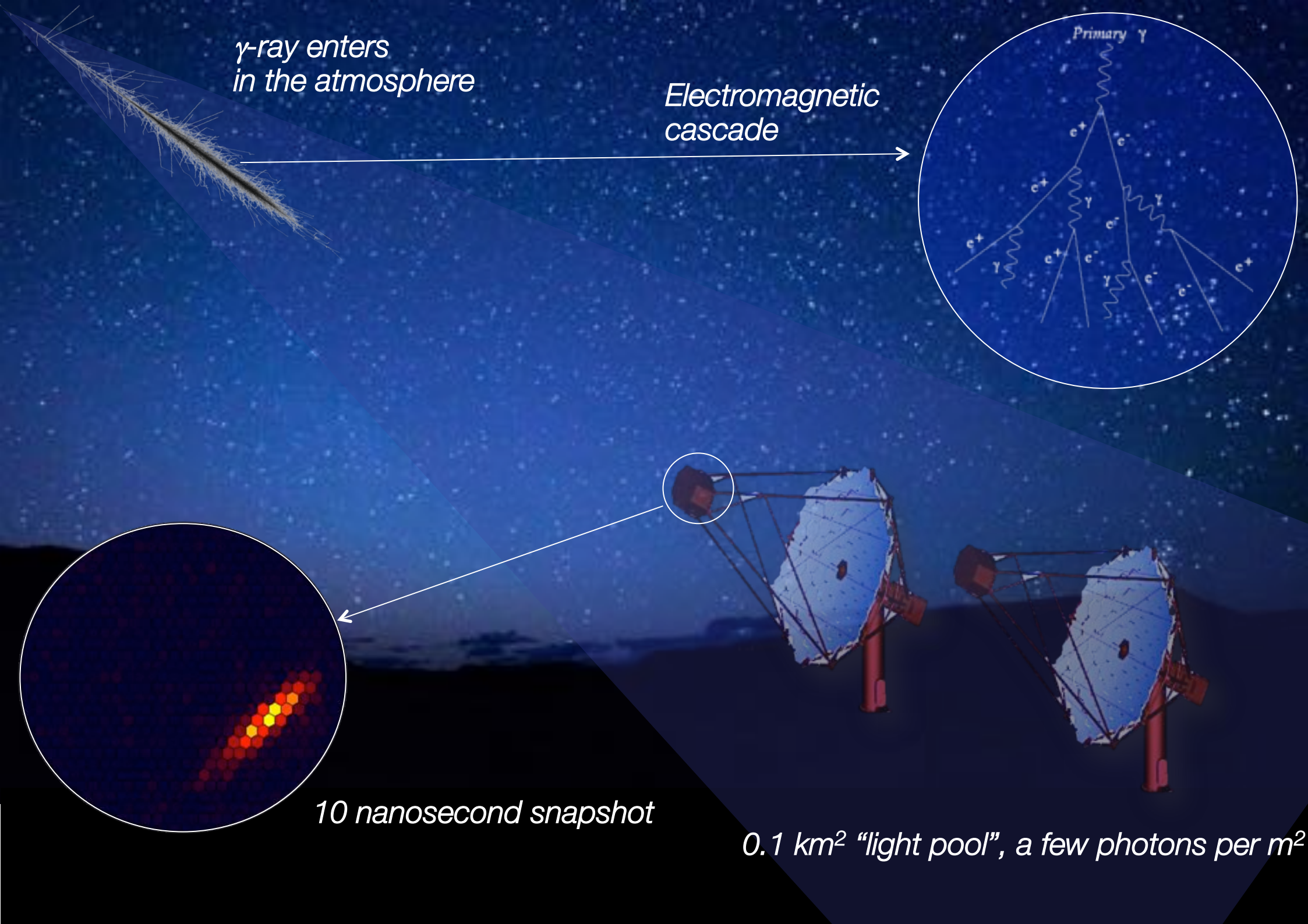
The Cherenkov Telescope Array

Status and science goal for fundamental physics

DISCRETE 2014
2nd - 6th December 2014
King's College, London

Emmanuel Moulin, CEA Saclay
for the CTA consortium


γ-ray enters
in the atmosphere
Electromagnetic
cascade
Primary γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m²

Current Cherenkov telescope arrays

MAGIC Canari Island, Spain
La Palma, 2225m a.s.l.
2 telescopes, Ø17m

2 - 5 Telescopes
- 500-2000 pixel camera
- 3.5 - 5.0° FoV
- ~0.1° angular res.
- ~15% energy res.
- sensitivity < 1% Crab
- ~30 GeV < E < ~50 TeV

VERITAS Arizona, USA
1275m a.s.l.
4 telescopes, Ø12m

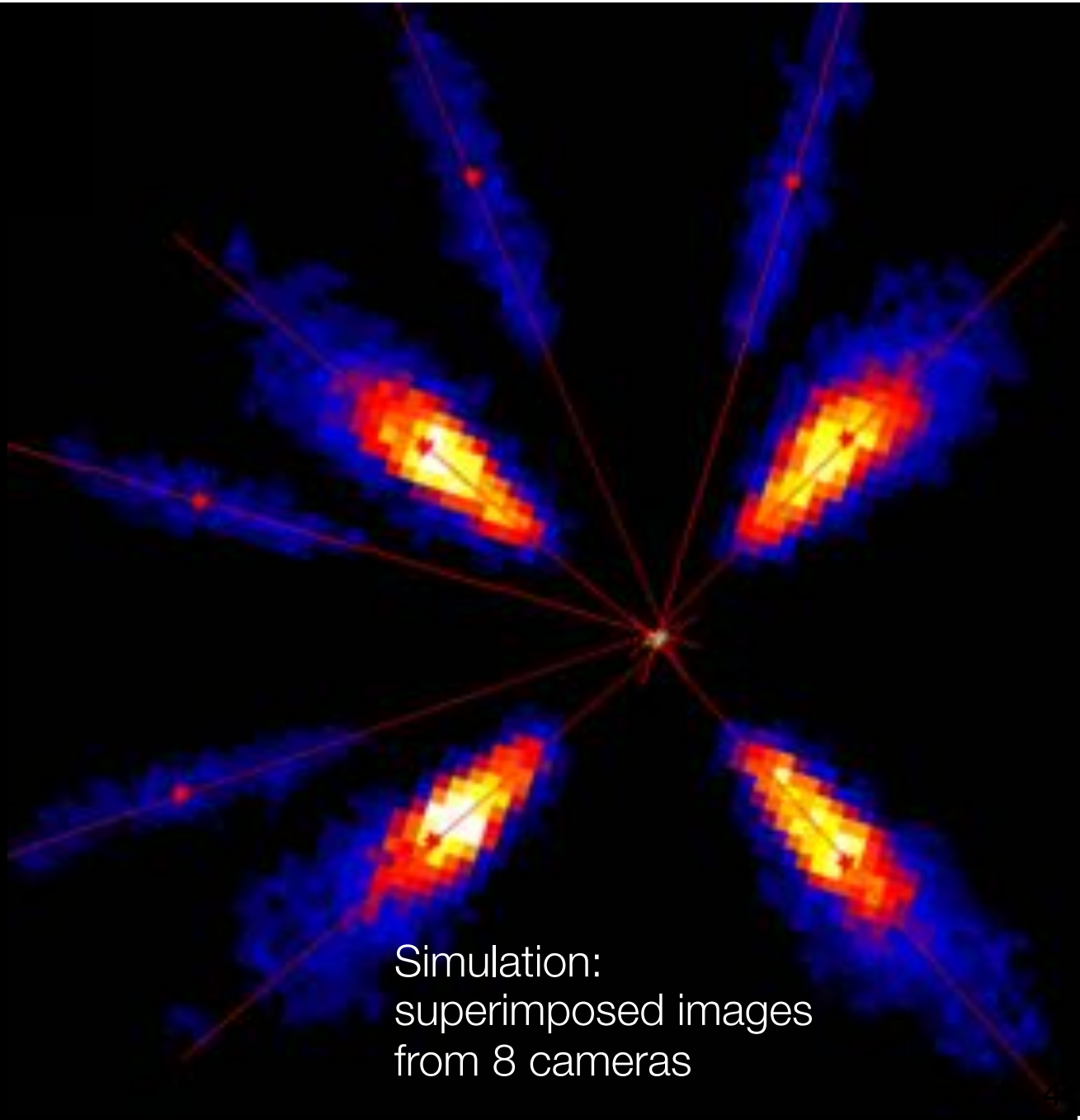
H.E.S.S. Namibia
1800m a.s.l.
4 telescopes, Ø13m
+ 1 telescope, Ø28m

How to do better ?

- More events
  – More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays

- Better events
  – More precise measurements of atmospheric cascades and hence primary γ-rays
    - Improved angular resolution
    - Improved background rejection power

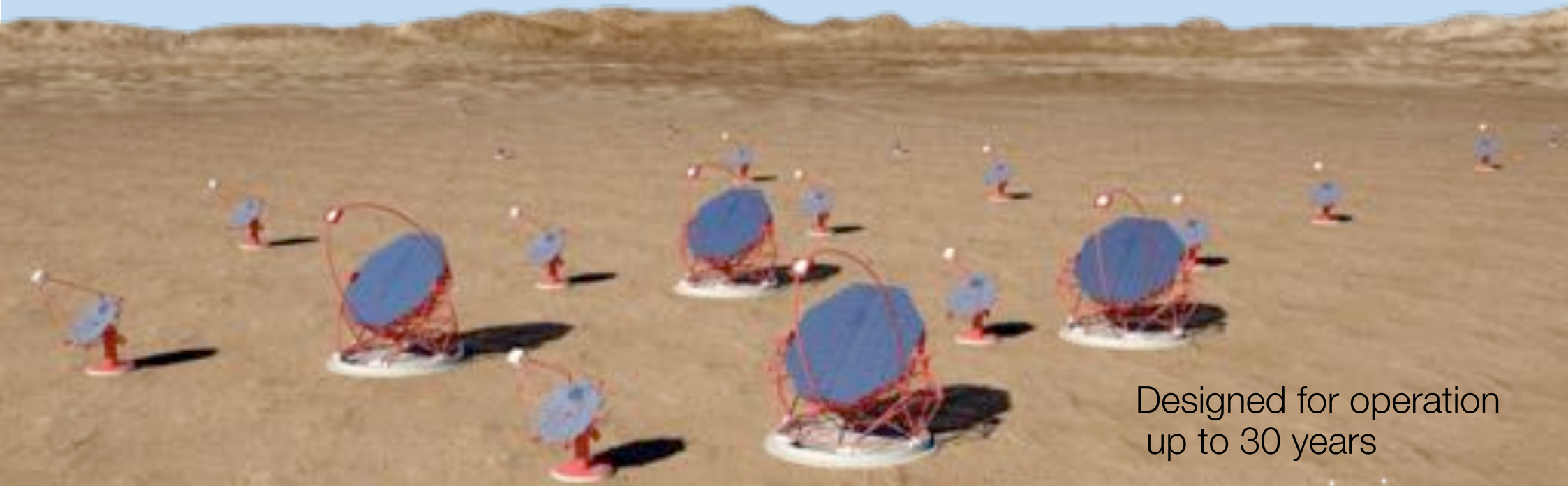
→ More telescopes!



Simulation: superimposed images from 8 cameras

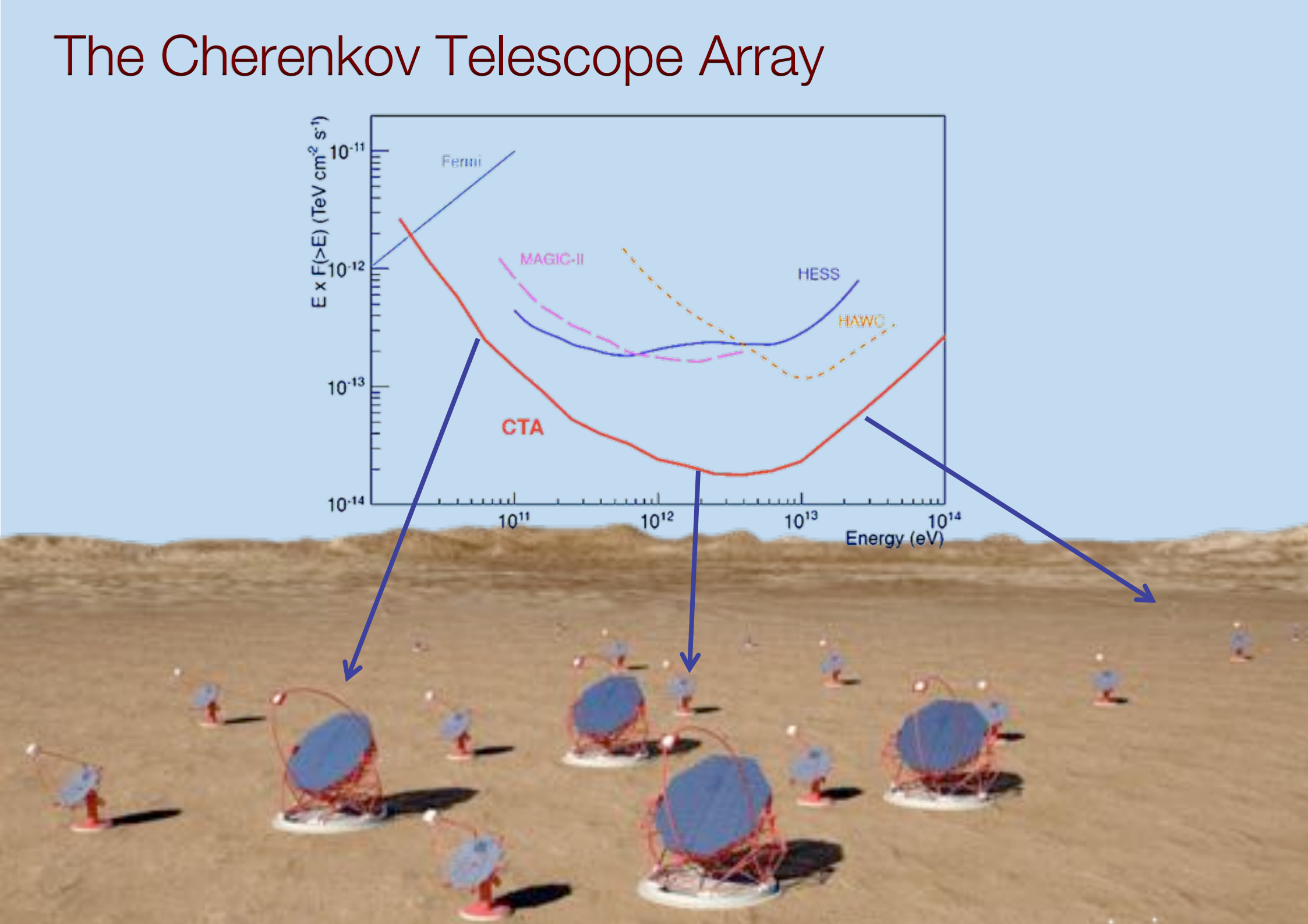
The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - ✓ A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - ✓ With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - ✓ Including everyone from HESS, MAGIC and VERITAS

