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Study of IW And-type dwarf novae through multicolor observations

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IW And-type dwarf novae, a subclass of Z Cam-type systems, exhibit brightness fluctuations during standstills that end with a terminal outburst followed by a decline into quiescence. These behaviors are challenging to explain within the framework of the standard thermal-viscous instability model for accretion disks. Two primary hypotheses have been proposed: variations in the mass-transfer rate from the companion star, and thermal-viscous instabilities in tilted accretion disks. However, the underlying mechanism remains unclear. In this study, we present multicolor imaging observations of IW And-type dwarf novae in the optical and near-infrared bands using the Kanata telescope at Hiroshima University. We focused on the IW And-type object KIC 9406652, capturing its brightness and color variations associated with all characteristic phenomena: oscillations at intermediate brightness, rebrightenings followed by deep dips, normal standstills, and normal outbursts. By analyzing the temporal evolution of the color index and magnitude, we detected a reddening trend when the object became brighter at the end of an oscillating standstill. This is the first time such behavior has been observed. The reddening suggests that the accretion disk radius gradually expands during this phase, providing new observational support for previous studies involving eclipses and negative superhumps.

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1. Introduction

Cataclysmic variables (CVs) are close binary systems composed of a white dwarf (primary star) and a late-type main-sequence star (companion star). Gas flowing from the companion star's surface forms an accretion disk around the primary star. Among CVs, systems which repeat outbursts by about 2–5 mag due to thermal instability of the accretion disk are classified as dwarf novae. A subclass of dwarf novae, the Z Cam-type systems, occasionally show a phenomenon called standstill during which the luminosity remains at intermediate brightness between the outburst and quiescent states.

IW And-type dwarf novae are a subclass of Z Cam-type systems [1] [2], and several unusual behaviors have been reported. These include periodic brightness fluctuations during standstills. In the Z Cam type systems, the standstill ends with a decrease in brightness, but the standstill of IW And systems is terminated by an outburst. The standard thermal-viscous instability model is difficult to explain the characteristic behavior in IW And-type dwarf novae. To explain these behaviors, two primary scenarios have been proposed, including models based on variations in the mass-transfer rate from the companion star [1] and models based on thermal–viscous instabilities in tilted accretion disks [3].

To explore the evolution of the accretion disk structure in IW And-type dwarf novae, we estimate temporal variations in the disk temperature and size from their color and flux variations. In our work, we present multicolor observations of the IW And-type dwarf nova in the optical and near-infrared bands.

2. Methods

2.1 Observation

Observations were conducted using the Kanata Telescope at the Higashi-Hiroshima Observatory and the Hiroshima Optical and Near-Infrared camera (HONIR). We selected KIC 9406652 as the observation target for this study[4]. This object was selected because its quiescent brightness of 14-15 mag enables high-precision (0.01-mag) photometric and color measurements. In addition, its sky position allows continuous monitoring from the Higashi-Hiroshima Observatory. Observations were conducted using 7 bands: 4 visible bands (B, V, R_c, I_c) and 3 near-infrared bands (J, H, K_s). The data were obtained between October 20, 2023, and August 15, 2025.

2.2 Model

In dwarf novae, the observed data include contributions not only from the accretion disk but also from the companion star, with this contribution becoming more pronounced in the near-infrared band. Using multicolor observations, we can obtain the flux distribution from the optical to the near-infrared region. This allows us to subtract the contribution from the companion star. As a result, the temporal variations in the temperature and size of the accretion disk can be estimated. We adopt a two component radiation model consisting of the accretion disk component and the companion star component.

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For the accretion disk, we employ the disk blackbody spectrum. Assuming a temperature profile $T(r) \propto r^{-3/4}$, the flux per unit area and unit wavelength is given by

$$S_{\lambda,1} = \frac{\cos i}{D^2} \frac{16\pi hc^2 R_{\rm in}^2}{3} T_{\rm in}^{8/3} \int_{T_{\rm out}}^{T_{\rm in}} \frac{1}{\lambda^5} \frac{T^{-11/3}}{\exp\left(hc/\lambda k_{\rm B} T\right) - 1} dT \tag{1}$$

$$= 10^a \int_{T_{\rm out}}^{T_{\rm in}} \frac{1}{\lambda^5} \frac{T^{-11/3}}{\exp\left(hc/\lambda k_{\rm B} T\right) - 1} dT \tag{2}$$

where i is the inclination angle of the disk, D is the distance to the disk, $R_{\rm in}$ is the inner disk radius, $T_{\rm in}$ and $T_{\rm out}$ are the temperatures at the inner and outer disk radius, a is the normalization constant for the accretion disk, h is Planck's constant, c is the speed of light, $k_{\rm B}$ is Boltzmann's constant and λ the wavelength [5]. In our study, we assumed $R_{\rm in} = 6 \times 10^6$m. Hence, the normalization factor reflects the variations in $T_{\rm in}$, $10^a \propto T_{\rm in}^{8/3}$.

