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POST-OUTBURST INFRARED SPECTRA OF V1647 ORI, THE ILLUMINATING STAR OF McNEIL'S NEBULA

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ABSTRACT

V1647 Ori is a low-mass star in the L1630 star-forming region that underwent an outburst in late 2003 and early 2004. We present postoutburst infrared spectra obtained with NIRSPEC (Keck II) and SpeX (IRTF) and compare these to spectra taken during the outburst. The results show that the temperature of the hot CO formed in the inner part of the disk has declined by ~800 K, while the water and CO ice and low-*J* CO gas features remained unchanged, consistent with previous assertions that the latter, low-temperature features arise in the foreground cloud. The P Cygni profiles of the Paschen series that were present in the outburst spectra taken in 2004 March disappeared by late 2004. The equivalent width of the helium absorption line at 1.0830 μm decreased from 8.9 to 3.9 Å between 2004 March and November, evidence that the hot, fast wind has decreased substantially. We discuss the implications for categorizing V1647 Ori among the known classes of outbursting young stars.

Subject headings: infrared: ISM — ISM: abundances — ISM: molecules — line: profiles

1. INTRODUCTION

The outbursting object V1647 Orionis is viewed as a cometary-shaped reflection nebula in the Lynds 1630 cloud in Orion (McNeil et al. 2004). Over the course of the outburst, the brightness increased by ~5 mag in the *I* band (Briceño et al. 2004) and ~3 mag in the *J*, *H*, and *K* bands (Reipurth & Aspin 2004). A subsequent search through earlier photographs of the region showed that V1647 Ori also exhibited nebulosity in 1966, suggesting that this may be a periodic event that reoccurs on timescales of decades (Mallas & Kreimer 1978). Spectroscopic analyses have led various researchers to conclude that V1647 Ori is either an FU Orionis object (FUor) or an EX Lupi star (EXor). In such objects, instabilities in the inner disk result in a rapid accretion event and subsequent mass ejection through a powerful wind (Hartmann & Kenyon 1996). The accretion event was not observed directly, and all observations subsequent to the brightening of V1647 Ori point to outflowing rather than inflowing material (Vacca et al. 2004). While the outburst amplitude of V1647 Ori was similar to that of FUors, the duration of its outburst is thought to be much shorter. V1647 Ori displayed a similar rise time and peak duration to those of EXors but did not experience the significant variations at maximum that are typical in EXors (Walter et al. 2004). Recent photometry has shown that rapid fading has occurred and that as of 2005 November, V1647 Ori has faded to 1 mag brighter than the pre-outburst level, giving it a fading time much shorter than an FUor (decades) but longer than a typical EXor (weeks to months) (Kóspál et al. 2005). This has given rise to some uncertainty as to which class of object V1647 Ori belongs and speculation that it is somewhat intermediate between FUors and EXors.

V1647 appears to be a pre–main-sequence Class I/Class II transitional object (Vacca et al. 2004). Estimates of the circumstellar mass range from ~0.05 to ~0.5 $M_\odot$, primarily due to different assumptions for the dust temperature (Ábrahám et al. 2004; Andrews et al. 2004). During the outburst, no evidence for shocked gas in H_2 (2.122 μm) was observed. However, the P Cygni profiles of the Paschen and Balmer lines of hydrogen indicated a strong, high-velocity outflow (Reipurth & Aspin 2004; Vacca et al. 2004). This is consistent with the idea that previous outbursts have cleared most of the ambient cloud material in the close vicinity of V1647 Ori. Emission lines of ^{12}CO (1–0), (2–1), and (3–2) were shown to originate from ~2500 K gas in an inner accretion disk region (Rettig et al. 2005). The

TABLE 1

Summary of Observations

Date (UT)	Instrument	Setting	Slit (arcsec)	Air Mass	Exposure Time (minutes)	SNR
2004 Nov 29.6	SpeX	LXD	0″.3	1.2–1.4	32	~40
2004 Nov 30.6	SpeX	SXD	0″.5	1.3–1.5	32	~100–200
2004 Jul 31	NIRSPEC	M-Wide1	0″.432	3.4–2.8	12	~25
2004 Jul 31	NIRSPEC	M-Wide2	0″.432	2.4–2.6	8	~15
2004 Jul 31	NIRSPEC	M-Wide3	0″.432	2.1–2.3	4	~15
2005 Mar 2	SpeX	SXD	0″.3	1.2–1.3	40	~100–200
2005 Mar 2	SpeX	LXD	0″.3	1.7–1.9	10	~40

narrower widths of the low-J CO emission lines are indicative of more distant, warm (~400 K) material in the inner disk. The low column density and cold temperature (~18 K) for the absorbing gas suggests that the disk is not oriented close to edge-on. This is consistent with Muzerolle et al. (2005), who fit an envelope plus accretion disk (inclined at 50°) model to the pre- and post-outburst spectral energy distributions (SEDs).

