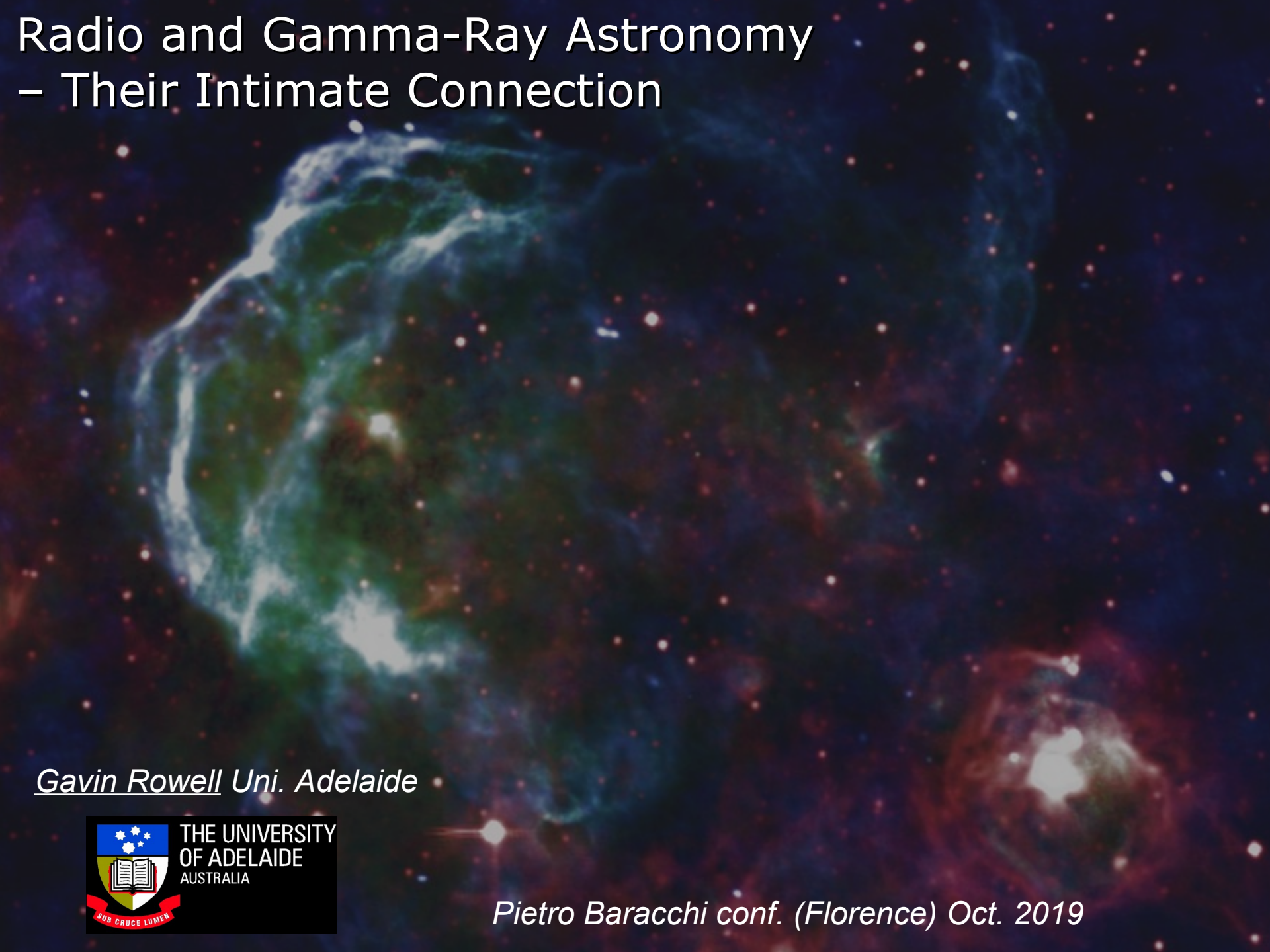
Radio and Gamma-Ray Astronomy – Their Intimate Connection



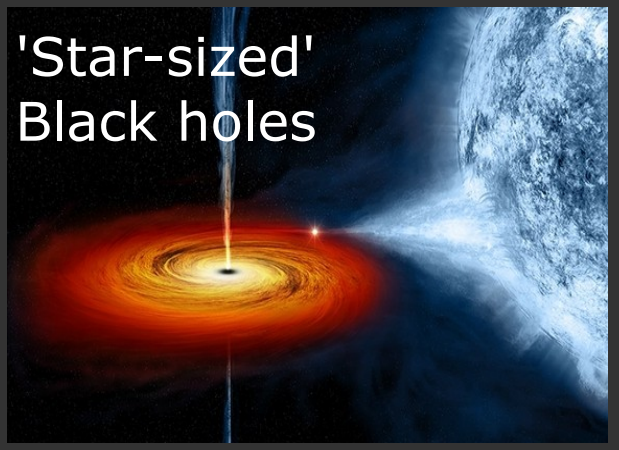
Gavin Rowell Uni. Adelaide

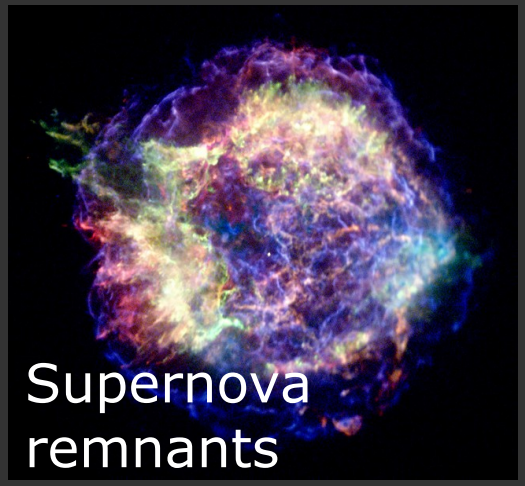
THE UNIVERSITY OF ADELAIDE AUSTRALIA

SUB CRUCE LUMEN

Pietro Baracchi conf. (Florence) Oct. 2019

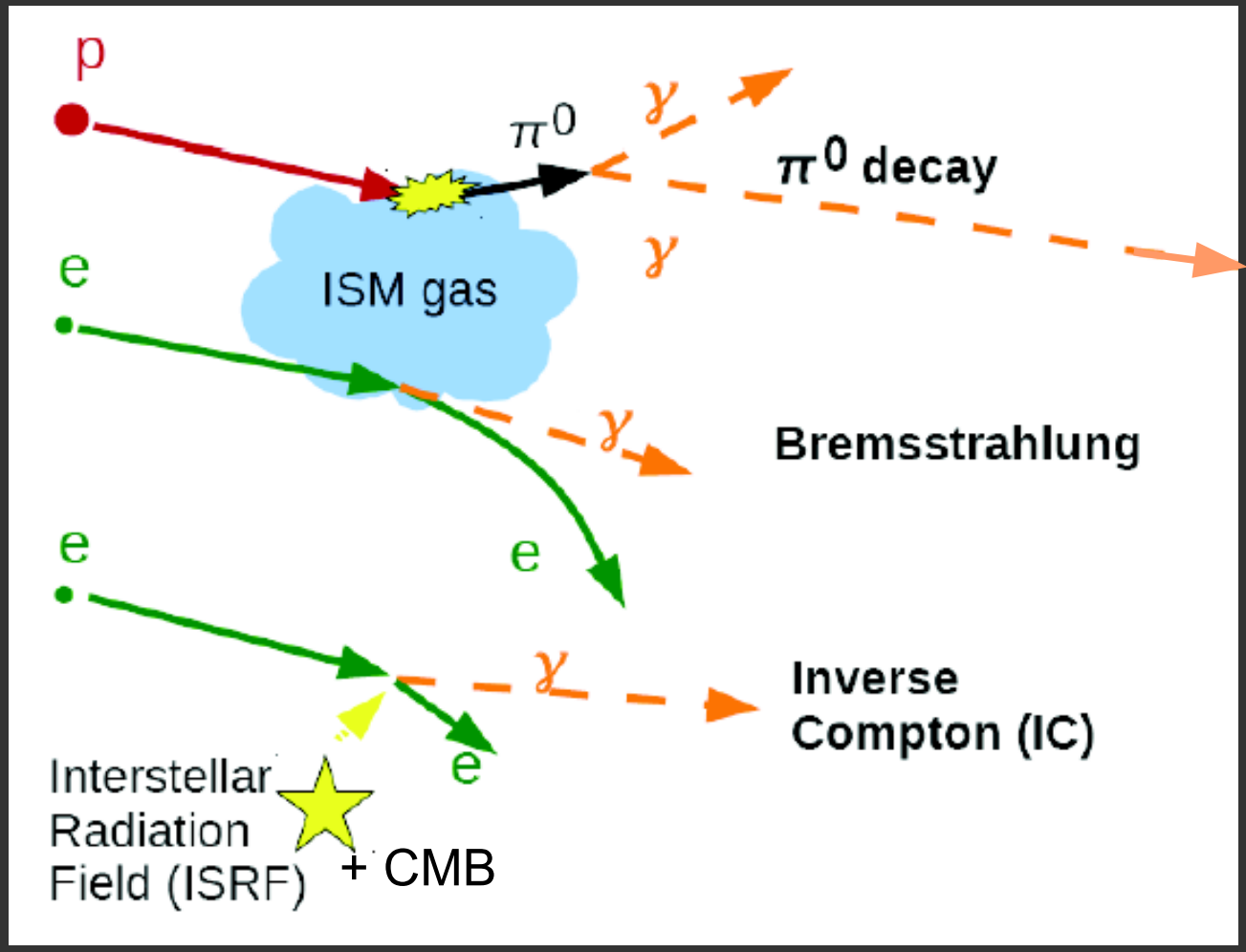
Some (potential) Cosmic-Ray and Electron Accelerators





All are extreme environments!

Gamma Rays from multi-TeV particles



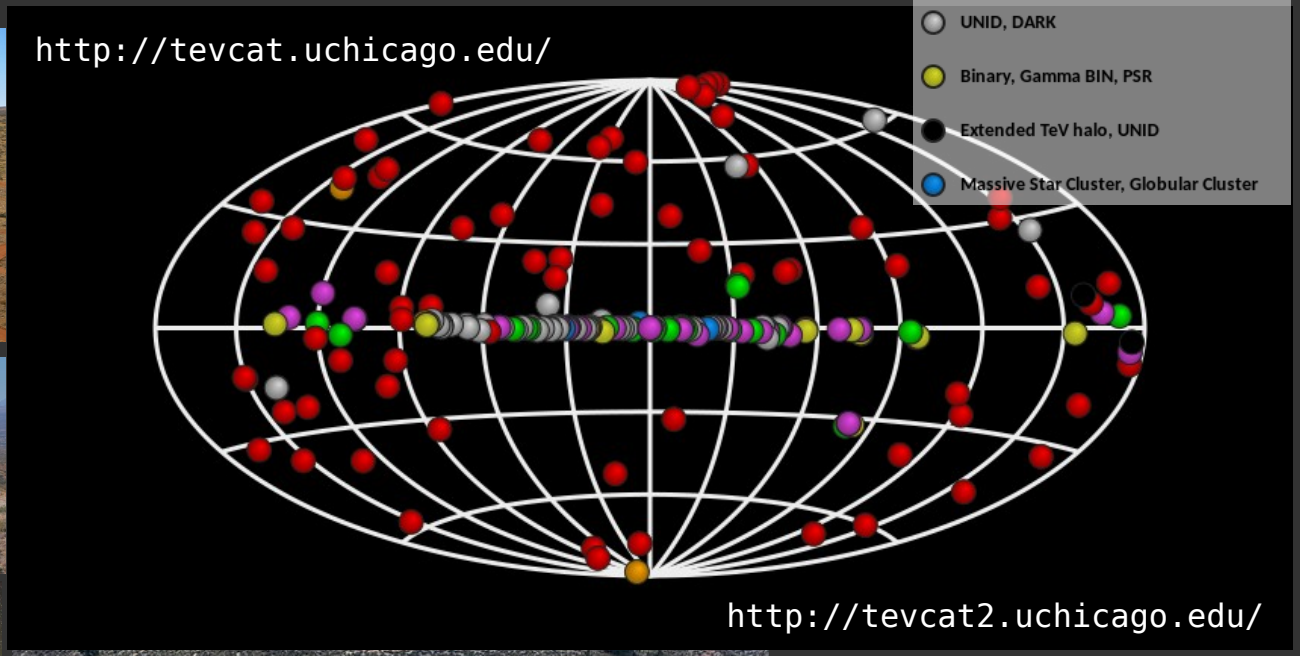
Protons: Gamma-rays and gas targets are generally spatially correlated
(need to map atomic and molecular ISM → mm radio astronomy)

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

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

Ground-based detection of Cherenkov emission

High impact > 20 Nature, Science, PRL papers since 2004

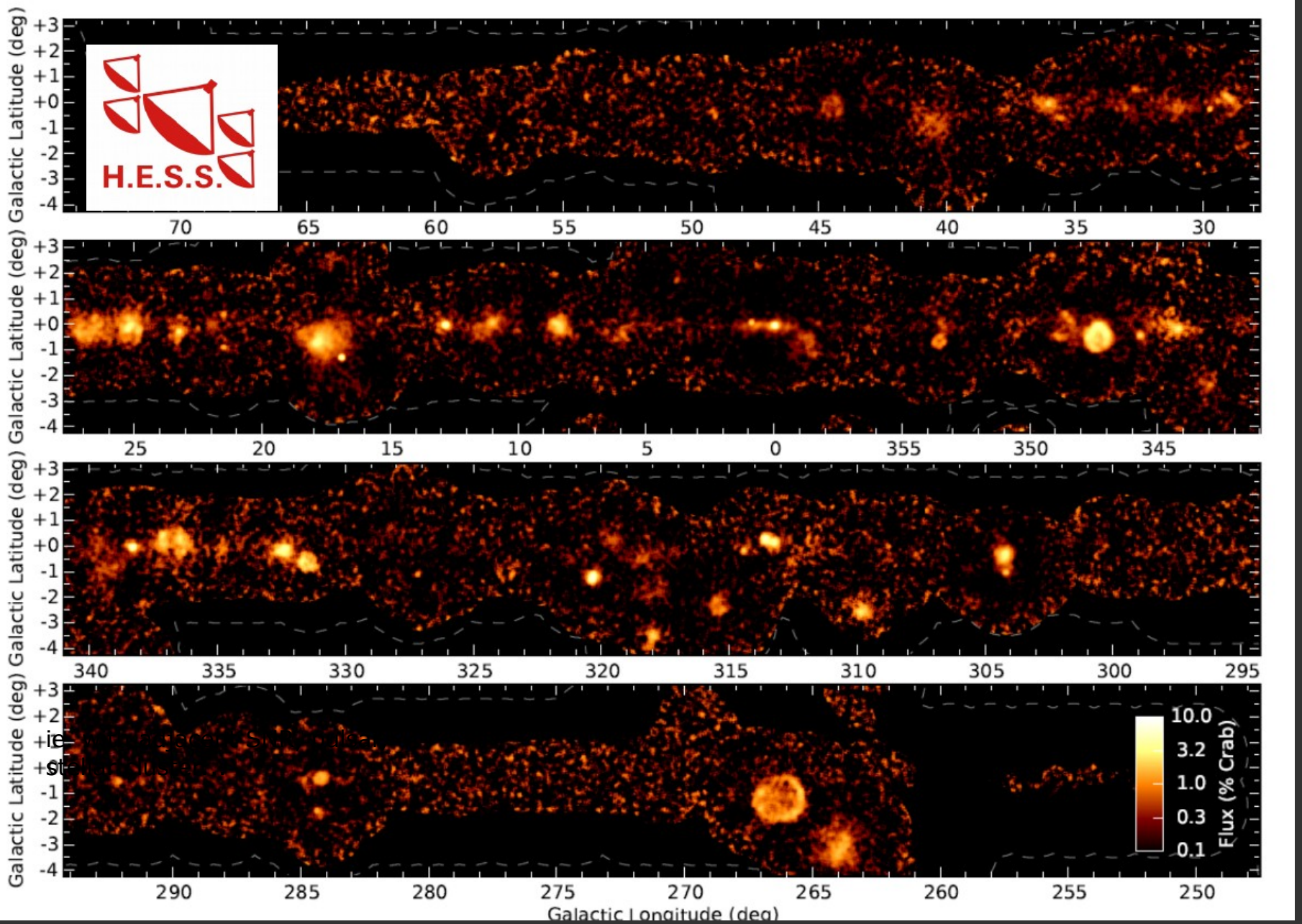


Great success with HESS, VERITAS, MAGIC, HAWC, building on the pioneering efforts of Whipple, HEGRA, CAT, CANGAROO, MILAGRO....

