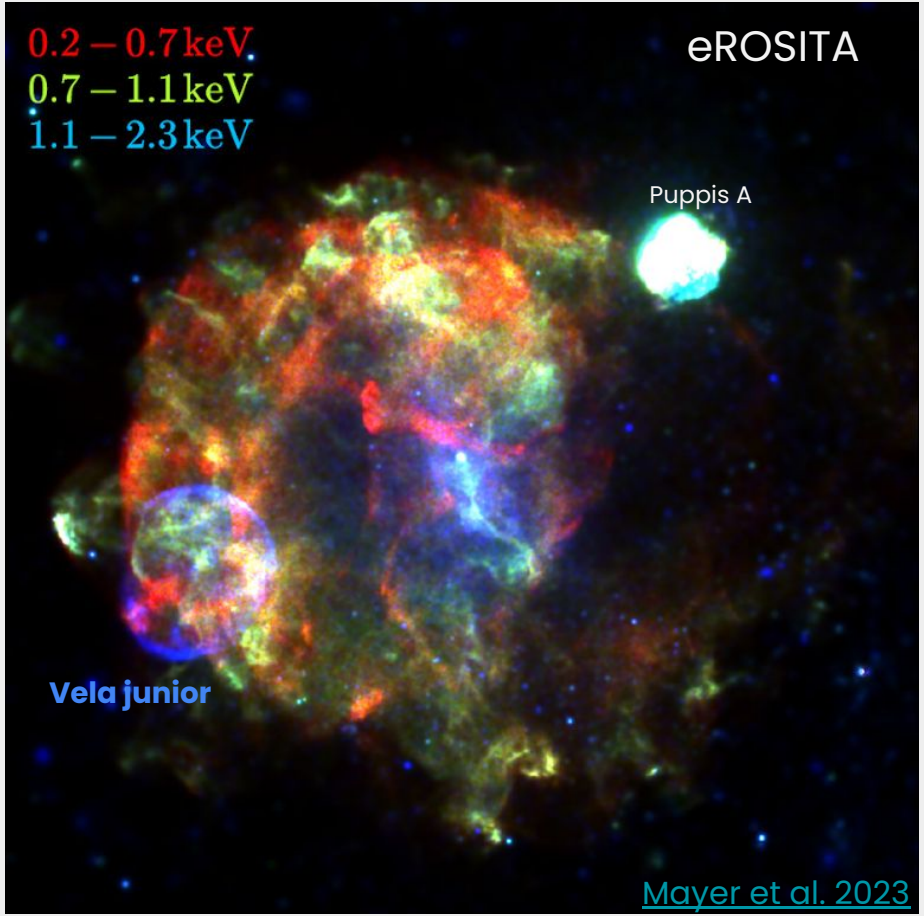


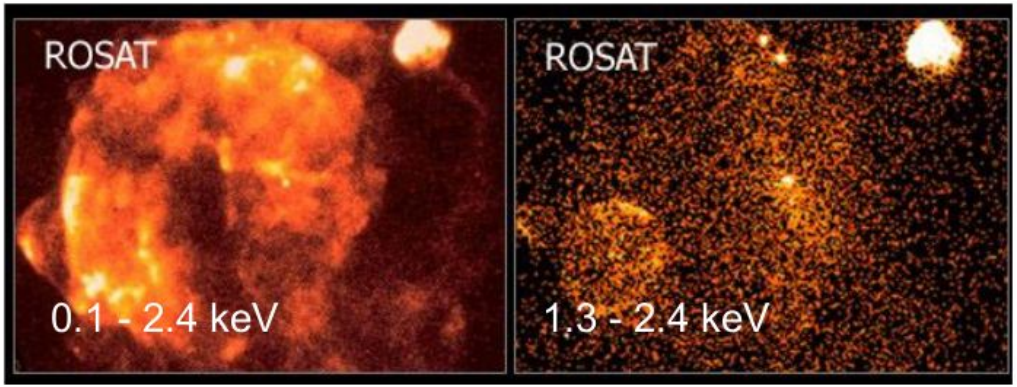
Discovery of TeV emission from the PWN of PSR J0855-4644

Kirsty Feijen (she/her)
Bruno Khélifi, Karl Kosack,
Régis Terrier and Fabio Acero
On behalf of the H.E.S.S. collaboration

TeVPA Valencia 2025

Vela Junior – History and observations

- **Discovery**: Aschenbach (1998) using data from the ROSAT All-Sky Survey (RASS)



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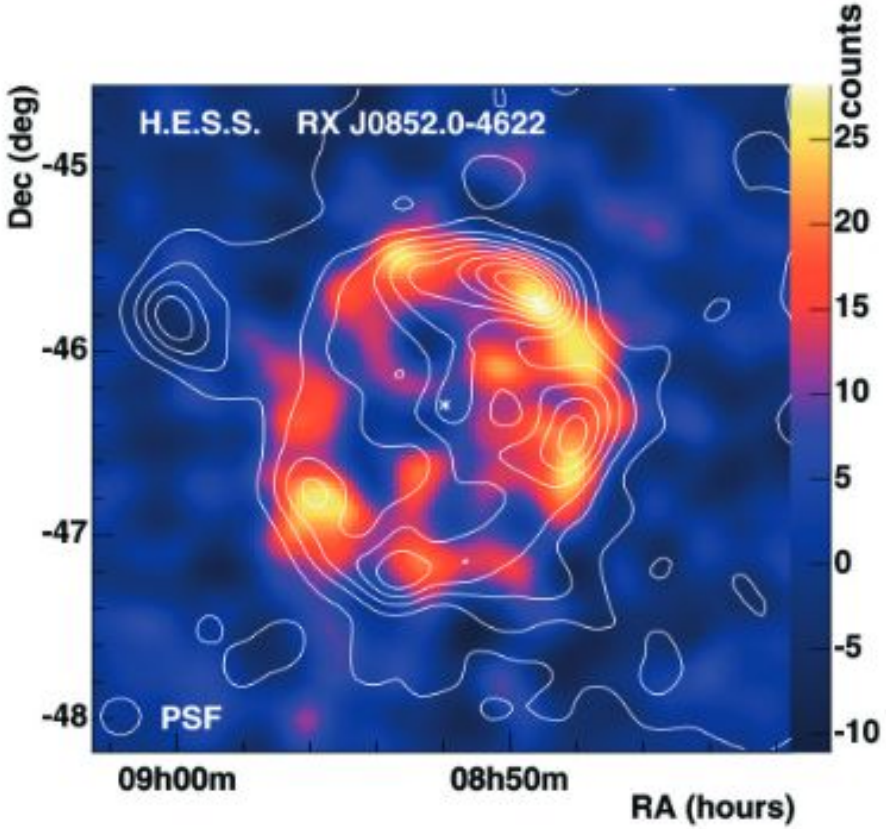

