The GeV – TeV Connection for PWN

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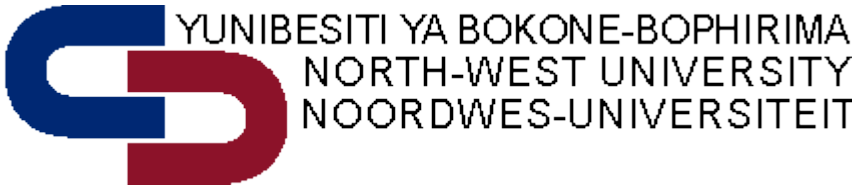
(Aspen, 2010)



PWN electron energies probed by TeV γ–ray observations

$$B = 10^{-5} B_{-5}\,\mathrm{G}$$

- Radio: Electron Energy = 45 $(B_{-5})^{-1/2}(\nu_{11})^{1/2}$ GeV
- X-rays: Electron Energy=70 $(B_{-5})^{-1/2}(E_{keV})^{1/2}$ TeV
- γ-rays: Electron Energy=18 $(E_{\gamma,TeV})^{1/2}$ TeV

TeV γ-rays probe lower electron energies compared to X-rays in **extended PWN** where B is typically around 10 μG – ICS on CMBR.

How do we compare GeV, TeV with synchrotron observations?

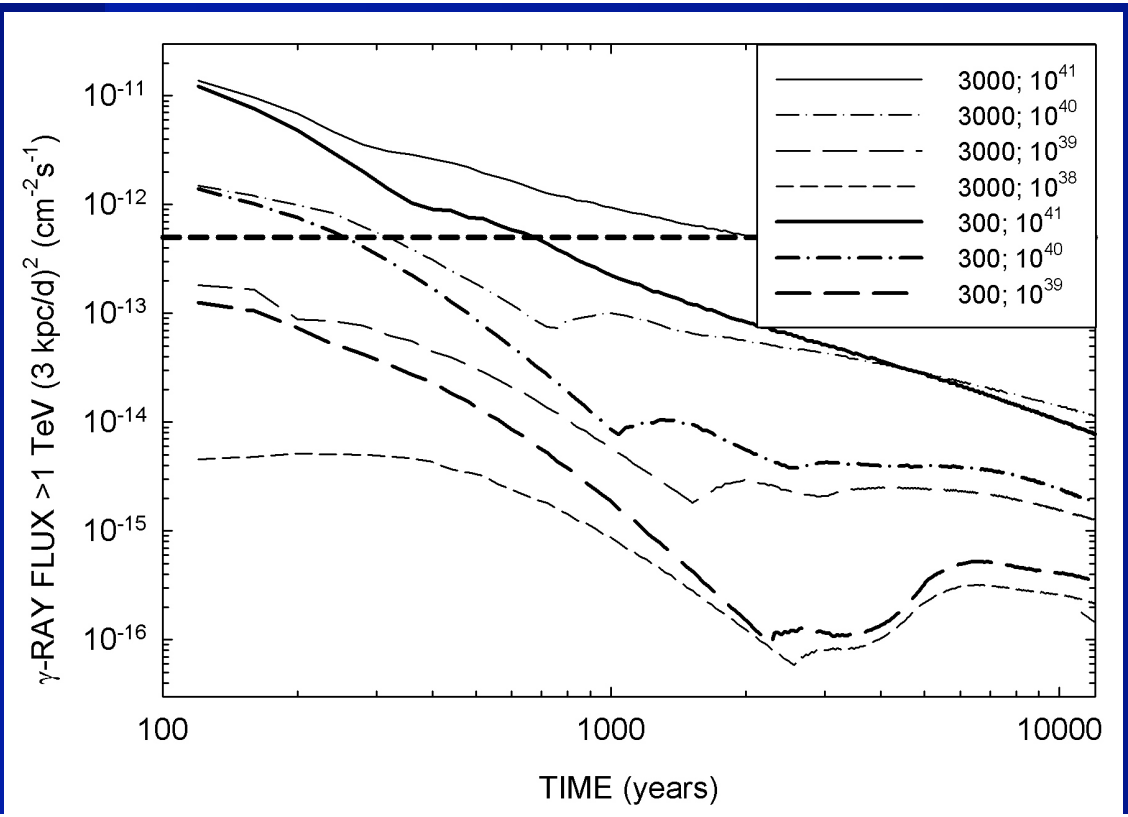
- Assuming inverse Compton scattering on the CMBR:
- Synchrotron energies in terms of the GeV & TeV γ-ray energy

- INFRARED: $E_X \cong 0.06\ B_{-5}\ E_{\gamma,GeV}$ eV (K-Band)
- EUV: $E_X \cong 60\ B_{-5}\ E_{\gamma,TeV}$ eV

We effectively probe Infrared to EUV synchrotron component of PWN up to distances of ~10 kpc.

New PWN Diagnostics from Gamma-Ray Astronomy Measurements - I

1. Probing the transport of the leptonic component
2. Is there a hadronic component visible? Maybe not, unless the target densities are > 10^3 cm^{-3}.



De Jager, Ferreira & Venter, in preparation

New PWN Diagnostics from Gamma-Ray Astronomy Measurements - II

1. Magnetic field strength estimates after comparing synchrotron & inverse Compton observations
2. Field sometimes below equipartition (e.g.)
    1. Crab
    2. G21.5-0.9
    3. Vela X

New PWN Diagnostics from Gamma-Ray Astronomy Measurements - III

- Pair production multiplicities after counting leptons in IC and extending calculation to low frequency radio synchrotron observations as proposed by de Jager (2005). E.g. for Vela X

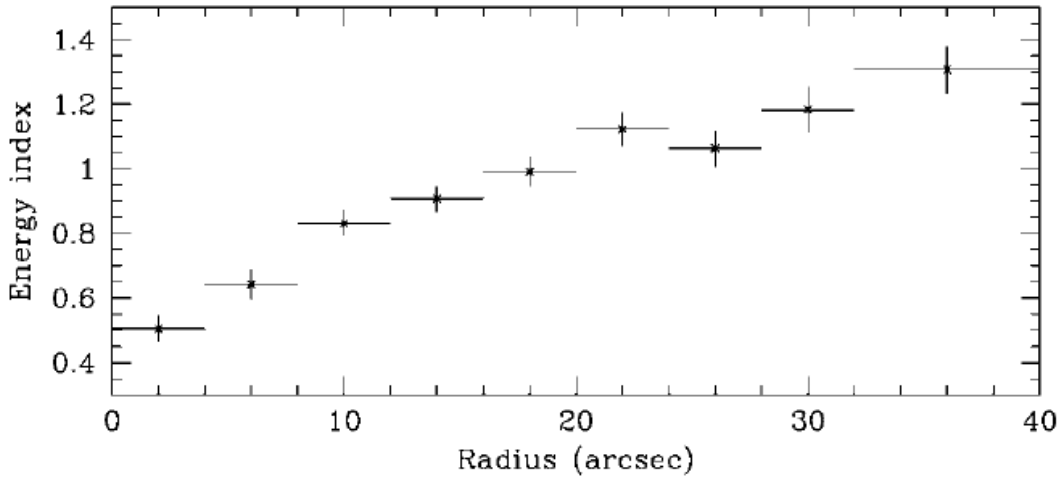
Mult = 10^5(B/5μG)

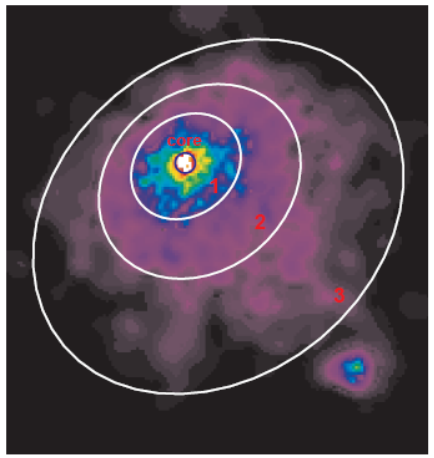
(normalised to GeV/TeV obs)

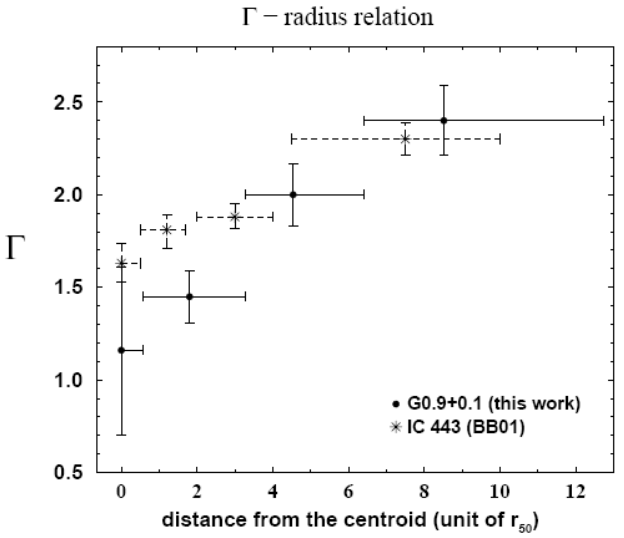
- Detailed 1-zone, time dependent calculations by Bucciantini et al. (2010) also show multiplicities up to 10^5.

Cooling in post shock flow spectra as measured in X-rays Aharonian et al. 2006

- Photon index of ~1.5 to >2.
- G21.5-0.9 – Slane et al. 2000
- G0.9+0.1 – Porquet et al. 2003

