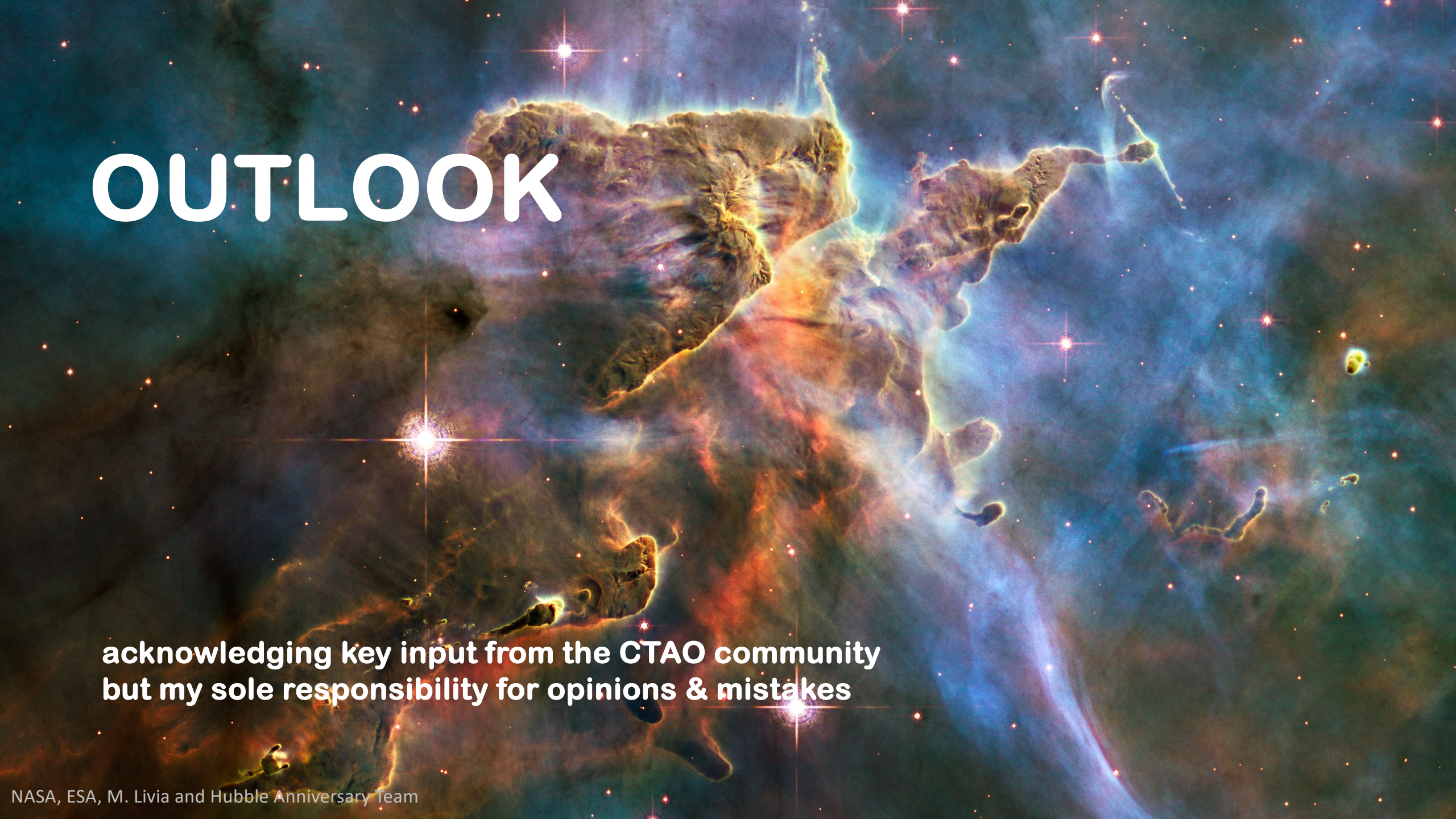
OUTLOOK

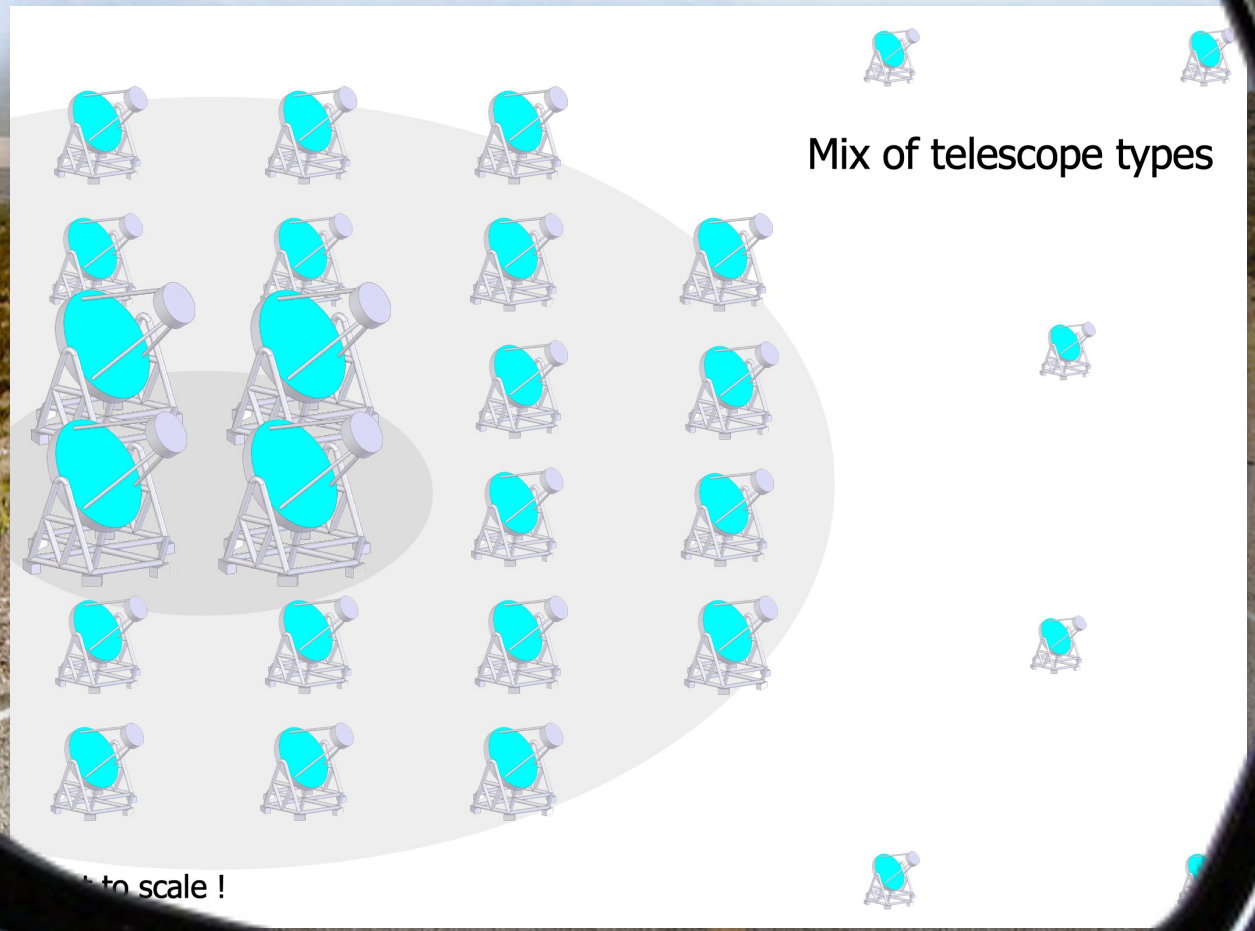


acknowledging key input from the CTAO community
but my sole responsibility for opinions & mistakes

NASA, ESA, M. Livia and Hubble Anniversary Team

Wikimedia Commons
& pixabay

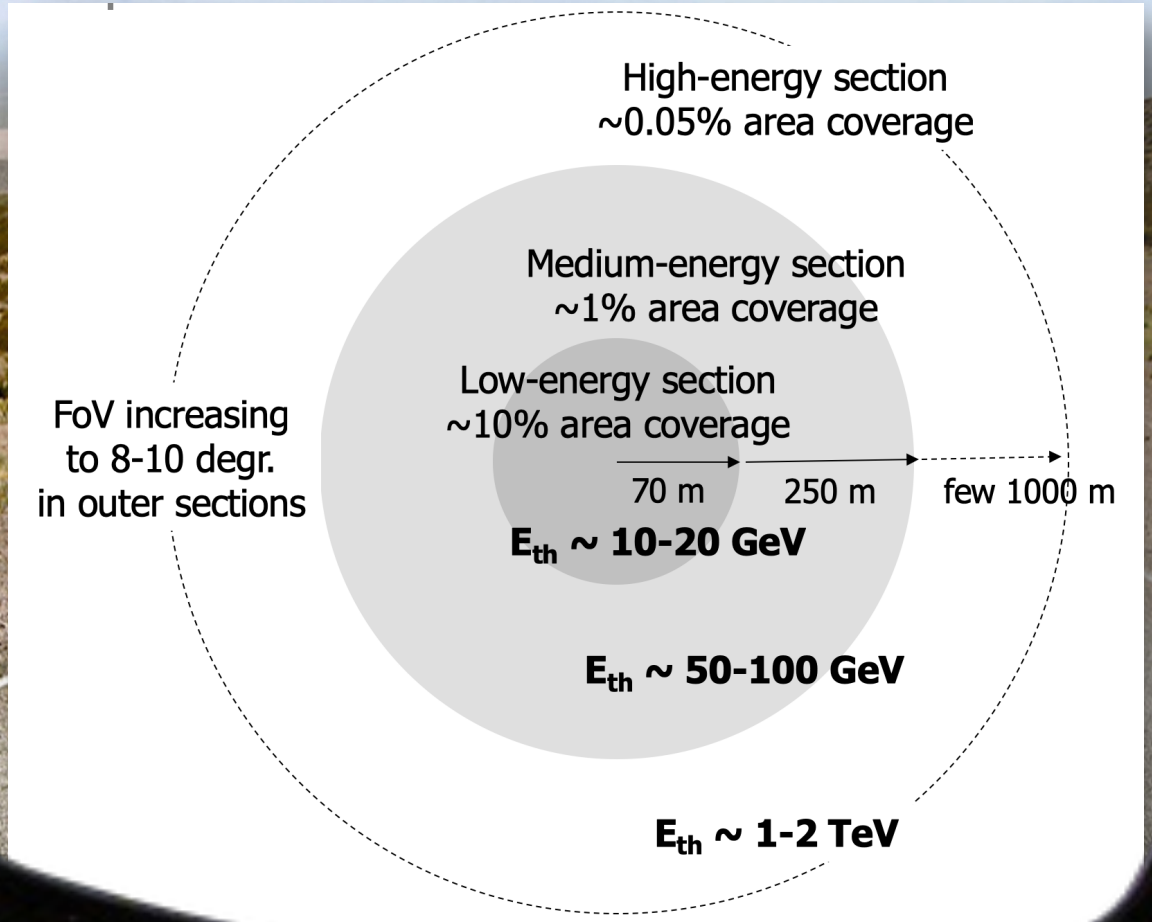
March 8, 2006:
ESFRI Brussels



LOOKING BACK

Wikimedia Commons
& pixabay

March 8, 2006: ESFRI Brussels



LOOKING BACK

Wikimedia Commons
& pixabay

Science environment has evolved significantly since the 2006 ESFRI presentation ...

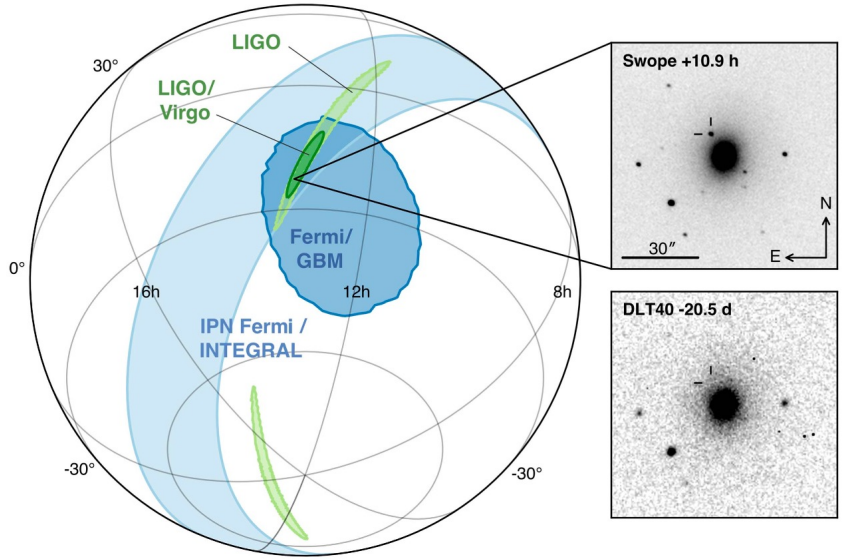
... and even since the 2017/18 “Science with CTA ” White Book

www.worldscientific.com/worldscibooks/10.1142/10986

MULTIMESSENGER ASTRONOMY

Gravitational waves

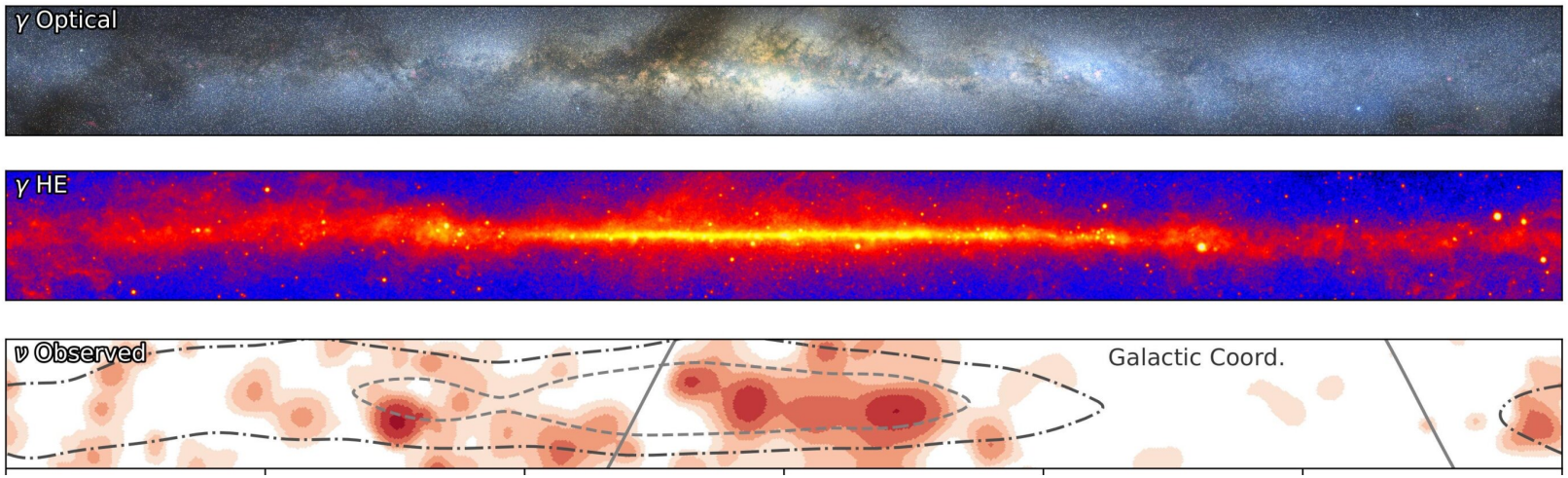
- BH mergers (2016)
- GW170817 NS-NS merger (2017)



Ligo et al.
APJL 2017

VHE neutrino sources

- TXS 0506+056 (2018)
- NGC 1068 (2022)
- Milky Way (2023)

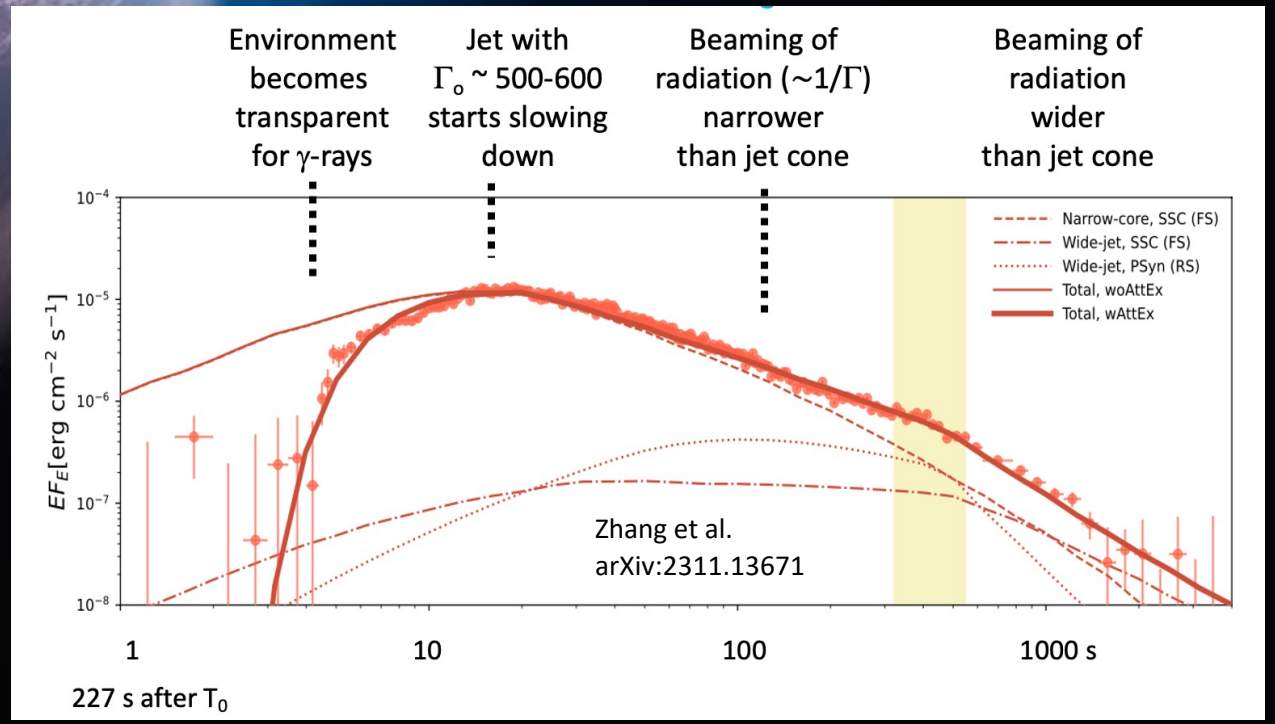


IceCube Collaboration/Science 2023

GRB'S DETECTED IN VHE GAMMA RAYS

MAGIC Coll.
– Nature 575 (2019)
– Nature 575 (2019)
H.E.S.S. Coll.
– Nature 575 (2019)
– Science 372 (2021)
LHAASO GRB 221009A
– Science (2023)
– Science Advances (2023)

