→ ElisaBete de Gouveia Dal Pino (IAG-USP)
On behalf of the CTA Collaboration

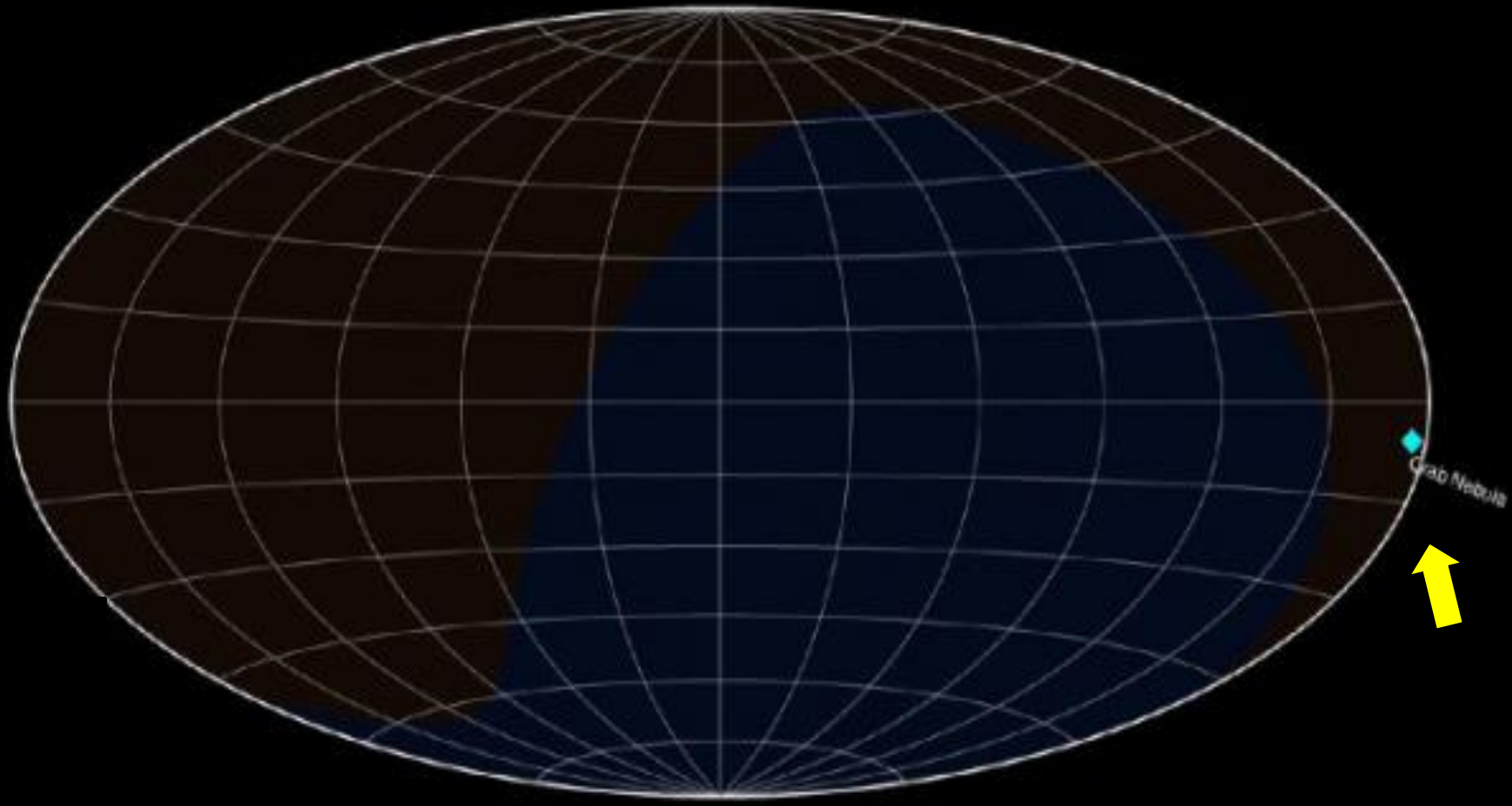
UFES, Vitoria, 8 de Outubro, 2018

20 years ago

The High-Energy Gamma Ray Sky (1989)

E > 100 GeV

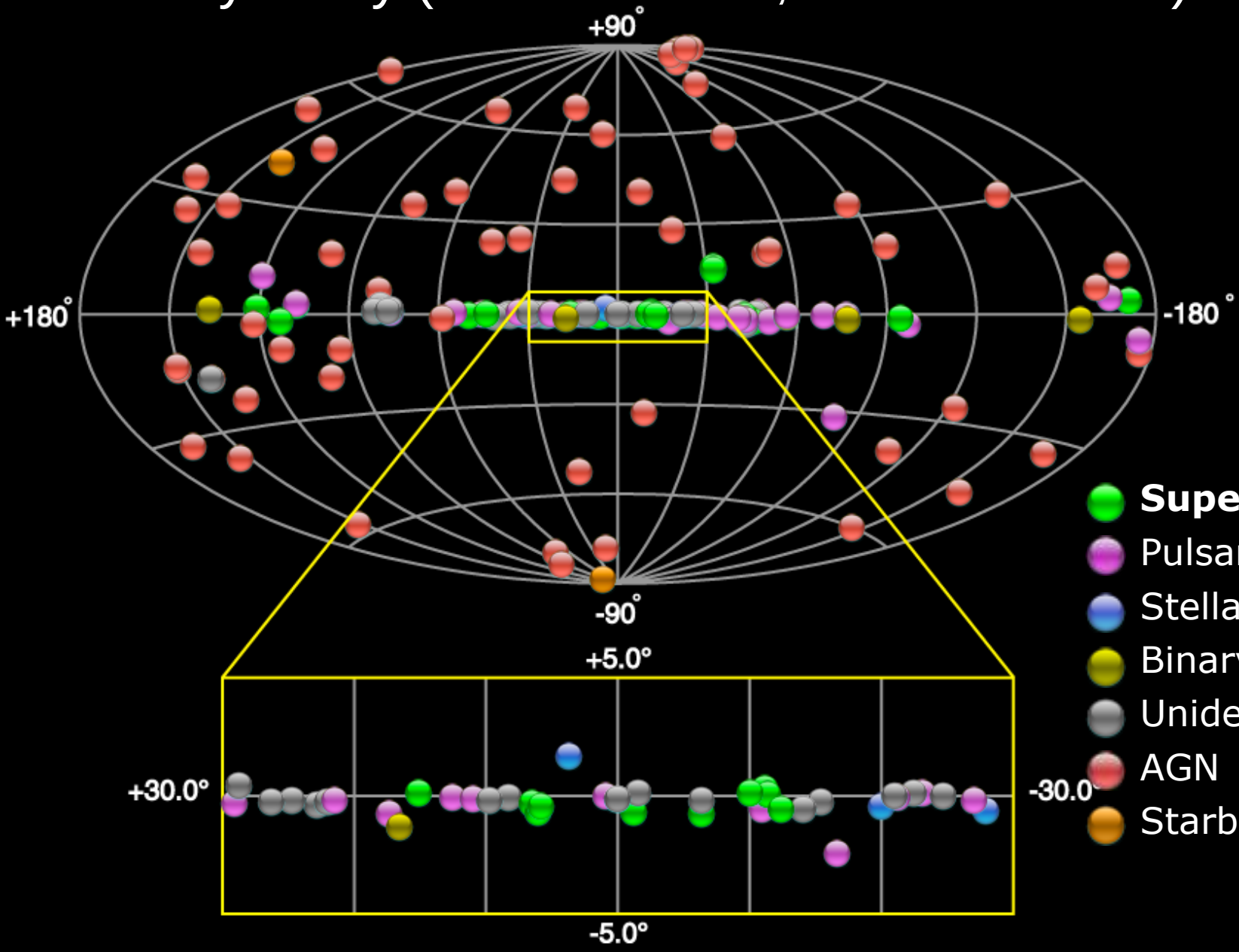
(Galactic coordinates)



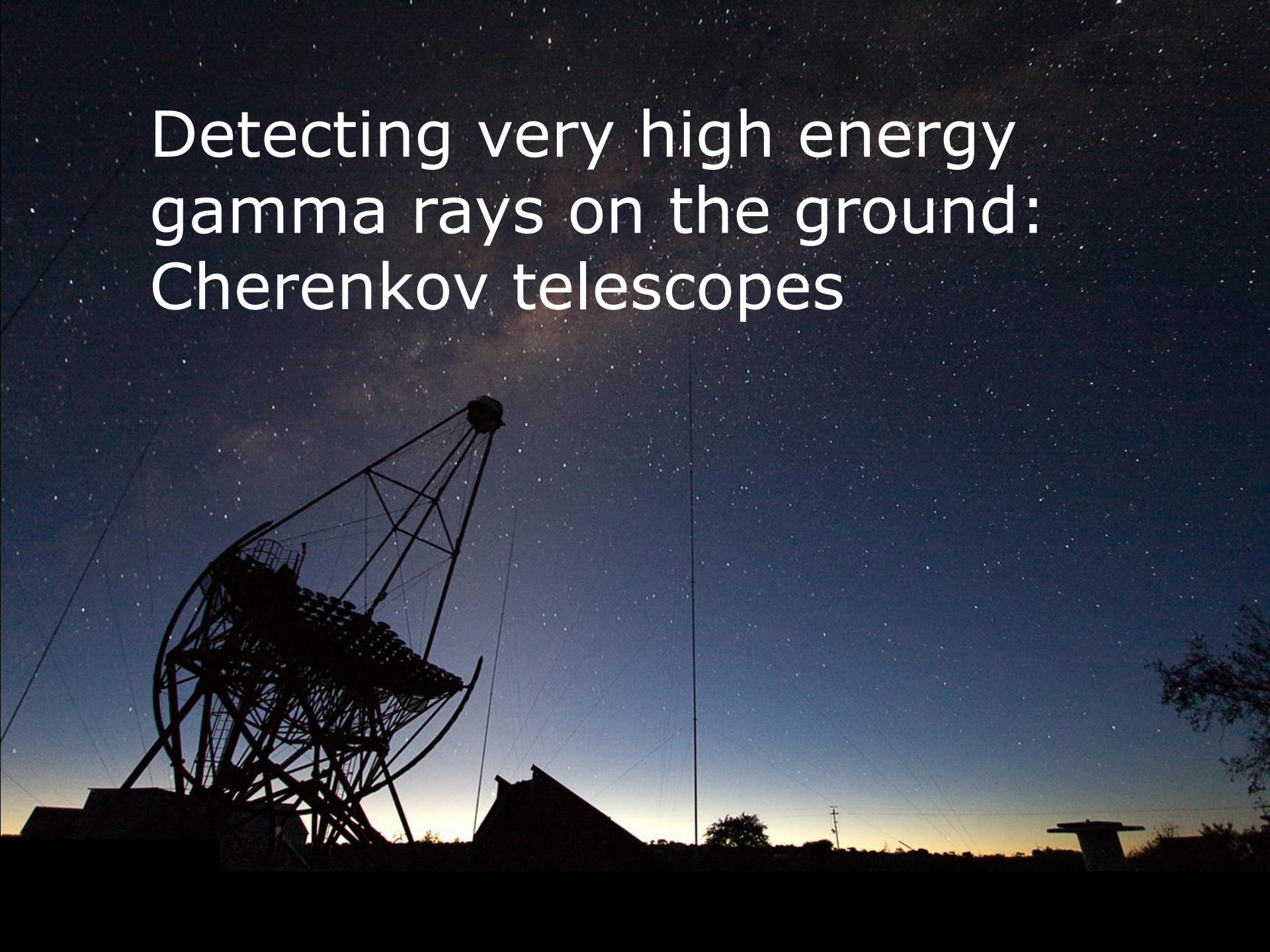
Background colours indicating northern / southern sky

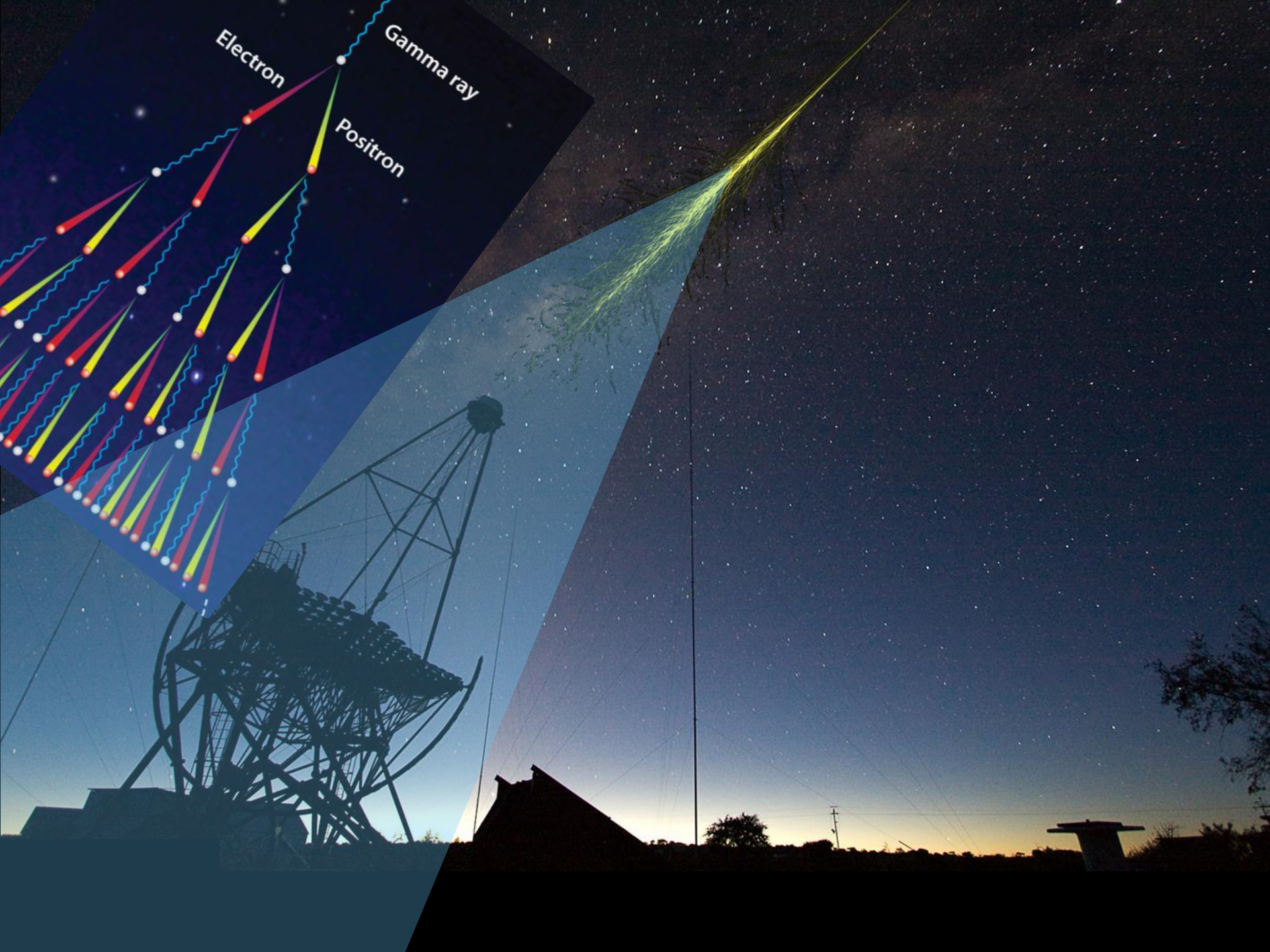
TeV sky today (~212 sources, 62 unidentified)

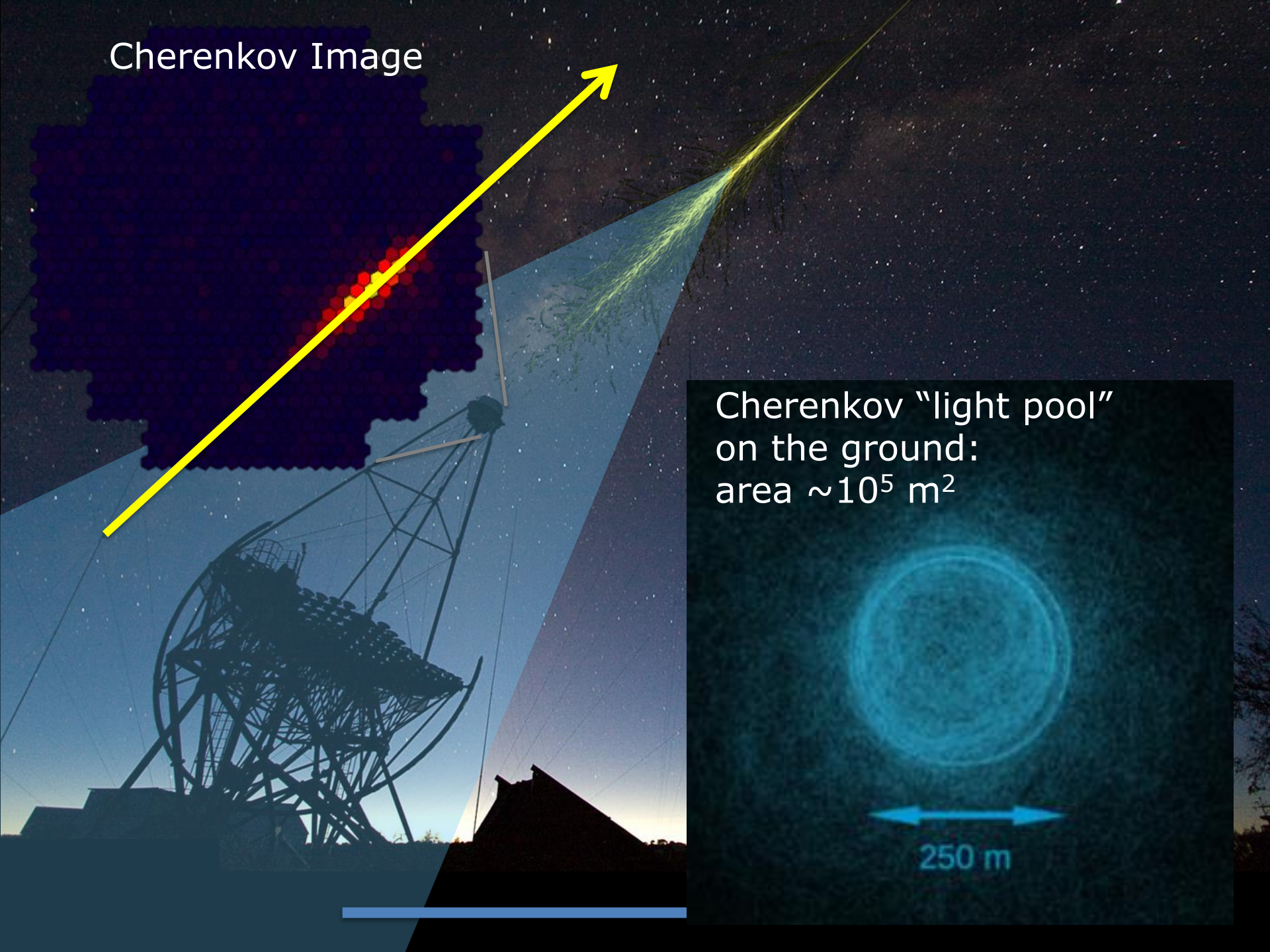
tevcat.uchicago.edu/



Detecting very high energy gamma rays on the ground: Cherenkov telescopes




Electron
Gamma ray
Positron


Cherenkov Image
Cherenkov "light pool"
on the ground:
area ~10^5 m^2
250 m

Current IACTs

Adapted from J. Hinton

50 GeV to ~ 50 TeV,
collecting area ~ $10^5 m^2$,
~ 4º FoV, angular res. ~ 0.1°
(TeV)

CTA: What one can (hopefully) afford

Key design goals:

