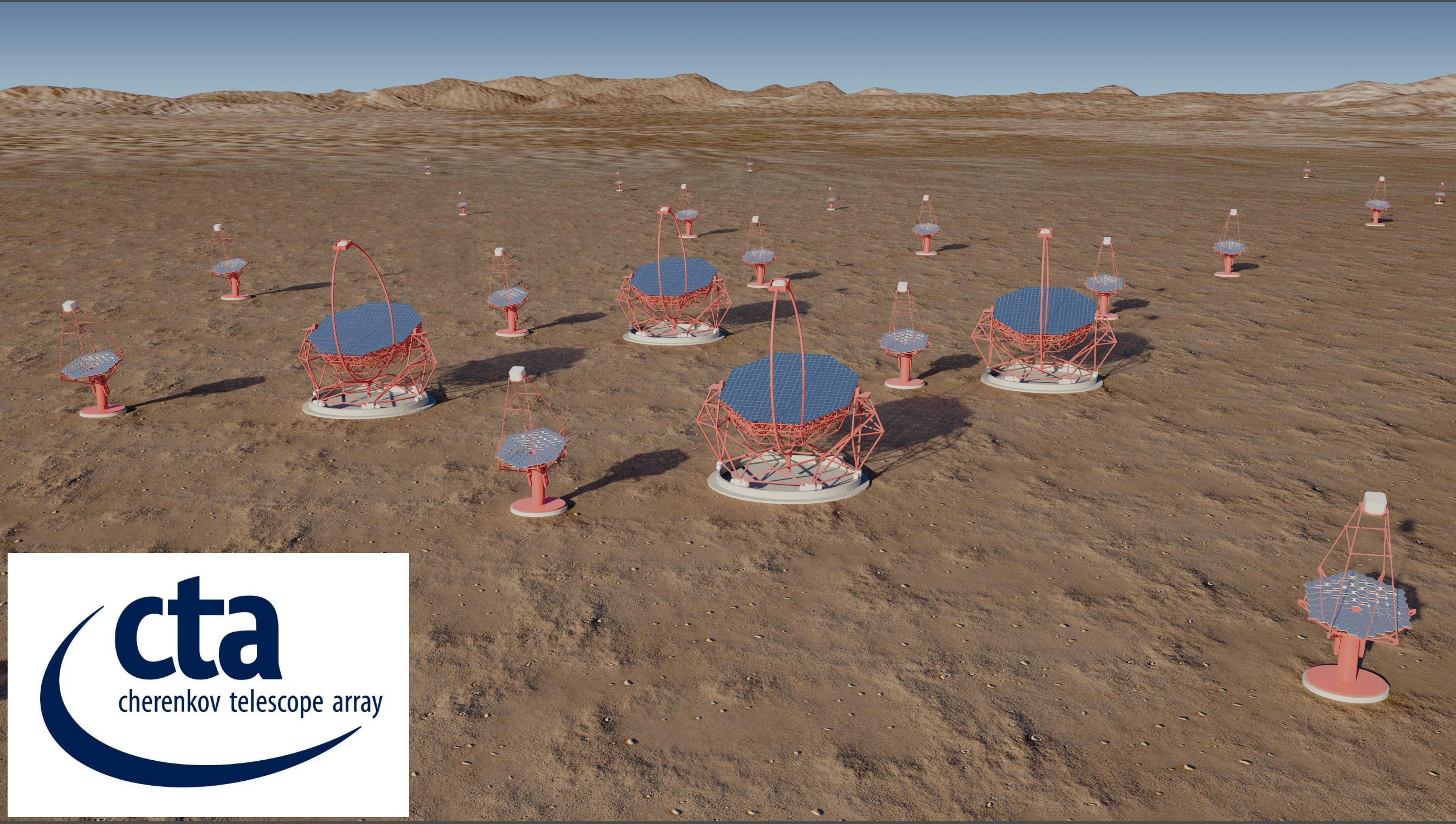
The Cherenkov Telescope Array & its Key Science Projects

Gavin Rowell Uni. Adelaide (for CTA-Australia)



CTA/MWL Meeting Sept. 2016 Adelaide

The Cherenkov Telescope Array

cta
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

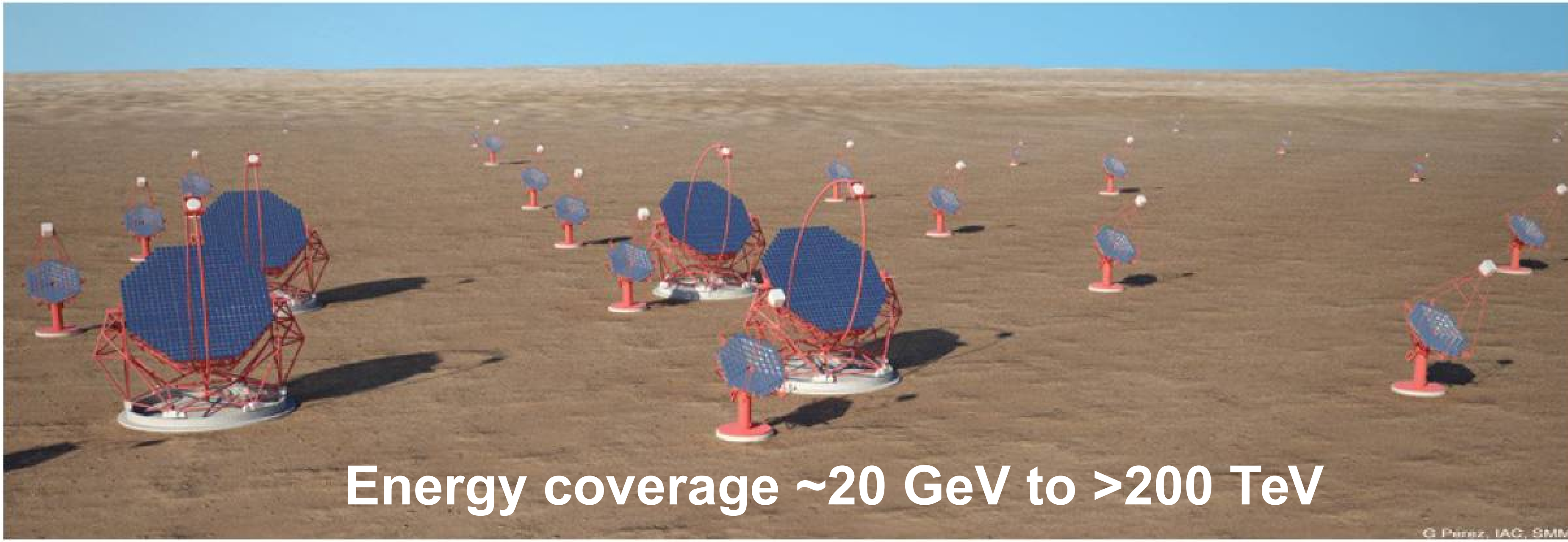
  Involves >90% of current TeV gamma-ray scientists + many others

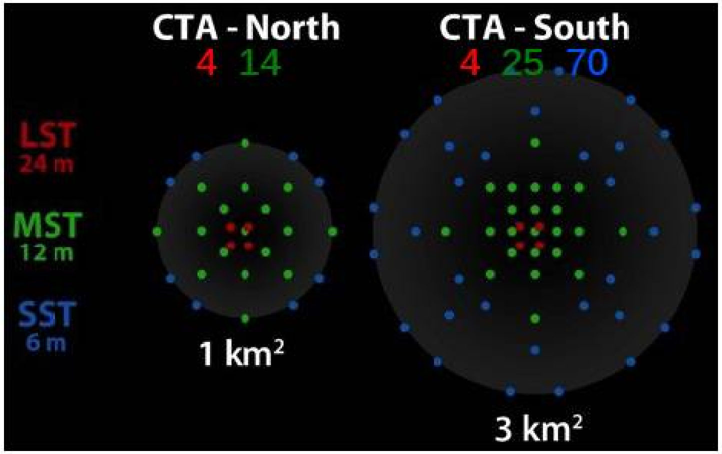
- EU ESFRI ranked project

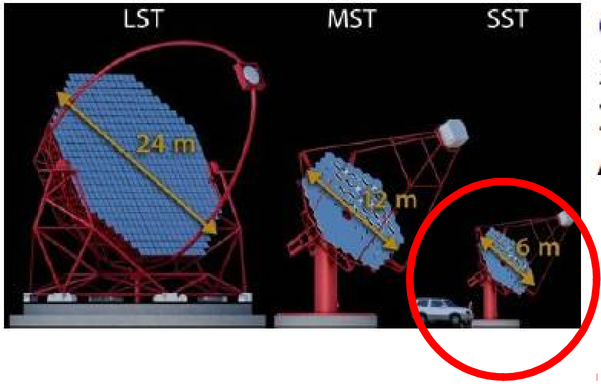
- Funding secured so far ~50%

ESFRI
European Strategy Forum
on Research Infrastructures

The CTA Observatory







Characteristics
3 telescope classes
2 sites (South and North)
About 120 (+25) telescopes

Australia contributes to the Small Sized Telescopes (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

Monash
C. Balazs, D. Galloway

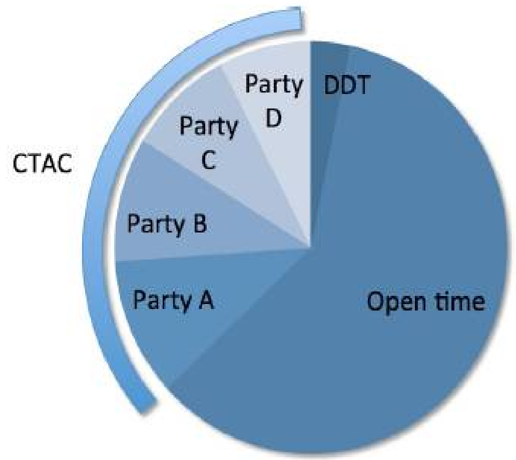
U. Syd
A. Green

Funding

ARC LIEF (hardware/commissioning)

NCRIS/AAL (travel, meetings, CTAO membership)

