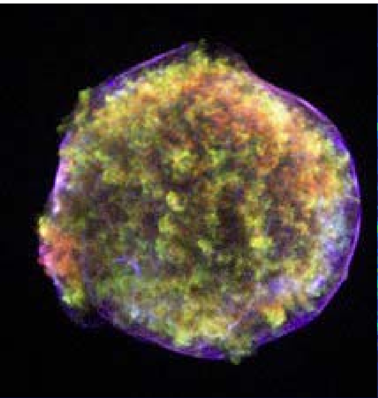
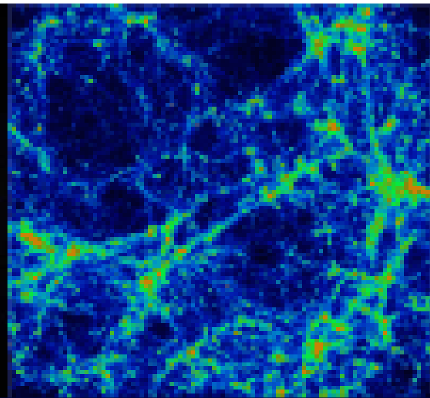
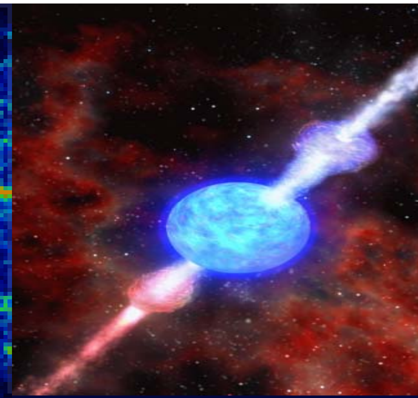
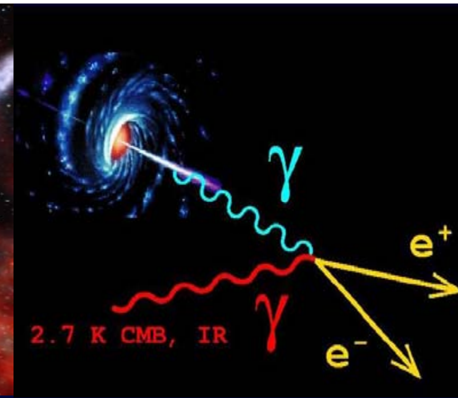
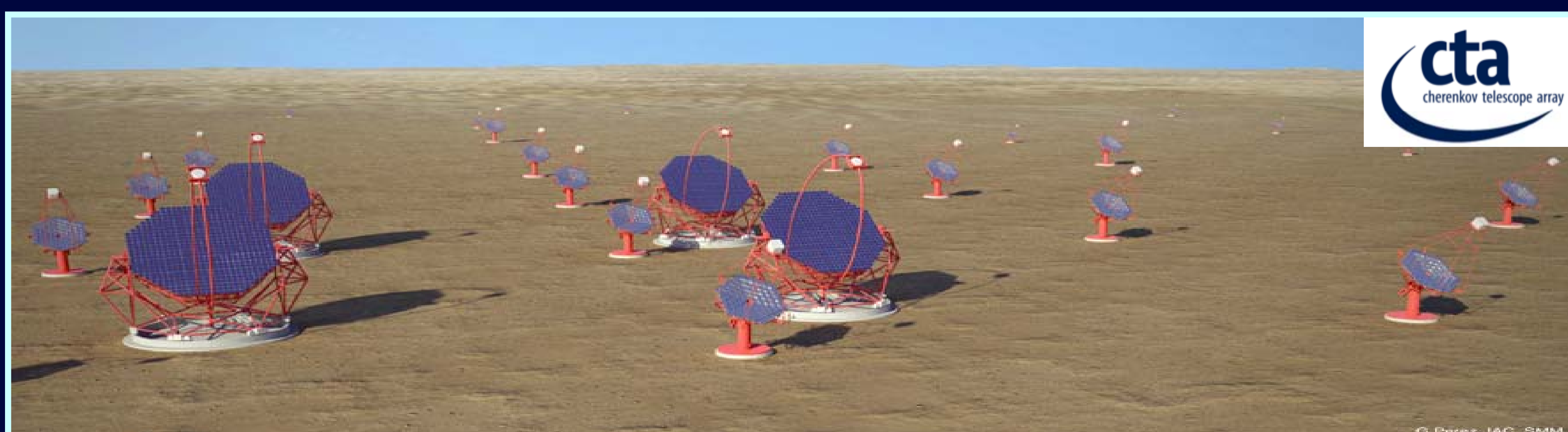


Very High Energy Astrophysics and the Cherenkov Telescope Array

Rene A. Ong (UCLA)

UBC, 3 December 2015



Outline

- **Scientific & Technical Motivation**

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

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

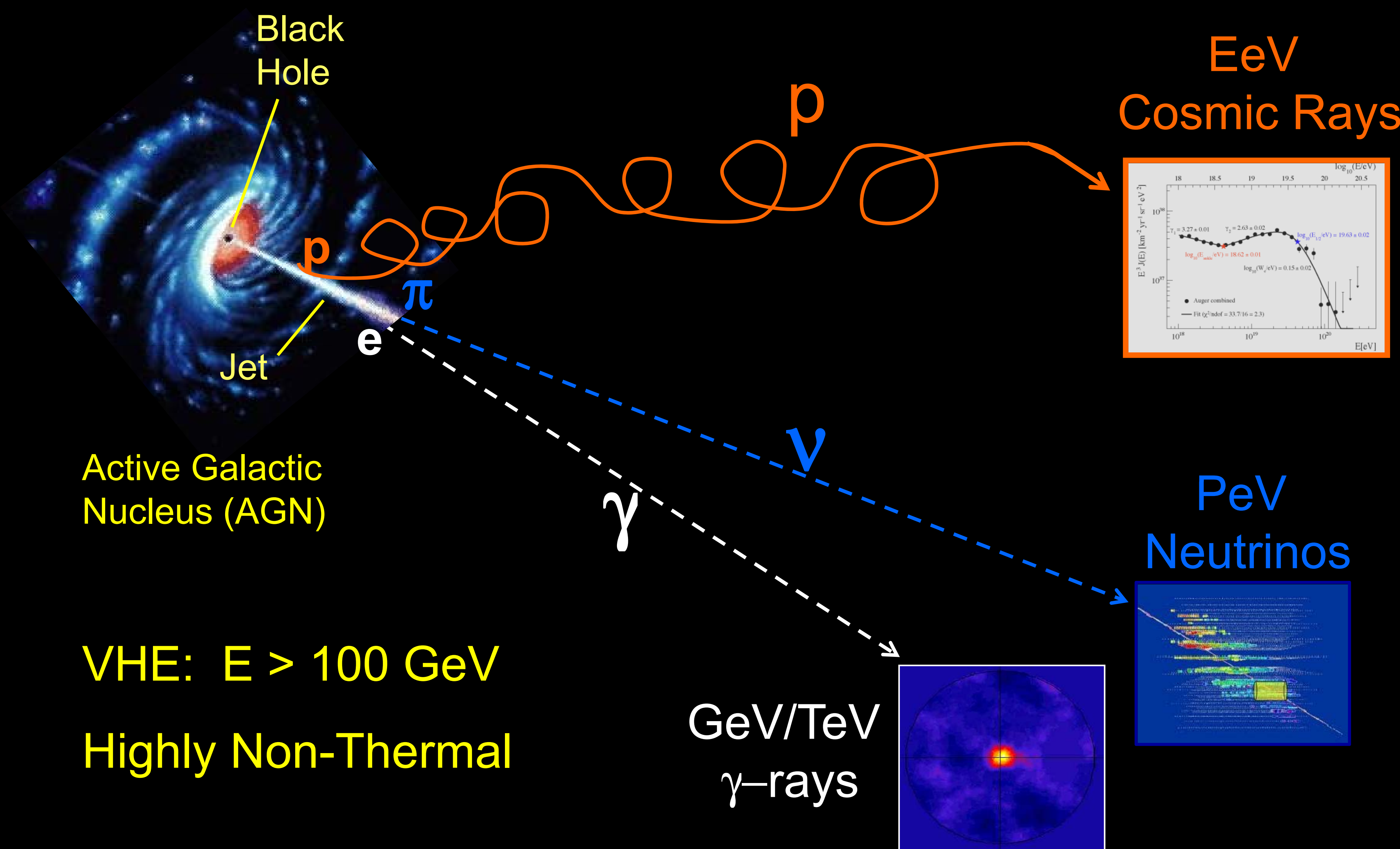
  Science Drivers → requirements
  CTA Design & Performance → **Scientific Capabilities**

- **CTA Implementation & Status**

  Implementation: design and prototype telescopes
  Present status (2015): site selection, timeline, etc.
  Key Science Projects (KSPs) – Core science – two brief examples

- **Summary**

Very High Energy (VHE) Astrophysics

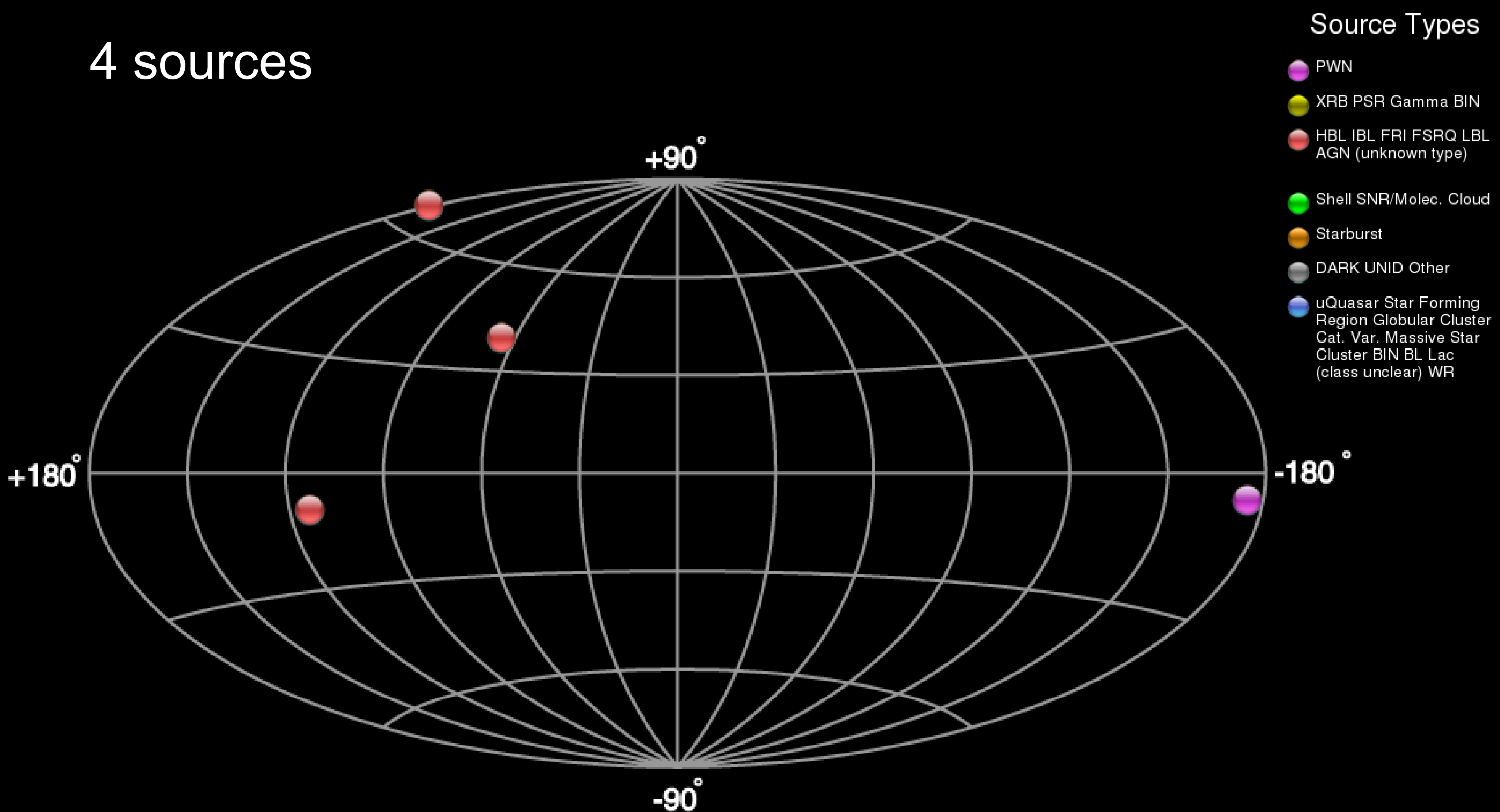


VHE: E > 100 GeV

Highly Non-Thermal

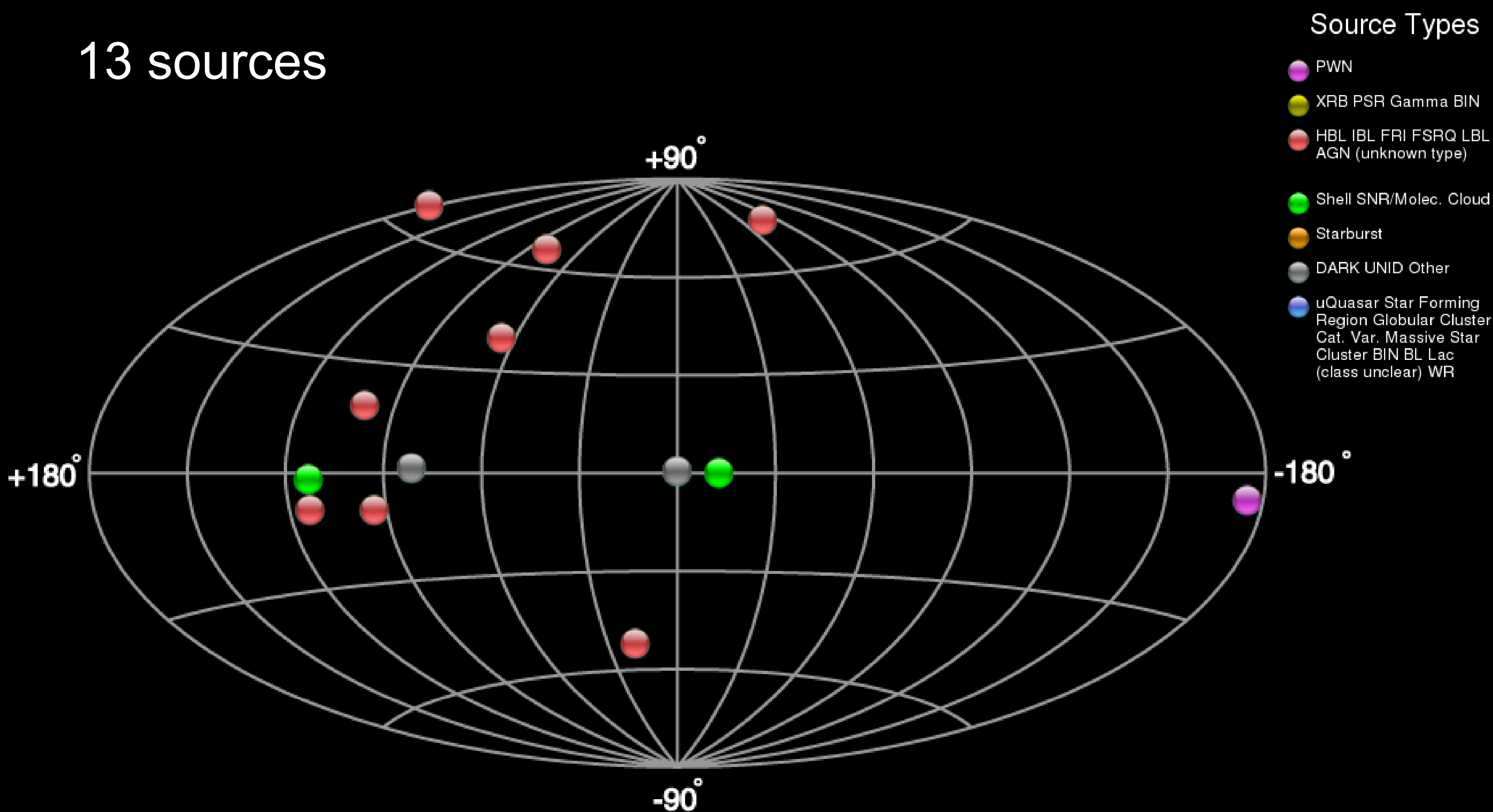
VHE γ-ray Sky c1997

4 sources



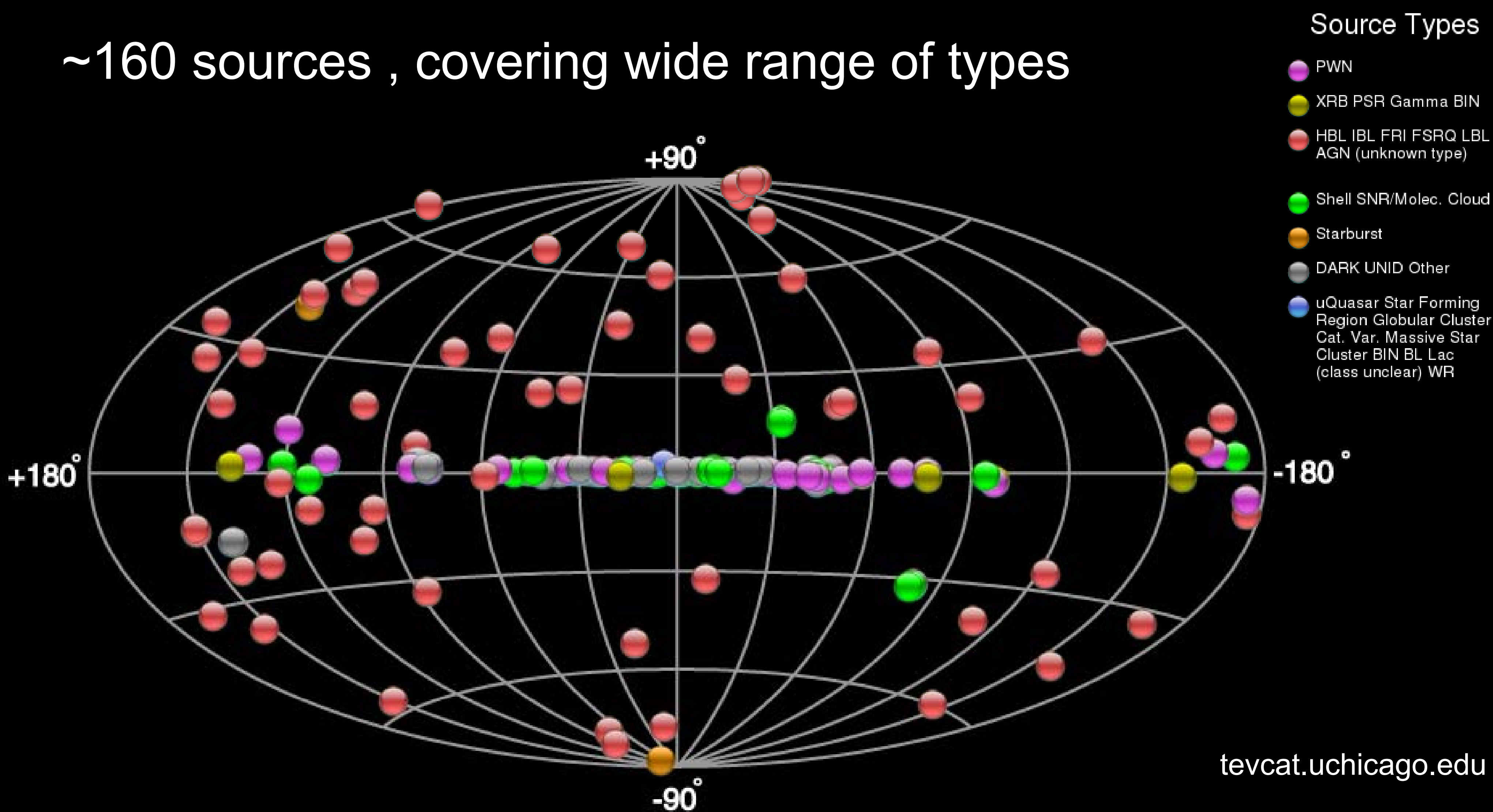
VHE γ-ray Sky c2005

13 sources



VHE γ-ray Sky c2015

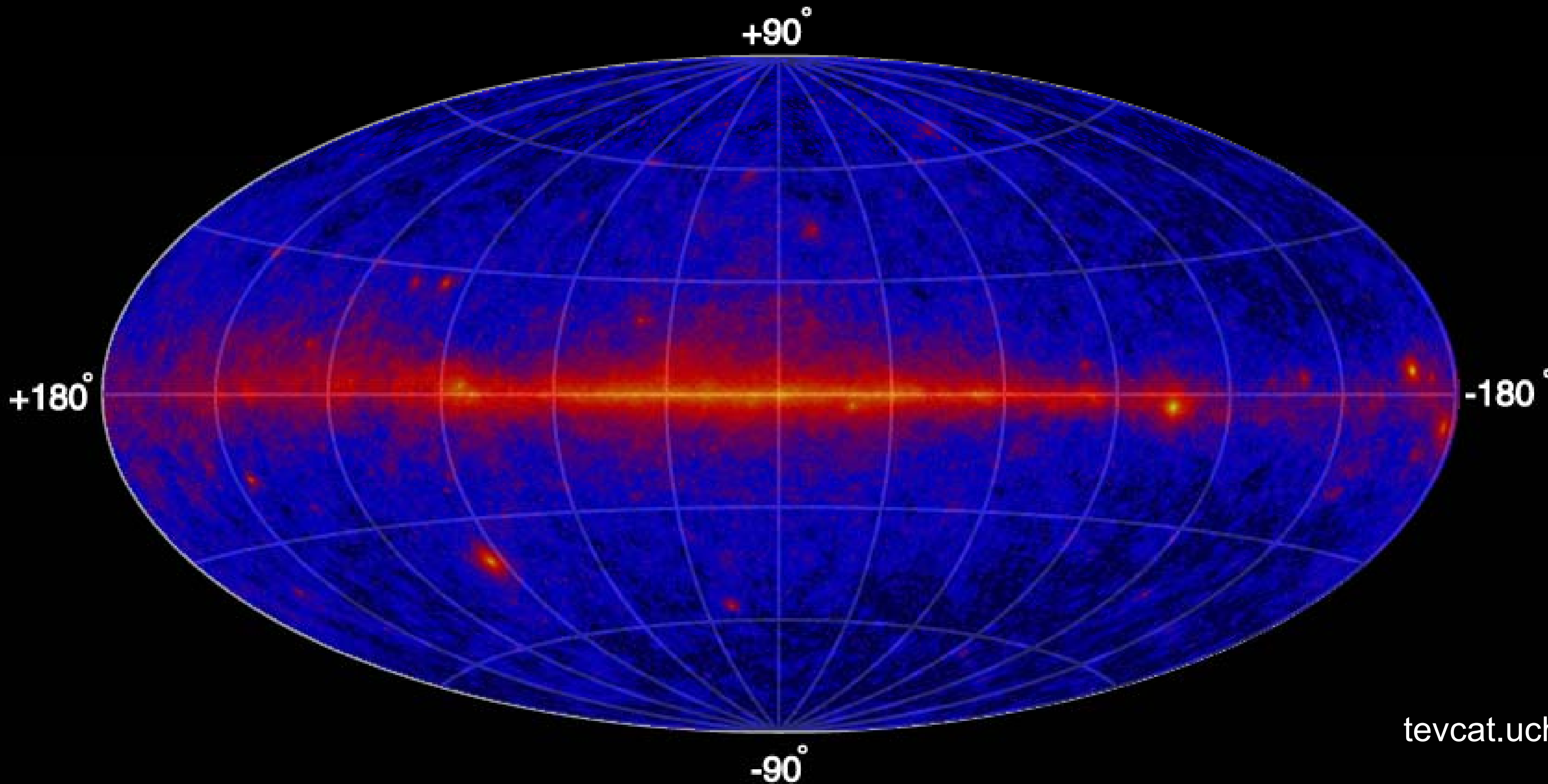
~160 sources , covering wide range of types



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

GeV γ-ray Sky c2015 (Fermi)

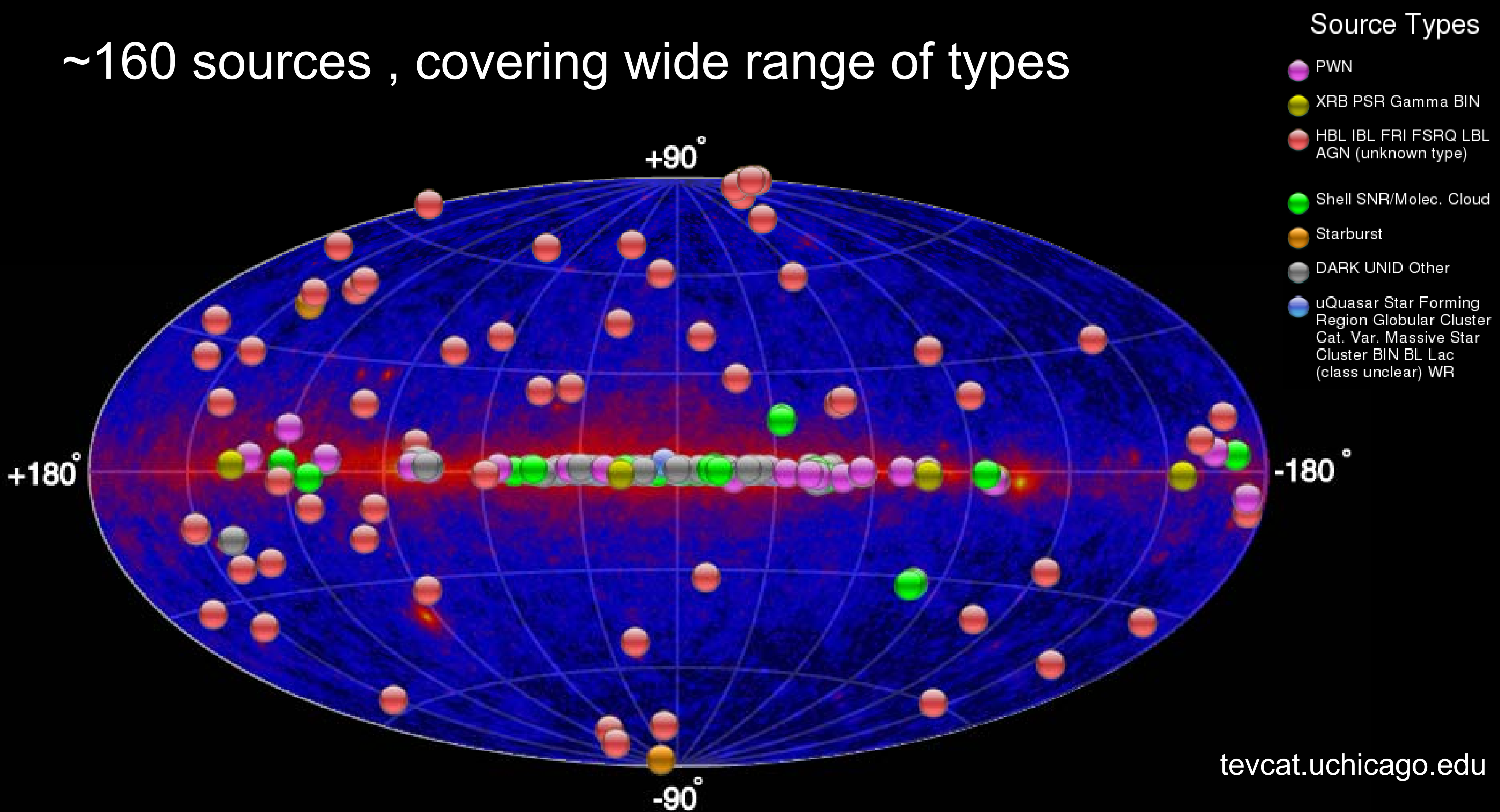
~160 sources , covering wide range of types



tevcat.uchicago.edu

VHE + GeV γ-ray Sky c2015

~160 sources , covering wide range of types



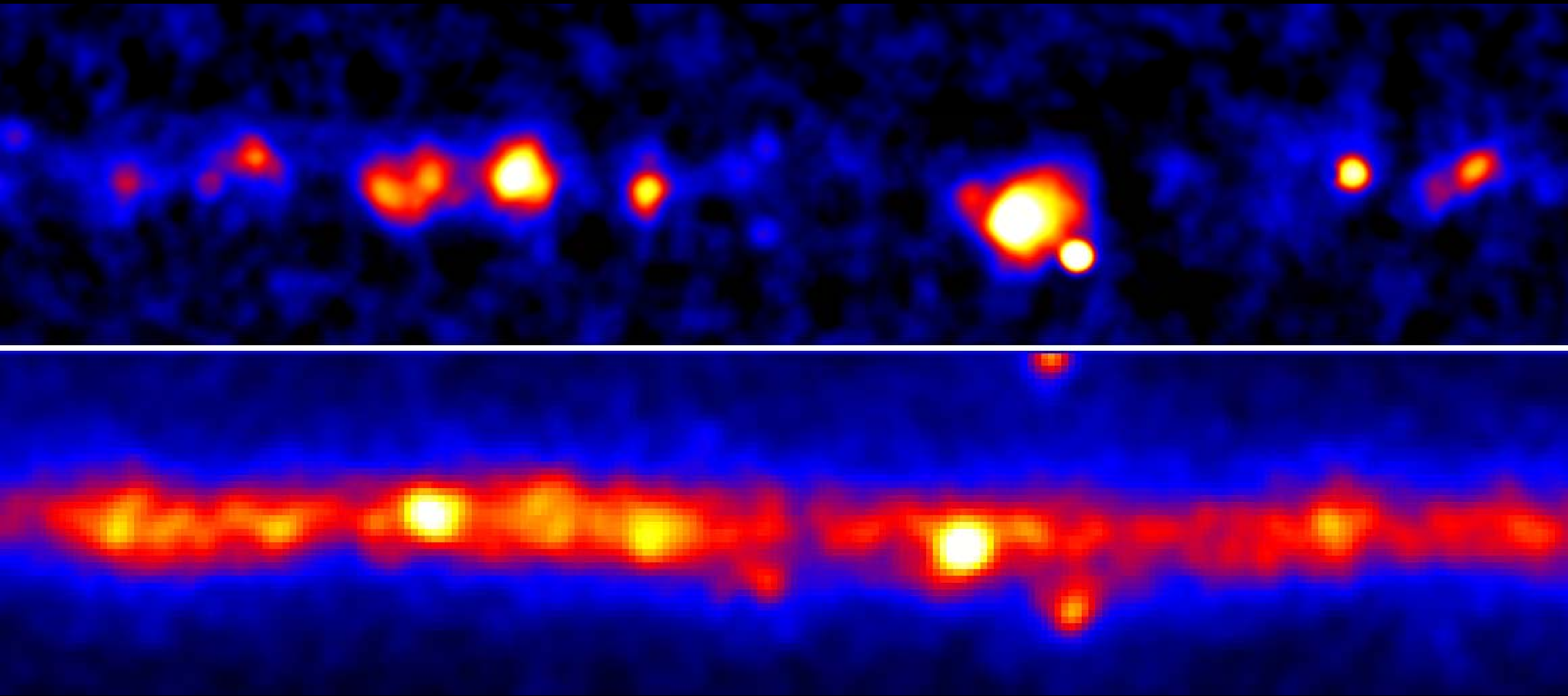
tevcat.uchicago.edu

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

The HE Milky Way (2015)

Extended sources, size typically few 0.1^{o}
few 10 pc

H.E.S.S. (TeV)



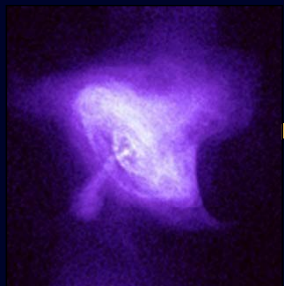
Fermi-LAT (GeV)

Courtesy of W. Hofmann

Exploring the non-thermal Universe “ASTRO”

Pulsars/PWN

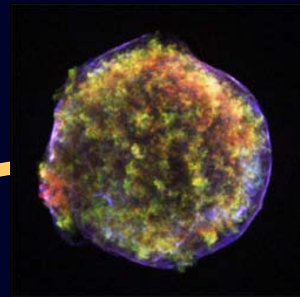
NS dynamo winds



Binaries

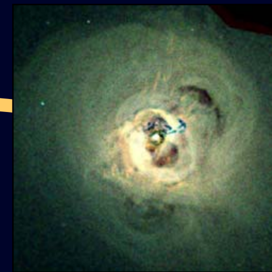
Jets, winds

SNRs



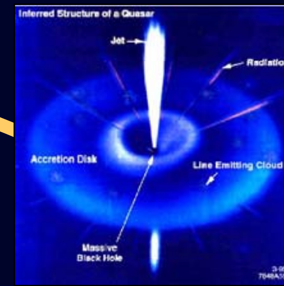
Shocks
Fermi Mech.

Starbursts



SN activity
Cosmic rays

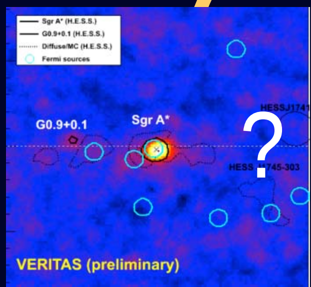
AGN



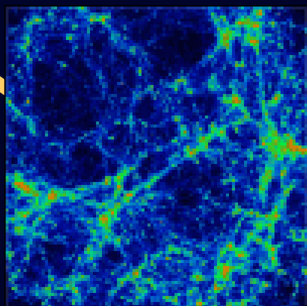
SMBH accretion, jets

GRBs

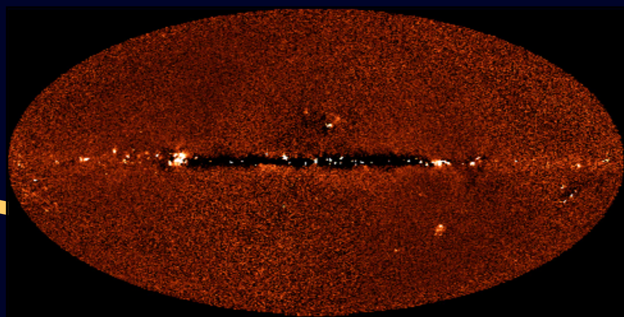
VHE γ-rays



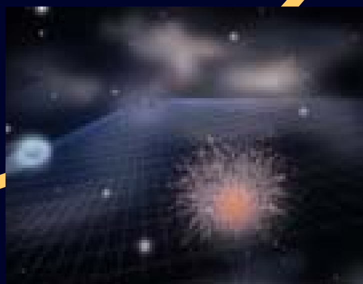
Unknowns
(Gal Center)



Dark Matter



Cosmological Fields

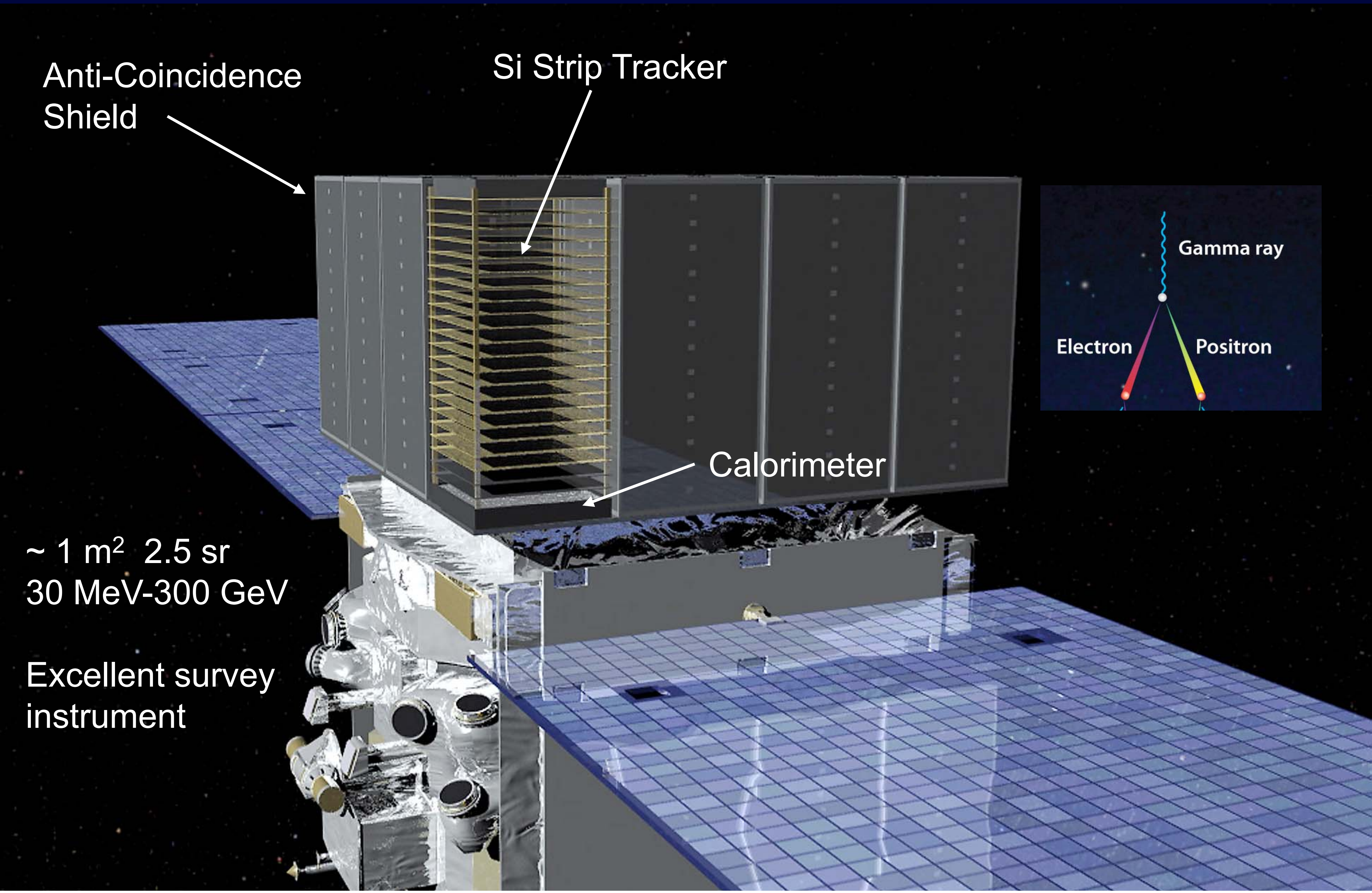


PBHs, QGrav

Probing New Physics at GeV/TeV scale “PARTICLE”

