The Cherenkov Telescope Array : A TeV Gamma-Ray Observatory

Gavin Rowell Uni. Adelaide (for CTA)

CTA-Oz Workshop #4 (WSU, Sydney) Apr. 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

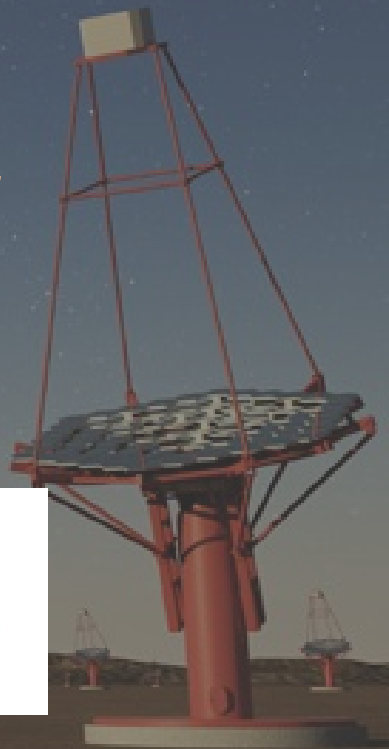
- An international project ~ €300M capital cost

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

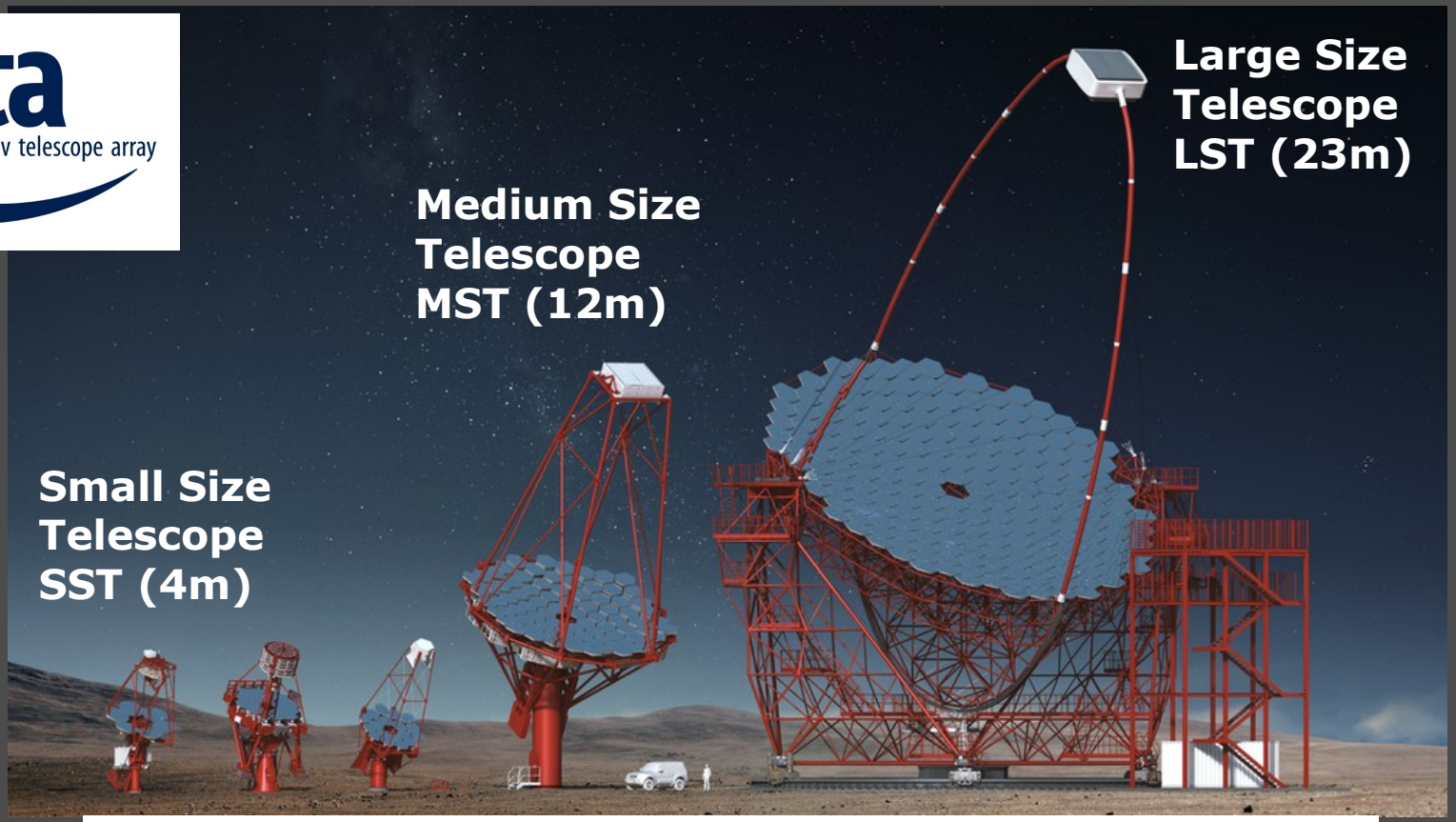
- EU ESFRI ranked project

ESFRI European Strategy Forum on Research Infrastructures

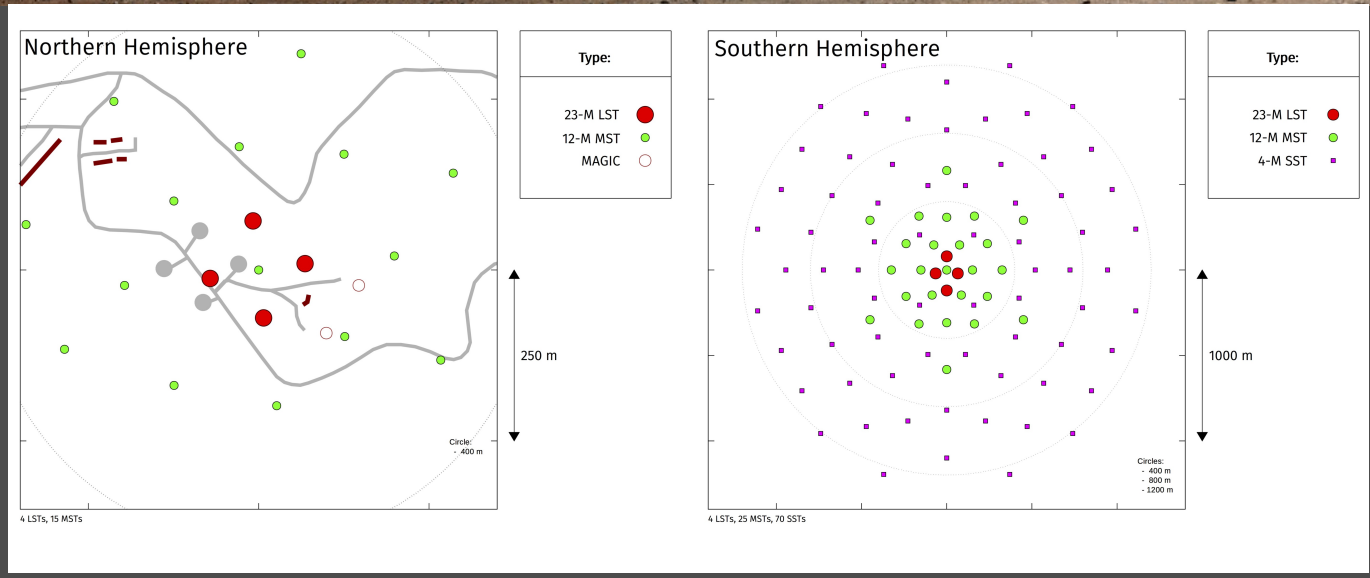
https://www.cta-observatory.org



cta
cherenkov telescope array



North
29 tels



South
99 tels

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

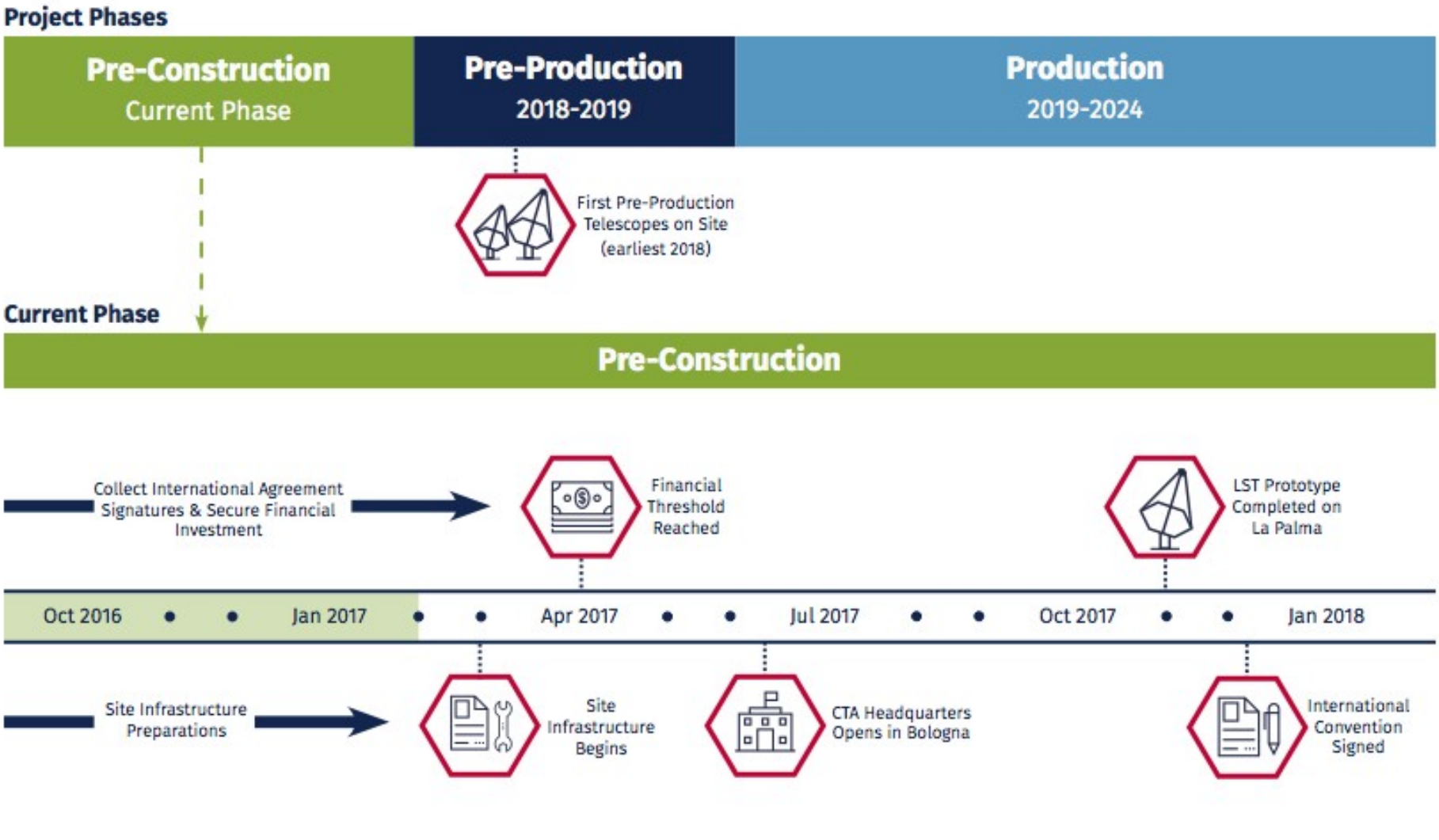
Monash
C. Balazs, D. Galloway

U. Syd
A. Green

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

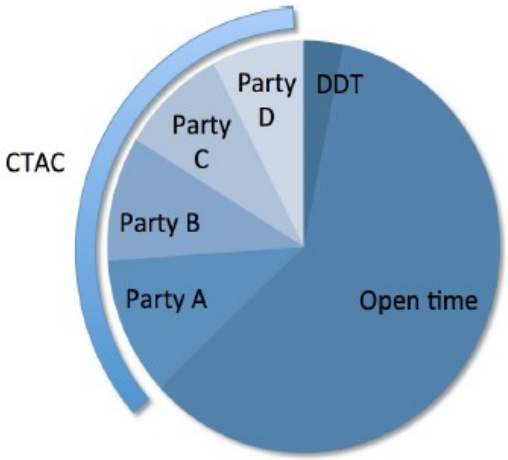
NCRIS/AAL (travel, meetings, CTAO membership)

CTA Timeline



Science operations from ~2021 (90% of all telescopes)

