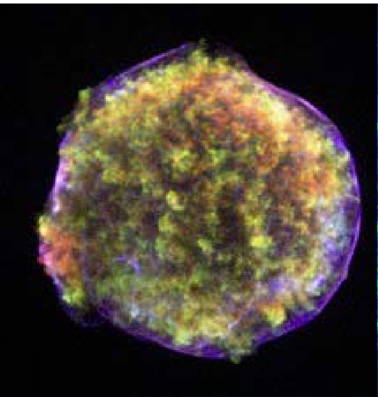
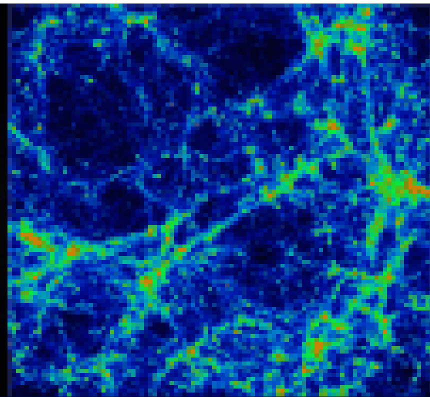
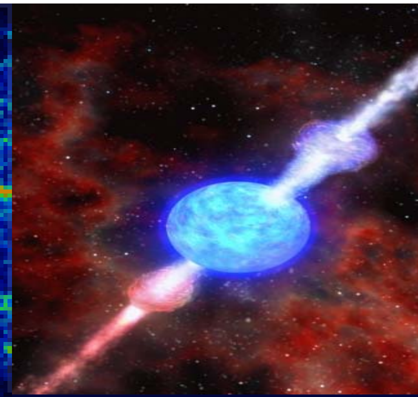
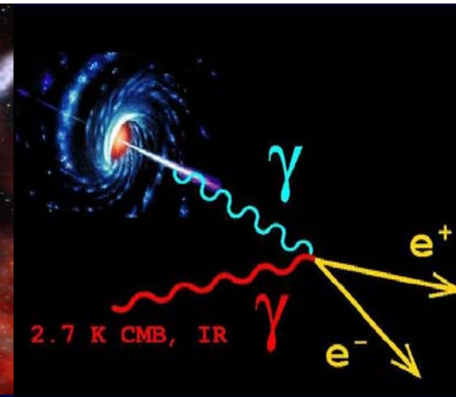
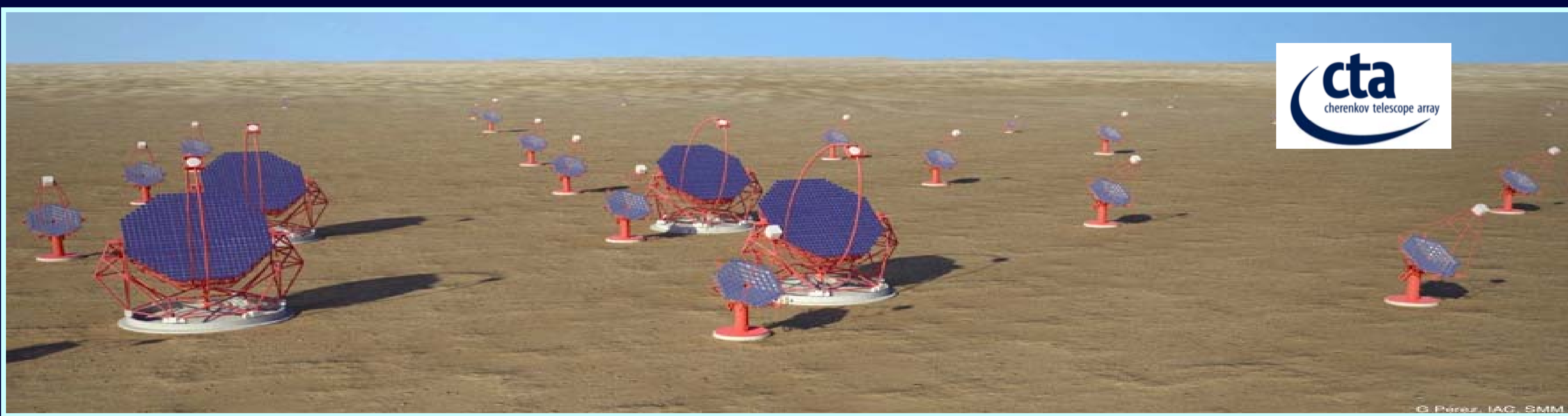





Cherenkov Telescope Array:
Scientific Perspective and Current Status

Rene A. Ong (UCLA)

INAF – OAR, 04 September 2018



Outline

- **Scientific & Technical Motivation**

  The highest energy photons
  Three science topics in brief
  Experimental Technique
  Planning for the Future → CTA

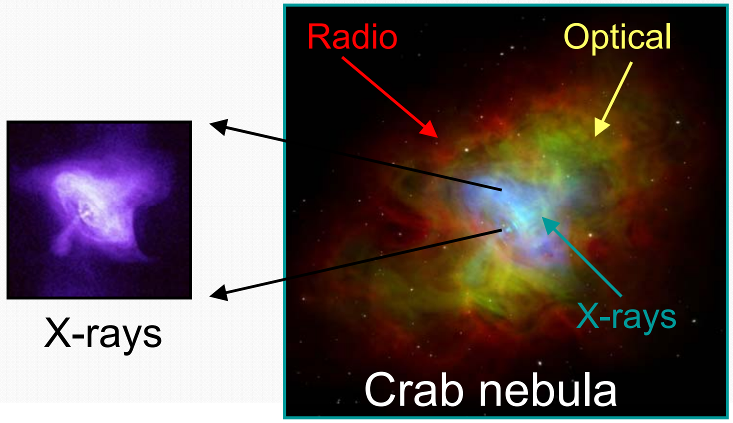
- **Cherenkov Telescope Array (CTA)**

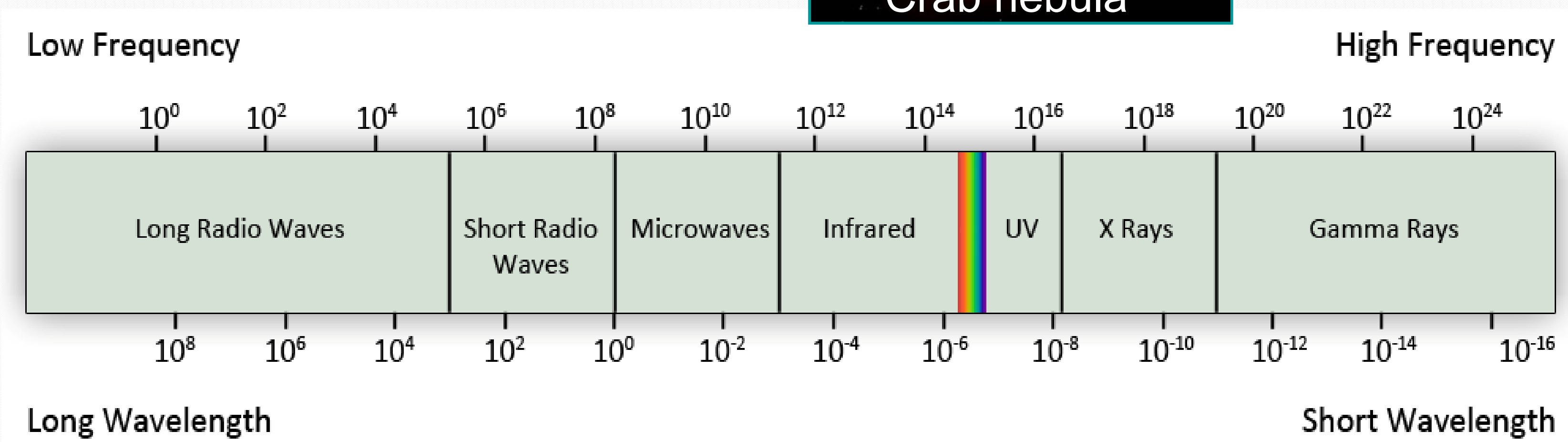
  CTA Design & Performance → Scientific Capabilities
  Implementation, status – sites & prototype telescopes
  CTA Key Science

- **Summary**

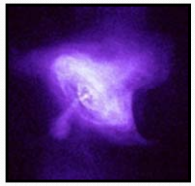
Caveat: general talk, with focus on science & technique; not a detailed talk on CTA technologies

