
VISITORS
PARKING

Imaging Atmospheric Cherenkov Telescopes: Present and Future.

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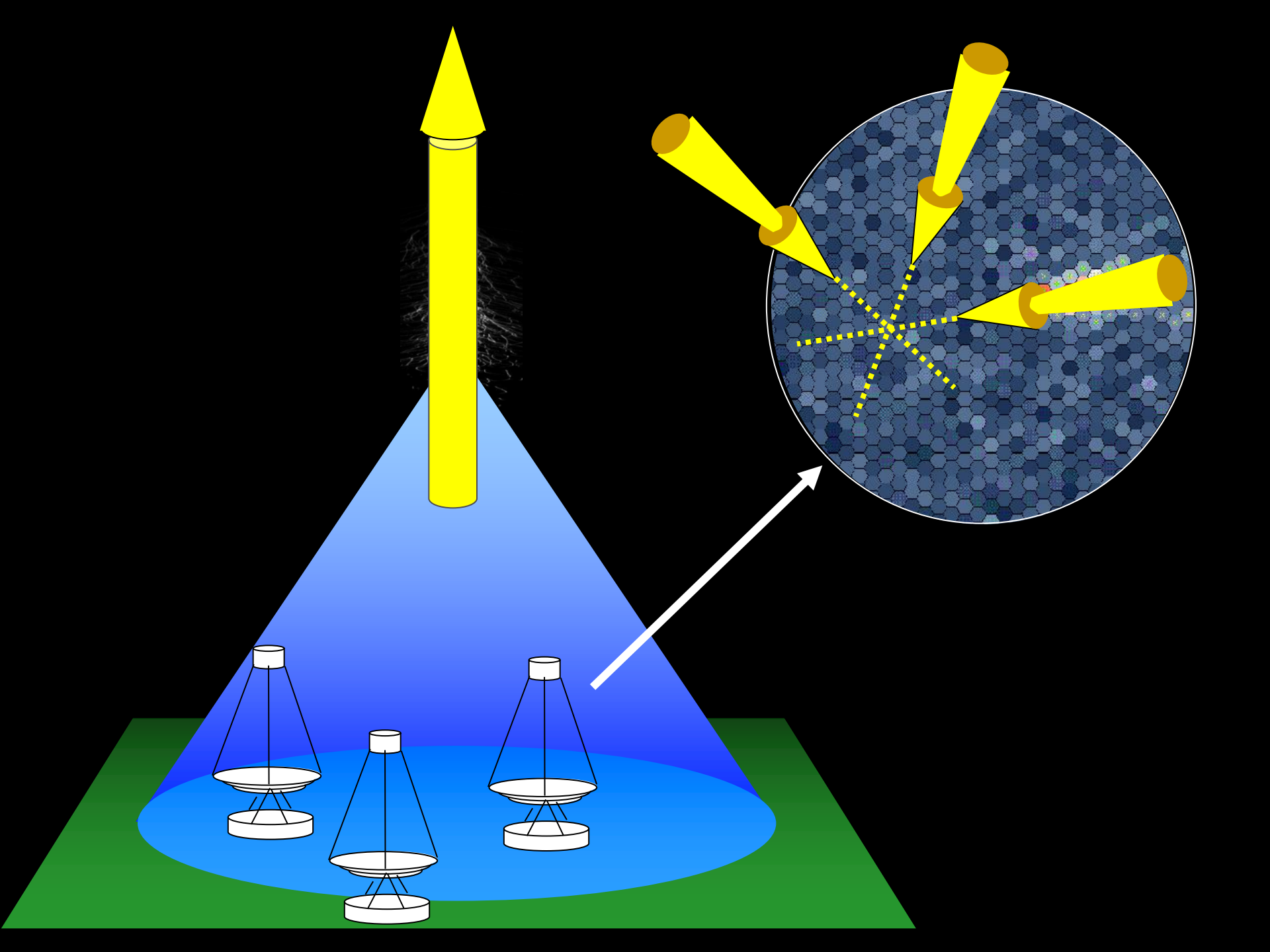
IceCube Particle Astrophysics Symposium
Madison
May 9th, 2017

The Charge:

"Your talk should be presented as a compact presentation of **recent results** and **major open questions** persisting in the field, with an emphasis on **what can be done** in the coming decade - experimentally, theoretically or both - to resolve these questions."

What **tools** will we use to resolve the questions?



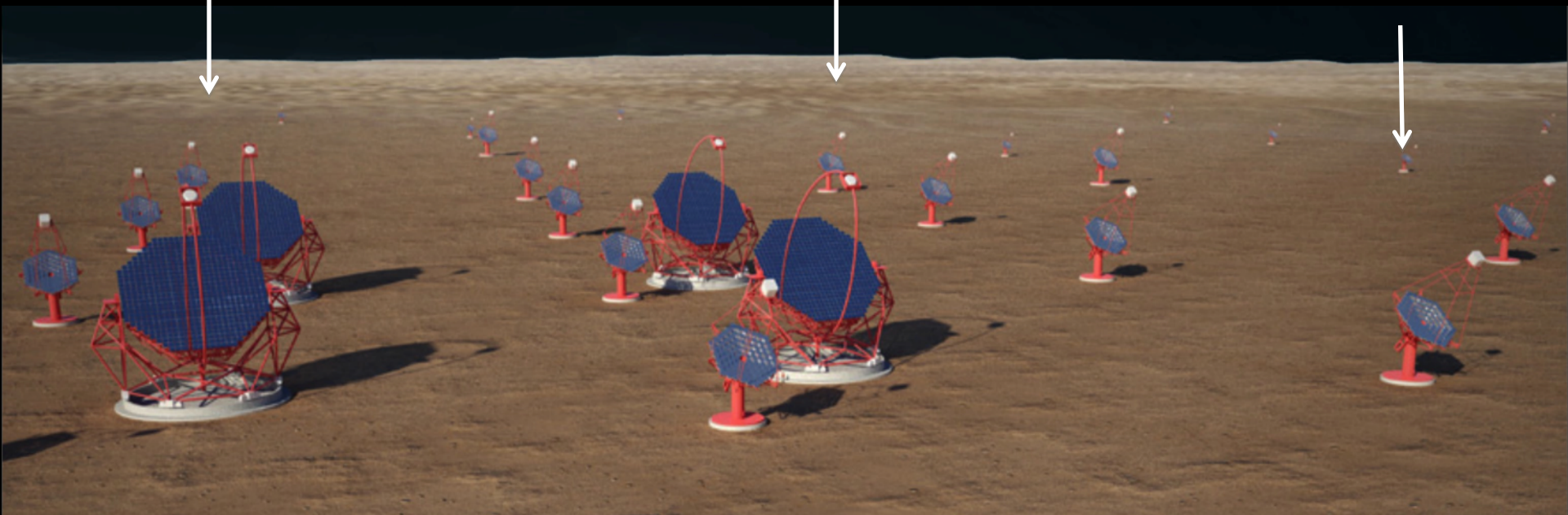
The Present

The Future: The Cherenkov Telescope Array

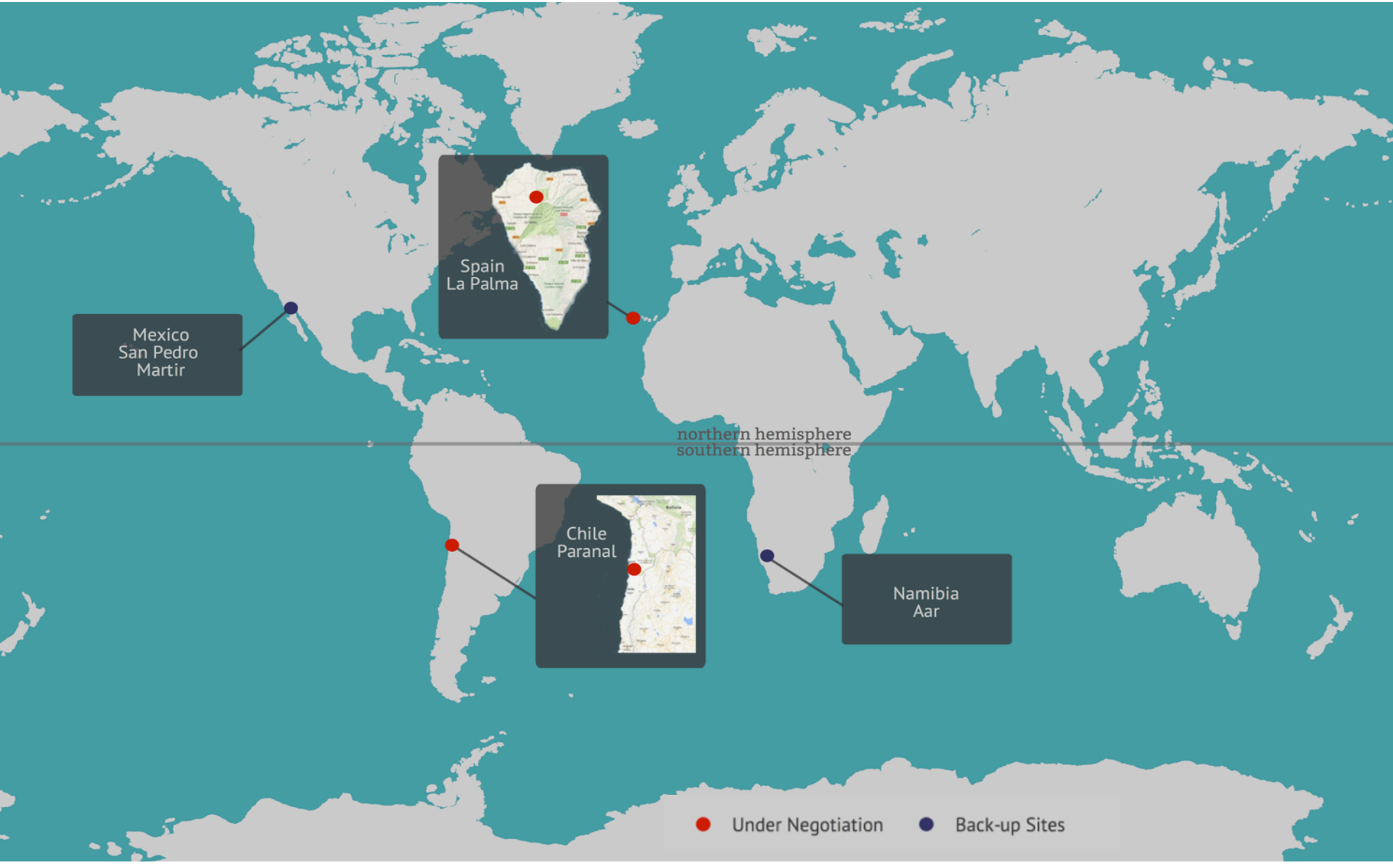
Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes (South)
4 telescopes (North)

Medium energies
100 GeV – 10 TeV
9.5 to 12 m diameter
25 medium-size telescopes (S)
15 medium-size telescopes (N)