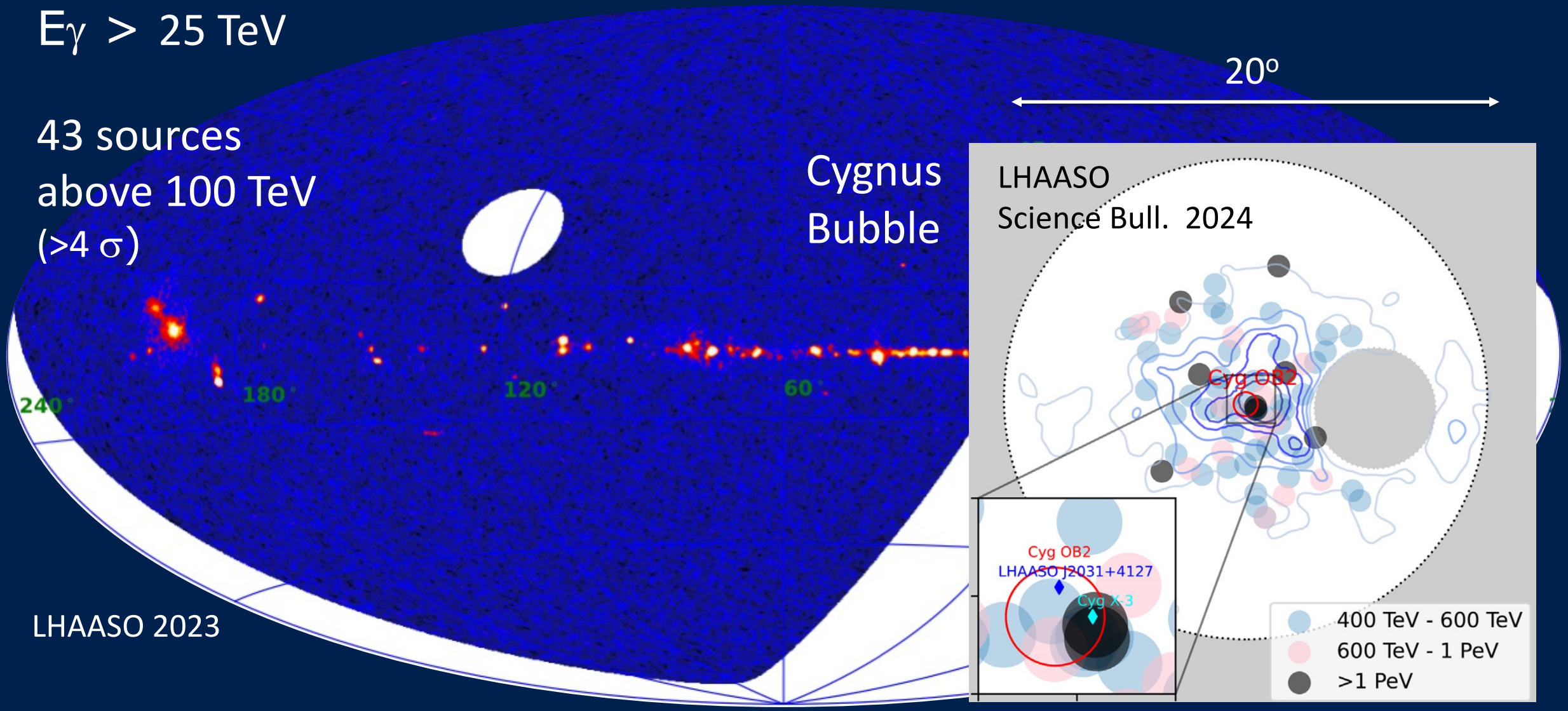
once every
10000 years



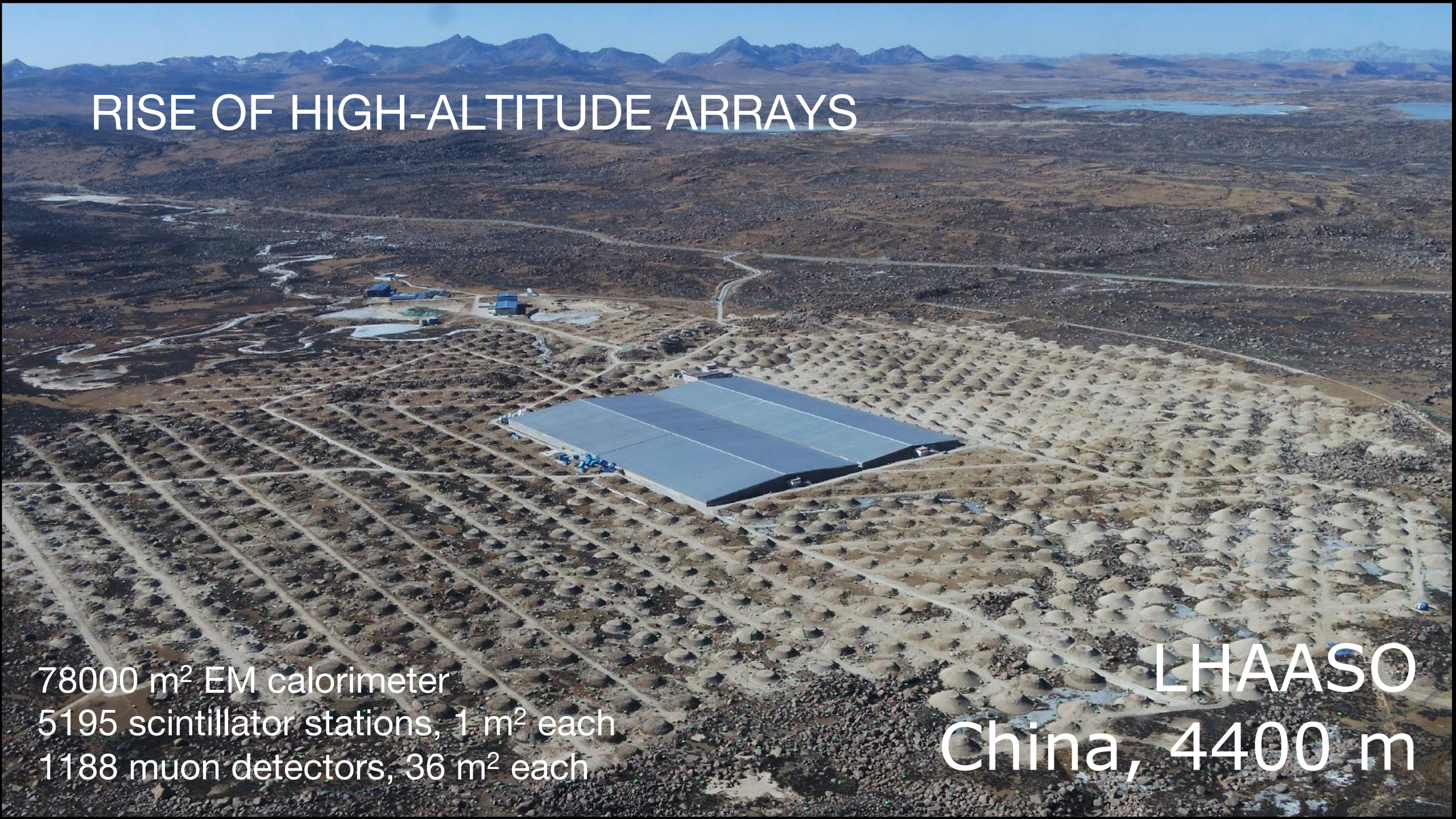
PEVATRONS & SUPER-PEVATRONS

$E\gamma > 25$ TeV

43 sources
above 100 TeV
(>4 σ)



LHAASO 2023


RISE OF HIGH-ALTITUDE ARRAYS
78000 m² EM calorimeter
5195 scintillator stations, 1 m² each
1188 muon detectors, 36 m² each
LHAASO
China, 4400 m

Some of these discoveries we hoped to make with CTAO

but

The high energy sky got a lot richer, opening many new opportunities


Future
Past


Small field of view(3º-10º)
Pointed towards the target
Only in dark nights
Lower threshold, higher sensitivity
Sharper images, better energy res.
Large field view (~60º)
Views the full sky
Day and night
Complementarity

Small field of view(3º-10º)
Pointed towards the target
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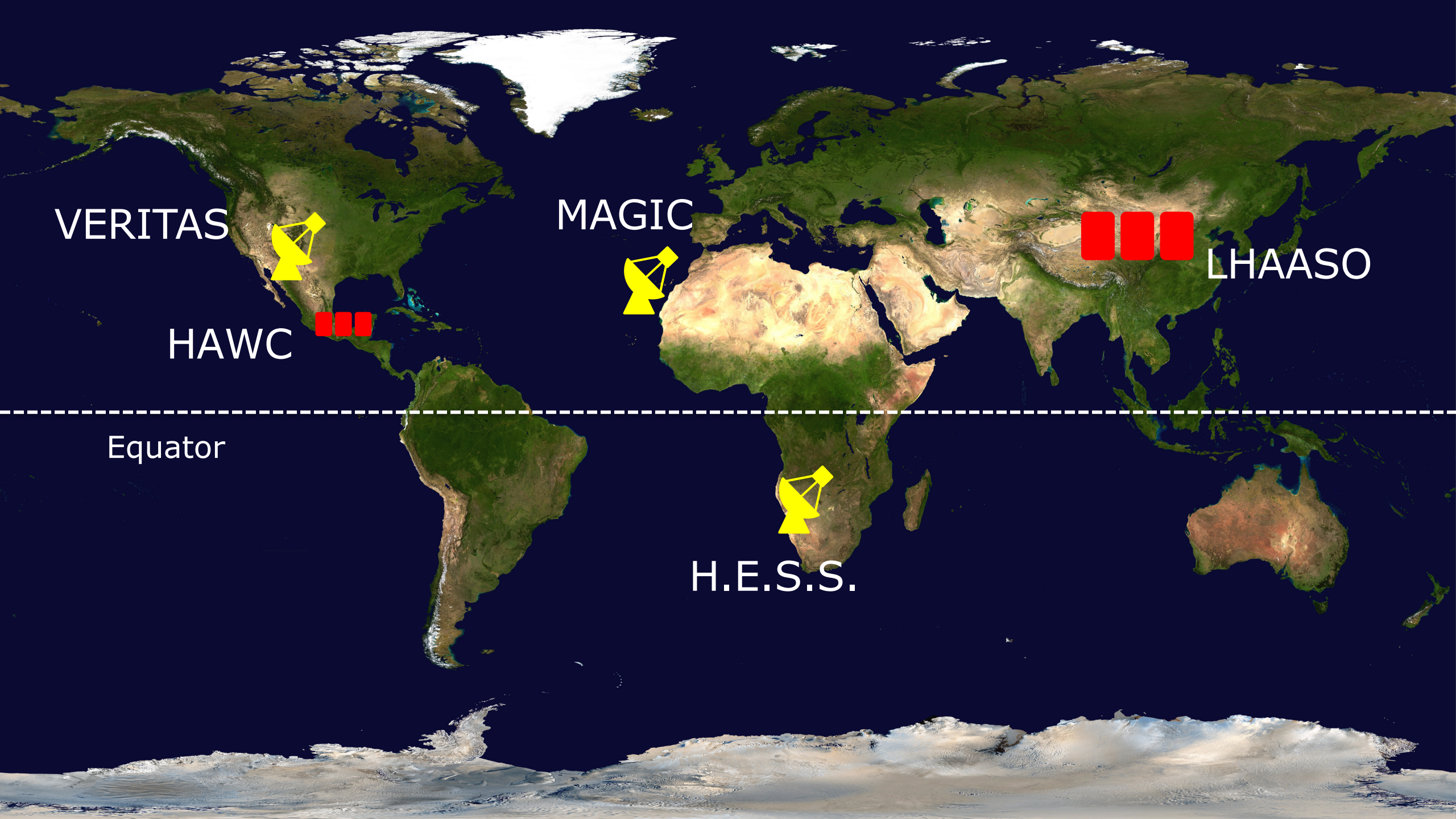
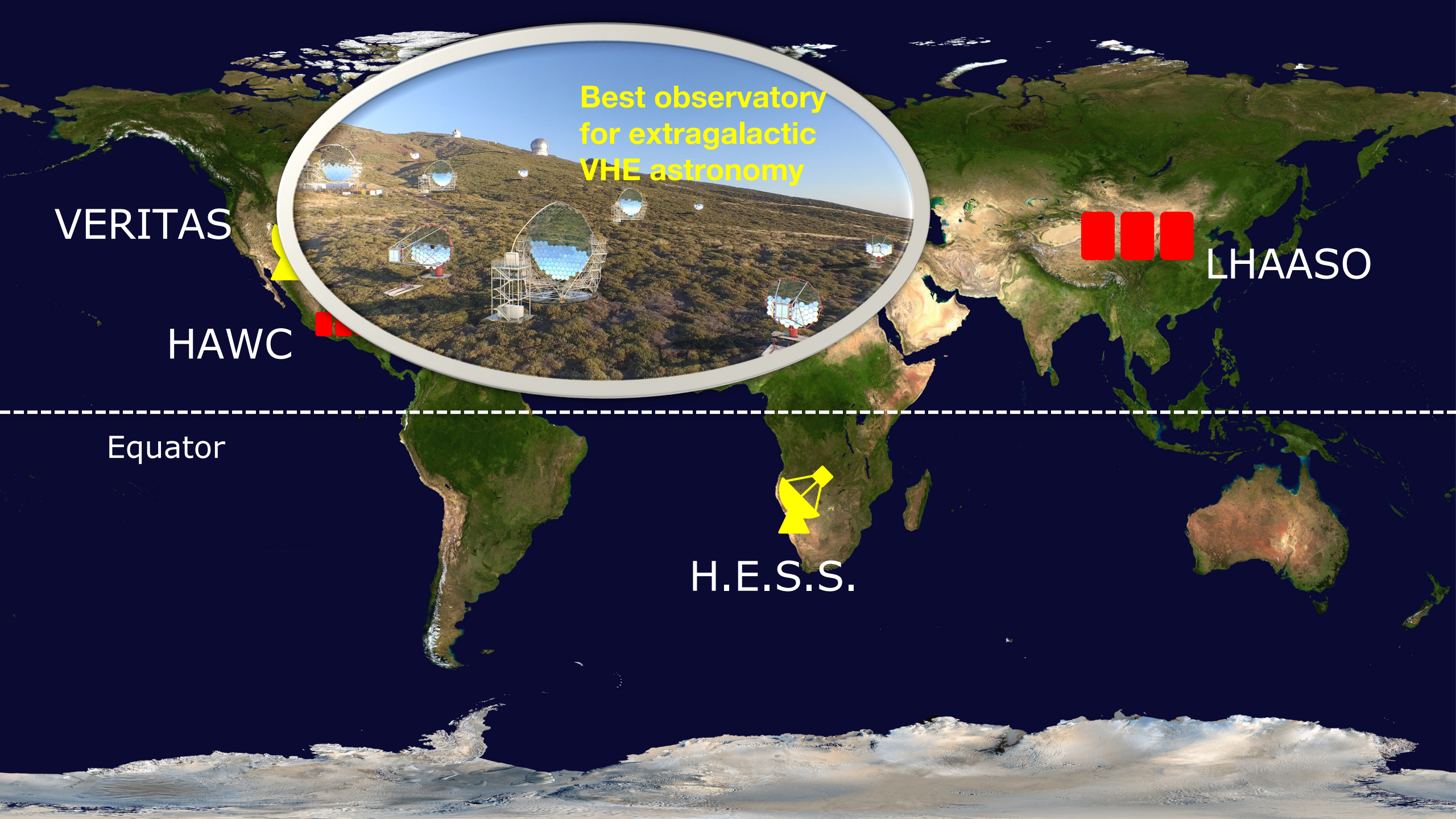
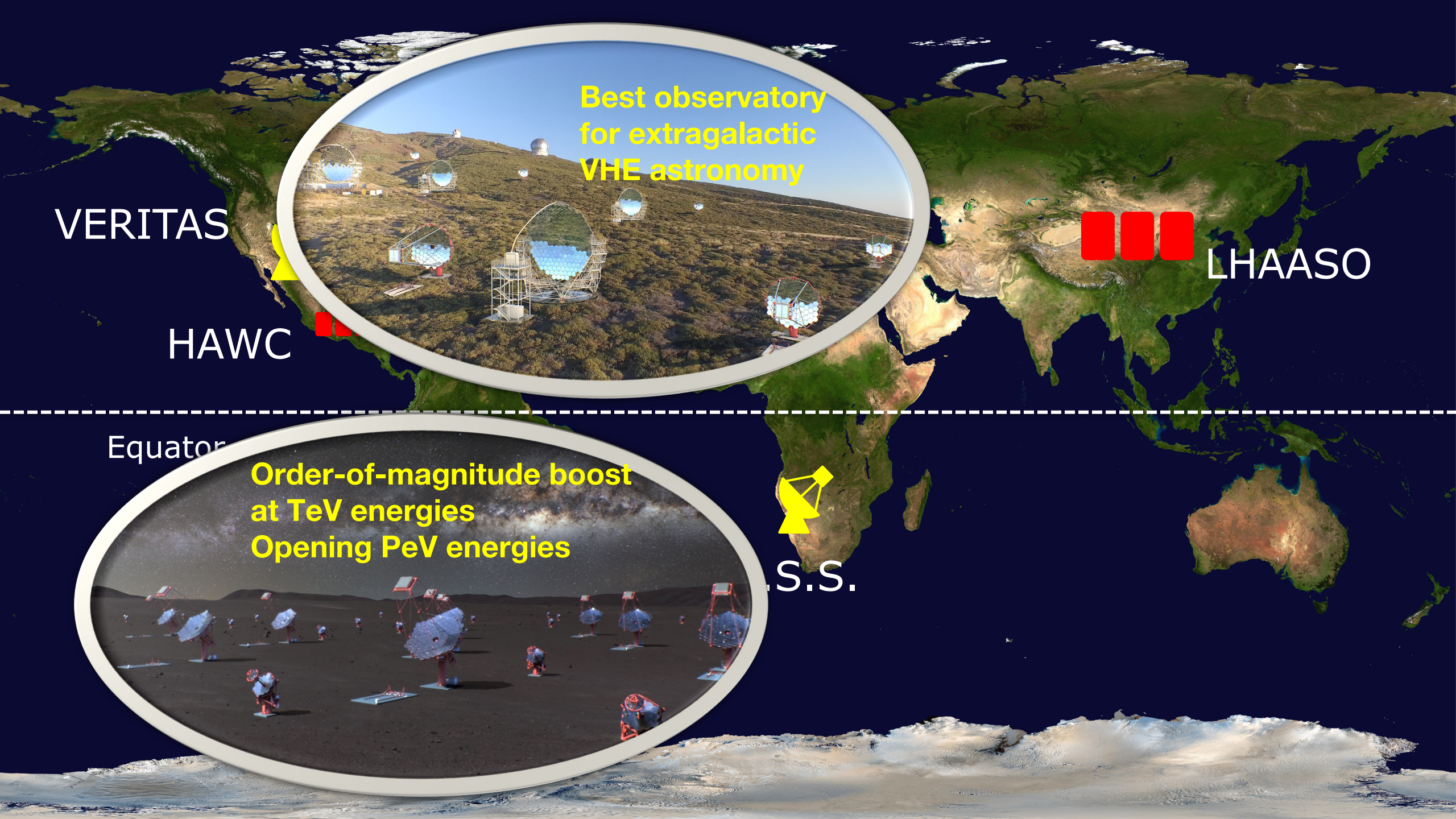

VERITAS
MAGIC
LHAASO
HAWC
Equator
H.E.S.S.


Best observatory
for extragalactic
VHE astronomy
VERITAS
HAWC
LHAASO
Equator
H.E.S.S.


Best observatory
for extragalactic
VHE astronomy
VERITAS
HAWC
LHAASO
Equator
Order-of-magnitude boost
at TeV energies
Opening PeV energies
S.S.

LA PALMA, THREE WEEKS AGO

Courtesy: Jelena Strišković

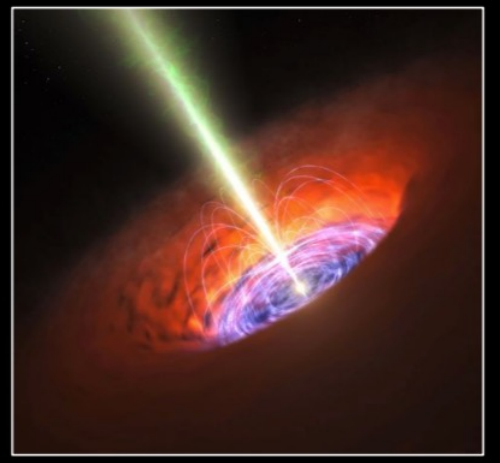
Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Reviews by Stefano & Elena

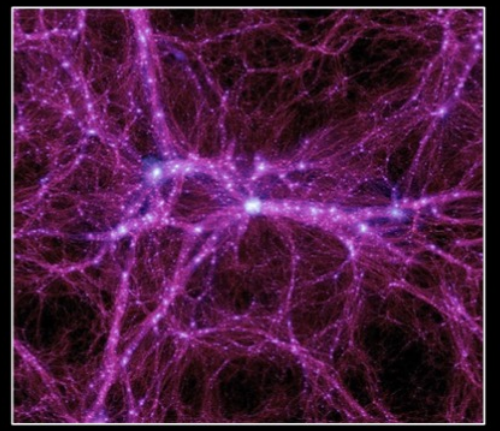
Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Characteristics of relativistic jets, winds and explosions?
- Cosmic voids: their radiation fields and magnetic fields



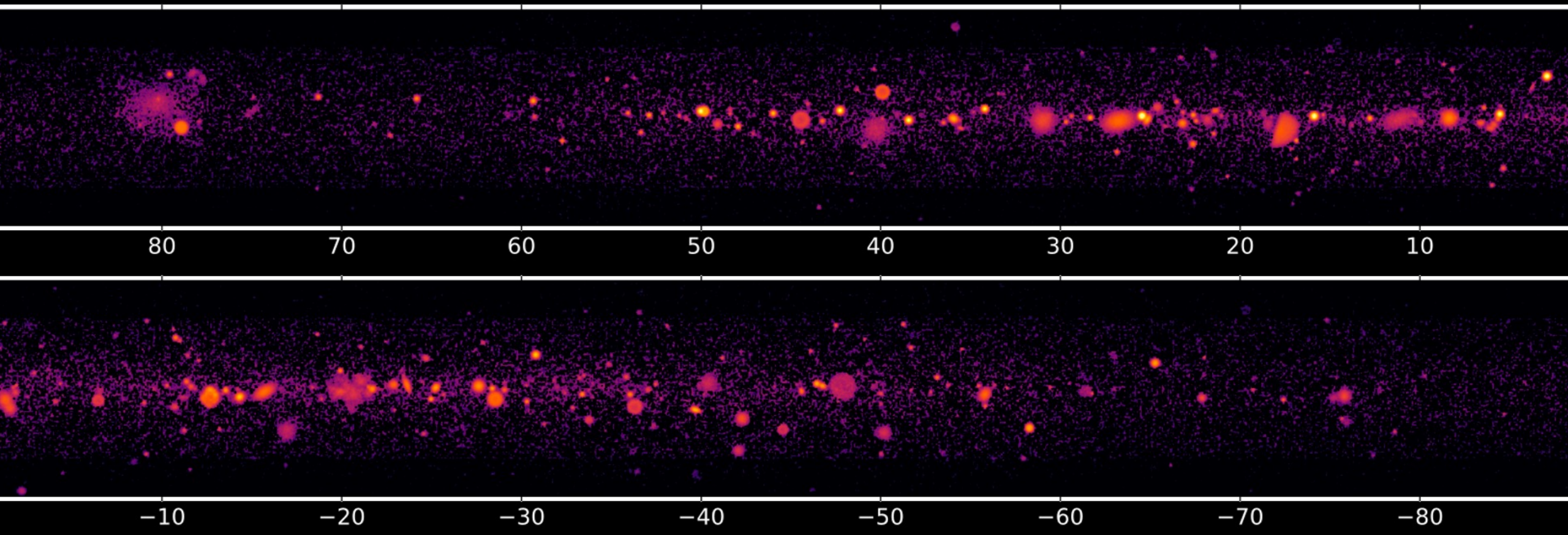
Theme 3: Physics Frontiers

- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?



GALACTIC PLANE SURVEY

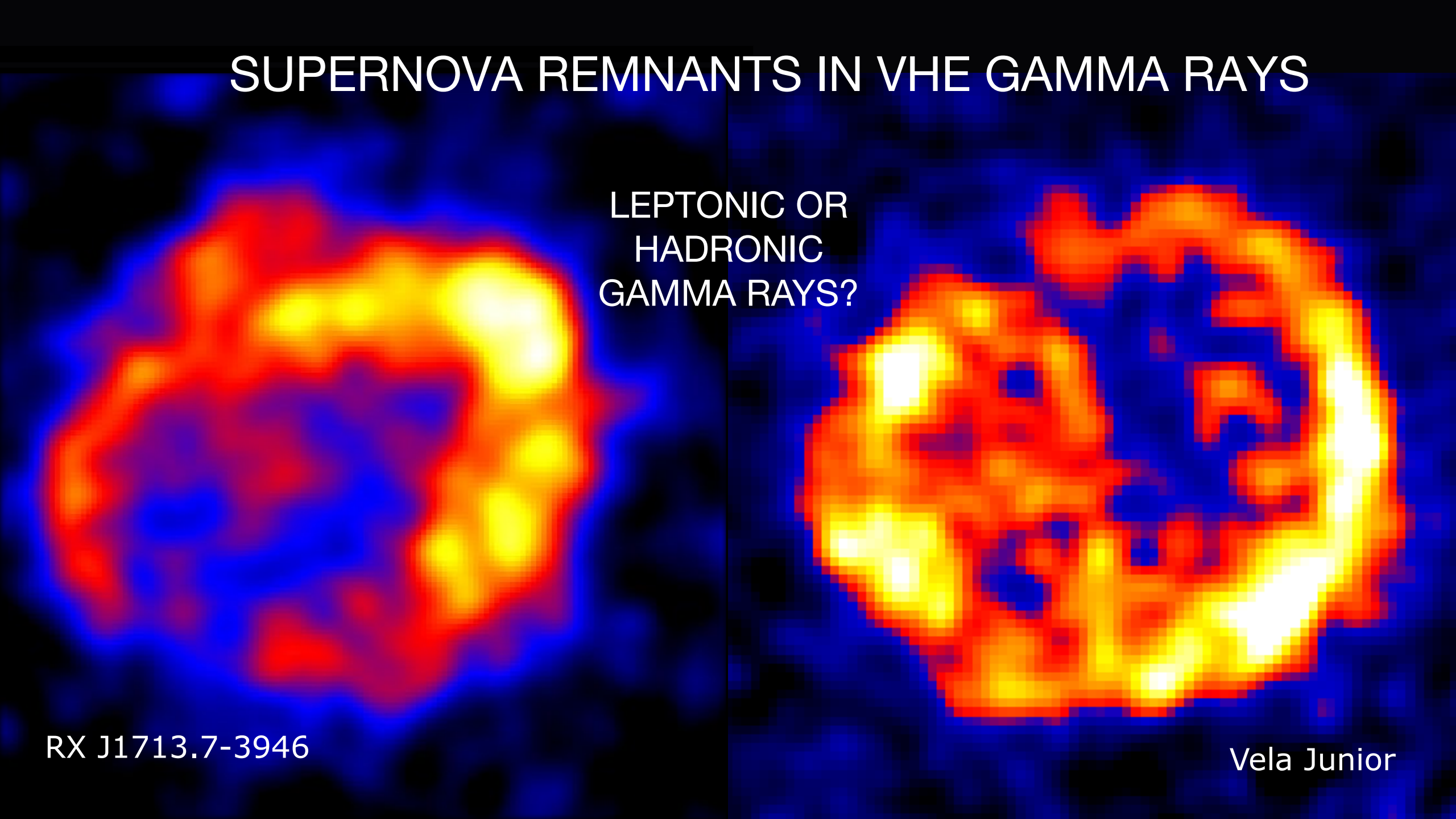
Prospects for a survey of the Galactic plane
with the Cherenkov Telescope Array
CTA Consortium, arXiv:2310.02828



about 500 source detections expected

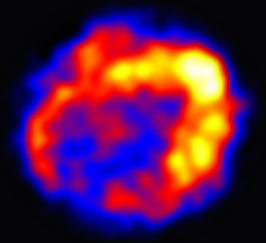
SUPERNOVA REMNANTS IN VHE GAMMA RAYS

LEPTONIC OR
HADRONIC
GAMMA RAYS?



