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V1818 Ori and NSV 16694 are surrounded by variable reflection nebulae

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Abstract: We report the discovery of optical variability in the reflection nebulae surrounding V1818 Orionis and NSV 16694 on timescales of only a few weeks. Similar to other known variable reflection nebulae, the changing brightness of the central stars appears to directly affect the illumination of the surrounding nebulae.

1 Introduction

Reflection nebulae are interstellar clouds that shine by scattering the light of nearby stars rather than emitting their own light. Because shorter wavelengths scatter more efficiently, they often appear bluish, as seen in Messier 78 or the Pleiades. Unlike emission nebulae, their stars do not ionize the gas but illuminate surrounding dust particles [1]. Although reflection nebulae were long believed to be optically constant, a small number — known as variable reflection nebulae — exhibit changes in brightness and shape within only weeks or months. These variations, seen in classic examples like Hubble's and Hind's variable nebulae [2, 3], arise from fluctuations in the illuminating star or from shadowing effects of orbiting dust.

In 2025, we discovered rapid variations occurring within just a few days in the reflection nebula vdB 24 ("StraBe 1") surrounding XY Per, thereby adding this fascinating object to this rare class [4]. For general background information on reflection nebula variability and our search strategy, we refer the reader to that publication.

Encouraged by this success, we continued our systematic search for similar objects. In this report, we present two additional variable reflection nebulae discovered as part of this ongoing effort: V1818 Orionis ("StraBe 2") and NSV 16694 ("StraBe 3"), suggesting that such dynamic behaviour may be more common than previously assumed. For consistency across our discoveries, we designate the names "StraBe" (derived from the authors Strauss and Bernhard) to identify variable nebulae found within this series of studies. To the best of our knowledge, based on a review of the literature via SIMBAD and NASA ADS, the variability of these two objects has not been reported previously.

Observation and data analysis

To search for further examples of this rare class of objects, we screened the International Variable Star Index (VSX) of the AAVSO [5] for young stellar objects that are both relatively bright (brighter than 14 mag) and strongly variable (amplitude greater than 0.8 mag), so that possible light echoes in nearby nebulae can be well observed. The resulting list was then visually inspected using the Aladin service of VIZIER to identify any surrounding reflection nebulosity. Objects meeting all of these criteria were subsequently examined using time-series imaging data from the Zwicky Transient Facility (ZTF), downloaded from the NASA/IPAC Infrared Science Archive (IRSA). Covering three passbands (g, r, and partially i), it achieves a limiting magnitude of 20.5 mag, making ZTF data highly suitable for variable-objects investigations [6-8].

During this systematic investigation of ZTF frames, we came across **V1818 Ori** and **NSV 16694**, which both show clear and well-resolved changes in their surrounding reflection nebulae. Fortunately, in these cases, the central stars lay within a brightness range that is not saturated in the ZTF images, in contrast to the situation described in our previous publication [4]. Therefore, in both cases the brightness variations of the star and its surrounding reflection nebula can be examined in parallel. Period analysis of the ZTF g data was performed using the Lomb-Scargle GLS method in Peranso [9]. To further investigate the variability of the reflection nebulae, we downloaded ZTF images via the NASA/IPAC Infrared Science Archive (IRSA) server for visual inspection and for creating animations.

2 Results

a) V1818 Ori in the head of the nebula GN 05.51.4

According to the entry in the International Variable Star Index (VSX) database, V1818 Ori is a young Herbig Ae star of spectral type B7Ve. It exhibits strong photometric variability, with its brightness ranging from approximately 10.7 to 14.4 mag in the V band. This variability is characteristic of UX Orionis-type stars and is often attributed to changing circumstellar extinction, likely caused by clumpy material in a protoplanetary disk seen at high inclination. Further details about V1818 Ori, such as its location within GN 05.51.4, can be found in [10]. An overview colour image is shown in Figure 1.