Photons of all wavelengths

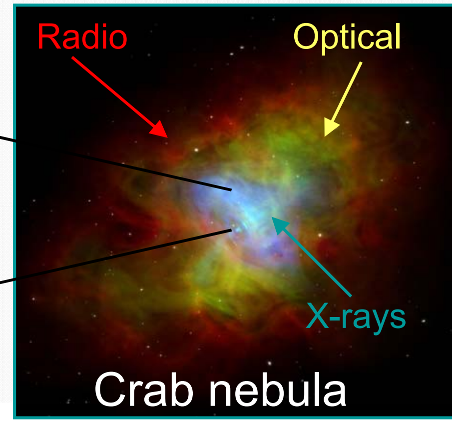


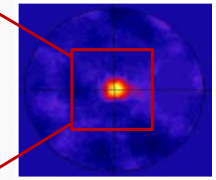


The Highest Energy Photons

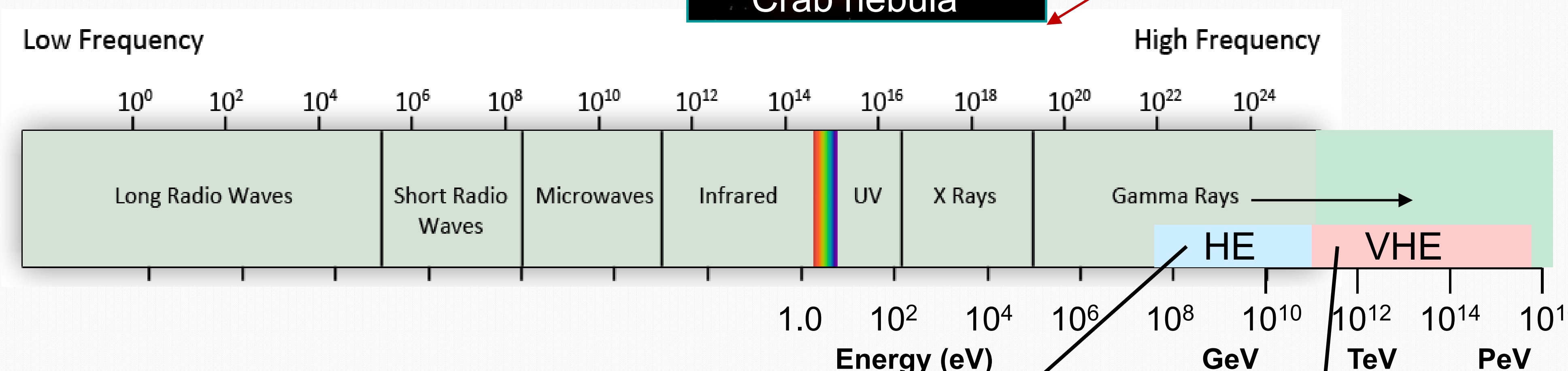


X-rays





TeV γ-rays

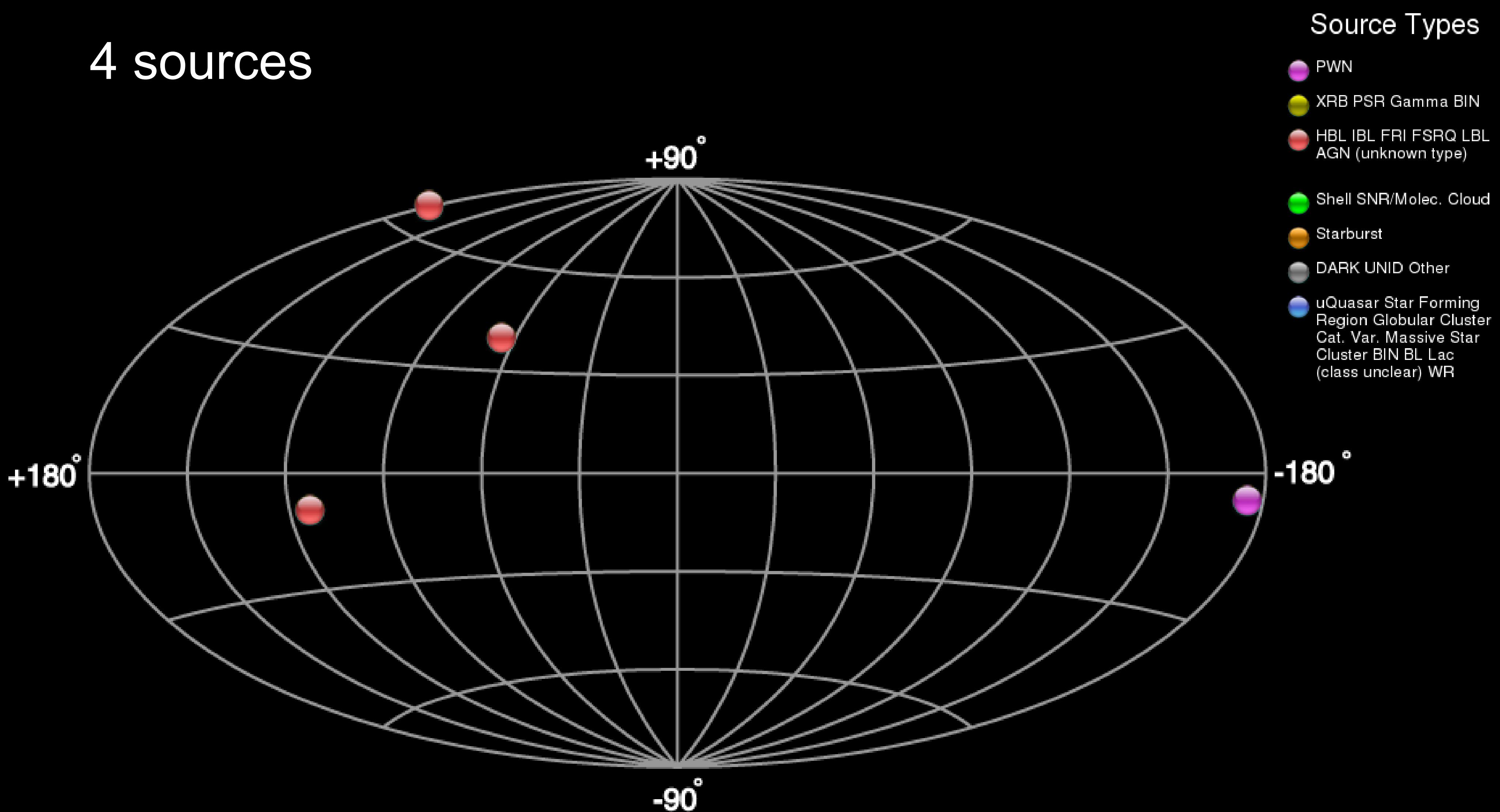


Fermi telescope

VERITAS telescope

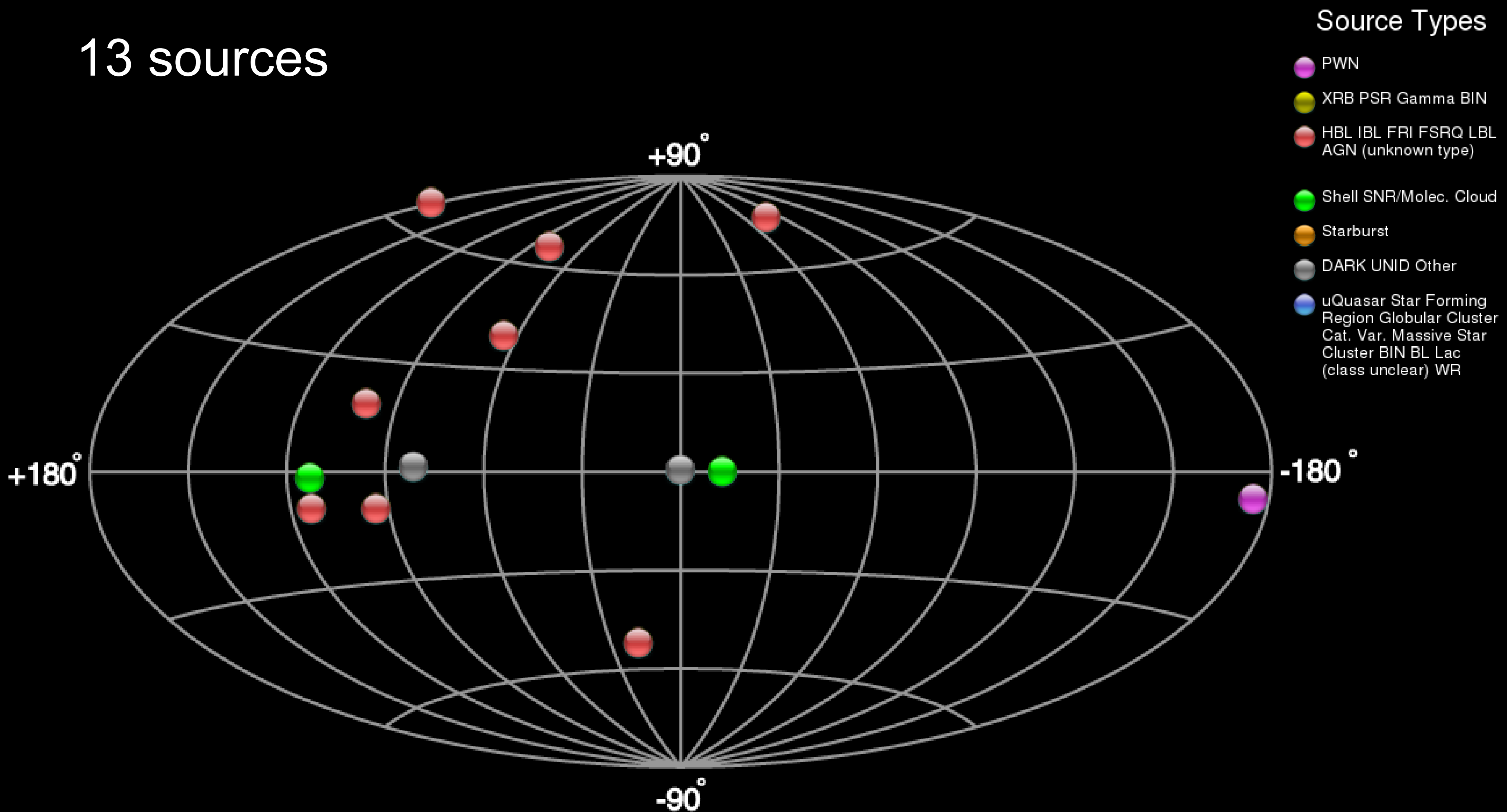
VHE γ-ray Sky c1995

4 sources



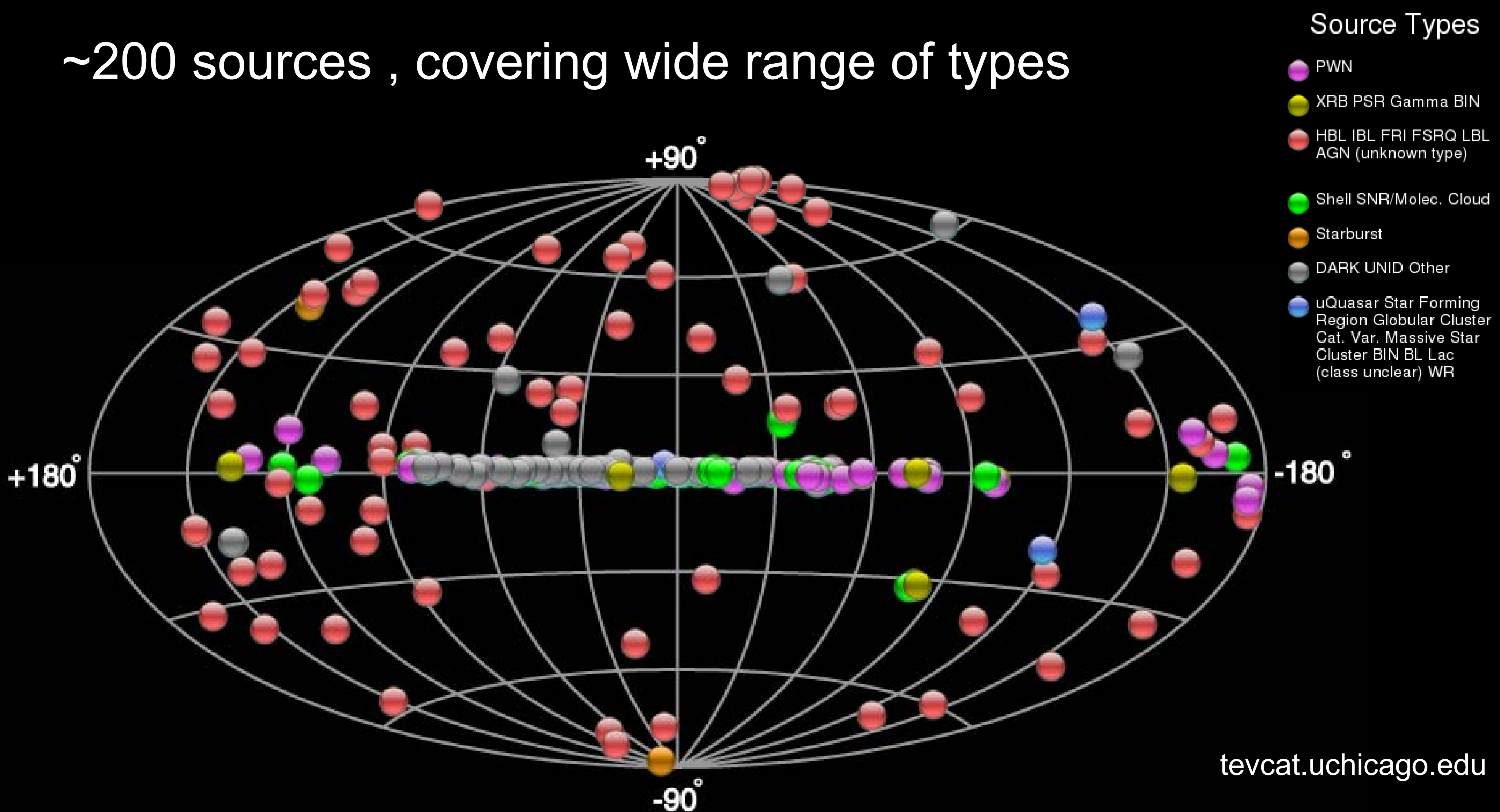
VHE γ-ray Sky c2005

13 sources



VHE γ-ray Sky c2018

~200 sources , covering wide range of types

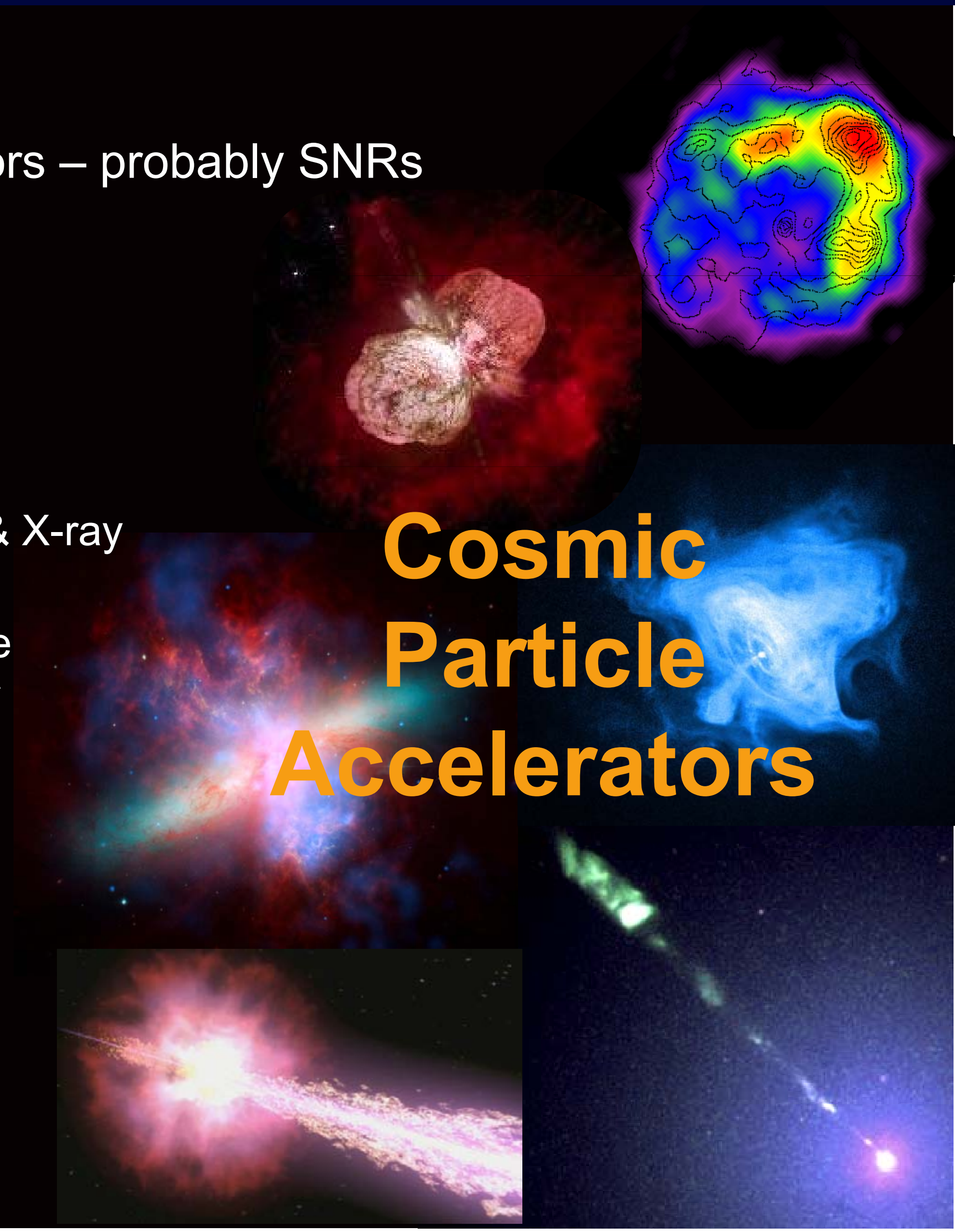


Detailed source information: spectra, images, variability, & MWL.

… and a similar revolution in the GeV band with Fermi

VHE Astronomy Comes of Age

- Dominant expectation (pre-1990)
  - Will find the “cosmic ray” accelerators – probably SNRs
- Reality (present day)
  - 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

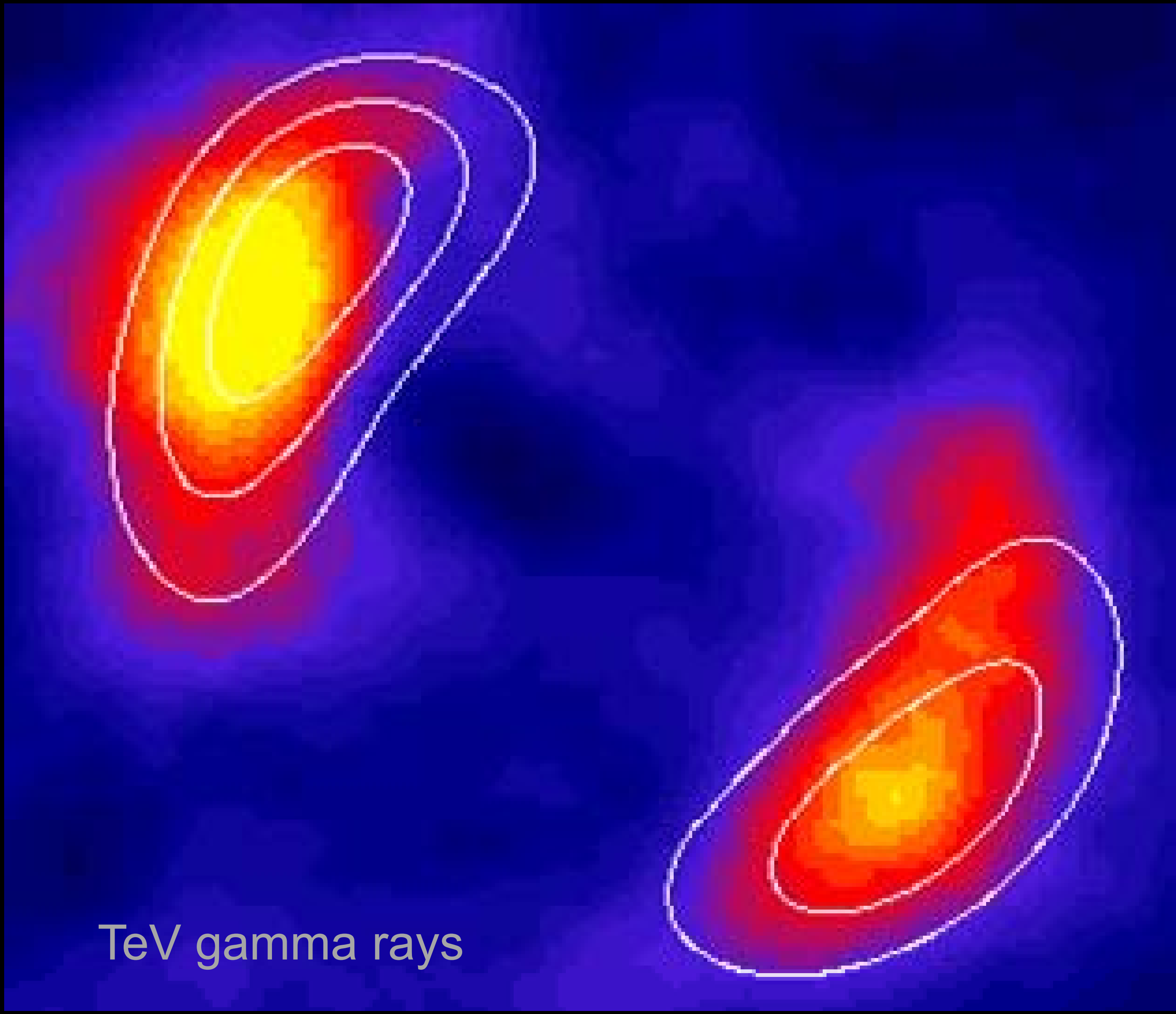


Three Science Topics (in brief)

- Supernova remnants & origin of cosmic rays
- Active Galactic Nuclei (AGN)
- Dark Matter & the Galactic Center

