TeV Gamma-Rays and Indirect Dark Matter Searches

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THE UNIVERSITY OF ADELAIDE AUSTRALIA

SUB CRUCE LUMEN

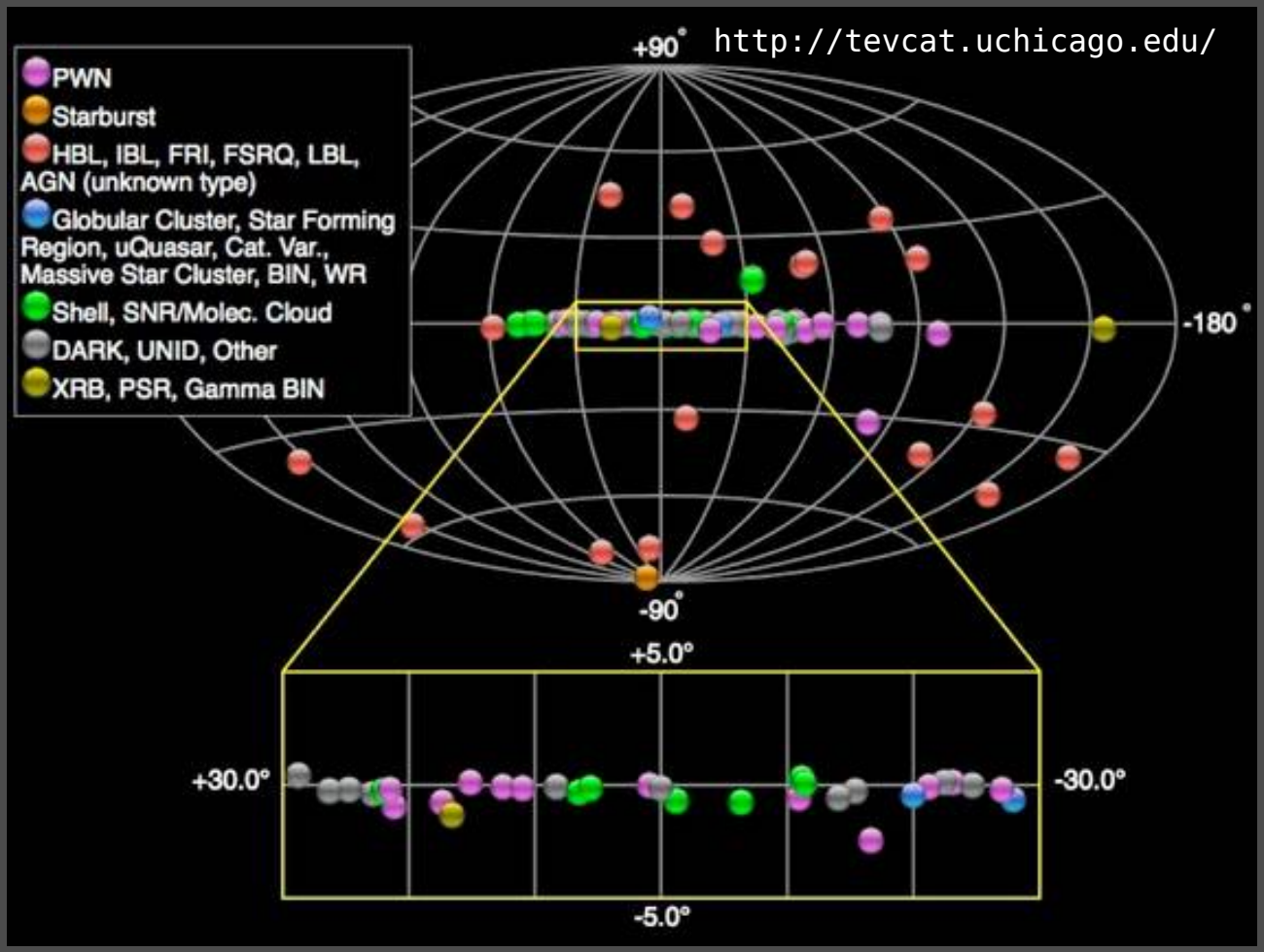
CAASTRO-CoEPP Meeting (Melb.) Jan/Feb 2017

Image Credit: NRAO

Gamma-rays (~30 GeV to ~500TeV)

Highly effective tracer of high energy particles

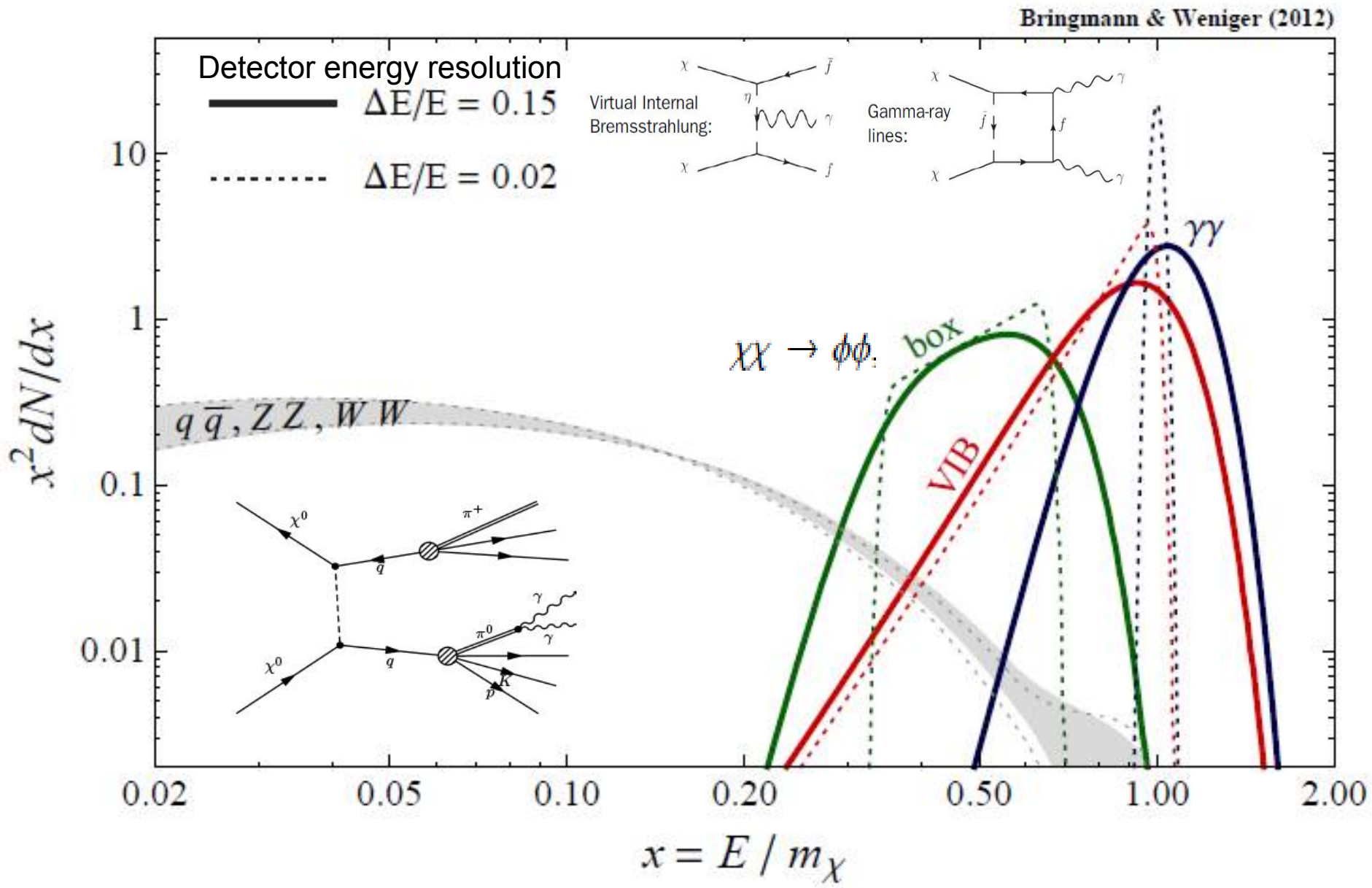
High impact results ~ 20 Nature, Science, PhysRevLett papers since 2004



Great success with HESS, VERITAS, MAGIC, MILAGRO

→ HESS-II, MAGIC-II, VERITAS upgrade, CTA, HAWC...

Gamma-Ray Annihilation Signatures from (WIMP) Dark Matter



Gamma-Ray Flux from Dark Matter Annihilation

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = B_F \cdot \frac{1}{4\pi} \underbrace{\frac{(\sigma_{ann} v)}{2 m_\chi^2} \sum_i BR_i \frac{dN_\gamma^i}{dE_\gamma}}_{Particle\ Physics} \cdot \underbrace{\bar{J}(\Delta\Omega)}_{Astrophysics}$$

$$\bar{J} = \int_{\Delta\Omega} d\Omega \int_{los} ds\, \rho^2(s, \Omega)$$

B_F - boost factor
BR_i - branch ratio

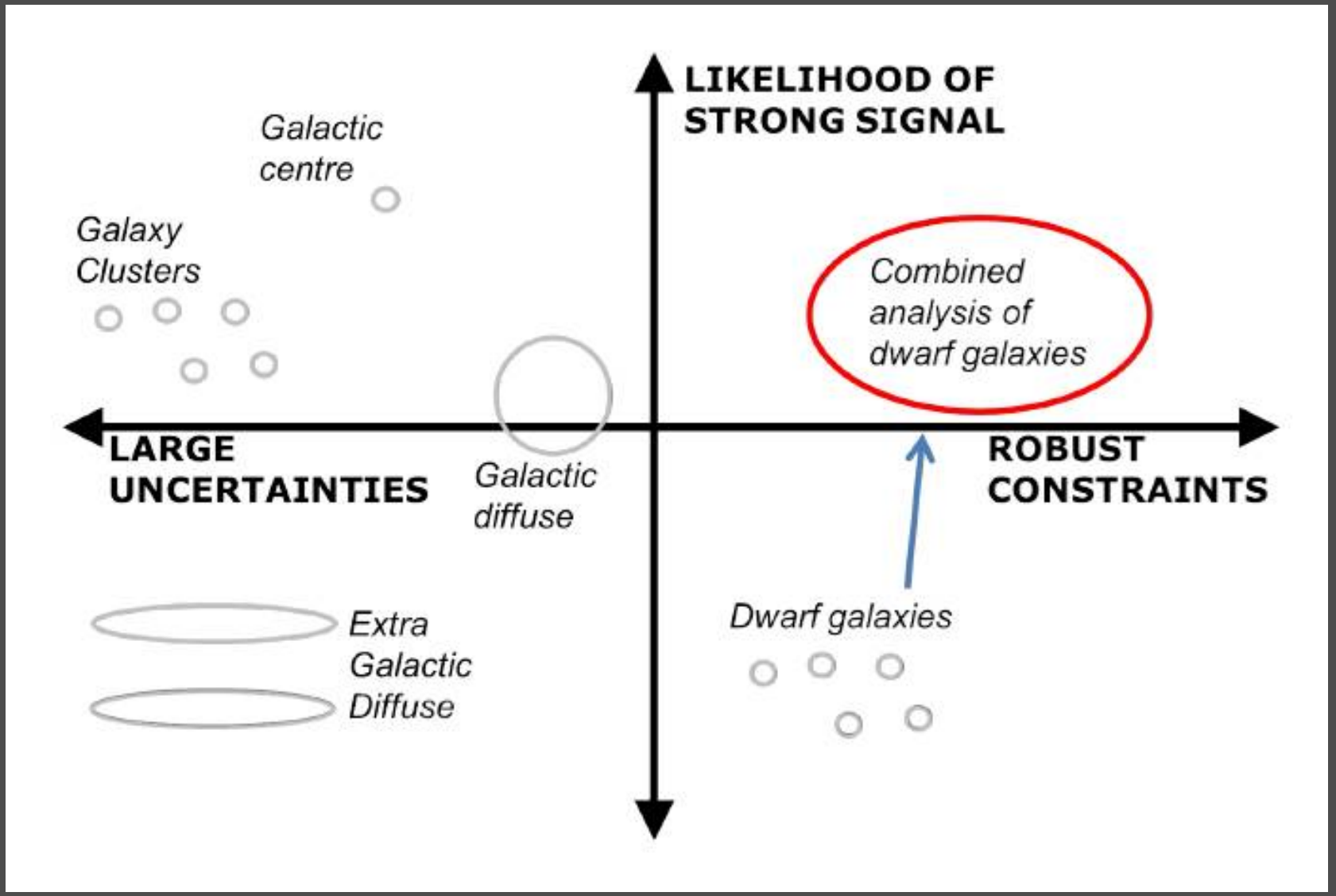
Astrophysics term:

- assume density profile of DM ρ (NFW, Einasto..)
- peaking at cores of galaxies, clusters, stars....

