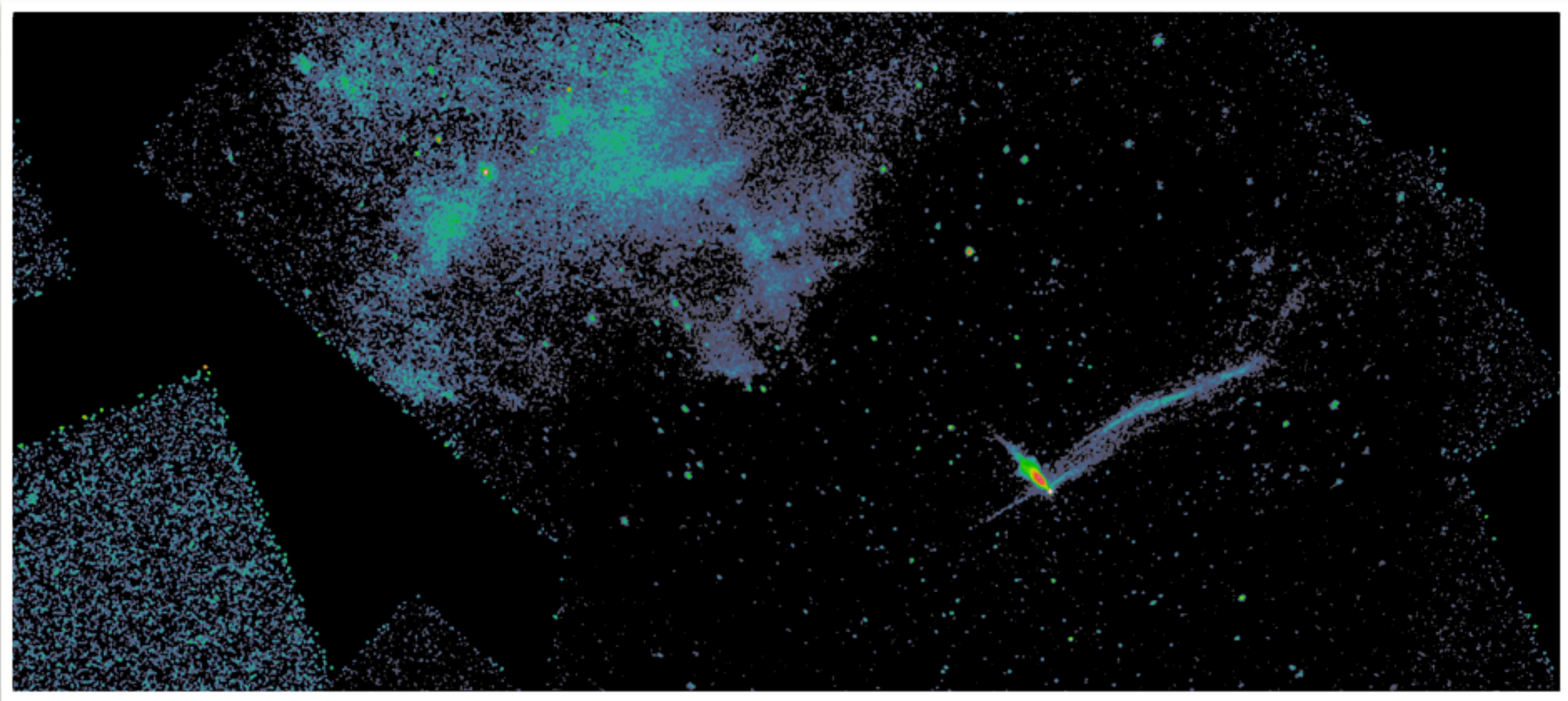

A new view on the Lighthouse Nebula, IGR J11014-6103

Lucia Pavan (ISDC Université de Genève)
Gerd Pühlhofer (IAAT Tübingen)
Pol Bordas (MPI-HD Heidelberg)

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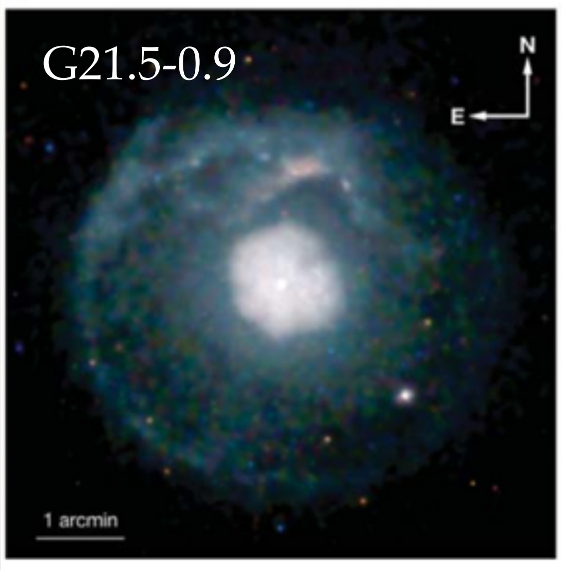
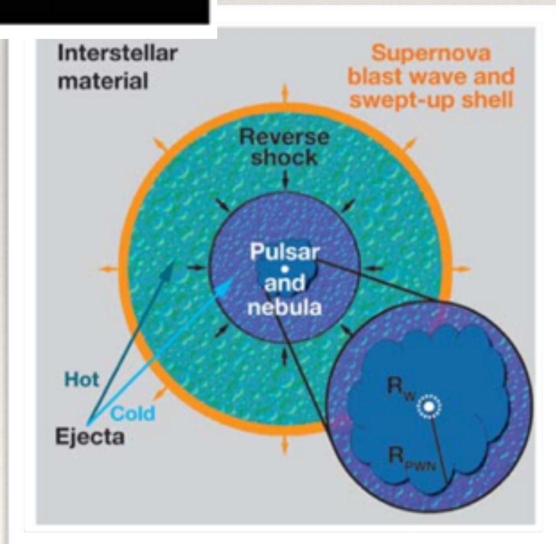
UNIVERSITÉ DE GENÈVE

PWNe (plerion)

Gaensler & Slane 2006 ARA&A 44 17

Matheson & Safi-Harb 2005 ASpR 35, 6





- **rotational energy loss** from the PSR
- relativistic magnetized wind (**e- e+ p+ …?**)
- sync + i.Compt+ opt Balmer lines
- PWNe from PSRs with $\dot{E} > 4 \cdot 10^{36}$ erg/s

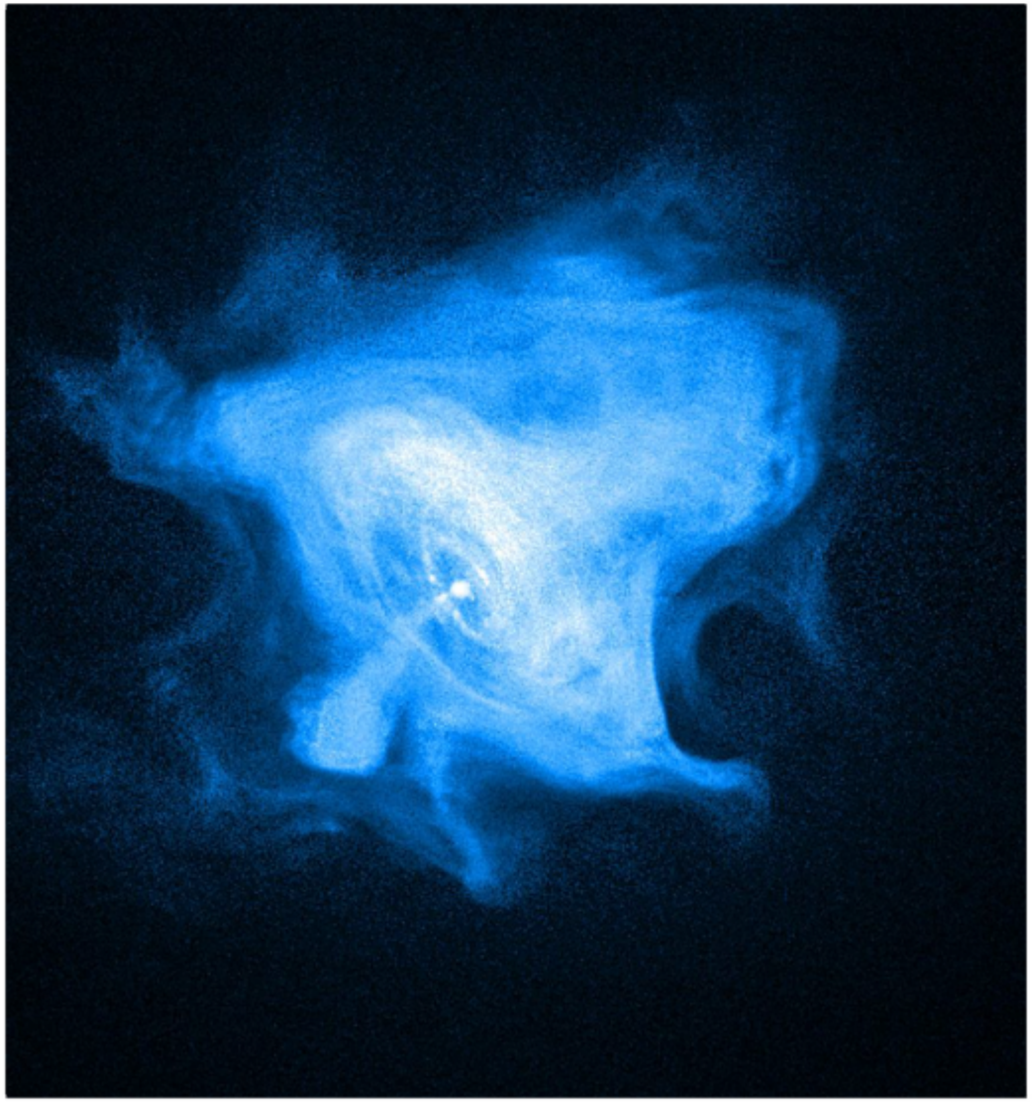
$\dot{E} = 4\pi^2 \, I \, P_{dot} / P^3$

$10^{30} < \dot{E} < 5 \times 10^{38}$ erg/s

Crab

- INGREDIENTS:
  - PSR
  - jets
  - PWN
  - SNR

Kargaltsev et al. 2015 Space Sci Rev 191, 391



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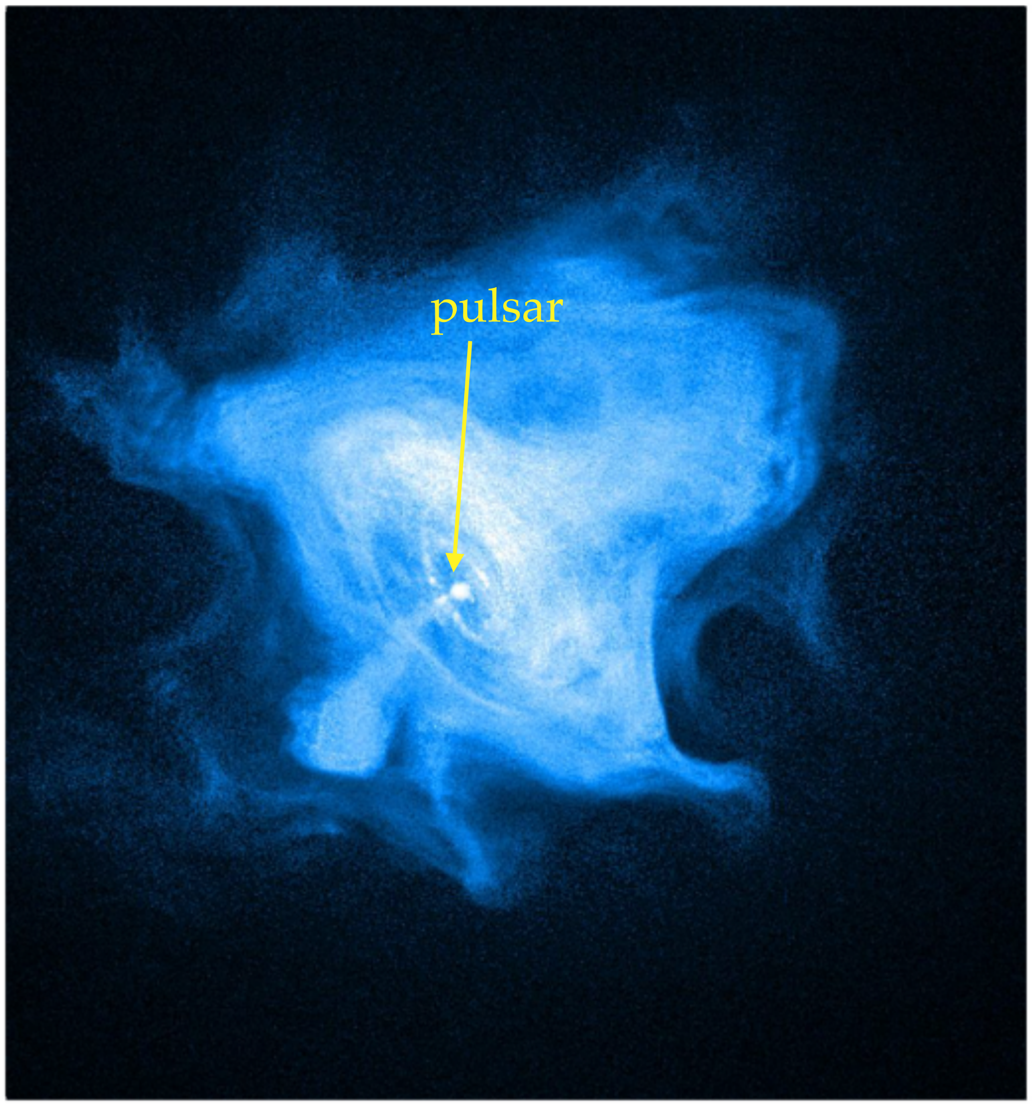
Kargaltsev et al. 2015 Space Sci Rev 191, 391