RX J1713.7-3946

Vela Junior

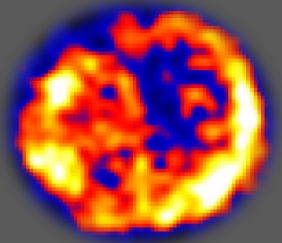


Fukui et al.
RX J1713.7-3946
arXiv:2105.02734

Hadronic 67 ± 8%
Leptonic 33 ± 8%

THE POWER OF MORPHOLOGY

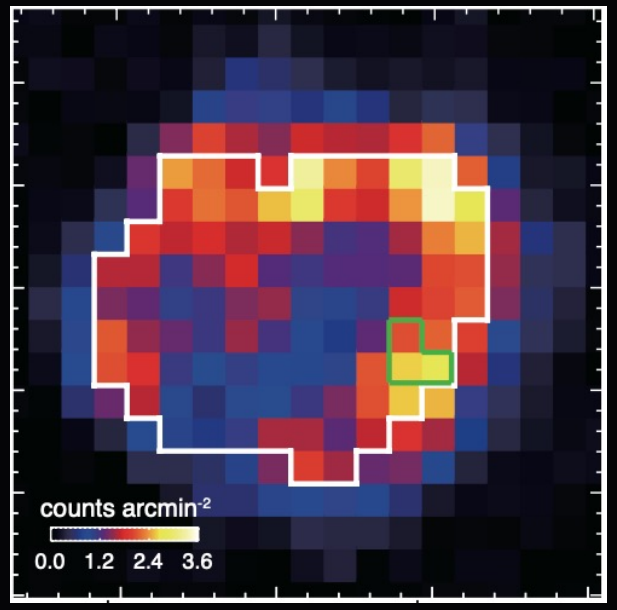
LEPTONIC OR HADRONIC GAMMA RAYS?



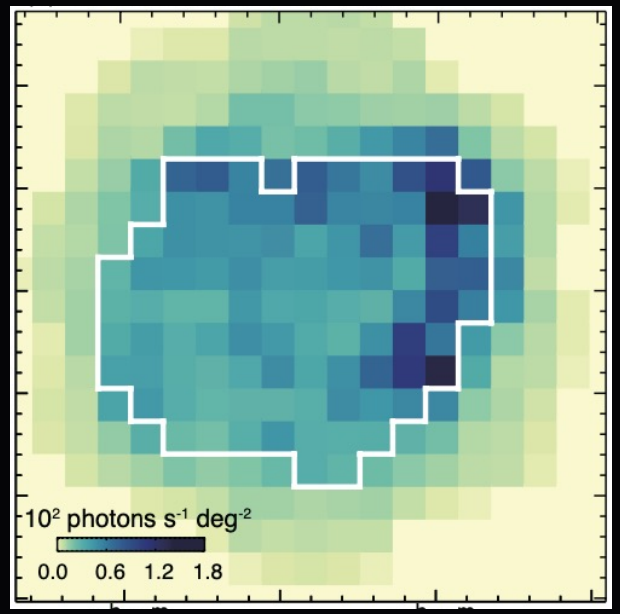
Fukui et al.
RX J0852.0–4622
arXiv:2311.11355v1

Hadronic 52 ± 1%
Leptonic 48 ± 1%

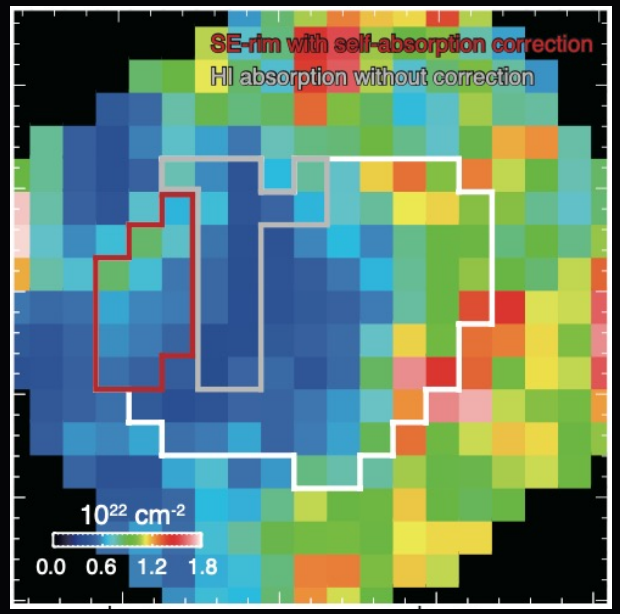
Gamma rays

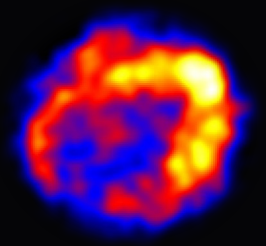


X-rays



Target gas





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THE POWER OF MORPHOLOGY

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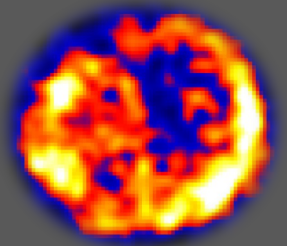

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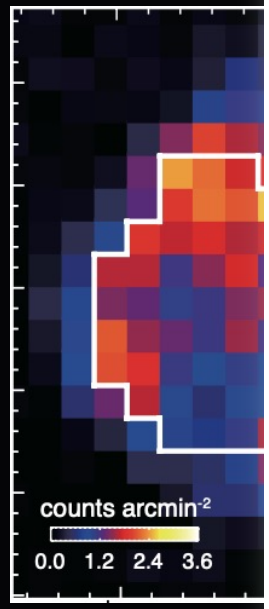
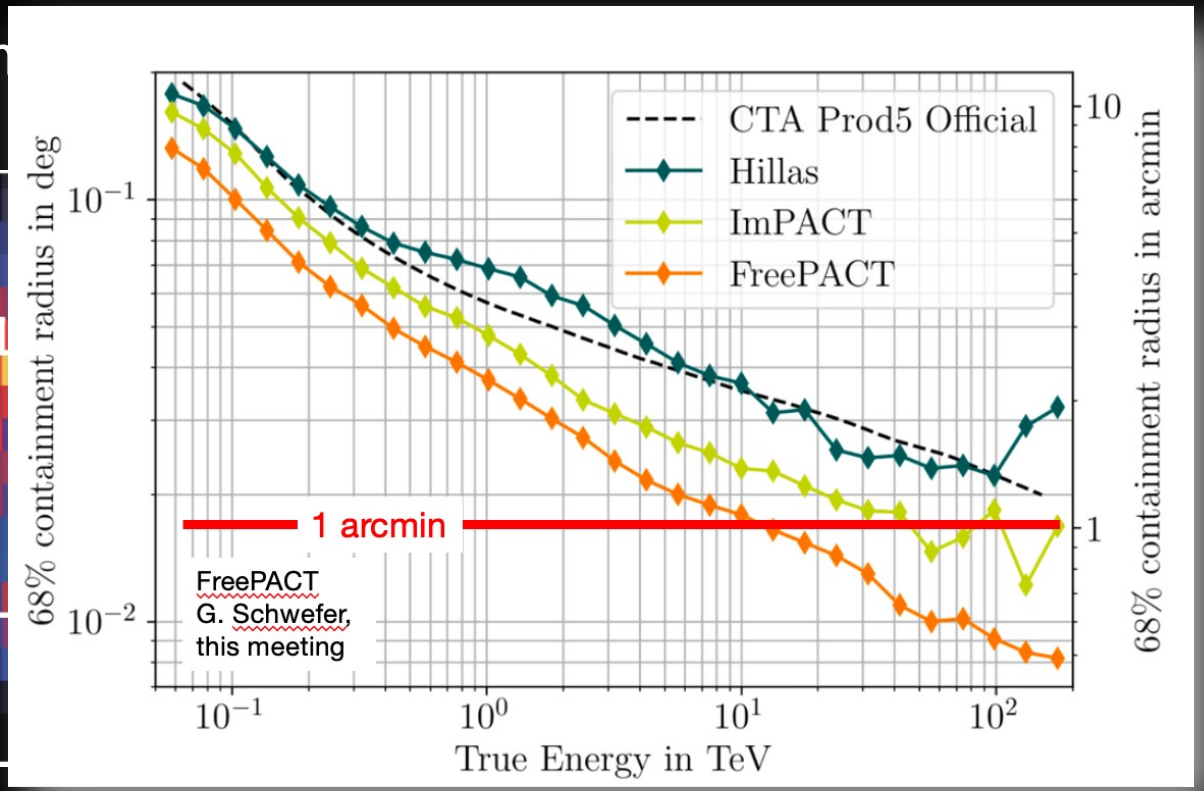
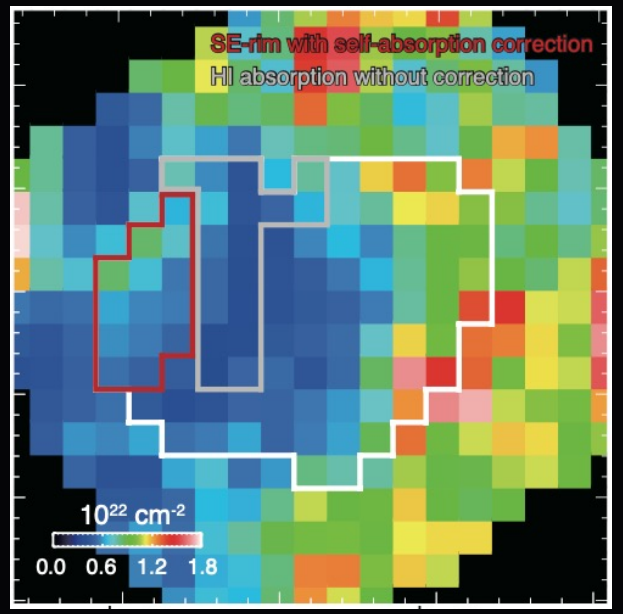
Gamm

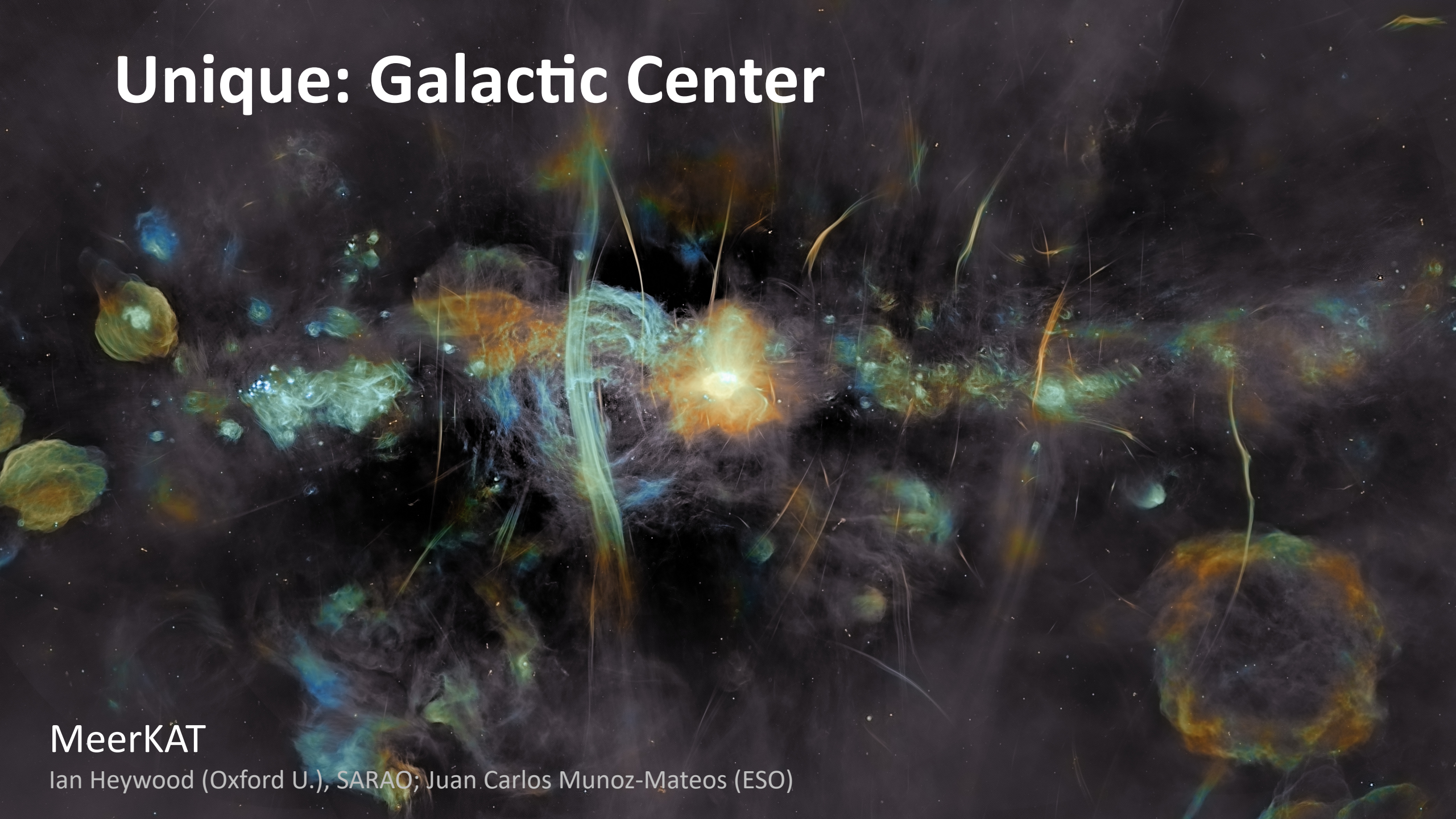




Target gas



Unique: Galactic Center

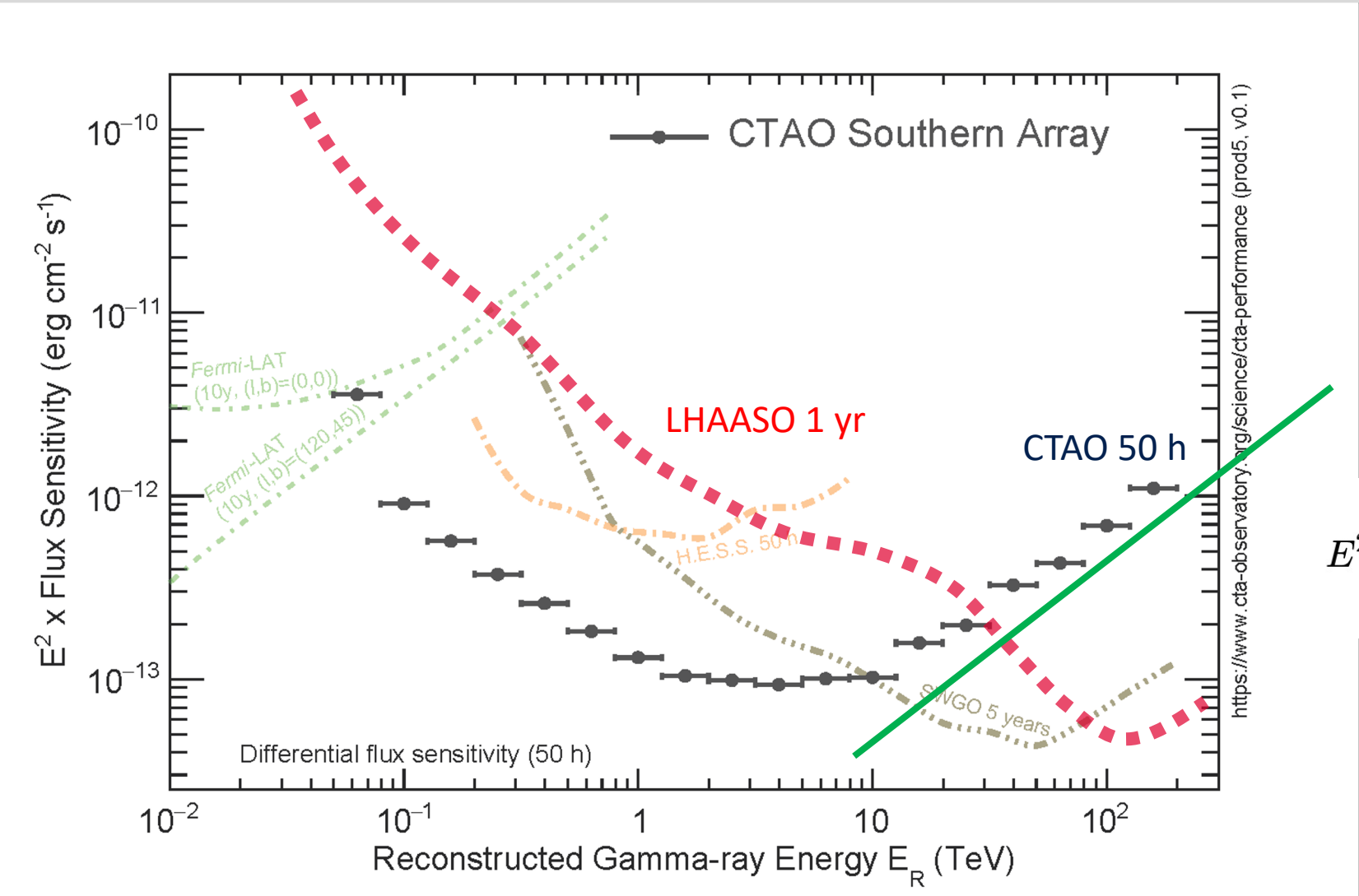


MeerKAT

Ian Heywood (Oxford U.), SARAO; Juan Carlos Munoz-Mateos (ESO)

PEVATRONS IN THE SOUTH

See also:
Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants,
APP 150 (2023) 102850



$E^2F(E) \sim E$
means limited by number of events
(rather than signal-to-background)

$$E^2F(E) = E^2\frac{1}{A}\frac{dN}{dE} = E\frac{1}{A}\frac{dN}{d\log E} = E\frac{N_{min}}{A}$$

PEVATRONS IN THE SOUTH

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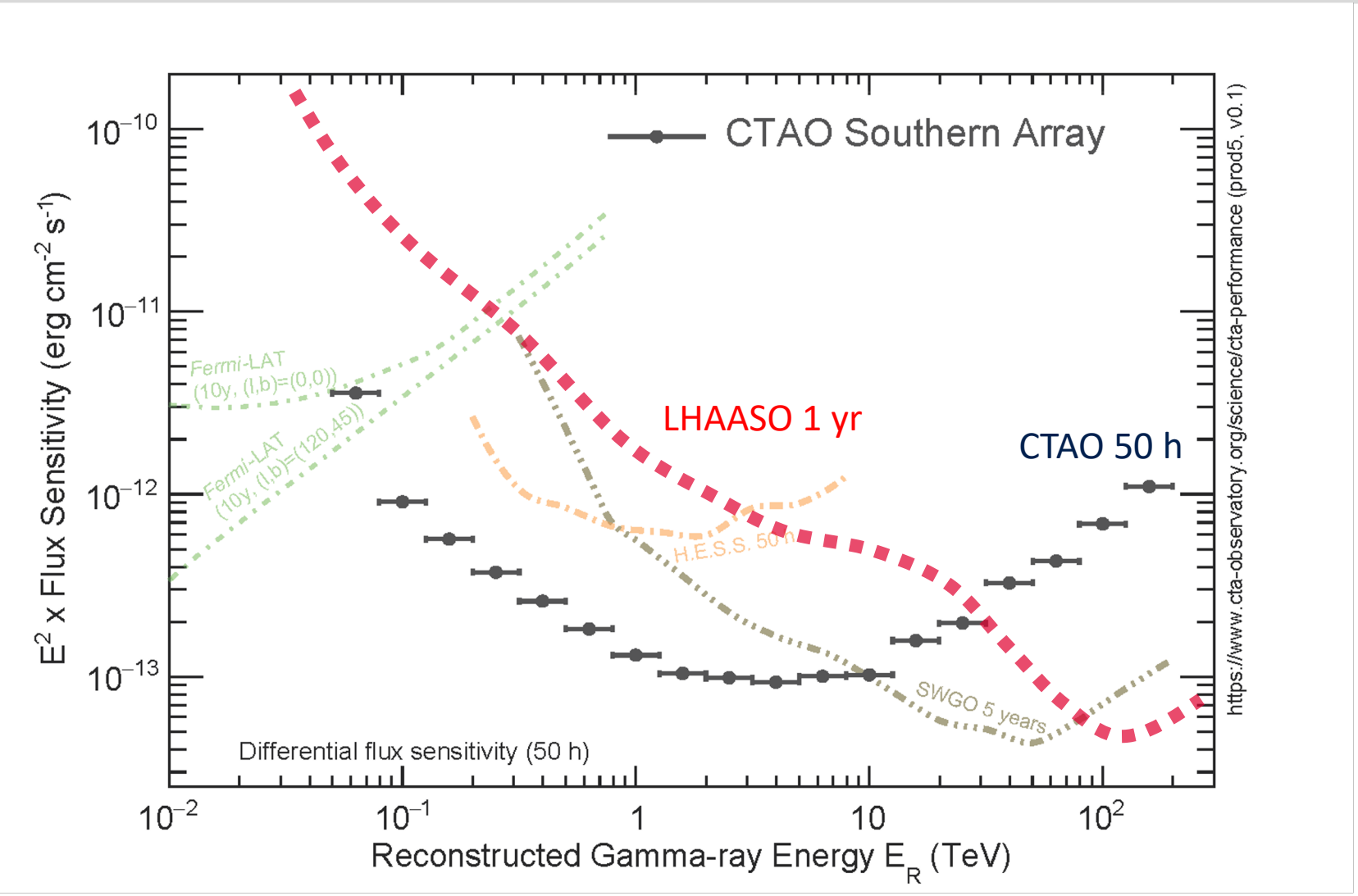

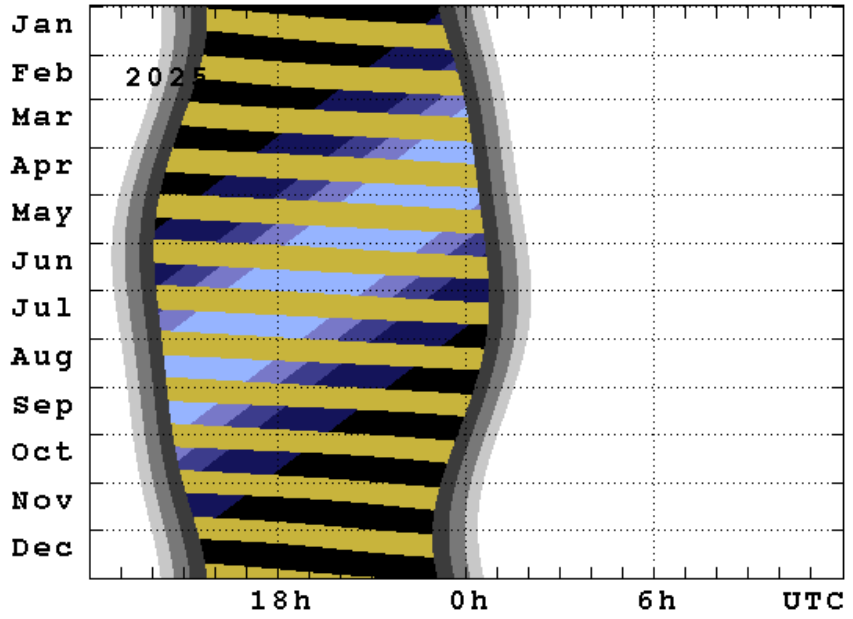

Galactic center:
644 h/yr above 30 deg. alt.
480 h/yr above 45 deg. alt.
318 h/yr above 60 deg. alt.