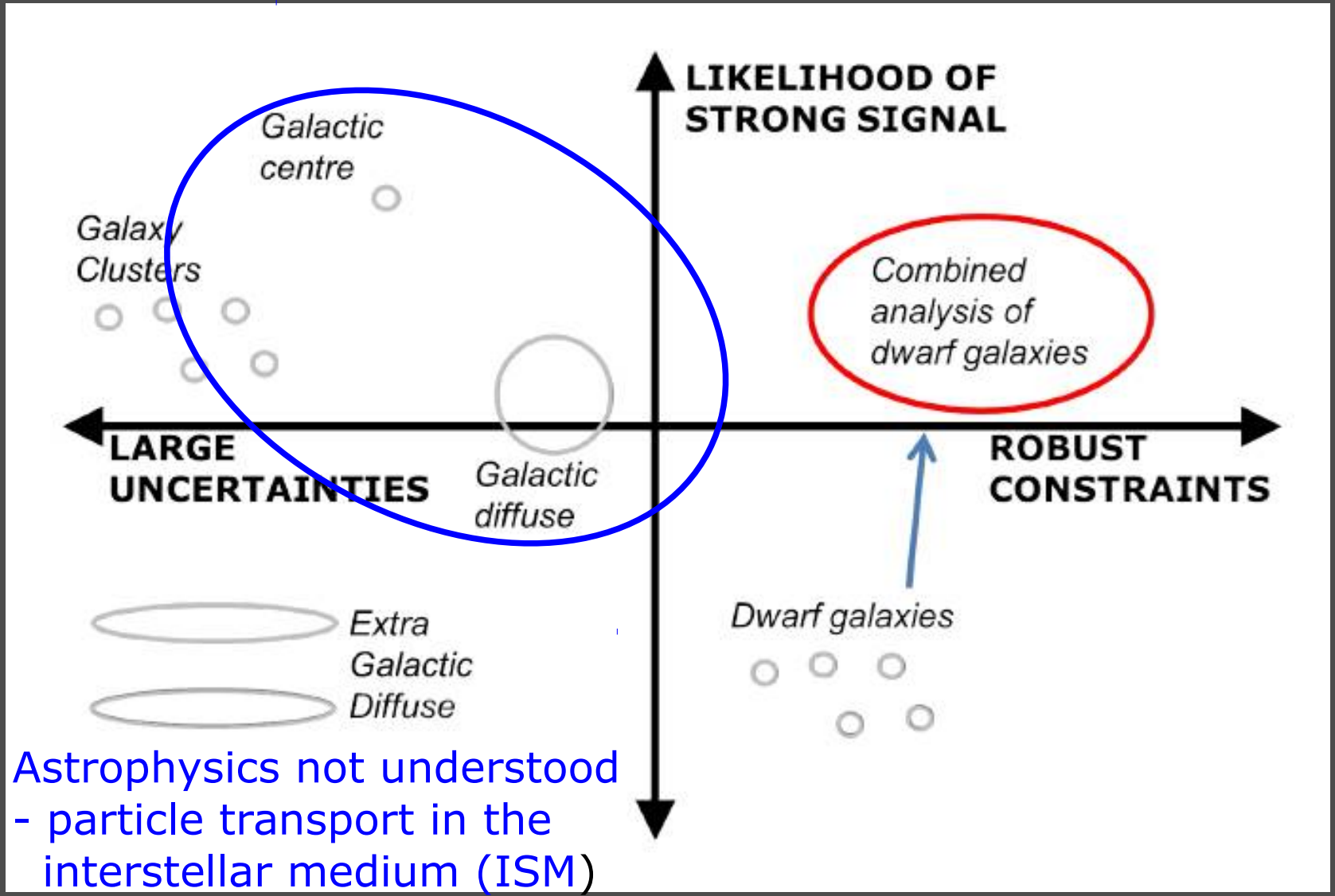
→ constraints on <σv>

Prefer astrophysically weak or 'understood targets

→ *Dwarf galaxies*
→ *Globular clusters?* — *TeV emission from ms pulsars, XRBs?*
→ *Galactic centre region?* — *GeV-TeV emission.. SMBH, SNRs, pulsars*
→ *Galaxy clusters..*


LIKELIHOOD OF
STRONG SIGNAL
Galactic
centre
Galaxy
Clusters
Combined
analysis of
dwarf galaxies
LARGE
UNCERTAINTIES
Galactic
diffuse
ROBUST
CONSTRAINTS
Extra
Galactic
Diffuse
Dwarf galaxies

Conrad 2014



Astrophysics not understood
- particle transport in the
interstellar medium (ISM)

Conrad 2014

The Cherenkov Telescope Array : A TeV Gamma-Ray Observatory

The Cherenkov Telescope Array

- Next generation gamma-ray observatory

- Huge improvement in all aspects of performance

x10 better sensitivity, better FoV + angular resolution, wider energy coverage, collection area >few km^2, wider survey capabilities

- User facility / proposal-driven observatory

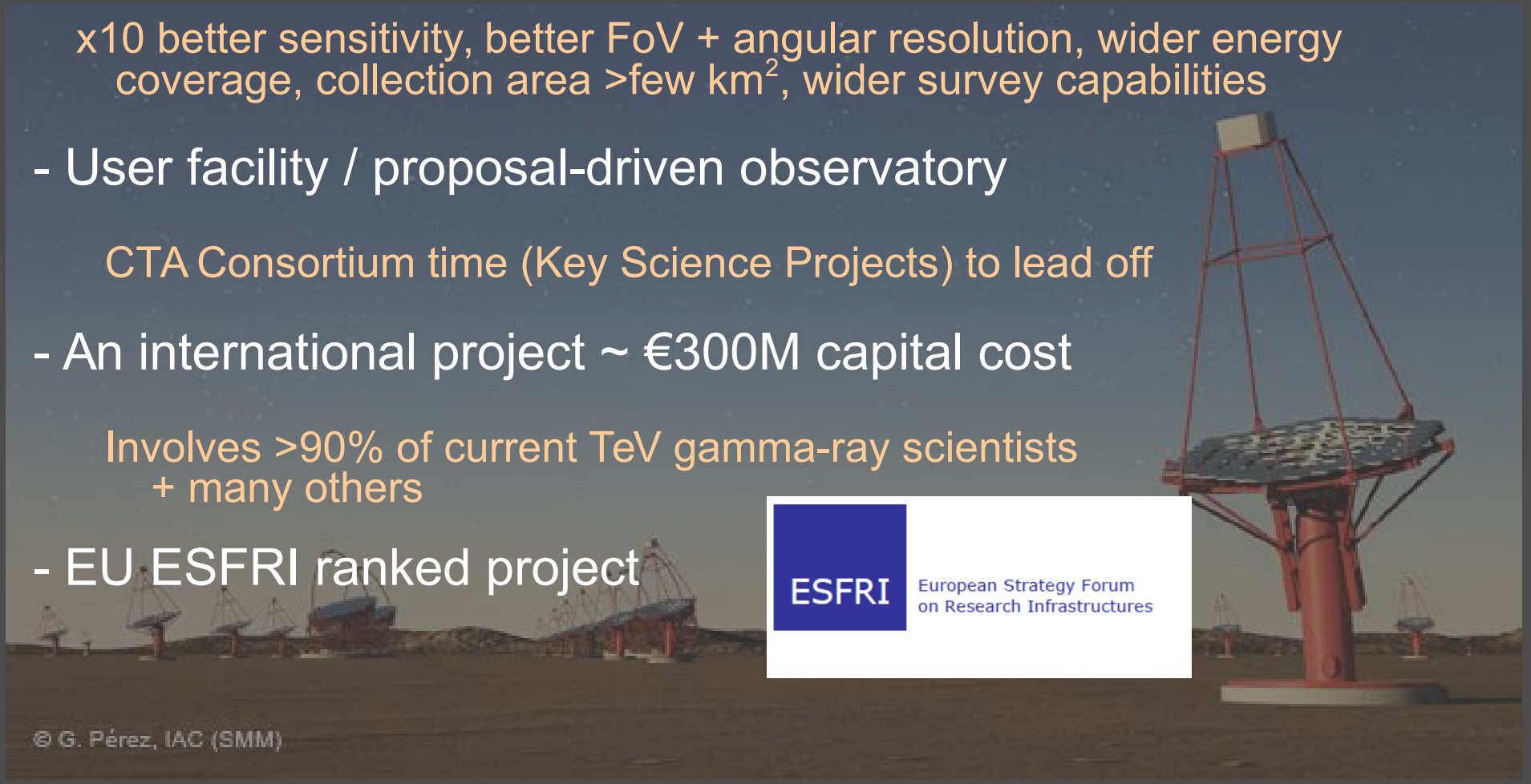
CTA Consortium time (Key Science Projects) to lead off

