

THE 1966–1967 OUTBURST OF V1647 ORIONIS AND THE APPEARANCE OF MCNEIL’S NEBULA

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ABSTRACT

We present the results of an investigation aimed at characterizing previous eruptions of V1647 Orionis, the illuminating star of McNeil’s Nebula. Photographic plates and films from the Asiago Observatory (1960–1998) and Harvard Observatory (1898–1974) collections were inspected for the nebula. We have determined that, to the plate limits, the known eruption of 1966–1967 is the only one detected during the 38 yr period covered by the Asiago archive. In the Harvard collection, we did not find any additional occurrences in approximately 400 plates of the region taken over the last 100 yr. Based on the Asiago material, we here present a study of the 1966–1967 event. McNeil’s Nebula and V1647 Ori are clearly visible on 19 plates obtained with the Asiago 67/92 cm Schmidt telescope from 1966 October 22 to 1967 March 4. The object is not seen on plates taken in 1966 March nor in 1967 November, thus setting a minimum duration time for the eruptive event of 5 months and a maximum of 20 months. The 19 plates showing McNeil’s Nebula were digitized, and a morphological and photometric analysis of the object was undertaken. These data show temporal photometric variability, as well as structural differences between different color bands. We finally compare the 1966–1967 event to the recent 2003–2006 eruption and consider the nature of V1647 Ori within the framework of EX Lupi– and FU Orionis–type eruptions.

Key words: stars: formation — stars: pre–main–sequence

1. INTRODUCTION

T Tauri stars accrete matter from their circumstellar disks at typical rates of $10^{-8} M_{\odot} \text{ yr}^{-1}$ (e.g., Hartmann et al. 1998). Long periods of more or less steady accretion are, at least in some stars, interspersed with sudden surges in accretion rate, which rises to as much as $10^{-4} M_{\odot} \text{ yr}^{-1}$ for periods of several to many decades. These are the FU Orionis–type outbursts (FUors) first discussed by Herbig (1966, 1977). Shorter lived eruptive events are EX Lupi–type outbursts (EXors; Herbig 1977, 1989). For an overview of these types of eruptions, see Hartmann & Kenyon (1996).

The last major outburst of a classical FUor occurred in 1970, when V1057 Cyg went into eruption (Herbig 1977; Herbig et al. 2003). It was therefore of considerable interest when McNeil (2003) announced that a faint star in L1630 in Orion had gone into outburst, illuminating what is now known as McNeil’s Nebula. The faint star is now designated as V1647 Ori and has been studied in great detail by numerous authors. The optical/infrared photometry and spectroscopy analyzed by Reipurth & Aspin (2004) suggested that V1647 Ori is an EXor, whereas Briceño et al. (2004) favored a FUor nature. Given our limited understanding of either group of stars, it is still unclear whether this is a semantic distinction, i.e., whether FUors and EXors are merely different shades of the same phenomenon and form a single group whose properties span a continuum or whether FUors and EXors are in some aspects fundamentally physically different. Further observations at a wide range of wavelengths have recently

been presented by Abrahám et al. (2004), Andrews et al. (2004), Briceño et al. (2004), Grosso et al. (2005), Kastner et al. (2004), McGehee et al. (2004), Muzerolle et al. (2005), Ojha et al. (2005), Rettig et al. (2005), Tsukagoshi et al. (2005), Vacca et al. (2004), and Walter et al. (2004).

Observations show that EXors have recurrent eruptions. The best-studied case is EX Lupi (Herbig 1977; Lehmann et al. 1995; Herbig et al. 2001). FUors have not been seen to erupt more than once, but this is probably due to the much longer duration of their eruptions. Indeed, on statistical grounds FUors are also expected to exhibit multiple outbursts (Herbig 1977; Hartmann & Kenyon 1996).

V1647 Ori is known to have erupted once before. Mallas & Kreimer (1970) include a photograph taken on 1966 October 22 that shows McNeil’s Nebula at about the same brightness as during its current eruption. To further clarify the historical events associated with this object, we have examined the plate archives of both the Asiago Observatory and the Harvard College Observatory (HCO), which together span the last century, and we discuss below the historical outburst of V1647 Ori and McNeil’s Nebula.

2. ARCHIVE SEARCH AND RESULTS

2.1. Asiago Plates Search

Searches for previous eruptions of V1647 Ori, the illuminating source of McNeil’s Nebula, used the Sofia Wide-Field Plate Database,⁶ which included information on plates in the Asiago plate archive. Efforts are being made, under an Italian and Vatican Observatory program, to digitize the Asiago plate archive (Barbieri et al. 2003a, 2003b).⁷ We used this program to obtain digital images of sections of plates containing the V1647 Ori field to look for past episodes when McNeil’s Nebula was visible. Three telescopes have contributed to the large Asiago collection:

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⁶ See <http://www.skyarchive.org>.

⁷ See <http://www.pd.astro.it/asiago/7000/7000.html>.

TABLE 1
OBSERVING LOG

Plate No.	UT Date and Time	Julian Date	Emulsion	Filter	Exp. Time (minutes)	Phot. Band	Lim. Mag.
239.....	1966 Mar 20 19:08	2,439,205.25	103a-E	RG1	50	<i>R</i>	18.0
374.....	1966 Oct 22 01:22	2,439,420.50	103a-O	...	15	<i>B</i>	19.4
383.....	1966 Nov 7 23:51	2,439,437.41	103a-O	...	15	<i>B</i>	19.2
385.....	1966 Nov 8 01:03	2,439,437.50	INsens	RG5	30	<i>I</i>	15.1
399.....	1966 Nov 16 02:35	2,439,445.54	Oa-O	...	25	<i>B</i>	17.9
411.....	1966 Nov 19 01:37	2,439,448.50	103a-E	RG1	40	<i>R</i>	18.0
412.....	1966 Nov 19 02:25	2,439,448.54	Oa-O	...	20	<i>B</i>	18.8
433.....	1966 Dec 8 22:48	2,439,468.37	INsens	RG5	30	<i>I</i>	15.1
434.....	1966 Dec 8 23:25	2,439,468.41	Oa-O	...	20	<i>B</i>	18.3
491.....	1966 Dec 21 00:43	2,439,480.45	IIIa-J arr ^a	...	60	<i>B</i>	19.7
519.....	1967 Jan 3 20:44	2,439,494.29	IIIa-J arr ^a	...	60	<i>B</i>	19.7
520.....	1967 Jan 3 21:40	2,439,494.33	Oa-O	...	30	<i>B</i>	17.9
528.....	1967 Jan 4 21:30	2,439,495.33	INsens	RG5	40	<i>I</i>	15.5
548.....	1967 Jan 11 22:39	2,439,502.37	103a-O	...	15	<i>B</i>	18.3
569.....	1967 Jan 15 23:21	2,439,506.41	INsens	RG5	40	<i>I</i>	15.6
570.....	1967 Jan 15 23:54	2,439,506.41	103a-O	...	15	<i>B</i>	18.8
578.....	1967 Feb 8 22:17	2,439,530.37	Oa-O	...	40	<i>B</i>	17.9
592.....	1967 Feb 10 21:24	2,439,532.33	INsens	RG5	40	<i>I</i>	15.6
596.....	1967 Feb 12 19:20	2,439,534.25	103a-O	...	15	<i>B</i>	17.9
613.....	1967 Mar 4 19:04	2,439,554.25	INsens	RG5	60	<i>I</i>	15.6
1081.....	1967 Nov 28 23:15	2,439,823.41	103a-O	...	15	<i>B</i>	17.9

