THE CONTINUING OUTBURST OF V1647 ORIONIS: WINTER/SPRING 2011 OBSERVATIONS

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ABSTRACT
We present optical and near-IR observations of the young eruptive variable star V1647 Orionis which illuminates McNeil's Nebula. In late 2003, V1647 Ori was observed to brighten by around 5 mag to \( r' \approx 17.7 \). In early 2006 the star faded back to its quiescent brightness of \( r' \approx 23 \), however in mid-2008 it brightened yet again by \( \sim 5 \) mag. Our new observations, taken in early 2011, show V1647 Ori to be in an elevated photometric state with an optical brightness similar to the value found at the start of the 2003 and 2008 outbursts. Optical images taken between 2008 and 2011 suggest that the star has remained in outburst from mid-2008 to the present. \( H \alpha \) and the far-red Ca \( ii \) triplet lines remain in emission with \( H \alpha \) possessing a significant P Cygni profile. A self-consistent study of the accretion luminosity and rate using data taken in 2004, 2007, 2008, and 2011 indicates that when bright, V1647 Ori has values of \( 16 \pm 2 L_\odot \) and \( (4 \pm 2) \times 10^{-6} M_\odot \text{yr}^{-1} \), respectively. We support the premise that the accretion luminosity and rate both declined by a factor of 2–3 during the 5 mag fading in 2007. However, a significant part of the fading was due to either variable extinction or dust reformation. We discuss these new observations in relation to previous published data and the classification schemes for young eruptive variables.

Key words: circumstellar matter – stars: formation – stars: individual (V1647 Ori)

Online-only material: color figures

1. INTRODUCTION
Photometric variability is often present in young low-mass stars and can take the form of either periodic or stochastic brightness modulations. They are generally associated with such physical processes as stellar rotation, changes in overlying circumstellar obscuration, or variable mass accretion. However, the most dramatic variability seen is that of an eruptive nature when large-amplitude photometric changes occur over relatively short periods of time, resulting in optical brightness increases of 100-fold or more. Such outbursts are thought to be an integral part of a young star's pre-main-sequence life, being times when the accretion rate dramatically increases, and hence, they are phases when a large fraction of the star's final mass is accreted. We refer the reader to the review articles by Hartmann & Kenyon (1996) and Reipurth & Aspin (2010) for more significant background on eruptive variables. Two varieties of eruptive variables have previously been found. These are colloquially termed FUors (Ambartsumyan 1971) and EXors (Herbig 1989). FUor outbursts are named after the first young star seen to exhibit such a dramatic brightness increase, namely, FU Orionis (Wachmann 1954; Herbig 1966). In the mid-1930s, FU Ori optically brightened by over 5 mag and has remained in this elevated state to the present day (i.e., over 70 years). EXors, named after the progenitor of the class EX Lup, are similarly energetic, however their outbursts typically result in a brightening of 1–4 mag. In addition, EXor events generally last weeks to months rather than years to decades as in FUors. The spectral characteristics of FUors and EXors are also significantly different. In outburst, FUors exhibit optical absorption features indicative of an F–G supergiant star (Herbig 1966, 1977) and NIR absorption features typical of an M giant (Mould et al. 1978; Reipurth & Aspin 1997). They typically show \( H \alpha \) absorption with an associated blueshifted component creating a P Cygni profile (Herbig 1966, 1977). Little to no \( H \alpha \) emission is observed. In outburst, EXors show an optical and NIR emission spectrum and often possess emission in the NIR CO overtone bandheads (see for example EX Lup, Aspin et al. 2010). Such a dichotomy is peculiar since, in both cases, the outbursts are thought to be driven by enhanced mass accretion. It remains a mystery how young star outbursts driven by the same physical mechanism can exhibit such different photometric and spectroscopic characteristics.

An alternative model for FUor outbursts that warrants consideration was proposed by Larson (1980) and subsequently further investigated by Herbig (1989), Petrov & Herbig (1992), Herbig et al. (2003), and Petrov & Herbig (2008). In this model a rapidly rotating young star develops a bar-like deformation that causes the outer layers of the star to heat up resulting in the observed increase in luminosity. Although not as popular as the accretion disk model, this model does have several attractive characteristics, none less than providing separate outburst mechanisms for FUors and EXors.

It is clearly important to find and study in detail new examples of both FUors and EXors. To date, out of the tens of thousands of young stars known, only a dozen or so of both types are known. One recent discovery was V1647 Ori. This young star is located near M 78 in Orion and was discovered by amateur astronomer Jay McNeil (McNeil 2004) when he found a previously unidentified nebula in the region. This nebula, now known as McNeil's Nebula, is illuminated by V1647 Ori, which appears at the apex of its monopolar geometry. In quiescence, V1647 Ori is a faint young star (\( r' \sim 23 \)) located near the Herbig–Haro (HH) objects HH 22, 23, and 24 (Herbig 1974). Since its discovery in late 2003, soon after it had brightened by \( \sim 5 \) mag, it was the subject of numerous observational studies at wavelengths spanning the electromagnetic spectrum from X-rays to radio. Rather than explicitly mention each of the 50+ papers published from 2004 to the present day, we refer the reader to Aspin & Reipurth (2009) for both a more comprehensive list and a discussion of the optical photometric and spectroscopic variability during the period 2003–2006.

Soon after discovery, V1647 Ori exhibited a strong emission spectrum in both the optical and NIR. This eruption (henceforth
referred to as the first outburst) lasted around two years, after which the star faded back to its pre-outburst quiescent brightness. All indications were that V1647 Ori was an example of the EXor class of eruptive variables especially in light of the presence of a previous outburst in 1966 (Aspin et al. 2006). However, it was subsequently shown that at high spectral resolution, the source possessed unique 2 μm spectral structure only found in FUors (Aspin et al. 2008). It was somewhat surprising that in 2008 V1647 Ori again optically brightened by ∼5 mag (Kun 2008; Aspin et al. 2009b). Observations taken during the new eruption (below referred to as the second outburst) showed almost identical features to the earlier event (Aspin et al. 2009b), from a similarly illuminated McNeil’s Nebula to an optically emission spectrum with a P Cygni profile Hα, and CO overtone bandhead emission. In the period 2008–2010, its X-ray flux varied on short timescales between 2 and 8 × 10^29 erg s^{-1}. This result implies that V1647 Ori was highly active during the above period and suggests that it was likely bright at optical and NIR wavelengths.

In this paper, we detail the status of the source in the period 2011 February–April, finding that it has remained in a highly active eruptive state.

### 2. OBSERVATIONS AND DATA REDUCTION

The complete observing log for the V1647 Ori observations presented below is shown in Table 1. Observations were acquired on three different telescopes, all located on Mauna Kea, Hawai‘i. The “Fredrick C. Gillett” Gemini-North 8 m telescope was used on five different occasions to obtain optical and NIR imaging and spectroscopy (under queue observing programs GN-2010A-Q-10 and GN-2011A-Q-37). Additional NIR spectroscopy was obtained in engineering time on the NASA Infrared Telescope Facility (IRTF) 3 m telescope. Optical images of V1647 Ori were also obtained at four different epochs on the University of Hawai‘i 2.2 m telescope (from 2008 to 2009).

Below we detail the observations acquired and briefly comment on their subsequent reduction and analysis.