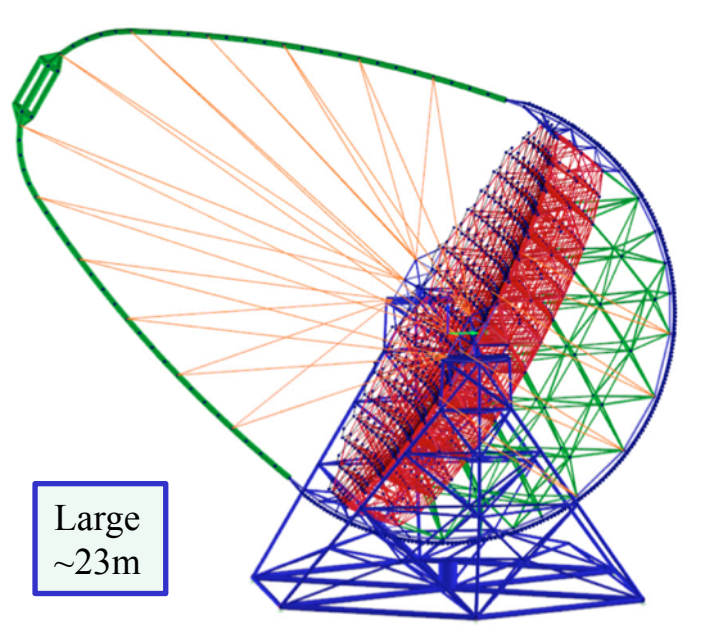
High energies
10 km^2 effective area
4m diameter
70 small-size telescopes (S)



SITES


Spain
La Palma
Mexico
San Pedro
Martir
northern hemisphere
southern hemisphere
Chile
Paranal
Namibia
Aar
Under Negotiation
Back-up Sites

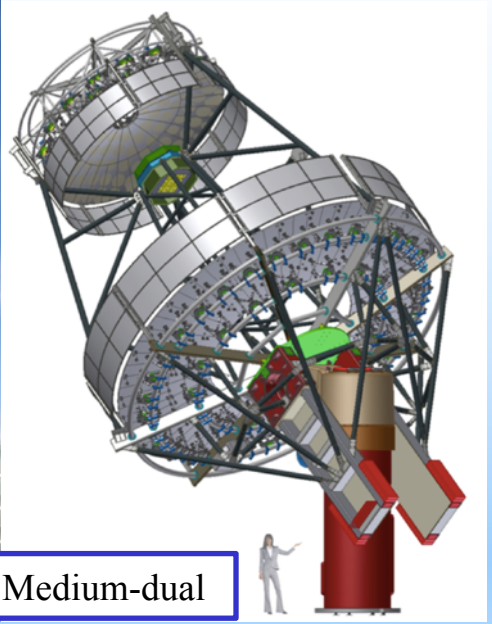
CTA Telescopes under development



Large
~23m

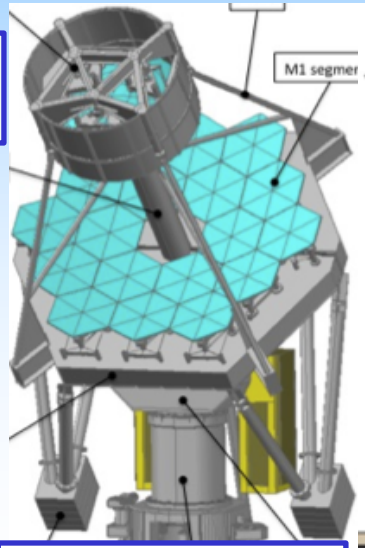
Medium
~12m

Medium-single



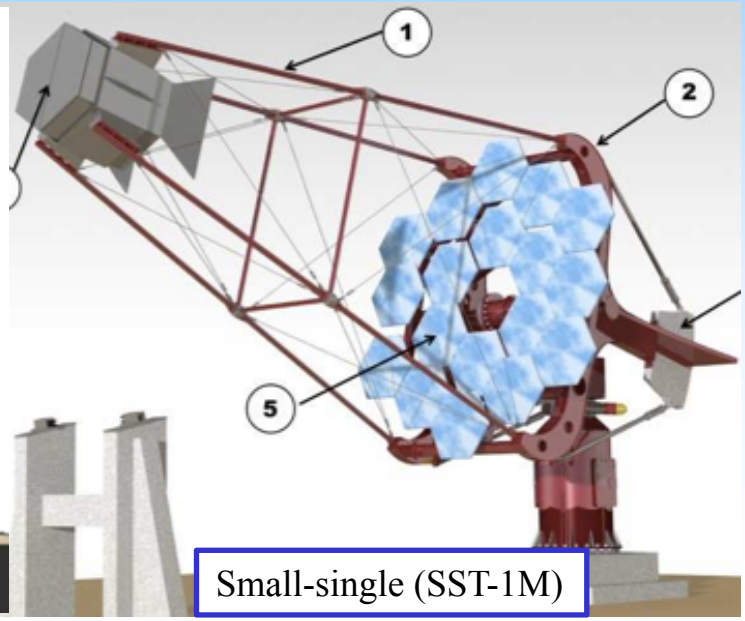
Medium-dual

Small
~4m



Small-dual (ASTRI)

Small-dual (GCT)



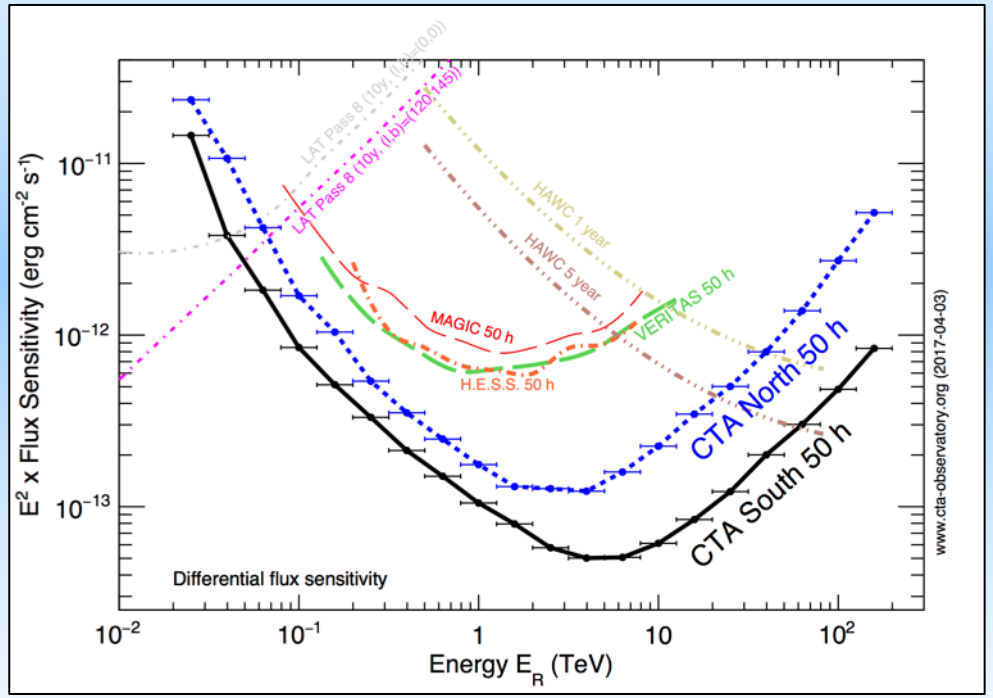
Small-single (SST-1M)

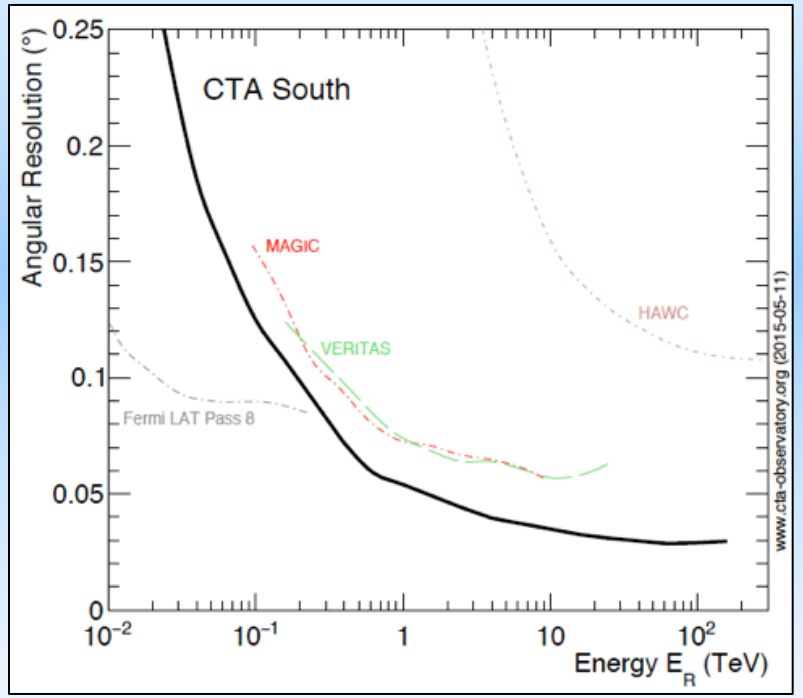

05-01-2017 11:26:20

Present vs Future

- Sensitivity improvement of an order of magnitude.
- Energy range extended both higher and lower.

- Improved angular (and energy) resolution.