CTA observing time



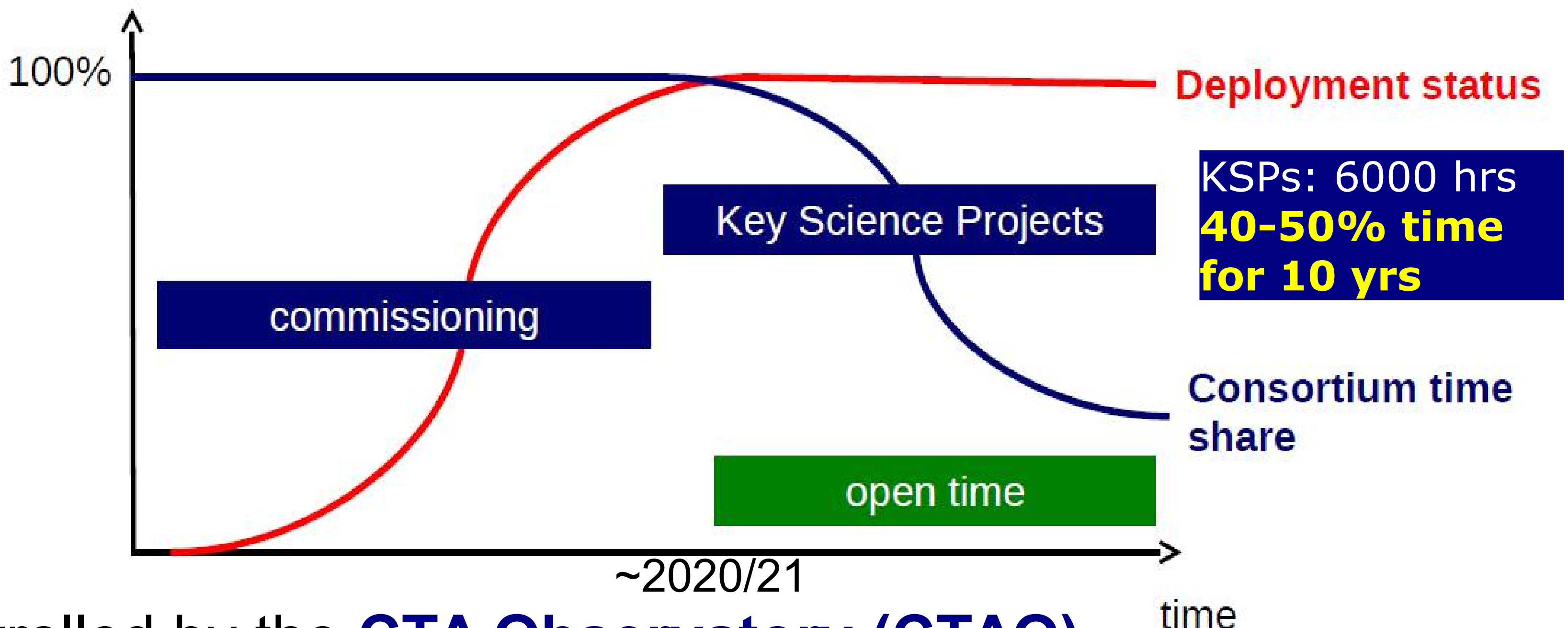
Current model

Contributing parties pool their time:

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

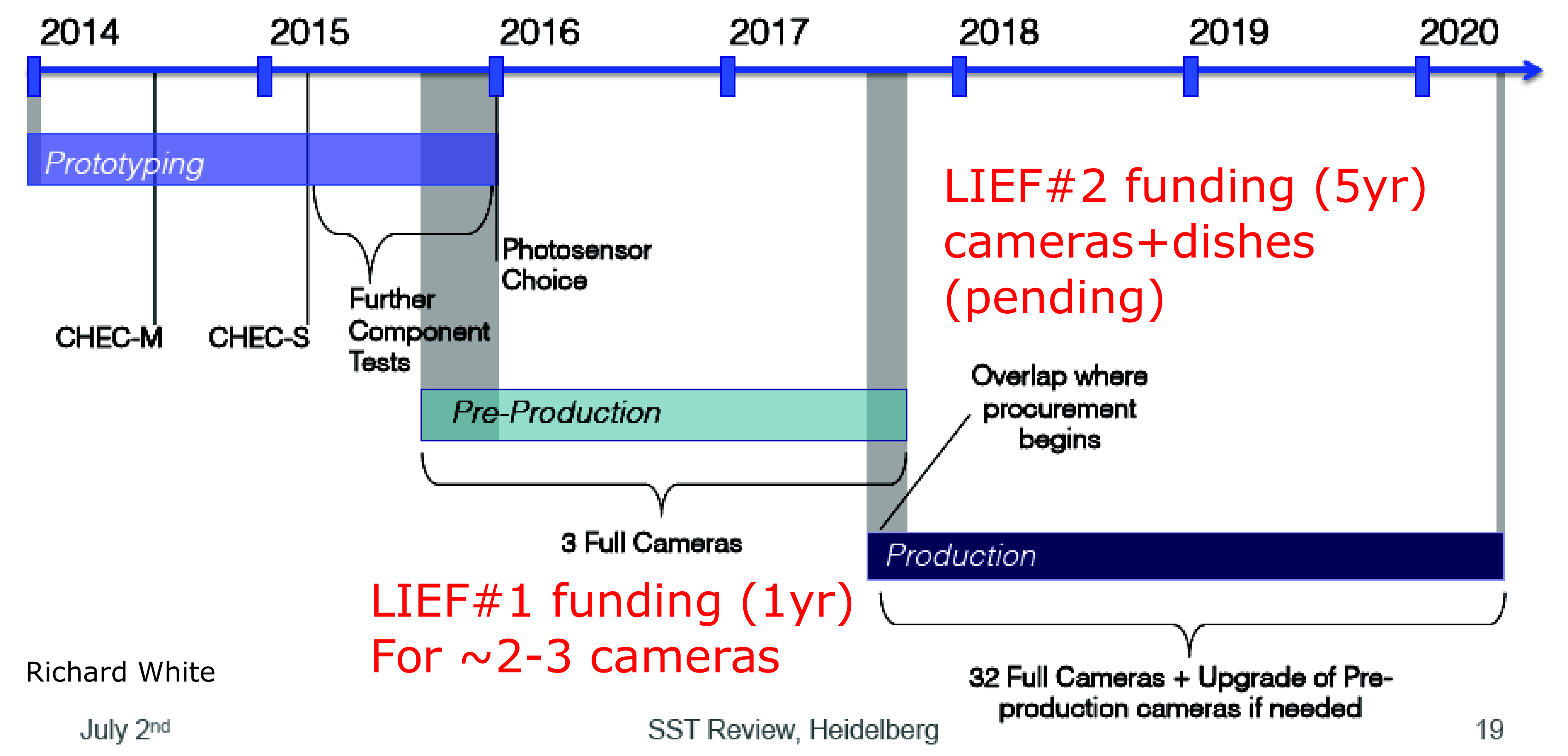
All data will become public to worldwide community after some proprietary period

(cf. C. Boisson)



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

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



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

Status (Sept. 2016)

- CTA is progressing rapidly

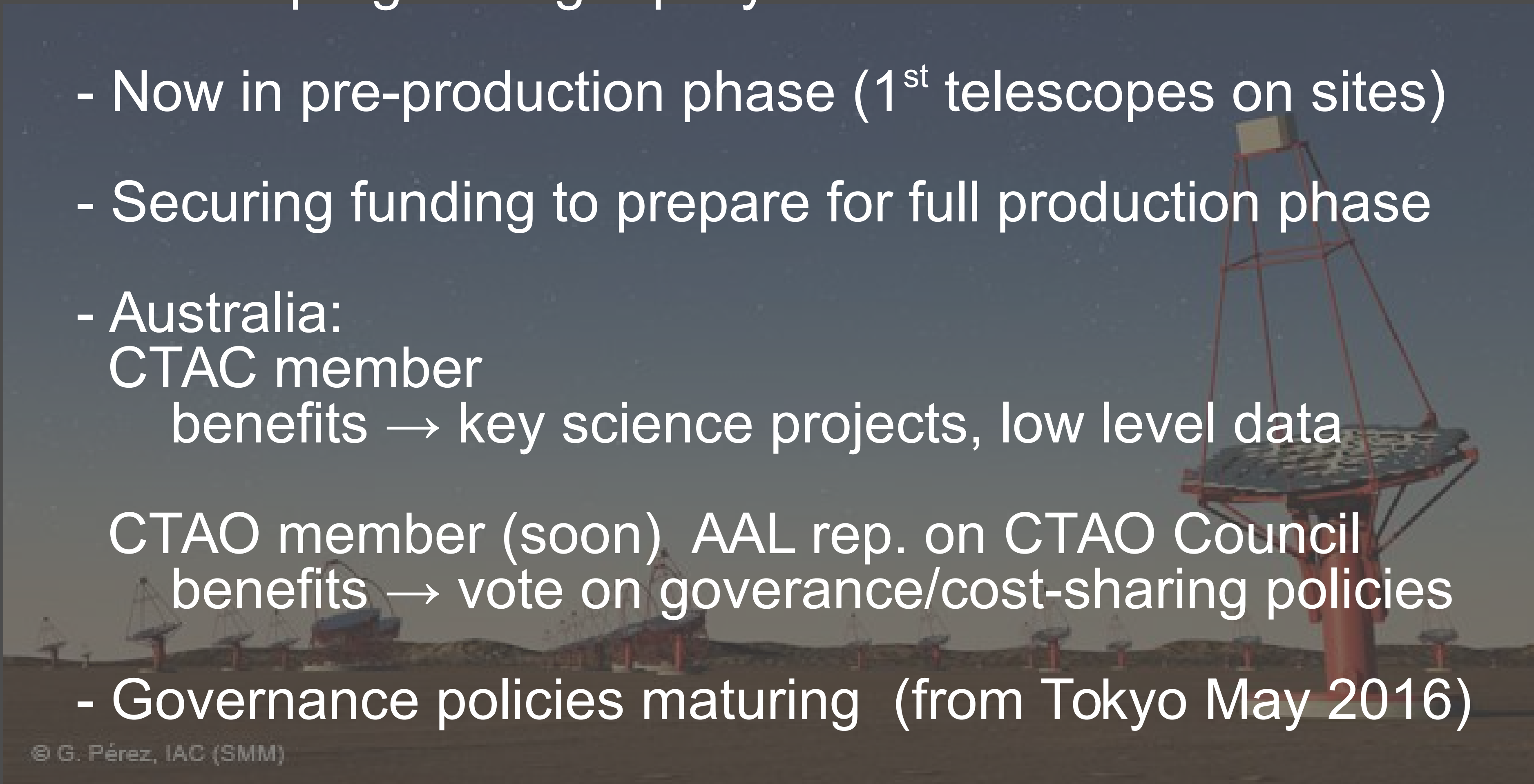
- Now in pre-production phase (1st telescopes on sites)

- Securing funding to prepare for full production phase

- Australia:
  CTAC member
  benefits → key science projects, low level data

  CTAO member (soon) AAL rep. on CTAO Council
  benefits → vote on goverance/cost-sharing policies

- Governance policies maturing (from Tokyo May 2016)



