

A Pulsar Wind Nebula Origin for Luminous TeV Source HESS J1640-465

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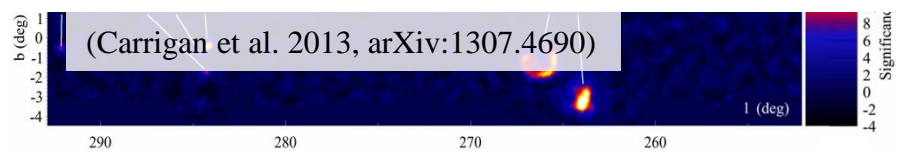
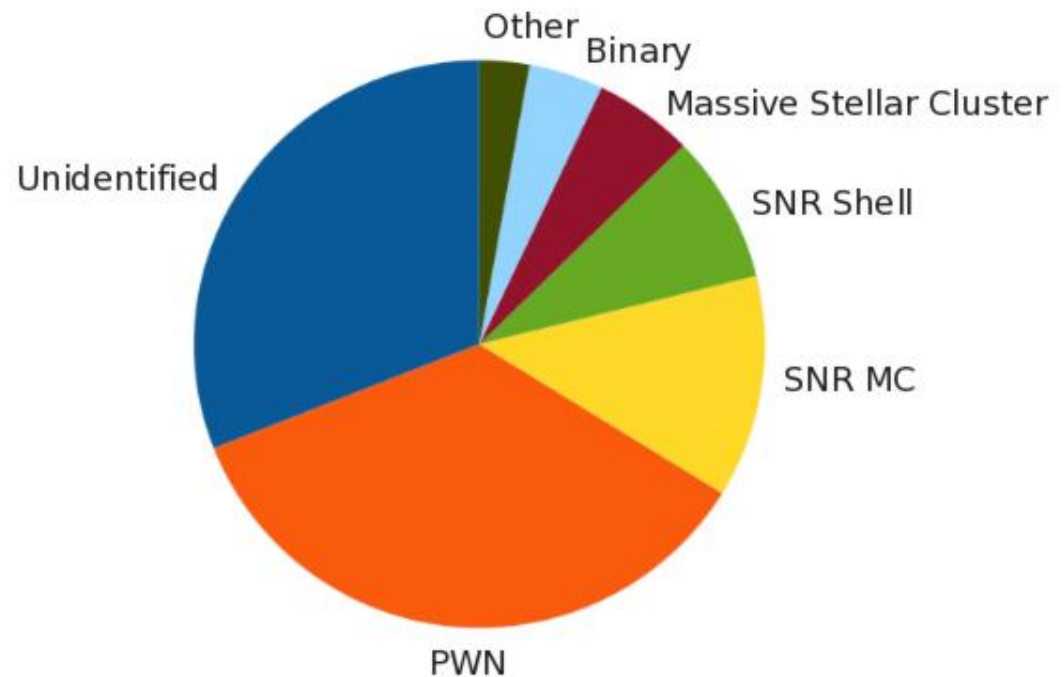
Outline

- Why study Galactic TeV sources?
 - TeV γ -rays \rightarrow $>$ PeV particles
 - Normally SNR or PWN.
- Why HESS J1640-465?
 - Most luminous TeV γ -ray source in Milky Way
 - Associated with a radio SNR, X-ray PWN, and a pulsar
- If HESS J1640-465 is a PWN...
 - pulsar spun down very rapidly
 - Initial spin period $P_0 \sim 20 - 35$ ms

Sources of TeV γ -ray emission

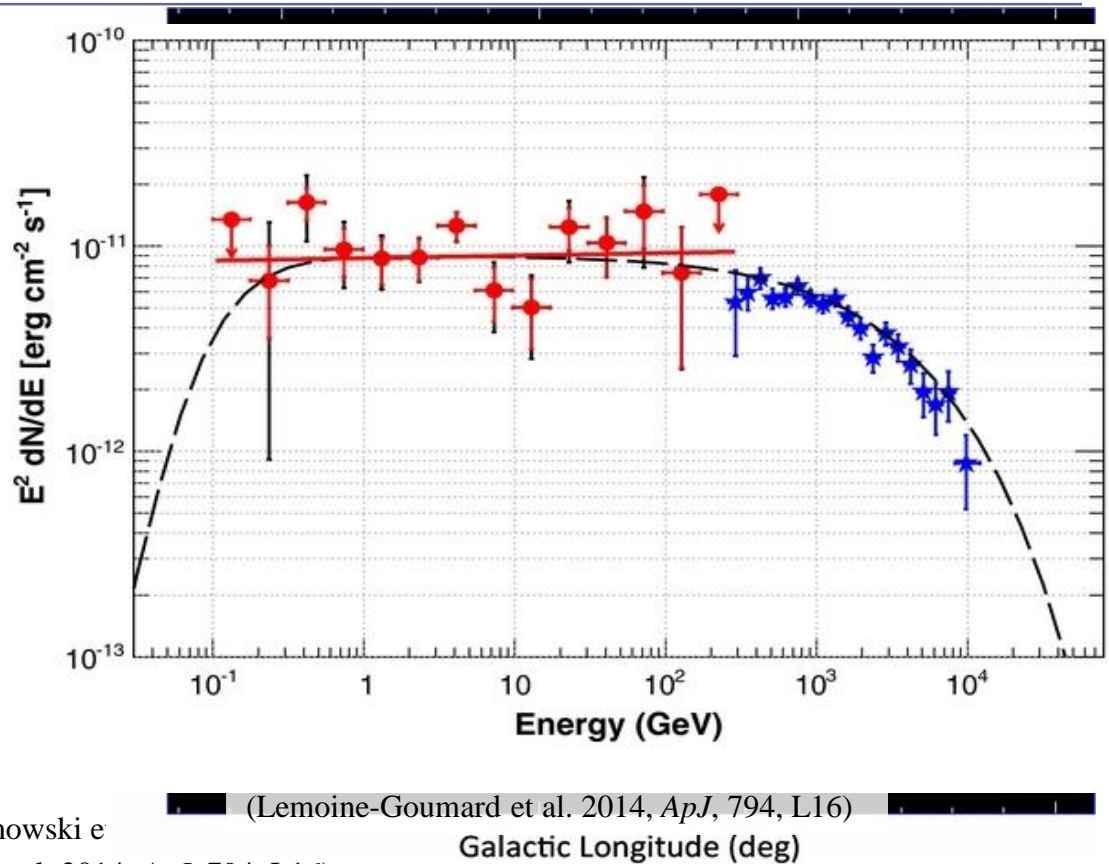
- Numerous discrete TeV γ -ray sources in Milky Way
- Main source classes:
 - Supernova Remnants (SNRs)
 - Pulsar Wind Nebulae (PWNe)
- Often associated with each other

