

# Modeling a Pulsar Wind Nebula inside a Supernova Remnant

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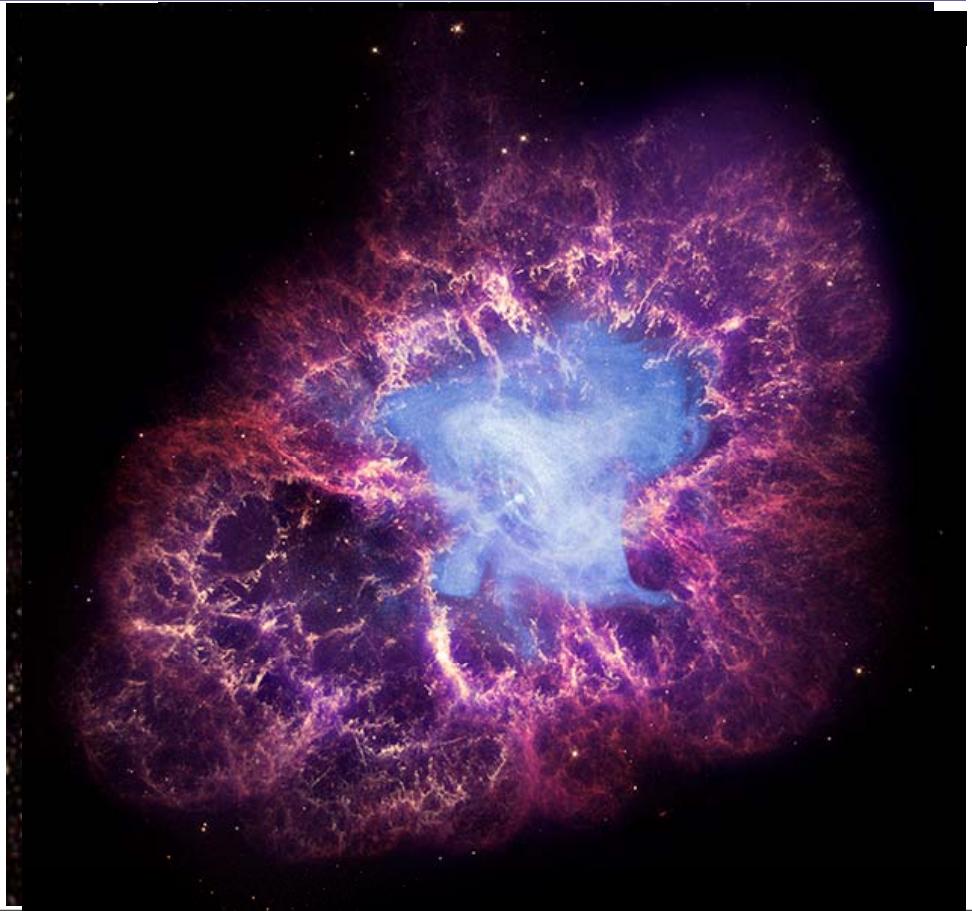
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# What is a Pulsar Wind Nebula?

- Neutron stars can have very strong magnetic fields and spin very quickly
- Generate a highly relativistic electron / positron “wind”
- Expansion of pulsar wind into its surroundings creates a PWN.

