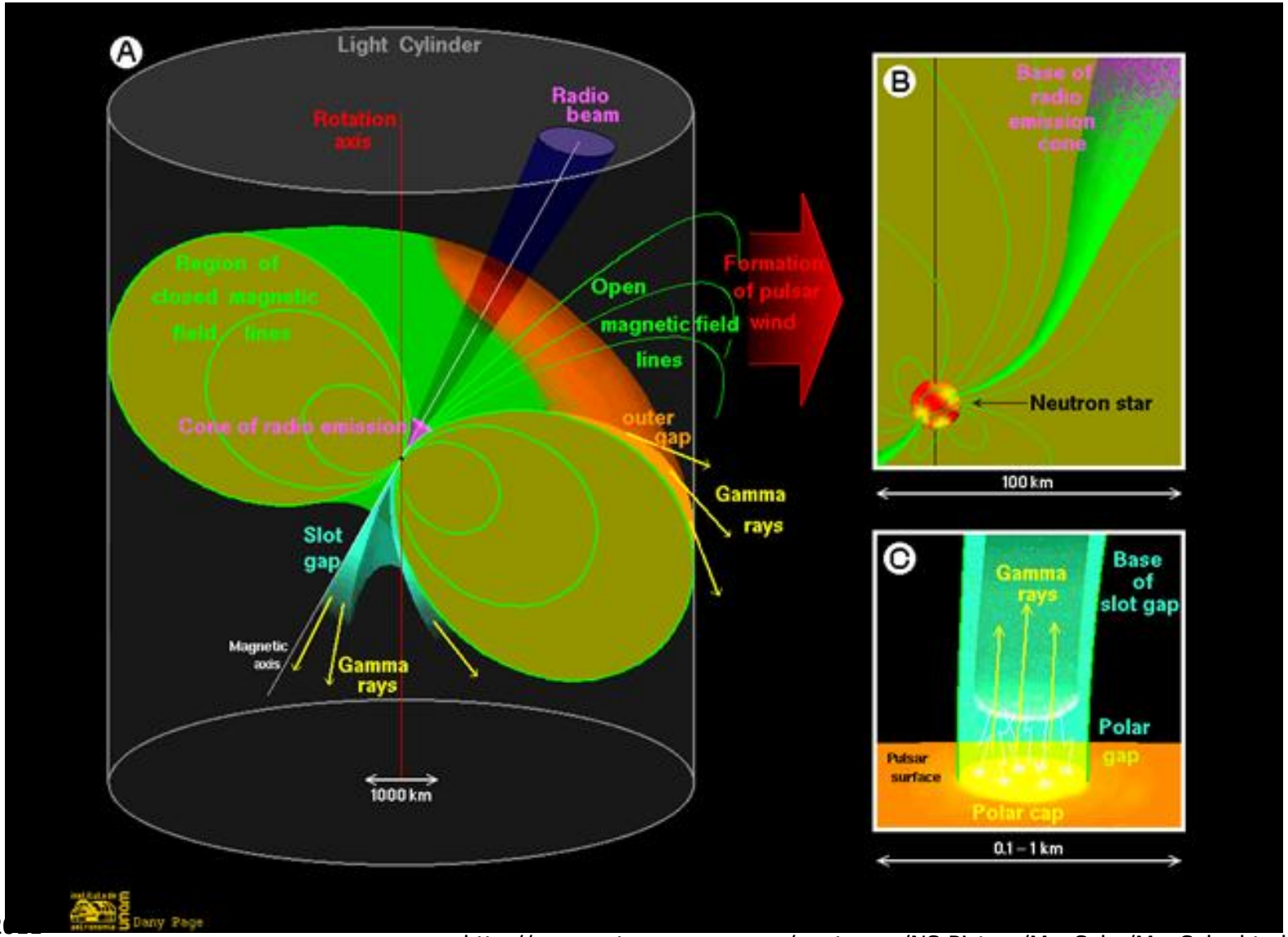
Radio Polarization Measurements of the Longest Pulsar Tail G315.9–0.0

Stephen C.-Y. Ng

McGill University

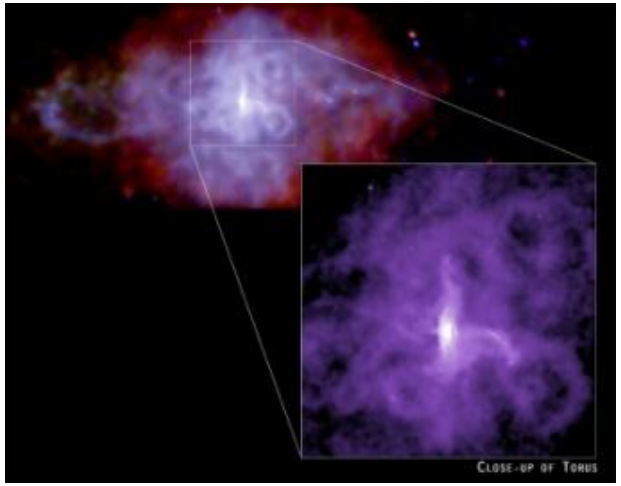
Collaborators: N. Bucciantini, F. Camilo, B. M. Gaensler, S. Chatterjee, A. Bouchard

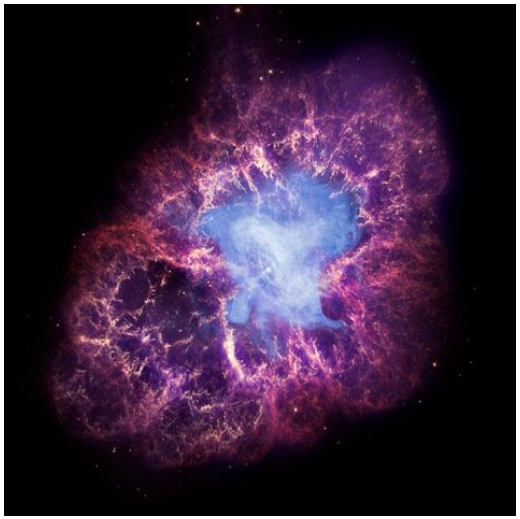
Pulsar Winds

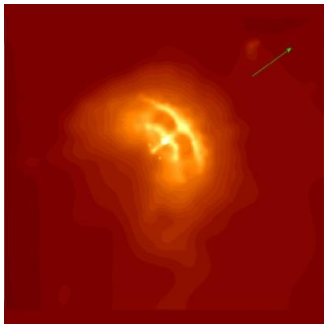


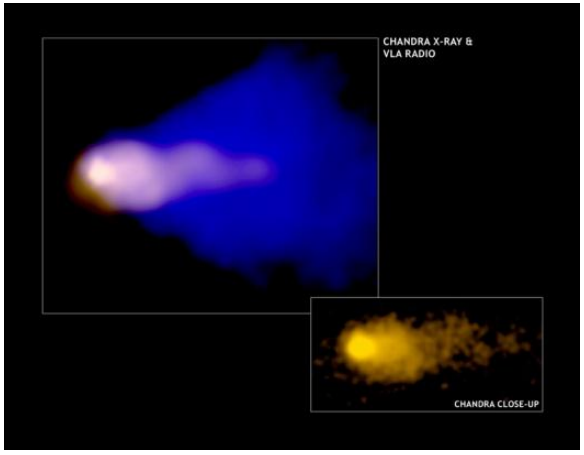
http://www.astroscu.unam.mx/neutrones/NS-Picture/MagSphe/MagSphe.html

