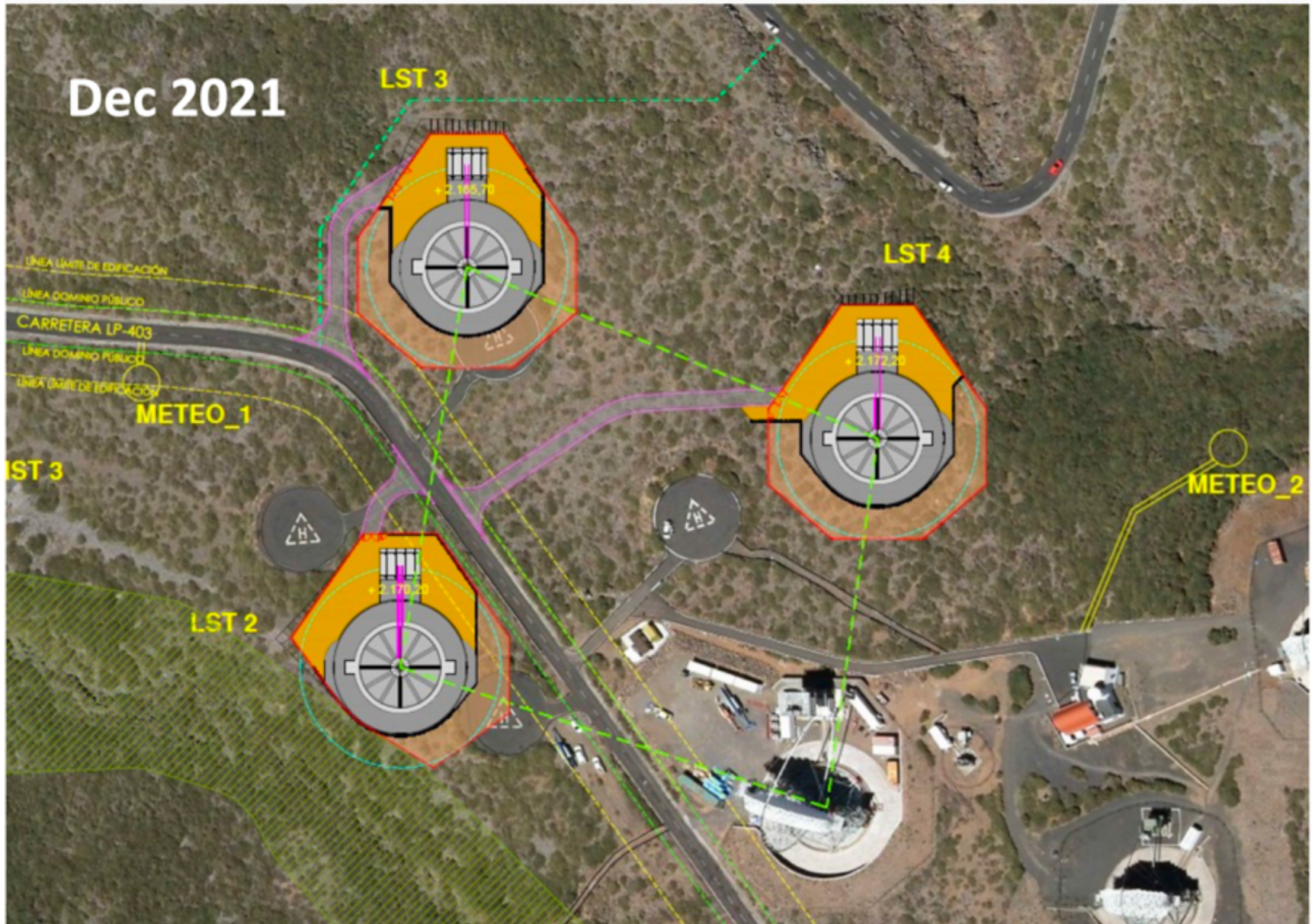
An Array of LSTs

Jun 2016

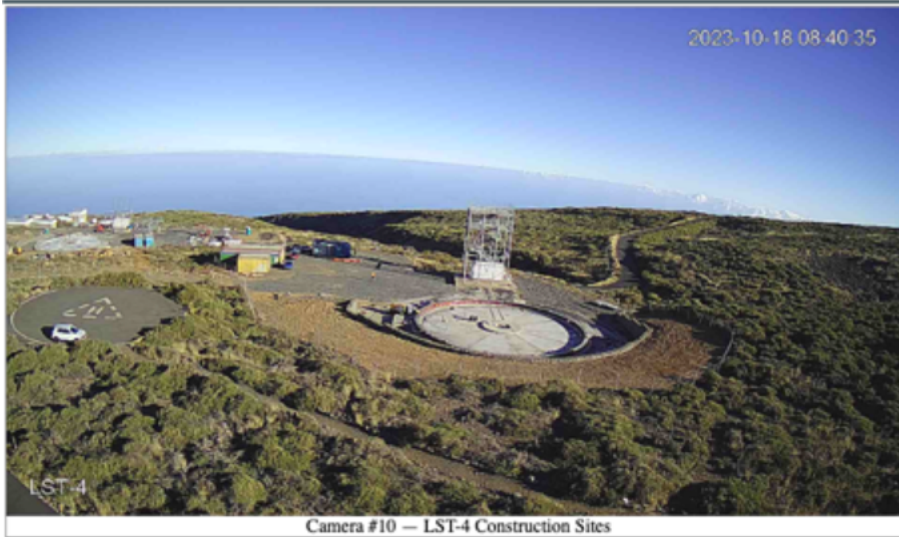