The Charge:

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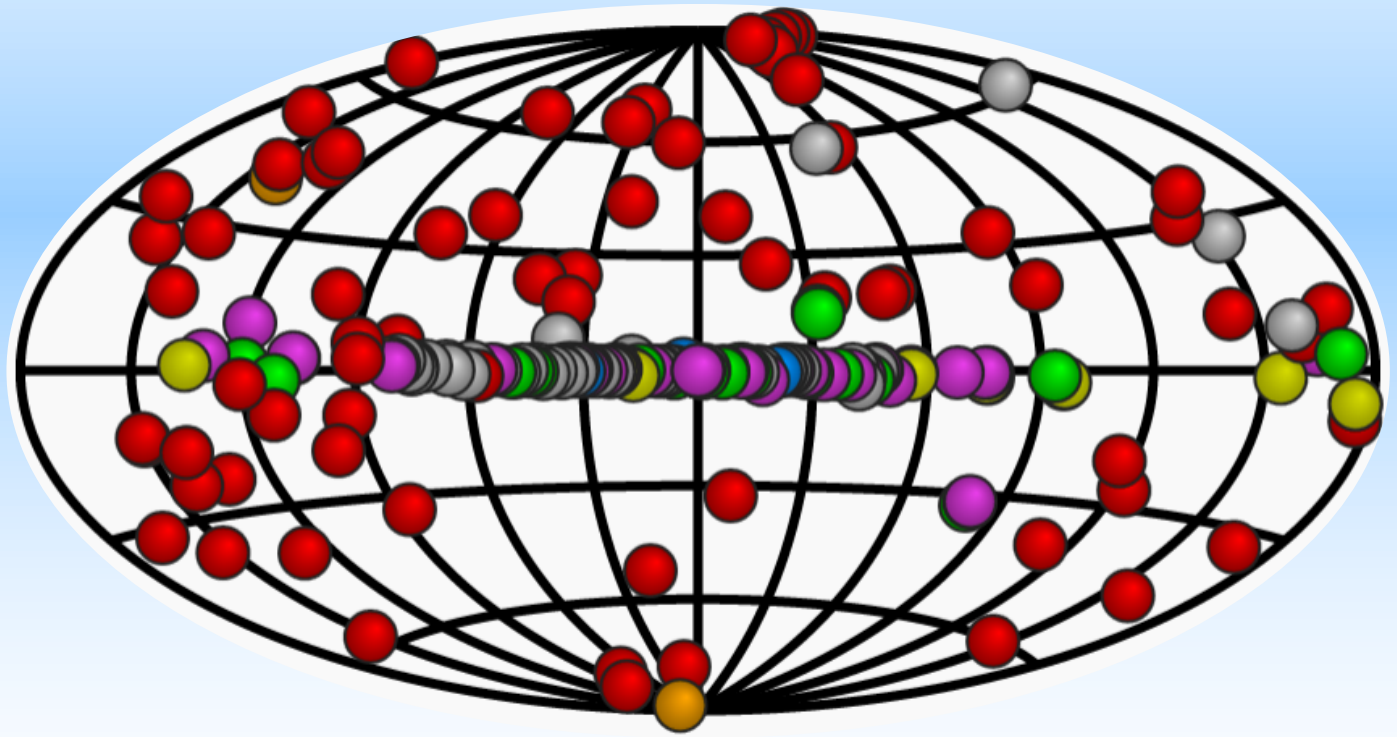
What are the questions?

Let's start with just a few of the original ones…

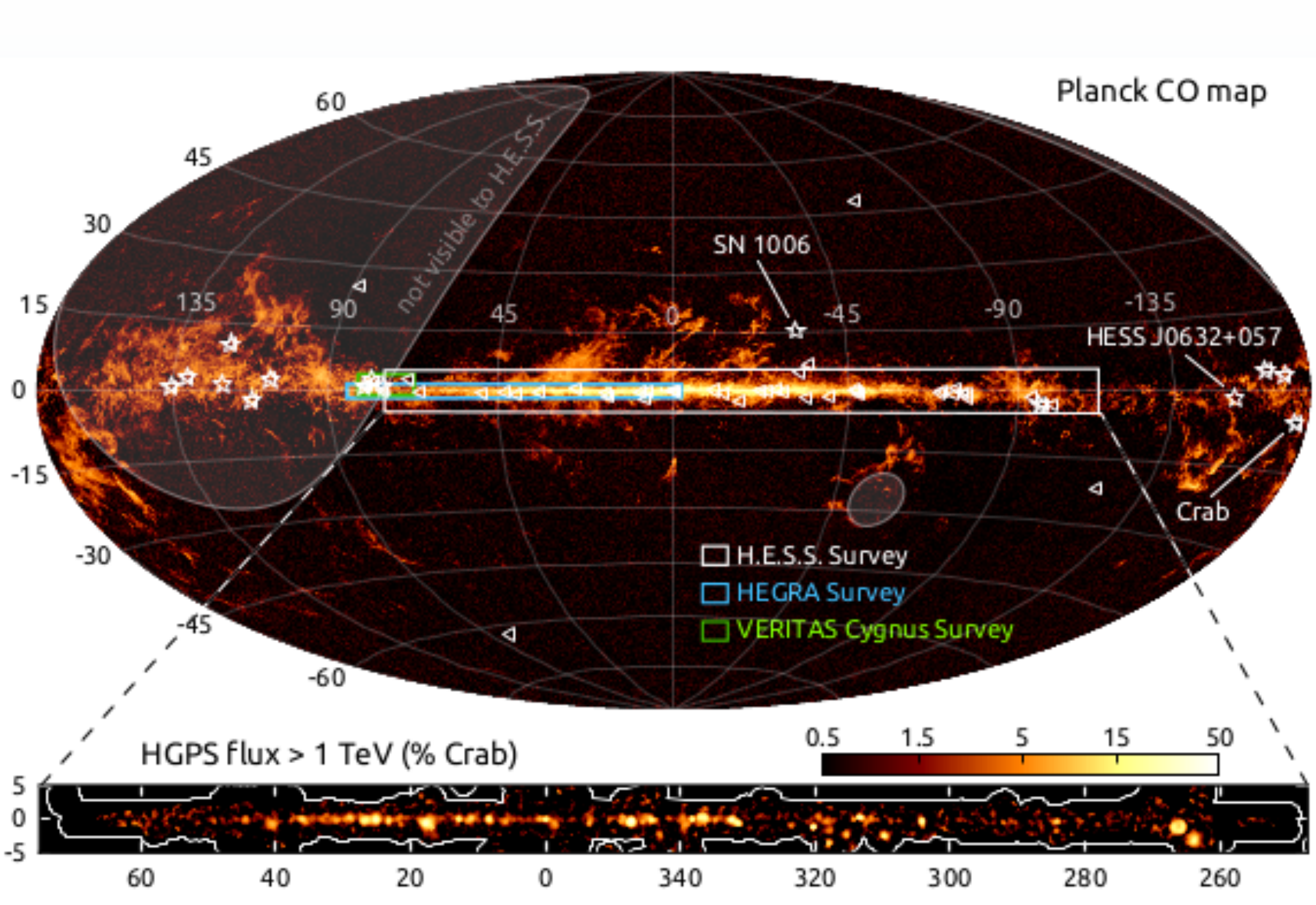
1. What is the population of TeV gamma-ray sources?

- Nearly 200 sources from many different source classes and sub-categories.



Pulsar wind Nebula
Active Galactic Nucleus
Supernova Remnant
Starburst Galaxy
Unidentified
Binary system
Stellar Cluster

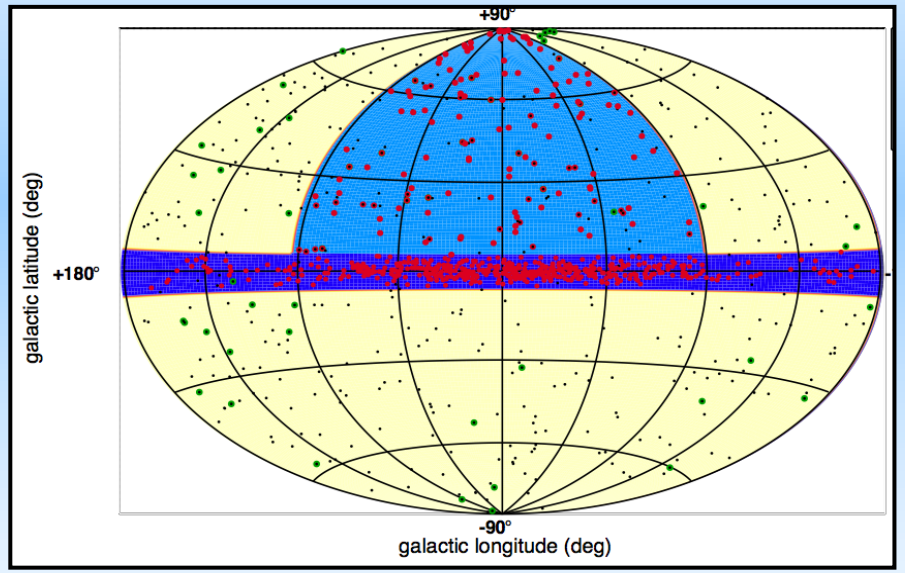
http://tevcat2.uchicago.edu/



https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2016/01/

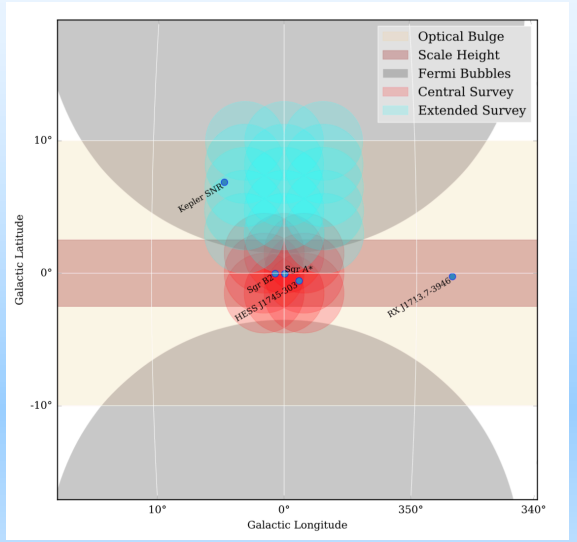
The Future: Surveys with CTA

- Extragalactic Survey
  - Quarter of the sky to ~6mCrab
  - 1000 hr in total

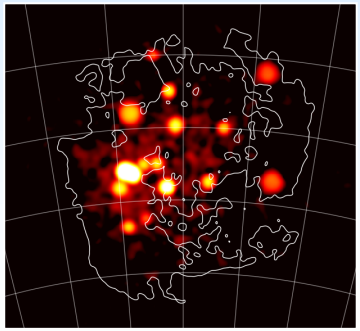


- Galactic Plane Survey
  - Entire plane to ~2 mCrab
  - 1620 hr in total

- Galactic Center Survey
  - Central region: 525 hr
  - Extended region (to +10°): 300 hr

