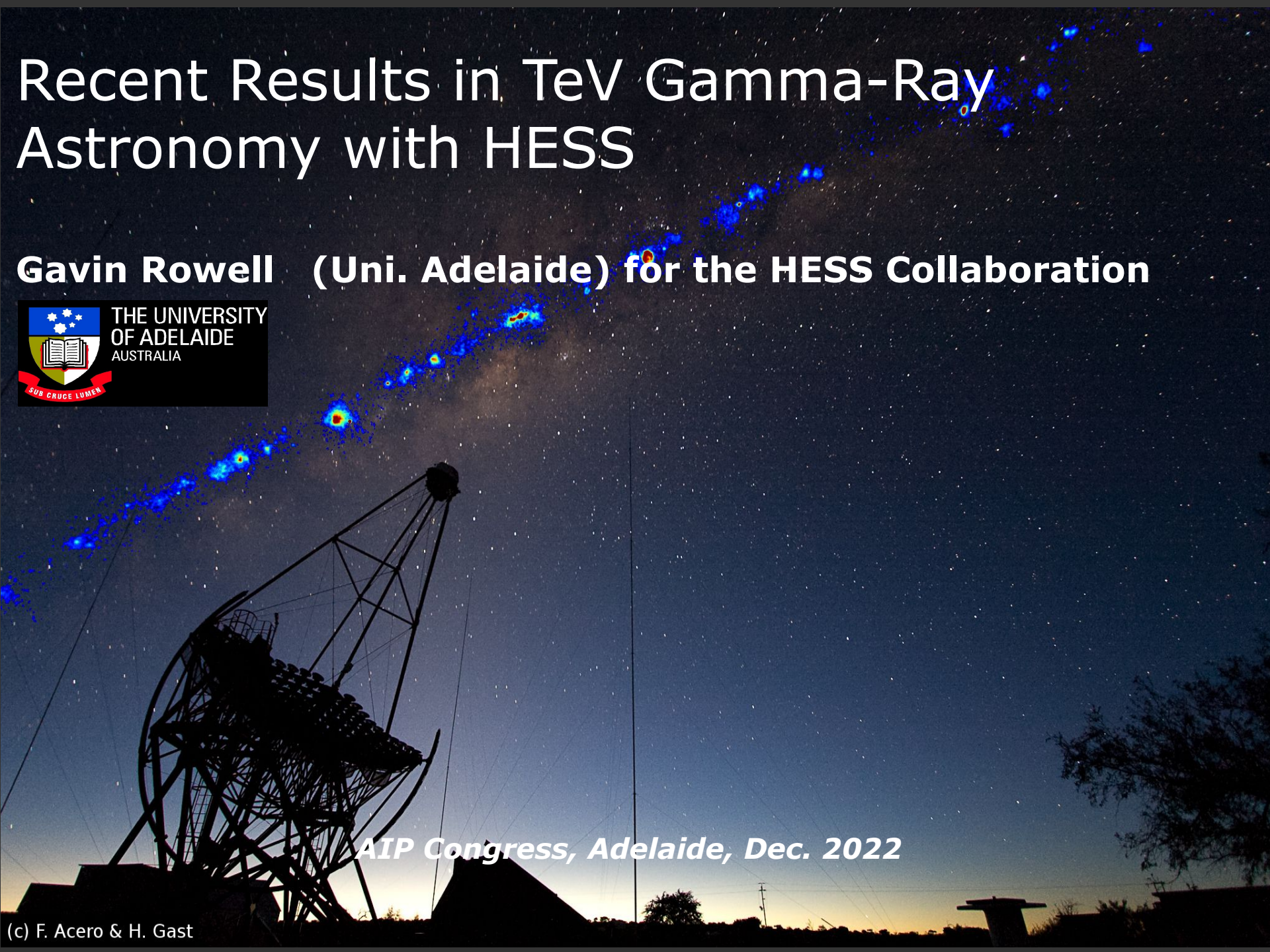
Recent Results in TeV Gamma-Ray Astronomy with HESS

Gavin Rowell (Uni. Adelaide) for the HESS Collaboration

THE UNIVERSITY OF ADELAIDE AUSTRALIA
SUB CRUCE LUMEN

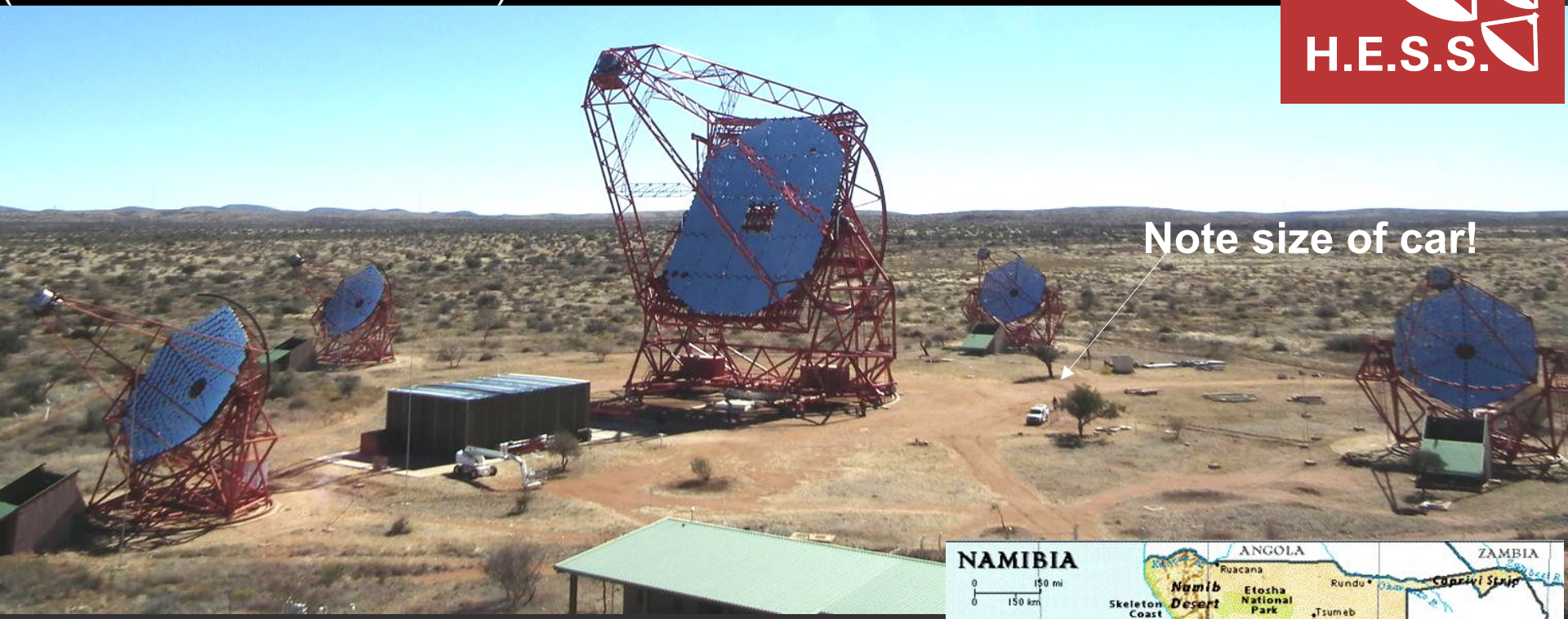


AIP Congress, Adelaide, Dec. 2022

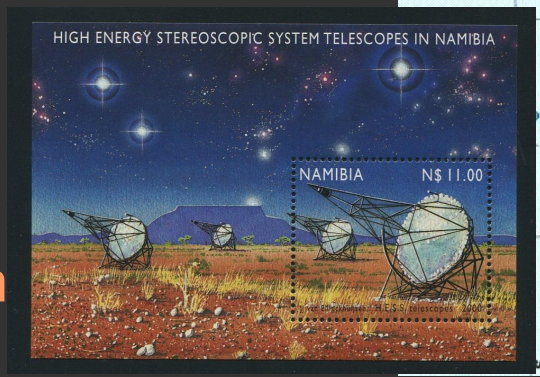
(c) F. Acero & H. Gast

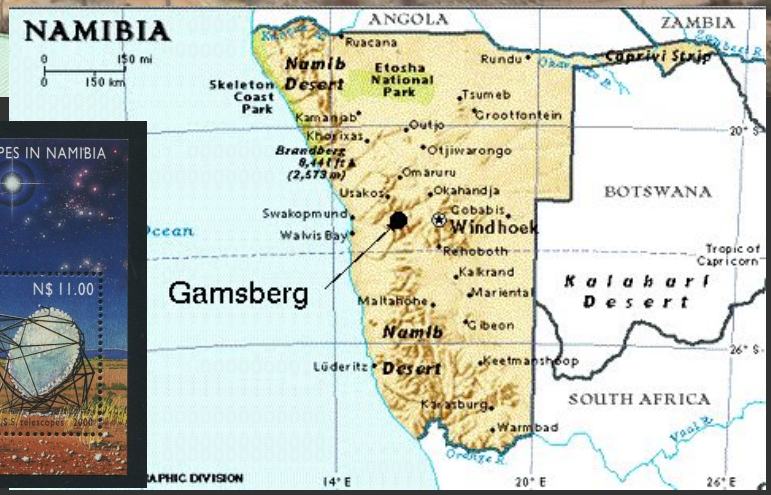
HESS (High Energy Stereoscopic System)

(22° S 1800m a.s.l. Namibia)



- 0.02 to ~ 20 TeV coverage
- HESS-II ~0.02 to 1 TeV
- Field of view 3 to 5°
- Angular res. ~3 to 6 arcmin

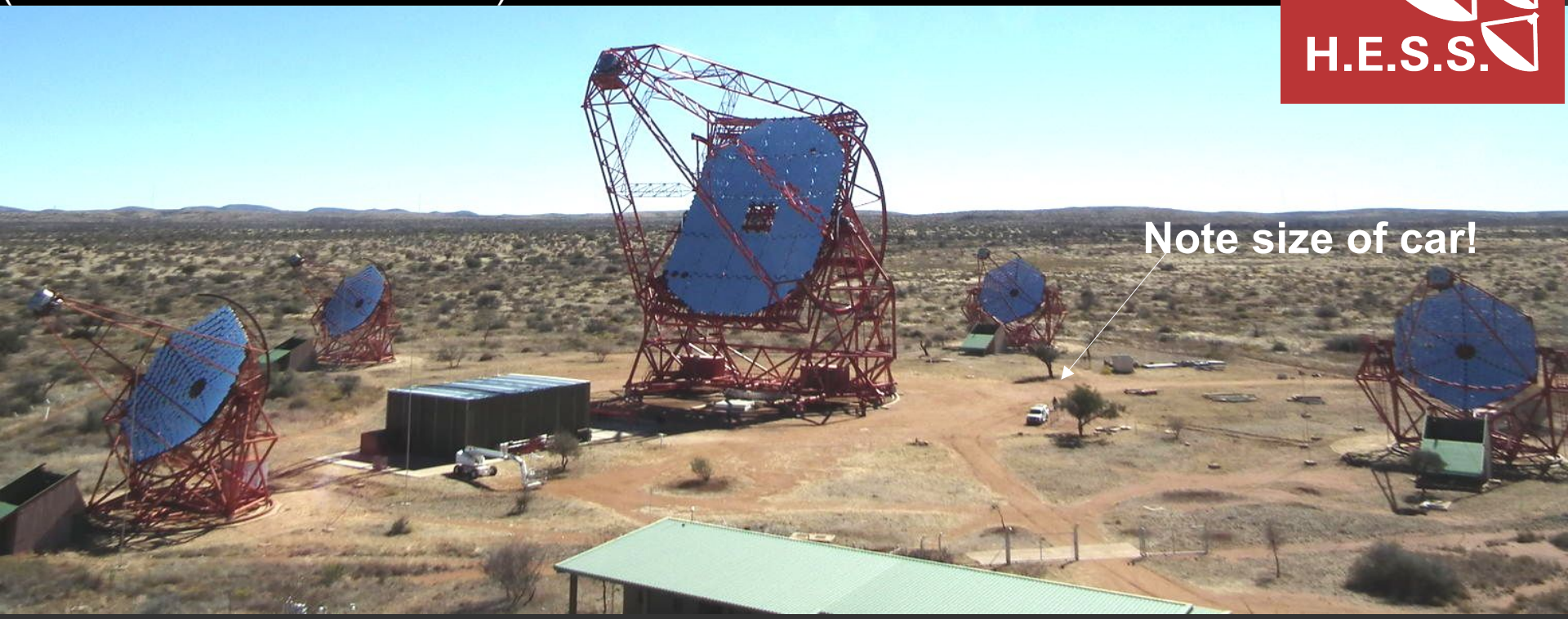




Commenced operations 2002.