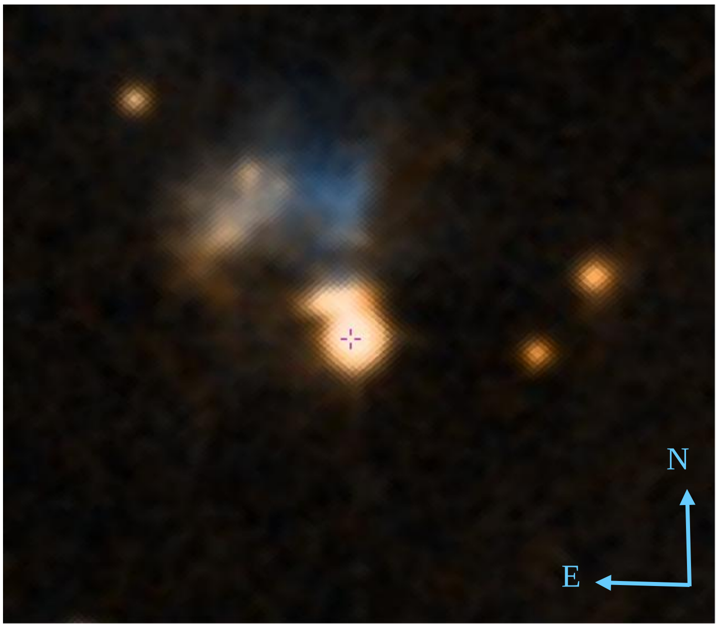

Figure 1: Overview DSS colour image of V1818 Ori, 1.8x1.8 arcmin

The essential data of V1818 Ori are listed in Table 1:

Table 1: Essential data of V1818 Ori

Spectral type	Herbig Ae [10]	
Identifiers	Gaia DR3 3011245246750171264 IRAS 05513-1024 2MASS 05534254-1024006	
Magnitude Range	11.3-15.0 (derived from ZTF zg band)	
Gaia DR3 [11]:	Right Ascension (J2000)	05 53 42.5559*
	Declination (J2000)	-10 24 00.727*
	Plx	1.5788±0.0567mas
	Gmag	10.81 mag

* All coordinates are taken from the Gaia DR3 catalogue (http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=I/355). The coordinates (epoch J2000) are computed by VizieR, and are not part of the original data from Gaia (note that the coordinates are computed from the positions and the proper motions).

The ZTF data of V1818 Ori cover the time interval from 2018 to 2025. The two bands zr and zg are shown in Figure 2. The amplitude of the object, reaching 3.7 mag in the zg band, is considerably large even for active young stars.

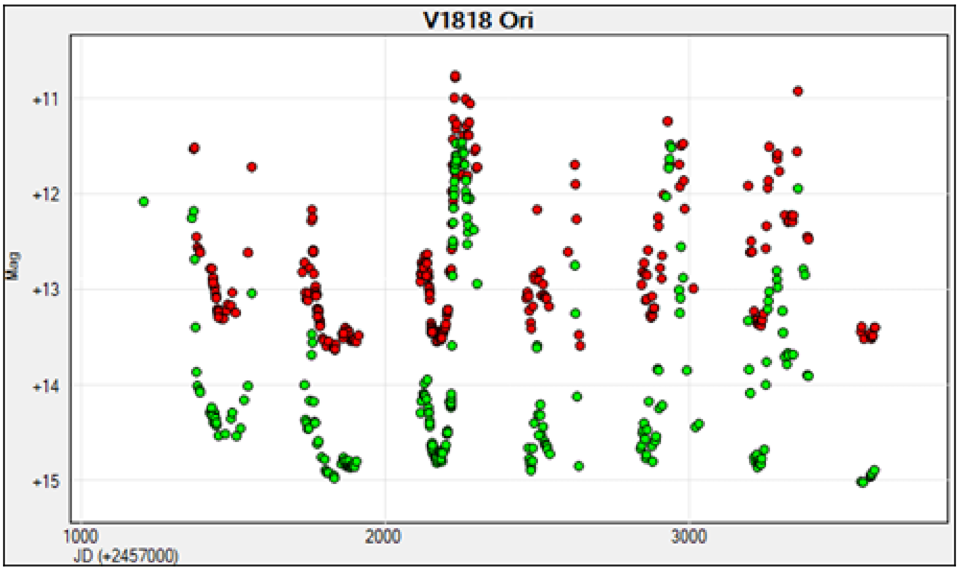

Figure 2: zr (red) and zg (green) brightness of V1818 Ori in the ZTF survey between 2018 and 2025

The light curve shows, at first glance, a semi-regular variability with a high outburst-like amplitude in both colour bands. A notable feature is the large scatter in the r band, particularly near the maxima. This phenomenon suggests a saturation effect in the zr band, which may lead to an underestimation of the total amplitude in the r band. For this reason, the period analysis was performed using only the zg band.

