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

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PWNe (plerion)

- Rotational energy loss from the PSR
- Relativistic magnetized wind ($e^- e^+ p^+ ... ?$)
- Sync + i.Compt+ opt Balmer lines
- PWNe from PSRs with $\dot{E} > 4 \cdot 10^{36} \text{ erg/s}$
  
  \[ \dot{E} = 4\pi^2 I \frac{P_{\dot{P}}}{P^3} \]

\[ 10^{30} < \dot{E} < 5 \times 10^{38} \text{ erg/s} \]
Crab

- INGREDIENTS:
  - PSR
  - Jets
  - PWN
  - SNR

Kargaltsev et al. 2015  Space Sci Rev. 191, 391
Crab

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  - PSR
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Kargaltsev et al. 2015 Space Sci Rev 191, 391

pulsar
Crab

- INGREDIENTS:
  - PSR
  - jets
  - PWN
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Kargaltcev et al. 2015 Space Sci Rev 191, 391
Vela

- INGREDIENTS:
  - PSR
  - jets
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  - SNR

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: $E_B \rightarrow E_{\text{plasma}}$
- “Jet” launching mechanism is quite inefficient.
- Still several unknowns!
adding velocity to the PSR...
adding velocity to the PSR...

- $\text{H}\alpha$ due to collisional excitation and charge exchange at forward shock
- A pulsar will typically cross its SNR shell after $\sim 40,000$ years.
- If the SNR is still in the Sedov phase, the bow shock has a Mach number $M \approx 3.1$ at this point (van der Swaluw et al., 2003).

\[ \rho v^2_s = \frac{\dot{E}}{4\pi c r^2_{bs}} \]
adding velocity to the PSR...

Morlà – 0.5 kpc
Lighthouse nebula
300 ks mosaic ACIS-I
L.Pavan et al. 2015

B0355+54
“mushroom nebula”


L.Pavan - Texas symposium 15 December 2015
kick velocity- pulsar spin alignment

Kaplan et al., 2008

Morla – 0.5 kpc

120 km/s

Crab – 2kpc

Vela – 0.3 kpc

61 km/s

Ng & Romani, 2007

390 km/s


Noutsos et al. 2013 MNRAS 430, 2281

Spruit & Phinney 1998 Nature 393, 139


Johnston et al. 2007 MNRAS 381, 1625

F❖ 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 $V \sim 800$ km/s (Harrison, Lyne & Anderson 1993 MNRAS, 261, 113)

- Frying pan radio PSR : $v \sim 1000$ 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
The Lighthouse nebula

- discovered serendipitously
  with INTEGRAL
The Lighthouse nebula

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- analysed all archival observations (XMM, optical, radio MOST) —> bsPWN from MSH 11-61A
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- 50 ks Chandra observation —> helical jet
The Lighthouse nebula

- discovered serendipitously with INTEGRAL
- analysed all archival observations (XMM, optical, radio MOST) \(\rightarrow\) bsPWN from MSH 11-61A
- 50 ks Chandra observation \(\rightarrow\) helical jet
- P and Pdot determination with XMM

Table 2: Timing Parameters for PSR J1101—6101

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.A. (J2000.0)</td>
<td>11°01'45&quot;46&quot;</td>
</tr>
<tr>
<td>Decl. (J2000.0)</td>
<td>-61°03'35&quot;76&quot;</td>
</tr>
<tr>
<td>Epoch (MJD TDB)(^b)</td>
<td>56994.000000012</td>
</tr>
<tr>
<td>Frequency, (f)</td>
<td>15.923547(14) (\times 10^{-13}) s(^{-1})</td>
</tr>
<tr>
<td>Frequency derivative, (\dot{f})</td>
<td>((-2.17 \pm 0.13) \times 10^{-15}) (\times 10^{-13}) s(^{-2})</td>
</tr>
<tr>
<td>Period, (P)</td>
<td>0.062000875(0) s</td>
</tr>
<tr>
<td>Period derivative, (\dot{P})</td>
<td>((8.36 \pm 0.31) \times 10^{-15}) (\times 10^{-15}) s(^{-2})</td>
</tr>
<tr>
<td>Range of dates (MJD)</td>
<td>56494–56817</td>
</tr>
<tr>
<td>Spin-down luminosity, (\dot{\epsilon})</td>
<td>(1.36 \times 10^{35}) erg (\times 10^{35}) s(^{-1})</td>
</tr>
<tr>
<td>Characteristic age, (\tau_c)</td>
<td>416 kyr</td>
</tr>
<tr>
<td>Surface dipole magnetic field, (B_s)</td>
<td>(7.4 \times 10^{14}) G</td>
</tr>
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</table>

Notes:
- \(^a\) Chandra position from Tomsick et al. (2012).
- \(^b\) Epoch of phase zero is Figure 3.
- \(\epsilon\) uncertainty in parentheses.
The Lighthouse nebula

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

- 50 ks Chandra observation —> helical jet
  

- P and Pdot determination with XMM
  

- 2014: 250 ks observation (5 shorter exposures)

  Pavan et al. 2015 A&A arXiv 1511.01944

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<td>R.A. (J2000.0)°</td>
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<tr>
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</tr>
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<td>((-2.17 ± 0.13) × 10(^{-13} ) Hz s(^{-1} ))</td>
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<tr>
<td>Period, ( P )</td>
<td>0.082000877(3) s</td>
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<td>Spin-down luminosity, ( \dot{E} )</td>
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<tr>
<td>Characteristic age, ( t_c )</td>
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</tr>
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<td>(7.4 × 10^{14} ) G</td>
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\(^a\) Chandra position from Tomsick et al. (2012).
\(^b\) Epoch of phase zero is Figure 3.
\(^c\) 1σ uncertainty in parentheses.
Lighthouse nebula: 300 ks mosaic ACIS-I
Lighthouse nebula: 300 ks mosaic ACIS-I

- PWN
- pulsar
- jet
- counter jet
- arcs

LP et al. 2015
The PWN
Photon index map

- Photon index map
- Distance from PSR vs. photon index
- Flux vs. photon index
- Main jet
The jets: an helical structure?
structures around the jet
structures around the jet
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?…
Thanks!

L.Pavan - Texas symposium  15 December 2015