A unique UV flare in the optical light curve of the quasar J004457.9+412344

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Abstract. We found that the nova candidate J004457.9+412344 is a radio-quiet quasar at $z = 2.109$ seen through the outer disk of M31 [4]. An AGN misclassified as a variable star is neither unexpected nor unprecedented. However, the confusion of a luminous radio-quiet high-$z$ quasar with a nova indicates a remarkably strong outburst in the far UV that points towards a spectacular event.

1. INTRODUCTION

J004457.9+412344 was originally discovered as a variable star-like source in our neighbour galaxy M 31 [1] and was classified as a nova with an unusual light curve [2] and a possible X-ray counterpart [3]. We found that the source is a faint radio-quiet type 1 quasar at $z = 2.109$ seen through the outer disk of M31 [4]. An AGN misclassified as a variable star is neither unexpected nor unprecedented. However, the confusion of a luminous radio-quiet high-$z$ quasar with a nova indicates a remarkably strong outburst in the far UV that points towards a spectacular event.

2. THE OPTICAL LONG-TERM LIGHT CURVE

We constructed a long-term light curve based on $\sim$400 observations from the Tautenburg Schmidt telescope between 1961 and 2012 in combination with archival observations, published data, and targeted new observations from altogether 14 wide-field telescopes. J004457.9+412344 was detected at 226 epochs between 1948 and 2012. In addition, we derived useful upper limits for 12 epochs between 1900 and 1949. The light curve (Fig. 1a) clearly displays two stages, a rather quiet “ground state” at $B \sim 20.5$ with typical fluctuations of 20 per cent and a single strong flare in 1992 that corresponds to an increase of the far UV flux by a factor of 20. With the comparison with the light curves of 8744 quasars from the stripe S82 [5,6] of the Sloan Digital Sky Survey clearly indicates that such strong+single events are extremely rare (Fig. 1b).

3. INTERPRETATION OF THE FLARE: MICROLENSING?

The quasar is seen through the outer disk of our neighbour galaxy at a galactocentric distance of 16 kpc in the midplane of M31. The optical depth, i.e., the probability for the quasar to fall into the Einstein radius of a foreground star, is $\tau = 2 \cdot 10^{-4}$ corresponding to an event rate of $\sim$1 per century for background quasars with $B < 20$. The best fit of the flare light curve is achieved for a microlensing low-mass binary star with $0.3 m_\odot$ and $0.1 m_\odot$ crossing the line of sight at minimum angular distances $u_{\text{min}} = 0.05$ and 0.8 (in units of the Einstein angle), respectively. However, the probability for a magnification as strong as in J004457.9+412344 (i.e., with such a small $u_{\text{min}}$) is very low. Moreover, the quasar has changed its colour in the flare by $\Delta(B - R) \sim 0.5$ mag. Chromatic amplification is expected if the angular size $\alpha_s$ of the source is comparable to $u_{\text{min}}$. However, the standard accretion disk model yields $u_{\text{min}} \geq 30 \alpha_s$. Hence, the size of the source is negligible, even if quasar accretion disks are $\sim 4$ times larger than predicted by the standard model (e.g., [7]). Microlensing is thus considered rather unlikely to explain the flare.

4. ... OR A STELLAR TIDAL DISRUPTION EVENT?

With the exception of the first stage of the onset of the flare, the observed shape of the light curve is in a good agreement with the predictions from the stellar tidal disruption (TD) theory (e.g., [8]): The profile is asymmetric with a sudden increase towards the peak

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followed by a power-law decline with an exponent of about $-5/3$ (Fig. 1c,d). If intrinsic and isotropic, the total radiated energy in the flare is $E_{\text{flare}} = 2 \times 10^{54}$ erg. This corresponds to a mass of the disrupted star of $M_c = E_{\text{flare}} f_{\text{acc}}^{-1} c^2 \eta^{-2} \sim 10 M_\odot$ assuming a mass-radiation conversion efficiency $\eta \sim 0.2$ [9] and a fraction $f_{\text{acc}} \sim 0.5$ of accreted mass. The peak monochromatic UV continuum luminosity of the flare at the rest-frame wavelength $\lambda = 1350 \,\text{Å}$ amounts to $\lambda L_{\lambda, \text{peak}} \sim 2 \times 10^{43}$ erg s$^{-1}$. According to the TD theory, the effective temperature $T_{\text{eff}}$ of the tidal debris depends on the luminosity $L_{\text{flare}}$, the black hole mass $M_{\text{bh}}$, and the radius and the mass of the star, $R_*, M_*$. From the spectrum of J004457.9+412344 and using the scaling relation for the CIV line [10] we derive $M_{\text{bh}} = 5 \pm 4 \times 10^8 M_\odot$. With $L_{\text{flare}}$ and $M_{\text{bh}}$ given and using $L_{\lambda, \text{peak}}$ as a free parameter, we compute the $R_*/M_*$ relation predicted from the TD model and compare it with stellar models (Fig. 2a). While main sequence stars are clearly excluded, there exists a solution for $\sim 10 M_\odot$ giants where the tidal radius $R_t$ is clearly out of the Schwarzschild radius $R_S$ of the black hole (Fig. 2b). The maximum of the blackbody radiation is emitted at $\lambda_{\text{max}} \sim 1300 \,\text{Å}$ and shifted into the B band due to the redshift $z \sim 2$ of the quasar. Further, we derive from the light curve a short return time of the debris of $\Delta t_0 = 1.3$ days corresponding to a deep penetration of the star by $\beta \equiv R_t/R_S \sim 30$ (Fig. 2c) and $R_0/R_S \sim 1$ ($R_0$: pericentric distance). It can be speculated whether or not the smooth increase of the flux in the earliest phase of the flare may be related to the high penetration factor, perhaps in combination with effects from the massive accretion disk of the quasar.

5. CONCLUSIONS

The observation of objects at redshifts $z \sim 2 - 3$ provides the opportunity to study intrinsic far UV flares at optical wavelengths. We present a single, outstandingly strong far UV bump in the B band long-term light curve of the $z \sim 2$ quasar J004457.9+412344 which is highly unusual for radio-quiet quasars. Its properties appear broadly consistent with the tidal disruption of a $\sim 10 M_\odot$ giant star by a $2.5 \times 10^3 M_\odot$ black hole [4]. If not caused in this way, the outburst of J004457.9+412344 would hint to a rare transient phenomenon which mimics TD flares. It can be assumed that projects like Pan-STARRS and LSST will discover more of them.

References

[8] Gezari, S., this conference