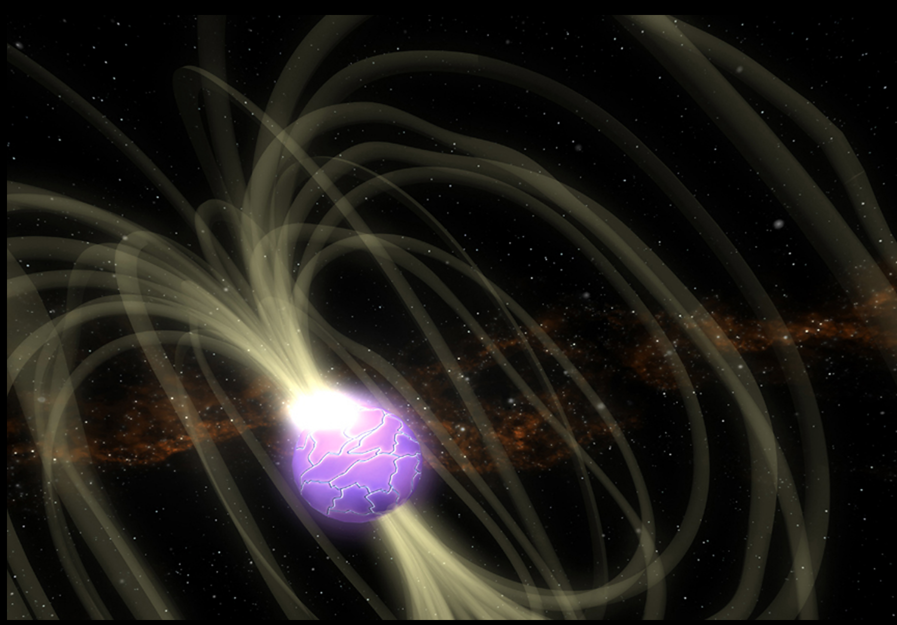
Extreme Galactic Particle Accelerators

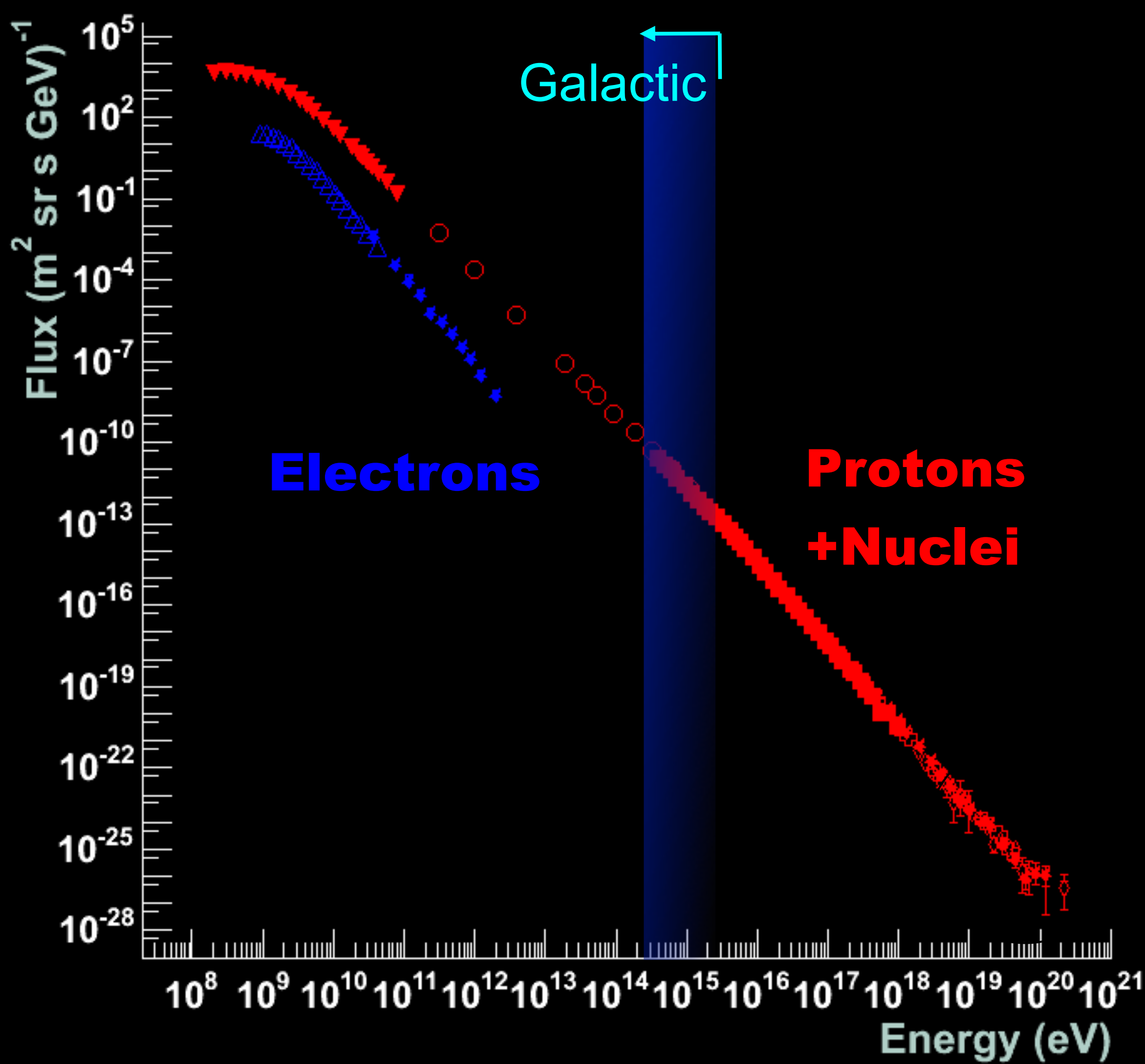
The case of HESS J1640-465



Stefan Ohm (Univ. of Leicester),
Peter Eger, for the H.E.S.S. Collaboration

High-energy particles in space

- Why are they important?
  - energy density of is comparable to star light, CMB, and interstellar B-fields
  - impact on star-formation process (chemistry in dense molecular clouds)
  - source of ionisation in the Galaxy
  - form significant contribution to the pressure in many astrophysical sources (e.g. SNRs, AGN)



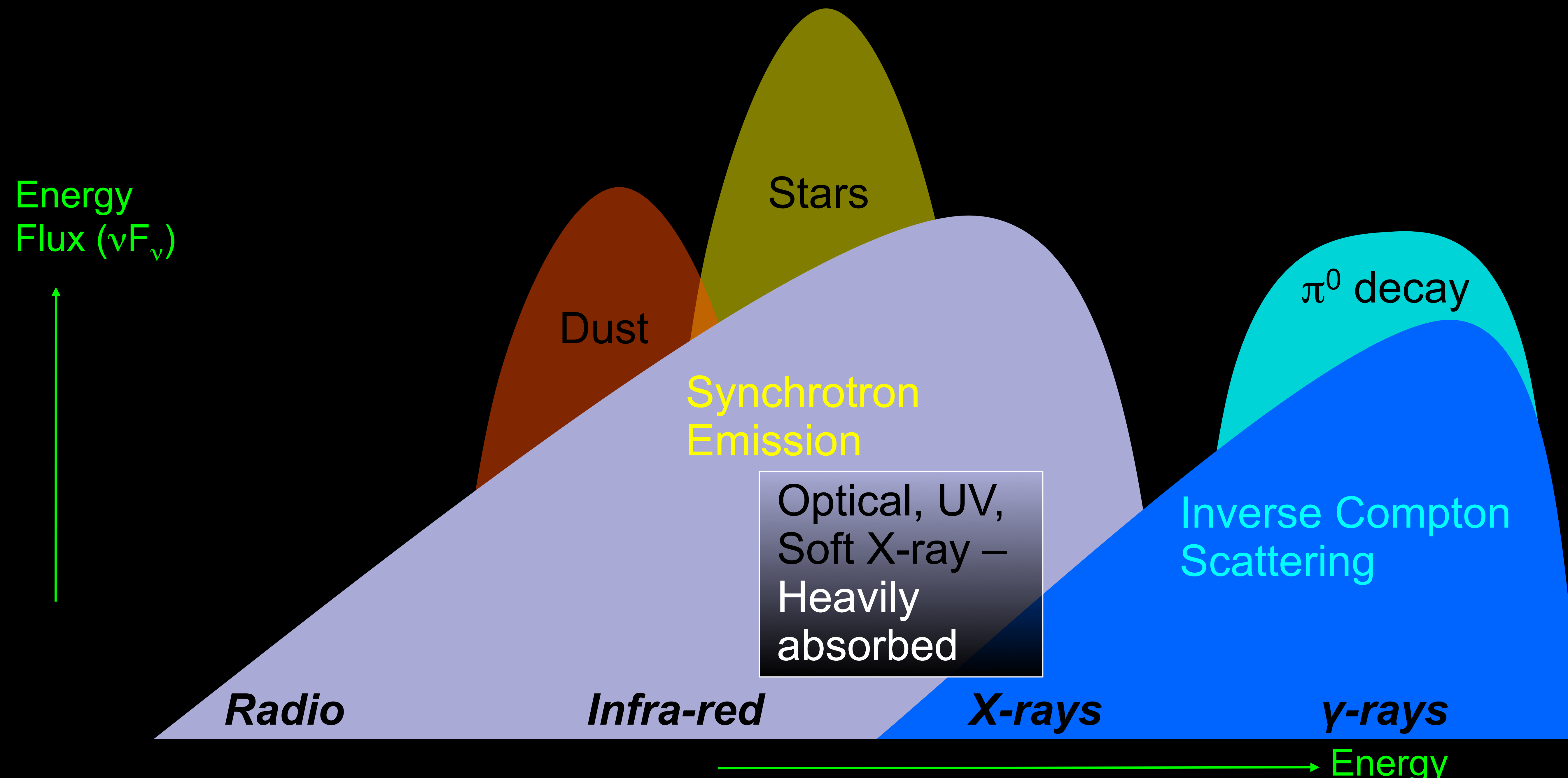
- Properties of cosmic rays
  - spectrum follows a power law in energy
  - >10 decades in energy, >30 decades in flux
  - produced by acceleration of particles
  - SNR shells likely acceleration site of CRs up to the “knee” (~3 x 10^{15} eV!)