- 10-fold increased sensitivity at TeV energies
- 10-fold increased effective energy coverage
- Larger field of view for surveys
- Improved angular resolution
- Full sky coverage: an array in each hemisphere

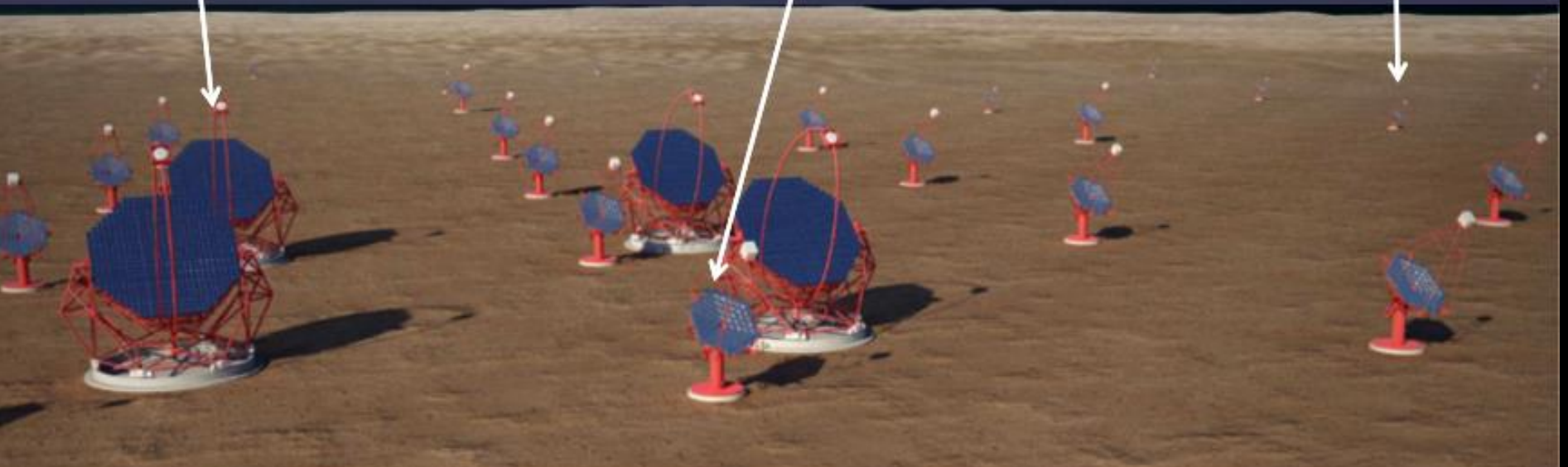
CTA Design (S array)

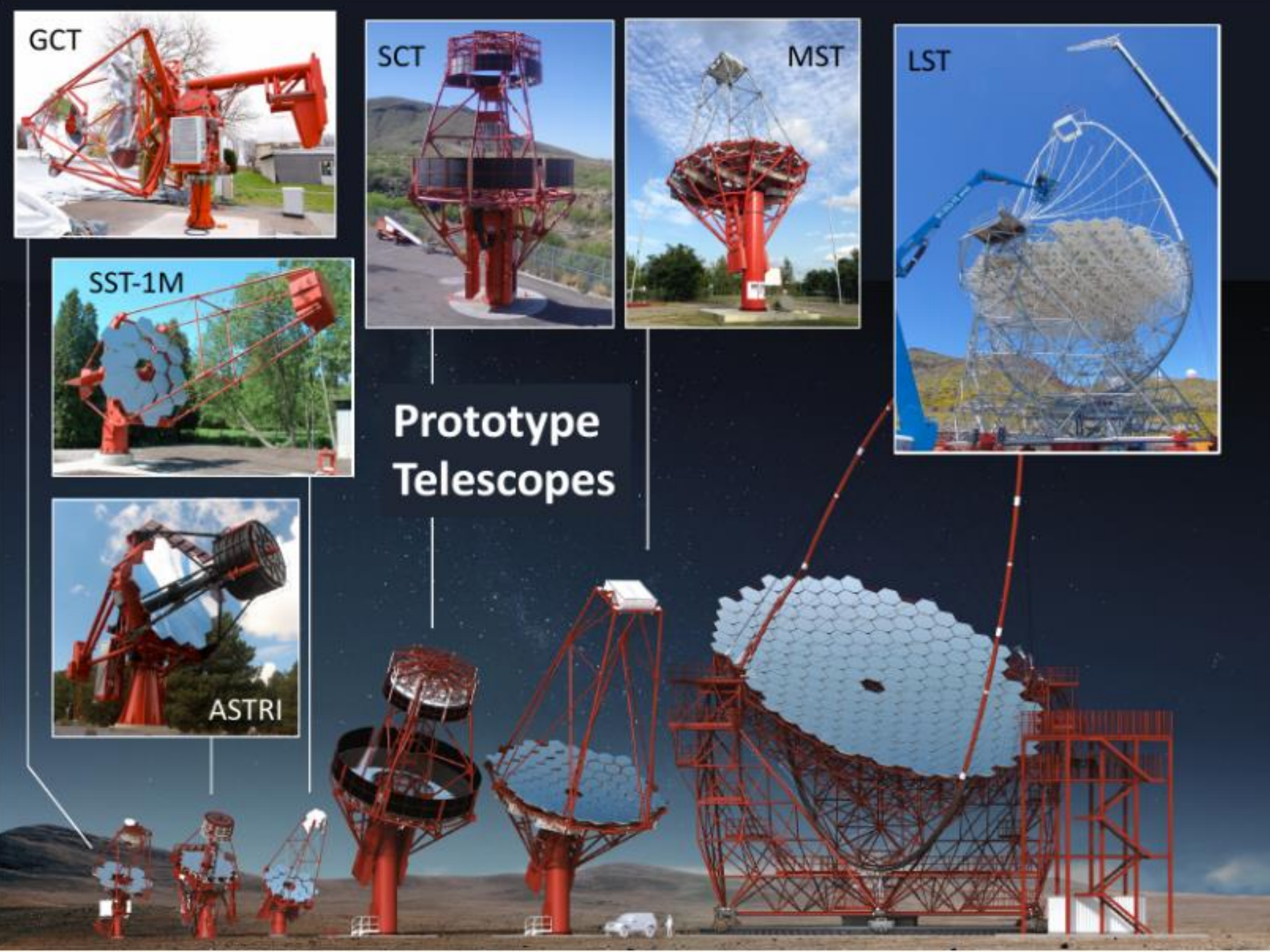
Science Optimization under budget constraints

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

Medium energies
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
(MST's/SCTs)

High energies
Up to > 300 TeV
10 km^2 eff. area @ 10 TeV
4m diameter
70 telescopes
(SST's)



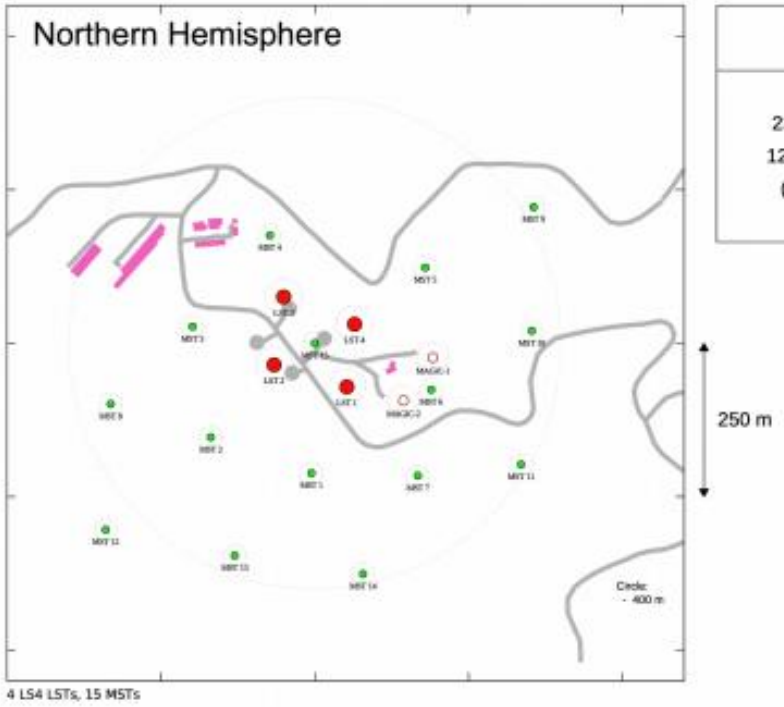

GCT
SCT
MST
LST
SST-1M
Prototype
Telescopes
ASTRI

CTA Consortium

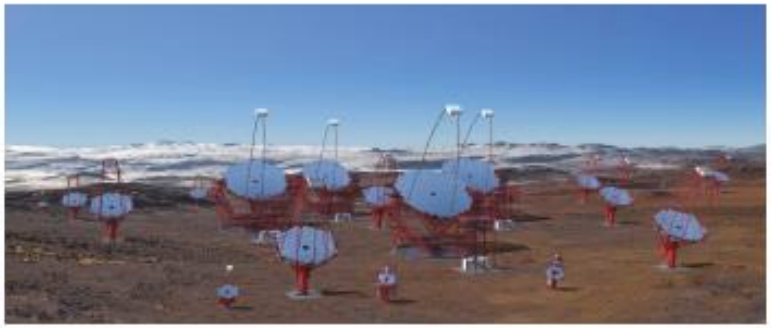
CTA is being developed by the CTA Consortium:

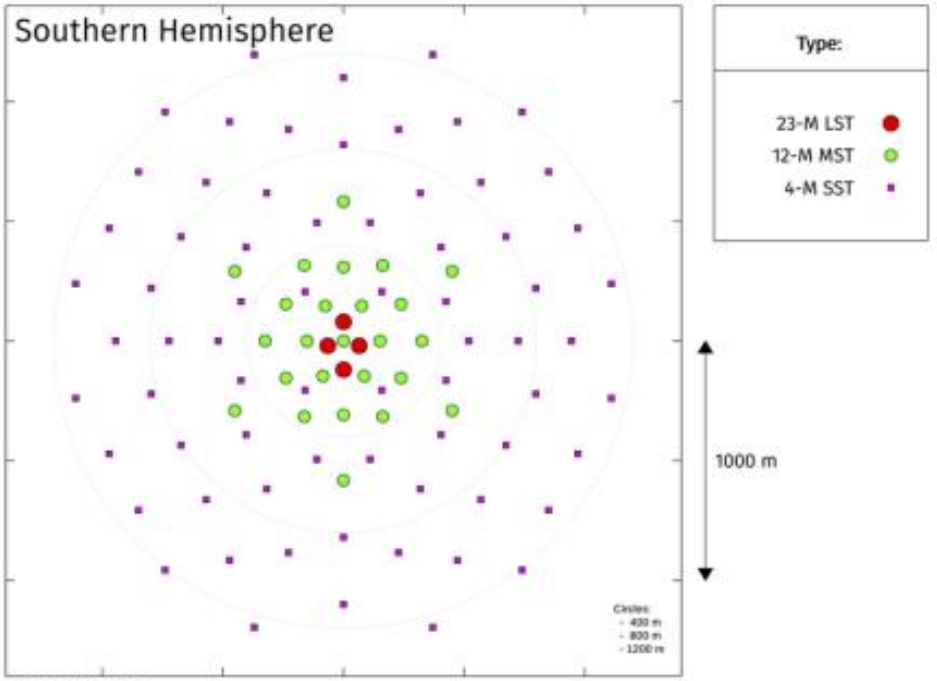
31 countries, 92 parties, 202 institutes, 1466 members (513 FTE)

Where to find us



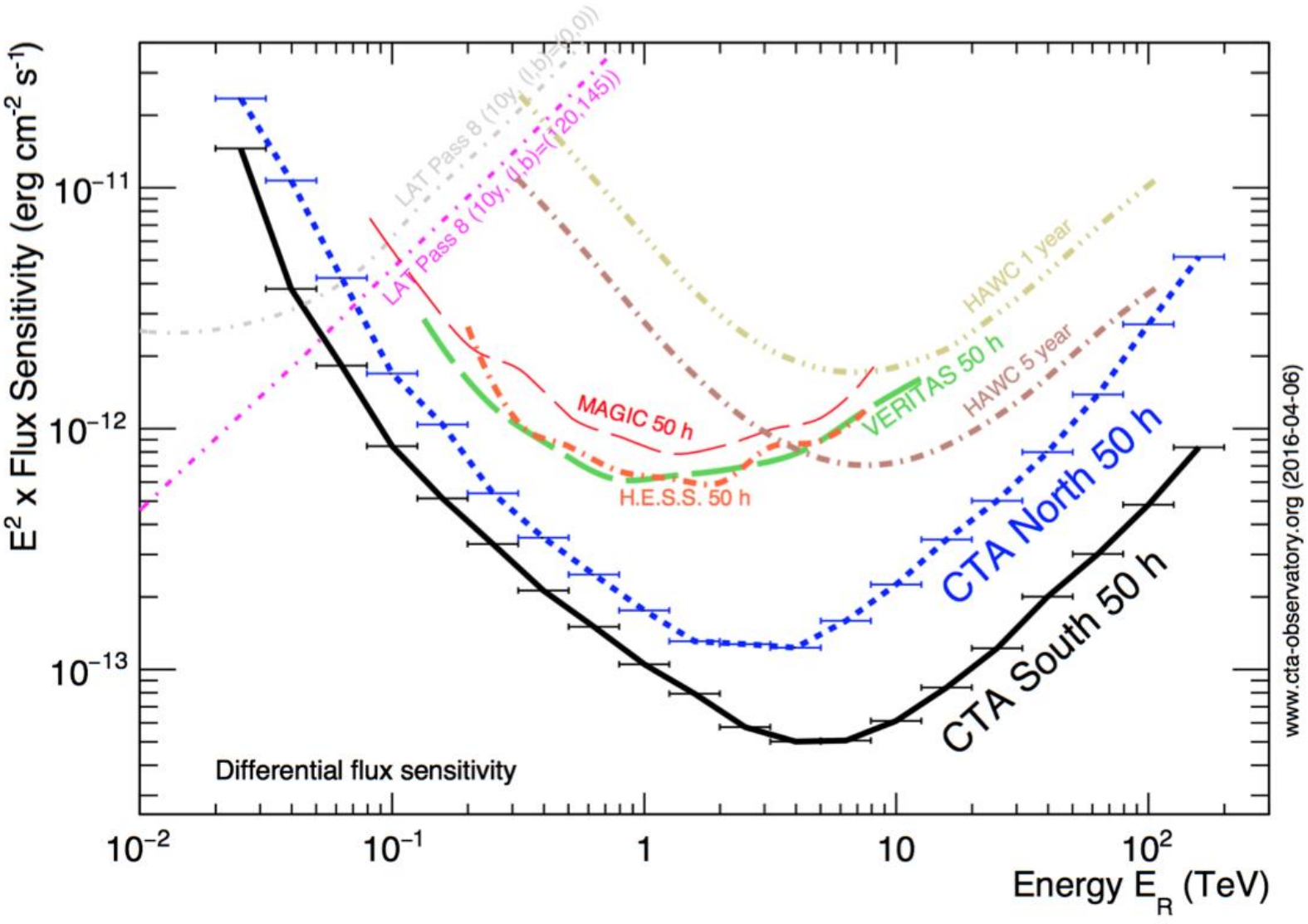
4 LS4 LSTs, 15 MSTs



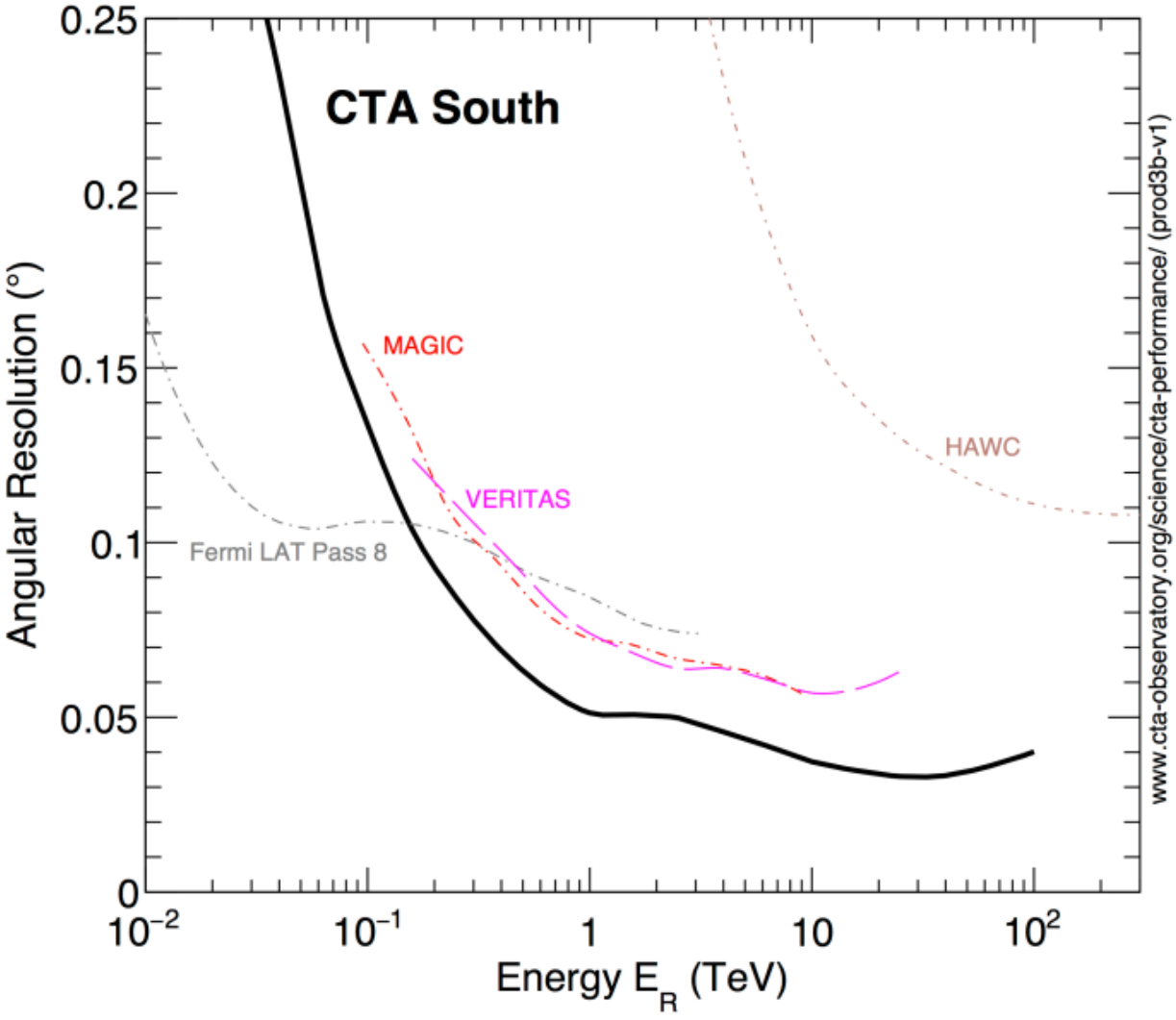


4 LSTs, 25 MSTs, 70 SSTs

CTA PERFORMANCE



CTA ANGULAR RESOLUTION



CTA SCIENCE CASE

Science with the CTA:

book to be published soon.