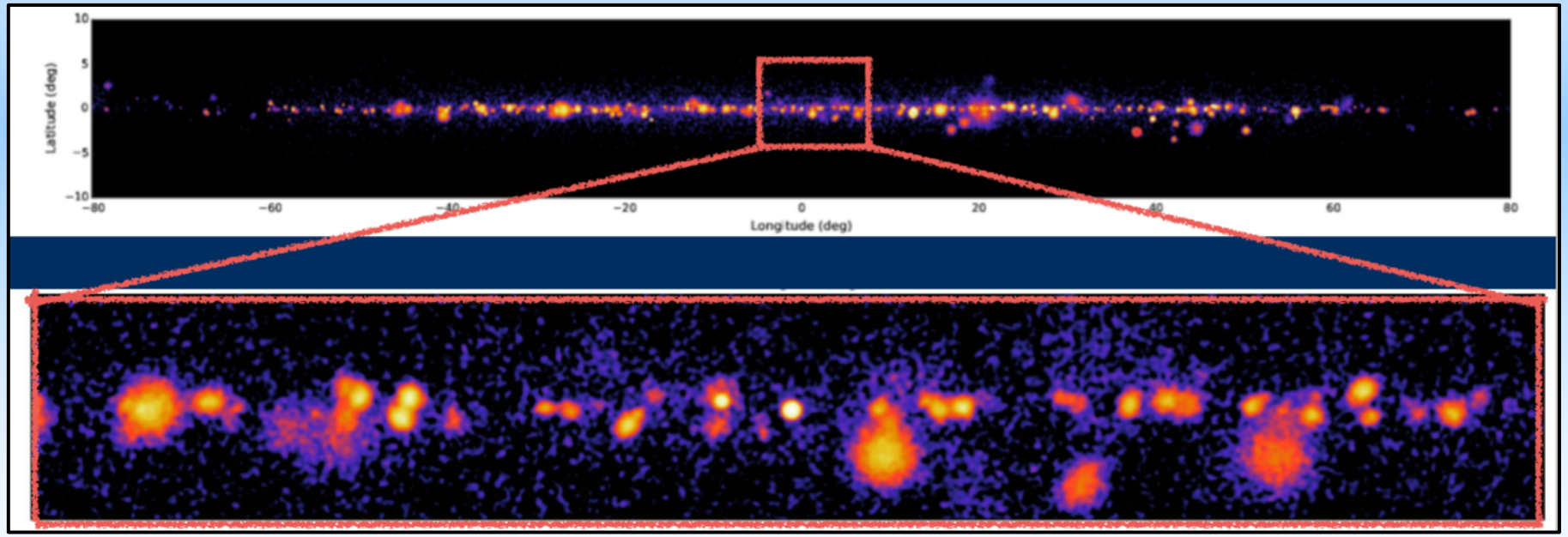


- Large Magellanic Cloud Survey
  - 340 hr



Galactic Plane Survey with CTA

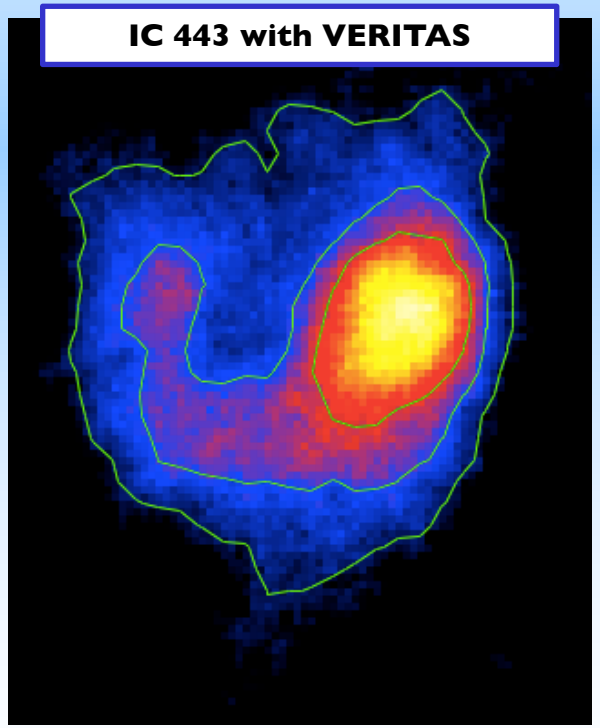
- Will detect many hundreds of sources.
- Provides population studies of pulsar wind nebulae, supernova remnants.
- Allows searches for new gamma-ray binaries and pulsars.
- Allows searches for PeVatrons, new source classes and transients.

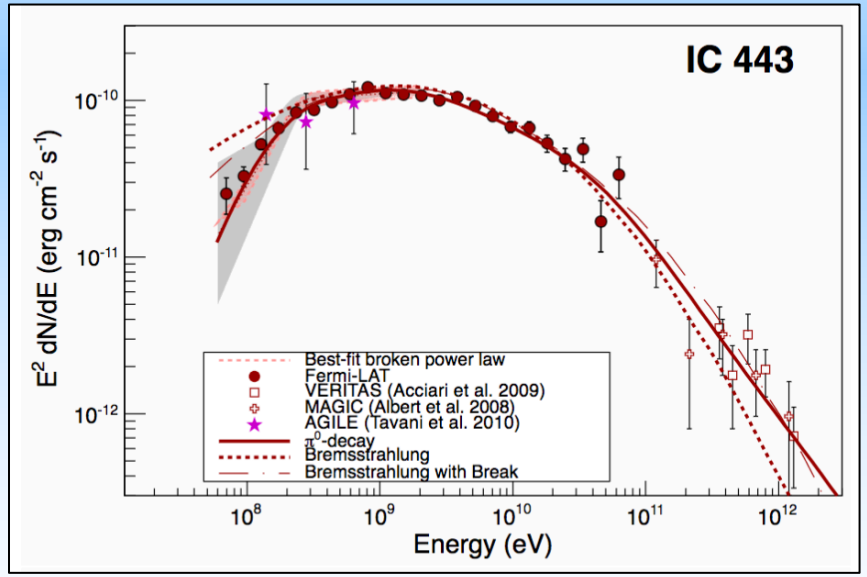


https://www.cta-observatory.org/ctas-galactic-plane-survey-will-provide-unprecedented-view-galaxy/

2. What is the origin of the cosmic rays?

- Particle acceleration takes place in supernova remnants.
- Gamma-ray emission identifies the acceleration sites.
- Particle population is ambiguous: leptonic or hadronic emission may dominate.
- Where hadronic emission is identified, the source spectra cut off at high energies.

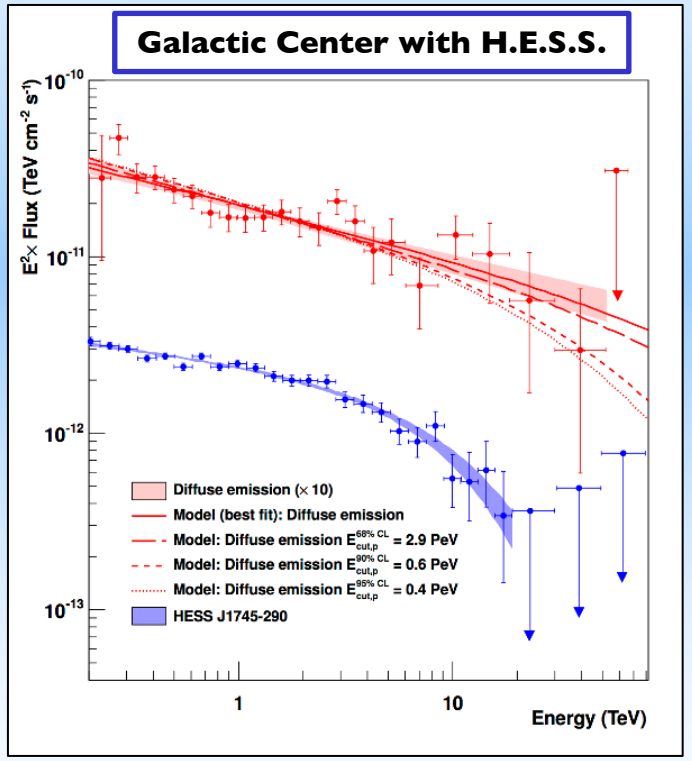




Fermi-LAT Collaboration Science 339, 807, 2013

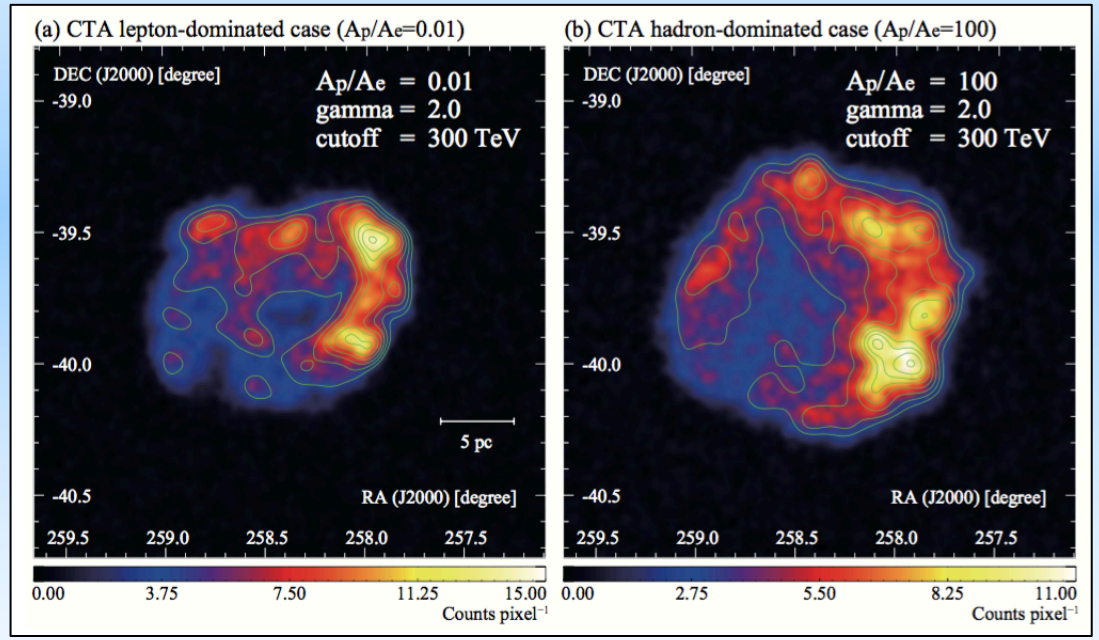
- To produce the Galactic population of cosmic rays up to the knee requires PeVatrons.
- There may be one at the Galactic Center (or there may *have* been).
- CTA will search for others, by extending the energy range to hundreds of TeV.
- Improved angular resolution will also help to discriminate between models.

Galactic Center with H.E.S.S.



H.E.S.S. Collaboration, Nature 531, 476-479 (2016)

