A Comparison of Radio and X-ray Observations of Evolved Pulsar Wind Nebulae

Roland Kothes

Dominion Radio Astrophysical Observatory
Herzberg Institute of Astrophysics, National Research Council Canada

Supernova Remnants and Pulsar Wind Nebulae in the Chandra Era,
Cambridge, MA, July 8, 2009

Overview

Introduction

Examples of PWNe

- G106.3+2.7
- DA 495

Outlook

- G63.7+1.1
- Gedankenexperiment

Summary

Collaborators

X-ray

- Samar Safi-Harb, University of Manitoba
- Zaven Arzoumanian, CRESST/NASA-GSFC/USRA

Radio

- Tom Landecker, NRC Canada, HIA, DRAO
- Wolfgang Reich, Max Planck Institut für Radioastronomie, Bonn

A Naive Look at X-ray vs. Radio

Evolved Pulsar Wind Nebulae

(PWNe beyond the passing of the reverse shock)

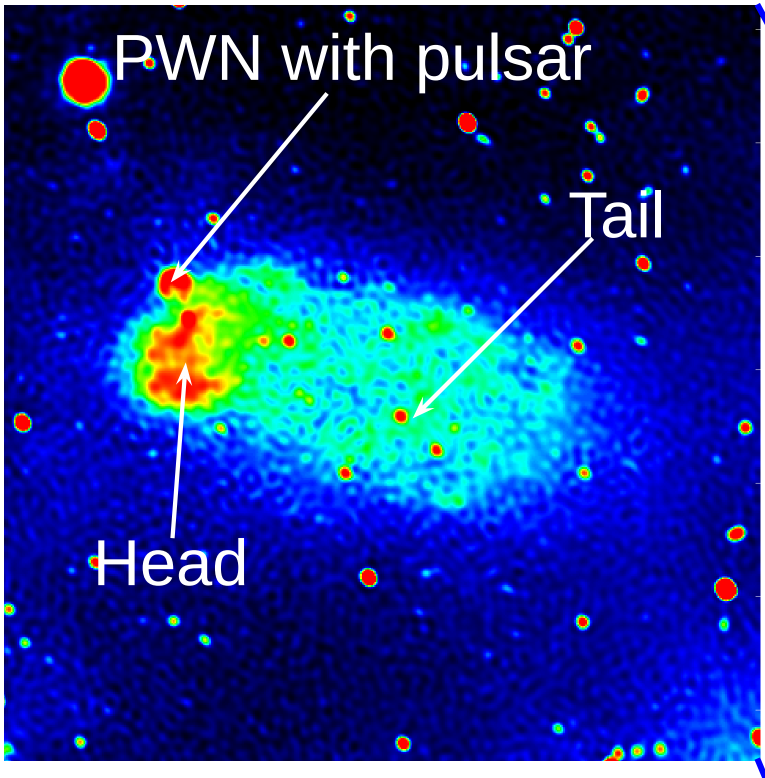
X-ray

- young electrons $\Rightarrow \dot{E}$
- neutron star + pulsar
- structure in the immediate vicinity of the neutron star

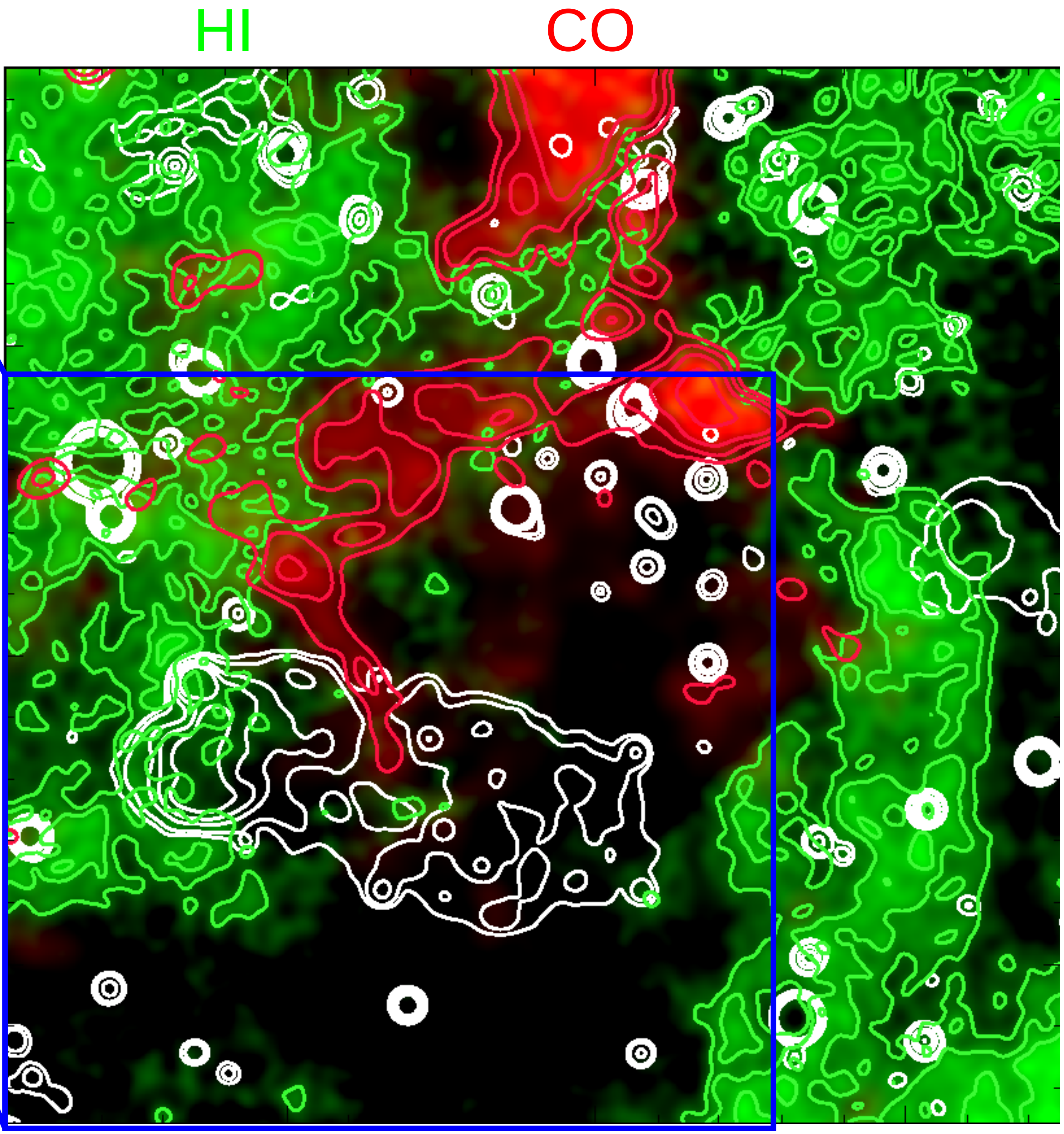
Radio

- old electrons $\Rightarrow \int_t \dot{E}$
- pulsar
- large-scale structure + magnetic field

