

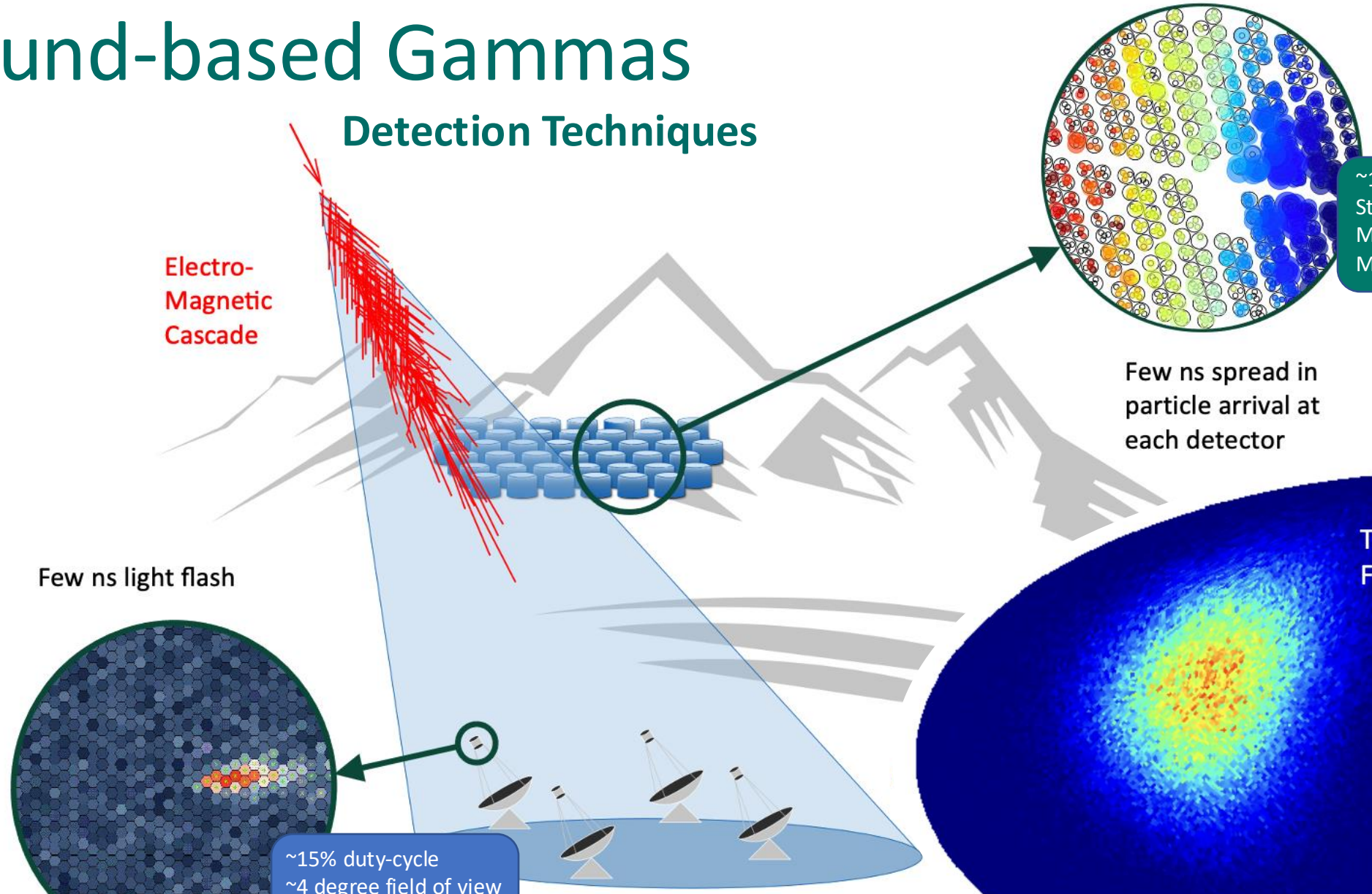
(Selected) News from Cherenkov Telescopes (+)

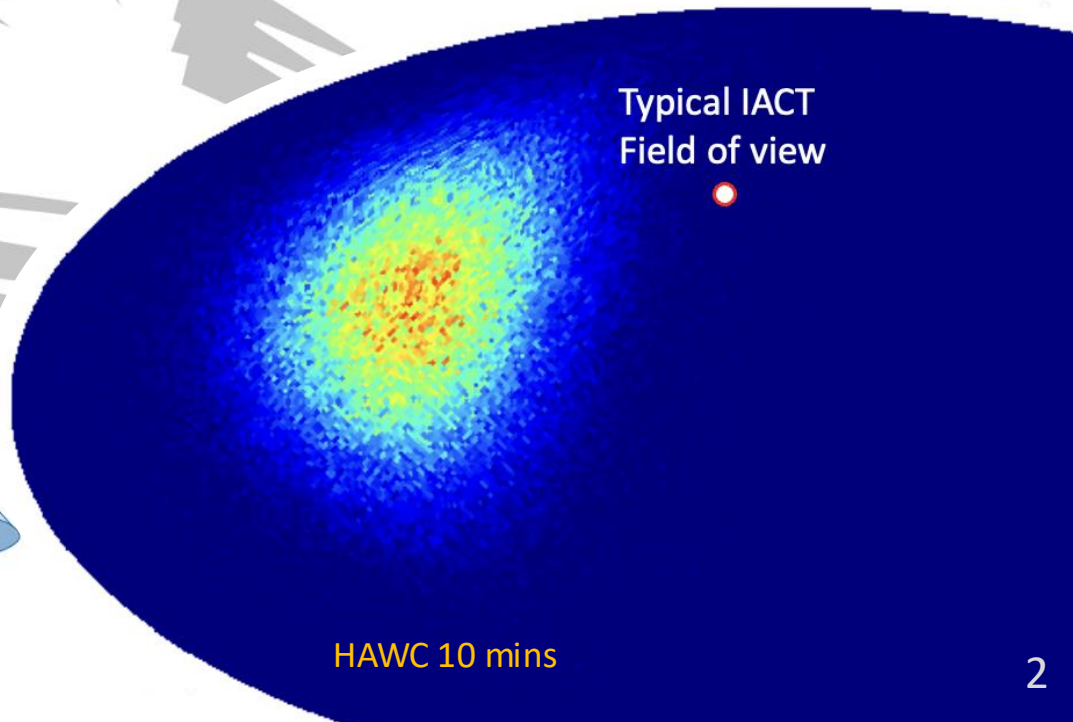
Jim Hinton, MPIK

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Ground-based Gammas

Detection Techniques



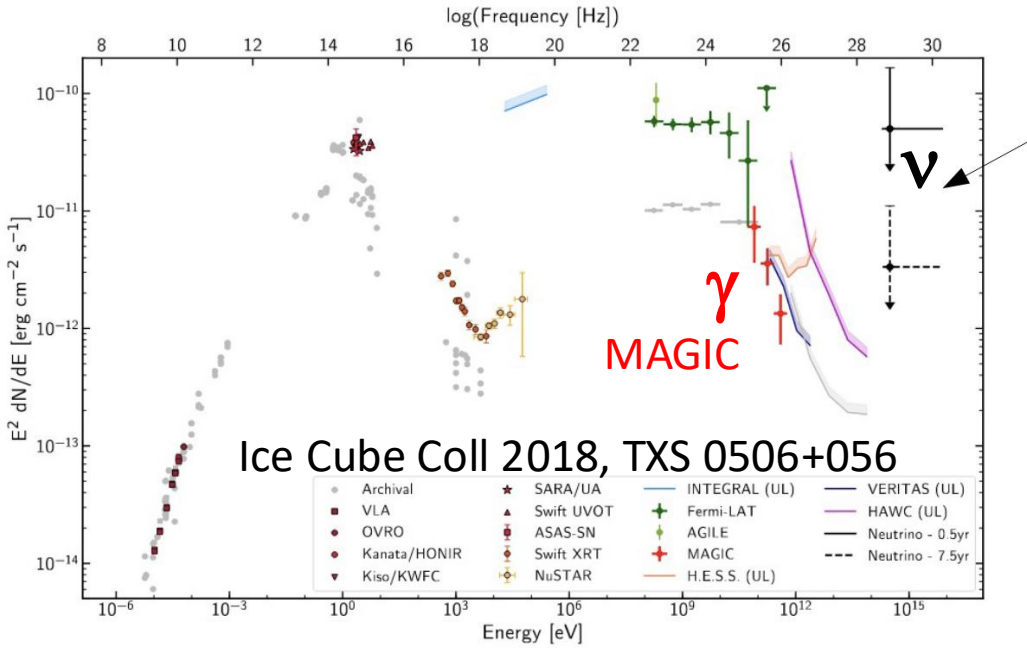


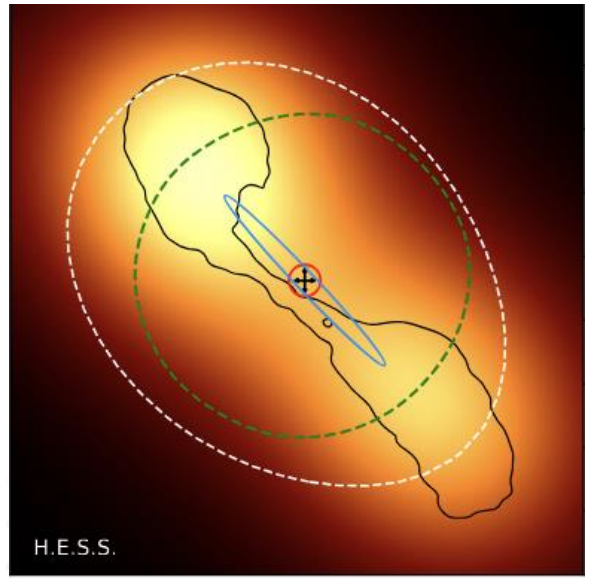
Links to Cosmic Rays & Neutrinos?

- Obvious: probing sites of cosmic ray acceleration and interaction
  - Pion decay leads to both neutrinos and gammas
  - IC emission from CR electrons
- BUT:
  - Efficient sources of UHECRs do not have to produce lots of gammas and neutrinos → particles need to avoid interaction to get to highest E and escape
  - Efficient sources of neutrinos do not have to produce UHECRs and lots of gammas → beam dump with no escape of particles or photons (γ-γ)
  - Efficient gamma-ray sources don't have to accelerate UHECRs
    - BUT if p-p then the neutrinos are there, just a question of sensitivity

Extragalactic Sources

- Extragalactic neutrino sources (so far) se have strong internal γ absorption
  - Important constraints set by IACTs+Fermi-LAT
- GRBs established as TeV sources, but…
  - No clear link to UHECRs nor neutrinos
- Nearby(<GZK) extragalactic sources
  - Cen A – resolved kpc-scale jet emission with HESS
    - Looks like IC emission, co-acc. protons would reach ~PeV
  - But UHE acceleration site may be different (e.g. Bell++ backflow) even if Cen A is a UHECR source (as seems likely)





https://cdy-institute.ie/wp-content/uploads/2022/03/Jim_Hinton_CDY_9Mar22.pdf

Pevatron Shopping List

- Detected VHE-UHE Emission
- Spectral curvature
  - Signature of Emax, KN, spectral breaks, +++
- Spatially-resolved emission
- Correlation with target material
  - Not perfect: i.e. emission is convolution of CR distrib. with gas
- Energy-dependent morphology
  - Expected in general due to energy dependence of transport and/or cooling, exceptions:
    - **Bohm** diffusion of electrons ($r \sim \sqrt{D\, t_{cool}}$), $D \sim E$, $t_{cool} \sim 1/E$)
    - Advection of protons (t_{cool} = const, $r \sim v\, t_{cool}$)
- A multi-wavelength counterpart!

