Friedrich-Alexander-Universität
Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU

News from gamma rays

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Junior Research Group Leader,
FAU Erlangen-Nürnberg

HEAMM workshop, ECAP, 09.05.23

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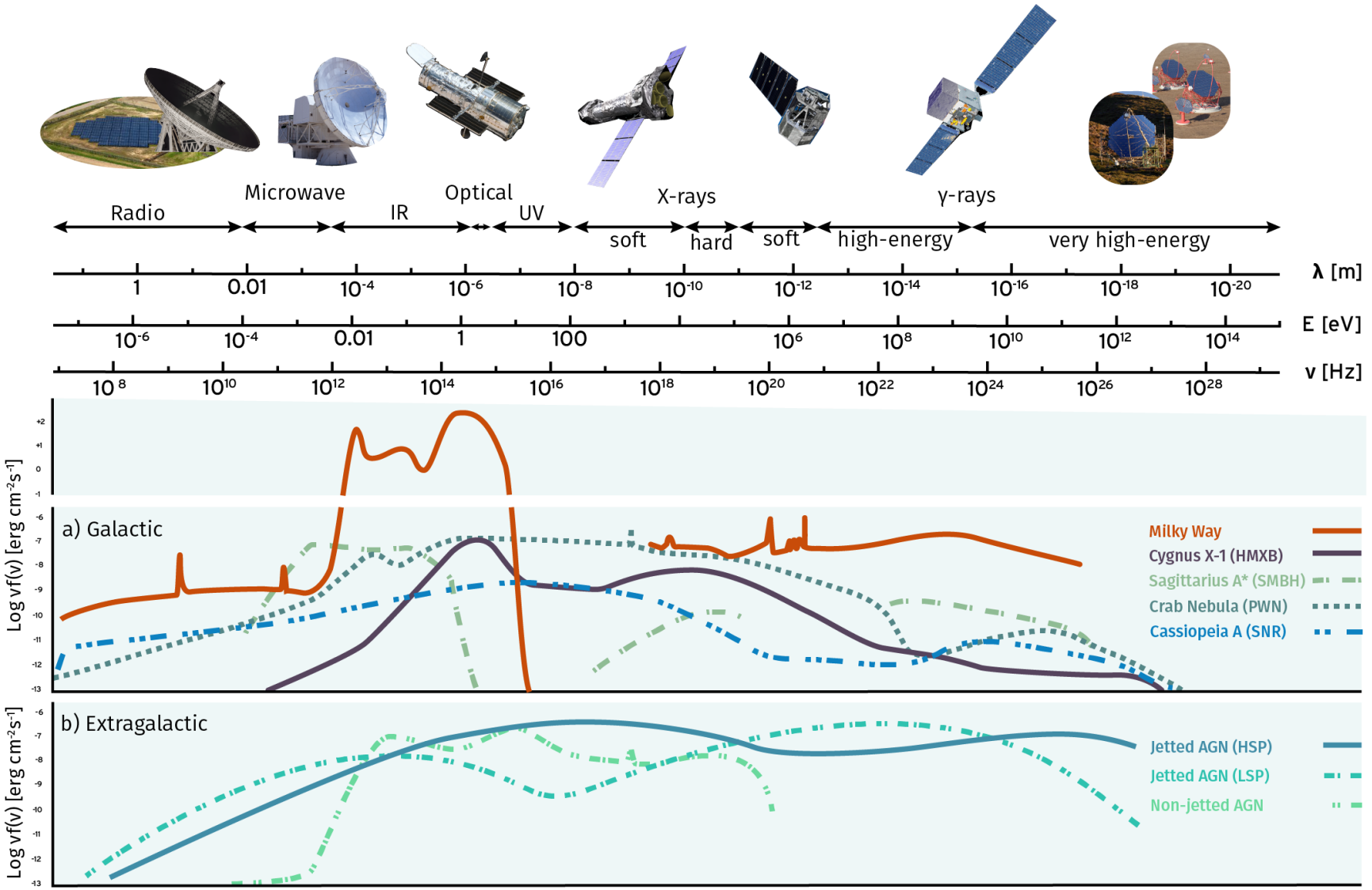
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

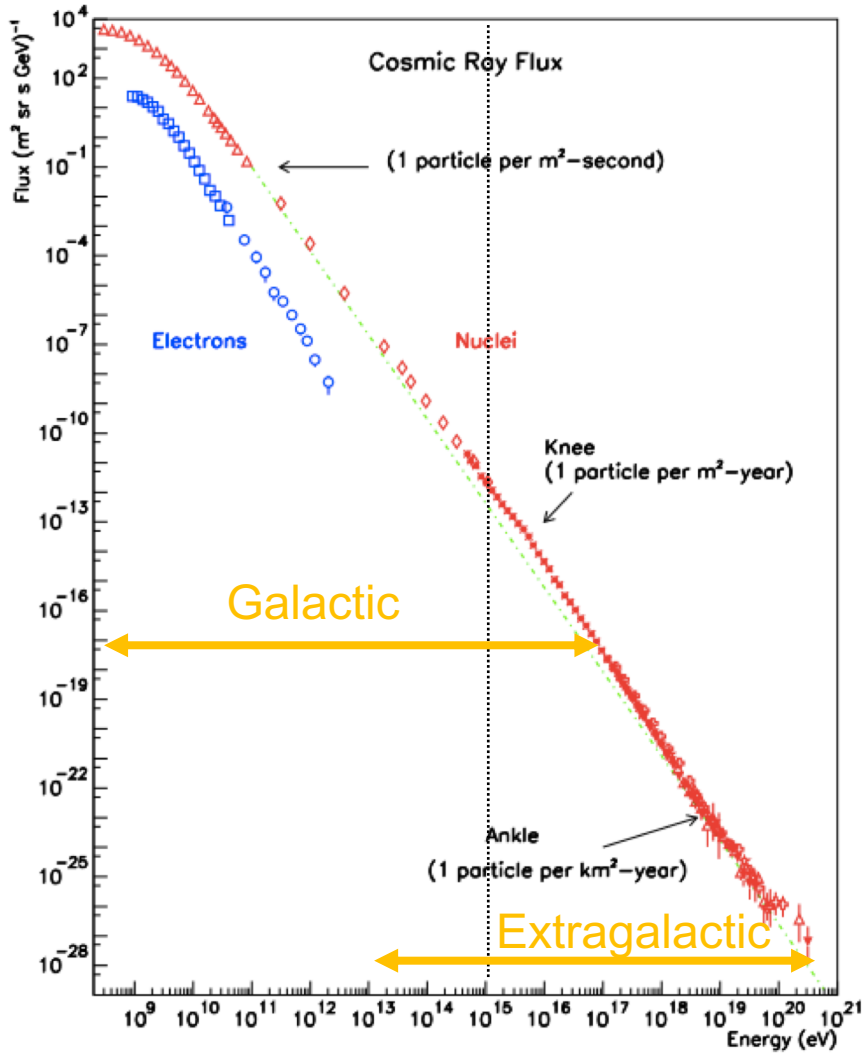
Gamma-ray Astronomy

The end of the electromagnetic spectrum

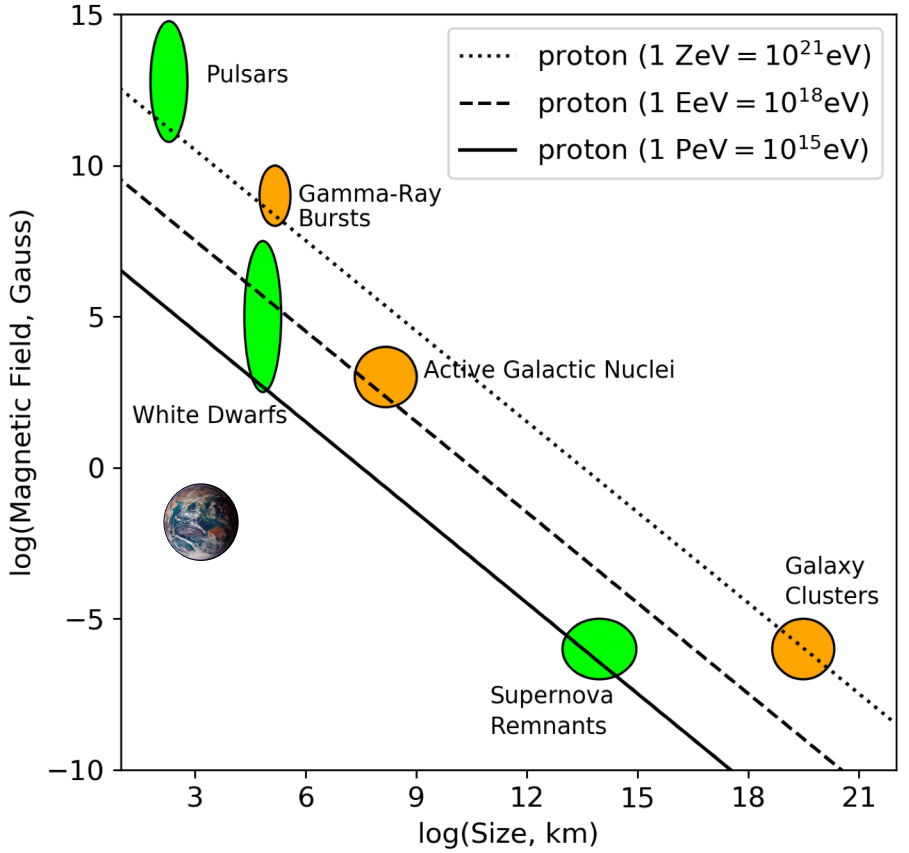


Credit: Annika Kreikenbohm, JMU Würzburg

The origin of Cosmic Rays?



- Cosmic Rays – highest energy particles in nature, up to 10^{20} eV
- "PeVatrons" = accelerators of particles to energies ≥ 10^{15} eV

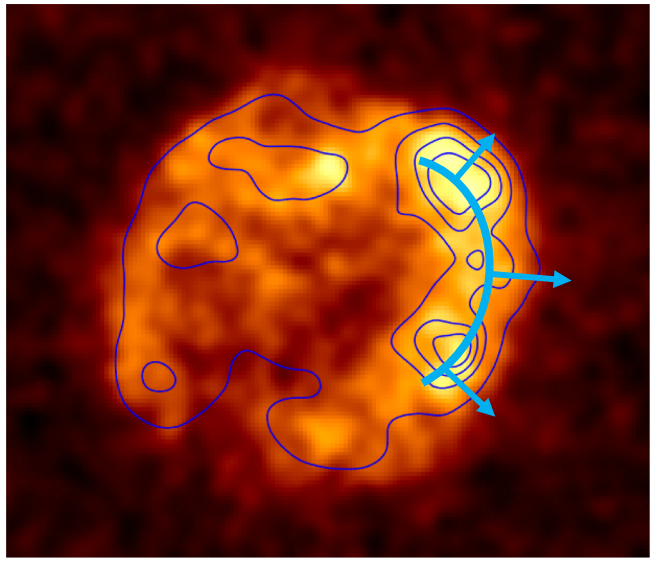


$$E_{\max} = Ze\beta cBL$$

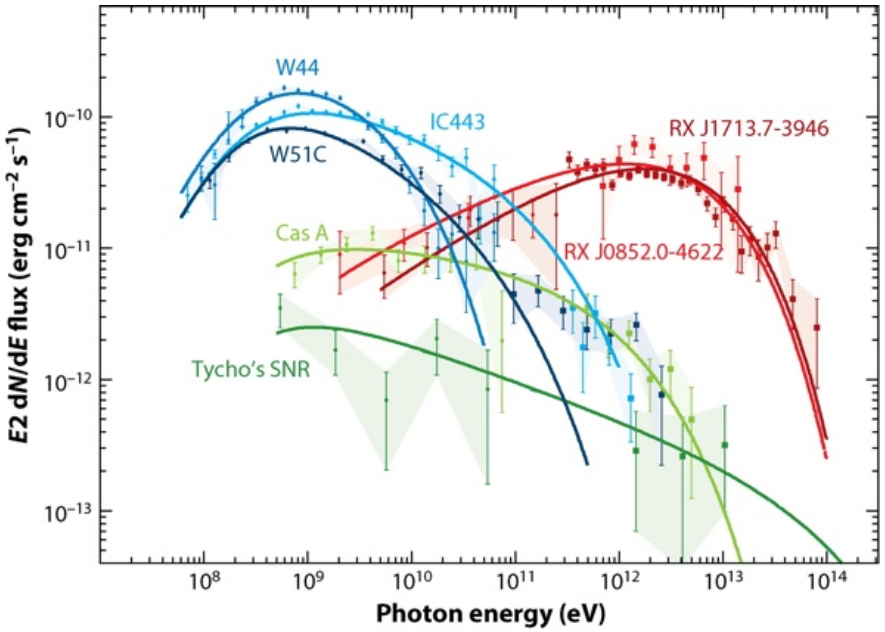
Supernova Remnants

– Acceleration at shock fronts of SNRs:
  – ~10^{51} erg per SN explosion
  – ~10% into proton / CR acceleration
  – ~ 3 events per century in Milky Way

→ Would be sufficient to power Cosmic Rays



- Cosmic rays: deflected by magnetic fields
- Interactions produce neutral messengers: gamma-rays & neutrinos point to source
- Motivation for gamma-ray astronomy
  → high energy particles



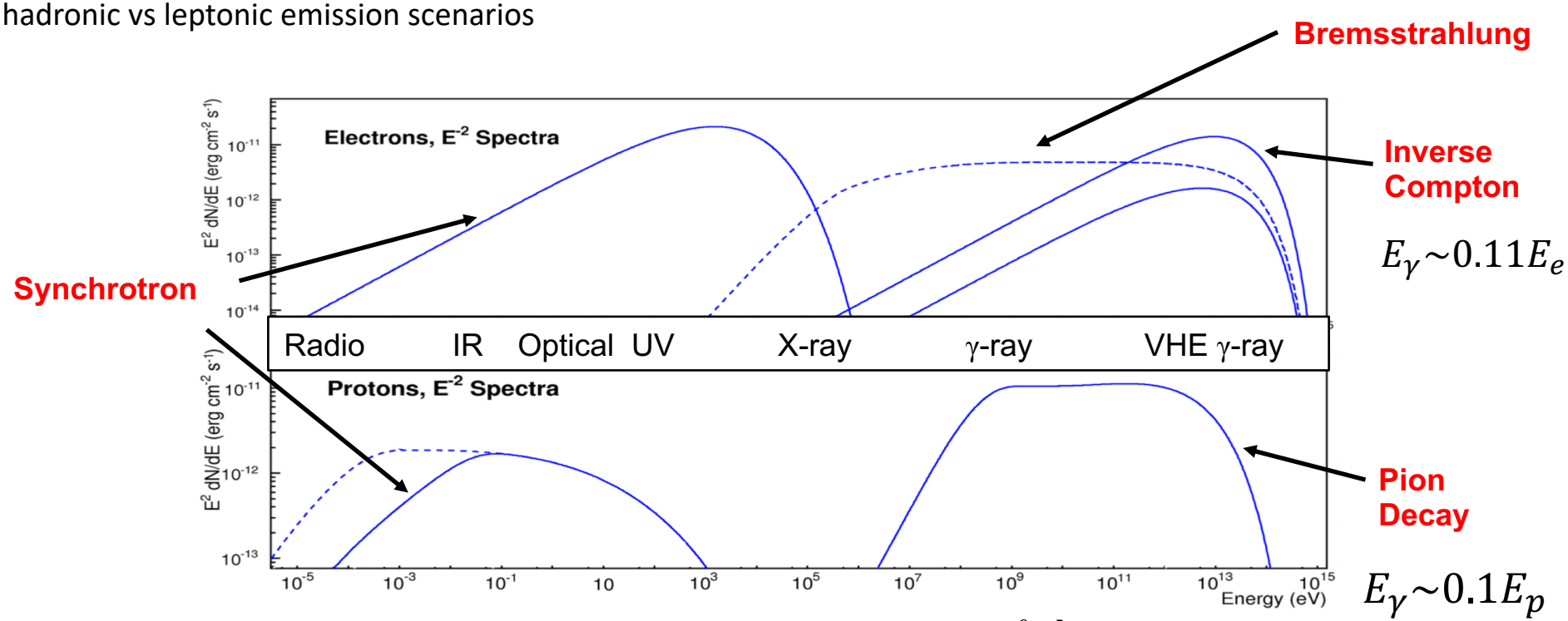
1 erg = 10^{-7} J = 0.62 TeV

Funk S. 2015.
Annu. Rev. Nucl. Part. Sci. 65:245–77

Gamma-ray emission mechanisms

Searching for the origins of hadronic cosmic rays

→ Constrain hadronic vs leptonic emission scenarios



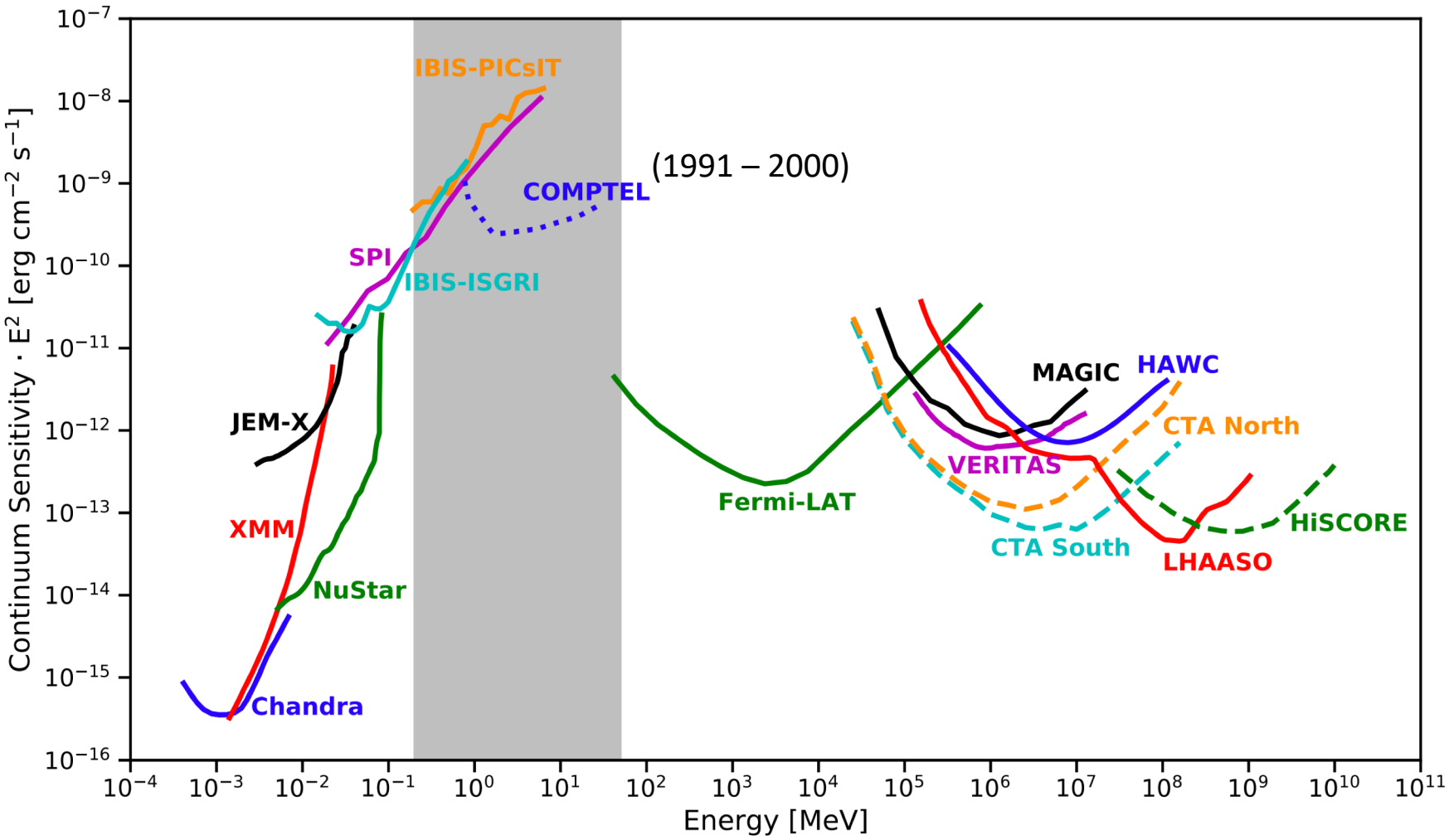
Target molecular material for hadronic interactions?

Coincident neutrinos as a smoking gun?

$\pi^+ \rightarrow \mu^+ + \nu_\mu$, $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

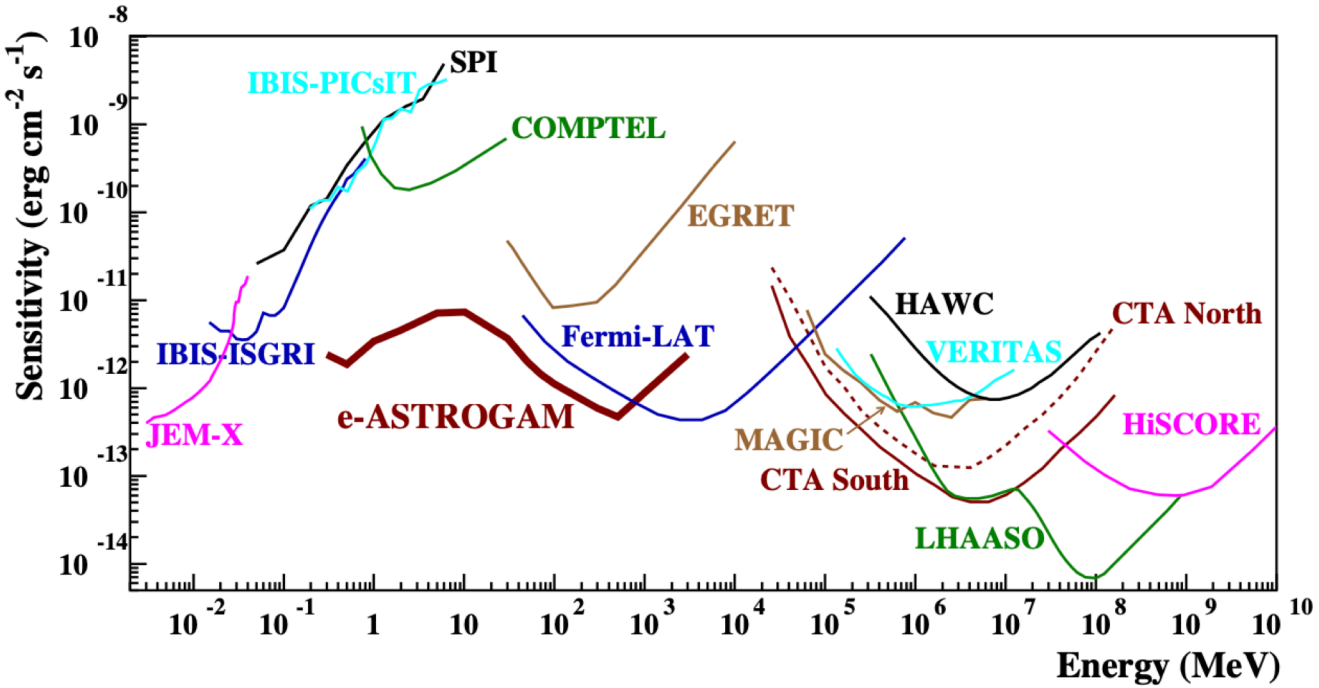
Gamma-ray Detection by Satellites

The MeV Gap

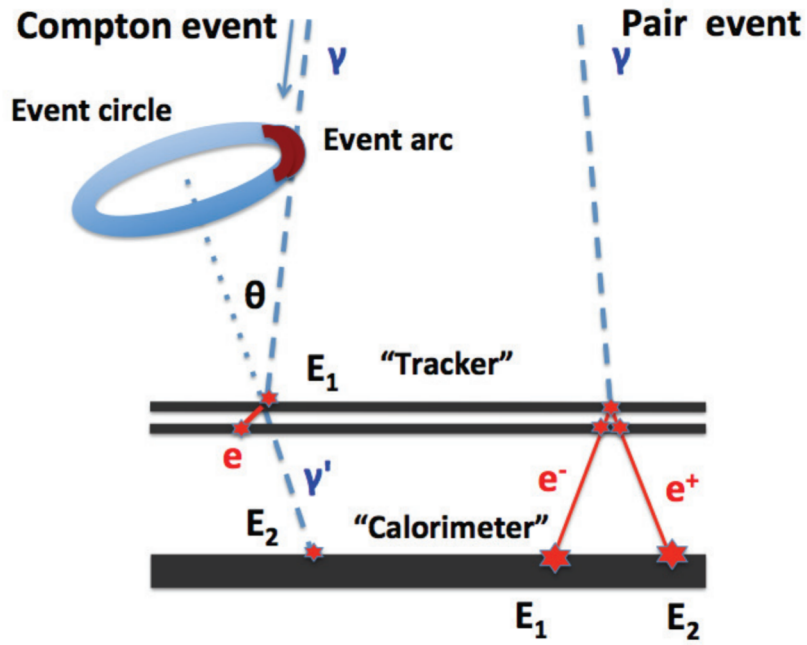


Lucchetta et al. JCAP08 (2022) 013

Gamma-ray Detection by Satellites



e-ASTROGAM collaboration, Exp. Astr. **44**, 25-82 (2017)



Moiseev et al., arXiv:1508.07349

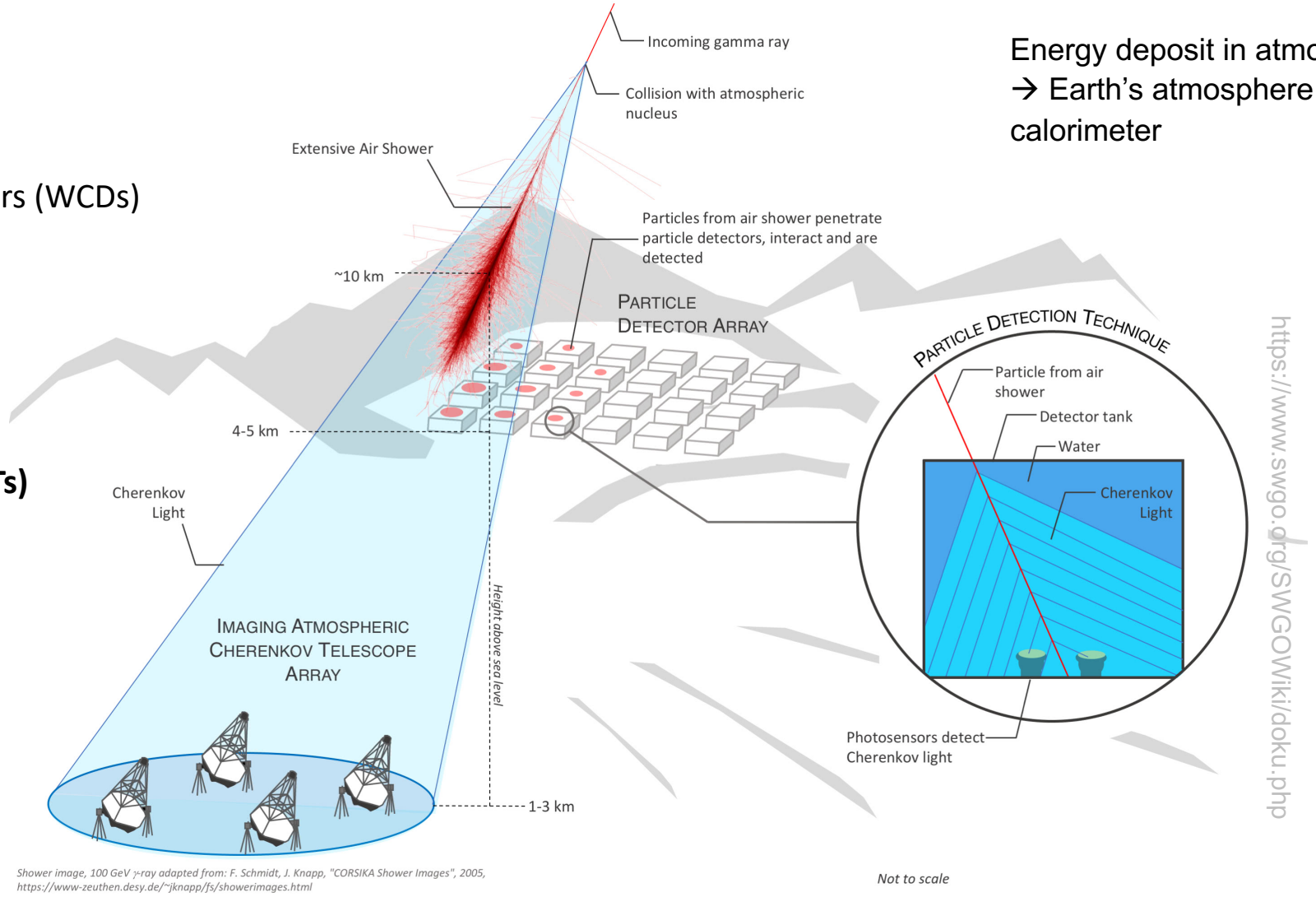
Compton scattering events

Pair-production events (Fermi-LAT = pair conversion detector)

Detection Techniques for Very-High-Energy gamma-rays

Two main detection methods:

- **Particle detector arrays:**
  - Water Cherenkov Detectors (WCDs)
  - Up to 24/7
- **Imaging Atmospheric Cherenkov Telescopes (IACTs)**
  - Night only, low moonlight



Energy deposit in atmosphere
→ Earth's atmosphere acts as a calorimeter

Imaging Atmospheric Cherenkov Technique

Extensive Air Shower detection

Key aspect: ability to distinguish gamma-ray initiated EAS from hadronic EAS background

Advances:

→ Hillas parameters

→ Boosted decision trees

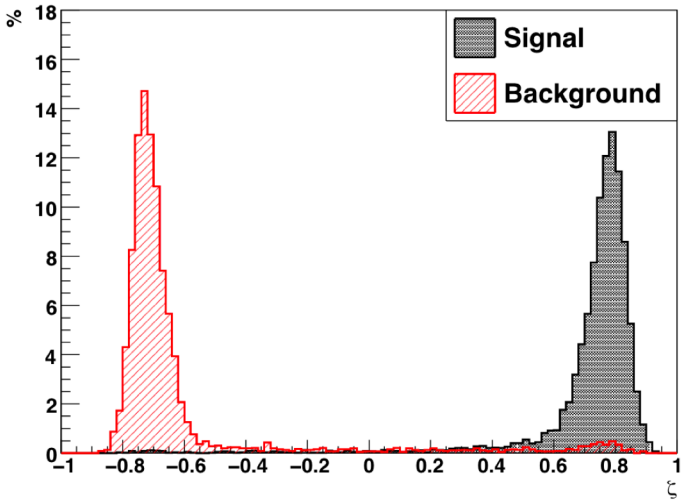
→ Deep learning approaches, muon tagging, event classes....

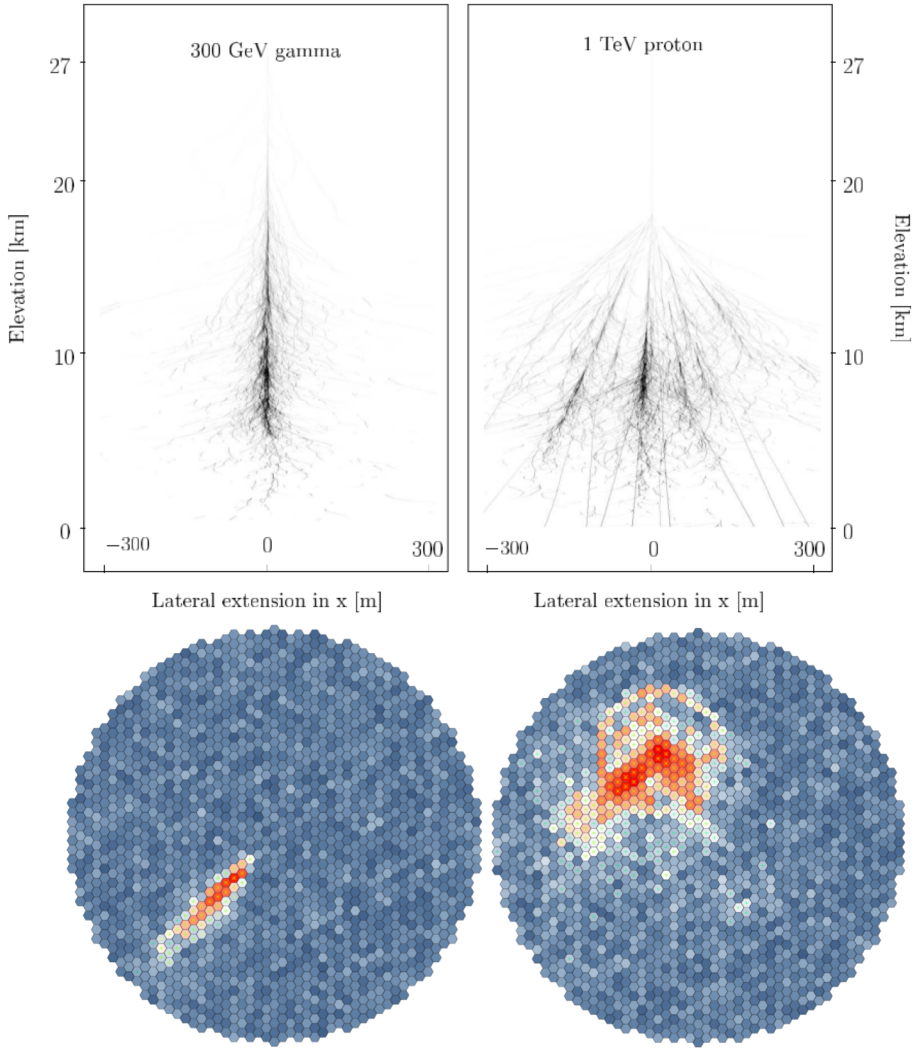
Limitations:

Neural network highly sensitive to environmental conditions
(e.g. NSB, atmosphere...)

→ computationally expensive re-training?

