MANYETİK KATAKLİSMİK DEĞİŞEN YILDIZLAR HU AQR VE V2069 CYG' NİN X-IŞIN VE FOTOMETRİK GÖZLEMLERİ

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Özet: Bu çalışmada iki manyetik kataklismik değişen yıldızın (polar HU Aqr ve orta kutup V2069 Cyg) X-ışın ve hızlı-fotometrik gözlemlerinden elde edilen sonuçlar sunulmaktadır. Hızlı-fotometrik gözlemler, Skinakas gözlemevi (Girit)'de bulunan 1.3m teleskop üzerine takılı OPTIMA (Optical Timing Analyzer, Kanbach ve ark. 2008) ve X-ışın gözlemleri XMM-Newton ve SWIFT/XRT uyduları kullanılarak yapılmıştır. Işık eğrilerinin zamansal analizden, V2069 Cyg'nin her iki dalga boyunda (optik ve X-ışın) çift tepeli bir yayınım profiline sahip olduğu gözlenmiş ve sistemdeki baş yıldızın (beyaz cüce) dönüş frekansı hesaplanmıştır. Sistemin çift tepeli bir yayınım profiline neden olan muhtemel mekanizma tartışılmış ve bunun baş yıldızın düşük manyetik alana ve kısa dönüş periyoduna sahip olmasından kaynaklandığı düşünülmüştür. Ayrıca sistemin X-ışın tayf analizi yapılmıştır. Bununla birlikte, tutulma gösteren yakın çift yıldız sistem olan HU Aqr'nin yörüngesel periyodunun uzun dönemli değişimleri incelenmiştir. Bu kaynak için literatürde bulunan tüm tutulma zamanları ile bu çalışmada elde edilen yeni tutulma zamanları birleştirilerek sistemin O-C eğrileri oluşturulmuş ve dönem değişimleri analiz edilmiştir. Bu analizler sonucu, sistemin yörüngesel periodunun zamanla azaldığı gözlenmiş ve buna sistemdeki üçüncü bir cismin neden olduğu LTT (Light Travel Time) etkisinin sorumlu olduğu düşünülmüştür. Ayrıca bu değişime neden olabilecek diğer olası mekanizmalar tartışılmıştır. Daha fazla ayrıntı için bu çalışmalar Nasiroglu ve ark. (2012) ve Gozdziewski & Nasiroglu ve ark. (2012)' de yeralmaktadır.

1. Introduction

Magnetic cataclysmic variables (CVs) are interacting close binary systems in which material transferred from a Roche lobe filling low-mass companion is accreted by a magnetic white dwarf (WD). Magnetic CVs are subdivided in two groups: polars (or AM Her type) and intermediate polars (IPs; or DQ Herculis type). In polars, the WD has a sufficiently strong magnetic field ($B \sim 10^7$–10^8 G) which locks the system into synchronous rotation ($P_{\rm spin} = P_{\rm orb}$) and prevents the accretion disc to form around the WD. In IPs, the field of the WD is one order of magnitude weaker ($B \sim 10^6$–10^7 G), and therefore insufficient to force the WD to spin with the same period as the binary system orbits ($P_{\rm spin} < P_{\rm orb}$). The accretion in IPs happens through a disc with a disrupted inner region (Warner 1995; Hellier 2001).

2. V2069 Cygni

V2069 Cyg (Motch et al. 1996) is a hard X-ray emitting intermediate polar (IP) with a soft X-ray component belonging to the group of Cataclysmic Variables and hosting a magnetic white dwarf (WD) accompanied by a Roche-lobe filling low mass star (Hellier 2001). Its orbital period is ~7.48 hr (Thorstensen &Taylor 2001) and spin period is ~743.2 s (de Martino et al. 2009).

