X-ray pulse timing and optical radial velocities of Be/X-ray binaries: Getting at the binary formation channel

Lee Townsend[1*], Vanessa McBride[1,2], Elizabeth Bartlett[1]
[1]University of Cape Town, [2]South African Astronomical Observatory, Cape Town, South Africa
Jamie Kennea[3]
[3]Pennsylvania State University, Pennsylvania, USA
Ignacio Negueruela[4]
[4]Universidad de Alicante, Alicante, Spain
Malcolm Coe[5], Tony Bird[5]
[5]University of Southampton, Southampton, UK
Frank Haberl[6]
[6]Max-Planck-Institut fur extraterrestrische Physik, Garching, Germany

Introduction

The Be/X-ray binaries (BeXRB) occupy a large area in the fundamental binary parameter space, spanning roughly 10-500 days in orbital period and 0.0-0.9 in eccentricity. The distribution of this parameter space offers a unique insight into the pathways taken by these systems during formation. However, an observational bias exists towards measuring periods and eccentricities in short period systems as the methods used, namely X-ray pulse timing and optical radial velocity shifts, require shorter X-ray outbursts and less telescope time to implement.

We will show here the ongoing projects using these methods to try and fill in some of the binary parameter space and describe how the distribution could be used to distinguish between supernova formation channels. We will also describe our VLT programme to measure the mass of the neutron star in a BeXRB for the first time.

Background

BeXRBs are the most numerous class of massive X-ray binary. Of the >150 known in the Milky Way and Magellanic Clouds, only one harbours a confirmed black hole (Casares et al., 2014).

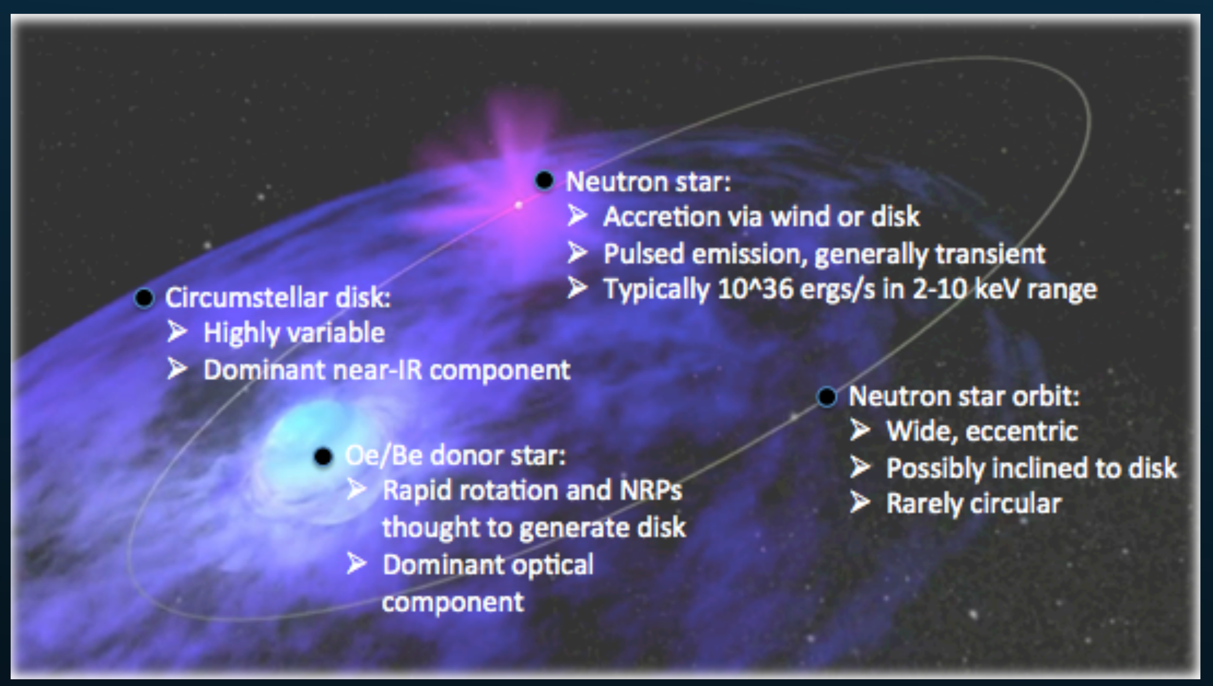

Figure 1: BeXRB schematic describing the major binary components and properties. The typical "wide and eccentric" orbit is shown, though this by no means applies to all systems. The large mass ratio and long orbits make measuring small radial velocity amplitudes and binary inclinations very difficult.