Supernova Remnants

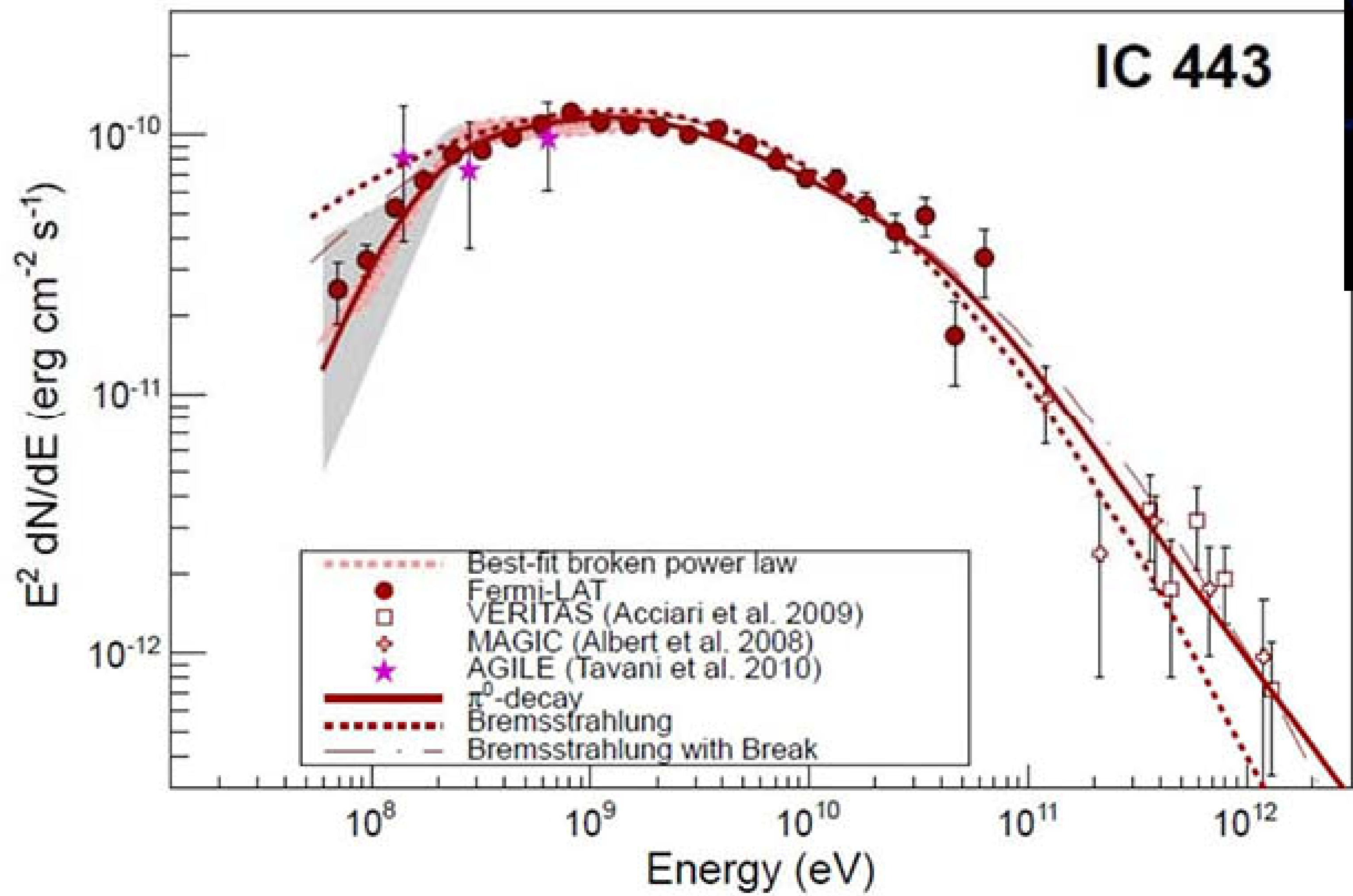
SN 1006

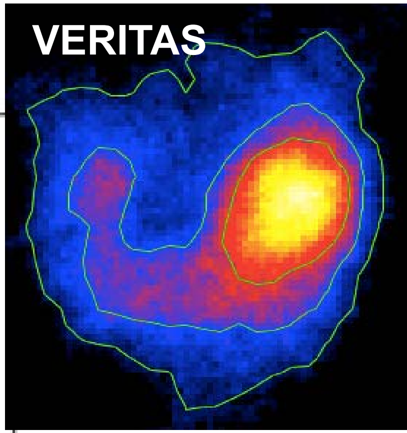


0.4°

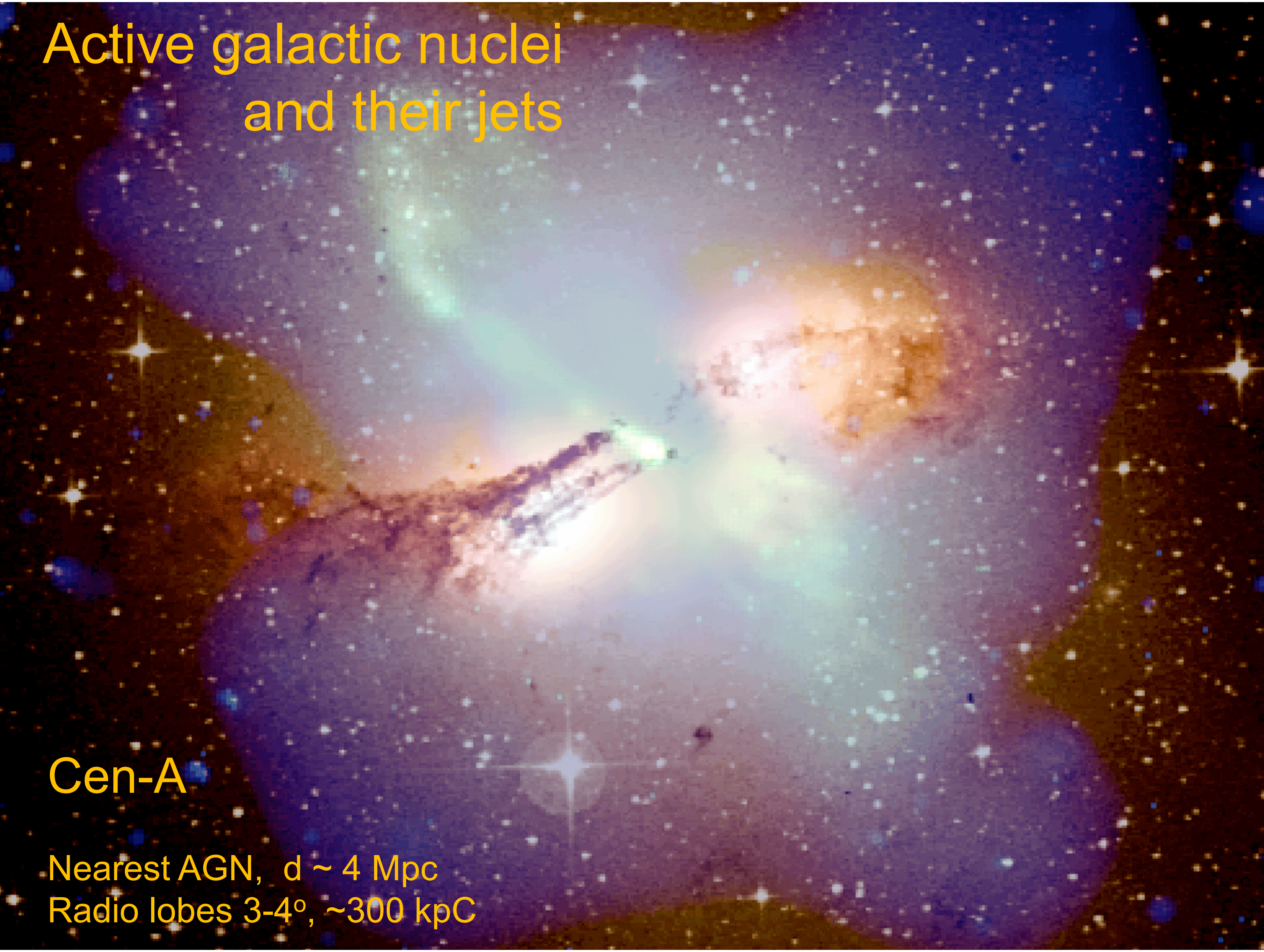
(Credits:
X-ray (blue): NASA/CXC/Rutgers/
G.Cassam-Chenai, J.Hughes et al.;
Radio(red):NRAO/AUI/NSF/GBT/VLA/
Dyer, Maddalena & Cornwell; Optical:
(yellow) Middlebury College/
F.Winkler, NOAO/AURA/NSF/CTIO
Schmidt & DSS)

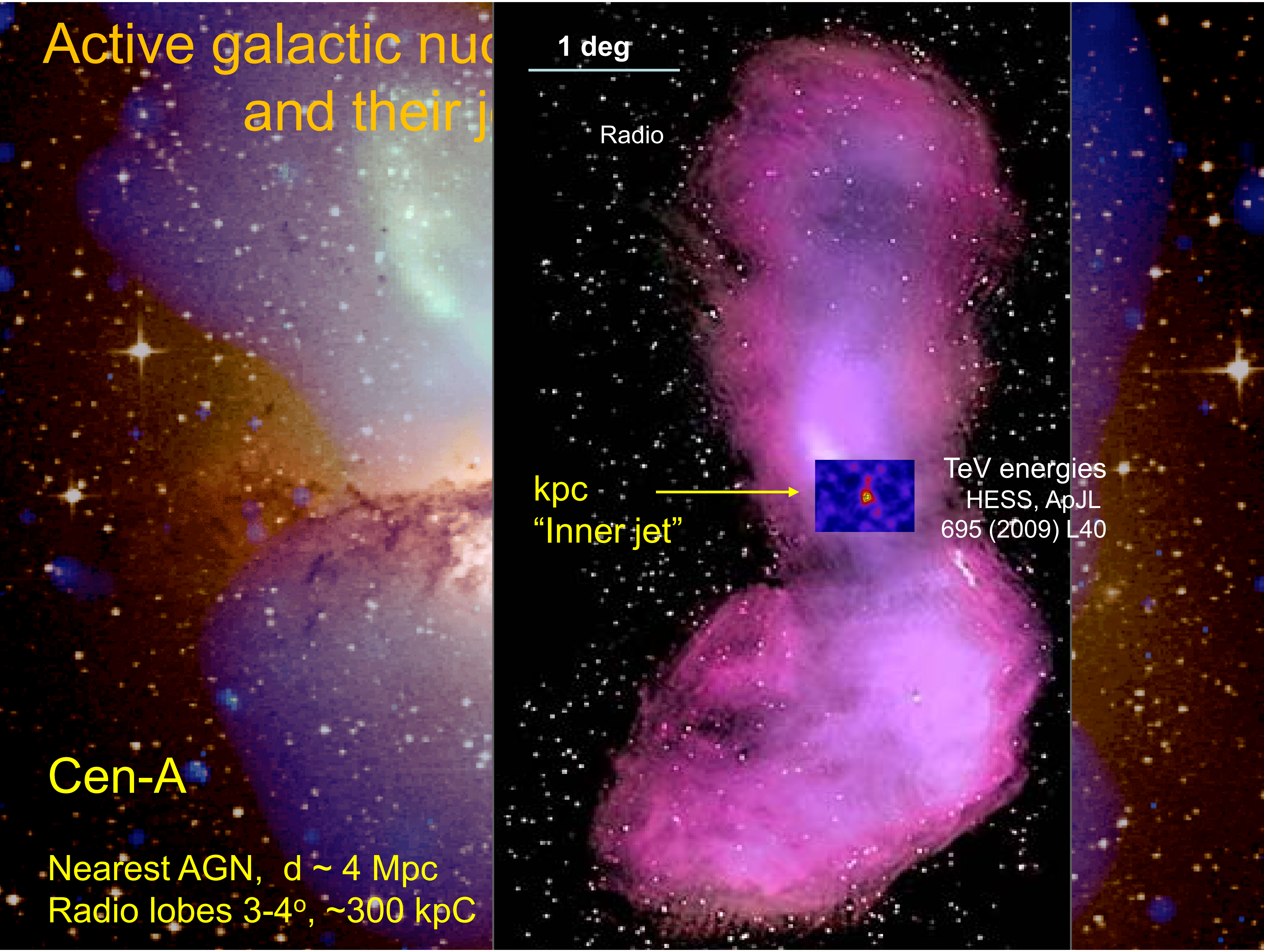
SNR IC 443 – a proton accelerator ?





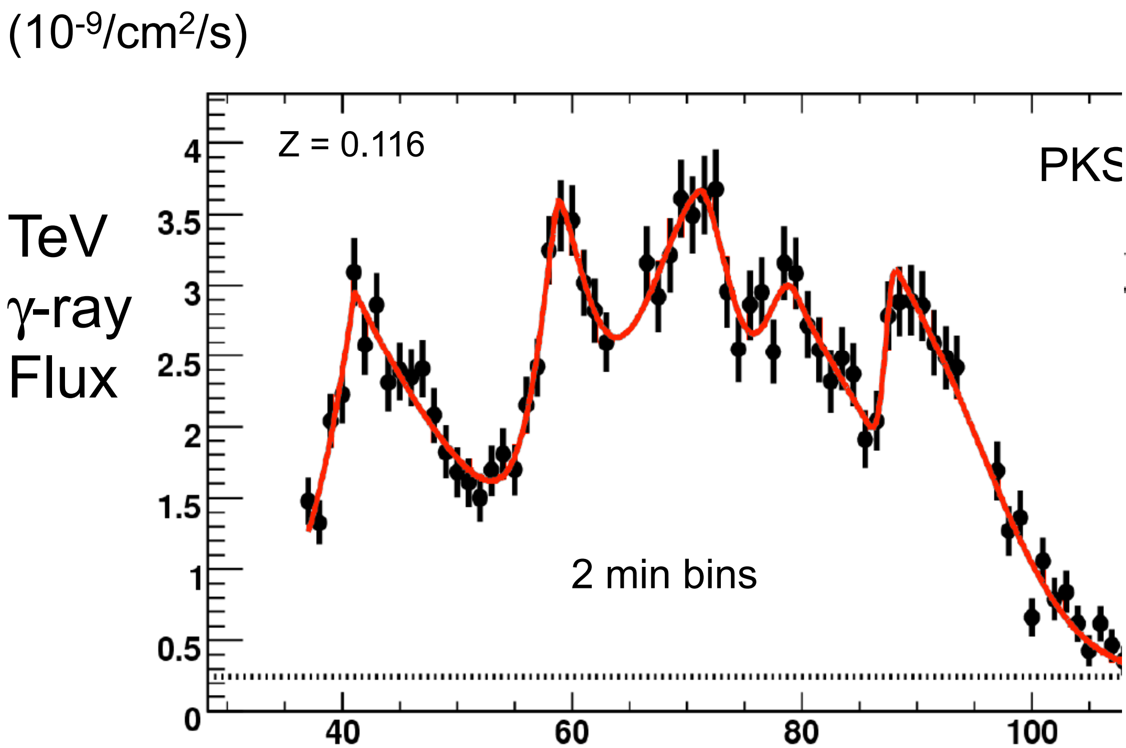
Supports the idea for proton acceleration.
But more sources and better data (spectra, morphology) are needed !


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

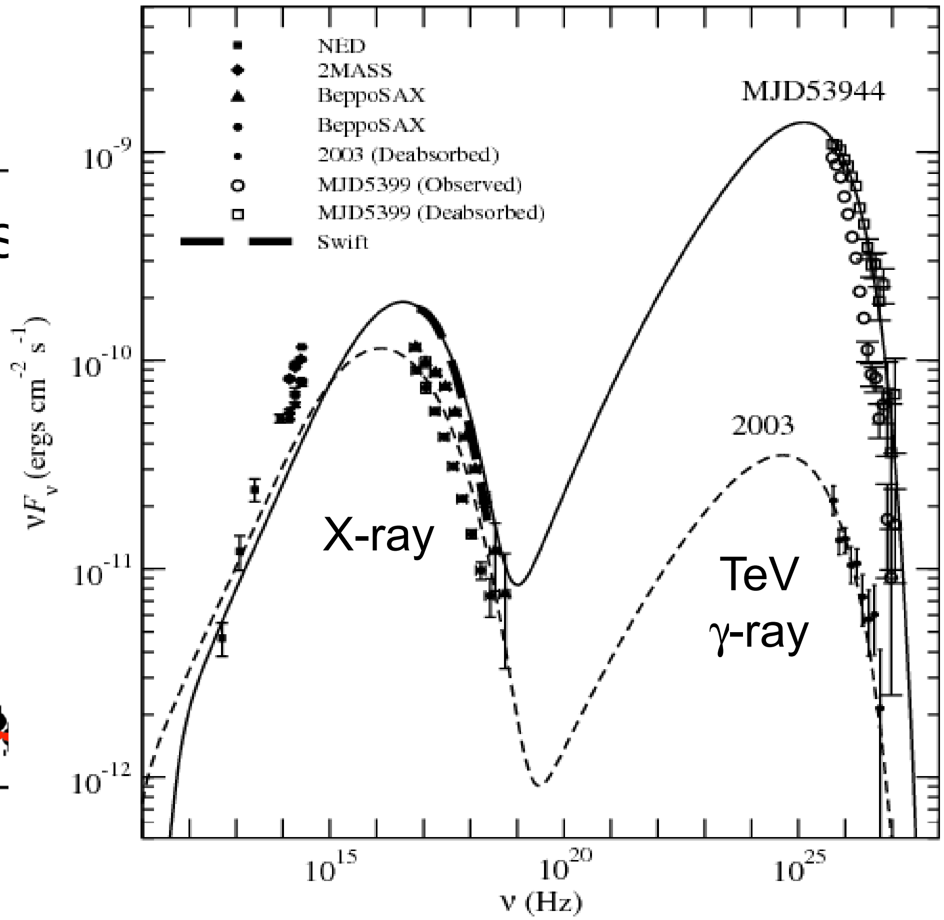

Active galactic nuc
and their j
1 deg
Radio
kpc
“Inner jet”
TeV energies
HESS, ApJL
695 (2009) L40
Cen-A
Nearest AGN, d ~ 4 Mpc
Radio lobes 3-4°, ~300 kpC

Blazars: AGN with jets pointed at us

Strong & highly variable TeV sources



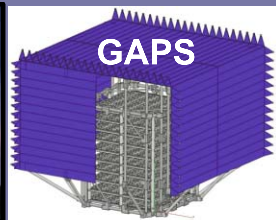
TeV γ-ray
isotropic luminosity 10^{46} erg/s
(luminosity of Milky Way: 10^{44} erg/s)

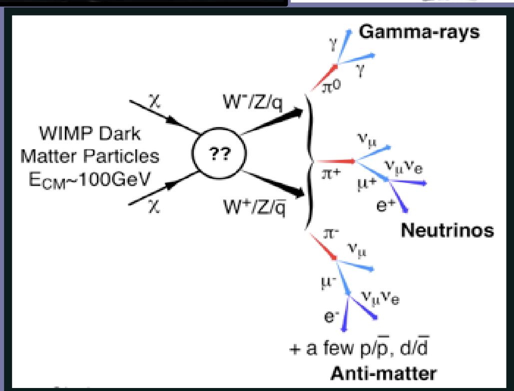


Broad-band SED fits
Multiple jet components & zones

Many important aspects not understood: energetics, particle type, emission zones …
Need for detecting sources at all flux levels, unbiased sample of luminosity function.