In this paper, we compare postoutburst high-resolution spectra taken with NIRSPEC from Keck II in 2004 July and moderate-resolution spectra acquired with SpeX from the Infrared Telescope Facility (IRTF) in 2004 November and 2005 March to spectra taken during the outburst (2004 February for NIRSPEC and 2004 March for SpeX) to look for and characterize variations with time. In § 2 we discuss the observations and data analysis. Section 3 discusses the principal similarities and differences in spectra taken during and after the outburst. In § 4 we discuss the implications for V1647 Ori.

2. OBSERVATIONS AND DATA ANALYSIS

SpeX observations of V1647 Ori were obtained on 2004 November 29 and 30 and 2005 March 2 on the NASA IRTF. SpeX is a moderate-resolution ($R \sim 1000$–2500) cross-dispersed infrared spectrograph covering the 0.8–5.4 μm spectral region (Rayner et al. 2003). Observations were performed in an observing sequence ABBA by nodding the telescope along the 15″ slit, where the A and B positions are located approximately one-quarter of the distance from the top and bottom of the slit, respectively. This allows cancellation of telluric absorption to first order while increasing time spent on source.

Details of the observations are given in Table 1. The short-wavelength (0.8–2.4 μm) cross-dispersed (SXD) spectra on both 2004 November and 2005 March were taken in 120 s exposures. The bright sky at long-wavelength cross-dispersed (LXD) mode (covering 2.2–5 μm) required shorter exposures (5 s with six co-adds in 2005 March and 2 s with 15 co-adds in 2004 November). Flats and arc frames were obtained on each night, and a standard A0 V star was observed prior to or immediately following observations of V1647 Ori, with the exception of November 30, where the standard star was at similar air mass but observed one hour earlier. Weather conditions were generally good, although there was variable light cirrus during the 2004 November observations and possibly light cirrus during the 2005 March observations. This may have affected the absolute continuum flux calibration, particularly in November.

The data were reduced using the Spextool package (Cushing et al. 2004) and the telluric correction and flux calibration methods described by Vacca et al. (2003). The individual orders were then spliced together. We found that the flux agreement between orders was very good, usually within about two percent. The SXD spectra are shown in Figure 1. Table 2 gives the equivalent widths and fluxes for the lines identified in Figure 1. Errors are typically 10%–20% and are determined from the standard deviation of the noise in the continuum. Note that there are many more weak emissions present on all three nights that are likely due to various metals.

We also observed V1647 Ori on 2004 July 31 in the M band with NIRSPEC on the Keck II telescope. NIRSPEC is a high-dispersion, cross-dispersed infrared spectrometer with a resolving

