Introduction to Key Science Projects & Particle Acceleration in CTA

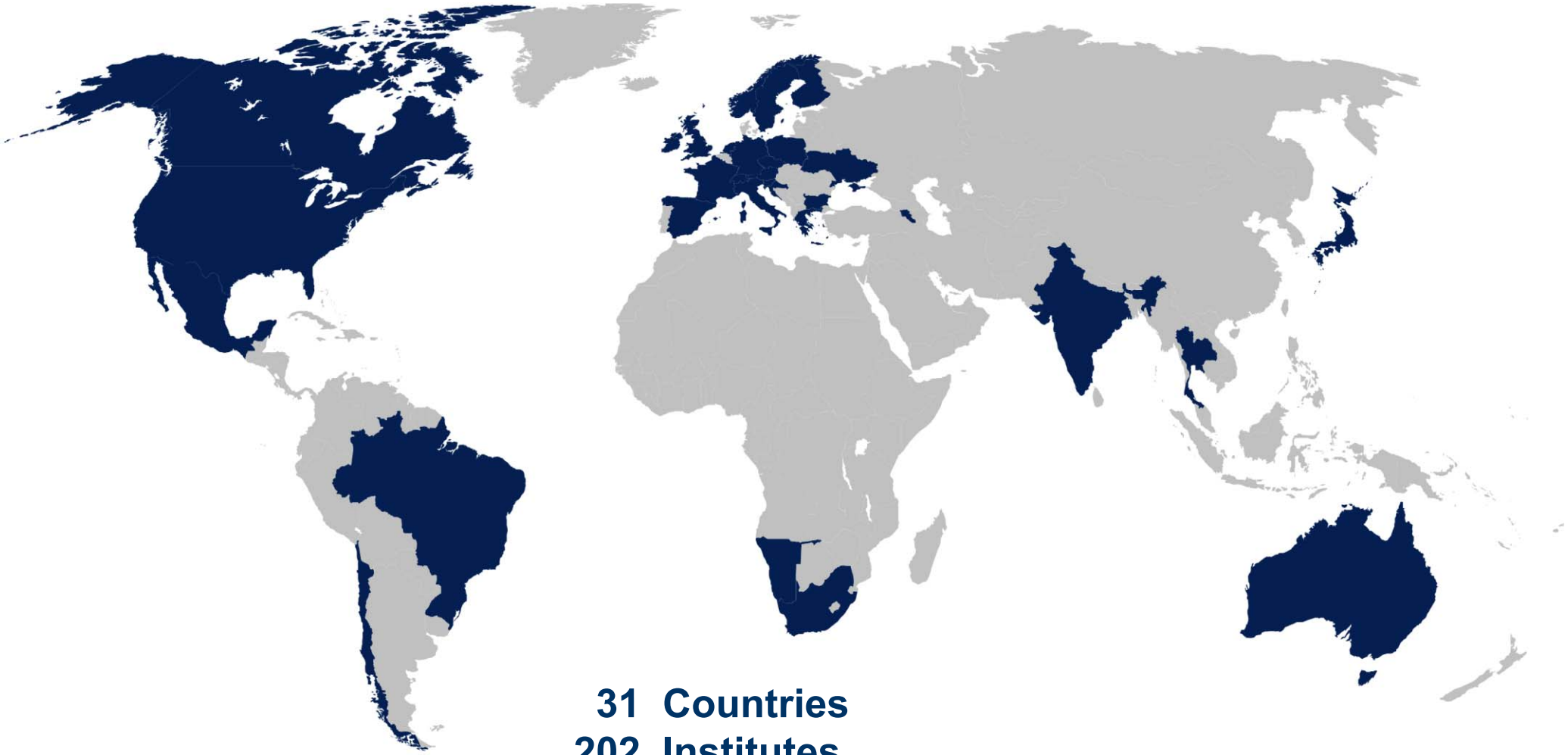
The CTA Consortium[1], represented by

Rene A. Ong[2]

[1]See https://www.cta-observatory.org/consortium_authors/authors_2019_05.html
[2]University of California, Los Angeles, CA 90095, USA

CTA Consortium

cherenkov telescope array



31 Countries
202 Institutes
1451 Members (508 FTE)

April 2019

We gratefully acknowledge financial support from the agencies and organizations listed here: http://www.cta-observatory.org/consortium_acknowledgments

Outline

- **CTA Key Science Project (KSPs)**

  Concept & Formulation

  Introduction to the (9) KSPs

- **CTA Survey KSPs**

  Galactic Plane Survey, Galactic Centre, and Extragalactic Survey, (LMC Survey)

- **Particle Acceleration in CTA**

  PeVatron and Star Formation Systems KSPs

- **Summary**

Caveat: Not able to cover in detail all of the CTA KSPs

CTA Main Scientific Themes

Cosmic Particle Acceleration

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

Explore origin and role of relativistic particles

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

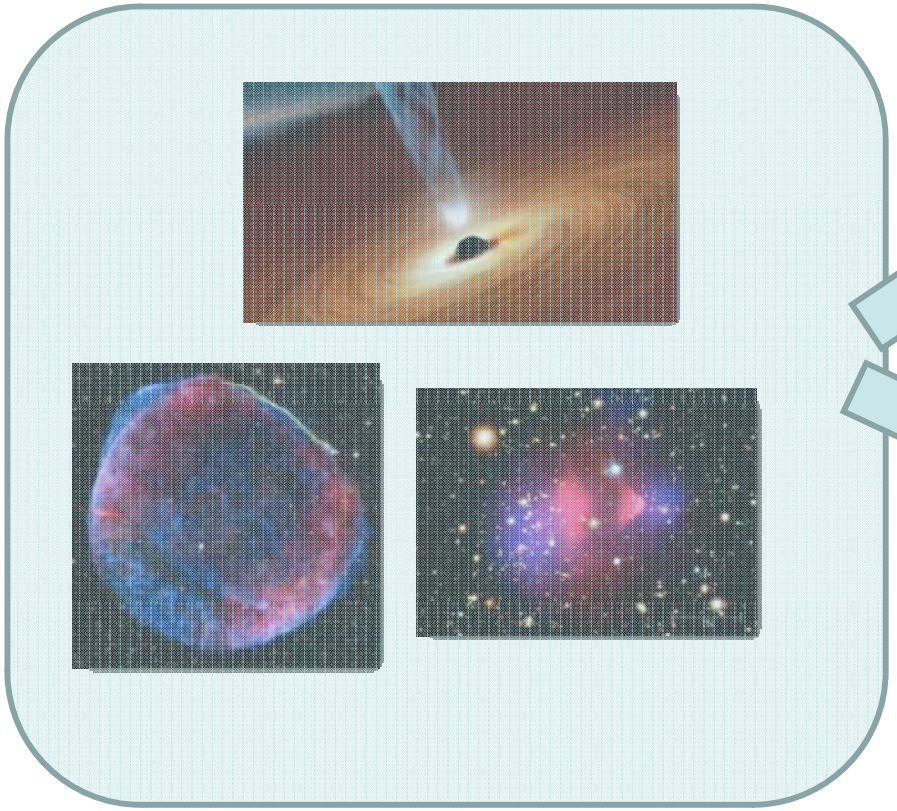
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high-energy photons?
- Do axion-like particles exist?

See S. Sarkar
"New Physics in Key Science Projects"

CTA Main Scientific Themes

cherenkov telescope array

CTA Science



Key Science Projects (KSP) ~40% Time

Guest Obs (GO) Programme 40-50% Time*

*Remaining is reserved host time (country,ESO)

KSP Concept

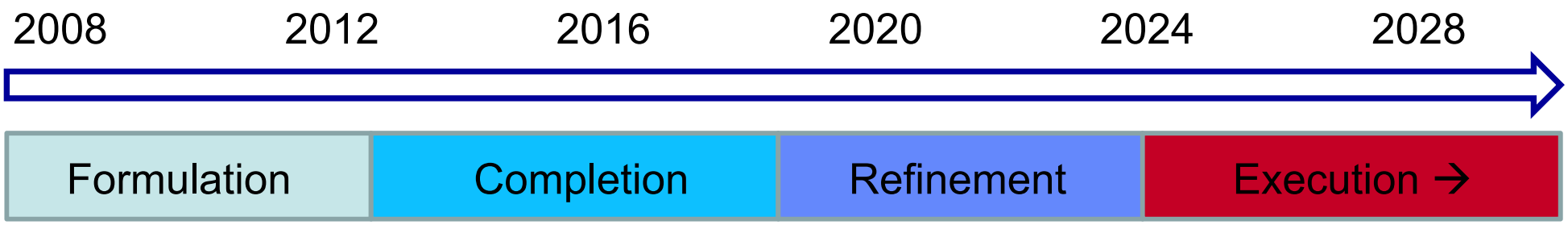
Concept

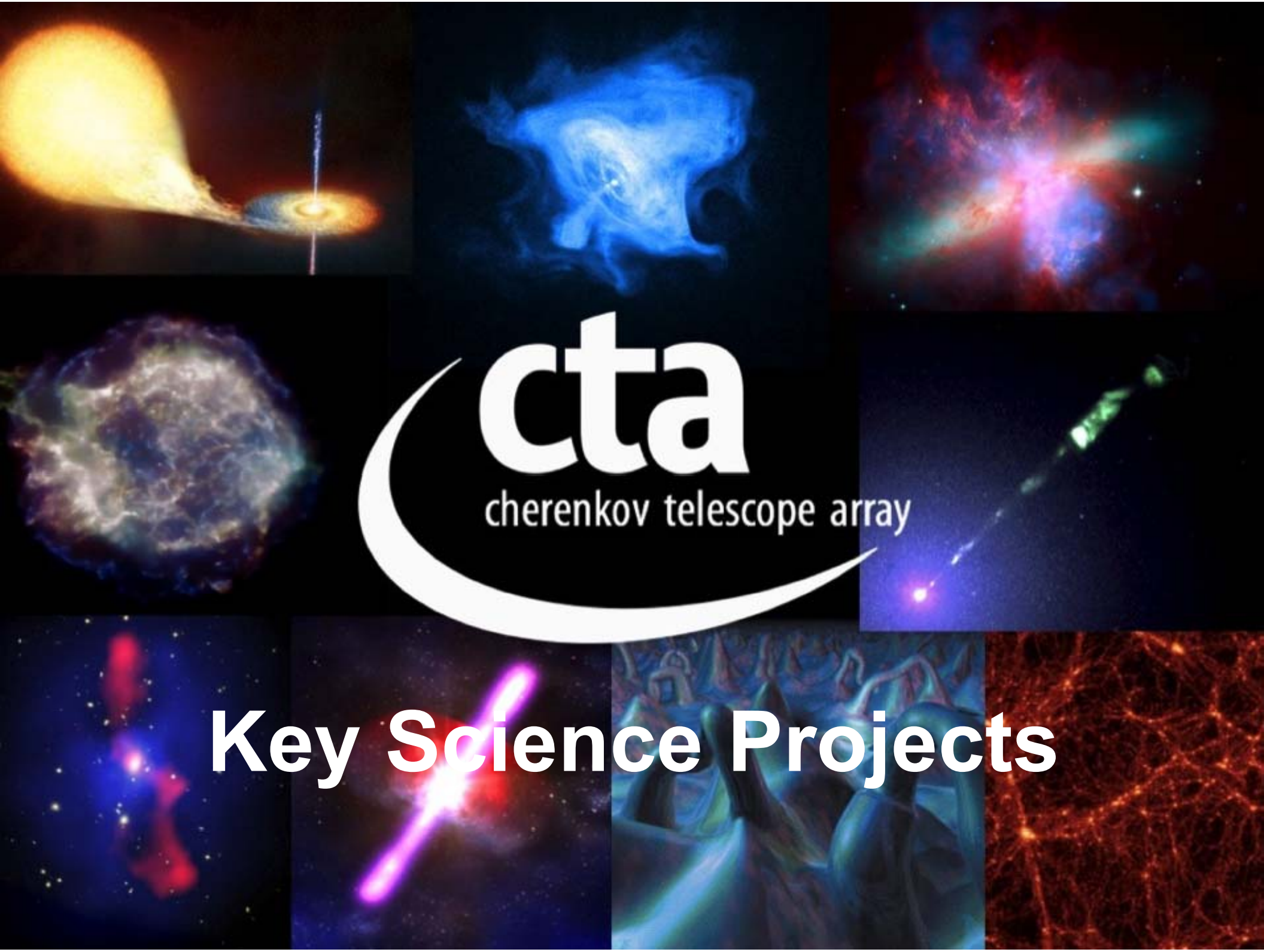
- Providing major insight into one or more physical problems through deep observations or sets of combined observations
- Major observational programmes (e.g. surveys), difficult to achieve in GO programme
- Maximize scientific return with early key science – provide “legacy” results and seed GO programme
- Logical mapping to CTA science themes
- Needing Consortium leadership – critical expertise with Cherenkov technique and analysis methods
- All data on public archive after proprietary period (of ~1 year)

KSP Development

KSPs developed via lengthy and rigorous process with input from many people

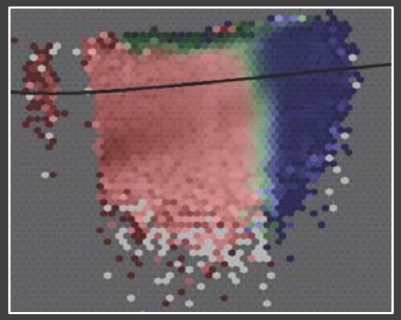
CTA Consortium: PHYS and MC/ASWG work packages