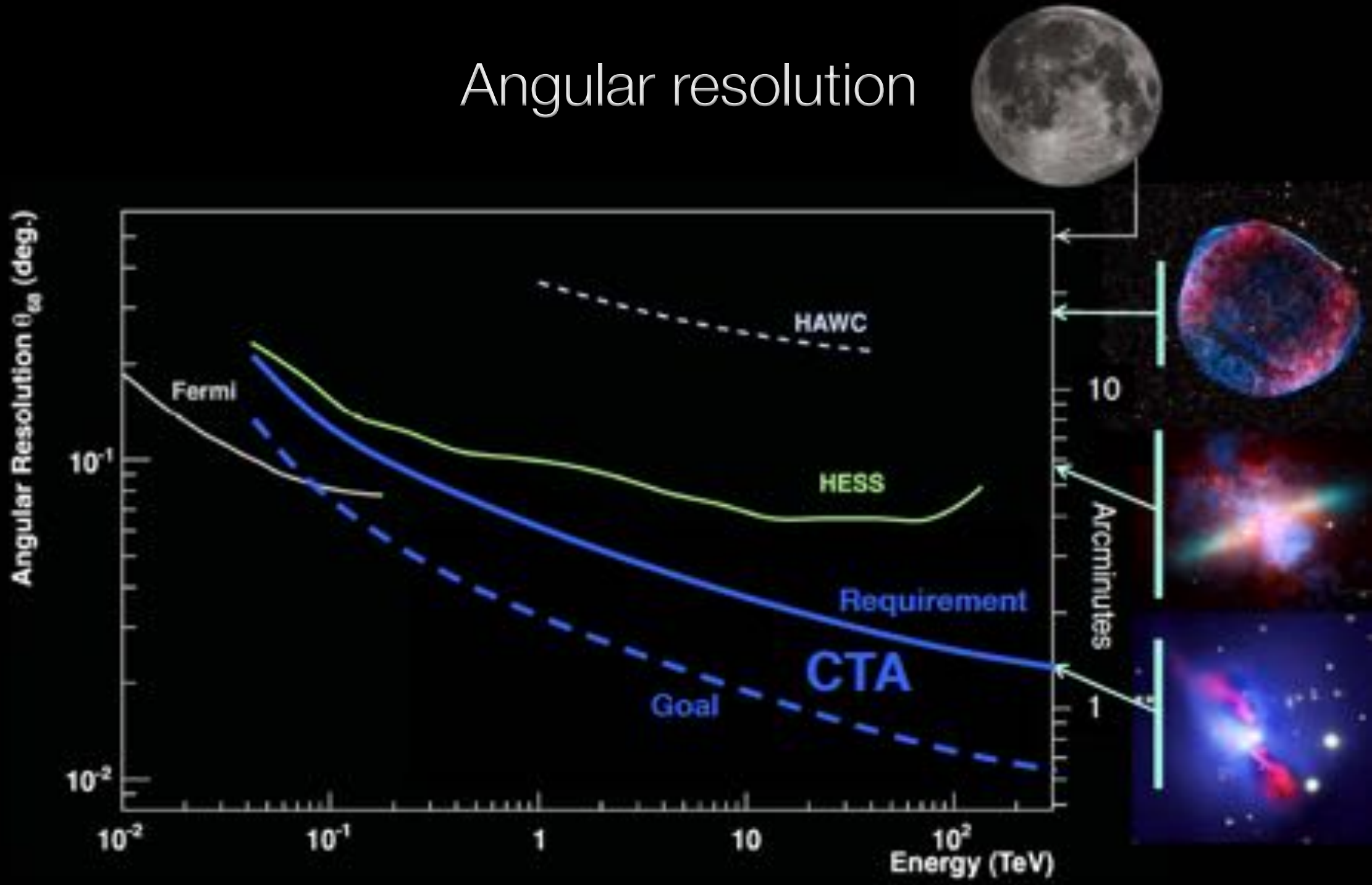


Designed for operation up to 30 years

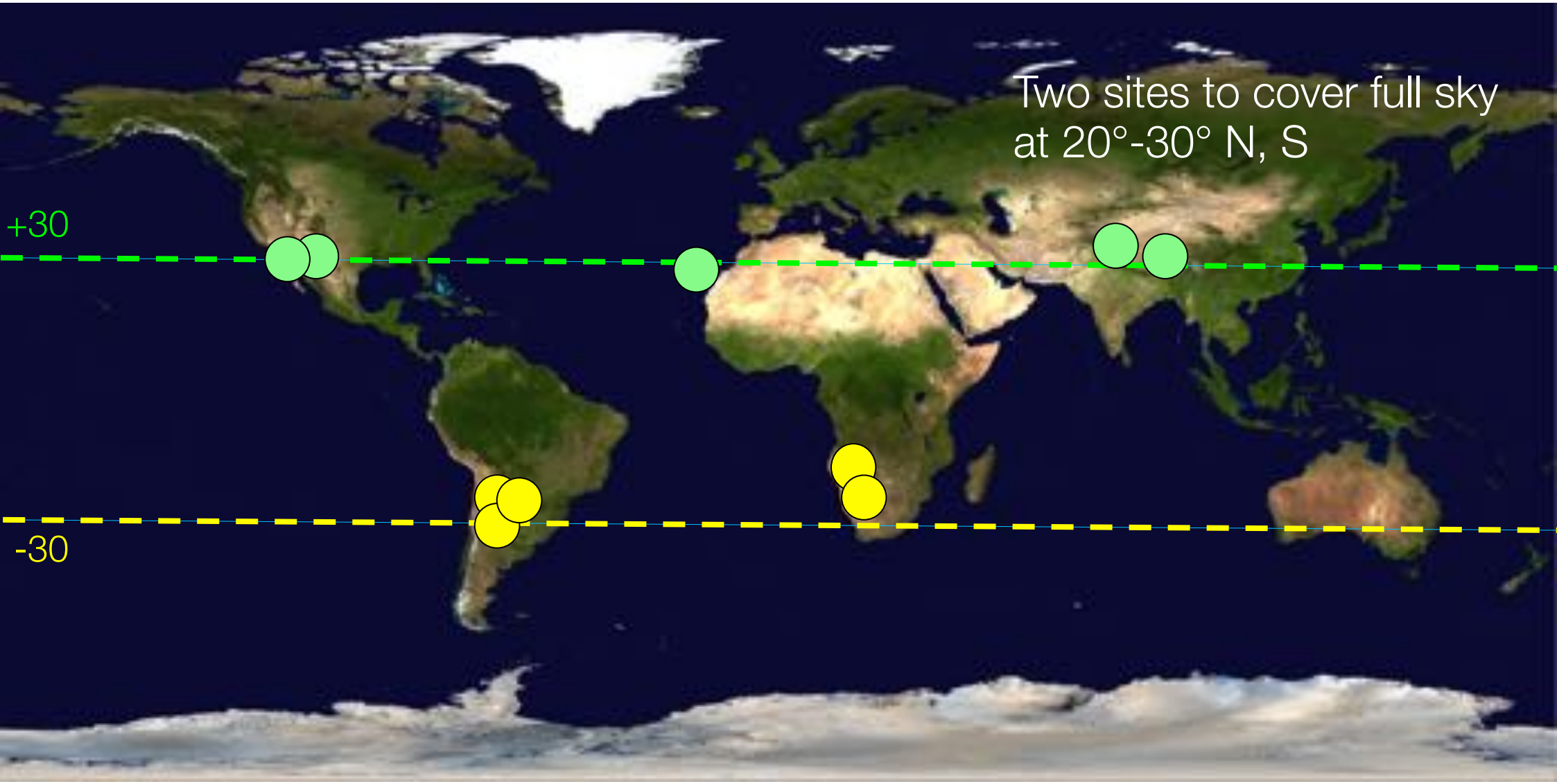
The Cherenkov Telescope Array



Angular resolution

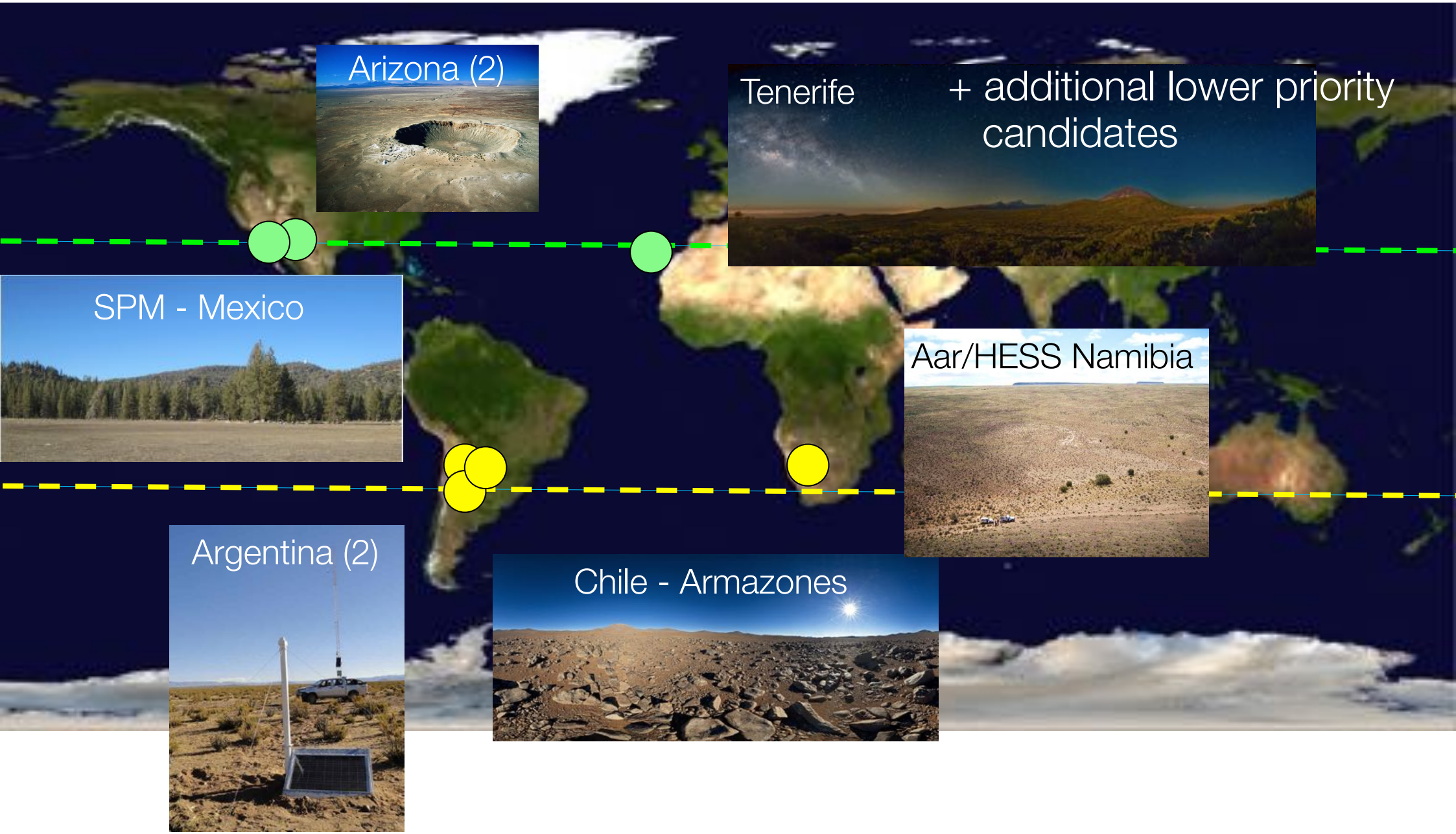


CTA sites: candidates



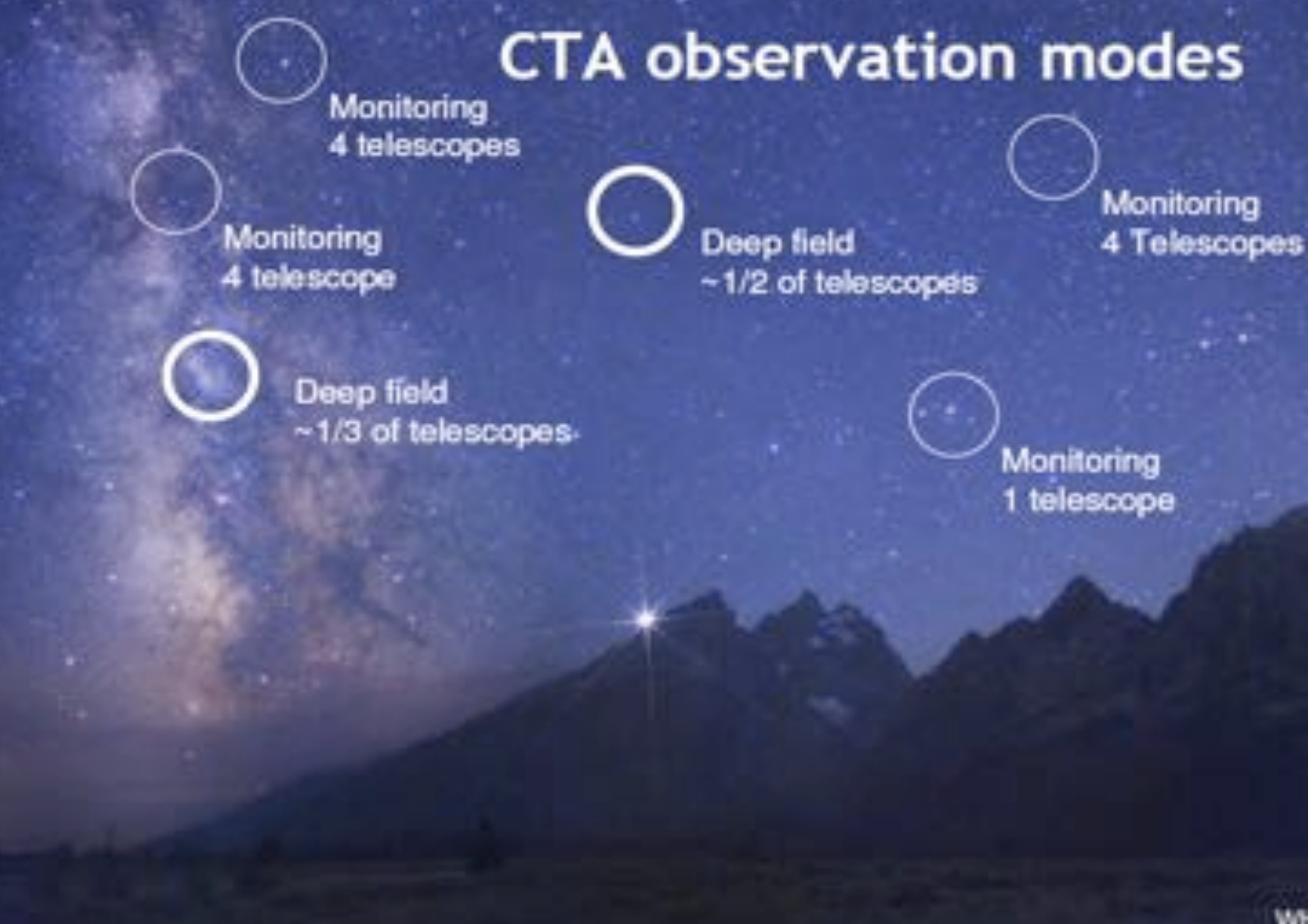
Warning: map not quite accurate

CTA sites: candidates



CTA sites: candidates

- South
  - ➢ Negotiations starting with Namibia and Chile → Decision soon
- North
  - ➢ Mexico, US and Spain still all under consideration → Decision 2015
- Site development 2017


CTA observation modes
Monitoring
4 telescopes
Monitoring
4 telescope
Deep field
~1/2 of telescopes
Monitoring
4 Telescopes
Deep field
~1/3 of telescopes
Monitoring
1 telescope

CTA observation modes

Very deep field

- high sensitivity observations
- requested for targeted searches

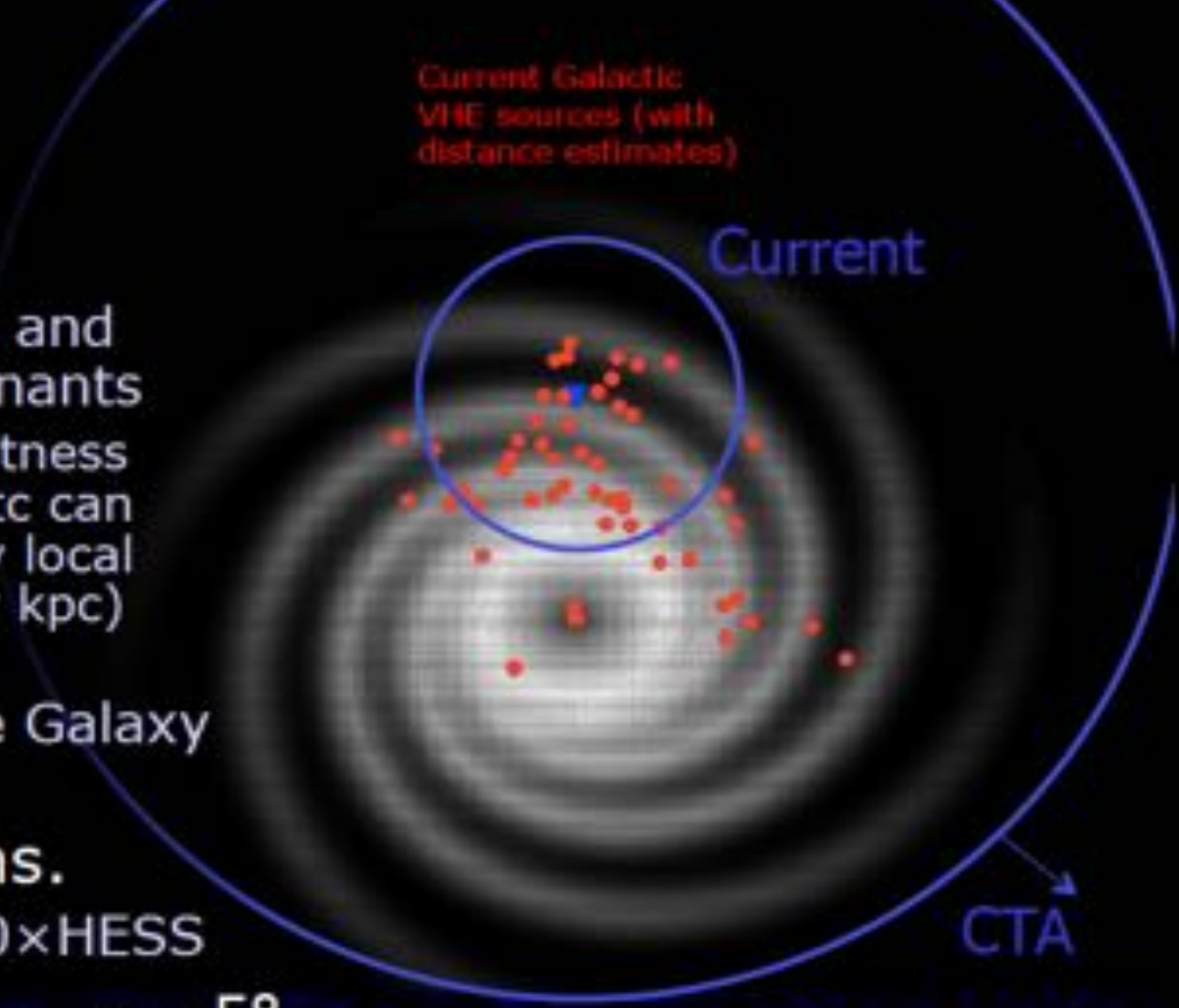
CTA observation modes

Survey mode:
Full sky at current
sensitivity in ~1 year