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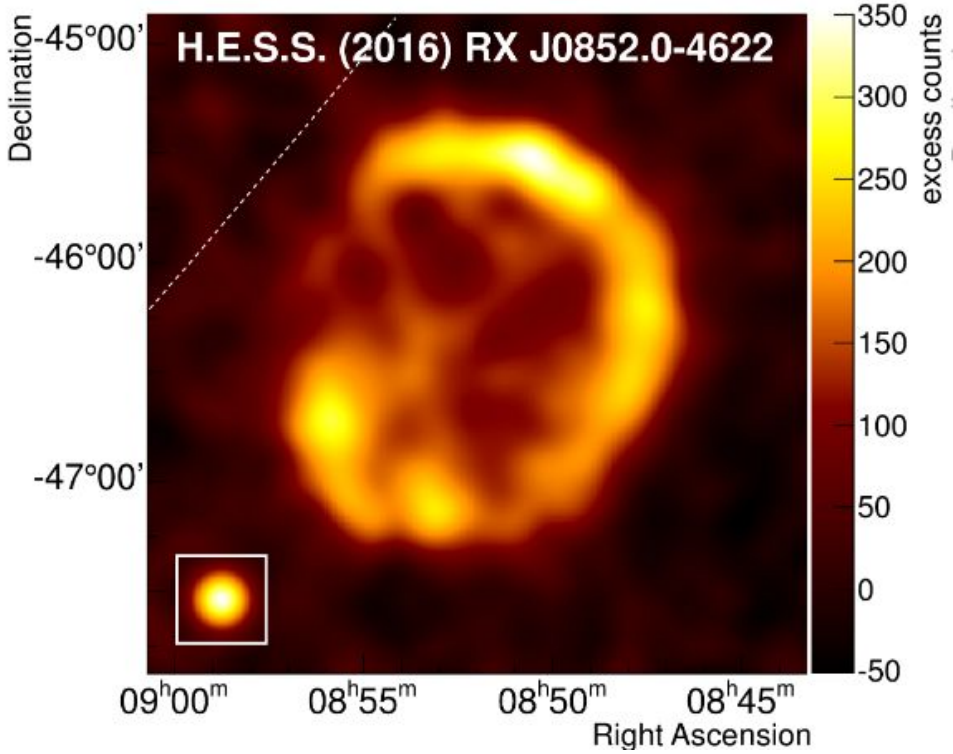
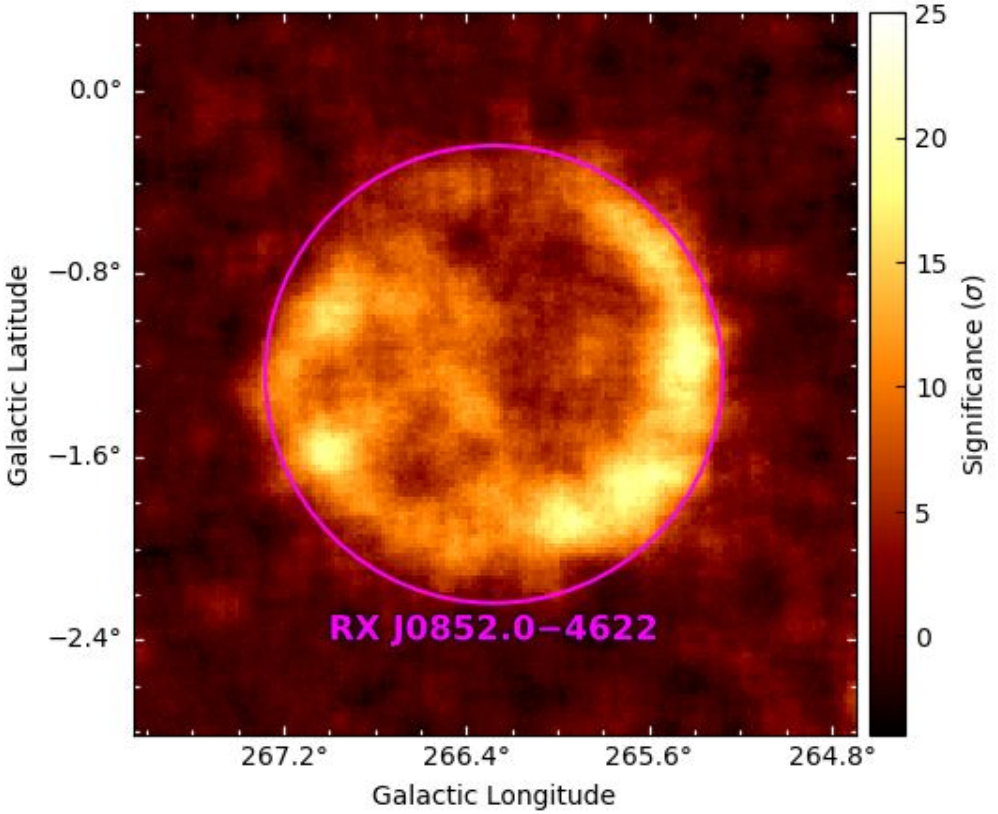
H.E.S.S. publications

- 2005: Detection + first spectrum
- 2007: Shell-like morphology
- 2016: Spatially-resolved spectrum (no significant variations) + MWL fit with Fermi