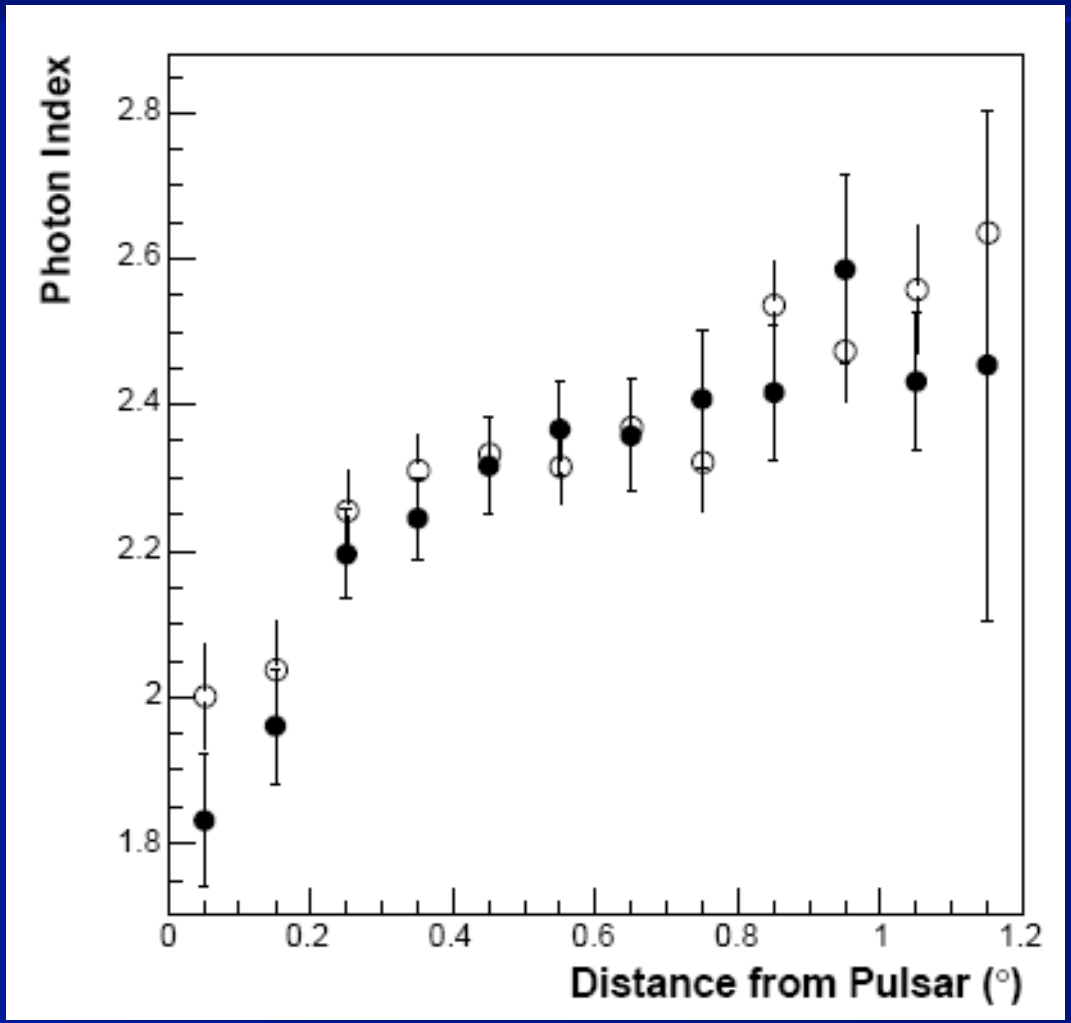




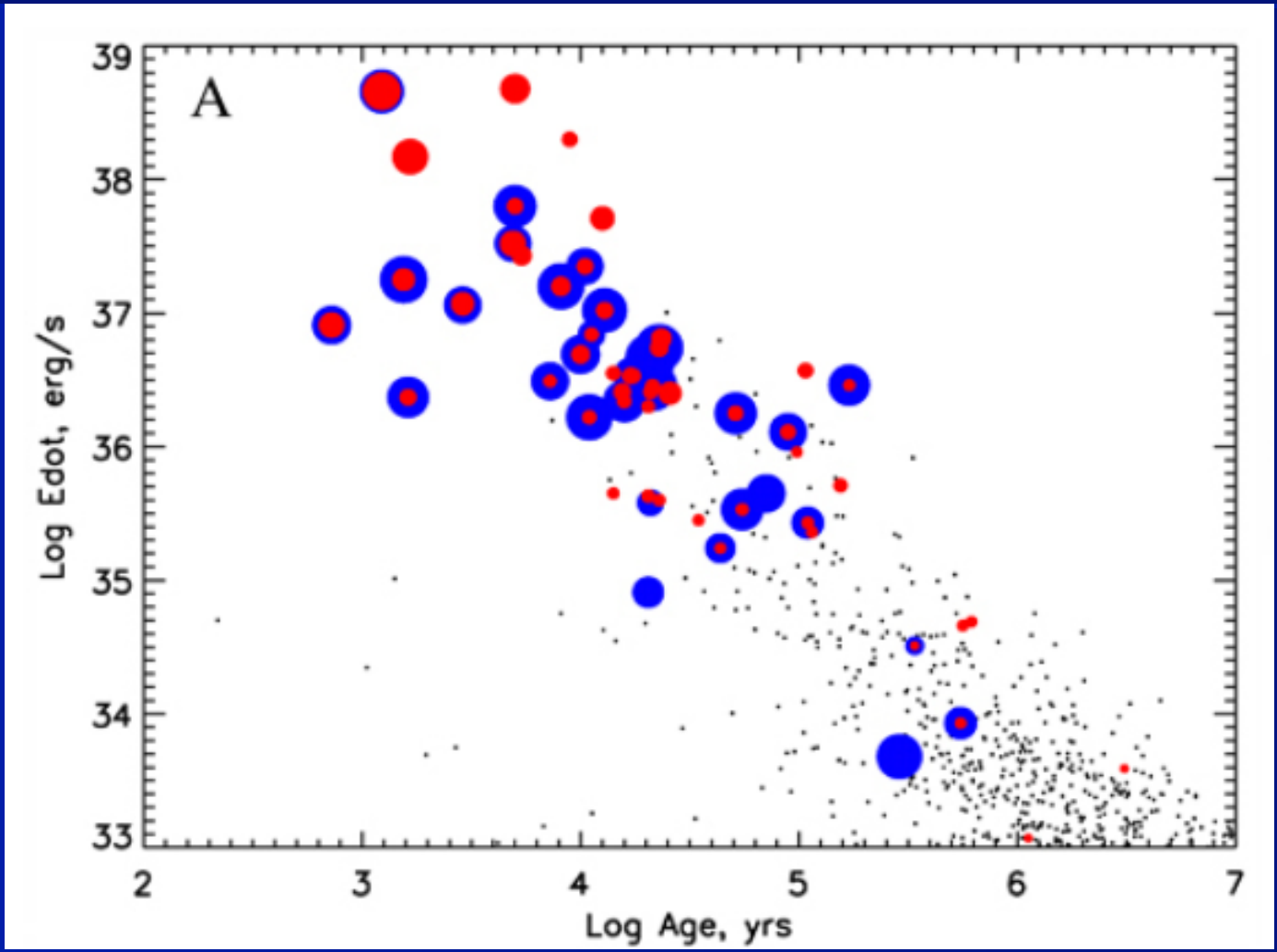


Cooling in post shock flow spectra as measured in TeV-rays from HESS J1825-137 – Aharonian et al. 2006

- Photon index of ~1.9 to 2.4
- Shift probably due to Klein-Nishina effects.

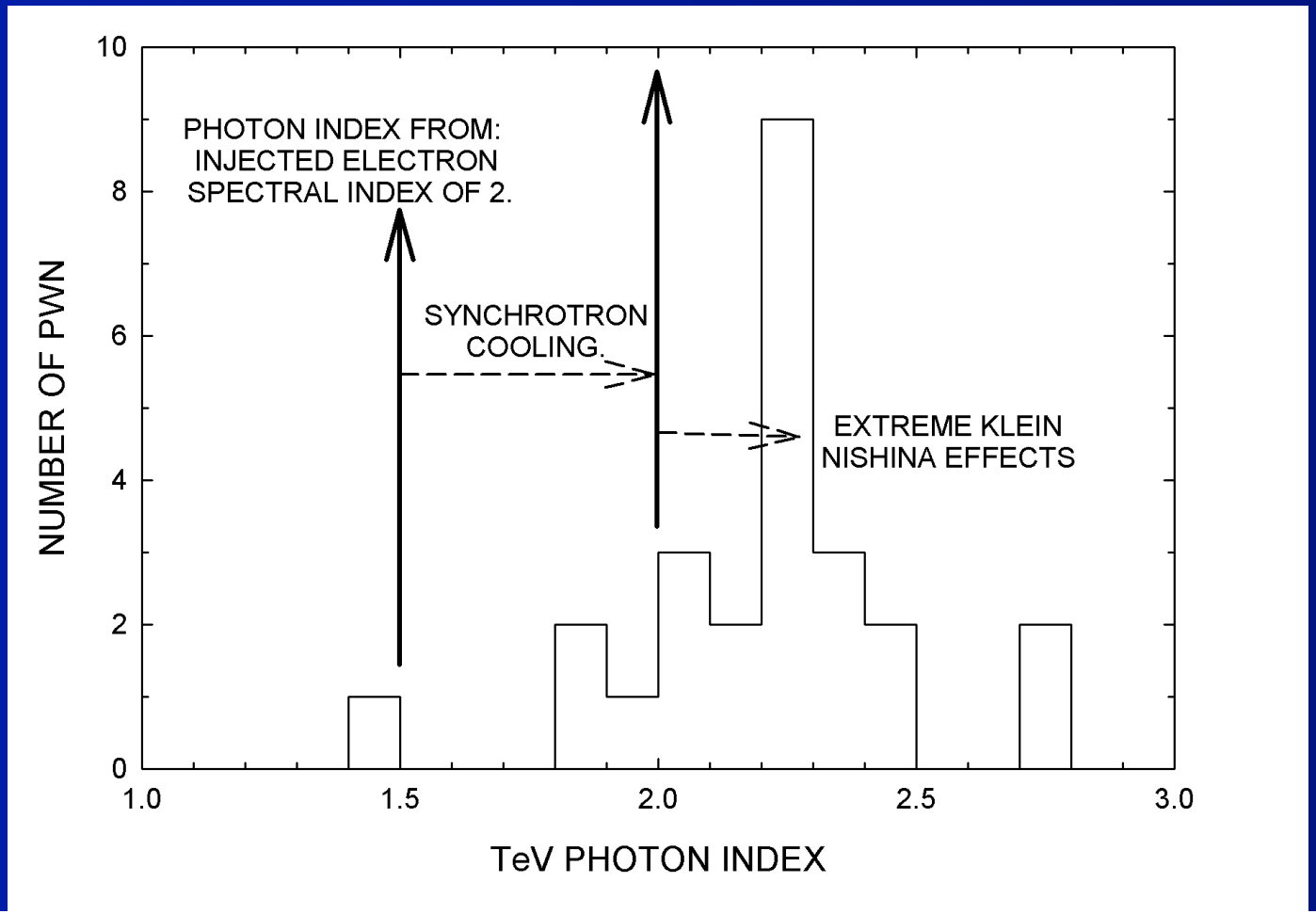


Are TeV associations of PWN and PWN candidates with energetic pulsars random? (from Kargaltsev & Pavlov, 2010)



TeV spectra of PWN and PWN candidates – from list of Kargaltsev & Pavlov 2010

- Almost all TeV PWN spectra are consistent with cooled lepton spectra, except Vela X cocoon.