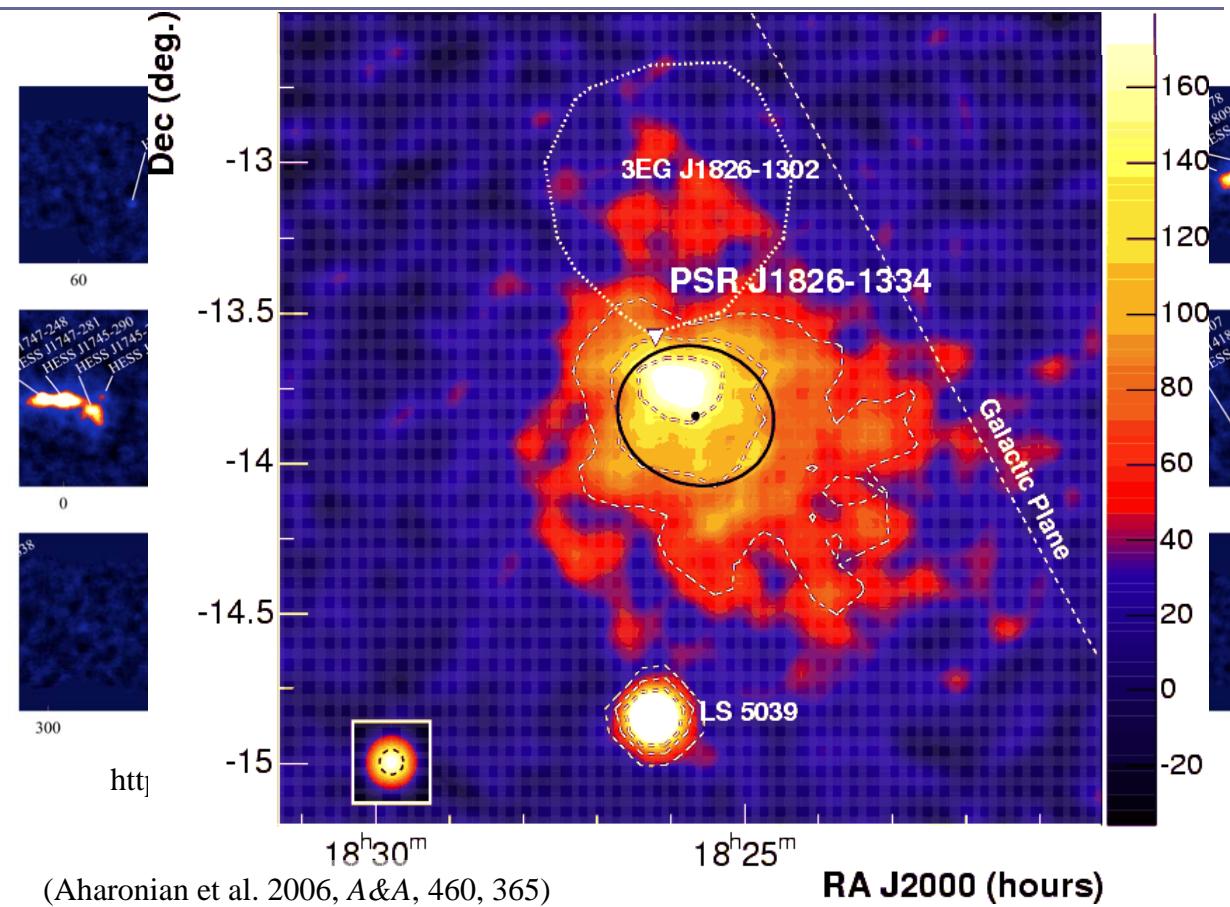
(Animation: CXC/D.Berry)



(X-ray: NASA/CXC/SAO/F.Seward; Optical: NASA/ESA/ASU/J.Hester & A.Loll; Infrared: NASA/JPL-Caltech/Univ. Minn./R.Gehrz)