Highest Energy Sensitivity

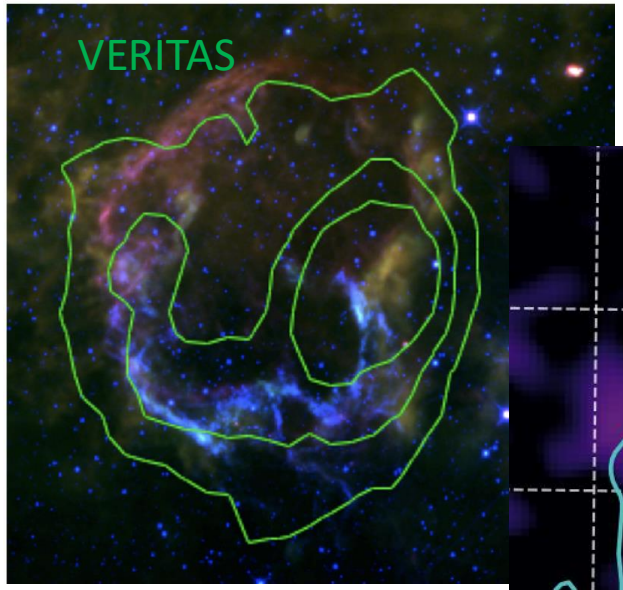
Wide band Sensitivity

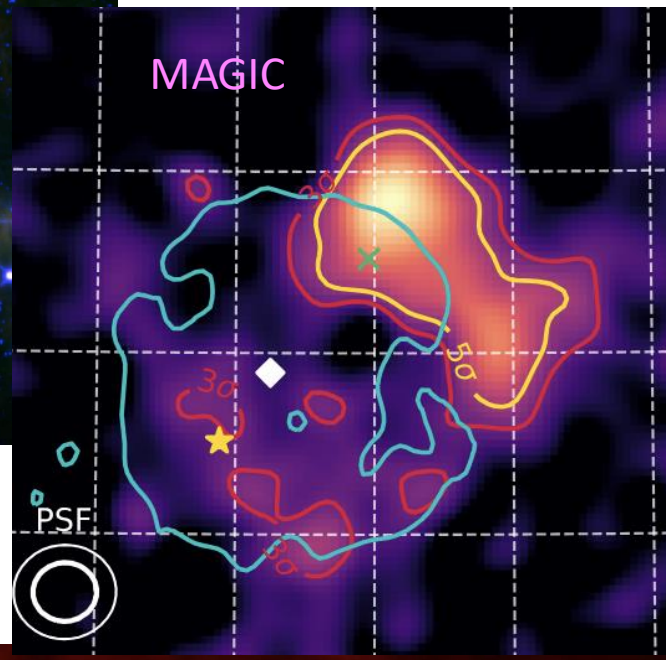
Angular Resolution

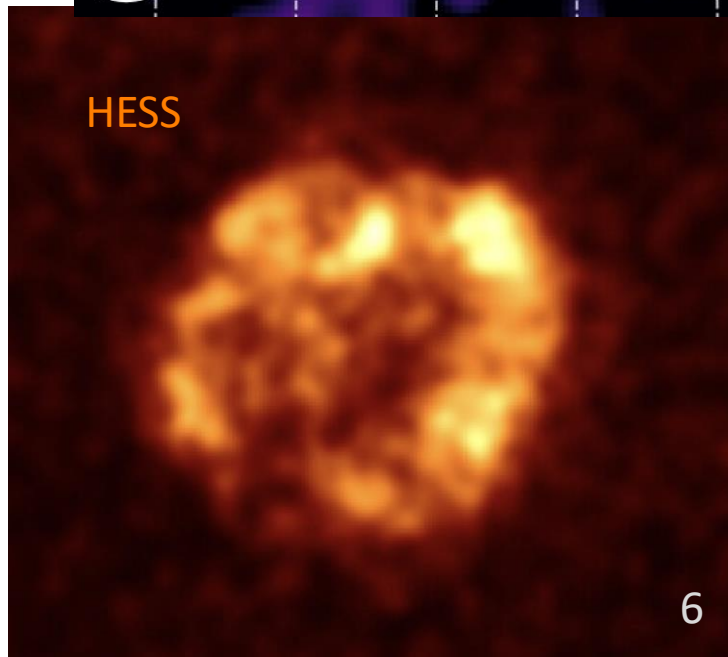
Supernova Remnants

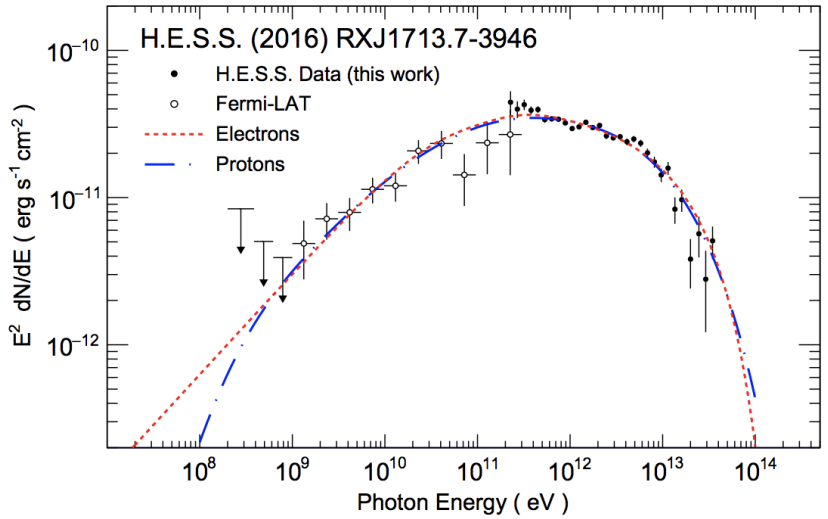
- Cherenkov telescopes played key role
  - Not much **new**, but …
- Resolved shells → shock acceleration
- Dominance by IC or pion decay is clear in some cases but not others
  - Cloud associations +
- E_{max} is … disappointing?

→ Jacco's talk





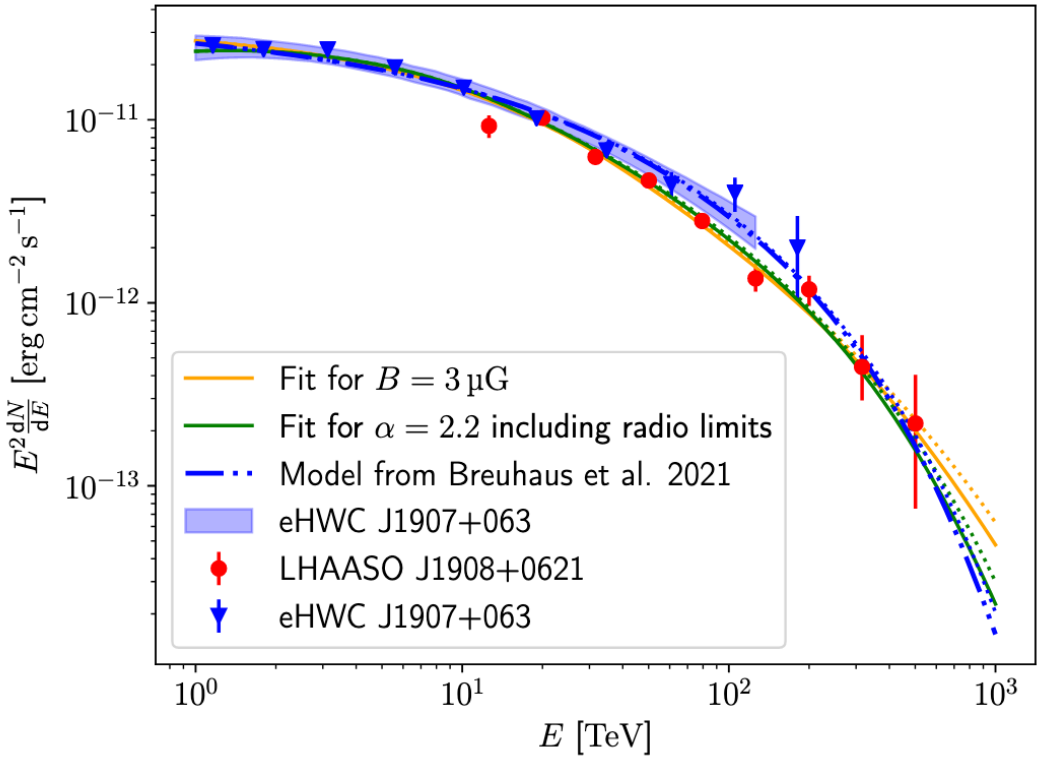




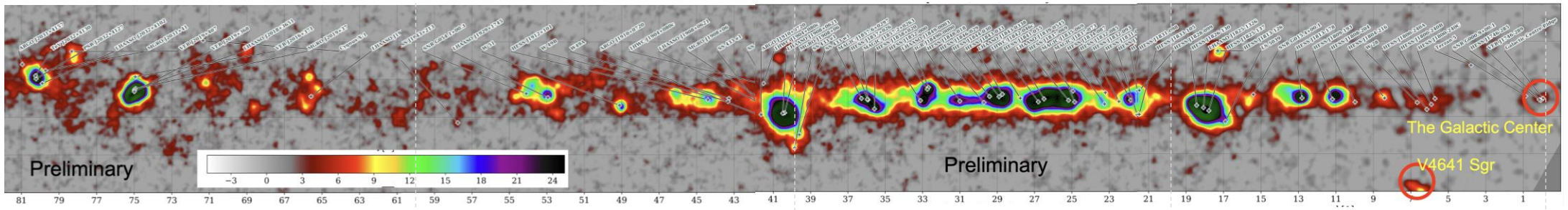
The UHE advance: LHAASO+HAWC

- **Northern** wide-field instruments with excellent UHE performance
- Emission beyond the reach of the Cherenkov telescopes (>1 PeV)
  - For many Galactic sources! But spectra are typically rather soft, e.g. J1908, inverse Compto model
- Modest resolution
  - Cherenkov telescopes needed to probe energy-dependent morphology, establish associations

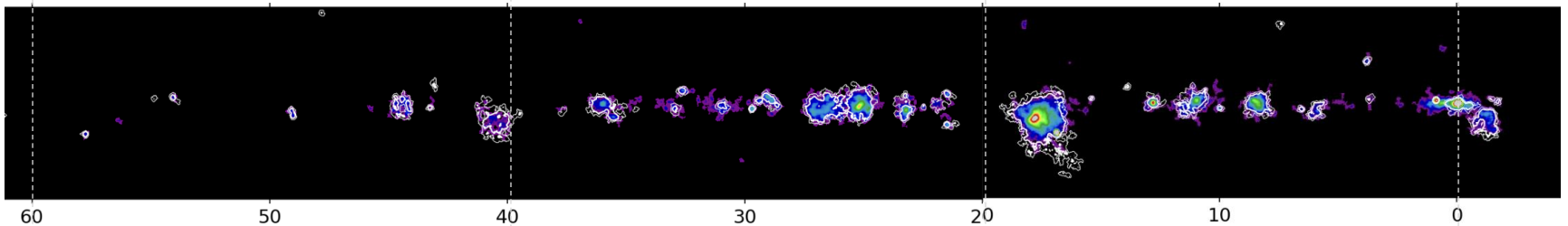
e.g.
M. Breuhaus, B. Reville, J. A. Hinton A&A 2022



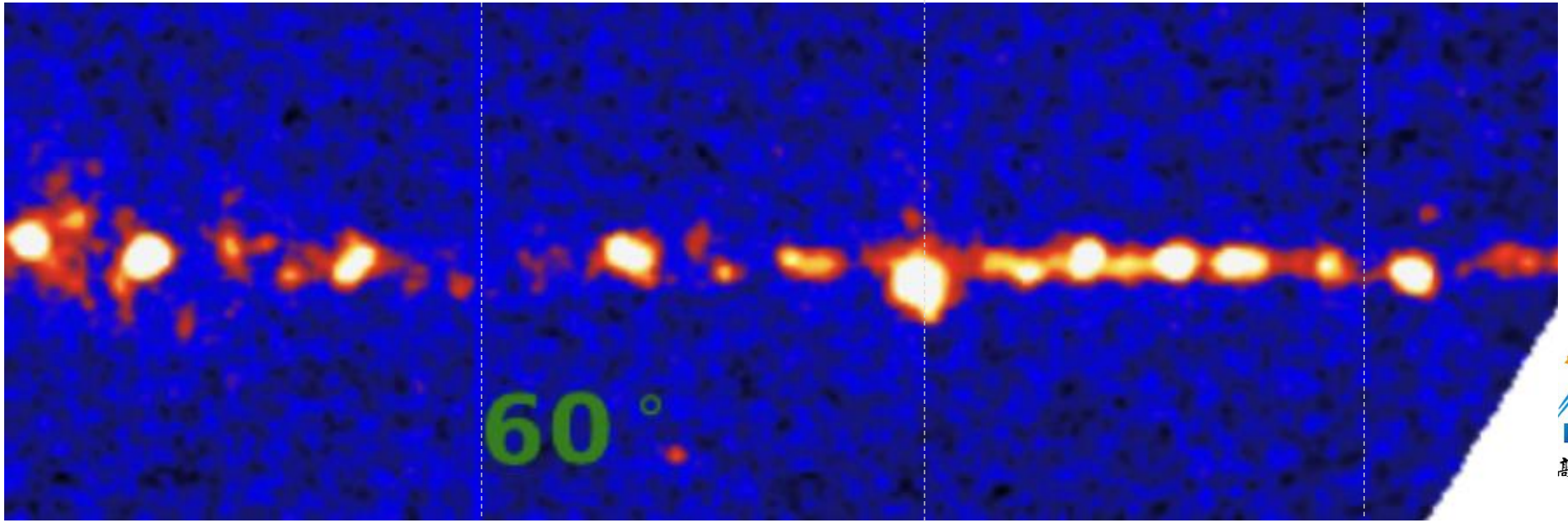
- Pass 5 prelim. Goodman Gamma2022



Targeted observations:
VERITAS, MAGIC, LST-1



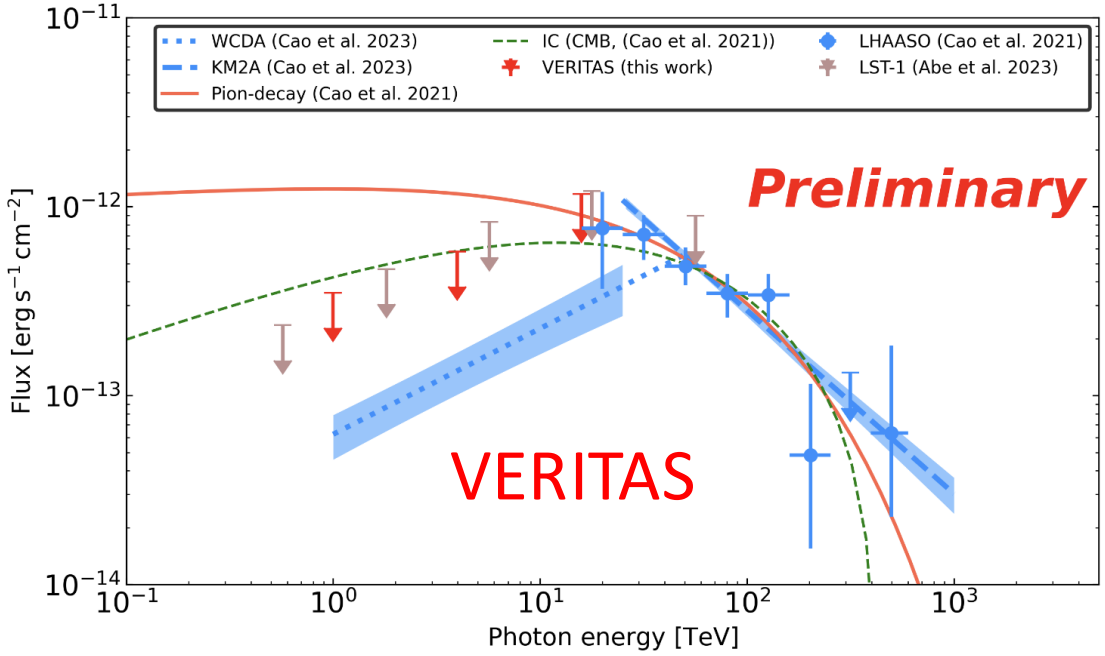
- Updated HESS GPS (Remy et al ICRC 2023)

