



# Orbital evolution and search for eccentricity and apsidal motion in the eclipsing HMXB 4U 1700–37

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## Abstract

In the absence of detectable pulsations in the eclipsing HMXB 4U 1700–37, the orbital period decay is necessarily determined from the eclipse timing measurements. We have used the earlier reported mid-eclipse time measurements of 4U 1700–37 together with new measurements from long term light curves obtained with the X-ray all sky monitors RXTE–ASM, Swift–BAT and MAXI–GSC, as well as observations with RXTE–PCA, to measure the long term orbital evolution of the binary. The orbital period decay rate of the system is estimated to be  $\dot{P}/P = -(4.7 \pm 1.9) \times 10^{-7} \text{ yr}^{-1}$ , smaller compared to its previous estimates. We have also used the mid-eclipse times and the eclipse duration measurements obtained from 10 years long X-ray light curve obtained with Swift–BAT to separately put constraints on the eccentricity of the binary system and attempted to measure any apsidal motion. For a reasonable rate of apsidal motion for this binary system, the eccentricity is found to be less than 0.008, which limits our ability to determine the apsidal motion rate from the current data.

## Curious case of HMXB 4U 1700–37

- ▶ 4U 1700–37 is an eclipsing HMXB with an orbital period of 3.412 days and eclipse lasting 1/5th of its orbital period.
- ▶ The companion star HD 153919 is a massive O6f star.
- ▶ The compact object is likely to be a neutron star. However, in the absence of pulsations, this can not be confirmed.
- ▶ Estimation of the orbital parameters using radial velocity measurements of the companion star HD 153919 from the ultraviolet and optical spectral lines was complex due to extreme mass loss rate of the companion as well as very high stellar wind.
- ▶ Apsidal advance rate

$$\dot{\omega} = 360 \times k \left( \frac{R_*}{a} \right)^5 (15qg(e) + \Omega^2(1+q)f(e)) \text{ deg/cycle}$$

- ▶  $q \sim 0.04$ ,  $R_* \sim 22 R_\odot$ ,  $a \sim 43 R_\odot$ ,  $\dot{\omega} \sim 10$  degrees/year. **Indication of a highly precessing system.**

## Why do orbits of X-ray binaries evolve ?

- ▶ The orbits of X-ray binaries evolve due to various mechanisms like
  - ▶ Mass and angular momentum exchange between the compact object and the companion star.
  - ▶ Tidal interaction between the binary components.
  - ▶ Stellar wind driven mass and angular momentum loss.
  - ▶ Gravitational wave radiation.
- ▶ In addition to orbital period evolution, the elliptic orbits of X-ray binaries also undergo apsidal motion, due to tidal interactions.

## Present Work

- ▶ Mid-eclipse epoch measurements of 4U 1700-37 obtained from previous measurements along with long term light-curves from all sky monitors
  - ▶ 16 years of RXTE ASM light-curves in 5-12 keV energy band, subdivided into 3 light-curves segments
  - ▶ 10 years of Swift BAT light-curves in 15-50 keV energy band, subdivided into 3 light-curves segments
  - ▶ 5 years of MAXI light-curves in 5-20 keV energy band
  - ▶ 11 orbital cycles coverage of eclipse with RXTE PCA

