Timing analysis of AE Aquarii X-ray observations

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Abstract. We reanalysed the archival X-ray observations of double system AE Aquarii, obtained using orbital observatories «XMM-Newton» and «Chandra» in 2001 and 2005 respectively. We made an independent timing analysis with two numerical methods. Our result confirmed the presence of 33 s rotational period of white dwarf in the system. In addition, we confirmed that X-ray pulsations with a period of 16.5 s, which were detected in optical and UV ranges, are absent in AE Aquarii spectrum. This may mean that the X-ray emission comes from one of the poles of white dwarf surface.

1. Introduction
AE Aquarii has been known as one of the most enigmatic magnetic Cataclysmic Variables on various aspects, including large optical flares and flickering large radio flares, TeV gamma-ray emissions and X-ray emission. AE Aquarii is a close binary system composed of a magnetized white dwarf and a Roche-lobe filling K3IV red dwarf. A white dwarf has a very short rotational period about 33.08 s, and the orbital period of double system is 9.88 hours [1]. This object does not fit into the generally accepted classification of explosive variables. A white dwarf in a system is an ejector, its period increases. X-ray periodicity of AE Aquarii has been investigated since 1991 [2]. The results published in the literature show period range of 33.062-33.08 s [2-6] with different suppositions on the nature of the system.

The aim of our work is independent determination of AE Aquarii white dwarf rotational period from the timing analysis of X-ray observation.

2. Observation and data analysis
2.1. Chandra
We reanalyzed archival Chandra data with ObsID="5431" and total exposition 78180 ks. First of all we extracted a background-subtracted light curve (figure 1) from the HEGT event data. This light curve had a step of 300 s and length of two orbital phase, about 78 ks. Our light curve matched well with analogical result [7]. We defined following time intervals in light curve.

Active, with a biggest rate: 2.41796·10⁸<T<2.41799·10⁸ s, 2.41801·10⁸<T<2.41803·10⁸ s, 2.41815·10⁸<T<2.41818·10⁸ s, 2.41832·10⁸<T<2.41835·10⁸ s.

Quiet, with a smallest rate: 2.4179·10⁸<T<2.41796·10⁸ s, 2.41799·10⁸<T<2.41801·10⁸ s, 2.41803·10⁸<T<2.41815·10⁸ s, 2.41818·10⁸<T<2.41832·10⁸ s, 2.41835·10⁸<T<2.41844·10⁸ s.

Middle, with a middle rate: T<2.4179·10⁸ s.

After we extracted four light curves with the length 78 ks and step of 2.55 s, 3 s, 4 s, 6 s. In addition, we extracted light curves with the same steps from listed intervals. We made periodicity searching by Z₂⁺-
test [8], for this, we wrote a program in Free Pascal and tested period range 32.8-33.35 s, step \(10^{-4}\) s. The results are shown in a table 1. Periodograms are shown in figure 2.

**Table 1.** The results of periodicity searching in different time intervals.

| Light curve step, s | Middle | Quiet | Aktiv | Total interval |
|---------------------|--------|-------|-------|----------------|
|                     | P, s   | \(Z^2_{\text{max}}\), rel. | P, s | \(Z^2_{\text{max}}\), rel. | P, s | \(Z^2_{\text{max}}\), rel. |
| 2.55                | 33.08978 | 6.5828 | 33.07808 | 30.8481 | 33.07587 | 8.8551 | 33.07718 | 39.8069 |
| 3                   | 33.20985 | 49.4438 | 33.20896 | 77.6087 | 33.20843 | 27.4999 | 33.20874 | 151.923 |
| 4                   | 32.90313 | 3.9326 | 33.07876 | 20.755 | 33.07347 | 5.5411 | 33.07787 | 24.609 |
| 6                   | 33.20863 | 10.2827 | 33.20936 | 56.0682 | 33.21042 | 6.1927 | 33.20925 | 50.1984 |

Also we filtered “HEGT” event data on four energy ranges by “dmcopy” CIAO 4.5 task. We extracted light curves with a 2.55 step from each range. We made \(Z^2\)-test for these light curves and tested the same periods 32.8-33.35 s, step \(10^{-4}\) s. The results are shown in table 3, and figure 4.

**Table 2.** The results of periodicity searching in different energy ranges.

| Energy range, keV | P, s   | \(Z^2_{\text{max}}\), rel. |
|-------------------|--------|-----------------|
| 0.2-12            | 33.07718 | 39.8069 |
| 0.2-2             | 33.07636 | 54.3983 |
| 2-4               | 33.07455 | 19.5406 |
| 4-6               | 33.0128 | 16.1708 |

**Figure 1.** Time light curve with a step of 300 s; X-axis of top panel is orbital phase, X-axis of bottom panel is time in seconds.

**Figure 2.** Periodogram of light curves with length of two orbital phases.
Figure 3. Periodograms for different energy ranges, step 2.55 s.