The companion star is a late-type main-sequence star, and thus we approximate its spectrum by a single-temperature blackbody:

$$S_{\lambda,2} = 10^b \frac{1}{\lambda^5 \left[\exp(hc/\lambda k_{\rm B} T_2) - 1\right]} \tag{3}$$

where b is the normalization constant for the companion star and T_2 is the stellar temperature.

The outer disk radius $R_{\rm out}$ is calculated as follows:

$$R_{\rm out} = R_{\rm in} \left(\frac{T_{\rm out}}{T_{\rm in}}\right)^{-\frac{4}{3}} \tag{4}$$

$$\frac{T_{\rm in}}{10^5} = \left(\frac{10^a}{10^{a_0}}\right)^{\frac{3}{8}} \tag{5}$$

where a_0 is the value of a at the reference day used to represent the baseline accretion rate.

3. Results

3.1 Light curve

The multi-band light curve of KIC 9406652 is shown in Figure 1. The figure includes the g-band data obtained by ASAS-SN as well as our observations [6] [7]. KIC 9406652 has another bright star very close to it, and with ASAS-SN's angular resolution, the contribution from this neighboring star cannot be neglected. The center-to-center separation between KIC 9406652 and the neighboring star is 13.72". The angular resolution of ASAS-SN images is about 16". Under these conditions, we estimated that the contribution of the neighboring star to the target flux is approximately 39% during the brightening state and 87% during the quiescence state. As a result, the observed g mag of KIC 9406652 appears brighter than its intrinsic flux, and its variability amplitude decreases. The neighboring object is catalogued as a K-type giant, KIC 9406638. In its Kepler light curve, a small variability with an amplitude of 0.000212 mag and a period of 0.33 d is detected, which is negligible in our study [8]. We consider its brightness to have remained nearly constant during our observing period. Therefore, the variability pattern itself is considered reliable, allowing it to be used to determine the object's state.

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During MJD 60237–60270 (Period 1), the *g* mag shows periodic brightening and dimming in an intermediate state between the outburst maximum and minimum. Therefore, Period 1 corresponds to the oscillatory state at intermediate brightness characteristic of IW And-type dwarf novae (IW And state). Similar behavior is observed during MJD 60499–60548 (Period 3) and MJD 60822–60863 (Period 4), indicating that these intervals also correspond to the IW And state. At MJD 60271, 60540 and 60863, the object increased in flux from an intermediate state to the same level as the outburst maximum, suggesting that terminal outbursts occurred. In particular, the terminal outburst of Period 3 was followed by a pronounced decline to the quiescent level, which is typical for terminal outbursts. In contrast, MJD 60409–60479 (Period 2) does not show a standstill but instead exhibits periodic cycles of brightening and fading, representing a continuous sequence of normal outbursts. MJD 60878–60902 (Period 5) shows magnitudes corresponding to the intermediate brightness level, but the amplitude of variation is limited to about 0.1—0.2 mag, with no clear periodic changes observed. Therefore, Period 5 is identified as a normal standstill state, similar to those observed in Z Cam-type dwarf novae. For the periods not shown here, we were unable to clearly identify the corresponding state due to insufficient data points.