^a Here “arr” indicates the emulsion was baked in a nitrogen atmosphere.

the 40/50 cm and 67/92 cm Schmidt telescopes and the 182 cm reflector. Table 1 gives more information on the available plates of the V1647 Ori region. We have inspected a total of 367 Asiago plates for McNeil’s Nebula. The breakdown of these plates into telescope and filter is also shown in Table 1. Figure 1 shows the temporal distribution of the plates that include the region of V1647 Ori. The majority of the plates inspected are blue sensitive, specifically, E-K 103a-O emulsions with no filter; thus, they contain only a small UV light contribution. Given the low elevation of the object from Asiago and the intrinsic reddening of the

nebular region, we consider any UV correction to be negligible, and henceforth we refer to these plates as Johnson *B*-band plates. Some equivalent Johnson *R*- and *I*-band plates of the McNeil region were also present in the archive. More information on the correspondence of the plates and filter combinations used and the Johnson filter system can be found on the Asiago Observatory Web site.⁸ All the plates have been visually inspected with a binocular microscope in order to ascertain their usefulness for

⁸ See <http://www.pd.astro.it/asiago/7000/7020.html>.

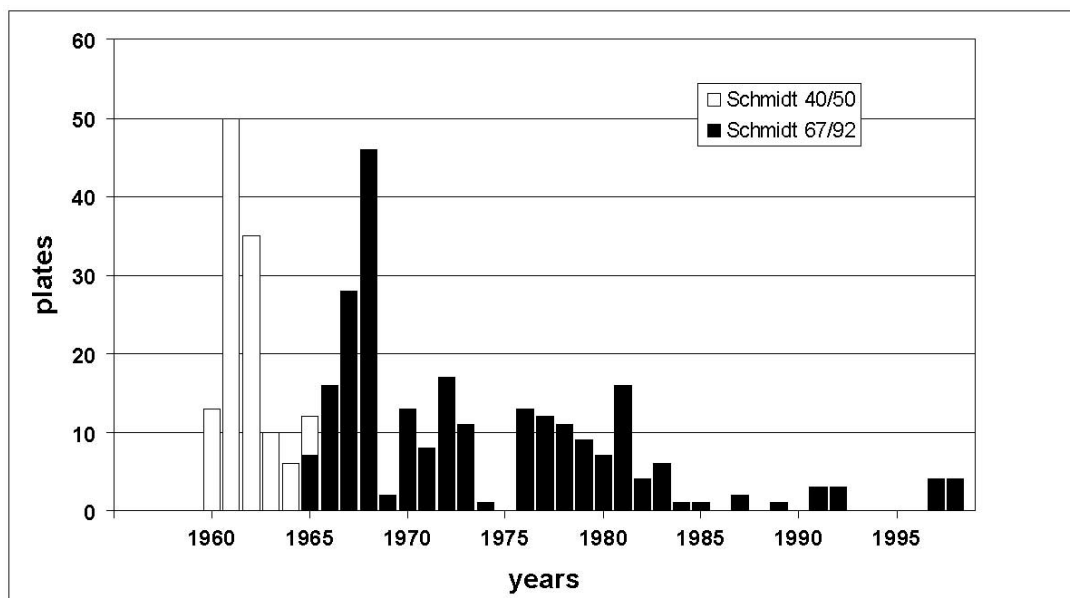


FIG. 1.—Histogram of the number of plates per year in the Asiago plate archive that included the position of McNeil’s Nebula/V1647 Ori. The 1960–1964 plates were taken with the 40/50 cm Schmidt telescope, while those from 1965–1998 were taken with the 67/92 cm Schmidt telescope. A reasonably good time sampling of the whole period is evident, suggesting that if McNeil’s Nebula had appeared during this period, the Asiago plates would have seen it. Only the 1966–1967 eruption of the object was detected.

TABLE 2
INSPECTED ASIAGO OBSERVATORY PLATES OF THE V1647 ORI REGION

Telescope Name	Focal Length (cm)	Date of First Plate	Date of Last Plate	No. of Plates or Films	Photometric Band ^a
S40/50	100	1960 Nov 26	1965 Oct 22	120	<i>B</i> (92), <i>V</i> (7), <i>R</i> (21)
S67/92	216	1965 Oct 30	1998 Feb 19	245	<i>B</i> (145), <i>V</i> (22), <i>R</i> (7), <i>I</i> (71)
182 Cass.....	1640	1977 Dec 5	1977 Dec 5	2	<i>B</i> (1), <i>R</i> (1)

^a Numbers in parentheses are the number of plates in that band.