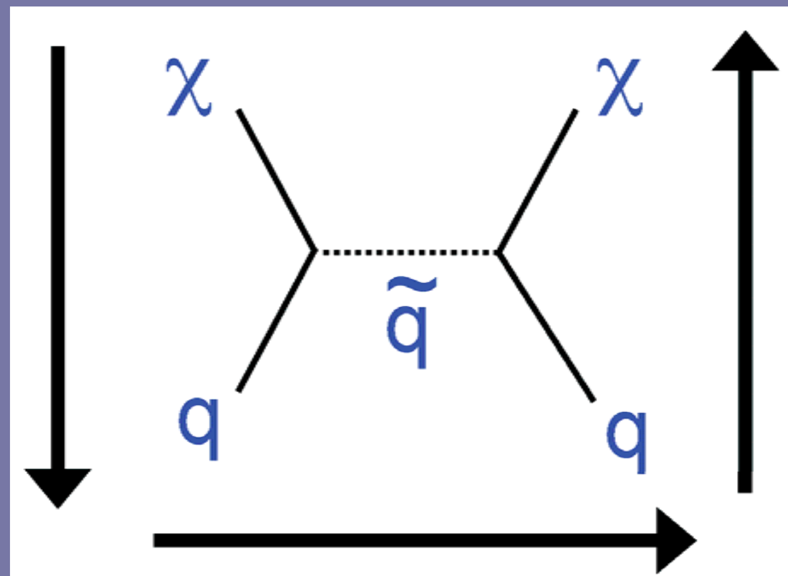
Dark Matter: Complementary Approaches

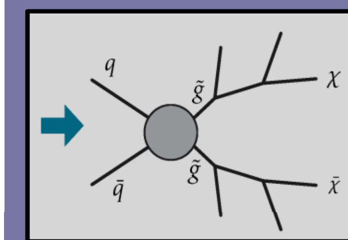


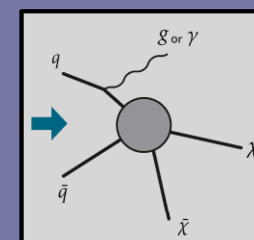


WIMP annihilation
In the cosmos

Indirect Detection

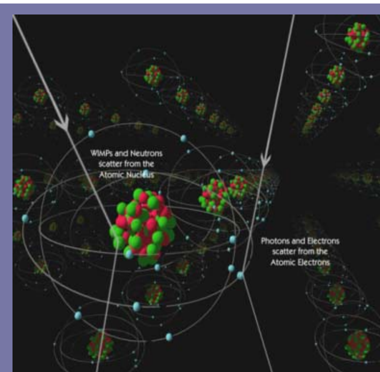






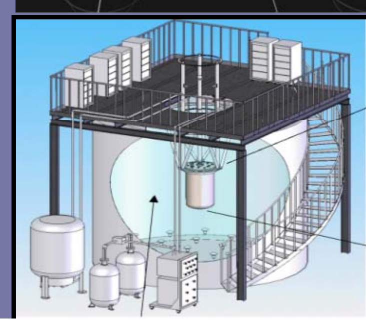
Heavy particle prod.
MET + jets

LHC Production

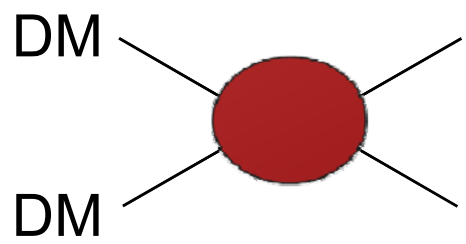


WIMP-Nucleon
Elastic scattering

Direct Detection



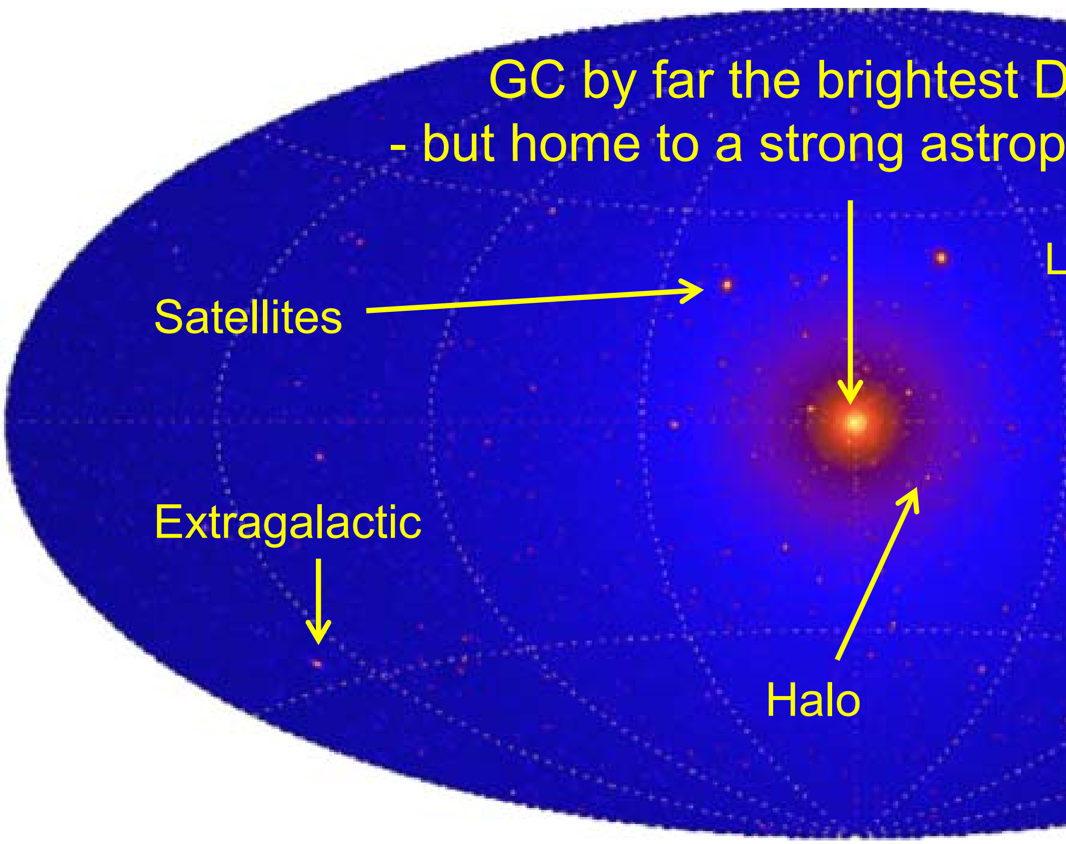
Indirect Detection of DM



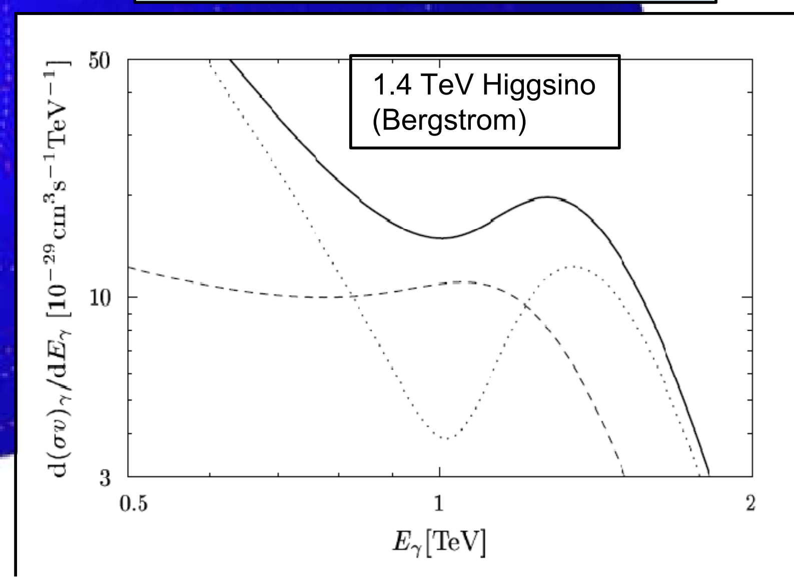
SM: b, W^+, Z, τ^+, …
Primary channels
SM: $\bar{b}$, W^-, Z, τ^-, …

Hadronization

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



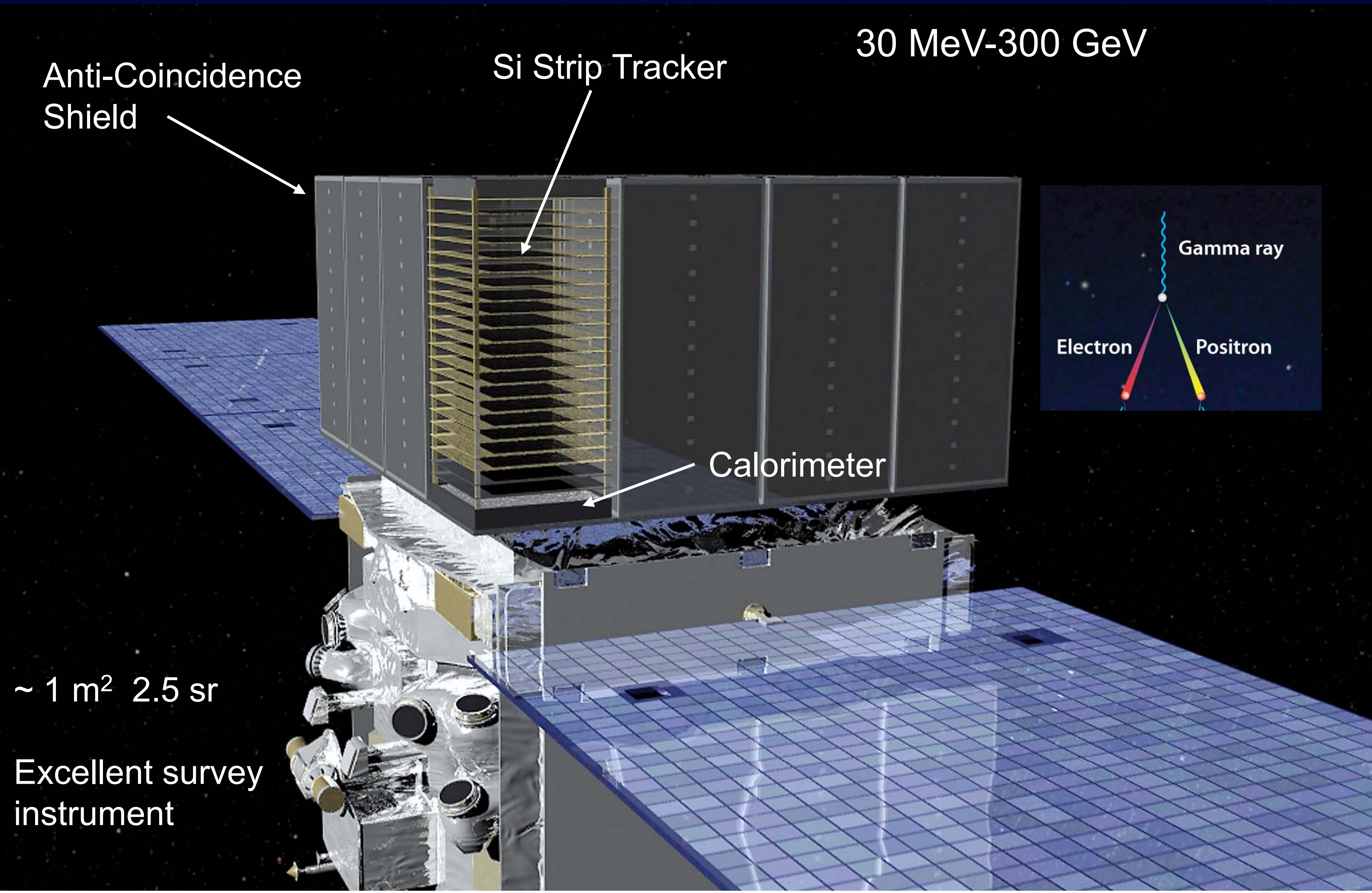
"Universal" Spectrum



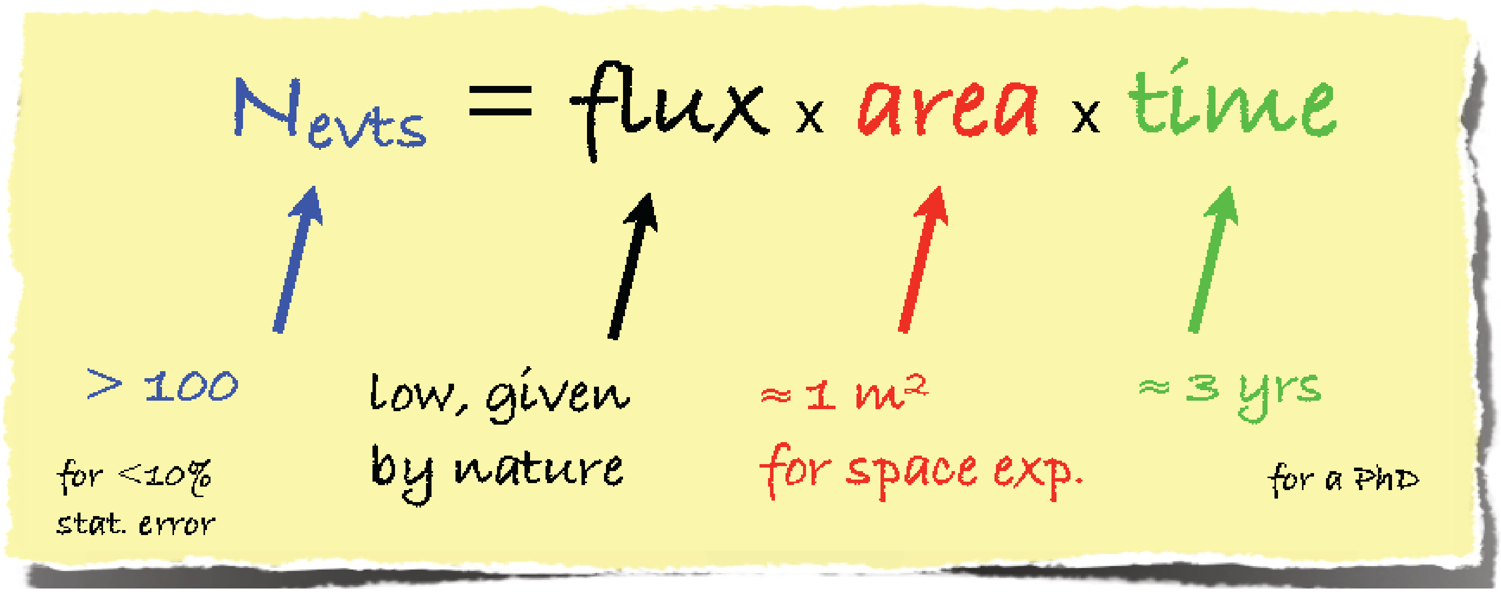
Ultimate goal: Dark Matter Astronomy

Experimental Technique
&
Planning for the Future

Fermi Large Area Telescope (LAT)



Beyond 100 GeV

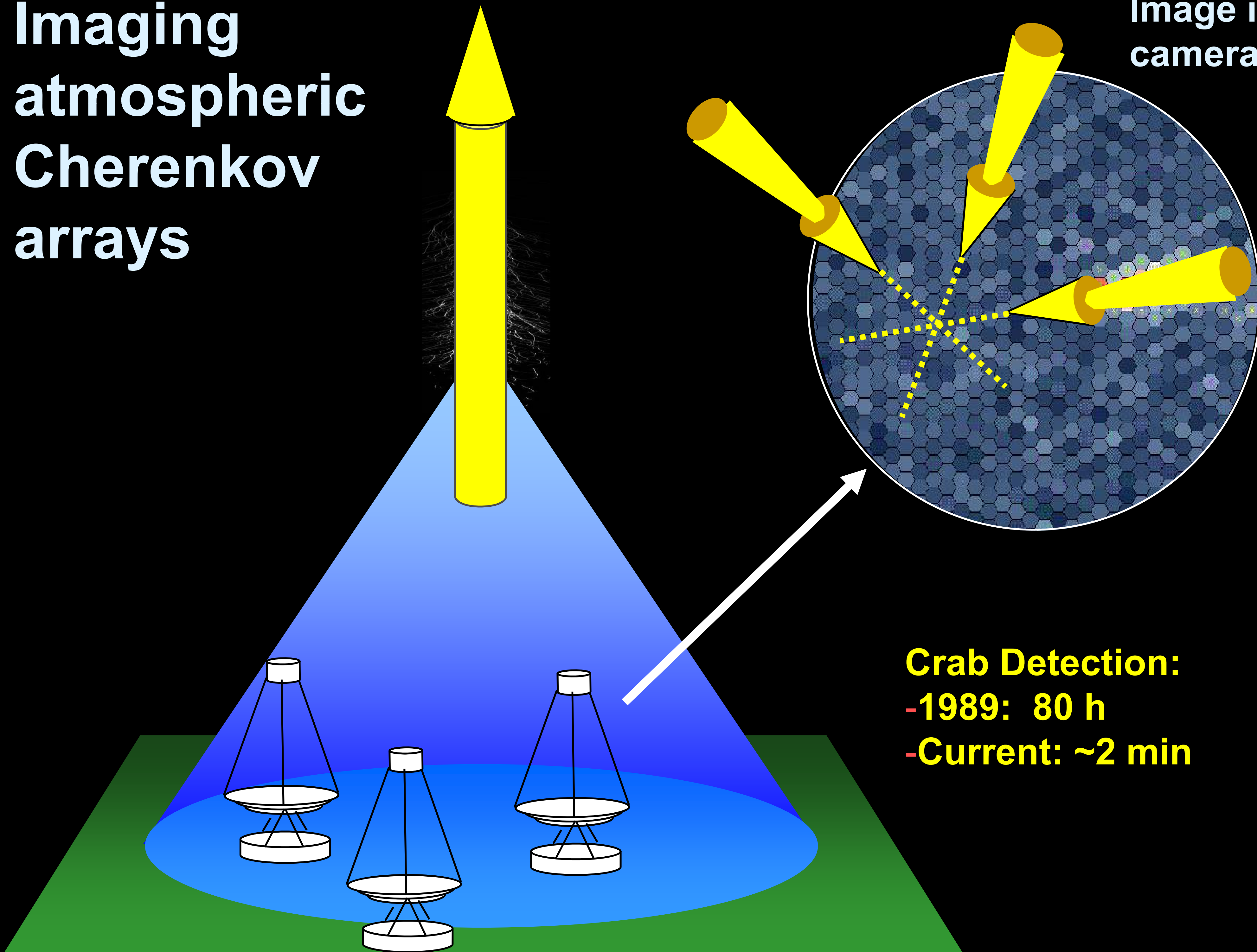


Steeply falling spectrum:

x10 in Energy → divide by 100-500 in flux

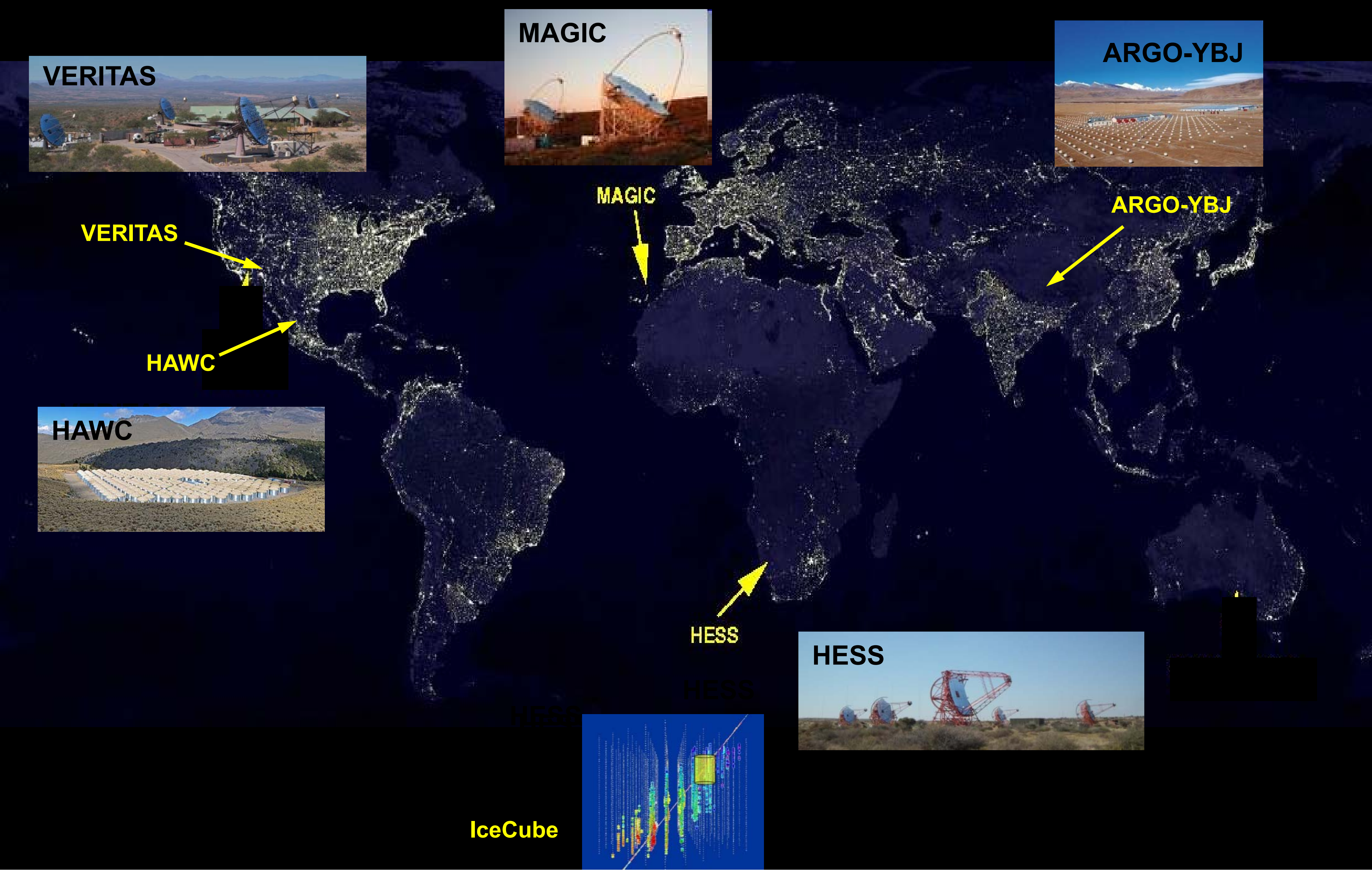
- Large effective area needed to get detectable signals at VHE
- Natural detector: *the atmosphere*