Experimental Technique

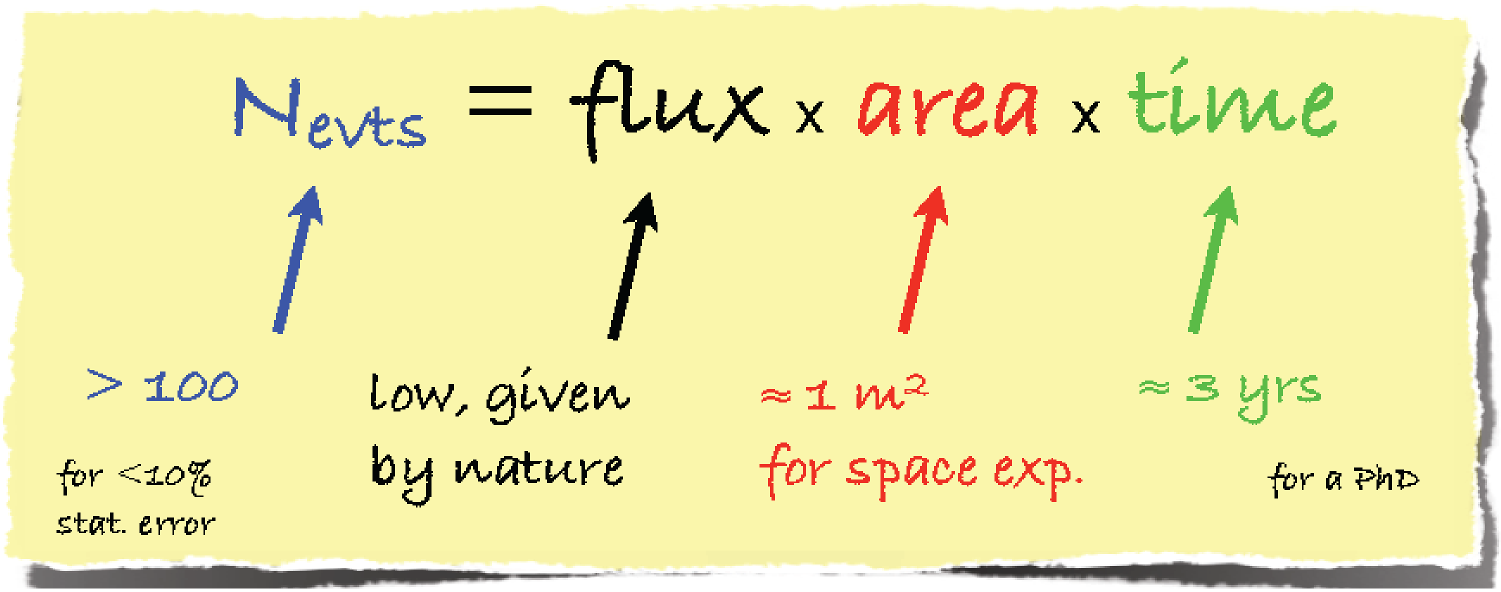
Fermi Large Area Telescope (LAT)



~ 1 m^2 2.5 sr
30 MeV-300 GeV

Excellent survey instrument

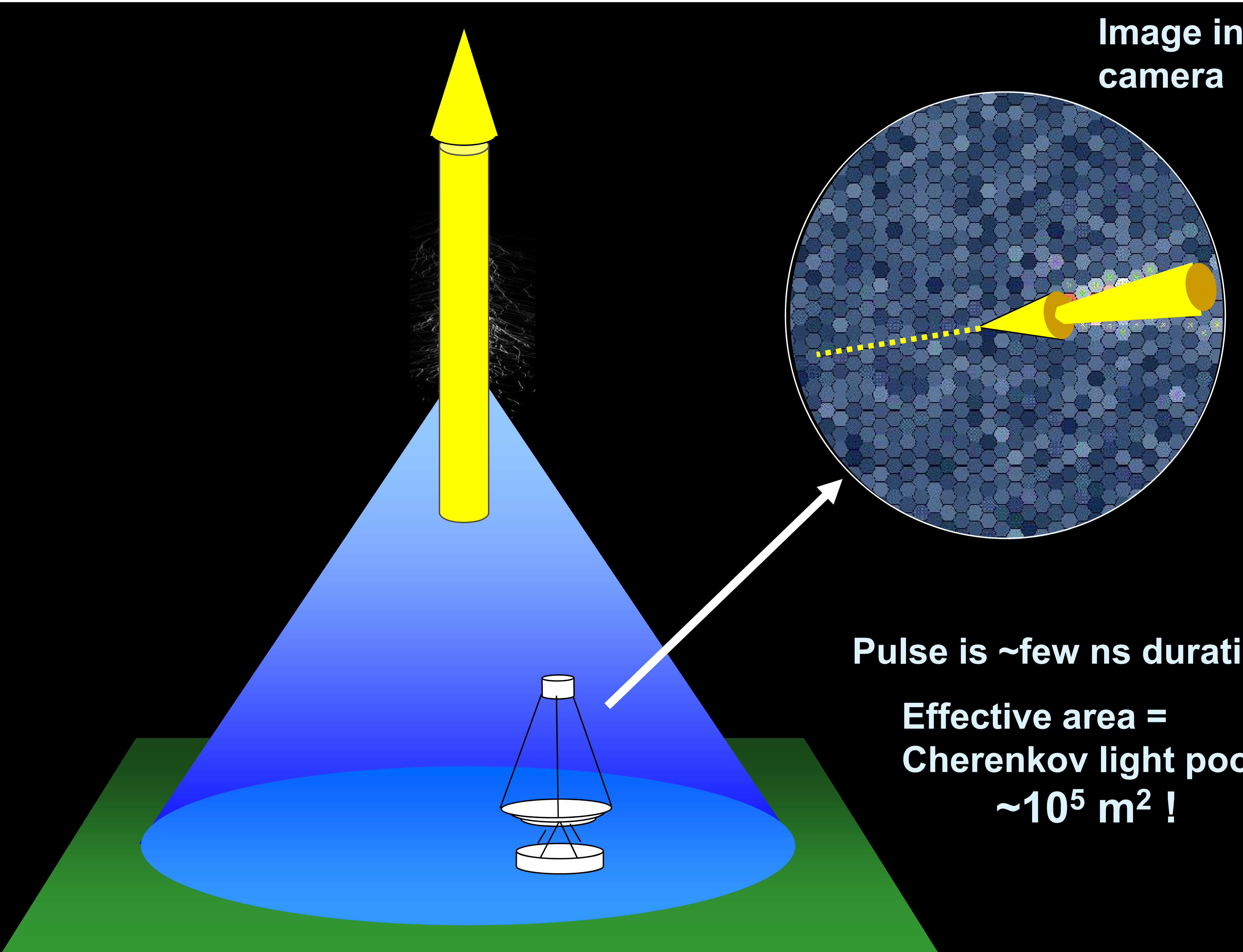
Beyond 100 GeV



Steeply falling spectrum:

x10 in Energy → divide by 100-500 in flux

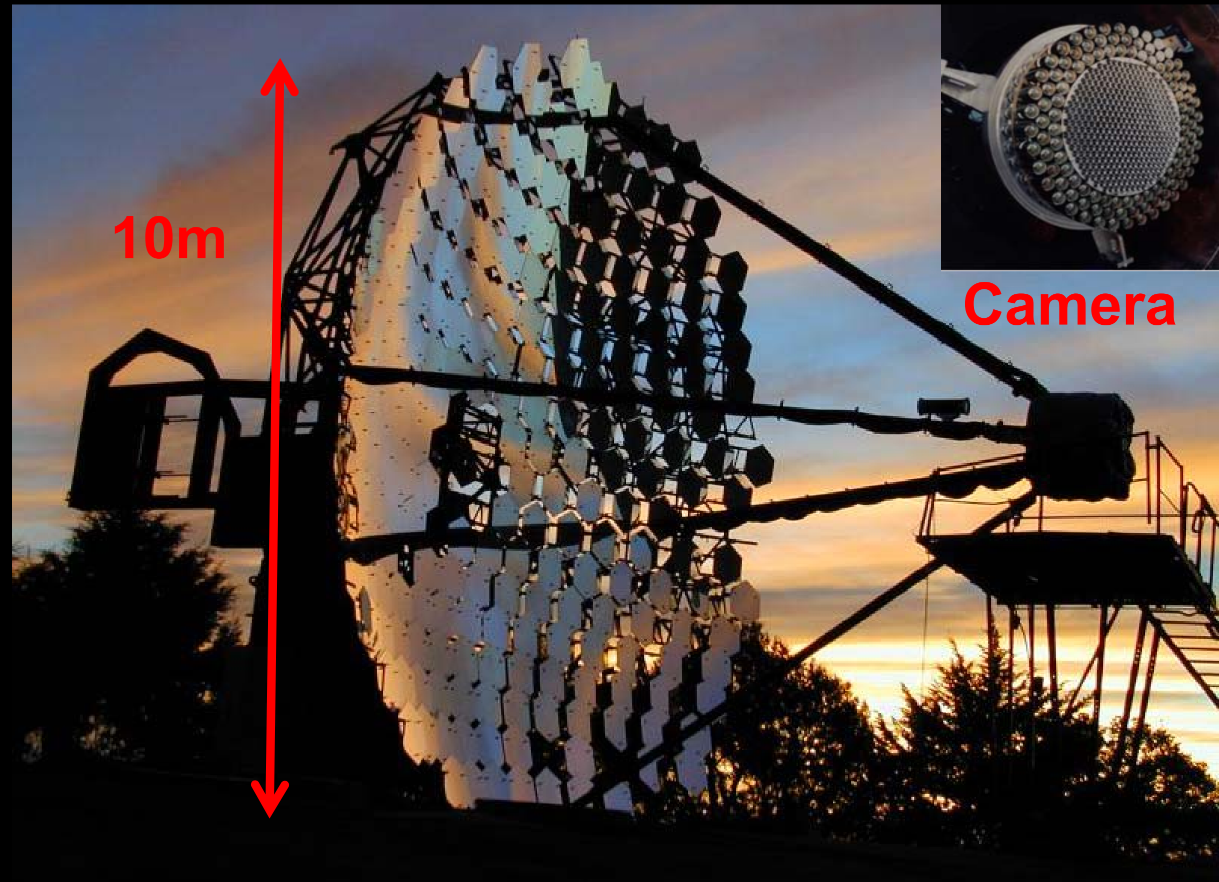
- Large effective area needed to get detectable signals at VHE
- Natural detector: *the atmosphere*



Pulse is ~few ns duration

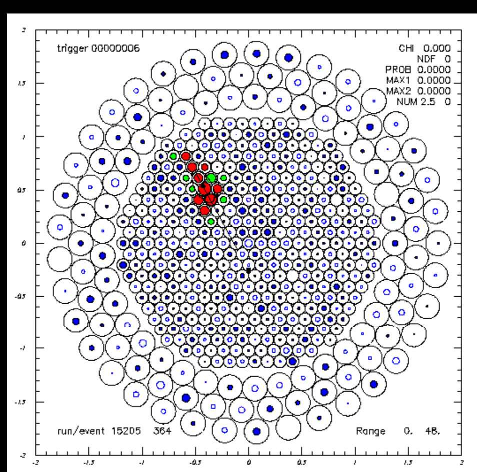
Effective area = Cherenkov light pool $\sim 10^5$ m^2 !

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

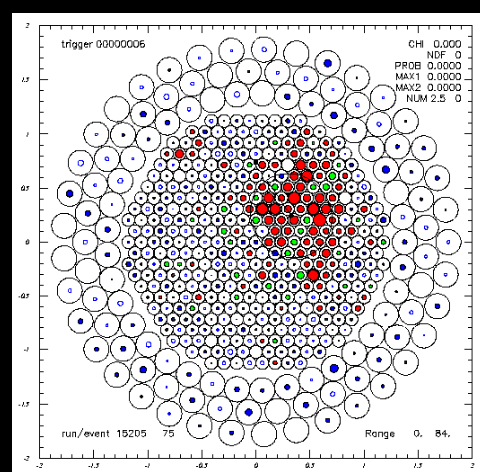


- Pioneered use of Imaging
- Made first source detection.
  (Crab Nebula in ~90 hours)

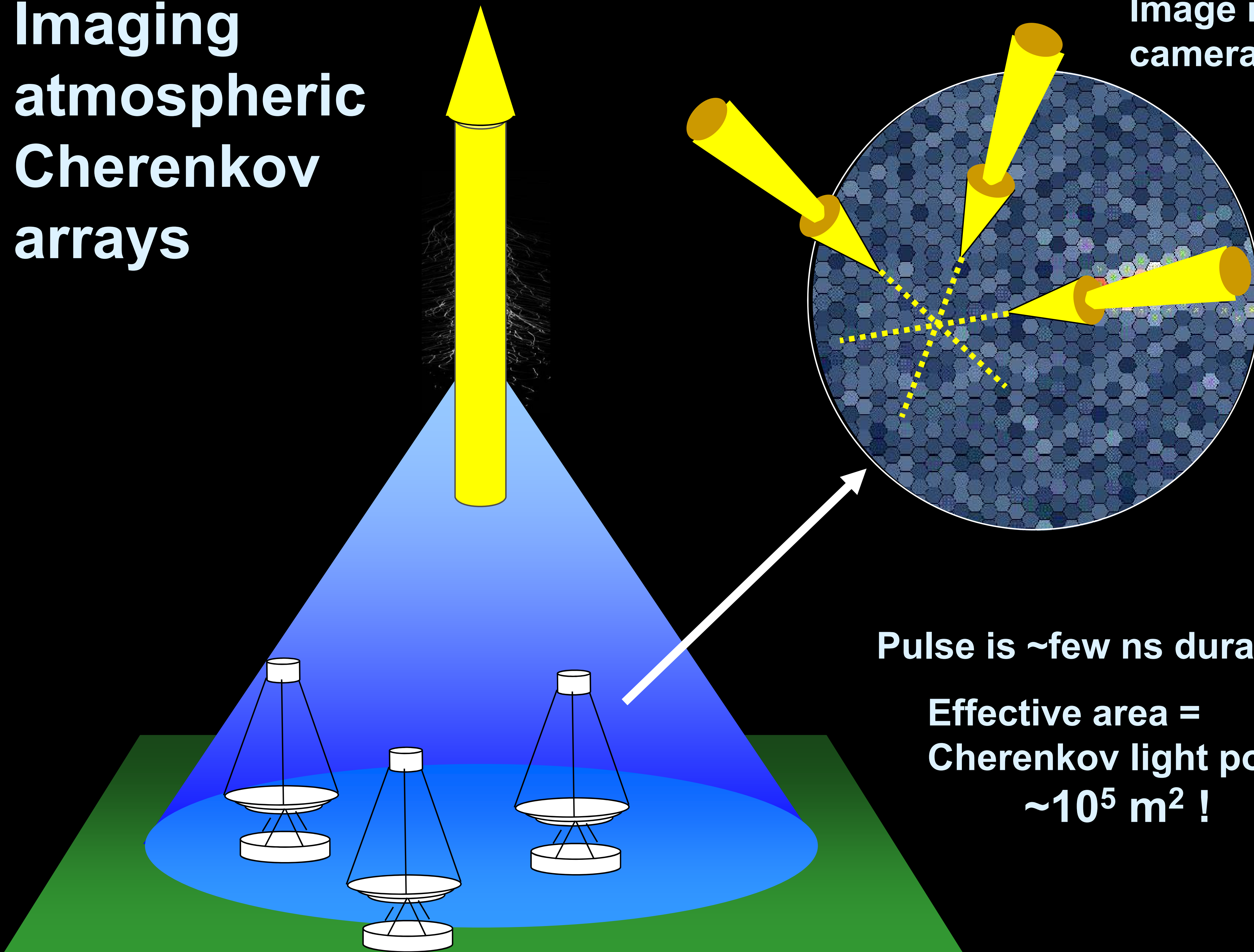
γ-ray



cosmic ray



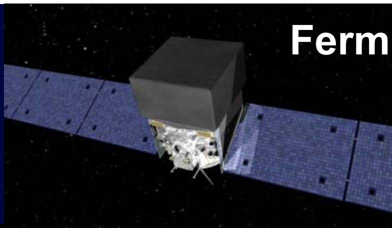
Imaging atmospheric Cherenkov arrays

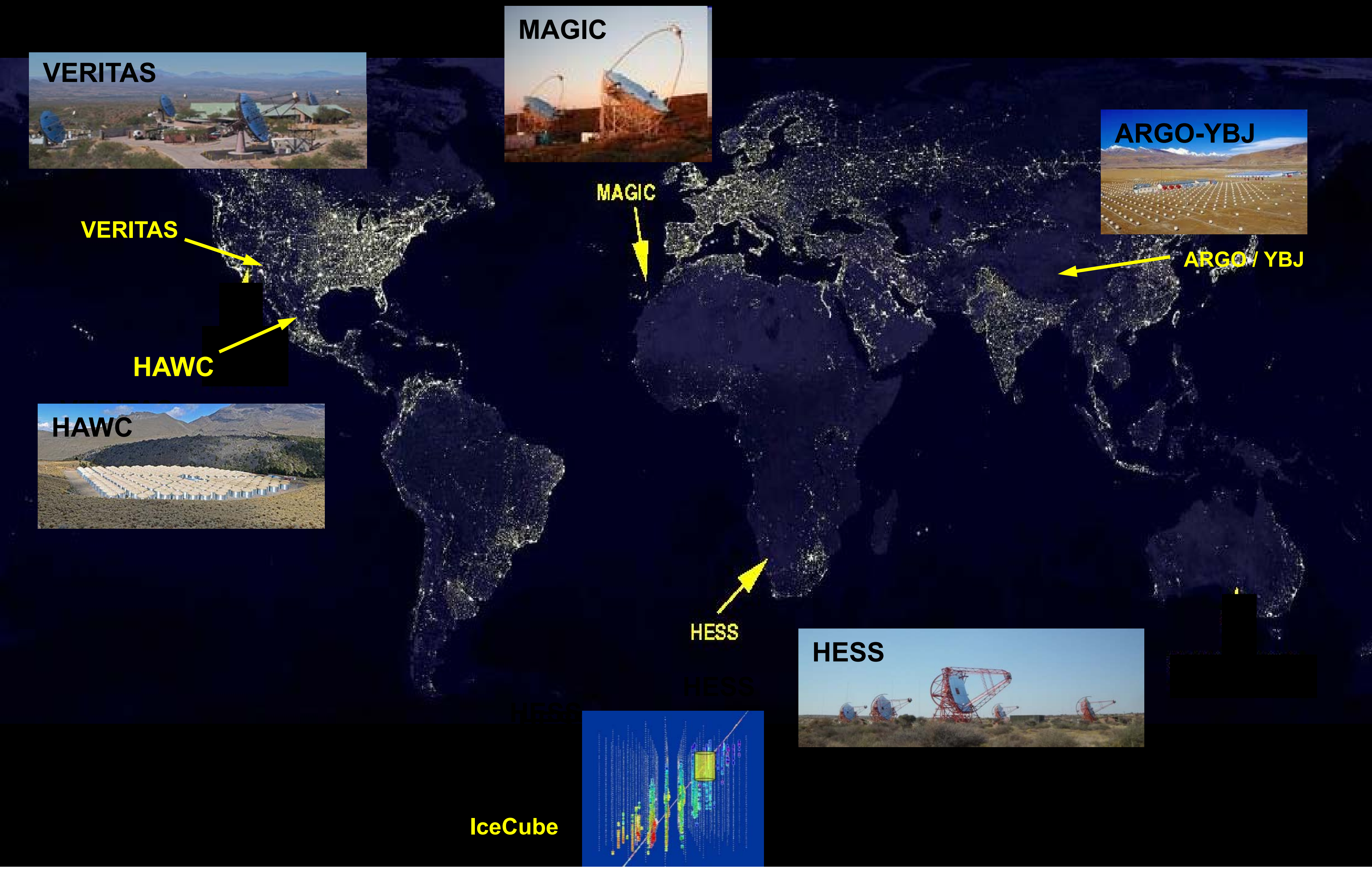


Pulse is ~few ns duration

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

VHE Telescopes (2015)



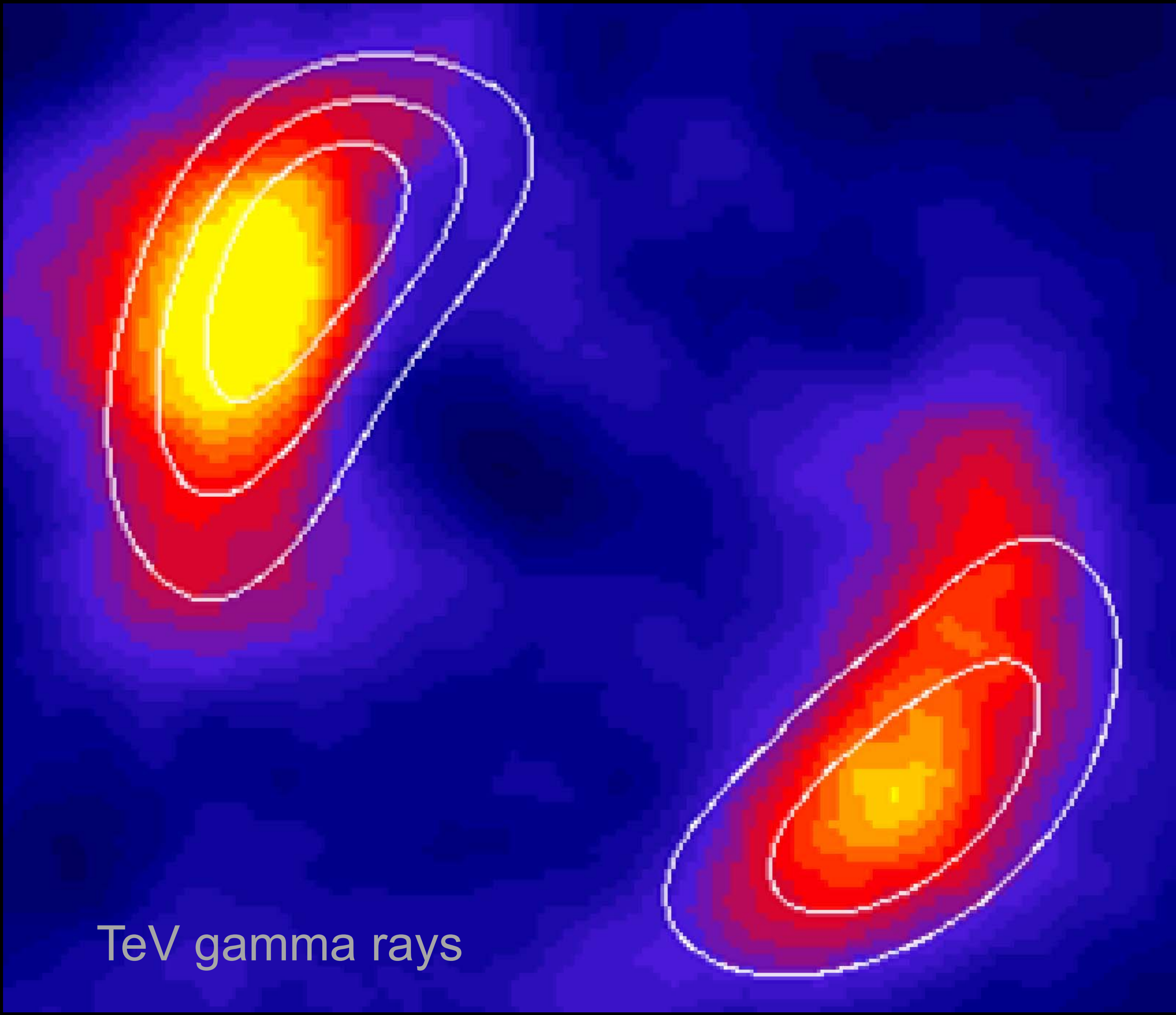


Selected Science Highlights

- Supernova remnants & origin of cosmic rays
- AGN and intergalactic radiation fields
- Un-Identified sources & Dark Matter

Supernova Remnants

SN 1006



0.4°

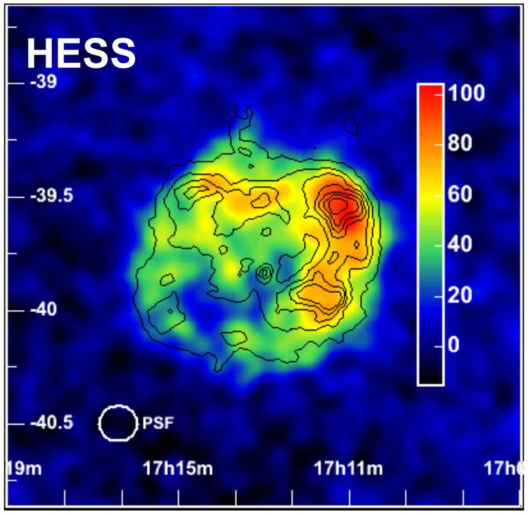
(Credit:X-ray: NASA/CXC/Rutgers/G.Cassam-Chenai, J.Hughes et al.; Radio: NRAO/AUI/NSF/GBT/VLA/Dyer, Maddalena & Cornwell; Optical: Middlebury College/F.Winkler, NOAO/AURA/NSF/CTIO Schmidt & DSS)

Supernova Remnants (SNRs)

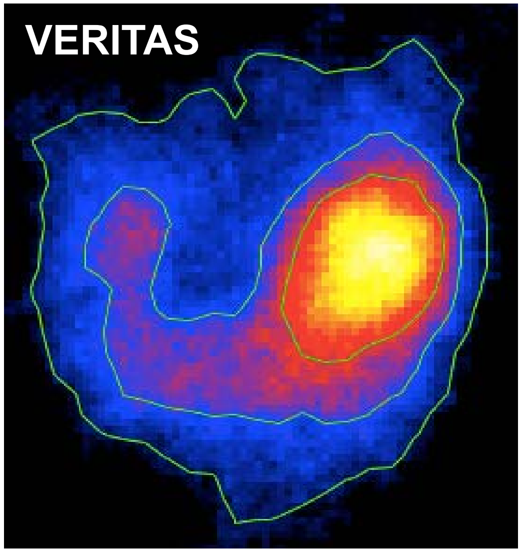
"Standard Model" for high-energy cosmic rays

- Supernova, where outer layers are ejected with v ~ several x 10^3 km/s.
- Expanding shell & shock front sweeps up material from ISM.
- Acceleration of particles via diffusive shock acceleration (originally Fermi mechanism).
- In ~ 10^4 yrs, blast wave deccelerates and dissipates.
- Can supply and replenish CR's if ε ~ 5-10%.

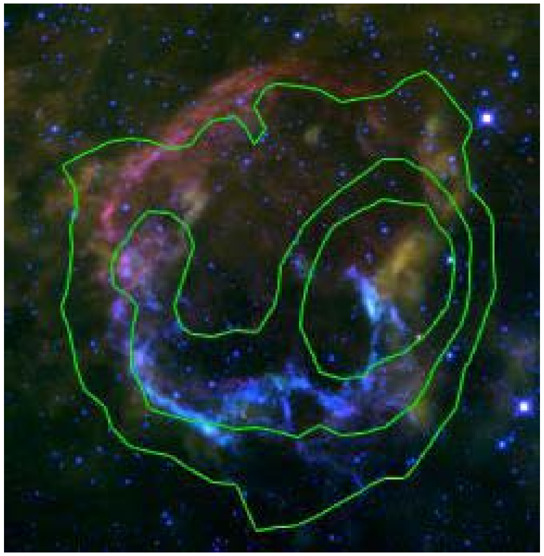
Good model … is it right ?



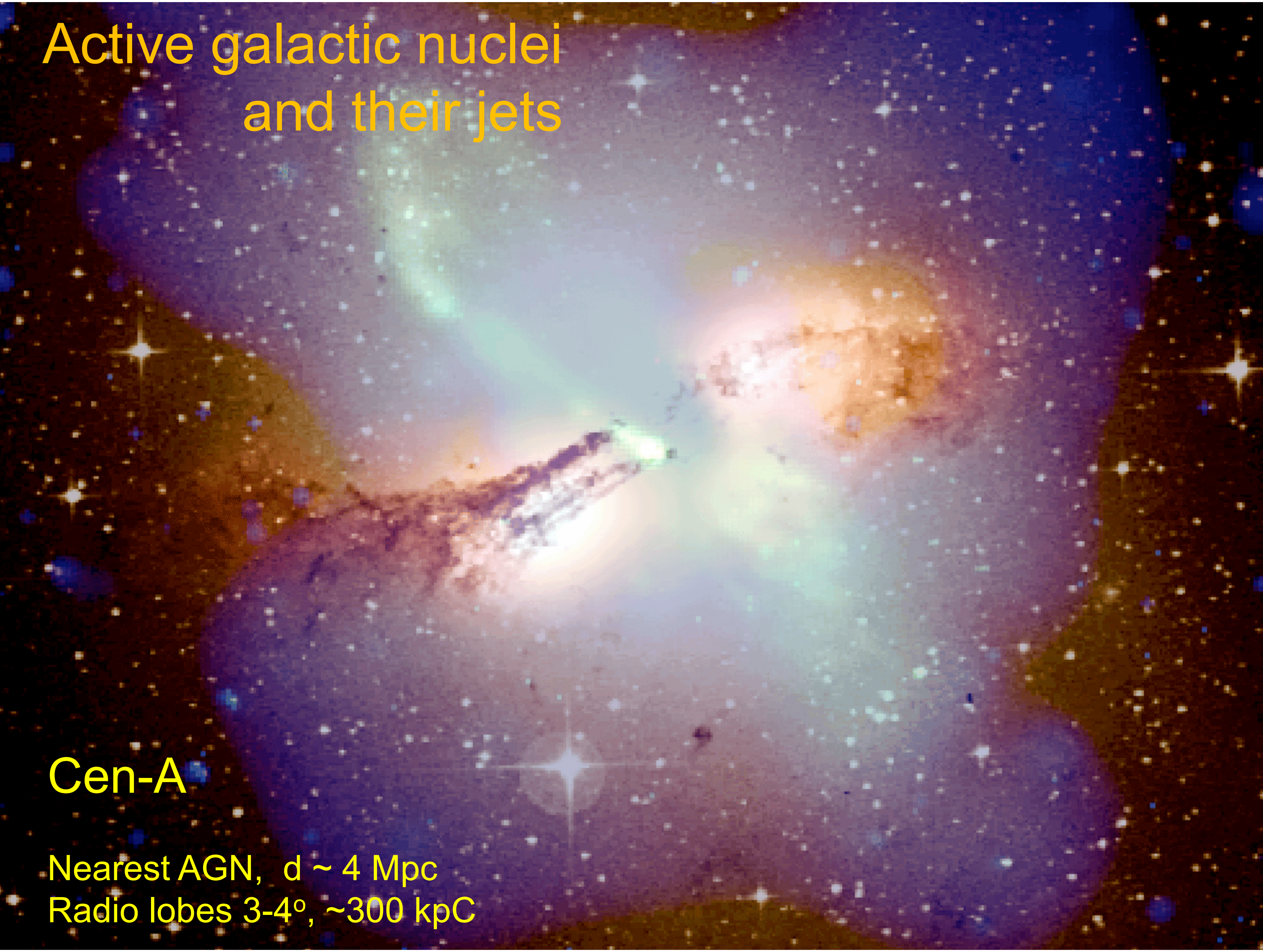
RXJ 1713-3946
Age = 1600y
D = ~1 kpc

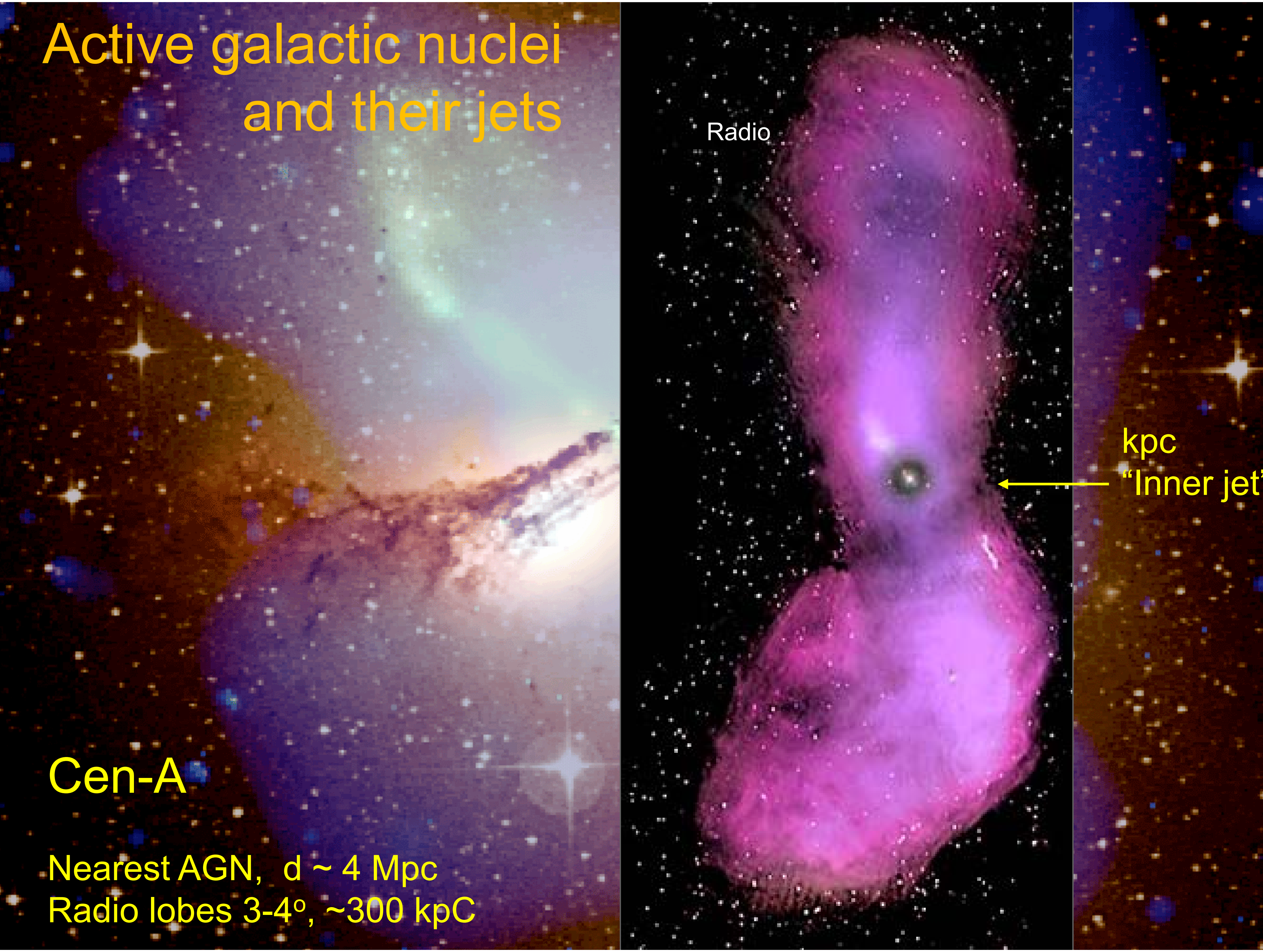


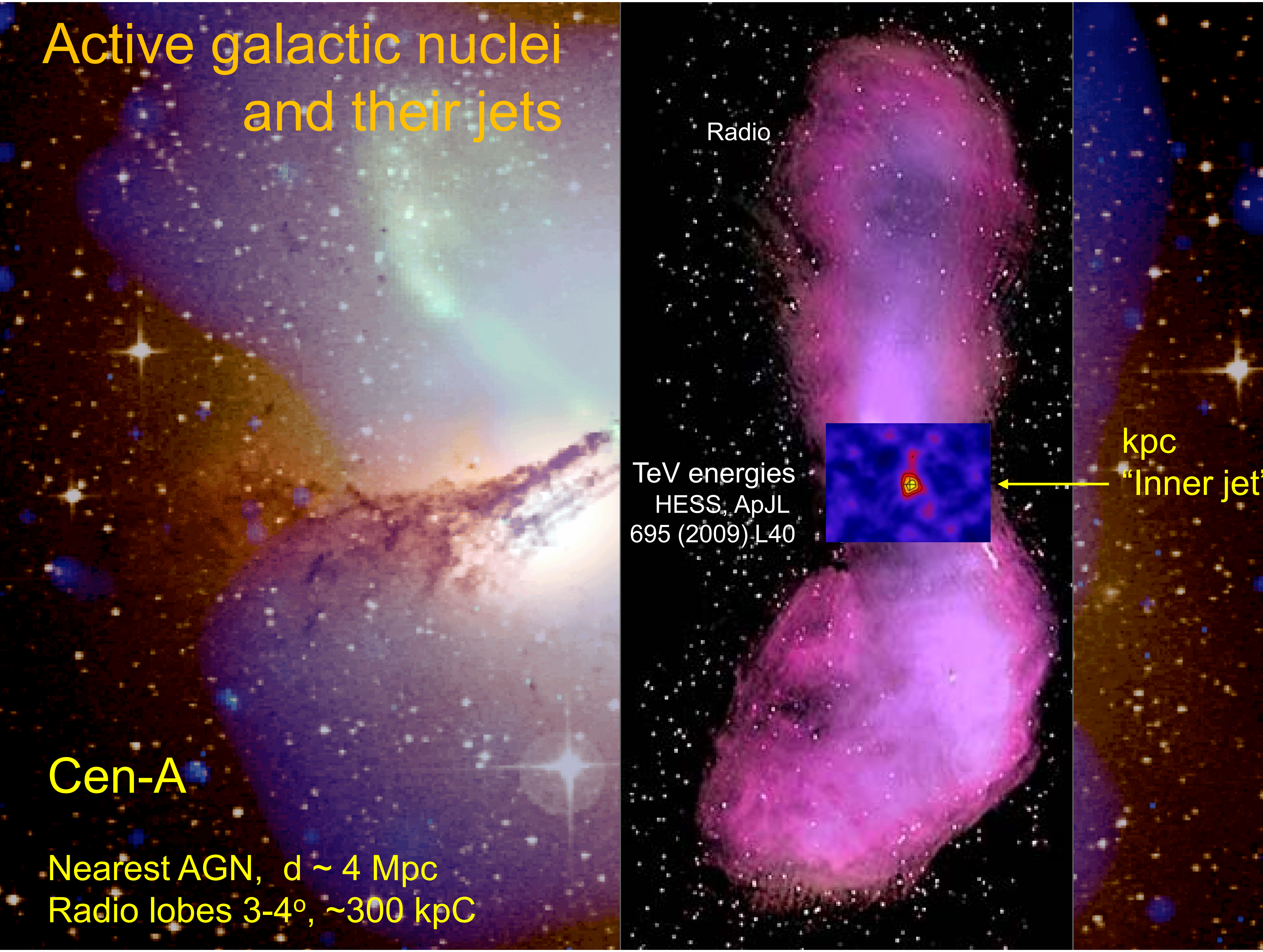
IC 443
Age ~ 30ky
D ~ 0.8kpc



IC 443
***WISE* – 22, 12, 4.6 μm**


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

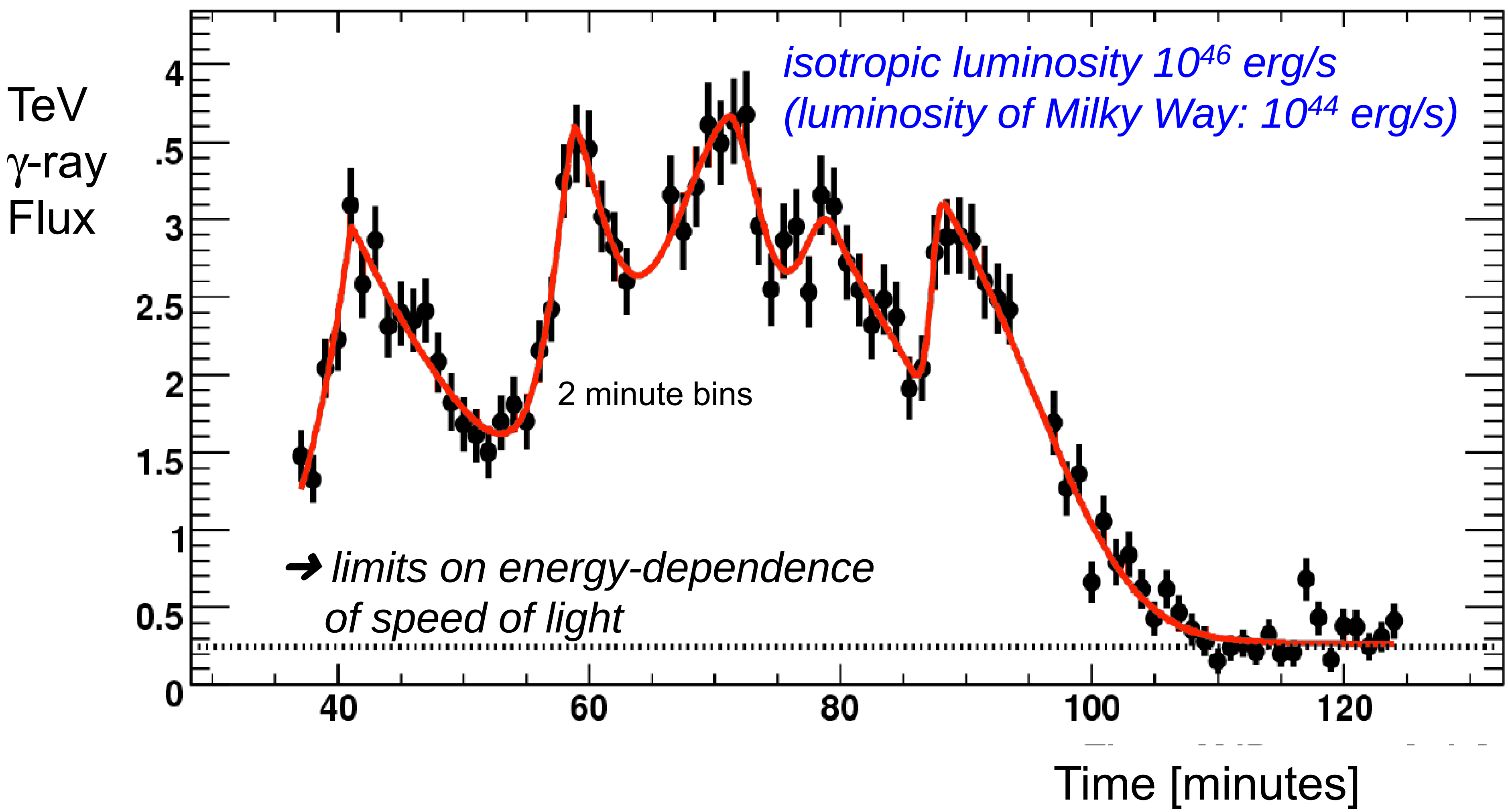

Active galactic nuclei
and their jets
Radio
kpc
"Inner jet"
Cen-A
Nearest AGN, d ~ 4 Mpc
Radio lobes 3-4°, ~300 kpC


