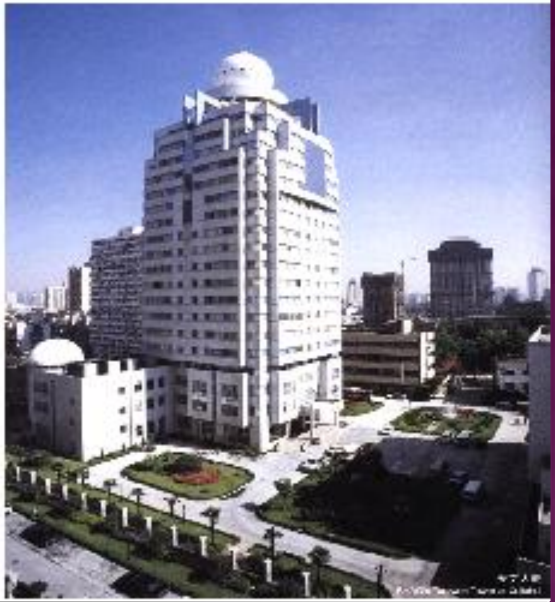


*Shanghai Astronomical Observatory,
Chinese Academy of Sciences*

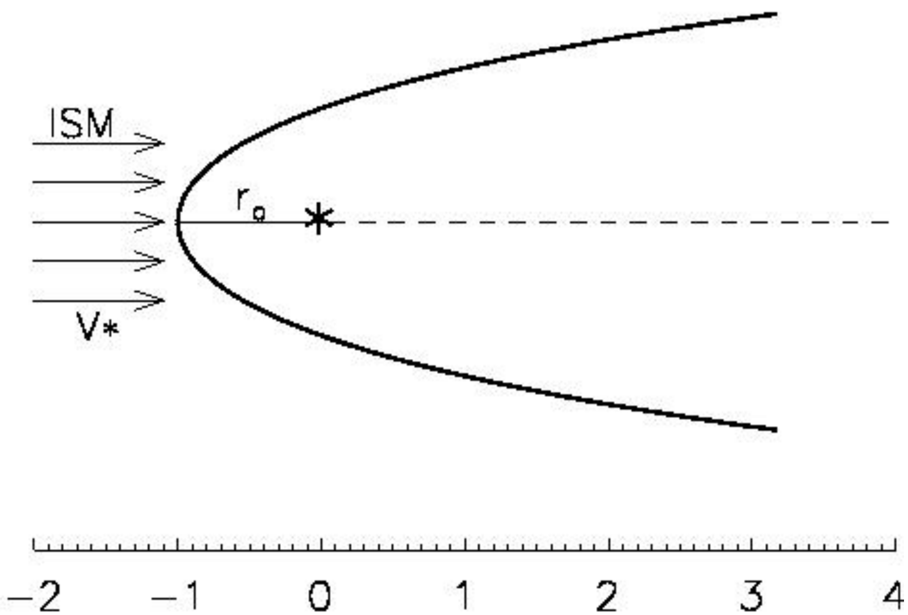
DISCOVERY OF AN INFRARED BOWSHOCK AROUND A PULSAR

Zhongxiang Wang

Spain/Madrid, 2013/5/24

Collaborators: D. L. Kaplan, P. Slane,
N. Morrell, V. M. Kaspi

FORMATION OF BOW SHOCKS

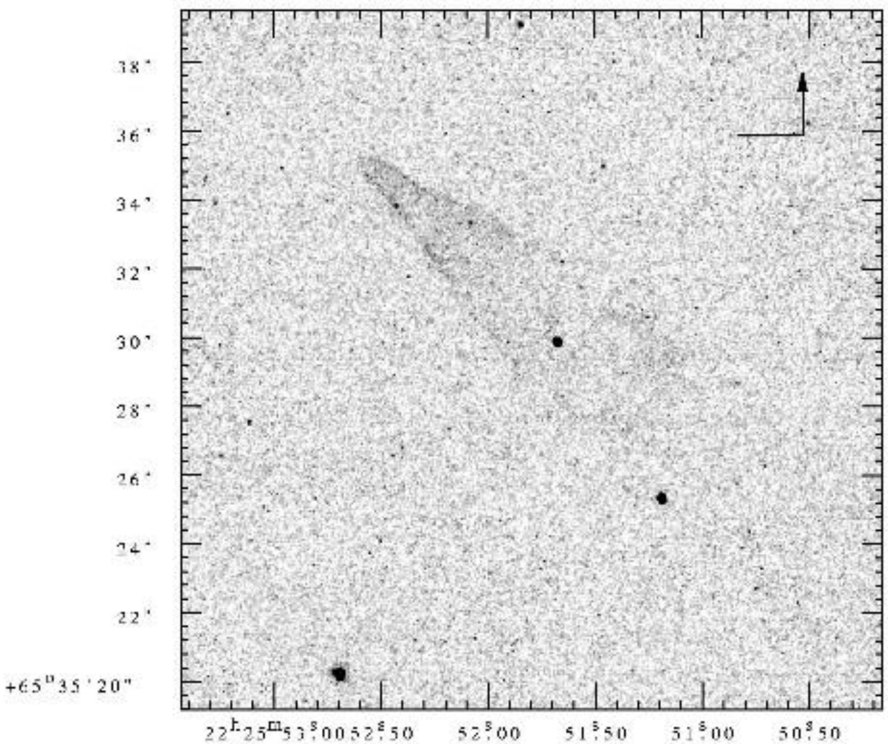


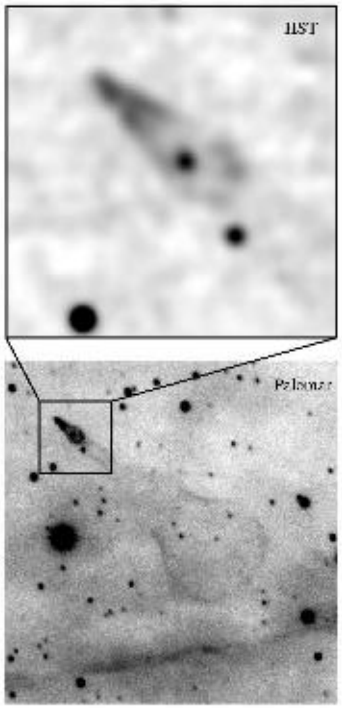
$$r\sin(\theta)=r_o[3(1-\theta/\tan(\theta)]^{(1/2)}$$

r_a: standoff distance (Wilkin 1996)