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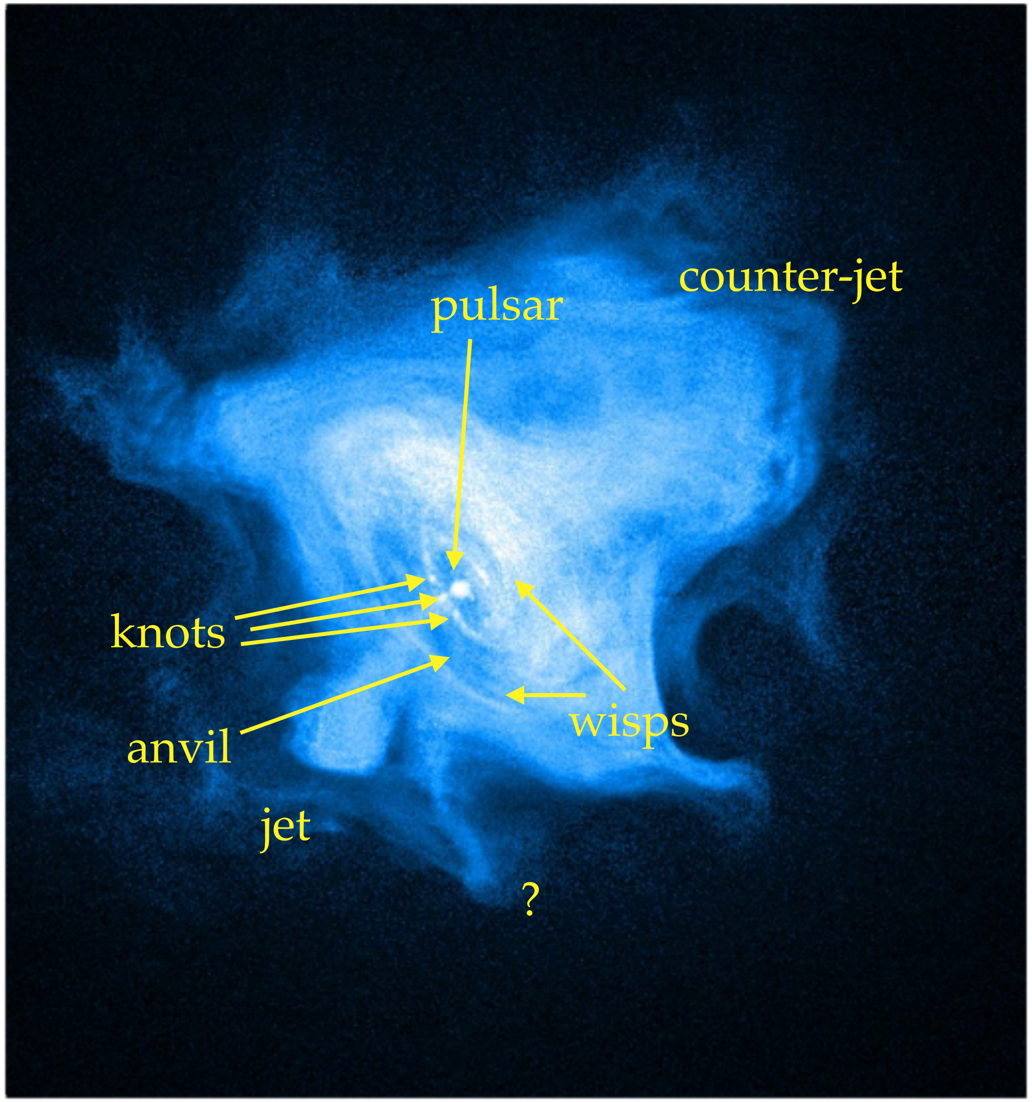
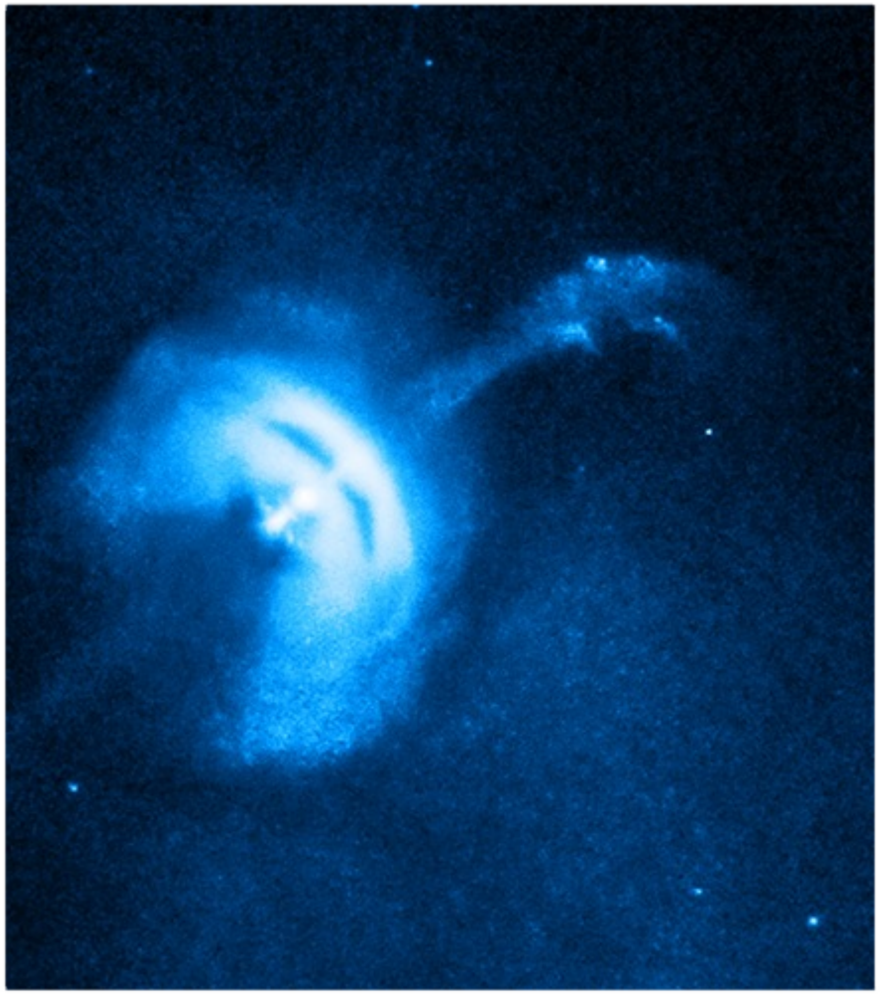
Kargaltsev et al. 2015 Space Sci Rev 191, 391



Vela

- INGREDIENTS:
  - PSR
  - jets
  - PWN
  - SNR

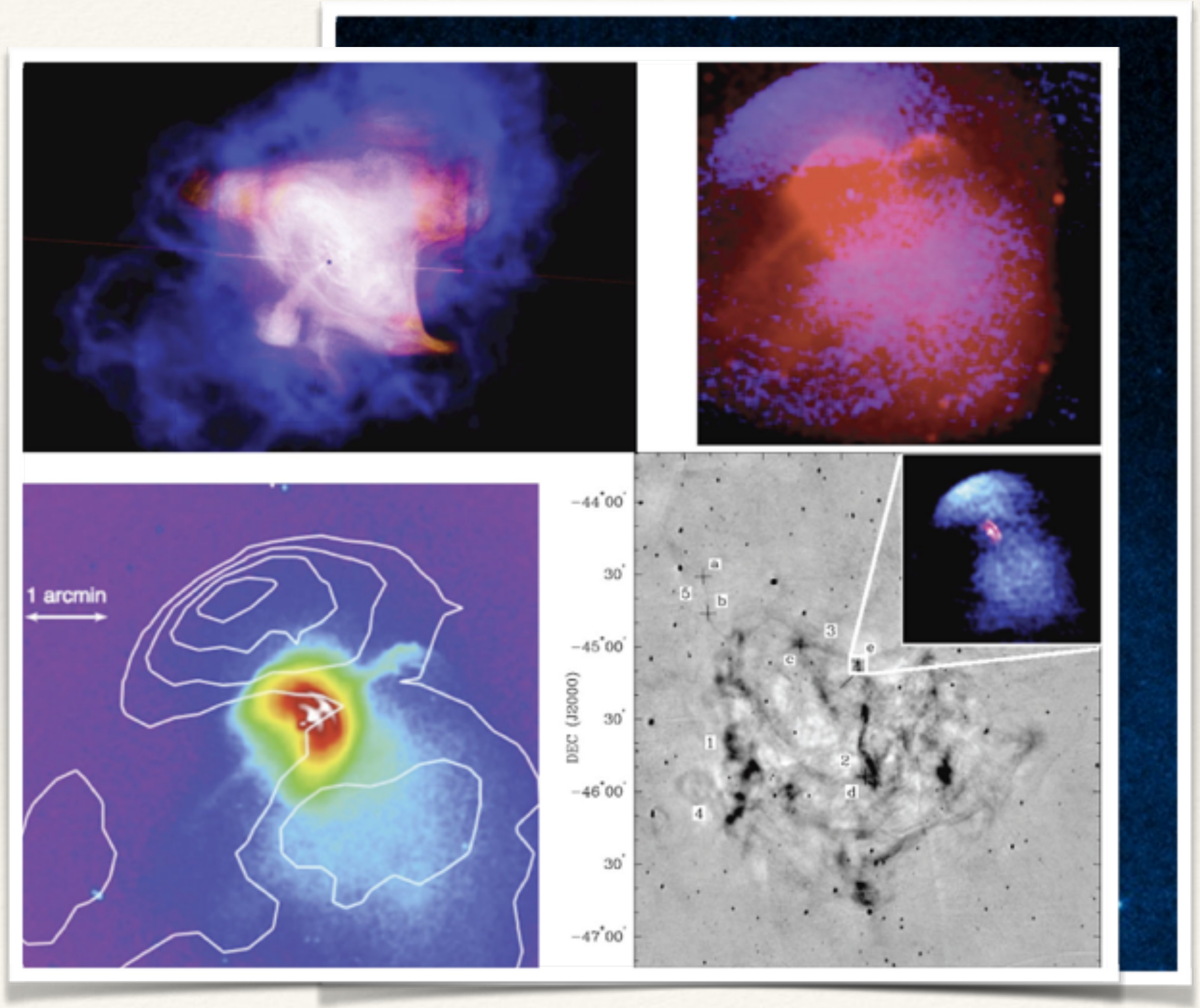


Durant et al. 2013 ApJ 763, 2

Vela

- INGREDIENTS:
  - PSR
  - jets
  - PWN
  - SNR

Kargaltsev et al. 2015 Space Sci Rev 191, 391



Crab vs Vela: differences

possible causes:

(see **Kargaltsev et al.** Space Sci Rev 2015, 191, 391)

Crab vs Vela: differences

possible causes:

- differences in the ambient medium? —not likely

(see **Kargaltsev et al.** Space Sci Rev 2015, 191, 391)

Crab vs Vela: differences

possible causes:

- differences in the ambient medium? —not likely
- differences in the PSR properties or view angle— not likely

(see **Kargaltsev et al.** Space Sci Rev 2015, 191, 391)

Crab vs Vela: differences

possible causes:

- differences in the ambient medium? —not likely
- differences in the PSR properties or view angle— not likely
- angle between B field and spin axis

  (or departures from simple dipole?)