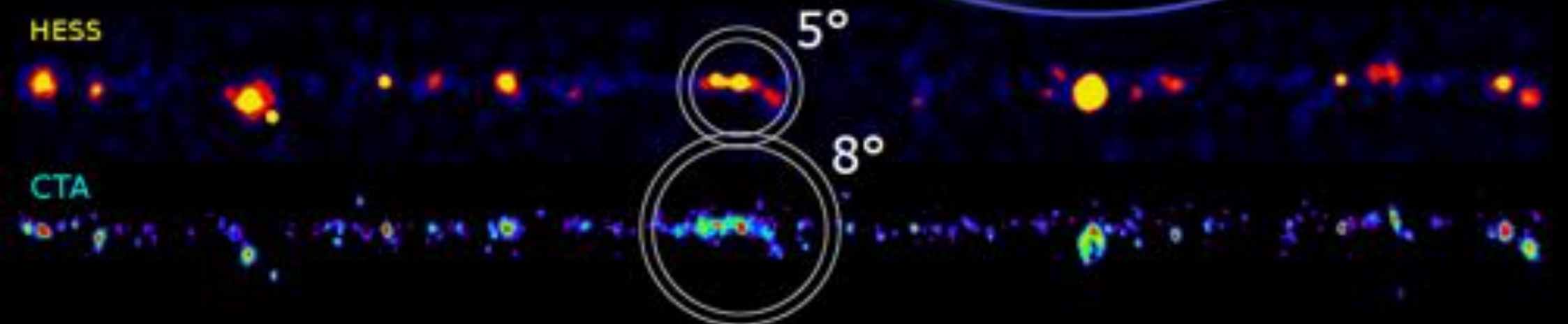
- systematic scan of part of the sky
- requested for blind searches

CTA Reach

- Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy



- Field of view + sens.
  - Survey speed ~300×HESS



CTA Science

Cosmic rays

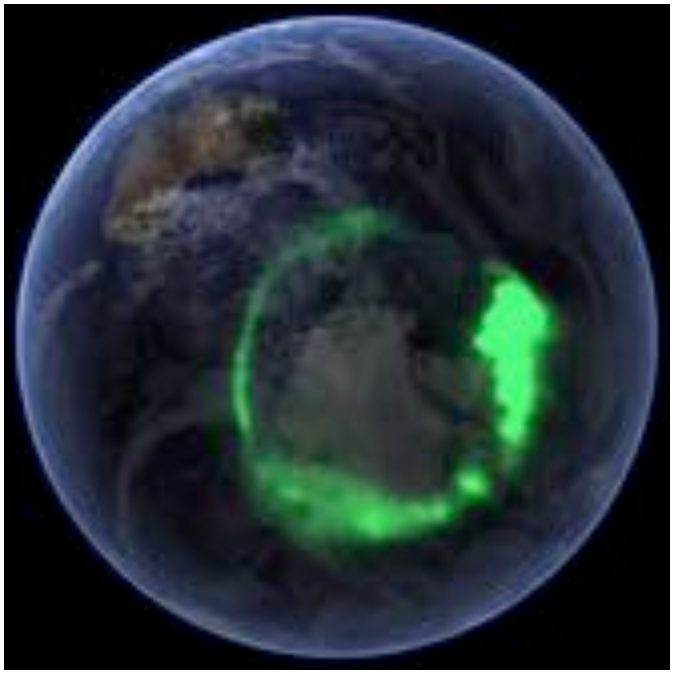
Origin of cosmic rays
Acceleration physics
Impact on environment

Black holes

Role as particle accelerators
Acceleration physics
Probes of the Universe

Physics Frontiers

Nature of dark matter
Search for axion-like particles
Test of Lorentz invariance



CTA observatory

CTA will be an Open observatory

- CTA Consortium, which builds the telescopes, will get guaranteed time (~50%) with rest open to external proposals.
- CTA Consortium in the process of defining a “Key Science Program” to use the consortium time allocation

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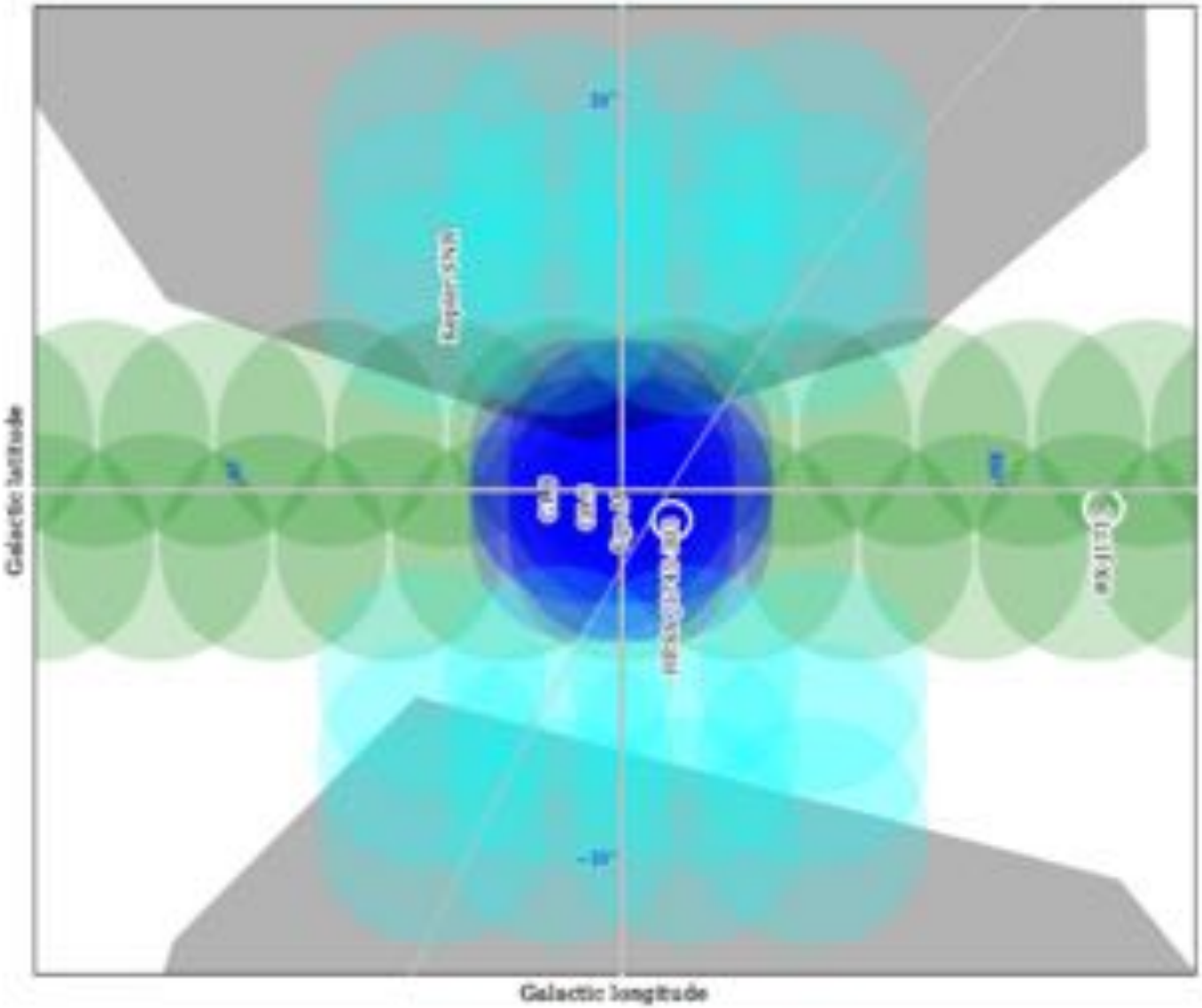
Aiming for project approval mid-2015

