Modelling the Circumstellar Disks of Be Stars in X-ray Binary Systems in the SMC & LMC

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Abstract: In recent years, the number of High Mass X-ray Binary systems in the Magellanic Clouds has increased exponentially. Here we look at the systems in which the donor star is a Be type star, and in particular the circumstellar disks around them. Our aim is to gain a greater understanding of the dynamics, structure and behaviour of the disk through detailed Infrared analysis.

1. Background:

A Be/X-ray binary consists of a Be type main sequence star and an orbiting neutron star or black hole, as shown in Figure 1. In recent years, the Small Magellanic Cloud (SMC) has been found to harbour a very large population of these systems, many more than could ever have been expected from Galactic observations.

It is known that X-ray emission from these Be/X-ray binaries is due to the compact object passing through and accreting from the circumstellar disk surrounding the Be star, and so understanding the disk behaviour is essential in furthering our understanding of these systems.

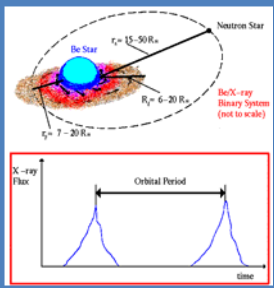


Figure 1: Schematic of a Be/X-ray binary system. The lower panel shows how the X-ray outburst can be used to measure the orbital period of the system.

It is also known that most of the Infrared emission from these systems comes from the disk, with almost no contribution from the star itself. Our aim is to use Infrared photometric data to study both the structure and dynamics of the disks, and to use this information to build models of each disk and to look at the population as a whole.

2. Data:

Simultaneous IR and optical photometric data were collected using the Japanese 1.4m IRSF telescope (Figure 2) and the 1m optical telescope at the South African Astronomical Observatory (SAAO). The 1m took images in the U, B, V, R & I bands whilst the IRSF took J, H & K band images.

Figure 2: The IRSF telescope at SAAO

The SIRIUS camera on the IRSF takes simultaneous J, H & K band images and is designed to take dithered images about the pointing position in a pre-programmed pattern: this is to remove the unwanted effects of bad pixels.

Figure 3 is an example of one of our X-ray activation histories produced from Lomb-Scargle analysis of RXTE PCA data. It is here to illustrate that not all of our systems emit X-rays periodically and so finding a way to use the disk to predict these random outbursts would be a very useful tool.

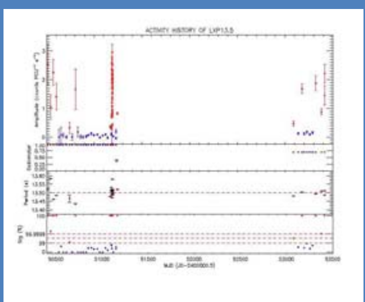


Figure 3: X-ray activation history of LMC X-4. The top panel shows the amplitude of each detection, with red being significant detections. The second panel shows where LMC X-4 was in the RXTE field of view (1 being the centre). The third panel is the pulse period of the source and the bottom panel is the significance of the detection.

3. Method:

The IR data was reduced using the Japanese SIRIUS pipeline in IRAF. This pipeline, designed specifically for IRSF data, flat fields and bias corrects the images and then recombines the dithered images to produce a final image. Figure 4 gives an example of this.

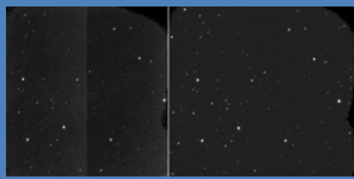


Figure 4: Raw J-band image of an SMC field (left). Reduced and recombined image from the SIRIUS pipeline (right).

The IRAF package DAOPHOT was used to do the necessary photometry on both the optical and IR data. This gives us the instrumental magnitudes of all the field stars. We then plotted these magnitudes against the magnitudes from the IRSF point source catalogue and used this as a calibration curve to get the actual magnitude of our target star.

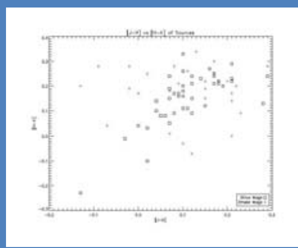


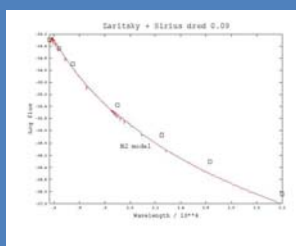
Figure 5: This colour-colour plot gives an idea of the sort of statistical analysis that can be done with our data. Here we show [J-H] vs. [H-K] for a sample of sources from the SIRIUS and 2MASS catalogues. You can almost believe that the SIRIUS data seem to be more correlated, but this is a bit tenuous and more work will be done in this area.

4. Results:

We are currently in the process of analysing these data and hope to be at the point where some interesting science can be done very soon. In this section I will show an example of a 'quick-look' analysis that can be done with the data.

Figure 6a shows optical and IR data points from the Zaritsky and Sirius catalogues plotted with the spectral model of that star. You can see that the U & B points in the top left match very well with the spectral model as there is no disk contribution here. As you move into the IR the points deviate from the stellar model, leaving us with an IR excess describing the disk.

Figure 6b shows this excess as a histogram. Here we fit a simple blackbody curve to the data, giving us an approximate temperature of the disk. This will obviously be done in more detail in the future as we would also like to be able to find temperature gradients in the disk.



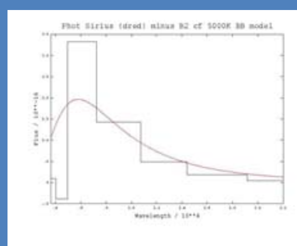


Figure 6a: Optical and IR band magnitudes plotted with the spectral model for a particular star (left). Figure 6b: Residual flux plotted as a function of wavelength with a blackbody model overlaid to get a temperature for the disk (right)

5. Summary/Future Work:

I have presented here early work on recently collected Infrared data from SAAO. The work is ongoing but I hope I have shown that good science can be achieved with this good quality photometric data and that we can learn a lot about disk dynamics as well as gaining an insight into the properties of these systems as a population. We plan to return to SAAO in the winter to collect follow-up Infrared photometric data along with H-alpha spectroscopic data, which we feel will further enhance our knowledge and improve disk models.

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