The Cherenkov Telescope Array : A TeV Gamma-Ray Observatory

Miroslav Filipovic Western Sydney University (for CTA)

cta
cherenkov telescope array

EWASS (Prague) June 2017

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

© G. Pérez, IAC (SMM)

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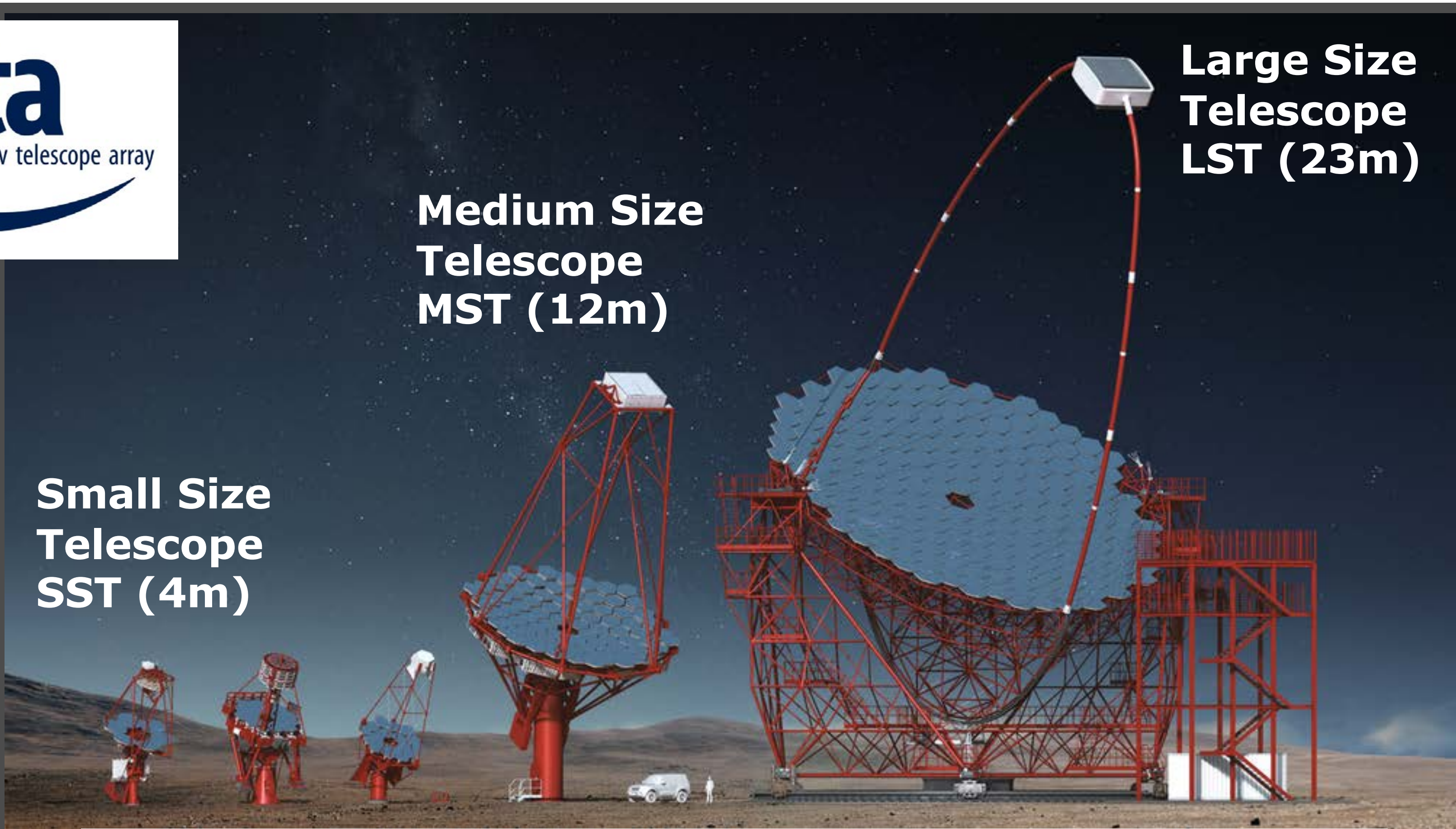
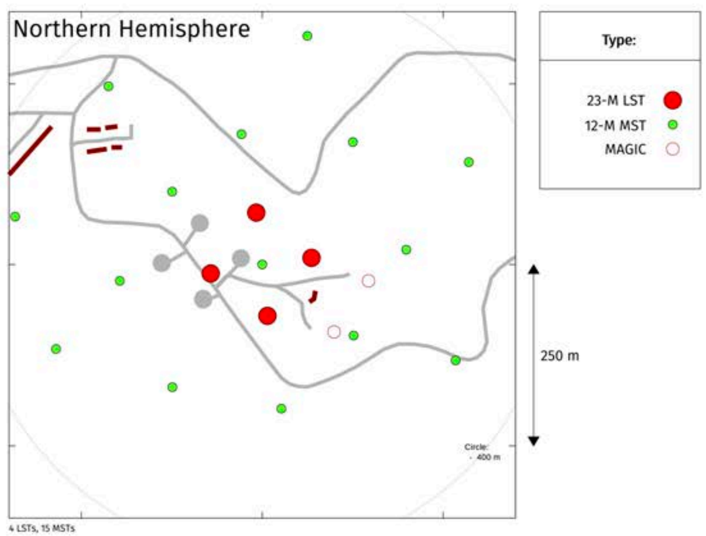
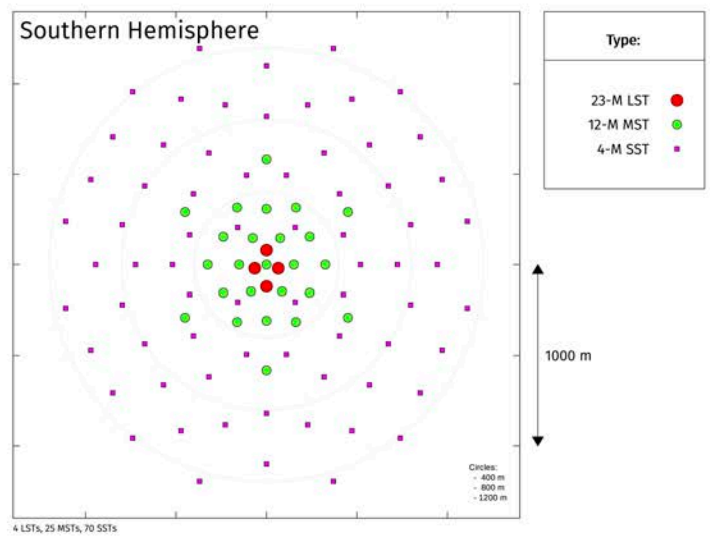
cherenkov telescope array

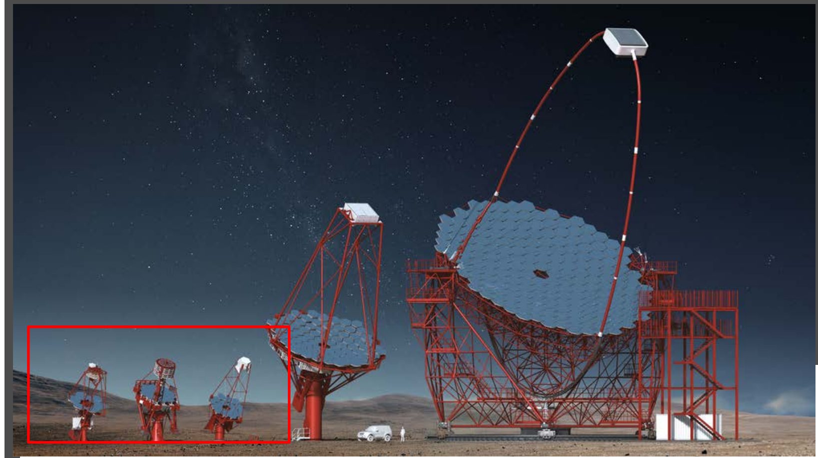


North
29 tels

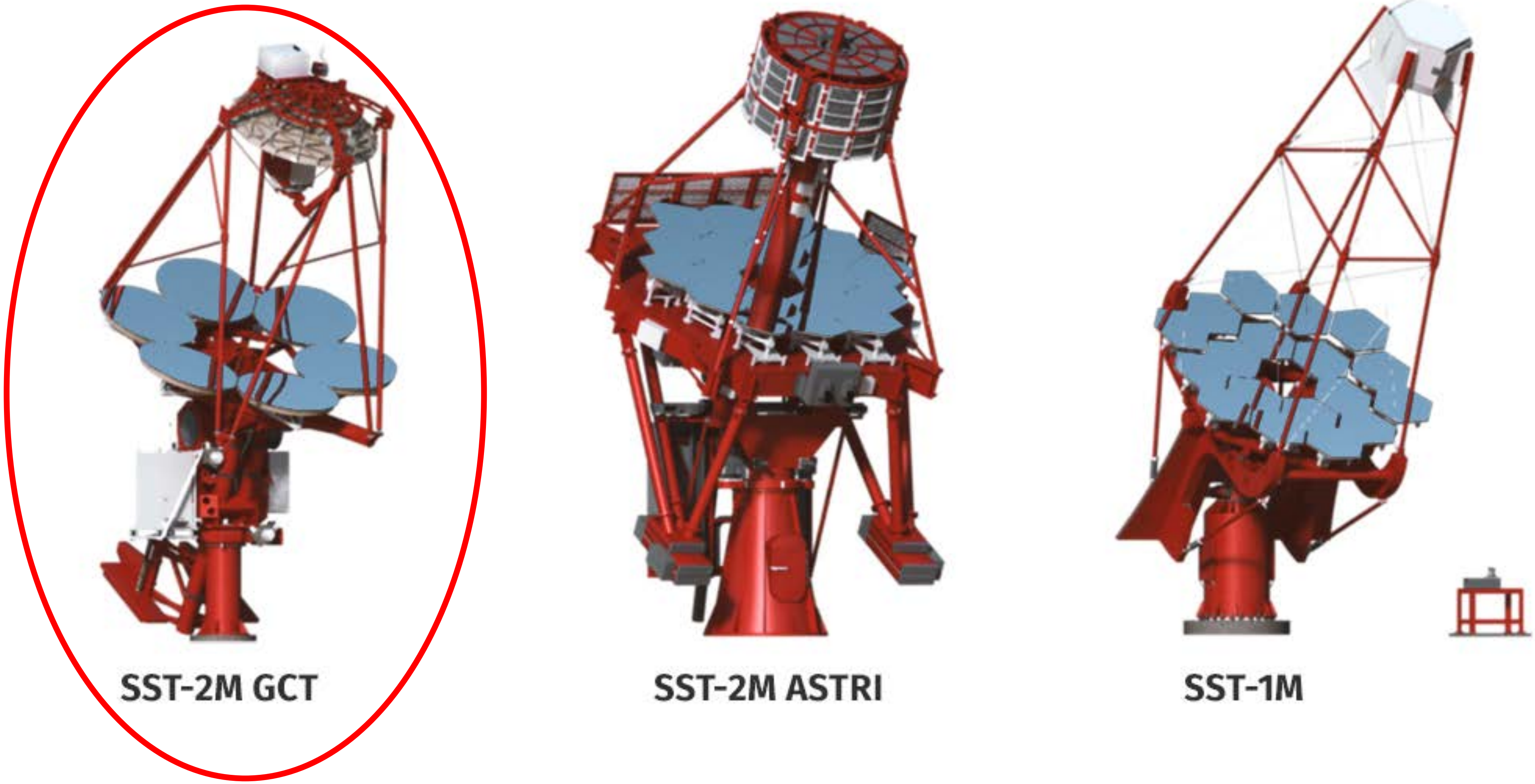




South
99 tels



Australia contributes funding to the “GCT” SST



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

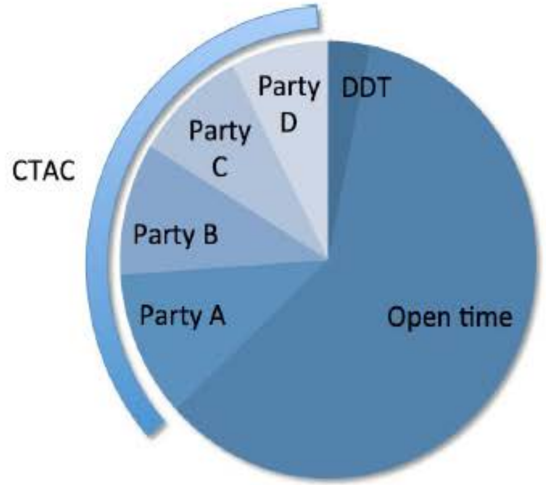
Monash
C. Balazs, D. Galloway

U. Syd
A. Green

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

NCRIS/AAL (travel, meetings, CTAO membership)

CTA observing time



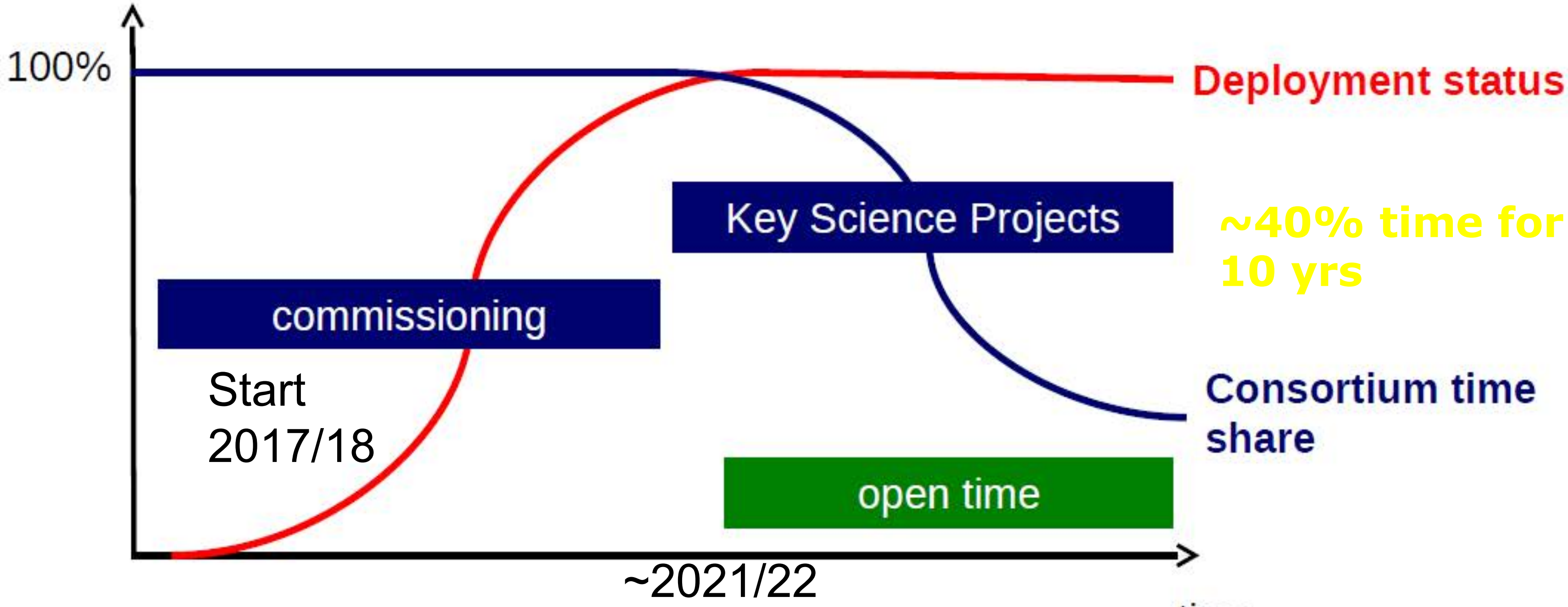
Current model

Contributing parties pool their time:

- Open time (accessible to scientists in contributing countries)
- CTA Consortium time (legacy Key Science Projects)
- Director's Discretionary Time

All data will become public to worldwide community after some proprietary period

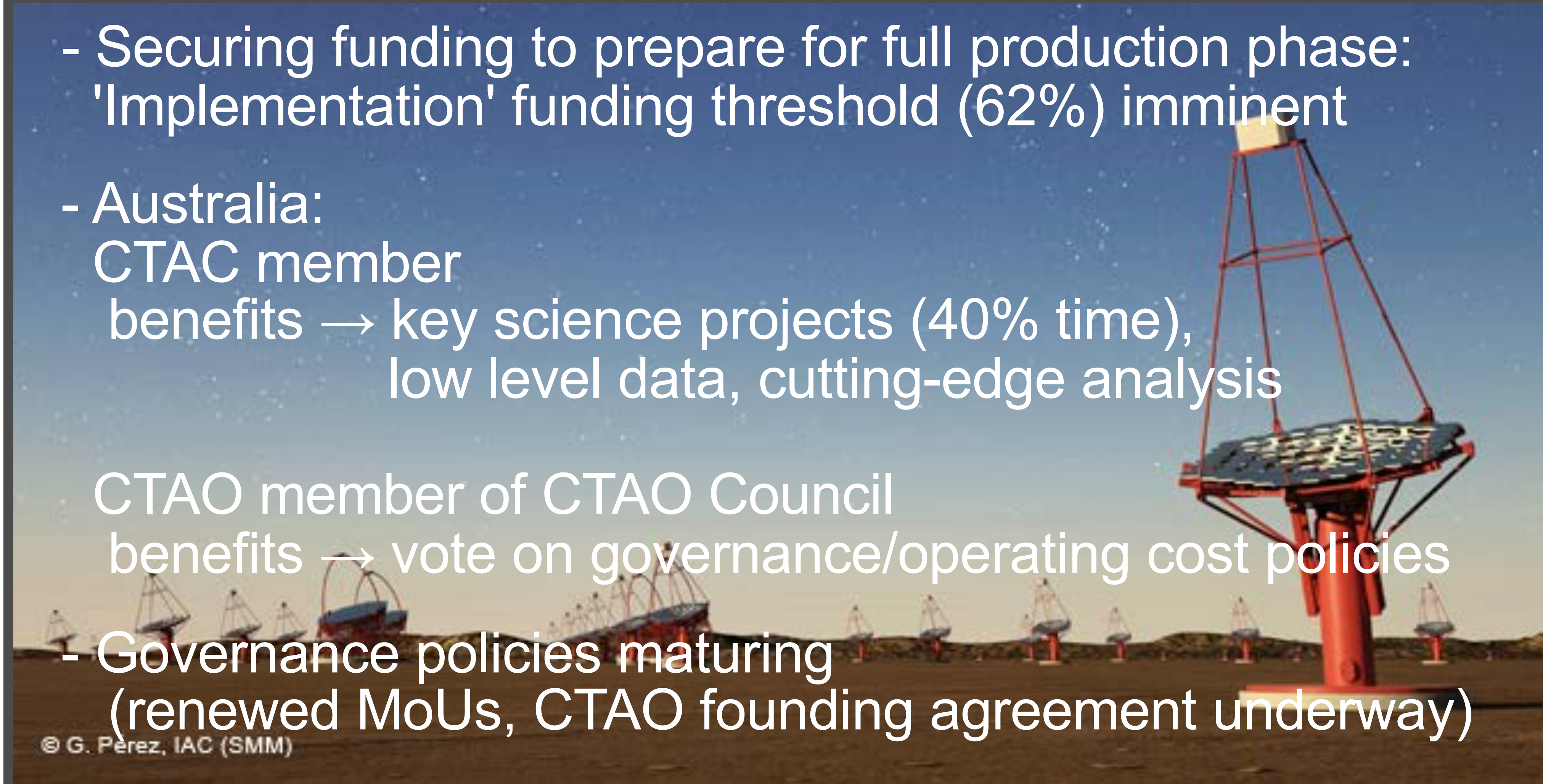
(cf. C. Boisson)



Controlled by the **CTA Observatory (CTAO)**

Status (Nov. 2016) – Bologna meeting Oct

- Pre-production phase: towards 1st telescopes on site(s)



- Securing funding to prepare for full production phase:
  'Implementation' funding threshold (62%) imminent

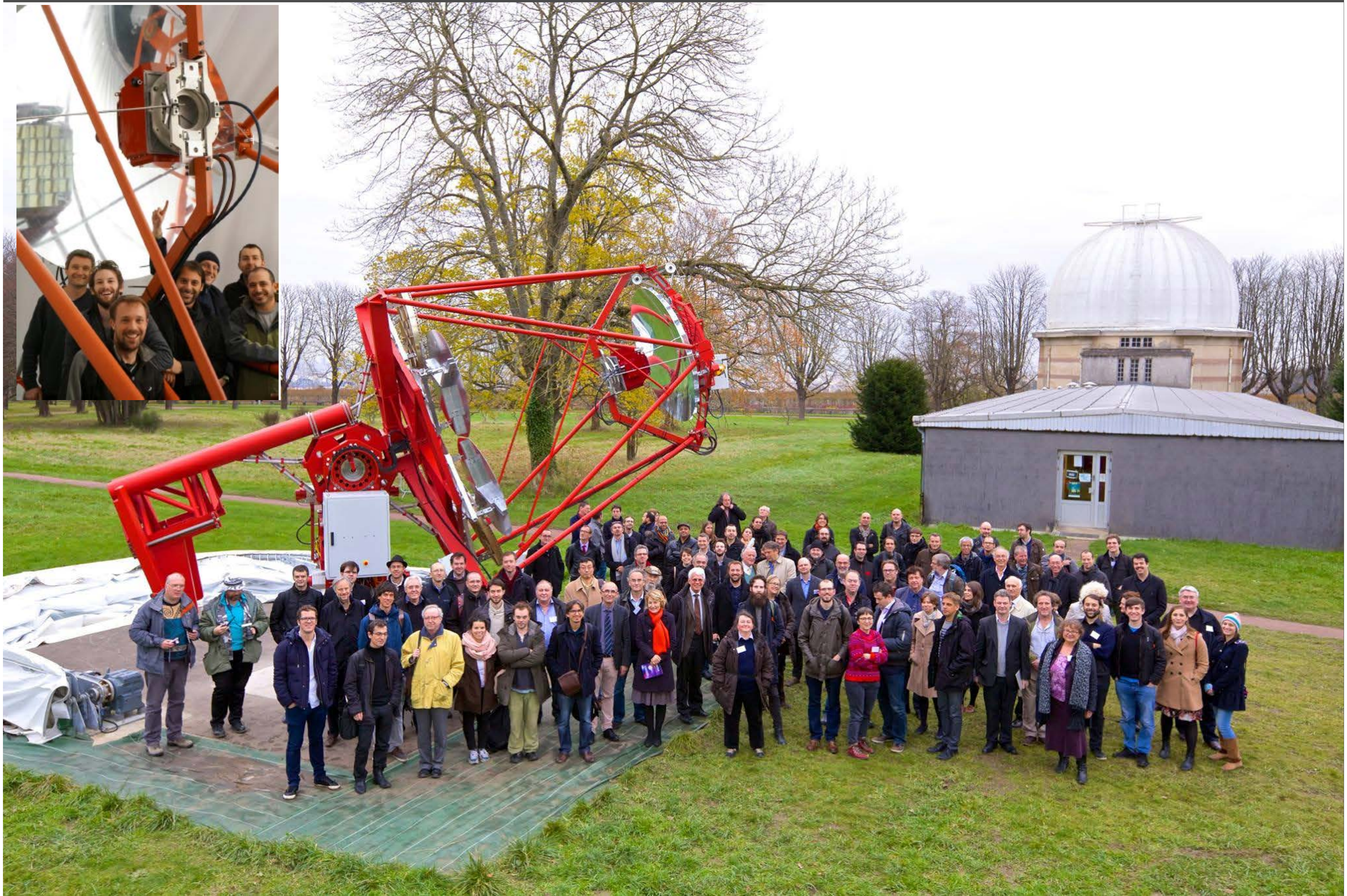
- Australia:
  CTAC member
  benefits → key science projects (40% time),
  low level data, cutting-edge analysis

  CTAO member of CTAO Council
  benefits → vote on governance/operating cost policies

- Governance policies maturing
  (renewed MoUs, CTAO founding agreement underway)

- Strong and growing links with Australian astronomy
  → multi-messenger astronomy

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

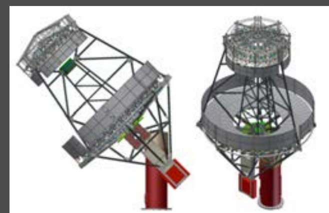


Australia - LIEF 2015 + 2017-21 support for GCT hardware and commissioning.

Other prototypes.....

MST (Berlin)

SST-2M ASTRI (Sicily)



SST-1M (Cracow)

CTA sites selected 16 July 2015

Ground breaking Oct. 9, 2015

13 June 2016 - CTA HQ (Bologna)

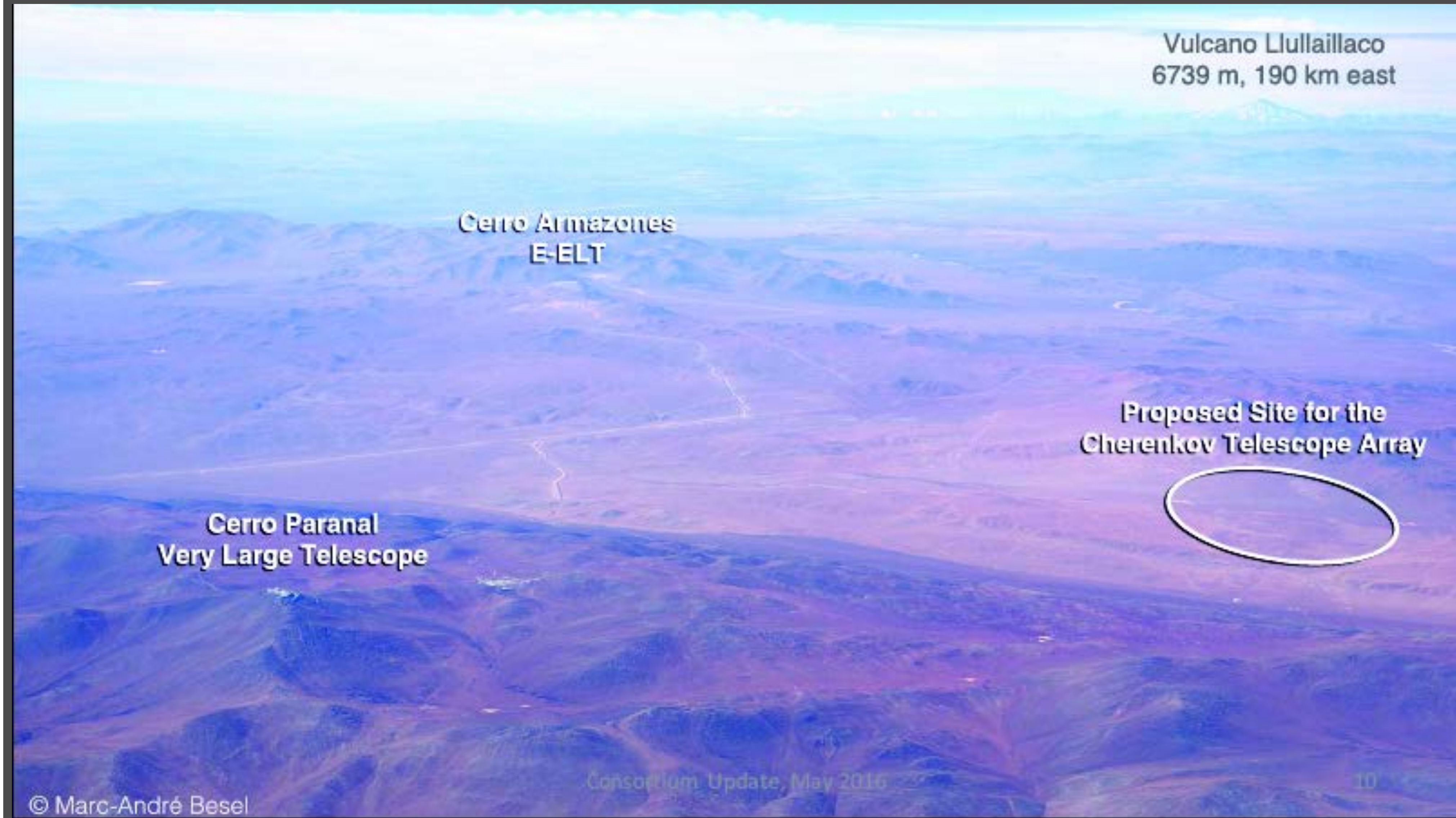
- CTA Data Management Centre (DESY Berlin)

LST prototype status (La Palma)

cherenkov telescope array

D. Mazin

CTA South : Paranal, Chile



Negotiations with ESO ongoing: Infrastructure sharing/piggyback

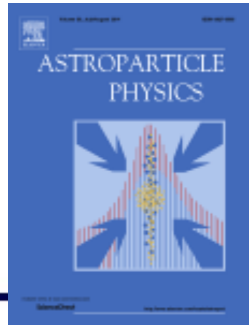
13 June 2016

CTA Headquarters
Bologna
Part of new Bologna University/INAF building

Data Management Centre
DESY Zeuthen Campus
New building

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

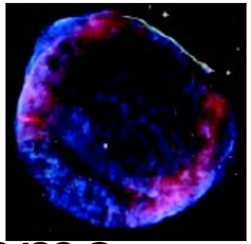
  intensity interferometry

  fast optical transients – milli-magnitude

  occultations (Kuiper belt population..)