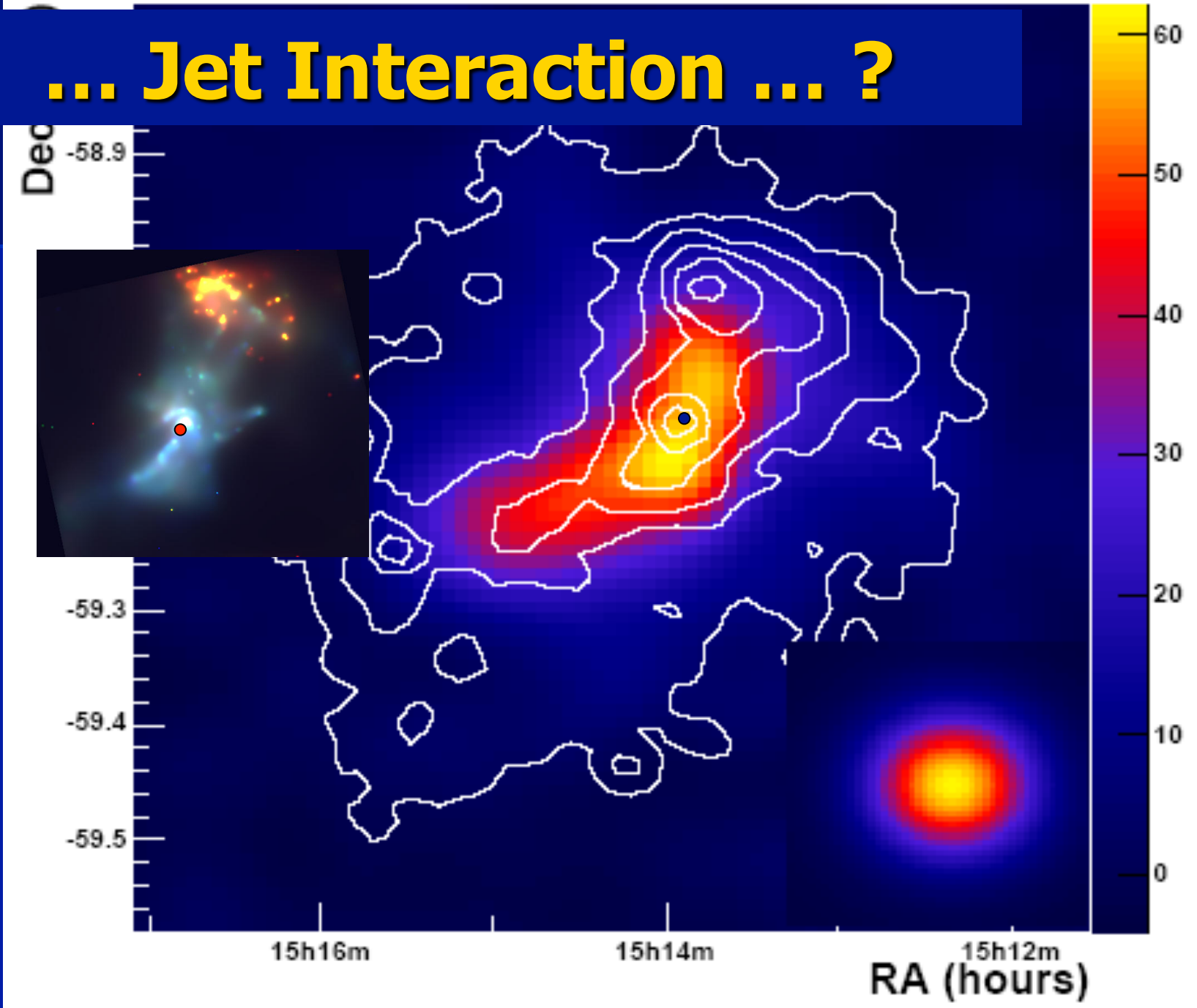


PWN of MSH15-52, driven by PSR B1509-58

First time that a rotationally induced jet has been resolved in Gamma-Rays - HESS

Aharonian et al 2005

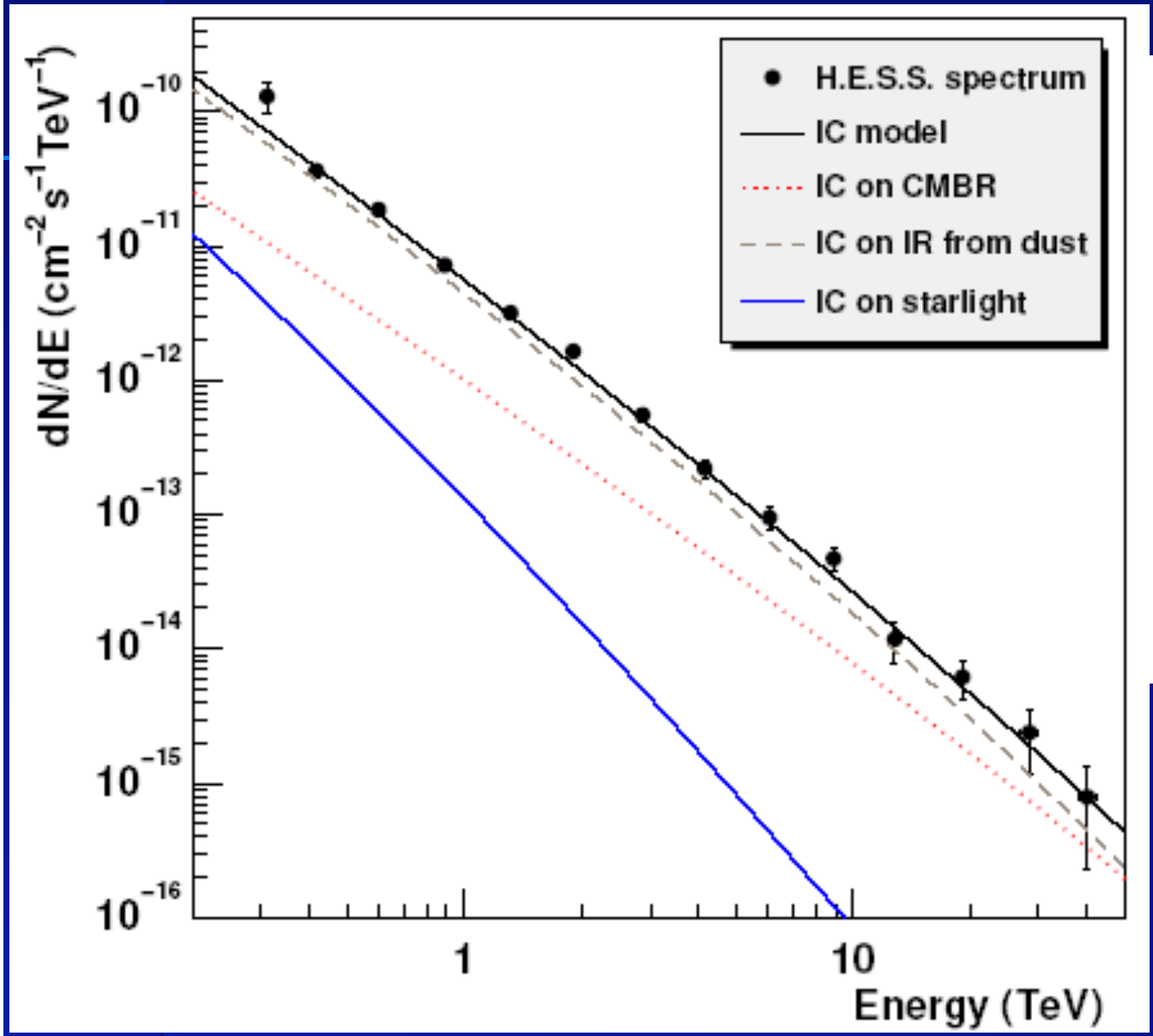
… Jet Interaction … ?



… Hadronic signal? No

RCW89 is a thermal nebula, not visible in γ-rays

TeV Spectrum of the Jet of PSR B1509-58



TeV:

$\Gamma_{TeV}=2.27\pm0.03$

X-RAYS Resolved Core:

$\Gamma_{core}\sim1.5$

$\Gamma_{diffuse}=2.05\pm0.04$

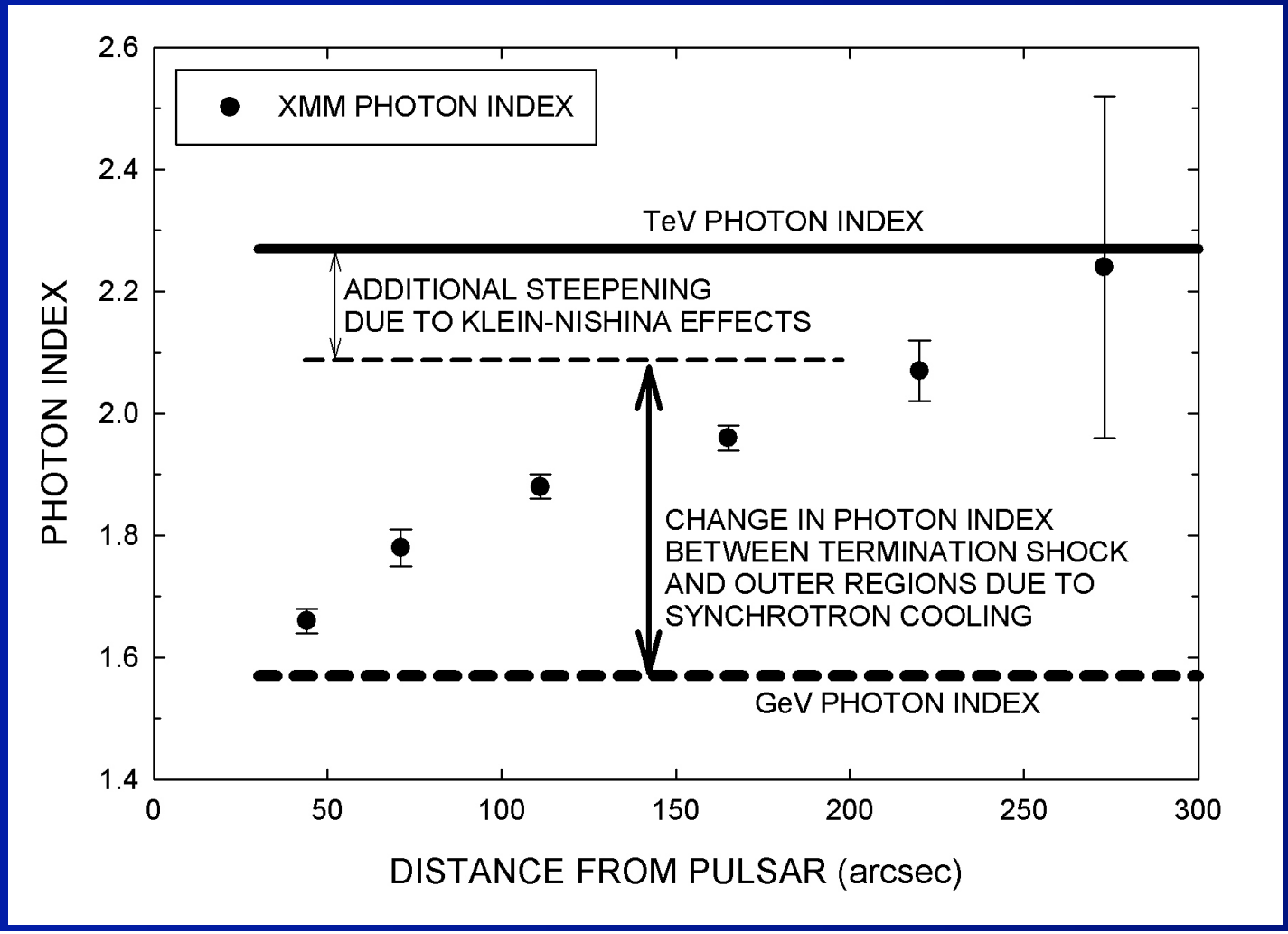
$\Delta\Gamma=2.27-2.05$

$=0.2$

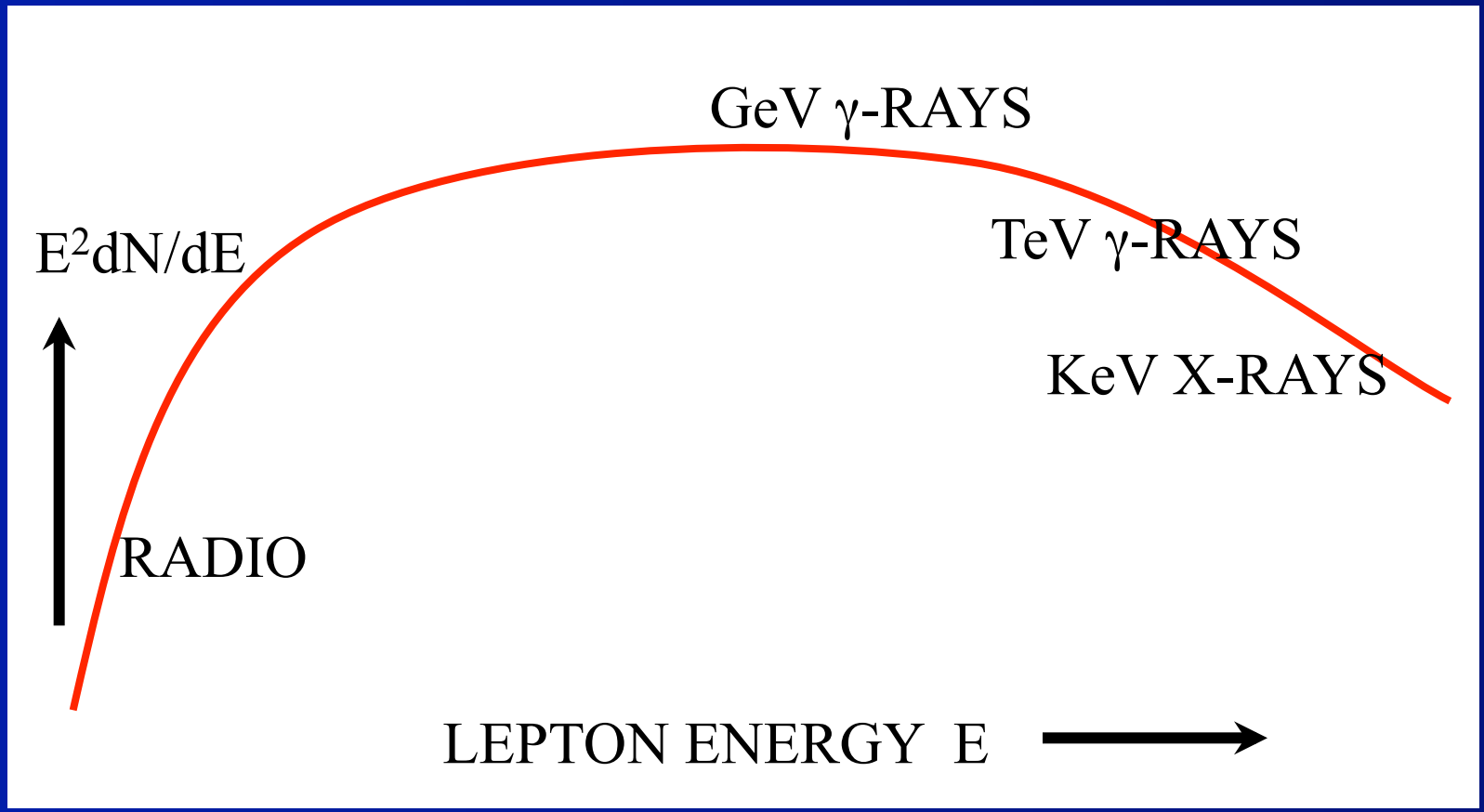
PWN of PSR B1509-58

XMM-Newton – Schoeck et al 2010

Fermi-LAT: Abdo et al 2010



PWN of PSR B1509-58 Total Lepton spectrum with associated radiation



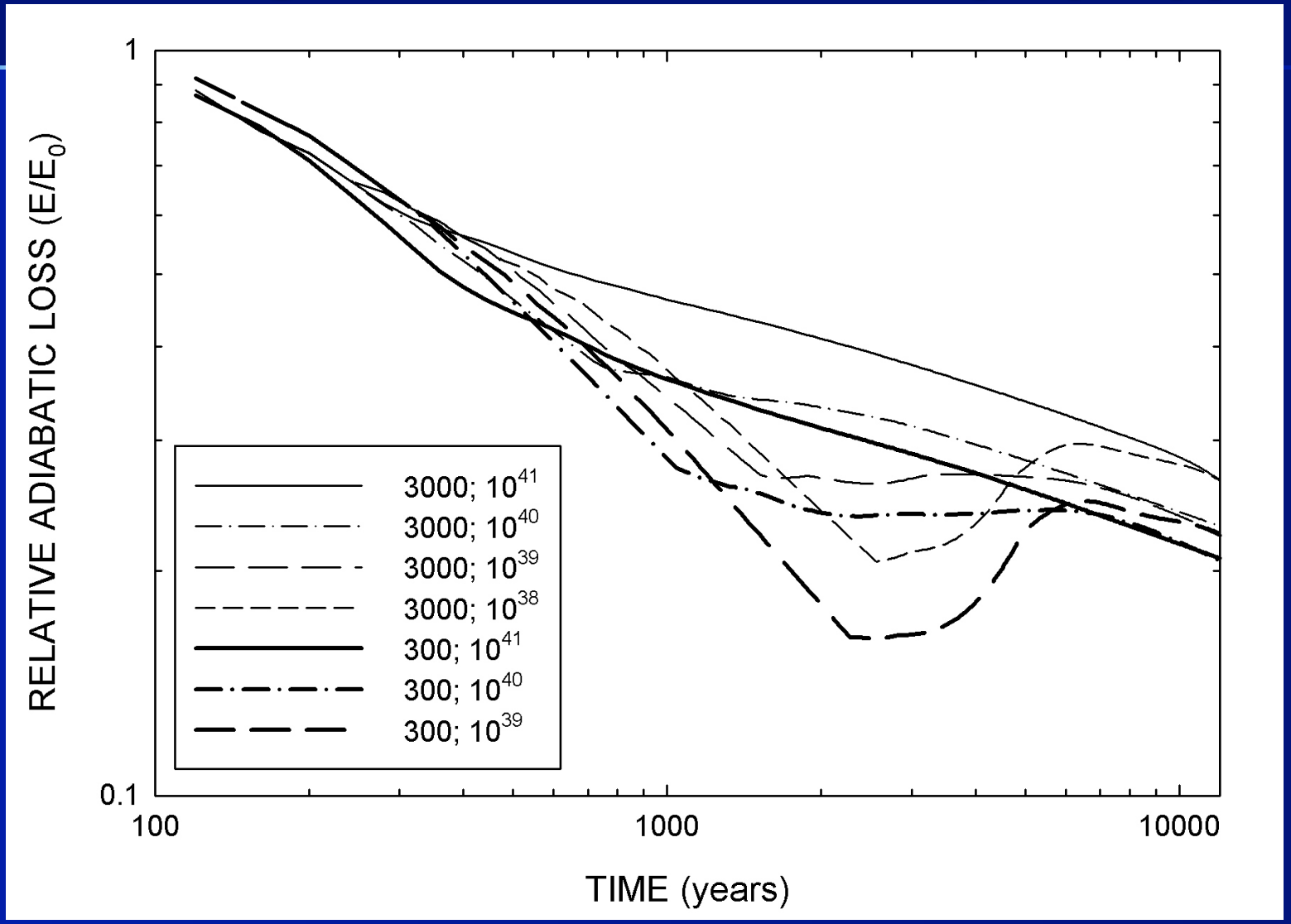
Calorimetric GeV Emission
de Jager 2008, 2010

$$\frac{dN_\gamma}{dt dE_\gamma} = 4 \times 10^{-8} \frac{(1+1.3U_{25})}{a_{10} P_{40}^2 d_{\rm kpc}^2} I_{45} \bar{\varepsilon} E_\gamma^{-1.5} \ {\rm cm}^{-2}{\rm s}^{-1}{\rm GeV}^{-1}. \quad (6)$$

The parameter U_{25} is the energy density of the galactic dust component (in units of eV/cm^2) at a temperature of $T \sim 25$K, which is comparable to the energy density of the CMBR in the local galactic region, but increases to ~ 1.4 eV/cm^3 at the distance of PSR B1509-58. [4]. The parameter $a_{10} \sim 1$ depends weakly (logarithmic) on the ratio of the unknown spectral boundaries of the injected $\sim E^{-2}$ electron spectrum as a result of the assumed number index of 2. The only real free parameters is then the birth period and distance to the source.

we arrive at a predicted integral GeV flux of $F(>1\ {\rm GeV}) = 4 \times 10^{-9}$ cm^{-2}s^{-1}, which is remarkably close to the observed Fermi-Lat flux [2] of $F(>\ {\rm GeV}) \sim 3 \times 10^{-9}$ cm^{-2}s^{-1}. *This prediction is remarkably close to the observed flux, given the significant uncertainty in the birth period.* In fact, this prediction indicates that the birth period of PSR B1509-58 cannot be much different from ~ 40 ms.[5]

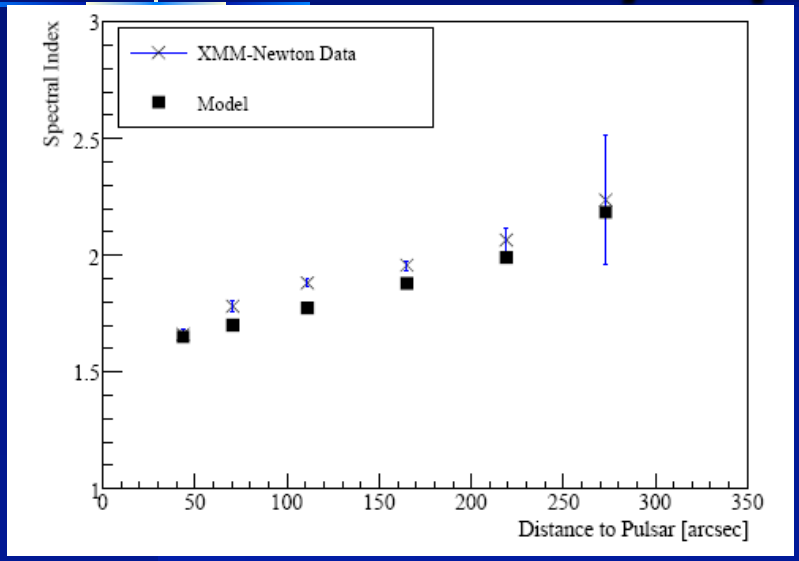
Volume averaged Adiabatic losses: 0.2 to 0.3 after 1700 yr de Jager, Ferreira & Venter (in prep)