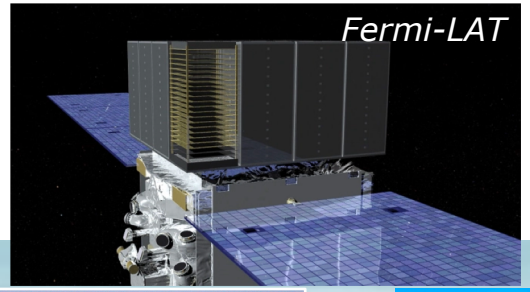
hadronic interaction model uncertainties

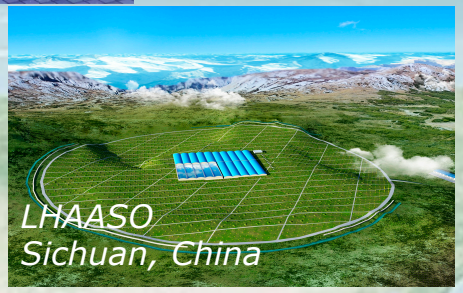




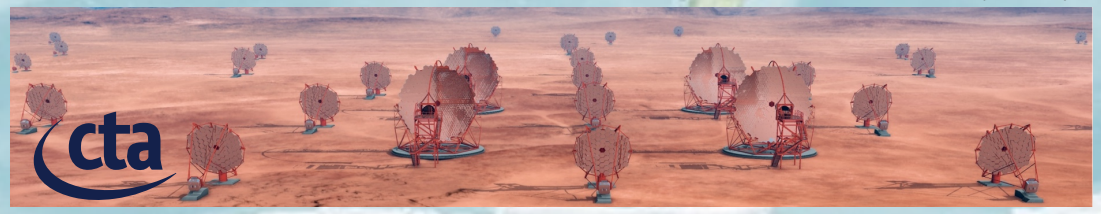
Ohm et al. Astropart. Phys. **31**, 383-391 (2009)

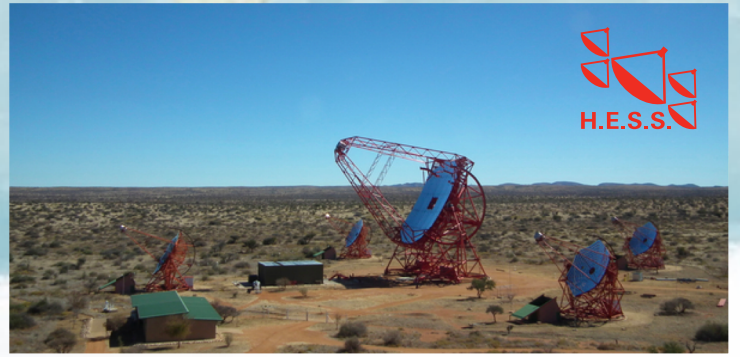
Complementary Facilities





SWGO
The Southern Wide-field Gamma-ray Observatory





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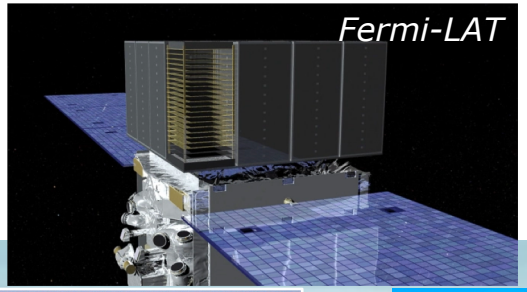
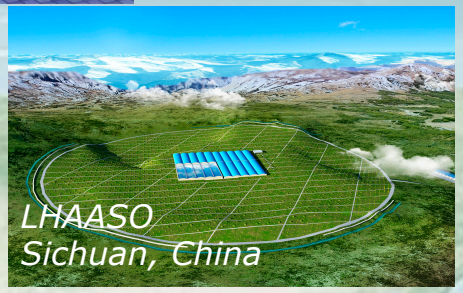




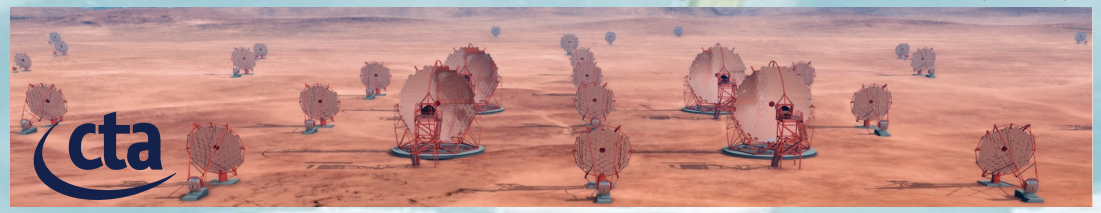
(HAWC)

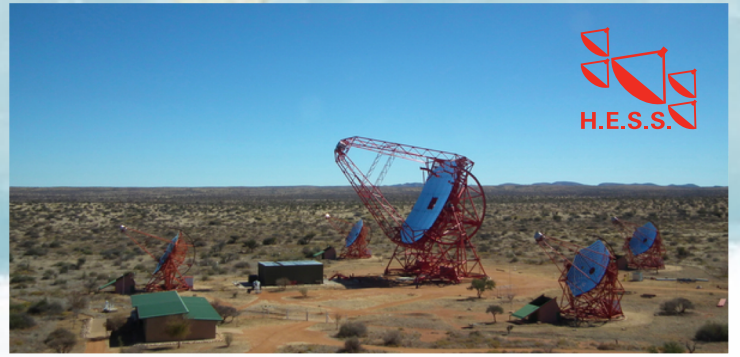
CTA-N

SWGO
CTA-S

H.E.S.S.

SWGO
The Southern Wide-field Gamma-ray Observatory

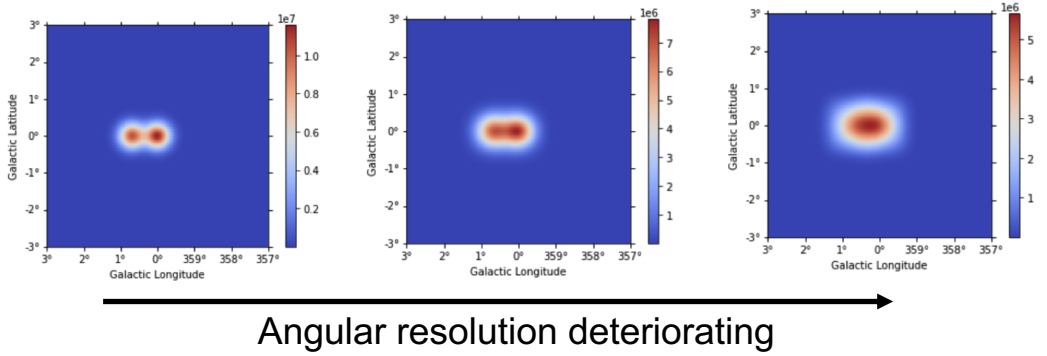


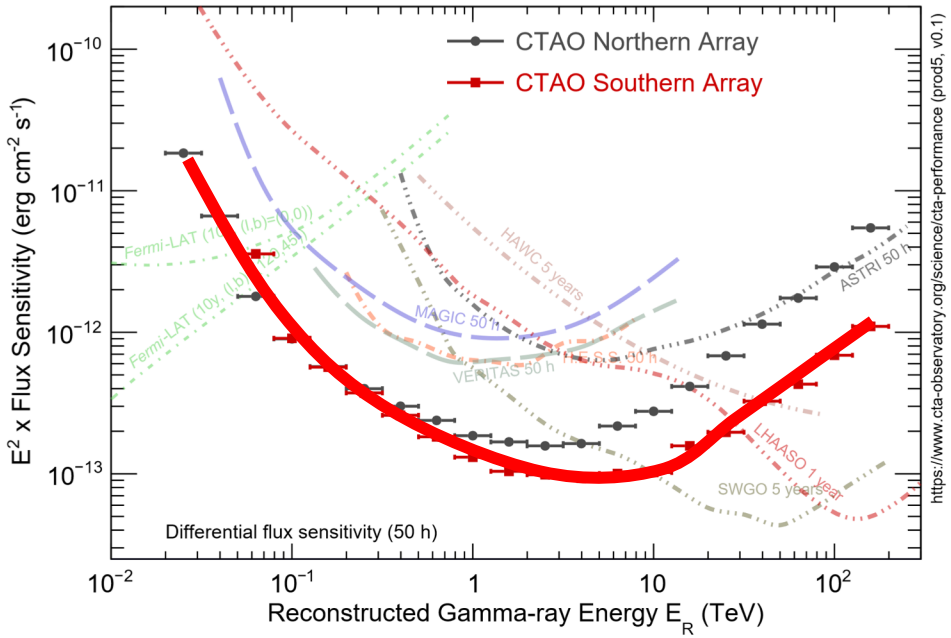


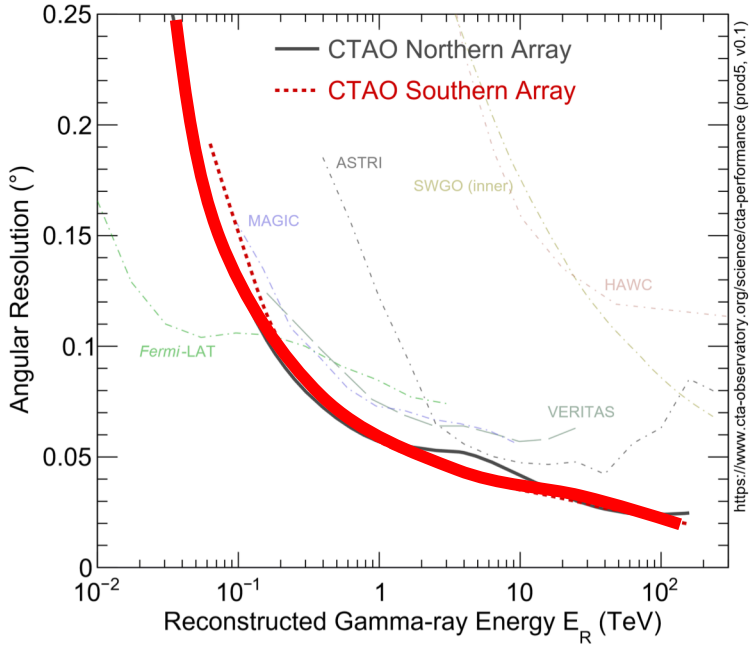
Complementary Facilities

Different techniques → different performance

IACTs







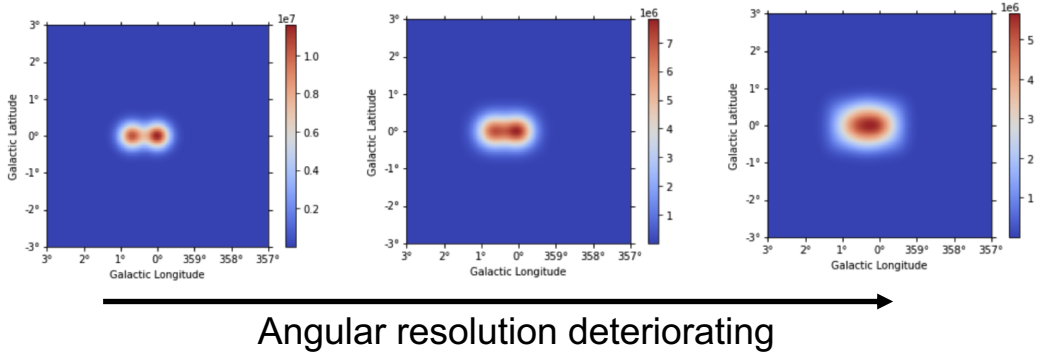
https://www.cta-observatory.org/science/ctao-performance/ , E. de Oña Wilhelmi+

Complementary Facilities

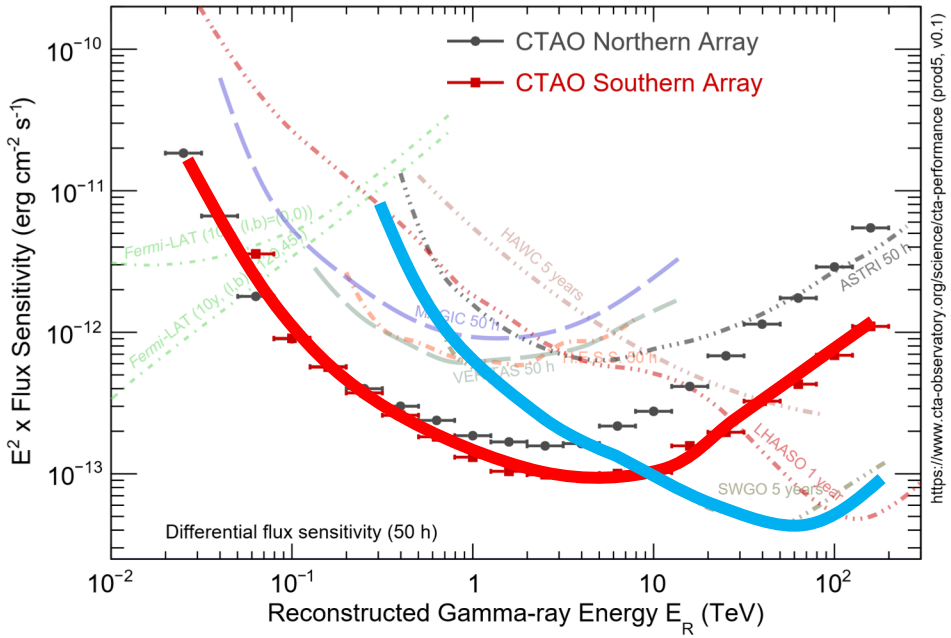
Different techniques → different performance

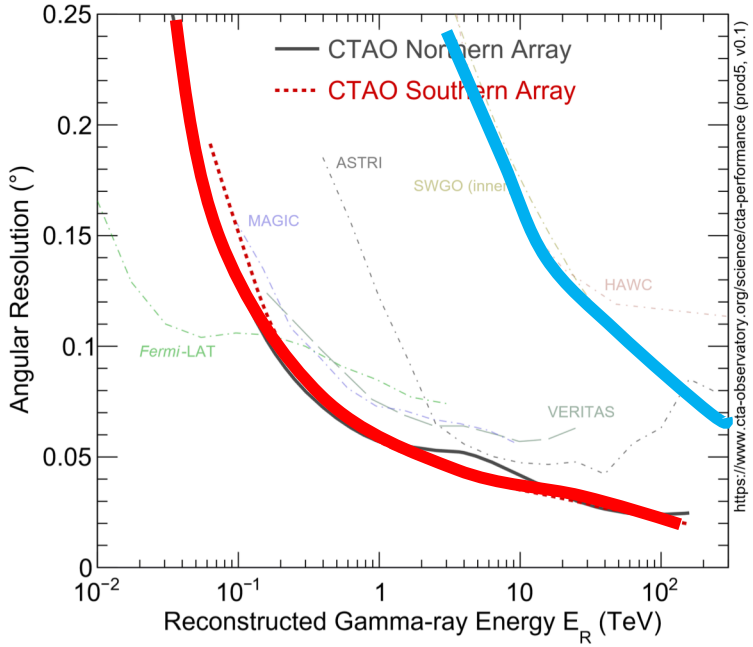
IACTs

WCDs



Angular resolution deteriorating





https://www.cta-observatory.org/science/ctao-performance/ , E. de Oña Wilhelmi+

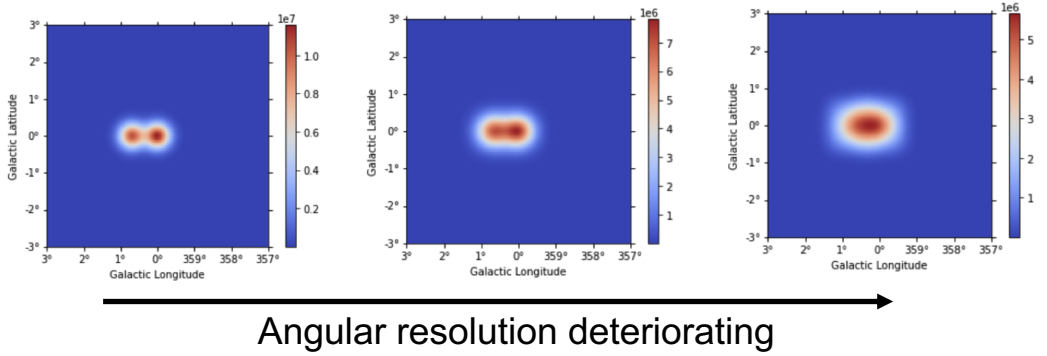
Complementary Facilities

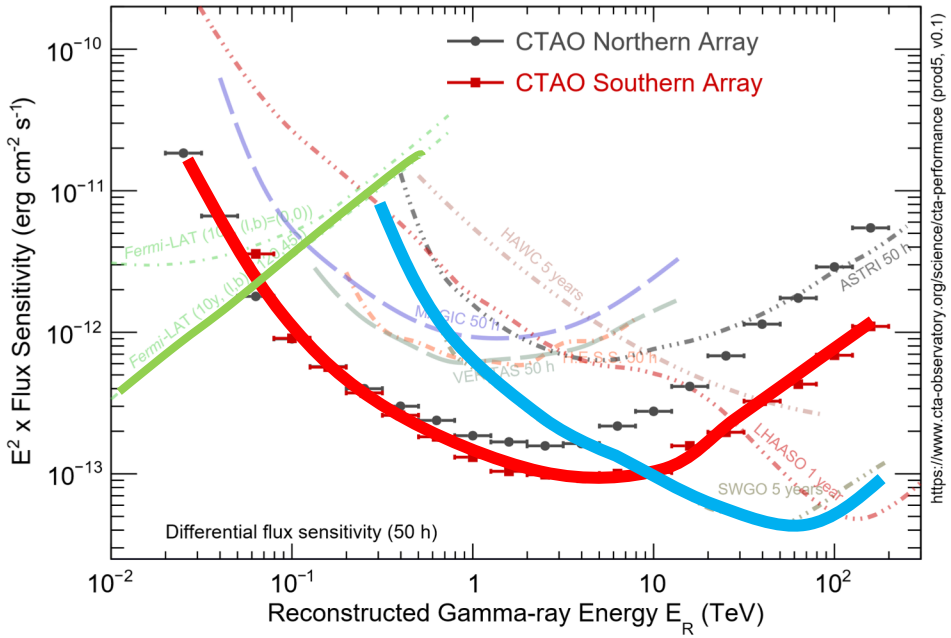
Different techniques → different performance

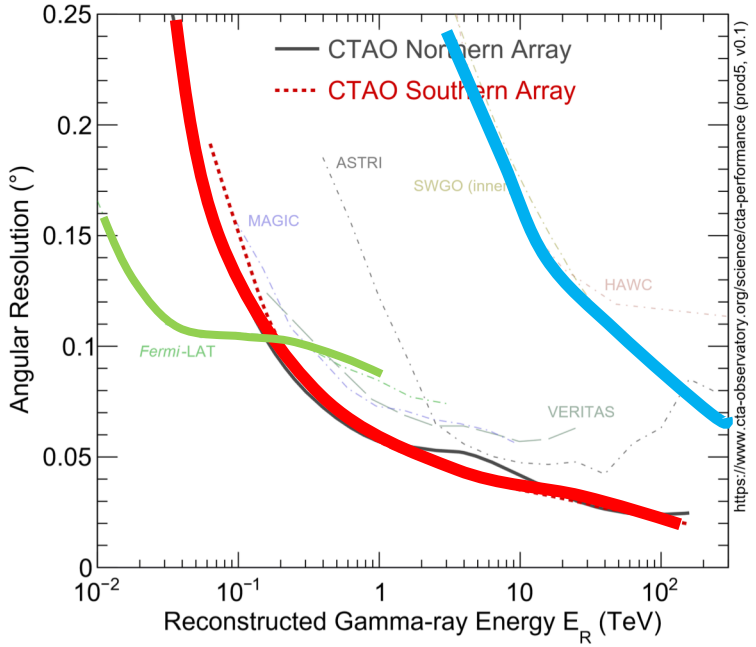
IACTs

WCDs

Satellite







https://www.cta-observatory.org/science/ctao-performance/ , E. de Oña Wilhelmi+

Complementary Facilities

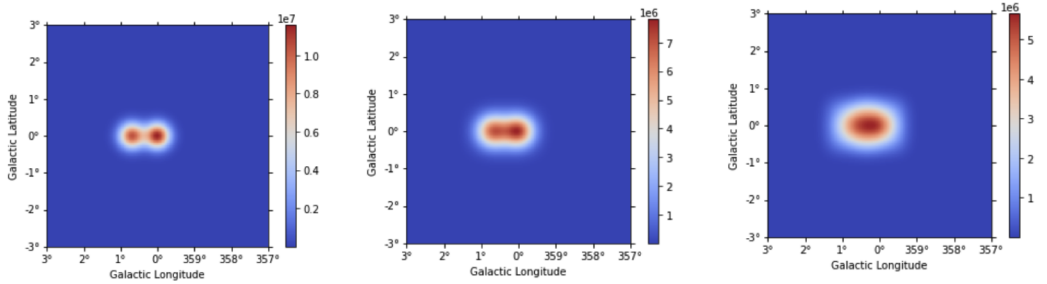
Different techniques → different performance

IACTs

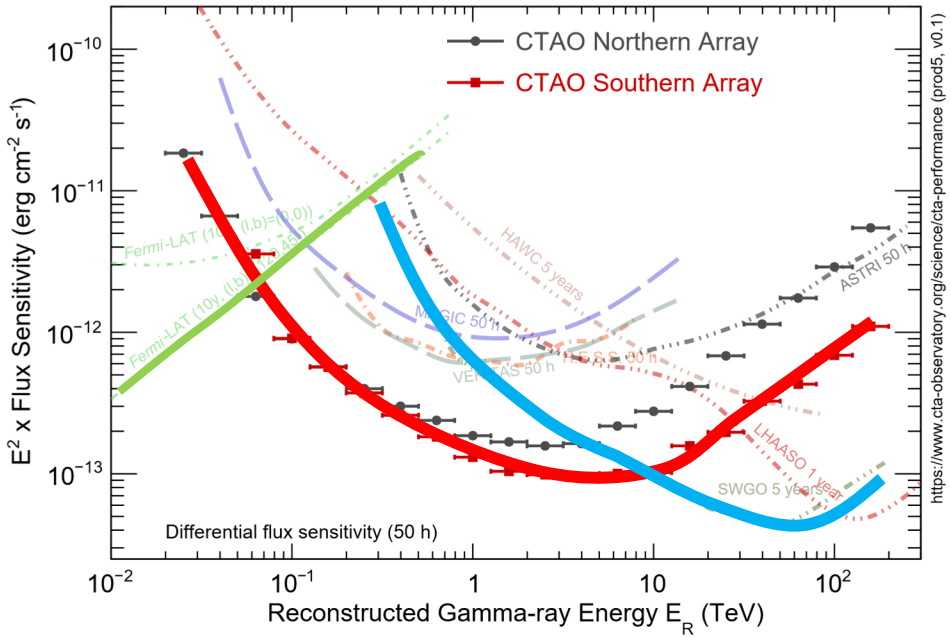
WCDs

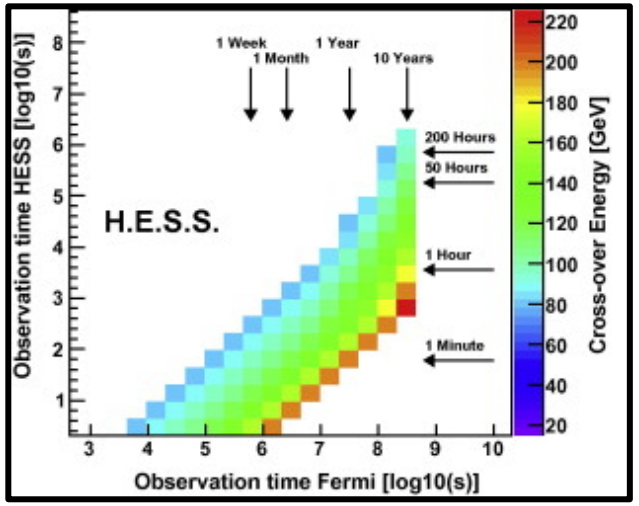
Satellite

Cross-over energy depends on exposure

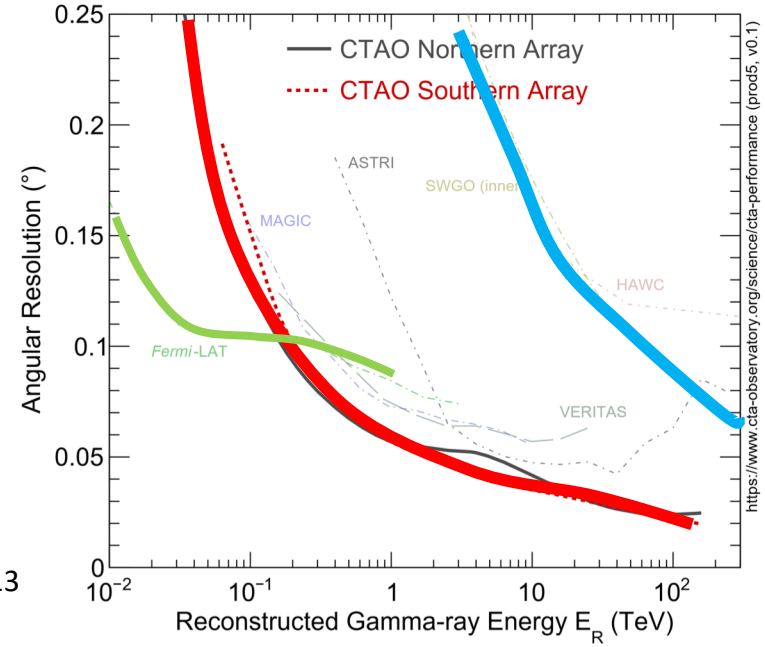


Angular resolution deteriorating



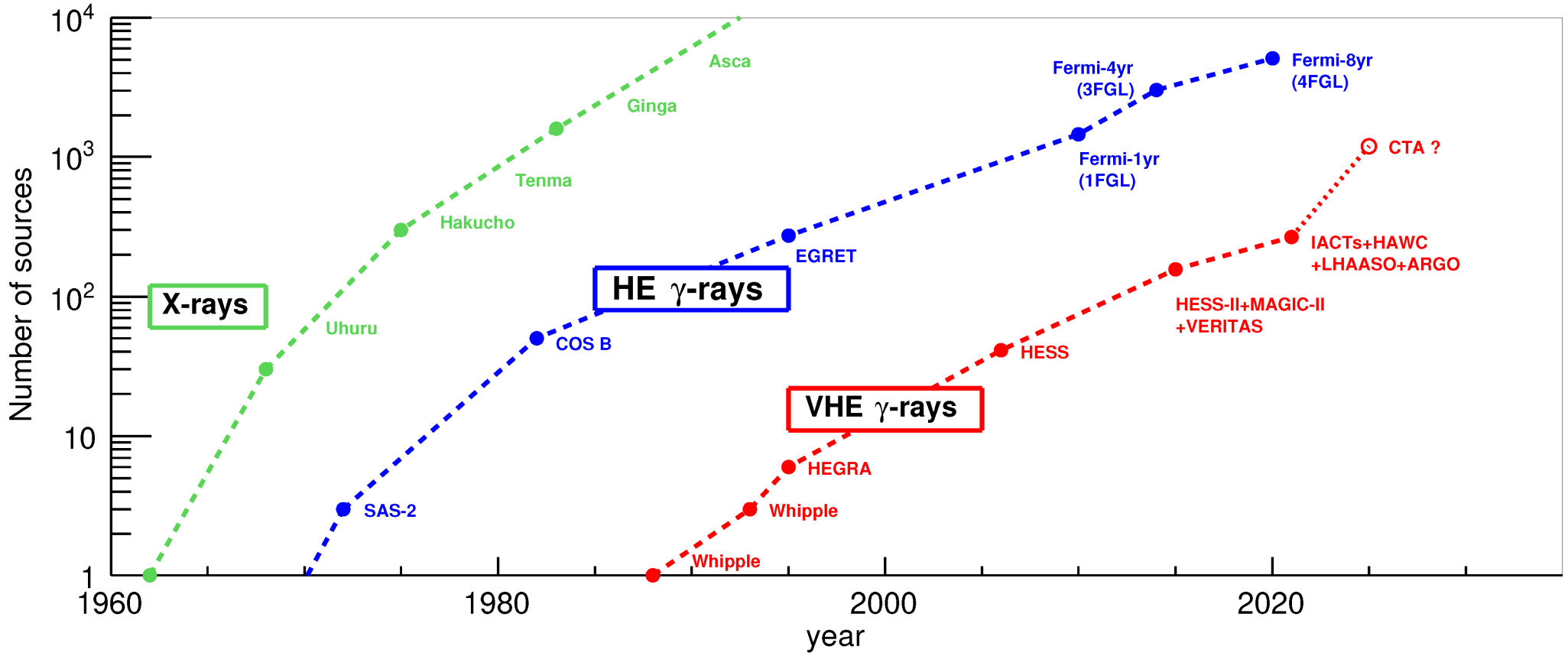


Funk & Hinton, Astropart Phys 43 (348-355), 2013



https://www.cta-observatory.org/science/ctao-performance/ , E. de Oña Wilhelmi+

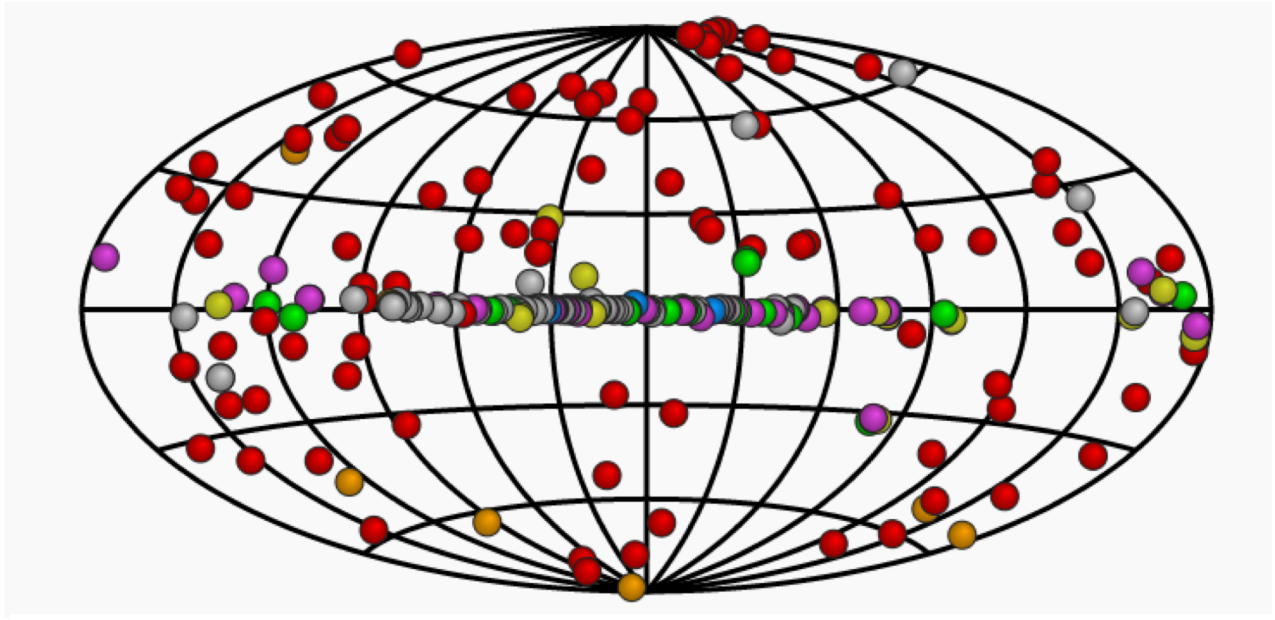
Development of VHE gamma-ray astronomy



de Naurois Universe **7** (2021) 421

Very High Energy Gamma-ray Sky

de Naurois Universe **7** (2021) 421
http://tevcat2.uchicago.edu/



GRB, Starburst, Superbubble

PWN, TeV halo, PWN/TeV Halo, Composite SNR, BIN

HBL, IBL, FSRQ, AGN (unknown type), FRI, Blazar, BL Lac (class unclear), LBL EHBL

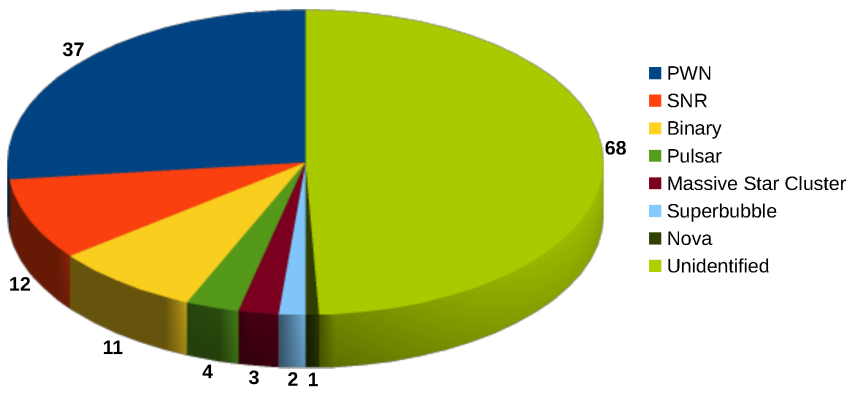
Shell, SNR/Molec. Cloud, Giant Molecular Cloud, Composite SNR