To analyze the data we used the HEAsoft package, v.6.9. The photon arrival times were converted to the solar system barycenteric time. The X-ray and optical raw data were binned with 1 s and the background counts were subtracted. The resulting light curves shows a prominent periodic variability (Figure 1). The power spectra (FFT algorithm) shows a prominent peak at spin frequency (0.00134277 Hz = 744.7 s) in both optical and X-ray data, a strong peak at the second harmonic in the optical, and harmonics up to the fourth in the X-ray data (Figure 2). By using the Xronos/*efsearch* task for the optical data and a Bayesian formalism (Gregory & Loredo 1996) for X-ray data, we found the best spin period of the WD as 743.38 ± 0.25 s and 742.35 ± 0.23 s, respectively (Nasiroglu et al. 2012).

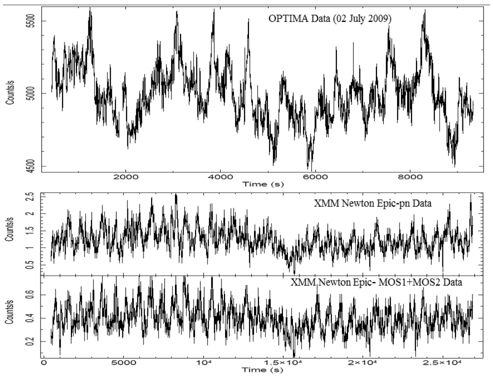

Figure 1. The optical (above) and X-ray (below, 0.2−10.0 keV) light curves of V2069 Cyg obtained with OPTIMA and XMM Newton Epic instruments.

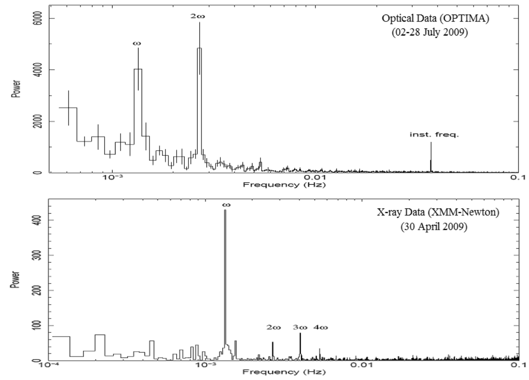

Figure 2. Optical (above) and X-ray (below) power spectrum of V2069 Cyg. The power spectrum shows strong peak at spin frequency (0.00134277 Hz) in both optical and X-ray data.

The optical and hard/soft X-ray light curve (folded with the spin period, 743.38 s and 742.35, respectively) show double-peaked pulse profiles (Figure 3). This is probably due to the changing viewing geometry onto the accreting polar caps. We view the emitting region most favourably when one of the poles points towards us (Evans & Hellier 2004).

We found that the pulse profiles of the optical and X-ray data are out of phase (Figure 4). In some IPs, the optical photons are thought to originate in the X-ray-heated magnetic polar caps and possibly in the accretion stream. During the emission, some part of the optical photons will be absorbed by the flow while the accretion flow is heating the second pole. At that time, the remaining optical modulations will be seen, which are shifted with respect to the X-rays (Norton. et al 2004, Revnivtsev et al. 2010).

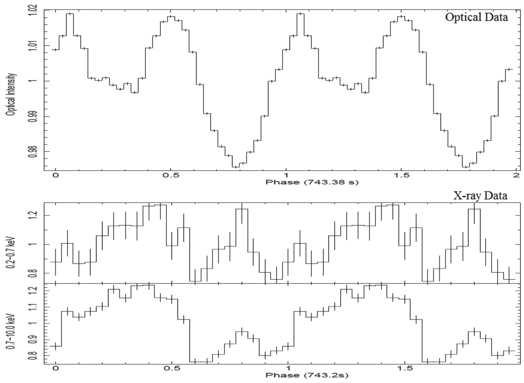

Figure 3. Double-peaked pulse profiles obtained from optical data folded with the 743.38s spin period (above) and soft -hard X-ray data with 742.35s (below).