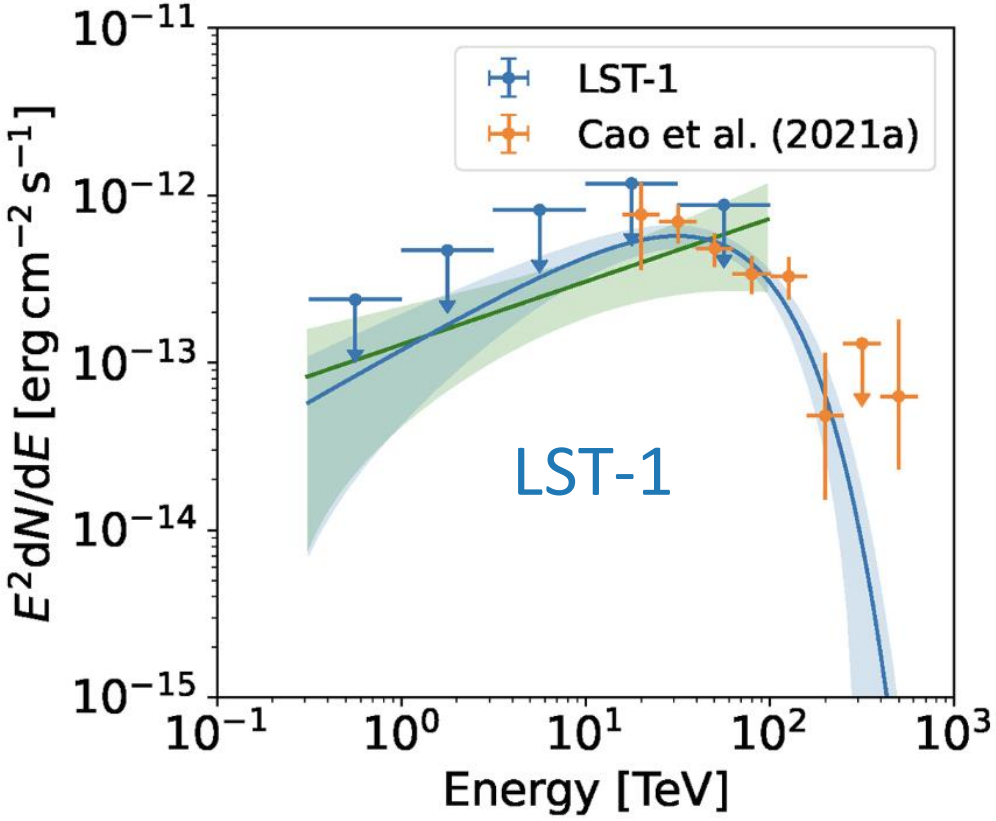


- 1st LHAASO Catalogue : KM2A

LHAASO Follow-up

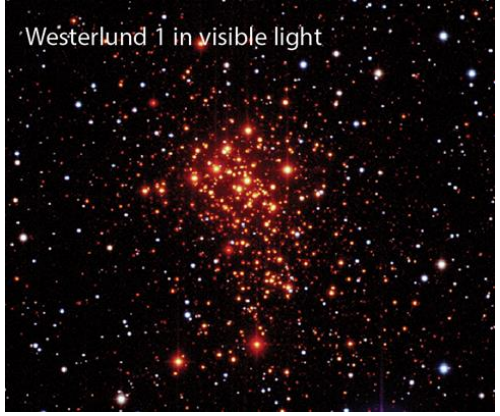
- Northern hemisphere IACTs follow up of LHAASO UHE detections
  - Largely supportive of IC origin, many are PWN



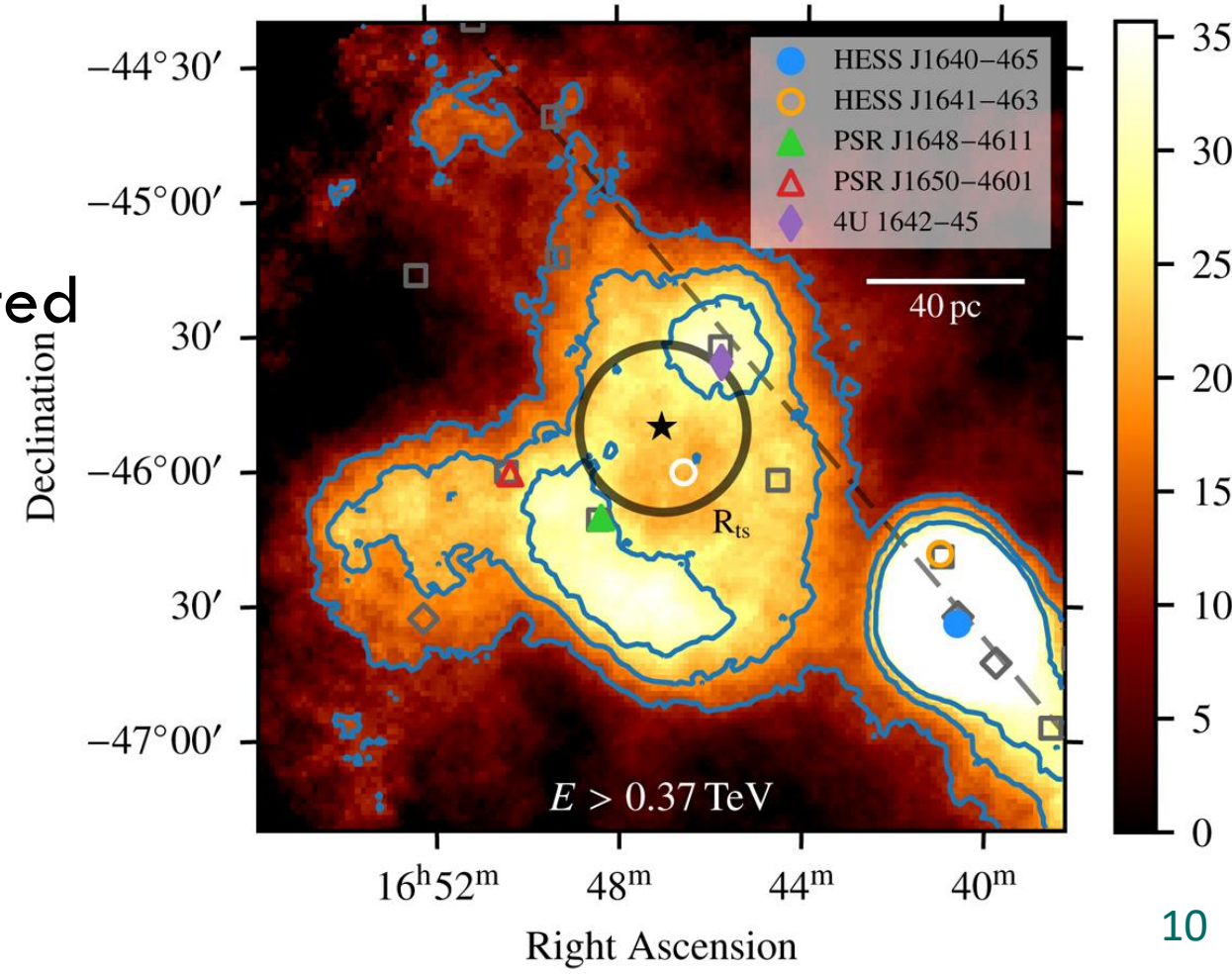


Massive Stellar Clusters

- Most massive stars born in clusters
  - Hence most SN explosions occur in/near clusters, plus
  - Wind-power significant (dominates until a few Myr, when SN ramp up)
- Direct evidence for acceleration associated to collective wind: Wd1
  - HESS sees shell-like emission around cluster close to expected radius of TS
  - Looks like IC from electrons
  - But co-acceleration of protons inevitable
- See Thibault's talk later

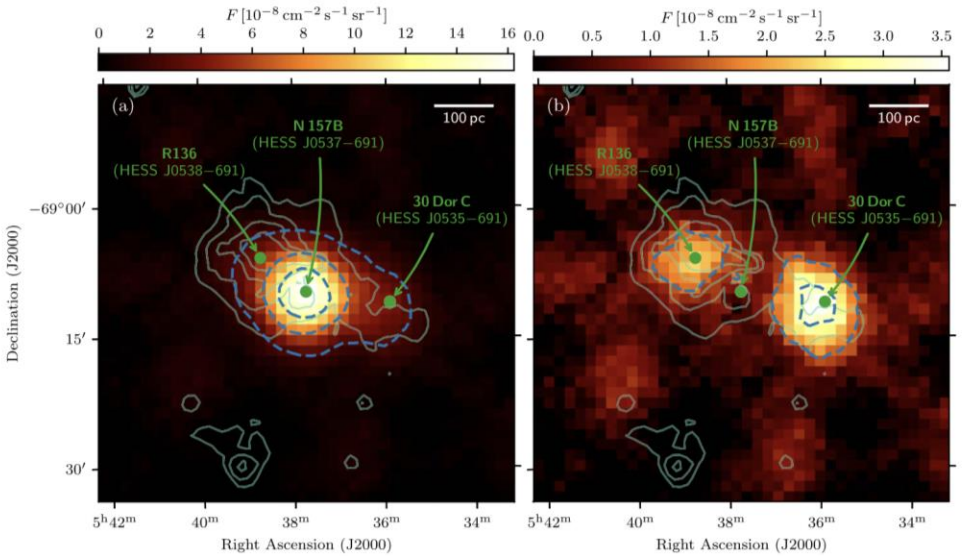


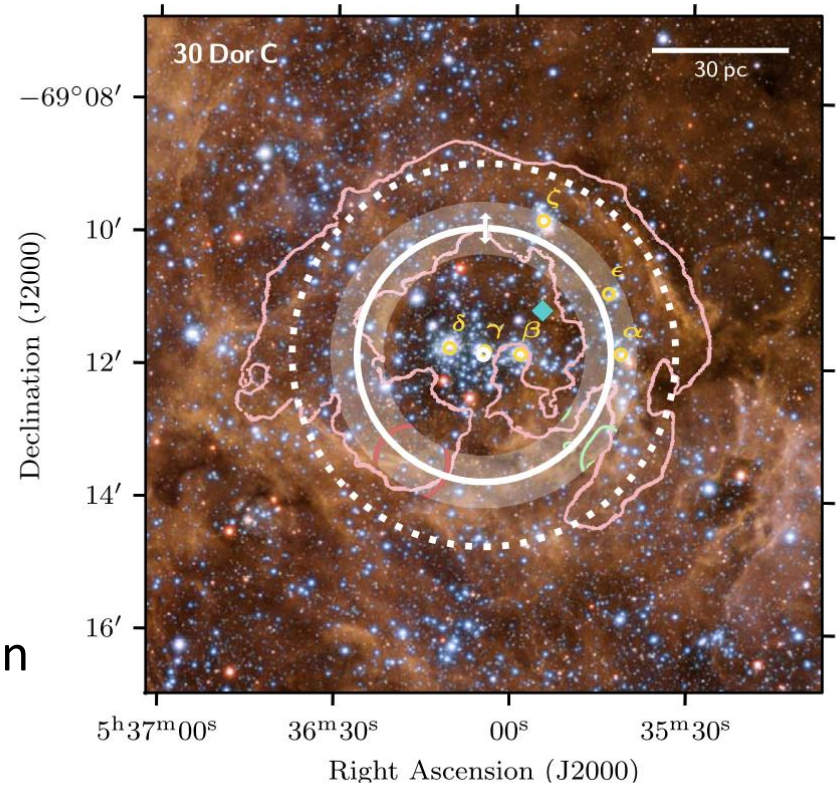
Westerlund I: HESS coll. +Härer et al 2023

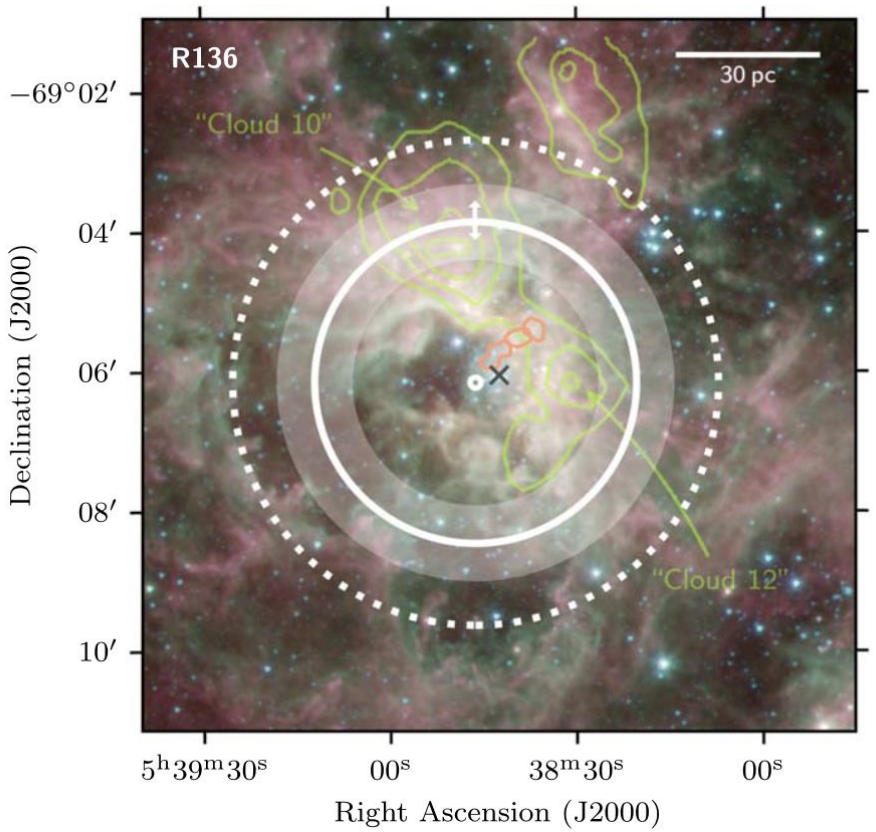


Massive Stellar Clusters

- Is W1 alone? **No – e.g.** R136 in the LMC
  - And 30 Dor C – known for some time