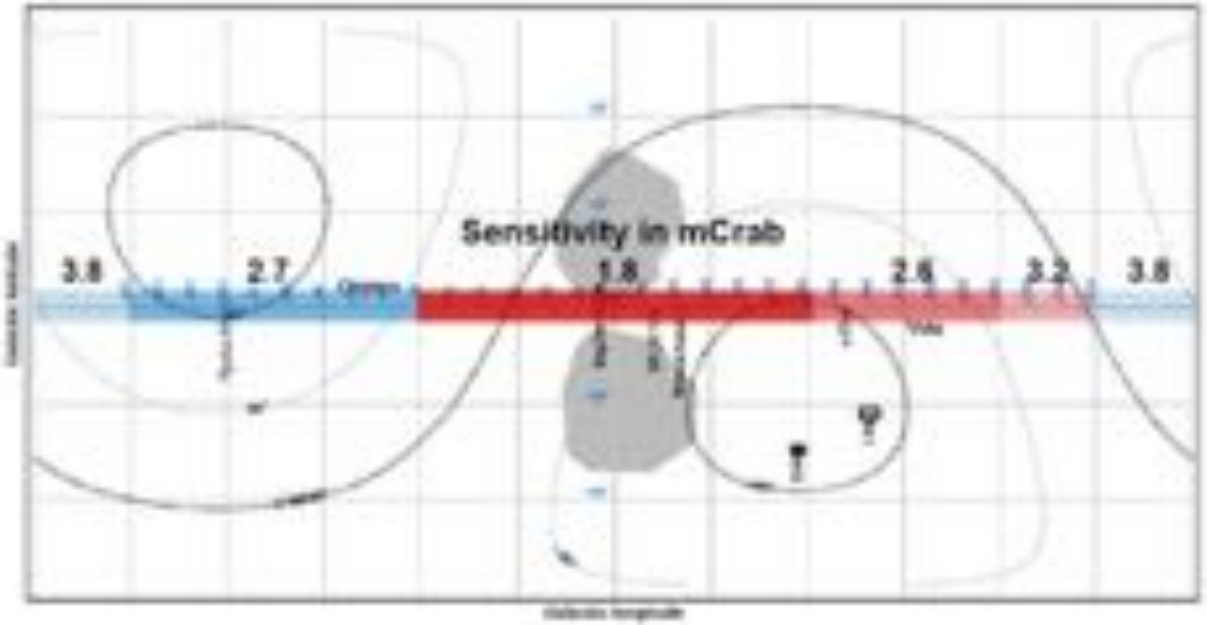
Deep survey of the Galactic Centre

500 h in the +/-5° around the Galactic Centre

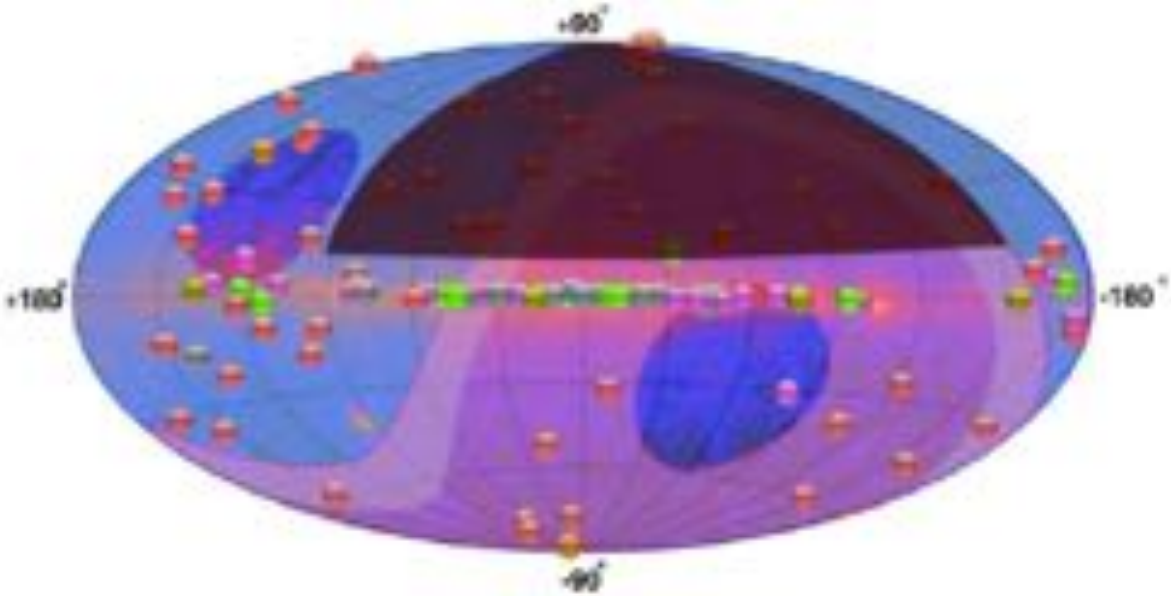


Systematic surveys

Galactic plane survey
+/- 4° in latitude



Extragalactic survey
25% of the whole sky



Why indirect searches with HE gamma rays?

- Why indirect ?
  → can reveal the abundance and distribution of dark matter

- High and very high energy gamma rays are powerful probes:
  → they do not suffer from propagation effects,
  → characteristic features such as lines or steps may be present in the energy spectrum at these energies

- Assuming thermodynamical equilibrium until the thermal decoupling
  → The natural value of the annihilation cross section is about $10^{-26}\,cm^3 s^{-1}$

Indirect dark matter search with gamma-rays

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\frac{dN_\gamma}{dE_\gamma}}_{\text{Particle Physics}} \times \underbrace{\int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s])ds}_{\text{Astrophysics}}$$

Particle Physics :

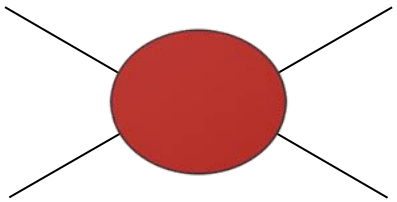
- Cross sections
- Differential photon yield
- DM particle mass

Astrophysics

→ modelling required for the DM distribution in the object

DM

DM



SM: b, W^+, Z, τ^+, …

Primary channels

SM: b, W^-, Z, τ^-, …

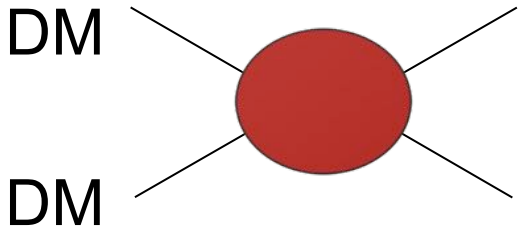
Hadronisation and/or decay

➡ γ, e^+, $\overset{(-)}{p}$, ν, …

Final states

➡ γ, e^-, $\overset{(-)}{p}$, ν, …

Spectral signatures



SM: b, W^+, Z, τ^+, …
Primary channels
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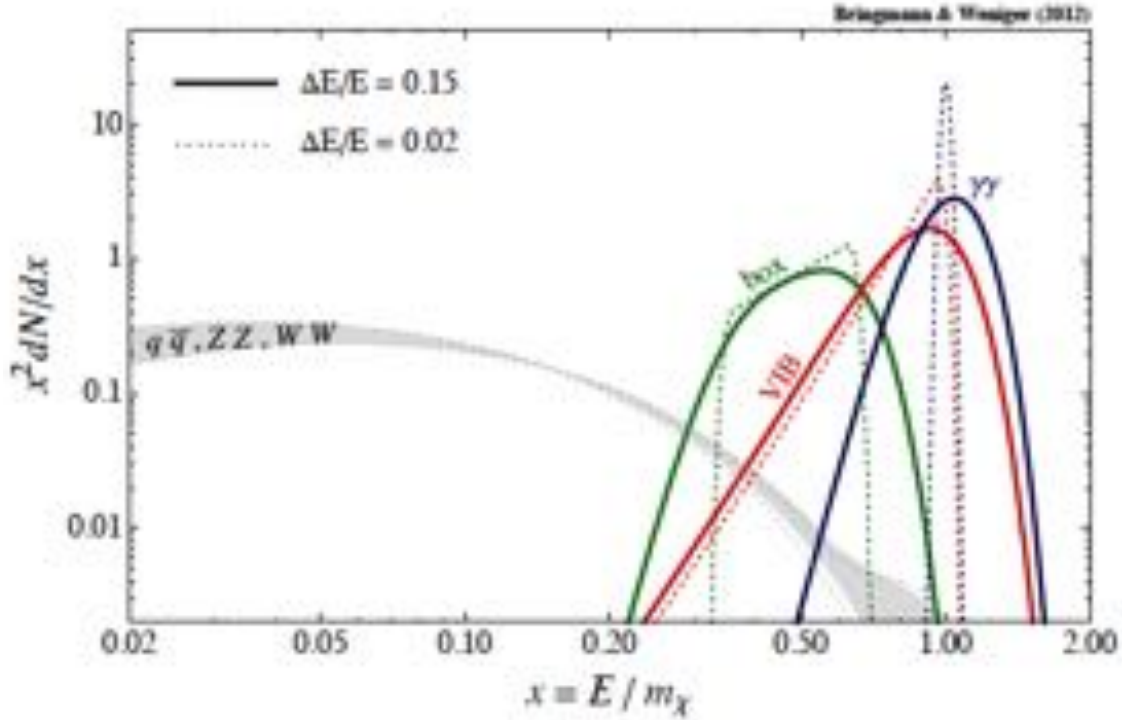
Hadronisation and/or decay

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

Continuum emission
("Secondary photons")
→ from fragmentation of quarks/massive gauge bosons (via π_0 decay)

Gamma-ray lines
→ from two-body annihilation into photons
→ forbidden at tree-level, generically suppressed by $O(\alpha^2)$



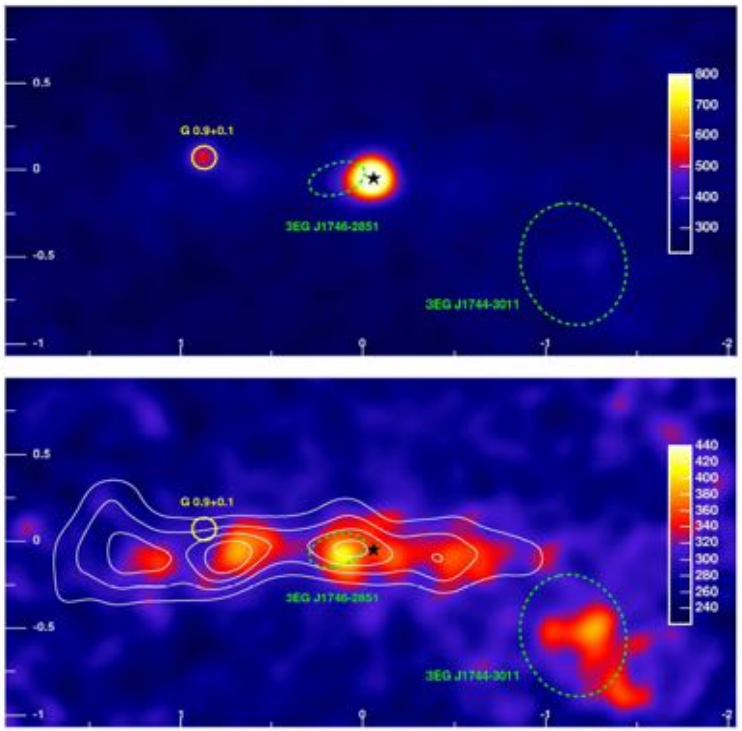
Virtual Internal Bremsstrahlung (VIB)
→ radiative correction to processes with charged final states
→ generically suppressed by $O(\alpha)$