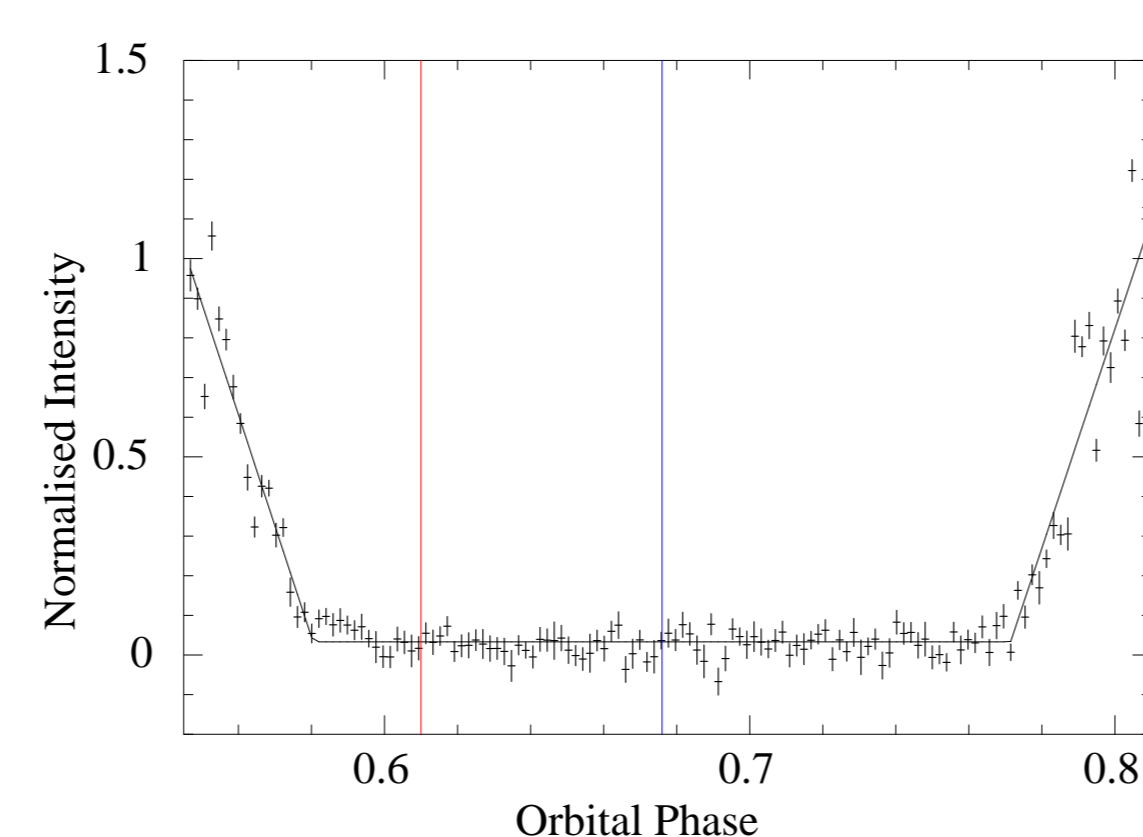


Figure : The orbital intensity profile near the eclipse is fitted with an asymmetric step and ramp function.

## Systematic errors on EXOSAT GSPC and RXTE PCA

- ▶ Presence of flares leads to an uncertainty in the mid-eclipse epoch.
- ▶ The error of 0.003 days for an EXOSAT mid-eclipse epoch used in earlier works, is an underestimate of the actual error.
- ▶ The mid-eclipse times measured from the long light-curves of the all sky monitors do not suffer from the uncertainties due to individual flares, because of averaging effects of continuous observations.