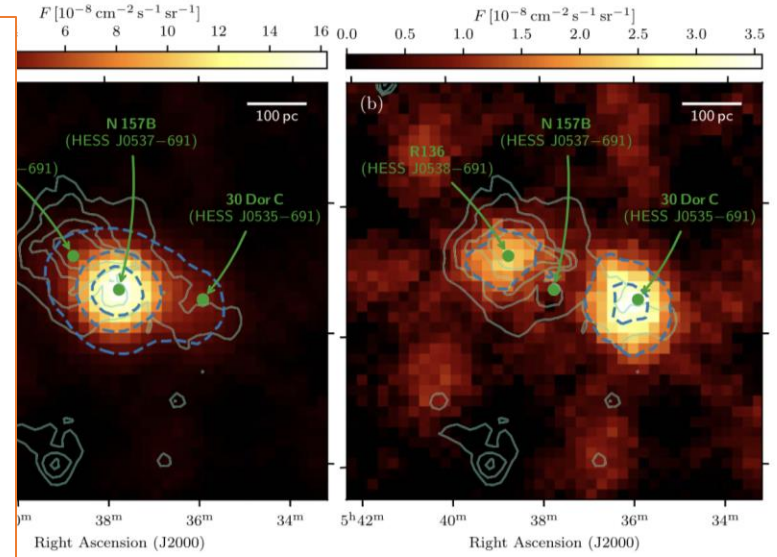
HESS Collaboration ApJL 2024

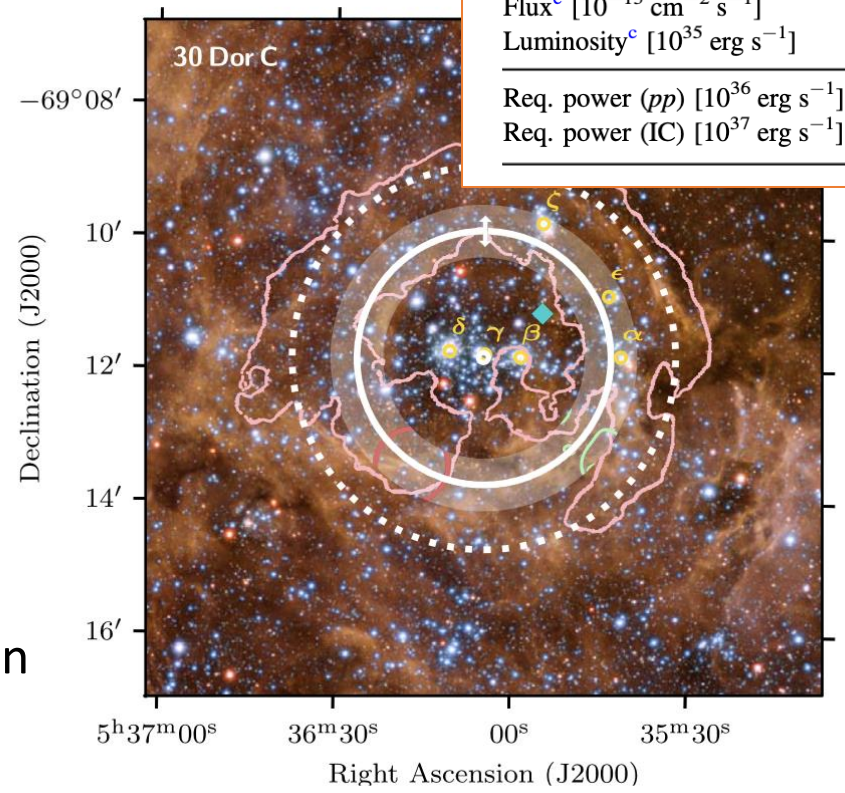
Massive Stellar

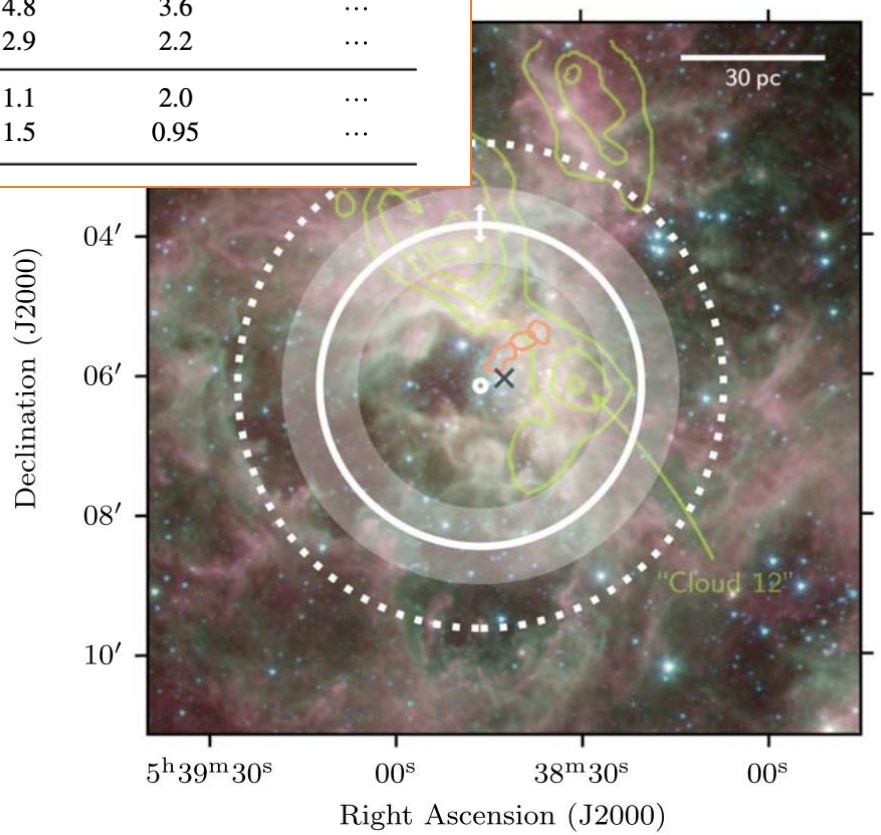
- Is W1 alone? **No – e.g**
  - And 30 Dor C – known

Table 1
YMC Properties

Property	LH 90	R136	References
Cluster age [Myr]	4	1.5	1, 2
Wind power[a] [10^{38} erg s^{-1}]	1.5	10	3, 4
Wind velocity [km s^{-1}]	3000	3000	5, 6
Average ISM density [cm^{-3}]	100	100	7–11
Magnetic field [μG]	15	15[b]	12
SB radius [pc]	74	56	···
Termination shock radius [pc]	7.9	8.7	···
2D Gaussian width [pc]	27.8	33.5	···
68% containment radius [pc]	42.0	50.5	···
Spectral index	−2.57	−2.54	···
Flux[c] [10^{-13} cm^{-2} s^{-1}]	4.8	3.6	···
Luminosity[c] [10^{35} erg s^{-1}]	2.9	2.2	···
Req. power (pp) [10^{36} erg s^{-1}]	1.1	2.0	···
Req. power (IC) [10^{37} erg s^{-1}]	1.5	0.95	···







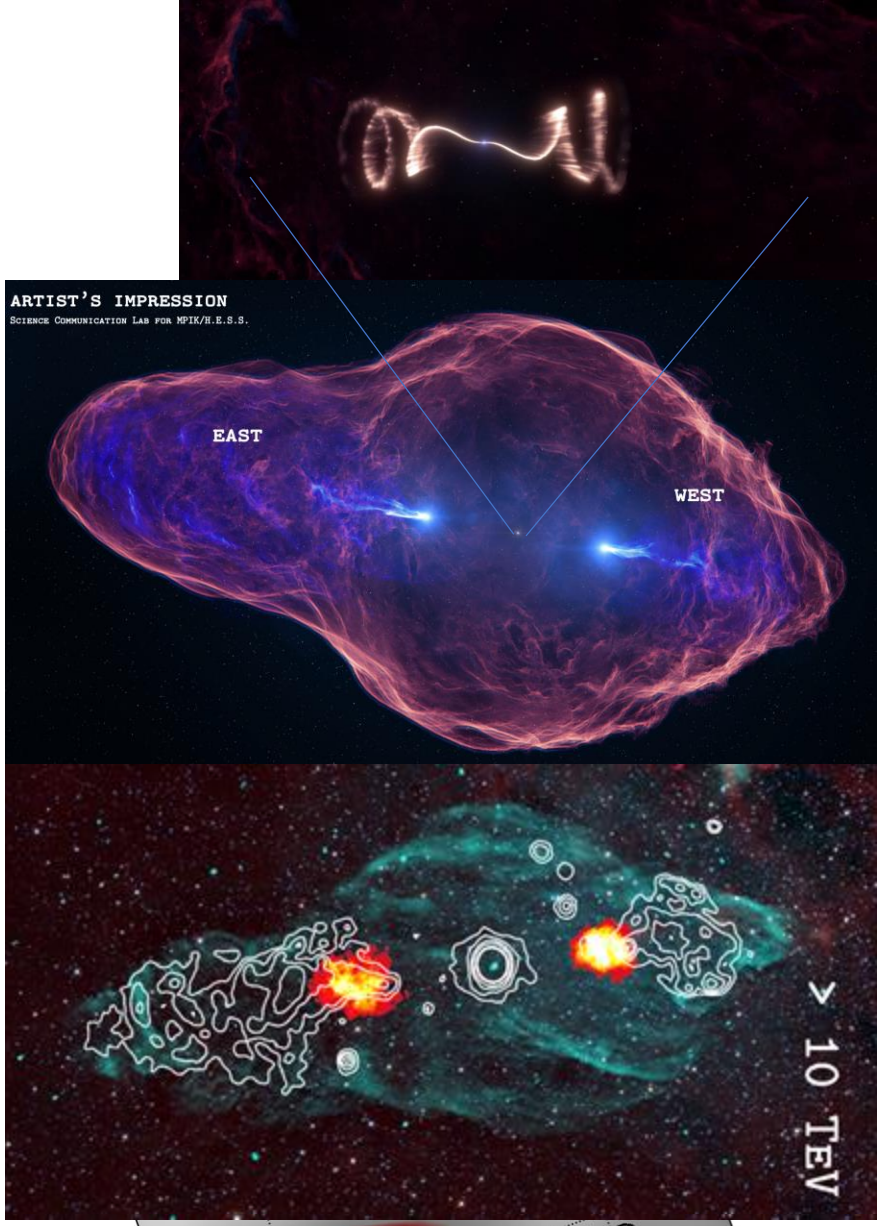
+Other galactic plane associations

HESS Collaboration ApJL 2024

Microquasars

- Accreting black hole in binary system produces jet
  - Often relativistic
- Detection of SS 443 was a game changer
  - Many previous searches focussed on time-variable emission from close to the BH
  - HAWC sensitivity at ~40 TeV needed to find it (Nature 2018)
  - HESS resolution to detect energy dependent morphology (Science 2023)

$$E_{\mathrm{Hillas}} \approx 10Z \left(\frac{B}{20\mu\mathrm{G}}\right)\left(\frac{u_1}{0.26c}\right)\left(\frac{R}{1.6\mathrm{pc}}\right)\mathrm{PeV}$$



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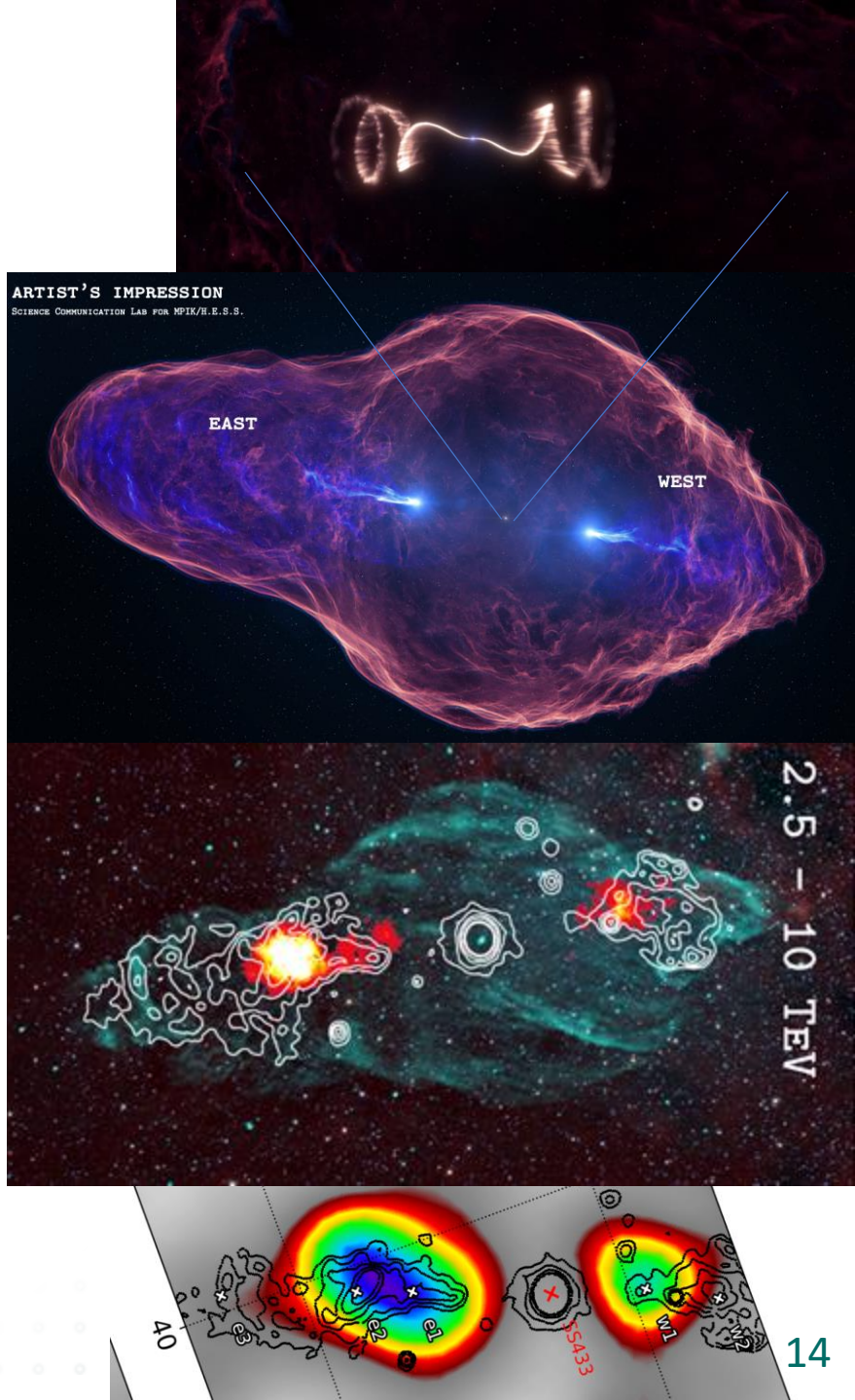
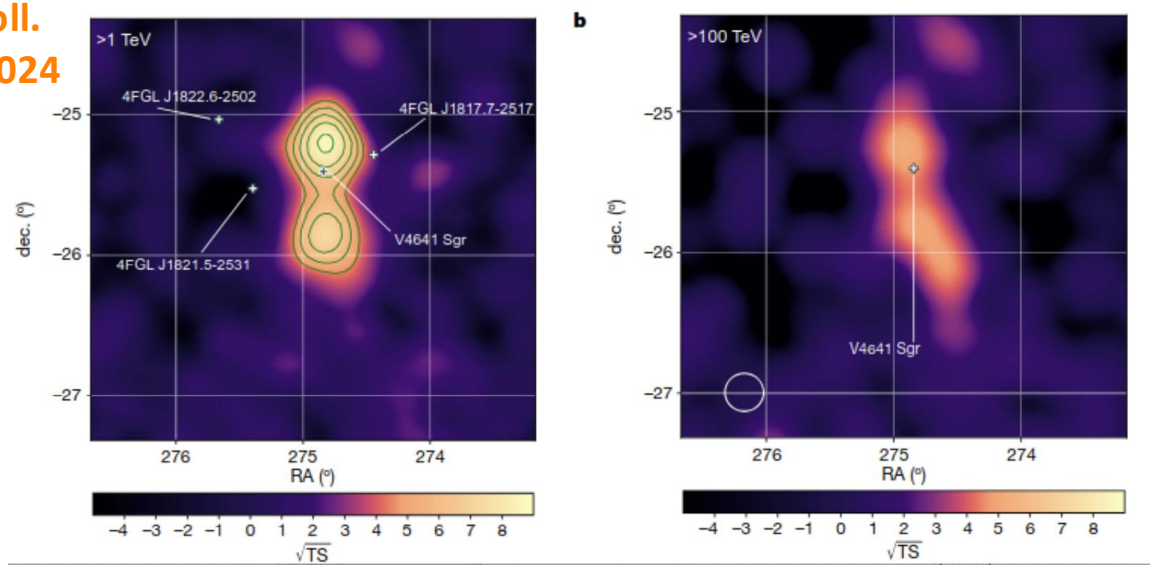
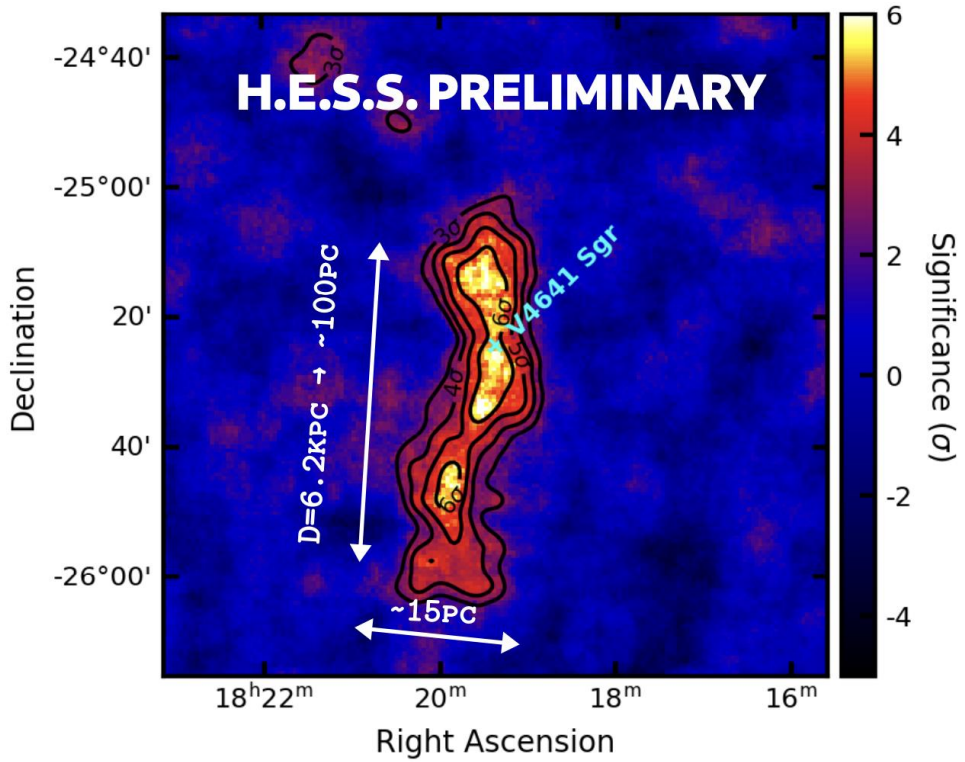