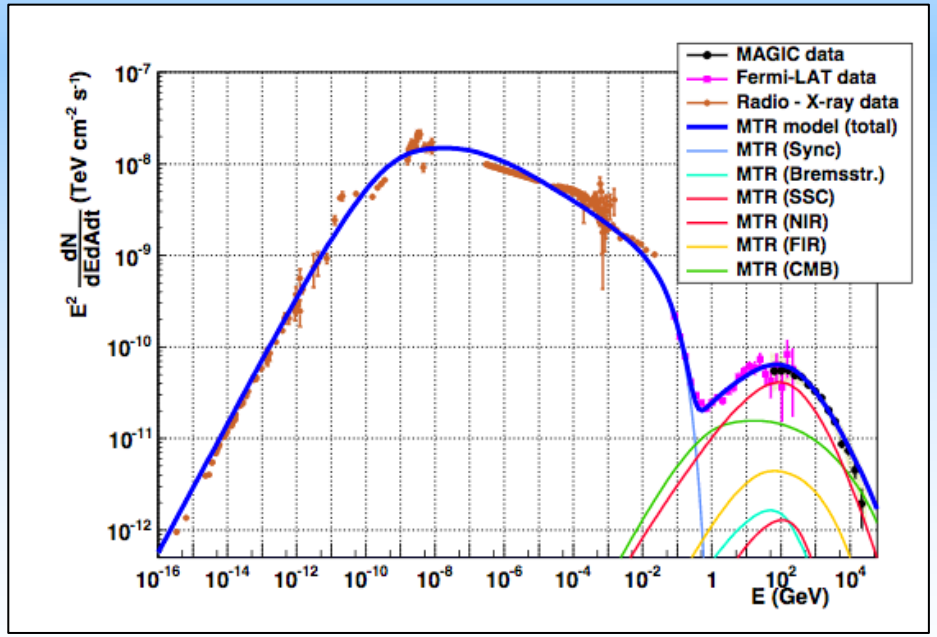
RX J 1713 .7-3946 with CTA

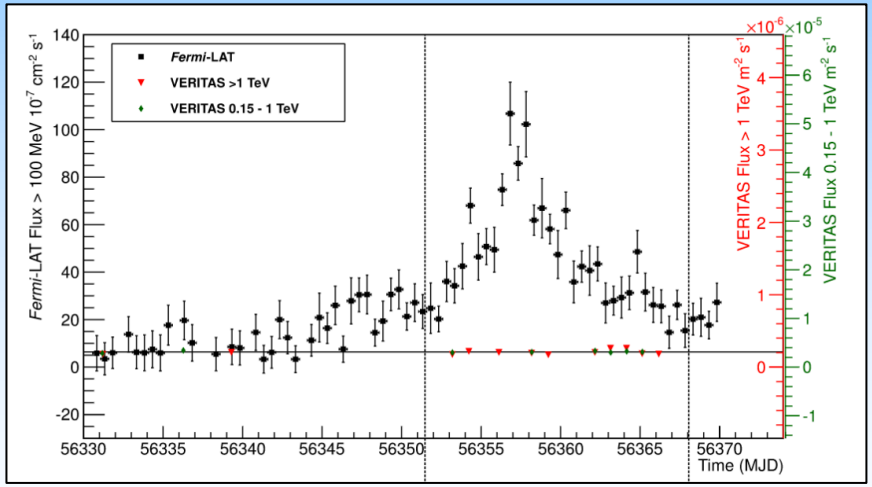


CTA Collaboration, ApJ (arXiv:1704.04136)

3. What is the nature of gamma-ray emission from the Crab?

- The Crab Nebula was the first astrophysical TeV gamma-ray source proposed (by Cocconi, 1959), and the first to be firmly detected (by Whipple, in 1989) – although at 1/10,000 of the predicted flux!
- Emission is SSC of leptons accelerated near the termination shock of the pulsar wind.
- The Fermi-LAT measured Crab flares have no counterpart at TeV.





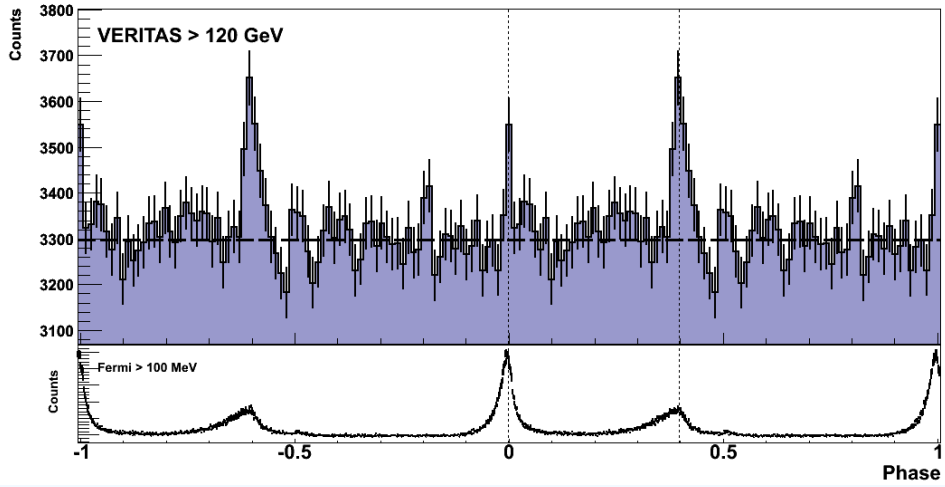
MAGIC Collaboration, JHEAp, 5, 30, 2015.

VERITAS Collaboration, ApJL, 781, 11, 2014.

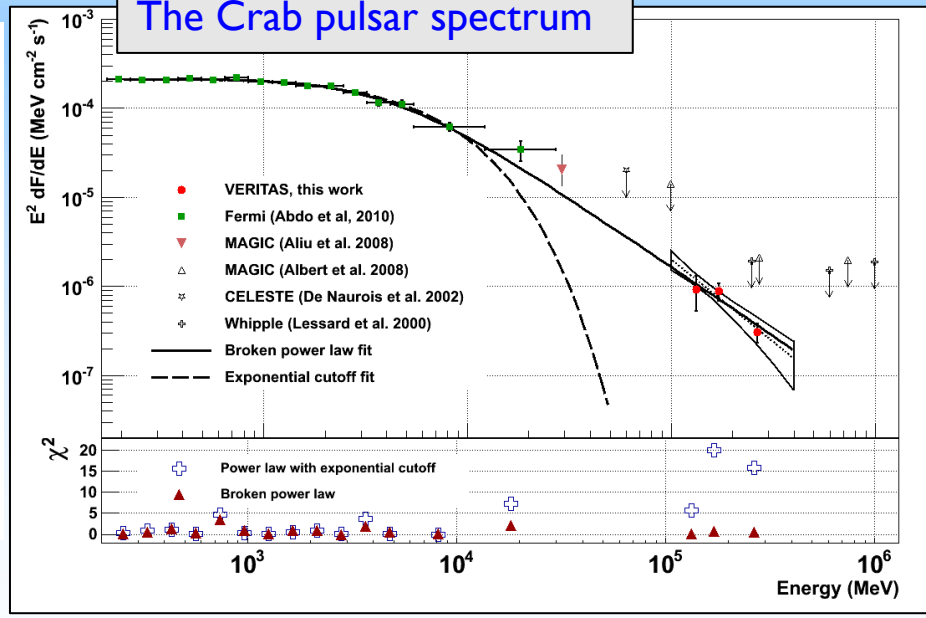
The Crab Pulsar

- Fermi-LAT measures a spectral break at 6 GeV
- VERITAS measures unpredicted emission above 100 GeV
- Implies emission region > 10 stellar radii.
- Absence of exponential cutoff makes curvature radiation unlikely as the dominant mechanism at these energies.
- Latest MAGIC results extend to 1 TeV.
- CTA will measure at least 12 Fermi pulsars, and tell us if the Crab is the only TeV pulsar.

The Crab pulsar lightcurve >120 GeV



The Crab pulsar spectrum

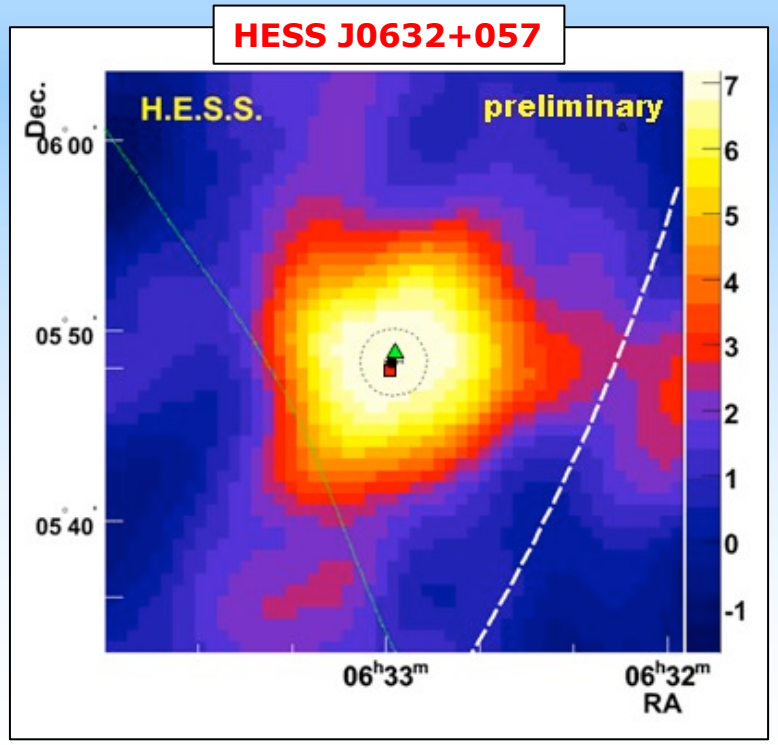


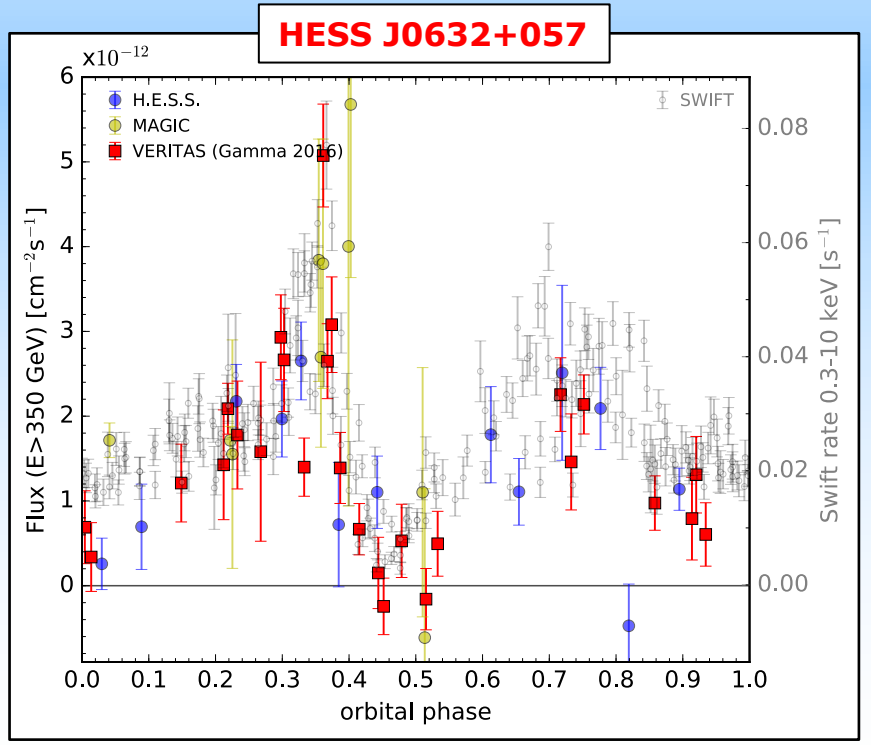
VERITAS Collaboration, Science, 334, 69, 2011.

4. Is Cyg X-3 a TeV gamma-ray source?

Are binary systems in general TeV sources?

- Cygnus X-3 motivated the birth of the field in the 70's and 80's.
- The early results were likely spurious. Cyg X-3 is a Fermi-LAT source, but the emission does not extend in to the >100 GeV range.
- A small population of TeV binaries have been detected.
- CTA will add to this – but probably not more than a handful.