The GLS periodogram shows a dominant peak near 347 days, with a secondary harmonic at P/2. The peak width suggests an uncertainty of about ± 10 days (Figure 3). The following ephemeris can be derived:

HJD(max) = 2459239+347*E

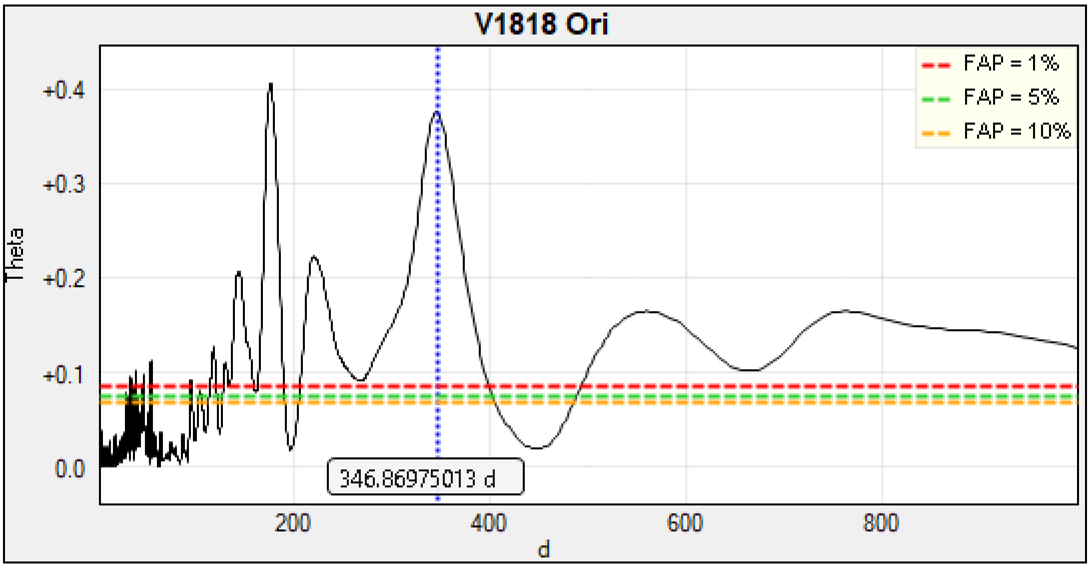

Figure 3: Peranso GLS Periodogram of the ZTF data between 2018 und 2025

The zg data reduced with this ephemeris are shown in Figure 4.

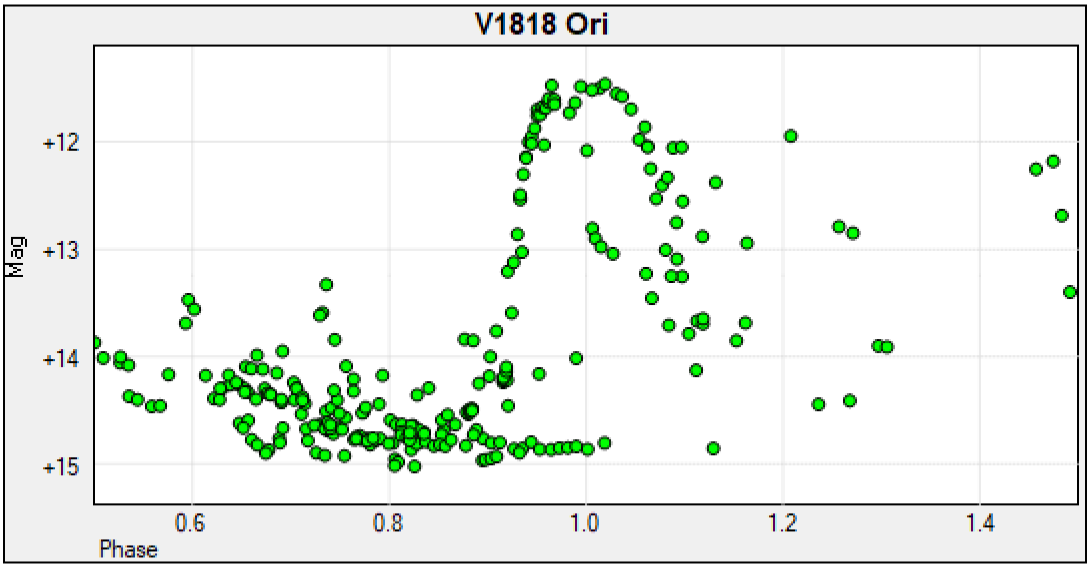

Figure 4: Reduced light ZTF zg curve with the ephemeris HJD(max) = 2459239+347*E

The reduced light curve indicates that the variability can at most be considered 'semi-regular', with irregular components also involved. To further investigate the variability of the reflection nebula, we downloaded ZTF images via the IRSA server. We created an animation composed of approximately 400 individual frames from the Zwicky Transient Facility (ZTF), covering the period from 2018 to 2025. For this animation, the frames in the zr band were used, as the reflection nebula is significantly more prominent in this band than in zg. Please note that the time intervals between individual images are not uniform:

https://zenodo.org/records/17560171

Obvious variations in the brightness and shape of the nebula can be seen throughout the entire period; in the following, a particularly prominent episode of these changes between December 2020 and February 2021 will be examined in detail.