Oct 2018



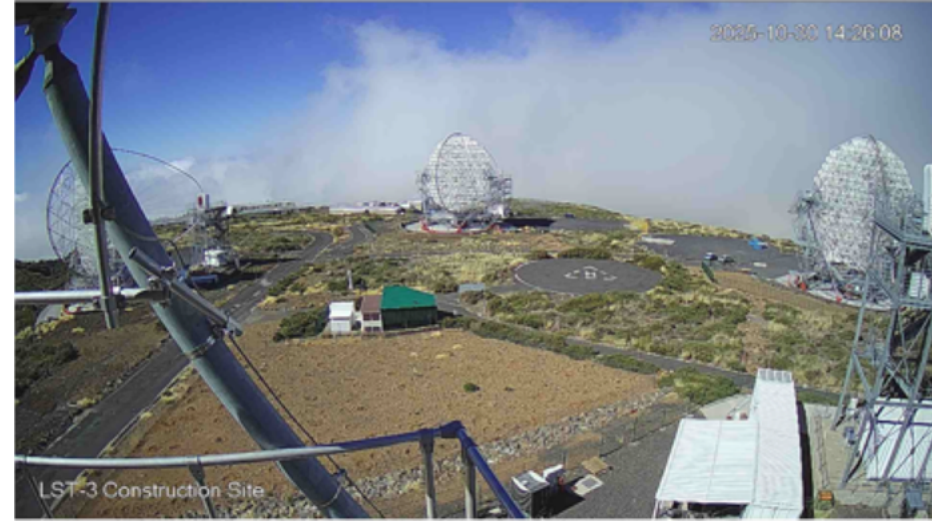
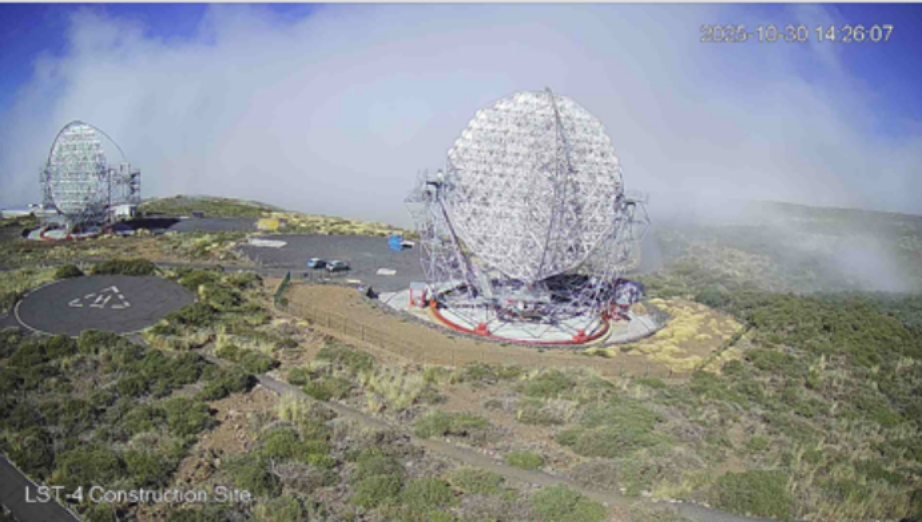