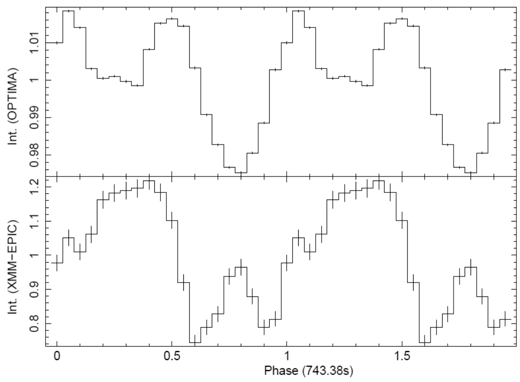

Figure 4. Pulse profiles folded with 743.38 s obtained from OPTIMA (above) and combined XMM-EPIC 0.2−10 keV (below) data.

The X-ray spectra obtained from the XMM–EPIC instruments were modelled (XSPEC v.12.5.0x) by a plasma emission and a soft blackbody component with a partial covering photoelectric absorption model with a covering fraction of 0.65 *(phabs*pcfabs*(mekal+bbody+gaussian)*constant).* An additional Gaussian emission line at 6.385 keV with an equivalent width of 243 eV is required to account for fluorescent emission from neutral iron. The iron fluorescence (~6.4 keV) and Fe XXVI lines (~6.95 keV) are clearly resolved in the EPIC spectra (Figure 5).

3. HU Aquarii

HU Aquarii (HU Aqr), is an eclipsing system belonging to Polar type of CVs hosting high magnetic WD (0.88 $M_{\odot}$) accompanied by a red dwarf (with a spectral type of M4V and a mass of 0.2 $M_{\odot}$). The system was discovered in 1993 in the ROSAT survey and has since been extensively studied in various wavelength bands. The magnetic field of WD strong enough to synchronize the spin period of the WD to the orbital period of the binary, which is 125 minutes.

To follow the secular changes of the orbital period, the eclipse times of HU Aqr have been observed in optical, UV and X-rays over the last 19 years (since 1993), including regular OPTIMA observations. Among these measurements, 68 eclipse times were obtained with OPTIMA instrument that operated mostly at the Skinakas Observatory since 1999. The currently available data set of HU Aqr egress times consists of 171 measurements in total. All of these eclipse egress times have been already published in recent publication, in Gozdziewski & Nasiroglu et al. (2012).

We have generated new fits to eclipse mid-egress times of HU Aqr, as well as reanalyzed many of the already published OPTIMA data. Measuring the time of mid-egress properly is critical to obtain the **O**bserved minus **C**alculated (O−C) diagrams, since it is the time marker of the eclipse (Schwarz et al. 2009). To determine the mid-egress times we fitted the OPTIMA count rates with a sigmoid function ($y[x]=A_1+[A_2-A_1]/[1+\exp(x_0-x)/\Delta x]$) and took the half intensity point of the egress time (x_0) as reference (Figure 6). We calculated the eclipse ephemeris using different least square fit models (linear, quadratic and sinusoidal functions). $T_{calc} = T_{ref}+E.P_{ref}$ where, T_{ref} and P_{ref} are reference time and period of the eclipse egress (respectively) calculated from the best fit line, E is the number of the eclipse cycles (orbital epoch) in the period P.

From the analysis of the (O−C) curve of HU Aqr, we found a periodic variation which is superimposed on a long-term period decrease, $\dot{P}_{orb} = -3.0\pm0.4)\times10^{-12}$ ss^{-1} (Nasiroglu et al 2010). This kind of periodic variations of (O−C) diagrams in binary systems have often been explained as a effect related to the one of three mechanisms: (i) the presence of a third body orbiting the binary, (ii) the magnetic activity in the binary system and (iii) the angular momentum loss by gravitational radiation or magnetic braking.

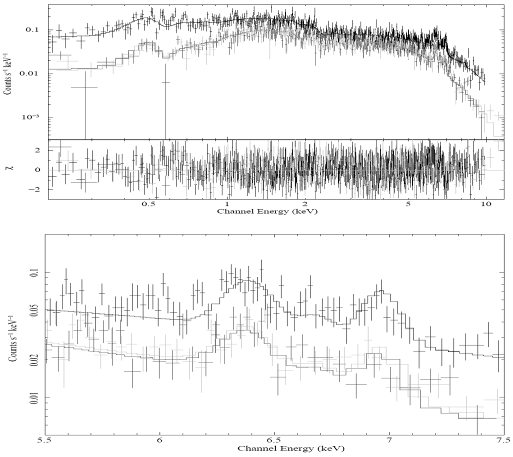

Figure 5. The composite model fitted to the spectrum of the EPIC-pn (black) and MOS (green- red) data (0.2−10 keV, above), and enlarged part of the spectra showing the Fe line complex (below).