How can we find the accelerators?

→ Neutral messenger particles (photons and neutrinos)

Non-Thermal Radiation

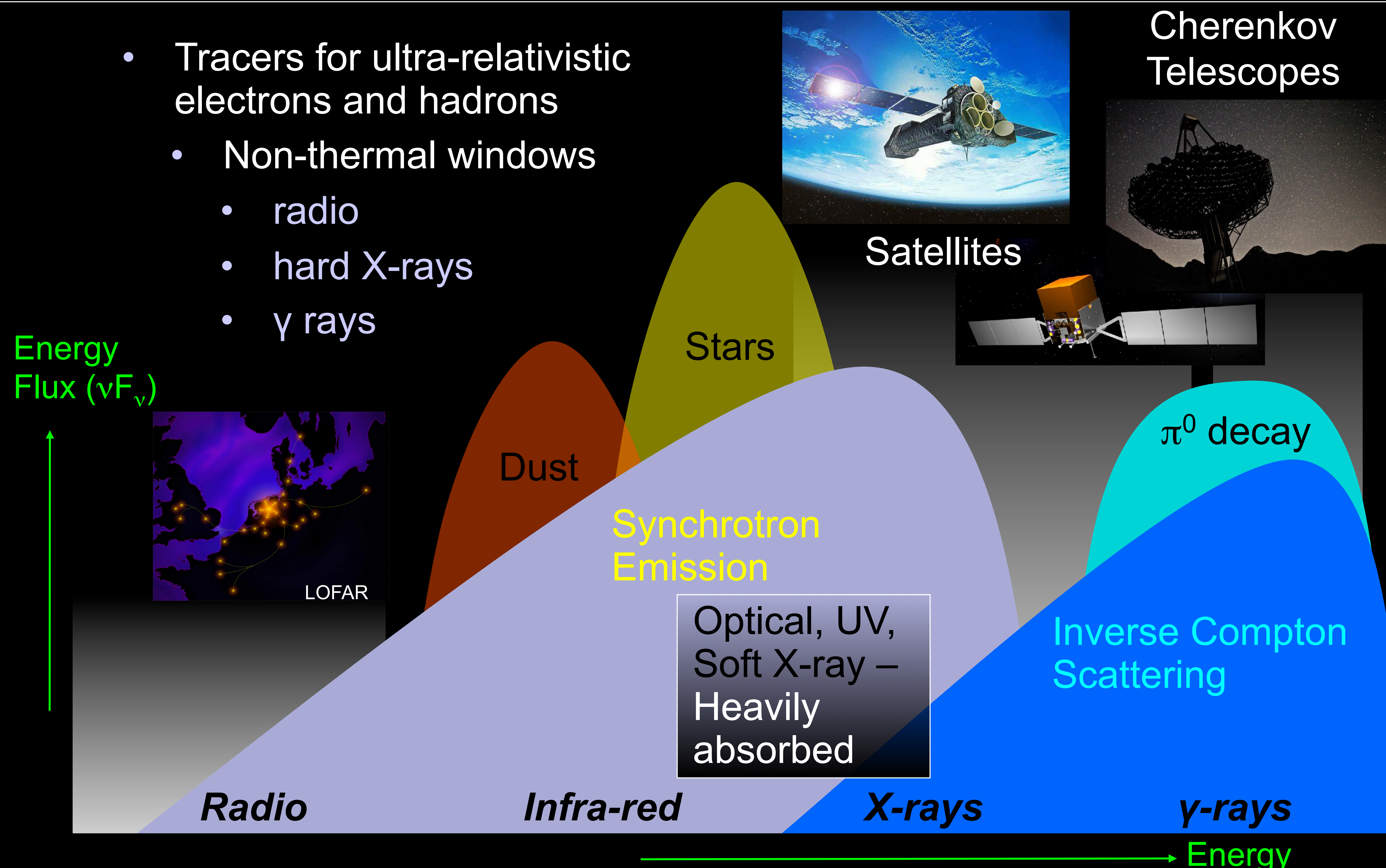
- Tracers for ultra-relativistic electrons and hadrons



adapted from W. Hofmann

Non-Thermal ‘Windows’

- Tracers for ultra-relativistic electrons and hadrons
  - Non-thermal windows
    - radio
    - hard X-rays
    - γ rays



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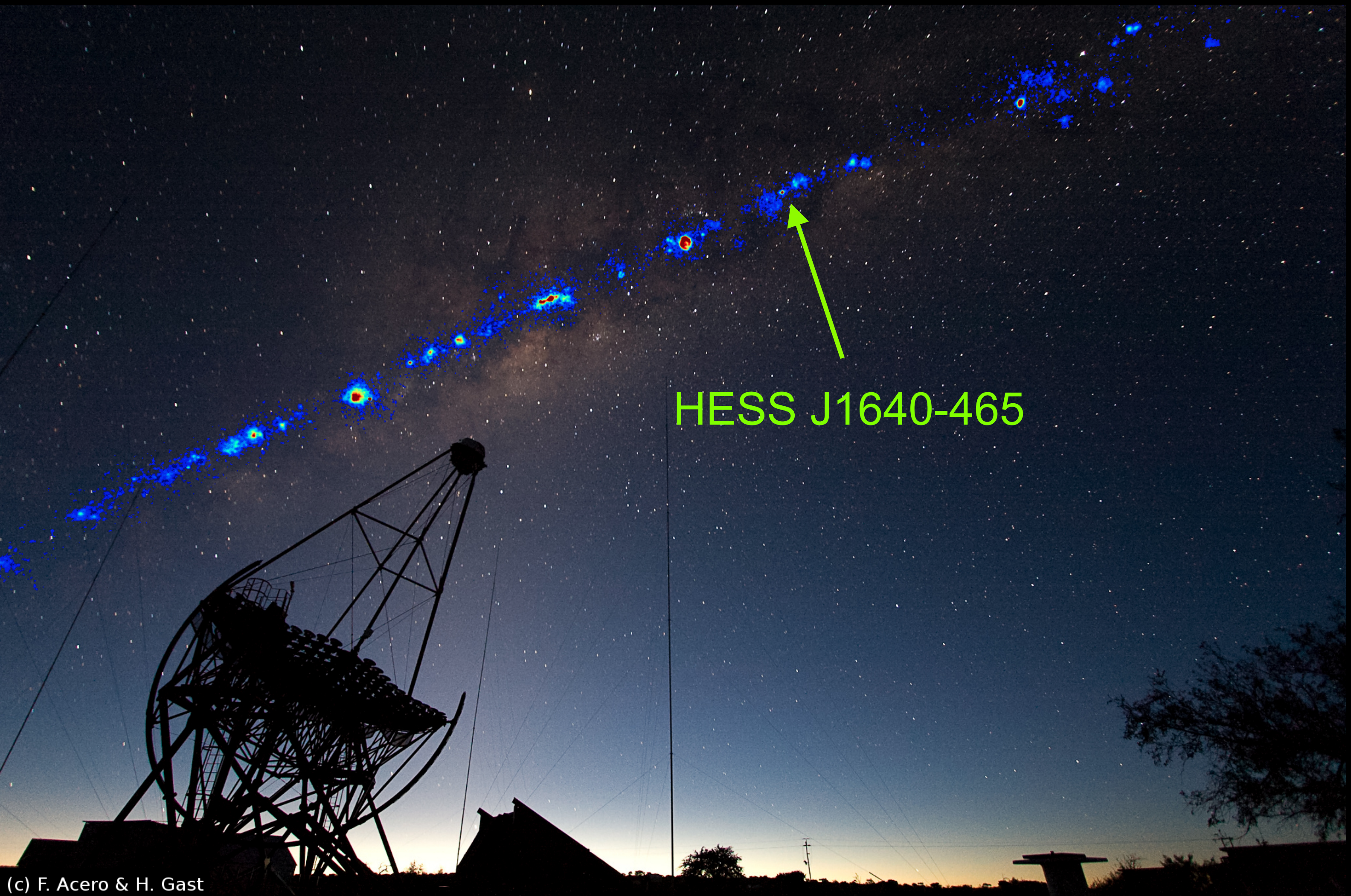
The H.E.S.S. telescope array

Key Parameters

- 5 imaging atmospheric Cherenkov telescopes located in Namibia
- Energy range: ~100 GeV - ~50 TeV
- Angular resolution: ~0.1º
- Energy Resolution: ~15%
- Field-of-View: 5º



Success of H.E.S.S.