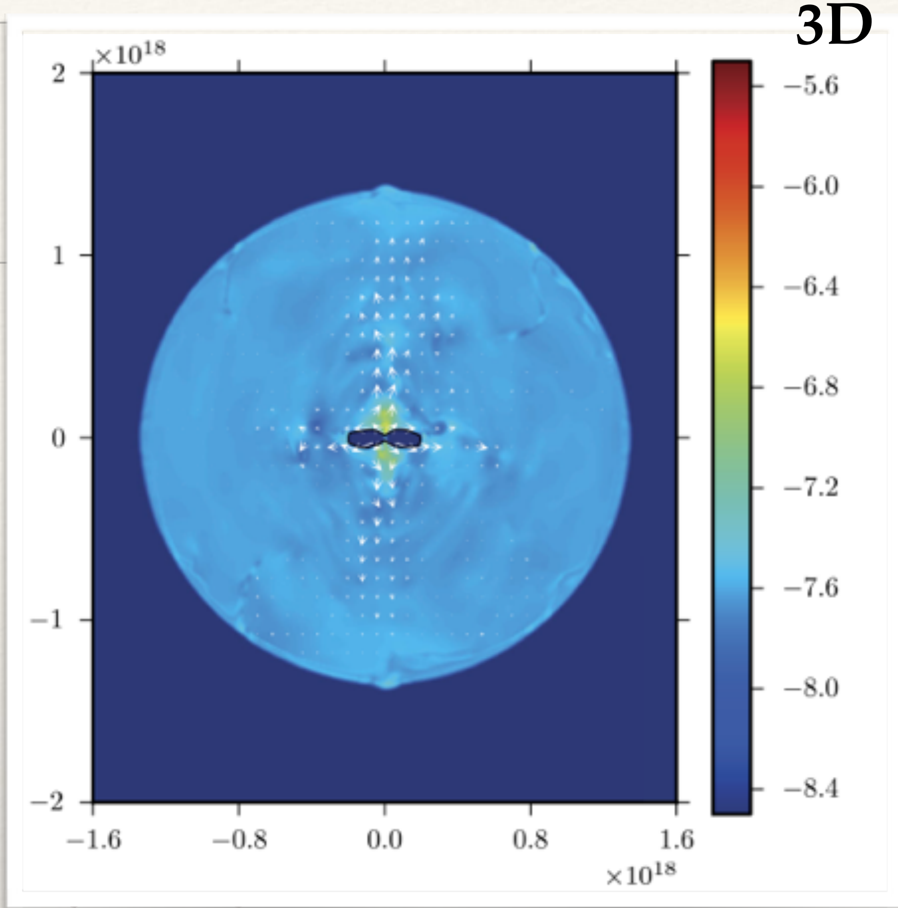
(see **Kargaltsev et al.** Space Sci Rev 2015, 191, 391)

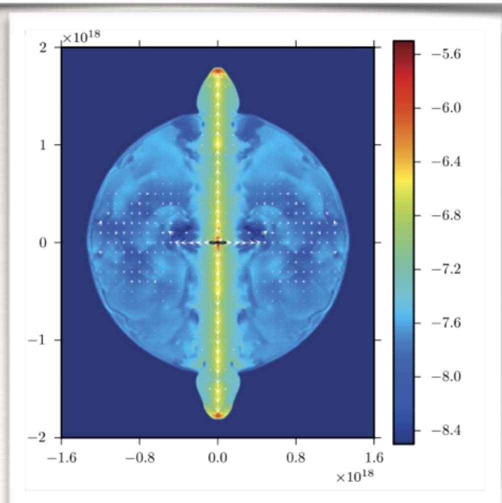
PSRs jets:

- jets would not be launched directly from the PSR, but rather from the wind
- magnetic hoop stresses in the highly magnetised wind, very close to the PSR polar axis: E_B —> E_{plasma}
- “jet” launching mechanism is quite inefficient
- still several unknowns!

Porth et al. 2014 MNRAS 438, 278

3D

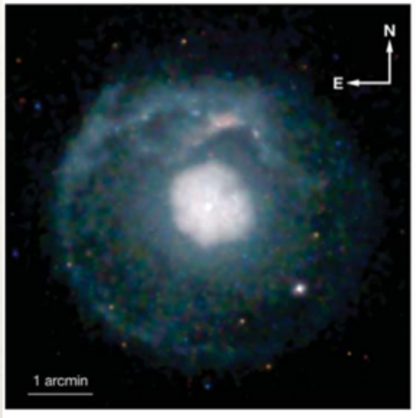


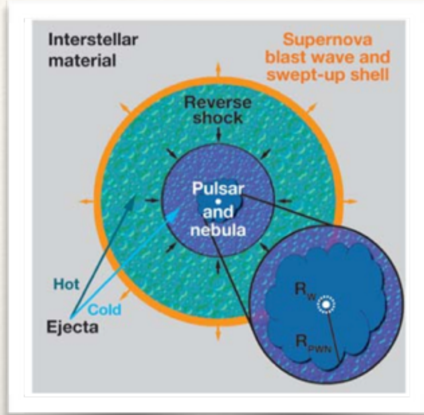


2D

adding velocity to the PSR…

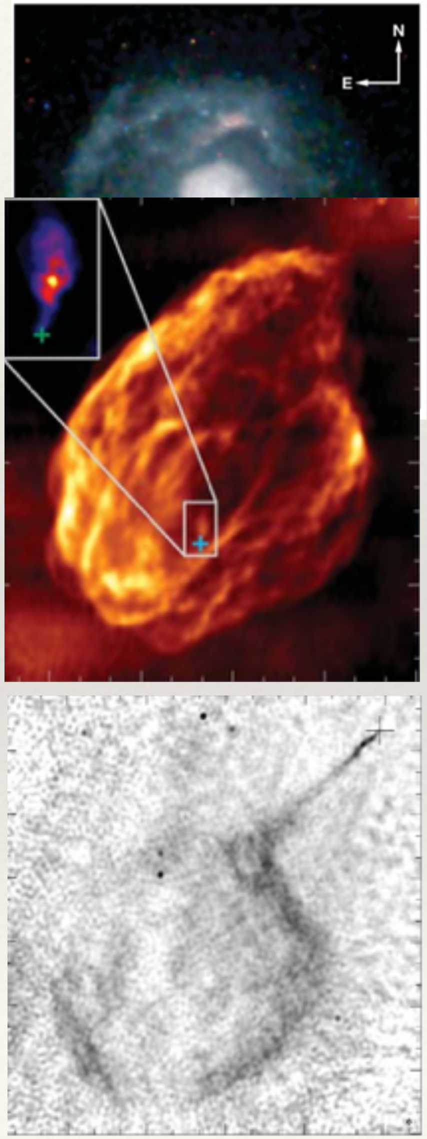
Gaensler & Slane ARA&A 2006, 44 17

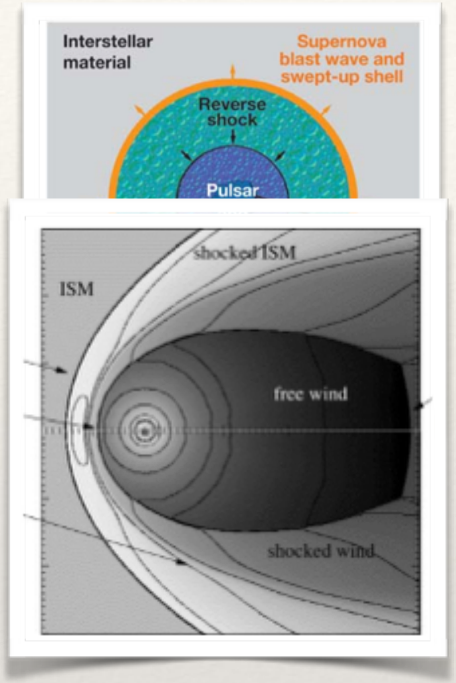




adding velocity to the PSR…

Ng et al. 2012 ApJ 746,105 **Gaensler & Slane** ARA&A 2006, 44 17





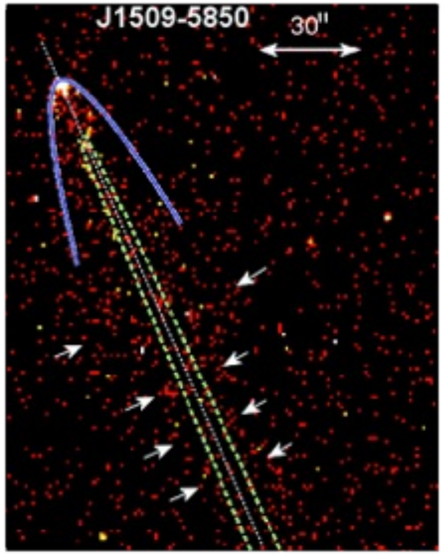
Bucciantini A&A 387, 1066 (2002)

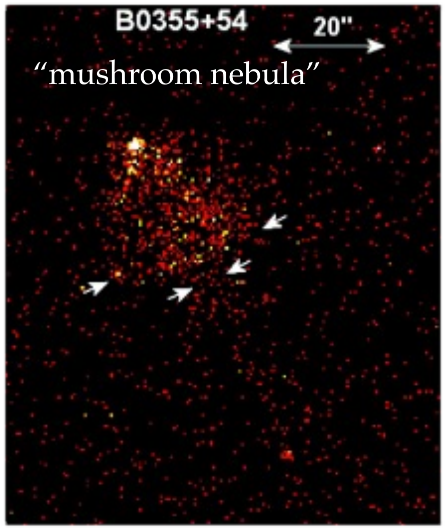
$$\rho v_*^2 = \frac{\dot{E}}{4\pi c r_{\rm bs}^2}$$

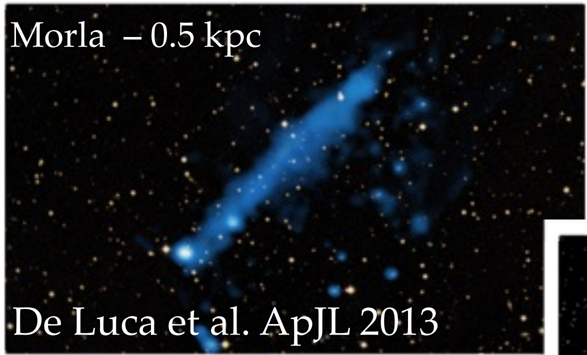
- Hα due to collisional excitation and charge exchange at forward shock
- A pulsar will typically cross its SNR shell after ~40,000 years.
- If the SNR is still in the Sedov phase, the bow shock has a Mach number M ≈ 3.1 at this point (**van der Swaluw** et al., 2003).