Motivation

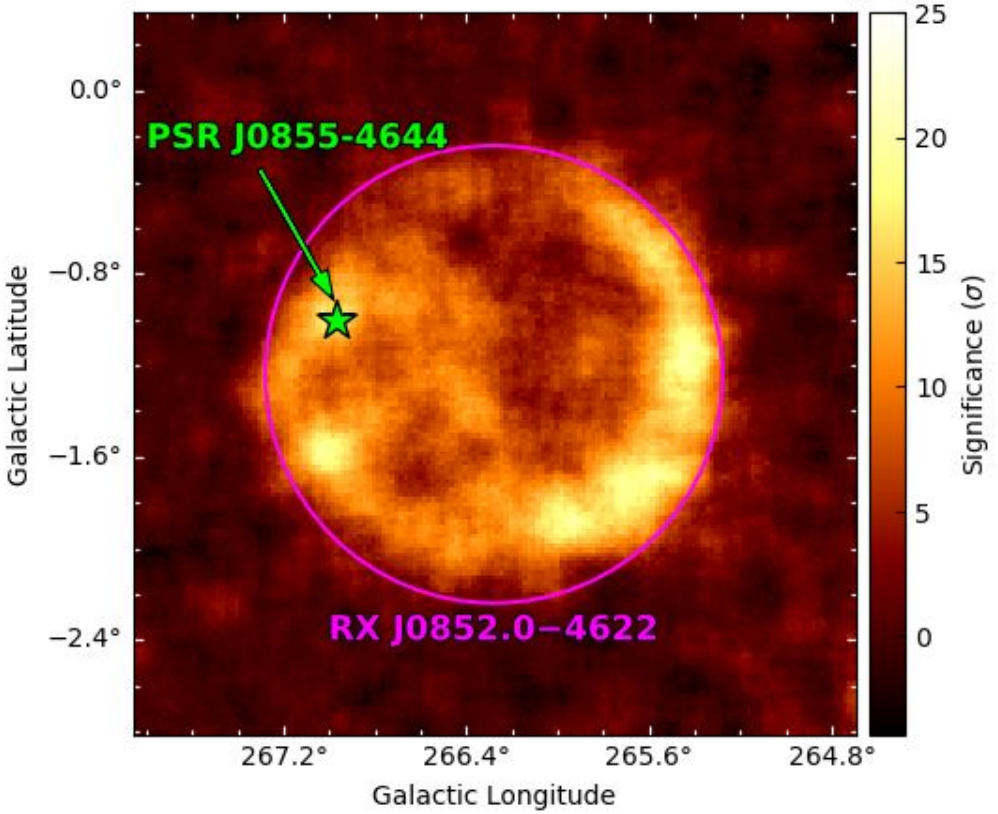
- These results all focus on the Vela Junior SNR



Motivation

- These results all focus on the Vela Junior SNR
- What about the pulsar?

PSR J0855-4644
- Spin-down energy: 1.1 x 10^{36} erg s^{-1}
- Characteristic age: 140 kyr
- Period: 65 ms



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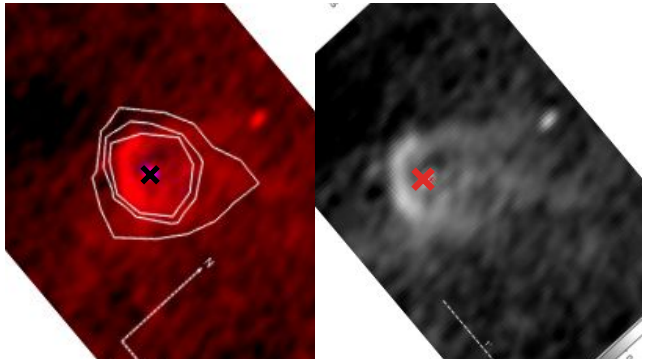
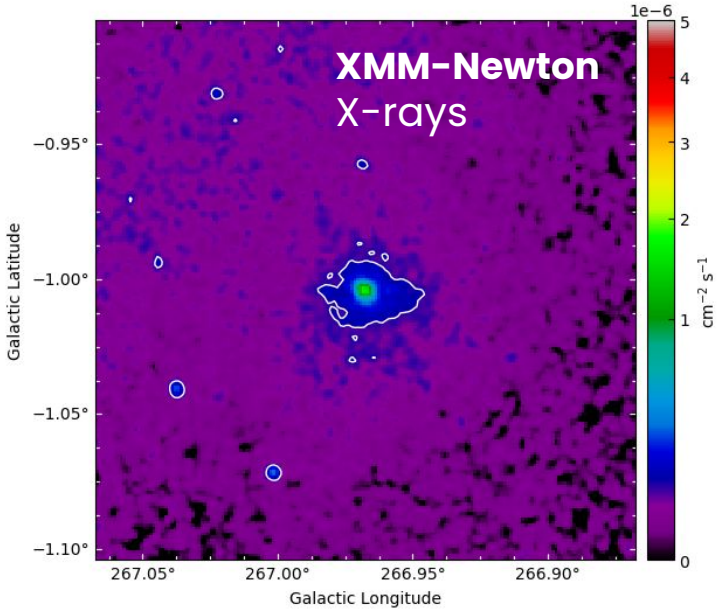
- XMM-Newton observations reveal an X-ray PWN (Acero et al. 2013)
  - Distance: ≤ 900 pc
- Radio observations show diffuse emission around the pulsar (Maitra et al. 2018)