HESS (High Energy Stereoscopic System)

(22° S 1800m a.s.l. Namibia)



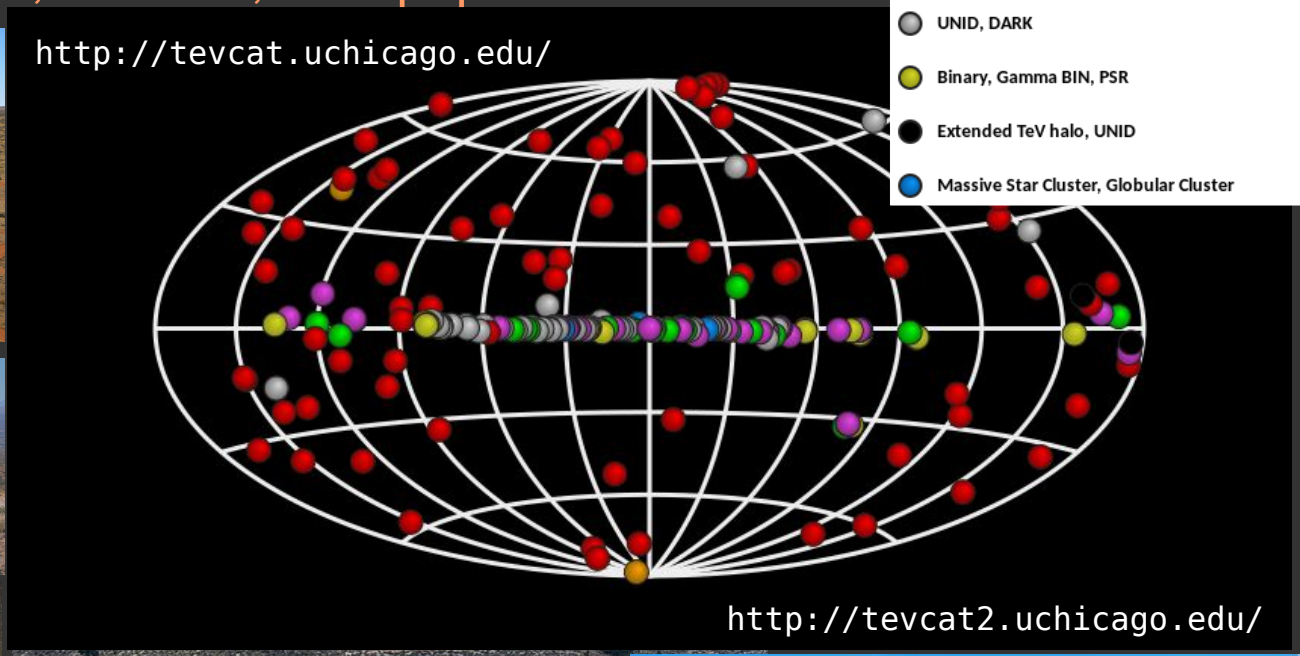
- Camera upgrades to HESS-I telescopes 2015/16
  - → Full timing (1 GHz) information on Cherenkov images
  - → Better skynoise/CR event reduction
- Camera upgrade to HESS-II telescope 2020/21
  - → NectarCAM design for CTA mid-sized telescopes (working well!)

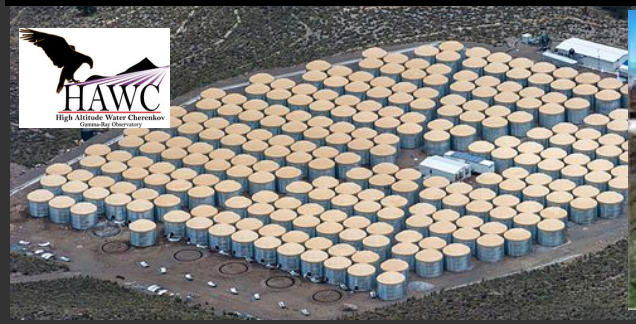
. Operations extended to 2025 at least.

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

Ground-based detection of Cherenkov emission

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



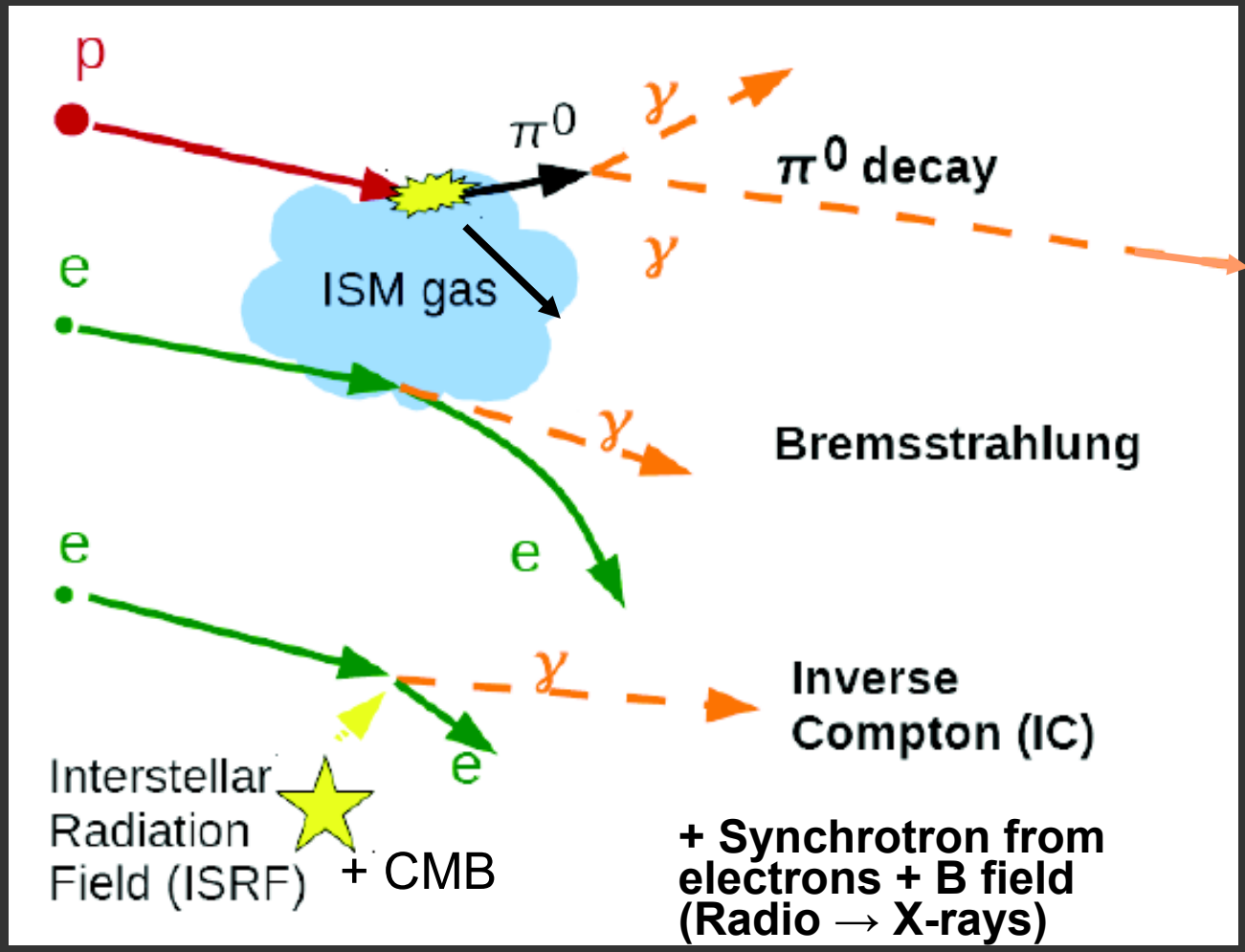


Great success with HESS, VERITAS, MAGIC, HAWC, building on previous generations

Continued operations of HESS/VERITAS/MAGIC/HAWC 2025+

Next generation → CTA, SWGO…

Gamma Rays from multi-TeV particles



"ISM" gas
Interstellar Medium

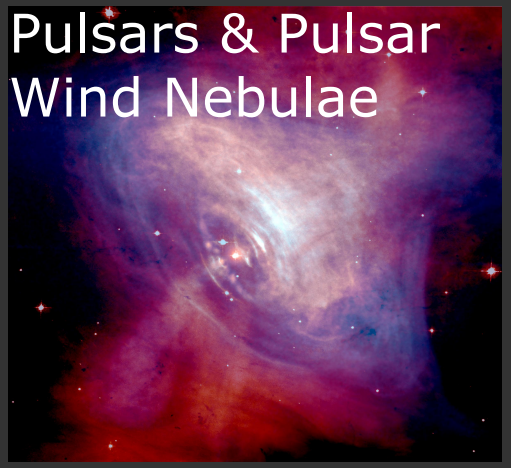
→ molecular + atomic + ionised gas in the Milky Way

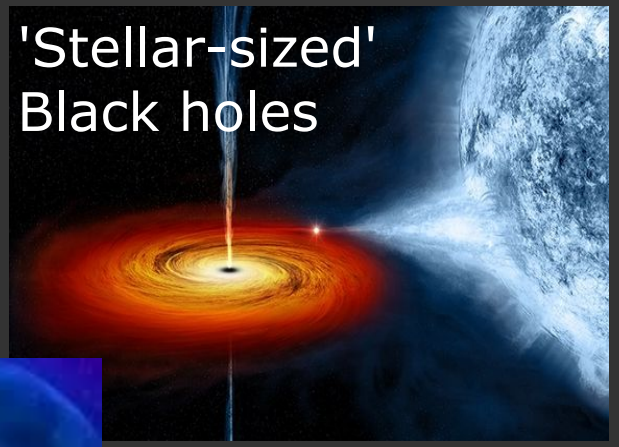
Protons: Gamma rays and ISM gas are generally spatially correlated

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

→ gamma-ray, X-ray, radio astronomy intimately connected

Some extreme particle accelerators in the Universe





Gamma-rays (GeV to >PeV Energies)

- Gamma rays: Highly effective tracer of particle acceleration

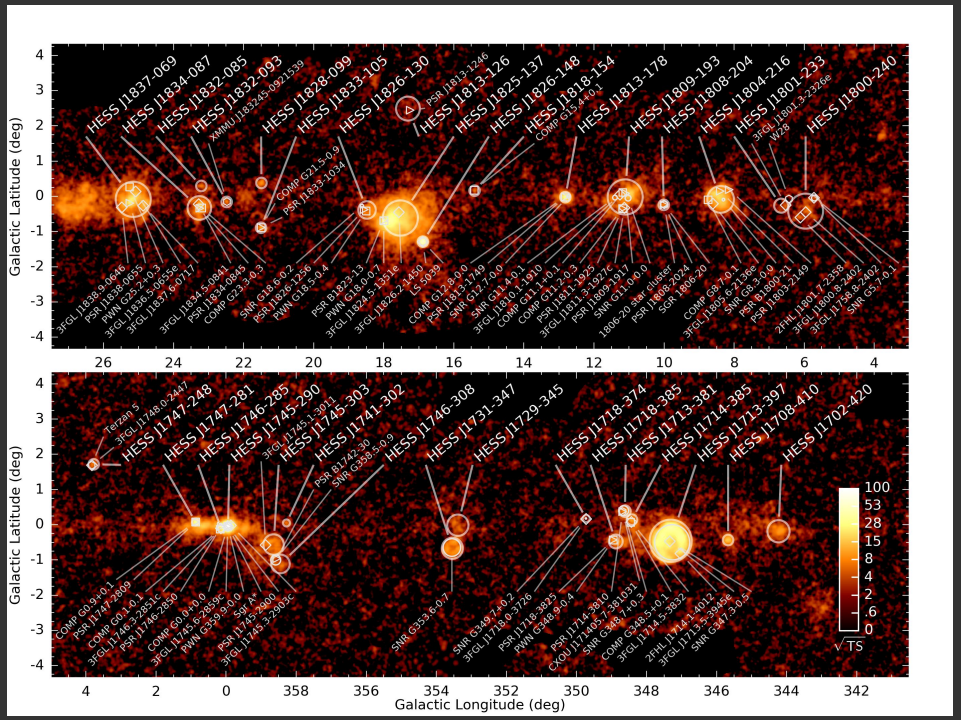
- Many gamma-ray source types + astro/particle physics impact