- An international project ~ €300M capital cost

Involves >90% of current TeV gamma-ray scientists + many others

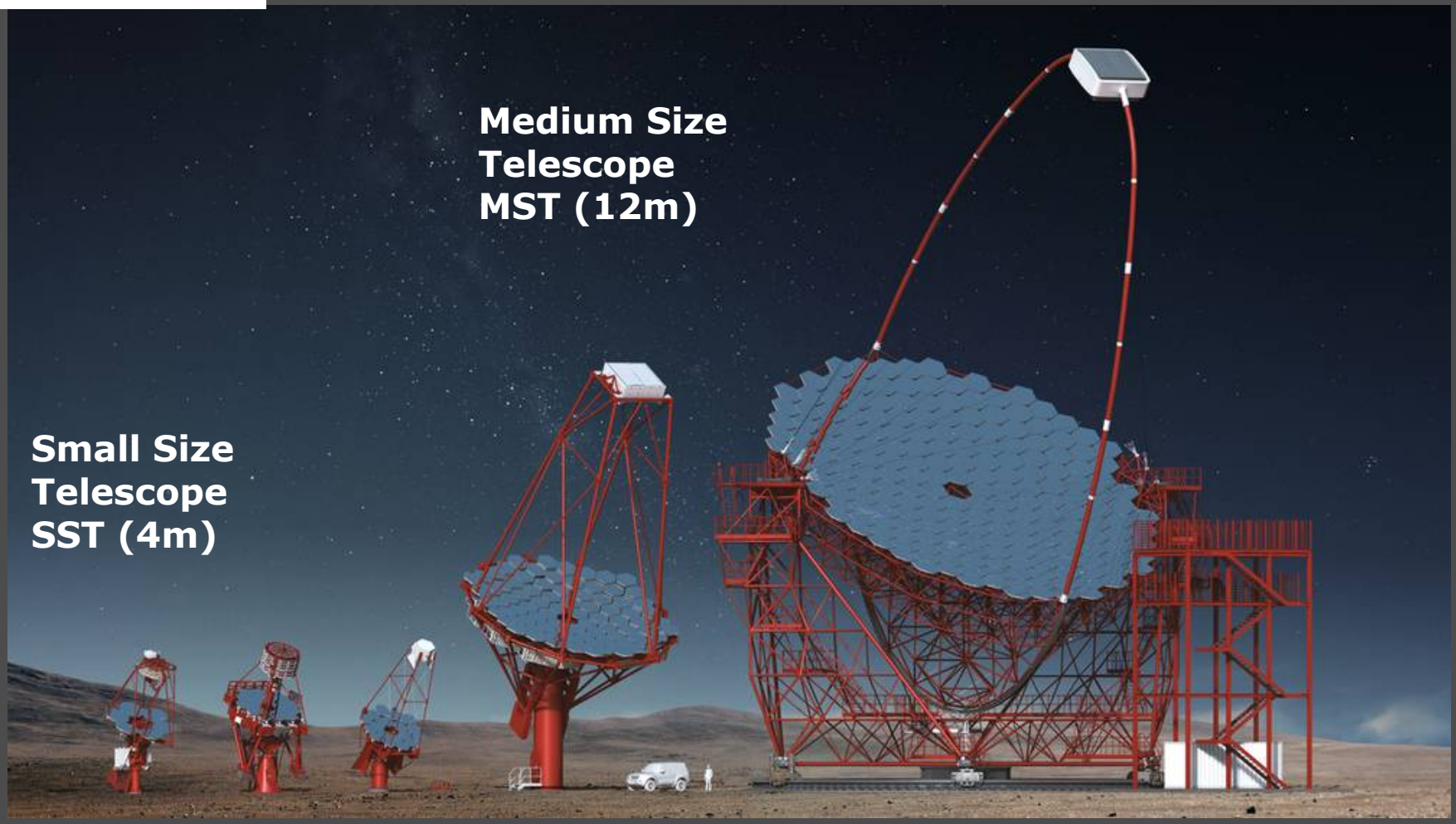
- EU ESFRI ranked project

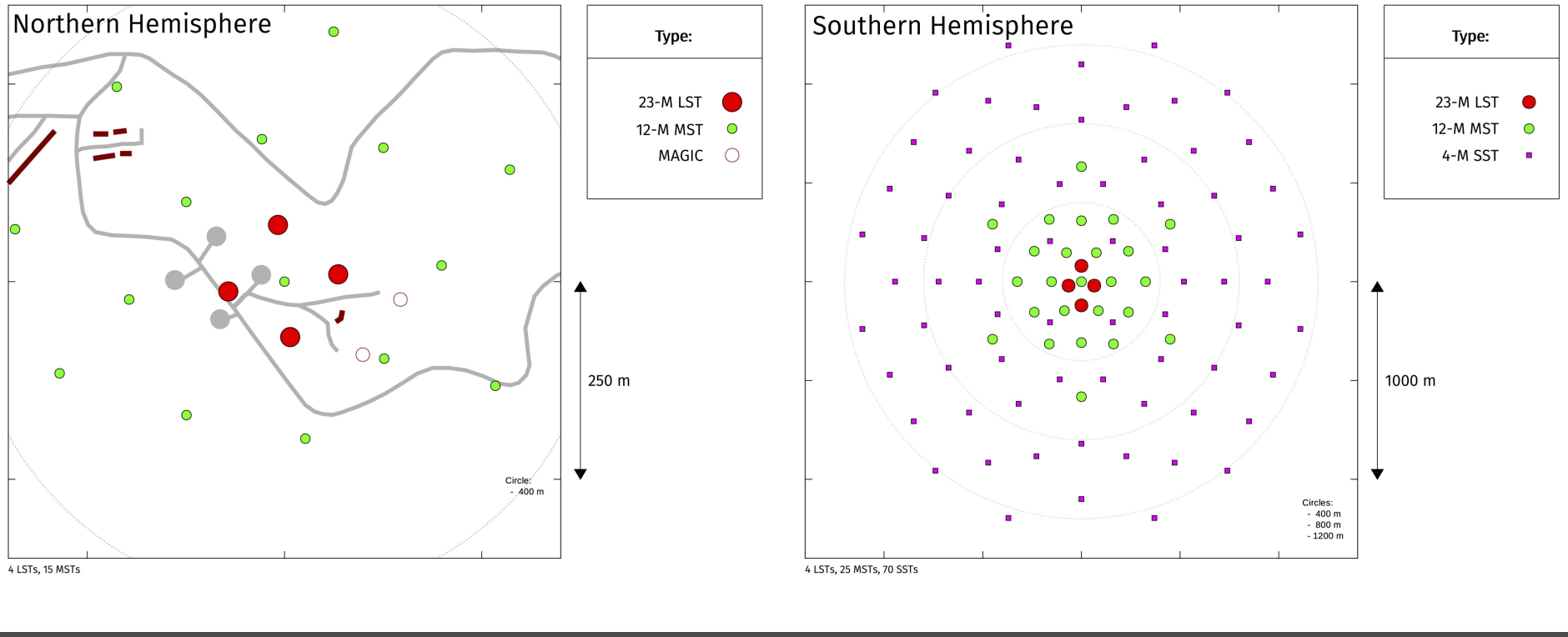
ESFRI European Strategy Forum on Research Infrastructures



cta
cherenkov telescope array

Large Size
Telescope
LST (23m)




Northern Hemisphere
Type:
23-M LST
12-M MST
MAGIC
250 m
Circle:
- 400 m
4 LSTs, 15 MSTs
Southern Hemisphere
Type:
23-M LST
12-M MST
4-M SST
1000 m
Circles:
- 400 m
- 800 m
- 1200 m
4 LSTs, 25 MSTs, 70 SSTs

CTA Consortium (CTAC)

July 2016

32 Countries
over 200 Institutes
over 1300 Members

CTA – Australia

U. Adelaide
G. Rowell, B. Dawson, R. Clay, P. Veitch, D. Ottaway, M. White, V. Stamatescu, L. Bowman, A. Malouf, N. Wild

UNSW
M. Burton, M. Ashley, C. Braiding, N. Maxted

WSU
M. Filipovic, N. Tothill

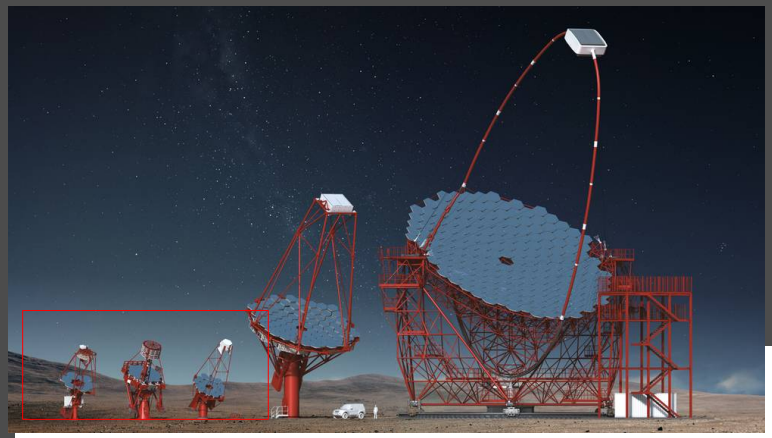
ANU
G. Bicknell, R. Crocker, I. Seitenzahl

Monash
C. Balazs, D. Galloway

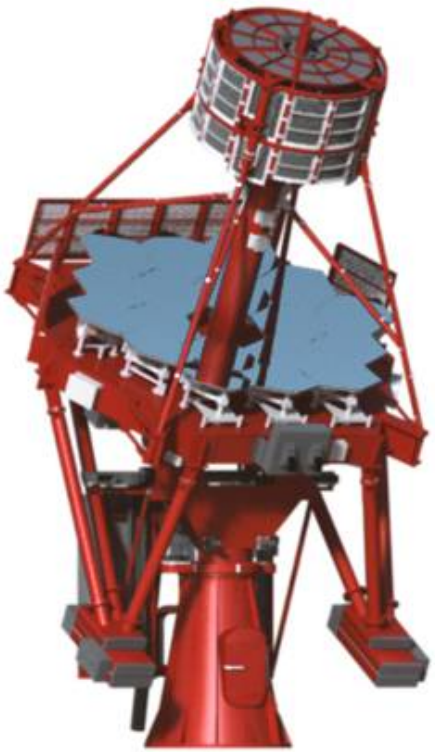
U. Syd
A. Green

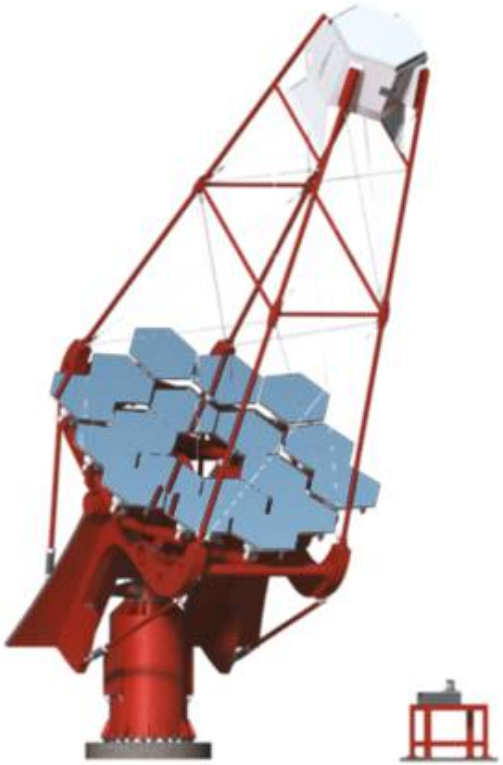
Funding
ARC LIEF 2015 + 2017-21
(hardware/commissioning/labour)

NCRIS/AAL (travel, meetings, CTAO membership)



Australia contributes funding to the “GCT” SST





GCT Prototype (Small Size Telescope) – Dec. 2015 Paris

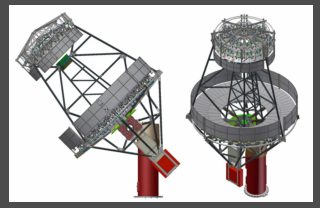
Australia - LIEF 2015 + 2017-21 support for GCT hardware and commissioning.

Other prototypes.....

MST (Berlin)

SST-2M ASTRI (Sicily)

SST-1M (Cracow)



SCT-MST (Arizona)

CTA sites selected 16 July 2015

Ground breaking Oct. 9, 2015

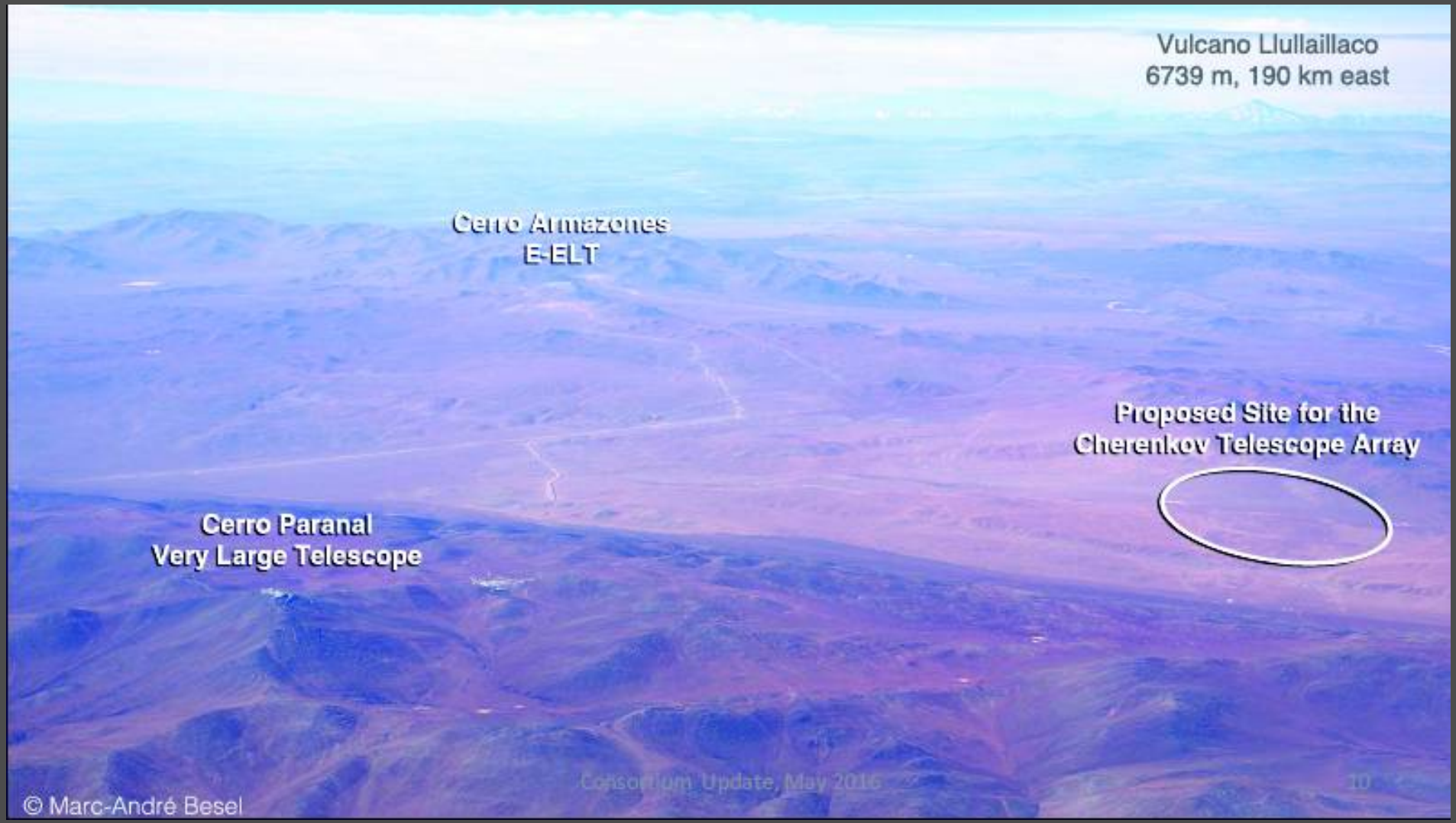
13 June 2016 - CTA HQ (Bologna)

- CTA Data Management Centre (DESY Berlin)

