Part 11

Accreting Pulsars

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An Accretion Column Model for the Accreting Pulsar Hercules X-1

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Abstract. A model is developed here to reproduce the pulse shape of Her X-1. The 35-day cycle of pulse shape changes during the 35-day Her X-1 cycle "High – Low – Short High – Low" is caused by varying obscuration of the emission region by the accretion disk. The observed sequence of pulse shape changes imply a pencil beam from the near pole and a fan beam from the far pole. Using a newly developed code for modeling accretion column emission, including accurate treatment of gravitational light-bending effects, the observed pulse shape of Her X-1 is modeled here.

1. Introduction

Her X-1/HZ Her is an unusual accretion-powered pulsar system exhibiting a great wealth of phenomena. This eclipsing system contains a 1.24-second period pulsar in a 1.7 day circular orbit with its optical companion HZ Her (Leahy & Scott 1998). In addition, the system displays a longer 35-day cycle (Scott & Leahy 1999) that was first discovered as a repeating pattern of High and Low X-ray flux states. A Main High and Short High state, lasting about ten and five days each respectively, occur once per 35-day cycle and are separated by ten day long Low states. X-ray pulsations are visible during the High states but cease during the Low states.

The X-ray pulse profile evolution is discussed in Scott et al. (2000). The main conclusion, derived from the change in pulse shape due to occultation by the inner disk edge, was that the emission region was only consistent with a pencil beam from the near pole and a fan beam from the far pole (called the "reversed fan beam"). The purpose of this paper is to discuss results of calculating a model of the emission region and comparing it to the observed pulse shape.

2. Observed pulse shape, modeling and results

Her X-1 was observed during main high state in 1997 Sep by the *RXTE* PCA. Figure 1 shows the pulse shapes in the 2–5 keV, 5–9 keV and 9–14 keV bands derived from these observations. There is a central peak dominant at high energy and two side peaks dominant at low energy.

The emission region is an accretion column emitting from the top and sides. The top produces a pencil beam, and the sides produce a fan beam. Two accre-

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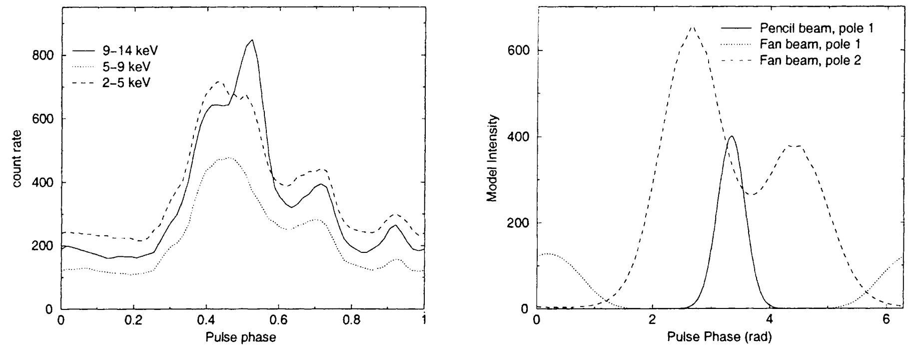

Figure 1. Observed pulse shape from Her X-1 in three energy bands (left); components of the model pulse shape for Her X-1 (right).

tion columns are located on the surface of the neutron star, one at each magnetic pole. The second column is offset from the axis of the first accretion column, which is necessary to produce the asymmetry in the observed pulse shape. Gravitational bending of light rays in their propagation from the accretion column to the observer is included in the calculations. Pulse shape models are discussed in Leahy (2004), which allow a variety of emissivities, including that of Meszaros & Nagel (1985). A 13.65 km radius and 1.4 solar mass neutron star were assumed. This is within the expected mass-radius relation for neutron stars (Heiselberg & Pandharipande 2000).

The parameters (height, width, etc.) of the accretion column and the orientation of rotation and magnetic axes of the neutron star were adjusted to give fan and pencil beam patterns which can reproduce the observed pulse shape. Figure 1 (right) shows the resulting fan and pencil beams from pole 1 and the fan beam from pole 2 (the pencil beam from pole 2 is not seen in the current orientation).

The emissivities of the pencil beam (surface normal to magnetic field) and of the fan beam (surface parallel to magnetic field) should be different: fan and pencil beams can combine in different ratios at different energies. Thus modeling of pulse shapes can not only give information on the geometry of emission regions but on the emissivities and the physics of the emission regions.

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