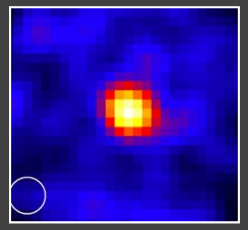


Key Science Projects

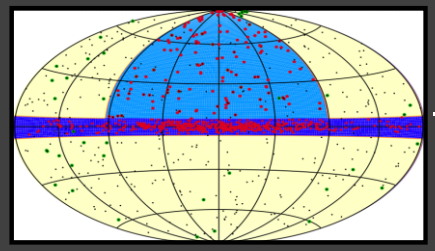
CTA Key Science Projects



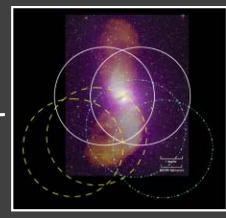
Dark Matter Programme



Galaxy Clusters



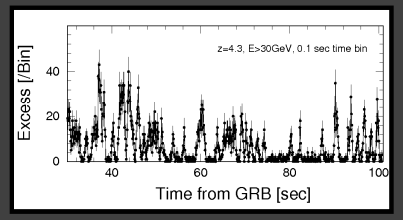
ExGal Survey



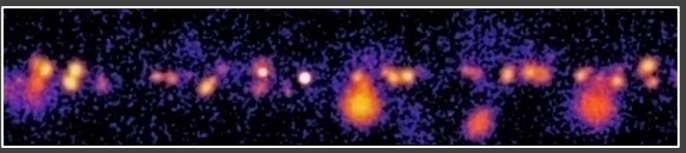
AGN

Extragalactic

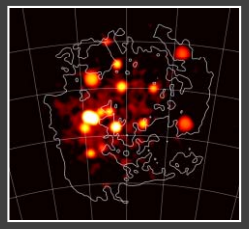
Star Forming Systems



Transients

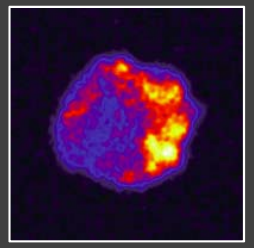


Galactic Plane Survey

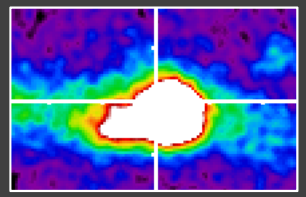


LMC Survey

Galactic



PeVatrons



Galactic Centre

Science Themes ← → KSPs

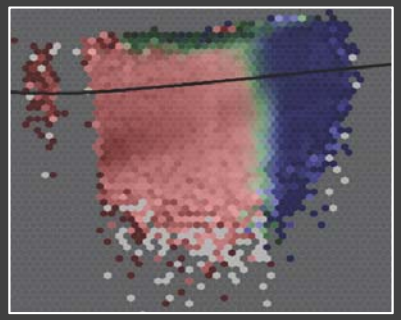
Mapping of Science Themes to KSPs

- Each theme/question is addressed by multiple KSPs
- Each KSP addresses multiple questions

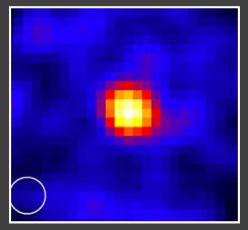
Theme		Question		Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
1	Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
		1.2	What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	
		1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
2	Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
		2.2	What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
		2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
3	Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
		3.2	Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
		3.3	Do Axion-like particles exist?					✔	✔			✔✔	

The Cherenkov Telescope Array Consortium, Science with the Cherenkov Telescope Array (World Scientific Publishing, 2019), ISBN 978-981-3270-08-4, arXiv: 1709.07997, DOI: 10.1142/10986

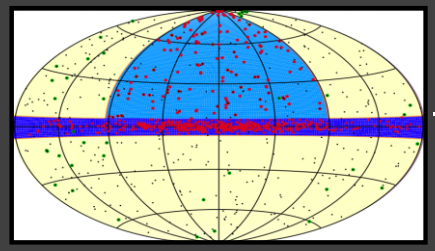
CTA Key Science Projects



Dark Matter Programme

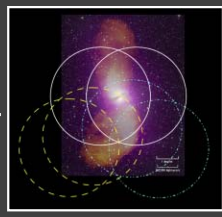


Galaxy Clusters



ExGal Survey

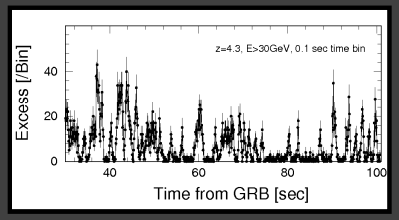
AGN

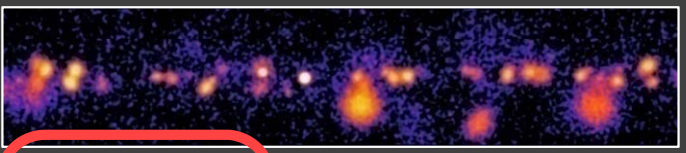


Extragalactic

Star Forming Systems

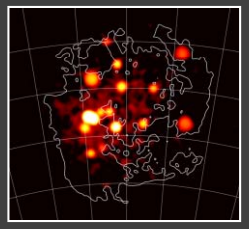
Transients





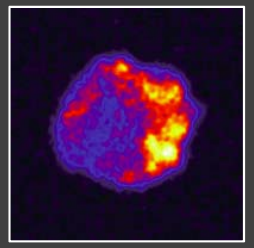
Galactic

LMC Survey

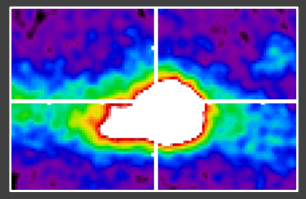


Galactic Plane Survey

PeVatrons



Galactic Centre



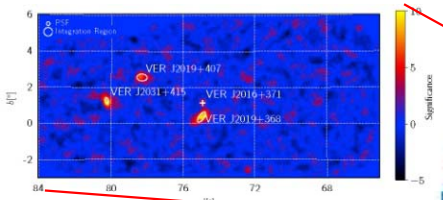
KSP Surveys
(LMC, see backup)

Galactic Plane Survey (GPS)

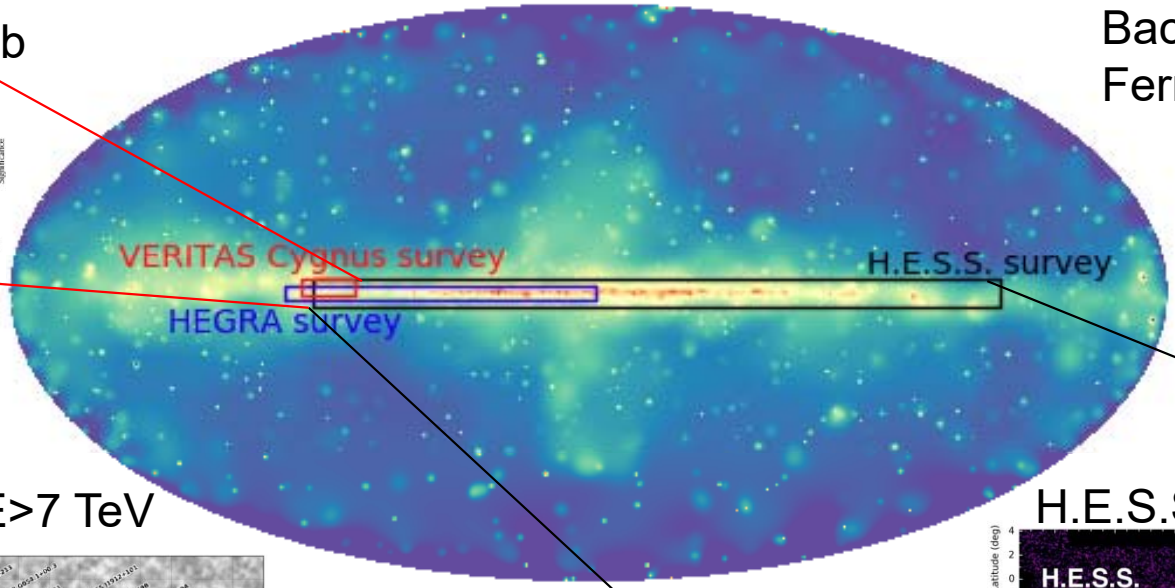
cherenkov telescope array

Previous plane surveys with VHE gamma rays:

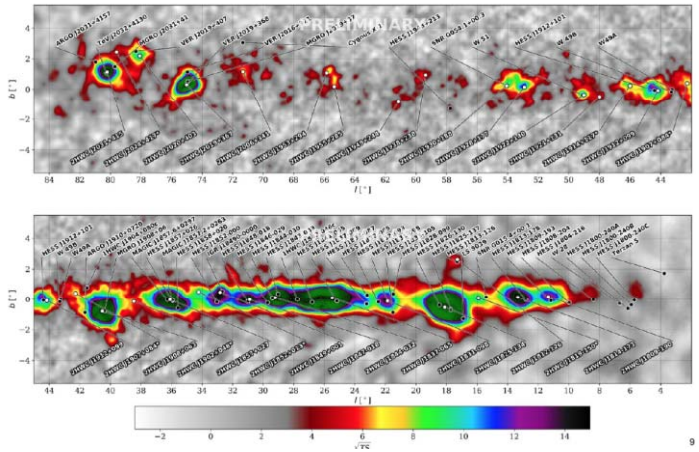
VERITAS ~2% Crab



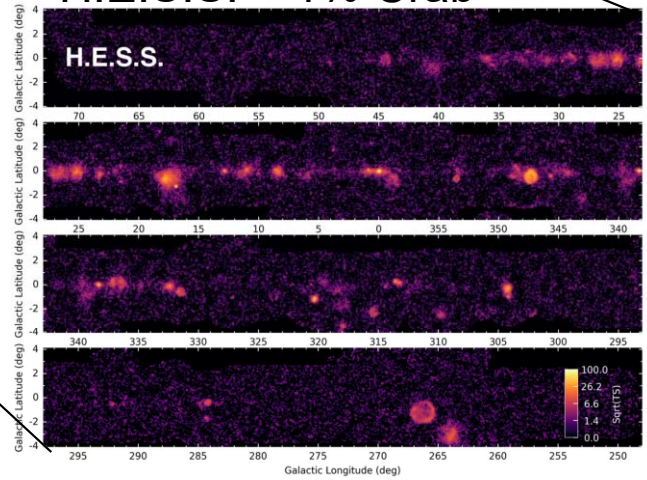
Background:
Fermi-LAT > 50GeV map



HAWC
Overhead sky, E>7 TeV



H.E.S.S. ~1% Crab



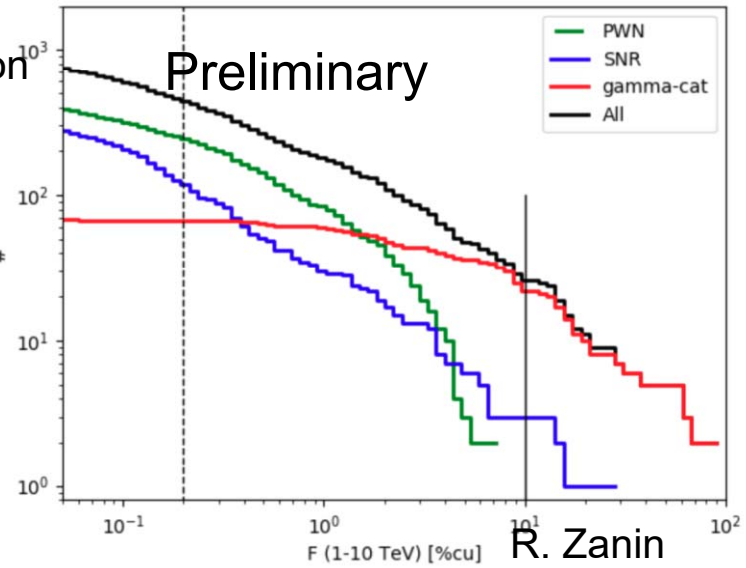
- Previous work important, but at medium sensitivity and at high E
- Need for a full plane survey at *high sensitivity* and *high resolution*

Galactic Plane Science

Population Studies

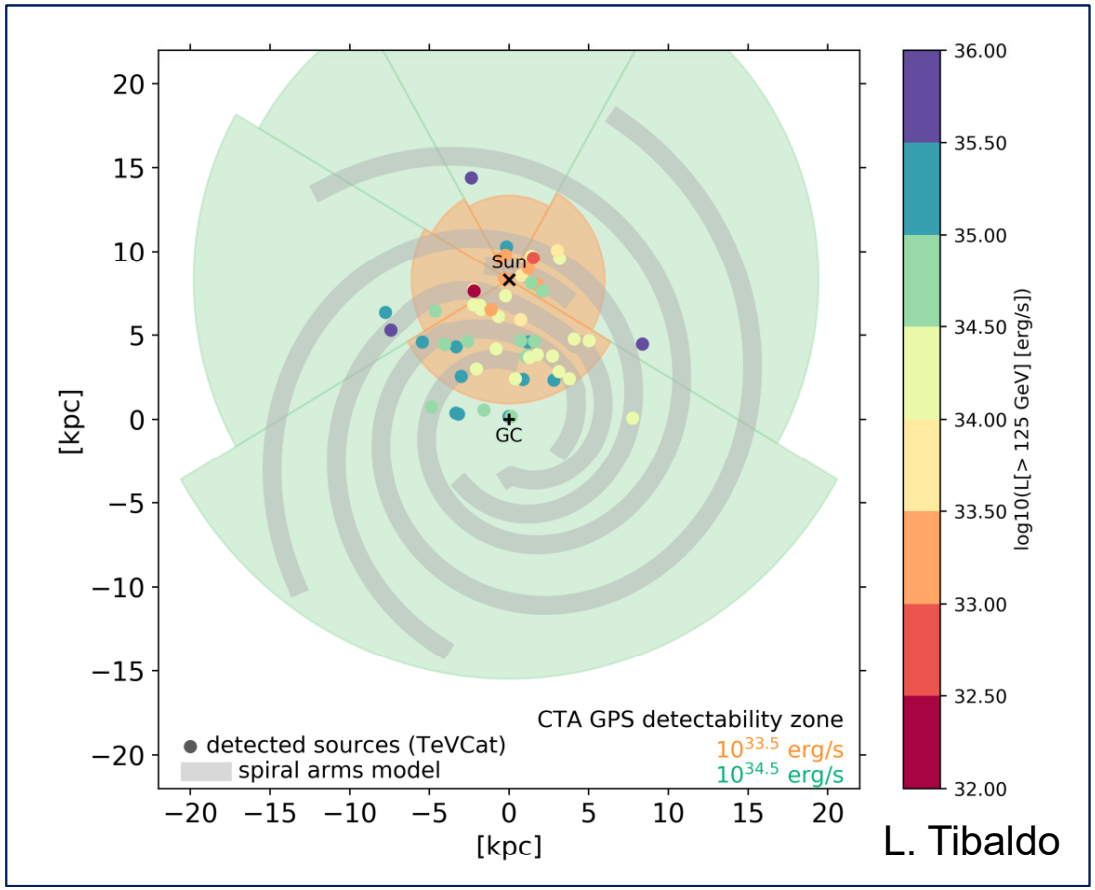
population models

detected sources



R. Zanin

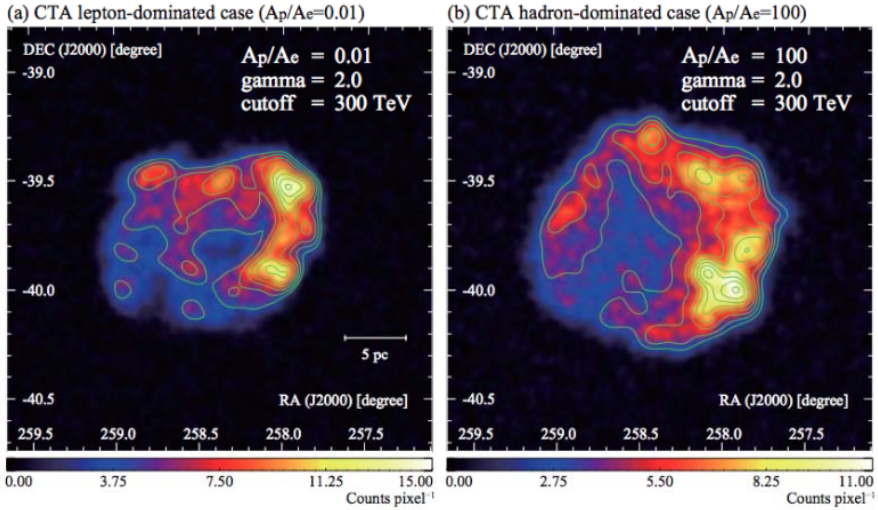
Reaching the entire Galaxy



L. Tibaldo

See L. Tibaldo "Survey of the Galactic Plane with the Cherenkov Telescope Array" (poster)

