Orbital Modulation and a New Ephemeris of Cygnus X-3

Shunji Kitamoto[1], Aya Watanabe[1], Kenta Nagasaki[1], Tetsuichi Kishishita[2]

[1] Department of Physics, Rikkyo University
3-34-1, Nishi-Ikebukuro, Toshima–ku, Tokyo 171–8501, Japan
[2] Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science
3-1-1, Yoshinodai, Sagamihara, Kanagawa, 229-8510, Japan
E-mail(SK): kitamoto@rikkyo.ac.jp

Abstract

We investigate an orbital X-ray modulation of the enigmatic X-ray binary, Cygnus X-3. It is a close binary system, composed of a Wolf-Rayet (WR) star and a compact star with a 4.8h orbital period. We determine a new precise orbital ephemeris and found that the orbital period is monotonically increasing with $\frac{1}{2}P\dot{P} = (5.62 \pm 0.09) \times 10^{-11}$ day, over more than three decades from 1970s. The obtained period derivative is explained by an intense stellar wind from the WR star with $\sim 10^{-6\sim-5}$ $M_\odot$ yr^{-1}. This mass loss rate is a reasonable value as a Wolf-Rayet star. This thick wind exposed to intense X-rays should be photo-ionized. Observed rich emission lines come from this photo-ionized plasma as well as some narrow radiative recombination continuums (RRCs). We investigate an orbital modulation of the emissions lines and the RRCs. We found that the emission lines show a large equivalent width around phase 0.0 (phase 0.0 means the X-ray intensity minimum phase). However, the RRCs show different modulation pattern from that of the emission lines.

Key words: Binaries: close — X-rays: binaries — stars: individual(Cygnus X-3)

1. Introduction

Cygnus X-3 is a bright X-ray source consisting of a compact star and a Wolf-Rayet (WR) star (van Kerkwijk 1992) with a 4.8 h orbital period. The dense wind from the WR star exposed to the intense X-rays from the compact star makes a unique binary system, providing interesting laboratory of a photoionized plasma. This system is also a unique sample of an end of evolution of massive binary stars. Here we provide a new ephemeris of the 4.8 h orbital period and orbital modulations of the spectral features obtained with Suzaku.

2. New Orbital Ephemeris

Suzaku observation of Cyg X-3 was performed from Nov. 13 to 15, 2006. The light curve of the energy range from 1 keV to 10 keV, obtained by the XIS onboard Suzaku, is shown in figure 1. A clear 4.8 h modulation can be seen. This light curve was fitted by a template light curve published by van der Klis & Bonnet Bidaud (1989) and the phase 0 time was determined. The template light curve with a slow rise and a steep decline can well fit the Suzaku light curve. This fact means that the light curve shape does not significantly change since the 1980s, when the template light curve was constructed by van der Klis & Bonnet Bidaud (1989). By compiling all published data, we determined a new ephemeris of the

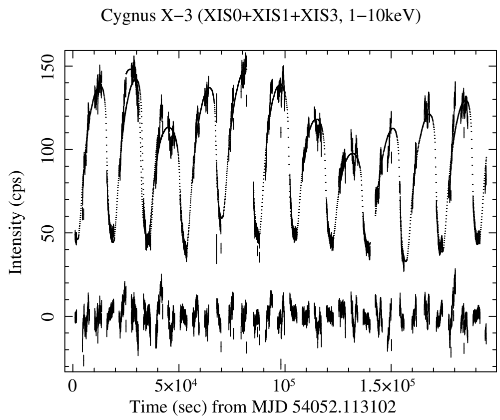

Fig. 1. The light curve in the energy range from 1 keV to 10 keV observed with XIS onboard Suzaku. The data points around 0 are residuals from the best fit template.

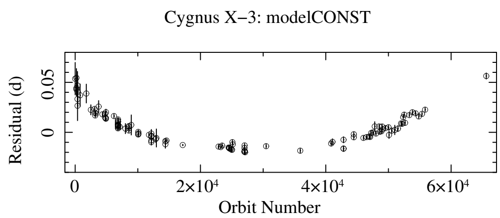

Fig. 2. Residuals of the phase 0 time from the constant period model. The quadratic curve means a positive $\dot{P}$.