(Carrigan et al. 2013, arXiv:1307.4690)



HESS J1640 – 465

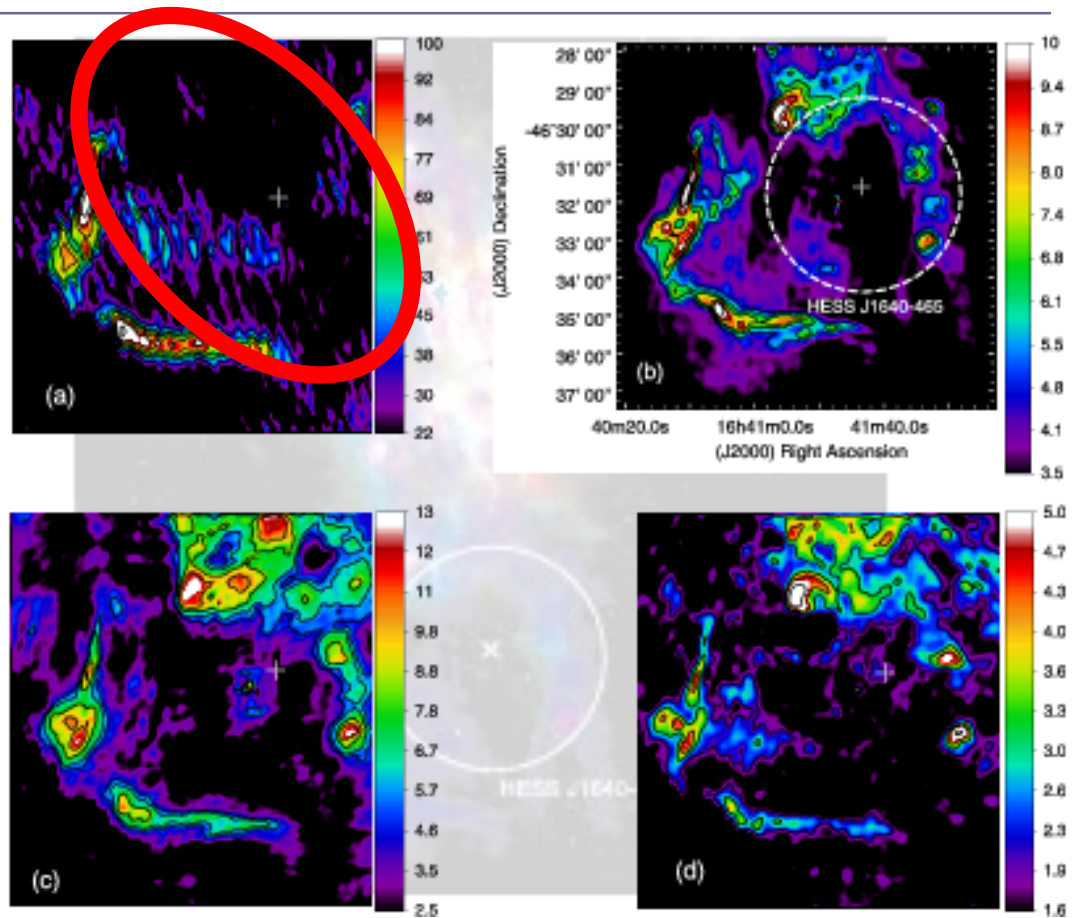
- Luminous TeV source in a crowded region
 - Borders HESS J1641-463
- MeV and GeV emission detected as well
 - GeV γ -rays predominantly from HESS J1640-465



Radio Supernova Remnant

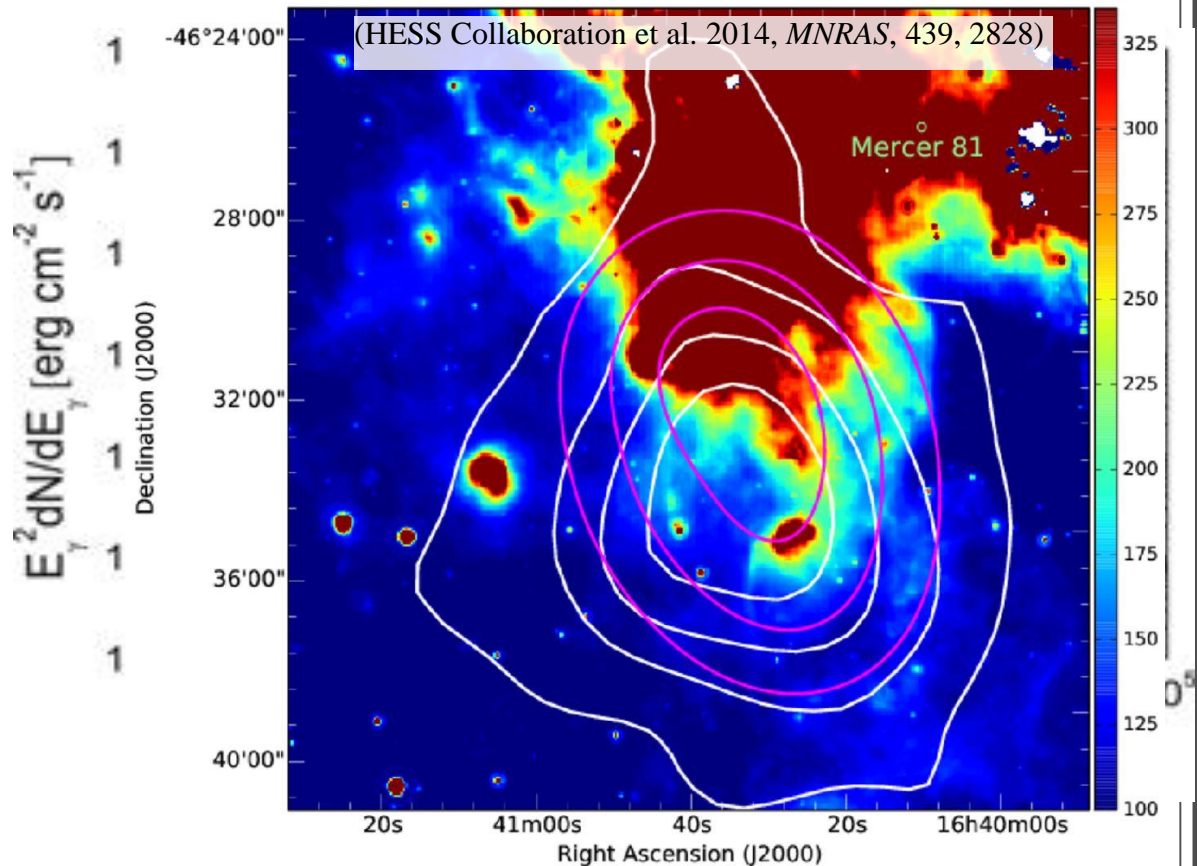
- Crowded region
 - Coincident with SNR G338.3-0.0
 - Located behind massive star cluster
- Electrons and protons accelerated to high energy in SNR shell
 - Inverse Compton emission from high-energy electrons
 - CR protons + Ambient protons $\rightarrow \pi^0 \rightarrow \gamma\gamma$ (“hadronic”)