HESS Galactic Plane Survey (HGPS)

→ 78 sources (13 new sources)

HESS 2018



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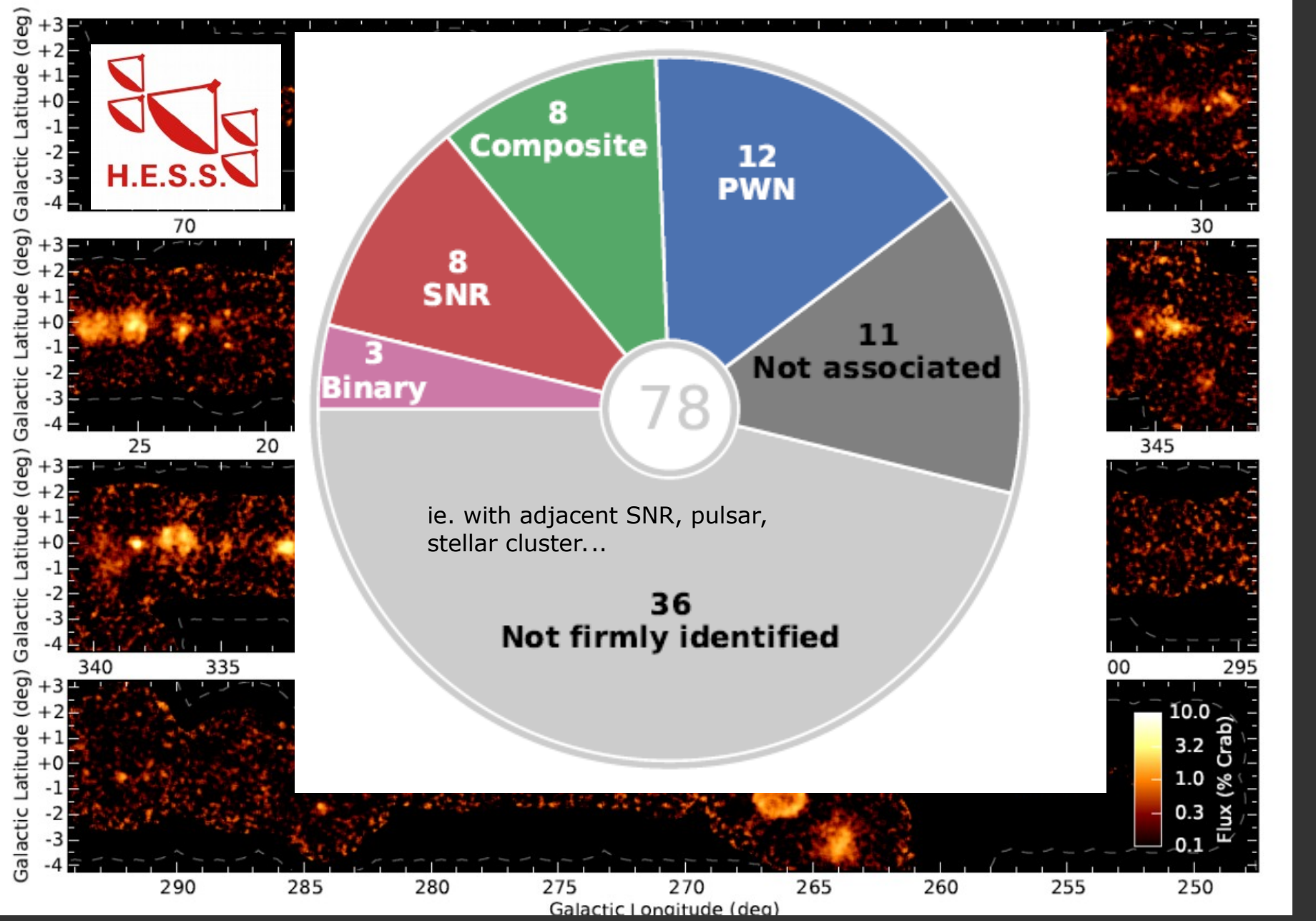


Science with CTA

https://www.worldscientific.com/worldscibooks/10.1142/10986

Key Science Projects

- Dark Matter Programme
- Galactic Centre
- Galactic Plane Survey
- Large Magellanic Cloud Survey
- Extragalactic Survey
- Transients
- Cosmic-Ray PeVatrons
- Star-forming Systems
- Active Galactic Nuclei
- Cluster of Galaxies
- Beyond Gamma Rays

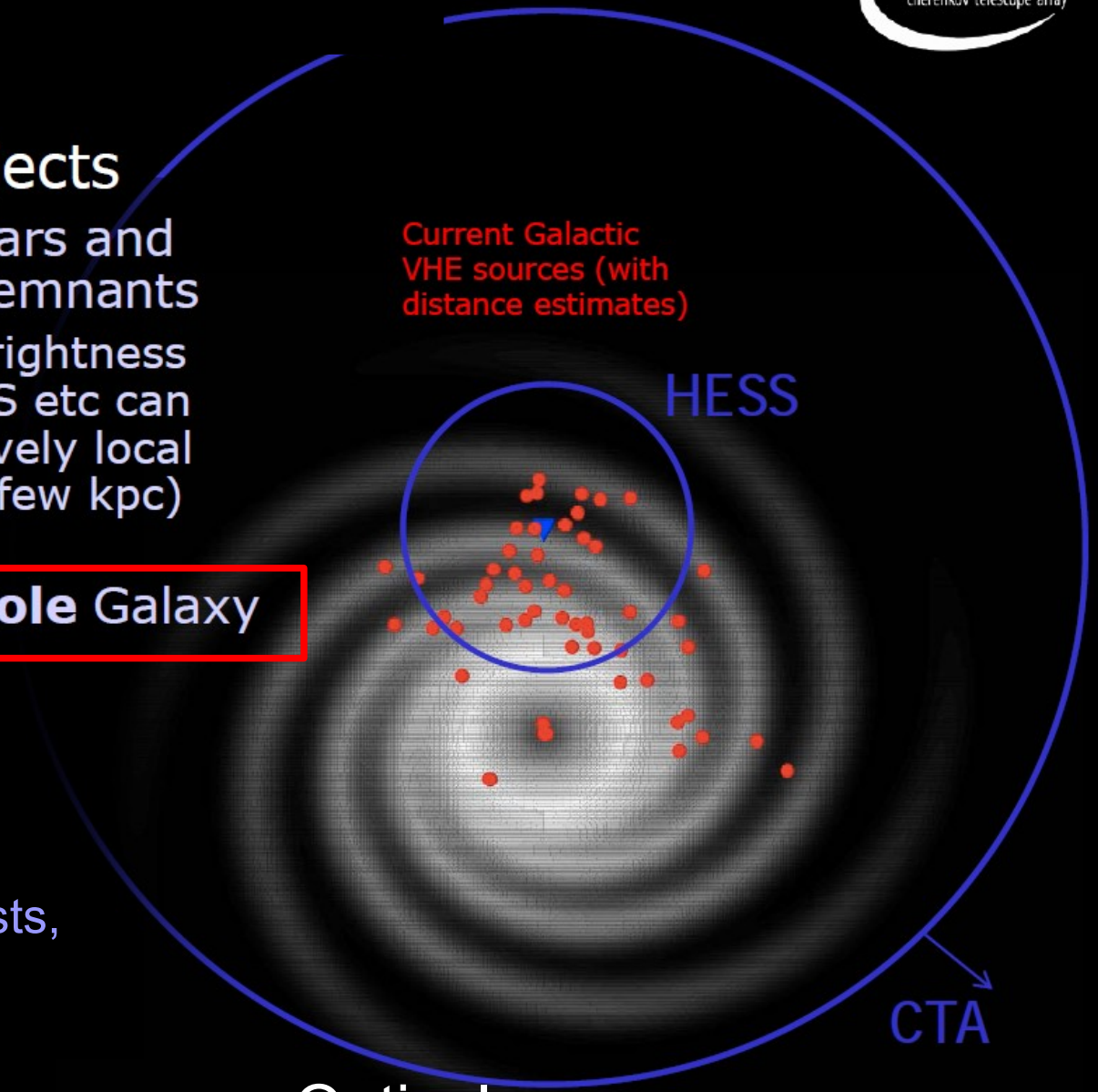
https://www.cta-observatory.org/

CTA-North (La Palma, Spain) – 29 telescopes
CTA-South (Paranal, Chile) – 99 telescopes

– x10 better sensitivity than HESS;
– Wider energy coverage <50 GeV to >100 TeV
– Arc-minute angular resolution

CTA Science Potential

- 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....

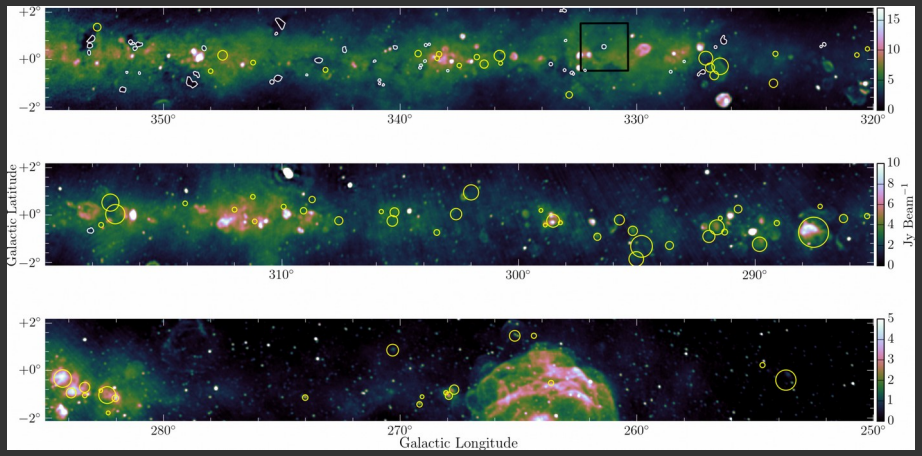
Optical
Intensity Interferometry, milli-mag photometry

Synergies with Radio Continuum Surveys

- Radio synchrotron & TeV gamma-ray (esp. hadronic) are often 'relics' of earlier particle acceleration.

- Dark TeV Sources:
  → Old/evolved SNRs & PWNe?
  → Missing Supernova remnants?

ASKAP – EMU, POSSUM, SCORPIO
MWA - GLEAM



MWA GLEAM 88 MHz (MWA Prelim 2016)

ASKAP EMU
Evolutionary Map of the Universe

POSSUM
POLARISATION SKY SURVEY OF THE UNIVERSE'S MAGNETISM

GLEAM

Synergies with interstellar gas surveys

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

HI (atomic H), OH, CS

CO

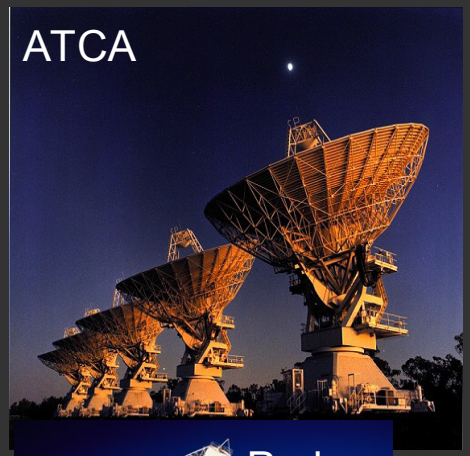
CO, NH_3, CS, SiO...

Gas density

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

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

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

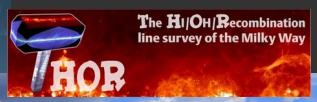


NANTEN
Submillimeter Observatory
なんてん電波天文台

国立天文台
NAOJ
National Astronomical Observatory of Japan

Mopra Telescope
CSIRO

CSIRO



GASKAP

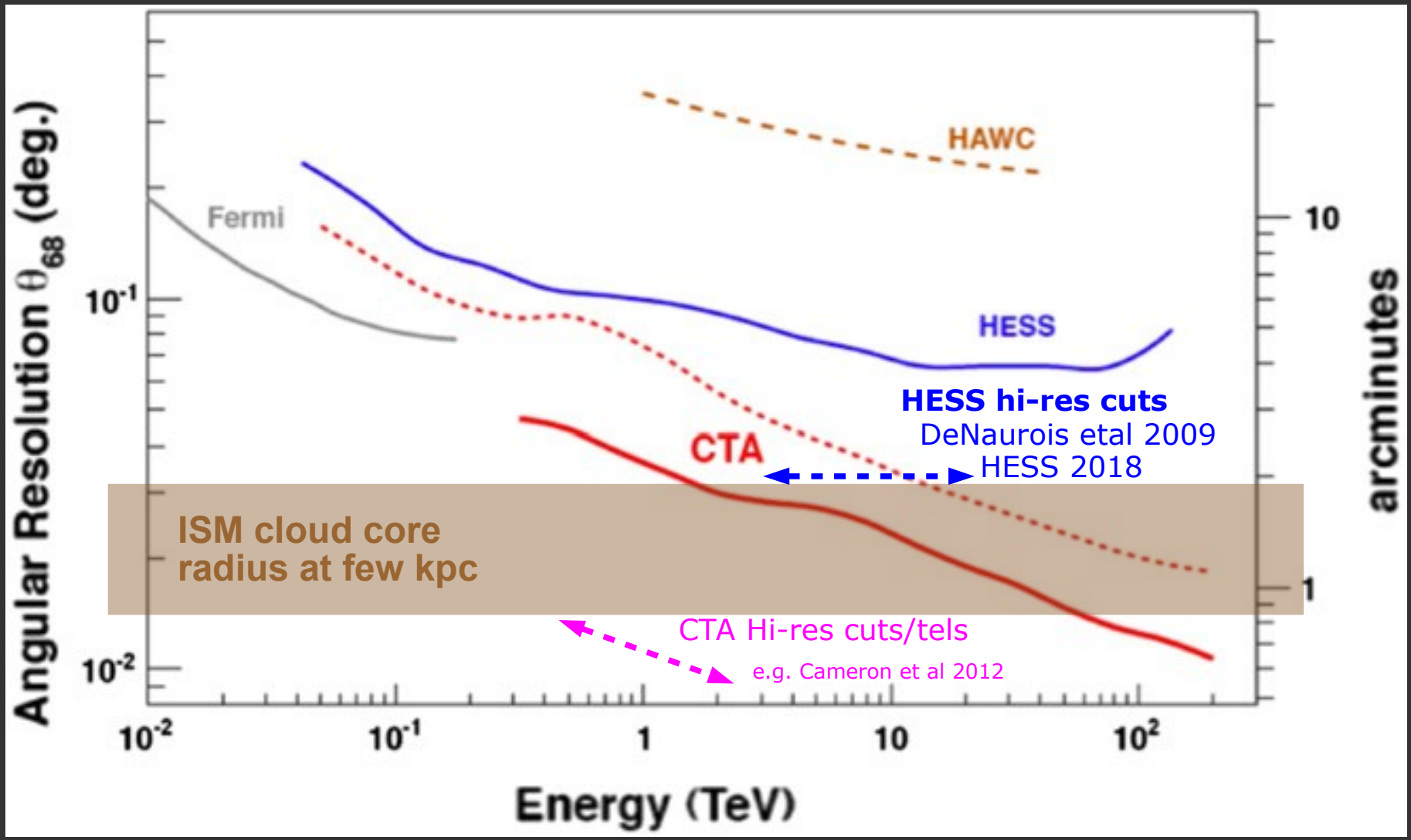
THz (Antarctica & High-alt)
[CI] + [CII]

AUSTRALIA TELESCOPE NATIONAL FACILITY
CSIRO

SCIENTIA
MANU ET MENTE

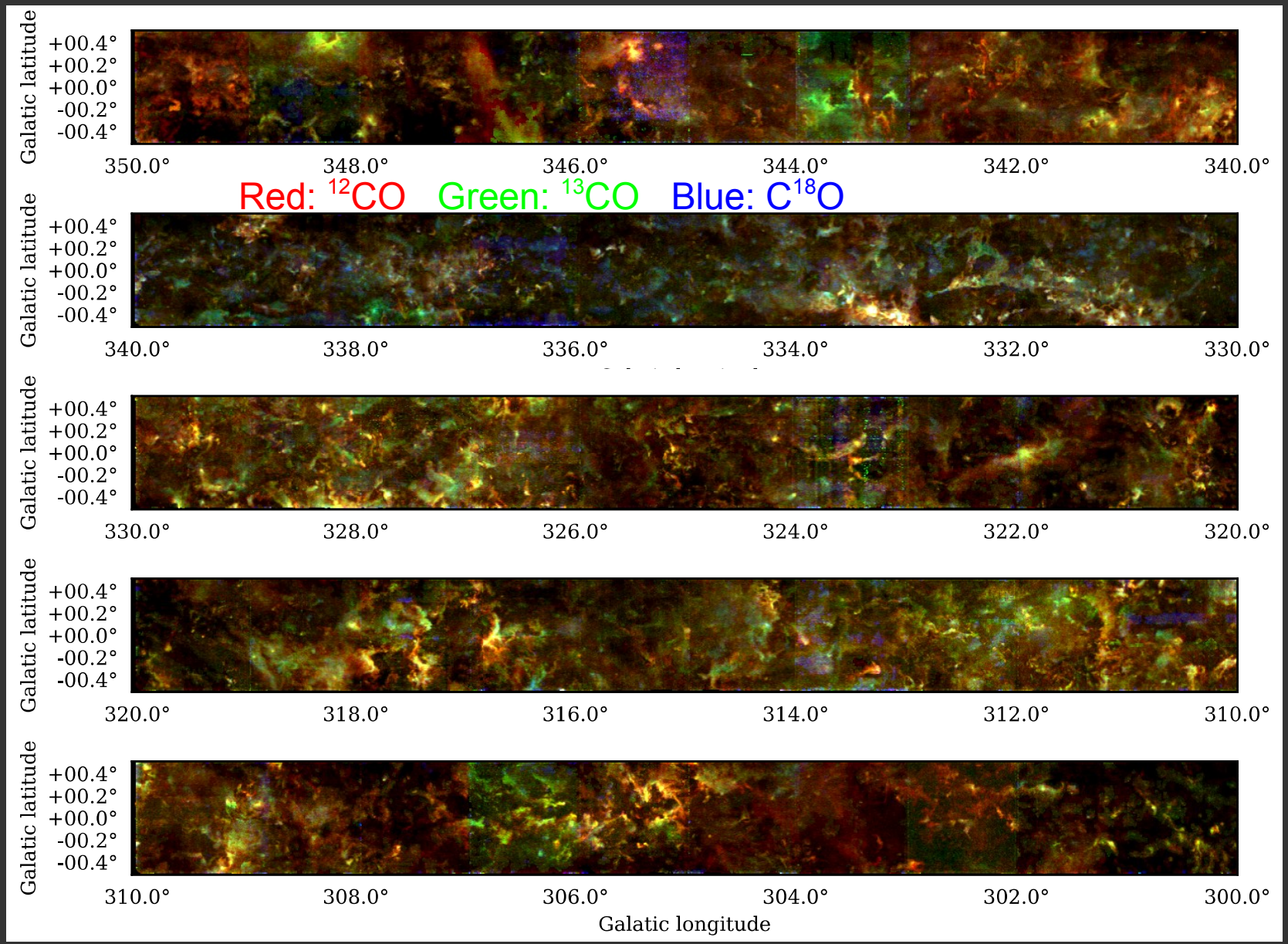
Angular Resolution 68% PSF (HESS, CTA, etc..)