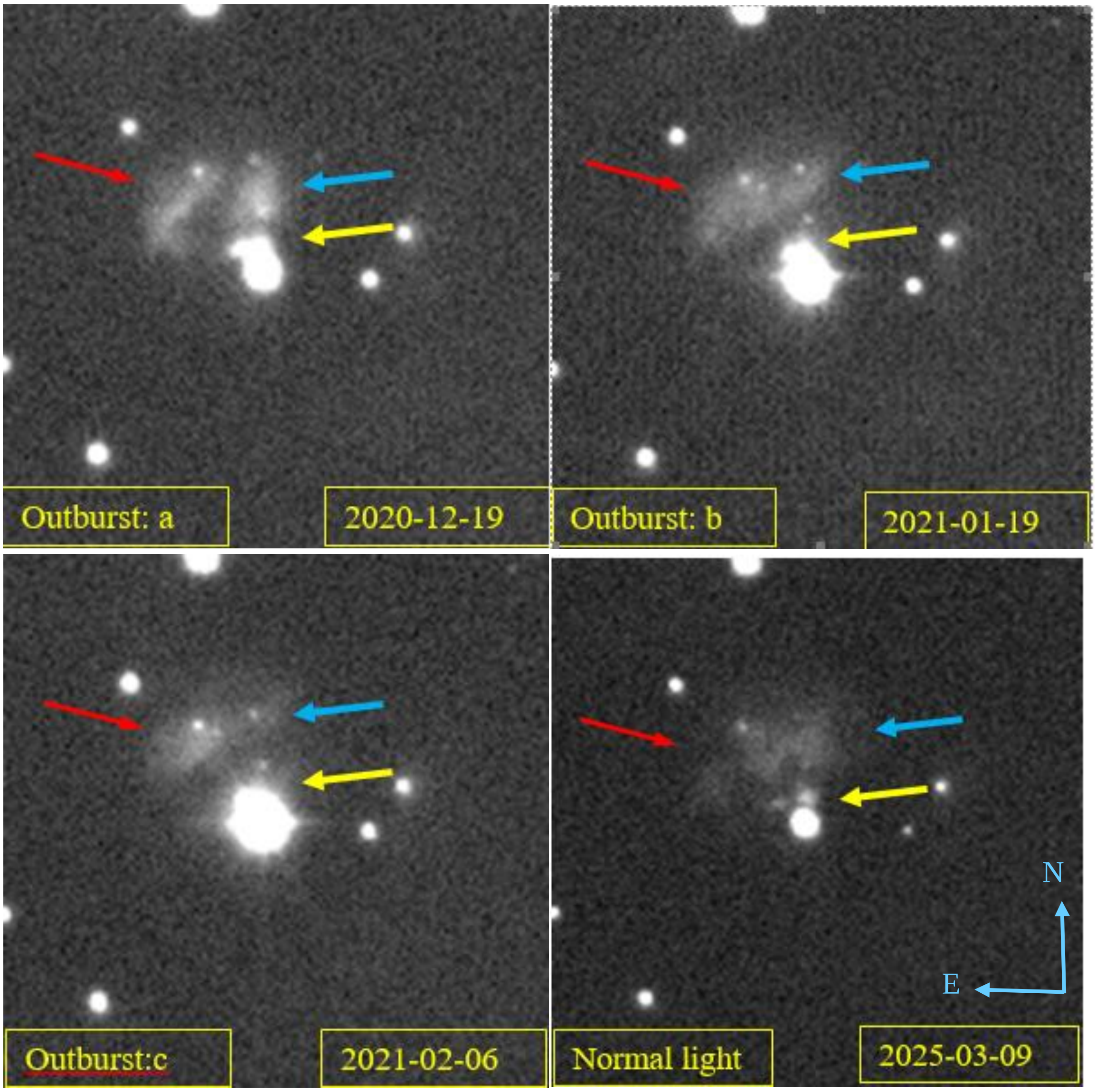

Figure 5: ZTF-r images at the beginning of an outburst (top left, “a”), before maximum brightness (top right, “b”), at maximum (bottom left, “c”), and for comparison during normal brightness (bottom right, “d”)