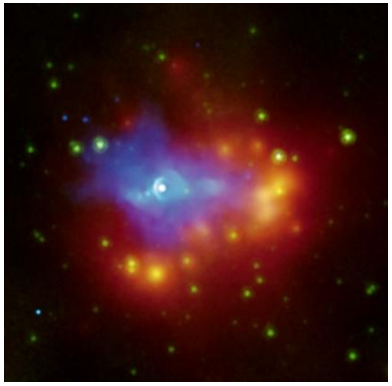
Pulsar Wind Nebulae



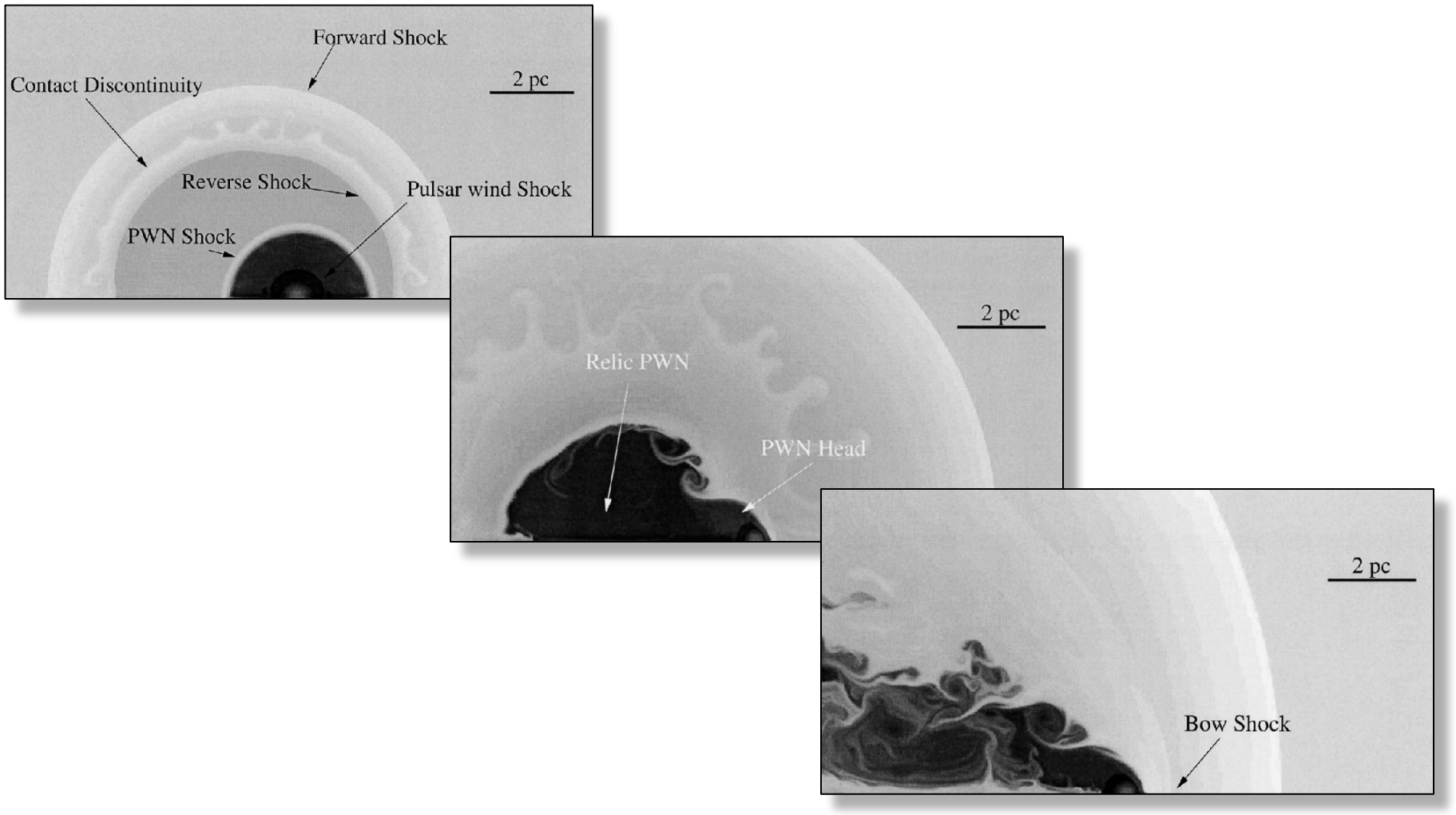






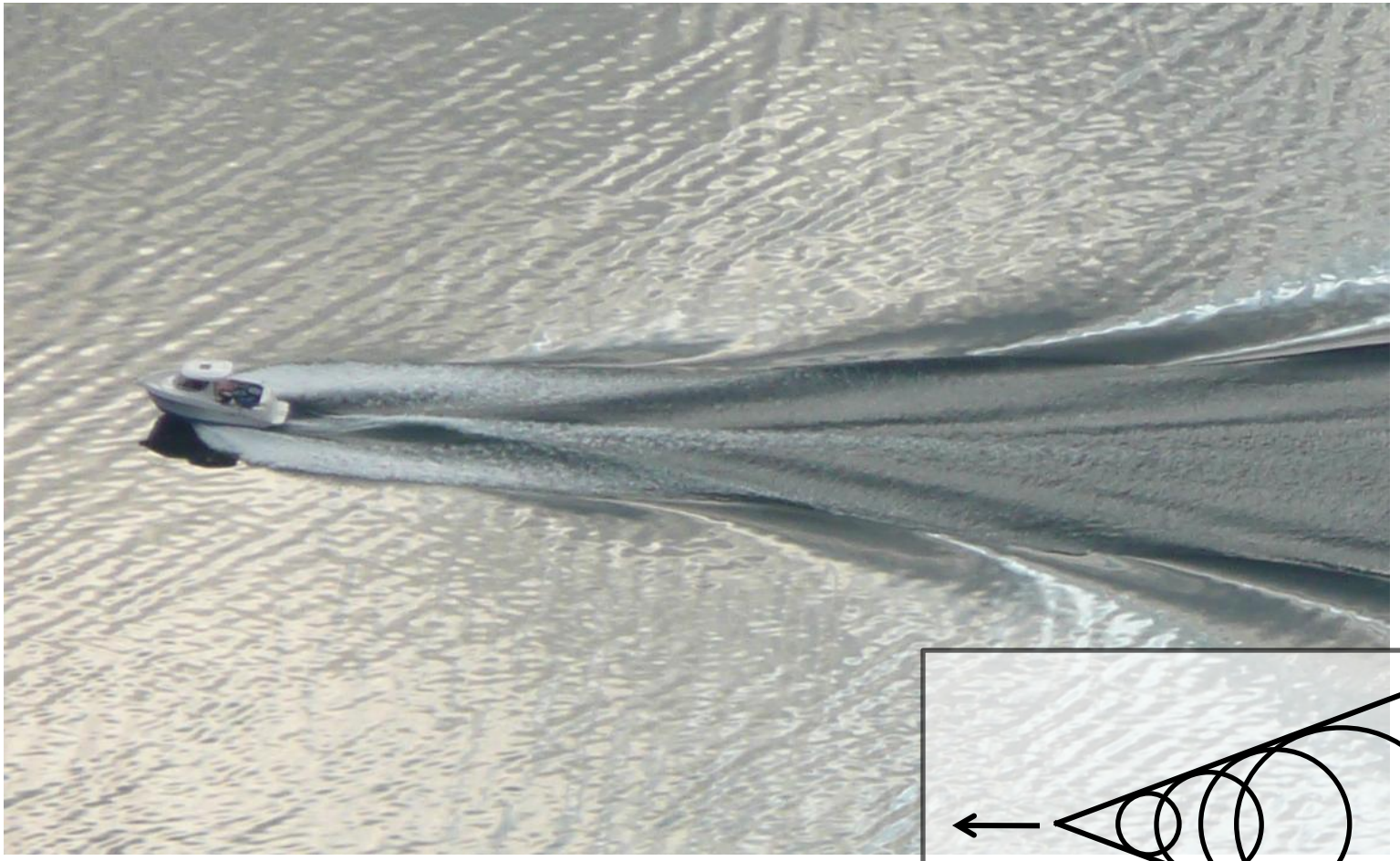


PWN Evolution

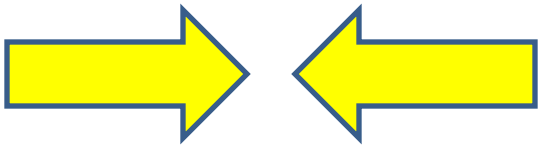


van der Swaluw et al. (2004)

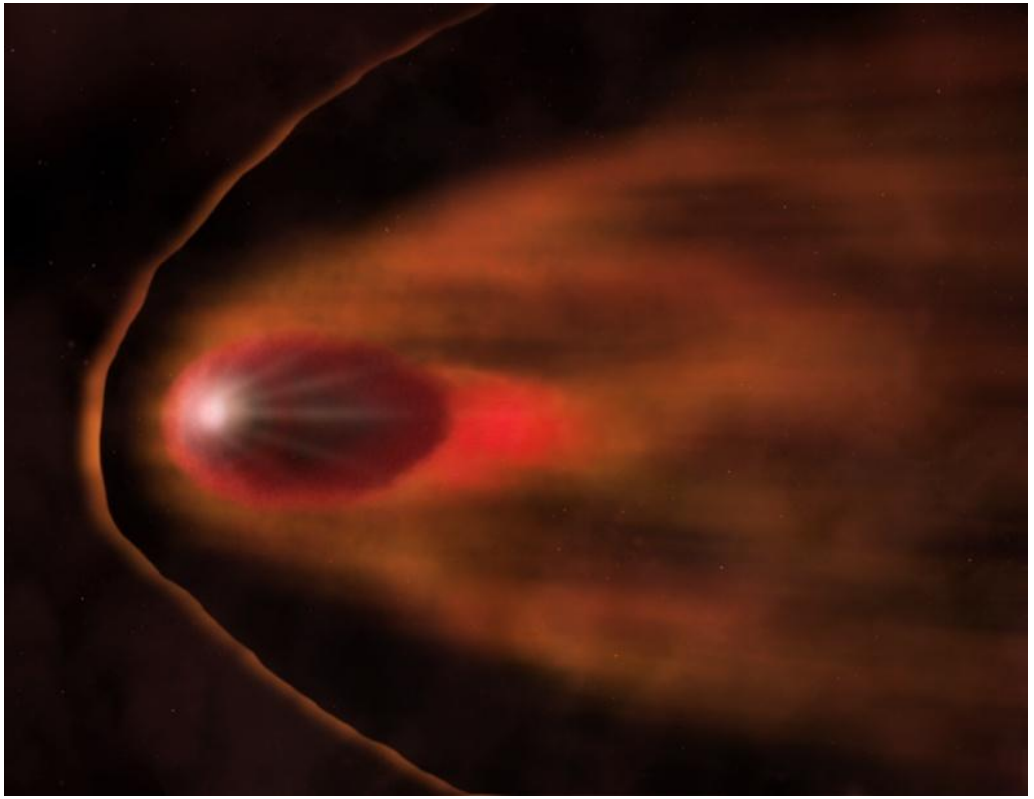
Bow Wave



Bow-shock PWN

ISM Ram Pressure  Pulsar Wind Pressure

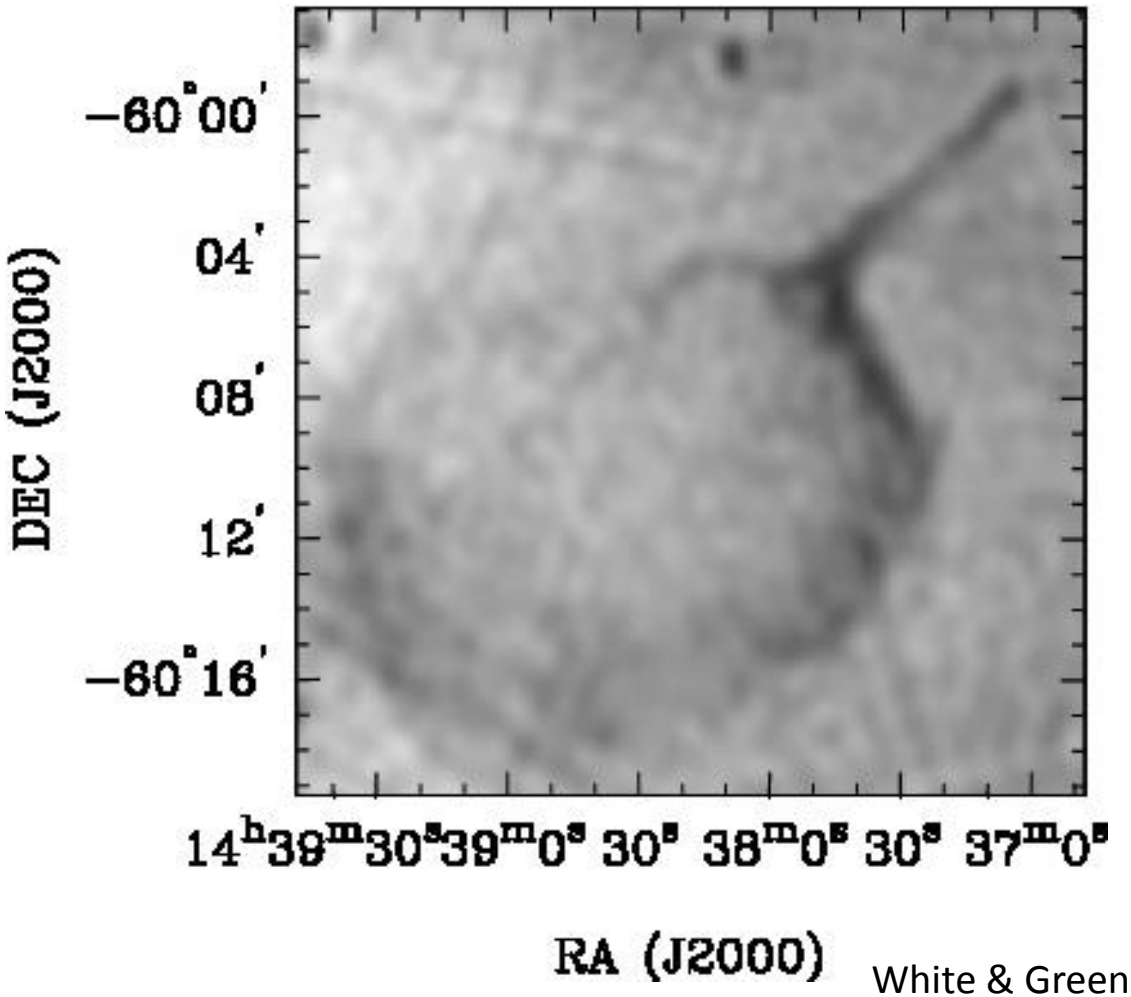
$$\rho v^2 = \frac{\dot{E}}{4\pi r^2 c}$$