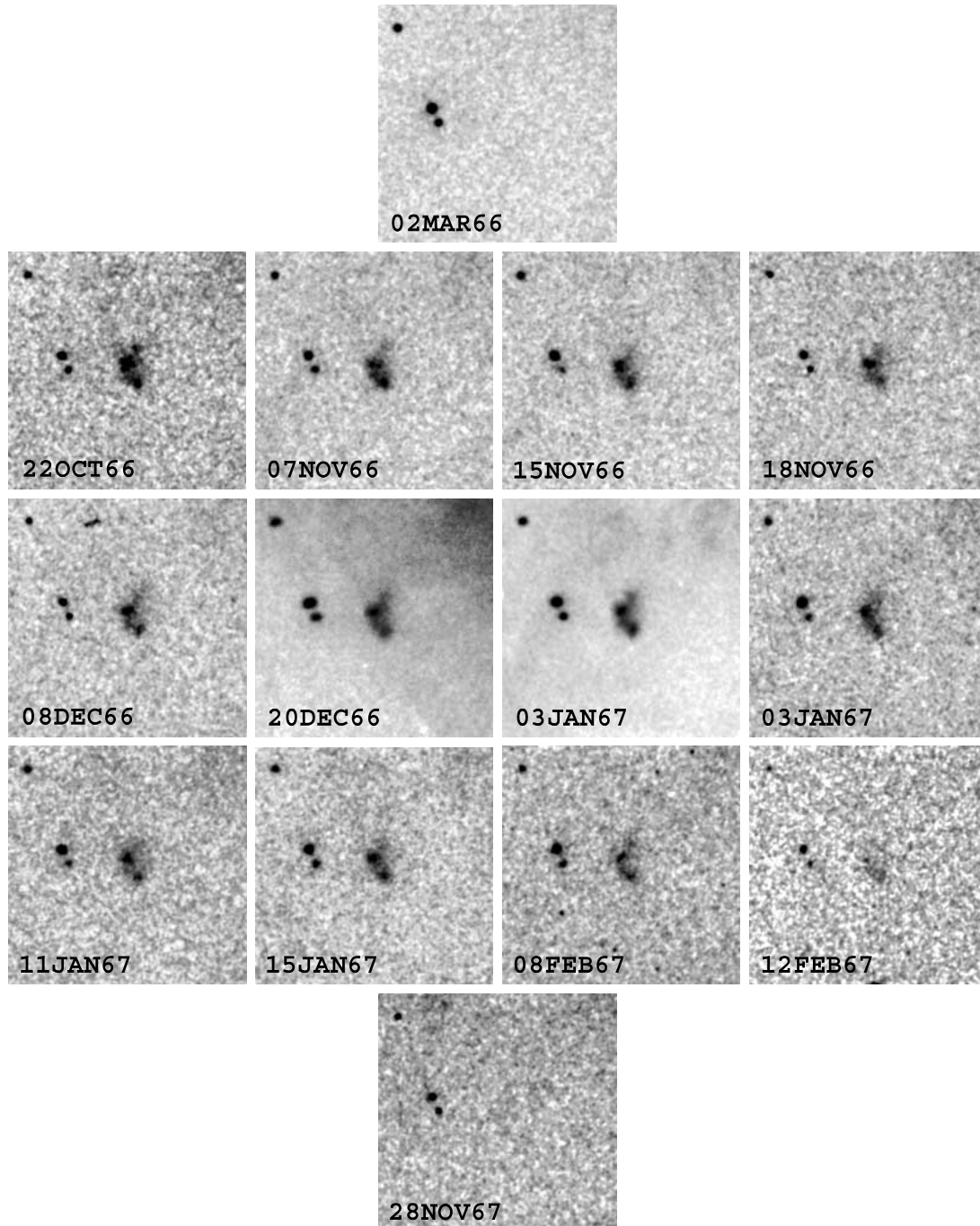


FIG. 2.—Digitized plates of the region including McNeil's Nebula/V1647 Ori. These *B*-band plates cover the period UT 1966 March 2 to UT 1967 November 28. In the first and last plate of this sequence, McNeil's Nebula is not visible. However, the nebula is visible from 1966 October 21 to 1967 February 12. Full details of the date, emulsion/filter, and exposure time of each plate can be found in Table 1.

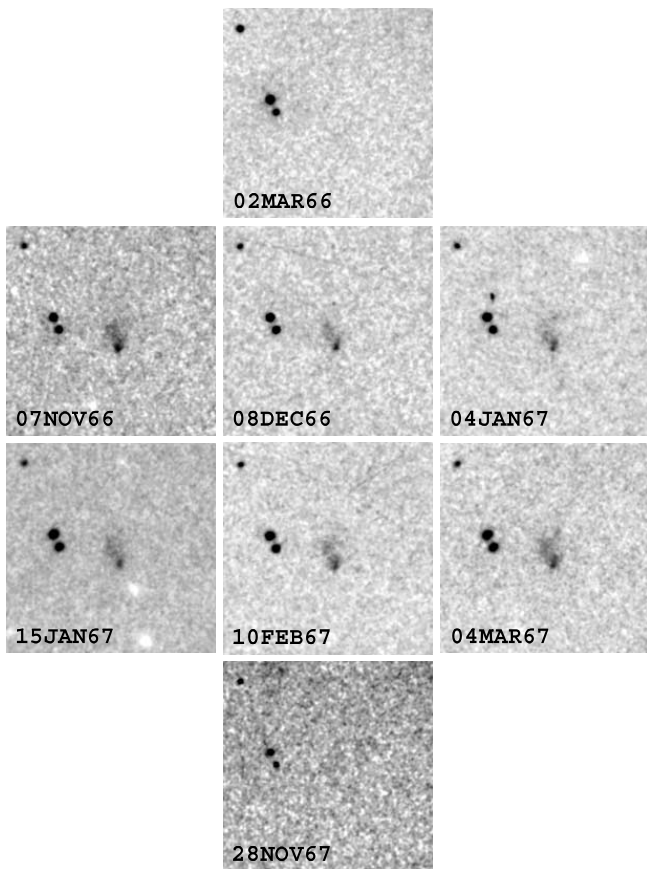


FIG. 3.—Same region shown in Fig. 2, but now in the I band. Again, the plates before the nebula appeared and after the nebula faded are shown.

our present purpose. Some of the plates (a total of 46) were originally taken under the Asiago flare stars project (Rosino 1969), whereby on each plate short, multiple (four or five) exposures with spatial offsets between them were taken. These plates do not allow a clear inspection of the region of interest and have not been considered further. Of the 321 plates inspected, 19 showed McNeil’s Nebula. These are listed in Table 2. Twelve of these plates are in the B band, one in the R band, and six in the I band. The first plate showing McNeil’s Nebula is dated UT 1966 October 22 01:22 and was likely taken only a few hours earlier than the one obtained by E. Kreimer (Mallas & Kreimer 1970). No evidence for McNeil’s Nebula was found on plates prior to 1966 October nor after 1967 February. The limiting magnitude of the plates is given in Table 2 and calculated using a CCD comparison sequence kindly provided by A. Henden (2004, private communication; McGehee et al. 2004). This also served to characterize the linearity of the scanner response in digitizing the plates. A total of 26 stars within $\sim 4'$ of V1647 Ori and with magnitudes in the range $15.5 \leq M(B) \leq 21$ were used.