Can we use that?

PEVATRONS IN THE SOUTH

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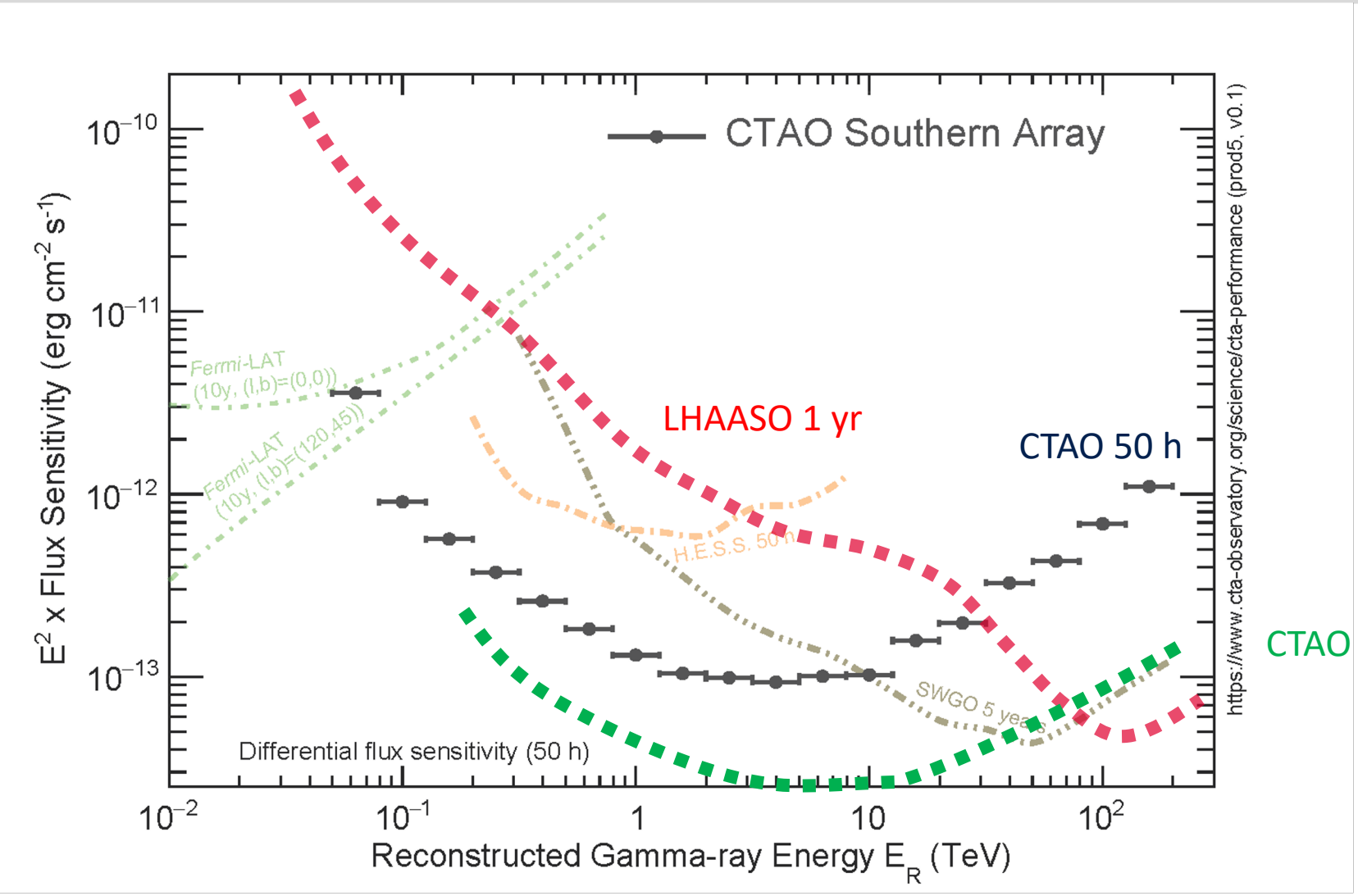
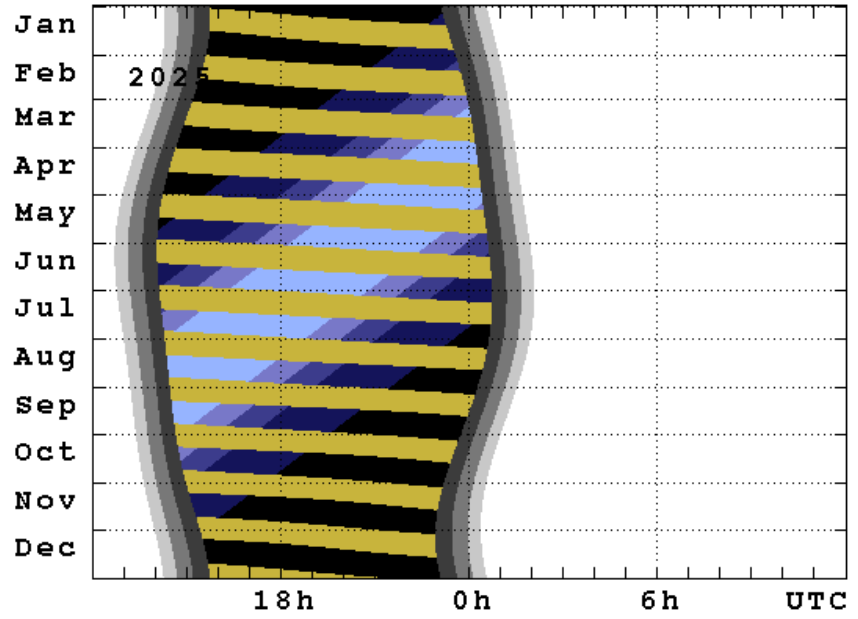
Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants, APP 150 (2023) 102850





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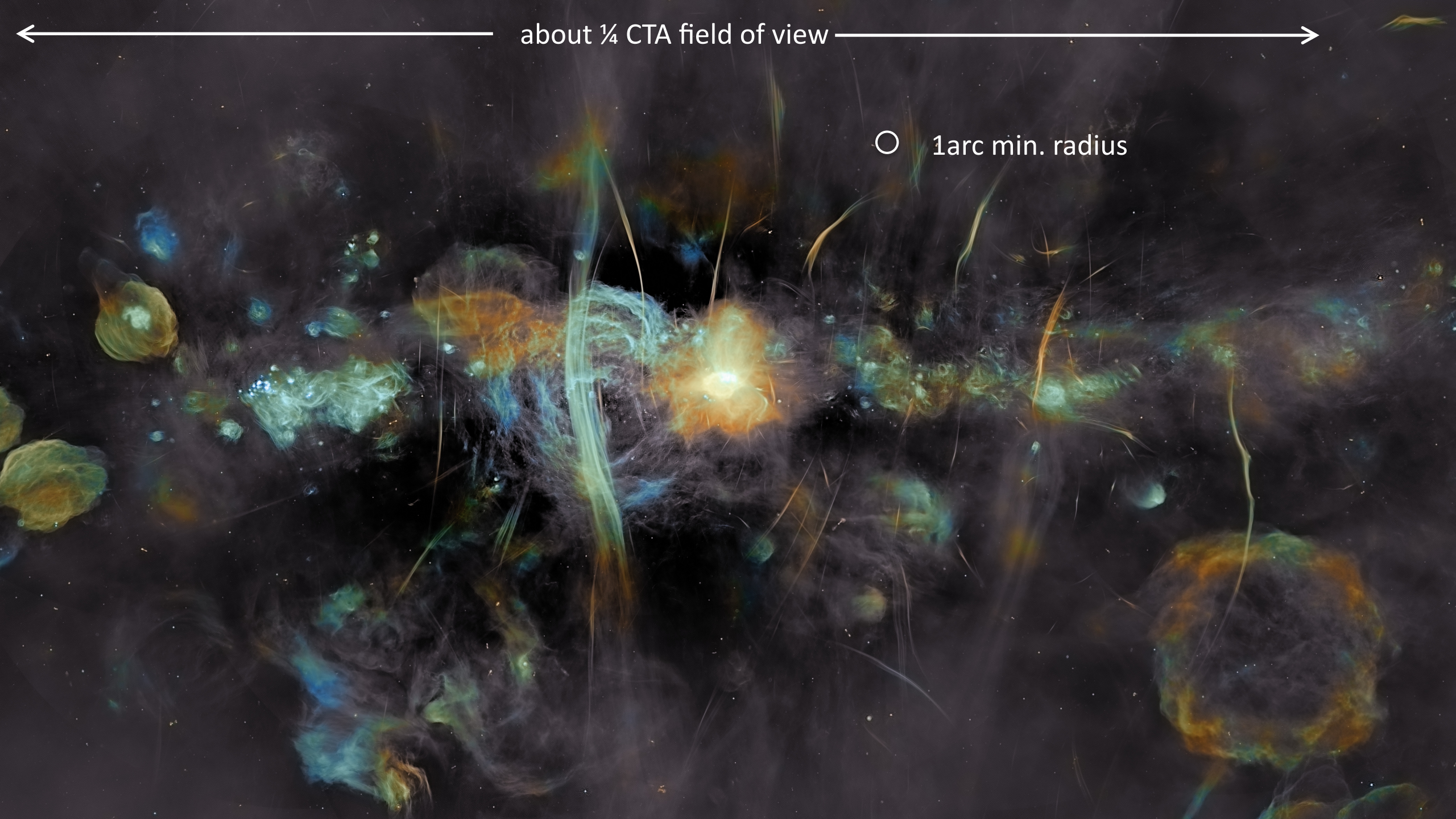
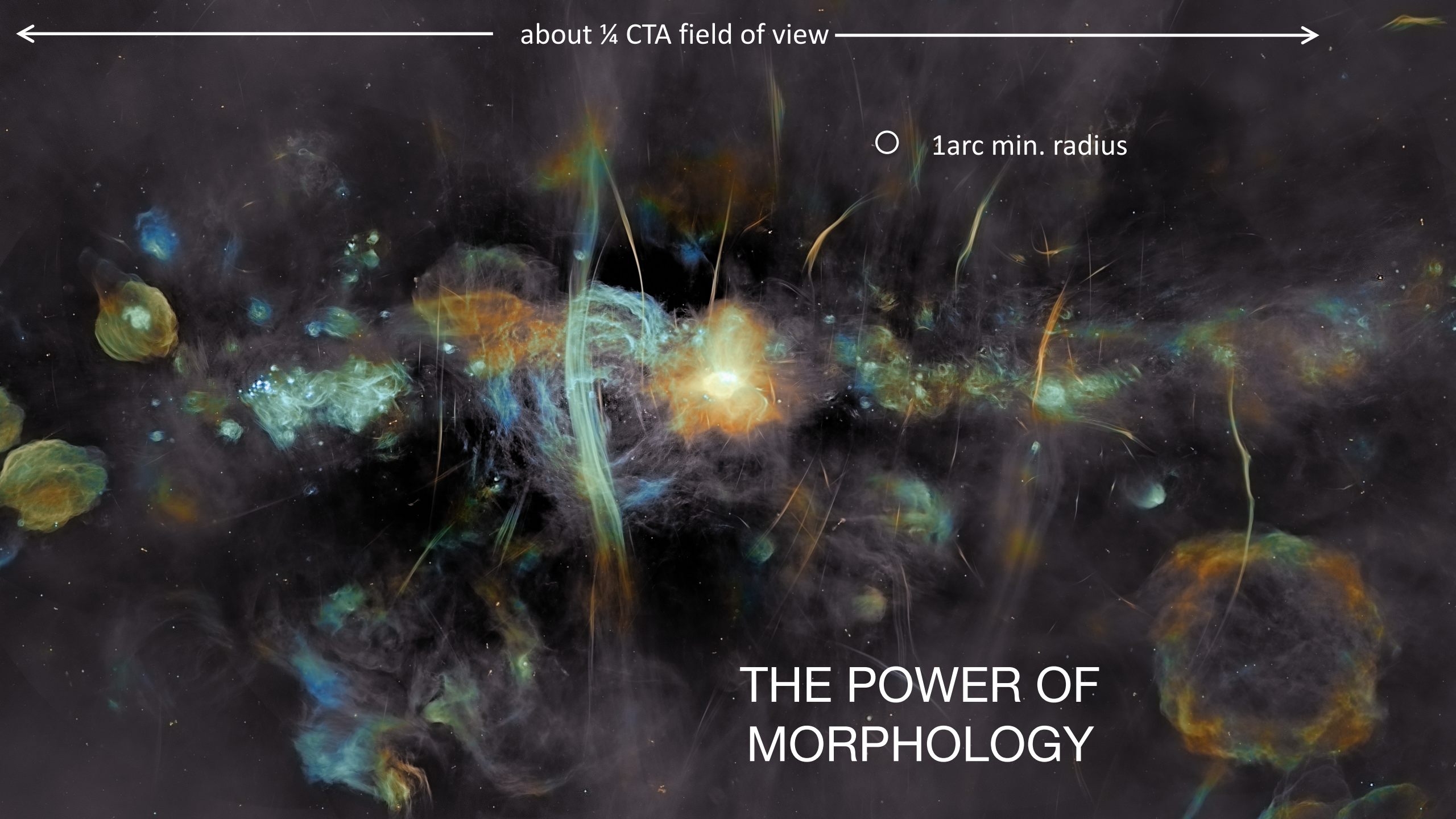
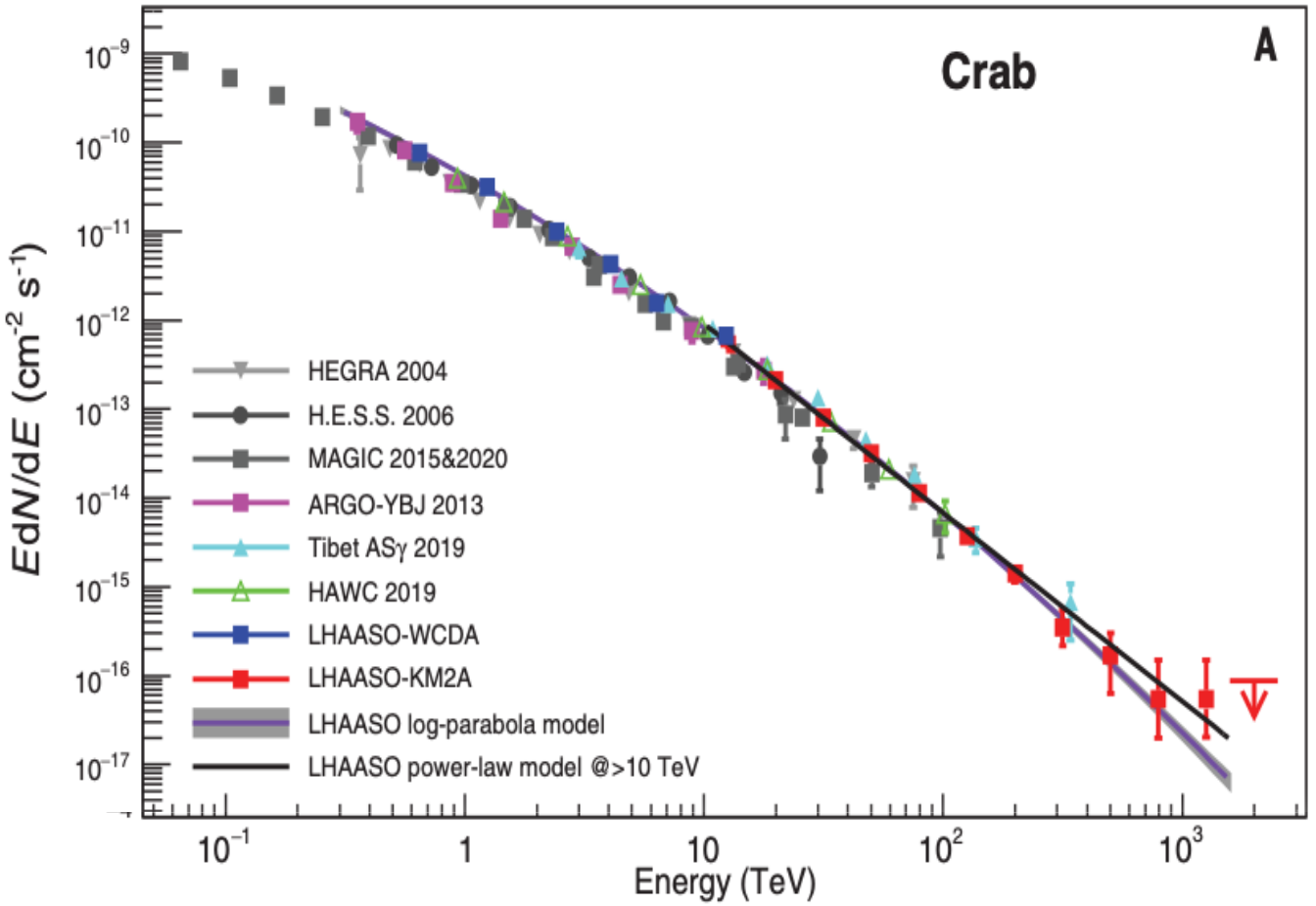

about ¼ CTA field of view
1arc min. radius


about ¼ CTA field of view
1arc min. radius
THE POWER OF
MORPHOLOGY

CRAB PEVATRON

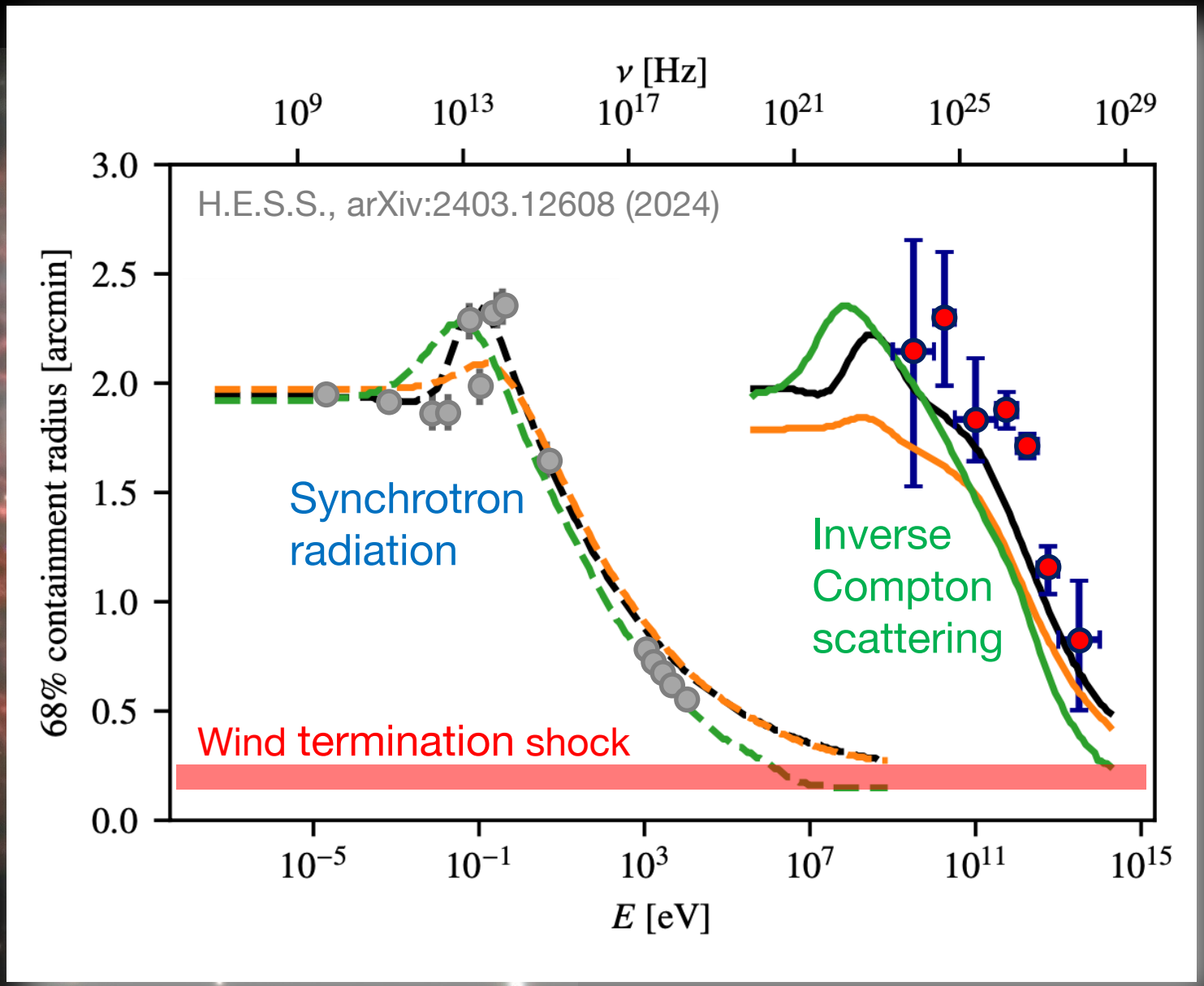
Optical images
Detlev Hartmann

LHAASO, Science 373, 425 (2021)



