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Second neutron star in globular cluster M4

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Abstract. We show that the optical counterpart of the brightest X-ray source C-X 1 in M4 is a $\sim$ 20th magnitude star, located in the color-magnitude diagram on (or very close to) the main sequence of the cluster, and exhibiting sinusoidal variations of the flux. We find the X-ray flux to be also periodically variable, with X-ray and optical minima coinciding. Stability of the optical light curve, lack of UV-excess, and unrealistic mean density resulting from period-density relation for semidetached systems speak against the original identification of CX 1 as a cataclysmic variable. We argue that the X-ray active component of this system is a neutron star, probably a millisecond pulsar.

Key words. binaries:close - globular clusters: individual (M4) - X-rays: stars

1. Introduction

Globular clusters (GCs) contain a large population of exotic binary stars with degenerate components, many of these are X-ray sources with various degrees of activity. Numerous such sources have been detected by the Chandra space observatory in over 80 distinct clusters, providing a valuable tracer population for large-scale numerical simulations of cluster evolution (Pooley 2010). One of the clusters surveyed by Chandra is M4 (NGC 6121). Eight of the X-ray sources were classified as chromospherically active binaries, one as a cataclysmic variable (CV), and one as a millisecond pulsar PSR1620-26. The CV-candidate, referred as CX 1 is the brightest among them.

Bassa et al. (2004) identified it with a bright V555=17.37 star, located on the main sequence of M4 just below the turnoff. They argued that its X-ray luminosity is too high for an active binary composed of two main-sequence stars, while its optical luminosity is too low for an active binary with a subgiant. Their identification of CX 1 as a CV was additionally supported by its rather hard X-ray spectrum and a high ratio of X-ray and optical flux. Bassa et al. (2004) noted that the optical centroid of the bright star is offset by 2σ from the Chandra position of CX 1, so the identification might be questionable. If this were the case, the actual counterpart of CX 1 could be much fainter, possibly lost in the glare of the brighter star. Indeed, the examination of the M4 photometry published by Anderson et al. (2008) showed that the object was a blend of two stars. We demonstrate that the X-ray activity is associated with the much fainter and redder component of the blend, and CX 1 is a millisecond pulsar or qLMXB rather than a CV.

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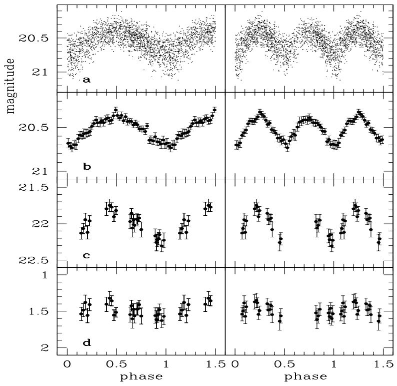

Fig. 1. Optical light curves of star 5274 phased with the ephemeris with P_1 - left column, and with P_2 - right column. (a) Ground-based, V-band; (b) the same data but binned 50 bins per period; (c) archival *HST* data; (d) color index.

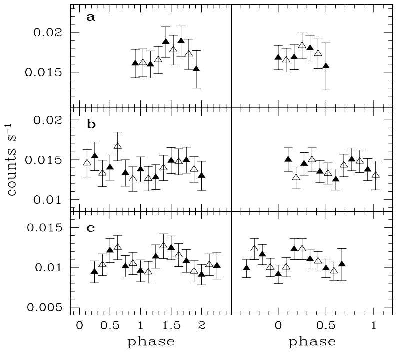

Fig. 2. X-ray light curves of CX-1. Left column: counts phased with the ephemeris with P_1 - left column, with P_2 - right column. Filled triangles represent counts binned in four intervals per period. Empty triangles: the same binning, but the bins are shifted by $\Delta\phi = 0.125$.

2. Observations

The M4 was observed in nine seasons between 1995 and 2009 as one of the objects included in the CASE project (Kałużny et al. 2005). The optical counterpart of CX 1 turned out to be a low-amplitude periodic variable with a stable light curve, suggestive of an ellipsoidal and/or irradiation effect. The analysis of variance yielded a period $P_1 = 0.2628216(1)$ days (Kałużny et al. 2012). There is an ambiguity concerning the period: a value $P_2 = 0.5256432(1)$ days is also acceptable, Fig. 1. *HST* archive contains four images taken with F814W filter with Texp= 40s. We extracted the photometry of both components of the pair and checked which one was variable. Star 5273 was constant within observational error, while star 5274 exhibited fluctuations with an amplitude of 0.5 mag. We found that the maxima of light curve were bluer by 0.2 mag than the minima, Fig. 1. Such behavior is indicative of the irradiation effect, which produces a light curve with one maximum per orbital period, as is observed when P1 is used in phasing. P2 produces two maxima per period - a feature characteristic of the ellipsoidal effect. M4 was observed three times with ACIS-S on Chandra (Kałużny et al. 2012). The resulting X-ray light curves are shown in Fig. 2. They exhibit a modulation similar to that of the optical light curves, with a minimum near 0. Spectral fitting of three combined observations from Chandra show smaller hardness ratio that in Bassa et al. (2004).

3. Conclusions

Thus, the available data favour the possibility that CX 1 is composed of a neutron star accompanied by a 0.6 Solar masses main sequence star or a partially ablated, slightly oversized 0.4 Solar masses star. If this interpretation is correct, then it must be a millisecond pulsar or a qLMBX. The X-ray luminosity and hardness ratio support the first possibility; in fact they locate CX 1 among the brightest millisecond pulsars in Fig. 6 of Bogdanov et al. (2010).

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