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#### 2.1. Optical Imaging

The Gemini-North instrument used for optical imaging was GMOS (Davies et al. 1997; Hook et al. 2004). Data were acquired on UT 2011 February 2. Photometric calibration was achieved using the field star sequence defined in Aspin & Reipurth (2009). We used the Sloan Digital Sky Survey (SDSS) r' filter with a 0′.14 pixel scale, and a total exposure time of 60 s. All images were reduced using the Gemini GMOS iraf package (v1.10). Photometry was extracted from the images using the Starlink GAIA package. Similar imaging observations were obtained with Gemini-North/GMOS in 2004 and 2007 (Aspin & Reipurth 2009).

The University of Hawai‘i 2.2 m telescope and the thinned backside-illuminated Tektronix 2048 × 2048 optical CCD camera, Tek, were used to obtain optical imaging on UT 2008 August 31 and October 9, and 2009 January 23 and September 11. All at three epochs, a Johnson–Cousins R_C filter was used with a detector-defined pixel scale of 0′.21. The exposure time in each case was 60 s. Photometric calibration again used the field star sequence mentioned above. Transformations to the SDSS r’ filter system was performed as outlined in Aspin & Reipurth (2009). The images were reduced using the Starlink package CCDPACK in a standard manner. The Starlink GAIA package was again used to perform photometry extraction.

#### 2.2. Optical Spectroscopy

As in the case of the Gemini-North imaging above, the instrument used for optical spectroscopy was GMOS. Data were acquired on UT 2011 February 2 using the B600 grating with a central wavelength 7500 Å. A 0′.75 wide slits was used resulting in a resolving power, R, of ∼1200 (0.45 Å pixel^{-1}). This value of R gives a full width at half-maximum (FWHM) of unresolved lines of ∼130 km s^{-1}. The total on-source exposure time for the spectroscopy was 300 s. Identical observations of the spectrophotometric standard star G191-B2B were also taken to allow flux calibration and sensitivity function definition. All spectra were reduced using the Gemini GMOS iraf package (v1.10). Feature extraction was performed using the iraf task spec.

#### 2.3. Near-IR Imaging

Our NIR imaging observations were taken using the Gemini-North facility NIR camera, NIRI (Hodapp et al. 2003). Data were acquired on UT 2011 February 6 using the f/32 camera due to the intrinsic brightness of the source (thus allowing shorter exposure times) in standard “Mauna Kea” J, H, K′, and L′ filters. For each filter, four dithered images were taken to allow for both sky subtraction and uncertainty estimation. Total exposure times of 20 s were used for J, H, and K′, and 48 s for L′. Similar observations of the NIR faint standard star FS 150 were taken for flux calibration purposes. The images were reduced using the Gemini NIRI iraf package (v1.10). Extraction of photometry from the reduced images was performed using the Starlink GAIA program. Flux from V1647 Ori was extracted using 5″ diameter circular apertures with sky values determined from regions of blank sky close to the source. Similar analysis was performed on the standard star. This technique gave us the star+nebula photometry within the aperture used, which is what we present below.

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1. Pre-outburst, V1647 Ori had an X-ray luminosity of ∼3 × 10^{30} erg s^{-1} while during the 2004 outburst it rose to ∼10^{31} erg s^{-1} (Kastner et al. 2004).

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### Table 1

Observation Log

| UT Date     | JD    | Telescope/Instrument | Details         |
|-------------|-------|-----------------------|-----------------|
| 2008 Aug 31 | 2454709 | UH 2.2 m/Tek           | Optical imaging |
| 2008 Oct 9  | 2454748 | UH 2.2 m/Tek           | Optical imaging |
| 2009 Jan 23 | 2454853 | UH 2.2 m/Tek           | Optical imaging |
| 2009 Sep 11 | 2455084 | UH 2.2 m/Tek           | Optical imaging |
| 2010 Jan 3  | 2455198 | Gemini-North/GMOS      | Optical imaging |
| 2011 Feb 2  | 2455593 | Gemini-North/GMOS      | Optical imaging |
| 2011 Feb 2  | 2455593 | Gemini-North/GMOS      | Optical spectroscopy |
| 2011 Feb 6  | 2455597 | Gemini-North/NIRI      | NIR imaging    |
| 2011 Feb 15 | 2455606 | Gemini-North/NIFS      | NIR IFU spectroscopy |
| 2011 Apr 19 | 2455671 | IRTF/SpeX              | NIR spectroscopy |
2.4 Near-IR Spectroscopy

Our first of the two epochs of NIR spectroscopic observations was acquired using the Gemini-North facility integral-field unit (IFU) spectrograph, NIFS (McGregor et al. 2003) using the J, H, and K-band gratings. Data were obtained on UT 2011 February 15 using total exposure times of 120 s per waveband, resulting in spectra with a spectral resolution of $R \sim 5000$. Sky observations, taken using an “ABA” offset sequence (where A is on-source and B is sky), were also acquired to facilitate accurate sky subtraction. Similar observations of the A0 V star HIP 103222 were taken to allow the removal of telluric features from the target spectra. The data were reduced using the Gemini NIFS iraf package (v1.10). The final spectra of the target and telluric standard are the sum of the IFU pixels lying within a 0.5 diameter software aperture centered on the targets. Telluric correction was performed using the IDL SpeX procedure xtellcor_general (Cushing et al. 2004). Conditions were clear and the seeing stable during the target and standard observations, and we consider the flux calibration good to the 5% level.

Our second epoch of NIR spectroscopy was acquired on the NASA IRTF telescope on UT 2011 April 19 using the facility NIR spectrograph SpeX (Rayner et al. 2003). The cross-dispersed (XD) mode was used and observations were acquired using the short-XD settings resulting in a spectral resolution of $R \sim 1500$. The data were reduced using the SpeX IDL package (Cushing et al. 2004). Telluric correction and flux calibration were performed using the A0 V telluric standard star HD 35656. Conditions were again clear and the seeing stable during the target and standard observations, and we consider the flux calibration good to the 10% level.

3. RESULTS

3.1 The Recent Photometric Behavior of V1647 Ori

V1647 Ori was originally observed to go into outburst in the fall of 2003 (Briceño et al. 2004). This phase lasted about two years and by the fall of 2005 had faded back to its pre-outburst quiescent brightness ($r' \sim 23$; Aspin et al. 2008). This behavior was very similar to the previously documented outburst of the source in 1966 (Aspin et al. 2006). However, to the surprise of the variable star community, in the summer months of 2008 (while Orion was behind the Sun) V1647 Ori yet again flared to a similar outburst brightness ($r' \sim 17$). Between 2008 and 2011 the photometric behavior of V1647 Ori remains unclear with little to no new data being published. The AAVSO database of amateur astronomer observations contains a few $V$-band and “clear” observations of the source from 2008 September to 2011 February; however, they are somewhat disparate in nature (some observations within a few days of each other have $\Delta V$ of over 4 mag) and we cannot consider them a truly reliable source for the recent photometric history of the young star. In Table 2 we have compiled several observations of V1647 Ori from data acquired by cooperative observers on the University of Hawai‘i 2.2 m telescope. Although sporadic in nature, these $R$-band observations suggest that between the second outburst of V1647 Ori in mid-2008 and the early months of 2011, V1647 Ori remained in an elevated photometric state with an optical $r'$ brightness between 16.9 and 17.8. Even though the gaps in our photometry are relatively large (ranging from 1 to 9 months), we believe that the temporal range, sampling frequency, and random nature of the observations all support the hypothesis that from 2008 August to 2011 February (i.e., around 32 months), V1647 Ori remained in outburst.