Contains most of the plots in this talk.

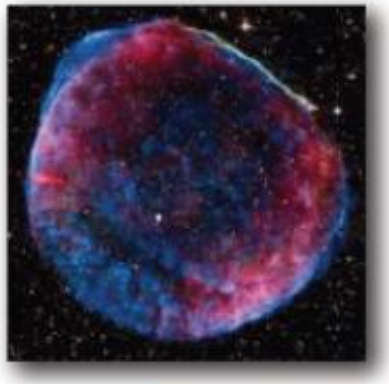
CTA is an open observatory with 40% of its time reserved for Key Science Projects.

(http://adsabs.harvard.edu/abs/2017arXiv170907997C)

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

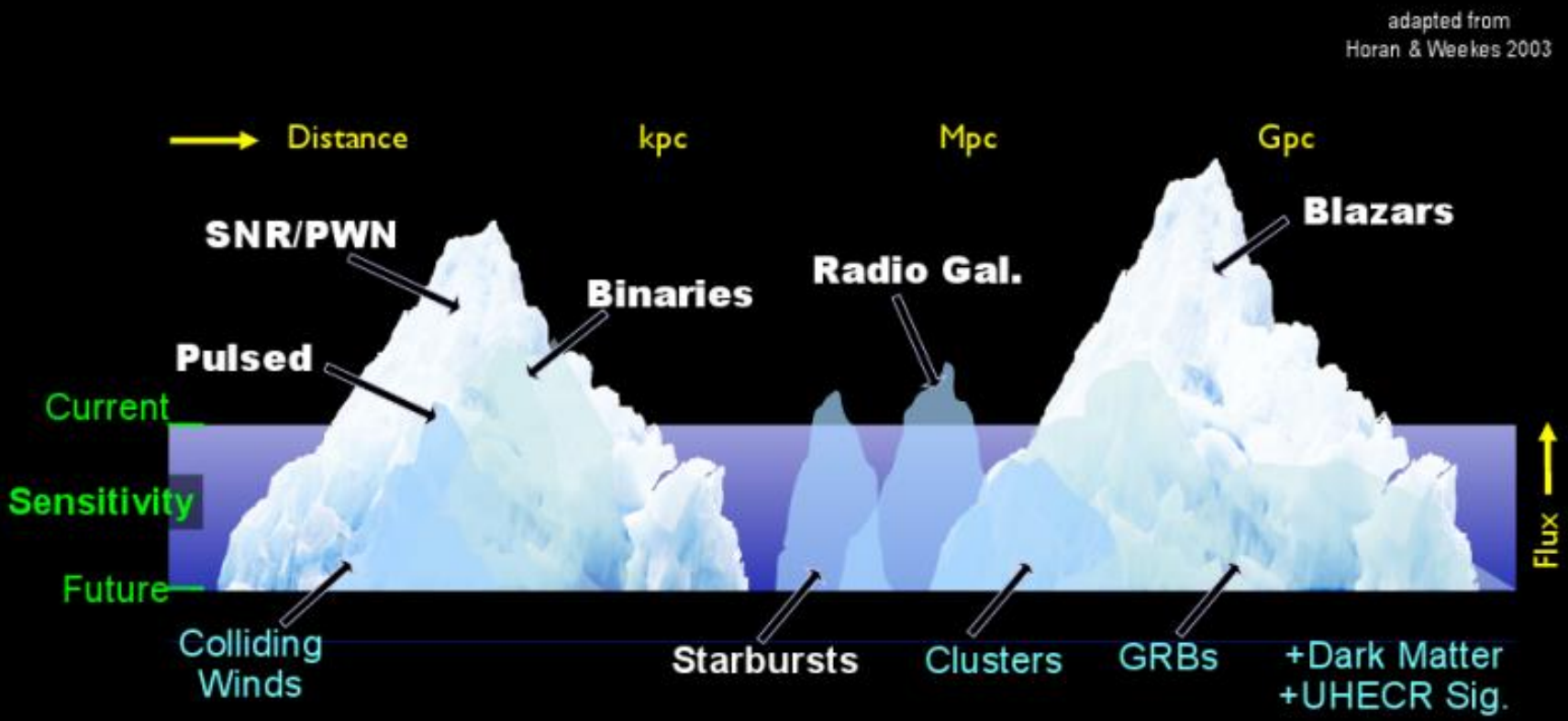
- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Exploring cosmic voids
- Probing IGMFs

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?

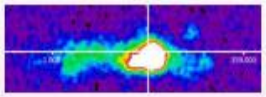
apted from J. Knödlseder.

Discovery Potential

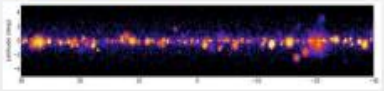


Key Science projects

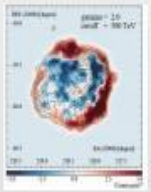
Galactic Centre



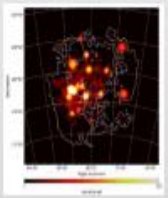
Galactic Plane Survey



Cosmic Ray PeVatrons

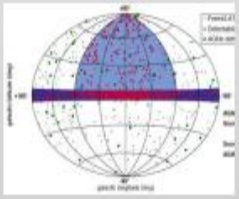


Star Forming Systems



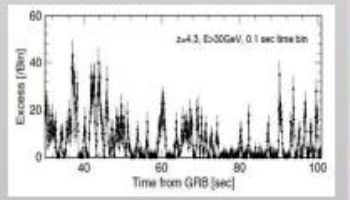
LMC Survey

Extragalactic Survey



Active Galactic Nuclei

Transients



Clusters of Galaxies

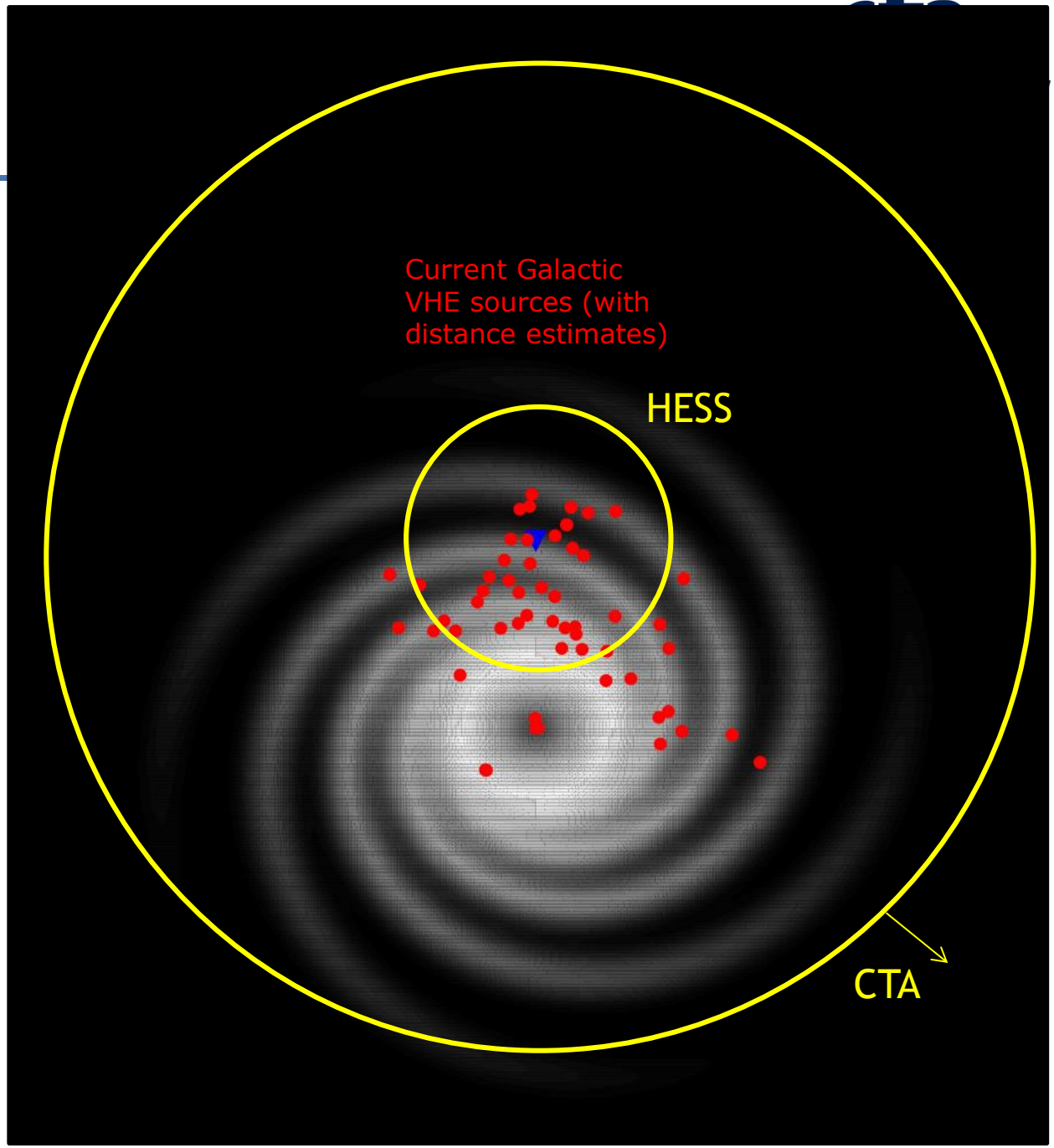
Dark Matter Programme

arXiv:1709.07997

cta cherenkov telescope array

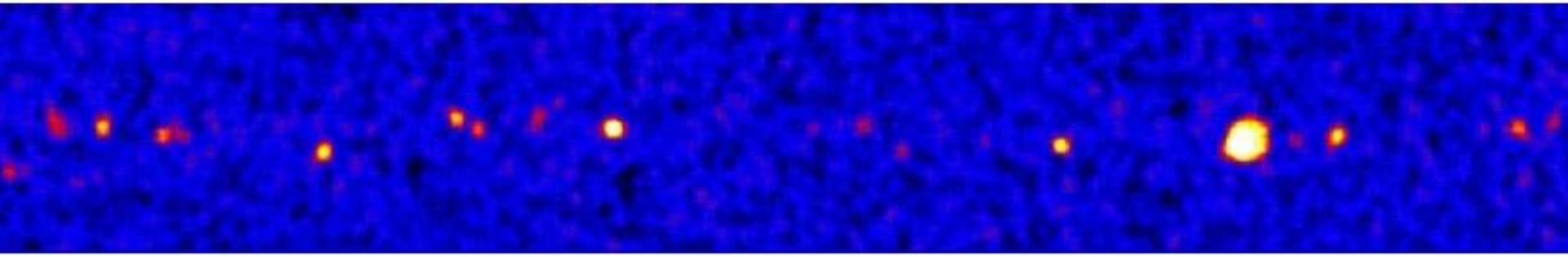
Science with the Cherenkov Telescope Array

CTA REACH

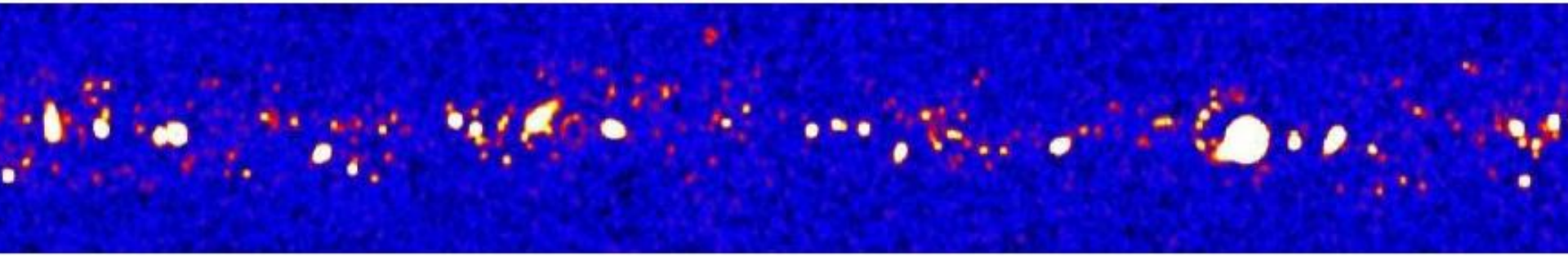

Current Galactic
VHE sources (with
distance estimates)
HESS
CTA

EXAMPLE: GALACTIC PLANE SURVEY

H.E.S.S.



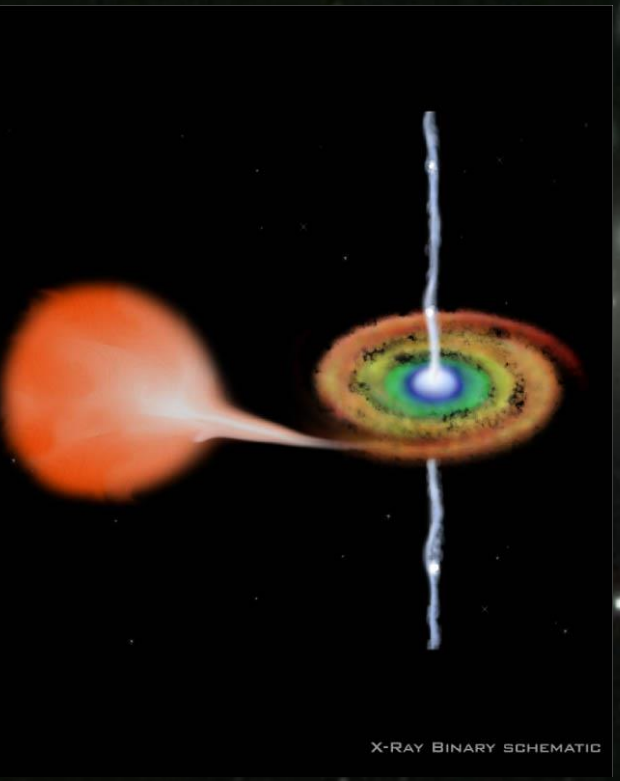
CTA, for same exposure



expect ~500 detected sources

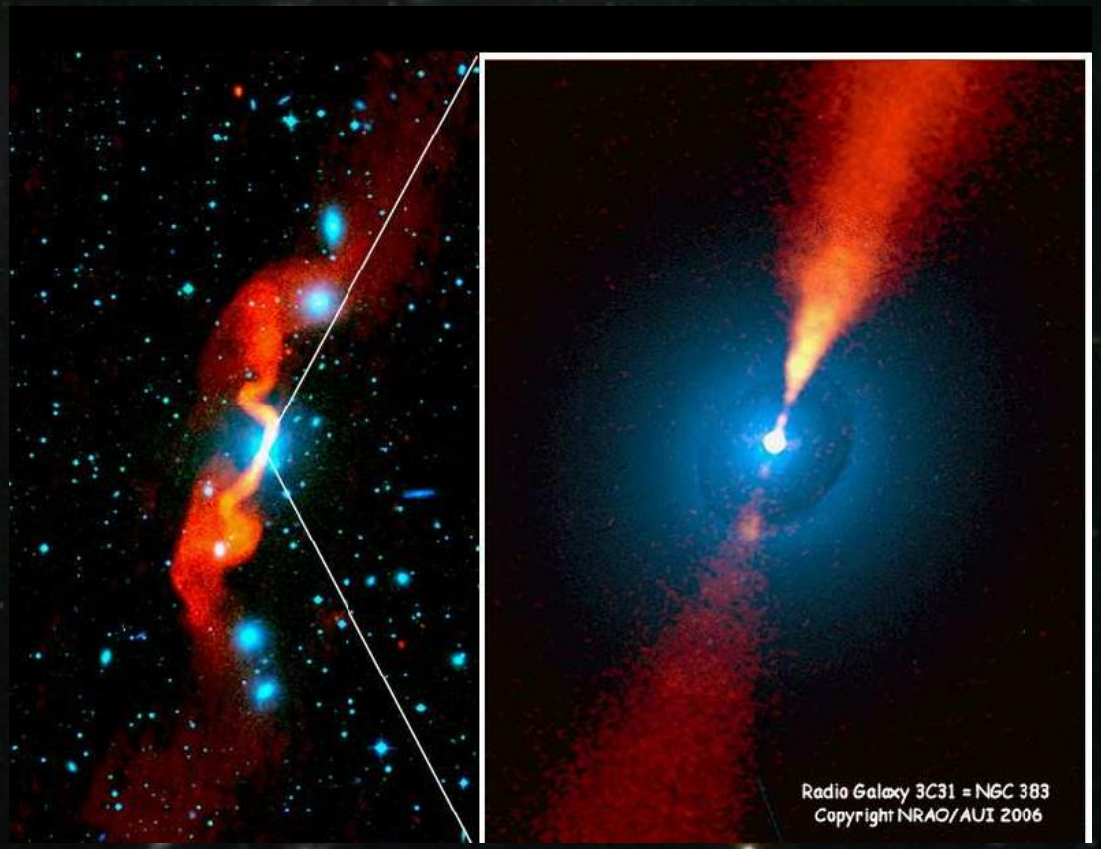
COSMIC ACCELERATORS
TEVS -> PEVATRONS:

Supernovae



Black Hole Binaries
(Microquasars)

AGNs (blazars, radio-galaxies, seyferts)



COSMIC RAY PEVATRONS (~10^{15} EV)