Dark matter targets

- DM density profile matters …
- Astrophysical background matters as well

DM targets for CTA

Milky Way halo



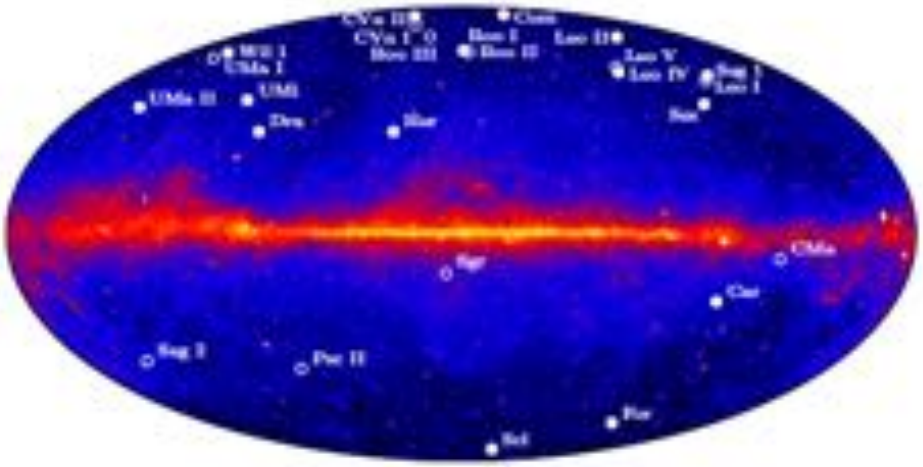
Large Magellanic Cloud

Dark targets:
Dwarf galaxies
Clumps

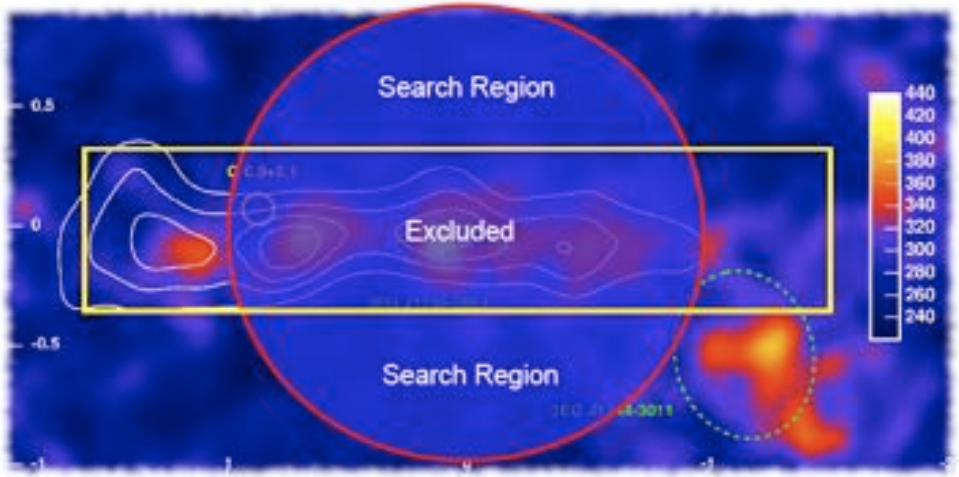
Studies are in progress to decide best way to use observation time

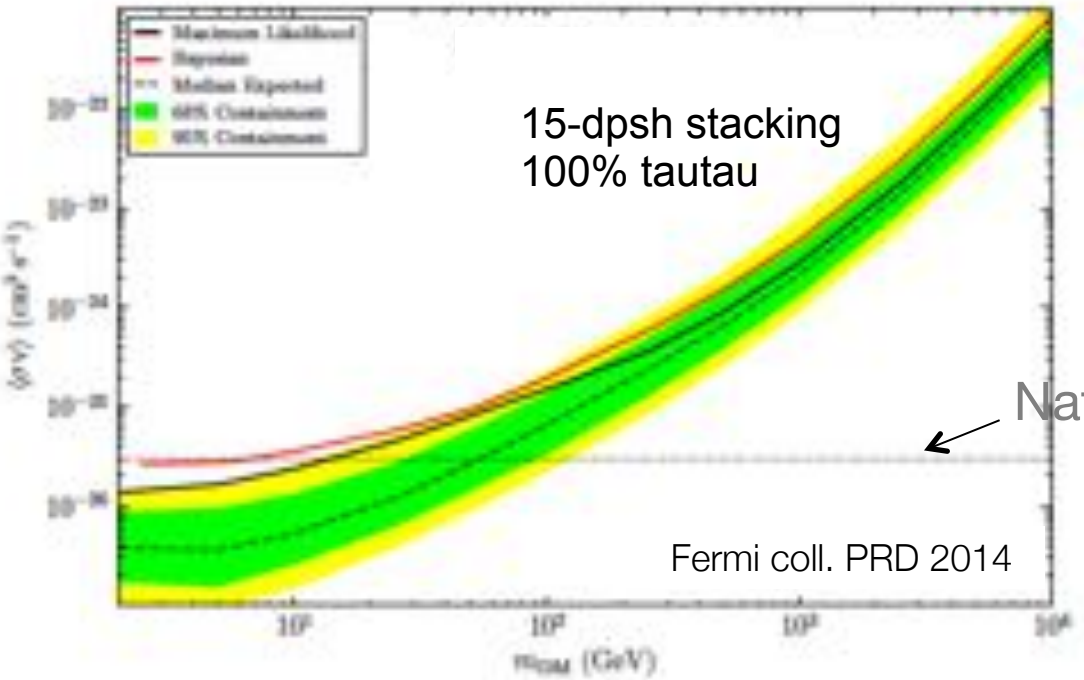
Strongest gamma-ray constraints to date

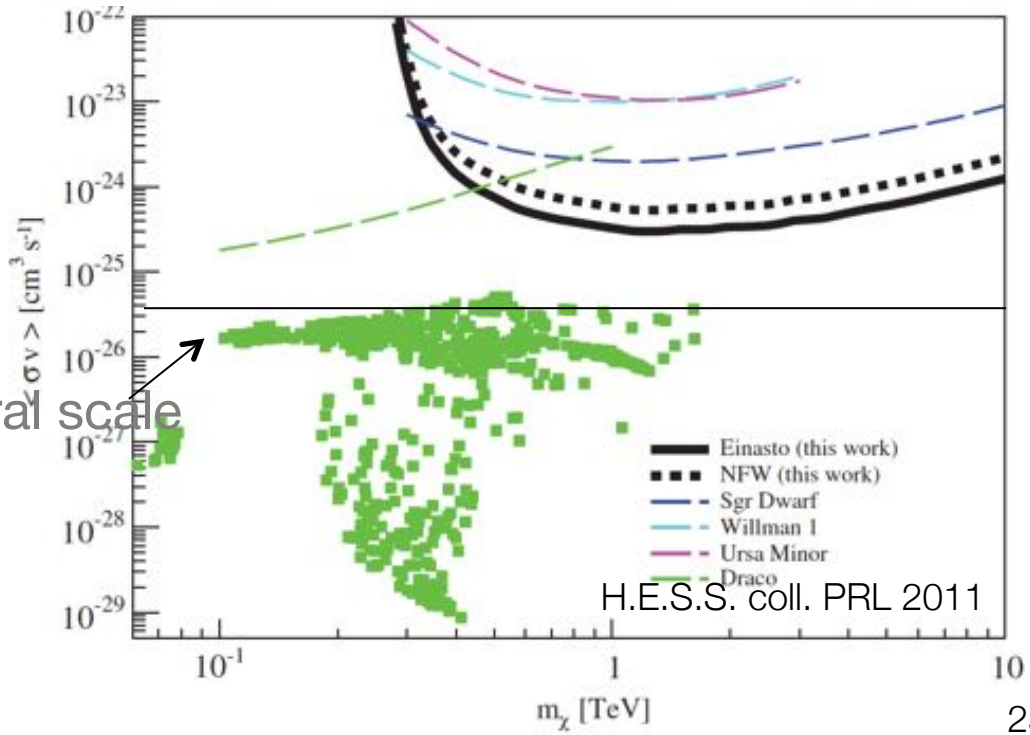
Nearby (~100kpc) dwarf galaxies



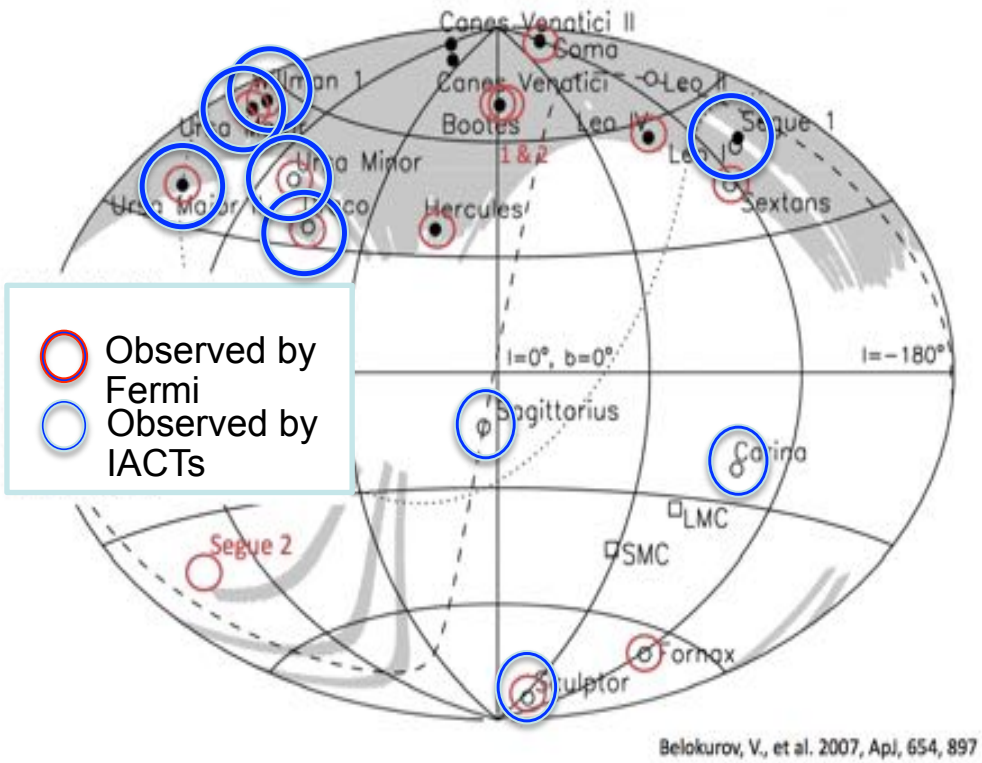
Inner Galactic halo







Dwarf satellites of the Milky Way



Belokurov, V., et al. 2007, ApJ, 654, 897

Choice of targets will be limited by the CTA site

- Southern site: Sculptor, Carina
- Northern site: Draco, Ursa Minor, Segue 1, Willmann 1, …

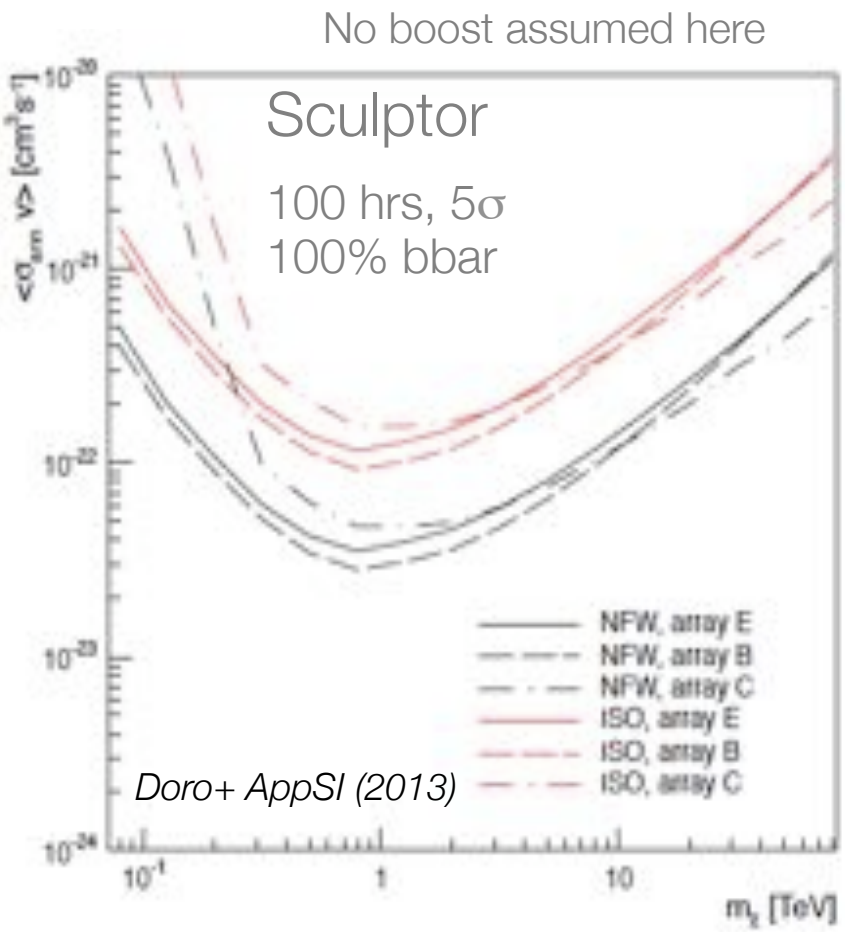
Most promising dwarf candidates

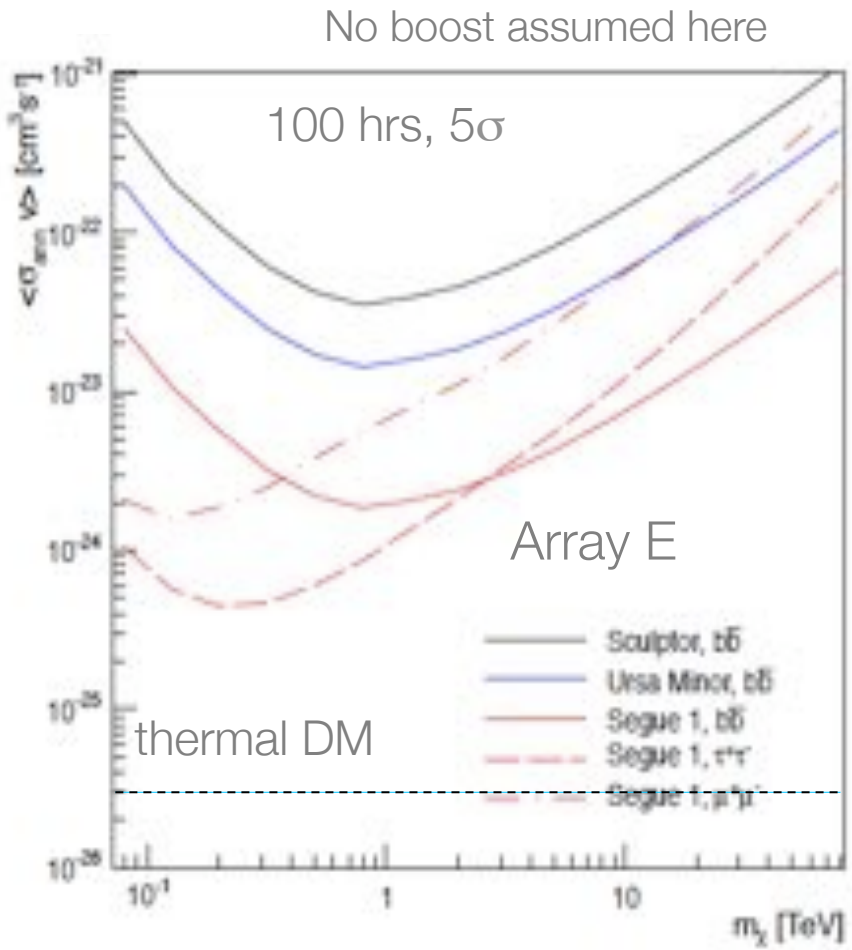
dSph	Dec. [deg]	D [kpc]	$\bar{J}$ [$GeV^2 cm^{-5}$]	Profile
Ursa Minor	+44.8	66	2.2×10^{18}	NFW
Draco	+34.7	87	7.1×10^{17}	NFW
Sculptor	−83.2	79	8.9×10^{17}	NFW
			2.7×10^{17}	ISO
Carina	−22.2	101	2.8×10^{17}	NFW
Segue 1	+16.1	23	1.7×10^{19}	Einasto
Willman 1	+51.1	38	8.4×10^{18}	NFW
Coma Berenices	+23.6	44	3.9×10^{18}	NFW