CTA observing time



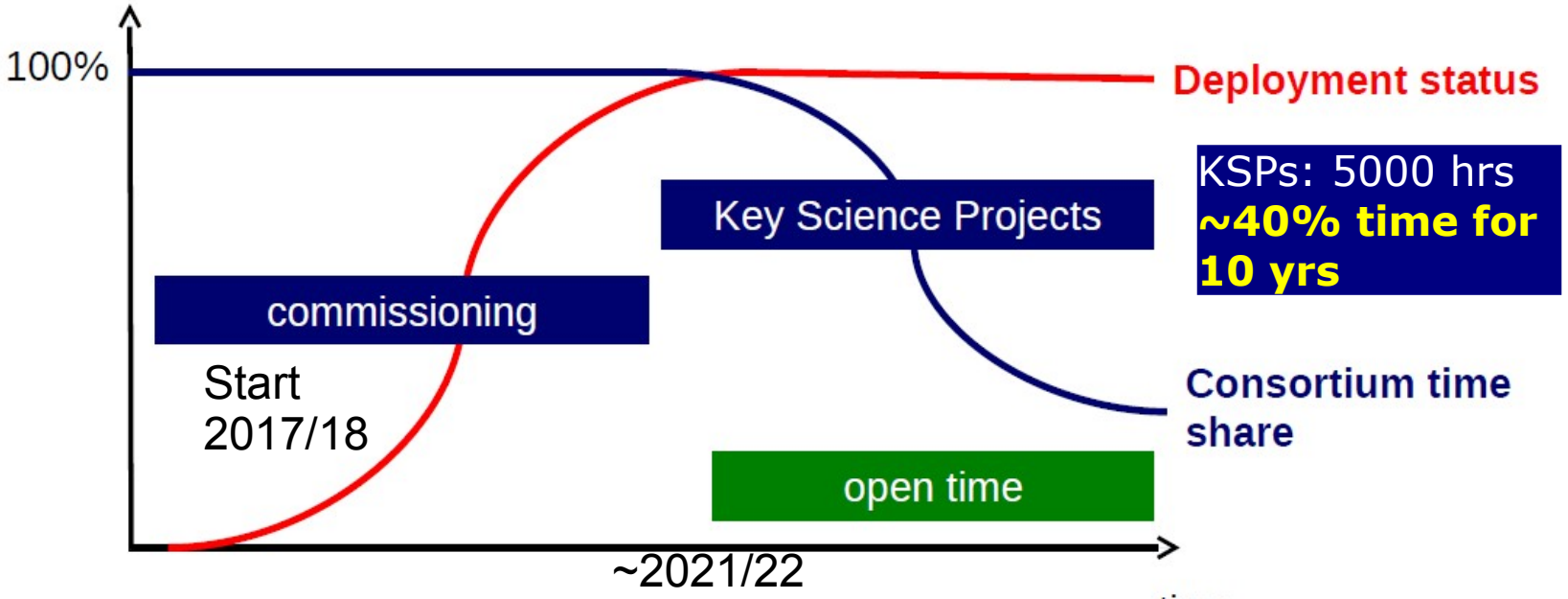
Current model

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)

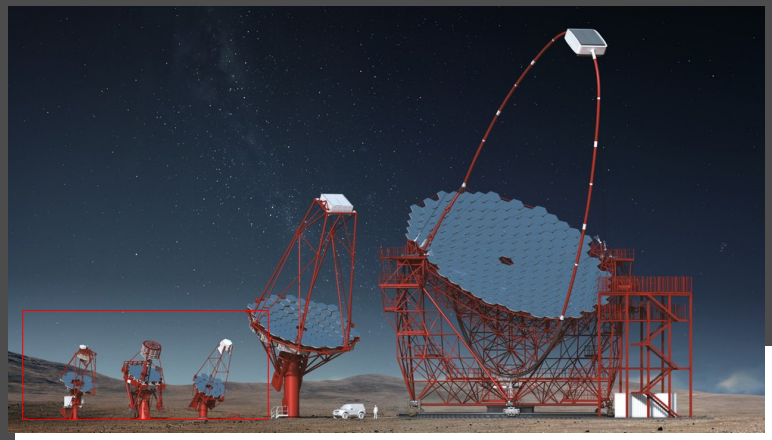
- Securing funding for full production phase:
  'Implementation' threshold (250MEuro 62%) imminent

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

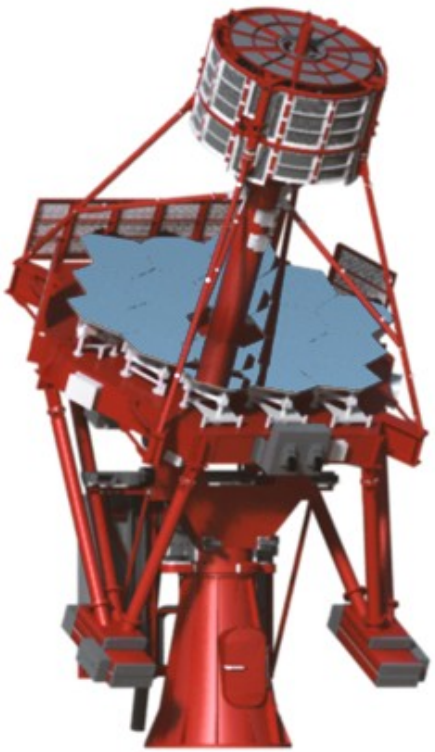
  CTAO member of CTAO Council
  benefits → vote on governance/operating cost policies

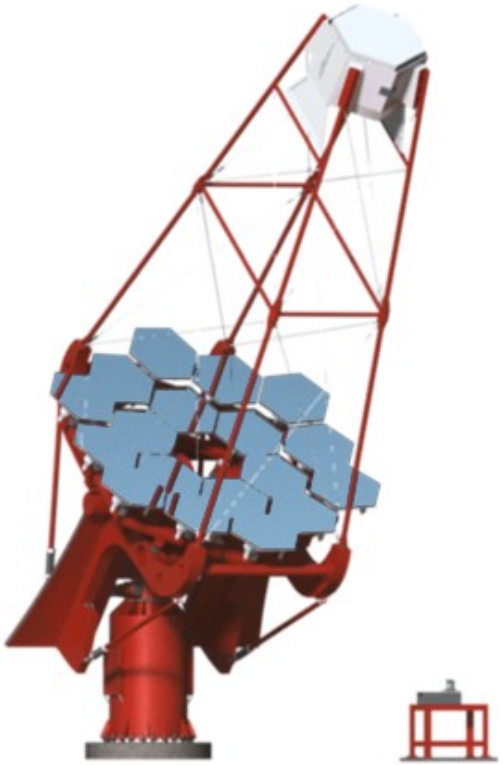
- Governance policies maturing
  (CTAO founding agreement underway; Move to Italy)

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



Australia contributes funding to the “GCT” SST





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

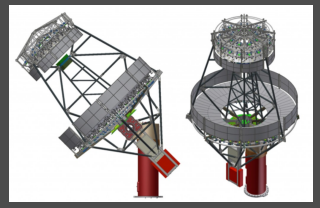
Australia - LIEF 2015 + 2017-21 support for GCT hardware and commissioning.

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

San Pedro Mártir, Mexico

La Palma, Canary Islands, Spain

Northern Hemisphere

Southern Hemisphere

Paranal, Chile

Aar, Namibia

Chosen sites

Backup sites

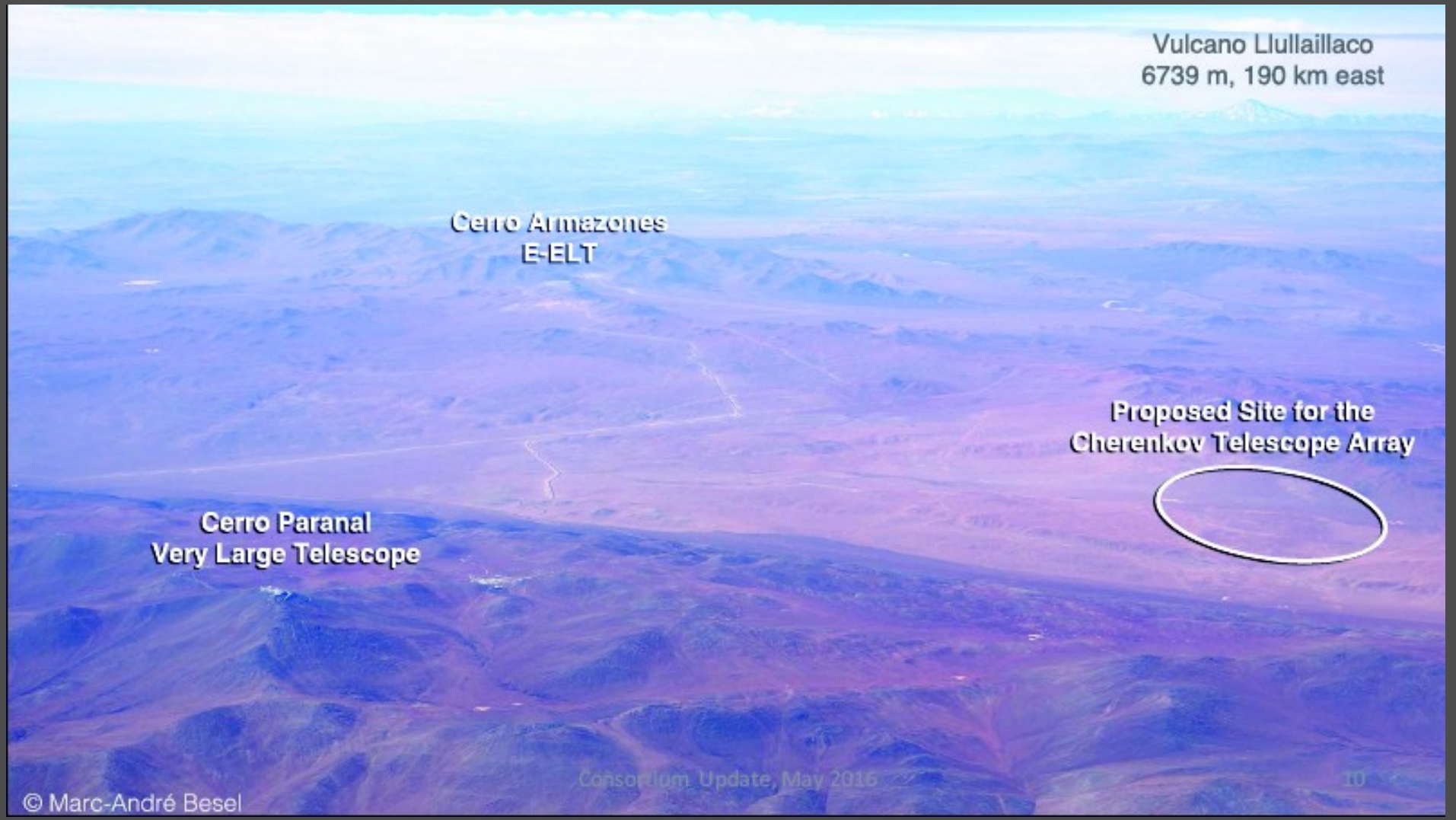
13 June 2016 - CTA HQ (Bologna)

- CTA Data Management Centre (DESY Berlin)

LST prototype status (La Palma)

cherenkov telescope array

CTA South : Paranal, Chile

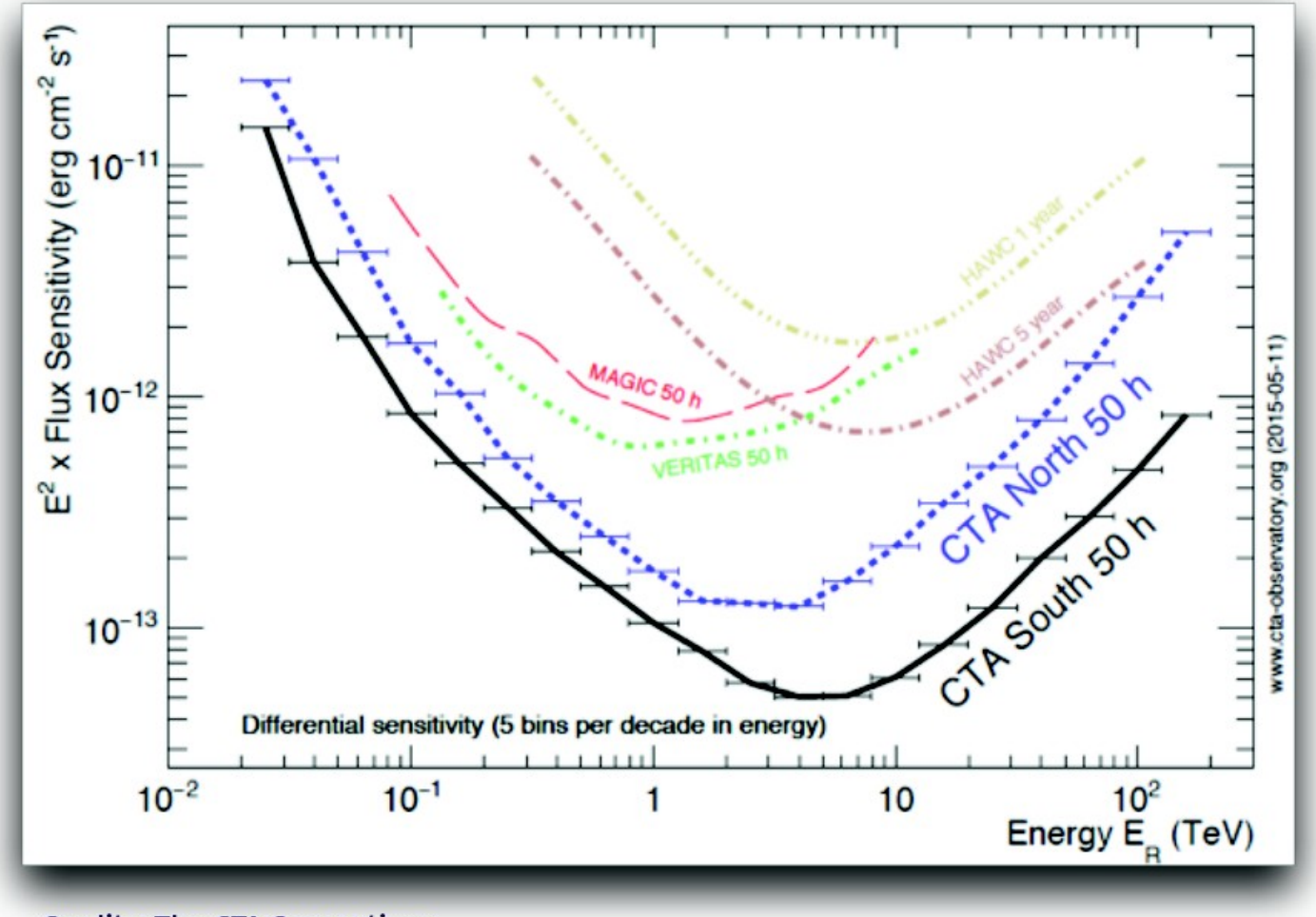


Negotiations with ESO ongoing: Infrastructure sharing/piggyback

CTA Performance

Energy coverage ~20 GeV to >200 TeV

Differential Sensitivity

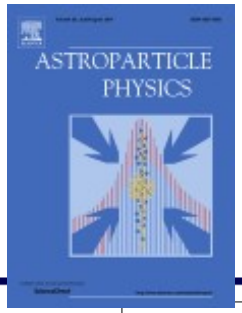


A factor of 5-10 improvement in sensitivity in the domain of about 100 GeV to some 10 TeV.