G106.3+2.7

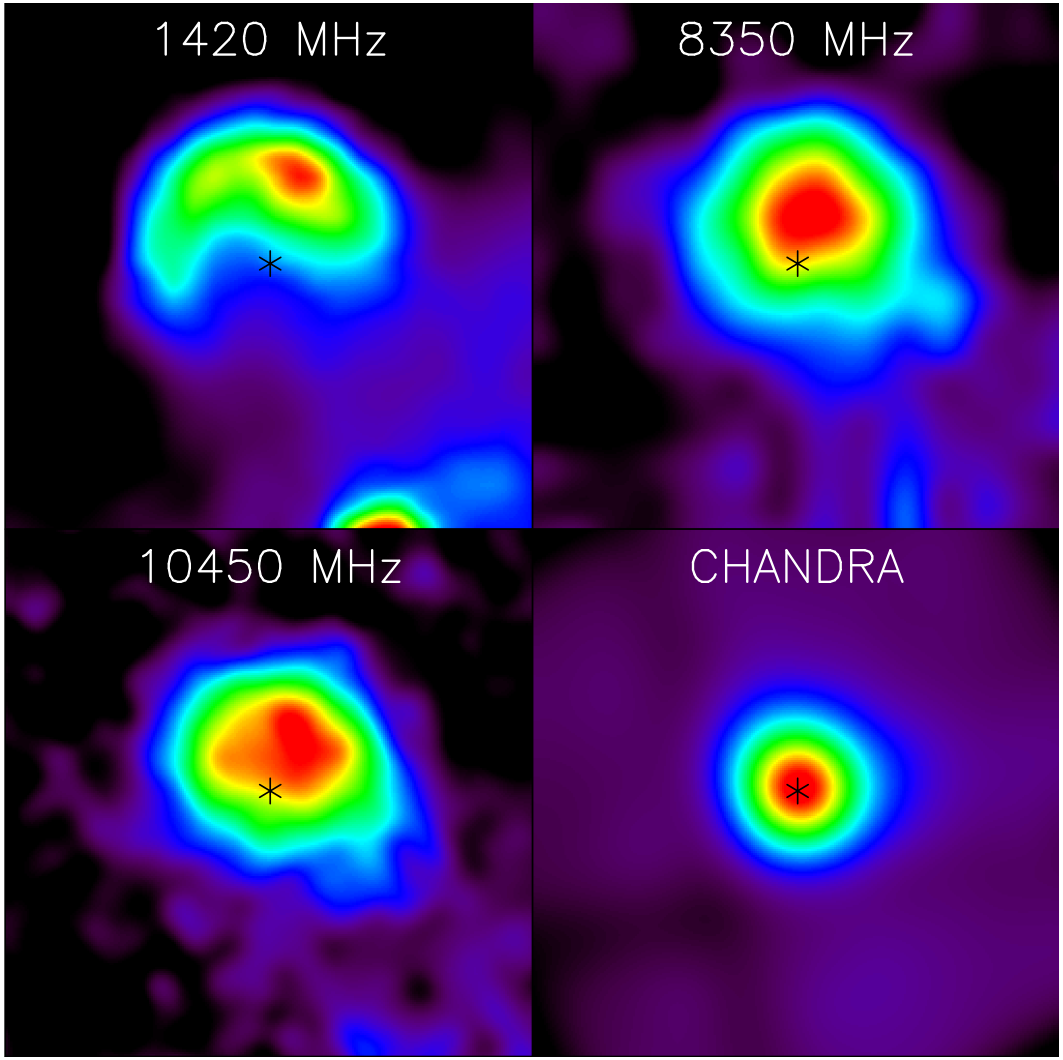


G106.3+2.7 at 1420 MHz



Kothes, Uyanıker, & Pineault, 2001, ApJ 560, 236

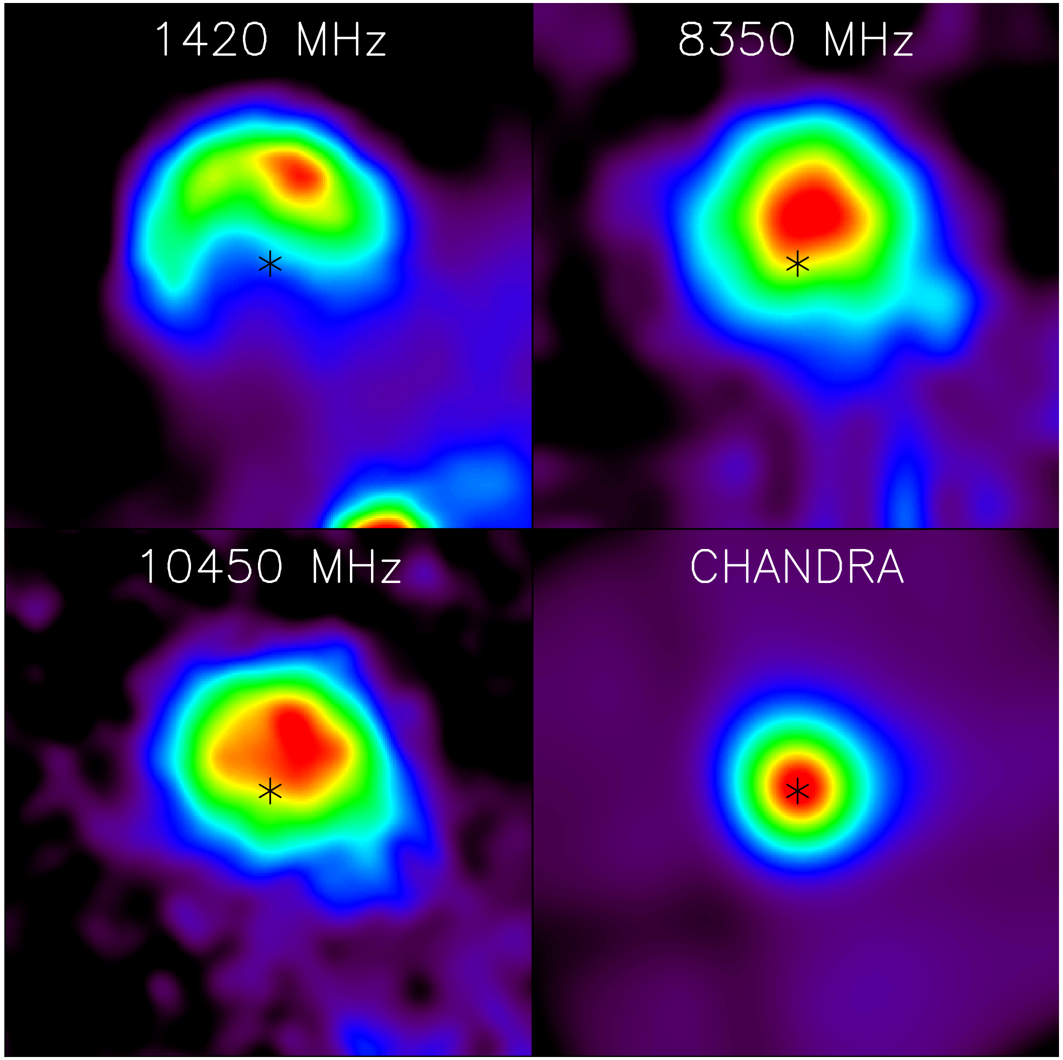
The PWN in G106.3+2.7



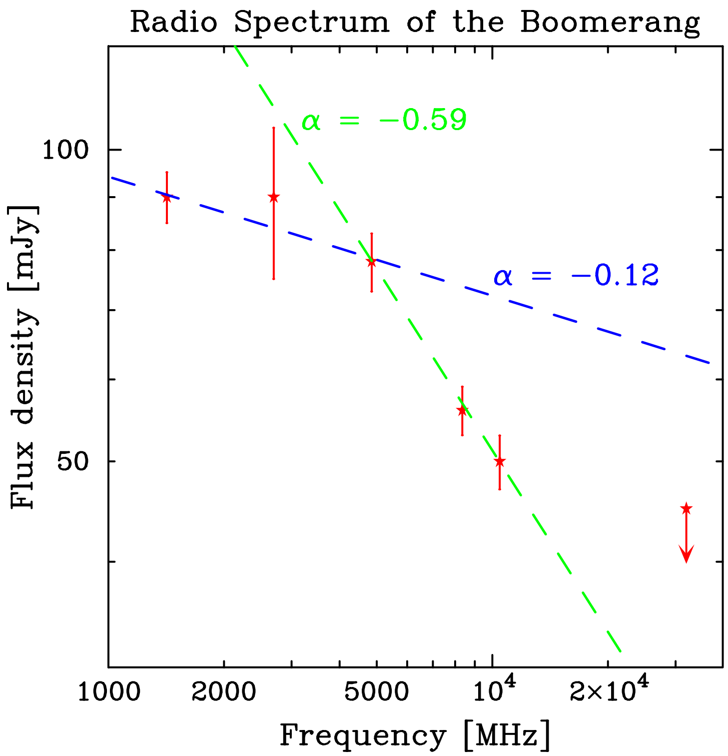
- The spectrum becomes steeper with distance from the pulsar.

Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

The PWN in G106.3+2.7

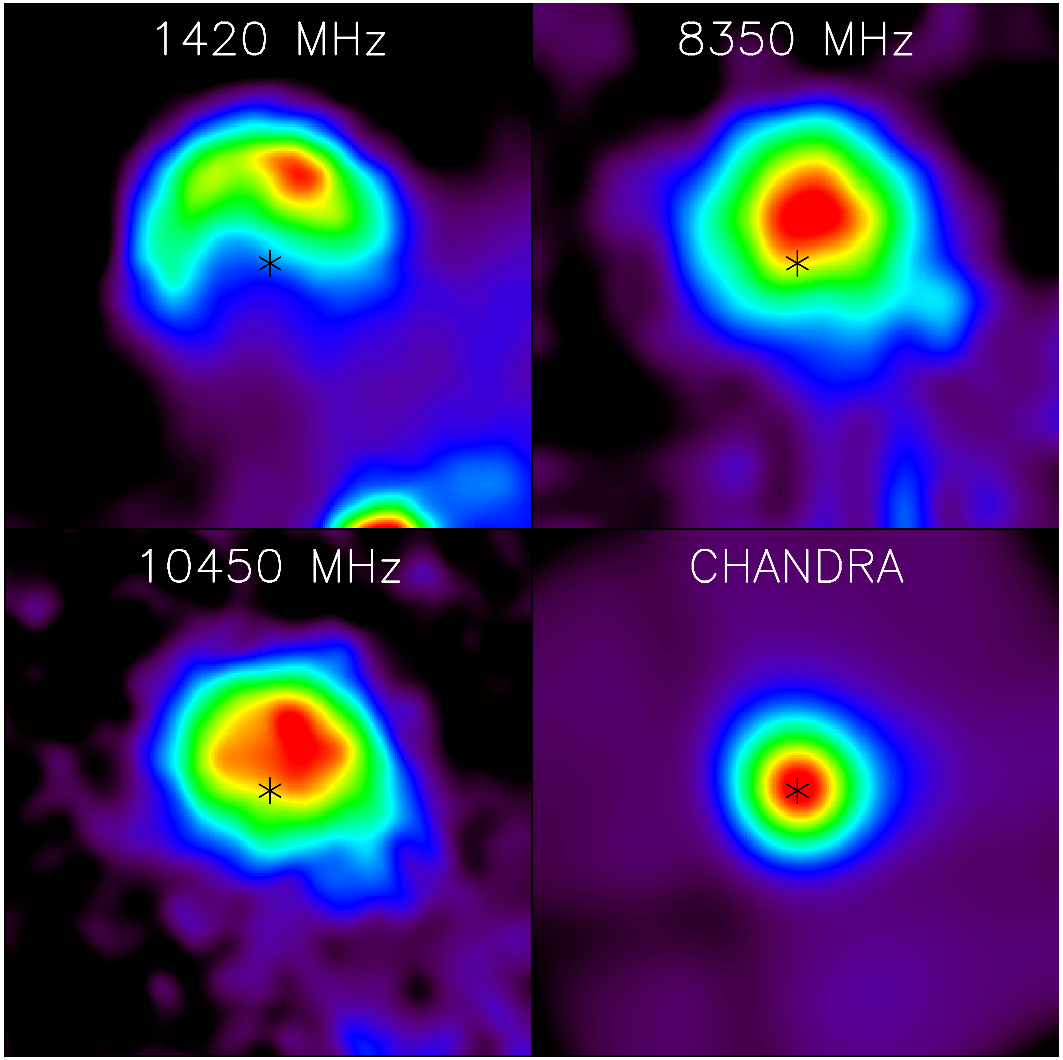


- The spectrum becomes steeper with distance from the pulsar.
- The PWN has a break in the radio spectrum at ∼5 GHz



Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

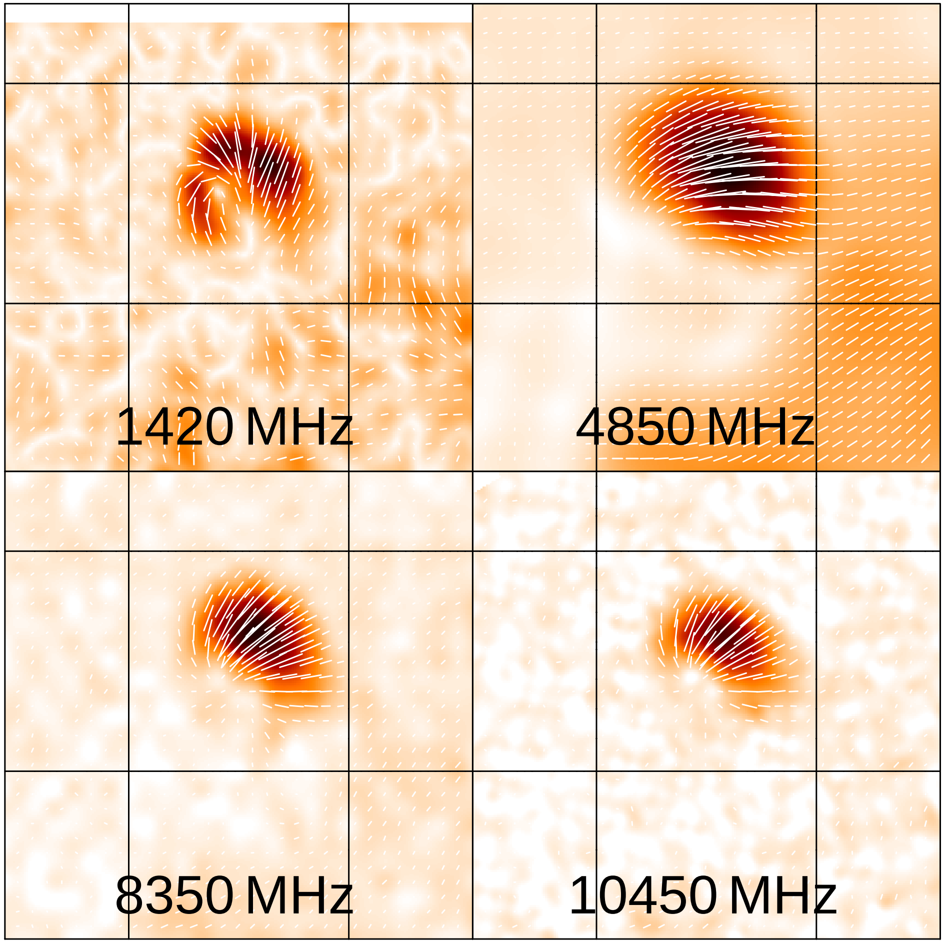
The PWN in G106.3+2.7

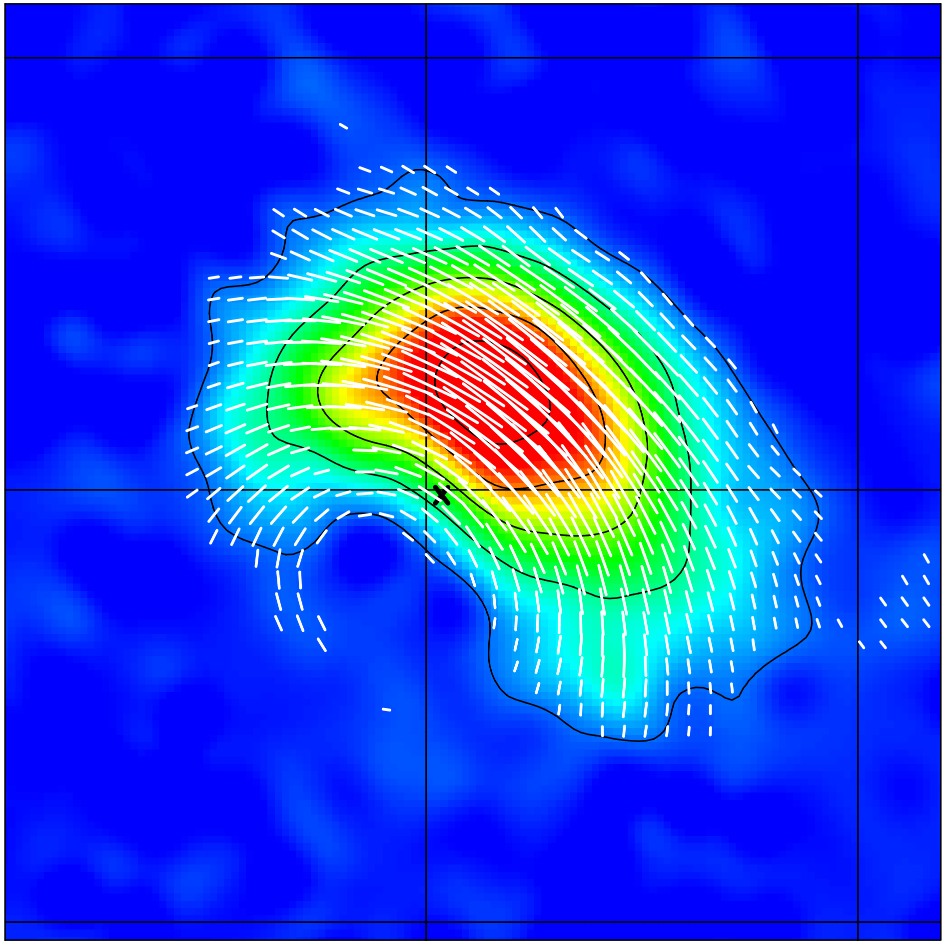


- The spectrum becomes steeper with distance from the pulsar.
- The PWN has a break in the radio spectrum at ∼5 GHz
- Electrons age very fast after they are generated by the pulsar.
- This requires a large magnetic field and a young pulsar.
- We derive an age of about 4000 years and a magnetic field of 2.6 mG.

Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

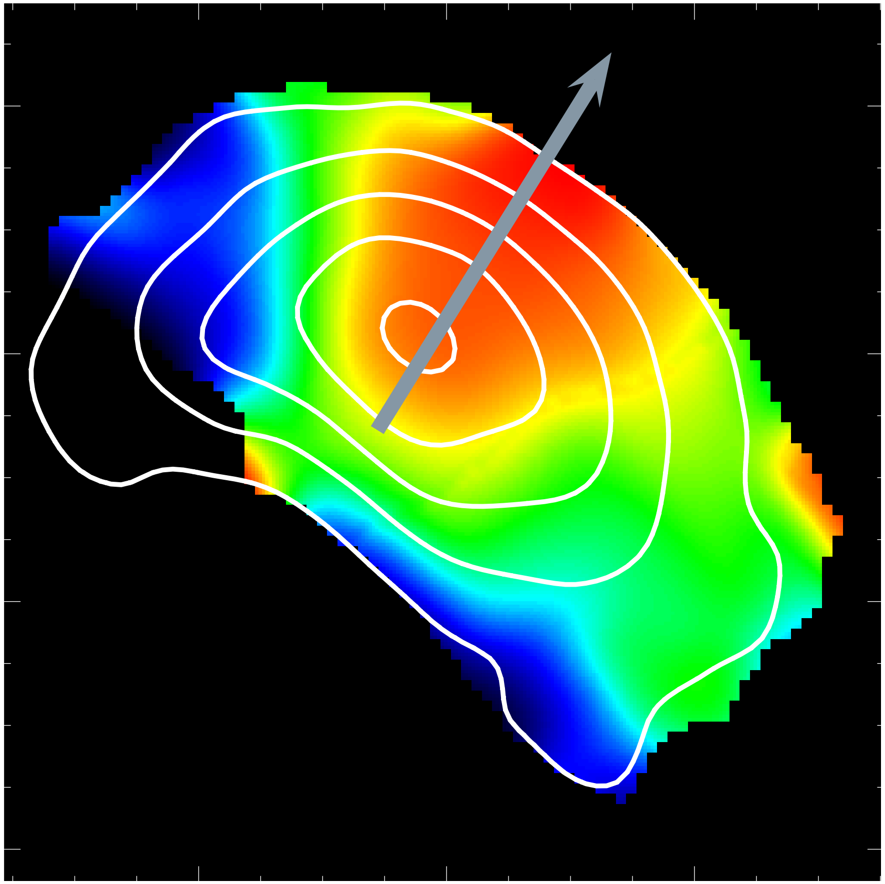
The PWN in G106.3+2.7





Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

The PWN in G106.3+2.7

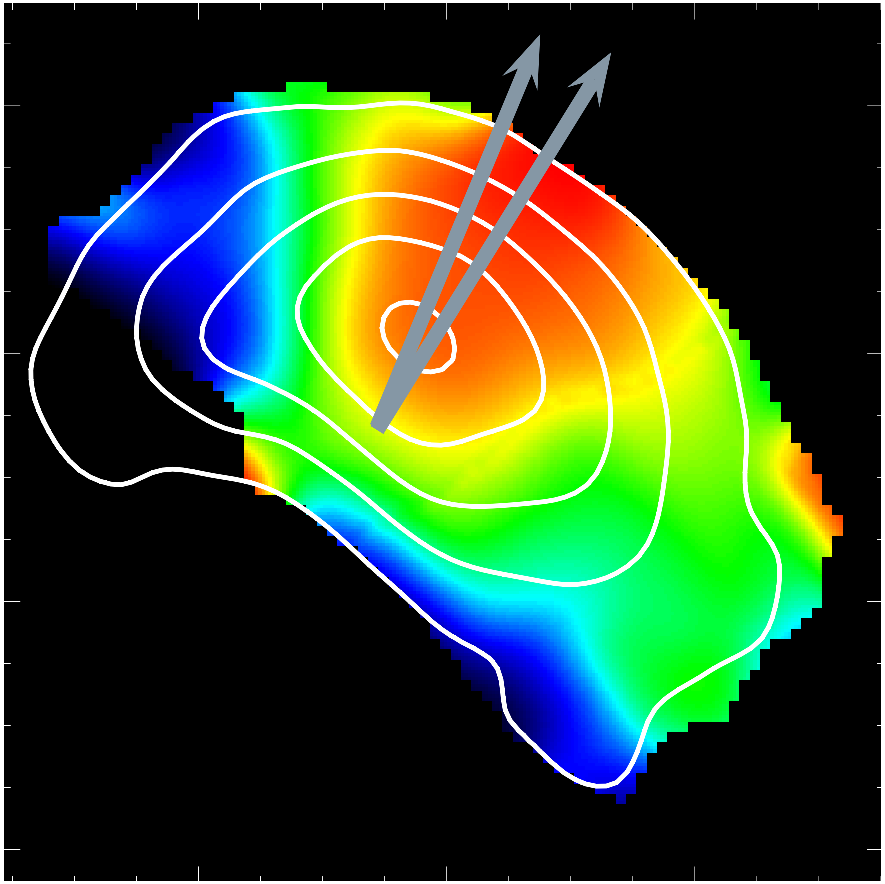


- RM structure implies a radial magnetic field (dipole field).
- the pulsar's spin axis goes over the RM minimum projected to the plane of the sky
- the spin axis is pointing away from us to the north-east

Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

The PWN in G106.3+2.7

Ng & Romani, 2004, ApJ 601, 479

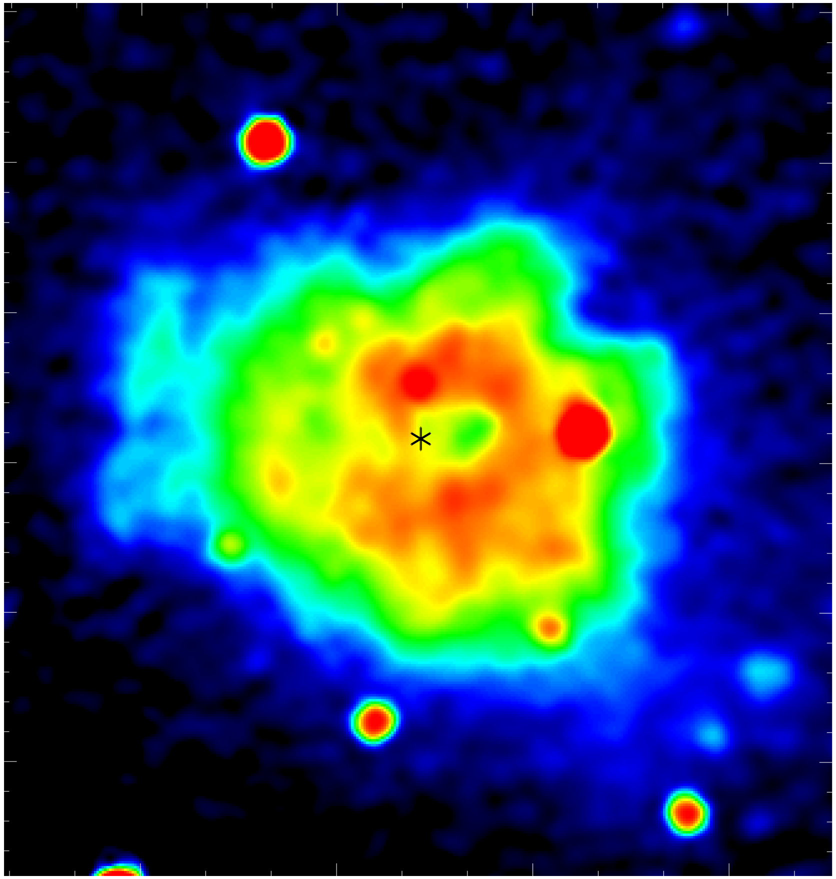


- RM structure implies a radial magnetic field (dipole field).
- the pulsar's spin axis goes over the RM minimum projected to the plane of the sky
- the spin axis is pointing away from us to the north-east

Kothes, Reich, Uyanıker, 2006, ApJ 638, 225

DA 495

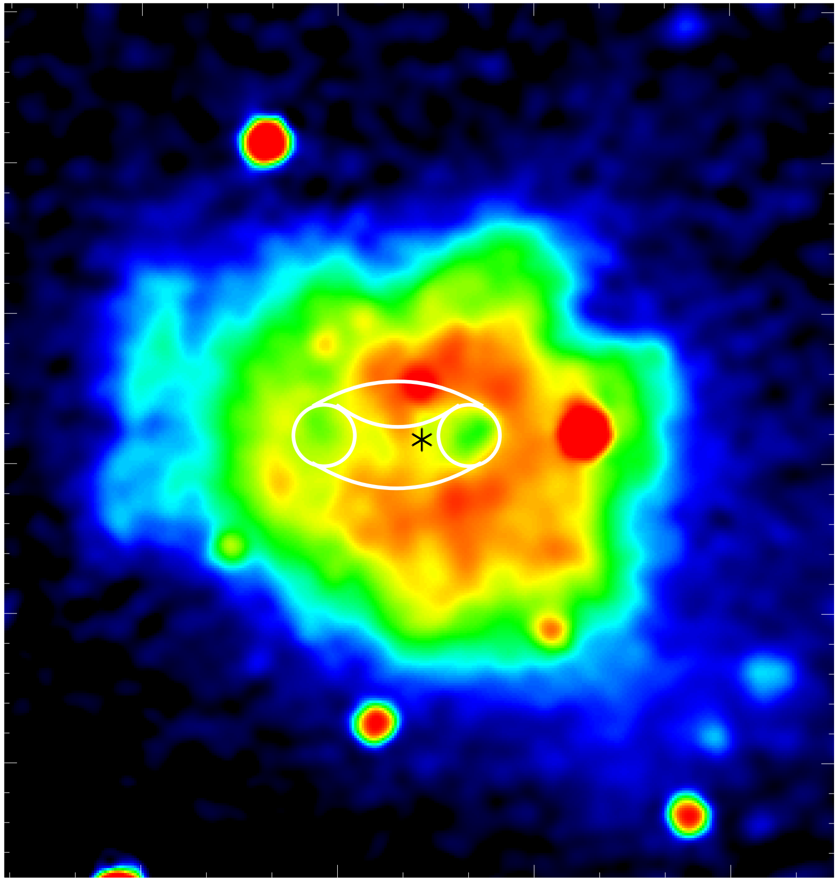
Combined CGPS + NVSS image at 1420 MHz:



- DA 495 is a pulsar wind nebula with a recently discovered neutron star in the centre.