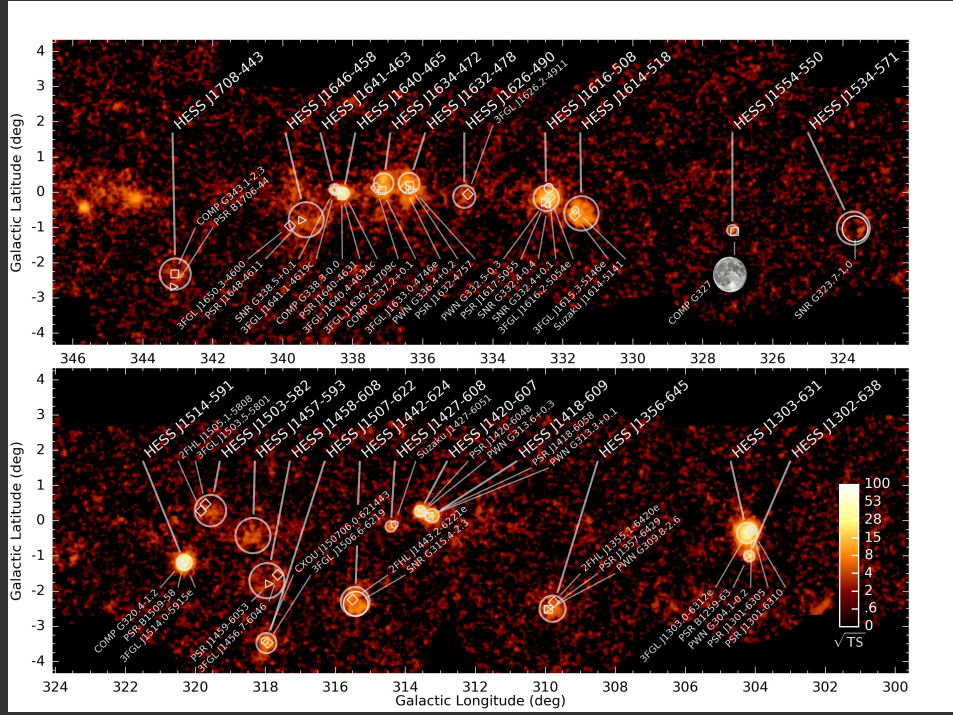
- *Supernova remnants*
- *Pulsars*
- *Pulsar-wind nebulae & their halos*
- *Compact binaries, stellar black holes*
- *Gamma-ray bursts (hypernovae & compact mergers)*
- *Novae*
- *Galactic centre region*
- *Massive stellar clusters*
- *PeVatrons → our galaxy's extreme accelerators*
- *Relativistic outflows; stellar winds; colliding wind interactions*
- *ISM molecular & atomic gas; ISM magnetic fields*
- *Unidentified & Dark TeV sources*
- *Active Galaxy Cores; super-massive black holes*
- *Star-burst galaxies*
- *Globular clusters (millisecond pulsars and/or X-ray binaries?)*
- *Extragalactic IR background constraints → cosmology*
- *Indirect dark matter search, quantum gravity, axions, beyond SM physics*
- *Cosmic ray electrons*

The H.E.S.S. Galactic Plane Survey (2018)

HGPS - The Southern Milky Way in TeV Gamma-Rays

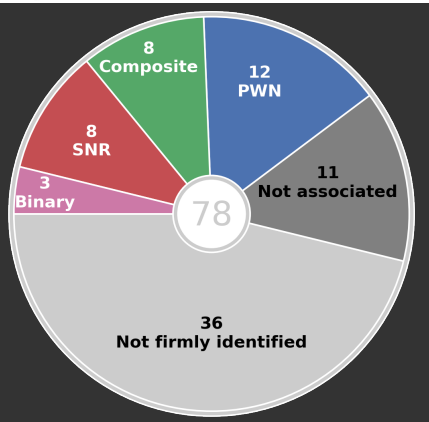
→ Major legacy survey (HESS A&A 2018)





- Over 70 sources of Galactic TeV gamma-rays (>50% unidentified)
- Model with discrete sources + diffuse emission (ad hoc)
- Log N vs. log S studies for the first time
- Three new TeV shells → gamma-ray bright supernova remnants?
- TeV source assoc. massive stellar cluster/LBV star/magnetar
- PeVatrons

Data download https://www.mpi-hd.mpg.de/hfm/HESS/hgps/



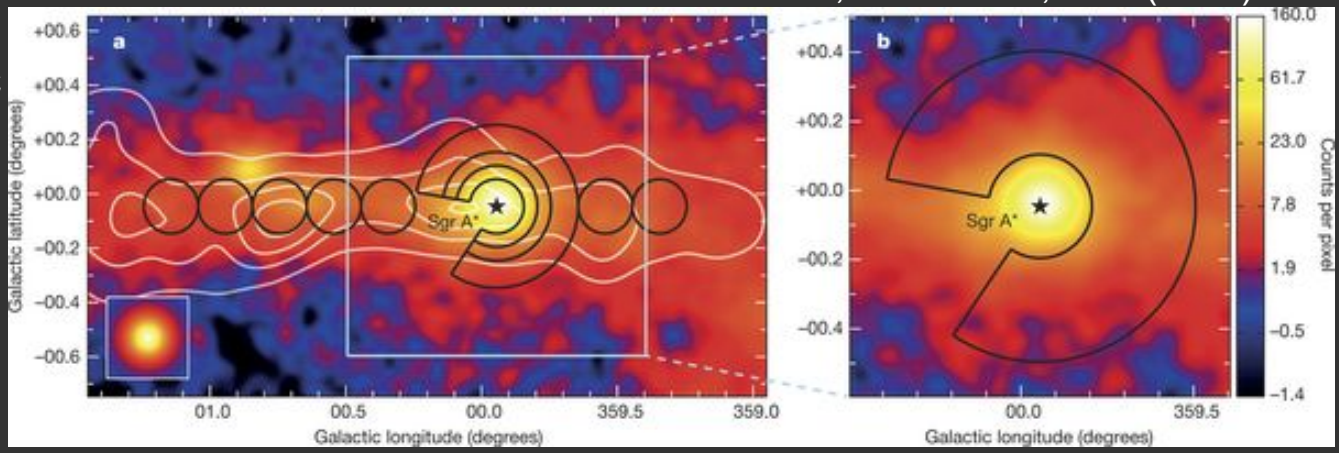
PeVatrons: Particle acceleration to >PeV energies

- Inferred from hard gamma-ray spectra above ~50 TeV $E_{gamma} \sim 10\ E_{particle}$

HESS, Nature 531, 476 (2016)

Galactic Centre Region

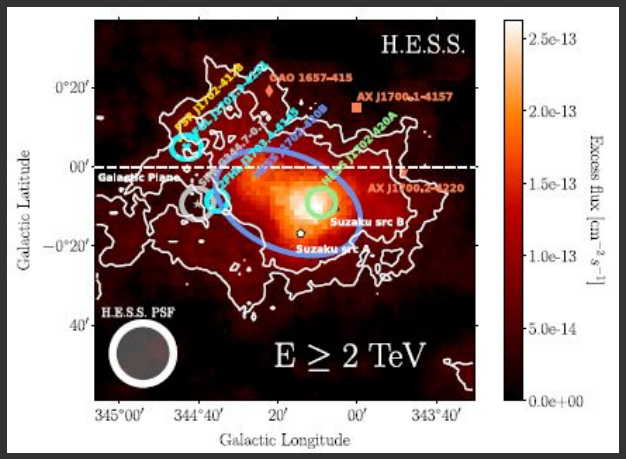
- Diffuse emission to 70pc
- Continous CR injector over ~few1000yr
- Central BH most likely accelerator

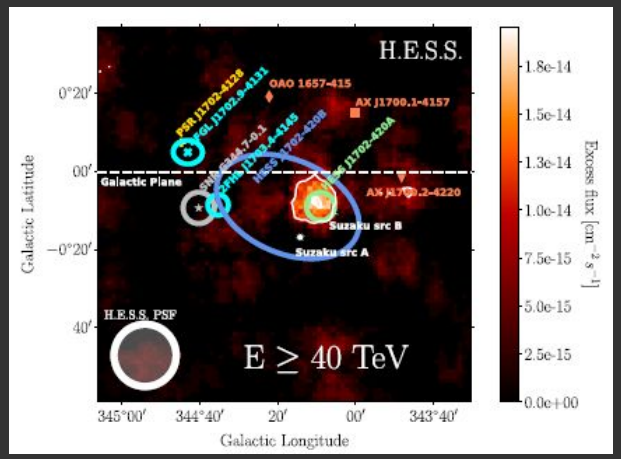


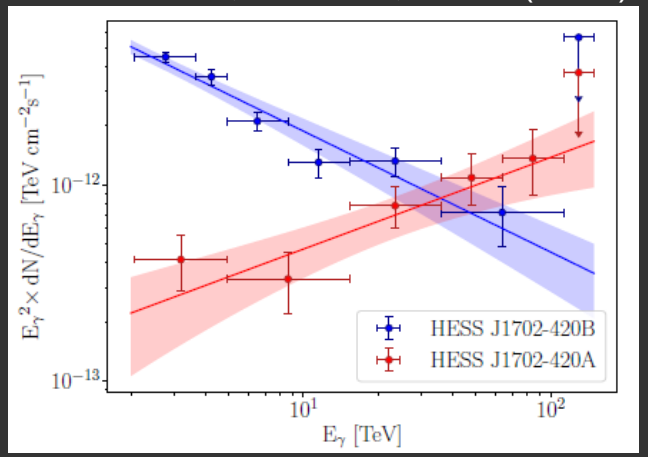
HESS J1702-420

- Resolved into two components A & B. Gamma rays from A > 100 TeV
- CR protons up to ~0.5 PeV, but leptonic scenario not ruled out.

HESS, A&A 653, A152 (2021)







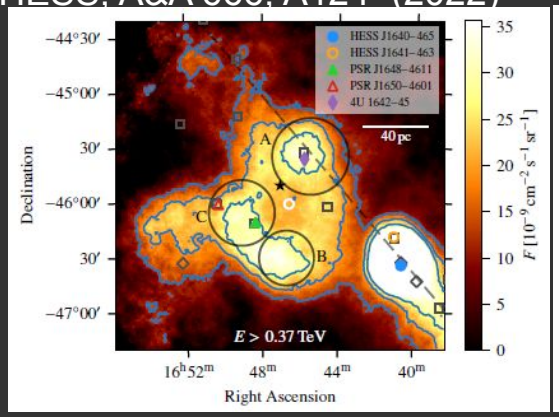
PeVatrons: Particle acceleration to >PeV energies

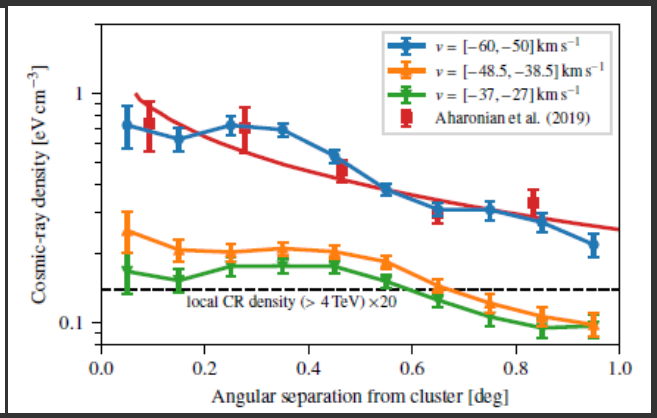
- Inferred from hard gamma-ray spectra above ~50 TeV $E_{gamma} \sim 10\ E_{particle}$

HESS, A&A 666, A124 (2022)

<u>Westerlund1 stellar cluster</u>

- >20 WR stars; L~10^{39} erg/s
- TeV emission 2 deg diam.
- TeV spectrum >50 TeV
- Deeper HESS obs reveal no spectral change with location.
- Shell-like structure centred on Cluster. TeV+ISM comparison compatible with continuous CR injector.

