Source of TeV gamma-rays in Cen X-3

H J Smit and B C Raubenheimer
Space Research Unit, Dept. of Physics,
PU for CHE, 2520 Potchefstroom, South Africa

1. Introduction

Imagine a celestial body, no bigger than New York City, giving off energy at a rate 10 000 times the total energy output of the sun. This would be enough to power over 400 million automobiles at 120 km/h for 10 billion years. This would give some idea of the bizarre properties of this relative newly discovered type of double star systems.

These X-ray binary systems consist of a very dense X-ray emitting source, orbiting closely around a much bigger normal star. Since so many discoveries have been made on these objects the last 25 years, it has become one of the most active branches of modern astronomy.

2. Periodic phenomena

This is of special importance in astronomy, not only because they convey immediate information about the physical nature of an object, but also because such periodicities can be measured with high precision to reveal subtle clues that can lead to new discoveries.

One such object which was observed in great detail all over the world is Cen X-3. Because of the regular increase and decrease in the pulseperiod of Cen X-3, it was realized that this source of X-rays was moving around an unseen companion star. Intensity variations further indicated that the source disappears behind the companion revealing a well defined eclipse.

Papers presented at the 3rd ASSA Symposium

3. Cen X-3

Cen X-3 is situated in the central plane of our galaxy, and its faintness is due to both distance and obscuring effects of interstellar matter. It is at a distance of 25 000 light years (8 kpc), and is approximately 12 million years old. The pulseperiod of the neutron star is 4.8 s, and its orbital period around the companion is 2.08 days. It is generally accepted that the pulseperiod in X-rays is roughly equal to the spinperiod of the neutron star. Another important parameter of this binary is the strong magnetic field with a strength of 10^{12} gauss.

4. Gamma-rays

Apart from the X-ray emission from this system, the production of high energy particles because of the strong magnetic field also takes place. These particles can then collide with other matter in the system to produce gamma-rays with energies in excess of 10^{15} eV.

If the X-rays and the gamma-rays are produced at the same spot in the system, then the pulse periods observed from both can be expected to be the same. On the contrary, many detections have been made of gamma-ray periods significantly different from the corresponding X-ray period. In Figure 1 the differences in the two pulse periods can be observed.

5. The model and results

Since the binary system Cen X-3 is an accreting system, a hypothesis that the source of TeV gamma-ray emission can be anywhere in the system, was introduced. The motion of the neutron star in the binary system, and subsequent Doppler effects, provide a means for testing this hypothesis. By correcting every arrival time of a TeV gamma-ray as if it originated at a position in the system, specified by values for the orbital phase and $a \sin(i)$, it was possible to test for source positions in the space domain of the

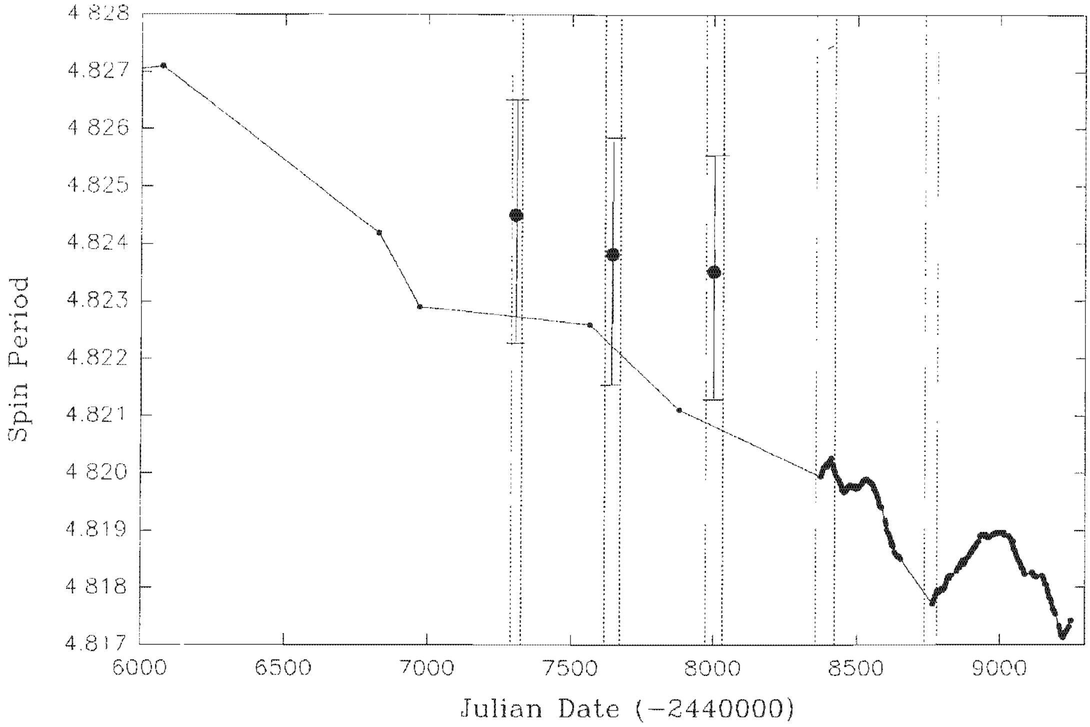

Figure 1. X-ray period history of Cen X-3. The dashed lines represent intervals when TeV gamma-ray observations were made with the Nooitgedacht Mk I telescope (De Jager et al. 1986). The TeV gamma-ray detections reported by North et al. (1990) are indicated as large dots.

binary. Data obtained by the Nooitgedacht Mk I telescope consisting of 59 observations from 1988 to 1992 were reanalysed. Results of these analyses showed emitting regions away from the neutron star. Four possible source regions were detected, of which the region with highest probability for emission of TeV gamma-rays is trailing the neutron star by 70±19° and is at a distance 0.93 ± 0.36 a sin (i) from the barycentre of the system. The source regions can be seen in Figure 2.

