High Resolution Radio Polarimetry Study of The Pulsar Wind Nebula MSH 15-52

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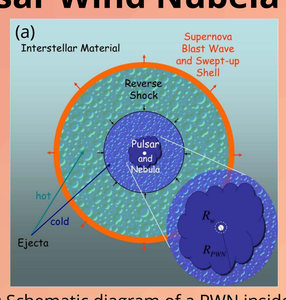
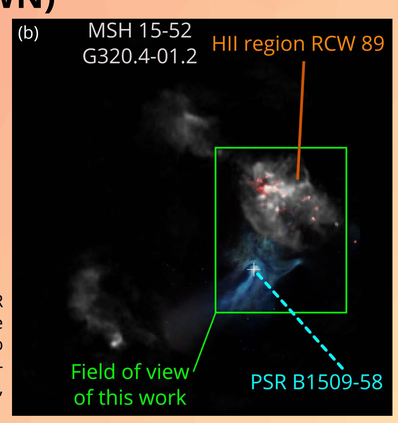
Abstract

We present a new high-resolution radio imaging study of the pulsar wind nebula (PWN) MSH 15-52, also dubbed as "the hand of God", with the Australia Telescope Compact Array observations. The system is powered by a young and energetic radio pulsar B1509-58 with high spin down luminosity of E-dot = 2x10^{37} erg/s. Previous X-ray images have shown that the PWN has a complex hand-shape morphology extending over 10 pc with features like jets, arc, filaments and enhanced emission knots in the HII region RCW 89. The new 6cm and 3cm radio images show different morphology than the X-ray counterpart. No radio counterpart of the X-ray jet is detected, instead we found enhanced emission in a sheath surrounding the jet. Additional small-scale features including a polarized linear filament next to the pulsar have also been discovered. Our polarisation measurements show that the intrinsic orientation of magnetic field aligns with the sheath. Finally, spectral analysis results indicate a steep spectrum for the system, which is rather unusual among PWNe. Implications of these findings will be discussed.

http://ryan-leung.github.io/msh1552

Pulsar Wind Nubela (PWN)





(Fig.1a) Schematic diagram of a PWN inside a SNR (Gaensler & Slang 2006). **(fig.1b)** ATCA 6cm image of MSH 15-52 showing radio morphology of two separated components (black & white) and the X-ray counterpart (colour). (Gaensler et al. 1999, hereafter G99, NASA/CXC/SAO/P.Slane, et al.)

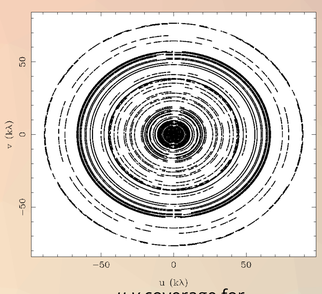
PSR B1509-58

- $t = 1700\,\mathrm{yr}$
- $d = 5.2 \pm 1.2\,\mathrm{kpc}$
- $P = 151\,\mathrm{ms}$
- $\dot{P} = 1.5 \times 10^{-12}$
- $\dot{E} = 2 \times 10^{37}\,\mathrm{erg\ s^{-1}}$
- $B = 3.1 \times 10^{13}\,\mathrm{G}$

Observations

We observed MSH 15-52 with the Australia Telescope Compact Array (ATCA) in 2011 and 2013 in 6cm and 3cm with CABB mode. Full polarization was recorded. Data are reduced and analyzed with *MIRIAD*.

Australia Telescope Compact Array (Credit: ATNF/CSIRO)