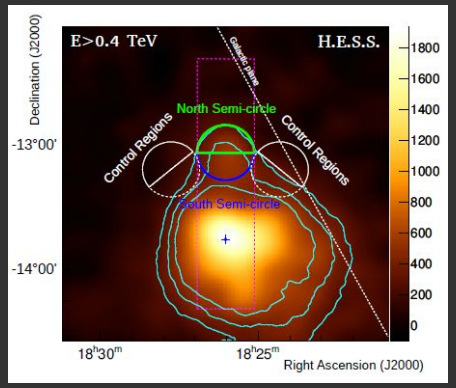


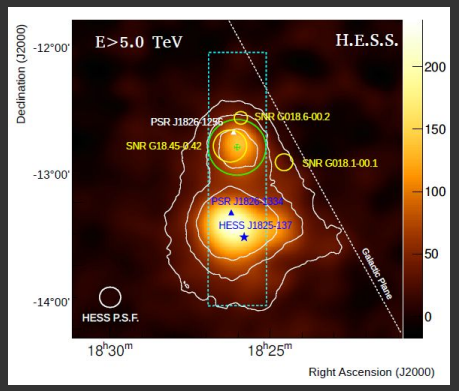


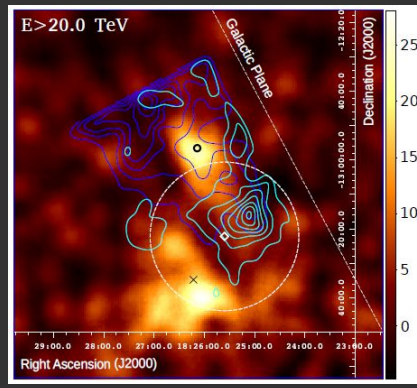
<u>HESS J1826-130</u>

- Adjacent to TeV PWN HESSJ1825
- TeV flux to ~50 TeV
- Overlaps dense ISM
- CRs escaping J1825 or PSR J1826-1256

HESS, A&A 644, A1112 (2020)





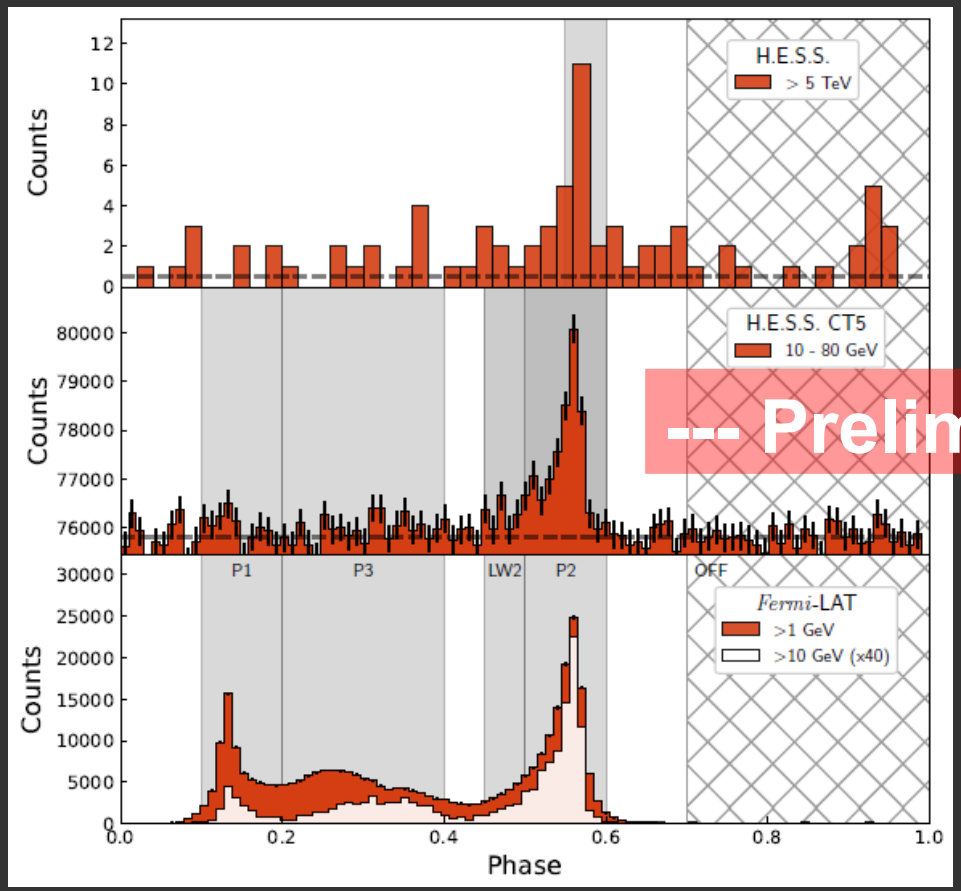


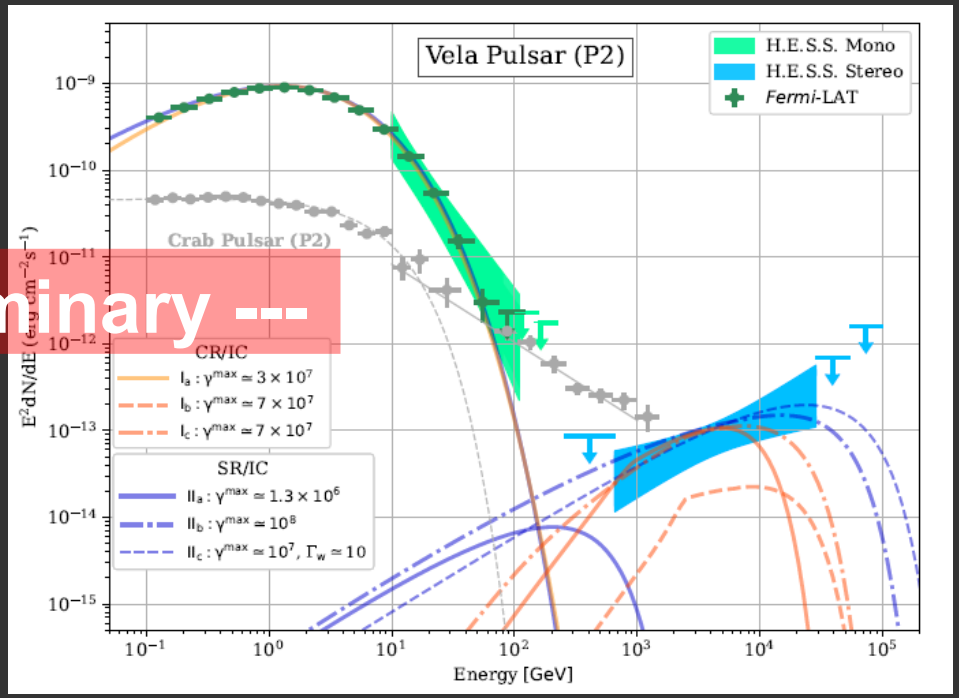
<u>Some other examples</u>

HESS J1809-193, HESS J1831-098 and HAWC, LHAASO discoveries >1 PeV

Vela Pulsar: 2nd Pulsar seen in TeV gamma rays

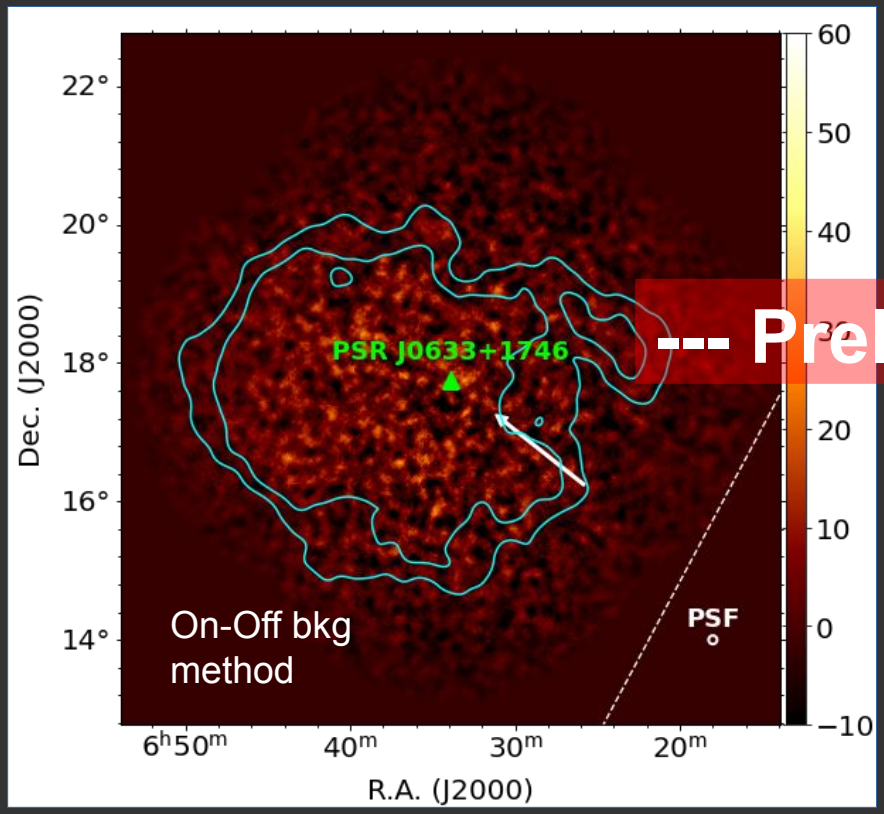
- Deep HESS observations with mono and stereo observations
- P2 component detected above 20 TeV!
  → highest-energy pulsed photons so far seen from a pulsar
  → additional hard spectral component
  → inverse-Compton from electrons up to Lorentz factor γ ~7x10^7
  → outer magnetospheric production region

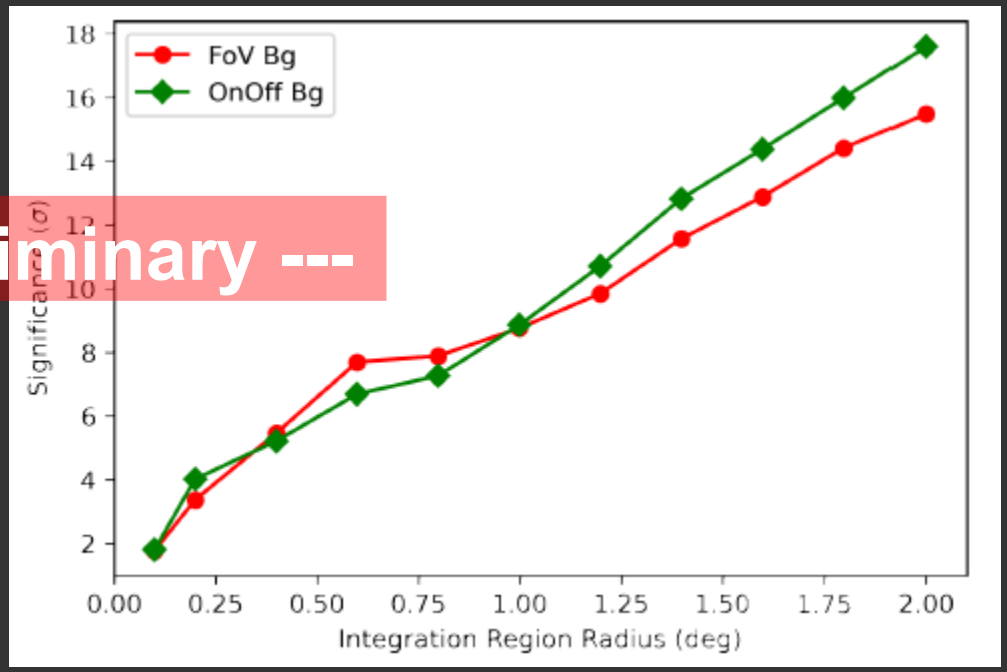




Pulsar Wind Nebula Halos Geminga

- Old (τ_c=342kyr) nearby pulsar (250 pc).
- HAWC detected extended TeV emission surrounding pulsar (Abeysekara etal 2017)
- Now HESS has detected similar morphology, but a challenge for HESS's FoV.
- Largest HESS TeV source (5deg diam; ~20pc)
- Extension requires slow diffusive transport of electrons, 100x lower that Galactic expection (as per HAWC conclusion).
  → PWN TeV halo