Microquasars

- Is SS 433 unique/alone? No:
  - V4641 Sgr (HAWC Nature 2024)
    - 5° off the galactic plane
    - Very large and consistent size with energy

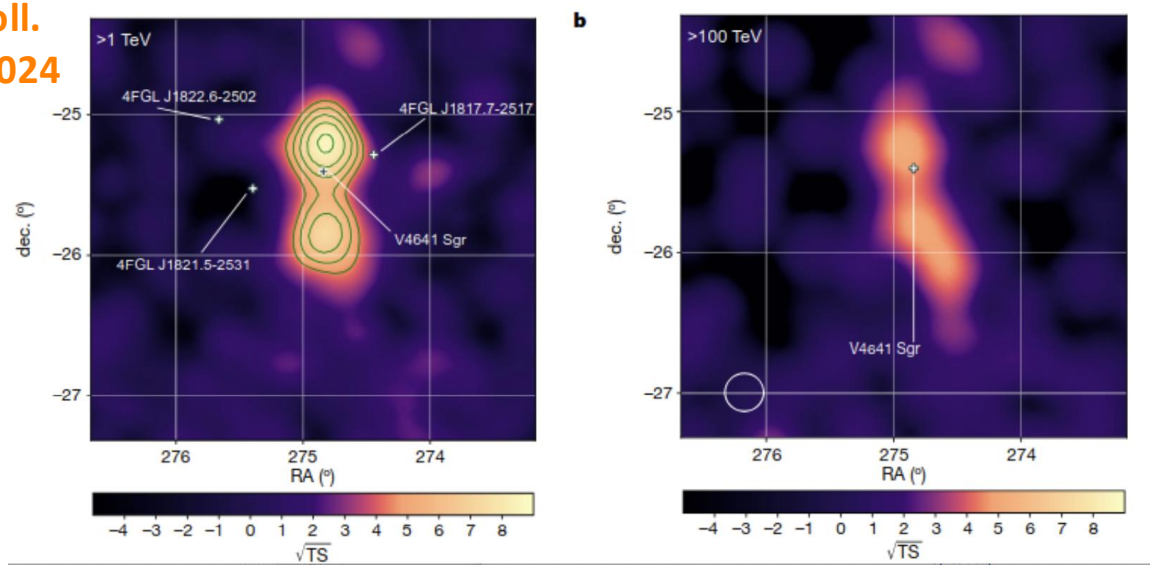
HAWC Coll.
Nature 2024





Microquasars

HAWC Coll. Nature 2024



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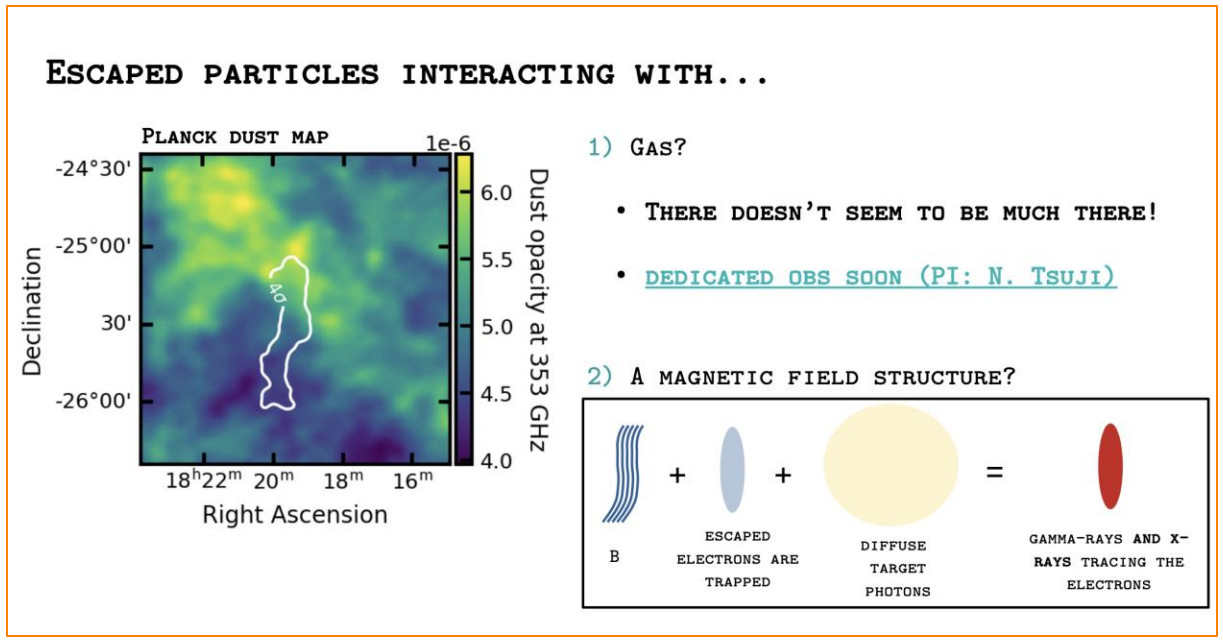
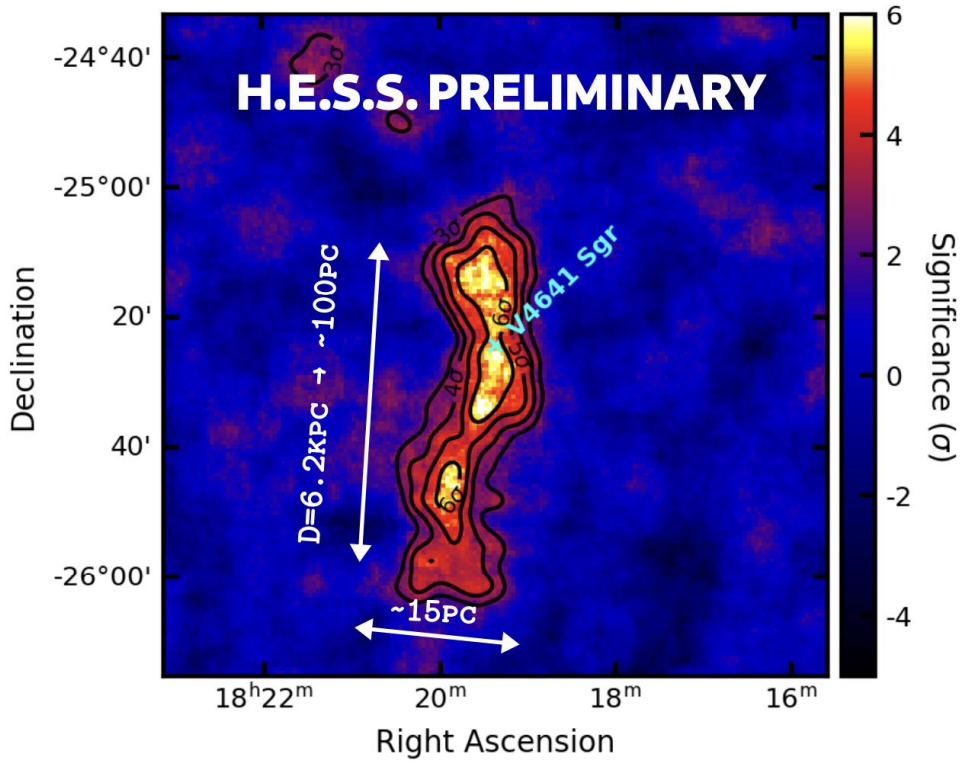
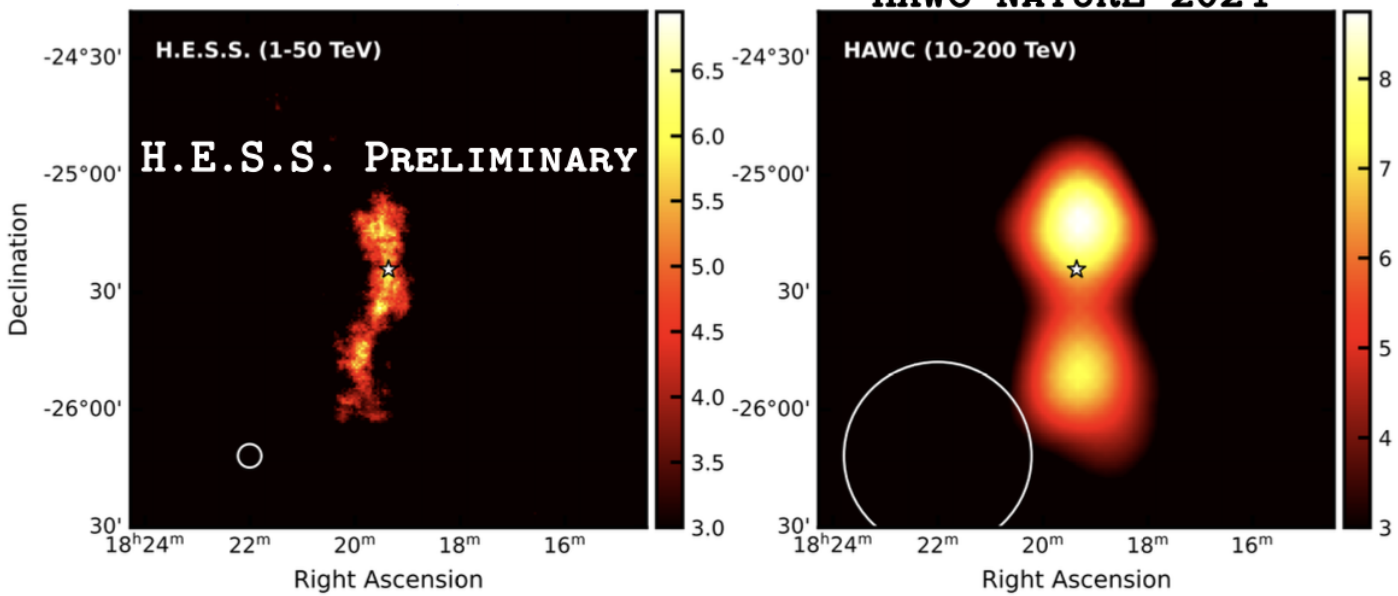
L. O-N CDY Talk