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

CTA sites selected 16 July 2015

Ground breaking Oct. 9, 2015

13 June 2016 - CTA HQ (Bologna)

- CTA Data Management Centre (DESY Berlin)

CTA South : Paranal, Chile

Negotiations with ESO ongoing: Infrastructure sharing/piggyback

KEY SCIENCE PROJECTS

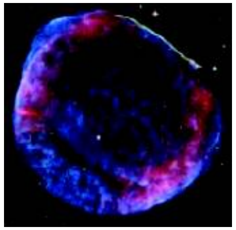
- Galactic Plane Survey
- Galactic Centre Survey
- Large Magellanic Cloud Survey
- Extragalactic Survey
- Transients
- Cosmic-Ray PeVatrons
- Star-Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies
- Dark Matter
- Non-Gamma-Ray Science

  intensity interferometry

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

Three Themes

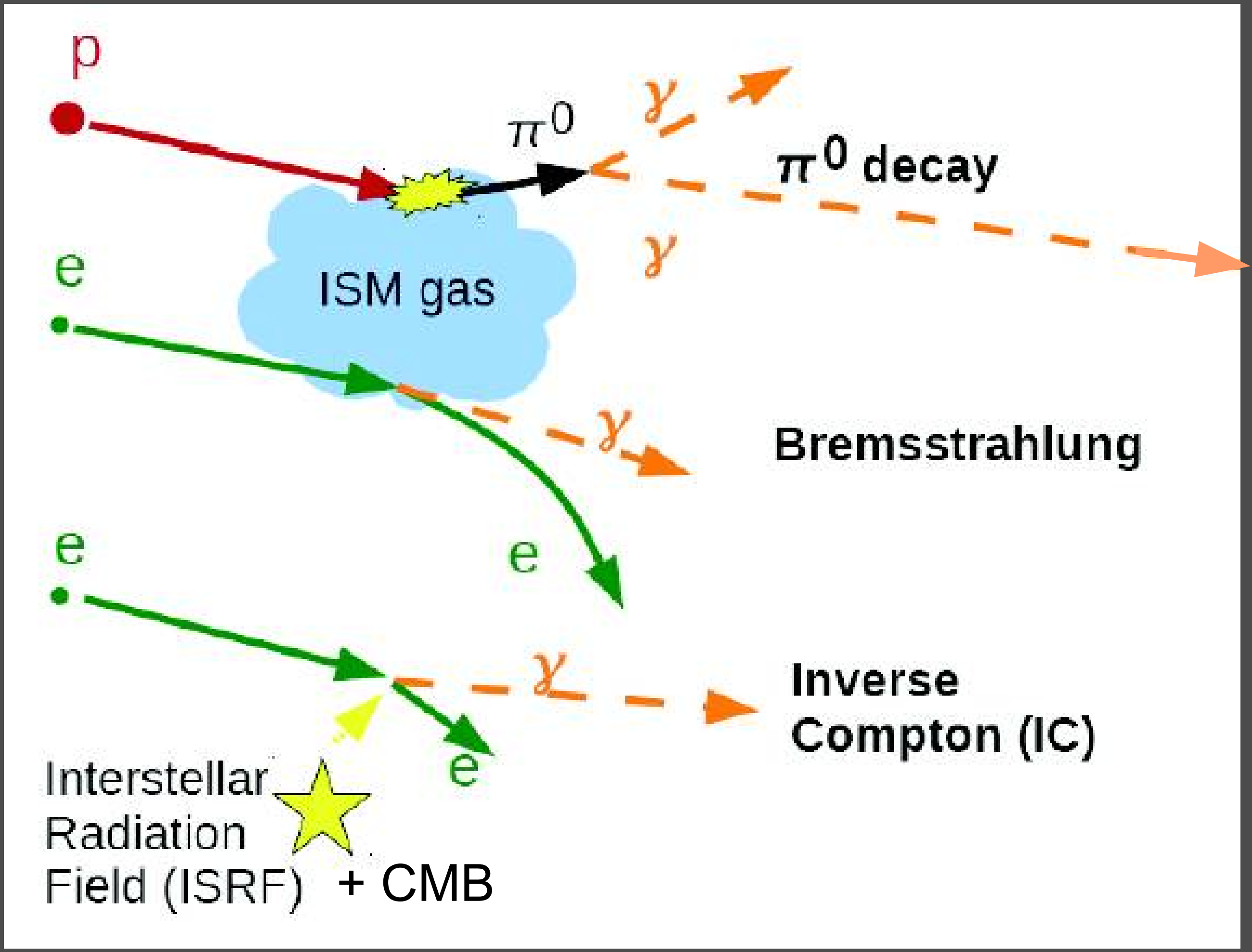
1. Cosmic Particle Acceleration



2. Probing Extreme Environments

3. Physics Frontiers: Beyond Standard Model

Gamma Rays from multi-TeV particles

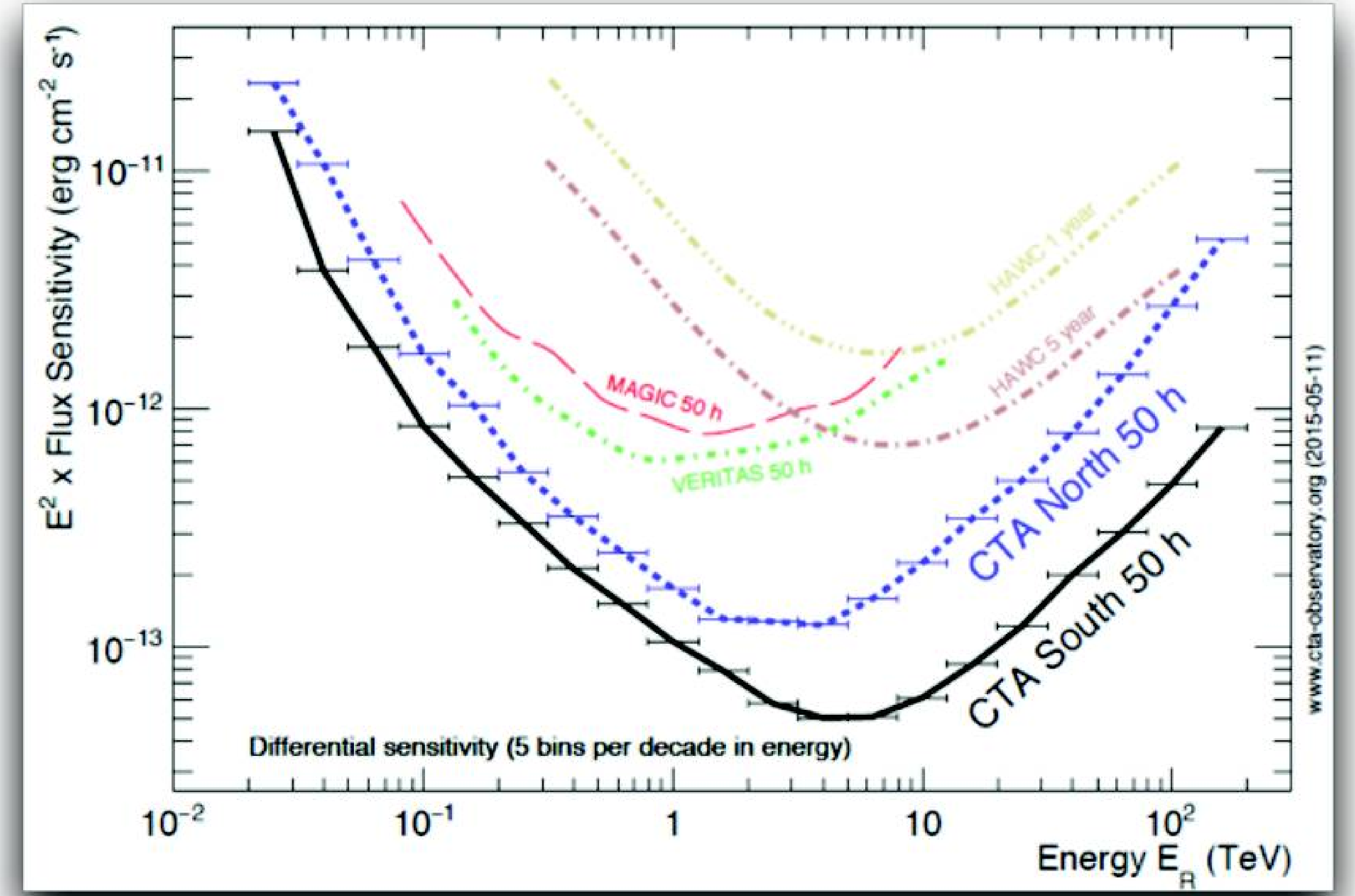


Protons: Gamma-rays and gas targets are generally spatially correlated
(need to map atomic and molecular ISM)

Electrons: Gamma-ray (IC) + X-ray, radio emission (synch.) coupled
(Bremss. usually minor)