Three Themes

1. Cosmic Particle Acceleration

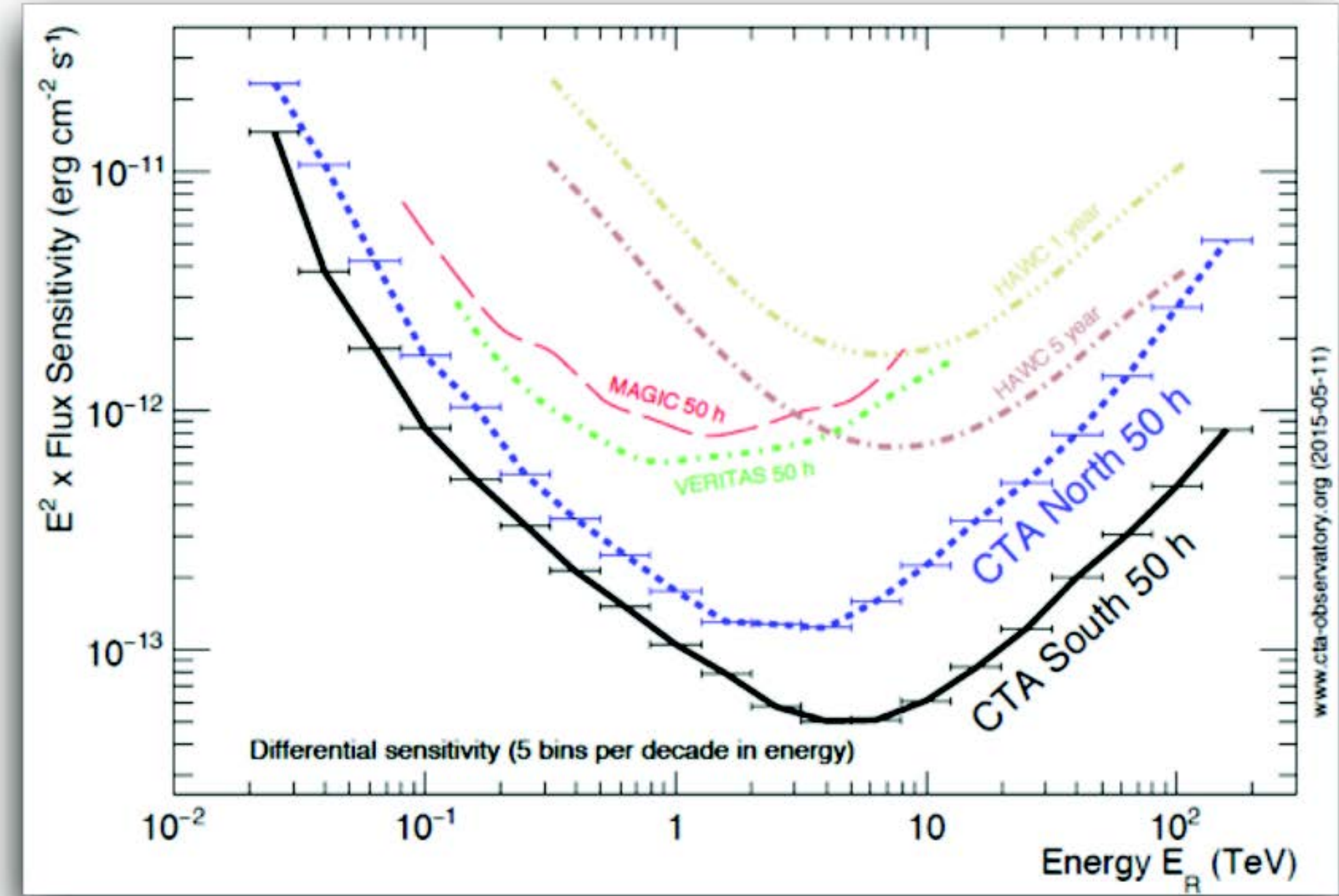


2. Probing Extreme Environments

3. Phys s: Beyond Standard Model

CTA Performance
Energy coverage ~20 GeV to >200 TeV

Differential Sensitivity

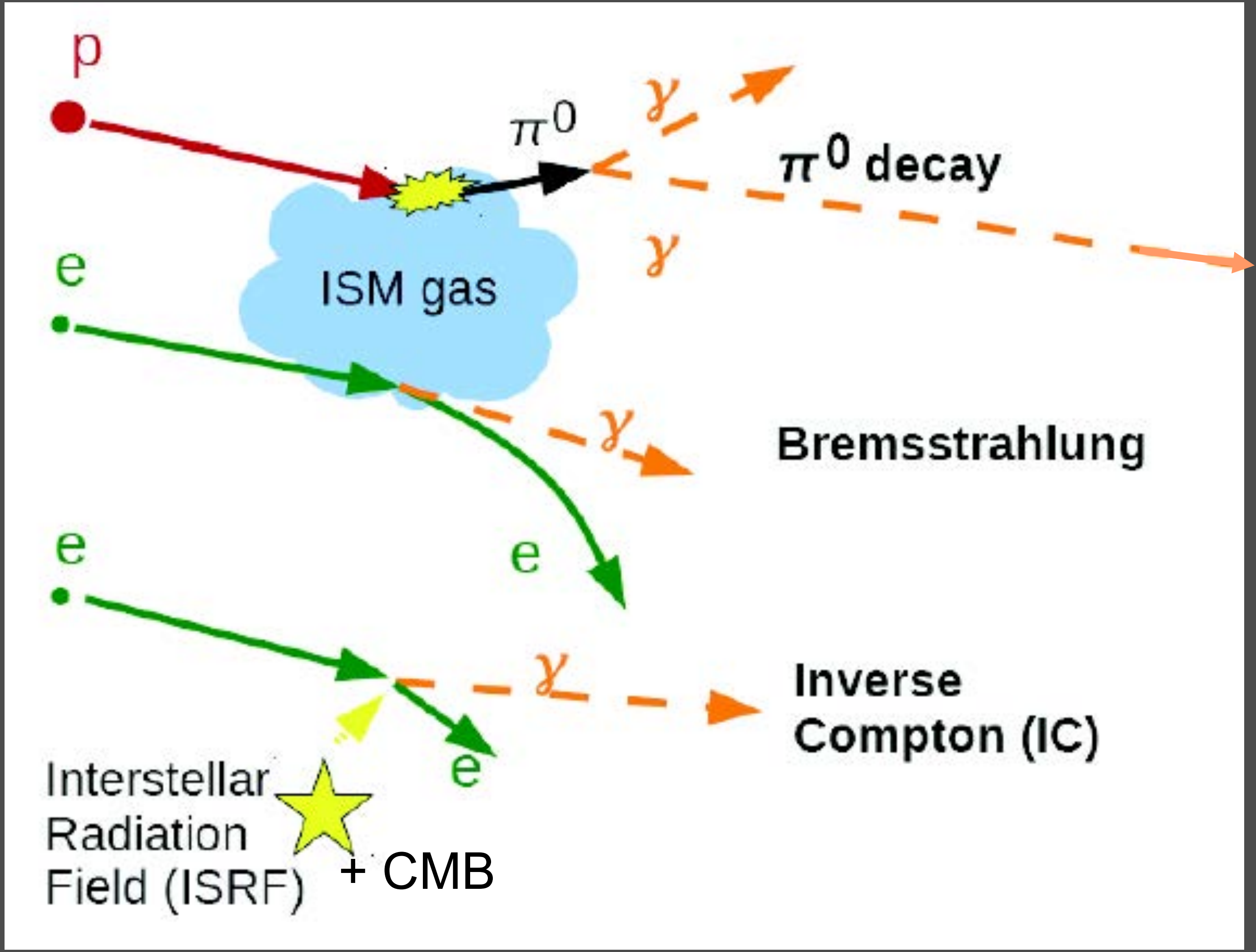


A factor of 5-10 improvement in sensitivity in the domain of about 100 GeV to some 10 TeV.

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

Credits: The CTA Consortium

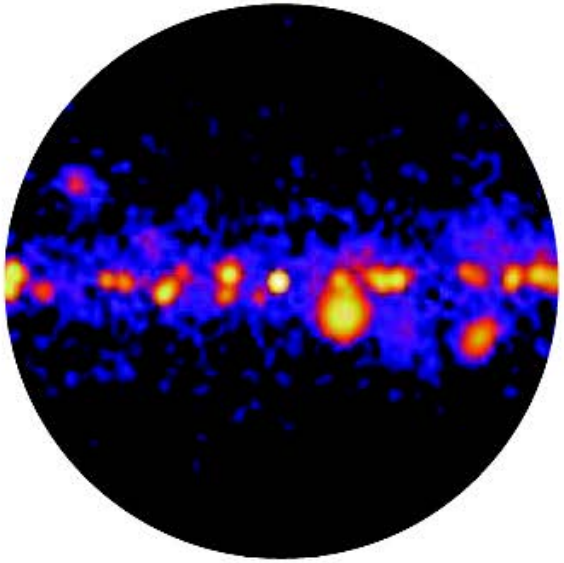
Gamma Rays from multi-TeV particles



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

The Galactic Plane Survey



Credits: The CTA Consortium

CTA will carry out a **survey of the full Galactic** plane using both the southern and northern CTA observatories.

The Survey will provide a **complete and systematic view of the Galaxy** to facilitate our understanding of Galactic source populations and diffuse emission, and **a comprehensive data-set and catalogue**.

The CTA GPS will be a factor of 5 – 20 more sensitive than surveys carried out by earlier or existing atmospheric Cherenkov telescopes.

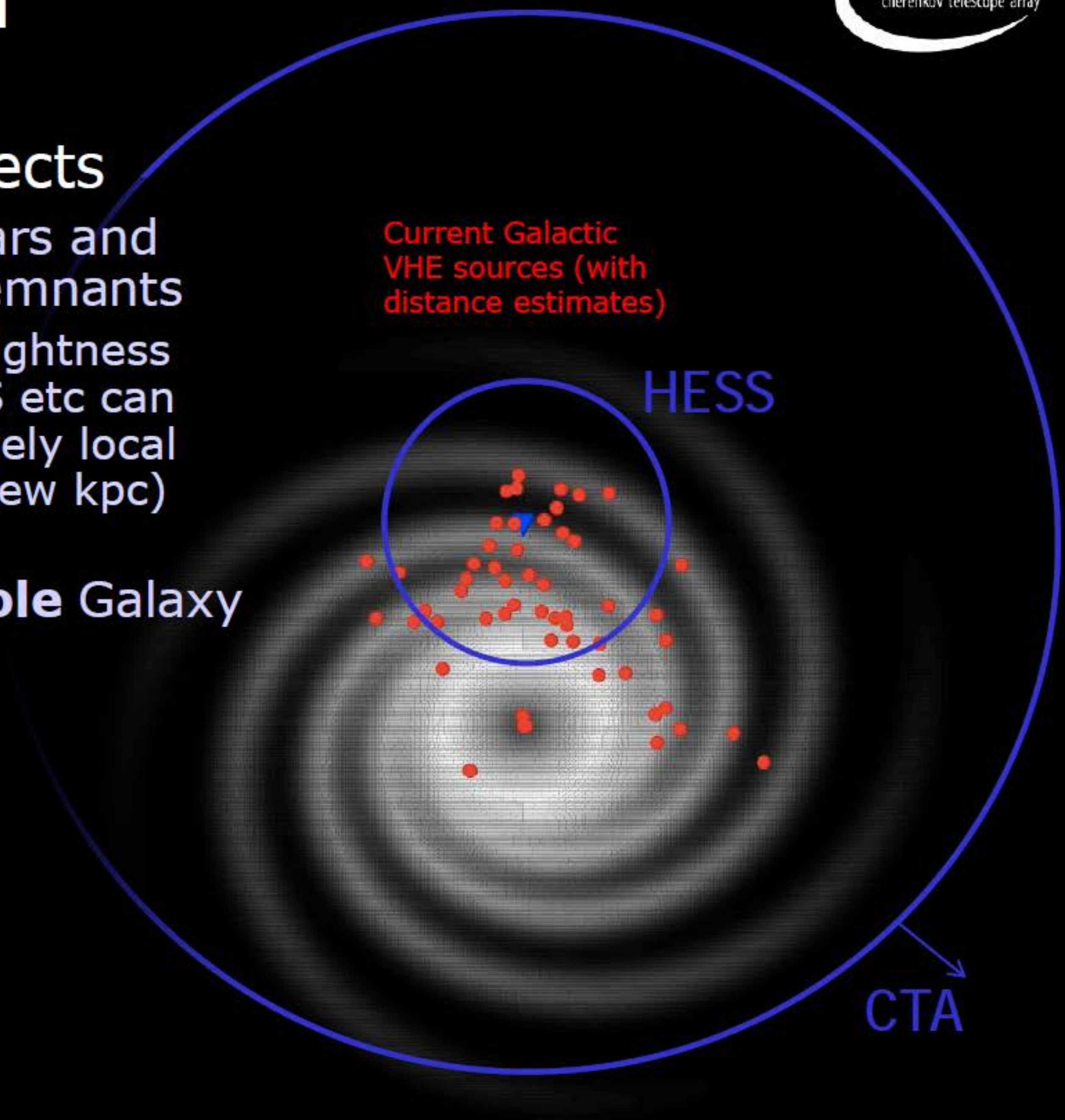
→ 300 to 500 new sources!

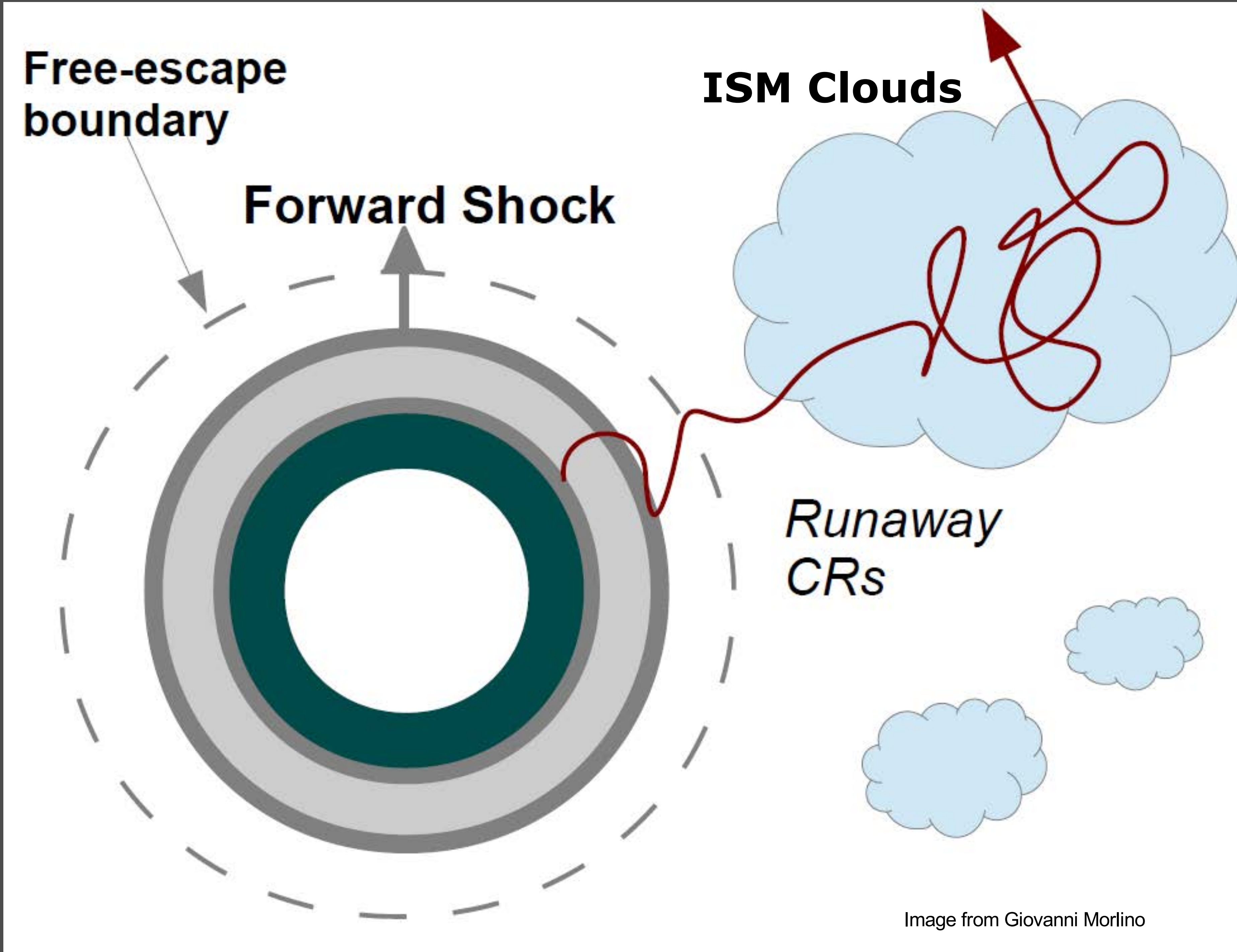
In the Northern Hemisphere, the CTA will complement/extend observations made by HAWC. **CTA will go deeper by a factor of 5 – 10 compared to HAWC**, at much lower energy and with substantially better angular resolution.

CTA Galactic Science

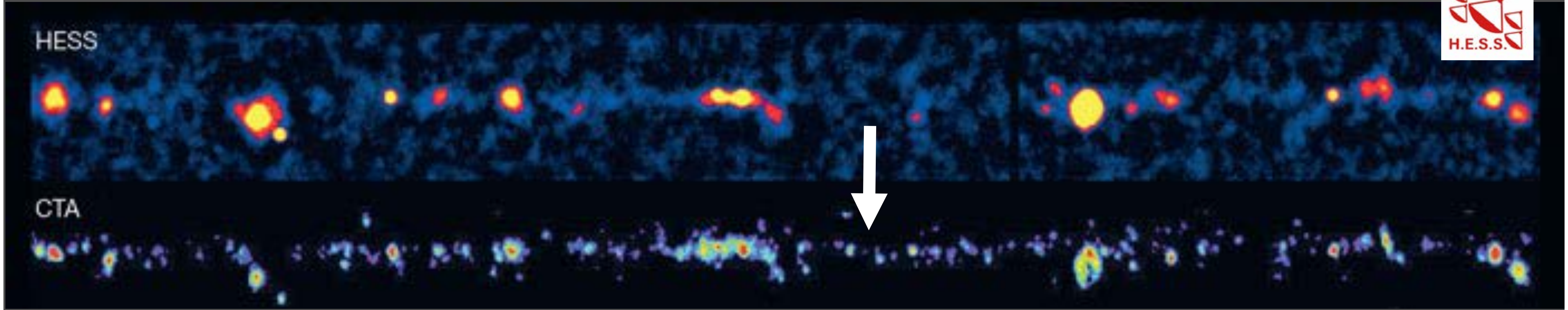
CTA Reach

- 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




Free-escape
boundary
Forward Shock
ISM Clouds
Runaway
CRs
Image from Giovanni Morlino

CTA Galactic Plane TeV Surveys : Major Issue

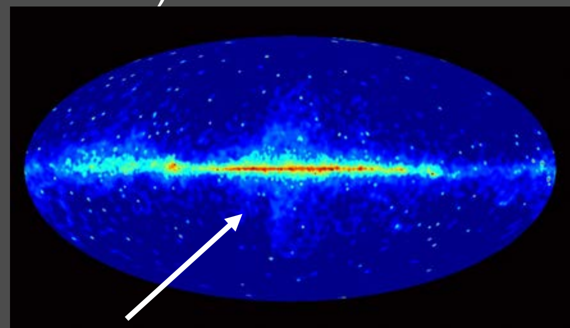


Funk et al 2012

- 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 $|b|<0.2^o$ $|l|<30^o$ (Dubus etal 2013)

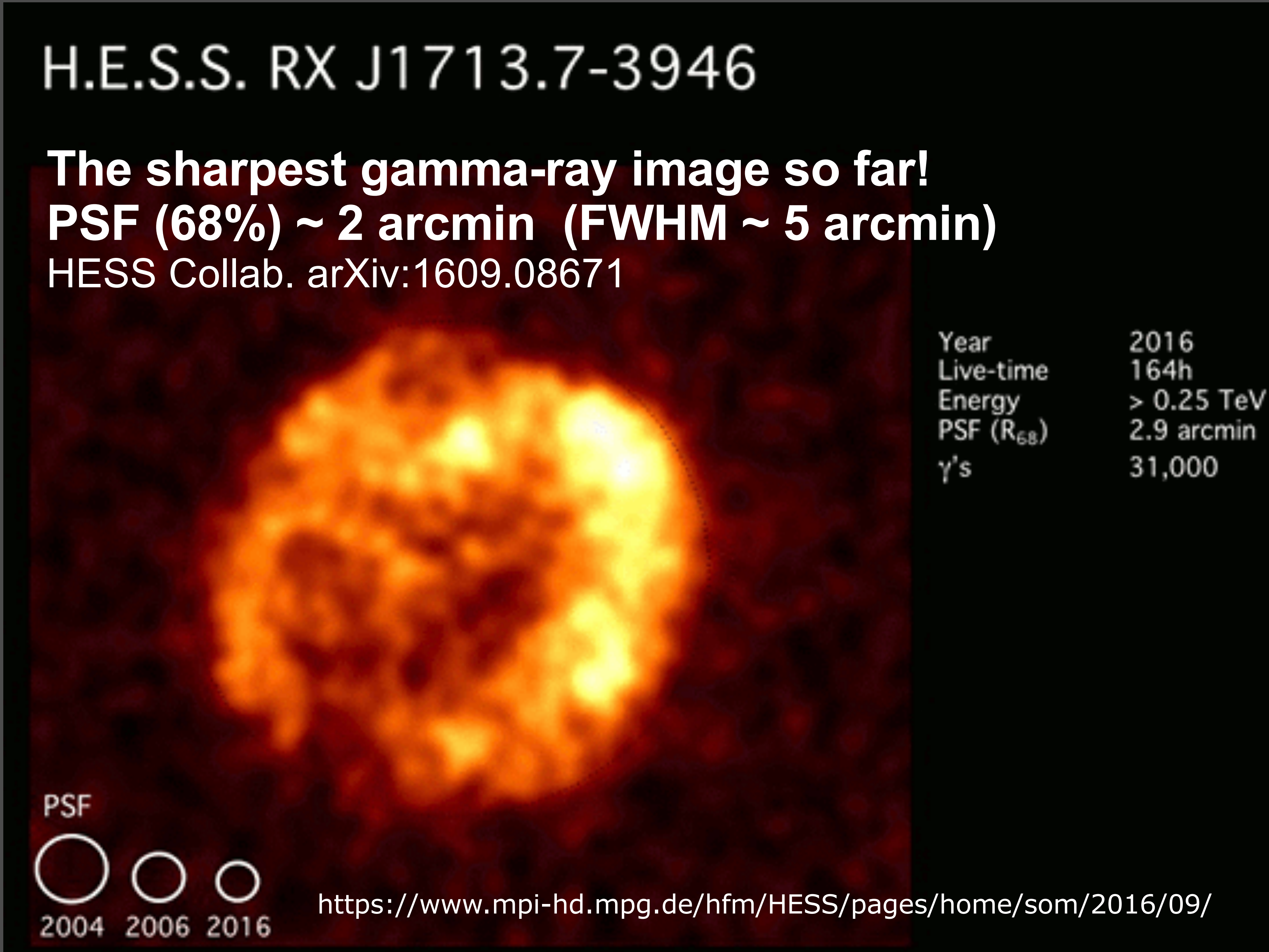
- Diffuse TeV components visible?
  from CR 'sea' – maybe
  local CR accelerator enhancements – yes



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+)

The sharpest gamma-ray image so far!
PSF (68%) ~ 2 arcmin (FWHM ~ 5 arcmin)
HESS Collab. arXiv:1609.08671

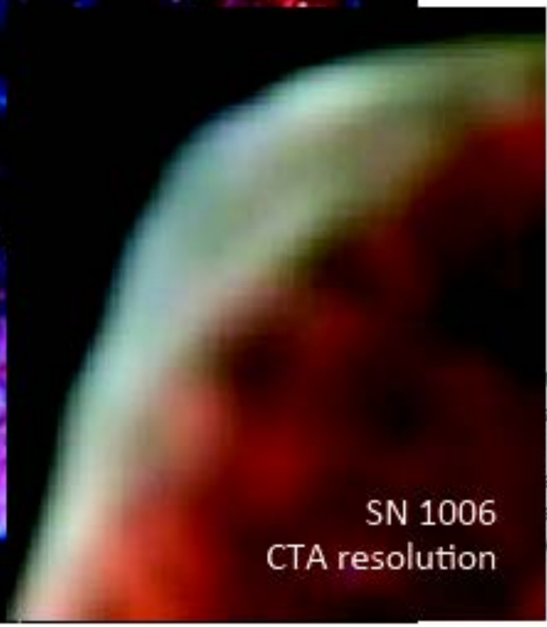


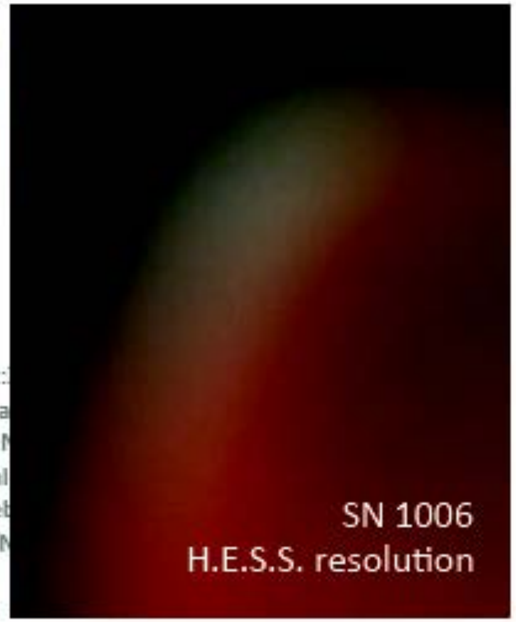
https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2016/09/

Angular resolution

Towards 1 arc-min (68% PSF) and better

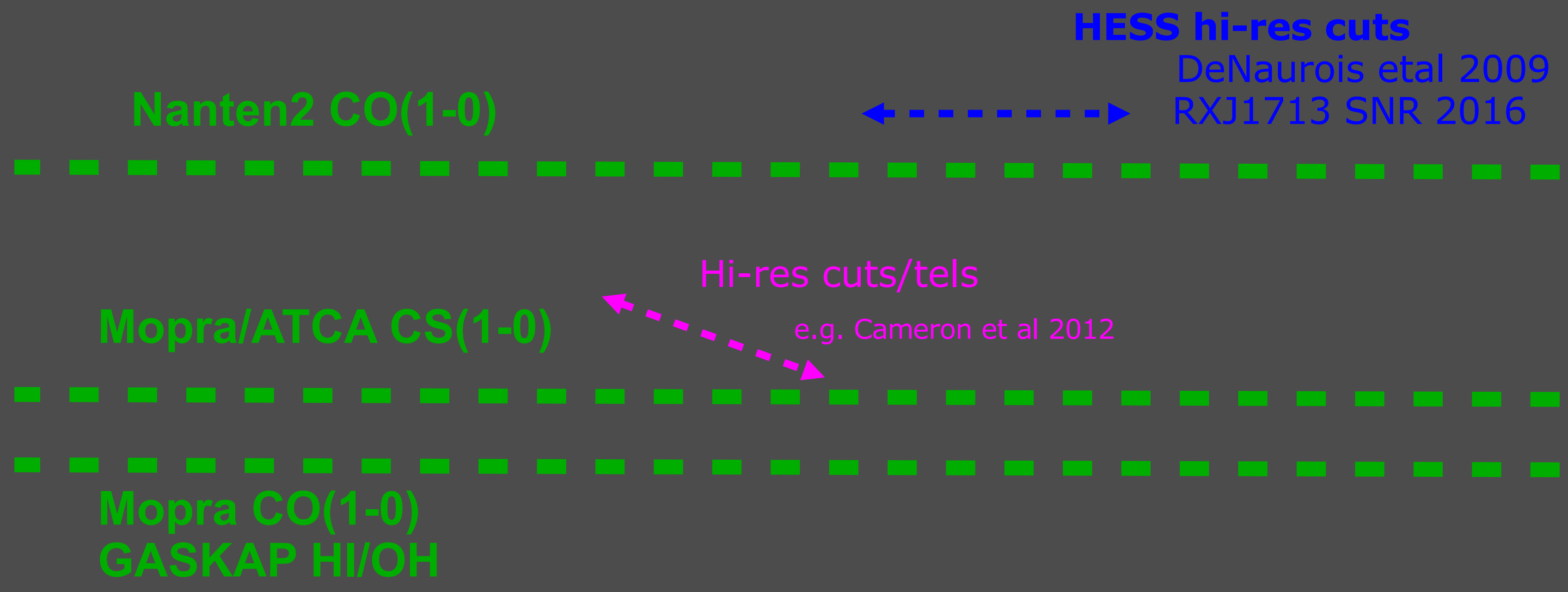
→ Imaging of shocks!