HAWC Nature 2024

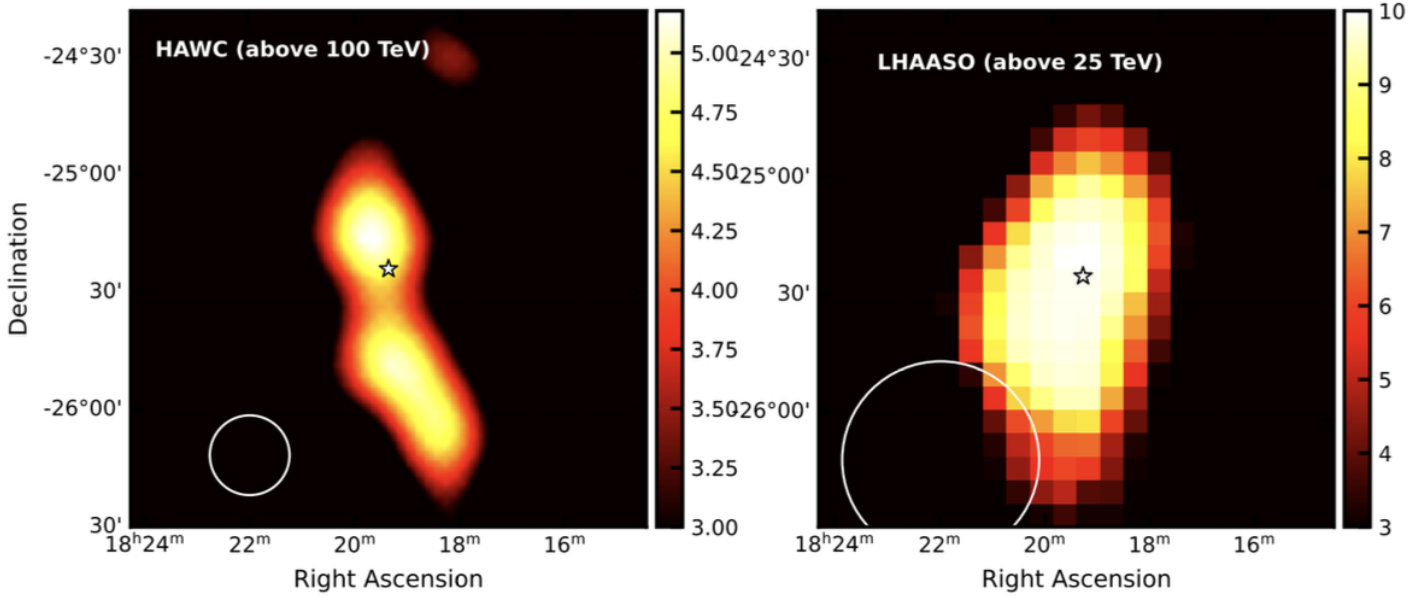


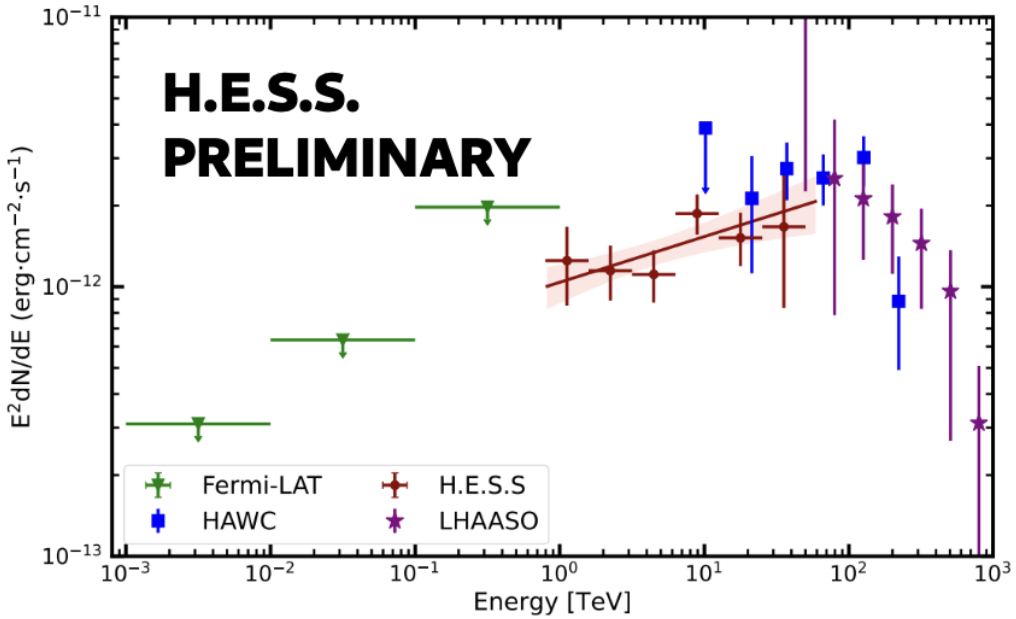
LHAASO detected photons up to 800 TeV from V4641 Sgr !!

LHAASO Collaboration 2410.08988

HAWC Nature 2024

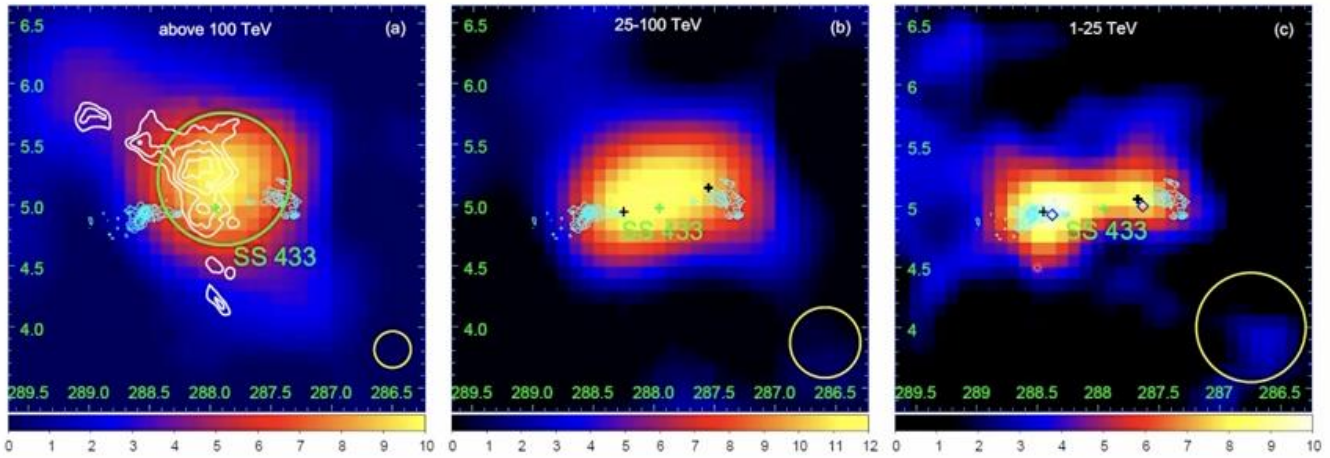
LHAASO arXiv 2024





https://www.youtube.com/watch?v=_eTQDce3Noo

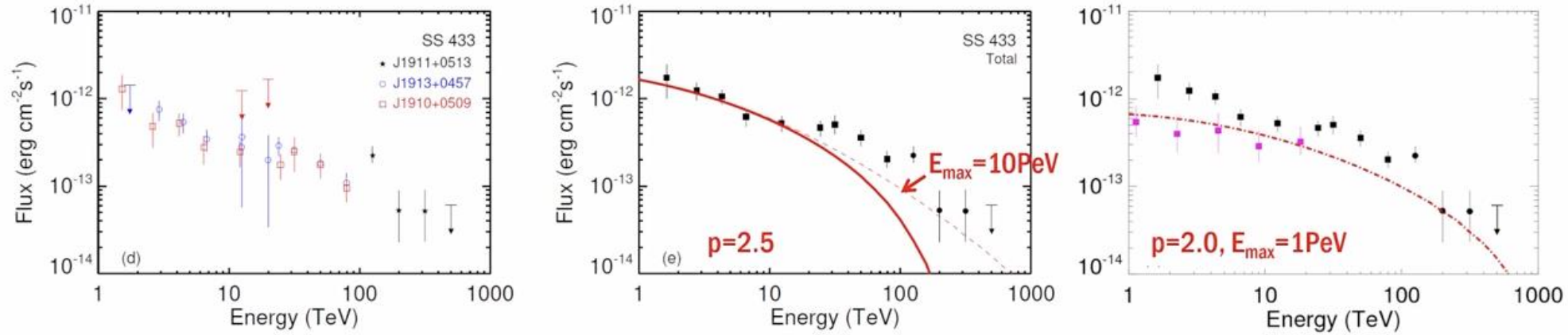
SS 433



dramatic change of the morphology between low energy and high energy

	1-25 TeV	25-100 TeV	above 100 TeV
ΔAIC	22.7	22.8	-12.5

ΔAIC<-10 favors Gaussian model
ΔAIC>-10 favors 2PS model



CDY Seminar - 2024 November 27

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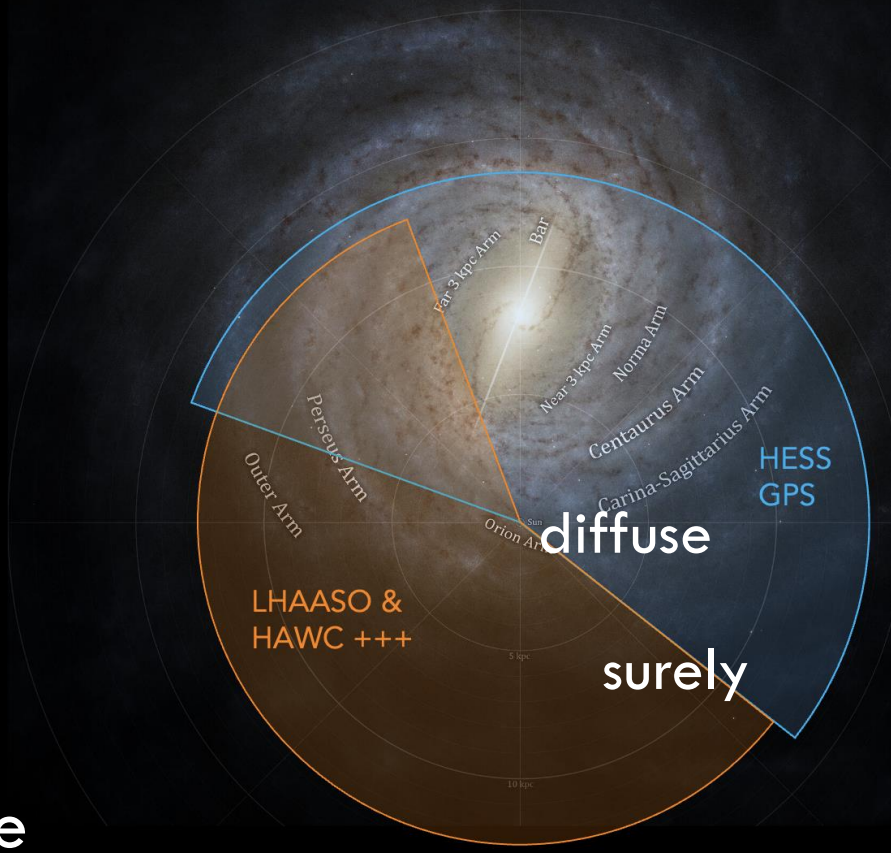
13 views 1 day ago
Title: Detection of microquasars by LHAASO
Speaker: Ruoyu Liu (Nanjing University) ...more

How to make progress?

- Need UHE γ-ray capabilities in the south
  - PeV acceleration sites in the inner galaxy
  - Full sky TeV-PeV gamma map to compare to neutrino emission
  - …and to the first Galactic neutrino sources – coming soon
- Need angular resolution as well as UHE coverage
  - Resolve accelerators and understand the physics
  - And deeper TeV range sensitivity (source populations, evolution, details!)



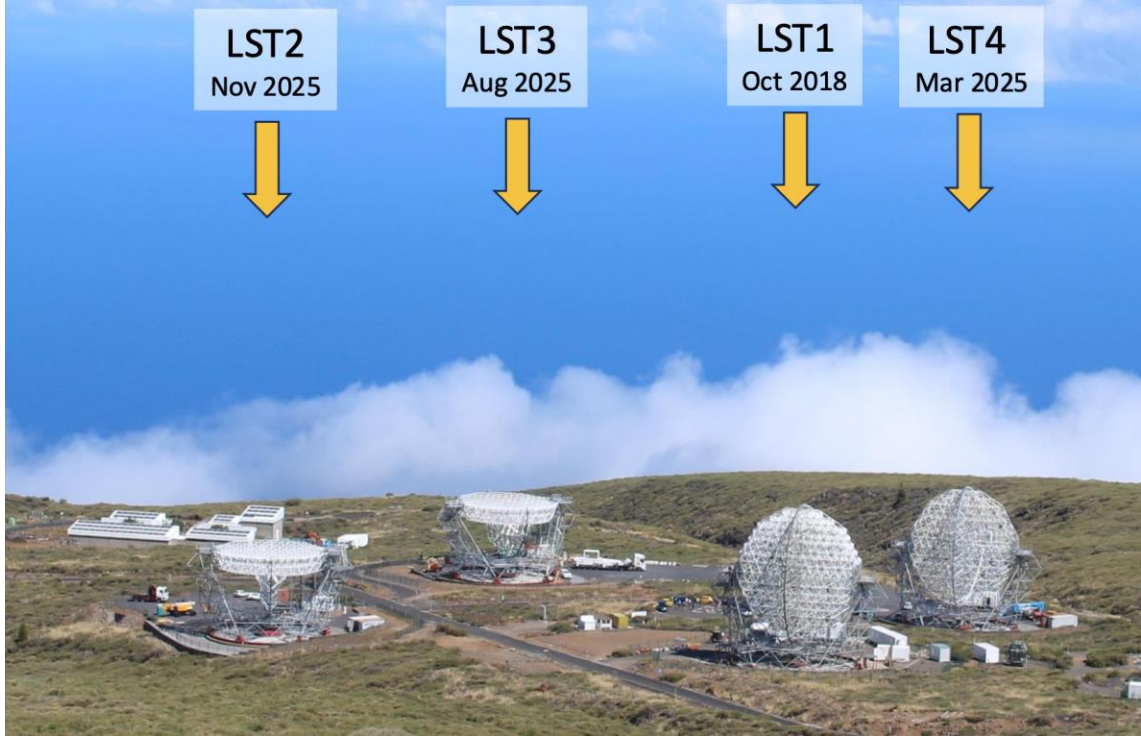
→ **CTAO and SWGO**

CTAO Status?

- Rapid progress on all fronts

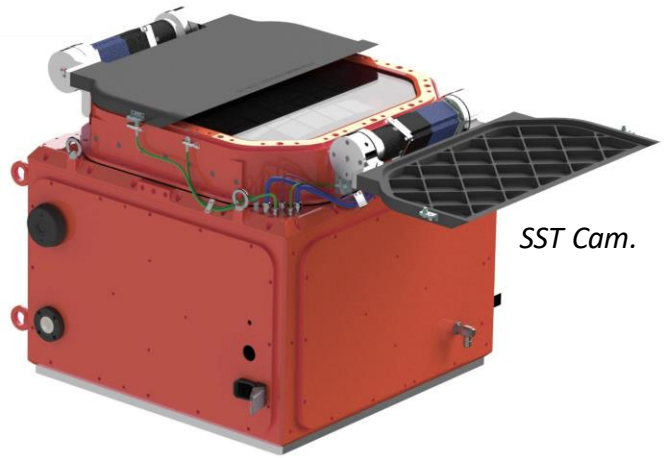
Everything prototyped and tested

Preparations for first CTA South 'Pathfinders'



LST Construction in La Palma

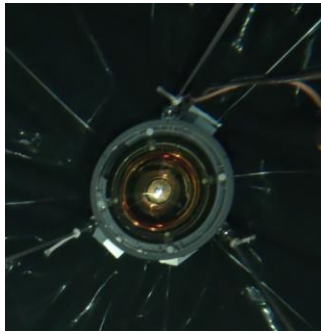
ASTRI array as proving ground for CTA SST technologies



Preparations for 'mass production' for Cherenkov Cameras

SWGO Status?