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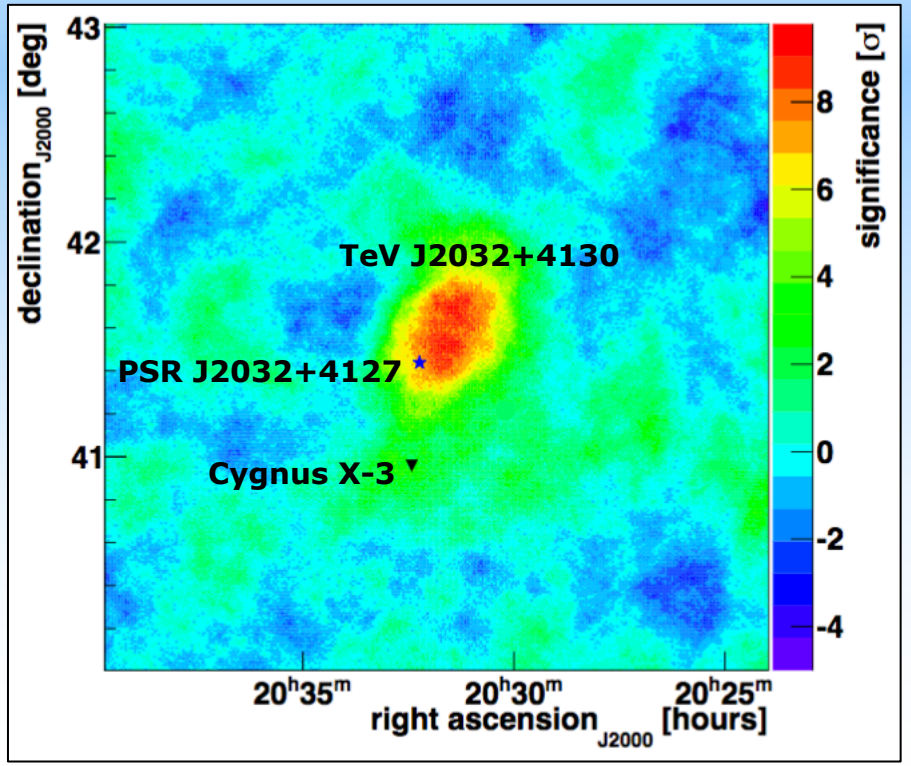
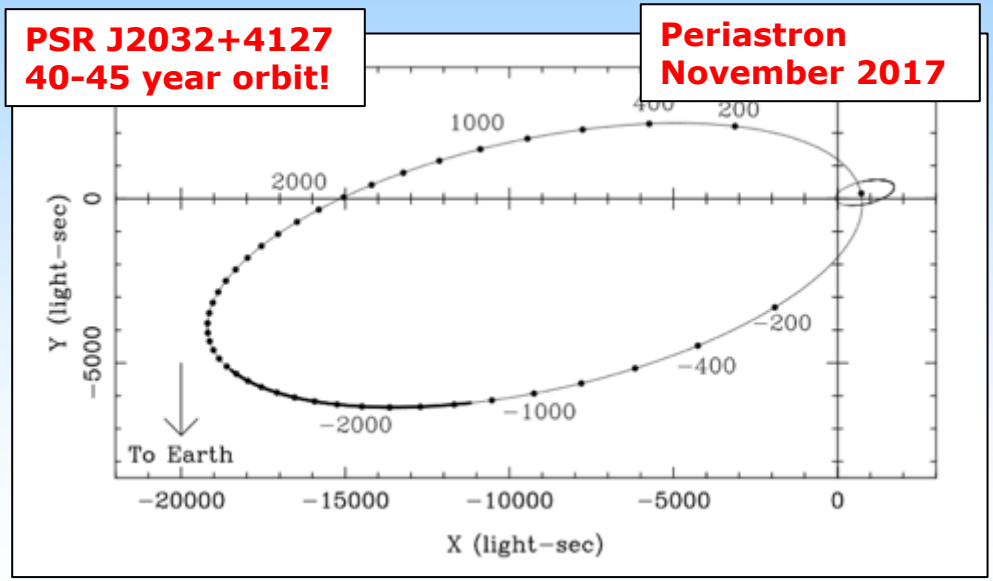


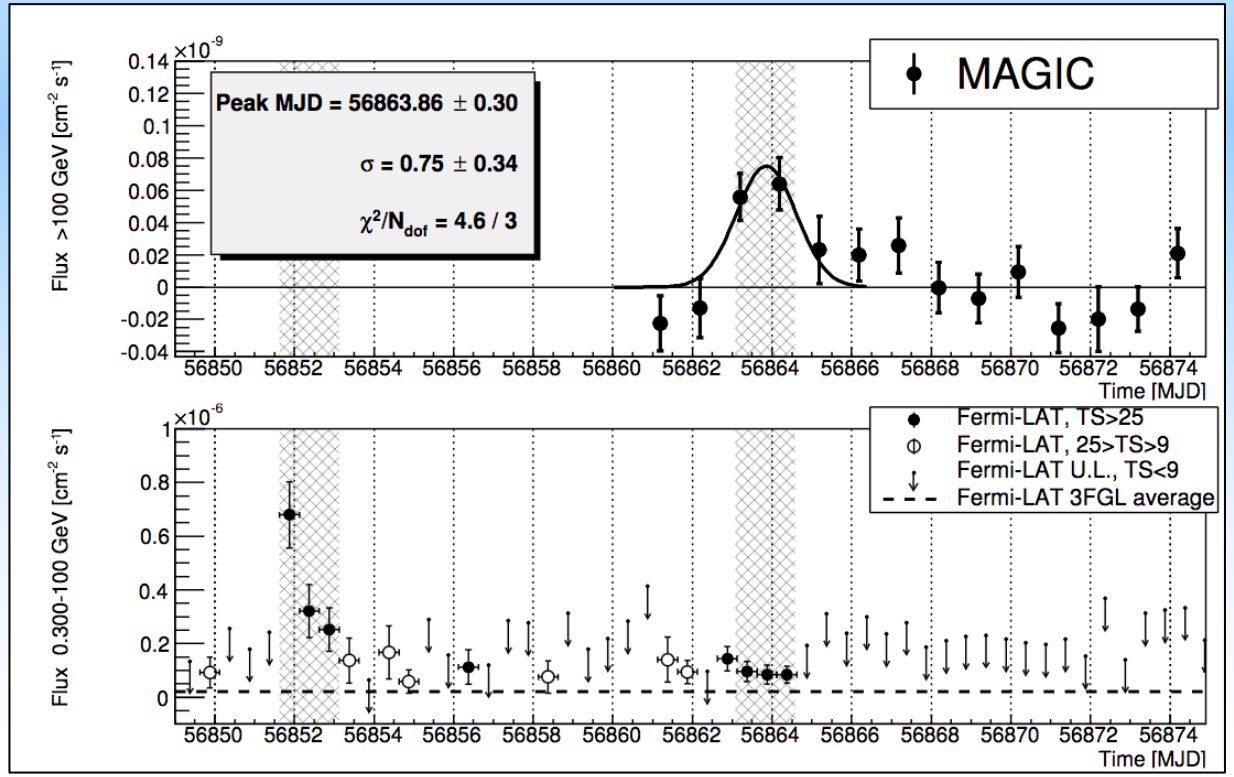
- Another one coming soon ?



5. How far can we see?

- Above 10 GeV, gamma-ray photons are absorbed by pair production with photons of the extragalactic background light.
  - This limits the gamma-ray observable Universe.
  - But allows to measure or constrain the EBL.
- Active Galactic Nuclei with redshifts of ~1 have been detected by the current generation.

QSO B0218+357
z=0.944



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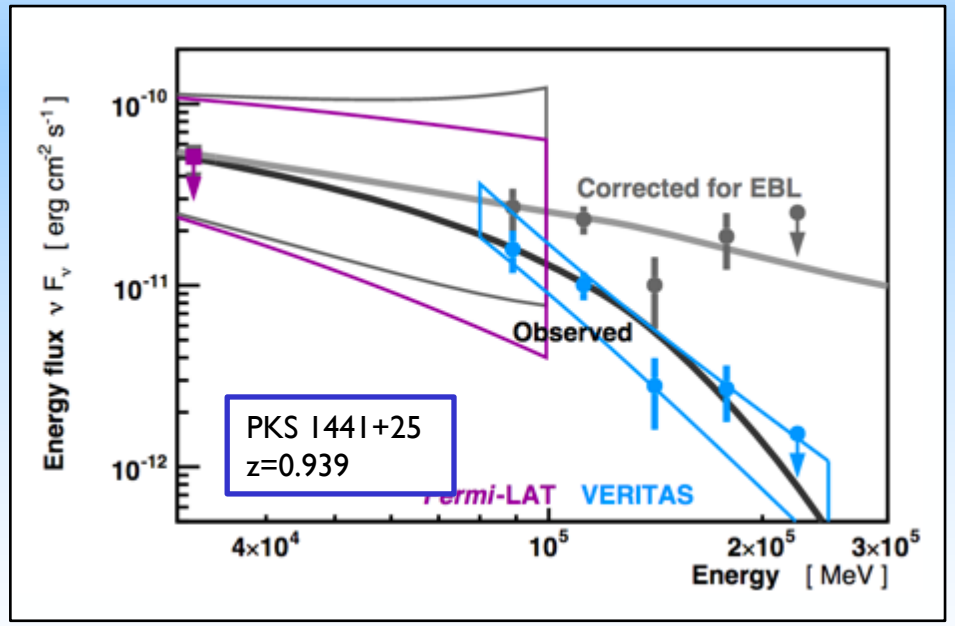
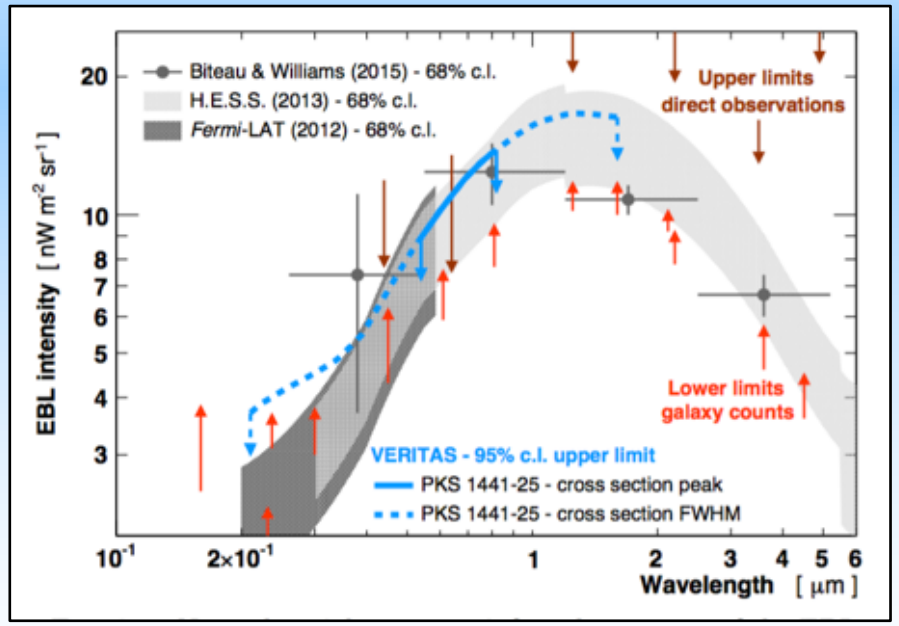
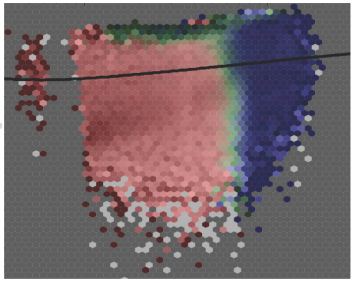
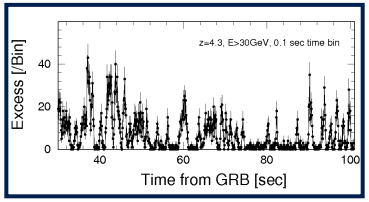