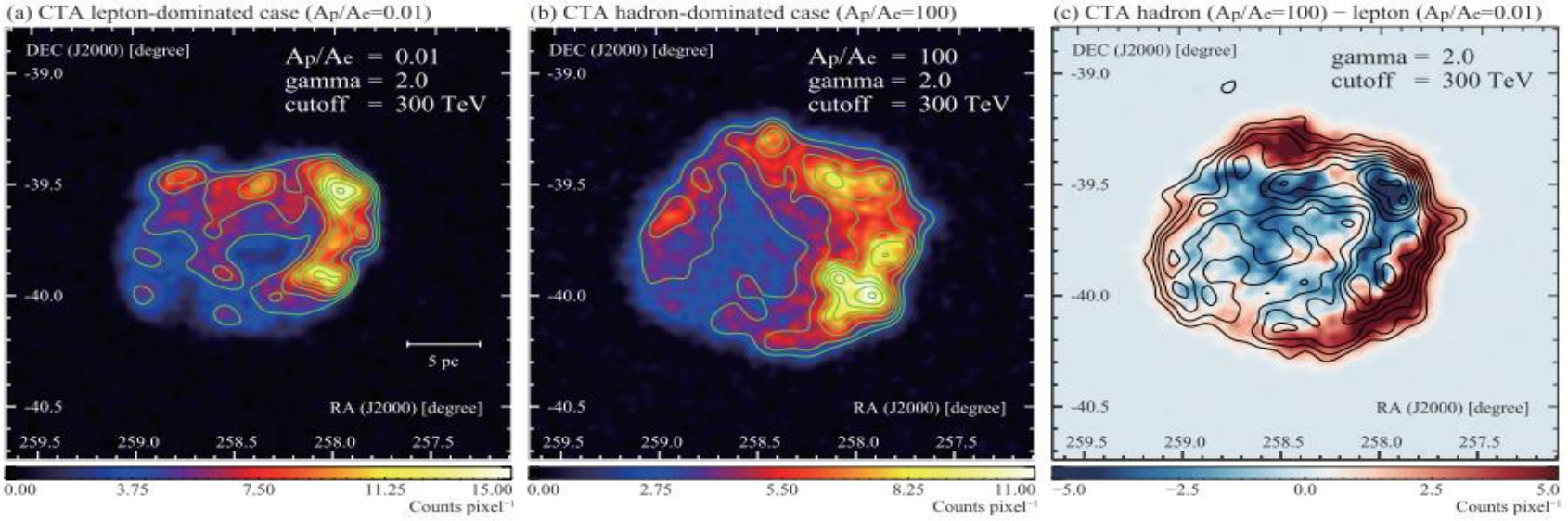
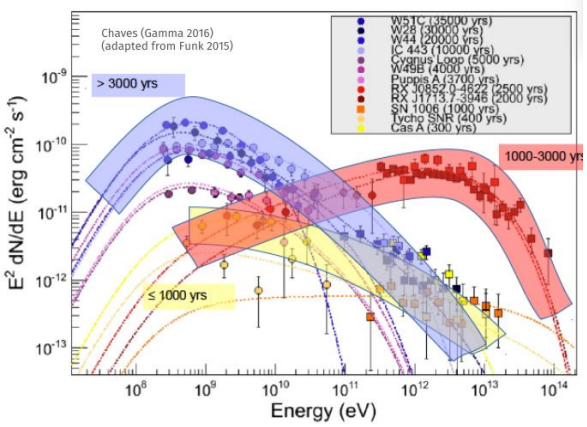


Figure 1.6 – Simulated CTA images of the TeV-bright supernova remnant RX J1713−3946 for different emission scenarios, showing the power of CTA to differentiate between these scenarios. Reproduced from [21].

(CTA coll., ApJ, 2017)

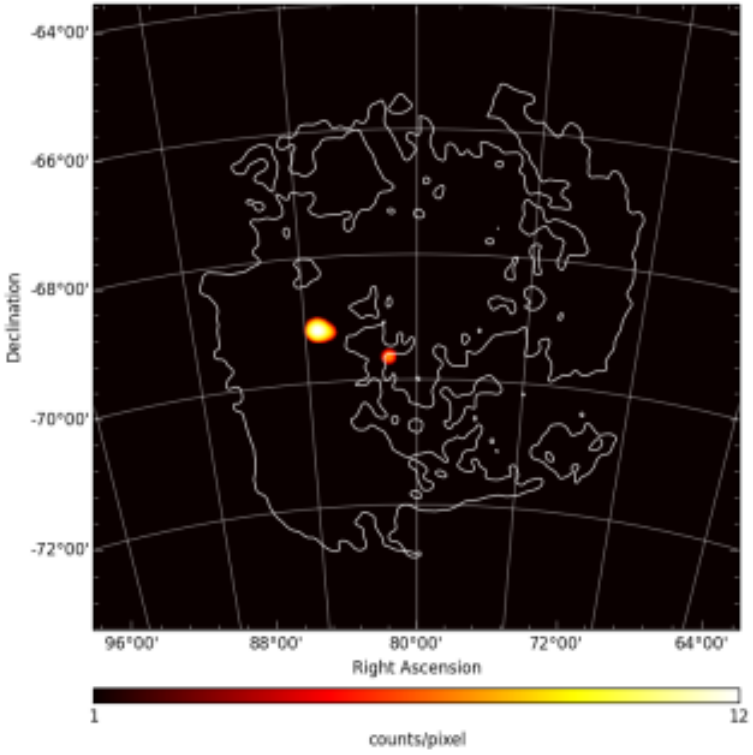


Detection gammas up to E ~100 TeV will imply:

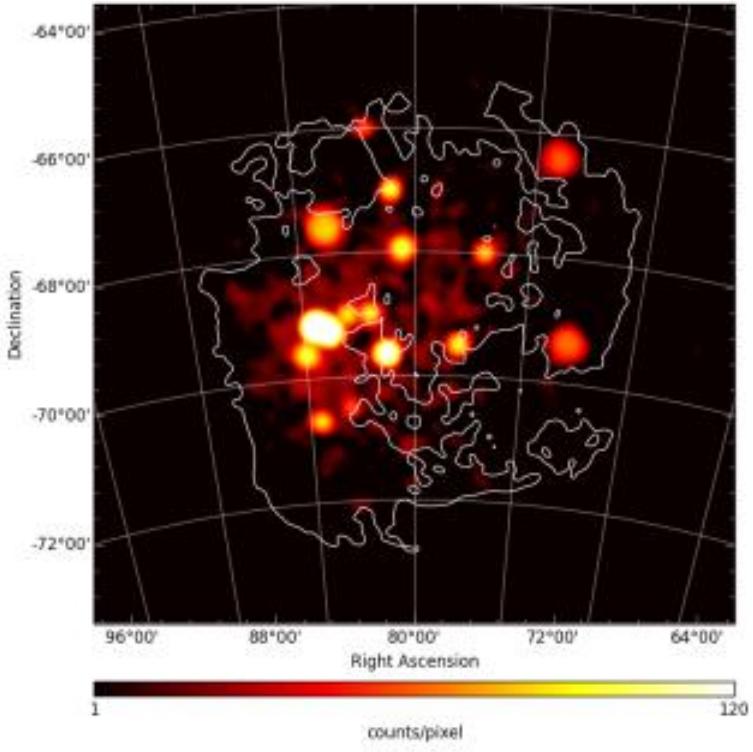
- ✓ emission is hadronic
- ✓ SNR is PeVatron (because ~100 TeV photons are produced by ~PeV protons)

Large Magellanic Cloud

Global view of a near star-forming galaxy at TeV energies
More than 60 SNRs



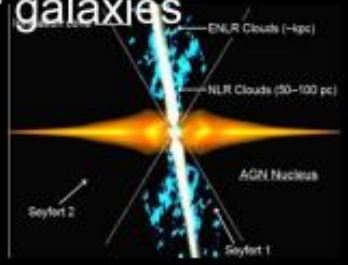
Current



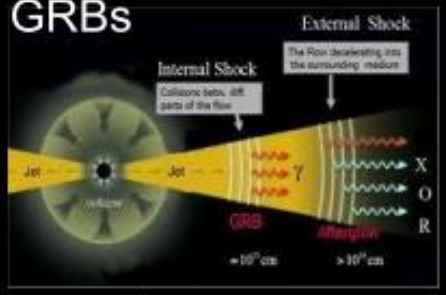
CTA

CTA EXTRAGALACTIC TARGETS

other galaxies



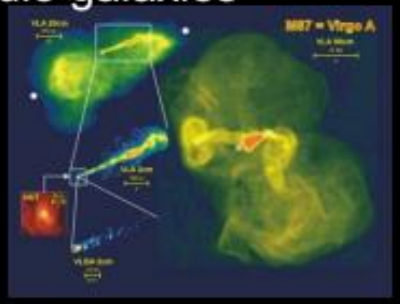
GRBs

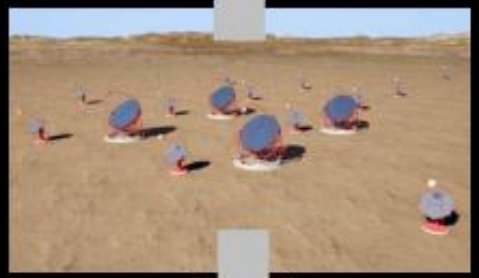


blazars

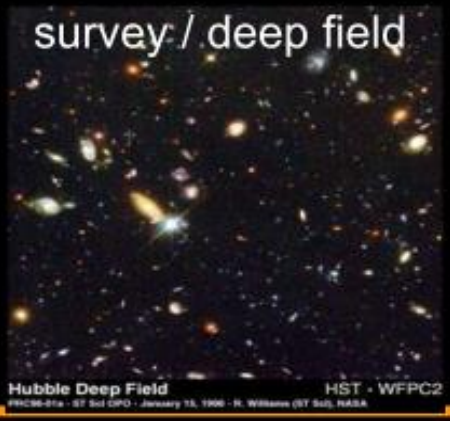
star forming regions

radio galaxies



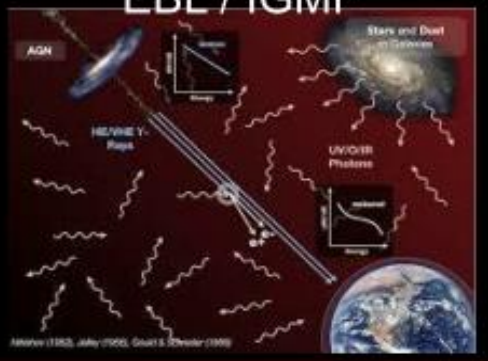


survey / deep field



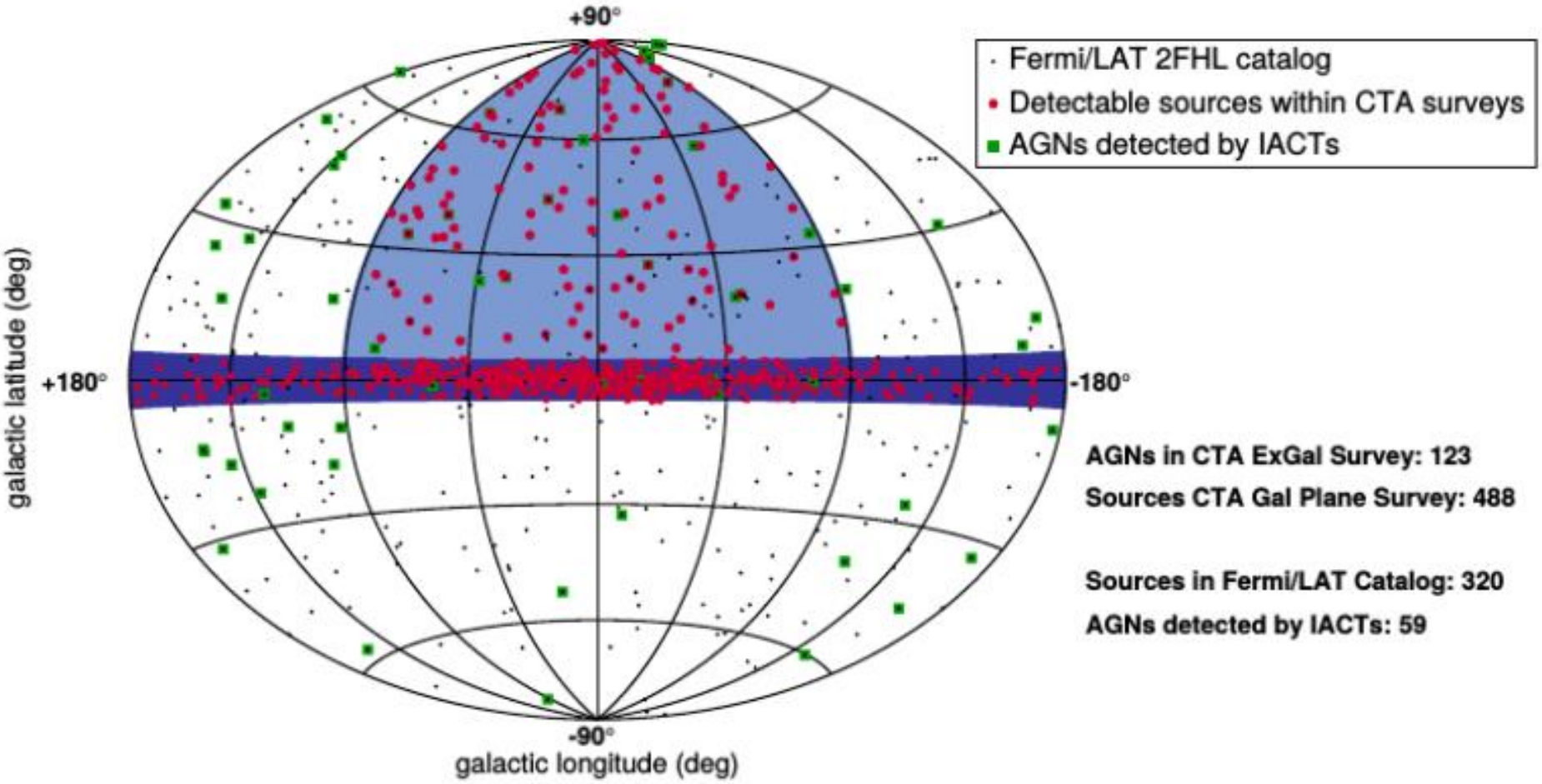
galaxy clusters

EBL / IGMF



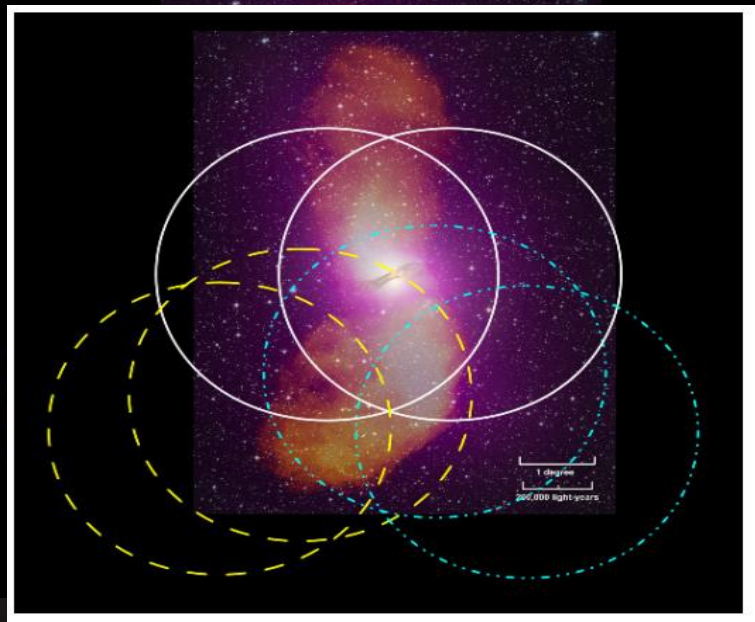
Thanks to D. Mazin

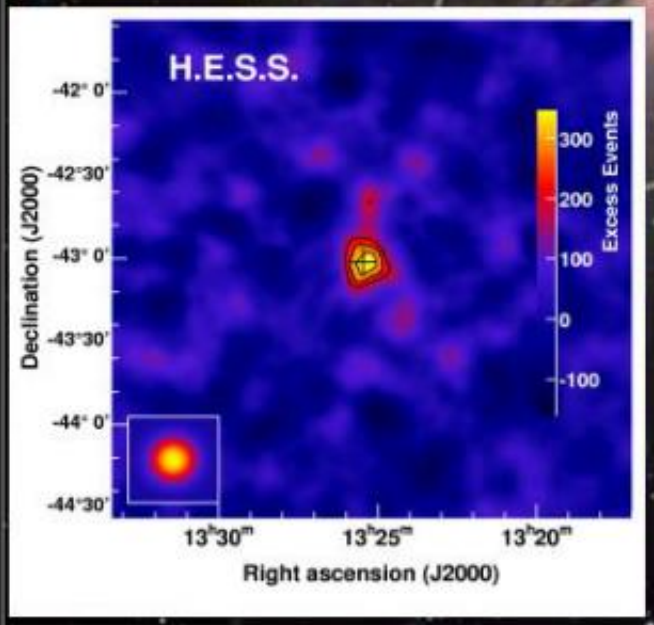
Galactic Plane and Extragalactic Survey



Cen A

Location of Gamma Emission in Radio Galaxies

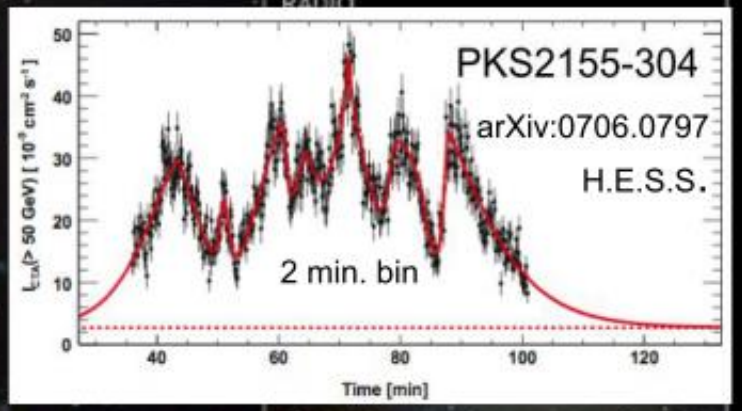




origin of variability at all scales?

location of emission region?