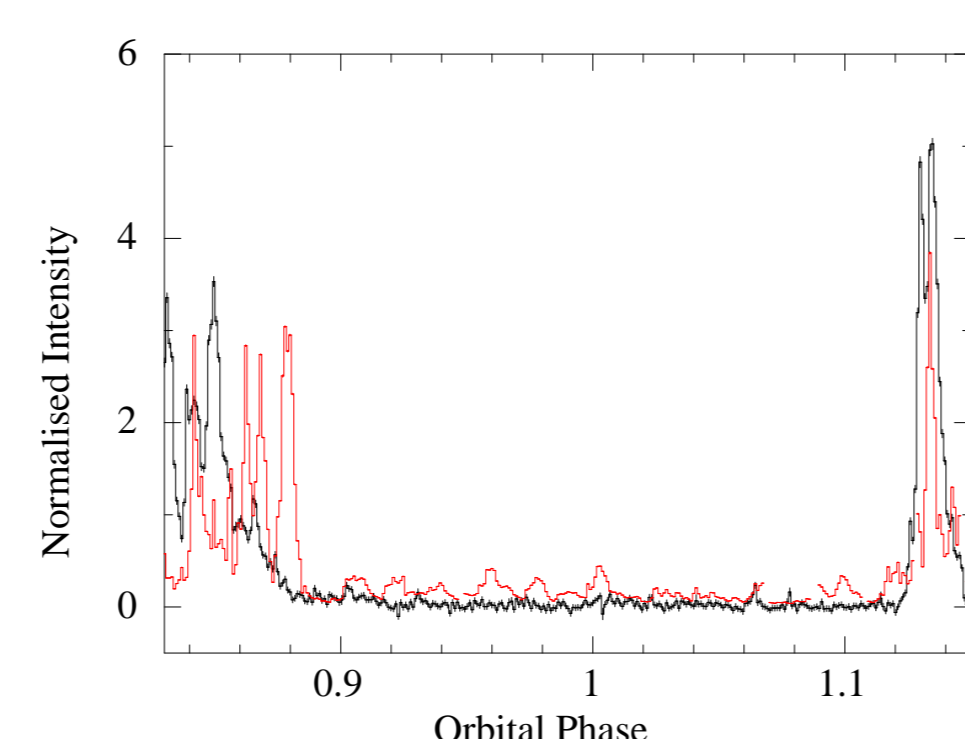
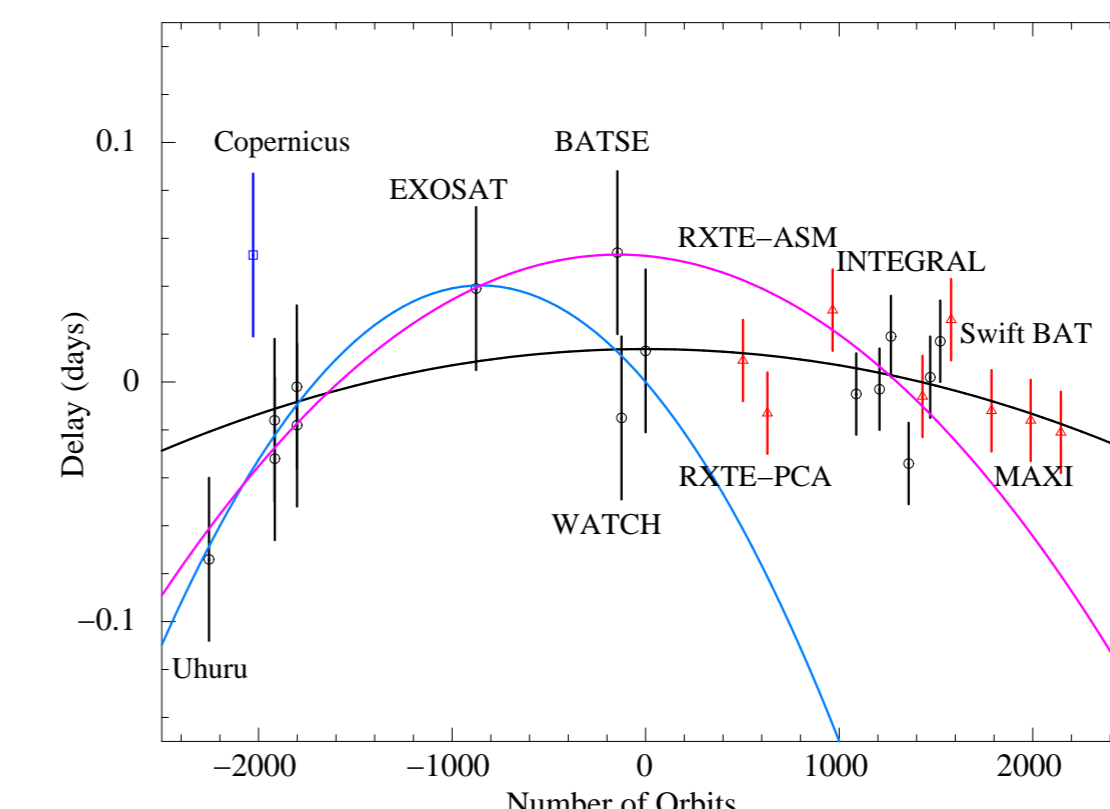


Figure : Light-curve of EXOSAT GSPC 8-14 keV are extracted and are used to create the orbital intensity profile (black line), which is then overlaid on the orbital intensity profile created from RXTE PCA observation (red line)

## References

1. Rubin B. C. et al., 1996, ApJ, 459, 259
2. Falanga, M., Bozzo, E., Lutovinov, A., et al. 2015, A & A, 577, A130, 865.
3. Gimenez A., Garcia-Pelayo J. M., 1983, Ap&SS, 92, 203.

## Orbital evolution



- ▶ The errors on the mid-eclipse epochs are re-calculated by dividing the mid-eclipse times into two segments and taken  $\sigma$  of a linear fit.
- ▶ Plot of delay in mid-eclipse epochs with respect to a constant orbital period. The black solid line represents the quadratic portion of the best fit to the epochs, corresponding to an orbital period decay  $\dot{P}/P = -(4.7 \pm 1.9) \times 10^{-7} \text{ yr}^{-1}$ , smaller compared to its previous estimates.
- ▶ The blue line and magenta line are the quadratic portion of the best fit to the mid-eclipse epoch in Rubin et al.(1996) and Falanga et al. (2015) with the orbital period decay estimation of  $\dot{P}/P$  of  $-3 \times 10^{-6} \text{ yr}^{-1}$  and  $-1.6 \times 10^{-6} \text{ yr}^{-1}$  respectively.