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

Acharyara etal 2013



Beam Sizes 68% containment radius

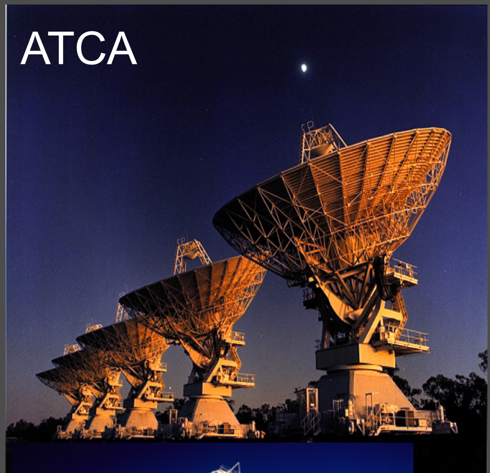
Interstellar gas tracers & telescopes..

www.atnf.csiro.au/research/HI/sgps

HI (atomic H), OH, CS

Gas density

~$10^{1\ \text{to}\ 4}$ cm^{-3}



ASKAP-GASKAP

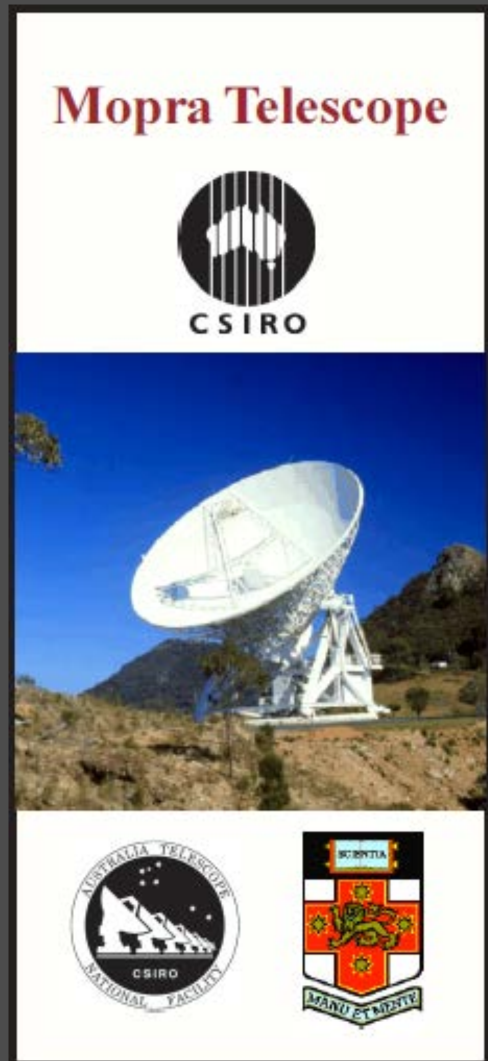
CO

~10^{3} cm^{-3}

HEAT – THz (Antarctica)
[CI] + [CII]

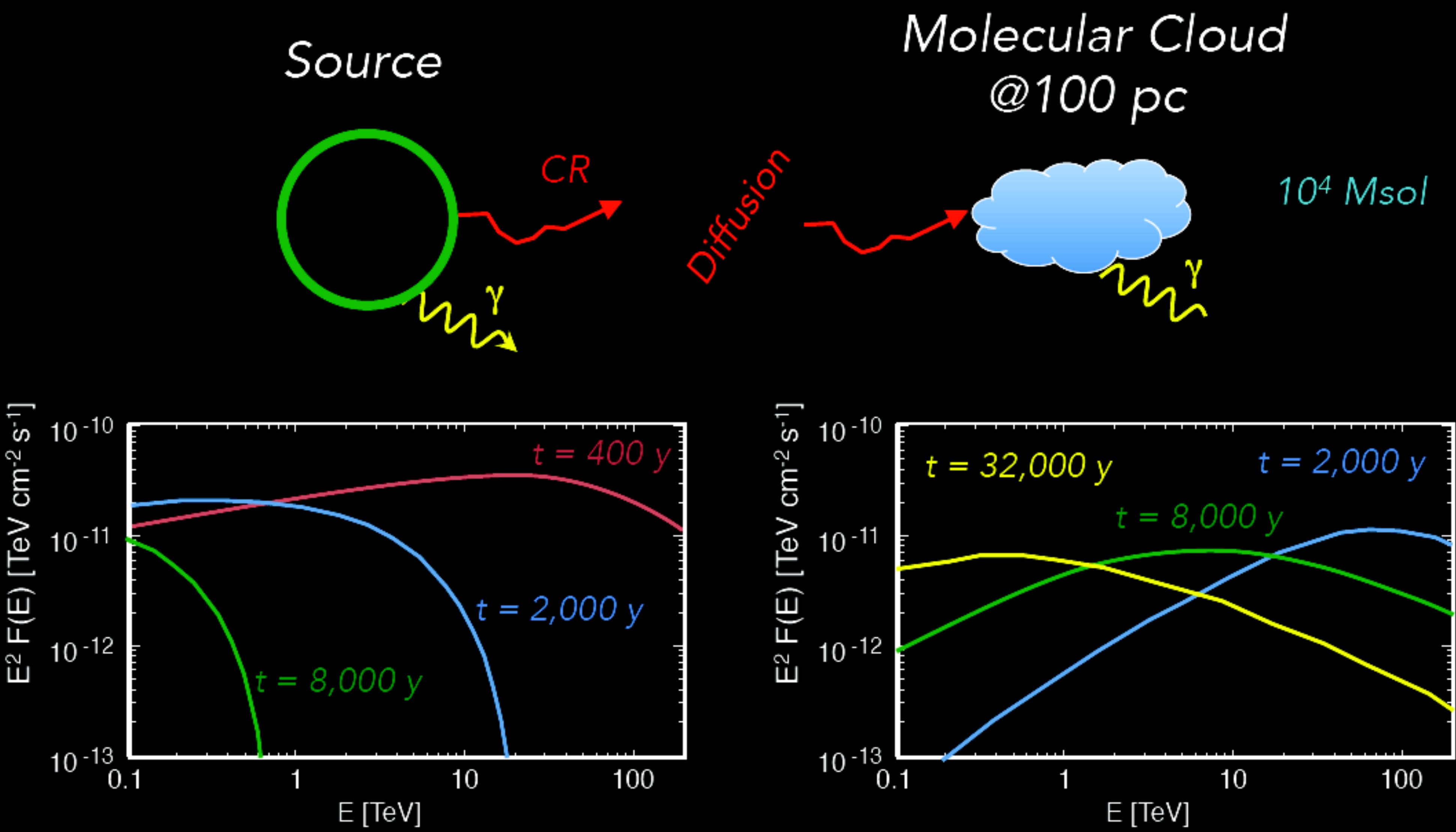
CO, NH_3, CS, SiO...

>$10^{3\ \text{to}\ 4}$ cm^{-3}



Gamma-ray spectra from local and escaped CRs

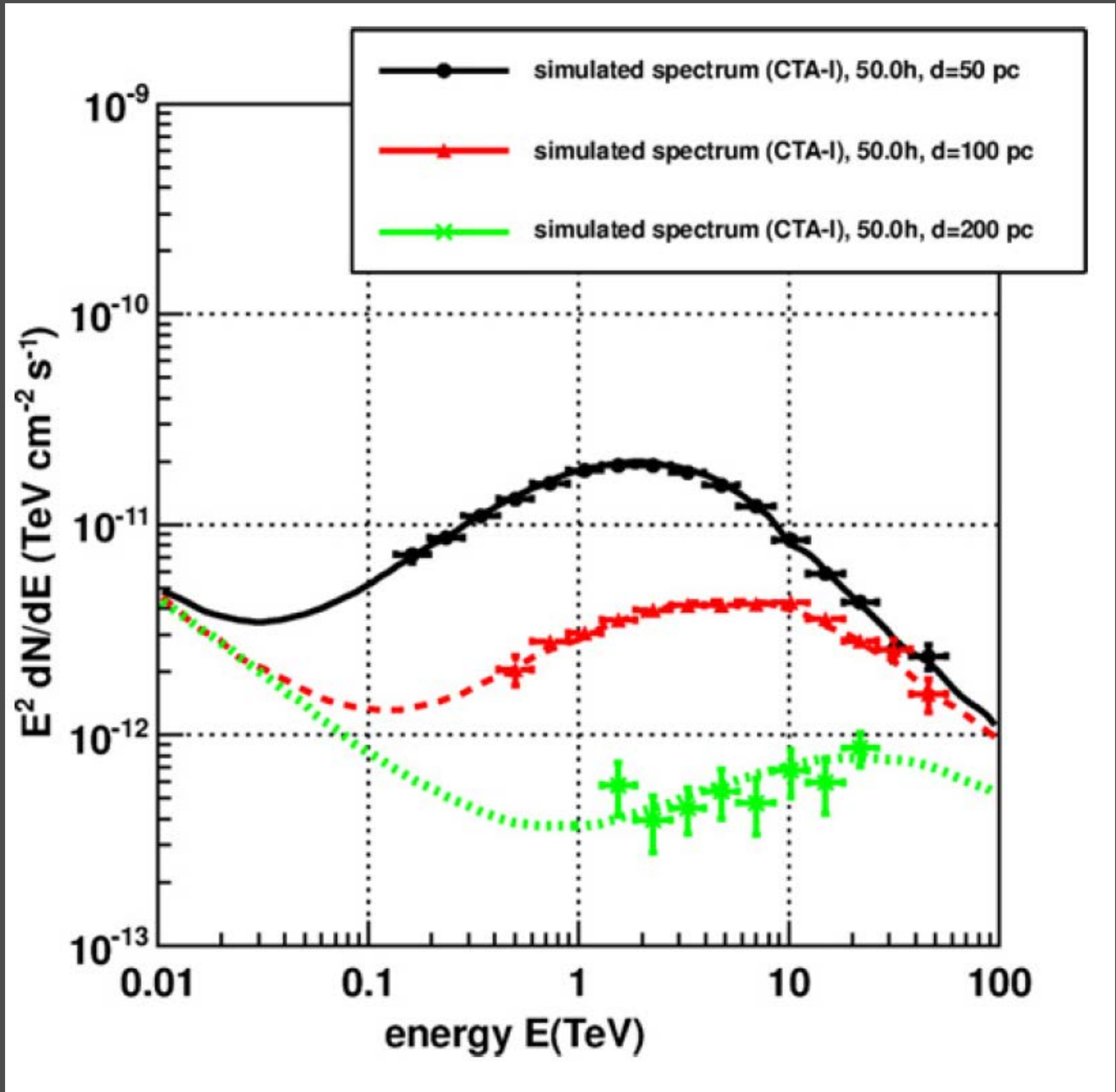
e.g. Aharonian & Atoyan 1996



From Gabici & Aharonian (2007)

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

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

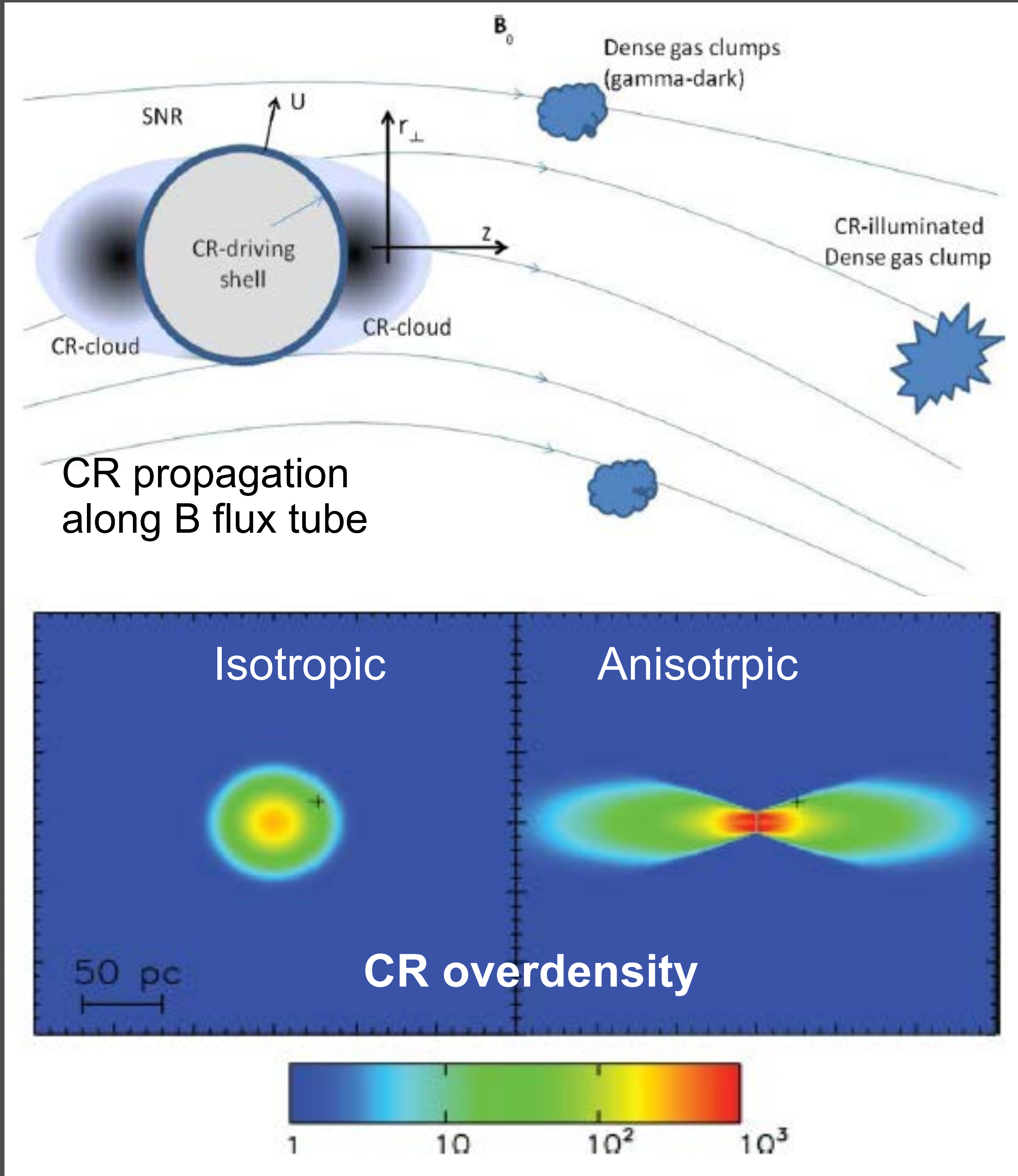
PeV CRs escape first and arrive at the cloud first!

Probe for CR PeVatrons

But confusion guaranteed in Gal. Plane!

Need wide ISM surveys → Mopra, Nanten2, Nobeyma, ASKAP (S&N)

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 & Fararr 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

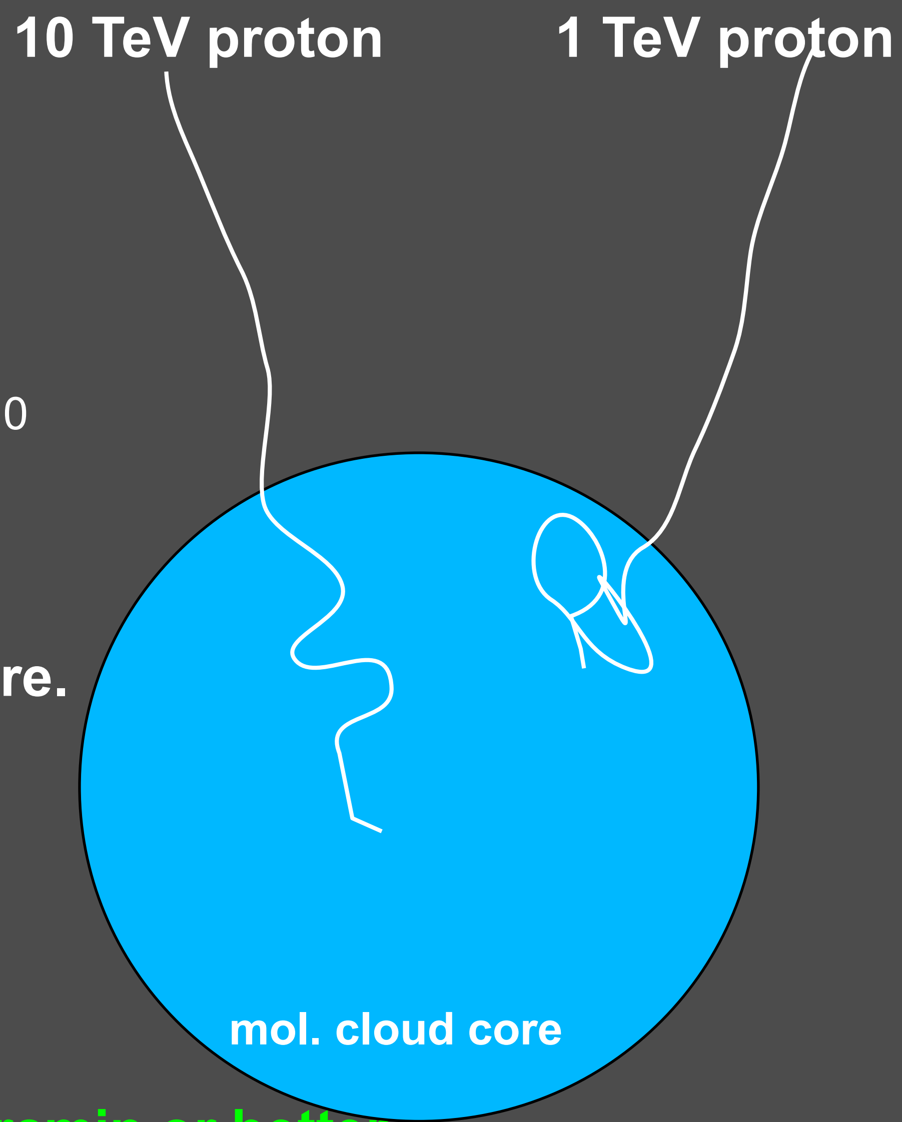
R ~ sqrt[6 D(E , B) t]

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

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

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

HESS hi-res cuts

DeNaurois etal 2009

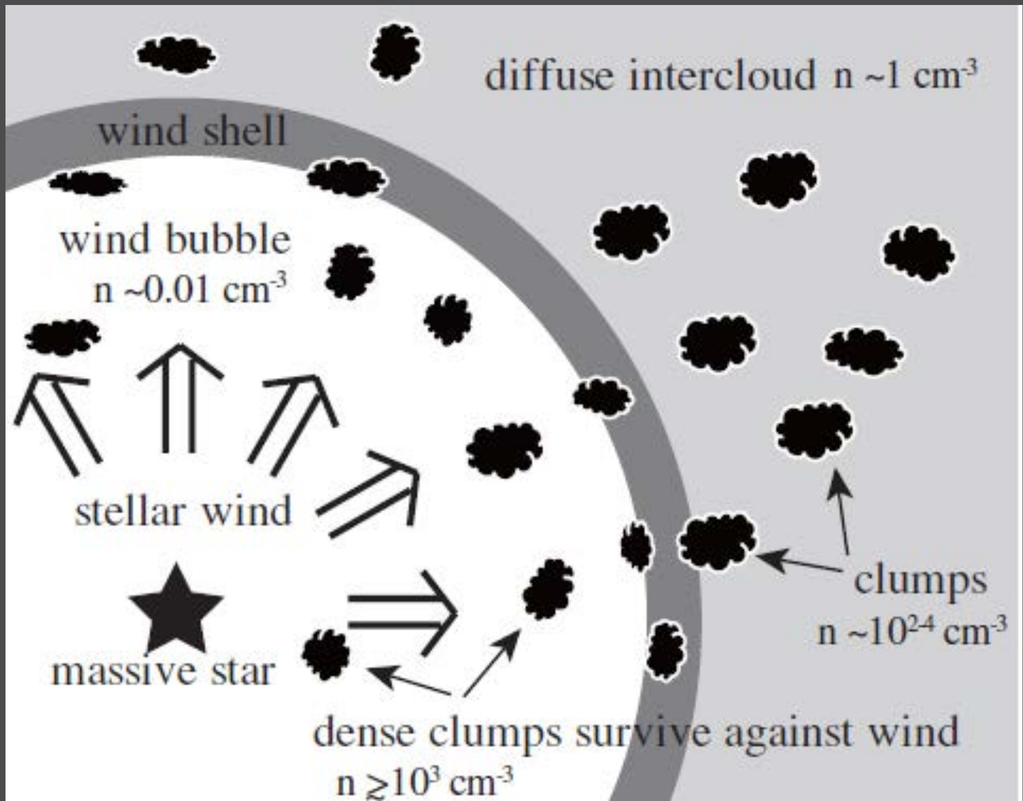
RXJ1713 SNR 2016

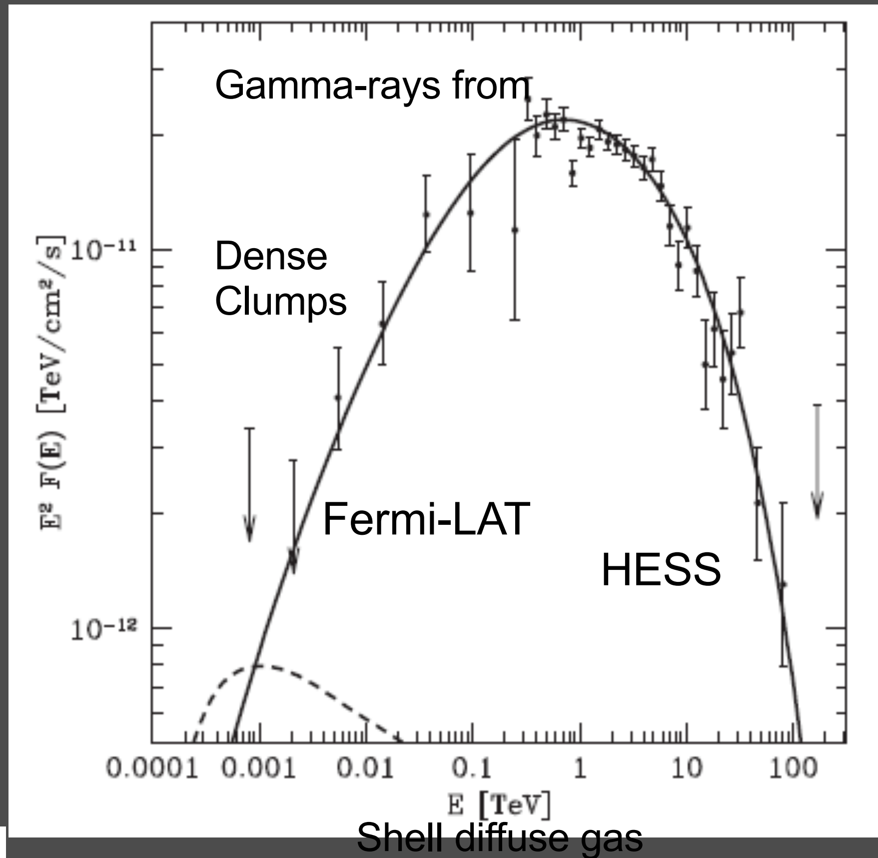
e.g. Cameron et al 2012

Hadronic Gamma-Rays from Clumpy ISM
SNR RXJ1713

Inoue et al. 2012

Gabici & Aharonian 2014





CR penetration depth

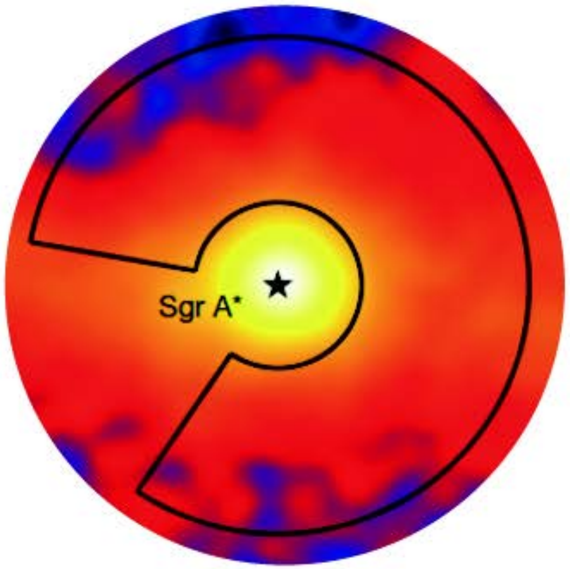
$$l_{pd} \simeq (\kappa_d t)^{1/2}$$

$$= 0.1\,\eta^{1/2} \left(\frac{E}{10\ \mathrm{TeV}}\right)^{1/2} \left(\frac{B}{100\ \mu\mathrm{G}}\right)^{-1/2} \left(\frac{t_{age}}{10^3\ \mathrm{yr}}\right)^{1/2}\ \mathrm{pc}$$

$\eta = B^2/\delta B^2$ $\kappa_d = 4\,\eta\, l_g\, c/3\pi$ (Skilling 1975)

→ **Dense clouds/clumps could play critical role in hadronic component**

Cosmic-ray PeVatrons



Credits: The H.E.S.S. Collaboraiton

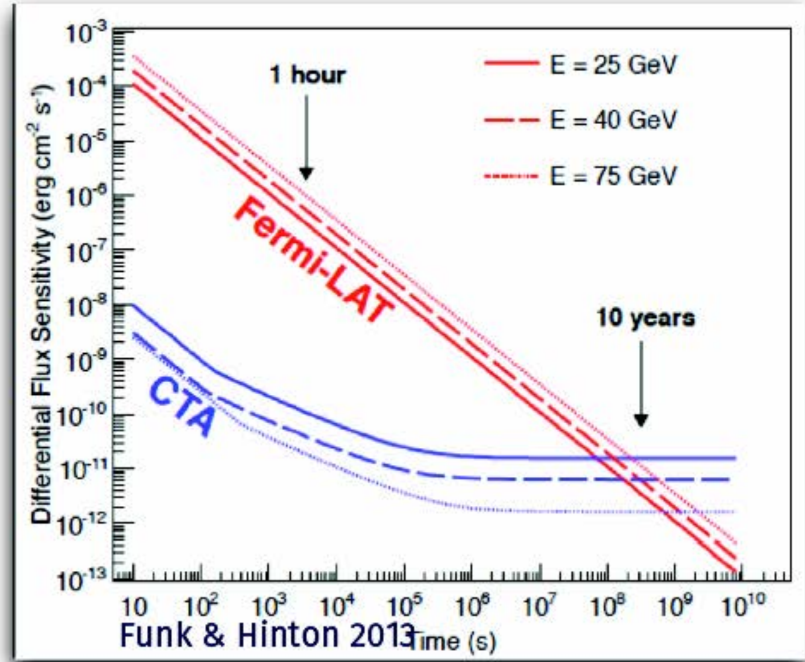
PeVatron at Galactic Centre
→ continuous CR source

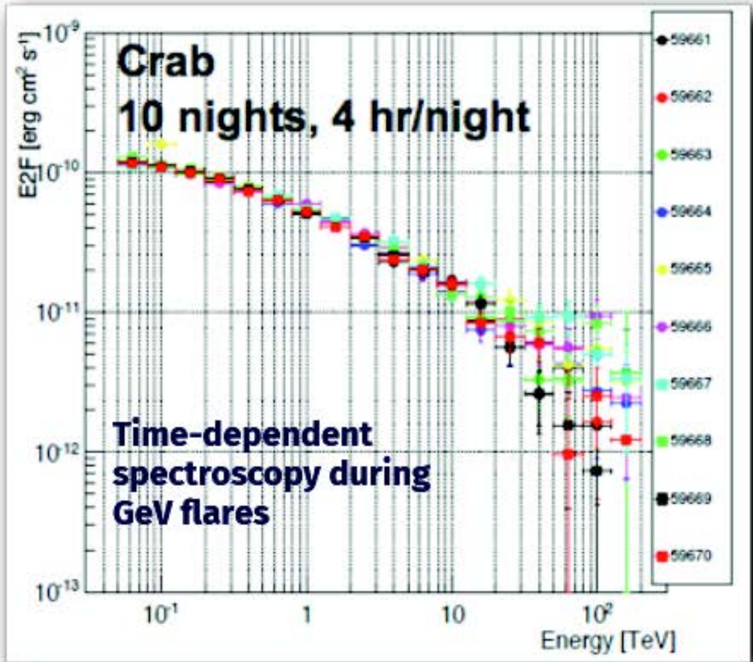
Cosmic rays are primarily **energetic nuclei**, which fill the Galaxy.

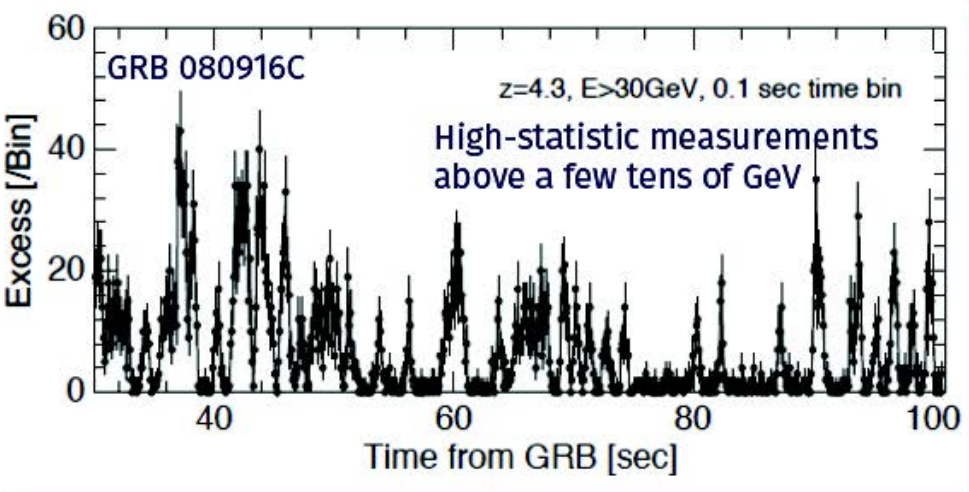
Supernova remnants might be able to satisfy the cosmic-ray energy requirement if they can somehow convert ~10% of the supernova kinetic energy into accelerated particles.

CTA will perform **deep observations of known sources with particularly hard spectra**. Moreover, it will search for **diffuse gamma-ray emission from the vicinity of prominent gamma-ray bright SNRs.** The interactions of such runaway PeV particles with the ambient gas produce gamma rays with a characteristic hard spectrum extending up to ~100 TeV.

Transients



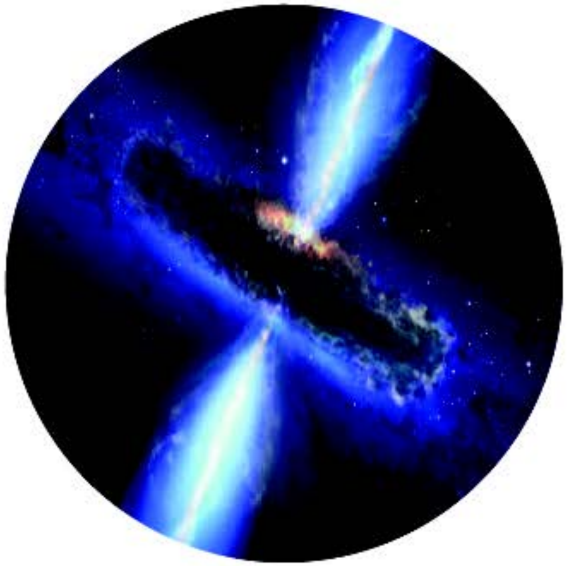




Inverse-Compton component of the 2011 April Crab flare assuming Γ=50. The variable tail from 10 to 100 TeV is clearly detectable.