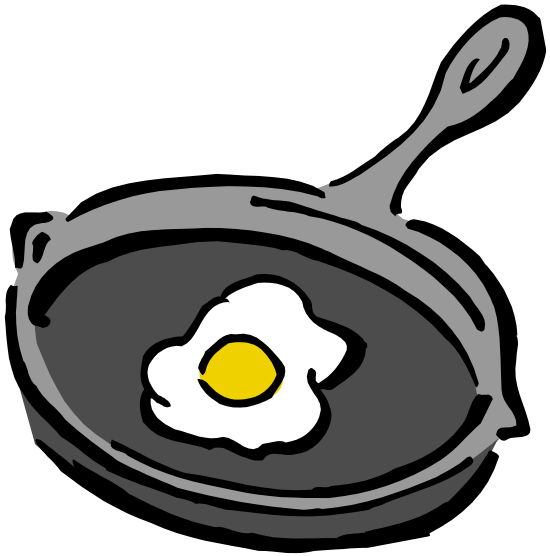


CXC/M. Weiss

G315.9–0.0: The Frying Pan

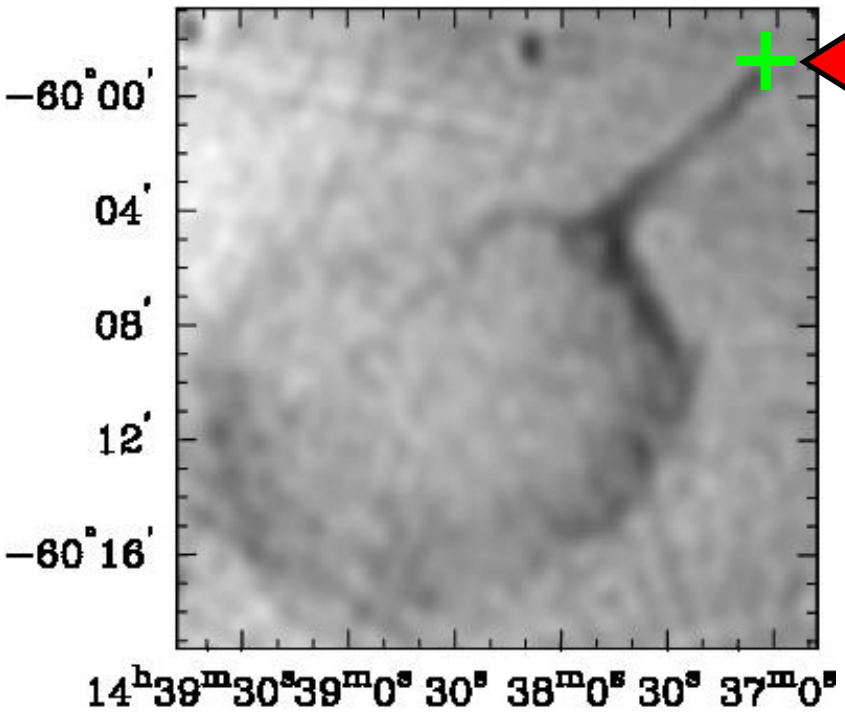
MOST 36cm

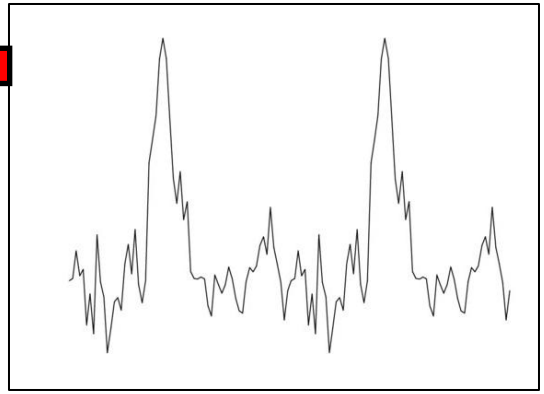




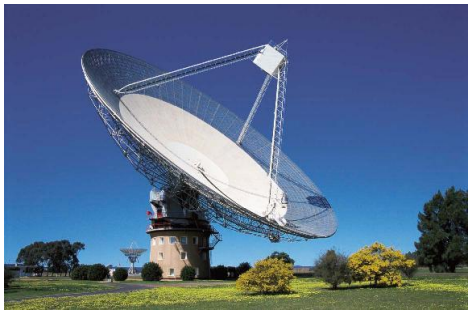
White & Green (1996)

PSR J1437-5959





Camilo, Ng, et al. (2009)

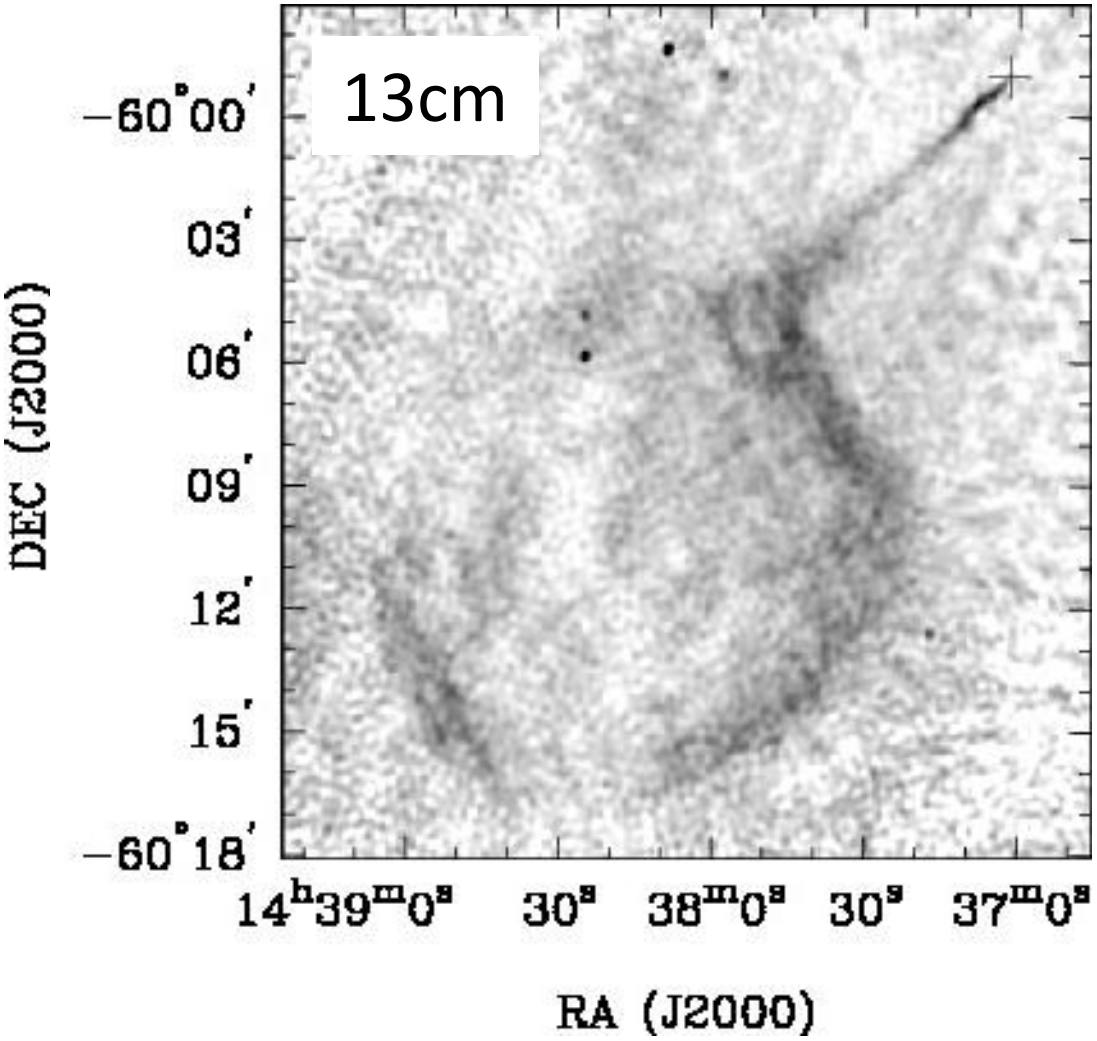


- $P = 0.061$s
- $\tau_c = P/2\dot{P} = 114$kyr
- $\dot{E} = 1.4 \times 10^{36}$erg/s
- $B = 7.4 \times 10^{11}$G
- $d = 8 \pm 2$kpc

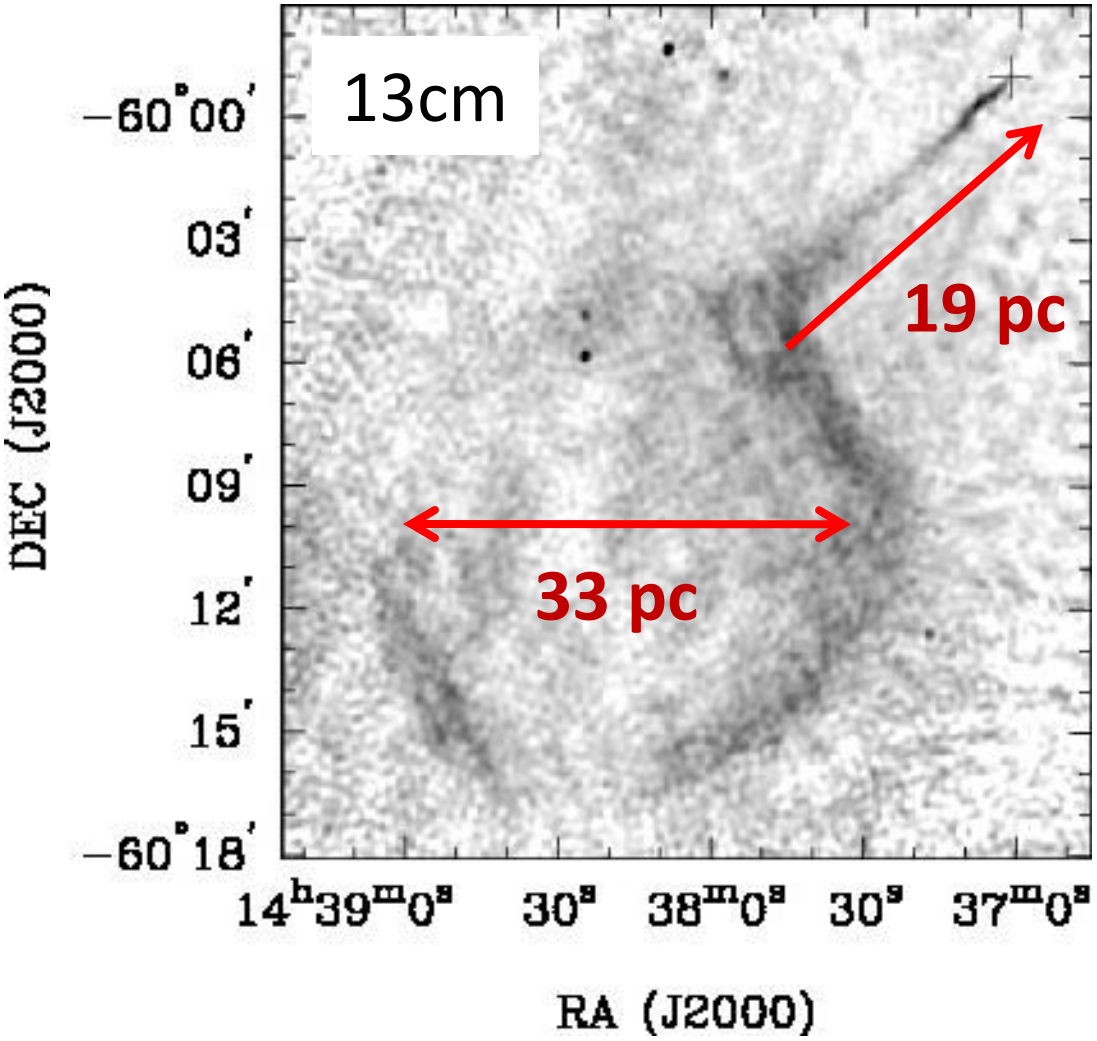
Radio Imaging

- Australia Telescope Compact Array (ATCA)
- New 3, 6cm observations (4x12hr)
- 2 observations done after the CABB upgrade
- Archival 20, 13cm data