## Mid-eclipse times as function of apsidal motion

- ▶ For a system having small eccentricity and undergoing apsidal motion, assuming an orbital inclination  $i = 90^\circ$ , the mid-eclipse times can be written as (Gimenez & Garcia-Pelayo 1983 )

$$T_N = T_0 + PN + \frac{eP_a}{\pi} \cos(\omega_0 + \Delta\omega N)$$

where  $\Delta\omega$  is the change in  $\omega$  in one orbital cycle.

## Eclipse duration as function of apsidal angle

- ▶ For orbital inclination of  $90^\circ$ , eclipse duration is given by

$$\Delta T(\omega') = \frac{a^2(1-e^2)^2}{L} \int_{\omega' - \phi_1}^{\omega' + \phi_2} \frac{d\theta}{(1 + e \cos \theta)^2}$$

where  $L = (G(M_* + M_C)a(1-e^2))^{\frac{1}{2}}$ .

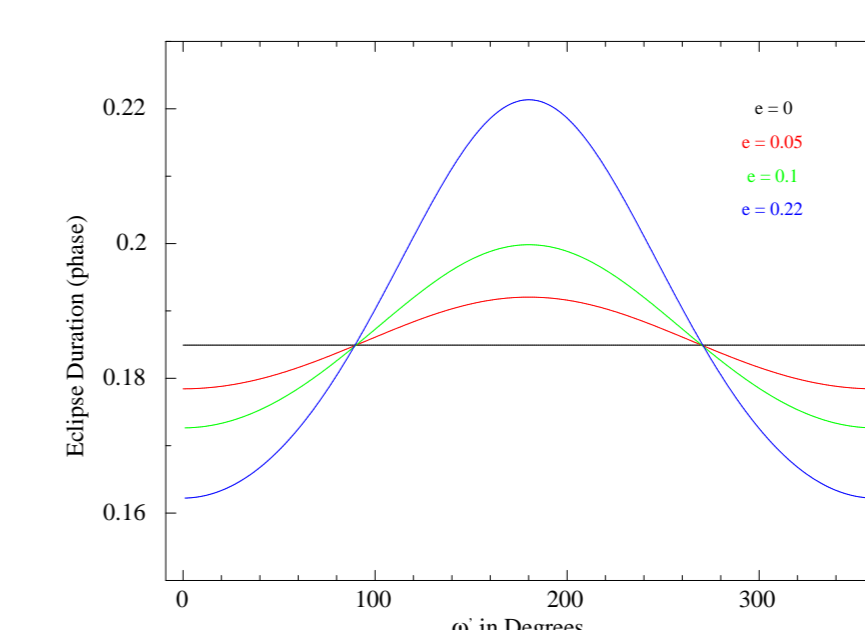
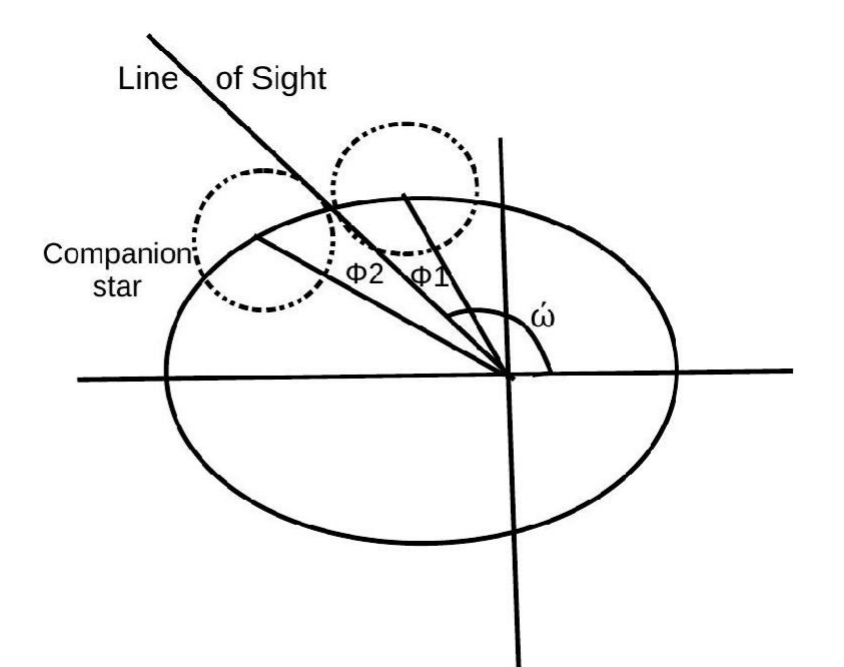