The assumed GRB template is the measured Fermi-LAT light curve above 0.1 GeV, extrapolating the intrinsic spectra to VHE with power-law indices as determined by Fermi-LAT. We expect to detect ~1 GRB yr^{-1} $site^{-1}$.

Active Galactic Nuclei



Credits: ESA/NASA

AGNs are known to emit **variable radiation** across the entire electromagnetic spectrum up to multi-TeV energies, with fluctuations **on time-scales** from **several years** down to **a few minutes.**

VHE observations of active galaxies harbouring super-massive black holes and ejecting relativistic outflows represent a unique tool to probe the **physics of extreme environments**, to obtain precise measurement of the **extragalactic background light** (EBL) and to constrain the strength of the **intergalactic magnetic field** (IGMF).

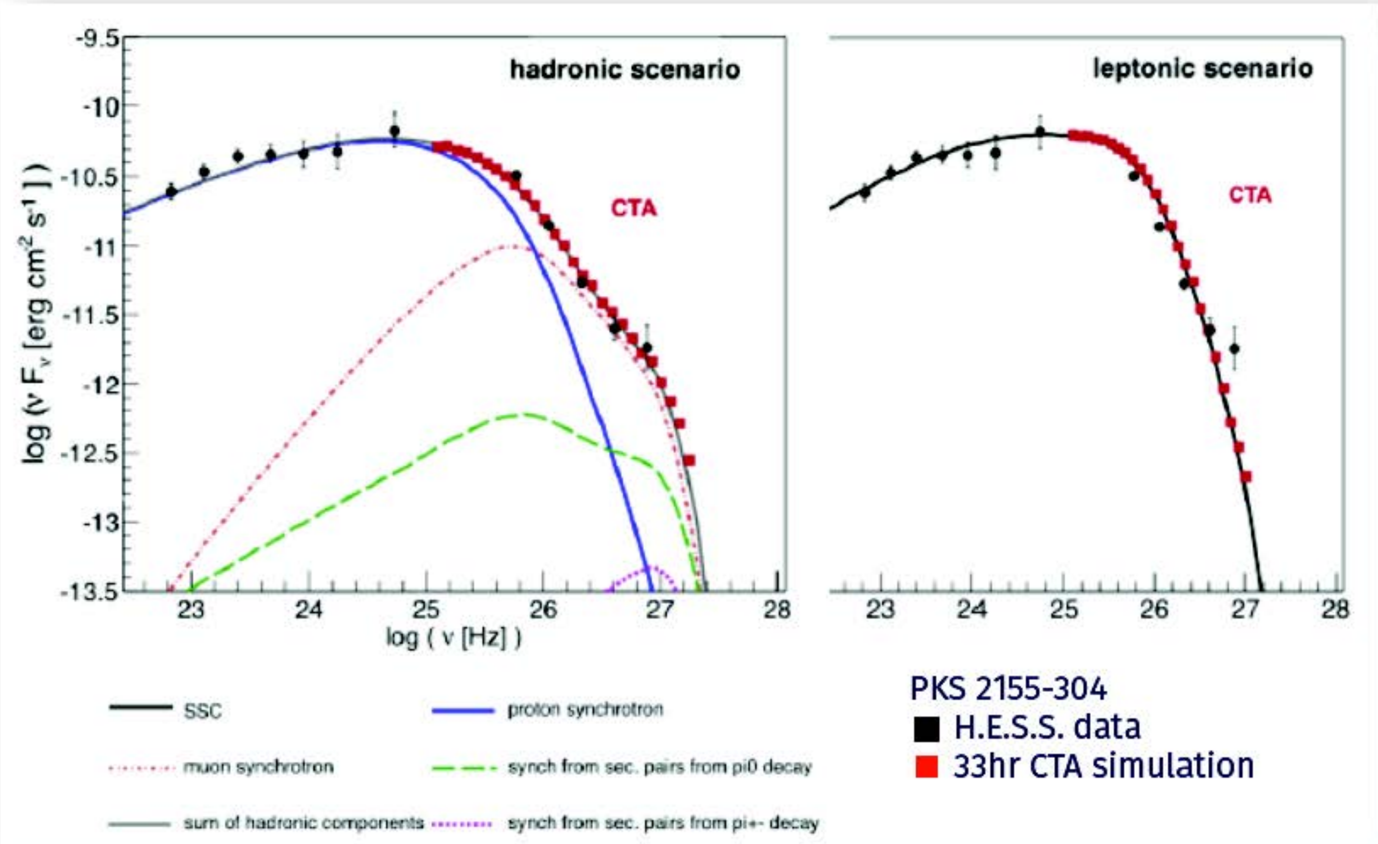
AGNs will be useful to investigate fundamental physics phenomena such as the **Lorentz invariance violation** and signatures of the existence of **axion-like particles**.

Also TeV-Detected

- **Radio galaxies**
- **Starburst gal.**
- **Grav. lensed flare**

Active Galactic Nuclei

Testing emission scenarios

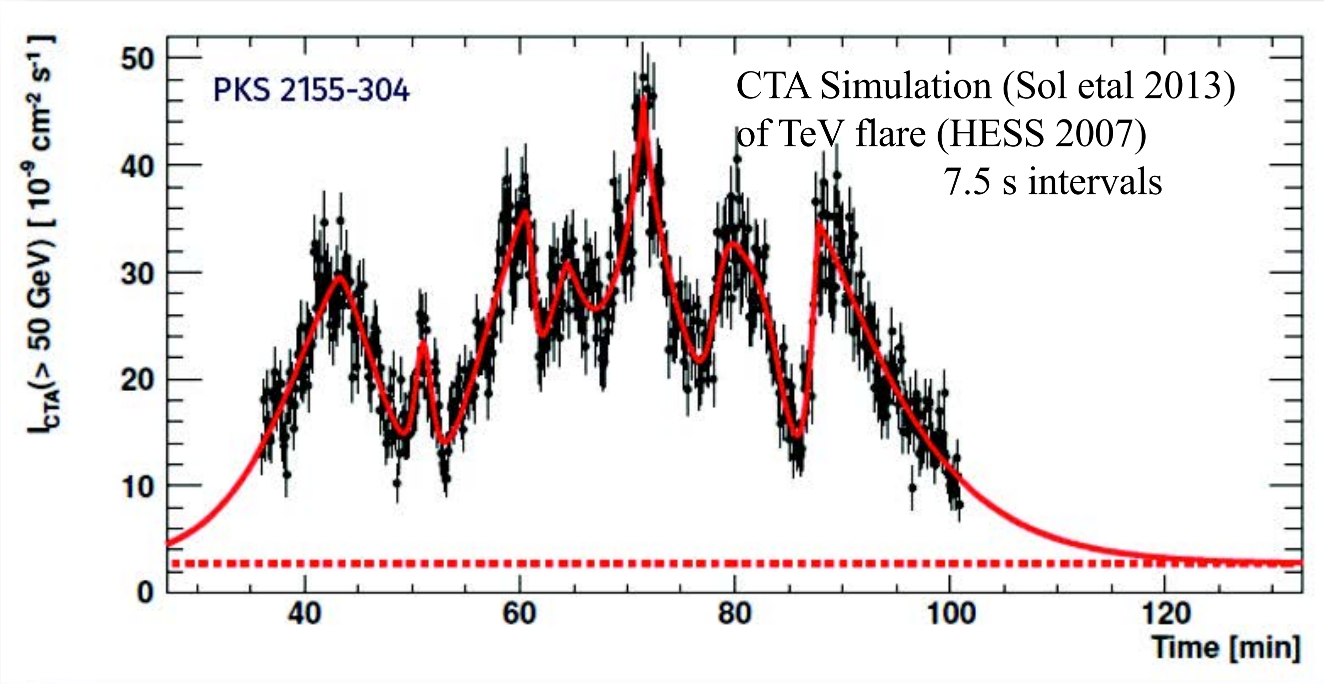


A set of high-quality spectra from different blazar types and different redshifts is needed to unambiguously distinguish intrinsic spectral features, such as shown here, from external absorption.

Zech etal 2013, Cerutti etal 2015, CTA Science Case (2016 in prep)

Active Galactic Nuclei

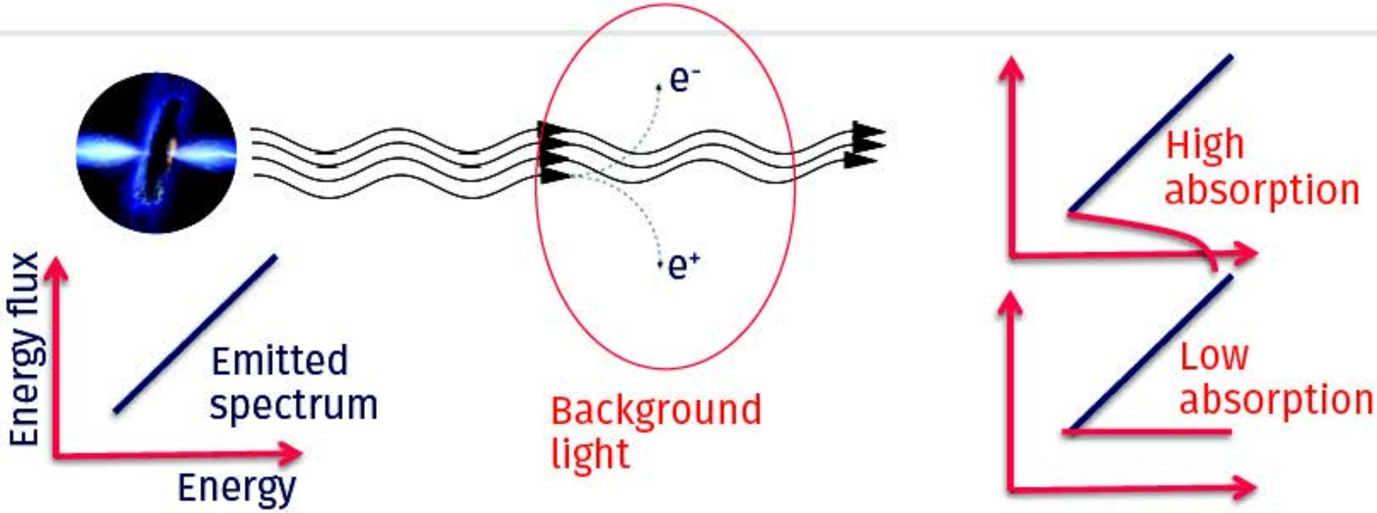
Testing variability in AGNs



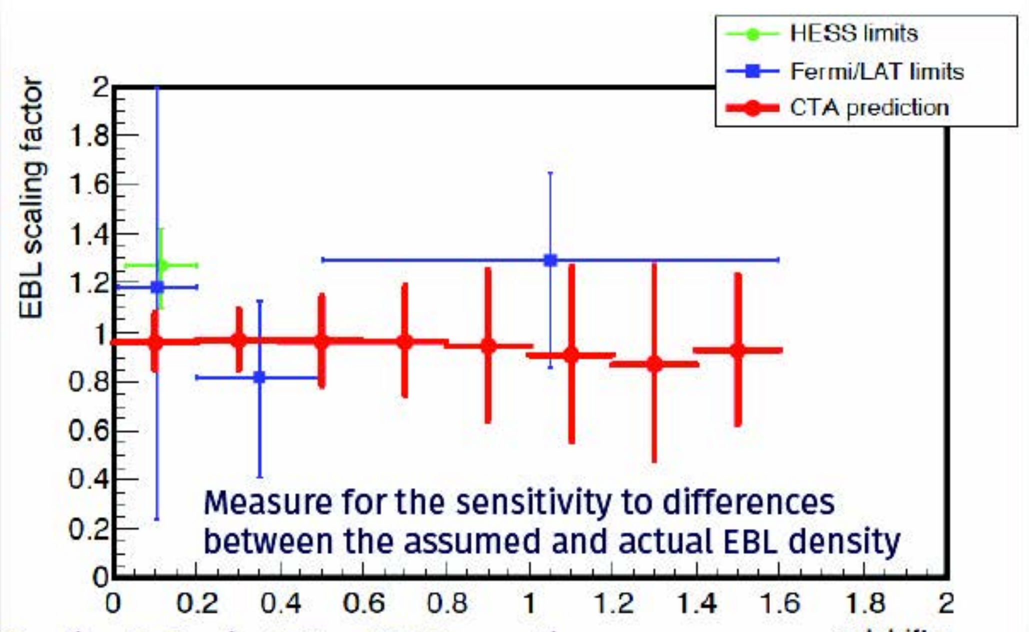
Sampling blazar fluxes below the light-crossing time scale of the SMBH, $T_G \sim 3hr \times (M/10^9 M_\odot)$, is a key strategy to understand the flickering behaviour of blazars on short time scales.

Such measurements put strong constraints on the bulk Doppler factor, as well as on particle acceleration and cooling processes.

Active Galactic Nuclei



The AGN KSP will lead to the **first precision measurement of the EBL spectrum** at z~0 and to a determination of its evolution up to z~1.

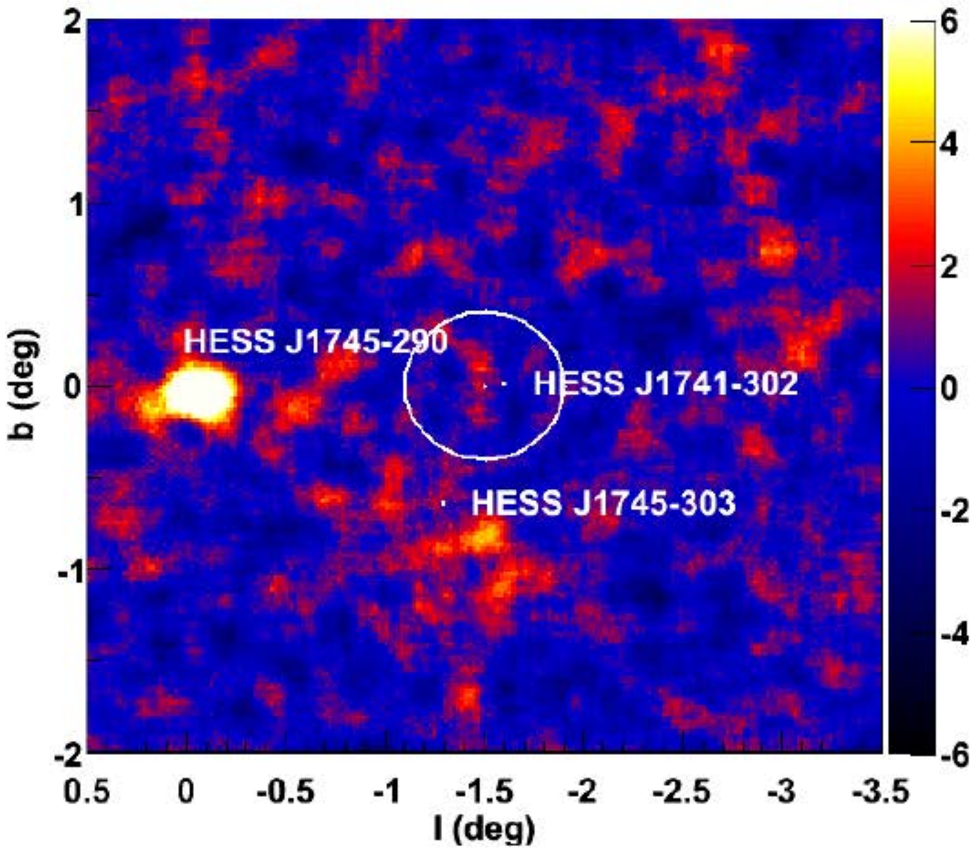


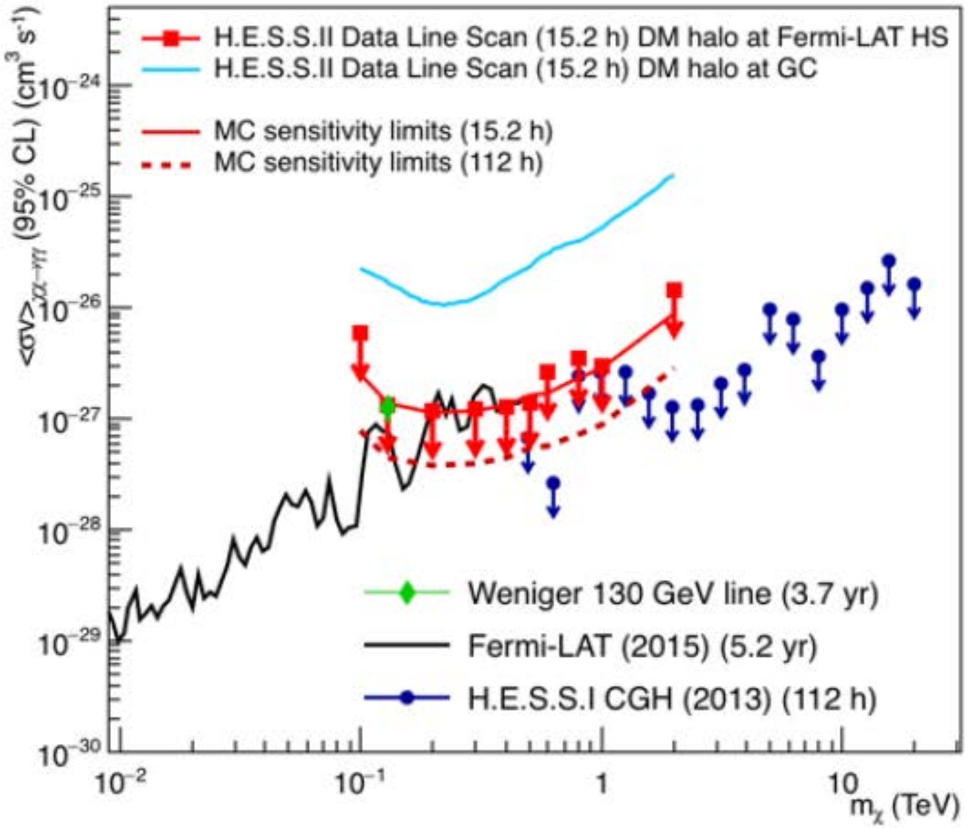
Credits: D. Mazin & The CTA Consortium

CTA will observe a large sample of blazars located at different redshifts. The detection of high-redshift sources, more likely during flares, would allow us to measure the evolution of the cosmic optical background.

130 GeV Dark Matter Line at Fermi-LAT Hotspot?

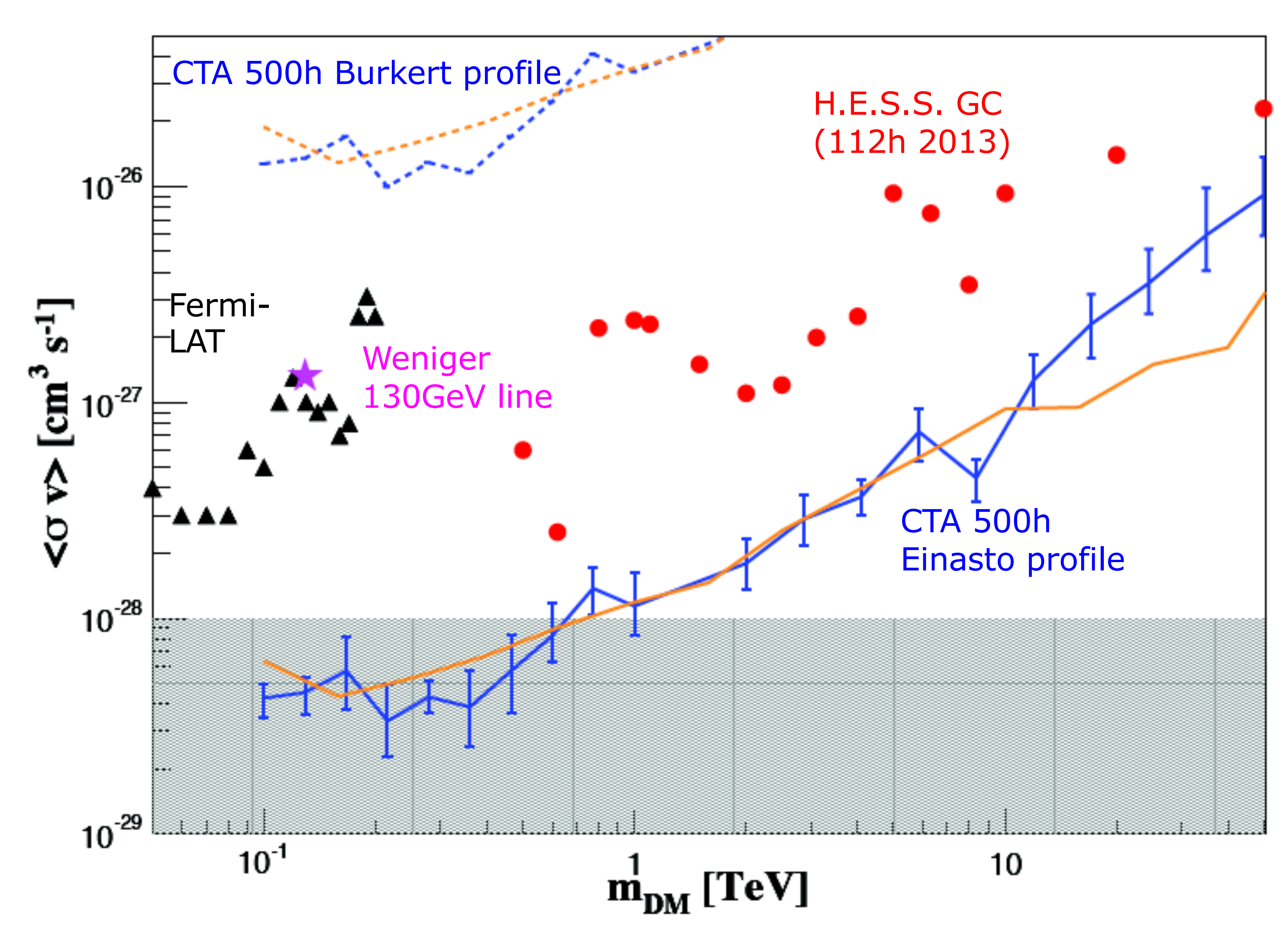
(Weniger 2012) Unfortunately No.





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

CTA Dark Matter Gal.Centre ($r<1^{o}$) 500hr $\chi\chi \rightarrow \gamma\gamma$

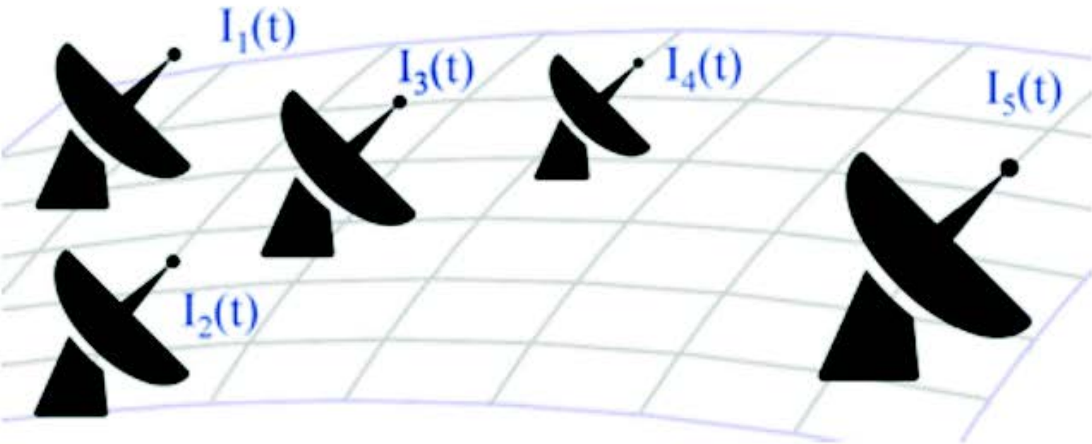


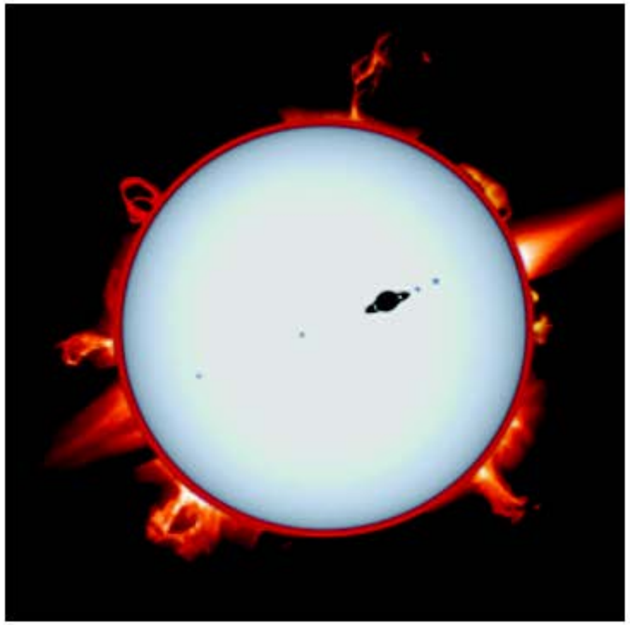
CTA Consortium - Science Case (in prep)

CTA Intensity Interferometry

Observing Strategy: Context

Optical imaging with angular resolution in the range of microarcseconds will reveal details across and outside stellar surfaces but requires kilometer-scale interferometers.
By connecting independent telescopes electronically only, the noise budget of intensity interferometers then relates to the electronic time resolution of a few nanoseconds (light-travel distance of ~0.5m), both circumventing atmospheric turbulence, and enabling the use of less precise light collectors such as Cherenkov telescopes for imaging in the optical/UV.





The angular resolution achievable by CTA exceeds that of the Hubble Space Telescope by almost three orders of magnitiude (although limited to bright sources only) making CTA the optical equivalent of ALMA.

Slide from D. Dravins (Bologna CTA Meeting)

Australia's Roles in CTA:

CTA Hardware & Array Design

- Telescope hardware & commissioning (ARC LIEF funding)
- Atmospheric characterisation (LIDAR, cloud monitoring)
- Analysis techniques & effect of clouds on CTA performance

Multi-wavelength/messenger strengths

- ISM surveys/studies (Mopra, ATCA, ASKAP, SKA)

  (sub)arcmin surveys vital for CTA's Galactic science
- Radio continuum: transients/steady (ATCA, MWA, UTMOST, ASKAP, SKA)
- X-ray astronomy (e-ROSITA, XMM-Newton, Chandra)

Theory Strengths

- Theoretical high energy astrophysics (e.g. Galactic Centre, jets/outflows)
- Astro-particle physics – Dark matter properties

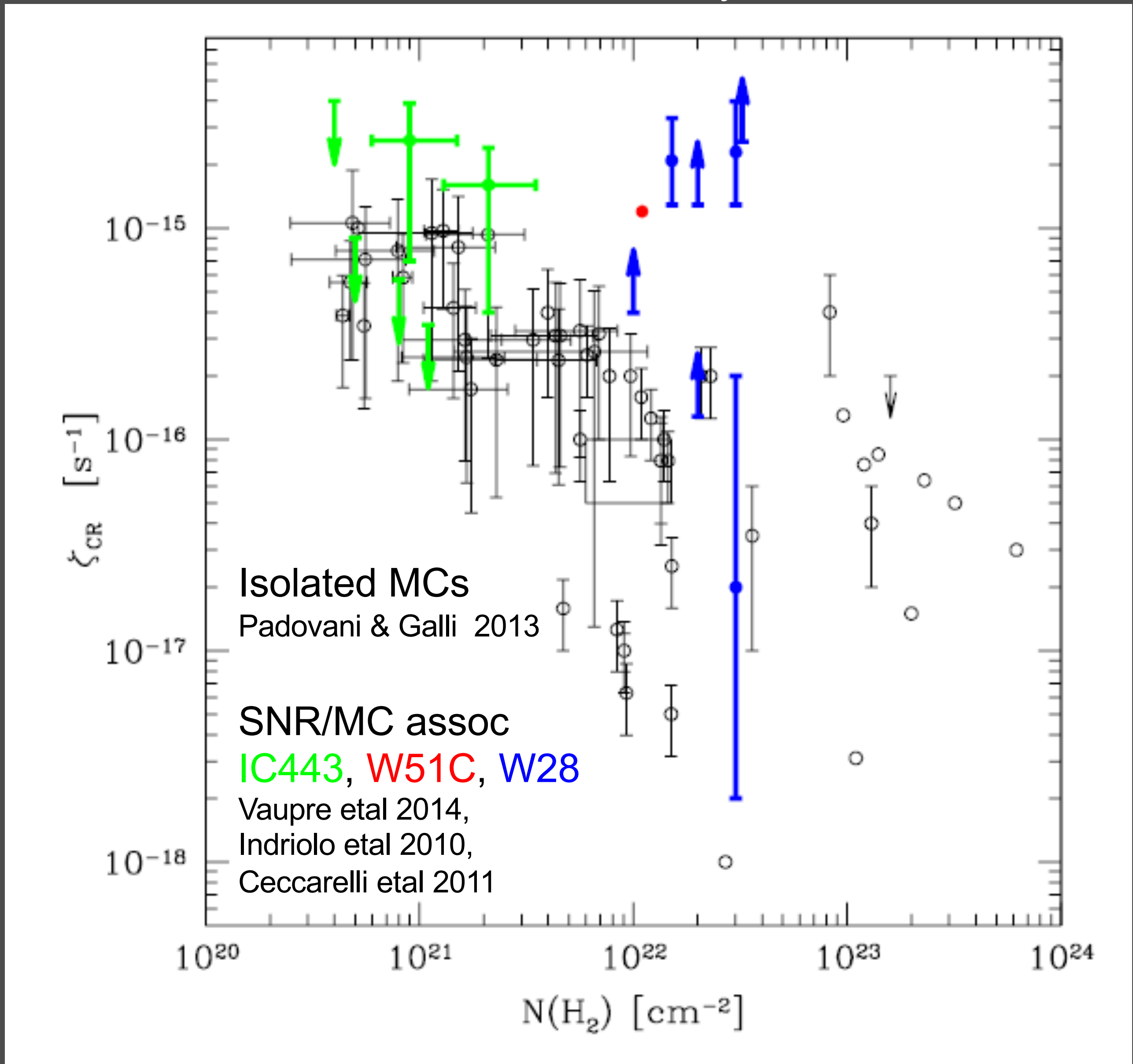
Great potential to link with....