Figure 1 shows $r'$-band images of V1647 Ori and McNeil’s Nebula from four different epochs ranging from early 2004 to early 2011. The data from 2004 (first outburst, top left), 2007 (quiescent phase between outbursts, top right), 2008 (second outburst, bottom left), and 2011 (bottom right) all appear morphologically similar with all nebulous features seen in the original outburst image from 2004 repeating in 2008 and 2011. The 2007 image, showing the source after the first outburst had faded (hence McNeil’s Nebula is only faintly visible), shows well the HH 22 object/jet which is present in all images but difficult to see due to the presence of the bright reflection nebulosity. The nature of the structure in the nebula is interesting in that over a period of $\sim 7$ years, the physical material which is reflecting the light from V1647 Ori appears static. The distance from V1647 Ori to the northern almost horizontal section of nebulosity is $5^\circ$ (directly north, sloping down from east to west). Assuming a distance of 450 pc and a nebula axis inclination with respect to the plane of the sky of $29^\circ \pm 14^\circ$ (Acosta-Pulido et al. 2007), this corresponds to 0.14 pc (and hence the light travel time between the two locations is $\sim 164$ days). If the nebulous structures are located on the walls of an evacuated cavity (created by an earlier molecular outflow as generally assumed) and are moving at typical CO flow values of $10 \text{ km} \text{s}^{-1}$, then even in 7 years the expected motion of the material along the cavity walls would be only $\sim 15$ AU or, at the above distance, $0'.04$. This would clearly not be detected in our natural seeing images.

3.2 NIR Color Variations

The compilation of NIR photometry of V1647 Ori in Table 3 shows observations from five epochs ranging from 2004 March to 2011 April. The purpose of this table is to show the relative consistency in photometry from the time of the original outburst (2004 March) to soon after the second outburst (2008 September) and onto the current observations (2011 February and April). Data from the quiescent phase between the first and second outbursts are also shown (2007 February). Clearly, V1647 Ori has maintained its optical and NIR outburst brightness and colors subsequent to its second outburst.

The NIR $J - H$, $H - K'$, and $K' - L'$ colors of the sources, and their variability, are shown in Figures 2 and 3. The $J-H$ versus $H-K'$ color–color (henceforth $JHK'$ c–c) diagram (Figure 2) shows the location of V1647 Ori at 10 different epochs (including the five shown in Table 3). These points, labeled 1 through 10, are in chronological order and show significant color variability during the period 1998 (Two Micron All Sky Survey,
Figure 1. Optical $r'$ images of McNeil’s Nebula and V1647 Ori from four different epochs. Each image is 100″ in size. North is up, east to the left in all panels. Top left from 2004 February, a few months after the start of the 2003 outburst. Top right from 2007, a year after the source had faded back to its quiescent brightness level. In this image the HH 22 complex is visible north and slightly east of V1647 Ori. Bottom left from 2008, soon after V1647 Ori had brightened for a second time. Bottom right from 2011, taken in early February. Note the similarity in structure in the 2004, 2008, and 2011 images. For comparison, the faint source to the southwest of V1647 Ori has an $r'$ magnitude of 21.00 ± 0.04 (Aspin & Reipurth 2009).

Table 3
NIR Photometry of V1647 Ori

| Filter/Color | UT 2004 Mar 4/9 a (mag) | 2007 Feb 22 b (mag) | 2008 Sep 22 c (mag) | 2011 Feb 2 d (mag) | 2011 Apr 19 e (mag) |
|-------------|------------------------|---------------------|---------------------|--------------------|--------------------|
| $r'$        | 17.91 ± 0.09           | 23.26 ± 0.15        | 17.53 ± 0.07        | 17.77 ± 0.04       | …                 |
| $J$         | 11.13 ± 0.10           | 14.72 ± 0.10        | 10.86 ± 0.07        | 11.22 ± 0.06       | 10.85 ± 0.10       |
| $H$         | 9.09 ± 0.07            | 11.90 ± 0.10        | 9.00 ± 0.07         | 9.22 ± 0.02        | 8.87 ± 0.10        |
| $K'$        | 7.48 ± 0.09            | 10.14 ± 0.10        | 7.74 ± 0.07         | 7.81 ± 0.03        | 7.58 ± 0.10        |
| $L'$        | …                      | 7.62 ± 0.10         | 5.76 ± 0.10         | 5.85 ± 0.10        | …                 |
| $J - H$     | 2.04 ± 0.12            | 2.82 ± 0.14         | 1.86 ± 0.10         | 2.00 ± 0.07        | 1.98 ± 0.14        |
| $H - K'$    | 1.61 ± 0.11            | 1.76 ± 0.14         | 1.26 ± 0.10         | 1.41 ± 0.04        | 1.29 ± 0.14        |
| $K' - L'$   | …                      | 2.52 ± 0.14         | 1.98 ± 0.14         | 2.23 ± 0.14        | …                 |

Notes.

a $r'$ data from Aspin & Reipurth (2009). J, H, K' data from Acosta-Pulido et al. (2007).
b Data presented in Aspin et al. (2008).
c Data presented in Aspin et al. (2009b).
d Data from this paper (Gemini/NIRI).
e Data from this paper (IRTF/Spex, SXD only).

2MASS) to 2011. Other than points 8–10, the values were compiled from other sources (listed in the figure caption). Aspin et al. (2008) interpreted the color variation seen in Figure 2 (points 1–7) as due to changes in overlying extinction caused by either the sublimation of dust in the outburst, or denser material moving into the line of sight, e.g., similar to what occurred in KH 15D (see Kusakabe et al. 2005 and references therein) since the variations were directly along standard reddening vectors. The additional photometric points (8–10) are all consistent with the values of the $JHK'$ colors at the time of the first outburst in 2004 March. Point 8 is from soon after the second outburst phase. Points 9 and 10 are from 2011 February and April, respectively. This behavior is consistent with the optical brightness of V1647 Ori at these times; the infrared colors are smaller during the outburst while they are larger colors in quiescence.

In Figure 2 we have plotted loci of varying contributions of a stellar photosphere at a blackbody temperature of 4000 K and dust emission from blackbody temperatures of 800–2000 K (dotted lines). At position “A” the contribution is 100% from the stellar photosphere while at position “B” it is 100% from
Figure 2. NIR $J - H$ vs. $H - K'$ color–color diagram showing the location of V1647 Ori at 10 different epochs including the data presented here (points 9 and 10). Typical observational uncertainties are shown as a cross at $J - H = 0.3$, $H - K' = 1.1$. The zero-age main sequence (ZAMS; open circles, labeled V) and giant branch (small filled circles labeled III) are shown and have Rieke & Lebofsky (1985) reddening vectors (solid lines) extending from them for $A_V = 20$ mag. The Meyer et al. (1997) locus of classical and weak-line T Tauri stars is also shown (dashed line, labeled CTTS). From the larger $H - K'$ end of this locus extends a reddening vector also for $A_V = 20$ mag (solid line). The dotted lines show the loci of varying contributions from (1) a blackbody “stellar” temperature of 4000 K and (2) blackbody dust temperatures of 800–2000 K in steps of 200 K. Along the loci the contributions vary from 100% stellar (close to the ZAMS) to 100% dust. The dotted line A–B indicates the loci of pure dust emission. Point 1 is from 2MASS catalog. Point 2 is from Reipurth & Aspin (2004). Point 3 is from the United States Naval Observatory telescope as presented in McGehee et al. (2004). Points 4 and 6 are from the Telescopio Carlos Sanchez (TCS) at the Teide Observatory presented by Acosta-Pulido et al. (2007). Point 5 is from the Himalayan Chandra Telescope (HCT) presented in Ojha et al. (2006). Point 7 is from Gemini presented in Aspin et al. (2008). Point 8 is from Gemini presented in Aspin et al. (2009b). Points 9 and 10 are from this work.