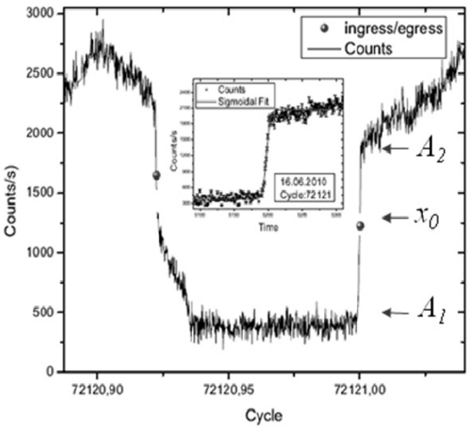

Figure 6. An example for sigmoid fit on a eclipse egress of HU Aqr. The reference for phase zero is the mid-time of the eclipse egress, which is obtained from a sigmoid fit.

Here we discussed the first mechanism, presence of smaller ’planetary’ bodies orbiting the compact binary at large distances. This mechanism effects the light-travel-time (LTT), which is seen as a small but significant changes (a monotonic increase or decrease) in the binary period. When the binary moves towards the observer, the light from the eclipse may seem to reach much faster to the observer (take shorter time) than when the binary is moving away. Therefore, the LTT effect causes the times of the eclipses to trace out as a cyclic changes in the (O−C) diagram. The sinusoidal variations and the presence of two different periods in our results (Nasiroglu et al. 2010) seemed to hint strongly at an explanation in terms of changes in the light travel time (LTT) due to the presence of smaller ’planetary’ bodies orbiting the compact binary at large distances.

In our recent work (Gozdziewski & Nasiroglu et al. 2012), the Keplerian-kinematic model of LTT signal in the three-body configuration is developed and the data set published in the literature re-analysed, following the 2-planet hypothesis in the literature. Using a new formulation of the LTT of the (O−C) to the available data of the HU Aqr system, we found that the 2-planet hypothesis is not likely. We used the new set of precision OPTIMA mid-egress measurements, as well as observations performed recently and we re-analysed planetary models to the whole set of data (in total 171 measurements) up to November 18th, 2011. We fitted the data with the linear and quadratic ephemeris models .

Firstly, we tested the 1-planet hypothesis. For the linear ephemeris model, the 1-planet solution is characterized by extreme eccentricity and displays large residuals and a strong trend present in the (O−C) diagram. A more general 1-planet LTT model with quadratic ephemeris to all available data are shown in Figure 7. This model fits the data very well in a large part of the time window. But, over approximately one fourth of the time-window, the data fit the synthetic curve rather poorly.

We claim that because the observations that currently exist in the literature are non-homogeneous with respect to different spectral windows (ultraviolet, X-ray, visual, polarimetric mode) and the reported mid-egress measurements errors, they may introduce systematics that affect orbital fits. To remove the possible inconsistency due to the different spectral windows and filters, we considered data sets consisting of the egress times measured only in the optical range (without polarimetric measurements which are in the white-light band), and we fitted the quadratic ephemeris 1-planet model again. The synthetic curve of this fit with data points over-plotted is shown in Figure 8.

The results of these models show that the 1-planet solution is relatively well constrained by available optical observations selected as a homogeneous data set. Because the early optical data (the white light and V-band measurements) are coherent with an impressive, very clear quasi sinusoidal signal exhibited by superior-precision like OPTIMA measurements, a single-companion hypothesis seems well justified. The observed (O−C) variations may be consistently explained by the presence of only one circumbinary planet of the minimal mass of ∼7 $M_{Jupiter}$, in an orbit with a small eccentricity of ∼0.1 at a distance of ∼4.5 AU and an orbital period of ∼10 yr, similar to Jupiter in the Solar System.