Figure 2 shows the plates containing McNeil’s Nebula in the B band at 12 different epochs. These digital images cover the time 1966 October 22 to 1967 February 12. Also shown are the two plates taken immediately before (1966 March 2) and after the first and last appearance of McNeil’s Nebula, respectively. Figure 3 shows I -band digital images of the same region from 1966 November 7 to 1967 March 4. The two plates before and after the appearance of the nebula are again shown for comparison. Since we have three-color digitized imaging of the object (although only one R -band image), Figure 4 shows the closest (in time) digital images taken in B , R , and I .

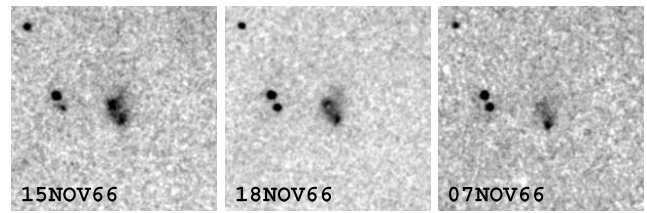


FIG. 4.—Same region as shown in Figs. 2 and 3, but showing the object in the B , R , and I bands. These three plates were taken within 11 days of each other. Note the increase in brightness of V1647 Ori and the fading of the nebula as we look from B to R and I .

In the B band (Fig. 2), the passband in which we have the best temporal coverage, McNeil’s Nebula is well detected even on the first plate taken on 1966 October 21. This suggests that we have not observed the rise of the object from quiescence to its elevated state. This must have occurred during the prior 7 months between 1966 March 2 and this date. The sequence of B plates shows some morphological and photometric changes in the object. For example, the brightest parts of the object are two nebulous regions herein referred to as the northern and southern knots. The relative brightness of the two knots is observed to vary with time and wavelength. In B , the object is dominated by the northern knot. This is not surprising, since the nebula is seen in reflected light and V1647 Ori itself is extinguished by circumstellar material. The northern knot also includes HH 22A (Eisloffel & Mundt 1997). The southern knot includes the exciting/illuminating source of McNeil’s Nebula, V1647 Ori, which is more heavily extinguished due to circumstellar material. The plate taken on 1967 February 12 is a little perplexing because at first glance it seems to imply that the object has faded significantly in only 4 days (since the previous plate). Since the 1967 February 12 plate has an exposure time of 40 minutes and the 1967 February 8 plate an exposure time of 15 minutes, this is difficult to explain. We note that the northern knot is not detected in the February 12 plate, suggesting that there is something peculiar about this observation (cloud, bad plate, etc.).

In the I band (Fig. 3), McNeil’s Nebula is dominated by the southern knot and perhaps therefore by V1647 Ori itself. Its more pointlike nature supports this hypothesis. The decline in brightness perhaps seen in B between 1967 February 8 and 12 is not evident at I . On 1967 February 10 and March 4, the southern knot/V1647 Ori is still well detected.

Comparing the objects appearance in different passbands at similar times (Fig. 4), we note that the northern knot (including HH 22A) dominates in the blue, while the southern knot (including V1647 Ori) dominates in the far-red. The sole R -band image of the region, taken on 1966 November 18, shows an intermediate status, with both knots appearing similar in brightness.

2.2. Harvard College Observatory Plate Search

The HCO plate collection was inspected by M. Tsvetkov. Over 400 plates of the appropriate region in Orion were found in the HCO collection and visually inspected for the presence of McNeil’s Nebula. These plates cover the period 1898–1974 and were from the A, AC, AM, AX, D, MC, and MF series. The plates are mostly blue-sensitive with an average limiting magnitude of the best plates of $M(\text{pg}) \sim 14$. This is somewhat brighter than the integrated magnitude of V1647 Ori/McNeil’s Nebula during the current (2003–2006) outburst and of the plate limit of the Asiago blue plates. We have found that McNeil’s Nebula was not detected on any plate inspected from the HCO collection. Fifteen plates (of 400 plus) had reasonable-to-good image

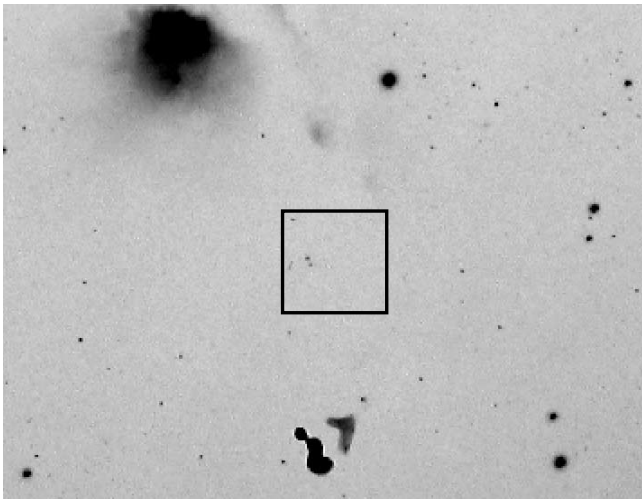


FIG. 5.—Digitized section of HCO plate A23963 from 1947 December. M78 is seen at the top of the plate. The feature at the bottom of the plate is a plate defect. The black box identifies the same area around McNeil's Nebula as shown in Figs. 2–4. The two stars to the east (*left*) of McNeil's Nebula are visible on this plate, but there is no sign of the nebula itself.

quality and were of good sensitivity. The two stars to the east of McNeil's Nebula (see the “02MAR66” panel in Fig. 2) were visible on only eight plates, and a representative digitized image of the appropriate region of one of these plates is shown in Figure 5.

3. DISCUSSION

Our aims in this project are to (1) determine whether any other outbursts of McNeil's Nebula have been detected over the last century and (2) characterize the 1966–1967 outburst of the object and compare it to the current event that began in 2003 November (see Briceño et al. 2004).