LST prototype status (La Palma)

cherenkov telescope array

CTA South : Paranal, Chile

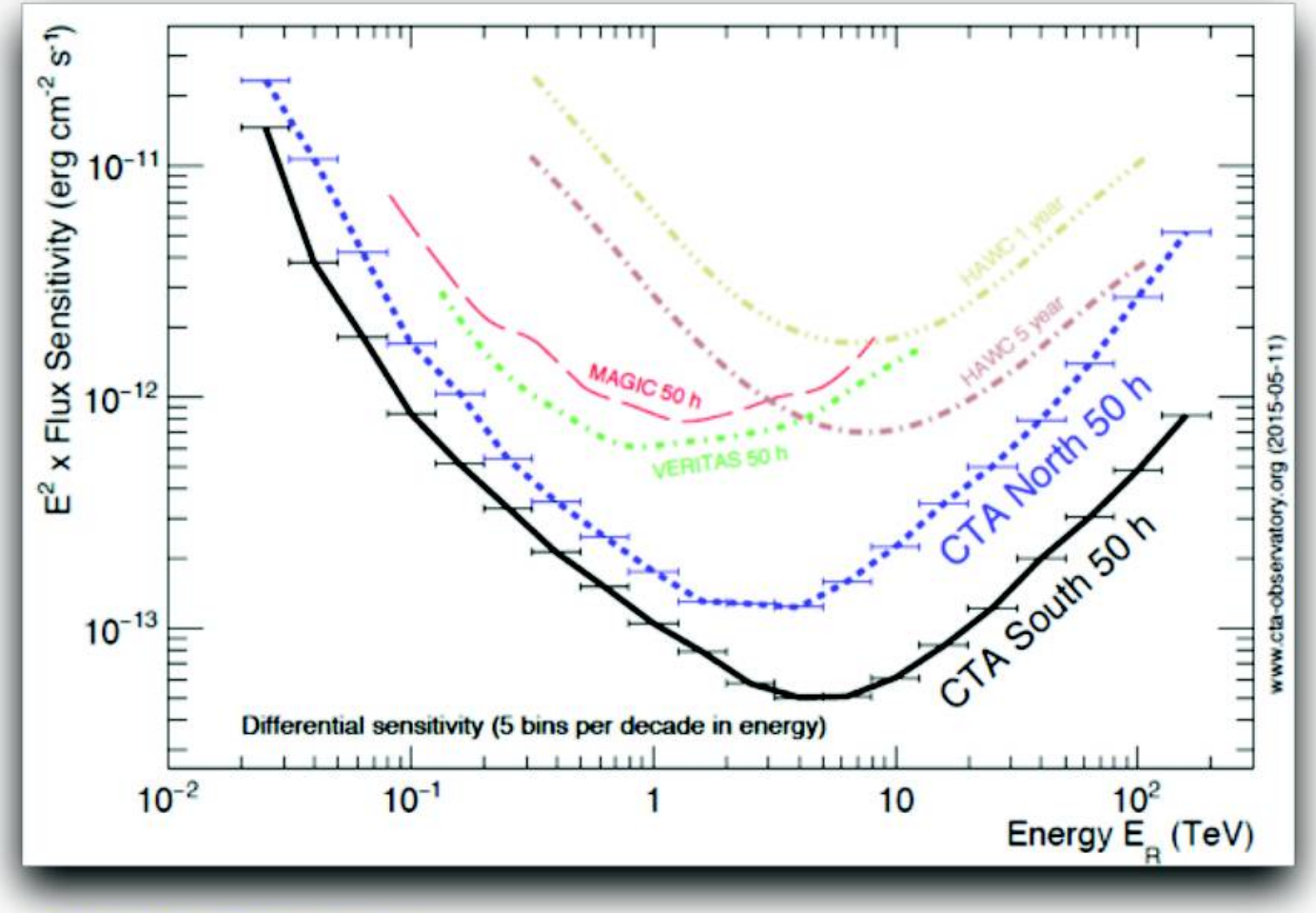


Access agreement with ESO – anticipating early 2017 signoff

CTA Performance

Energy coverage ~20 GeV to >200 TeV

Differential Sensitivity



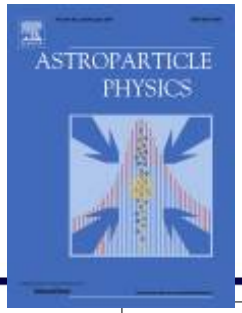
A factor of 5-10 improvement in sensitivity in the domain of about 100 GeV to some 10 TeV.

Extension of the accessible energy range from well below 100 GeV to above 100 TeV.

Credits: The CTA Consortium

CTA Science Case - on arXiv soon

KEY SCIENCE PROJECTS



Special Issue Vol 43, Pg 1-356 (Mar 2013)

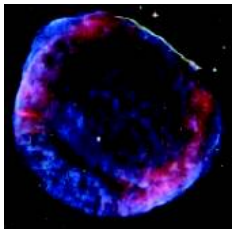
cta cherenkov telescope array

- Galactic Plane Survey
- Galactic Centre Survey
- Large Magellanic Cloud Survey
- Extragalactic Survey
- Transients
- Cosmic-Ray PeVatrons
- Star-Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies
- Dark Matter
- Non-Gamma-Ray Science

  intensity interferometry
  fast optical transients – milli-magnitude
  occultations (Kuiper belt population..)

Three Themes

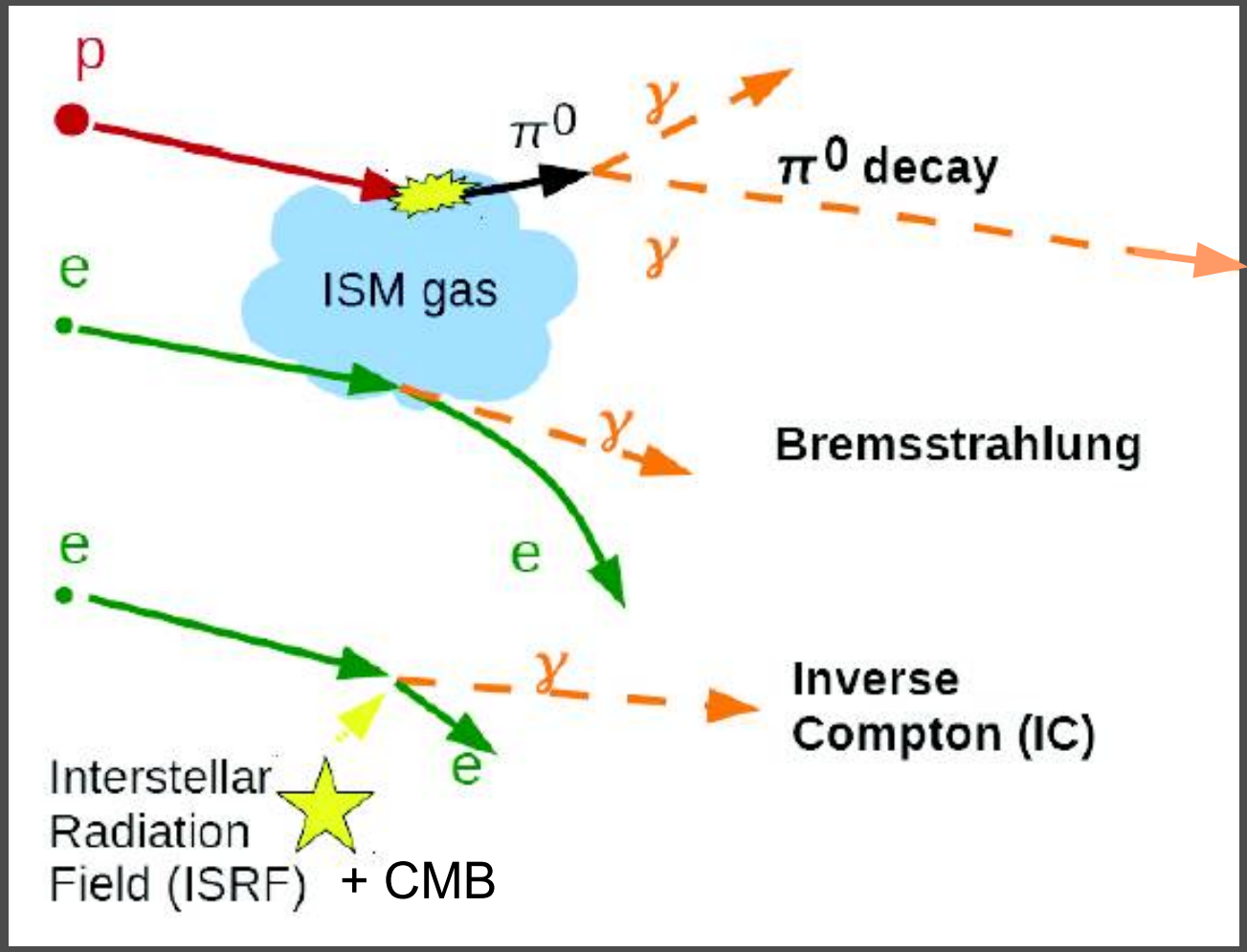
1. Cosmic Particle Acceleration



2. Probing Extreme Environments

3. Physics Frontiers: Beyond Standard Model

Gamma Rays from multi-TeV particles



Protons: Gamma-rays and gas targets are generally spatially correlated
(need to map atomic and molecular ISM → mm radio astronomy)

Electrons: Gamma-ray (IC) + non-thermal X-ray, radio emission (synchrotron)
highly coupled

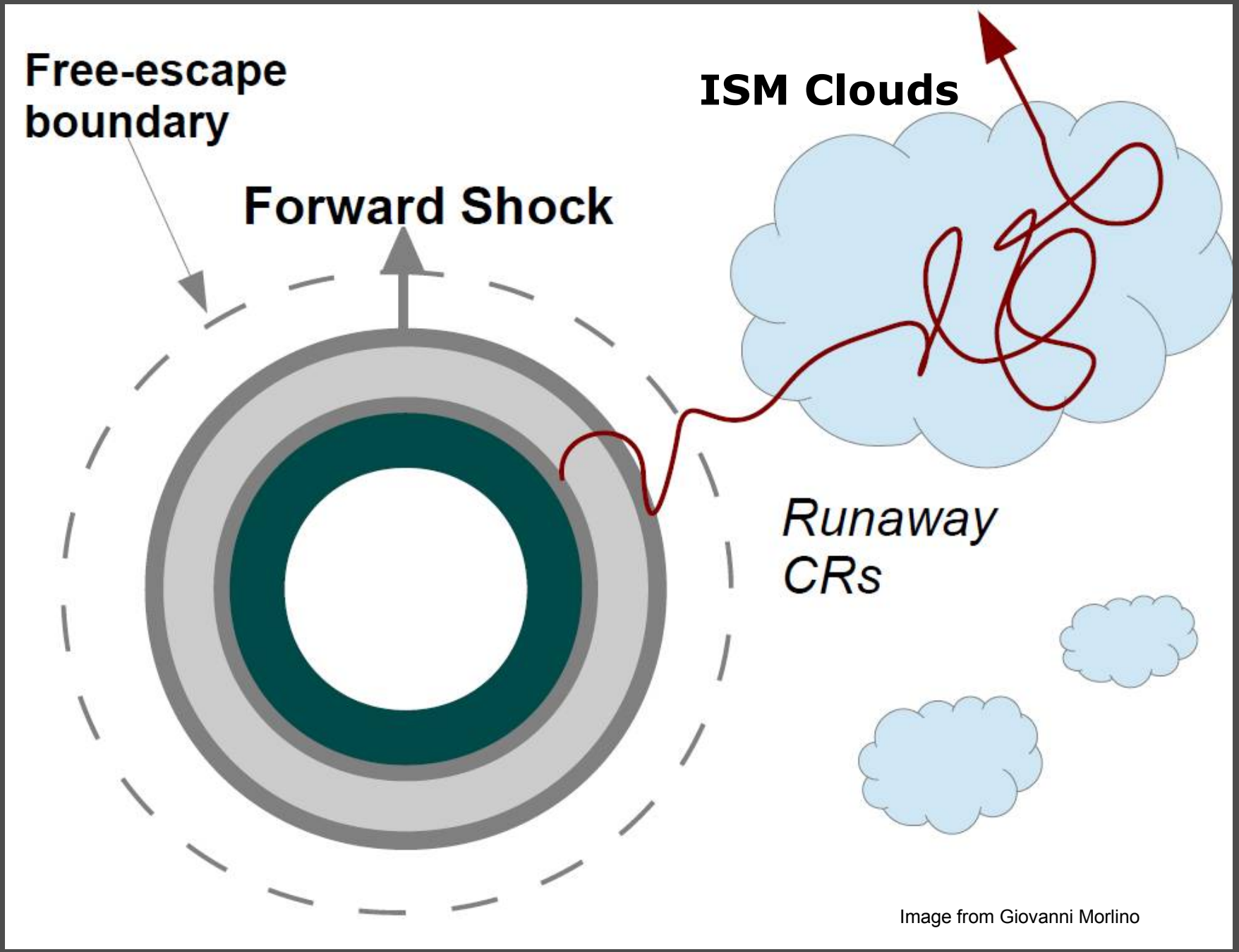
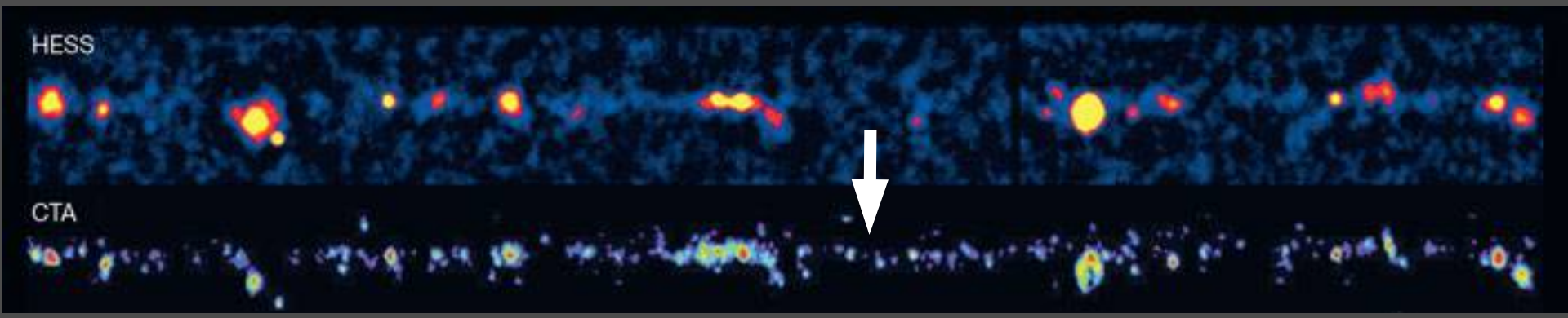