UNID, TeV halo, DARK

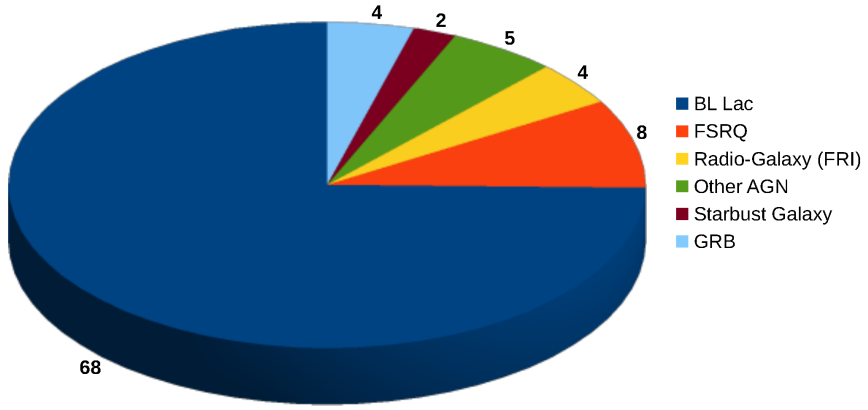
Binary, PSR, Gamma BIN, Nova

Massive Star Cluster, Globular Cluster

Galactic Sources

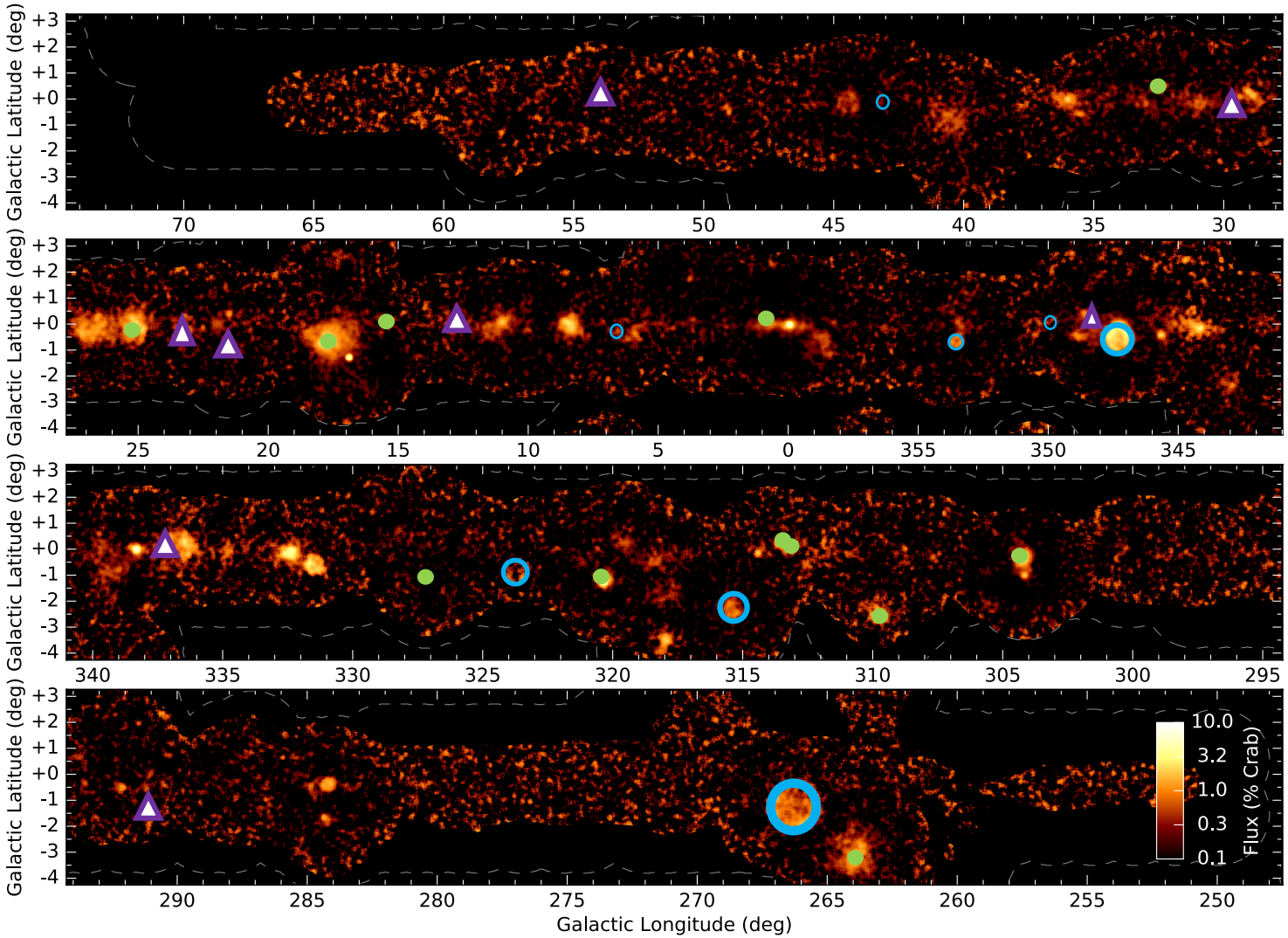


Extragalactic Sources



Very High Energy Gamma-ray Sky

H.E.S.S. Galactic Plane Survey

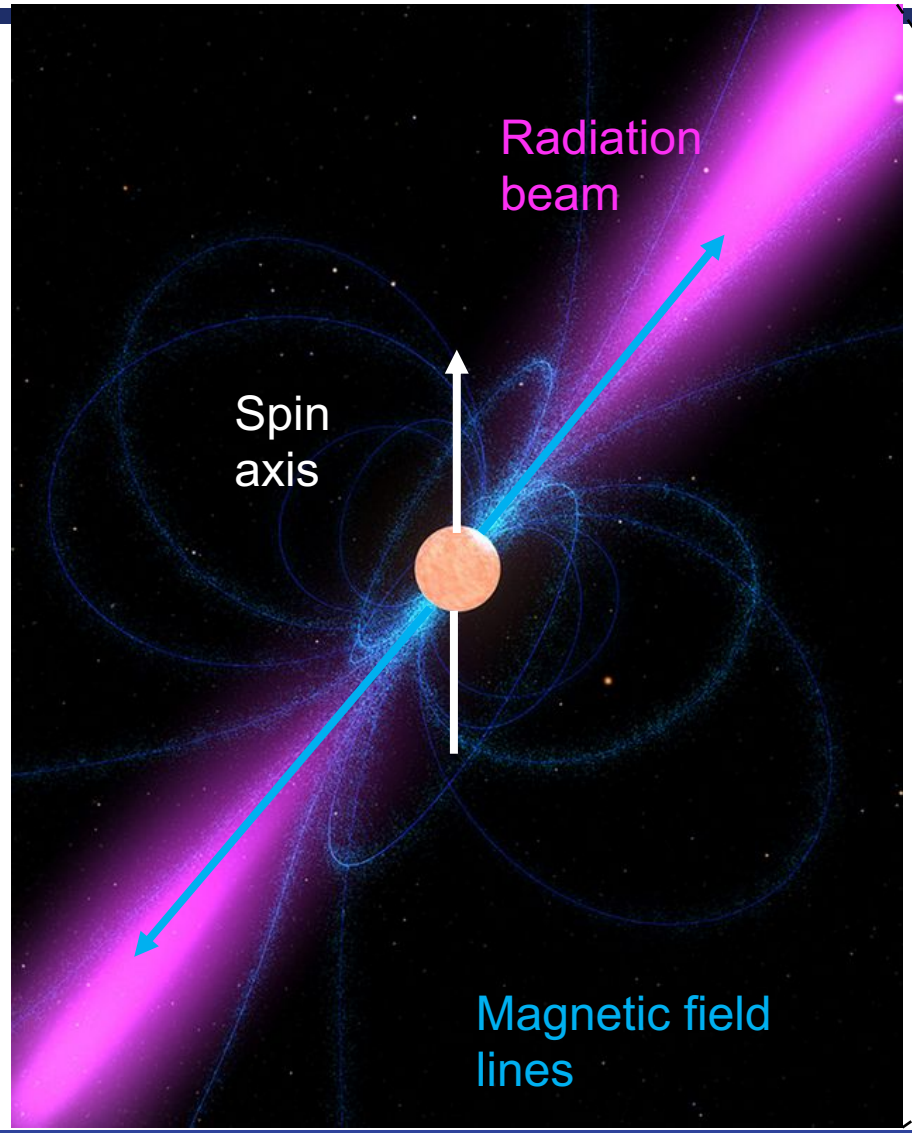


SNRs

PWNe

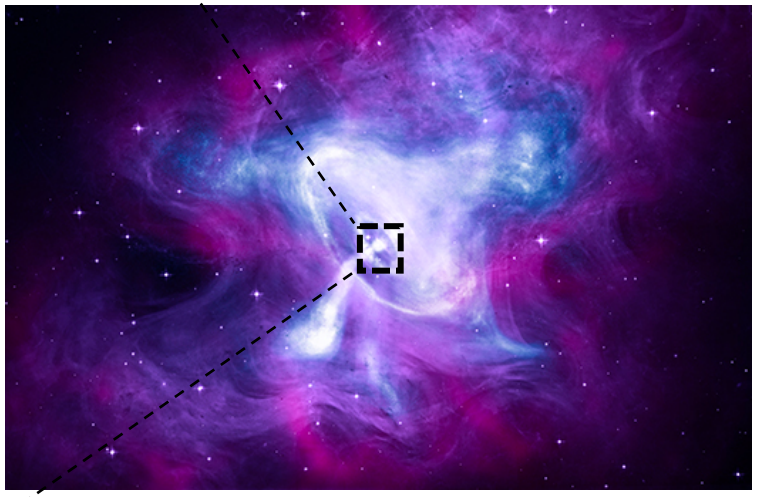
composite

What are Pulsars?



Pulsar: Rotating neutron star

Very rapid rotation, very strong and variable B field $\sim 10^{11} - 10^{14}$ Gauss



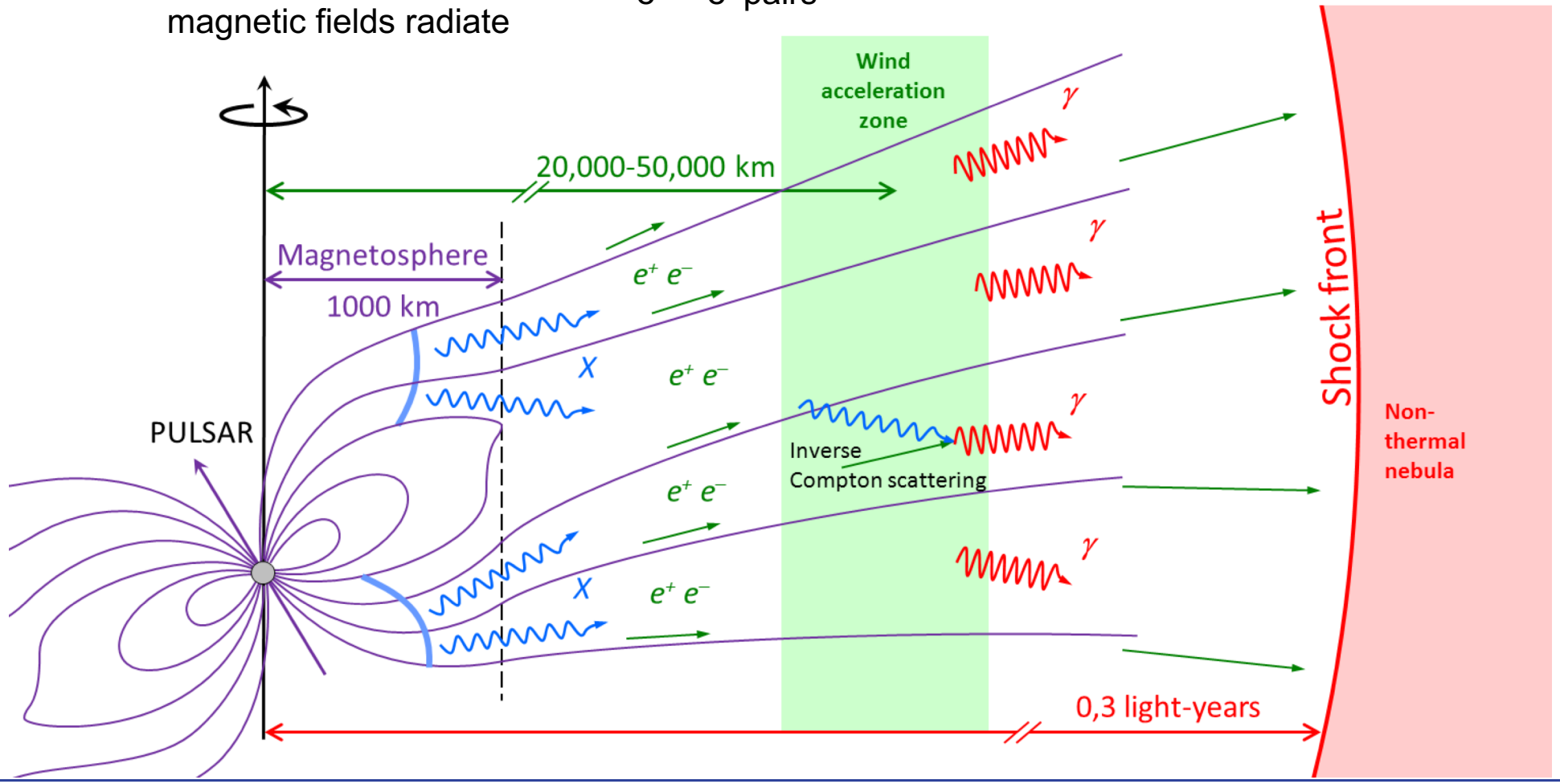
Crab pulsar: X-ray, infrared & optical
Credit: NASA/CXC/SAO/STScI

Pulsar – Pulsar Wind – Pulsar Wind Nebula

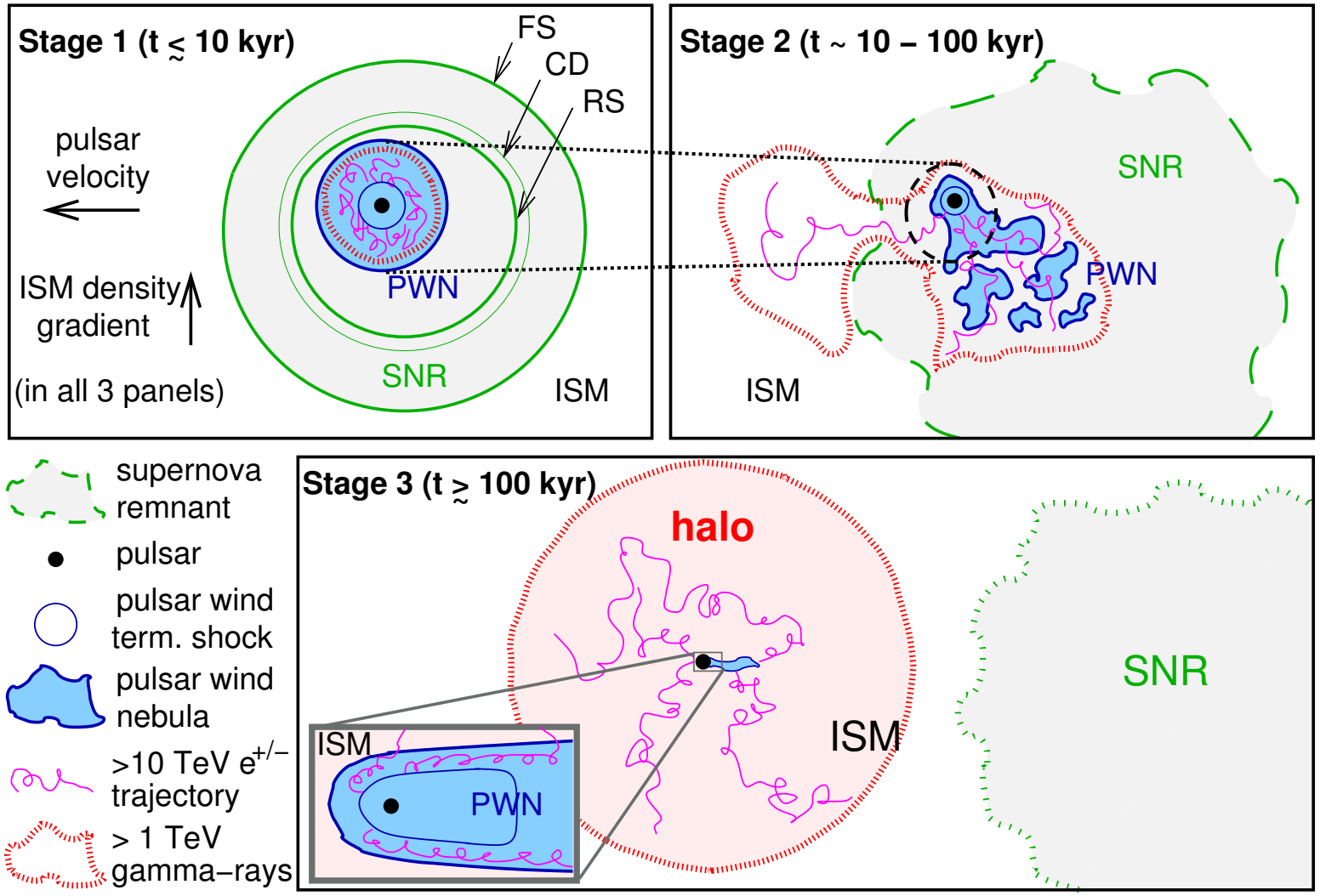
→ Charged particles accelerated in magnetic fields radiate

→ Radiation produces $e^+ – e^-$ pairs

Nebula of high energy particles → Mainly $e^{\pm}$



Evolutionary stages of pulsar environments

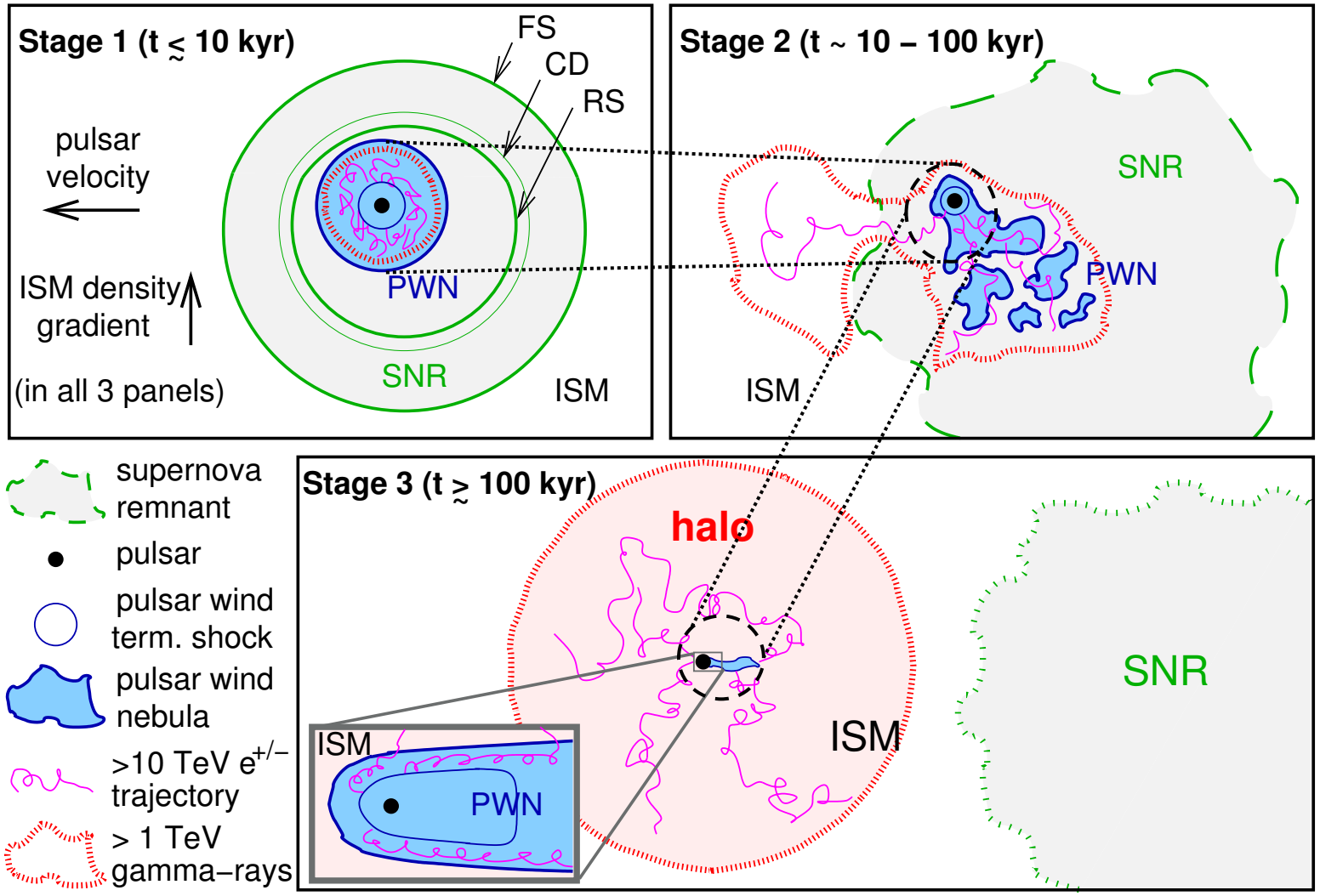


Pulsar Wind Nebulae (PWN)

1 pc = 3.26 ly

Giacinti, AM, Lopez-Coto et al, A&A **636**, A113 (2020)

Evolutionary stages of pulsar environments



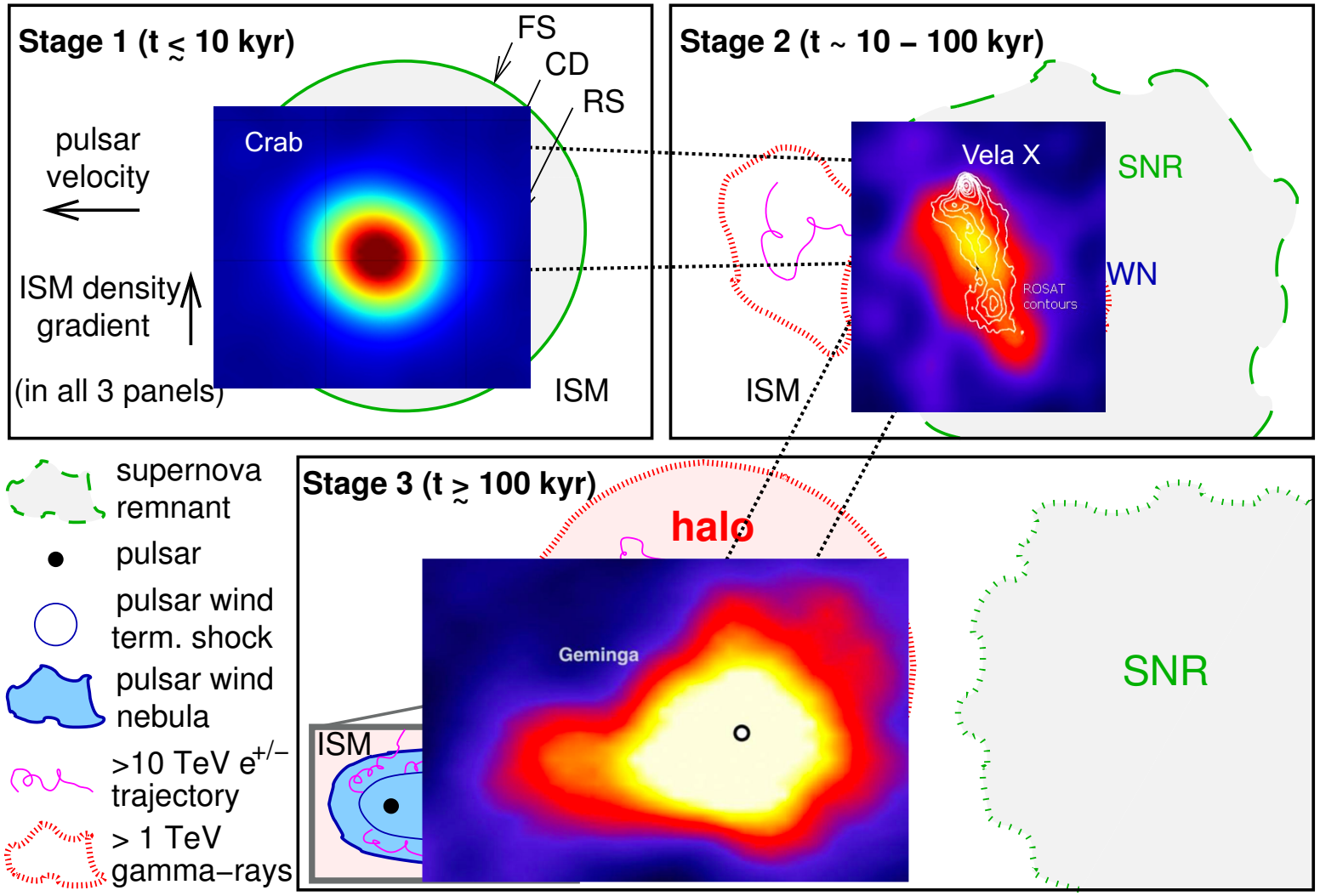
Pulsar Wind Nebulae (PWN)

→ Pulsar Halos

1 pc = 3.26 ly

Giacinti, AM, Lopez-Coto et al, A&A **636**, A113 (2020)

Evolutionary stages of pulsar environments



Pulsar Wind Nebulae (PWN)

→ Pulsar Halos

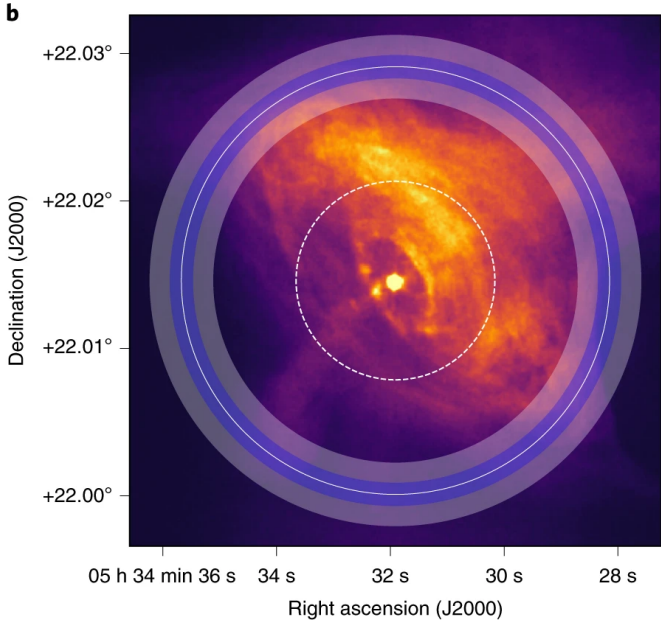
1 pc = 3.26 ly

Giacinti, AM, Lopez-Coto et al, A&A **636**, A113 (2020)

Crab Nebula

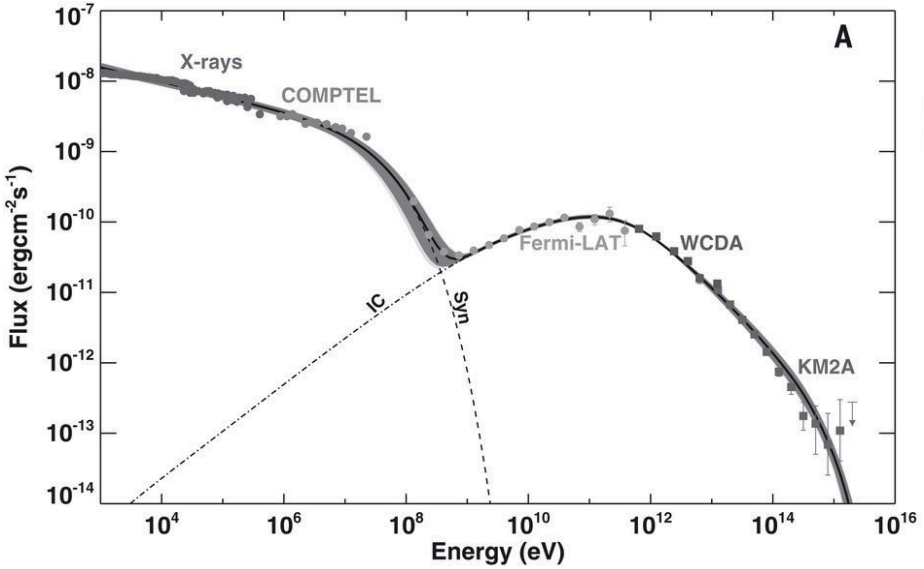
Pulsar Wind Nebula – “Standard candle” of TeV gamma-ray astronomy

- First TeV source: Whipple 1989
- Highest energy photons > 1 PeV
- Brightest VHE gamma-ray source → ”Crab” units
- t = 0.94 kyr, $\dot{E}$ = 4.5x10^{38} erg/s, d = 2 kpc

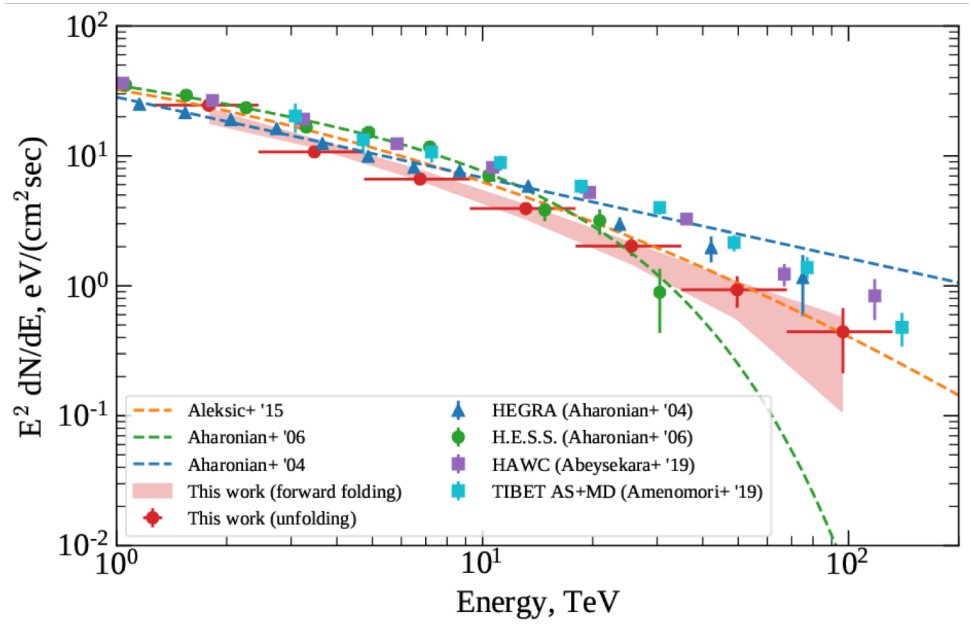


VHE extension: 52”

H.E.S.S. collaboration,
Nature Ast. **4**, 167-173 (2020)



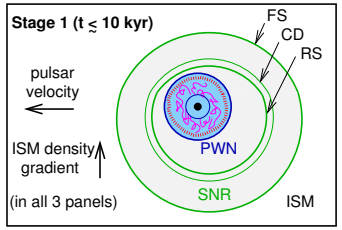
Z. Cao et al. LHAASO collaboration, Science **373**, 425-430 (2021)

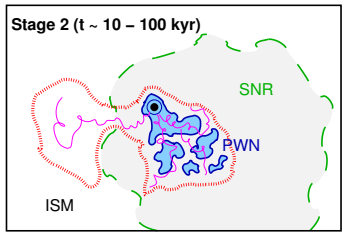


Very Large Zenith Angle observations
→ extend IACT spectrum to 100 TeV

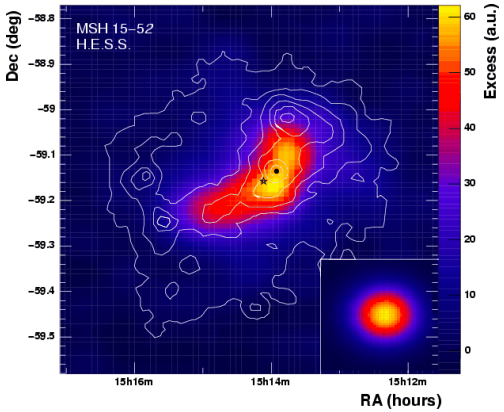
MAGIC collaboration
A&A **635** A158 (2020)