- In ISM: c_s ~ 10 (T/10^4 K)^(1/2) km/s ~ 1-100 km/s
- Requirements: an object ejects material and moves at a speed of $V^* > C_s$
- Bow shocks are seen around wind-blowing massive stars, mass-ejecting giant stars, and pulsars

PULSAR BOW SHOCKS



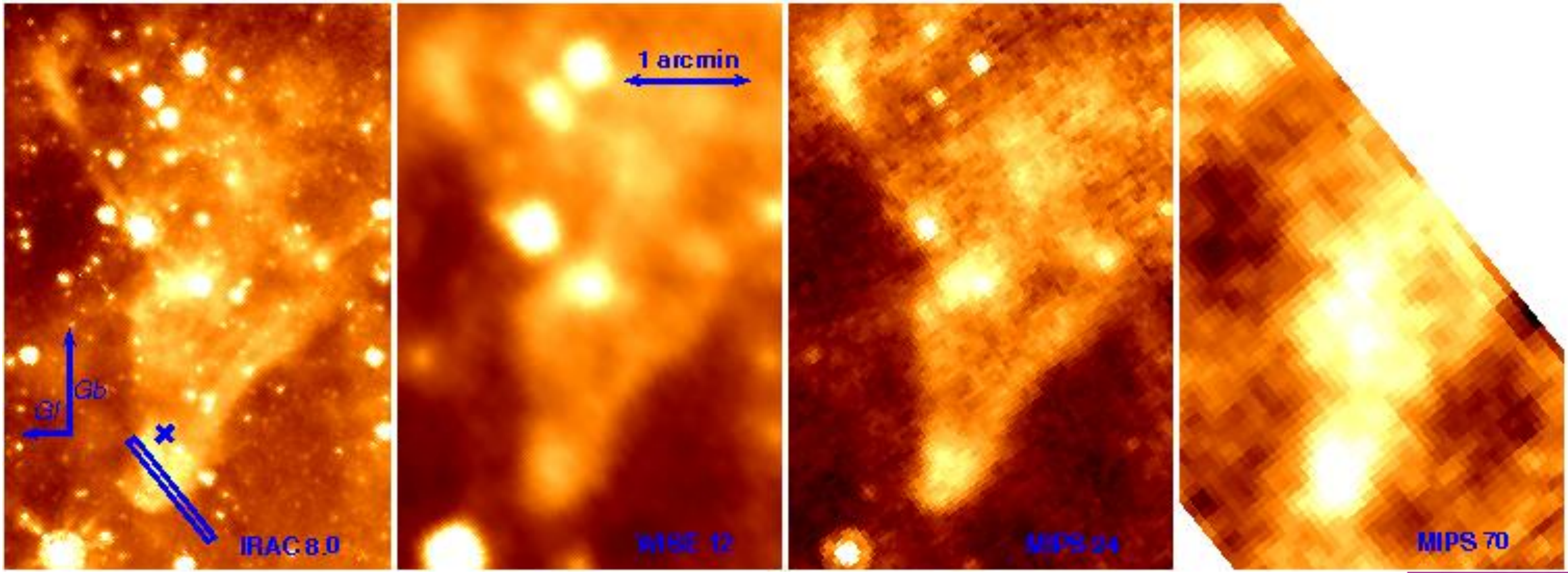


Pulsars:

- V*>100 km/s
- Have a pulsar wind
- 5 detected at Hα, a few at X-ray or radio

Guitar (Hα) nebula
(Chatterjee & Cordes 2002)