Arzoumanian, Safi-Harb, Landecker, & Kothes, 2004, ApJ 610, L101

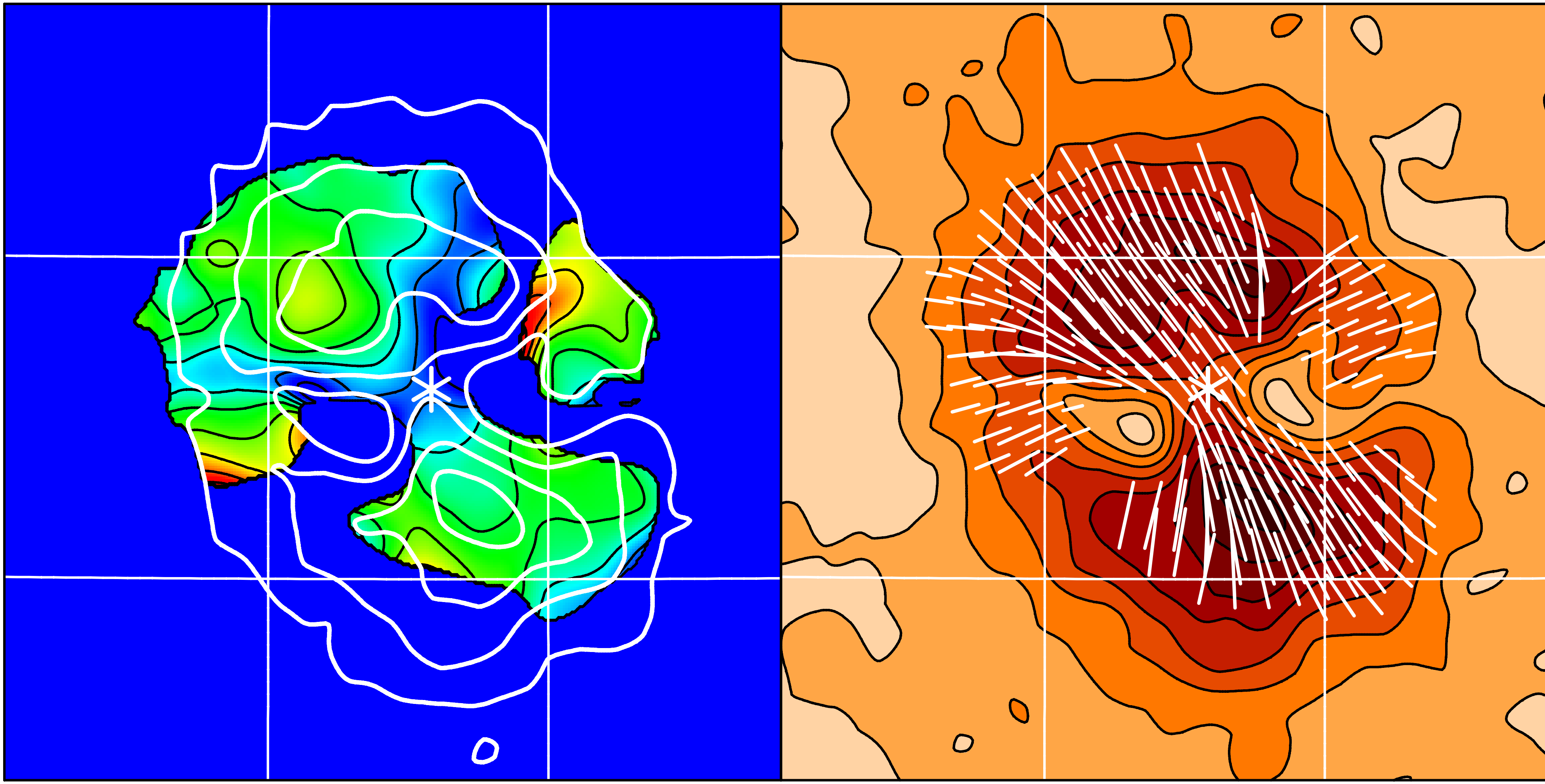
Combined CGPS + NVSS image at 1420 MHz:



- DA 495 is a pulsar wind nebula with a recently discovered neutron star in the centre.
- We believe the two holes indicate an equatorial torus of material ejected by the progenitor star.
- DA 495 is about 20,000 yr old with a magnetic field of 1.5 mG.

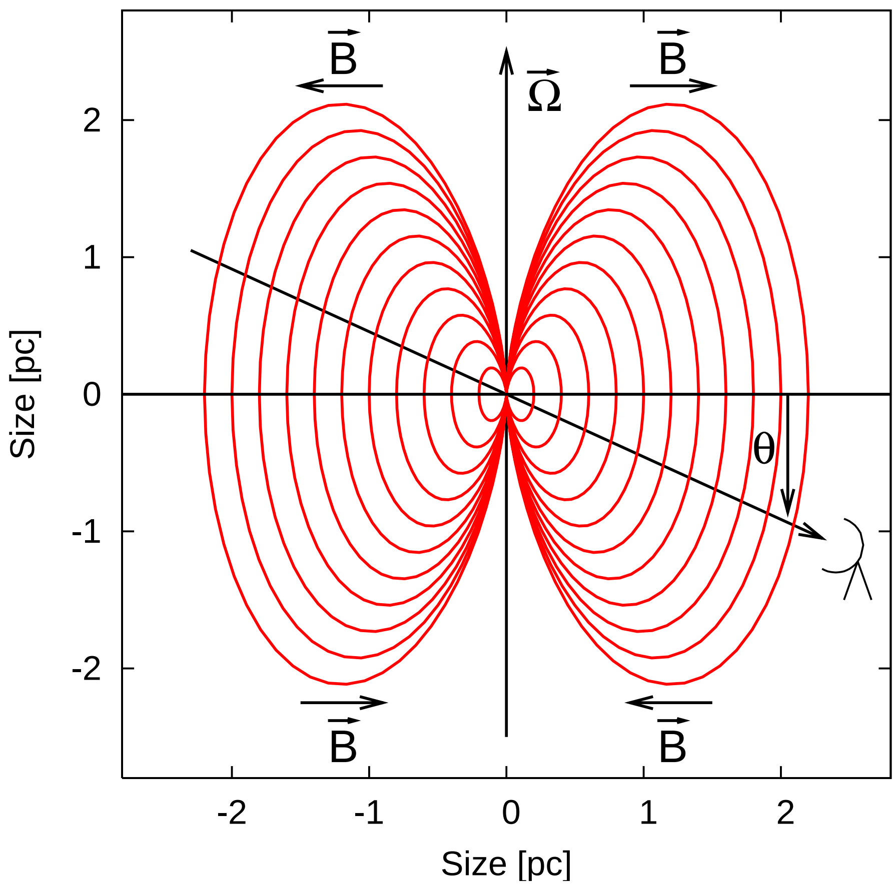
Kothes, Landecker, Reich, Safi-Harb, & Arzoumanian, 2008, ApJ 687, 516

DA 495



Kothes, Landecker, Reich, Safi-Harb, & Arzoumanian, 2008, ApJ 687, 516

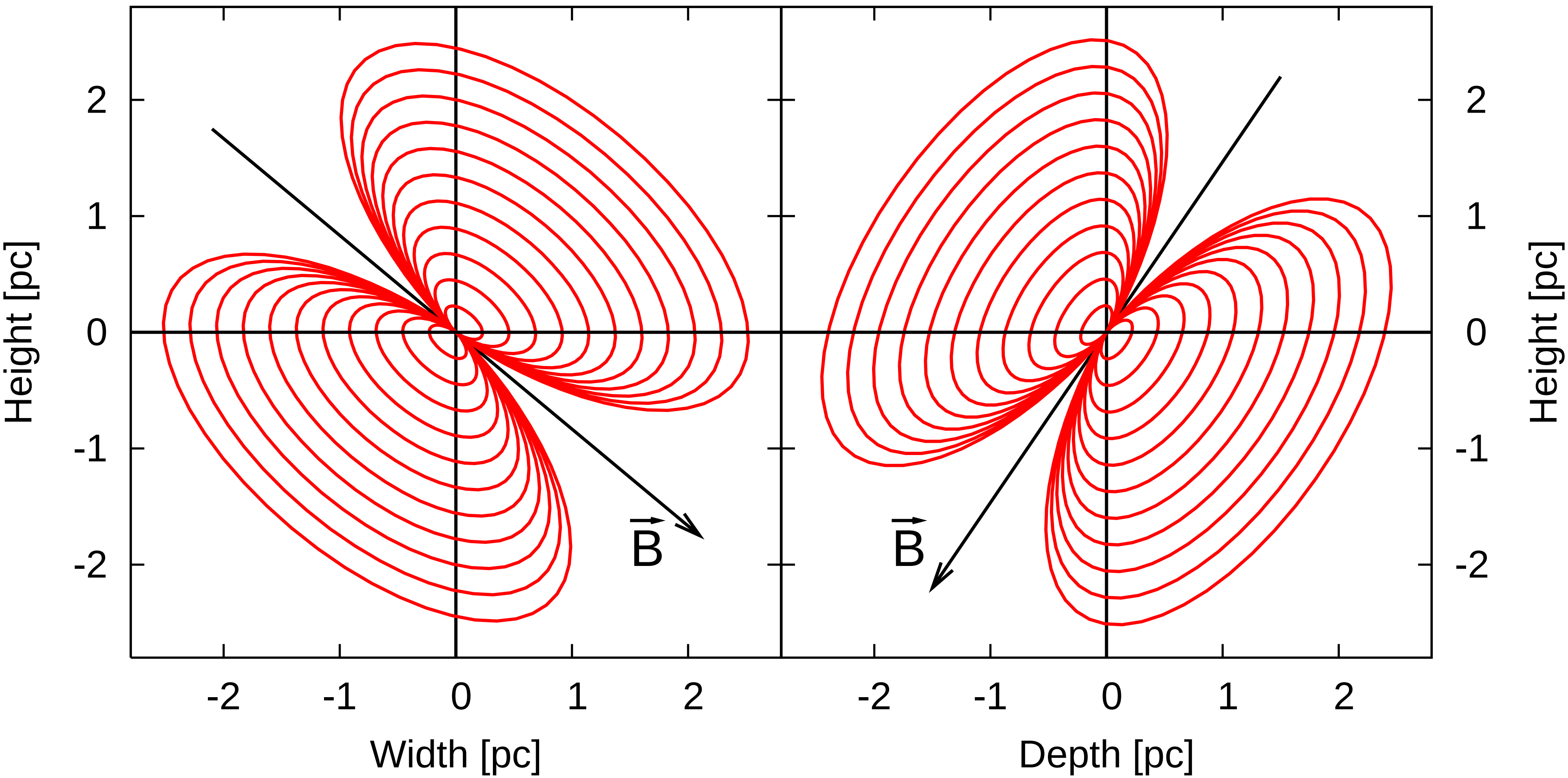
DA 495



- Assuming that a dipole field is responsible for the Faraday rotation inside DA 495, we fitted this model to the RM map.
- We derive a magnetic field of 1.5 mG and an electron density of 0.3 cm^{-3} inside the nebula.