(Castelleti et al. 2011, *A&A*, 536, A98)



SNR Interpretation of HESS J1640-465

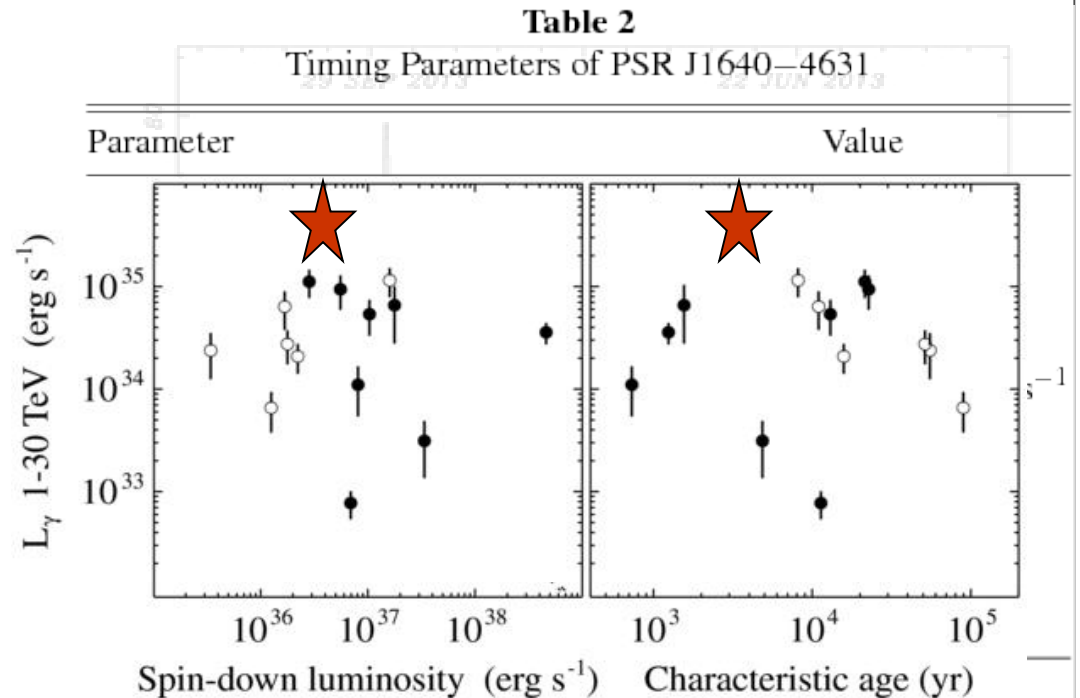
- γ -rays predominantly hadronic
 - CR energy $\sim 5 \times 10^{48}$ ergs
 - HESS J1641-463: diffusing CRs interacting with nearby molecular cloud
- Problem: No direct evidence for interaction between SNR G338.3-0.0
 - No thermal X-rays
 - No OH masers
 - CO nearby, but not coincident



X-ray Pulsar

■ PSR J1640-4631

- Fairly high \dot{E} ,
fairly low
characteristic age
- Properties
consistent with
that observed
from other γ -ray
PWNe