- Stereoscopic approach (γ/hadron separation, sensitivity, energy resolution, ...)
- Southern hemisphere location (see inner Galaxy)

Galactic VHE γ-ray sources

- cluster tightly along the Galactic plane
- Trace molecular gas and regions of massive star formation
- Many sources coincident with objects at late evolutionary stages:

→ Pulsar Wind Nebulae (1/4)

→ Shell-type SNRs or SNR – MC interaction regions (1/5)

→ γ-ray binaries, stellar cluster

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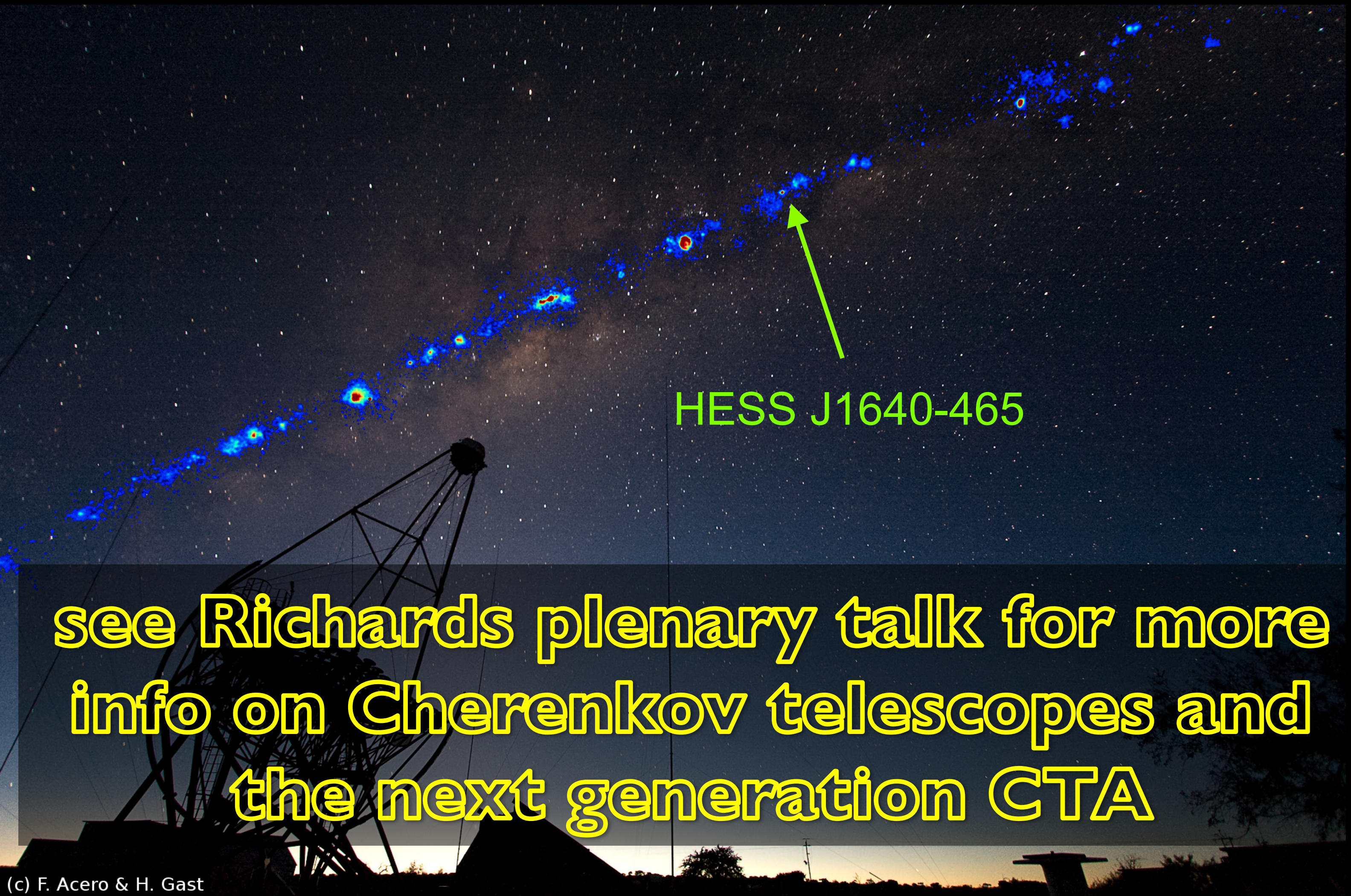

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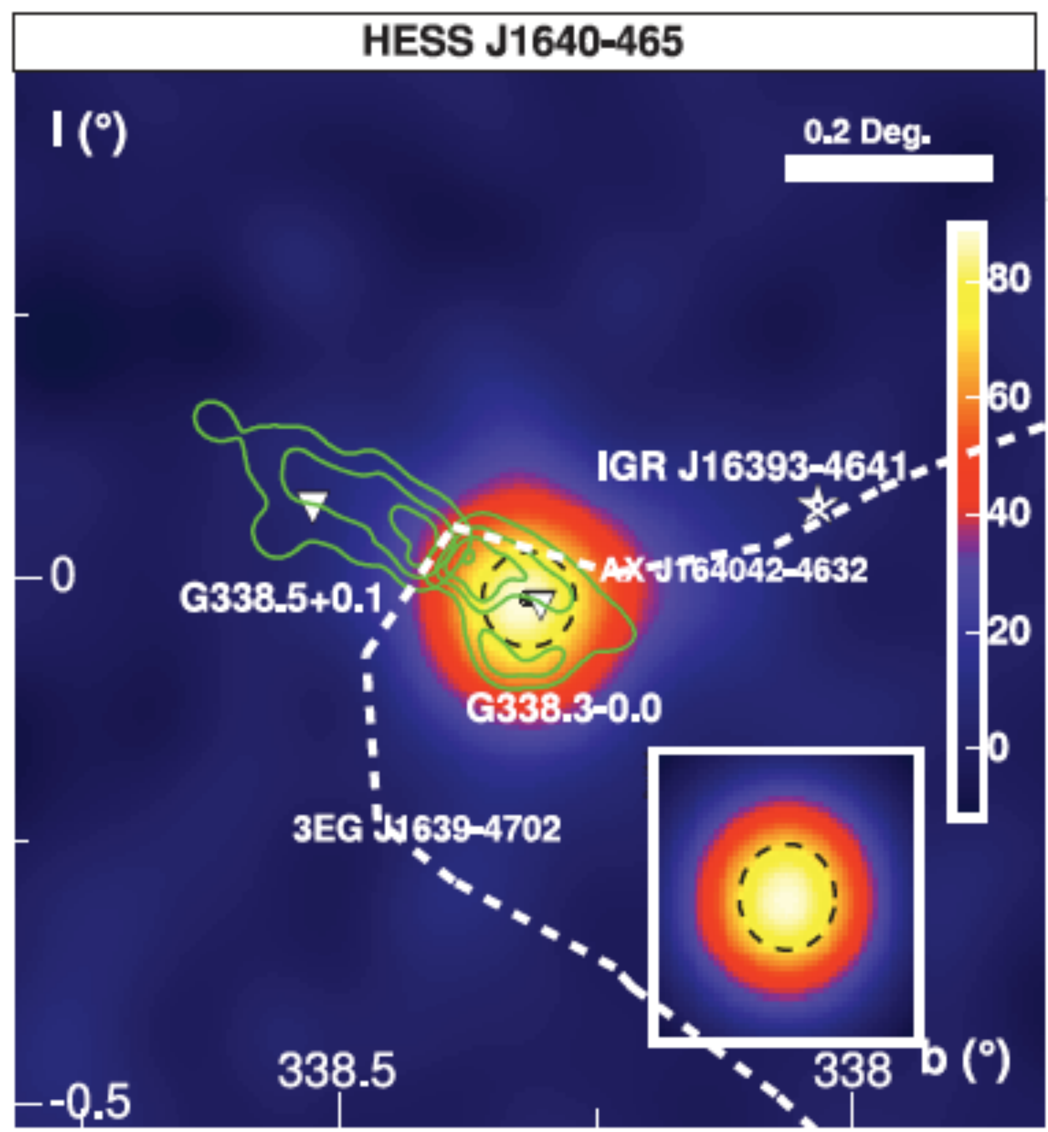
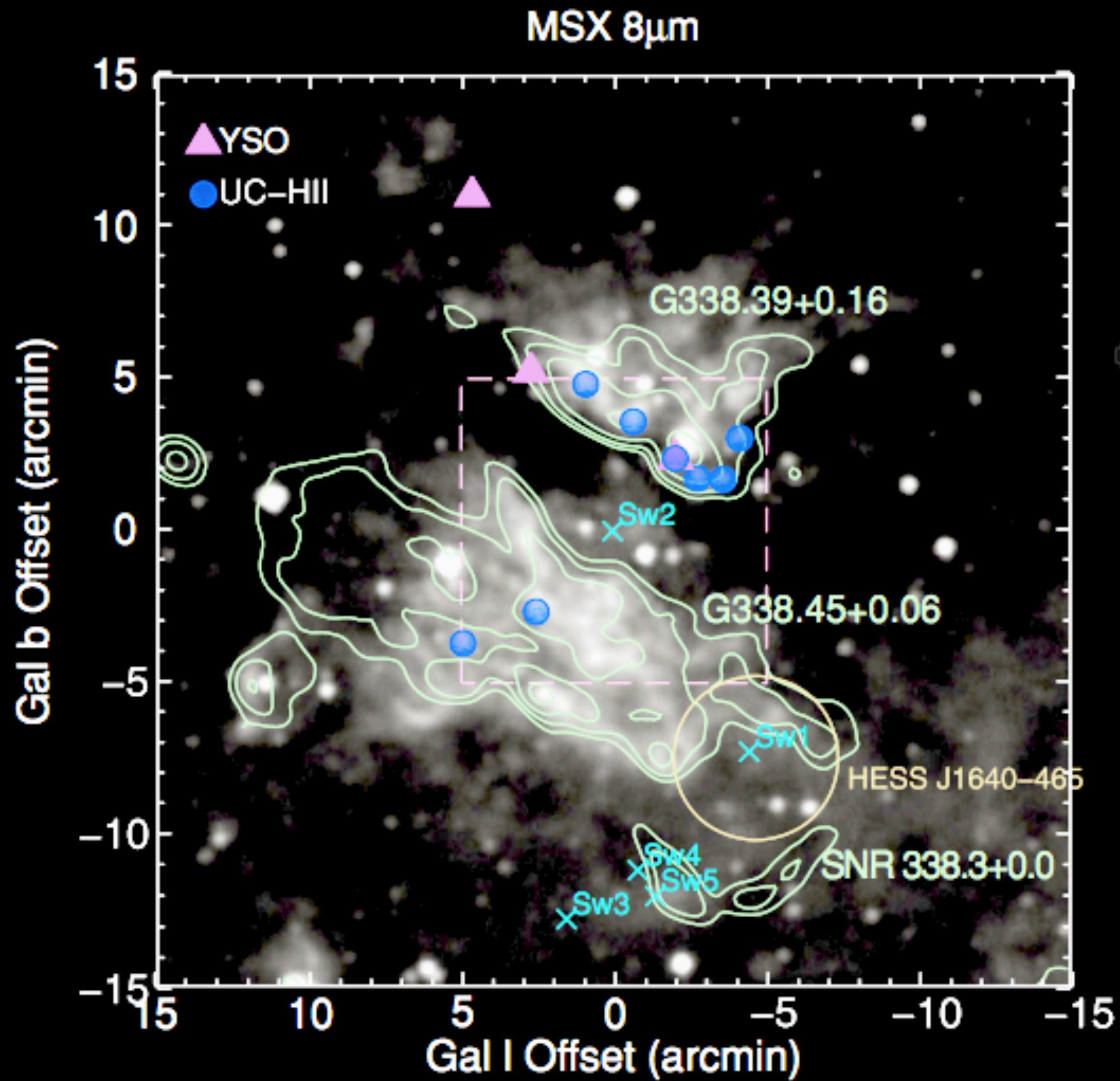
HESS J1640-465