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 3-4°, ~300 kpC

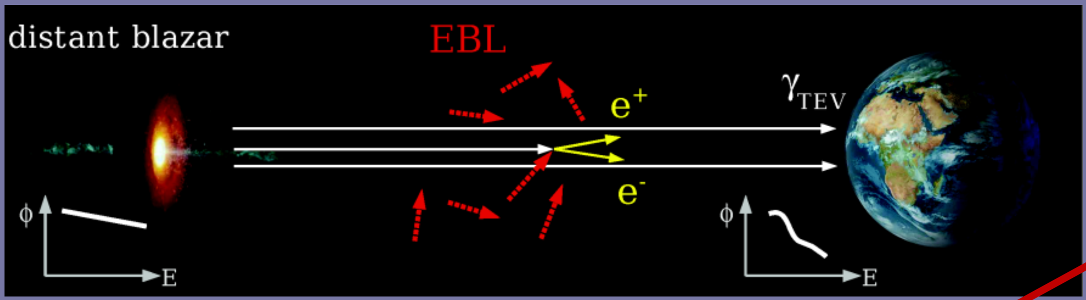
AGN: Extreme Variability

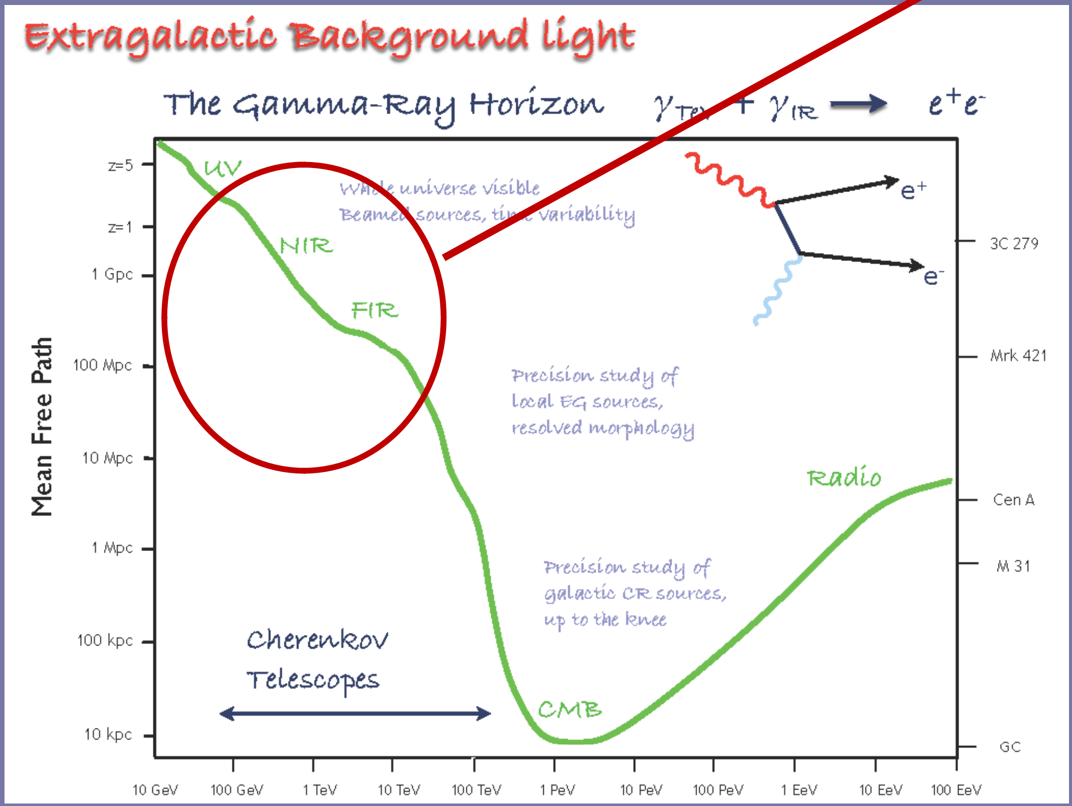
“Blazars”: AGN with jets pointed towards us
strong VHE emitters

PKS 2155-304 flare
arXiv:0706.0797



VHE γ-rays as Cosmological Probes





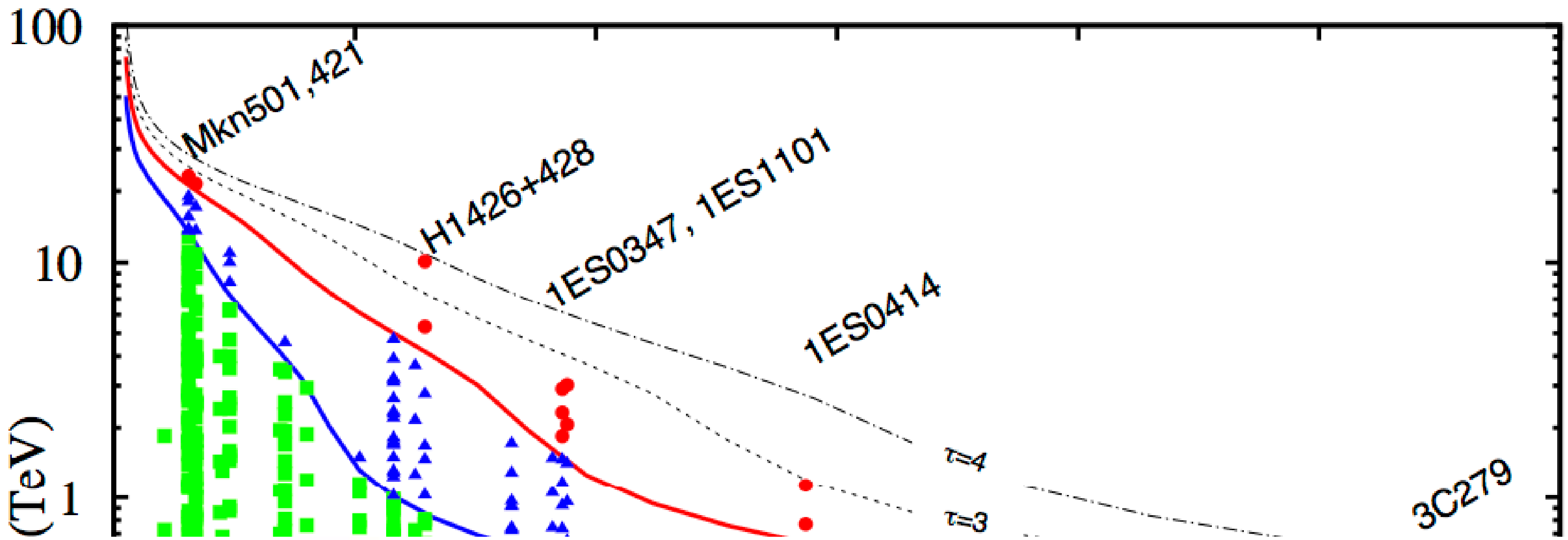
1 TeV **1 PeV** Energy

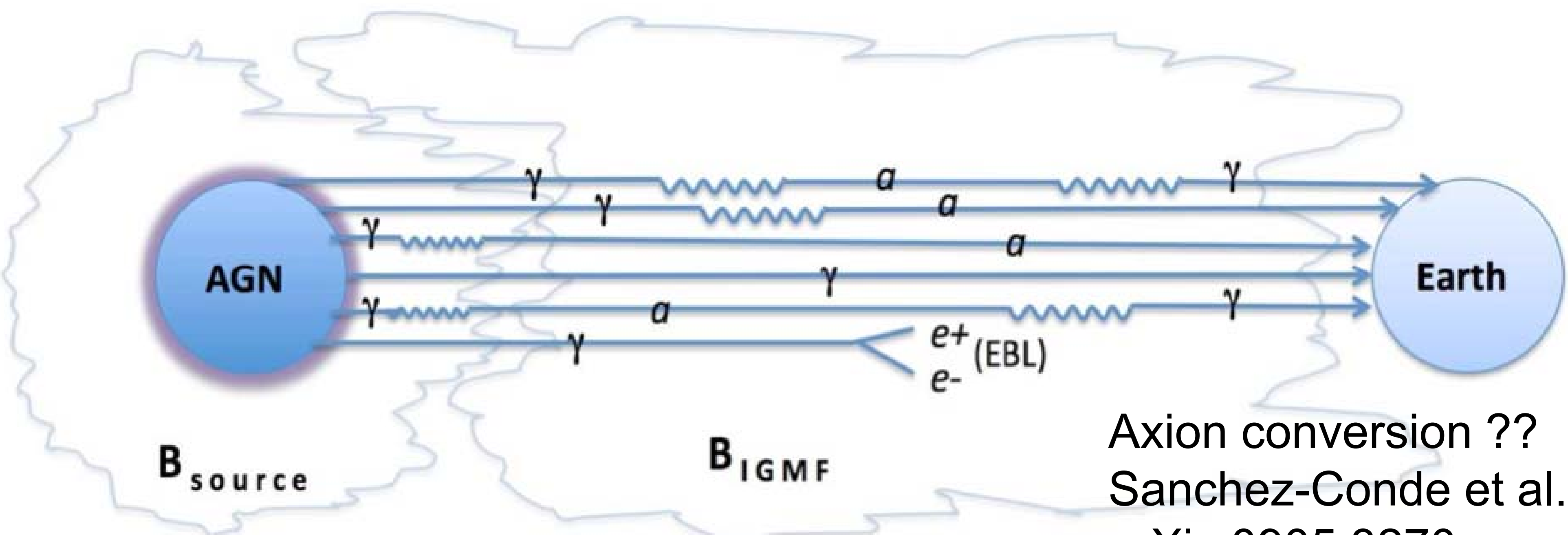
Extragalactic Background Light (EBL):

- OIR diffuse background produced by star-formation throughout history of universe.
- γγ interaction probes EBL density, uniformity, evolution
- Potential way to measure tiny extragalactic magnetic field (EGMF).

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

Is the Universe too Transparent ?

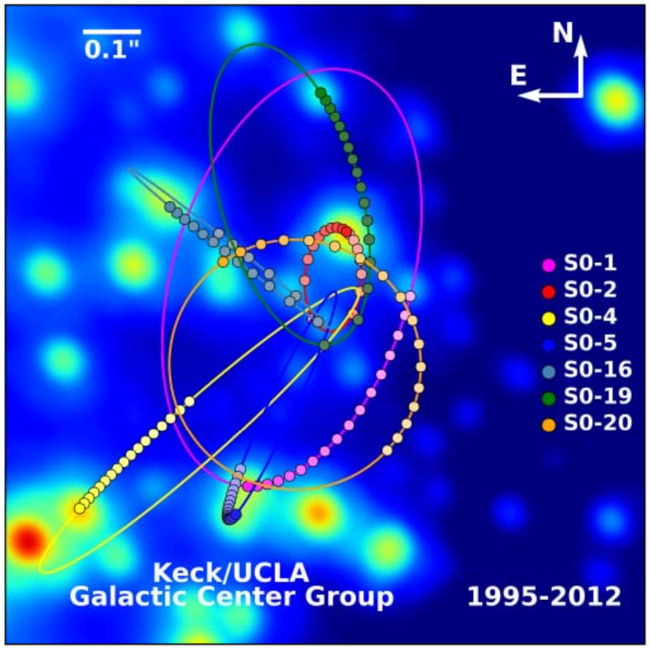




Axion conversion ??
Sanchez-Conde et al., arXiv:0905.3270

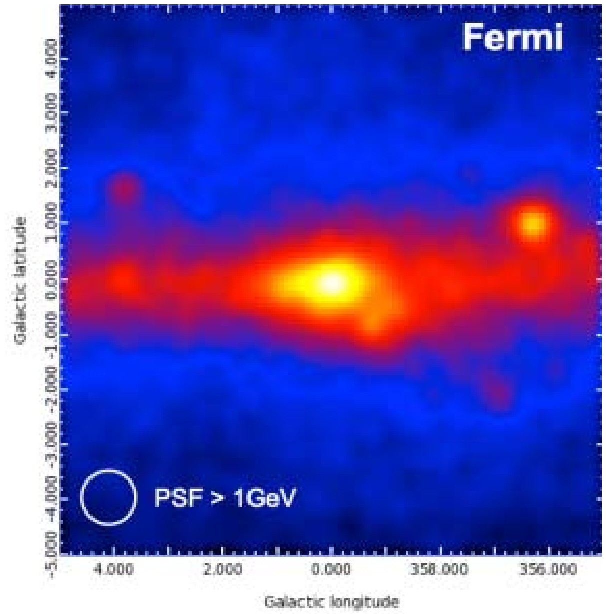
Galactic Center

Infrared

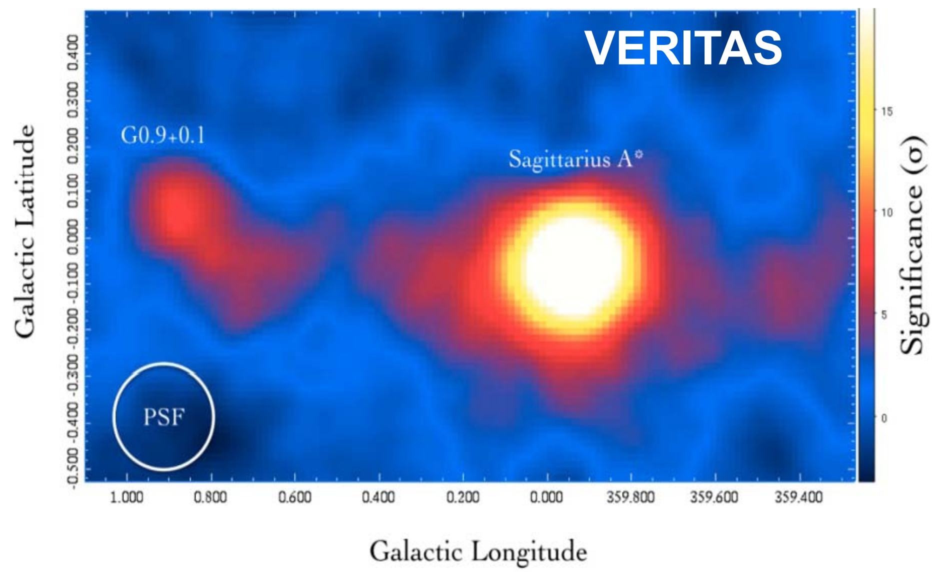


Ghez et al., 2012
1″ x 1″

GeV γ-rays



S. Murgia,
"Dark Attack 2012"
10º x 10º



TeV γ-rays

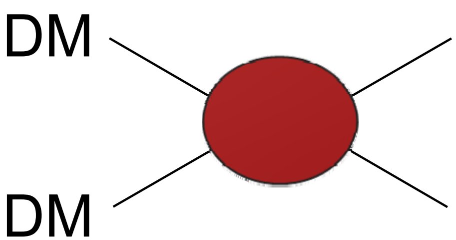
A, Archer et al.
VERITAS Coll.
(2015)
1º x 2º

GeV & TeV emission is:

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

Dark Matter ??

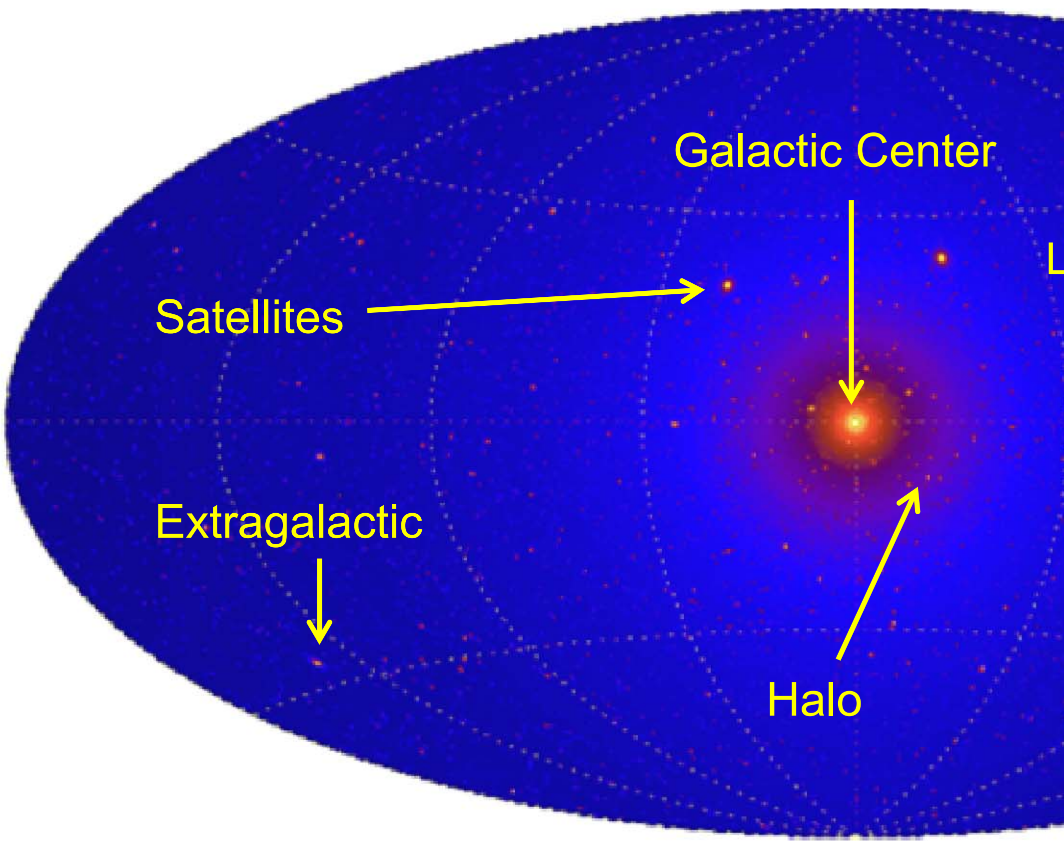
Dark Matter Detection



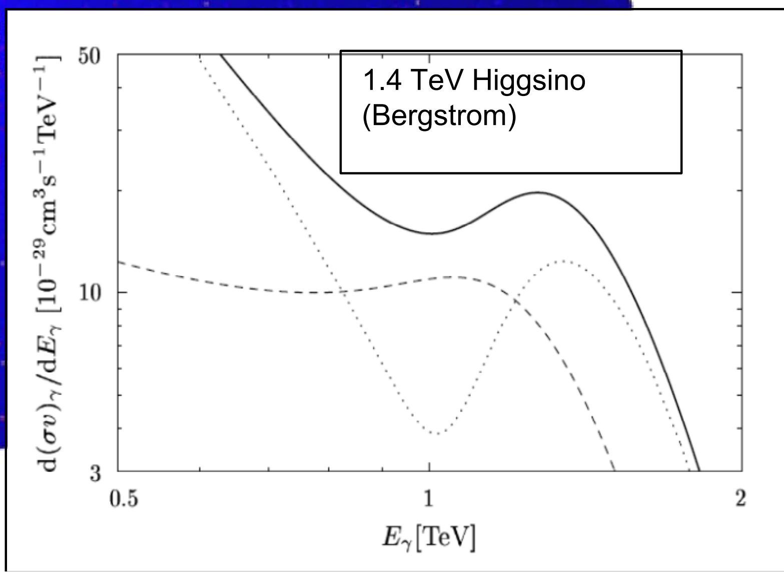
SM: b, W⁺, Z, τ⁺, …
Primary channels
SM: b, W⁻, Z, τ⁻, …

Hadronisation and/or decay

➡ γ, e⁺, $\overset{(-)}{p}$, ν, …
Final states
➡ γ, e⁻, $\overset{(-)}{p}$, ν, …



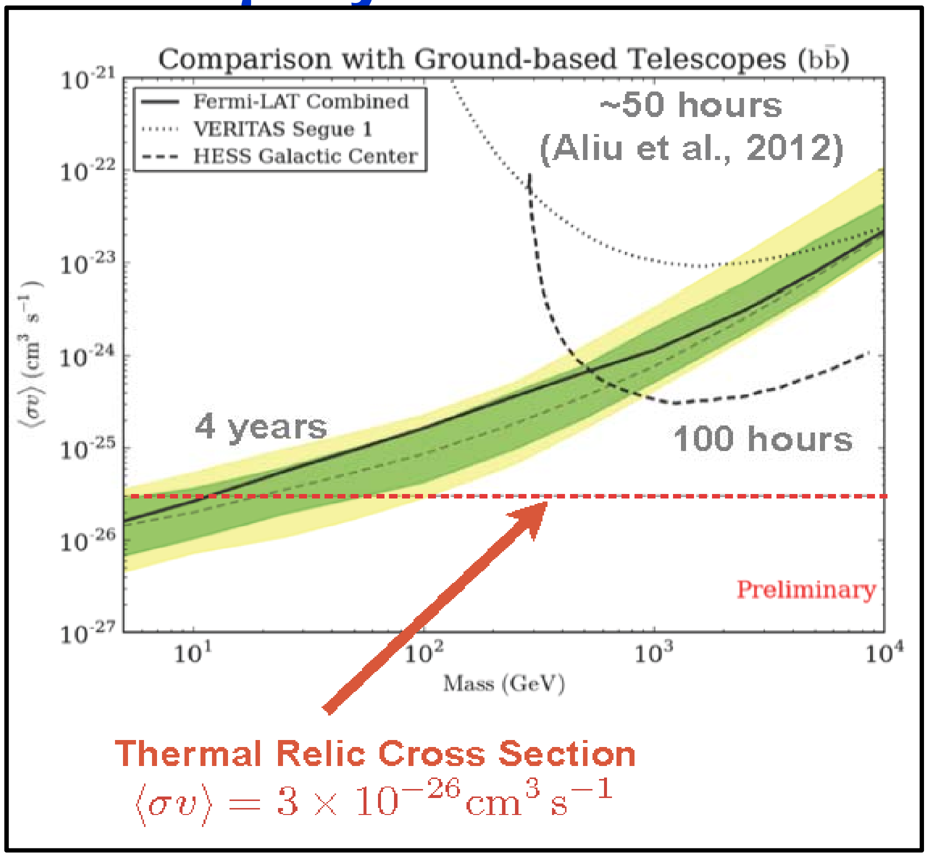
"Universal" Spectrum



Ultimate goal: Dark Matter Astronomy

Dark Matter Results

γ-ray DM limits



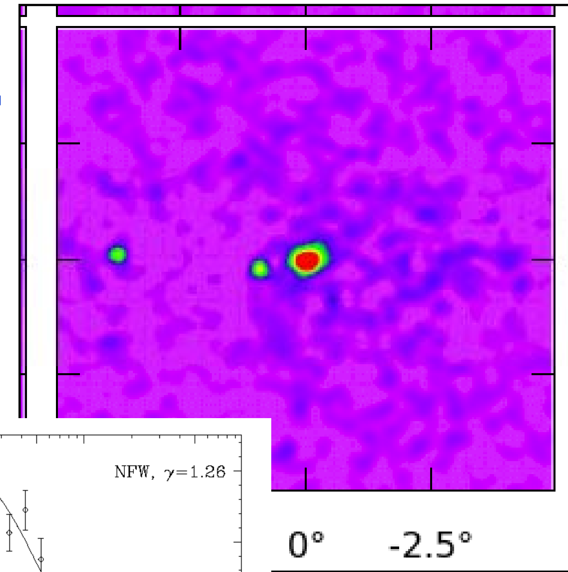
R.A. Ong, Nobel Symposium 154

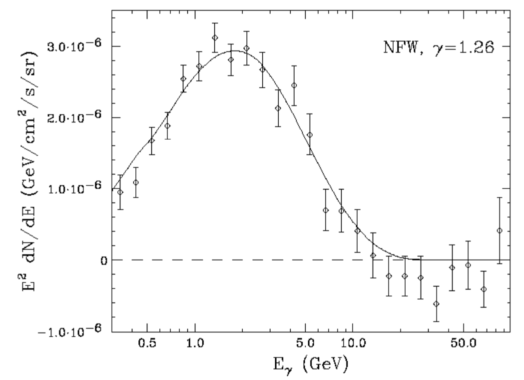
No signal (yet)

- 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.

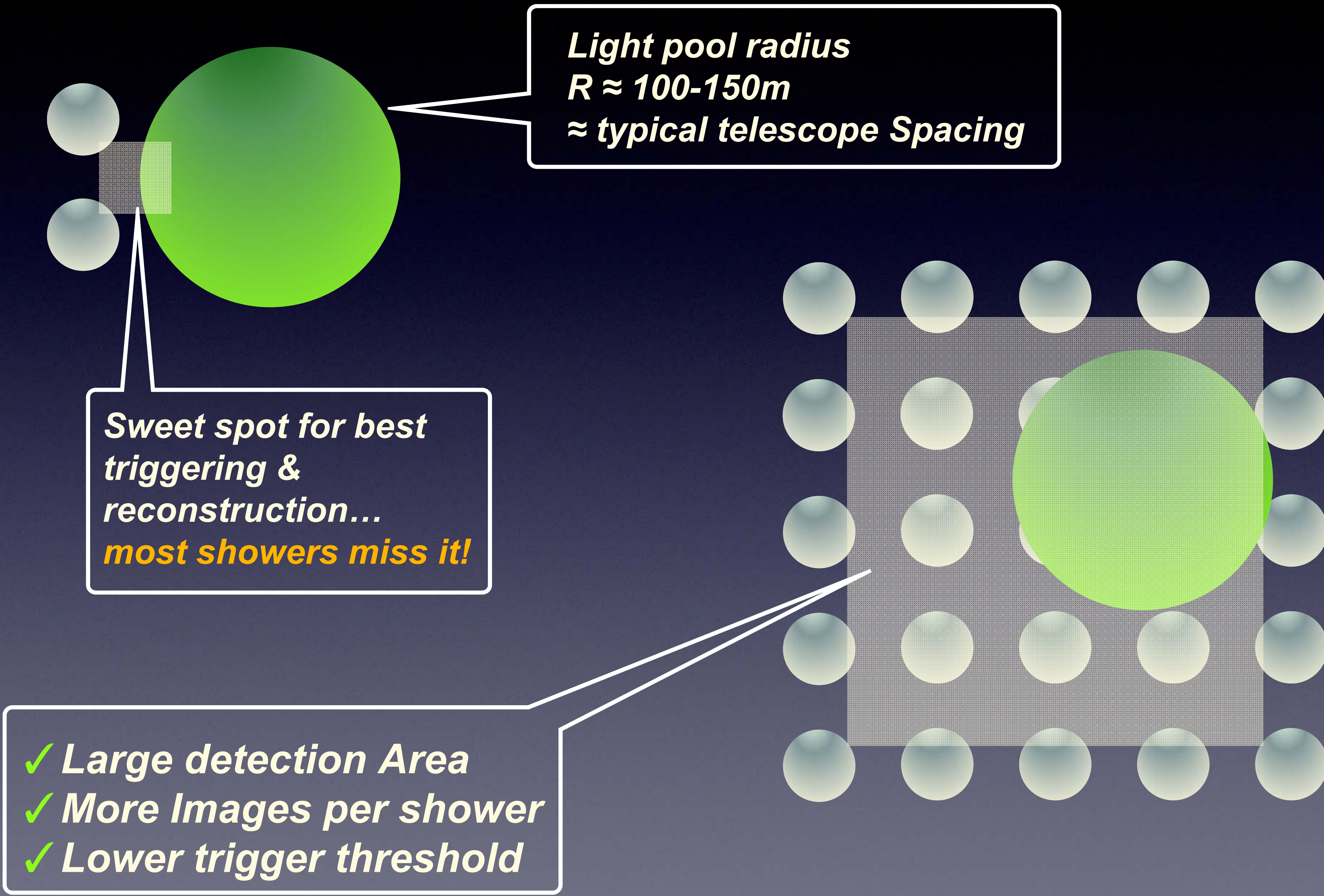
Summary of Key Science Questions

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.

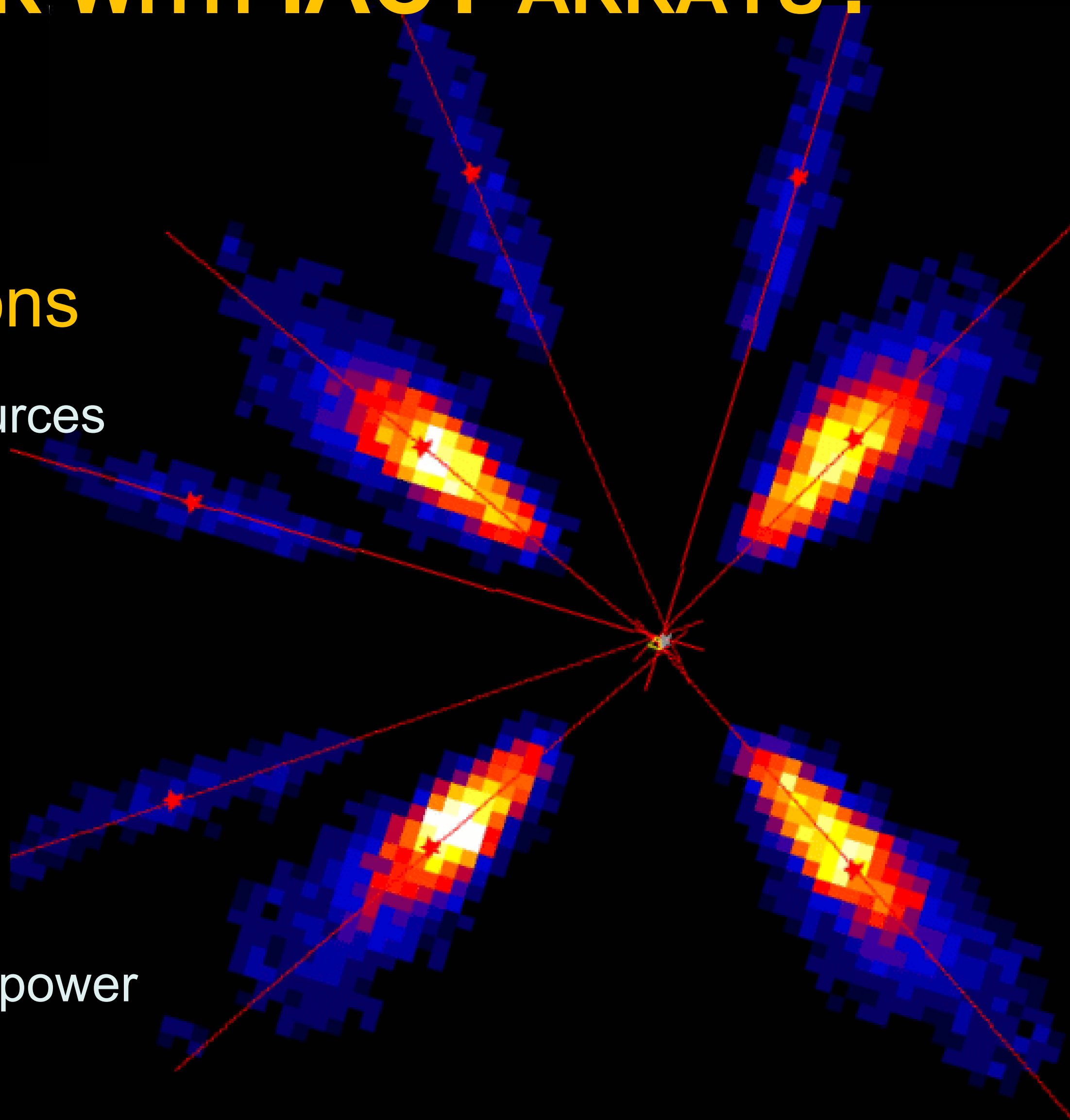
1. Where and how are the bulk of CR particles accelerated in our Galaxy and beyond? (one of the oldest surviving questions of astrophysics)
2. Can we understand the physics of jets, shocks & winds in the variety of sources we see, including pulsars, binaries, AGN, starbursts, and GRBs?
3. How do black 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, and unexpected, phenomena will be revealed by exploring the non-thermal Universe?

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

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 do we know, based on current instruments?