3.1. Previous Outbursts of McNeil's Nebula

Our Asiago and HCO plate searches did not detect additional appearances of McNeil's Nebula, resulting from outbursts of V1647 Ori, beyond the previously known 1966–1967 and recent (2003–2006) events. Given the limiting magnitudes of the HCO plates (≤ 14 mag) and their blue sensitivity, we cannot rule out that an event similar to the 1966–1967 or current outbursts occurred prior to 1966 but only a “superoutburst” that would have been 3–4 mag brighter. Figure 6 illustrates this by showing the *B*-band photometry of the southern knot of McNeil's Nebula during the 1966–1967 event. The number of plates studied (~ 400) and their temporal coverage (1898–1974) are such that we consider that we should have detected a superoutburst if one had occurred, assuming that the length of the event was similar to that in 1966–1967. The Asiago plates from 1960–1998 are considerably more sensitive, and the 1966–1967 outburst is well documented, but again, no additional outbursts are seen. If we were to assume that the time between the current and previous outburst is characteristic for eruptions in V1647 Ori, then we would maybe have expected an outburst ~ 38 yr earlier, i.e., in approximately 1928.⁹

⁹ We have additionally found 18 plates from the Bamberg Observatory collection taken between 1932 and 1939. These are blue-sensitive and have a limiting magnitude of 12–13. As might be expected, no appearance of McNeil's Nebula was detected.

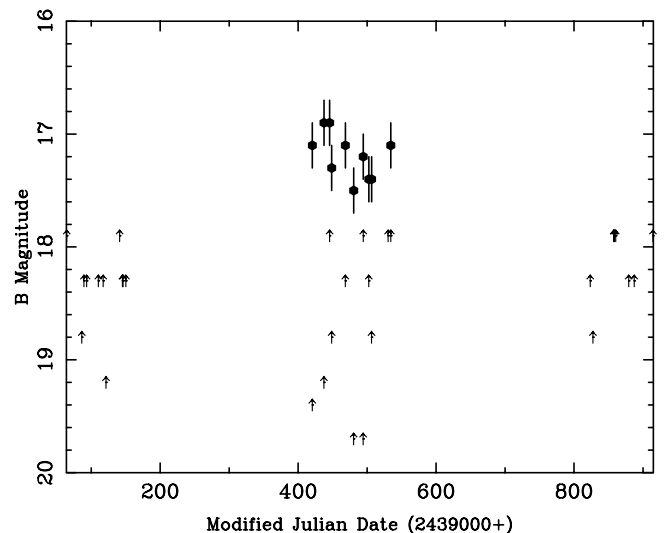


FIG. 6.—Limiting *B* magnitudes (*arrows*) of the plates taken from 1965 October to 1968 February. Also shown are the *B* photometric points for V1647 Ori from 1966 October to 1967 February (*circles*). Clearly, even in the worst case of *B* limiting magnitude the detection of V1647 Ori is statistically significant. The plot also proves that if V1647 Ori had been bright prior to 1966 October or after 1967 February, the Asiago plates would have detected it. Similar quality plates were taken from 1960 through to 1998.

3.2. Comparison of the 1966–1967 and Current Outbursts

3.2.1. Overall Morphology

Above, we describe the numerous plates that show McNeil's Nebula during the 1966–1967 outburst. All these plates were found in the Asiago Observatory collection and contain McNeil's Nebula photographed in the *B* (Fig. 2), *R* (Fig. 4), and *I* (Fig. 3) passbands. We can directly compare the morphology of the nebula in 1966, using the digitized plate images, with recent CCD images taken in 2004 during the current outburst. For this we use the sole *R*-band Asiago plate image (411) and compare it to a Gemini GMOS *r'*-band image (UT 2004 September 3). We have selected the *R*-band Asiago plate, since it is of high sensitivity and good image quality. To spatially match the images we have recalculated the world coordinate system of both data sets using *Hubble Space Telescope* (*HST*) Guide Star Catalog objects as reference. Since the pixel scale of the digitized Asiago plate is poor with respect to the GMOS image ($\sim 1''.5$ and $0''.144$ pixel⁻¹, respectively) the accuracy of the solution to the plate data is estimated to be accurate to $\pm 0''.5$. Figure 7 (*left*) shows McNeil's Nebula in 1966 overlaid with contours of its morphology in 2004. In addition and for further clarity, we also present in Figure 7 (*right*) the 2004 GMOS image overlaid with contours of the object as it appeared in 1966. The triangles show the location of the Two Micron All Sky Survey (2MASS) objects 2MASS J05461313–0006048 and 2MASS J05461423–0005261, the first being V1647 Ori itself, while the second corresponds to the mid-IR source associated with HH 22 detected by Muzerolle et al. (2005) from *Spitzer Space Telescope* IRAC and MIPS data. Muzerolle et al. (2005) referred to this object as HH 22, but since it is not a Herbig-Haro object but a young Class I source we henceforth designate it as HH 22-MIR.

The overall shape and size of the nebula in 1966 and 2004 are quite similar. Two major features seen in 1966, the northern and southern knots, correspond well in size and shape to features seen in 2004, specifically HH 22A and the fanlike structure extending from V1647 Ori to the north-northwest. There appears to be only slight differences in the morphology of these two regions, as well