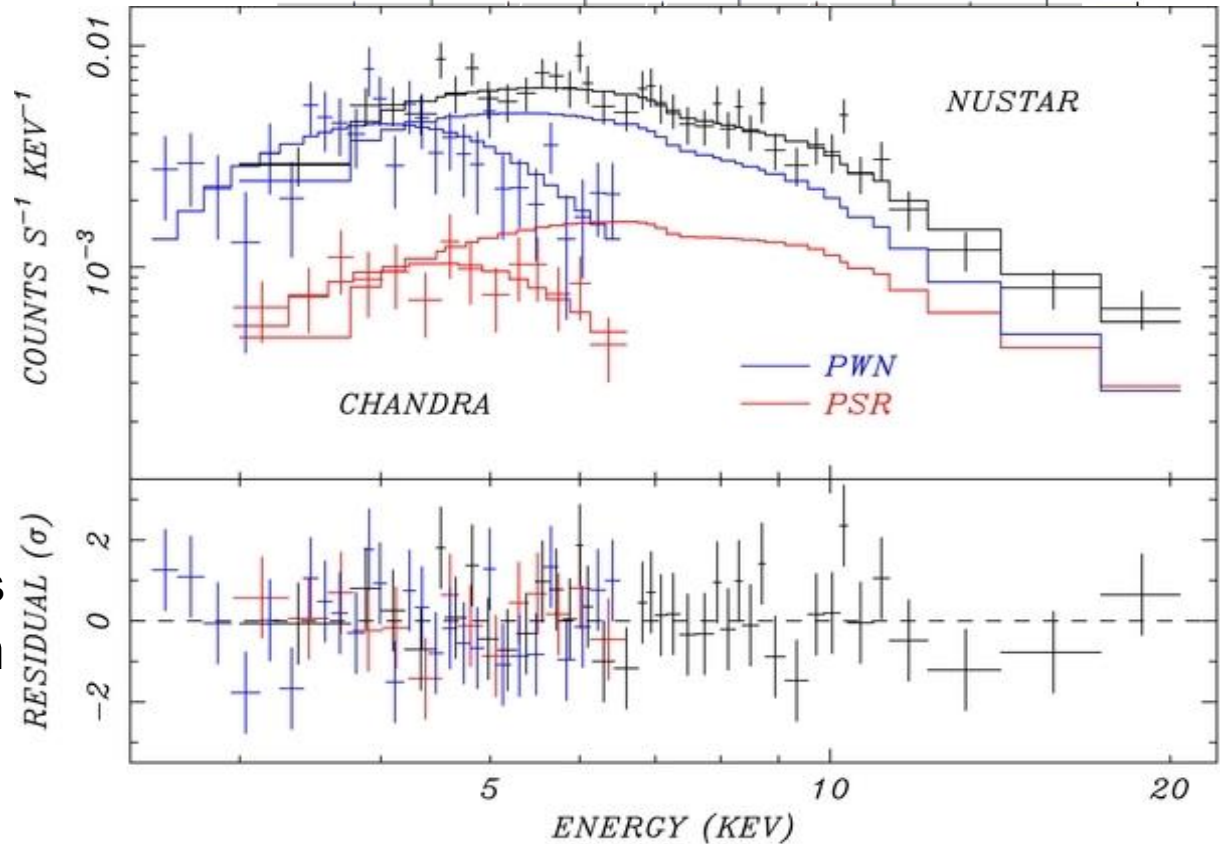


^a *Chandra* position from [Lemiere et al. \(2009\)](#)
(Mattana et al. 2009, *ApJ*, 694, 12)

^b 1σ uncertainties given in parentheses.
(Gothelf et al. 2014, *ApJ*, 788, 155)

X-ray Pulsar Wind Nebula

- Discovered before pulsar
- X-ray size \ll γ -ray size
- *Chandra* spectrum
 - Uncertain due to high $N_H \rightarrow$ limited bandwidth
 - $\Gamma = 1.4 \pm 0.4$ dependent on abundance models
- *NuSTAR* spectrum
 - Contaminated by pulsar
 - $\Gamma = 2.3 \pm 1.0$

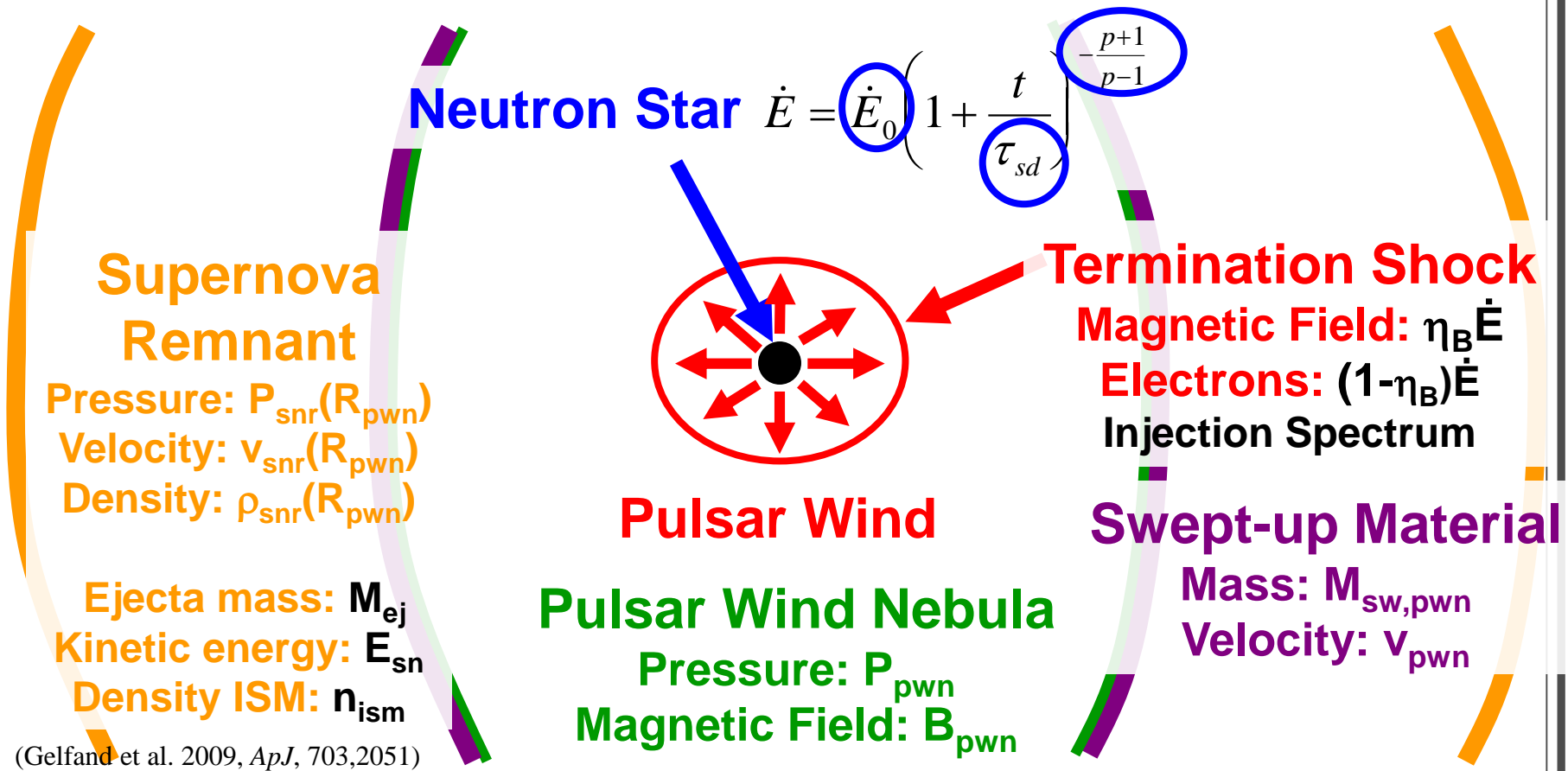


(Gotthelf et al. 2014, *ApJ*, 788, 155)

Is HESS J1640–465 a Pulsar Wind Nebula?