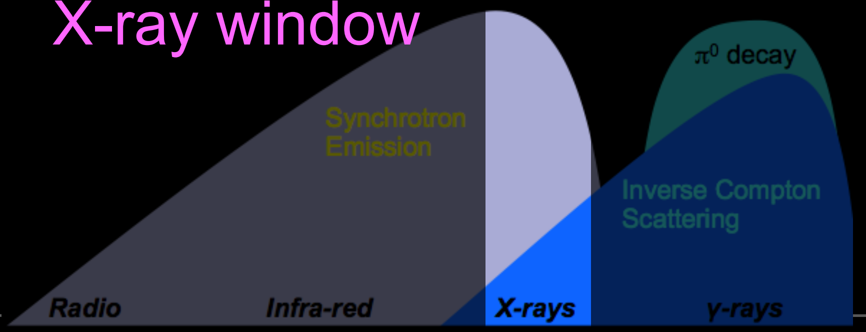
- HESS source
  - discovered in Galactic Plane Scan (2005)
  - rather compact, strong γ-ray emitter
  - coincident with SNR G338.3-0.0





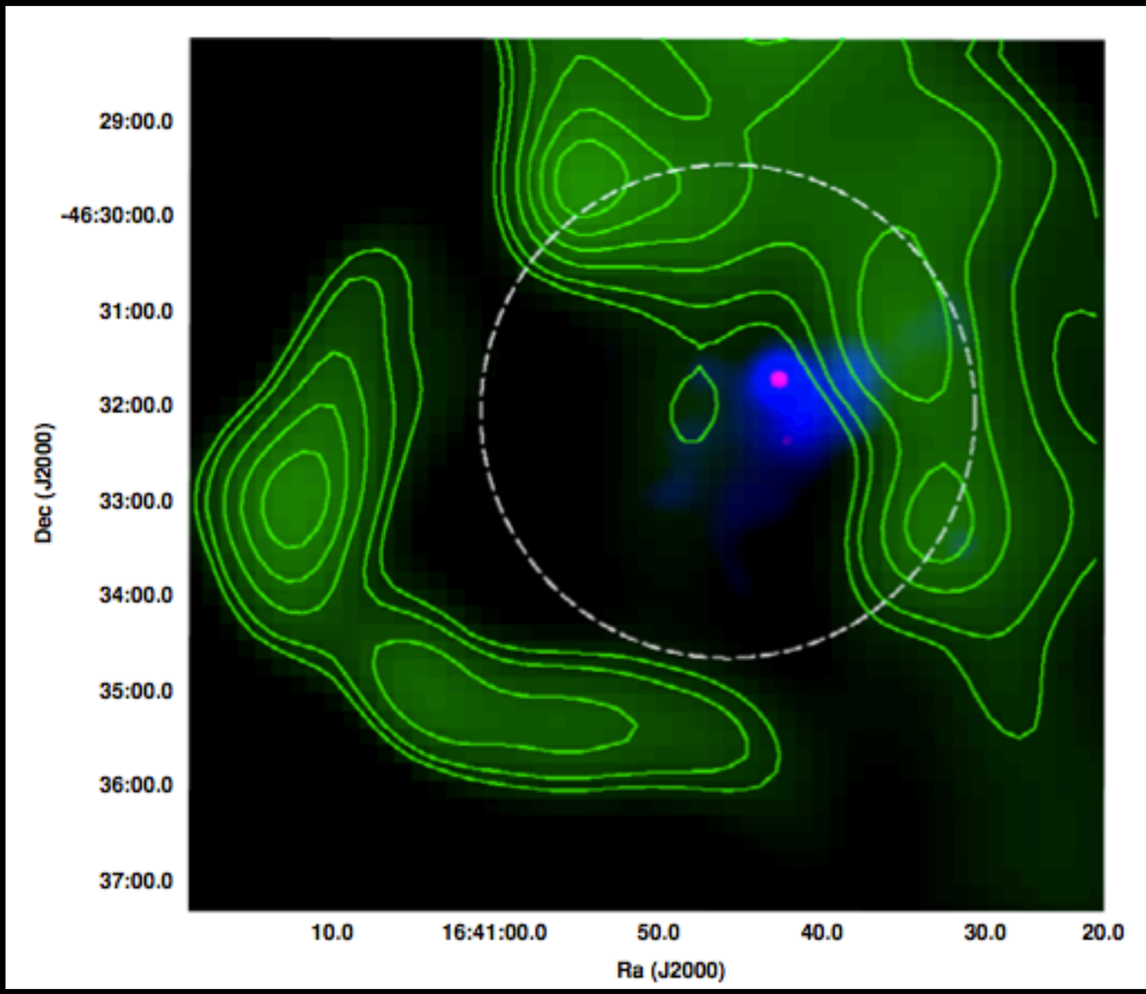
- Environment
  - in a very complex region (e.g. HII region and stellar cluster nearby)
  - not much known about the SNR (incomplete shell, 8' size, no spectral measurement)
  - HI and X-ray absorption measurements suggest large distance of ~10 kpc

Association / X-rays



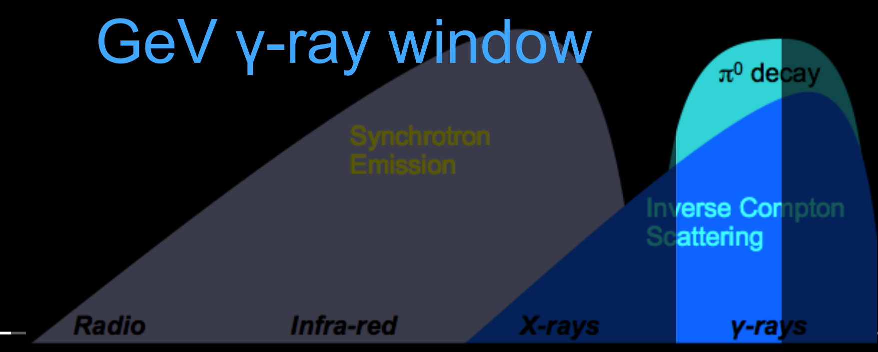
- Swift (Landi et al. 2006)
  - found point-like source
- XMM (Funk et al. 2007)
  - nothing spectacular in the low energy map
  - 2 keV – 10 keV maps shows significantly extended source
- Chandra (Lemiere et al. 2009)
  - detect point-like object (PSR) and confirm extended PWN candidate
  - also other characteristics point towards PWN origin

