Modelling of Infrared emission from Cyg X-3 and the UKIRT IRCAM3 point spread function

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Abstract

Modelling of the point spread function of the UKIRT IRCAM3 array was conducted in order to test for any extended emission around the X-ray binary Cyg X-3. We found that the point spread function cannot be represented by a simple Gaussian, but modelling of the stars required additional functions, namely Lorentzian and exponential components. After modelling for the PSF, we found that Cyg X-3 could be represented by two stellar-type profiles, 0.56″ apart.

1 Introduction

Cyg X-3 has been studied for 30 years after its discovery in 1966. During that time, data from the radio, infrared and X-ray wavelengths has shown it to be a highly unusual source. This paper concentrates on the deepest infrared image of Cyg X-3 (Fender & Bell Burnell, 1996) and subsequent modelling of the profile of Cyg X-3.

The images were taken by Fender using the IRCAM3 array at the UKIRT telescope in July 1994. IRCAM3 is a 256 × 256 InSb imaging array, operating in the 1 – 5 μm wavelength range. The data here are composite images from the four bands: H, K, L and J.
2  H,K,L, J-band images

Figure 1 shows the four bands, H, K, L and J in the wavelengths 2.2, 1.65, 1.25 and 3.45 $\mu$m respectively. The images represent 355 individual frames with integration times between 2 and 25 seconds, binned up for a total integration time of 800 seconds. Stars in the K-band have fluxes ranging from 12 magnitude (Cyg X-3) to 18th mag for some of the faintest stars. The positions of the stars used in this paper were from north to south: Cyg X-3, Star Z and Star D. These are the three brightest stars in the images.

Fig. 1. H,K,L and J-band images of the Cyg X-3 field using the UKIRT IRCAM3 instrument.
2.1 *k-band image*

The k-band image, figure 2 or the finder chart provided by Fender (Fender & Bell Burnell 1996) was used for all the modelling done for the IRCAM PSF and the IR emission we are presenting. The points of interest are a slight extension to the west of Cyg X-e and that the image is not quite circular.

Modelling was then done using the Starlink *pisa* programme. A typical stellar profile from this image was obtained using the southern star, D. It is important to use a star which is well separated from the rest of the field as we are important in the faint extended emission. This template star has to also be


| Parameter | Value |
|-----------|-------|
| $\tau$    | 0.32  |
| $\sigma$  | 1.89  |
| $Q$       | 0.066 |
| $R_c$     | 2.02  |

Table 1

Parameters fitting the profile shown in figure 3.

bright enough so its image covered enough pixels. Star D was a good compromise between brightness and separation. With that as a template PISA fitted a profile as in figure 3. Parameters to the profile are shown in table 1, the meaning of which are explained below.

![Residuals plot](image1)

![Radial profile](image2)

Fig. 3. Profile fitted to the southern star 'D' in the K-band image.

These parameters correspond to a set of equations shown below. You see that the profile fits very well to the data. RA wobble in the telescope is shown in the profile plot by every 3rd point being slightly brighter than the mean profile.

3 Profile equations

The equation governing the profile and also the PSF of the IRCAM3 array can be expressed as:
\[ I_a = \frac{1}{\pi \sigma^2} \left( 1 + \frac{\tau}{2 \ln (1/\tau)} \right)^{-1} \left[ \frac{Q}{1 + r^2/(\sigma^2 \ln 2)} + (1 - Q) \exp \left\{ \frac{-r^2}{\sigma^2} \right\} \right] \]

For \( r \leq R_c \)

\[ I_b = \frac{1}{\pi \sigma^2} \left( 1 + \frac{\tau}{2 \ln (1/\tau)} \right)^{-1} \left[ \frac{Q}{1 + r^2/(\sigma^2 \ln 2)} + \frac{1}{\tau} (1 - Q) \exp \left\{ \left( \frac{-2r}{\sigma} \right) \left( \ln (1/\tau) \right)^{\frac{1}{2}} \right\} \right] \]

For \( r \geq R_c \)

where

\( \tau \) - Percentage of peak for crossover where the function changes from Gaussian to exponential.
\( \sigma \) - Gaussian sigma.
\( Q \) - Percentage of Lorentzian component.
\( R_c = \sigma (\ln (1/\tau))^{\frac{1}{2}} \) - Changeover radius from Gaussian to exponential.

The PSF can be modelled by three parts:

▷ Central Gaussian + Lorentzian modification
▷ Exponential tail-off + Lorentzian modification

inside a given radius, \( R_c \), (2 pixels) the profile is modelled by a Gaussian with the Gaussian being modified by Lorentzian wings. Outside a radius of 2 pixels, the profile has an exponential tail-off with the same Lorentzian wings.

Using the profile, PISA then searched the k-band image for all objects that had profiles of the template type and subtracted them from the image. After subtracting, PISA then re-fitted the image for any underlying stellar images and figure 4 shows the results of this.

Here PISA found emission out to a lower level (represented by the size of the circles) for all of the stars identified on the finder chart, except the star to the far west. We think that is because of the small dynamic-range for that star and even thought the peak is similar to other stars found, the background is higher and so it was not found.

The most interesting thing about this fit is that after re-iterating the image, PISA could fit an additional component to the Cyg X3 image, either in foreground or background. We are not sure whether this is a star co-incidental with Cyg X3 or whether it is an artifact of PISA.
Fig. 4. PISA fit for all 'stellar' images to the k-band image using the PSF described above. Units are pixels, 1 pixel=0.286′′

4 Results and conclusions

This paper attempts to model the UKIRT IRCAM3 point spread function based on the finder chart and H,L,J-band images. We find that a simple Gaussian function is not sufficient in modelling the PSF, and that one needs to include other functions. We find that a composite function of Gaussian with exponential tail-off together with a Lorentzian modification is sufficient in modelling the PSF.

When the PSF is applied to the K-band finder chart, one can fit two separate images to the image of Cyg X-3. These two images are separated by 0.56″ and have a flux ratio of 11:1 (left—right).

5 References

Fender R.P. & Bell Burnell S.J., 1996, A&A, 308, 497