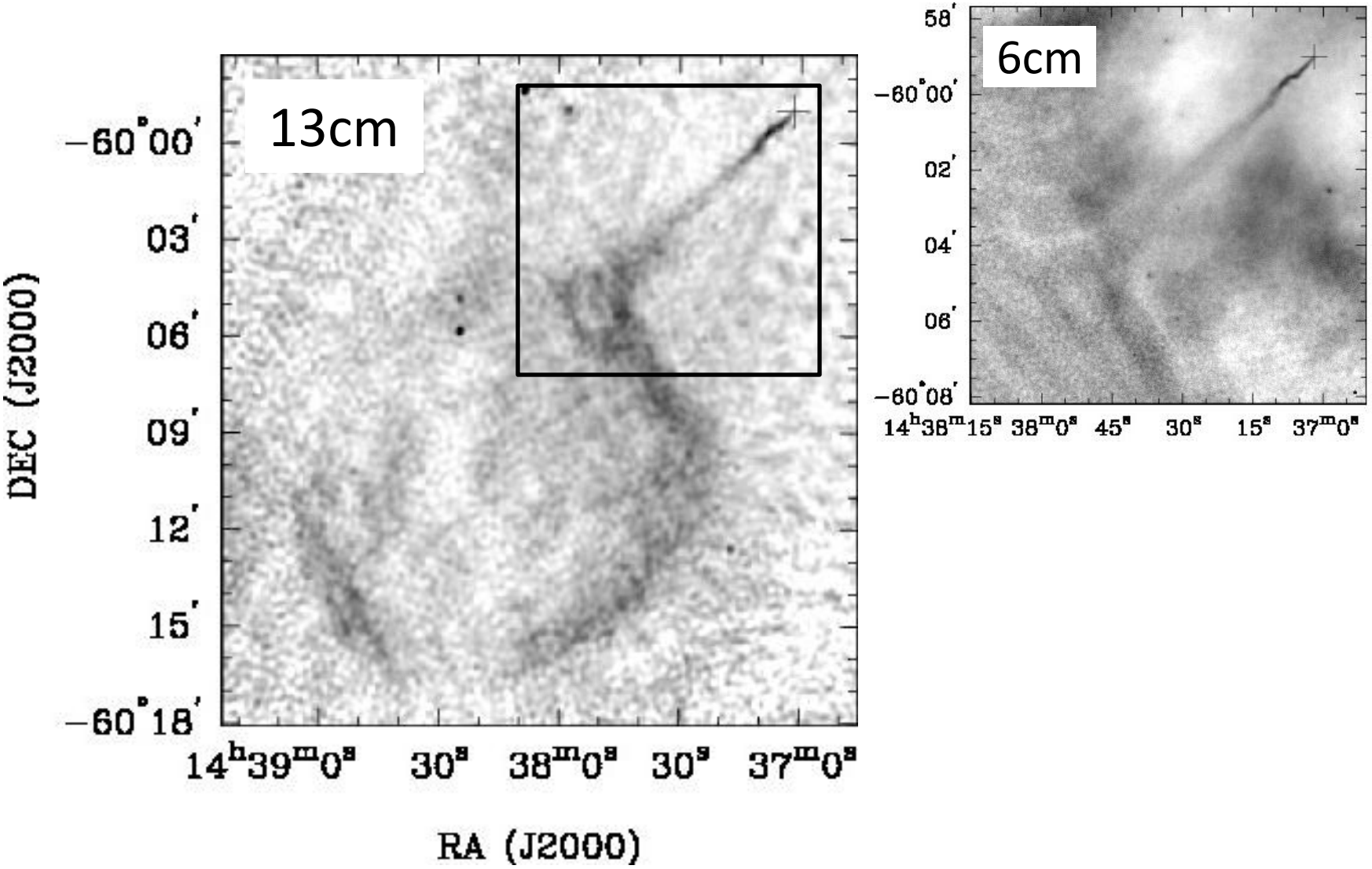
G315.9–0.0


13cm
−60°00′
03′
06′
09′
12′
15′
−60°18′
DEC (J2000)
14h39m0s
30s
38m0s
30s
37m0s
RA (J2000)

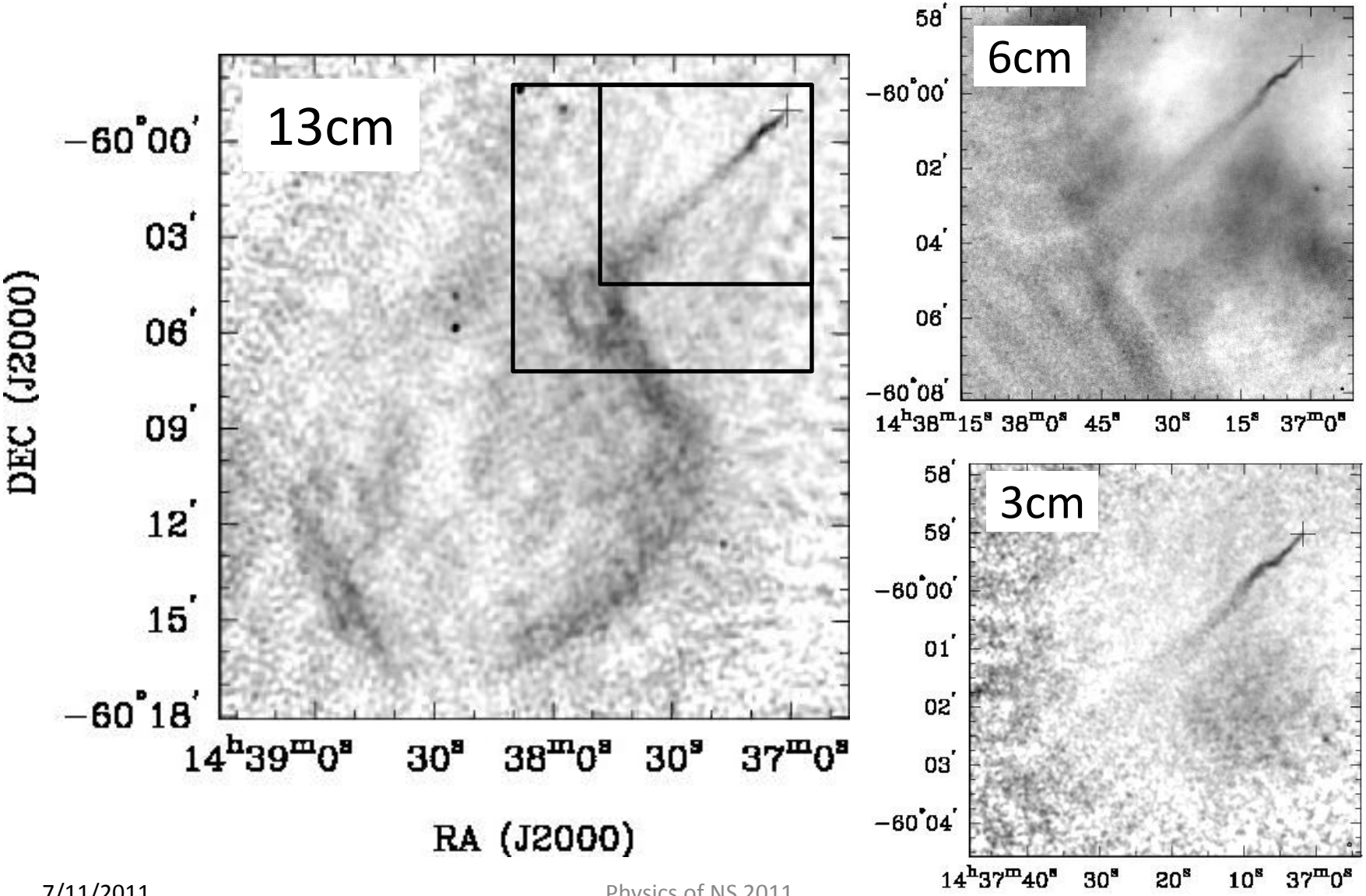
G315.9–0.0


13cm
19 pc
33 pc
−60°00′
03′
06′
09′
12′
15′
−60°18′
DEC (J2000)
14h39m0s
30s
38m0s
30s
37m0s
RA (J2000)