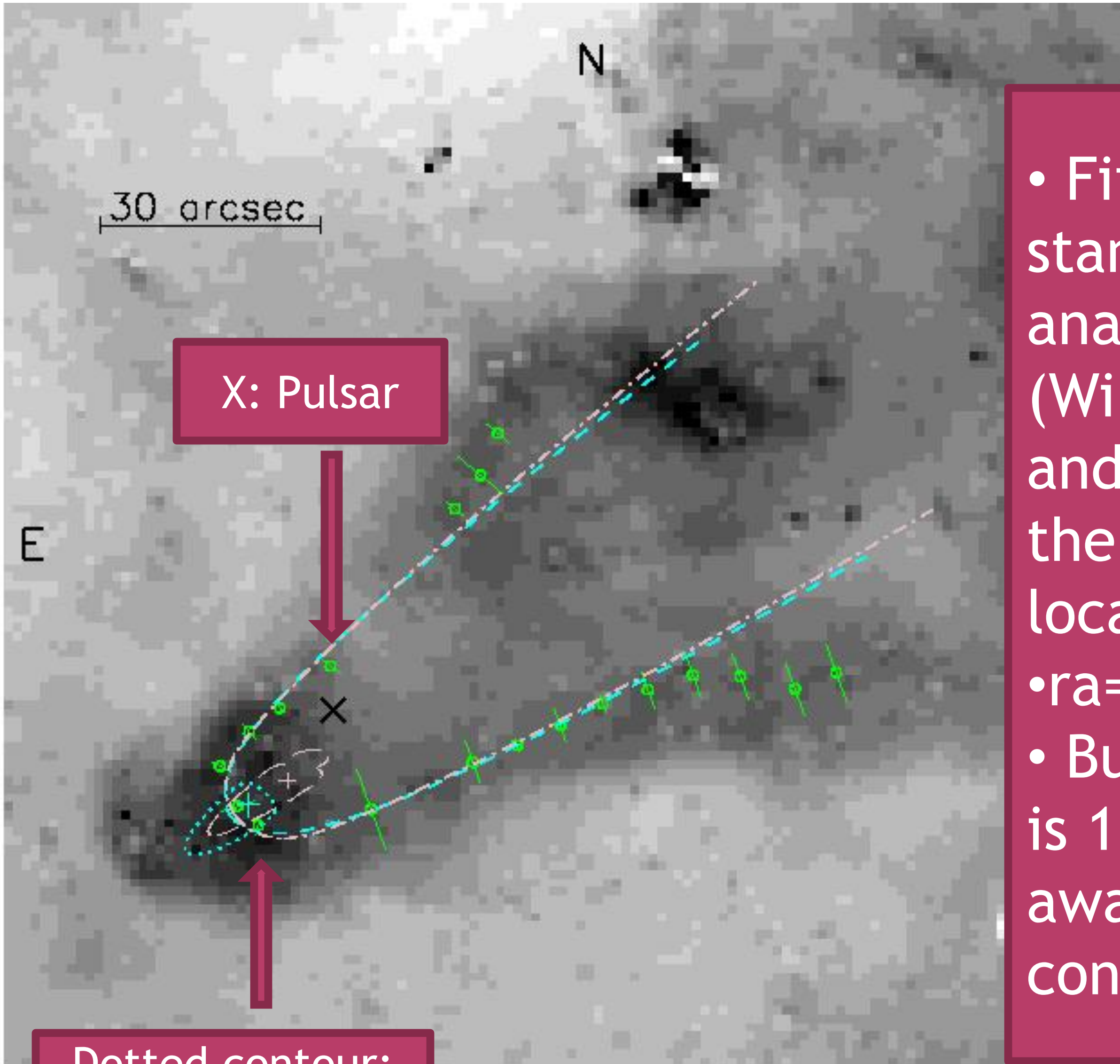
SPITZER IRAC SURVEY OF A FEW MIDDLE-AGE PULSARS



Detection of a mid-IR bow shock in the field of PSR J1549-4848.

Great, the first mid-IR bow shock driven by a pulsar!?

DETAILED ANALYSIS

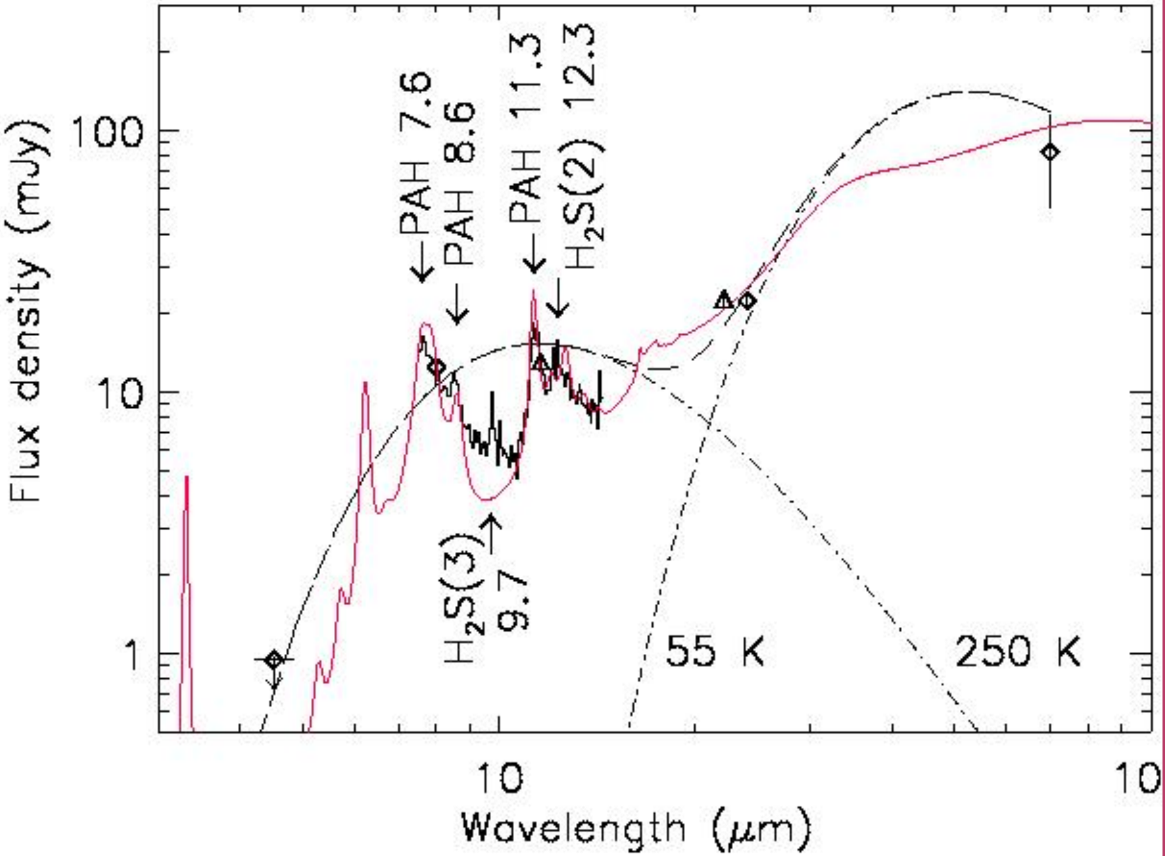


X: Pulsar

Dotted contour: host object

- Fit with the standard analytic form (Wilkin 1996) and determine the host object location
- ra=2.9 arcsec
- But the pulsar is 15 arcsec away from the contour region

INFRARED SPECTRUM



: Spitzer photometry
Δ: WISE 12 and 22 μm photometry
Solid curve: Spitzer/IRS spectrum

- Observed with Spitzer/IRS
- Detected PAH and H_2 emission features, arising due to irradiation or shock collision
- Two dust emission components: T=55 K & 250 K, masses of 10^29 and 10^25 g, luminosities of 10^32 and 6x10^31 erg/s (if distance ~ 1 kpc)

CROSSCHECK :ASSOCIATED WITH A STAR ?