*Principal contact: townsend@ast.uct.ac.za

The giant X-ray outburst of SXP5.05: The first eclipsing Be/X-ray binary

SXP5.05 = IGR J00569-7226 is a recently discovered BeXRB in the Small Magellanic Cloud (SMC; Coe et al., 2015). The system was discovered in 2013 in a giant X-ray outburst that lasted at least 130 days. *Swift* monitoring showed a periodic dip in the X-ray flux every ~17 days, interpreted as an eclipse of the neutron star.

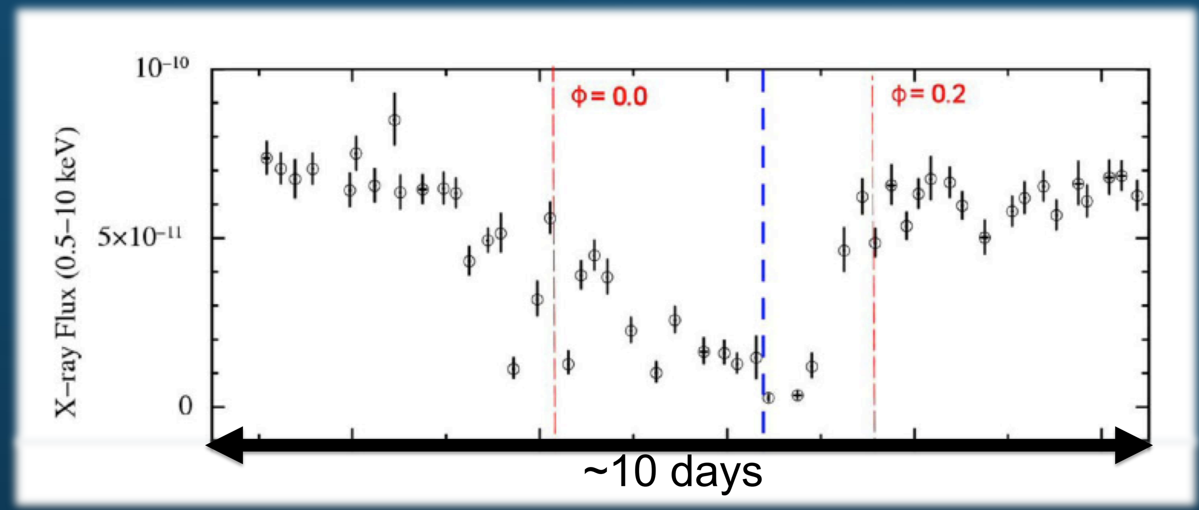

Figure 2: Swift/XRT monitoring of the eclipse feature seen in SXP5.05. The rapid variability is real and due to the non-uniform nature of the disk.

X-ray pulse timing of SXP5.05

By measuring the spin period of the accreting neutron star at various points during an extended X-ray outburst, one can see how the period changes around the orbit.

