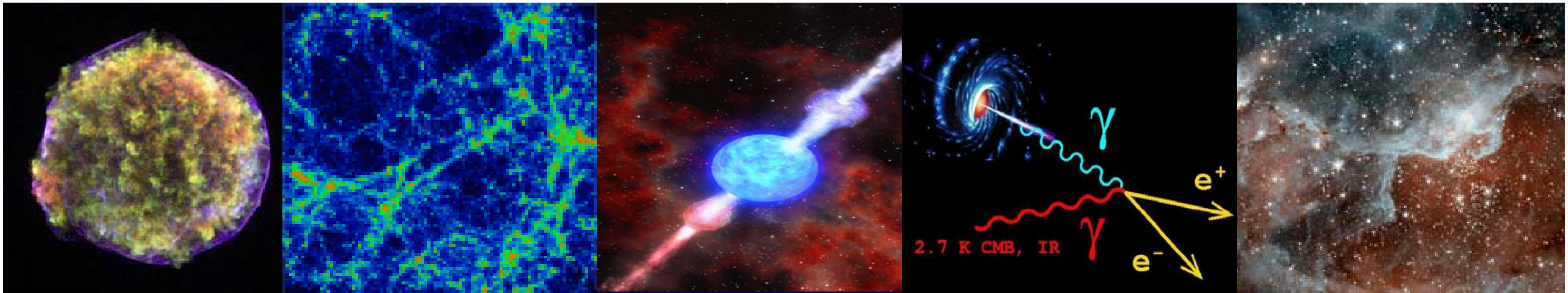
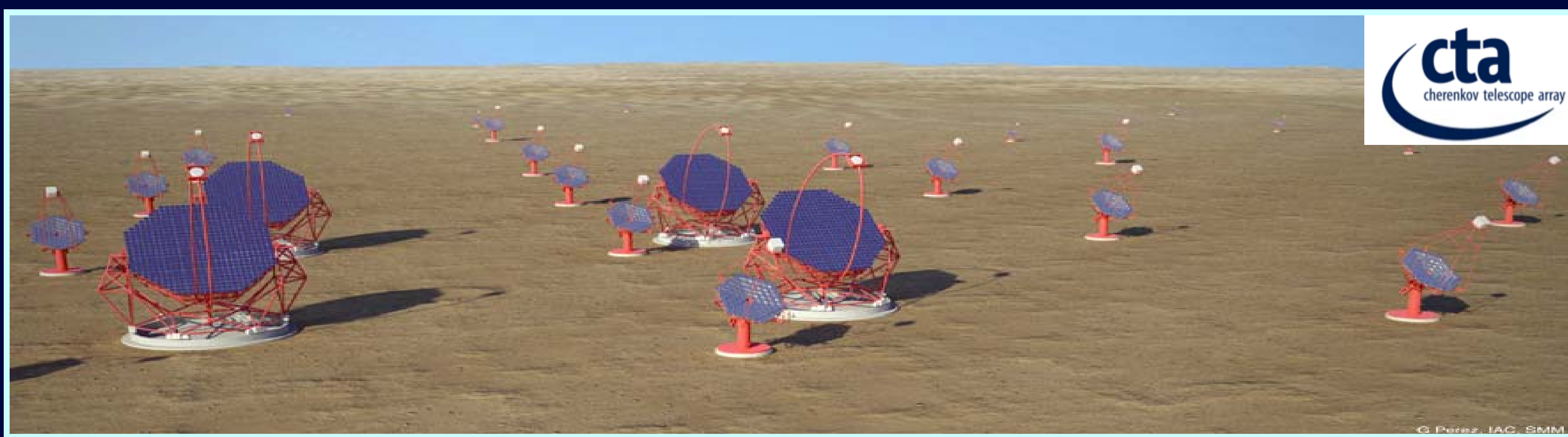


The Future of Very High-Energy Astrophysics

Rene A. Ong (UCLA and ICRR)

ICRR Seminar, 28 September 2016



Outline

- **Scientific & Technical Motivation**

  Science Overview – VHE gamma-ray sky
  Three selected science topics in brief
  Experimental Technique
  Planning for the Future → CTA

- **Cherenkov Telescope Array (CTA) Concept**

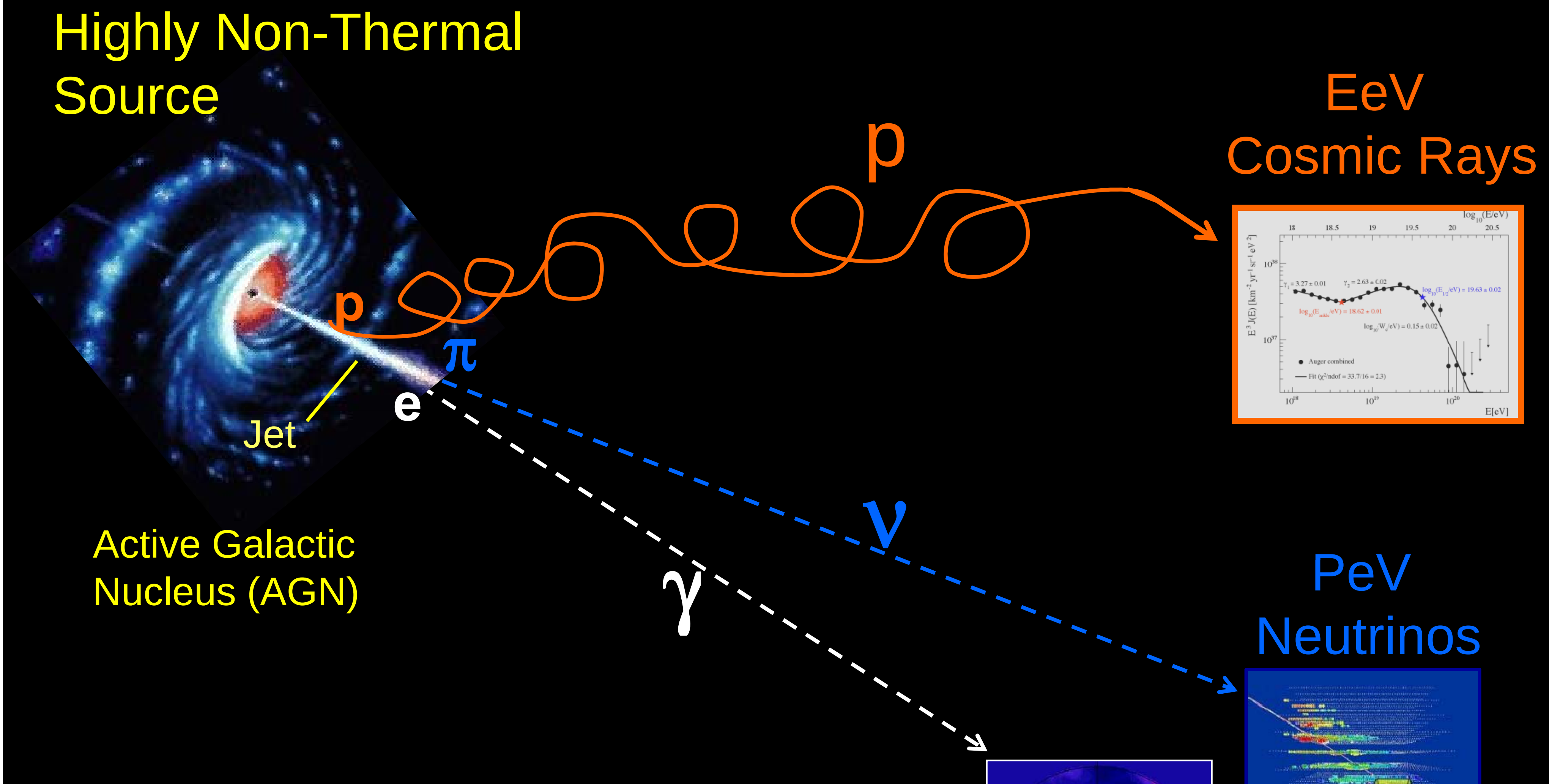
  Science Drivers → requirements
  CTA Design & Performance → **Scientific Capabilities**

- **CTA Implementation & Status**

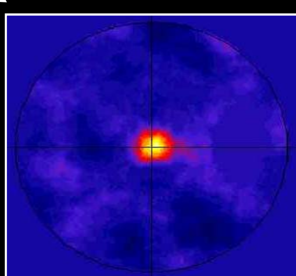
  Implementation: design and prototype telescopes
  Present status (2016): status of sites, timeline, etc.
  Key Science Projects (KSPs) – Core science – a few examples

- **Summary**

Very High Energy (VHE) Astrophysics



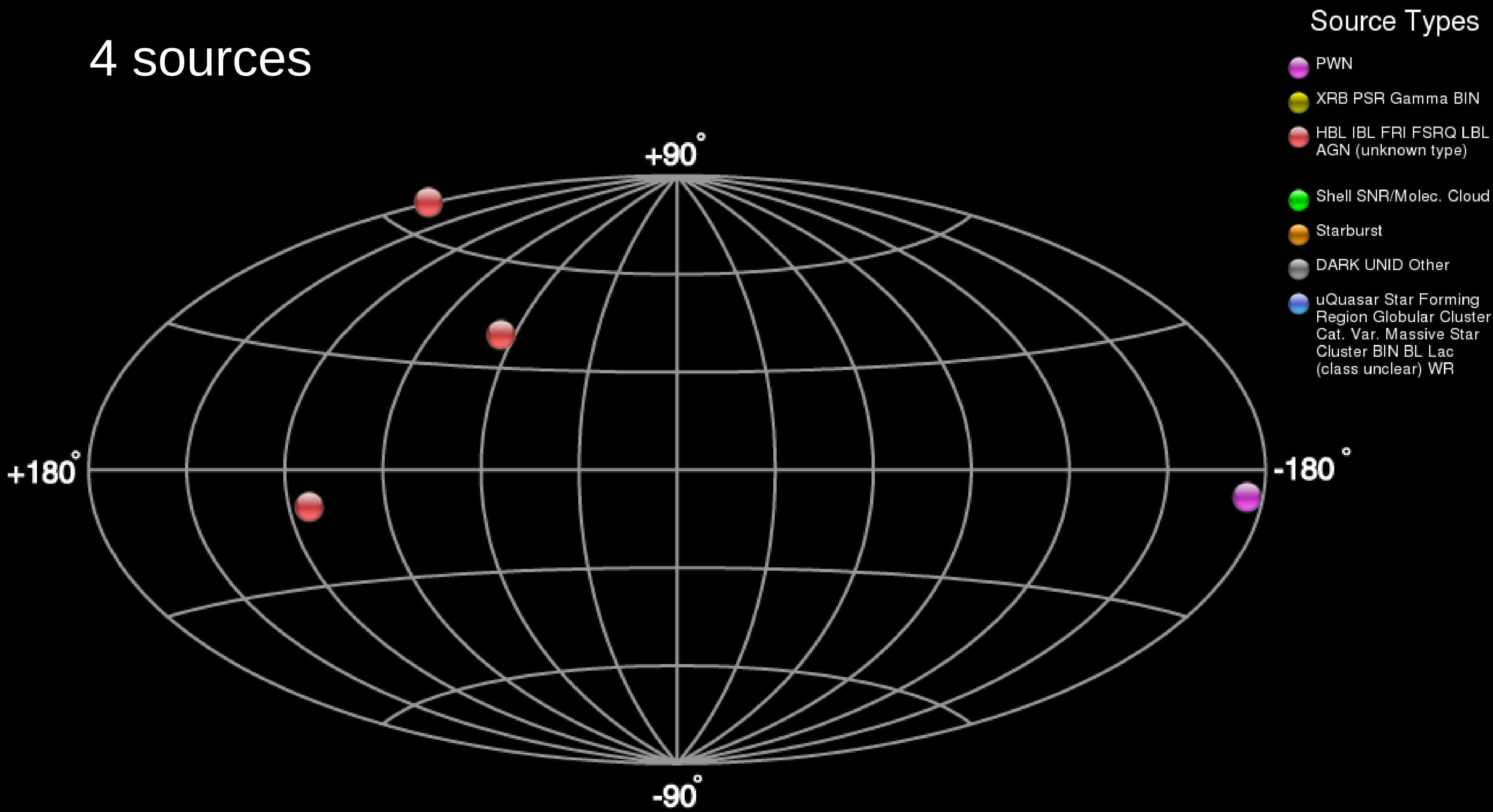
GeV/TeV γ–rays



γ-rays provide, by far, the most direct information

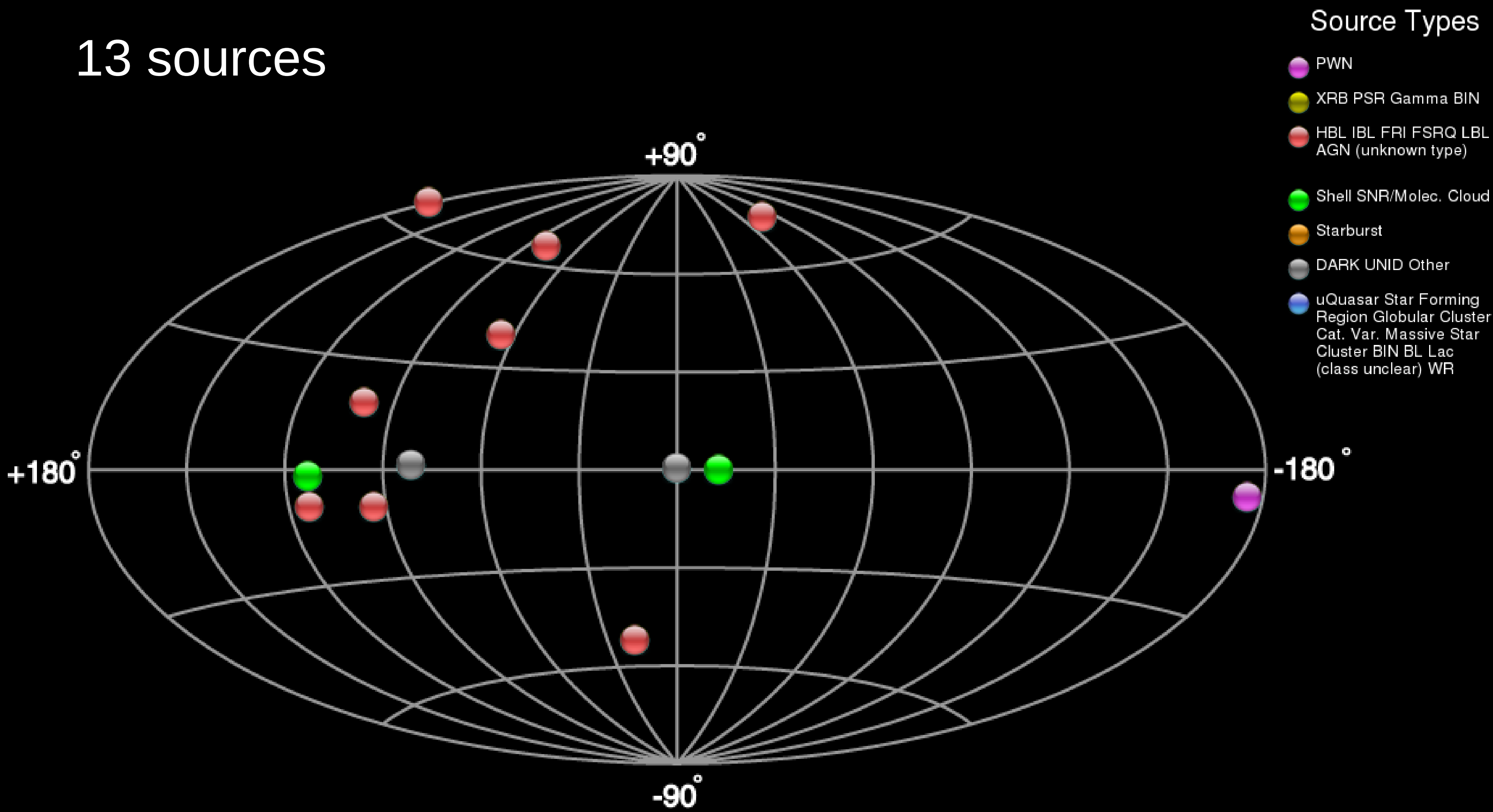
VHE γ-ray Sky c1997

4 sources



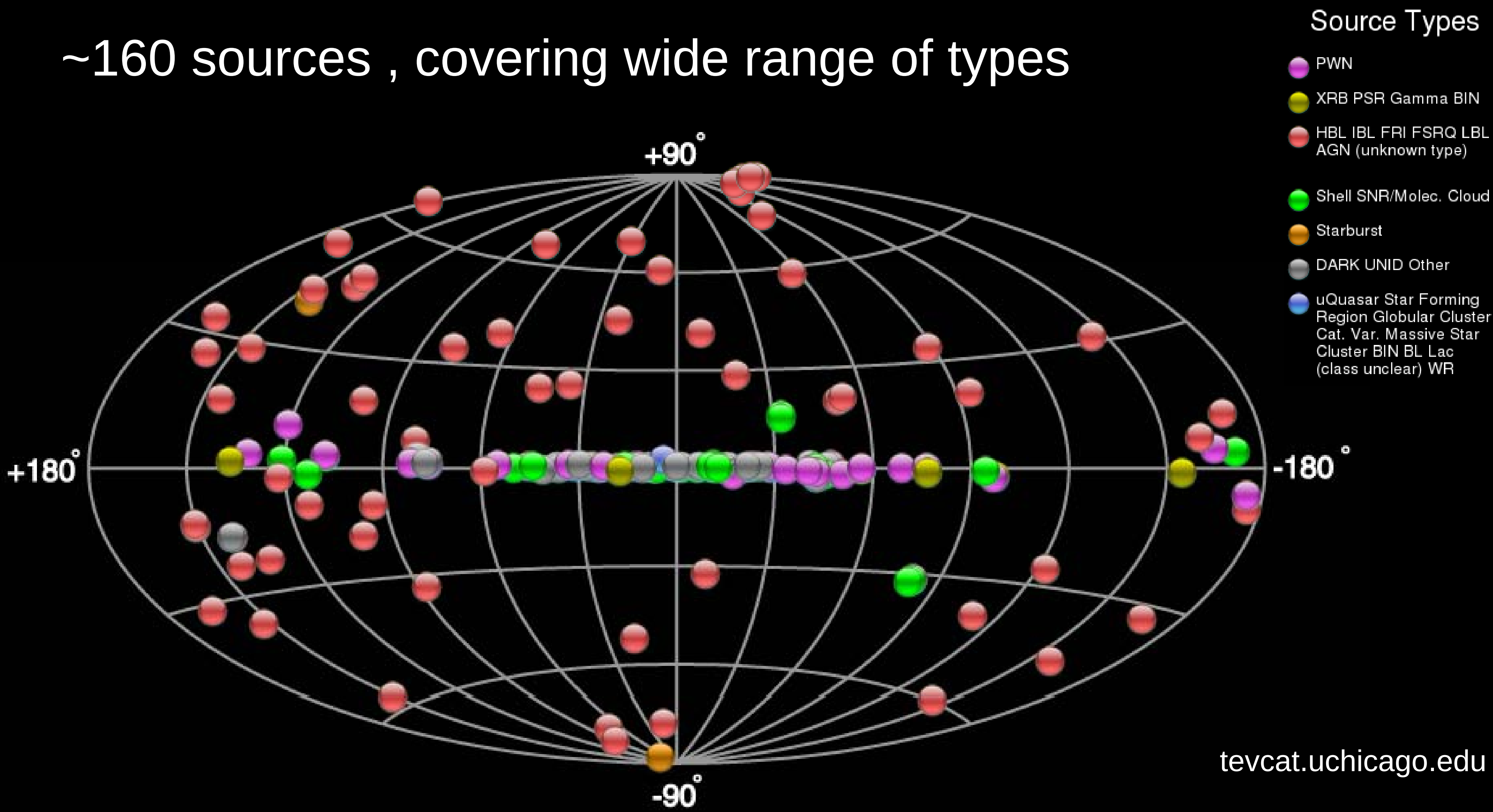
VHE γ-ray Sky c2005

13 sources



VHE γ-ray Sky c2016

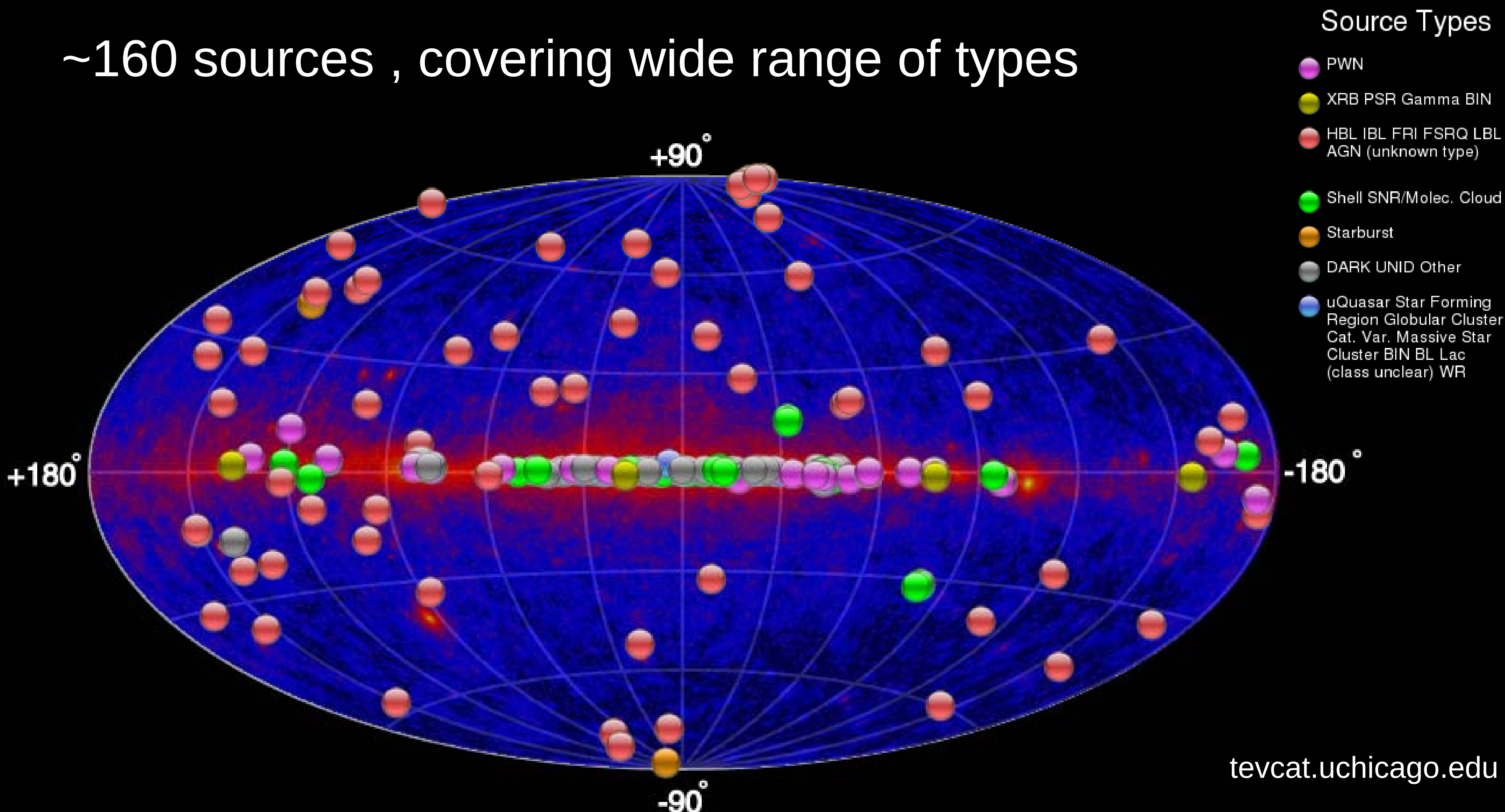
~160 sources , covering wide range of types



Detailed source information: Spectra, Images, Variability, MWL …

TeV + GeV γ-ray Sky c2015

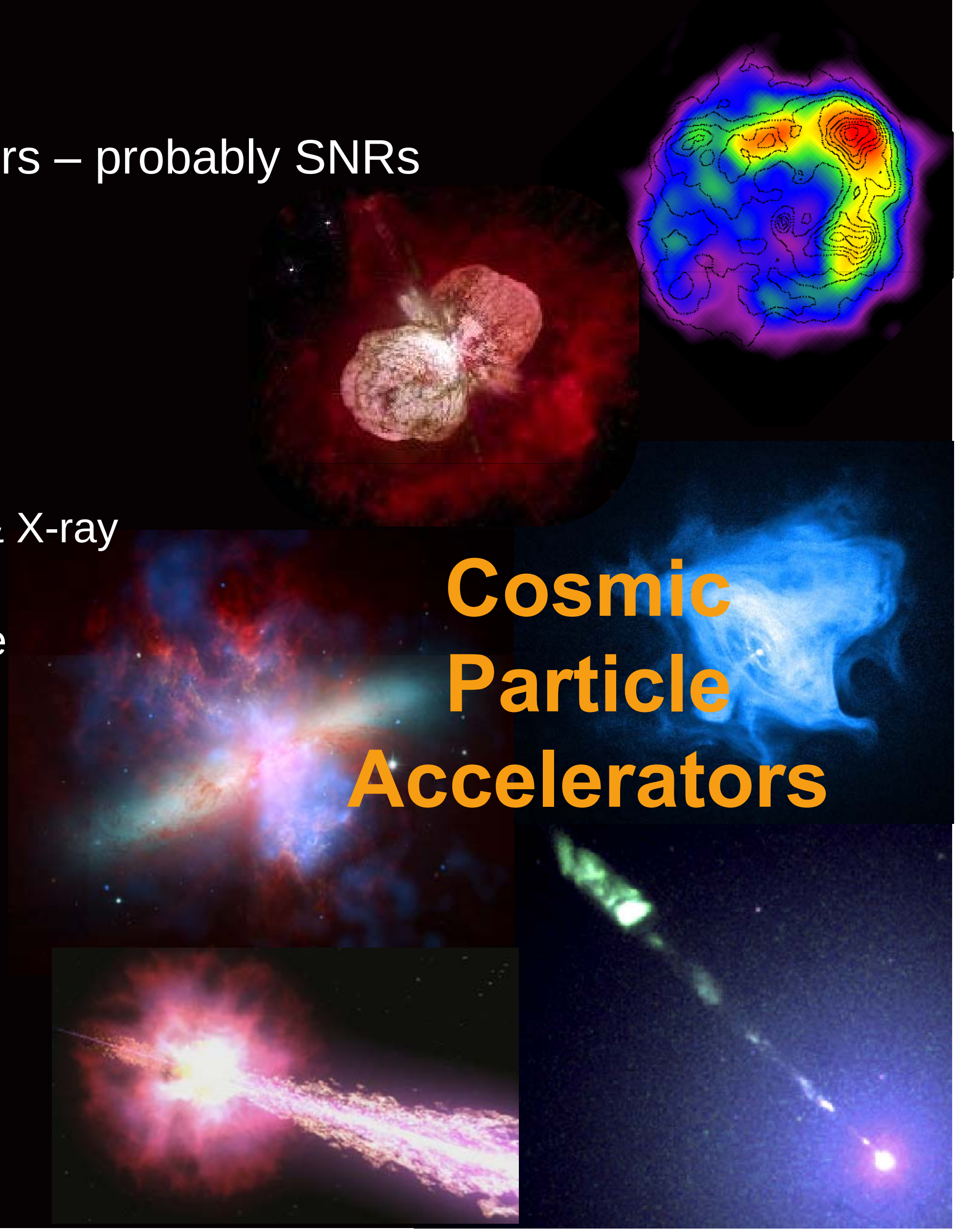
~160 sources , covering wide range of types



Detailed source information: Spectra, Images, Variability, MWL …
+ FERMI-LAT map

VHE Astronomy Comes of Age

- Dominant expectation (pre-1990)
  - Will find the “cosmic ray” accelerators – probably SNRs
- Reality (~2016)
  - Astonishing variety of TeV* emitters
    - Within the Milky Way
      - Supernova remnants
      - Bombarded molecular clouds
      - Stellar binaries - colliding wind & X-ray
      - Massive stellar clusters
      - Pulsars and pulsar wind nebulae
      - Supermassive black hole Sgr A*
    - Extragalactic
      - Starburst galaxies
      - MW satellites
      - Radio galaxies
      - Flat-spectrum radio quasars
      - ‘BL Lac’ objects
      - Gamma-ray Bursts

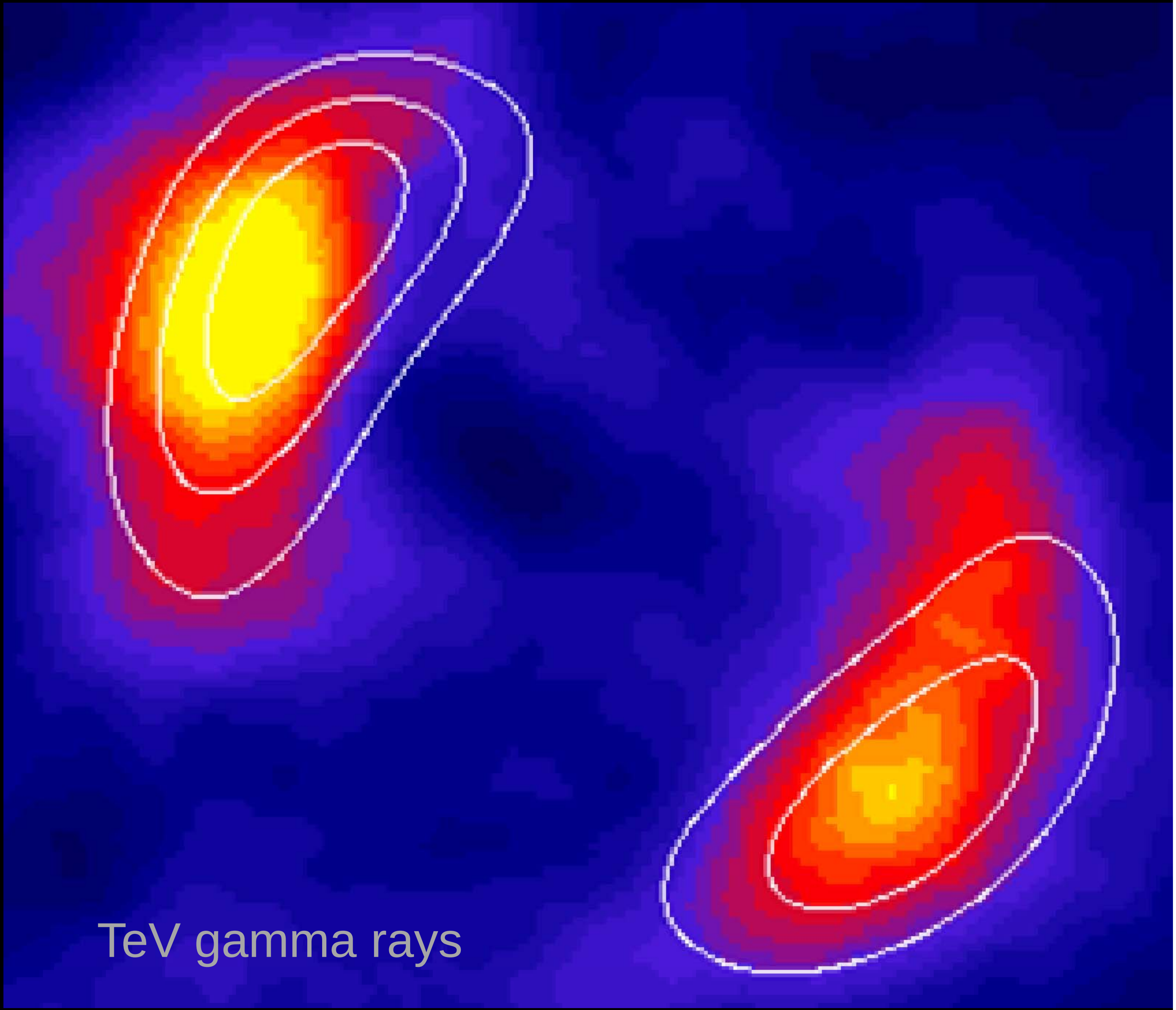


*0.05-50 TeV

Three Selected Science Topics

- Supernova remnants & origin of cosmic rays
- AGN and intergalactic radiation fields
- Galactic Center & Dark Matter

Supernova Remnants



SN 1006

Blue: X-ray
Yellow: Optical
Red: Radio

(Credit:X-ray: NASA/CXC/Rutgers/G.Cassam-Chenai, J.Hughes et al.; Radio: NRAO/AUI/NSF/GBT/VLA/Dyer, Maddalena & Cornwell; Optical: Middlebury College/F.Winkler, NOAO/AURA/NSF/CTIO Schmidt & DSS)

0.4°

Supernova Remnants (SNRs)

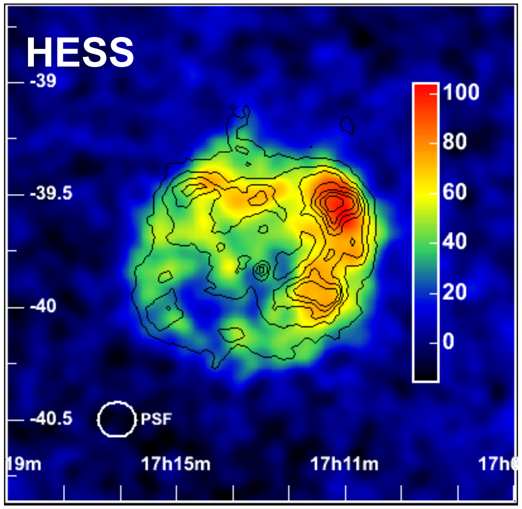
"Standard Model" for high-energy cosmic rays

- Expanding shell of SNR & shock front sweeps up ISM material.
- Acceleration of particles via diffusive shock acceleration.
- Can supply and replenish CR's if $\varepsilon \sim$ 5-10%.

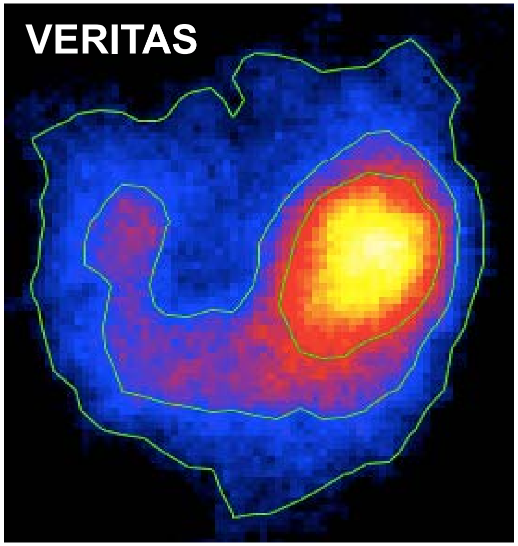
Good model … is it right ?

CTA will:

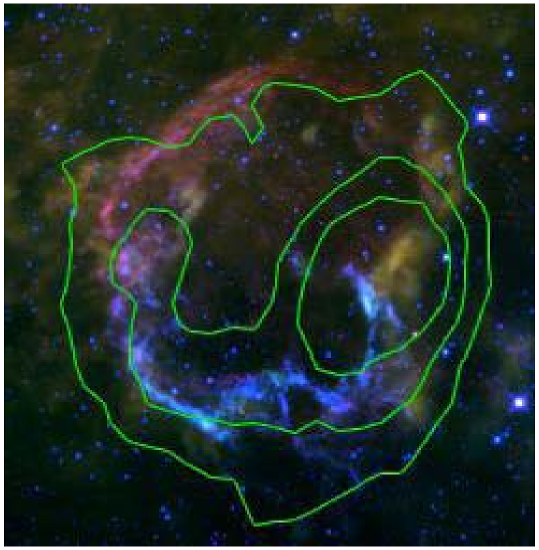
- discover many SNRs, including perhaps a few PeVatrons, and
- characterize them (morphology, SED, etc.) much better than present-day instruments.