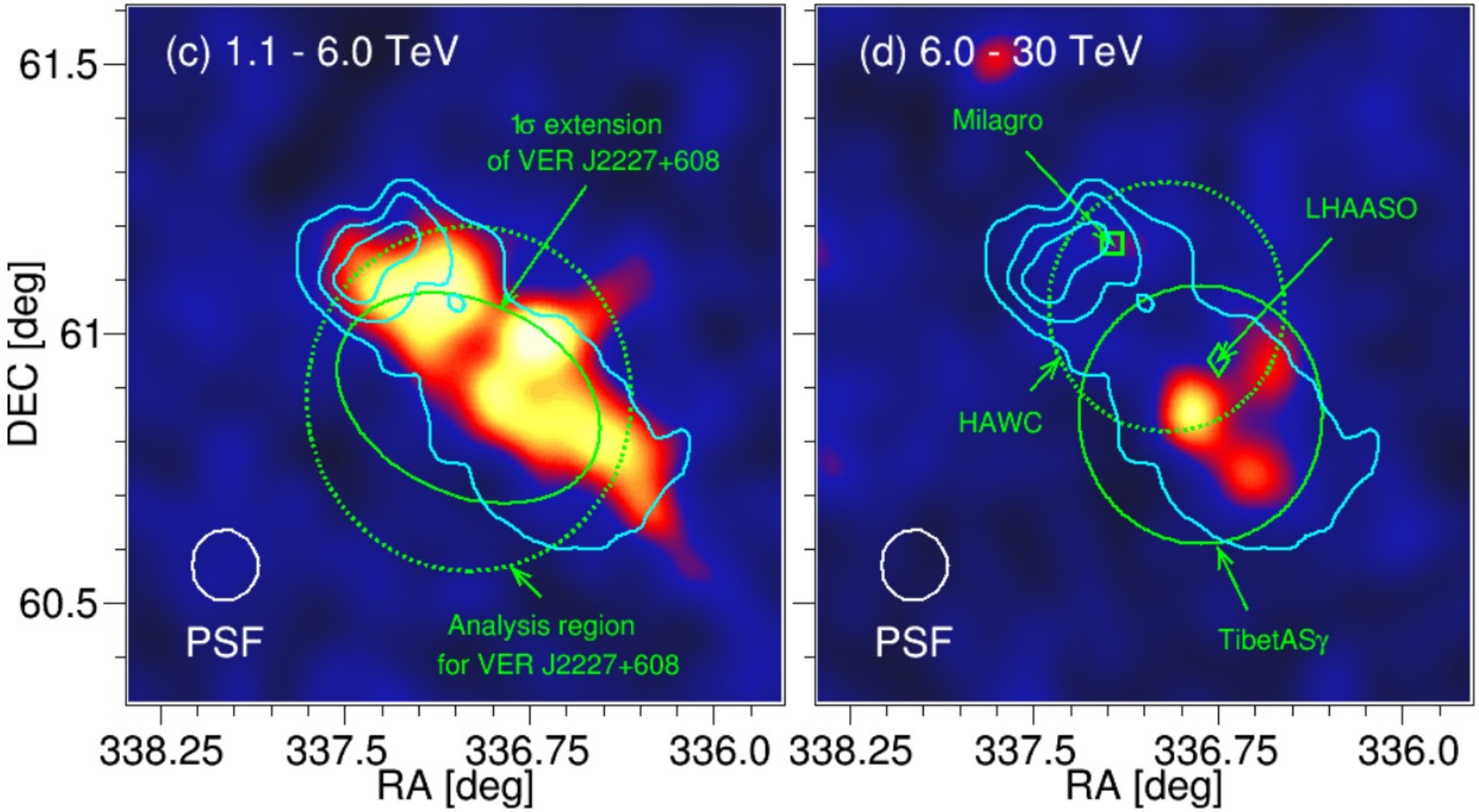
CRAB MORPHOLOGY

Optical images
Detlev Hartmann

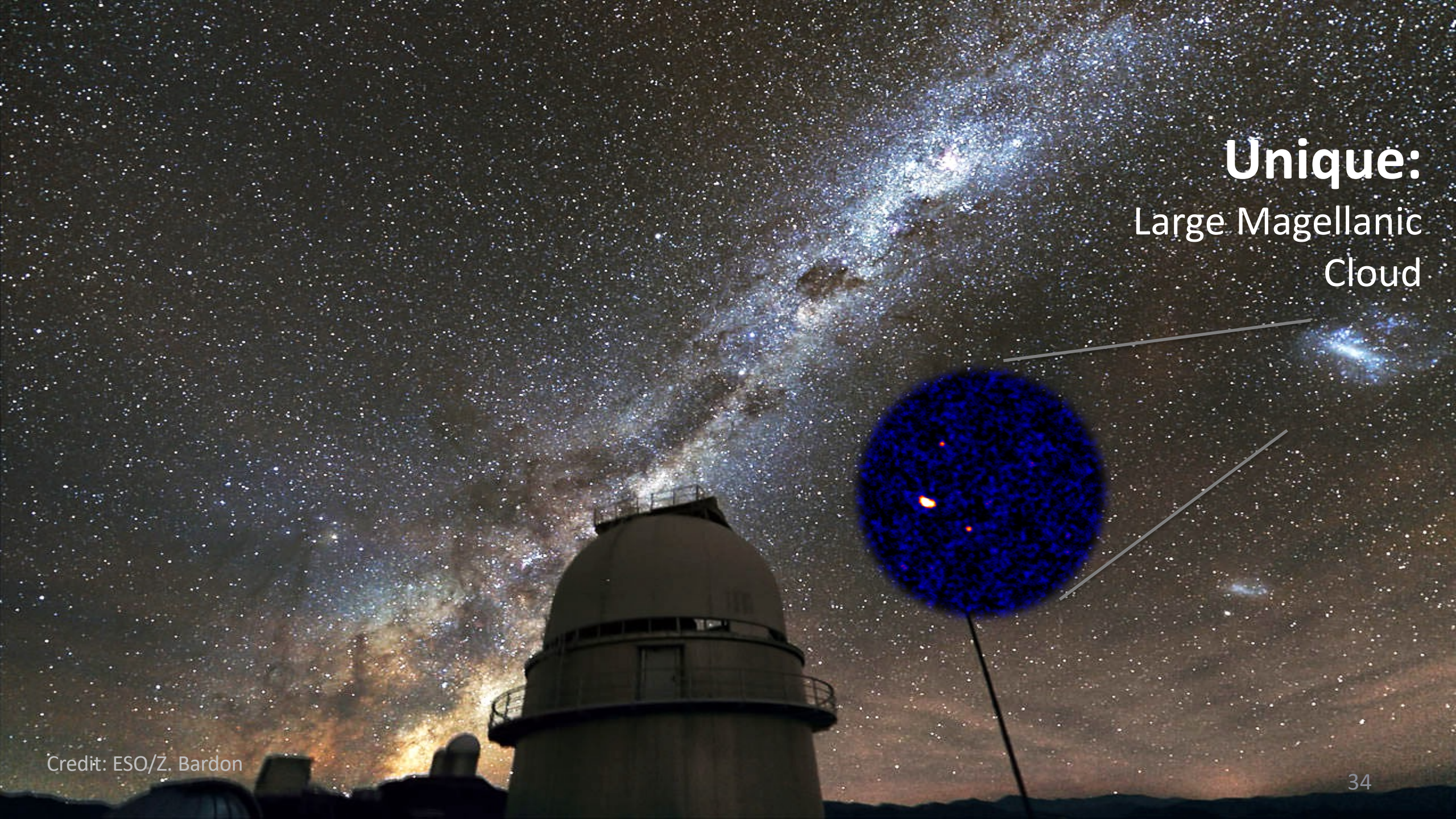


SNR G106.3+2.7

MAGIC, A&A 671, A12 (2023); LST1, this meeting



Credit: ESO/Z. Bardon



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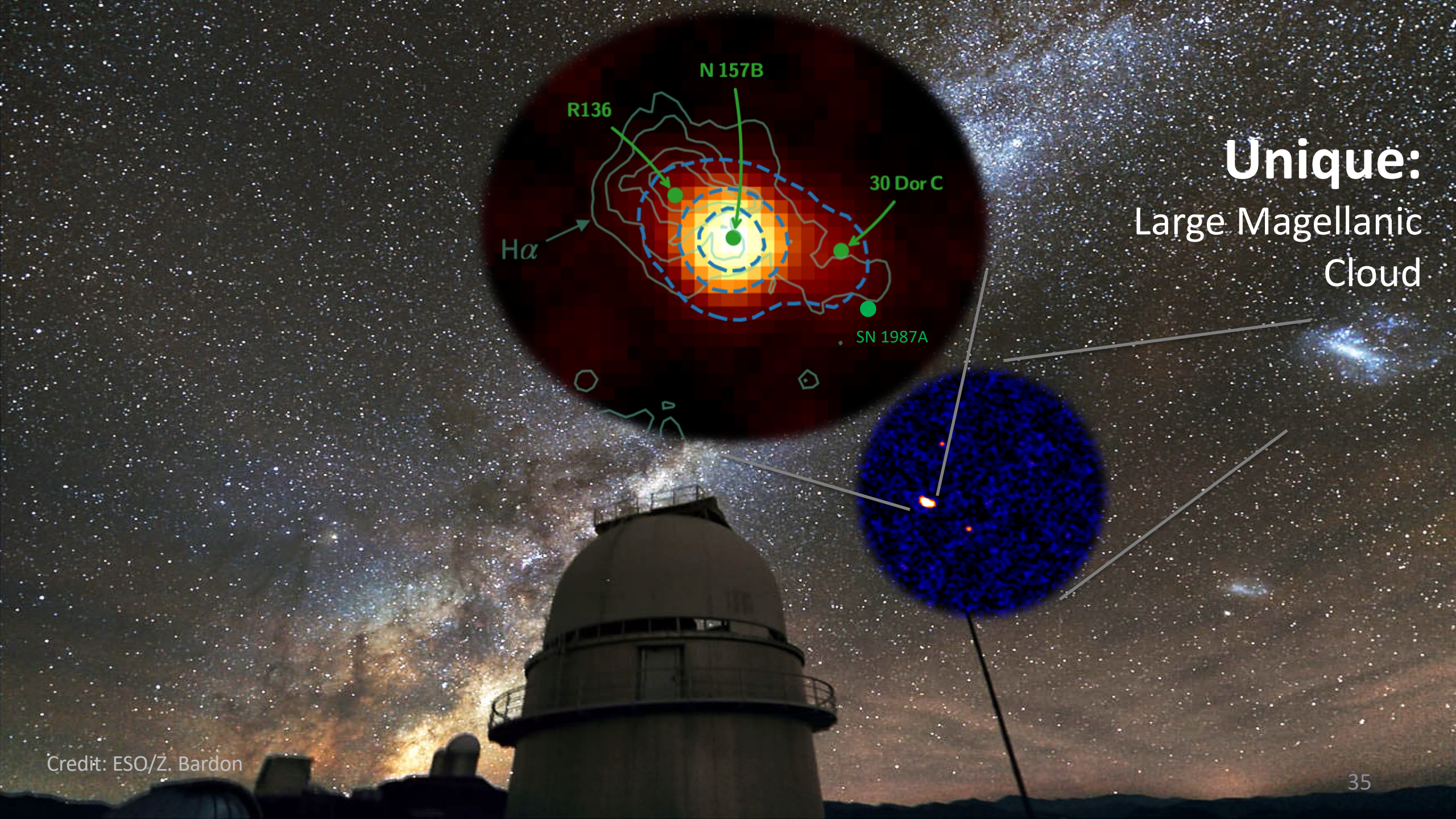
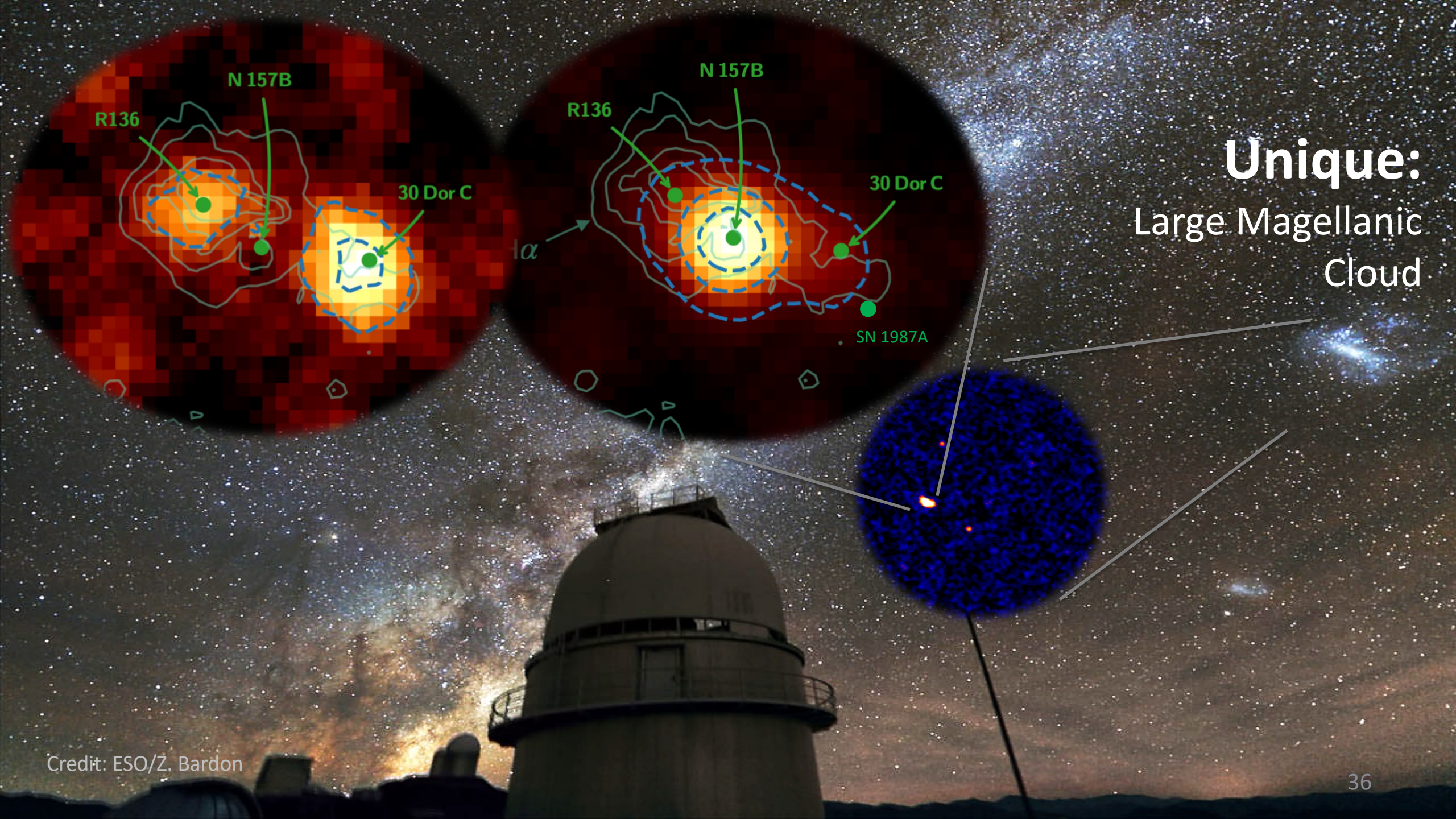


Unique:

Large Magellanic Cloud

Credit: ESO/Z. Bardon



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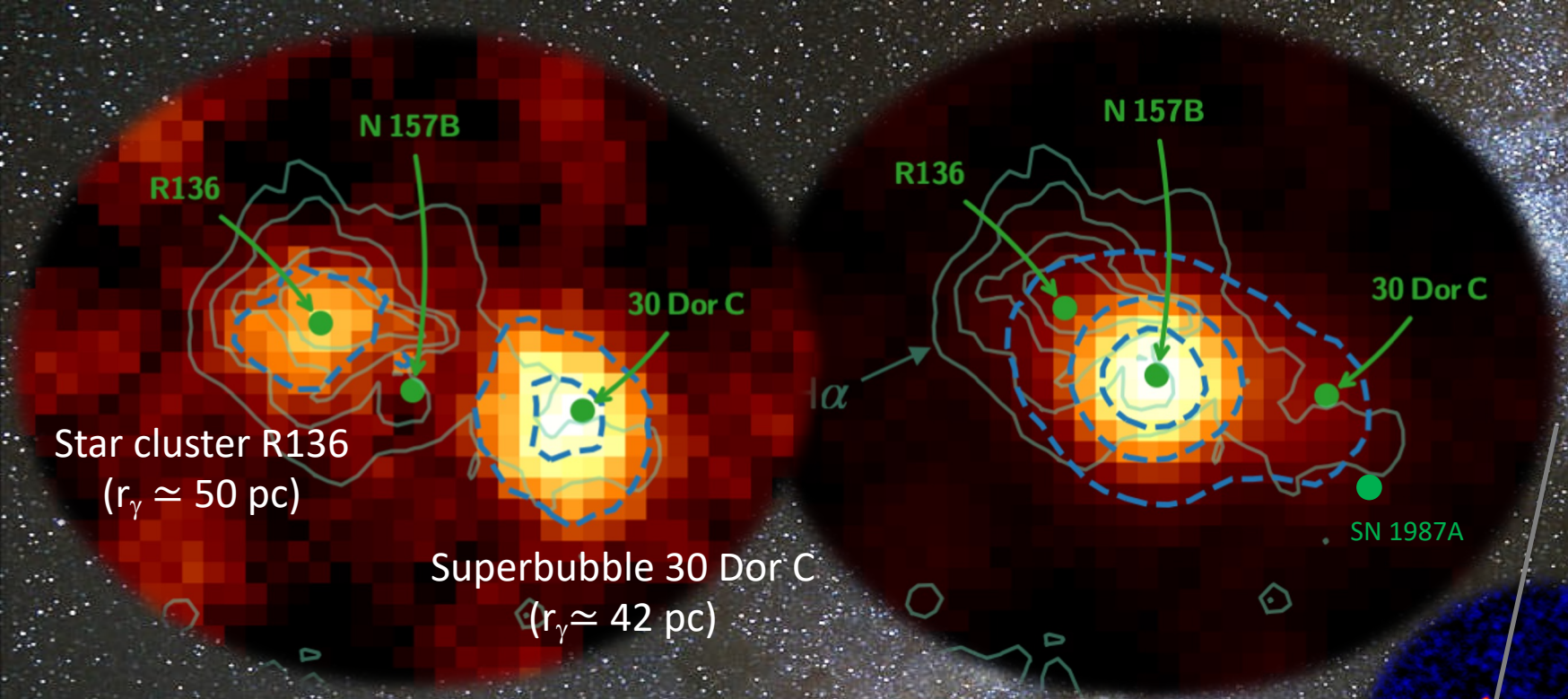

Unique:

Large Magellanic Cloud

L. Mohrmann, N. Komin
TeVPA 2023

Credit: ESO/Z. Bardon

Sensitivity of the Cherenkov Telescope Array to TeV photon emission from the Large Magellanic Cloud
CTA Consortium, MNRAS 523, 5353–5387 **(2023)**