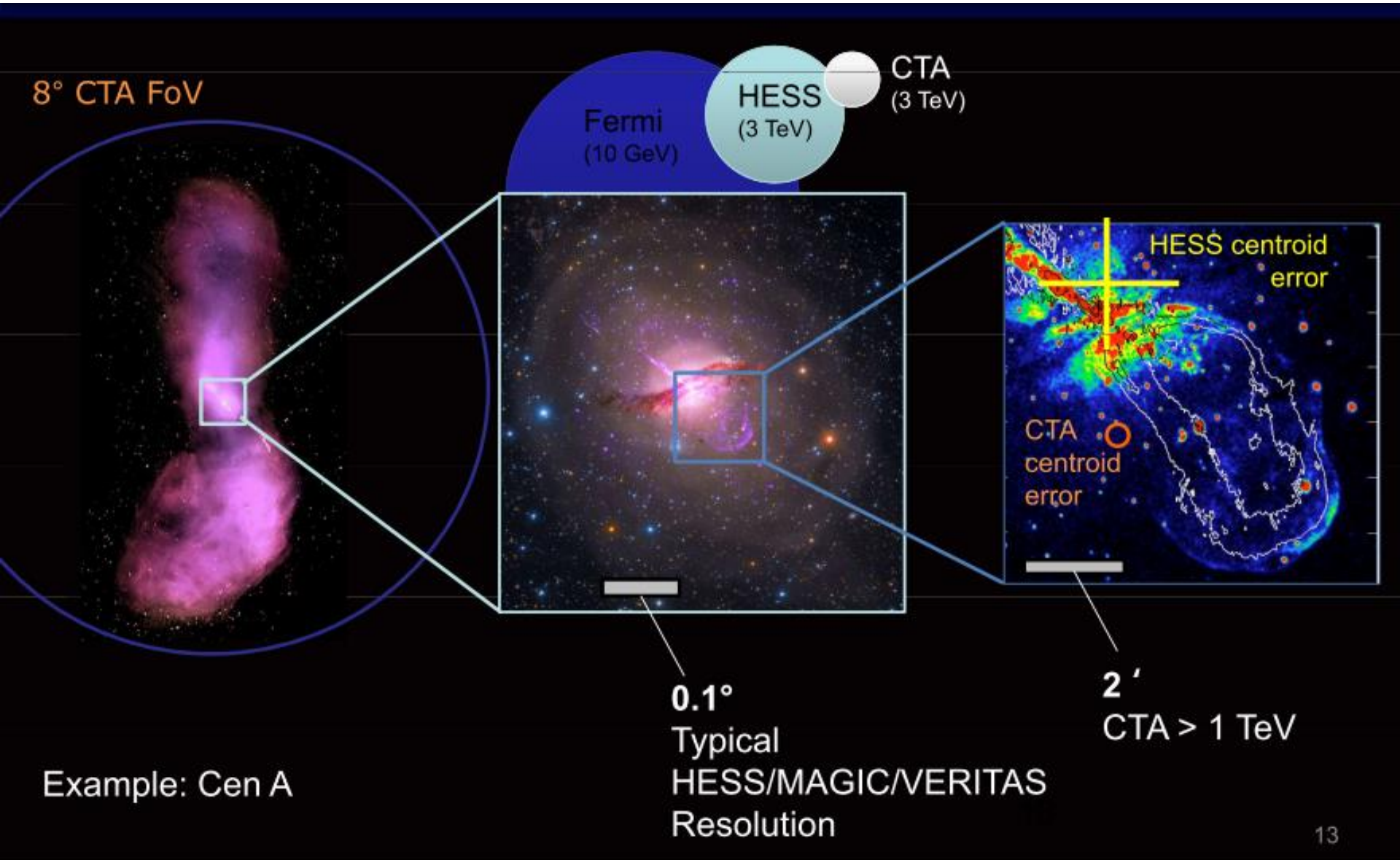
duty cycle?



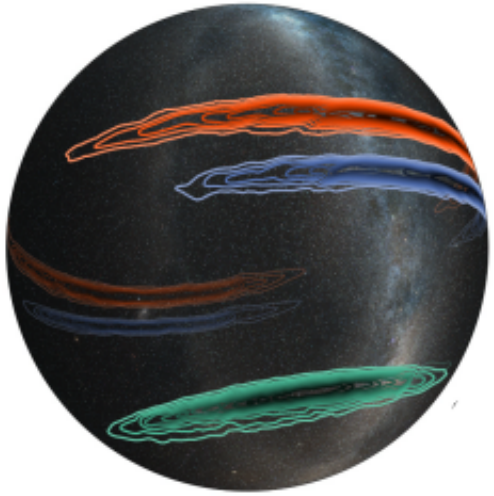
RADIO

OPTICAL

Resolving Complex Sources



Transients



Credits: The LIGO Scientific Collaboration

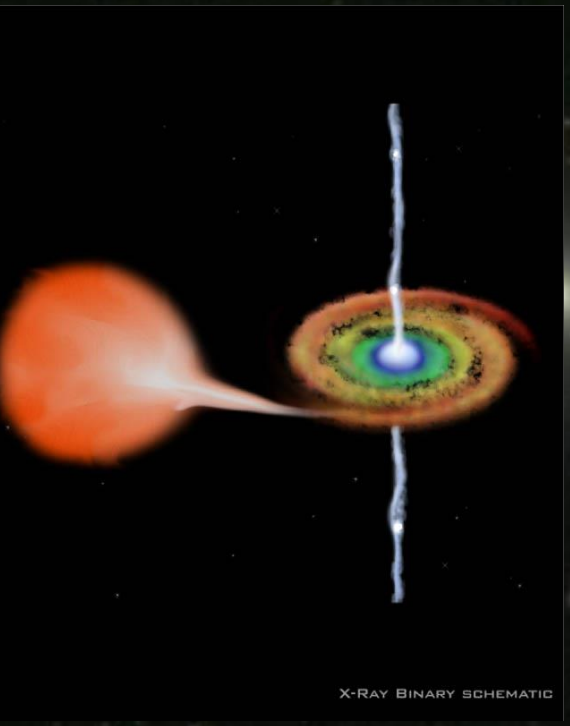
Transients are a diverse population of astrophysical objects. Some are known to be prominent **emitters of high-energy gamma-rays**, while others are sources of non-photonic, multi-messenger signals such as cosmic rays, **neutrinos and/or gravitational waves**.

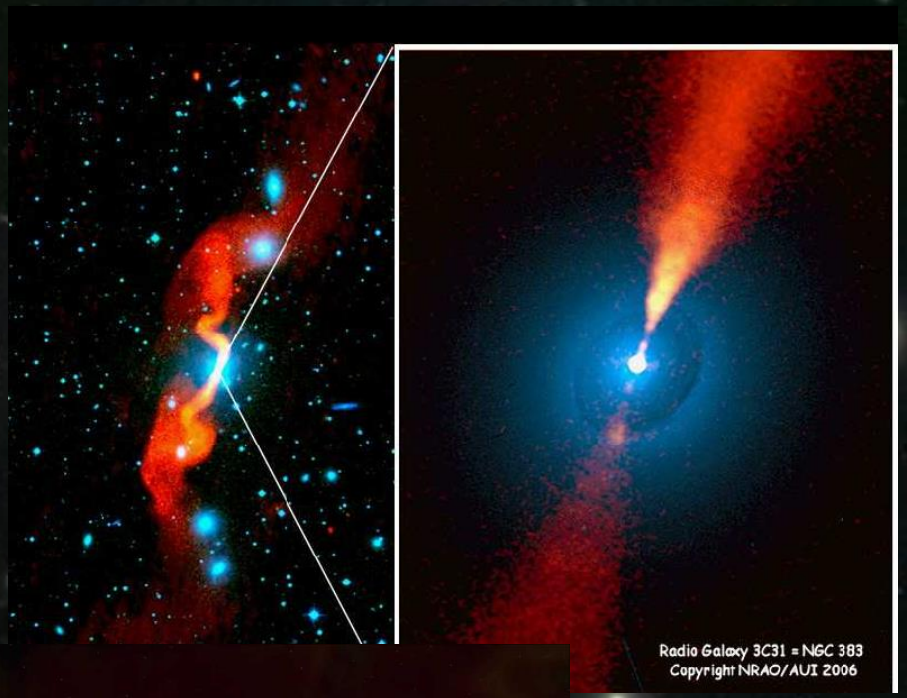
Possible classes of targets

- Gamma-ray bursts
- Galactic transients
- High-energy neutrino transients
- Gravitational wave transients
- Radio, optical, and X-ray transients
- Serendipitous VHE transients

BLACK HOLE SOURCES: PEVATRONS, TRANSIENTS

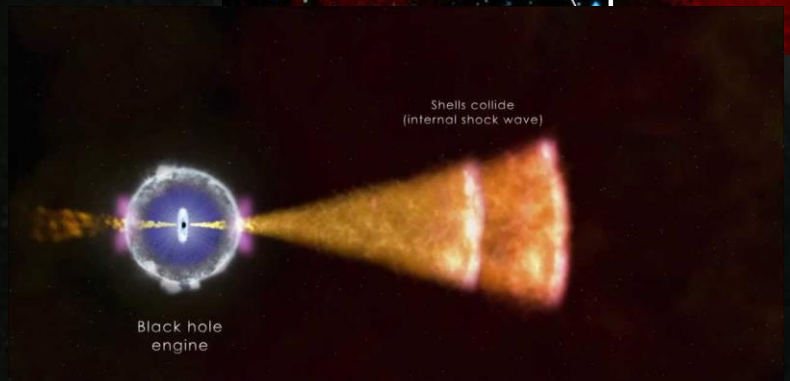
AGNs (blazars, radio-galaxies, seyferts)



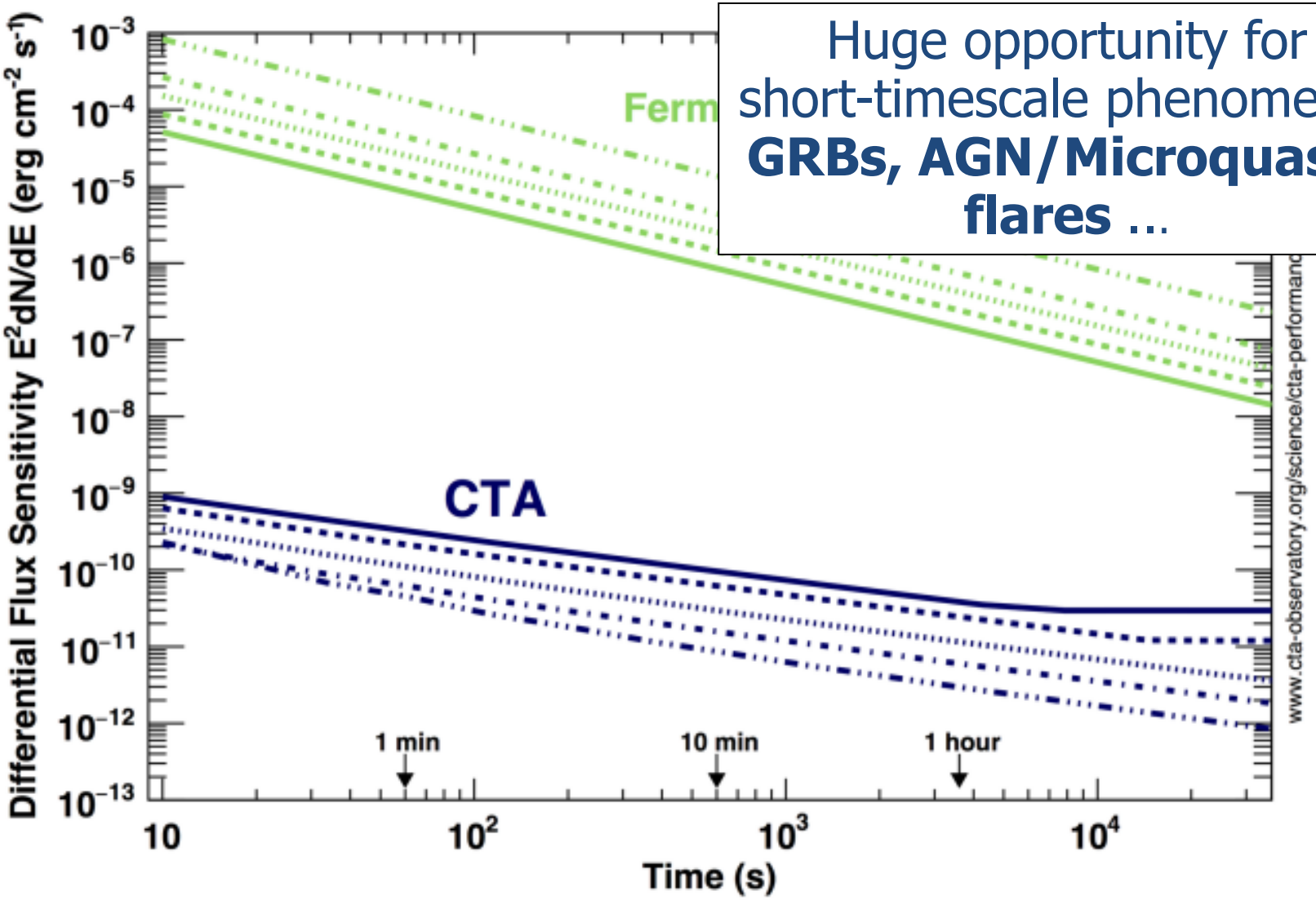


Black Hole Binaries
(Microquasars)

GRBs

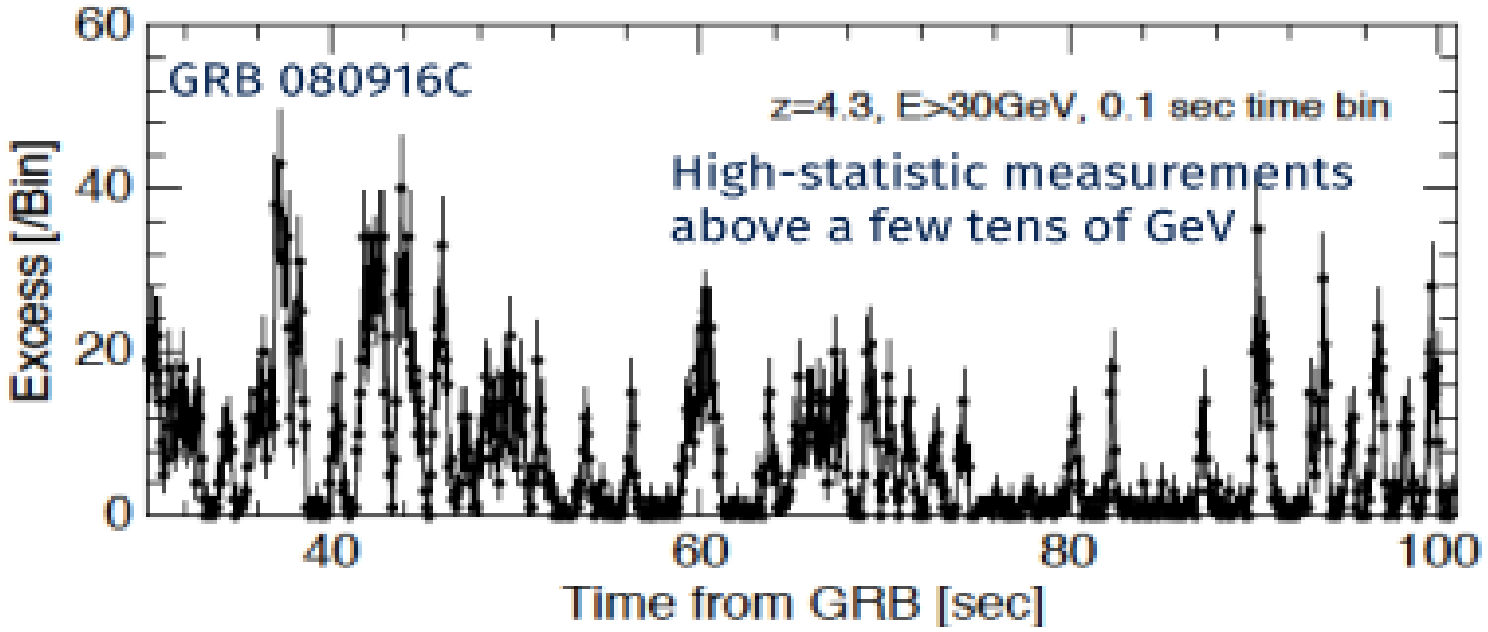


TRANSIENTS WITH CTA



Huge opportunity for short-timescale phenomena: **GRBs, AGN/Microquasar flares …**

CTA WILL RESOLVE GRB LIGHT CURVES !



CTA is potentially capable of resolving GRBs light curve in exquisite detail

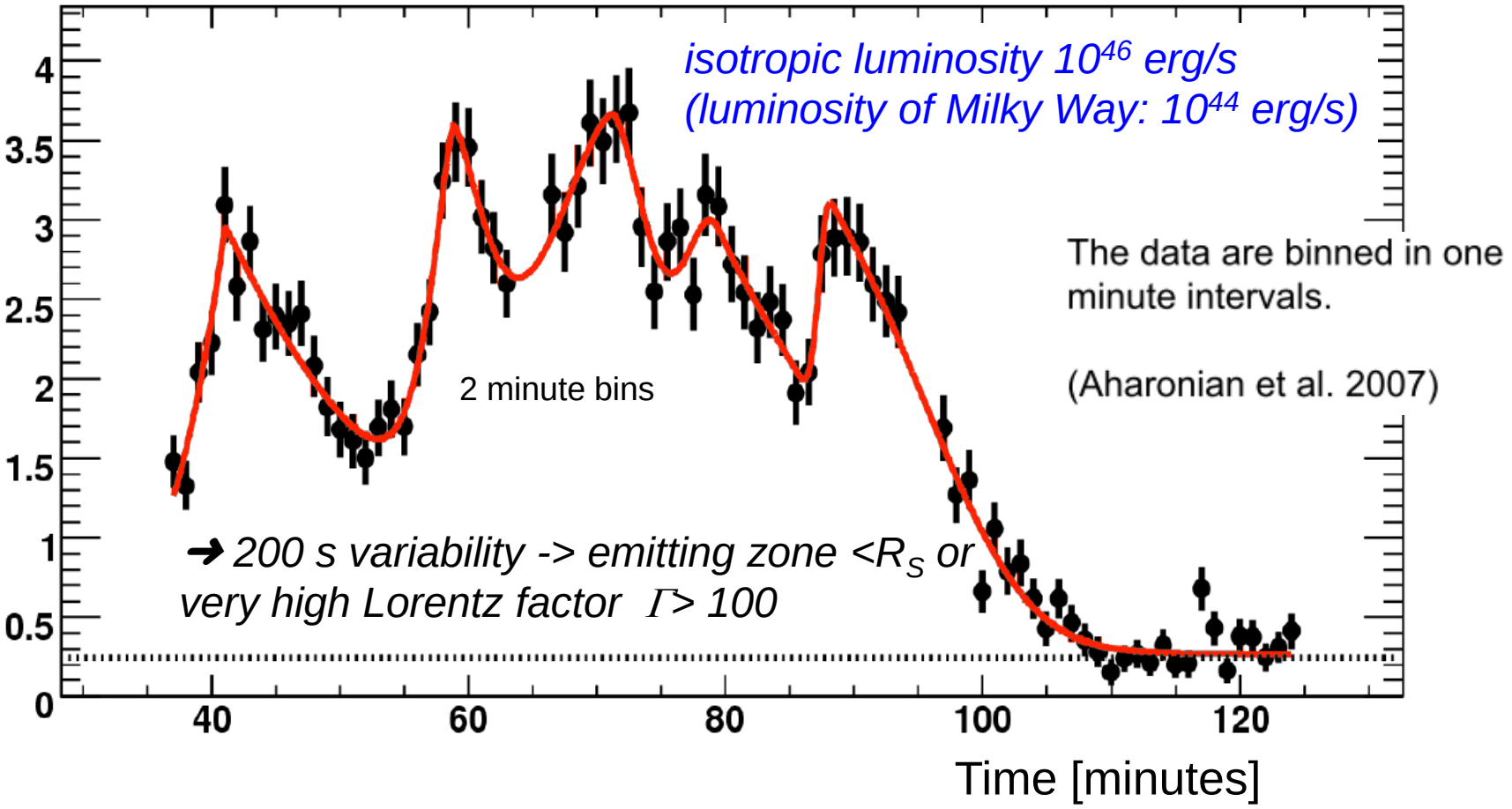
GRB template is the measured Fermi-LAT light curve above 0.1 GeV extrapolating the intrinsic spectra to VHE

We expect to detect ~1 GRB/yr / site

AGN: ORIGIN OF VARIABILITY AT ALL SCALES? LOCATION AND SIZE OF EMISSION REGION?