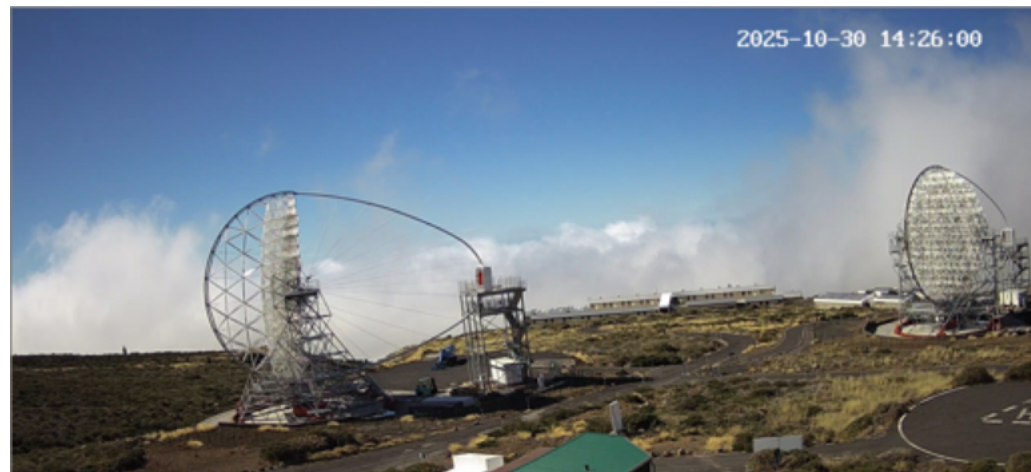


18/10/2023

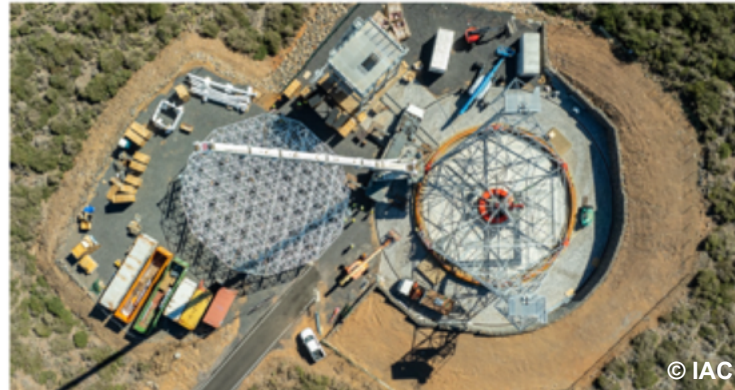




30/10/2025

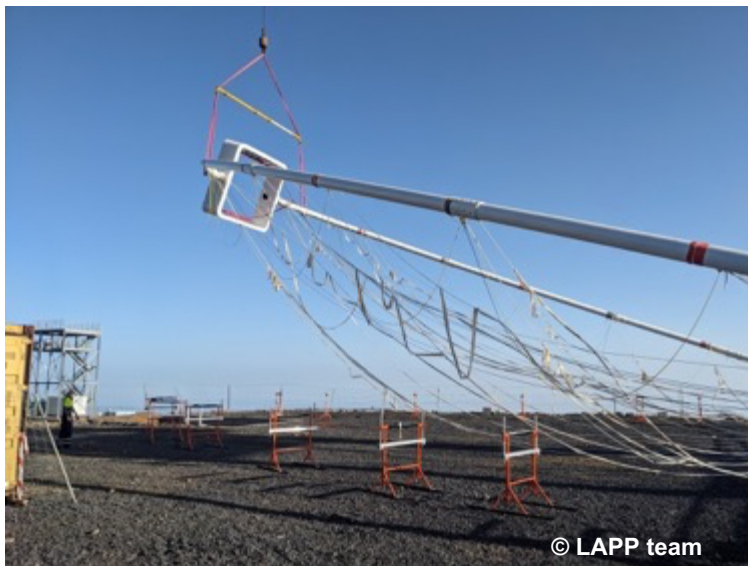


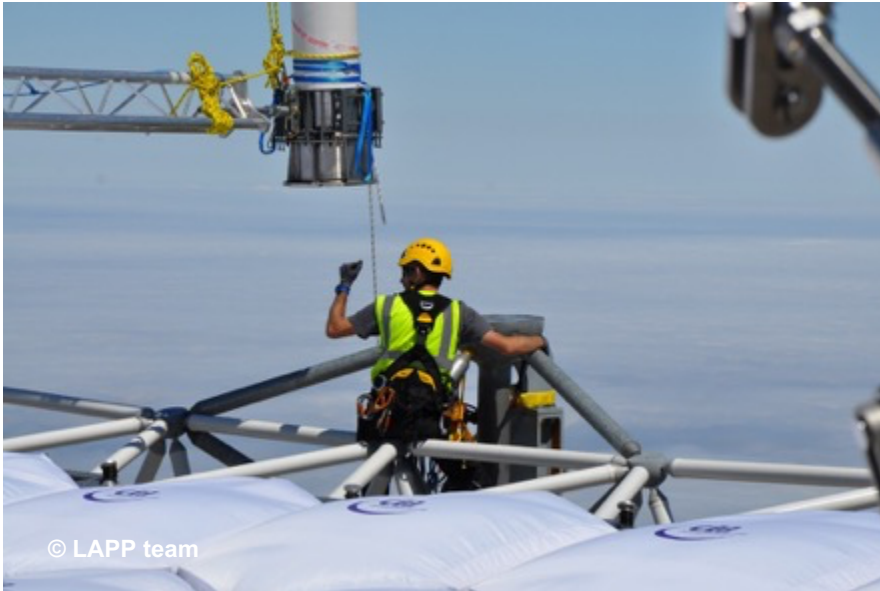
How to build a LST?