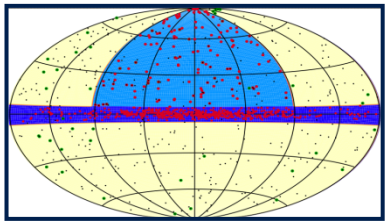
Addressing new questions: CTA Key Science Projects



Dark Matter Programme

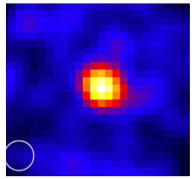


Transients



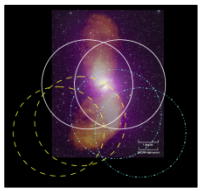
ExGal Survey

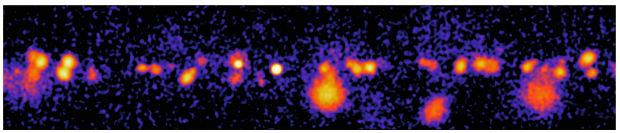
Galaxy Clusters



Star Forming Systems

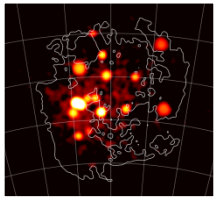
AGN



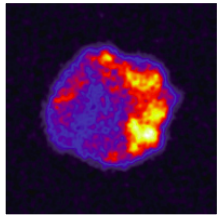


Galactic Plane Survey

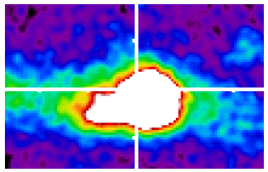
LMC Survey



PeVatrons



Galactic Centre

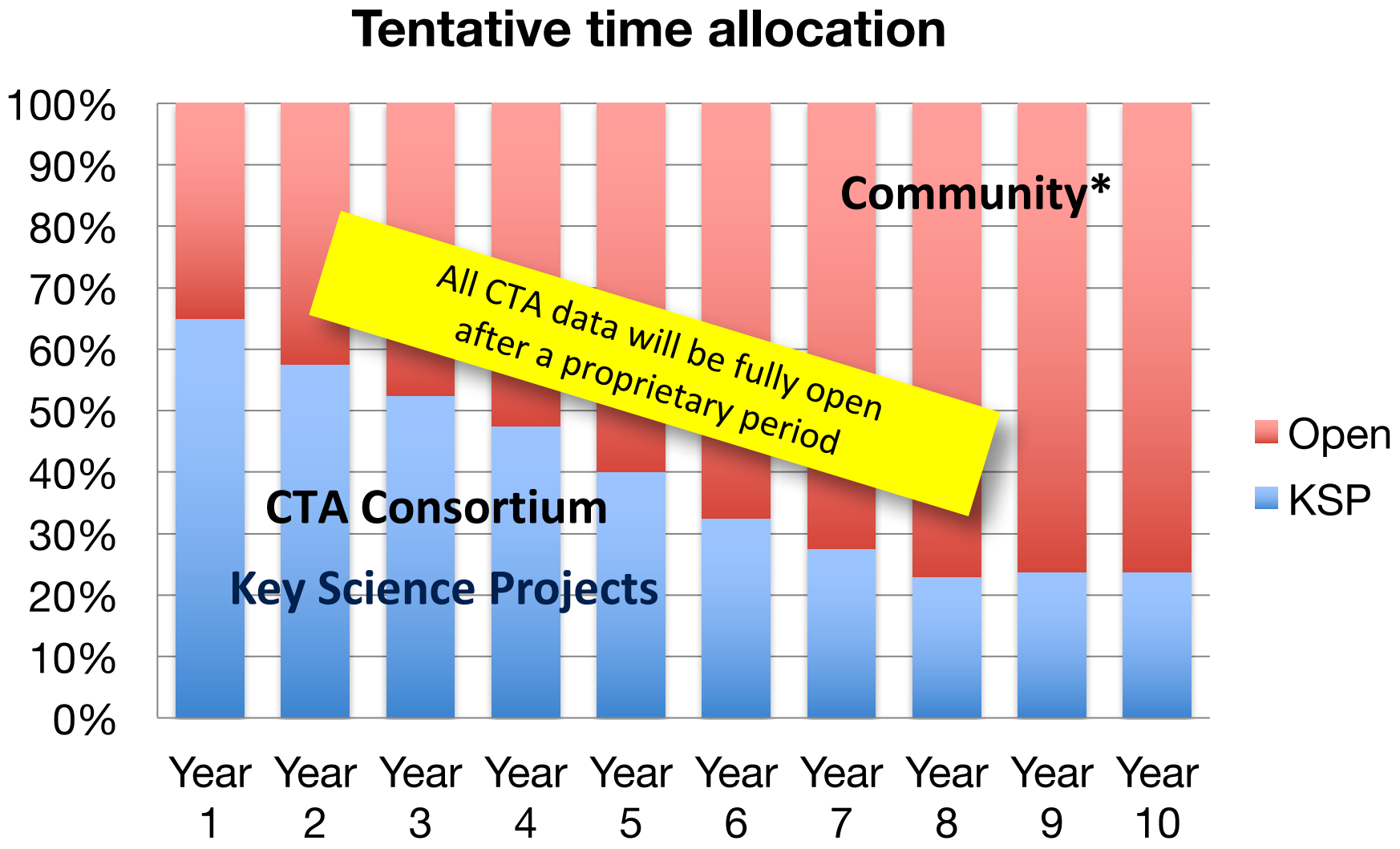


Extragalactic

Galactic

25

Time Allocation & Community Access



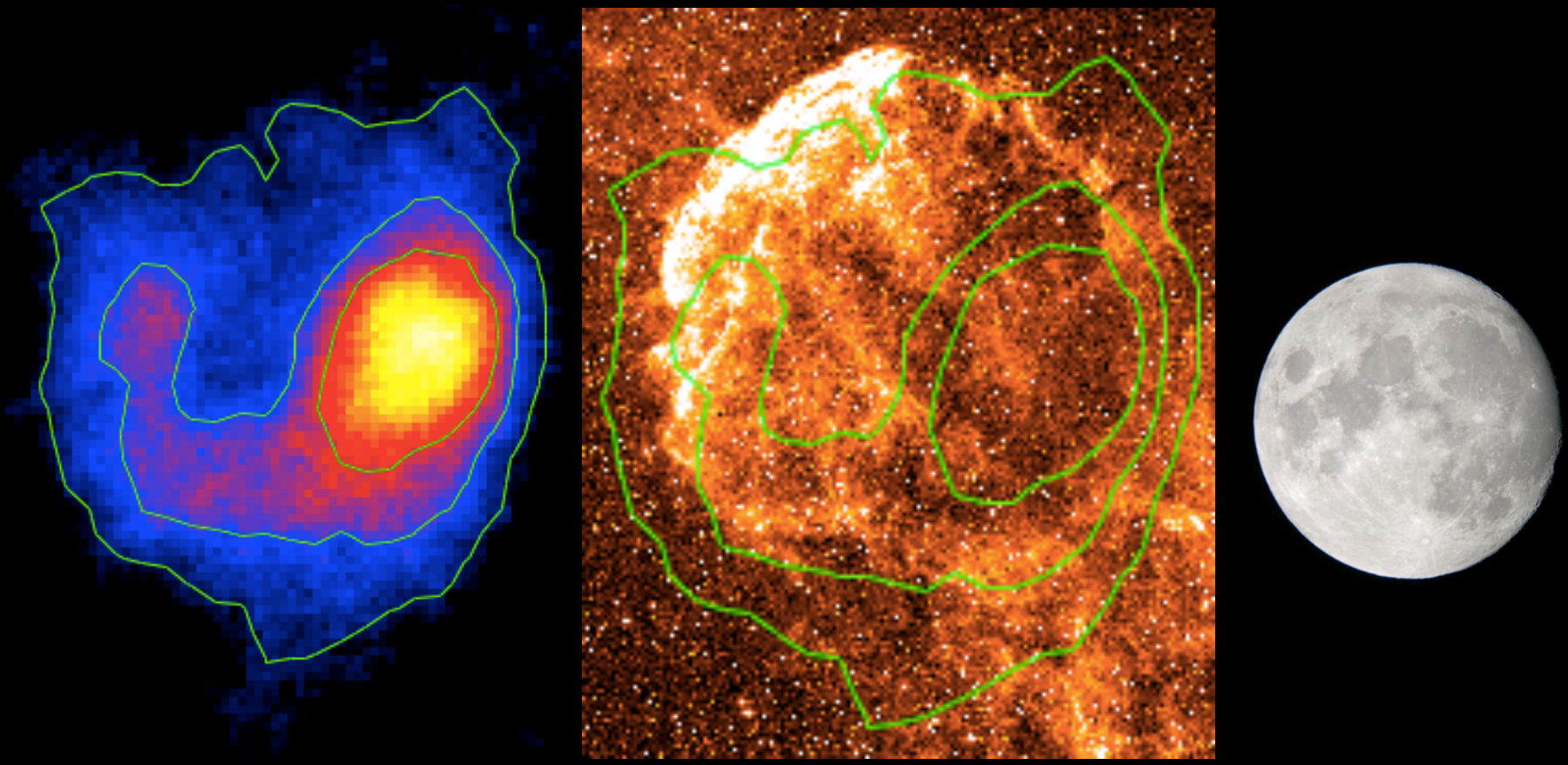
*of scientists from nations contributing to CTA construction and operations and from site host nations