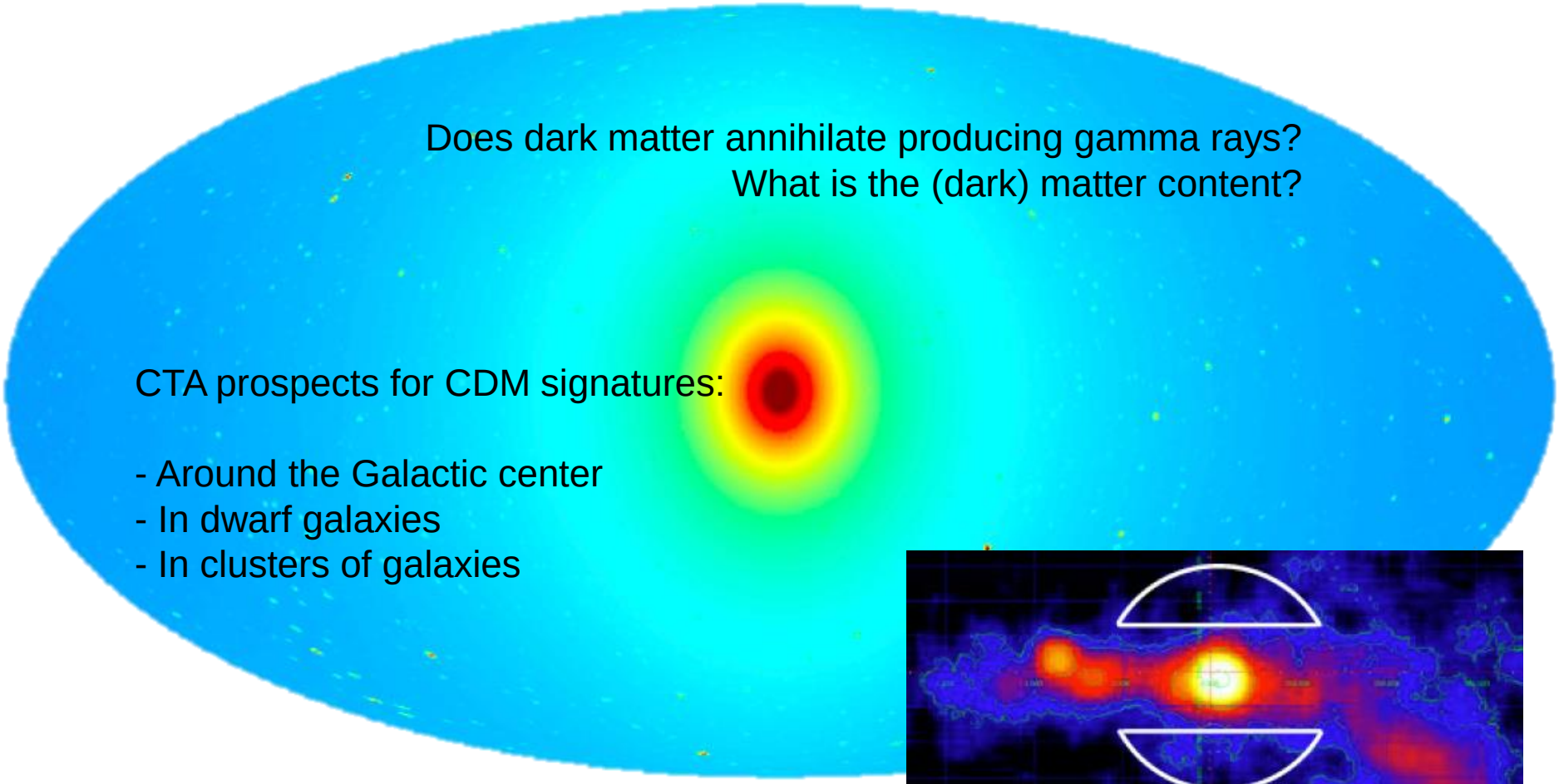
CTA: flares should be detectable within seconds rather than minutes

PKS 2155-304 flare
arXiv:0706.0797
H.E.S.S.



SEARCHING FOR DARK MATTER ANNIHILATION

V. Springel et al.
arXiv:0809.0894

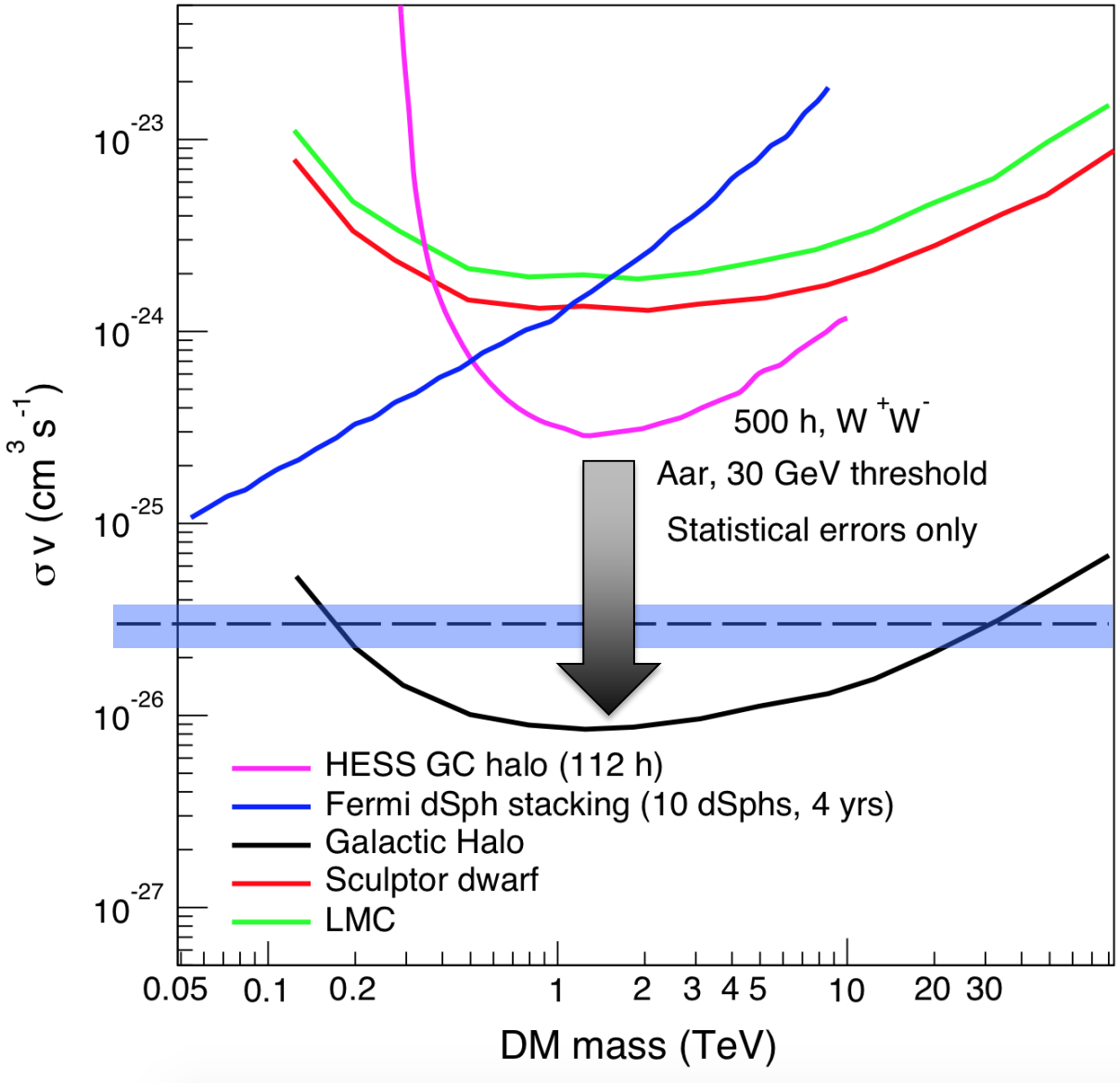


Does dark matter annihilate producing gamma rays?
What is the (dark) matter content?

CTA prospects for CDM signatures:

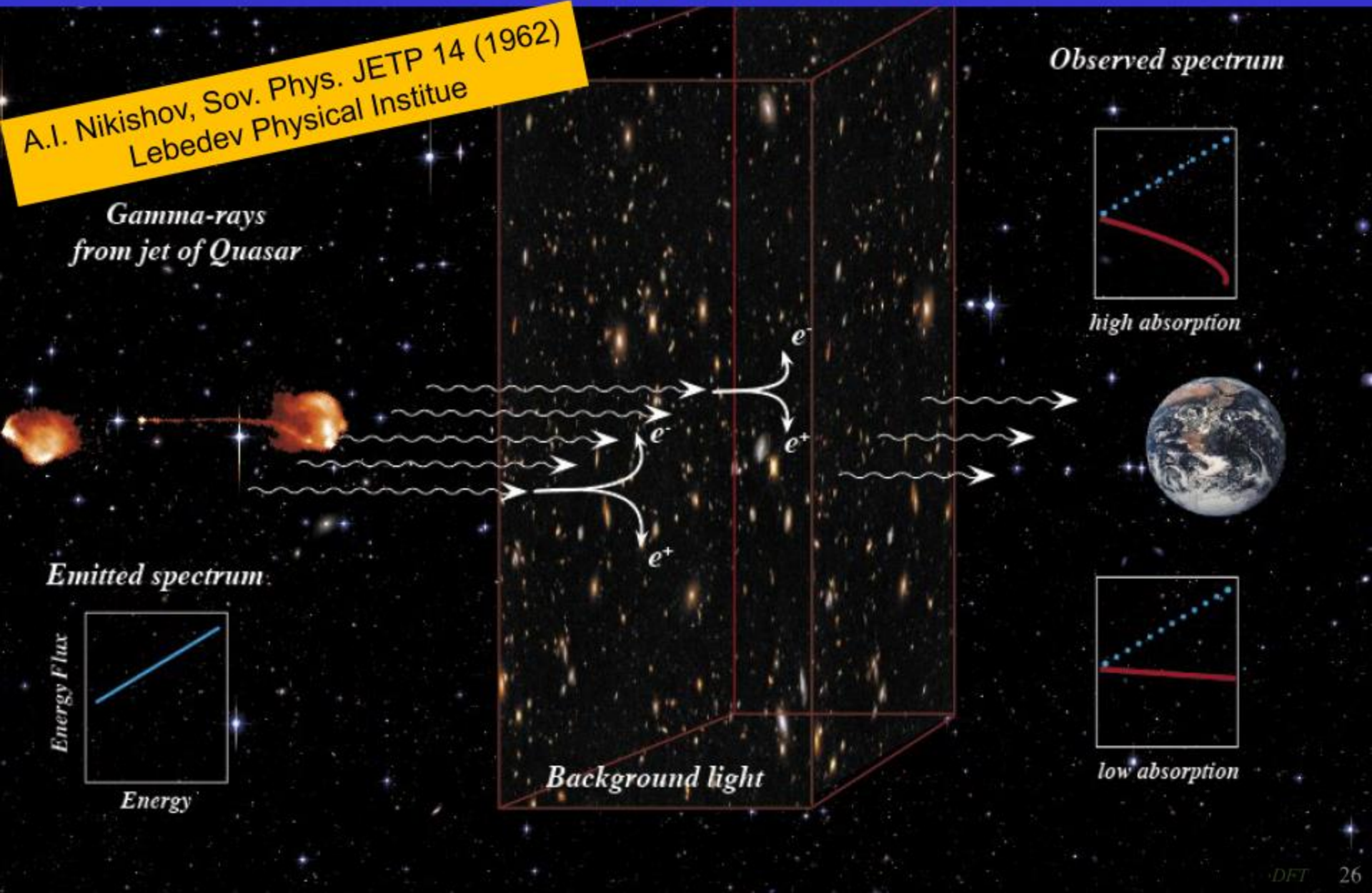
- Around the Galactic center
- In dwarf galaxies
- In clusters of galaxies

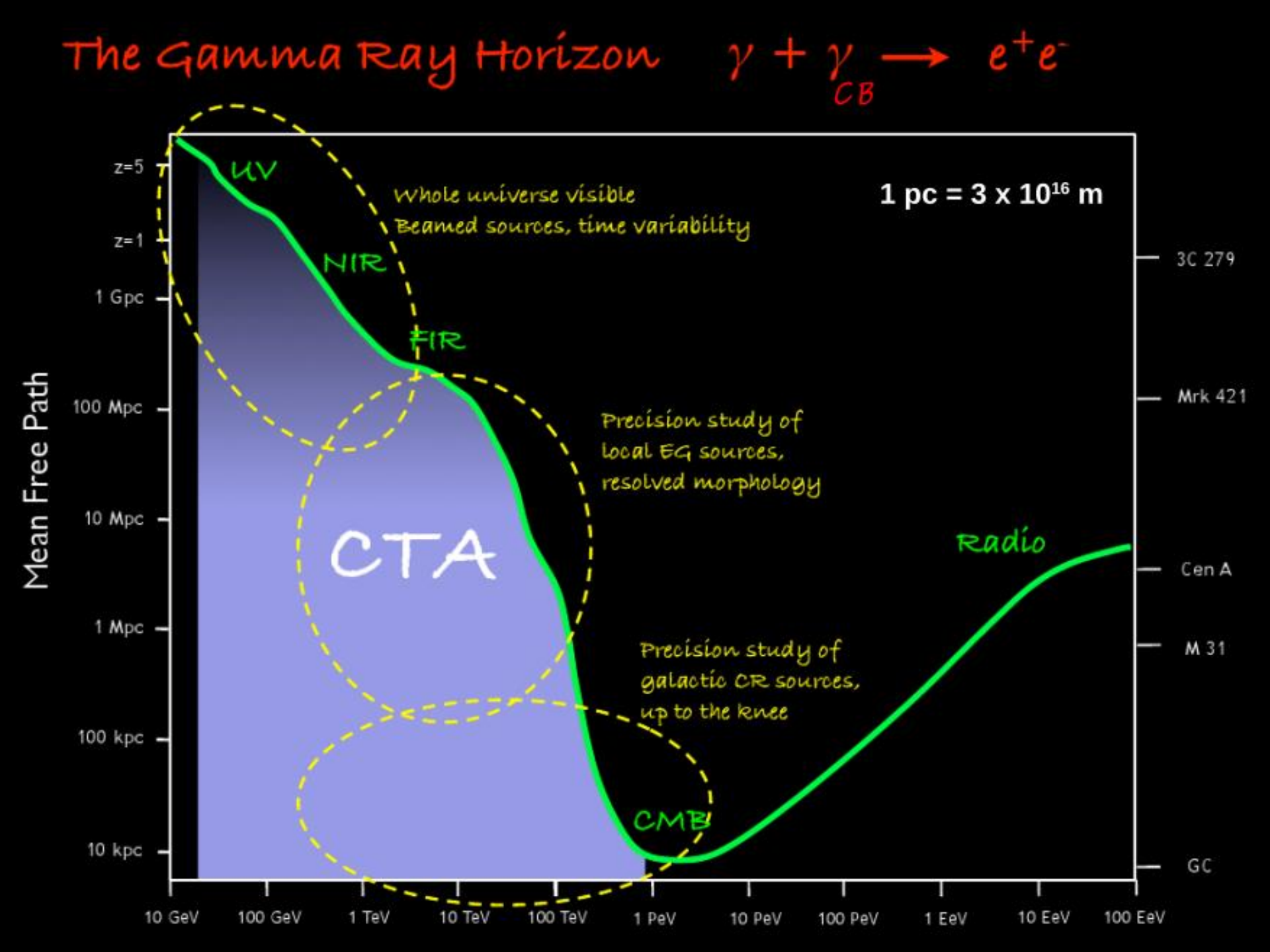
DARK MATTER ANNIHILATION



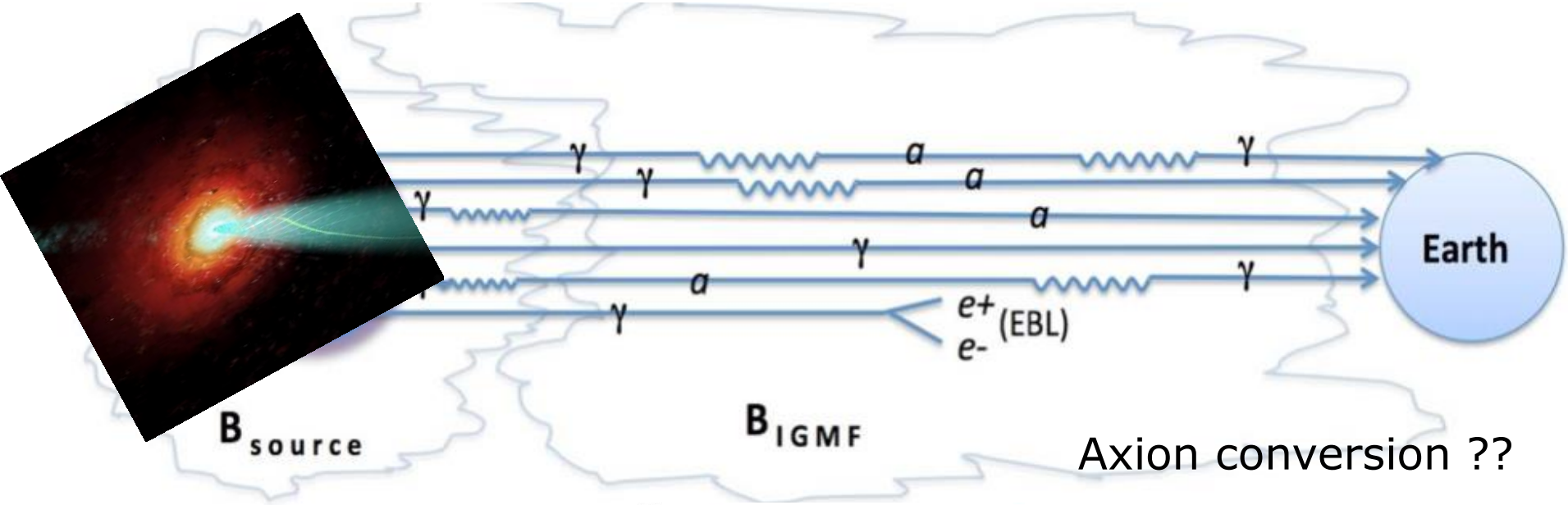
Canonical cross section

Studies of Extragalactic Background Light with CTA



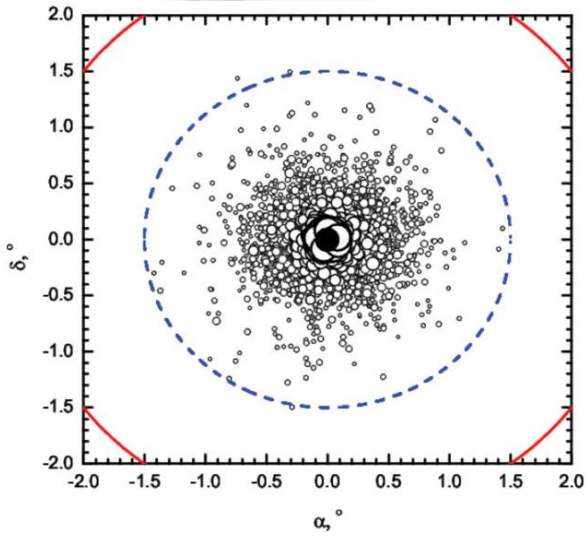

The Gamma Ray Horizon
$\gamma + \gamma_{CB} \rightarrow e^+e^-$
Mean Free Path
z=5
z=1
1 Gpc
100 Mpc
10 Mpc
1 Mpc
100 kpc
10 kpc
UV
NIR
FIR
CMB
Radio
CTA
Whole universe visible
Beamed sources, time variability
Precision study of
local EG sources,
resolved morphology
Precision study of
galactic CR sources,
up to the knee
1 pc = 3 x 10^16 m
3C 279
Mrk 421
Cen A
M 31
GC
10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
1 PeV
10 PeV
100 PeV
1 EeV
10 EeV
100 EeV