Constraining the current conversion efficiency of spindown power to leptons in the PWN of PSR B1509-58

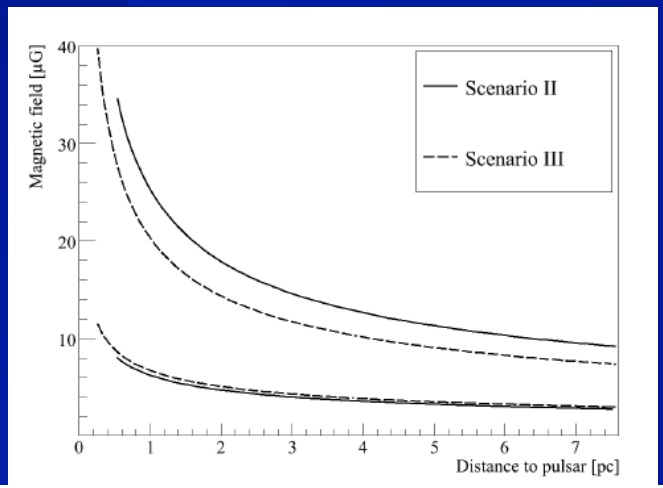
ε>30% (Schoeck et al. 2010, A&A)

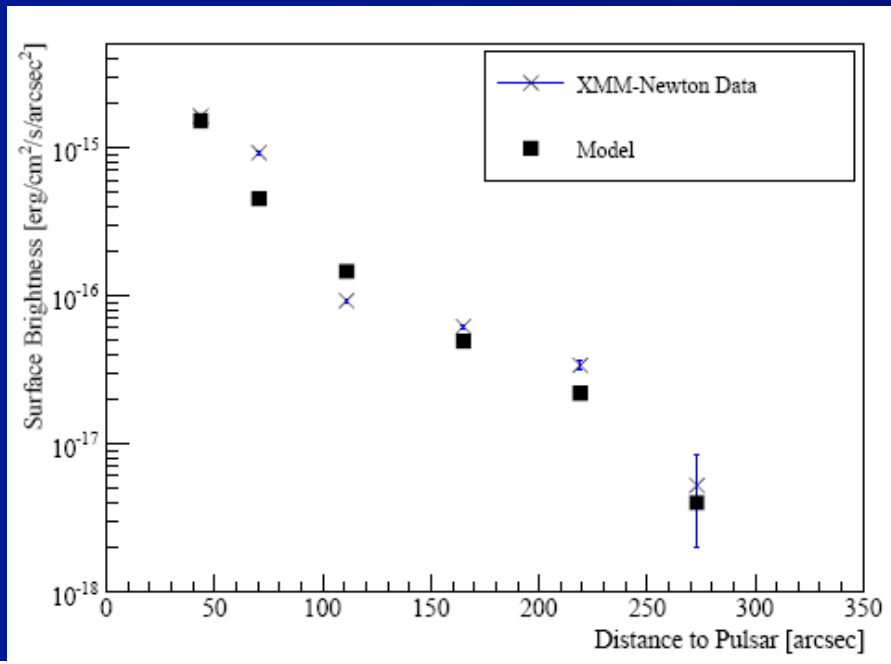
Result is weakly dependent on assumed geometry.



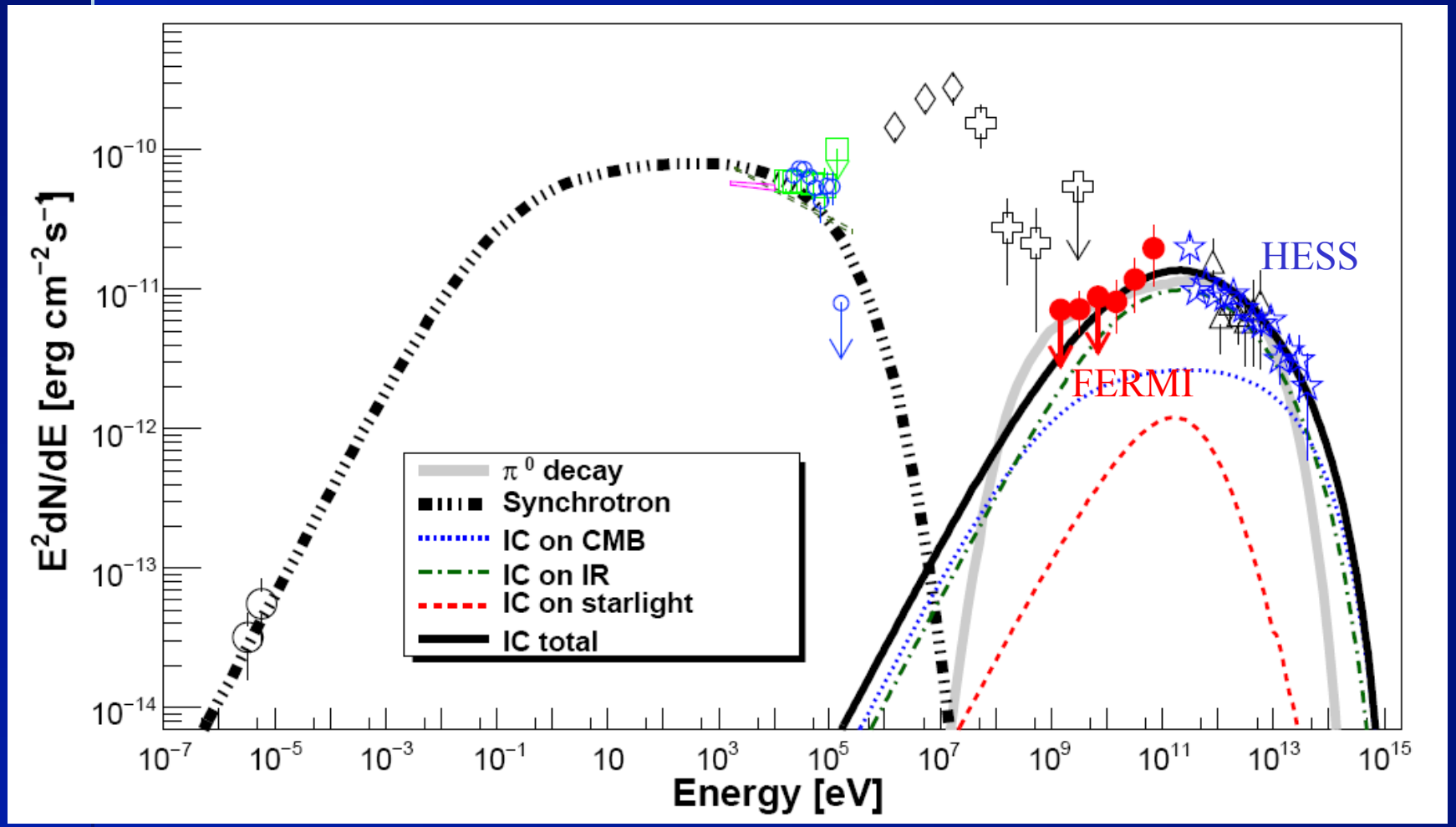
$$Bvr = B_S v_S R_S = \text{const.},$$

$$v(r) = v_S \left(\frac{R_S}{r}\right)^{\alpha},$$





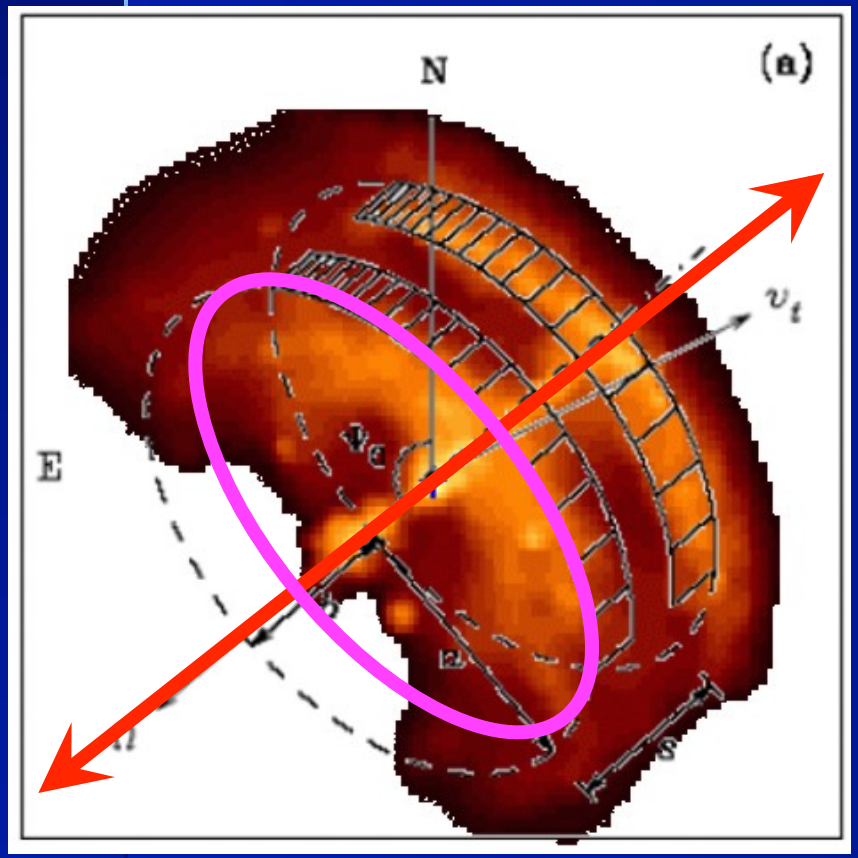
Fermi detection of PWN of PSR B1509-58 - Abdo et al. 2010