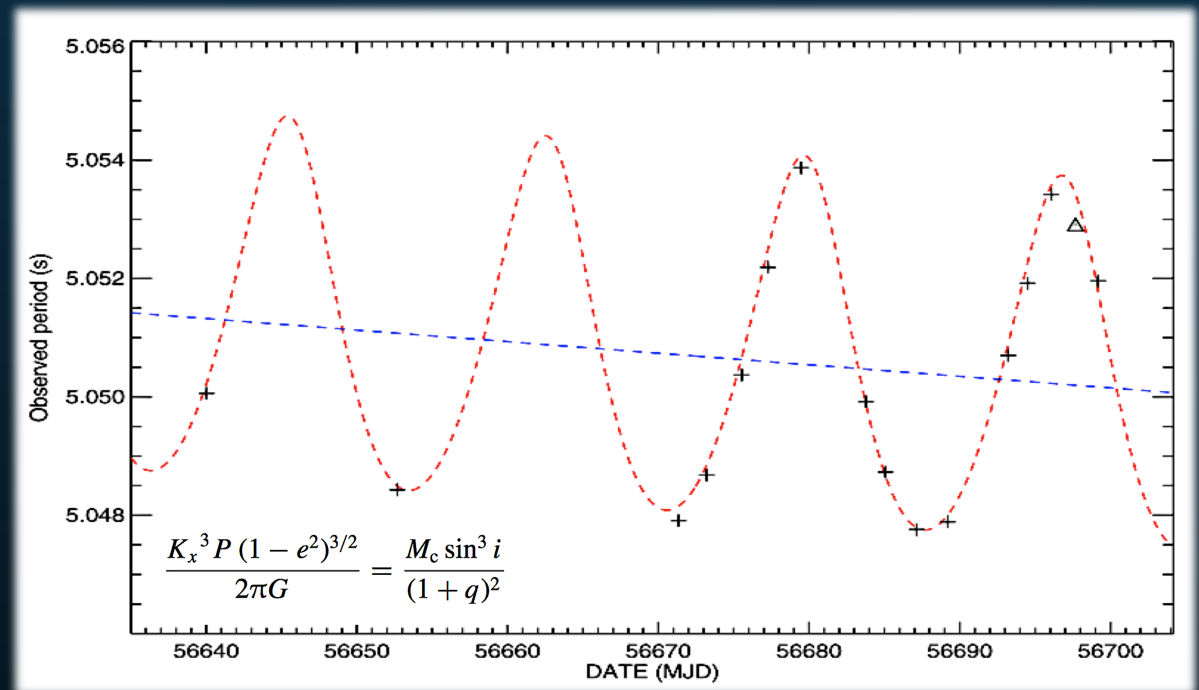

Figure 3: Spin period measurements of SXP5.05. The best fitting radial velocity model (red) and linear spin-up caused by accretion torques on the neutron star surface (blue) are over-plotted. The equation shows the X-ray mass function. The best fit yields the following values for the main binary parameters: P_{orbit} = 17.13 ± 0.14d, e = 0.16 ± 0.02, $a_x \sin i$ = 142 ± 3 light-seconds. The errors come from boot-strapping simulations.

VLT / UVES radial velocity of SXP5.05: Measuring the stellar masses

The eclipse measured in SXP5.05 gives us a very tight constraint on the system inclination of >83°, given a conservative estimate of the B0.2V donor star radius (Coe et al., 2015).

This, along with the measured X-ray mass function, means the only requirement to measure the masses in this system is a measurement of the optical mass function. The spectra required to do this form an active programme on VLT/UVES this semester. Once completed, we will have dynamical measurements of the stellar masses in a BeXRB for the first time.

SALT / HRS radial velocity programme

The new high-resolution spectrograph on the Southern African Large Telescope (SALT) was designed to have three resolution modes. We are using the low resolution mode (R~16000) to measure velocity amplitudes and eccentricities for a number of Galactic BeXRBs (Table 1). Figure 4 shows some very early data from this new instrument. When fully analysed, the data could help infer information about the natal supernova (see next section).

Source	Pspin (s)	Porb (d)	e	axsini (lt-s)	Sp Type
4U 0728-25	103.2	34.5	?	?	O8-9Ve
4U 1036-56	862	61.0	?	?	B0Ve
1A 1118-61	407.7	24.0	<0.16	54.9	O9.5Ve
4U 1145-61	292.4	186.5	>0.5	?	B1Ve

Table 1: Spin period, orbital period and spectral type of the four sources under observation. The aim is measure the eccentricity and semi-major axis for each source and place a constraint on the neutron star mass for 1A 1118-61 using the known X-ray mass function.

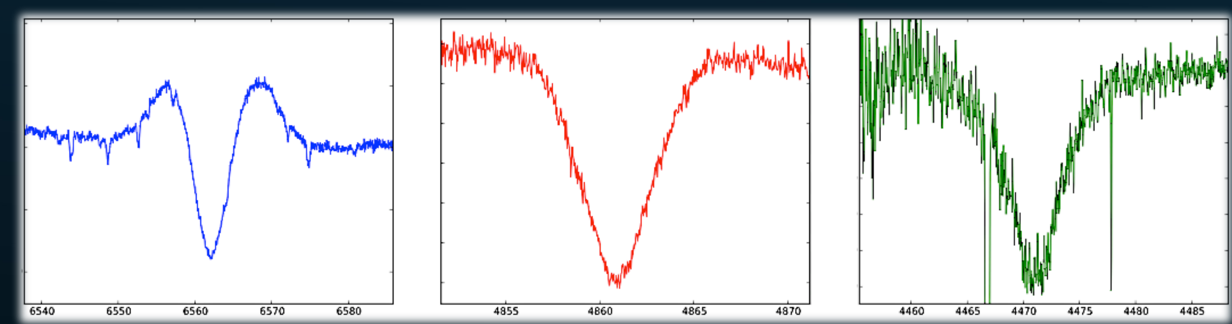

Figure 4: Detailed Hα, Hβ and HeI 4471 line profiles of 4U 1036-56 taken with SALT/HRS. Measuring radial velocities from the HeI and Fe lines in these spectra will give us the eccentricity and optical mass functions.