- Radio (ASKAP-EMU, -POSSUM, -VAST/CRAFT, MWA, UTMOST)
- Optical (e.g. GALAH, Skymapper), interferometry, transients
- Cosmic-rays (Pierre Auger Obs.)
- Grav. Waves (A/LIGO)
- Neutrinos (IceCube)
- HP Computing (Pawsey...) – transients, MWL features, local data centre


Thank you....
© G. Pérez, IAC (SMM)

Sub-GeV CR penetration into MCs – Ionisation rates

Review by Gabici & Montmerle 2015



→ **low E CRs less penetrating in denser clouds**

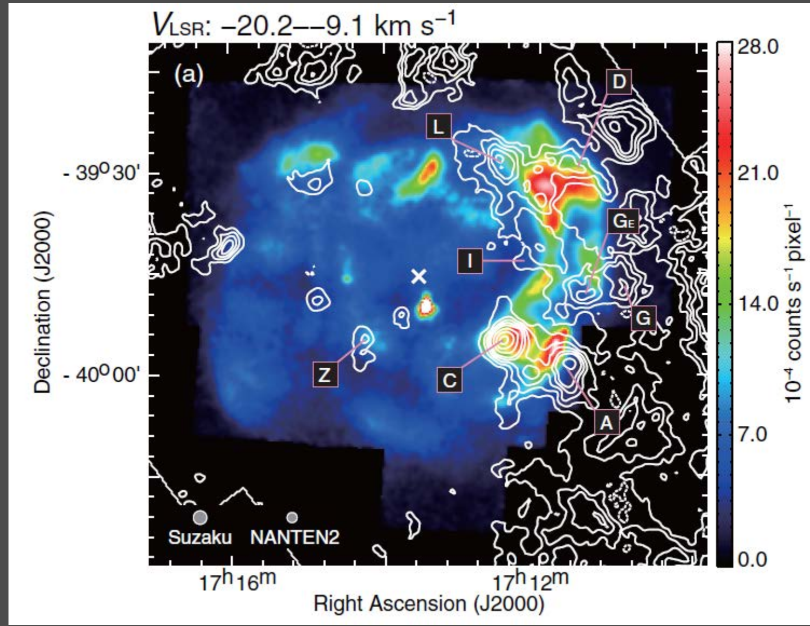
→ **synergies with ionisation rate tracers: HCO+/DCO+ ; H_3^+ ; OH etc..**

Dense Cores **filter out external electrons!** e.g. RXJ1713.7-3946:

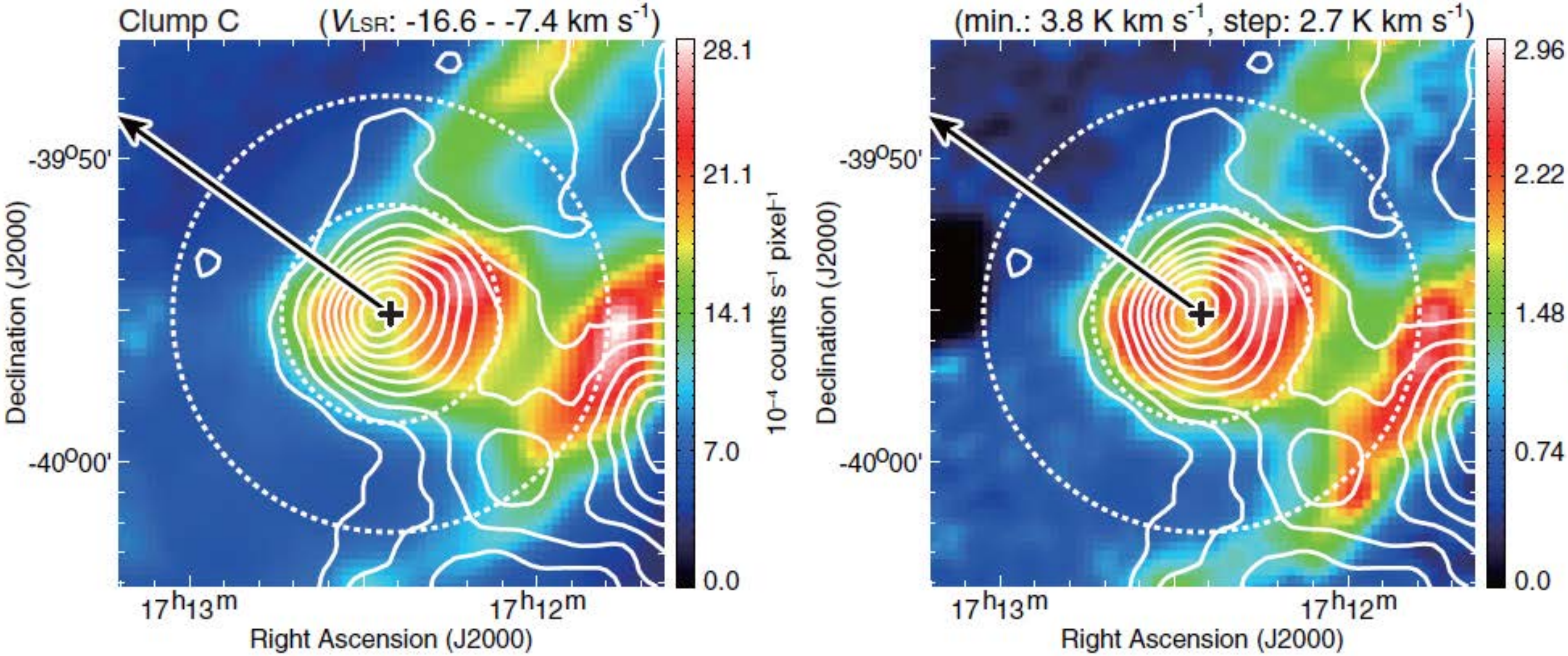
Sano etal 2013

- **CO(2-1) Nanten2 contours +X-ray images**
- **Synch cooling length < pc for**
  30 TeV electrons, 6 keV X-rays,
  n=10^5 /cc, B~400μG

See also Uchiyama et al 2007



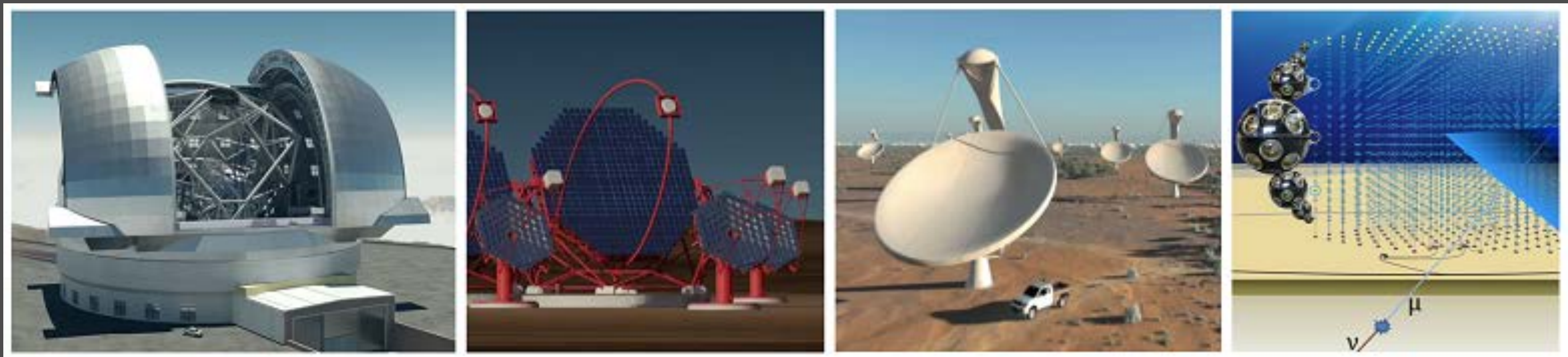
Suzaku 1–5 keV (left) and 5–10 keV (right) images



Asterics
Astronomy ESFRI & Research Infrastructure Cluster

Horizon 2020
European Union funding
for Research & Innovation

The Astronomy ESFRI and Research Infrastructure Cluster



15MEuro programme to tap synergies between: E-ELT, CTA, SKA, KM3Net

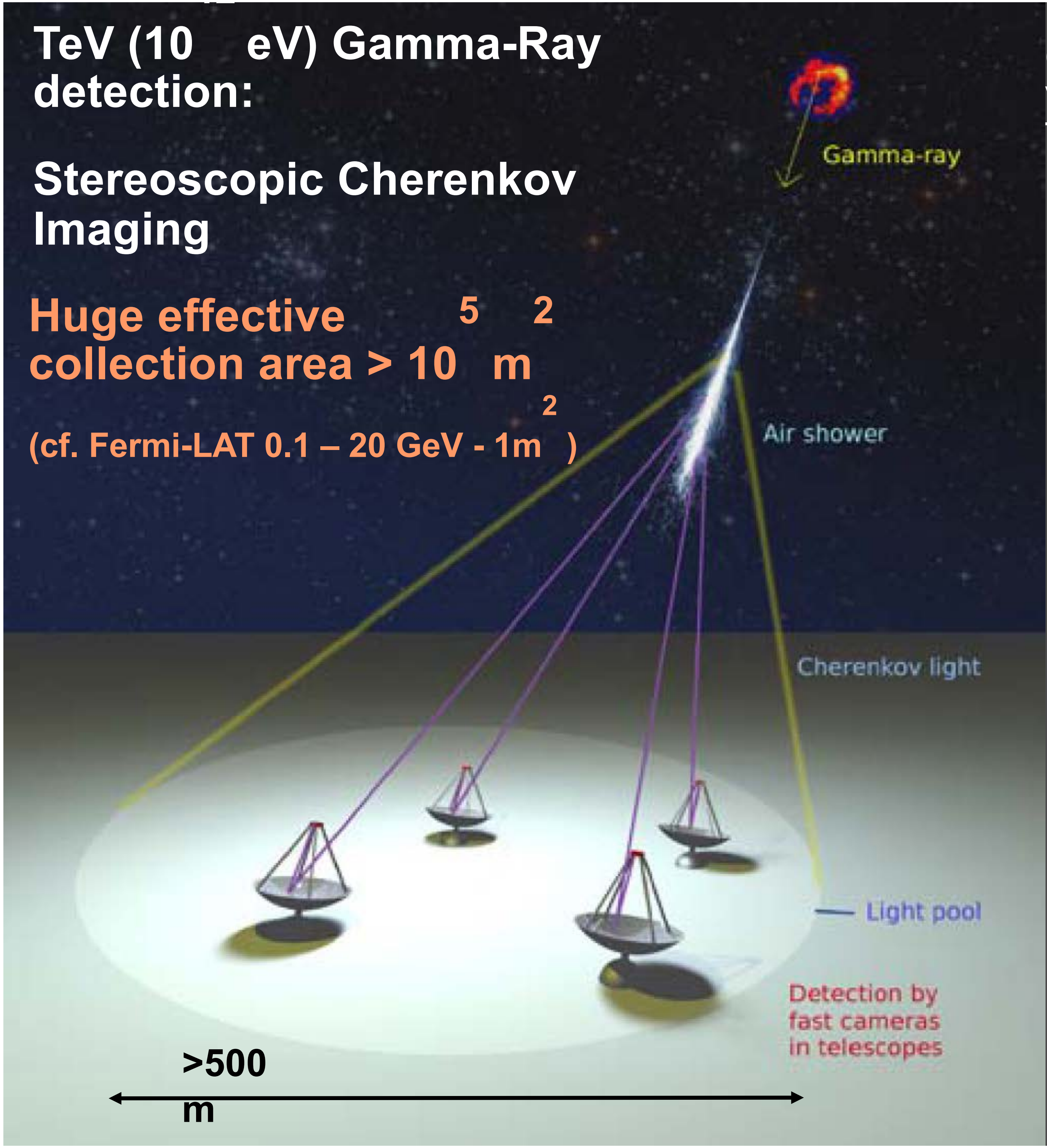
https://www.asterics2020.eu

TeV (10 eV) Gamma-Ray detection:

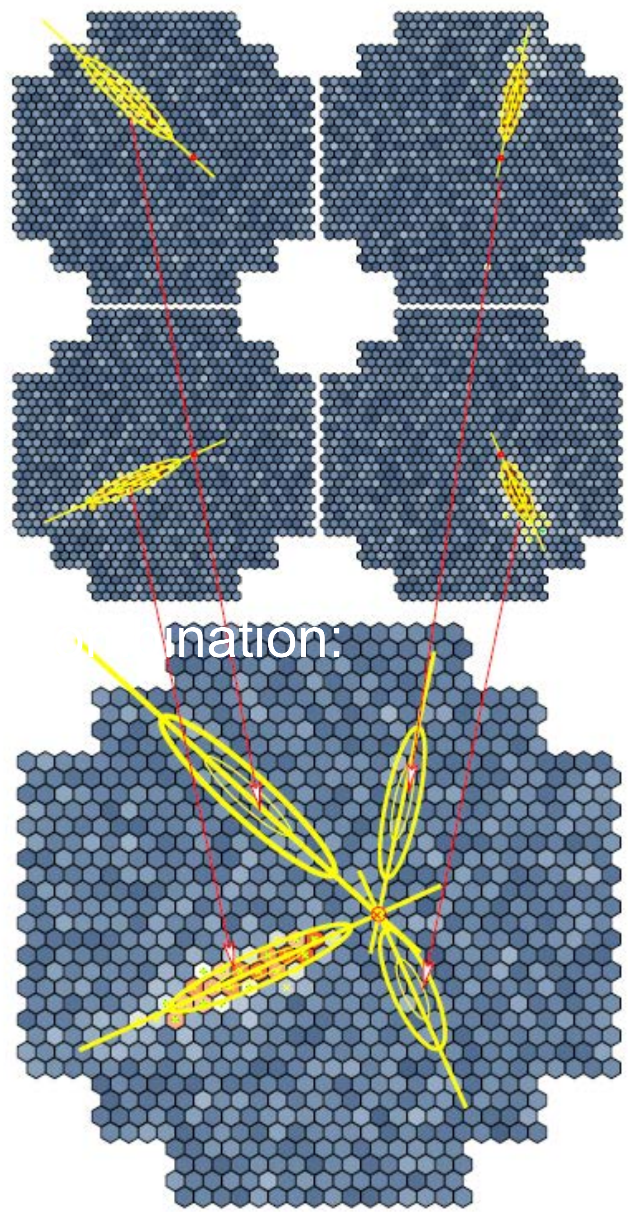
Stereoscopic Cherenkov Imaging

Huge effective collection area > 10^5 m^2

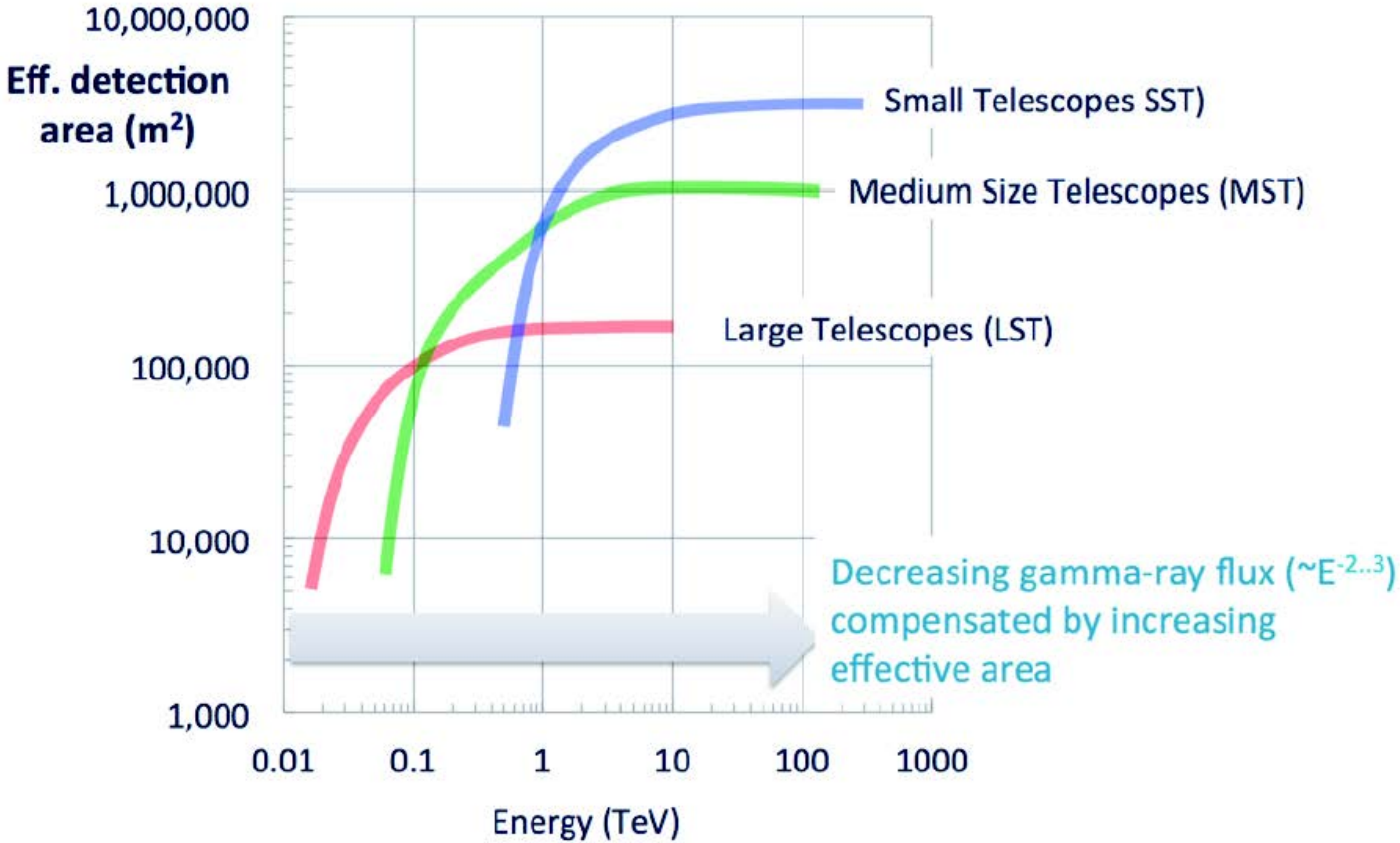
(cf. Fermi-LAT 0.1 – 20 GeV - $1m^2$)



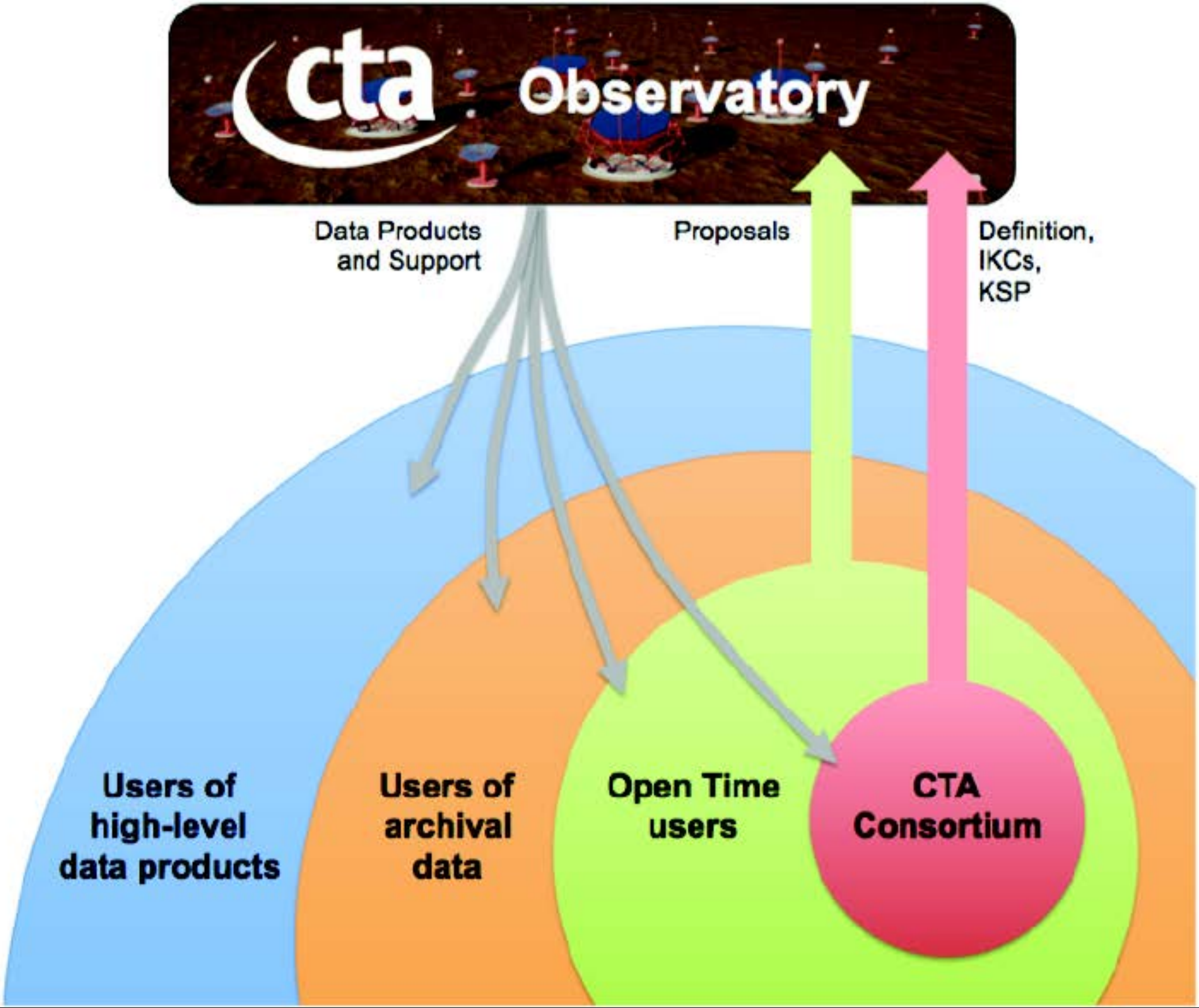
Cherenkov 'image' as viewed by each telescope



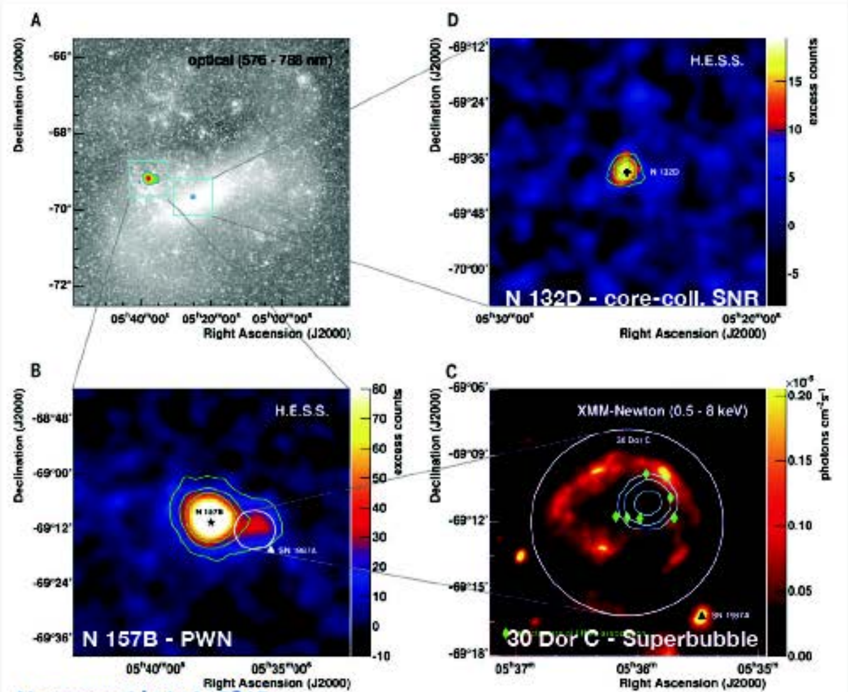
Cherenkov light pool



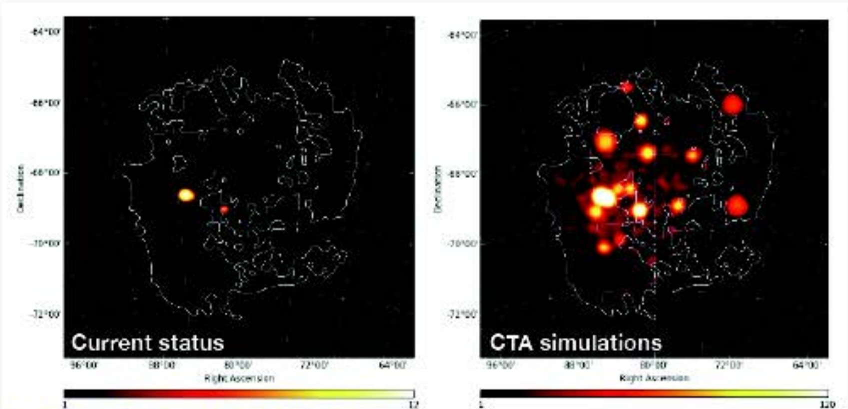
Organization: observatory



LMC Survey



Abramowski et al., 2015



Credits: The CTA Consortium

Three luminous examples of cosmic-ray sources in an external galaxy.
HESS Collab. (2015)

30 Dor C is the first super-bubble detected at VHE.

Super-bubbles may provide the right conditions for **particle acceleration up to very high energies.**

Simulation includes currently detected sources, plus ten point-like sources with $L_{(E > 1\,TeV)}$ ~10^{34} erg s^{-1}, and a handful of regions enriched in cosmic rays.

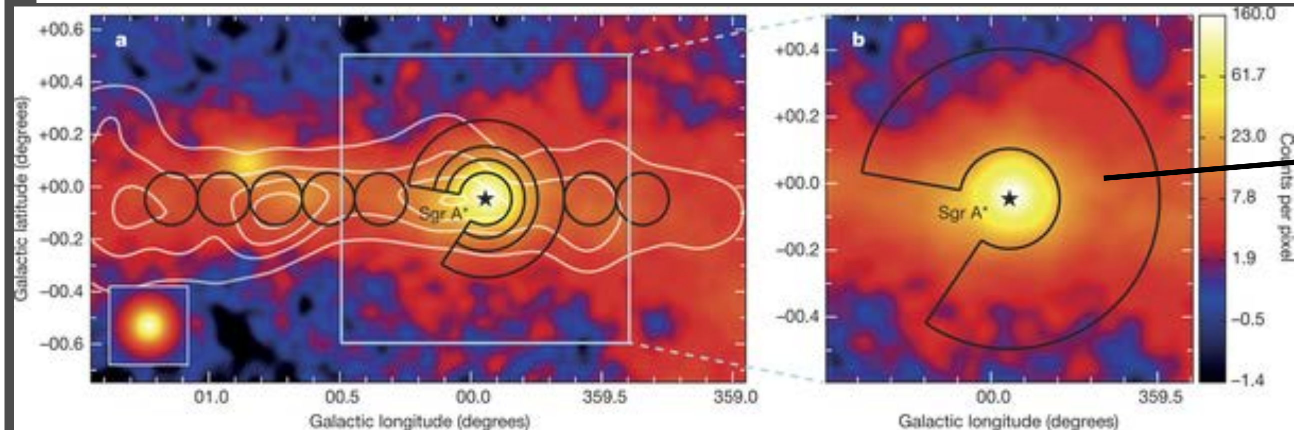
Excellent prospects for CTA investigations of the LMC.