CTA Performance

Differential Sensitivity



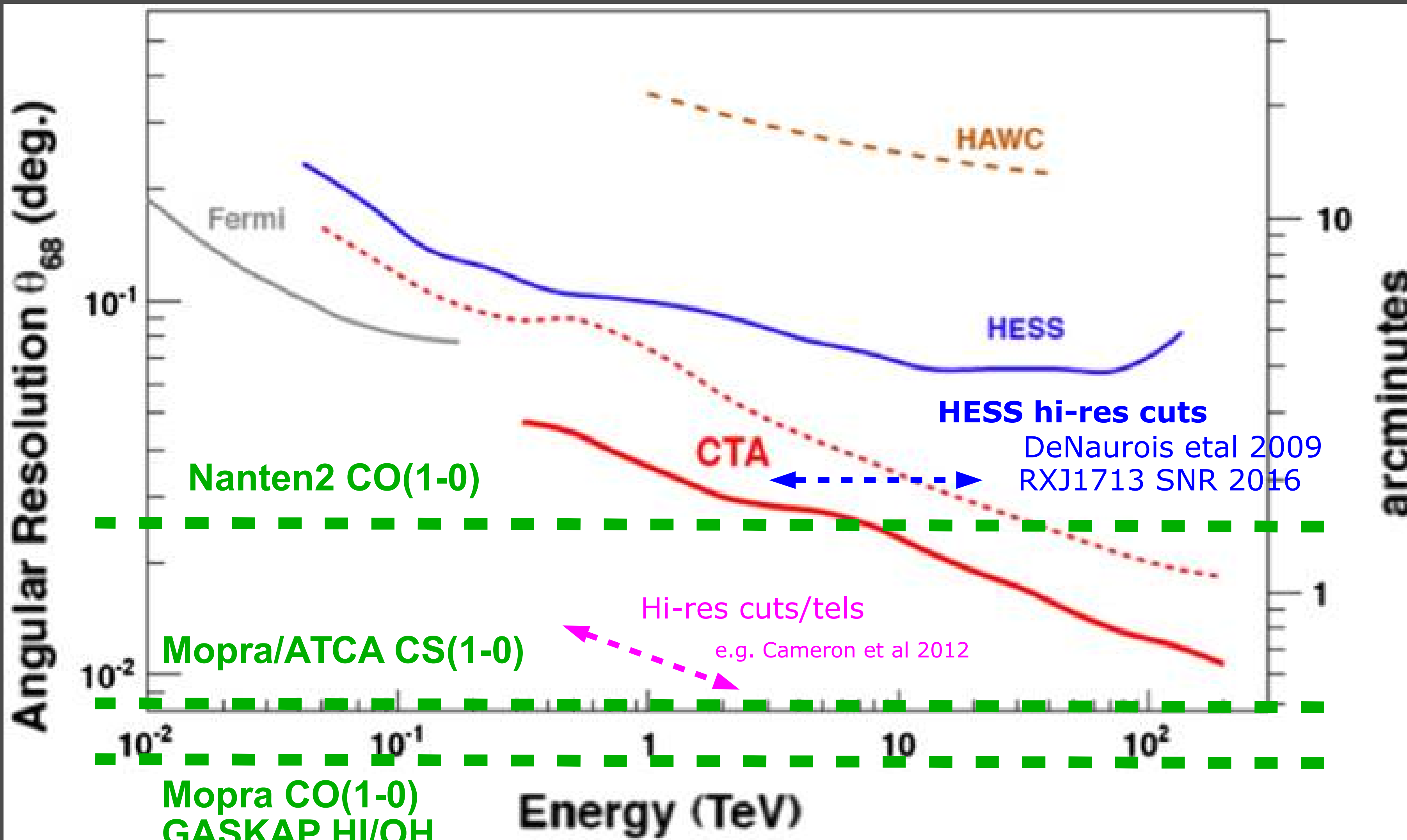
A factor of 5-10 improvement in sensitivity in the domain of about 100 GeV to some 10 TeV.

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

Credits: The CTA Consortium

Angular Resolution (HESS, CTA..)

Acharyara etal 2013



Beam Sizes 68% containment radius

H.E.S.S. RX J1713.7-3946

**HESS Collab.
in prep 2016**

Year	2016
Live-time	164h
Energy	> 0.25 TeV
PSF (R_{68})	2.9 arcmin
γ's	31,000

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

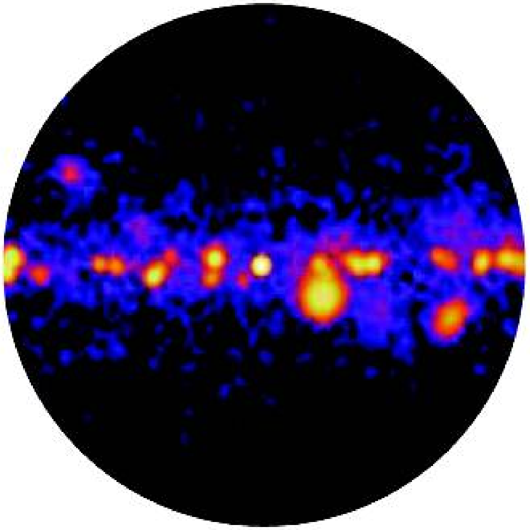
CTA Key Science Projects

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**

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.

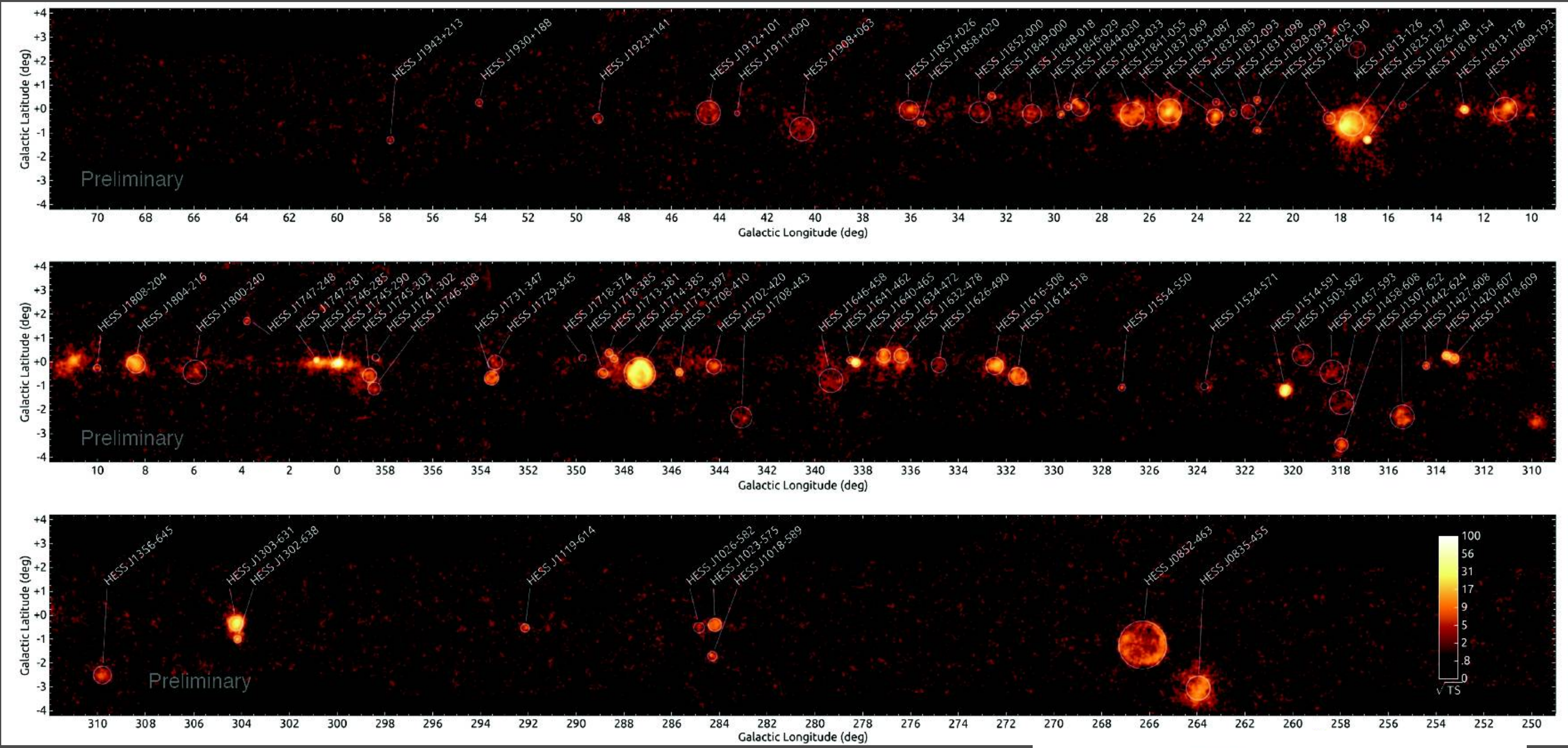
→ 300 to 500 new sources!

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.

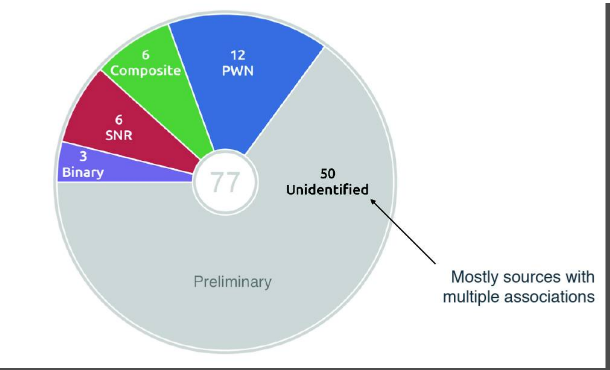
HESS Galactic Plane Survey (HGPS) – Skymaps

Deil et al 2015

→ 77 sources (13 new sources)

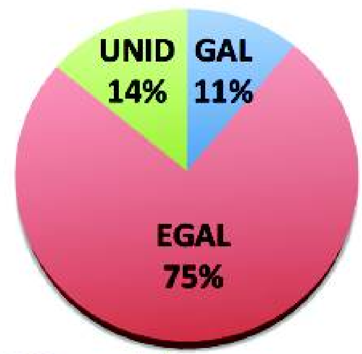


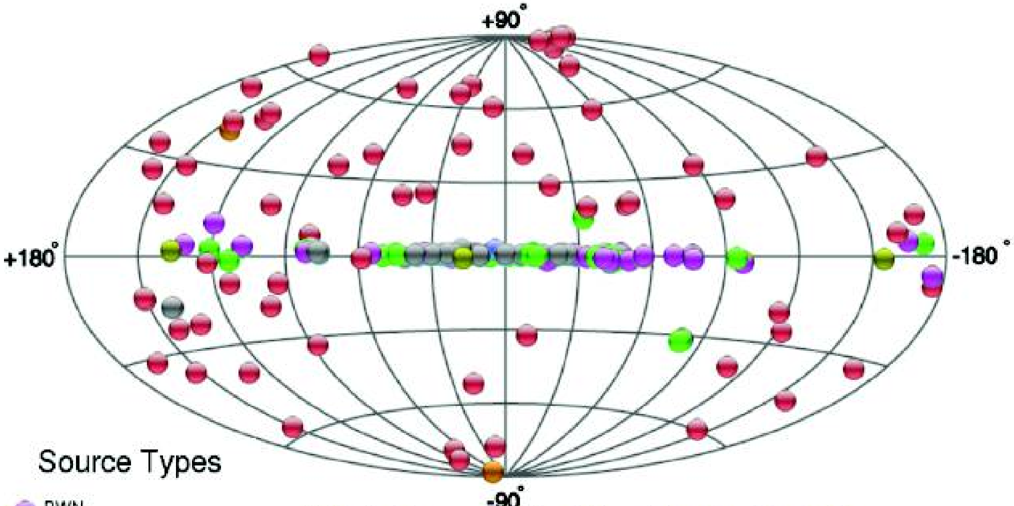
12 – pulsar wind nebulae
6 – SNRs
6 – composite SNRs
3 – binary (NS/BH + star)
50 – unidentified (confused associations) incl. GC region