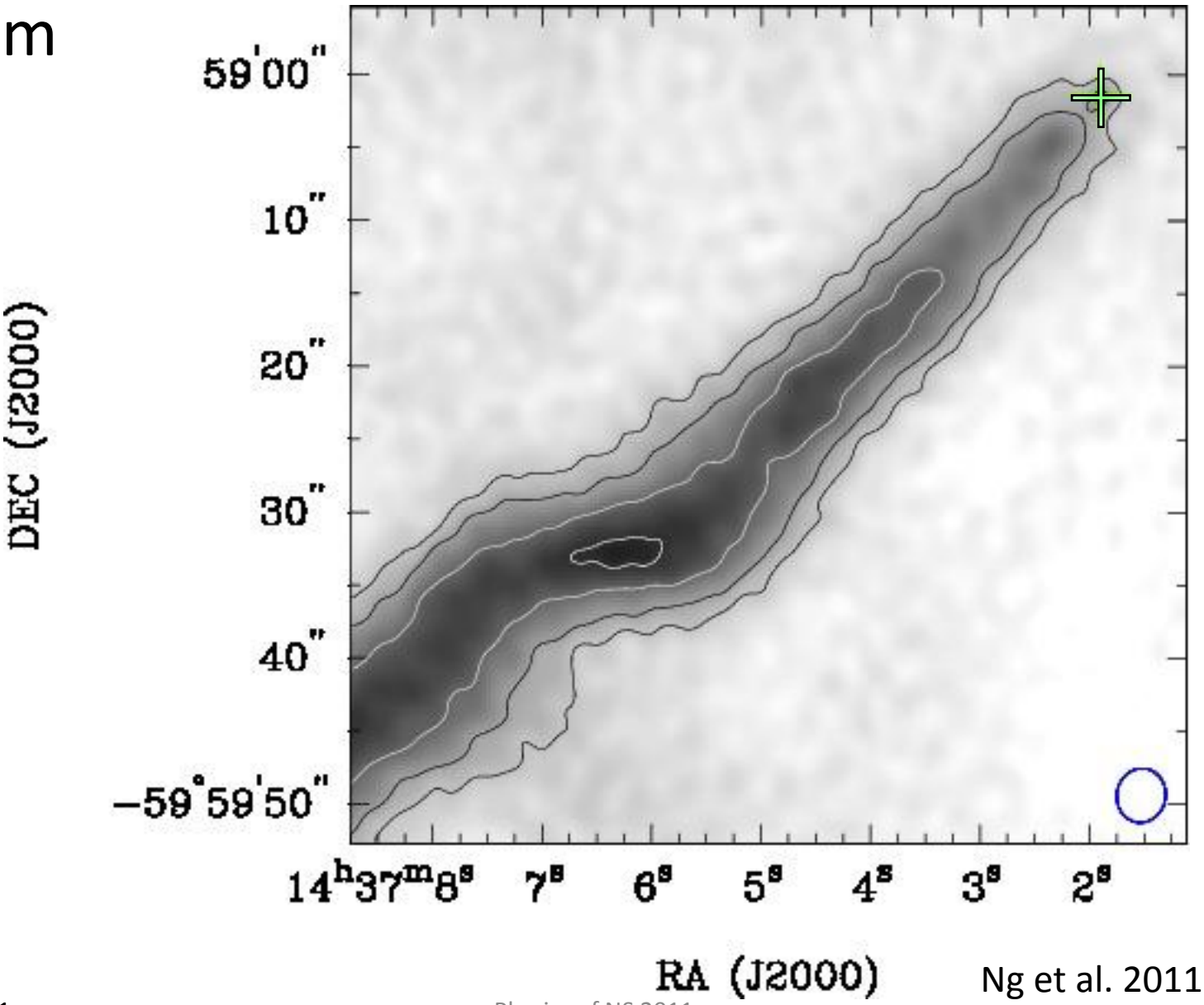
G315.9–0.0


13cm
6cm
DEC (J2000)
RA (J2000)
−60°00′
03′
06′
09′
12′
15′
−60°18′
14h39m0s
30s
38m0s
30s
37m0s
58′
−60°00′
02′
04′
06′
−60°08′
14h38m15s
38m0s
45s
30s
15s
37m0s

G315.9–0.0

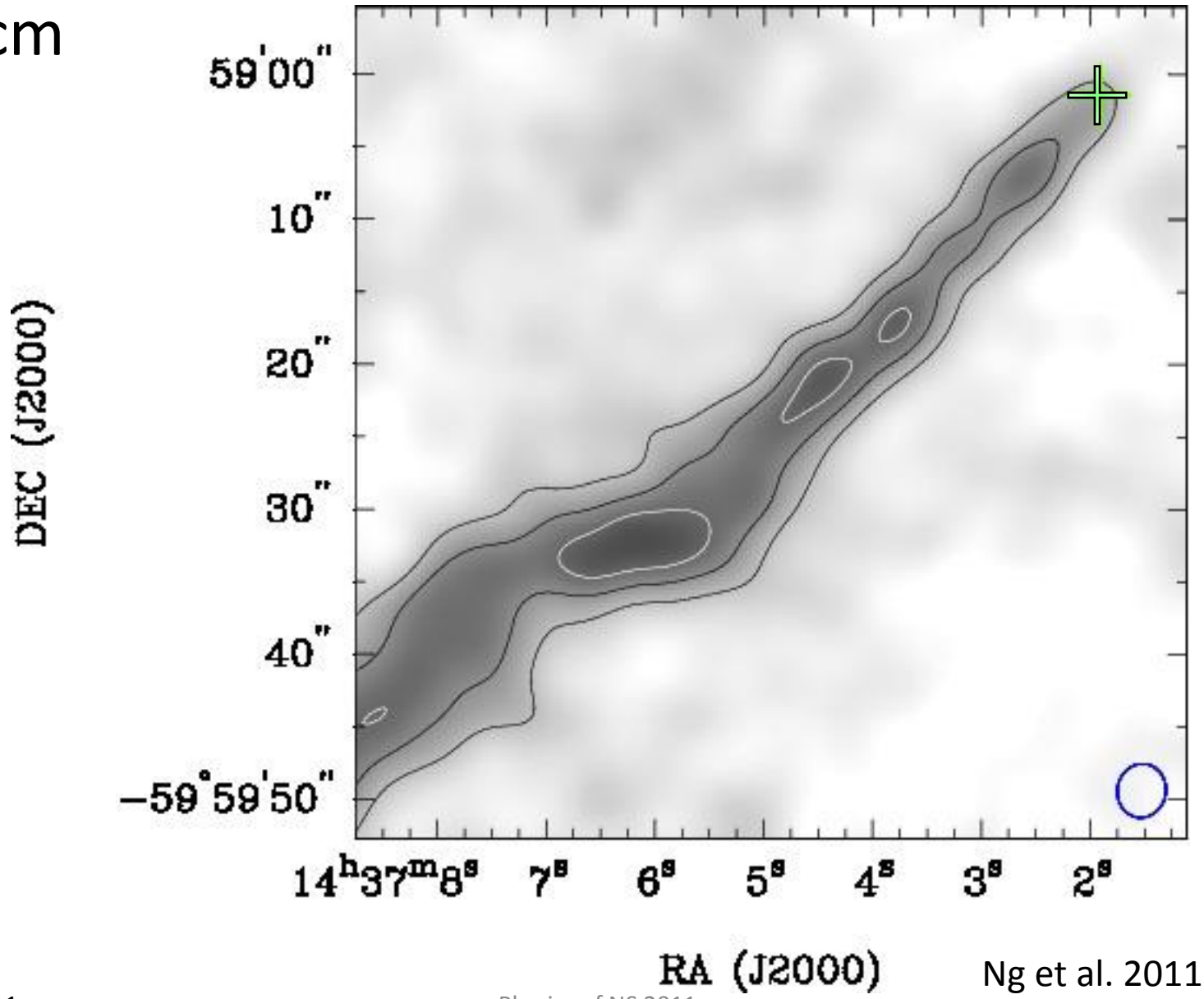

13cm
6cm
3cm
DEC (J2000)
RA (J2000)
−60°00′
03′
06′
09′
12′
15′
−60°18′
14h39m0s
30s
38m0s
30s
37m0s
58′
−60°00′
02′
04′
06′
−60°08′
14h38m15s
38m0s
45s
30s
15s
37m0s
58′
59′
−60°00′
01′
02′
03′
−60°04′
14h37m40s
30s
20s
10s
37m0s

6cm



Ng et al. 2011 in prep.

3cm



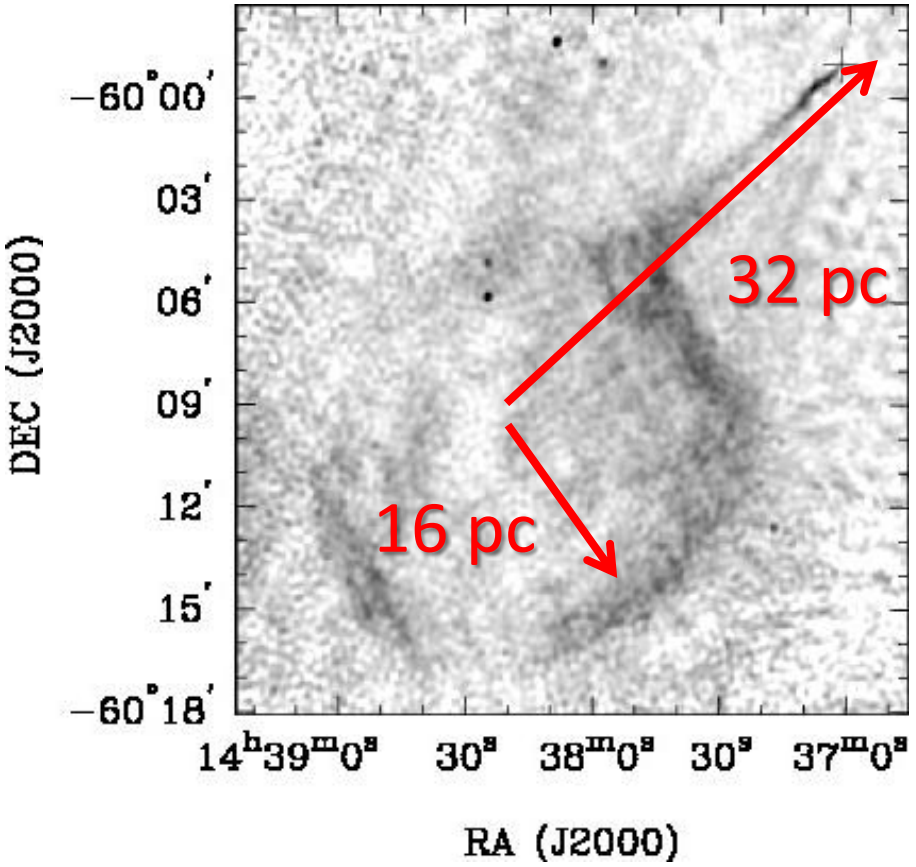
Ng et al. 2011 in prep.