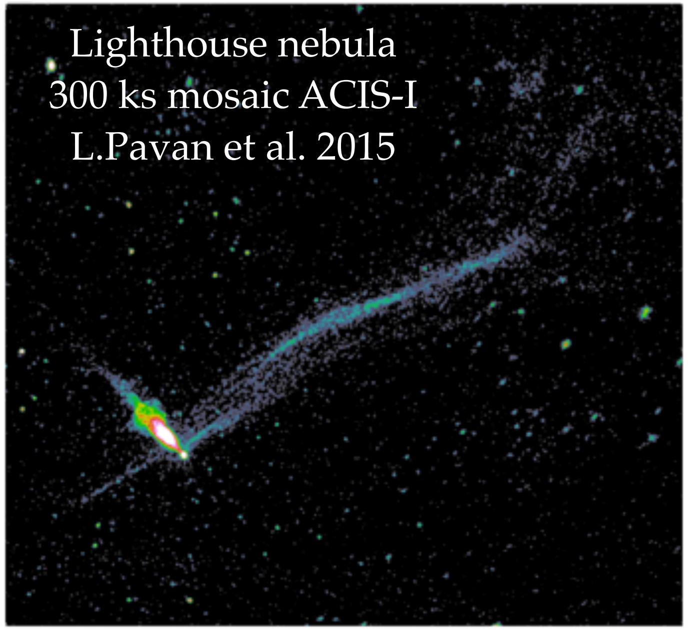
adding velocity to the PSR…

Kargaltsev et al. ApJ 2008, 684 542



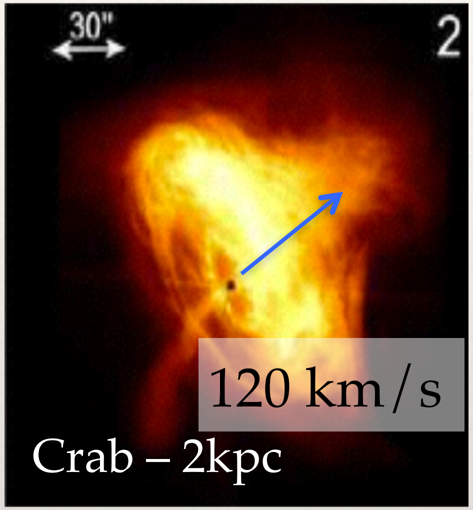


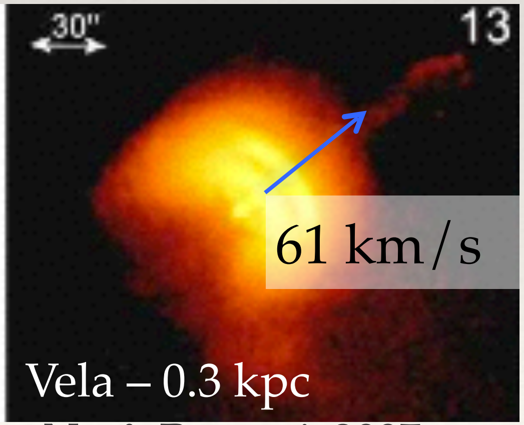




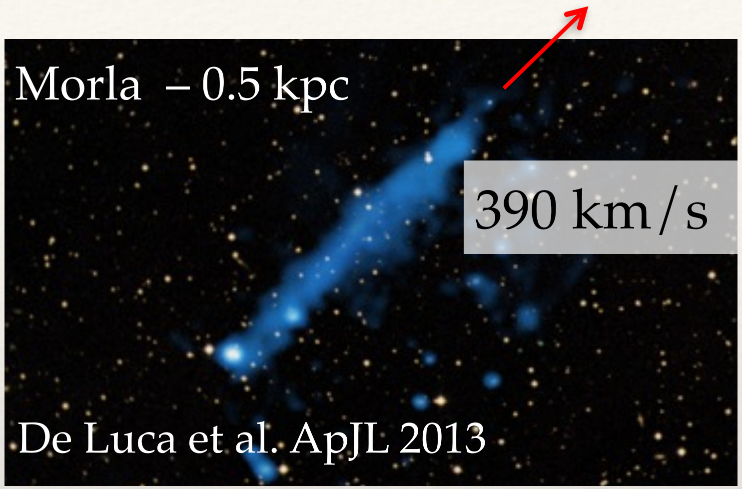
kick velocity- pulsar spin alignment

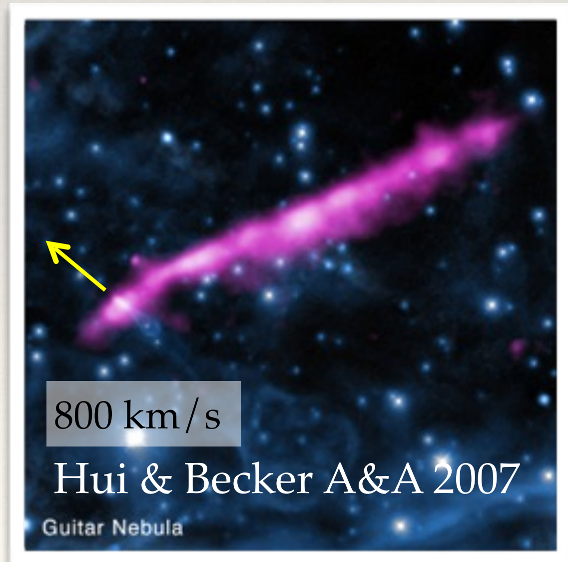
Kaplan et al. , 2008





Ng & Romani, 2007





Spruit & Phinney 1998 Nature 393, 139
Lai et al. , 2001 ApJ 549, 1111
Johnston et al. 2007 MNRAS 381, 1625
Noutsos et al. 2013 MNRAS 430, 2281

- kicks due to asymmetric core-collapse Sne (**Janka**, 2012 ARNPS 62, 407)
- correlation between velocity direction and spin axis

- hydrodynamical kicks
- asymm. neutrino emission
- electromagnetic rocket (postnatal kick)

- jets are on the spin axis (no equatorial jet)
- polarization data for 25 pulsars → P.A. of the linear polar. → P.A. of spin axis
- orthogonal pol. modes in the PSR radio emission: either // or ⊥

(Johnston et al. 2005, 2007)

extreme velocities…

… but how fast can they go?

- PSR B1508+55—> parallax: v_{PSR}= 1083+/-100 km/s (Chatterjee et al. 2005 ApJ, 630, L61)
- Guitar nebula: proper motion V~800 km/s (Harrison, Lyne & Anderson 1993 MNRAS, 261, 113)
- Frying pan radio PSR : v~1000 km/s (Ng et al. 2012)
- measures of PSRs de-projected vel: 10s—1000s km/s (Hobbs et al. 2005 MNRAS, 360, 974)
- are they producing a bow shock? yes!

but not only! —> Guitar, Lighthouse nebulae

beyond the separation torus/jet vs. bow-shock

- evidences for a counterjet (Guitar?, Lighthouse: sure!)
- what produces the jets?
  - new efficient launching mechanism?
  - collimation in the ISM? (but hardening with time in the Guitar…)

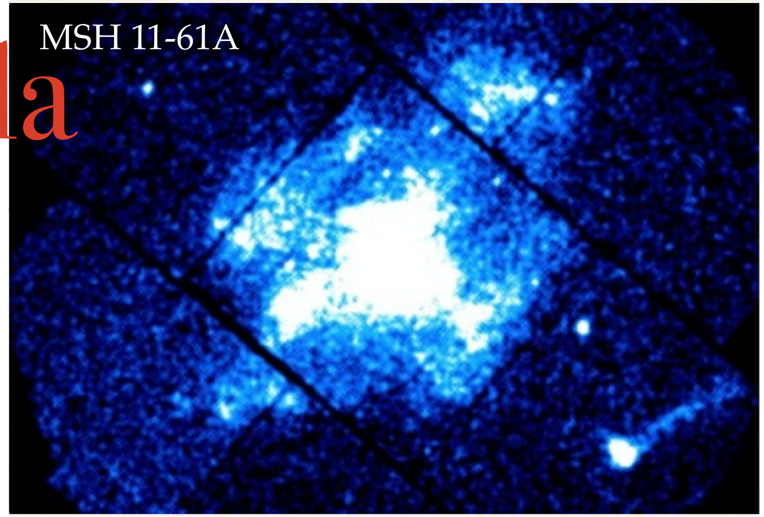
Johnson & Wang 2010 MNRAS 408, 1216

Hui & Wang 2012 ApJ 747, 74

The Lighthouse nebula

- discovered serendipitously with INTEGRAL

The Lighthouse nebula



- discovered serendipitously with INTEGRAL
- analysed all archival observations (XMM, optical, radio MOST) —> bsPWN from MSH 11-61A

  Pavan et al. 2011 A&A, 533A, 74

  Tomsick et al. 2012 ApJ 750, 39

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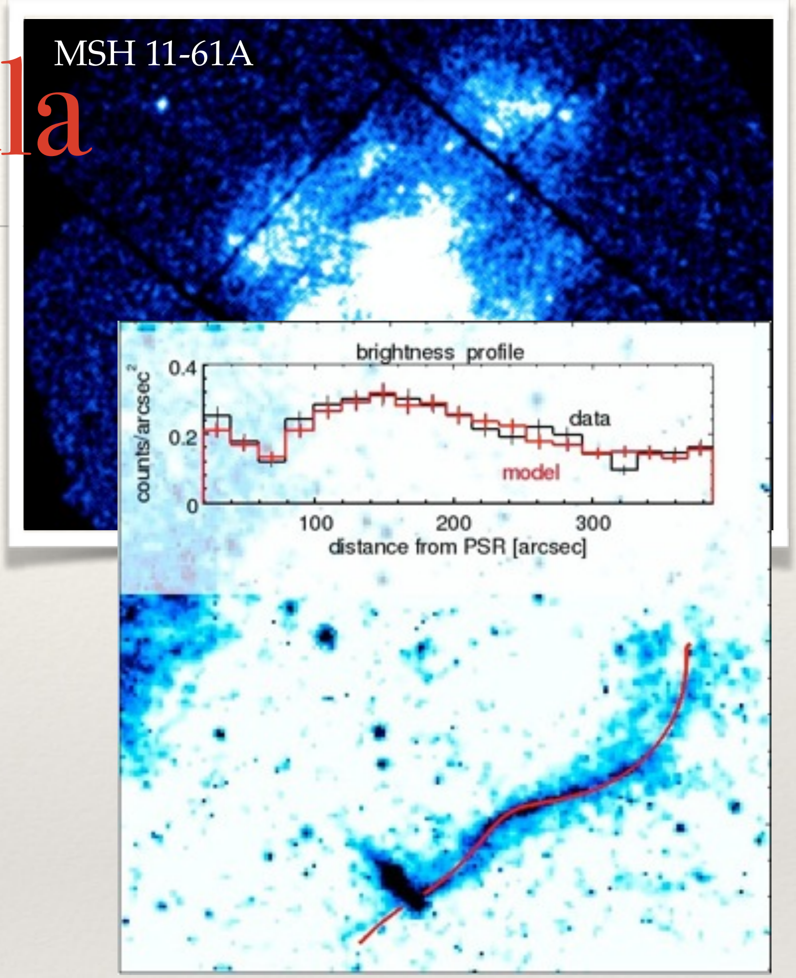

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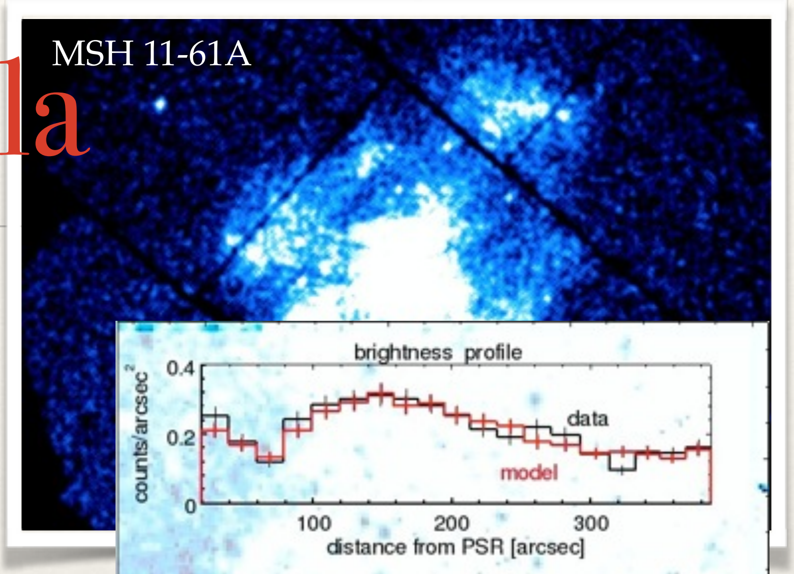