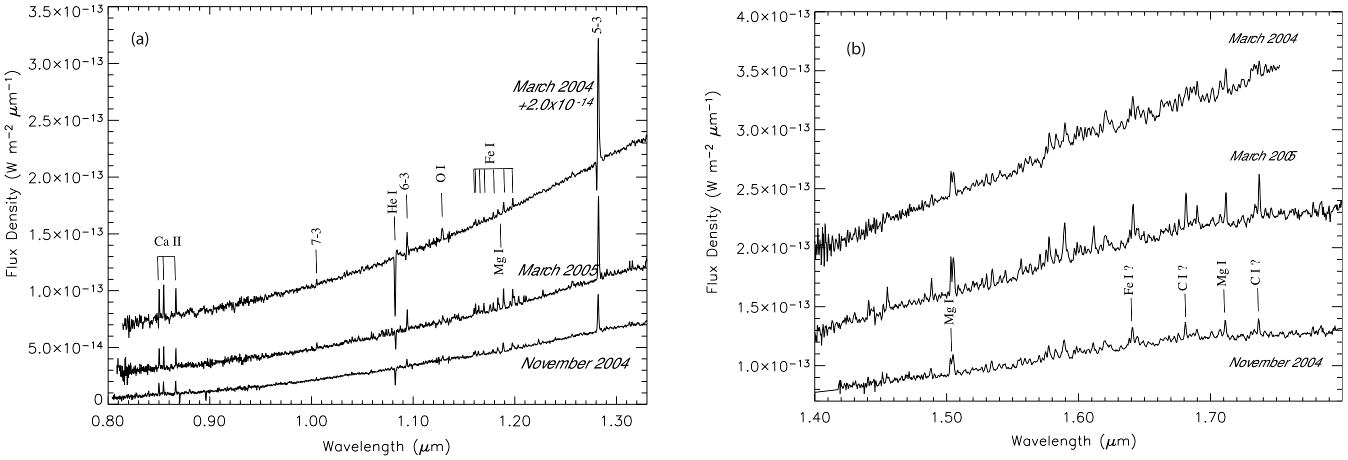

Fig. 1.—SpeX SXD spectra in 2004 March (during outburst) and November and 2005 March (postoutburst) illustrate the similarities and differences with time. (*a*) The wavelength region from 0.8–1.3 μm. (*b*) The 1.4–1.8 μm wavelength region. The 2004 March data in (*a*) were shifted vertically ($+2 \times 10^{-14}$) to separate the spectra.

TABLE 2

Comparison of Spectral Lines on Three Dates

Line ID	Wavelength (μm)	2004 Mar	2004 Nov		2005 Mar	
		EW (Å)	EW (Å)	Flux (W m^{-2})	EW (Å)	Flux (W m^{-2})
Ca II	0.8498	−9.8(1.0)[a]	−12.0(0.20)	9.67(−18)	−12.2(0.23)	1.4(−17)
Ca II	0.8542	−12.4(1.2)[a]	−11.7(0.14)	9.75(−18)	−9.3(0.16)	1.1(−17)
Ca II	0.8662	−10.1(1.0)[a]	−10.4(0.15)	9.46(−18)	−8.1(0.16)	1.0(−17)
H I (7–3)[c]	1.0049	−0.6(0.06)[a]	−0.4(0.1)	8(−19)	−1.72(0.59)	3.9(−18)
He I[c]	1.0830	−2.0(0.2)	...	...	...	...
		8.9(0.9)[a]	3.86(0.24)	1.2(−17)	2.68(0.30)	1.1(−17)
H I (6–3)[c]	1.0938	−2.8(0.3)[a]	−2.06(0.21)	6.80(−18)	−4.05(0.36)	2.0(−17)
O I	1.1287	−1.9(0.2)[a]	−1.94(0.26)	7.38(−18)	−1.72(0.44)	8.3(−18)
Fe I	1.1595	−0.19(0.04)	−0.68(0.08)	2.91(−18)	−0.85(0.23)	4.8(−18)
Fe I	1.1611	−0.39(0.06)	−1.06(0.09)	4.58(−18)	−1.44(0.26)	8.4(−18)
Fe I	1.164	−0.19(0.04)	−0.67(0.09)	2.91(−18)	−1.02(0.23)	6.3(−18)
Fe I	1.179	−0.22(0.03)	−0.50(0.06)	2.29(−18)	−0.82(0.20)	4.8(−18)
Mg I	1.1828	−0.31(0.06)	−0.66(0.09)	3.09(−18)	−1.27(0.20)	1.2(−17)
Fe I	1.1895	−0.64(0.06)	−1.54(0.08)	7.34(−18)	−2.08(0.21)	1.6(−17)
H I (5–3)[c]	1.2818	−10.9(1.1)[a]	−6.94(0.15)	4.45(−17)	−10.3(0.27)	1.0(−16)
		0.97(0.1)	<0.14[b]	<9(−19)	...	...
Mg I	1.503	−2.2(0.2)[a]	−3.99(0.12)	2.20(−17)	−4.1(0.36)	5.8(−17)
Fe	1.6445	−1.38(0.19)	−2.67(0.07)	3.06(−17)	−3.7(0.27)	6.7(−17)
C I?	1.689	−0.83(0.09)	−2.24(0.07)	2.71(−17)	−1.6(0.19)	3.1(−17)
Mg I	1.7109	−0.90(0.12)	−2.38(0.05)	2.93(−17)	−2.0(0.18)	3.9(−17)
H I (8–4)+Ca I	1.9446	−3.4(0.3)[a]	−6.37(0.13)	9.62(−17)	−6.19(0.33)	1.6(−16)
Ca I	1.9506	−0.82(0.13)	−2.94(0.07)	4.47(−17)	−1.35(0.23)	6.0(−17)
Ca I	1.9777	−0.63(0.16)	−1.75(0.04)	2.70(−17)	−2.19(0.24)	5.5(−17)
Ca I	1.9862	−0.62(0.14)	−1.28(0.05)	1.99(−17)	−2.33(0.29)	5.5(−17)
He I[c]	2.0581	−0.3	...	...	...	...
		0.7(0.07)[a]	<0.13[b]	<2.1(−18)	<0.10[b]	<7(−19)
H I (7–4)	2.1655	−4.6(0.5)[a]	−5.06(0.13)	8.89(−17)	−5.2(0.21)	1.6(−16)
Na I	2.2084	−0.9(0.1)[a]	−0.81(0.08)	3.80(−17)	−0.7(0.13)	2.1(−17)
H I (5–4)	4.0512	−12(1.2)[a]	−11.3(2.4)	2.09(−16)	−9.4(1.4)	3.0(−16)

Note.—A negative number for equivalent width denotes emission; positive denotes absorption.

