XMM-Newton observation of XTE J1807-294

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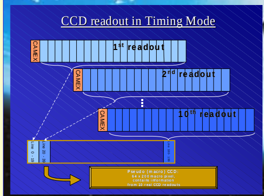
XMM-Newton

- 3 instruments (EPIC, RGS, OM)
- EPIC: 3 cameras (2 MOS, 1 pn)
- Pn-camera: 5 modes to accommodate brightness and improve time resolution

EPIC-pn:

- Energy range: 0.15 - 15 keV
- Energy resolution 130 eV @ 6 keV
- time resolution: 30/7 µs
- rel. timing accuracy: $\Delta P/P \sim 10^{-9}$
- abs. timing accuracy: 300-600 µs
- sensitivity (after 10 ks): 10^{-14} erg s^{-1} cm^{-2}
- angular resolution: 6'' (FWHM)
- effective area (at 1 keV): 1300 cm^2



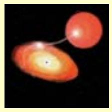
Timing Mode:

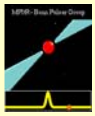
- time resolution
- pile-up limit for a point source is 1500 cts/s, corresponding to a maximum flux of 160 mCrab.
- provides only spatial resolution in one dimension and hence a point source is smeared out in the Y-direction.

accreting ms pulsars

general

- missing link between X-ray binaries and ms radio pulsars
- ms pulsars possible end state of low-mass X-ray binary (LMXB) evolution
- neutron star in LMXB spin-up due to accretion toque to millisecond period while losing its magnetic field, due to accretion matter from its stellar companion
- at the end of accretion phase, it may turn on as a radio millisecond pulsar





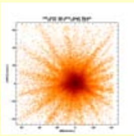
features

- short period
- X-ray transients
- ultra-compact binary systems, orbital period < 4 h
- binary parameters imply ~0.01 M_{sun} white dwarf donors with moderately high inclination
- extremely low mass transfer rates (M': 10^{-10} M_{sun}/year) provide easy detection during out-burst phase, otherwise difficult to detect due to magnetic screening by freshly accreted matter onto the neutron star which can prevent the formation of persistent X-ray pulses when the accretion rate reaches a critical limit (Cumming, Zweibel & Bildsten 2001).
- weak magnetic fields (SAX J1808.4-3658 1-5 10^8 Gauss, Di Salvo & Burderi 2003, measured from source luminosity in quiescence)

known objects

- SAX J1808.4-3658: first evidence of spun-up neutron star by mass accretion in LMXB
  (Wijnands & van der Klis 1998) P_{spin}: 2.49 ms, P_{orb}: 120 min
- XTE J1751-305
  (Markwardt & Swank 2002) P_{spin}: 2.30 ms, P_{orb}: 42.0 min
- XTE J0929-314
  (Remillard, Swank & Strohmayer 2002) P_{spin}: 5.41 ms, P_{orb}: 43.6 min

- **XTE J1807-294**
  (Markwardt, Smith & Swank 2003) P_{spin}: 5.25 ms, P_{orb}: 40.07 min



MOS1 Small Window mode image. Due to the extremely high brightness of the source, the mirror support construction of the XMM-Newton X-ray mirrors is reflected in the X-ray image as a number of radially oriented 'spokes'.

  - **Feb. 21 2003:** discovered by RXTE (Markwardt et al., IAUC/ 8080)
  - **March 10:** Chandra best fit position R.A. = 18h06m59.80s, DEC= -29°24'30" (equinox 2000.0; uncertainty about 1")
  - **March 16:** orbital period: 40.0741 +/- 0.0005 minutes (Markwardt et al.) → shortest period of any of the four accreting millisecond pulsars
  - **March 22:** ToO observation XMM-Newton (01579601)

- XTE J1814-338 P_{spin}: 3.18 ms, P_{orb}: 4.275 h
  (Strohmayer, Markwardt, Swank, et al.2003)

Note: sources are ordered by date of discovery

summary

- The accreting millisecond pulsar XTE J1807-294, discovered by RXTE on February 21, was observed as Target of Opportunity (ToO) by *XMM-Newton* on March 22, 2003 using the EPIC camera with an exposure of 9 293 s. The source was detected in bright phase with an observed count rate of 33.3 cts/s in the pn-camera in the 0.5-10 keV band (3.7 mCrab).
- Using the best-fit orbital period of 40.0741 ± 0.0005 minutes reported by Markwardt et al. (ATEL #127) and assuming a circular orbit as first approximation, we derived 4.8 ± 0.1 light-ms for the projected orbital radius and an orbital phase of 52720.67415(16) (MJD).
- The barycentric mean spin-period of the pulsar was derived as 5.2459427 ± 0.0000004 ms.
- X-ray pulse profiles of XTE J1807-294 showed both energy and orbital phase dependence. Pulse profiles of XTE J1807-294 show orbital phase dependent changes and variation of pulsed fraction. These effects are also seen in other X-ray pulsars due to geometrical effects with respect to the line of sight and physical conditions of the pulsar (Wang & Welter 1981). The sudden increase of the pulsed fraction value, particularly during phase 3 in orbit 2, decreases gradually during subsequent orbits and is caused very likely by a sudden but marginal increase in mass accretion. This causes an increase in the pulsed fraction of the pulsar which then gradually decreases due to the reduction of accreting matter and hence the pulsed fraction when neutron star poles are visible at the line of sight corresponding to a particular orbit phase 3.