Image from Giovanni Morlino

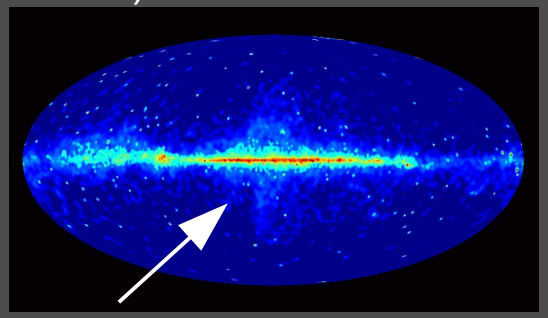
CTA Galactic Plane TeV Surveys : Major Issue



Funk et al 2012

- CTA will provide Galactic Plane TeV Gamma-ray maps
  at ~arc-min scales
  (sub-arc-min possible – with high quality cuts)

- >3 sources per deg^2 |b|<0.2° |l|<30° (Dubus etal 2013)



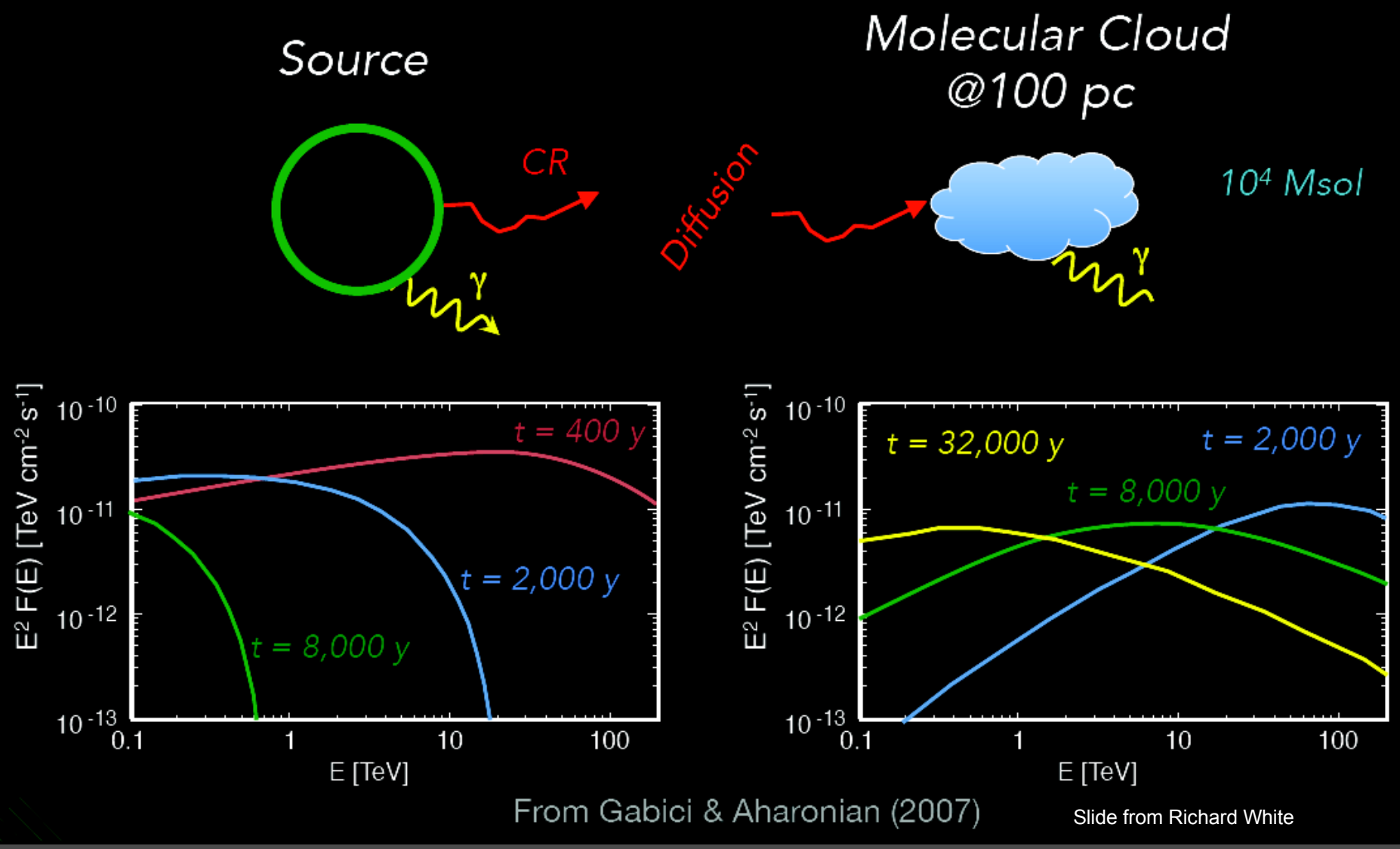
- Diffuse TeV components visible?
  from CR 'sea' – maybe
  local CR accelerator enhancements – yes

Confusion guaranteed (same as for Fermi-LAT at GeV energies!)

- Mapping the ISM on arc-min scales over the plane will be essential
Mopra (CO, CS), Nanten2 (CO), ASKAP (HI, OH), THz (CI, C+)

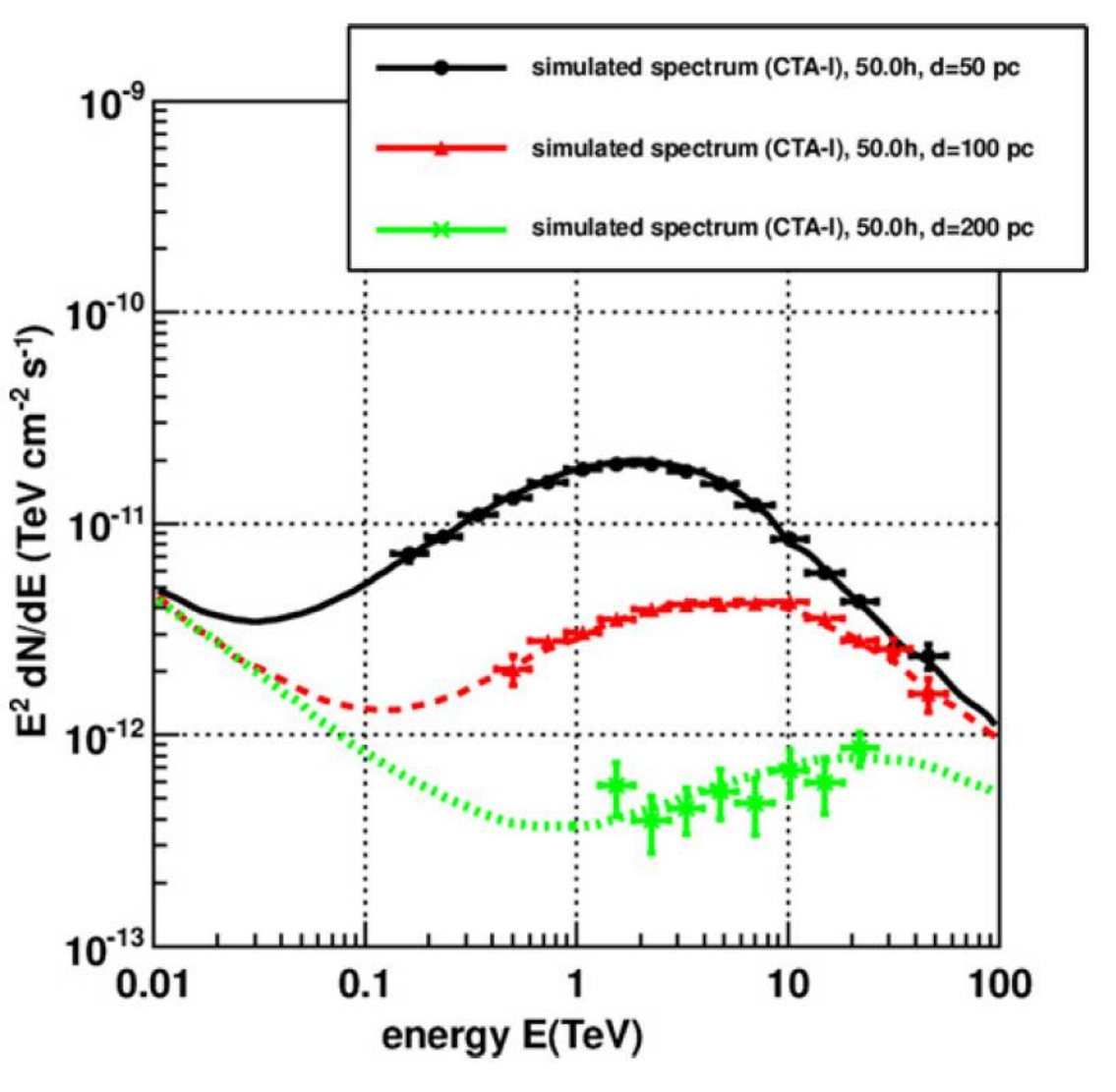
Gamma-ray spectra from local and escaped CRs

e.g. Aharonian & Atoyan 1996



Slide from Richard White

CTA 50h Observation - CRs escaping accelerators Acero etal 2013



SNR age 2000 yr

Cloud mass 10^5 M_{sun}

d = 1 kpc

$D=10^{28}(E/10GeV)^{0.5}$ cm^2/s

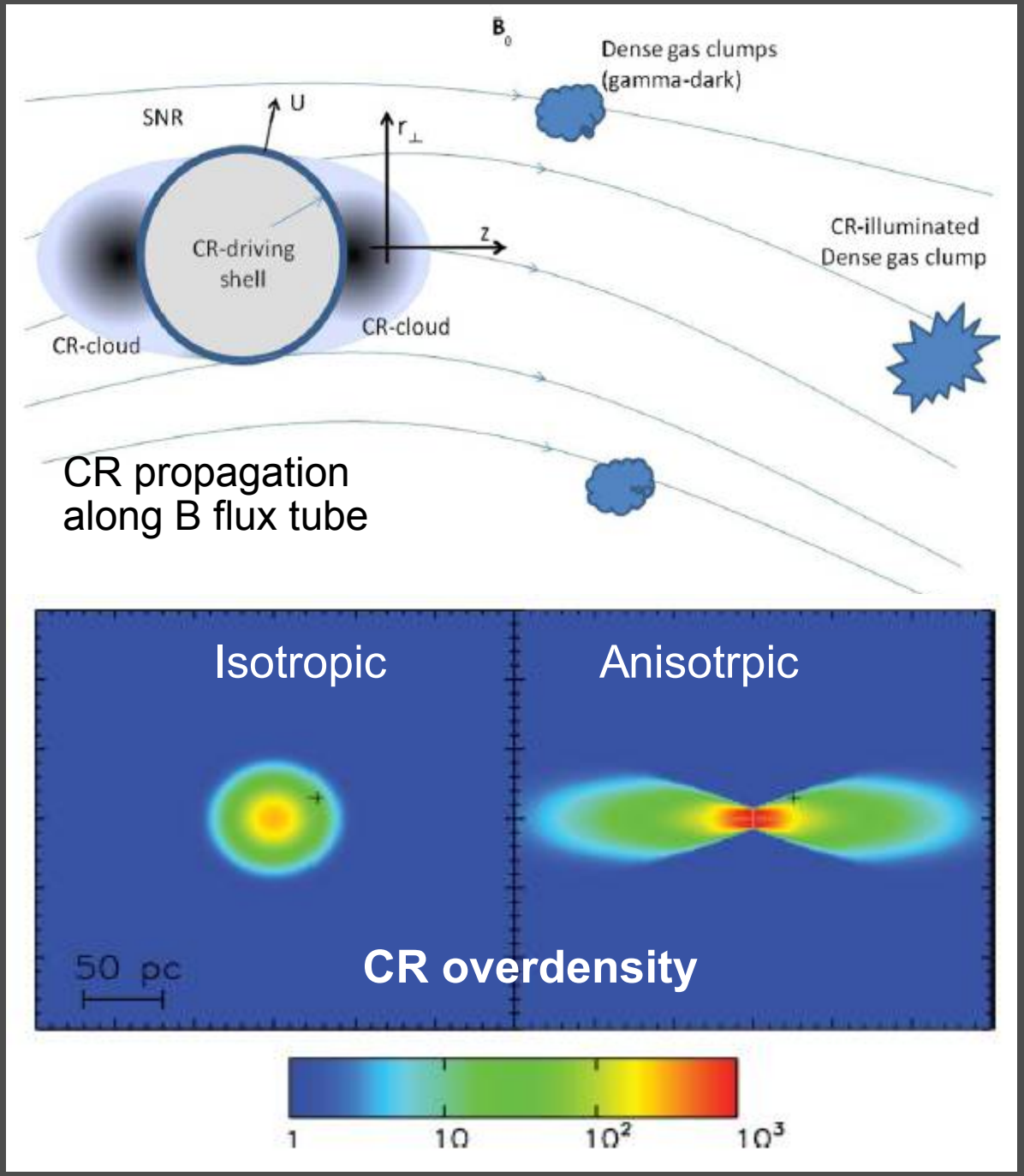
PeV CRs escape first and arrive at the cloud first!