Classical dwarf

Ultra-faint dwarf

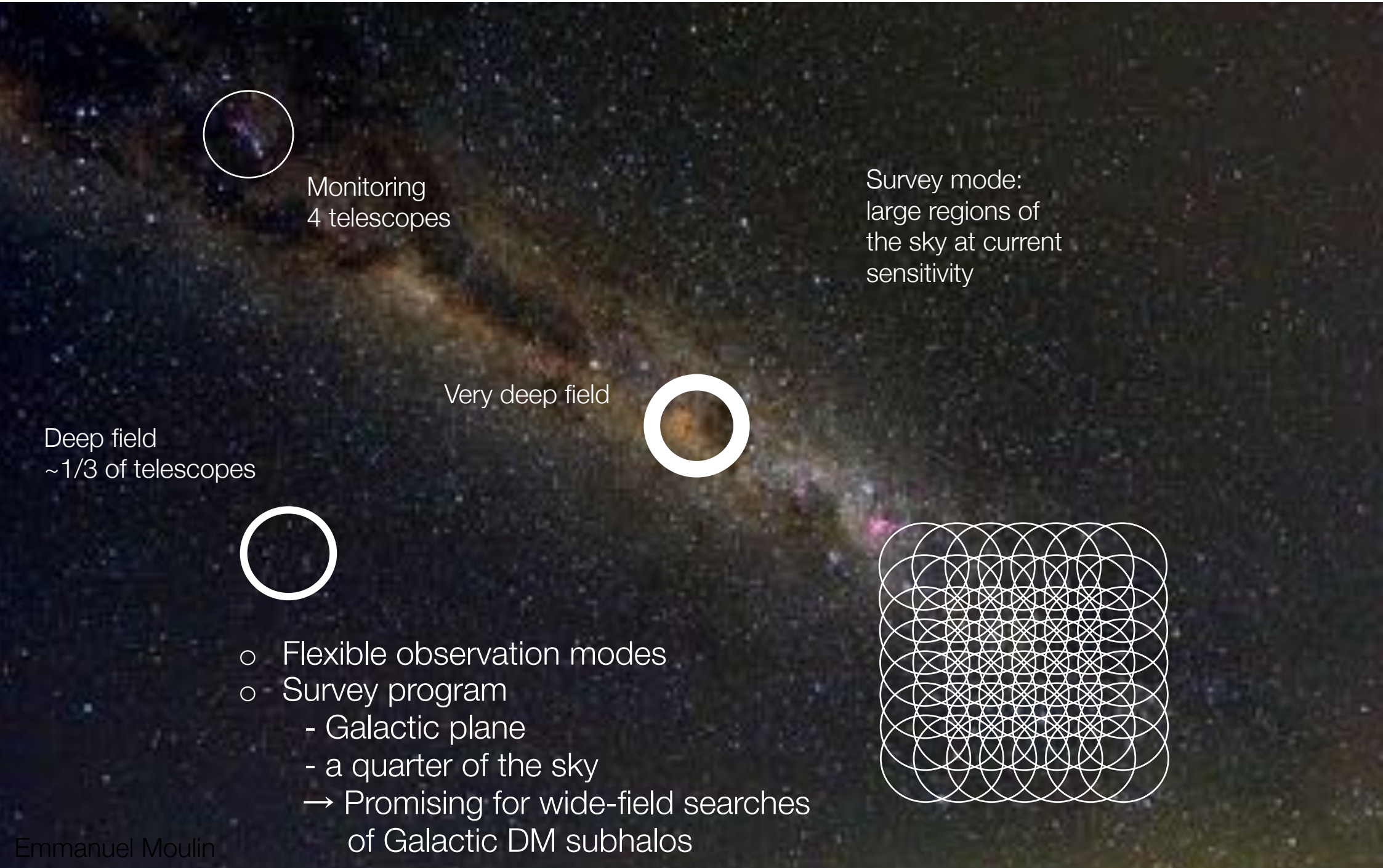
Dwarf satellites of the Milky Way





- Need boost of at least 10-100 to reach thermal relic cross section
- *New experiments will surely detect new dwarf galaxies (and better constraints known) in the time from here to CTA*

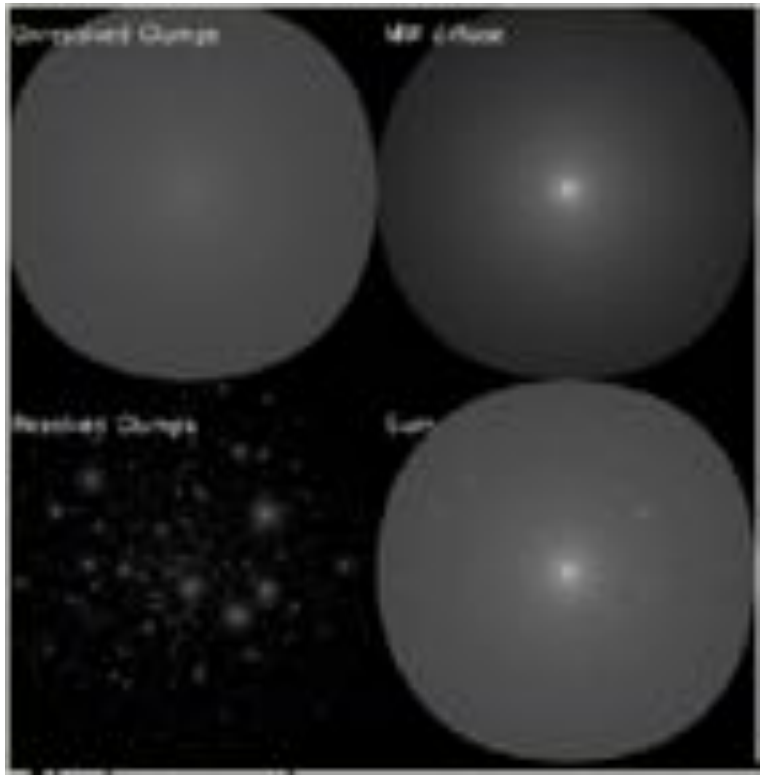
Dark matter subhalos: observation strategy



- Flexible observation modes
- Survey program
  - Galactic plane
  - a quarter of the sky

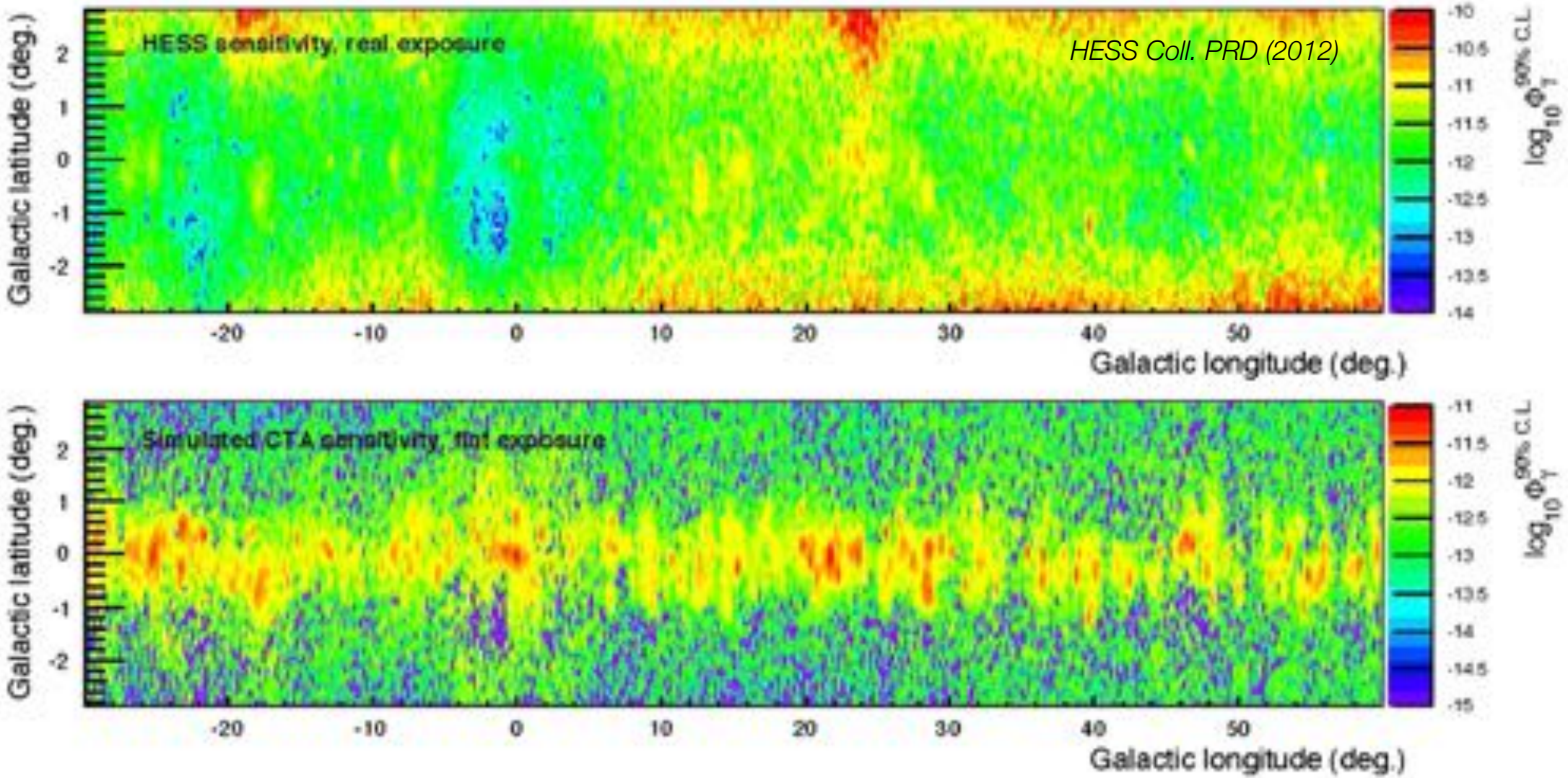
  → Promising for wide-field searches of Galactic DM subhalos

Dark matter subhalos



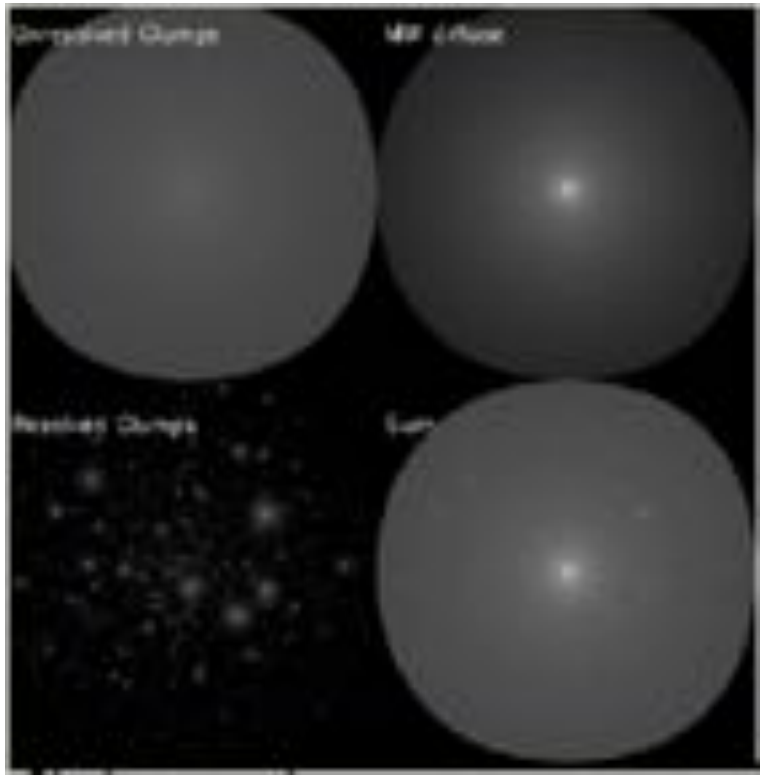
- Clumps of DM could be gamma-ray *dark* emitters
- Some of them could be Unidentified Fermi Sources
- Fermi could be blind of them if DM is above few hundreds of GeV

