The eclipsing massive X-ray binary M33 X−7: New X-ray observations and optical identification

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The eclipsing X-ray binary M33 X−7 was in the field of view during several observations of our XMM-Newton M33 survey and in the archival Chandra observation 1730 which cover a large part of the 3.45 d orbital period. We detect emission of M33 X−7 during eclipse and a soft X-ray spectrum of the source out of eclipse that can best be described by bremsstrahlung or disk blackbody models. No significant regular pulsations of the source in the range 0.25−1000 s were found. The average source luminosity out of eclipse is 537 (0.5−4.5 keV). In a special analysis of DIRECT observations we identify as optical counterpart a BOI to O7I star of 18.89 mag in V which shows the ellipsoidal heating light curve of a high mass X-ray binary with the M33 X−7 binary period. The location of the X-ray eclipse and the optical minima allow us to determine an improved binary period and ephemeris of mid-eclipse as HJD (245 1760.61±0.09)±N×(3.45376±0.00021). The mass of the compact object derived from orbital parameters and the optical companion mass, the lack of pulsations, and the X-ray spectrum of M33 X−7 may indicate that the compact object in the system is a black hole. M33 X−7 would be the first detected eclipsing high mass black hole X-ray binary.

Galaxies: individual: M33 - X-rays: individuals: M33 X−7 - X-rays: binaries - binaries: eclipsing

Introduction M33 X−7 (hereafter X−7) was detected as a variable source with a luminosity brighter than 38 in Einstein observations 1981ApJ...246L..61L,1983ApJ...275..571M,1988ApJ...325..531T,1989ApJ...336..140P suggested that the X−7 variability pattern can be explained by an eclipsing X-ray binary (XRB) with an orbital period of 1.7 d and an eclipse duration of ~ 0.4 d. This finding was the first identification of a close accreting binary system with an X-ray source in an external galaxy other than the Magellanic Clouds. It was confirmed combining Einstein observatory and first ROSAT data 1993ApJ...408..678,1994ApJ...426L..58S. With the inclusion of more ROSAT and ASCA data 1999MNRAS.302.731D99 [1] hereafter 1999MNRAS.302.731D1997AJ....113..618L,1999MNRAS.302.731D the orbital period turned out to be twice as long. The shape of the eclipse could be described by a slow ingress (∆Φ ingress = 0.10 ± 0.05), an eclipse duration of ∆Φ eclipse = 0.20 ± 0.03, and a fast eclipse egress (∆Φ egress = 0.01 ± 0.01) with an ephemeris for the mid-eclipse time of HJD 244 8631.5±0.1 + N×(3.4535±0.0005). In addition, 1999MNRAS.302.731D discovered evidence for a 0.31 s pulse period. The orbital period, pulse period and observed X-ray luminosity are remarkably similar to those of the Small Magellanic Cloud neutron star XRB SMC X−1 2000AAS.147...25L. However, if the pulse period of X−7 can not be confirmed, the source could also resemble high mass black hole XRBs (BHXB) like LMC X−1 or LMC X−3. It would be the first eclipsing object within this rare class of XRBs.

The position of X−7 correlates with the dense O−B association HS13 1980APJS...44..319H and therefore no individual counterpart could be identified based on position only. However, its location in HS13 is consistent with the expectation of a massive companion. As 1999MNRAS.302.731D point out, the optical counterpart is likely to show ellipsoidal and/or X-ray heating variations 1986AA...154...77T which can be used for the optical identification.

Variable optical sources within M33 were systematically searched for in the DIRECT project 2001AJ....122.2477MMO1b [see e.g.| hereafter 2001AJ....122.2477M]2001AJ....122.2477M. Many eclipsing binaries, Cepheids, and other periodic, possibly long-period or nonperiodic variables were detected. X−7 is located in DIRECT field M33B. The variability of the optical counterpart was not detected in the previous analysis due to the limitations of the variable search strategy for such small amplitude variables in crowded regions.
As a follow-up of our study of the X-ray source population of M33 based on all archival ROSAT observations 2001AA...373.438HH01, we hereafter 2001AA...373.438H[2001AA...373.438H, we planned a deep XMM-Newton raster survey of M33 based on 22 Telescope Scientist guaranteed time (proposal no 010264) and AO2 (proposal no 014198) observations, each with a duration of about 10 ks [for first results see][2003AN....324...85P. X−7 was covered in 13 of these observations at varying off-axis angles and covering different orbital phases.