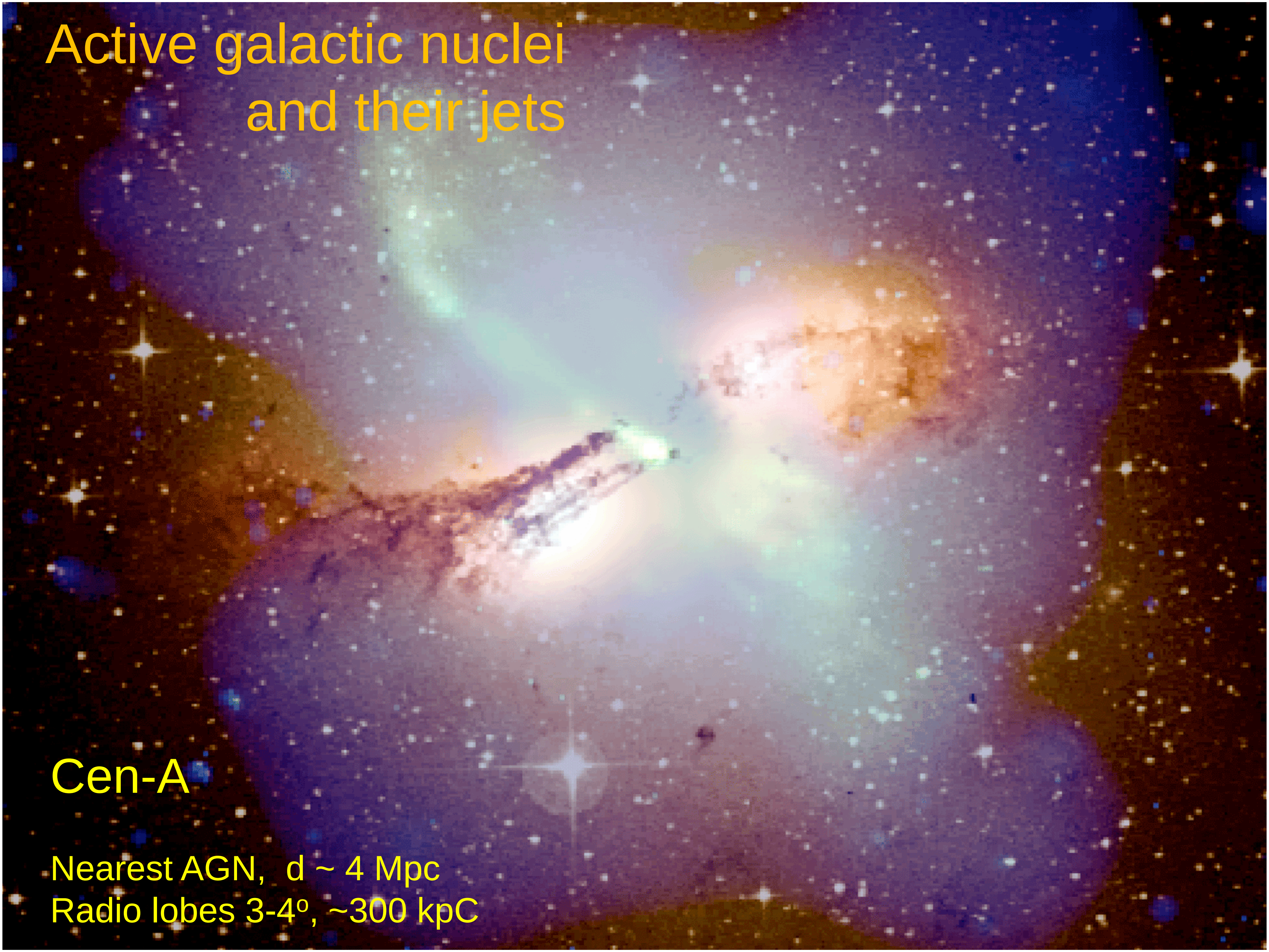
RXJ 1713-3946
Age = 1600y
D = ~1 kpc

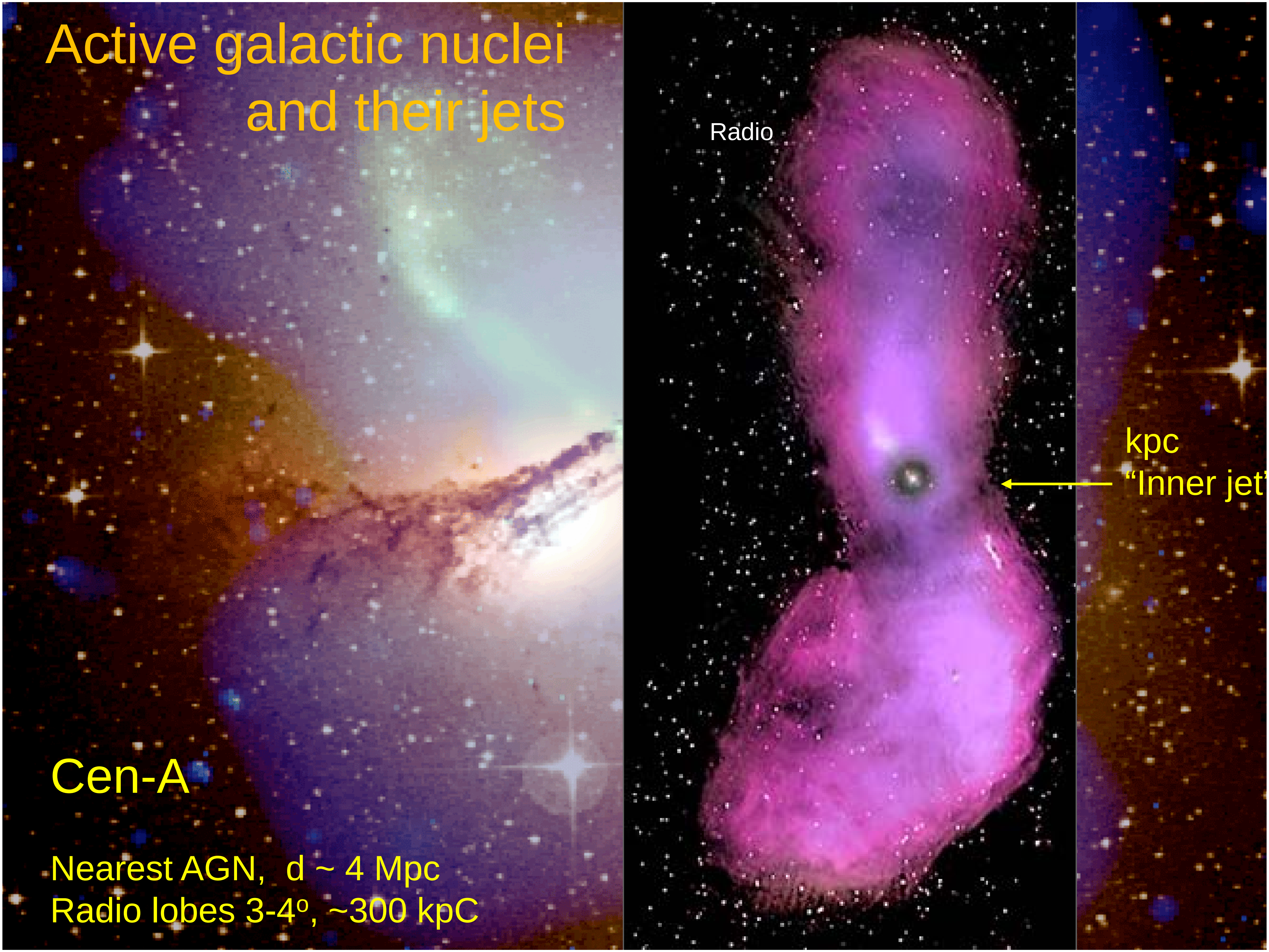


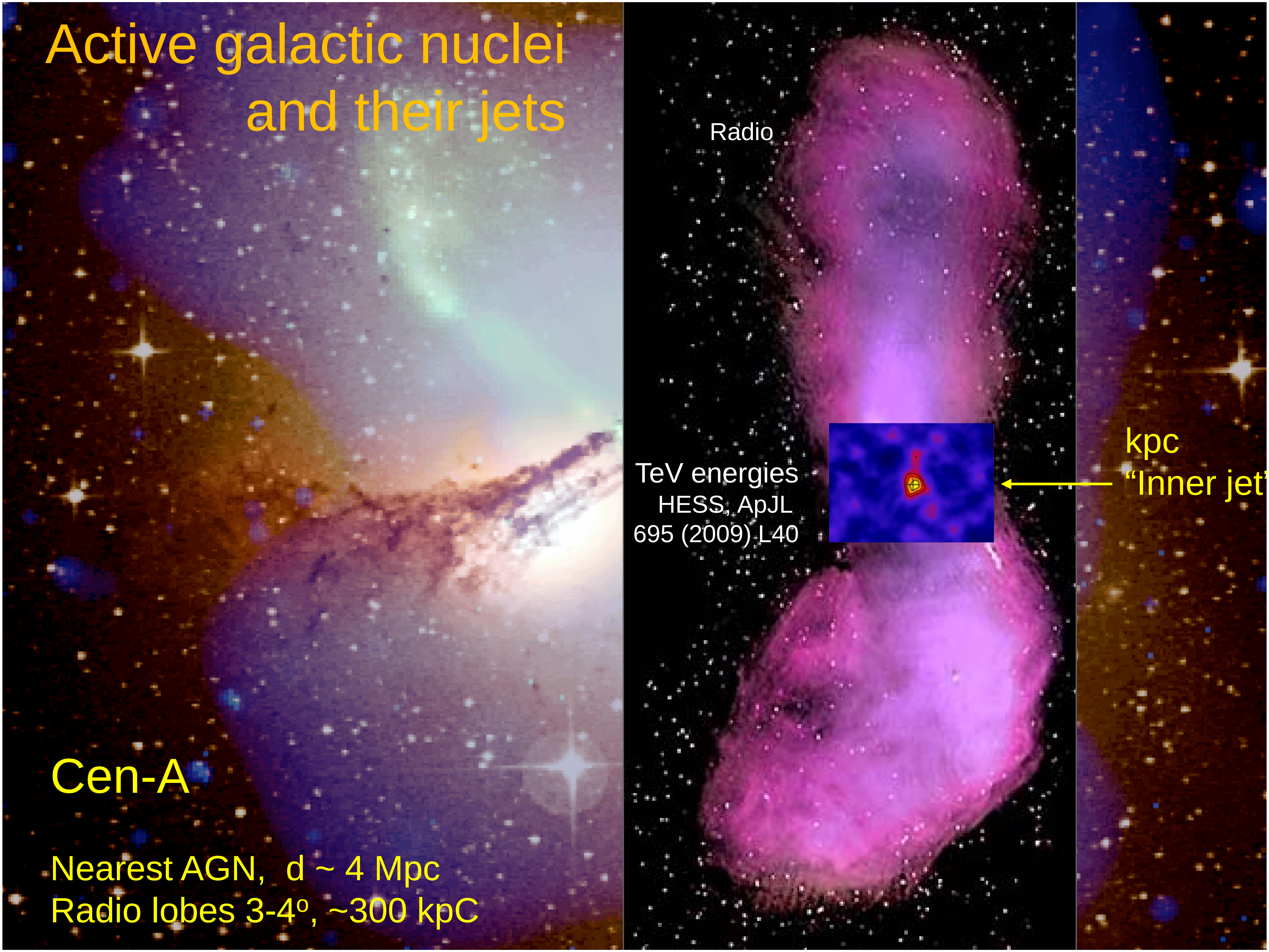
IC 443
Age ~ 30ky
D ~ 0.8kpc



IC 443
WISE* – *22, 12, 4.6 μm


Active galactic nuclei
and their jets
Cen-A
Nearest AGN, d ~ 4 Mpc
Radio lobes 3-4º, ~300 kpC


Active galactic nuclei
and their jets
Radio
kpc
“Inner jet”
Cen-A
Nearest AGN, d ~ 4 Mpc
Radio lobes 3-4º, ~300 kpC

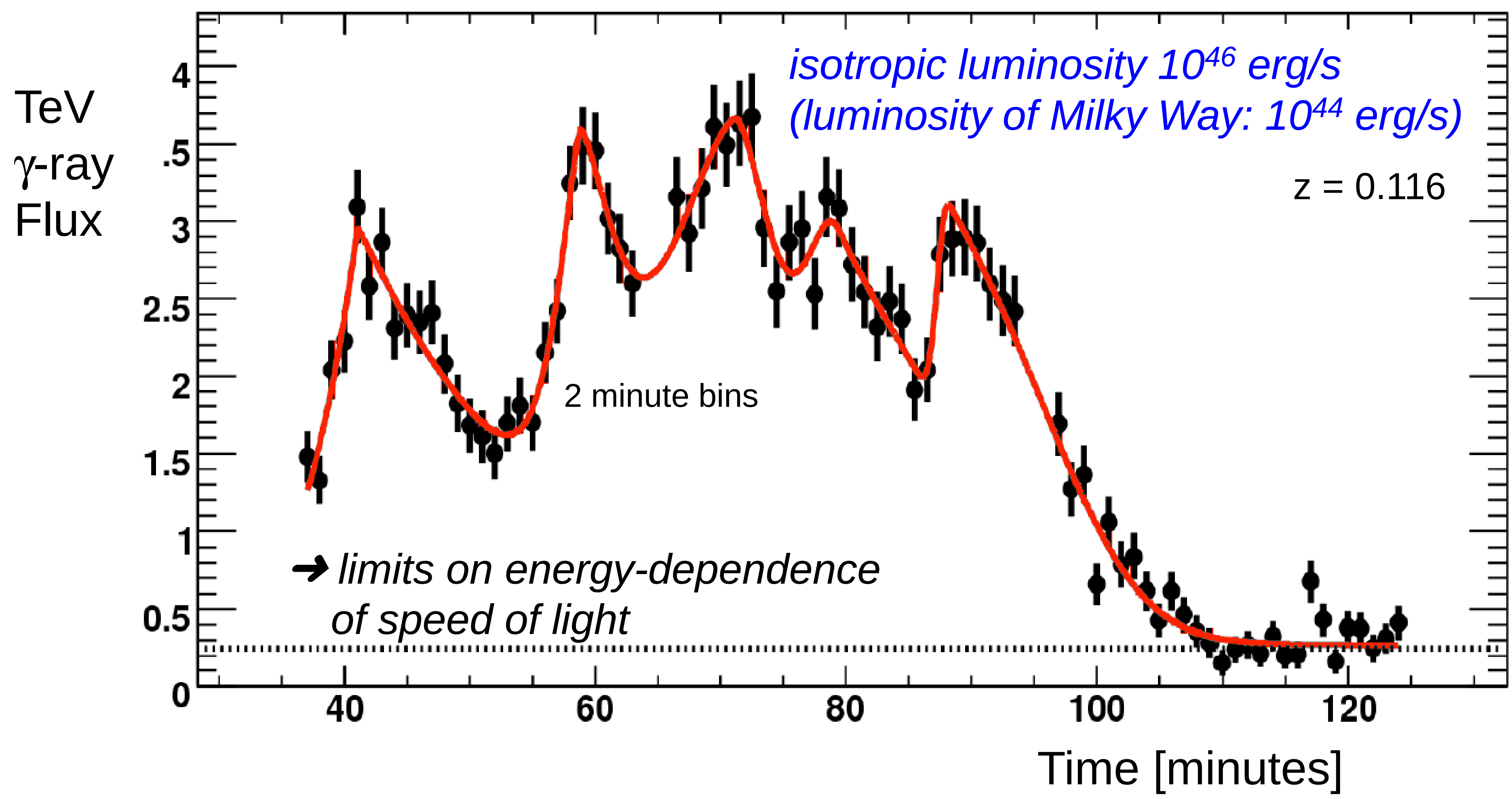


Active galactic nuclei
and their jets
Radio
TeV energies
HESS, ApJL
695 (2009) L40
kpc
"Inner jet"
Cen-A
Nearest AGN, d ~ 4 Mpc
Radio lobes 3-4º, ~300 kpC

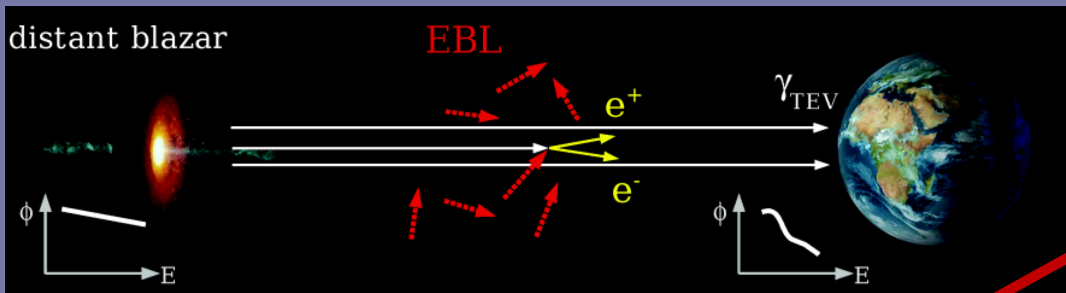
AGN: Extreme Variability

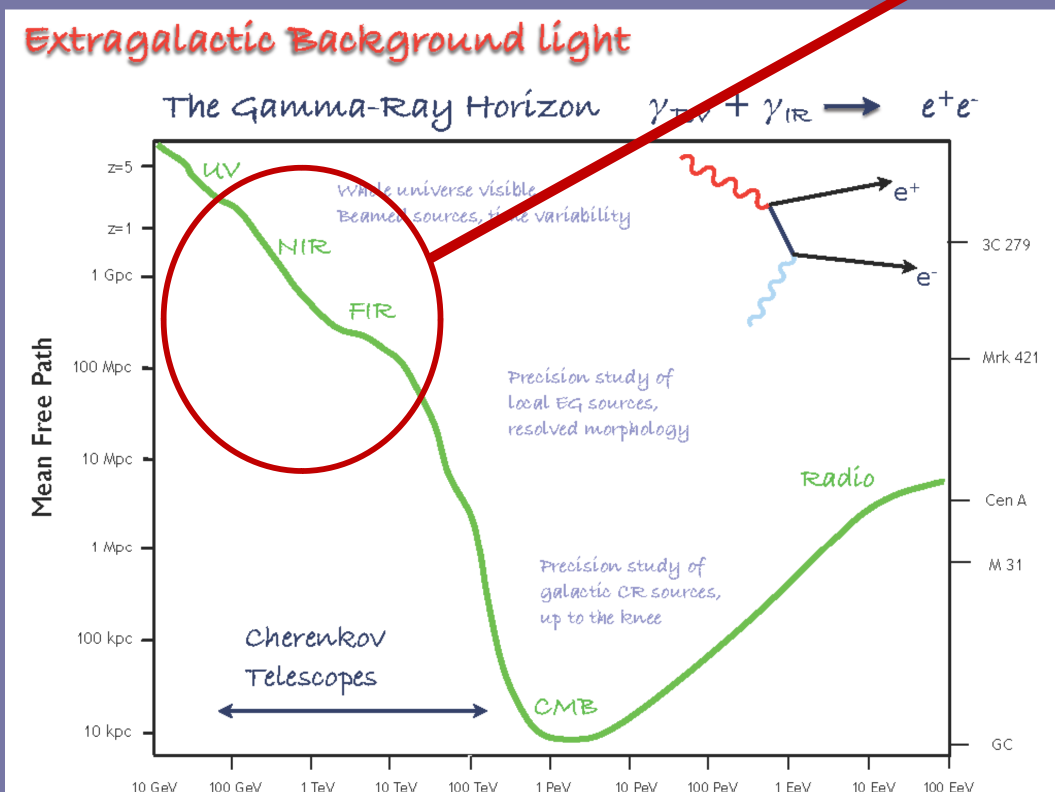
"Blazars": AGN with jets pointed towards us
strong VHE emitters

PKS 2155-304 flare
arXiv:0706.0797



VHE γ-rays as Cosmological Probes





1 TeV **1 PeV** Energy

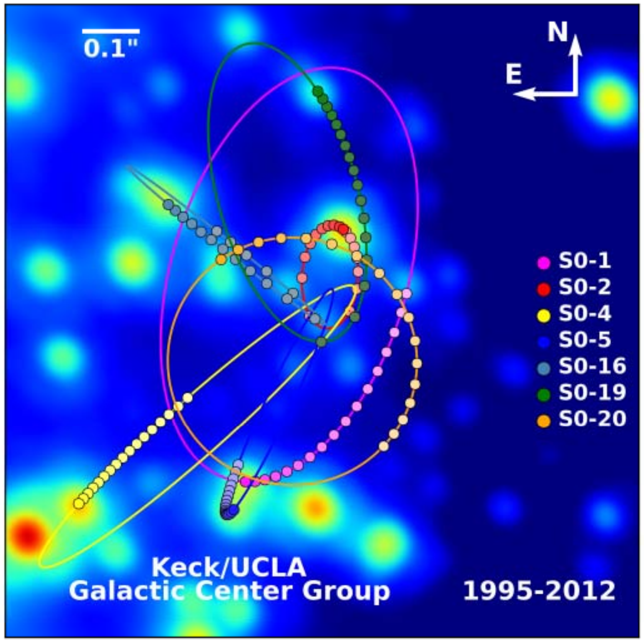
Extragalactic Background Light (EBL):

- OIR diffuse background produced by star-formation throughout history of universe.
- $\gamma\gamma$ interaction probes EBL density, uniformity, evolution.
- A way to measure/constrain tiny intergalactic magnetic field (IGMF):

$$B \sim 10^{-10} - 10^{-18}\ G$$

Galactic Center

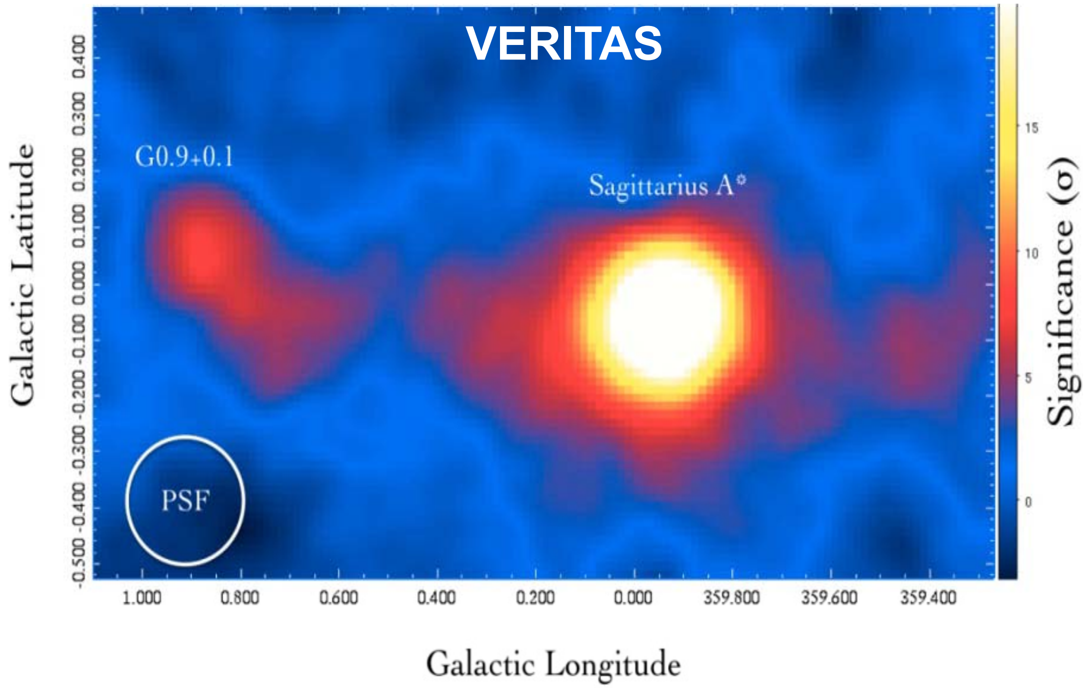
Infrared



Ghez et al., 2012
1″ x 1″

TeV γ-rays

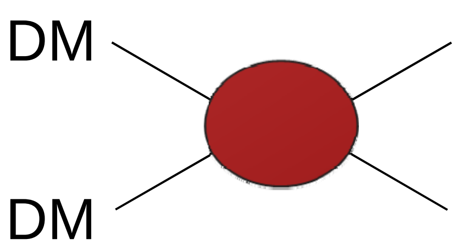
A, Archer et al.
VERITAS Coll.
(2015)



GeV & TeV emission is:

- intense & non-thermal
- totally unexpected
- not understood !

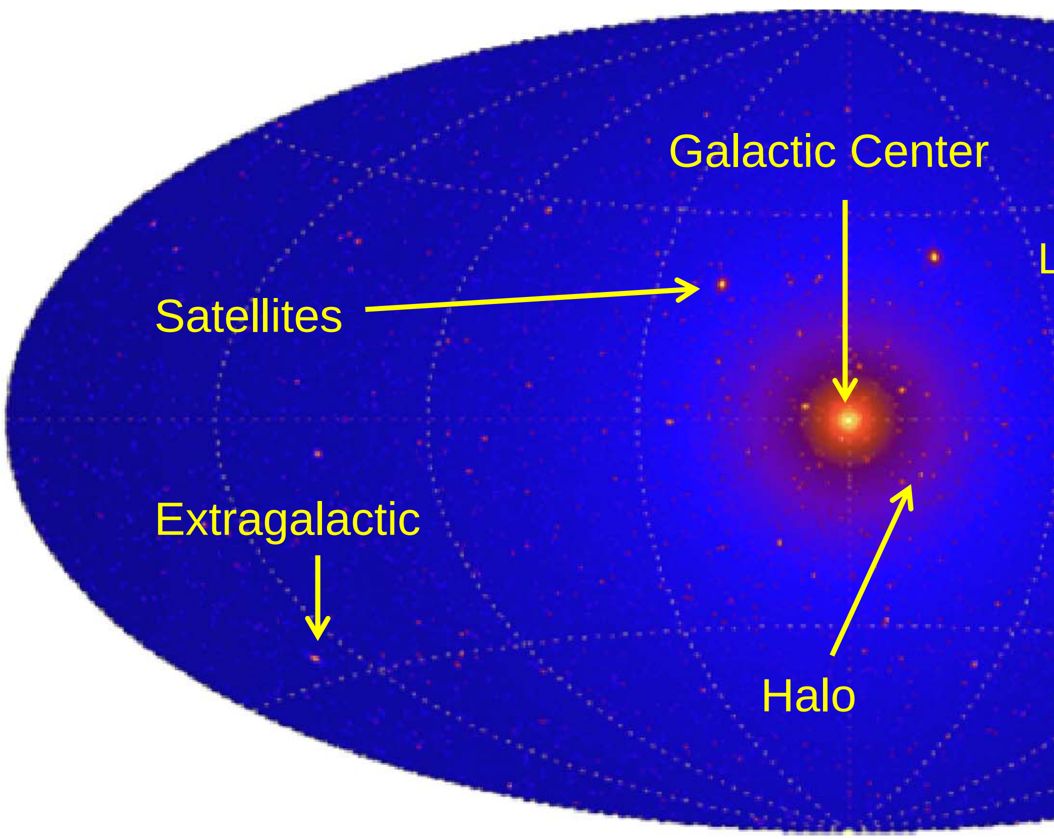
Dark Matter Detection



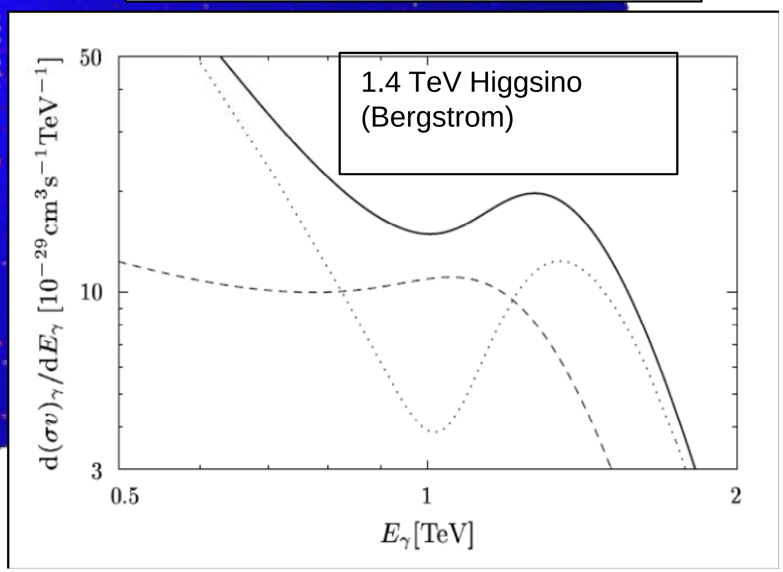
SM: b, W^+, Z, τ^+, …
Primary channels
SM: b, W^-, Z, τ^-, …

Hadronisation and/or decay

➡ γ, e^+, $\bar{p}$, $\bar{\nu}$, …
Final states
➡ γ, e^-, p, ν, …

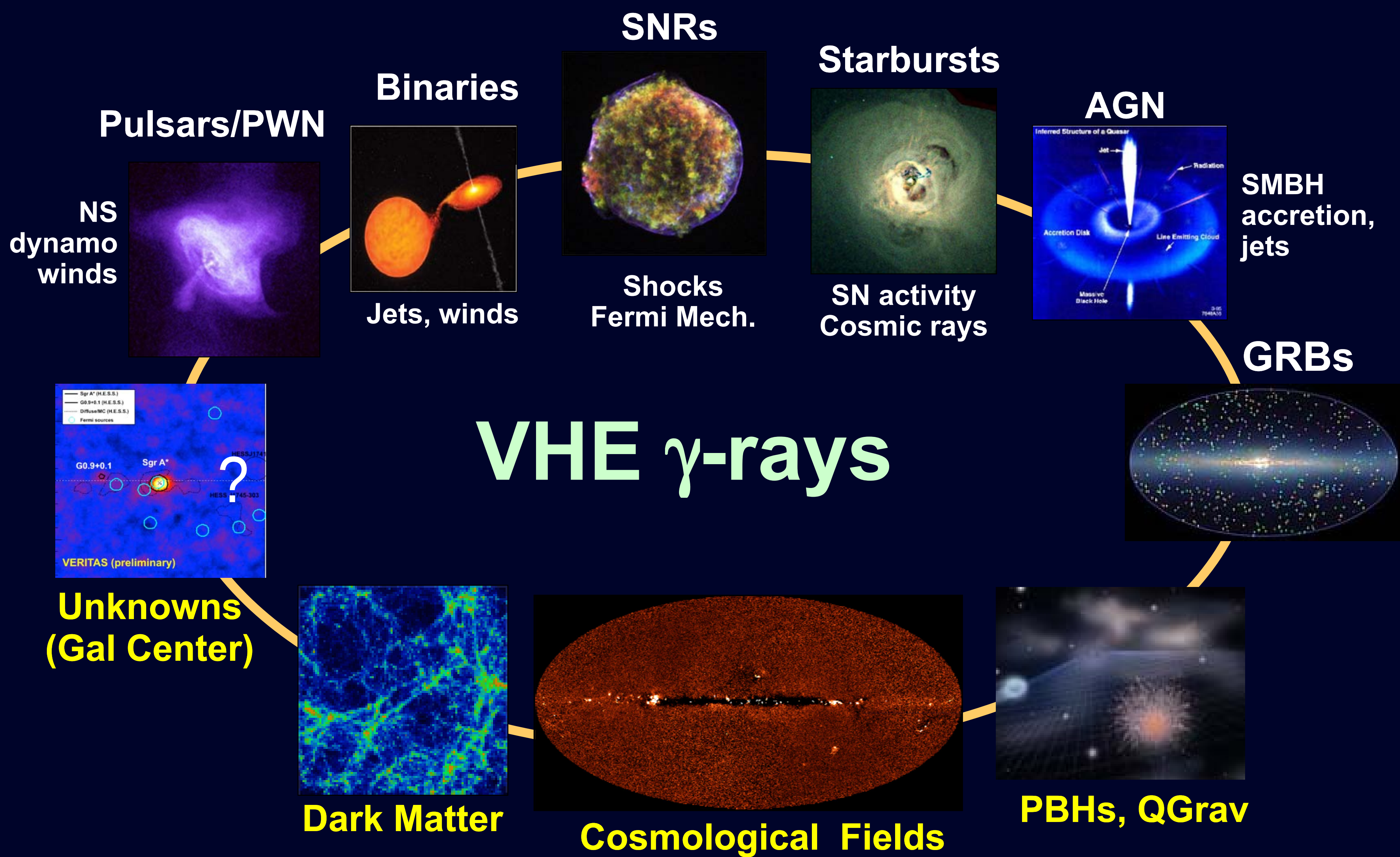


"Universal" Spectrum



Ultimate goal: Dark Matter Astronomy

Exploring the non-thermal Universe “ASTRO”



Probing New Physics at GeV/TeV scale “PARTICLE”

Summary of Key Science Questions

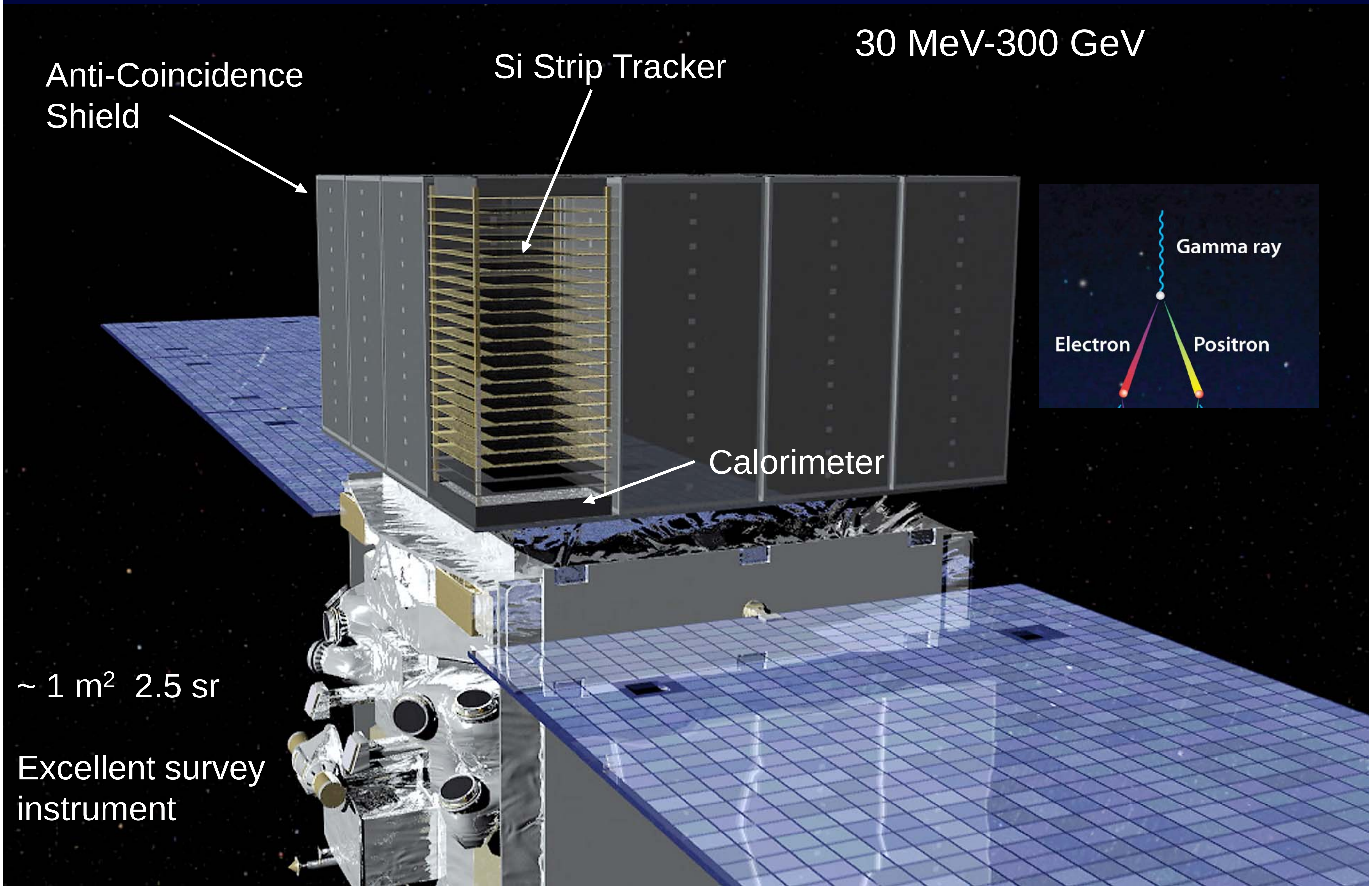
Bottom line: GeV and TeV gamma-ray sources are ubiquitous in the universe and probe extreme particle acceleration, and the subsequent particle interactions and propagation.

1. How are the bulk of cosmic ray particles accelerated in our Galaxy and beyond? (one of the oldest surviving questions of astrophysics)
2. Can we understand the physics of jets, shocks & winds in the variety of sources we see, including pulsars, binaries, AGN, starbursts, and GRBs?
3. How do black holes of all sizes efficiently particles? How are the structures (e.g. jets) formed and how is the accretion energy harnessed?
4. What do high-energy gamma rays tell us about the star formation history of the Universe, intergalactic radiation fields, and the fundamental laws of physics?
5. What is the nature of dark matter and can we map its distribution through its particle interactions?
6. What new unexpected phenomena will be revealed by exploring the non-thermal Universe?

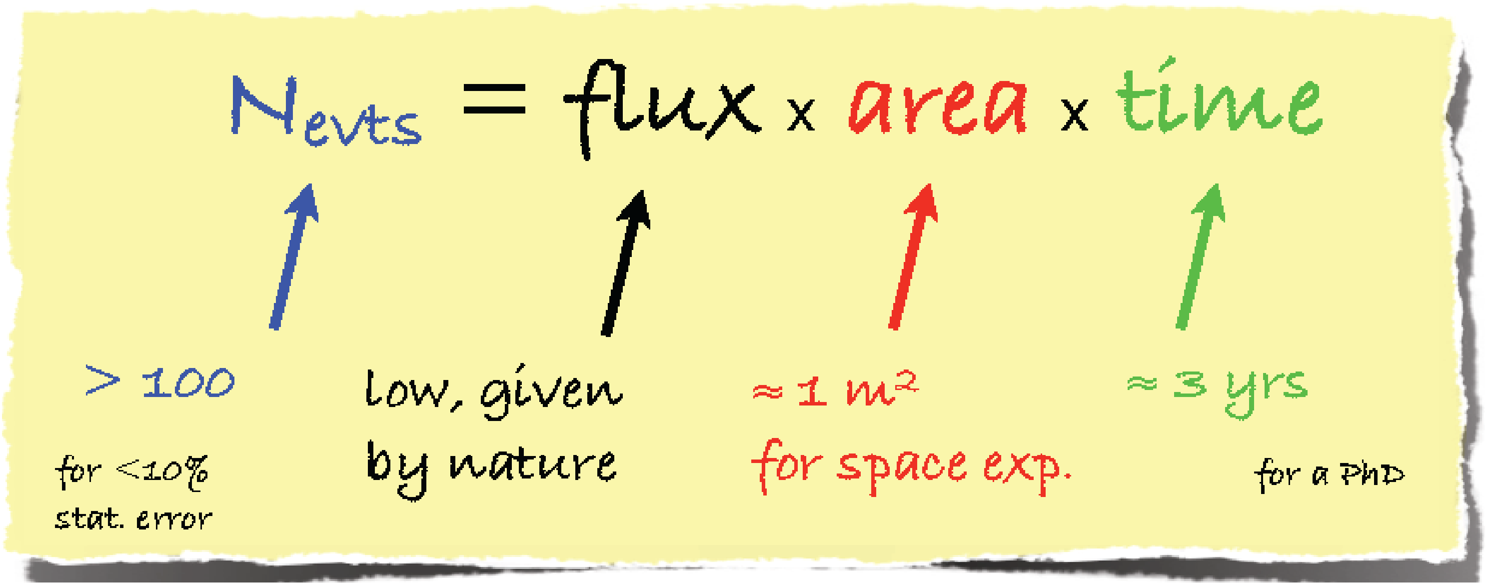
Bonus science: optical interferometry, cosmic-ray physics, OSETI, etc.

Experimental Technique
&
Planning for the Future

Fermi Large Area Telescope (LAT)



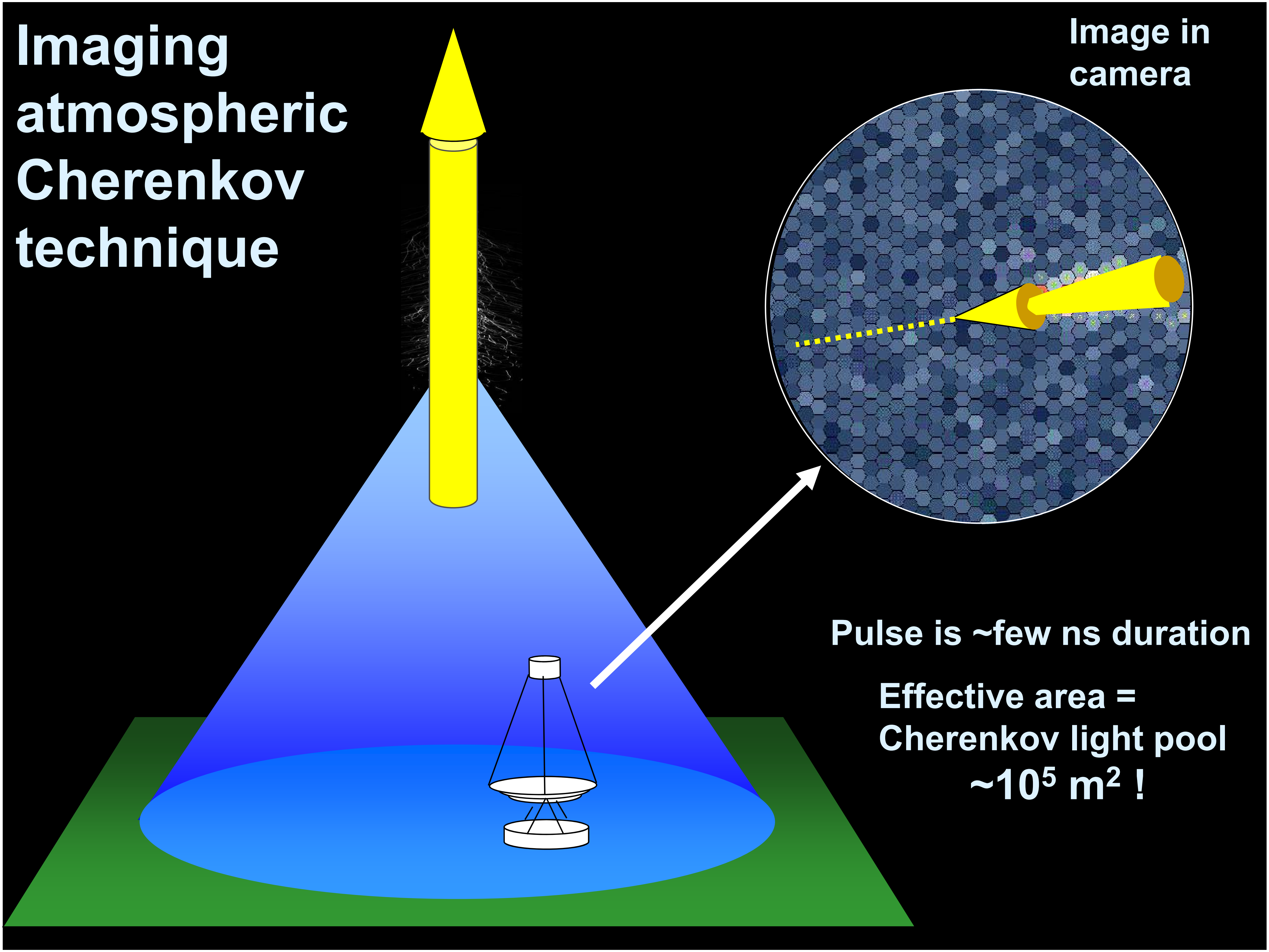
Beyond 100 GeV



Steeply falling spectrum:

x10 in Energy → divide by 100-500 in flux

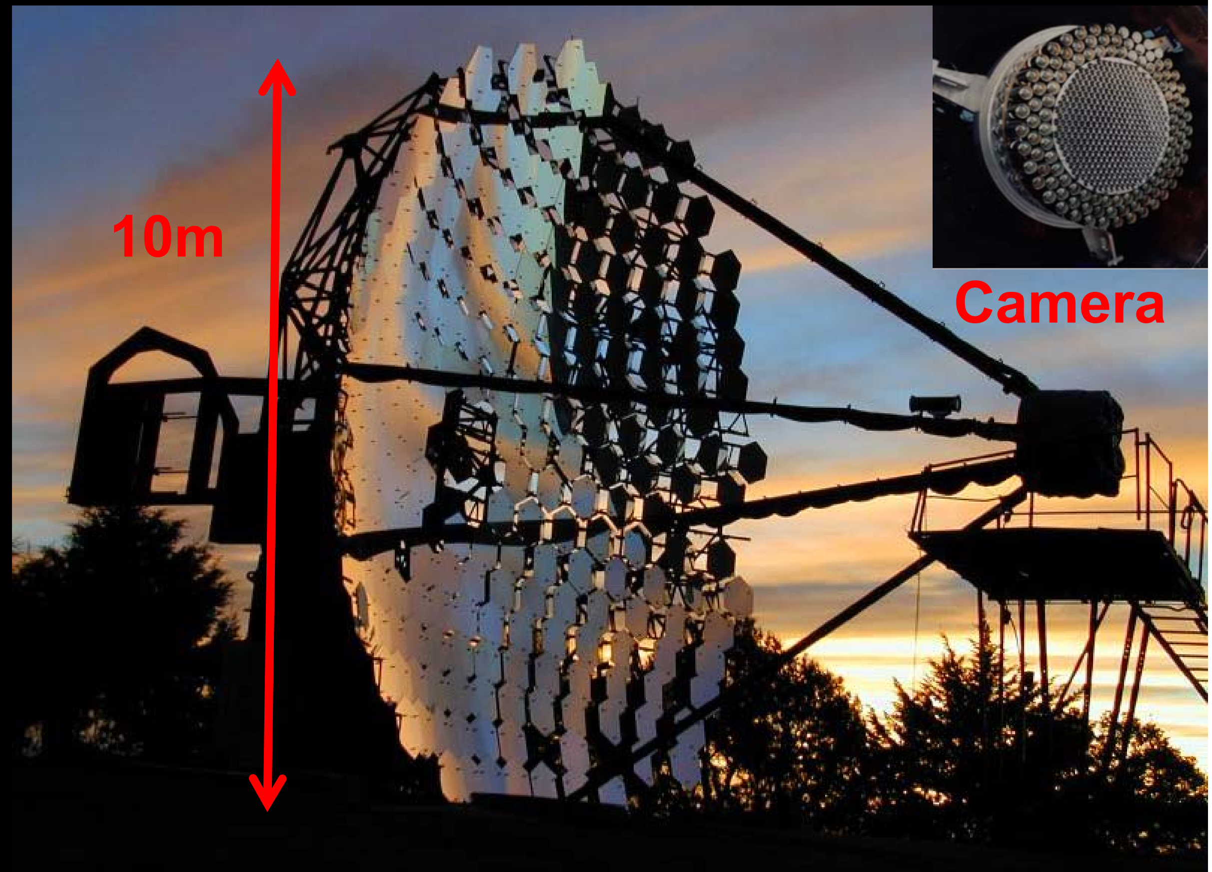
- Large effective area needed to get detectable signals at VHE
- Natural detector: *the atmosphere*



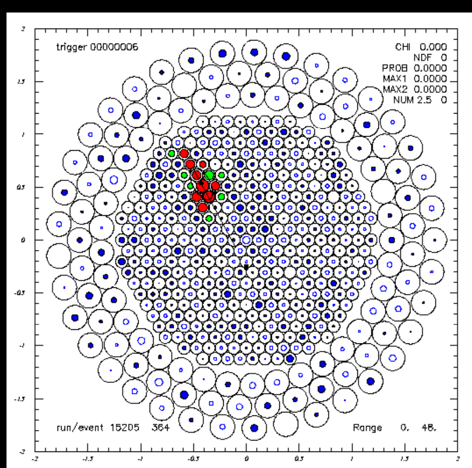
Imaging atmospheric Cherenkov technique
Image in camera
Pulse is ~few ns duration
Effective area = Cherenkov light pool
~10^5 m^2 !