The heated dust. The simple model used generated blackbody fluxes using the IDL routine PLANCK which takes as input the required wavelength and temperature. We generated fluxes at the central wavelengths of the NIR filters for both the stellar temperature and the heated dust temperature and then divided both by the corresponding values from an A0 star (at 10,000 K). These scaled fluxes were then normalized to unity at the middle wavelength (i.e., the $H$ band for $J$, $H$, and $K$ filters) and the results used to calculate the NIR colors in the standard manner. Although the generated fluxes are not integrated over specific filter profiles, we consider that the values at the central wavelengths of the filters are sufficiently accurate for our needs. The contributions to the derived colors from the stellar photospheric and heated dust fluxes vary from 0 to 1 and 1 to 0, respectively. This results in the (dotted) lines shown in Figure 2.

One interesting fact is that the line joining points A and B is close to being parallel to the reddening vector from the extreme of the Meyer et al. (1997) classical T Tauri star locus (dotted line). One could therefore interpret the change in colors of V1647 Ori as being the result of changing blackbody dust temperatures from $\sim 900$ K at point 7 to $\sim 1200$ K close to the group of points centered on point 9. However, this interpretation would assume that all the emission from the source originates as blackbody dust emission with no stellar photospheric contribution. This seems unreasonable for three reasons: (1) the source is optically bright, (2) Aspin et al. (2008) found photospheric absorption features in the NIR spectrum of V1647 Ori during quiescence (in 2007), and (3) the low inclination of the outflow cavity ($\sim 29^\circ \pm 14^\circ$ with respect to the plane of the sky) and the lack of a southern counterpart outflow lobe suggests we are not looking through dust-dominated material (i.e., through the disk) along our line of sight to the circumstellar regions. We therefore consider that our new data support the interpretation of the change in $JHK'$ colors as due to extinction changes resulting from the outburst event as proposed earlier by Aspin & Reipurth (2009).

In Figure 3 we show the $H - K'$ vs. $K' - L'$ color–color diagram for V1647 Ori. Three points from different epochs are plotted (7–9), specifically, 2007 February, 2008 September, and 2011 February.2 These three points lie parallel to the reddening vectors consistent with the suggestion that the changes observed are due to variations in overlying extinction. Point 7 has the largest colors in both the $JHK'$ and $HK'L'$ c–c diagrams and was taken in 2007 February, between the first and second outbursts. Point 8 has the smallest colors in both diagrams and at that time (2008 September), V1647 Ori was in a bright phase just after its second outburst. Point

2 The point numbering corresponds to those in Figure 2.
Figure 4. Optical spectrum of V1647 Ori from UT 2011 February 2. This Gemini/GMOS spectrum covers the wavelength range 6000–9000 Å and was taken using the B600 grating and a 0.75 wide long slit resulting in a resolving power of $R \sim 1500$. Top is the full continuum-subtracted spectrum showing H$\alpha$ in emission with a P Cygni profile. Also in emission are the far-red Ca$\text{ii}$ triplet lines. [O$\text{i}$] at 6300 Å is in emission while O$\text{i}$ at 7775 Å is in absorption. Middle is an expanded view of the region surrounding H$\alpha$ showing the blueshifted absorption. Bottom is the region around the Ca$\text{ii}$ triplet lines.

9 represents the latest observation (2011 February) and, within the associated uncertainties, is very similar to the 2008 elevated state value (No. 8). The $A_V$ difference between points 8 and 9 amounts to only a few magnitudes in both c–c diagrams (1.5 in $JHK'$ and 3 in $HK'LL'$). The $A_V$ differences between points 7 and 8 is $\sim 8$ mag in both diagrams.

3.3. Optical Spectroscopic Features

During the two recent outburst phases (i.e., 2004 March and 2008 September), V1647 Ori typically showed an optical emission spectrum which included a strong H$\alpha$ line with associated sub-continuum blueshifted absorption (i.e., a P Cygni profile) and strong far-red Ca$\text{ii}$ triplet emission. Examples of these spectra can be found in Aspin & Reipurth (2009). In its faint phase between the above outbursts (i.e., in 2007 February), the source also exhibited an optical emission spectrum but with significantly weaker H$\alpha$ emission (with no sub-continuum blueshifted absorption) plus, as in outburst, Ca$\text{ii}$ triplet line emission. Our 2011 February optical spectrum of V1647 Ori is shown in Figure 4. The line fluxes extracted from this spectrum are shown in Table 4. The top panel shows the complete GMOS spectrum covering the wavelength range 6000–9000 Å. This spectrum has been continuum-subtracted to enhance the visibility of the spectral features present.$^3$

$^3$ The optical continuum simply rises to the red through the above wavelength region.
The FWHM values of and it seems they are marginally resolved with deconvolved very close to the nominal Hα. 2008, and 2011, the model emission component peak occurs red dashed line is the difference (observed–model). In 2004, emission profile, the green line is the best-fit Gaussian, and the is the observed Hα. In 2007, the absorption minimum is slightly blueshifted (+70 km s⁻¹) and is skewed with an extended blue wing. The fact that the peak emission and minimum absorption components have very similar velocity offset results in an absorption-dominated observed profile with only weak redshifted emission. The purple line will be discussed further below.

Table 4
Optical Spectral Features

| Line | λ (Å) | EW † (Å) | FWHM ‡ (km s⁻¹) | Line Flux † (erg cm⁻² s⁻¹) | Continuum † (erg cm⁻² s⁻¹ Å⁻¹) |
|------|------|---------|-----------------|------------------------|------------------------|
| [O i] | 6300 | −0.9 | 170 | 1.19(−16) | 1.32(−16) |
| Hα | 6656 | −32.6 | 310d | 6.72(−15) | 2.02(−16) |
| O i | 7773 | +2.3 | 270 | 1.60(−15) | 7.04(−16) |
| Fe ii | 8228 | +0.8 | 190 | 4.42(−16) | 7.37(−16) |
| Fe i | 8388 | −0.6 | 170 | 4.75(−16) | 7.91(−16) |
| O i | 8446 | −0.5 | 240 | 5.20(−16) | 8.17(−16) |
| Ca ii | 8498 | −8.6 | 160 | 7.09(−15) | 8.15(−16) |
| Fe i | 8516 | −0.5 | 190 | 5.31(−16) | 8.25(−16) |
| Ca ii | 8543 | −9.0 | 160 | 7.76(−15) | 8.41(−16) |
| Ca ii | 8663 | −7.7 | 160 | 6.40(−15) | 8.47(−16) |

UT 2011 Apr 19f
| Ca ii | 8498 | −13.0 | 330 | 1.66(−14) | 1.24(−15) |
| Ca ii | 8543 | −11.0 | 330 | 1.40(−14) | 1.31(−15) |
| Ca ii | 8663 | −8.0 | 330 | 9.59(−15) | 1.43(−15) |

Notes.