Dark matter subhalos: wide field survey



What the Galctic plane may look like… numerous sources will shine

Dark matter subhalos: wide field survey

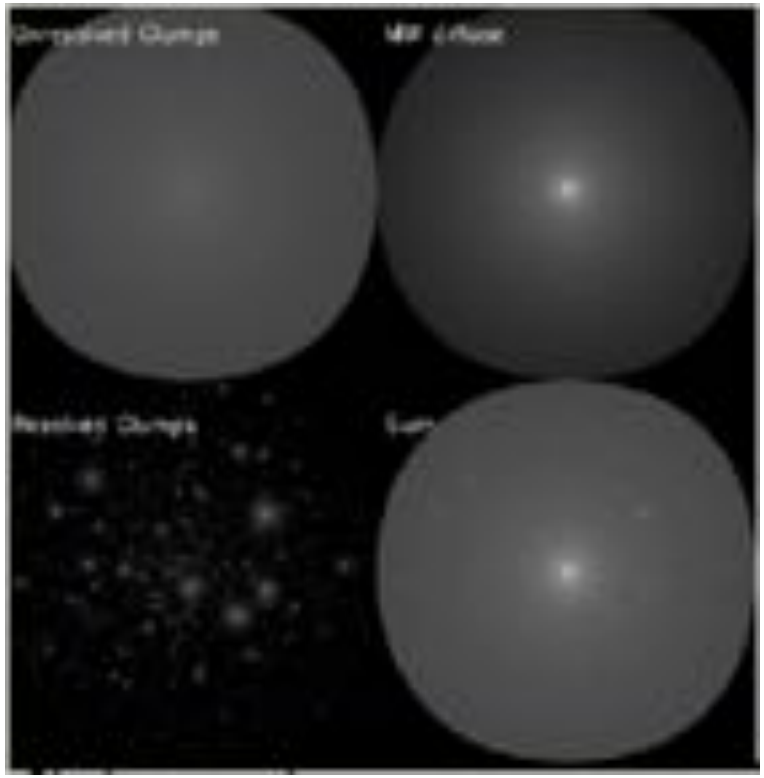


- Clumps of DM could be gamma-ray
- Some of them could be Unidentified Fermi Sources
- Fermi could be blind of them if DM is above few hundreds of GeV

<u>Observation strategy:</u>

- Avoid the Galactic plane where numerous sources will shine, those imply a decrease in the clump sensitivity
- But not too far from the galactic centre region since clump distribution is peaked towards the centre of the halo

Dark matter subhalos: wide field survey



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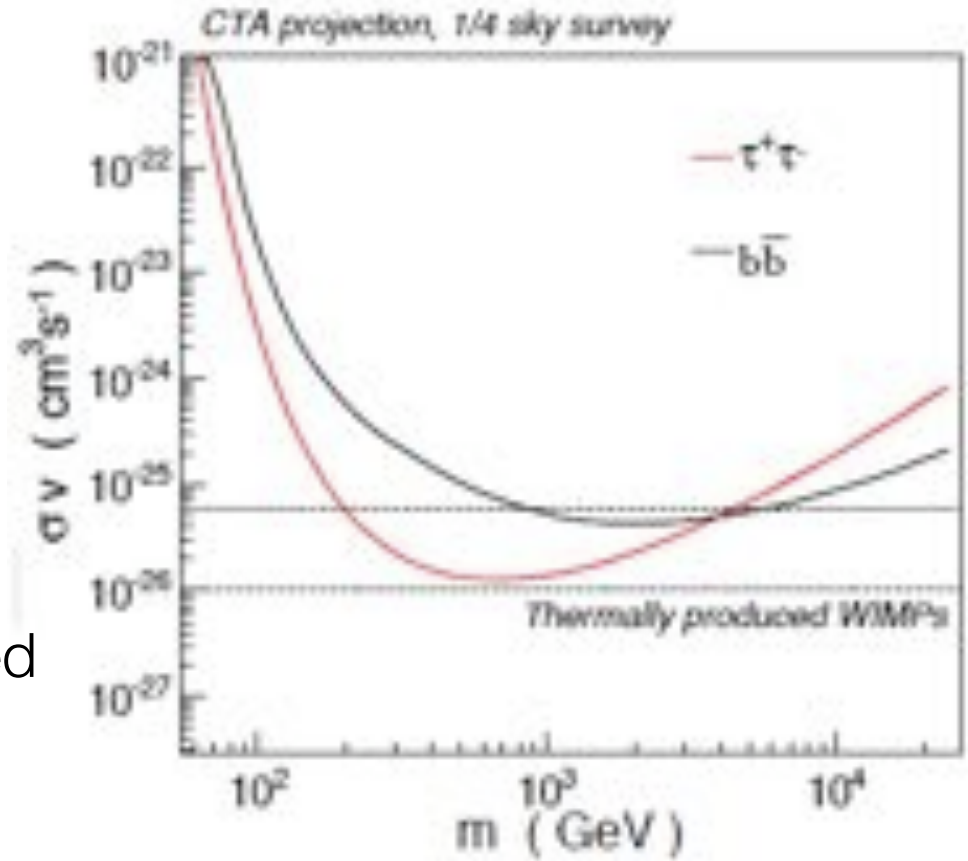
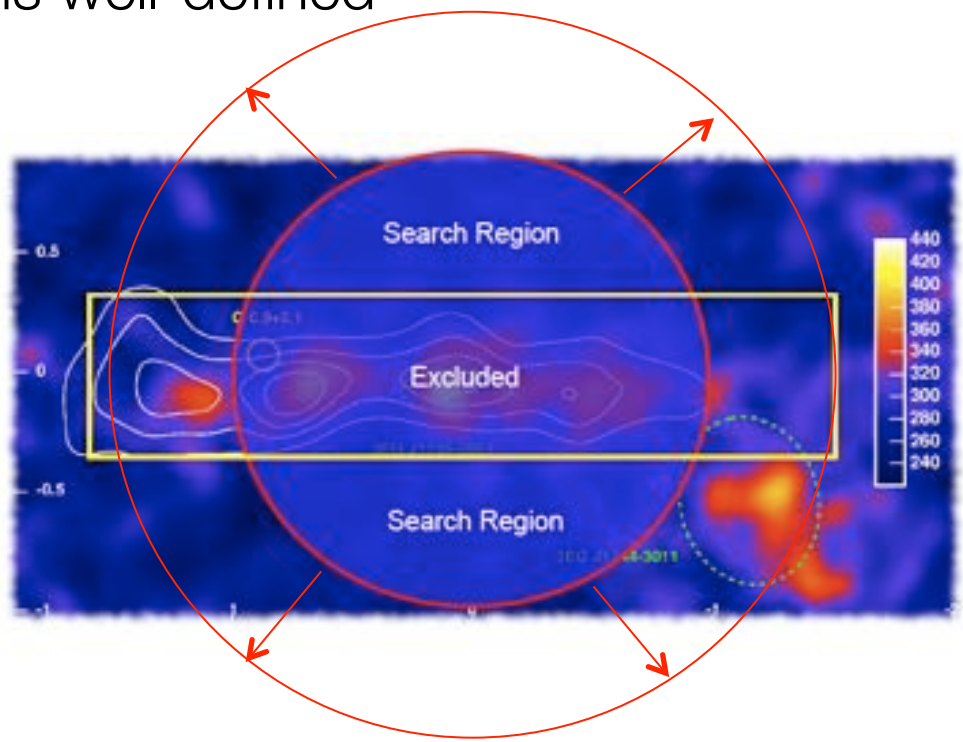
- Wide field survey:
  a quarter of the sky
  @10 mCrab sensitivity
  → natural scale can be probed



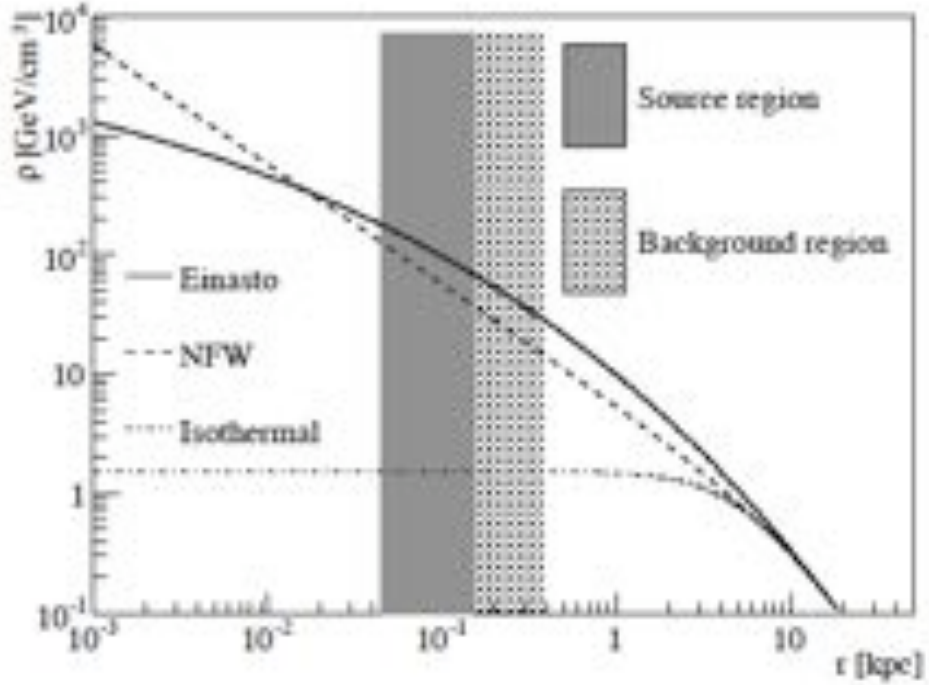
P. Brun, EM, J. Diemand, J.F. Glicenstein
PRD83, 015003 (2012)

Galactic halo

- Galactic center obvious target for DM searches, but crowded region
- Galactic halo at short distance from GC is well-defined



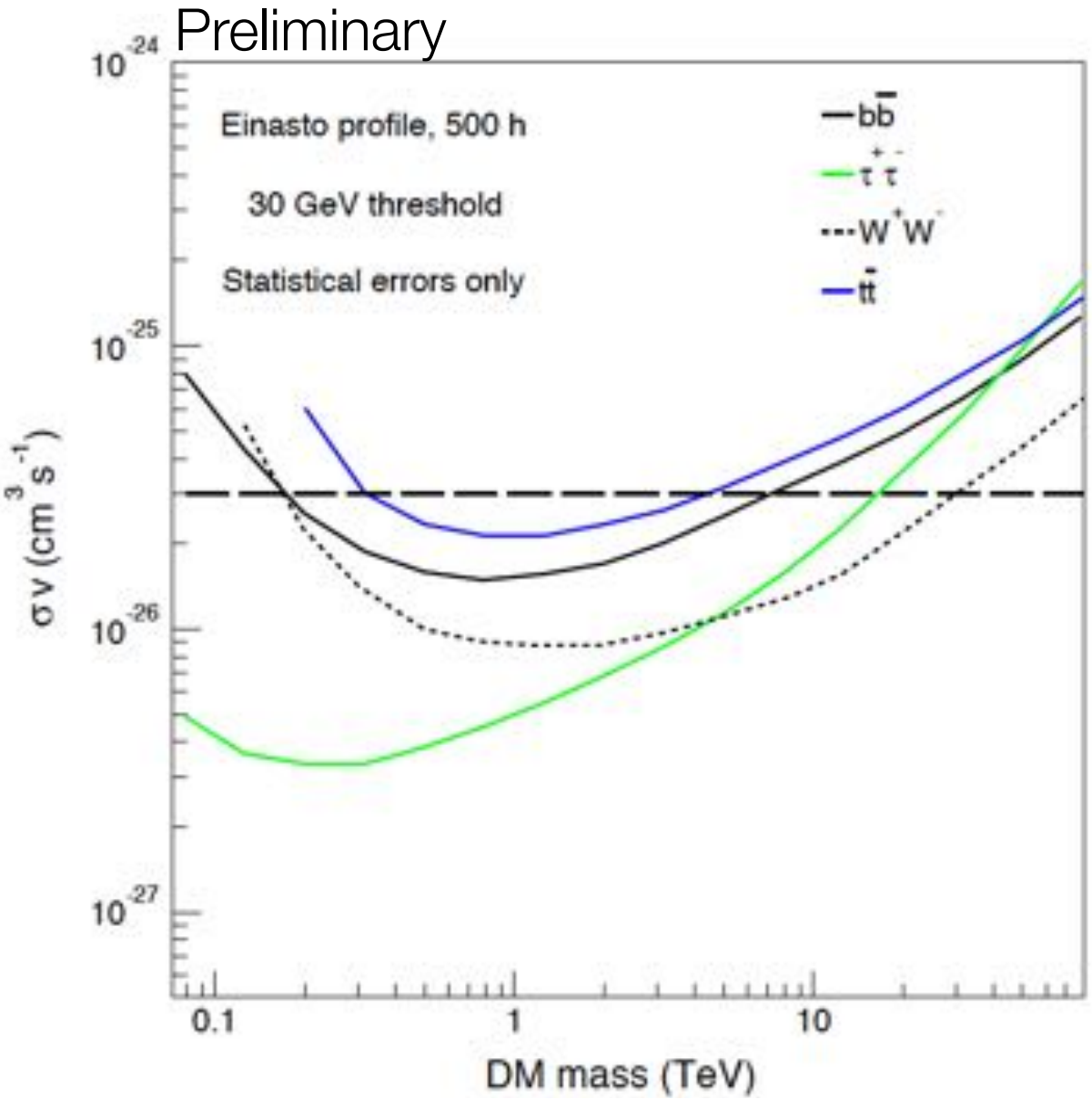
HESS Coll. PRL 106 (2011)