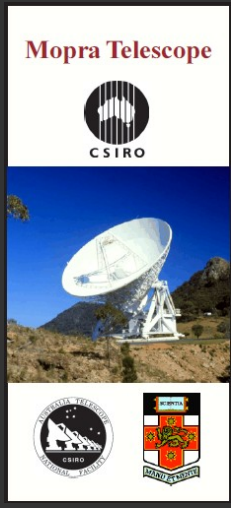
Acharyara etal 2013



Mopra CO Peak Intensity (Braiding etal 2018) @ 35 arc-sec beam

Data download https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LH3BDN



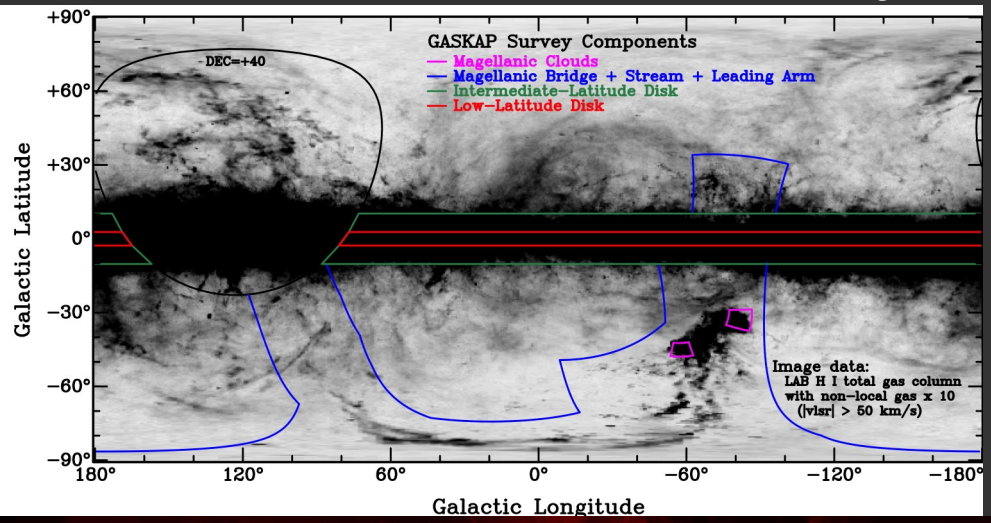


→ Extension to |b| = 1, l>250 deg done → legacy ISM survey for CTA

GASKAP

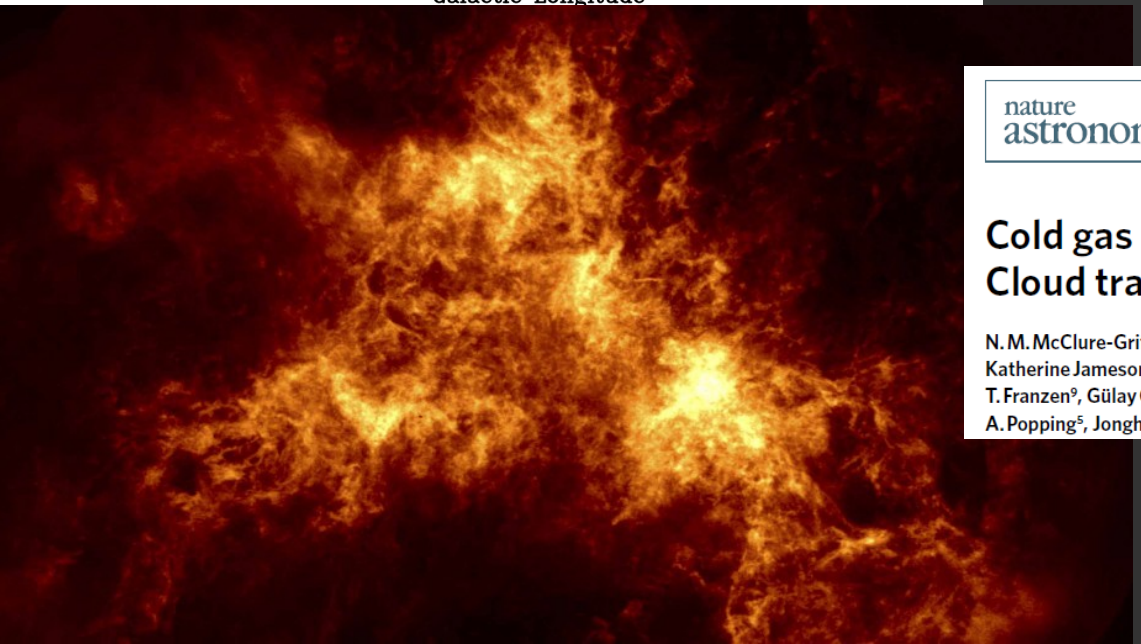
New HI + OH survey with the ASKAP
- ~30 arc-sec resolution
- Commencing 2019

www.atnf.csiro.au/research/GASKAP/



ASKAP - Australian Square Kilometre Array Pathfinder

- HI & OH lines, B-field & turbulence



nature astronomy

LETTERS

https://doi.org/10.1038/s41550-018-0608-8

Cold gas outflows from the Small Magellanic Cloud traced with ASKAP

N. M. McClure-Griffiths[1*], H. Dénes[1,2], J. M. Dickey[3], S. Stanimirović[4], L. Staveley-Smith[5,6], Katherine Jameson[1], Enrico Di Teodoro[1], James R. Allison[6,7], J. D. Collier[2,8], A. P. Chippendale[2], T. Franzen[9], Gülay Gürkan[9], G. Heald[9], A. Hotan[9], D. Kleiner[2], K. Lee-Waddell[2], D. McConnell[2], A. Popping[5], Jonghwan Rhee[5], C. J. Riseley[9], M. A. Voronkov[2] and M. Whiting[2]

CTA View of the Galactic Plane

- Over 2000 TeV sources + diffuse emission → extremely complex
- Need (sub)arc-min ISM data for diffuse models (ala Fermi-LAT but x10 better res.)

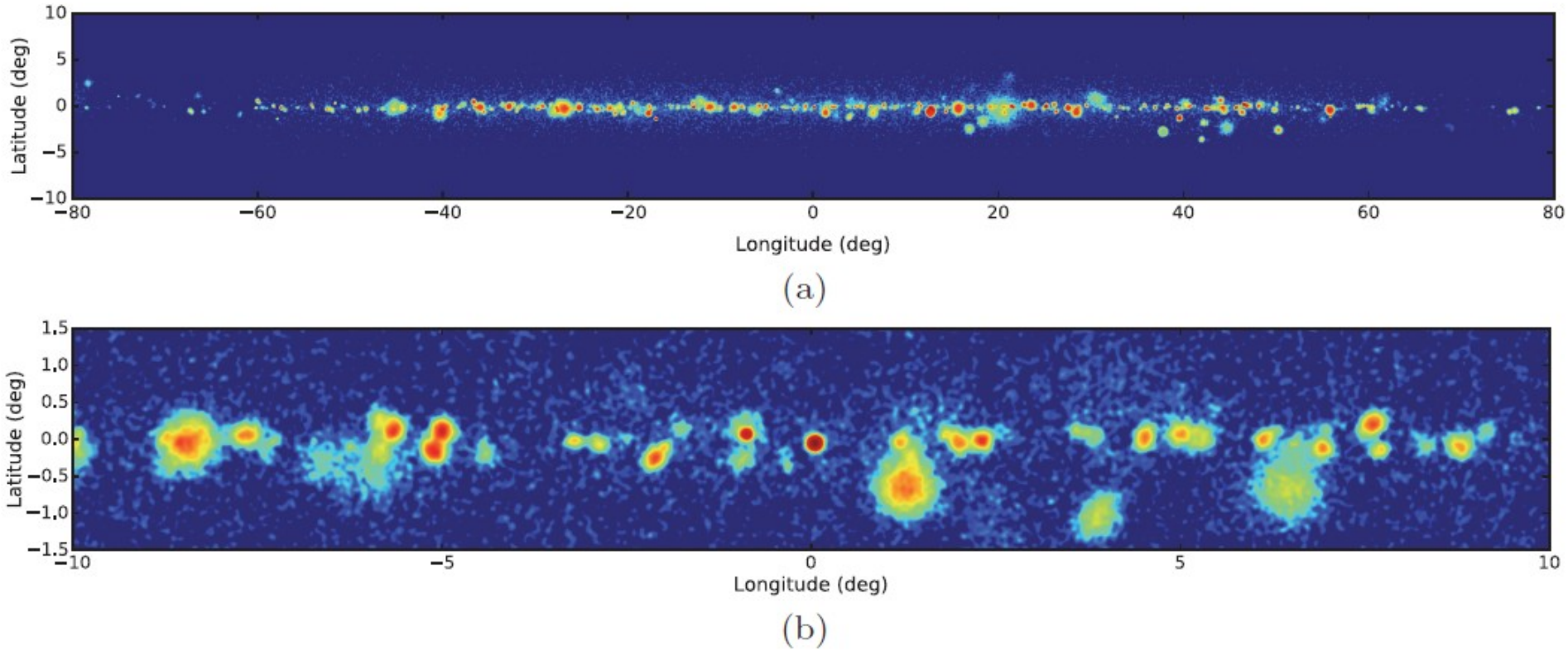


Figure 1.3: (a) Simulated CTA image of the Galactic plane for the inner region, $-80° < l < 80°$, adopting the proposed GPS KSP observation strategy and a source model incorporating both supernova remnant and pulsar wind nebula populations, as well as diffuse emission. (b) A zoomed image of an example 20° region in Galactic longitude.

TeV gamma-rays & non-thermal radio to X-ray

Energy loss or "Cooling" Time of particles: 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: $t_{IC} \approx 3 \times 10^8 (U_{rad}/\mathrm{eV/cm}^3)^{-1} (E_e/\mathrm{GeV})^{-1})$ 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

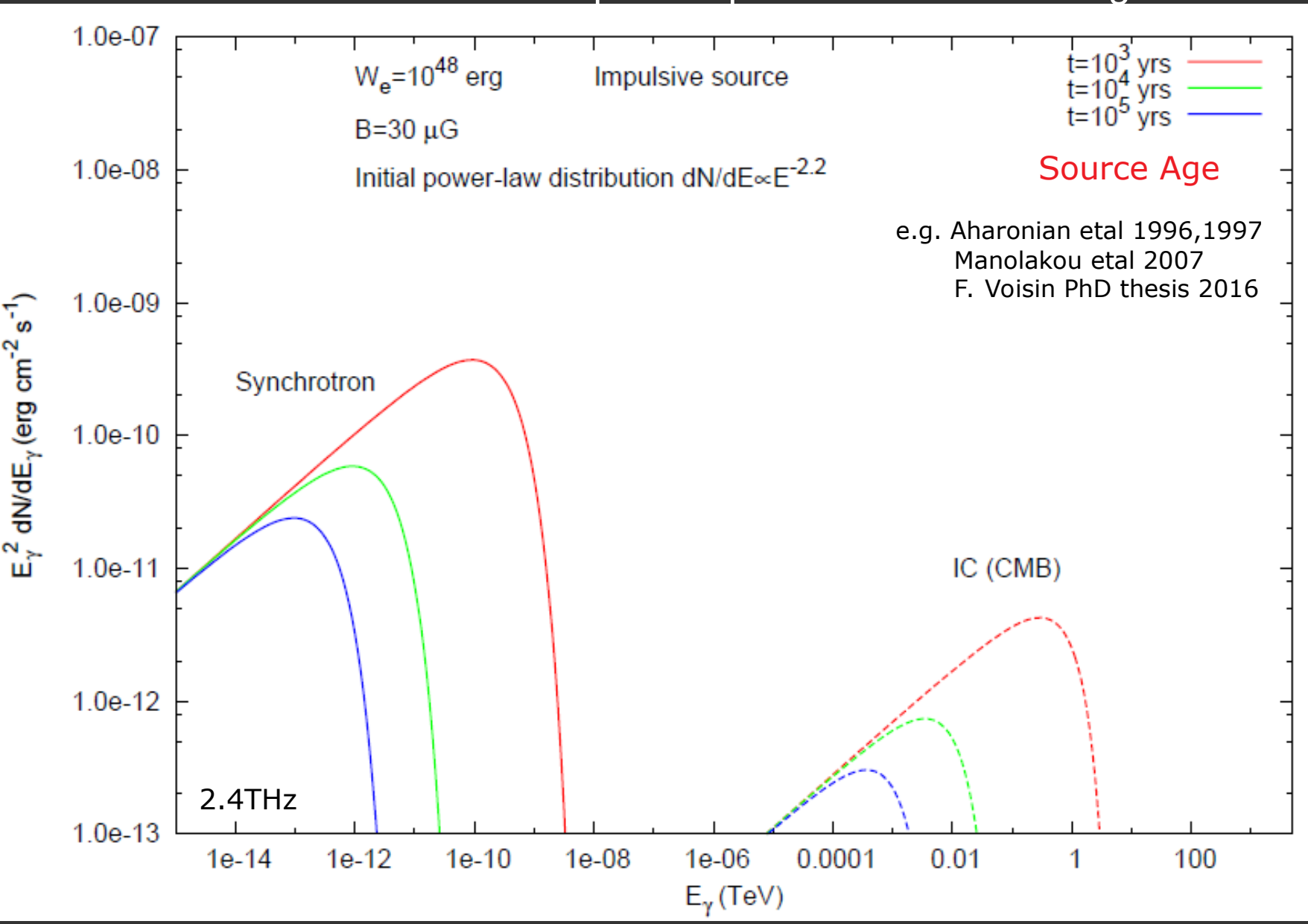
→ Radiative propagation limits for particles (e.g. source size)

→ t >=10,000 yr often for TeV gamma + Radio synch (B<10μG)

→ Gamma and radio emission can be 'fossil' records of ancient particle acceleration!

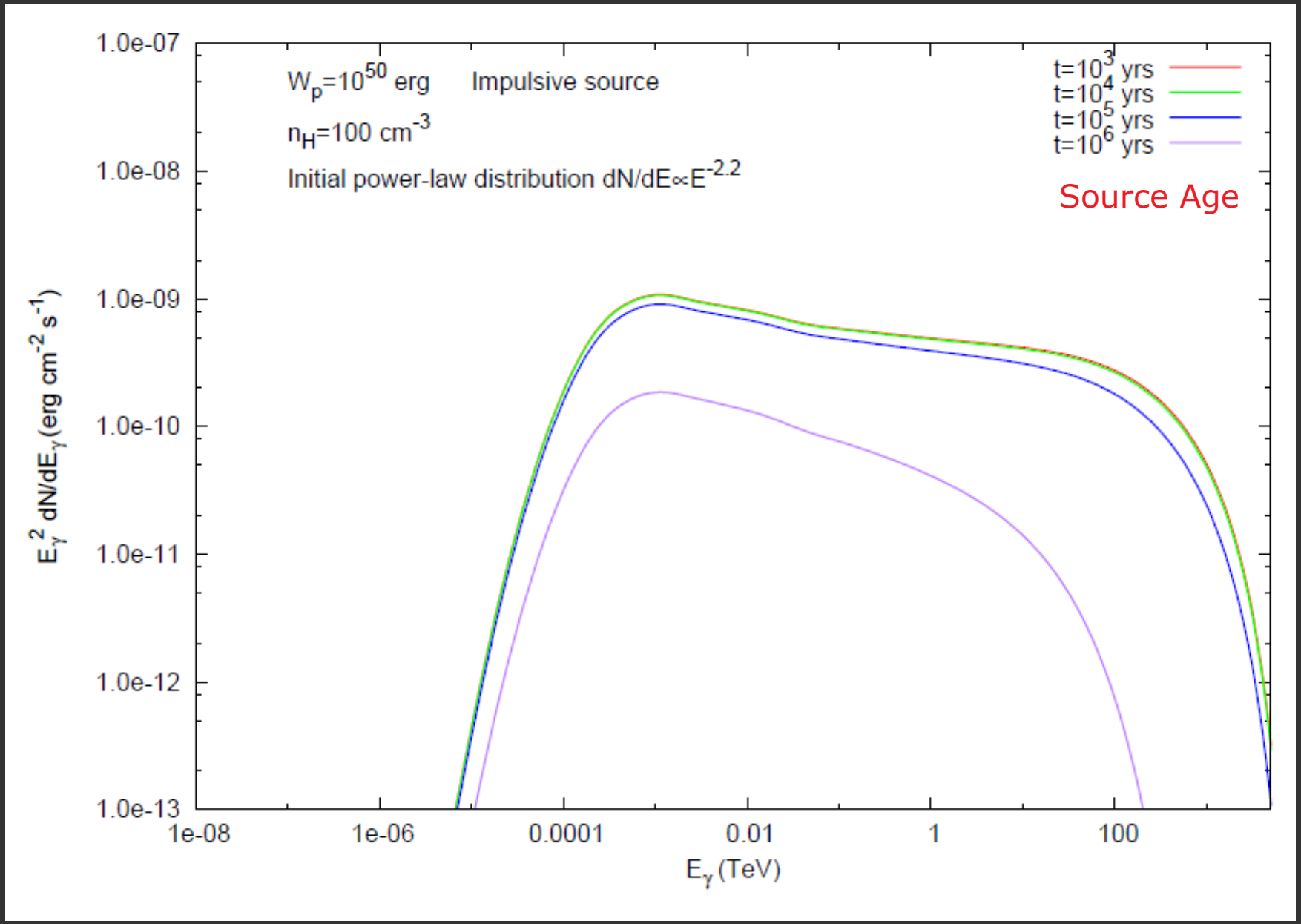
Leptonic: Synchrotron + Inverse-Compton Evolution