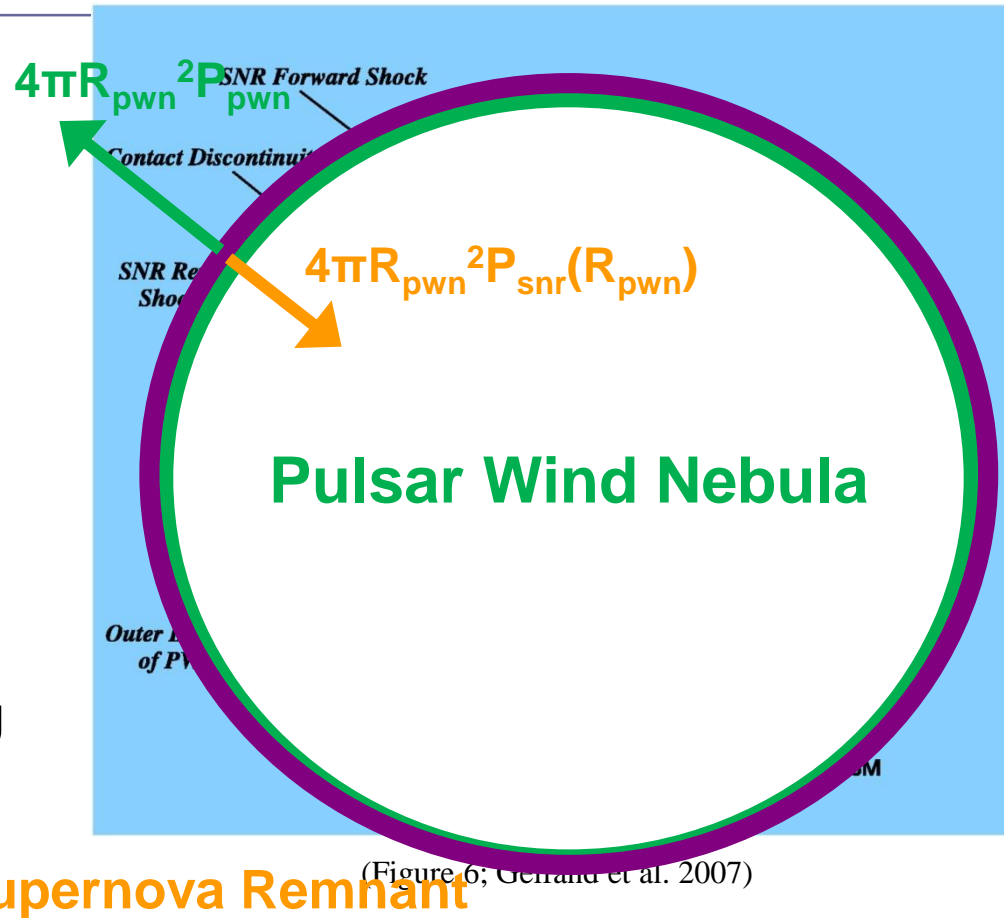
- Observed Properties
 - SNR radius
 - PWN radius = TeV radius
 - Radio upper-limit
 - *Chandra* X-ray spectrum
 - *Fermi* spectrum
 - HESS spectrum
 - Current pulsar \dot{E} , characteristic age
- Uncertainties
 - Initial kinetic energy E_{sn} and mass M_{ej} of supernova ejecta
 - Density of surrounding ISM n_{ism}
 - Pulsar braking index p and spin-down timescale τ_{sd}
 - Magnetization η_B and particle spectrum (E_{min} , E_{break} , E_{max} , p_1 , p_2)
 - Temperature and energy density of background photon field(s)
 - Distance

Schematic of a Pulsar Wind Nebula inside a Supernova Remnant



Evolutionary Model for a Pulsar Wind Nebula Inside a Supernova Remnant

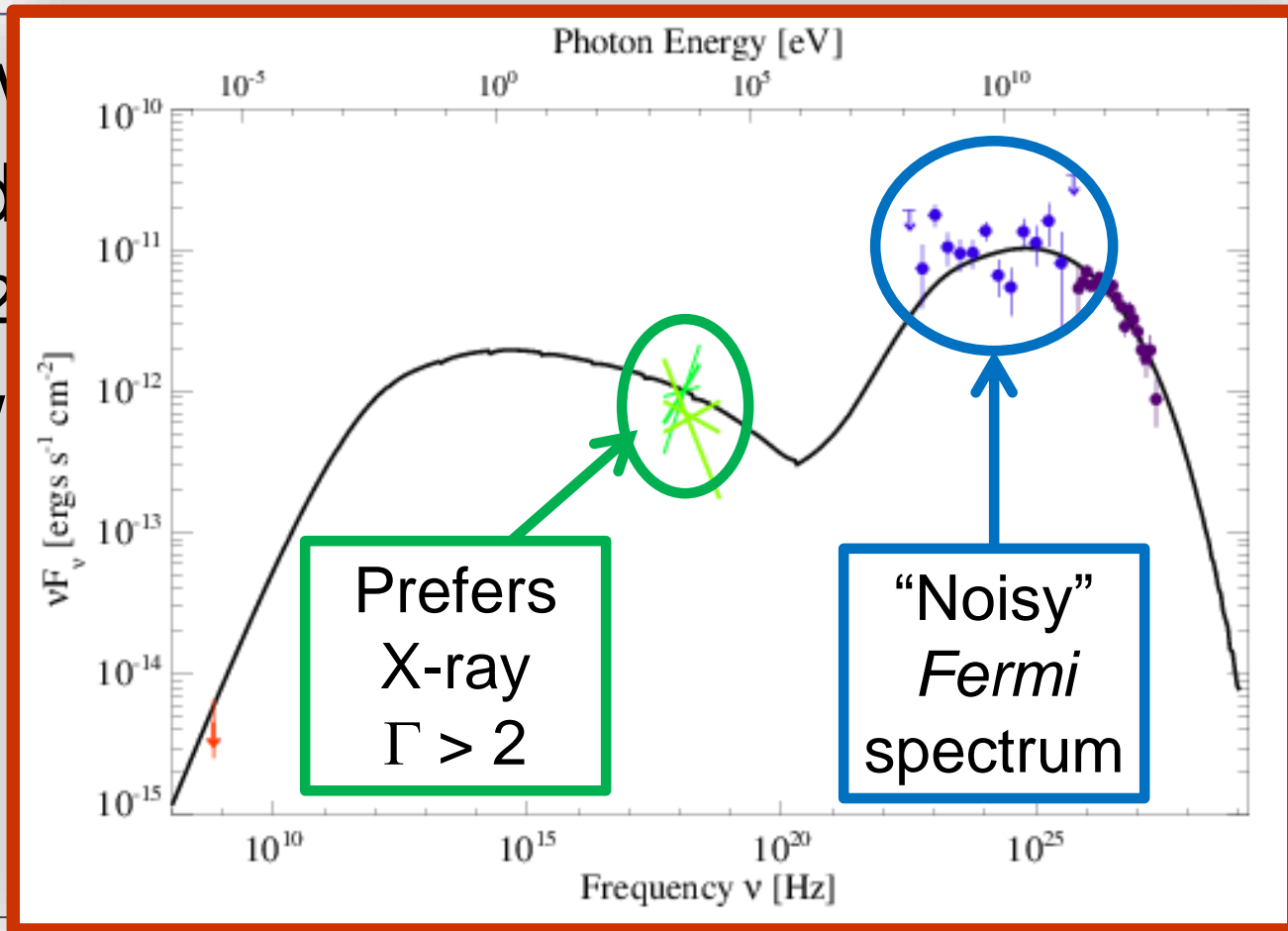
- Homogeneous ISM, Pulsar Wind Nebula (PWN)
 - One-zone model
- Dynamical evolution determined by motion of swept-up material
 - Net force from pressure difference between PWN and Supernova Remnant (SNR)
- Emission dominated by synchrotron radiation and Inverse Compton scattering of electrons off background photons