Double 8-10 “ PMT module



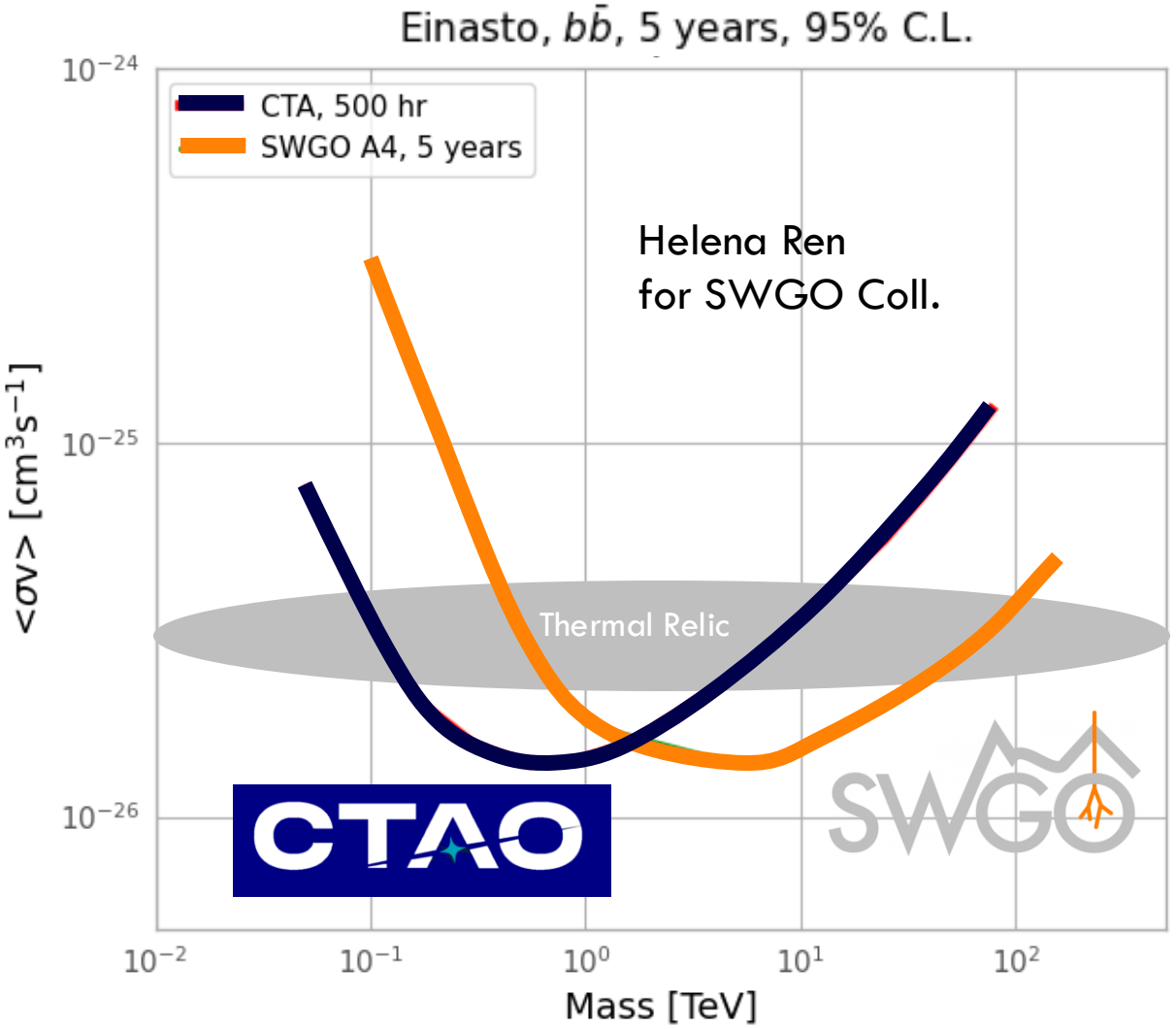
FlashCam readout

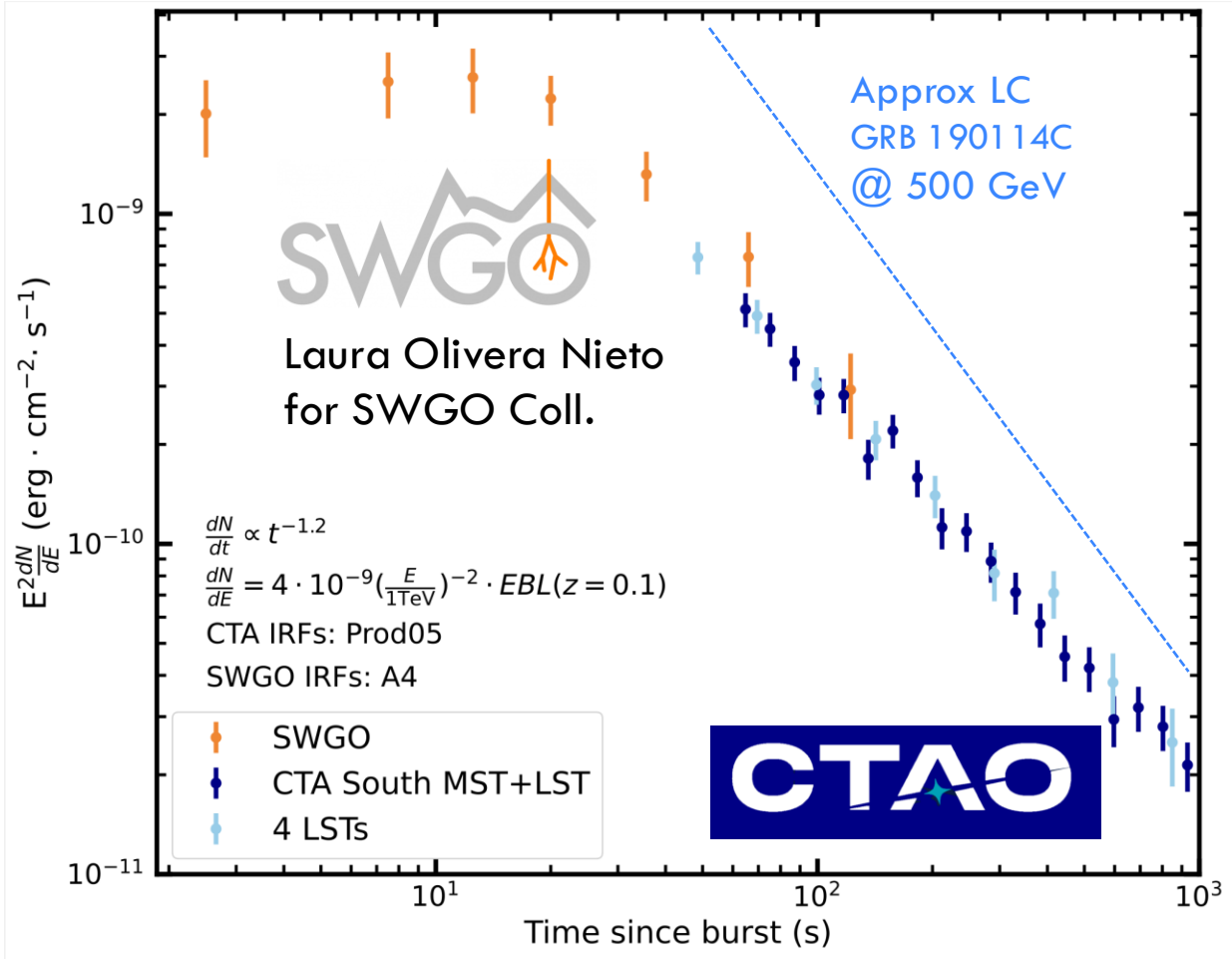
Inner array baseline

5.2 m diameter dual-layer WCD

Prototype @ HAWC

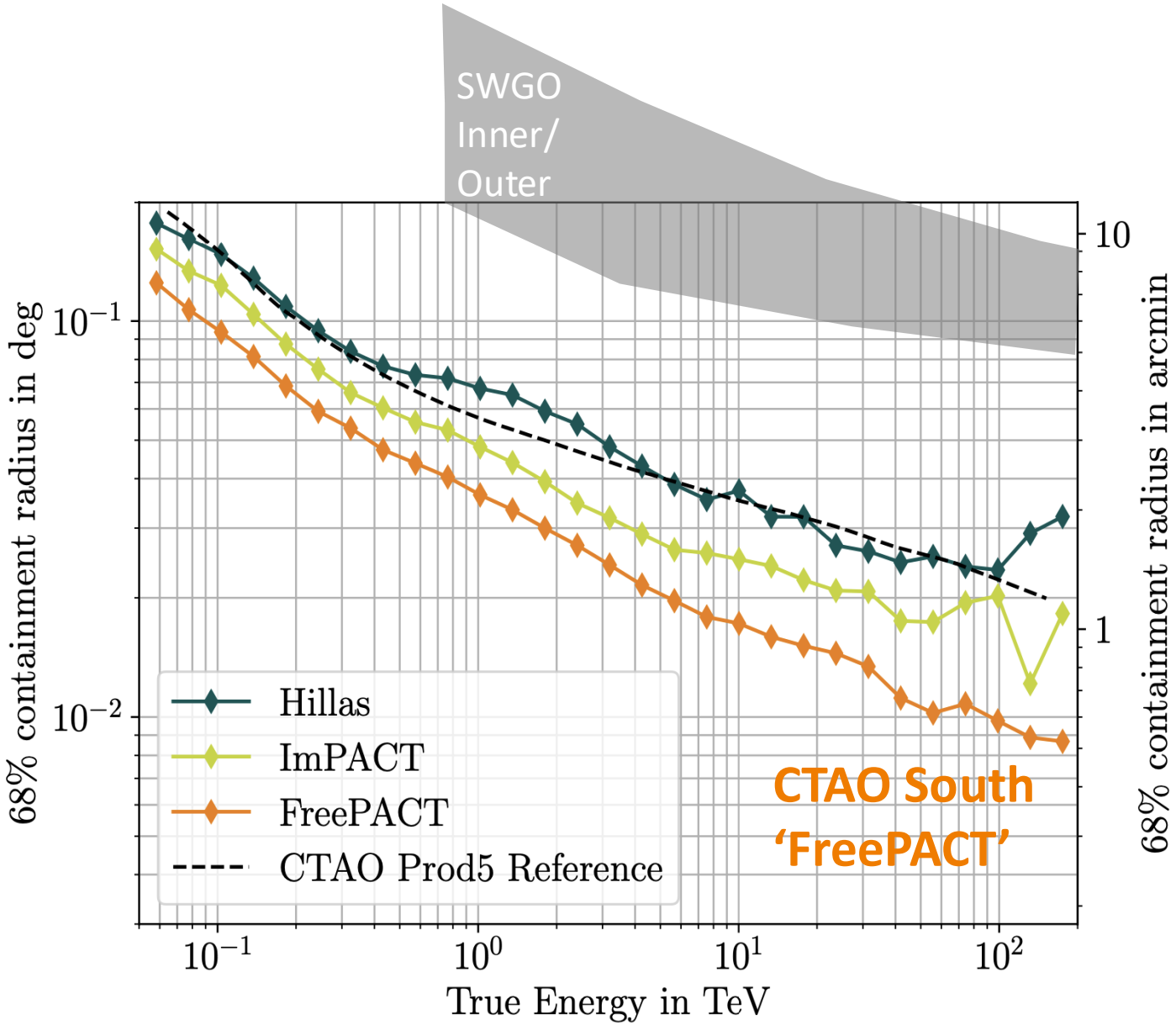
SWGO+CTAO


Einasto, $b\bar{b}$, 5 years, 95% C.L.
CTA, 500 hr
SWGO A4, 5 years
Helena Ren
for SWGO Coll.
Thermal Relic
CTAO
SWGO
$<\sigma v>$ [cm^{3}s^{-1}]
Mass [TeV]


Approx LC
GRB 190114C
@ 500 GeV
Laura Olivera Nieto
for SWGO Coll.
$\frac{dN}{dt} \propto t^{-1.2}$
$\frac{dN}{dE} = 4 \cdot 10^{-9} (\frac{E}{1\text{TeV}})^{-2} \cdot EBL(z = 0.1)$
CTA IRFs: Prod05
SWGO IRFs: A4
SWGO
CTA South MST+LST
4 LSTs
CTAO
$E^2 \frac{dN}{dE}$ (erg · cm^{-2}· s^{-1})
Time since burst (s)

Angular Resolution

- Ground-particle arrays cannot compete with CTAO
- Huge opportunity for precision astronomy at energies > ~10 TeV (SSTs)
  - e.g. new hybrid machine learning/likelihood fitting
    - Schwefer, Parsons, Hinton 2024 (APh 163, 103008)
  - 30 arcsecond resolution possible with CTA at 100 TeV!