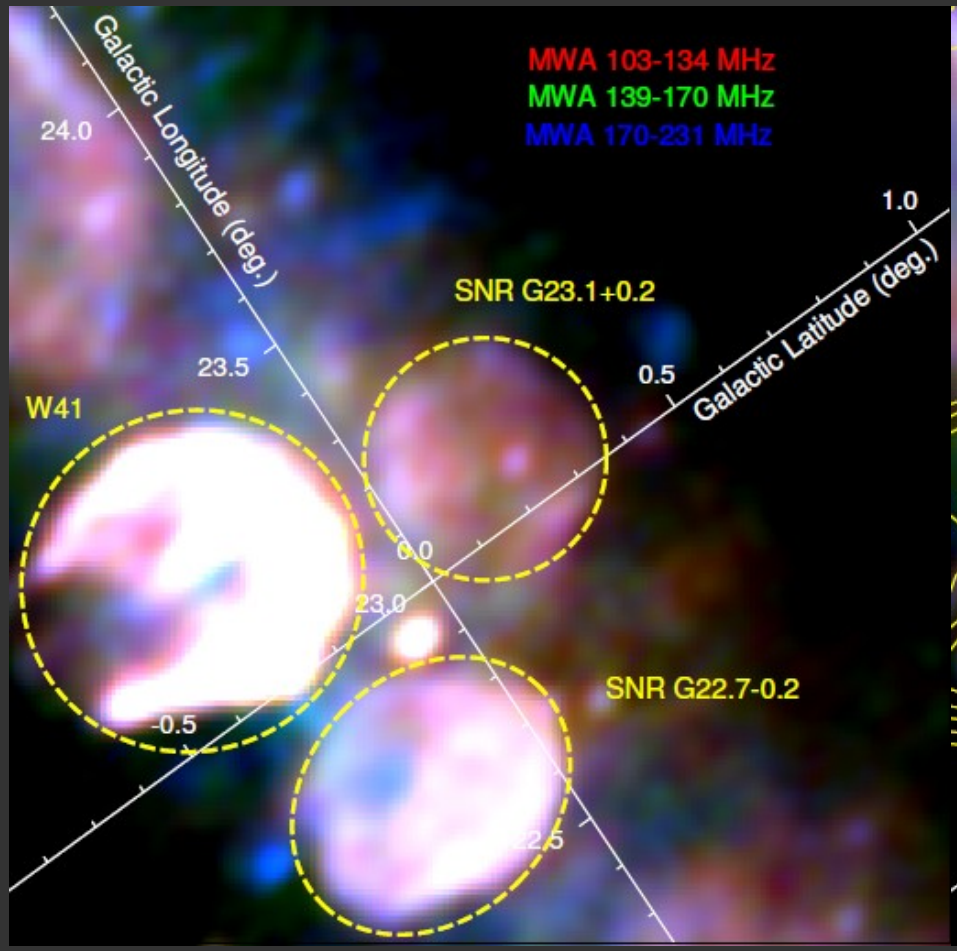
Impulsive particle accelerator e.g. SNR

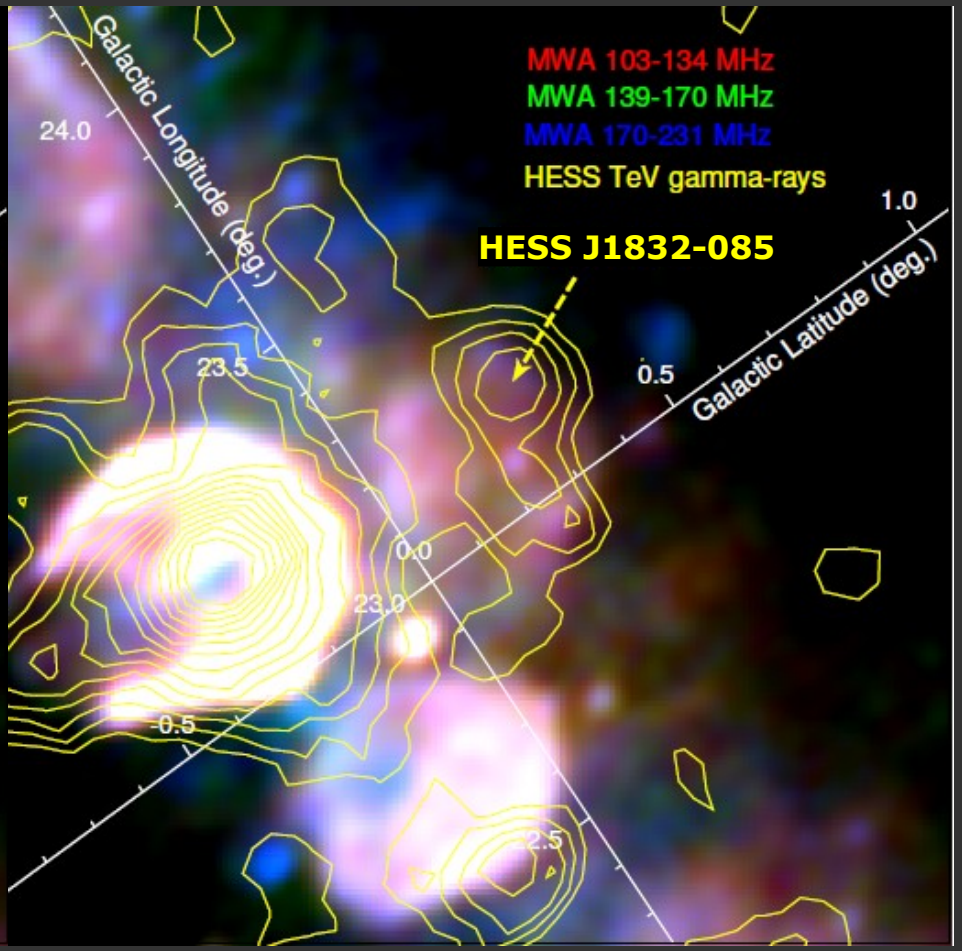


Hadronic: CR + ISM Interaction – Spectral Evolution

Impulsive particle accelerator e.g. SNR





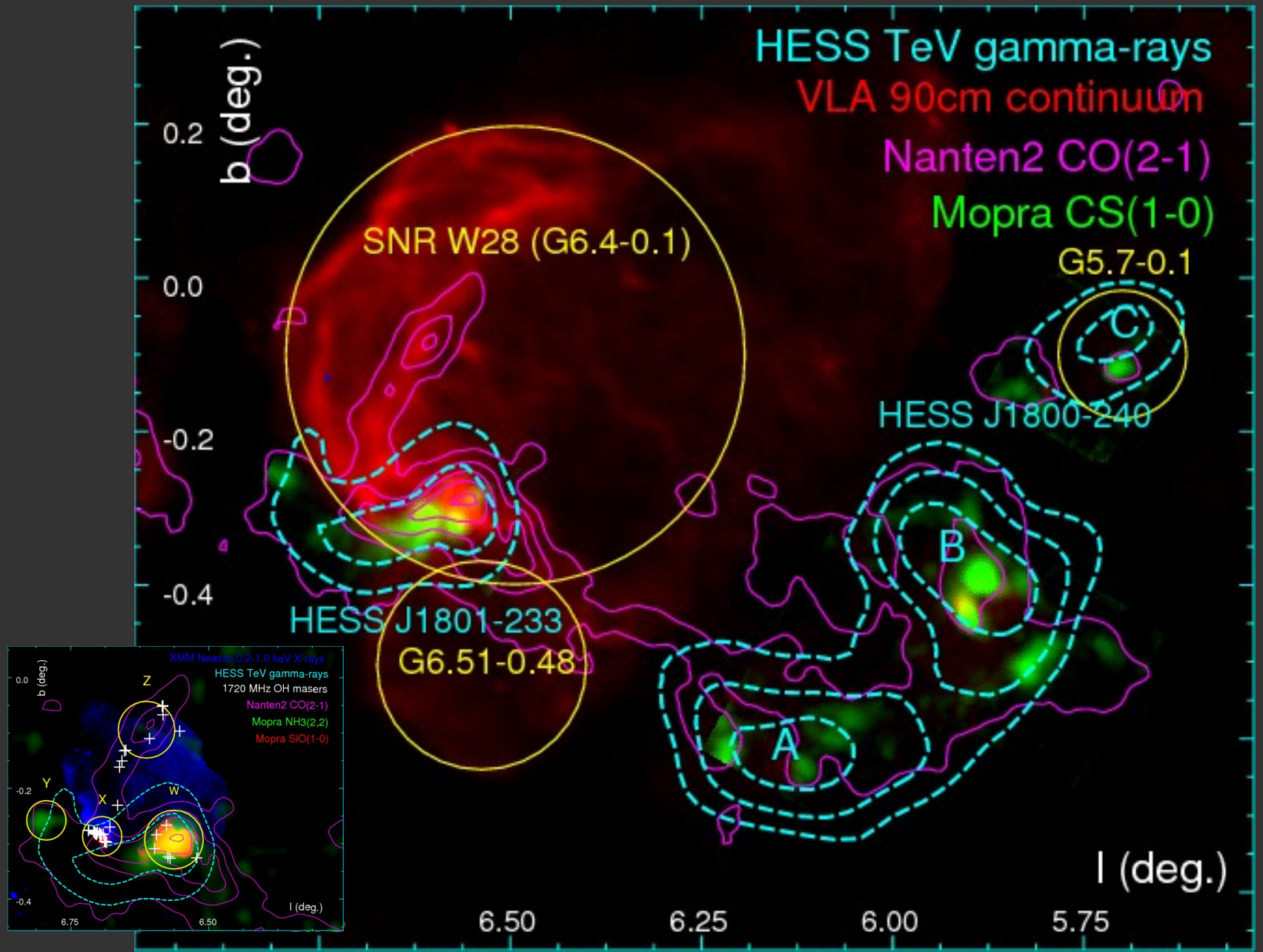


- MWA SNR candidate G23.11+0.18; Also seen with VLA THOR (Anderson et al 2017)
- Overlaps unidentified TeV gamma-ray source HESSJ1832-085
- No X-ray emission → old-ish (>~10kyr) SNR?

Maxted etal. 2019

Mature SNR W28 – Radio to TeV

HESS 2008, Niicholas etal 2011, 2012, Maxted etal 2016, 2017



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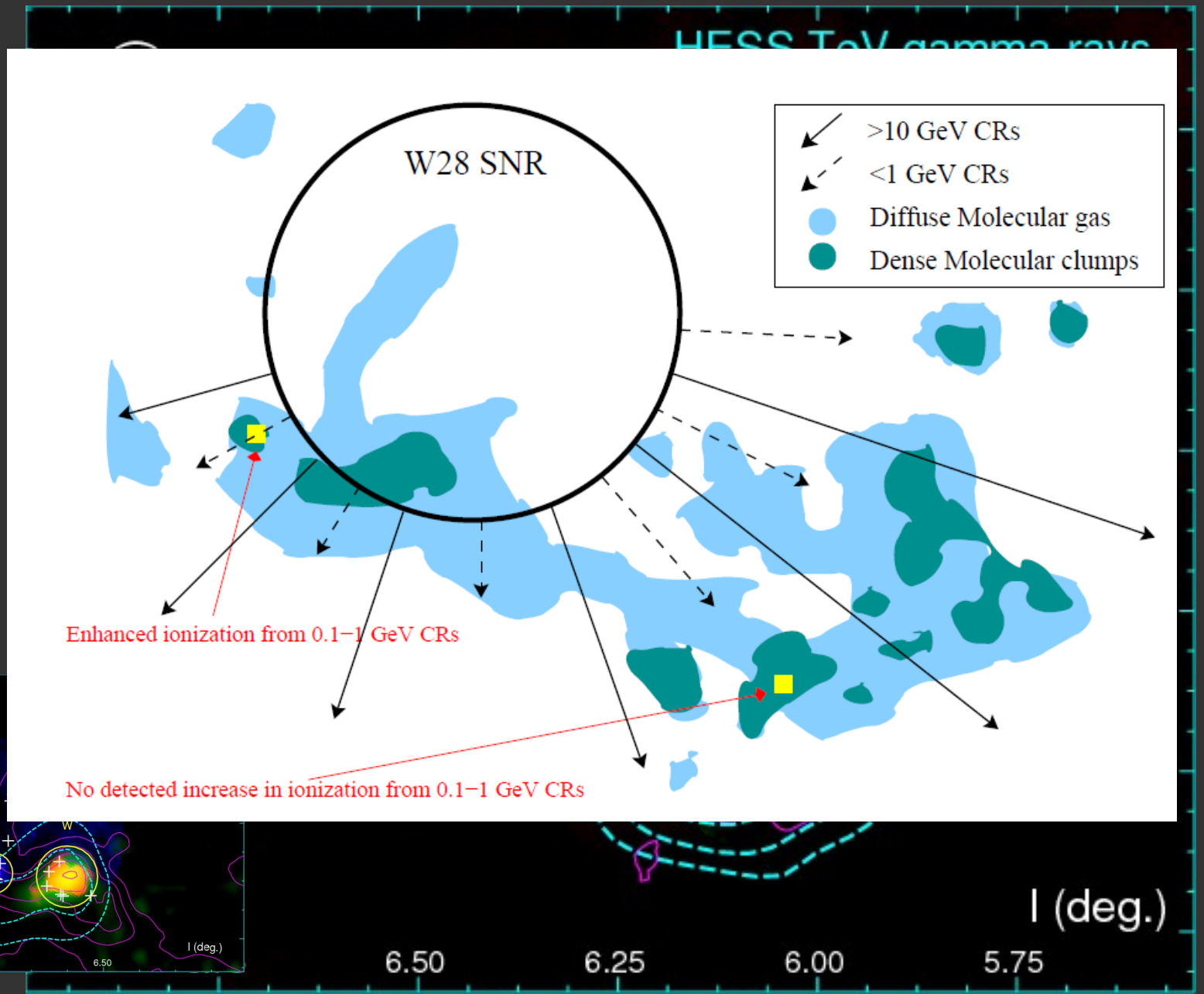
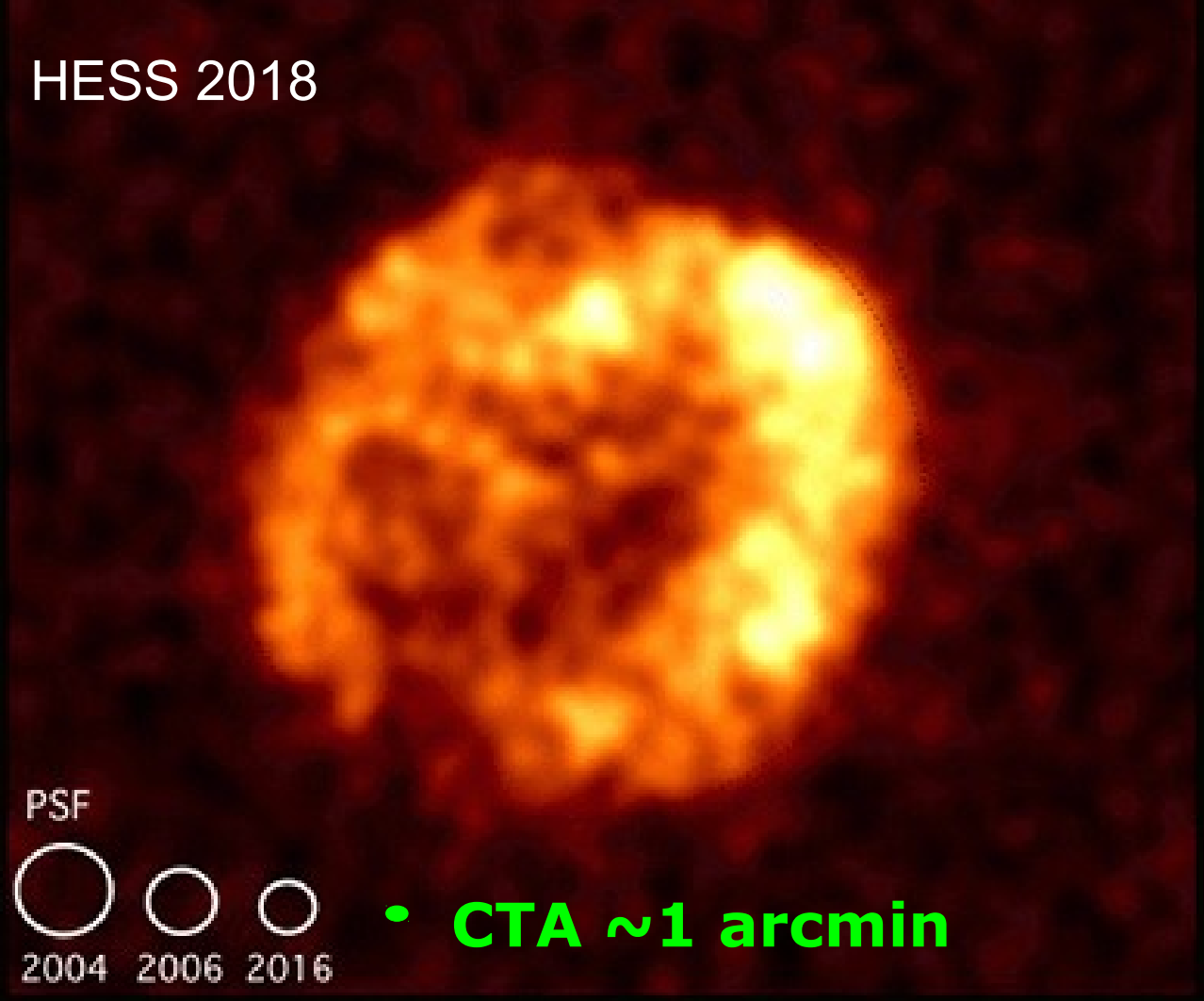


H.E.S.S. RX J1713.7-3946

The sharpest gamma-ray image so far!
PSF (68%) ~ 2 - 3 arcmin (FWHM ~ 5 arcmin)

HESS 2018

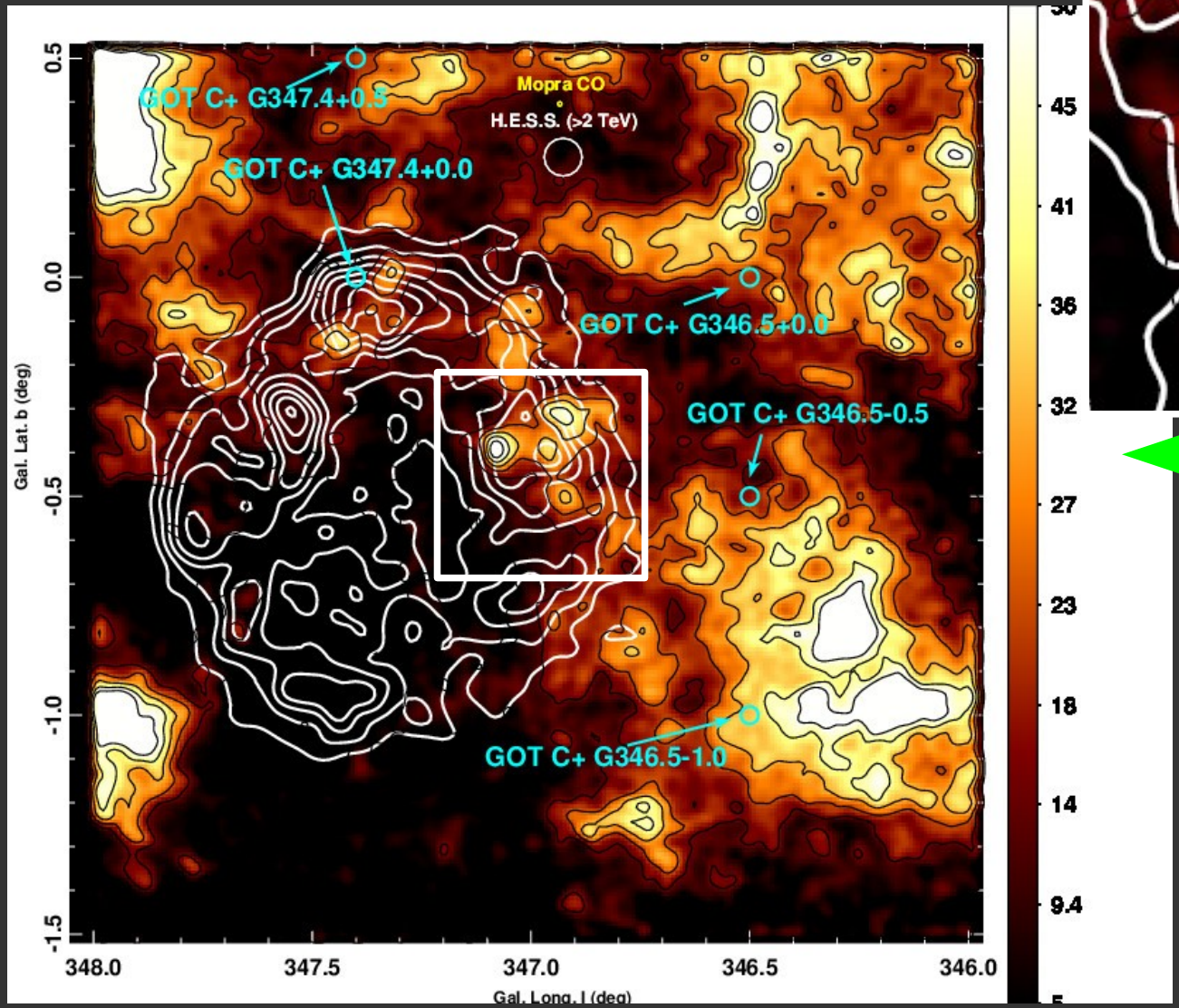


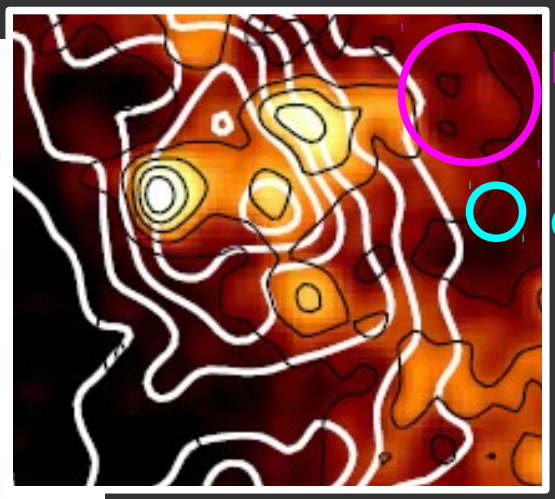
Year	2016
Live-time	164h
Energy	> 0.25 TeV
PSF (R_{68})	2.9 arcmin
γ's	31,000

- **CTA ~1 arcmin**

Young SNR RXJ1713 TeV and ISM on Parsec Scales!