PWN Environment

- Assume *d*=8kpc

$$l = v_* t = 32\mathrm{pc}$$

$$R = 16\mathrm{pc}$$



PWN Environment

- Supernova remnant in Sedov phase

$$R = 1.15\left(\frac{E_0 t^2}{\rho}\right)^{1/5} = 1.15\left(\frac{E_0 l^2}{\rho v_*^2}\right)^{1/5}$$

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- Pressure balance in the bow-shock

$$\frac{\dot{E}}{4\pi r^2 c} = \rho v_*^{\ 2}$$

PWN Environment

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- Pressure balance in the bow-shock

$$\frac{\dot{E}}{4\pi r^2 c} = \rho v_*^2$$

Small Stand-off Distance

- $$r = \left(\frac{\dot{E}}{4\pi c E_0 l^2} \right)^{1/2} \left(\frac{R}{1.15} \right)^{5/2} = 0.002\mathrm{pc}$$
- Independent of $v_*,\ \rho,\ t$!
- Smallest *r* observed, *cf.* the Mouse (*r*=0.02pc), J1509 (*r*=0.01pc), J1740 (*r*=0.005pc)
  (Gaensler et al. 2004; Kargaltsev et al. 2008)

High Pulsar Velocity

- $v_* = 1700 n_0^{-1/2} \mathrm{km/s}$
- $t = 19 n_0^{1/2} \mathrm{kyr}$

- $\gamma P_{\mathrm{ISM}} \mathcal{M}^2 = \rho v_*^2$
- $\mathcal{M}$ = 200 for $P_{\mathrm{ISM}}=10^{-12}$dyn cm^{-2}

B-field

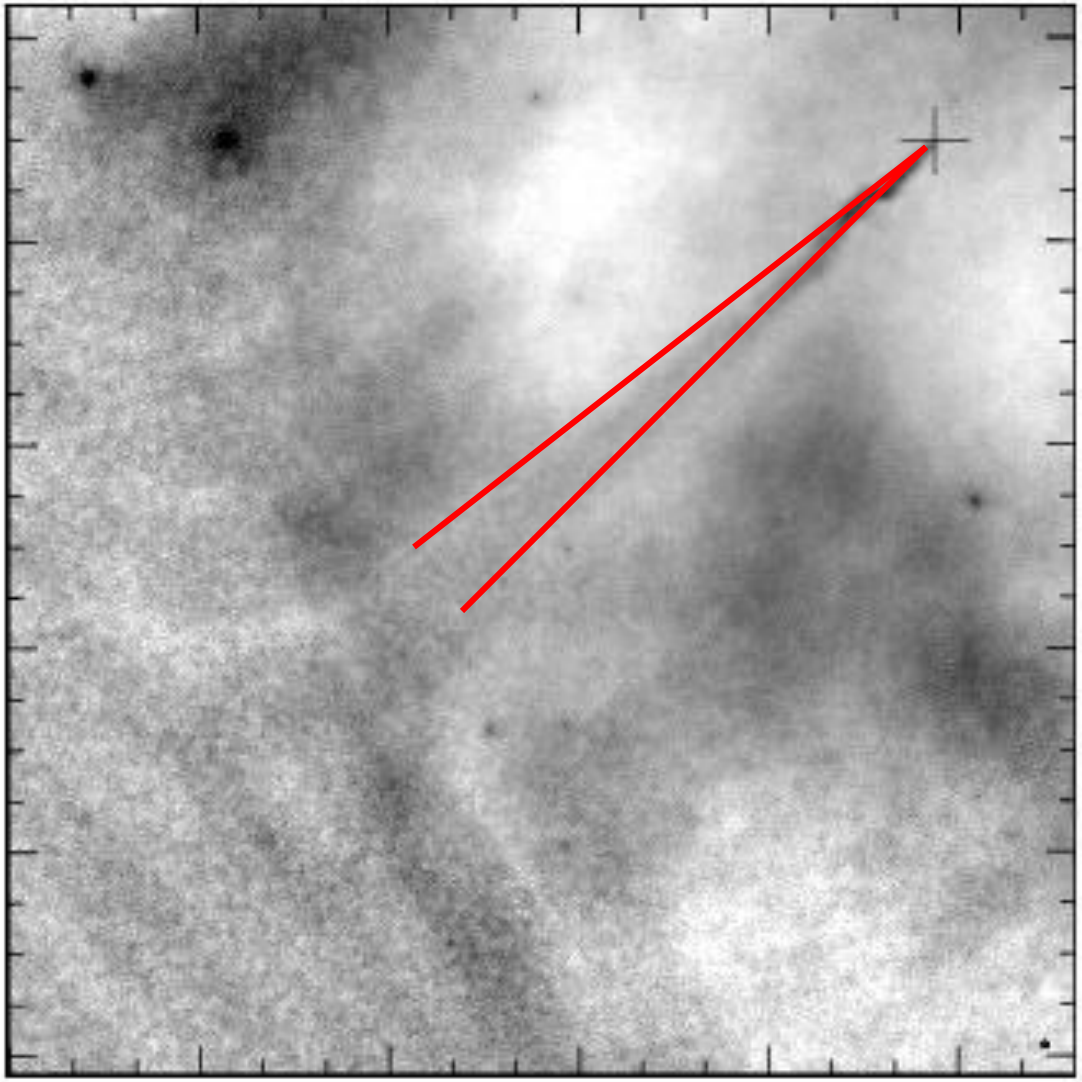
- Define $k_m = \dfrac{\text{magnetic energy density}}{\text{particle energy density}}$ (Pavlov et al. 2003)

$$B = 60 k_m^{2/7}\,\mu\text{G} = 30\,\mu\text{G} \qquad \text{for } k_m\text{=0.1}$$

- Energy conservation

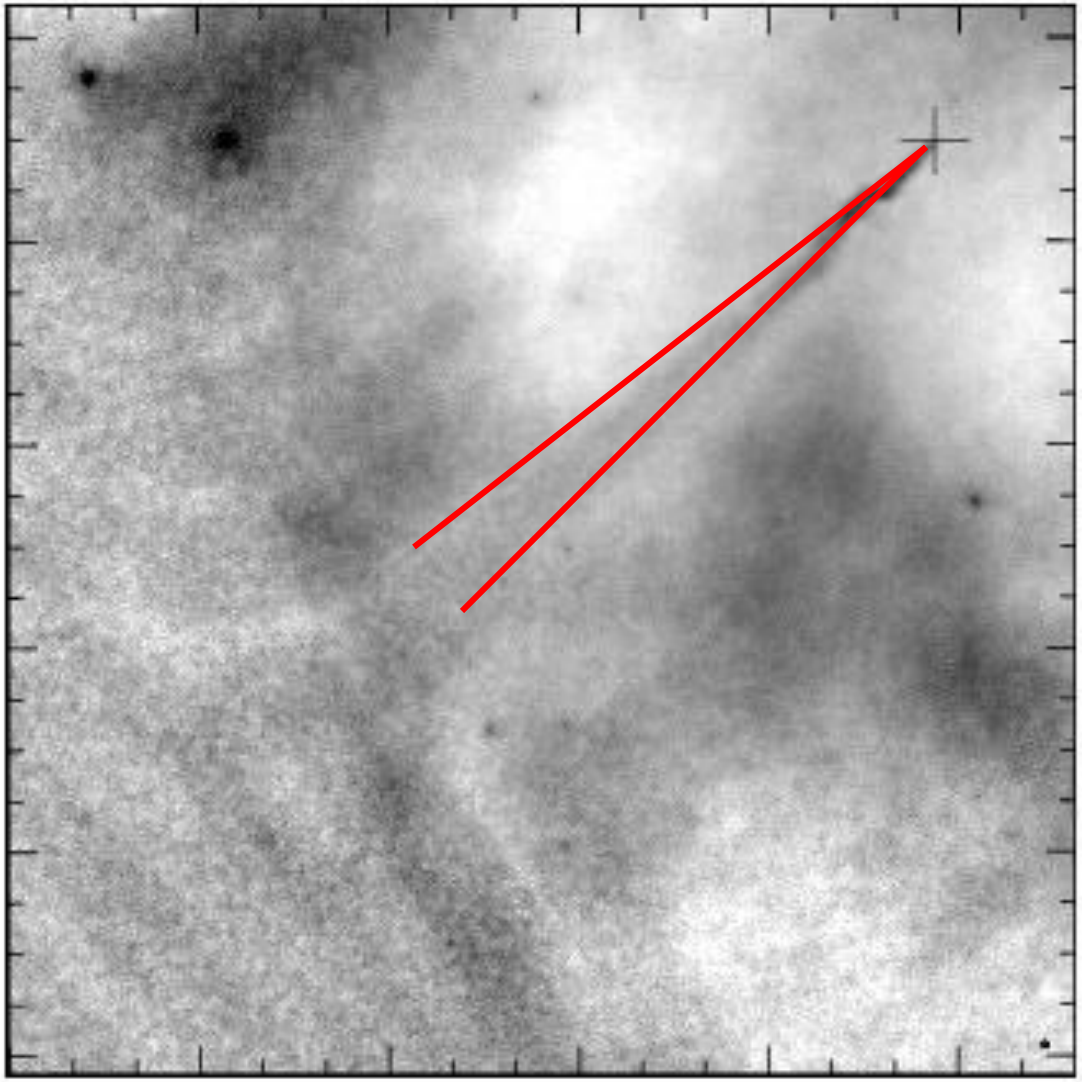
$$v_{flow} = 8.6\times10^4\,\frac{k_m^{3/7}}{1+k_m}\,\text{km/s} = 0.1c \quad \text{for } k_m\text{=0.1}$$

Mach Cone



$\mathcal{M}$ = 200
but observed
opening angle ~ 1/15

Mach Cone



$\mathcal{M}$ = 200
but observed
opening angle ~ 1/15

Highly overpressed!

$$\frac{P_{\text{tail}}}{P_{\text{head}}} = \left(\frac{1}{15}\right)^2$$

Pressure

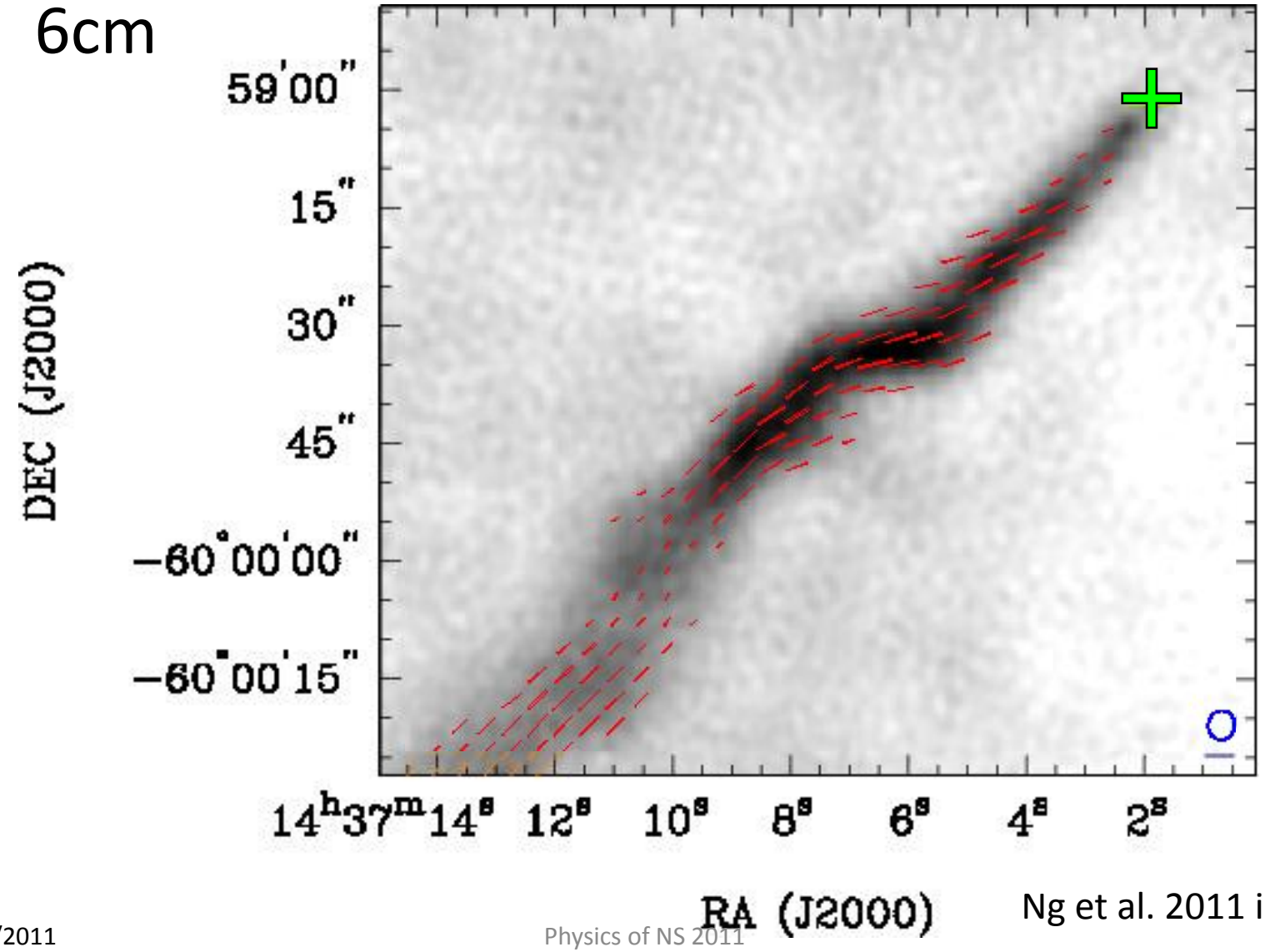
$$P_{\rm tail} = \frac{B^2}{8\pi} + \frac{U_p}{3} = 1.7\times10^{-10}\,{\rm dyn\,cm^{-2}}$$ for k_m=0.1