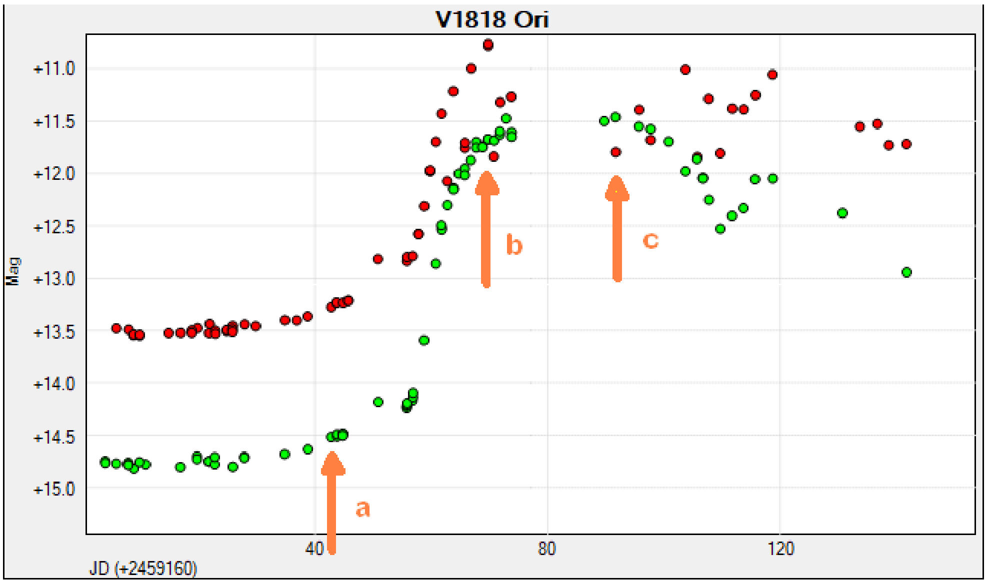

Figure 6: Observation times of the corresponding frames shown in Figure 4 (a–c)

Figures 5 and 6 show three ZTF-r frames obtained near the onset of an outburst (labelled a, b, and c) compared to the quiescent state (d). At the beginning of the event (a), both the central star and the innermost parts of the reflection nebula close to it (yellow arrow) become noticeably brighter than in the quiescent image. As the outburst evolves, variable illumination produces apparent changes in the appearance of the two more distant nebular regions (red and blue arrows). In (b), the structures that were still separated in (a) appear to merge, while in (c) the blue-marked region decreases in brightness, beginning to approach the quiescent level for example observed in 2025 (d).

An estimate of the motion of the light echo can be made using the two images b and c in Figure 5. Between January 19, 2021 and February 6, 2021 (a span of 18 days), the lower edge of the nebula shifted by about 3.9 arc seconds. This corresponds to a tangential velocity of 3.9 / 18 = 0.21 arc seconds per day. For comparison, the tangential motion corresponding to the speed of light, based on the Gaia DR3 parallax (1.5788 mas, equivalent to 636 pc or 2070 light years), can be calculated as 0.27 arc seconds per day. Thus, tangentially, the light echo around V1818 Ori appears to propagate at roughly 80 % of the speed of light. The difference of 0.21 / 0.27 = 22 % can be attributed to the geometric orientation of the reflecting clouds in three-dimensional space. It is important to note that this is not a physical motion of matter, but rather a consequence of light-travel-time effects in a three-dimensional medium. This interpretation also effectively rules out alternative explanations such as the expansion of material, which would not be consistent with the observed high apparent velocities.

b) NSV 16694 surrounded by the cometary cloud L1617

The next object we found in the same way is NSV 16694. According to the entry in the International Variable Star Index (VSX) database, NSV 16694 is a young Herbig-Haro object in the cometary cloud L1617. It exhibits remarkable photometric variability, with its brightness ranging from approximately 11.8 - 13.4 in the V band. This amplitude, though somewhat smaller than seen in V1818 Ori, is still characteristic of UX Orionis-type stars and is often attributed to changing circumstellar extinction, likely caused by clumpy material in a protoplanetary disk seen at high inclination. An overview colour image is shown in Figure 7.