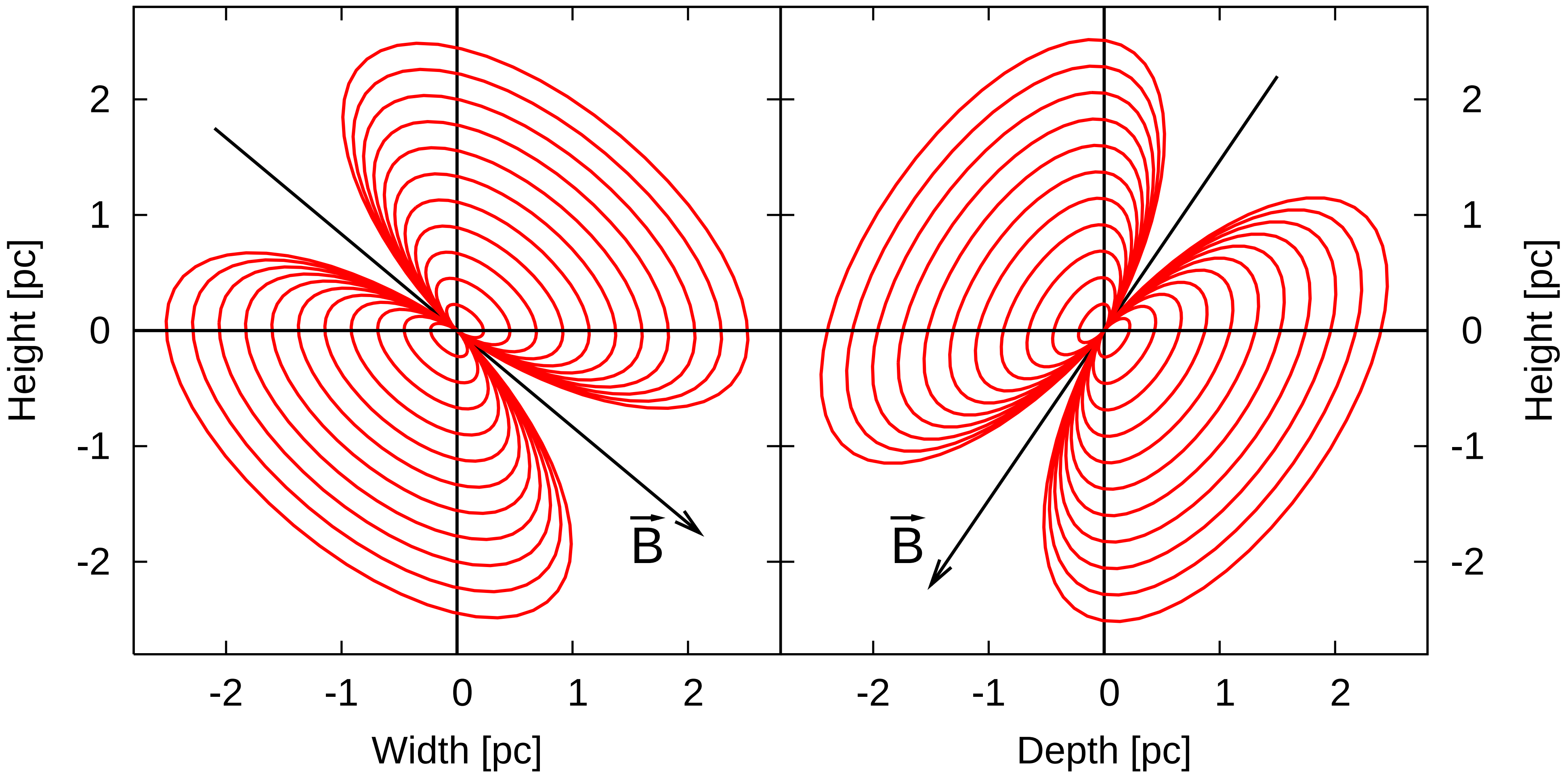
Kothes, Landecker, Reich, Safi-Harb, & Arzoumanian, 2008, ApJ 687, 516