Radio (843 MHz) X-rays



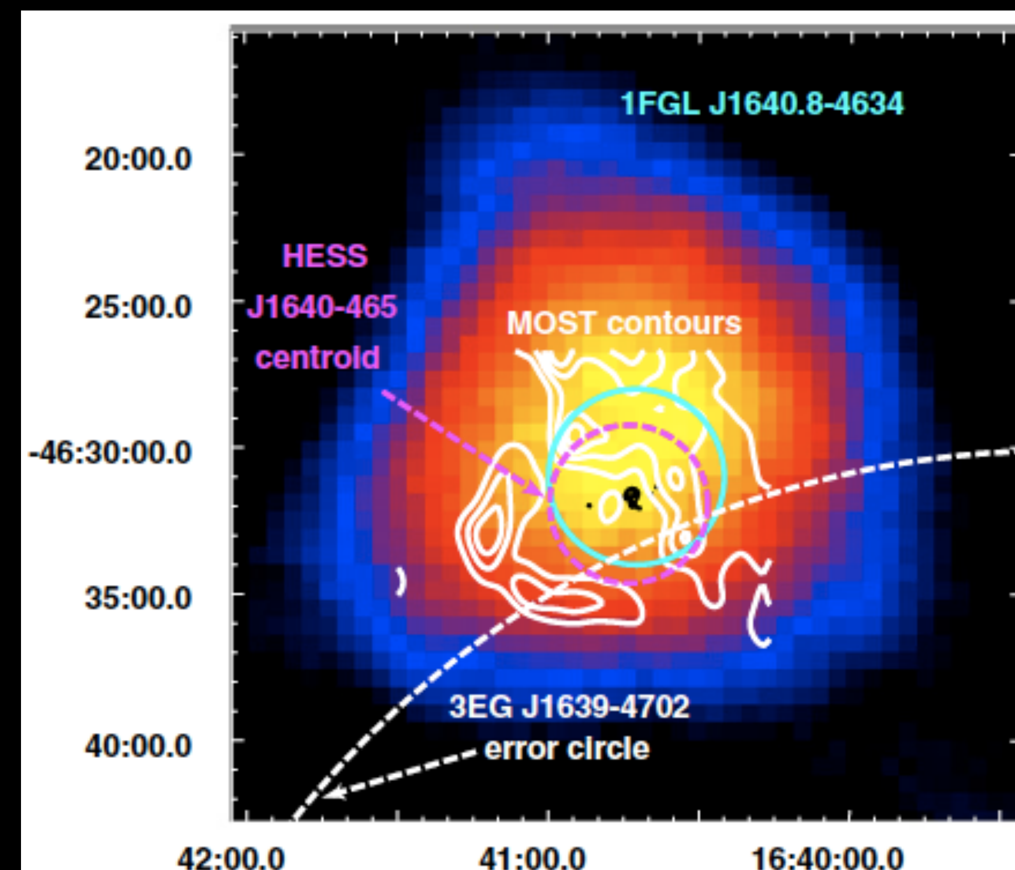
→ suggests central source is of non-thermal nature (PSR) and powers synchrotron nebula

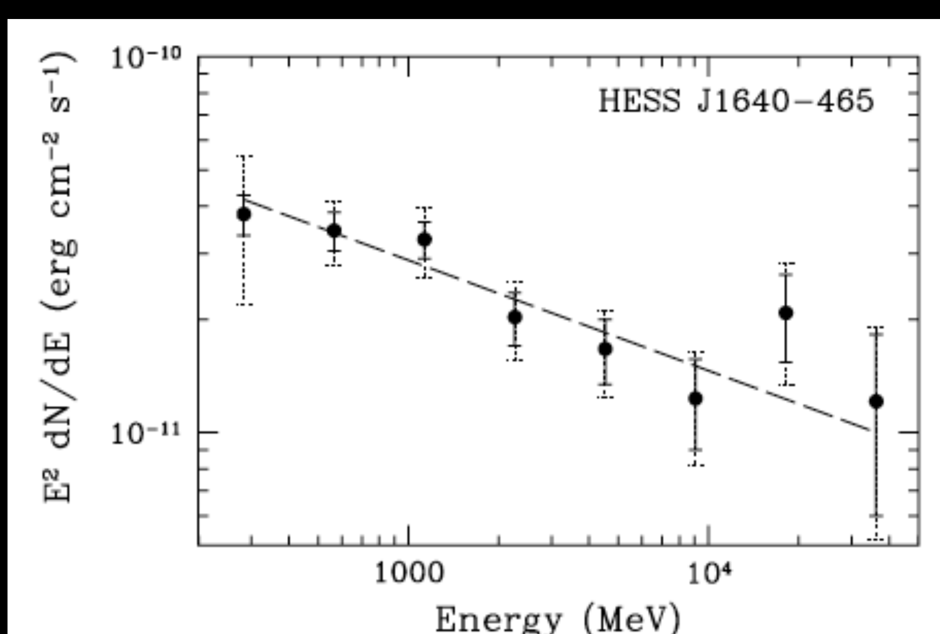
Association / GeV γ-rays

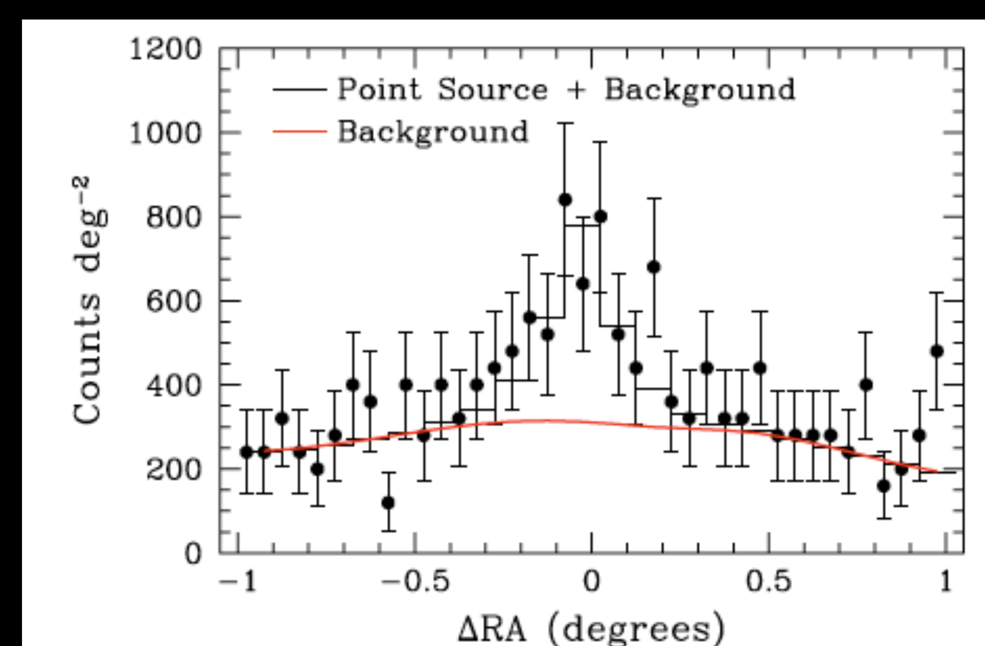


- Slane et al. (2010)
  - 15 months of data acquired with Fermi satellite
  - position consistent with HESS
  - no extension detected
  - reconstructed spectrum between 200 MeV – 50 GeV
  - connects with TeV spectrum