† Equivalent widths have associated uncertainties of ±0.2 Å.
‡ FWHM line width. These values have associated uncertainties of ±10 km s⁻¹.
§ Number in parentheses is exponent, e.g., 9.24(−17) means 9.24 × 10⁻¹⁷.
* FWHM measured on the model fit to the observed Hα profile.
f Data from IRTF/Spex spectrum that extends down to 8000 Å.

to 800 and +540 km s⁻¹, on the blue and red side, respectively, and the absorption minimum occurs at −240 km s⁻¹. The Ca ii triplet lines are also in emission and it seems they are marginally resolved with deconvolved FWHM values of ~90 km s⁻¹. The ratios of the equivalent width (EW) values for the three lines (i.e., −8.6, −9, and −7.7 Å) are 1.9:2:1.7. This places V1647 Ori in the highly optically thick region of Figure 3 from Herbig & Soderblom (1980) and Figure 8 of Hamann & Persson (1992).

Since Hα is clearly a composite of emission and absorption components, we have fit an emission profile to the red wing of the Hα emission (the wing not effected by the blueshifted absorption component) and attempt to determine the underlying structure of the emission. Figure 5 shows the result of this analysis together with similar analysis for Hα in 2004, 2007, and 2008. Due to the high-velocity wings of the emission, the 2004, 2008, and 2011 spectra are best fit with a composite Voigt profile (Gaussian + Lorentzian). For the 2007 spectrum, a simple Gaussian suffices. In all four panels, the black line is the observed Hα profile, the blue line is the best-fit Voigt emission profile, the green line is the best-fit Gaussian, and the red dashed line is the difference (observed–model). In 2004, 2008, and 2011, the model emission component peak occurs very close to the nominal Hα wavelength of 6562.8 Å. In 2007 (between the outbursts), the peak is redshifted by −120 km s⁻¹. Similarly, in 2004, 2008, and 2011, the absorption component minimum, resulting from (observed–model) emission profiles, is significantly blueshifted (~240, −385, and −110 km s⁻¹, respectively) while in 2007, the absorption minimum is slightly redshifted (+70 km s⁻¹). This implies that in 2004, 2008, and early 2011, there was both significant mass accretion from disk to stellar surface and significant mass outflow from a stellar/disk wind. In 2007, the redshifted nature of both emission and absorption suggests that both the Hα emitting and absorbing gas are associated with infalling material.

For comparison with the above V1647 Ori profiles, in Figure 6 we show a similar analysis of the Hα profile of FU Orionis from Gemini/GMOS B600 grating spectrum taken on UT 2010 October 7. We note that here, both emission and absorption components are slightly blueshifted (by −60 km s⁻¹). The emission component (blue/green line) is reproduced with a simple Gaussian with an FWHM of 290 km s⁻¹ and full-width 10% intensity, FW10%, of 580 km s⁻¹. The absorption component (red dotted line) has an FWHM = 177 km s⁻¹, and is skewed with an extended blue wing. The fact that the peak emission and minimum absorption components have very similar velocity offset results in an absorption-dominated observed profile with only weak redshifted emission. The purple line will be discussed further below.

Table 5 details the velocity structure present in Hα during the two outbursts (2004 and 2008), in the quiescent phase between them (2007), and in our latest spectrum (2011). Also included is the same information for FU Ori. The velocity information for V1647 Ori compares well with that from FU Ori. Comparing these values suggests that in 2011, V1647 Ori was very similar in characteristics to when it was observed in 2004 and 2008. This, coupled with the suggestions that the source has remained bright since the second outburst implies that V1647 Ori has remained in an elevated eruptive state for at least the last three years.

3.4. NIR Spectroscopic Features

Our two epochs of NIR spectroscopic observations of V1647 Ori are shown in Figure 7. The four panels show the full wavelength range of the data (top left), plus individual panels
Figure 5. $\text{H}\alpha$ emission profiles (black) from four different epochs overlaid with a model profile (blue). The model parameters were determined by fitting the red wing of the emission. The extended wings on the line profiles from 2004, 2008, and 2011 are best fit using a V oigt profile. The best-fit Gaussian is also shown (green). The dashed (red) line is the difference between the observed and best-fit model profile, i.e., the associated absorption component. The parameters of the model emission (blue) and absorption (red) components for all profiles are given for each epoch.

(A color version of this figure is available in the online journal.)

for the $J$ (bottom left, blue), $H$ (top right, green), and $K$ (bottom right, red) bands. The Gemini/NIFS spectra from UT 2011 February 15 is the bottom of the two spectra while the IRTF/SpeX spectra from UT 2011 April 19 is at the top. The SpeX spectrum extends to shorter wavelengths than that from NIFS although the NIFS spectrum is of somewhat higher spectral resolution. The spectra from the two epochs are very similar, both being dominated by strong water vapor absorption bands extending over the wavelength ranges 1.3–1.65 $\mu$m, 1.7–2.2 $\mu$m, and 2.3 $\mu$m to the long-wavelength extreme of the $K$ band. The individual passband plots show that the spectra from the two epochs exhibit almost identical spectral details. The main atomic features present are Pa$\beta$ (1.208 $\mu$m) and Br$\gamma$ (2.166 $\mu$m), both in emission. The SpeX spectrum includes both the He$\lambda$ (1.082 $\mu$m) line, which is in absorption, and the far-red Ca$\text{II}$ triplet lines, which are in emission (as they were in our optical spectra presented above). Line fluxes from both the above NIR spectra are shown in Table 6. In the SpeX spectrum, the Ca$\text{II}$ triplet lines have ratios of 2.4:2:1.5 (or in the units of Hamann & Persson 1992, 1.2:0.7). These values are somewhat different from the values encountered 2.5 months earlier (see above). In these data, the location of V1647 Ori, in Figure 8 of Hamann & Persson (1992) and Figure 3 of Herbig & Soderblom (1980), is close to the region occupied by classical T Tauri stars (henceforth CTTSs) with the nearest being CW Tau.

Conspicuously absent from the $K$-band spectra are the CO overtone bandheads that, when present, extend redward from 2.294 $\mu$m. In both $K$-band spectra, no CO bandheads are observed with the spectra being featureless at those wavelengths. This is in contrast to the NIR spectra taken during the 2004 outburst (Reipurth & Aspin 2004) which showed strong CO

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5 The water vapor bands are intrinsic to the source and not telluric features.
overtones emission bands. In 2007 (between outbursts; Aspin et al. 2008) and in 2008 (during the second outburst; Aspin et al. 2009b), the CO bandheads were weakly in absorption. Figure 8 shows an inter-comparison of the 1–2.5 μm spectral structure in 2004, 2007, 2008, and 2011.

### 3.5. Accretion Luminosities and Rates

Several methods have been presented in the literature to allow estimation of accretion luminosities and rates from observed quantities. Almost all, however, rely on an accurate determination of overlying extinction so that true dereddened fluxes can be determined. Dahm (2008) presented a comprehensive discussion of the techniques involved and applied them to young solar mass stars in IC 348. He found that estimating accretion parameters from optical and NIR emission line fluxes (using predictions made by standard magnetospheric accretion models, e.g., Muzerolle et al. 1998, 2001; Kurosawa et al. 2006) and continuum excess emission determination (Valenti et al. 1993; Gullbring et al. 1998) were in reasonable agreement for the sample of quiescent young stars observed. It is unclear, however, if such an agreement can be obtained for eruptive variables such as V1647 Ori. The one method that does not rely on extinction is the measurement of the FW10% of the Hα wavelength of 6562.8 Å) measured from the best-fit model.