Dish of LST 4 lifted 03 May 2024
 LST 3 : 13 June 2024
 LST2 : 12 August 2024



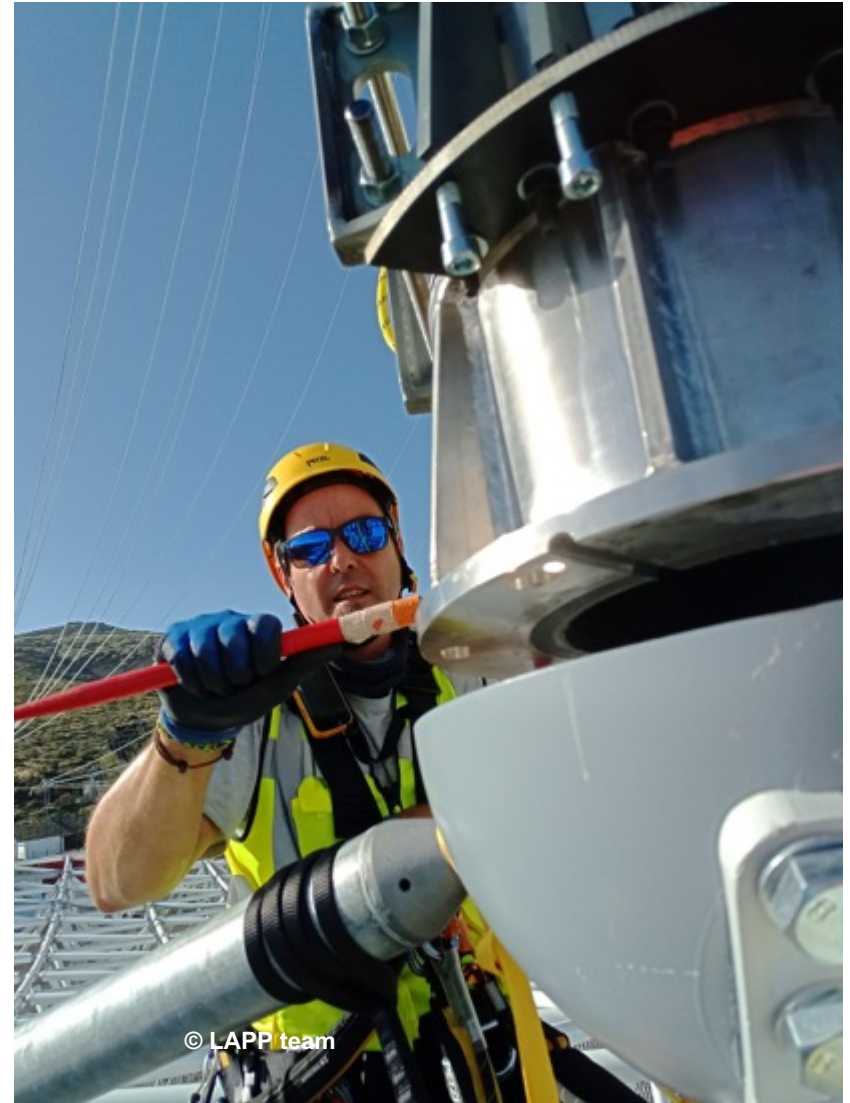




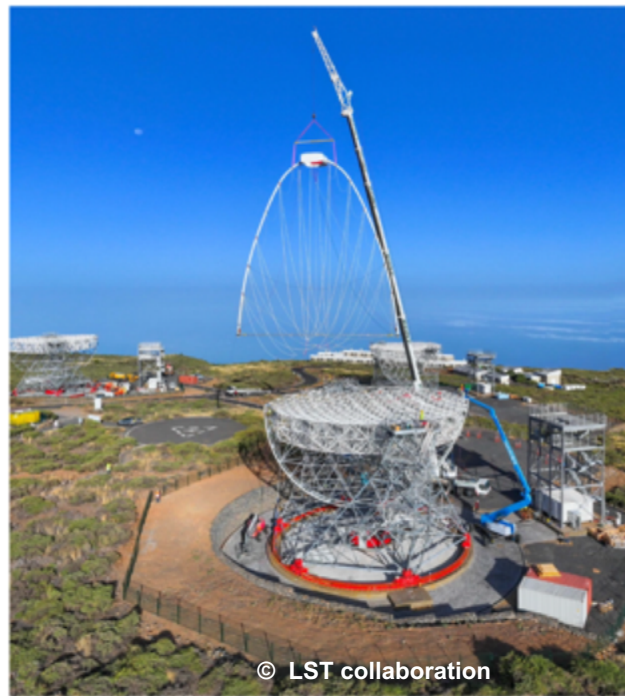
© LAPP team