Great scientific potential exists in the VHE domain

- *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

- *CTA must develop the instrument and the observatory*


cta
cherenkov telescope array

Requirements & Drivers

Energy coverage down to 20 GeV
(Discovery domain: GRBs, Dark Matter)

Energy coverage up to 300 TeV
(Pevatrons, hadron acceleration)

Good energy resolution, ~10-15%:
(Lines, cutoffs)

Large Field of view 8-10°
(Surveys, extended *sources, flares)*

Rapid Slew (20 s) to catch flares:
(Transients)

10x Sensitivity & Collection Area
(Nearly every topic)

Angular resolution < 0.1° above most of E range
(Source morphology)

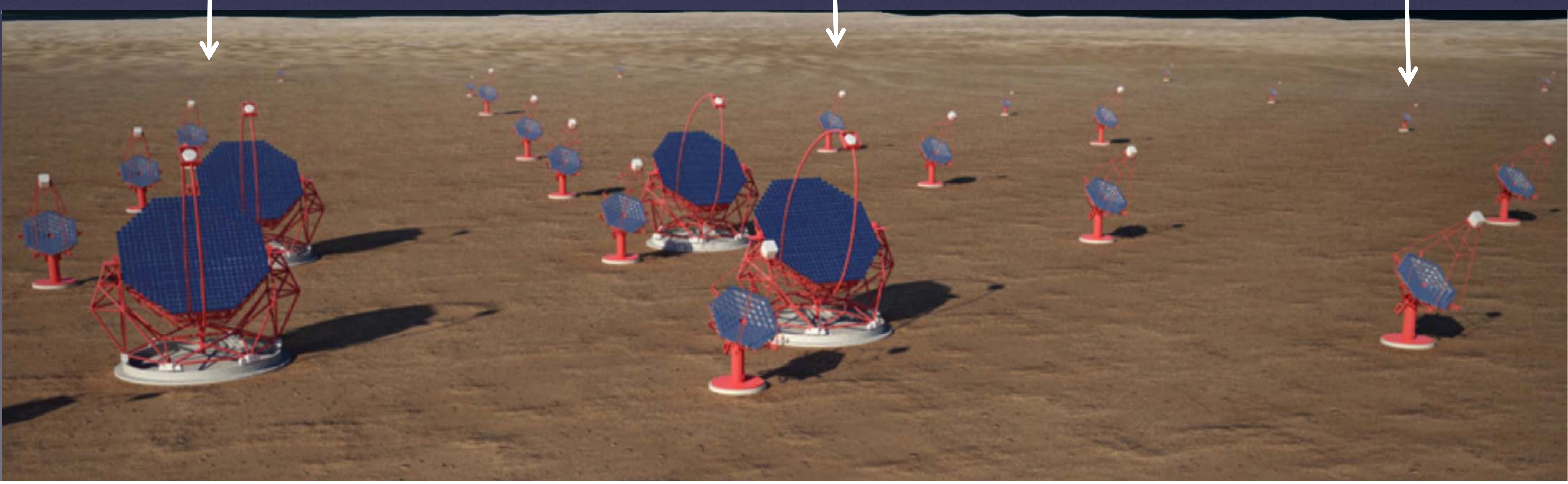
CTA Design (S array)

Science Optimization under budget constraints

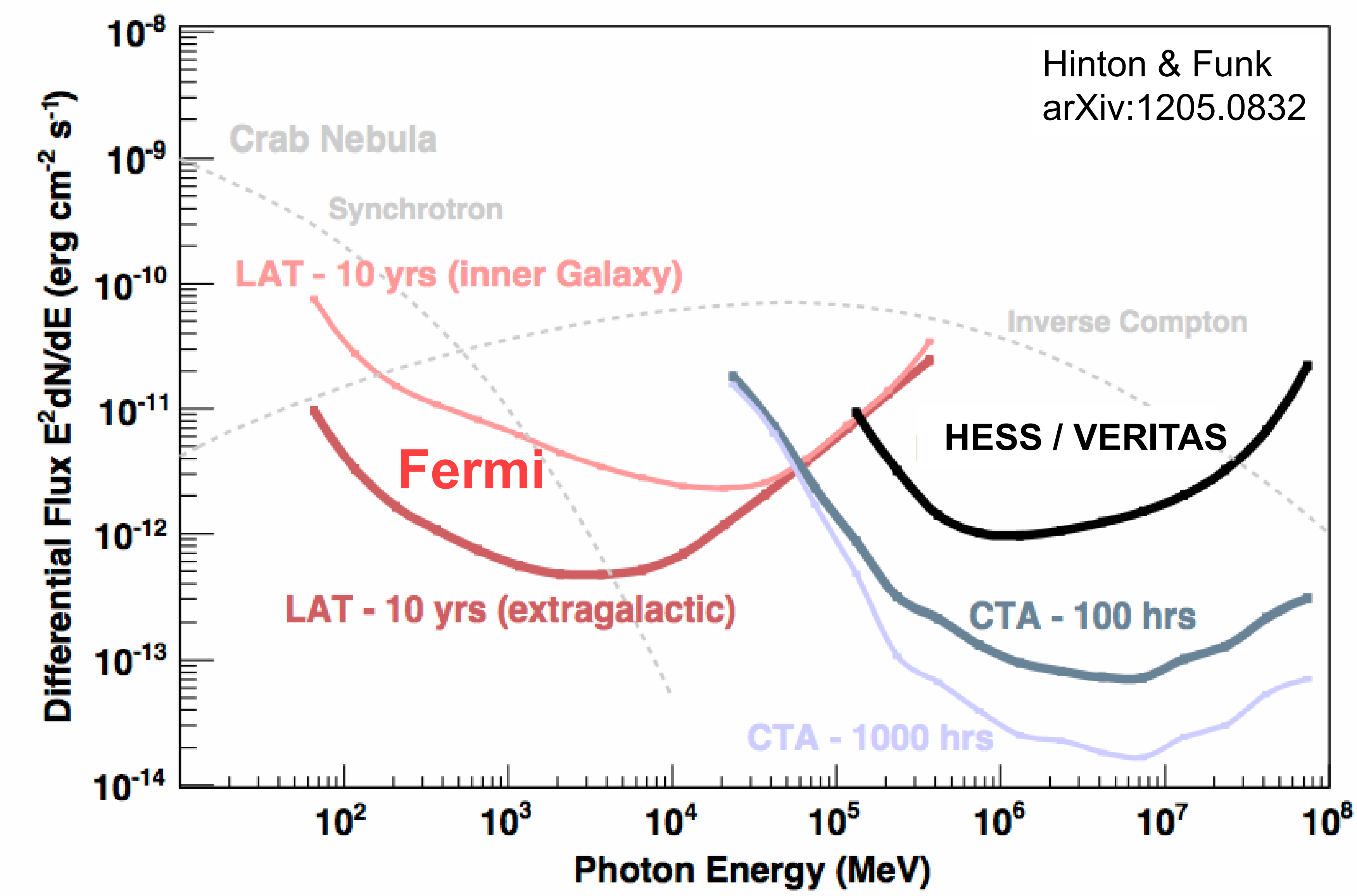
Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

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

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



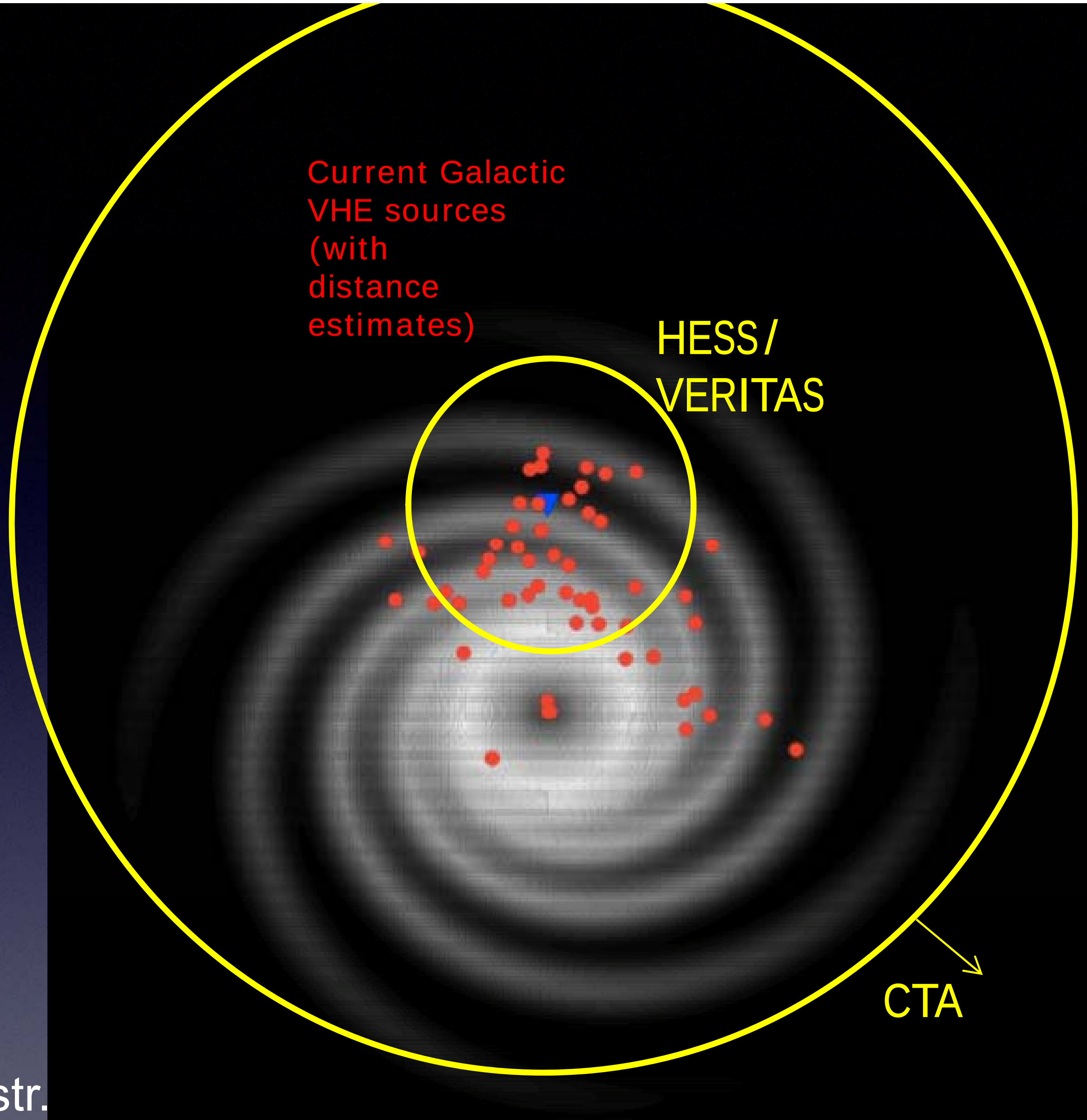
Differential Flux Sensitivity



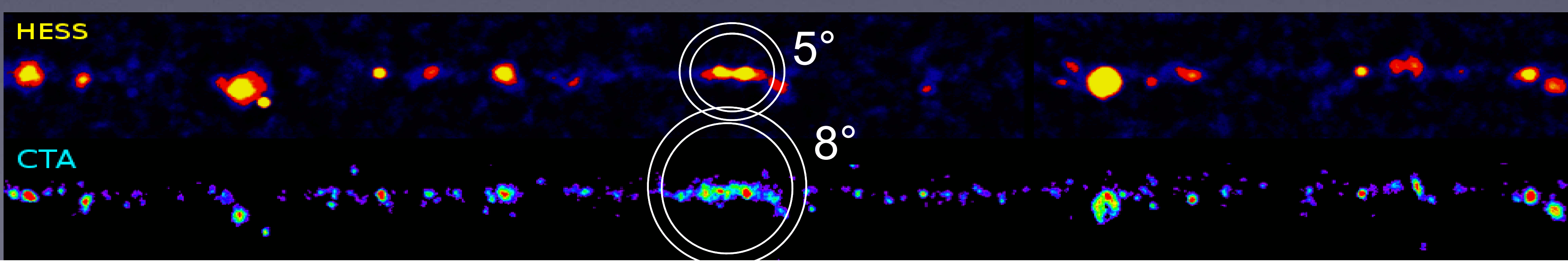
Major sensitivity improvement & wider energy range

→ Factor of ~x10 increase in source population

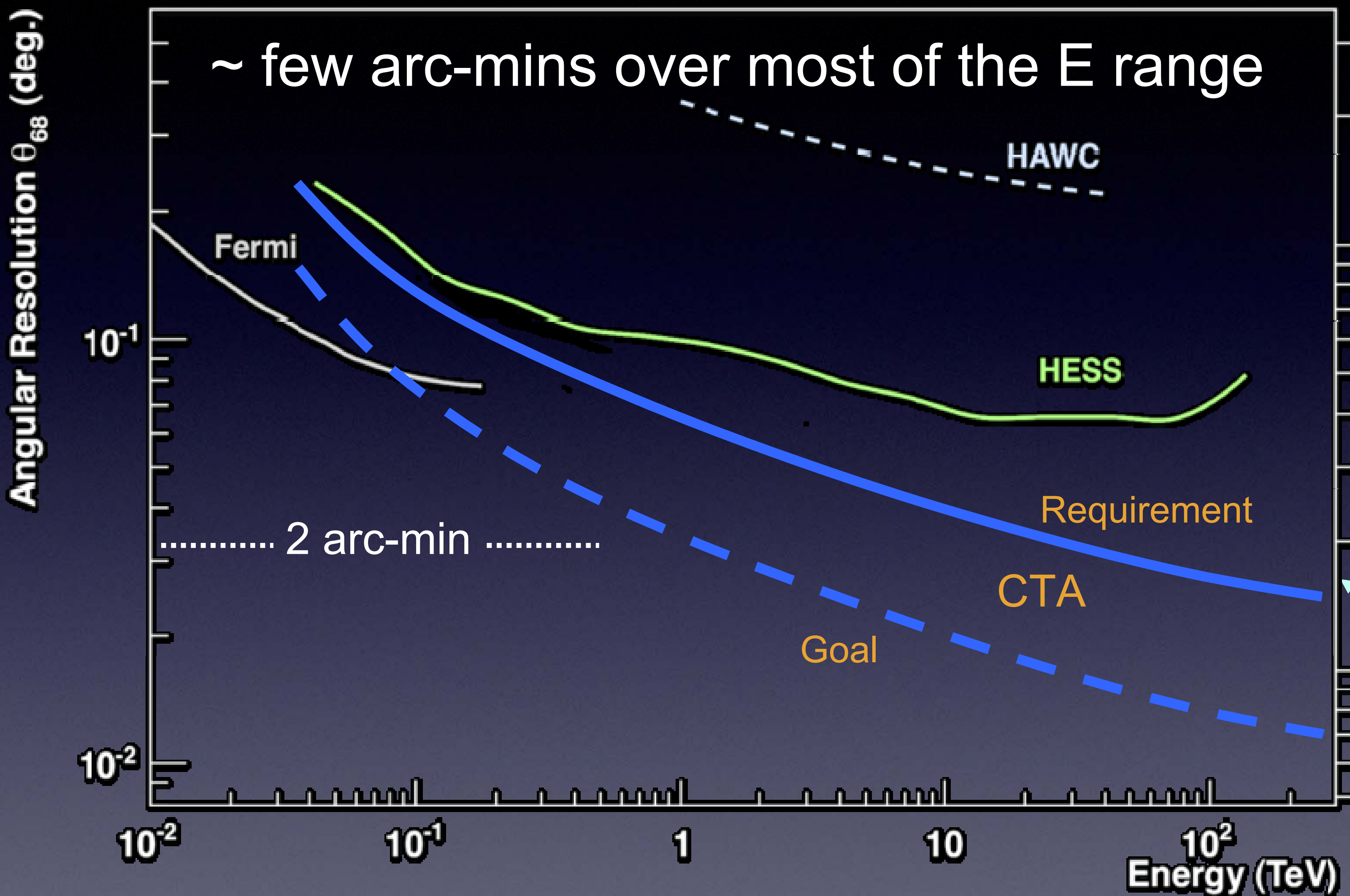
Galactic Discovery Reach



Survey speed:
x300 faster than current instr.

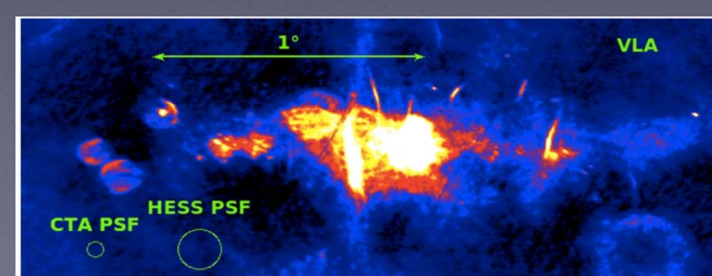


Angular Resolution



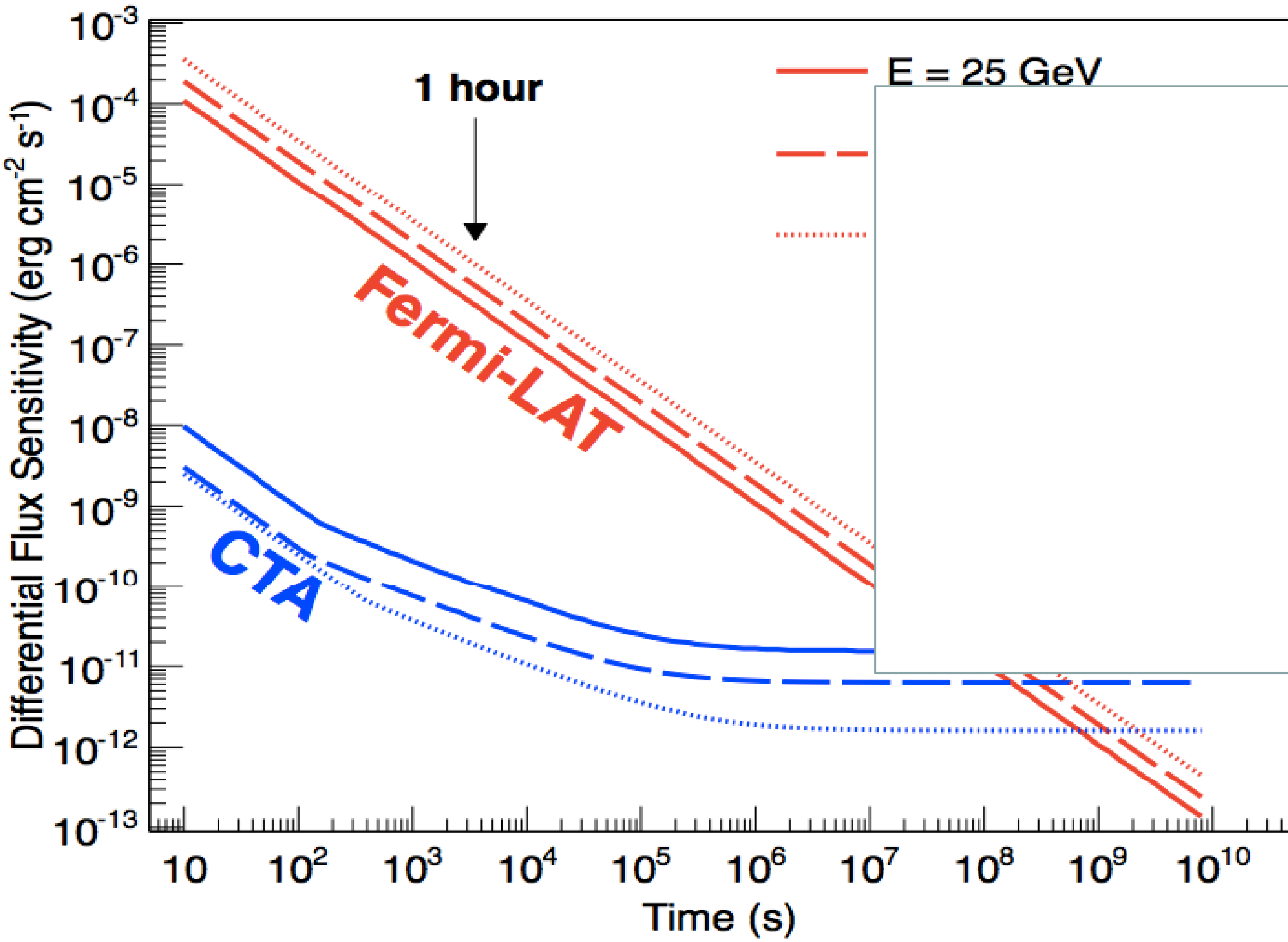
Angular resolution critical for
Source morphology and identification

Galactic-Center region

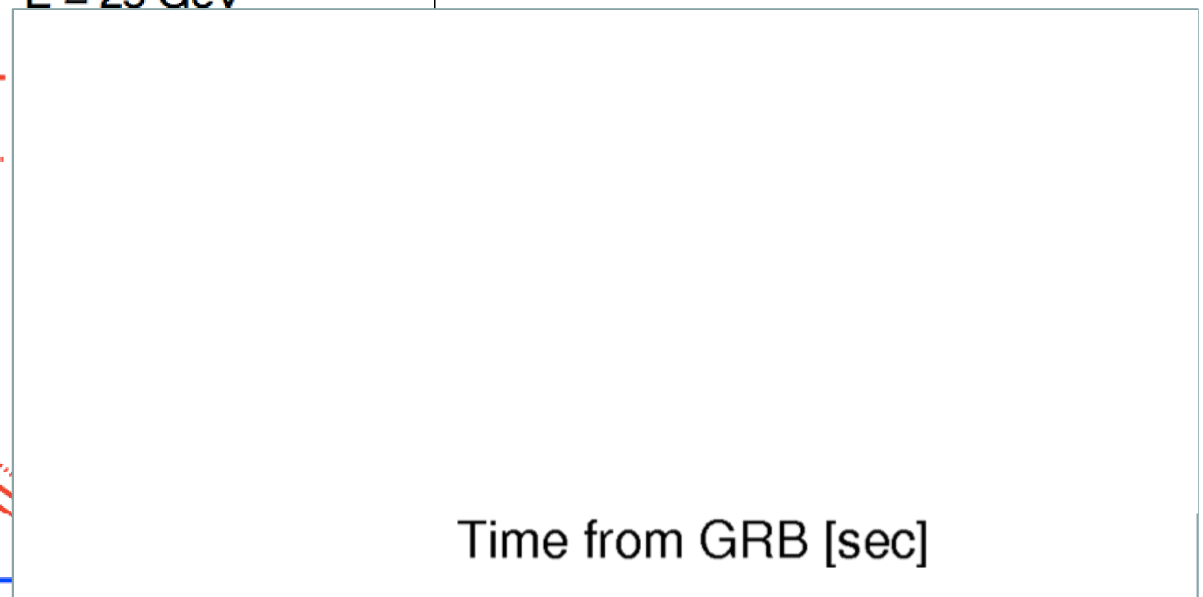


Transient Capability (< 100 GeV)

Hinton & Funk
arXiv:1205.0832



S. Inoue et al.,
arXiv:1301.3014



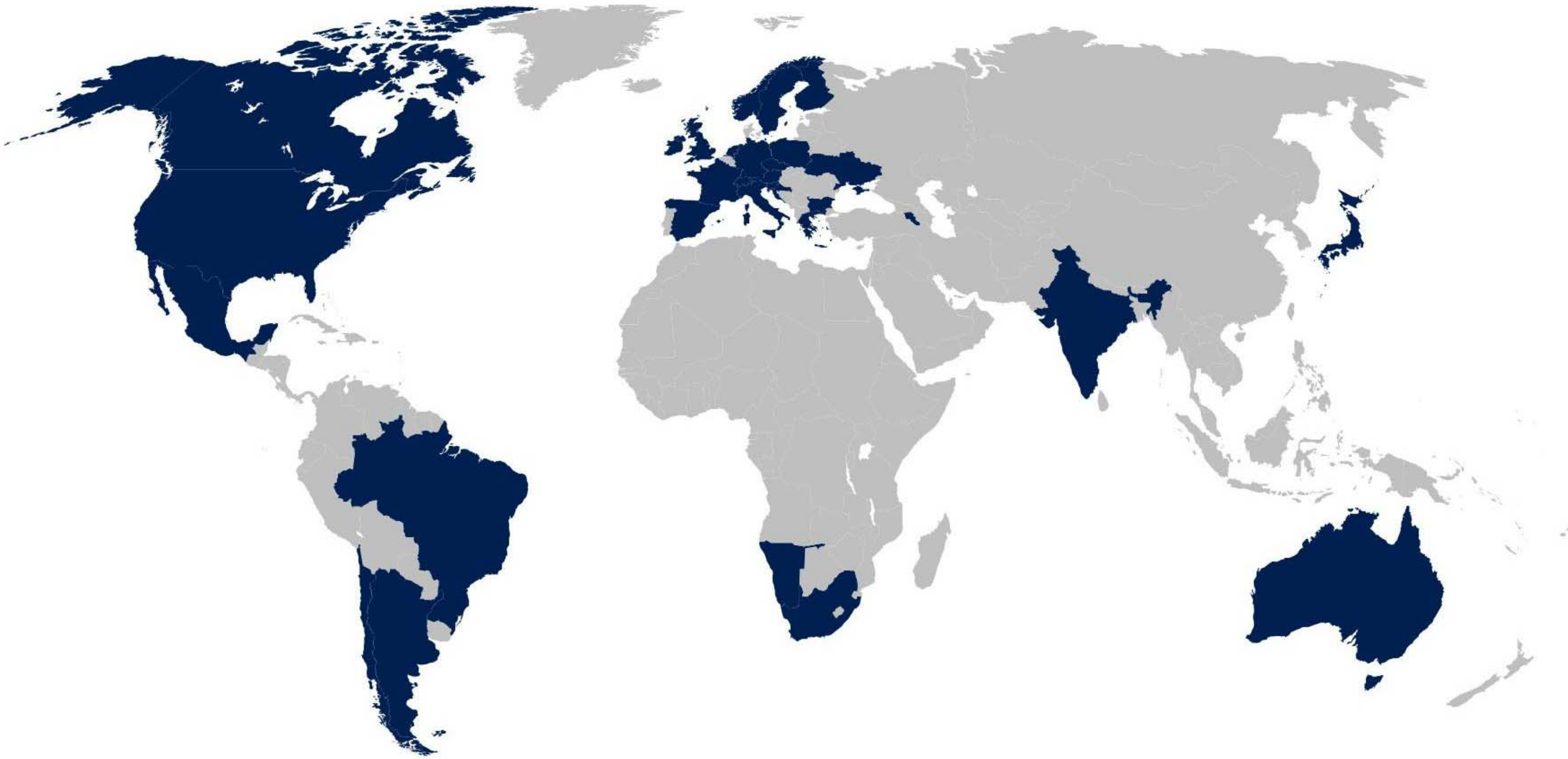
GRB (z=4.3) Light curve

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

CTA Implementation & Status

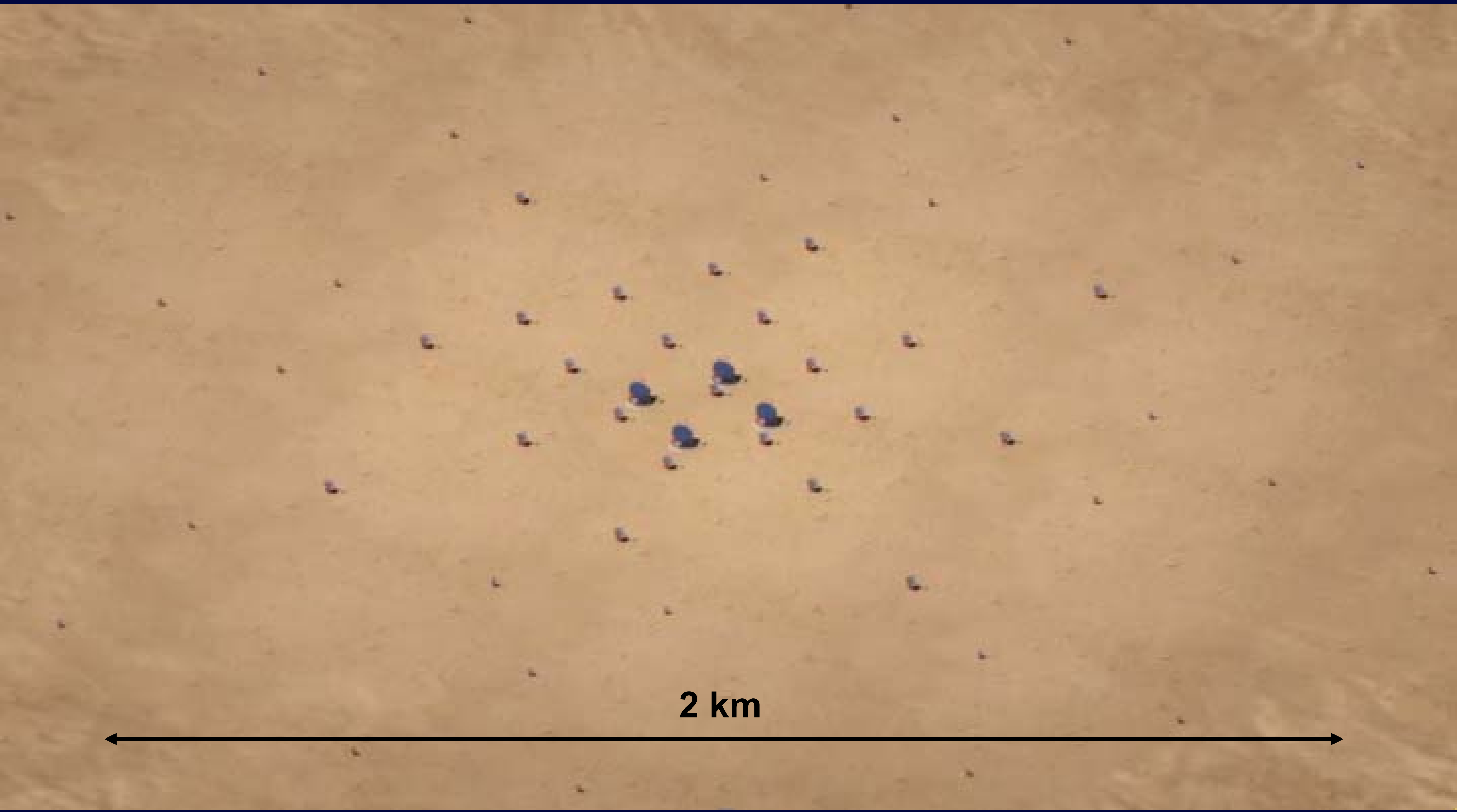
CTA Consortium

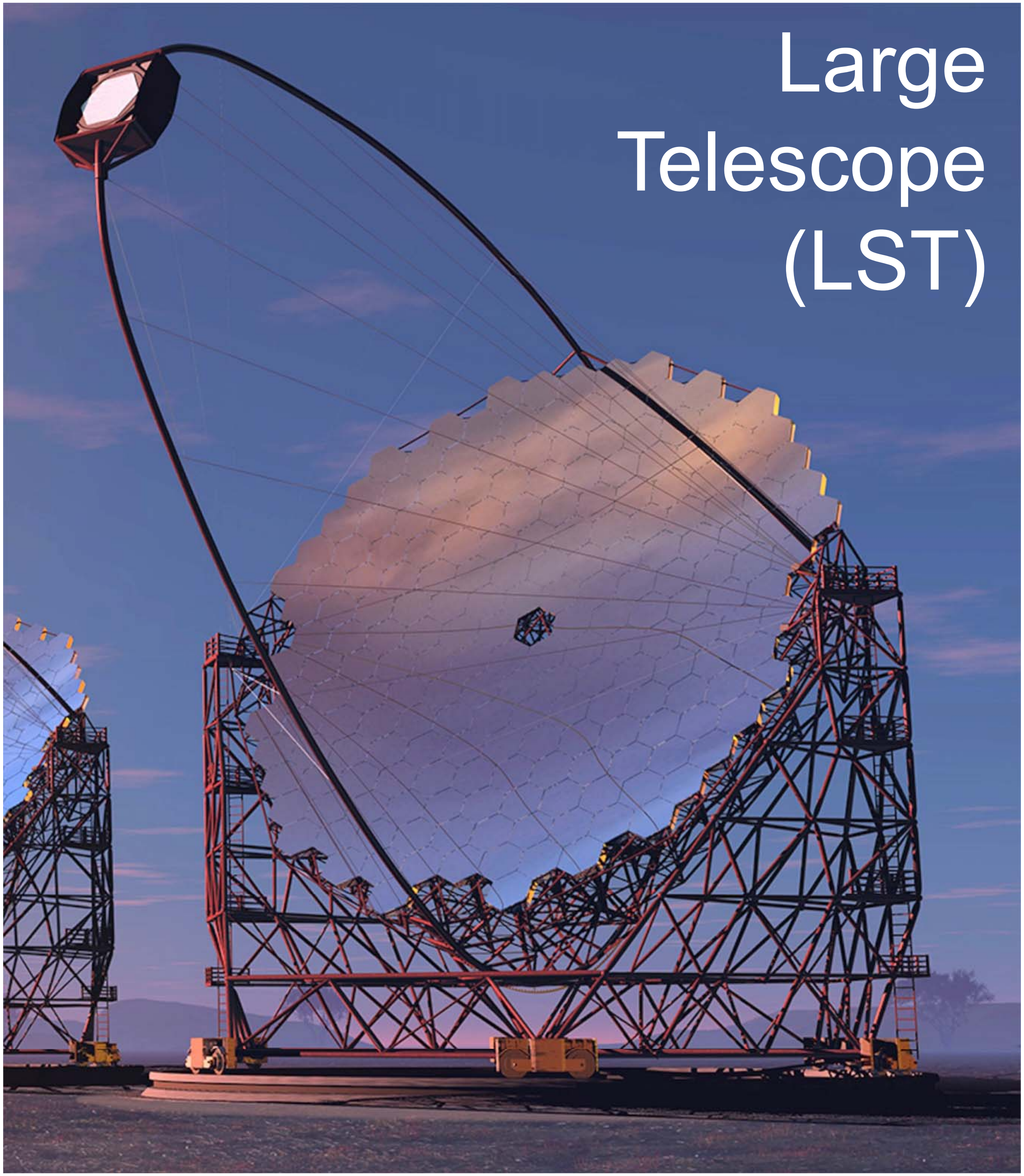
CTA is being developed by the CTA Consortium:



31 countries, ~1270 scientists, ~180 institutes, ~420 FTE

CTA South Array





23 m diameter
390 m^2 dish area
28 m focal length
1.5 m mirror facets

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

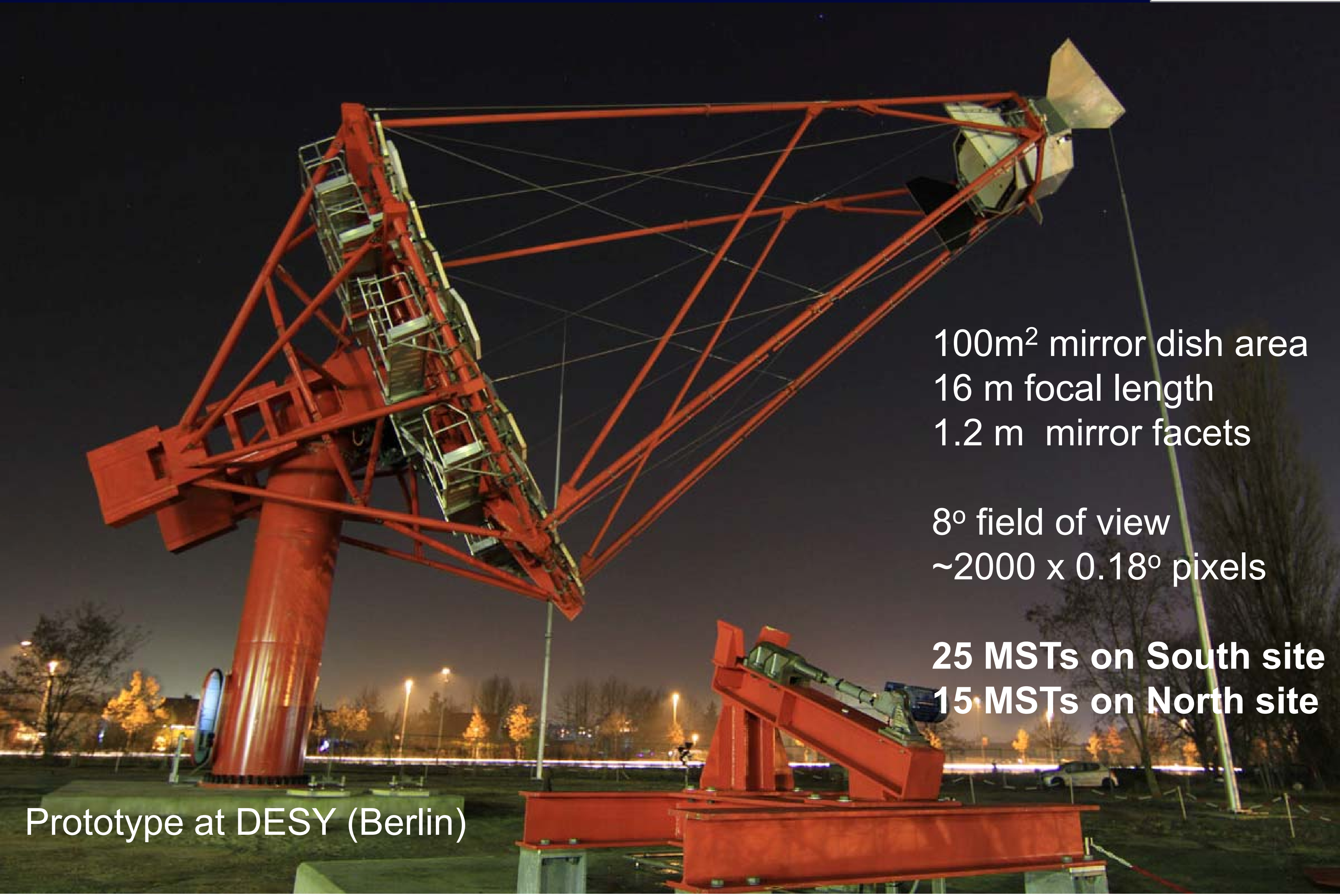
Carbon-fiber structure
for 20 s positioning

Active mirror control

4 LSTs on South site
4 LSTs on North site

Prototype construction
Underway (La Palma)

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

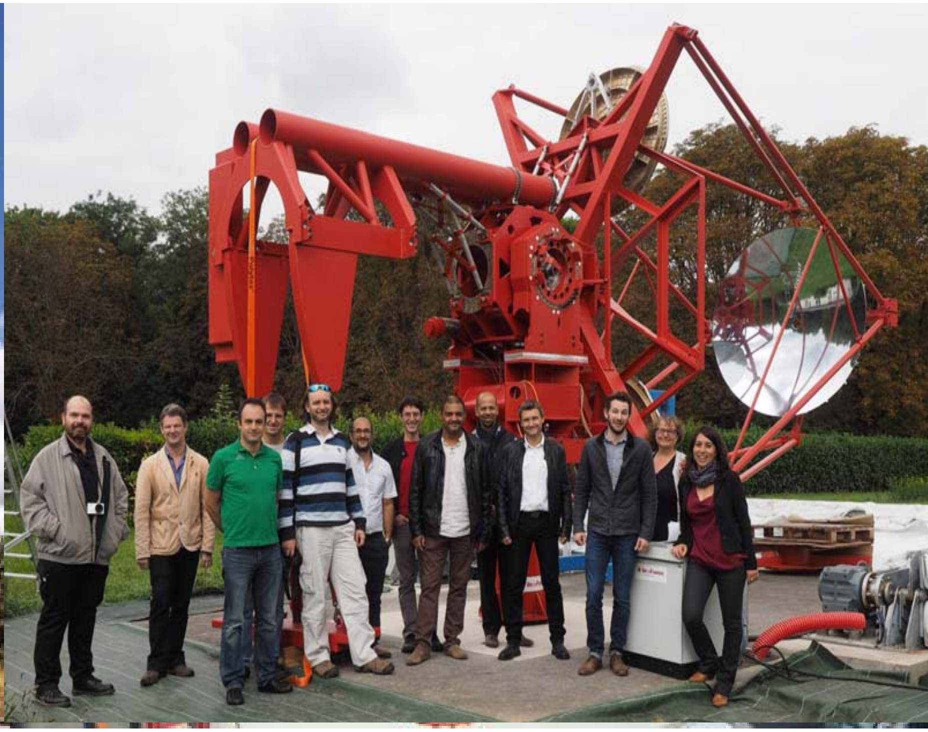
Prototype at DESY (Berlin)

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

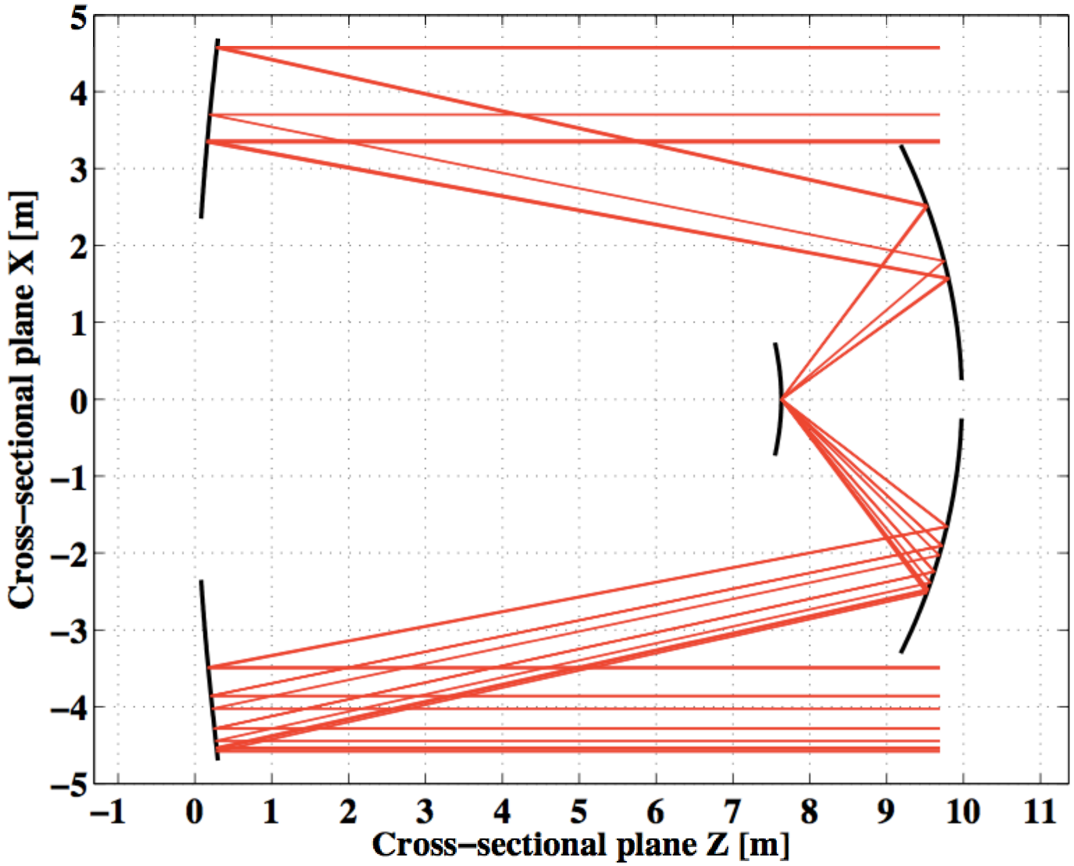


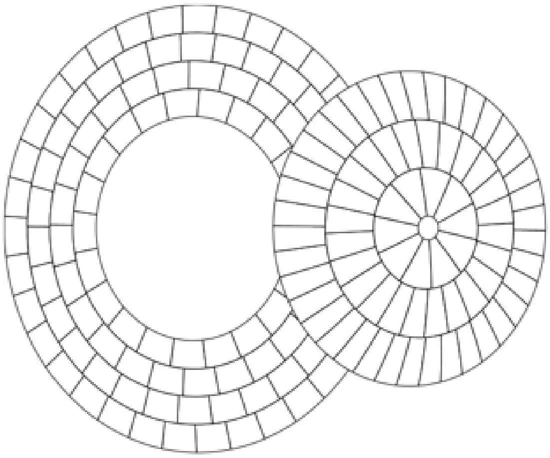
SST-2M GCT
Meudon, France

Two-Mirror Telescopes

Schwarzschild-Couder (SC) Design

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





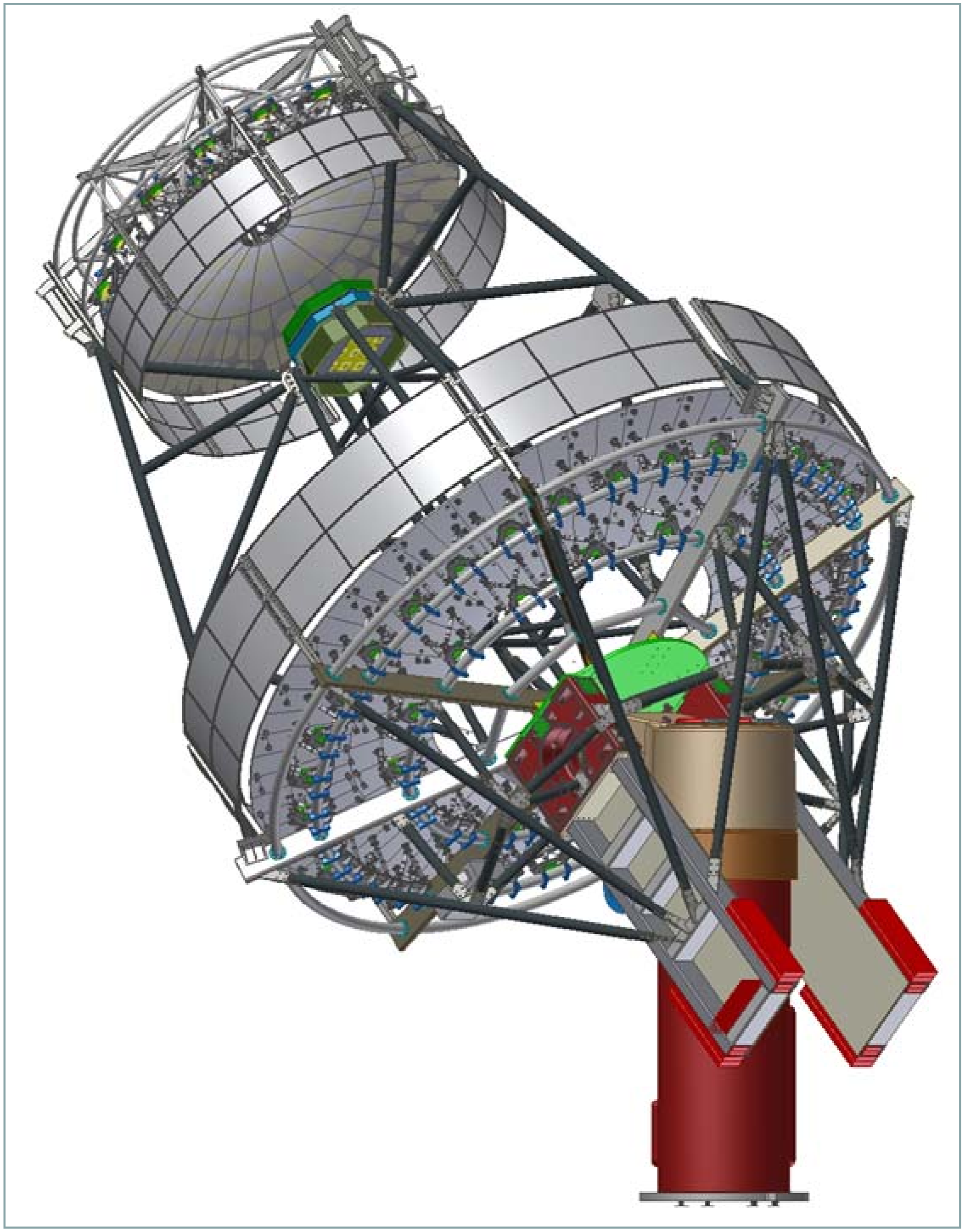
- Reduced plate scale
- Improved PSF
- Uniform PSF across f.o.v.