Imaging atmospheric Cherenkov arrays



Crab Detection:
- -1989: 80 h
- -Current: ~2 min

VHE Telescopes (2018)



Planning for the Future

What we know, based on currents instruments:

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

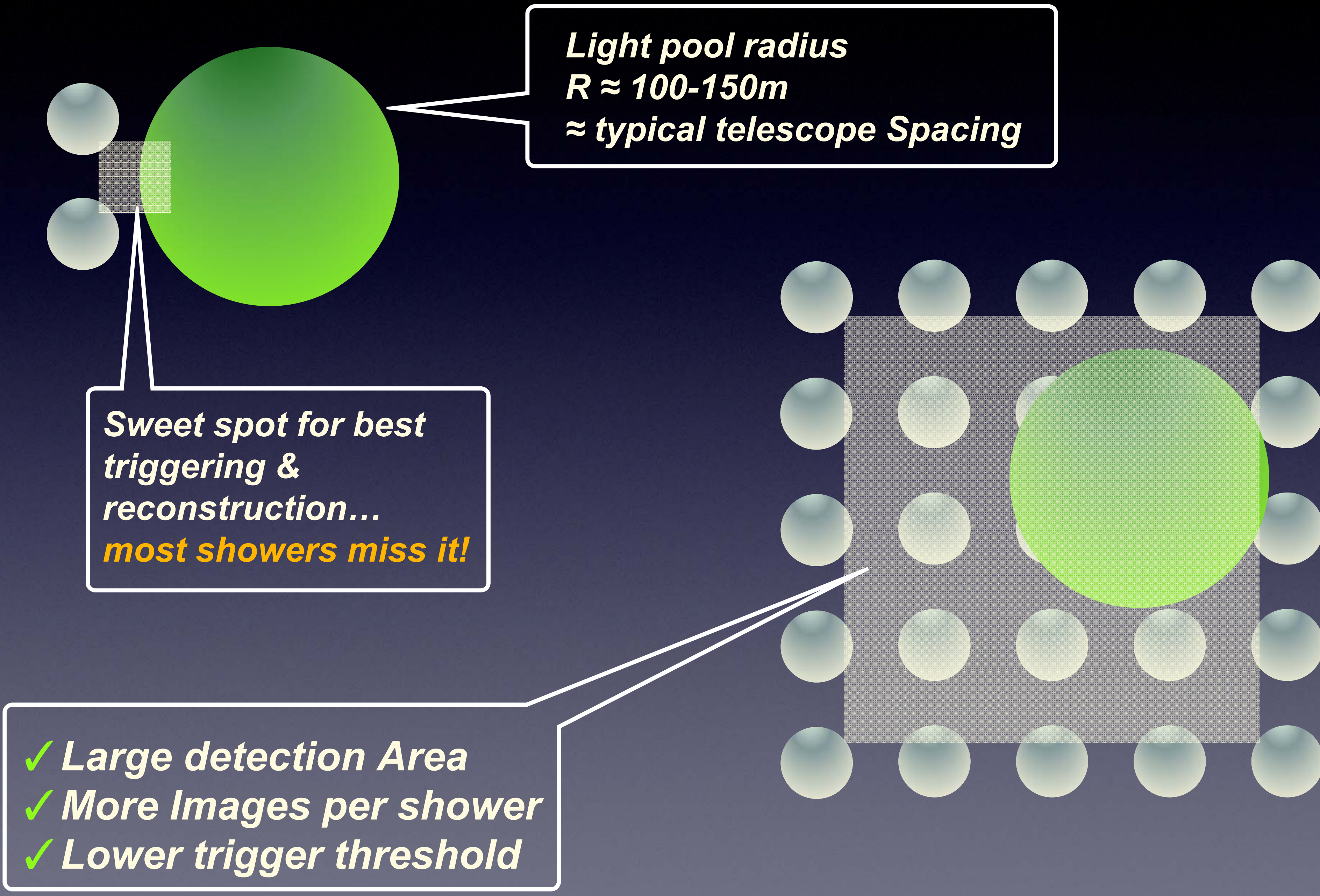
- *Open data/access, MWL connections to get the best science*

International Partnerships required by scale/scope

- *Project must develop the instrument and the observatory*


cta
cherenkov telescope array

From current arrays to CTA



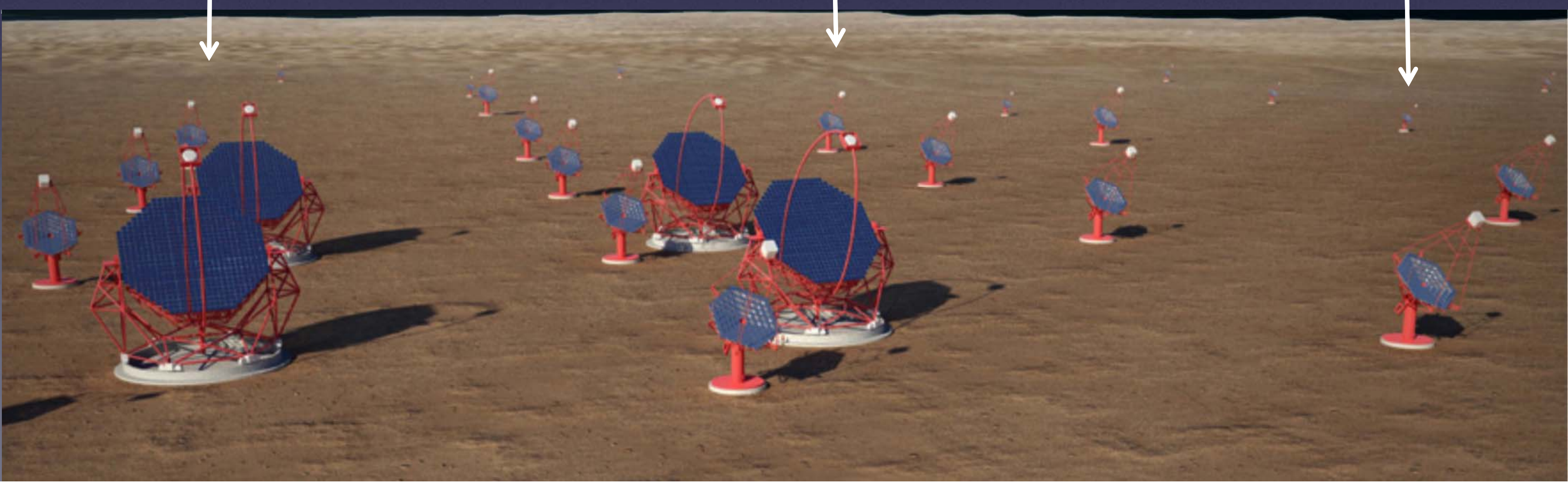
CTA Concept – S array

Science Optimization under budget constraints

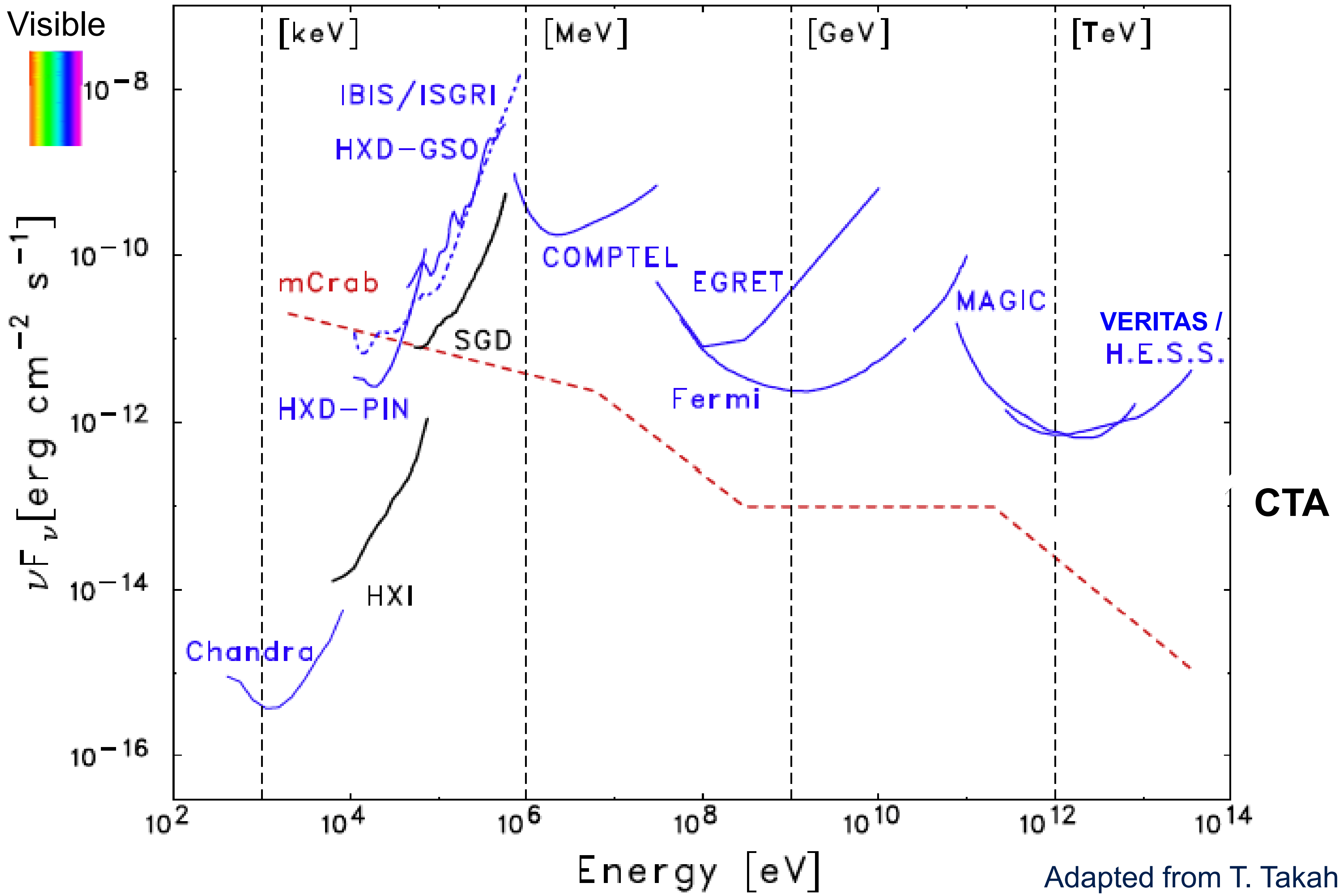
<u>Low energies</u>
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

<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)