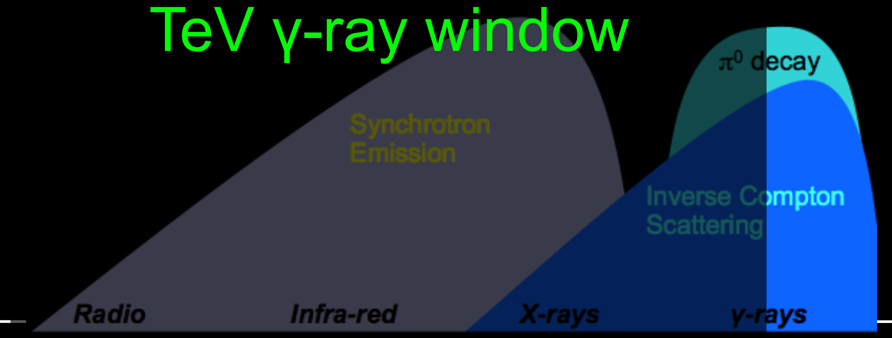
  → Also interpreted in PWN scenario





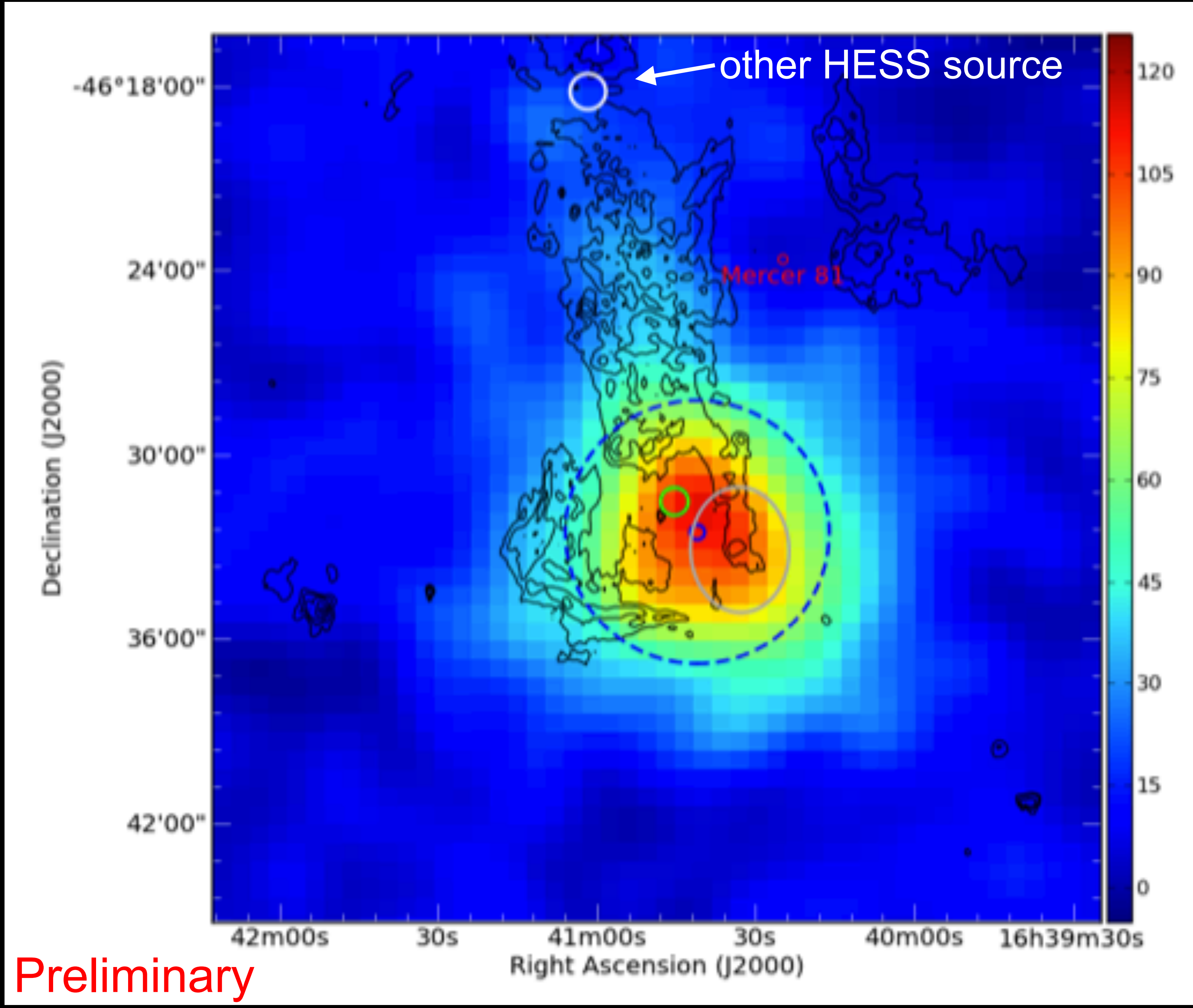


HESS J1640-465 today



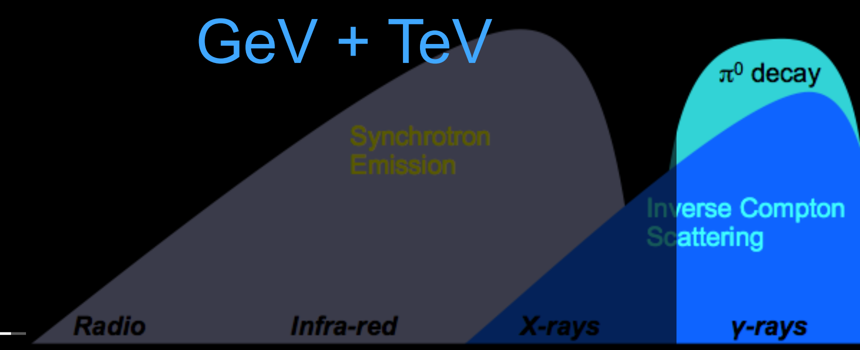
- Data & Analysis
  - much more data (14 → 83 hr)
  - improved analysis techniques
  - γ-ray excess: 330 → 1850
- Position & Extension
  - significantly extended emission: σ_{Gauss} = 4.3' ± 0.3'
  - extended towards HII region
  - suggestive of asymmetry along northern SNR shell (2σ effect)
  - within HESS extension PWN and northern SNR shell

HESS γ-ray excess + 610 MHz radio contours

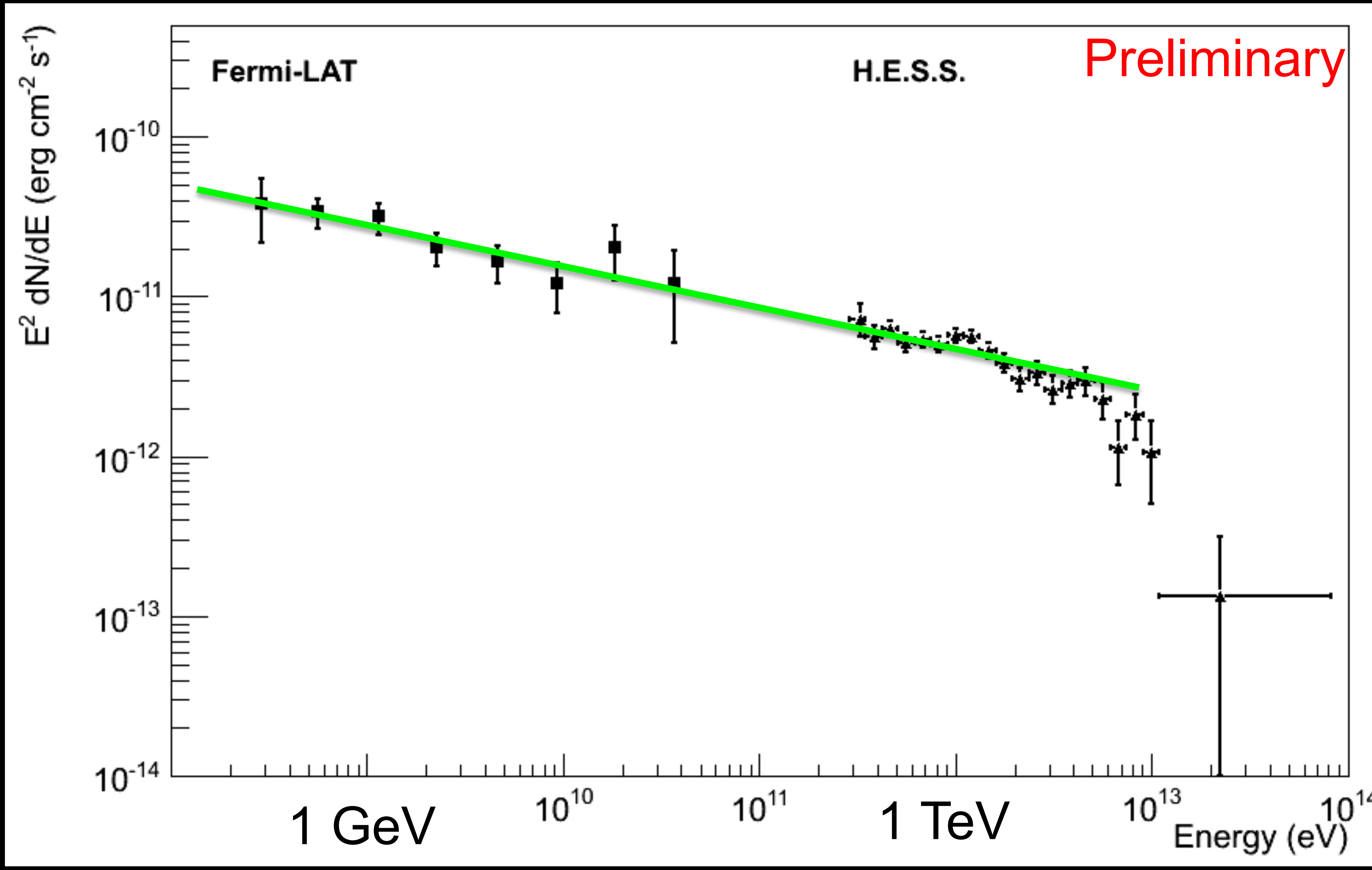


PWN (XMM) Fermi HESS position/extension

HESS J1640-465 today



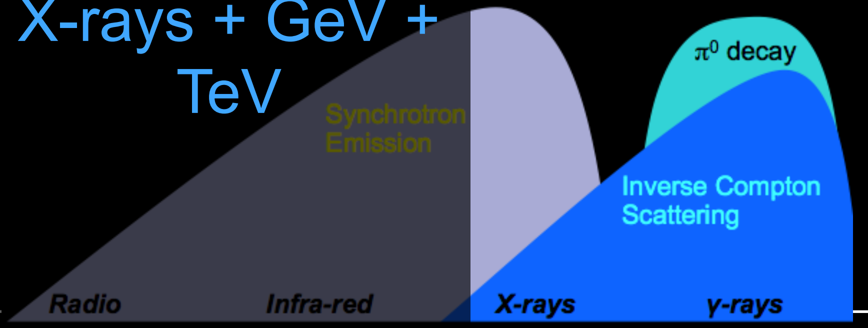
- Spectrum
  - nicely connects with Fermi spectrum at lower energies
  - fit of exponential cut-off power law gives to TeV:
    - $\Gamma = 2.15 \pm 0.1$
    - $E_c = (7.3 \pm 2.0)$ TeV
  - pure power law cannot be ruled out (1% probability)
  - spectral points up to 10 TeV



- What is the source of the TeV γ-ray emission?
  - SNR or PWN?
  - investigate spectral and morphological characteristics