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



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

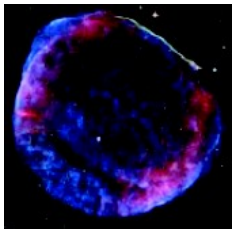
KEY SCIENCE PROJECTS

- 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

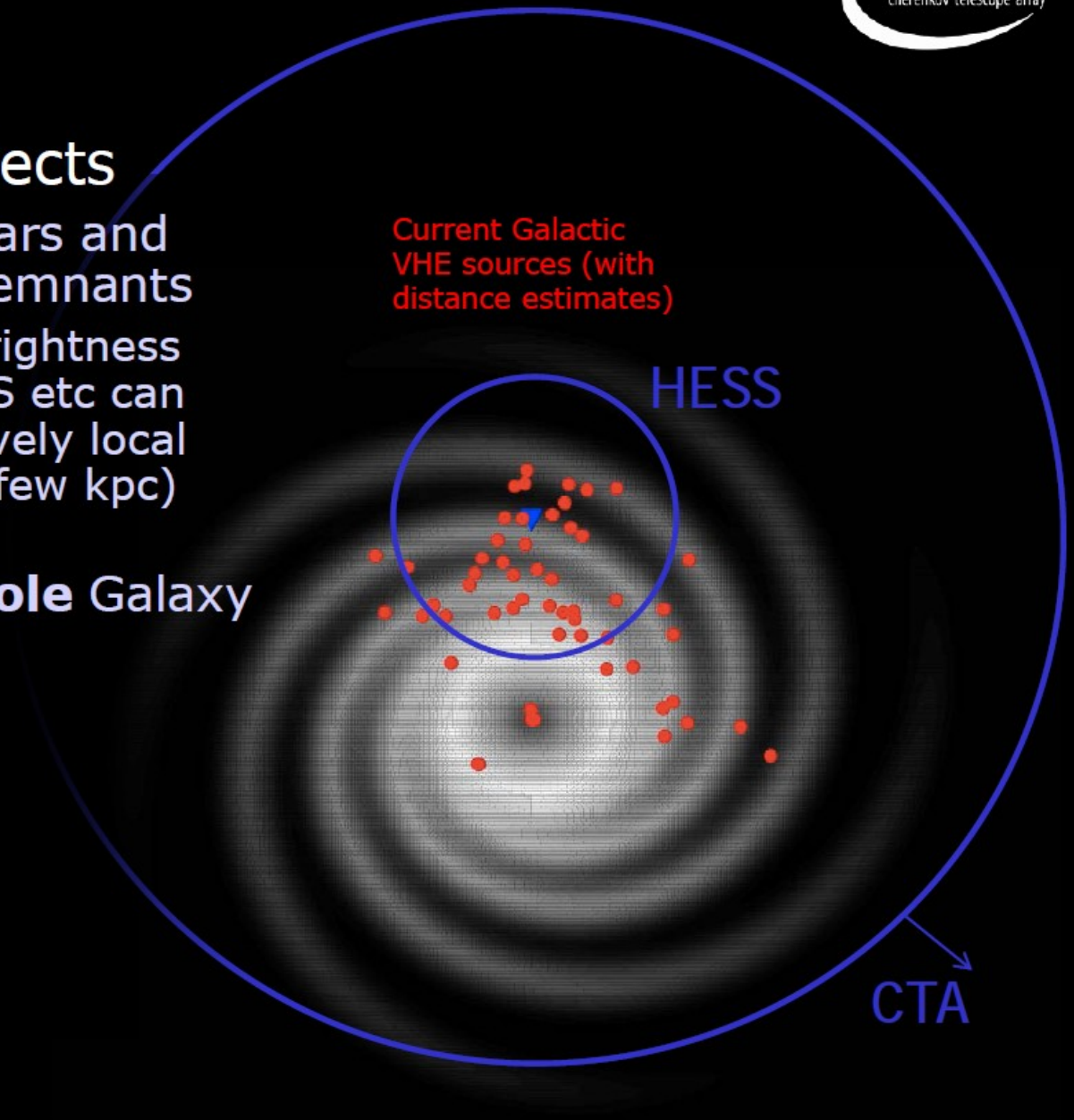


2. Probing Extreme Environments

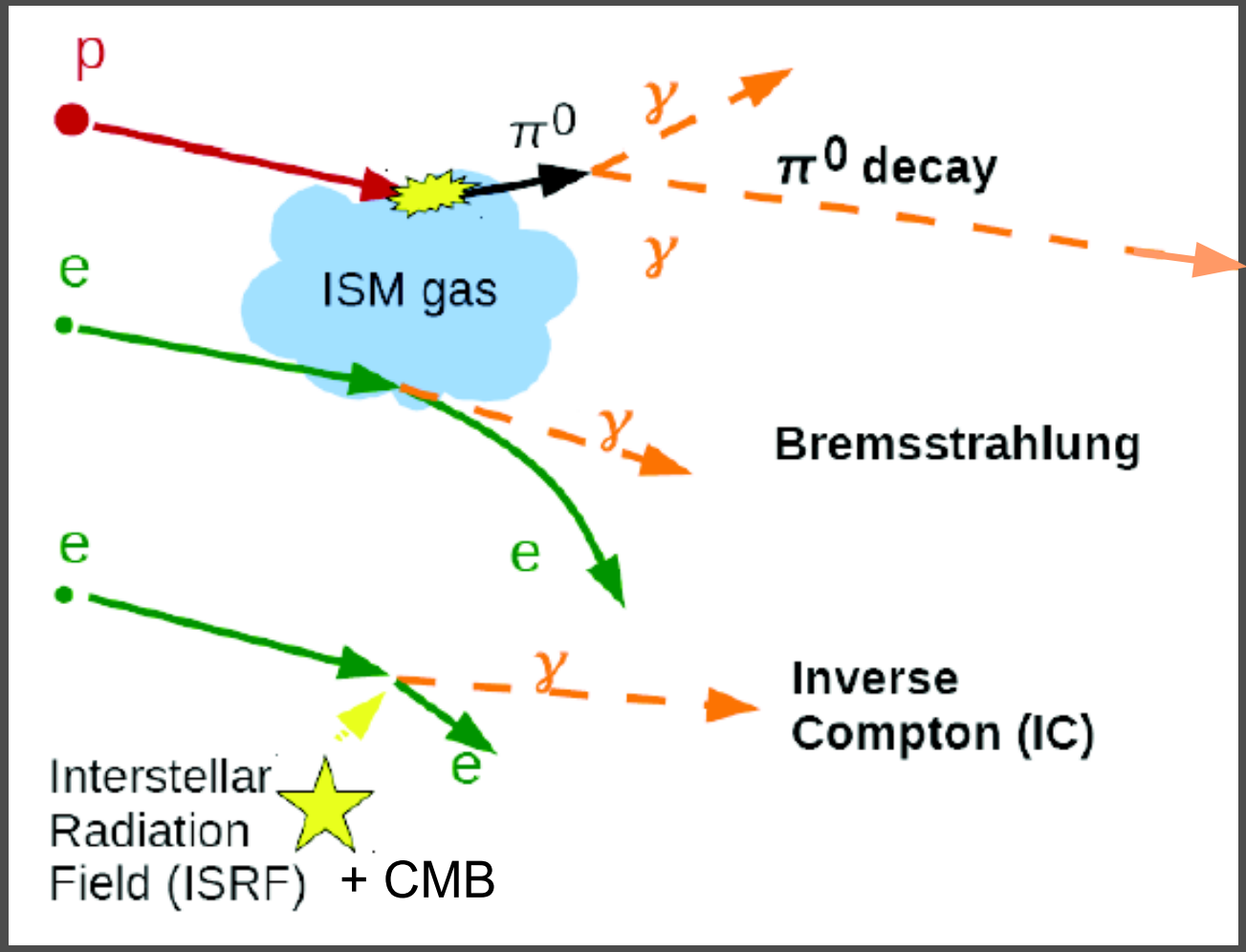
3. Physics Frontiers: Beyond Standard Model

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



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

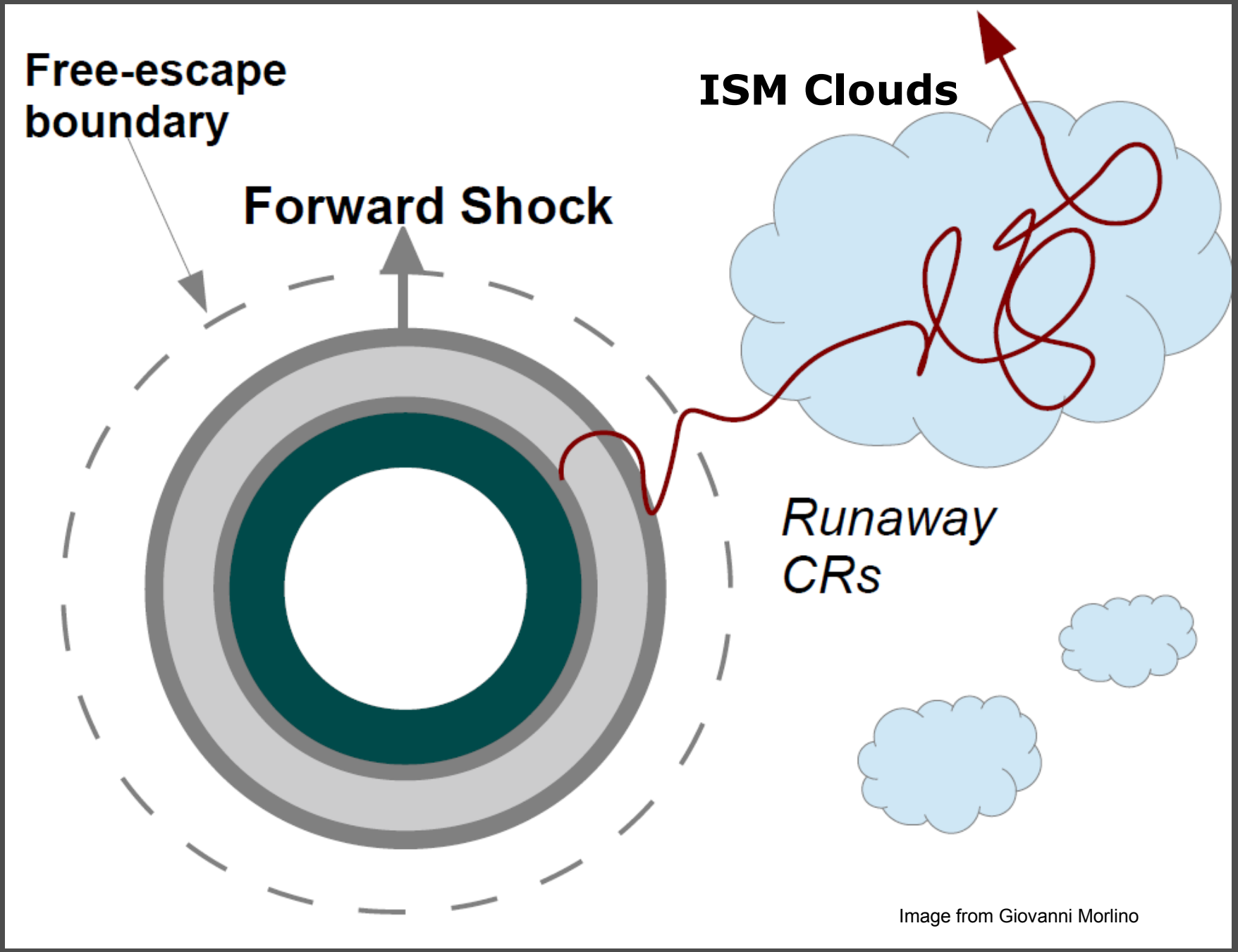
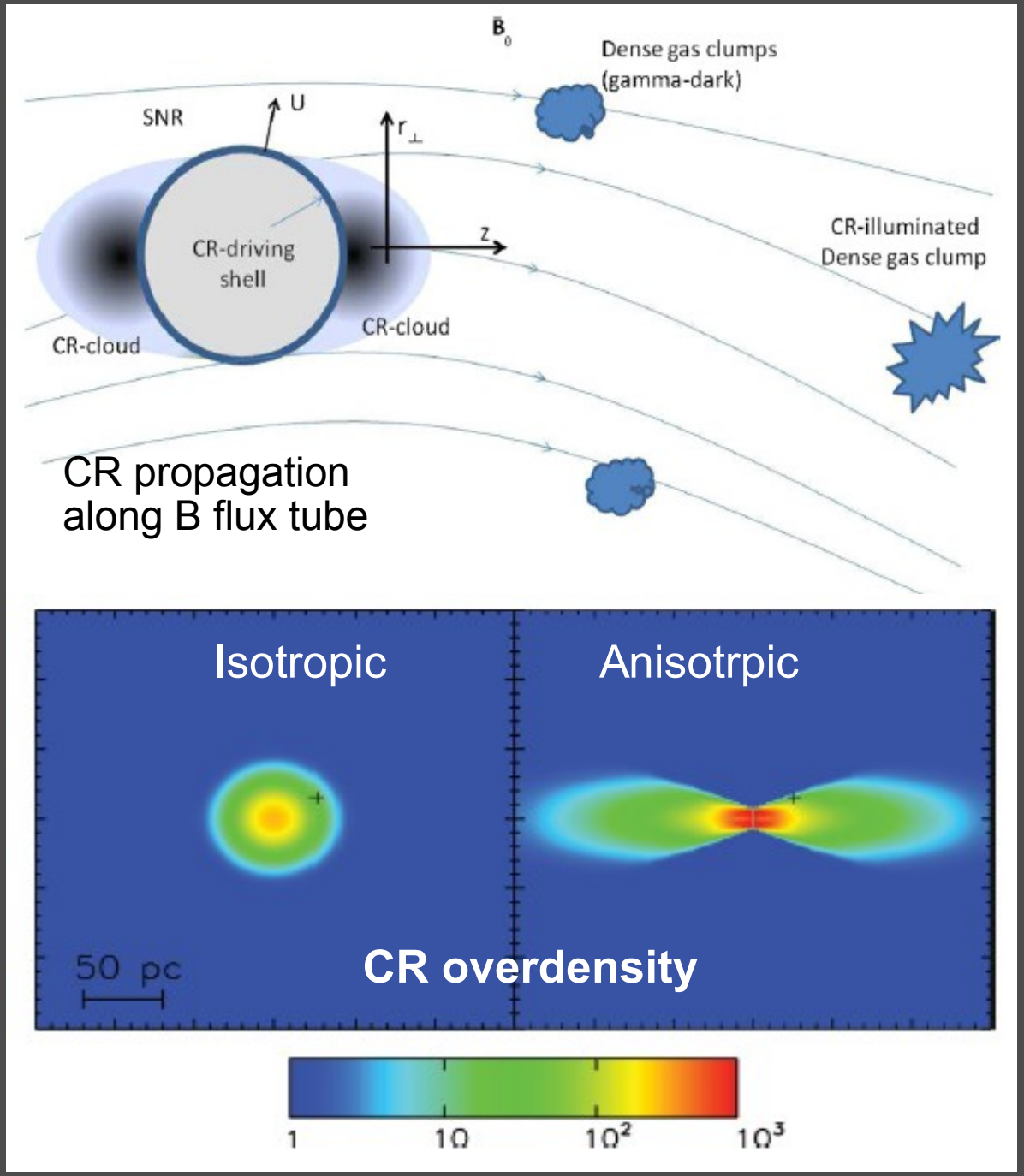