Theme 1: Cosmic Particle Acceleration

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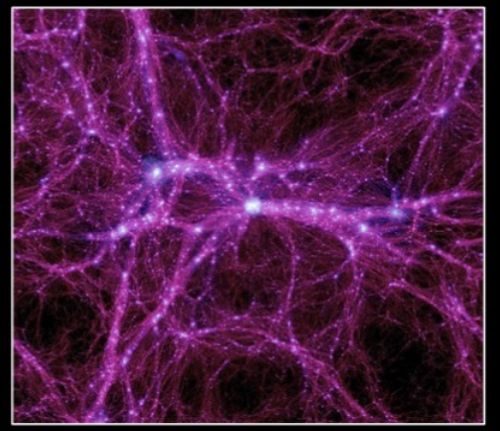
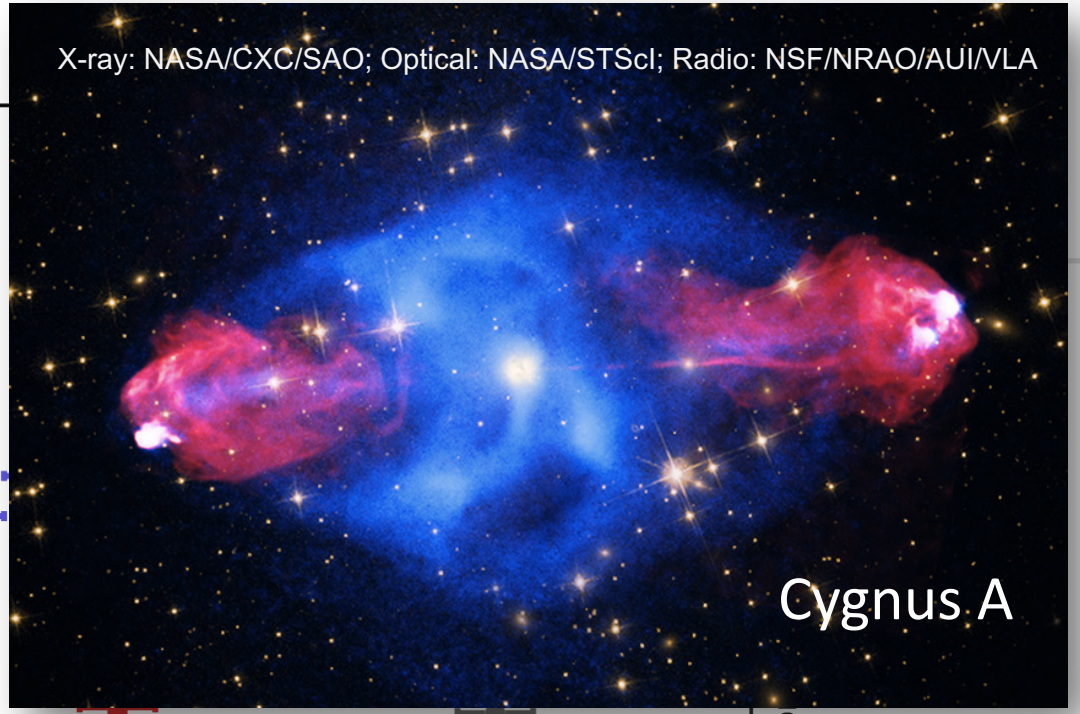
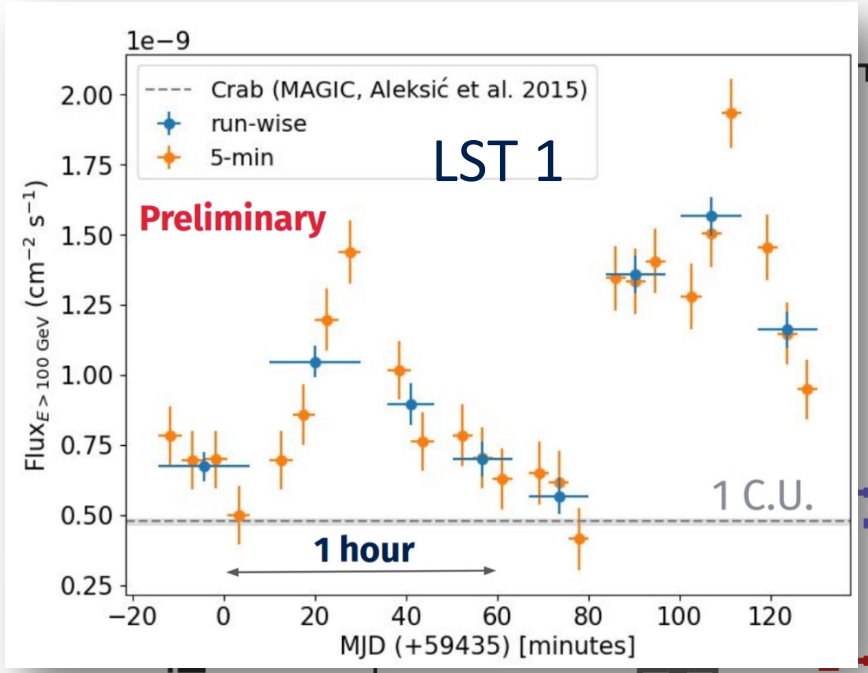
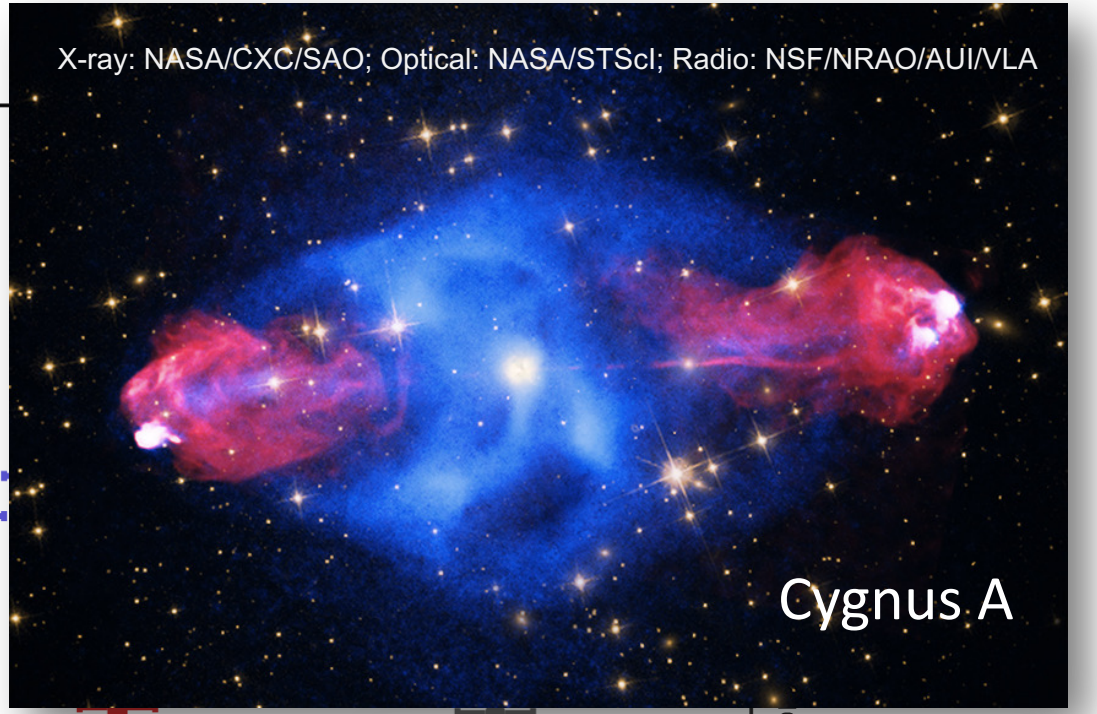


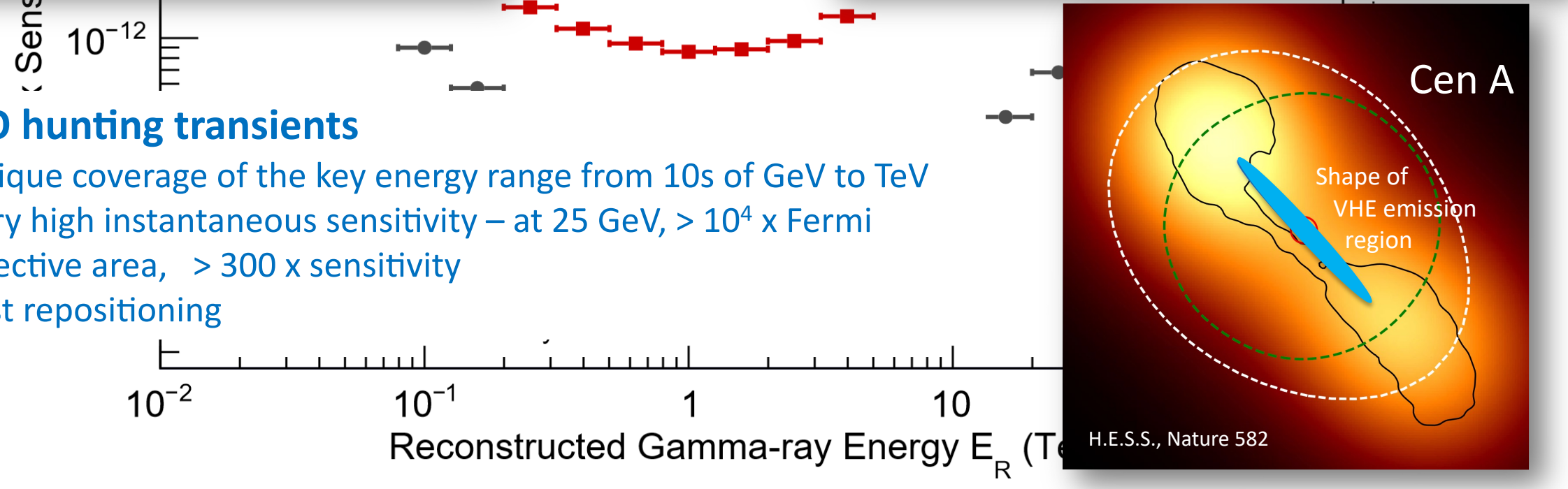


CTAO hunting transients

- Unique coverage of the key energy range from 10s of GeV to TeV
- Very high instantaneous sensitivity – at 25 GeV, > 10^4 x Fermi effective area, > 300 x sensitivity
- Fast repositioning







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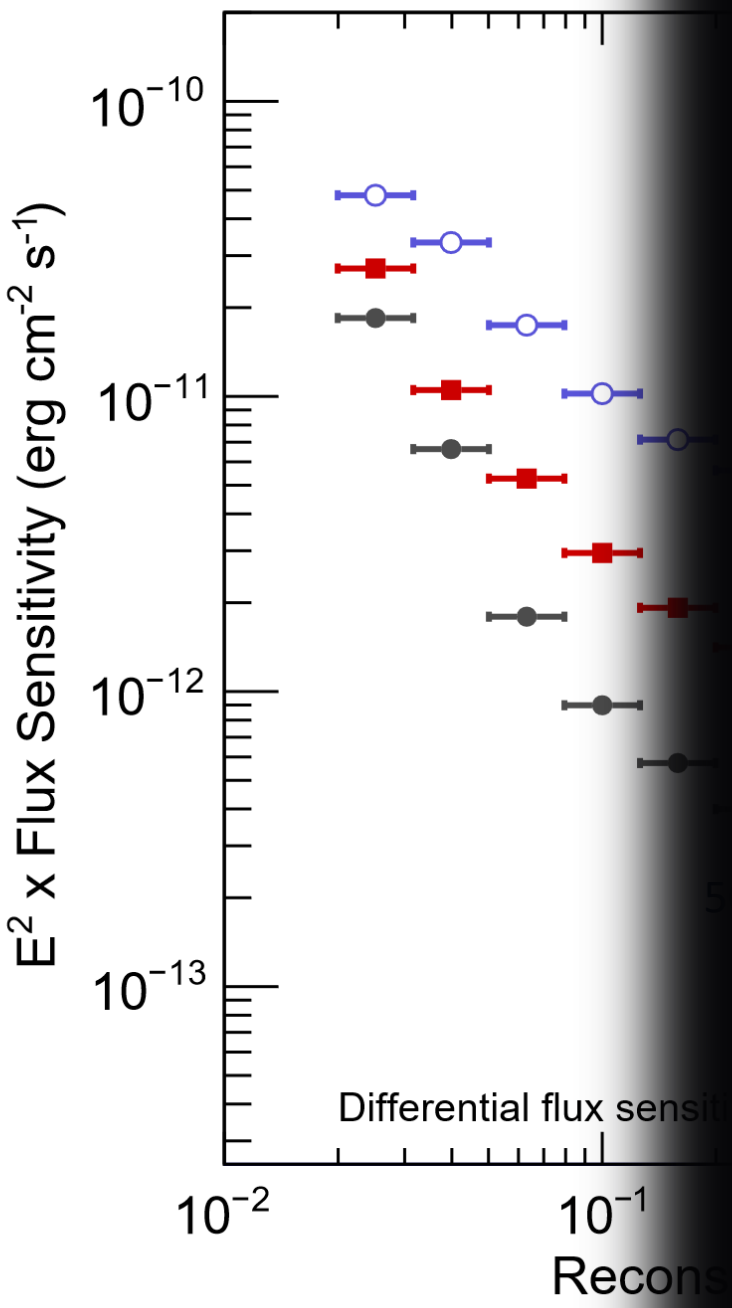
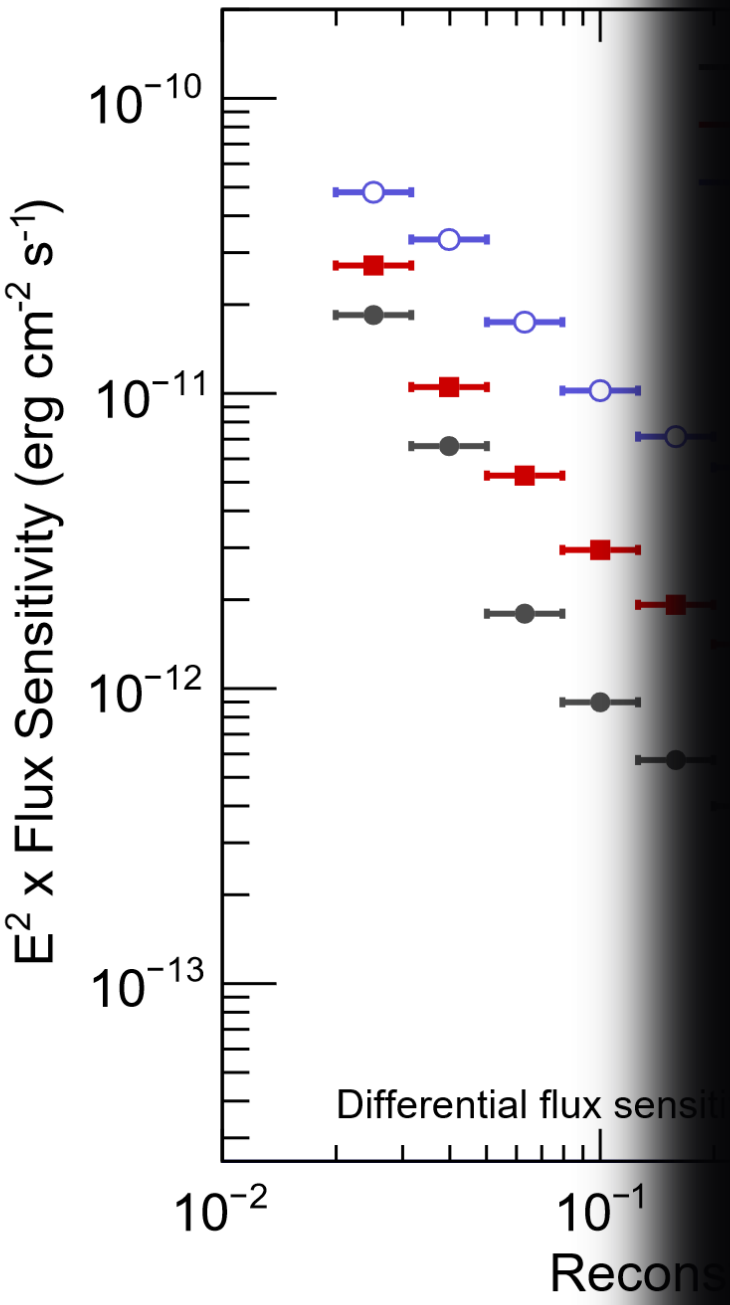
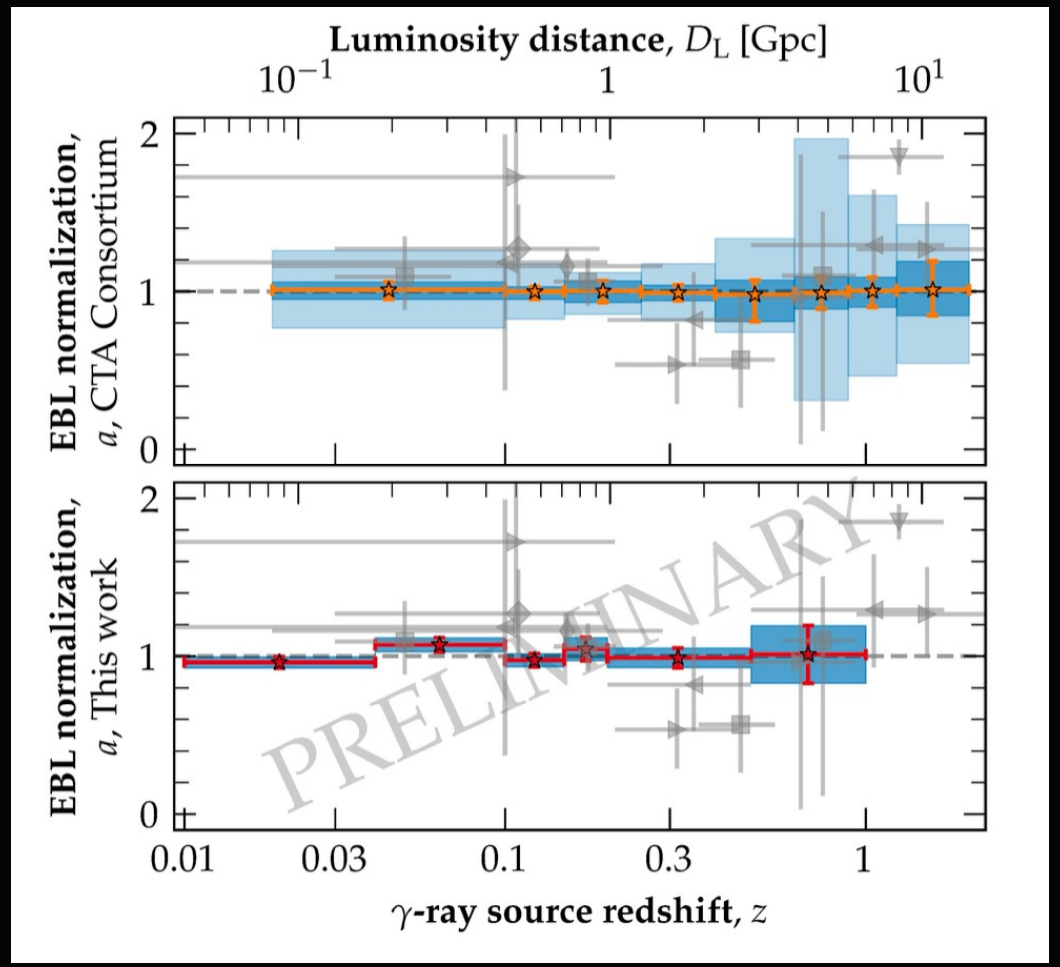
- Very high instantaneous sensitivity – at 25 GeV, > 10^4 x Fermi effective area, > 300 x sensitivity
- Fast repositioning


10^{-10}
10^{-11}
10^{-12}
10^{-13}
E^2 x Flux Sensitivity (erg cm^{-2} s^{-1})
Differential flux sensi
10^{-2}
10^{-1}
Recons

Redshift 1

Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation
CTA Consortoum, JCAP02(2021)048





L.s Gréaux, J. Biteau, this meeting

LST1 / OP 313 AT Z=0.997

[Previous | Next | ADS]

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

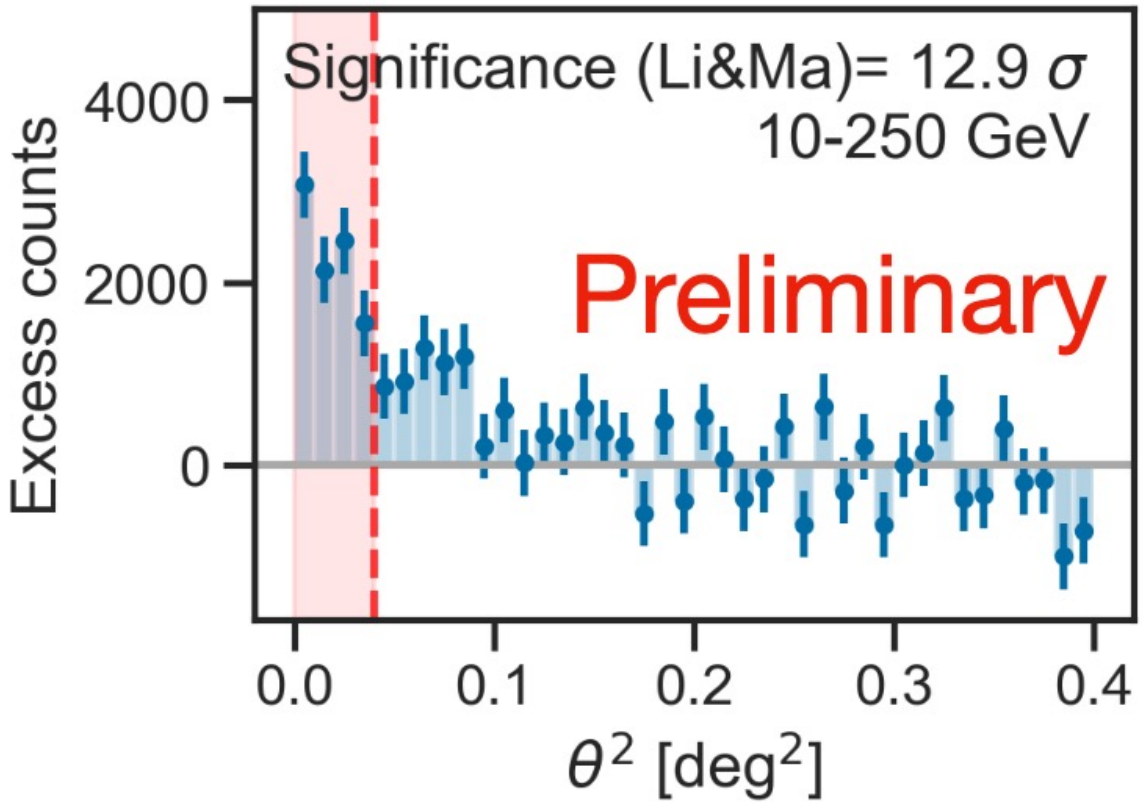
ATel #16381; *Juan Cortina (CIEMAT) for the CTAO LST collaboration*
on 15 Dec 2023; 14:31 UT
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

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 #16356) and several optical facilities (ATel #16360) in early December, the Fermi-LAT emission of OP 313 has been closely monitored using the FlaapLUC 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 (dmorcuende@iaa.es), Jorge Otero-Santos (joteros@iaa.es) and Seiya Nozaki

D. Morcuende et al.,
this meeting



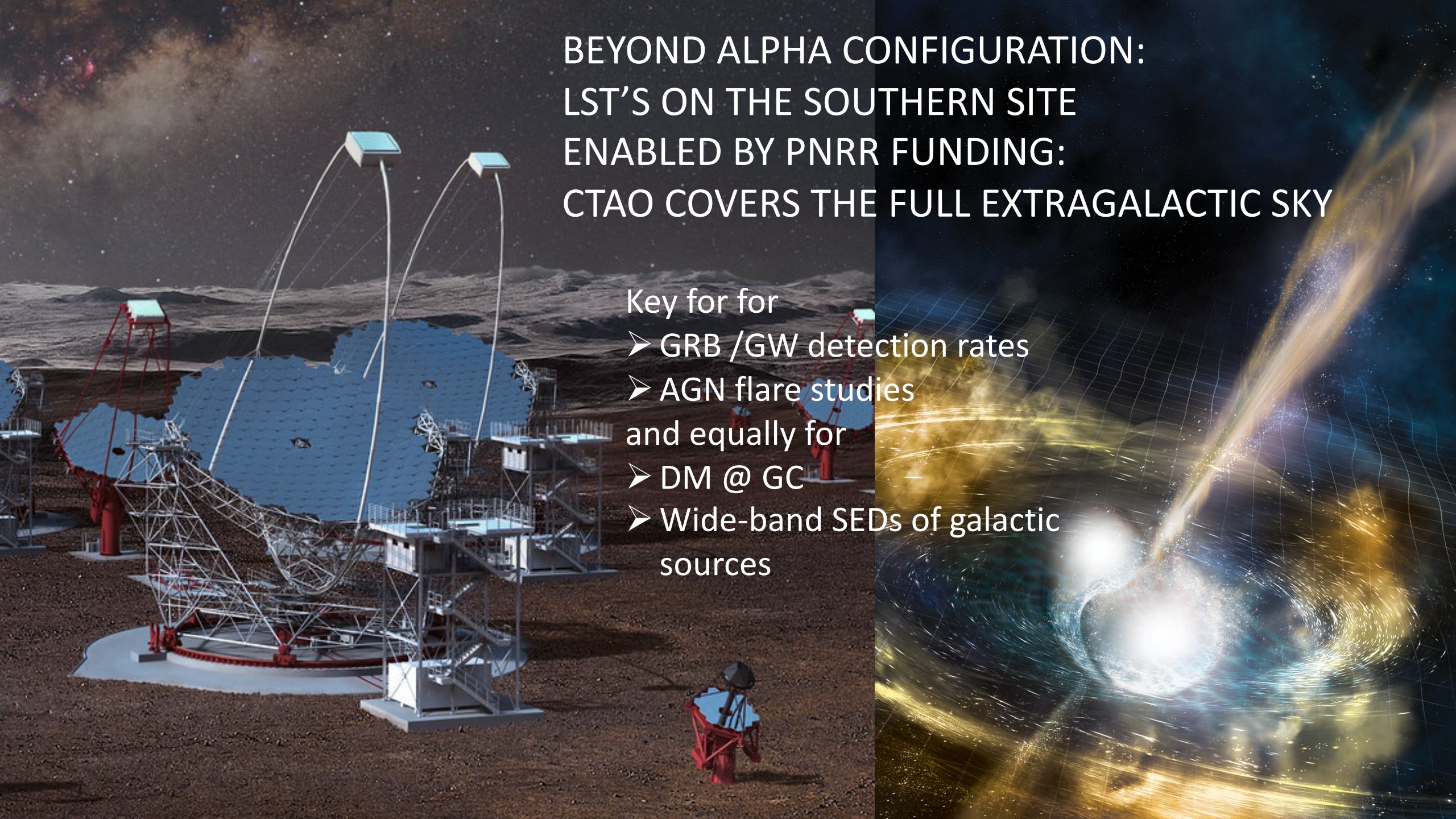
BEYOND ALPHA CONFIGURATION: LST'S ON THE SOUTHERN SITE ENABLED BY PNRR FUNDING: CTAO COVERS THE FULL EXTRAGALACTIC SKY