Probing Intergalactic Magnetic Fields



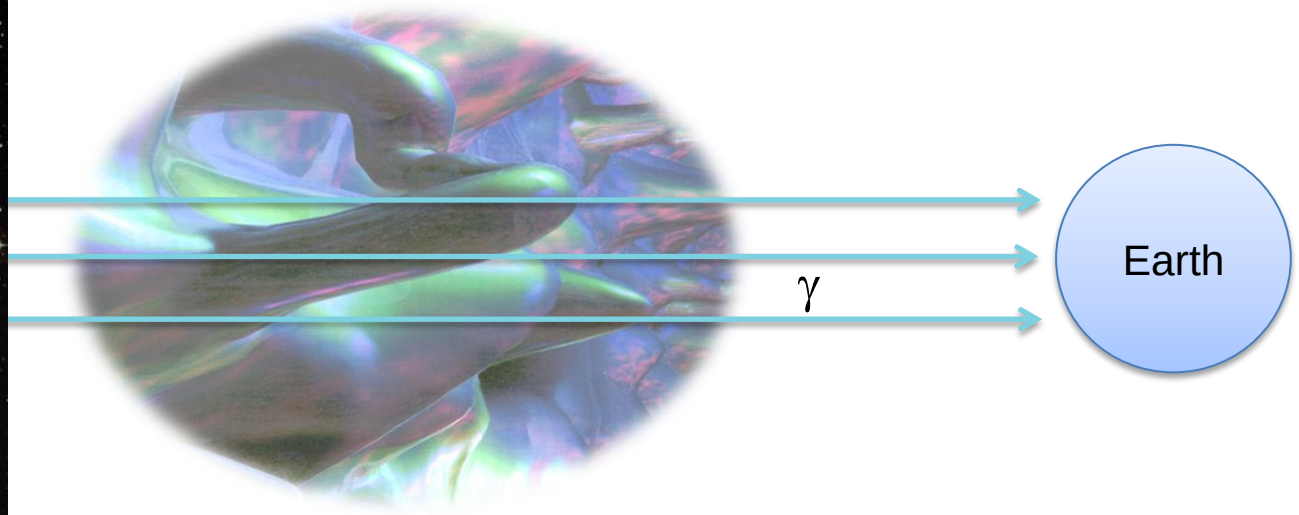
Axion conversion ??

$B_{sim} > 10^{-15}$ G



(Sol et al. 2013)

PHOTON PROPAGATION: LI VIOLATION



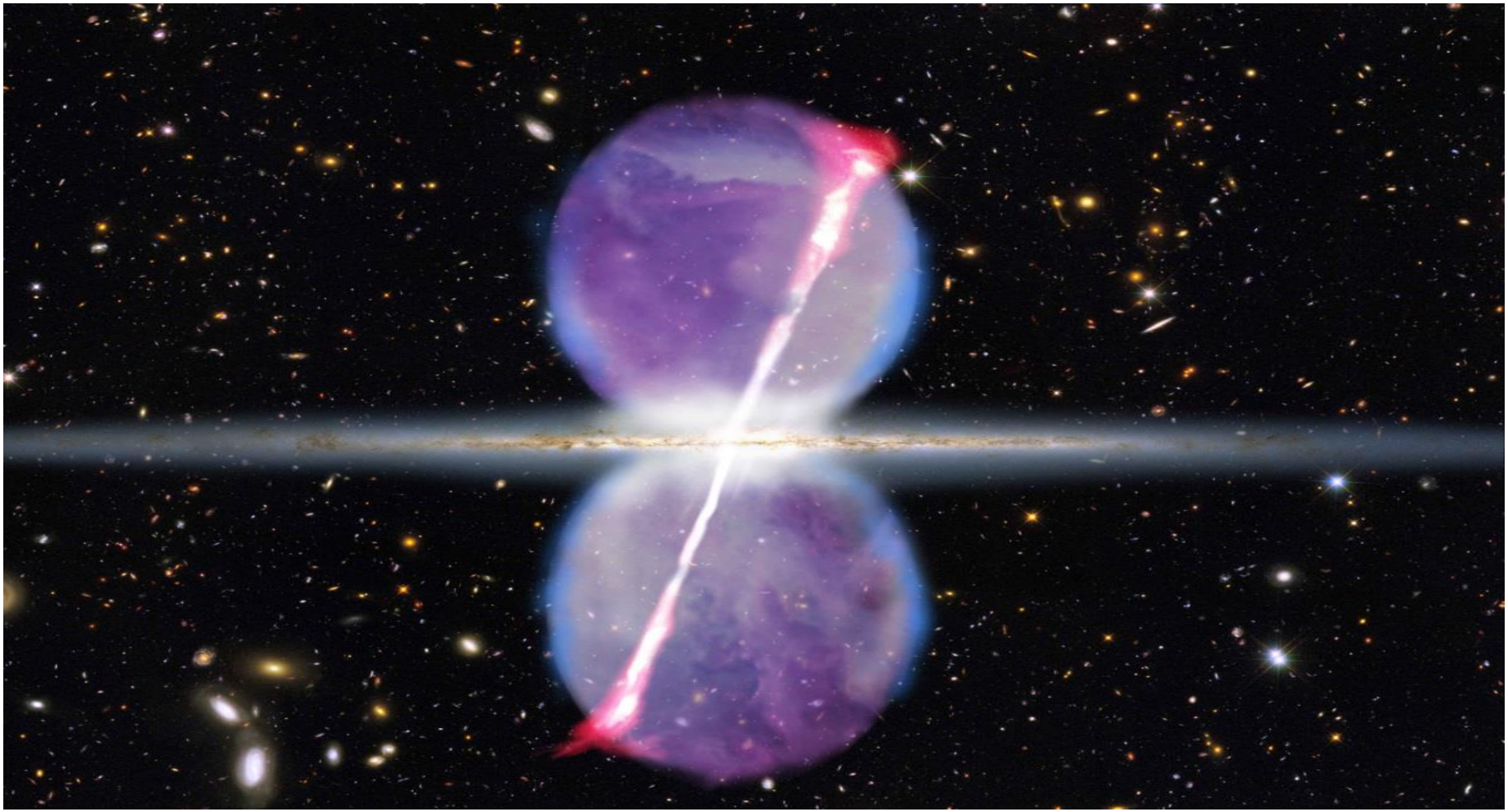
HESS, arXiv:1101.3650
arXiv:0810.3475

Quantum gravity effects -> arrival time delays between photons of different energies travelling large distances -> **variation of light speed** (*non-trivial refractive index of the vacuum*)

GALACTIC CENTER REGION

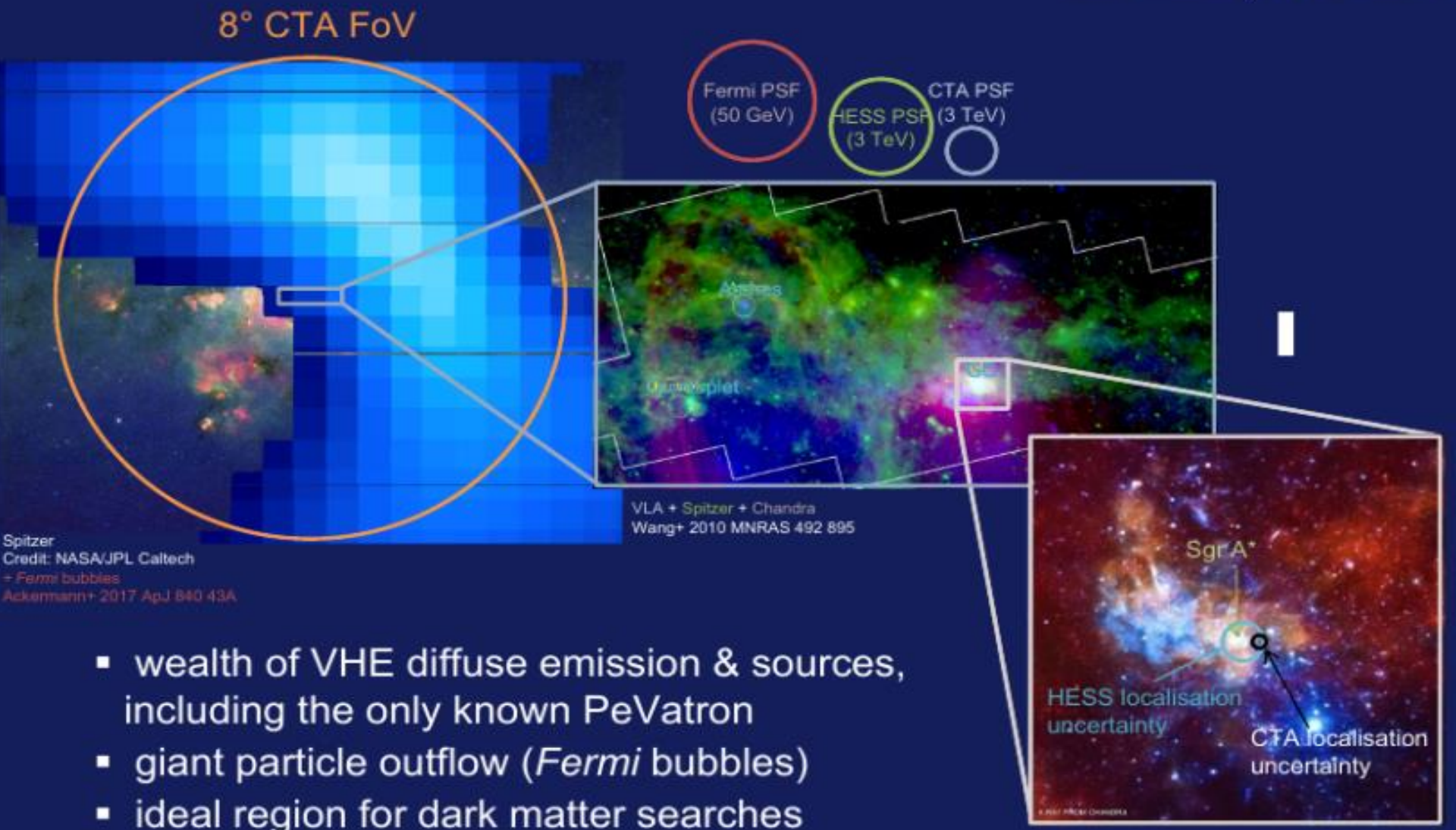
Complex, structured VHE source (BH)
Gas clouds illuminated by Pevatron?

Dark matter halo emission?
Launch of Fermi bubbles?



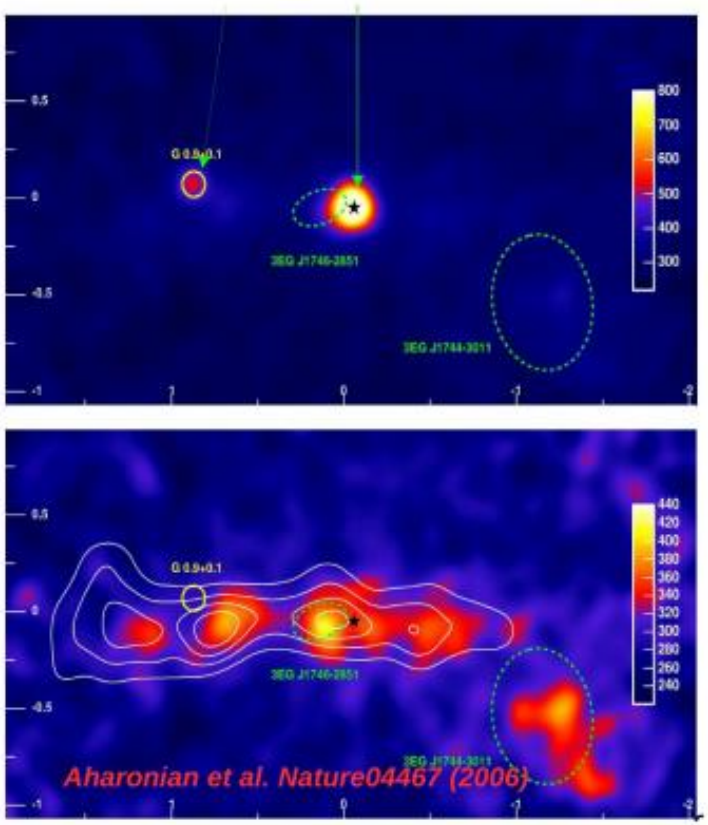
GALACTIC CENTER REGION

Slide courtesy of L. Tibaldo

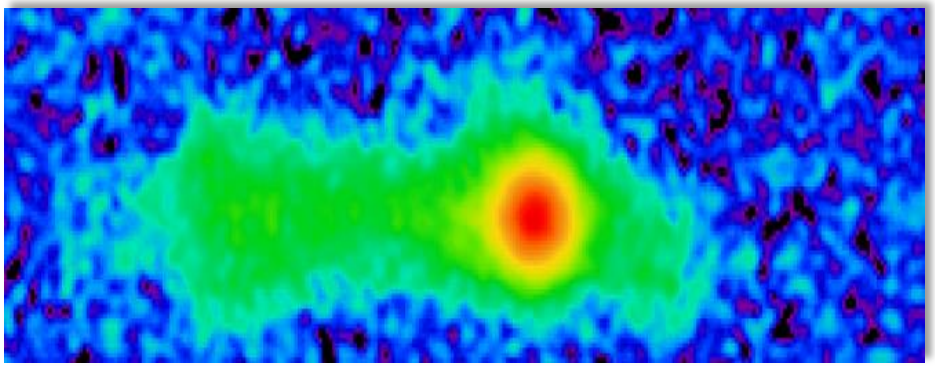


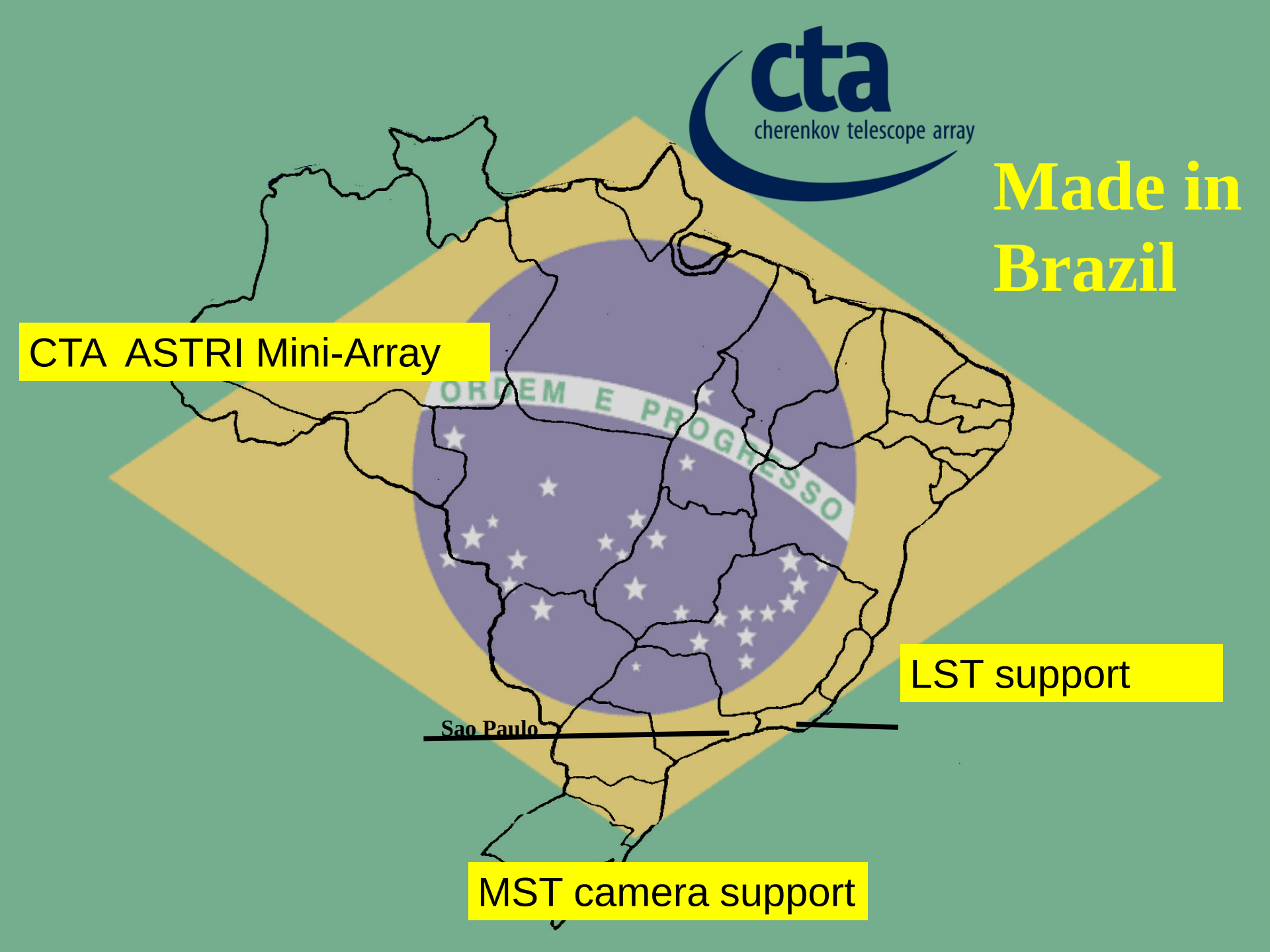
- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (*Fermi* bubbles)
- ideal region for dark matter searches