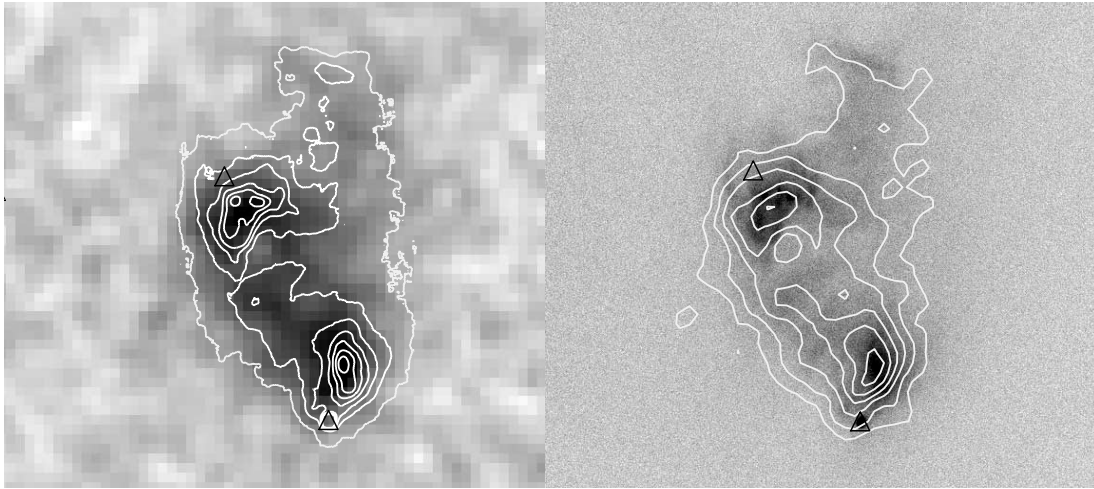


FIG. 7.—*Left*: R -band plate (411) from 1966 November 18 overlaid with contours of the Gemini GMOS r' image taken on 2004 September 3. *Right*: Reverse of the left image, the GMOS r' CCD image overlaid with contours of the R -band plate. In both panels, north is at the top and east to the left. The coordinate system of both images was determined by comparison to *HST* Guide Star Catalog objects in the images. Due to the poor pixel scale in the 1966 digitized images ($\sim 1''.5 \text{ pixel}^{-1}$), the error in the relative positioning of the two data sets is estimated to be $\sim 0''.5$. We note that the morphology of the nebula is very similar in 1966 and 2004, with only slight positional differences in the main features seen. In both plots, the triangles show the 2MASS sources present in the vicinity of V1647 Ori. The southern 2MASS source is V1647 Ori itself (2MASS J05461313–0006048), while the northern source (2MASS J05461423–0005261) is the 2MASS object located at the position of the mid-IR source associated with HH 22 detected by Muzerolle et al. (2005) using the *Spitzer Space Telescope* (HH 22-MIR).

as of the whole nebula, and these can be readily explained by small changes in the illumination of the nebula at the two epochs. Since the light-travel time from V1647 Ori to the northernmost region of the nebula is only ~ 100 days, radiation escaping from the circumstellar environment of the young star via slightly different paths could easily produce a significantly different appearance in 1966 and 2004. In fact, since the nebula is mostly of a reflection origin, it is perhaps surprising that the nebula morphology is so similar in data taken ~ 38 yr apart. This fact implies that the pathways opened by the outburst phenomenon (which allow radiation to escape into the nebula and result in the brightening observed) are remarkably similar.

In Figure 8 we show a similar plot to that in Figure 7 but at longer optical wavelengths, the I band in 1966 and the i' band in

2004. We note that there appear to be slight differences in morphological structure between the two data sets, particularly close to V1647 Ori itself. Without wishing to overinterpret these two images with very different pixel scales and seeing characteristics, it does nevertheless appear that the nebulosity closer to V1647 Ori pointed more to the north in 1966 than in 2004, where it extends considerably more to the northwest. The most likely explanation here also is varying illumination effects, since even at $I[i']$ the nebula is still seen primarily in reflection.

3.2.2. V1647 Ori

V1647 Ori itself is clearly detected in the I -band plate from 1966, as well as in the i' image from 2004 (see Fig. 9). At shorter wavelengths, however, it is indistinct in the 1966 R -band plate

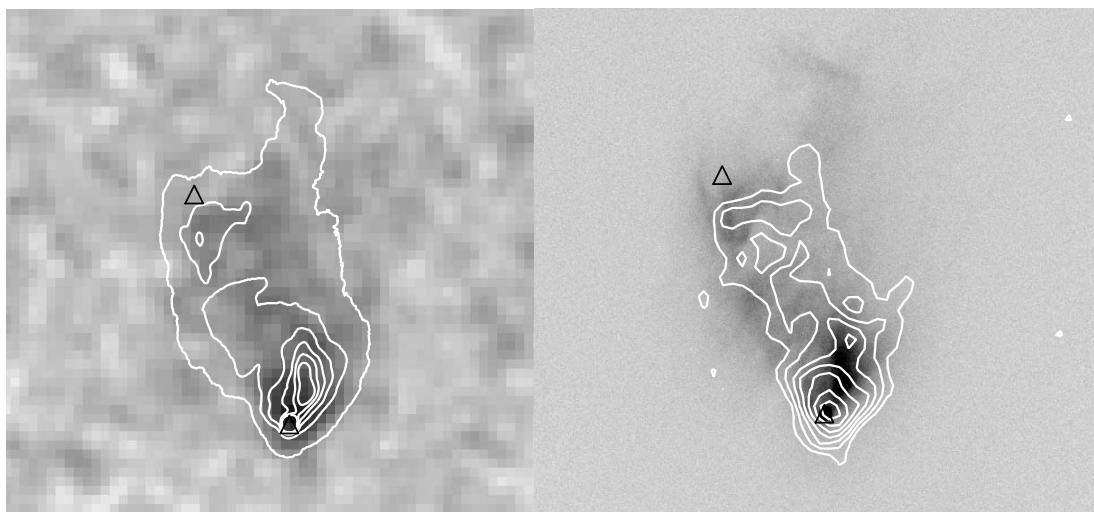


FIG. 8.—*Left*: I -band plate (385) from 1966 November 8 overlaid with contours of the Gemini GMOS i' image taken on 2004 September 3. *Right*: Reverse of the left image, the GMOS i' CCD image overlaid with contours of the I -band plate. In both, north is at the top and east to the left. The coordinate system of both images was determined by comparison to *HST* Guide Star Catalog objects in the images. Due to the poor pixel scale in the 1966 digitized images ($\sim 1''.5 \text{ pixel}^{-1}$), the error in the relative positioning of the two data sets is estimated to be $\sim 0''.5$. We note that at I the morphology of the nebula is similar in 1966 and 2004, although less so than at R . In both plots, the triangles show the 2MASS sources present in the vicinity of V1647 Ori. The southern 2MASS source is V1647 Ori itself (2MASS J05461313–0006048), while the northern source (2MASS J05461423–0005261) is the 2MASS object located at the position of HH 22-MIR.