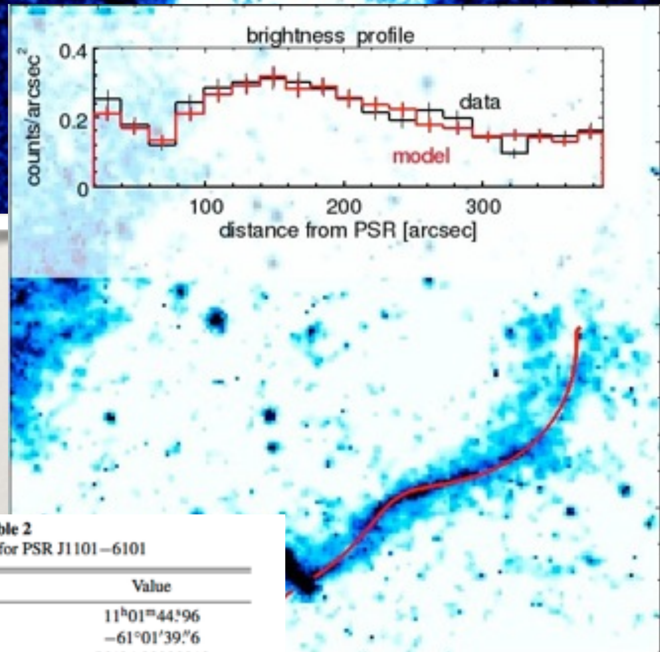
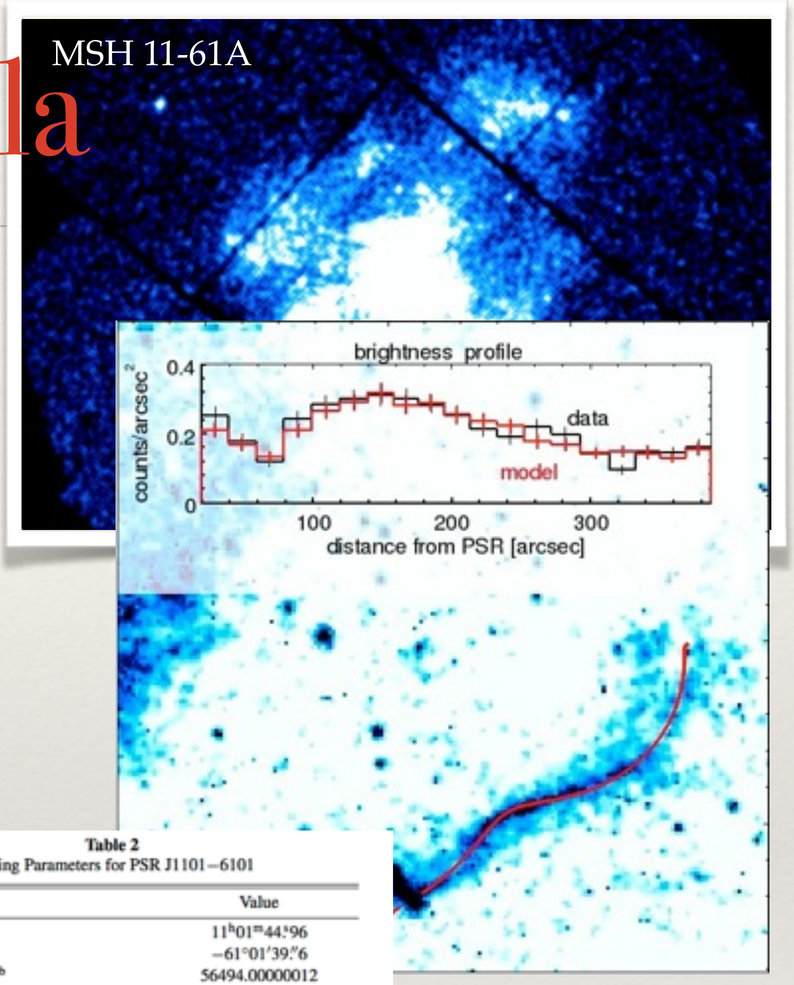


Table 2
Timing Parameters for PSR J1101−6101

Parameter	Value
R.A. (J2000.0)[a]	$11^h01^m44^s.96$
Decl. (J2000.0)[a]	$-61°01'39''.6$
Epoch (MJD TDB)[b]	56494.00000012
Frequency[c], f	15.9235474(14) s^{-1}
Frequency derivative[c], $\dot{f}$	$(-2.17 \pm 0.13) \times 10^{-12}$ s^{-2}
Period[c], P	0.062800077(6) s
Period derivative[c], $\dot{P}$	$(8.56 \pm 0.51) \times 10^{-15}$
Range of dates (MJD)	56494–56817
Spin-down luminosity, $\dot{E}$	1.36×10^{36} erg s^{-1}
Characteristic age, τ_c	116 kyr
Surface dipole magnetic field, B_s	7.4×10^{11} G

Notes.
[a] *Chandra* position from Tomsick et al. (2012).
[b] Epoch of phase zero in Figure 3.
[c] 1σ uncertainty in parentheses.

The Lighthouse nebula



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- 2014: 250 ks observation (5 shorter exposures)
  Pavan et al. 2015 A&A arXiv 1511.01944

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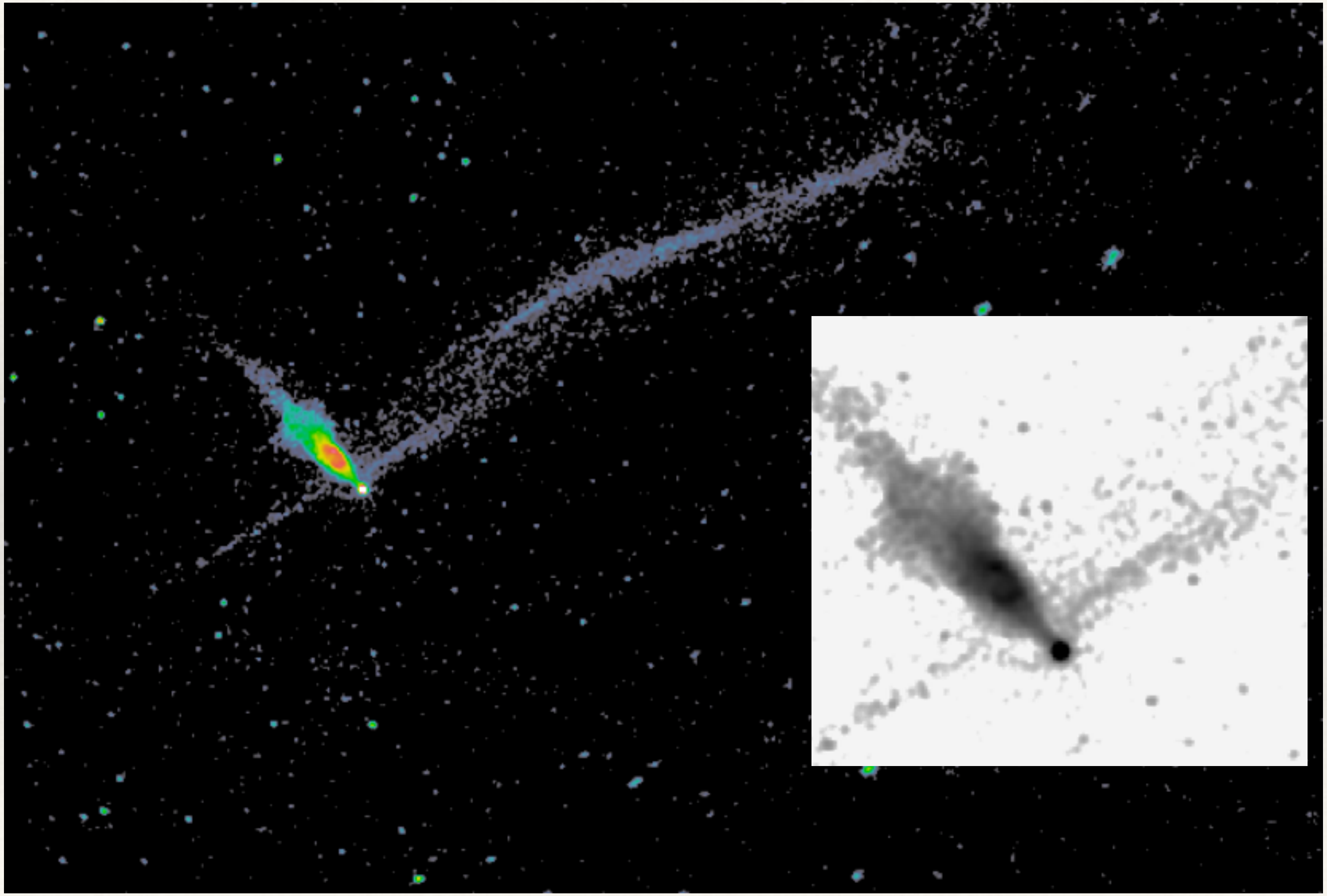
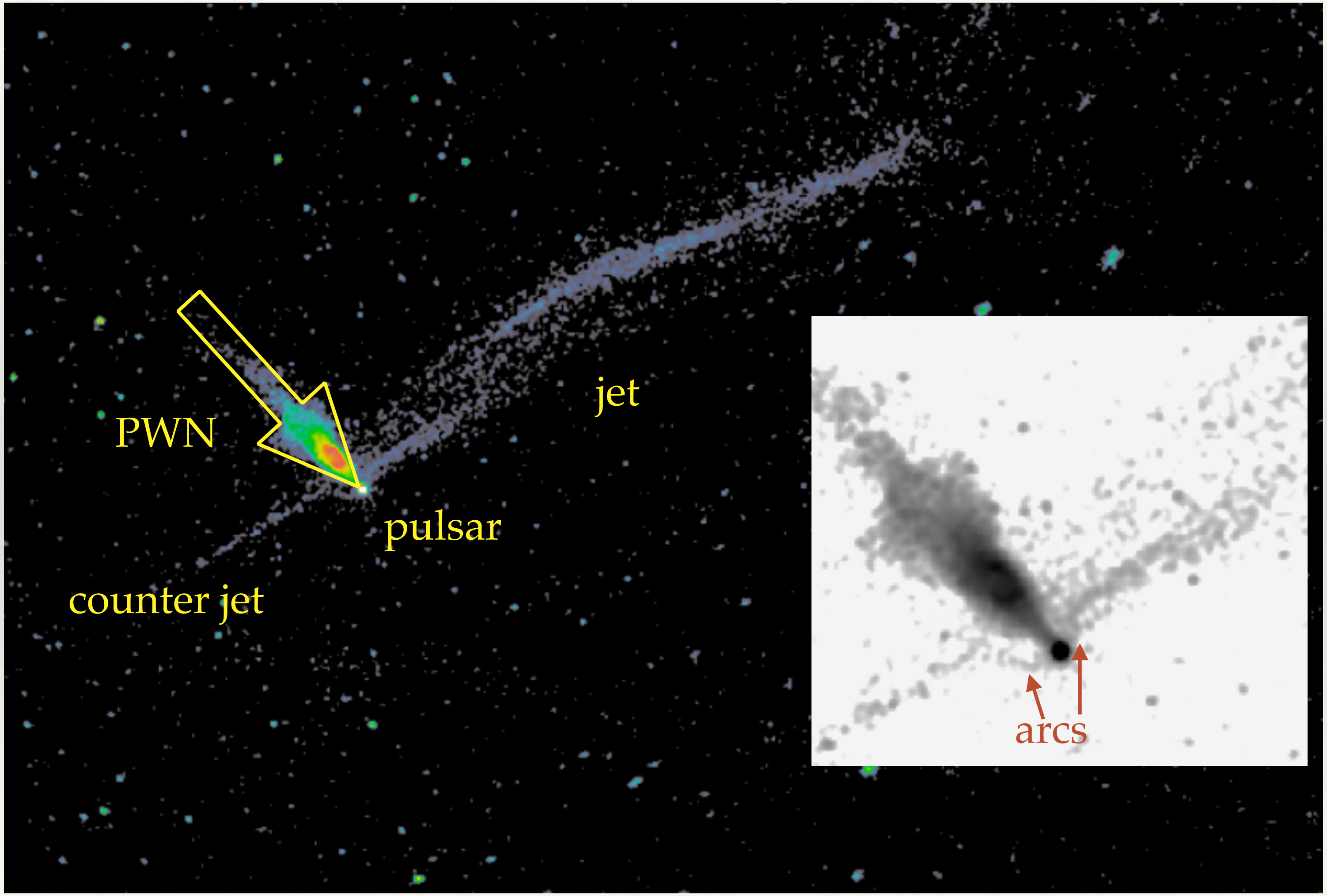
Lighthouse nebula: 300 ks mosaic ACIS-I