GMRT
Radio



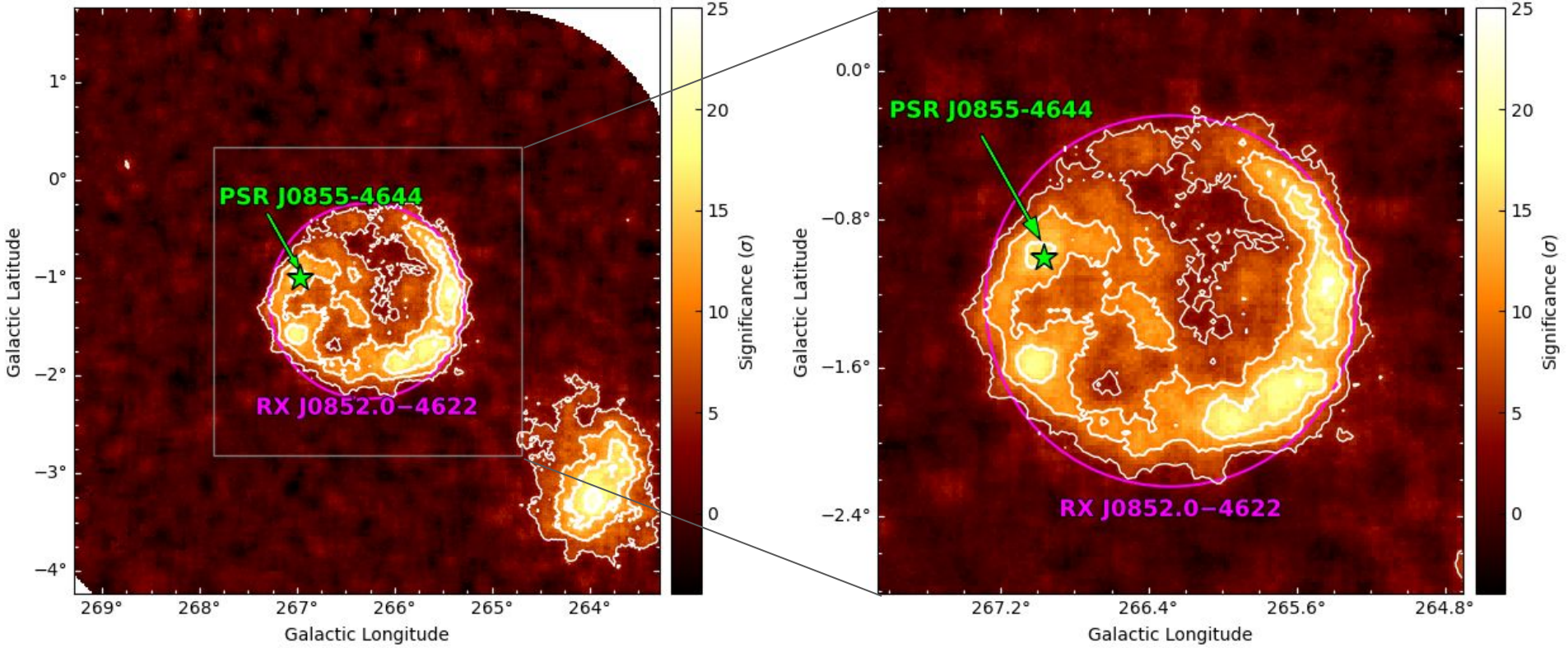


Motivation

- Due to the spatial coincidence with the SNR shell, it is not possible to disentangle the contribution from the SNR shell from the contribution of the PWN with traditional background estimation methods
  → **UNTIL NOW with the use of 3D analysis techniques with Gammapy** (Donath et al. 2023, Acero et al. 2025)

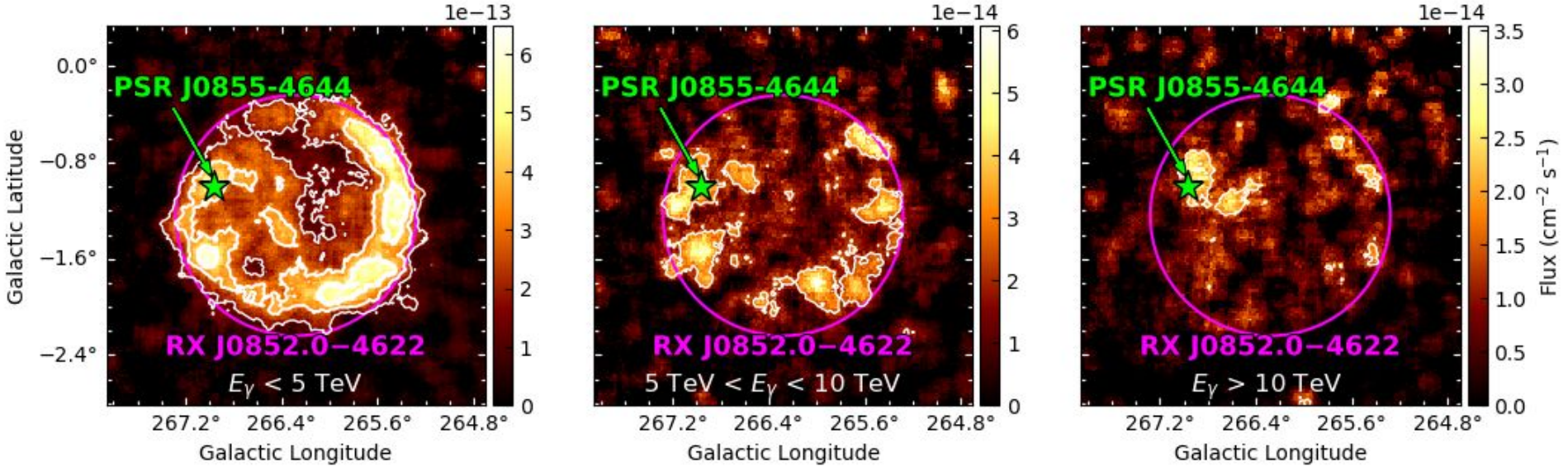
Gamma-ray significance maps >0.7 TeV

- Significance contours at 5, 10, and 20σ
  → increasing line width for increasing significance



Maps - energy resolved flux maps

- Indication of energy-dependent morphology
  - Northwest rim is a very bright feature of the Vela Junior shell at lower energies
  - Above 10 TeV – significant emission coincides with the position of PSR J0855-4644
    → **indication of TeV emission at the pulsar position**
    → **motivation to study the region further with new techniques**



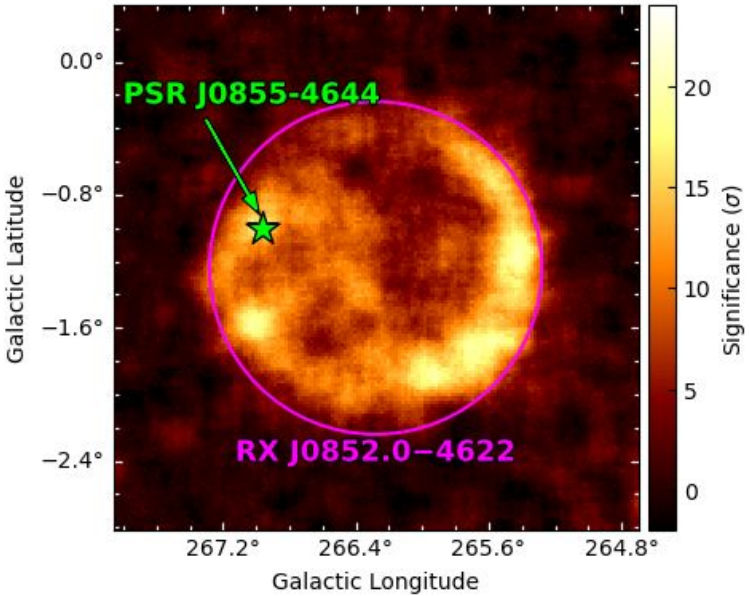
3D analysis technique

A Python package for gamma-ray astronomy

- Iterative modelling procedure

→ add source components until no significant emission remains

- Start by modelling the brightest objects in the region
- First the partial shell morphology at the eastern edge of Vela Junior
    - Utilise a template model that matches the TeV morphology