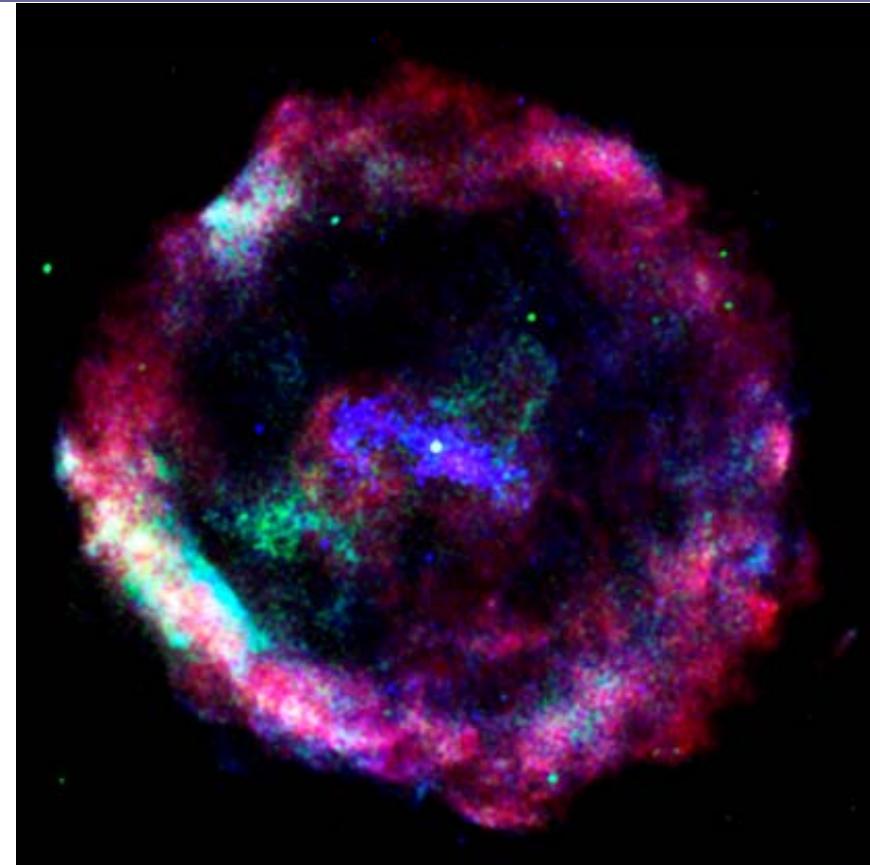
# Galactic sources of $\gamma$ -rays

- Many  $\gamma$ -ray sources in Galactic Plane
  - Most coincident with “young” pulsars
  - PWN likely dominates TeV emission
- PWN of young pulsar likely inside a supernova remnant



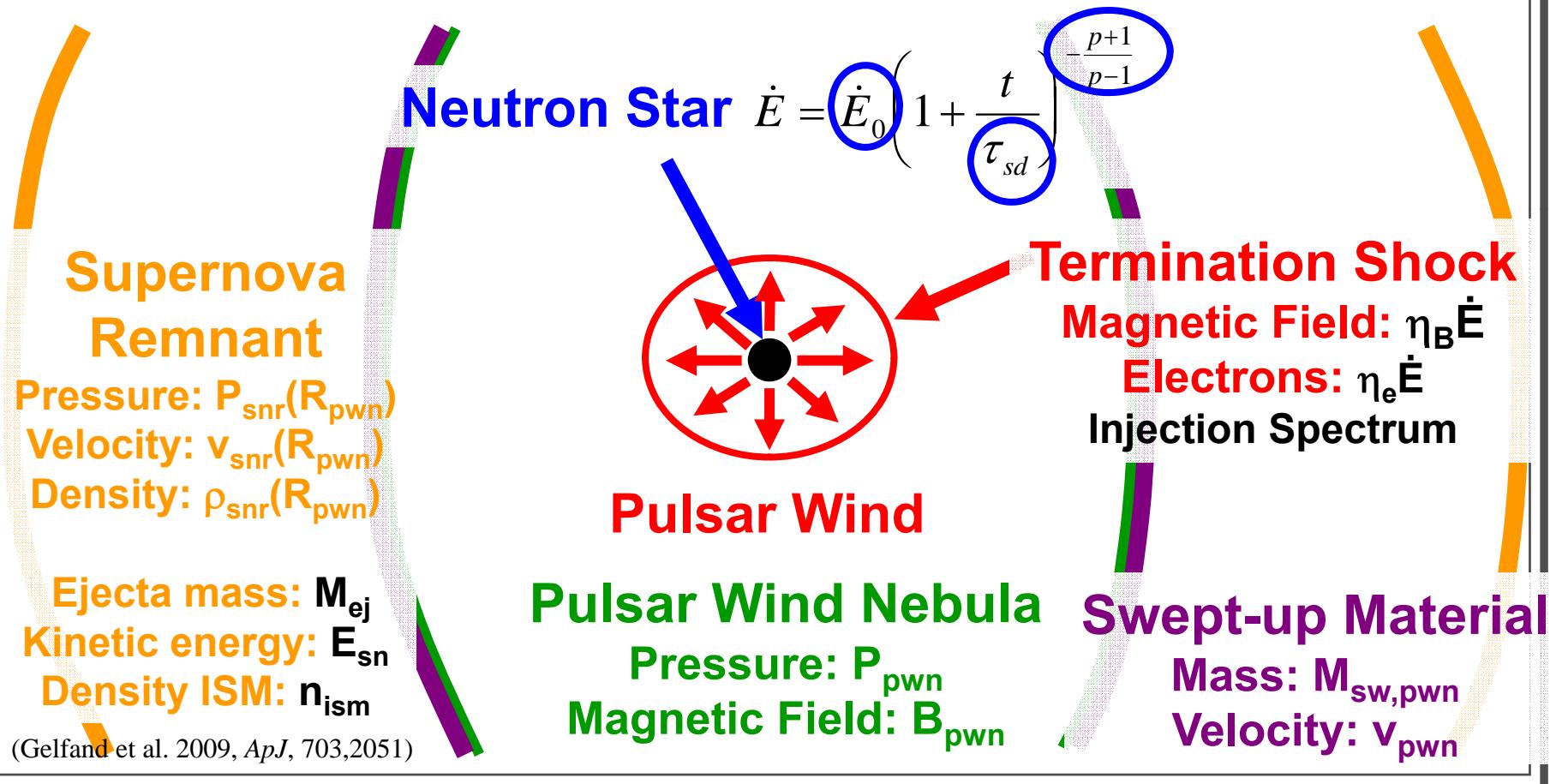
# Pulsar Wind Nebula inside a Supernova Remnant