### 3.5.1. Using Paβ and Brγ to Derive \( \dot{M}_{\text{acc}} \)

Muzerolle et al. (1998) demonstrated how dereddened Paβ and Brγ emission line fluxes are correlated with mass accretion rate in CTTSs. The relationship determined by Muzerolle et al.
(1998) was used by Aspin et al. (2008) and Aspin et al. (2009b) to obtain estimates of $L_{\text{acc}}$ and $M_{\text{acc}}$ for V1647 Ori during the faint period between the two outbursts and soon after the start of the second outburst. Since both the correction to the observed line flux (to account for overlying visual extinction), and the stellar/disk parameter values used are of importance in such an analysis, we here detail a self-consistent analysis using a fixed set of stellar/disk characteristics and $A_V$ values obtained from the $JHK'$ c-c diagram shown in Figure 2. The $JHK'$ photometry of the source during the first outburst (epoch 2004 March, point 2 in the above figure), the second outburst (epoch 2008 August, point 8), and in early 2011 (points 9 and 10) all result in very similar NIR colors. If we dereddened their absorption (red) components are given. The purple curve is the required associated absorption component. The parameters of the model emission (blue) profile to give an emission profile (black) for FU Orionis overlaid with a model line is the difference between the observed and best-fit model profile, i.e., the best-fit Gaussian is also shown (green). The dashed (red) profile (blue). The model parameters were determined by fitting the red wing of the emission. The best-fit Gaussian is also shown (green). The dashed (red) profile (blue). The model parameters were determined by fitting the red wing of the emission.

Figure 6. Hα emission profile (black) for FU Orionis overlaid with a model profile (blue). The model parameters were determined by fitting the red wing of the emission. The best-fit Gaussian is also shown (green). The dashed (red) line is the different between the observed and best-fit model profile, i.e., the associated absorption component. The parameters of the model emission (blue) and absorption (red) components are given. The purple curve is the required profile to give an $M_{\text{acc}}$ value of $1 \times 10^{-3} M_\odot$ yr$^{-1}$ using the Natta et al. (2004) relationship between $H\alpha$ FW10% and $M_{\text{acc}}$.

(A color version of this figure is available in the online journal.)

(1998) was used by Aspin et al. (2008) and Aspin et al. (2009b) that Paβ emission (1.28 μm) in V1647 Ori is very likely optically thick due to the significant deviation of the ratio Paβ/Brγ from that obtained for Case B recombination theory (Hummer & Storey 1987). Subsequently, they only used the Brγ emission line flux for their estimate of $L_{\text{acc}}$ and $M_{\text{acc}}$. In Table 7 we show the results of our analysis using both Paβ and Brγ line fluxes from 2004 March, 2007 February, 2008 August, and 2011 February and April. Also shown are the $A_V$ value used in dereddening and the above line flux ratio values. Case B recombination theory results in a value of $P_{\beta}/B_{\gamma}$ of ~6 for temperatures in the range $T = 7500$–$20,000$ K and electron densities in the range $n_e = 10^4$–$10^{10}$ cm$^{-3}$ (Hummer & Storey 1987, Table 6). The only value of Paβ/Brγ that is close to this is from 2007 February when it had a value of ~5. This date corresponds to the faint period between the first and second outbursts. At all other times (i.e., early in the first and second outbursts and in early 2011), the ratio is much smaller with a typical value of ~2. We interpret this as evidence that the Paβ emission is optically thick during periods when the star is bright, and close to being optically thin during its fainter periods. This is supported by the similarity of the derived values for $L_{\text{acc}}$ and $M_{\text{acc}}$ using the Paβ and Brγ line fluxes in 2007 February and the significantly different values at the other three epochs. The conclusion we can draw from Table 7 is that close to the start of the first and second outbursts, and in 2011, the accretion luminosity was $L_{\text{acc}} \sim 16 \pm 2 L_\odot$ and the accretion rate was $M_{\text{acc}} \sim (4 \pm 2) \times 10^{-6} M_\odot$ yr$^{-1}$. In the faint phase between the first and second outbursts, the accretion luminosity and rate both declined by a factor of ~3. Although the statistical significance of this decline is relatively small, we postulate that it is real since something clearly changed in 2007 to cause the 5 mag fading of V1647 Ori. It is unlikely that this decline is a result of an incorrect $A_V$ value since it would require an $A_V \sim 25$ mag (instead of 19 ± 2 mag) to give the factor three decline in the observed $L_{\text{acc}}$ and $M_{\text{acc}}$.

3.5.2. Using Hα FW10% to Derive $M_{\text{acc}}$

The relationship between the FW10% width of the Hα emission profile and the accretion rate derived by Natta et al. (2004) relies on the assumption that the Hα emission is generated by the accretion process. Under this assumption, the relationship is linear in nature, although the spread of values around their best-fit line is significant. The formula is reproduced below in Equation (1).

$$M_{\text{acc}} = -12.89(\pm 0.3) + 9.7(\pm 0.7) \times 10^{-3} \times \text{FW10%}. \quad (1)$$

The stars upon which the relationship was defined were a combination of young brown dwarfs of spectral type M6–M8.5 with accretion rates in the range 10$^{-11}$ to 10$^{-9}$ $M_\odot$ yr$^{-1}$, and young T Tauri stars ($M_* > 0.3 M_\odot$) with accretion rates in the range 10$^{-9}$ to 10$^{-6}$ $M_\odot$ yr$^{-1}$. Over all the sources, the range of Hα emission FW10% values was 200–700 km s$^{-1}$.

The above correlation has implicit uncertainties defined by both the errors on the observed quantities and the non-simultaneity of the measurement of Hα FW10% and the independent determination of $M_{\text{acc}}$. Natta et al. state that the derived value of $M_{\text{acc}}$ should be “used with care” for individual objects. Nevertheless, it is informative to apply this analysis to the data on V1647 Ori and compare the results with those obtained from the Brγ line flux measurements.

Table 8 shows the results of this analysis for V1647 Ori for the four epochs all of which are close in time to those used to derive $M_{\text{acc}}$ from the Paβ and Brγ fluxes (and shown in Table 7). Comparing the derived values of $M_{\text{acc}}$ in Table 8 with those in Table 7, we see significant differences; in all cases the $M_{\text{acc}}$ values determined from the Hα FW10% value are considerably smaller than those estimated from the Brγ flux. For example, on 2004 March 9, the dereddened Brγ flux gives a value of $M_{\text{acc}} = 5.3 \times 10^{-6} M_\odot$ yr$^{-1}$. One day later, the Hα FW10% gave $M_{\text{acc}} = 2 \times 10^{-8} M_\odot$ yr$^{-1}$ some 265× smaller. Using the relationship of Natta et al. (2004), we would require a value of FW10% of 785 km s$^{-1}$ (instead of the observed 530 km s$^{-1}$) to obtain the $M_{\text{acc}}$ value derived from the Brγ line flux. A similar situation occurs for all four epochs of Hα FW10%
dereddened Br et al. (2004) tends to give considerably smaller values than those.

A classical FUor is one whose rise from quiescence to outburst was documented. Examples of classical FUors are FU Ori, V1057 Cyg, V1515 Cyg, and V1735 Cyg.

The characteristic optical absorption spectrum of an F–G type supergiant, which all four classical FUors (FU Ori, V1057 Cyg, and V1515 Cyg) exhibit, has not been seen.