Whipple 10m
γ-ray Telescope
(1968-2011)

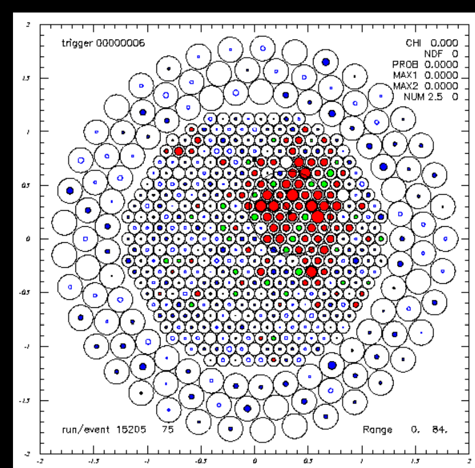
- Pioneered use of Imaging
- Made first source detection.
  (Crab Nebula in ~90 hours)



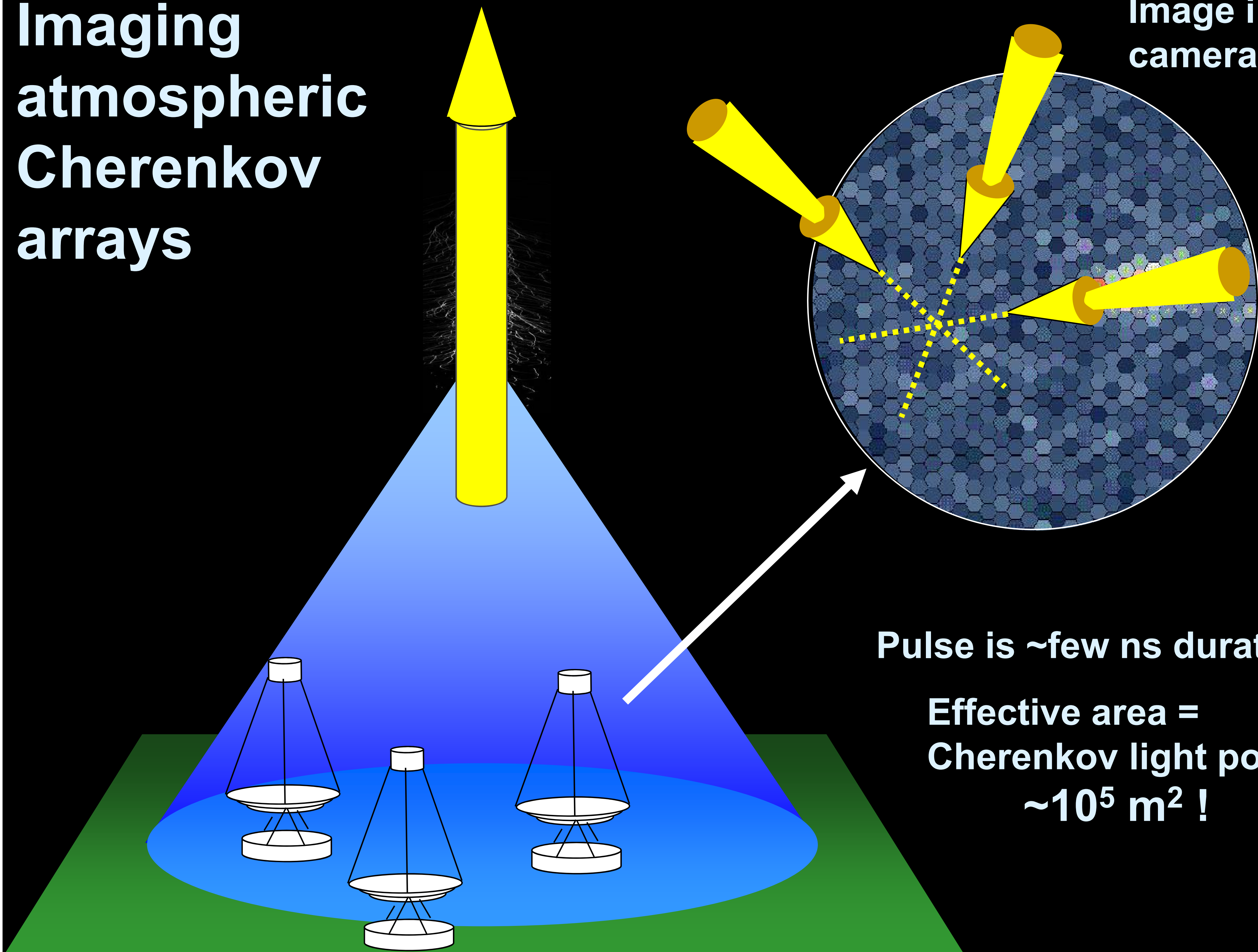
γ-ray



cosmic ray



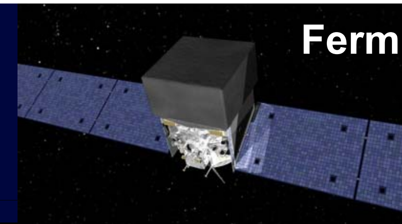
Imaging atmospheric Cherenkov arrays

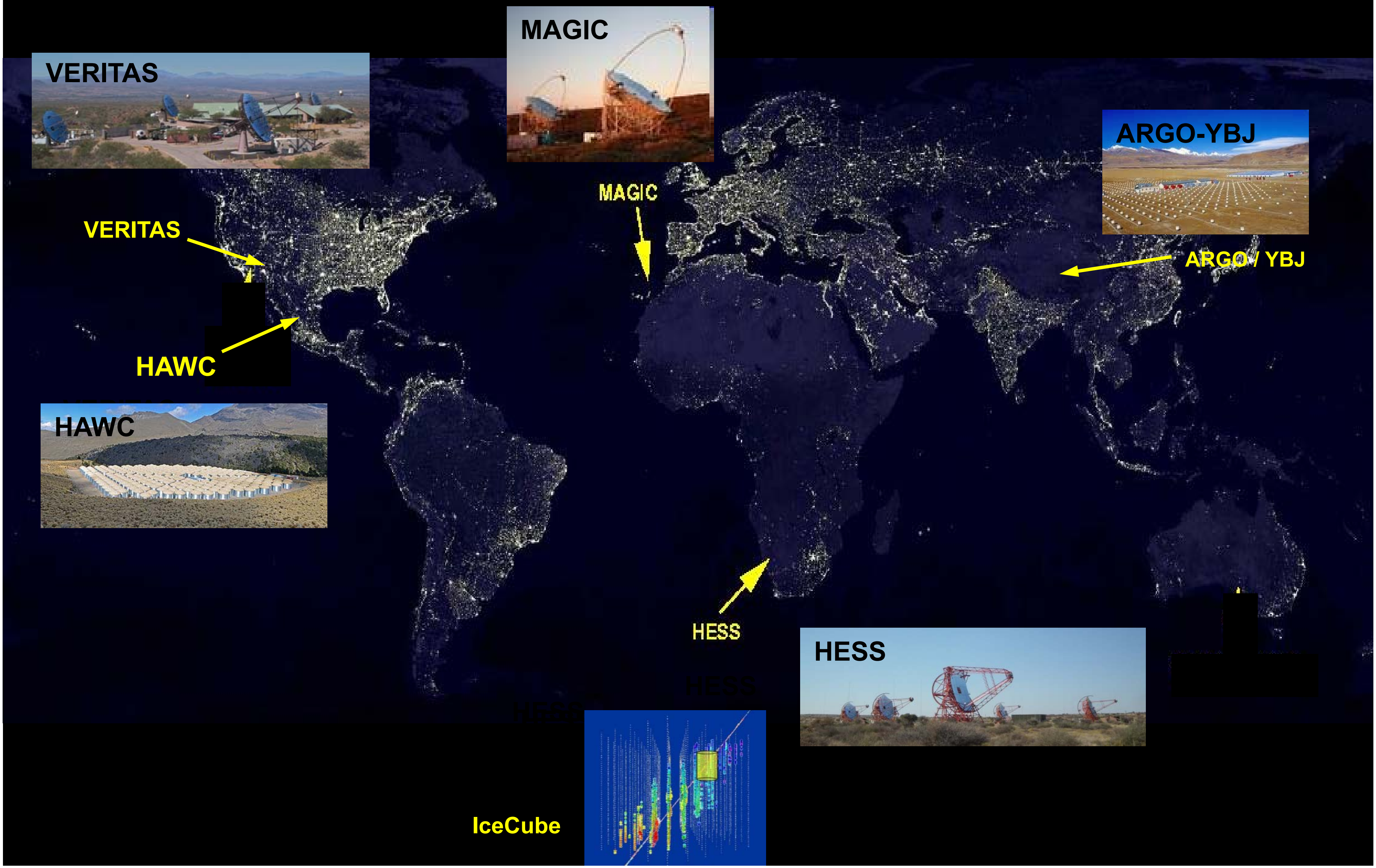


Pulse is ~few ns duration

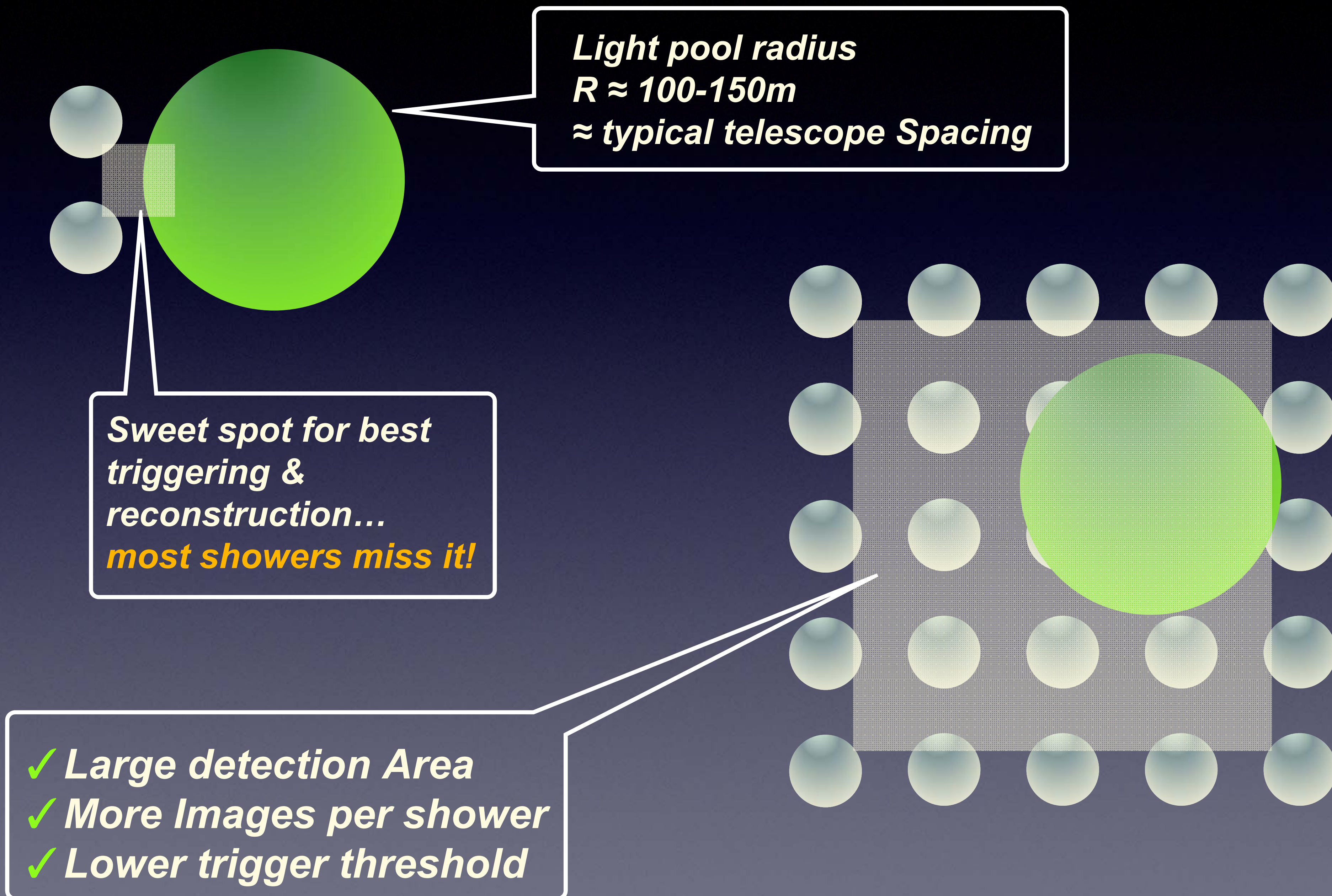
Effective area = Cherenkov light pool $\sim 10^5$ m^2 !

VHE Telescopes (2016)





From current arrays to CTA

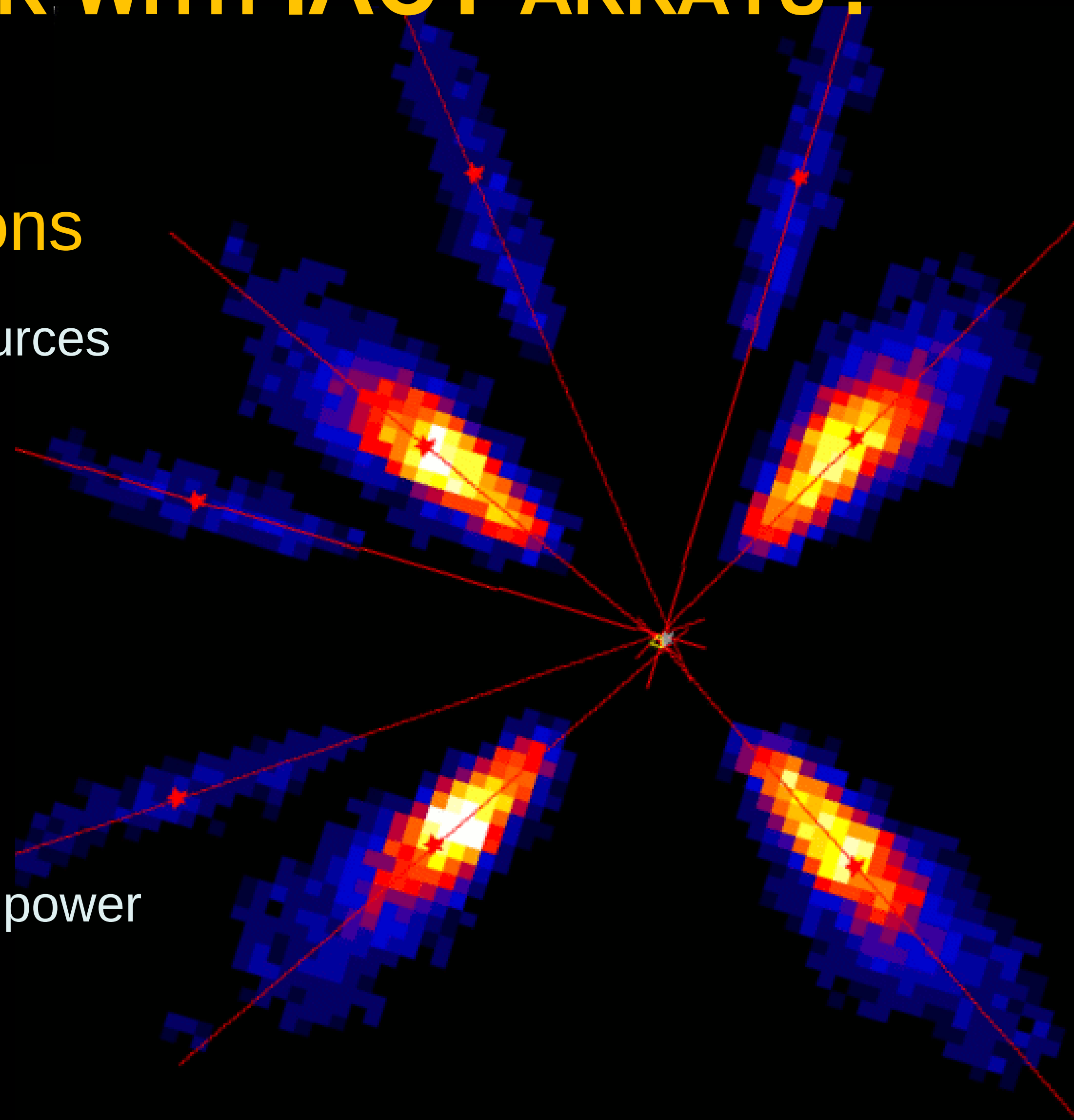


How to do better with IACT arrays?

➡ More events, more photons

- Better spectra, images, fainter sources
  - ✓Larger light collecting area
  - ✓Better reconstructed events
- Better measurement of air shower and hence primary gammas
  - ✓Improved angular resolution
  - ✓Improved background rejection power

➡ More telescopes!



Simulation:
Superimposed images from 8 cameras

Planning for the Future

What we know, based on H.E.S.S., MAGIC, VERITAS:

Great scientific potential exists in the VHE domain

- *Expect many more sources & deeper probes for new physics*

IACT Technique is very powerful

- *Have not yet reached its full potential → large Cherenkov array*

Exciting science in both Hemispheres

- *Argues for an array in both S and N*

Open Observatory → Substantial reward

- *Open data/access, MWL connections to get the best science*

International Partnerships required by scale/scope

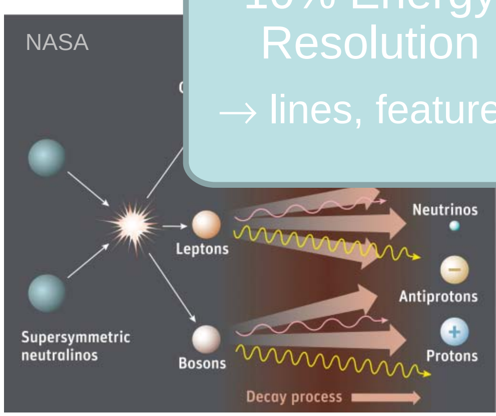
- *Project must develop the instrument and the observatory*


cta
cherenkov telescope array

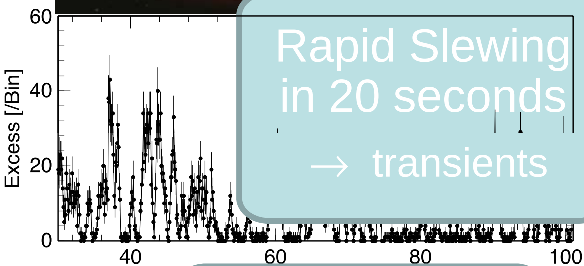
Science Drivers

10% Energy Resolution

→ lines, features

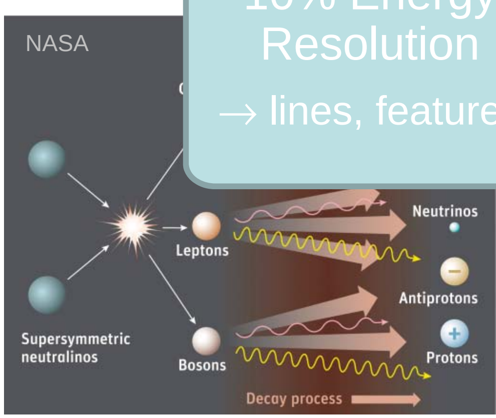


Science Drivers



Rapid Slewing in 20 seconds

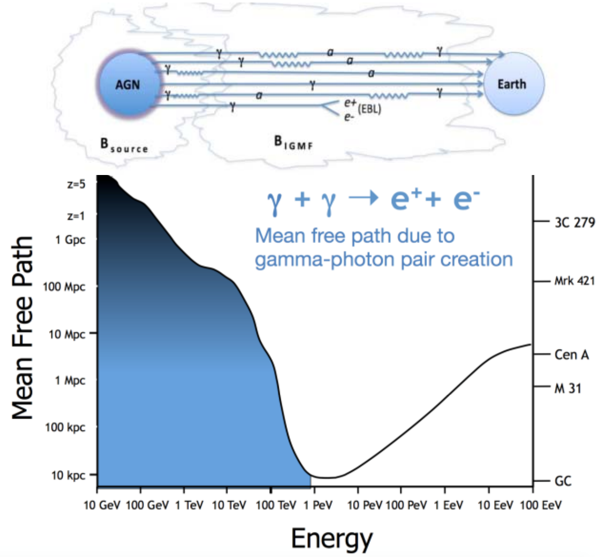
→ transients



10% Energy Resolution

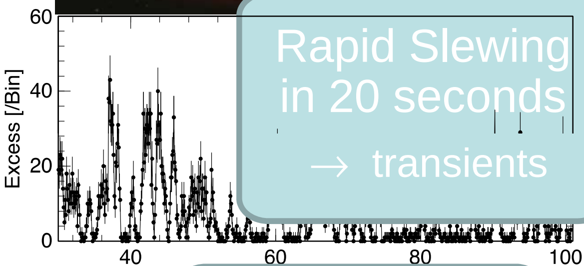
→ lines, features

Science Drivers



Energies down to 20 GeV

→ Cosmology++



Rapid Slewing in 20 seconds

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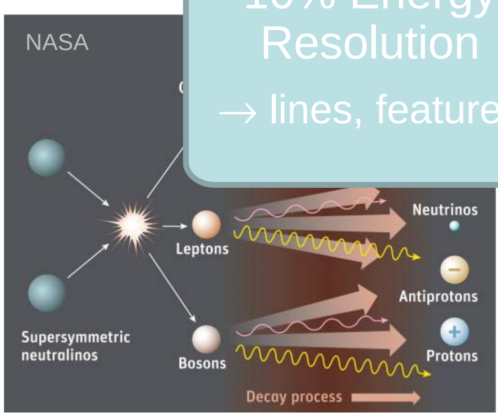
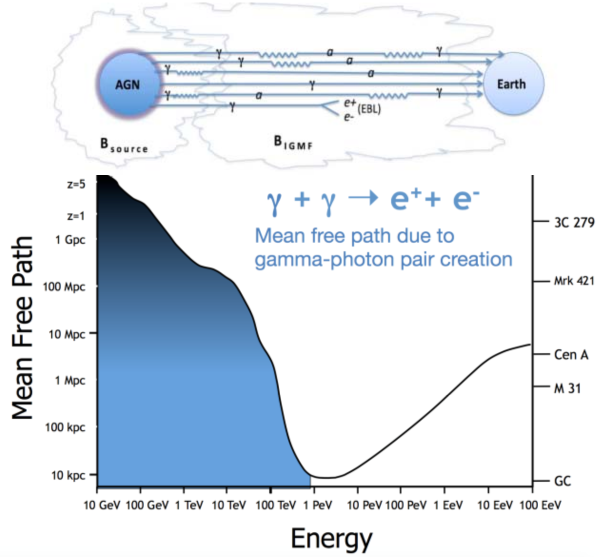


10% Energy Resolution

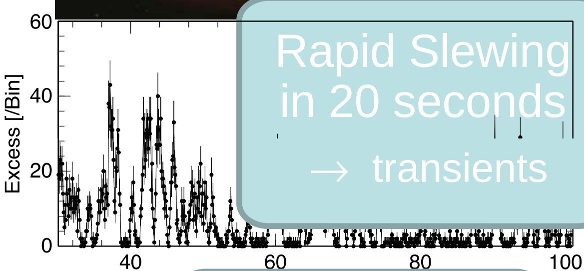
→ lines, features

Science Drivers



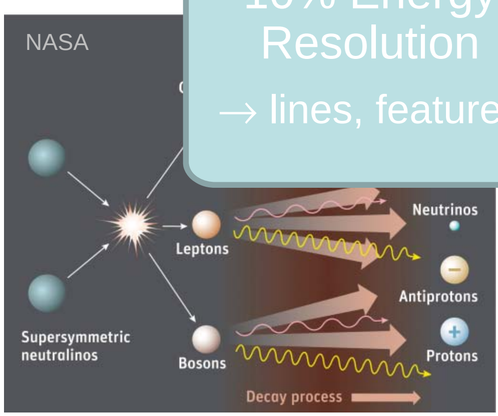
Energies down to 20 GeV

→ Cosmology++



Rapid Slewing in 20 seconds

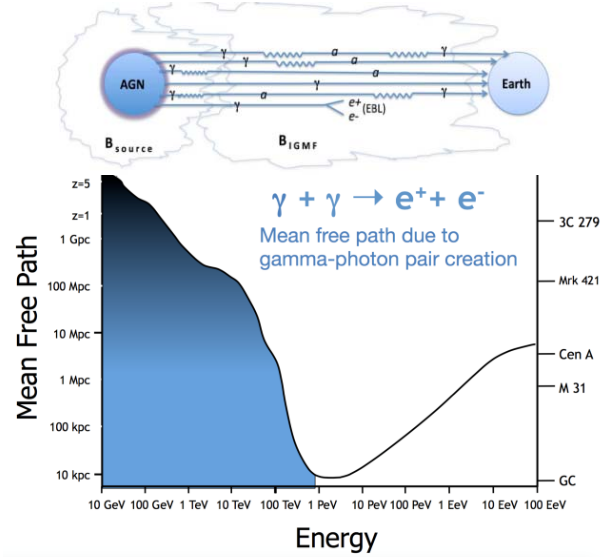
→ transients

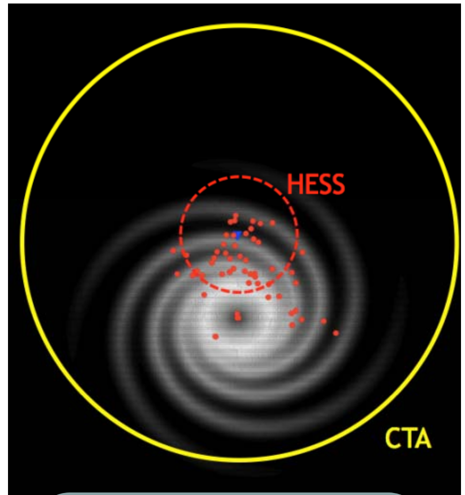


10% Energy Resolution

→ lines, features

Science Drivers



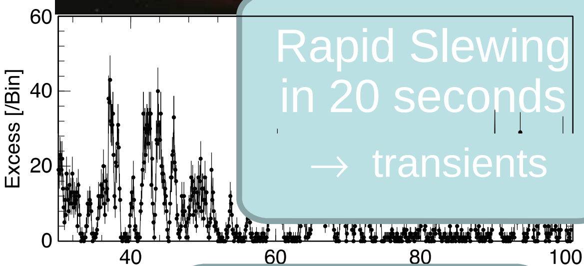


10 x Sensitivity, Large Collection Area

→ all topics

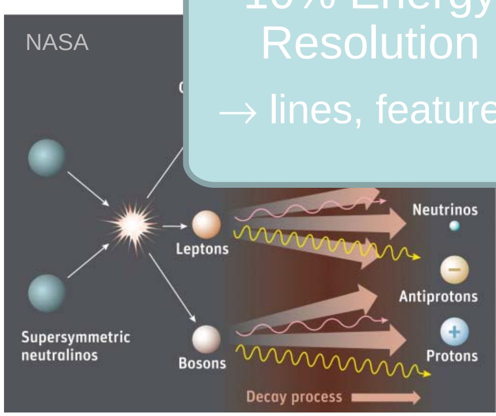
Energies down to 20 GeV

→ Cosmology++



Rapid Slewing in 20 seconds

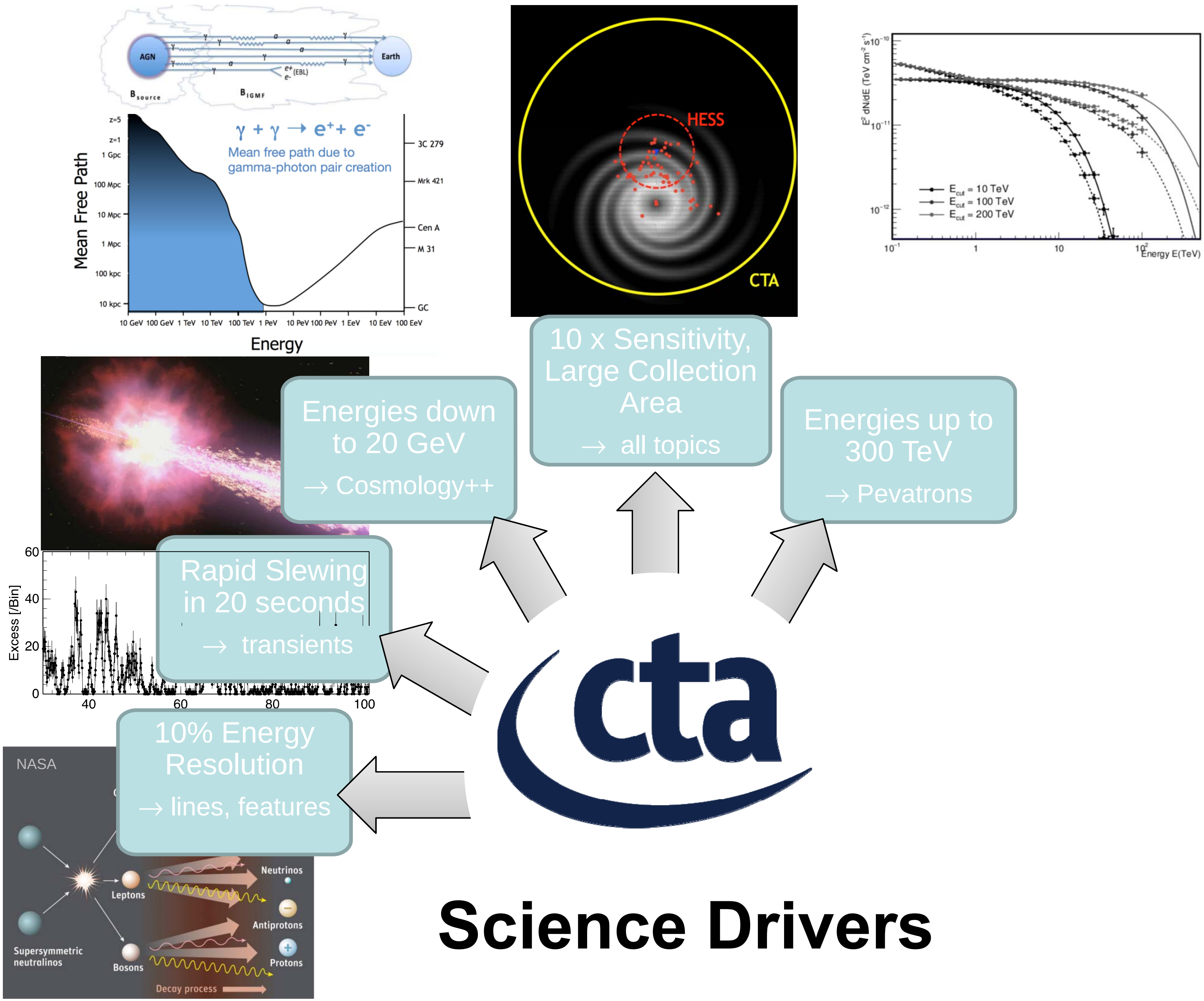
→ transients



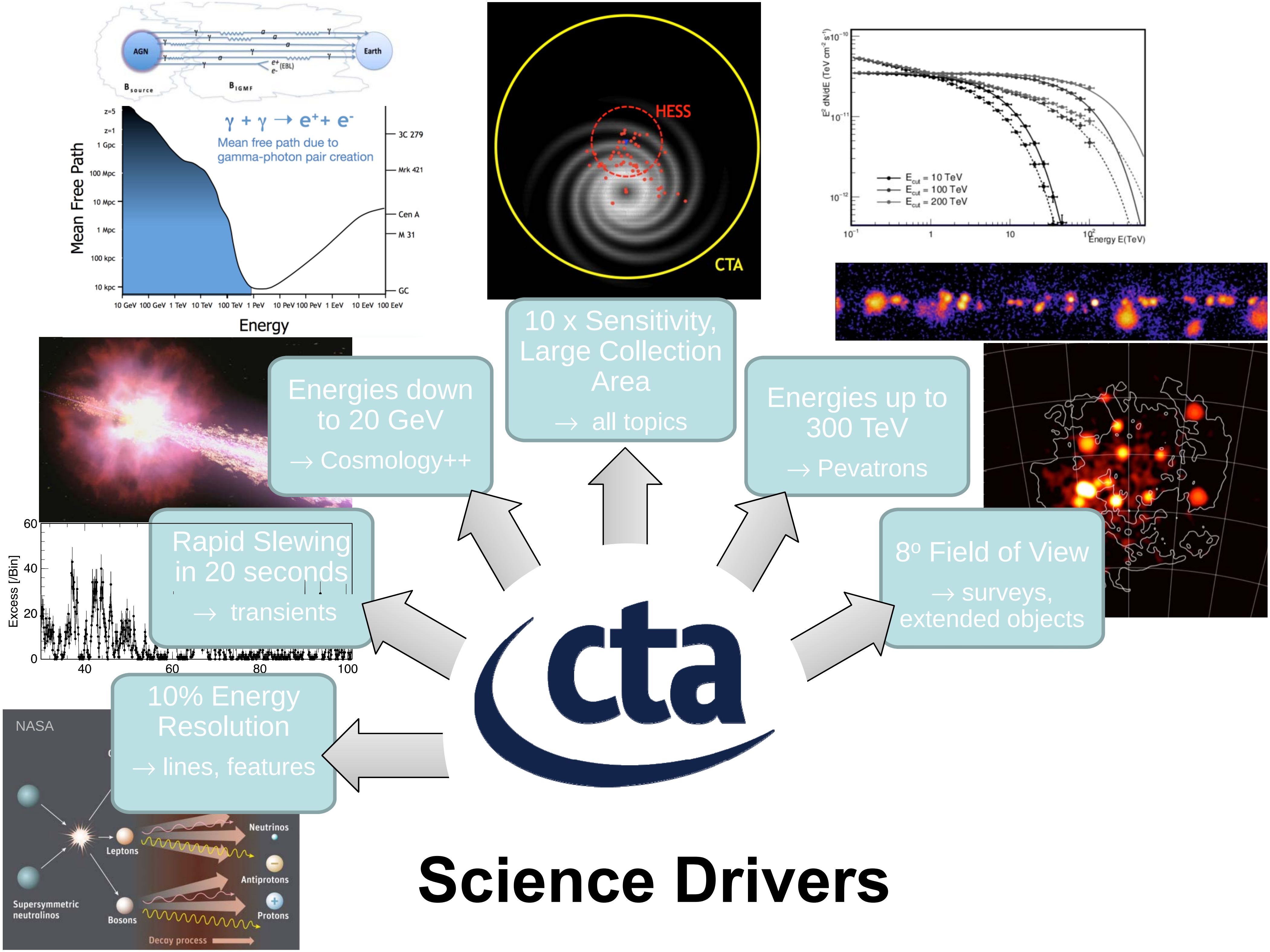
10% Energy Resolution

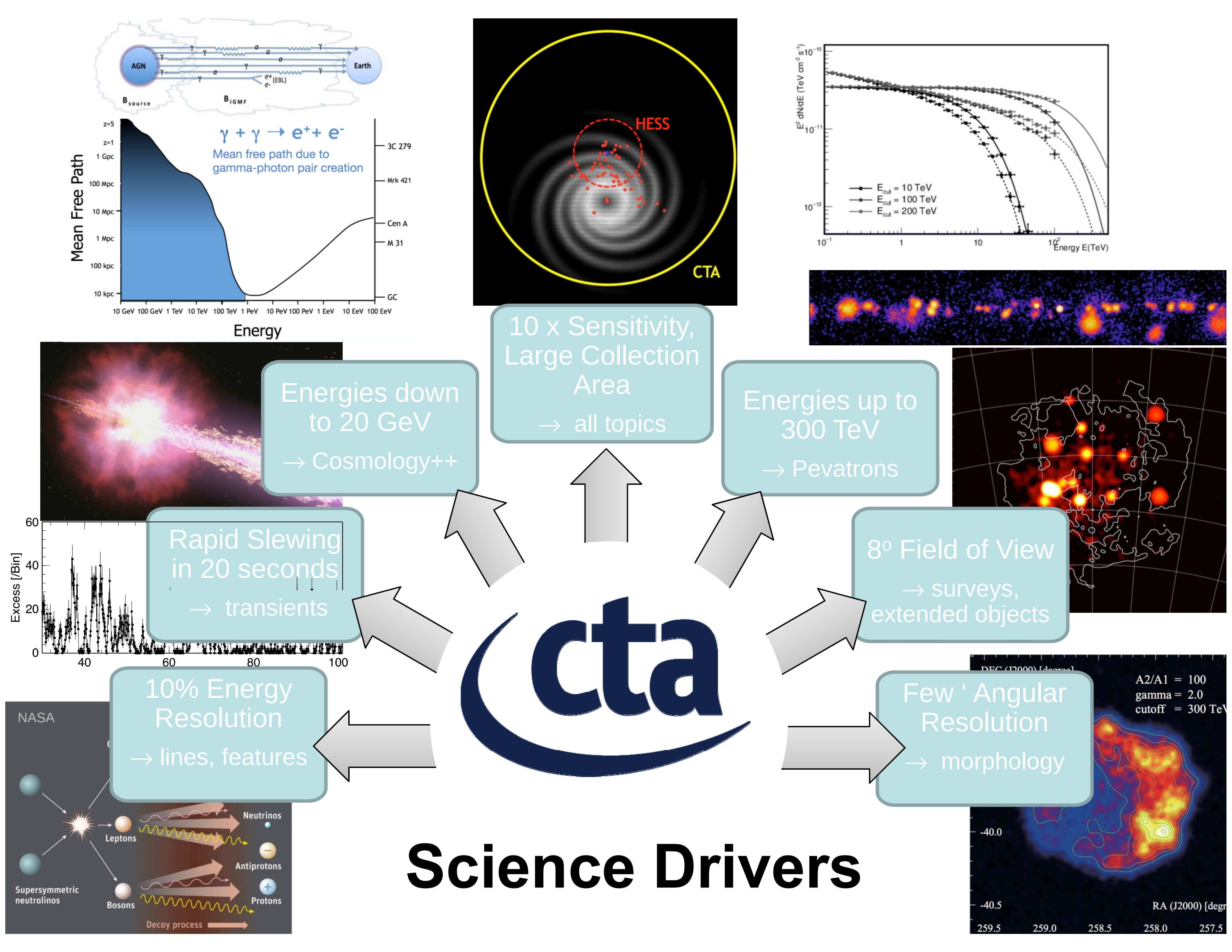
→ lines, features

Science Drivers



AGN
Earth
$\gamma + \gamma \rightarrow e^+ + e^-$
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
3C 279
Mrk 421
Cen A
M 31
GC
HESS
CTA
E_{cut} = 10 TeV
E_{cut} = 100 TeV
E_{cut} = 200 TeV
Energy E(TeV)
10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
Rapid Slewing in 20 seconds
→ transients
Excess [/Bin]
10% Energy Resolution
→ lines, features
NASA
Supersymmetric neutralinos
Leptons
Bosons
Neutrinos
Antiprotons
Protons
Decay process
cta
Science Drivers