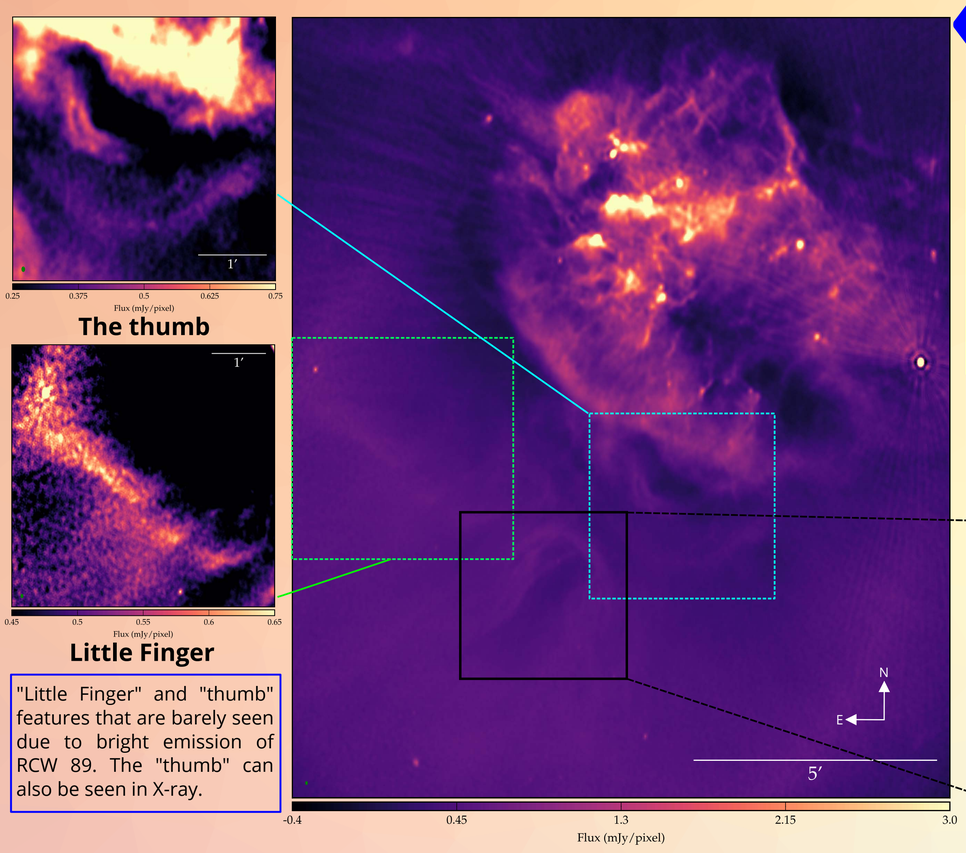


u-v coverage for 6cm observations

Obs. Date	Array Config.	Maximum baseline (m)	Time on source (hr)
2011-11-14	750D	4469	9.2
2011-12-03	EW367	4408	8.5
2012-02-23	1.5D	4439	9.1
2013-12-16	6A	5939	11.1
2013-03-01	6B	5969	9.4

Observation parameters

6cm image of MSH 15-52



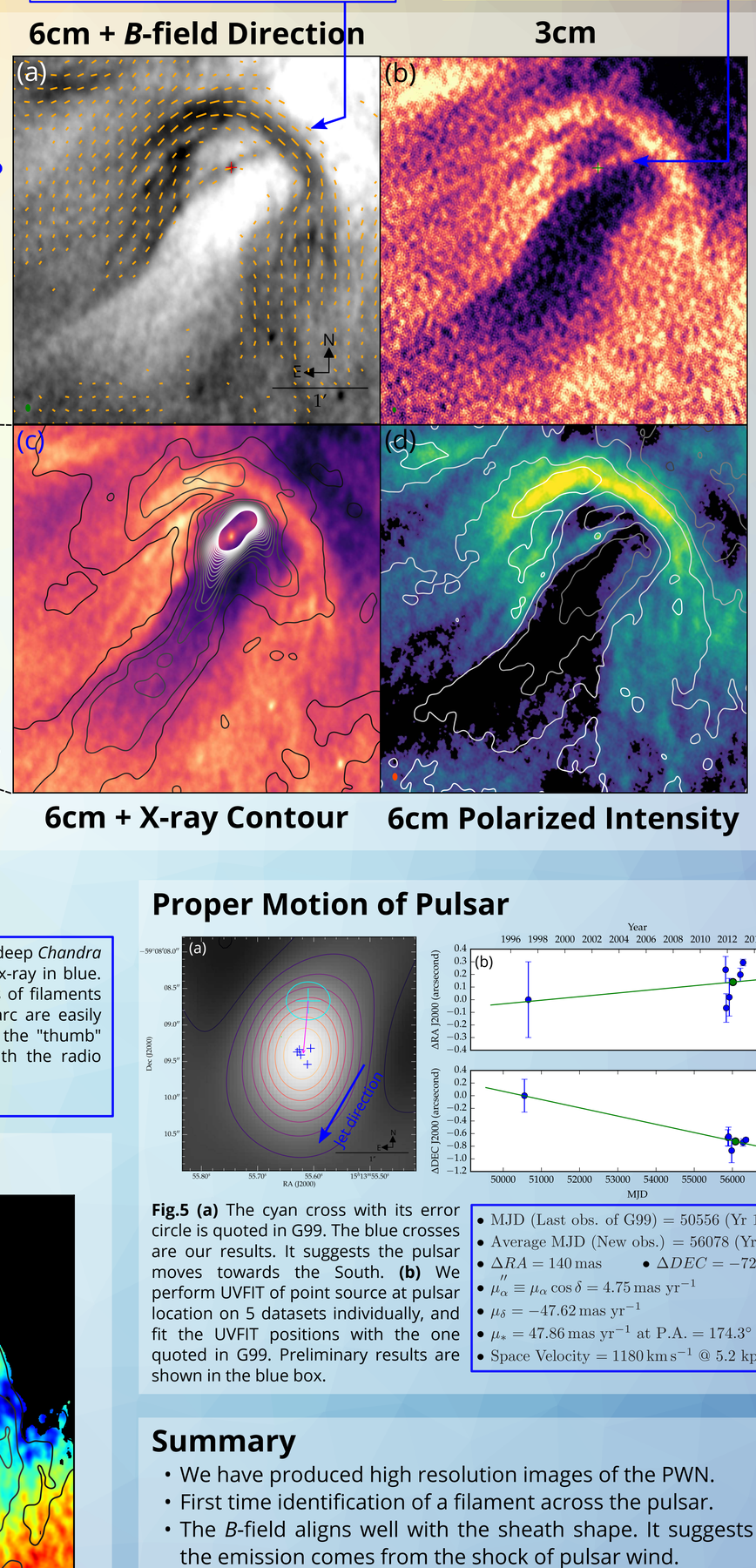
"Little Finger" and "thumb" features that are barely seen due to bright emission of RCW 89. The "thumb" can also be seen in X-ray.