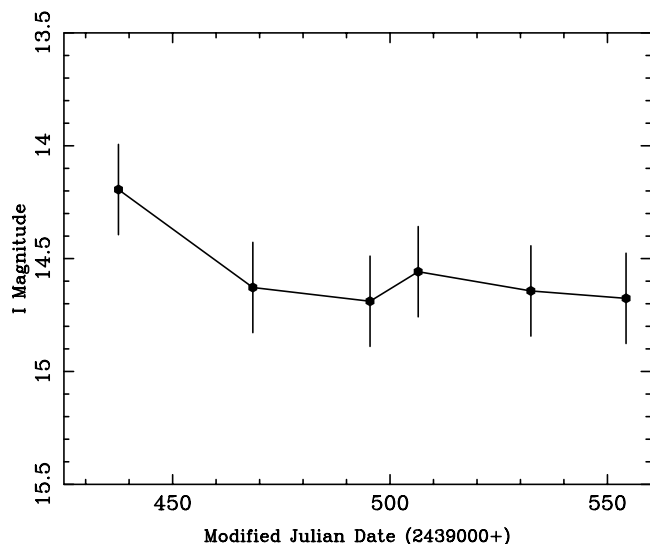


FIG. 9.—*I*-band photometry of the region including V1647 Ori from the Asiago plates taken between early 1966 November and early 1967 March. The photometry has been corrected to make the average of a selection of field stars identical at each epoch of observation. The typical photometric error is ± 0.2 mag.

(the emission is dominated by the southern knot rather than the point source) yet clearly observed in the 2004 r' images. This does not seem to be merely caused by the pixel scale differences, since V1647 Ori is obviously well-detected in the 1966 *I*-band data.

3.2.3. The Northern Knot and HH 22A

With regard to the northern knot that includes HH 22A, the object appears morphologically very similar in 2004 and in 1966. Because the spatial resolution of the 1966 Asiago plate data is relatively poor (compared to the 2004 GMOS data), it is difficult to relate the structures observed more precisely. However, comparing the knot in R and r' with that at I and i' suggests that HH 22A was present in 1966—the northern knot is considerably brighter at both epochs in R and r' than at I and i' ; this is very likely caused by the intrinsic line emission from the HH object itself falling in the R/r' passbands. If we assume a typical HH collimated outflow velocity of 100 km s^{-1} , then in 38 yr HH 22A should have moved $< 2''$. Since this amount is similar to the FWHM of the Asiago plate data (specifically, $\sim 2''.5$), we can only state that it appears to be present and in a similar location at the two epochs. We cannot shed any further light on the origin of the HH 22 complex from this comparison but note that the only source close to the location of HH 22A is a bright IR source detected in *Spitzer* images by Muzerolle et al. (2005), HH 22-MIR. The fan-shaped structure extending from HH 22-MIR detected in their $4.5 \mu\text{m}$ IRAC image is reminiscent of outflow cavity walls, suggesting that this source could possess an active (bipolar) outflow. Lis et al. (1999) had previously detected a compact millimeter continuum core, designated LMZ 10, at this location and suggested that this was the driving source of the HH 22. Eisloffel & Mundt (1997) considered HH 22A the terminal shock-excited object in a 0.4 pc -long flow extending from the east toward HH 22A. Motion connected to this flow could have also resulted in a displacement of HH 22A.

3.2.4. The Southern Knot

The southern knot appears to be a fanlike structure extending from the vicinity of V1647 Ori to the north-northwest. In 1966 this knot appeared to be somewhat more compact than in 2004,

although the differences, given the large pixel scale of the earlier epoch data, are relatively small. The region does appear brighter in the i' -band image from 2004 than on an *I*-band plate from 1966, where V1647 Ori is clearly dominant.

3.2.5. Photometry of V1647 Ori

Regarding the photometry of V1647 Ori, to improve the separation of the star from the nebula we consider the Asiago *I*-band plates most appropriate, since, as we have seen, these are dominated by the stellar source rather than the reflection nebulosity. The *I*-band photometric results shown in Figure 9 were obtained from the digitized images using a $5''.5$ diameter software aperture. The relative photometric calibration was achieved using photometry of ~ 7 field stars. Using the average magnitude per plate of these stars (average to reduce the effect of one or two possibly variable objects), we calculated a correction for each plate to make this average value identical in all plates. This correction was applied to the photometry of V1647 Ori itself. We estimated, from a study of multiple exposures close in time, that the photometric error per measurement for V1647 Ori was $\sim \pm 0.2$ mag. The time span of the *I*-band photometry is approximately 120 days from 1966 early November to 1967 early March, and the digitized images from which the photometry was derived are shown in Figure 3. Inspection of Figure 9 shows that over the monitoring period V1647 Ori faded by approximately ~ 1 mag, with most of this decline occurring within the first month. The average *I*-band magnitude for V1647 Ori during this period was ~ 14.5 . During the first few months of the current eruption Briceño et al. (2004) quoted an *I*-band magnitude for V1647 Ori of approximately 14.6 in a $4''$ aperture. Thus, the 1966 photometry in outburst (from the Asiago plates) is consistent with the maximum brightness of V1647 Ori in 2003 (from Briceño et al. 2004) with an outburst amplitude of ~ 4.5 mag (using the 2003 October pre-outburst magnitude from Briceño et al. as the quiescent brightness in both cases). We consider this comparison a reasonable one, since, in both cases, the measurements were made using large (software) apertures (unlike the 2004 February photometry of Reipurth & Aspin 2004). We summarize the photometry data on V1647 Ori from both the 1966 and 2003 events in Table 3.

3.2.6. Outburst Rise Timescale

The rise time for the V1647 Ori outburst in 2003 was characterized by Briceño et al. (2004). Their Table 1 and Figure 3 show that the source increased in brightness by ~ 3.6 mag from $I \sim 18$ over a period of ~ 4 months. In 1966, McNeil's Nebula was not present in early March but was very bright in early November. This period is 8 months, and hence the length of the rise time in 1966 would be < 8 months, which is consistent with that in 2003.

3.2.7. Outburst Lifetime and Decline Timescales

In 2005 October, Aspin & Reipurth (2005) reported that V1647 Ori had already started to fade and estimated that at r' it was ~ 1 mag fainter than at maximum brightness. In 2006 January we have found that McNeil's Nebula was extremely faint and likely close to its quiescent brightness. At this time, V1647 Ori had an r' magnitude of 20.94 ± 0.1 , some 4.3 mag fainter than at maximum. It appears then that we can characterize the 2003 outburst timescale at ~ 26 months, which is slightly longer than, yet still consistent with, the 1966–1967 estimate of 5–20 months.