Precision Morphology

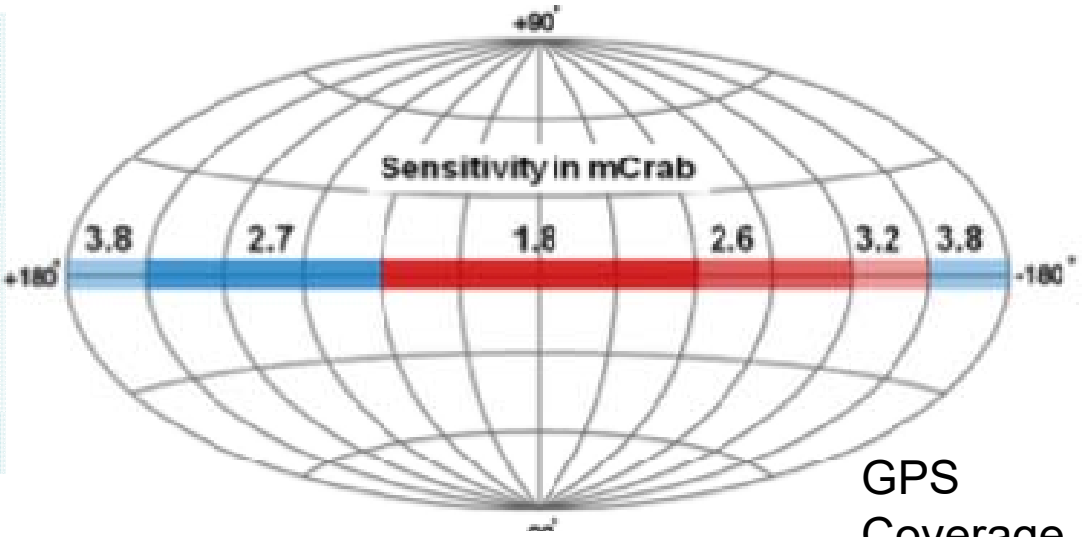


RXJ 1713-3946

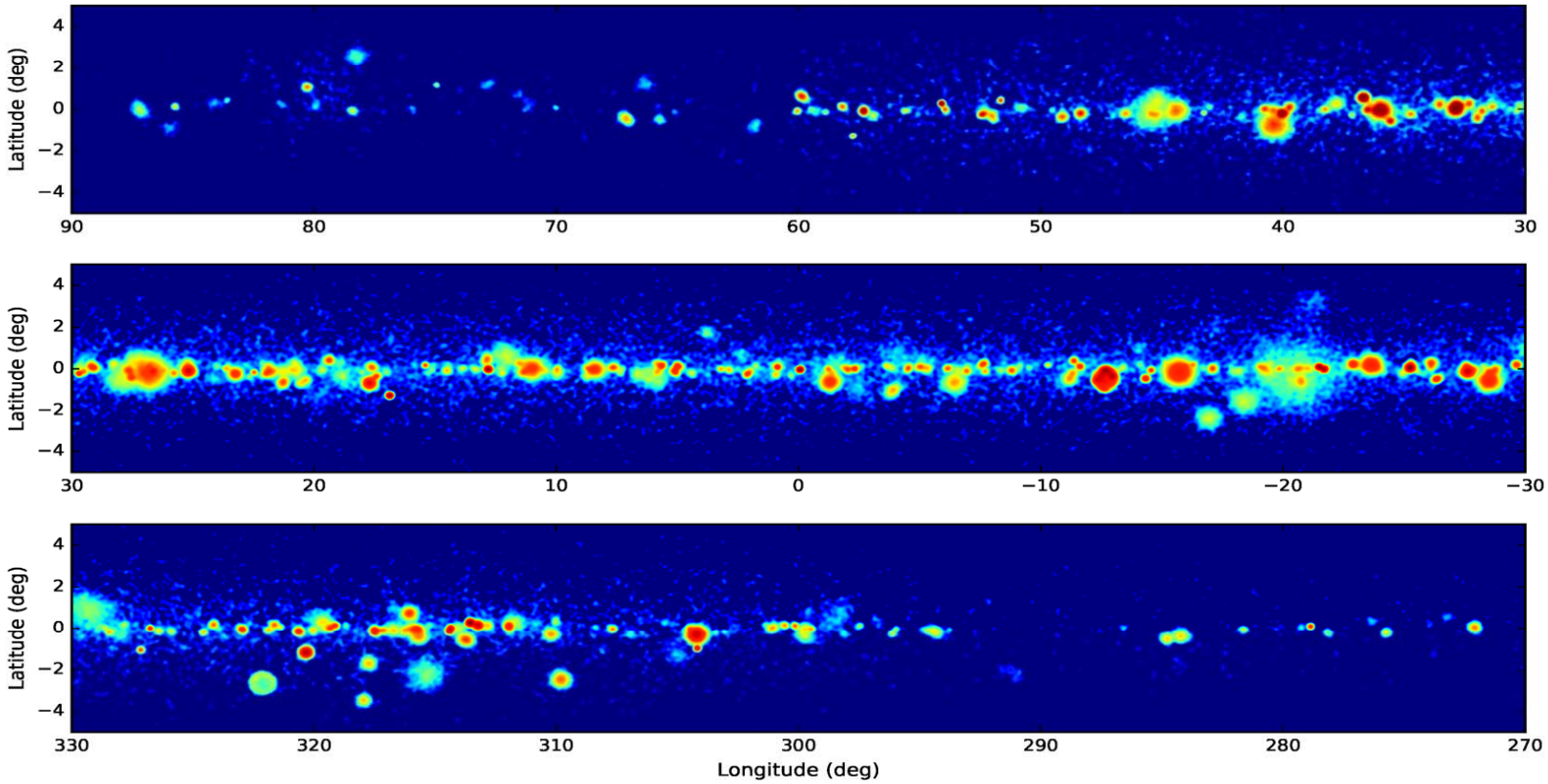
CTA Consortium
ApJ 840, 74 (2017)

GPS Plan & Attributes

- First high sensitivity survey at TeV energies
- Full-plane survey at arc-minute resolution
- Expect many100's of new sources: e.g. PWNe, SNRs and binaries
- Detailed view of diffuse γ-ray emission: *MWL information of high importance*
- **Great potential for new discoveries !**



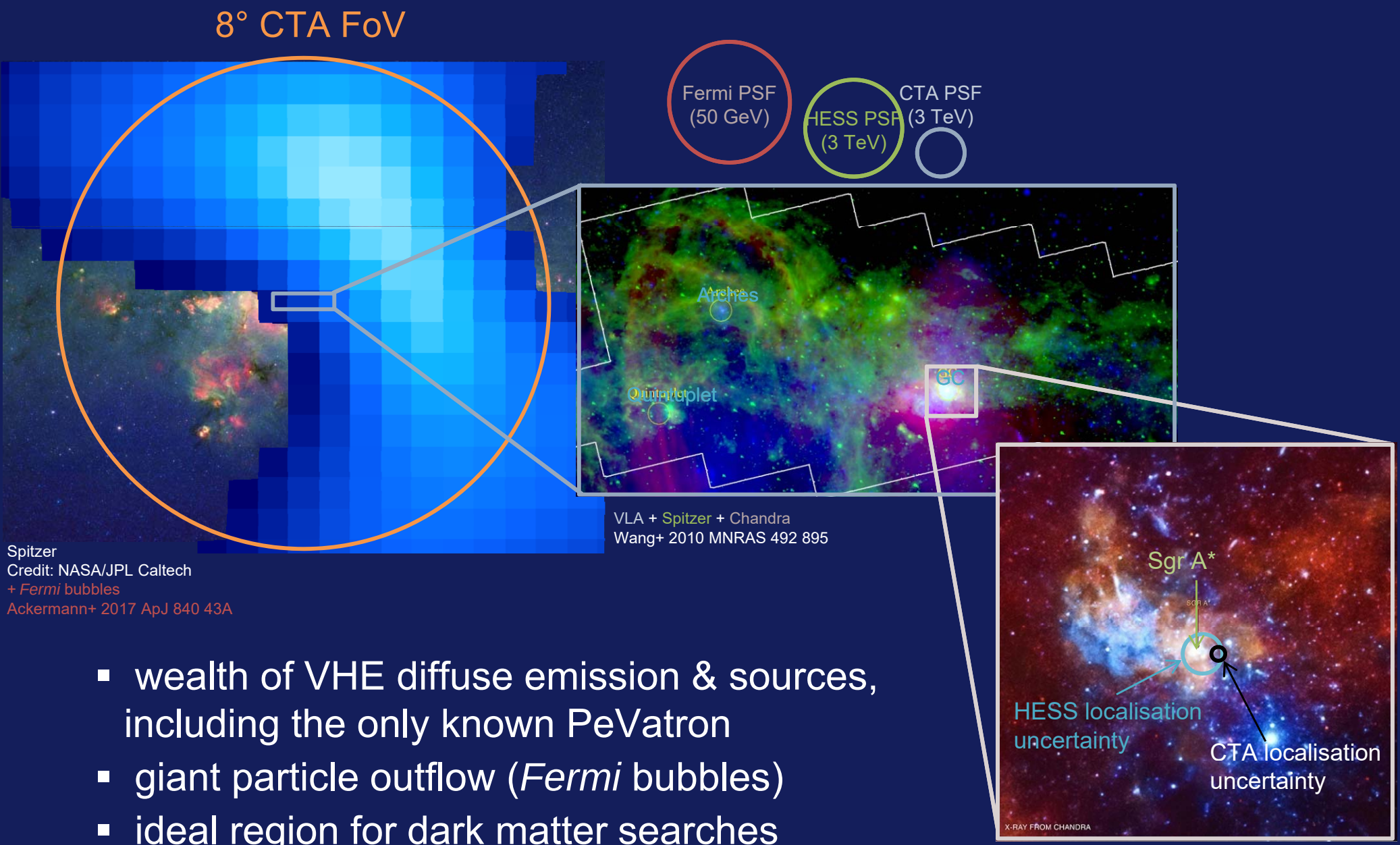
GPS Coverage



Simulated GPS Skymap (CTAC)

Galactic Centre with CTA

Slide courtesy of L. Tibaldo



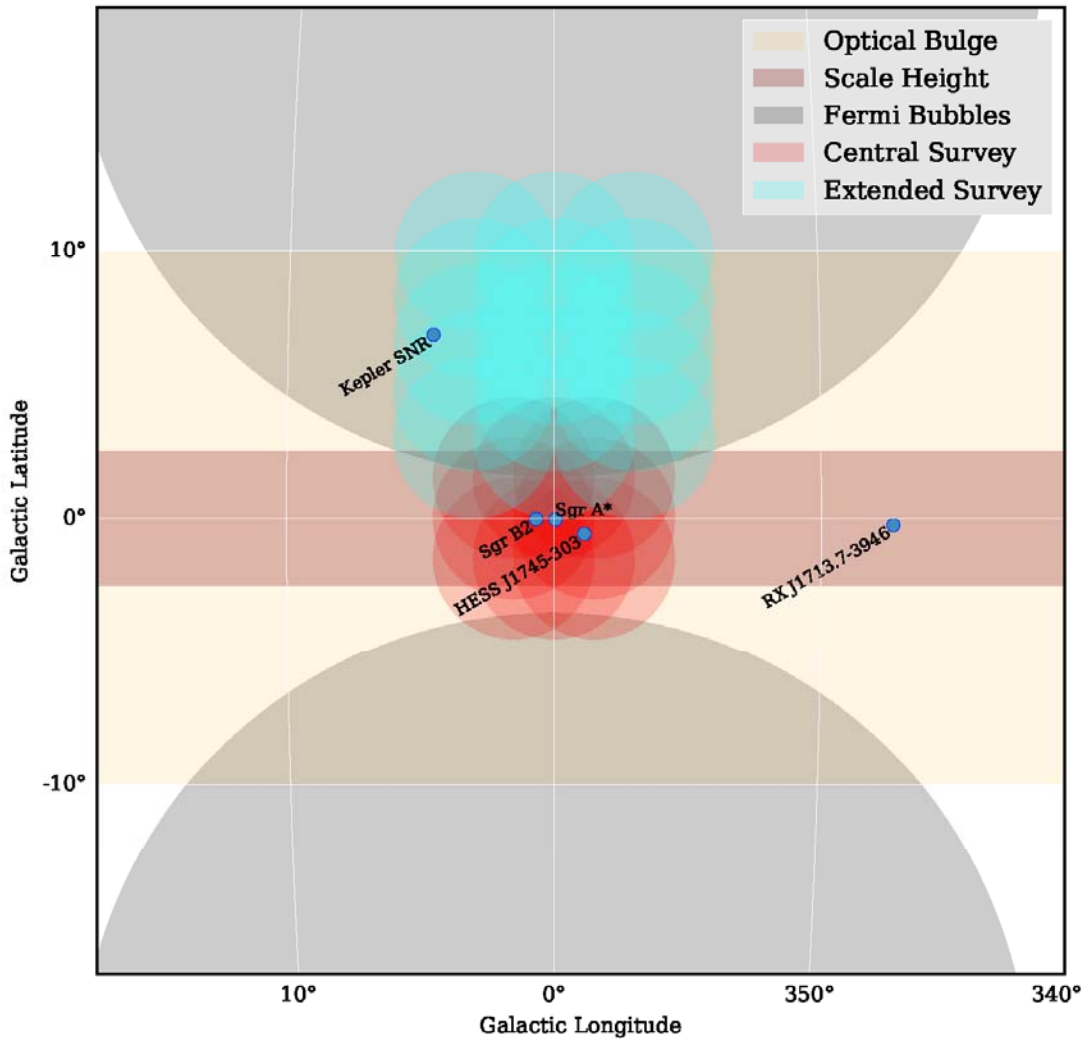
Spitzer
Credit: NASA/JPL Caltech
+ *Fermi* bubbles
Ackermann+ 2017 ApJ 840 43A