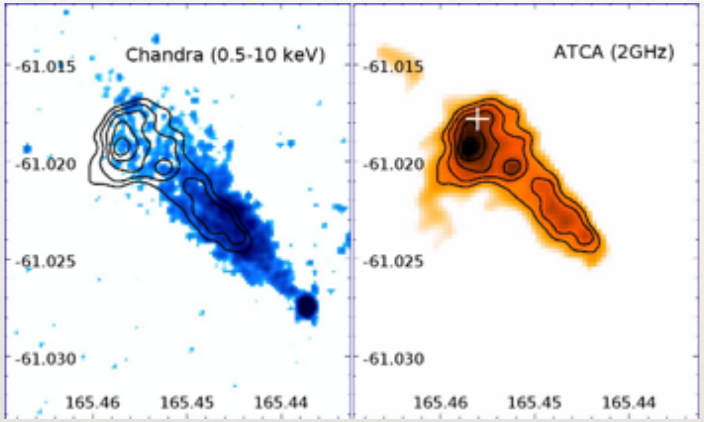
LP et al. 2015

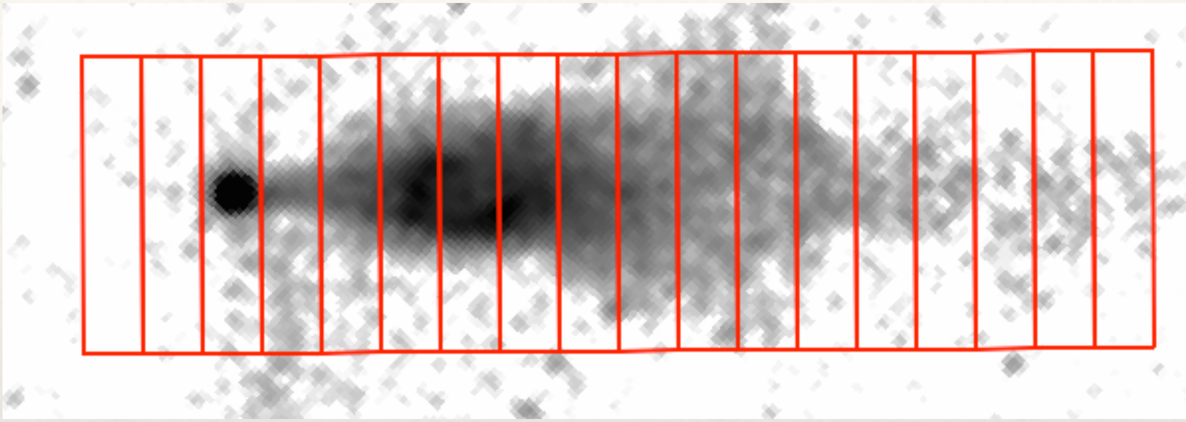
Lighthouse nebula: 300 ks mosaic ACIS-I

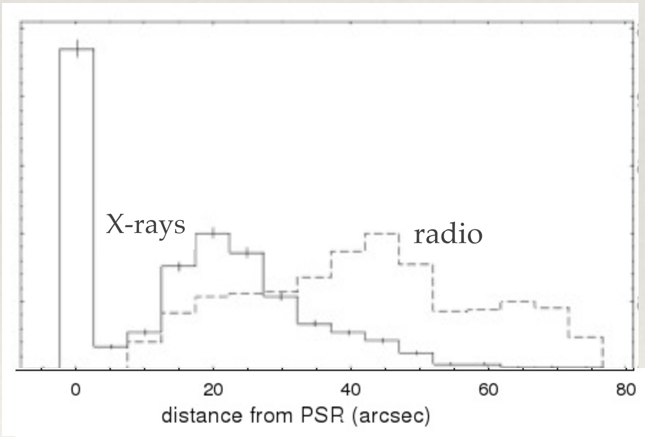


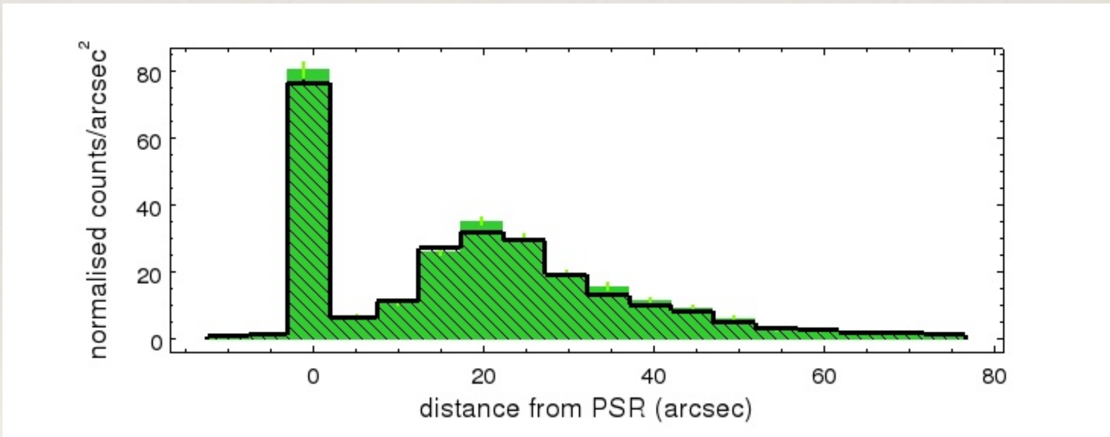
LP et al. 2015

The PWN





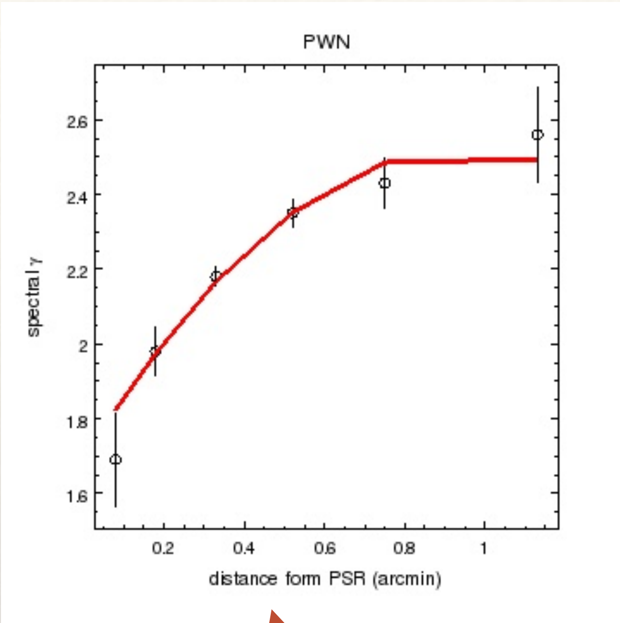


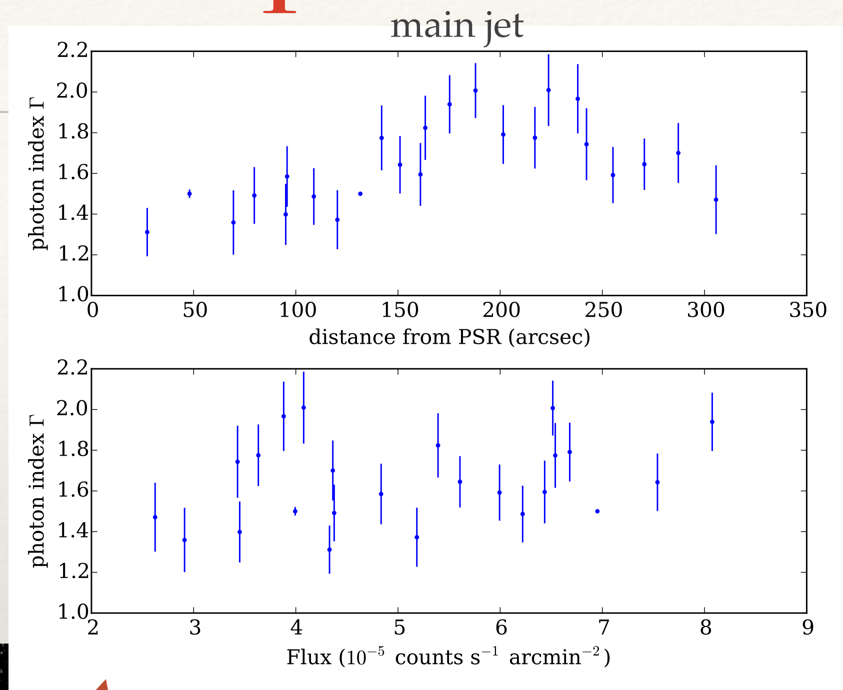


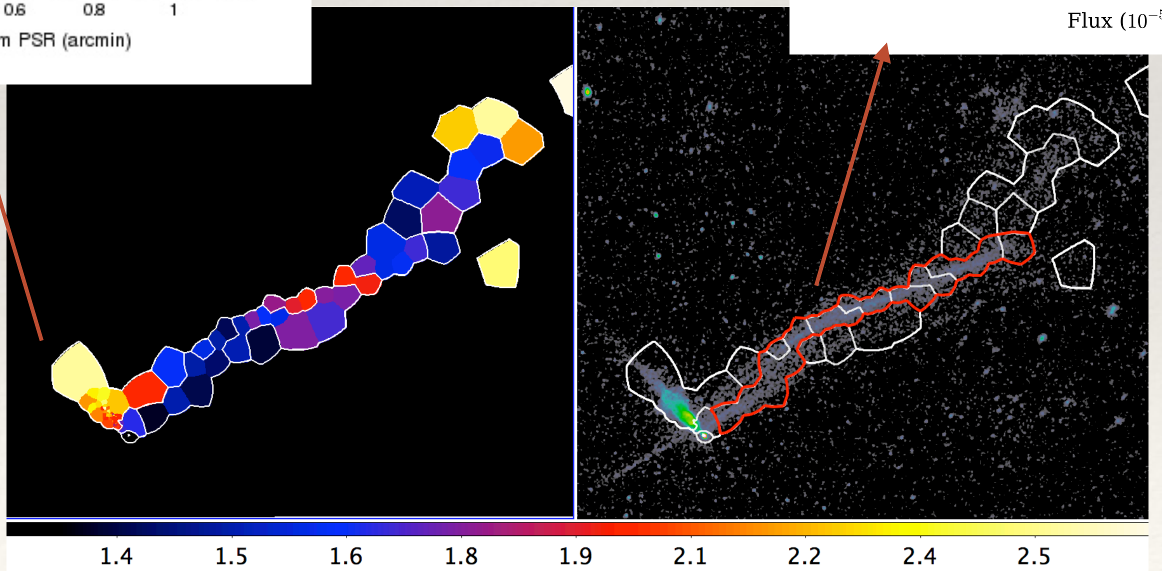
LP et al. 2014

LP et al. 2015

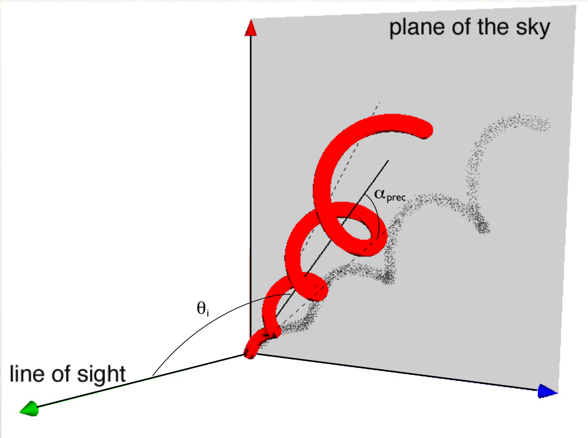
Photon index map

