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Pulsating Soft Components in the Accreting X-ray Pulsars LMC X-4 and SMC X-1

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Abstract. We report here spectral study of two accreting binary X-ray pulsars LMC X-4 and SMC X-1 made with the *Beppo*-SAX observatory. The energy spectrum of both the pulsars in 0.1–10.0 keV band can be described by a model consisting of a hard power-law component, a soft excess and an iron emission line at 6.4 keV. In addition, the power-law component of SMC X-1 also has an exponential cutoff at $\sim$ 6 keV. Pulse-phase resolved spectroscopy confirms a pulsating nature of the soft spectral components in both the pulsars, with a certain phase offset compared to the hard power-law component. Dissimilar pulse profiles of the soft and hard X-ray components and a phase difference between the pulsating soft and hard spectral components give evidences for different origins.

Keywords : stars: neutron- Pulsars: individual: LMC X-4, SMC X-1 -X-rays: stars

1. Introduction

The X-ray continuum spectra of accreting binary pulsars are either described by a broken power-law or a power-law with high energy cutoff. The pulsars, which are away from the Galactic plane, experience less interstellar absorption and show the presence of a soft component in the X-ray spectra. The soft component is often described as a blackbody or a thermal bremsstrahlung type emission. In some pulsars, the soft excess is also found to pulsate, sometimes with a phase difference with respect to the hard component. Origin of the pulsating soft component is not yet understood clearly, at least for the bright pulsars in the Magellanic Clouds. It is, therefore, interesting to probe in detail the nature of soft components in case of pulsars in the Magellanic Clouds. To investigate the nature of soft component at different pulse phases, we have selected two bright accreting binary pulsars, LMC X-4 and SMC X-1 with pulse periods of 13.5 and 0.7 s, orbital

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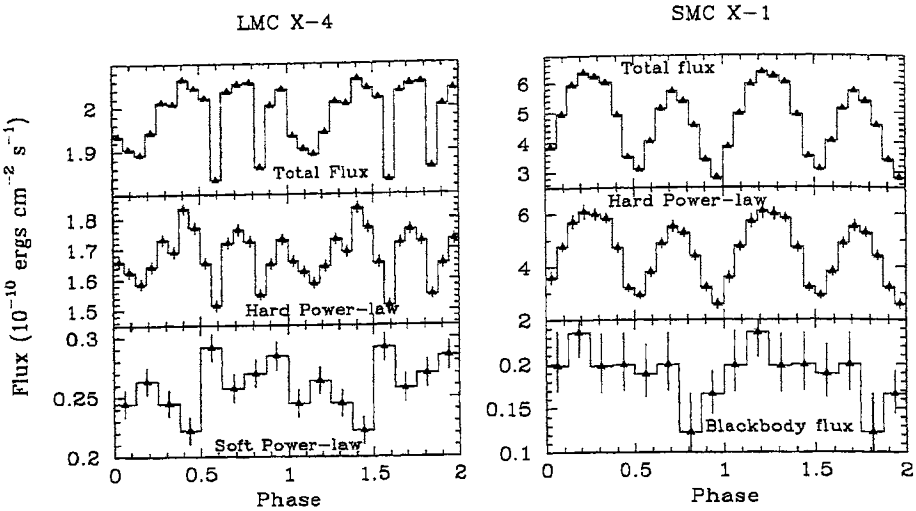

Figure 1. Modulation of the total flux, hard power-law flux and flux of the soft spectral component in 0.1 – 10.0 keV energy band of LMC X-4 (left panels) and SMC X-1 (right panels) obtained from the phase-resolved spectroscopy of the LECS and MECS spectra during the high intensity state of the super-orbital period. The lower panels are rebinned to 8 bins per pulse for clear visibility of the pulsations in the soft component.

periods of 1.4 and 3.9 days and super-orbital periods of 30.5 and 40–60 days respectively. The details of the *Beppo*-SAX observations, analysis and results are described in following sections.

2. Observations, Analysis and Results

The observations of LMC X-4 and SMC X-1 presented here were made with the *Beppo*-SAX narrow field instruments in 1997 March 13–15 and 1997 March 02 respectively. For a detailed description of the instruments in *Beppo*-SAX mission, we refer to Boella et al. (1997). Standard procedures for data selection and background estimation have been applied (as described in Naik & Paul 2003). For spectral fitting, the September 1997 LECS and MECS1 response matrices were used. Events were selected in the energy ranges 0.1–4.0 keV for LECS, 1.65–10.0 keV for MECS detectors. Combined spectra from LECS and MECS detectors were fitted simultaneously for both the sources. From spectral fitting, the presence of soft excess is clearly seen in both the sources. In case of SMC X-1, the soft excess can be fitted to a blackbody emission, but it requires two components e.g. a blackbody emission and a soft power-law component in case of LMC X-4.

For phase-resolved spectroscopy, the photon arrival times in the LECS and MECS event files were converted to the solar system barycenter and corrections were made for the arrival time delays due to orbital motion. Spectra were accumulated into 16 pulse phases. For the phase resolved spectra, the iron-line energy, line-width and N_H were fixed to their phase-averaged values and all the other spectral parameters were allowed to vary. The continuum flux and the fluxes of the soft and hard components in 0.1 – 10.0 keV energy range were estimated for all the 16 phase-resolved spectra. The modulation in the X-ray flux for the hard and soft spectral components and the total flux are shown in Figure 1 along with the 1σ error estimates. Pulse phase resolved spectral analysis shows that modulation of the the hard power-law flux is very similar to the pulse profile in 2.0–10.0 keV energy range. A pulsating nature of the soft-spectral component is clearly detected in both the pulsars irrespective of the spectral model used.

3. Discussion

A soft excess above the hard power-law component is now known to be present in several accreting pulsars and the soft component is also known to be pulsating in some of these sources. The soft excess has been modeled with several different types of emission, but no single model is applicable to all sources with soft excess. A black-body type pulsating soft excess can describe the emission from Her X-1 well (Endo et al. 2000). However, in case of the more luminous sources like SMC X-1 and LMC X-4, a large soft excess luminosity requires the blackbody emission region to be much larger than the inner accretion disk (Paul et. al. 2002). In some sources, a bremsstrahlung type of soft emission describes the spectrum well. However, for a bremsstrahlung type of emission giving rise to a large emission measures, the emission region has to be very large and the cooling time scale is also very large, such an emission is not expected to pulsate. In the present work with *Beppo*-SAX, we have obtained definite detection of pulsations in the soft excess in LMC X-4 and SMC X-1 irrespective of the spectral model used. The pulsating nature of the soft blackbody component with a certain phase difference compared to the hard component and heterogeneous pulse profiles at different energy bands suggest different origin of emission of the soft and hard components.

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