We noticed that period was seen best of all in observation part with a small rate and in energy range 0.2-4 keV, because values of $Z_2^2$ are very big. Periodograms of light curves with a step of 3 s, 6 s have a second maximum in $P\approx33.2$ s. We also tested a period range 15.8-17.2 s, step $10^{-4}$ s. In this range a value, equal to a half of period, could be seen. The result showed that periodograms have not maximum in this point, but periodograms of light curves with a step of 3 s, 6 s have a maximum in $P\approx16.6$ s, a half of $P\approx33.2$ s.

2.2. XMM-Newton

We reanalyzed the archival AE Aquarii observation, obtained by “XMM-Newton” in 2001, ObsID=”111180201”, total exposition 17120 s. First, we extracted light curves with a step as 256 s from “EPIC” data (figure 4). Our results matched well with analogical light curves from Itoh et al. (2004). We used for timing analysis only “EPIC MOS” data because it has a timing resolution as 0.9 s. We extracted a light curves from the circle source region with a radius 50.6” [9]. Our light curves had a step as 0.91 s, 1 s, 3 s. After we made periodicity searching by $Z_2^2$-test, we tested period range 32.8-33.35 s, step $10^{-4}$ s. Periodograms are shown in figure 5. As we can see from this diagram, all periodograms have one maximum. We tested period range 15.8-17.2 s, step $10^{-4}$. Periodograms have no maximum in these parts. Thus, the second peak is not associated with AE Aquarii nature.

In addition, we defined in a “EPIC MOS” light curve with a step of 256 s two time intervals: quiet $T<1.2157\times10^6$ s, rate is small, active $T>1.2157\times10^6$ s, rate is big. We extracted light curves with step 0.9 s, 1 s, 3 s from these intervals and analysed these light curves for periodicity. Also we filtered “EPIC MOS” data by “evselect” SAS 14.0 task into different energy ranges and extracted light curves with a step 0.91 s from each range. We made a periodicity searching for these light curves. The results are shown in tables 4, 5. As we can see from these tables, period is seen best of all in soft energy range 0.2-4 keV.

Figure 4. “XMM-Newton” light curve with a step of 256 s.
Figure 5. Left panel: “EPIC MOS1” light curves with small steps; right panel: “EPIC MOS2” light curves with small steps.

Table 3. The results of “XMM-Newton” periodicity search in two time intervals.

| Light curve step, s | EPIC MOS1 | EPIC MOS2 |
|--------------------|-----------|-----------|
|                    | Quiet     | Aktiv     | Quiet     | Aktiv     |
|                    | P, s      | $Z^2_{\text{max}}$, rel. un. | P, s          | $Z^2_{\text{max}}$, rel. un. |
| 0.91               | 33.08714 | 31.3427   | 33.05577 | 32.95024 | 33.05478 | 2.9025 |
| 1                  | 33.08413 | 21.5070   | 33.05334 | 29.2525  | 33.07117 | 1.8120 |
| 3                  | 33.07042 | 0.9443    | 33.20898 | 0.0175   | 32.983   | 0.0336 |

Table 4. The results of periodicity searching in different energy ranges.

| Detector   | Energy range, keV | P, s | $Z^2_{\text{max}}$, rel. un. |
|------------|-------------------|------|-------------------------------|
| EPIC MOS2  | 0.2-10            | 33.06321 | 21.7991 |
| EPIC MOS1  | 0.2-10            | 33.07408 | 20.4369 |
| EPIC MOS1  | 0.2-2             | 33.07113 | 18.3957 |
| EPIC MOS1  | 2-4               | 33.07054 | 35.2442 |

3. Periodicity search by epoch folding method

For checking $Z^2_{\text{chisq}}$-test results, we made a more detailed periodicity search by epoch folding method for “XMM-Newton” data only. We did not managed do this for “Chandra” data. We used “pfold” CIAO 4.5 tool for epoch folding method and tested period range 32.9-33.2 s, $10^{-6}$ s. The results are following:

EPIC MOS1: P=33.076165 s, $Z^2_{\text{max}}=0.18674$.

EPIC MOS2: P=33.064493 s, $Z^2_{\text{max}}=0.18160$.

These periods match well with our results of $Z^2_{\text{chisq}}$-test method.

4. Conclusions

Figure 6 shows a diagram of results of period determination in different years, the data was taken from papers [2-6, 10], line connecting points is guide to the eyes only. Our periods 33.063-33.087 s match well with published data, so the main conclusion of our work is: the white dwarf in AE Aquarii is really rotates with a small period about 33 s. Moreover, we have the following results of our work.

1. We confirmed, that there are no 16.6 s pulsations in X-ray range. This may mean, that only one white dwarf pole emits, because the half of period is detected in optical and UV-ranges [10, 11].
2. We made more detailed analysis of emission periodicity in different narrow ranges, than the authors of papers [4] and [6]. We made periodicity searching in each narrow range. From this work is should pulsed component spectrum to be soft, the main part of the energy to be emitted in a range 0.2-4 keV.
3. We made detailed periodicity searching in the different time intervals in “Chandra” observation. The results is; period is visible best of all in the intervals of small rate. The analogical result we have also for “XMM-Newton” observation.

![Figure 6. The results of AE Aquarii period determination in different years.](image)

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