DA 495



Kothes, Landecker, Reich, Safi-Harb, & Arzoumanian, 2008, ApJ 687, 516

DA 495

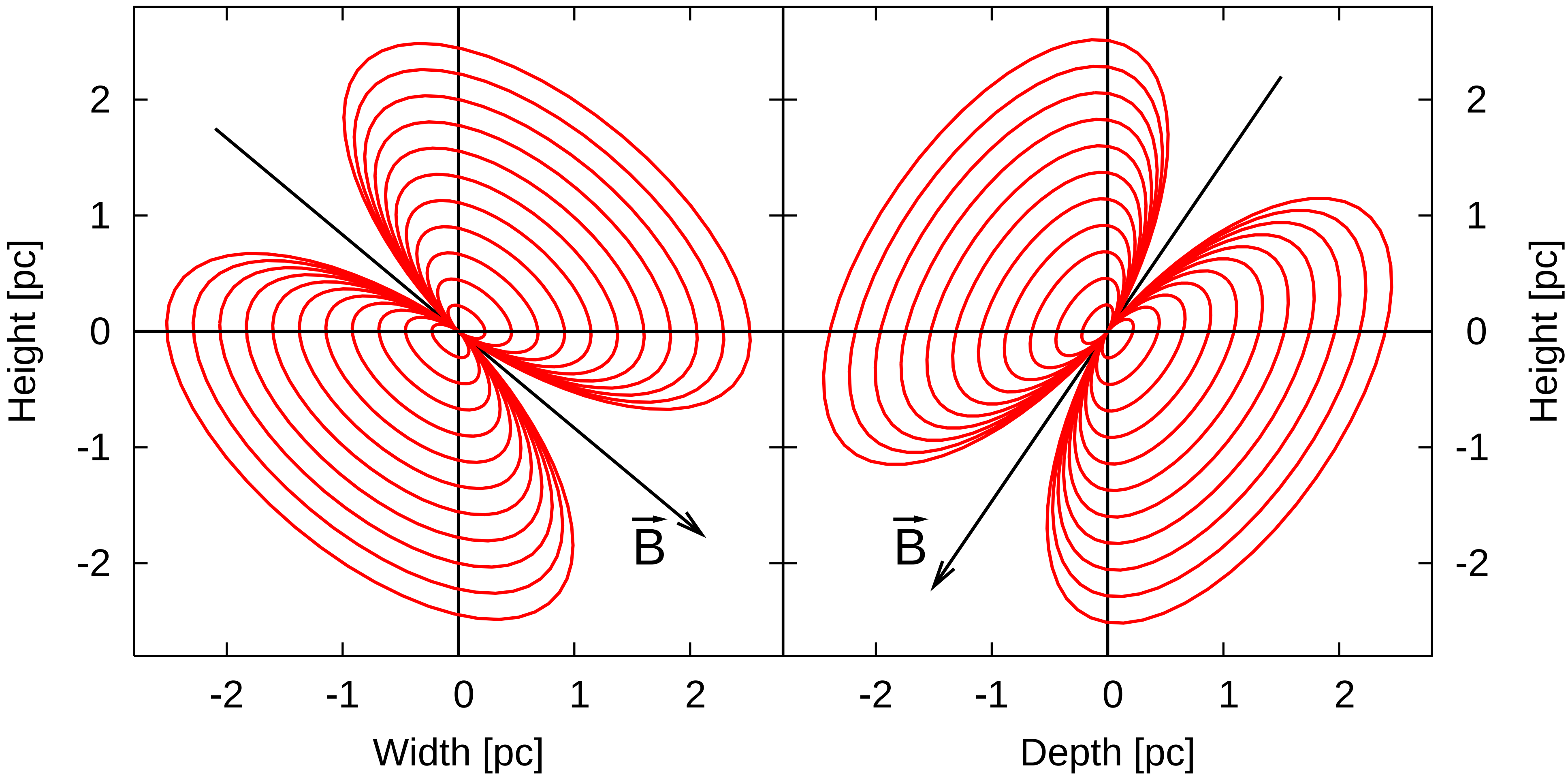


Kothes, Landecker, Reich, Safi-Harb, & Arzoumanian, 2008, ApJ 687, 516

Confirmed with CHANDRA by

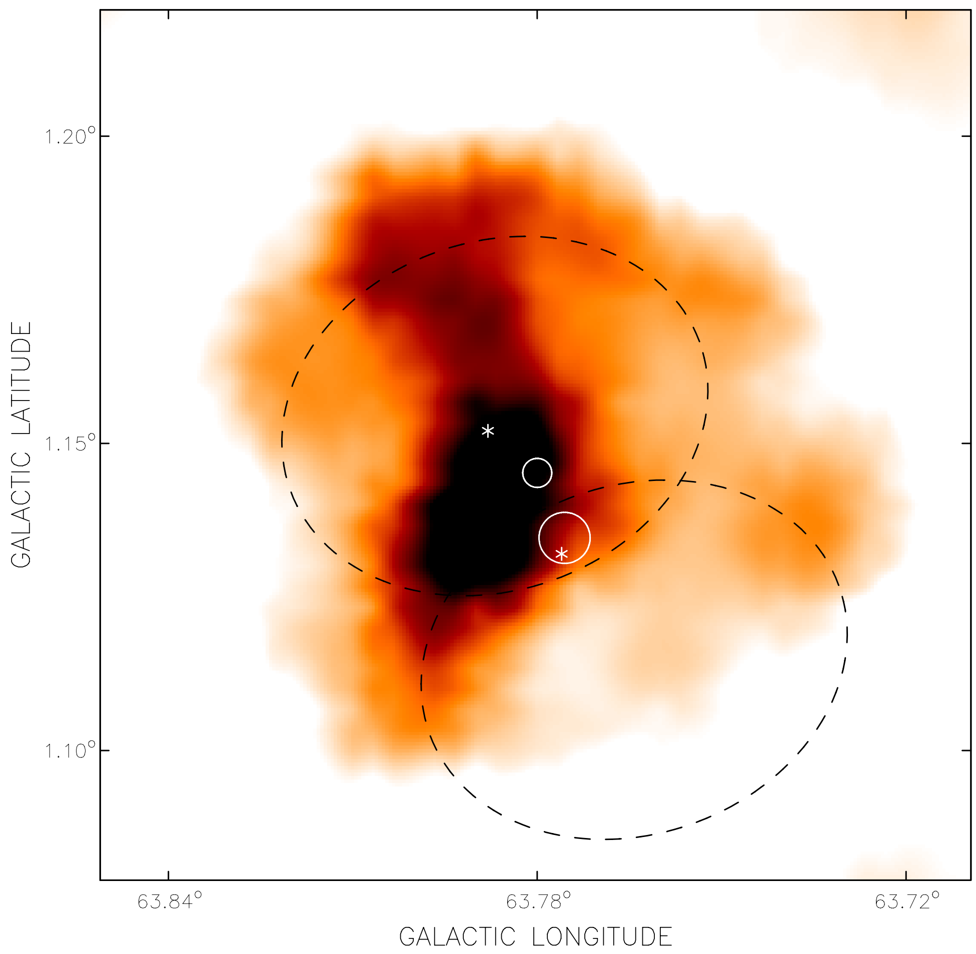
Arzoumanian, Safi-Harb, Landecker, Kothes, & Camilo, 2008, ApJ 687, 505

DA 495

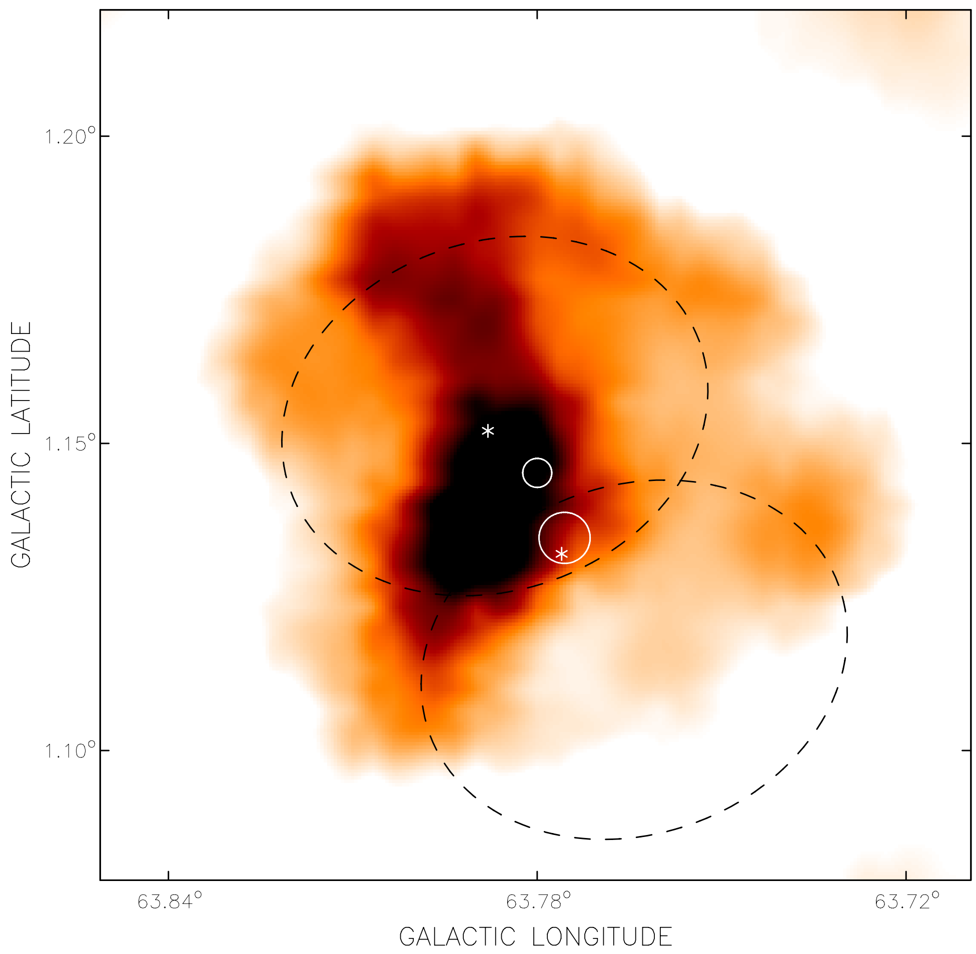


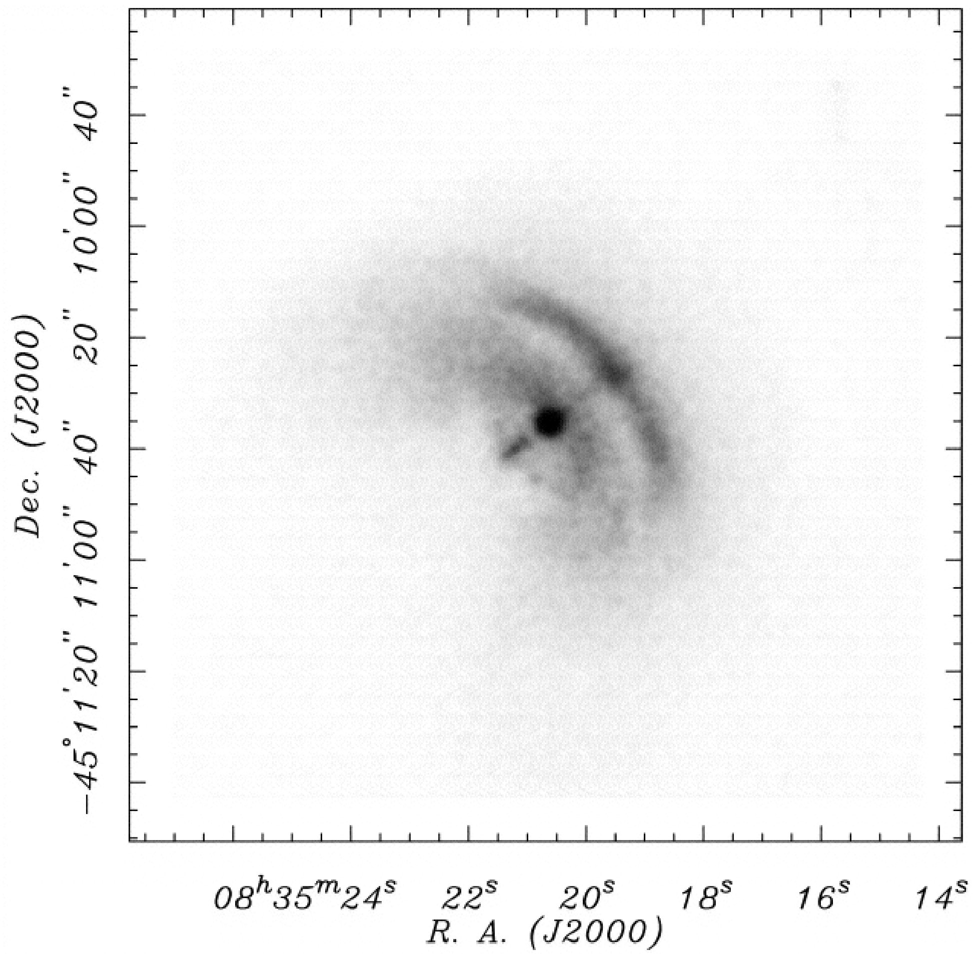
See also talk: A Pulsar Wind Nebula in the Radio SNR G76.9+1.0 by Z. Arzoumanian