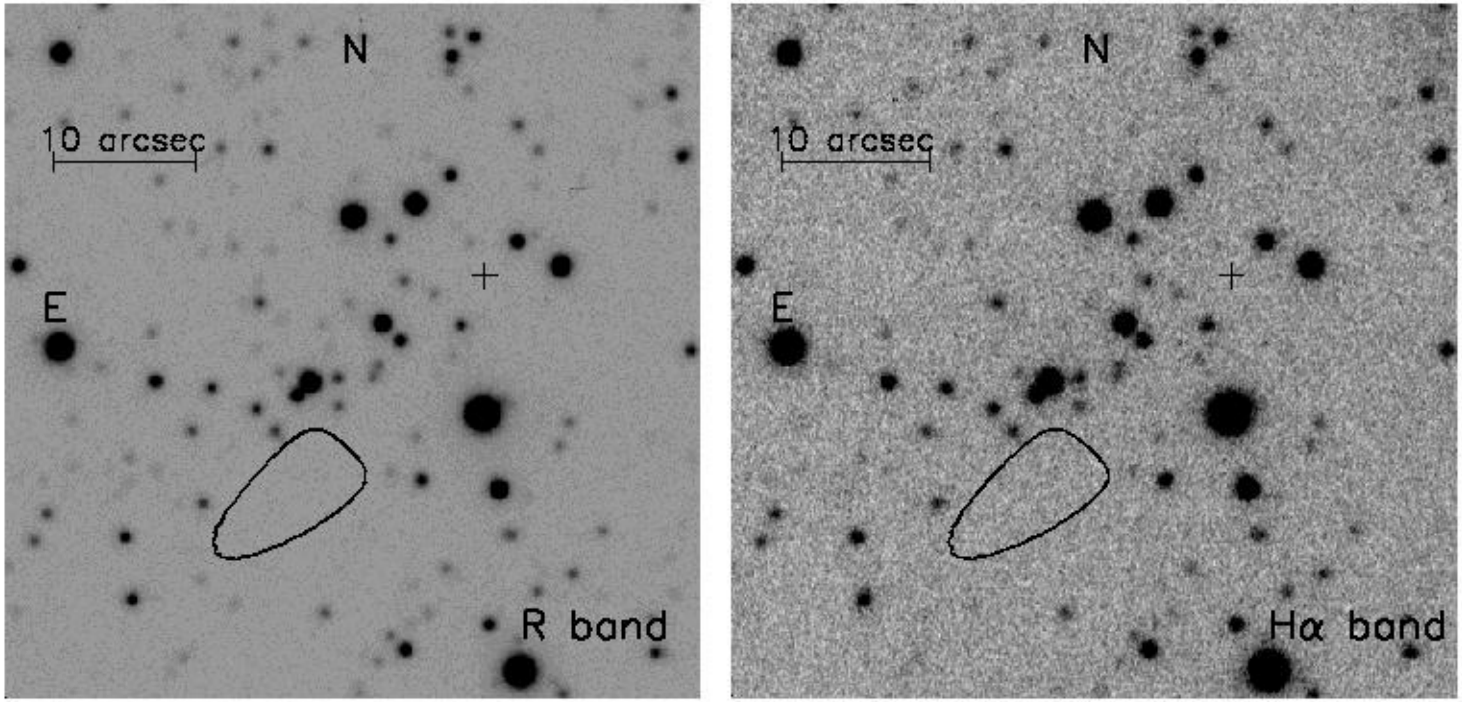
$$r_a = (\dot{m}_w V_w / 4\pi\rho V_*^2)^{1/2}$$

⇒ n_H~1 cm^-3

- $\dot{m}_w$ ~10^-8—10^-5 *Msun/yr* , mass lose rate
- V_*=*30 km/s*, star velocity
- V_w=*10^3 km/s*, for an O/B star's wind velocity, or