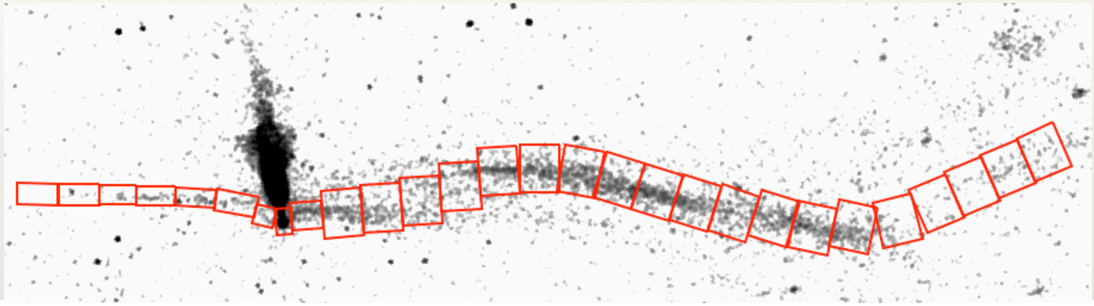


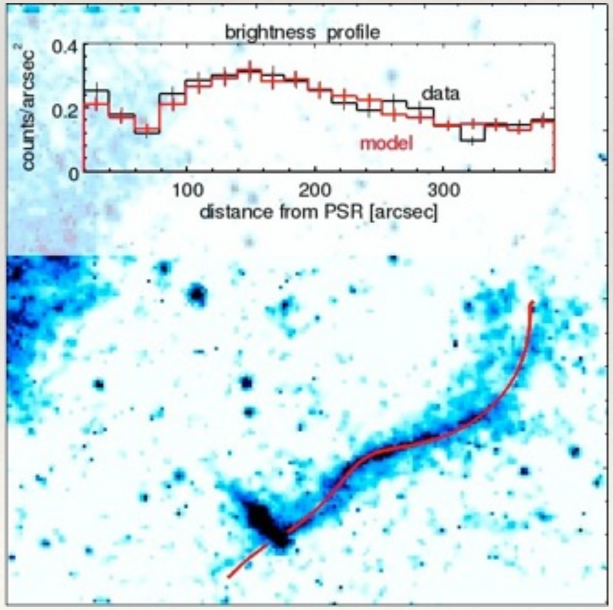


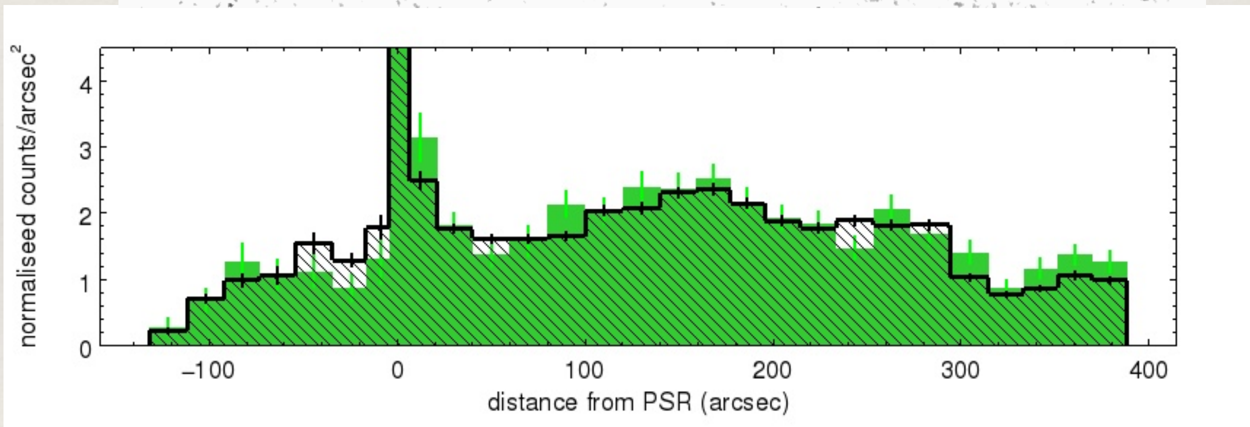


The jets: an helical structure?

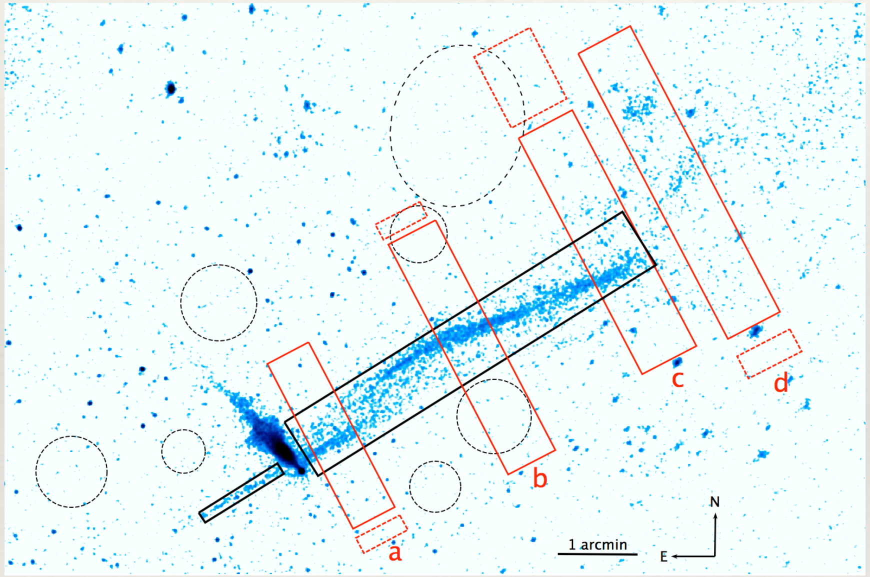


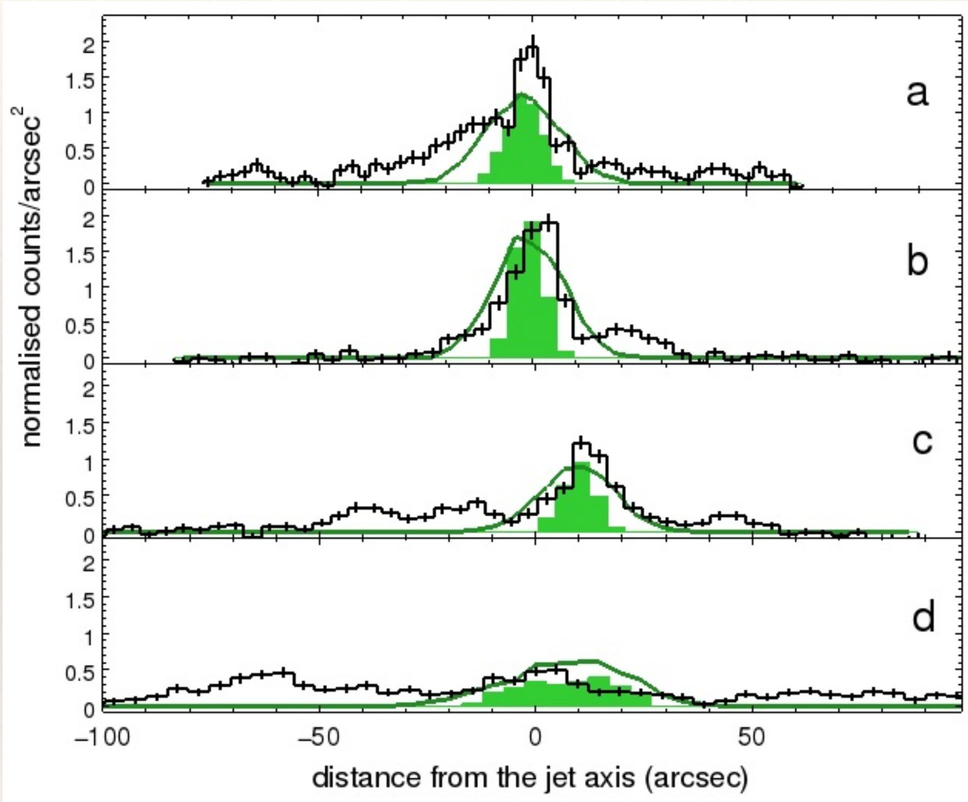






structures around the jet





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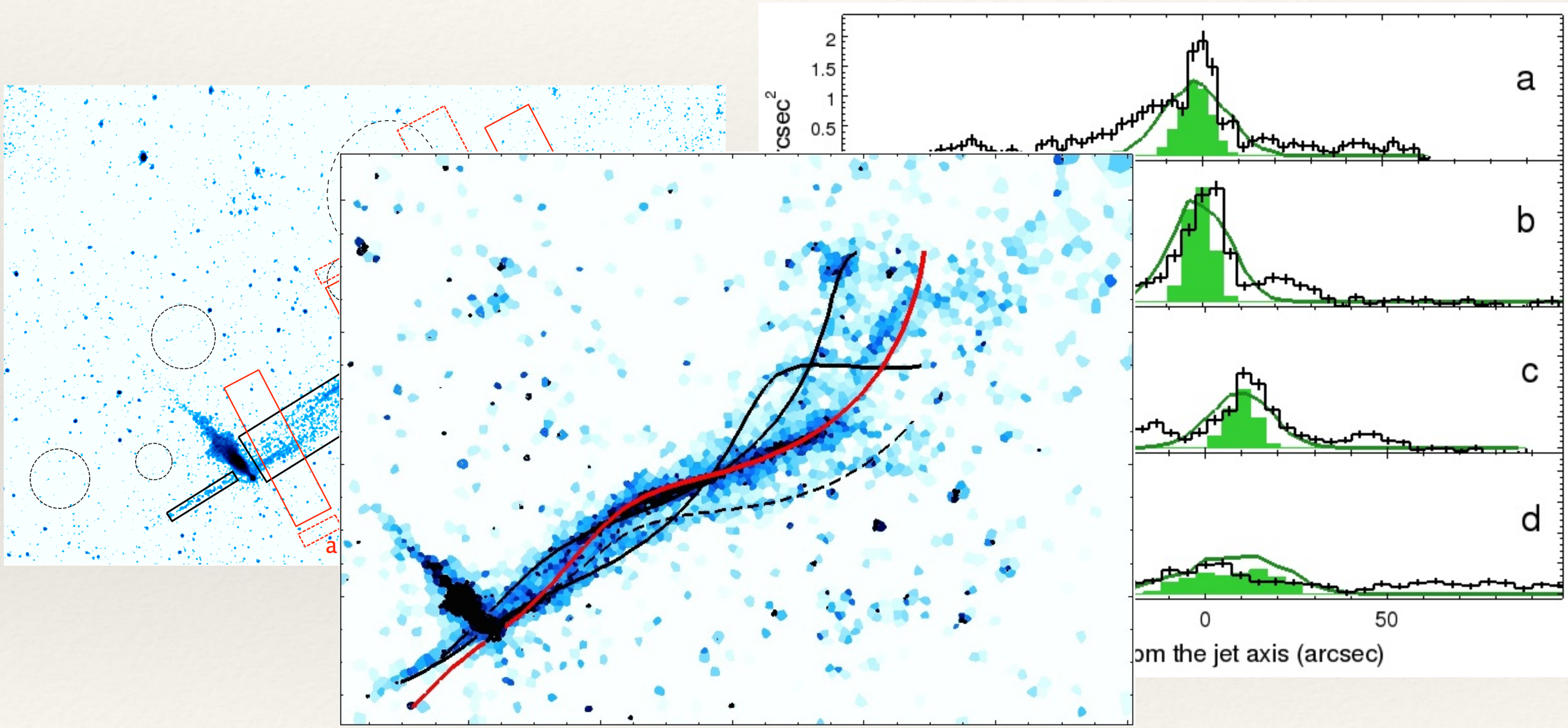
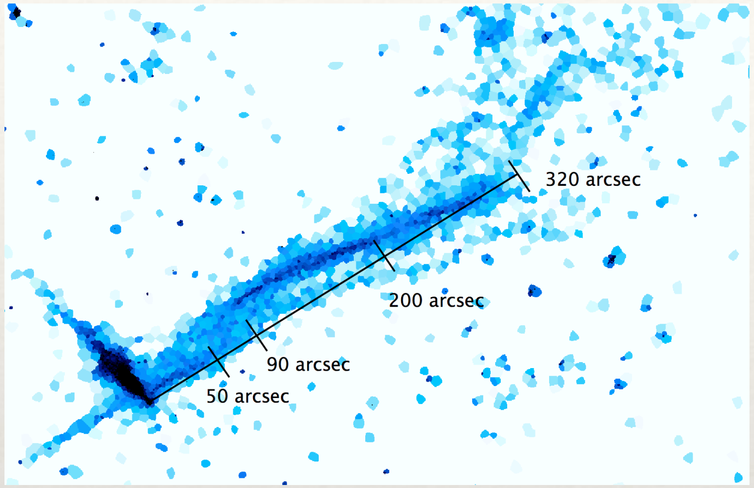
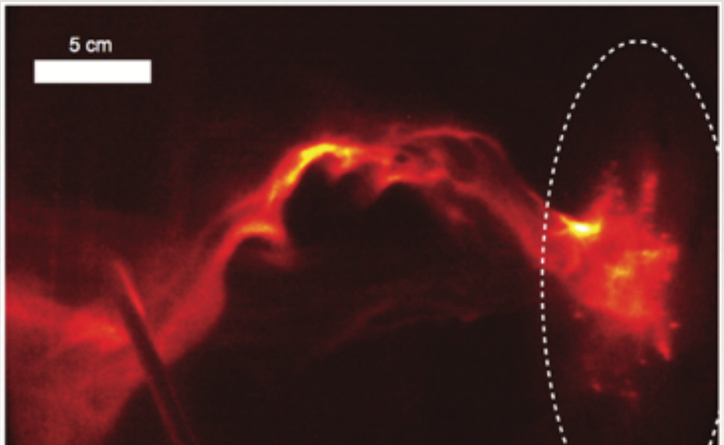
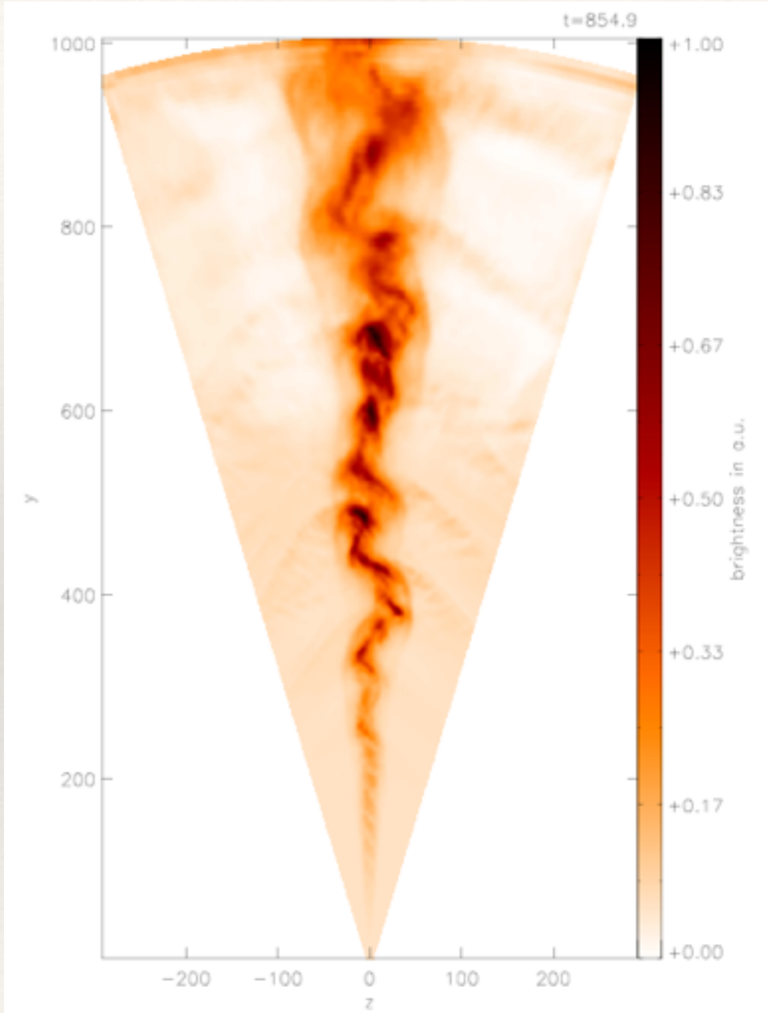