This region has a significance of 99.5% when the individual analysis of the observation taken on 3 April 1989 was carried out. By combining this result with the other 58, a better location of its position could be obtained. The combination result can be seen in Figure 3 (overleaf).

Evidence was also obtained that this source is constant in time, and that it can be associated with the detection of a period shifted signal at the position of the neutron star. The positions of the four

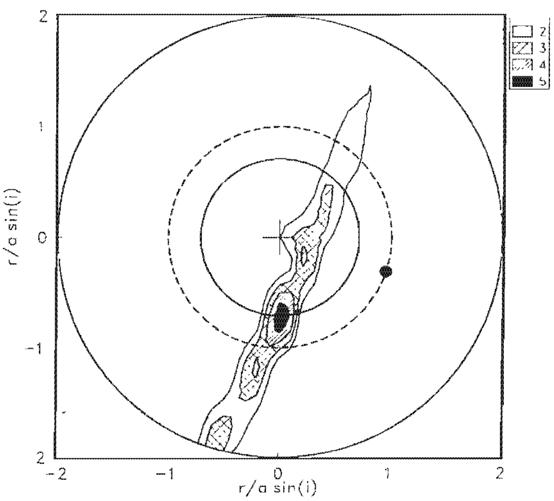

Figure 2. Probability contour in the orbit of Cen X-3 for the observation of 3 April 1989. The black dot indicates the position of the neutron star during the observation, and X-ray phase zero is at the top. The small full circle is the companion.

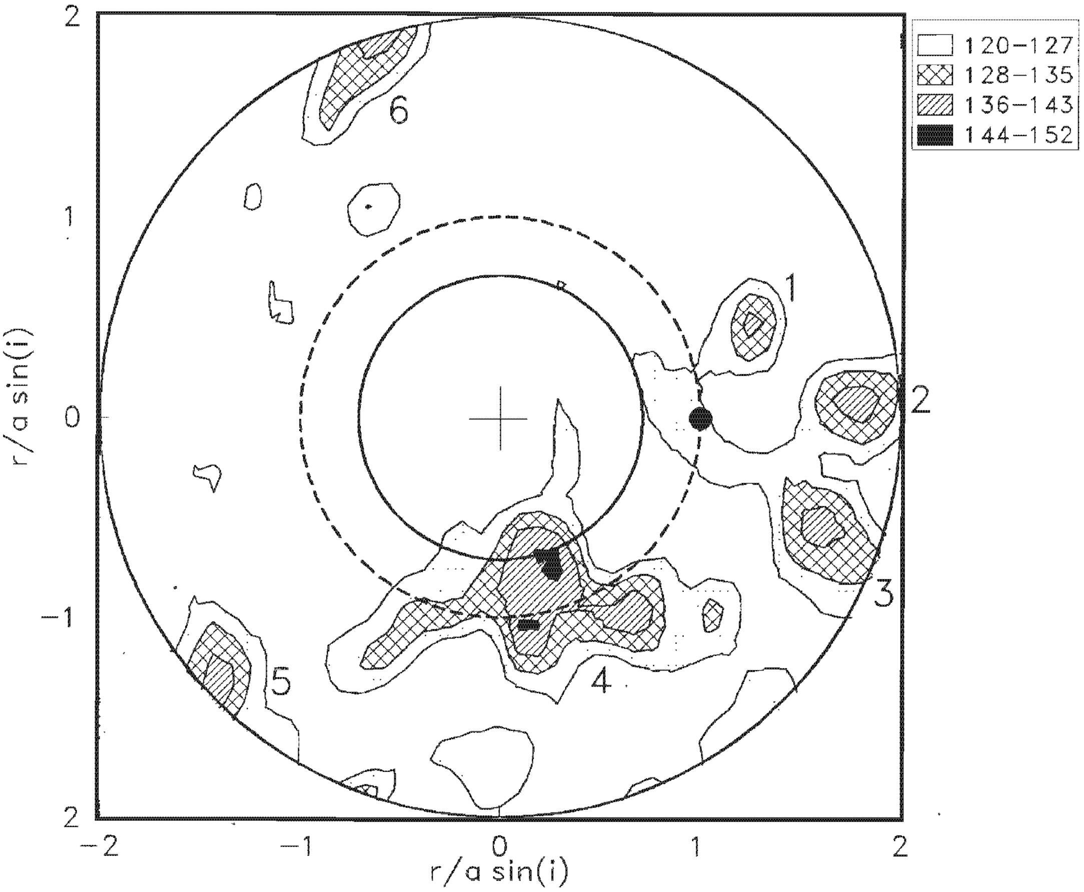

Figure 3. Combined result of all 59 observations of Cen X-3.

possible regions is in agreement with models of an accretion wake trailing the neutron star.

6. Conclusions

These detections confirm existing models on the possible source of the emission, and can explain the differences between the expected X-ray period and TeV gamma-ray period that has been measured by North et al. (1990) and Caraminana et al. (1989).