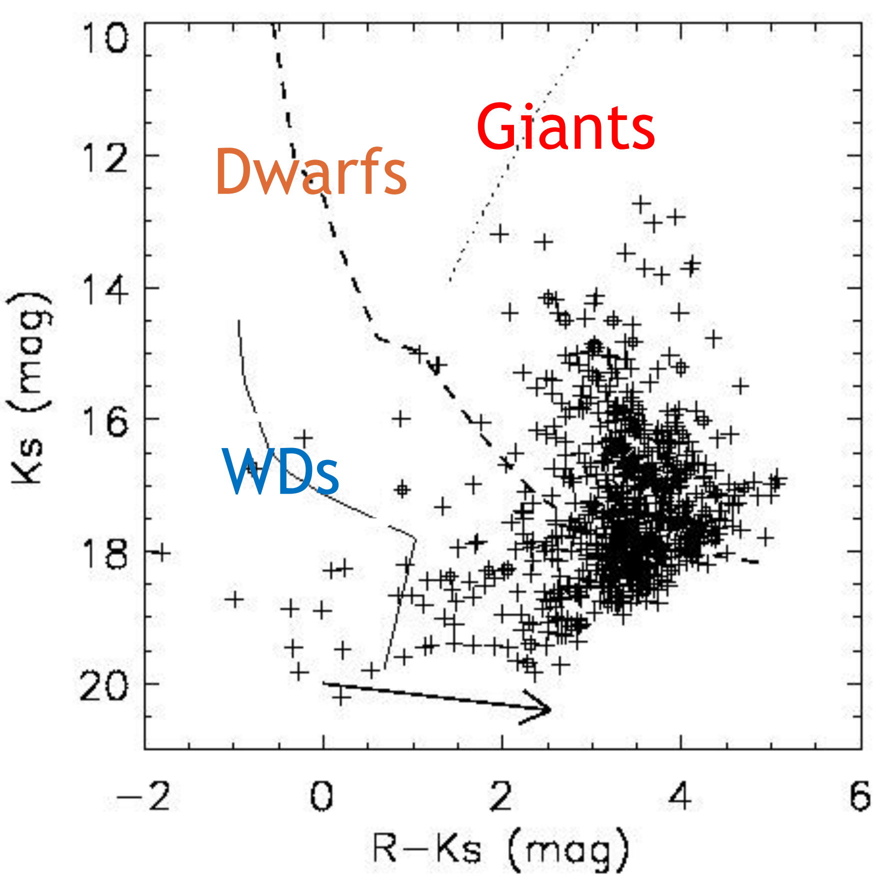
  V_w=10 km/s, for a giant star with mass ejection
- ra=2.9 arcsec at distance d=1 kpc (because Gb=4.3 deg, and H_2 gas stays <0.1 kpc from the Galactic plane)