CTA Sensitivity in Context



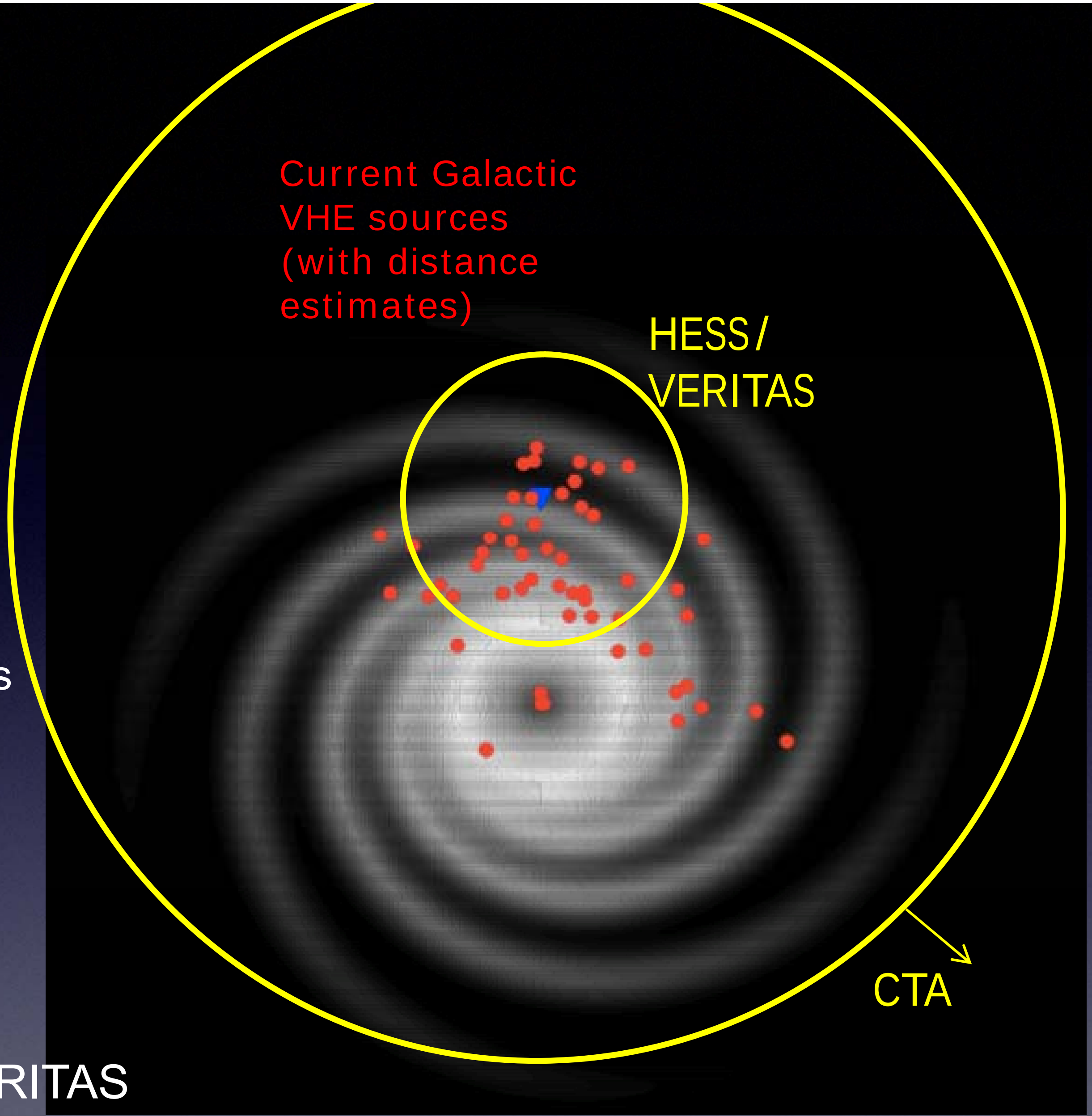
Adapted from T. Takahashi

Galactic Discovery Reach

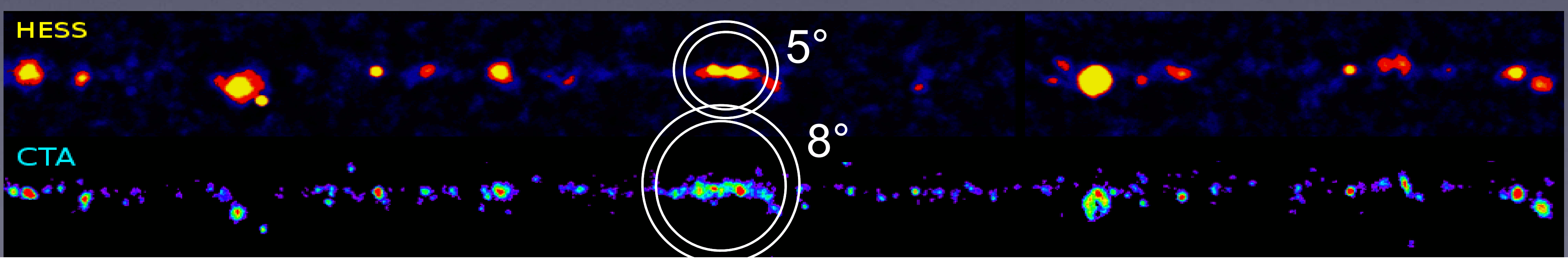
Young pulsars and SNRs

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

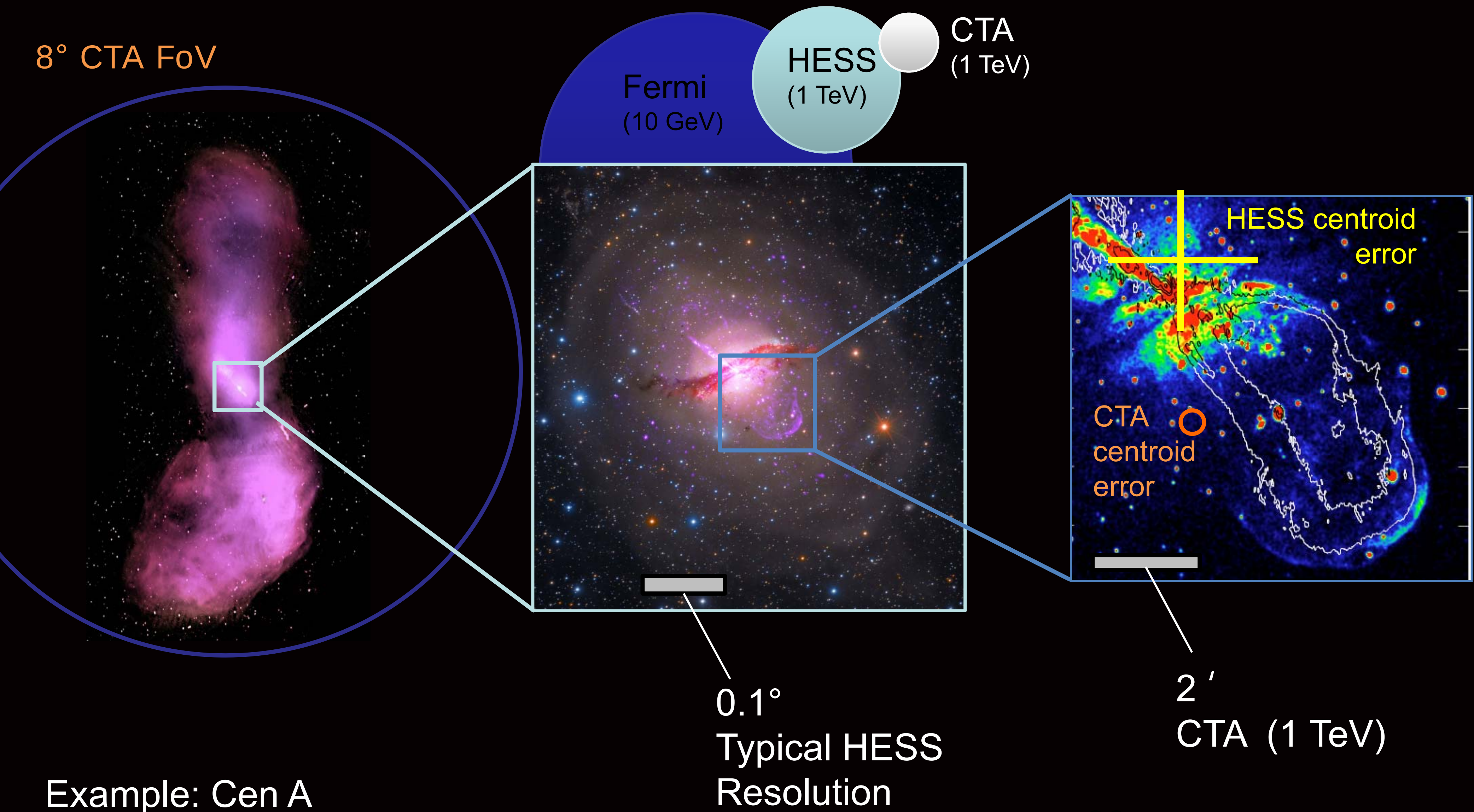
CTA will see **whole** Galaxy



Survey speed:
x300 faster than HESS/VERITAS



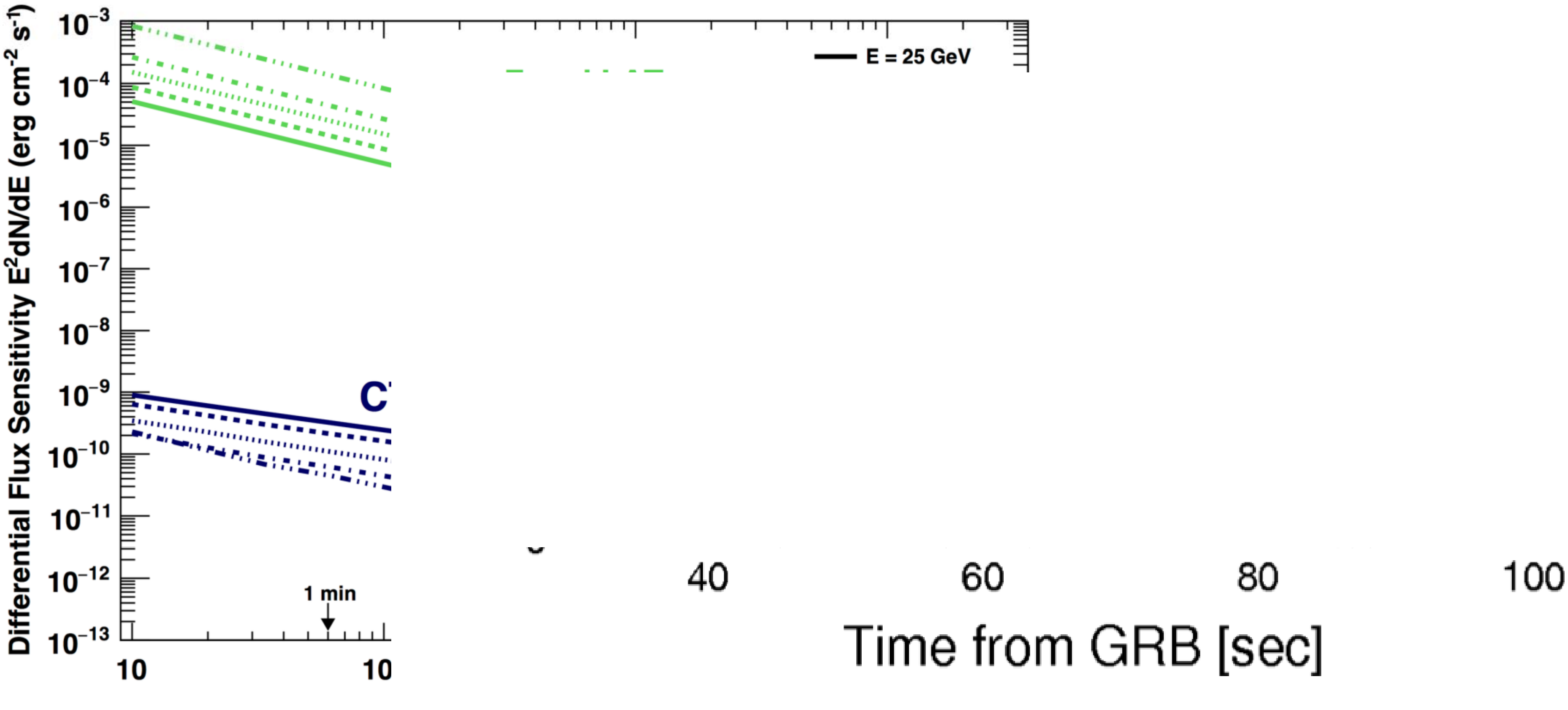
Angular Resolution



Example: Cen A

Transient Capability (< 100 GeV)

S. Inoue et al.,
arXiv:1301.3014



GRB (z=4.3) Light curve

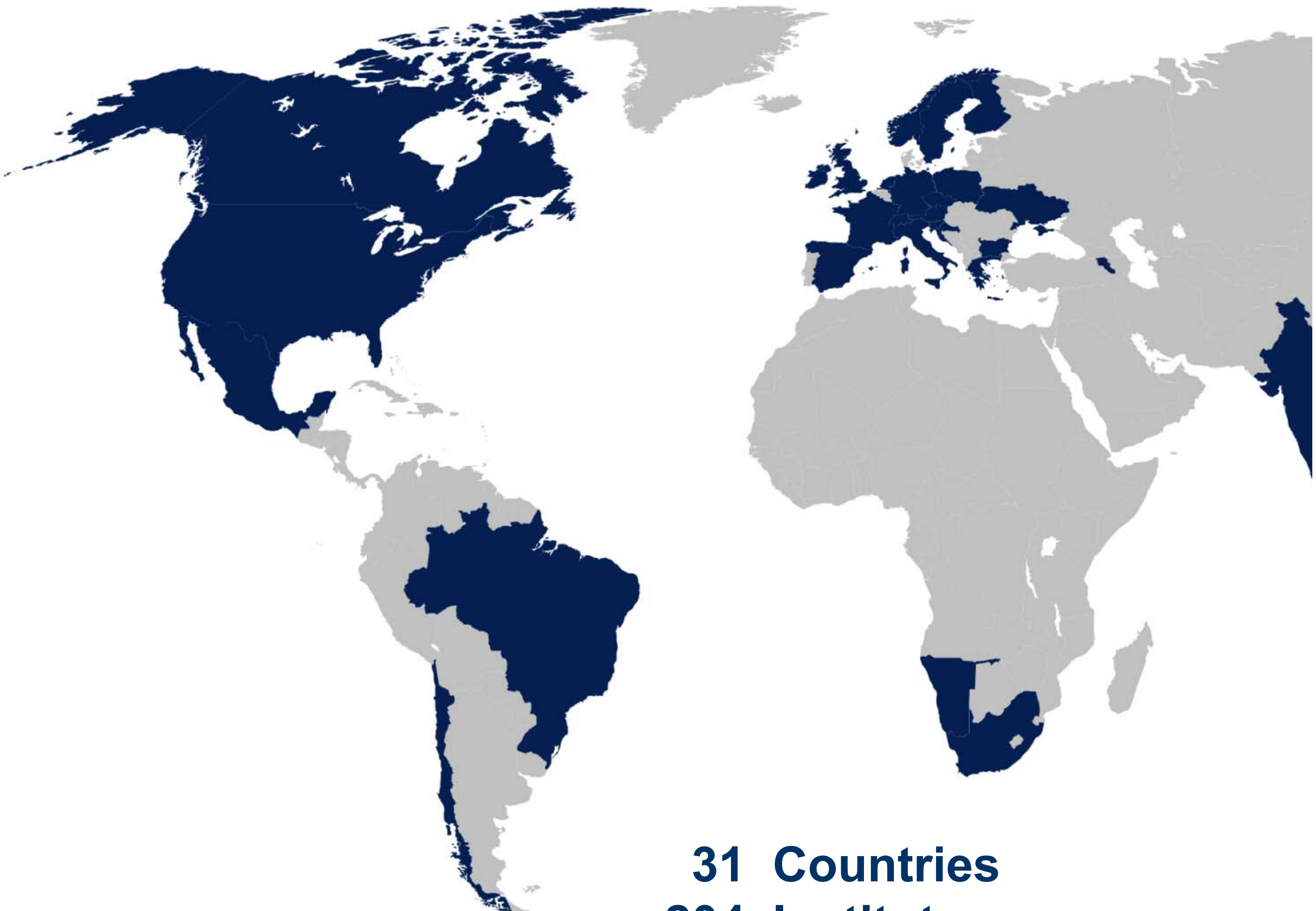
Huge potential for short-timescale phenomena (GRB's, AGN, μquasars, alerts from neutrino and GW telescopes, etc.) → <u>Transients Key Science Project</u>

CTA Implementation

CTA Consortium

cherenkov telescope array

The Consortium developed CTA and will construct the bulk of the CTA components through in-kind contributions

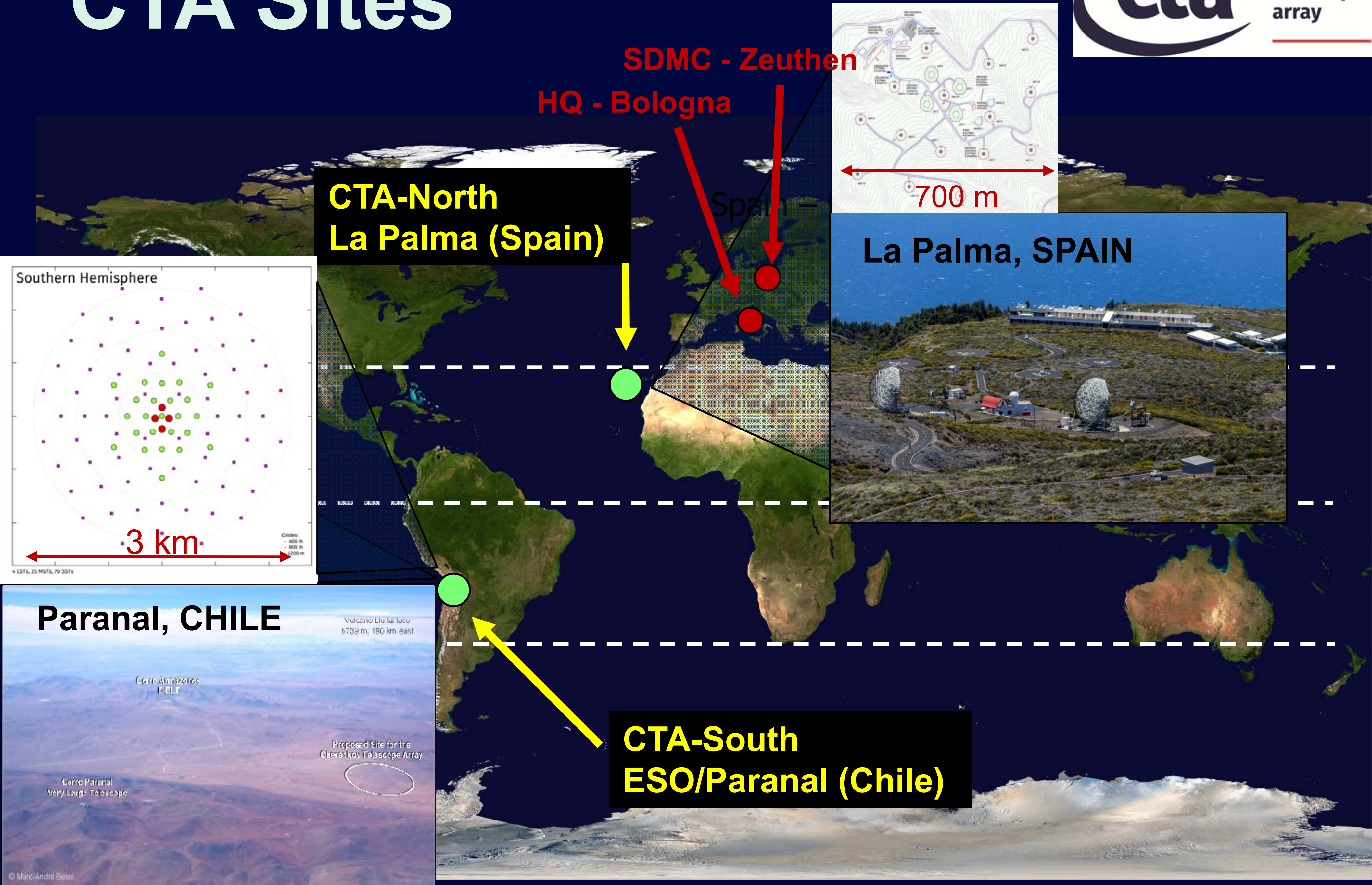


Country	Members	FTE	FTE (%)
Italy	268	101,6	20,0%
Germany	204	87,2	17,1%
France	221	86,4	17,0%
Spain	112	50,4	9,9%
Japan	124	37,4	7,4%
USA	74	22,0	4,3%
Poland	60	18,1	3,6%
United Kingdom	57	17,0	3,3%
Switzerland	27	16,7	3,3%
Brazil	46	14,6	2,9%
Chile	49	7,6	1,5%
Czech Republic	29	6,8	1,3%
Netherlands	13	4,8	0,9%
South Africa	19	4,2	0,8%
Australia	25	3,4	0,7%
Croatia	12	2,9	0,6%
Ukraine	9	2,8	0,5%
Norway	7	2,5	0,5%
Slovenia	10	2,5	0,5%
Greece	23	2,3	0,5%
Mexico	10	2,3	0,5%
Austria	9	2,2	0,4%
India	10	2,2	0,4%
Canada	6	2,0	0,4%
Thailand	5	1,9	0,4%
Argentina	10	1,7	0,3%
Ireland	10	1,4	0,3%
Sweden	6	1,2	0,2%
Finland	5	1,1	0,2%
Armenia	4	0,9	0,2%
Bulgaria	7	0,6	0,1%
Namibia	2	0,3	0,1%

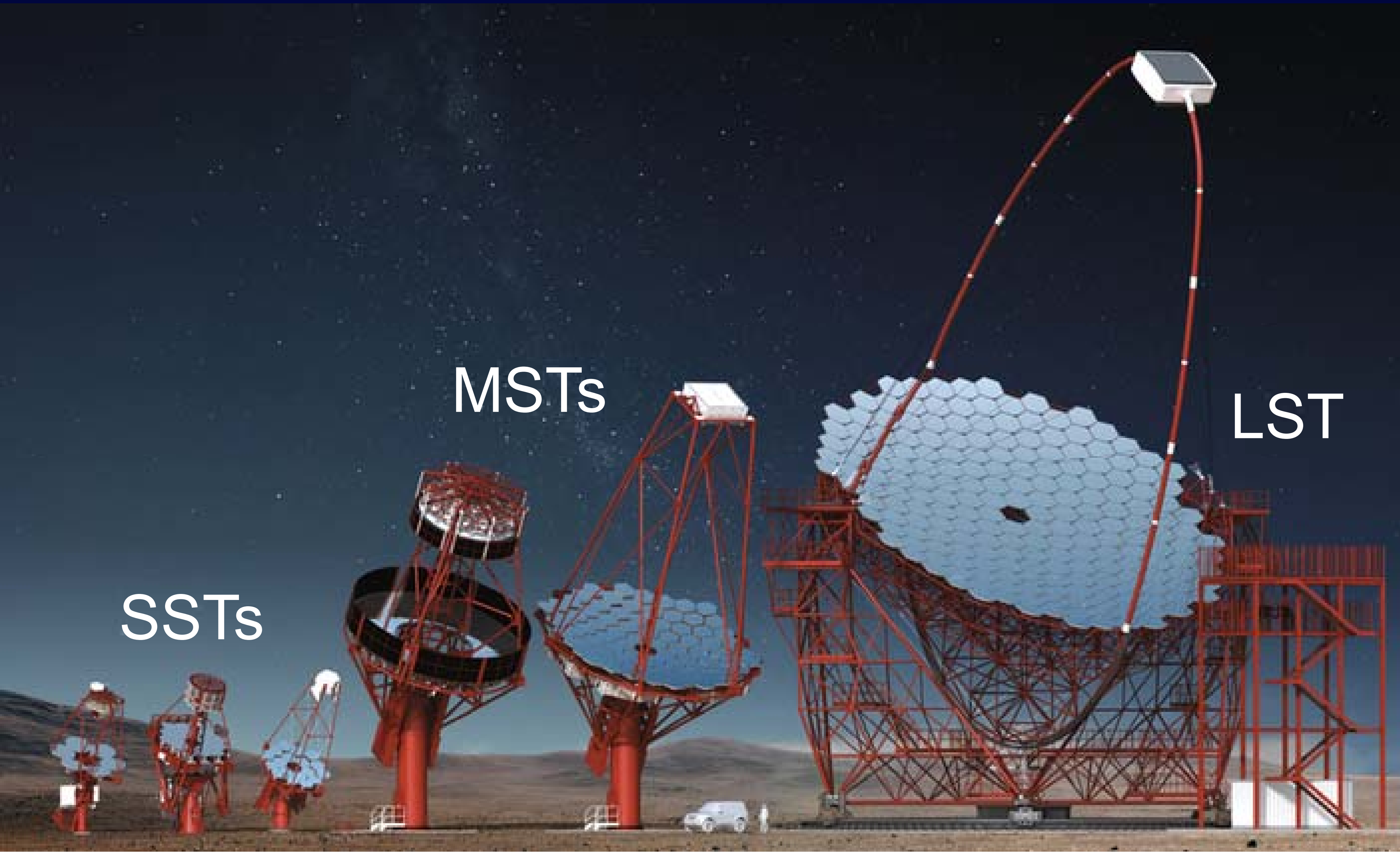
31 Countries
204 Institutes
1461 Members (503 FTE)