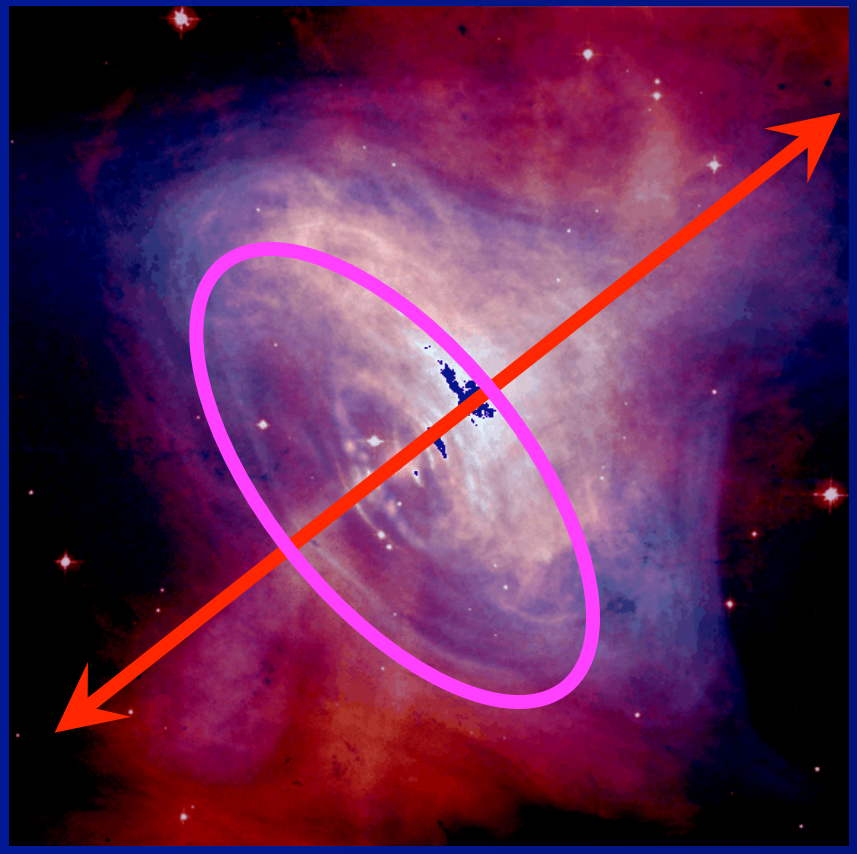


General: GeV Emission from 1-Component PWN

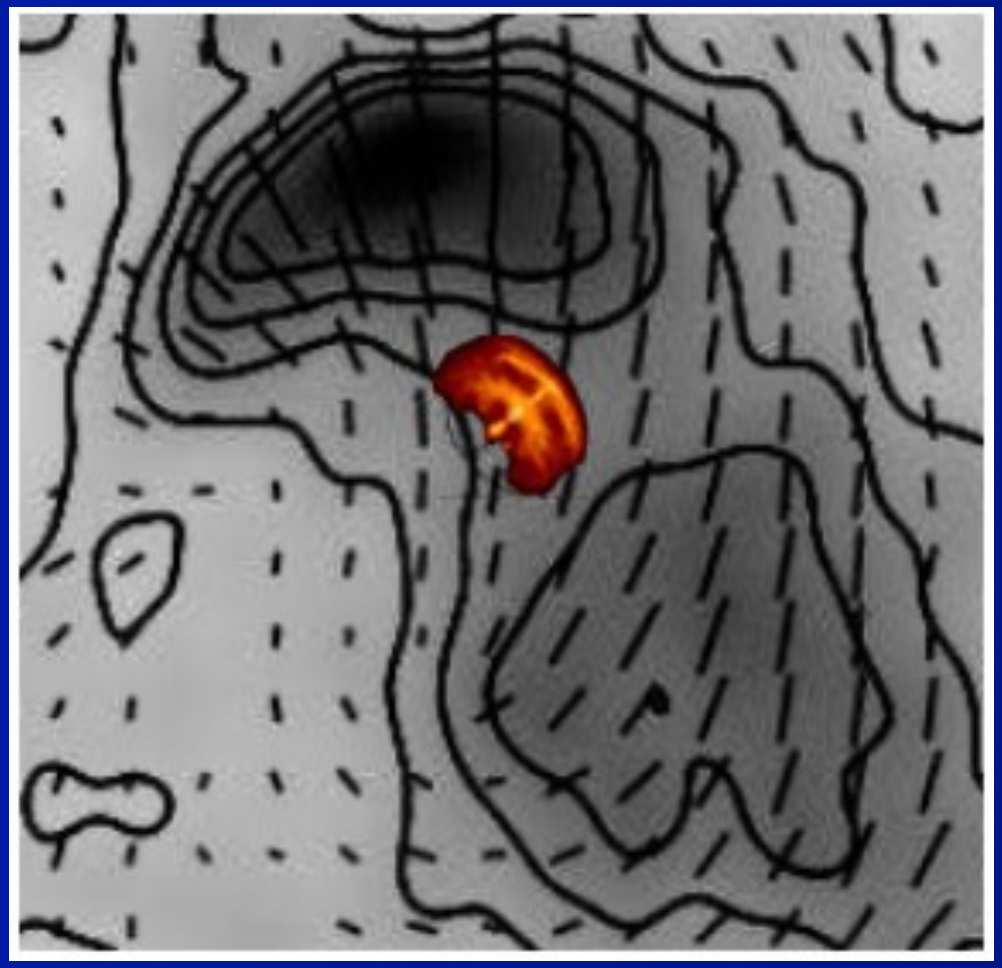
- Lifetime of GeV emitting leptons is much longer than TeV emitting leptons, which is why we see a calorimetric effect – GeV luminosity depends mainly on change in rotational kinetic energy.
- Flat photon spectrum (1.5 to 1.6) makes Fermi-Lat detection difficult - background
- GeV spectrum steepens to a photon index of >2 in the TeV range due to cooling.

Resolving Large Scale Effects of Rotation Vela & Crab

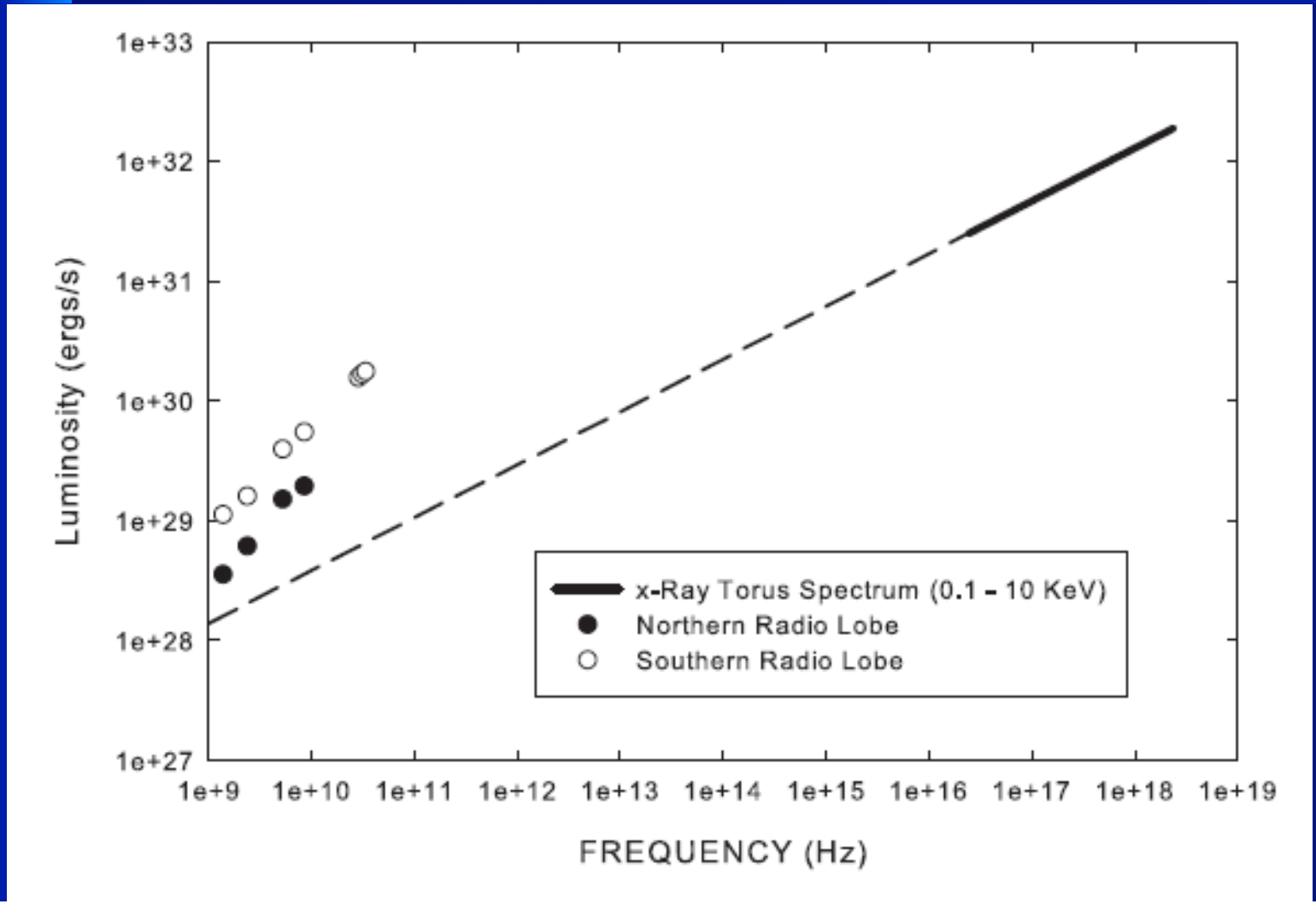




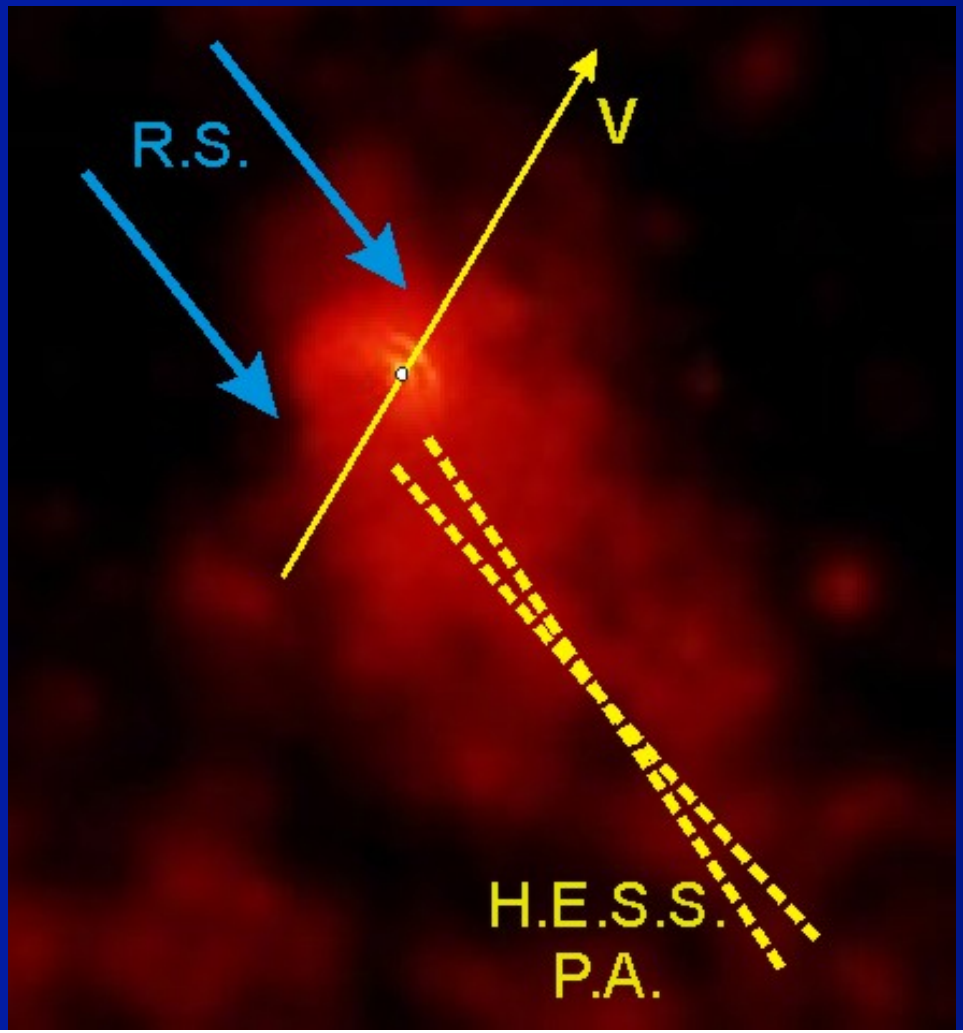
Radio & X-ray Torii of Vela PSR (Dodson et al. 2003, Helfand et al. 2001