Mopra CO(1-0) Image + HESS > 2 TeV contours



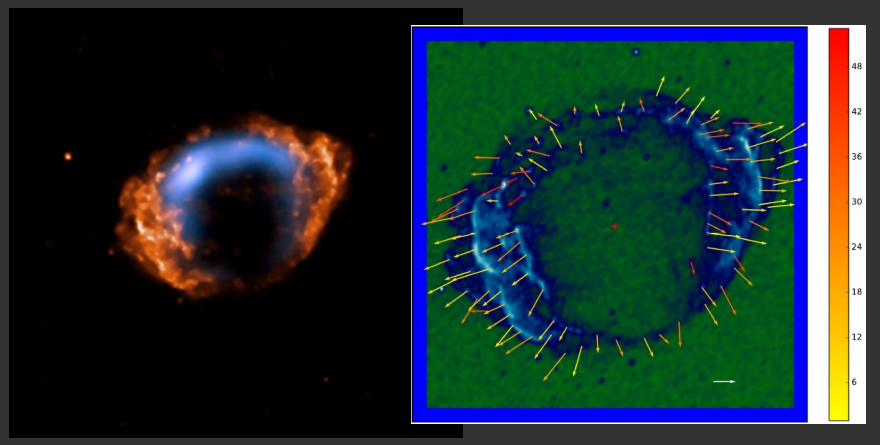


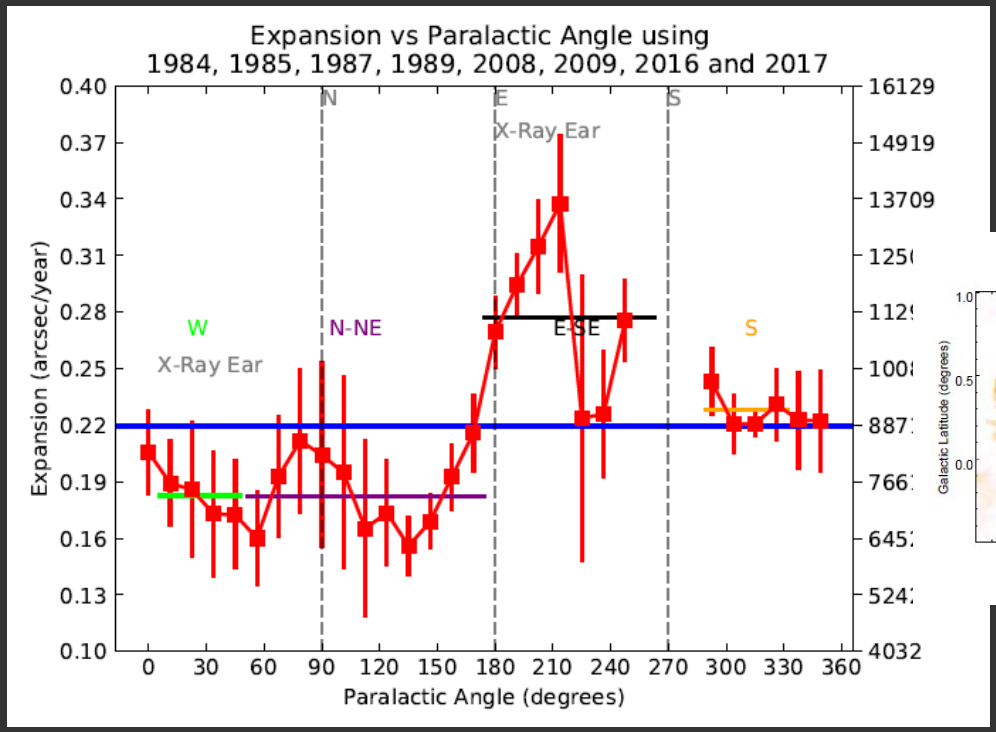
7 pc

CTA will finally be able to probe diffusion properties of hadronic cosmic rays

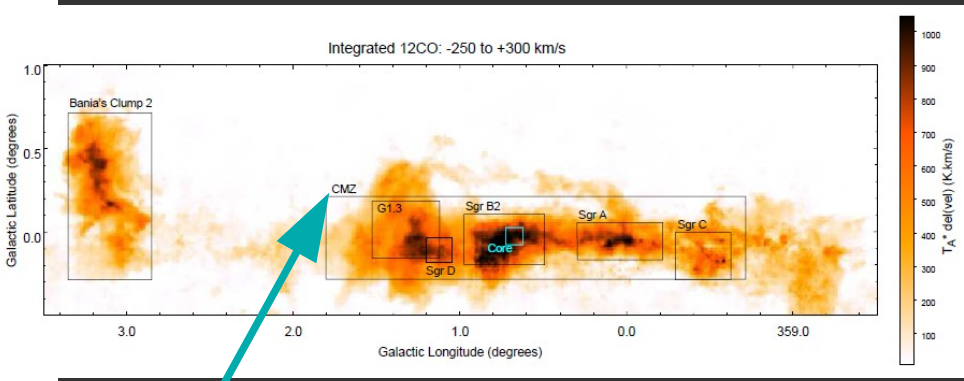
Youngest Galactic SNR – G1.9+0.3 (~100 yrs)

- Radio and X-ray expansion
  → shock speed > 10,000 km/s
  e.g. Borkowski et al. 2017
- "Central Molecular Zone" at ~ 8.5 kpc
- Lots of ISM target for PeV cosmic-rays
  → The perfect SNR "PeVatron"





Mopra CO(1-0)
Blackwell etal 2019 submitted

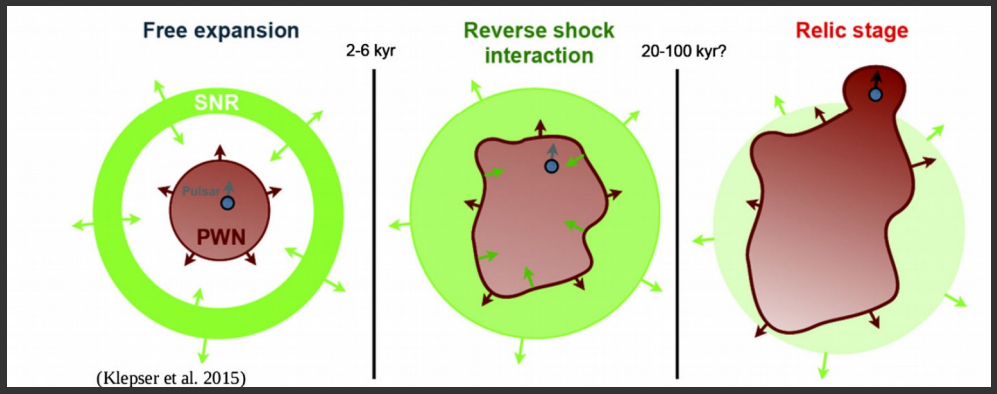


G1.9+0.3

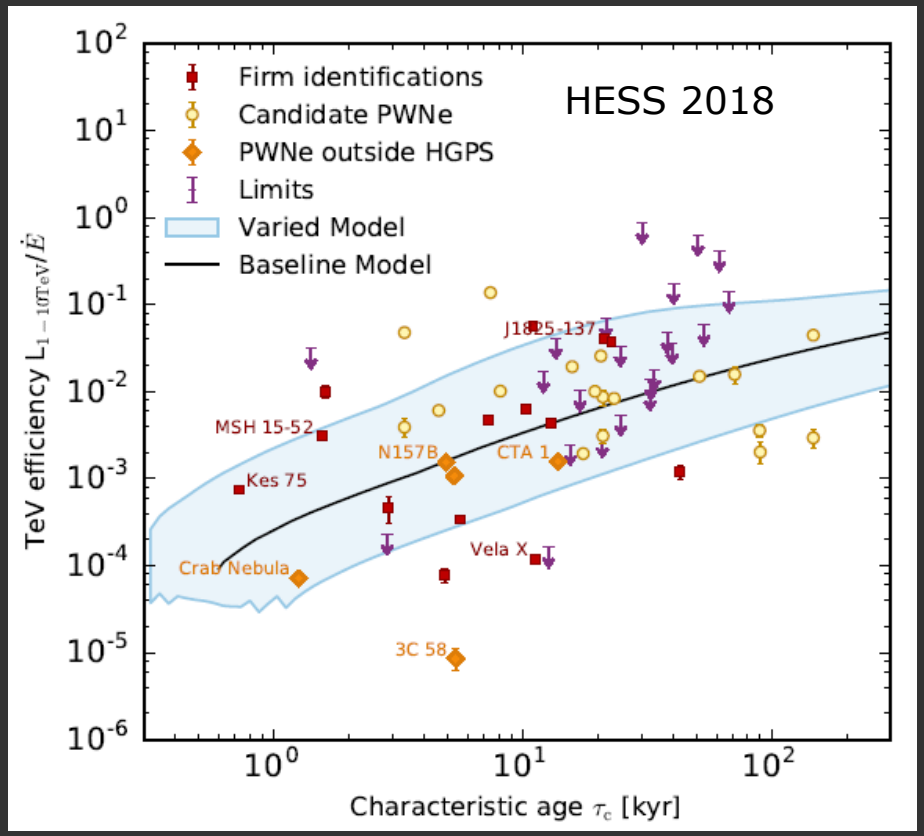
Latest ATCA study Luken etal 2019 submitted

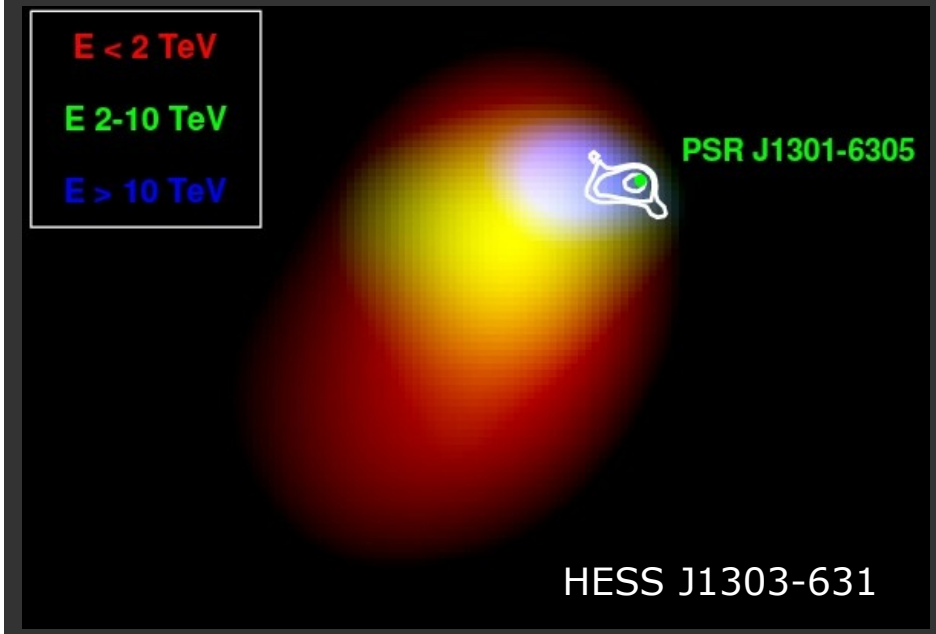
TeV Pulsar Wind Nebulae (PWN)

- Most populous Galactic TeV class
- Old PWNe as UnID TeV sources
  (e.g. Aharonian etal 1997, Kargaltsev etal 2013)
- ISM influence on development
- TeV efficiency increases with time
  → less X-ray synchrotron
  → more inverse-Compton



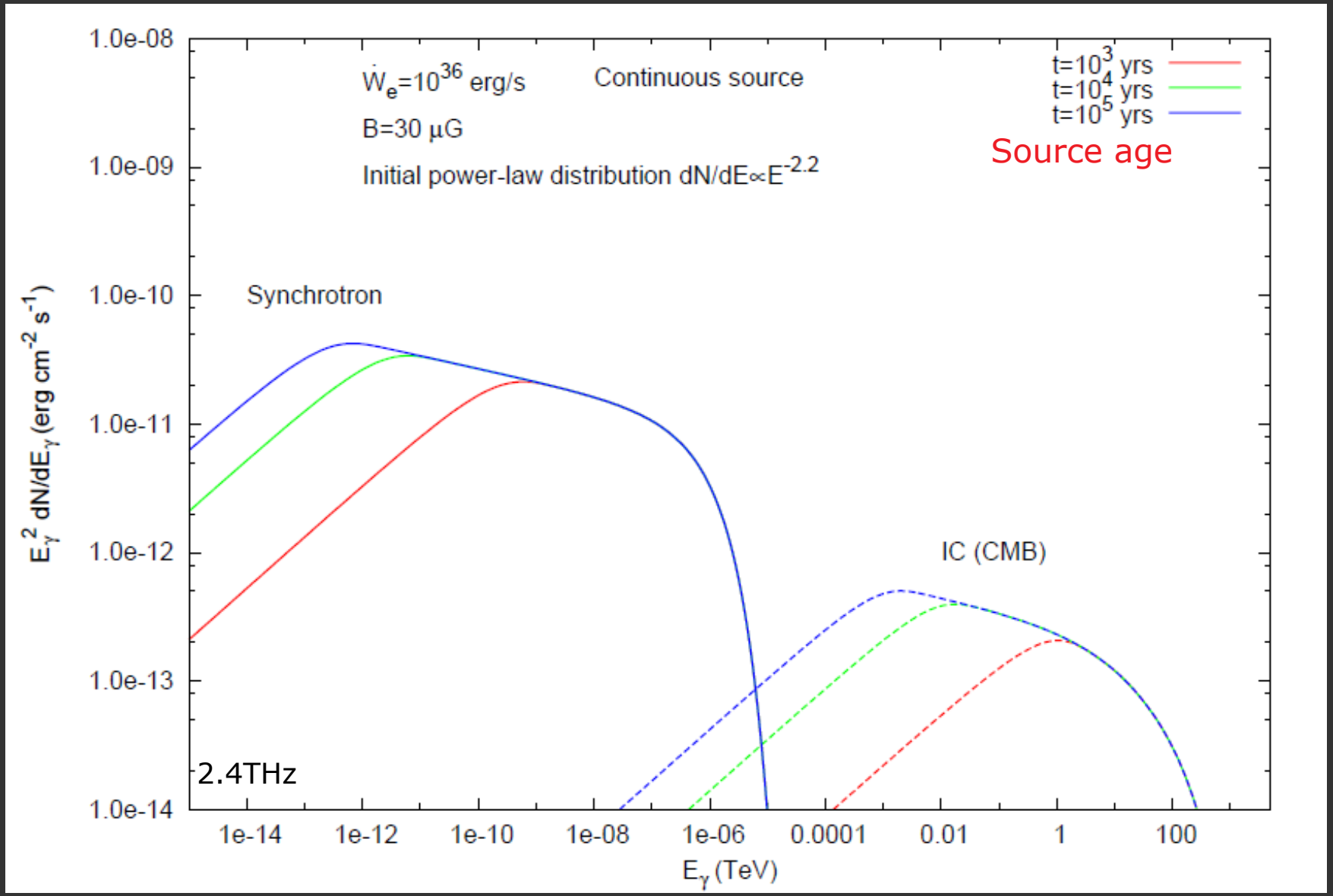
Reynolds (2017)



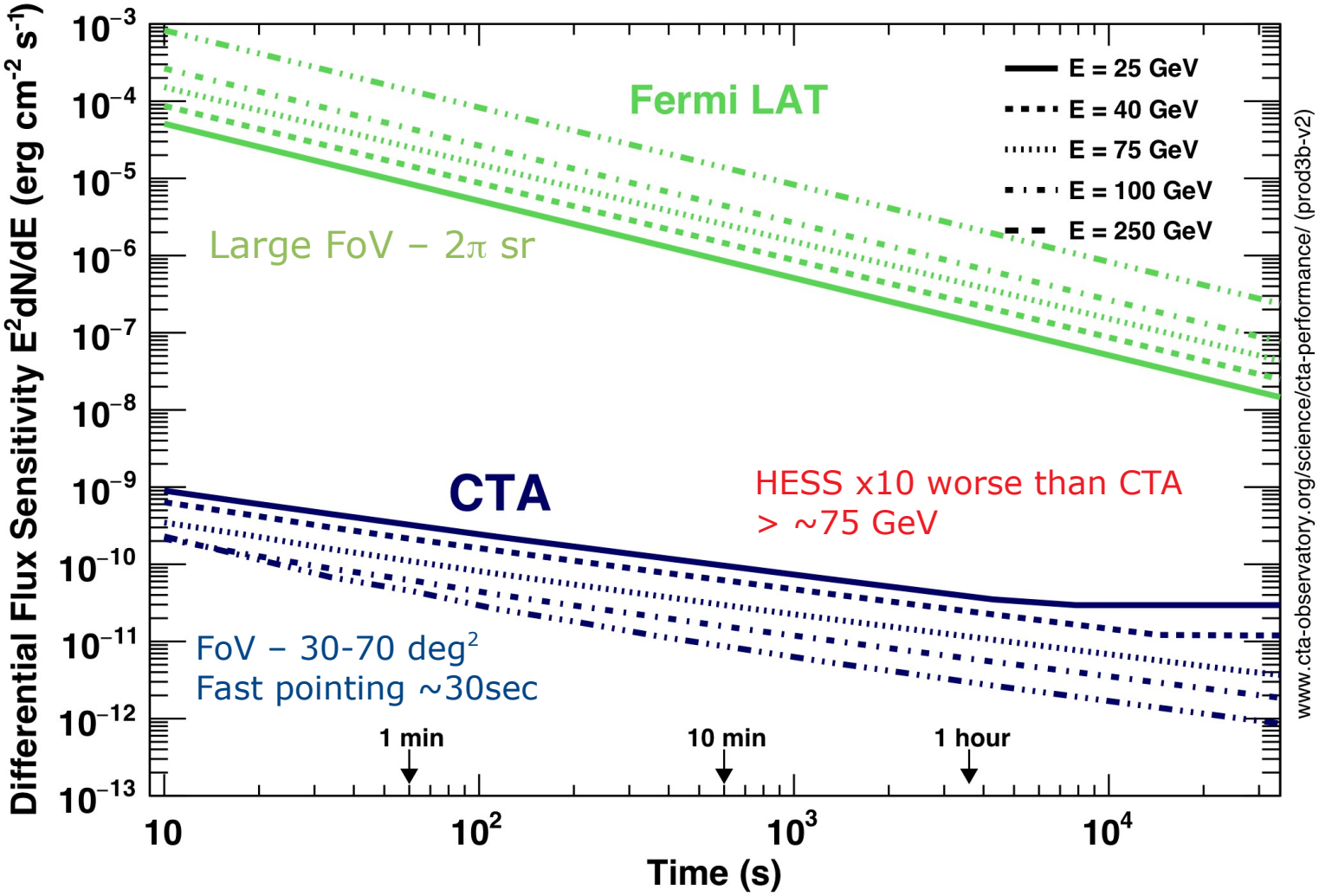


Leptonic: Synchrotron + Inverse-Compton Evolution

Continous particle accelerator e.g. PWN



CTA Sensitivity vs. Time (CTA Collab 2019)

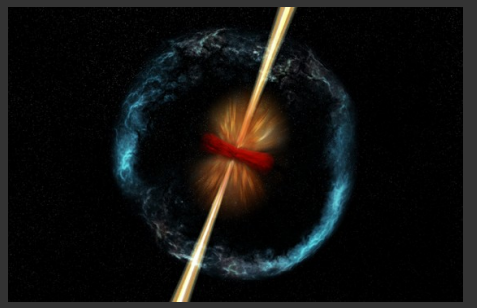


CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

→ GRBs, AGN, giant pulses, FRBs, GW, SGR bursts.....