VLA + Spitzer + Chandra
Wang+ 2010 MNRAS 492 895

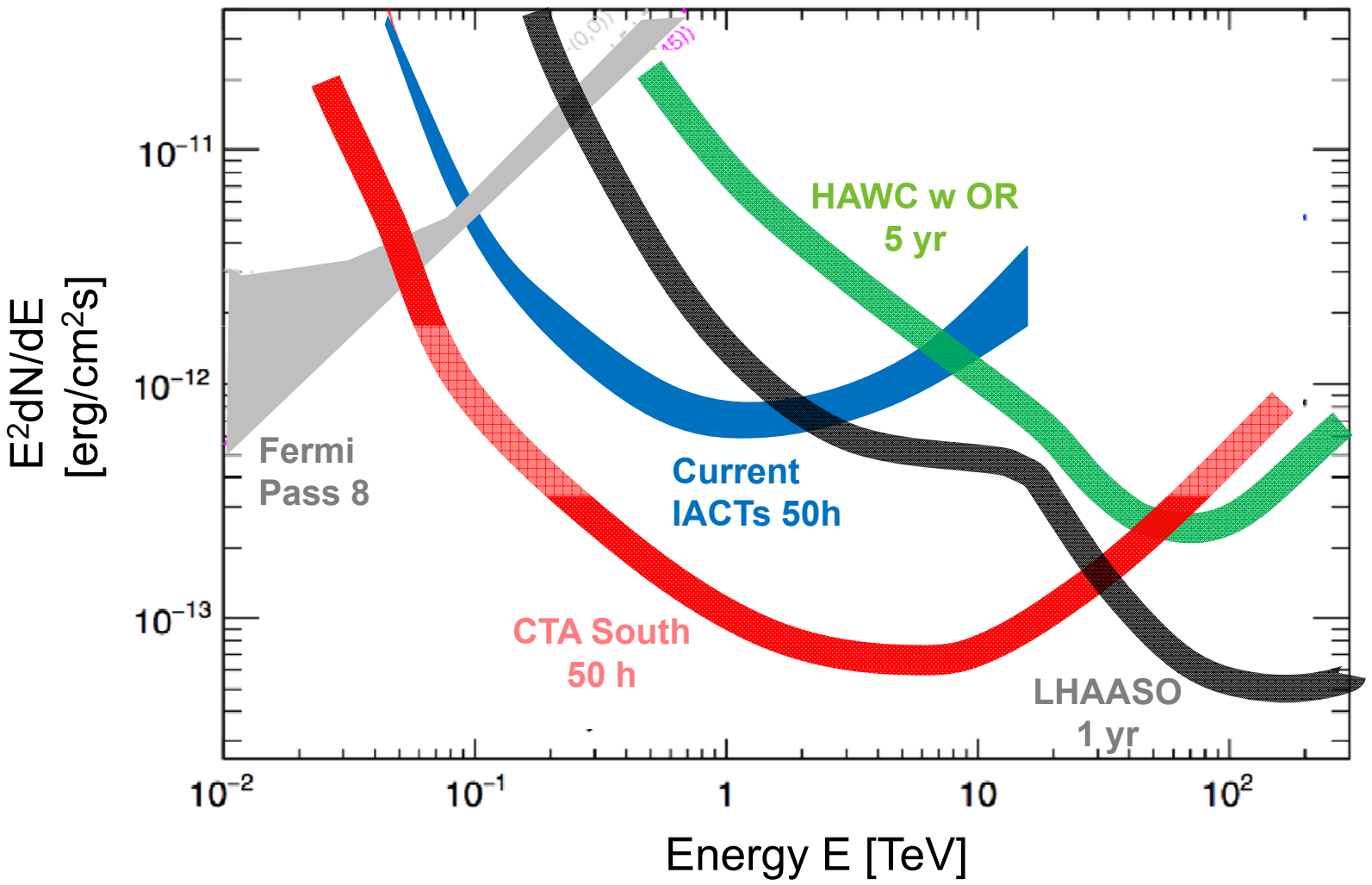
- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (*Fermi* bubbles)
- ideal region for dark matter searches

Galactic Centre Survey

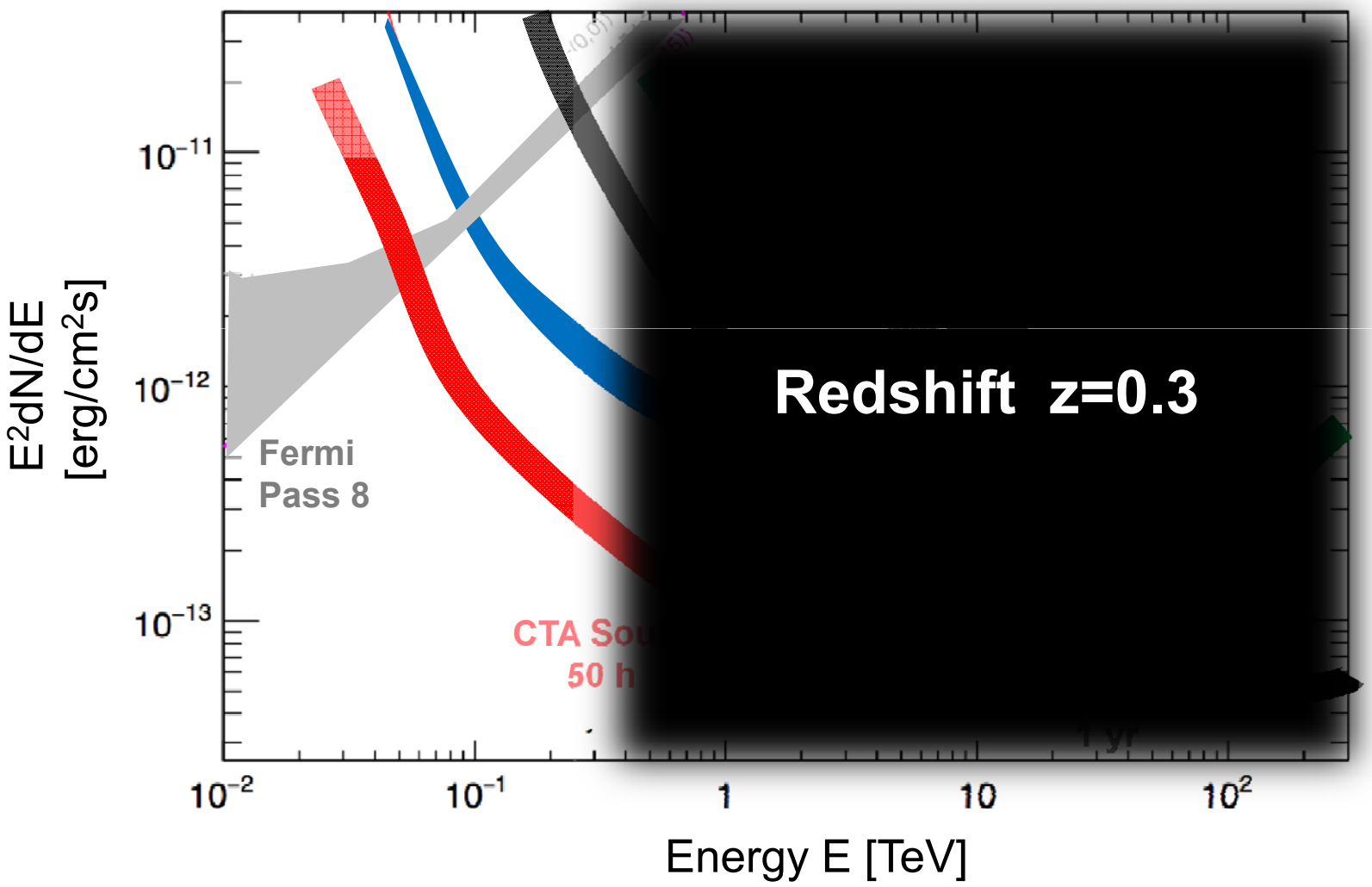
- First 3 years: deep survey of central region (525h, in addition to GPS exposure)
- Later: an extended survey out to 10^{o} (300h)
- Observing plan to be optimized based on CTA characteristics and MWL perspective



Extragalactic Survey

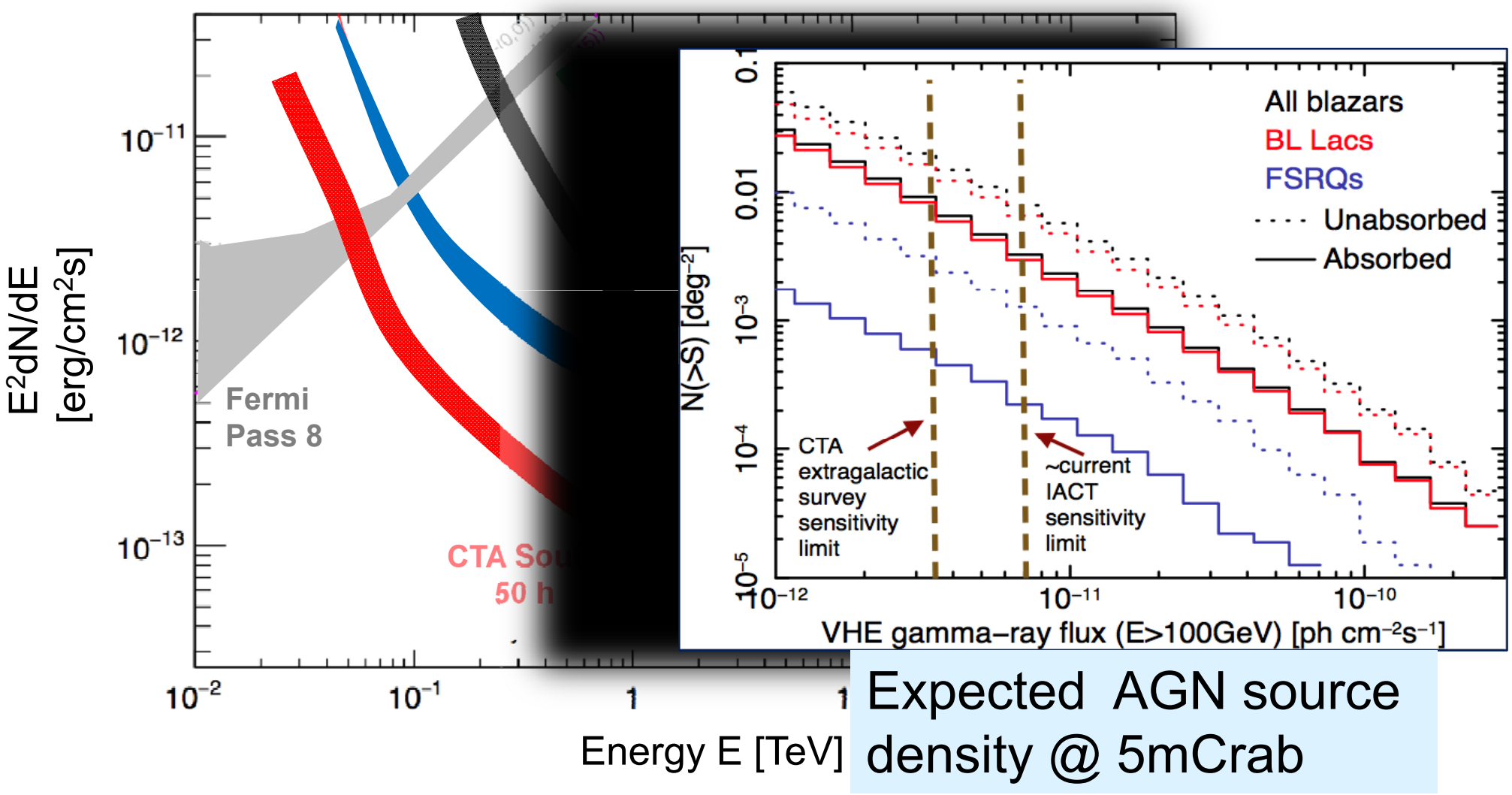


Extragalactic Survey



- Large gap in E not covered by any sensitive instrument
- Precisely where most extragalactic sources lie
- Survey designed to cover this gap over large portion of the sky