Image from Giovanni Morlino



CR diffusion – not necessarily Isotropic!

Malkov etal 2013
Nava & Gabici 2013

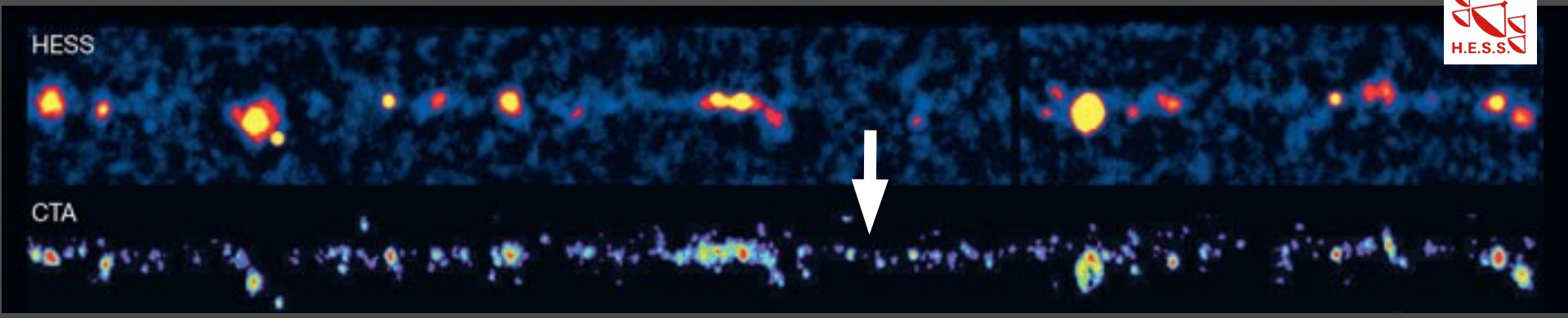
→ Nearby clouds will see different CR densities

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

B-field Faraday RM
Jansson & Farar et al 2012

→ **ASKAP POSSUM!**

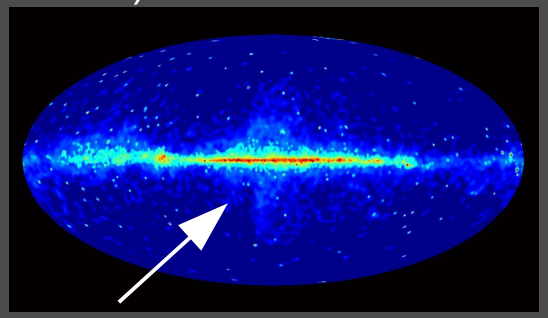
CTA Galactic Plane TeV Surveys : Major Issue



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+)

CR Diffusion *Into* Molecular Clouds

e.g. Gabici etal 2007, Inoue etal 2012

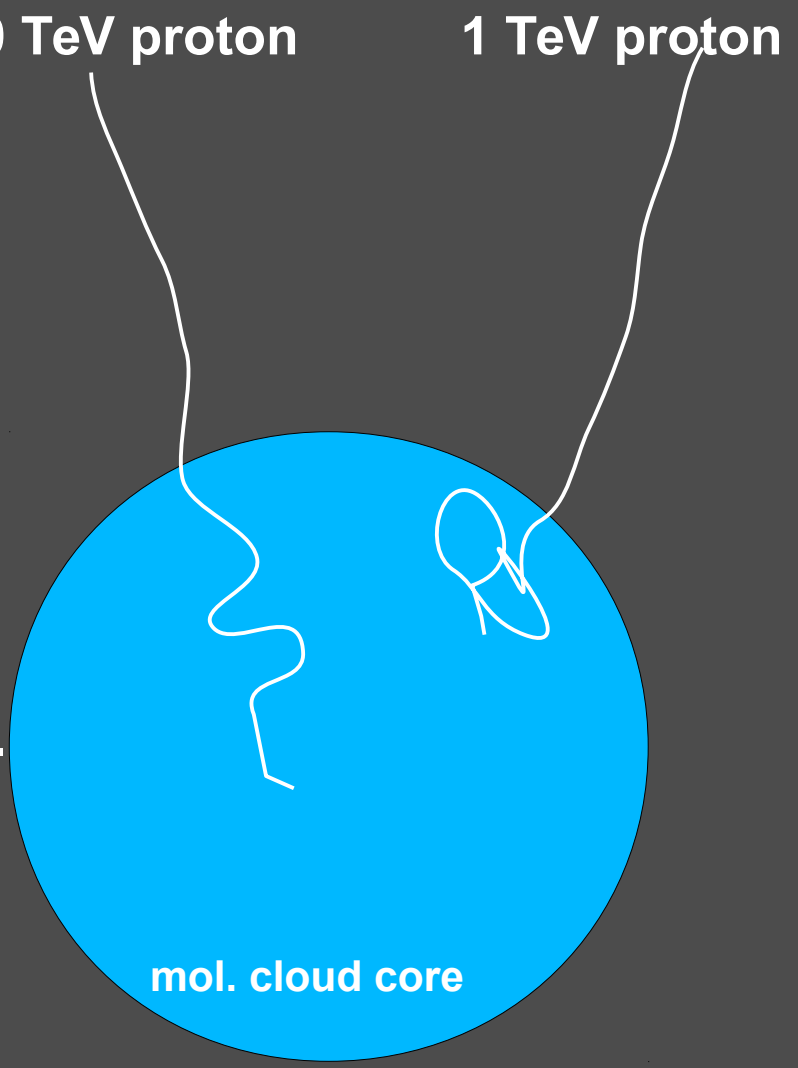
R = distance CR travels into molecular cloud core

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

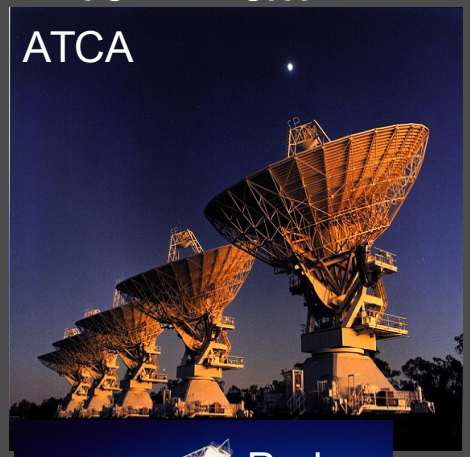
Interstellar gas tracers & telescopes..

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

HI (atomic H), OH, CS

Gas density

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



CSIRO

ASKAP-
GASKAP

CO

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

NANTEN
Submillimeter Observatory
なんてん電波天文台

国立天文台
NAOJ
National Astronomical
Observatory of Japan

HEAT – THz (Antarctica)
[CI] + [CII]

CO, NH_3, CS, SiO...