In this paper we report on time and spectral variability of X−7 within the XMM-Newton raster survey. We add results from an archival Chandra observation, which covered the source, and a dedicated timing analysis of the DIRECT data of the HS13 region.

X-ray observations and results table center M33 X−7 observations with the observatories XMM-Newton (proposal numbers 010264 and 014198) and Chandra (1730). Besides observation 0102642101, where M33 X−7 was only in the field of view of the MOS detectors, for XMM-Newton we give EPIC PN count rates, hardness ratios and luminosities. For the low state observations, no hardness ratio could be determined.

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<thead>
<tr>
<th>Obs. id.</th>
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<th>Count rate</th>
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For the detailed analysis of X−7 we mostly used data from XMM-Newton EPIC. From the M33 observations in the Chandra archive only the observation with identification no 1730 covered the X−7 field. Table observations summarizes the observation identifications (Col. 1), observation dates (2), elapse time (3), extraction radius Rext used for count rates, light curves, and spectra (4), X−7 raw count rates in the 0.5–4.5 keV band (5), hardness ratios (6), and luminosities in the 0.5–4.5 keV band (7). For the XMM-Newton observations, values in columns 4 to 7 correspond to the EPIC PN detector if not indicated differently, since it gives about twice the number of photons than the EPIC MOS cameras. Off axis angle of X−7 (8) and phase coverage within the binary orbit according to the ephemeris of 1999MNRAS.302..731D (9) are also given. As hardness ratio (HR) we use the ratio of the counts in the 1.2–3.0 keV band to the counts in the 0.5–1.2 keV band. Luminosities were determined from thermal bremsstrahlung spectra (see Sect. 2.3). During observations 0102640101 and 0102641101 X−7 was in low state and source statistics did not allow us to derive hardness ratios. For these observations we assumed that the source spectrum was similar to the spectrum during observation 0102642301 and scaled the source luminosity from the vignetting corrected count rates.

In the XMM-Newton observations 2001AA...365L...1J the EPIC PN and MOS instruments 2001AA...365L..1SS, 2001AA... were mostly operated in the full frame mode resulting in a time resolution of 73.4 ms and 2.6 s, respectively. Only for the first two observations in Table observations, the PN detector was operated in the extended full frame mode (time resolution 200 ms) and during observation 0102640101 the MOS detectors were operated in the small window mode (0.3 s time resolution for the inner CCDs). The medium filter was in front of the EPIC cameras in all but the first two observations which were performed with the thick filter. We used all EPIC instruments for imaging, position determination and for the timing and spectral investigations of X−7. In most of the observations the source is located at high off-axis angle (see Table observations), and could be outside of the field of view in some of the cameras. Also, the cameras normally cover different times. The XMM-Newton point spread function (PSF) required extraction radii Rext larger than 225 to encircle > 80% of the source photons. Depending on the location of the source, counts could be missing due to CCD gaps. Many of the XMM-Newton observations suffer from times of high particle background. To be able to also use these times to cover as much as possible of the X−7 binary orbit, we restricted the energy band for light curve and hardness ratio analysis to 0.5–3.0 keV where the source is brightest.

Four Chandra ACIS observations 2000SPIE.4012...2W of M33 were obtained from the Chandra Data Archive (http://asc.harvard.edu/cgi-gen/cda). However, only the ACIS I observation 1730 (see Table observations) covered the X−7 field. The instrument was operated in the full frame mode (3.2 s time resolution). X−7 is positioned in the outer corner of the front-illuminated CCD chip I2 during the observation.

The deep space orbits of the satellites XMM-Newton and Chandra led to long continuous observation times of X−7. The low earth orbits of the Einstein, ROSAT, ASCA and BeppoSAX observatories on the other hand, led to observations split in many short intervals of typically less than 1 500 s.

The data analysis was performed using tools in the SAS v5.4.0, CIAO v2.3, EXSAS/MIDAS 1.2/1.4, and FTOOLS v5.2 software packages, the imaging application DS9 v2.1b4, the timing analysis package XRONOS v5.19 and spectral analysis software XSPEC v11.2.
For the time variability investigations all X−7 event times were corrected to solar system barycenter arrival times.

Time variability figure! XMM-Newton EPIC light curves and hardness ratio of M33 X−7 during observations 0141980801, 0102641201, and 102642301 with time zero corresponding to HJD 245 2683.14827, 245 1758.79473, 245 2301.91542, respectively (solarsystembarycentercorrected). Count rates −0.23, 0.54 − 0.58, and 0.81 − 0.85 (left to right, ephemeris of 1999 MNRAS.302..731D). epicc