Nature or Nurture - neutron stars in Be/X-ray binaries

Malcolm Coe
University of Southampton

Currently in collaboration with:

- Robin Corbet (GSFC/NASA/UMCP)
  - Frank Haberl (MPE)
- Vanessa McBride & Matthew Schurch (UCT, South Africa)
  - Christian Knigge (Southampton)
  - Phillip Podsiadlowski (Oxford)
- Liz Barlett, John Jones & Lee Townsend (Southampton)

BeXRB Valencia 2011
Structure of presentation

• Accretion physics
• SN kicks
• Spectral classification
• Spin period distribution
• Conclusions
Accretion physics at work..... X-ray monitoring using RXTE
13 years of weekly observations of the SMC with RXTE

Movie produced by Vanessa McBride

BeXRB Valencia 2011

1 count/pcu/s
~ 0.4 \times 10^{17} \text{ erg/s}

Dashed vertical lines indicate proposed binary period

ACTIVITY HISTORY OF SXP46.6

Orbital period: 137.55 \pm 0.34 \text{ days} \quad 100.00\% \text{ significance}

Amplitude (counts, PCU/1 s)

4000 days

Long term pulsar spin-up

BeXRB Valencia 2011
An example of the spin period changes seen in one system, SXP59.0. The straight lines show the chi-sq best fit to each data set. The fit gives us $\dot{P}$.

$\dot{P}$ is normally negative (i.e. spin-up) but there are exceptions.

The observed relationship between equilibrium spin period and the rate of spin change during an outburst:

The four points marked with a solid squares have positive $P_\text{dot}$ values (spin down), the rest are negative (spin up). This suggests that torque-reversal does not change the basic accretion physics.

The straight line ($P_\text{dot} \propto P^2$) is that predicted by Ghosh & Lamb (1979) for disk accretion.
How bright are the X-ray outbursts?

The relationship between the absolute values of the short (~couple of months) spin changes and the longer term changes (~10 years).

Luminosities typical of "Type I" outbursts (once per binary cycle).

"Type II" outbursts can be a factor of 10 brighter, but are much less common.

The dashed line shows the simple relationship:

\[ \text{Long } P_{\text{dot}} = 0.2 \times \text{Short } P_{\text{dot}} \]

This suggests that such accreting systems are only active for ~20% of the time.
The fundamental relationship between spin period change and X-ray luminosity

- Accreting material generate torques on the magnetic field of the NS and alters the spin period.

- From Ghosh & Lamb (1979) and subsequently other authors e.g. FKR page 125:

$$- \dot{P} = 5.0 \times 10^{-5} \mu_{30}^{2/7} m(\omega) S_{1}(M)(P L_{3}^{3/7})^{2} \text{s yr}^{-1}$$

- This predicts that a graph of log($P_{\text{dot}}$) against log($P L_{3/7}$) should be a straight line

Ghosh & Lamb (1979) for galactic accreting pulsars
New version for twice as many systems, again with NS magnetic moments of $\mu=0.48$.

The average mass of the neutron stars in the SMC sample is found to be $1.62 \pm 0.29 \, M_\odot$.

A record of SN kicks?
The fields around 4 Be/X-ray binary systems as a clue to HMXB evolution

- In each case we note the presence of a nearby cluster.

- But is the proximity just random, or are these the clusters in which the system was born?

Red confirmed SXP, blue XMM candidates

Boundary defined by the cluster distribution of Bica & Dutra 2000

A total of ~600 clusters selected – with the criteria that the cluster contains evidence for emission-line stars
Clustering implications

- Using a value of 60 kpc for the distance to the SMC, then 2.8 arcminutes corresponds to ~50 pc.

- Savonije & van den Heuvel (1977) estimate the maximum possible lifetime of the companion Be star after the creation of the neutron star to be ~5 million years.

- So 50 kpc travel in 5Myr indicates a minimum average transverse velocity of the SXP systems is 13 km/s.