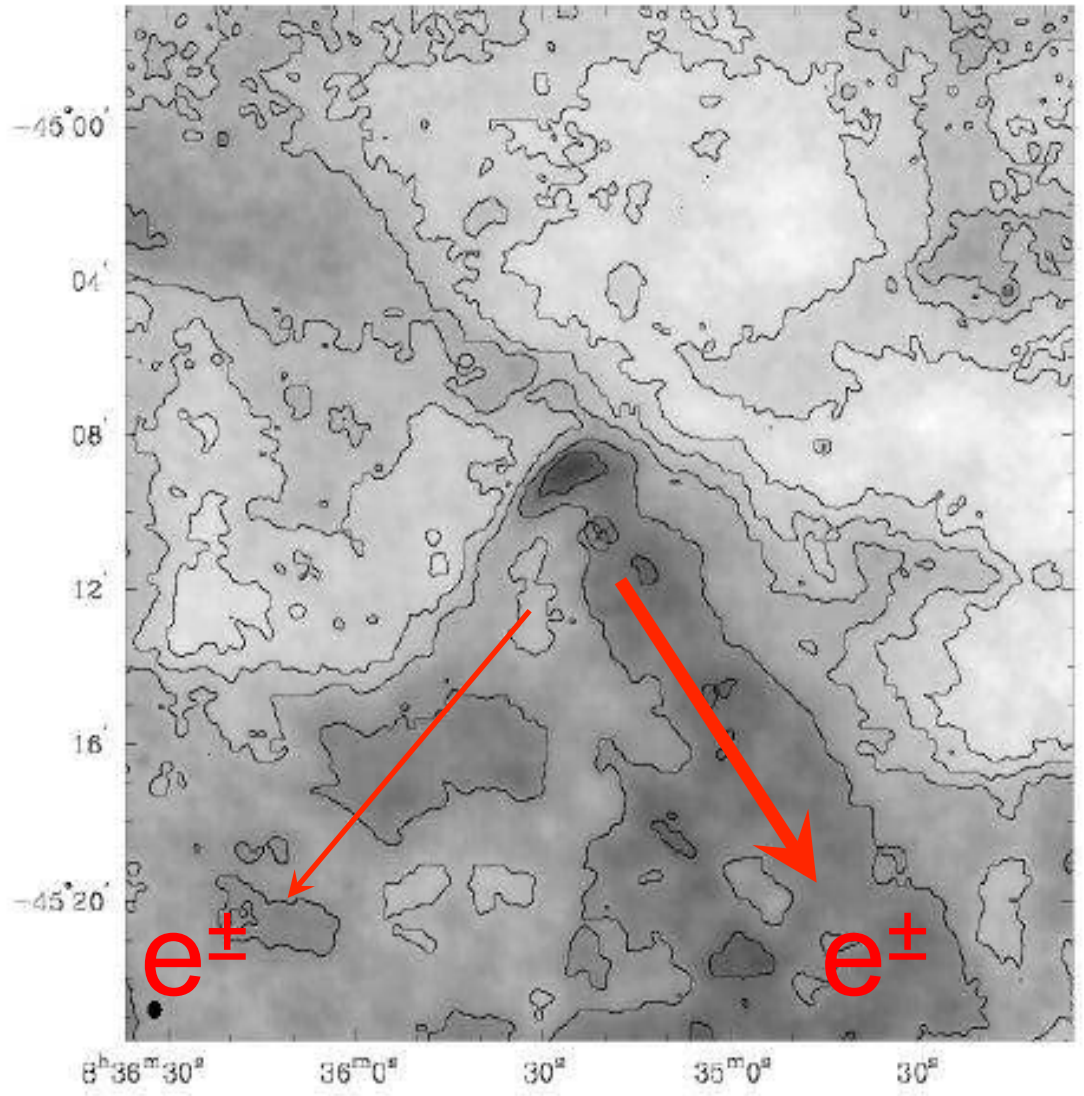
Spectra: Radio & X-ray Torii of Vela PSR (Dodson et al. 2003, Helfand et al. 2001 2-Component effect already visible



Reverse Shock Crushing of X-ray Torus?



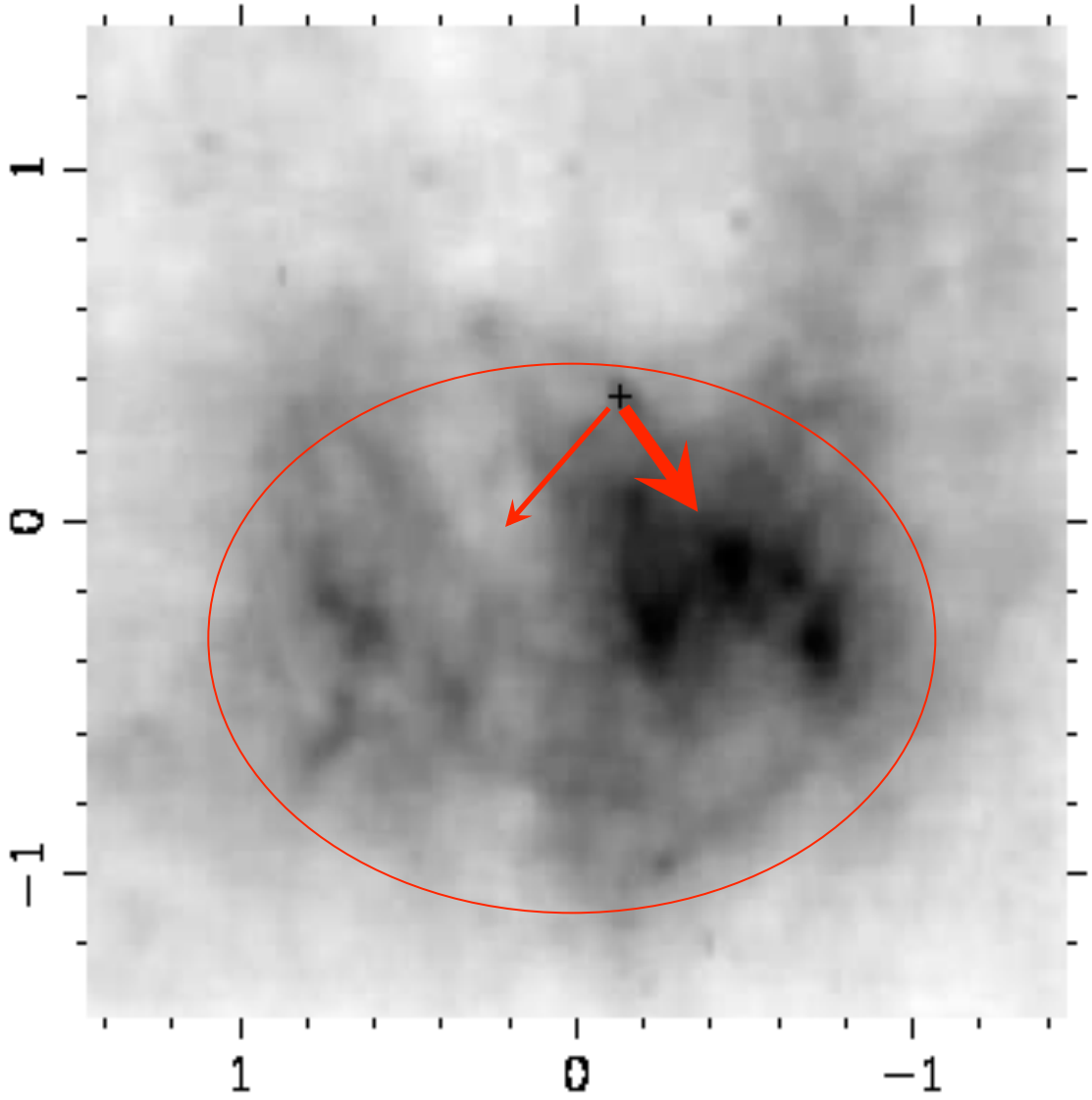
Vela-X Plerion in Radio (0.2 to 0.3 degree scale)



16+ arcmin nebula

Vela X - 2x3-Degree Radio PWN

Hales et al. 2004



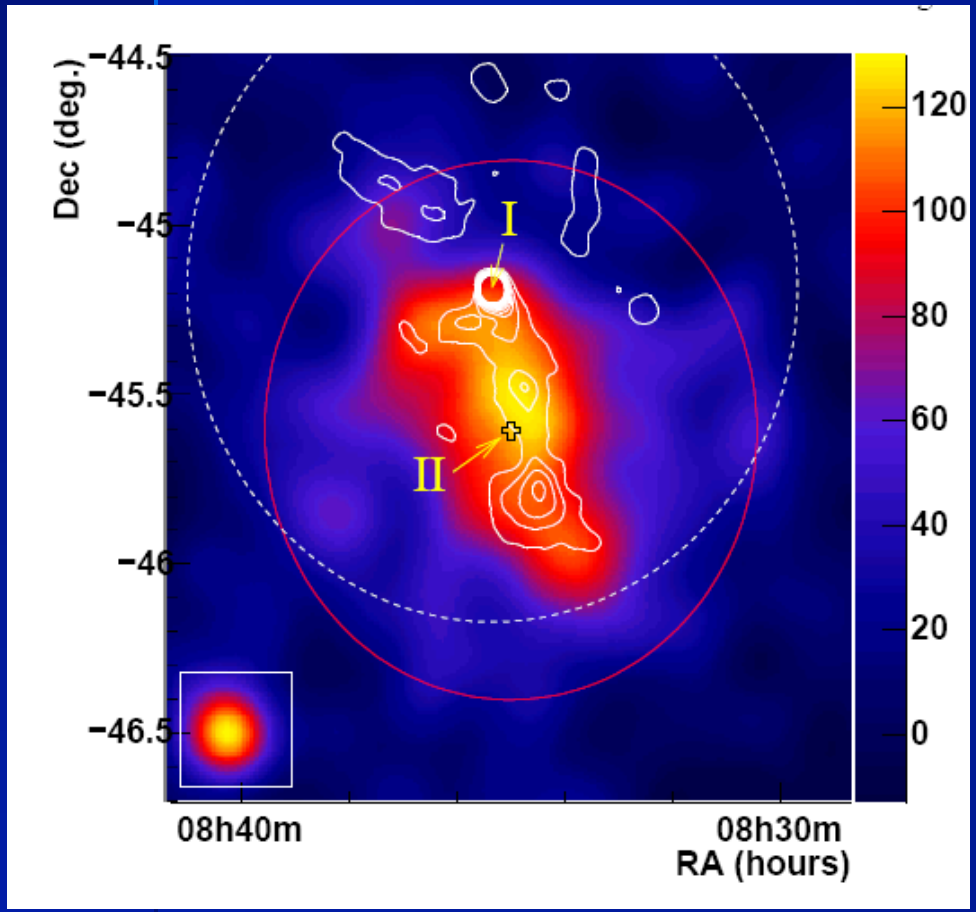
Time Integrated Conversion Efficiency of spindown power to radio & GeV emitting leptons: 40 – 50%