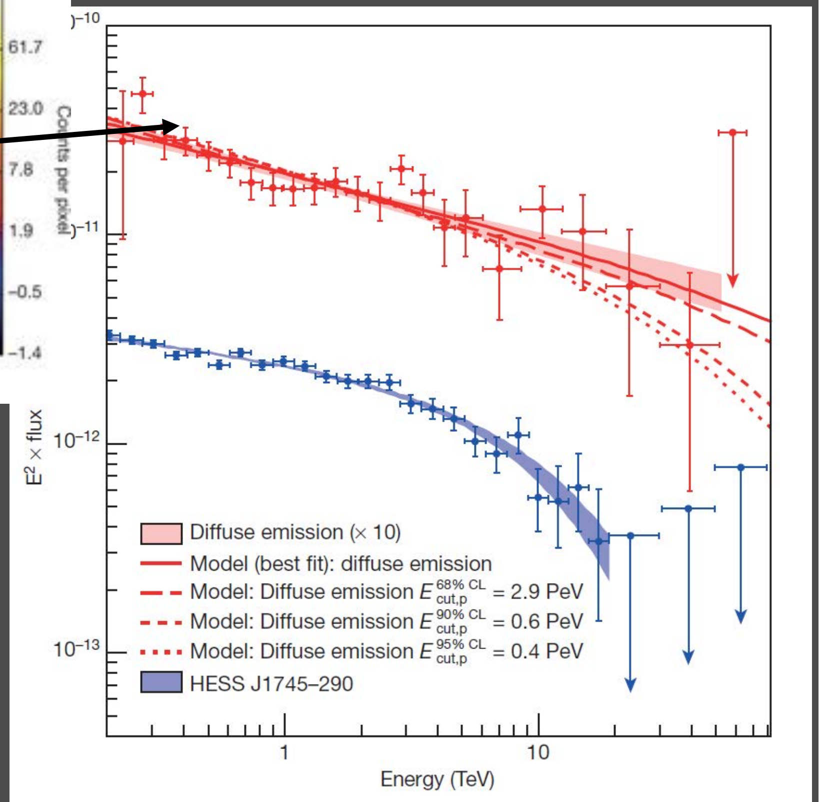
LETTER

doi:10.1038/nature17147

Acceleration of petaelectronvolt protons in the Galactic Centre

HESS Collaboration*



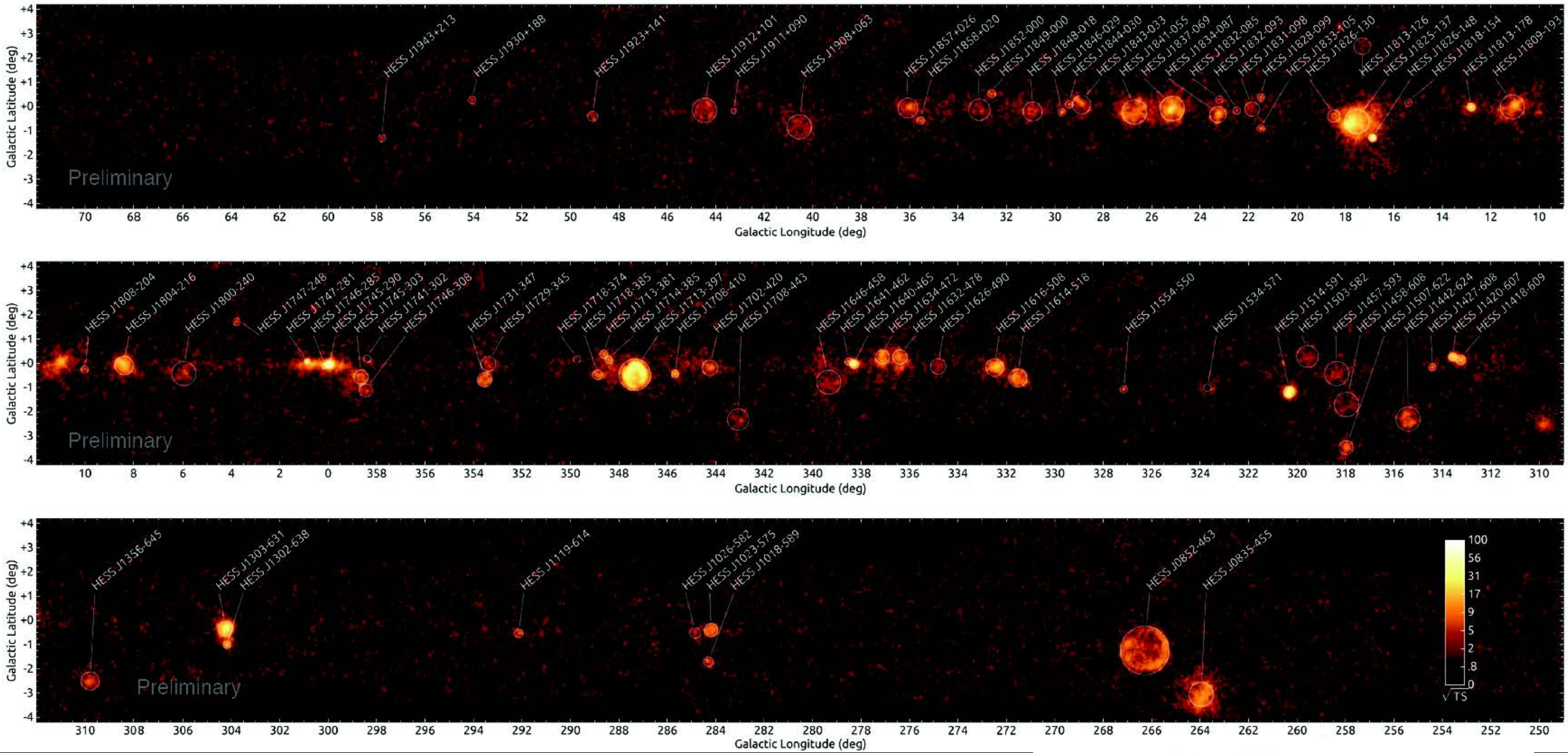


- Hard spectrum from diffuse region 70pc
- Cutoff ~ PeV energies
- Continous CR injector over ~few1000yr

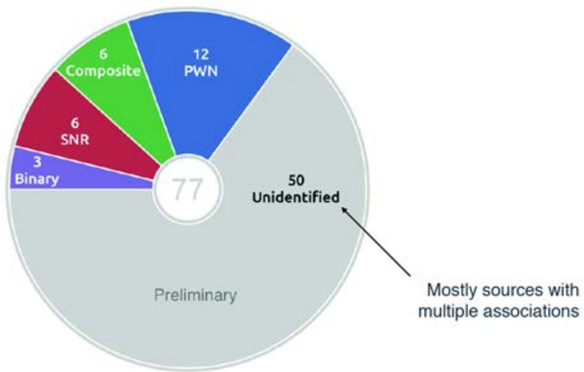
→ Central BH most likely accelerator
→ Could explain galactic CRs >0.1 PeV
if BH more active in past.
(SNRs may still contribute some PeV CRs)

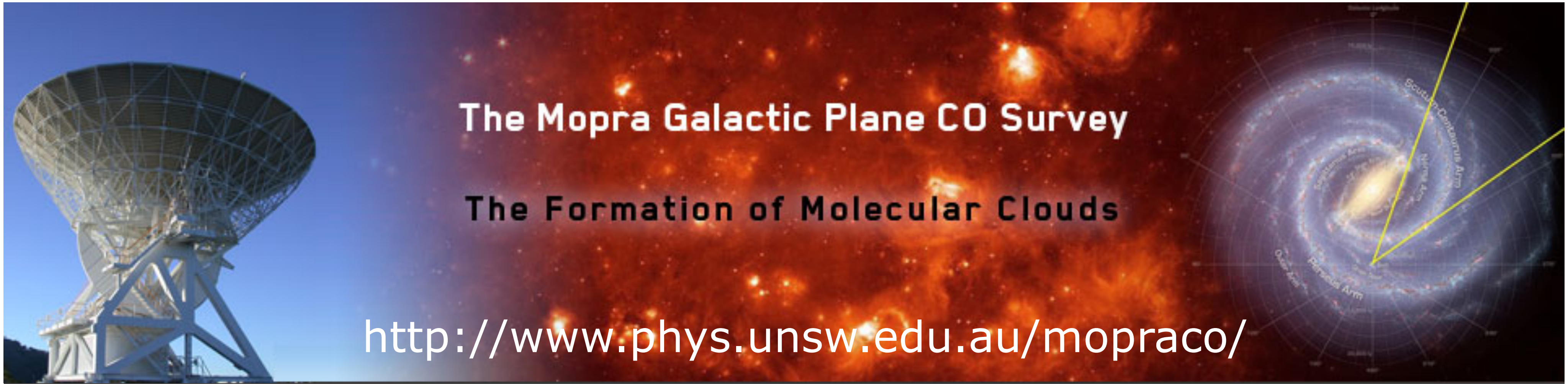
HESS Galactic Plane Survey (HGPS) – Skymaps
→ 77 sources (13 new sources)

Deil et al 2015



12 – pulsar wind nebulae
6 – SNRs
6 – composite SNRs
3 – binary (NS/BH + star)
50 – unidentified (confused associations) incl. G



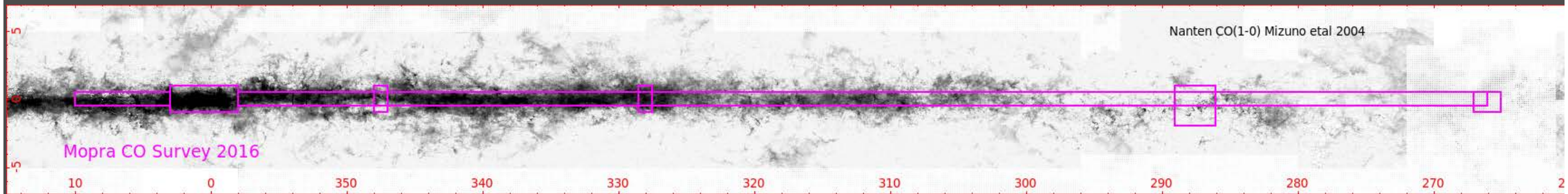


35” beam @ ~0.1 km/s resolution (also 70” CO survey Barnes etal 2015)

CO(1-0), ^{13}CO(1-0), C^{17}O(1-0), C^{18}O(1-0)

l = 265 to 358; b = ±0.5deg   mostly complete

extension to ±1.0deg l=2 to 10deg   (compare to Dame etal 2000 ~8arcmin beam)



Data cubes publicly available once processed

l = 320 – 330 deg available now

Complementary to Nanten2 CO (+ThruMMs) surveys over wider area

& Nobeyama CO survey (20” beam) in the north (Nishimura etal 2015)

& GASKAP HI/OH, VLA-THOR HI

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

Currently:
HESS follow-ups of Parkes SUPERB FRBs

Missing Gas :"Dark" HI & H_2

Inferred by MeV/GeV gamma-ray observations
e.g. Greiner etal 2005, Ackermann etal 2011

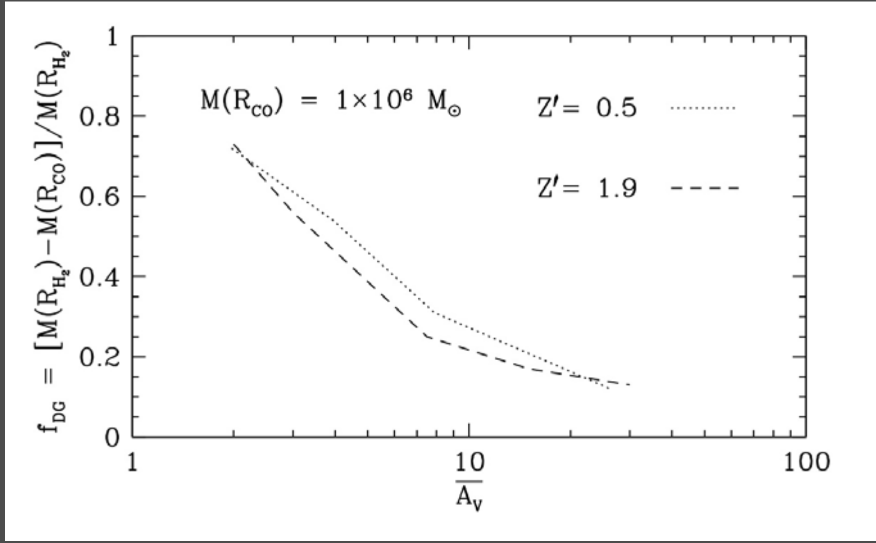
Dark molecular gas has little/no CO, but carbon and OH present

→ optically thick HI (Yasuo Fukui)

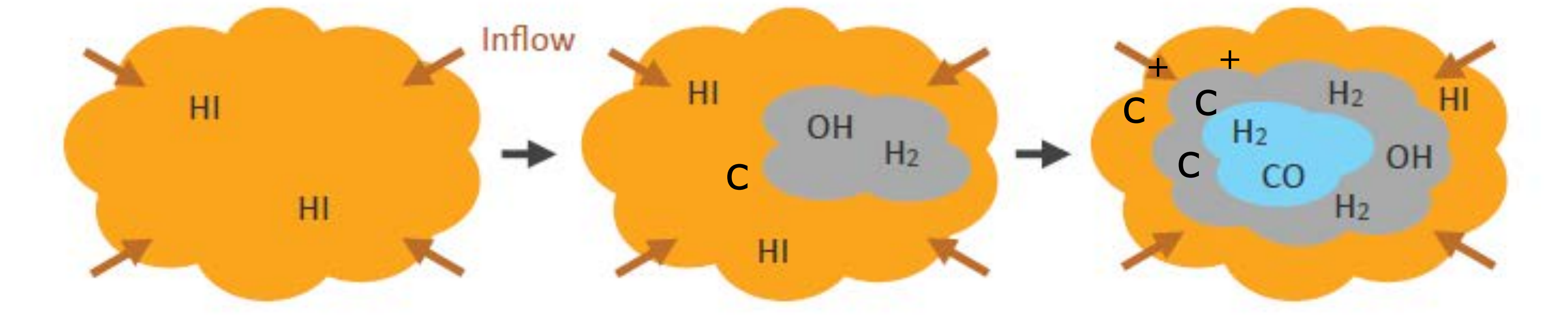
→ OH 1.6/1.7 GHz lines
(Parkes, ASKAP)

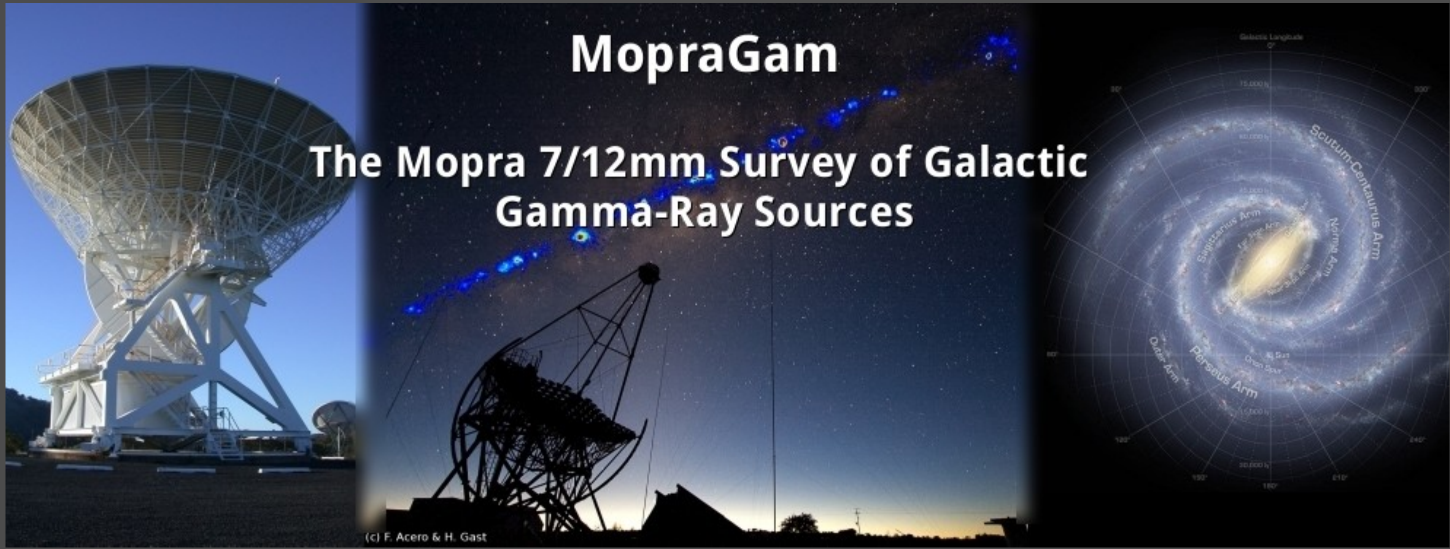
→ CI, C+ ~THz lines
(Nanten2, HEAT, STO2, SOFIA, STO2, DATE5,)

Perhaps one-third of the molecular gas is "dark"?!
Wolfire, Hollenbach & McKee, 2010



Graphic adapted from J. Dawson





http://www.physics.adelaide.edu.au/astrophysics/MopraGam/

Main ISM Tracers

CS(1-0), SiO(1-0), CH_3OH

Targets

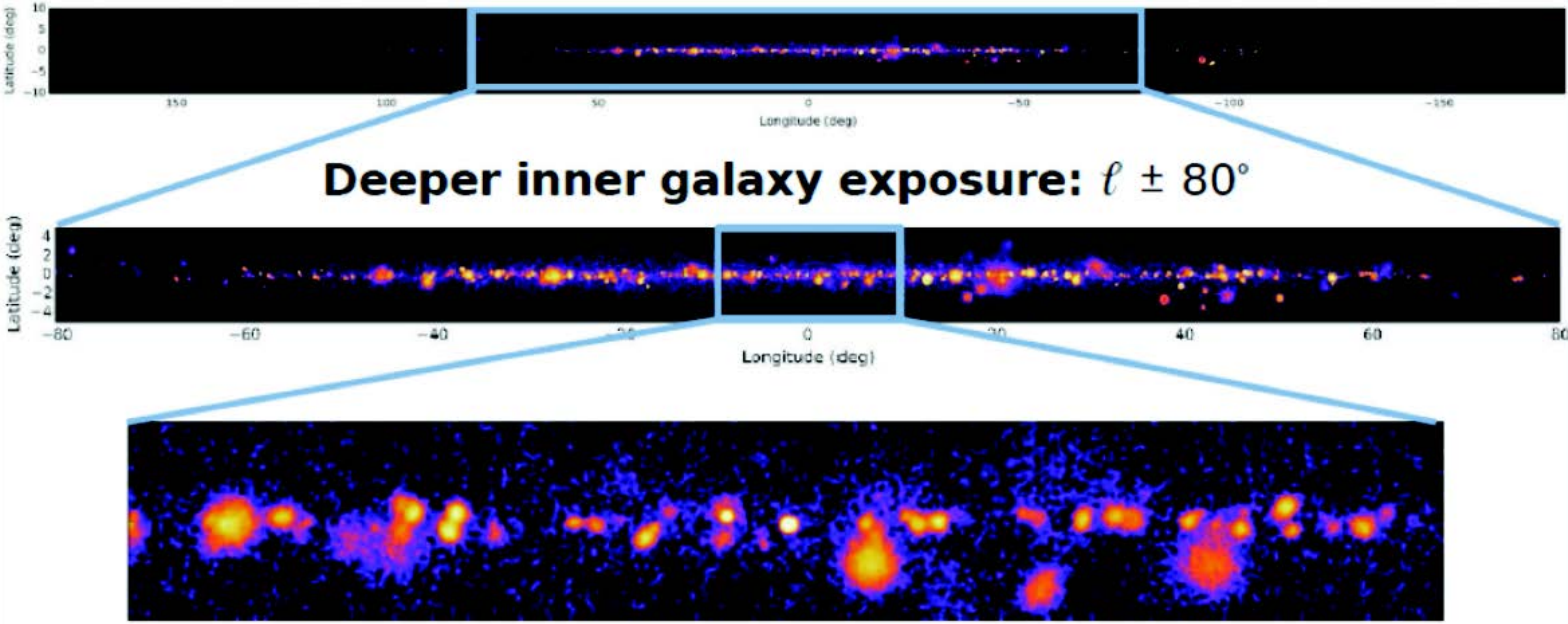
Since 2012 observed over ~40 bright UnID TeV gamma and high energy sources (>1500 hrs)

→ Determine distance to cloud components (often difficult with CO)
→ Understand particle propagation
→ Disentangle hadronic/leptonic components

Coverage is limited to discrete sources → ATCA Systematic survey MALT45+

Galactic Plane Survey

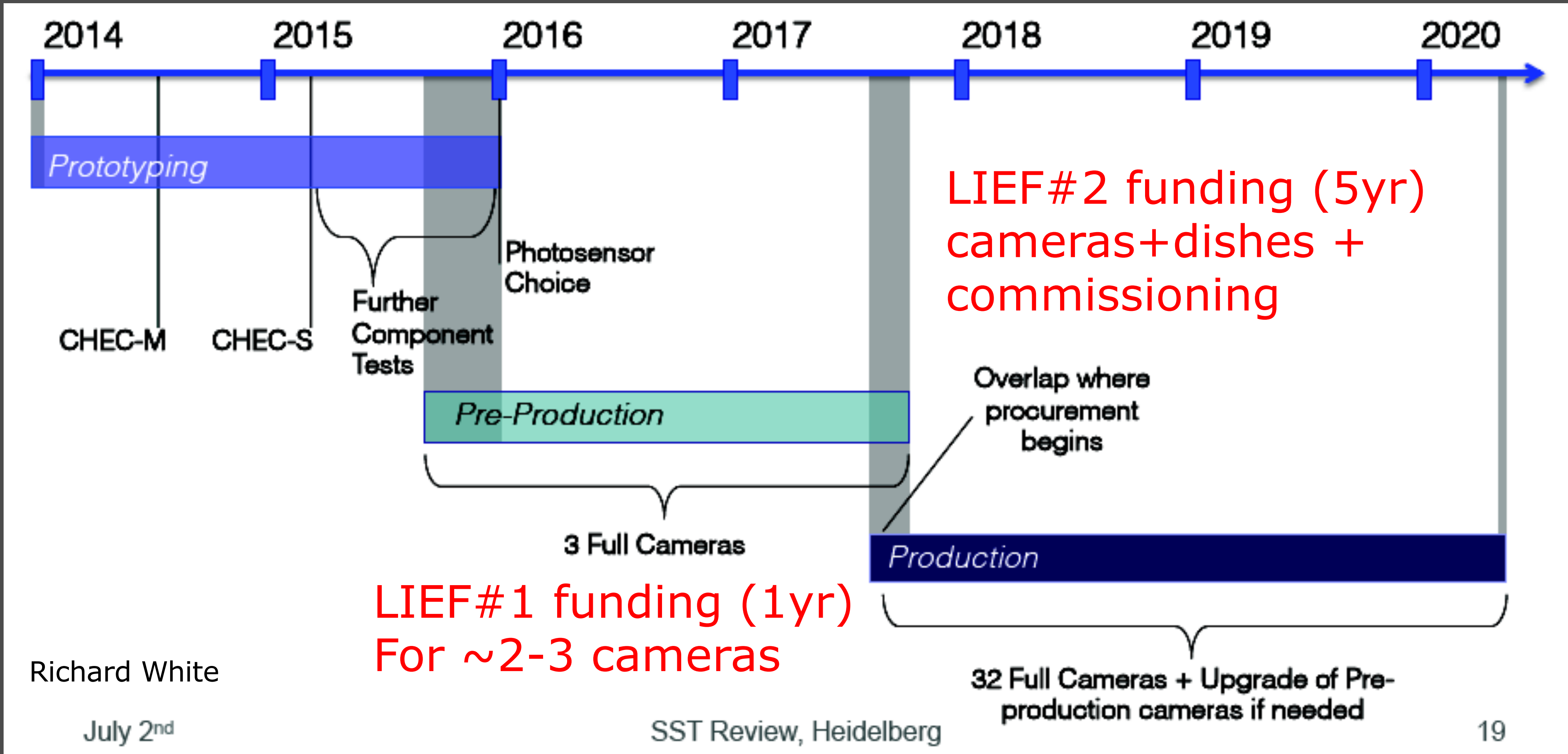
Full-plane coverage: longitude ± 180°, latitude *b* ± 10°



Fine detail revealed with **~arcmin PSF**

J. Knödlseder and CTA Consortium

Timeline for CTA Small Size Telescopes (SST-GCT) Sub-consortium (aim 35 telescopes)



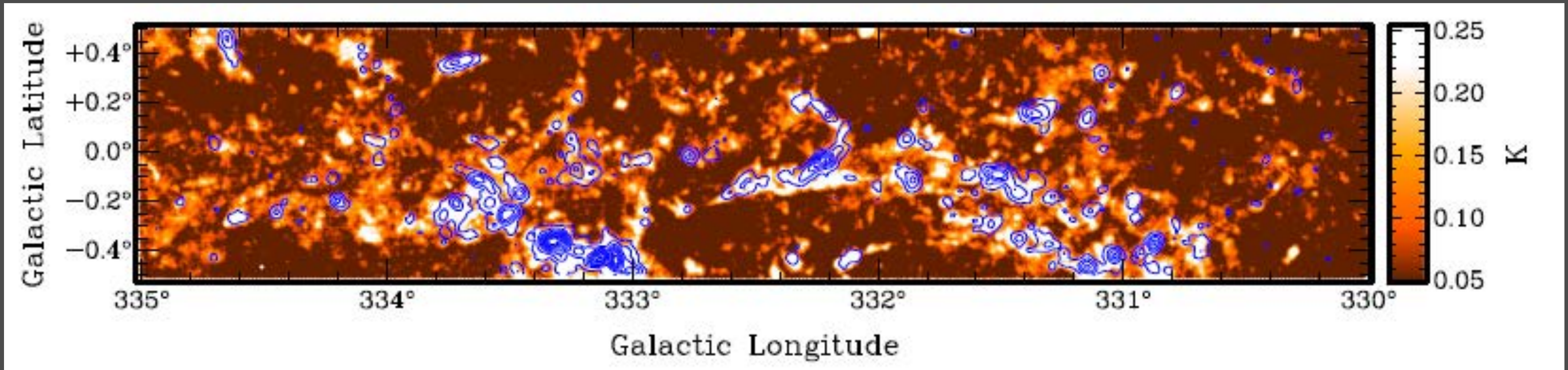
Timeline for all other aspects of CTA v. similar..

MALT45 7mm Survey with ATCA

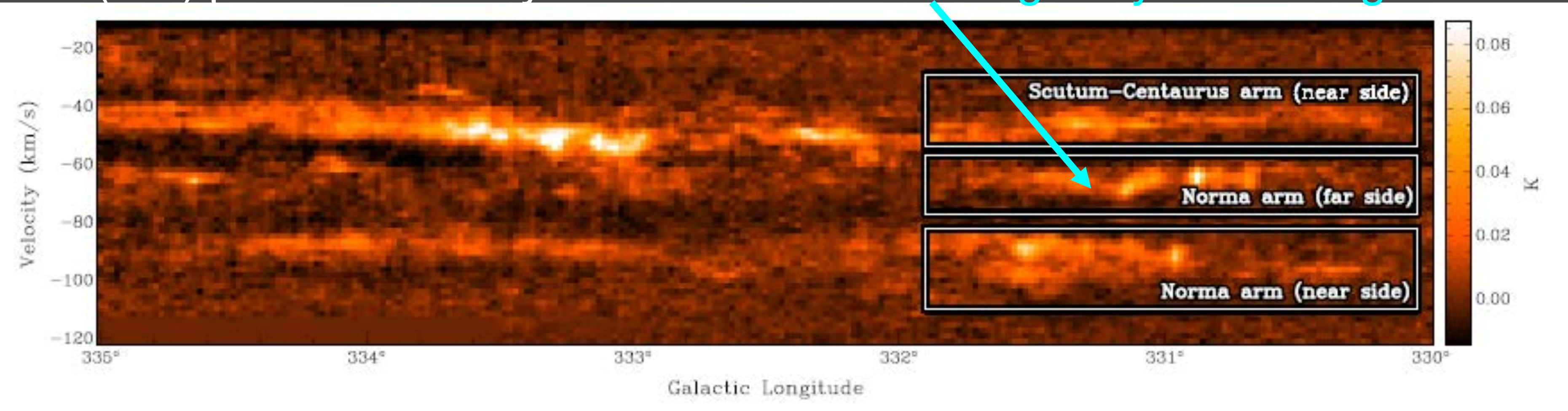
(Jordan etal 2013, 2015)

> 5x more sensitive than Mopra

CS(1-0) peak pixel image with HOPS NH3(1,1) contours

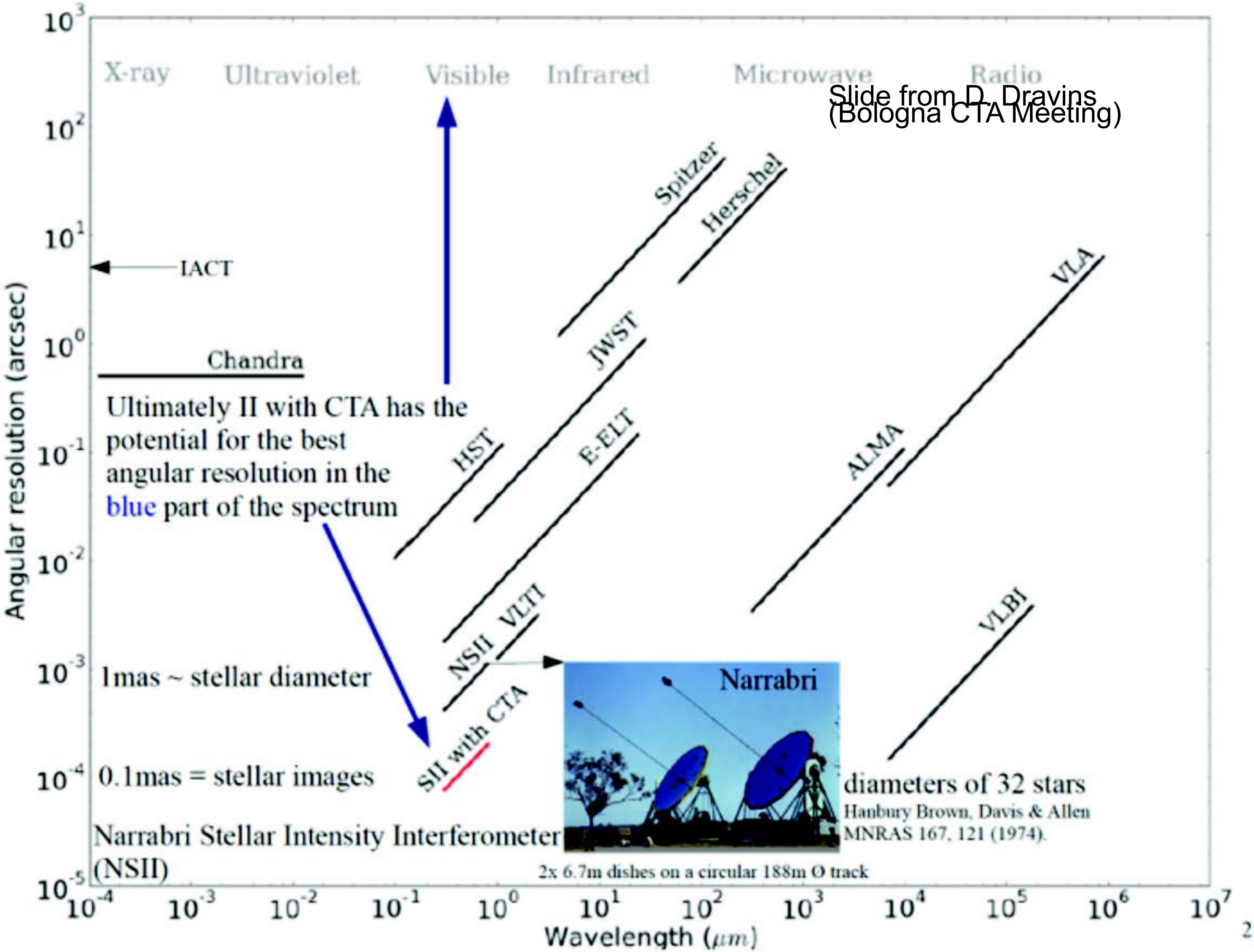


CS(1-0) position/velocity → can see far side of galaxy in dense gas!