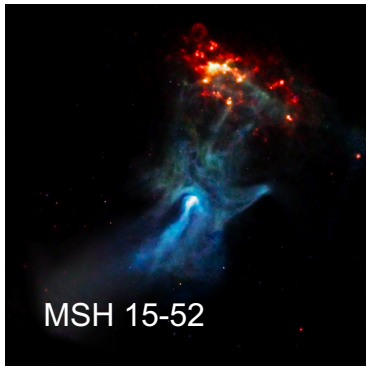
Pulsar Wind Nebulae

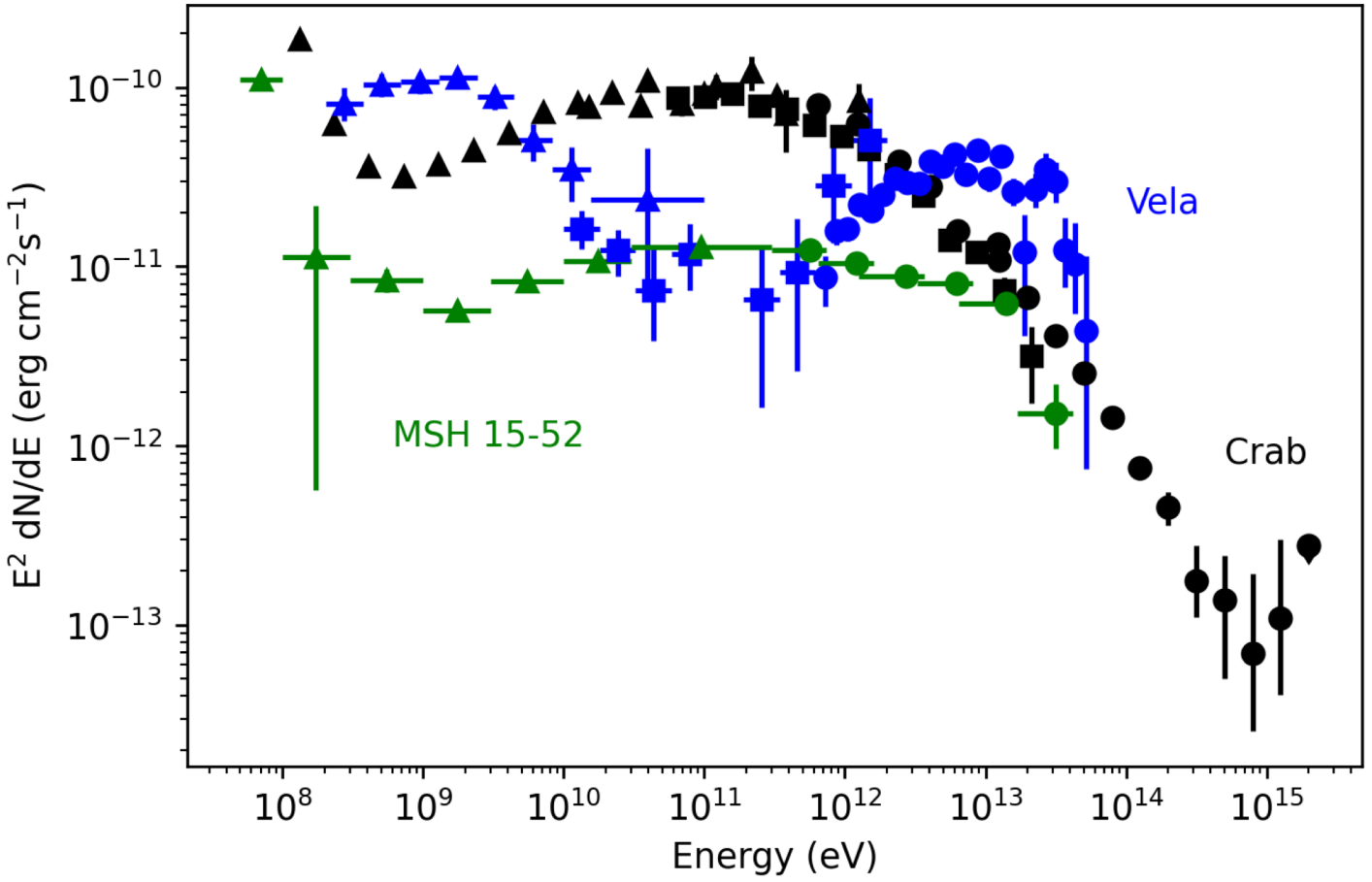


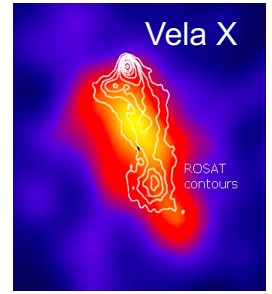


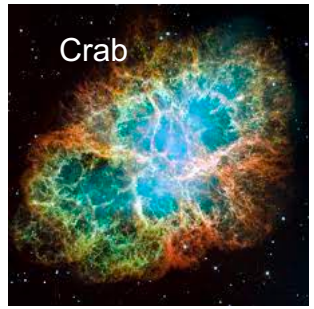
- Most numerous source class in the VHE gamma-ray sky

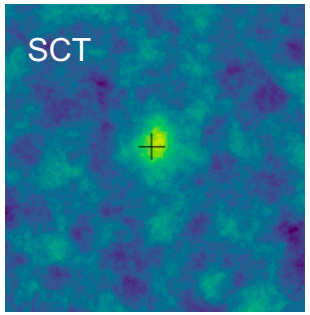






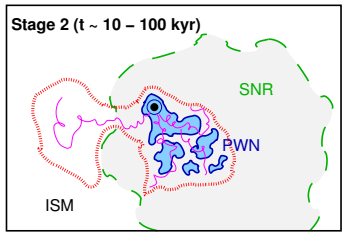




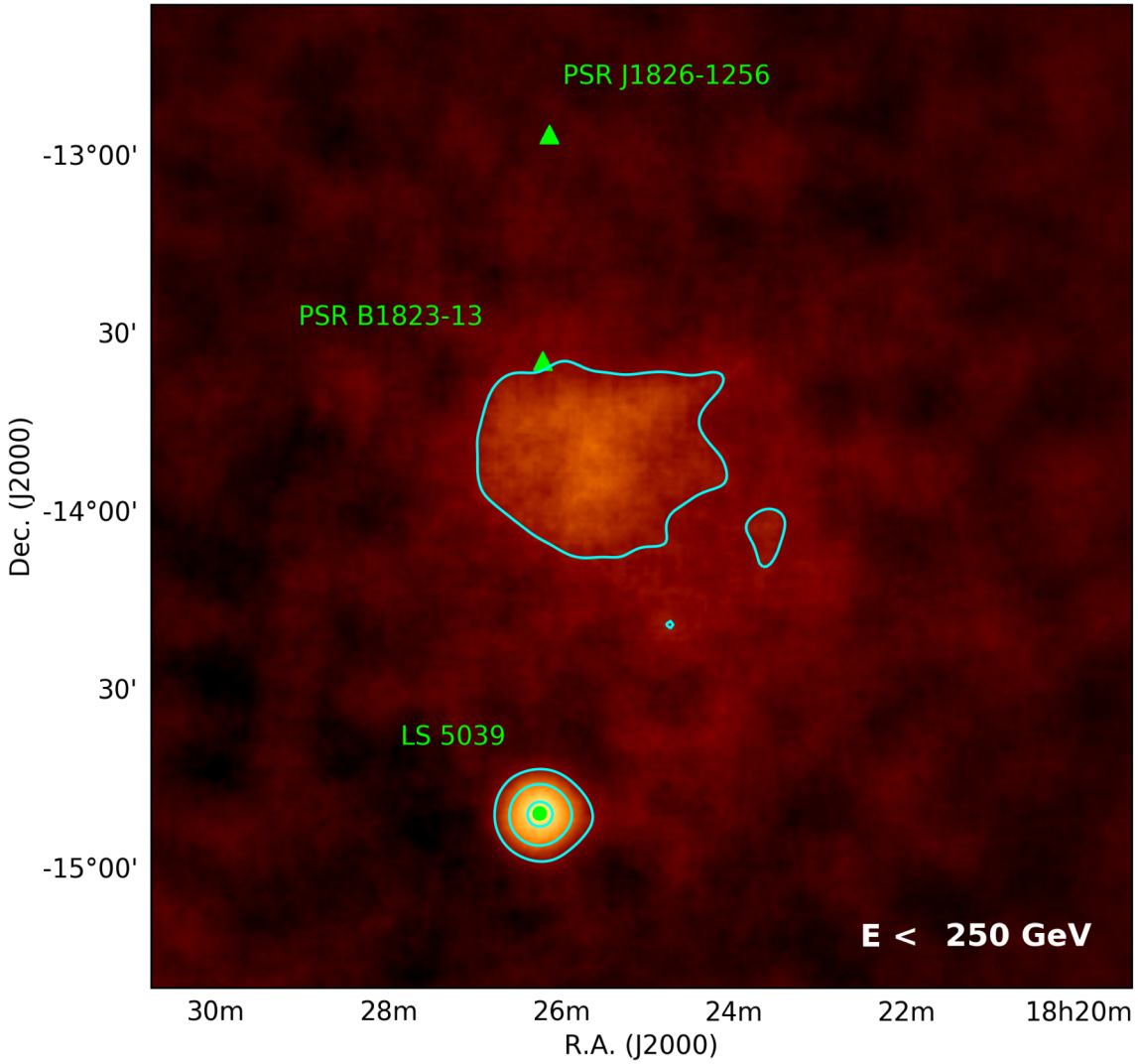


A&A **435**, L17-L20 (2005) https://news.ucsc.edu/2020/06/crab-nebula.html

Pulsar Wind Nebulae

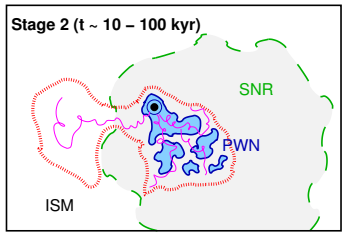


HESS J1825-137



H.E.S.S. collaboration et al. A&A **621** (2019) A116

Pulsar Wind Nebulae



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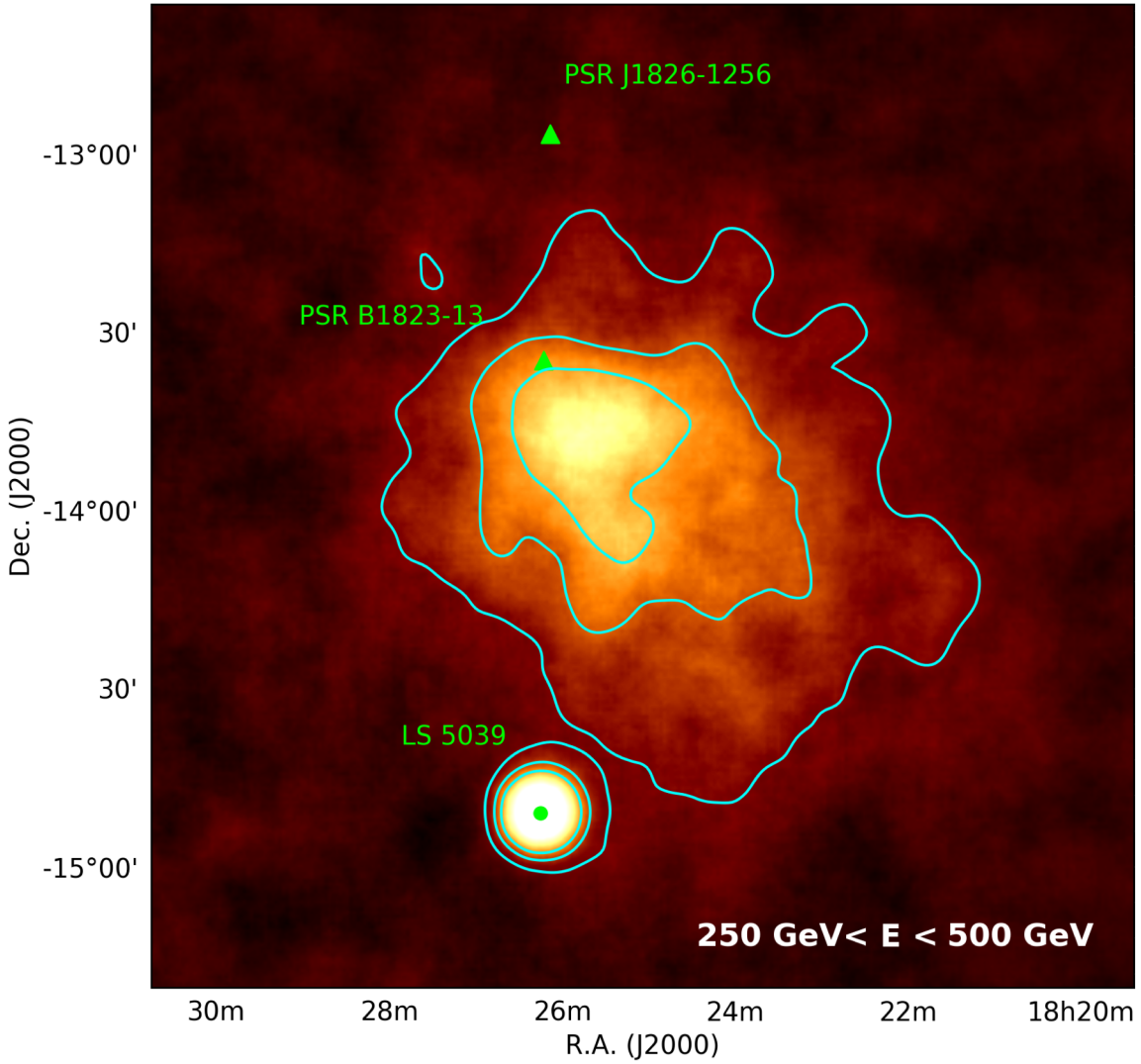

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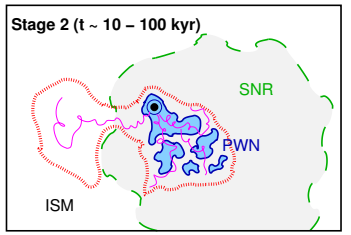

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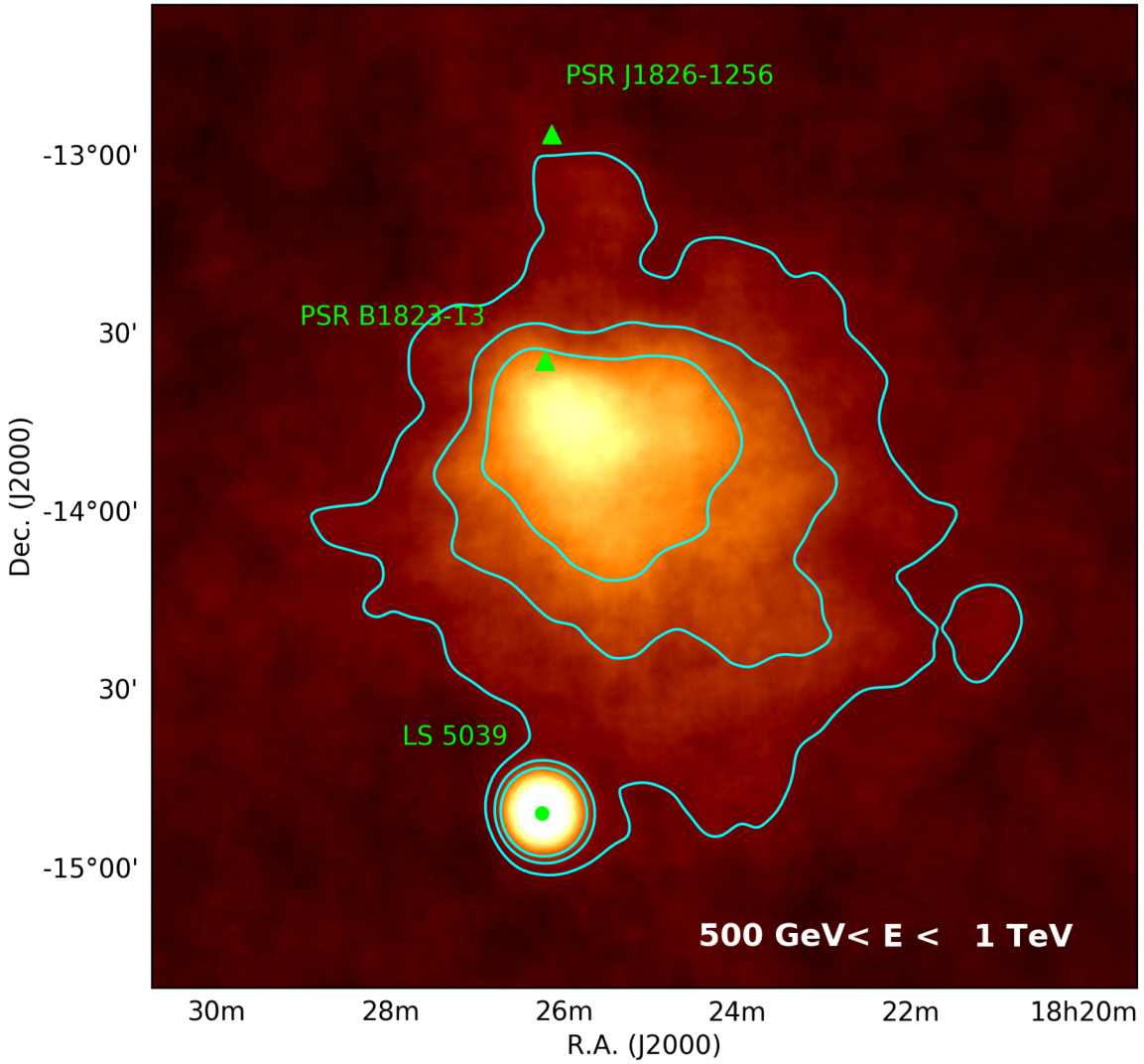

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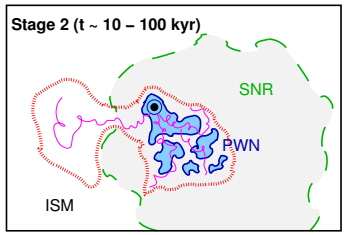
Pulsar Wind Nebulae



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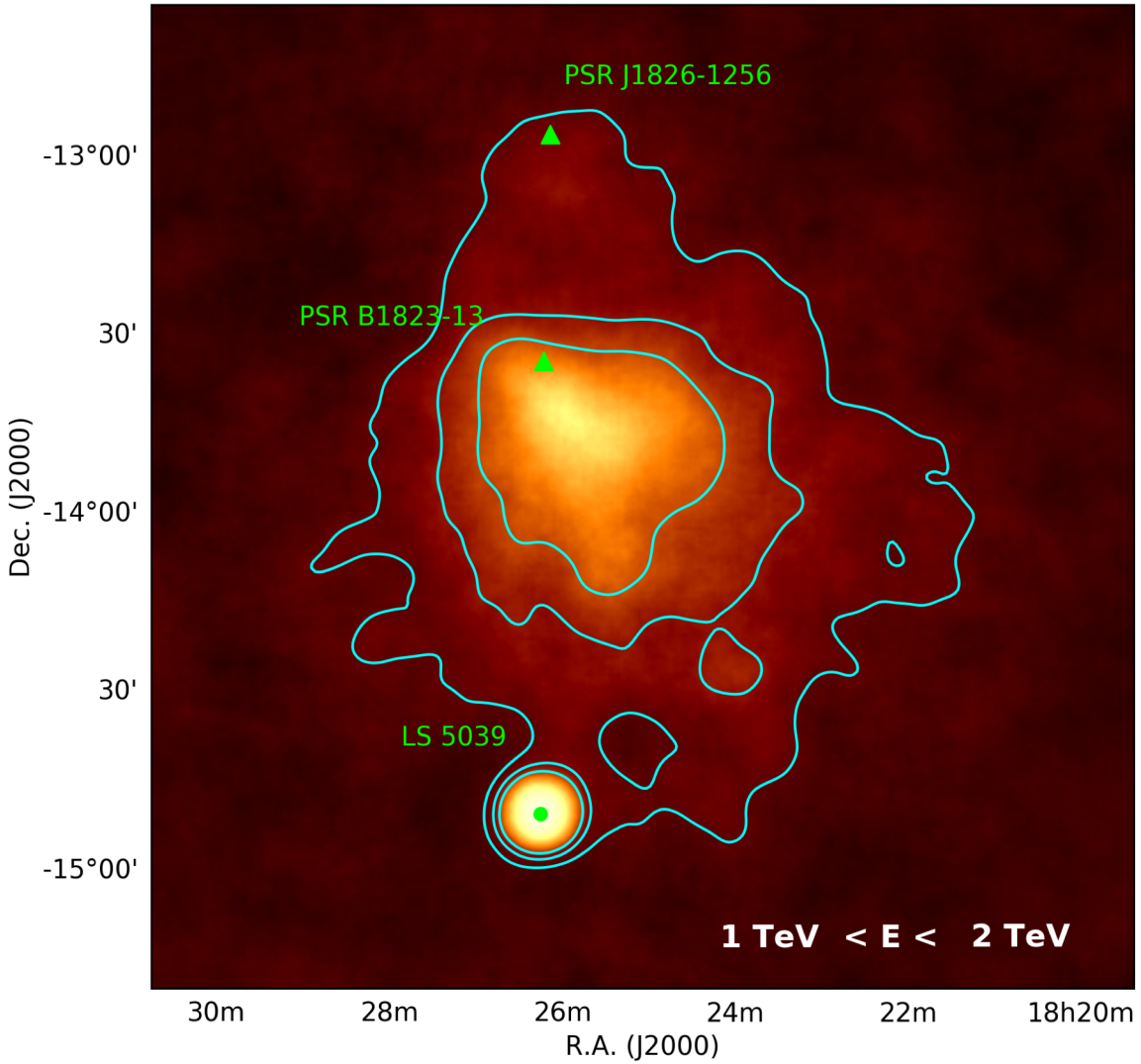

H.E.S.S. collaboration et al. A&A **621** (2019) A116

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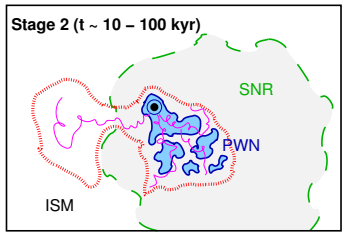

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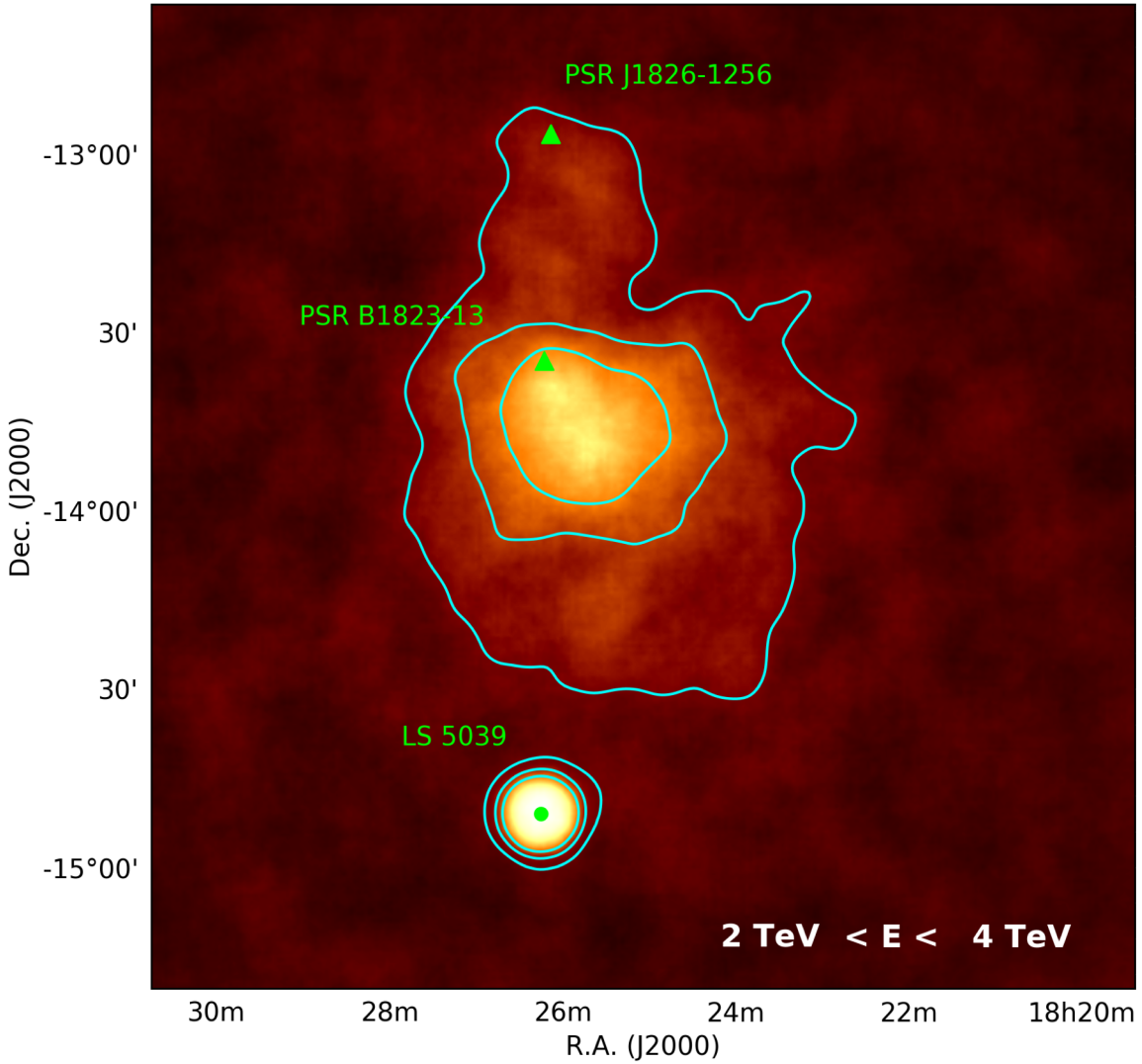

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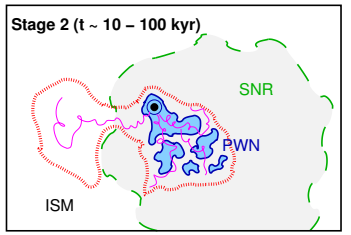

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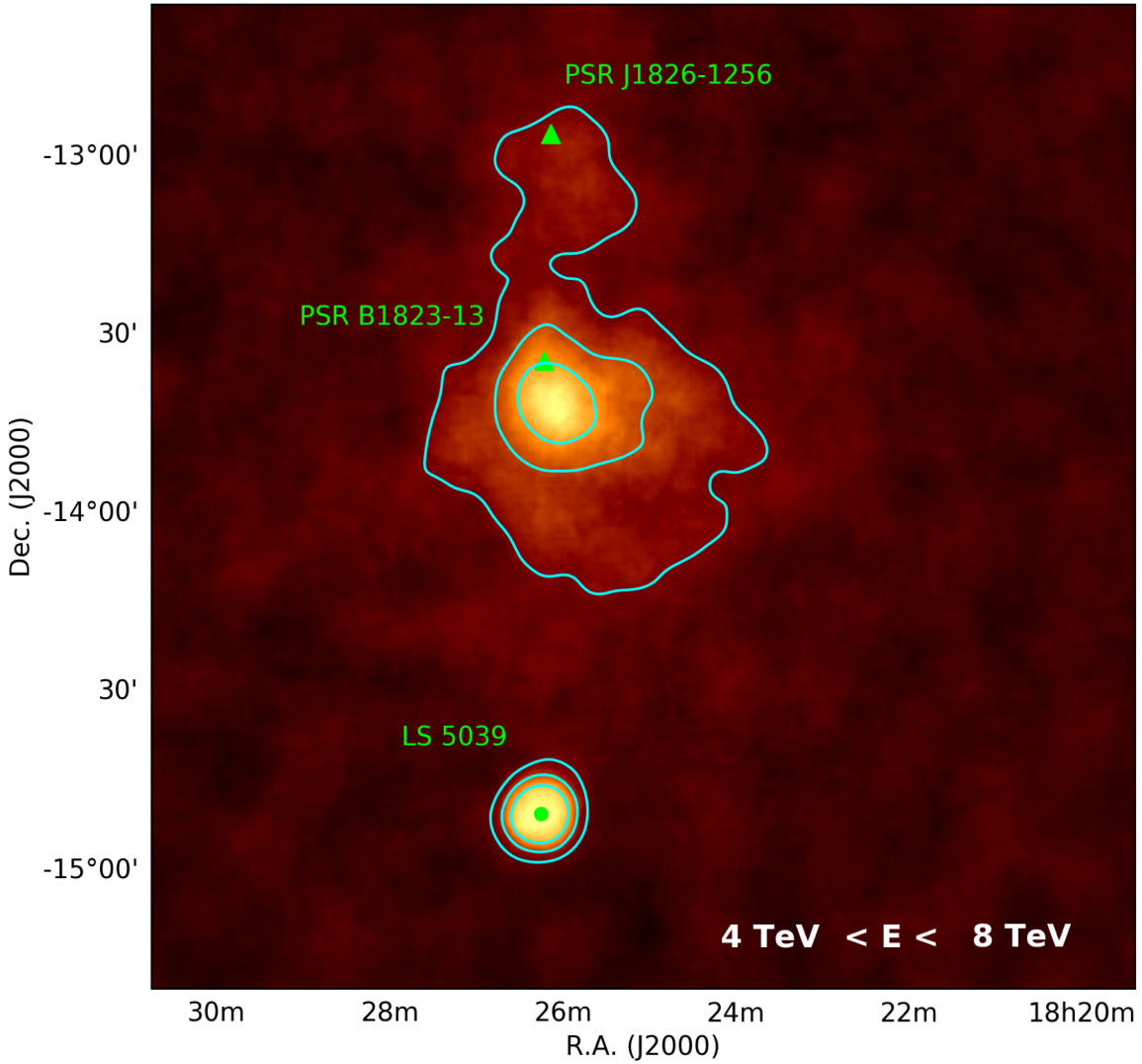
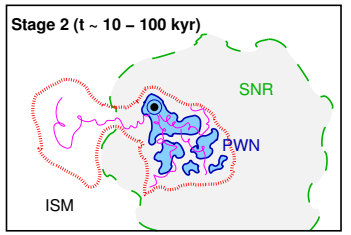


H.E.S.S. collaboration et al. A&A **621** (2019) A116

Pulsar Wind Nebulae



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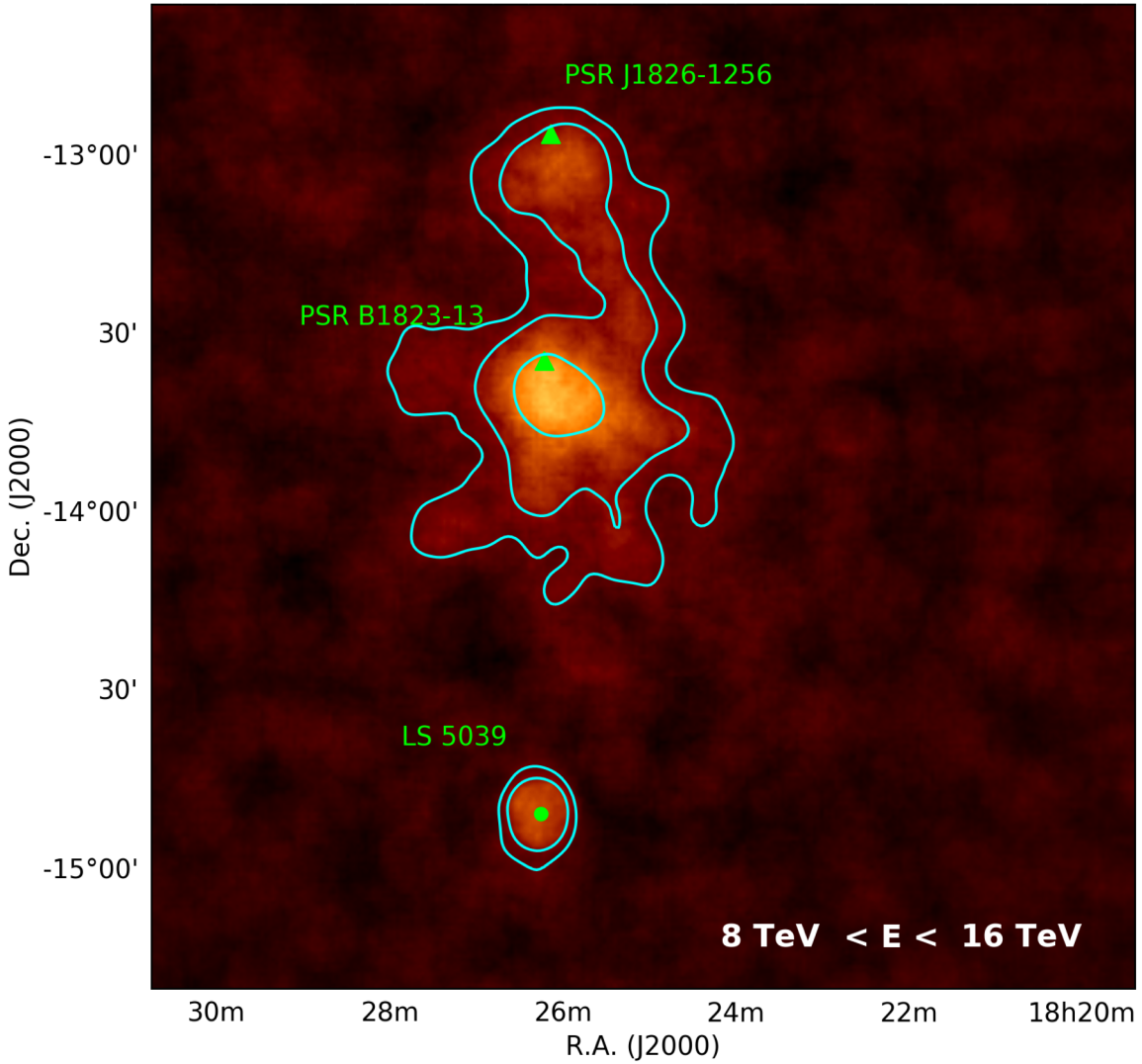

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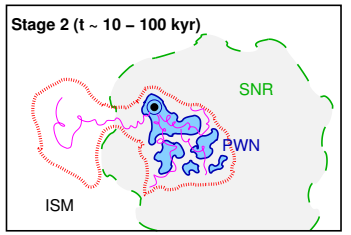