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

Mopra Telescope

CSIRO

AUSTRALIA TELESCOPE NATIONAL FACILITY
CSIRO

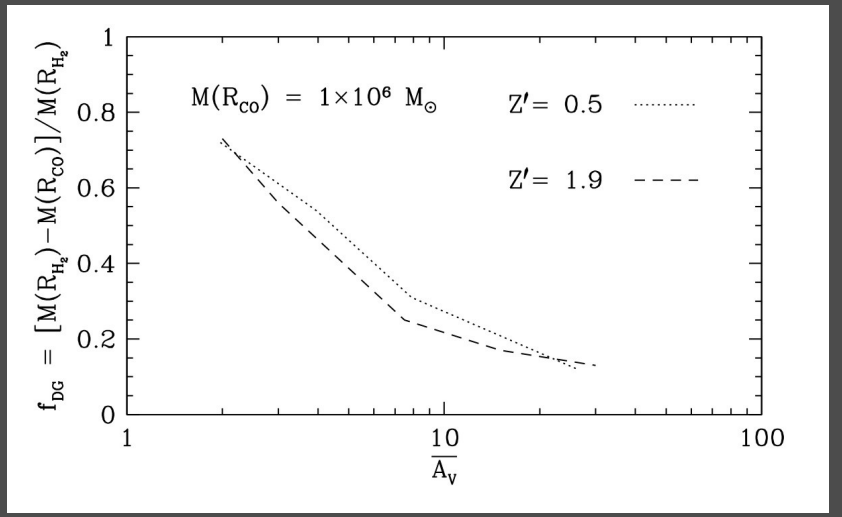
SCIENTIA
MANU ET MENTE

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

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

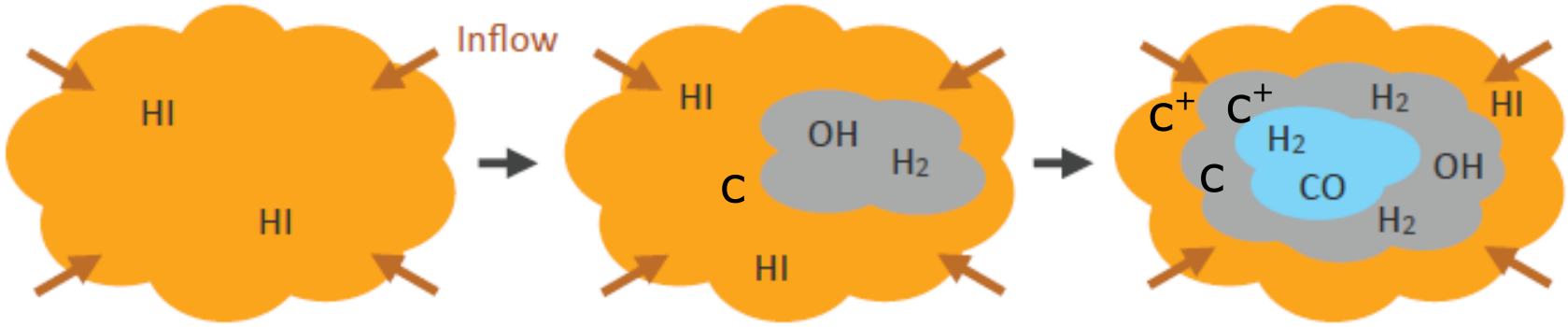


→ **optically thick HI (Yasuo Fukui)**

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

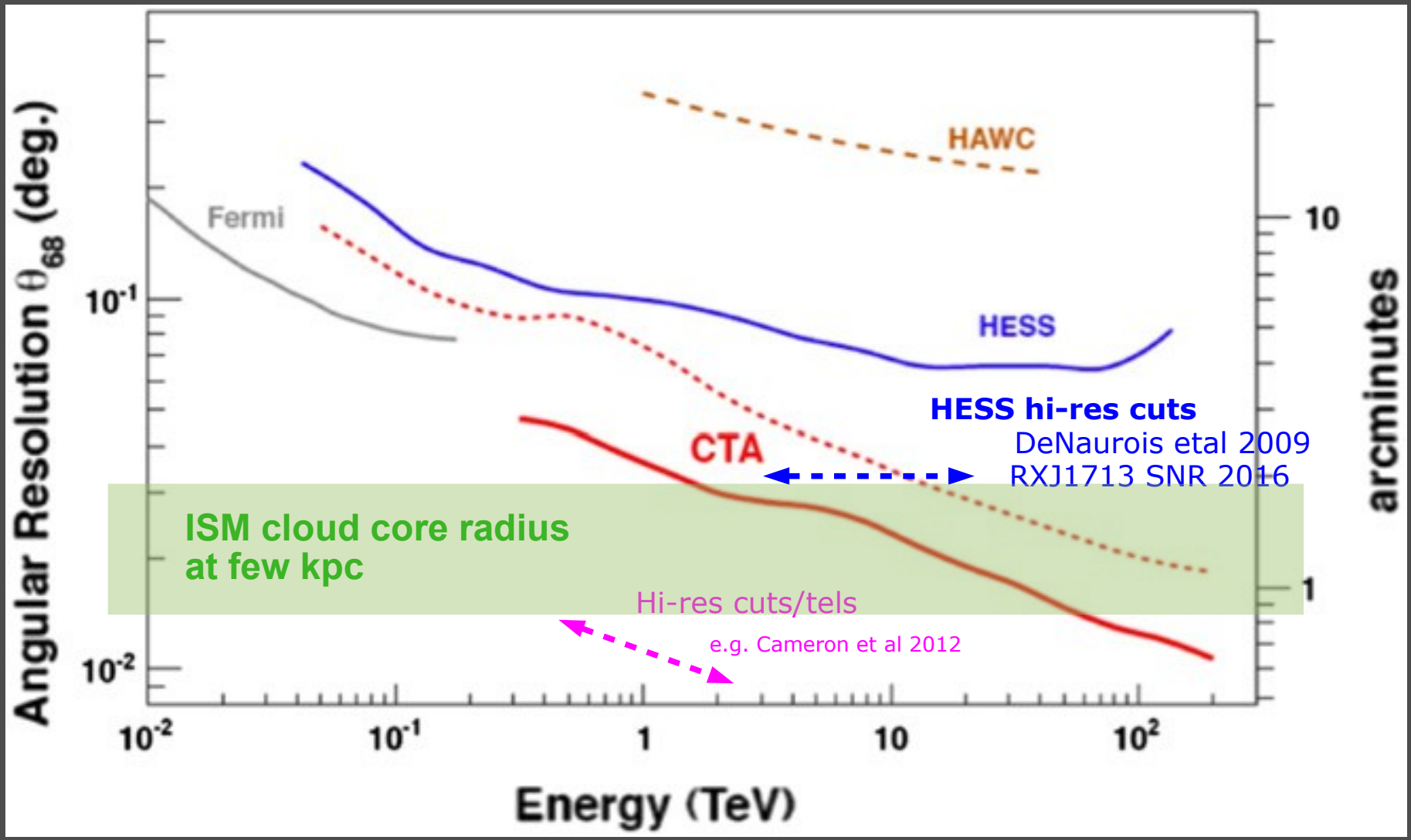
→ **CI, C+ ~THz lines**
(Nanten2, HEAT, STO2, SOFIA, STO2, DATE5,)

Graphic adapted from J. Dawson



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

Acharyara etal 2013



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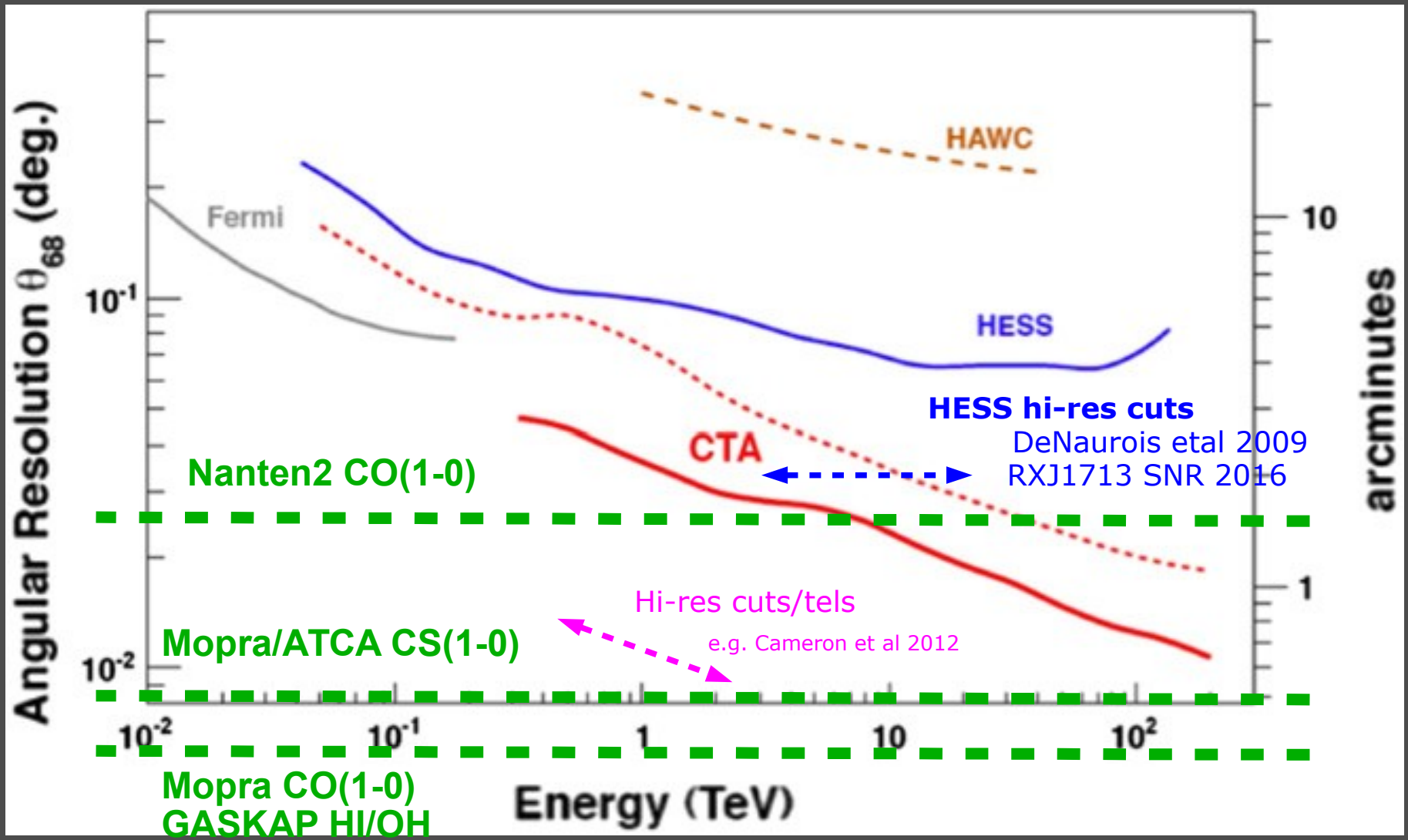
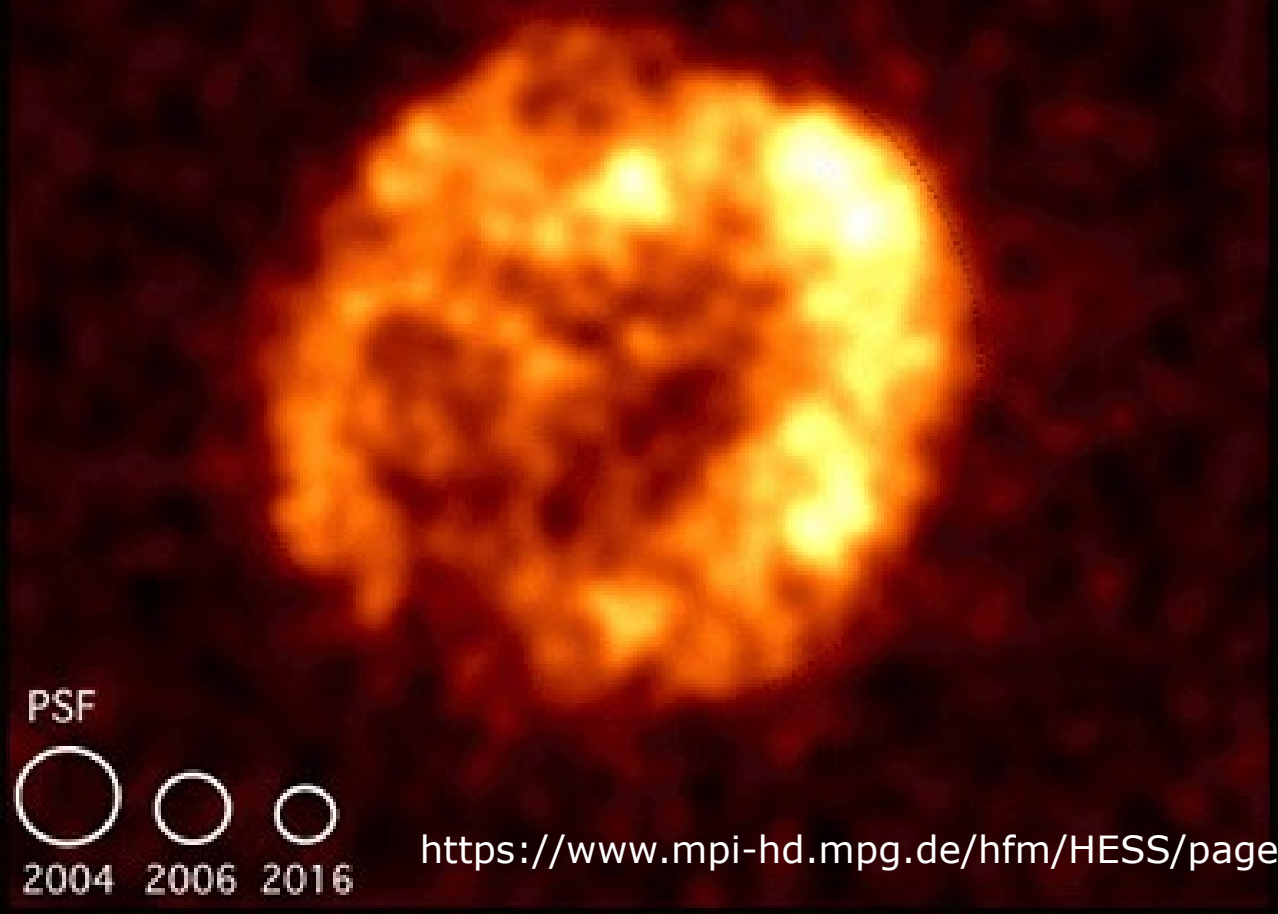


Beam Sizes 68% containment radius

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

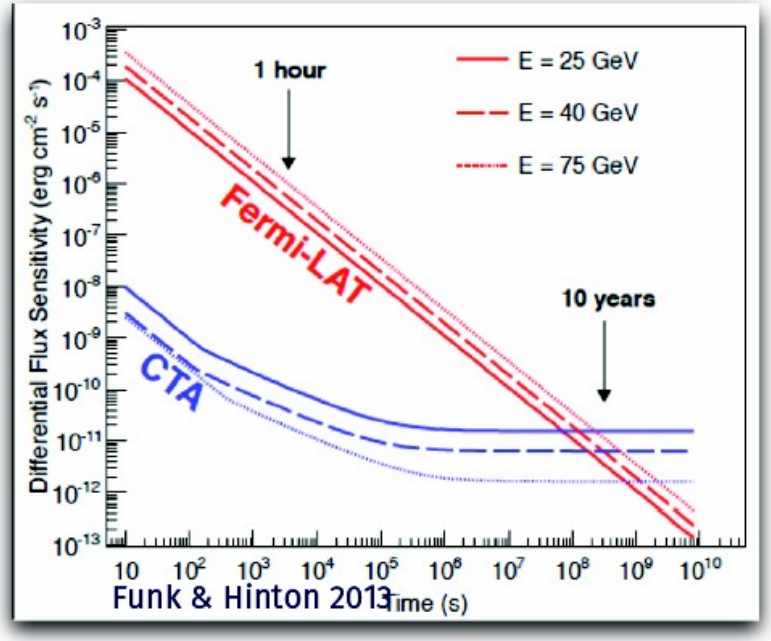
The sharpest gamma-ray image so far!
PSF (68%) ~ 2 - 3 arcmin (FWHM ~ 5 arcmin)
HESS Collab. arXiv:1609.08671