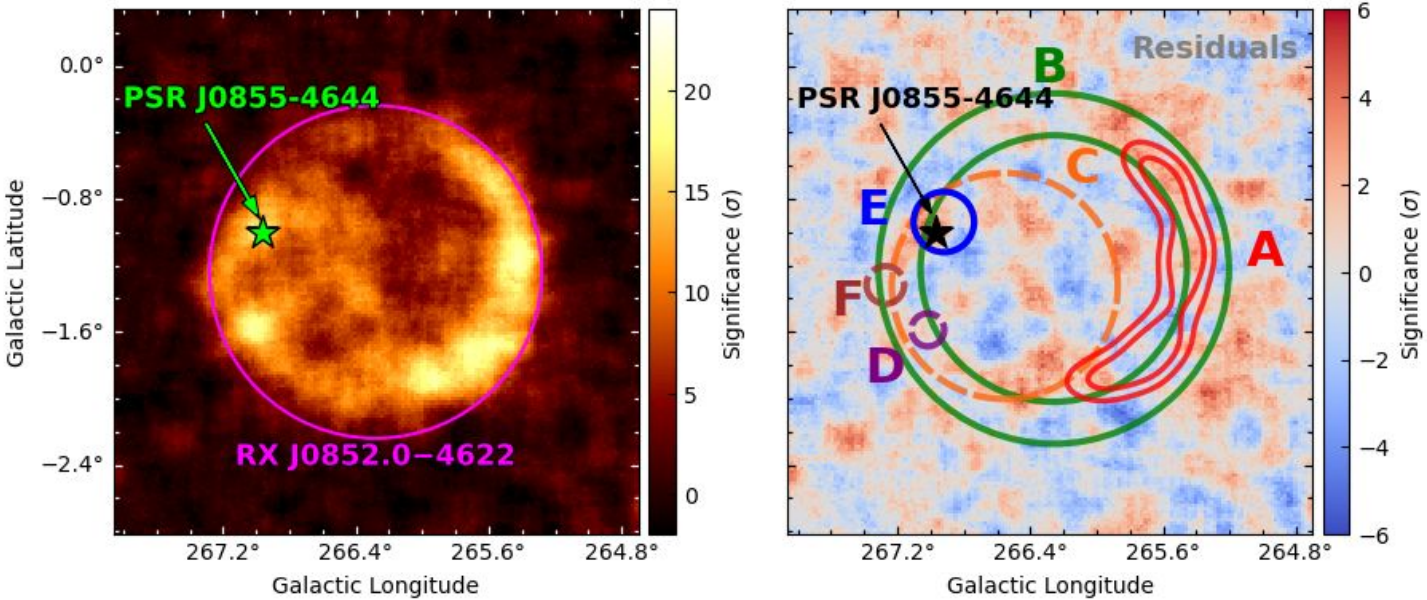


3D analysis technique

- Iterative modelling procedure

→ add source components until no significant emission remains

- Start by modelling the brightest objects in the region
- First the partial shell morphology at the eastern edge of Vela Junior
  - Utilise a template model that matches the TeV morphology
- This leads to 6 components within the FoV labeled alphabetically from “A” to “F”



Modelling

- Now that we have those we test 2 hypotheses:
  - H_0: spectral parameters (index and cutoff) shared with the shell model (exponential cut-off power law)
  - H_1: spectral parameters independent, with power law assumption

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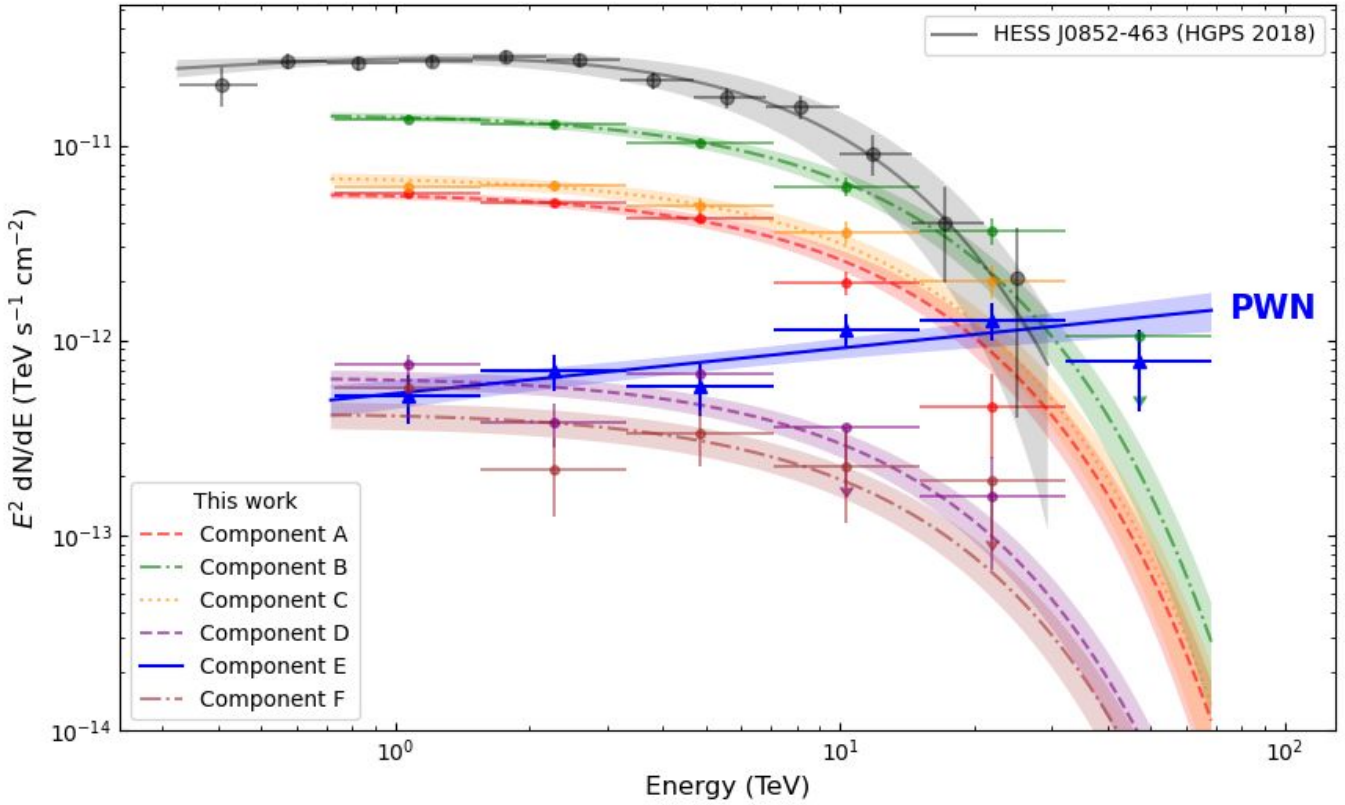
  - H_1: spectral parameters independent, with power law assumption