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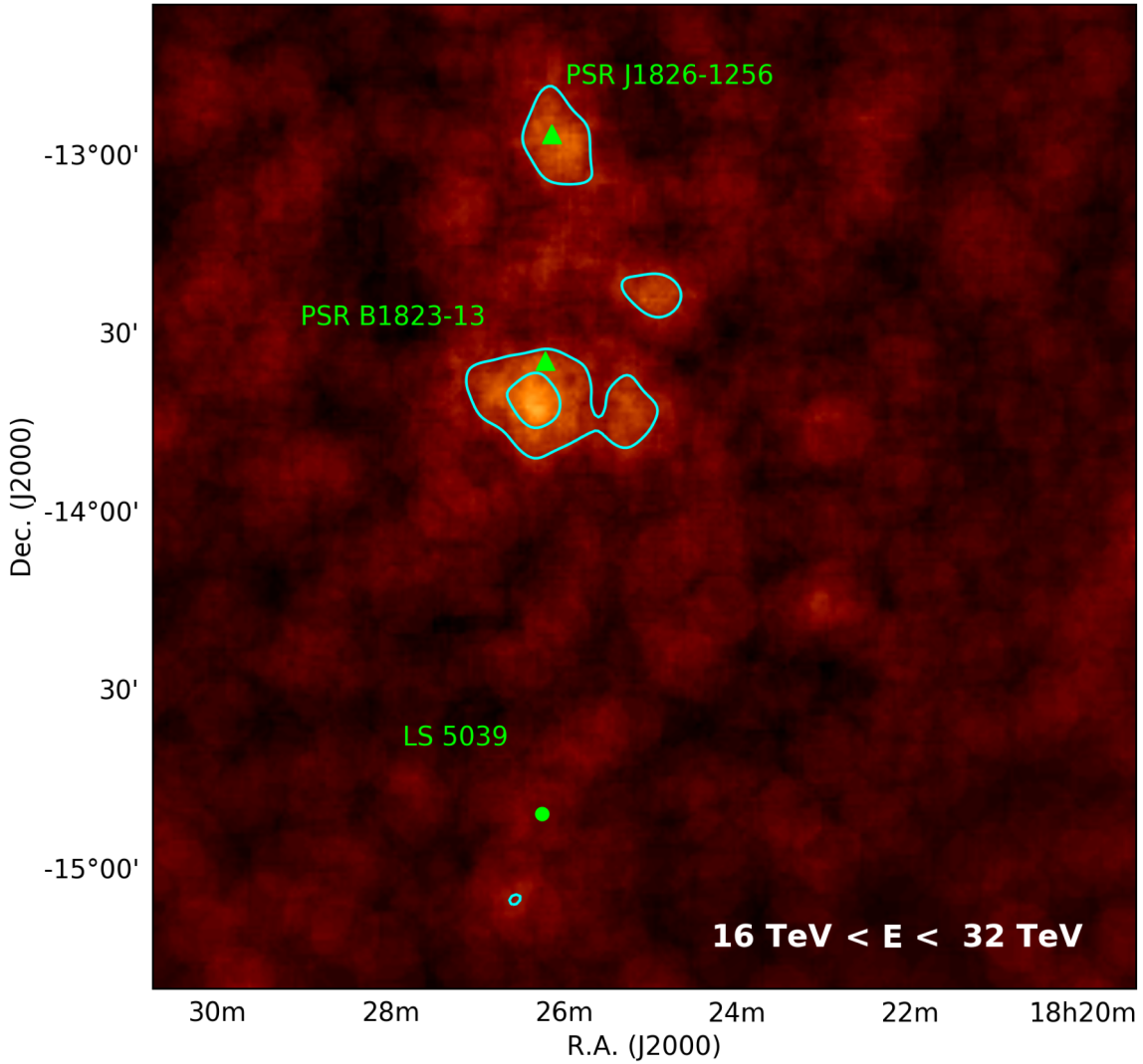

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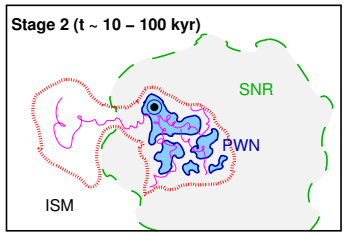

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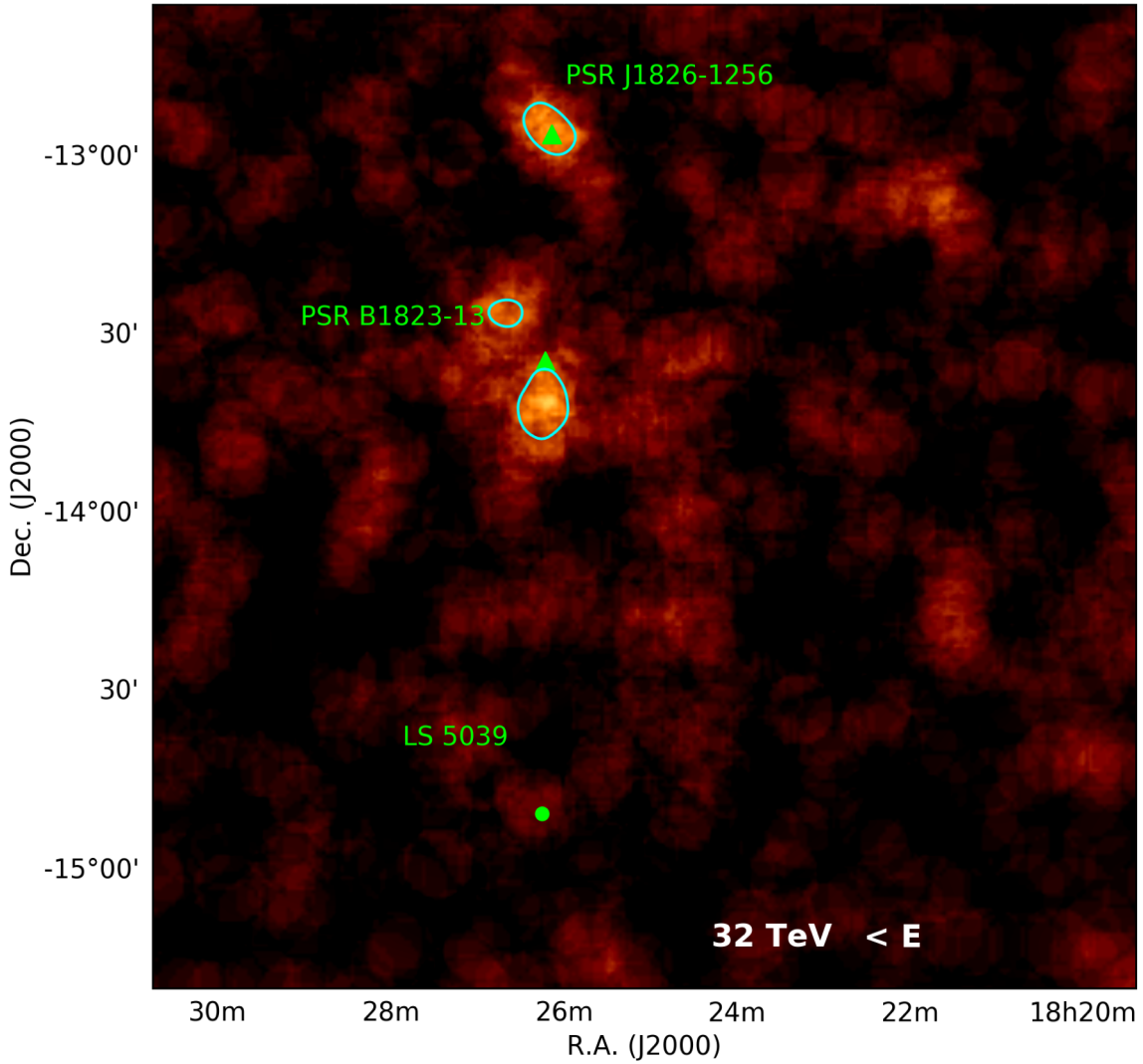
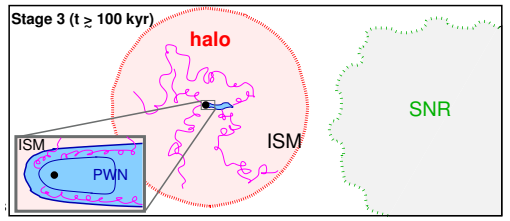


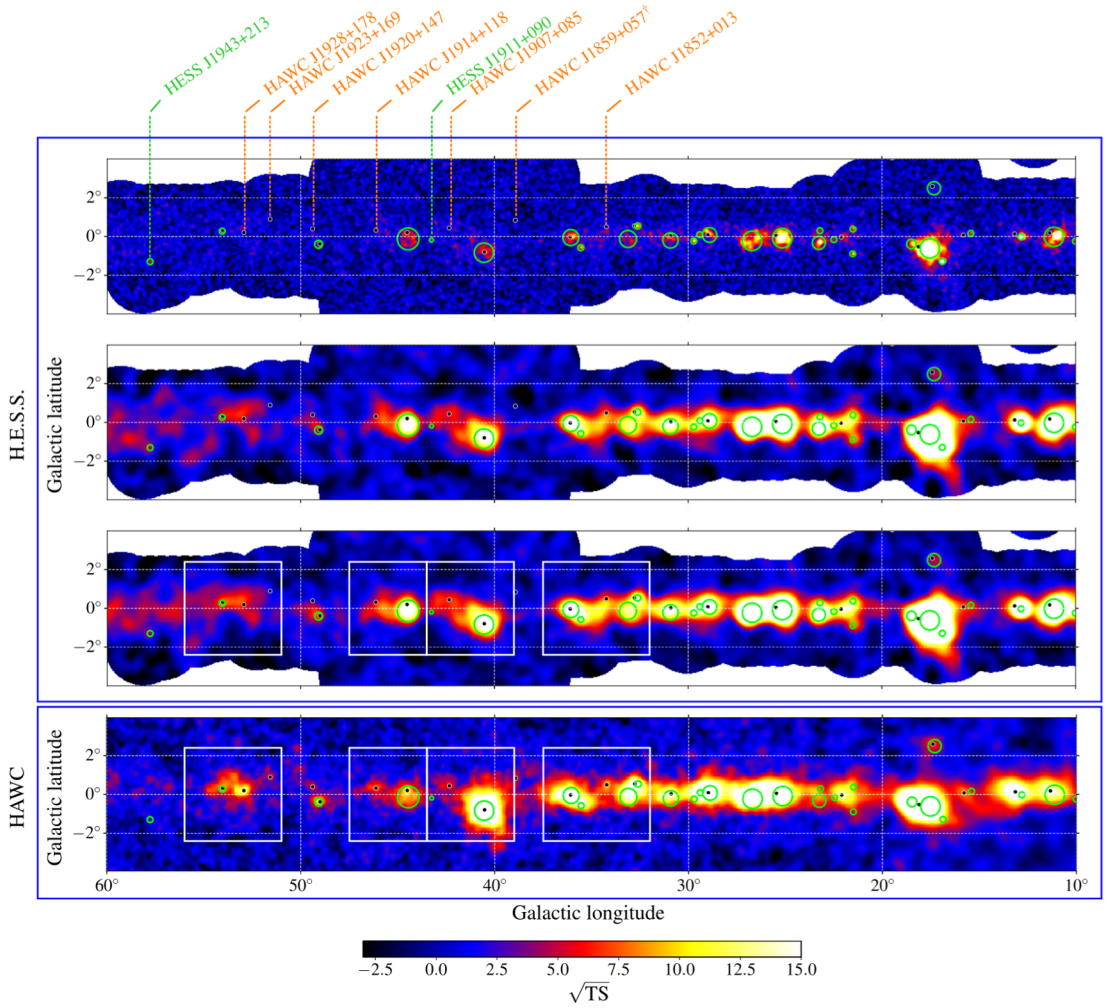
H.E.S.S. collaboration et al. A&A **621** (2019) A116

Pulsar halos: e.g. Geminga

Why are we seeing halos now*? (*in the last five years)



- First identified at TeV energies by Water Cherenkov Detector HAWC
  Larger field-of-view → less angular size bias
- IACTs such as H.E.S.S. have since put effort into improving analysis sensitivity to extended sources
  - Consistent view of the Galactic Plane (H.E.S.S. & HAWC, ApJ, **917**, 2021, 6)
    → several extended sources seen by HAWC now detected in H.E.S.S. data



H.E.S.S. & HAWC Collaborations, ApJ **917** (2021) 6

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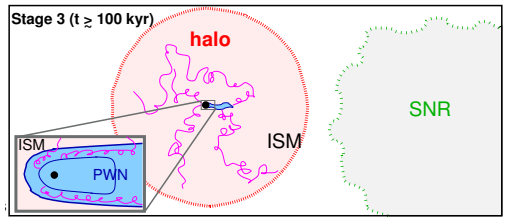

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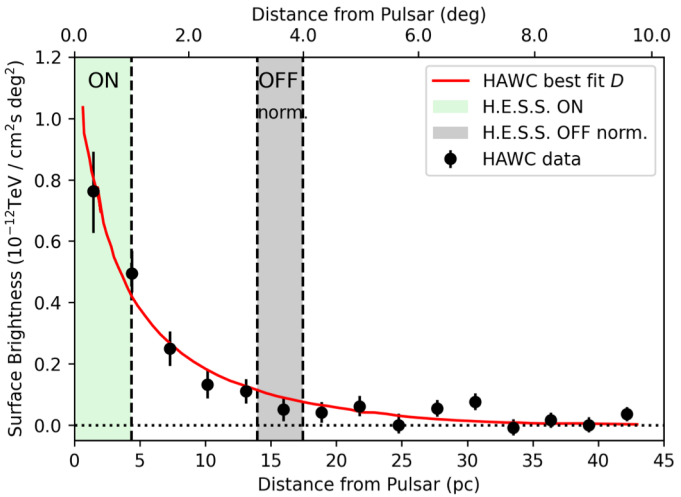
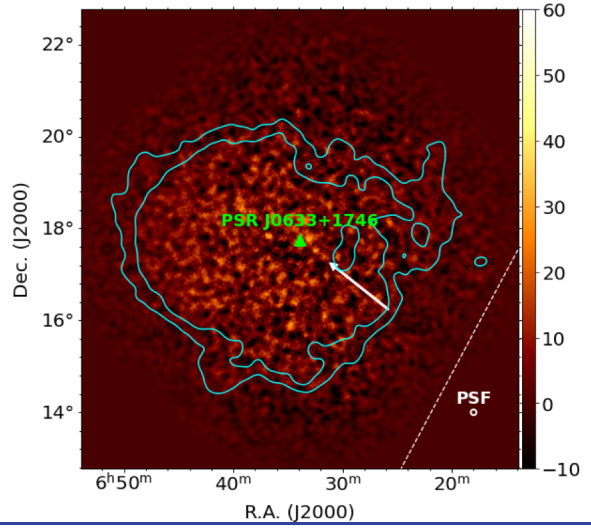
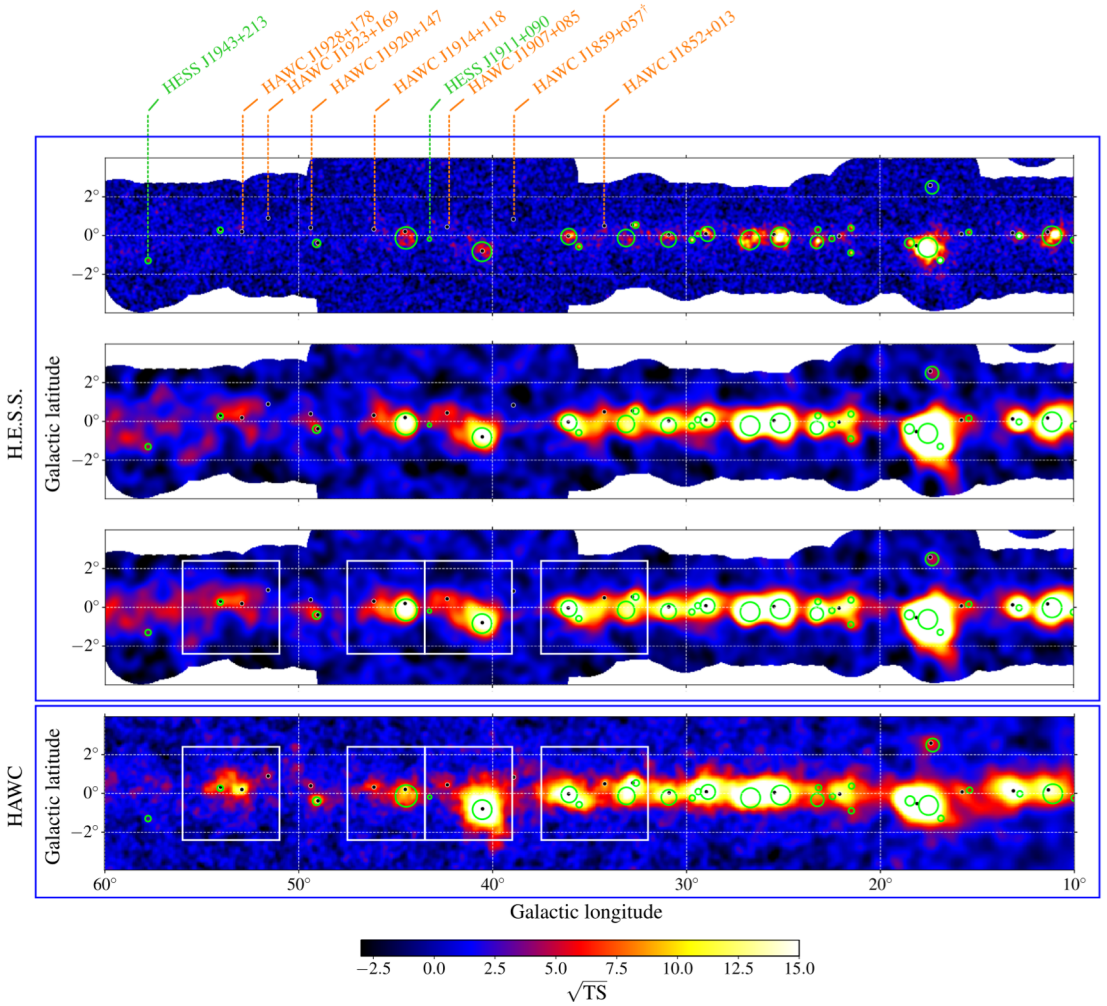
  - Detection of the canonical halo around the Geminga pulsar
  - t = 342 kyr, $\dot{E}$ = 3.2x10^{34} erg/s, d = 0.25 kpc





HESS A&A (2023)

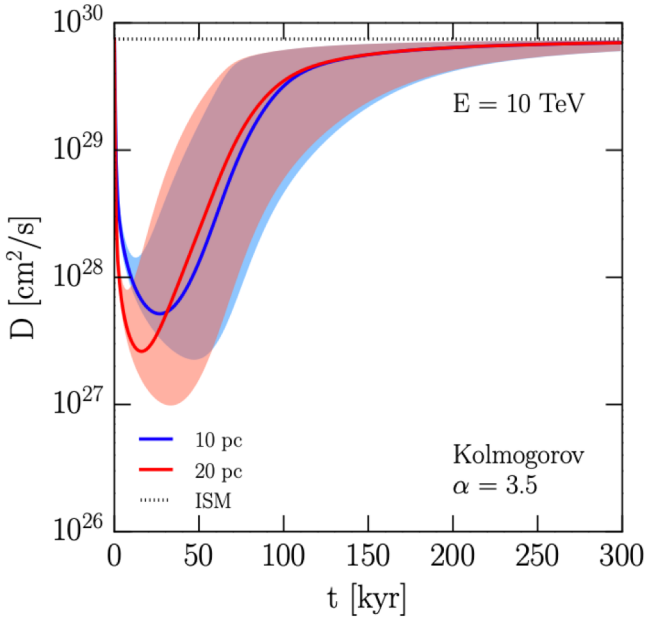


H.E.S.S. & HAWC Collaborations, ApJ **917** (2021) 6

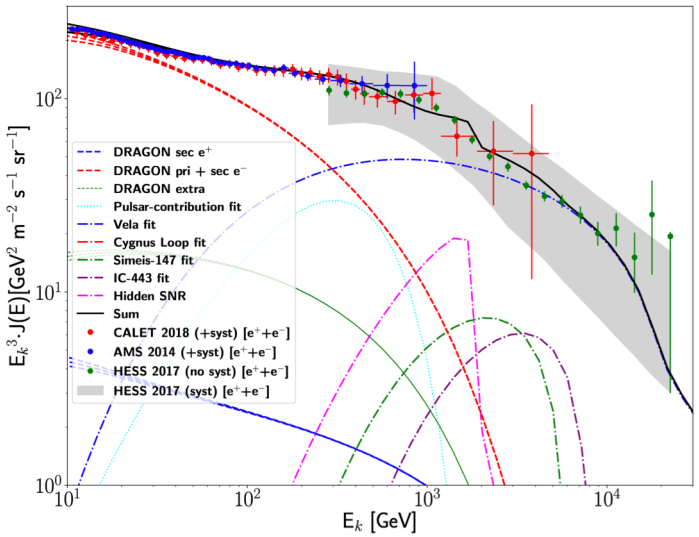
Cosmic Ray Electron Spectrum

- Recent measurements of slow diffusion in accelerator vicinity
- Generally need a local source contribution to explain the high energy CR electron spectrum
- Nature unclear: local SNR, local pulsar....

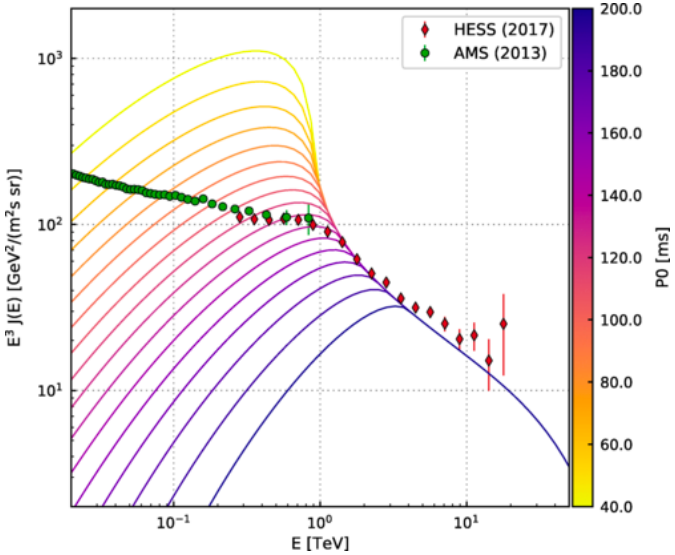
ΔE ± 15% due to hadronic interaction model uncertainties



Evoli et al PRD **98**, 063017 (2018)



Fornieri et al. JCAP **02** (2020) 009



Lopez-Coto et al. PRL **121** (2018) 251106

PeVatron candidates

Supernova Remnants, Stellar Clusters...

Search for origins of Galactic Cosmic Rays:

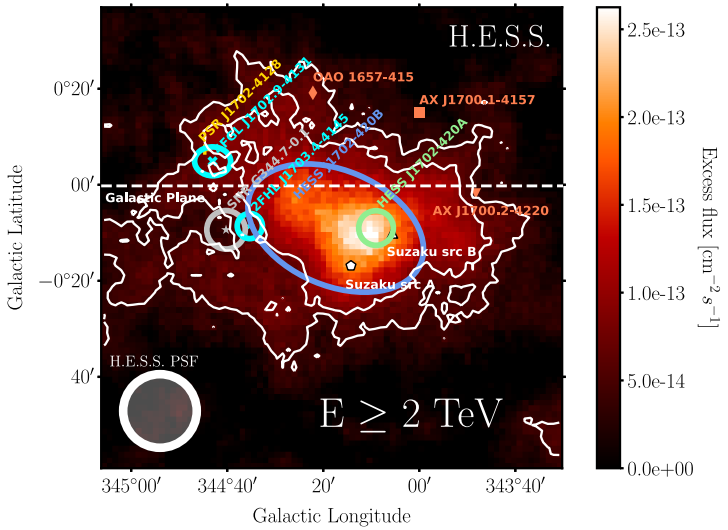
-- supernova remnants?

-- Galactic Centre region?

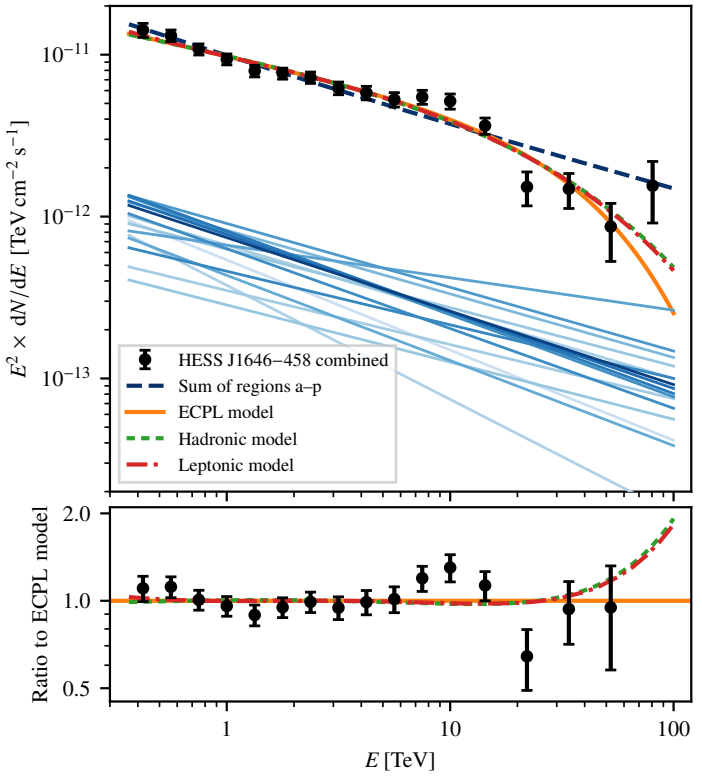
-- stellar clusters?

-- escaping CRs interacting with clouds?

HESS J1702-420

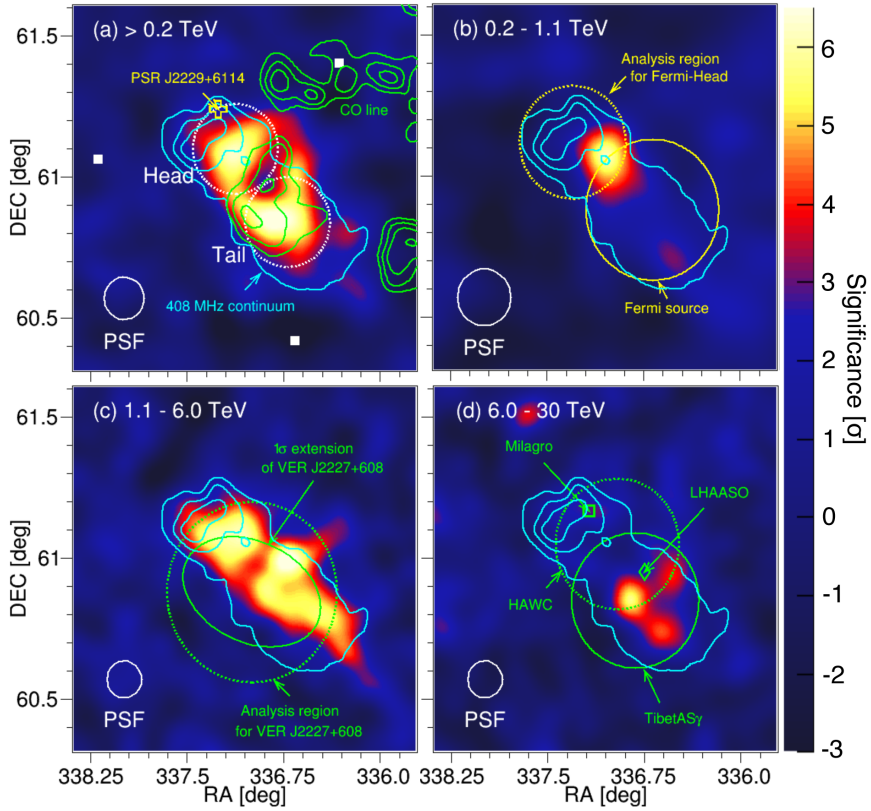


H.E.S.S. Collaboration A&A **653** A152 (2021)



Westerlund 1

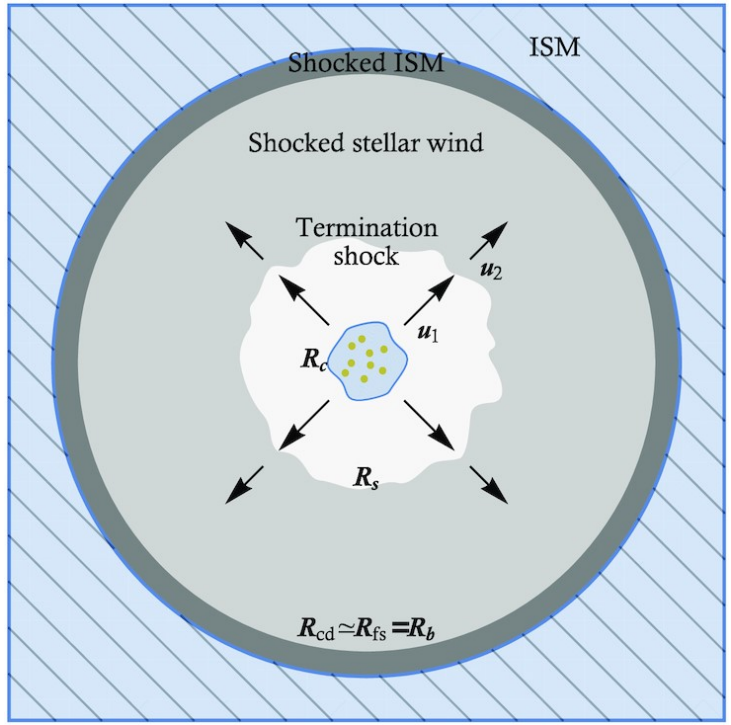
HESS Collaboration A&A **666** A124 (2022)



G106.3+2.7 / Boomerang nebula

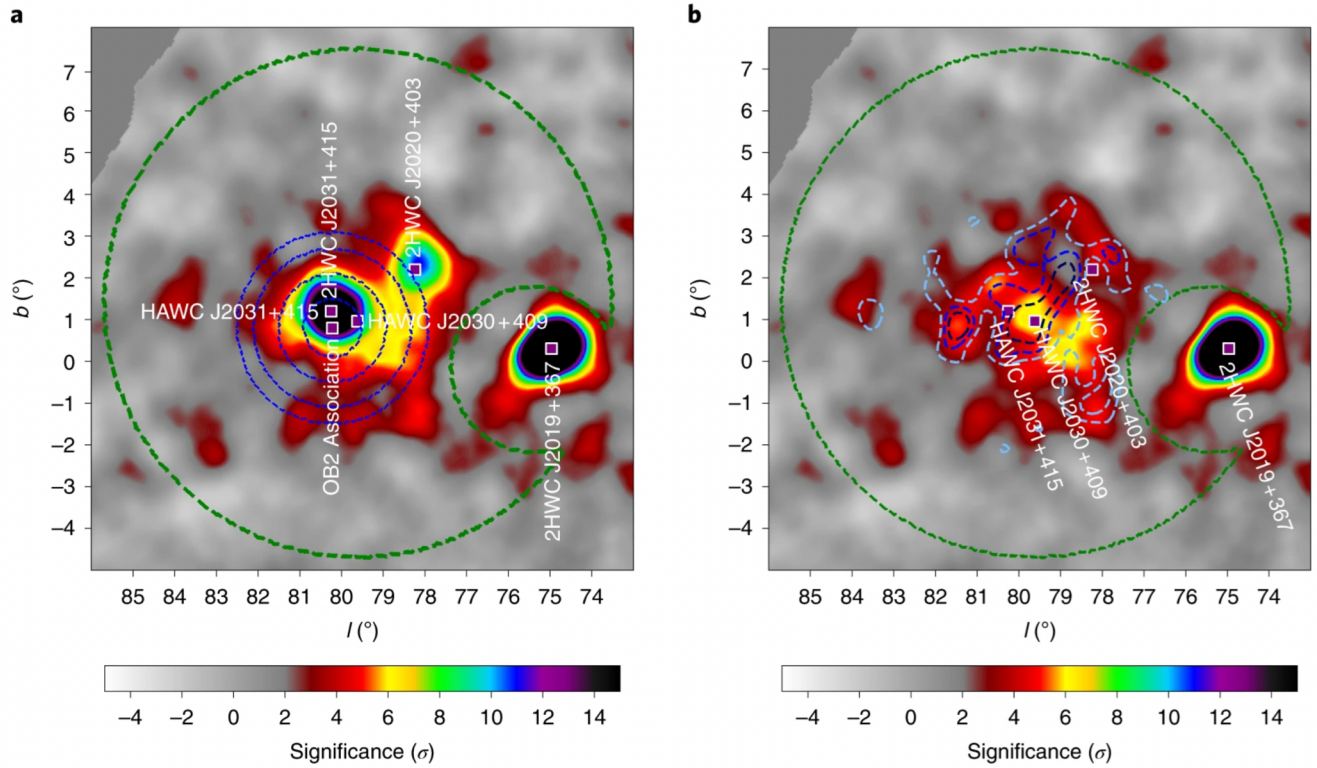
MAGIC collaboration A&A **671**, A12 (2023)

Stellar Clusters and Cygnus Superbubble



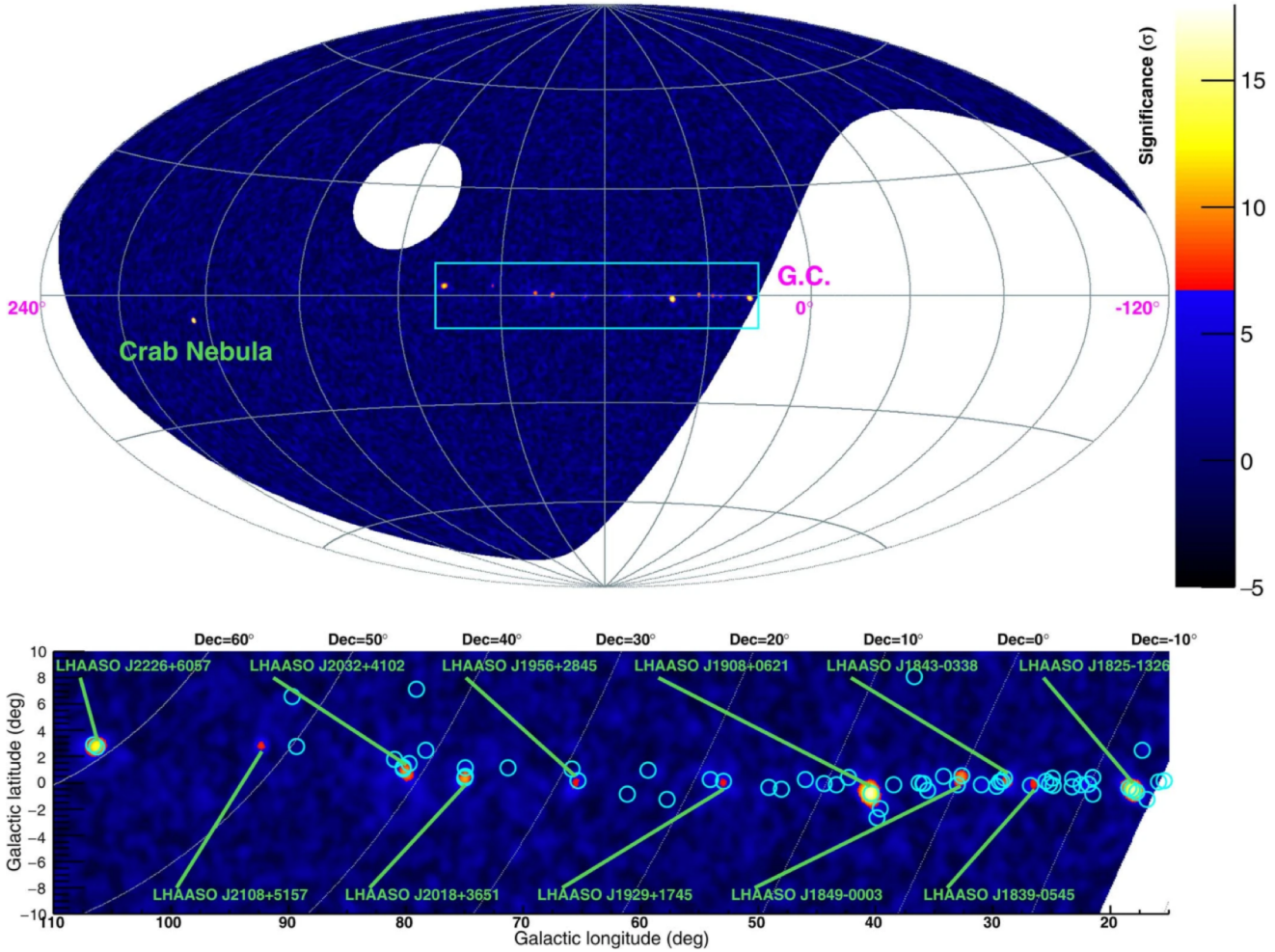
Morlino et al. MNRAS **504** (2021) 6096-6105