Implications and Conclusions

The discovery of a bi-modality in the distribution of orbital periods of BeXRB is proposed as tentative evidence of the population forming through two distinct channels of supernova: electron-capture and core-collapse (short and long period systems respectively; Knigge et al., 2011). This two-channel formation theory is also proposed to explain the small, but distinct group of BeXRBs with near-circular orbits; as opposed to the majority that have moderate to high eccentricities (Pfahl et al., 2002).

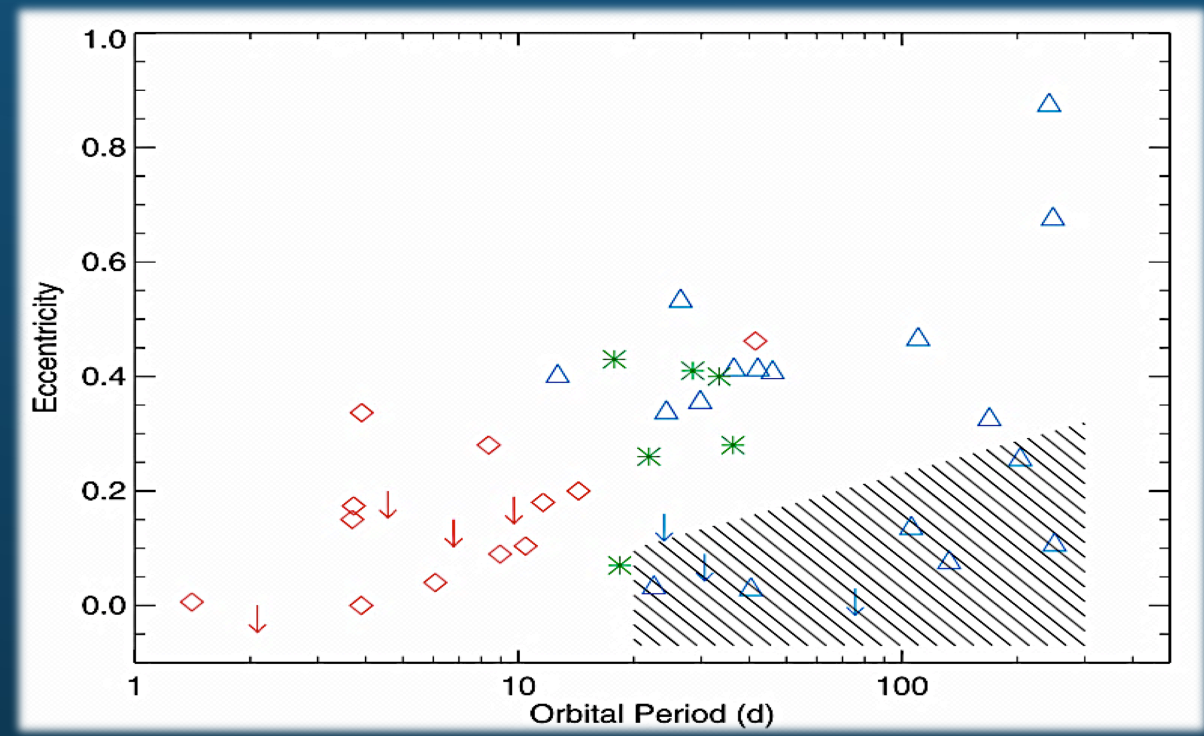

Figure 5: Orbital period vs. eccentricity for all HMXBs. BeXRBs are in blue and green. Supergiant systems are in red. The shaded area represents the "low eccentricity" regime proposed by Pfahl et al.

Placing the systems in Table 1 on Figure 5 will help determine whether the eccentricity distribution is continuous or bimodal and lead our ideas on their formation. SXP5.05 can also be placed on this diagram, and the additional measurement of the inclination in this system will allow for direct mass measurements in a BeXRB for the first time.

References

Casares, J. et al., 2014, Nature, 505, 378
Coe, M.J. et al., 2015, MNRAS, 447, 2387
Knigge, C. et al., 2011, Nature, 479, 372
Pfahl, E. et al., 2002, ApJ, 574, 364

Acknowledgements

I would like to thank the Claude Leon Foundation for supporting my research via their postdoctoral fellowship programme and for allowing me the opportunity to present my work through their post-doctoral travel grant.
I am also grateful to the University of Cape Town Research Committee for contributing towards my travel grant.