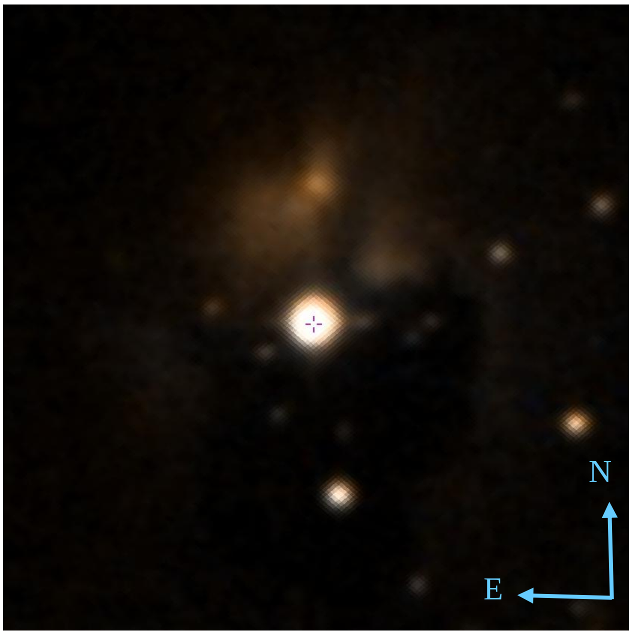

Figure 7: Overview DSS colour image of NSV 16694, 2.0x2.0 arcmin

The essential data of NSV 16694 are listed in Table 2:

Table 2: Essential data of NSV 16694

Spectral type	emission star [12]	
Identifiers	Gaia DR3 3319205667570451456	
	2MASS J05505371+0307293	
	ASAS J055054+0307.5	
	ASASSN-V J055053.73+030729.7	
	IRAS 05482+0306	
Magnitude Range (zg)	12.5-14.2 (derived from ZTF zg band)	
Gaia DR3 [11]:	Right Ascension (J2000)	05 50 53.7143*
	Declination (J2000)	+03 07 29.346*
Gmag	12.22 mag	
Further information	known as Binary [13]	

* All coordinates are taken from the Gaia DR3 catalogue (http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=I/355). The coordinates (epoch J2000) are computed by VizieR, and are not part of the original data from Gaia (note that the coordinates are computed from the positions and the proper motions).

The ZTF data of NSV 16694 cover the time interval from 2018 to 2025. The only available band zg is shown in Figure 2. Although zr frames are available, the brightness appears saturated in this band. The amplitude of the object, reaching 1.7 mag in the zg band, is rather typical for active young stars.

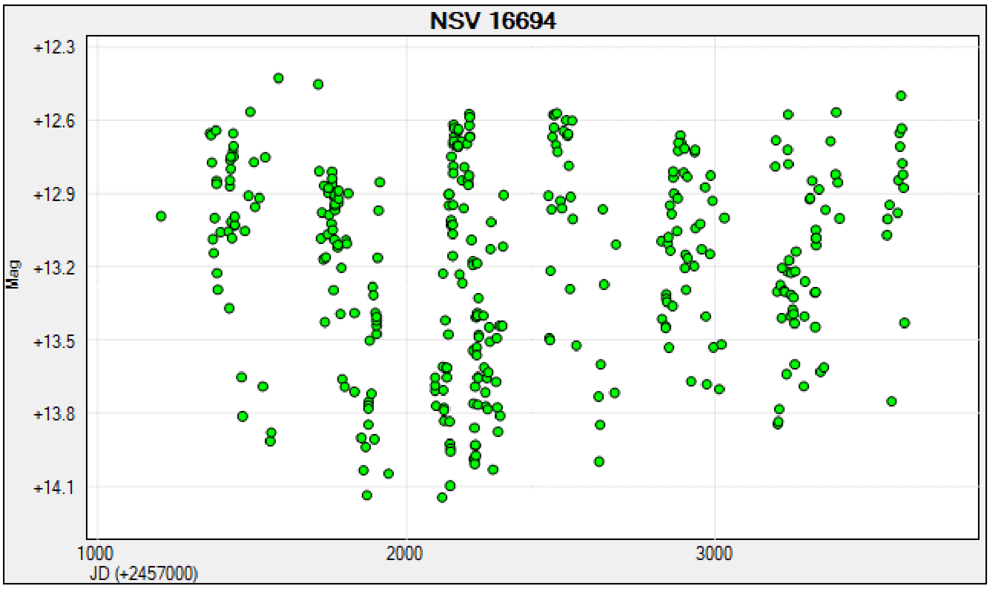

Figure 8: zg (green) brightness of NSV 16694 in the ZTF survey between 2018 and 2025

The light curve shows, at first glance, a clearly more irregular shape than that of V1818 Ori, with only weakly pronounced maxima. The period analysis was carried out using the zg band.