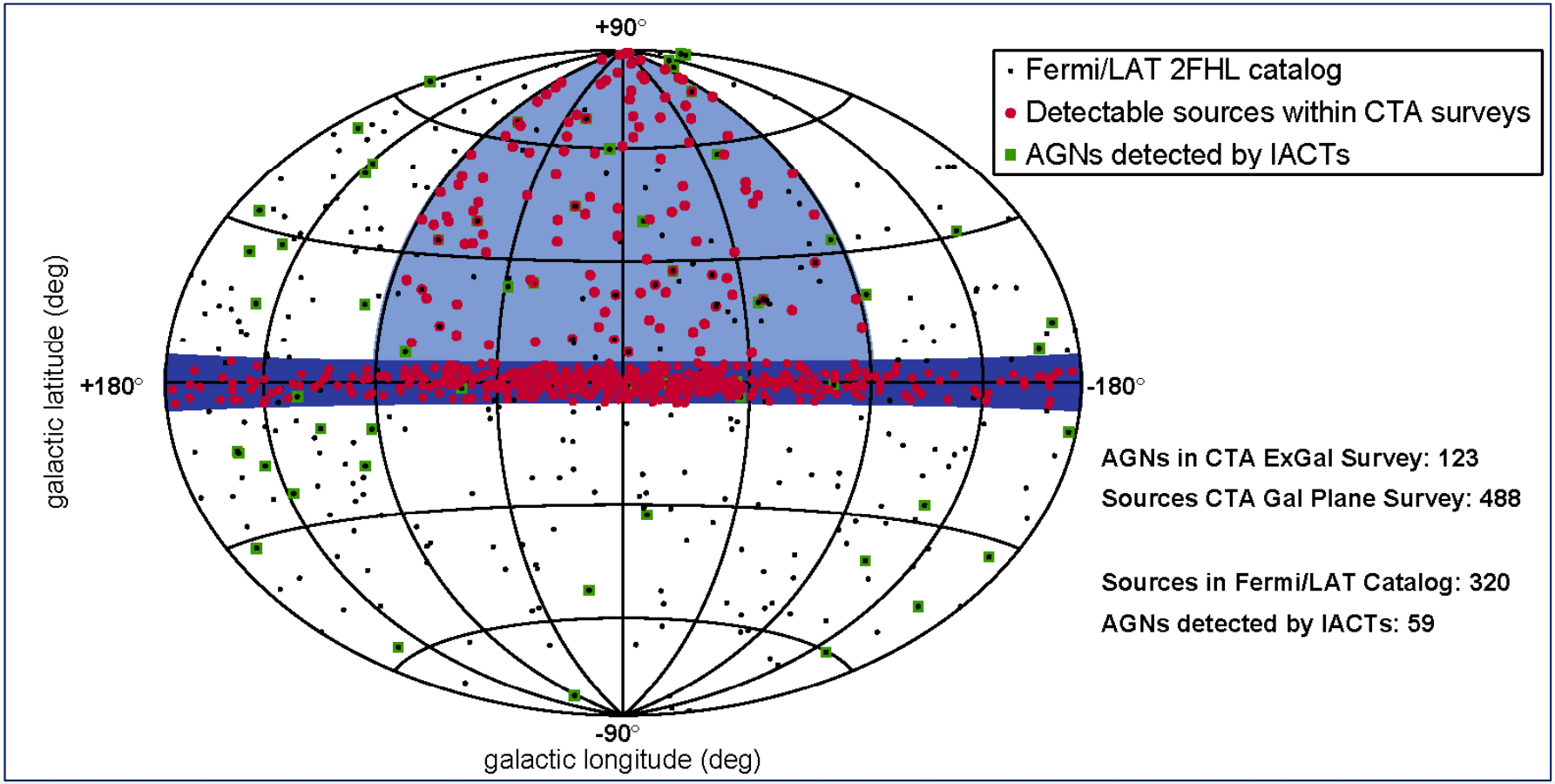
Extragalactic Survey



Expected AGN source density @ 5mCrab

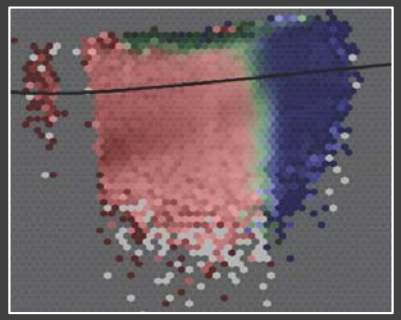
- Large gap in E not covered by any sensitive instrument
- Precisely where most extragalactic sources lie
- Survey designed to cover this gap over large portion of the sky

Extragalactic Survey

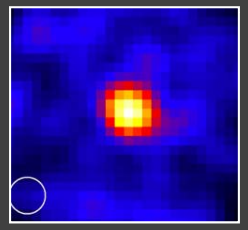


- Survey of ¼ sky to limiting sensitivity of 5 mCrab
- Unbiased determination of blazar luminosity function
- EGal Survey connects to Galactic Plane Survey & covers Coma, Virgo, Cen A, & Fermi bubbles (N)
- Wide-survey: excellent for transients and something unexpected !

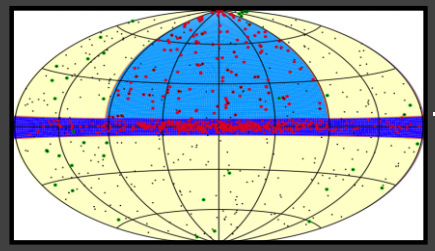
CTA Key Science Projects



Dark Matter Programme



Galaxy Clusters



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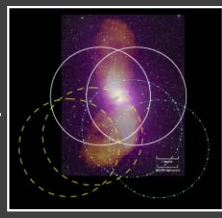
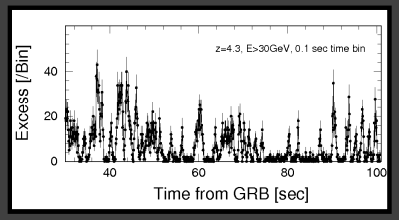
AGN

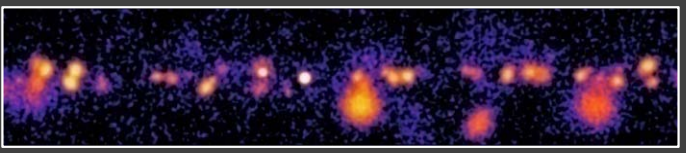


Extragalactic

Star Forming Systems

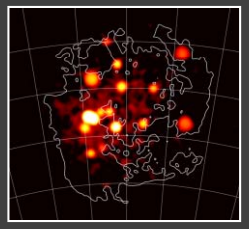
Transients





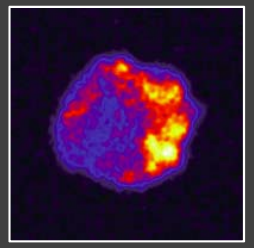
Galactic Plane Survey

LMC Survey

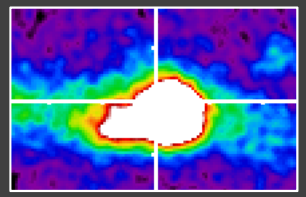


Galactic

PeVatrons



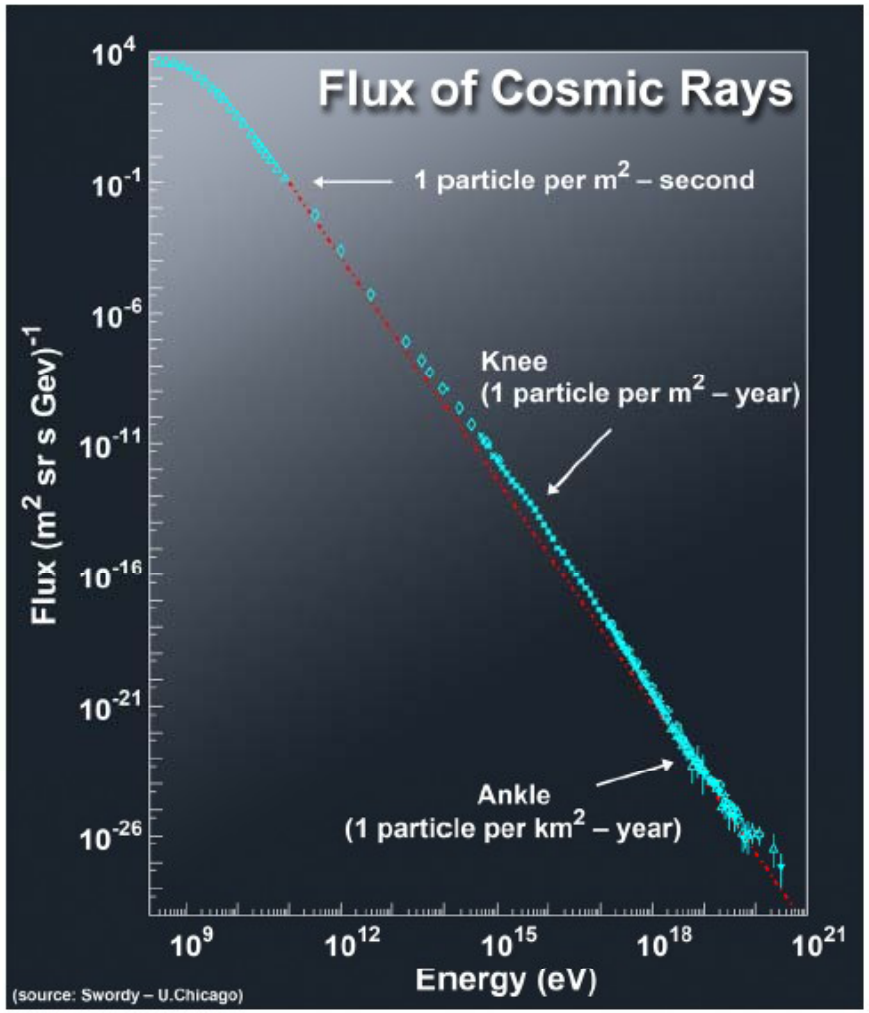
Galactic Centre



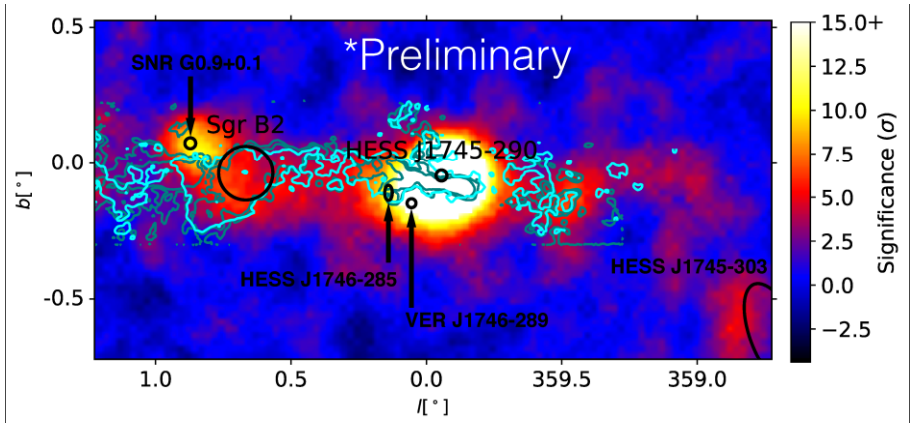
Particle Acceleration

PeVatron KSP

Q: What sources accelerate hadrons to the knee?



- CR origin: ~100 year old mystery !
- Standard picture: shock-accel. in SNRs – satisfies power & spectrum
- BUT: only a few SNRs provide good evidence for hadronic acceleration & only up to ~10-20 TeV

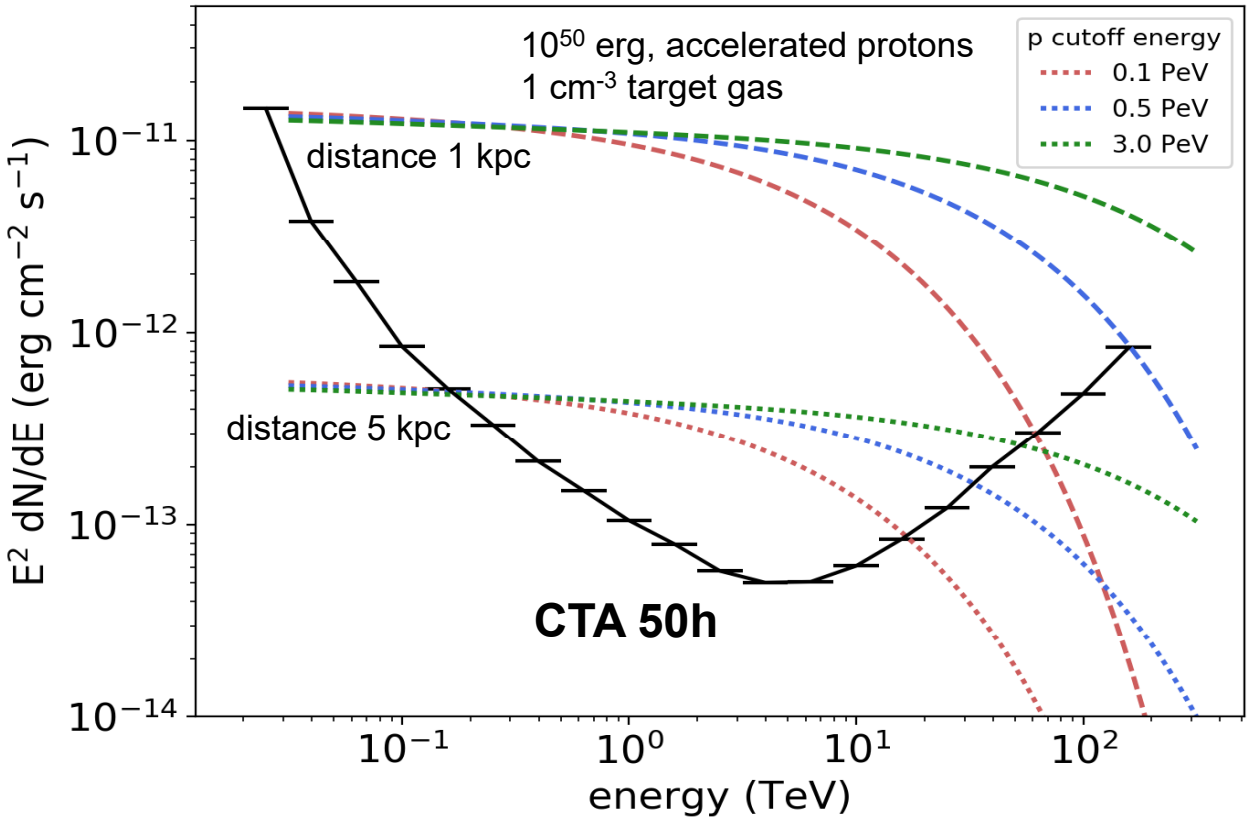


Evidence for PeVatron near GC (H.ES.S., VERITAS)
→ Probably not powerful enough, by itself

PeVatron KSP

- **Search for PeVatrons via the > 100 TeV spectrum**
  - Use GPS as finder and follow-up (5) brightest sources with no cutoff
  - Electrons' emission suppressed above 100 TeV (Klein-Nishina)
  - MWL information critical for identification