Summary

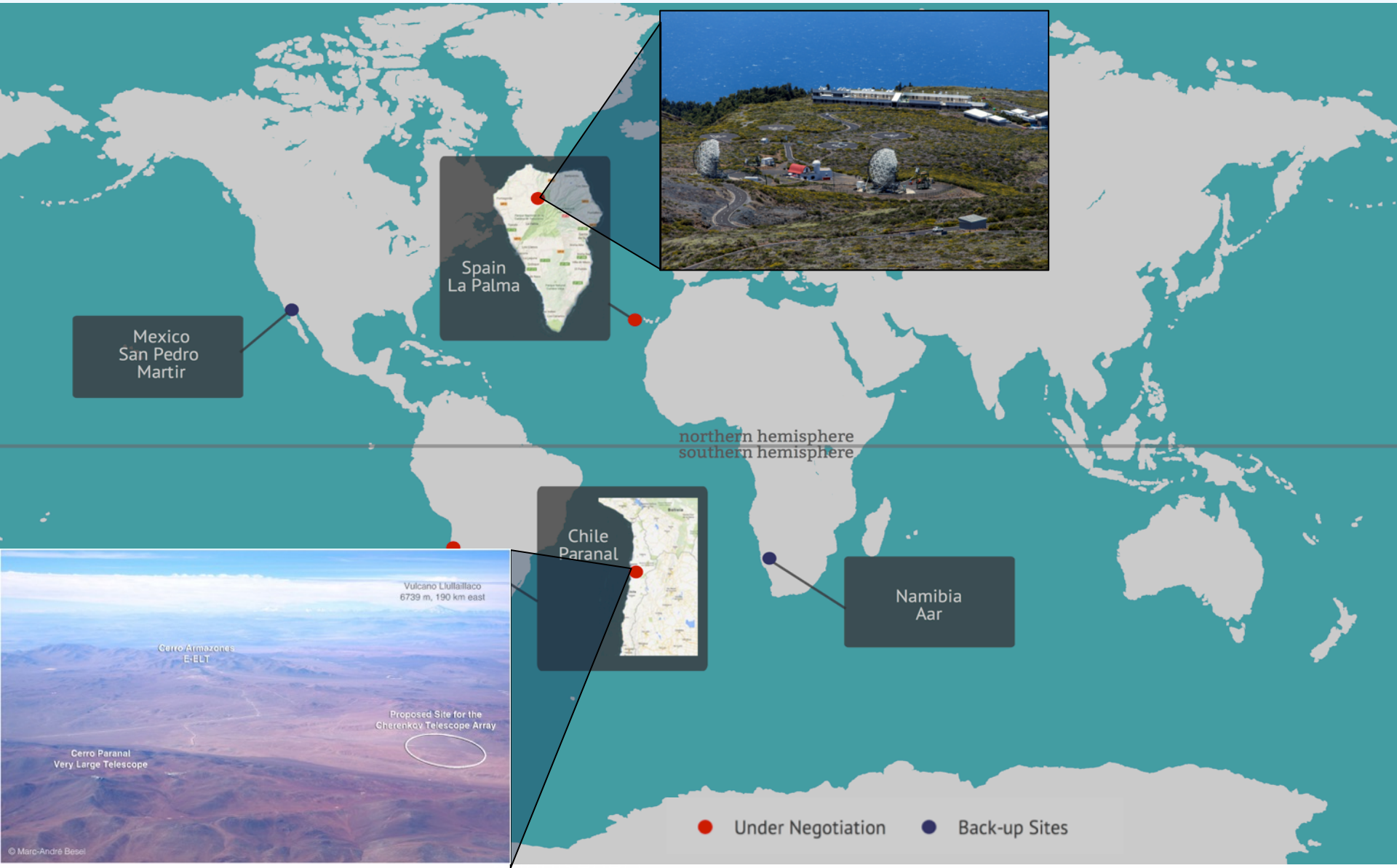
"Your talk should be presented as a compact presentation of **recent results** and **major open questions** persisting in the field, with an emphasis on **what can be done** in the coming decade - experimentally, theoretically or both - to resolve these questions."

- TeV gamma-ray astronomy is rich with results, but is far from reaching its full potential.
- Great progress has been made on many of the original questions.
- The answers lead to new (and interesting) questions!
- See Brian Humensky's talk at this meeting for prospects for gamma-ray searches for astrophysical neutrino counterparts.

IC 443 with VERITAS



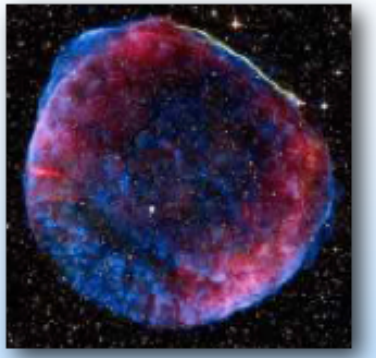
SITES


Spain
La Palma
Mexico
San Pedro
Martir
northern hemisphere
southern hemisphere
Chile
Paranal
Namibia
Aar
Vulcano Llullaillaco
6739 m, 190 km east
Cerro Armazones
E-ELT
Proposed Site for the
Cherenkov Telescope Array
Cerro Paranal
Very Large Telescope
© Marc-André Besel
Under Negotiation
Back-up Sites

New Questions: CTA Science Themes

Cosmic Particle Acceleration

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



Probing Extreme Environments

- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Exploring cosmic voids

Physics frontiers – beyond the Standard Model

- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high-energy photons?
- Do axion-like particles exist?

See: Astroparticle Physics, Vol. 43, 1-356 (2013) & CTA Contributions to the 2015 ICRC Conference [arXiv:1508.05894]

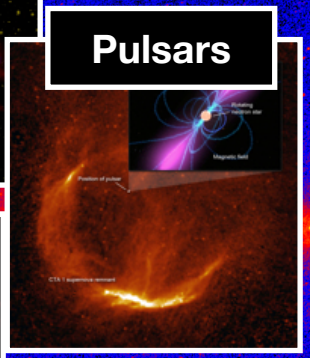
Broad Spectrum of Science

Particle Acceleration

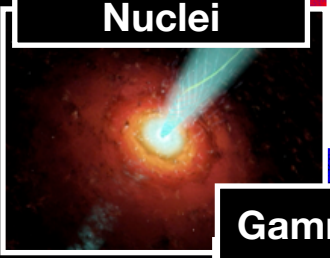
Cosmic Rays

Supernova Remnants

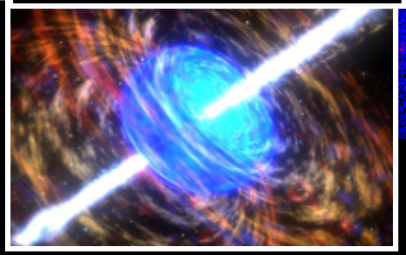
Pulsars



Active Galactic Nuclei

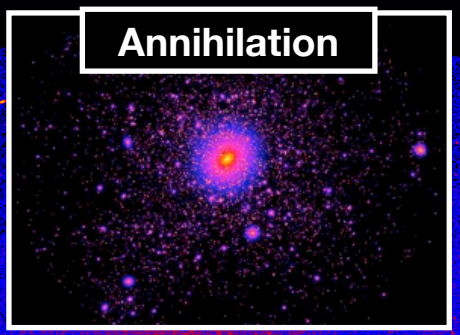


Gamma-ray Bursts



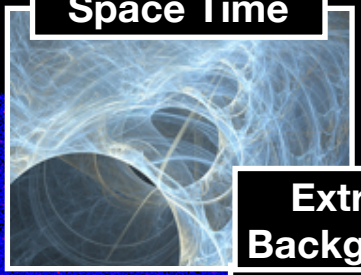
Dark Matter

Annihilation



Cosmology

Space Time



Extragalactic Background Light

Primordial Black Holes

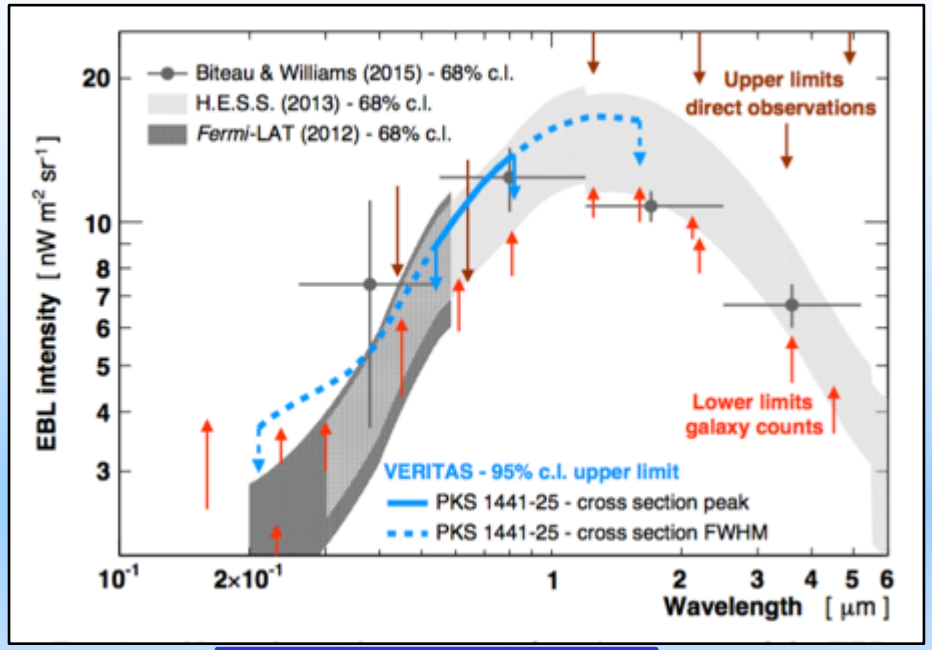
Axion-like Particles

... ?

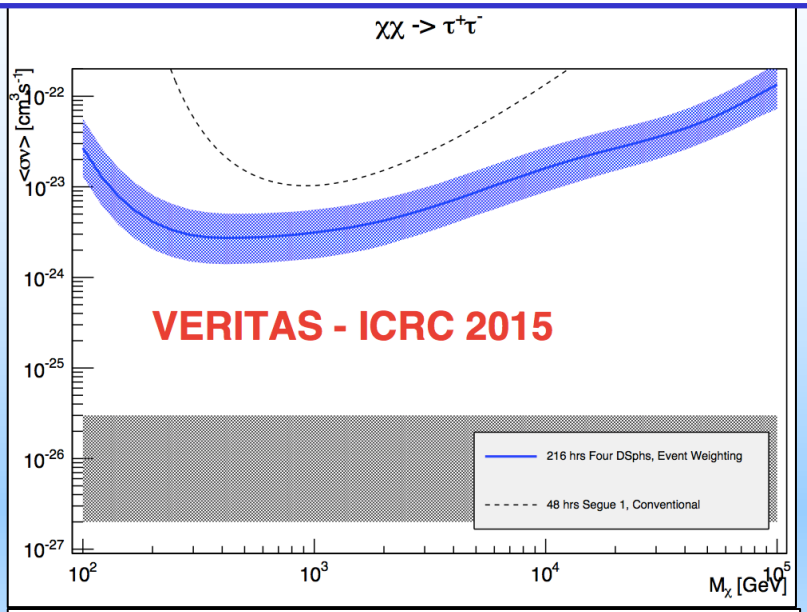
Opens discovery space by major improvements in sensitivity, FoV, energy range

Particle Astrophysics and Fundamental Physics

Using distant blazars as **cosmological probes**



Hunting for **dark matter** in dwarf spheroidals and galaxy clusters



Cosmic ray measurements