© Cyril FRESILLON / LAPP / CNRS Images.



© LAPP team



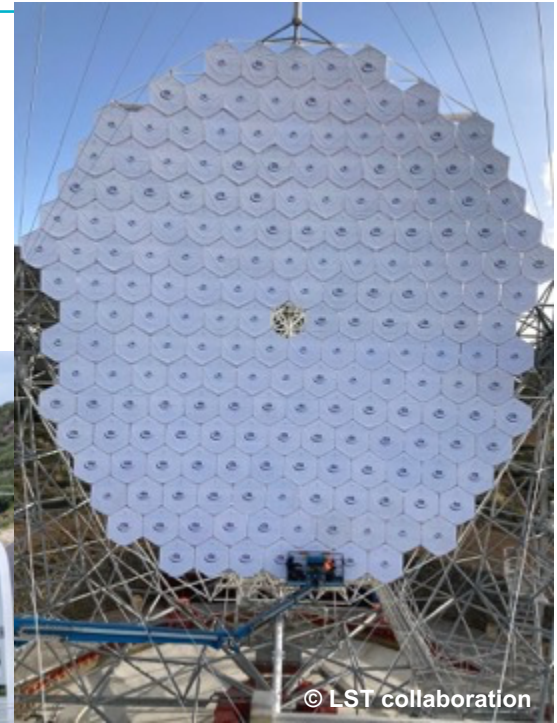
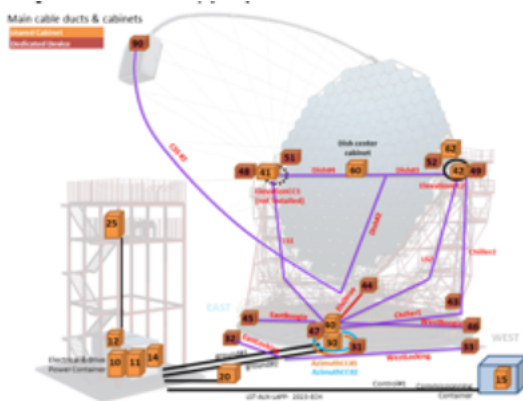
~ Half a day to lift it and release the crane