- van den Heuvel et al. (2000) interpreted the Hipparcos results for galactic HMXBs in terms of models for kick velocities, and obtained values around 15 km/s.
Brandt & Podsiadlowski (1995)
“Effects of SN kicks on orbital properties...”

Transverse velocity calculated assuming an age of ~1Myr

Optimum age to maximise the number of systems within the 98% zone
Spectral classification.

What about the population of Be stars in the Be/X-ray binaries?

Negueruela (1998)
Spectral distribution, determined from blue spectra of ~40 Be/X-ray binaries in the SMC (red), as compared the distribution of Be/X-ray binaries in the Galaxy (blue). (McBride et al 2007)
Evolution at work?

**XRB populations**

Questions:

Where are the Supergiant and BH systems in the SMC?

Where are the Be/WD systems?

BeXRB Valencia 2011
How many HMXBs with a Be star as the mass donor and NS as compact companion?

- ~60 known in the SMC
- ~70 in the Milky Way
- ~12 in LMC

BeXRB Valencia 2011

The question:

- Does the nature of the birth of the neutron star in an HMXB system have any effect on its currently observed spin period?
- Or is the period simply defined by its current accretion environment?
Gold or Silver?

- Gold – definite BeX-ray system: pulse period & opt ctpt with spectral class defined; plus perhaps orbital period.

- Silver – all of the Gold systems plus any that are probably a BeX-ray system: optical ctpt, pulse and/or orbital periods known, but no spectral identification yet.

<table>
<thead>
<tr>
<th>GOLD</th>
<th>SILVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMC – 40</td>
<td>SMC – 56</td>
</tr>
<tr>
<td>LMC – 4</td>
<td>LMC – 12</td>
</tr>
<tr>
<td>MILKY WAY - 22</td>
<td>MILKY WAY - 79</td>
</tr>
</tbody>
</table>

BeXRB Valencia 2011
Why might we have a bimodal distribution?

- Recently, people working on stellar synthesis models have started to predict that there may be two main channels producing the neutron stars in BeX systems:
  - Belczynski et al (2009) predict approx equal numbers from two routes that differ in whether mass is, or isn’t lost from the binary system during evolution.
  - Schwab, Podsialdowski & Rappaport (2010) also discuss two channels. In their evolutionary scenarios they distinguish between two different types of SN explosion (iron-core collapse or electron-capture). They predict differing orbital characteristics.
SN Kick eccentricities

• Though none of the theoretical work predicts different spin periods for the two formation channels, they do predict different kick velocities & eccentricities from the two routes.

• The iron-core collapse model predicts high velocities, and hence high eccentricities. The e-capture model predicts low kick velocities.

• So we can test to see if our two pulsar period populations have differing eccentricities.

Problem!

• Only a modest sub-set of our sample have had their orbital parameters determined.

• Only 30 of the Silver group (148 systems) have measurements (Lee Townsend’s current work has produced 4 of them).

• It is especially hard to get eccentricity data on the longer orbital periods.
The dip in the pulsar distribution corresponds to a spin period ~40s.

So, at the 2–3σ level there seems to be a difference.

Unfortunately it will be quite a while before this sample can be substantially improved.
What about Ecc v Porb?

No evidence for significant difference…but need more data!
What about kick velocities vs spin period?

So where are we?

- There appears to be very strong evidence for two different spin period populations amongst BeX systems.

- There are models suggesting different evolutionary paths, that would generate two approx equal sample size of neutron star populations.

- But testing this link is hard, critical observational data (eg eccentricities) are missing....however there are encouraging suggestions we are on the right path....

BeXRB Valencia 2011
Future work:

• Need to increase the sample size – not just more objects, but also much better knowledge of the known systems.

• We need more exact spectral classifications – remember, less than 1/3 of the MW systems have reliable spectral types.

• And we need more orbital solutions – specially eccentricity values.

Questions?