- Neutron Star
  - Initial Spin Period and Spin-down Luminosity
  - Spin-down Timescale
  - Braking Index
- Pulsar Wind
  - Fraction of energy in magnetic fields, electrons / positrons
  - Acceleration mechanism: minimum and maximum particle energy, energy spectrum
- Progenitor Supernova
  - Ejecta Mass
  - Initial Kinetic Energy



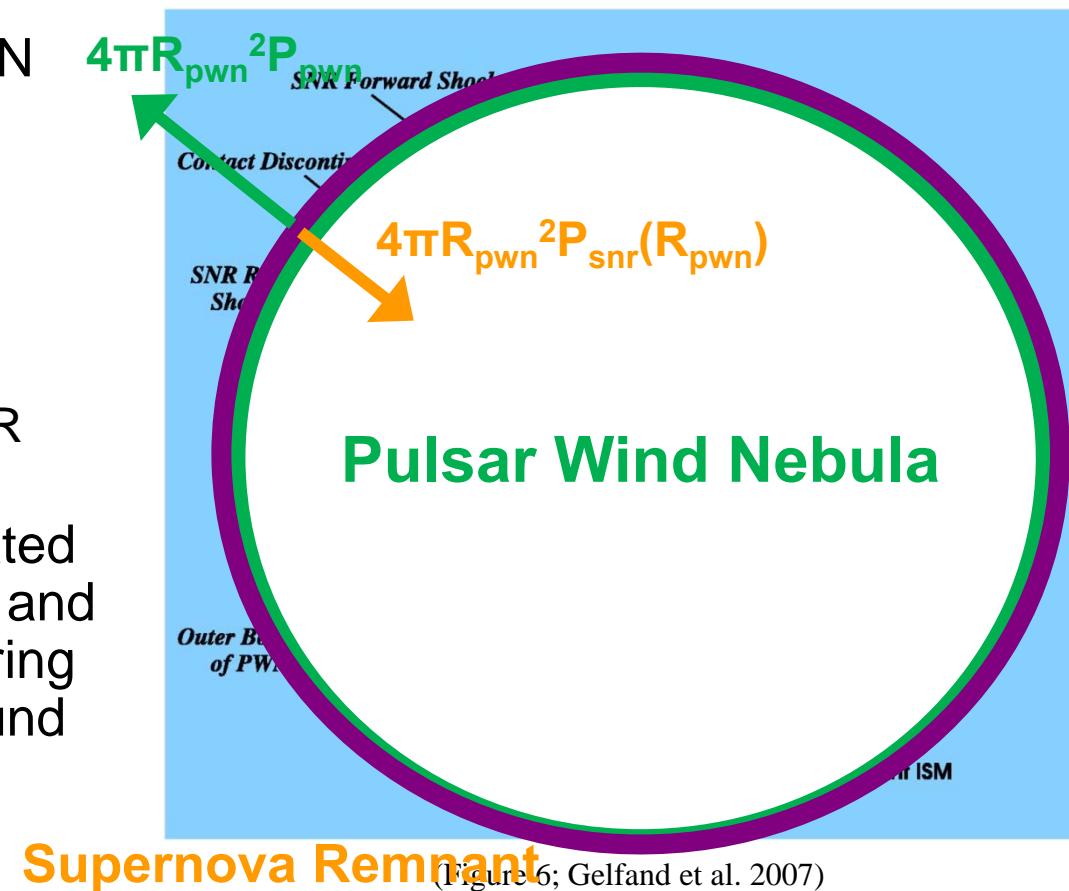
(Credit: X-ray: NASA/CXC/Eureka Scientific/M.Roberts et al.; Radio: NRAO/AUI/NSF)

# Schematic of a Pulsar Wind Nebula inside a Supernova Remnant



# Evolutionary Model for a Pulsar Wind Nebula Inside a Supernova Remnant

- Homogeneous ISM, PWN
  - One-zone model
- Dynamical evolution determined by motion of swept-up material
  - Difference in pressure between PWN and SNR results in net force
- PWN's emission dominated by synchrotron radiation and Inverse Compton scattering of electrons off background photons