TeV Gamma Ray Bursts : A New Era Begins

(MAGIC 2019, HESS 2019)



First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

[Previous | Next | ADS]

GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.

ATel #13052; ***M. de Naurois (H. E.S. S. Collaboration)***
*on **30 Aug 2019; 07:12 UT***
Credential Certification: Fabian SchÃÂ¼ssler (fabian.schussler@cea.fr)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Tweet

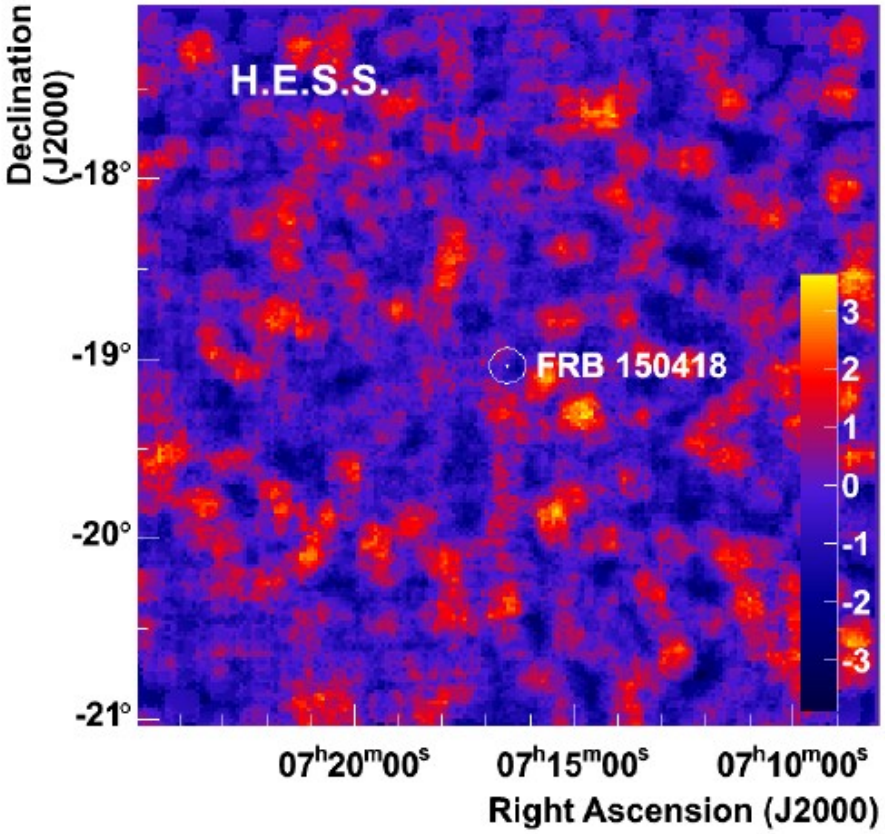
The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552). At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date. H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A. Further analyses of the data are on-going and further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths. H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

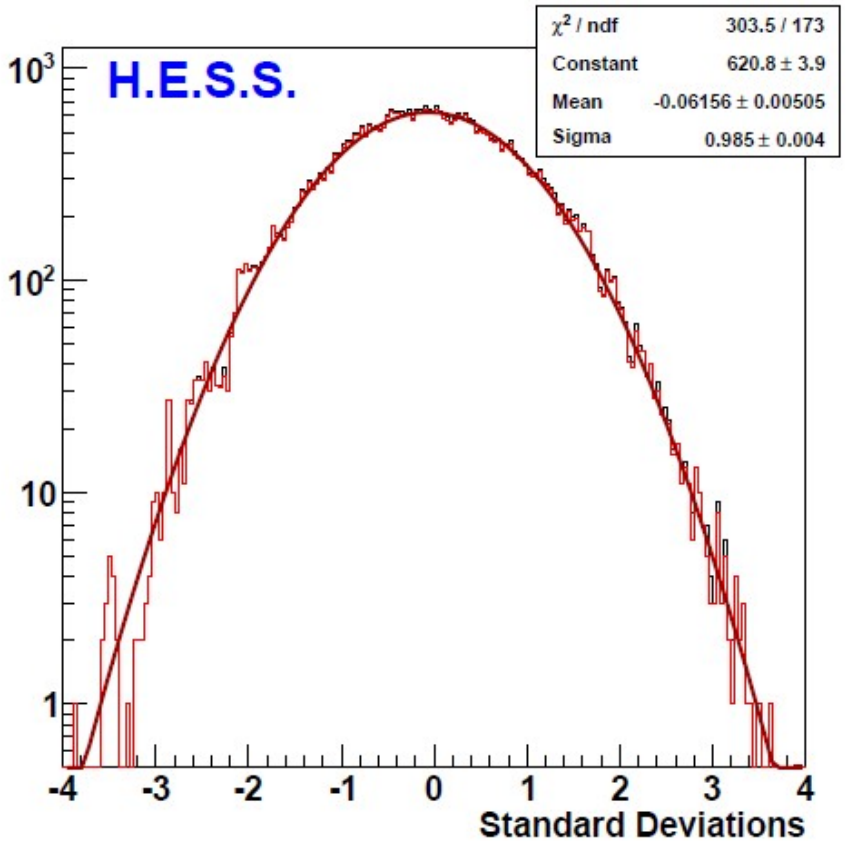
- Three TeV GRBs (LongGRBs) GRB180720B, GRB190114C, GRB1900829A
  z=0.653 0.424 0.079
- Long GRBs
- GRB190114C seen at >300 GeV at low elevation during moonlight!

> 1000's photons > 50 GeV → gamma-ray spectra on sub-minute timescales

HESS Follow-up of FRB 150418 (T+14.5hr)

- Triggered via email from the Parkes SUPERB team





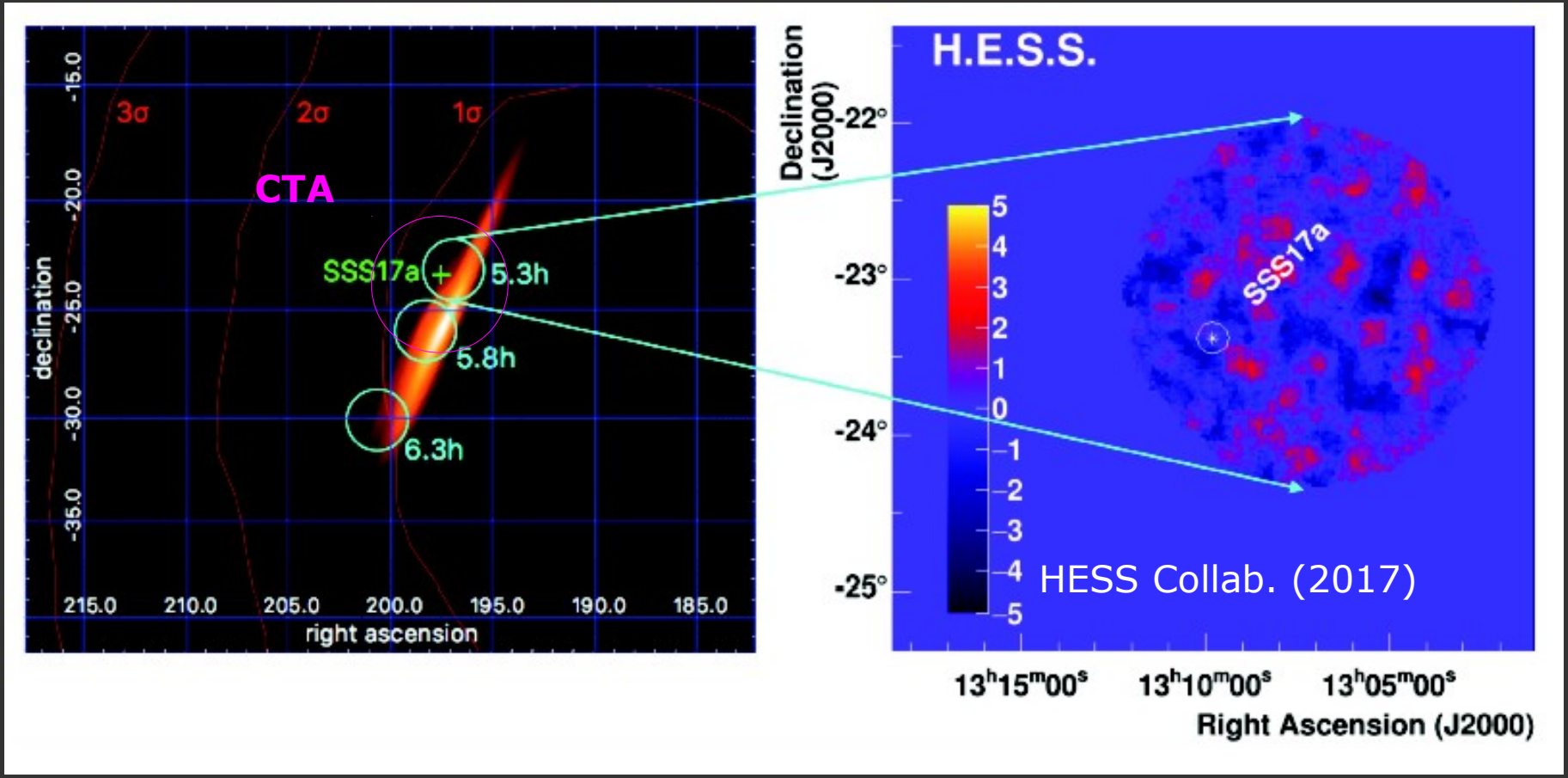
- TeV upper limit only (HESS+SUPERB A&A 2016)
- Also FRB150215 T+9days (Petroff etal MNRAS 2017)

→ Faster response needed: auto alerts & auto slewing ala GRBs

- Now receiving VOEvents from UTMOST FRB190806 (T+5hr)
- Soon auto-slewing with HESS → on-target in < few mins.

GW170817 – HESS Follow-up (HESS 2017)

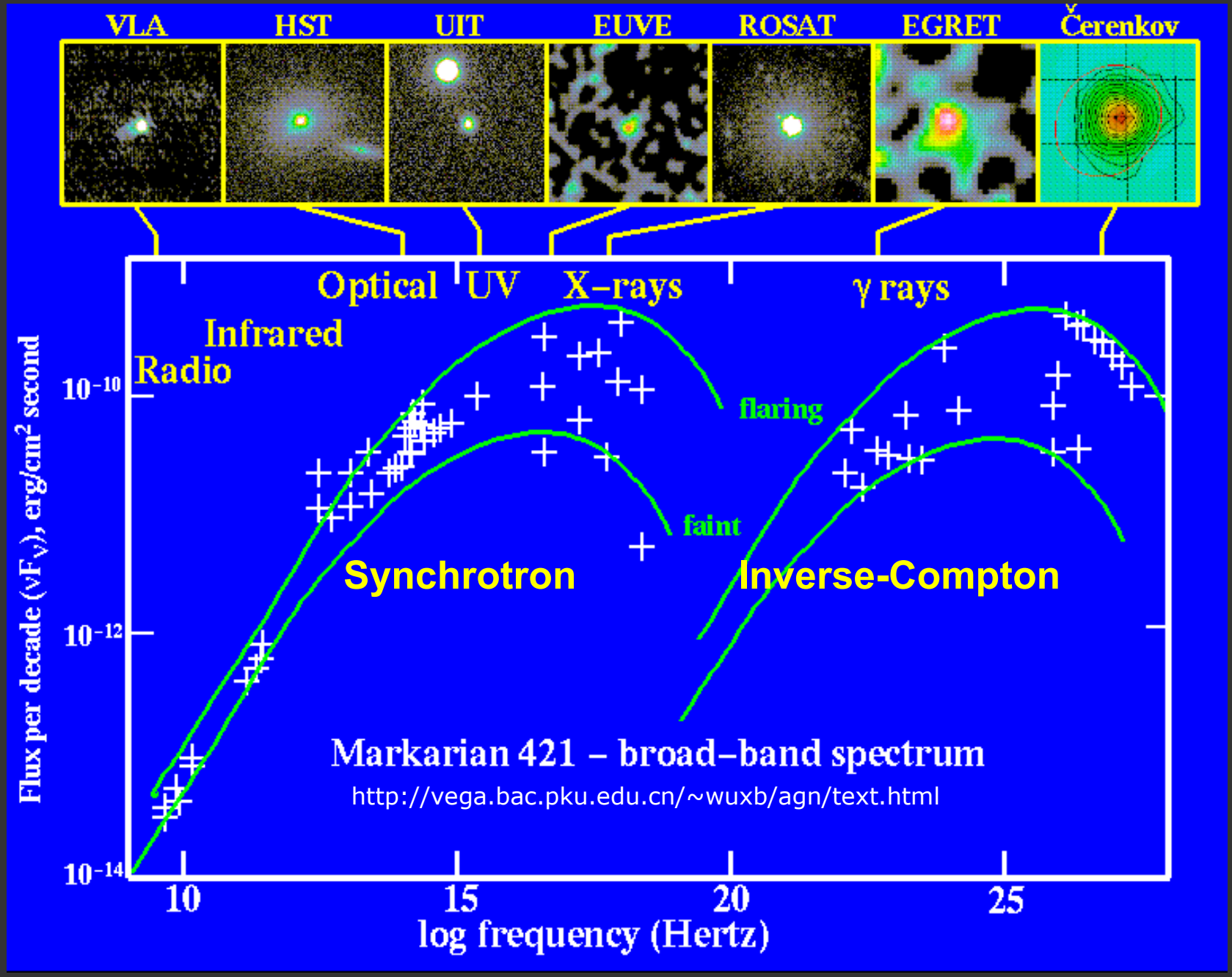
- 5.3h after GW event (first pointed telescope on target!)



FoV FWHM: HESS ~3.0 deg
CTA >5.0 deg

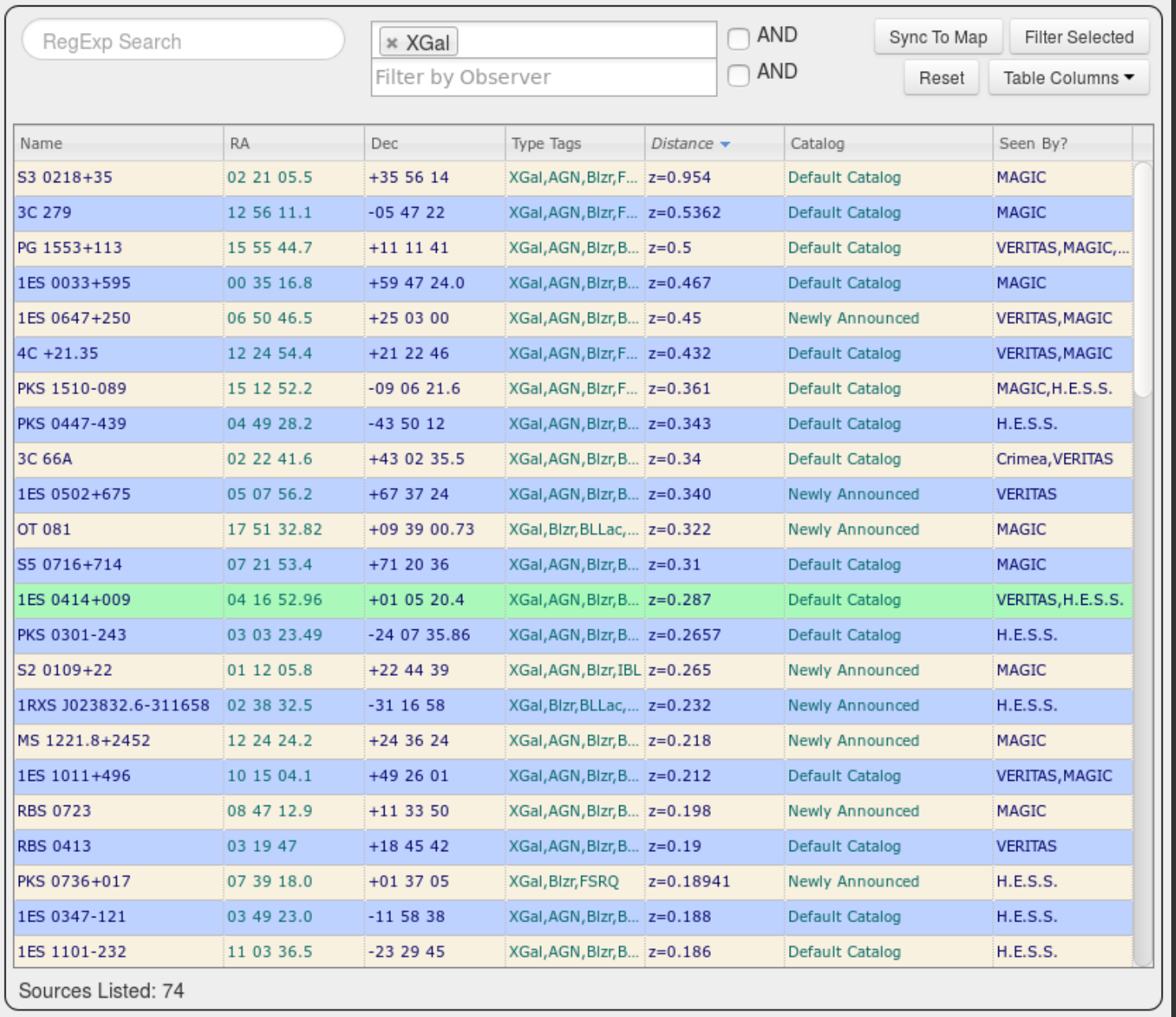
- TeV upper limit only.
- EM counterparts in radio, optical, X-ray