Key for for

- GRB /GW detection rates
- AGN flare studies

and equally for

- DM @ GC
- Wide-band SEDs of galactic sources

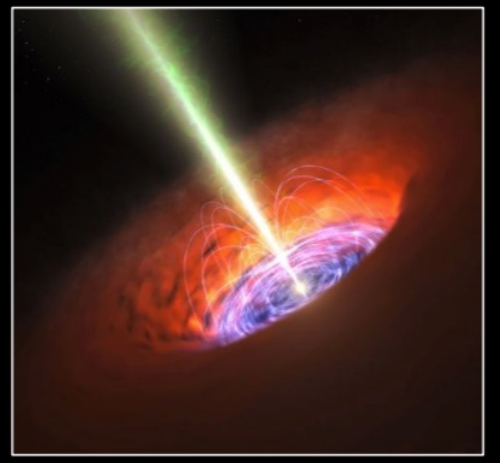


Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Theme 2: Probing Extreme Environments

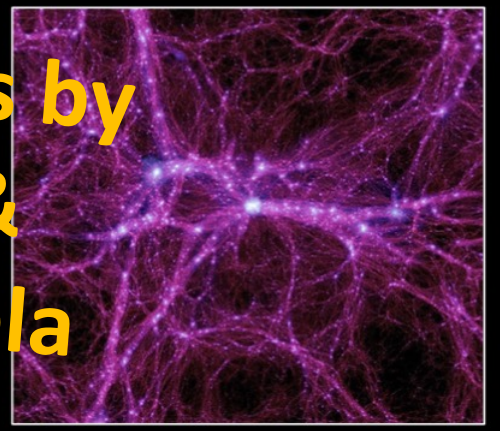
- Processes close to neutron stars and black holes?
- Characteristics of relativistic jets, winds and explosions?
- Cosmic voids: their radiation fields and magnetic fields



Theme 3: Physics Frontiers

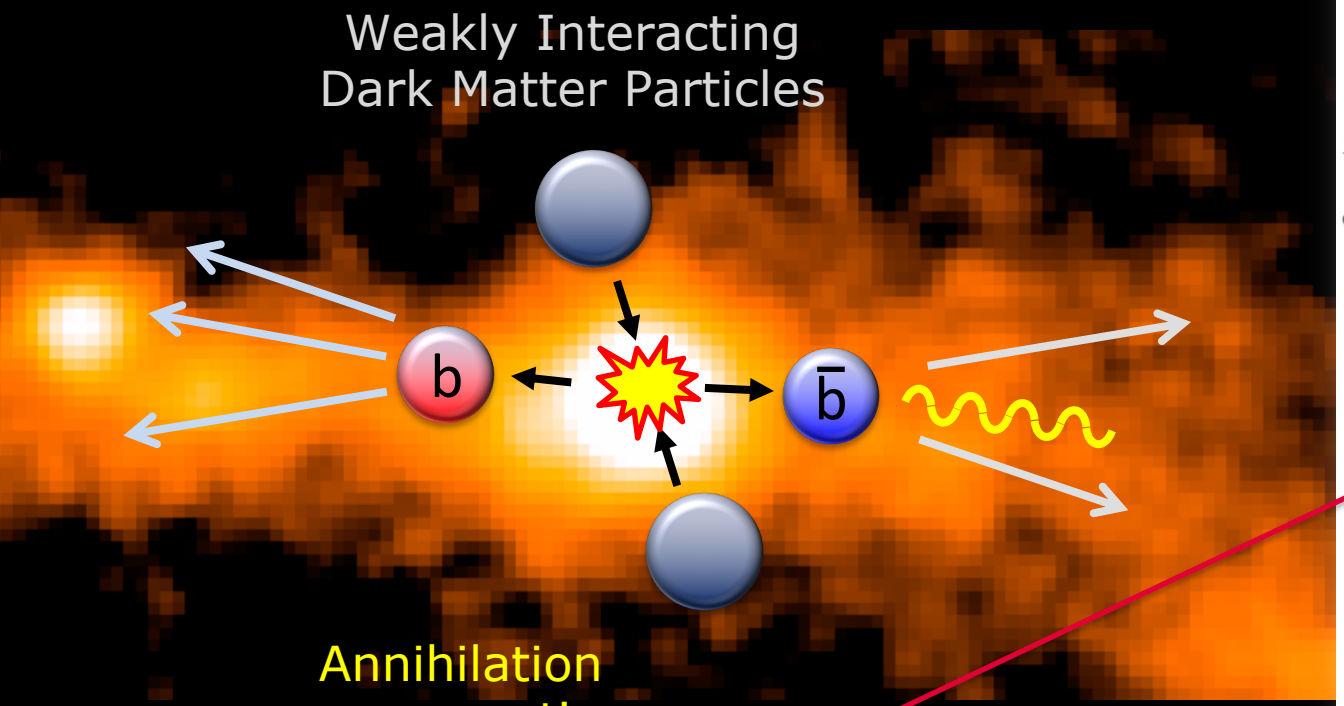
- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

Reviews by Tim & Gabrijela

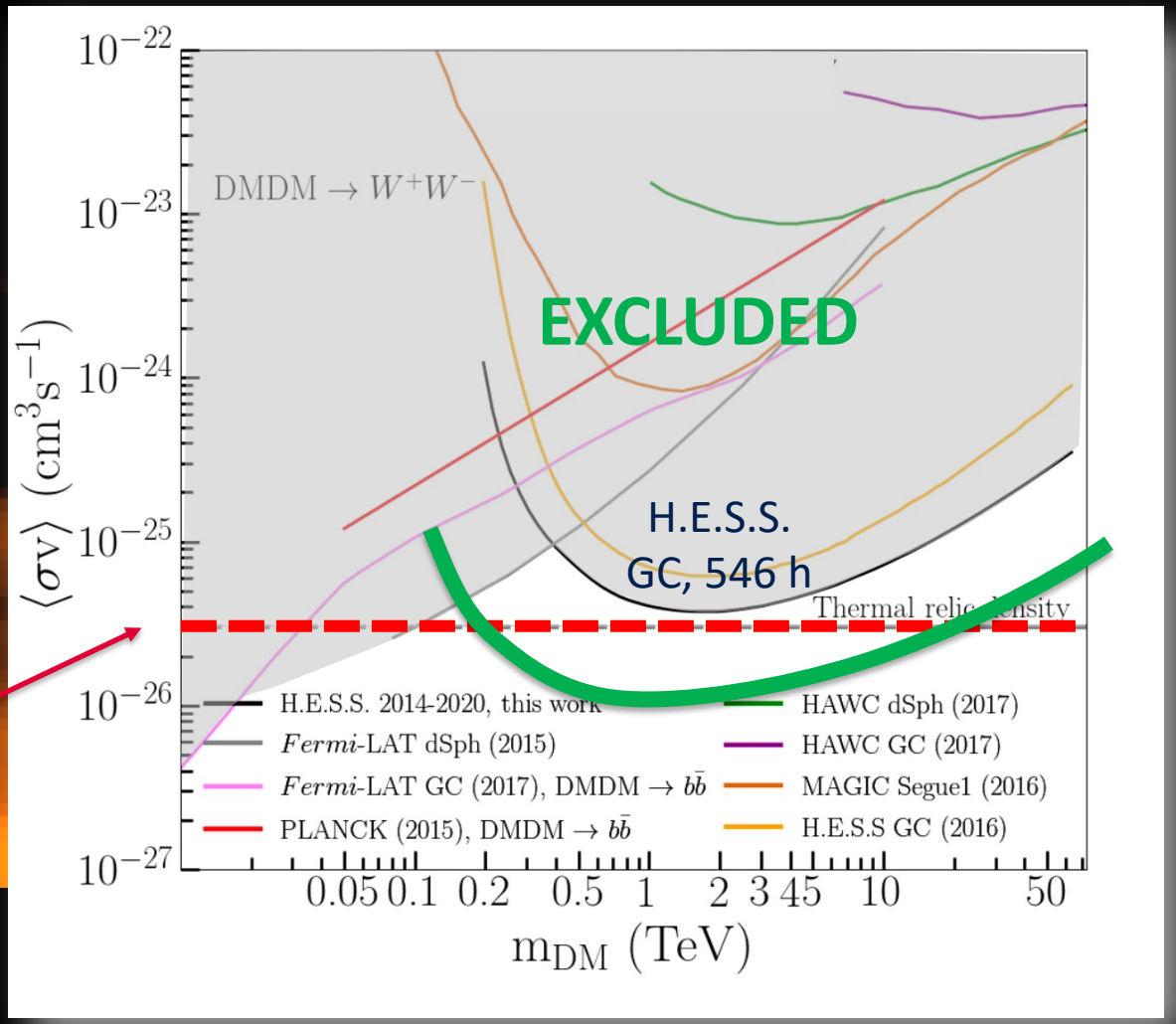


GALACTIC CENTER & DARK MATTER

GC: JCAP01(2021)057
LMC: MNRAS 523, 5353 (2023)
Perseus: arXiv:2309.03712



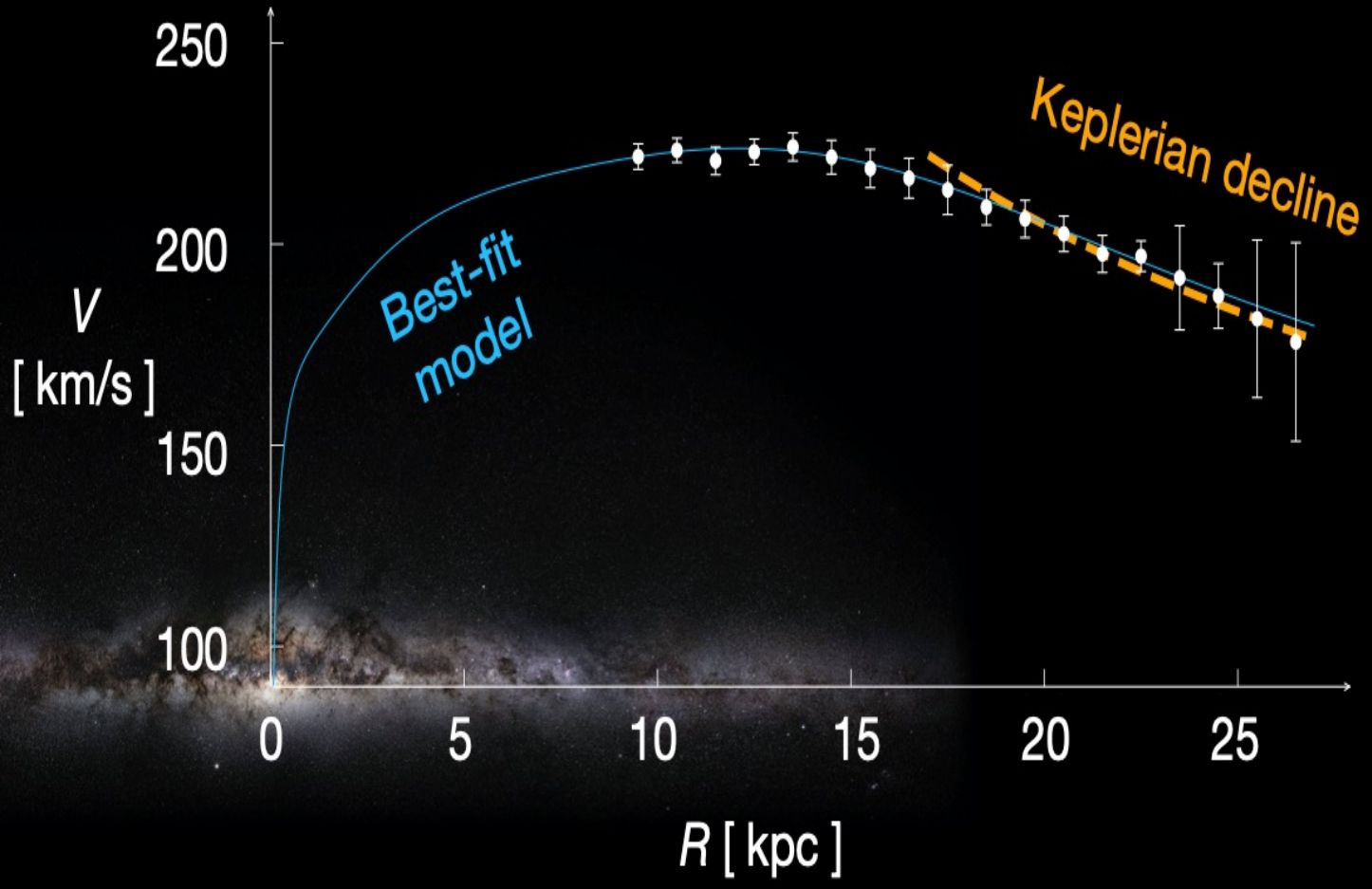
Annihilation cross section "known" from Dark Matter abundance



adapted from A. Montanari et al, PoS (ICRC2021)511
A. Acharyya et al JCAP01(2021)057

J-FACTOR UNCERTAINTY

Detection of the Keplerian decline in the Milky Way rotation curve
Y. Jiao et al. A&A 678, A208 (2023)



Several papers, using latest Gaia release:

Little matter (luminous & dark) beyond 20 kpc; no DM halo

Mass of MW revised to $\sim 2 \cdot 10^{11}\ M_{\odot}$

J factor lowered by factor ~7 compared to NFW

... if one believes in Einasto!

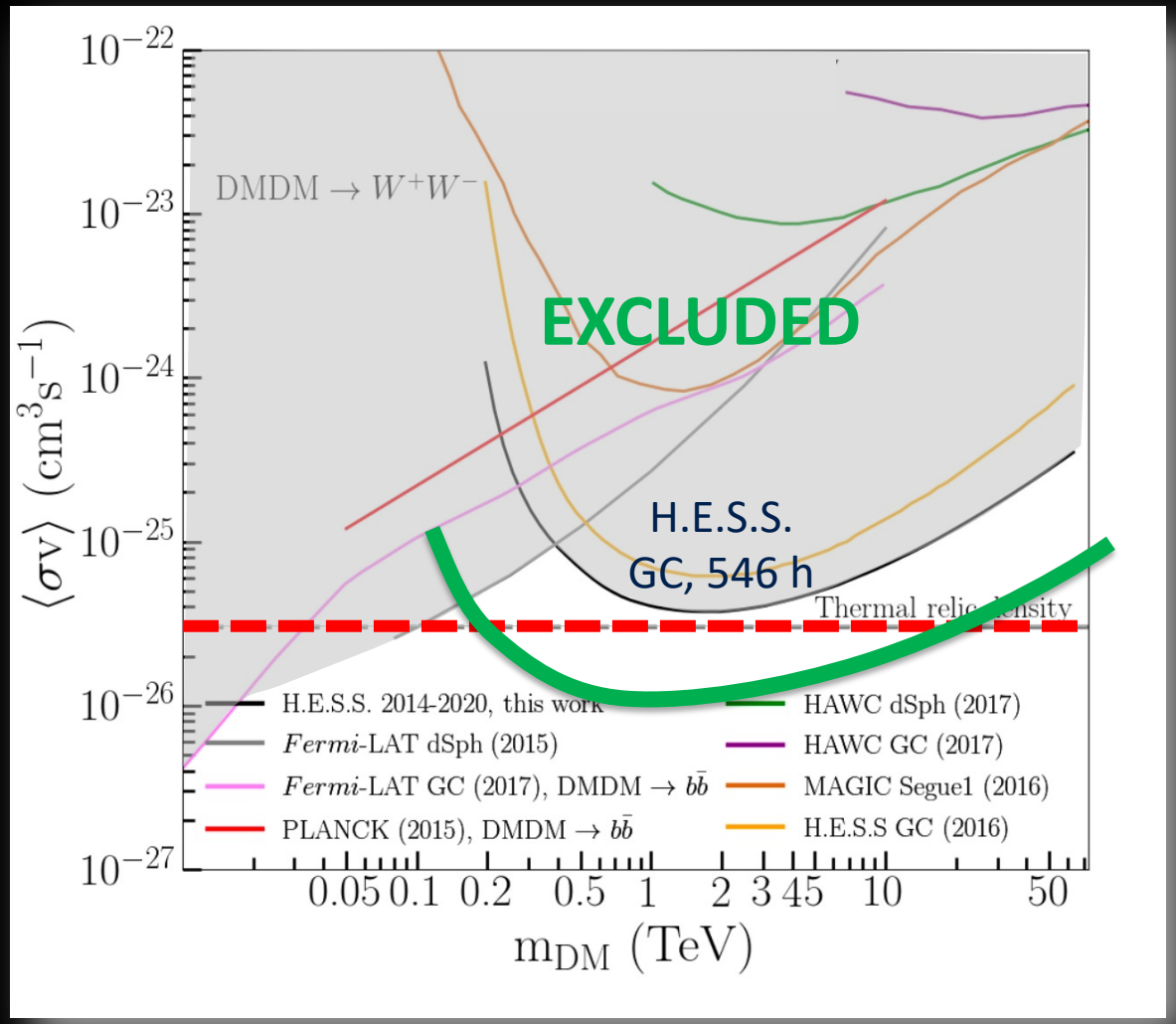
GALACTIC CENTER & DARK MATTER

GC: JCAP01(2021)057
LMC: MNRAS 523, 5353 (2023)
Perseus: arXiv:2309.03712

Based on today's knowledge:

Detection of TeV WIMPS is well within reach of CTAO (if they exist)

but **exclusion is hard**



adapted from A. Montanari et al, PoS (ICRC2021)511
A. Acharyya et al JCAP01(2021)057

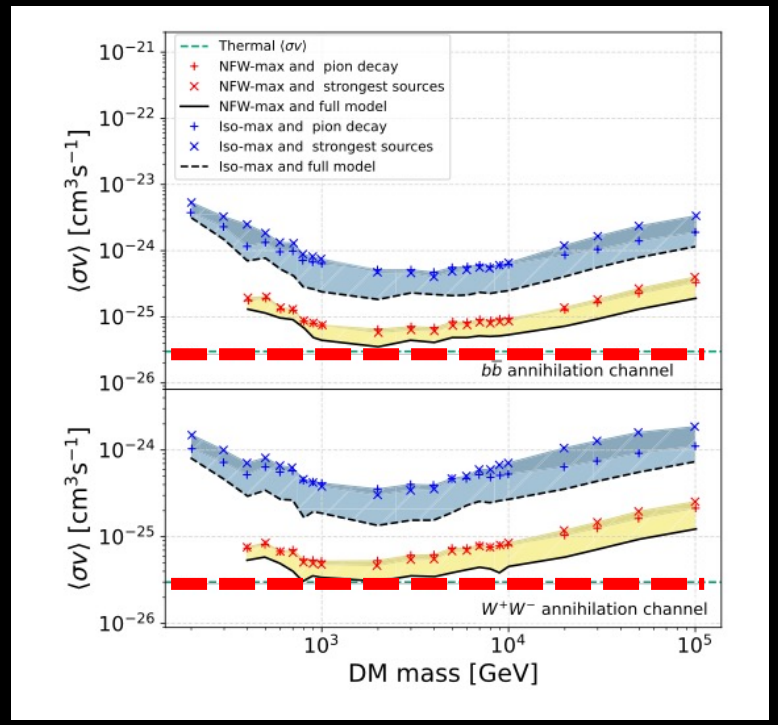
WHAT IF .... CTAO SEES A SIGNAL ...

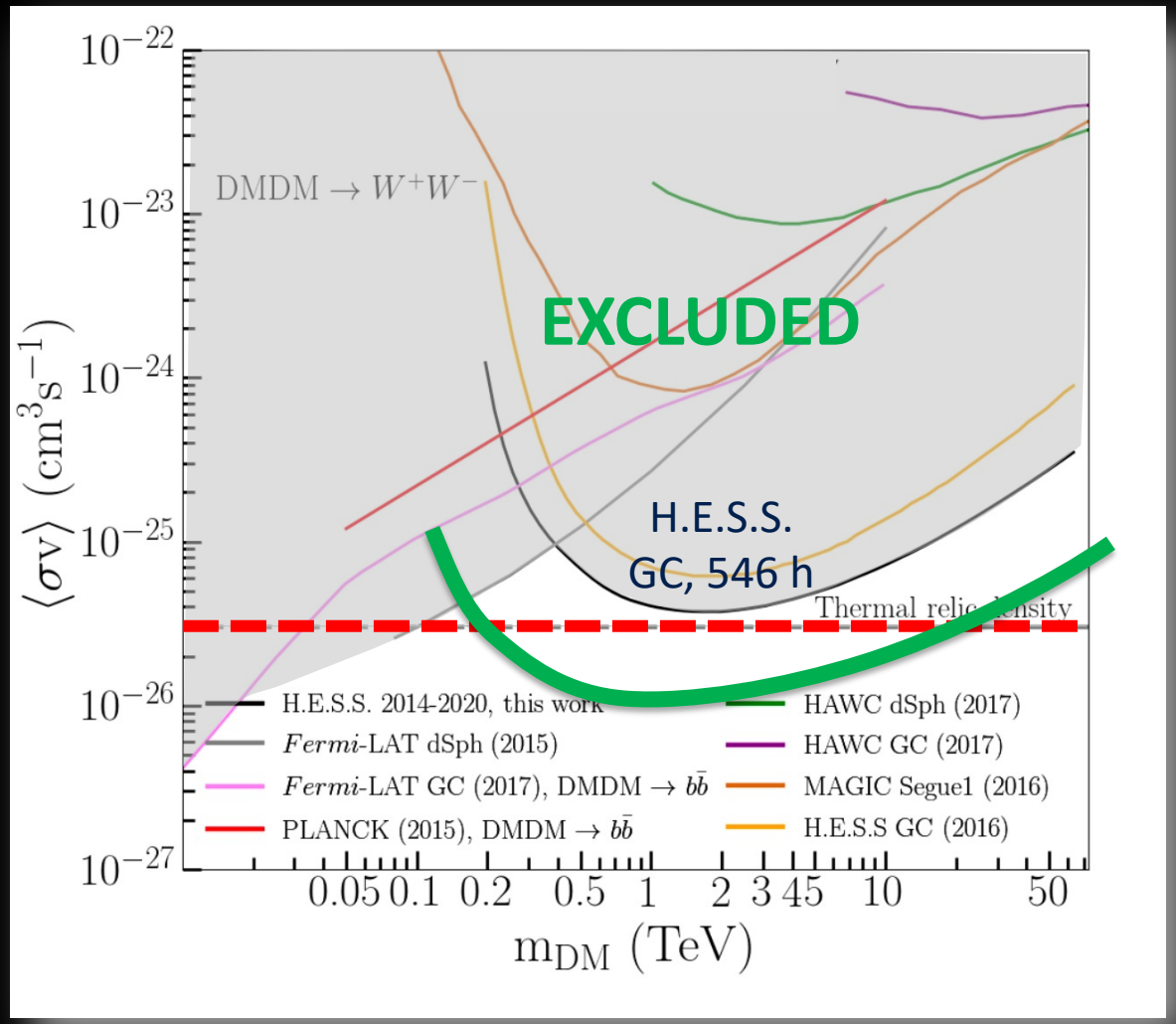
Need to confirm with other target:

Perseus: 2-3 orders of magnitude missing

LMC (300 h)

Super-Dwarf like Ursa Major III ?