➜ 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.

Medium Telescope 2-mirror (SCT)



9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
50 m^2 mirror dish area
PSF better than 4.5’
across 8^o FOV

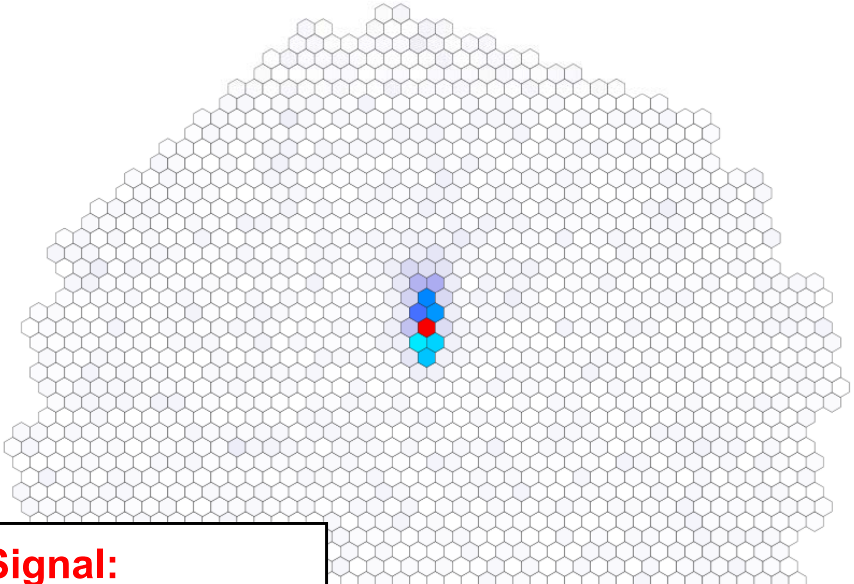
8^o field of view
11328 x 0.07^o SiPMT pixels
TARGET readout ASIC

SCTs can augment / replace MSTs in either S or N
→ proposed US contribution

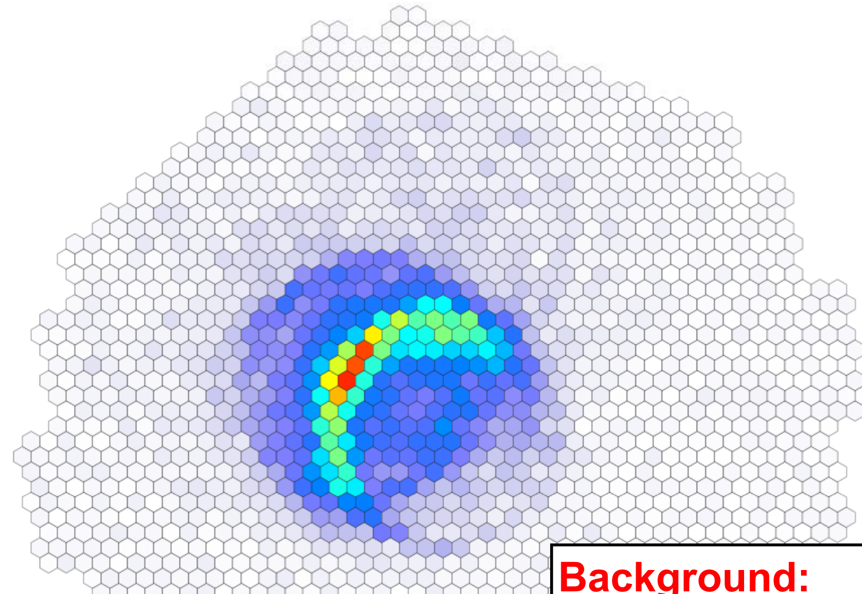
➜ Increased γ-ray collection area
➜ Improved γ-ray ang. resolution
➜ Improved DM sensitivity

SCT → Superior Imaging

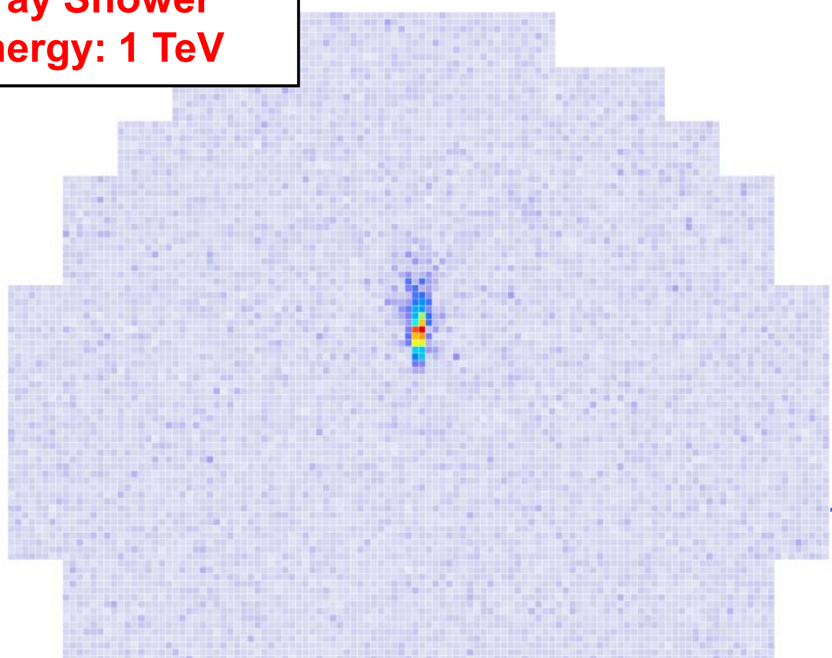
Made possible by Si-PMT's !



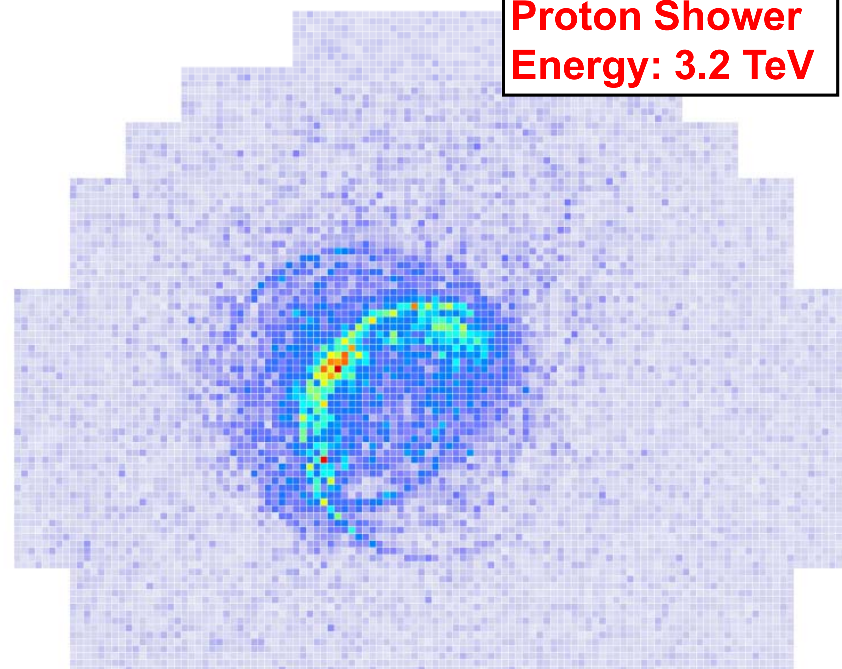
"Baseline"
Single-Mirror
Telescope
Images
8° field of view
0.18° pixels
1,570 channels



Signal:
γ-ray Shower
Energy: 1 TeV



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



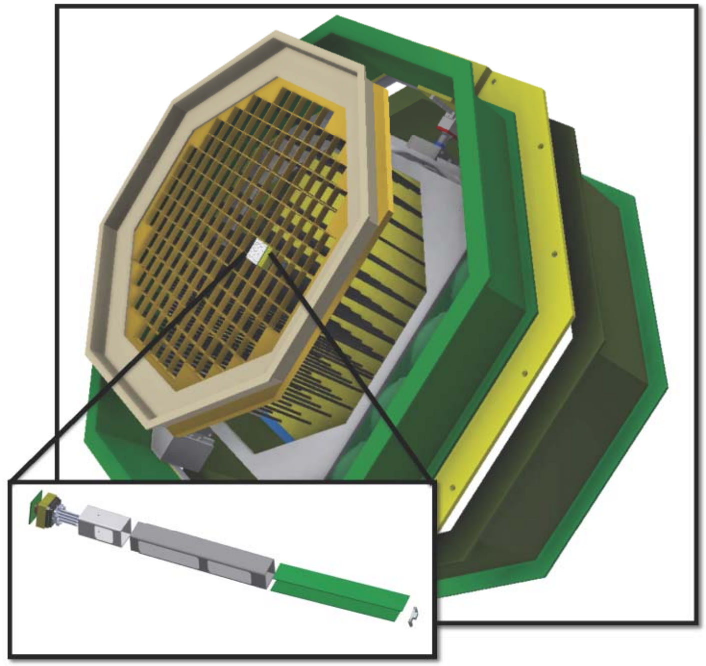
Background:
Proton Shower
Energy: 3.2 TeV

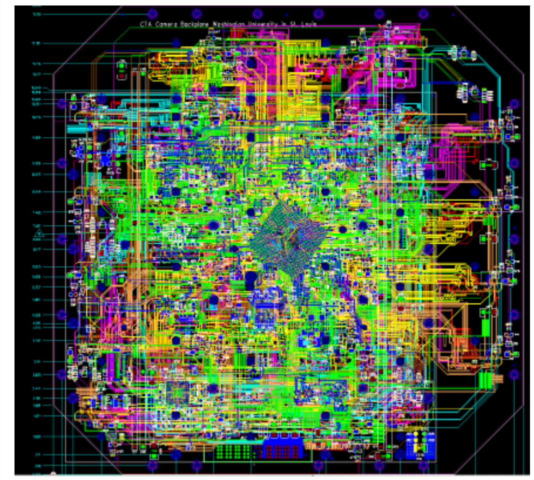
SCT Prototype Development

Prototype panels for
primary mirror (M1)

Prototype under construction in Arizona

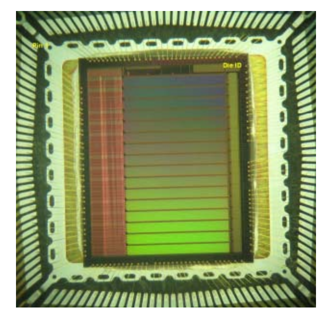
Camera design, backplane and elements





Backplane

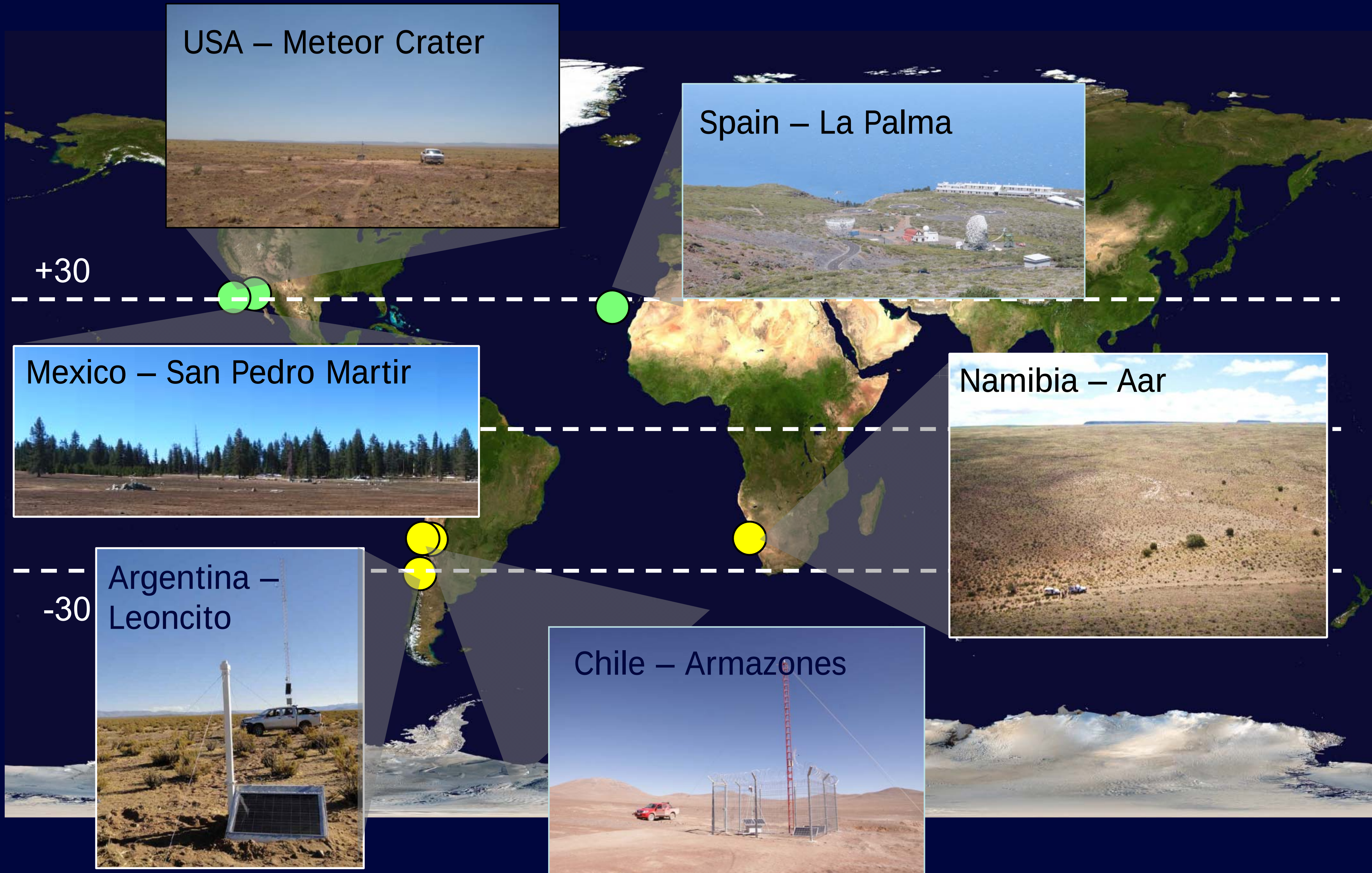
Individual (64-chan)
Camera module



TARGET-7
ASIC

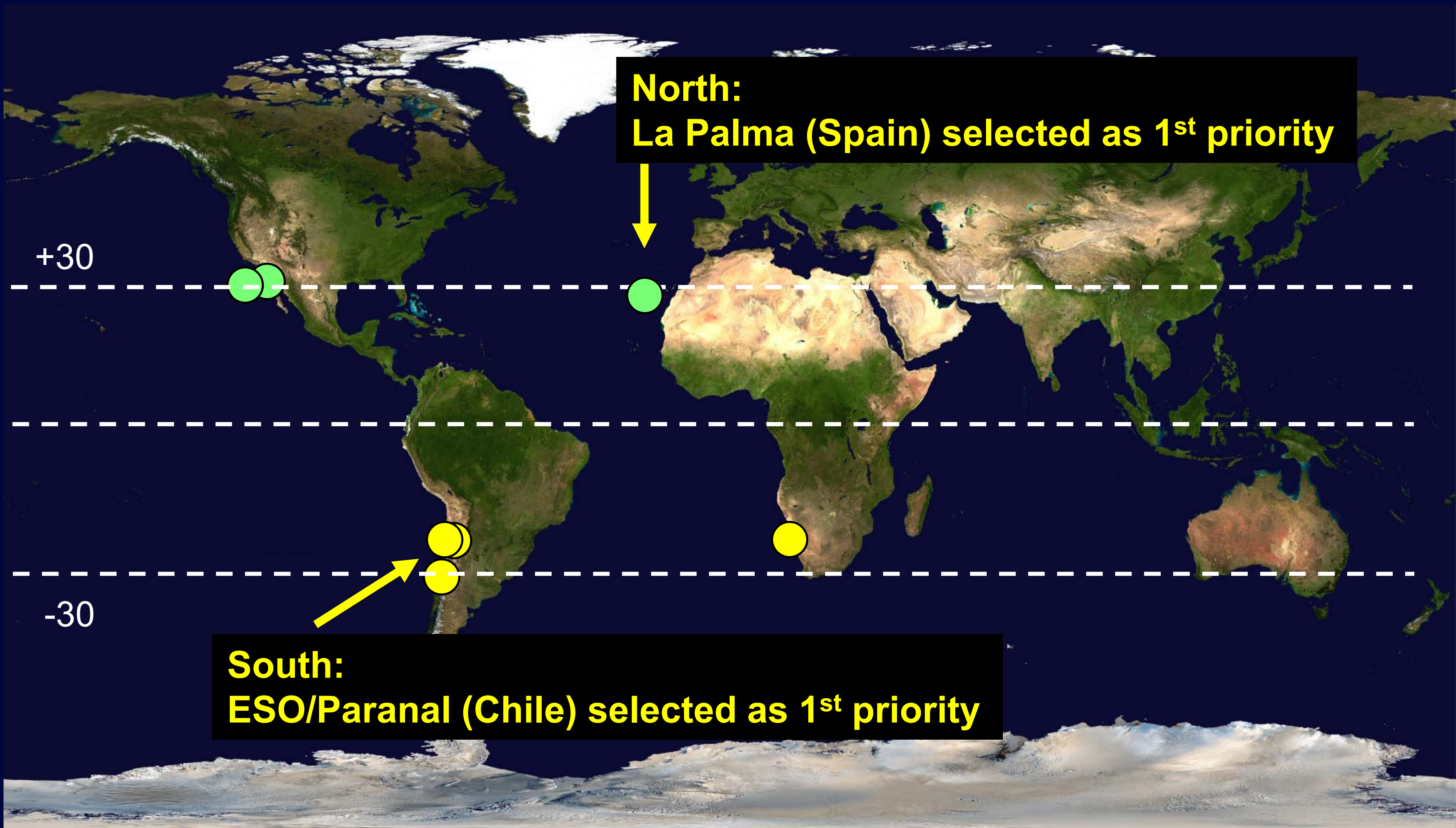
Site Selection

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



Site Selection

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



Steps Towards Approval

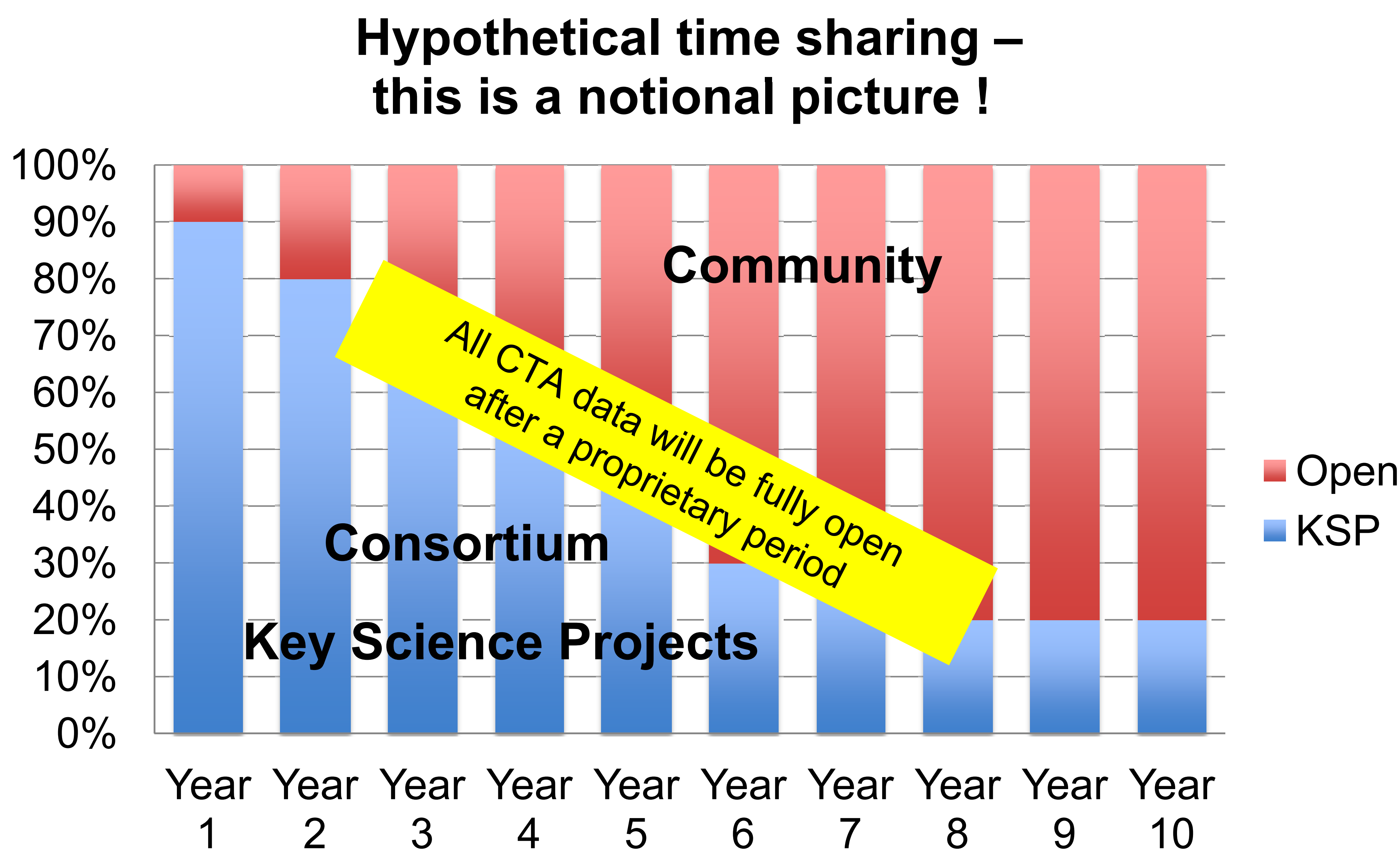
cherenkov telescope array

Science Performance and Preliminary Requirement Review	Preliminary Technical Design Report /Preliminary Design Review	Technical Design Report / Critical Design Review	Site Negotiations Founding Agreement
Feb. 2013 ✔	Nov. 2013 ✔	June 2013 ✔	2016

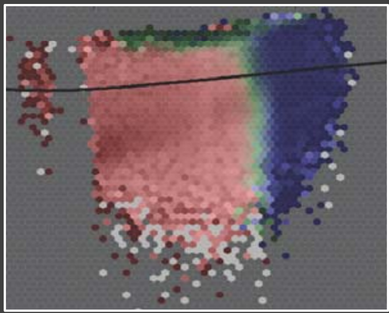
CDR carried out in June 2015 by
Science and Technical Advisory Committee (STAC) – Chair. R. Blandford

2016-2017: Site negotiations, founding agreement, pre-production reviews, initial site construction

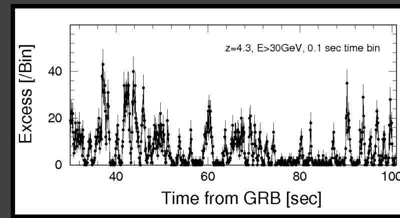
Scheduling KSPs and GO program



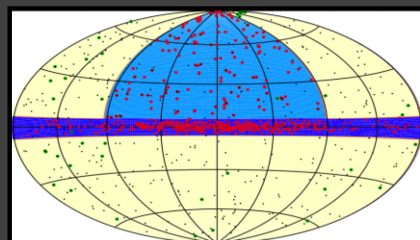
Key Science Projects (KSPs)



Dark Matter Programme

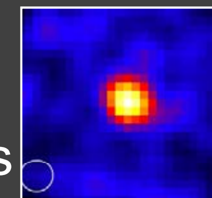


Transients



ExGal Survey

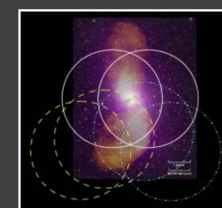
Galaxy Clusters

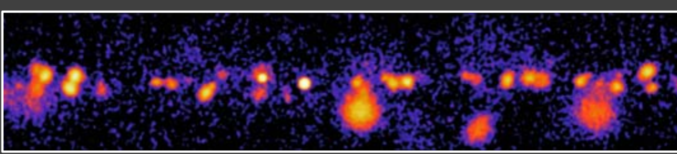


Extragalactic

Star Forming Systems

AGN

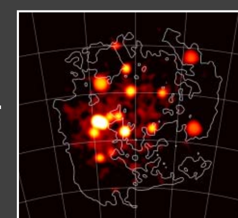




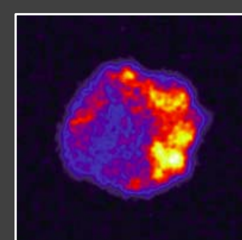
Galactic Plane Survey

Galactic

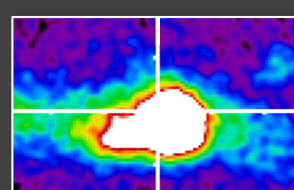
LMC Survey



PeVatrons

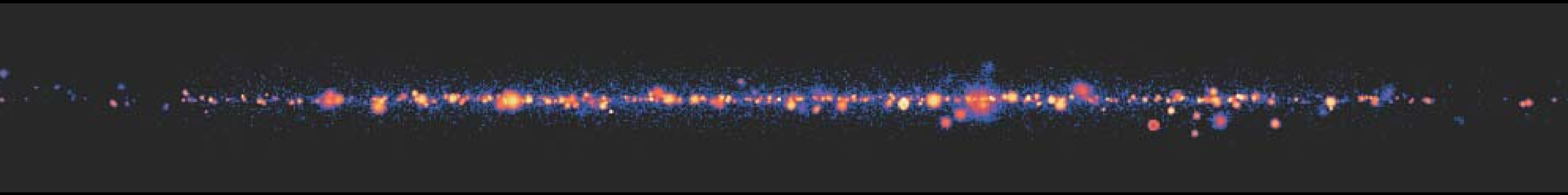


Galactic Centre

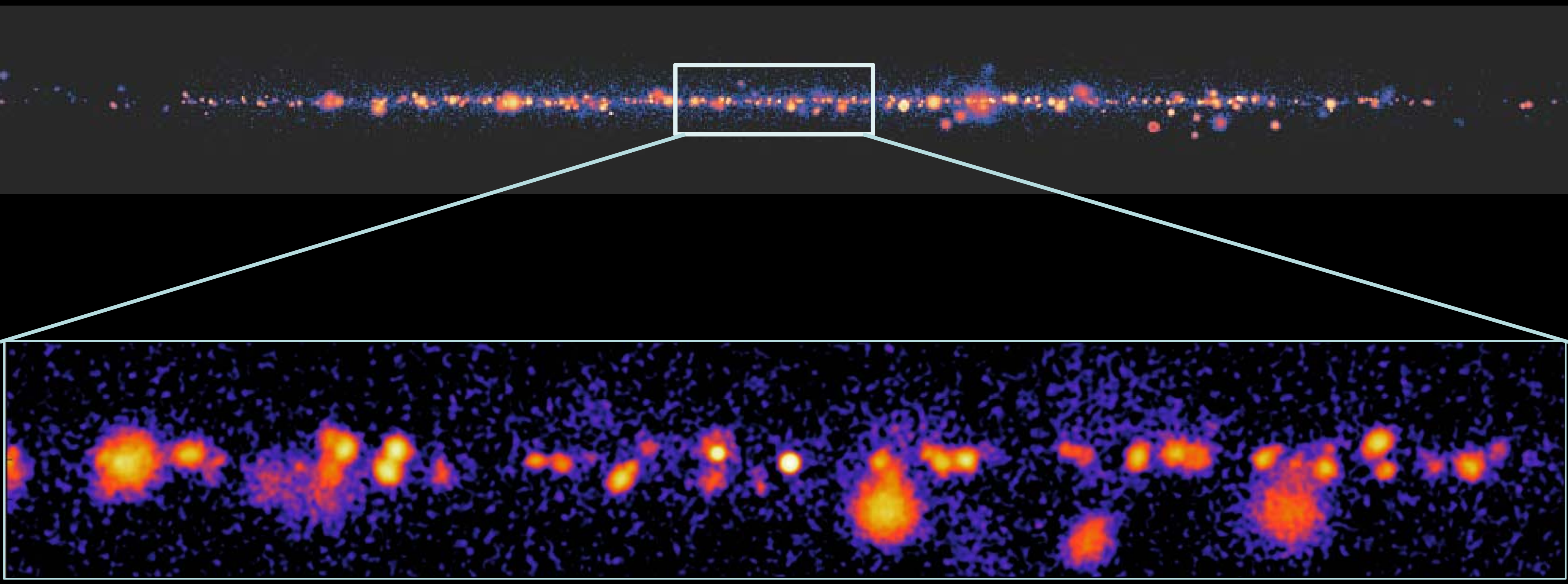


cta cherenkov telescope array

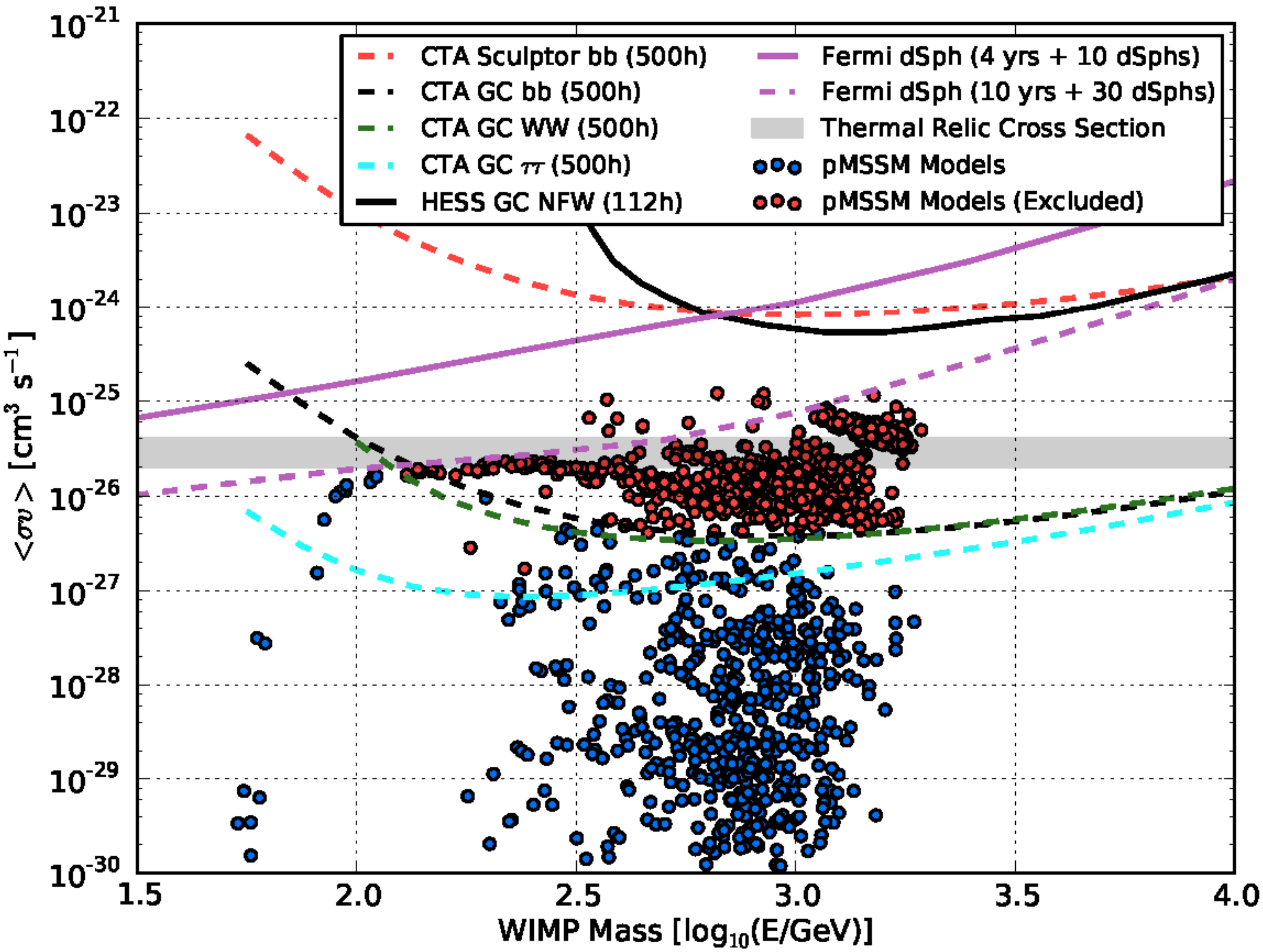
Galactic Plane Survey (GPS)



Galactic Plane Survey (GPS)



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*

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

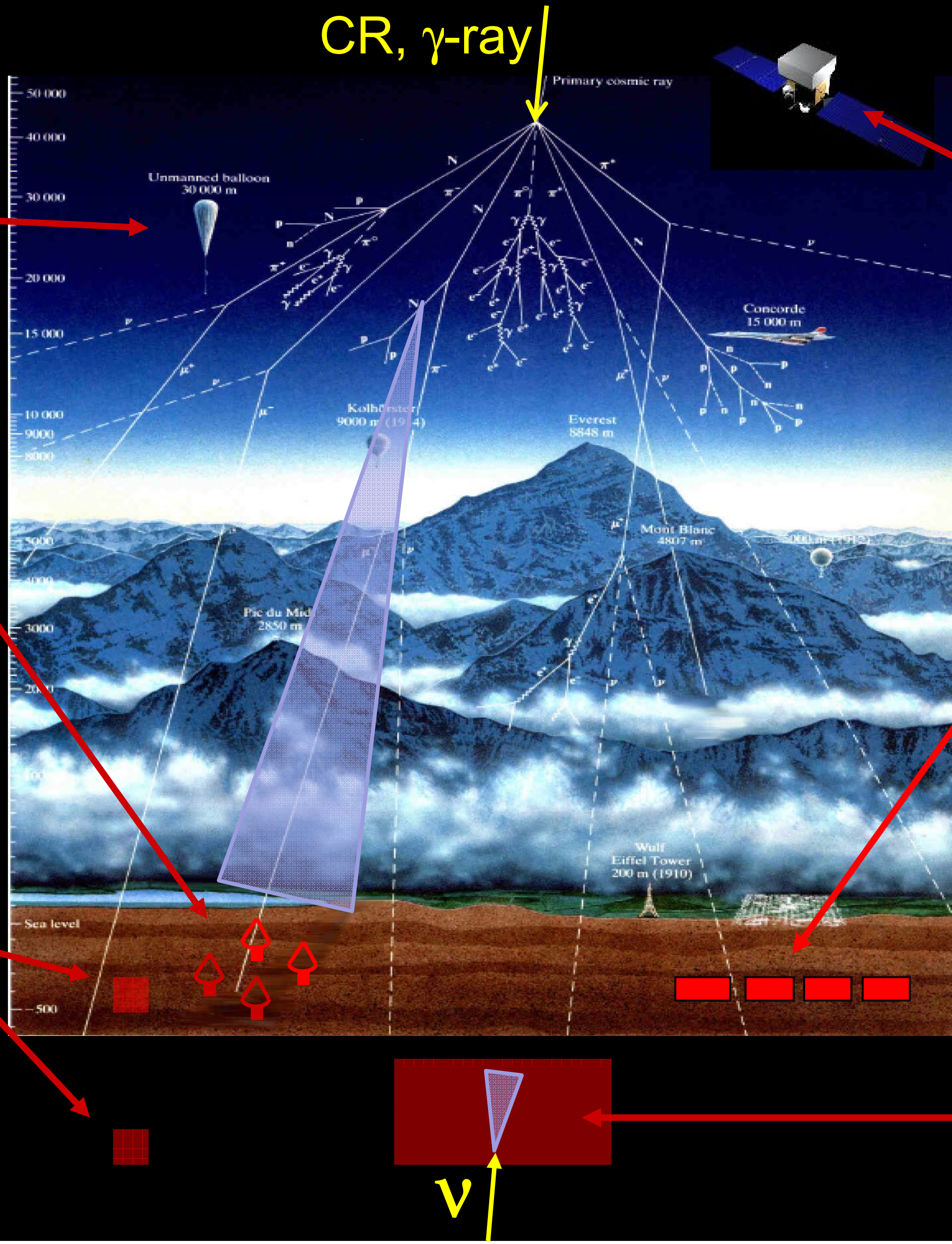
- In next decade, CTA will start to provide high-quality data, not seen with any HE/VHE technique, but there is still a great deal to do !