In 1967, all we can say is that McNeil's Nebula had completely disappeared from the Asiago plates within 9 months of

TABLE 3
SUMMARY OF COLLECTED PHOTOMETRY OF V1647 ORI

Period	State	<i>B</i> (mag)	<i>V</i> (mag)	<i>R</i> (mag)	<i>I</i> (mag)	Aperture ^a (arcsec)	Photometry Source
1966 Nov–1967 Mar	Outburst	16.8–17.5	...	...	~14.5	5.5	Asiago plates
2004 Jan	Outburst	...	...	...	14.6	4	Briceño et al. (2004)
2003 Oct	Preoutburst	...	...	...	~18	4	Briceño et al. (2004)
2004 Feb ^b	Outburst	...	22.8	17.4	15.6	0.9	Reipurth & Aspin (2004)
2006 Jan ^c	Postoutburst	...	...	20.94	...	2	Unpublished data

^a Aperture diameter in arcseconds.

^b Photometry in SDSS *g'*, *r'*, and *i'* filters.

^c Photometry in SDSS *r'* filter.

the last observation shown in Figure 9. During the recent outburst we can again only constrain the decline timescale, since it clearly began during the period when Orion was behind the Sun. From the date of observation prior to this time, when V1647 Ori appeared still in outburst, we estimate that the timescale for decline is ≤ 6 months. Again, the two timescales are consistent.

3.3. V1647 Ori and the EXor/FUor Phenomena

The paper by Herbig (1989) presents a comprehensive study of FUor and EXor events and defines the classes in terms of their observed characteristics. The major differences between these two types of eruptions are that (1) EXor eruptions appear to be much shorter in duration than FUor events; (2) at maximum light the optical spectra of EXors are dominated by T Tauri-like emission, whereas FUors show absorption spectra that resemble F- or G-type supergiants; (3) EXors appear to exhibit greater short-term photometric variability than FUors; and (4) the increase in brightness during an EXor eruption is often smaller than that associated with a FUor eruption. Herbig (1989) Tables 1 and 3 show typical outburst parameters for several FUors and EXors, with more details on the prototype EXor, EX Lupi, during several outbursts presented by Herbig et al. (2001). We now compare the derived outburst parameters for V1647 Ori with those for other eruptive variables. We note the following:

1. The rise time of V1647 Ori in 2003 was ~ 4 months (120 days). This number is consistent with the rise time in 1966 (constrained to be < 8 months) and is similar to the rise time of several other EXors, as well as FU Ori itself (120–380 days in 1936). Typically, however, a FUor outburst rise time is longer than that of an EXor. Examples of the latter were quoted by Herbig (1989) as being from one to several years.

2. The duration of the V1647 Ori outburst in 1966–1967 was between 5 and 20 months, while for the 2003 outburst it was ~ 26 months. This duration is more typical of EXor outburst periods, although a wide range of values have been found, from about 6 months to over 1 yr, with some examples (e.g., V1143 Ori) being over 4 yr (Herbig 1989). FUor outbursts are considerably longer, and that of FU Ori is still ongoing after 70 yr.

3. The decline time for V1647 Ori in 1967 is not well constrained but was definitely < 9 months. Recent observations support a decline timescale of the 2003 event of ≤ 6 months. Since there is no typical decline time for FUors, except that they are all very long, what we know about the V1647 Ori outburst decline again seems more consistent with that of an EXor.

4. EXors are characterized by multiple outbursts (e.g., EX Lupi), whereas FUors have to date only been observed to brighten once. Since we have evidence for two outbursts of V1647 Ori, this seems more consistent with an EXor interpretation.

5. At maximum light during the spring of 2004, V1647 Ori showed an optical spectrum dominated by H α emission with a strong and highly blueshifted absorption component. The optical spectra of FUors at maximum light, soon after outburst, are generally characterized by G-type giant photospheric features. Herbig (1989) states that EXors tend to show optical features more similar to classical T Tauri stars than FUors. Since it is likely that heavy veiling is present in the spectrum of V1647 Ori (Reipurth & Aspin 2004), we cannot draw any conclusions on whether the underlying spectrum of the source appears at all FUor-like.

6. The near-IR spectrum of V1647 Ori is dominated by 2.3 μm CO emission, with Br γ also in emission. Similar observations of EX Lupi (Herbig et al. 2001) showed a dwarflike near-IR spectrum with CO in absorption and weak Br γ emission. A generally accepted near-IR characteristic of FUors is deep CO absorption with little else present (cf. Reipurth & Aspin 1997). The near-IR spectrum of V1647 Ori more resembles that of SSV 13 in NGC 1333 (Aspin & Sandell 1994), which is considered to be an EXor based on its photometric behavior. CO emission is seen in other young stars and is generally interpreted as coming from dense, high-temperature regions of accreting material.

4. CONCLUSIONS

We have searched for past eruptions of the pre-main-sequence variable V1647 Ori, which illuminates McNeil's Nebula, using the plate archives of the Asiago Observatory and the Harvard College Observatory (HCO) and have obtained the following results:

1. During the period from 1960 to 1998, a total of 367 plates were obtained at the Asiago Observatory that included the region of V1647 Ori. In this time interval, V1647 Ori was visible on 19 plates taken between 1966 October 22 and 1967 March 4, corresponding to one full winter observing season at Asiago. The last measurement of the previous winter season was taken on 1966 March 20, and the first measurement of the following season was taken on 1967 November 28. V1647 Ori and McNeil's Nebula were not visible on either of these plates. The 1966–1967 eruption was thus at least 134 days (4.4 months) long but did not exceed 618 days (1.7 yr).

2. The plate collection of HCO contains about 400 blue-sensitive plates taken between 1898 and 1974 that include the region of V1647 Ori. The limiting magnitude of the best HCO plates is $M_{\text{ph}} \sim 14$ mag, and on none of the plates is V1647 Ori visible. All we can conclude from these plates is that no *major* eruption (> 3 mag larger than the two known) took place during this period.

3. The appearance of McNeil's Nebula in the 1966–1967 period was very similar to that observed in the 2003 eruption,

although some minor differences exist, likely due to changes in nebula illumination.

4. V1647 Ori itself appears to be of similar maximum optical brightness during the two outbursts.

5. The duration of the 1966 outburst is consistent with that of the current outburst.

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