The Sky above 50 GeV

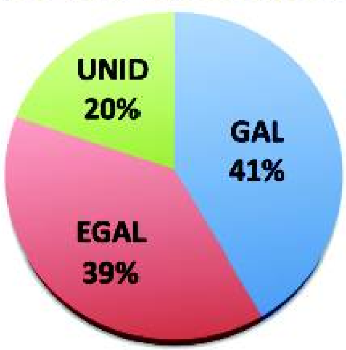
360 F-LAT sources E>50 GeV

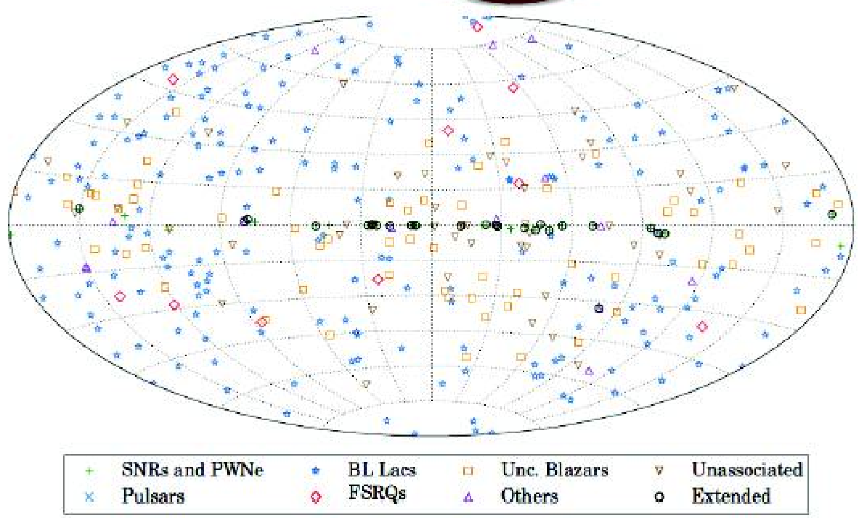




Wakely & Horan http://tevcat.uchicago.edu/

175 TeVCat sources



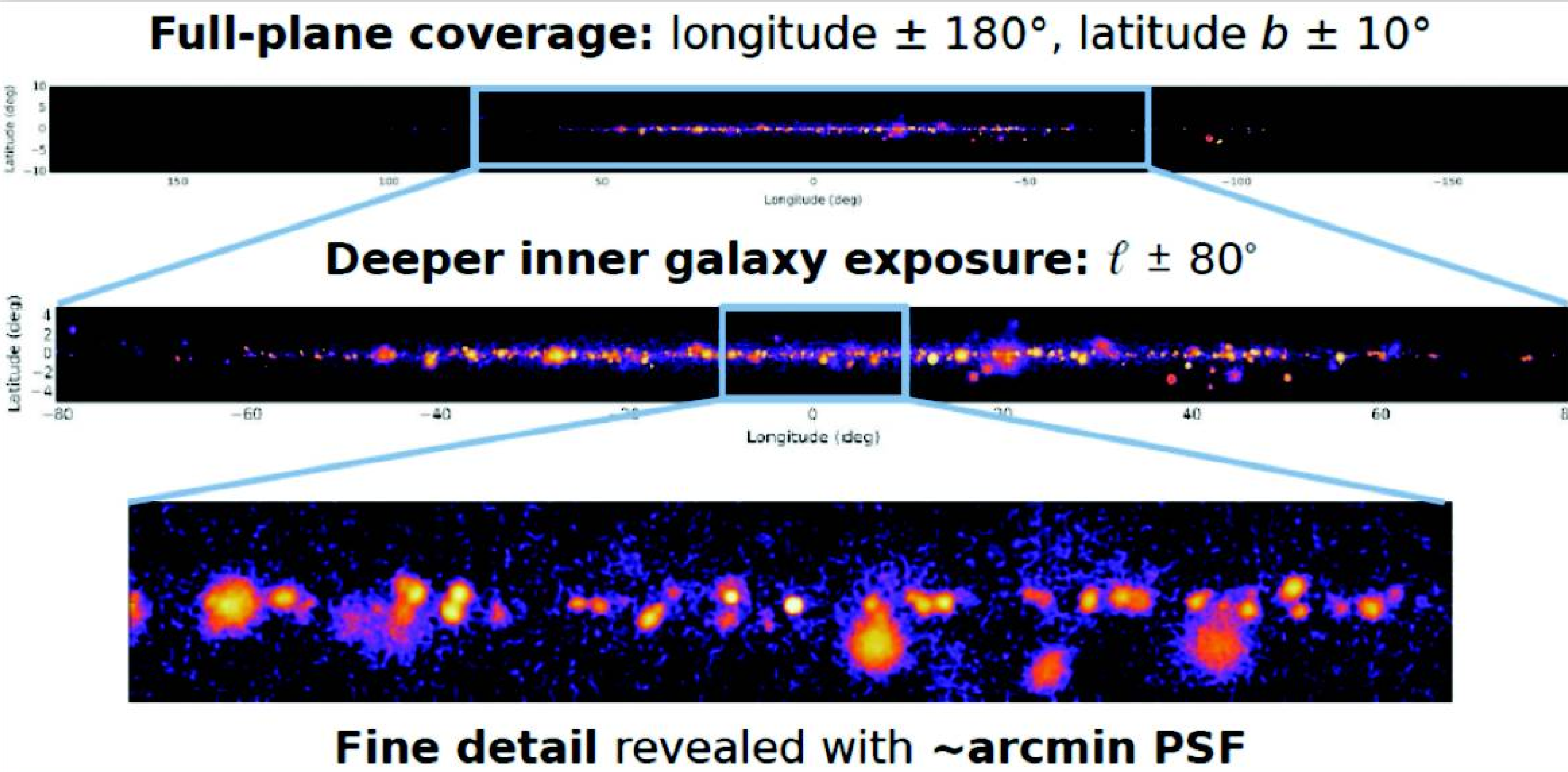


2FHL Ackermann et al., 2016, ApJS, 222, 5

Only 25% of the 2FHL sources have been previously detected by Cherenkov telescopes.

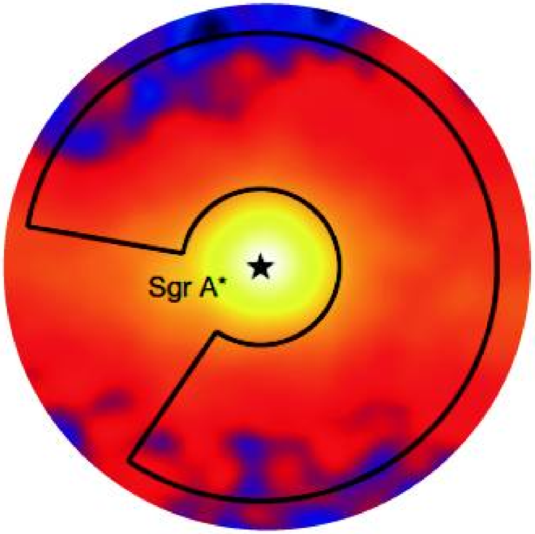
2FHL provides a reservoir of candidates to be followed up at very high energies.

Galactic Plane Survey



J. Knödlseder and CTA Consortium

Cosmic-ray PeVatrons



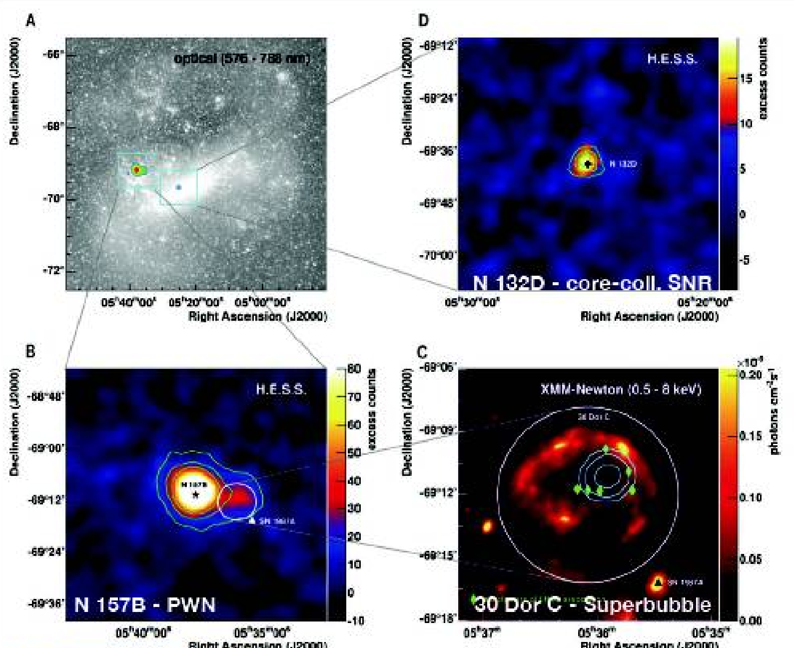
Credits: The H.E.S.S. Collaboraiton

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

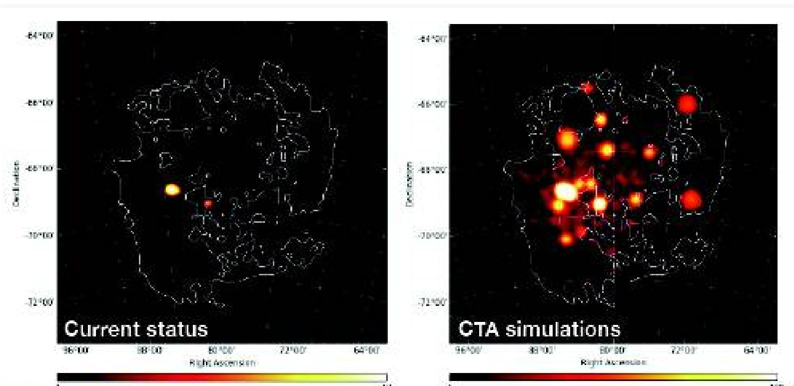
Supernova remnants might be able to satisfy the cosmic-ray energy requirement if they can somehow convert ~10% of the supernova kinetic energy into accelerated particles.

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.

LMC Survey



Abramowski et al., 2015



Credits: The CTA Consortium

Three luminous examples of cosmic-ray sources in an external galaxy.

HESS Collab. (2015)

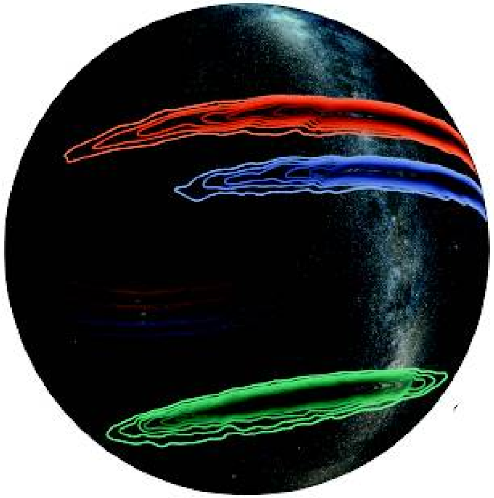
30 Dor C is the first super-bubble detected at VHE.