AGN
Earth
(EBL)
Bsource
BIGMF
γ + γ → e⁺+ e⁻
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
3C 279
Mrk 421
Cen A
M 31
GC
HESS
CTA
Energy E(TeV)
Ecut = 10 TeV
Ecut = 100 TeV
Ecut = 200 TeV
10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
Rapid Slewing in 20 seconds
→ transients
Excess [/Bin]
8º Field of View
→ surveys, extended objects
10% Energy Resolution
→ lines, features
NASA
Neutrinos
Leptons
Antiprotons
Supersymmetric neutralinos
Bosons
Protons
Decay process
cta
Science Drivers



AGN
Earth
(EBL)
γ + γ → e⁺+ e⁻
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
3C 279
Mrk 421
Cen A
M 31
GC
HESS
CTA
E_{cut} = 10 TeV
E_{cut} = 100 TeV
E_{cut} = 200 TeV
Energy E(TeV)
10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
Rapid Slewing in 20 seconds
→ transients
Excess [/Bin]
8º Field of View
→ surveys, extended objects
10% Energy Resolution
→ lines, features
Few ' Angular Resolution
→ morphology
NASA
Neutrinos
Leptons
Antiprotons
Supersymmetric neutralinos
Bosons
Protons
Decay process
A2/A1 = 100
gamma = 2.0
RA (J2000) [degr
cta
Science Drivers

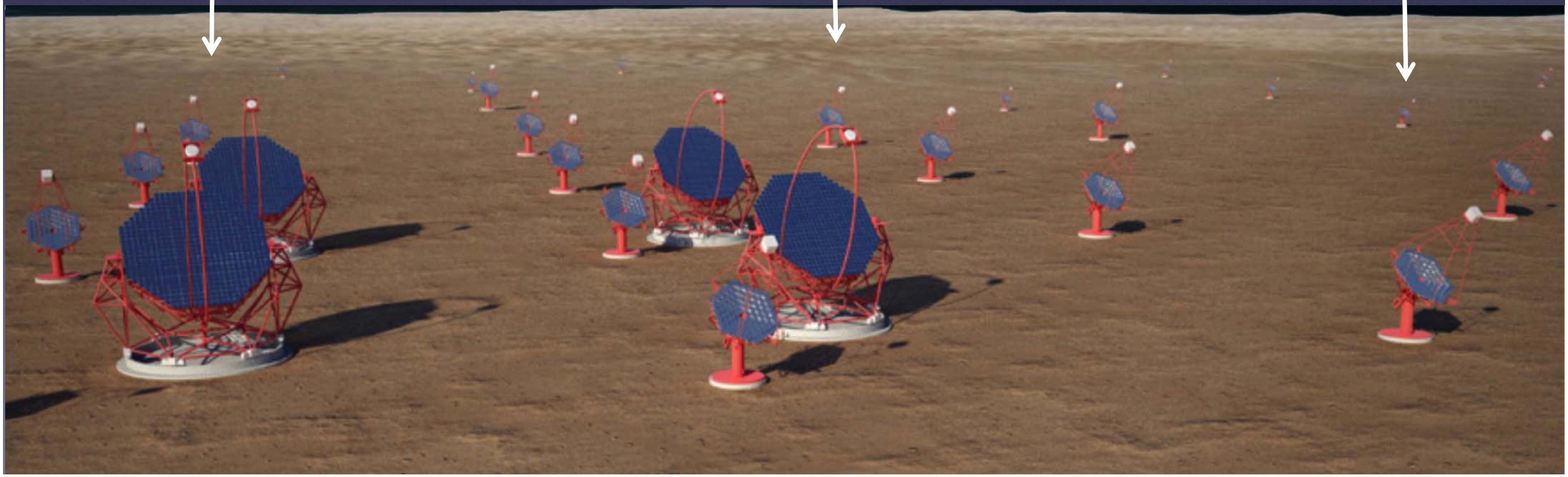
CTA Design (S array)

Science Optimization under budget constraints

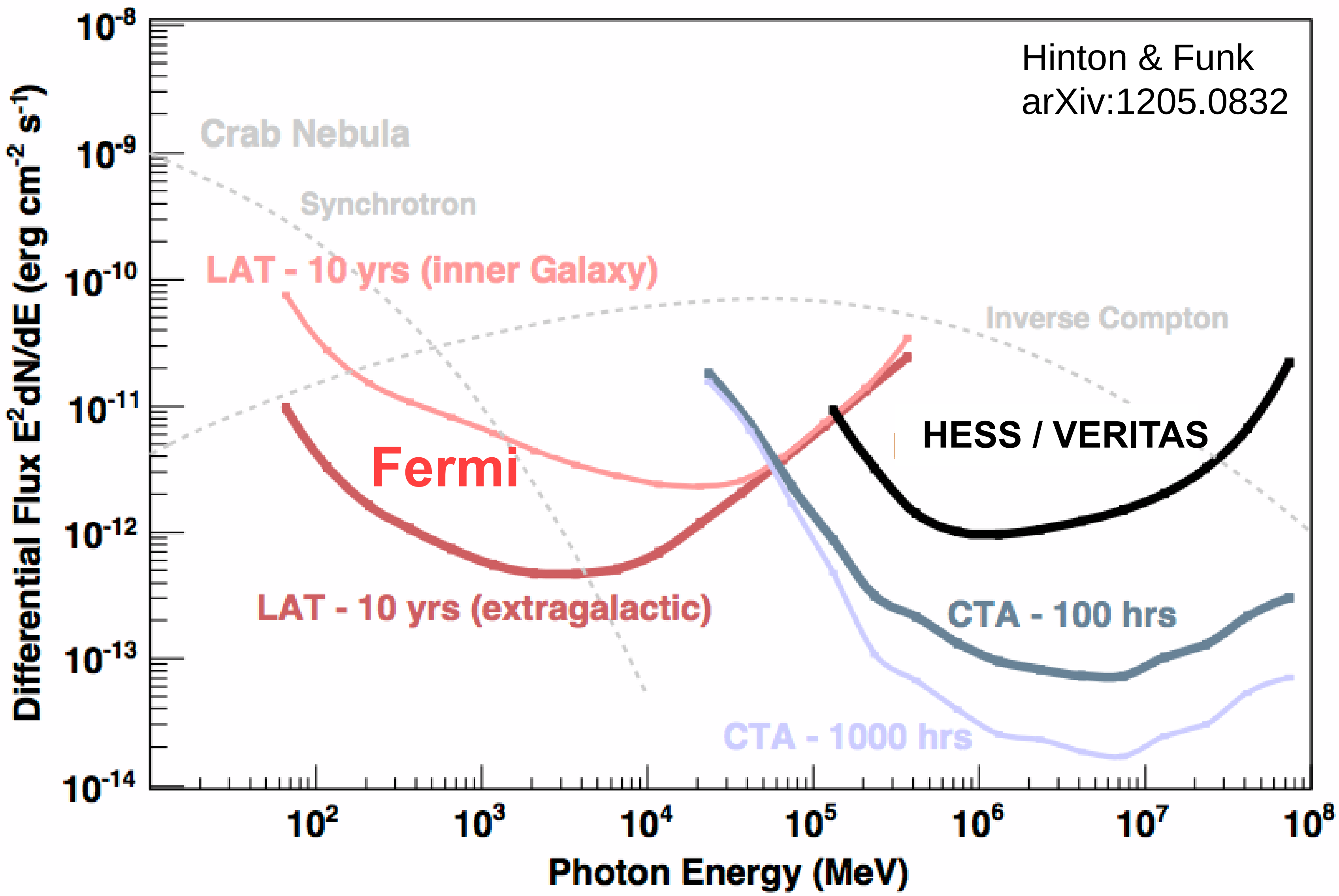
<u>Low energies</u>
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

<u>Medium energies</u>
100 GeV – 10 TeV
9.5 to 12 m diameter
25 single-mirror telescopes
up to 24 dual-mirror telescopes
(MST's/SCTs)

<u>High energies</u>
10 km^2 area at few TeV
3 to 4m diameter
70 telescopes
(SST's)



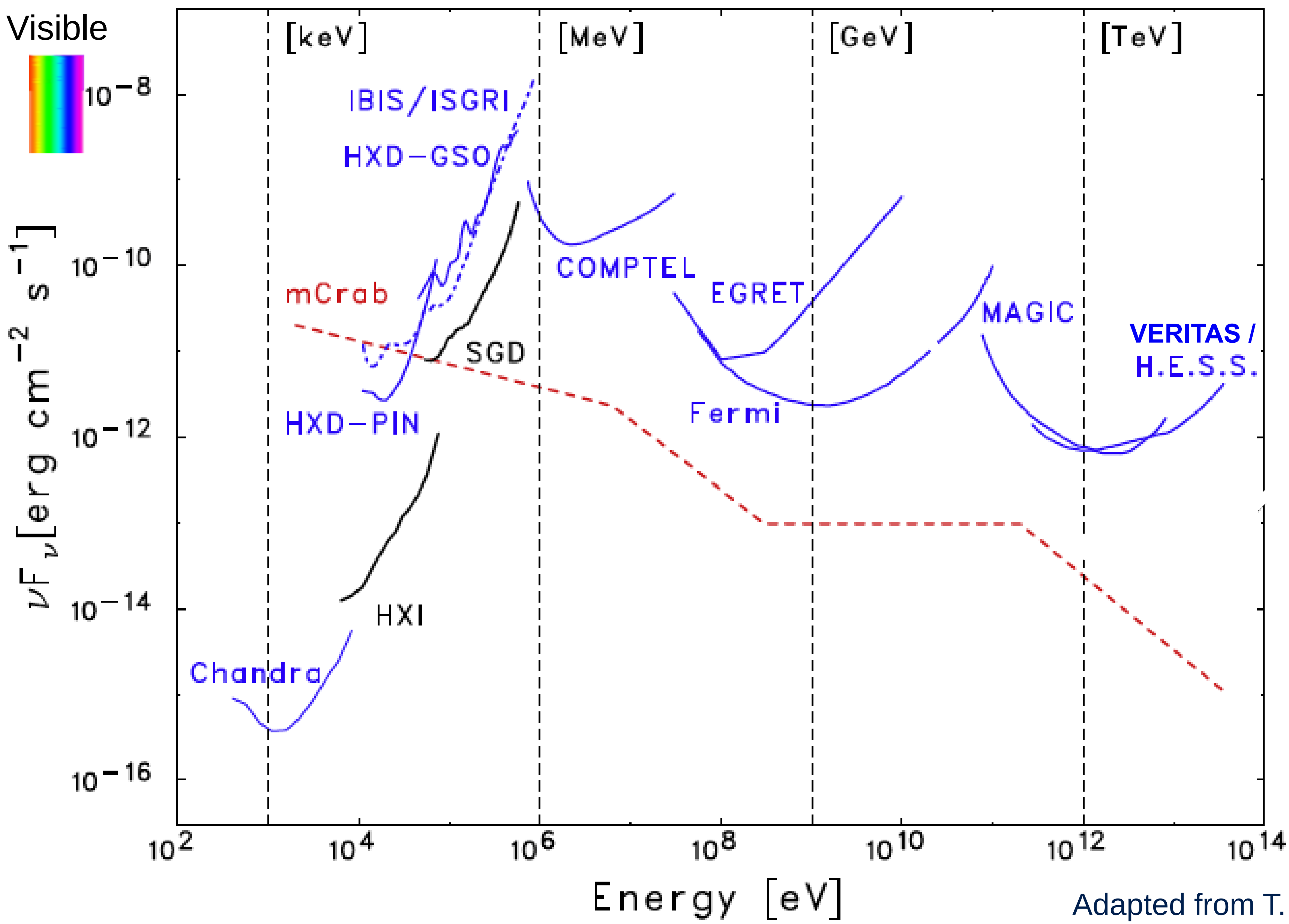
Differential Flux Sensitivity



Major **sensitivity improvement &** ***wider*** **energy range**

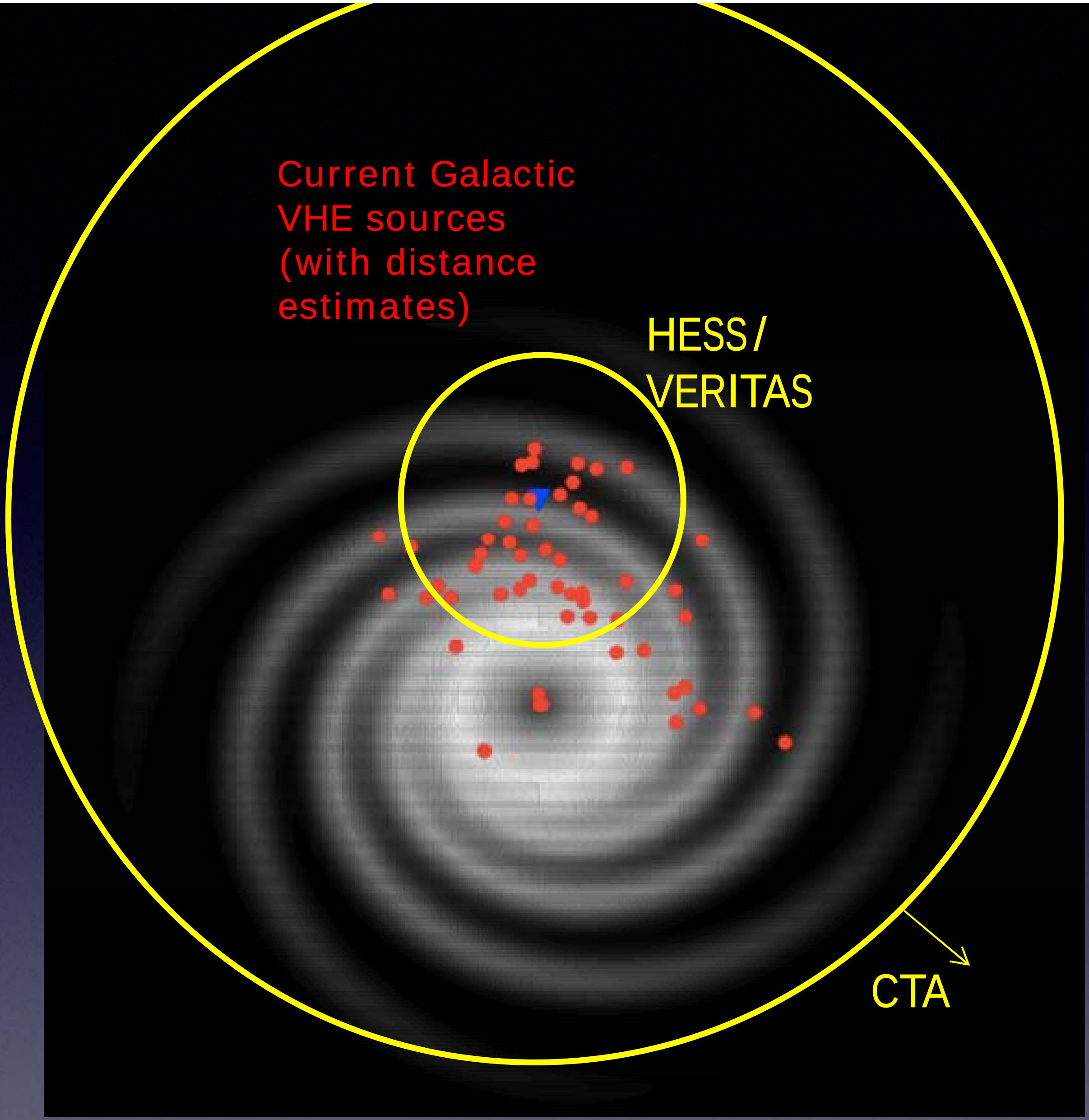
→ Factor of ~x10 increase in source population

CTA in Context

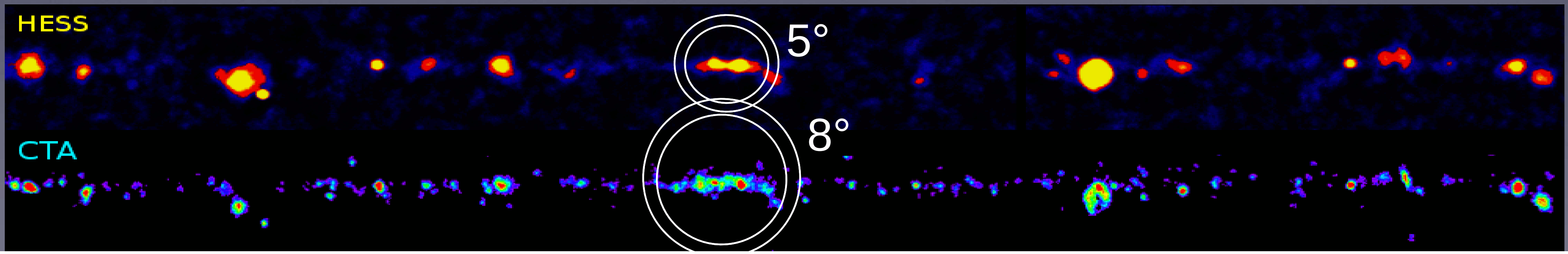


Adapted from T. Takahashi

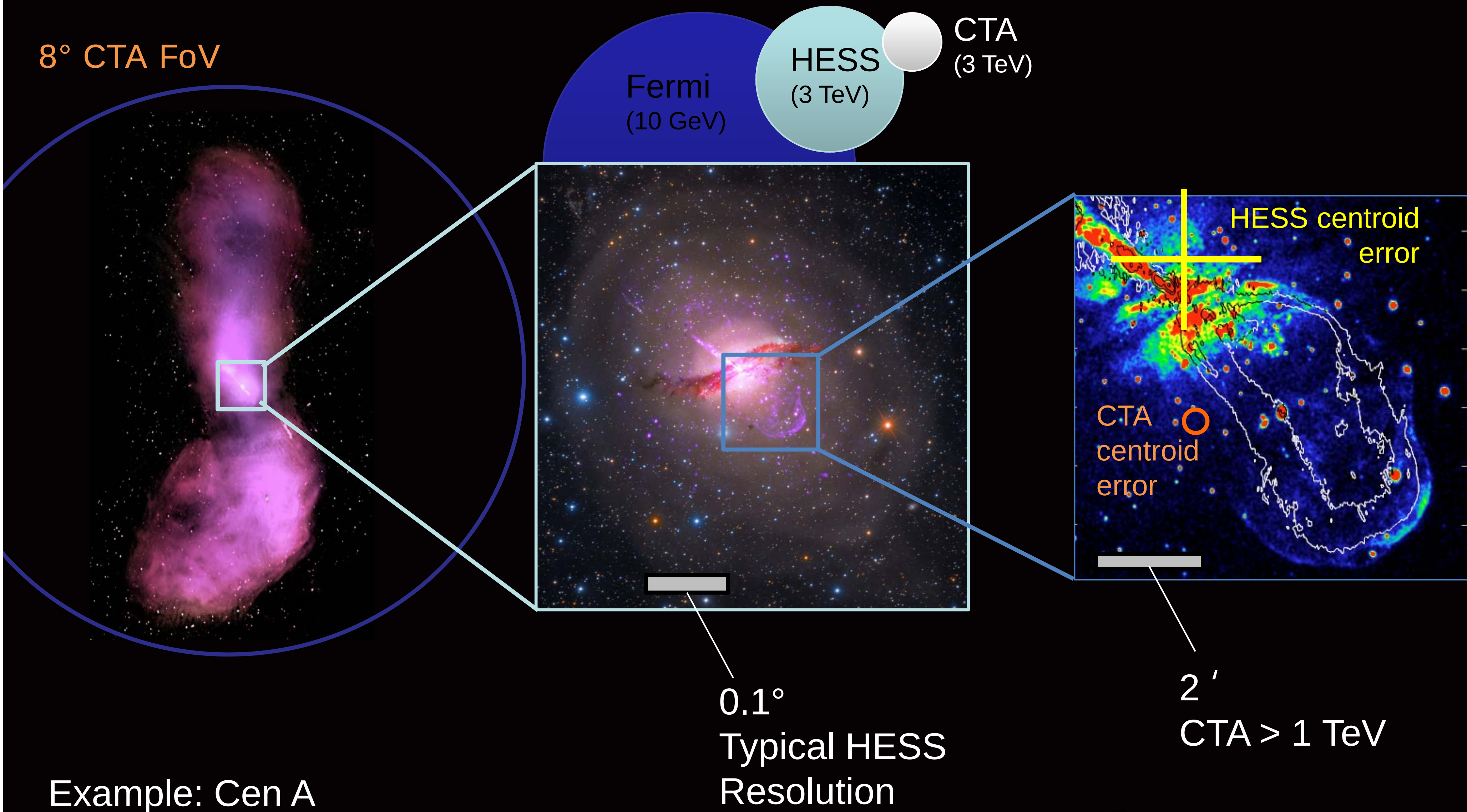
Galactic Discovery Reach



Survey speed:
x300 faster than HESS



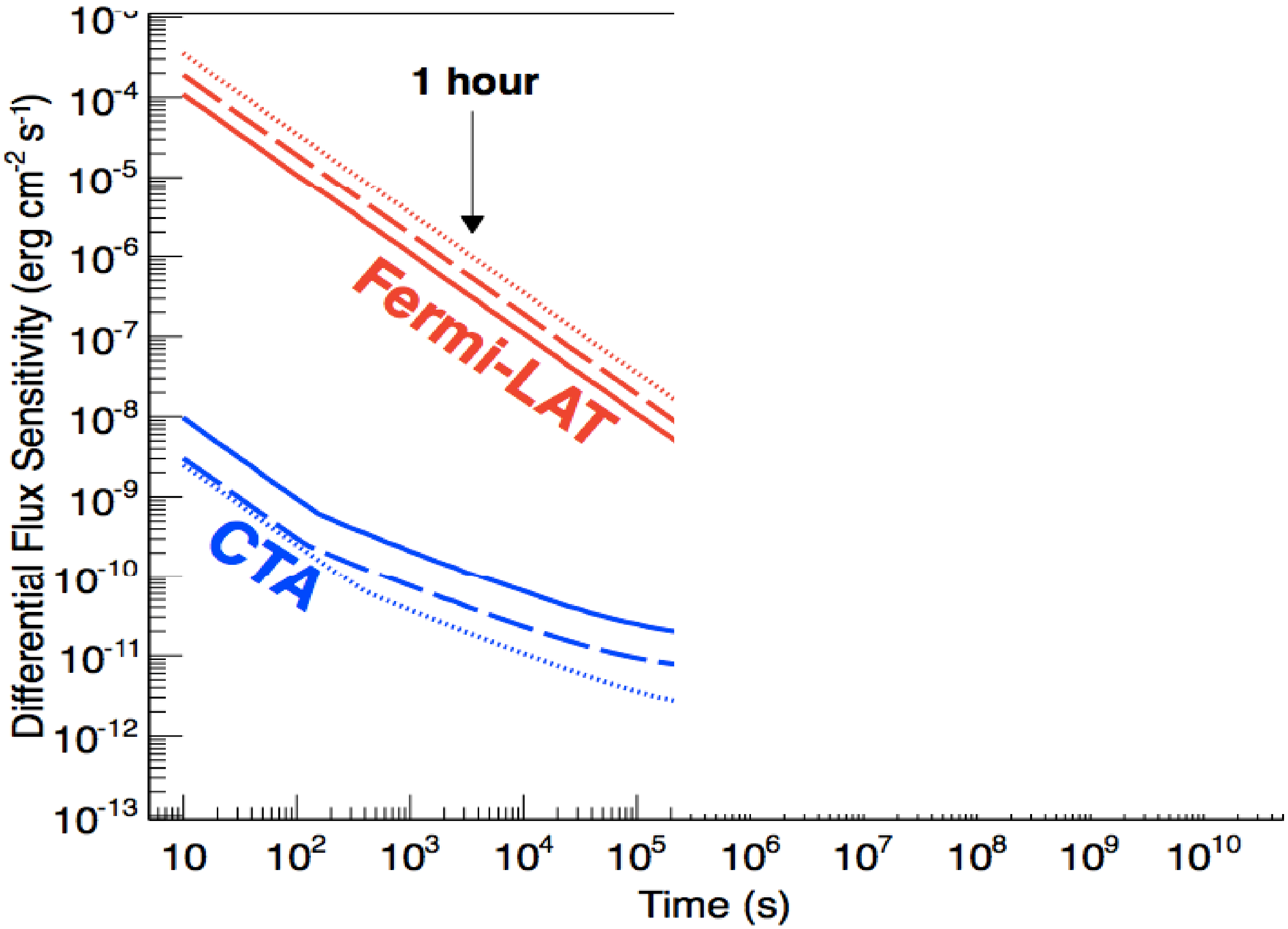
Angular Resolution



Transient Capability (< 100 GeV)

S. Inoue et al.,
arXiv:1301.3014

Hinton & Funk
arXiv:1205.0832



GRB (z=4.3) Light curve

Huge potential for short-timescale phenomena
(GRB's, AGN, Micro-quasars, etc.)

CTA Implementation & Status

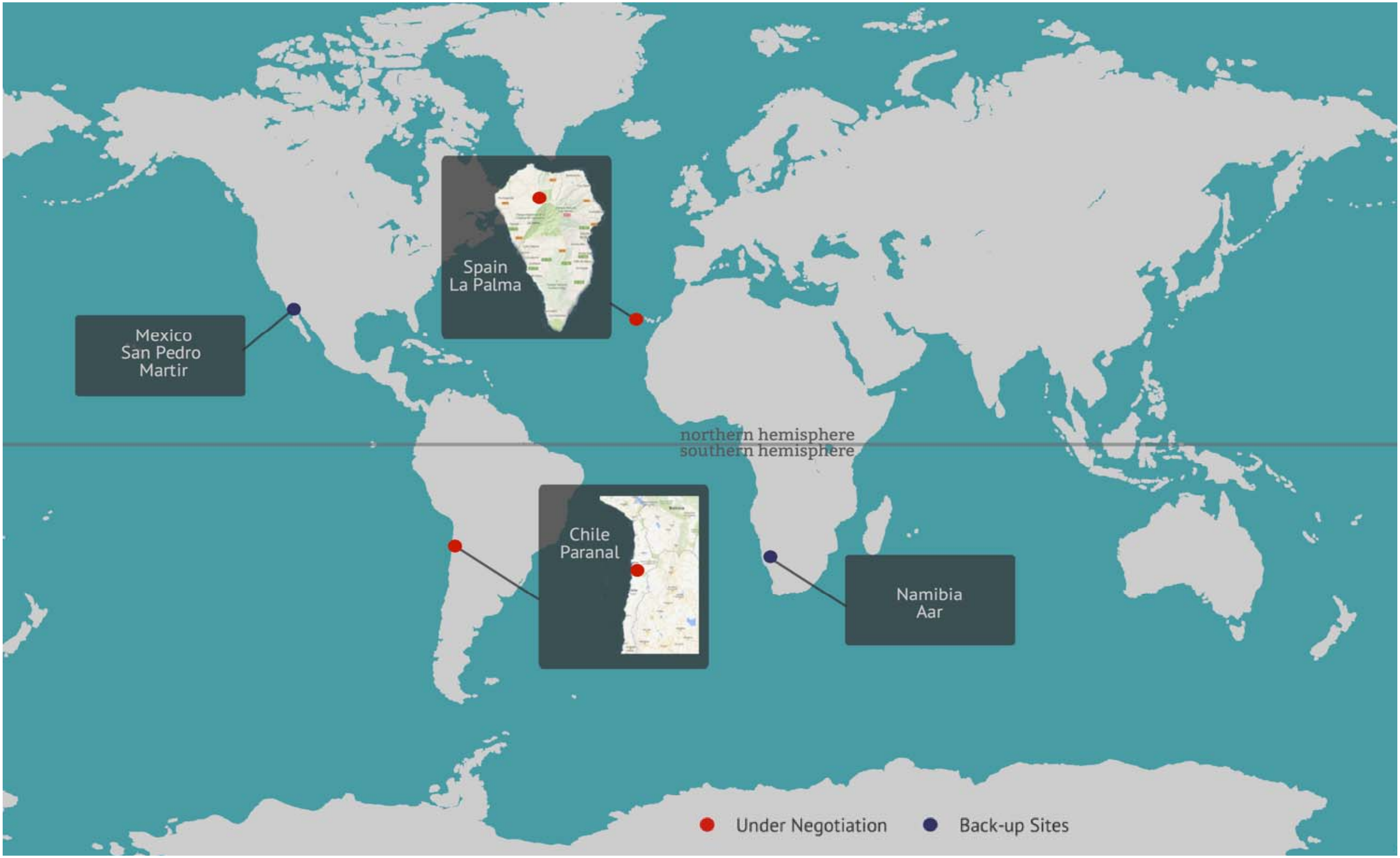
CTA Consortium

CTA is being developed by the CTA Consortium:

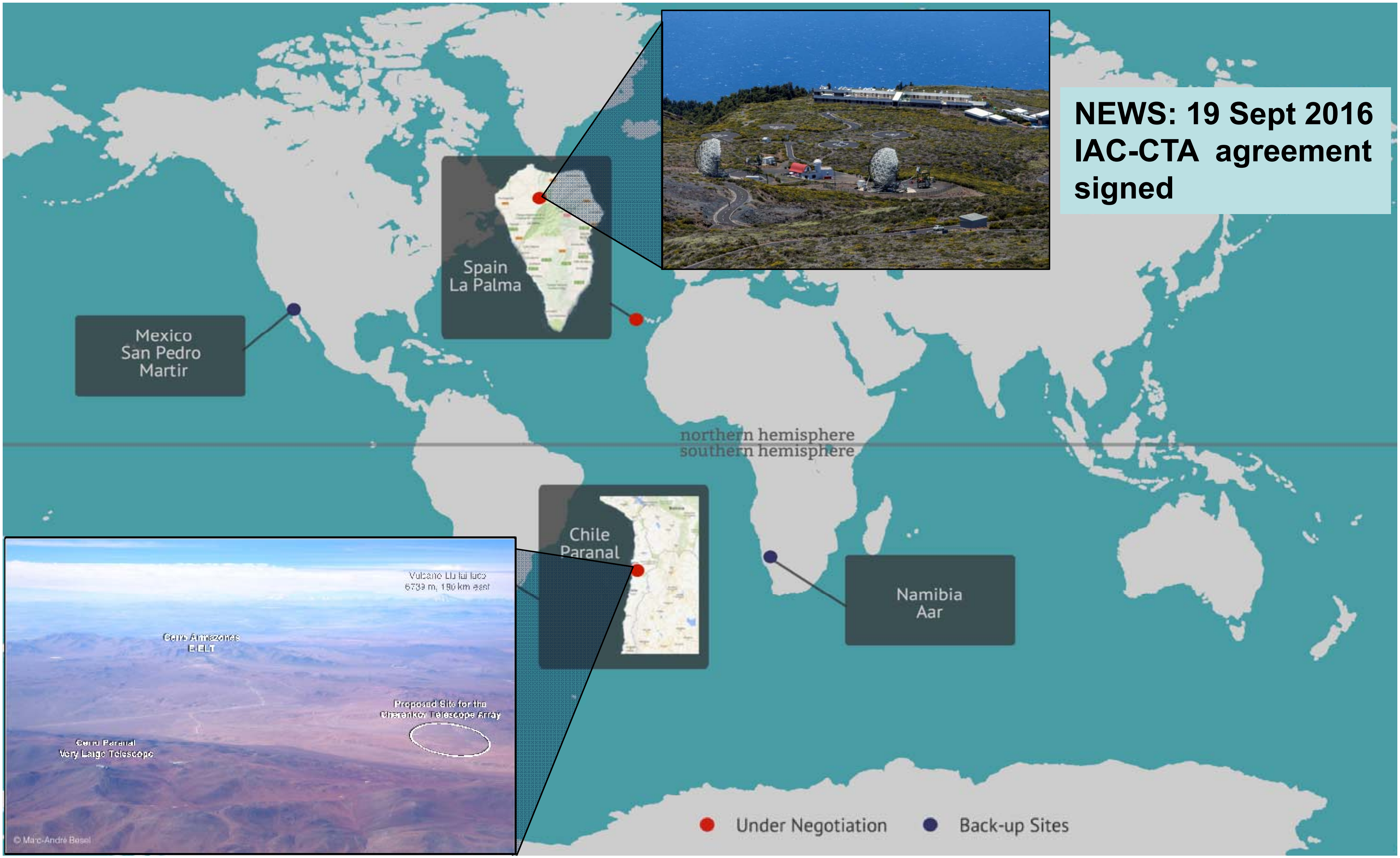
(full version shows pie chart with Japan FTE highlighted)

32 countries, ~1300 scientists, ~200 institutes, ~440 FTE

Status of Sites

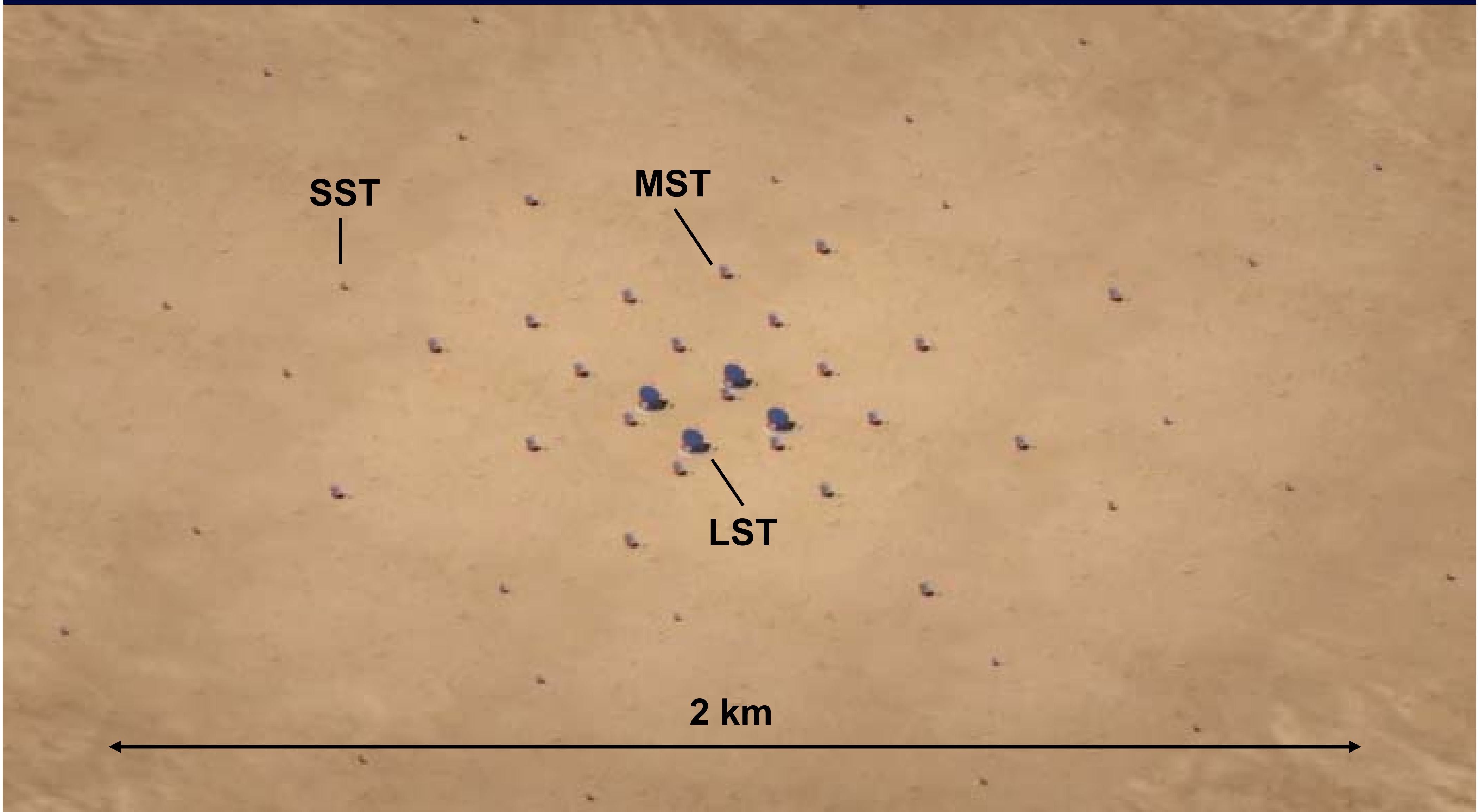


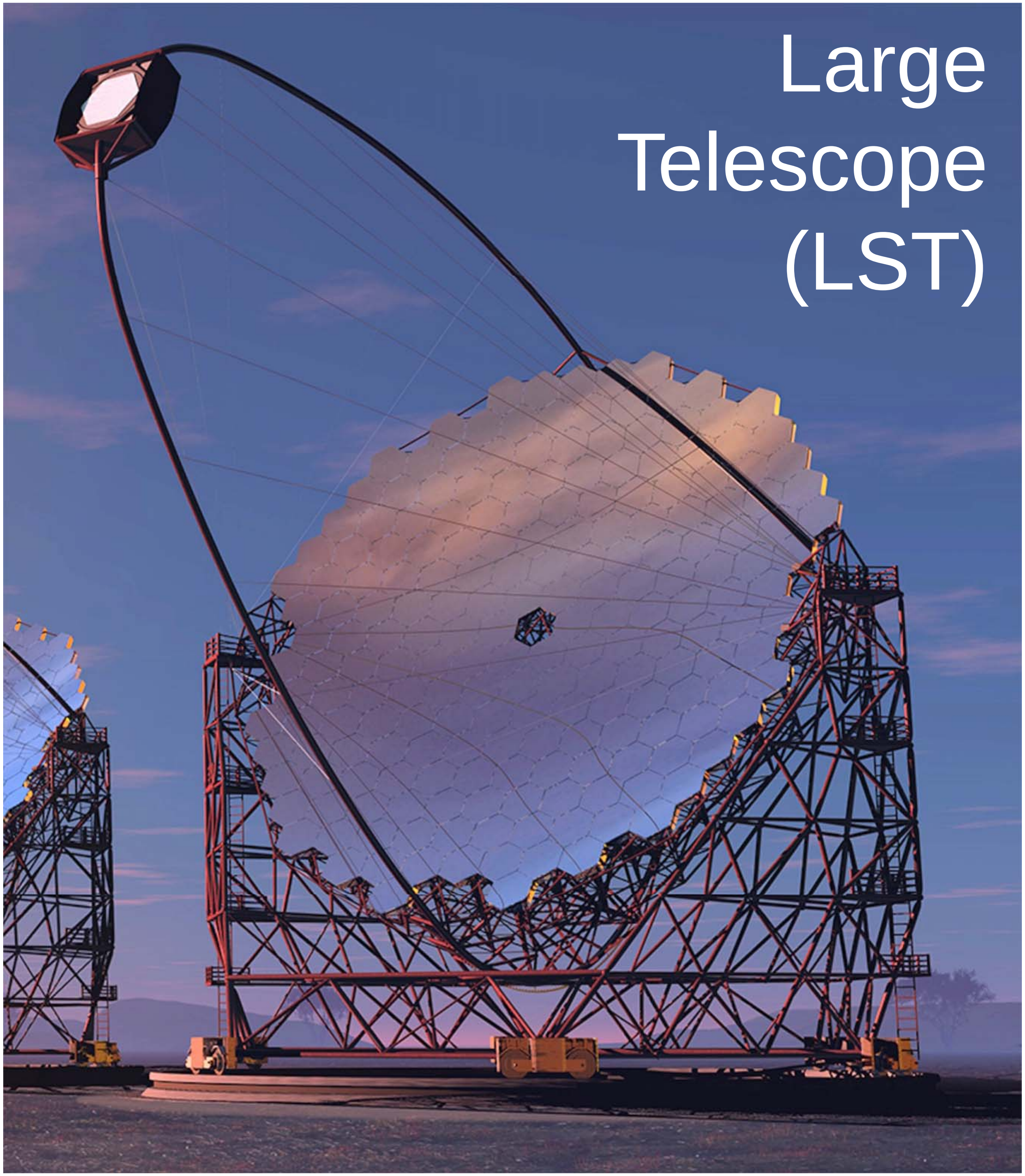
Status of Sites



NEWS: 19 Sept 2016 IAC-CTA agreement signed

CTA South Array
4 LSTs, 25 MSTs, 70 SSTs





23 m diameter / f = 28m
390 m^2 dish area
1.5 m mirror facets

4.5^o field of view
0.1^o pixels
Camera ∅ over 2 m

Carbon-fiber structure for 20 s positioning

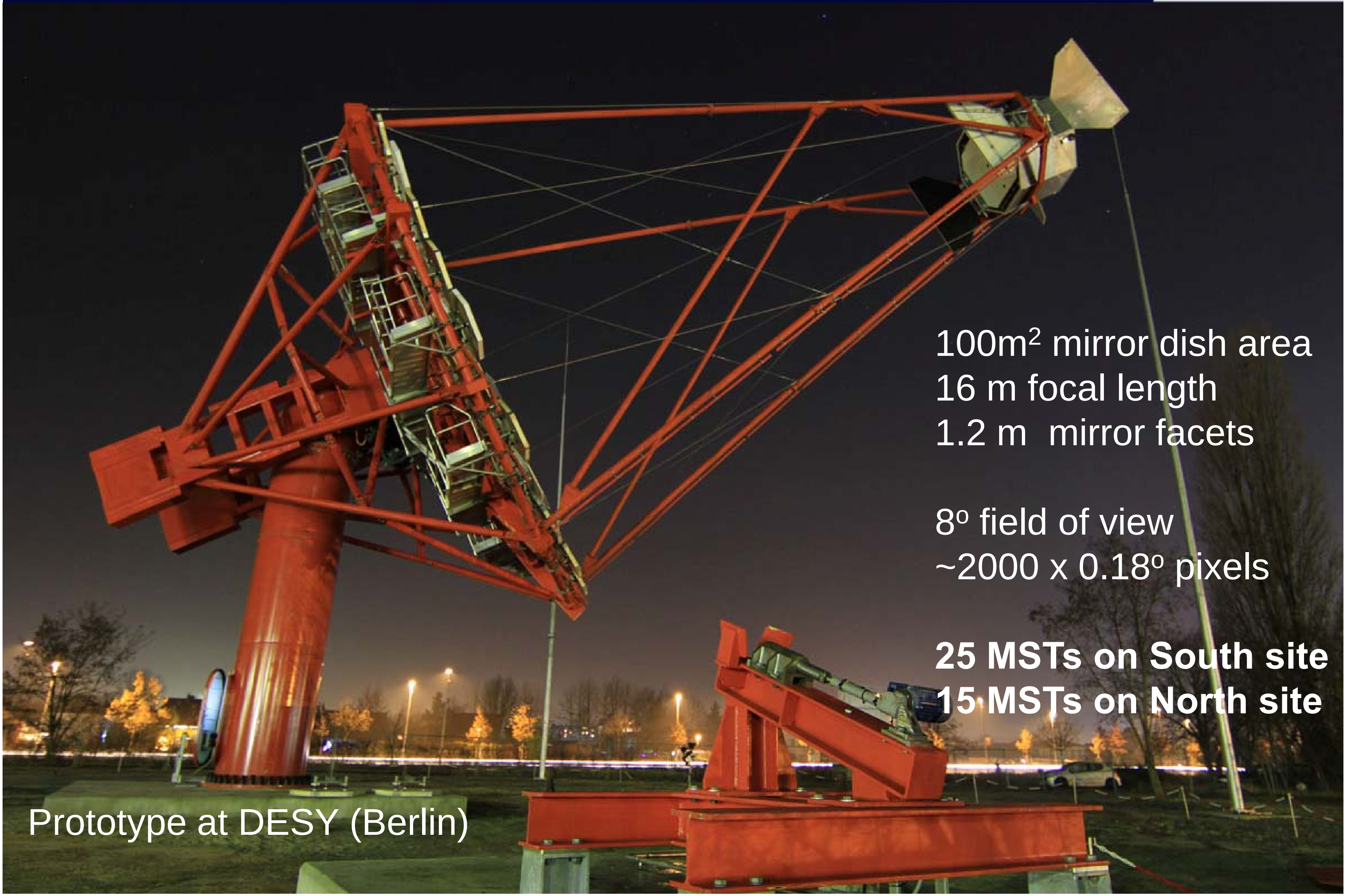
Active mirror control

4 LSTs on South site
4 LSTs on North site

Prototype construction Underway (La Palma)