AGN Blazars : Radio to TeV



TeVCat v2 Extragalactic Sources

http://tevcat2.uchicago.edu/



RegExp Search

× XGal

Filter by Observer

AND

AND

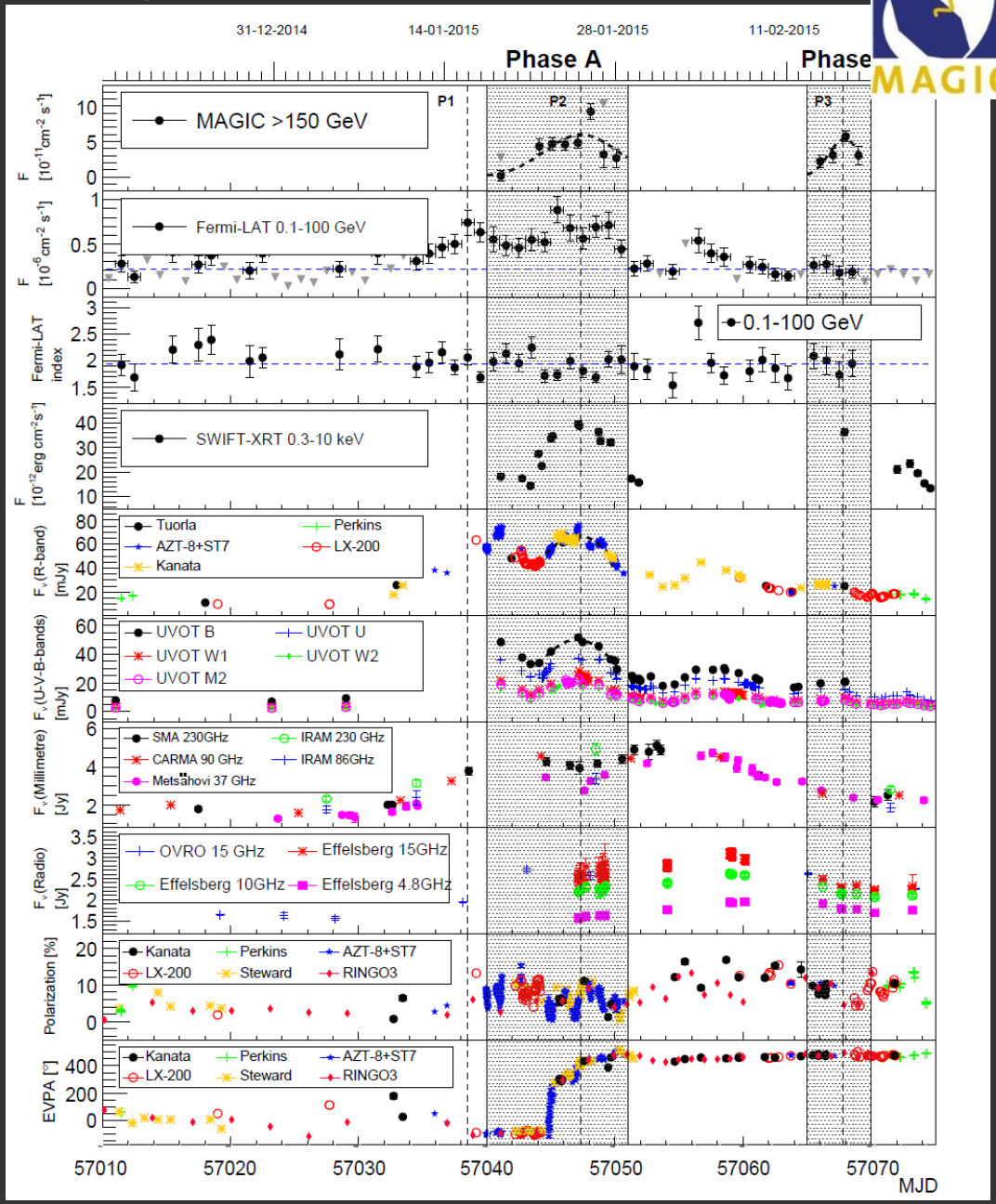
Sync To Map | Filter Selected | Reset | Table Columns

Name	RA	Dec	Type Tags	*Distance*	Catalog	Seen By?
S3 0218+35	02 21 05.5	+35 56 14	XGal,AGN,Blzr,F...	z=0.954	Default Catalog	MAGIC
3C 279	12 56 11.1	-05 47 22	XGal,AGN,Blzr,F...	z=0.5362	Default Catalog	MAGIC
PG 1553+113	15 55 44.7	+11 11 41	XGal,AGN,Blzr,B...	z=0.5	Default Catalog	VERITAS,MAGIC,...
1ES 0033+595	00 35 16.8	+59 47 24.0	XGal,AGN,Blzr,B...	z=0.467	Default Catalog	MAGIC
1ES 0647+250	06 50 46.5	+25 03 00	XGal,AGN,Blzr,B...	z=0.45	Newly Announced	VERITAS,MAGIC
4C +21.35	12 24 54.4	+21 22 46	XGal,AGN,Blzr,F...	z=0.432	Default Catalog	VERITAS,MAGIC
PKS 1510-089	15 12 52.2	-09 06 21.6	XGal,AGN,Blzr,F...	z=0.361	Default Catalog	MAGIC,H.E.S.S.
PKS 0447-439	04 49 28.2	-43 50 12	XGal,AGN,Blzr,B...	z=0.343	Default Catalog	H.E.S.S.
3C 66A	02 22 41.6	+43 02 35.5	XGal,AGN,Blzr,B...	z=0.34	Default Catalog	Crimea,VERITAS
1ES 0502+675	05 07 56.2	+67 37 24	XGal,AGN,Blzr,B...	z=0.340	Newly Announced	VERITAS
OT 081	17 51 32.82	+09 39 00.73	XGal,Blzr,BLLac,...	z=0.322	Newly Announced	MAGIC
S5 0716+714	07 21 53.4	+71 20 36	XGal,AGN,Blzr,B...	z=0.31	Default Catalog	MAGIC
1ES 0414+009	04 16 52.96	+01 05 20.4	XGal,AGN,Blzr,B...	z=0.287	Default Catalog	VERITAS,H.E.S.S.
PKS 0301-243	03 03 23.49	-24 07 35.86	XGal,AGN,Blzr,B...	z=0.2657	Default Catalog	H.E.S.S.
S2 0109+22	01 12 05.8	+22 44 39	XGal,AGN,Blzr,IBL	z=0.265	Newly Announced	MAGIC
1RXS J023832.6-311658	02 38 32.5	-31 16 58	XGal,Blzr,BLLac,...	z=0.232	Newly Announced	H.E.S.S.
MS 1221.8+2452	12 24 24.2	+24 36 24	XGal,AGN,Blzr,B...	z=0.218	Newly Announced	MAGIC
1ES 1011+496	10 15 04.1	+49 26 01	XGal,AGN,Blzr,B...	z=0.212	Default Catalog	VERITAS,MAGIC
RBS 0723	08 47 12.9	+11 33 50	XGal,AGN,Blzr,B...	z=0.198	Newly Announced	MAGIC
RBS 0413	03 19 47	+18 45 42	XGal,AGN,Blzr,B...	z=0.19	Default Catalog	VERITAS
PKS 0736+017	07 39 18.0	+01 37 05	XGal,Blzr,FSRQ	z=0.18941	Newly Announced	H.E.S.S.
1ES 0347-121	03 49 23.0	-11 58 38	XGal,AGN,Blzr,B...	z=0.188	Default Catalog	H.E.S.S.
1ES 1101-232	11 03 36.5	-23 29 45	XGal,AGN,Blzr,B...	z=0.186	Default Catalog	H.E.S.S.

Sources Listed: 74

AGN Flares : Many Synergies!

MWL light-curve (MAGIC 2018)



BL-Lac S5 0716+714

- AGN flare radio to TeV.
- Polarisation angle swing looks very interesting!
- CTA is considering its own on-site 1m class telescopes

1. Limiting magnitude 20 for photometry
2. Limiting magnitude 17 for polarimetry
3. Polarimetric accuracy 0.5 to 1%
4. 5'x5' Field of View (FoV)
5. Intranight cadence
6. Fast (< 2 arc-min) re-pointing

- 2m class telescope access via MoUs etc.

<u>Australia:</u>

Unique longitude coverage in S hemisphere (optical/radio)

H.E.S.S. and ATOM detect a high flux state in the blazar PKS 1510-089

ATel #12965; ***Mathieu de Naurois for the H. E.S. S. Collaboration***
*on **30 Jul 2019; 12:04 UT***
Credential Certification: Michael Zacharias (mz@tp4.rub.de)

Subjects: VHE, Request for Observations, AGN, Blazar, Quasar

Tweet

The High Energy Stereoscopic System (H.E.S.S.) conducted observations on the flat spectrum radio quasar PKS 1510-089 (z=0.361) last night (July 29, 2019) as part of its regular monitoring campaign on this source. While this source usually cannot be detected within a single night at very-high-energy gamma-rays (E>100GeV), during observations last night an exceptional high state was detected with a preliminary flux exceeding 10^-10 ph/cm^2/s (E>100GeV) or about 25% of the flux of the Crab Nebula above the same energy threshold. The observations were conducted under favorable conditions and lasted for 3h50.

A VHE gamma-ray flux like this has only been seen once before, namely in 2016 (ATel #9102, #9105). In that instance the flare lasted for only 2 nights, and therefore follow-up observations are strongly encouraged.

The Automatic Telescope for Optical Monitoring (ATOM) measured an optical B-band flux of 13.9 at MJD 58693.80. PKS 1510-089 went on to exhibit strong variability on timescales below 10 minutes -- including a drop of 0.2 magnitudes over less than 30 minutes.

H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia.

Flat Spectrum Radio Quasar PKS1510-089 (z=0.361)

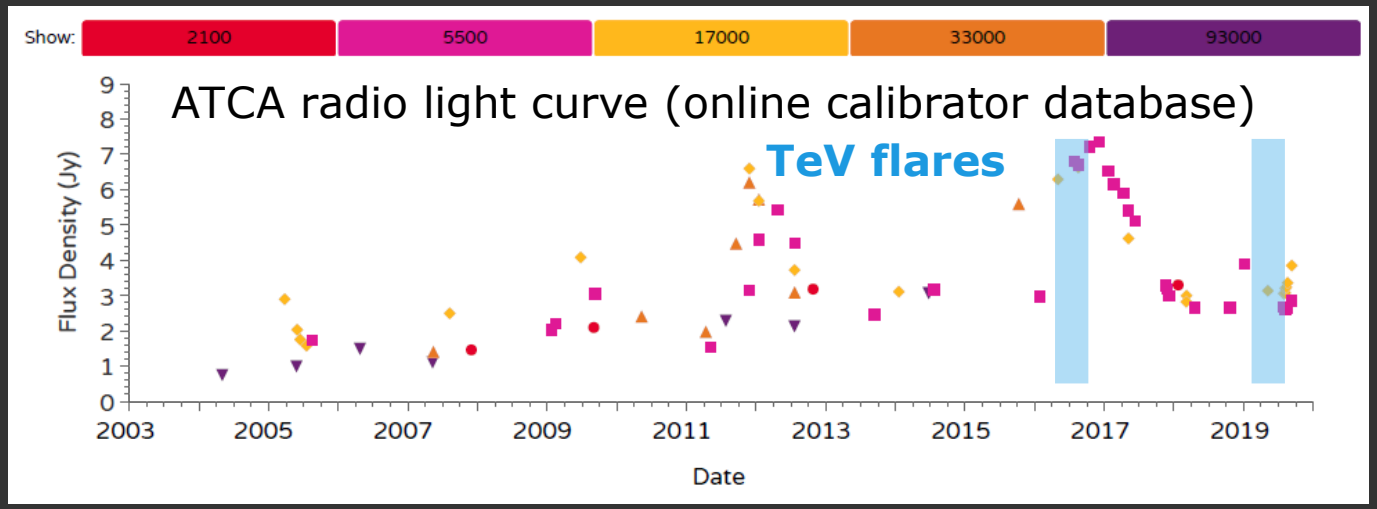
- TeV/optical flare again in July 2019

- Previous TeV flare late 2016 with lag for ATCA radio (2-20 GHz) high state

→ waiting for another ATCA rise?

- mm-VLBI (Boston) obs > 40 GHz
  Probe initial jet outflows

→ mm-VLBI for Australia!!
  Currently max ~20 GHz



CTA will detect 100's of AGN

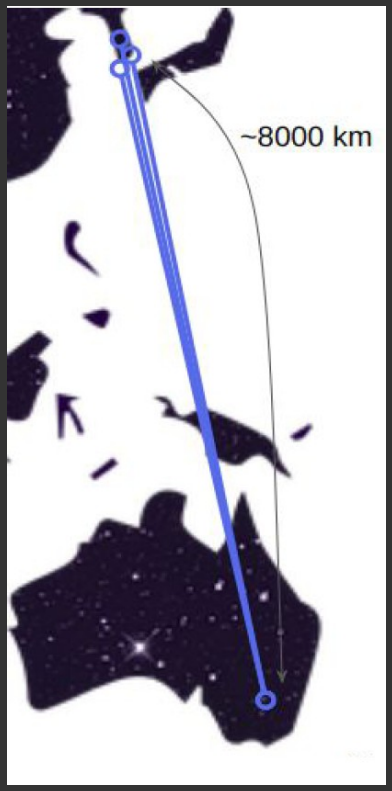
→ FoV 10 degrees
→ several AGN in FoV at one time.

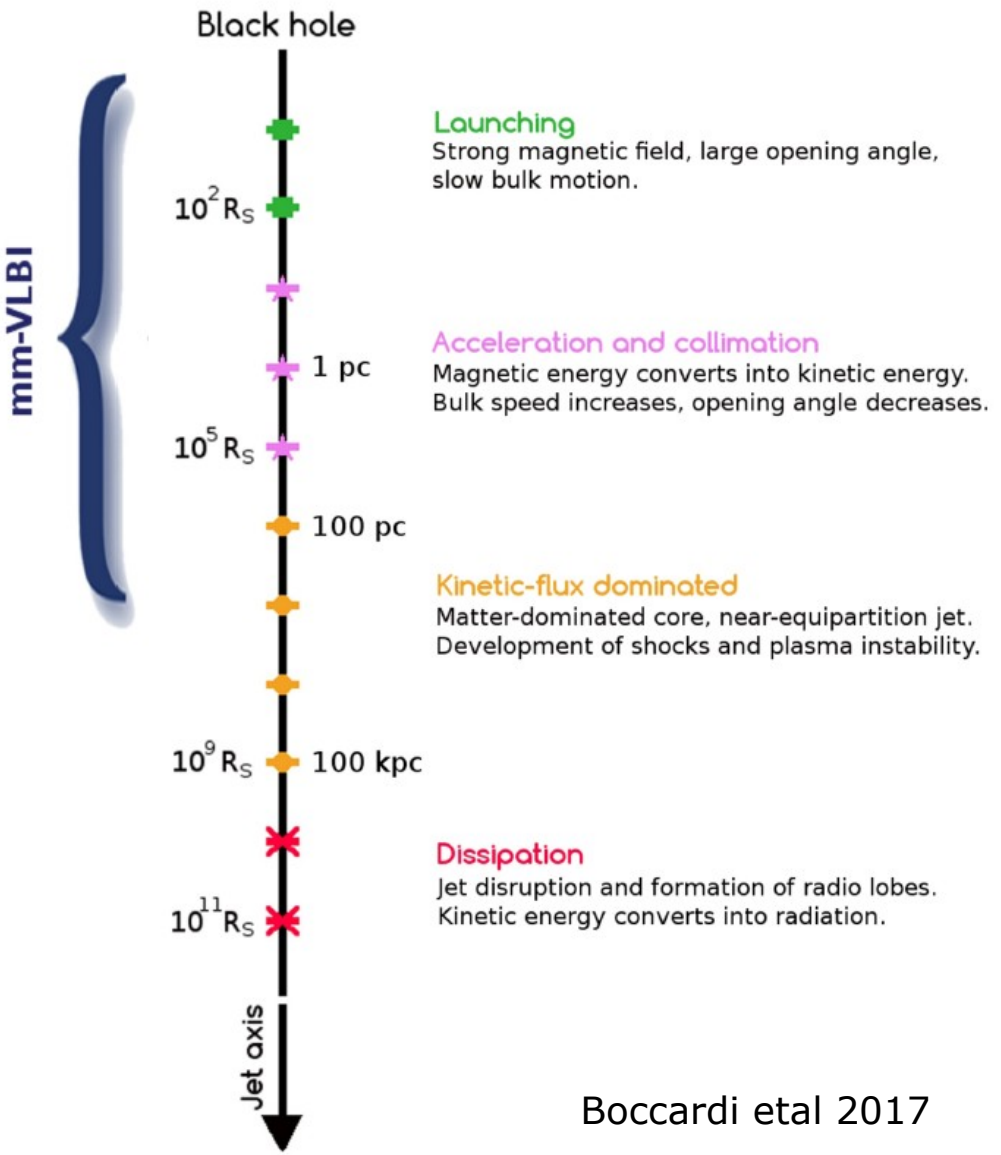
Mopra upgrade for mm-VLBI

- ARC Linkage Project 2019: UNSW (CI M. Cunningham), KASI, CSIRO, WSU, Adelaide, UTas, UWA.

KASI – Korean Astronomy and Space Science Inst.

- New VLBI backend
→ Probe AGN jets down to their base
→ Distance indicators for AGN..
→ EventHorizonTelescope at 3mm
→ Further mm mapping for CTA
→ Trigger on TeV flares (HESS/CTA)





Boccardi etal 2017

Fast Transients : The Way Forward?

- Many transients (FRBs, GRBs, SGRs, GW etc.) < minute/seconds duration
- Fastest follow-up ~ 1 minute (fully robotic).
  → too slow for follow-ups of FRBs, magnetar bursts etc..
  → gamma, X-ray, optical FRB signals may even precede radio..