BACKUP

Some of the many topics not covered

- “Fermi Bubbles”
- Gamma-ray “lines” near Galactic center
- Primordial black holes
- Fermi “haze”
- Positron excess – Geminga ?
- Lorentz invariance violation (LIV)
- Extragalactic magnetic field (EGMF)
- Pion bump in several SNRs – origin of CR’s
- VHE binary systems – “Swiss clocks”?
- Crab pulsar – unexpected flares and TeV emission
- Cosmic-ray anisotropy – evidence for local accelerator(s)?

Multi-faceted Astroparticle Physics



Balloon Instruments

ANITA

Atmospheric Cherenkov Telescopes

HESS, VERITAS MAGIC …

Ground or Underground Detectors

CDMS, Xenon …
ADMX, CAST …

Satellite Instruments

Fermi, AMS PAMELA …

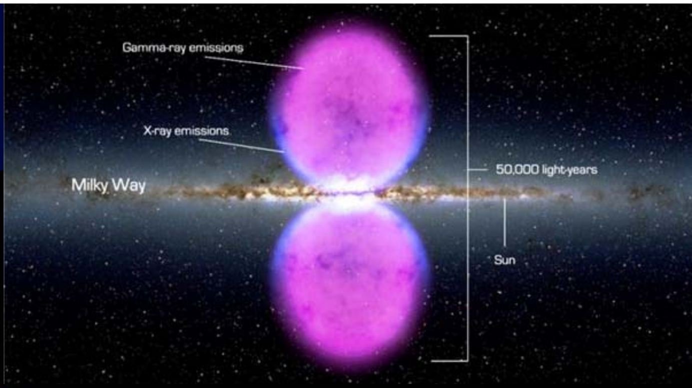
Air Shower Arrays

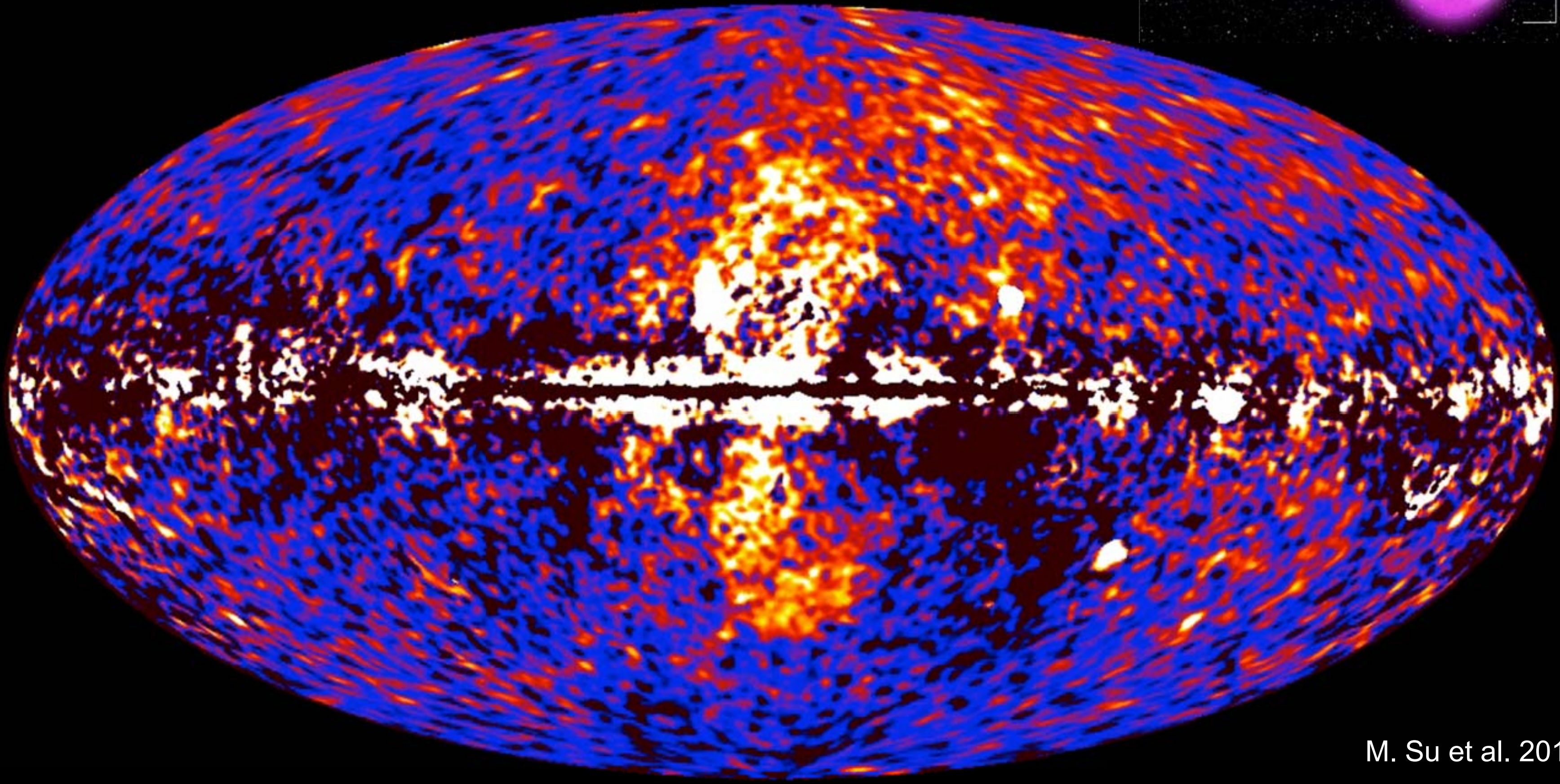
Auger, TA …

IceCube …

Ice/Water Cherenkov Detectors

Fermi Bubbles





M. Su et al. 2010

Complete Surprise !

- Very extended (10 kpc) with hard spectrum.
- Related to earlier history of Galactic center ?

CTA Key Science Projects (KSPs)

cta cherenkov telescope array

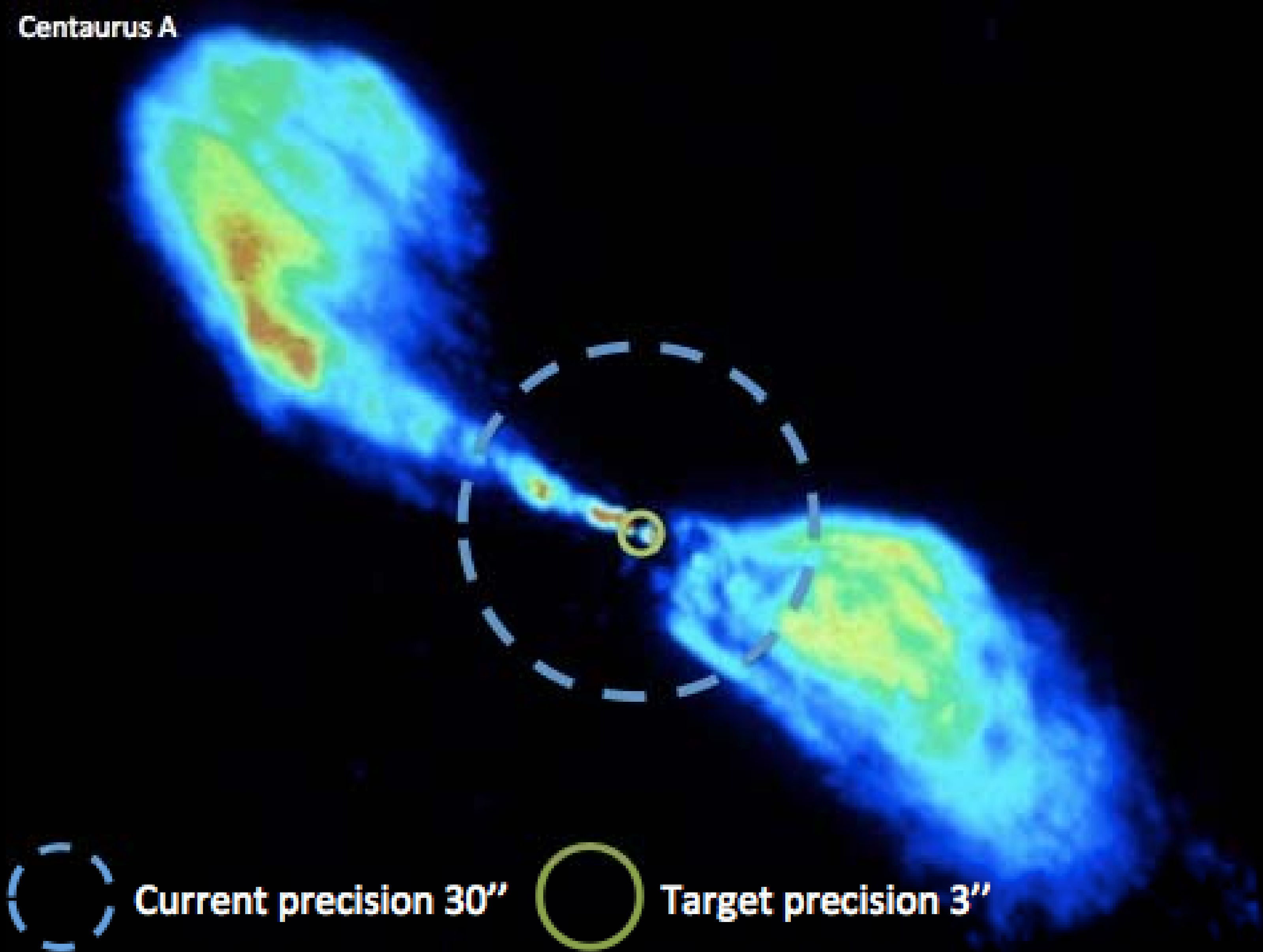
Science Questions DM ← KSPs →

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 …

The importance of pointing precision

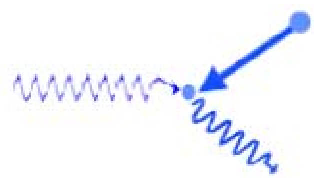


SNR Questions

Supernova remnants accelerate particles to ~PeV energies!

Electrons → TeV γ-rays

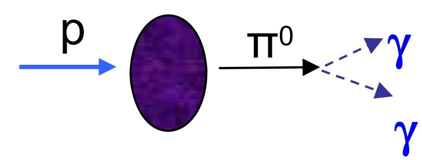
Up-scattering of soft photons



inverse-Compton scattering

Protons → TeV γ-rays

Target interaction, π^0 decay



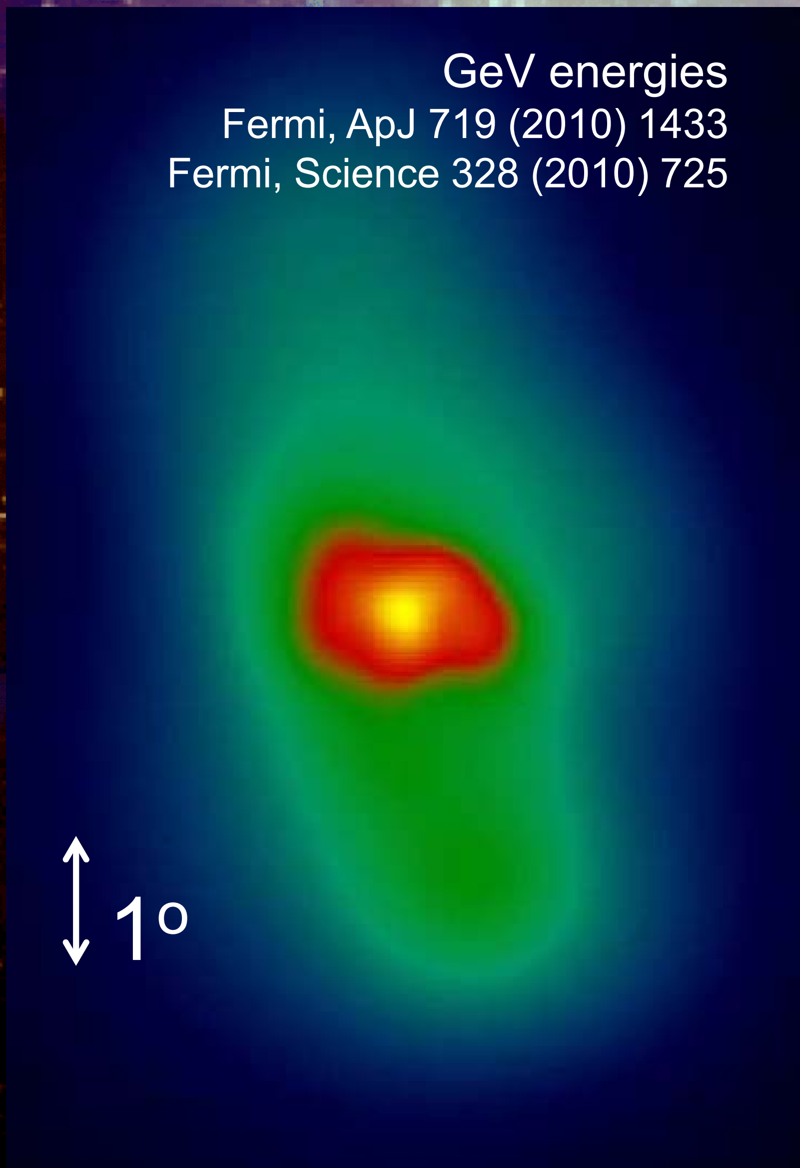
π^0 and target material

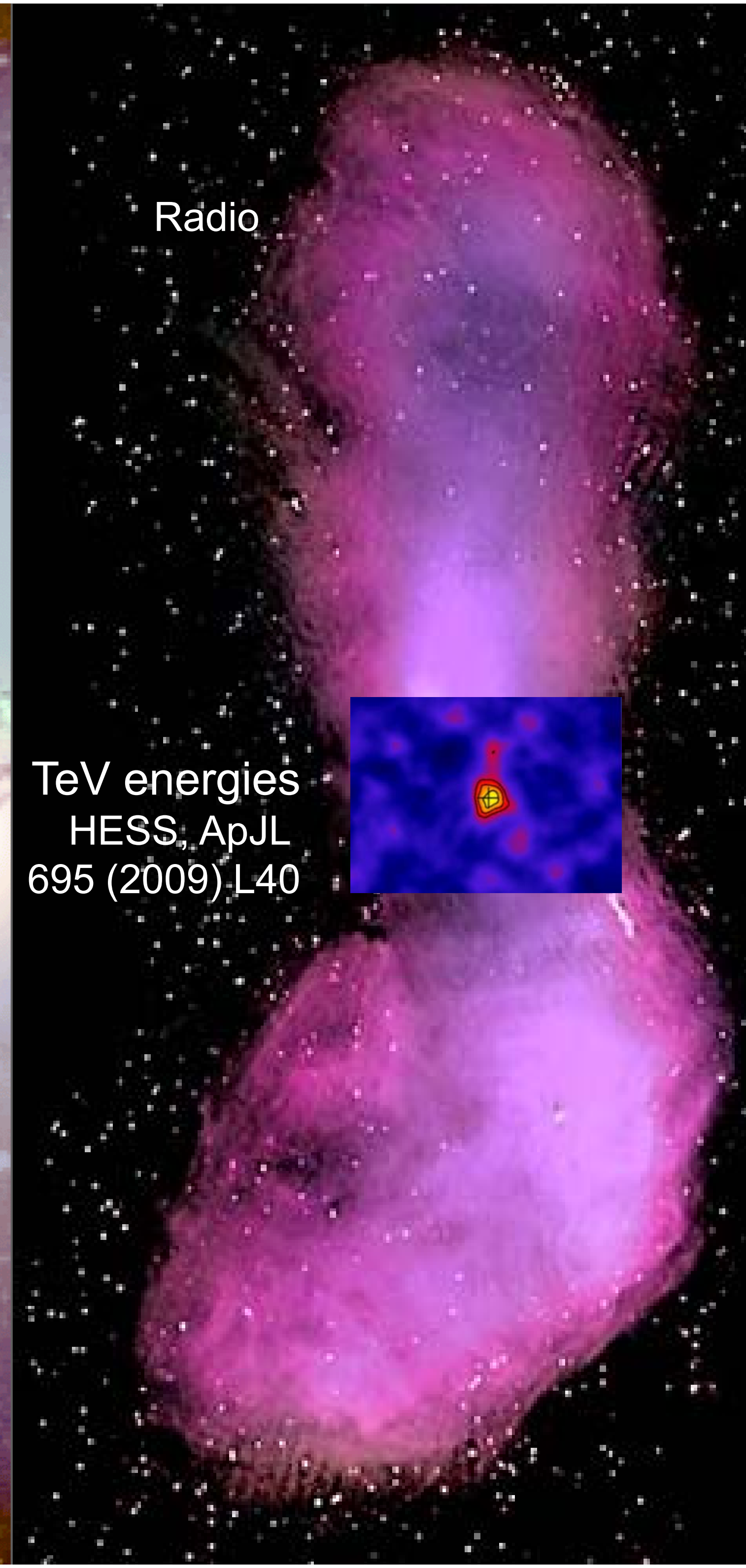
but …

- Which particles are accelerated?
- Can we quantitatively account for the CR spectrum and yield?
- How and when are the particles released from the accelerator ?
- How do they propagate away from accelerator?

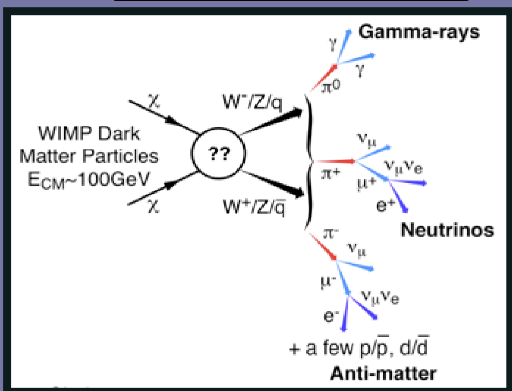
There is now good evidence for SNR acceleration of CRs, but there is still a lot to understand.

Active galactic nuclei and their jets



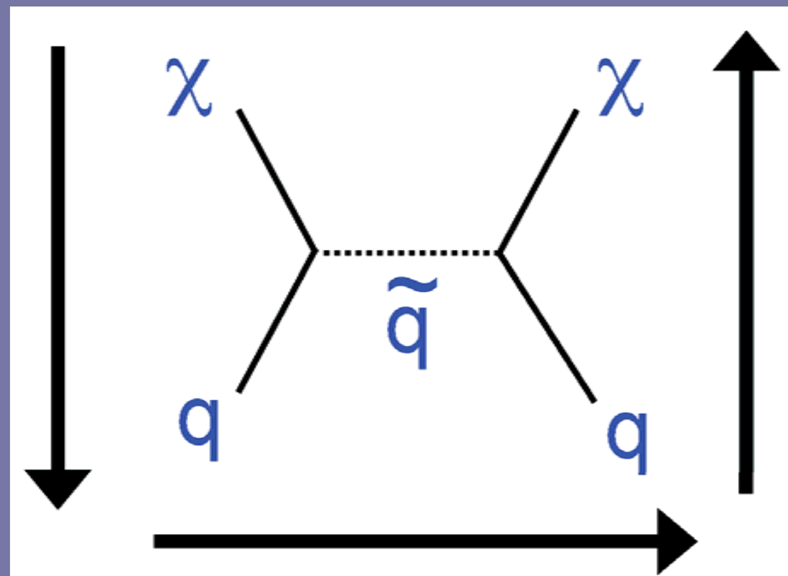


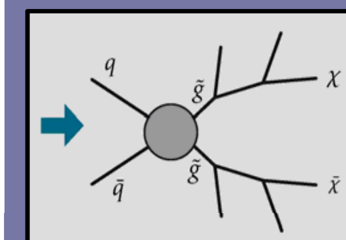
WIMP DM Complementary Approaches

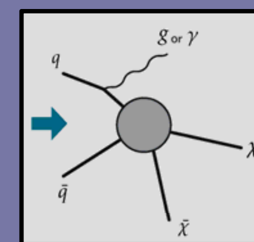


WIMP annihilation
In the cosmos

Indirect Detection

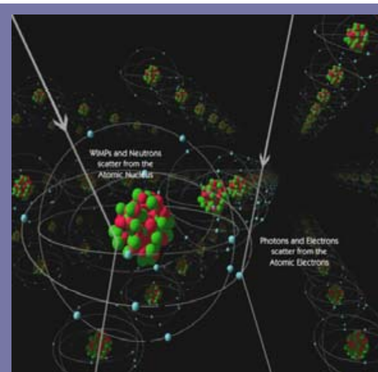






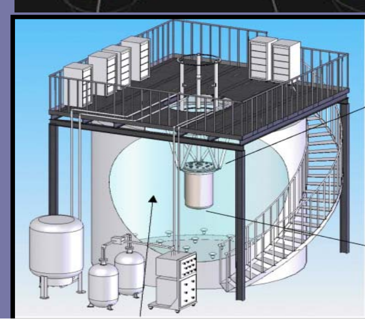
Heavy particle prod.
MET + jets
Weak pair prod.
MET + monojet

LHC Production



WIMP-Nucleon
Elastic scattering

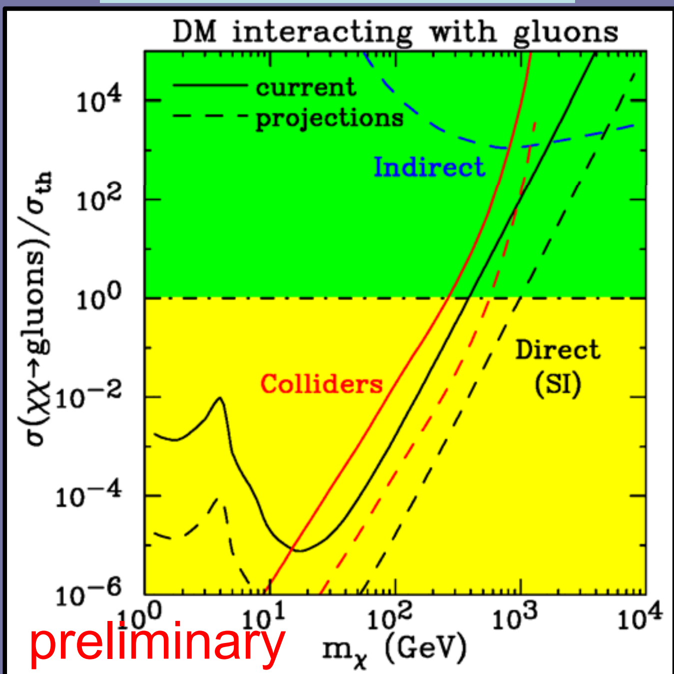
Direct Detection



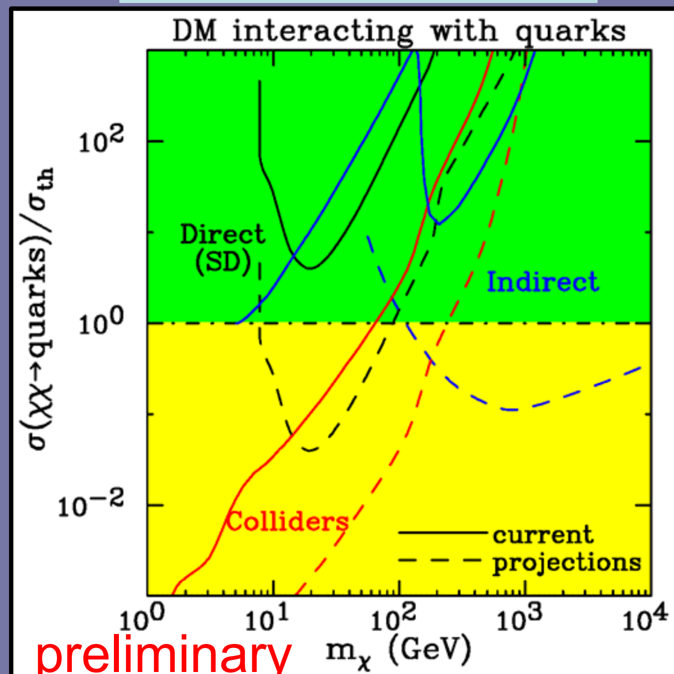
WIMPs: a More General Framework

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

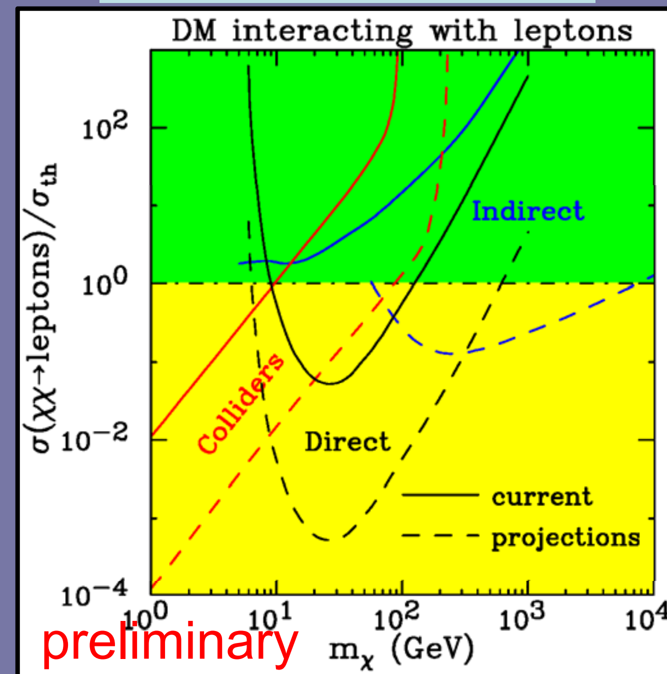
Gluon Interactions



Quark Interactions



Lepton Interactions

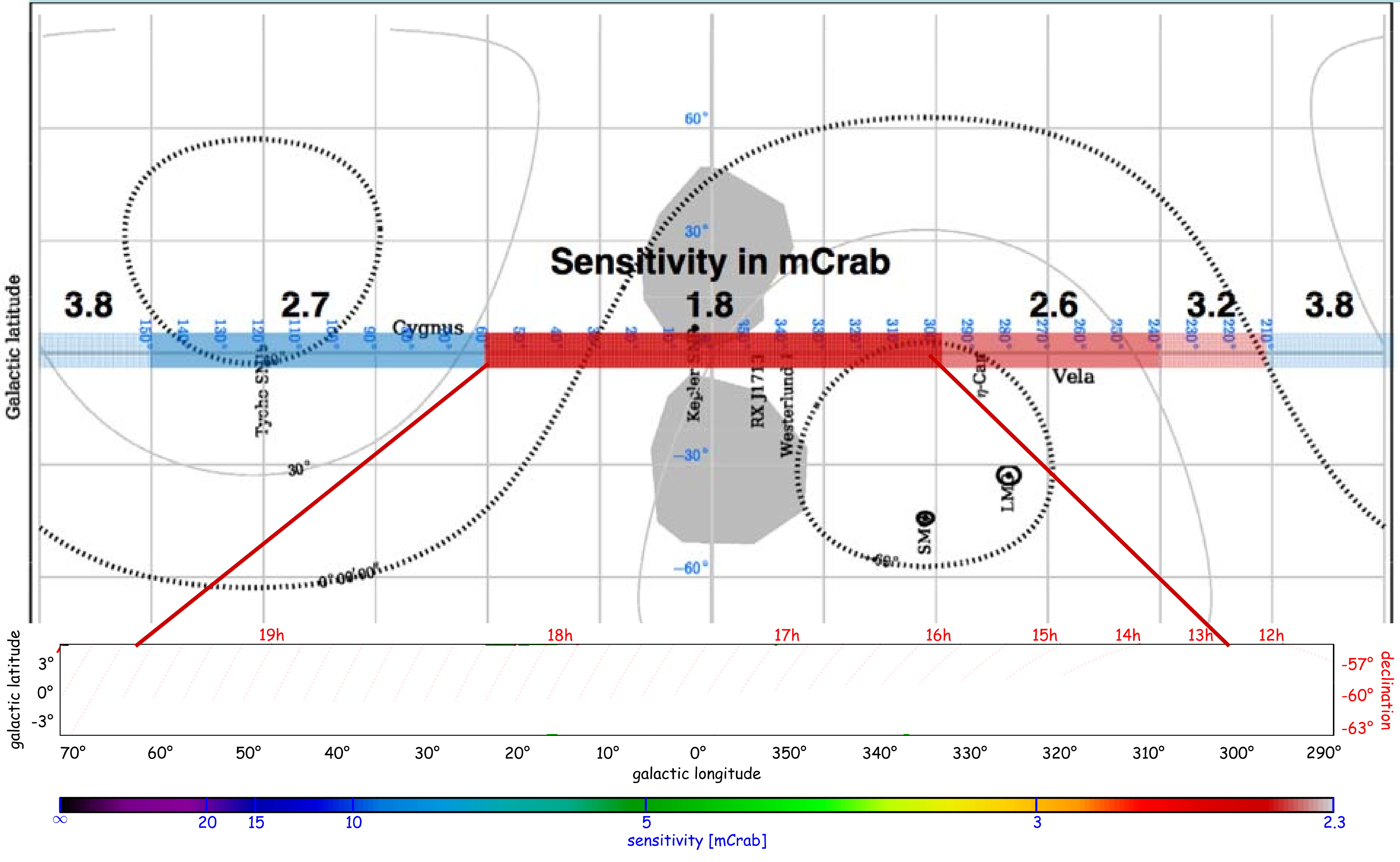


1.0 = expected thermal relic cross-section

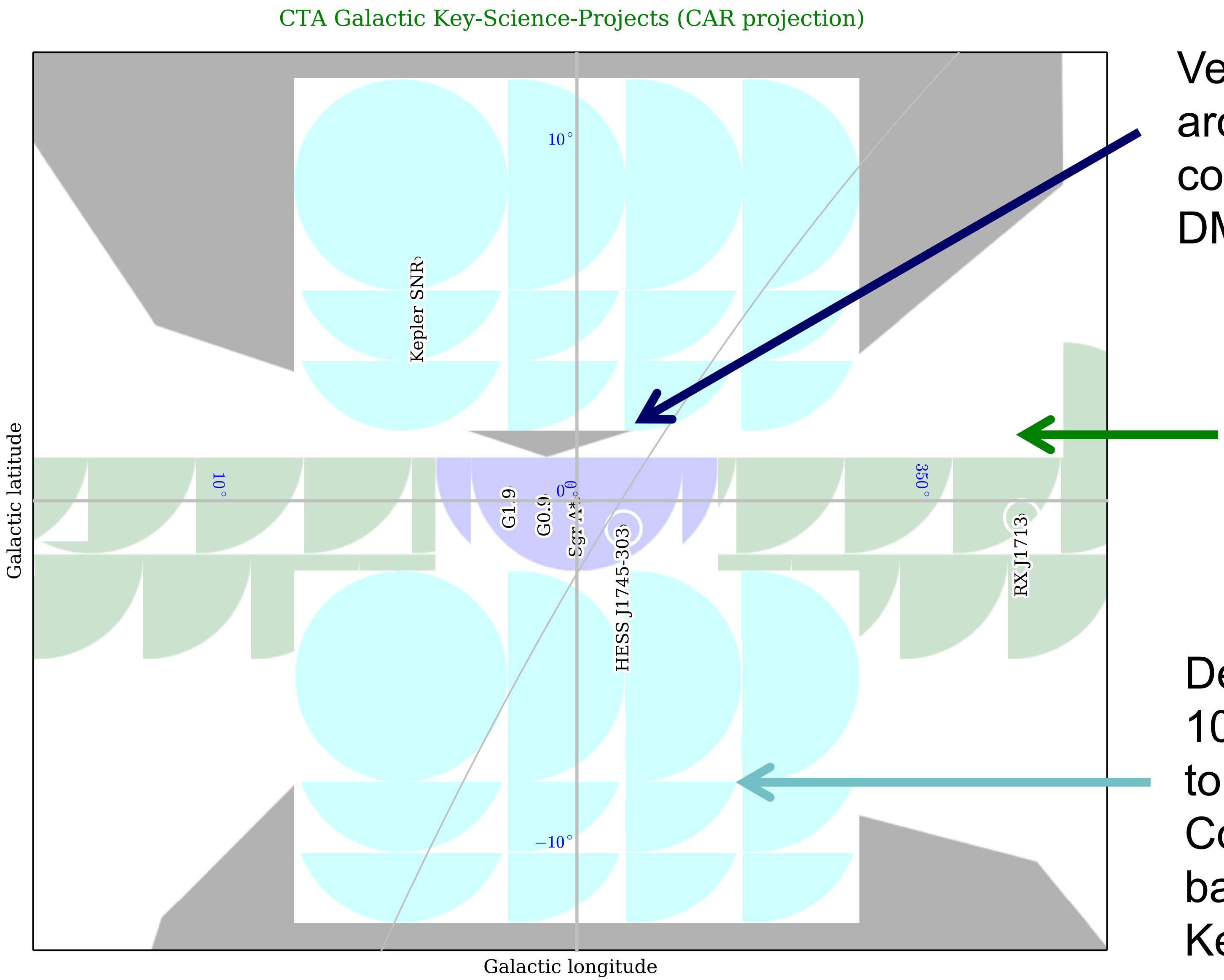
- **For gluon/quark interactions, LHC competitive or dominates at energies below ~few 100 GeV.**
- **For gluon and lepton interactions, direct expts. are important.**
- **For quark and lepton interactions, indirect expts are important.**

Galactic Plane Survey (GPS)

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



Galactic Center



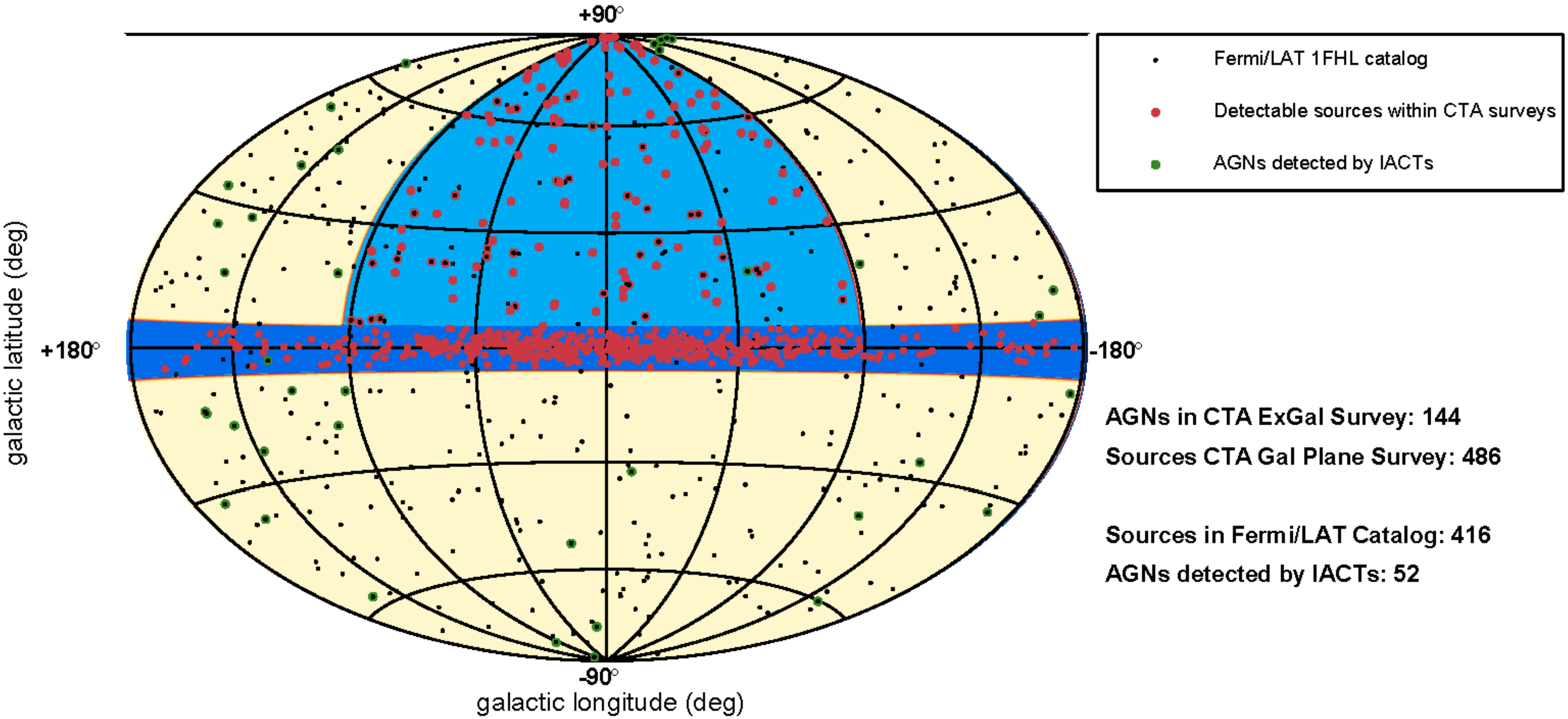
Very deep exposure around SGR A*, covering central source, DM halo, radio lobes