Major contribution from JAPAN

Medium Telescope (MST)



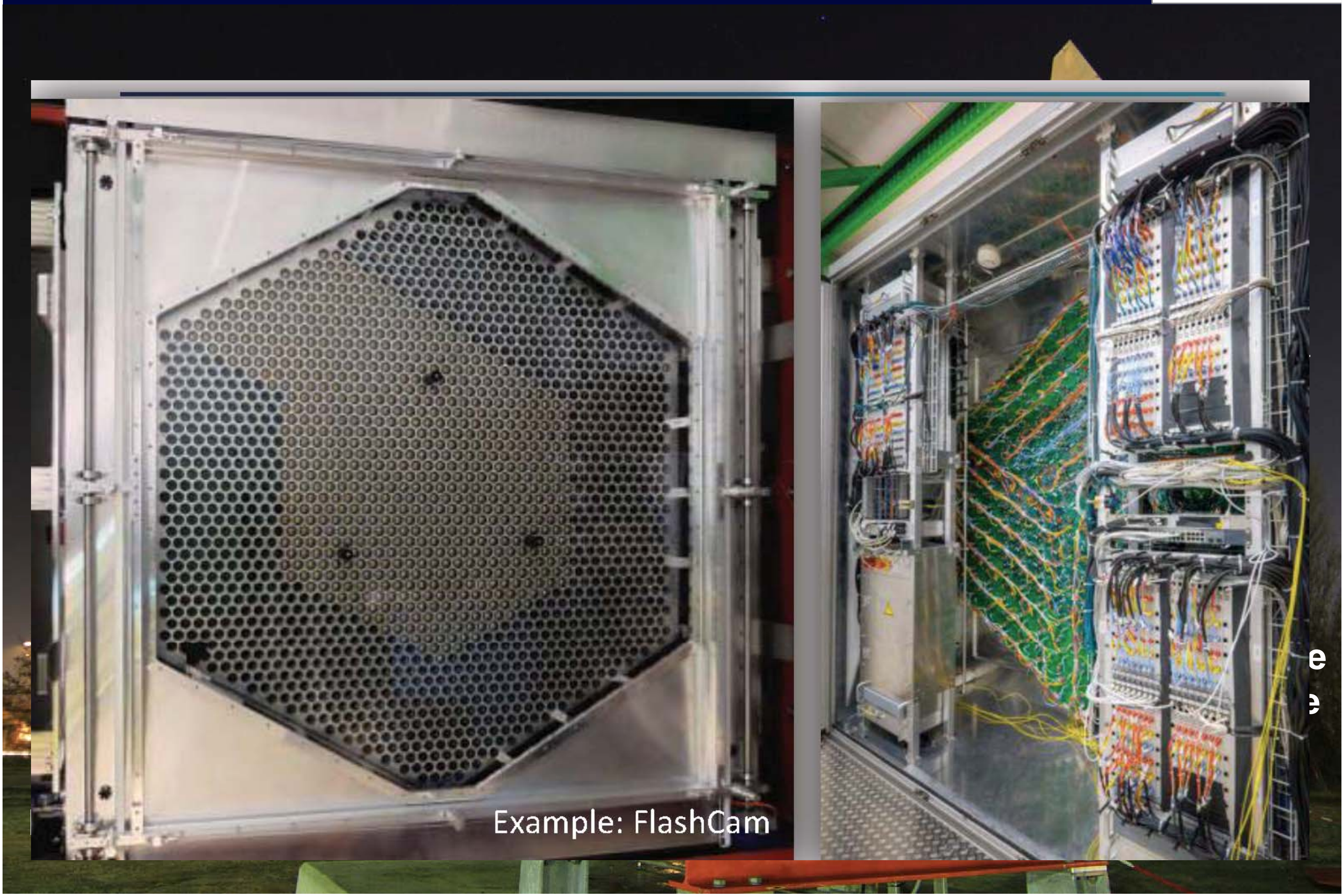
100m^2 mirror dish area
16 m focal length
1.2 m mirror facets

8^o field of view
~2000 x 0.18^o pixels

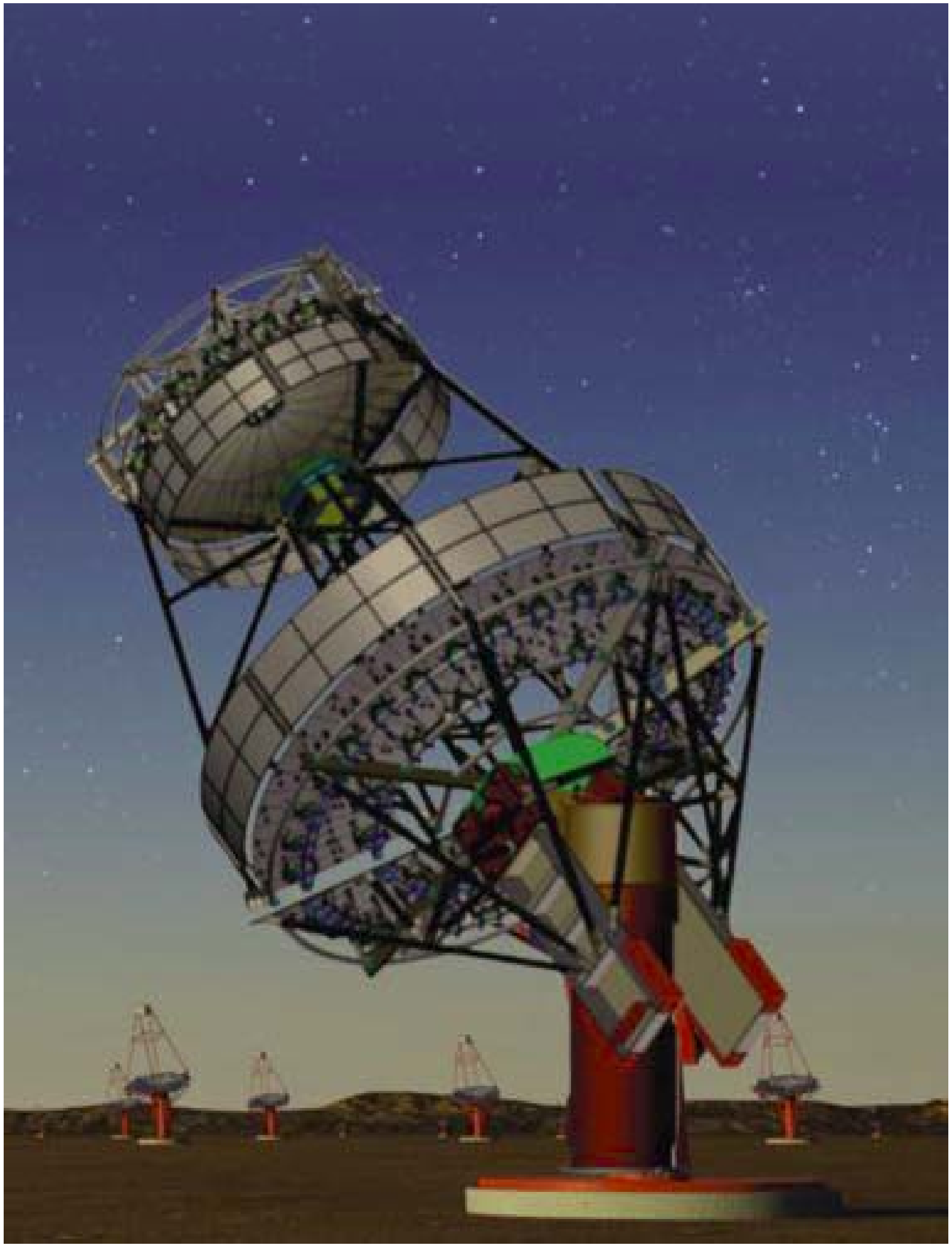
25 MSTs on South site
15 MSTs on North site

Prototype at DESY (Berlin)

MST Integrated Camera



Dual-Mirror MST



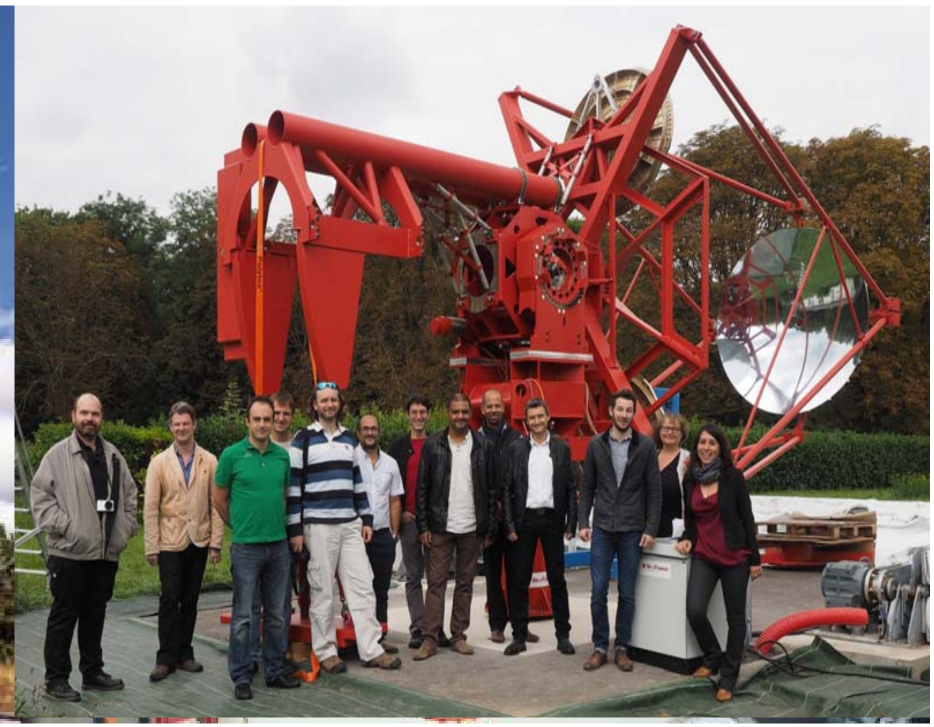
- Schwarzschild-Couder design (V. Vassiliev et al.)
- 9.7m primary, 5.4m secondary
- 11328 x 0.07^{o} Si-PMT pixels
- 8^{o} field-of-view
- Prototype under construction: Whipple Obs. (Arizona, USA)

Small Sized Telescopes (SSTs)

- 3 different prototype designs
- 2 designs use two-mirror approaches (Schwarzschild-Couder design)
- All use Si-PMT photosensors
- 7-9 m^2 mirror area, FOV of 9^o

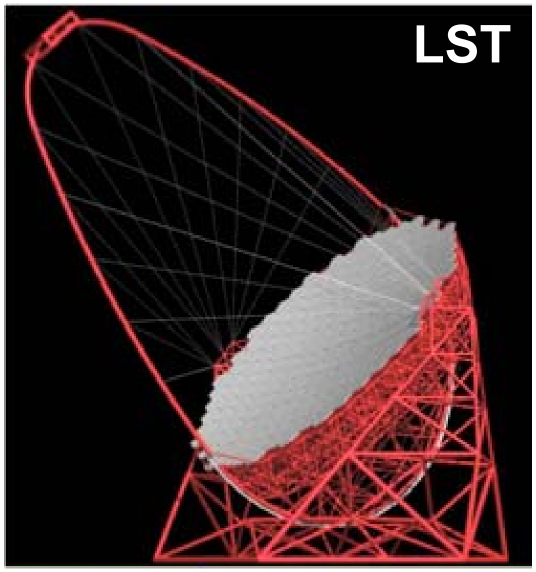
SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy



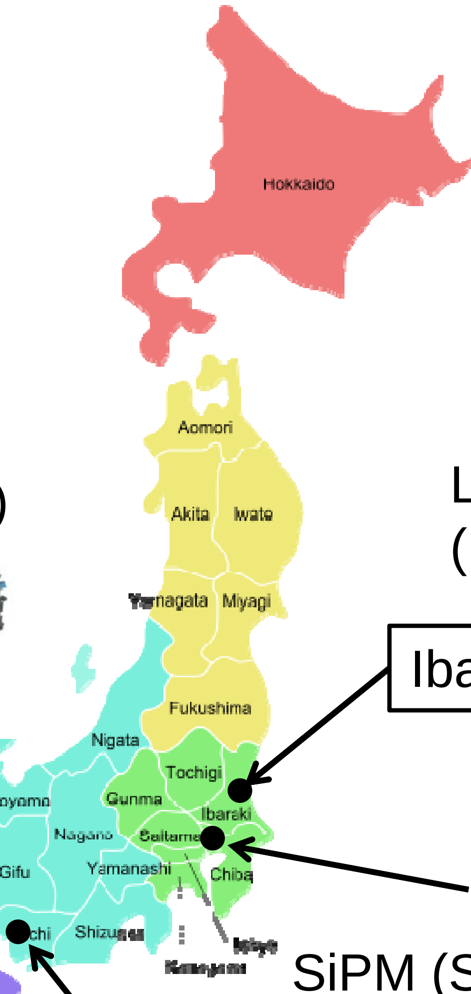
SST-2M GCT
Meudon, France
Contribution from Japan

Japanese Contributions to CTA



SST-GCT

Front-end electronics (LST)




Major Contributions

\+

Software

Simulations

Science …

Light concentrator (LST)

Kyoto

Ibaraki

ICRR

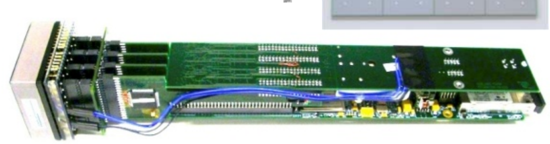
Nagoya

Konan

Mirror (LST)

SiPM (SST)

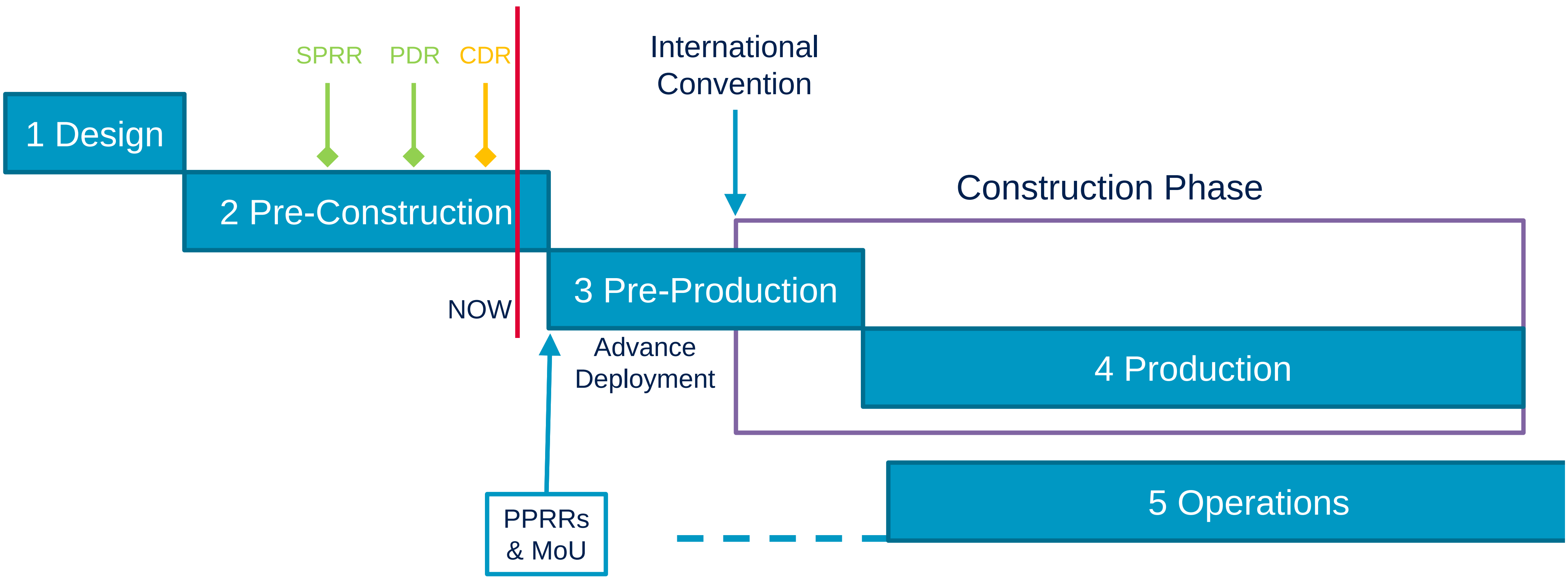
PMT (LST)



Front-end electronics (SST/ SCT)

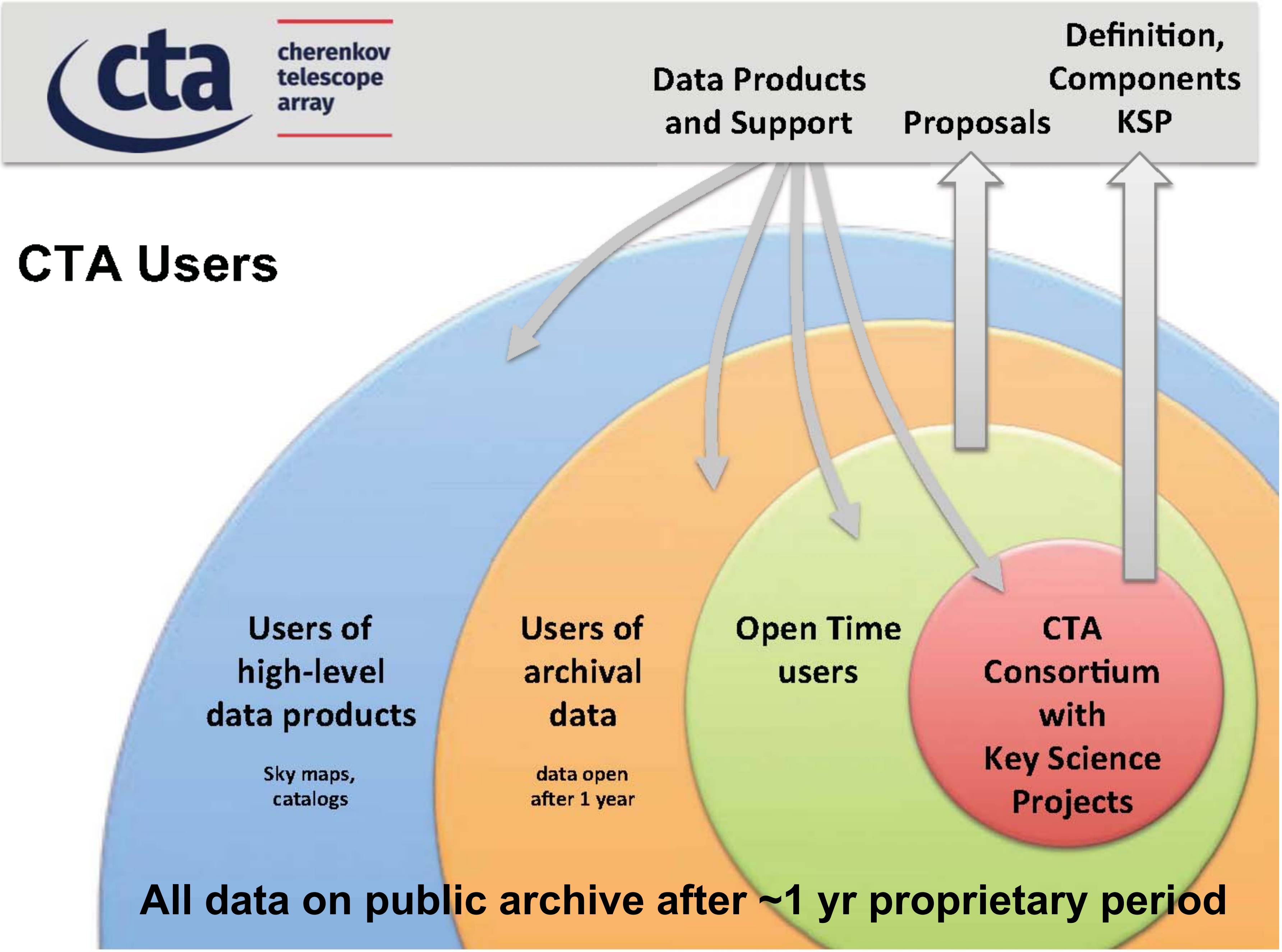
H. Tajima

CTA Phases

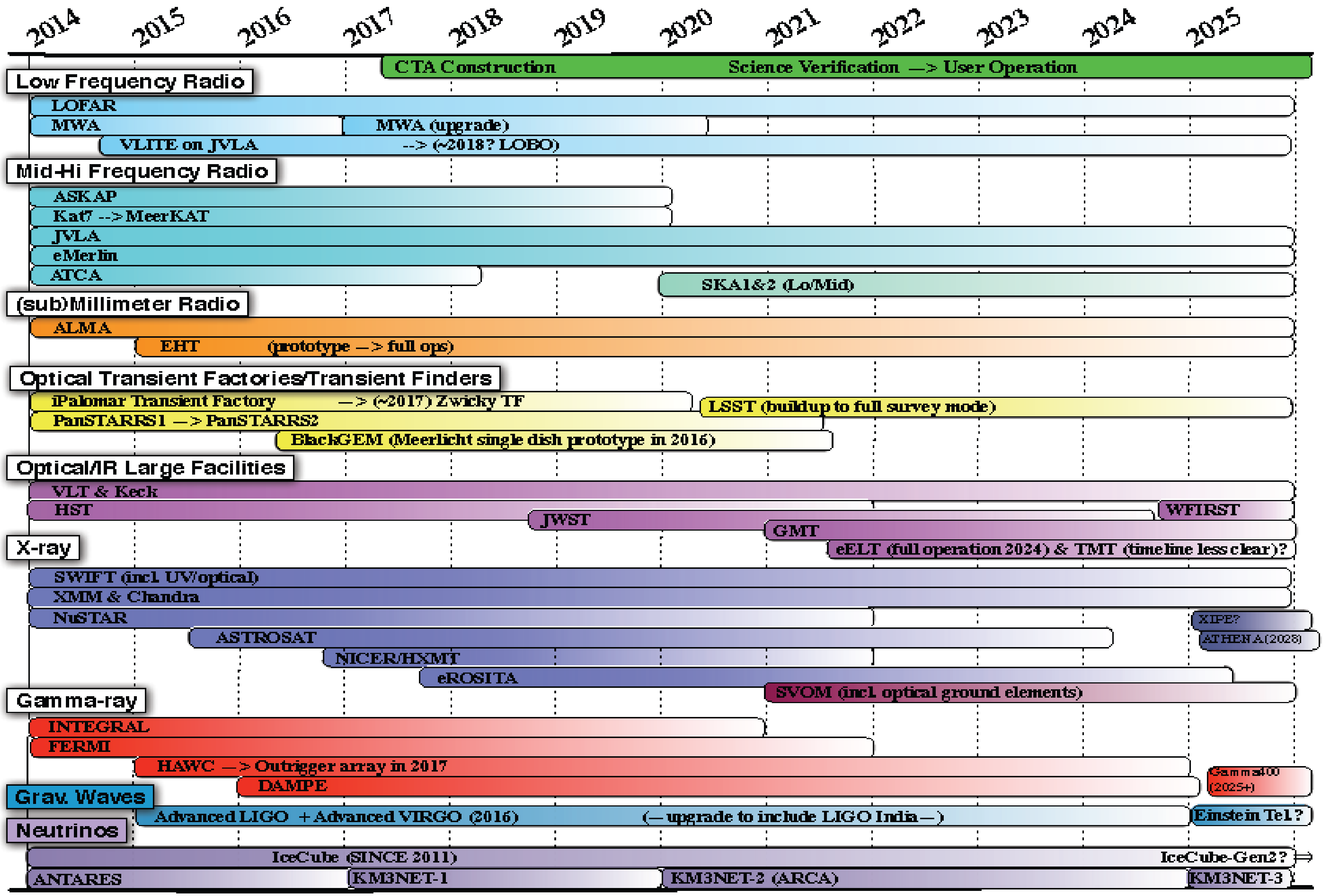


- Signed MoU for construction and site agreements in 2016
- Site preparations start in 2016 (N) and 2017 (S)
- Construction period of 4-5 years
- Initial science with partial arrays possible from 2018 (N) and 2019 (S)
- Note: LSTs in N completed on earlier time scale

CTA: An Open Observatory

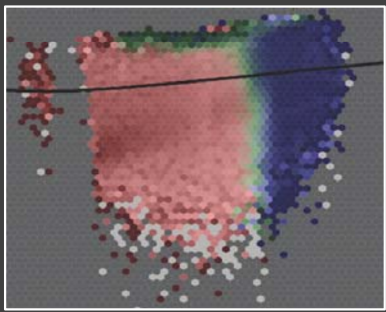


Important MWL Synergies

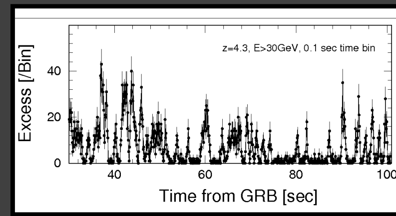


Caveat: Observatory timelines are very uncertain; this represents a notional picture based on available information

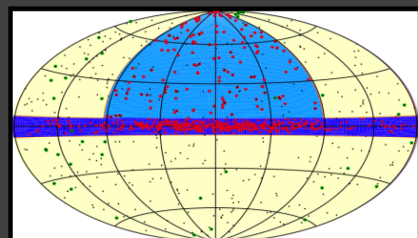
Key Science Projects (KSPs)



Dark Matter Programme

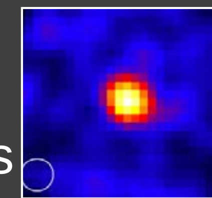


Transients



ExGal Survey

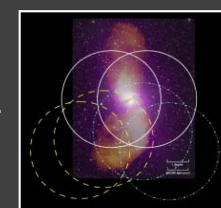
Galaxy Clusters

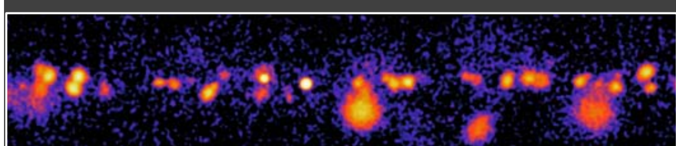


Extragalactic

Star Forming Systems

AGN

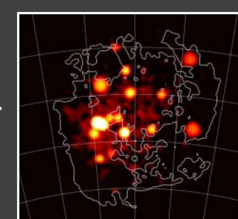




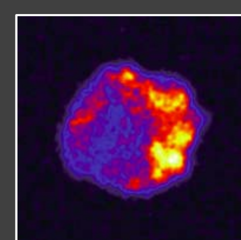
Galactic Plane Survey

Galactic

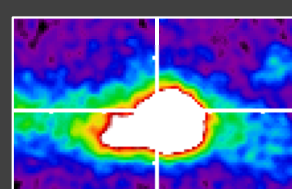
LMC Survey



PeVatrons

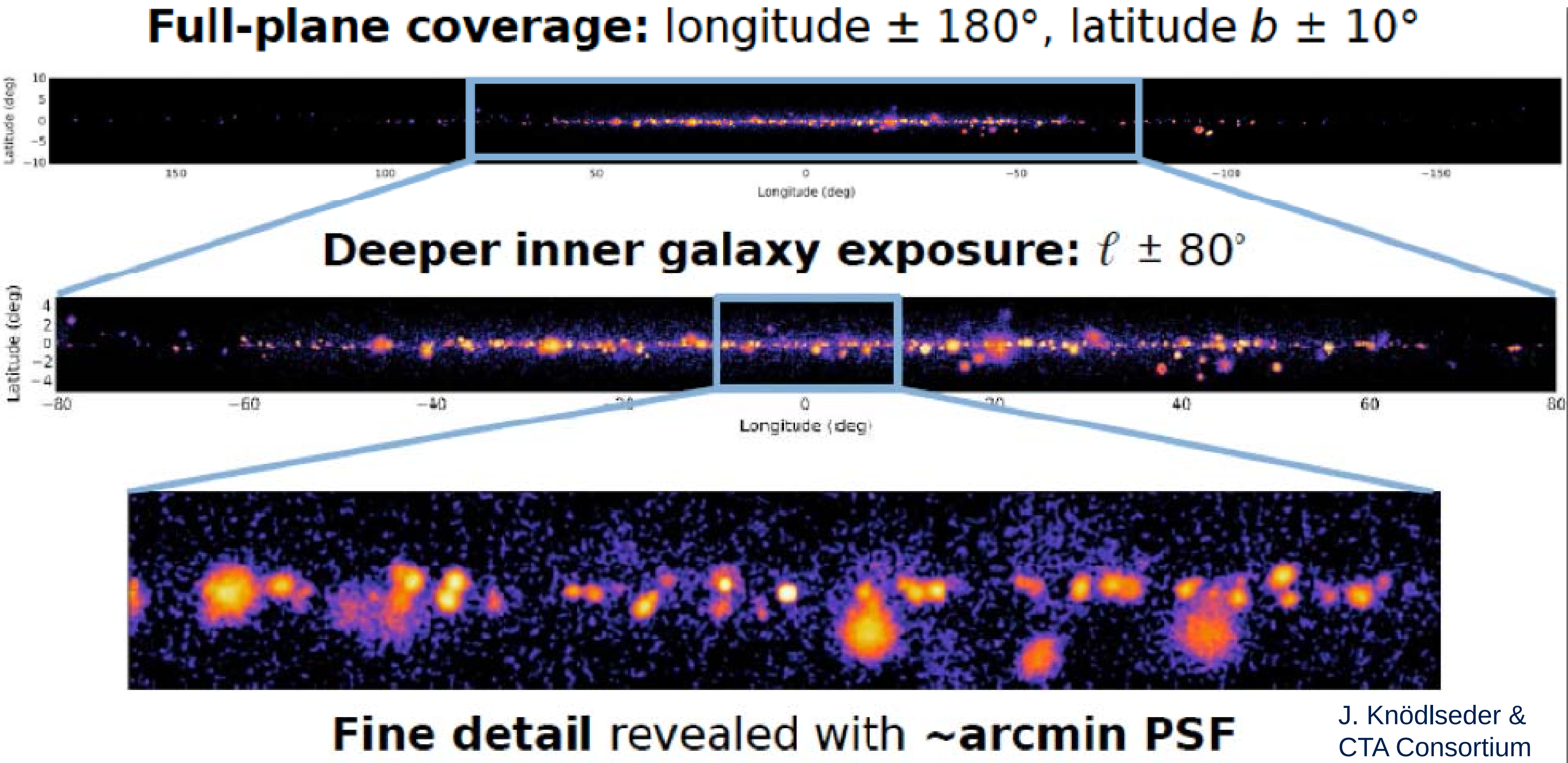


Galactic Centre



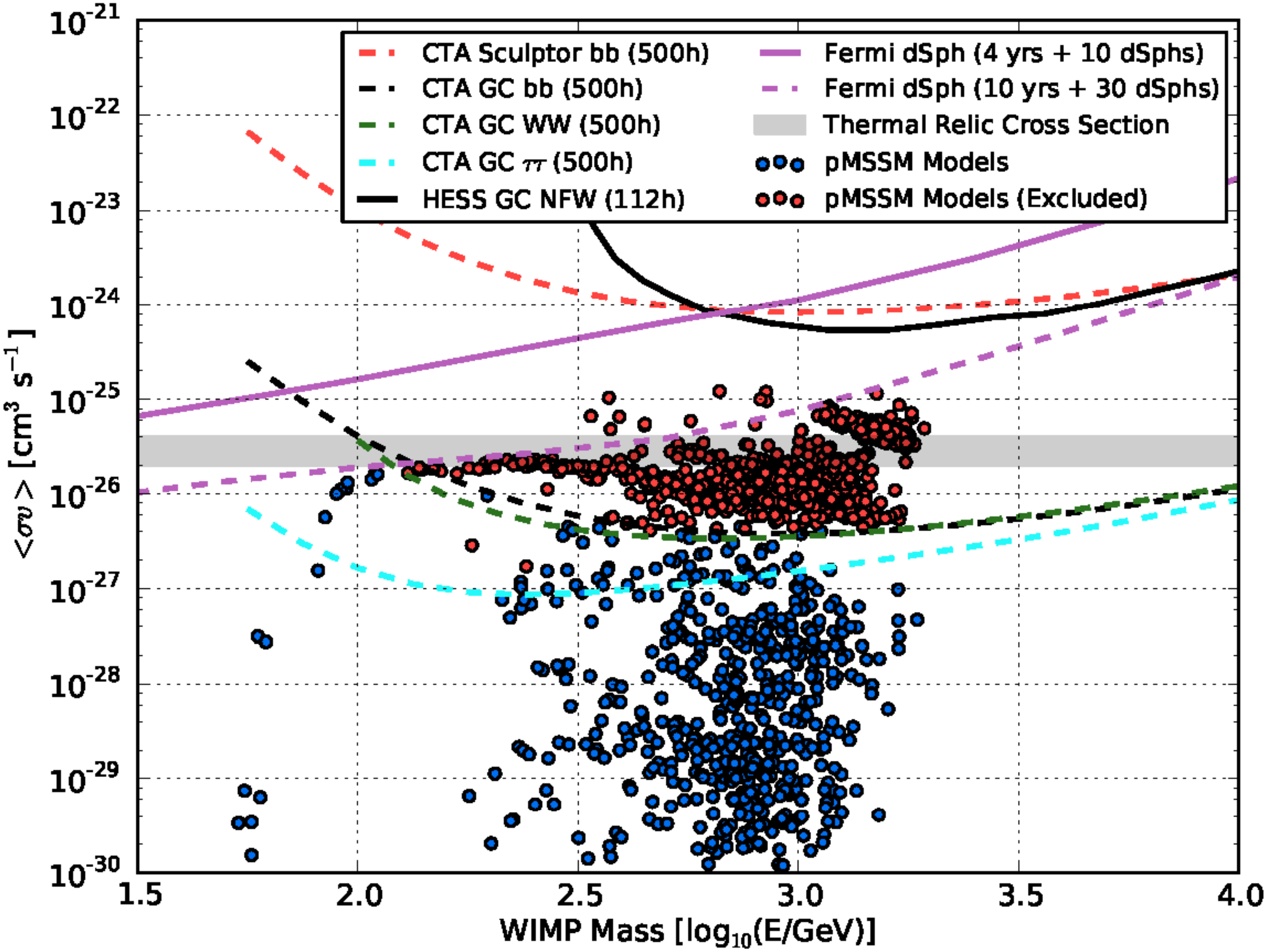
cta cherenkov telescope array

Galactic Plane Survey (GPS)



SNRs / PeVatrons: Discovered in GPS → deep follow-up observations

Dark Matter Reach



M. Wood et al.
arXiv:1305.0302

Sensitivity below thermal relic in TeV mass range

- *critical reach, not achieved by direct detectors or LHC*

CONCLUSIONS

- With many discoveries, VHE γ-rays are now a well-recognized astrophysical discipline & part of growing multi-messenger science.
- VHE photons explore non-thermal universe and aspects of fundamental physics
- Outstanding science potential & power of atmospheric Cherenkov technique → CTA
- **Cherenkov Telescope Array (CTA)**

  Outstanding sensitivity & resolution over wide energy range

  Far-reaching key science program

  Open observatory with data released to public

  CTA requires a broad partnership of countries and communities – with a major contribution from Japan

Summary

- **We've learned a lot from previous/present experiments**

  With many discoveries, VHE γ-rays are now a well-recognized astrophysical discipline

  Outstanding science potential & the power of the atmospheric Cherenkov technique → CTA

- **Cherenkov Telescope Array (CTA)**

  Outstanding sensitivity & resolution over wide energy range

  Far-reaching key science program

  Open observatory with all data released to public

  US contribution focused on novel, high-resolution SC telescope

  CTA requires a broad partnership of countries and communities

- In next decade, CTA will start to provide high-quality data, not seen with any HE/VHE technique, but there is still a great deal to do !

BACKUP

CTA Main Scientific Themes

Cosmic Particle Acceleration

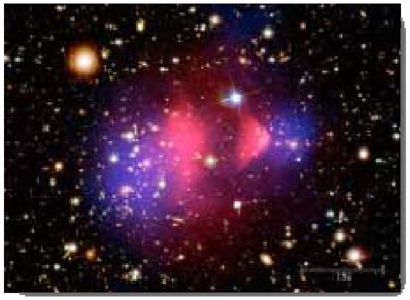
- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

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?