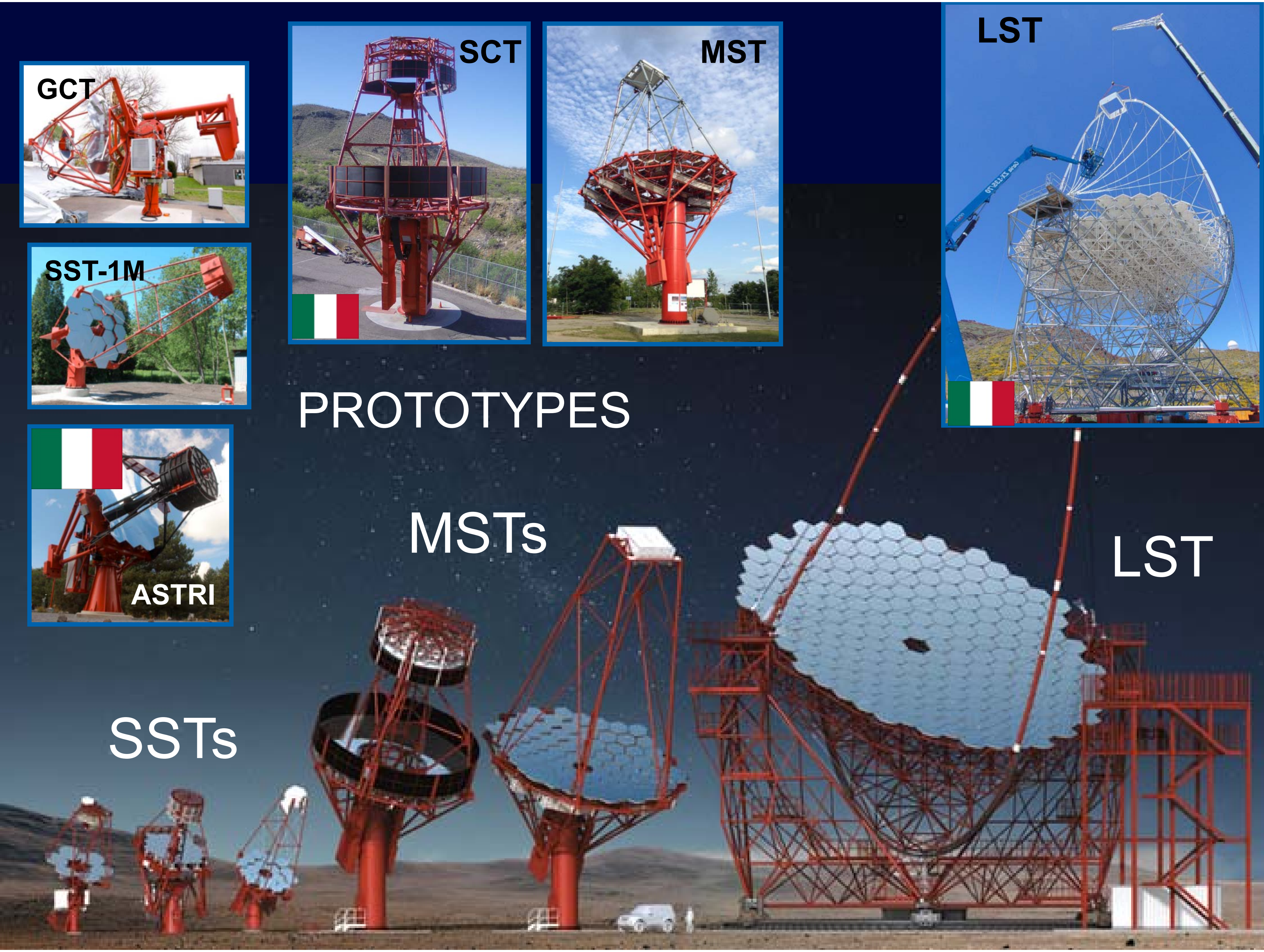
Sept 2018

CTA Sites

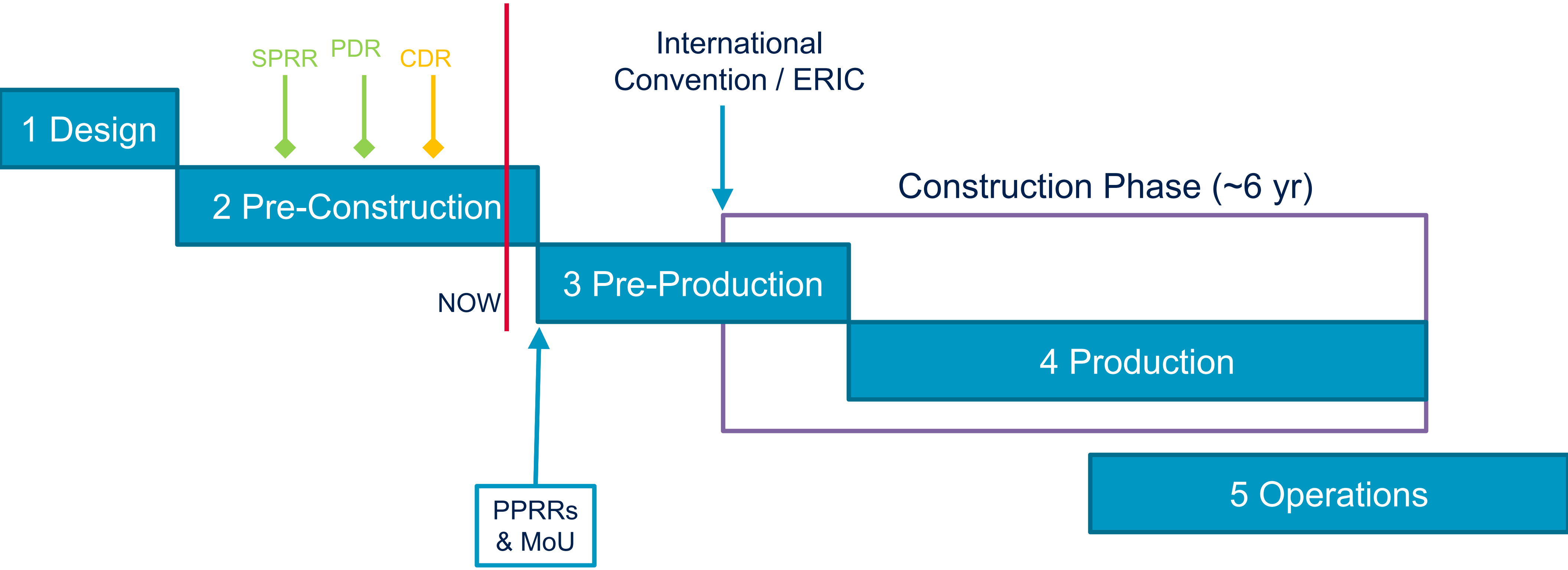

SDMC - Zeuthen
HQ - Bologna
CTA-North
La Palma (Spain)
700 m
La Palma, SPAIN
Southern Hemisphere
3 km
Paranal, CHILE
CTA-South
ESO/Paranal (Chile)

Telescope Types




GCT
SST-1M
ASTRI
SCT
MST
LST
PROTOTYPES
MSTs
LST
SSTs

CTA Phases & Timeline



- 2017-8: Hosting agreements, site preparations start
- 2019: Start of construction (?)
- Construction period of ~6 years
- Initial science with partial arrays possible before construction end

CTA Key Science

CTA Main Scientific Themes

cherenkov telescope array

Cosmic Particle Acceleration

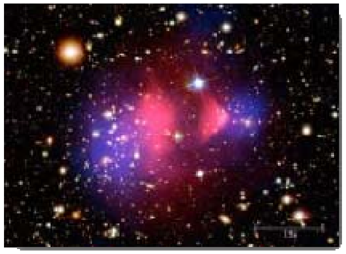
- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

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?

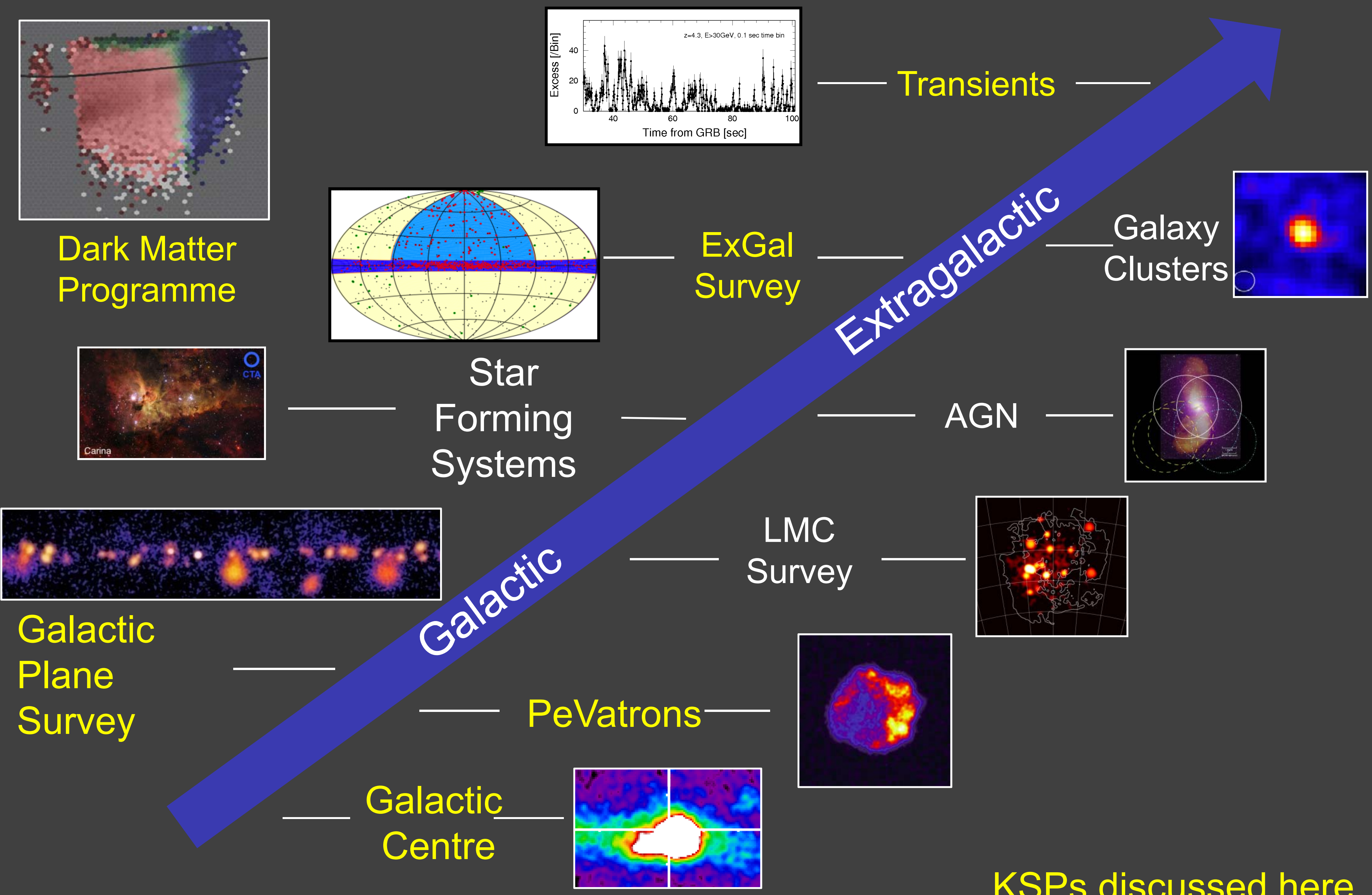


CTA Science Program

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

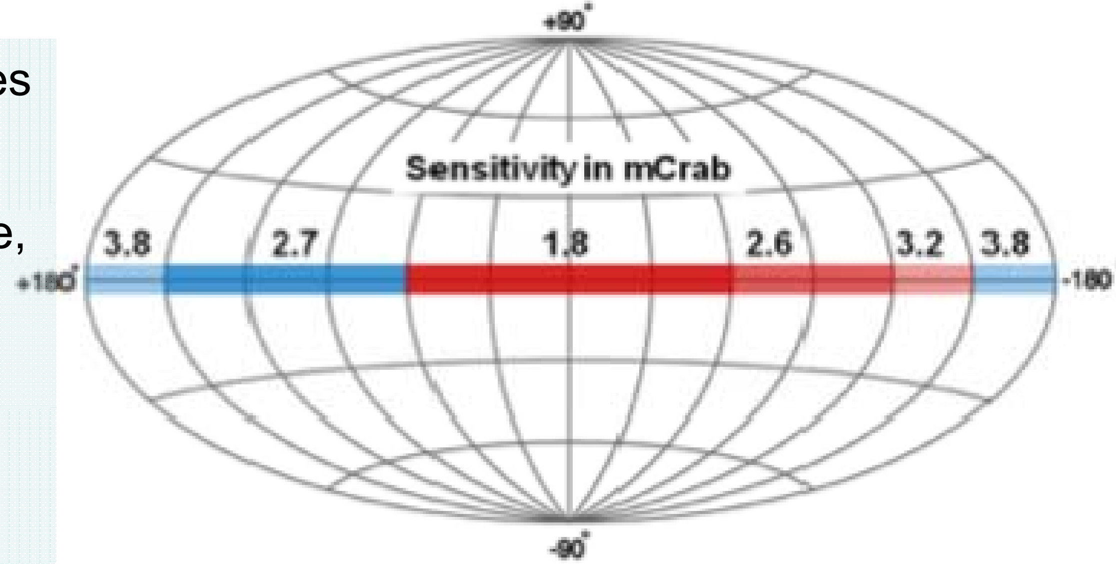
KSP Programme described in
Science with CTA document
arXiv:1709.07997
(soon to be published as a book)

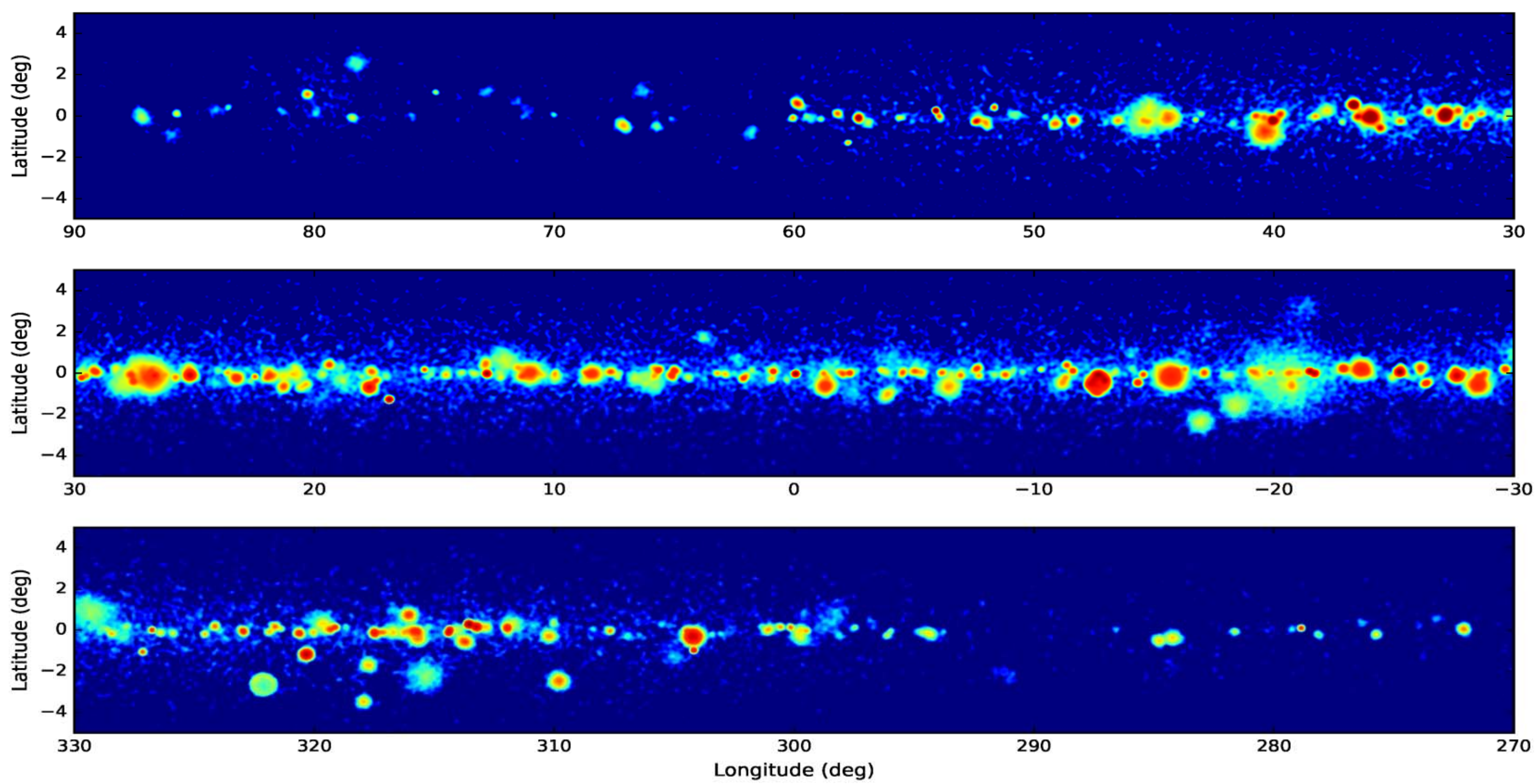
Key Science Projects (KSPs)