- Collective stellar winds drive a shock in the interstellar medium
- Requires typically young stellar clusters / massive star forming regions
- Highest energy photon measured to date: 1.42 ± 0.13 PeV → from Cygnus region? LHAASO J2032+4102 (Cao et al. Nature **594** (2021) 33-36)
- HAWC Cygnus cocoon (Nature Astro. **5** (2021) 465-471)



Highest energy gamma-ray sky > 100 TeV

- Sky maps by LHAASO, Tibet-ASγ and HAWC:
- $E_\gamma > 100$ TeV ($E_p \sim 1$ PeV; $E_e \sim 183$ TeV)
  → ~12 sources
- Cao et al. Nature **594** (2021) 33-36



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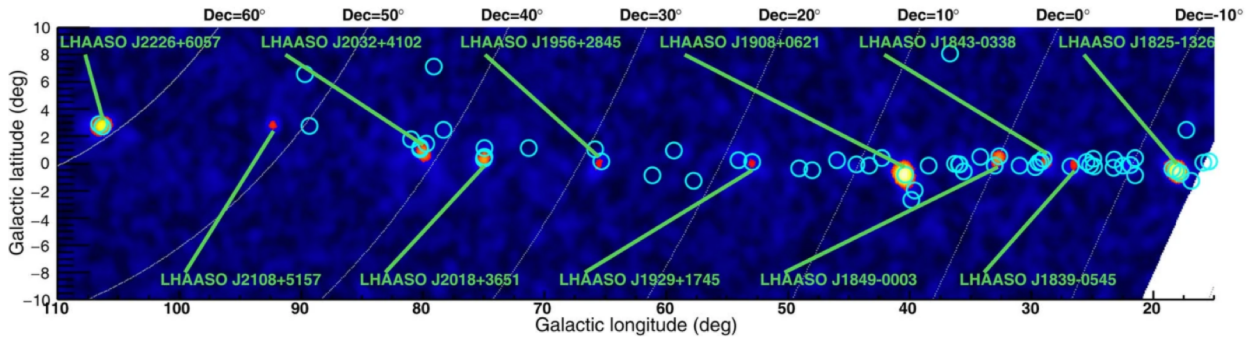
- Most associated with pulsars
- Generally, pulsars are associated with leptonic emission (e^+ & e^-)

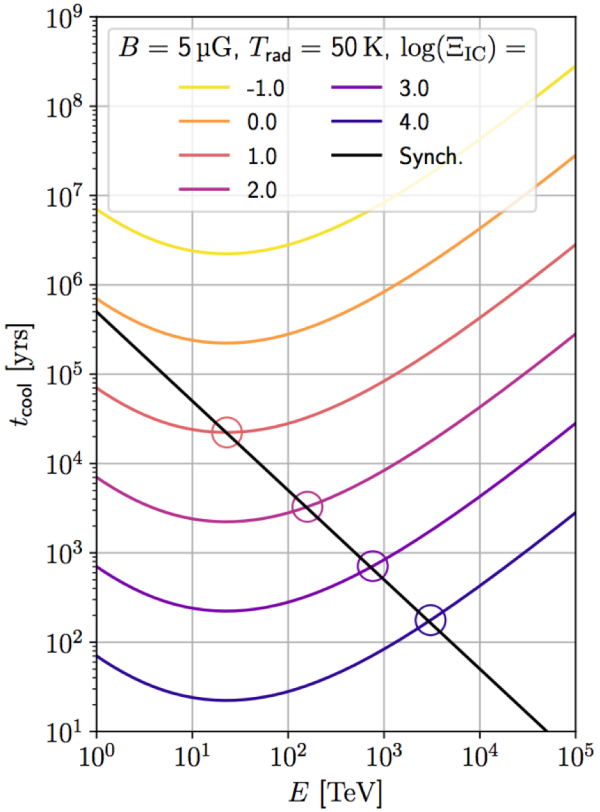
Source	Location (l,b)	Detected > 100 TeV by	Possible Origin
Crab Nebula	(184.557, -5.784)	HAWC, MAGIC, LHAASO, Tibet-ASγ	PSR
HESS J1702-420	(344.304, -0.184)	H.E.S.S.	?
Galactic Centre	(0-1.2, -0.1– +0.1)	H.E.S.S.	SMBH?
eHWC J1825-134	(18.116, -0.46)	HAWC, LHAASO	PSR
LHAASO J1839-0545	(26.49, -0.04)	LHAASO	PSR
LHAASO J1843-0338	(28.722, 0.21)	LHAASO	SNR
LHAASO J1849-0003	(32.655, 0.43)	LHAASO	PSR, YMC
eHWC J1907+063	(40.401, -0.70)	HAWC, LHAASO	SNR, PSR
LHAASO J1929+1745	(52.94, 0.04)	LHAASO	PSR, SNR
LHAASO J1956+2845	(65.58, 0.10)	LHAASO	PSR, SNR
eHWC J2019+368	(75.017, 0.283)	HAWC, LHAASO	PSR, H II/YMC
LHAASO J2032+4102	(79.89, 0.79)	LHAASO	YMC, PSR, SNR?
LHAASO J2108+5157	(92.28, 2.87)	LHAASO	?
TeV J2227+609	(106.259, 2.73)	Tibet-ASγ, LHAASO	SNR, PSRs

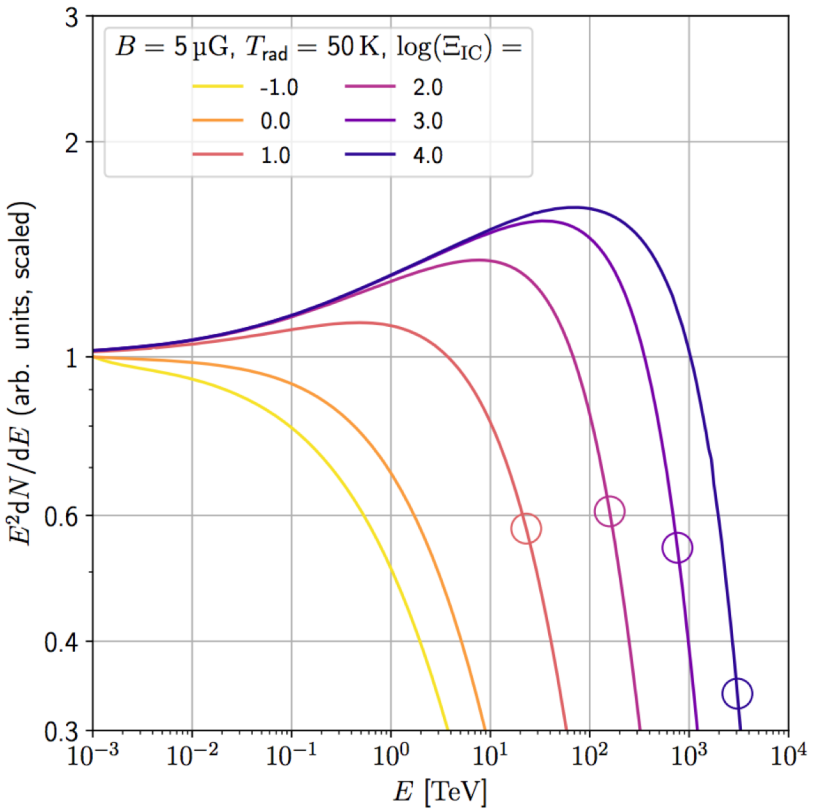


UHE leptonic emission & Klein-Nishina effect

$$\Xi_{IC} \equiv {}^{U_{rad}}/_{U_B}$$

- In high radiation environments, synchrotron cooling dominates over IC losses, even into Klein-Nishina regime. (IC cross-section suppressed)
- Resulting spectrum is harder / cut-off is less pronounced.
- Leptonic spectra out to PeV energies can be observed

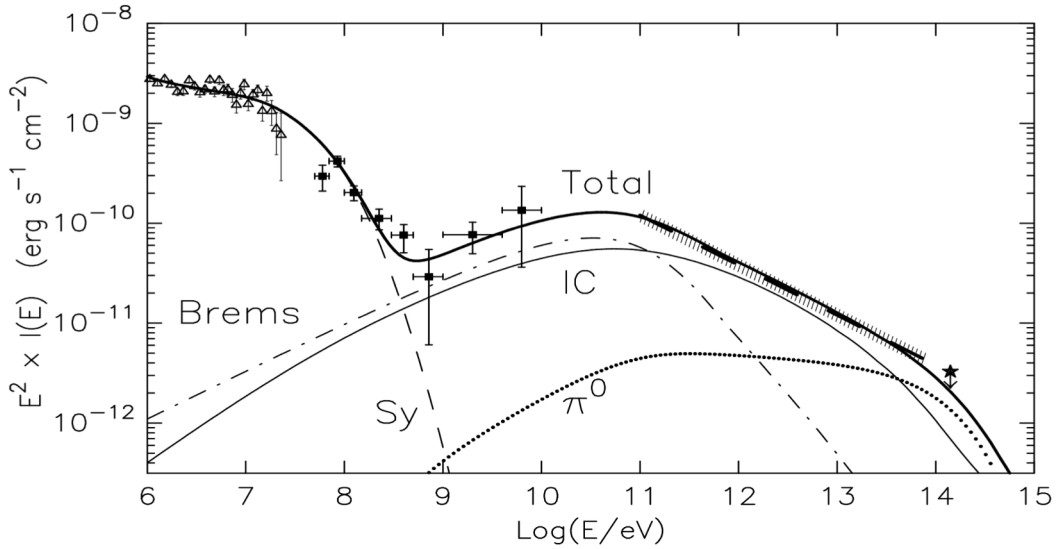




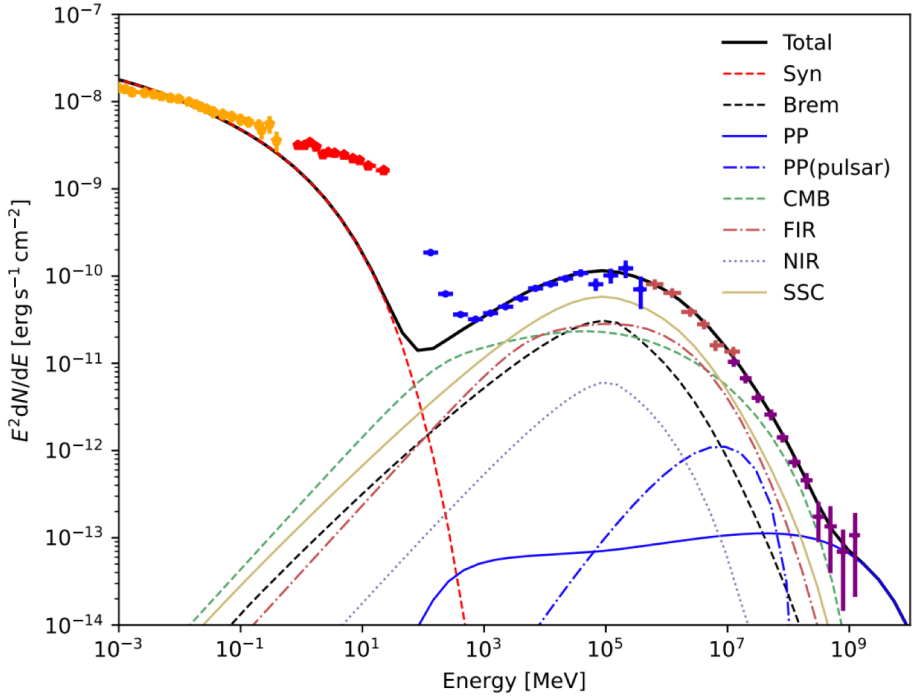
Breuhaus et al. ApJL **908** L49 (2021)

Klein-Nishina cut-off → sub-dominant hadronic component

A sub-dominant hadronic component could be revealed at the highest energies, beyond the Klein-Nishina cut-off



Aharonian & Atoyan, proc. “Neutron Stars and Pulsars” 439 (1998)



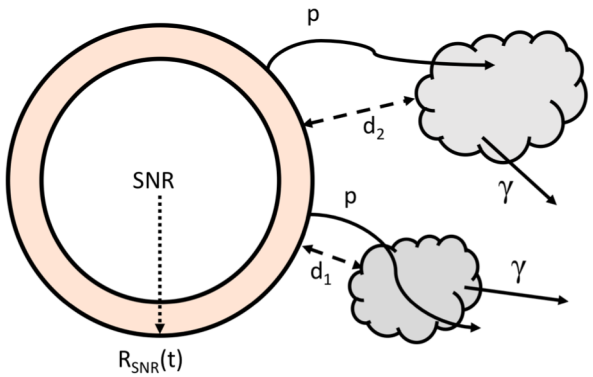
Nie et al, ApJ 924, 42 (2022)

Gamma-ray signatures of cosmic rays

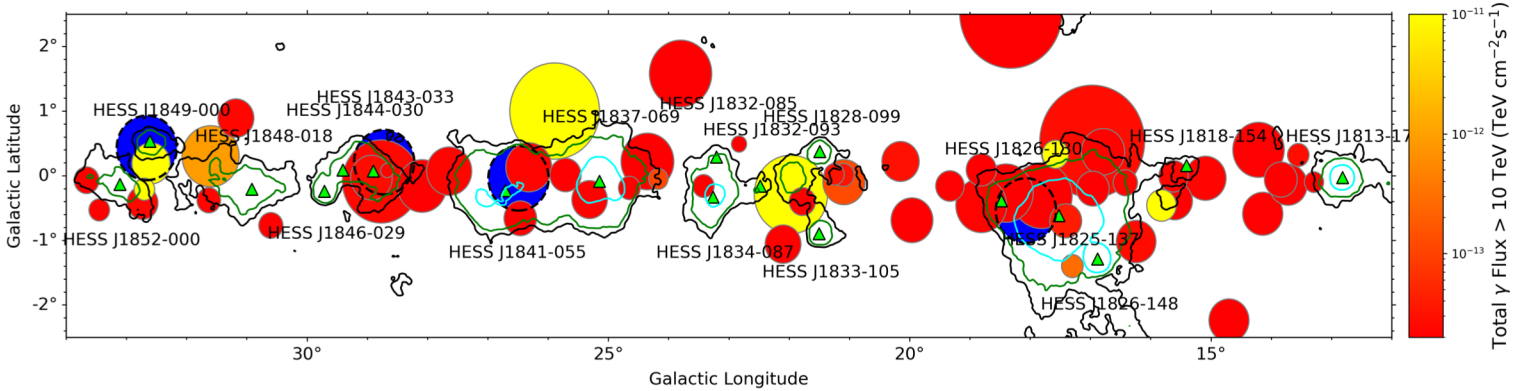
→Protons (and heavier nuclei) escape from accelerator – will interact with nearby clouds

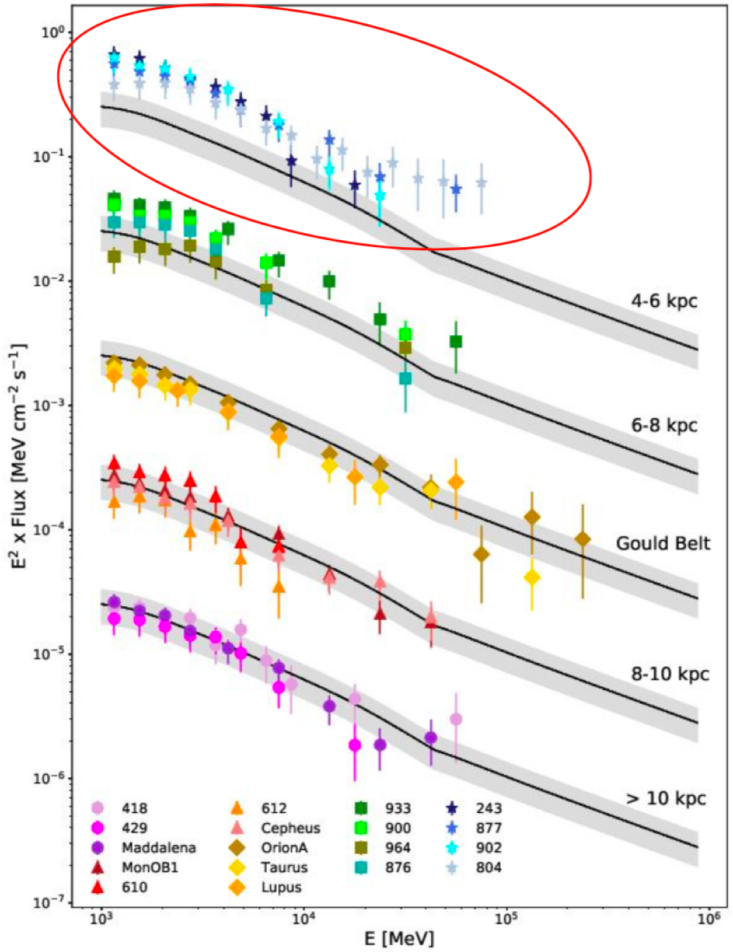
→Predict and search for gamma-rays from clouds identified in radio

→Can use clouds in vicinity of accelerators to probe escape of protons and constrain their presence



*AM et al. MNRAS **503** 3522-3539 (2021)*





Aharonian et al, PRD **101**, 083018 (2020)

Binary Systems: Microquasars, Colliding wind binaries...

Gamma-ray emitting binaries:

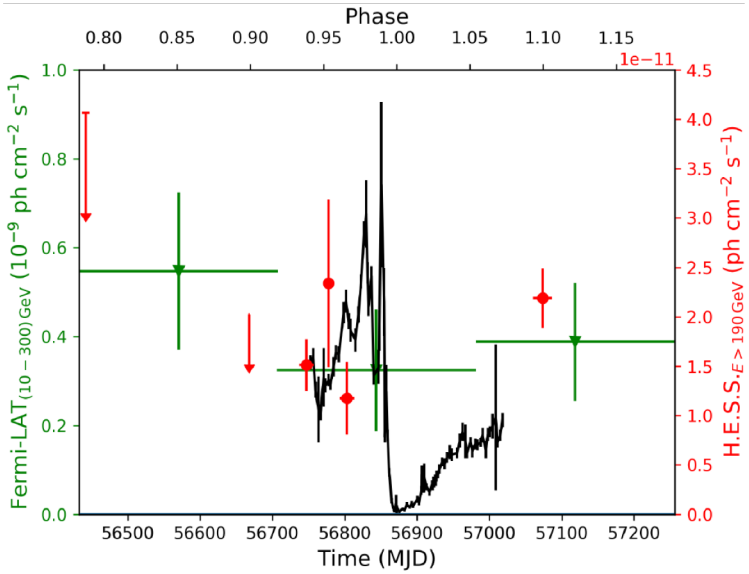
→ Colliding Wind Binaries

→ Gamma-ray binaries

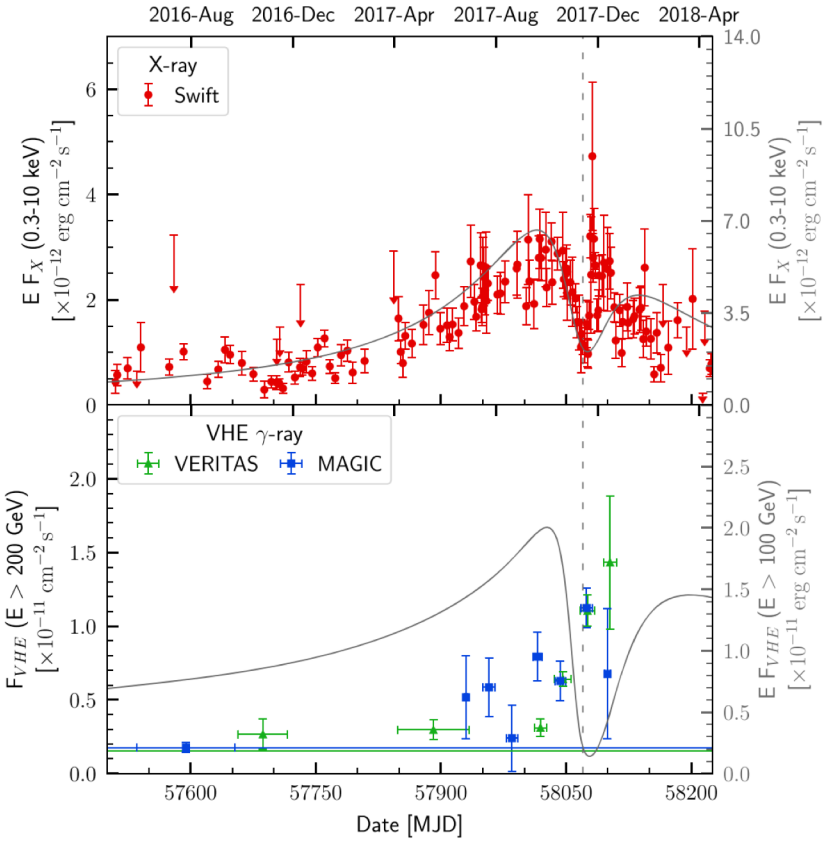
→ Microquasars (solar mass BHs)

→ Novae

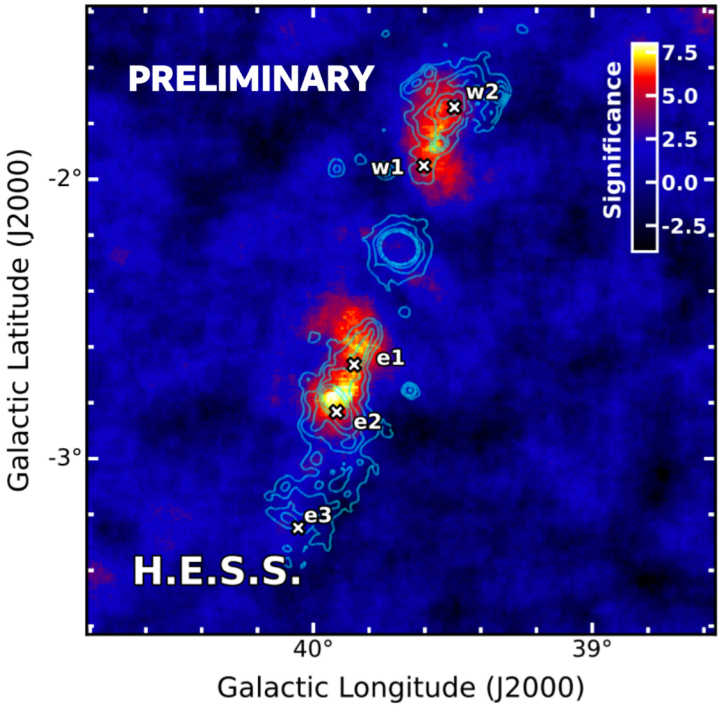
Eta Carinae: P ~5.5yr



PSR J2032+4127/Be: P ~50yr



SS433: jets



H.E.S.S. Collaboration A&A **635** A167 (2020)

MAGIC & VERITAS Collaborations ApJ **867** L19 (2018)

Introduction to Novae

Novae – outbursts from accreting binary systems (White Dwarf + massive donor):

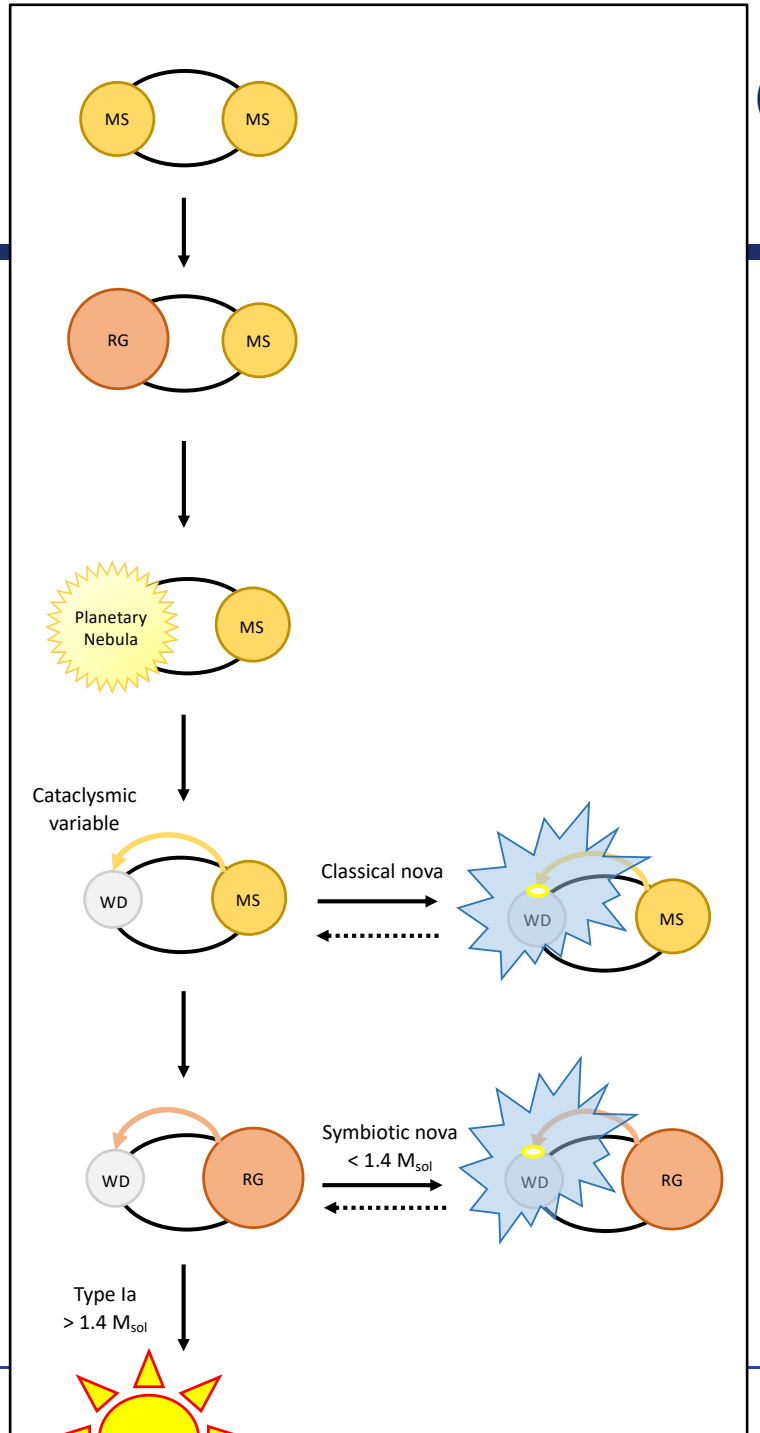
- (Classical) Novae → outbursts from cataclysmic variables
- Symbiotic Novae → red giant / "evolved" donor star
- Recurrent Novae → multiple observed outbursts
- Dwarf Novae → mini-outbursts (not thermonuclear)

Thermonuclear explosion ignited on surface of white dwarf

Increase in optical brightness Δm_v ~ 8 to 15

Typical optical duration weeks to months

$$E_{\max} = 1.5|Z|\left(\frac{\xi_{\mathrm{esc}}}{0.01}\right)\left(\frac{\dot{M}/v_{\mathrm{wind}}}{10^{11}\ \mathrm{kg\ m^{-1}}}\right)^{1/2}\left(\frac{u_{\mathrm{sh}}}{5000\ \mathrm{km\ s^{-1}}}\right)^{2}\ \mathrm{TeV}$$



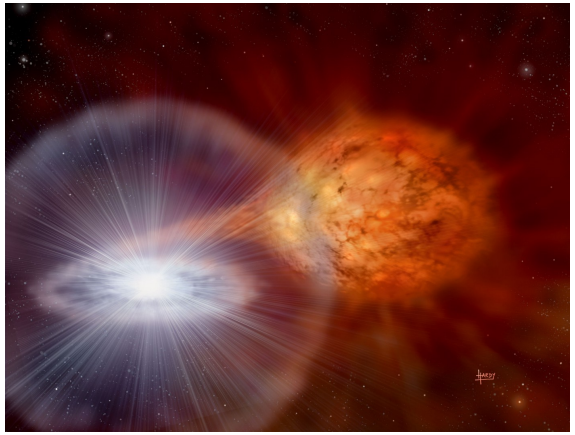
First Nova in VHE gamma-rays: RS Ophiuchi

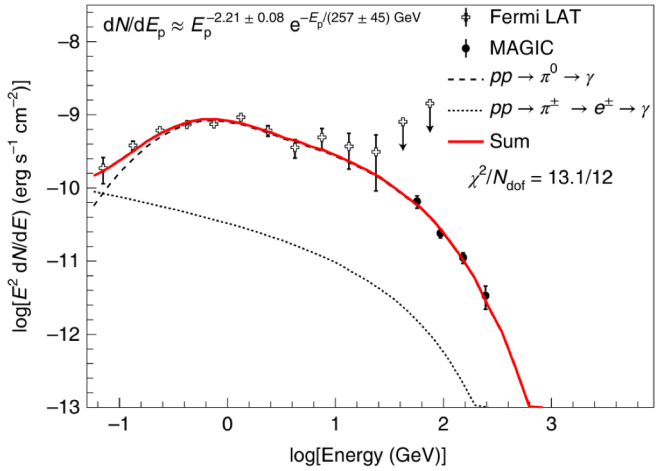
Binary of white dwarf and red giant

- Binary system comprised of white dwarf and red giant at ~1.4 kpc distance
- Semi-regular explosions observed since 1898
- Last two: 12th February 2006 and **8th August 2021** reaching $m_v = 4.6$ (cf quiet state $m_v = 12.5$)

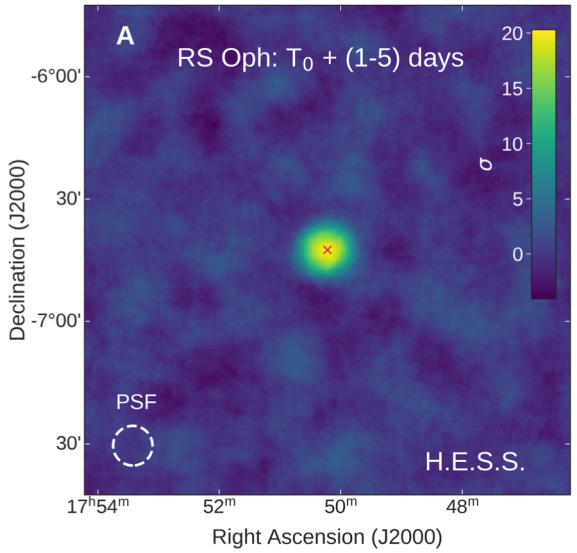
→ Detected by H.E.S.S., MAGIC and LST in VHE gamma-rays (Atel 14844)