- All components except one prefer H_0
  - Test shows these detected component are part of the SNR emission i.e. have a linked spectral model
  - **Find that component E is significantly different from the others (6σ)**
- Test for a cut-off in component E , but found no significant evidence for one (<1σ)

TeV Spectra

The PWN of PSR J0855-4644 can be clearly separated from the shell of Vela Jr at TeV energies

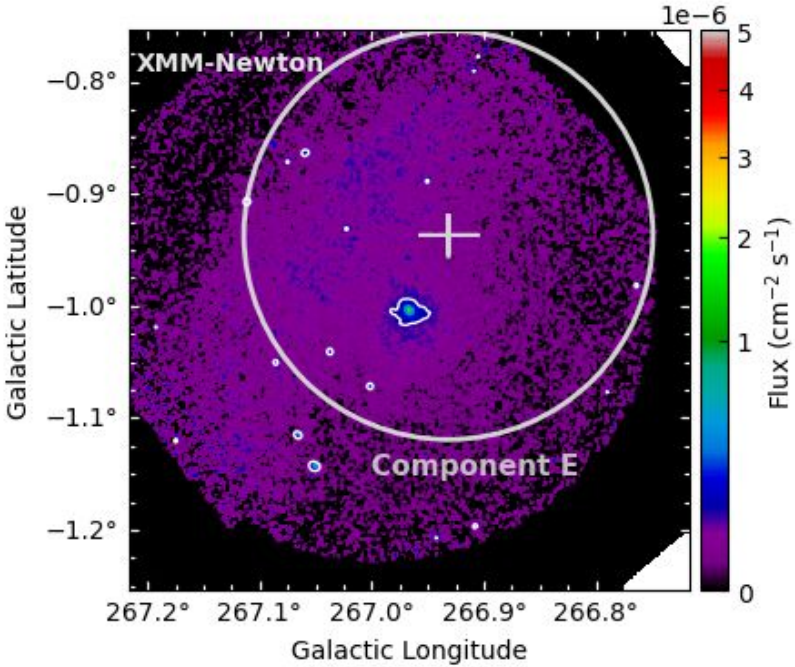
- It is preferred as a PL: Γ_E=1.78 ± 0.08 with no cut off



X-ray emission

Spatial positioning

- Component E overlaps with PSR J0855-4644 indicating that the TeV emission is produced as a PWN
- PWN: detected in X-rays and radio → natural to assume also in gamma-rays



- The spectral index of component E is hard (Γ_E ~ 1.8), which is consistent with expectations from the inverse-Compton emission from an energetic PWN

X-ray emission

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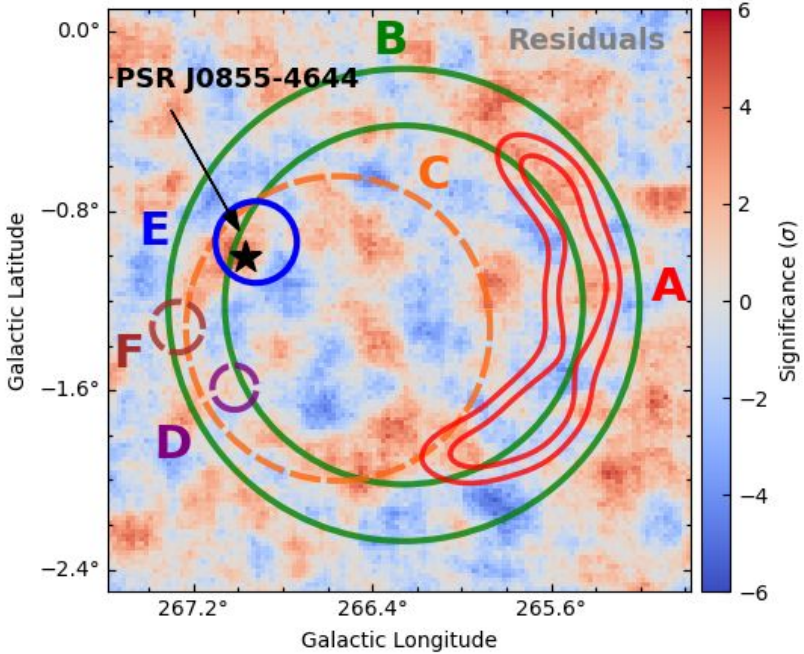