Fig.2 6cm image of MSH 15-52 using all 5 observations. The beam size is marked at lower left corner. Top-right (north-west) is bright emission from RCW 89. The PWN is located ~7' south-east to RCW 89 nebula.

Fig.3 Various images to illustrate the PWN around the pulsar. **(a)** *B*-field polarization angle (vectors) overlaid onto 6cm radio intensity map in grey scale, the red cross indicates pulsar position. **(b)** 3cm radio intensity map with a colour scale. **(c)** *Chandra* X-ray intensity (contours) overlaid onto 6cm radio map in colour scale. **(d)** 6cm radio map (contours) overlaid onto the 6cm polarized intensity in colour scale.

The *B*-field wraps around the "radio sheath" and match well with its shape. This suggests a toridial *B*-field with opening at the South.

Resolved filament structure at the pulsar can be seen in both 6cm and 3cm images. It is more likely a filament than an inner jet.



Radio - X-ray composite image

Fig. 4 Radio and X-ray composite image. X-ray data is deep *Chandra* X-ray image which shows soft x-ray in red and hard x-ray in blue. The magenta radio image is our 6cm data. Networks of filaments and compact knots, a bright one-sided jet and an arc are easily distingushed from the X-ray image. Detail image of the "thumb" can refer to Fig. 2. The X-ray jet anti-correlates with the radio counterpart. The shape of the hollow part aligns very well with the X-ray jet.

Spectral Analysis

Fig. 6 Spectral index distribution across the PWN between 5.5 GHz and 9 GHz. The colour map indicates different spectral index around the PWN. Pulsar position is indicated as a red cross.

Proper Motion of Pulsar

Fig.5 (a) The cyan cross with its error circle is quoted in G99. The blue crosses are our results. It suggests the pulsar moves towards the South. **(b)** We perform UVFIT of point source at pulsar location on 5 datasets individually, and fit the UVFIT positions with the one quoted in G99. Preliminary results are shown in the blue box.

- MJD (Last obs. of G99) = 50556 (Yr 1997)
- Average MJD (New obs.) = 56078 (Yr 2012)
- $\Delta RA = 140\,\mathrm{mas}$ • $\Delta DEC = -720\,\mathrm{mas}$
- $\mu''_\alpha \equiv \mu_\alpha \cos\delta = 4.75\,\mathrm{mas\ yr^{-1}}$
- $\mu_\delta = -47.62\,\mathrm{mas\ yr^{-1}}$
- $\mu_* = 47.86\,\mathrm{mas\ yr^{-1}}$ at P.A. = 174.3°
- Space Velocity = 1180 km s^{-1} @ 5.2 kpc

Summary

- We have produced high resolution images of the PWN.
- First time identification of a filament across the pulsar.
- The *B*-field aligns well with the sheath shape. It suggests that the emission comes from the shock of pulsar wind.
- Clearly no radio counterpart is observed at the site of the bright X-ray jet. The multiwavelength composite shows the radio sheath wraps well around the X-ray jet.
- We have detected a small proper motion of the pulsar at ~ 0.05" per year towards south.

Acknowledgement

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Reference

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