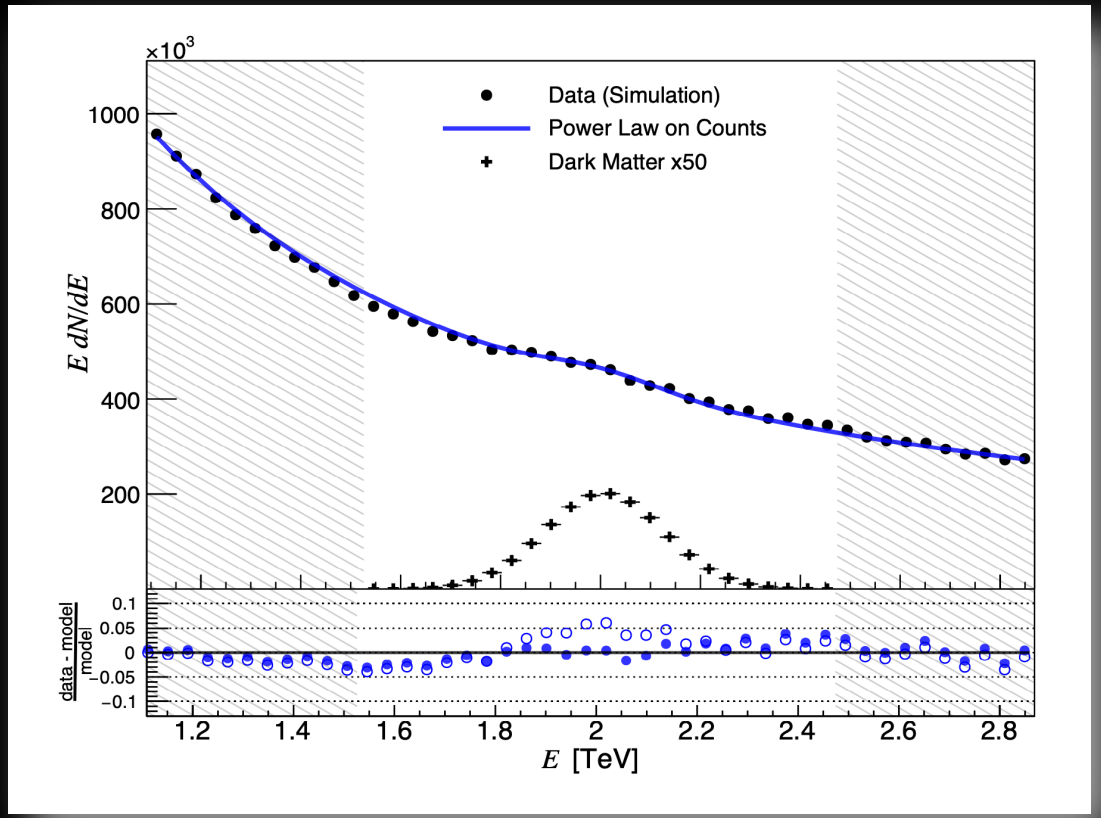
adapted from A. Montanari et al, PoS (ICRC2021)511
A. Acharyya et al JCAP01(2021)057

The smoking gun:
a line signal

typical CTAO energy
resolution in TeV range: ~7%

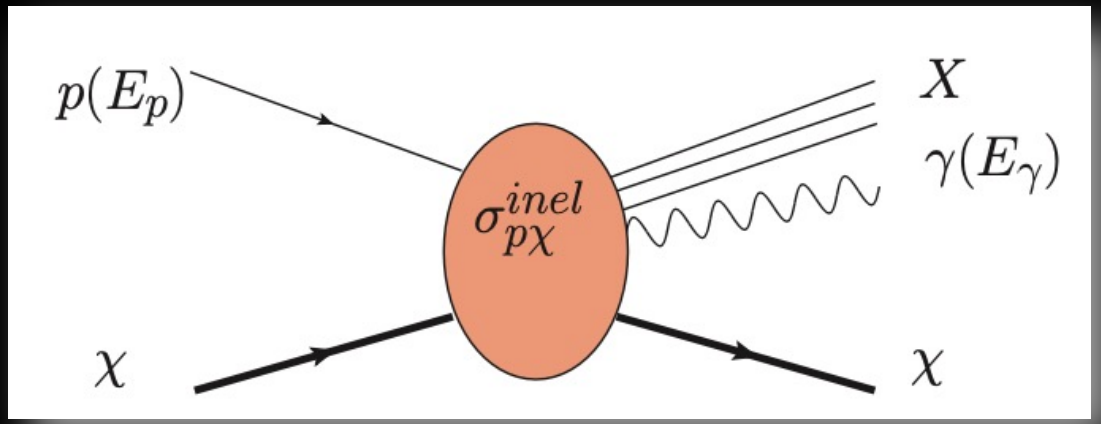
➢ **CTAO is a discovery machine**

not an exclusion machine



New ideas towards
detection of light DM @ GC:
CR + χ → χ + γ + X

(Reis et al., arXiv:2403.09343)

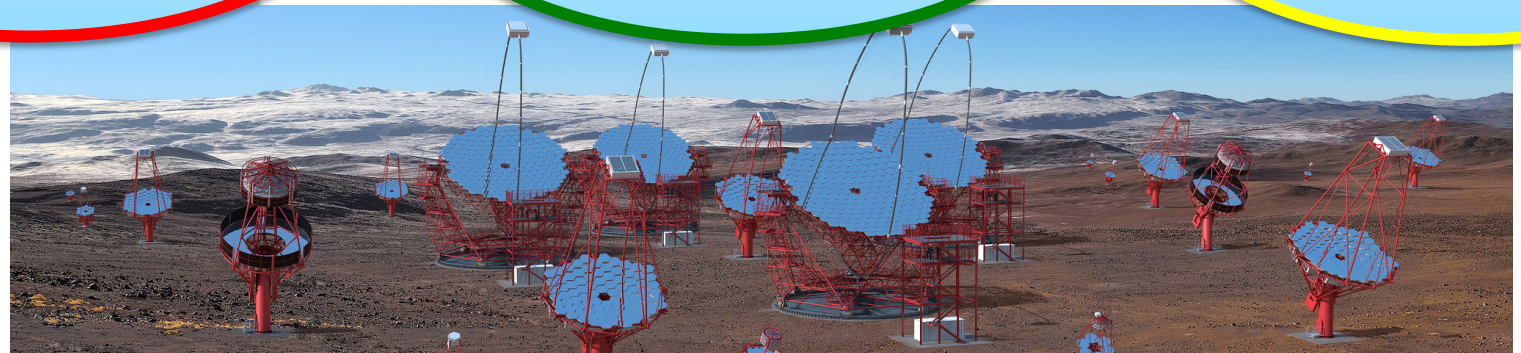


CTAO THRIVES IN A MULTIWAVELENGTH & MULTIMESSENGER WORLD

Target selection & ToOs

Object characterization

Wide-band & MM SED



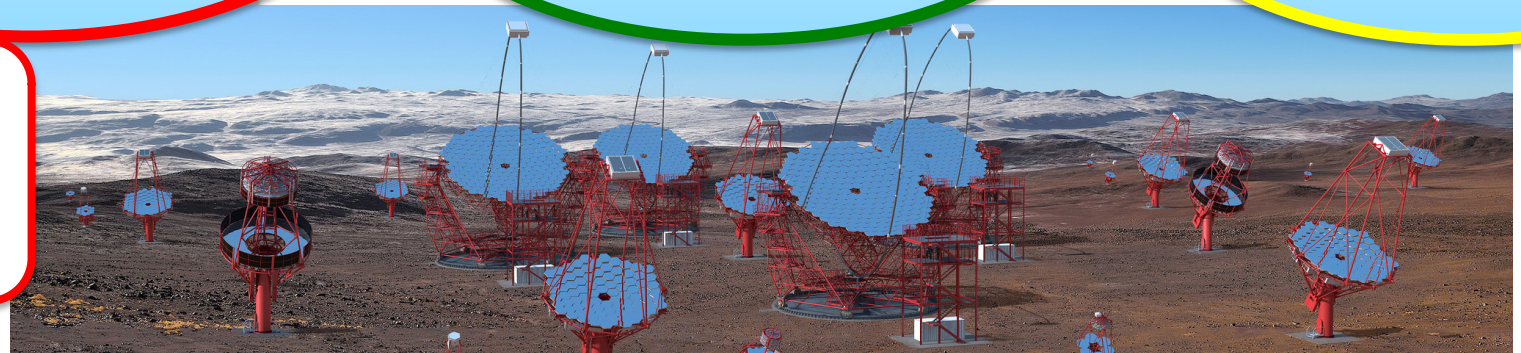
CTAO THRIVES IN A MULTIWAVELENGTH & MULTIMESSENGER WORLD

Target selection & ToOs

Object characterization

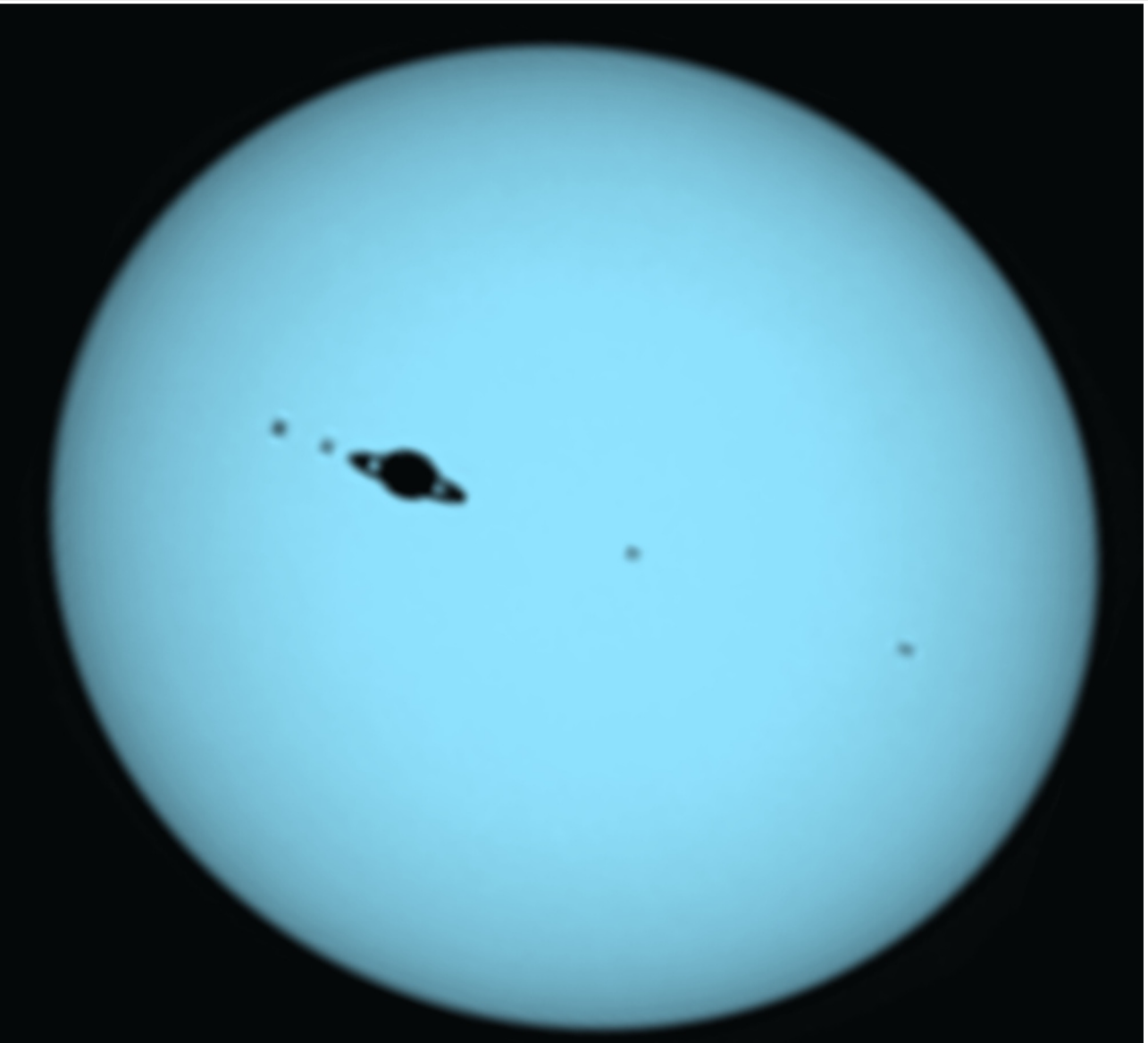
Wide-band & MM SED

ToO selection challenge



NASA, ESA, M. Livia and Hubble Anniversary Team

INTENSITY INTERFEROMETRY

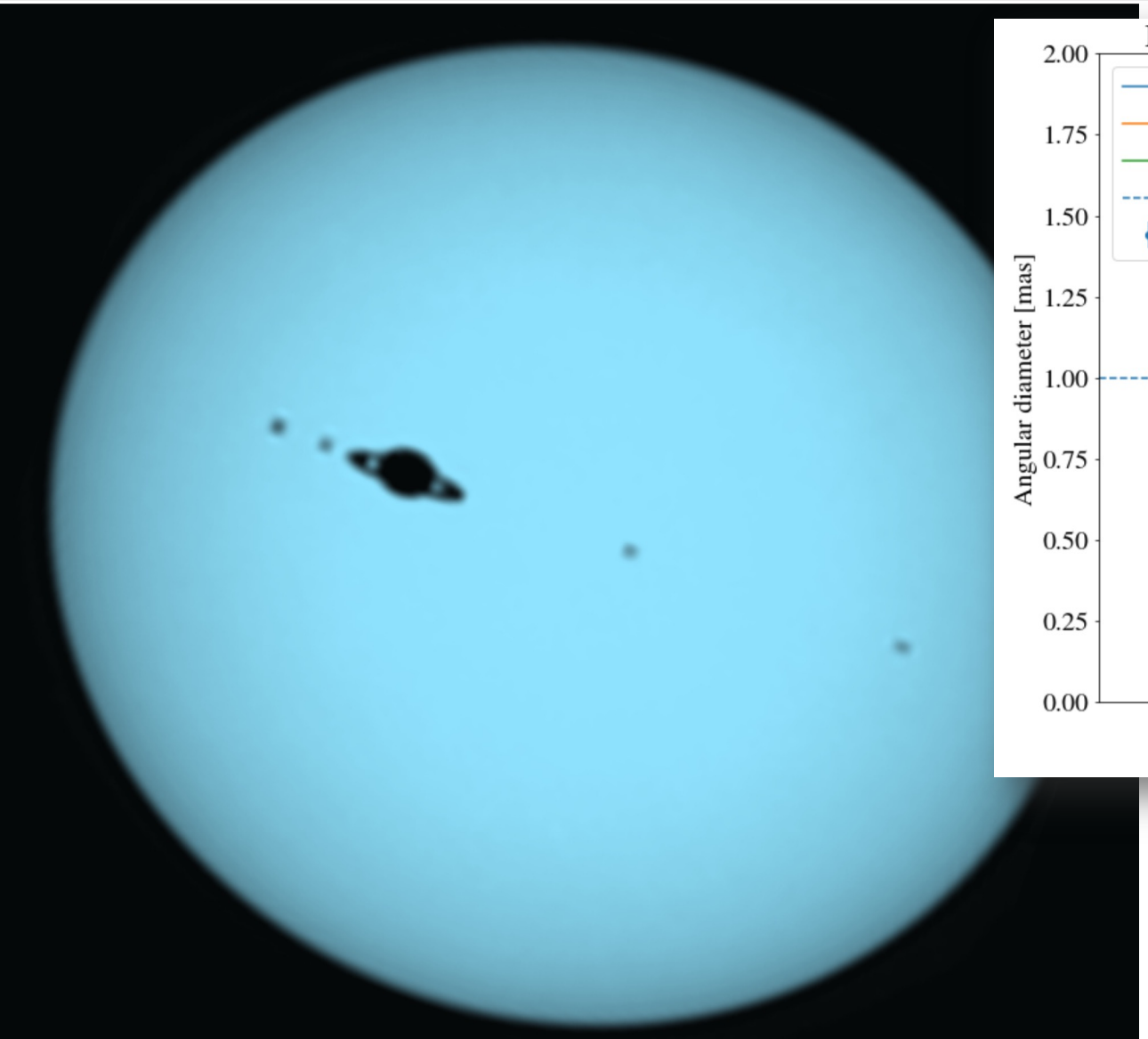


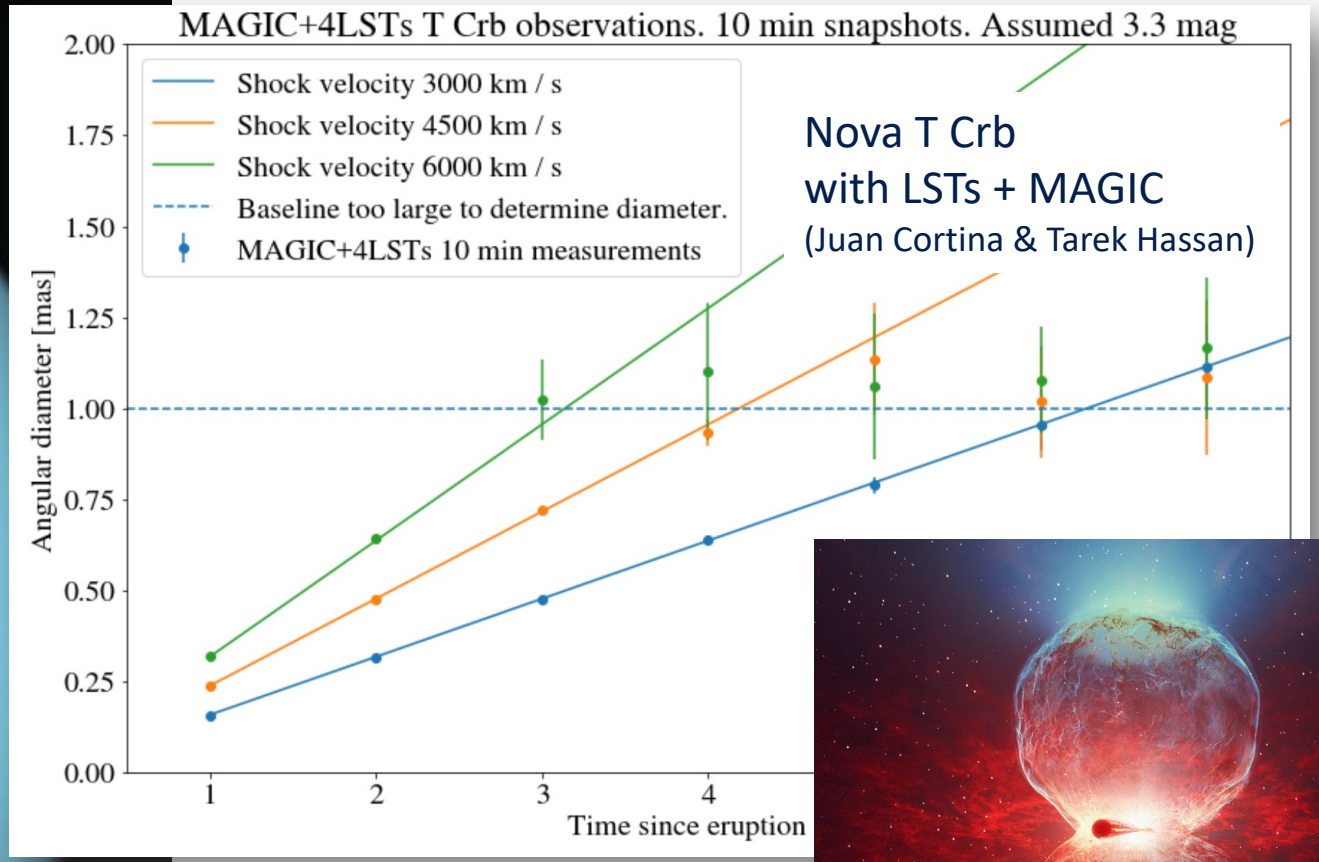
D. Dravins et al.
A&A 580, A99 (2015)

Hypothetical exoplanet crossing the disk of Sirius, viewed with a Cherenkov telescope array spanning 2 km

INTENSITY INTERFEROMETRY @ IACTs

e.g. MAGIC Coll., arXiv:2402.04755
VERITAS Coll., Nature Astr. (2020)





Nova T Crb
with LSTs + MAGIC
(Juan Cortina & Tarek Hassan)

II: Very interesting option for CTAO


pa/Westend61/Werner Dieterich

Preventing a few trees and birds from being killed now

or

Preventing many trees and bird species from being killed in the next decades?


pa/Westend61/Werner Dieterich

Preventing a few trees and birds from being killed now

or

Preventing many trees and bird species from being killed in the next decades?

Knödlseder et al., Nature Astronomy (2022):
"36.6 ± 14.0 tCO_2e per year per astronomer"
"research infrastructures make
the single largest contribution"

Burtscher et al., Nature Astronomy (2021):
ESO: 40; ICRAC: 42; MPIA 18 tCO_2e /yr/researcher

See also Lang et al., arXiv:2403.03308v1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See also Lang et al., arXiv:2403.03308v1

CTAO is designed to last
30 years or more

We all need to contribute that
society can still afford
astronomy 30 years from now!

Thanks

- for excellent talks and posters – I learned a lot
- for the great interest in CTAO science
- for fascinating outlooks at the science ahead of us

NASA, ESA, M. Livia and Hubble Anniversary Team