LST 4 and LST 3 CSS installed in 2024
LST 2 CSS in 2025



4 structures Ready :

- Arch have been installed
- Drive test LST4 finished
- Camera LST4 installed



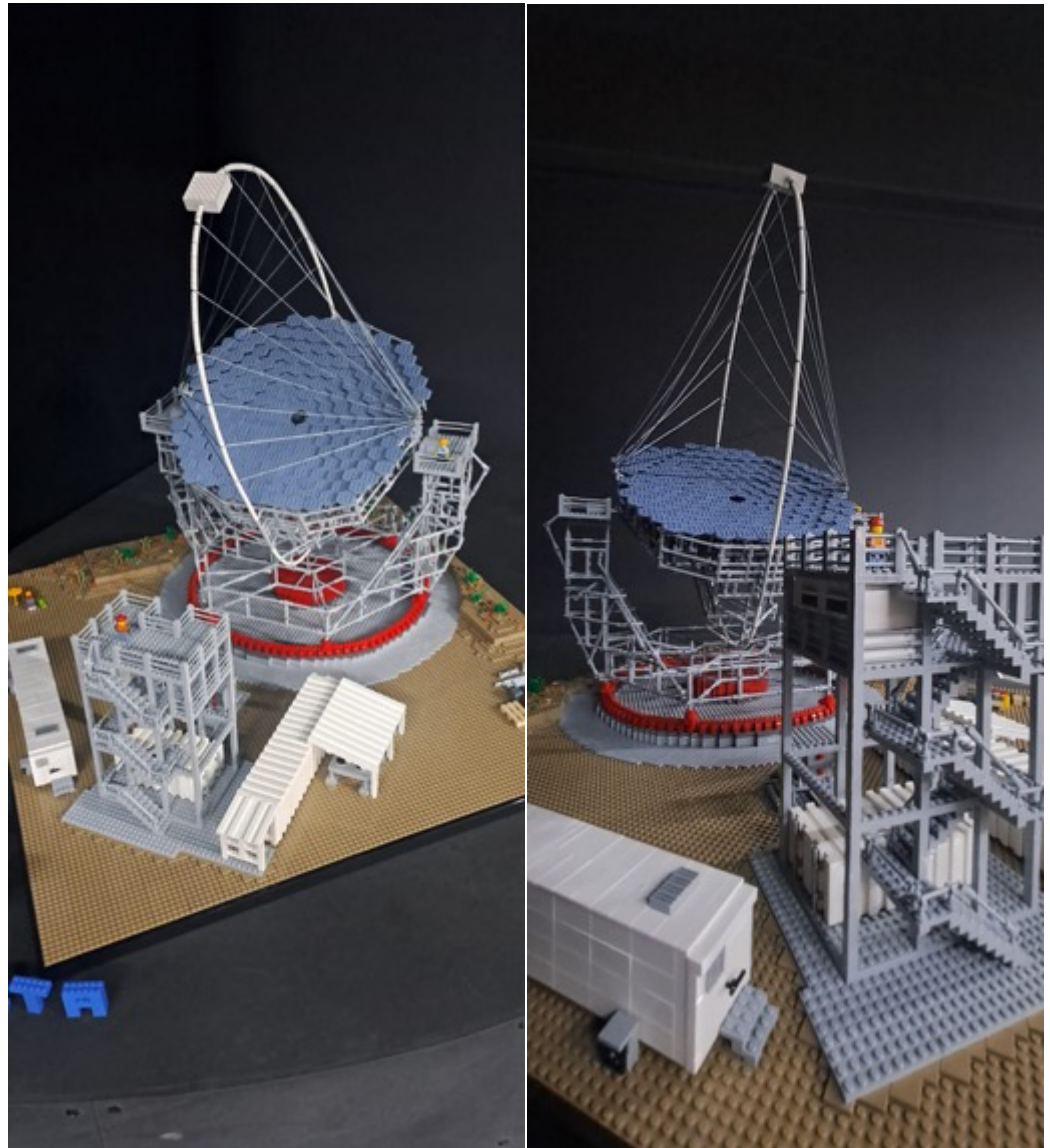
- Cabling
- Mirror facets installation
- Drive tests
- Camera installation
- Auxilliary devices



Concepteur : Eric Pilhan

<https://ericpilhan.fr/>

Financement :
ENIGMASS+LAPP



Thanks you for your attention