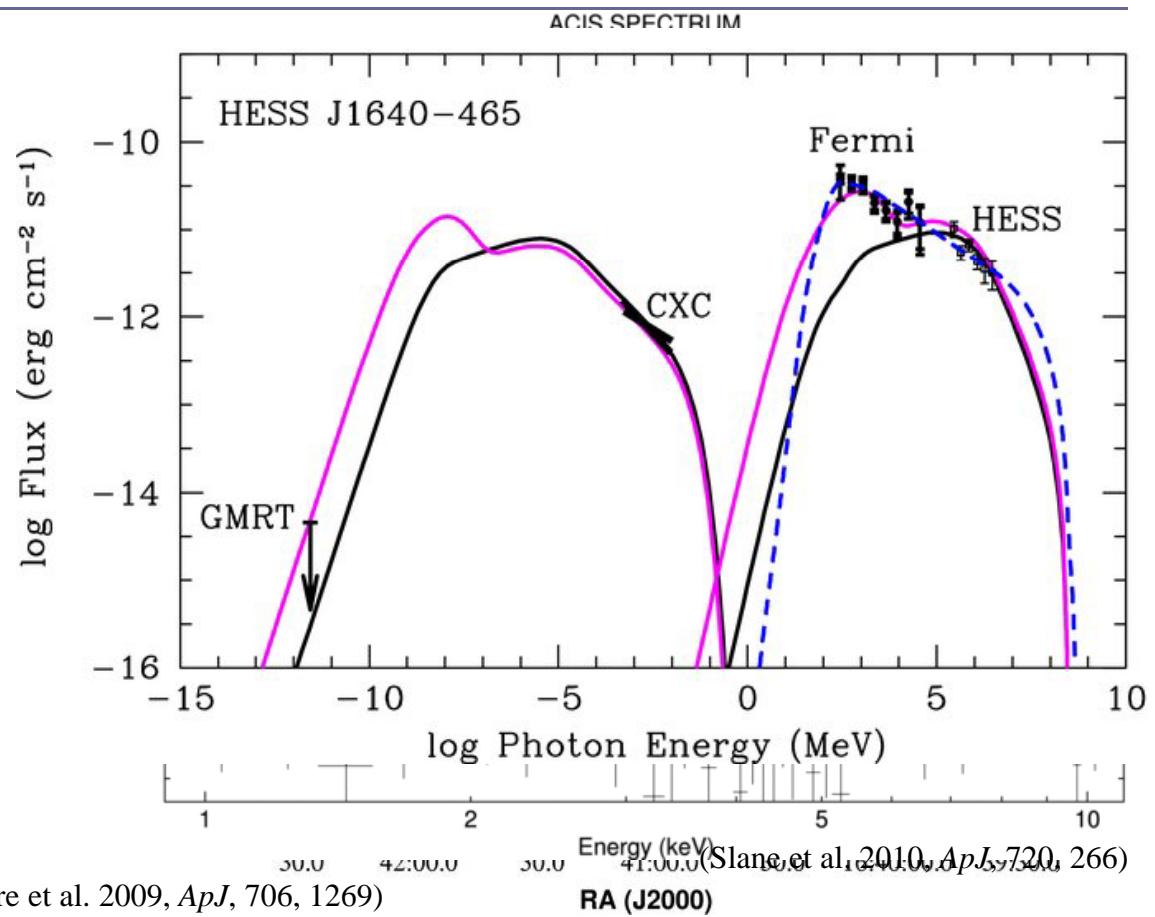


(Gelfand et al. 2009, *ApJ*, 703,2051)

Supernova Remnant (Figure 6; Gelfand et al. 2007)