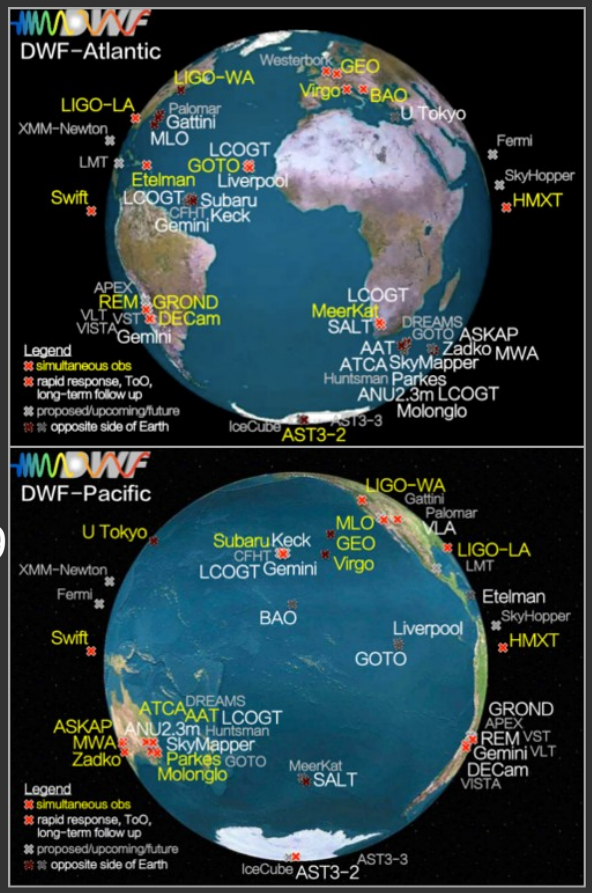
→ Contemporaneous/shadowing campaigns (e.g. DeeperWiderFaster)
→ Slaved telescopes
(e.g. 1m optical telescope at CTA sites.)

– DeeperWiderFaster June 2019
MeerKAT, HESS, DeCAM, SPT, Auger, IceCube..

– DeeperWiderFaster December 2019
MeerKAT?, HESS?…

– MeerKAT+HESS shadow FRB171019 Sept/Oct 2019

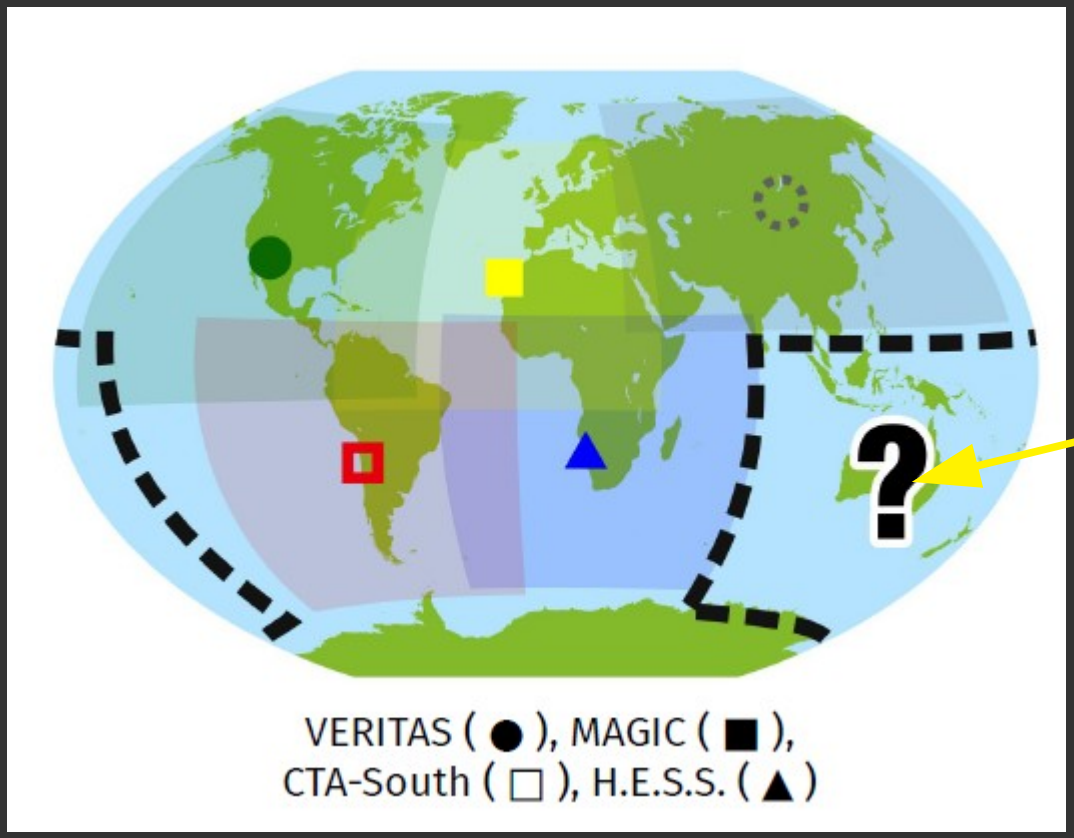
→ "Practise" for the CTA era
HESS+ASKAP+Skymapper (near)shadowing?

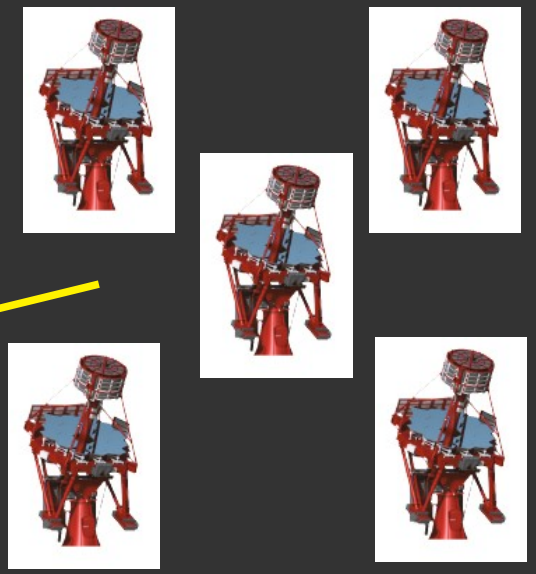


Cherenkov Telescope Ring (CTR)

Rohde etal 2017, Ruhe etal 2019
+ Einecke, Rowell, Lee….

- Worldwide network of Cherenkov telescopes
- Transients and variable TeV sources:
  Rapid follow-up, discovery and monitoring
- Missing coverage in Australia!





Small array of CTA-type SSTs or MSTs?
→ fully robotic!

Summary: Radio to TeV

- Fundamental physics links gamma rays to radio, optical, X-ray bands

- Gamma, radio, optical:
  - old or "fossil" emission from Galactic particle accelerators (unID TeV sources)
  - AGN TeV flares → radio follow-up, optical polarimetry

- Arc-min ISM surveys (molecular+atomic) critical to CTA's Galactic surveys.

- Critical MWL facilities in Australia for HESS and CTA MWL needs.

- CTA will revolutionise TeV gamma-ray astronomy
  → 100's of AGN, >2000's Galactic sources, many transients!

- CTA MWL needs report (discussed this week in Bologna)
  → requires >100hrs/year follow-up optical/radio

- But contemporaneous observations needed for fast transients (FRBs)
  → shadowing essential

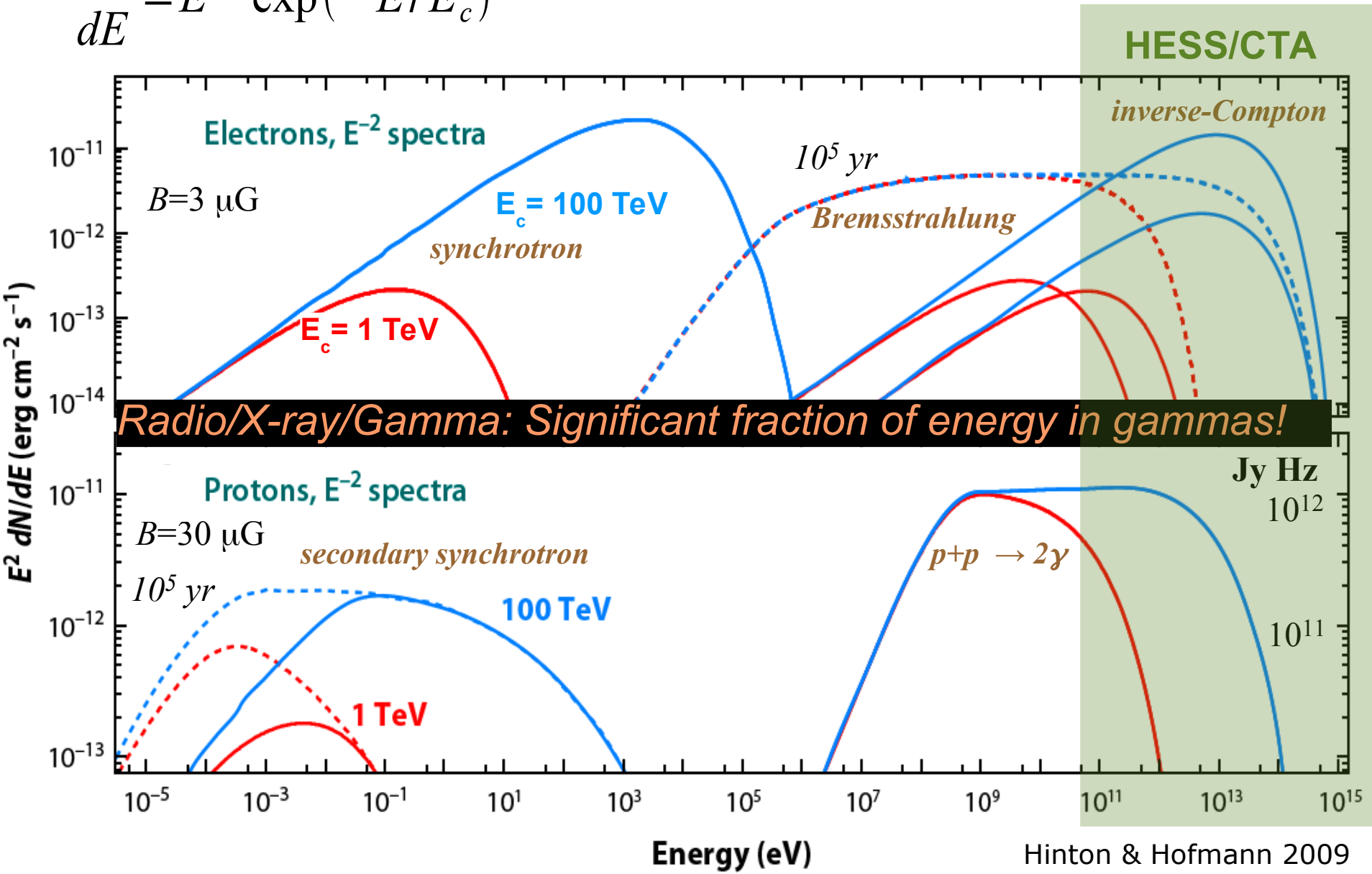
Besides existing radio/optical facilities in the south we need:
→ mm-VLBI
→ optical polarimetry
→ eventually: TeV telescopes in Australia (TeV monitoring)

Back up....

Non-Thermal Energy-fluxes (From a hypothetical particle accelerator)

$$\frac{dN}{dE} = E^{-2}\exp(-E/E_c)$$

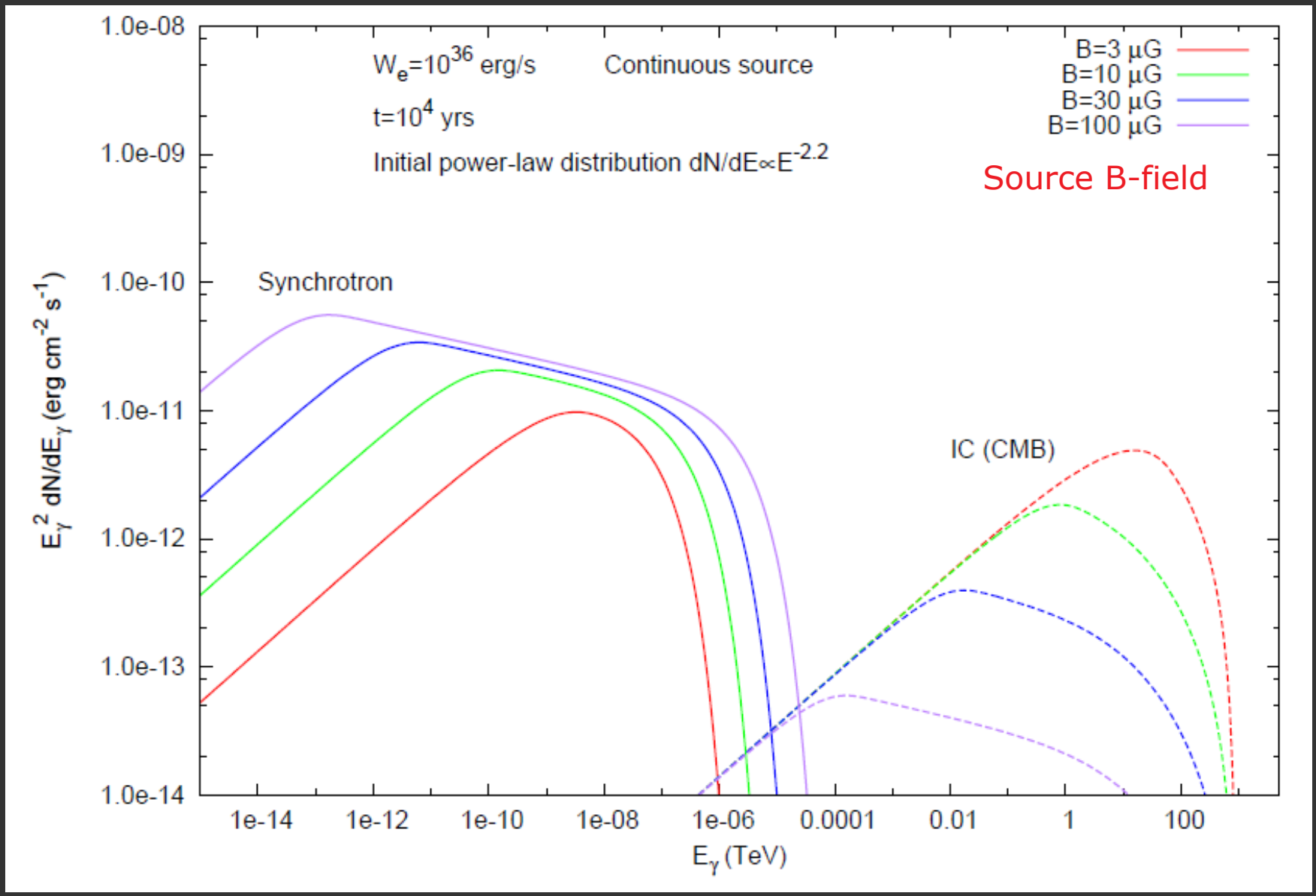
$W_p = W_e = 10^{48}$ erg; d = 1 kpc; Age = 10^4 yr, CMB+FIR+Opt; n=100 cm^{-3}



Hinton & Hofmann 2009

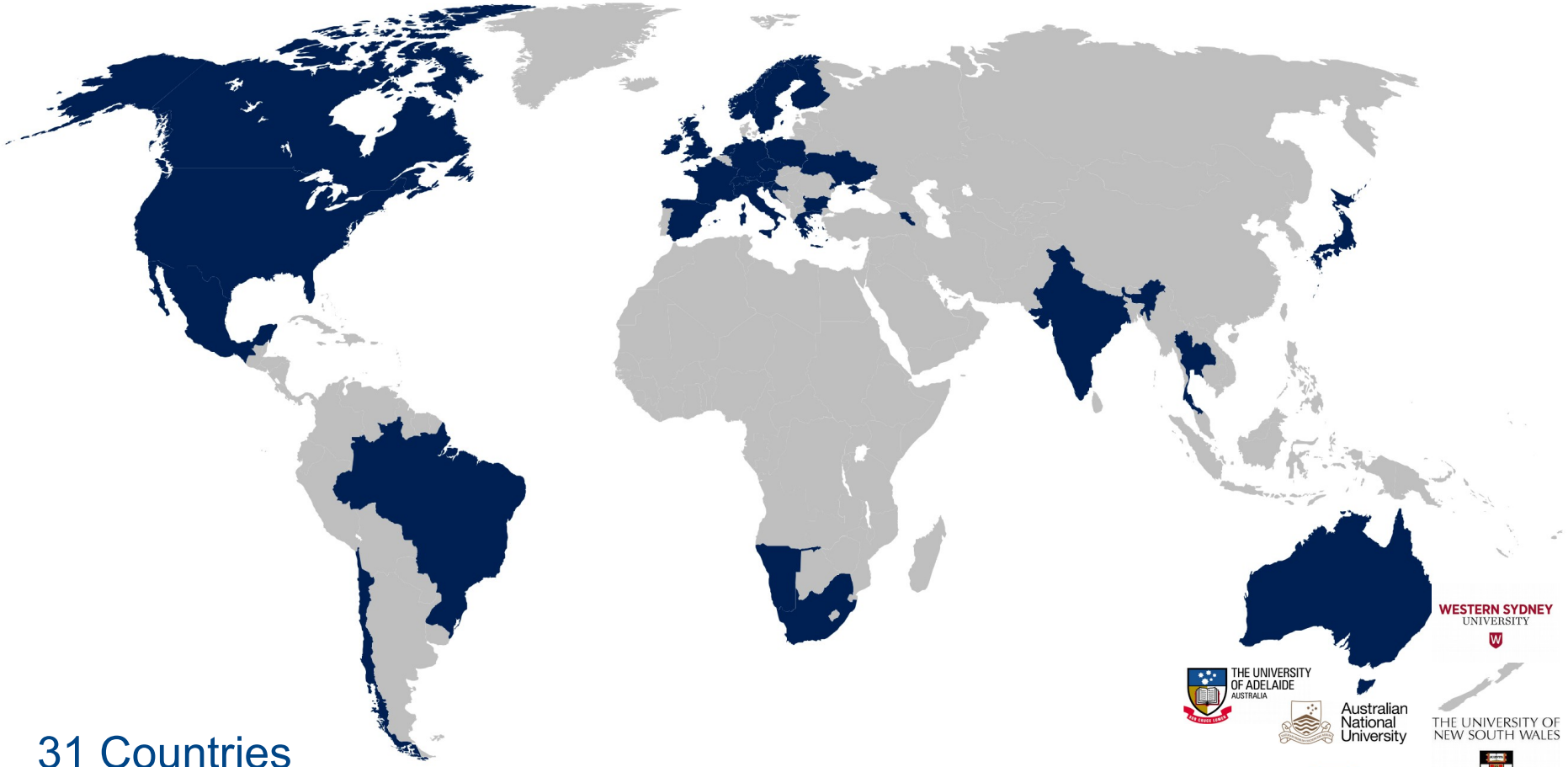
Leptonic: Synchrotron + Inverse-Compton Evolution

Continous particle accelerator e.g. PWN



CTA Consortium (CTAC)

Dec. 2018



31 Countries
> 200 Institutes
>1400 Scientists