HOWEVER: OPTICAL IMAGING



- No detection of any sources in the 3σ contour region down to R=23 mag

NO CANDIDATE STAR HOST FOUND

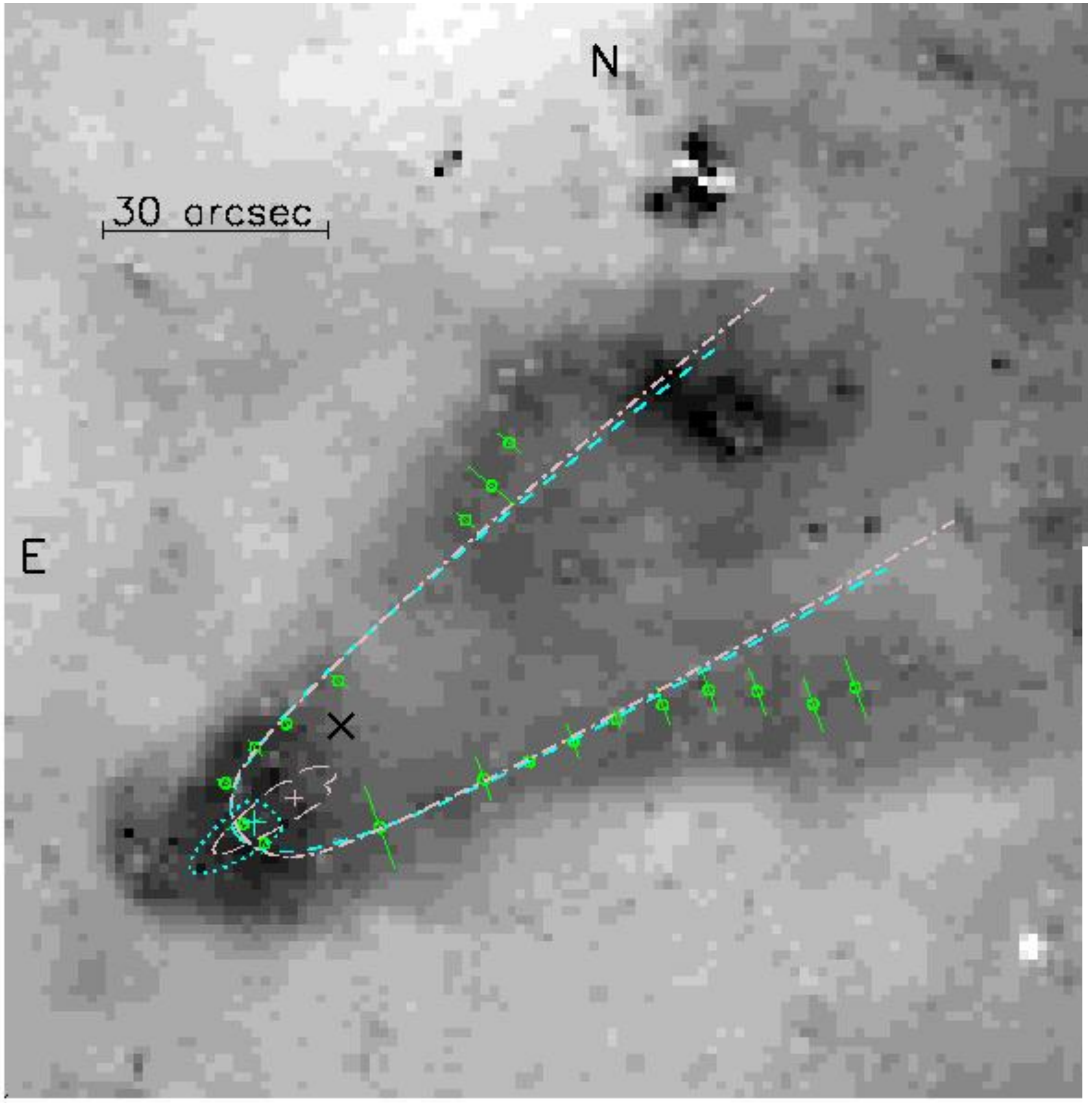


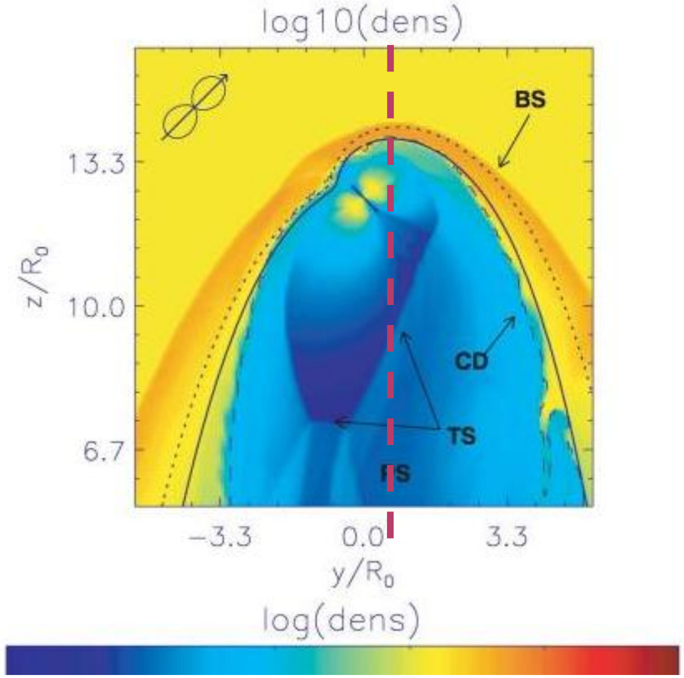
- White dwarfs: 0.1 kpc
- Main-sequence: 2.5 kpc
- Giant stars: 10 kpc
- Impossible to have any massive stars or giant stars at a reasonable distance range in the field
- Note Gb=4.3 deg

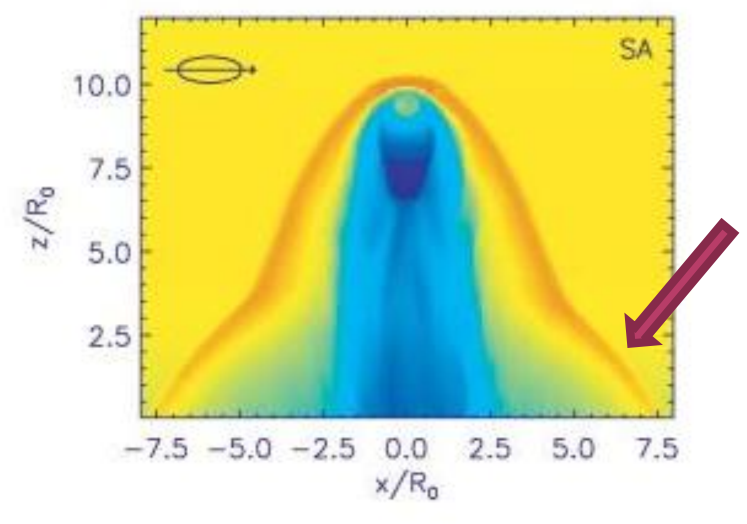
CROSSCHECK (FOR THE PULSAR J1549-4848)

- PSR J1549-4848 has Spin-down rate Edot=2.3e+34 erg/s, distance=1.5 kpc
- 1.6% of Edot is required, reasonable if the pulsar wind/emission illuminates the bow shock dust
- Kinematic energy of the pulsar could also contribute to dust heating, e.g., if Vp=200 km/s, E_K = 6E+33 erg/s
- But, the pulsar is at least 15 arcsec (or 0.11 pc for distance 1.5 kpc) away from the apex of the bow shock

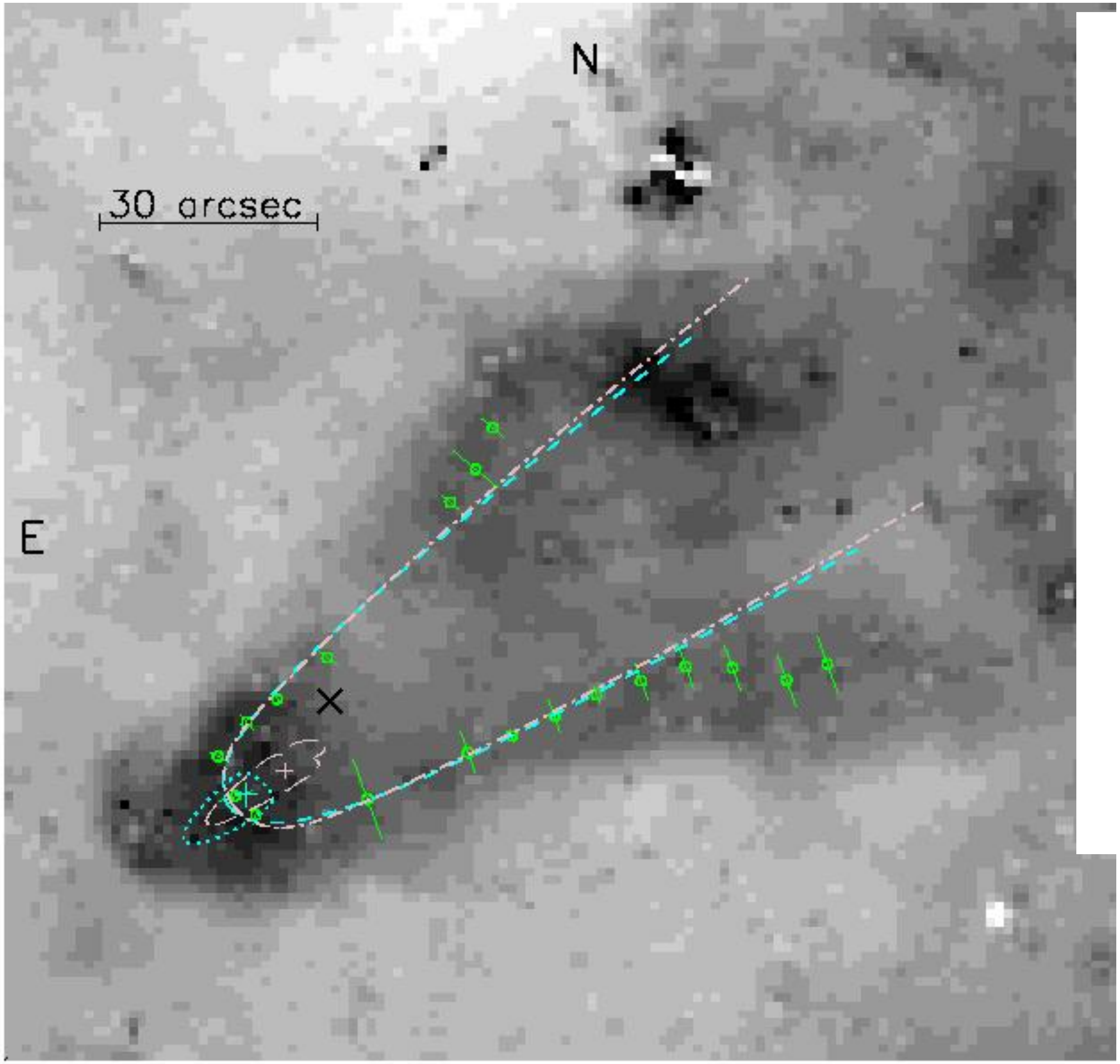
SIMULATIONS OF PULSAR WIND BOW SHOCKS (VIGELIUS ET AL. 2007)