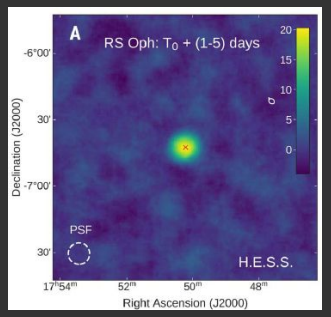


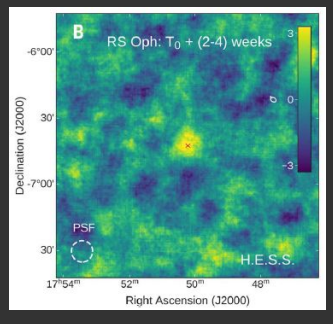
--- Preliminary ---

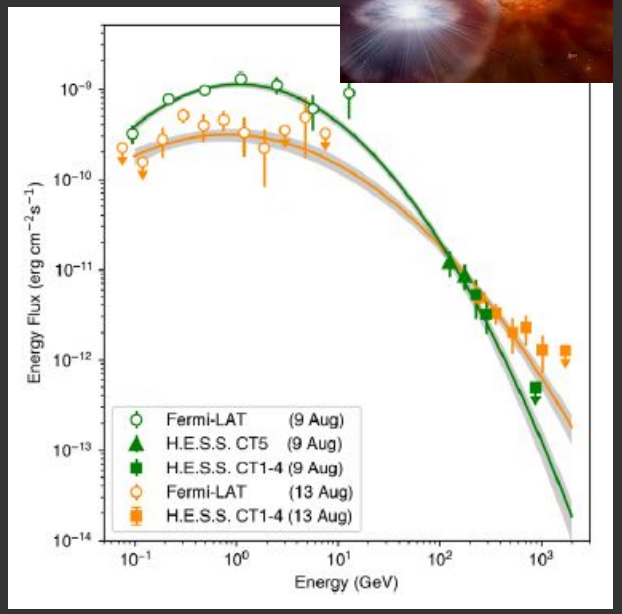
RS-Oph Recurrent Nova – First Galactic TeV Transient

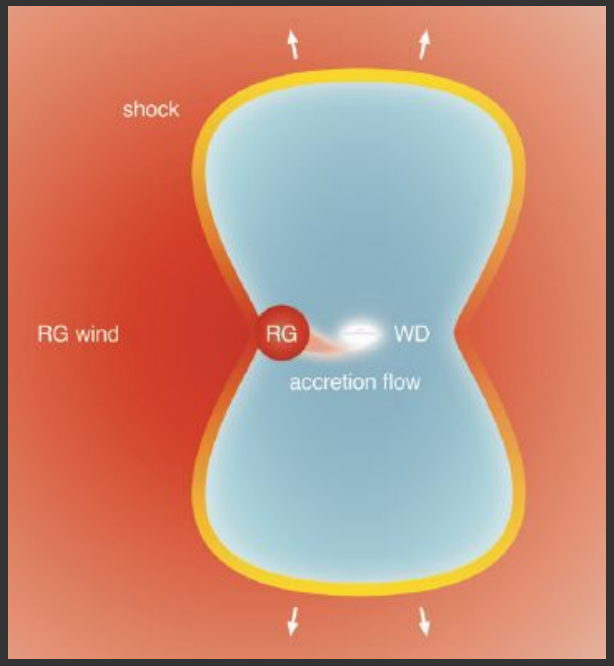
HESS, Science 376, 6588 (2022)

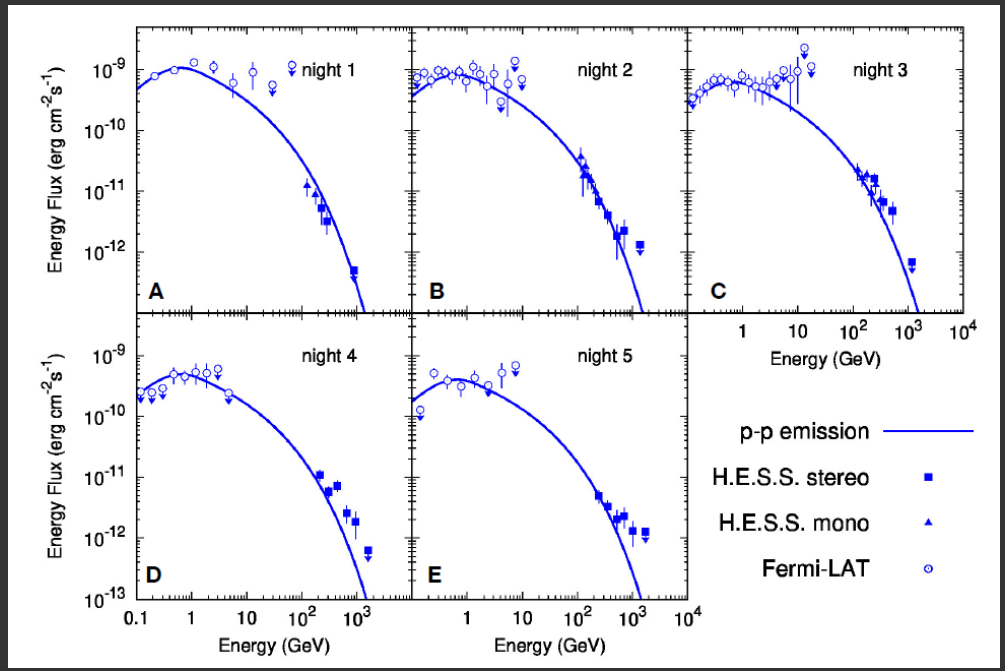
- WD and massive companion RG star
- Flaring via thermonuclear detonation and particle acceleration.
- GeV emission from Fermi-LAT
- HESS obs. of 2021 outburst triggered by optical flare (prev. outburst ~9-26 yrs)
- >6sigma/day in first 5 nights with HESS
  (also seen by MAGIC Acciari etal 2022)
- Hadronic model preferred.











PKS1510-089 FSRQ z=0.361

HESS, MAGIC , A&A 648, A25 (2021)

TeV & optical intra-day variation (May 2016)

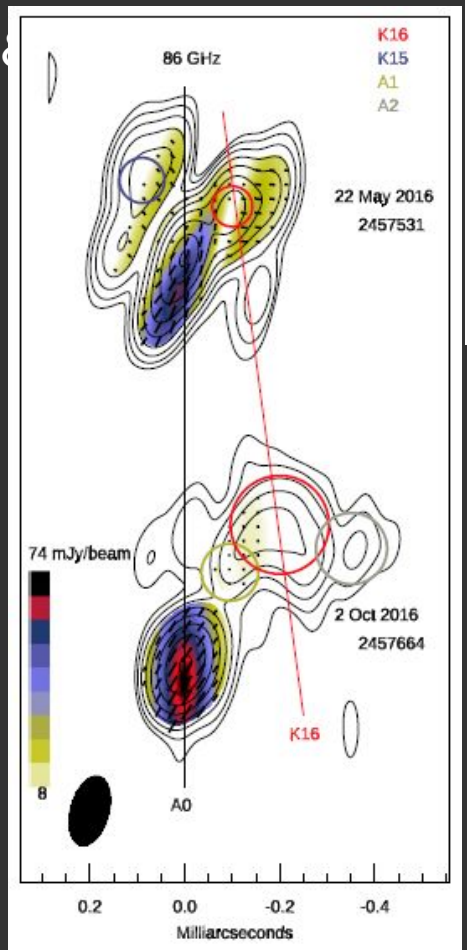
HESS+MAGIC+Femri-LAT (gamma)
ATOM (optical R-band)
VLBA + GMVA (radio 43

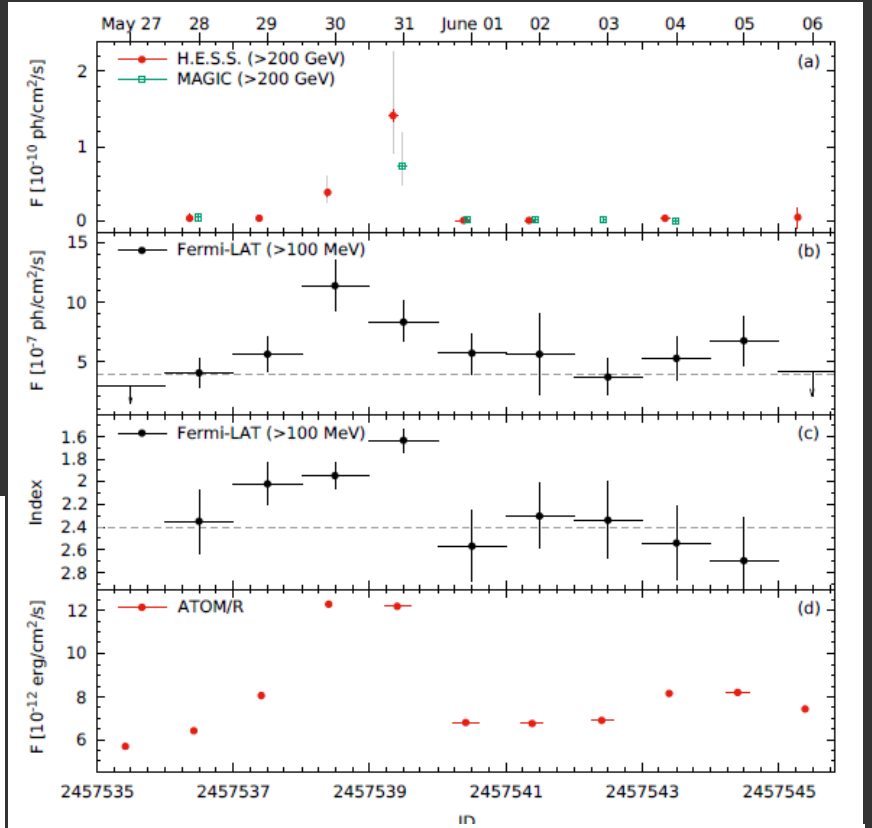
- Rapid cessation of TeV and optical flaring on sub-day timescale

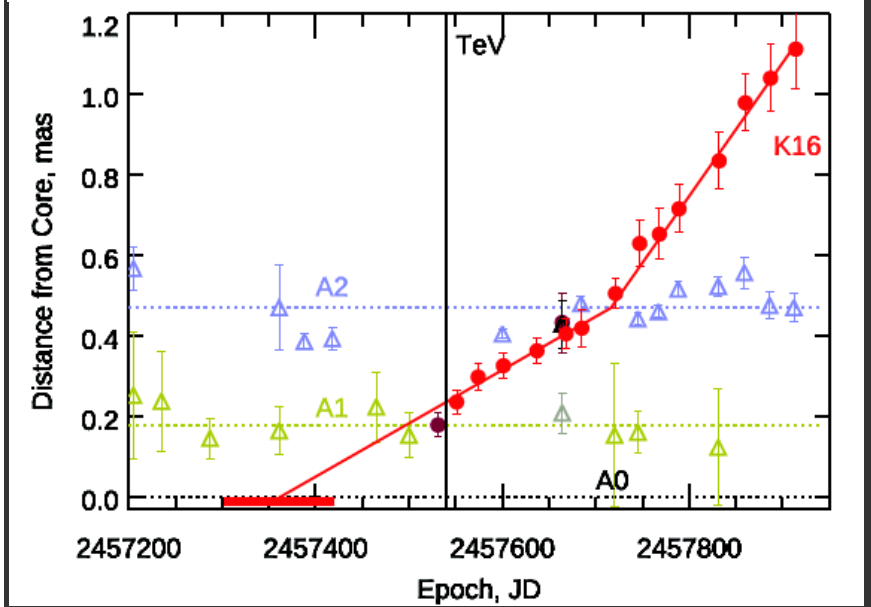
- GeV+TeV spectral curvature → absorption from EBL, not BLR.