Galactic Plane Survey

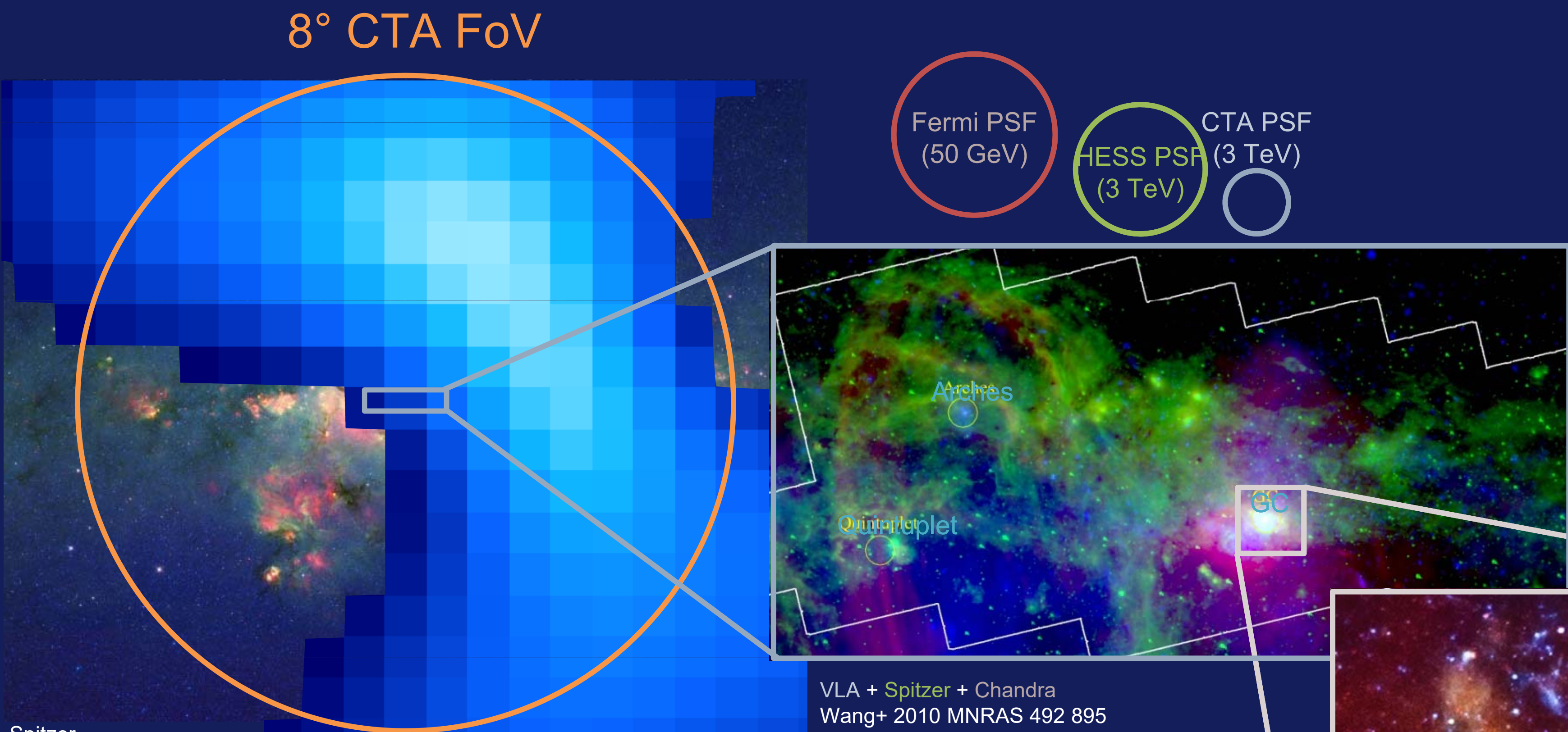
- First high sensitivity survey at TeV energies
- Full-plane survey at arc-minute resolution
- Expect many100's of new sources, PWNe, SNRs and binaries → population studies
- Great potential for discovery of new phenomena
- Detailed view of diffuse γ-ray emission





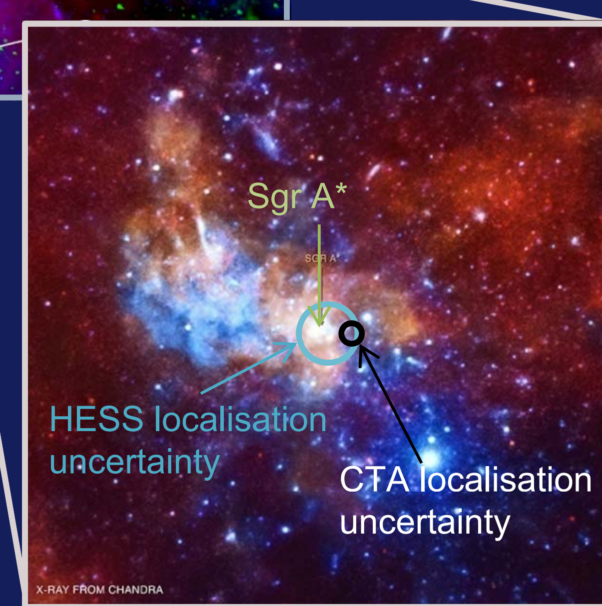
Galactic Centre

Slide courtesy of L. Tibaldo



VLA + Spitzer + Chandra
Wang+ 2010 MNRAS 492 895

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

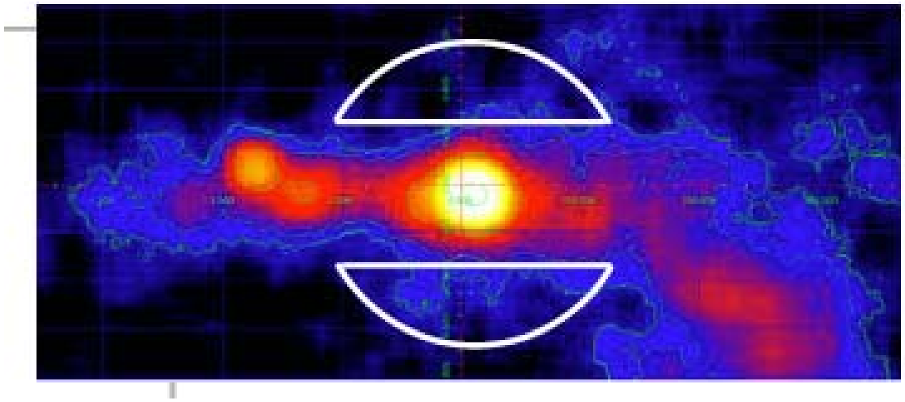


- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (*Fermi* bubbles)
- ideal region for dark matter searches

Dark Matter Programme

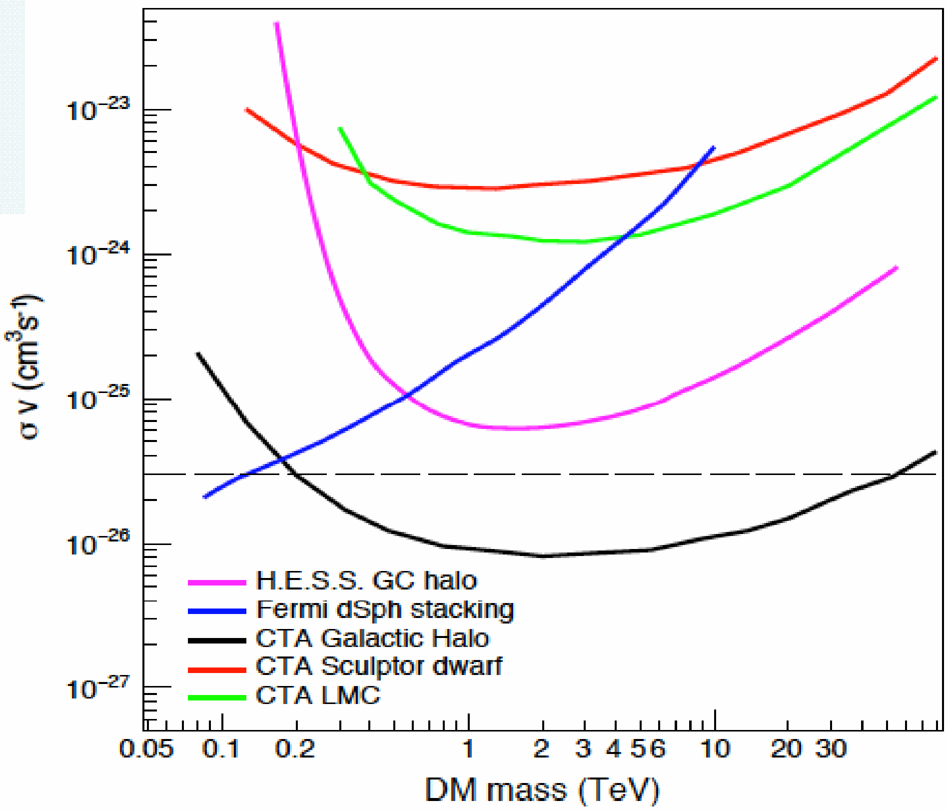
Existence of DM well established !

- CTA will search for DM via indirect detection technique: WIMP annihilation or decay
- Targets: GC, dSphs, LMC, G. Clusters



Programme strategy focused on a possible detection:

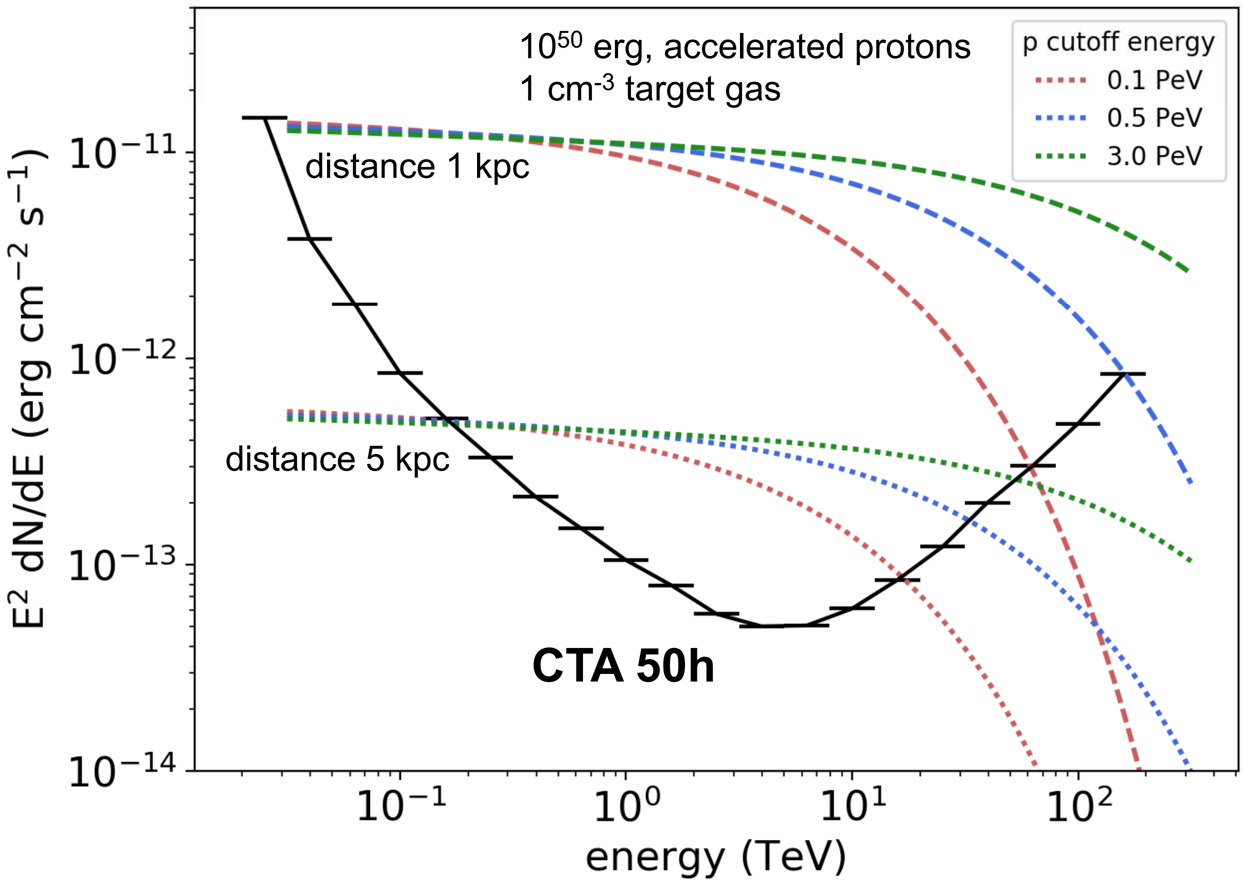
- Key target: Galactic centre halo with deep observation (O 500h) to reach relic x-section over wide mass range
- Complementary data on other targets



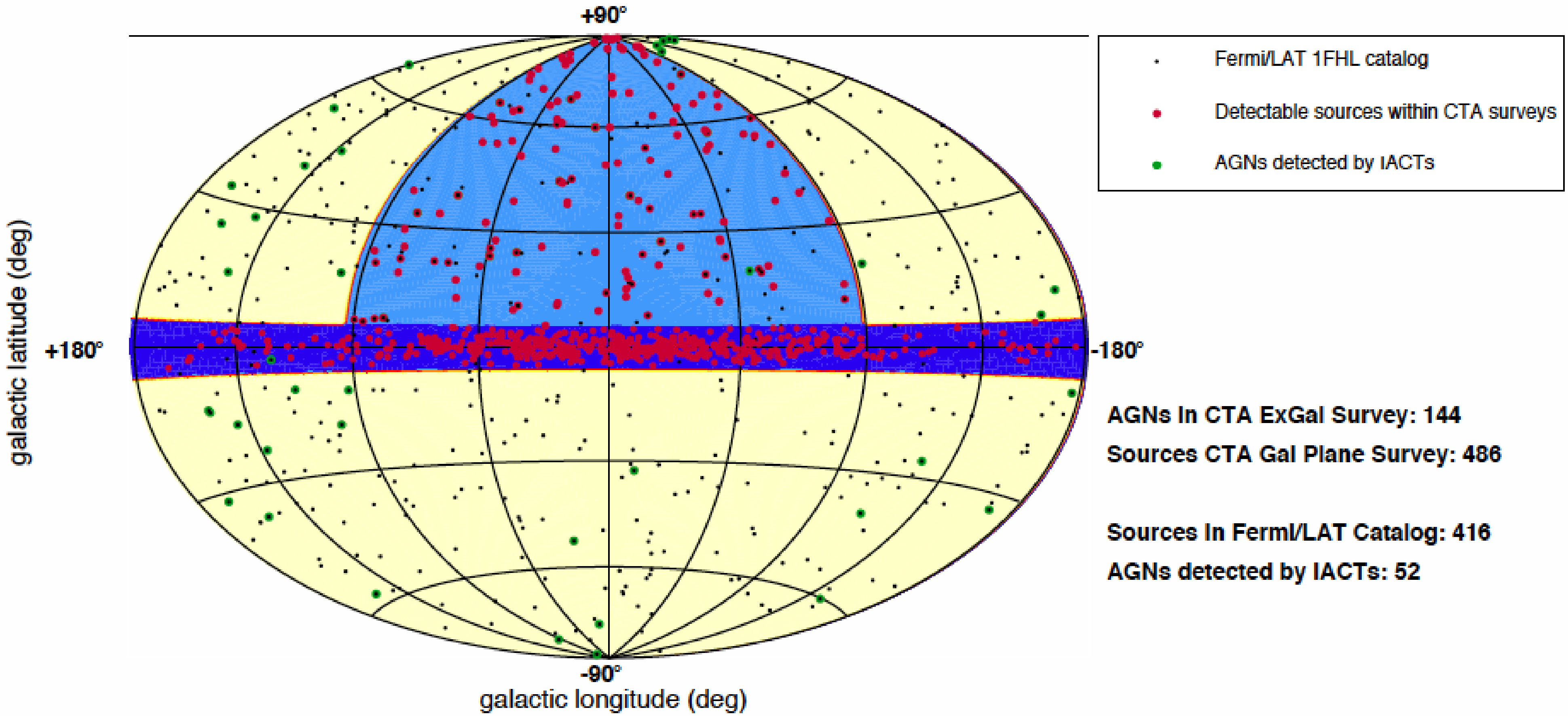
Cover WIMP masses above reach of direct detectors and the LHC

PeVatron Search

- **What sources accelerate hadrons to the knee?**
  - SNRs are standard paradigm, but only a handful provide strong evidence for hadronic acceleration so far, and only up to ~ 10 TeV.
- **Search for PeVatrons (beyond the GC) via the > 100 TeV spectrum – SSTs vital !**
  - Use GPS as finder and follow-up 5 brightest sources with no cut-off
  - Electrons' emission suppressed above 100 TeV (Klein-Nishina)
  - MWL information critical for identification



Extragalactic Survey



AGNs In CTA ExGal Survey: 144

Sources CTA Gal Plane Survey: 486

Sources In Fermi/LAT Catalog: 416

AGNs detected by IACTs: 52

- Survey of ¼ sky to limiting sensitivity of 5 mCrab
- Connects to Galactic plane survey & covers Coma, Virgo, Cen A, & Fermi bubbles (N)
- Unbiased determination of blazar luminosity function
- Possibility of divergent pointing strategy: excellent for transients

CONCLUSIONS

- With many discoveries, VHE γ-rays are now a well-recognized astrophysical discipline & part of growing multi-messenger science.
- VHE photons explore the very non-thermal universe and key questions in 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 – strong participation from Italy