Probe for CR PeVatrons

But confusion guaranteed in Gal. Plane!

Need wide ISM surveys → Mopra, Nanten2, Nobeyma, ASKAP

→ Many spectral shapes possible !



CR diffusion – not necessarily Isotropic!

Malkov etal 2013
Nava & Gabici 2013

→ Nearby clouds will see different CR densities

→ Need detailed maps of ISM gas + B-field direction

B-field Faraday RM
Jansson & Farar et al 2012

→ **ASKAP POSSUM!**

CR Diffusion *Into* Molecular Clouds

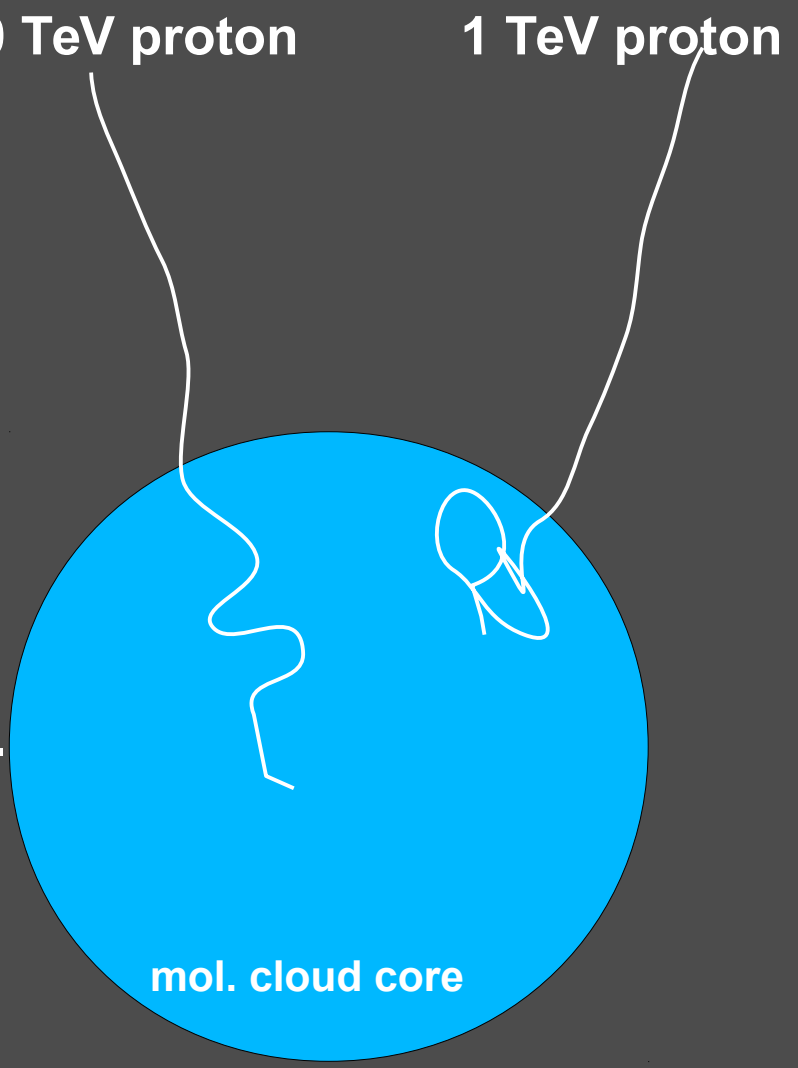
e.g. Gabici etal 2007, Inoue etal 2012

R = distance CR travels into molecular cloud core

R ~ sqrt[6 D(E_p, B) t]

$$D(E_P, B(r)) = \chi D_0 \left(\frac{E_P/\mathrm{GeV}}{B/3\,\mu\mathrm{G}} \right)^{0.5} \quad [\mathrm{cm}^2\,\mathrm{s}^{-1}],$$

$$B \sim 10(n/300\mathrm{cm}^{-3})^{0.65}\mu\mathrm{G}$$ Crutcher 2010



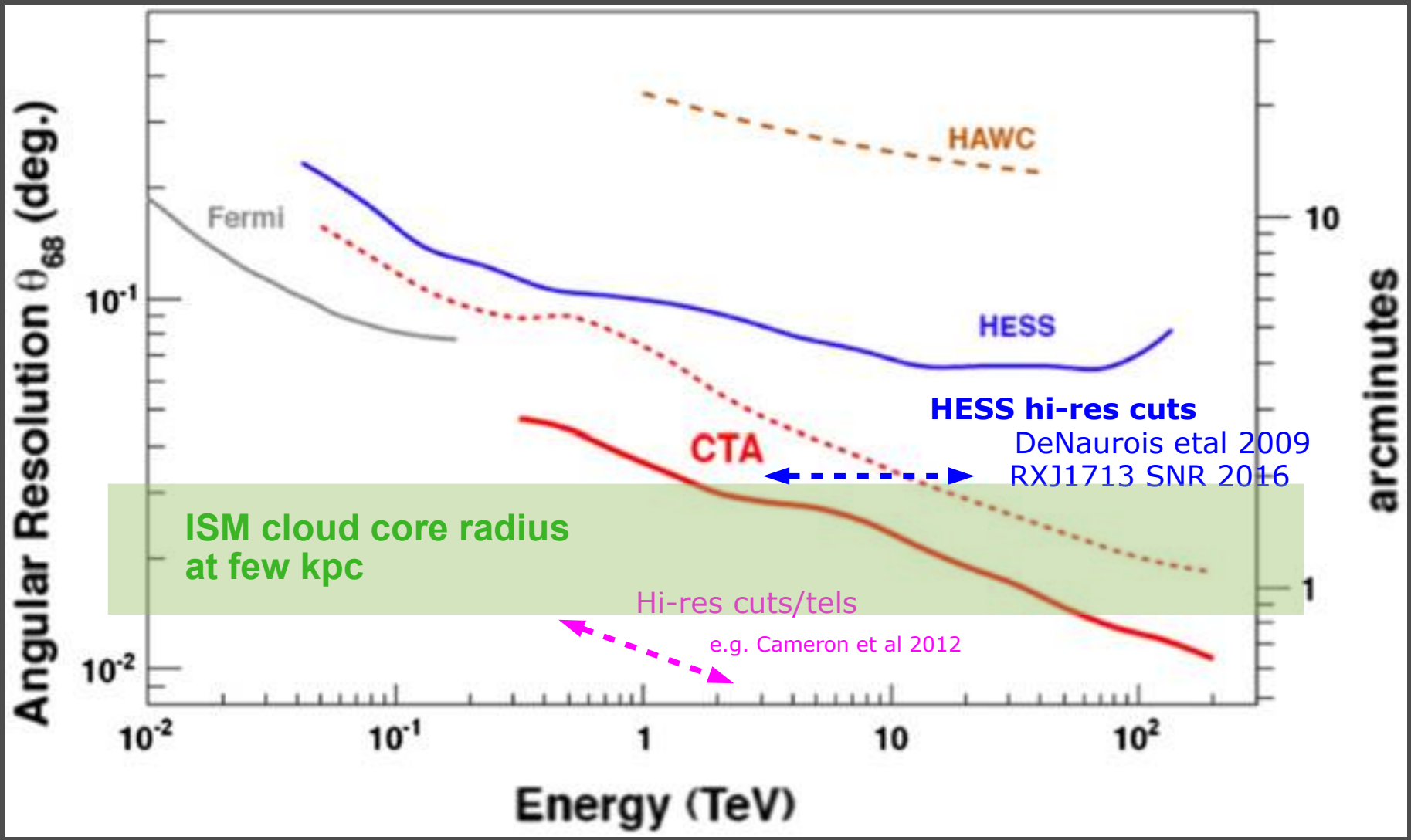
χ=diffusion suppression factor

→ Low energy CRs can't reach cloud core.
→ Harder TeV spectra from cores.
→ Depends on B-turbulence
(e.g. Morlino & Gabici 2015)
→ *Don't expect electrons to penetrate!!*
(due to sync. losses)

→ Need to map dense cloud cores ~1 arcmin or better

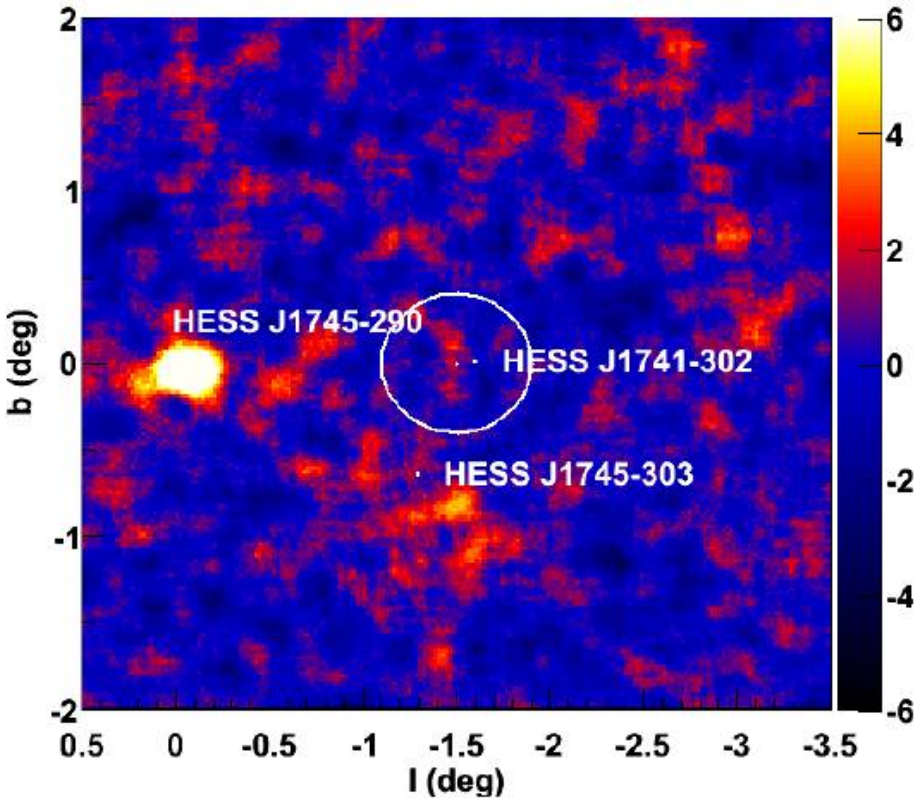
Angular Resolution 68% PSF (HESS, CTA..)

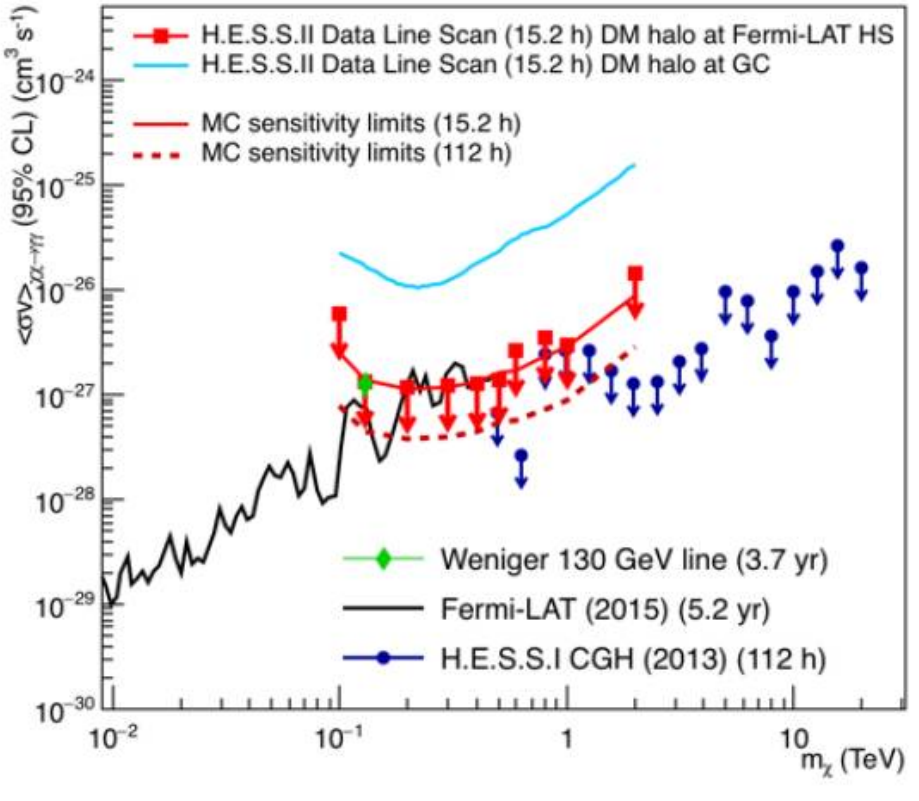
Acharyara etal 2013



130 GeV Dark Matter Line at Fermi-LAT Hotspot?

(Weniger 2012) Unfortunately No.