Proposal to extend to “Full Strength MALT 45” l = 300 to 360

→ dense gas ISM survey: Essential legacy for CTA's Galactic science

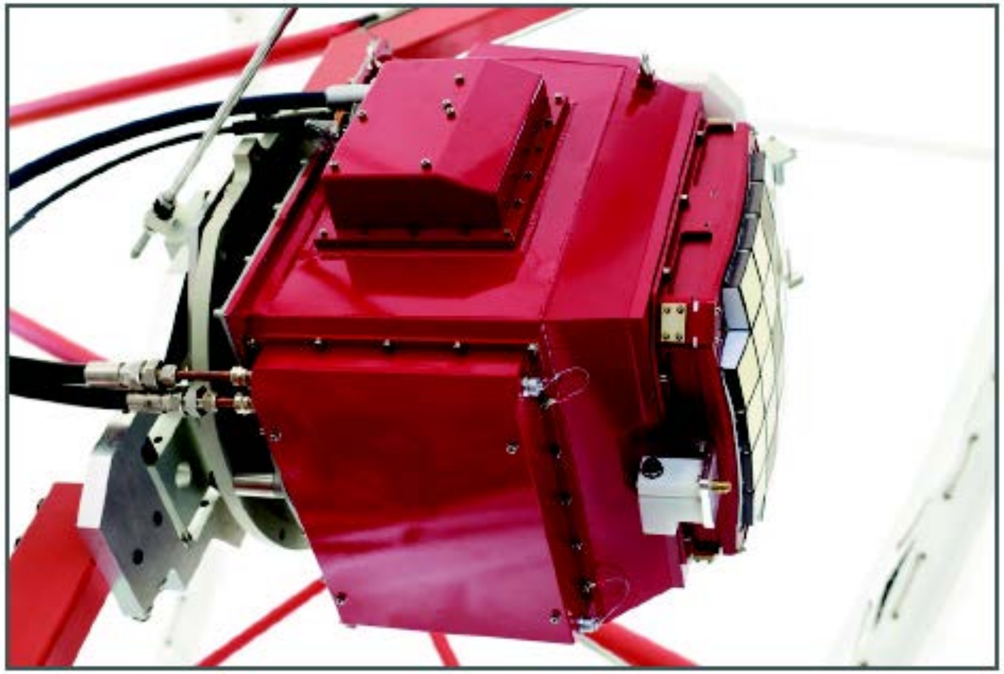

Slide from D. Dravins
(Bologna CTA Meeting)
X-ray
Ultraviolet
Visible
Infrared
Microwave
Radio
IACT
Chandra
Spitzer
Herschel
JWST
HST
E-ELT
VLA
ALMA
VLTI
NSII
VLBI
SII with CTA
Ultimately II with CTA has the potential for the best angular resolution in the blue part of the spectrum
1mas ~ stellar diameter
0.1mas = stellar images
Narrabri Stellar Intensity Interferometer (NSII)
Narrabri
diameters of 32 stars
Hanbury Brown, Davis & Allen
MNRAS 167, 121 (1974).
2x 6.7m dishes on a circular 188m Ø track
Angular resolution (arcsec)
Wavelength (μm)

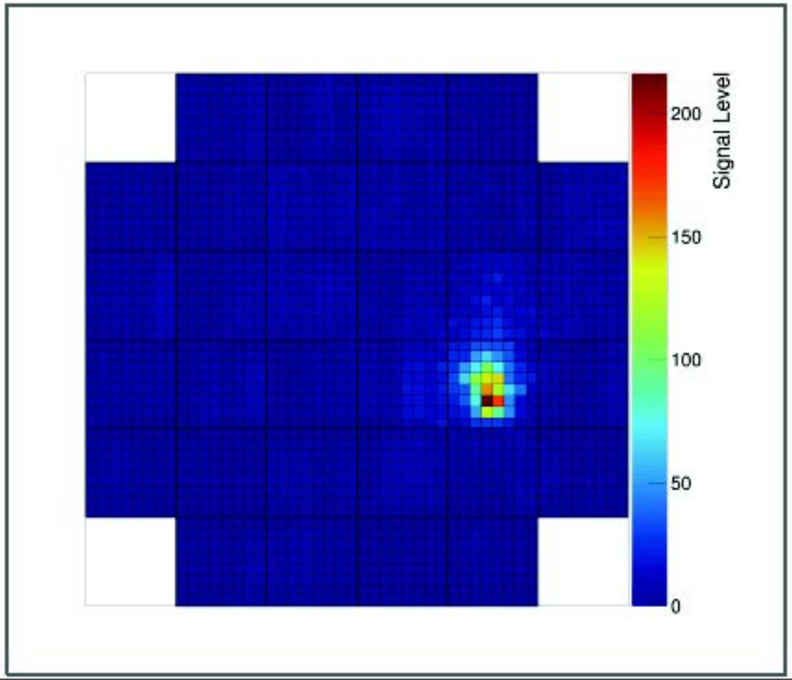
FOR IMMEDIATE RELEASE
8 December 2015

CTA Prototype Telescope Achieves "First Light"

Paris, France – On 26 November 2015, a prototype telescope proposed for the Cherenkov Telescope Array, the Gamma-ray Cherenkov Telescope (GCT-Figure 1), recorded CTA's first ever Cherenkov light while undergoing testing at l'Observatoire de Paris in Meudon, France. The GCT is proposed as one of CTA's small size telescopes (SSTs), covering the high end of the CTA energy range, between about 1 and 300 TeV (tera-electronvolts). Another SST prototype, the ASTRI telescope, captured the first optical image in May 2015 with its diagnostic camera.

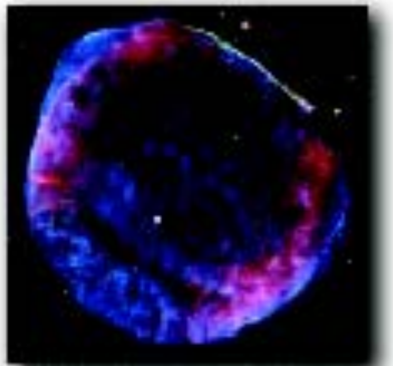
FIGURE 1: GCT Prototype





CTA Main Scientific Themes

Cosmic Particle Acceleration

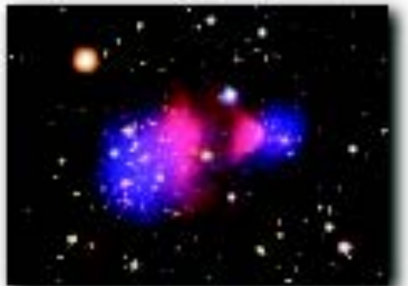


- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Probing Extreme Environments

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

Physics frontiers – beyond the Standard Model

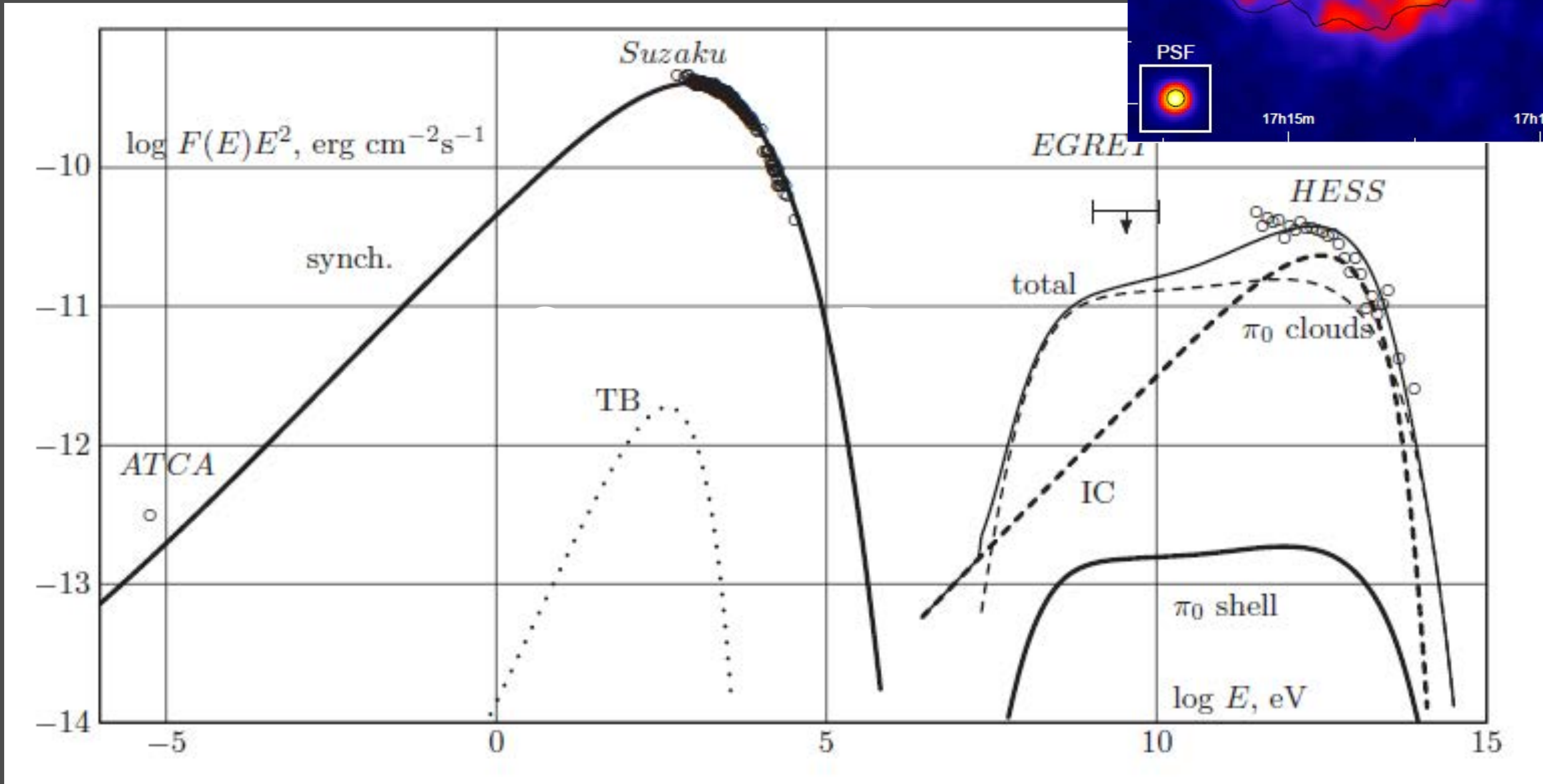


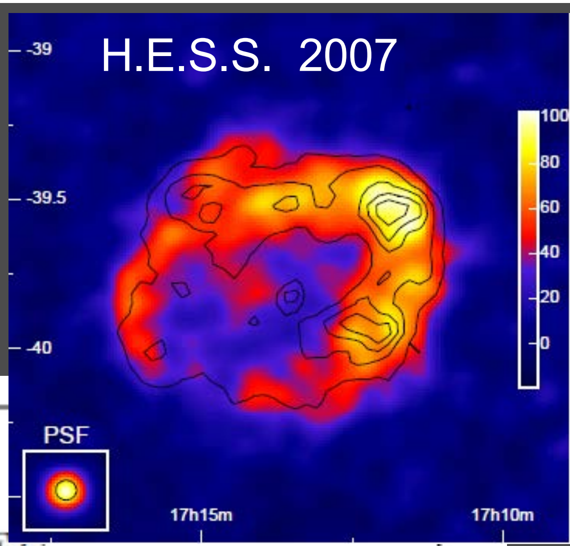
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high-energy photons?
- Do axion-like particles exist?

Adapted from J. Knödlseder.
More information on Astroparticle Physics, Vol. 43, 1-356 (2013) & CTA Contributions to the 2015 ICRC Conference [arXiv:1508.05894]

Radio to TeV SED:
Young Supernova Remnant
RXJ1713.7-3946

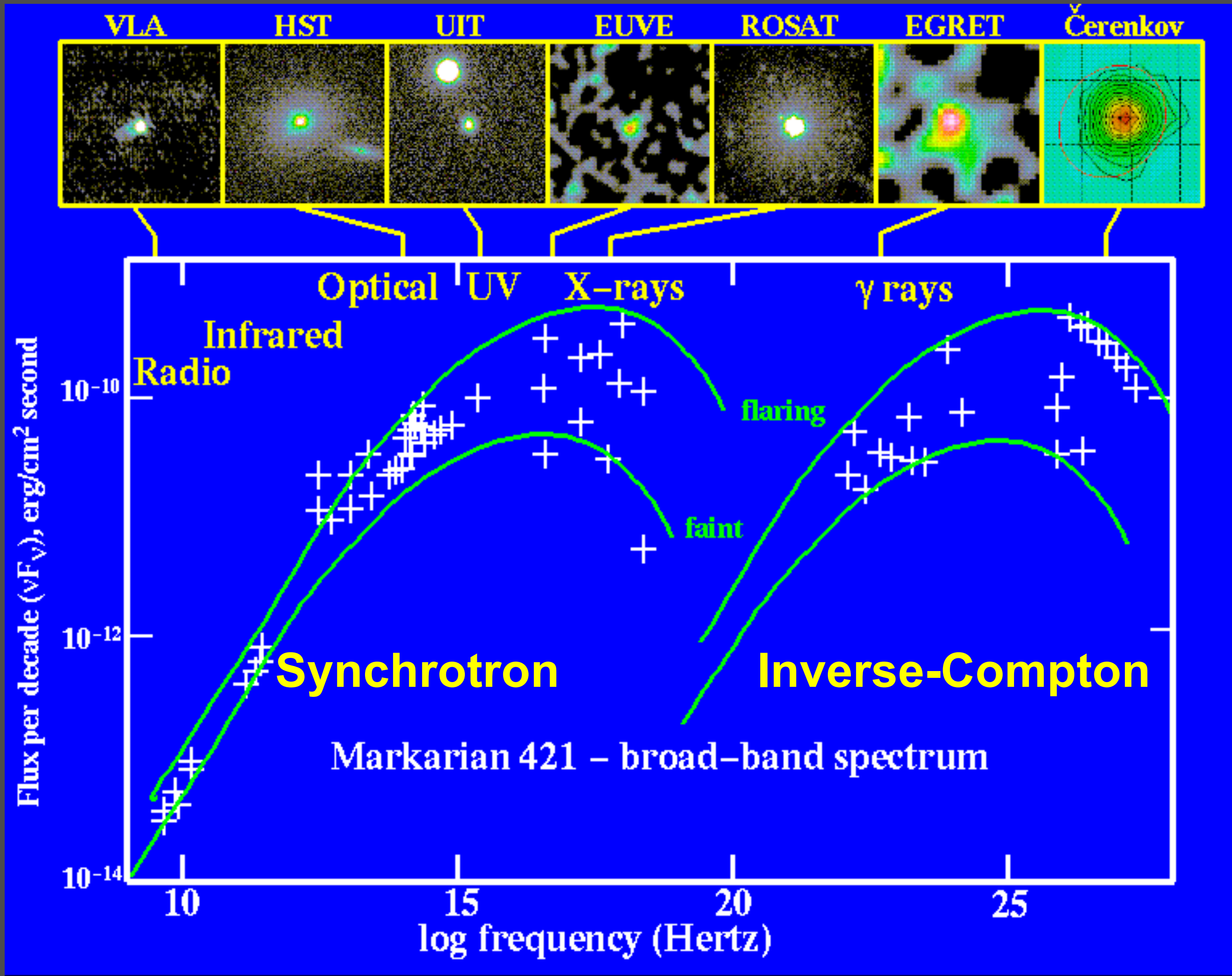
e.g. Zirakashivilli & Aharonian 2010





ATCA, Parkes, MOST used in many Galactic gamma source studies: SNRs, Pulsar Wind Nebulae, Pulsars, Massive stellar clusters...

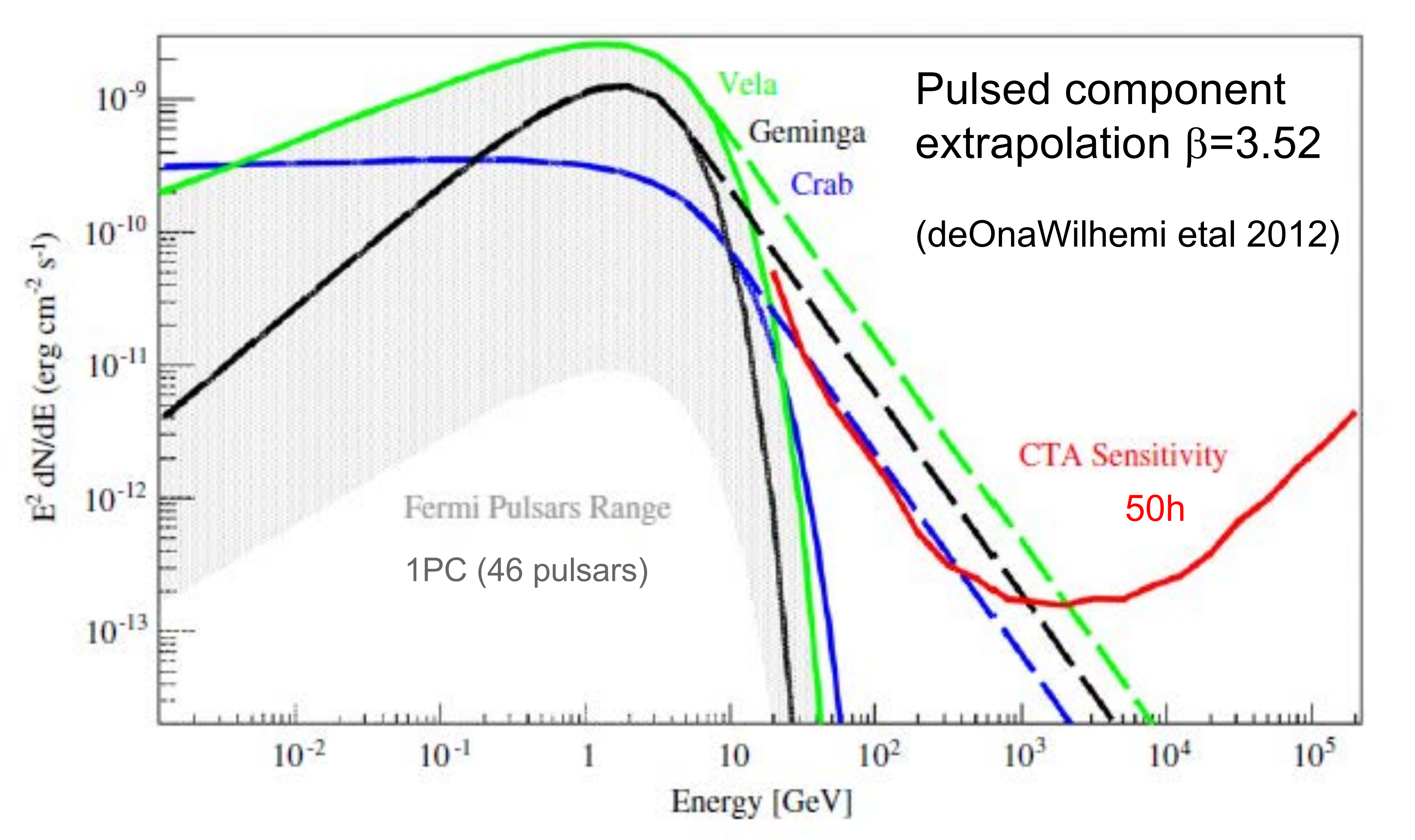
Radio to TeV SED: AGN Blazars



http://vega.bac.pku.edu.cn/~wuxb/agn/text.html

ATCA (+ MWA recently) used in gamma blazar/AGN studies
– e.g. flare follow-ups

CTA : Prospects for pulsed emission studies



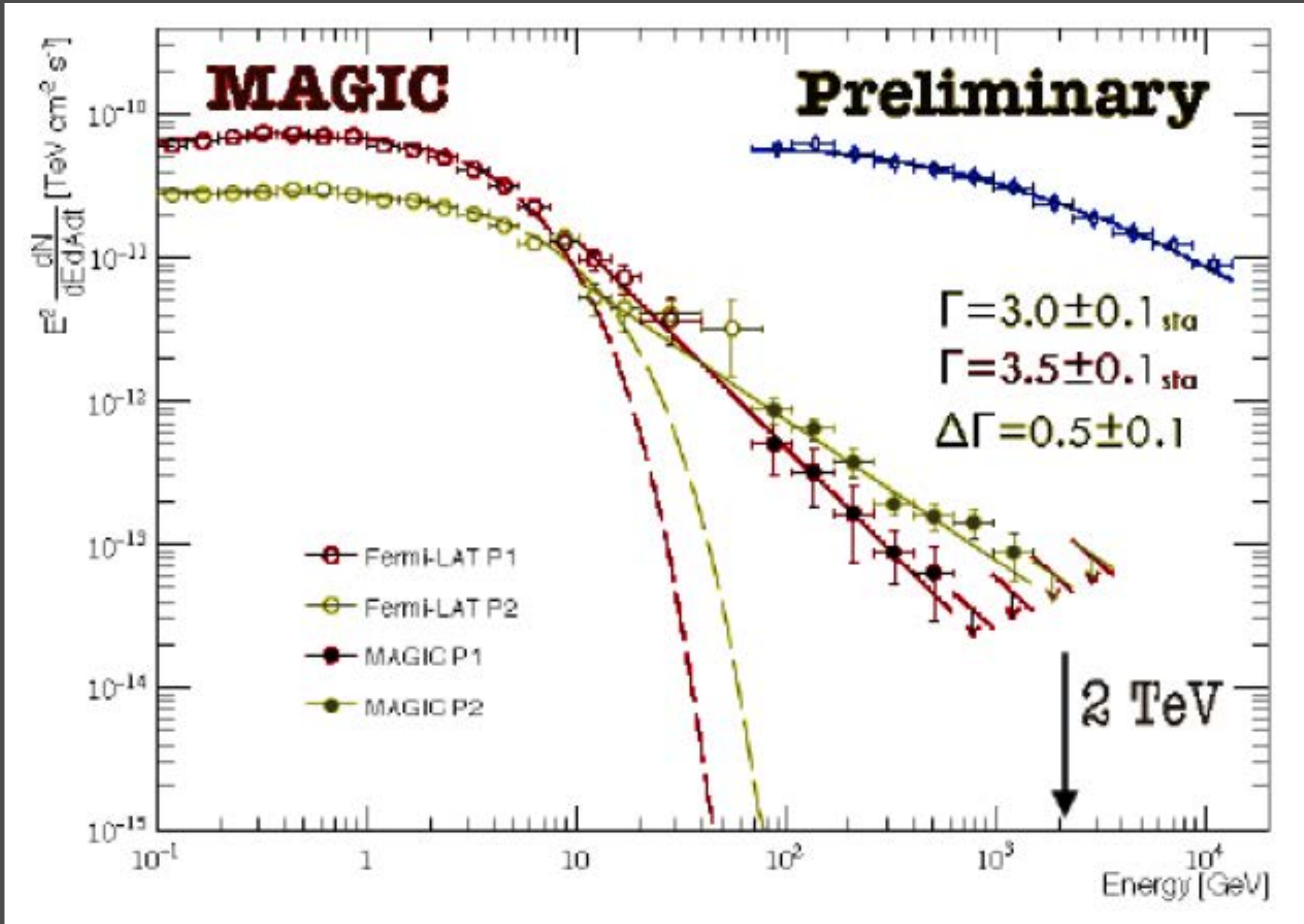
Assume Crab-like power law extension

→ ~40% of Fermi 1PC pulsars potentially detectable (optimistic?)

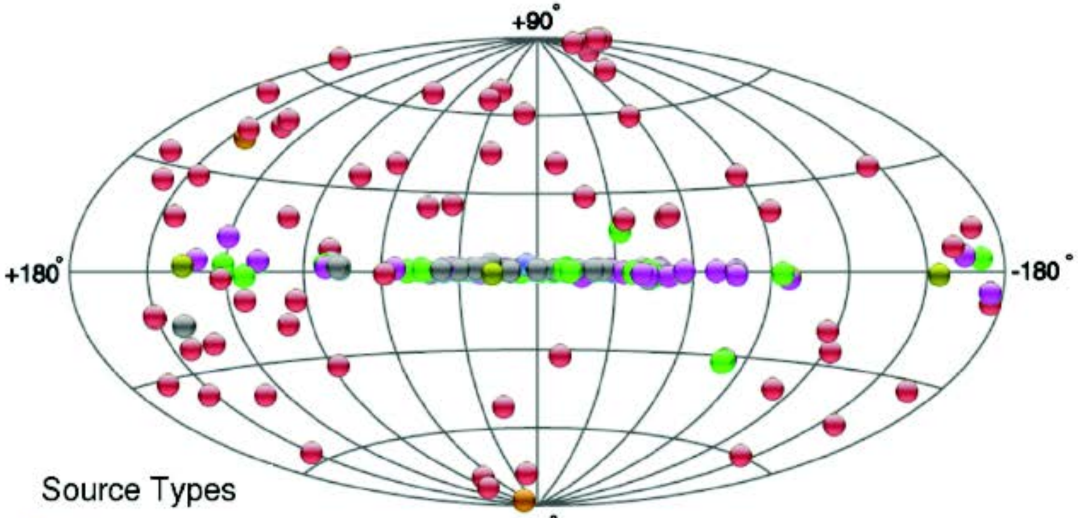
- Vela pulsar now detected by HESS-II

- Crab pulsed to >1 TeV → new electron component needed → new opportunities for CTA.

