Particle Transport in Young Pulsar Wind Nebulae

Xiaping Tang and Roger A. Chevalier

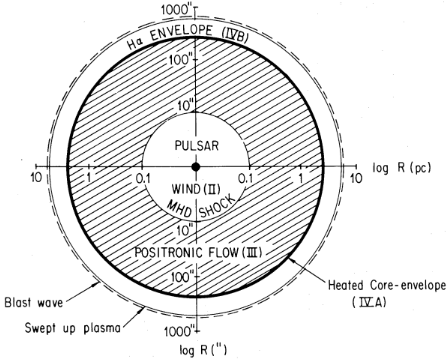
University of Virginia

August 26, 2012, IAU symposium 291

Schematic view of pulsar wind bubble expanding in a supernova

advection+ synchrotron

- MHD model: current standard picture for pulsar wind nebula(PWN)
- charaterized by a termination shock(TS) between PWN and unshocked pulsar wind.
- relativistic particles are injected at TS and follow advective flow to the outer boundary

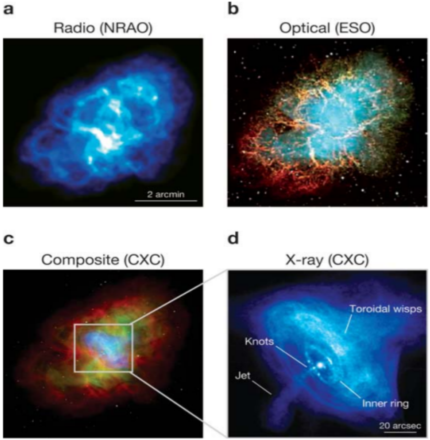


Kennel&Coroniti 1984a

MHD model by Kennel&Coroniti 1984(KC84)

1D steady state spherical symmetric MHD model valid from IR to γ-ray for Crab

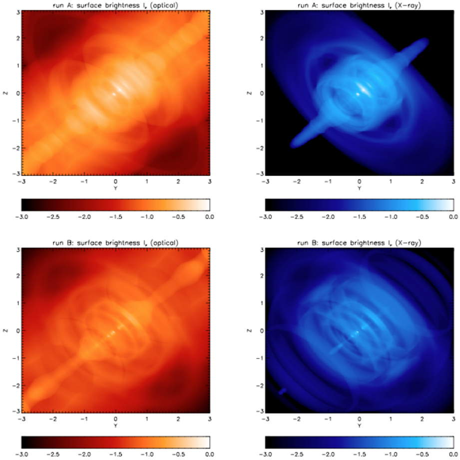
- diminishing size of Crab Nebula as frequency increases
- model the integrated spectrum
- predict the position of the termination shock



Multiwavelength image of Crab Nebula , Gaensler&Slane 2006

Current 2D MHD simulation

- assume pulsar power depends on polar angle
- create toroidal structure in the advective flow surrounding central pulsar
- integrated spectrum of Crab Nebula from radio to TeV
- time variability of the inner structure

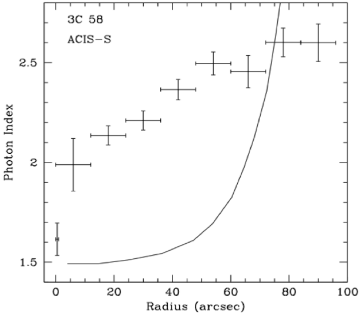


Del Zanna et al. 2006

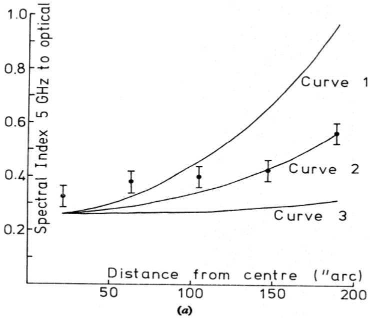
Challenge for MHD model

3C 58 and G21.5-0.9: young PWN show spherical symmetry

Sign of diffusion?



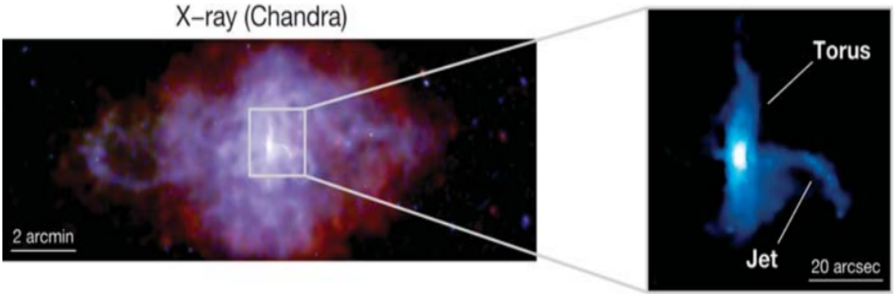
Photon index distribution of 3C 58 between 2.2 and 8kev. Slane et al 2004



Spectral index distribution of Crab Nebula between radio and optical. Wilson, A. S. 1972