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 $L_{(E > 1\,TeV)} \sim 10^{34}$ erg s^{-1}, and a handful of regions enriched in cosmic rays.

Excellent prospects for CTA investigations of the LMC.

Transients



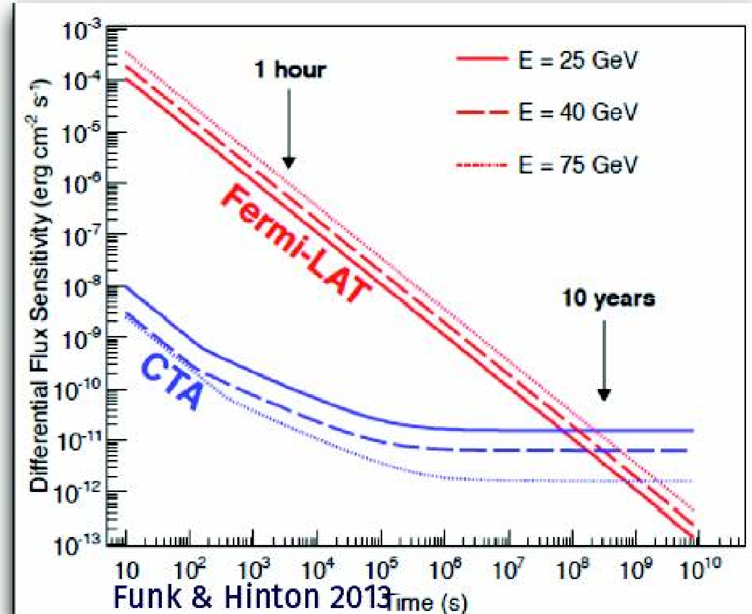
Credits: The LIGO Scientific Collaboration

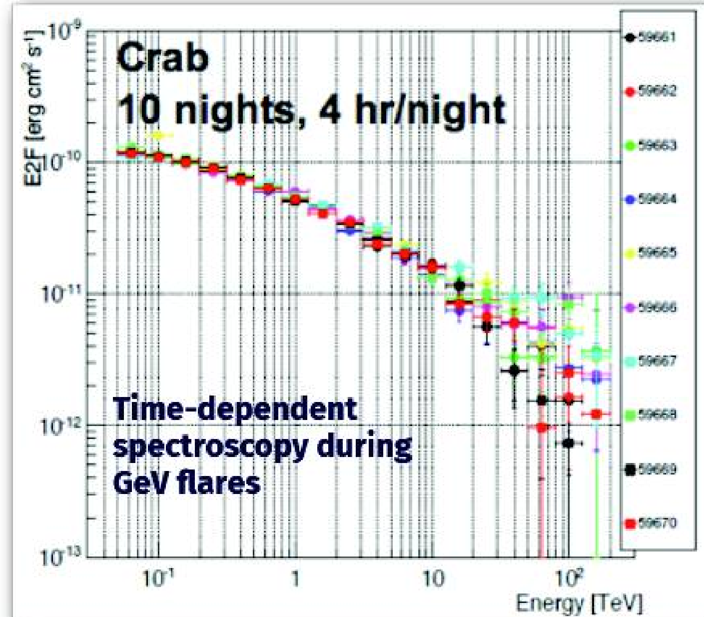
Transients are a diverse population of astrophysical objects. Some are known to be prominent **emitters of high-energy gamma-rays**, while others are sources of non-photonic, multi-messenger signals such **as cosmic rays, neutrinos and/or gravitational waves**.

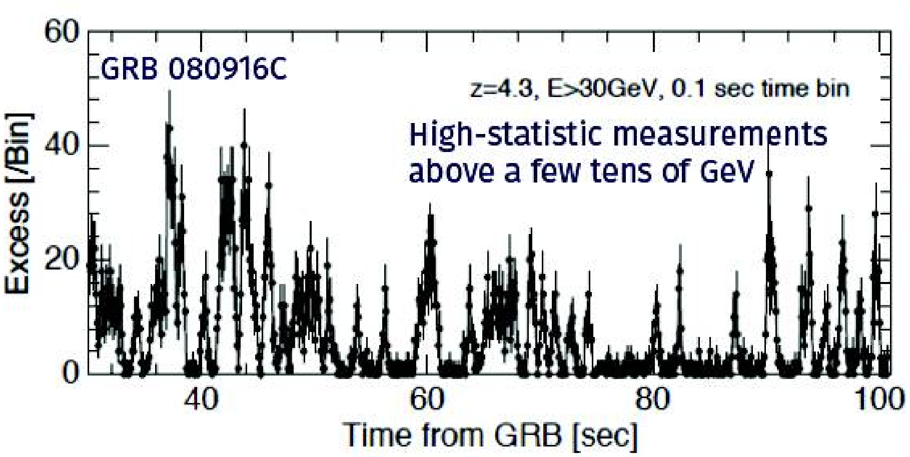
Possible classes of targets

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

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

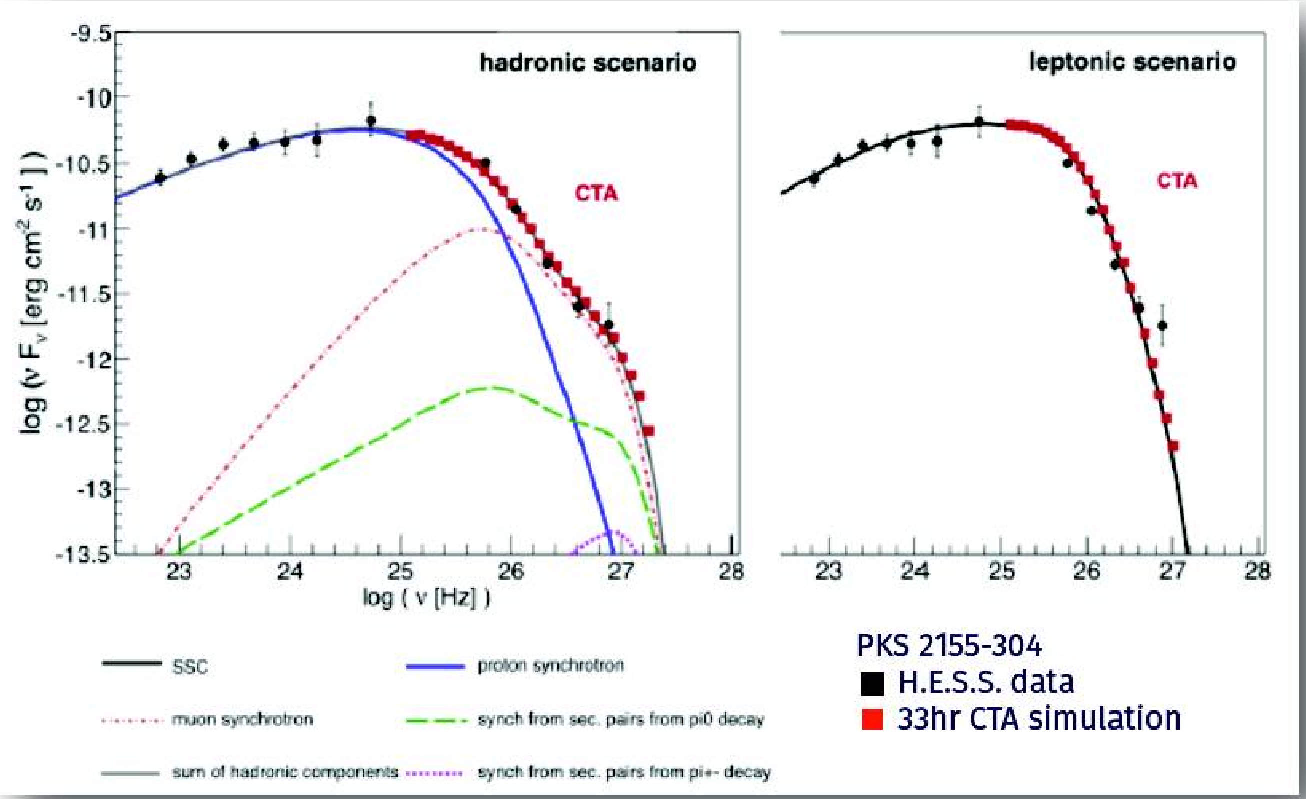
AGNs are known to emit **variable radiation** across the entire electromagnetic spectrum up to multi-TeV energies, with fluctuations **on time-scales** from **several years** down to **a few minutes.**

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**.

Active Galactic Nuclei

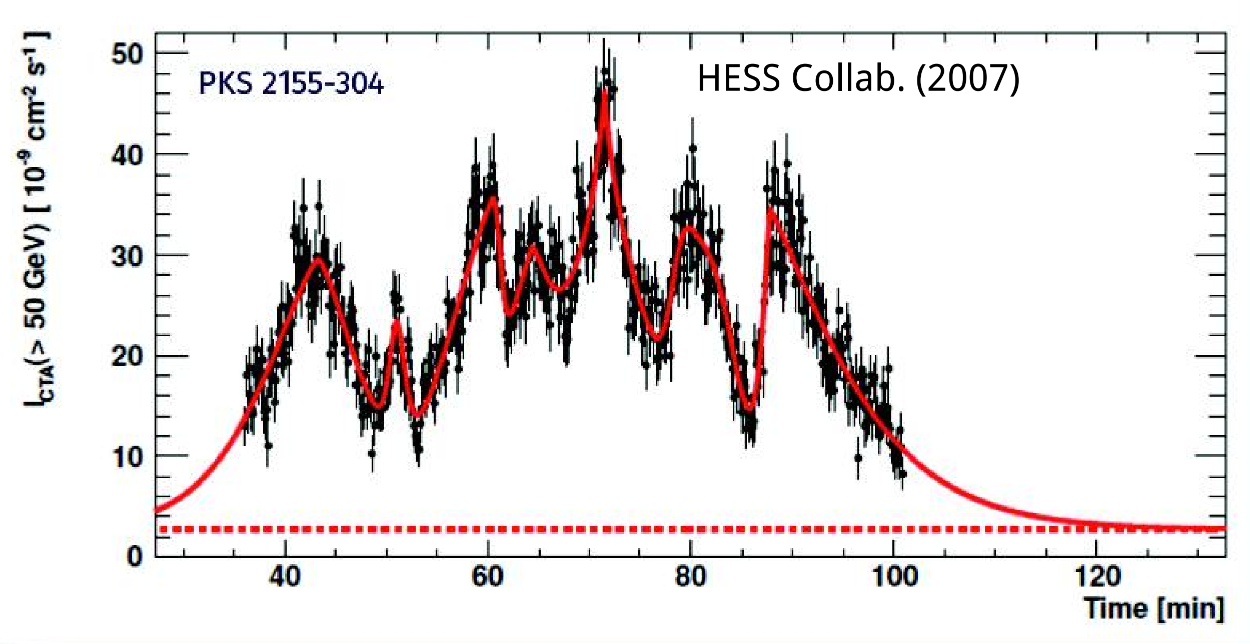
Testing emission scenarios



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.