- Gamma emission >2.6$R_{_BLR}$ from BH

- Flare associated with rapidly moving radio knot K16?

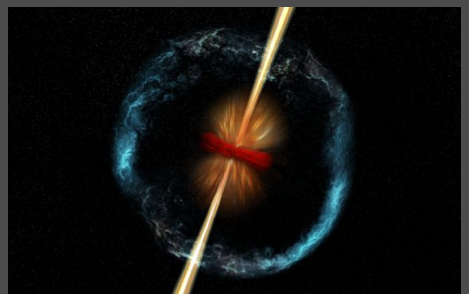


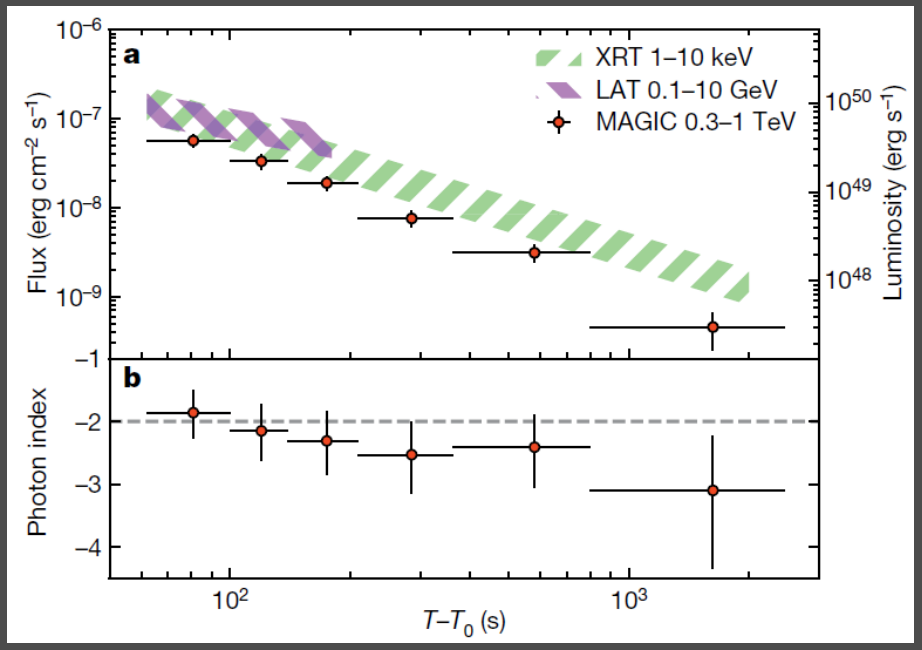


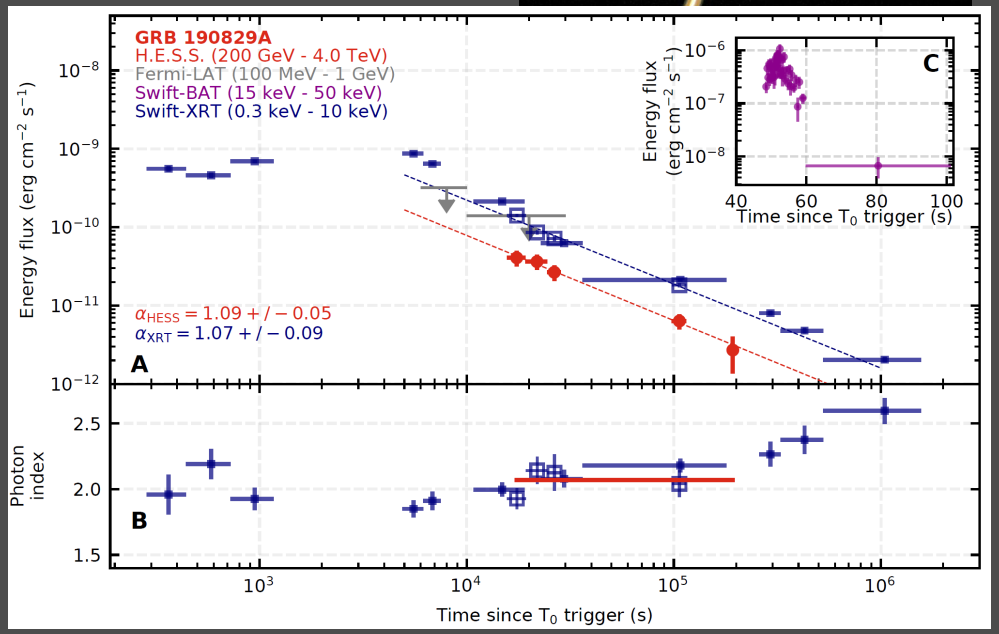


TeV Gamma Ray Bursts : A New Era Begins

(MAGIC 2019, 2021, HESS 2019, 2021)







- Three Long GRBs GRB180720B, GRB190114C, GRB1900829A
  z=0.653 0.424 0.079
- One Short GRB GRB160821B (z=0.162) marginal!

- GRB190114C seen at >300 GeV at low elevation during moonlight!
- GRB1900829A seen T+2 days
  > 1000's photons > 50 GeV → gamma-ray spectra on hourly timescales

- Rapid radio follow-up in place (HESS+ATCA; e.g. Anderson etal 2022 submitted)

GW170817

- HESS prompt follow-up (upper limit)
  HESS, ApJ Lett 850, L22 (2017)

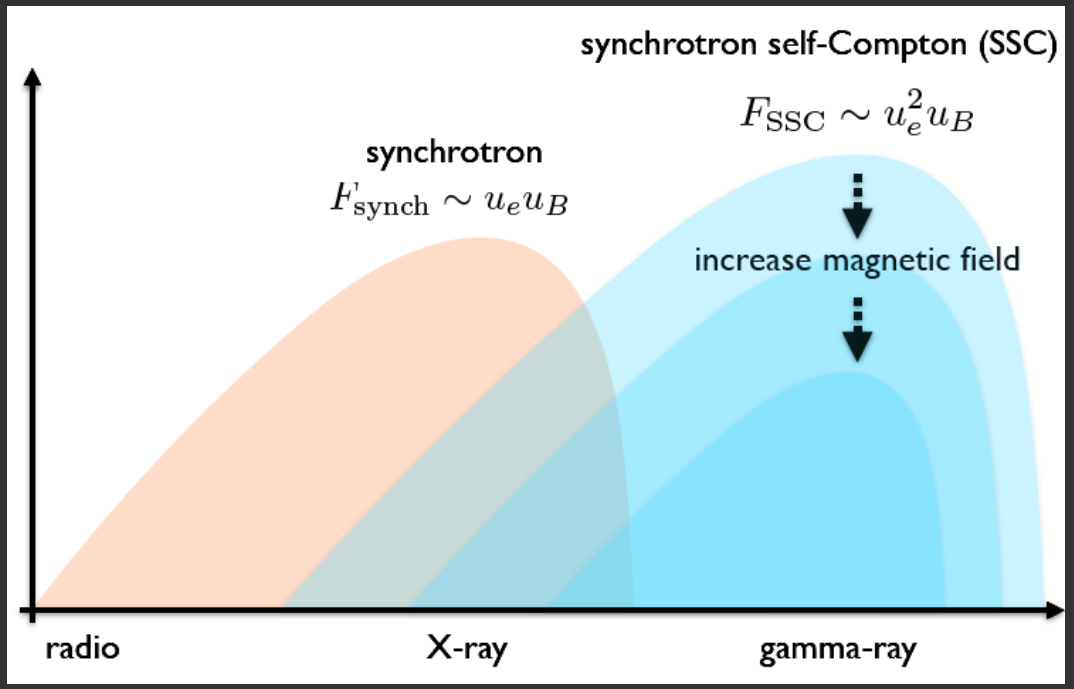
But after ~100 days, expect strong X-ray synchrotron emission – seen with Chandra
Troja et al (2017)

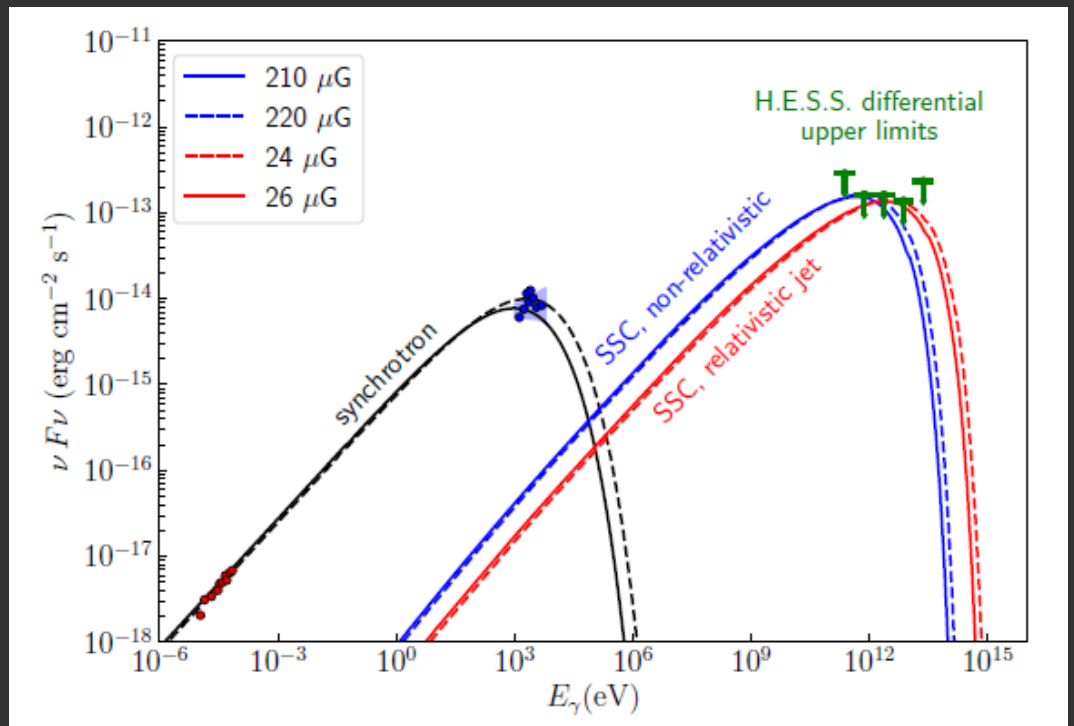
→ TeV inverse-Compton!

Synch-self-Compton (SSC) in fact.

Isotropic non-relativistic wind or relativistic jet (observed slightly off-axis at 20 degrees)
(Takami etal 2014, Rodrigues etal 2019, HESS 2020)

→ Constrain B-field with HESS
HESS, ApJLett 894, L16 (2020)





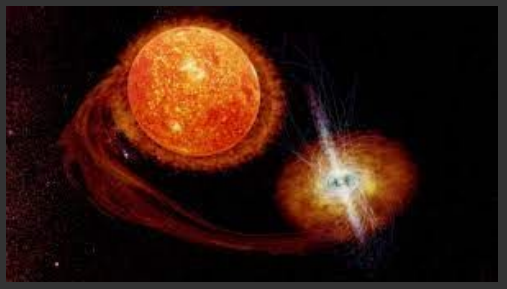
Some Recent Transients Studies with HESS

HESS, ApJ 919, 106 (2021)

<u>SGR/Magnetar flares</u>
– Triggers from Swift-BAT, Fermi-LAT
– SGR1935+2154 ‘Cluster’ of X-ray bursts in 2021 with radio bursts
→ First links to repeating FRBs!