$$>> P_{\rm ISM}$$ highly overpressed

$$\frac{P_{\rm tail}}{P_{\rm head}} = \frac{P_{\rm tail}}{\rho v_*^2} \approx \left(\frac{1}{20}\right)^2 \quad cf. \quad \left(\frac{1}{15}\right)^2$$

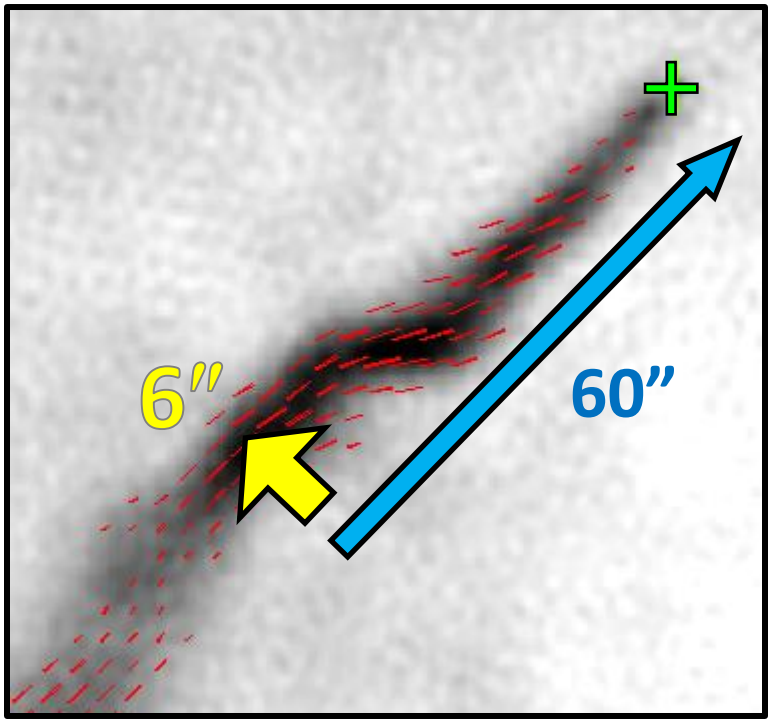
Small magnetization in the postshock wind (k_m=0.01–0.1)

B-field Geometry



Ng et al. 2011 in prep.

The Kink

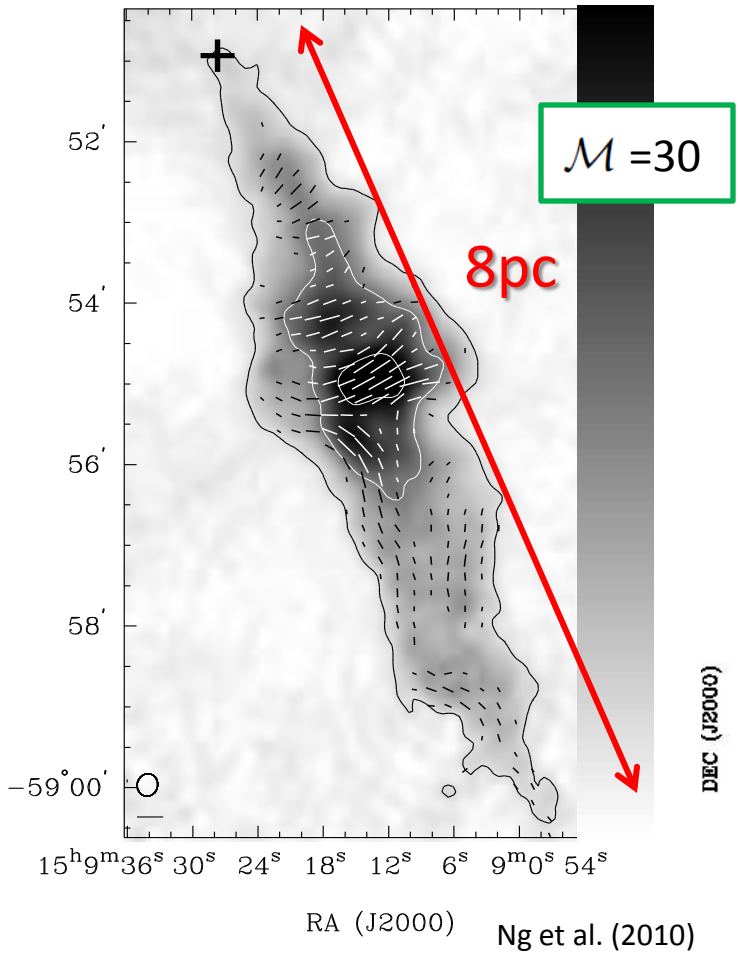


- Flow instability ✗
- ISM pressure gradient ✗
- ISM turbulence ✓

$v_{ISM} = 0.1 v_*$
supersonic turbulence

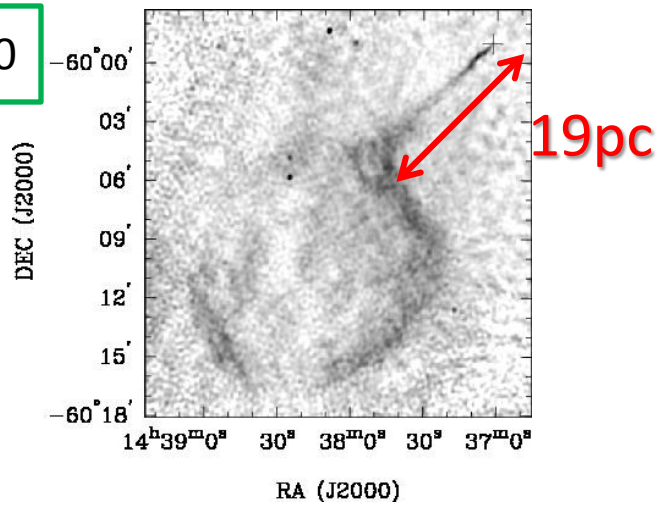
Compare with other Long Tails

PSR J1509-5850

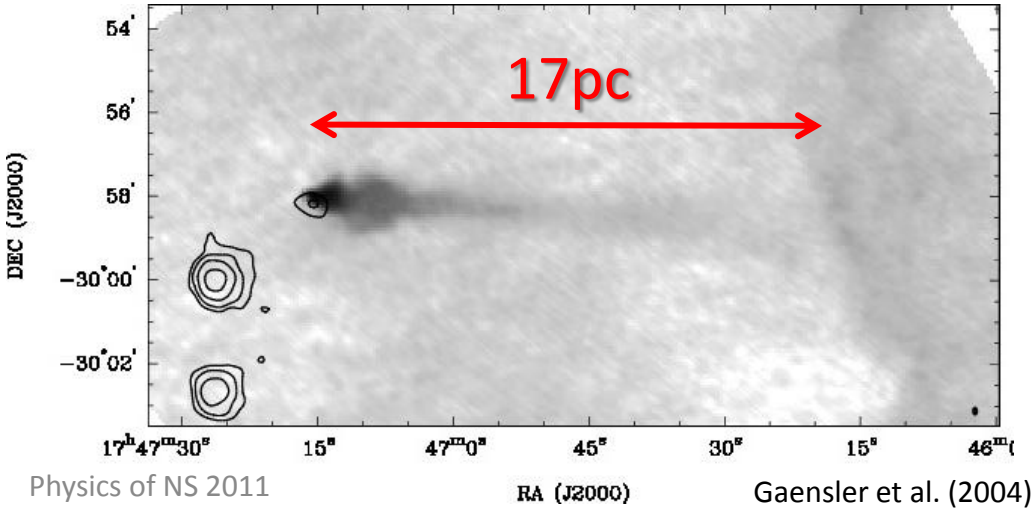


Ng et al. (2010)