# HESS J1640 – 465

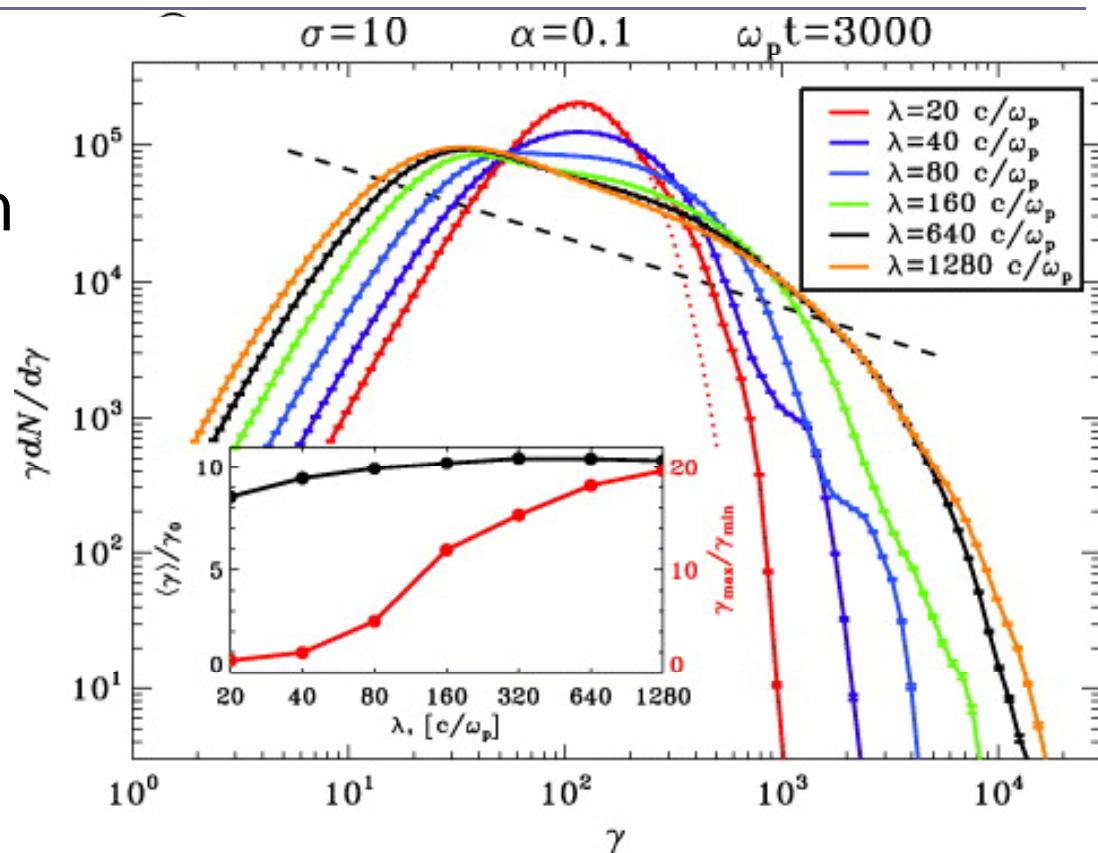
- GeV & TeV  $\gamma$ -ray Spectrum
- PWN Radius =  $2.7 \pm 0.5$  arcmin
- SNR Radius =  $4.5 \pm 0.5$  arcmin
- Radio upper-limit
- X-ray Spectrum
- No pulsations



(Lemiere et al. 2009, *ApJ*, 706, 1269)

# Pulsar Wind Nebula dominated $\gamma$ -ray emission

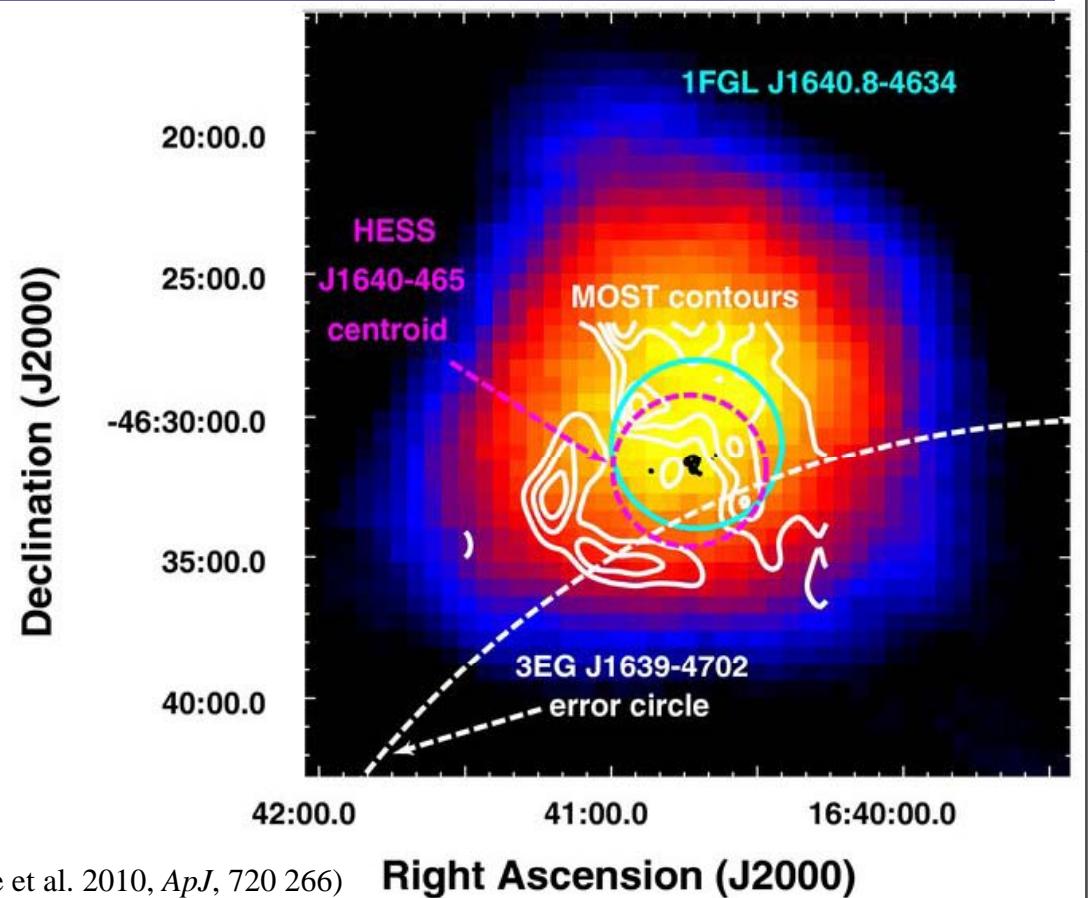
- Good fit favors Maxwellian + Power-law injection spectrum
  - Required for  $\sim 100$  MeV emission
  - Rough agreement with recent PIC simulations
  - Most PWN favor broken power-law injection spectrum