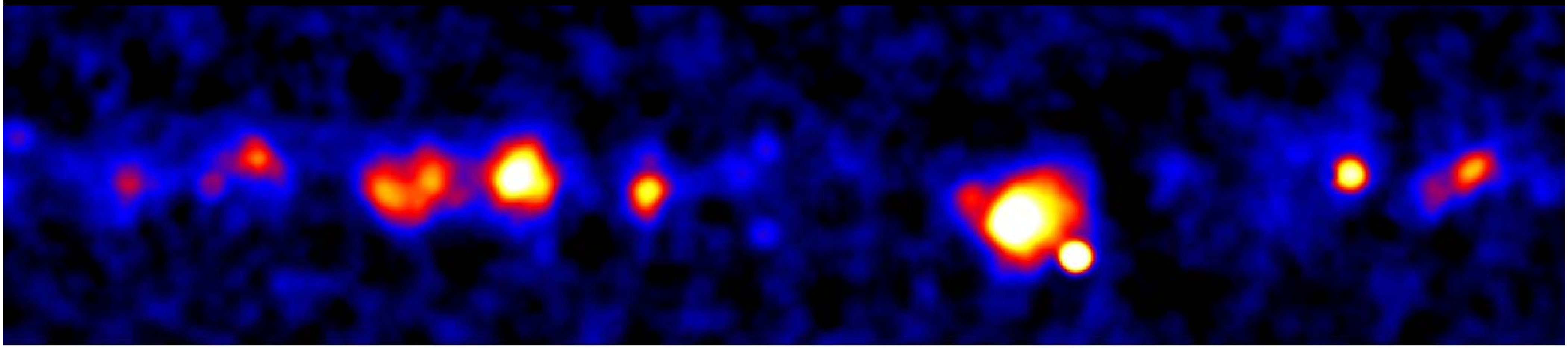


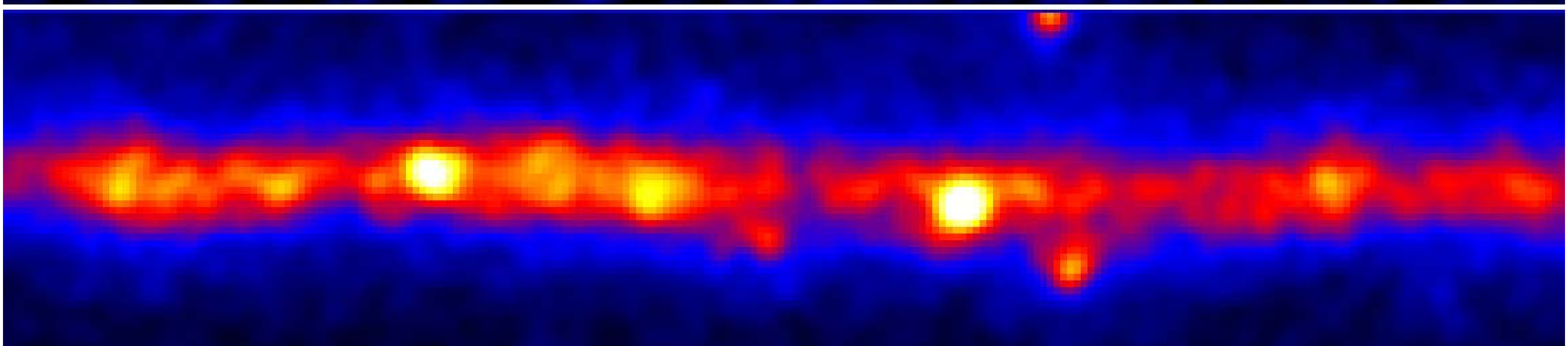
More information on Astroparticle Physics, Vol. 43, 1-356 (2013) & CTA Contributions to the 2015 ICRC Conference [arXiv:1508.05894]

The HE Milky Way

Extended sources, size typically few 0.1°
few 10 pc

H.E.S.S. (TeV)

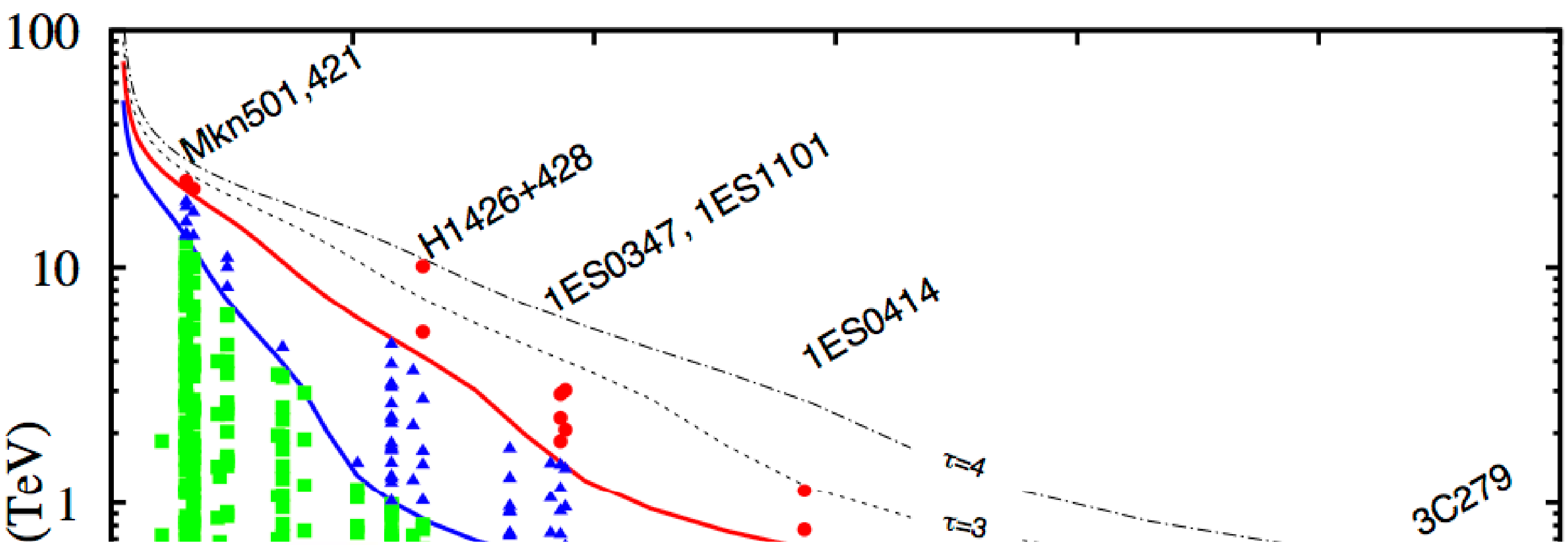


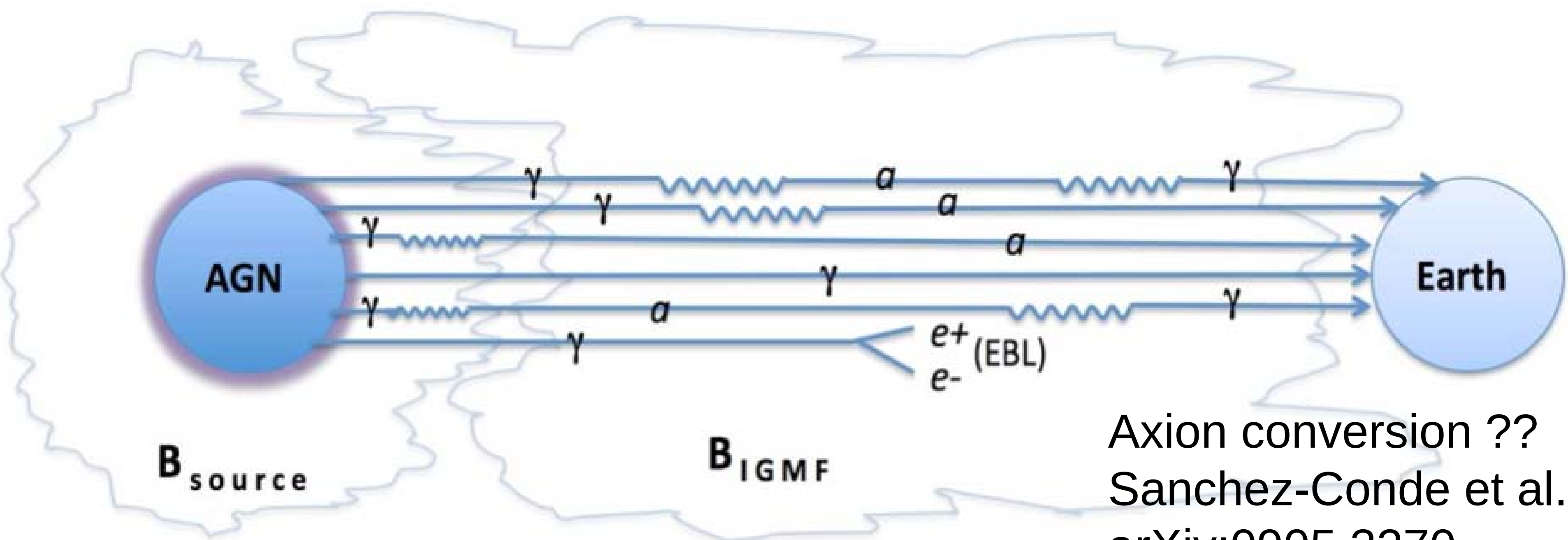


Fermi-LAT (GeV)

Courtesy of W. Hofmann

Is the Universe too Transparent ?

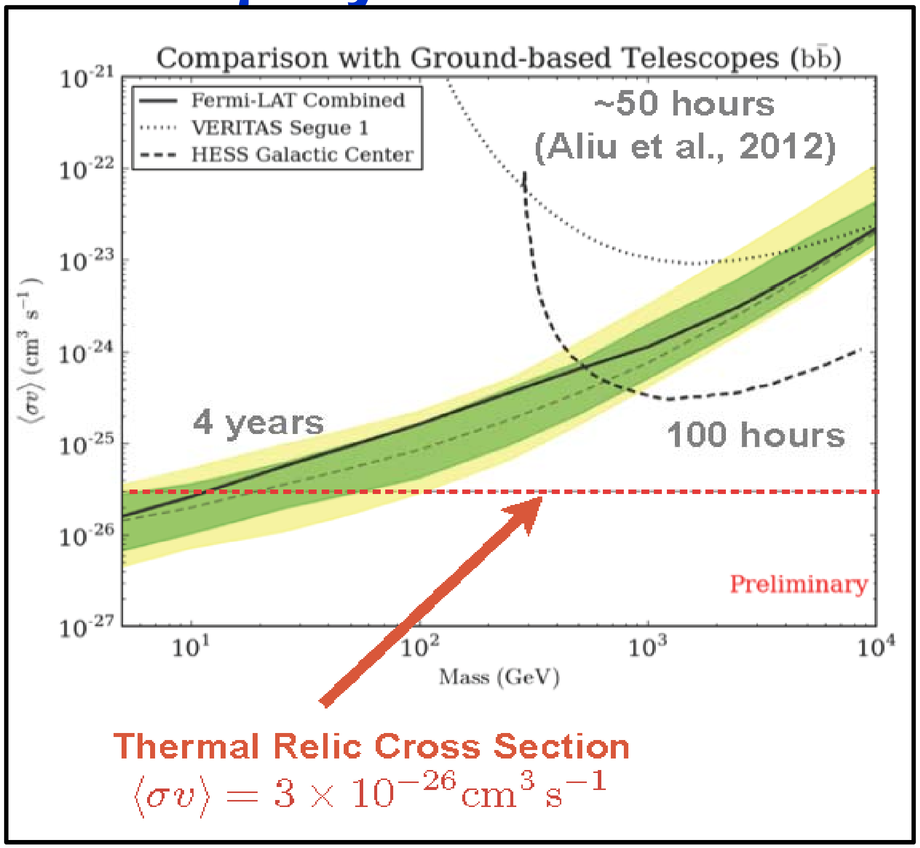




Axion conversion ??
Sanchez-Conde et al., arXiv:0905.3270

Dark Matter Results

γ-ray DM limits



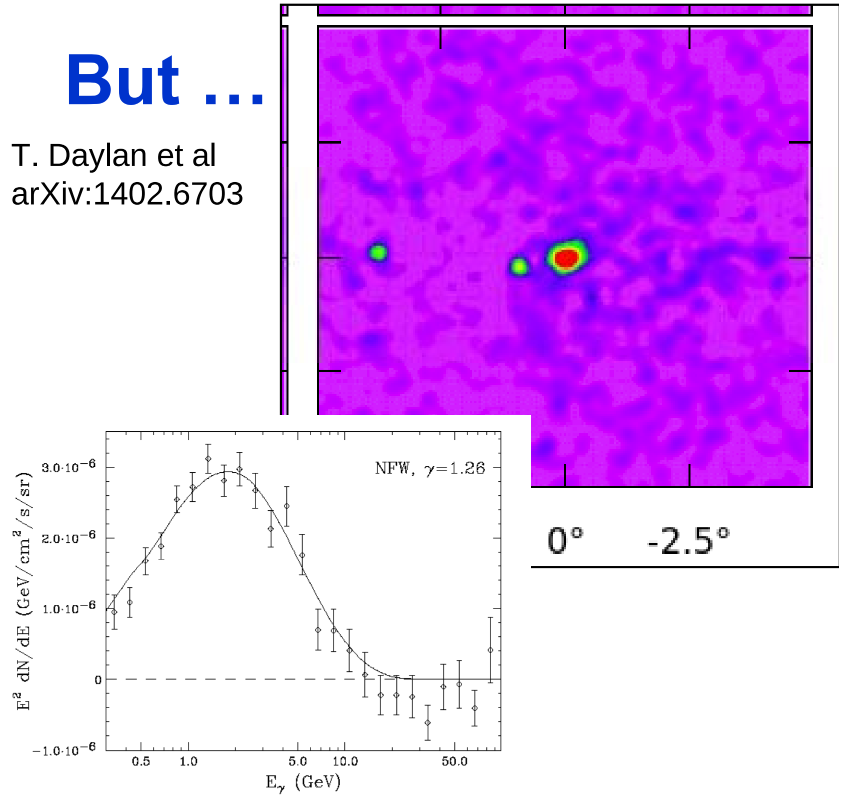
R.A. Ong, Nobel Symposium 154

No signal (yet)

- Limits approaching the thermal relic cross section.
- Gamma-ray instruments probe high mass region not easily accessible by other techniques

But …

T. Daylan et al
arXiv:1402.6703



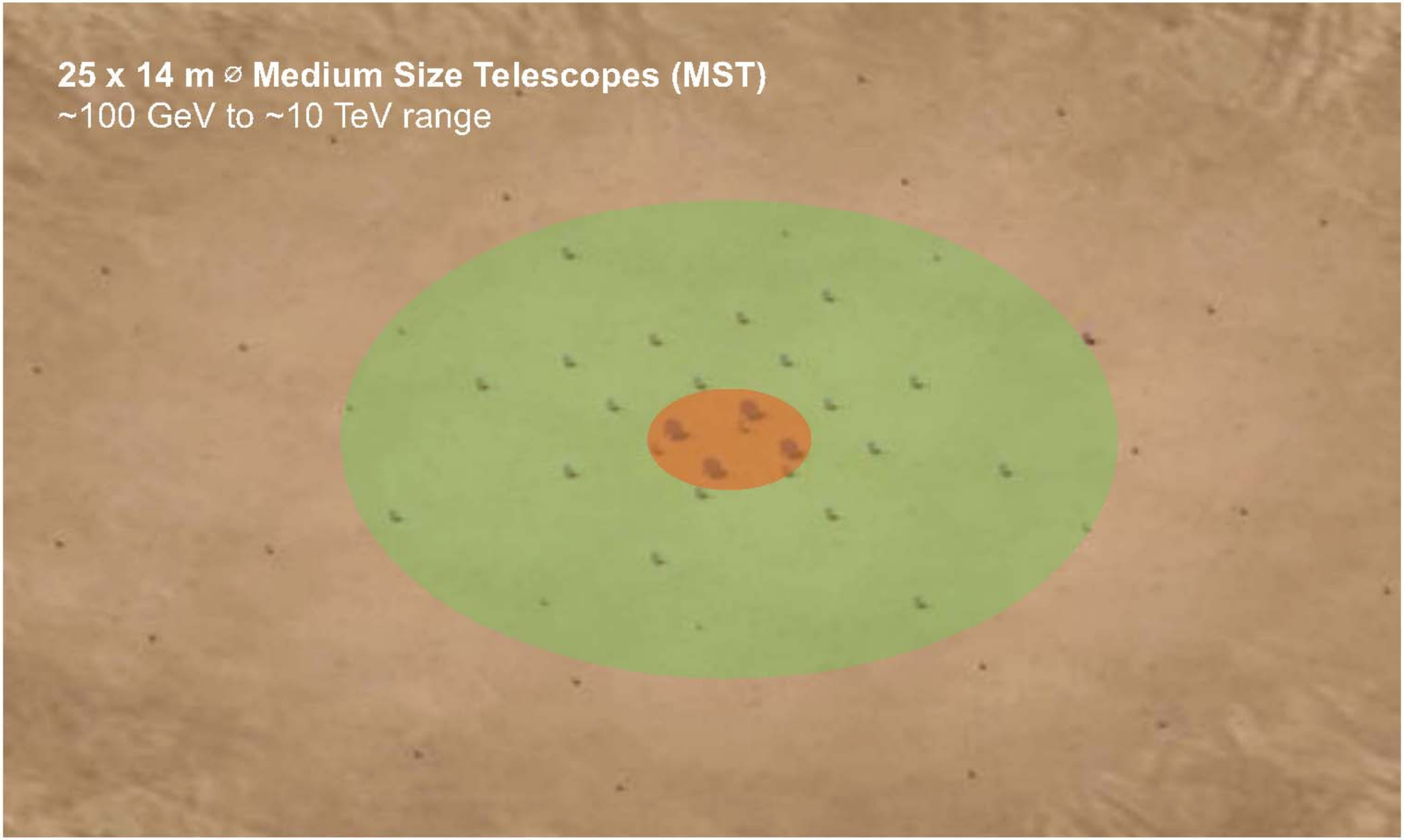
GeV excess in GC

- very significant.
- seen by multiple authors.
- consistent with DM profile and 30-40 GeV mass.
- Complicated region with multiple astrophysical components.

The Cherenkov Telescope Array

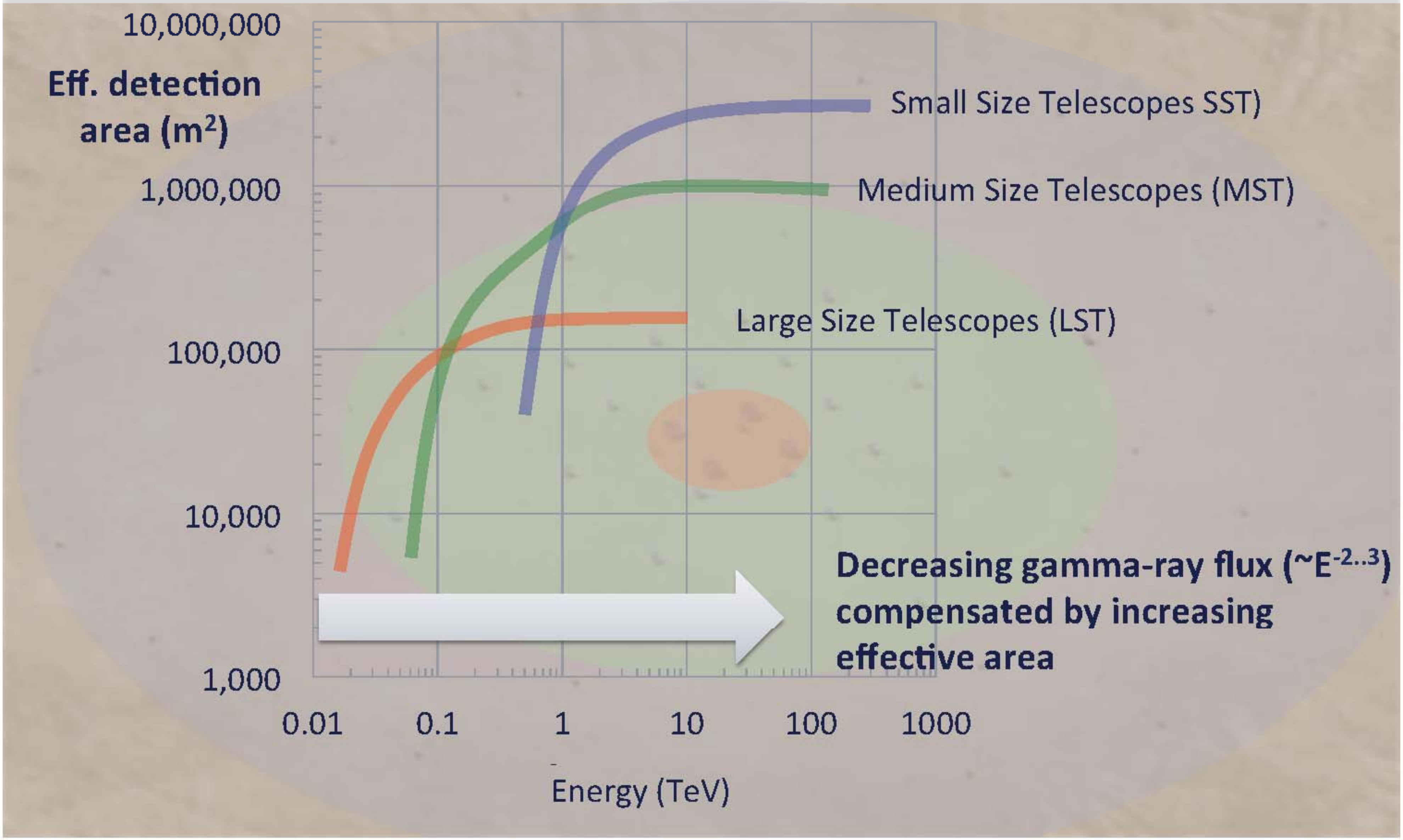
The Cherenkov Telescope Array

The Cherenkov Telescope Array



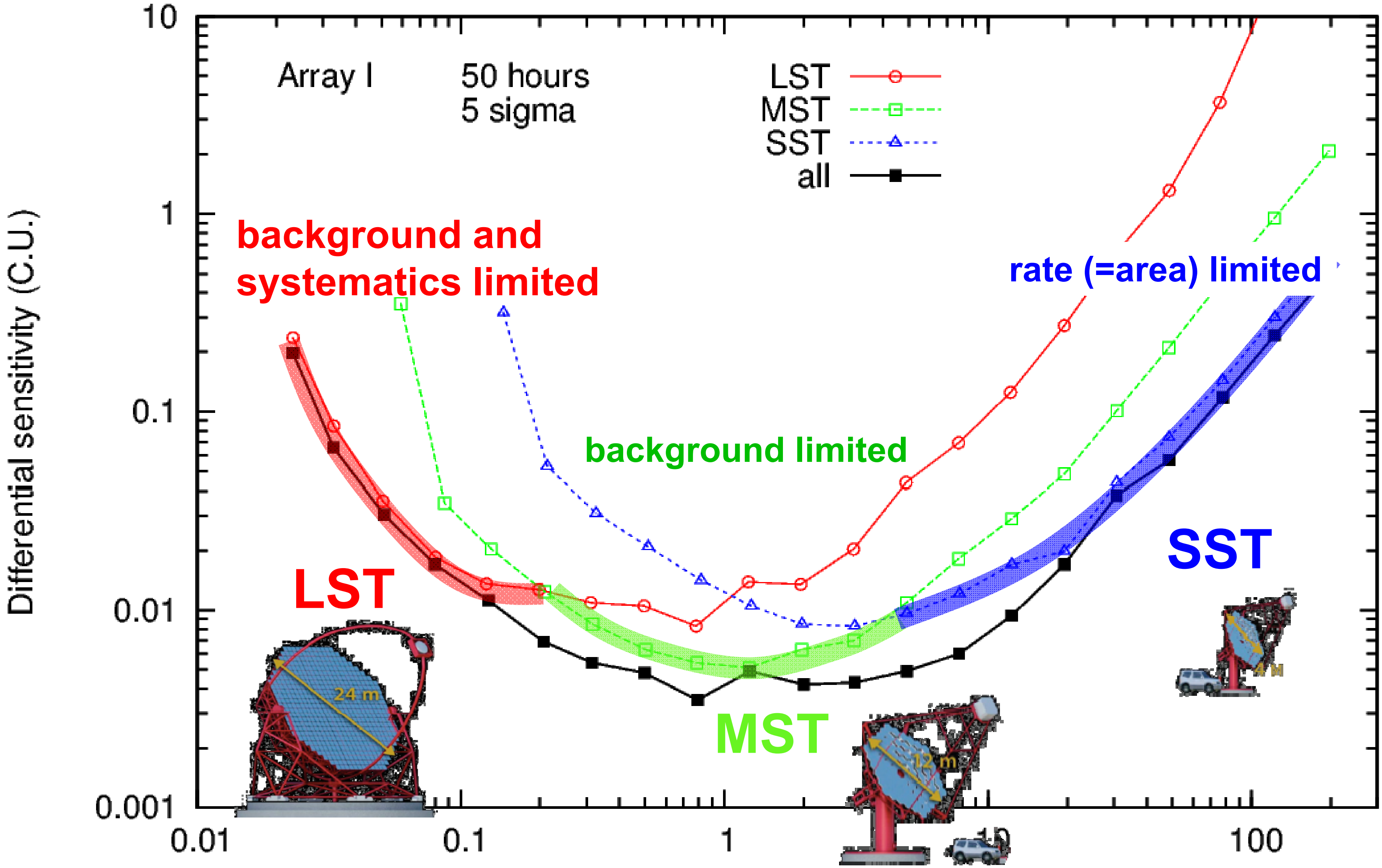
The Cherenkov Telescope Array

Effective Area for Gamma-Ray Detection

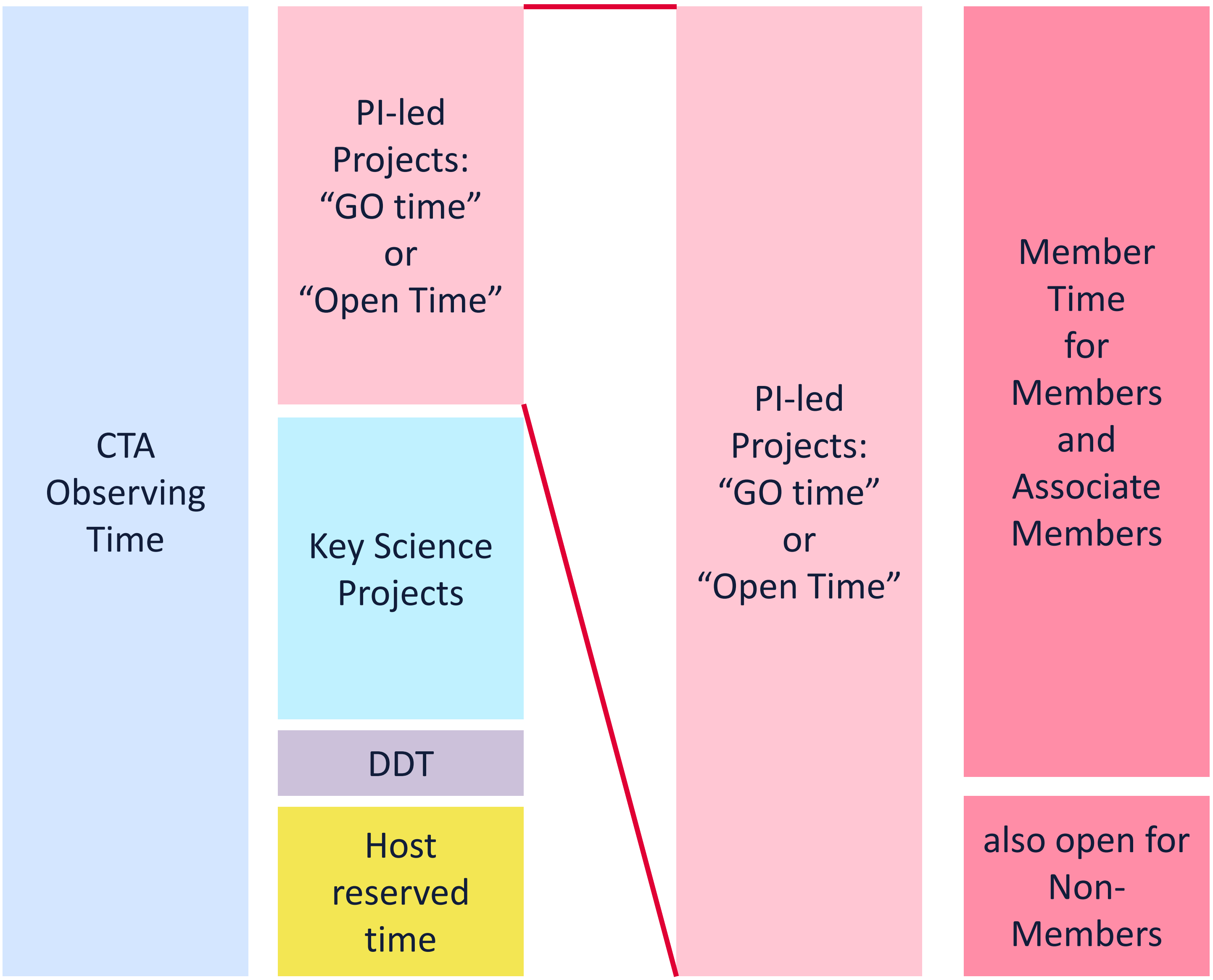


Flux Sensitivity (Crab units)

For detection in each 0.2-decade energy bin



CTA Observing Time



Scientific excellence as criterion for selection

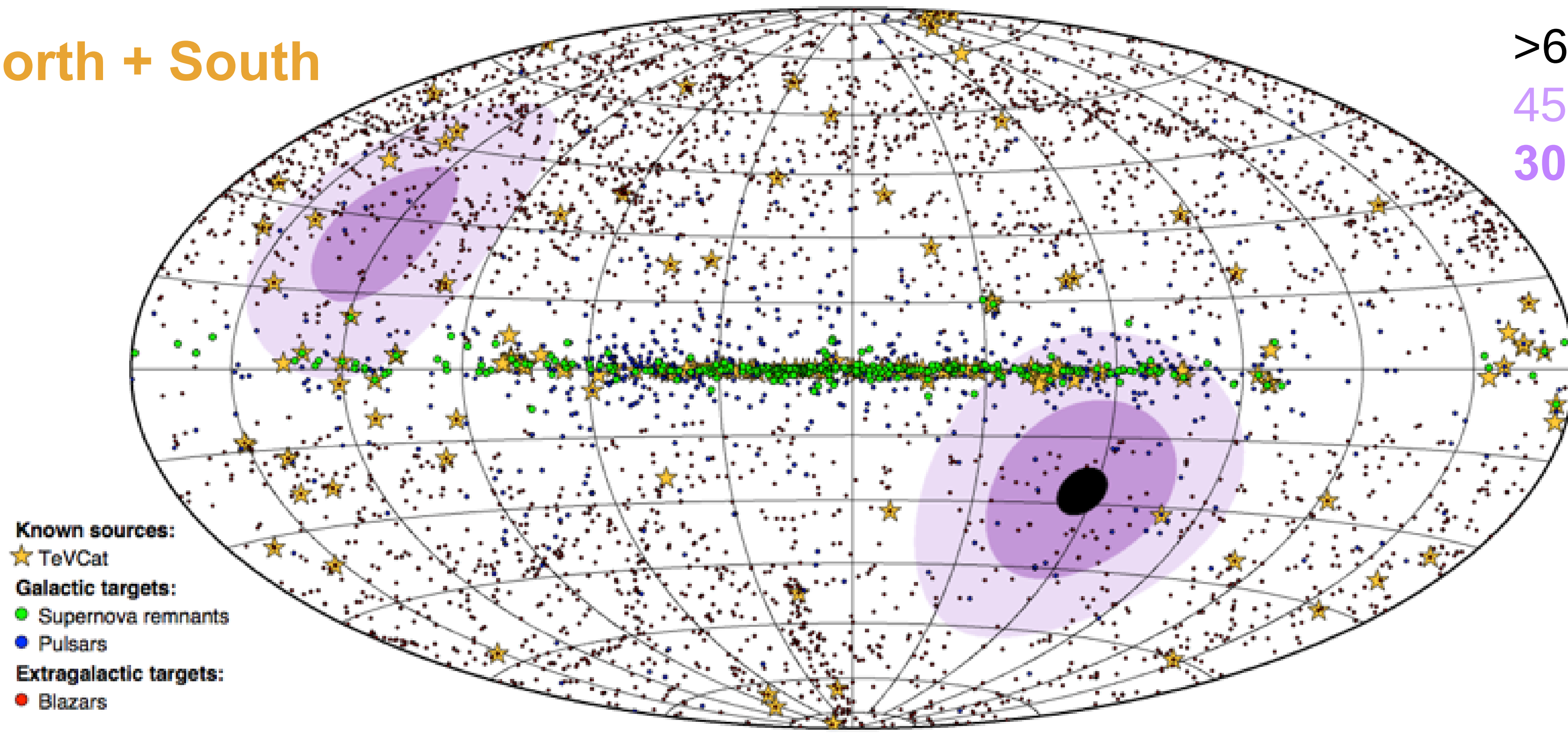
Long term balance between participating countries to be monitored