[a] From Vacca et al. (2004).

[b] 3 σ upper limit.

[c] This spectral line changed significantly from outburst to postoutburst.

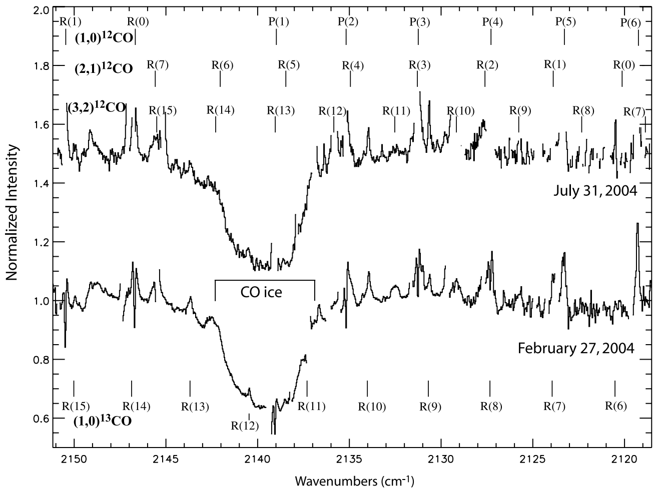

Fig. 2.—NIRSPEC spectra of V1647 Ori taken on 2004 July 31 (*top*) and February 27 (*bottom*). The CO features are labeled. The strengths of the ice feature as well as the gas phase CO emission lines have not changed within the uncertainty of the measurements. Most visible differences are accounted for by the different geocentric Doppler shifts between February and July and the higher air mass of the July observations. Where the atmospheric transmittance is poor (<50%) no data are presented.

power of ~25,000 (McLean et al. 1998), which is sufficient to resolve $v = 1$ rovibrational lines of ^{12}CO and ^{13}CO. The data were processed similarly to that of Brittain et al. (2003). The fundamental CO gas emission and absorption features and the CO ice absorption feature at 4.67 μm are shown in Figure 2. We note that the geocentric Doppler shift on July 31 (~5–10 km s^{-1}) was insufficient to shift the narrow absorption lines of ^{12}CO from their telluric counterparts. For this reason, we restrict the analysis to ^{12}CO 2–1, ^{13}CO 1–0, and high-J ^{12}CO 1–0 transitions, which are less affected by Earth's atmosphere.

3. RESULTS

The SpeX data for V1647 Ori obtained in 2004 March were presented by Vacca et al. (2004). It was noted that V1647 Ori exhibited a red continuum, very prominent emission lines due to H I Paschen and Brackett series, and strong H_2O and CO ice absorptions. Also present were Ca II, Fe I, Mg I, Na I, and Ca I emission lines and He I lines in absorption. Prominent P Cygni profiles in the Paα, Paβ, and Paγ lines were reported.

3.1. *Cold Ice and Gas*

An analysis of the H_2O and CO ices was presented by Rettig et al. (2005) using the 2004 March SpeX data by Vacca et al. (2004) and the 2004 February NIRSPEC spectra. The ice absorption features were fit to laboratory spectra and found to be consistent