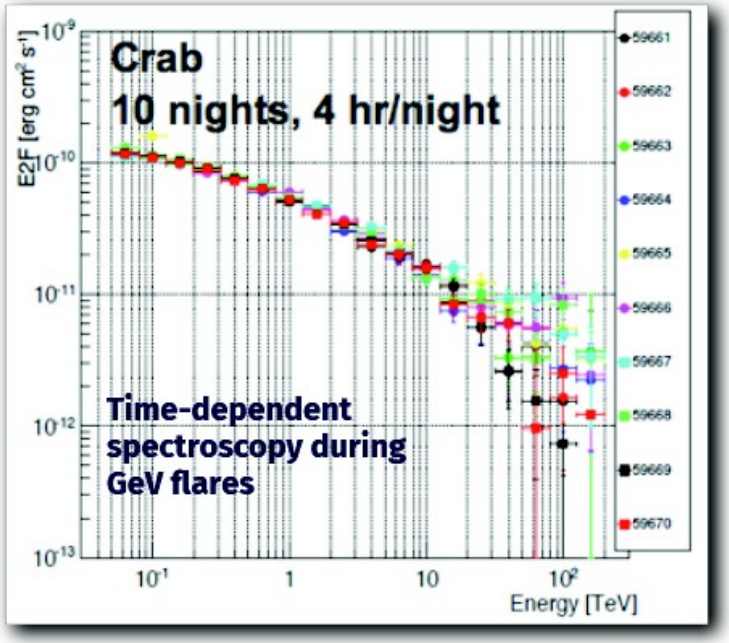


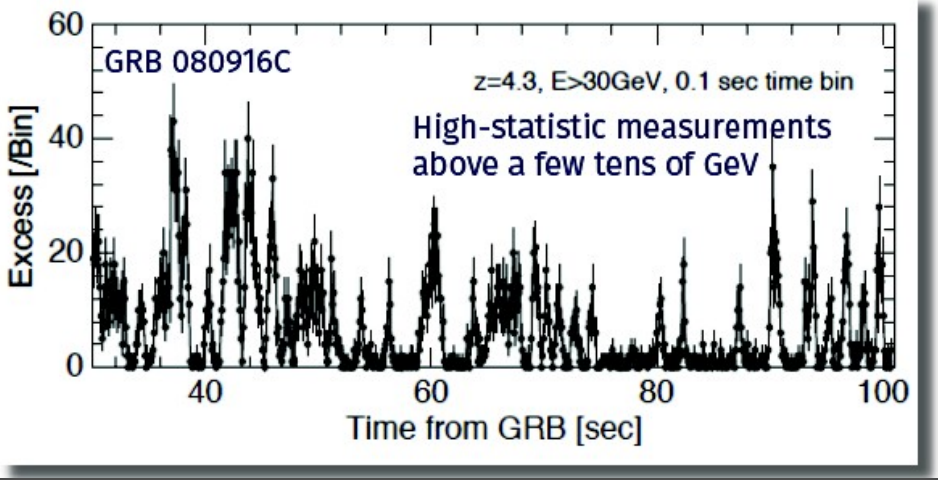
CTA
~1 arcmin

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

Transients



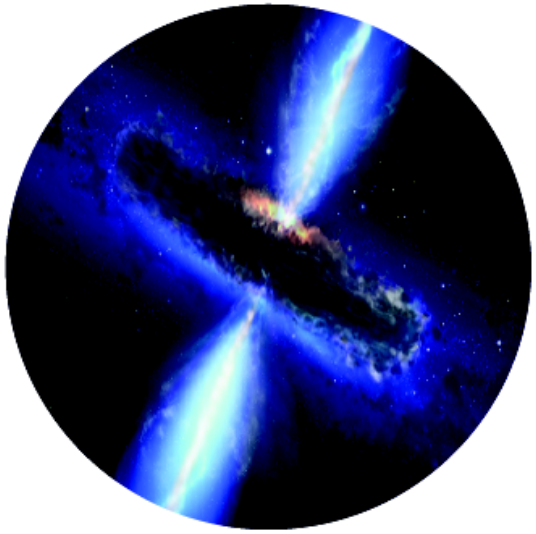




Inverse-Compton component of the 2011 April Crab flare assuming Γ=50. The variable tail from 10 to 100 TeV is clearly detectable.

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

Also TeV-Detected

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

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**.

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)

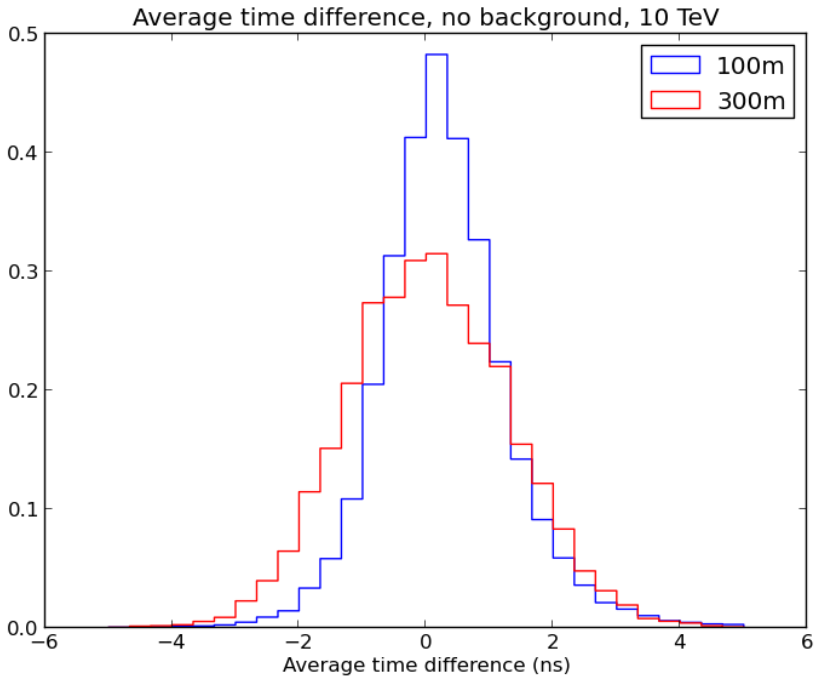
Theory Strengths

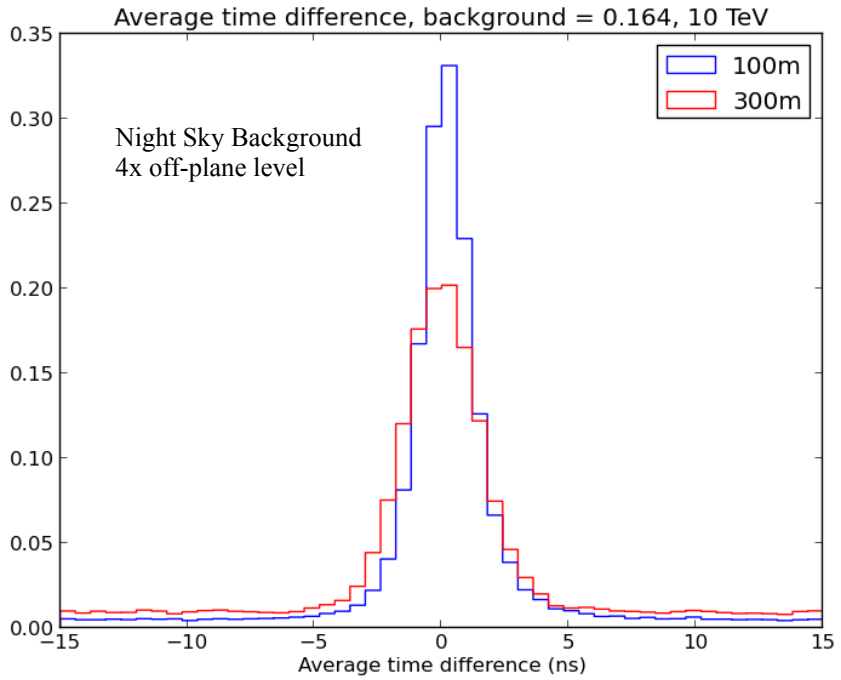
- Theoretical high energy astrophysics (e.g. Galactic Centre, jets/outflows)
- Astro-particle physics – Dark matter properties

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

Time-based 'cleaning' of Cherenkov images (Luke Bowman MSc)





- Cherenkov image is narrow in time: adjacent pixels <= few ns difference
- Night sky background pixels are random in time

→ Use camera pixel signal times to remove night sky background (NSB) pixels. Apply max time difference (few ns) for adjacent pxels.

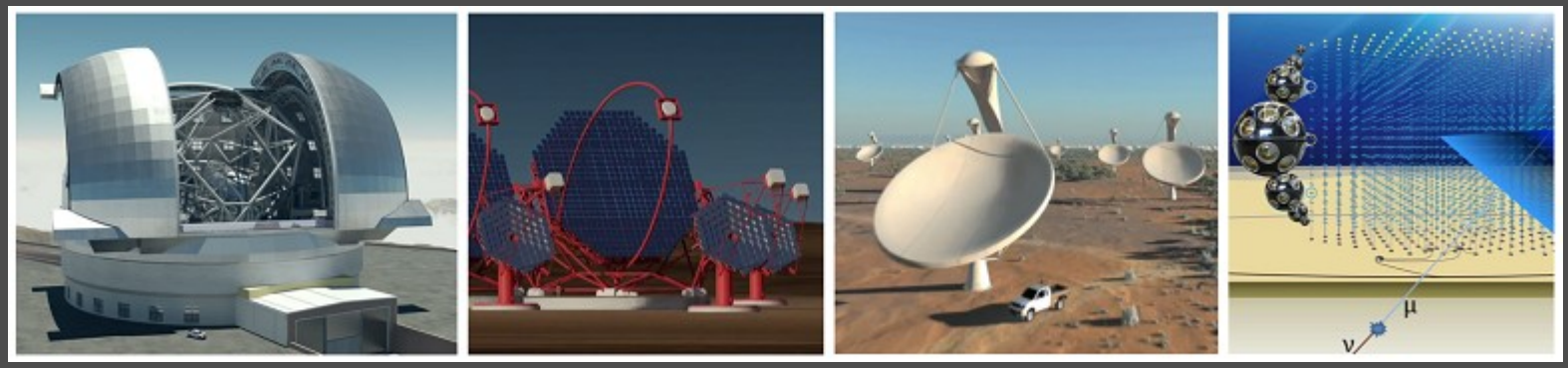
→ Prev. work (J. Denman PhD thesis) suggested improvement to ang. res.
→ Now being applied to CTA-SST simulations (L. Bowman)

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

Radio – γ-ray: Transient Alert Mechanisms Rγ-TAM

26–28 September 2017
Amsterdam, the Netherlands

https://indico.astron.nl/conferenceDisplay.py?ovw=True&confId=62

David Berge
GRAPPA, API, UvA

Felicia Krauß
GRAPPA, API, UvA

Asterics

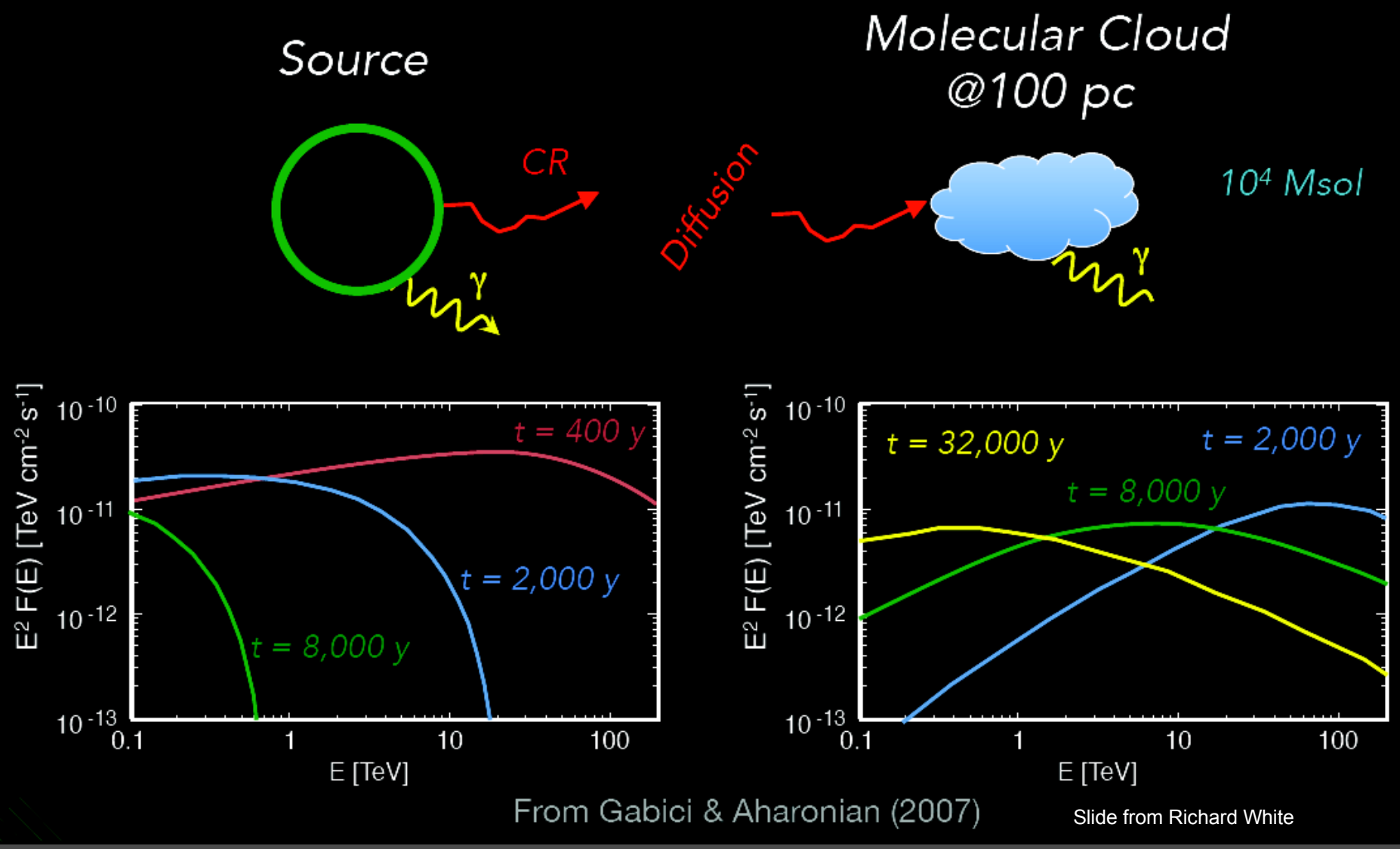
Grant Nr. No 653477

GRAPPA

Thank you....