HESS, MNRAS 515, 1365 (2022)

<u>Fast Radio Bursts</u>
– Triggers from UTMOST & Parkes-SUPERB
– Campaigns on three repeating FRBs with MeerKAT, eMERLIN, & Swift



HESS, MNRAS 517, 4736 (2021)

<u>X-Ray Binaries (Low-Mass)</u>
– MAXI J1820+070 2018 outburst
– HESS, MAGIC, VERITAS campaign
→ constraints on B field and emission region

HESS, MNRAS 626, A57 (2019)

<u>Nearby Core-Collapse Supernovae</u>
– Ten SN 4 to 54 Mpc distant (incl. SN2016adj in CenA)
– Constraints on mass loss rates fewx10^{-5} to 10^{-3} Msun/yr

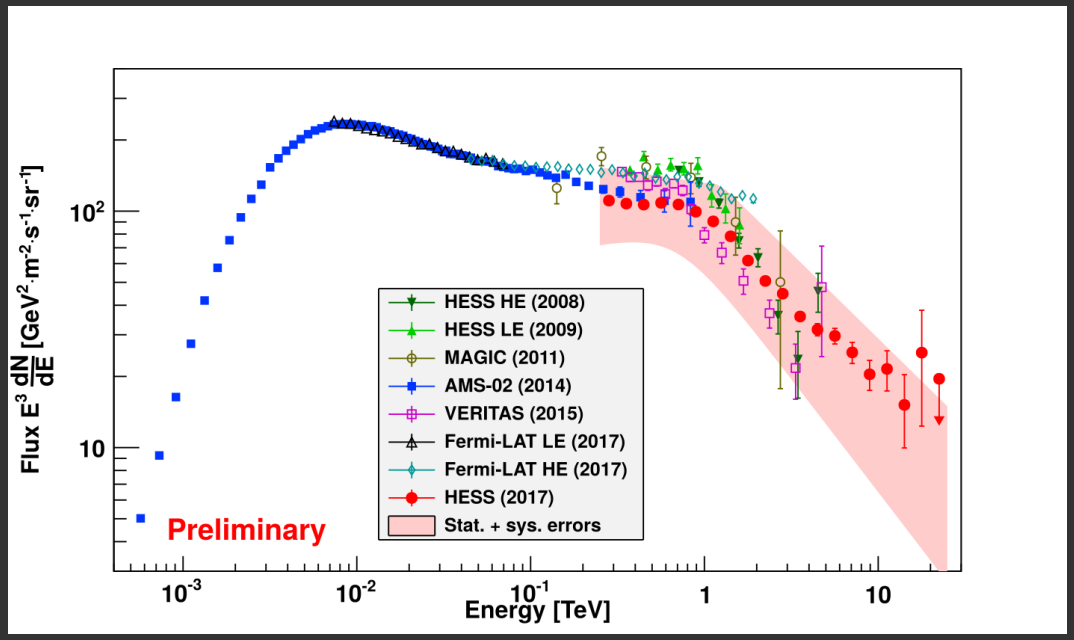
Electron Spectrum as seen by HESS

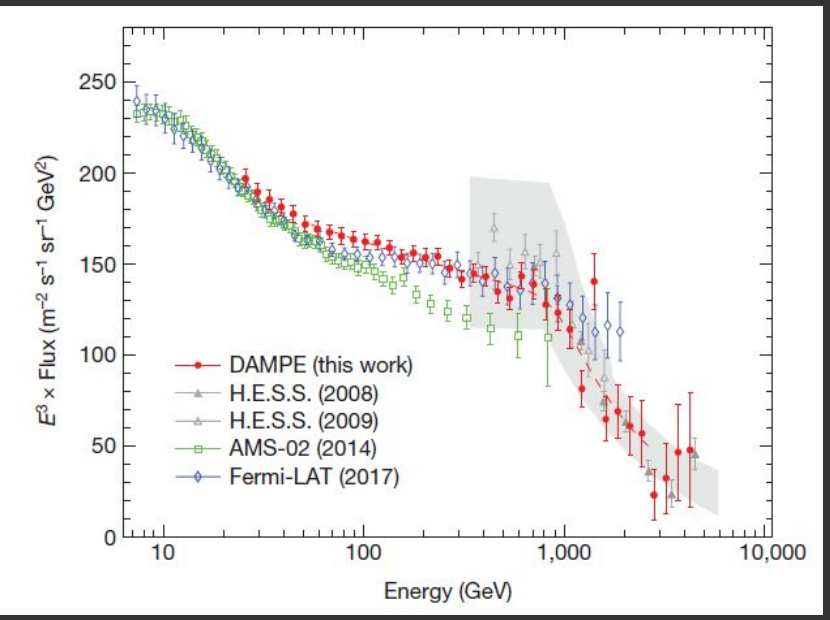
– HESS pushes electron spectrum up to ~20 TeV HESS (2017)

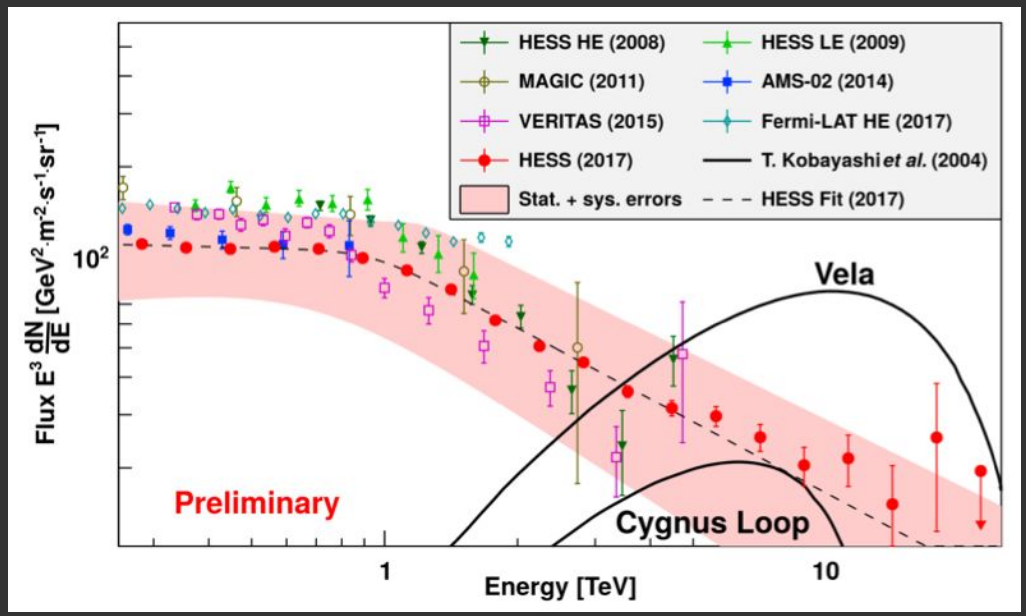
– Spectral break at ~1 TeV

– Spectral break also reveal by DAMPE (2017)

– Electron spectrum >1 TeV constrains local accelerators



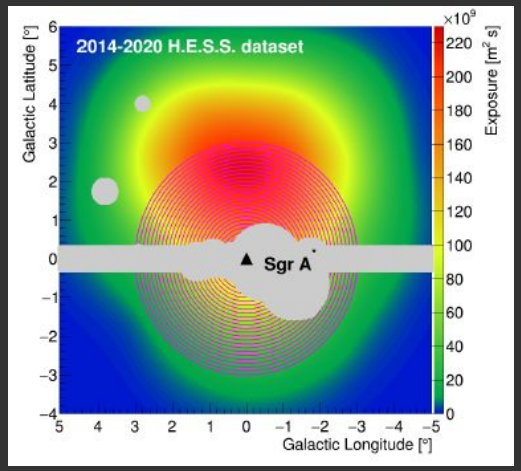


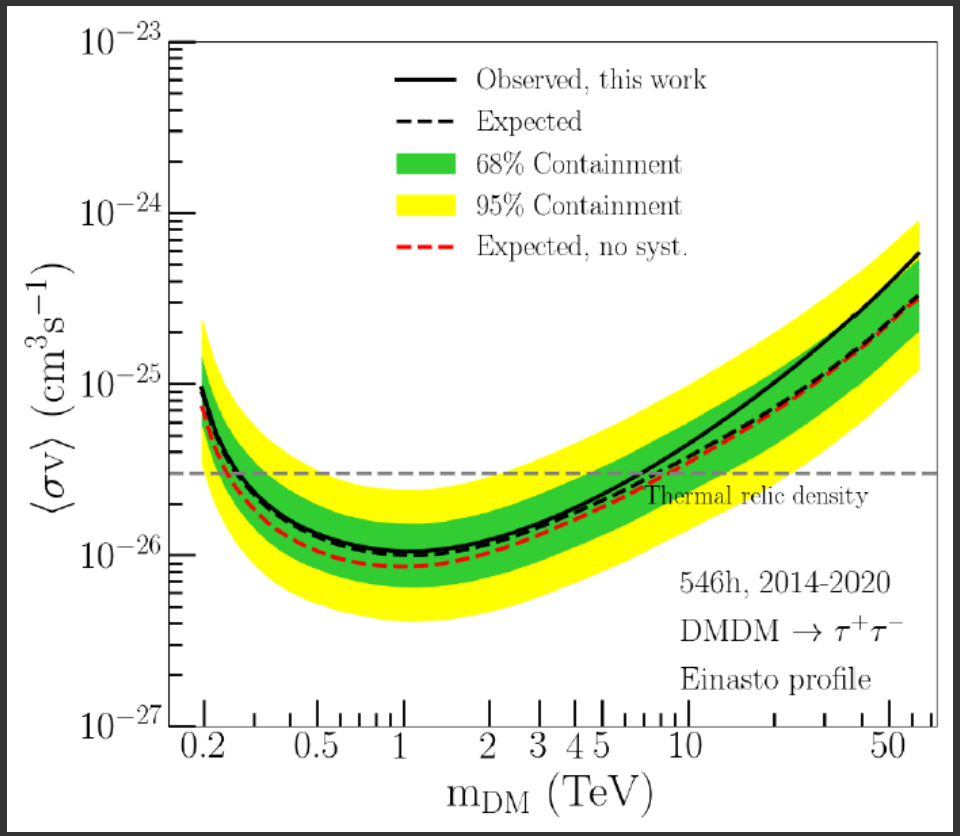


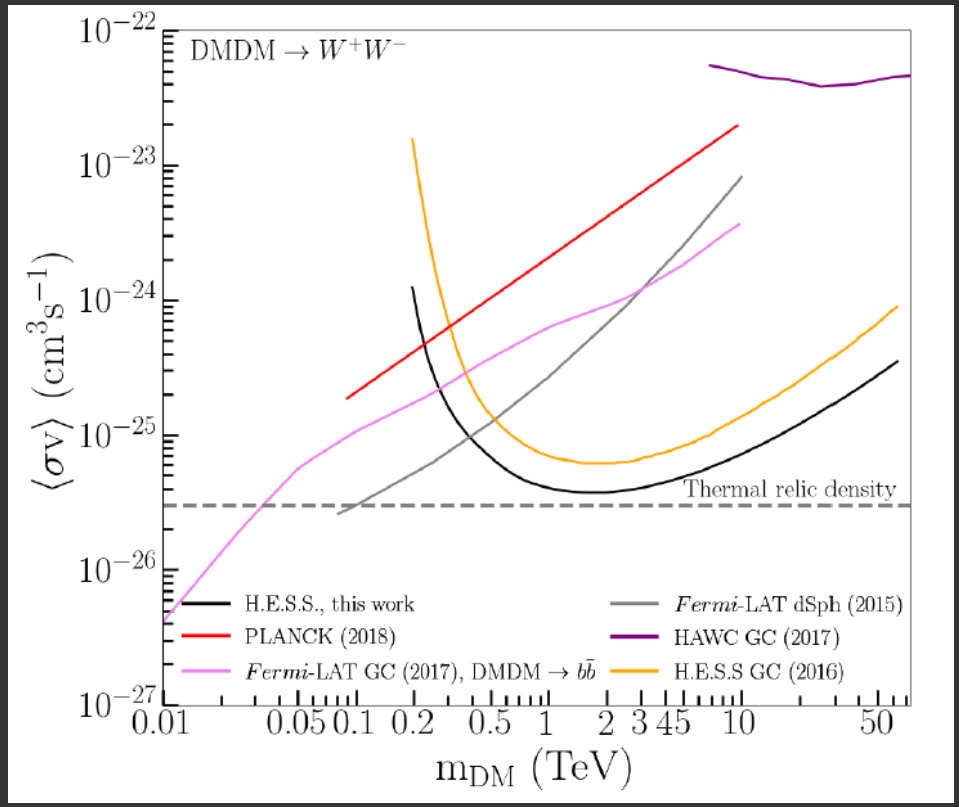
Dark Matter Search – Inner Galaxy Survey

HESS, PRL 129, 111101 (2022)

- 546 hr obs. of inner Galaxy region (2014 - 2020)
- Testing WIMP self-annihilation into quark, lepton, gauge boson and Higgs channels.
- Lowest constraints for $\tau^+\tau^-$
  → below thermal relic density
- All other channel v.close to thermal relic.
- HESS most sensitive constraints >0.5 TeV from gamma