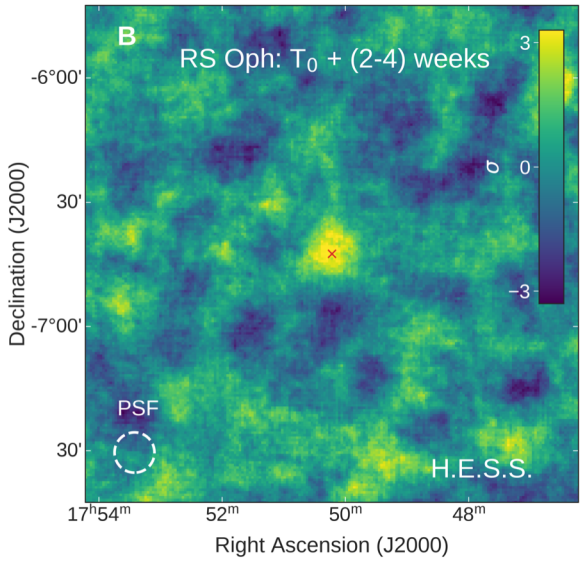
Hadronic scenario preferred





MAGIC collaboration
Nat. Astr. **6** (2022) 689-697





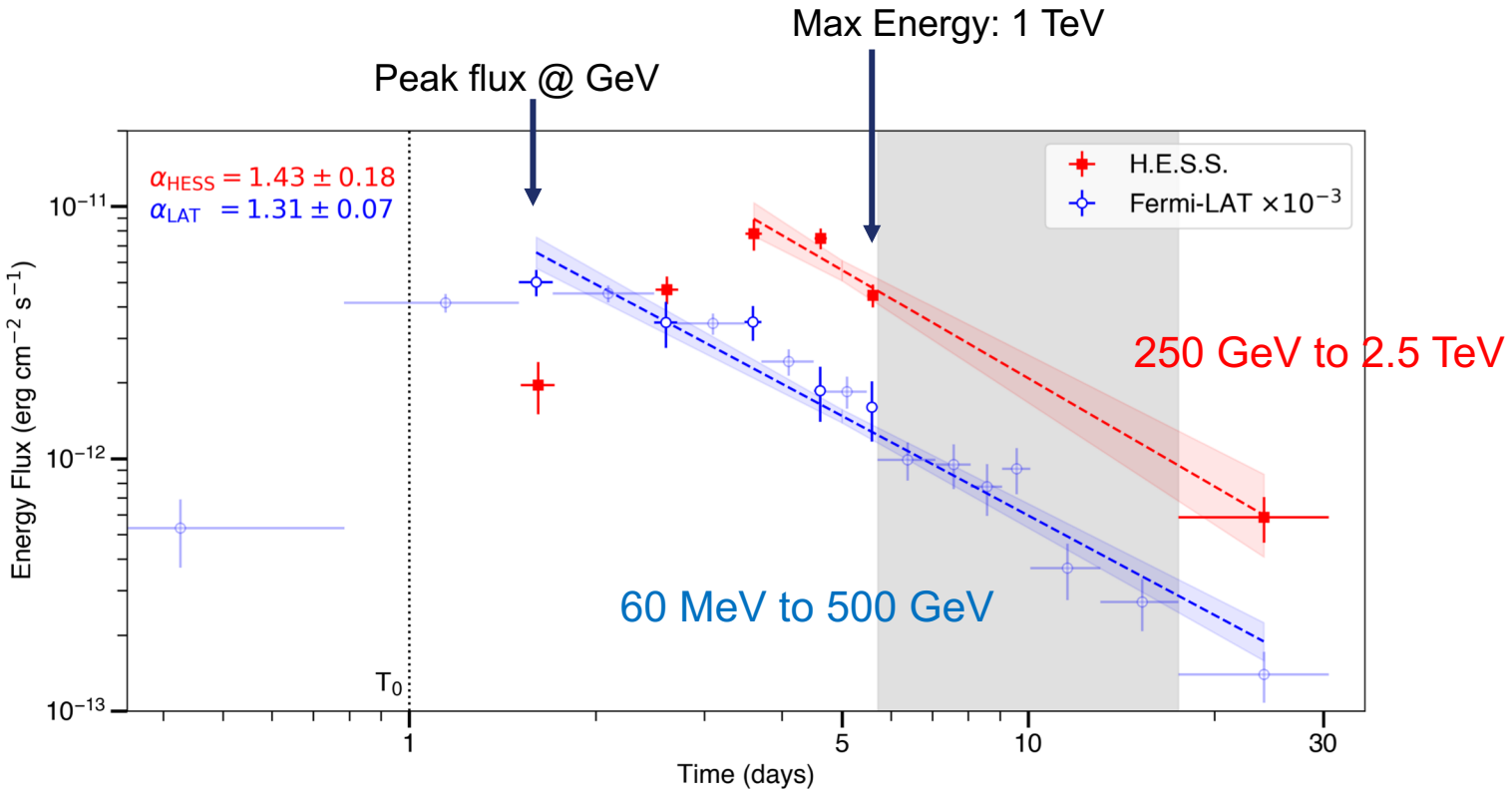
H.E.S.S. collaboration Science **376** (2022) 77-80

Gamma-ray flux decay

Optical peak occurred at T_0 = 59435.25 (MJD)

VHE gamma-ray flux peak seen by H.E.S.S. is delayed with respect to Fermi-LAT

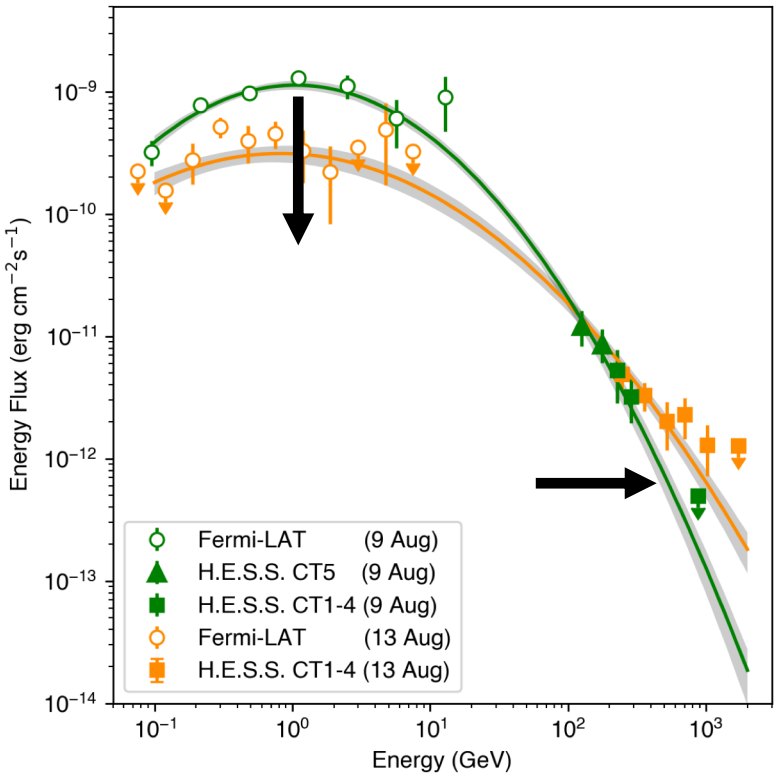
Consistent decay slope after peak flux is attained



It takes time to reach the theoretical maximum energy

Either: cooling limited (leptonic)

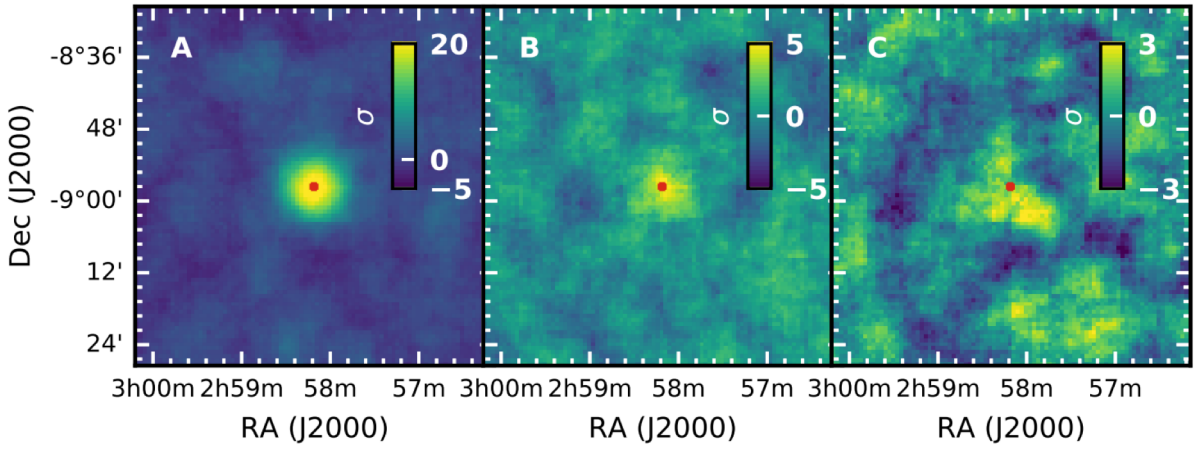
Or: confinement limited (hadronic)
until particles become sufficiently energetic to escape the shock

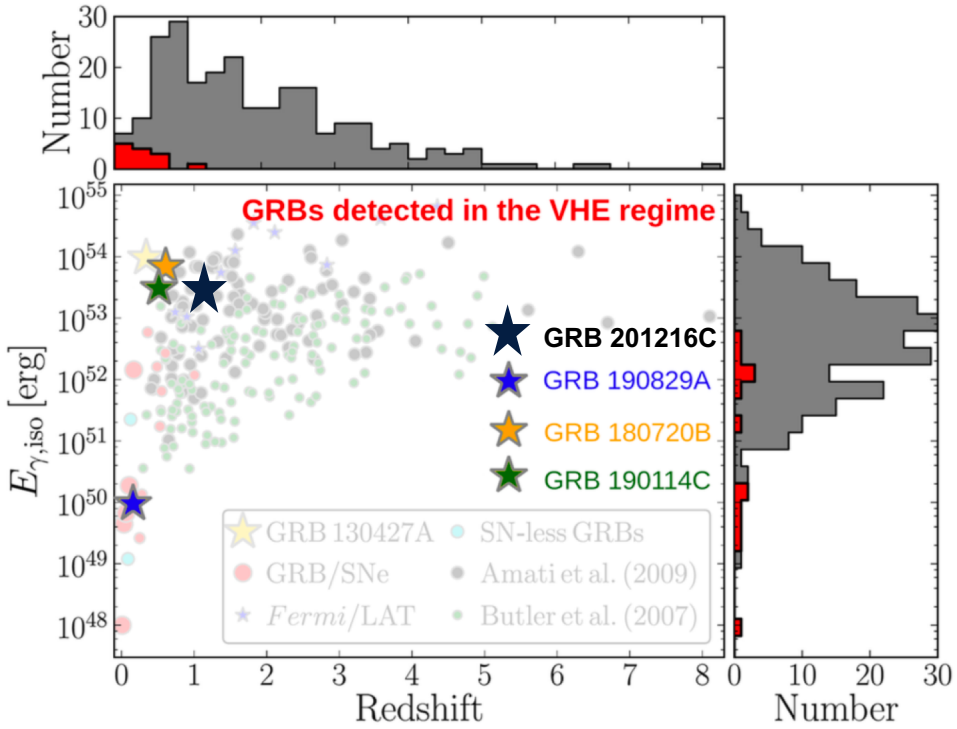


Transients: Gamma-Ray Bursts

First four VHE GRBs detected by H.E.S.S. & MAGIC between 2018 – 2020 (long GRBs, detected during afterglow phase)

- GRB 180720B, z ~ 0.654 (H.E.S.S.)
- GRB 190114C, z ~ 0.4245 (MAGIC)
- GRB 190829A, z ~ 0.08 (H.E.S.S.)
- GRB 201216C, z ~ 1.1 (MAGIC)





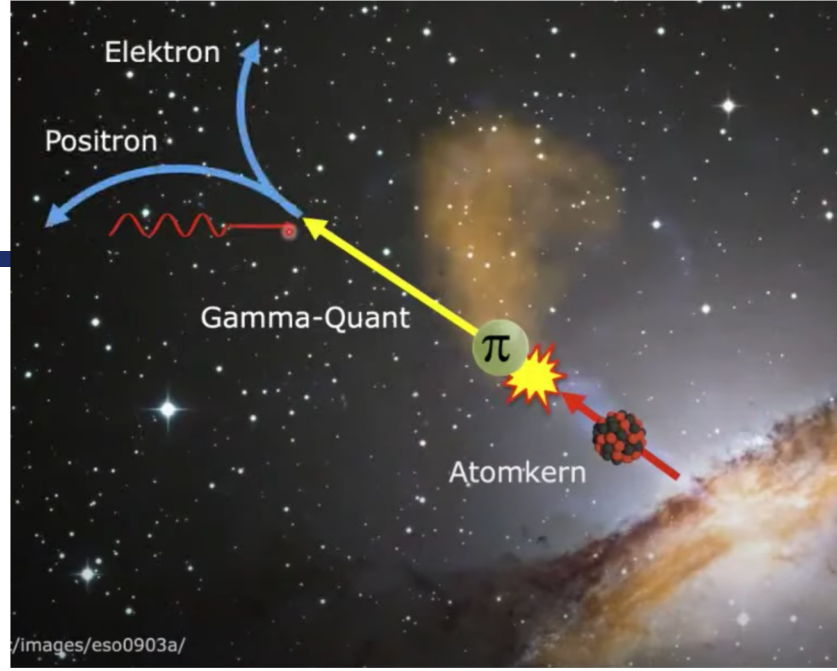
Large distances z ≥ 1 → severe attenuation due to the Extragalactic background light

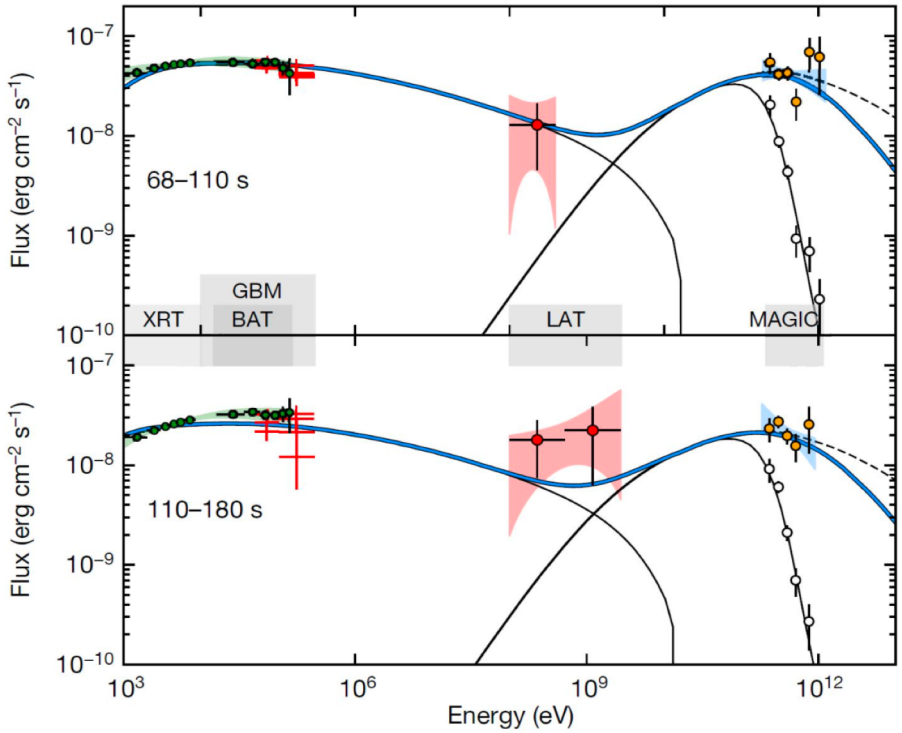
Interactions with EBL → strongly attenuated spectra

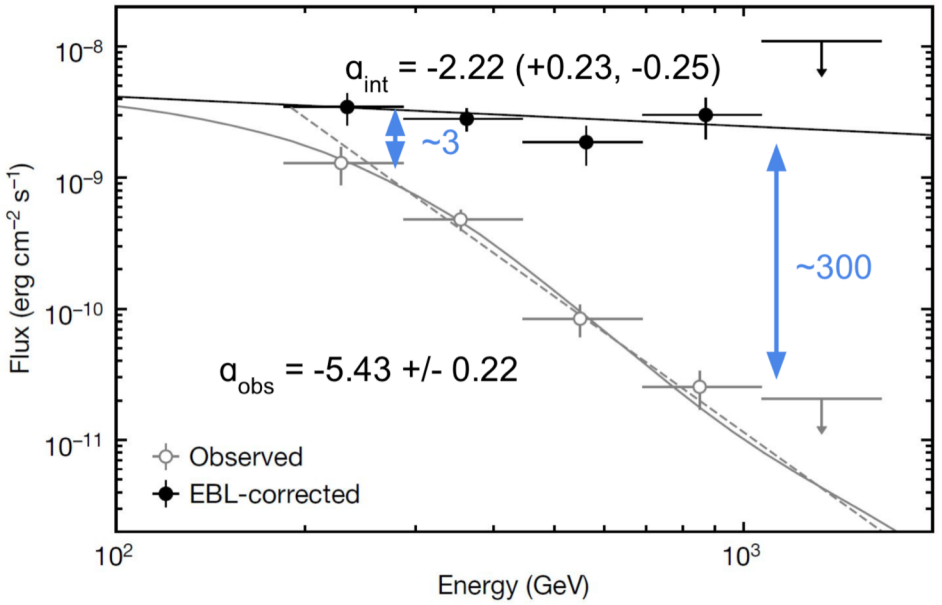
H.E.S.S. collaboration Science **372** (2021) 1081-5

GRB 190114C and EBL absorption

- Synchrotron self-Compton (SSC) component:
  Necessary or not?
- Absorption by Extragalactic Background Light (EBL)
  → large uncertainties on models
  → Need to correct spectrum







GRB 221009A – The BOAT

Brightest of all time

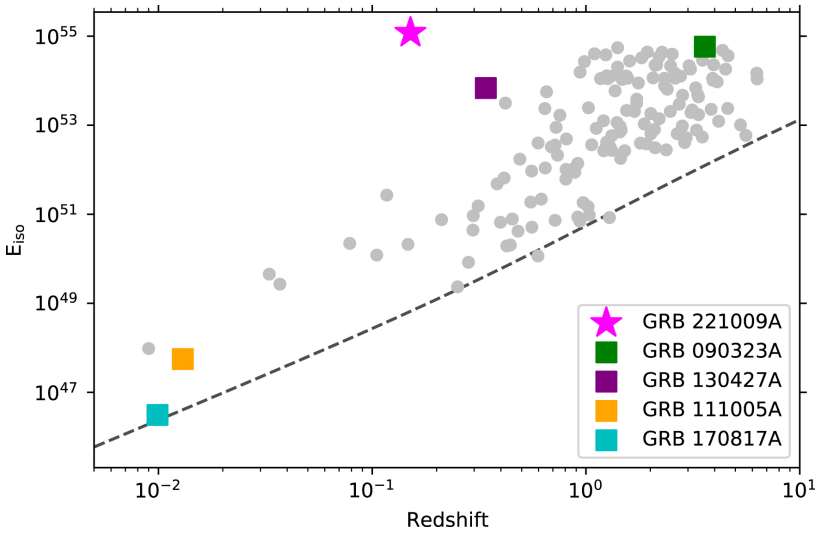
October 9th 2022 – extremely bright GRB (“once in 10,000 years event”)

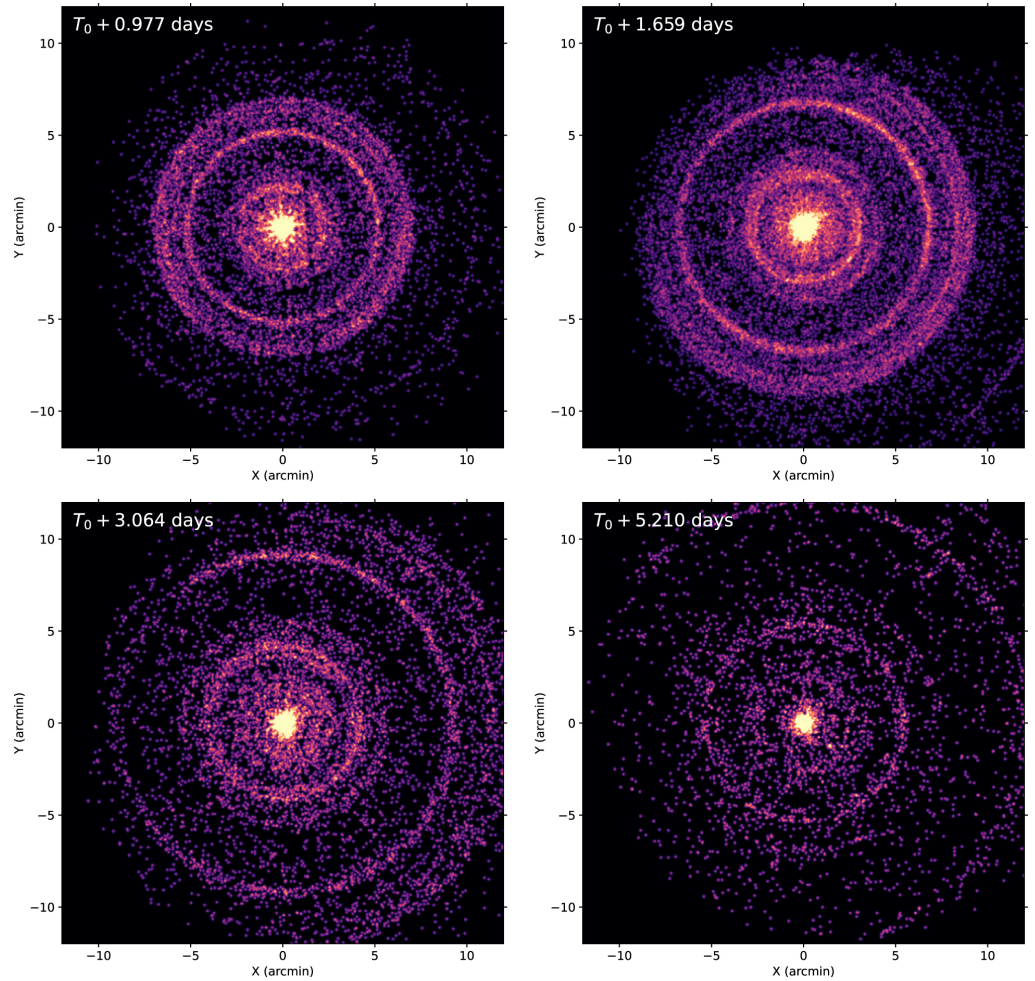
Full moon: no IACT detection ☹

Special collection in ApJLett volume **946** (2023)

Saturated detectors (e.g. SWIFT)

LHAASO detection of > 5000 photons between 0.5 and 18 TeV (!!)
GCN 2677





Transient network

Target of Opportunity (ToO) observations of transient phenomena

Multiwavelength and multi-messenger observations are key to building a complete picture

How to share information rapidly? Alert networks

→ VS-net = Variable Star network

→ ATel = Astronomer's Telegram

→ GCN = General Coordinates Network

→ AAVSO = American Association of Variable Star Observers

→ ZTF = Zwicky Transient Facility

....

Combining all channels?

e.g. https://astro-colibri.science/

astro-colibri

Astro-COLIBRI

Select action | Latest transients | Cone search

Personalize

Status: logged out

Infos: v2.4.0

Observatories: Swift | Fermi | HAWC | IceCube | AMON | Integral | GECAM | FLaapLUC | LVC | other

Event type: FRB | OT | SN | GRB | burst | neutrino | GW | nuem | 4FGL | TeVCAT | SGR/AXP

2023-04-23 — 2023-05-08

04-23 04-24 04-25 04-26 04-27 04-28 04-29 04-30 05-01 05-02 05-03 05-04 05-05 05-06 05-07 05-08

GRB 230506C
Gamma-ray burst
RA/Dec: 134.37°/45.13° (± 0.05°)
2023-05-06 17:09:19

Gamma-ray burst
RA/Dec: 133.37°/42.86° (± 1.59°)
2023-05-06 17:09:16

IceCube-230506A
Neutrino
RA/Dec: 50.19°/21.06° (± 3.12°)
2023-05-06 15:53:45

GRB 230506B
Gamma-ray burst
RA/Dec: 326.98°/44.51° (± <0.00°)
2023-05-06 12:45:18

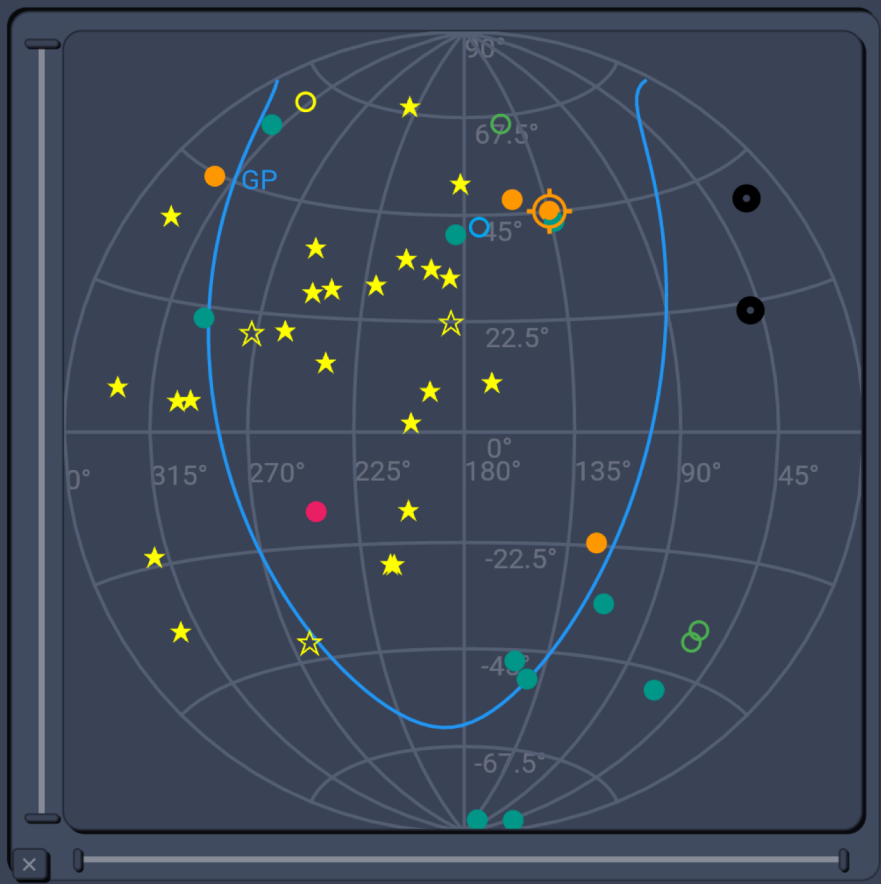
GRB 230506A
Gamma-ray burst
RA/Dec: 296.12°/20.41° (± 1.65°)

GRB 230506C
Gamma-ray burst

Cone search

Custom cone search

RA / Dec: 134.37° 45.13°
source: GRB 230506C
radius: 1°



RA : 8h57m29.57s Dec : 45d7m32.16s
error [deg] : 0.0500
observatory: Swift instrument: BAT
notice: BAT_GRB_Pos
Photometry:

Search for ATels!

Get Swift-XRT lightcurve

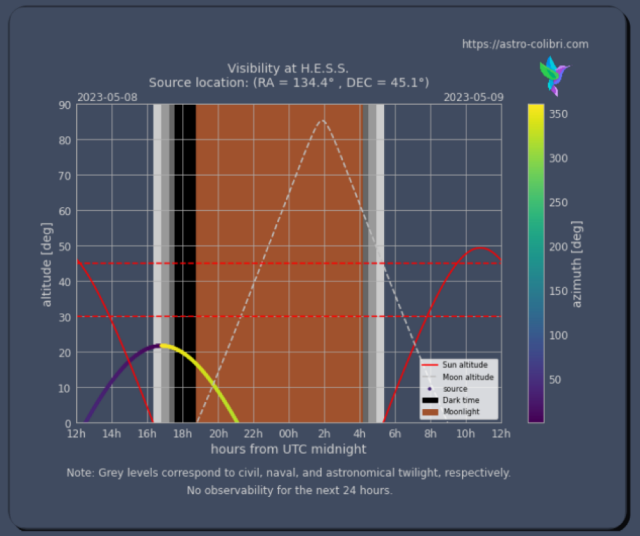
visibility: 2023-05-08

Daily

Monthly

weather: forecast seeing

sky view: HeavensAbove



Links for further details — auto scroll

GCN-n
GCN notices: rapid alert message

GCN-c
GCN circulars: announcements of new transient events

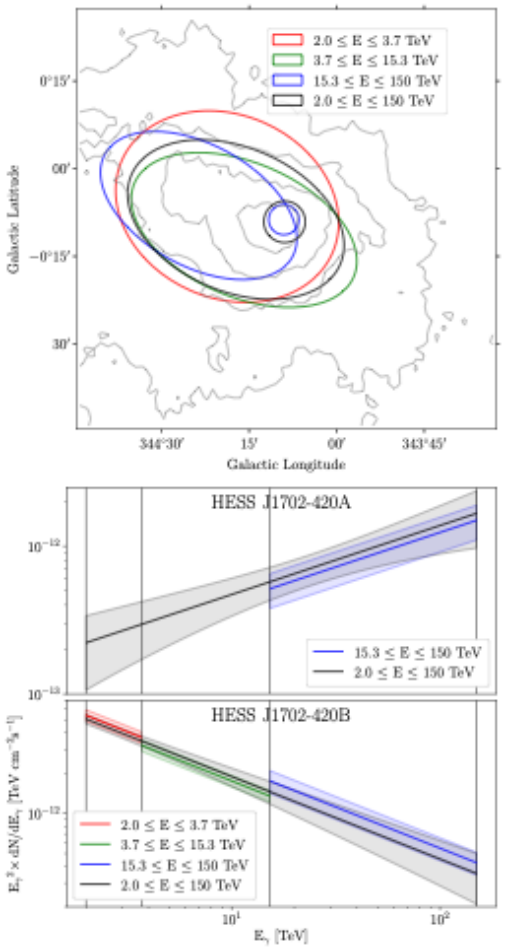
Swift
Overview of this Swift detected GRB

BAT
Analysis results of Swift-BAT

XRT
Analysis results of Swift-XRT

Gammapy ($\gamma\pi$) and 3D analysis approaches

A **Python** package for **gamma-ray** astronomy



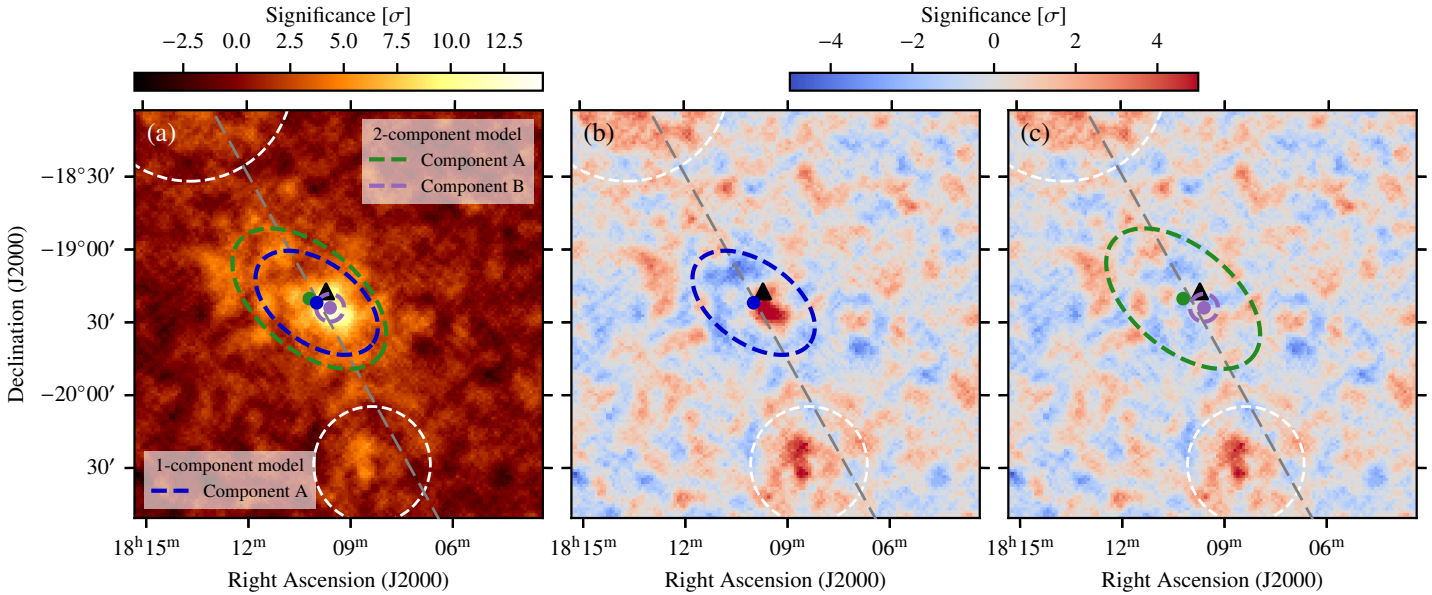
HESS Collaboration A&A **653** (2021) A152

3D analysis fitting:
→ enabling multiple components to be simultaneously fit in spatial and energy dimensions

Especially powerful for studies of complex regions or sources with complex morphology

Examples: HESS J1702-420, HESS J1809-193...

https://gammapy.org/



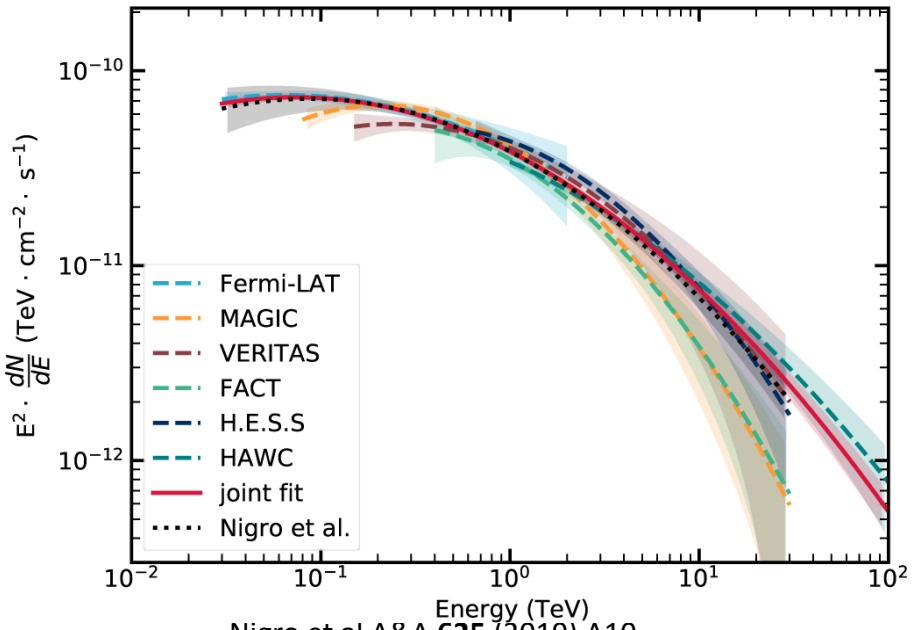
HESS Collaboration A&A **672** (2023) A103

Multi-instrument joint analyses

Common formats enable data from multiple instruments to be analysed simultaneously (GADF: gamma-astro-data-formats)

Incl. KM3NET (see T. Unbehaun tutorial)

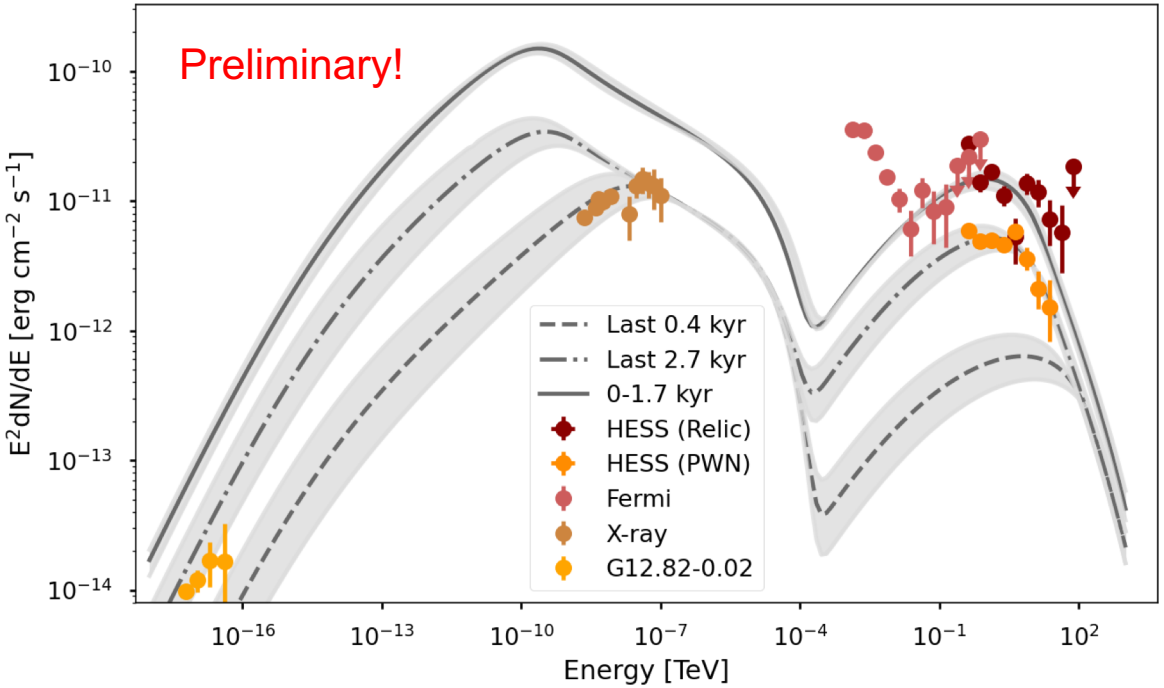
e.g. Multi-instrument fit to the Crab nebula spectrum: calibration source for VHE gamma-rays



Nigro et al A&A **625** (2019) A10

HAWC collaboration A&A **667** (2022) A36

Simultaneous 3D fitting of data from multiple instruments e.g. Fermi-LAT and H.E.S.S. for HESS J1813-178 (T. Wach)

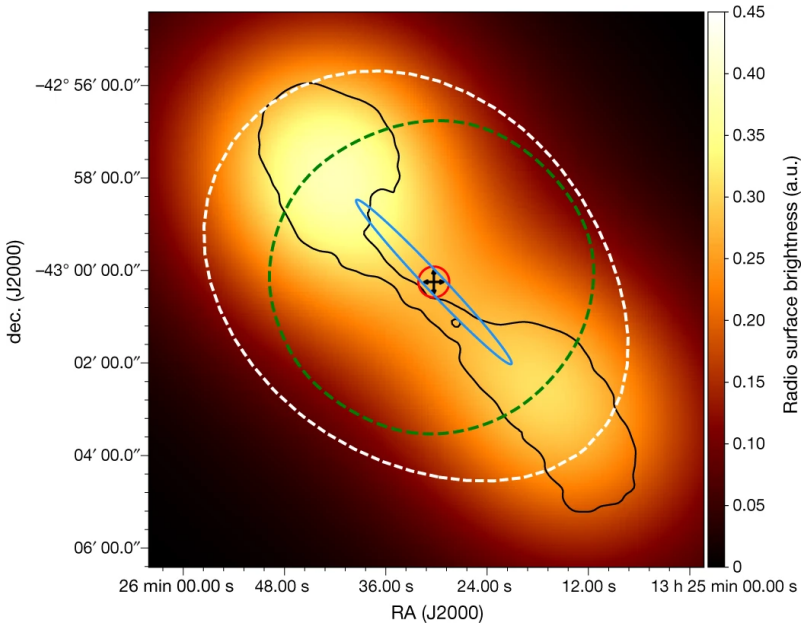


Active Galactic Nuclei: flaring activity, neutrinos?