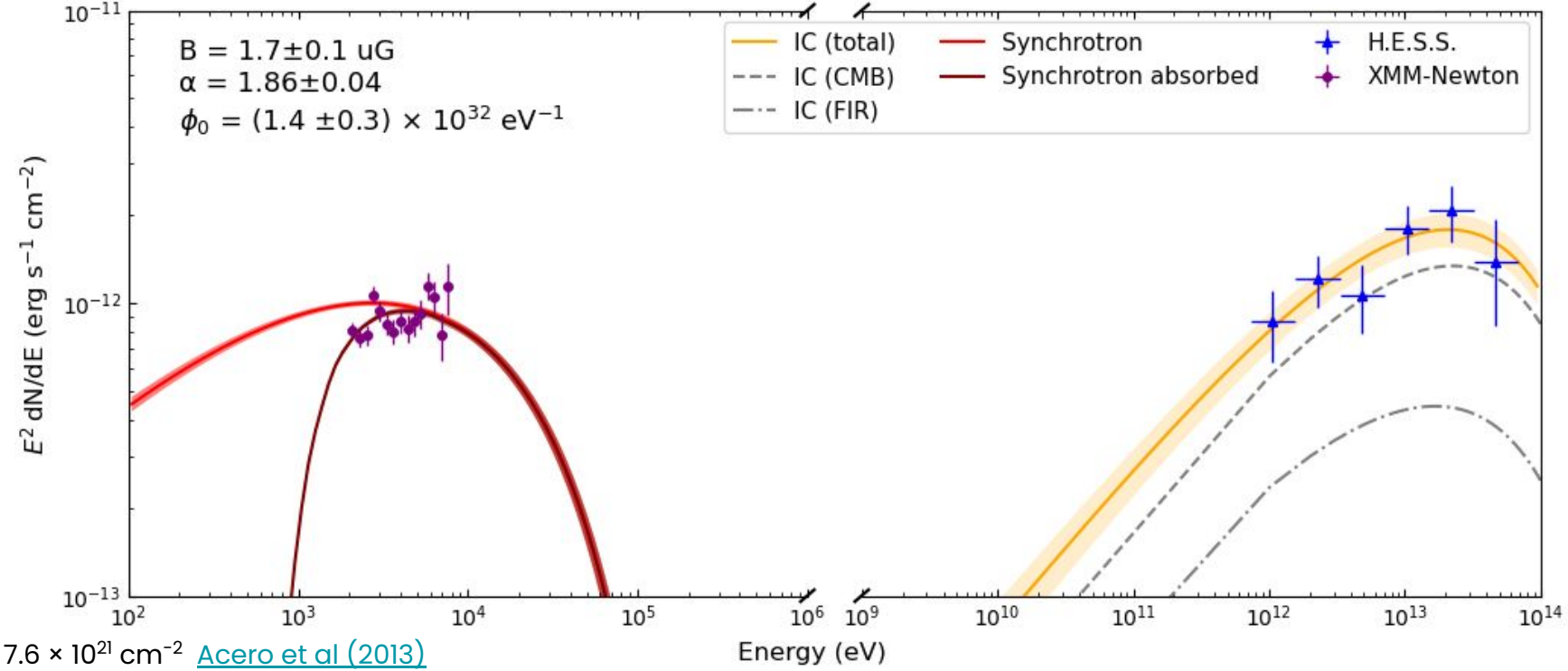
- Perform a number of tests with Component C and E to see if there is some extended halo component → no indication that C is connected to E
- Component C spectrum is also better of linked with B → indicates that it is part of the emission region of the SNR rather than the PWN
  - Preferred over a simple power law (like component E) by 6.4σ

Multi-wavelength modelling

- Perform a joint multi-wavelength fit to both the X-ray and gamma-ray emission utilising Naima and XSPEC in the Gammapy framework[1]
  - This is a full forward modelling technique (not flux point fitting)
  - X-rays: 2-8 keV range to avoid the thermal contamination from the Vela SNR and the rim of Vela Junior

Multi-wavelength modelling

- Electron spectral index of α ~ 1.9
  - Reasonable value as PWN are expected to exhibit a hard spectral index (i.e. see de Jager et al. (2008), Olmi et al. (2023))



$N_H = 7.6 \times 10^{21}$ cm^{-2} Acero et al (2013)

Summary

- For the **first time** the **PWN** of PSR J0855-4644 has been **separated** from the Vela Junior **SNR** shell at TeV energies
  - Only possible through the **3D analysis** allowing to separate the emission component spectral different from the rest of the shell
- **Spectrum well represented by a hard (Γ_E ~ 1.8) power law with no cut off**

Spatial positioning

- Component E is spatially coincident with the PWN of PSR J0855-4644
- Hard TeV emission is likely caused by inverse-Compton from the PWN

Energetics

- Component E flux 3×10^{-13} erg^{-1} cm^{-2} s^{-1} corresponds to $L_{1\text{-}10\ TeV}=3.2\times10^{32}(d/kpc)^2$ erg s^{-1}
- Assuming distance of 900pc → TeV gamma-ray efficiency ~0.02%

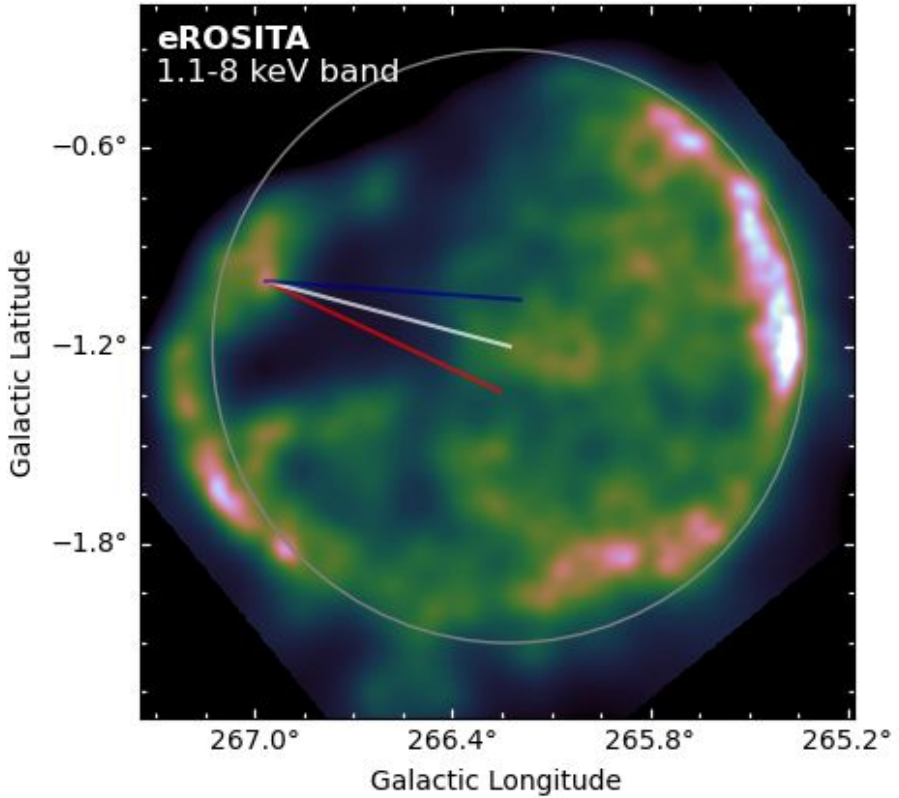
Paper will be submitted soon

Thanks for your time!