Active Galactic Nuclei

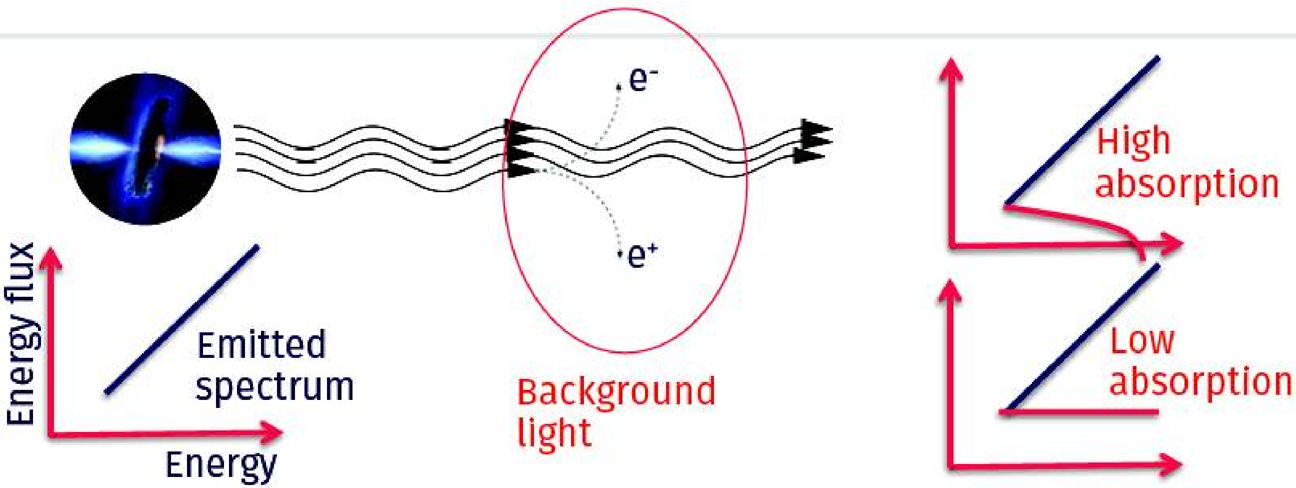
Testing variability in AGNs



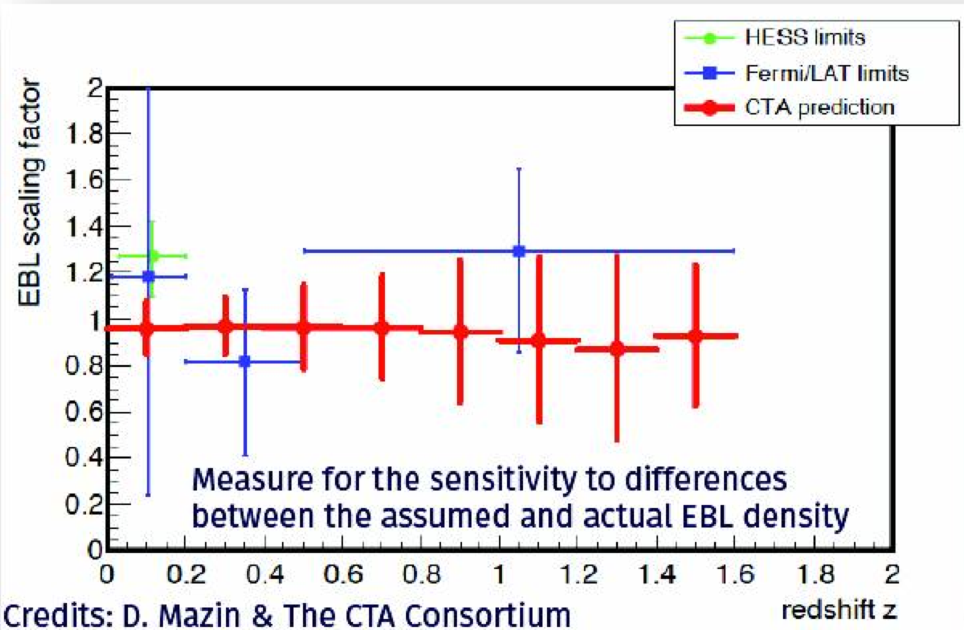
Sampling blazar fluxes below the light-crossing time scale of the SMBH, $T_G \sim 3hr \times (M/10^9 M_\odot)$, is a key strategy to understand the flickering behaviour of blazars on short time scales.

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

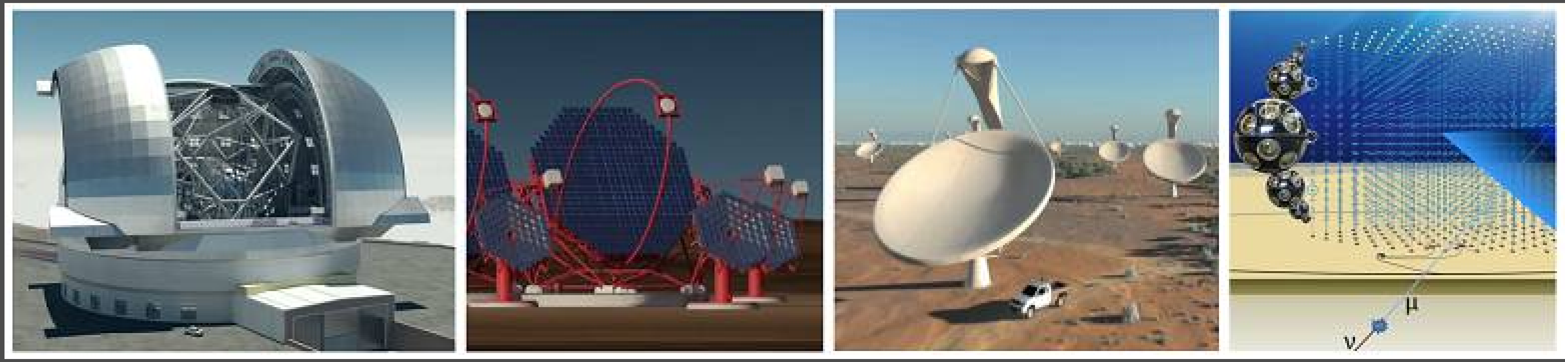
CTA will observe a large sample of blazars located at different redshifts. The detection of high-redshift sources, more likely during flares, would allow us to measure the evolution of the cosmic optical background.

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

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 Cherenkov images

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

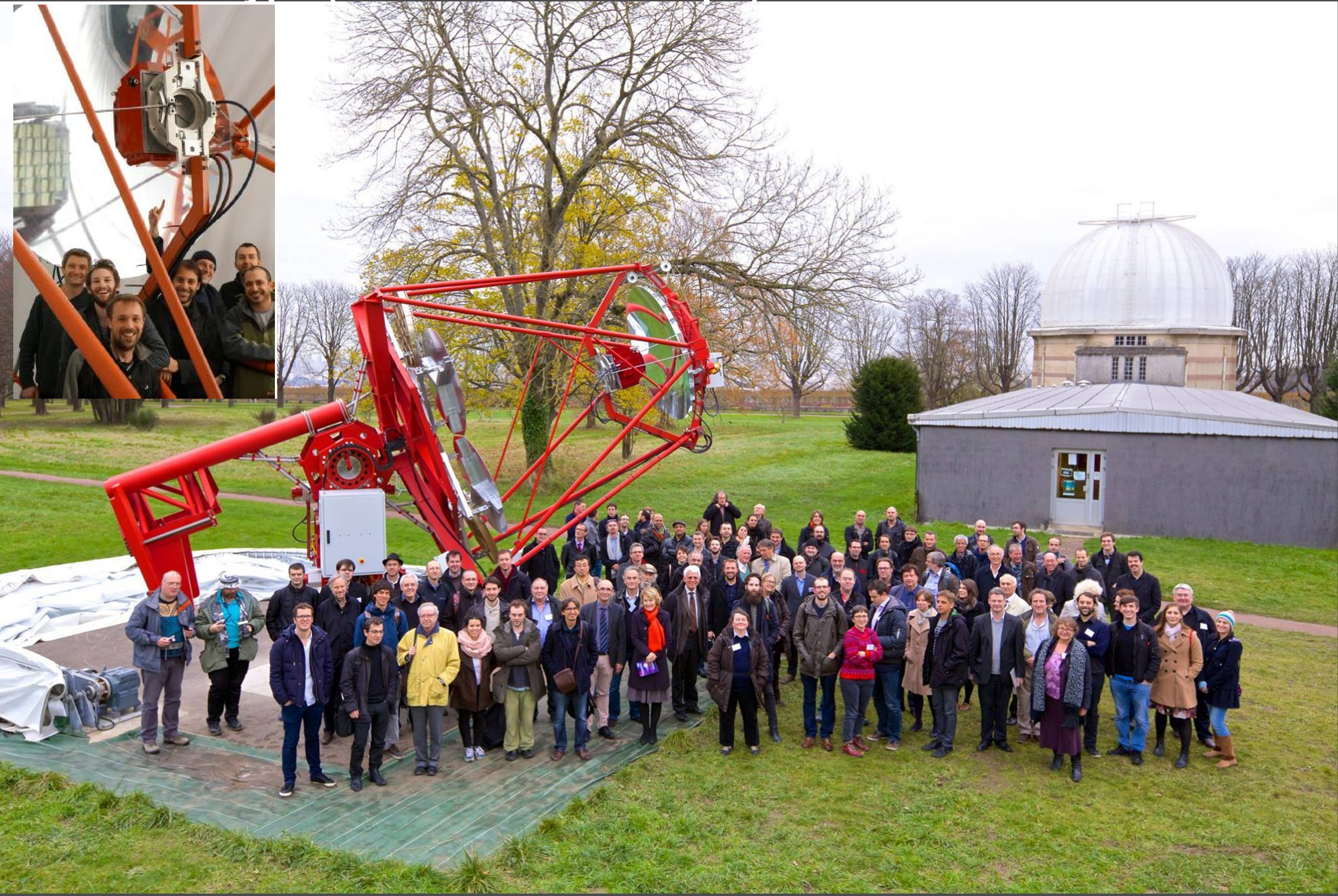
- Theoretical high energy astrophysics (e.g. Galactic Centre, jets/outflows)
- Astro-particle physics – Dark matter properties

Great potential to link with....