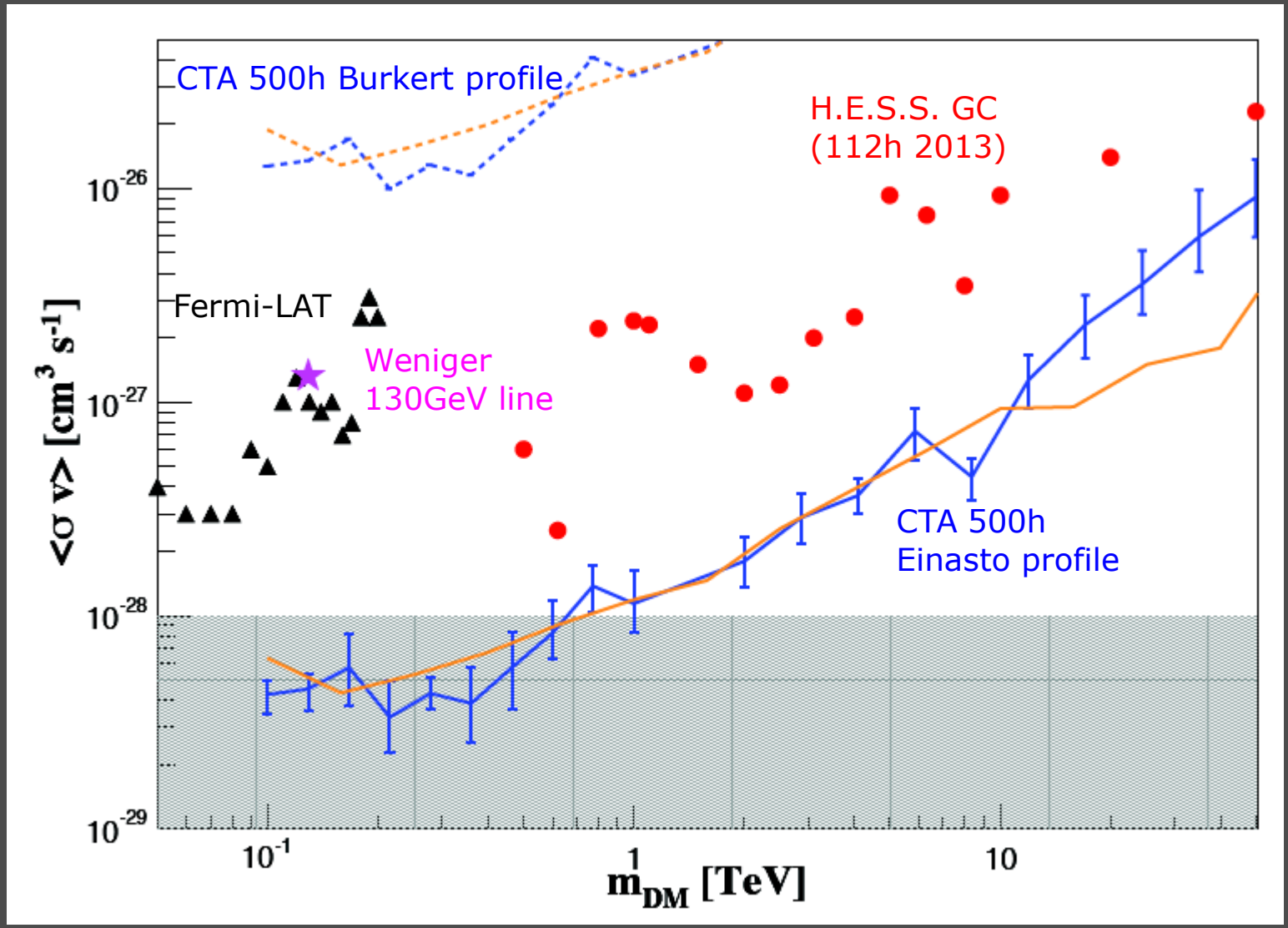




H.E.S.S.

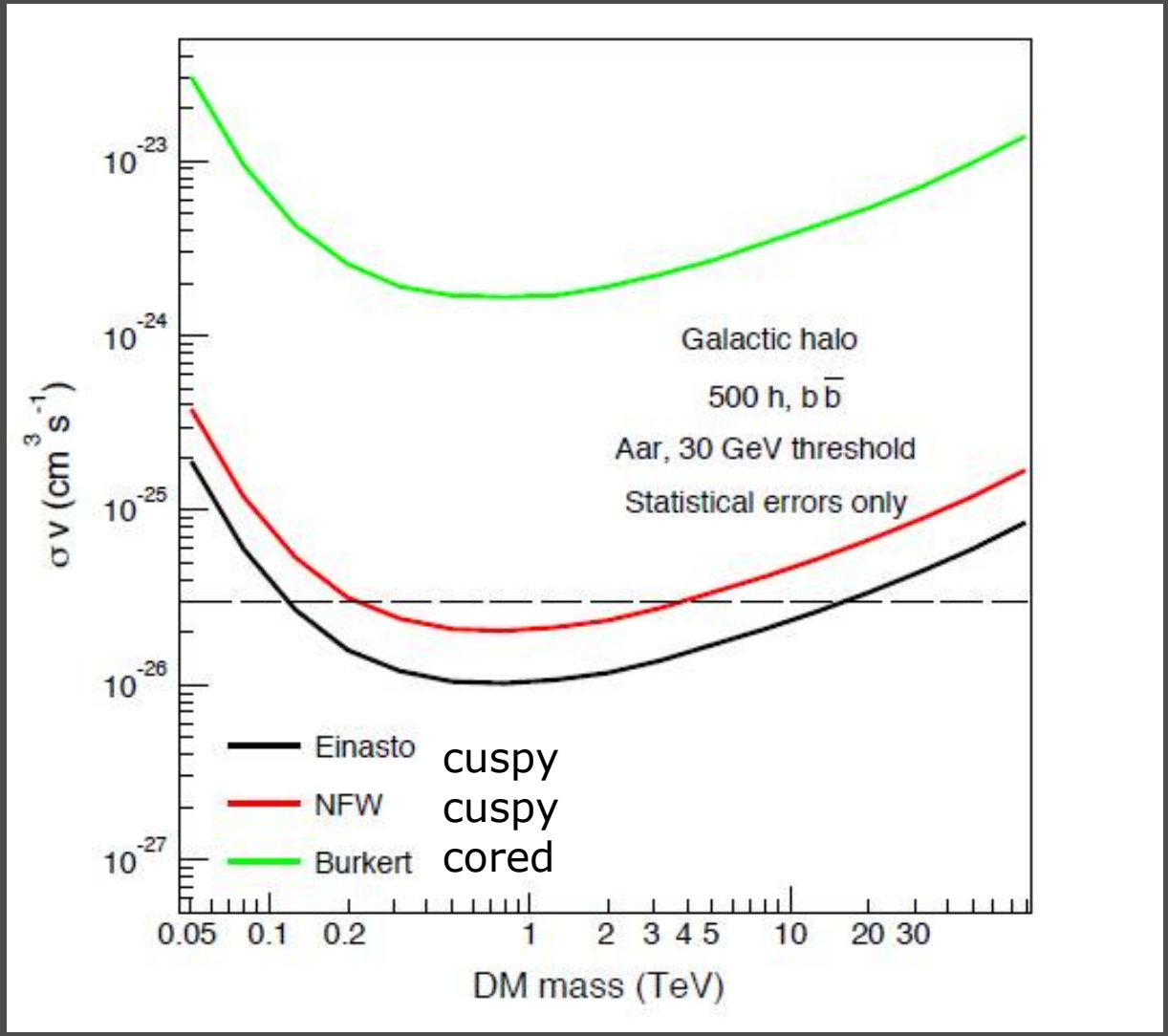
H.E.S.S. Collab Rhys Rev. Lett 2016

CTA Dark Matter Line Gal.Cen. (r<1°) 500hr $\chi\chi \rightarrow \gamma\gamma$



CTA Consortium - Science Case (in prep)

CTA Dark Matter continuum Gal.Cen. (r<1°)
500hr $\chi\chi \rightarrow b\bar{b}$



CTA Consortium - Science Case (in prep)

Summary

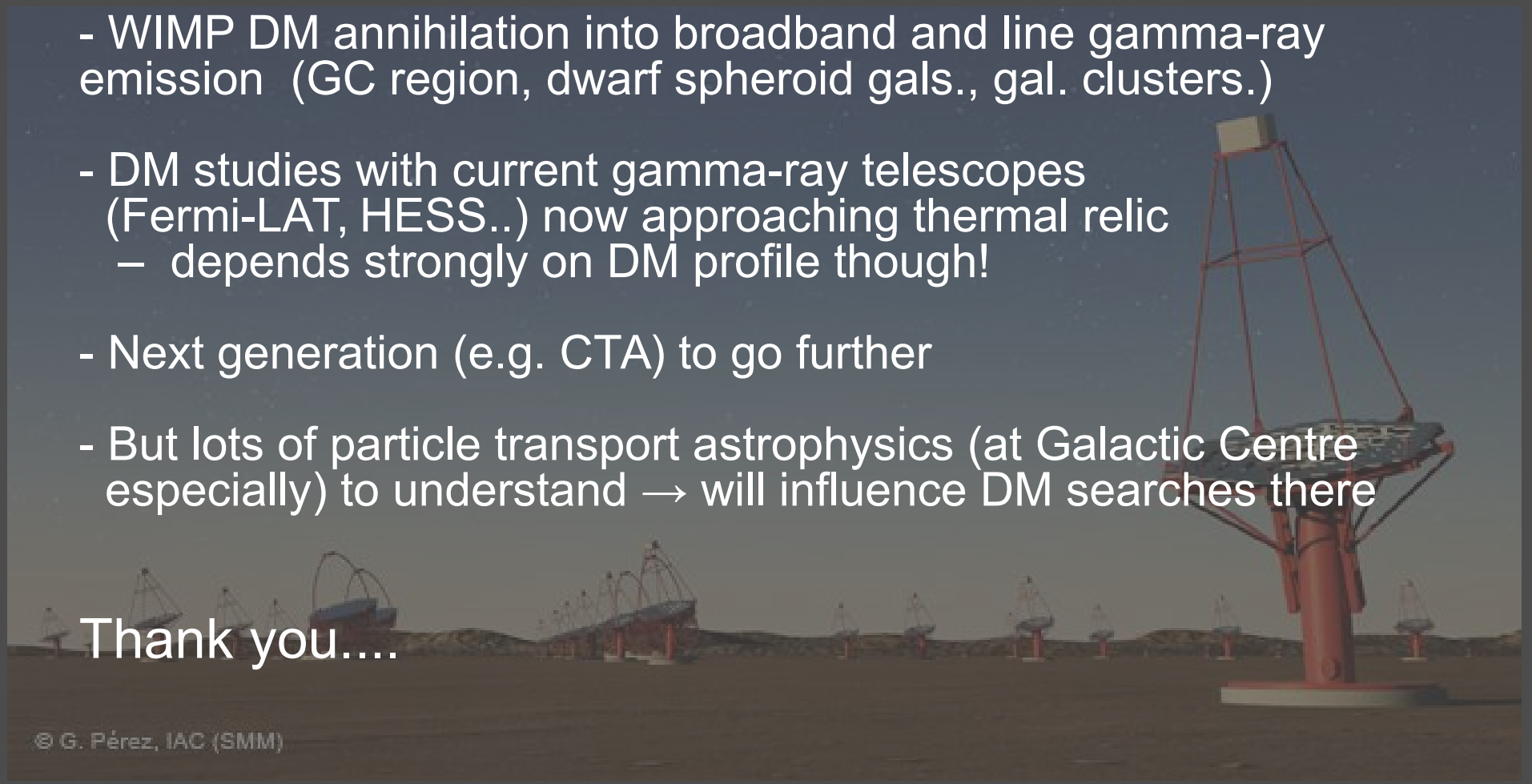
- WIMP DM annihilation into broadband and line gamma-ray emission (GC region, dwarf spheroid gals., gal. clusters.)

- DM studies with current gamma-ray telescopes (Fermi-LAT, HESS..) now approaching thermal relic
  – depends strongly on DM profile though!

- Next generation (e.g. CTA) to go further

- But lots of particle transport astrophysics (at Galactic Centre especially) to understand → will influence DM searches there

Thank you....