Challenge for MHD model

- toroidal structure only in region close to pulsar, filamentary and loop-like structure in the outer part of nebula
- nebula size remain the same from radio to X-ray due to lower magnetic field



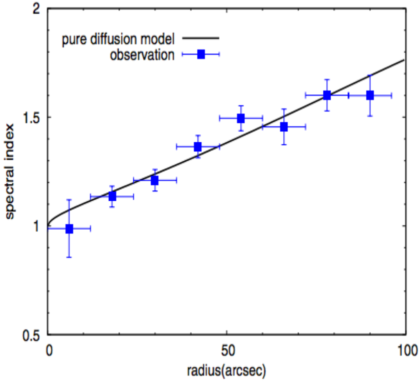
X-ray image of 3C 58, Gaensler&Slane 2006

Pure diffusion model

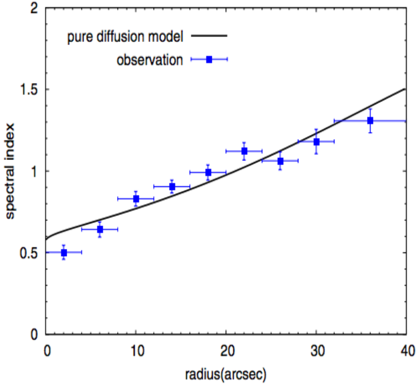
Model assumption

- point source ⇒ extend source
- injected particles follow single power law ⇒ double power law(Crab)
- transmitting boundary ⇒ reflecting boundary
- synchrotron emission at critical frequency ⇒ full synchrotron spectrum
- constant diffusion coefficient ⇒ energy dependent diffusion
- pure diffusion ⇒ diffusion and advection

fitting of 3C 58 and G21.5-0.9

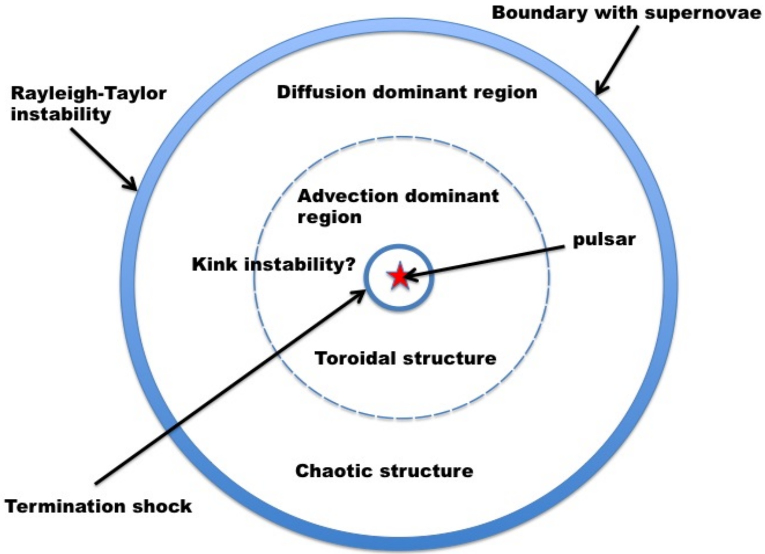


spectral index distribution fitting of 3C 58 between 2.2and 8kev. Tang&Chevalier 2012 (Here after TC12)



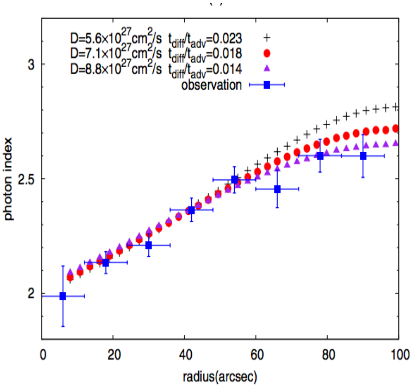
spectral index distribution fitting of G21.5-0.9 between 0.5 and 10kev. TC12

Diffusion and advection model



fitting of 3C 58 with diffusion advection model

- advection follows $V \propto r^{-2}$
- reflecting inner and outer boundary
- constant B for simplification
- advection is less important than in Crab Nebula



photon index distribution of 3C 58
TC12

Origin of diffusion process?

- chaotic structure of the magnetic field in the outer part of the PWN due to Rayleigh-Taylor and/or kink. Instability makes radial diffusion possible
- young PWN has small scale elements with loop or finger-like structure
- magnetic field lines are draped around thermal filaments and stretched in the radial direction

Hester 2008 ARA&A

Summary

- Both diffusion and advection are important for young PWN like Crab, 3C 58 and G21.5-0.9.
- Advection dominates the region close to the termination shock(TS) as there is clear toroidal structure shown near the TS. Diffusion dominates the larger part of the nebula.
- The spectral index distribution and nebula size behavior of 3C 58 G21.5-0.9 can be explained by the diffusion and advection model very well. The model could also improve the fitting of the Crab nebula.
- Rayleigh-Taylor instability at outer boundary of nebula and kink instability at TS may allow radial diffusion.
- filamentary and loop-like structure help the diffusion process; combining with slow cross field line diffusion may mix the particles thoroughly thus explaining the small spatial variation in radio spectral index