- Radio (ISM, continuum, transients)
- Optical (e.g. GALAH, Skymapper), interferometry
- Cosmic-rays (Pierre Auger Obs.)
- Grav. Waves (A/LIGO)
- Neutrinos (IceCube)
- HP Computing (Pawsey....) transients, MWL features,, local data centre

Backup slides...

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



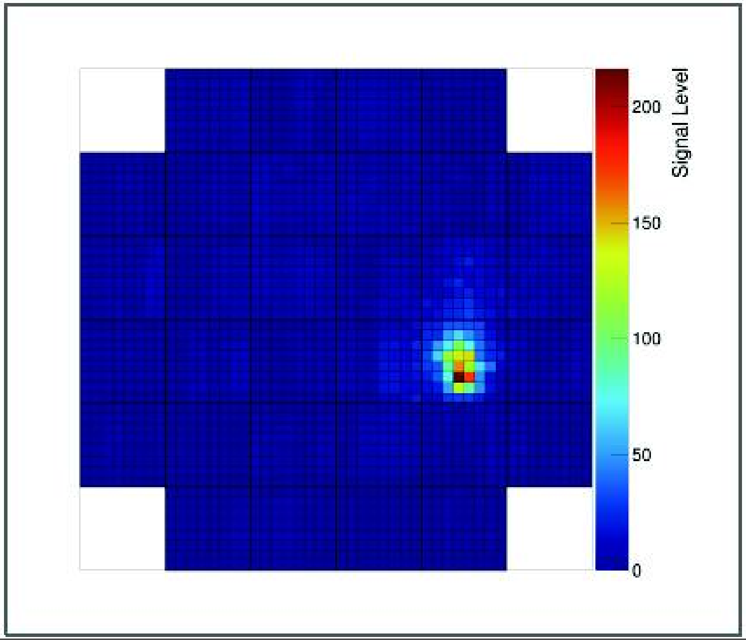
Australia - LIEF 2015 support for GCT hardware and commissioning. LIEF#2 submitted

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



Other prototypes.....

MST (Berlin)

SST (Sicily)

SST (Cracow)

SCT-MST (Arizona)

13 June 2016

CTA Headquarters
Bologna

Part of new Bologna University/INAF building

Data Management Centre

DESY Zeuthen Campus

New building

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **416**, 3075–3082 (2011) doi:10.1111/j.1365-2966.2011.19255.x

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

Brian C. Lacki[1,2]★

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Accepted 2011 June 14. Received 2011 June 6

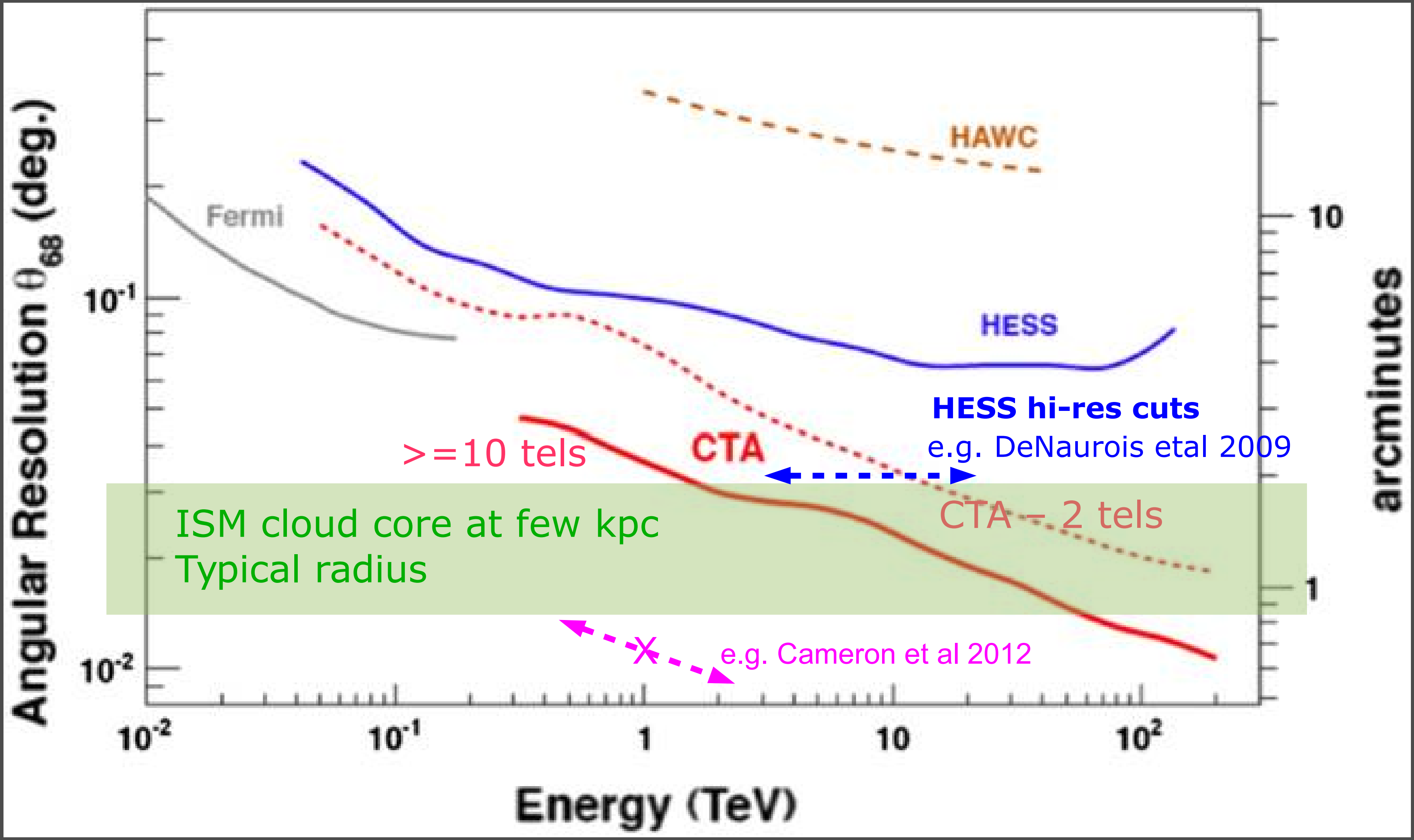
ABSTRACT

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.

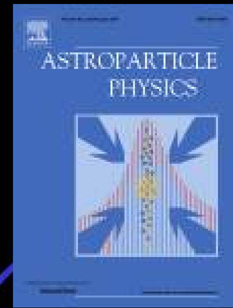
Angular Resolution (HESS, CTA..)

Acharyara etal 2013



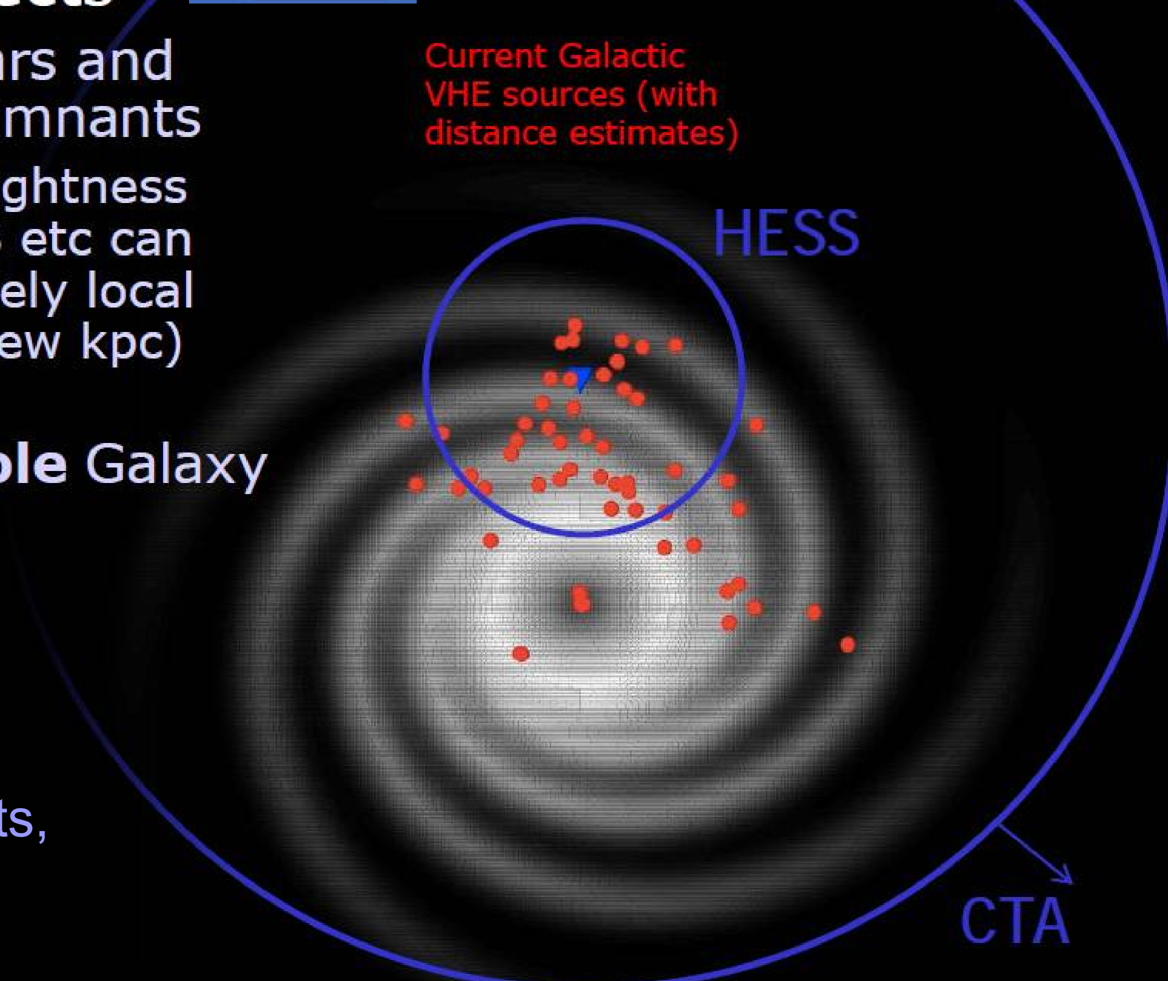
CTA MST-SCTs with small pixels and/or hi-res cuts → resolve cloud cores!

CTA Science



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

- 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



Extragalactic

AGN z>0.5, GRBs, Star-bursts, Gal. clusters, AGN haloes..

Astro-particle

Dark matter, Lorentz invariance....

Optical

Intensity Interferometry