(Slane et al. 2010; Sironi & Spitkovsky, 2012, doi:10.1088/1749-4699/5/1/014014)

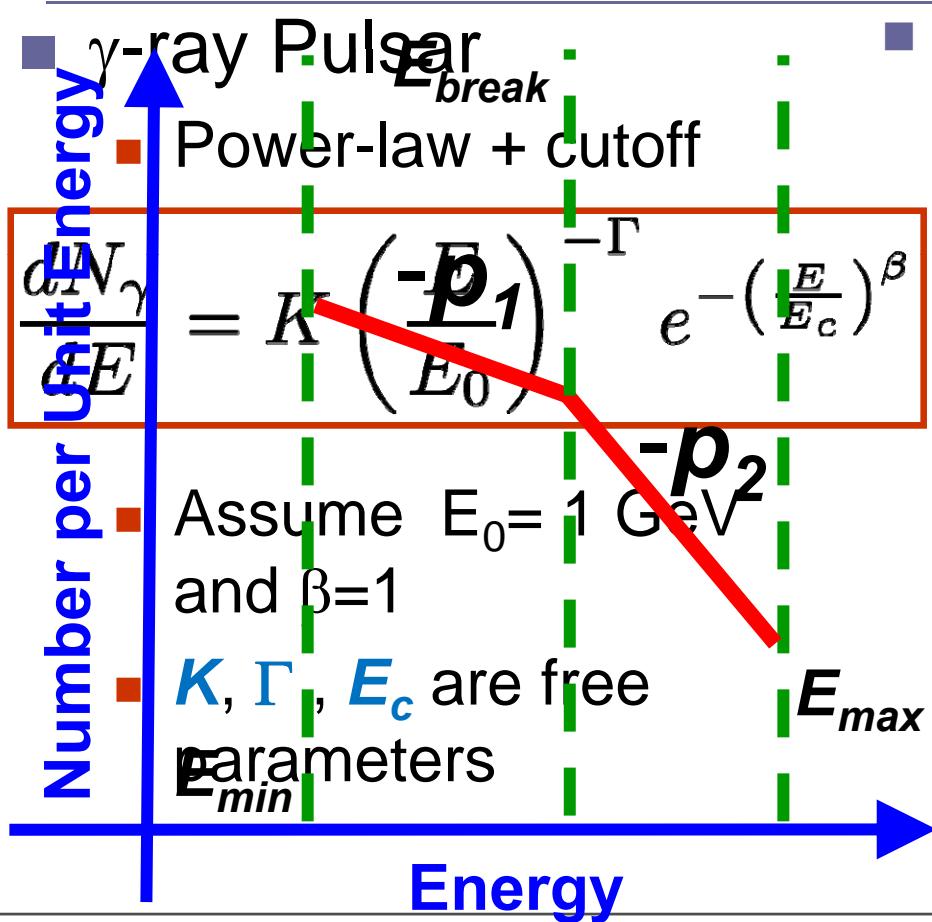
# Origin of MeV $\gamma$ -ray emission

- Possibilities:
  - Different acceleration mechanisms in different PWNe?
  - MeV  $\gamma$ -ray emission from pulsar?
- Test second possibility



(Slane et al. 2010, *ApJ*, 720 266)