(Gelfand et al. 2009, *ApJ*, 703,2051)

Model Results

- MCMC model
- 22
- Low



s of

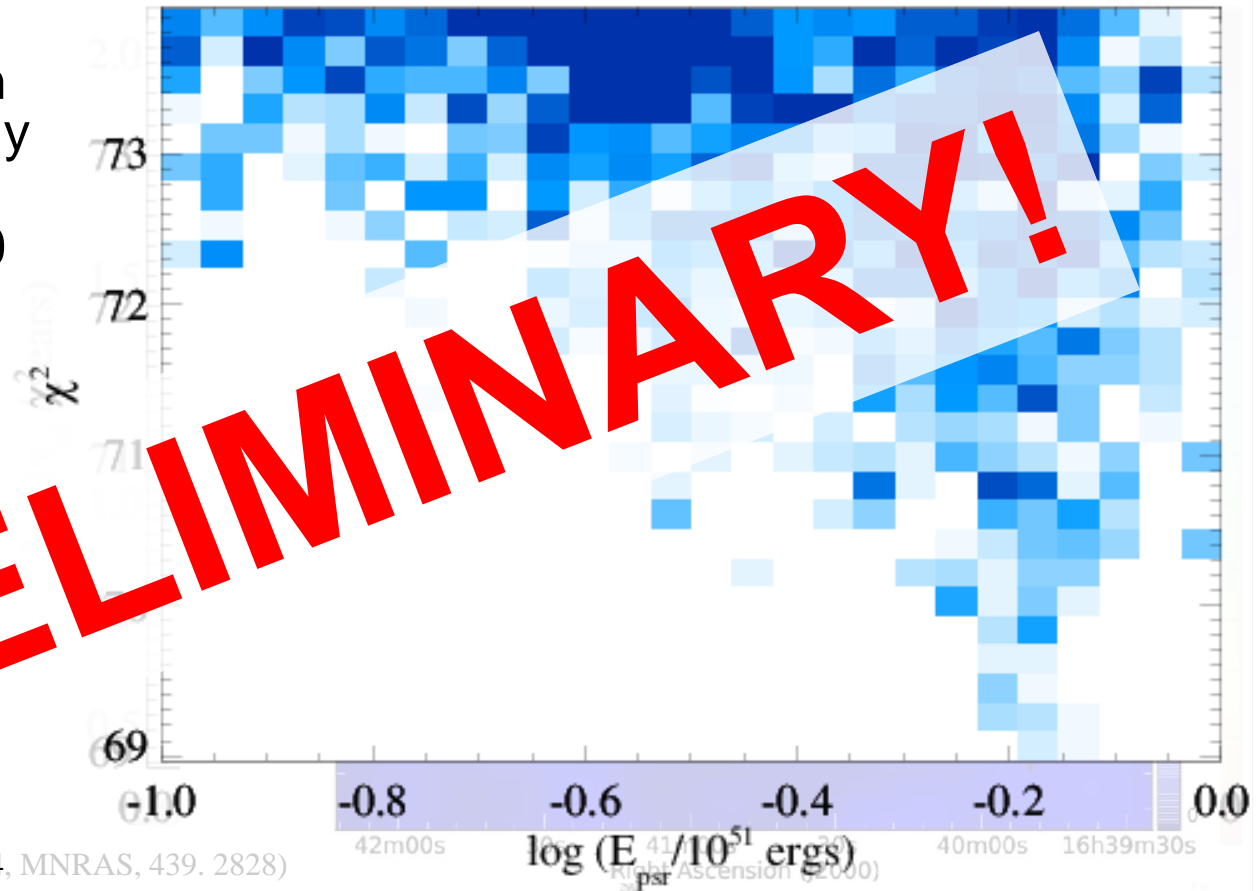
PSR J1640-4631 properties

- Pulsar braking index p , spin-down timescale τ_{sd} largely unconstrained
 - ... but $\tau_{sd} \leq 100$ years

Why?