Table 7

| UT Date | Aν | Paβ/Brγ | Lacc | Macc | Paβ | Brγ |
|---------|----|---------|------|------|-----|-----|
| 2004 Mar 9e | 8 ± 2 | 2.2 ± 0.3 | 5.1 ± 2 | 1.3 ± 0.6 (−5.88) | 20 ± 6 | 5.3 ± 3 (−5.28) |
| 2007 Feb 23e | 19 ± 2 | 4.9 ± 0.3 | 3.4 ± 2 | 0.9 ± 0.3 (−6.06) | 5 ± 2 | 1.2 ± 1 (−5.92) |
| 2008 Aug 31e | 8 ± 2 | 1.4 ± 0.3 | 2.4 ± 1 | 0.6 ± 0.2 (−6.19) | 16 ± 5 | 4.0 ± 3 (−5.39) |
| 2011 Feb 15f | 8 ± 2 | 1.3 ± 0.3 | 2.4 ± 1 | 0.6 ± 0.2 (−6.20) | 17 ± 5 | 4.5 ± 2 (−5.35) |
| 2011 Apr 19f | 8 ± 2 | 1.9 ± 0.3 | 2.8 ± 1 | 0.7 ± 0.2 (−6.13) | 12 ± 4 | 3.2 ± 2 (−5.50) |

Notes.

a Visual extinction used to deredden line fluxes. Derived from dereddening J−H versus H−K’ colors.

b Ratio of dereddened Paβ and Brγ line fluxes. Case B recombination theory gives a value of ~6.

c Determined from the dereddened Paβ line flux.

d Determined from the dereddened Brγ line flux.

e Fluxes from Vacca et al. (2004).

f Values in parentheses are log10 of the preceding accretion rates.

g Fluxes from Aspin et al. (2008).

h Fluxes from Aspin et al. (2009b).

i Fluxes from this paper.

determined from dereddened Paβ and Brγ emission line fluxes. Since this also appears to be the case for the classical FUor FU Orionis (when compared to the definitive values of 10−4 to 10−5 $M_\odot$ yr−1) then perhaps using the Hα FW10% width to estimate $M_{acc}$ is not valid for high accretion rate eruptive variables such as V1647 Ori and FU Ori. One possibility is that the strong star/disk wind present in FUors significantly contributes to or modifies the Hα emission observed (as suggested by Lima et al. 2010).

4. DISCUSSION

From the data and analyses presented above, we support the hypothesis that V1647 Ori has remained in an elevated eruptive state since the time of the second outburst which occurred in mid-2008. Although the star likely underwent a decline in outburst activity in early 2007, its accretion luminosity and rate remained at the upper end of the range seen in CTTSs (Hartigan et al. 1995; Gullbring et al. 1998). At that time, the decline in accretion characteristics was accompanied by a change in overlying visual extinction, caused by either the reformation of circumstellar dust or motion of dust into the line of sight. This resulted in an increase in extinction of over 10 mag. At the time of the second outburst, the enshrouding dust either sublimated or rotated out of the line of sight, and has remained absent.

Although both the optical/NIR line emission characteristics of V1647 Ori and the apparent decline in its optical brightness after ~2 yr more resemble those of the shorter period EXor variables, the source has several features in common with FUors, e.g., the similarity of the NIR spectral absorption characteristics, e.g., the presence of strong water absorption bands and the unique spectral structure, identified at high spectral resolution in FUors and V1647 Ori (Aspin et al. 2009a). However, V1647 Ori exhibits several peculiarities that are not seen in the classical FUors. Specifically,

1. The characteristic optical absorption spectrum of an F–G type supergiant, which all four classical FUors (FU Ori, V1057 Cyg, and V1515 Cyg) exhibit, has not been seen.

We note that this decline is of relatively low significance with respect to the uncertainties on the derived values.
Figure 7. NIR spectra of V1647 Ori covering the wavelength region 0.8–2.4 μm. Spectra from two epochs are shown, specifically from UT 2011 February 15 and April 19. The bottom of the two spectra per panel is the Gemini/NIFS spectrum with $R \sim 5000$. The top spectra per panel is the IRTF/Spex spectrum with $R \sim 1500$. The top spectra have been shifted vertically by +1 units for clarity. Top left is the full wavelength range observed. Bottom left, top right, and bottom right are closer views of the $J$ band (blue), $H$ band (green), and $K$ band (red), respectively. The main features in these spectra are strong water vapor absorption bands (indicated by horizontal solid lines), the H emission lines Paβ and Brγ, and He i in absorption. No CO bandhead emission nor absorption is observed in either spectra.

(A color version of this figure is available in the online journal.)

V1647 Ori has instead shown few absorption lines and strong emission features such as Hα and the far-red Ca ii triplet (see Figure 4).

2. The four classical FUors exhibit deep and highly variable blueshifted Hα absorption with at most a weak emission component (Bastian & Mundt 1985). In addition, the far-red Ca ii triplet lines can either be in emission or absorption (Welty 1991; Welty et al. 1992). During outburst, however, V1647 Ori showed strong Hα emission with associated blueshifted absorption and the far-red Ca ii triplet lines are in emission.

3. The deep NIR CO overtone bandhead absorption features, typical of the four classical FUors (Reipurth & Aspin 1997; Connelley & Greene 2010), have not been observed in V1647 Ori, rather CO bandhead emission was seen soon after the first outburst. As the outburst subsided, the CO bandhead region became relatively featureless other than the weak CO absorption occurring in the quiescent period between the first and second outburst phases (see Figure 8).

4. The curving nebulous structure prototypical of classical FUors (Goodrich 1987) is replaced in V1647 Ori by an extensive monopolar structure, McNeil’s Nebula (see Figure 1).

One possibility to explain the dichotomy is that the viewing geometry of the young star/disk system plays a role in what spectral features are observed. High inclinations could easily result in selective illumination and/or obscuration. The telltale sign of an FUor, the presence of curving nebulosity extending away from the star (Goodrich 1987 presented several good example images) could be explained in terms of selective
illuminated by the presence of material located either in the walls of an evacuated cavity created by an earlier large-scale molecular outflow, or in the outer regions of the circumstellar disk. An earlier molecular outflow is very likely the origin of the monopolar nebula (McNeil's Nebula) in V1647 Ori, which, as we have seen, has an estimated inclination (with respect to the plane of the sky) of $\sim$29° ± 14° (Acosta-Pulido et al. 2007). The opening angle of this cavity may also play a role in what nebulous structures are illuminated and hence observed. The lack of monopolar or bipolar structure associated with the classical FUors may well suggest that they are viewed at a much larger inclination (closer to 90°). This interpretation would be unacceptable if the four classical FUors were the only FUors known, since statistically, this would be highly improbable. However, two sources postulated to be FUors, Par 21 (Staude & Neckel 1992; Köslé et al. 2008) and HH381 IRS (Reipurth & Aspin 1997; T.-Yu. Magakian et al. 2011, in preparation), both have bright monopolar cavities seen in reflected light and have inferred inclinations <30°. Other FUor-like objects8 also possess well-defined outflow cavities, e.g., PP 13S (Sandell & Aspin 1998; Aspin & Sandell 2001), L1551 IRS5 (Mundt et al. 1985), and V2495 Cyg (also known as the Braid Nebula Star; Movsessian et al. 2006). This means that a line of sight toward the four classical FUors with, say, $i > 70°$ is not as unlikely as one might expect.

5. CONCLUSIONS

Our conclusions are as follows.