Comparison of spectra with CTA sensitivity (50h)



Science with CTA (2019)

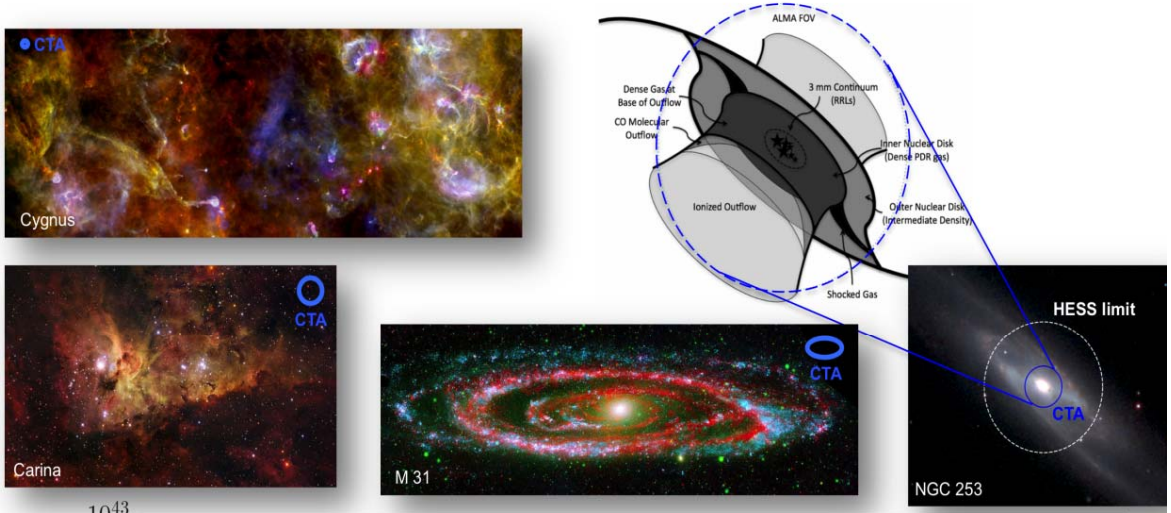
Star Forming Systems KSP

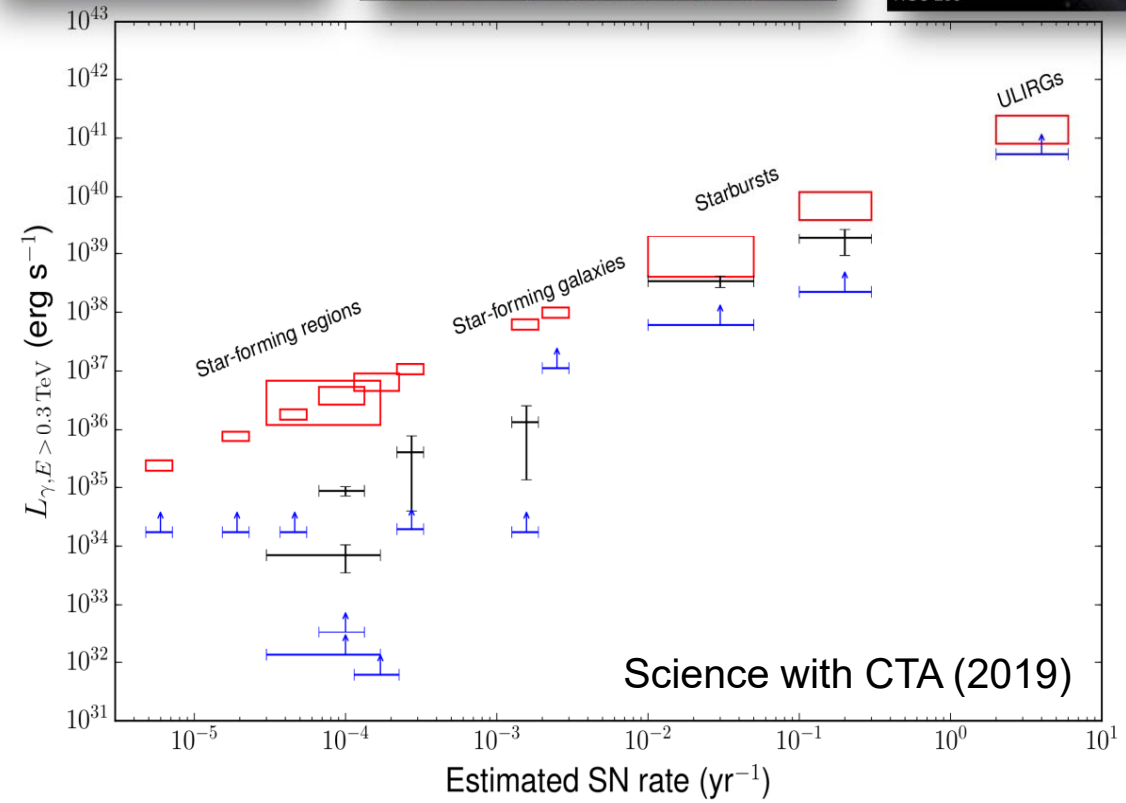
Key Questions:

- How do CRs propagate and what is their impact on the ISM?
- What is the relation between star formation (SF) and particle acceleration in systems of all scales?

Methodology: deep observations of a set of characteristic objects at different scales.

Motivated by connections seen in FIR, GeV γ-rays and, now TeV γ-rays.





Summary

- **CTA will usher in a new era in VHE Astrophysics**

  Rich science program addressing many pressing questions
  Great opportunity for discovery of something new !

- **Key Science Projects (KSPs)**

  Major legacy projects, formulated by Consortium over many years
  Critical effort to produce long-lasting results and seed GO Programme
  Now time to foster links to broader MWL/MM communities

- **KSPs reviewed here:**

  - *Galactic Plane Survey: 1st VHE survey @high resolution & high sensitivity*
  - *Galactic Centre: rich region imaged by CTA at arc-min resolution*
  - *Extragalactic Survey: blind survey of ¼ of the sky to 5 mCrab sensitivity*
  - *PeVatrons: pin down the sources of PeV cosmic rays*
  - *Star Formation Systems: study relation between CRs and SF on all scales*

***We gratefully acknowledge financial support from the agencies and organizations listed here: http://www.cta-observatory.org/consortium_acknowledgments**

Summary

- **CTA will usher in a new era in VHE Astrophysics**

  Rich science program addressing many pressing questions
  Great opportunity for discovery of something new !

- **Key Science Projects (KSPs)**

  Majo…s
  Criti…mme
  Now…

Please help us make CTA a great scientific success !

- **KSPs**

  - *Gala… …ensitivity*
  - *Galactic Centre: rich region imaged by CTA at arc-min resolution*
  - *Extragalactic Survey: blind survey of ¼ of the sky to 5 mCrab sensitivity*
  - *PeVatrons: pin down the sources of PeV cosmic rays*
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BACKUP

Large Magellanic Cloud Survey

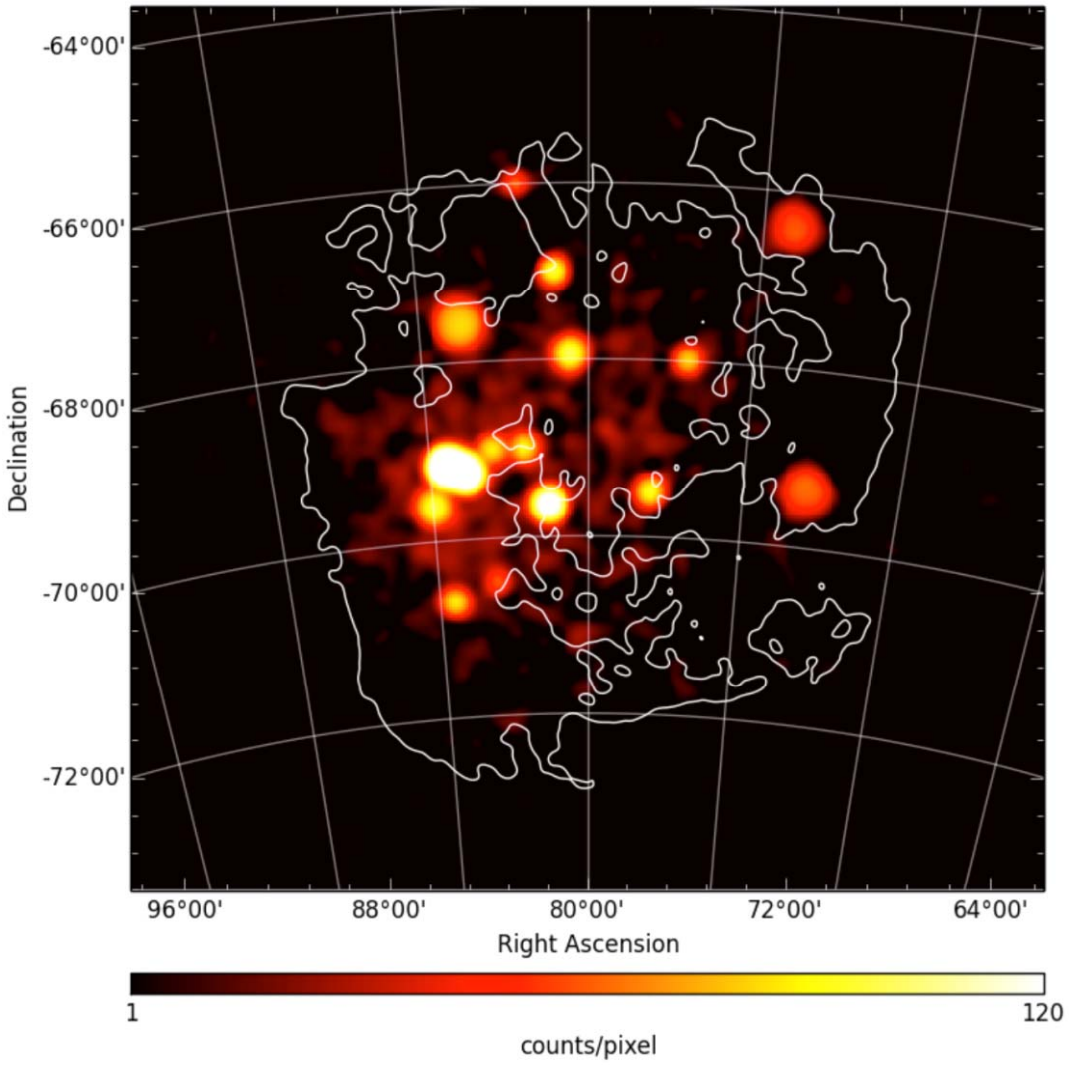
340h deep survey of the galaxy
+150h monitoring of SN1987A

Deep and resolved external view of a star-forming galaxy

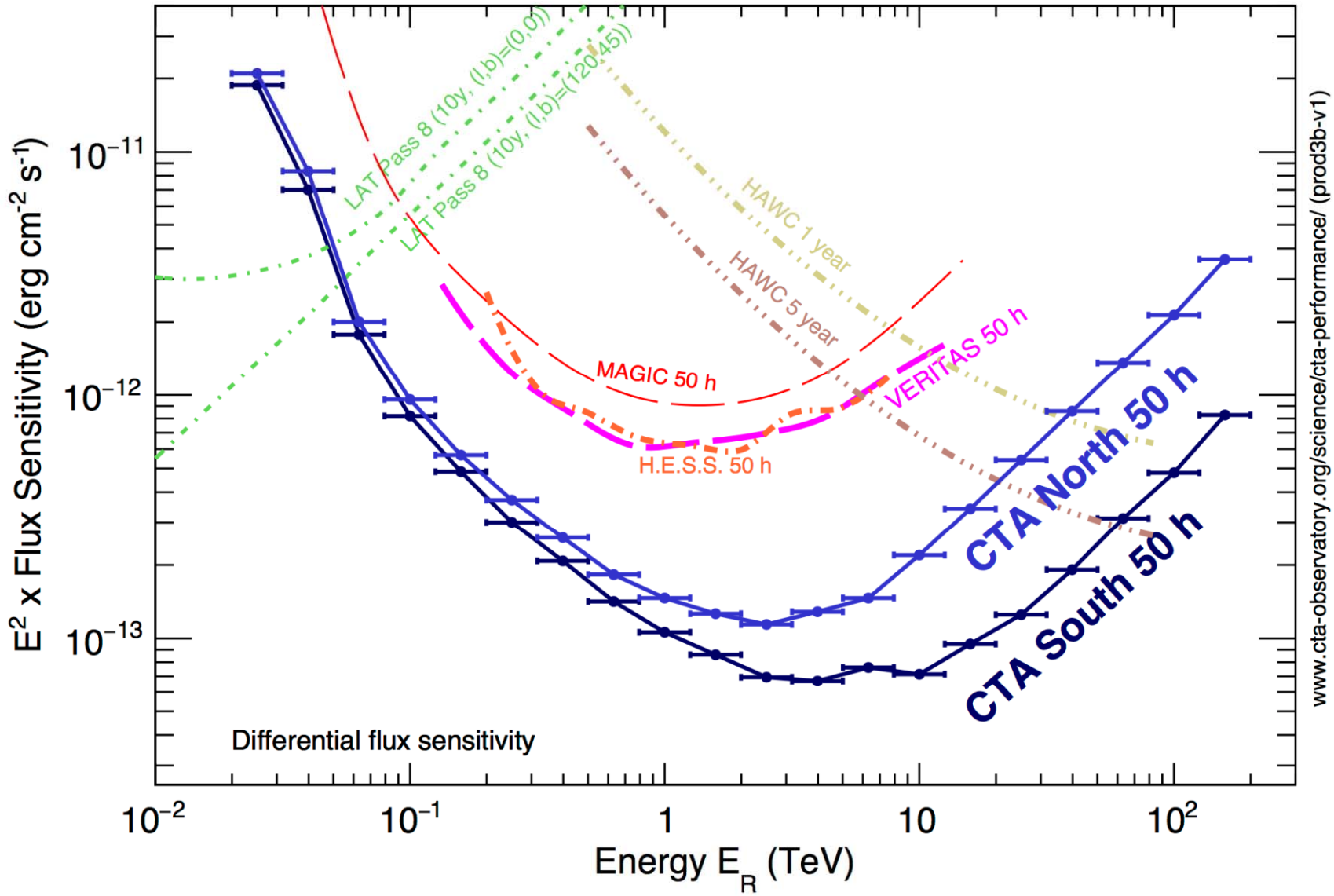
Scientific objectives

- Particle acceleration in young and powerful objects (SN1987A, 30 Dor C, LMC P3,…)
- Early stages of the cosmic-ray life cycle in connection with galactic properties