→ Avoid sky regions with strong astrophysical gamma ray signals

→ Focus at the same time on regions with an expectedly large DM density

Galactic halo

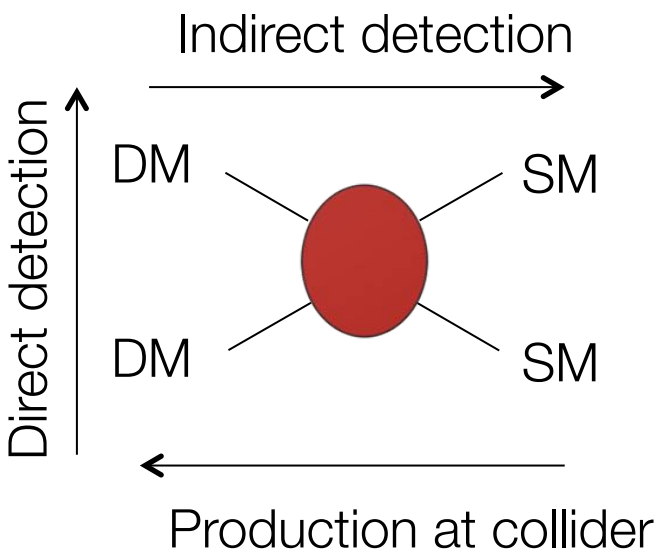


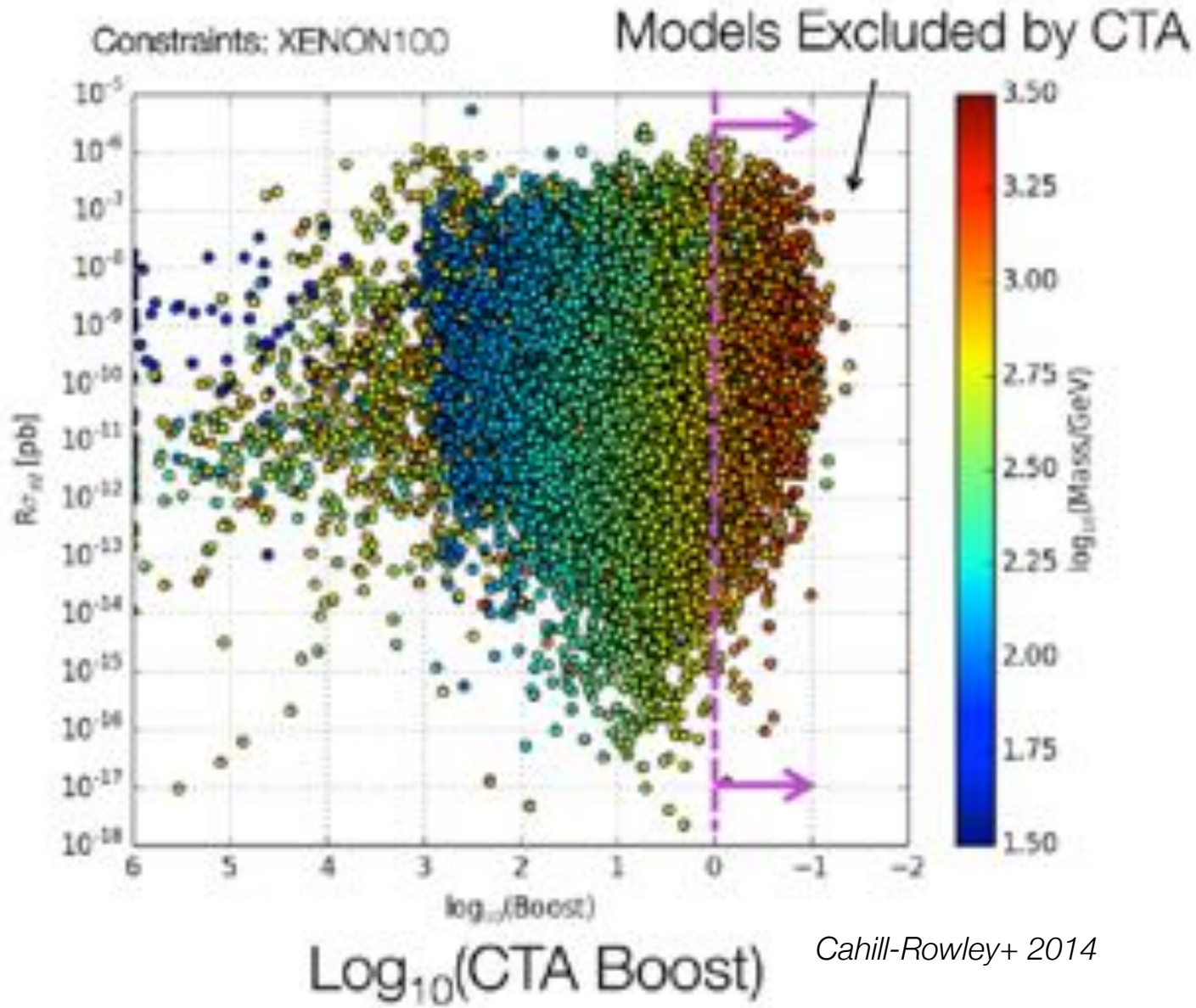
- 500 h in the inner 5° around GC
- Careful selection of signal and background region
- Control of diffuse gamma-ray background
- Control of background systematics
- Results robust for cuspy profile but not for a core profile

Natural scale is within the reach of CTA:
for the first time in indirect detection with IACTs, CTA has the sensitivity to probe the expected parameter region for popular models

Final observational pointing strategy not decided

Will CTA be competitive?



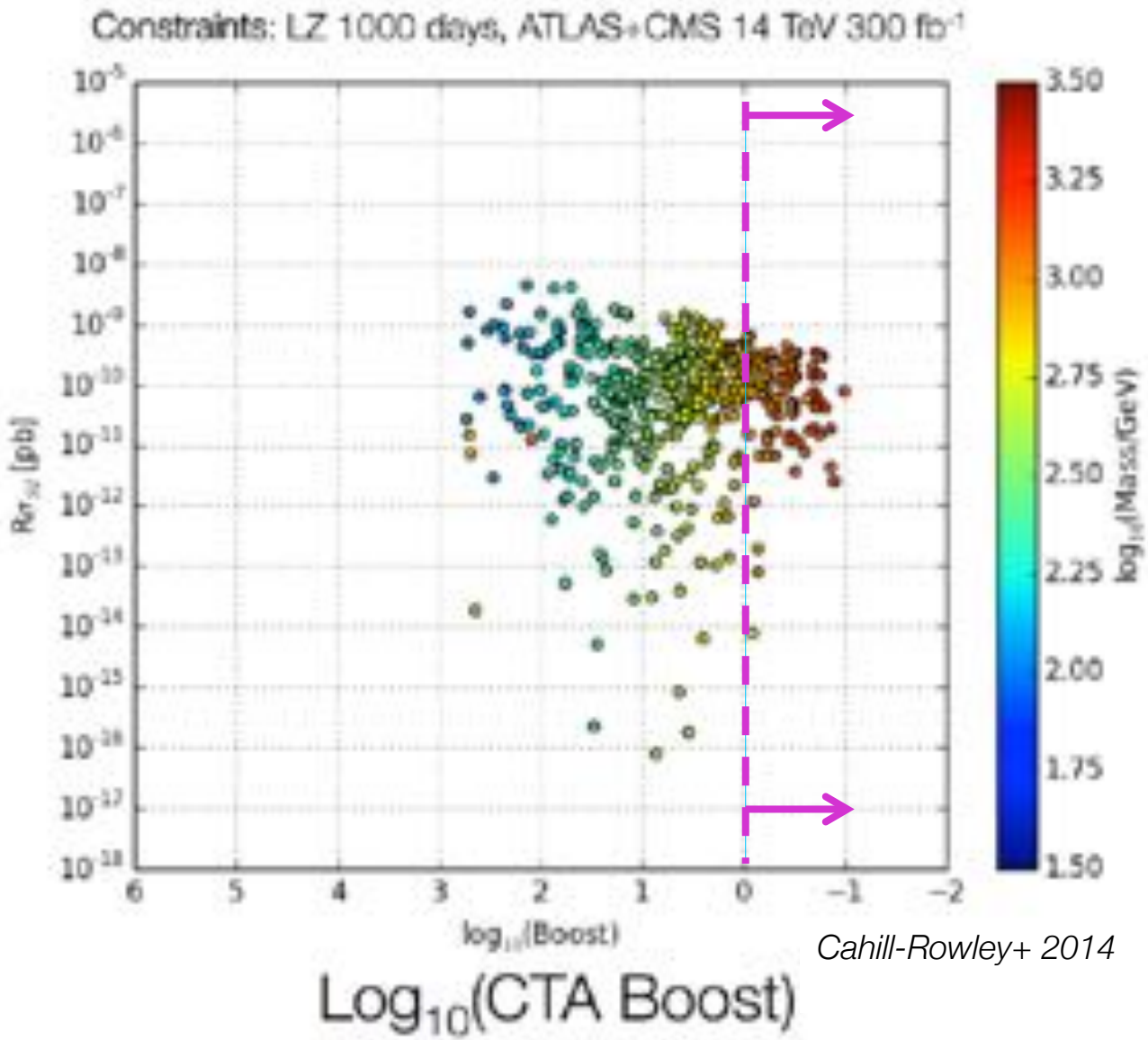


Cahill-Rowley+ 2014

Good sensitivity at high (> 1 TeV) LSP mass

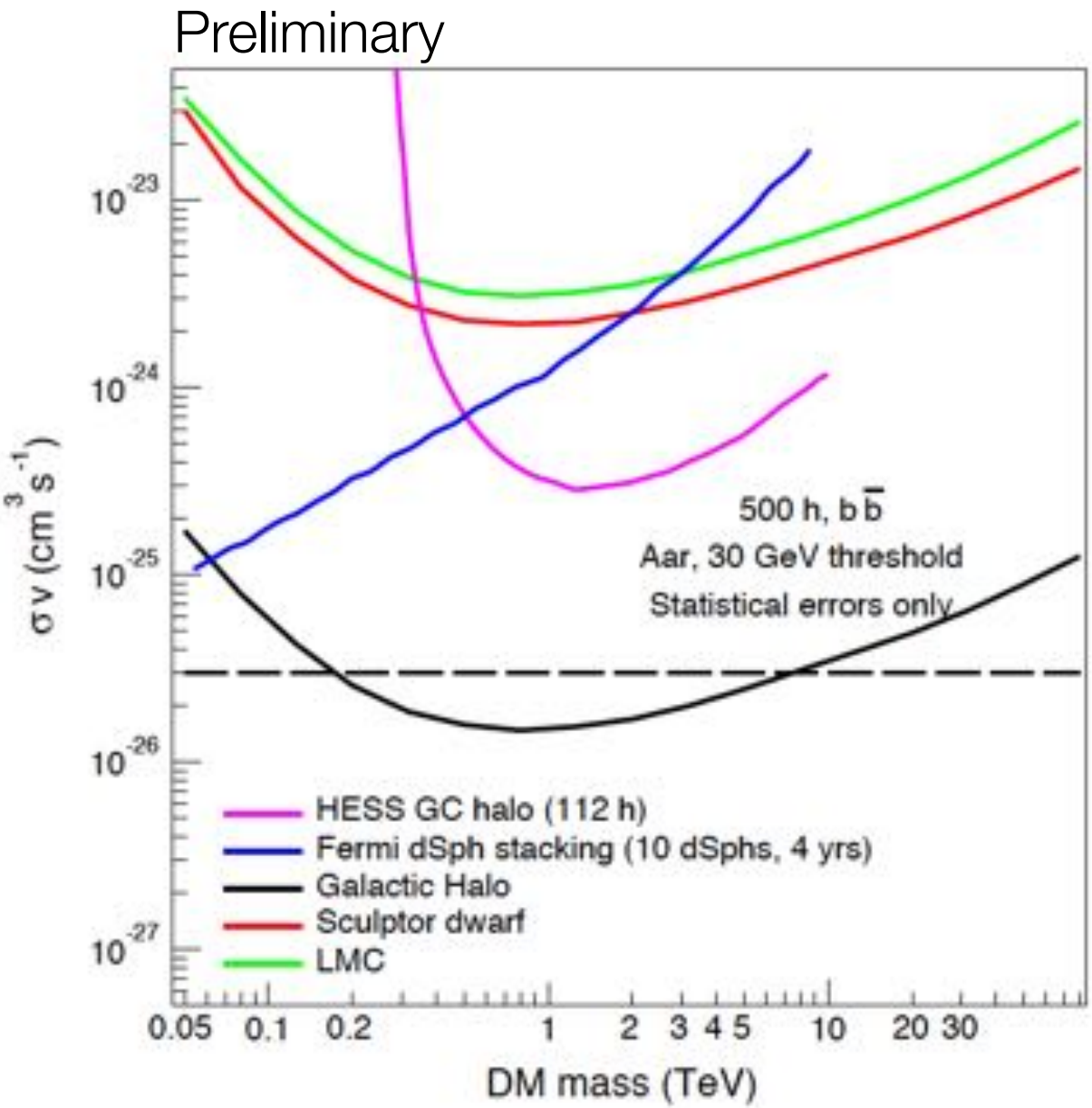
Will CTA be competitive?

- CTA is complemantary to LHC and direct searches
- If LHC-14 do not discover DM, CTA has still chance if DM is heavy



Cahill-Rowley+ 2014

Dark matter sensitivity predictions



- Final observational pointing strategy not decided
- Control of background systematics
- Sensitivity to natural scale for the Galactic halo

Conclusions

- CTA will be the first open IACT observatory
  - Factor 10 improvements on existing facilities
  - Full sky coverage

- Major recent progress towards realizing the observatory
- On track for completion ~2020
  - CTA expected to start science in 2017

- Great possibility to discovery dark matter
  - CTA will be a key player for TeV DM

- And very many other science opportunities