A period analysis of the ZTF g data using the Lomb-Scargle GLS method revealed a dominant period of 184 days (with an additional peak at the second harmonic). The following ephemeris can be derived from the ZTF zg data:

HJD(max) = 2458240+184 *E

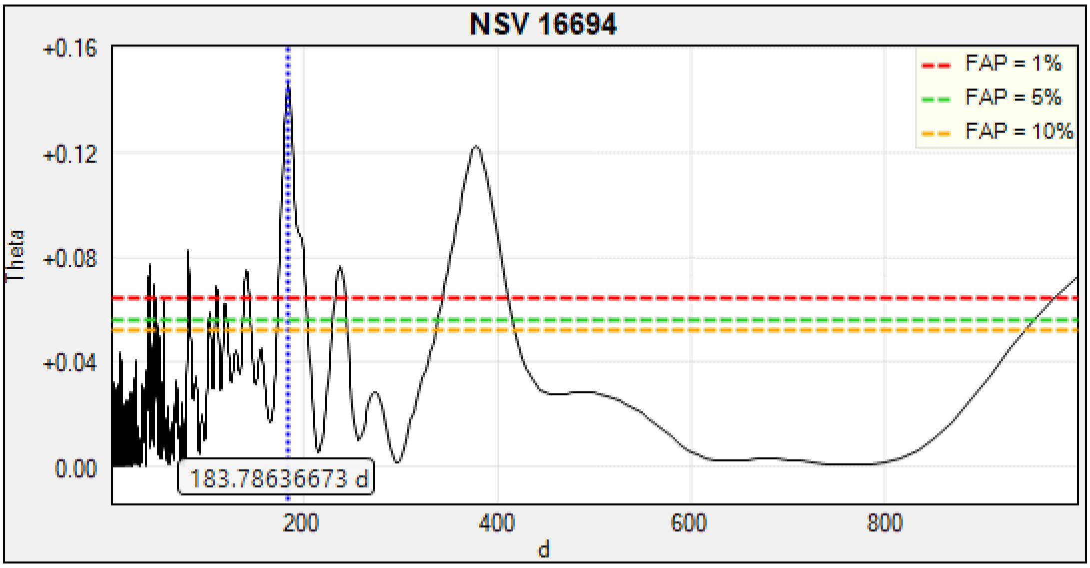

Figure 9: Peranso GLS Periodogram of the ZTF data between 2018 und 2025

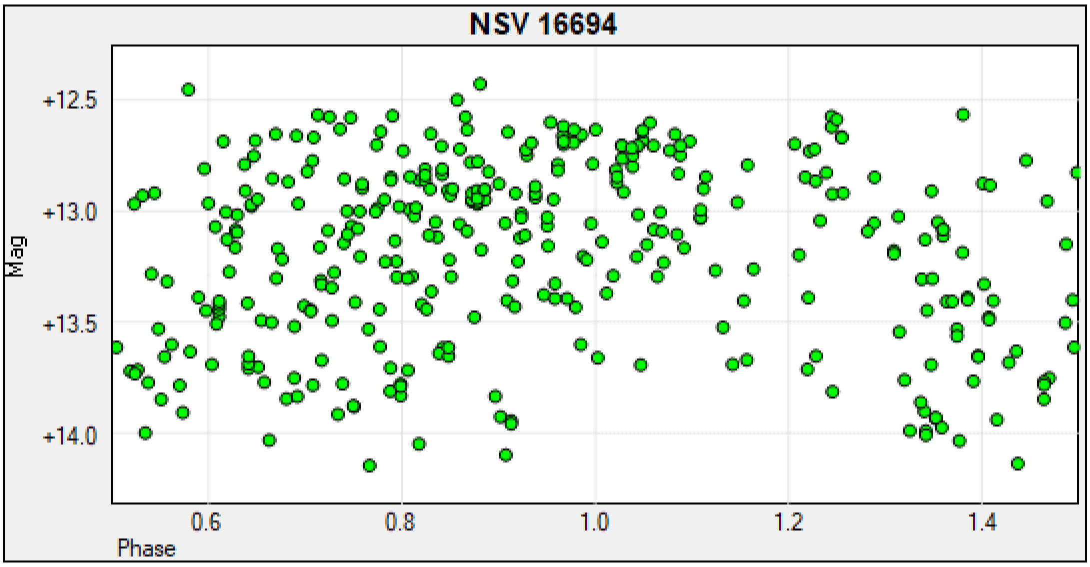

Figure 10: Reduced light ZTF zg curve with the ephemeris HJD(max) = 2458240+184 *E

The reduced light curve indicates that the variability can at most be considered 'semi-regular', with irregular components also involved. Furthermore, it is possible that the detected period is also influenced by the distribution of observations throughout the year.