Gamma-ray spectra from local and escaped CRs

e.g. Aharonian & Atoyan 1996



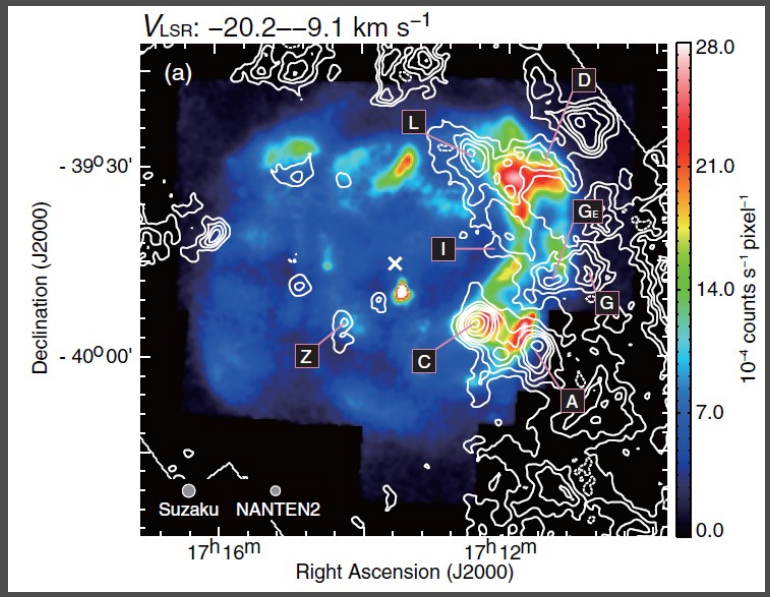
Slide from Richard White

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

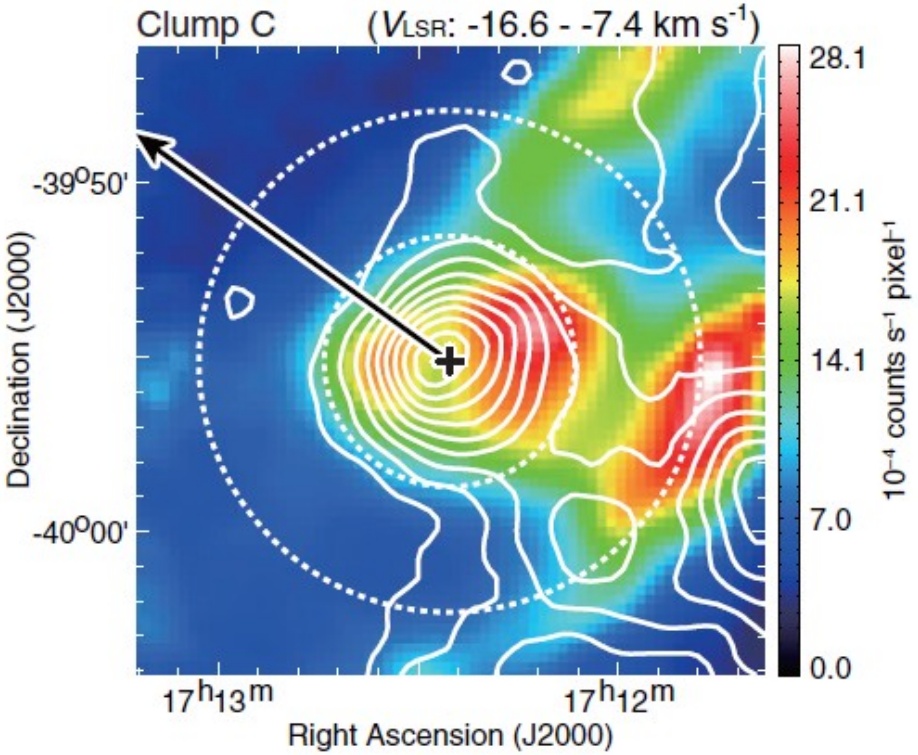
Sano etal 2013

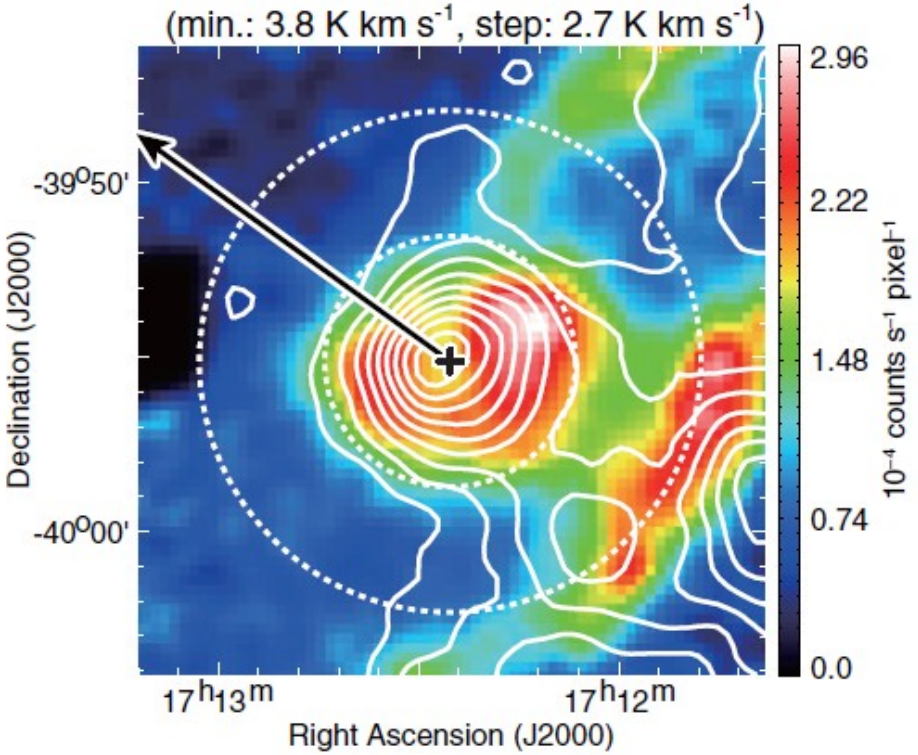
- CO(2-1) Nanten2 contours +X-ray images
- Synch cooling length < pc for
  30 TeV electrons, 6 keV X-rays,
  $n=10^5$/cc, B~400μG