All data accessible on public archive after 1 year

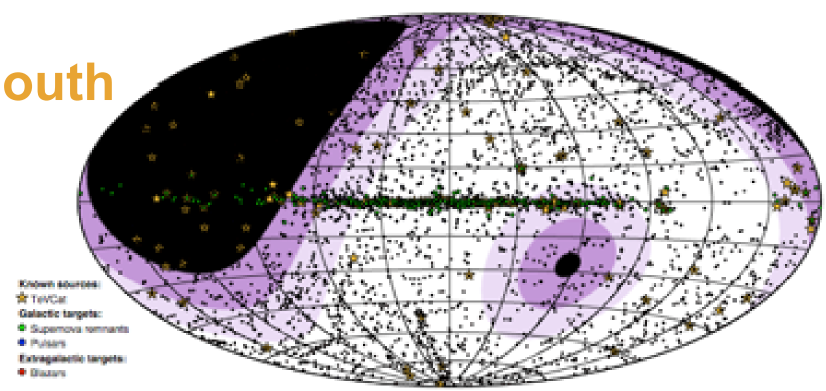
Full Sky Coverage

North + South

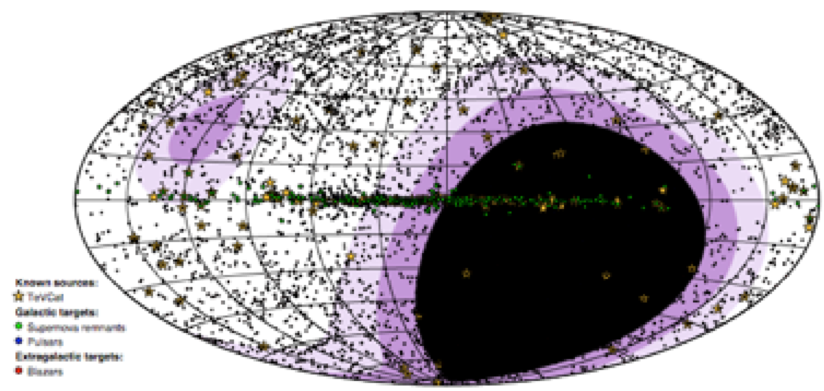
>60º zenith
45º-60º
30º-45º



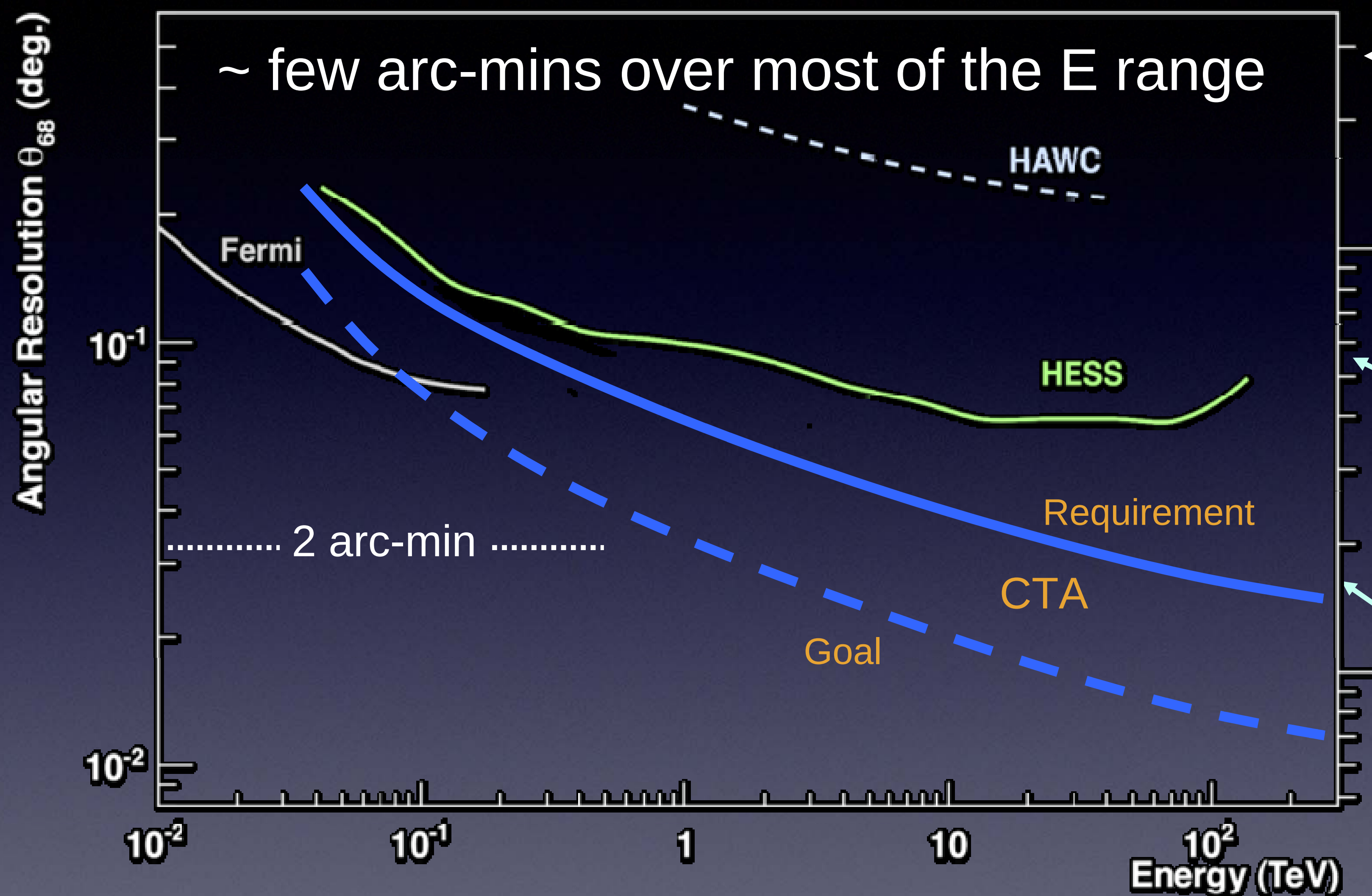
South

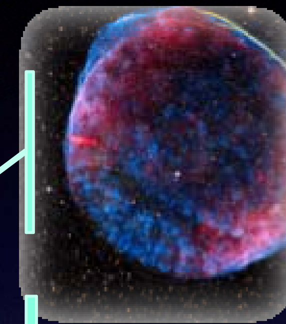


North



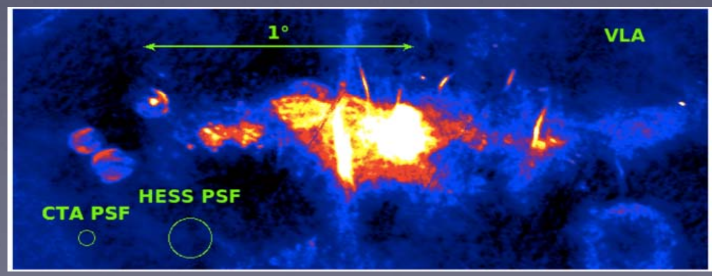
Angular Resolution



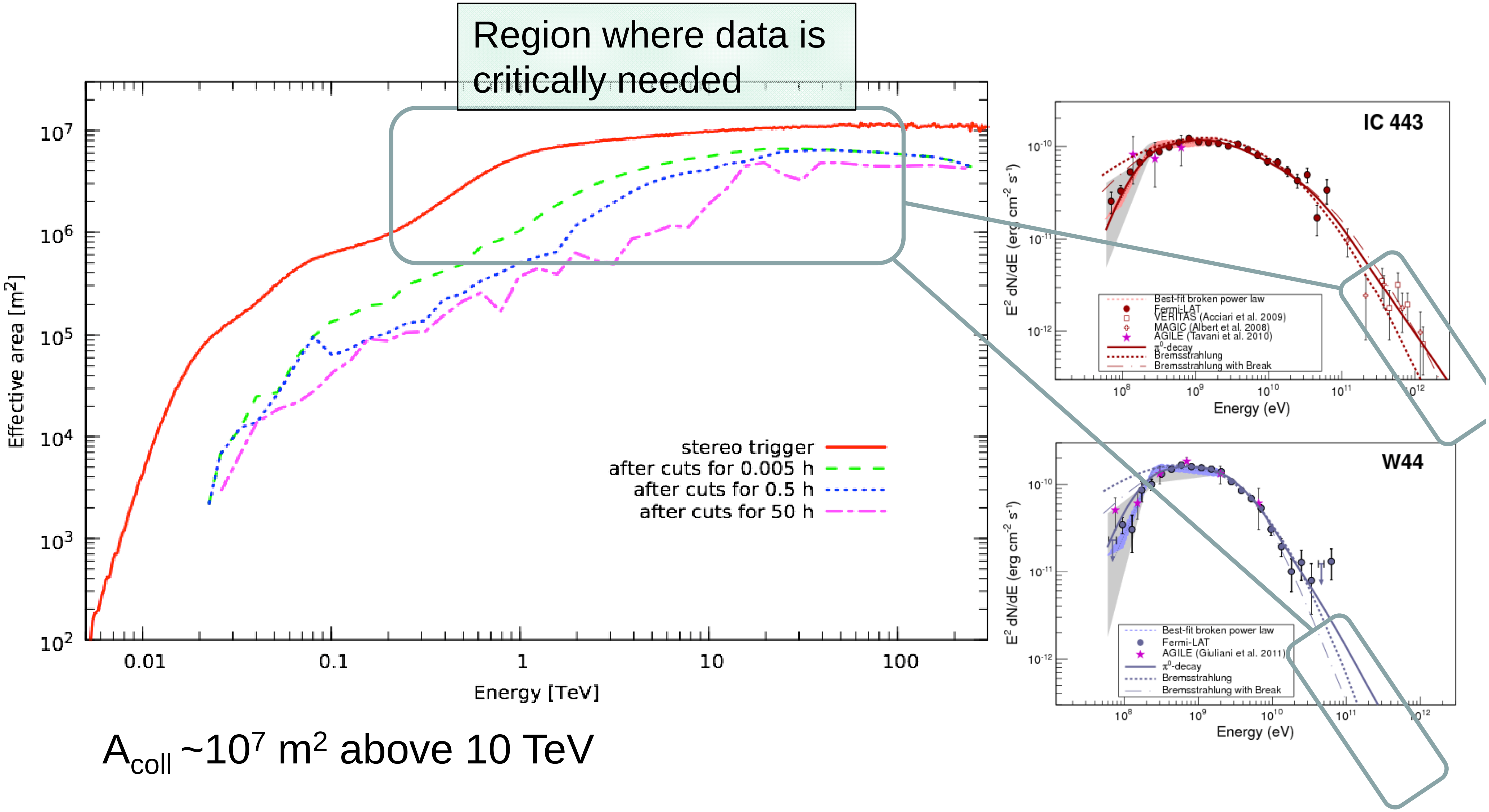


Angular resolution critical for
Source morphology and identification

Galactic-Center
region



CTA Collection Area



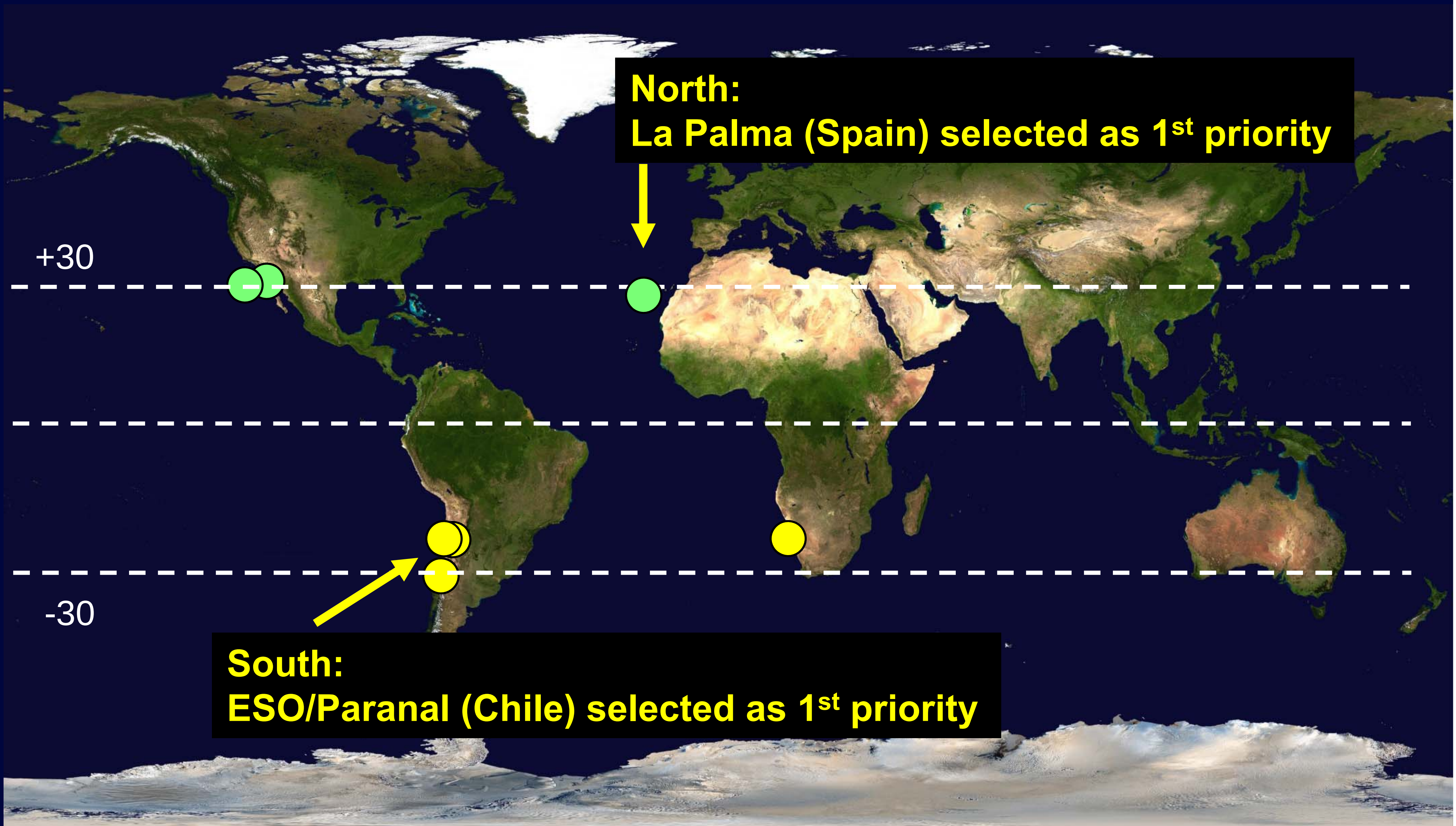
$A_{coll} \sim 10^7$ m^2 above 10 TeV

Crucial for:

High-energy spectra, discovery of Pevatrons → Origin of CRs

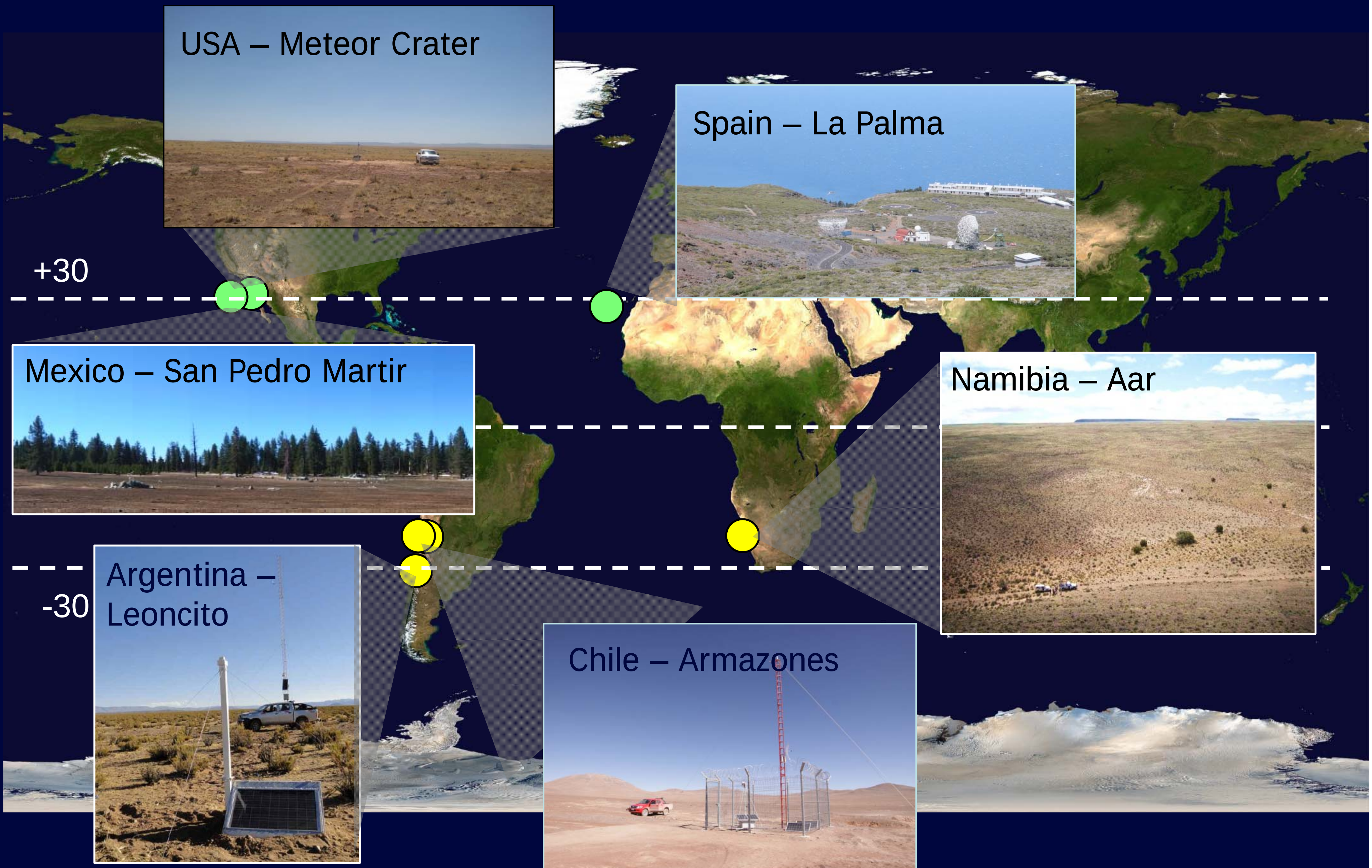
Site Selection

Two sites to cover full sky at 20^o-35^o N, S



Site Selection

Two sites to cover full sky, latitude 20^{o}-35^{o} in N, S



CTA Key Science Projects (KSPs)

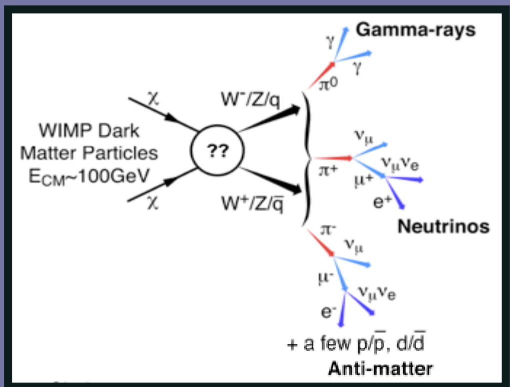
Science Questions — DM ← KSPs →

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?					✔	✔			✔✔	

Nine KSPs + DM Programmed are proposed

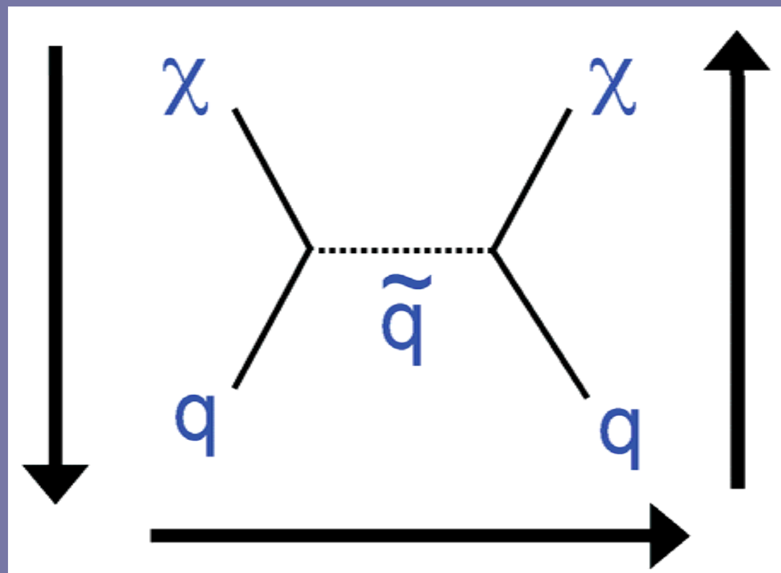
Here, show just a few of the KSPs …

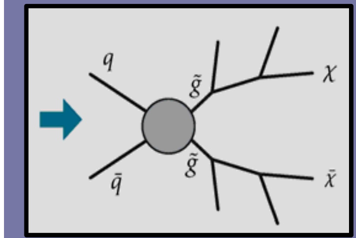
WIMP DM Complementary Approaches

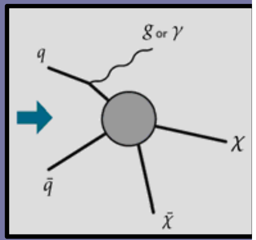


WIMP annihilation
In the cosmos

Indirect Detection

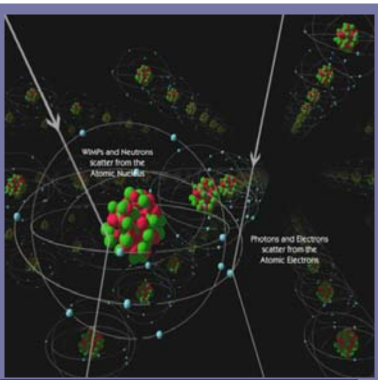


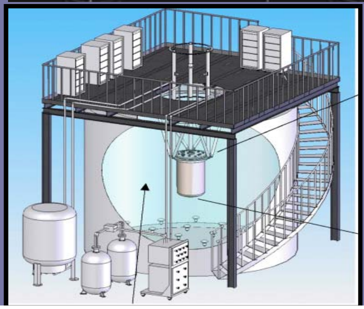




Heavy particle prod.
MET + jets
Weak pair prod.
MET + monojet

LHC Production





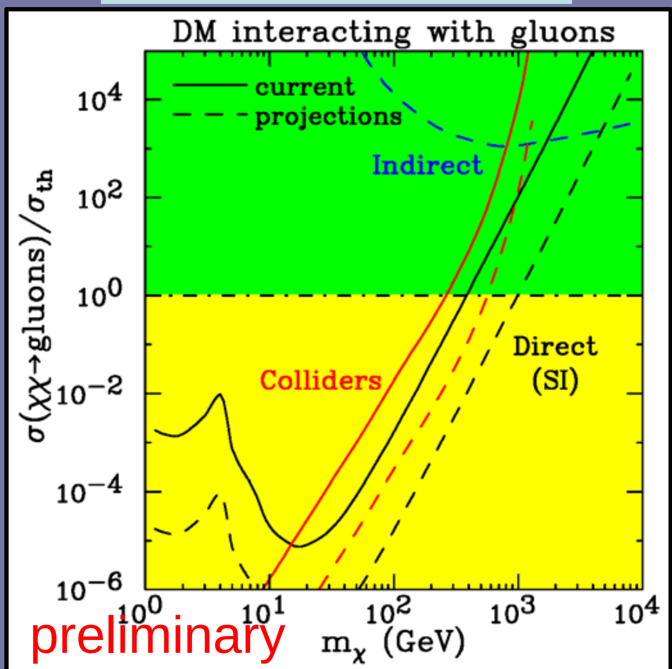
WIMP-Nucleon
Elastic scattering

Direct Detection

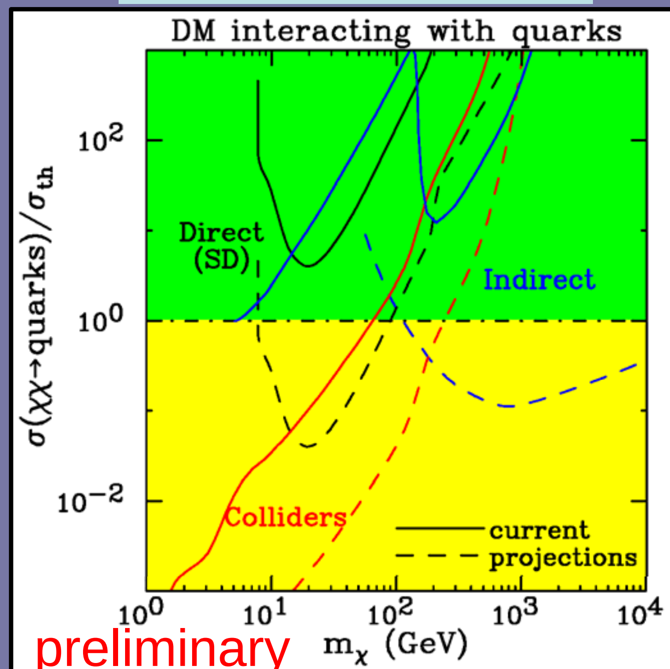
WIMPs: a More General Framework

D. Bauer et al., "Dark Matter in the Coming Decade: Complementary Paths to Discovery and Beyond," White Paper for Snowmass 2013.

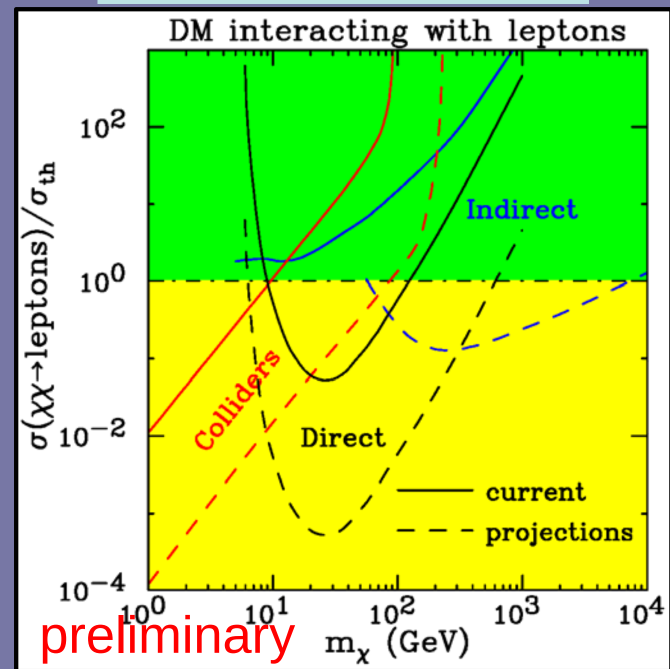
Gluon Interactions



Quark Interactions



Lepton Interactions

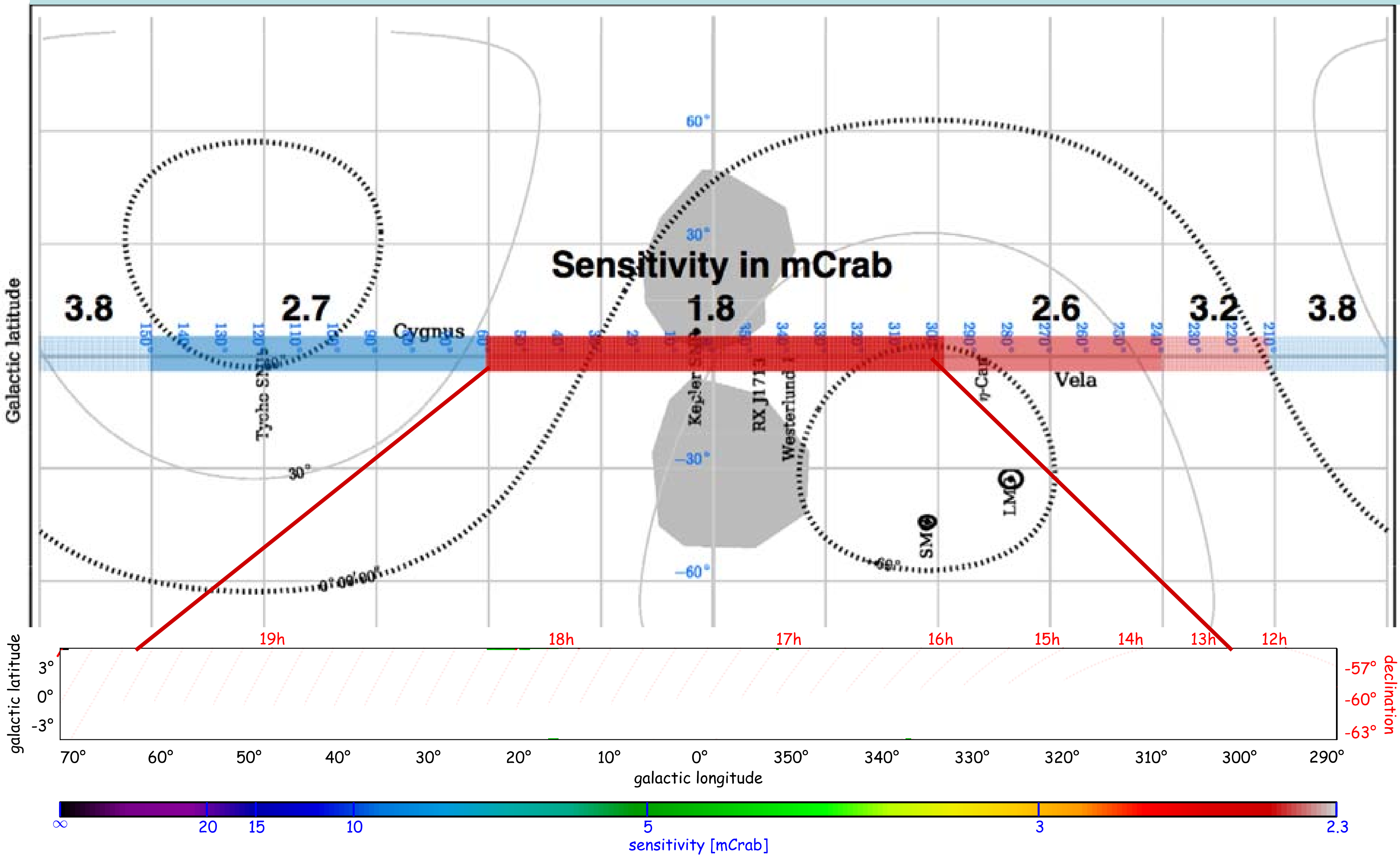


1.0 = expected thermal relic cross-section

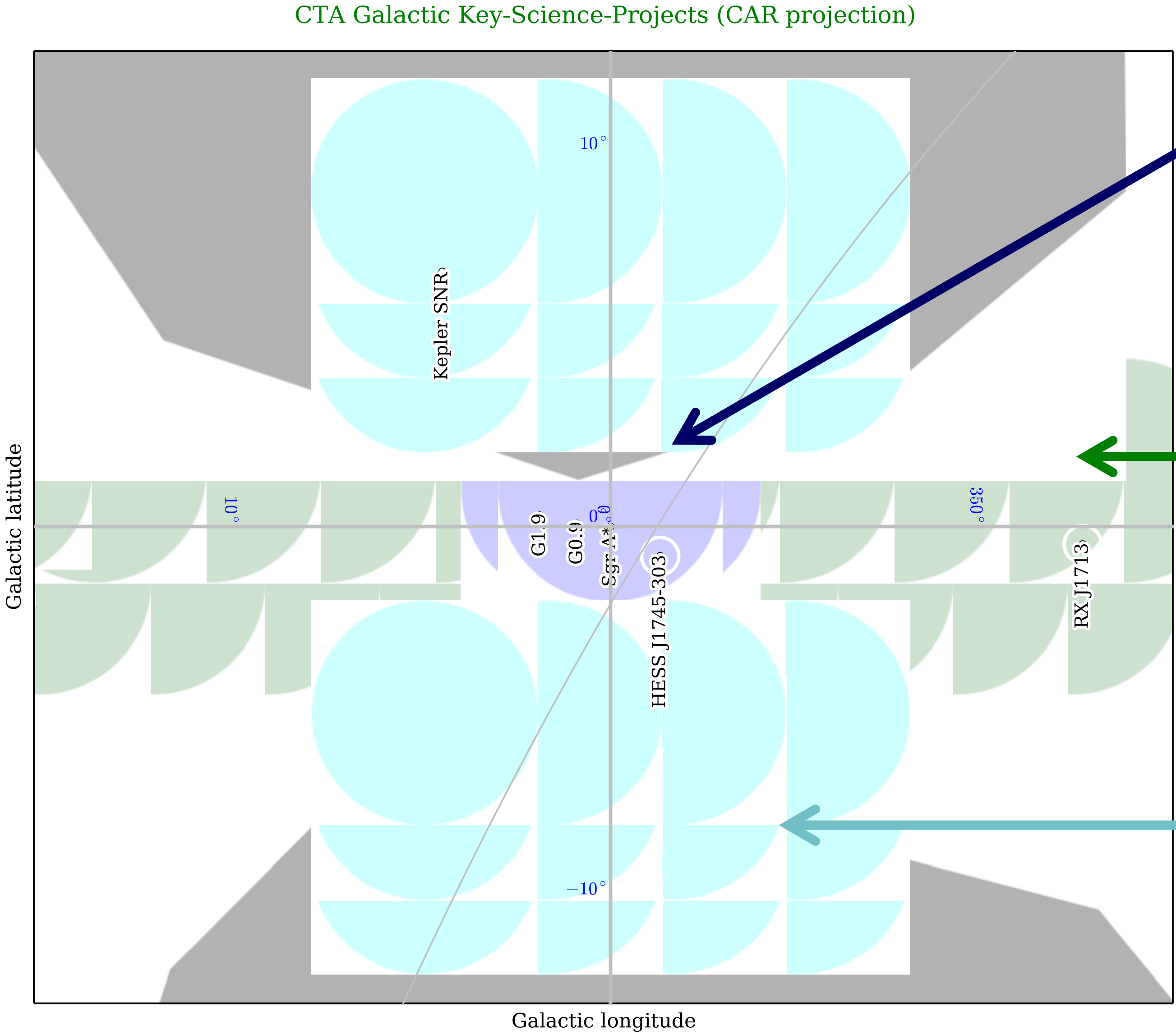
- **For gluon/quark interactions, LHC competitive or dominates at energies below ~few 100 GeV.**
- **For gluon and lepton interactions, direct expts. are important.**
- **For quark and lepton interactions, indirect expts are important.**

Galactic Plane Survey (GPS)

Entire plane surveyed to < 3.8 mCrab - several 100's of sources



Galactic Center



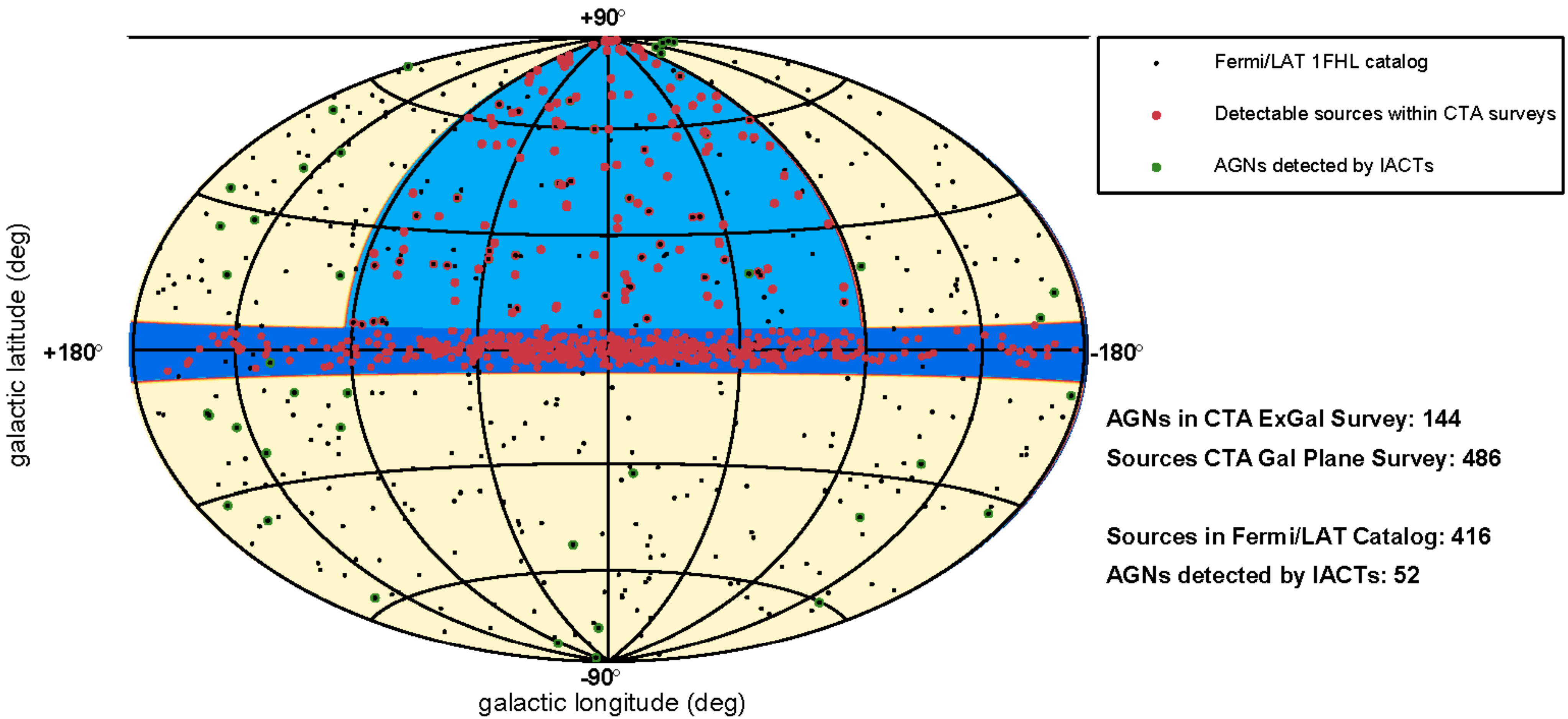
Very deep exposure around SGR A*, covering central source, DM halo, radio lobes

GPS pointings

Deep exposure in 10º by 10º region, to edge of Gal. bulge, Covering radio spurs, base of Fermi bubbles, Kepler SNR

Extragalactic Survey

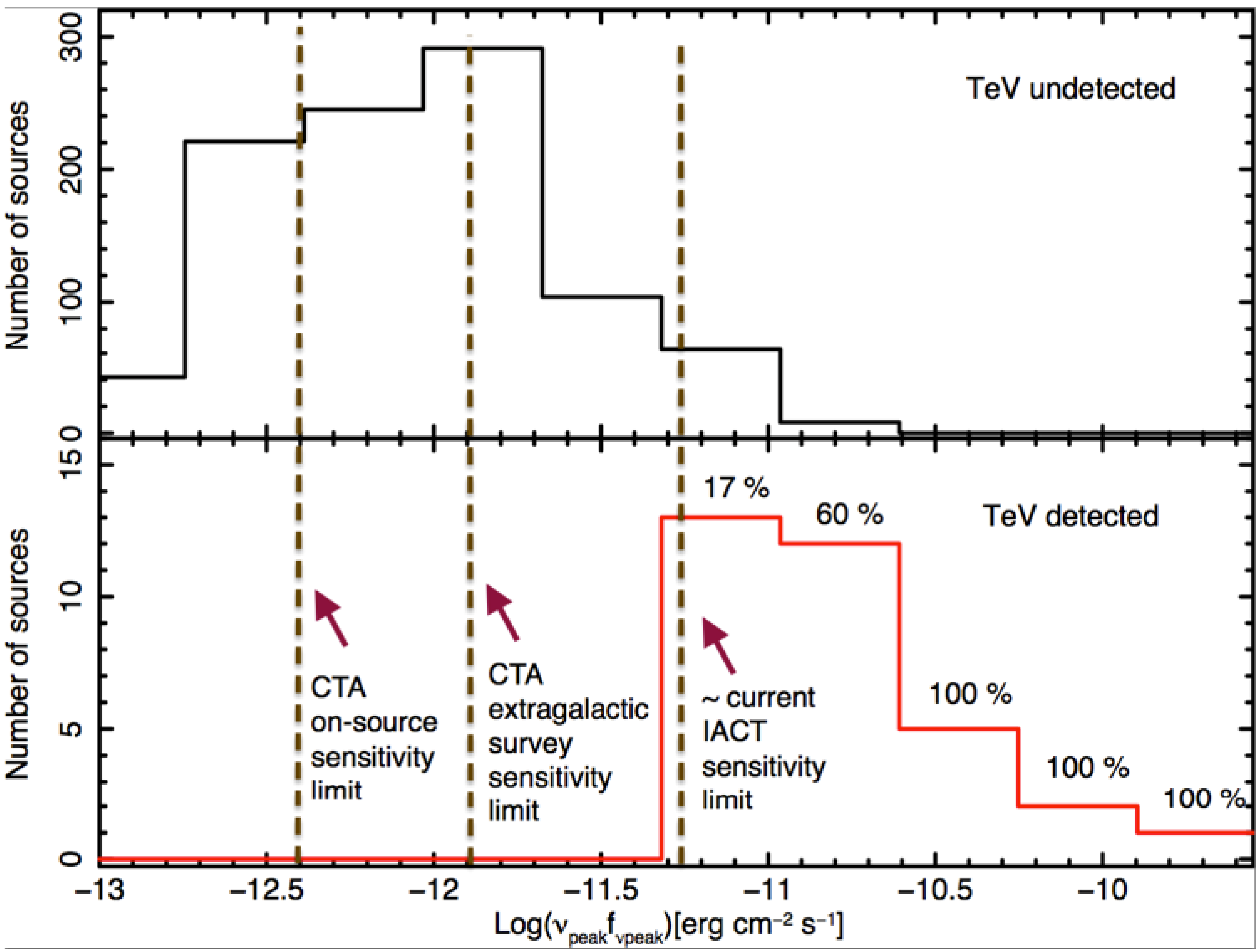
Survey ~1/4 of sky (adjoining GPS)



- Unbiased sample of blazars, log N – log S, extreme blazars, etc.
- Wider coverage of serendipitous events – e.g. GRBs
- Unexpected phenomena – e.g. ULIRGs, Seyferts, dark clumps,

Extragalactic Survey

Blazar luminosity function



Telescope Specifications

cta cherenkov telescope array

SiPM Cameras

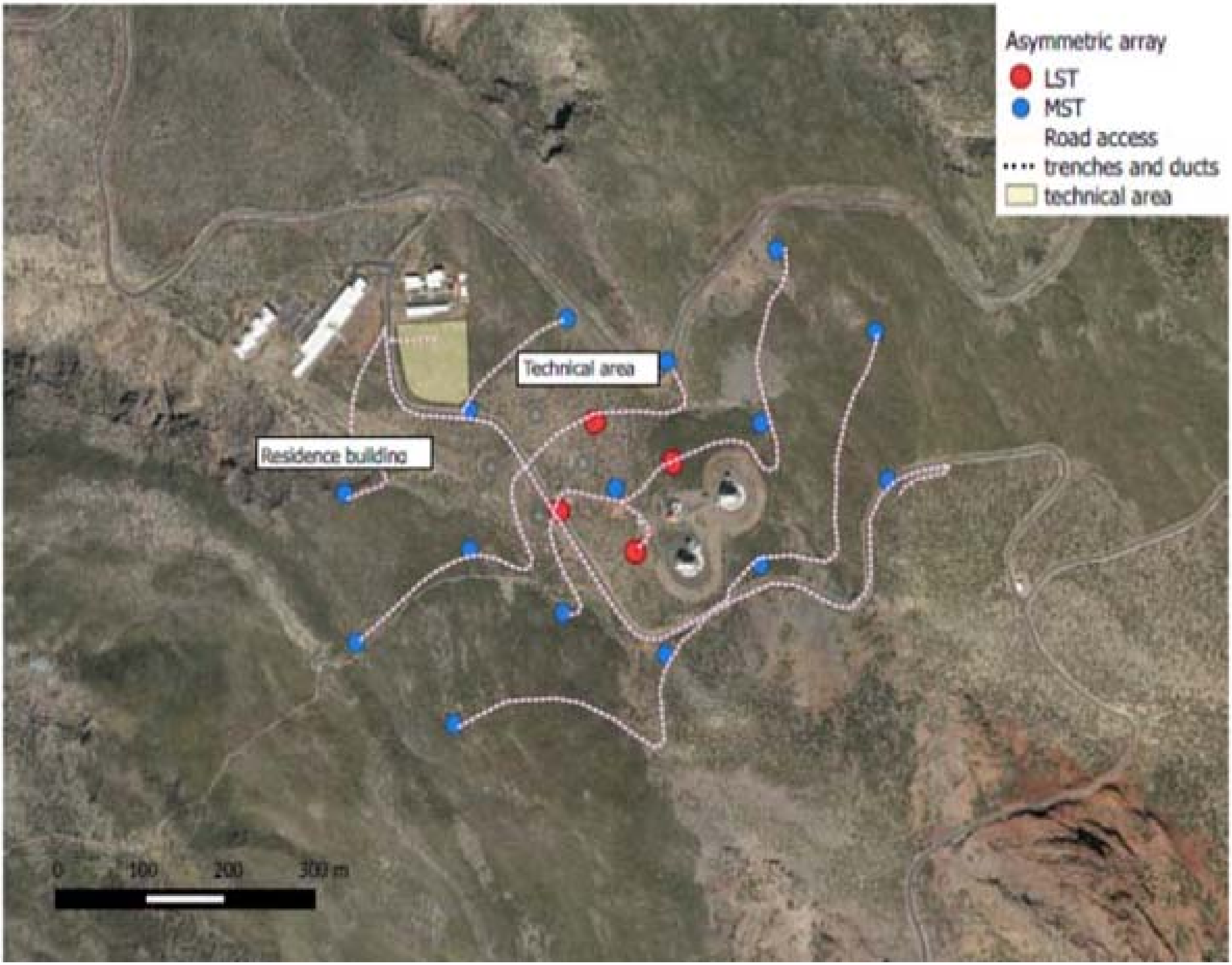
3 SST types

	LST "large"	MST "medium"	SCT "medium 2-M"	SST "small"
Number	**4 (S) 4 (N)**	**25 (S) 15 (N)**	**≤ 24 (S and N)**	**70 (S)**
Energy range	20 GeV to 1 TeV	200 GeV to 10 TeV	200 GeV to 10 TeV	> few TeV
Effective mirror area	> 330 m^2	> 90 m^2	> 50 m^2	> 5 m^2
Field of view	> 4.4^o	> 7^o	> 7^o	> 8^o
Pixel size ~PSF θ_{80}	< 0.12^o	< 0.18^o	< 0.07^o	< 0.25^o
Positioning time	50 s, 20 s goal	90 s, 60 s goal	90 s, 60 s goal	90 s, 60 s goal
Target capital cost	7.4 M€	1.6 M€	< 2.0 M€	500 k€

LA PALMA

- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
- Site of LST prototype & existing MAGIC telescopes

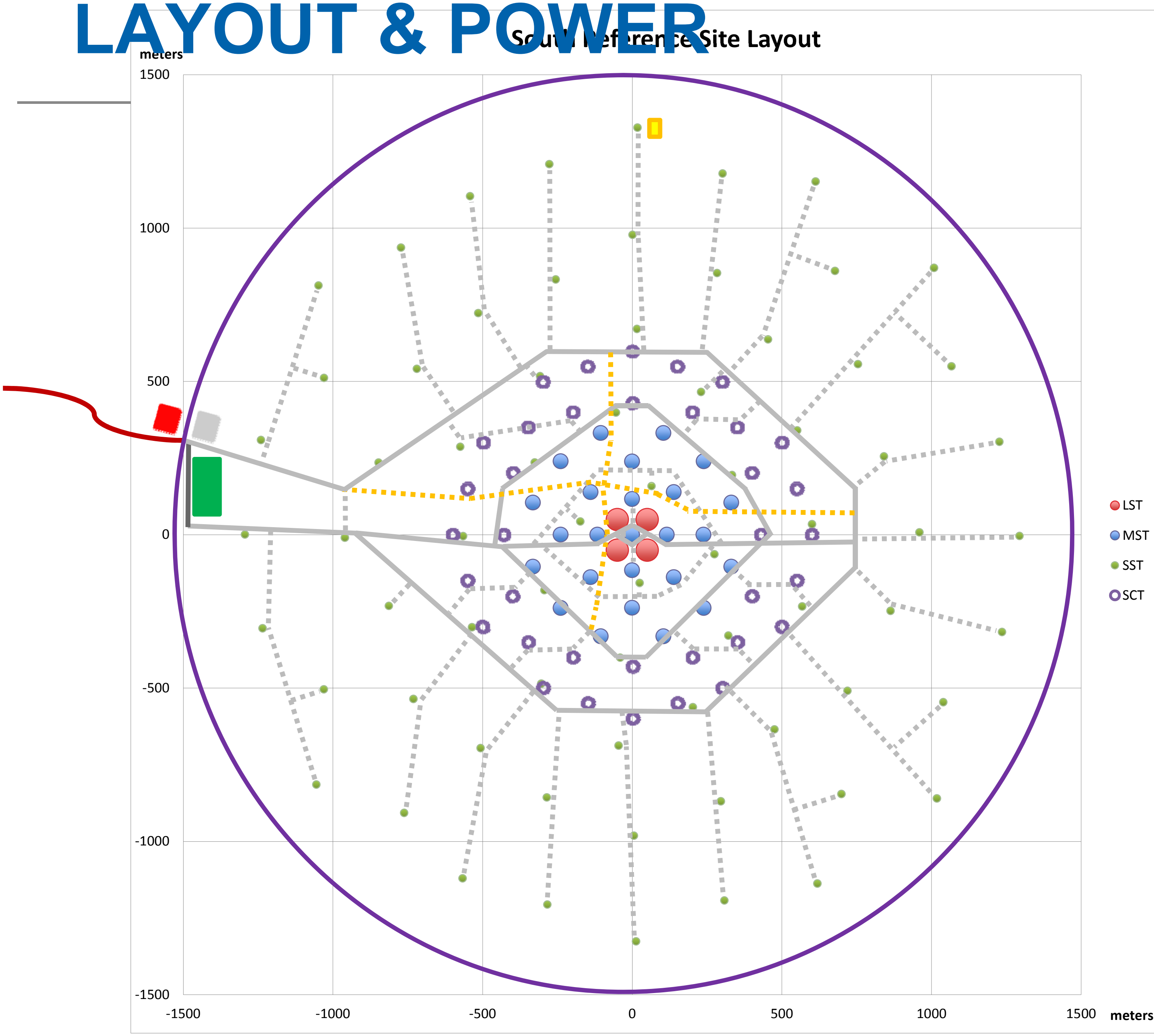
LA PALMA – Possible Layout



ESO/PARANAL

- Atacama Desert, Chile
- Below Cerro Paranal
- Existing observatory, under management by European Southern Observatory (ESO)
- Near a set of existing (VLT) and future (ELT) telescopes