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

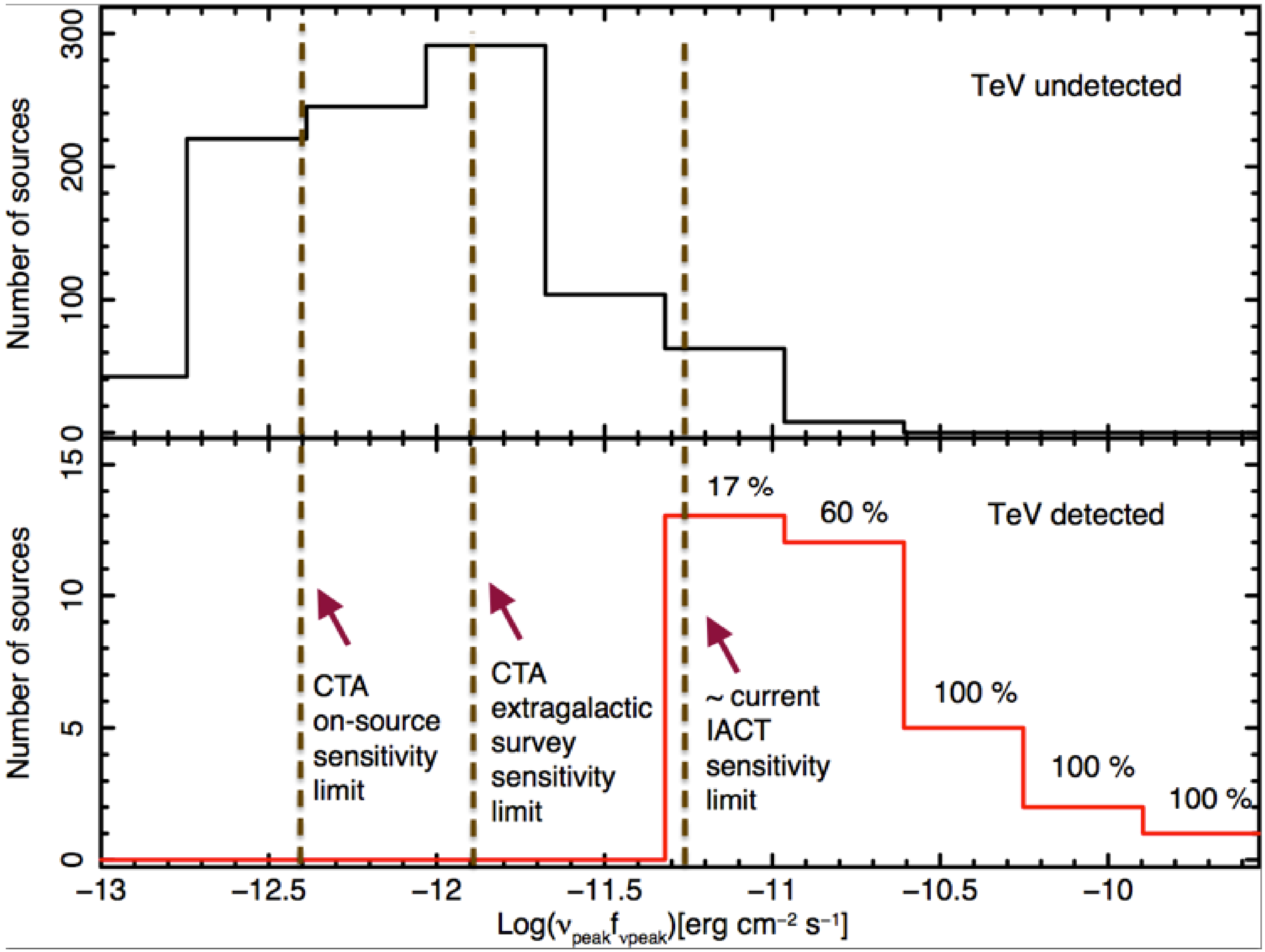
Survey ~1/4 of sky (adjoining GPS)



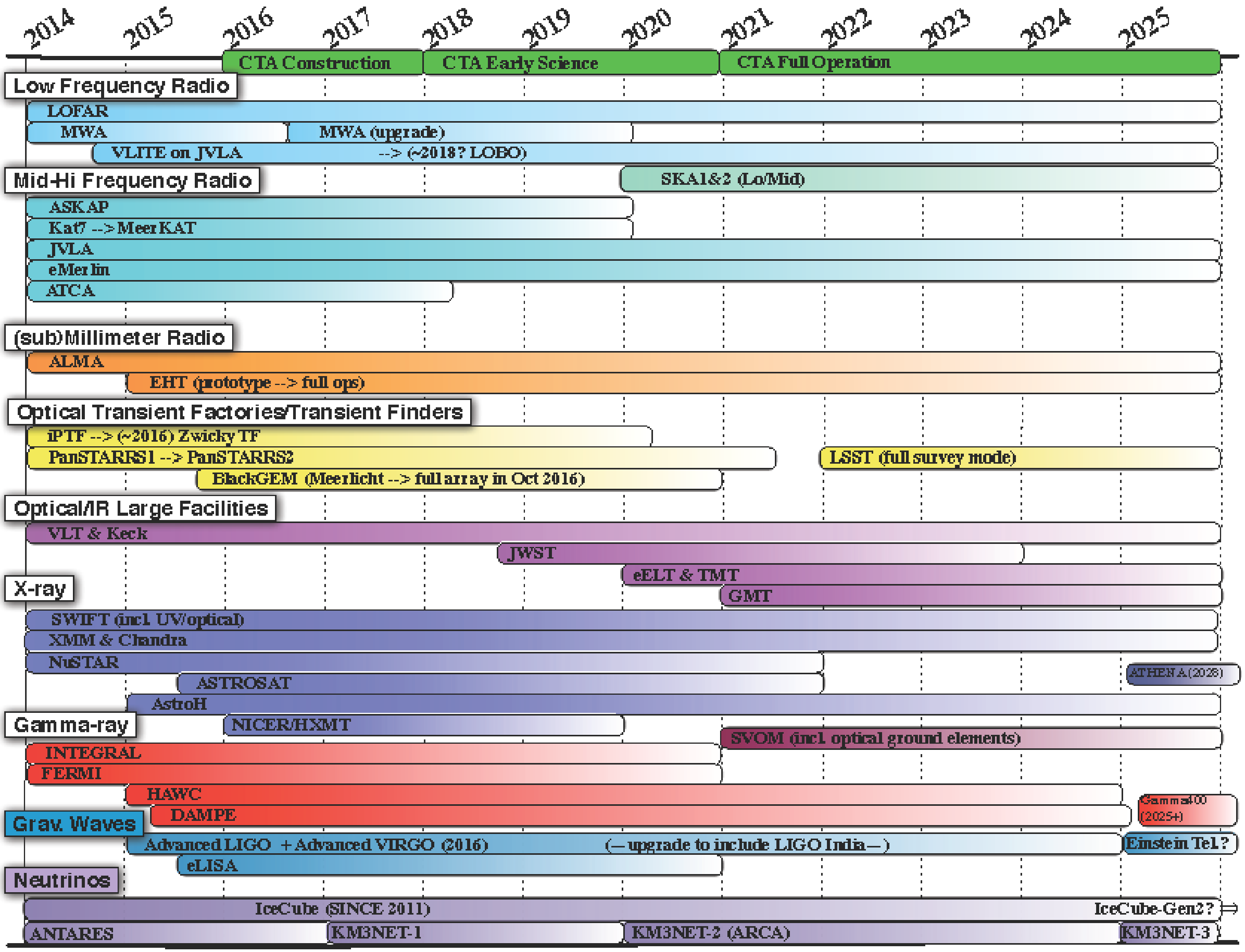
- Unbiased sample of blazars, log N – log S, extreme blazars, etc.
- Wider coverage of serendipitous events – e.g. GRBs
- Unexpected phenomena – e.g. ULIRGs, Seyferts, dark clumps,

Extragalactic Survey

Blazar luminosity function



Important MWL Synergies



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

Science Themes

Theme 1: Cosmic Particle Acceleration

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

Theme 2: Probing Extreme Environments

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

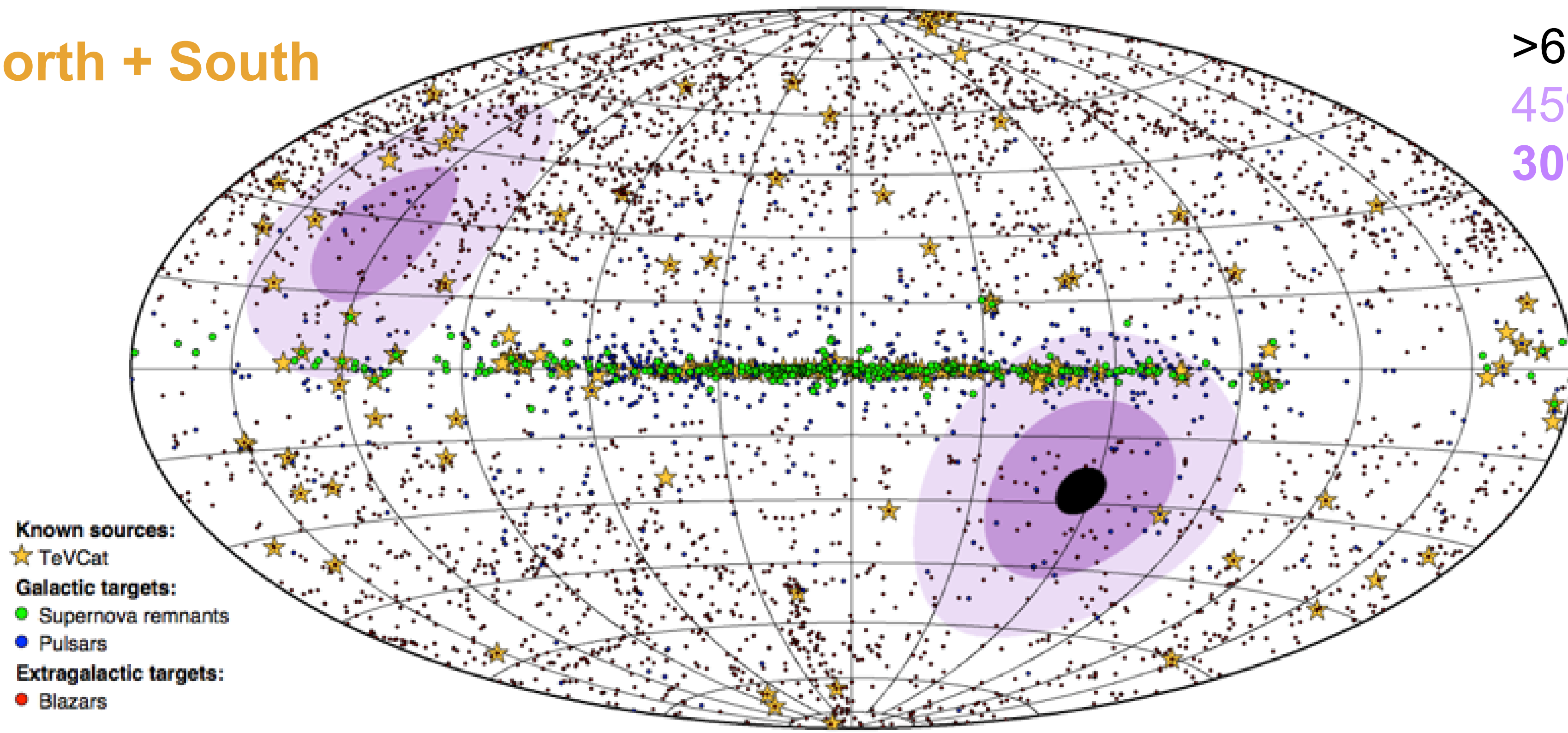
Theme 3: Physics Frontiers – beyond the SM

- 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?

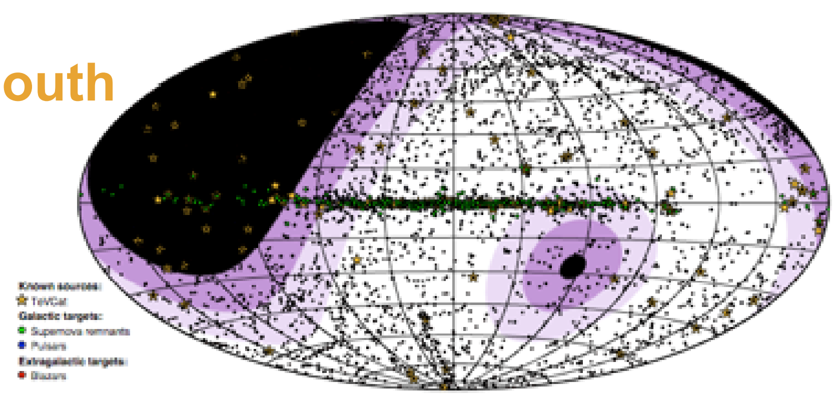
Full Sky Coverage

North + South

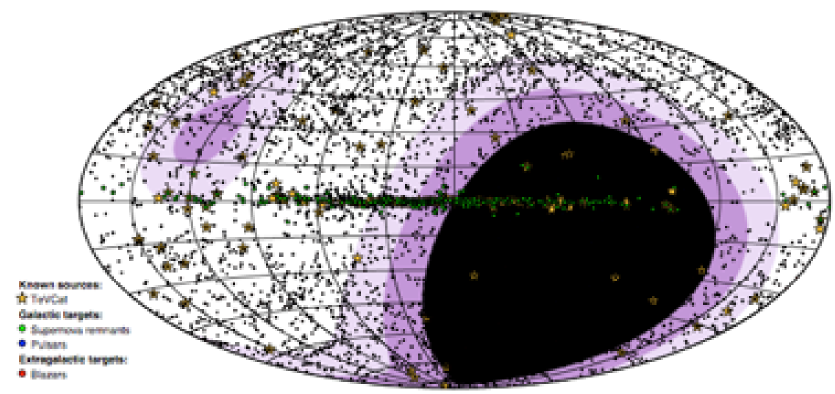
>60º zenith
45º-60º
30º-45º



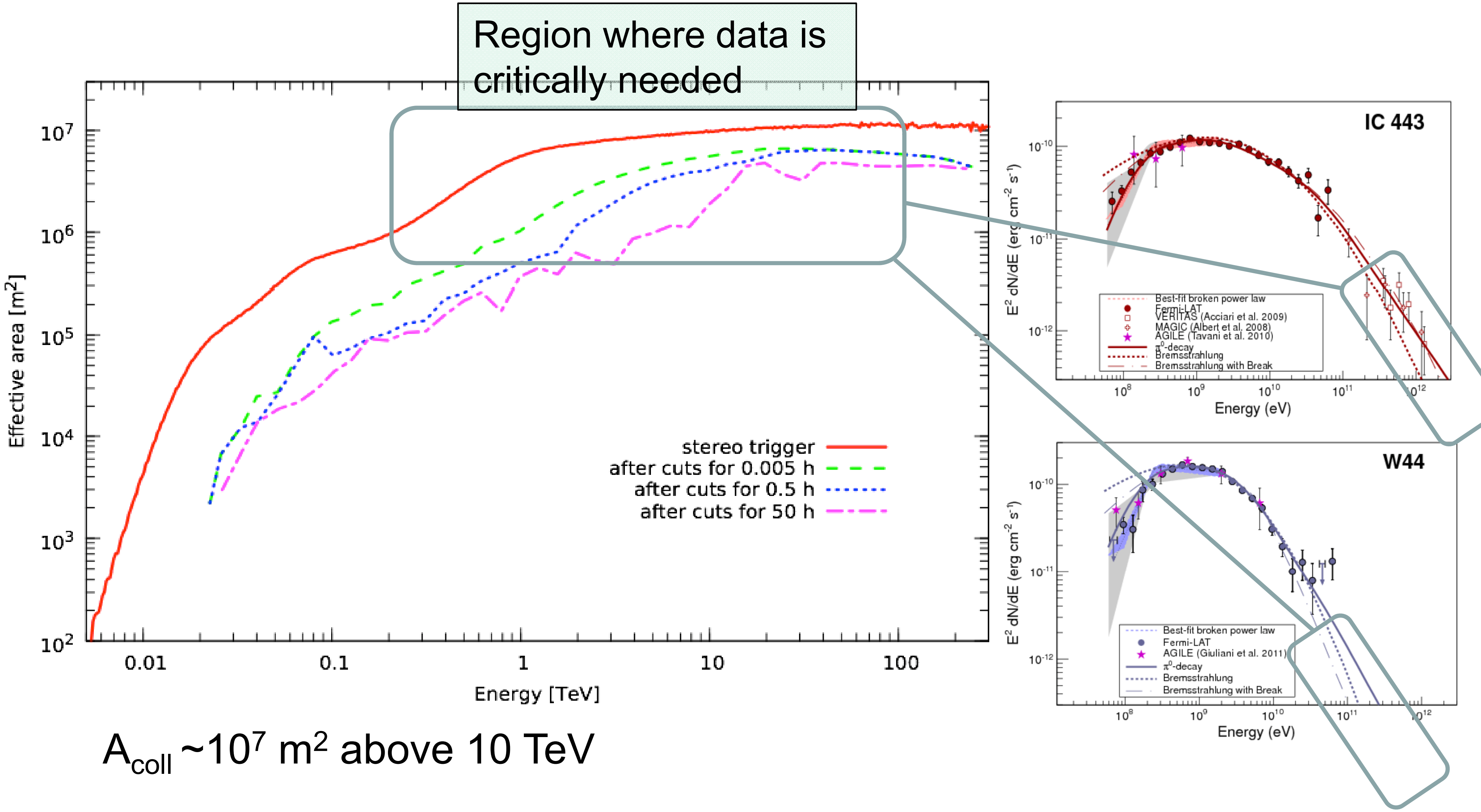
South



North



CTA Collection Area

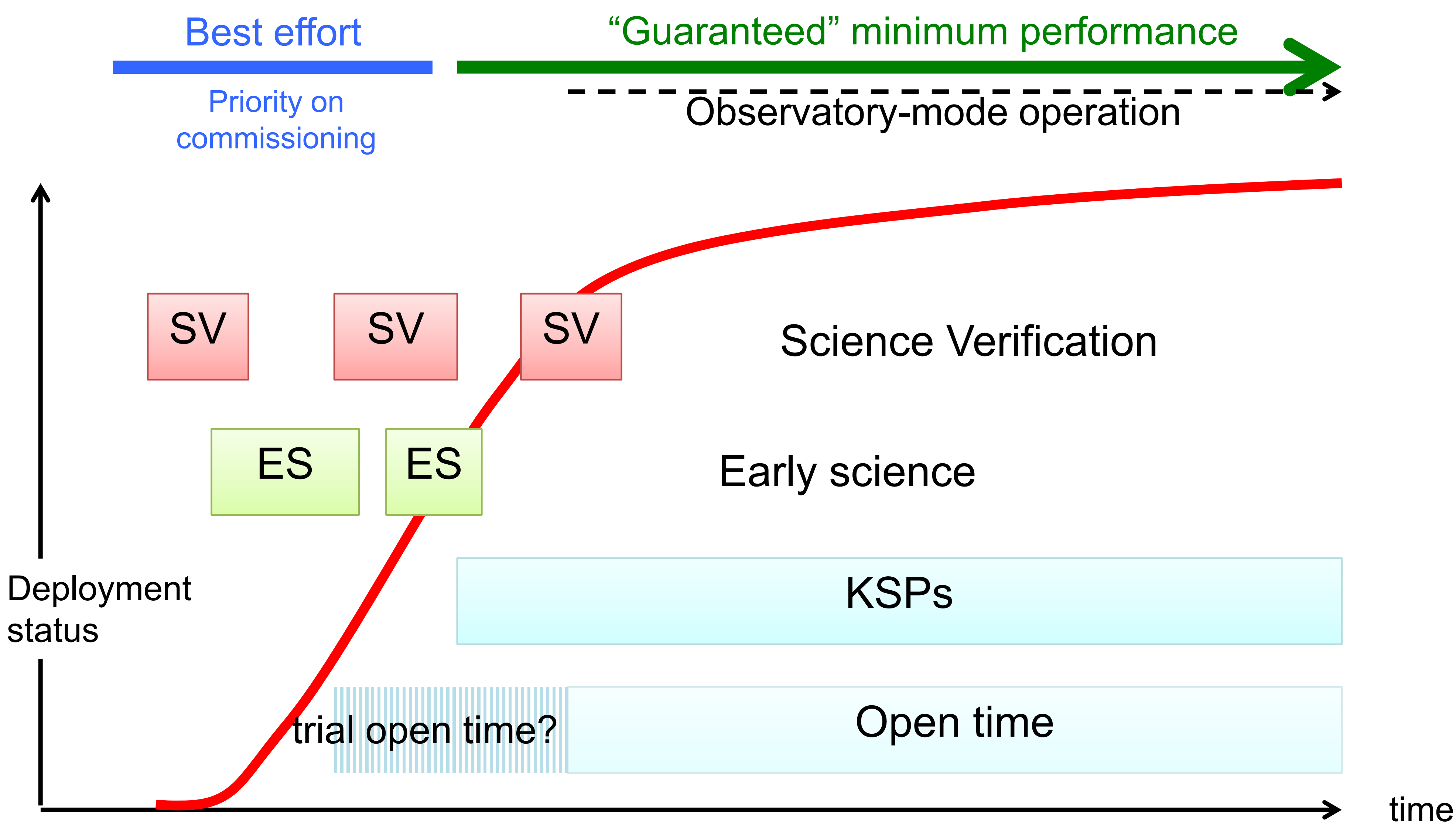


$A_{coll} \sim 10^7\ m^2$ above 10 TeV

Crucial for:

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

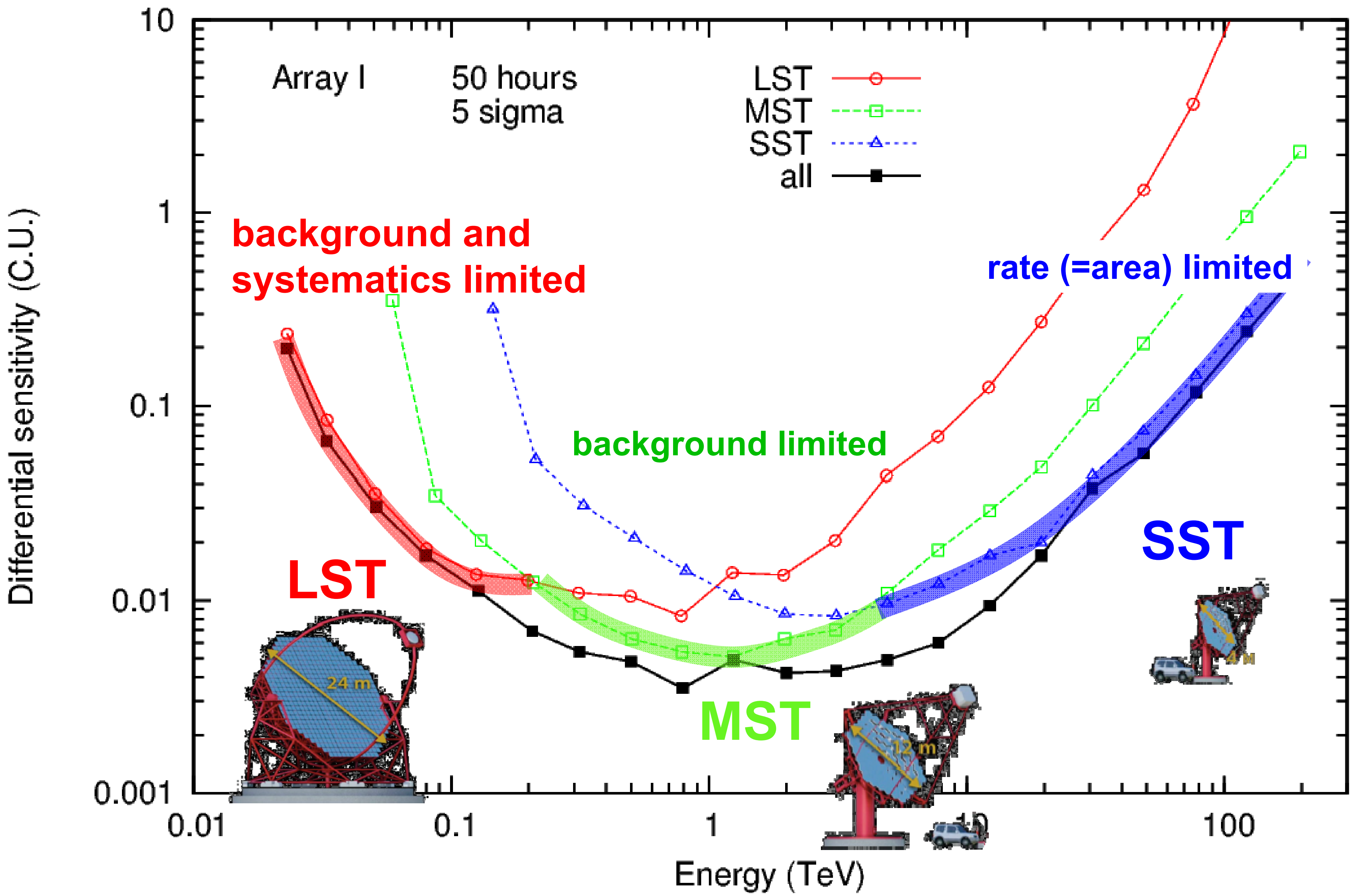
Science Verification, Early Science



This is a notional view !

Flux Sensitivity (Crab units)

For detection in each 0.2-decade energy bin



Telescope Specifications

cta cherenkov telescope array

SiPM Cameras

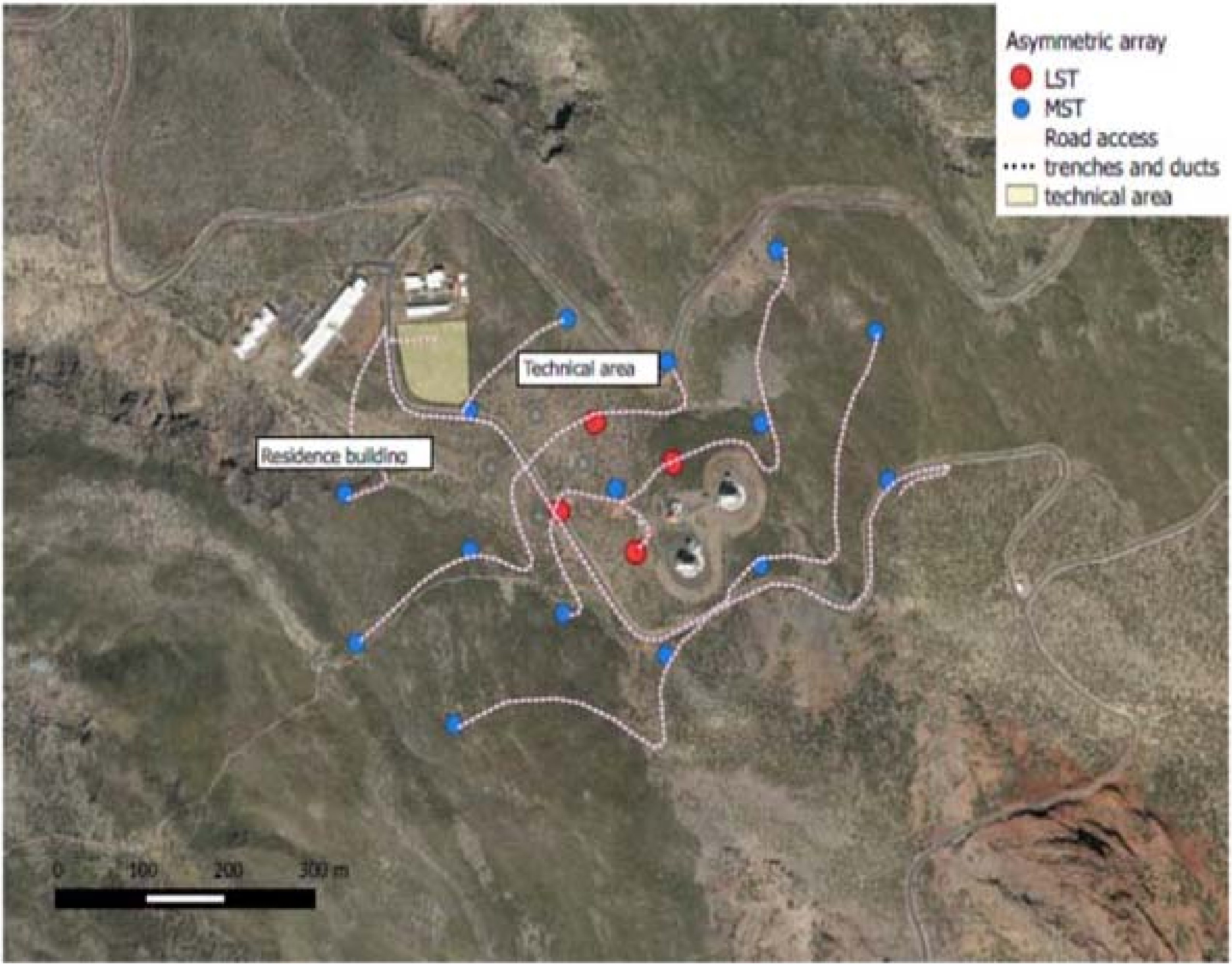
3 SST types

	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

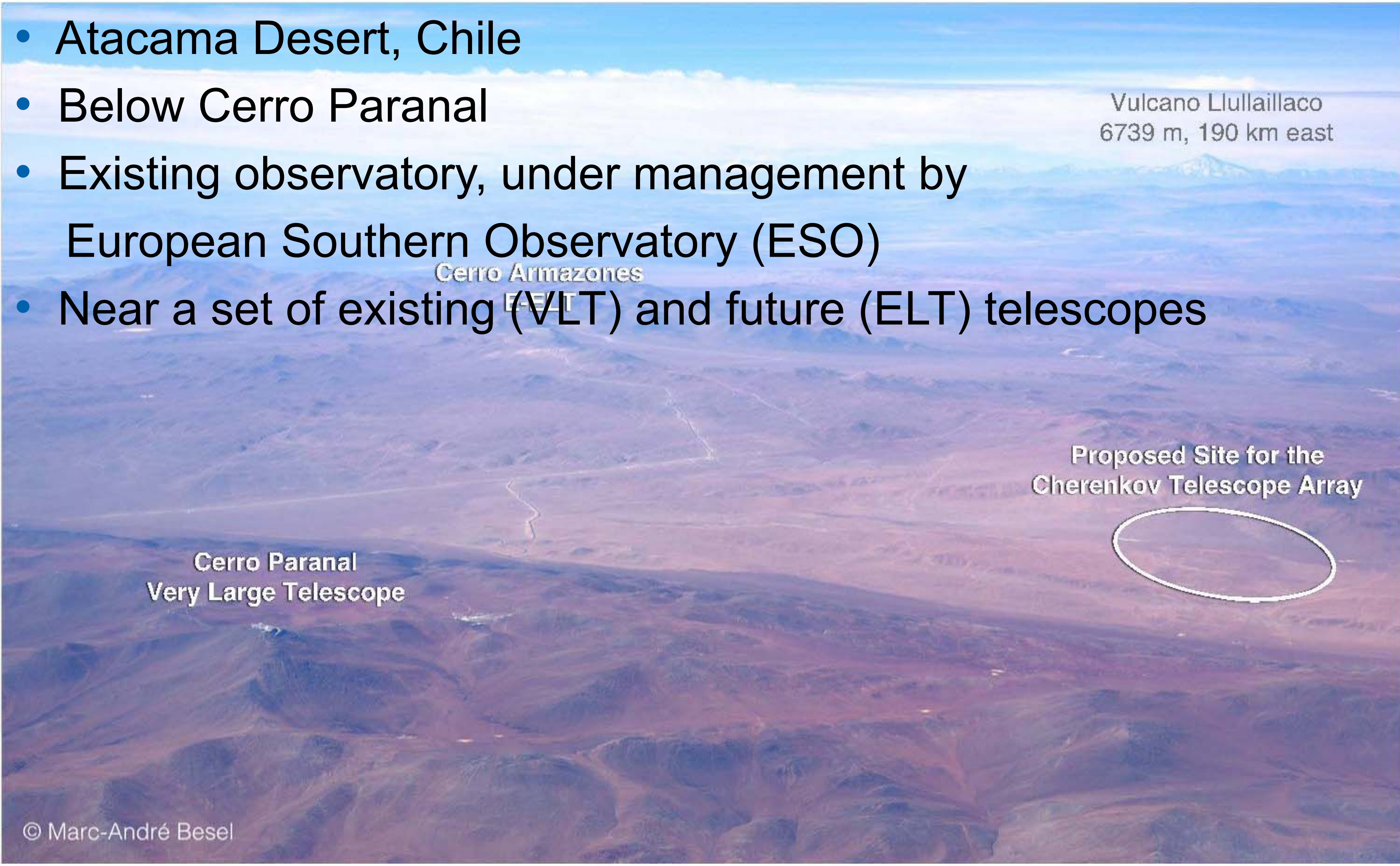
- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
- Site of LST prototype & existing MAGIC telescopes

LA PALMA – Possible Layout

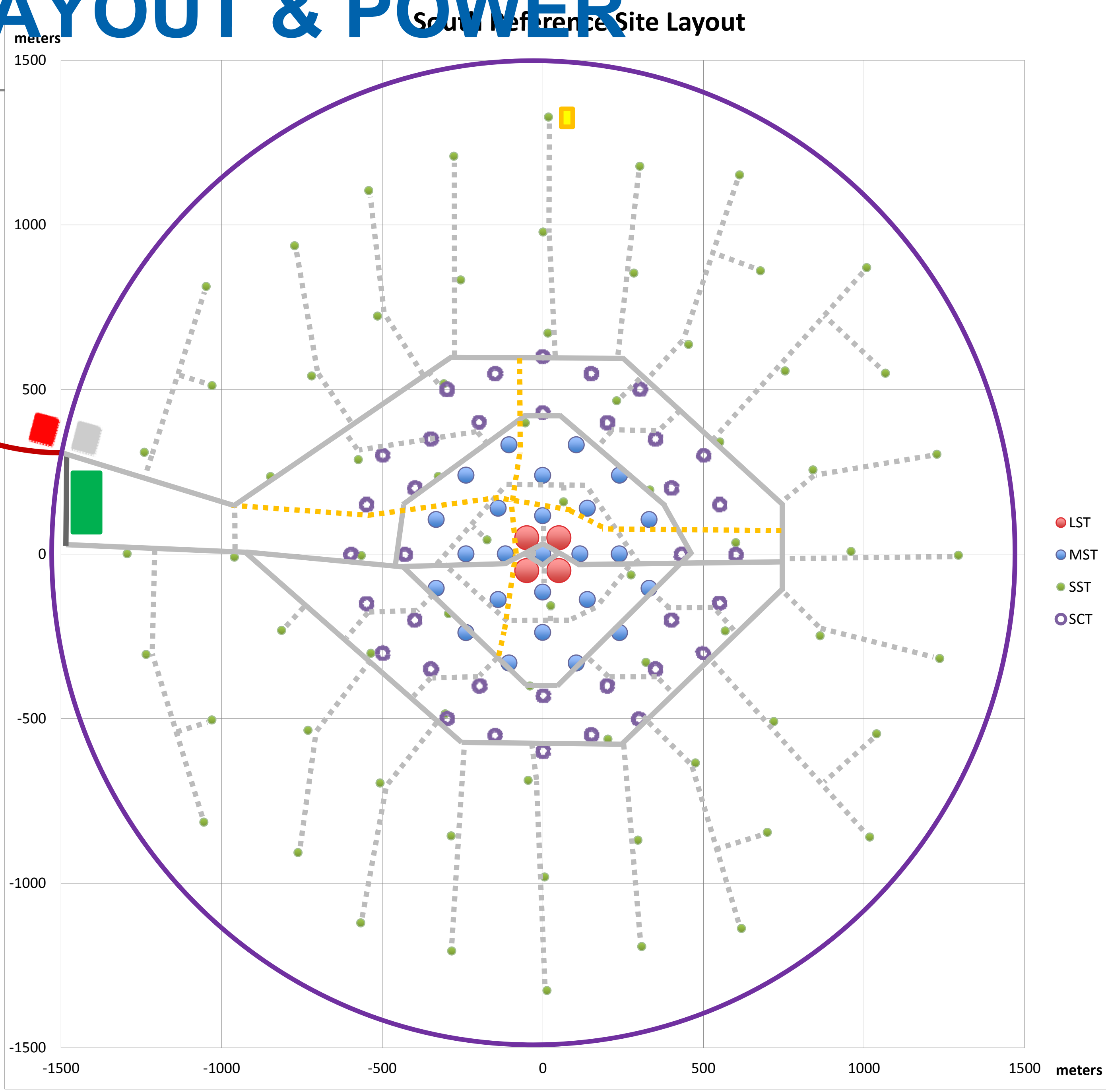


ESO/PARANAL

- 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



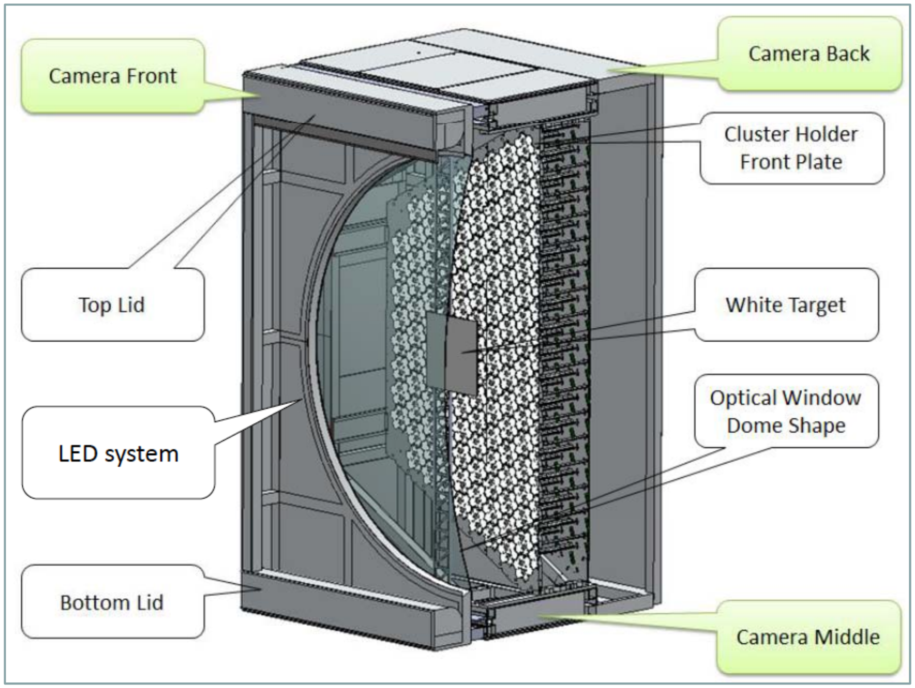
ESO/PARANAL – POSSIBLE LAYOUT & POWER



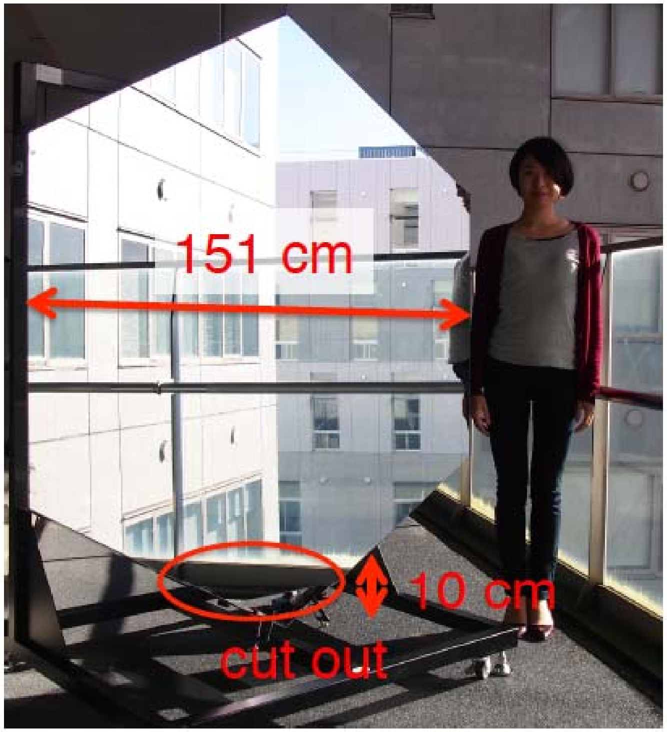
LST Full Prototype

Elevation drive prototype

Prototype Camera design



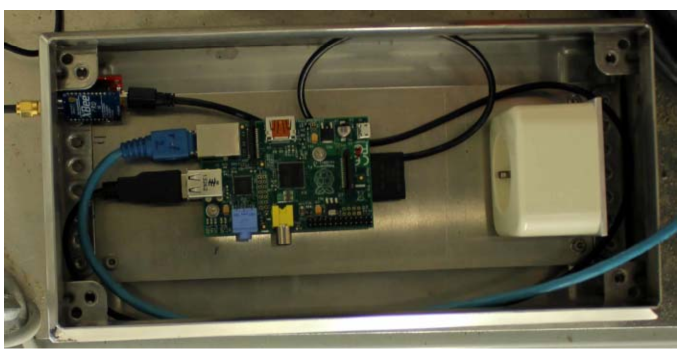
Mirror prototype
(cold-slump, Sanko)