See also Uchiyama et al 2007

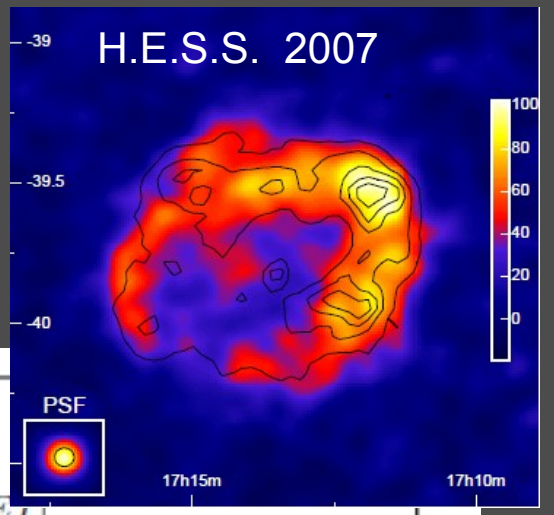


Suzaku 1–5 keV (left) and 5–10 keV (right) images

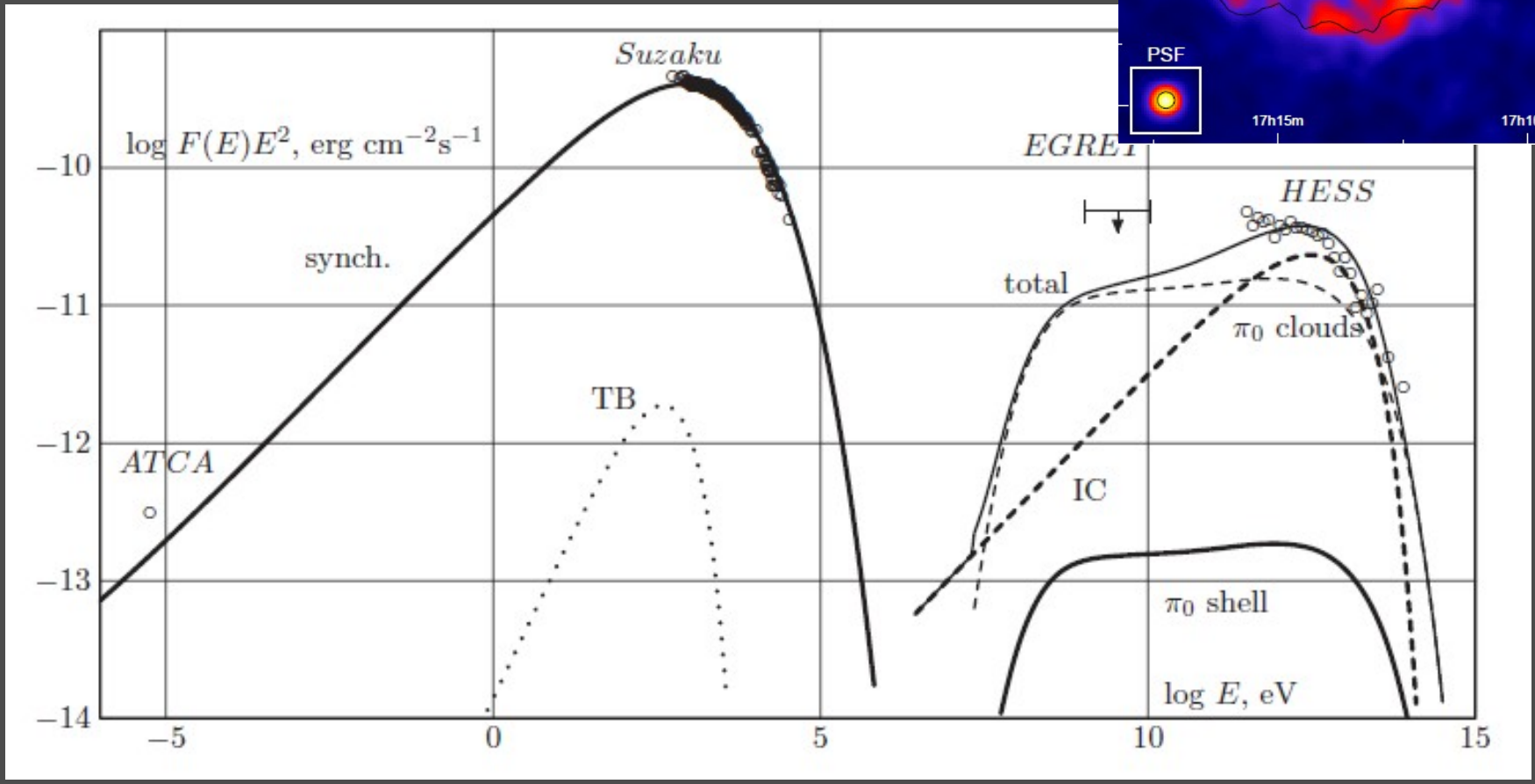




Radio to TeV SED: Young Supernova Remnant RXJ1713.7-3946

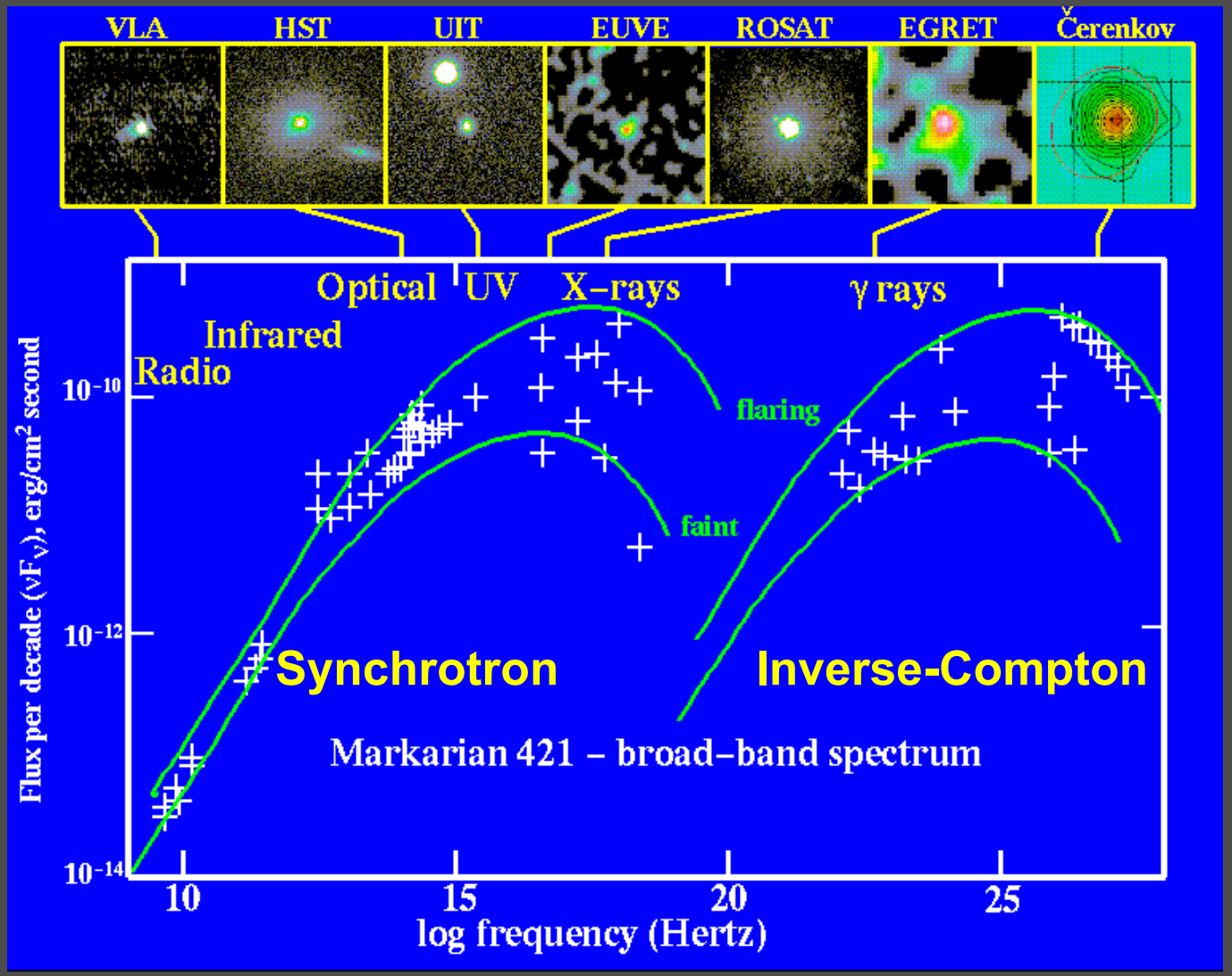


e.g. Zirakashivilli & Aharonian 2010



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

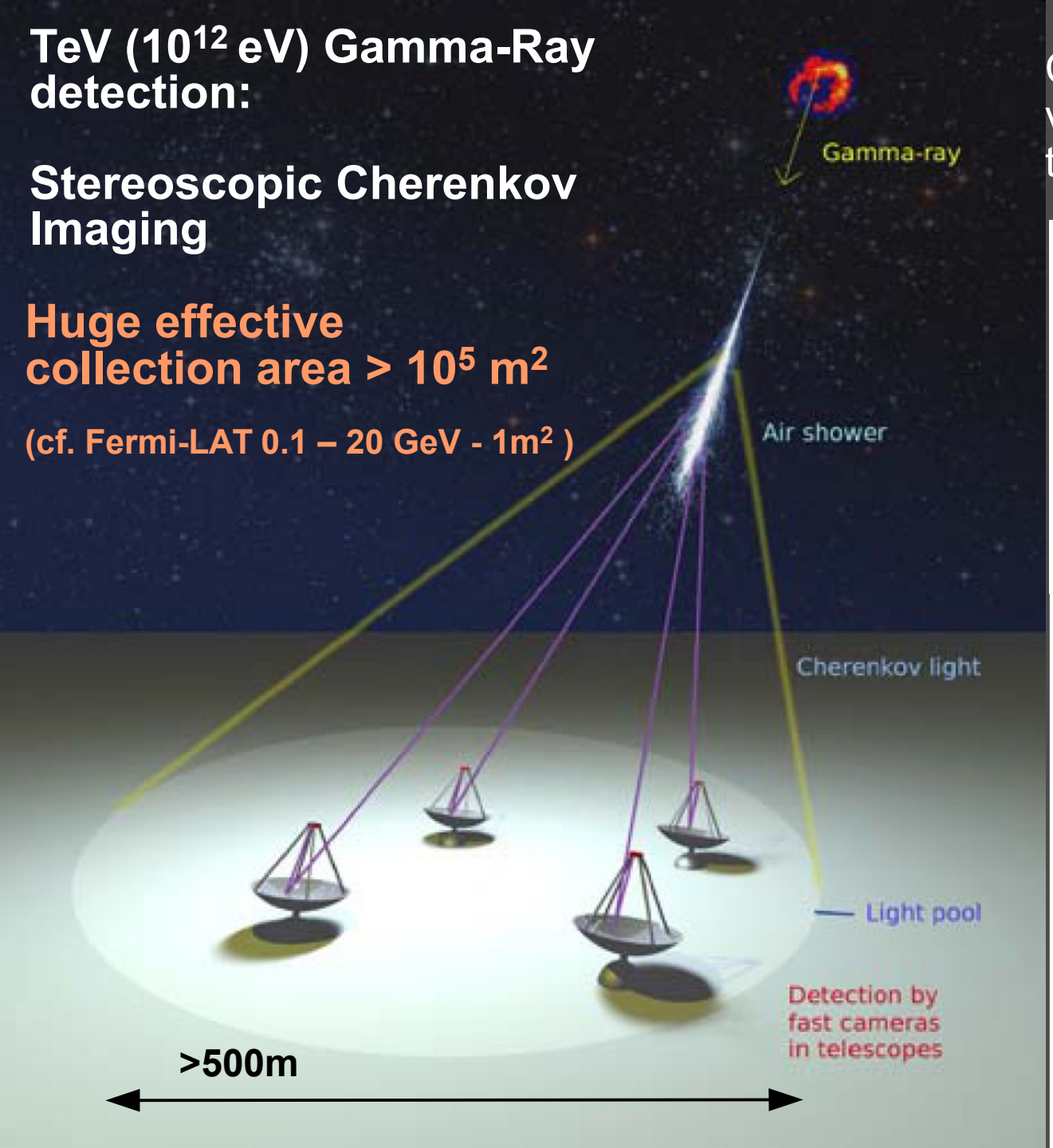
ATCA (+ MWA recently) used in gamma blazar/AGN studies
– e.g. flare follow-ups

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

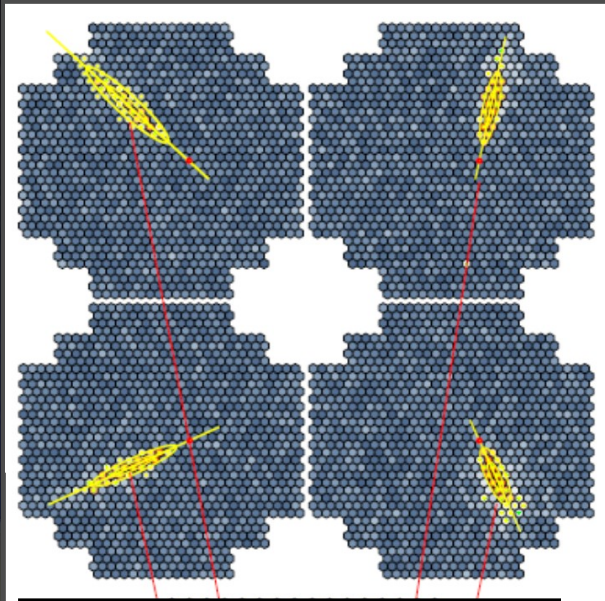
Stereoscopic Cherenkov Imaging

Huge effective collection area > 10^5 m^2

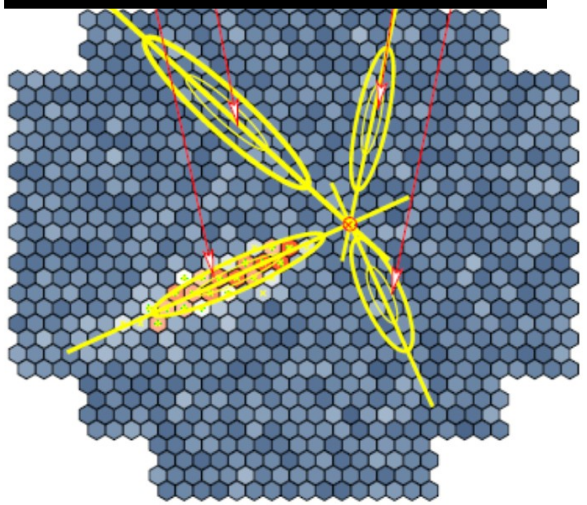
(cf. Fermi-LAT 0.1 – 20 GeV - 1m^2)



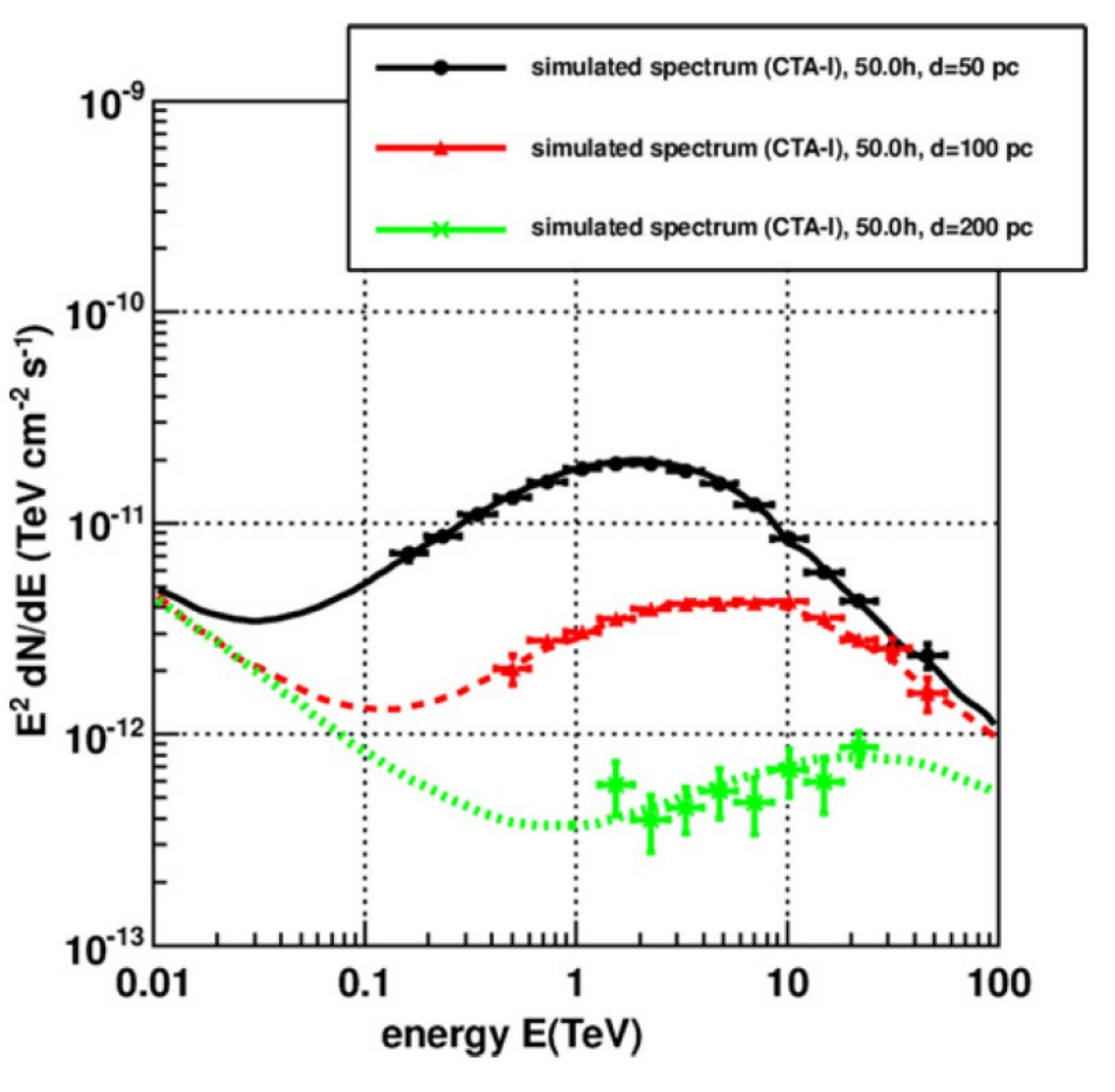
Cherenkov 'image' as viewed by each telescope



Combination:



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)