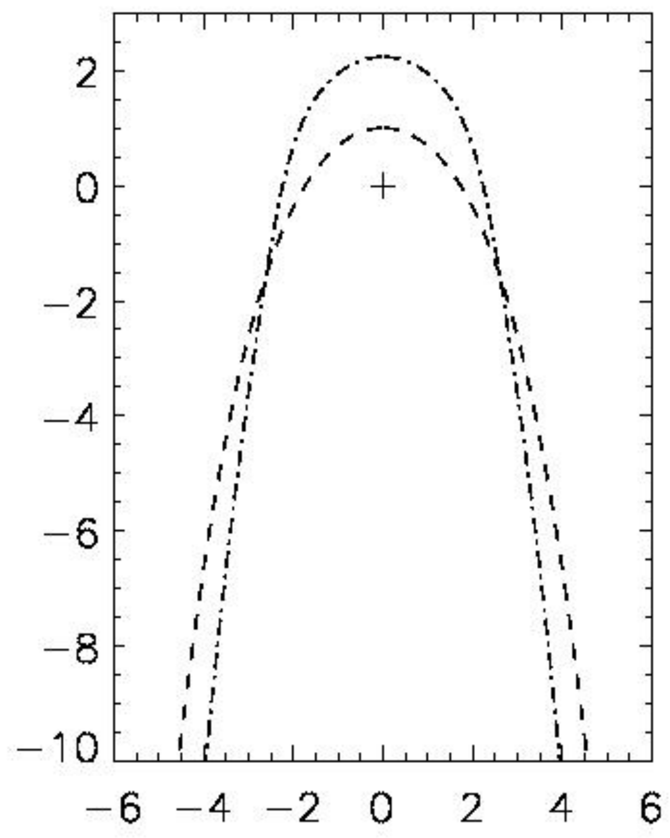






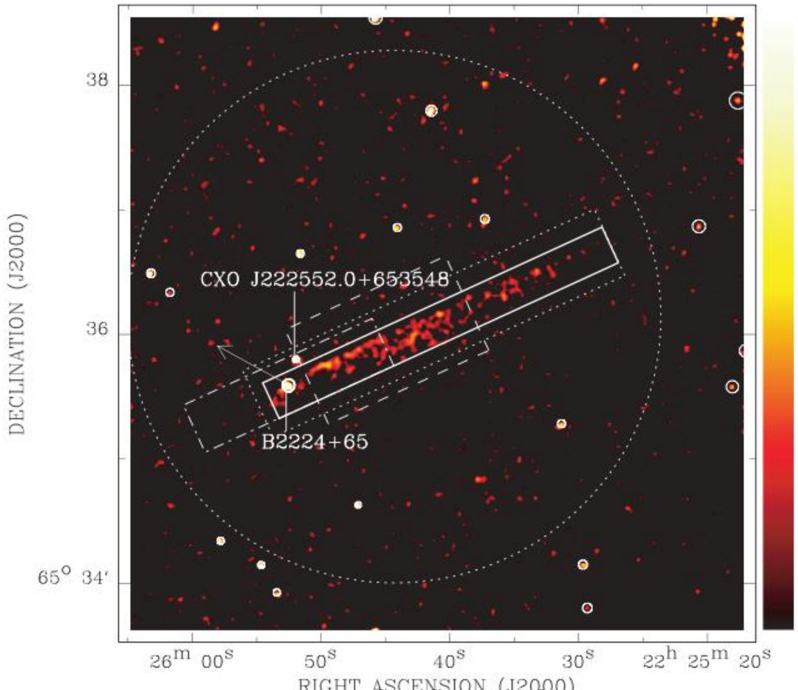
SIMULATIONS OF PULSAR WIND BOW SHOCKS (VIGELIUS ET AL. 2007)



