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 \( B \sim 10^{6–7} \) 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.\(^2\)

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\(^3\) 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\(^3\) 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 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 plasma model with two temperatures of 1.0\(^{+0.2}_{-0.2}\) and 4.6\(^{+1.6}_{-0.8}\) keV in combination with a power-law component with index of 2.5\(^{+0.2}_{-0.2}\), although the derived index is inconsistent with the Suzaku value (1.1\(^{+0.6}_{-0.2}\)) 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\(^2\)-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\(^5\). 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 ± 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 \( \sim 30 \) 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
2) Y. Terada et al.: PASJ 60, 387 (2008)
6) K. Aizu: PTPh 49, 1184 (1973)