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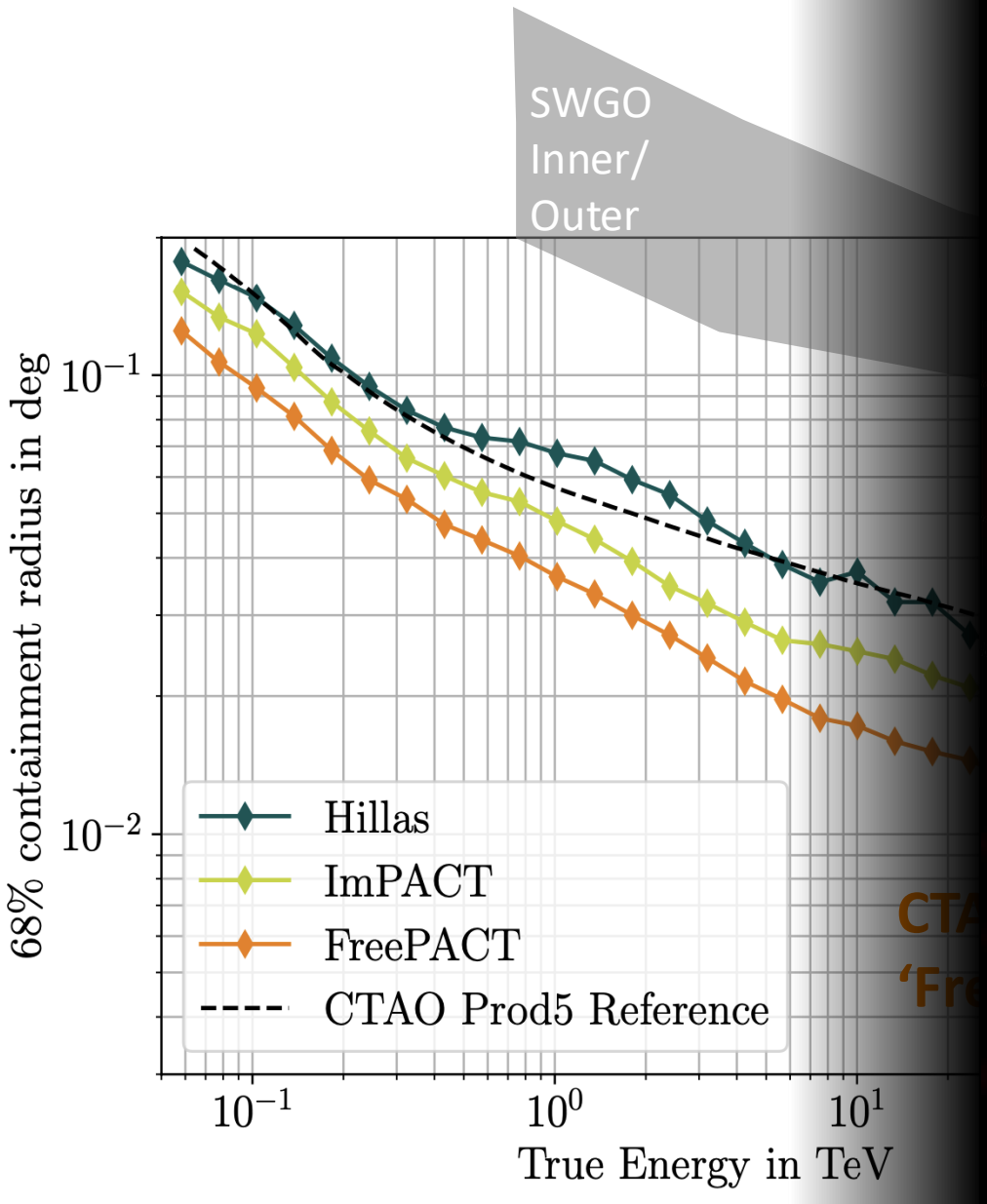
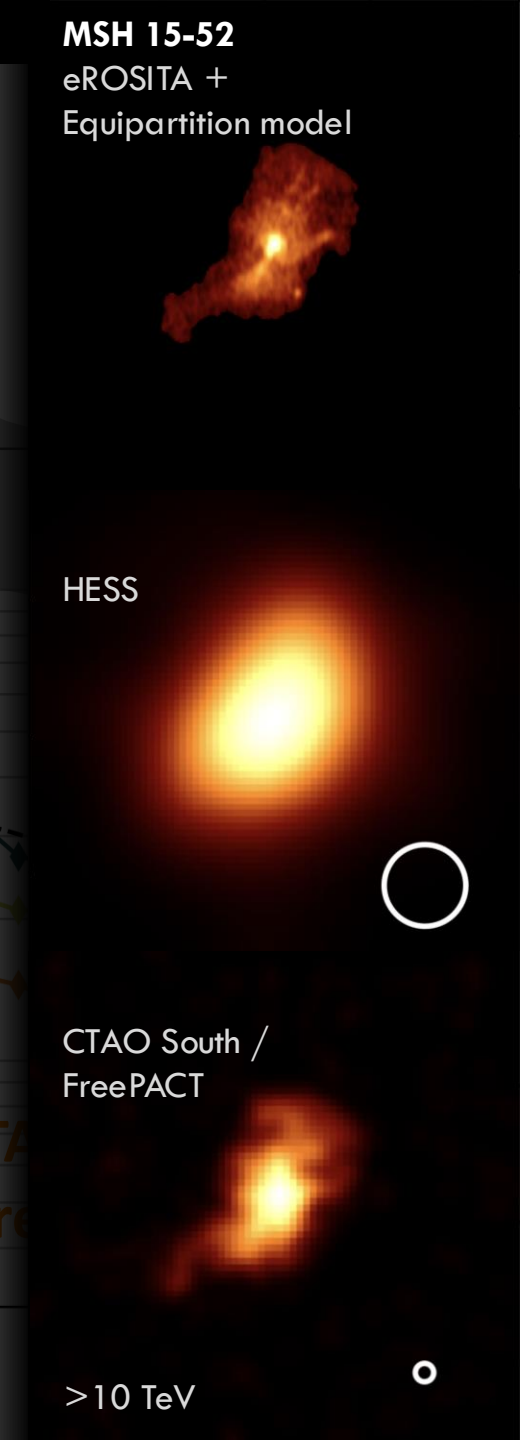
  - 30 arcsecond resolution possible with CTA at 100 TeV!

Schwefer et al (in prep.)

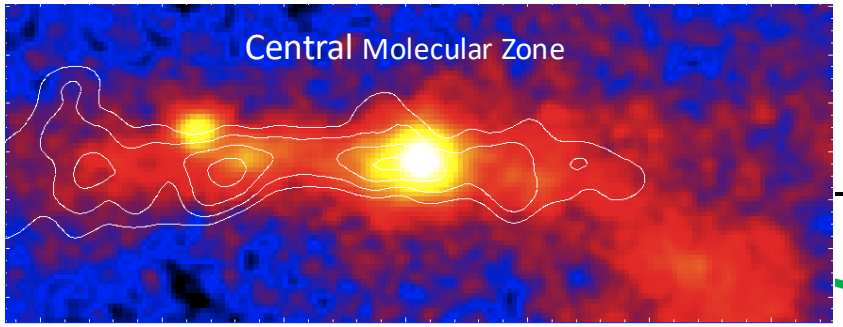




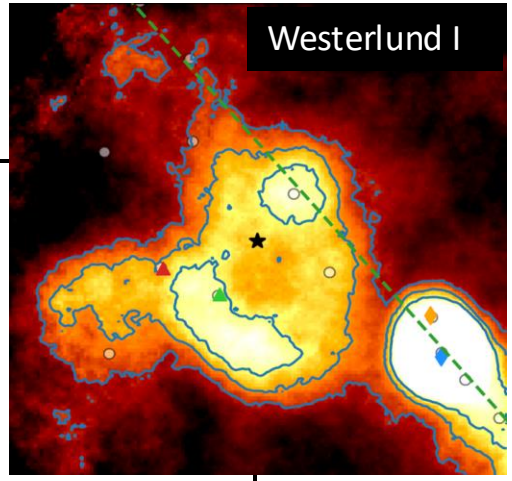
Conclusions

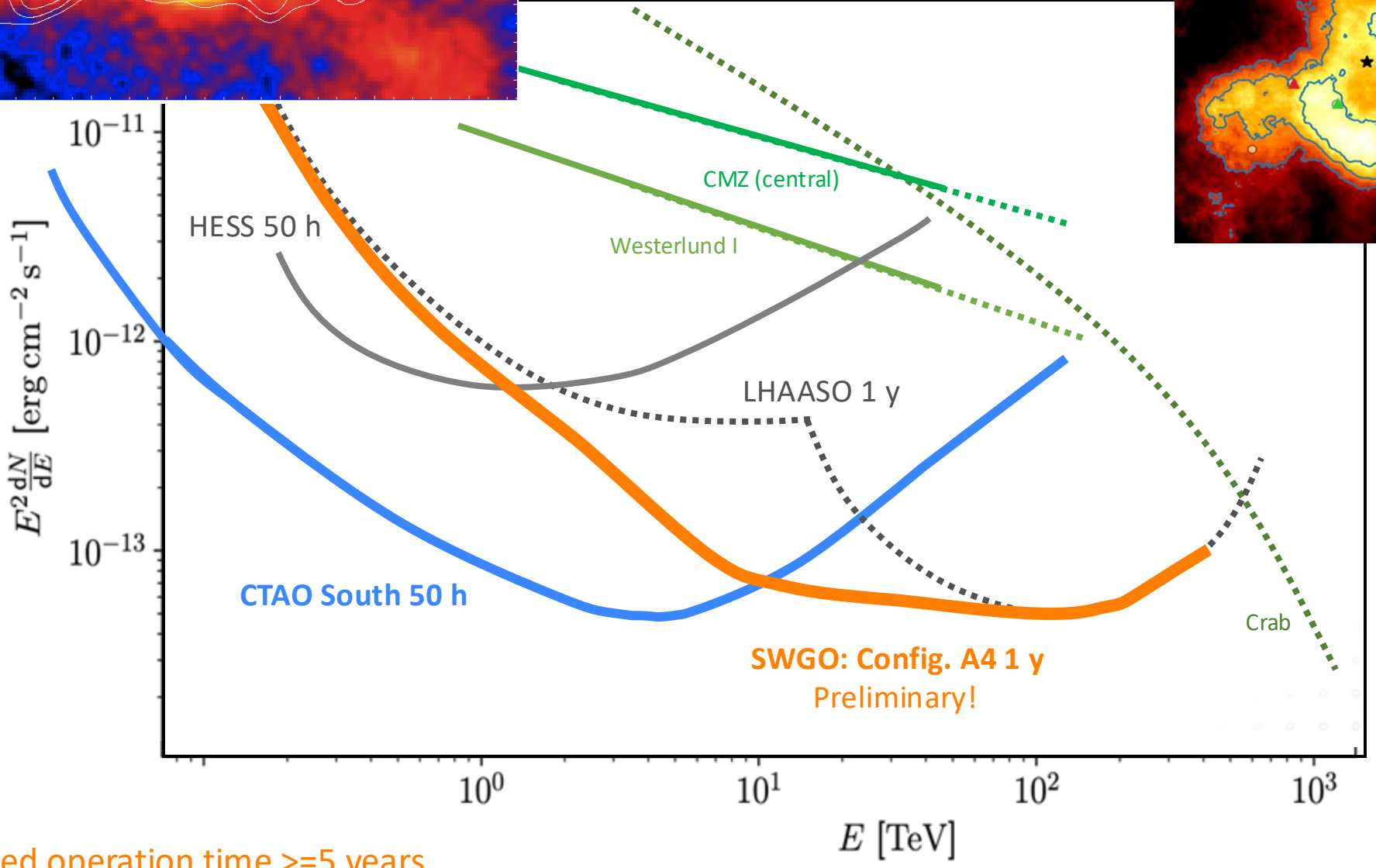
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- Cherenkov Telescopes continue to play a major role in identifying cosmic ray accelerators
  - Recent advances on massive stellar clusters and micro-quasars
- Strong complementarity to ground-level particle detectors
  - IACT follow-up of LHAASO sources, resolution versus UHE/wide-field
  - Future CTAO + SWGO
    - NB also the direct CR capabilities of these instruments – CTA electron spectrum/anisotropy ++, SWGO mass-group resolved anisotropy, …
- In general
  - Close link of gamma-ray and neutrino astronomy (which will grow in the future) and of course to cosmic rays



Southern Hemisphere UHE sources



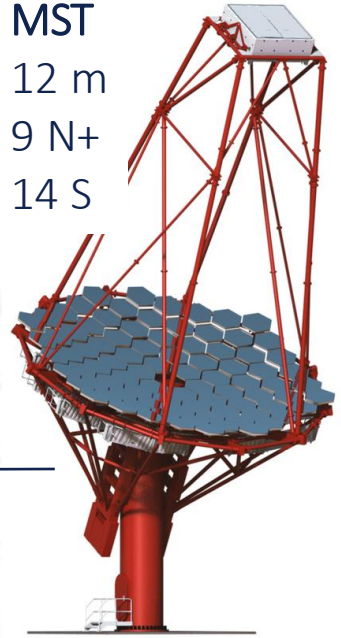


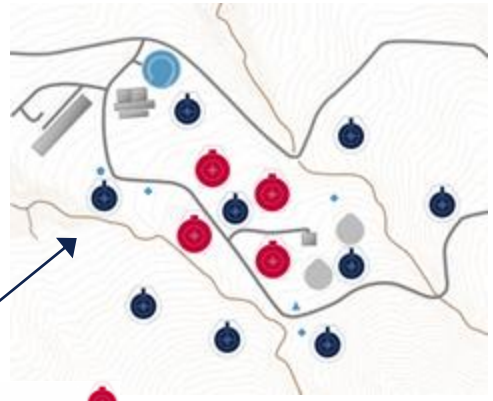
*planned operation time >=5 years

Paranal

1 km

MST
12 m
9 N+
14 S

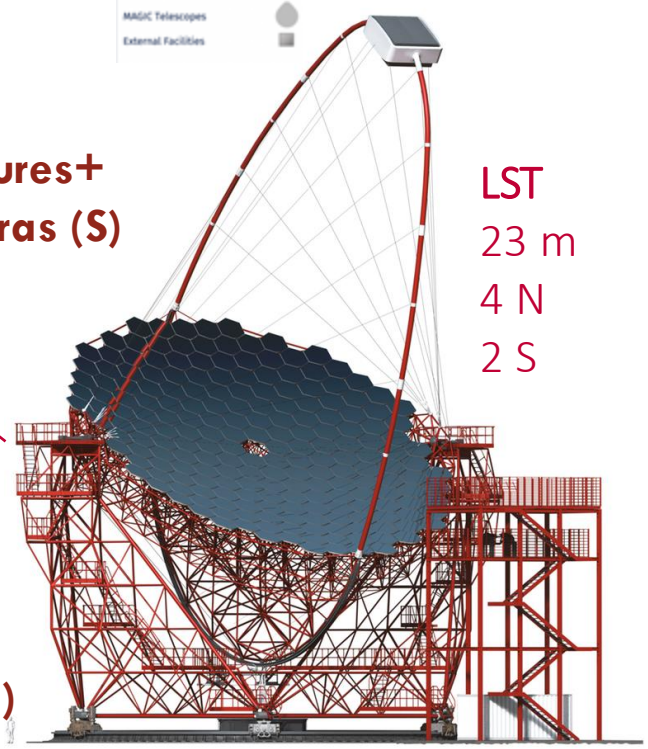




La Palma

DE: Structures+ Cameras (S)

LST
23 m
4 N
2 S



SST
4 m
42 S

DE: Cameras

CTAO
Initial Phase Plan

DE: Structures+ (N)