Backup slides

- There is also an eROSITA study towards this region (Camilloni et al. 2023)
  - PSR is shown by the bright peak
  - SNR: north, north-eastern region appears almost circular

Red: from the geometry of the radio bow shock nebula
Blue: from the geometry of the elongated PWN (Chandra)



eROSITA fits file courtesy of Martin Mayer

Modelling

Component A
- Template spatial model
- ΔTS = 620 → 25σ

Component B
- Shell spatial model
- ΔTS = 522 → 23σ

Component C
- Gaussian spatial model
- ΔTS = 243 → 16σ

Component D
- Gaussian spatial model
- ΔTS = 114 → 11σ

Component E
- Gaussian spatial model
- ΔTS = 116 → 11σ

Component F
- Gaussian spatial model
- ΔTS = 47 → 7σ

- The SNR spectrum is compatible with the one of the 2018 HESS
  - paper: Γ=1.90±0.05, Ecut =(8.0±1.1)TeV,
  - This work: Γ=1.96±0.03, Ecut =(10.55±0.94)TeV

Component E → PWN

PSR J0855-4644

- Spin-down energy: 1.1 x 10^{36} erg s^{-1}
- Characteristic age: 140 kyr
- Period: 65 ms

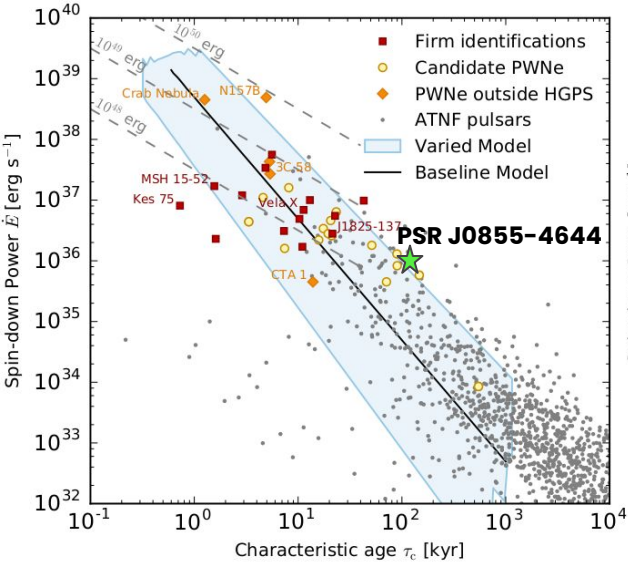
Component E

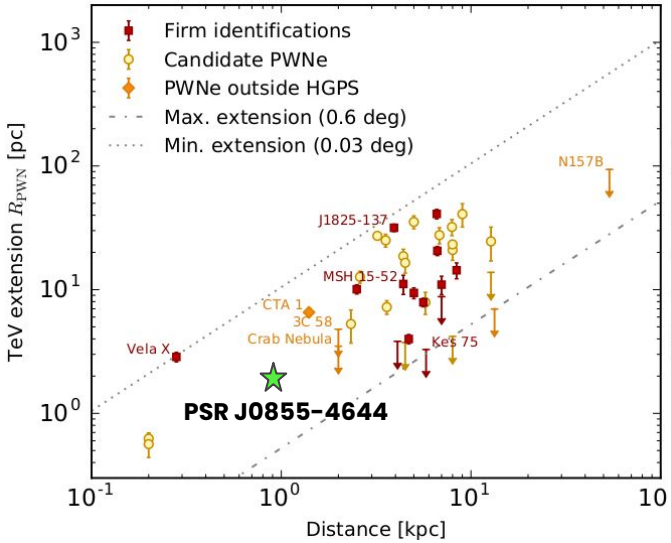
- TeV extension: 0.12° ~ 1.9 pc

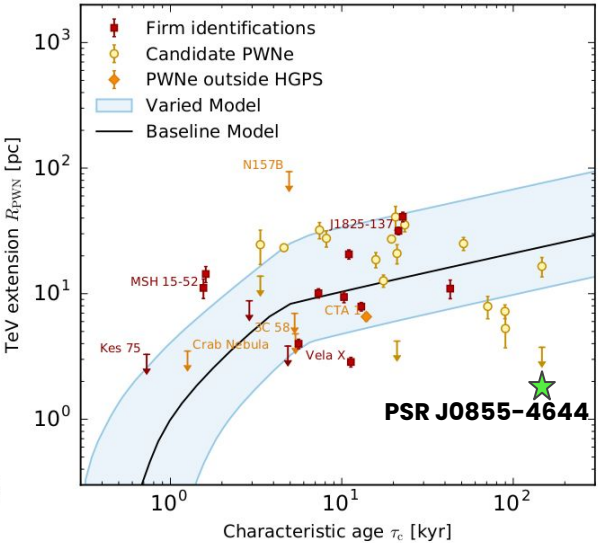
A compact closeby X-ray PWN:

- Angular size of 0.15°
- Distance ≤ 900 pc (Acero+2013)
- Physical size ≤ 2.4 pc

- Place the pulsar on the TeV PWN population plots from H.E.S.S. (2018)







Pulsar energetics

- Spin-down energy: **1.1×10^{36} erg s^{-1}**
- Flux of component "E" in gammas: 3.0×10^{-13} erg^{-1} cm^{-2} s^{-1}
- The luminosity in gammas at distance of 900 pc ($L_\gamma = 4\pi d^2 F_\gamma$):
  - $L_{\gamma,1\text{-}10\text{TeV}}$ = **2.6×10^{32} erg s^{-1}**

$\eta_\gamma = L_{\gamma,1\text{-}10\text{TeV}} / \dot{E} \sim 2 \times 10^{-4} \sim$ **0.02%**