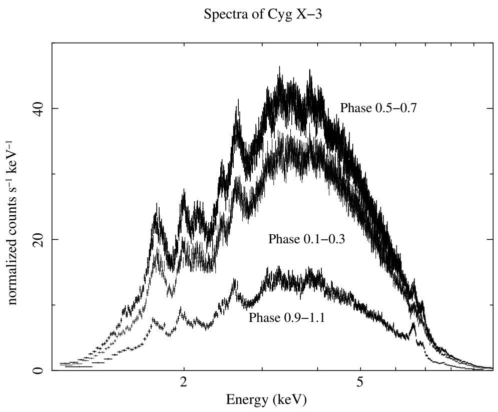

Fig. 3. Observed energy spectra in the phase range from 0.1-0.3, 0.5-0.7, and 0.9-0.1.

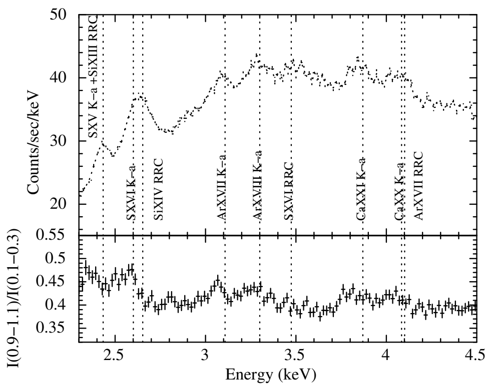

Fig. 4. Upper: An energy spectrum and line identifications. Lower: The ratio of the spectra in 0.9-1.1 to that in 0.1-0.3.

orbital period. Figure 2 shows the residual times from the best fit constant period model as a function of the orbital number from Uhulu data (Leach et al. 1975). The parabolic residuals means a positive $\dot{P}$. Thus we fitted the data points by a constant $\dot{P}$ model. The constant $\dot{P}$ model well fitted the observed data points over the 30 years. The best fit period and its derivative were obtained as P_0 =0.199684509± 0.000000053 day and $\frac{1}{2}P\dot{P}$ = (5.62 ± 0.09) × 10^{-11} day. These are completely consistent with the previous works (Kitamoto et al.1995; Singh et al. 2002). This value is consistent with a expected value of the spherical mass loss from the WR star with $\sim 10^{-5\sim-6}$ $M_\odot$ yr^{-1}.

3. Energy Spectra

In figure 3, spectra of Cyg X-3 in three intervals of the orbital phase are shown. We can recognize various emission lines and can find a clear change of iron line equivalent width. Its equivalent width at the small-intensity phase is larger than the high-intensity phases. This modulation pattern is consistent to the observation result by ASCA (Kitamoto et al. 1994).

In figure 4, another plot of the spectrum is shown. In the upper panel, identifications of emission lines and RRCs are indicated. The RRC around 3.5 keV is from S XVI and is isolated well from other lines. Ratios of the spectral data in the phase 0.9-1.1 to that in 0.1-0.3 are plotted in the lower panel. The ratios of continuum region have values around 0.4. However those of lines have ∼0.45. This means that the equivalent width of the lines changes. The new finding is that the ratio around RRCs, especially the 3.5 keV RRC, is ∼ 0.4, which is the value of the continuum and is not of the emission lines.

This fact means that the modulation pattern between emission lines and RRCs is different from each other, and the RRCs modulates its intensity in the same manner as the the continuum emission.

4. Summary

We provide a new orbital ephemeris of Cyg X-3. The history of the orbital period is well described by a constant $\dot{P}$ model. The value of $\dot{P}$ can be explained by a spherical wind from the WR star. The light curve shape is consistent with that observed in 1980s. We obtained an orbital modulation of the emission lines and the RRCs. We found that the behavior of the orbital modulation of the RRCs are different from that of the emission lines but rather similat to the continuum. This fact indicates that the line emissions and RRCs does not originate from a simple equilibrium photoionized plasma.

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