GALACTIC CENTER REGION IN GAMMA RAY



CTA




cta
cherenkov telescope array
Made in Brazil
CTA ASTRI Mini-Array
ORDEM E PROGRESSO
LST support
Sao Paulo
MST camera support

Brazilian Involvement

Slide by V. de Souza

CTA Brazil

12 Instituions

25 Scientists

16 Students

5 Technicians

CTA - SP - MST

- IFSC- USP
  - Prof. Vitor de Souza
  - Profa. Manuela Vecchi
  - Profa. Cibelle Celestino
  - Dr. Humberto Huerta
  - Dr. Aion Viana
  - Edyvania Martins
  - Rodrigo Lang
  - Luan Arbeletche
  - Andres Delgado
  - Rodrigo Guedes Lang
  - Danielle Kaori
- IF-USP
  - Prof. Edivaldo Moura
  - Douglas Pimentel
- UFABC
  - Prof. Marcelo Leigui
  - Raquel de Almeida
- UFSCar
  - Dr. Gustavo Rojas
- UFPR
  - Prof. Rita de Cássia
- EEL / USP
  - Prof. Fernando Catalani
  - Prof. Carlos Todero
- SAIFR / IFT - UNESP
  - Dr. Fabio Iocco
  - Dr Ekaterina Karukes
  - Maria Benito

CTA - Rio

- CBPF
  - Prof. Ulisses de Almeida
  - Prof. Ronald Shellard
  - Bruno Arsioli
  - Bernardo Fraga
  - Rodrigo Cardoso
  - Amanda Carvalho

CTA - SP - SST

- IAG – USP
  - Profa. Elisabete dal Pino
  - Prof. Rodrigo Nemmen
  - Dr. Rafael Batistai
  - Dr. Chandra Singh
  - Dr. Grzegorz Kowal
  - Dr. Reinaldo Lima
  - Dr. Paramita Barai
  - Dr. Luis Kadowki
  - Dr. Claudio Melioli
  - Dr. Juan Ramirez
  - Tania Torrejon
  - Renato Gimenes
  - Pankaj Kushwaha
  - Saib Hussain
  - Carlos Fermino
  - Raniere Menezes
  - William Bohórquez
  - Lucas Santos
- UNICSul
  - Prof. Anderson Caproni
- EACH / USP
  - Prof. Diego Falceta-Gonçalves
  - Mohammad Ali

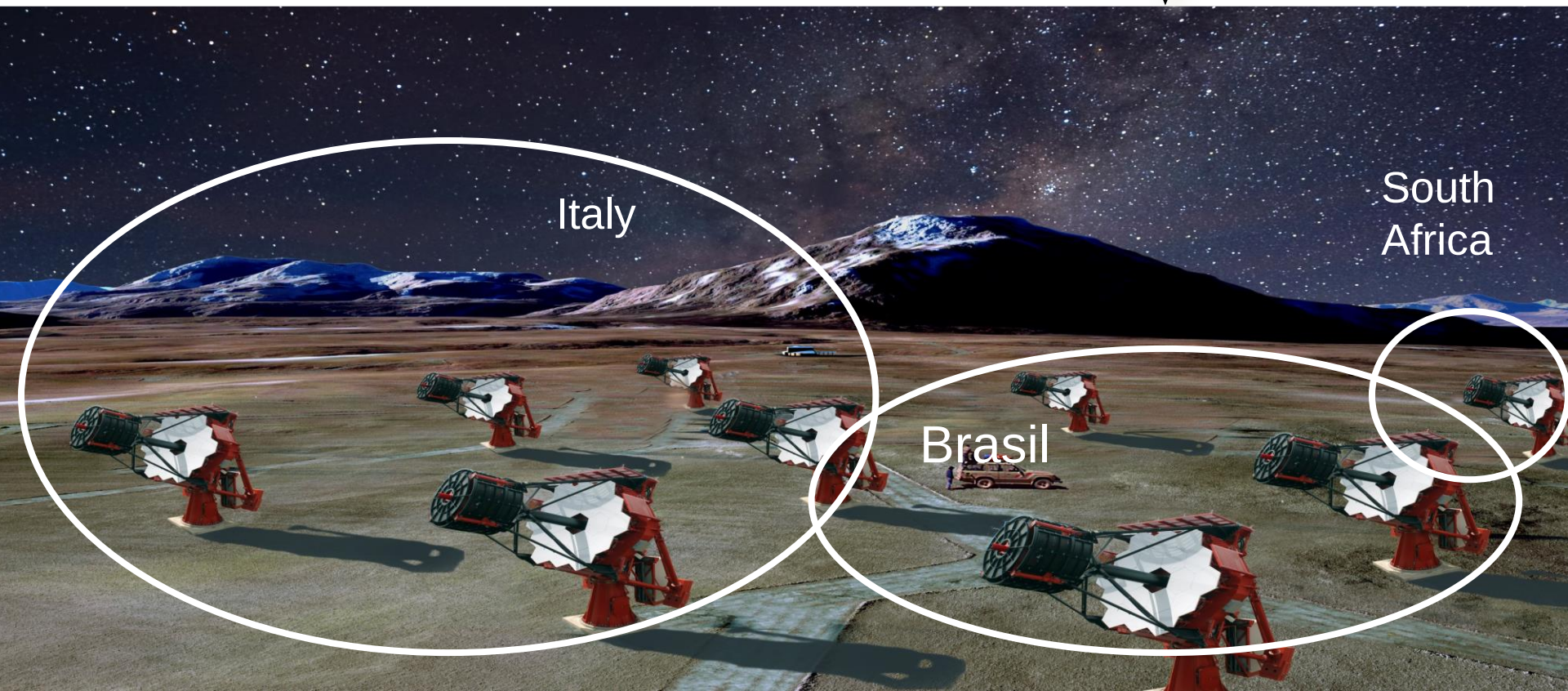
(Slide by V. de Souza)

BRAZILIAN BUDGET FOR CTA SO FAR

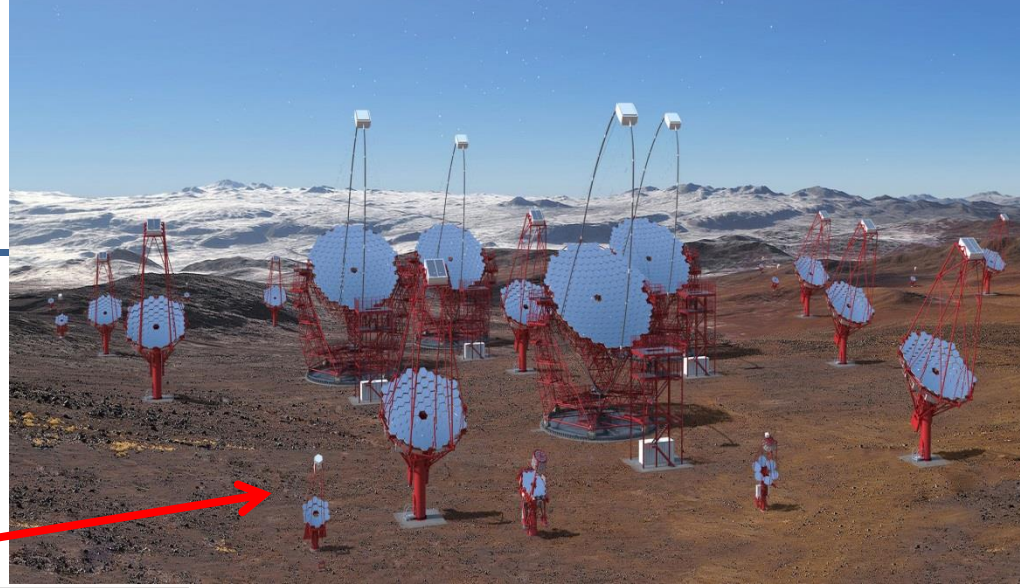
- FAPESP : total budget awarded: **R$ 17.3M**
  - Thematic Project (Elisabete de Gouveia Dal Pino, IAG-USP): **12,2 M R$ + 2,7 M R$** (posdoc scholarships and international school)
  - JP Grant (Paramita Barai, IAG-USP): **618 K R$**
  - Thematic Project (Vitor de Souza, IFSC-USP): **1,8 M R$**
- FAPERJ : total budget awarded: ~ **R$ 500 K**

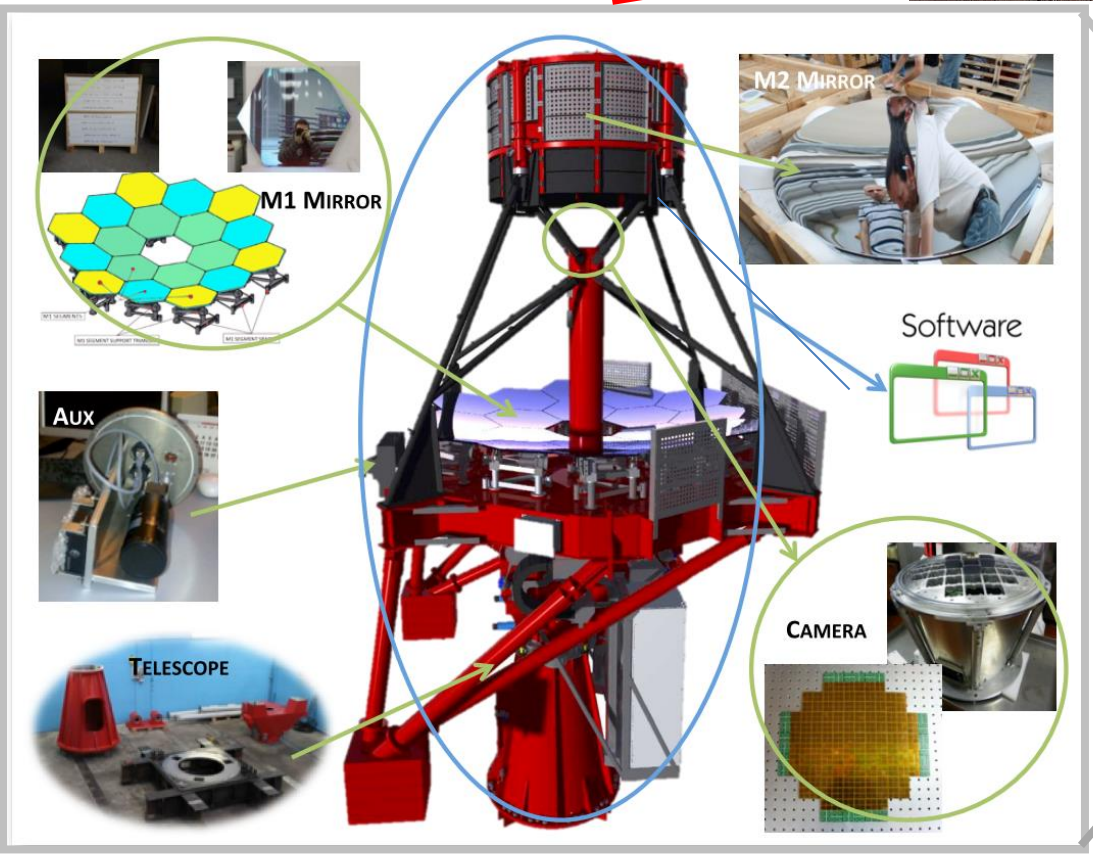
The ASTRI Mini-Array: CTA precursor

Mini-array with 9 SST-2M telescopes at the CTA south site (Chile): our 3 telescopes are currently in construction -> in 2019



CTA





ASTRI Telescopes

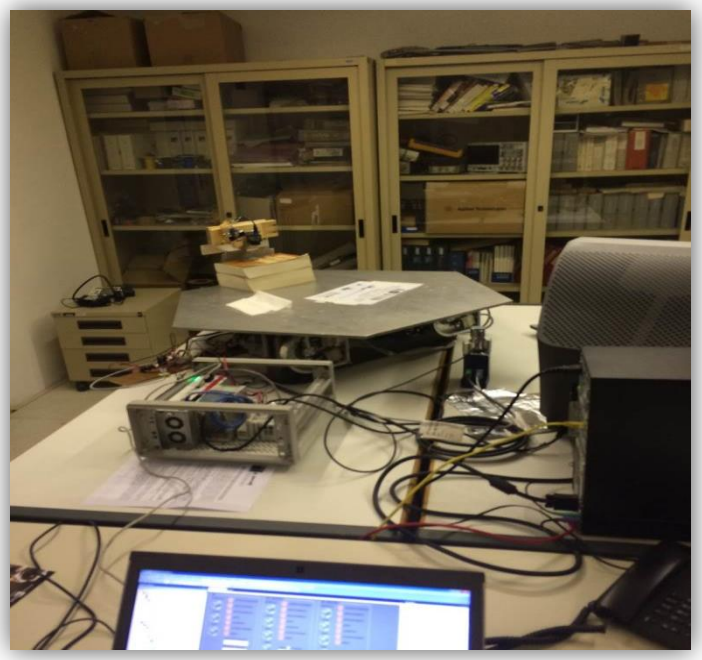
Brazilian engineers @ ASTRI: structure/software development

Active optics tests (Torino)

- With Daniele Gardiol & Federico Russo

Performed task:

- Segment motion
- Data colection and callibration
- Repeatability verification

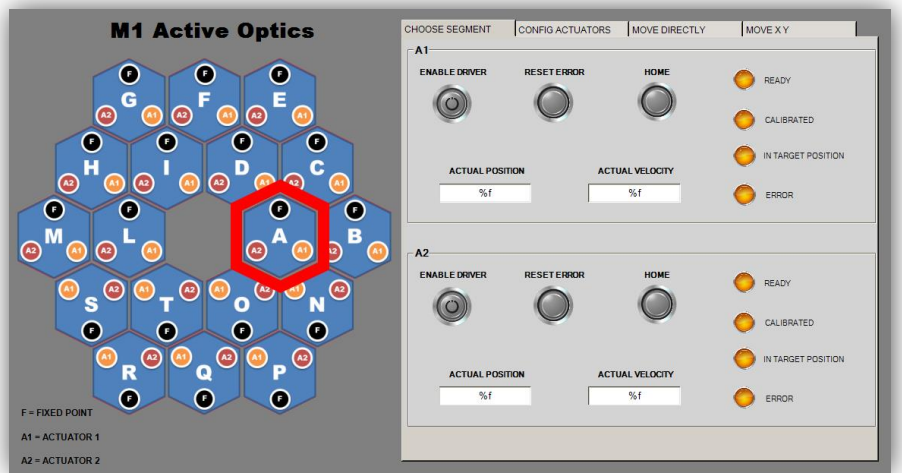


M1 Interface elaboration (Catania)

- W/ Matteo Munari, Salvo Scuderi, Enrico Giro, Luca Stringhetti, Elisa Antolini

Performed task:

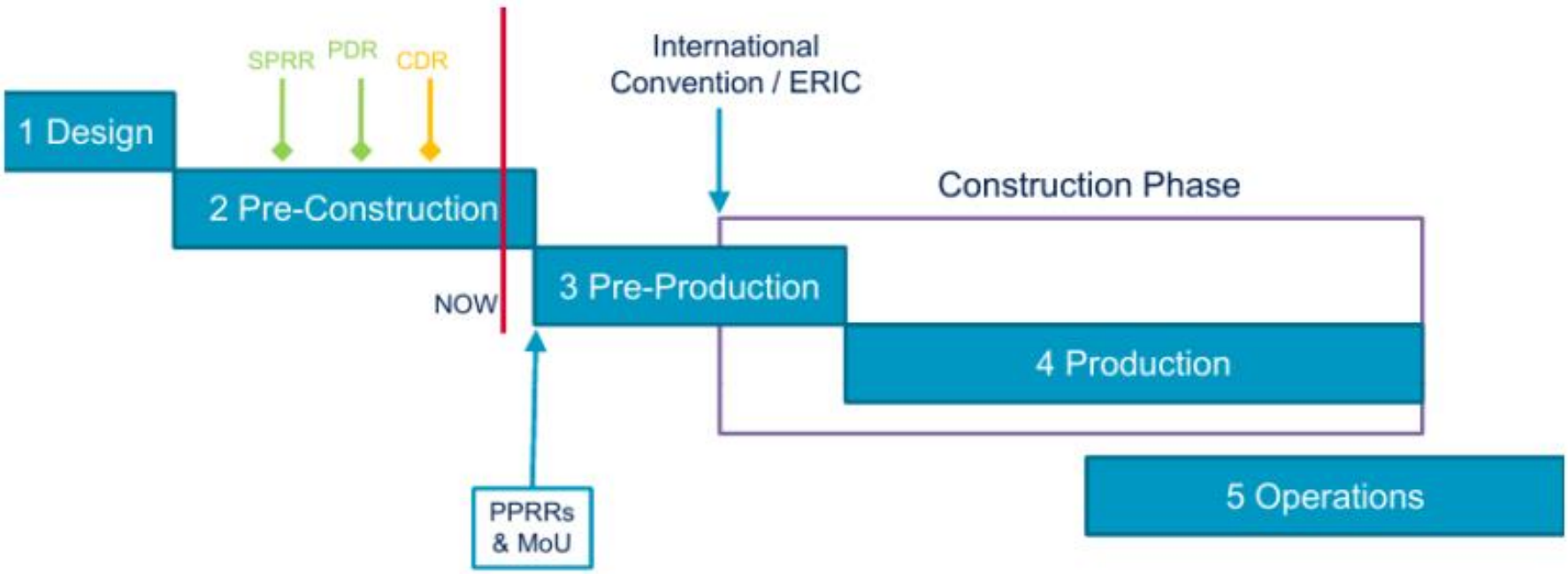
- Actuator configuration as in CANopen
- Screens preparation for driving motors
- interface implementation with users, scheduling tests, etc.
- Teaching on operation of logics for future change and implementation
- Teatching hardware & software Beckhoff



CTA-BR NEEDS

- Shareholder in CTA-Observatory on behalf of Brazil (under negotiation with MCT-C)
- Increase the current investiments at least 10 MEuro
- Country wide participation
- Currently mainly FAPESP
- Partners in national industries (currently a few involved)

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

Slide by Rene Ong.