Crab Pulsed Emission (MAGIC Collab. ICRC2015)

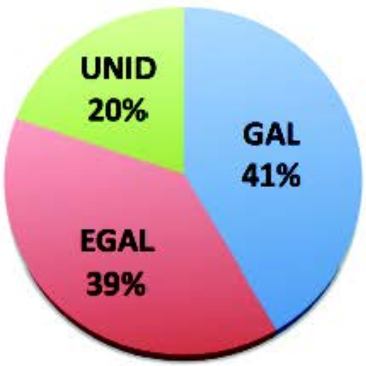


The Sky above 50 GeV

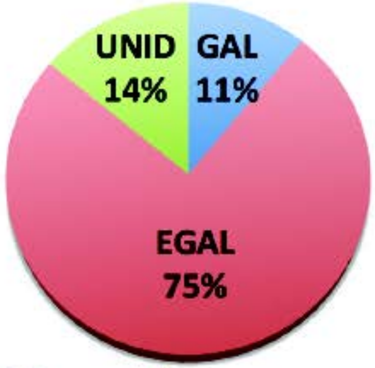


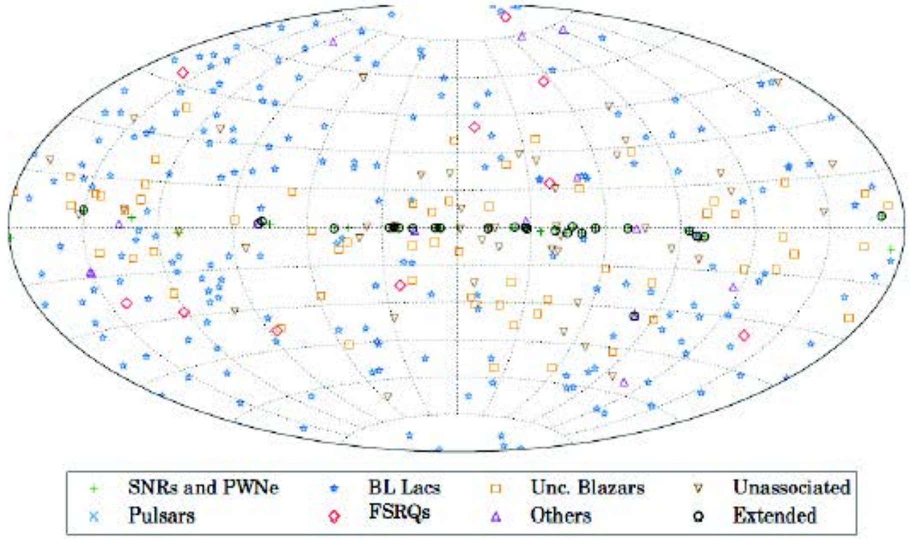
Wakely & Horan http://tevcat.uchicago.edu/

175 TeVCat sources



360 F-LAT sources E>50 GeV

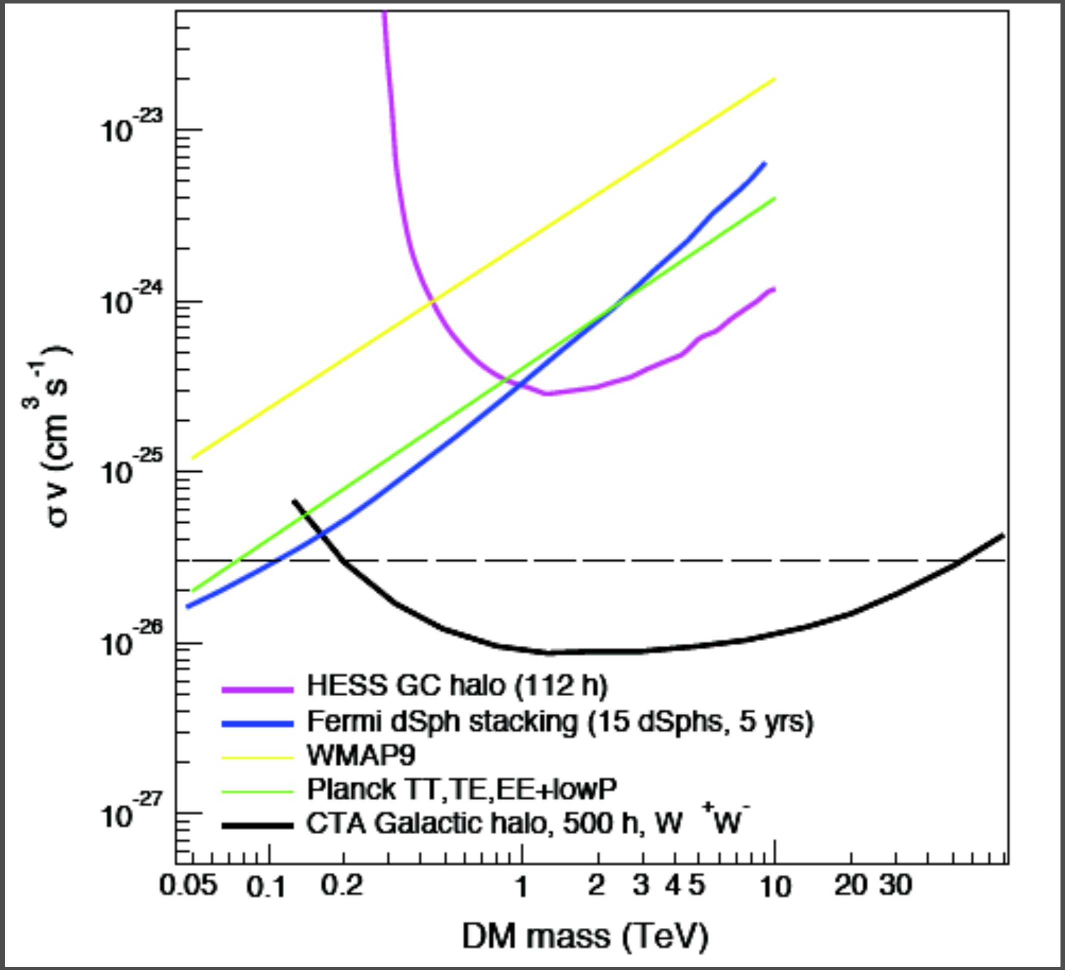




2FHL Ackermann et al., 2016, ApJS, 222, 5

Only 25% of the 2FHL sources have been previously detected by Cherenkov telescopes.
2FHL provides a reservoir of candidates to be followed up at very high energies.

CTA Dark Matter
W^+W^-



CTA Consortium - Science Case (in prep)

TeV gamma-ray production:

1. Cooling Time t = E / (dE/Dt)

Pi-zero decay: $t_{pp} = (n\sigma_{pp} f c)^{-1} \approx 5.3 \times 10^7 (n/\mathrm{cm}^3)^{-1}$ yr

IC scattering: $t_{IC} \approx 3 \times 10^8 (U_{rad}/\mathrm{eV}/\mathrm{cm}^3)^{-1} (E_e/\mathrm{GeV})^{-1})$ yr

Bremsstrahlung: $t_{br} \approx 4 \times 10^7 (n/\mathrm{cm}^3)^{-1}$ yr

Synchrotron: $t_{sync} \approx 12 \times 10^6 (B/\mu\mathrm{G})^{-2} (E_e/\mathrm{TeV})^{-1}$ yr

Cooling times lead to radiative propagation limits for particles

2. Diffusive Transport: **distance ~ $[6\ D(E,B)\ t]^{0.5}$**

(for turbulent B-field)

for diffusion coefficient D(E,B)

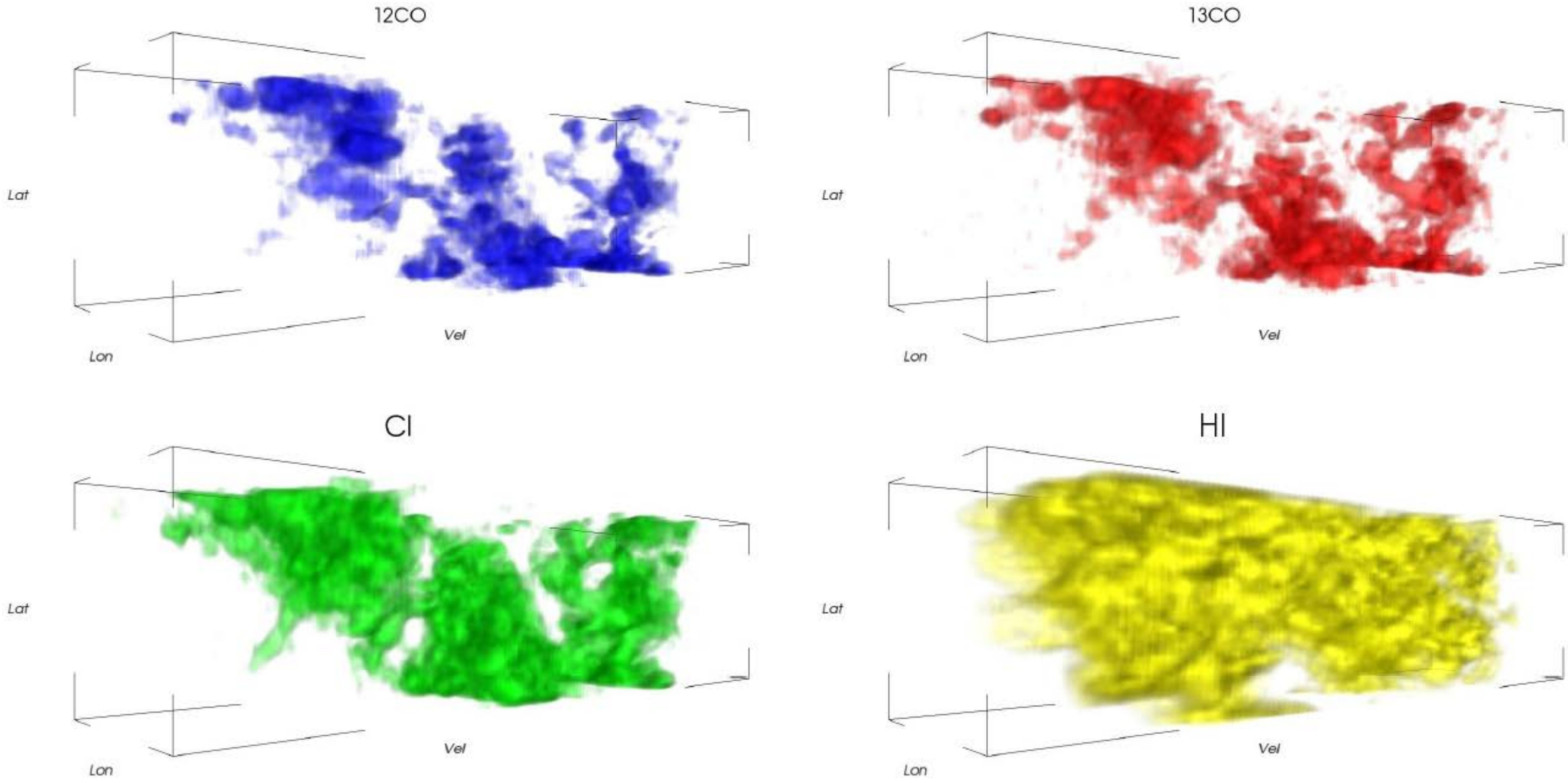
ISM density n; B-Field B(n)

→ ISM has critical influence on gamma-ray source size and spectra.

→ Need to measure ISM over degree scales, and at arc-min resolution

CI, CO, HI towards G328 region (1x1 deg) **(Burton et al 2013, 2015)**

CI (2-1) – HEAT 2' beam
CO(1-0) – Mopra 30” beam
HI – Parkes/ACTA 2' beam



3D pixel (voxel) analyis → 50% increase in CI / ^{13}CO ratio at cloud edges.

CTA Observatory gGmbH

Founded in summer 2014; located at Heidelberg

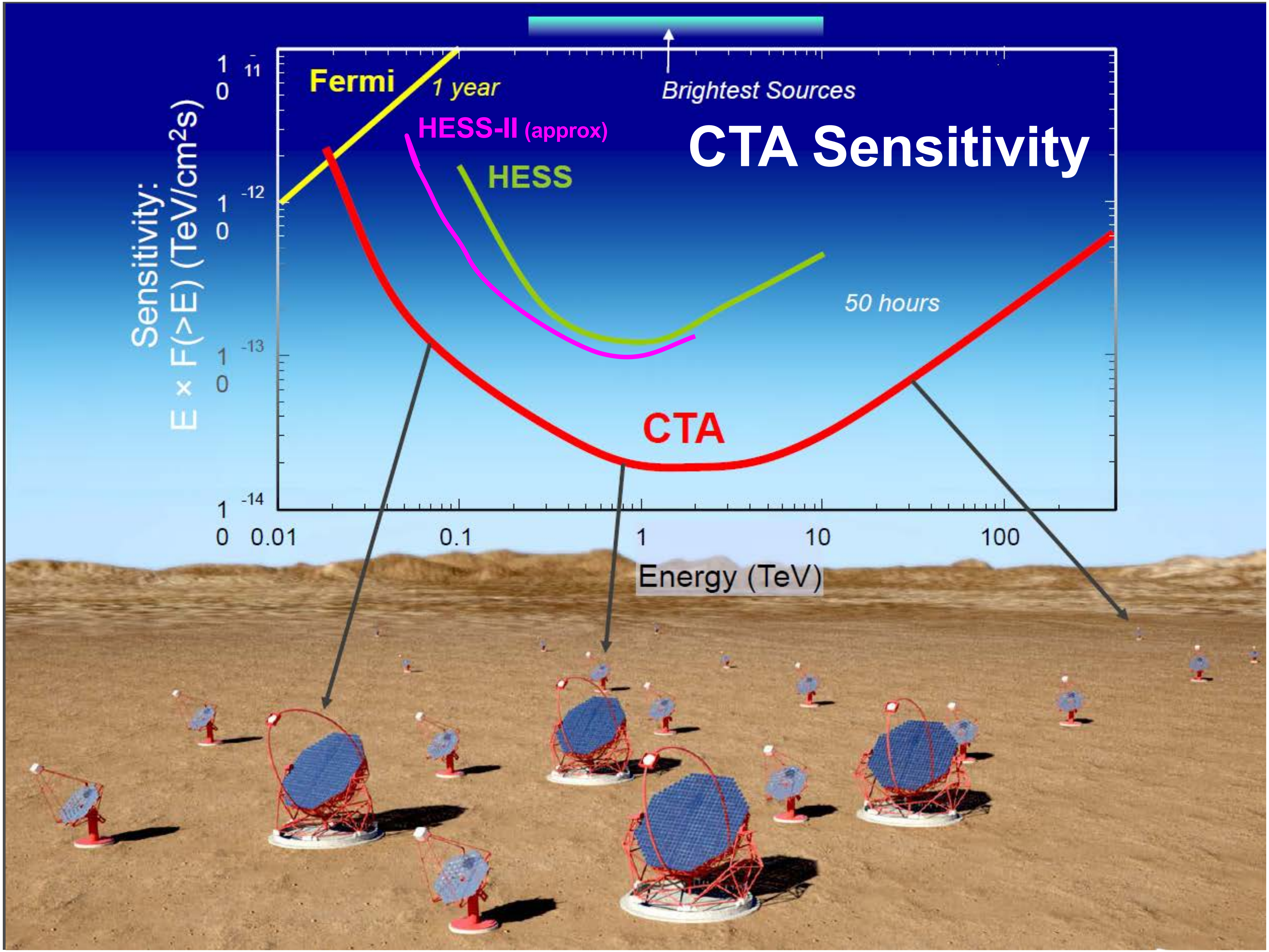
Shareholders

- Austria (Univ. Innsbruck)
- Czech Republic (Academy of Sciences)
- France (CNRS, CEA)
- Germany (DESY, MPG)
- Italy (INAF)
- Japan (ICRC)
- Spain (IAC)
- Switzerland (Univ. Zurich)
- UK (STFC)

Associates

- Netherlands
- South Africa
- Sweden

Provides legal and organisational framework
Runs central CTA Project Office



CTA Sensitivity
Brightest Sources
Fermi
1 year
HESS-II (approx)
HESS
50 hours
CTA
Sensitivity:
E × F(>E) (TeV/cm2s)
10-11
10-12
10-13
10-14
0.01
0.1
1
10
100
Energy (TeV)

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Cherenkov telescopes as optical telescopes for bright sources: today's specialized 30-m telescopes?

Brian C. Lacki[1,2]★

[1]*Department of Astronomy, The Ohio State University, 140 West 18th Avenue, Columbus, OH 43210, USA*
[2]*Center for Cosmology and Astro-Particle Physics, The Ohio State University, Columbus, OH 43210, USA*

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ABSTRACT

Imaging Atmospheric Cherenkov Telescopes (IACTs) use large-aperture (3–30 m) optical telescopes with arcminute angular resolution to detect TeV gamma-rays in the atmosphere. I show that IACTs are well suited for optical observations of bright sources ($V \lesssim 8$–10), because these sources are brighter than the sky background. Their advantages are especially great on rapid time-scales. Thus, IACTs might study many phenomena optically, including transiting exoplanets and the brightest gamma-ray bursts. In principle, an IACT could achieve millimagnitude photometry of these objects with second-long exposures. I also consider the potential for optical spectroscopy with IACTs, finding that their poor angular resolution limits their usefulness for high spectral resolutions, unless complex instruments are developed. The high photon collection rate of IACTs is potentially useful for precise polarimetry. Finally, I briefly discuss the broader possibilities of extremely large, low-resolution telescopes, including a 10 arcsec resolution telescope and space-borne telescopes.

Key words: techniques: photometric – techniques: polarimetric – techniques: spectroscopic – telescopes.

Milli-mag optical photometry and occultation studies.

On the Use of Cherenkov Telescopes for Outer Solar System Body Occultations

Brian C. Lacki[1]
[1] *Institute for Advanced Study, Einstein Drive, Princeton, NJ 08540, USA, brianlacki@ias.edu*

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ABSTRACT

Imaging Atmosphere Cherenkov Telescopes (IACT) are arrays of very large optical telescopes that are well-suited for rapid photometry of bright sources. I investigate their potential in observing stellar occultations by small objects in the outer Solar System, Transjovian Objects (TJOs). These occultations cast diffraction patterns on the Earth. Current IACT arrays are capable of detecting objects smaller than 100 metres in radius in the Kuiper Belt and 1 km radius out to 5000 AU. The future Cherenkov Telescope Array (CTA) will have even greater capabilities. Because the arrays include several telescopes, they can potentially measure the speeds of TJOs without degeneracies, and the sizes of the TJOs and background stars. I estimate the achievable precision using a Fisher matrix analysis. With CTA, the precisions of these parameter estimations will be as good as a few percent. I consider how often detectable occultations occur by members of different TJO populations, including Centaurs, Kuiper Belt Objects (KBOs), Oort cloud objects, and satellites and Trojans of Uranus and Neptune. The great sensitivity of IACT arrays means that they likely detect KBO occultations once every $\mathcal{O}(10)$ hours when looking near the ecliptic. IACTs can also set useful limits on many other TJO populations.

Key words: Kuiper belt: general — Oort cloud — minor planets, asteroids, general — occultations

CTA Key Science Projects

Key Science Projects

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
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?		✔		✔				✔✔	✔	✔
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?					✔	✔			✔✔	
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?					✔	✔			✔✔	

Surveys

Targets

From CTA AGN overview by Sol etal 2013

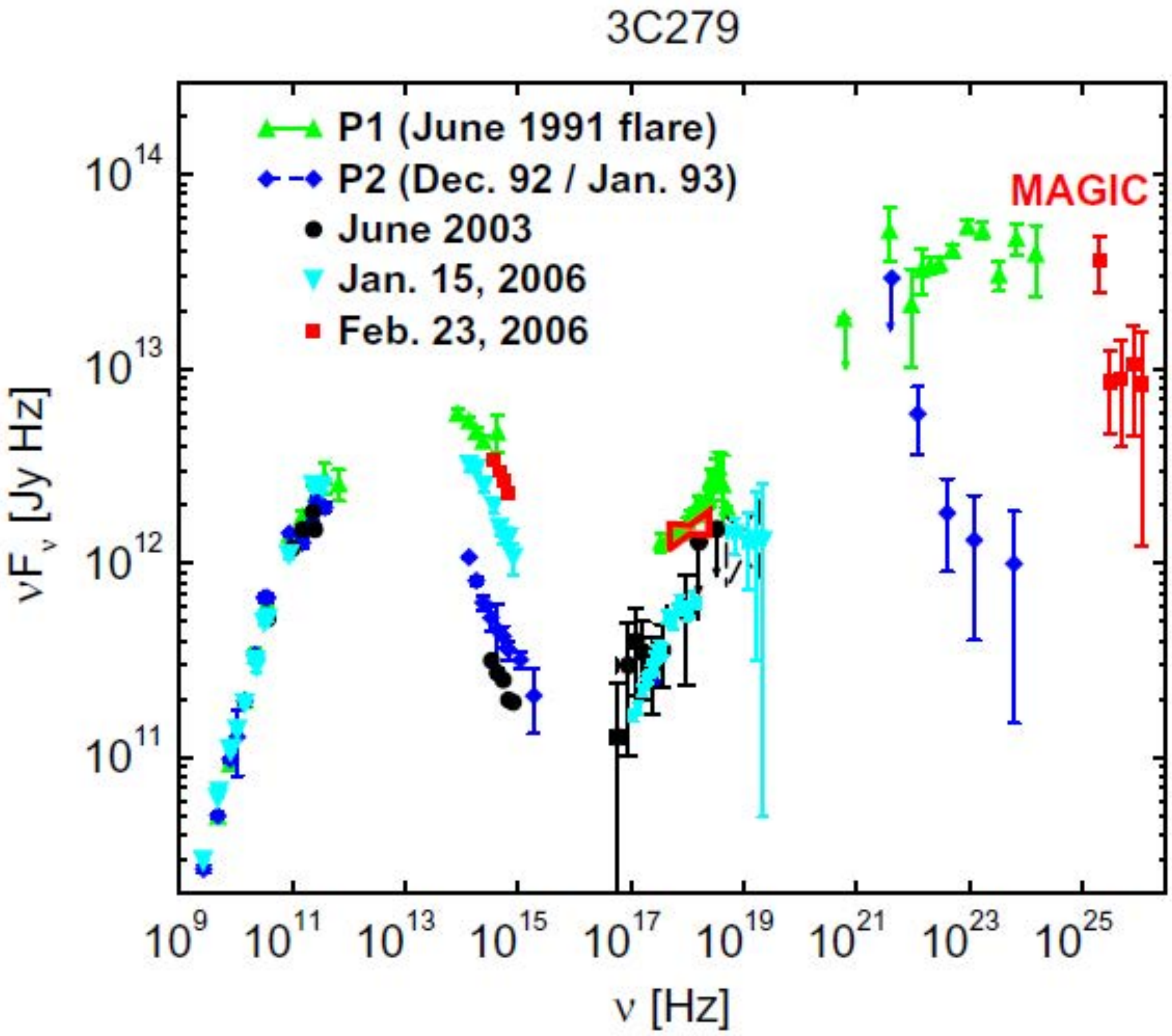
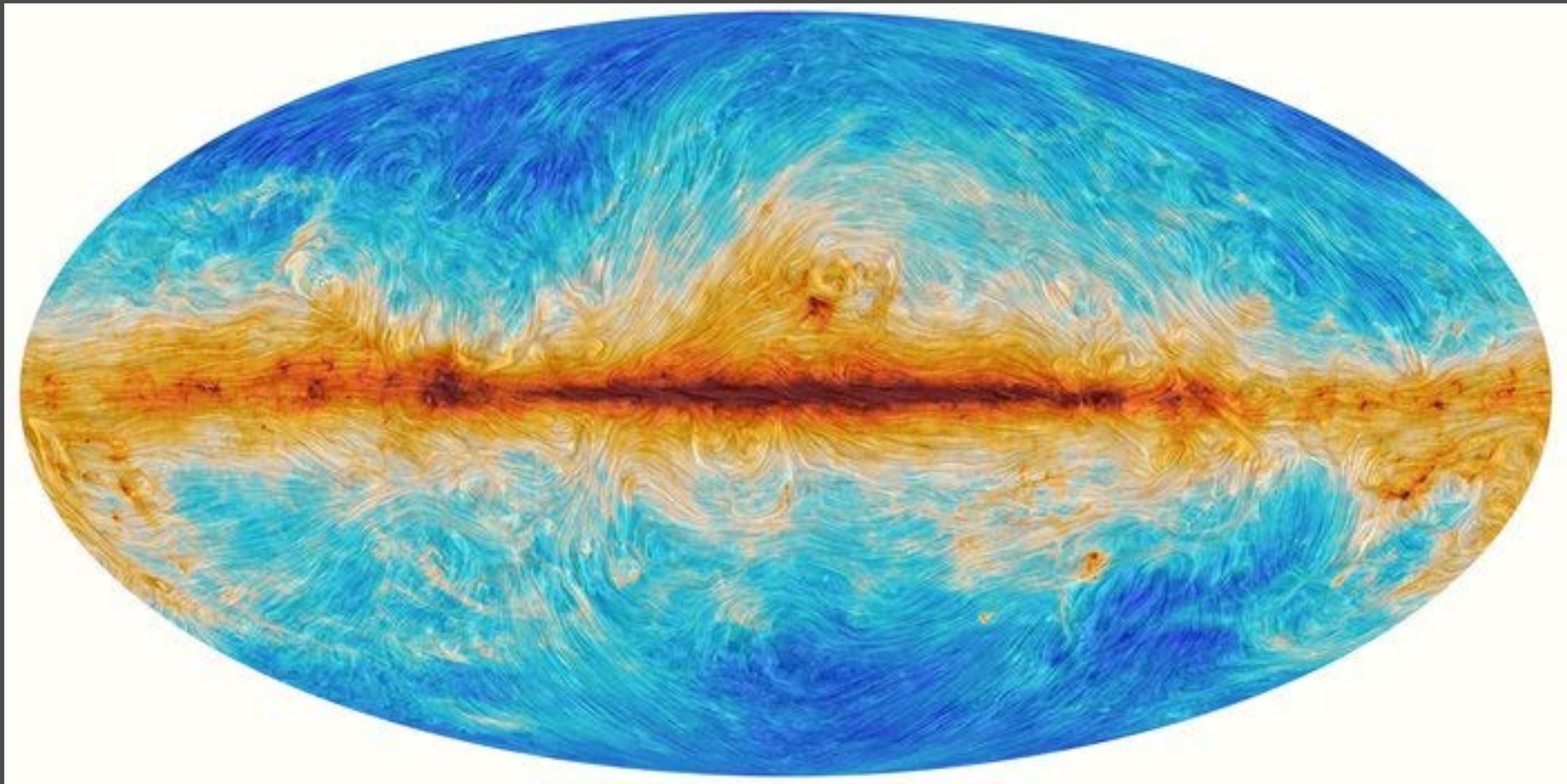


Fig. 4. Broadband spectral energy distribution of FSRQ 3C 279 during the June 1991 and February 2006 flaring state in comparison to 1992/1993 and 2003 observations where the source was in a quiescent state [39].

Planck map of B-field direction (dust polarisation)

http://www.esa.int/spaceinimages/Images/2015/02/Polarised_emission_from_Milky_Way_dust



Note: In Gal. plane this is dominantly the ***foreground B-field direction***.
Next Step: ASKAP POSSUM (Faraday rotation measures in great detail)

Galactic **TeVatrons** and **PeVatrons**

What are the particle accelerators to E ~ 10^{15} eV (1 PeV)?

- **Shell Type Supernova Remnants?** $L_{All-SNR} \sim \text{few} \times 10^{42}$ erg s^{-1}
  W_{CR} ~ 10^{50} erg per SNR
  $E \approx 1(B/\text{mG})(\Delta T/100 \text{ years}) \text{ PeV}$
- **Pulsar Wind Nebulae?**
  Pulsar *spin-down* power $\dot{E} = I\omega\dot{\omega} \sim 10^{32}$ to $\sim 10^{39}$ erg s^{-1}
- **Pulsars? Rotating dipole B** $E_{max} \approx 8 \times 10^{20} Z(B/10^{13}\text{G})(\omega/3000\text{Hz})^2$ eV
- **WR, O & B stars, Massive Stellar Clusters, Massive Star Formation?**
  Stellar wind KE $L_w = \frac{1}{2}\dot{M}v_\infty^2$
  B-star L_w ~10^{34-35} erg/s
  WR star L_w **~ 10^{38-39} erg/s**
- **X-Ray Binaries, Microquasars, Active galaxies (AGN)?**
  Accretion power $L_{acc} = \eta c^2 \dot{M}/2$ η=10 to 20%
  Galactic $L_{acc} \sim 10^{40}$ erg s^{-1} **AGN** $L_{acc} \sim 10^{46}$ erg s^{-1}

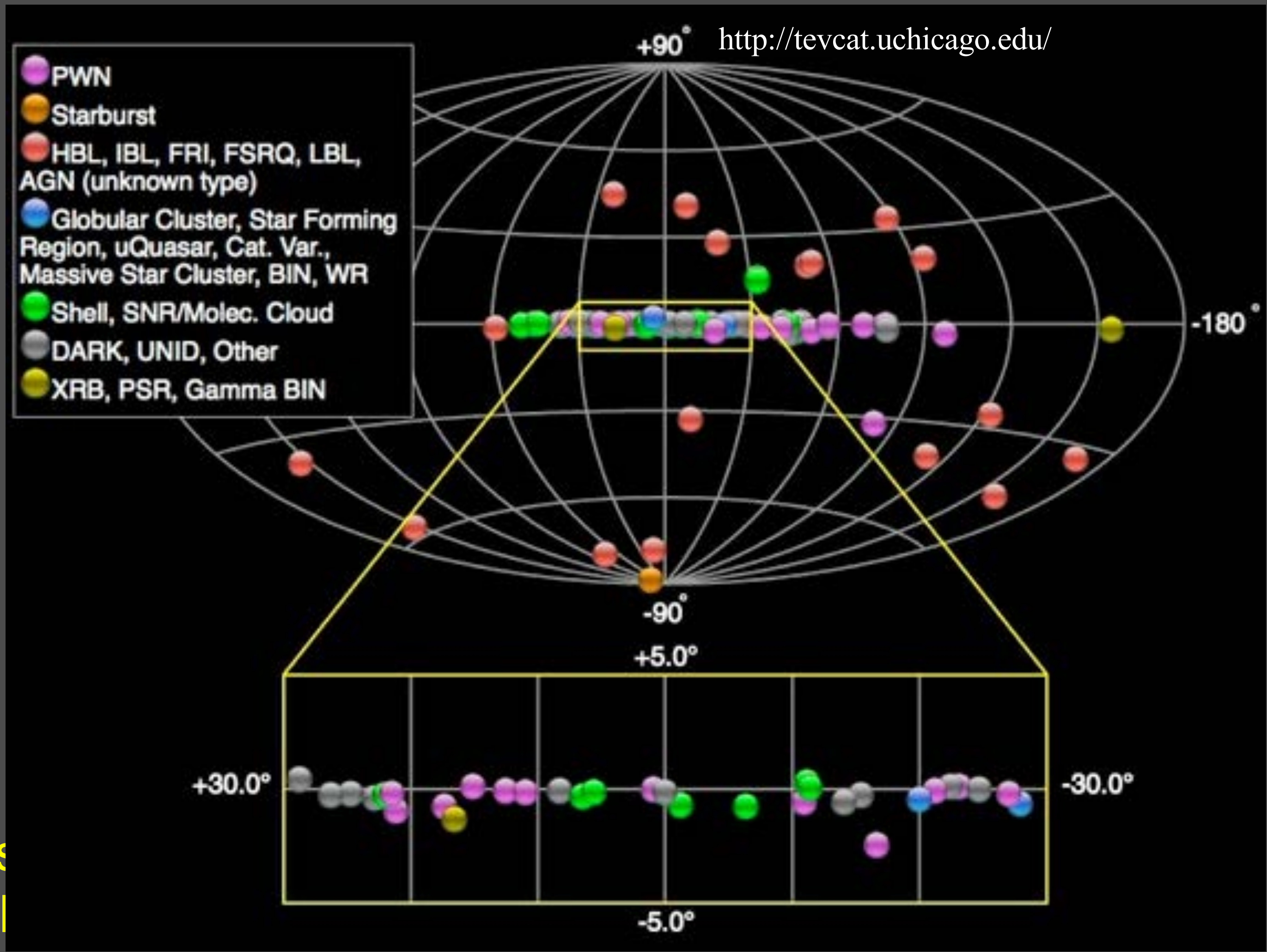
PeV cosmic-rays:

- Show you what the accelerator is capable of (just like a car at ful throttle..)

→ constraints on fundamental parameters e.g. B field, shock speed....

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

Highly effective tracer of high energy particles
High impact results ~ 20 Nature, Science, PhysRevLett papers since 2004



→ HESS-II, MAGIC-II, VI