NuSTAR observation of the fast rotating magnetized white dwarf AE Aquarii†

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AE Aquarii (AE Aqr) is a cataclysmic variable classified as a member of the DQ Herculis or intermediate polar (IP) class, consisting of a white dwarf (WD) and a K4–5 V star. In the IP class, the WD is generally thought to possess a magnetic field ($B \sim 10^{5-7}$ G) sufficiently strong to channel the accretion flow from the secondary star to the WD poles. Accordingly, hard X-rays are produced by the shock-heated gas, which reaches temperatures of a few tens of keV near the WD surface. The X-ray emission exhibits spin modulation caused by the varying aspect of the accreting poles with respect to the rotation of the WD[1].

The 33.08 s period makes AE Aqr the fastest-spinning magnetic WD with intriguing emission features. In comparison to many IPs, AE Aqr shows a thermal soft X-ray spectrum with a very low luminosity, and therefore the mechanism and location of the X-ray emission are uncertain. In addition, a *Suzaku* observation[2] showed that AE Aqr may emit non-thermal hard X-rays with a narrow pulse profile at the spin period, suggesting that the source may accelerate charged particles in a manner similar to rotation-powered pulsars[3]. However, a more recent *Suzaku* observation[2] did not reproduce the earlier result, leaving the detection of non-thermal X-rays uncertain.

The Nuclear Spectroscopic Telescope Array (*NuSTAR*) satellite[4], launched in 2012 June, carries the first focusing hard X-ray (3–79 keV) telescope in orbit. Owing to focusing optics, *NuSTAR* achieves the highest sensitivity ever observed in this band, and it has the capability to detect hard X-ray point sources with a flux down to sub μCrab. Therefore, *NuSTAR* can help measure the maximum temperature of the thermal plasma in AE Aqr and test the presence of any beamed non-thermal component. We performed a long observations of this source with *NuSTAR* for an exposure of 125 ks in 2012 September.

Spectral analysis shows that hard X-rays are well fitted by an optically thin thermal plasma model with three temperatures of $0.8^{+0.2}_{-0.5}$, $2.3^{+1.0}_{-0.8}$, and $9.3^{+6.1}_{-2.2}$ keV, the highest of which is higher than that previously observed for this source (3.0 keV)[2]. In addition, the spectrum is also characterized by an optically thin thermal plasma model with two temperatures of $1.0^{+0.3}_{-0.2}$ and $4.6^{+1.6}_{-0.8}$ keV in combination with a power-law component with index of 2.5 ± 0.2, although the derived index is inconsistent with the *Suzaku* value (1.1 ± 0.6[2]) and is steeper than those found for rotation-powered pulsars (0.6–2.1)[3]. Compared with the three-temperature model, the fit with the two-temperature model with the power-law emission is slightly but not significantly preferred. We cannot distinguish whether the hard X-ray component detected with *NuSTAR* is thermal or non-thermal emission.

A timing analysis with Z_1^2-statistic or Rayleigh test[5] shows that the spin period in the 3–10 keV band is 33.0769 ± 0.0004 s, which is consistent with previously measured values[2]. The 3–20 keV pulse profile obtained by folding data at the best determined period is broad and approximately sinusoidal with a pulsed fraction of $16.6 \pm 2.3\%$. We do not find any evidence for a sharp feature in the pulse profile.

Two energy sources could, in principle, power the observed X-ray luminosity: liberation of gravitational energy of accreting matter and the rotational energy of the WD. The observed X-ray emission is difficult to explain as a result of rotation-powered emission because synchrotron radiation, which is observed for rotation-powered pulsars, is expected to be strongly beamed along the field lines, which is inconsistent with the observed broad pulse profile. Instead, accretion-powered emission is more probable, although the observed spectrum with the highest temperature of $9.3^{+6.1}_{-2.2}$ keV is softer than a postshock temperature of ~ 30 keV predicted by the standard accretion column model[6] under the assumption that the WD mass is $\sim 0.7\ M_\odot$ as determined in the optical measurement[7].

The standard model assumes a high-accretion column heated by the shock close to the WD surface and cooled by thermal bremsstrahlung. However, the accretion rate in AE Aqr is considerably small, which is a consequence of the low X-ray luminosity. We suggest two modifications of the standard model to explain the AE Aqr spectrum: the shock temperature could be low because of a tall accretion column comparable with the WD radius, and cyclotron emission with $B > 10^6$ G could additionally cool down the accretion plasma. Detailed calculations of such models will hopefully reproduce the spectrum and pulse profile of AE Aqr with the optically determined WD mass.

References

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