Figure : Plot of variation of eclipse duration as a function of  $\omega'$  for different value of eccentricity, assuming an orbital inclination of  $90^\circ$ . The ratio of maximum to minimum eclipse duration is equal to  $\frac{1+e}{1-e}$ .

## Constraints on eccentricity

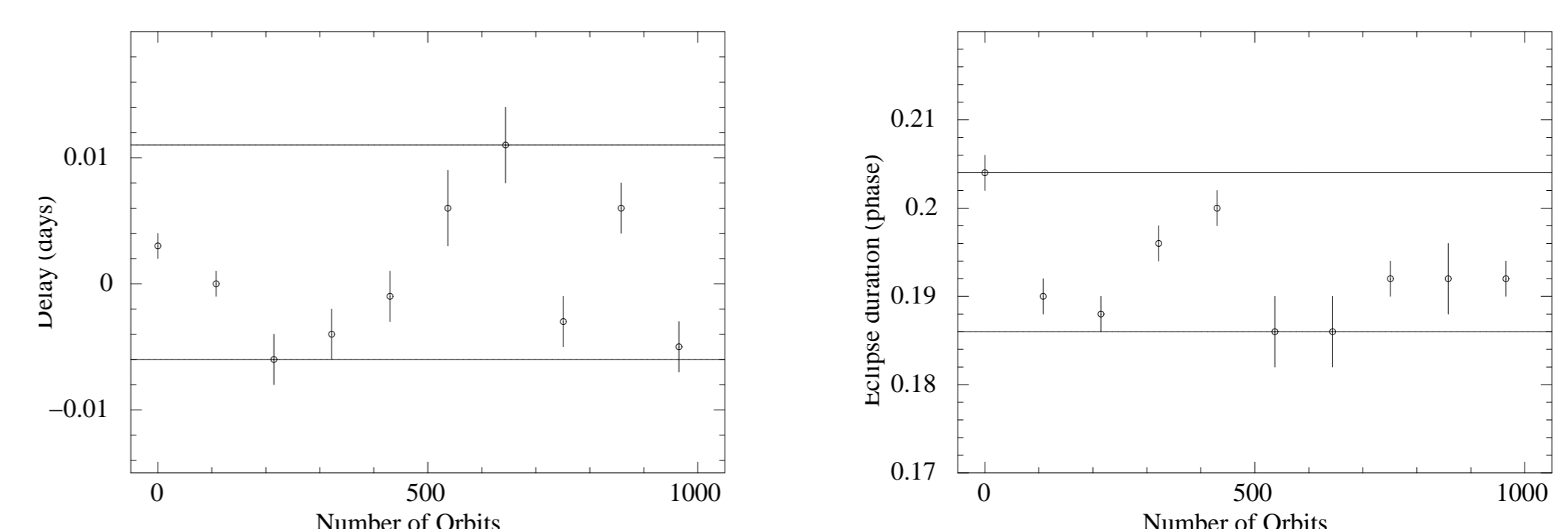


Figure : Left panel: Delay in mid-eclipse times with respect to a constant orbital period for 10 segments of 1 year Swift–BAT light curves plotted as function of number of orbits, along with solid lines showing the maximum and minimum value of the delay. Right panel: Plot of eclipse duration as function of orbit number calculated from 10 segments of 1 year Swift–BAT light curves, along with solid lines showing the maximum and minimum value of the eclipse duration. These two plots do not give a consistent value of the apsidal advance rate. We therefore, compare the amplitude of the difference in the left panel to  $\frac{eP}{P}$  and determine an upper limit for the value of eccentricity. Similarly, the upper limit of 0.008 on variation of the eclipse duration, when compared to  $\frac{1-e}{1+e}$  gives an upper limit of 0.05 on eccentricity.