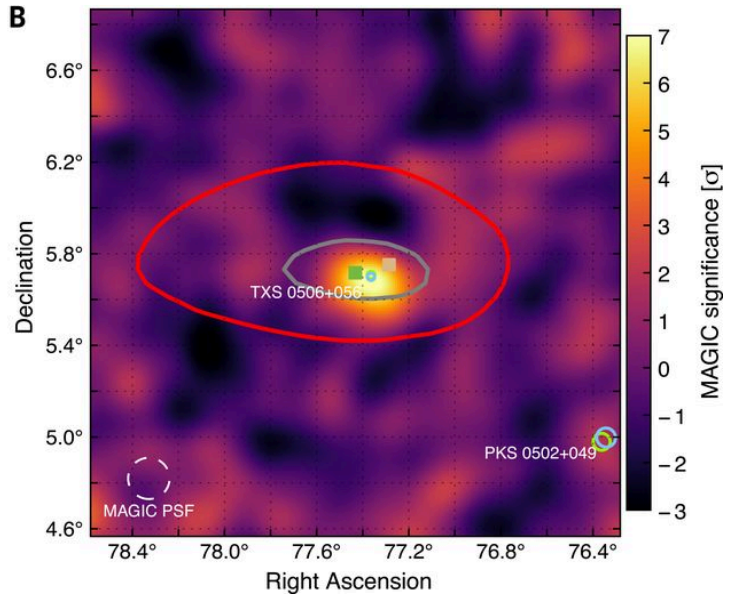
Majority of extragalactic sources – blazars

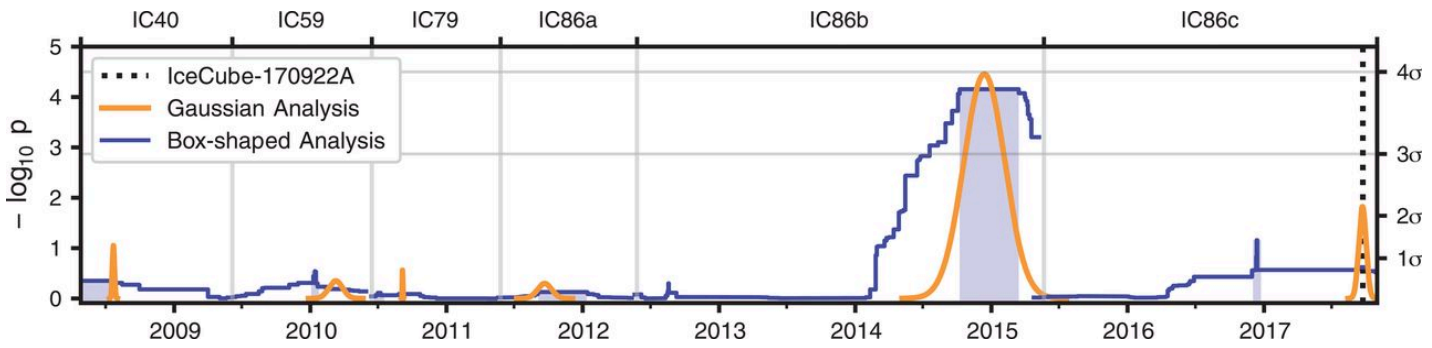
First indications of a neutrino source: TXS 0506+056 (z=0.3365)
Associated gamma-ray detection of flaring activity by Fermi-LAT & MAGIC
Chance coincidence disfavoured at ~3 sigma → **Multi-messenger astronomy**

Resolving extension of Centaurus A jets ≥ 2.2 kpc



H.E.S.S. collaboration Nature **582** (2020) 356-359





Science **361** (2018) eaat1378

Science **361** (2018) 147-151

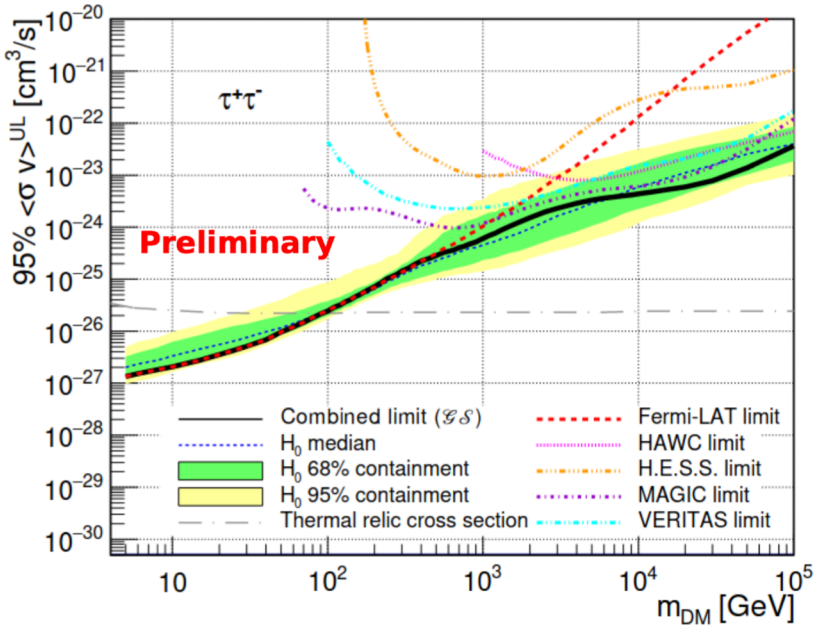
Searching for Dark Matter

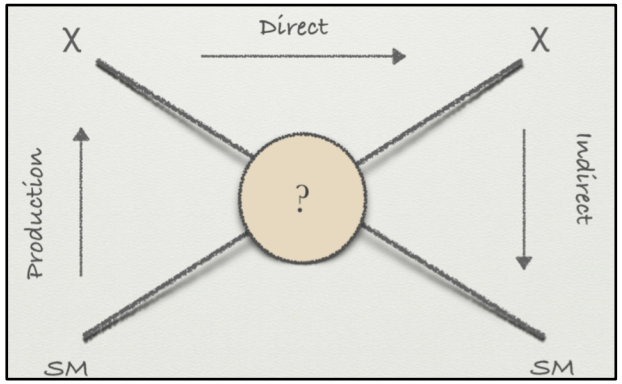
Dark Matter upper limits from observations of dwarf spheroidal galaxies

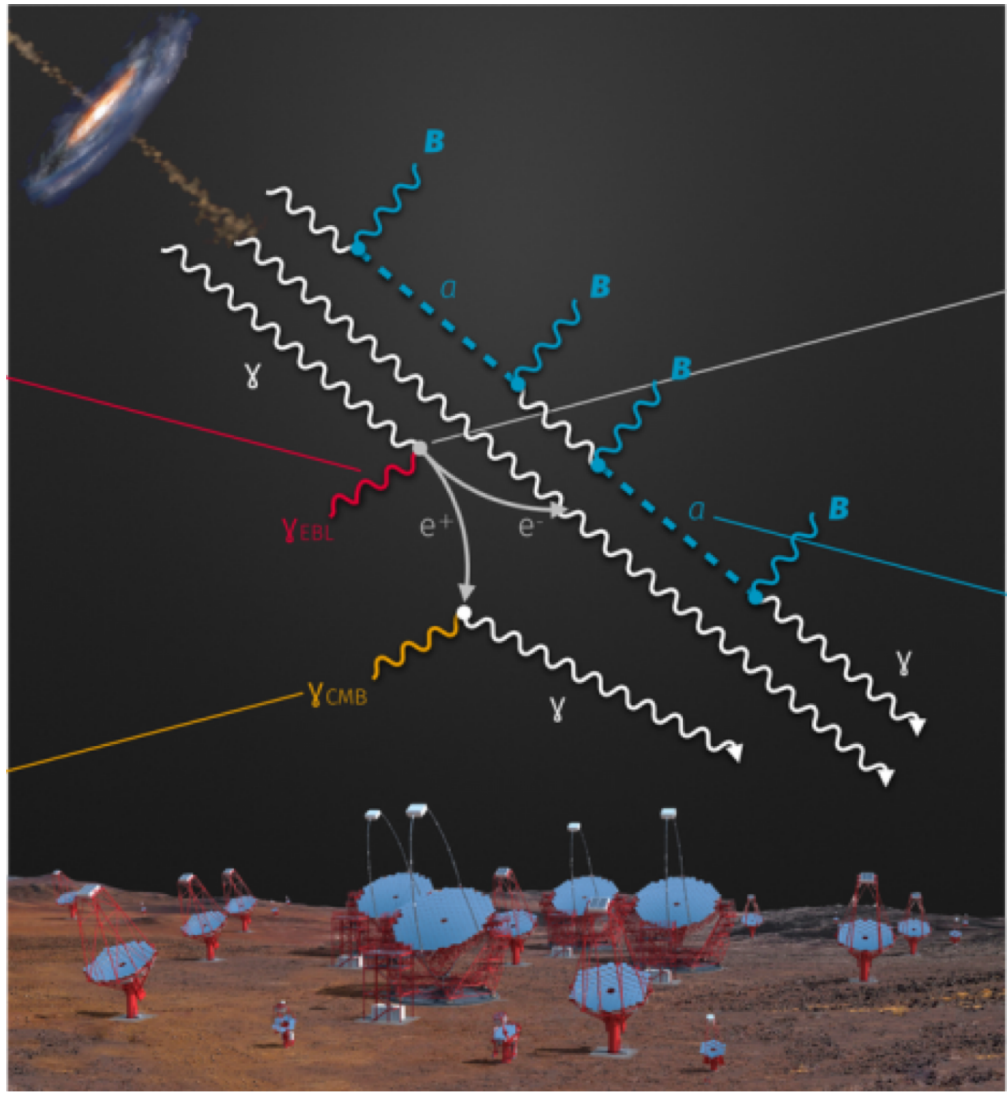
Combined likelihood more constraining

Other targets: Galactic centre, Galaxy clusters...

Other DM candidates: Axions → modify gamma-ray spectrum
via a boost at high energies / reduction in EBL absorption







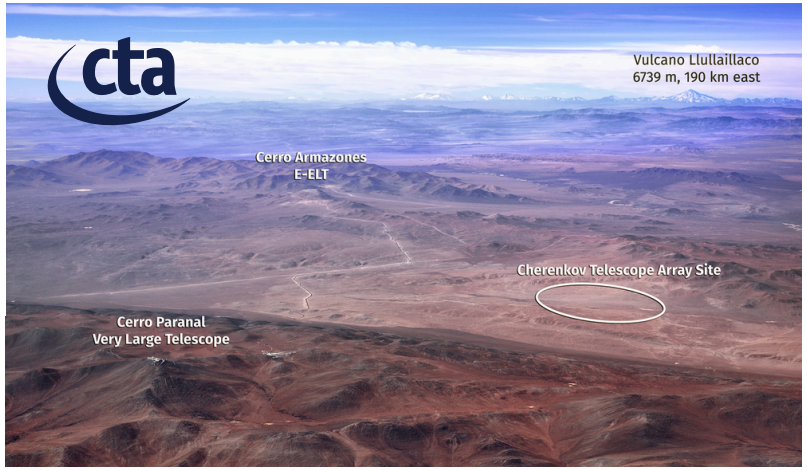
Biteau & Meyer https://www.cta-observatory.org/what-propogation-of-energetic-light-can-tell-us/

Future for IACTs

Current generation IACTs continue to make discoveries

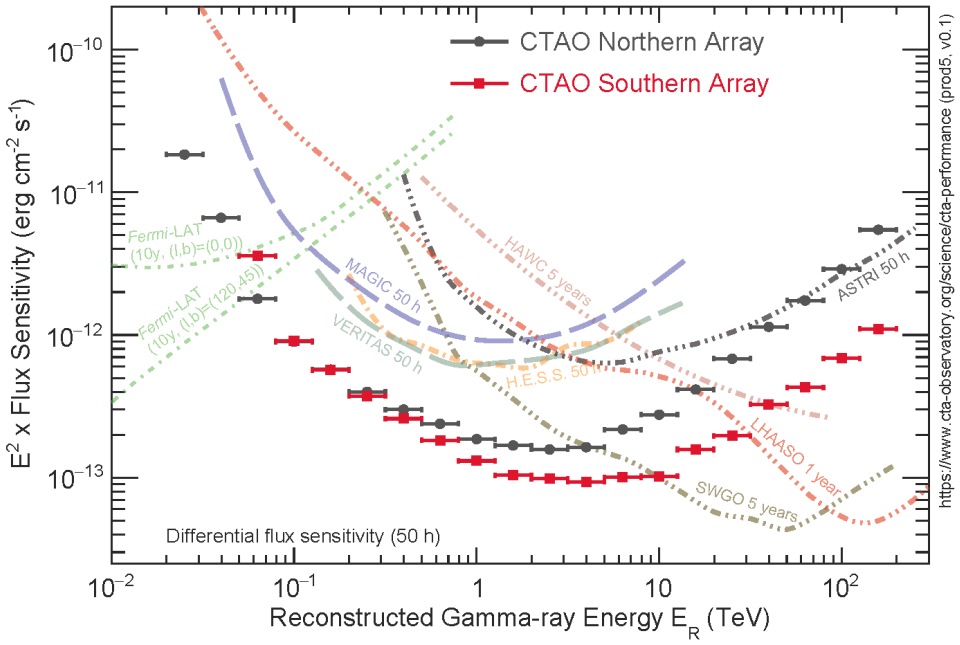
→ New source classes at TeV energies

First alert from a CTA telescope:
LST detects flaring activity from BL Lacertae (Atel 14783, 2021)



<u>Forthcoming IACT facilities:</u>

→ CTA-North La Palma, Spain
→ CTA-South Paranal, Chile
→ ASTRI mini-array Tenerife,



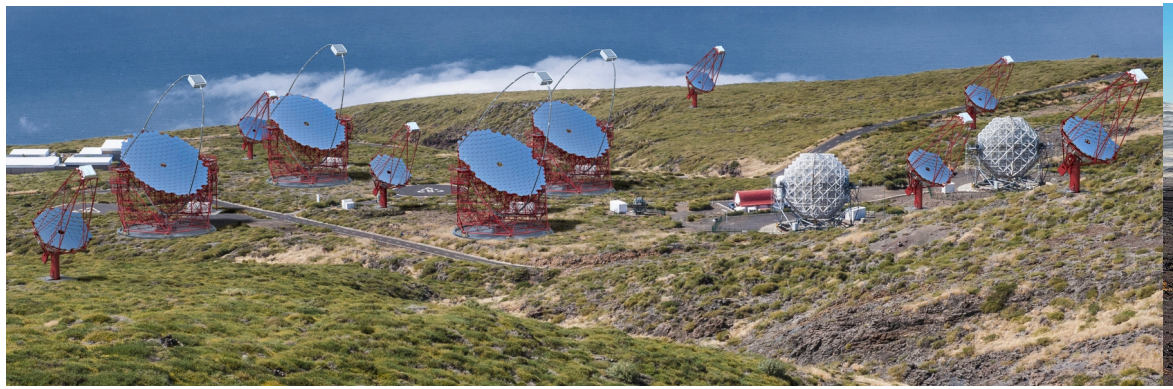
Strengths of IACTs:

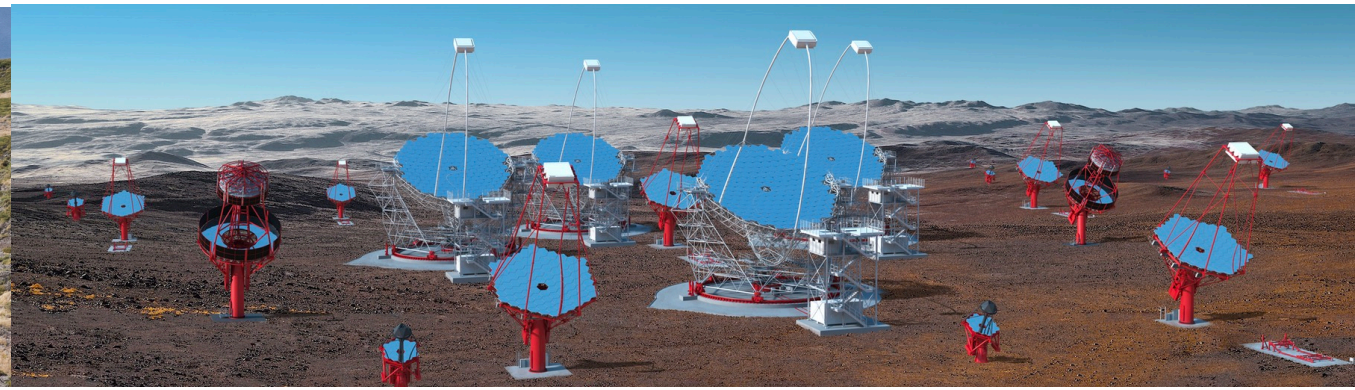
→ Good angular and energy resolution

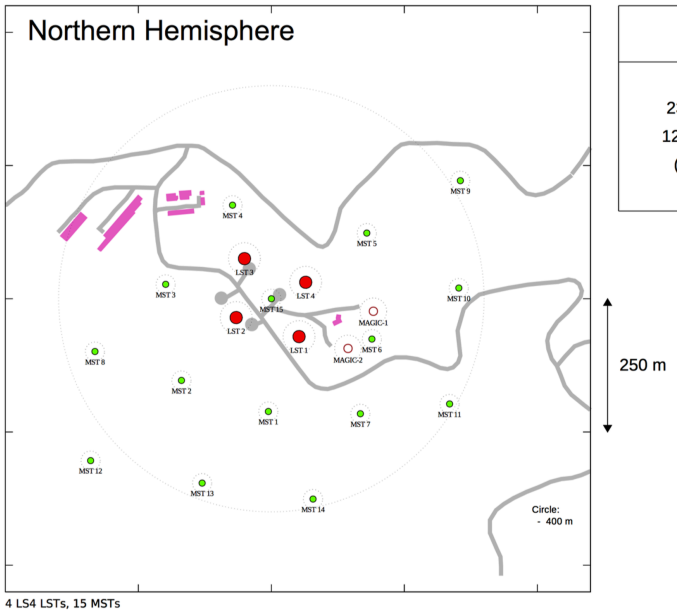
→ Reaction and sensitivity to transient phenomena

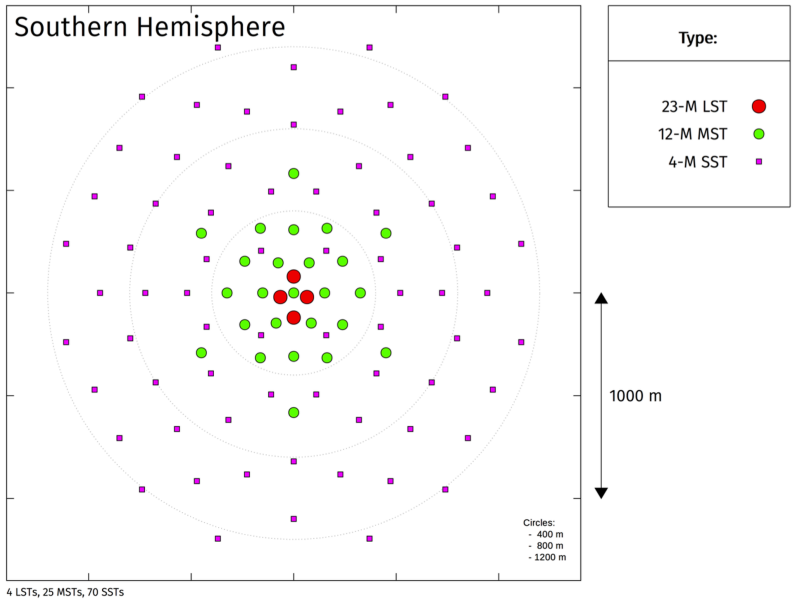
Cherenkov Telescope Array

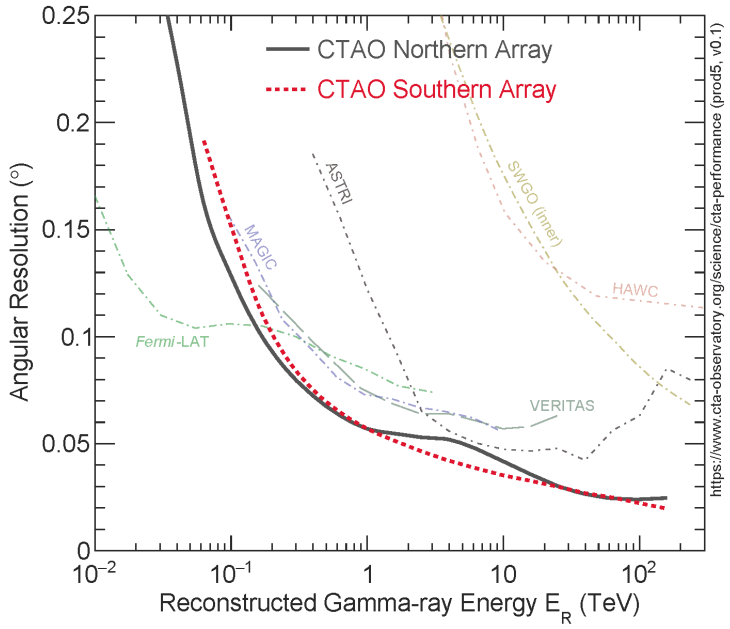
https://www.cta-observatory.org/







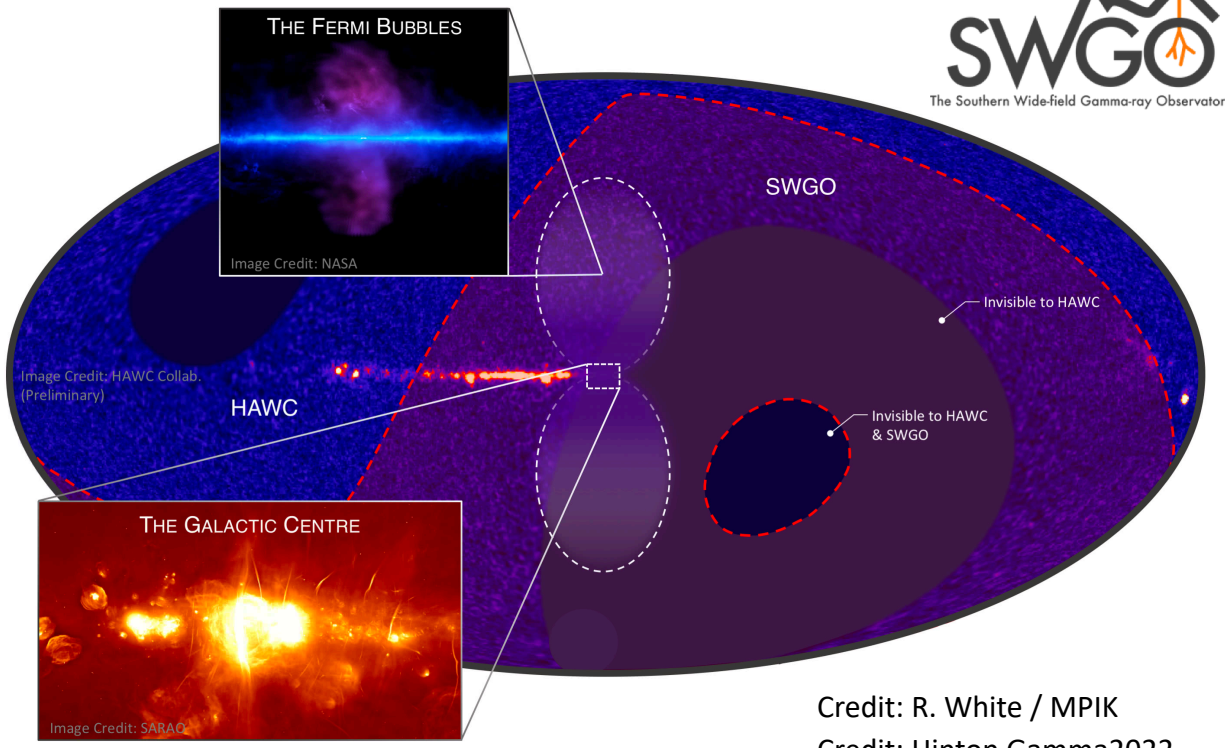




Southern Wide-field Gamma-ray Observatory

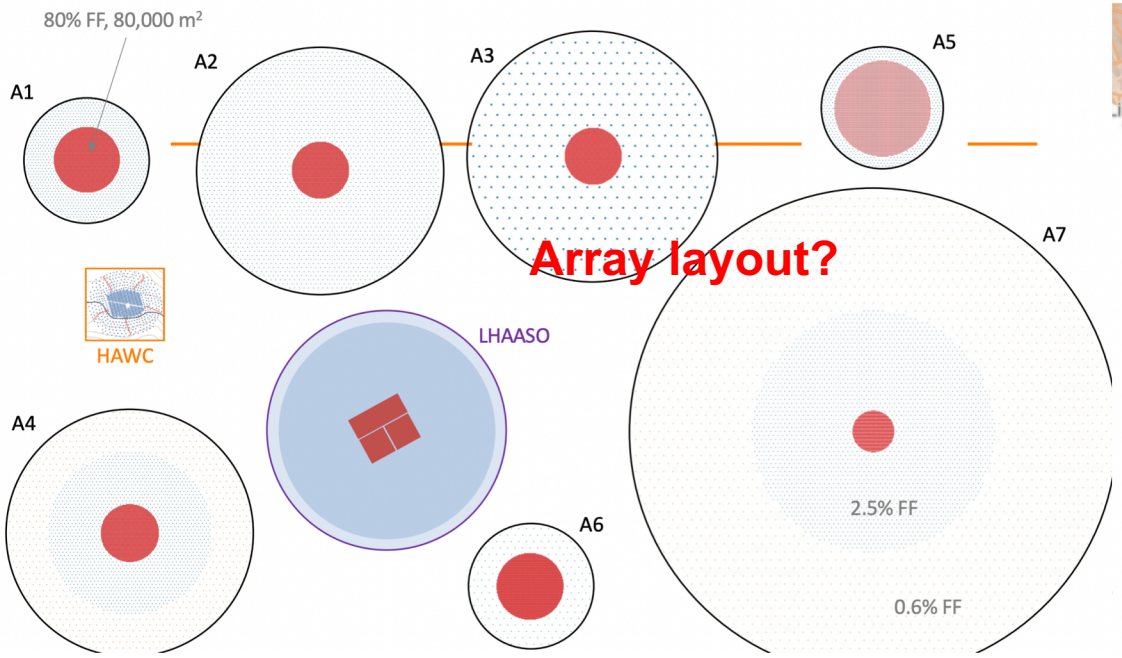
https://www.swgo.org/

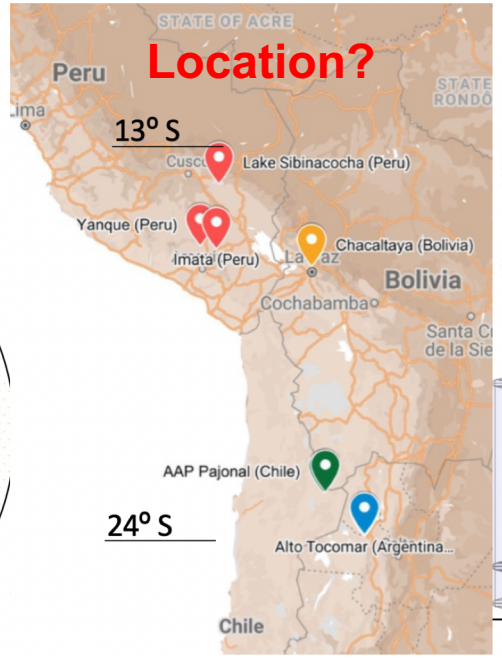
- Ground-based water Cherenkov detectors are well suited to the highest energies and full sky surveys.
- Impressive results from current experiments (HAWC, LHAASO...)
- Future → observe the Southern sky
- (Galactic Science for SWGO → E.O. Angüner & AM)

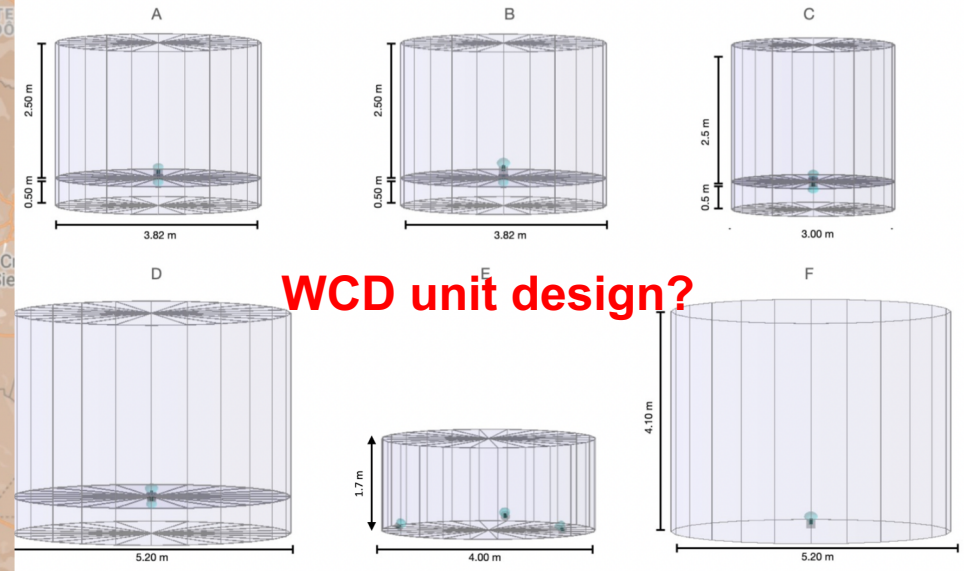


Credit: R. White / MPIK

Credit: Hinton Gamma2022







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Thank you for your attention

PhD position → Apply by 10th June!

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