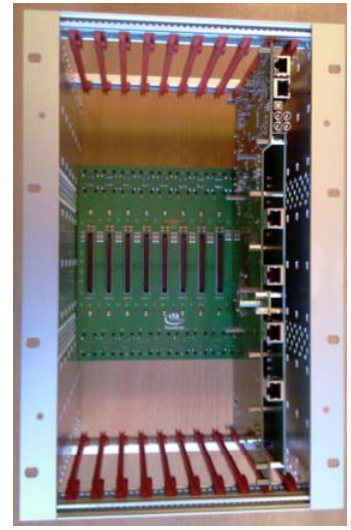
Area = 1.96 m^2
Mass = 47 kg

MST Cameras and Mirror Control

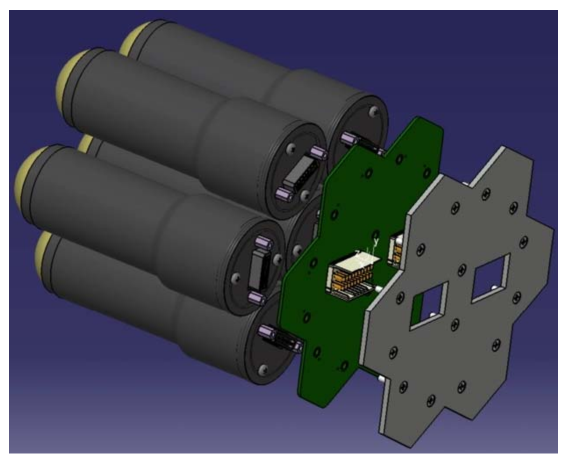
Prototype automatic mirror control (AMC)

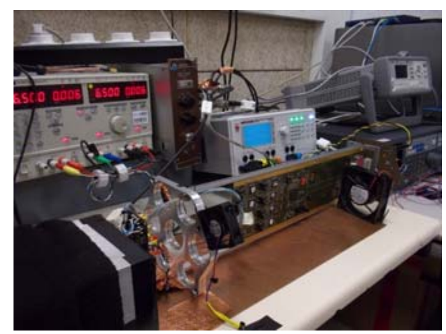


Flash-ADC + digital trigger + rack electronics (“FlashCAM”)



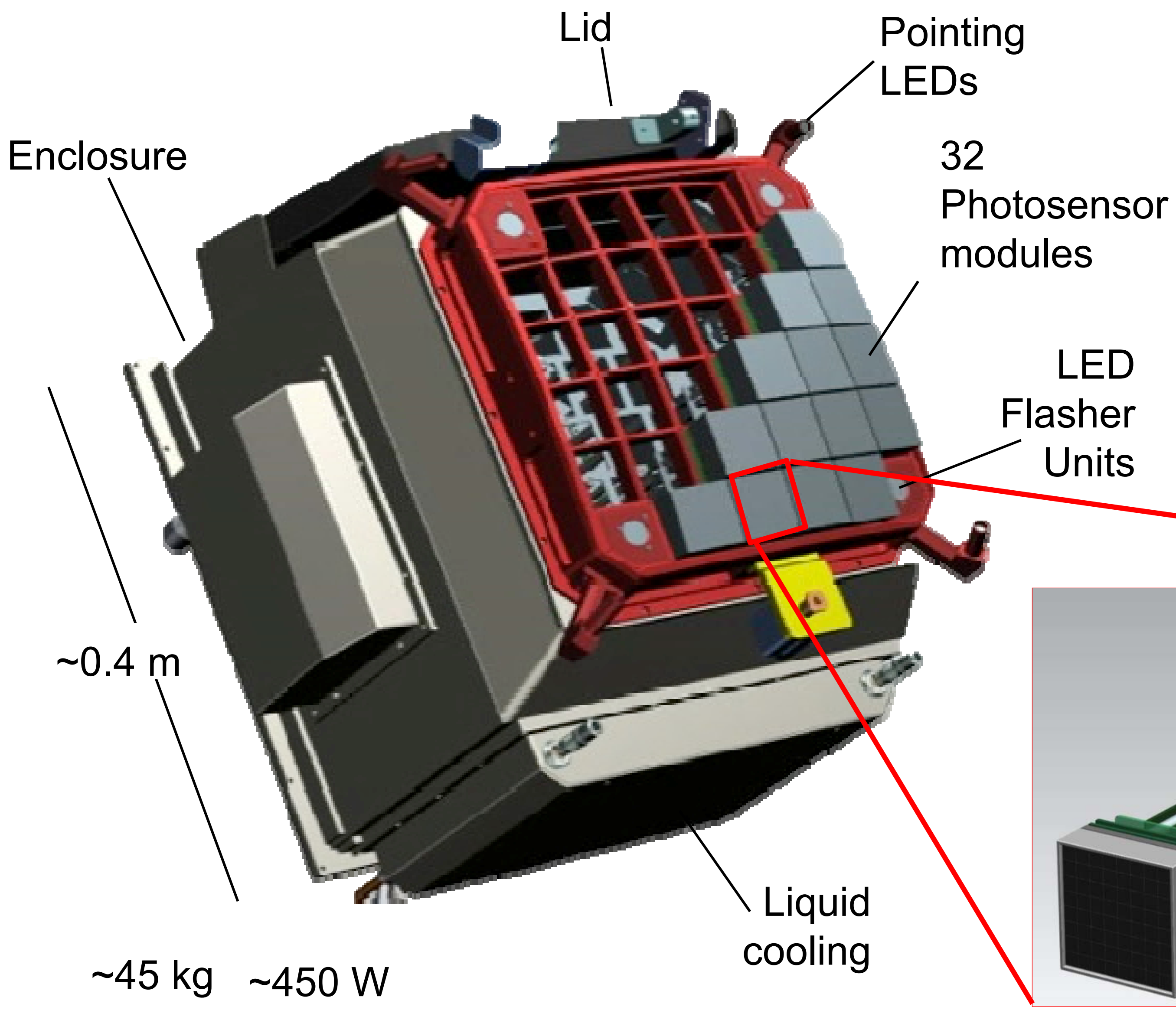
Capacitor pipeline + analog trigger + fully-contained “drawers” (“NectarCAM”)

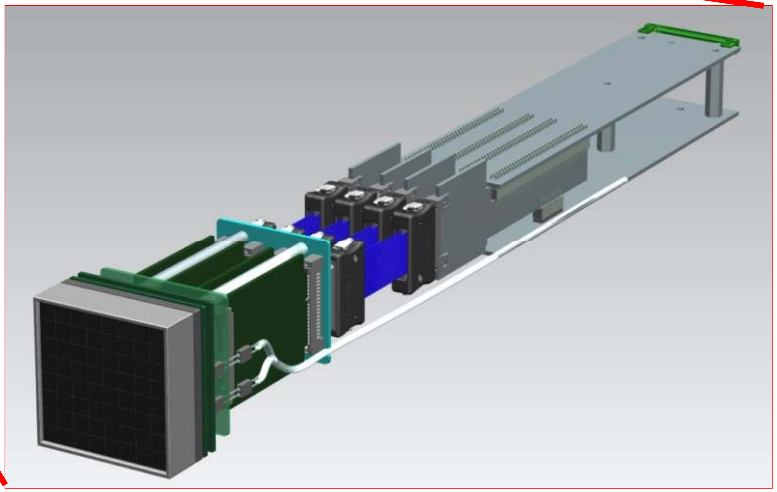




Nectar-board prototype

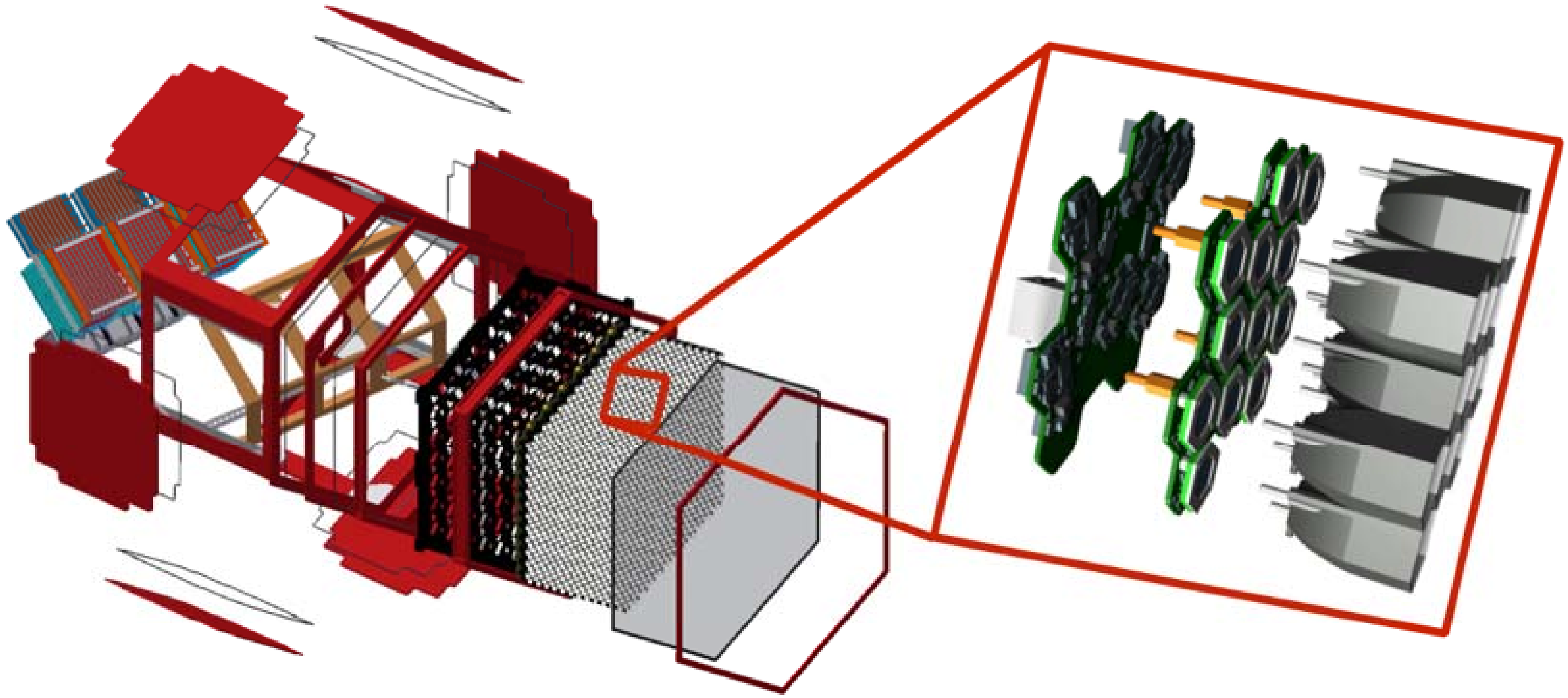
SST-2M-GCT Camera + Module

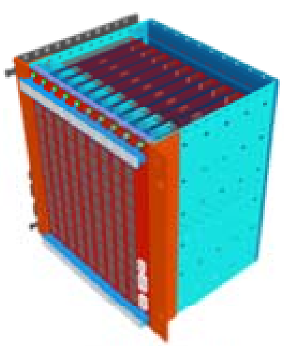




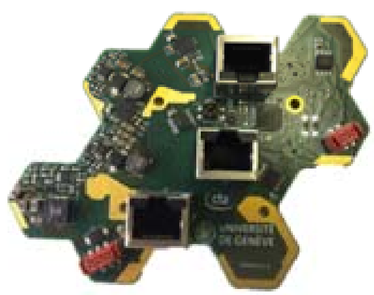
Photosensor module

Silicon-PMT Camera

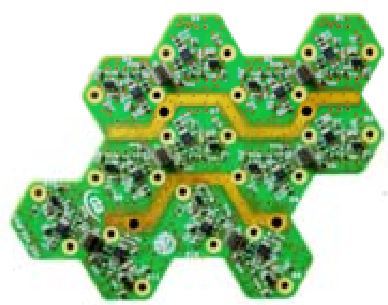




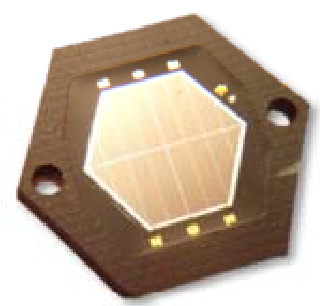
DigiCam



Slow Control Board



Preamplifier board



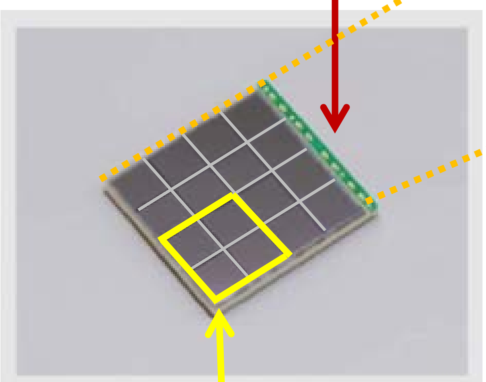
Hexagonal sensors

Light guides

SST-2M -ASTRI Focal Plane

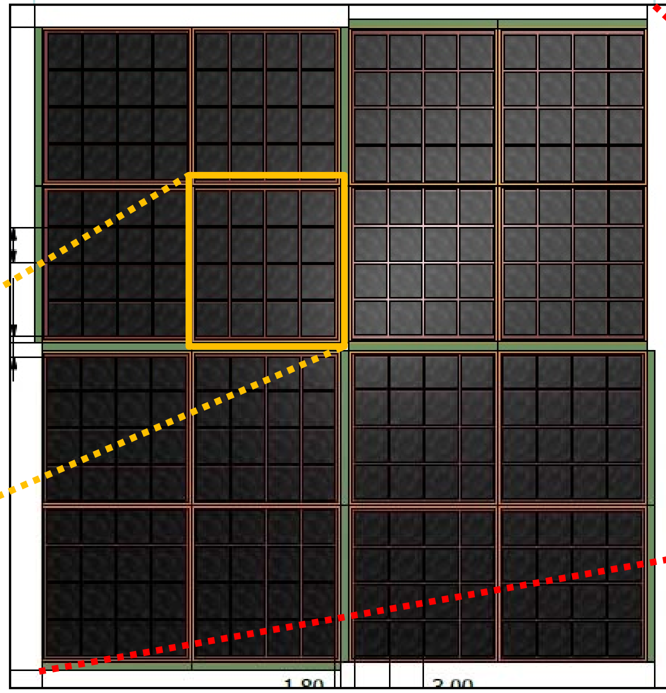
S11828-3344M1
the 'Unit'

geometrical dead area



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

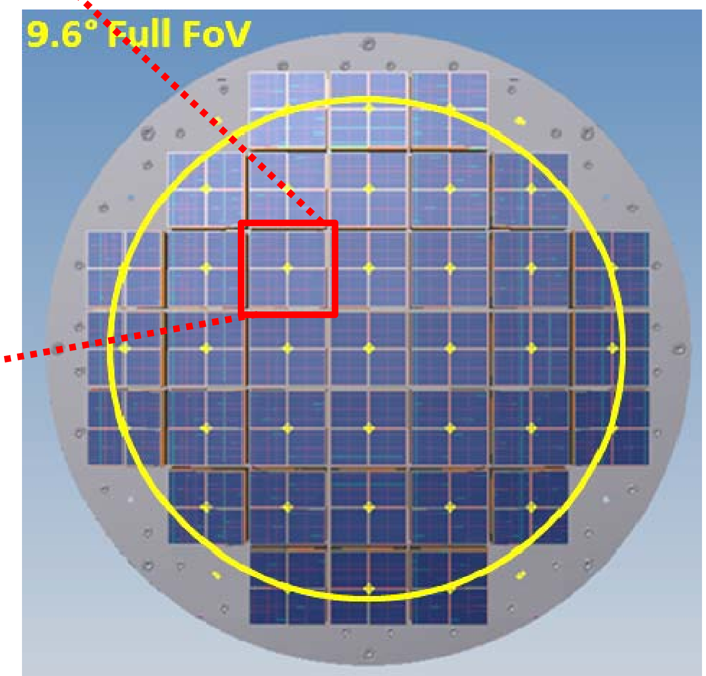
Photon Detection Module
PDM



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

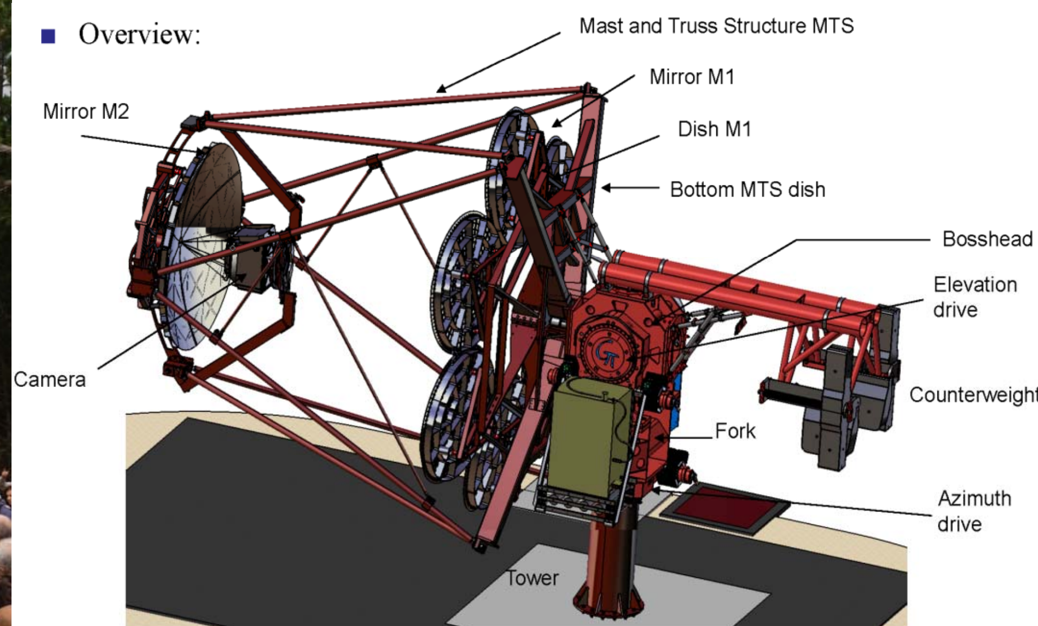
Each PDM works independently from the others

ASTRI Focal Plane



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

Small Telescope 2-mirror (SST-2M)



SST-2M –ASTRI Prototype Inauguration, 24 Sept 2014 (Serra La Nave, Sicily)

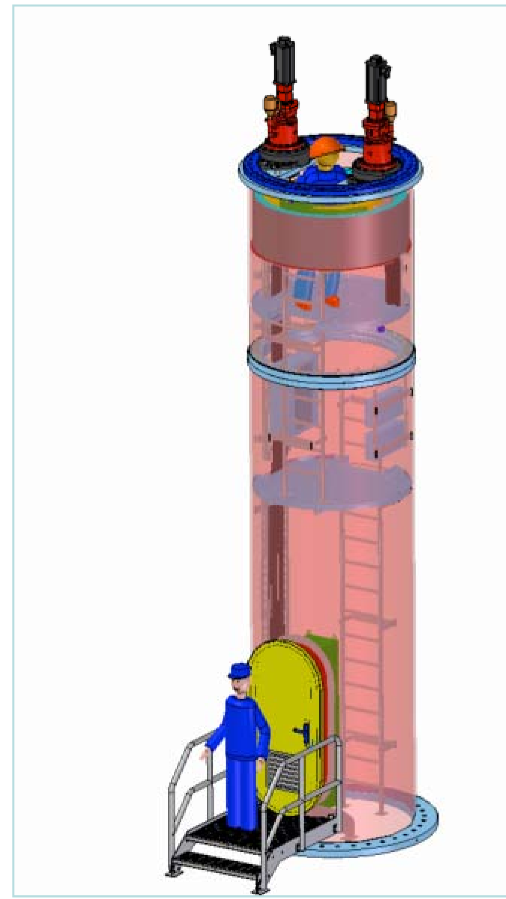
SST-2M-GCT (Gate-CHEC Telescope)

Both 2-Mirror SST Designs use compact, Silicon-PM Cameras

SCT Prototype @ Whipple Obs.

Prototype location at Whipple basecamp
(near VERITAS, Arizona USA)

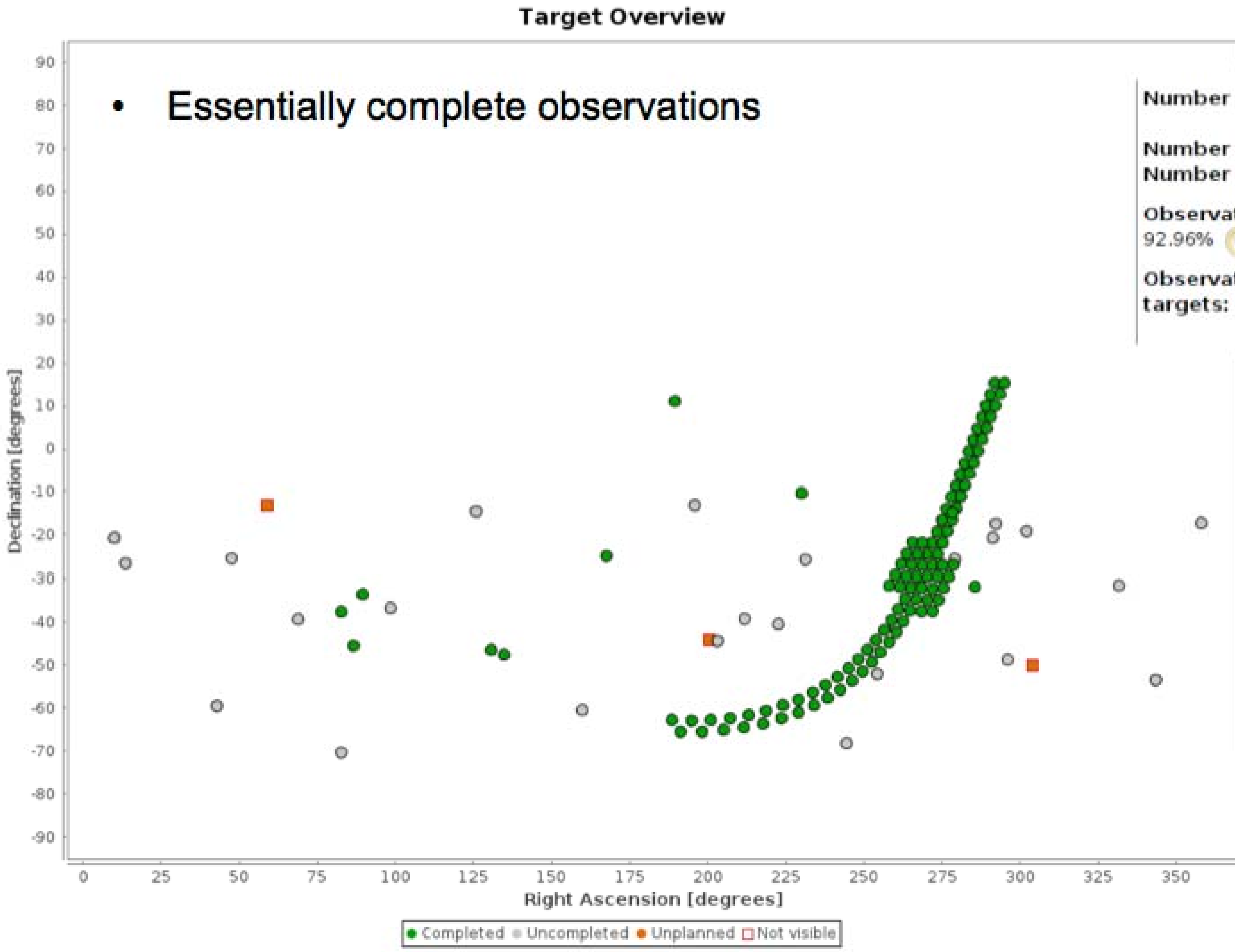
Fall : Assembly of telescope
Delivery of camera
Start of comissioning



Positioner from DESY
(Same as MST)

Observing Schedule (S, Yrs 1-2)

- Essentially complete observations



Number of days planned: 731

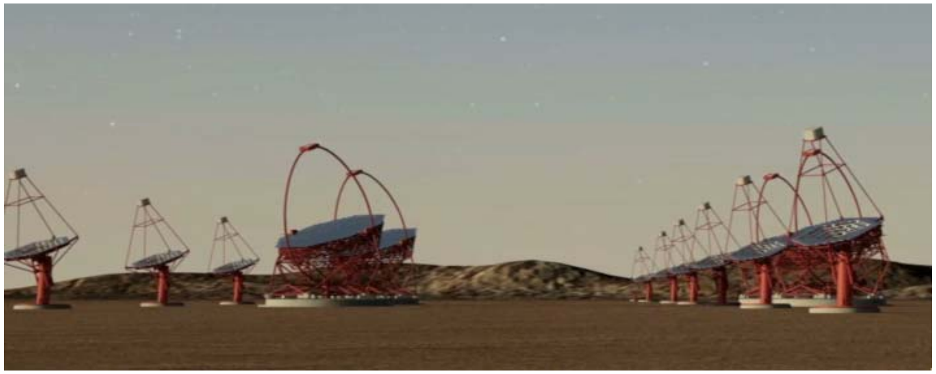
Number of total targets: 113
Number of planned targets: 110 Details

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.

HAWC & CTA

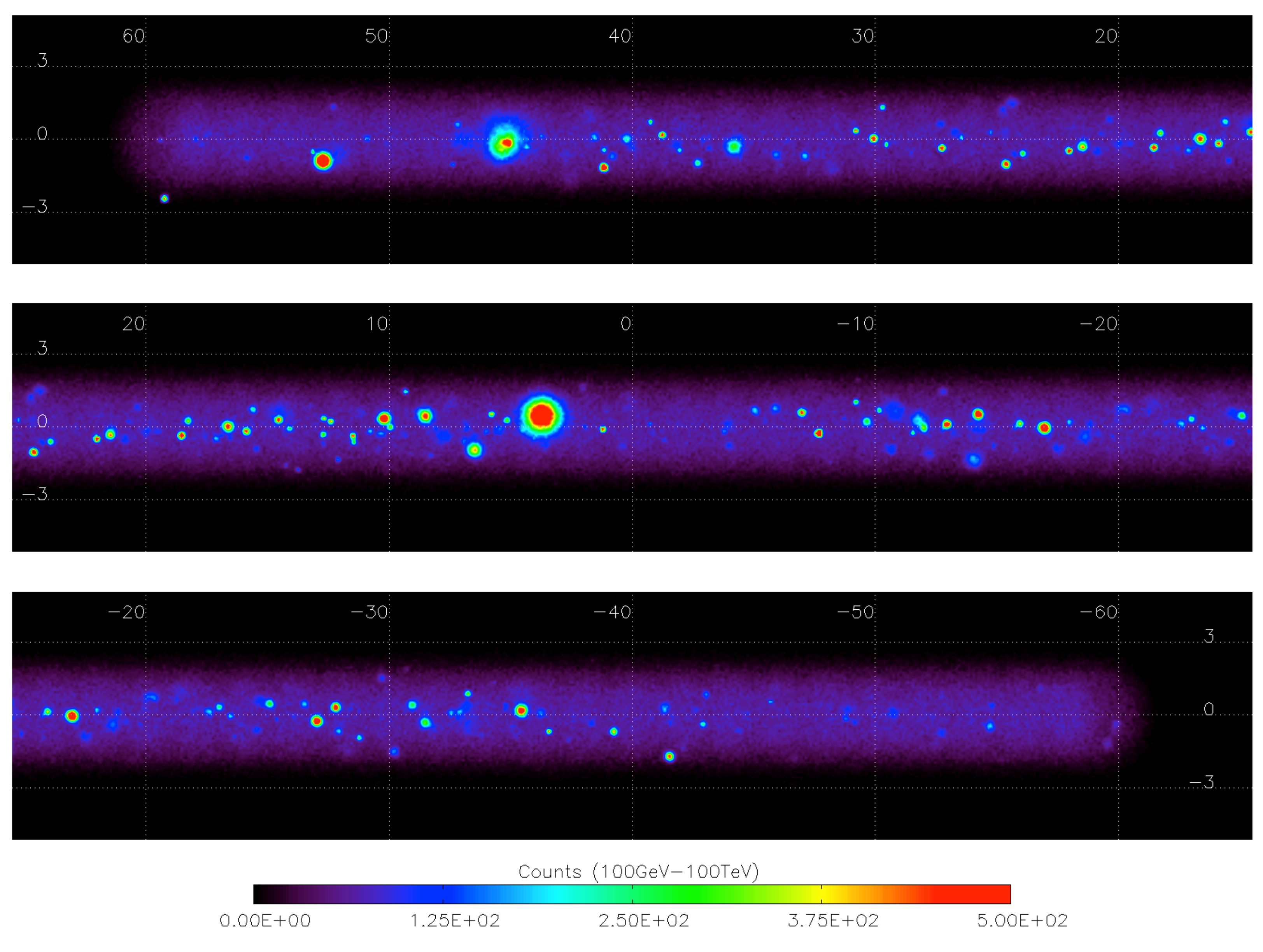


Wide FOV	Moderate FOV
Medium sensitivity	High sensitivity
Moderate resolution	High resolution
100% duty cycle	15% duty cycle
N hemisphere	N & S hemispheres

Complementary Capabilities !

We can envision many ways to collaborate effectively

CTA Galactic Plane Survey

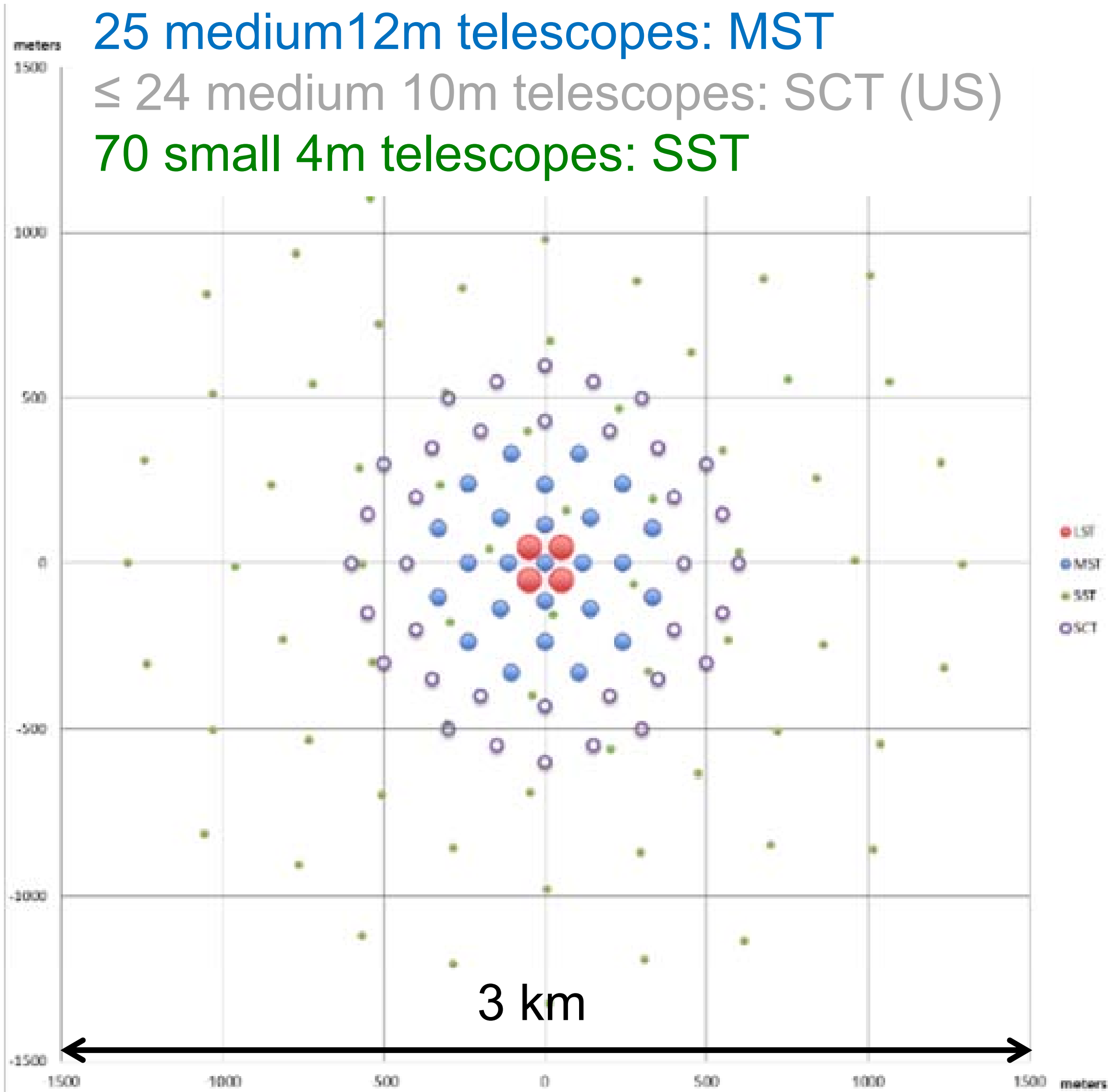


Simulation for | l | < 60°

Possible Layouts for N,S Arrays

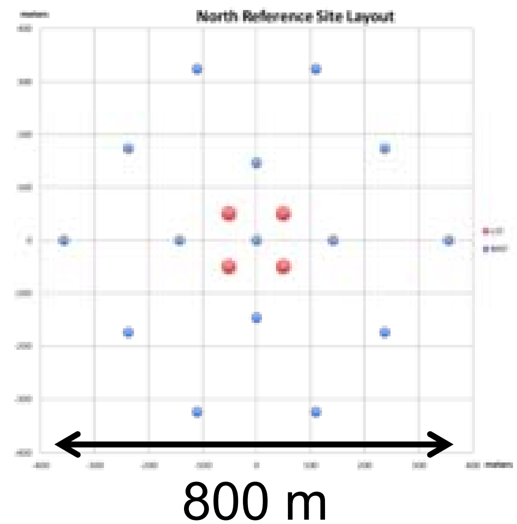
South site

4 large 23m telescopes: LST
25 medium12m telescopes: MST
≤ 24 medium 10m telescopes: SCT (US)
70 small 4m telescopes: SST



North site

4 large LST
15 medium MST



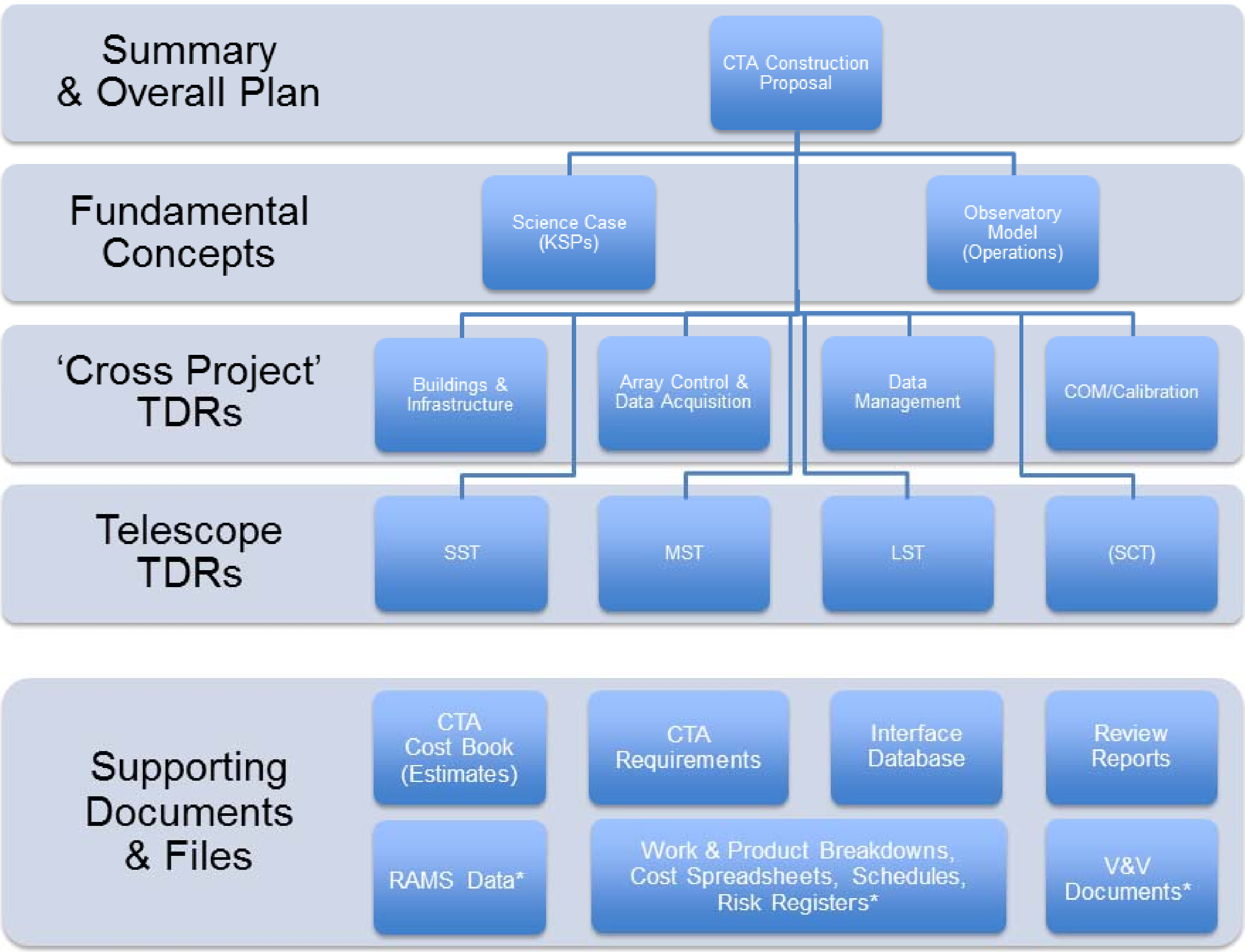
Key Science Projects (KSPs)

The KSPs are:

- to ensure that some of the key science questions for CTA are addressed in a coherent fashion, with well-defined strategy,
- typically hard to carry out within a Guest Observer program,
- planned, proposed, carried out by CTA Consortium under guaranteed time, and
- conceived to provide legacy data sets for use by the entire community.

TDRs Delivered on May 25

Three years of work by many people



Open Access, Public Data

First Time in this field