1. V1647 Ori has remained in an elevated photometric state since late 2008, which means that the current (second) eruption is now almost three years old.
2. McNeil's Nebula has remained bright and has a morphology very similar to that seen during the 2004 and 2008 outbursts.
3. CO overtone bandhead emission, seen in 2004 close to the beginning of the first eruption, is no longer present, with the spectral region from 2.9–2.4 μm now being featureless.
4. Water vapor absorption bands seen in the 1–2.5 μm spectral region, which developed as the first eruption proceeded, remain strong.
5. Hα still maintains a P Cygni profile indicative of the presence of a strong star/disk wind. The minimum in the absorption component is found to be at around $-100 \, \text{km} \, \text{s}^{-1}$. The Hα FW10% value of 620 km s$^{-1}$ implies that accretion rates are high although the value derived using the analysis of Natta et al. (2004) is at least a factor of 100 less than that obtained from the dereddened Brγ emission line fluxes.
6. The accretion luminosity and rate in early 2011, derived from the dereddened $Br'\gamma$ flux, are $14 \pm 4 L_\odot$ and $(3.8 \pm 2) \times 10^{-6} M_\odot \text{yr}^{-1}$, respectively. These are statistically similar to those found throughout the sources elevated photometric state. Although much of the 2007 fading of V1647 Ori was caused by the changes in line-of-sight extinction, we believe that the accretion luminosity and rate at that time declined by a factor of 2–3.

We wait with anticipation to track the changes occurring in V1647 Ori over the next few years.

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REFERENCES

Acosta-Pulido, J. A., Kun, M., Ábrahám, P., et al. 2007, AJ, 133, 2020
Ambartsumyan, V. A. 1971, Astrophysics, 7, 331
Aspin, C., Barbieri, C., Boschi, F., et al. 2006, AJ, 132, 1298
Aspin, C., Beck, T. L., & Reipurth, B. 2008, AJ, 135, 423
Aspin, C., Greene, T. P., & Reipurth, B. 2009a, AJ, 137, 2968
Aspin, C., & Reipurth, B. 2009, AJ, 138, 1137
Aspin, C., Reipurth, B., Beck, T. L., et al. 2009b, ApJ, 692, L67
Aspin, C., Reipurth, B., Herczeg, G. J., & Capak, P. 2010, ApJ, 719, L50
Aspin, C., & Sandell, G. 2001, MNRS, 328, 751
Bastian, U., & Mundt, R. 1985, A&A, 144, 57
Briceno, C., Vivas, A. K., Hernandez, J., et al. 2004, ApJ, 606, L123
Connelley, M. S., & Greene, T. P. 2010, AJ, 140, 1214
Cushing, M. C., Vacca, W. D., & Rayner, J. T. 2004, PASP, 116, 362
Dahm, S. E. 2008, AJ, 136, 521
Davies, R. L., Allington-Smith, J. R., Bettes, P., et al. 1997, Proc. SPIE, 2871, 1099
Goodrich, R. W. 1987, PASP, 99, 116
Gullbring, E., Hartmann, L., Briceno, C., & Calvet, N. 1998, ApJ, 492, 323
Hamann, F., & Persson, S. E. 1992, ApJS, 82, 247
Hartigan, P., Edwards, S., & Gandour, L. 1995, RevMexAA Conf. Ser., 3, 93
Hartmann, L., & Kenyon, S. J. 1996, ARA&A, 34, 207
Herbig, G. H. 1966, Vistas Astron., 8, 109
Herbig, G. H. 1974, Lick Obs. Bull., 658
Herbig, G. H. 1977, ApJ, 217, 693
Herbig, G. H. 1989, in ESO Workshop on Low Mass Star Formation and Pre-Main Sequence Objects, ed. B. Reipurth (Garching: ESO), 233
Herbig, G. H., Petrov, P. P., & Duemmler, R. 2003, ApJ, 595, 384
Herbig, G. H., & Soderblom, D. R. 1980, ApJ, 242, 628
Hodapp, K. W., Jensen, J. B., Irwin, E. M., et al. 2003, PASP, 115, 1388
Hook, I., Jorgensen, I., Allington-Smith, J. R., et al. 2004, PASP, 116, 425
Hummer, D. G., & Storey, P. J. 1987, MNRS, 224, 801
Kastner, J. H., Rich mond, M., Grosso, N., et al. 2004, Nature, 430, 429
Kóspál, Á., Ábrahám, P., Apai, D., et al. 2008, MNRS, 383, 1015
Kun, M. 2008, Inf. Bull. Var. Stars, 5850, 1
Kurosawa, R., Harries, T. J., & Symington, N. H. 2006, MNRS, 370, 580
Kusakabe, N., Tamura, M., Nakajima, Y., et al. 2005, ApJ, 632, L139
Larson, R. B. 1980, MNRS, 190, 321
Lima, G. H. R. A., Alencar, S. H. P., Calvet, N., Hartmann, L., & Muzerolle, J. 2010, A&A, 522, A104
McGehee, P. M., Smith, J. A., Henden, A. A., et al. 2004, ApJ, 616, 1058
McGregor, P. J., Hart, J., Conroy, P. G., et al. 2003, Proc. SPIE, 4841, 1581
McNeil, J. W. 2004, IAU Circ., 8284
Meyer, M. R., Calvet, N., & Hillenbrand, L. A. 1997, AJ, 114, 288
Mould, J. R., Hall, D. N. B., Ridgway, S. T., Hintzen, P., & Aaronson, M. 1978, ApJ, 222, L123
Movsessian, T. A., Khanzadyan, T., Aspin, C., et al. 2006, A&A, 455, 1001
Mundt, R., Stocke, J., Strom, S. E., Strom, K. M., & Anderson, E. R. 1985, ApJ, 297, L41
Muzerolle, J., Calvet, N., & Hartmann, L. 2001, ApJ, 550, 944
Muzerolle, J., Hartmann, L., & Calvet, N. 1998, AJ, 116, 2965
Natta, A., Testi, L., Muzerolle, J., et al. 2004, A&A, 424, 603
Ojha, D. K., Ghosh, S. K., Tej, A., et al. 2006, MNRS, 368, 825
Petrov, P. P., & Herbig, G. H. 1992, ApJ, 392, 209
Petrov, P. P., & Herbig, G. H. 2008, AJ, 136, 676
Rayner, J. T., Toomey, D. W., Onaka, P. M., et al. 2003, PASP, 115, 362
Reipurth, B., & Aspin, C. 1997, AJ, 114, 2700
Reipurth, B., & Aspin, C. 2004, ApJ, 606, L119
Reipurth, B., & Aspin, C. 2010, in Evolution of Cosmic Objects through Their Physical Activity, ed. H. Harutyunyan, A. Mckaelian, & Y. Terzian (The Victor Ambartsumian Centennial Volume; Yerevan, Armenia: Gitutyun Publishing House), 19
Rieke, G. H., & Lebofsky, M. J. 1985, ApJ, 288, 618
Sandell, G., & Aspin, C. 1998, A&A, 333, 1016
Staude, H. J., & Neckel, T. 1992, ApJ, 400, 556
Teets, W. K., Grosso, N., Hamaguchi, K., et al. 2011, BAAS, 43, 21734030
Vacca, W. D., Cushing, M. C., & Simon, T. 2004, ApJ, 609, L29
Valenti, J. A., Basri, G., & Johns, C. M. 1993, AJ, 106, 2024
Vakounzian, A. 1954, Z. Astrophys., 35, 74
Welty, A. D. 1991, PhD thesis, Univ. Massachusetts, Amherst
Welty, A. D., Strom, S. E., Edwards, S., Kenyon, S. J., & Hartmann, L. W. 1992, ApJ, 397, 260
White, R. J., & Basri, G. 2003, ApJ, 582, 1109