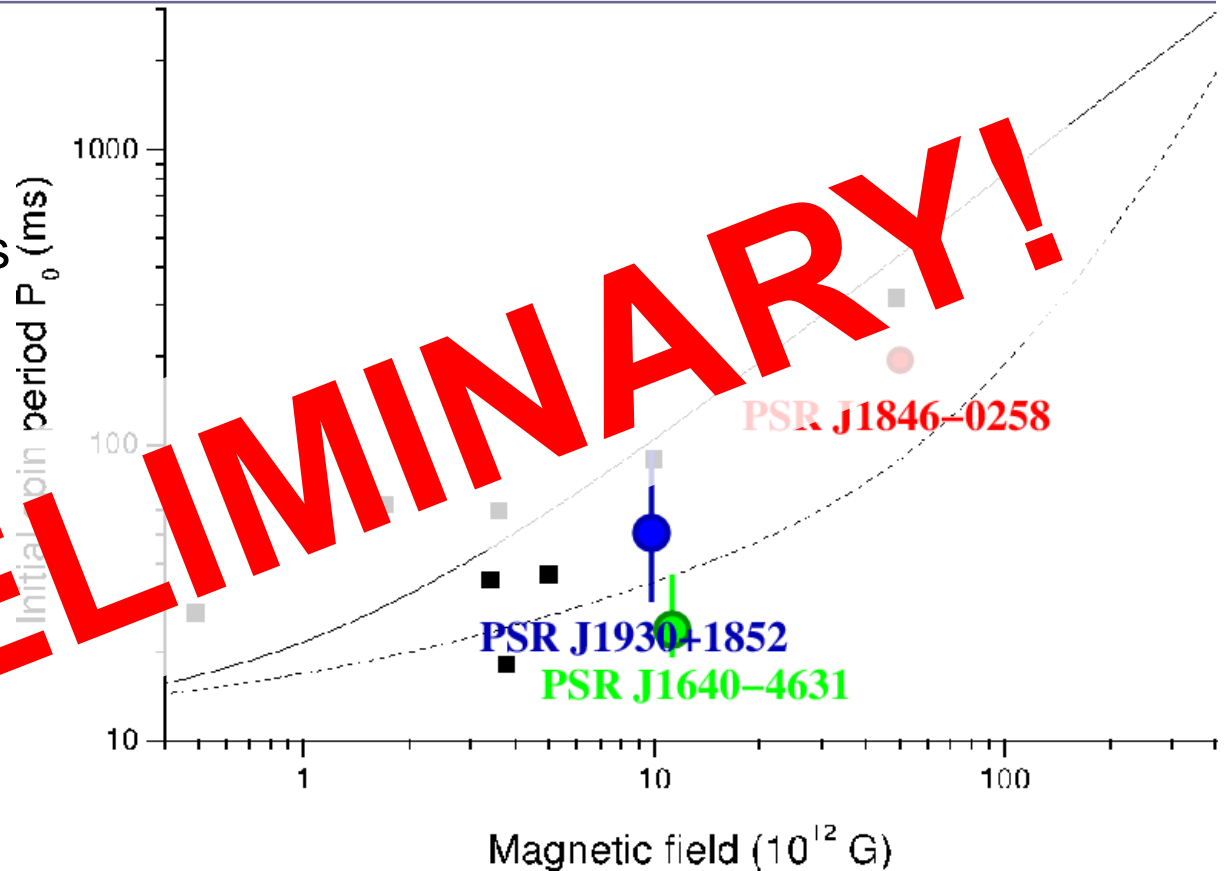
- PWN size \approx SNR size
- Occurs $\sim 10^4$ times per rotation
- Energy $\sim 10^{41}$ ergs
- Much higher in the past

(HESS Collaboration et al. 2014, MNRAS, 439, 2828)



Initial Spin Period of PSR J1640-4631

- Initial spin period $P_0 \ll P \approx 206$ ms now
 - $P_0 \sim 20 - 35$ ms
- Compare with models / other pulsars
 - Somewhat lower than other pulsars
 - Inconsistent with P_0 limited by GW emission?

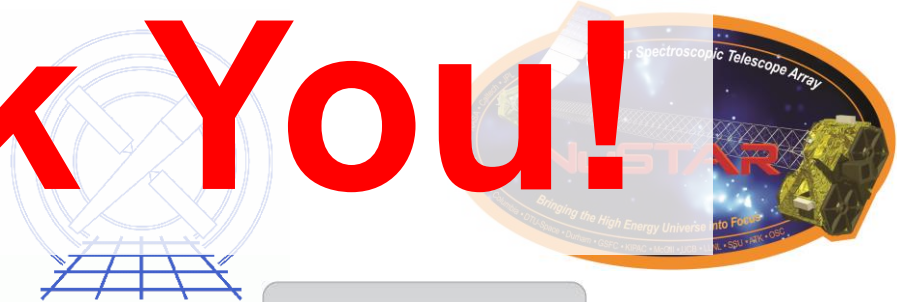


Summary

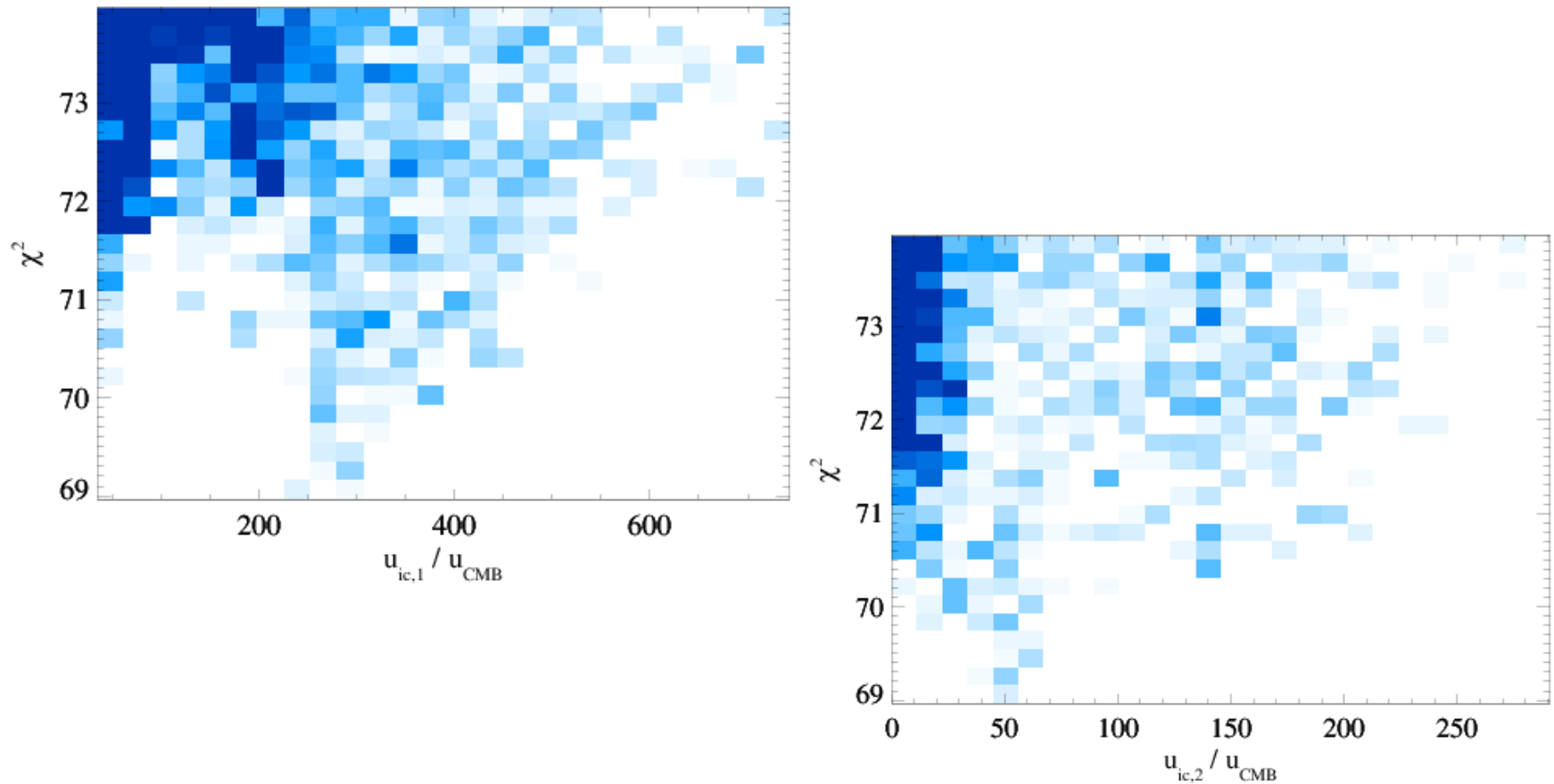
- Can reproduce properties of HESS J1640-465 with PWN model **IF** PSR J1641-4631 spun down rapidly
- Need to:
 - Determine MeV spectrum from additional Fermi data
 - Better measure X-ray extent spectrum of PWN
 - Utilize possible pulsar braking index measurement by *NuSTAR*
 - Detect PWN in radio (SKA?)
- Add SNR component to modeling
 - Include effects of cosmic ray acceleration on SNR evolution