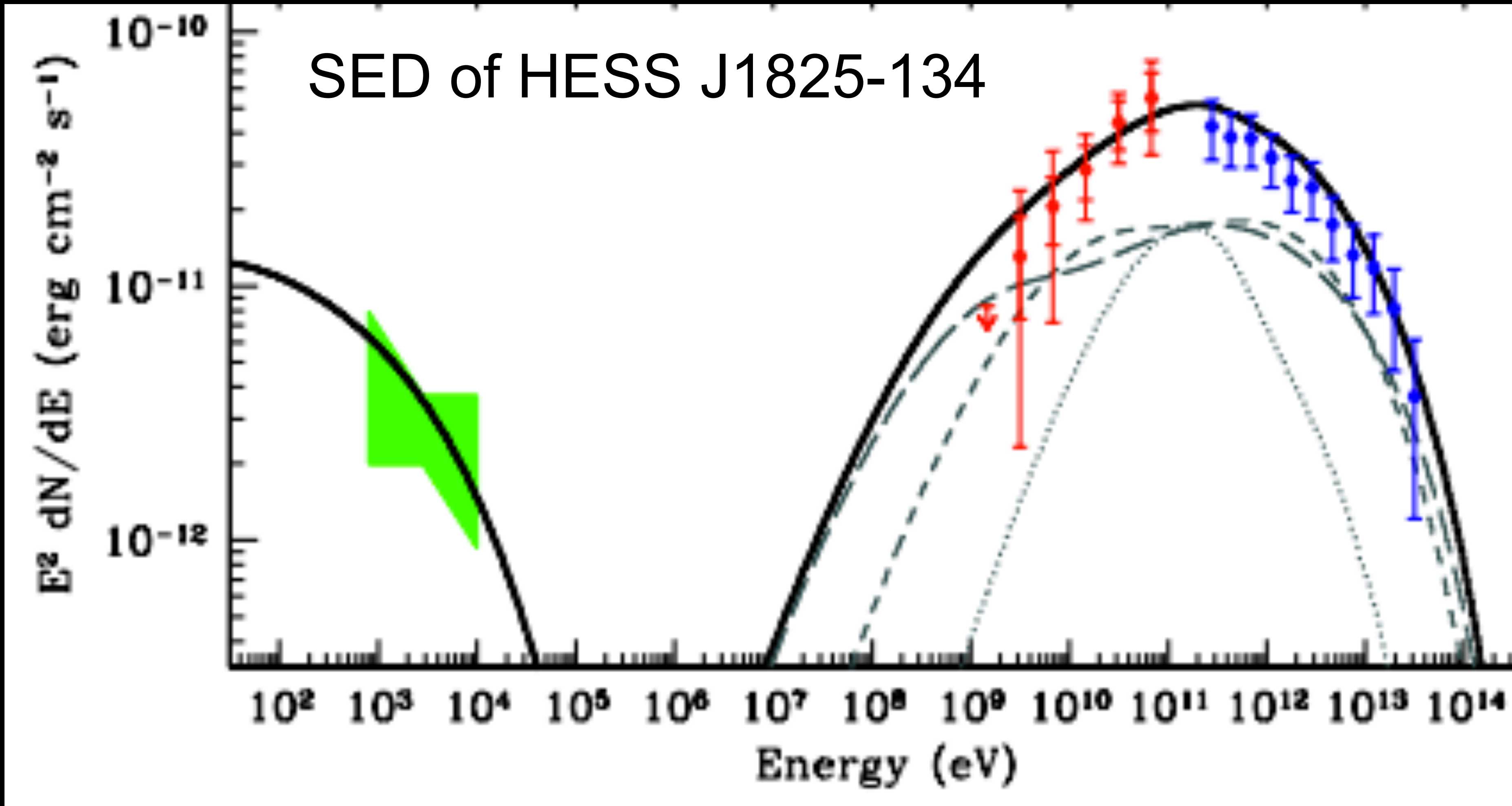
What is the source of γ-rays?

X-rays + GeV + TeV

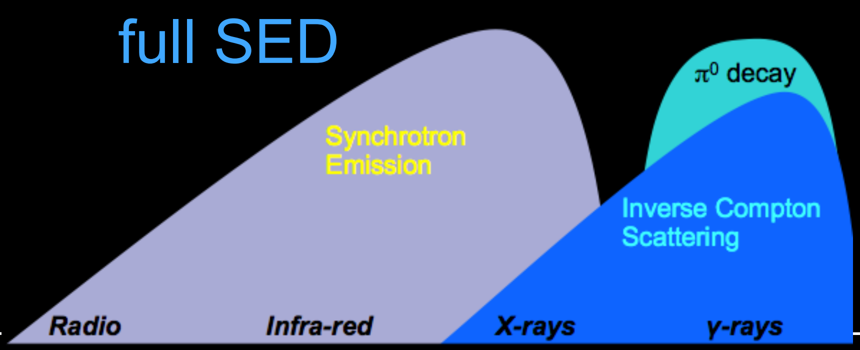


- Pulsar Wind Nebula
  - quite common source of very-high-energy γ-rays
  - spatial coincidence of GeV and TeV source with PWN candidate in X-rays

- What you would expect:
  - Inverse Compton + synchrotron emission
  - peak between Fermi and HESS range
  - very hard Fermi spectrum



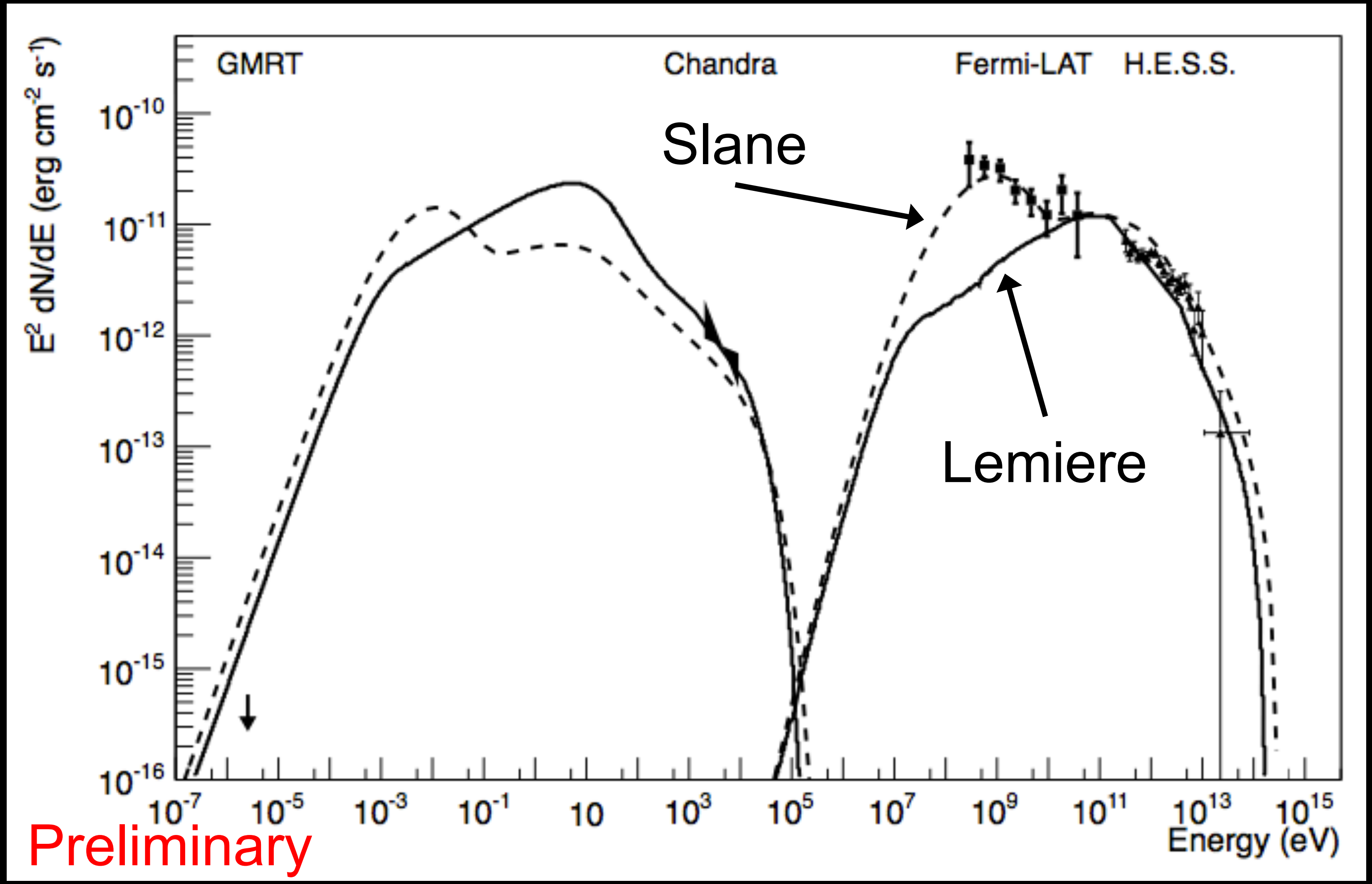
PWN scenario



- Pros
  - quite common source of very-high-energy γ-rays
  - spatial coincidence of GeV and TeV source with PWN candidate in X-rays, but...
- Cons
  - smooth γ-ray spectrum (not seen in any other PWN)
  - TeV source more extended than SNR (not seen in any other PWN)
  - no radio emission seen from PWN, upper limit factor ~5 below models