Frying Pan



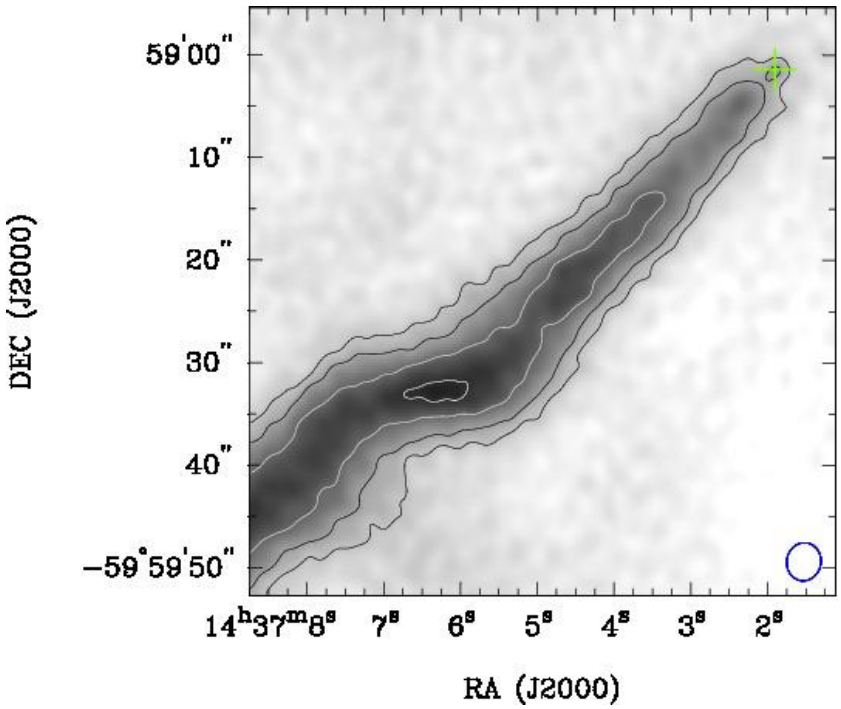
PSR J1747-2958 / Mouse



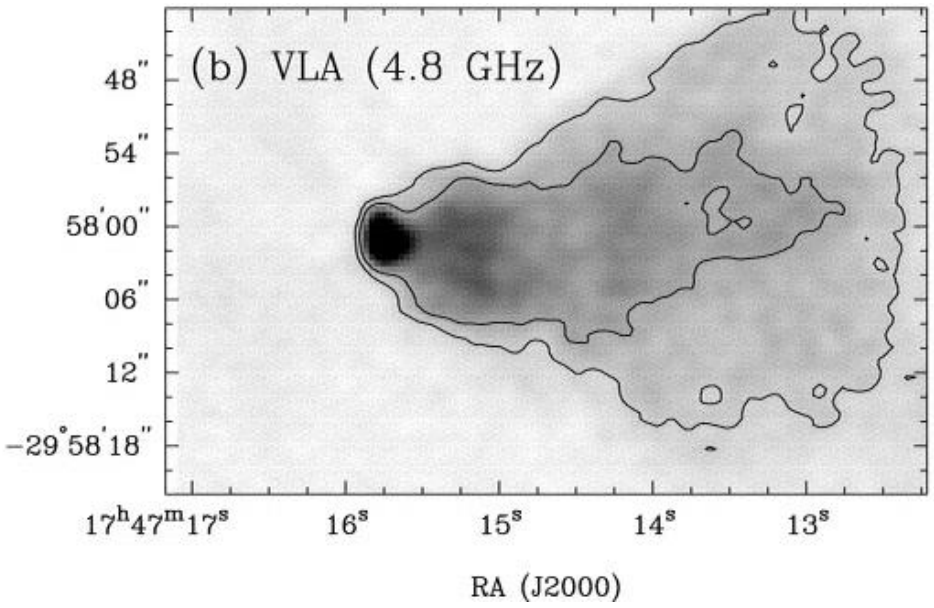
Gaensler et al. (2004)

Compare with other Long Tails

Frying Pan



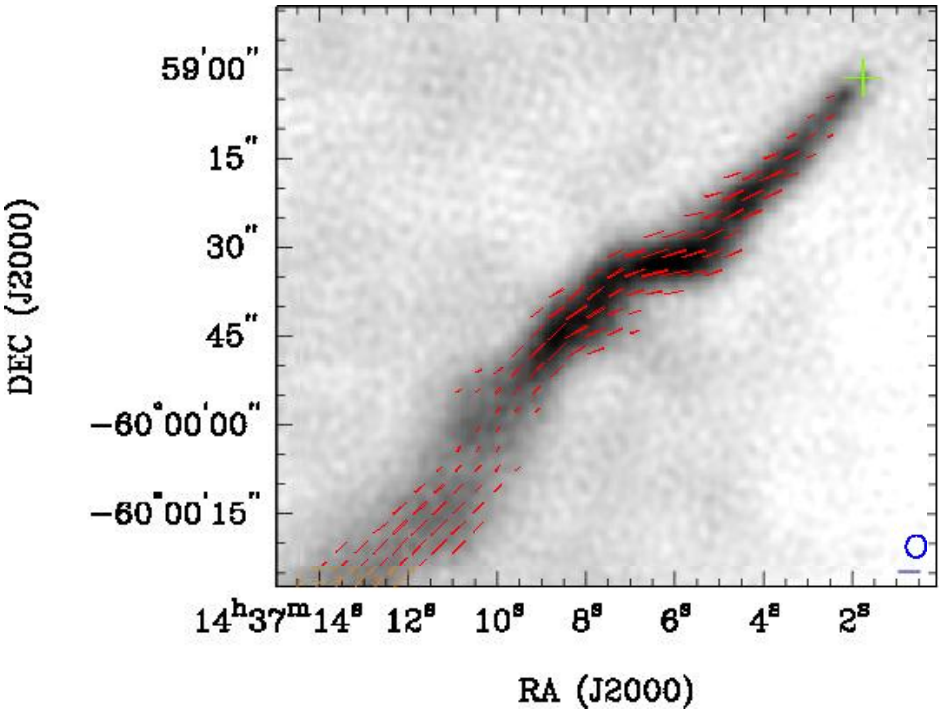
PSR J1747-2958 / Mouse



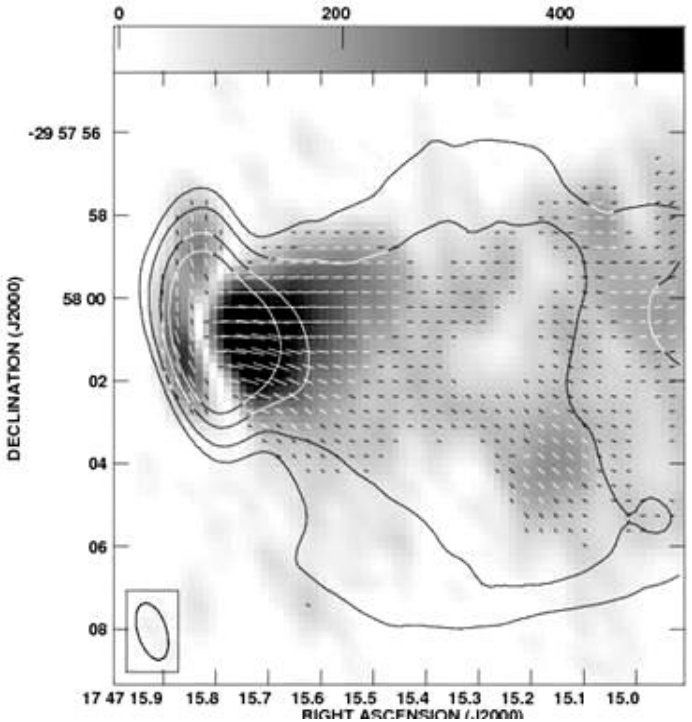
Gaensler et al. (2004)

Compare with other Long Tails

Frying Pan



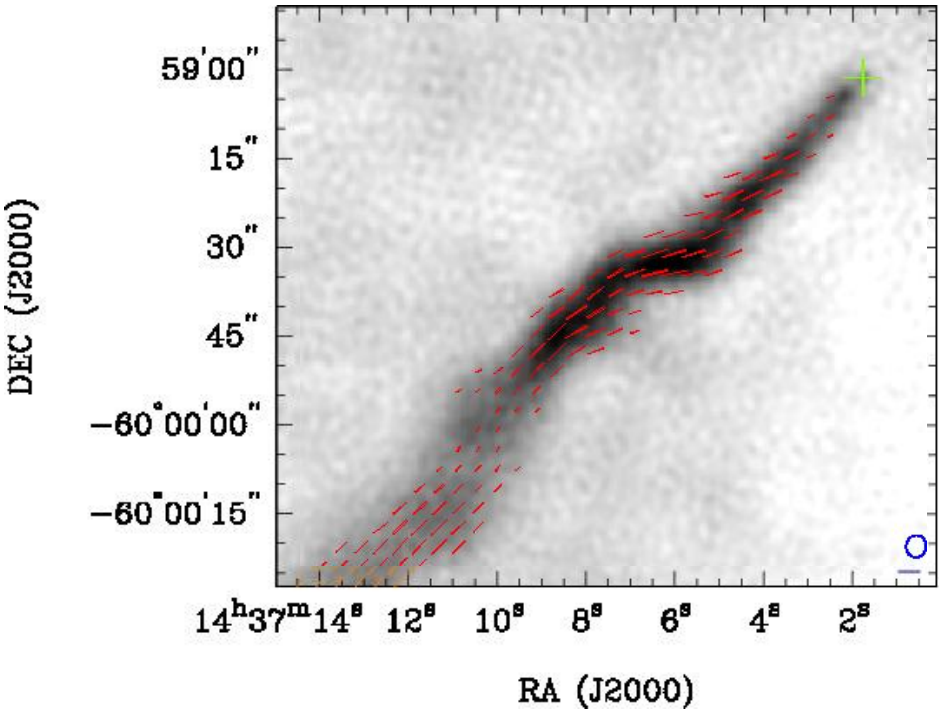
PSR J1747-2958 / “The Mouse “



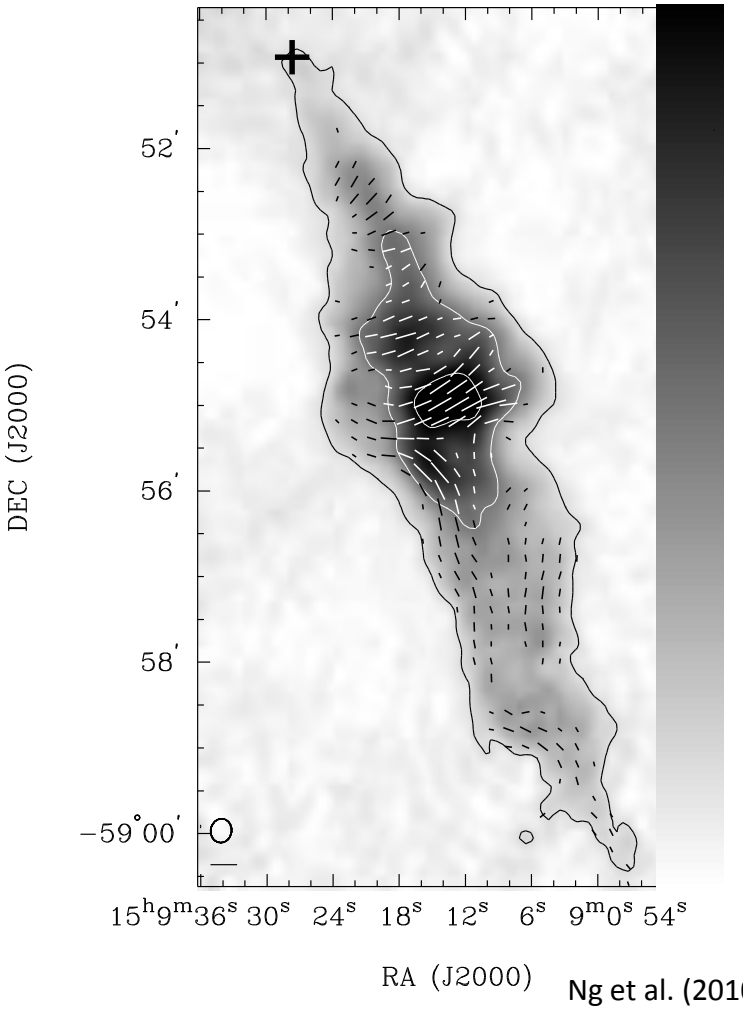
Yusef-Zadeh & Gaensler (2005)

Compare with other Long Tails

Frying Pan



PSR J1509-5850



Ng et al. (2010)

Summary

- G315.9–0.0 is a rare case: both the shell and bow-shock PWN are observed
- Longest radio tail (20pc), smallest stand-off distance (0.002pc), high velocity ($\mathcal{M}$ = 200)
- Highly ordered *B*-field parallel to the tail
- Highly overpressured
- Hint of small postshock wind magnetization (k_m~0.1)
- Evidence of supersonic turbulence in the ISM