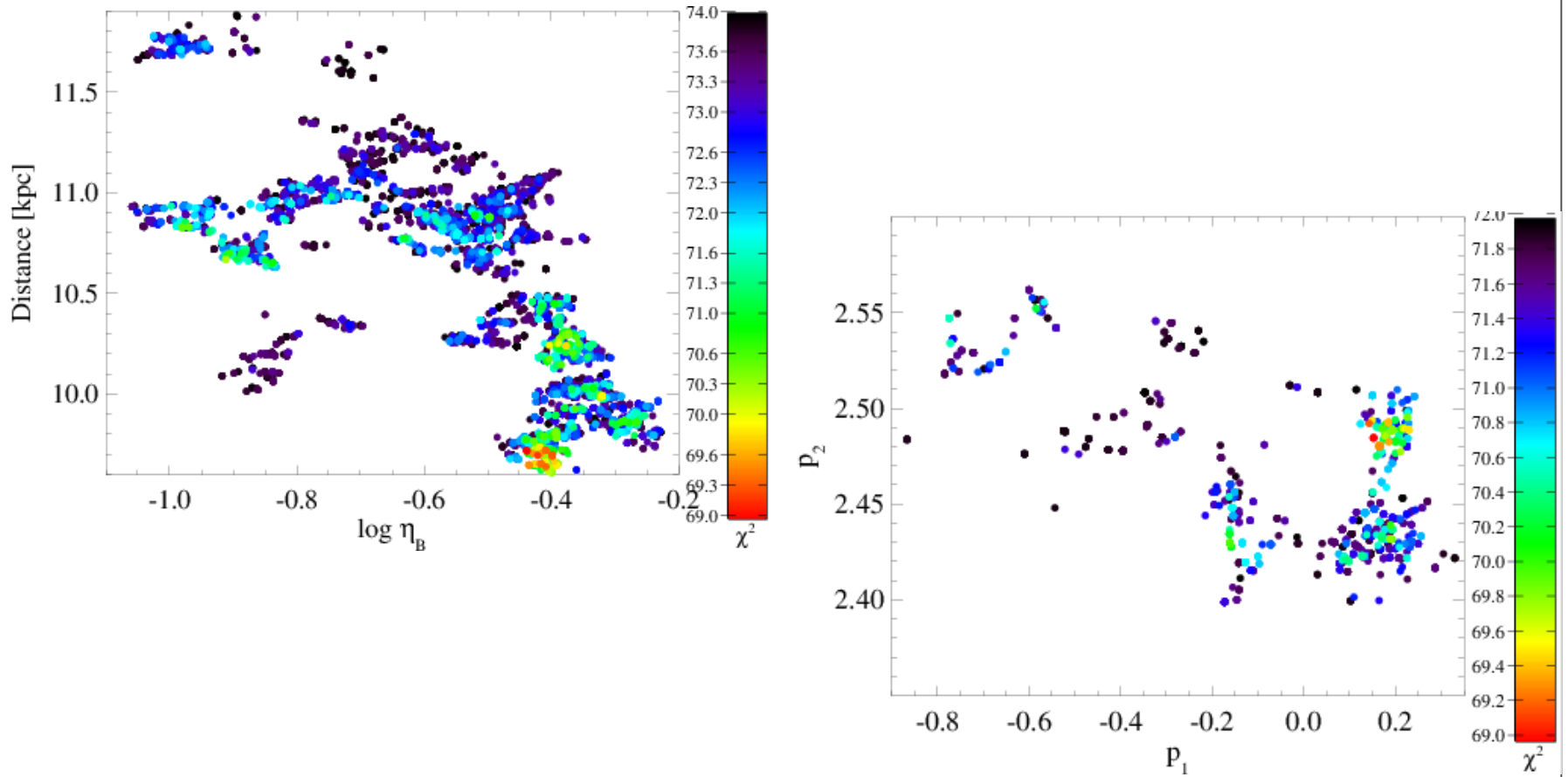
Thank You!



Background Photon Field



Pulsar Wind Properties



Combined Emission from Pulsar & Pulsar Wind Nebula?

■ Pulsar

- Power-law with exponential cut off
- Constant γ -ray efficiency η_γ

■ Pulsar Wind Nebula

- One-zone evolutionary model
- Broken power-law injection spectrum

(Gelfand et al. 2009, *ApJ*, 703,2051)