G63.7+1.1


1.20°
1.15°
1.10°
GALACTIC LATITUDE
63.84°
63.78°
63.72°
GALACTIC LONGITUDE

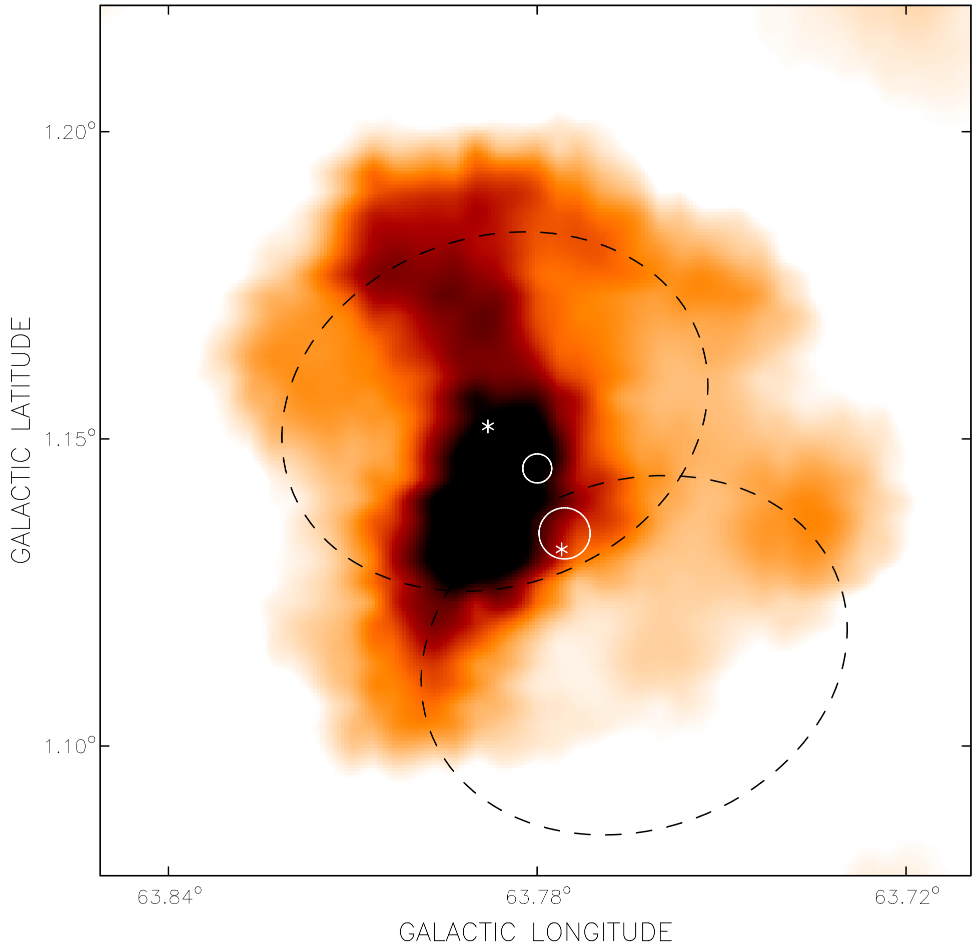
G63.7+1.1

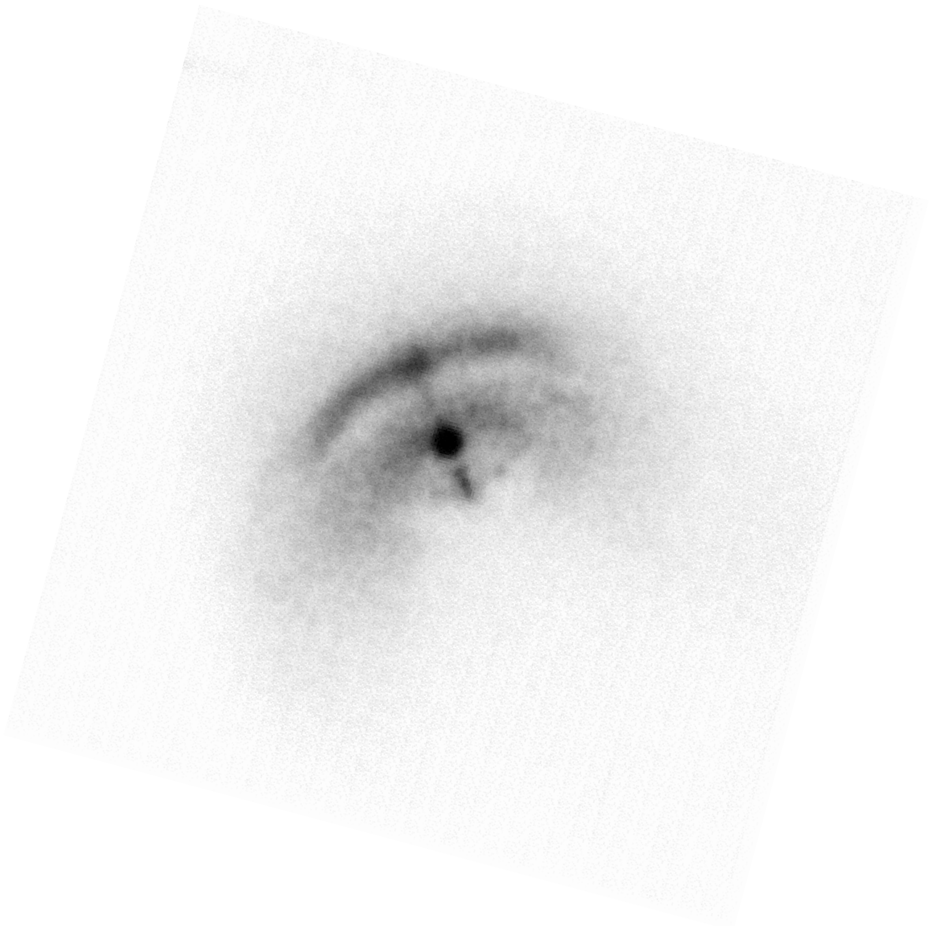




Helfand et al., 2001

G63.7+1.1





see also poster:

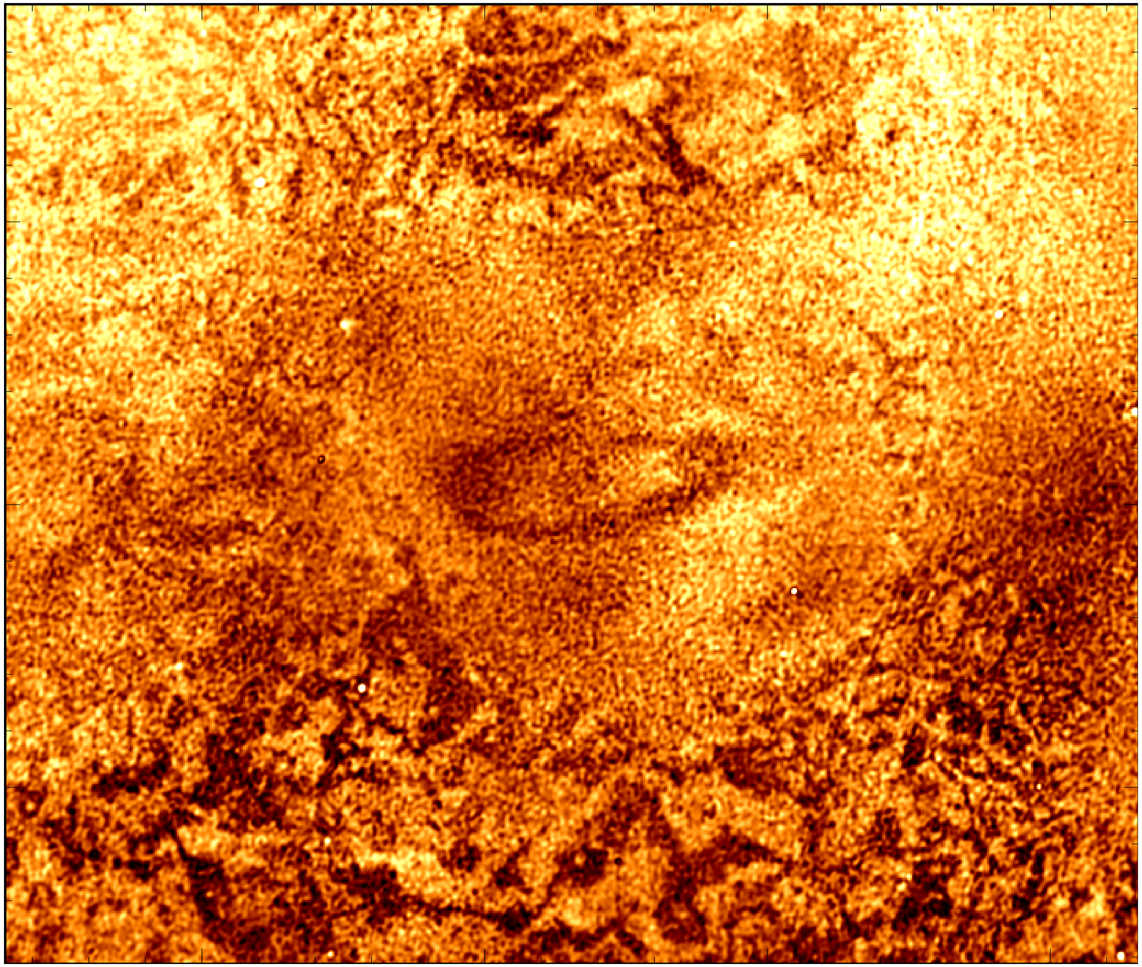
Unveiling the Properties of the Supernova Remnant G63.7+1.1 by S. Safi-Harb

Gedankenexperiment

A brief look into very late stages of evolution:

- $S_{syn} \sim B^{1.85}$, $RM \sim B$
- To make DA 495 invisible at 1420 MHz we have to reduce its flux density by a factor of 100 at its current size.
- If we expand the pulsar wind nebula until it is invisible, taking the reduction of the magnetic field into account, we have to double its size.
- This would result in an invisible object that still produces a Faraday rotation of 60 - 80 rad/m^2 for polarized emission coming from its background,
- with a neutron star close to the centre/nearby.

Polarization Lens



Gray, Landecker, Dewdney, Taylor, 1998, Nature 393, 660

Summary

- A comparison of the radio and X-ray emission characteristics of evolved pulsar wind nebulae gives us a powerful tool to study their life history.
- Observations at both frequency bands can give independent but comparable information about characteristics of the central engine.
- I propose a CHANDRA search for neutron stars in polarization lenses to study the possibility of those being old pulsar wind nebulae.