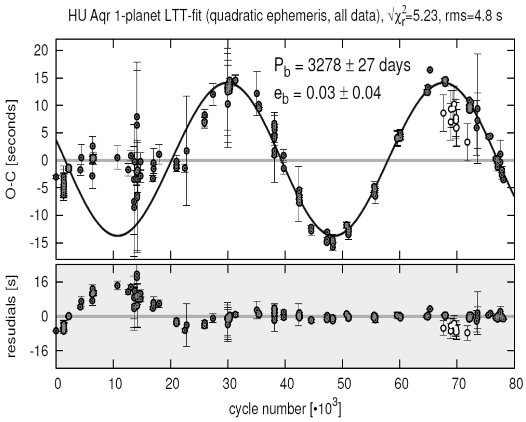

Figure 7. Synthetic curve of the 1-planet LTT model with quadratic ephemeris to all available data, gathered in this work, including the very recent mid-egress. [Taken from Gozdziewski & Nasiroglu et al. (2012)]

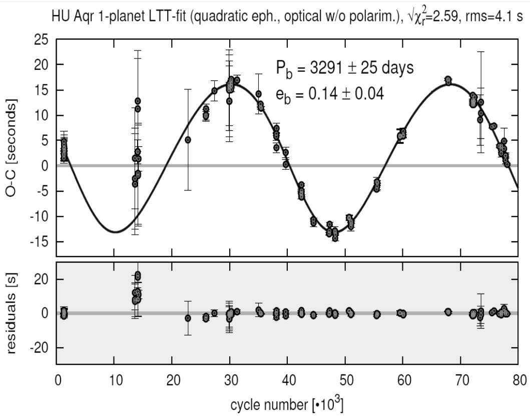

Figure 8. Synthetic curve of the 1-planet LTT model with quadratic ephemeris to observations in white light+V band without measurements in polarimetric data. [Taken from Gozdziewski & Nasiroglu et al. (2012)]

4. Conclusion

V2069 Cygni;

We conclude that V2069 Cyg is an example of an IP that shows double-peak emission profiles in both optical and X-ray wavelength at the WD spin period, which are probably caused by a weak magnetic field, in a WD with short spin period. The emission profiles of the optical and X-ray data are out of phase. This phase shift exists most probably due to the X-ray and optical/infrared photons originating from two different regions. The X-ray spectra can be described by thermal plasma emission (kT of ~20 keV) plus a soft blackbody component with complex absorption and an additional fluorescent iron-K emission line, which originates on the WD surface (at 6.4 keV).

HU Aquarii;

We investigated the long term orbital period change of the eclipsing binary system HU Aqr. We presented new modeling of the orbital ephemeris and created observed minus calculated (O−C) diagram of the system including recent 2008-2011 observations together with the existing data in the literature. We improve the Keplerian, kinematic model of Light Travel Time effect and re-analyse the whole currently available data set. We added almost 60 new, yet unpublished, mostly precision light curves. We determine new mid-egress times with a mean uncertainty at the level of 1 second or better. We claim that because the observations that currently exist in the literature are non-homogeneous with respect to spectral windows (ultraviolet, X-ray, visual, polarimetric mode) and the reported mid-egress measurement errors, they may introduce systematics that affect orbital fits.

Many qualitatively different and best-fit 2-planet configurations in the literature, including self-consistent, Newtonian N-body solutions may be able to explain the data. However, using a new formulation of the Light Travel Time model of the (O−C) to the available data of the HU Aqr system, we found that the previous 2-planet hypothesis is not likely. Morover, using a much extended, precision data set obtained by OPTIMA, we have found that the (O−C) deviations may be consistently explained by the presence of a single circumbinary companion orbiting (with an orbital period of ∼10 yr) at a distance of ∼4.5 AU with a small eccentricity of ∼0.1 and having ∼7 $M_{Jupiter}$, masses.

5. References

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