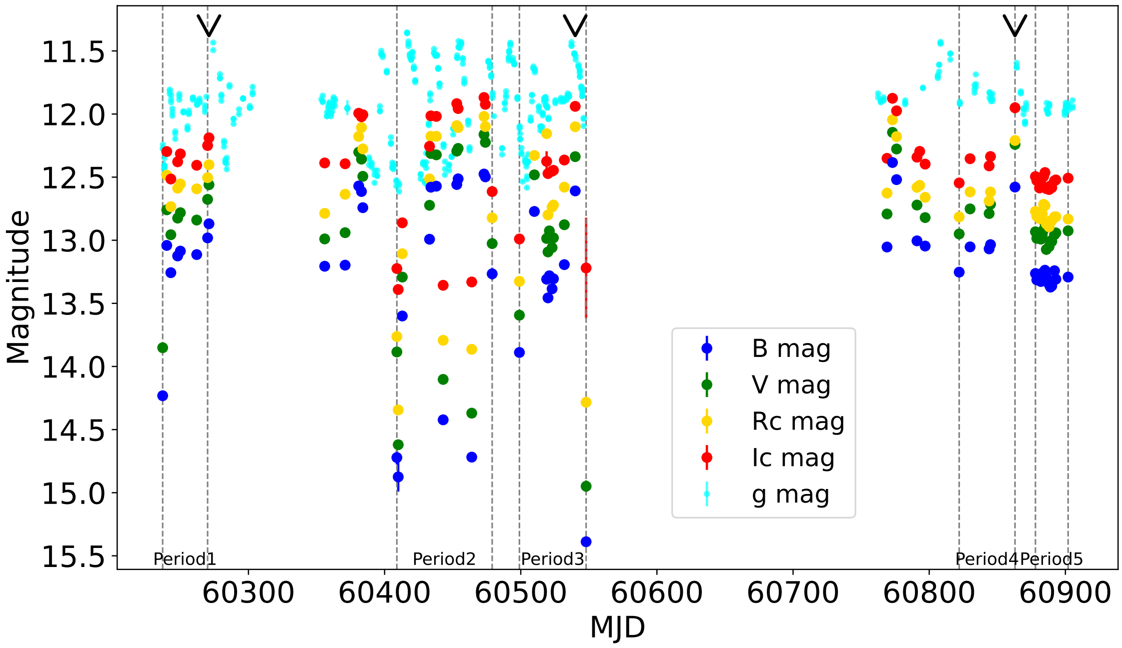

Figure 1: Light curve of KIC 9406652 in the optical from October 2023 to August 2025. For comparison, the *g* band light curve using ASAS-SN data is also shown. The gray dashed lines indicate the boundaries between the IW And state, standstill, and normal outburst state. Periods 1, 3, and 4 correspond to the IW And state, Period 5 corresponds to the standstill, and Period 2 corresponds to the normal outburst state. The "V" marks represents terminal outbursts.

3.2 Color Magnitude Diagram

Figure 2 shows the color–magnitude diagram of $B-V$ versus the V mag. During the normal outburst state, $B-V$ tended to become bluer as the object brightened in the V band, indicating a clear bluer-when-brighter trend. This behavior is consistent with the color variations expected in dwarf nova outbursts in which a transition to the high viscosity state leads to higher temperature and luminosity of the accretion disk. A similar trend was also observed in the early stage of the IW And state; in Period 1, during MJD 60237–60243, the object became bluer-when-brighter. However, in the later stages, particularly toward the end of the IW And stage, the opposite trend was observed, where the object became redder-when-brighter. Furthermore, the standstill state (Period 5) showed a redder color compared to the same magnitude of the normal outburst state (Period 2).

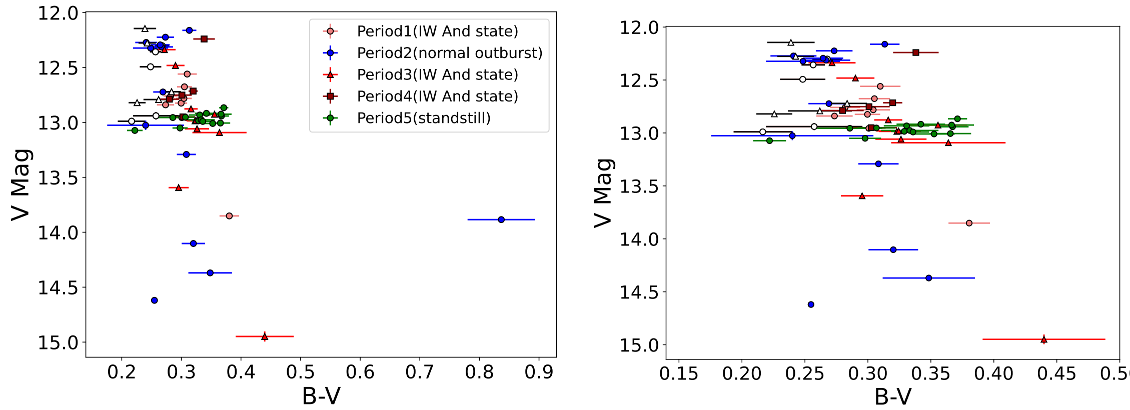

Figure 2: Color-magnitude diagram of KIC 9406652 from October 2023 to August 2025. The vertical axis shows the V magnitude, and the horizontal axis shows the $B-V$ color index. (Left: Full dataset; Right: Enlarged view excluding MJD 60409 from the full data.)

3.3 Outer Disk Temperature and Radius

Figure 3 shows the time evolution of V mag and the physical quantities for KIC 9406652 estimated with our model described in section 2. Focusing on the IW And state periods, a decrease in the outer disk edge temperature $T_{\rm out}$ accompanied by an increase in the outer disk edge radius $R_{\rm out}$ is observed within each period.

4. Discussion

The bluer-when-brighter trend during the normal outburst state is expected by an increase in disk temperature associated with a higher accretion rate. In contrast, the IW And state exhibits the redder-when-brighter trend, as shown in Fig 2, which cannot be explained only by the increase of the disk temperature. In the standard accretion disk, temperatures are higher in the inner regions and lower in the outer regions. Hence, the emitting region must shift toward cooler and larger regions to reproduce the redder-when-brighter trend. This means that the accretion disk expands outward throughout the IW And state. This radial expansion of the disk is demonstrated in Fig 3.