spectral variation

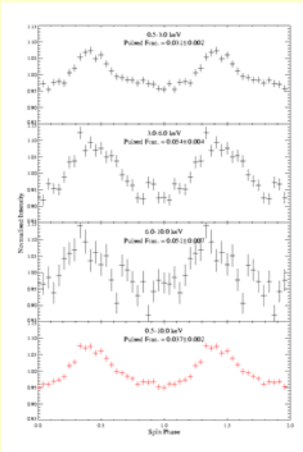


Figure 1:
Folded spin light curves of XTE J1807-289 in different energy ranges. From top to bottom: 0.5-3.0, 3.0-6.0, 6.0-10.0 and 0.5-10 keV. The pulse profile is shown twice for clarity

- **data analysis:**
  The accreting millisecond pulsar XTE J1807-294, discovered by RXTE on February 21, was observed as Target of Opportunity (ToO) by *XMM-Newton* on March 22, 2003 using the EPIC camera with an exposure of 9 293 s. The data were processed with *SAS 5.4.1*. Event times were corrected to the solar system barycentre with the *SAS* tool *barycen*. In the *Timing* mode of the pn camera, a point source will be completely smeared out in the DETY direction. Hence, this mode provides only one-dimensional spatial information.Therefore, we used a nine column (37 arcsec) wide source extraction region centred on the source, consisting of CCD columns 33-41. CCD columns 03-11 were used for the background extraction region. An average counting rate of 33.7cts/s was detected from the source in the 0.5-10 keV band (3.7 mCrab), while an average background of 0.4 cts/s was detected.
- **orbital parameters determined by χ^2-grid search:**
  Using the best fit orbital period of 40.0741 ± 0.0005 minutes, and assuming a circular orbit, the relevant orbital parameters (projected orbital radius x_0, and orbital phase t_0) were determined through maximum χ^2-epoch folding using 6 bin pulse profiles to $x_0 = 4.8 \pm 0.1$ light-ms and $t_0 = 52720.67415(16)$ (MJD).
- **spin period**
  the barycentric mean spin period of the pulsar using the above mentioned orbit parameters was found at **5.2459427 ± 0.0000004 ms**.
- **epoche folding:**
  By epoch folding the data with the derived period with respect to the epoch at MJD 52720.72457, we established spin pulse profiles in four different energy bands between 0.5-10 keV as shown in Figure1. These profiles show a very prominent primary pulse (1.5 ms FWHM) and indications of a much weaker secondary pulse. The shapes and relative strengths of these profiles vary with energy. In the 3.0-6.0 keV band the secondary pulse is most prominent, with a 3-sigma significance with respect to the pulse minimum.

orbital variation

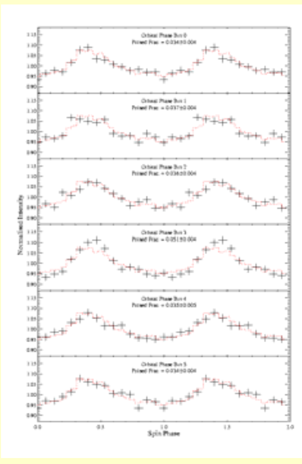


Figure 2:
Folded light curves of XTE J1807-289 at different orbit phases in the energy range 0.5-10 keV. Orbit phase 0 relates to t_0-44.08 s

variation of the spin pulse profile with the orbit :

- To study the variation of the spin-pulse profile with orbital phase, we grouped the data in six different phases covering the complete binary orbit, where phase 0 starts at t_0-44.08 s. The folded light curves corresponding to six orbital phases derived for the 0.5-10.0 keV energy band are shown in Figure 2. The spin-pulse profile corresponding to orbital phase 3, shows a significantly higher pulsed fraction.
- We then performed a detailed analysis for each of the four observed orbits and detected a significantly higher pulsed fraction corresponding to orbital phase 3 of orbit 2, which gradually declines during orbits 3 & 4. Figure 3 gives the pulsed fraction calculated for six orbital phases for all the four binary orbits in the 0.5-3.0 keV energy band.

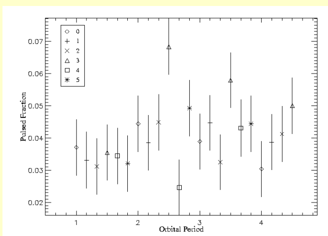


Figure 3:
Pulsed fraction values for 6 orbital phases indicated by different symbols for all the four orbits in the 0.5-3.0 keV energy band.

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