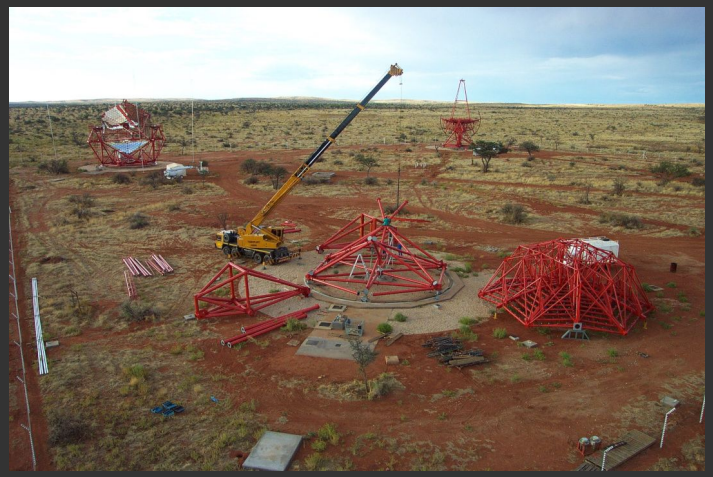




HESS 20th Anniversary Celebrations – Namibia, November 2022

<u>High-Impact Papers Since 2002</u>

9 – Science
6 – Nature
1 – Nature Astronomy
11 – Phys Rev Lett



Looking forward to HESS continuation well into the era of CTA

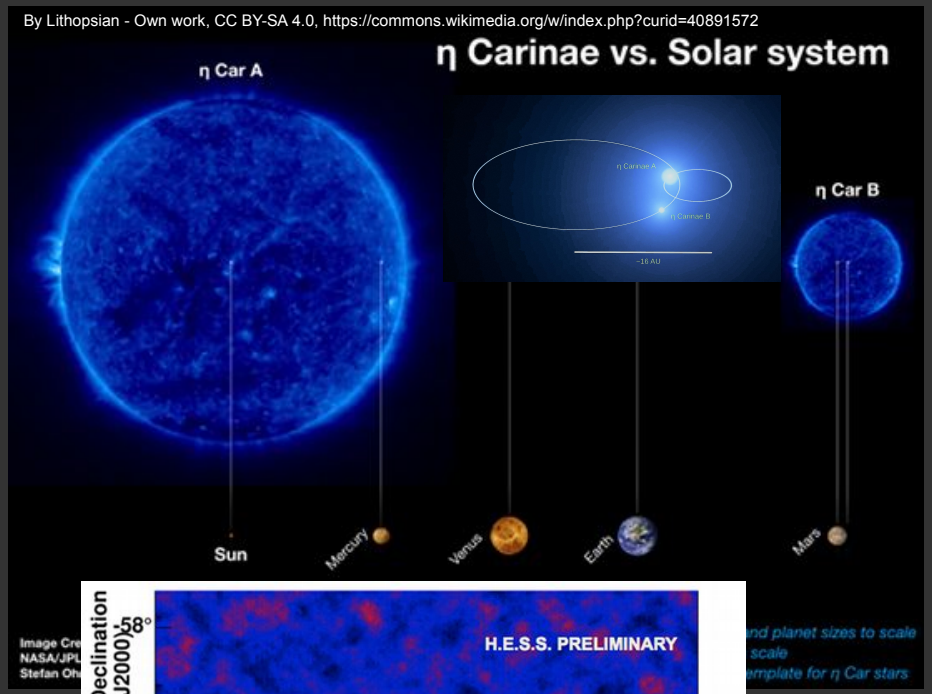
HESS publications:
https://www.mpi-hd.mpg.de/hfm/HESS/pages/publications/pubs_jour.shtml

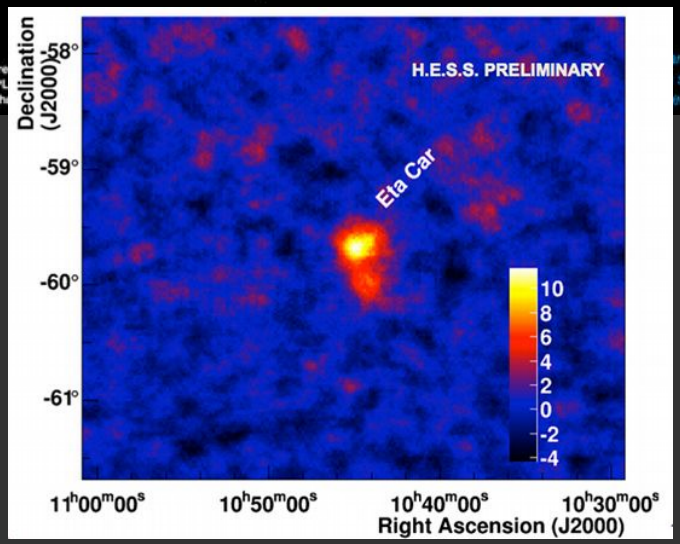
Backup….

Eta-Carina

HESS, A&A 635, A167 (2020)

- Colliding wind **stellar** binary system (LBV + O/B); 5.54 yr orbit
- TeV emission just prior and around periastron

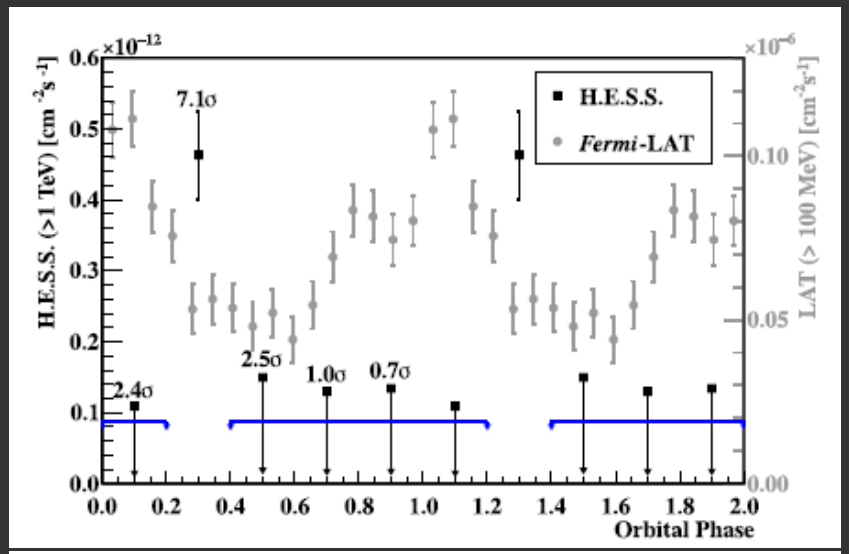


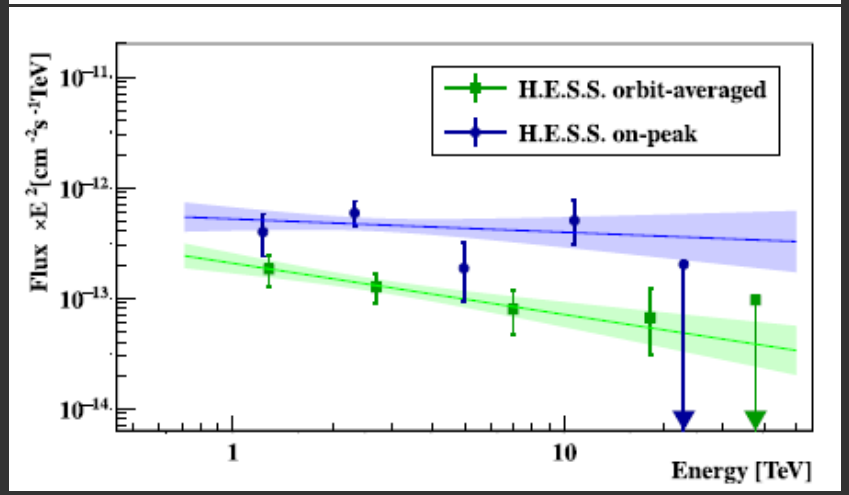


LMC P3

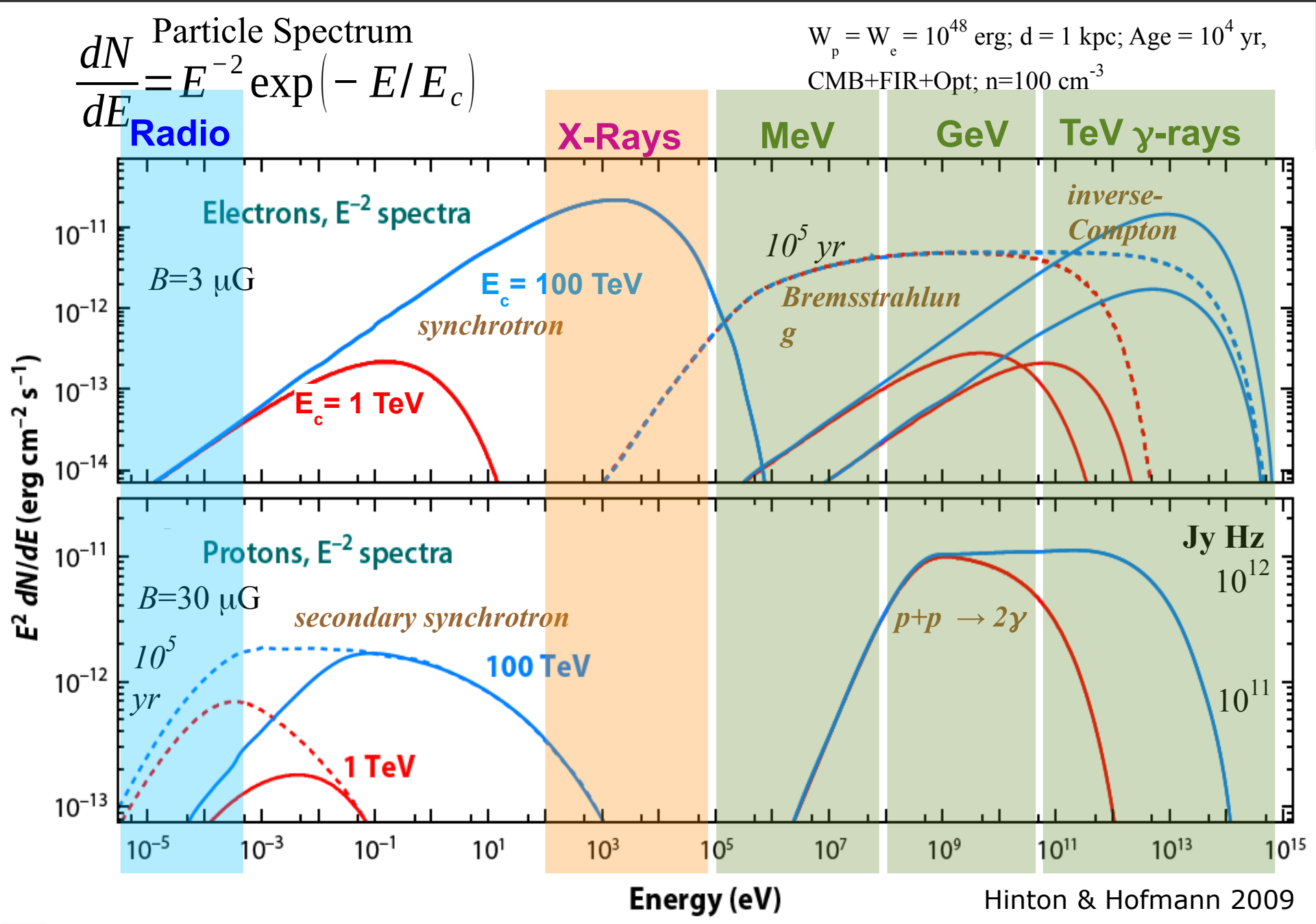
- O5 III and NS (BH also possible)
- Discovered by Fermi-LAT (GeV)
- TeV emission at phase ~ 0.3
- Most luminous gamma-ray binary.

HESS, A&A 610, L17 (2018)





Non-Thermal Photon Energy-fluxes (hypothetical particle accelerator)



Hinton & Hofmann 2009