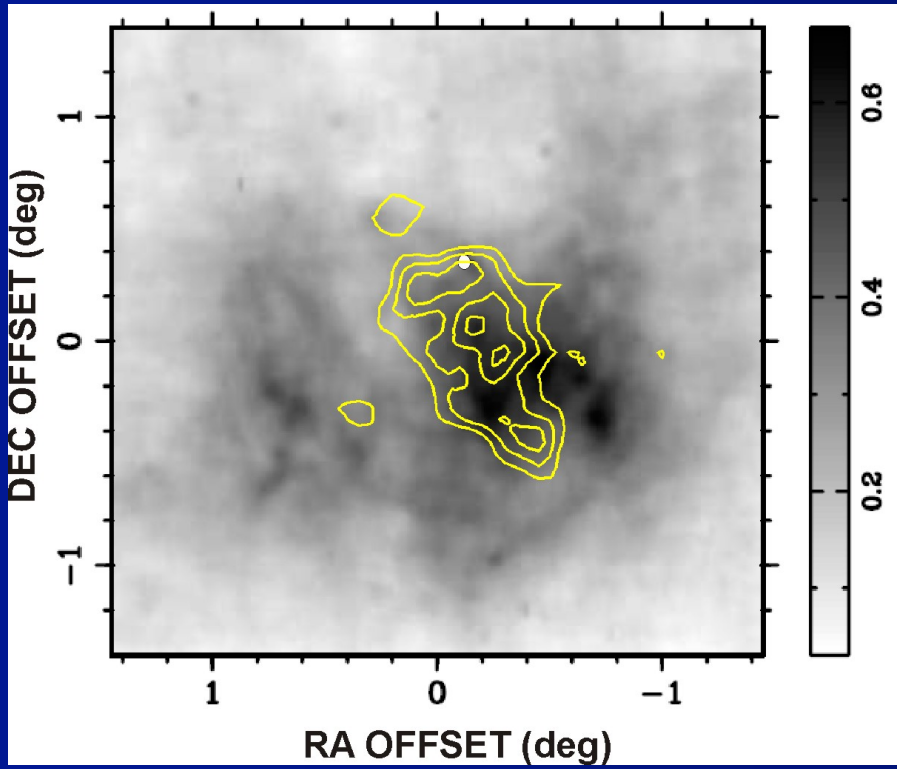
De Jager, Slane & LaMassa, 2008

Vela X X-ray/TeV cocoon

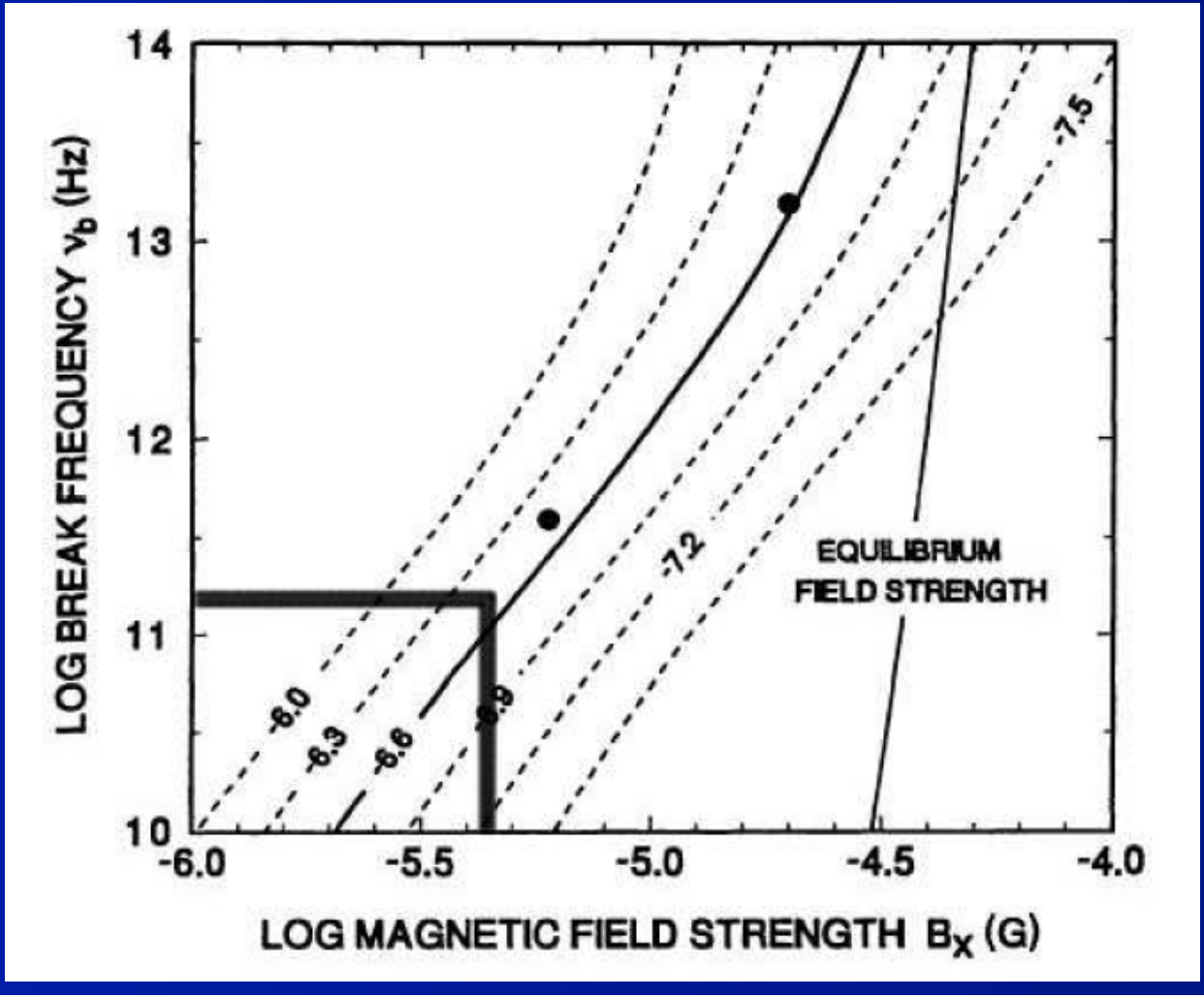
Aharonian et al. 2005

Time Integrated Conversion Efficiency of spindown power to TeV emitting leptons: 0.3%





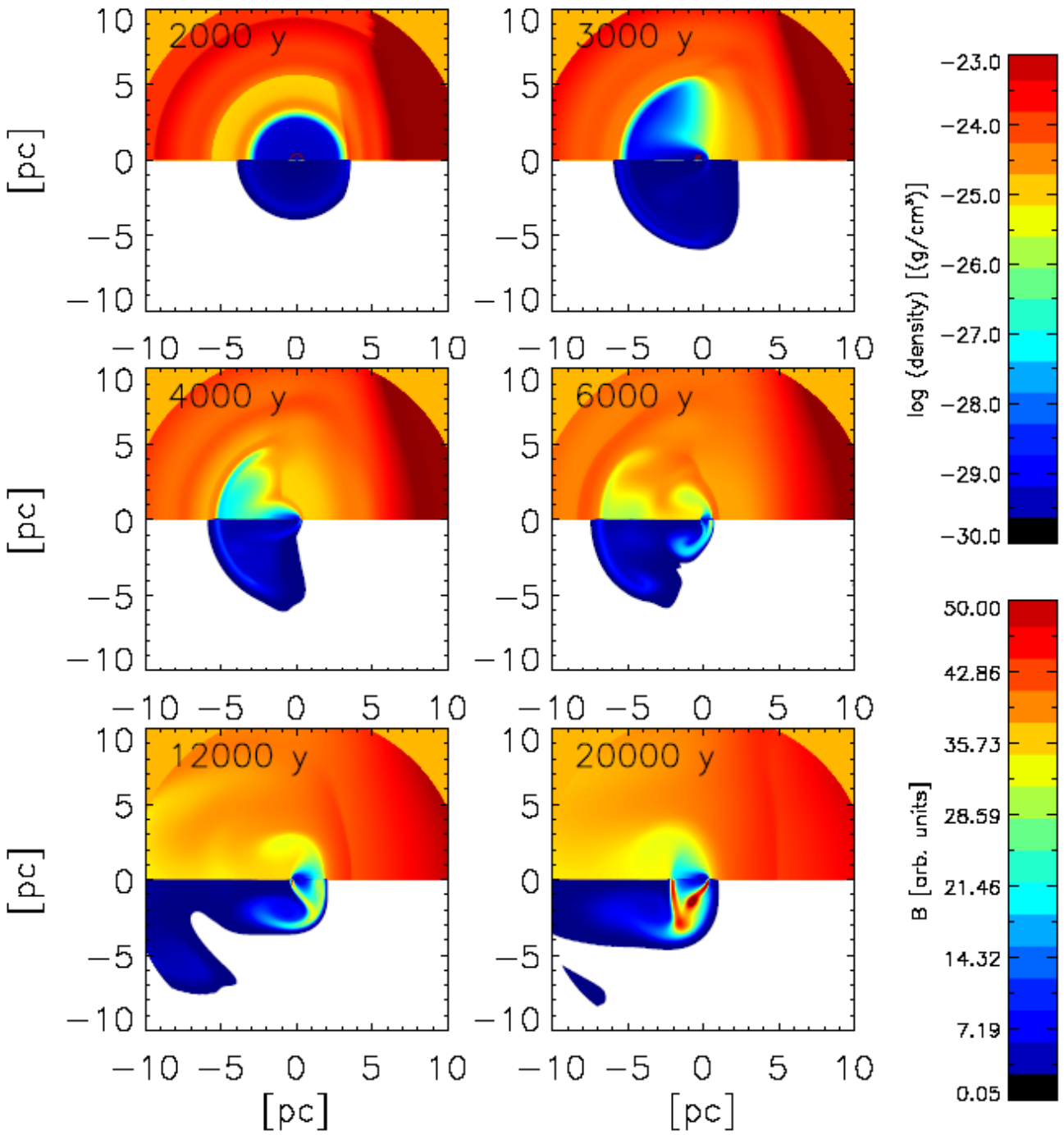
First prediction of Vela X 2-component (de Jager & Harding et al. 1996, A&AS) de Jager, Slane & LaMassa (2008) added HESS, X-rays to fix B.



Full MHD, 3D, Spherical

8 Solar Mass ejecta

10^{38} ergs/s initial spindown power



Full MHD, 3D, Spherical

8 Solar Mass ejecta

10^{39} ergs/ s initial spindown power