# Modeling Pulsar + Pulsar Wind Nebula

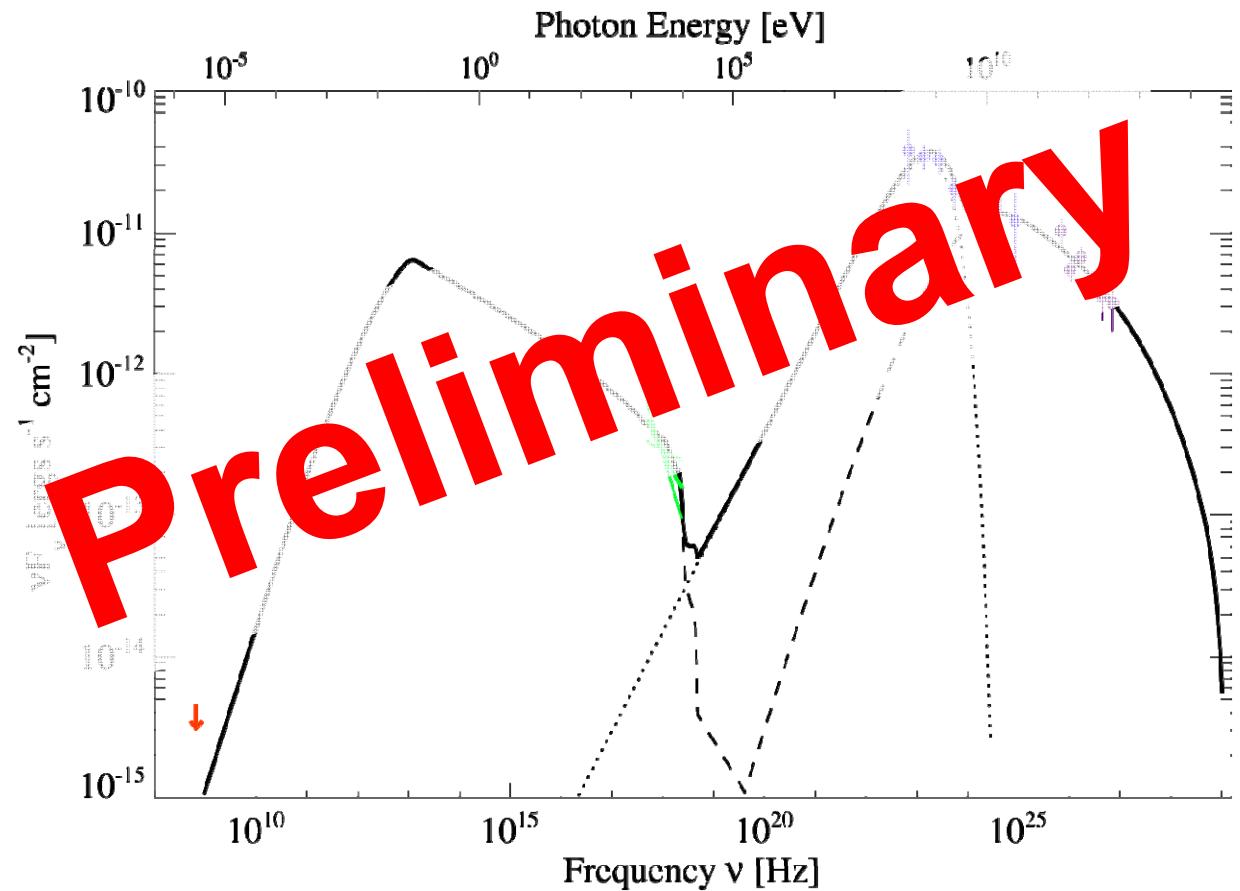


# Best fit model

- ~ 3500 yrs old
- Broken power-law injection spectrum

- $E_{min} \sim 10$  MeV
- $E_{break} \sim 1$  TeV
- $E_{max} \sim 1$  PeV
- $p_1 \sim 0.0$
- $p_2 \sim 0.0$

Very  
GeV



# Summary

- Possible pulsar  $\gamma$ -ray emission in HESS J1640-465
  - $\sqrt{F_{\text{P}}/\Delta^2} = 1.22 \times 10^{-7}$   
 $(\text{erg cm}^{-2} \text{s}^{-1})^{1/2} \text{ pc}^2$
- Explore PWL space with pulsar  $\gamma$ -ray emission
- Test with additional observables
  - Hard X-ray flux and photon index

## ■ Future Work

- Apply technique to other systems, e.g. PSR B1133+16, 3C58
- Offer detailed comparison at the time

Thank You!