To further investigate the variability of the reflection nebula, we again downloaded ZTF images via the IRSA server. We created an animation composed of approximately 430 individual frames from the Zwicky Transient Facility (ZTF), covering the period from 2018 to 2025. For this animation, the frames in the zr band were used, as the reflection nebula is significantly more prominent in this band than in zg. Please note that the time intervals between individual images are not uniform:

https://zenodo.org/records/17560399

Obvious variations in the brightness and shape of the nebula can be seen throughout the entire period, although they are clearly weaker than in V1818 Ori and mainly affect the portion of the nebula located upper left of the central star in the images. Nevertheless, the variability of the nebula is clearly visible during several episodes.

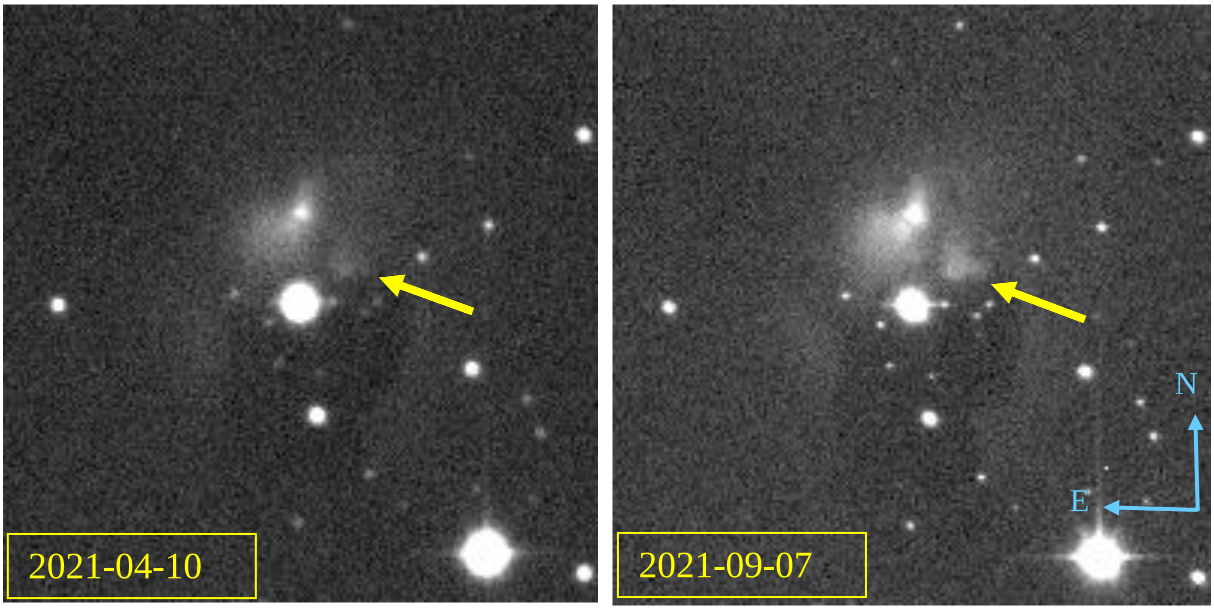

Figure 11: ZTF-r images of a gradual brightening of a part of the surrounding nebula between April and September 2021

Figure 11 shows the clear brightening of the nebula part marked with a yellow arrow between April 10, 2021 (left) and September 7, 2021 (right) in the ZTF-r images: In the animation, light echoes can be seen to a lesser extent than in V1818 Ori. Nevertheless, over a timespan of several weeks to a few months, they become clearly visible, as shown in Figure 11.

3 Conclusion

V1818 Ori and NSV 16694, along with their surrounding nebulae GN 05.51.4 and L1617, are two additional examples of young stellar objects whose surrounding reflection nebulae show clearly detectable brightness variations of both the central star and the surrounding nebula. Further observations of such objects may provide valuable constraints on the geometry and scattering properties of circumstellar environments.

Acknowledgements

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