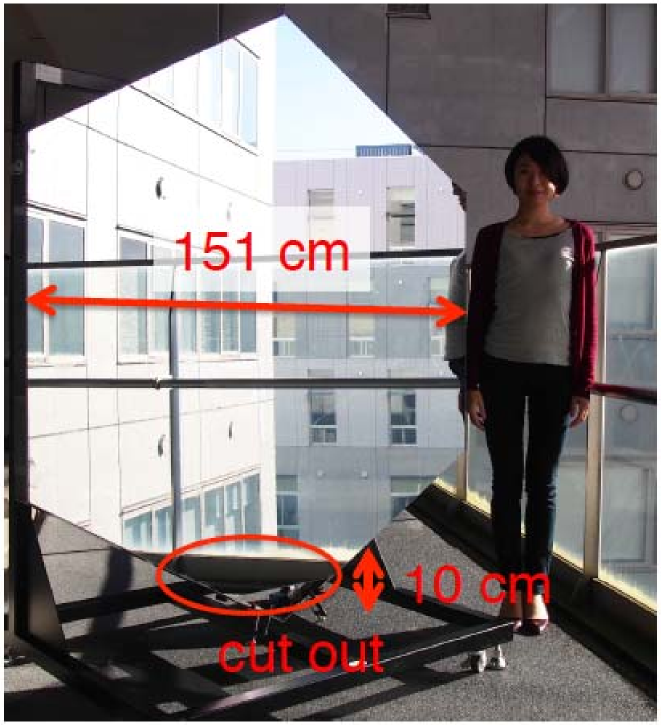
ESO/PARANAL – POSSIBLE LAYOUT & POWER



LST Full Prototype

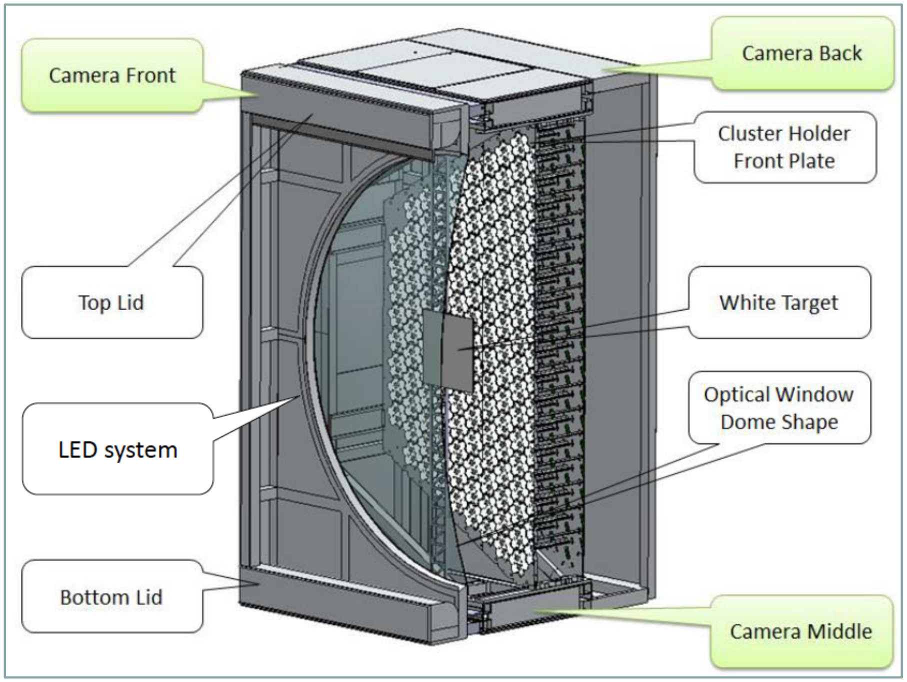
Elevation drive prototype

Mirror prototype
(cold-slump, Sanko)



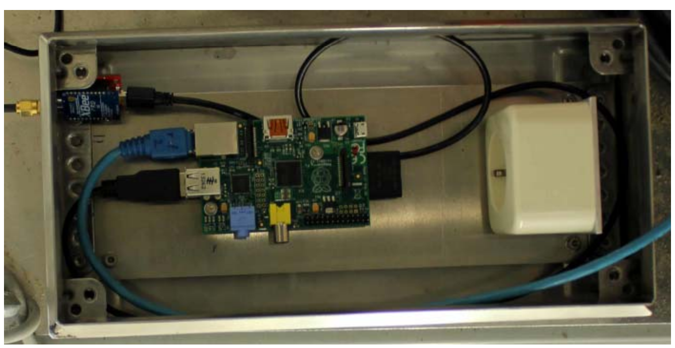
Area = 1.96 m^2
Mass = 47 kg

Prototype Camera design

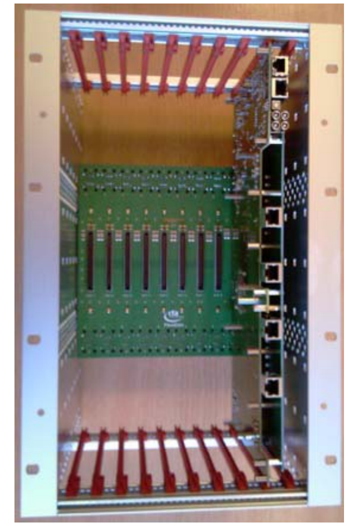


MST Cameras and Mirror Control

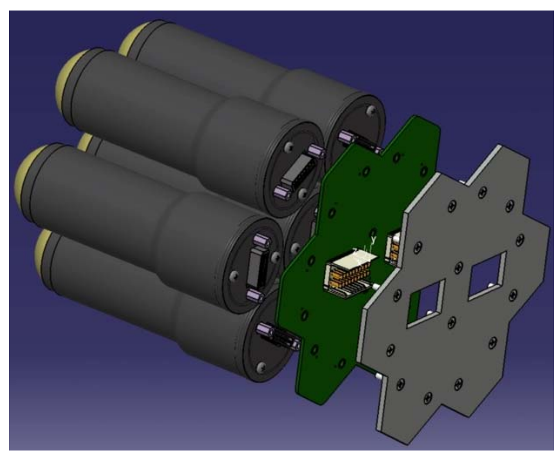
Prototype automatic mirror control (AMC)

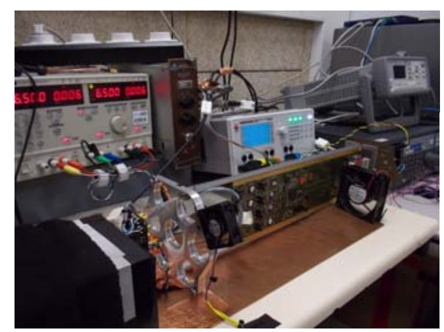


Flash-ADC + digital trigger + rack electronics (“FlashCAM”)



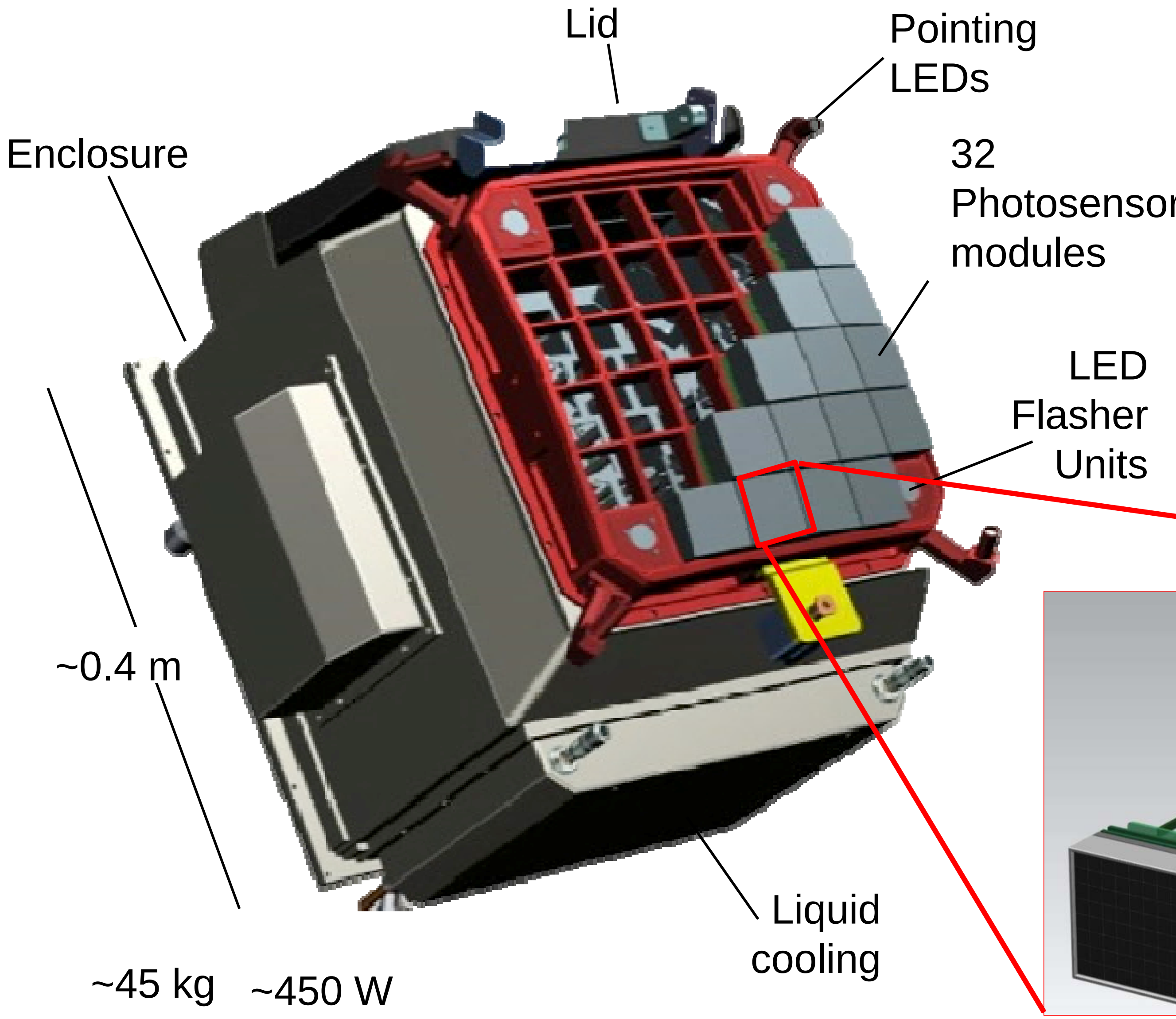
Capacitor pipeline + analog trigger + fully-contained “drawers” (“NectarCAM”)

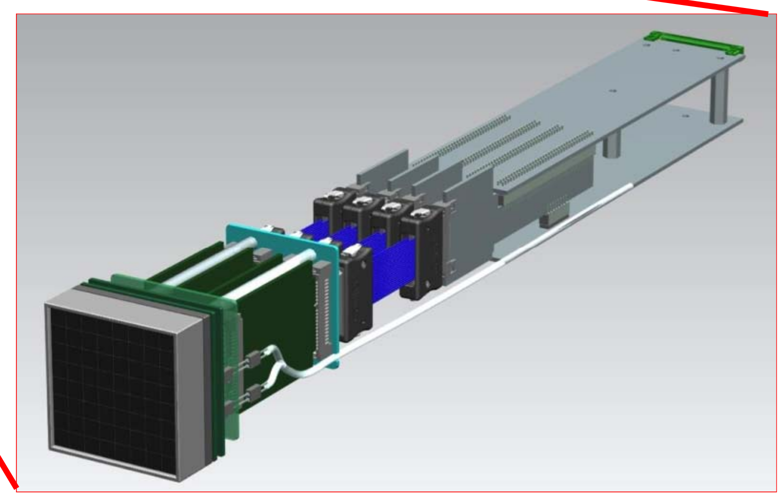




Nectar-board prototype

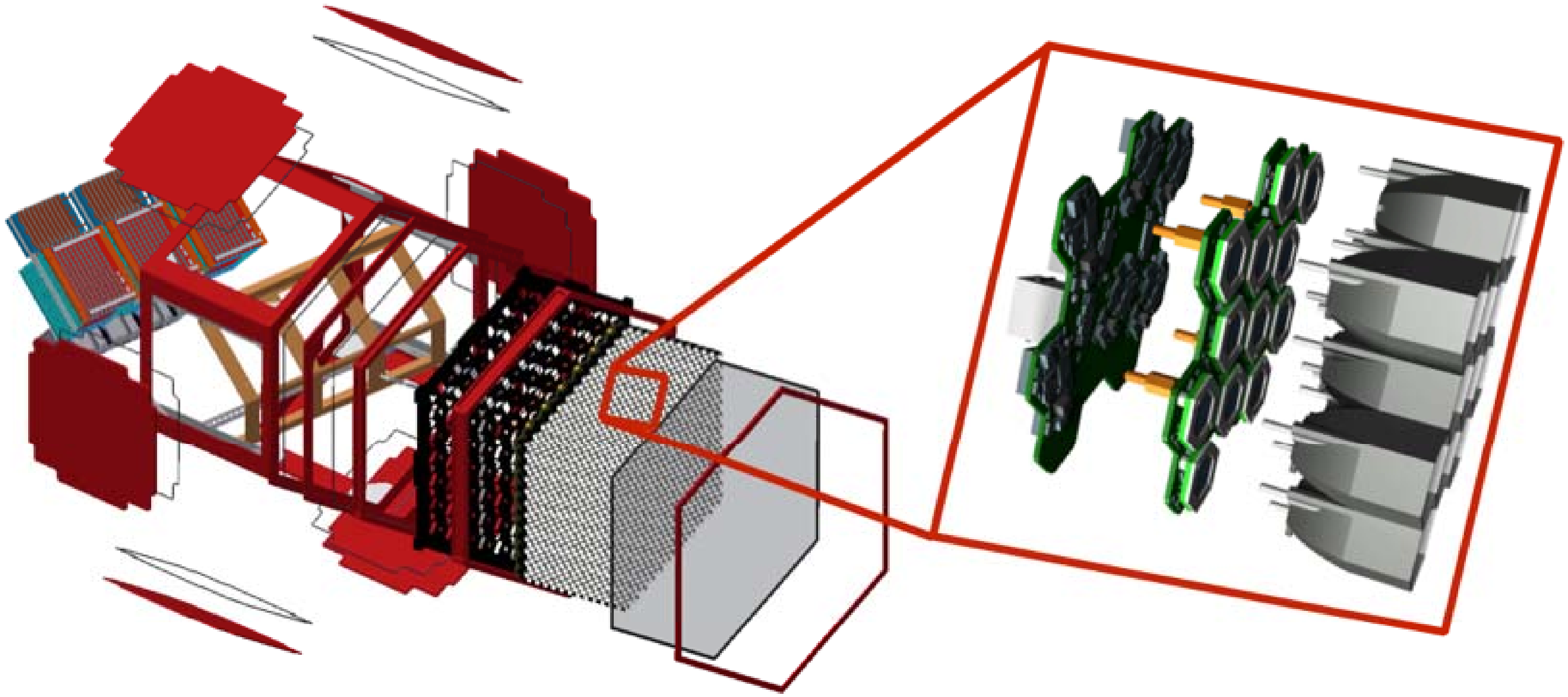
SST-2M-GCT Camera + Module

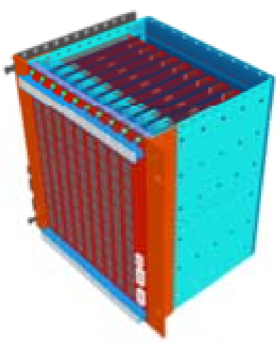




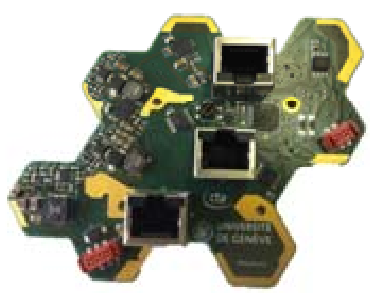
Photosensor module

Silicon-PMT Camera

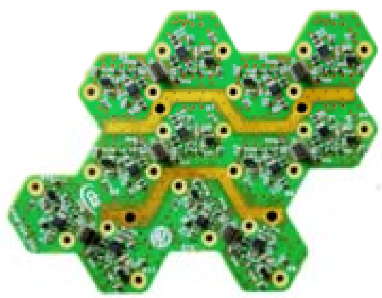




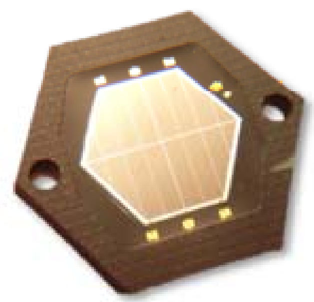
DigiCam



Slow Control Board



Preamplifier board



Hexagonal sensors

Light guides

SST-2M -ASTRI Focal Plane

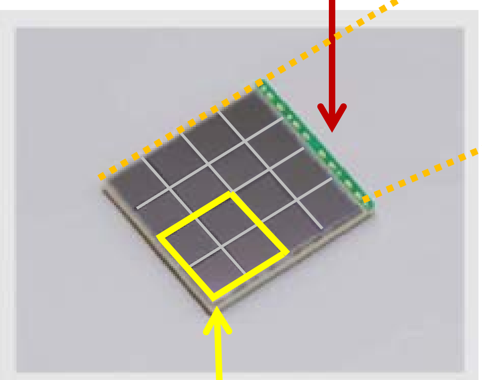
cta cherenkov telescope array

Photon Detection Module
PDM

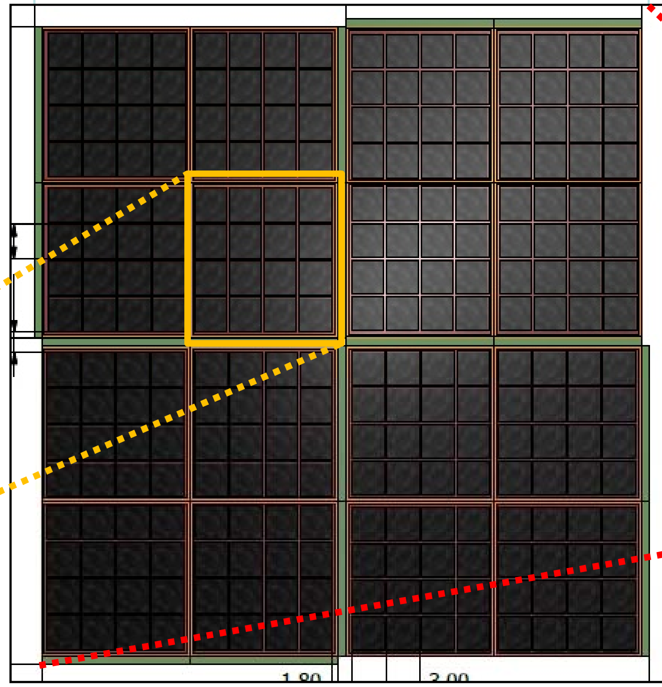
Each PDM works independently from the others

S11828-3344M1
the 'Unit'

geometrical dead area

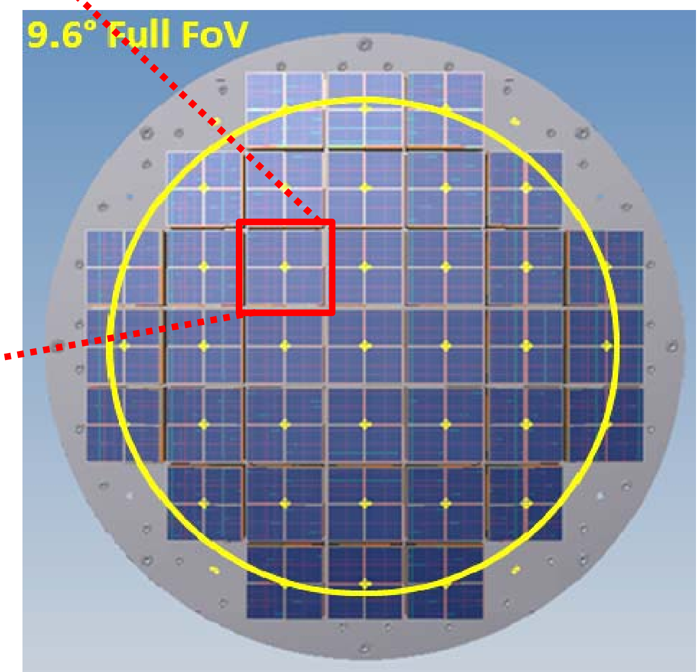


Logical pixel
6.2×6.2mm
≡ 0.17°
(4 channels)



4×4 Units → 1 PDM
56×56mm
(64 channels)

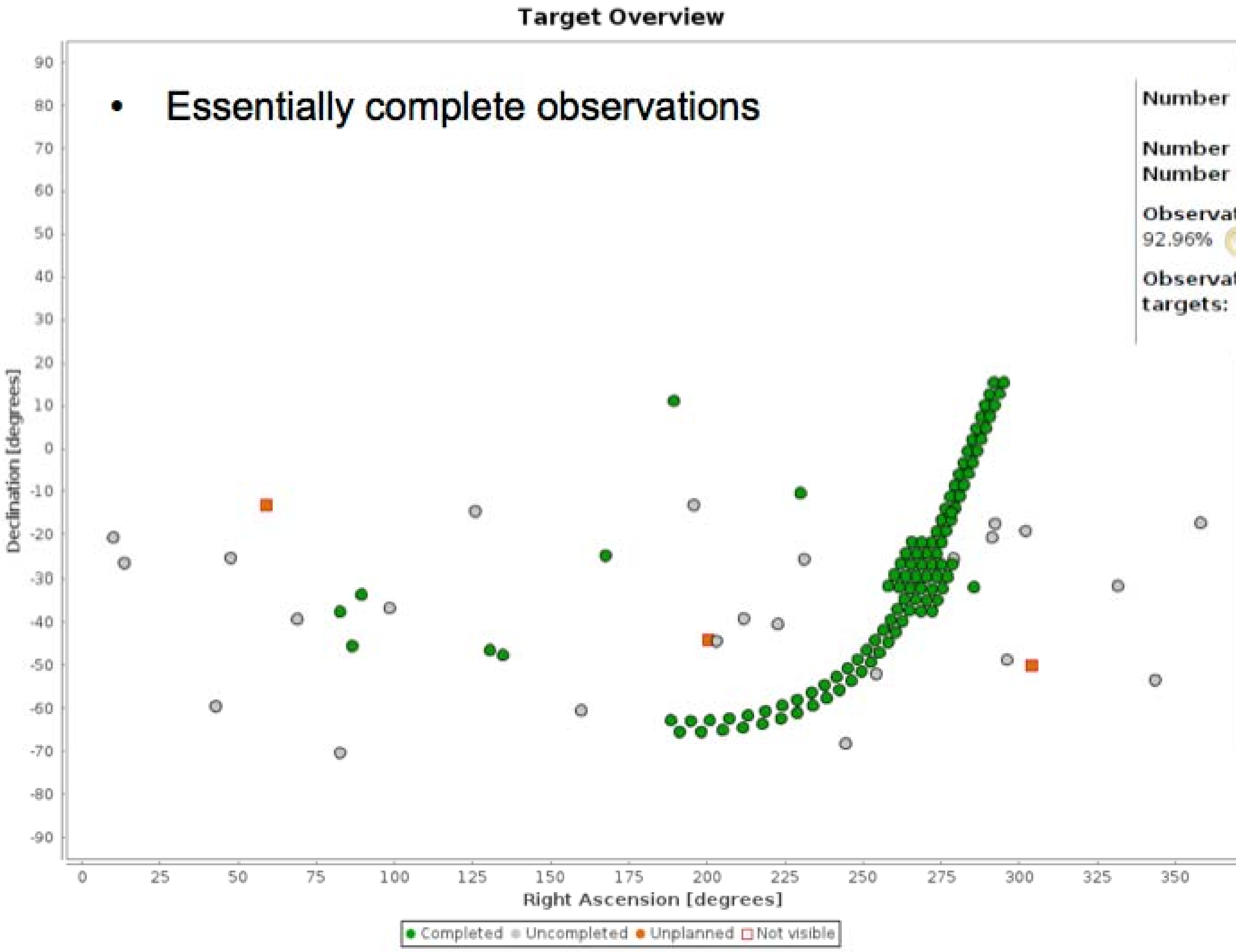
ASTRI Focal Plane



37 PDMs → Focal Plane
560×560mm
(1984 channels)

Observing Schedule (S, Yrs 1-2)

- Essentially complete observations



Number of days planned: 731

Number of total targets: 113
Number of planned targets: 110 Details

Observation completeness according to all the targets: 92.96% Details

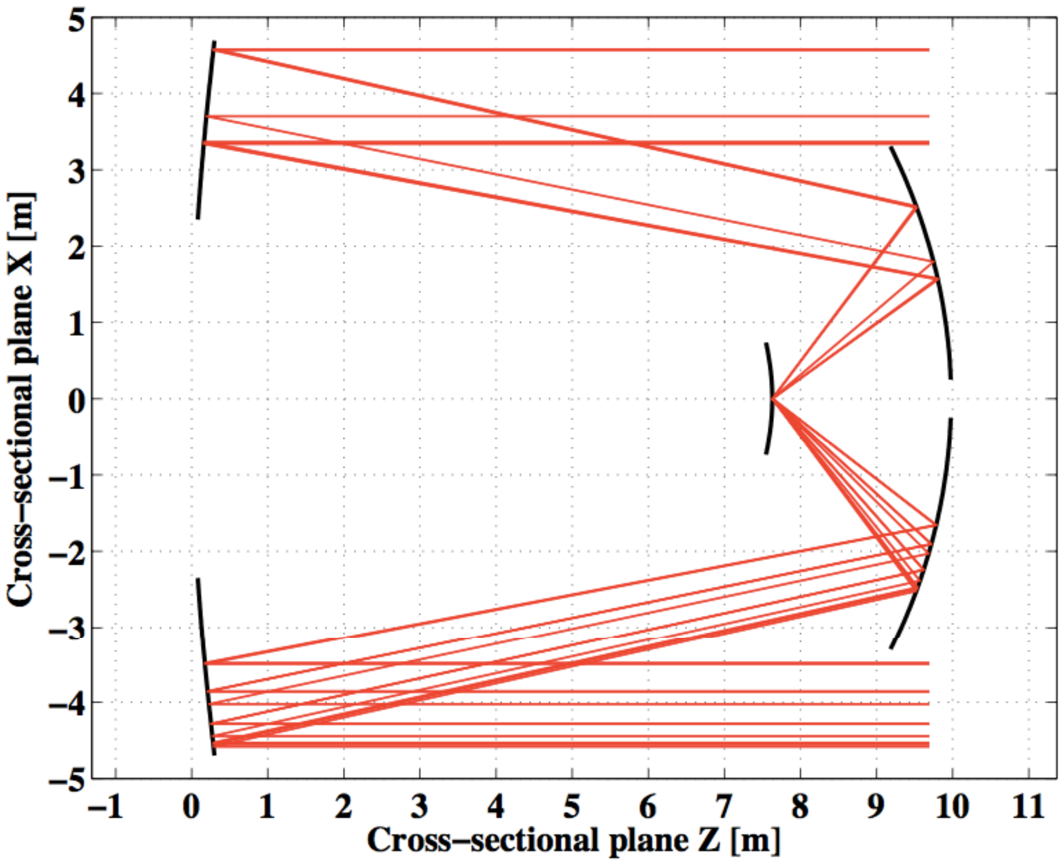
Observation completeness according to the planned targets: 95.49%

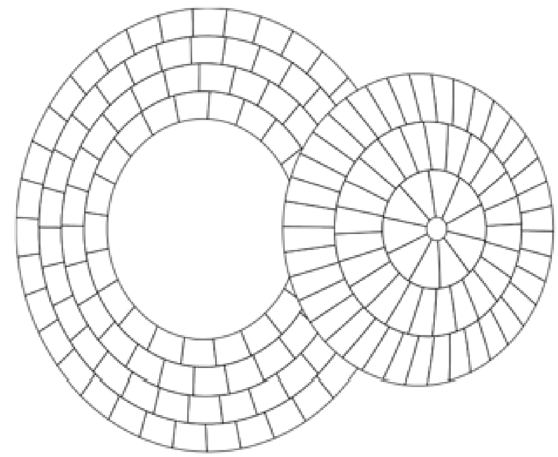
Essentially all KSP observations completed in the two years.

Two-Mirror Telescopes

Schwarzschild-Couder (SC) Design

Vassiliev, Fegan, Brousseau
Astropart.Phys.28:10-27,2007





- Reduced plate scale
- Improved PSF
- Uniform PSF across f.o.v.

➜ Low-cost small telescopes with compact sensors (SST-2M)

➜ Higher-performance, cost-effective, medium telescope (MST-SCT)

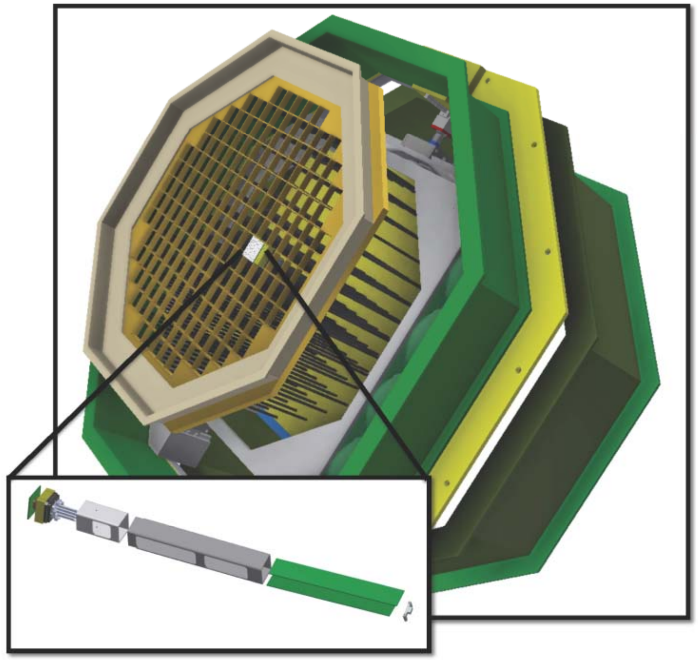
3 telescope prototypes within CTA are using two mirror designs - All make use of Si-PMT cameras.

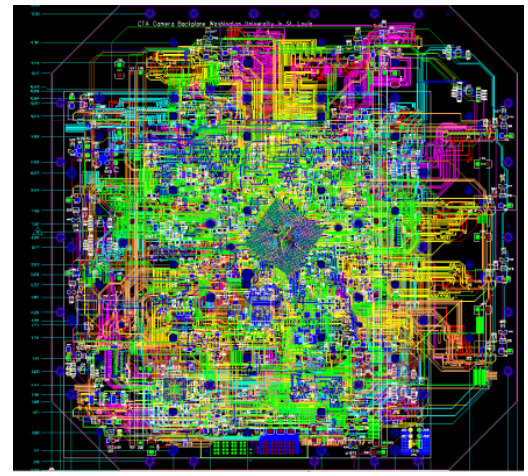
SCT Prototype Development

Prototype panels for primary mirror (M1)

Prototype under construction in Arizona

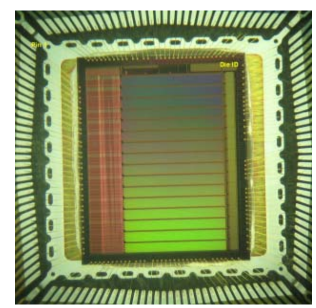
Camera design, backplane and elements





Backplane

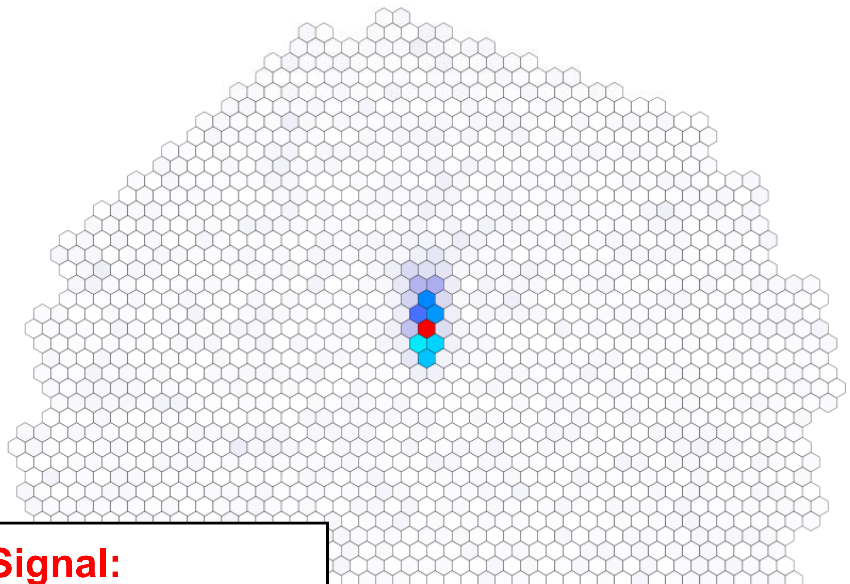
Individual (64-chan) Camera module



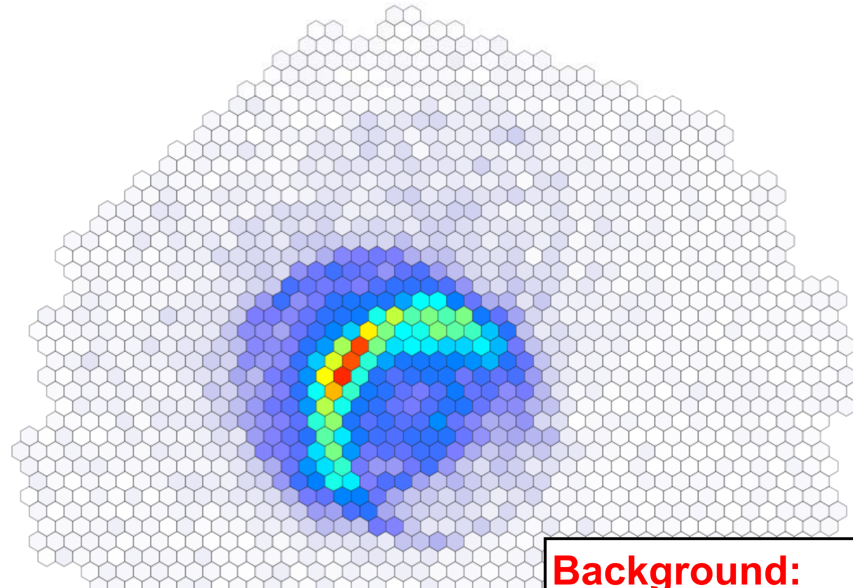
TARGET-7 ASIC

SCT → Superior Imaging

Made possible by Si-PMT's !

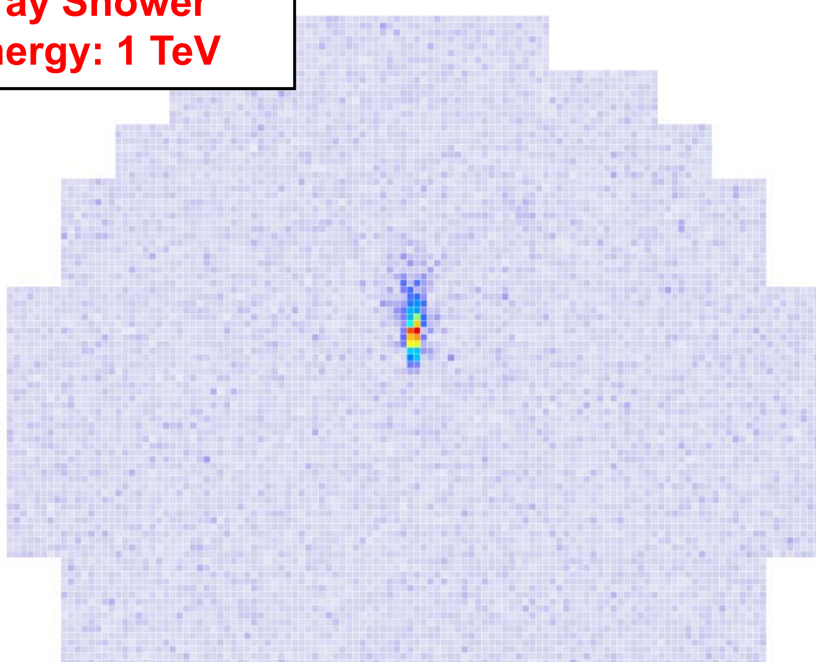


"Baseline"
Single-Mirror
Telescope
Images
8° field of view
0.18° pixels
1,570 channels

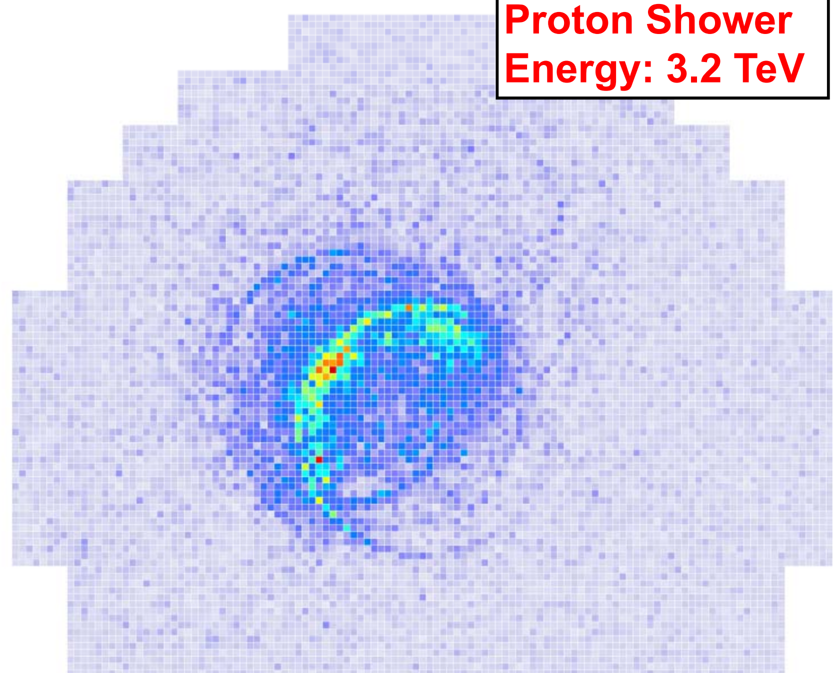


Signal:
γ-ray Shower
Energy: 1 TeV

Background:
Proton Shower
Energy: 3.2 TeV



SCT
Two-Mirror
Telescope
Images
8° field of view
0.067° pixels
11,328 channels



Key Science Projects & GO Programme

Key Science Projects

- Ensure that important science questions for CTA are addressed in a coherent fashion and with a well-defined strategy,
- Conceived to provide legacy data sets for the entire community

Example: galactic and extragalactic surveys

- Deep investigation of known sources
- Follow-up of KSP discovered sources
- Multiwavelength campaigns
- Follow-up of ToOs from other wavebands / messengers
- Search for new sources
- …

Proposal-Driven User Programme