Previous studies have also suggested a possible increase in disk radius during the IW And state. The study examining eclipses of IW And-type systems reported an expansion trend of the disk during the IW And state, which is similar to our result [9]. Another study inferred the disk radius evolution during the IW And state based on the negative superhump frequency, suggesting

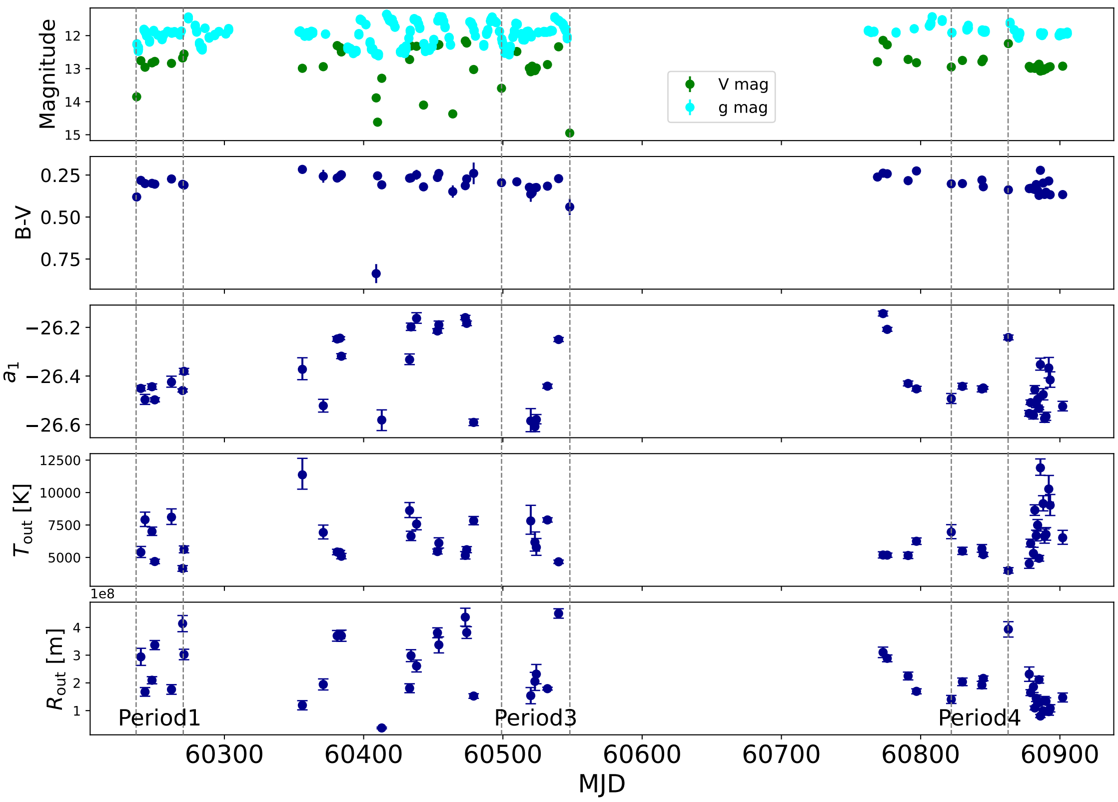

Figure 3: Time evolution of luminosity and physical quantities for KIC 9406652 from October 2023 to August 2025. From top to bottom: V and g light curves, color index $B - V$, normalization a, outer disk edge temperature $T_{\rm out}$, outer disk edge radius $R_{\rm out}$.

an increase in the disk radius [4]. These earlier suggestions of the disk expansion are consistently confirmed by our multicolor observations.

However, the increase in disk radius during the IW And state is not consistent with theoretical models. Models invoking variations in the mass-transfer rate do not account for disk expansion [1], and simulations of the tilted disk model even predict a decrease in disk radius during standstill [3]. The mechanism of the disk-radius increase during the IW And state is still an open issue.

5. Summary

We conducted optical and near-infrared multicolor observations of the IW And-type dwarf nova KIC 9406652. These observations successfully observed all phenomena characteristic of IW And-type dwarf novae, including oscillations at intermediate brightness, rebrightenings followed by deep dips, normal standstills, and normal outbursts. In addition, a comparison of the temporal evolution of the color index and magnitude revealed a redder-when-brighter trend during the IW And state. This result suggests that the radius of the accretion disk increased during the IW And state, and our multicolor observations support the previous studies which also reported a similar expansion of the disk. However, the increase in disk radius observed in the IW And state has not yet been fully explained by the currently proposed theoretical models, and further discussion is required.

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