Will complement the view offered by the GPS and SFS KSPs

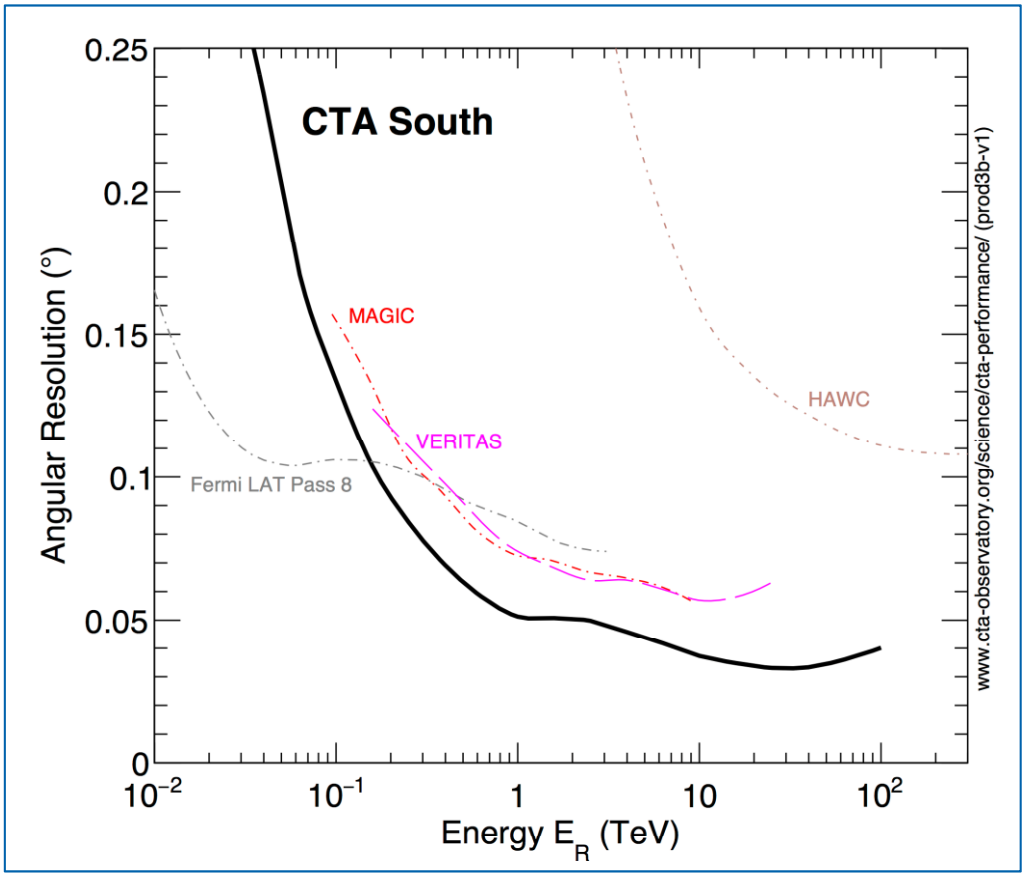


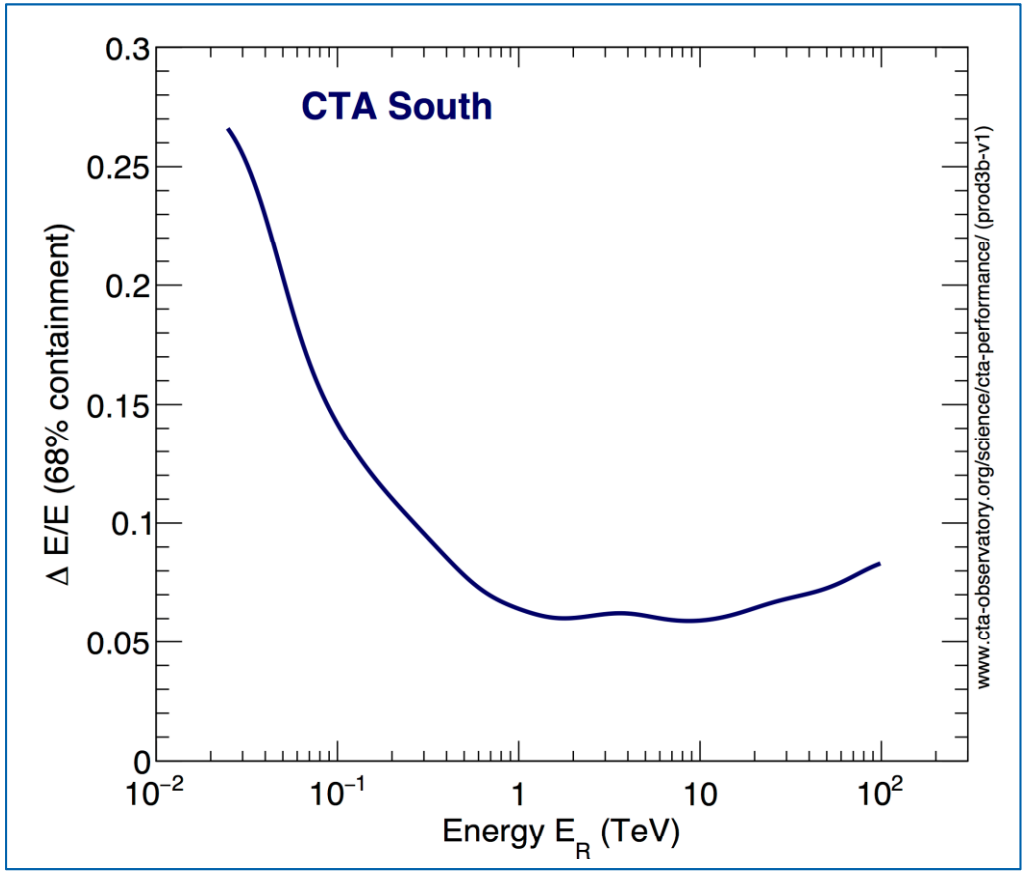
Flux Sensitivity



Major sensitivity improvement & wider energy range

Angular & Energy Resolutions





Important for resolving morphology of sources

Important for spectral precision

CTA Science Program

- Open observatory
- Proposals for Guest Observer Programme – essential for major community involvement
- All data on public archive after proprietary period (typically 1 year)
- ~40% time in Key Science Projects (KSPs), carried out by CTA Consortium

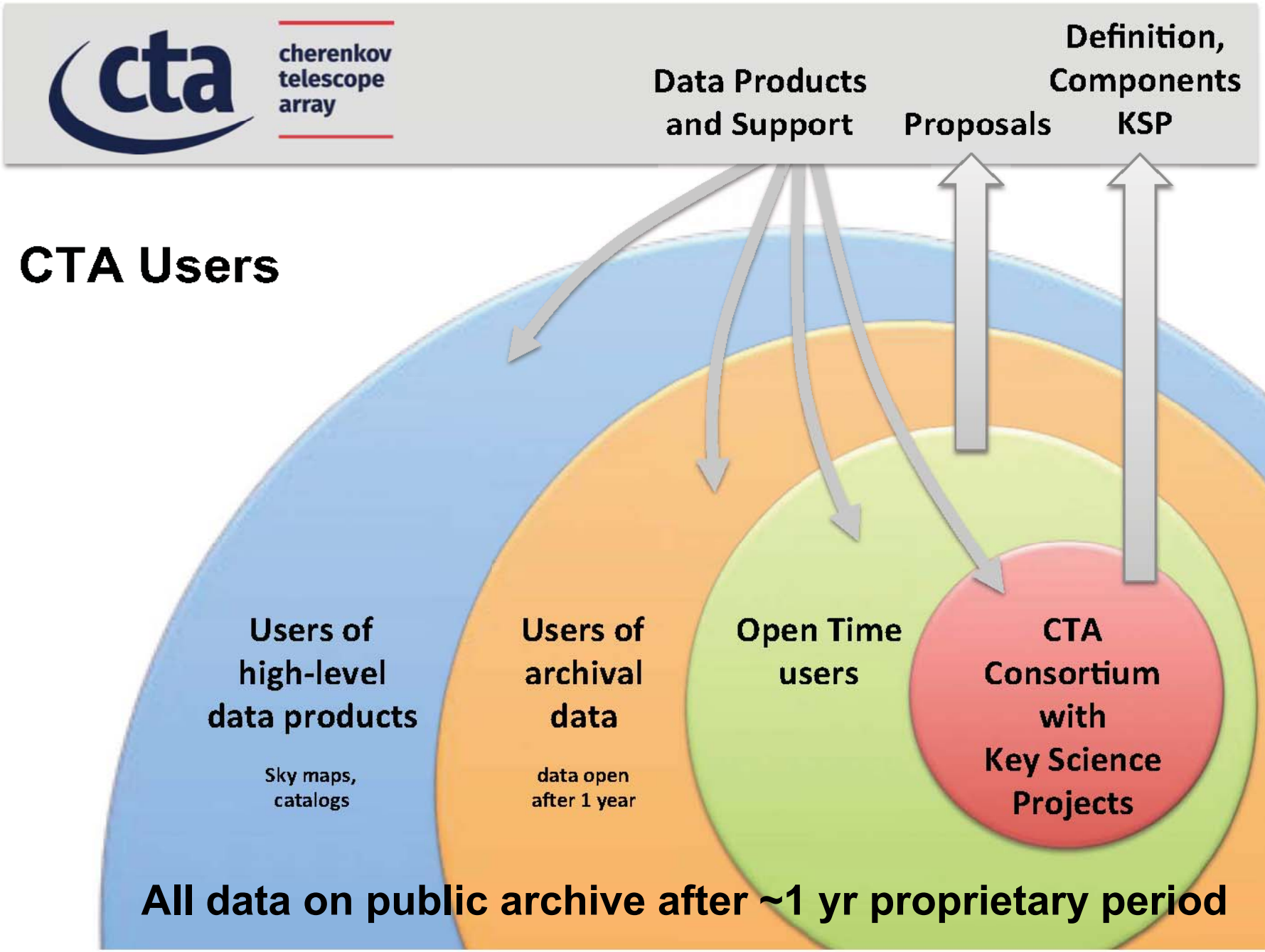
KSPs described in

Science with CTA document

arXiv:1709.07997

(published as a book by World Scientific)

CTA: An Open Observatory

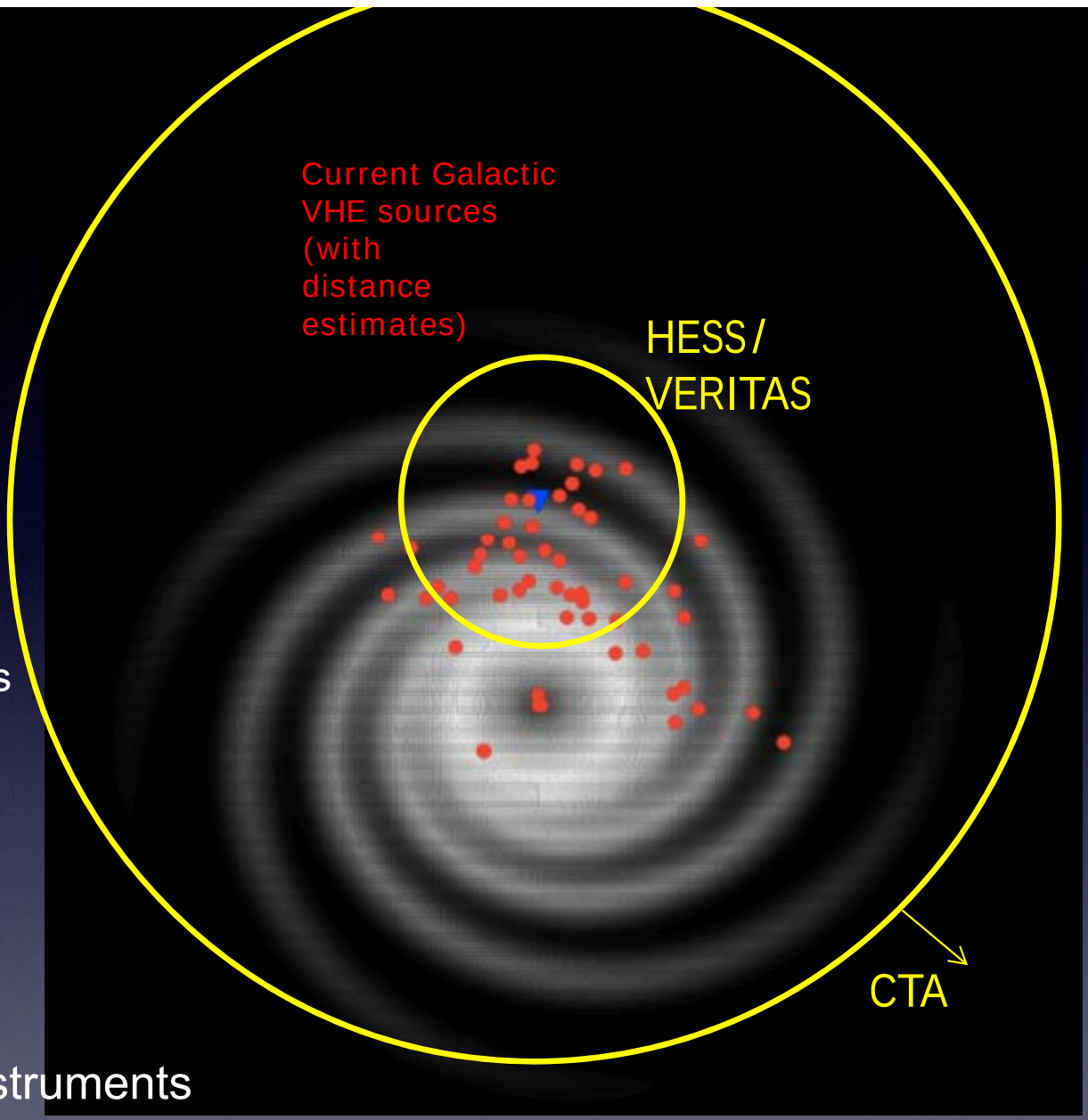


Galactic Discovery Reach

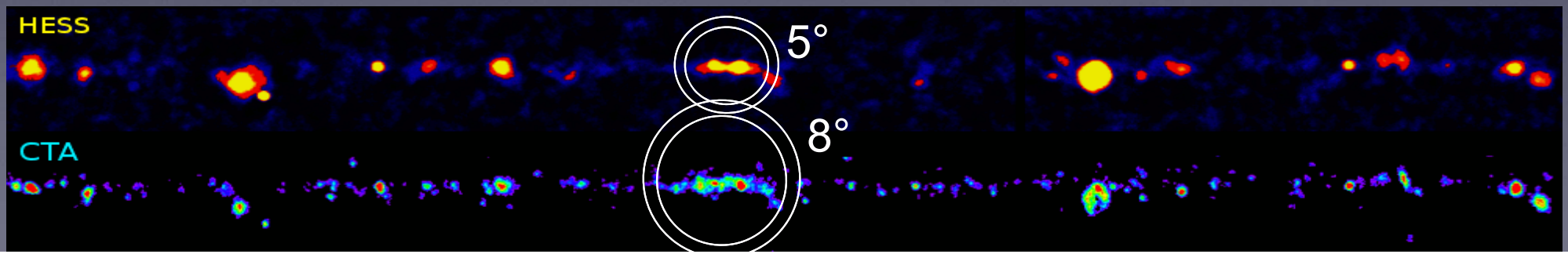
Young pulsars and SNRs

- have typical brightness such that current instruments can see only relatively local objects