TeV (10^{12} eV) Gamma-Ray detection:

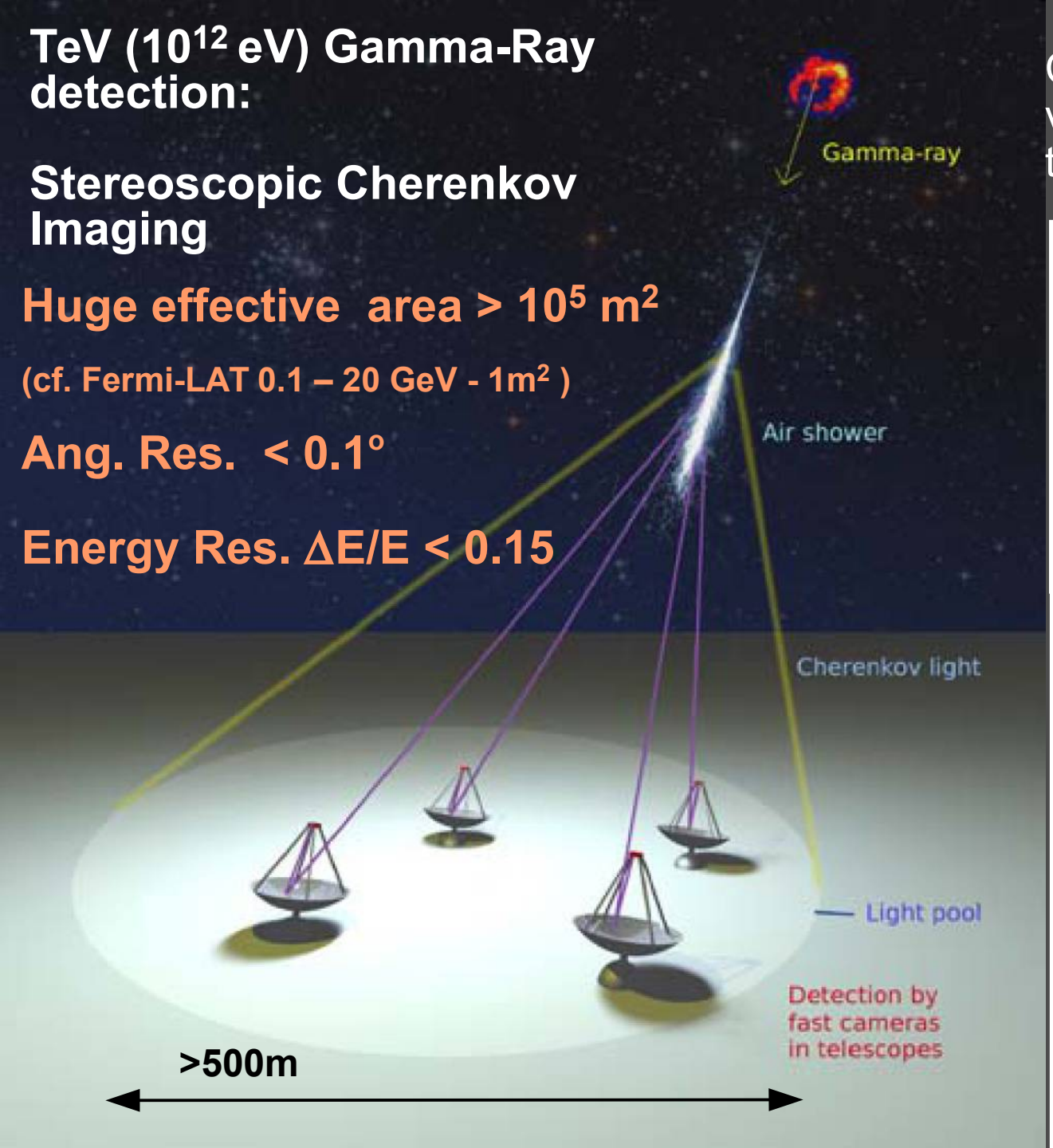
Stereoscopic Cherenkov Imaging

Huge effective area > 10^5 m^2

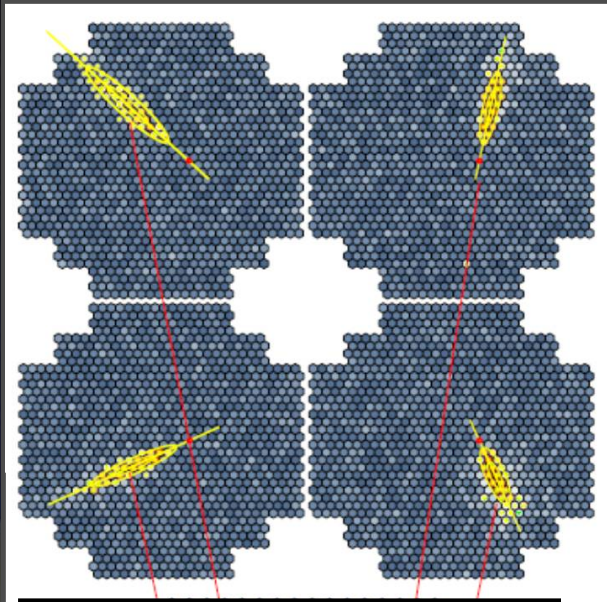
(cf. Fermi-LAT 0.1 – 20 GeV - 1m^2)

Ang. Res. < 0.1°

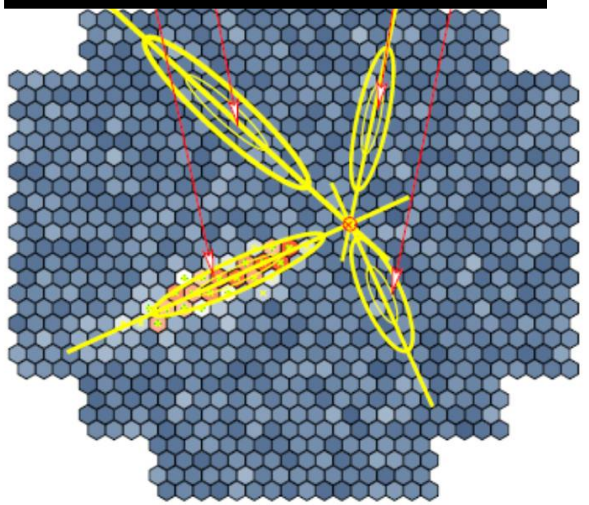
Energy Res. ΔE/E < 0.15



Cherenkov 'image' as viewed by each telescope

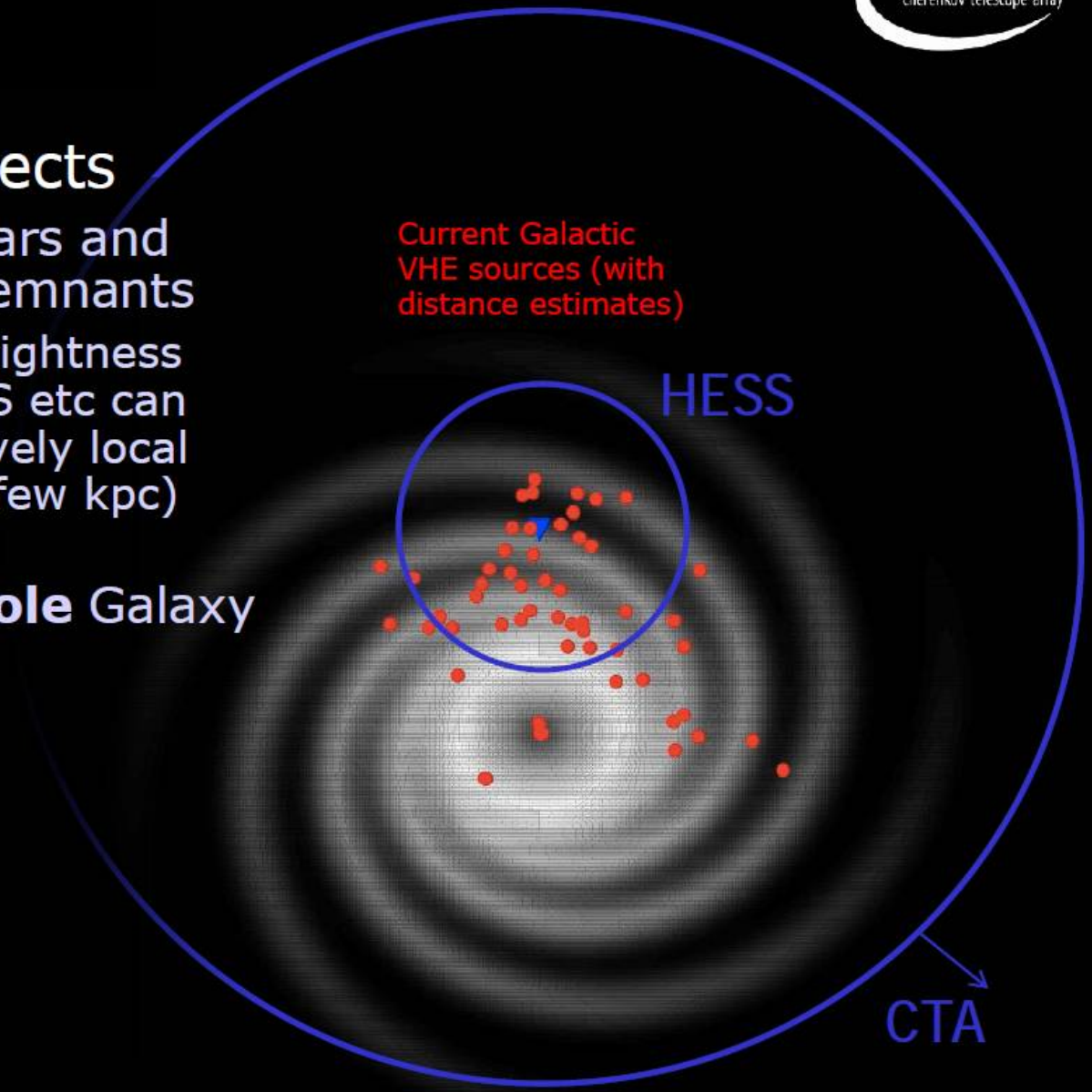


Combination:



CTA Galactic Science

- e.g. 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
- Survey speed ~300×HESS

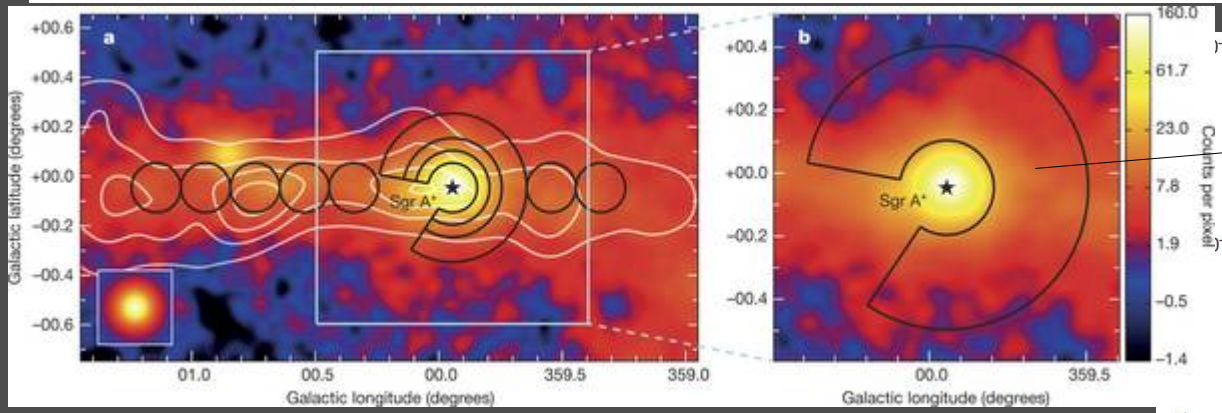


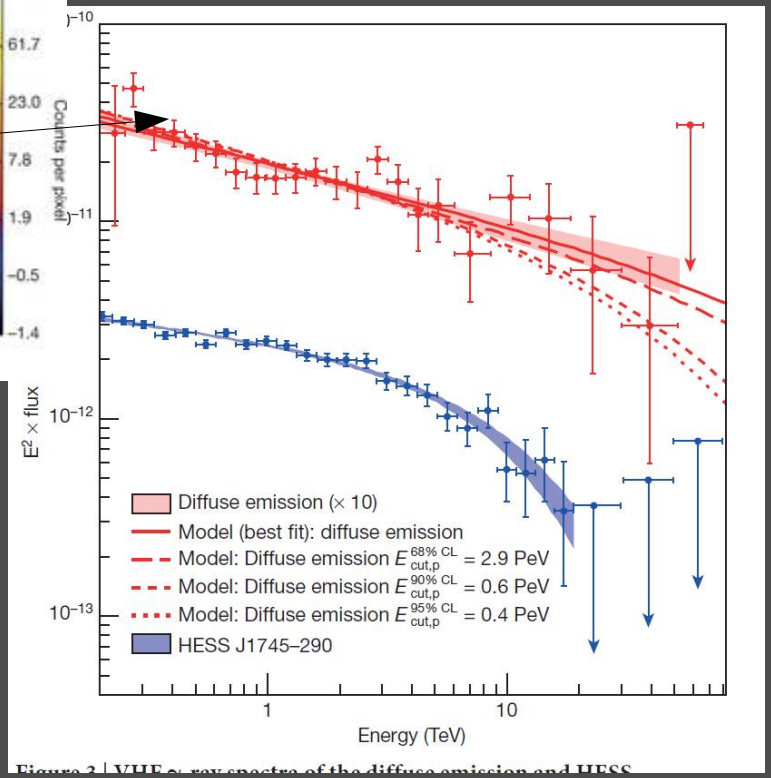
LETTER

doi:10.1038/nature17147

Acceleration of petaelectronvolt protons in the Galactic Centre

HESS Collaboration*





- Hard spectrum from diffuse region 70pc
- Cutoff ~ PeV energies
- Continous CR injector over ~few1000yr

→ Central BH most likely accelerator

→ Could explain galactic CRs >0.1 PeV if BH more active in past.

(SNRs may still contribute some PeV CRs)