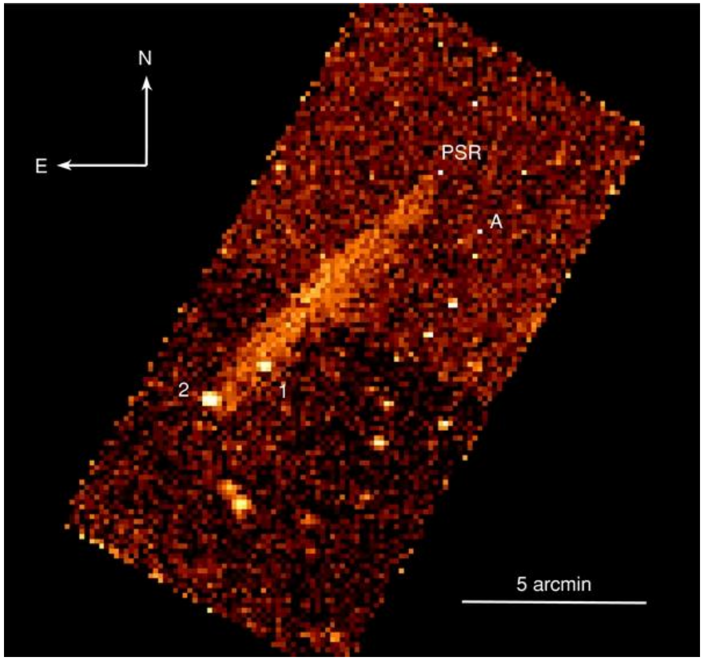


Dash-dotted curve: jet-like outflow case

JETS FROM PULSARS



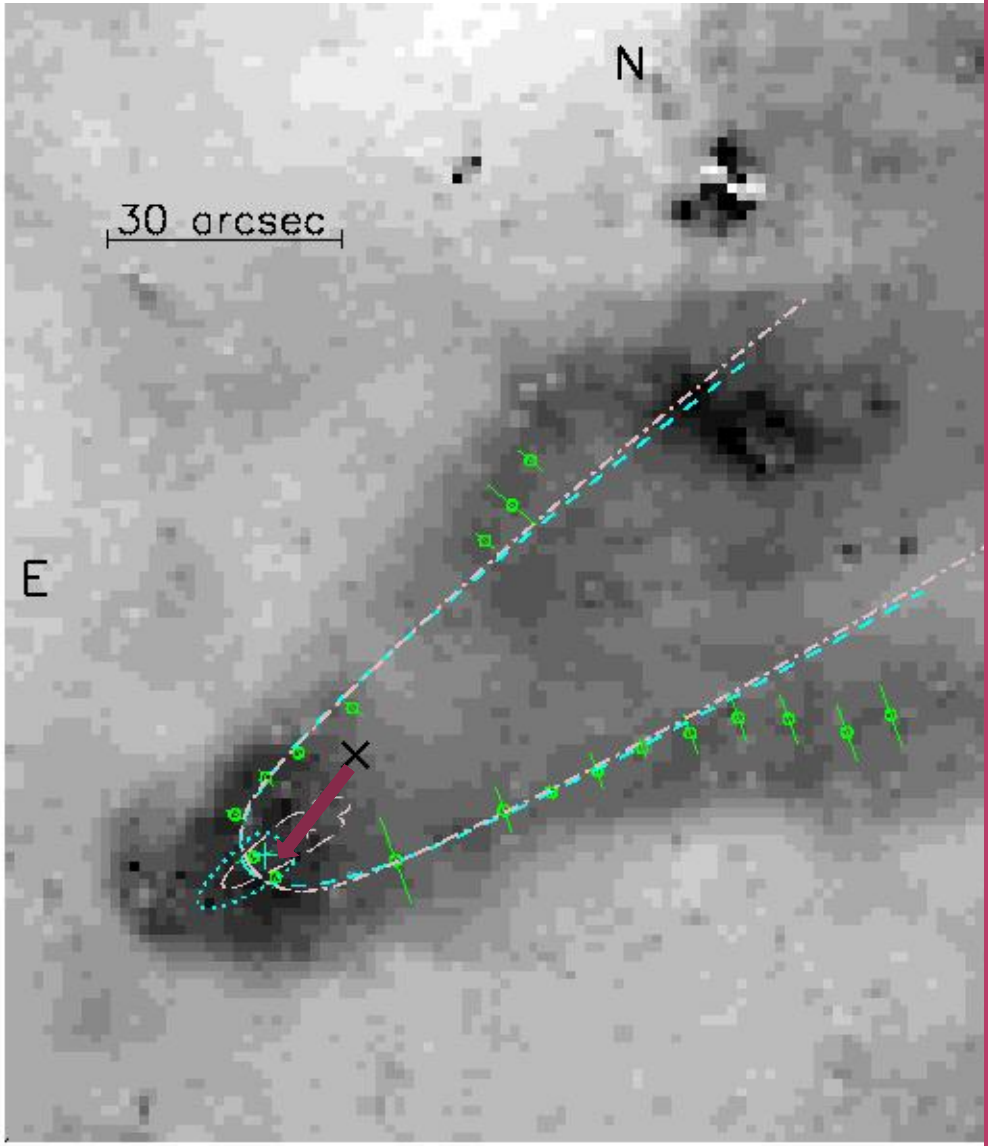
Guitar nebula pulsar (Johnson & Wang 2010)



PSR J0357+3205 (De Luca et al. 2011)

- Pulsars are known to have jet-like outflows
- The guitar nebula pulsar has a X-ray jet, not fully understood
- A few line structures are seen associated with X-ray points sources in the Galactic center (pulsar jets?)
- PSR J0357+3205 recently was found with a long X-ray tail

A POSSIBLE SCENARIO?



- The pulsar J1549-4848 might also have a jet-like outflow
- The outflow –ISM interaction drives the bow shock, which reflects the pulsar's motion?
- Radio VLBI imaging to detect proper motion of the pulsar is underway
- We have also proposed Chandra X-ray imaging to detect an X-ray nebula

For details, see Wang et al. 2013, ApJ, 769, 122

THANKS FOR YOUR ATTENTION !