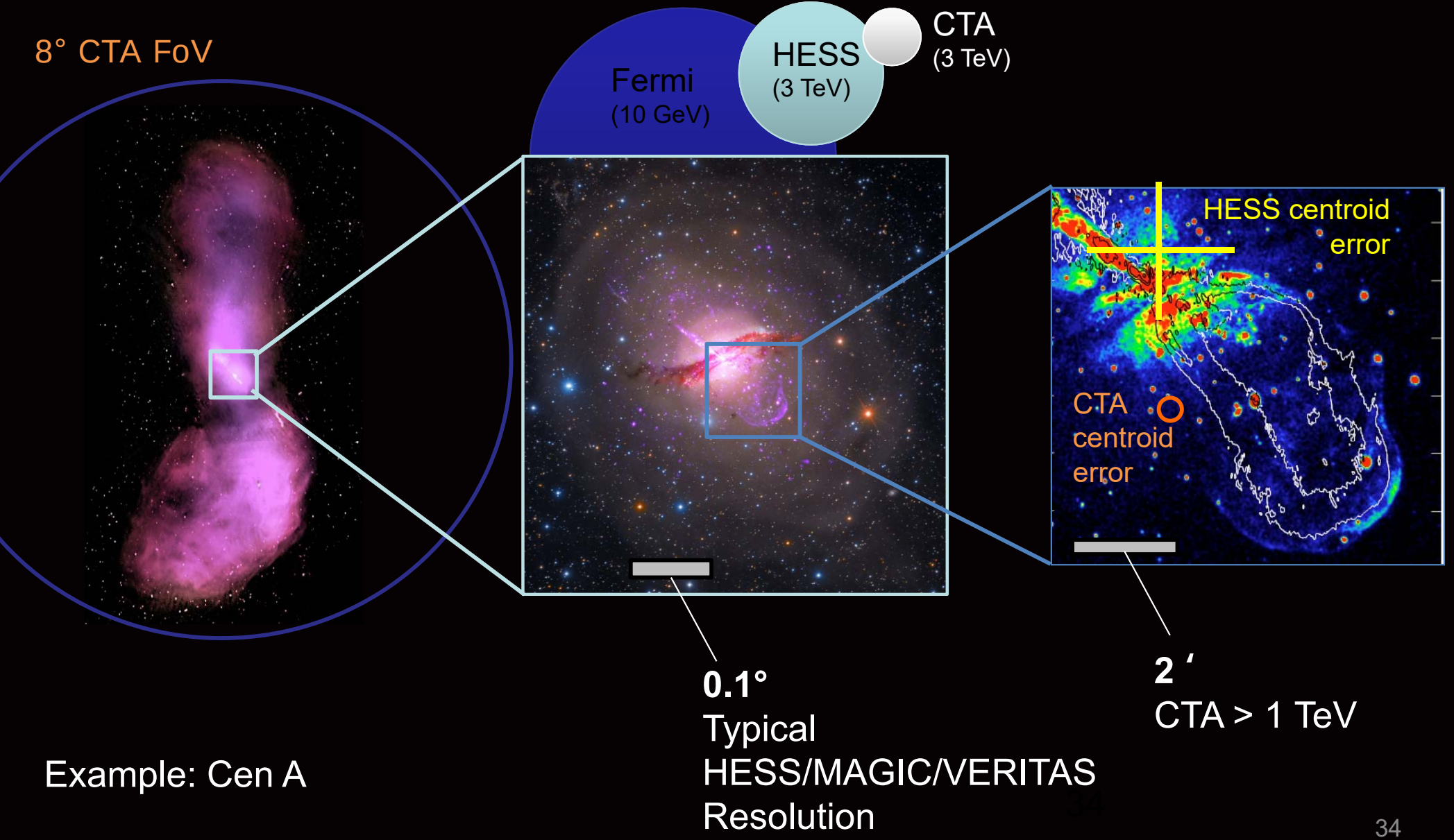
CTA will see **whole** Galaxy



Survey speed:
x300 faster than current instruments

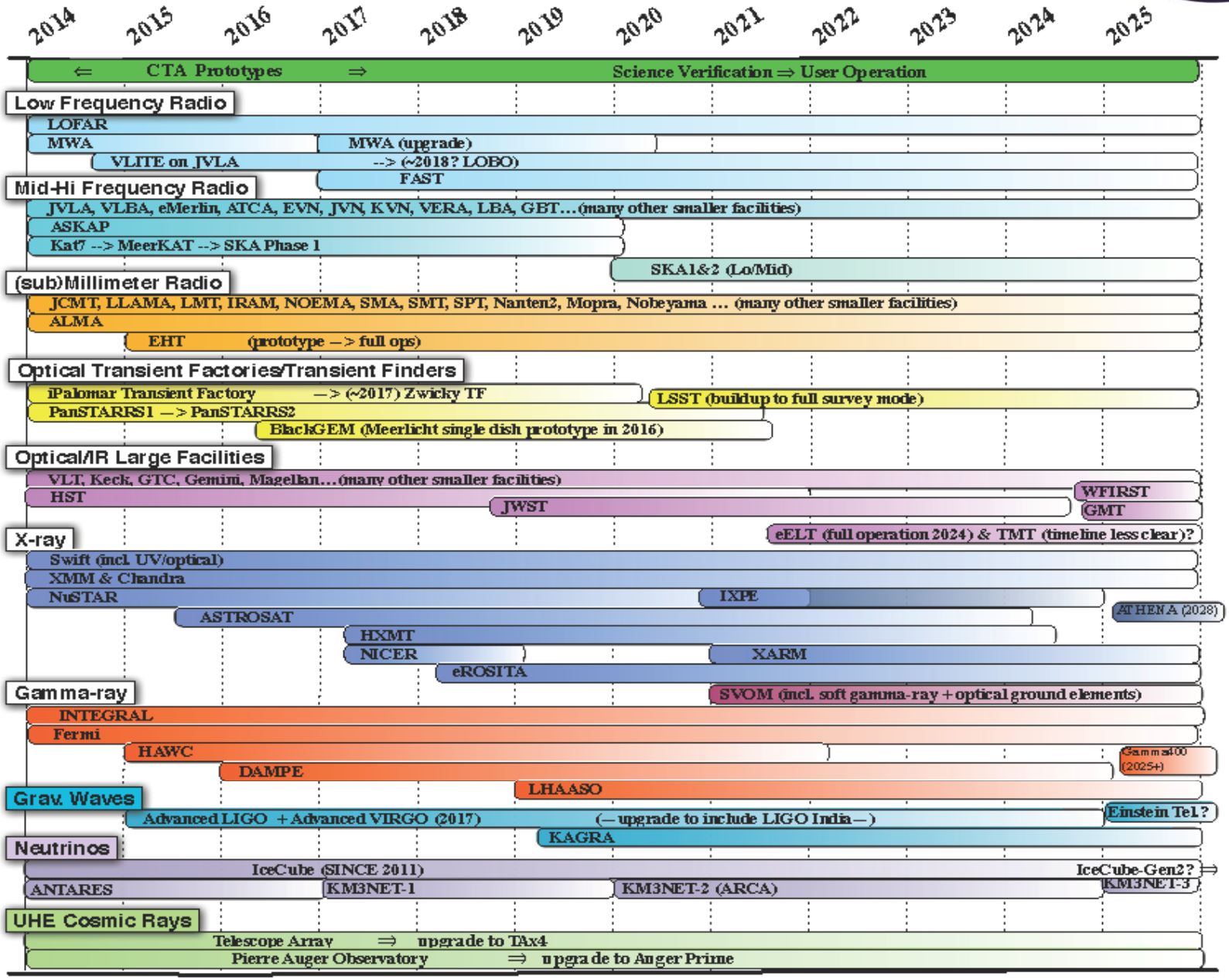


Angular Resolution



Important MWL/MM Synergies

cherenkov telescope array



Caveat: Observatory timelines are very uncertain; this represents a notional picture based on available information

CTA as a Transient Factory

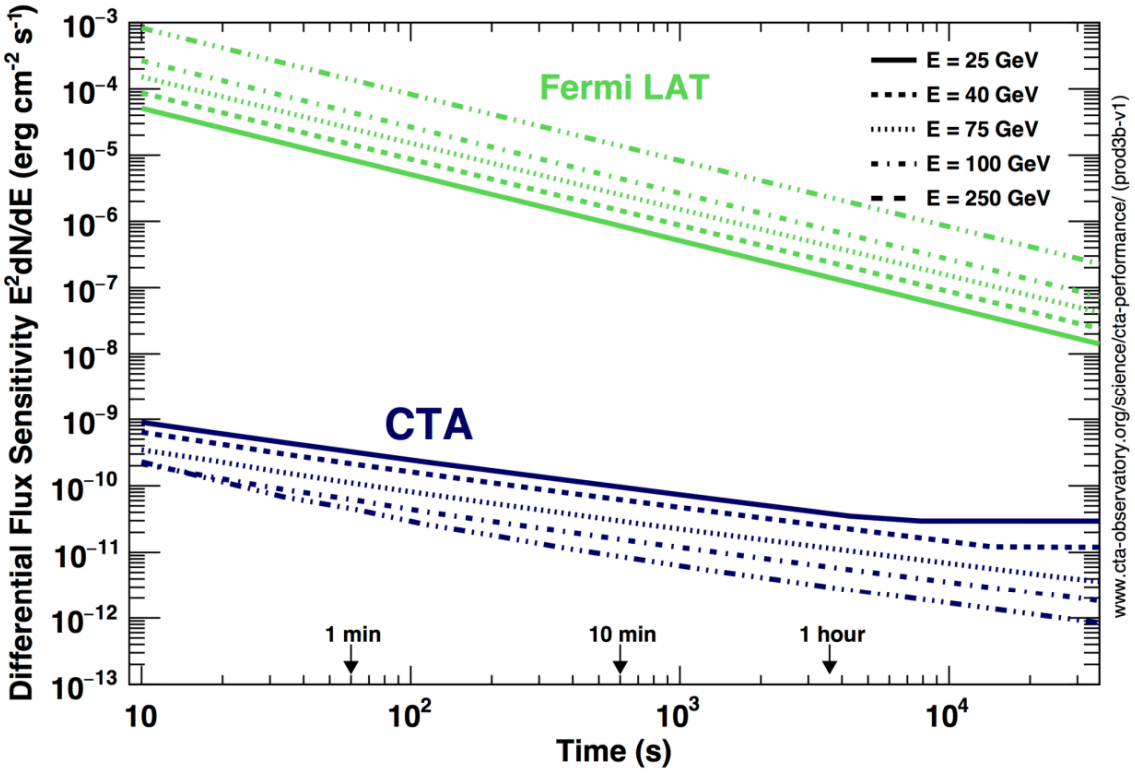
Advantages:
over Fermi and HAWC in energy range of overlap for ~min to ~ day timescales:

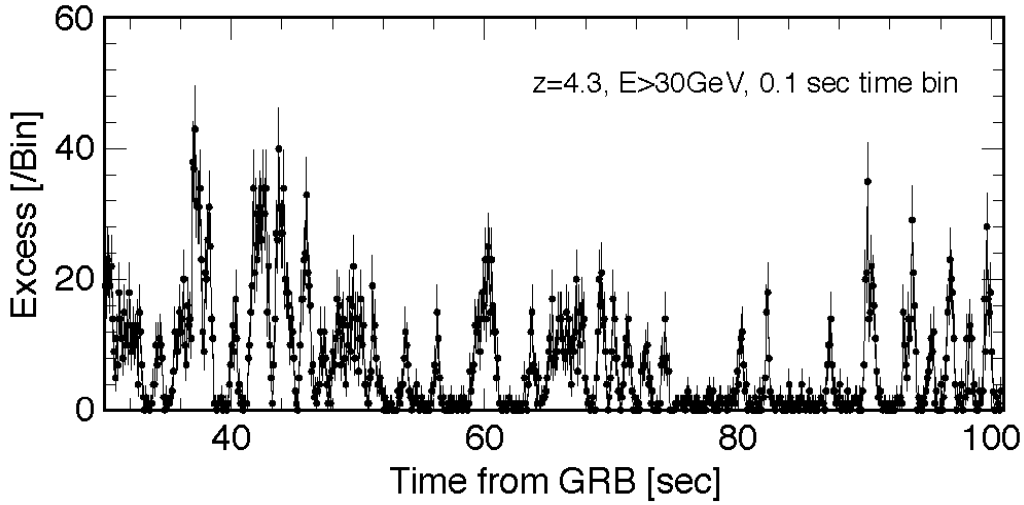
- Explosive transients (e.g. GRBs, GW events, etc.)
- AGN flares
- γ–ray binaries

Disadvantages:

- Limited FoV (more focused on follow-ups)
- Prompt reaction is critical

CTA capabilities → Key Science Project devoted to Transients





GRB (z=4.3) Light curve