Kink instabilities





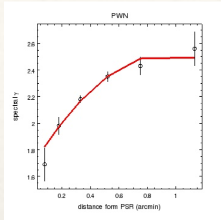
Moser & Bellan 2012, Nature, 482, 379
Kink + RT instabilities



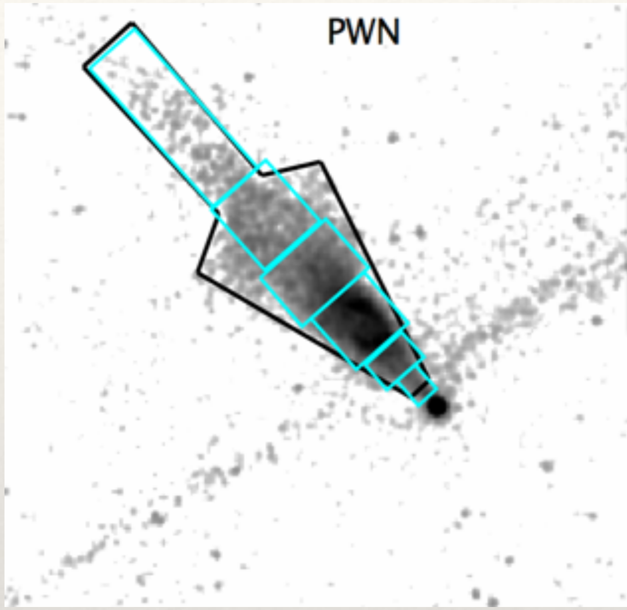
R. Moll 2010 PhD thesis

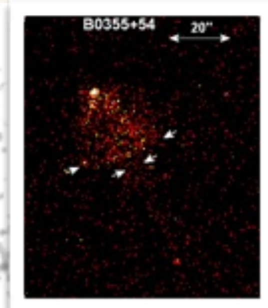
possible explanations…

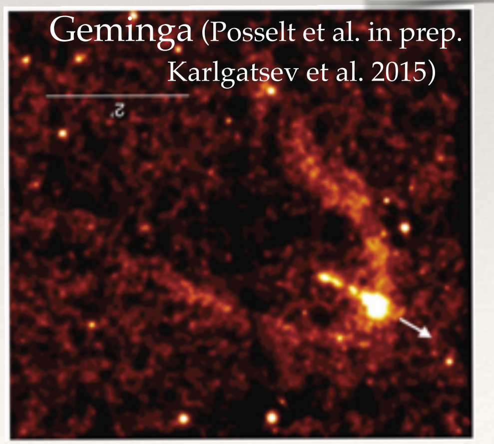
- collimated PWN: cooling of particles



- a shaft? —> similar to Mushroom (PSR B0355+54), or PSR J1509-5850 nebulae
  - first hypothesis for those objects: a rear jet on top of the PWN —> here it is not possible!
  - different degree of (mag) collimation?
- arcs: similar to Geminga?

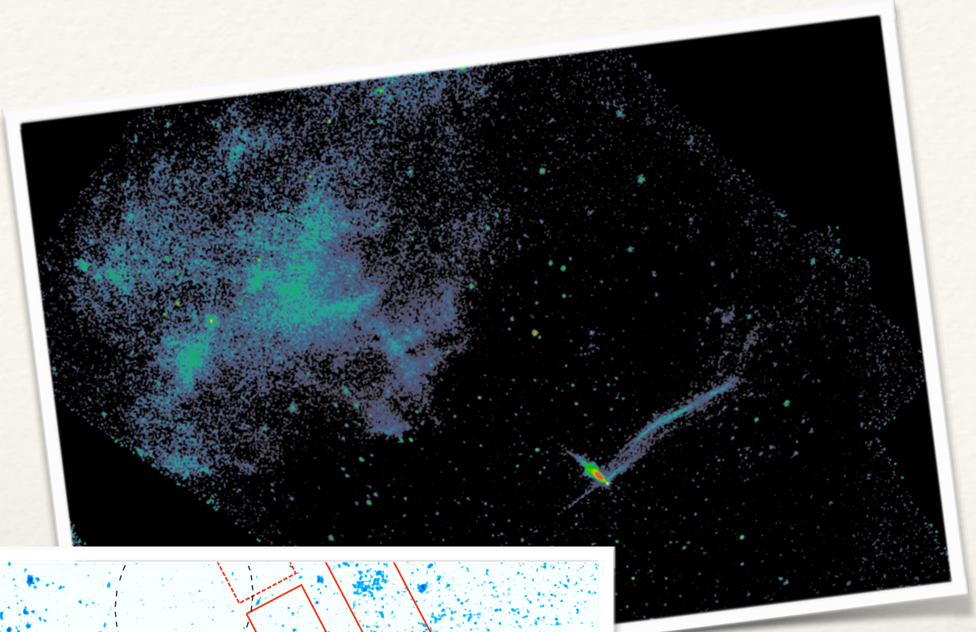


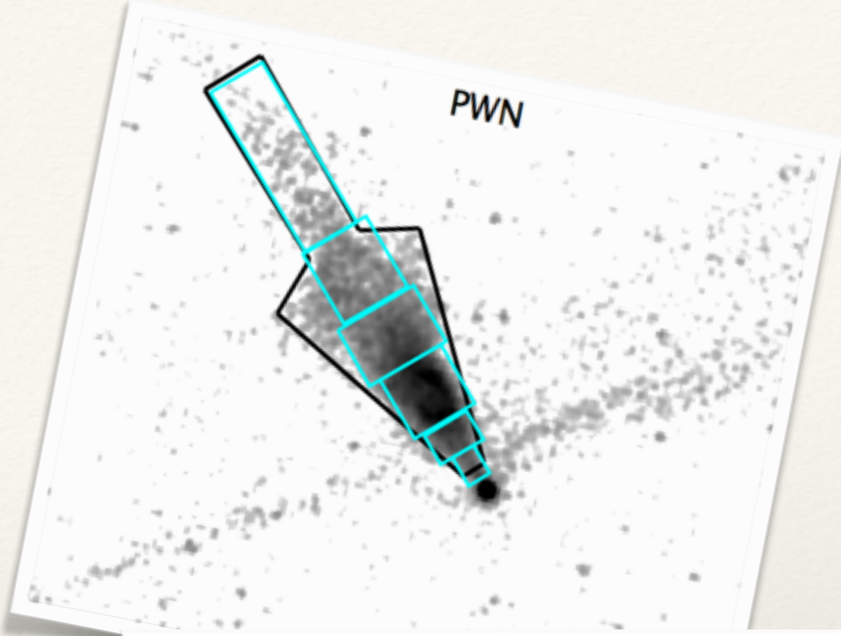


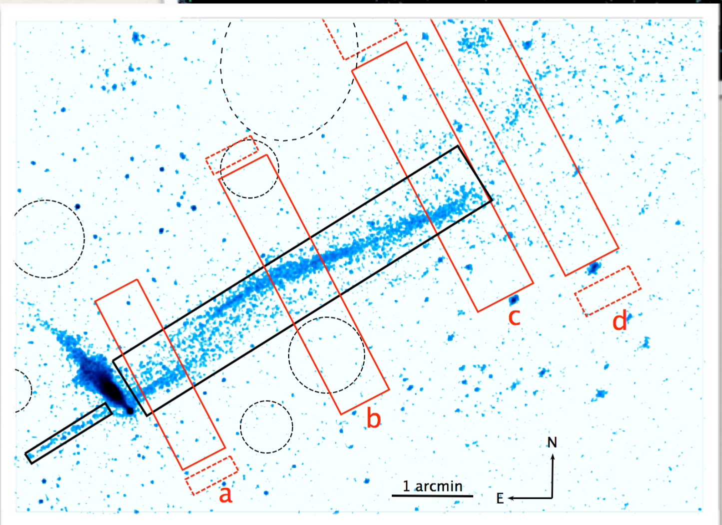


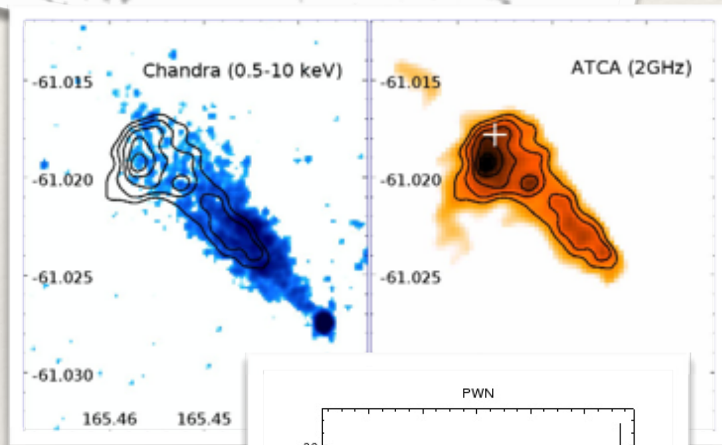
possible explanations…

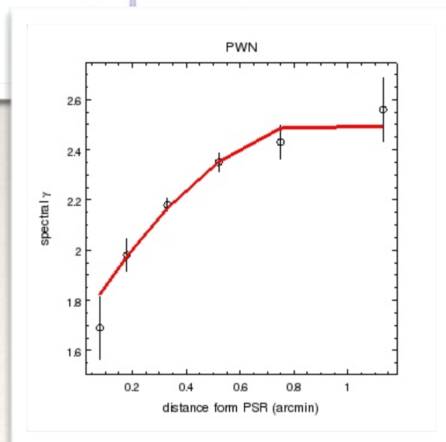
- jet/counterjet : extremely powerful launching mechanism?
- extended emission around the jet
  - which mechanism?…




PWN


a
b
c
d
1 arcmin
N
E


Chandra (0.5-10 keV)
ATCA (2GHz)
-61.015
-61.020
-61.025
-61.030
165.46
165.45


PWN
spectral γ
distance form PSR (arcmin)
2.6
2.4
2.2
2
1.8
1.6
0.2
0.4
0.6
0.8
1

Thanks!