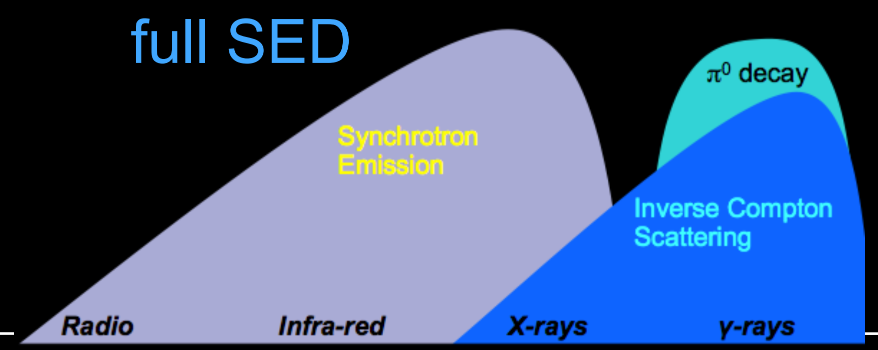
→ GeV very hard to explain as from PWN

→ fine-tuning required to match GeV and TeV



- Spectrum looks like other prominent GeV and TeV-detected SNRs

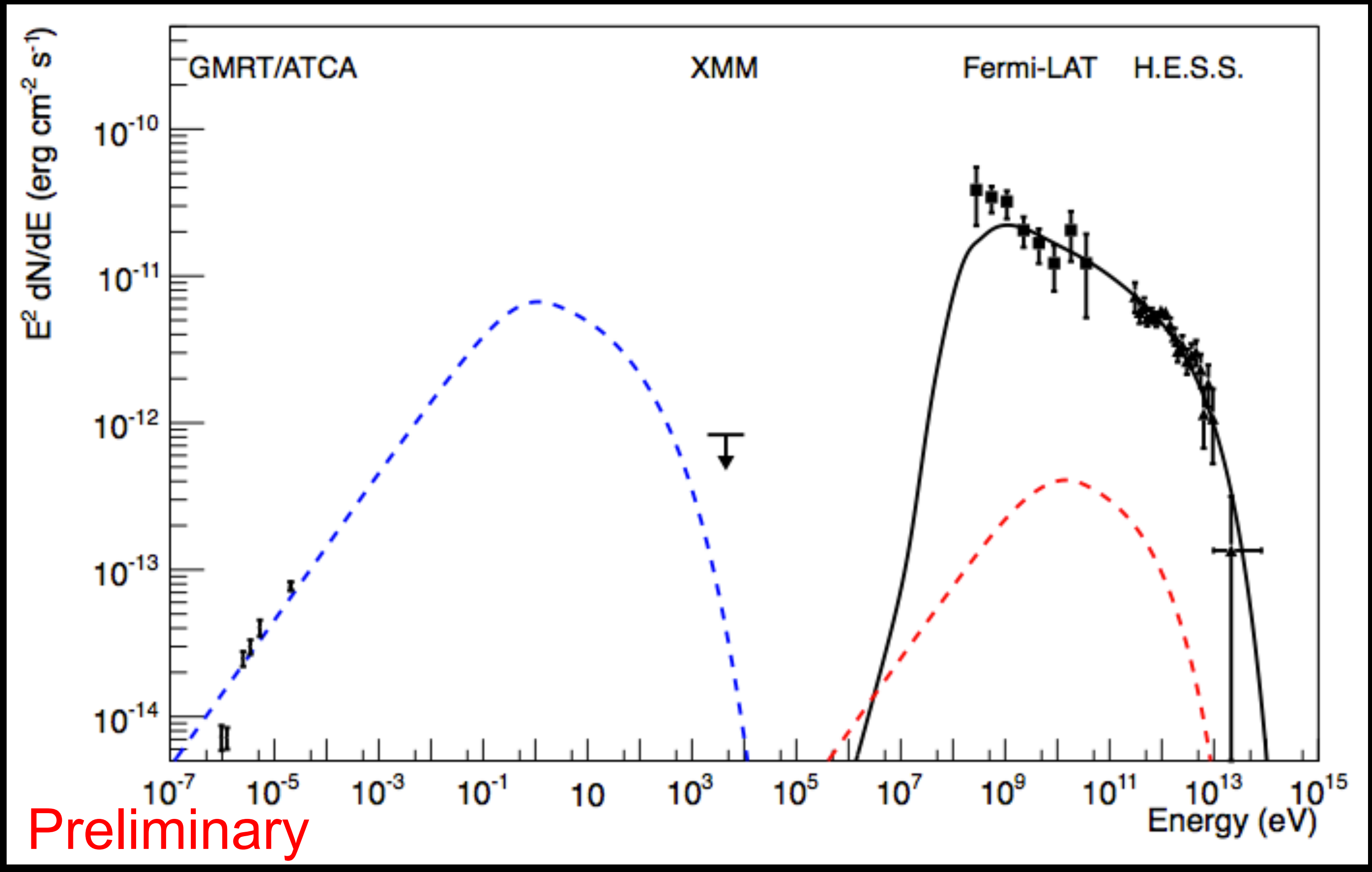
SNR scenario



- Pro SNR
  - New radio measurements (Castelletti et al., 2011) show non-thermal radio emission from shell
  - Re-analysis of XMM data didn't show non-thermal X-ray emission from shell
  - Fermi-LAT position and HESS extension compatible with protons interacting with gaseous material that produce γ-rays
  - Simple model can explain the SED without any fine-tuning:
    - $B = 25\mu G$, $E_{c,e} = 10$ TeV,
    - $\Gamma_e = 2.0$, e/p ratio of 1/100

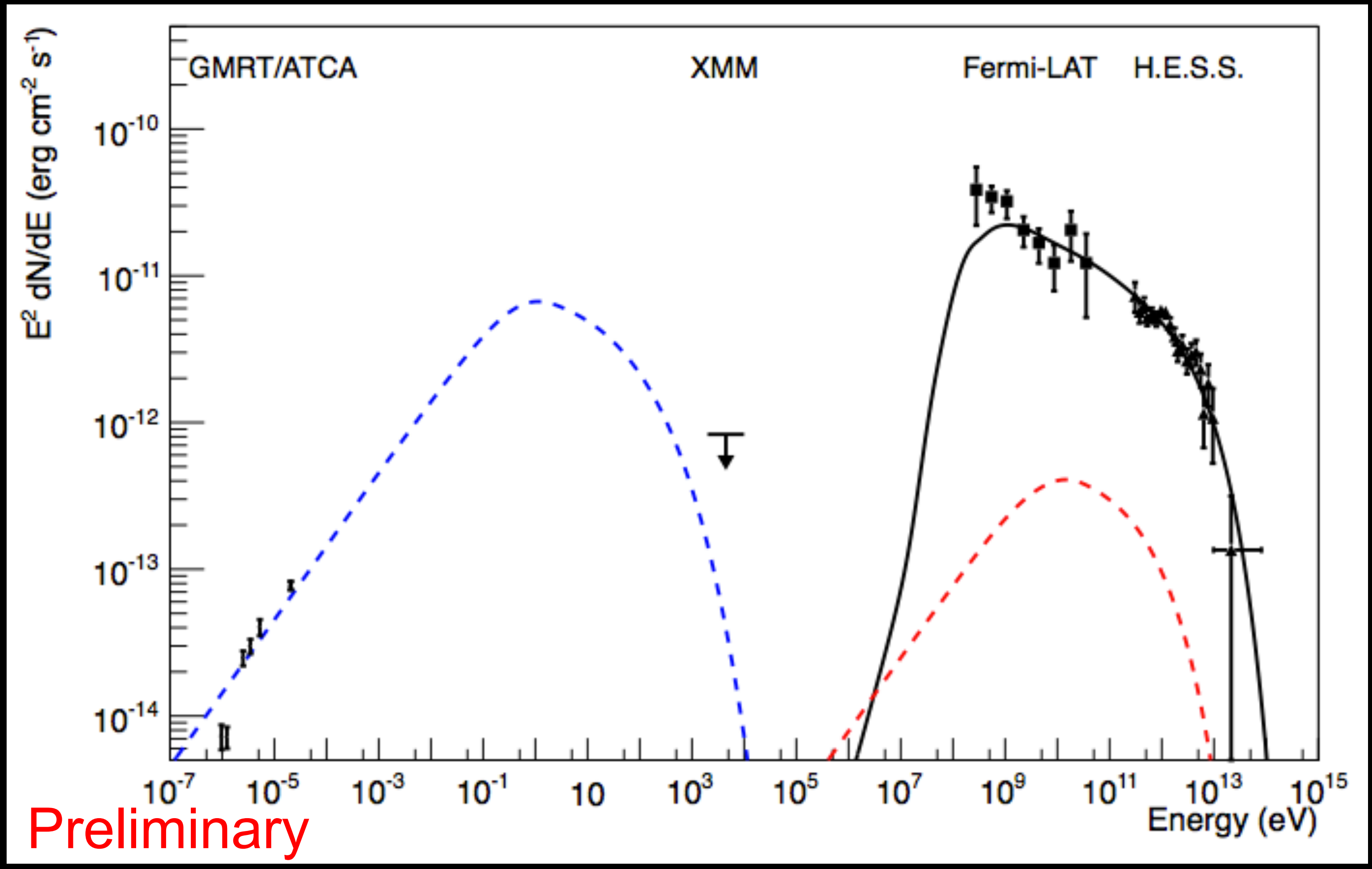
→ Inverse Compton emission orders of magnitude below measurements

- $E_{c,p} = 50$ TeV, $\Gamma_p = 2.2$,
- $n_H = 150\ cm^{-3}$
- $W_p = 2.5 \times 10^{50}$ erg



HESS J1640-465 an extreme accelerator

- Implications
  - Product of energy in protons and target density of 4 x 10^{52} erg cm^{-3} is required to explain observed luminosity
  - need high densities to reduce energy in relativistic protons (could be up to 350 cm^{-3})
  - such dense gas has not been found yet



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  - need high densities to reduce energy in relativistic protons (could be up to 350 cm^{-3})
  - such dense gas has not been found yet
- Why is that extreme?
  - Canonical SN has $E_{kin} = 10^{51}$ erg, and $E_{kin} \rightarrow E_{CR} = 10\%$
  - these particles interact and produce γ-rays.
  - for density of ~100 cm^{-3} and canonical 10% in CRs:

→ E_{SN} could be ~4×10^{51} erg

→ Acceleration efficiency could be up to 40%

Extreme implies

- *very efficient accelerator and/or very energetic supernova*
- *potentially higher, as only part of SN shell interacts with dense material*
- *brightest SN in TeV γ-rays (factor 10), as bright as other SNe in GeV γ-rays*

The future

- HESS J1640-465
  - Need better PSF and sensitivity to disentangle PWN from SNR shell and maybe even resolve the shell
  - Need spectral coverage to detect photons of 100 TeV energies (→Pevatrons)
- How to do that?
  - HESS 2 (600 m^2 telescope) will deliver some of that
  - CTA will be the next big thing → see Richard's talk after the coffee break!

H.E.S.S. 2 (2012)

CTA (2016 – 2020)