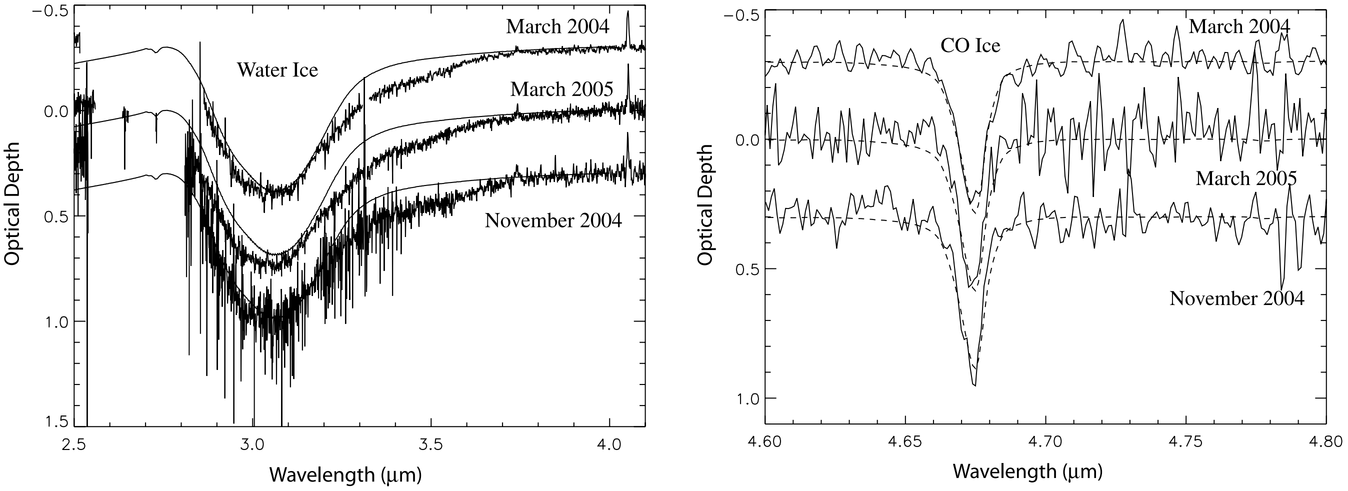

FIG. 3.—SpeX LXD spectra of (*a*) water ice and (*b*) CO ice in V1647 Ori from 2004 March, 2004 November, and 2005 March with laboratory spectra from Rettig et al. (2005) overplotted. Note that the excess absorption in the wing of the water band is a common feature and is likely due to contributions from the C-H stretch mode of absorbing molecules such as CH_4 or CH_3OH and possibly scattering effects.

with cold (~20 K) amorphous ice. The CO ice was primarily apolar (CO mixed with a nonpolar species like CO_2 or O_2) rather than polar (mixed with H_2O). Figure 3 shows the optical depth profiles of water and CO ice on three nights with the laboratory spectrum from Rettig et al. (2005) overplotted. As can be seen, the 2004 November and 2005 March ice profiles (relative to 2004 March) are unchanged at the level of the observational errors. This is also apparent when comparing the CO ice profile from NIRSPEC data in 2004 February and July (Fig. 2). The narrow, cold (~18 K) CO gas absorption lines and cold ice, coupled with the Doppler-shifted gas absorption (~6 km s^{-1} relative to V1647 Ori), are consistent with the claim (Rettig et al. 2005) that the cold ice and gas are due to intervening interstellar material that is not directly associated with V1647 Ori.

3.2. *Hot* CO *Emission*

The CO emission can be divided into two regions: a hot (~2500 K) inner disk traced by the high-*J* lines and a warm (~400 K) inner disk traced by the low-*J* lines (Rettig et al. 2005). The hot emission provides an excellent probe for measuring the physical and structural changes due to, for example, rapid replenishment of material in the inner disk. Due to the small Doppler shift (~5 km s^{-1}) on 2004 July 31, potential changes to the low-*J* CO emission profiles could not be determined. However, the high-*J* lines and the ^{12}CO 2−1 lines were less affected by telluric features and could be analyzed. An excitation plot of the high-*J* lines (see Fig. 4) reveals an inner disk temperature of 1700 ± 100 K, lower than was determined in 2004 February (~2500 K). Also, the half-width at zero intensity (HWZI) of the P30 line has dropped by ~20 km s^{-1}, consistent with the derived lower temperature. However, the signal-to-noise ratio (S/N) is insufficient to determine whether the narrowing of P30 is significant. The implication is that the hot inner disk does not extend inward as far as it did during the outburst. Future observations will be required to determine if physical characteristics of replenishment of the inner disk can be measured with high-resolution spectral observations of hot gas in the inner disk.

3.3. H I *Emission*

Key differences in the spectra become apparent when the 0.8–2.3 μm emission features are compared between 2004 March and November and 2005 March, most notably the Paschen lines of H I. Vacca et al. (2004) noted a significant P Cygni profile to the Paschen lines that indicated an outflow velocity of ~400 km s^{-1}. They found that the blueshifted component peaked near −300 km s^{-1} and extended to less than −500 km s^{-1}.

However, in 2004 November and 2005 March the blueshifted absorption was not present, and the 3 σ upper limit for the absorption equivalent width was a factor of ~3 less than in 2004 March. This is illustrated in Figure 5 (see also Table 2), which shows the velocity profile of the Paβ line in 2004 March (*dashed line*) and November (*solid line*) and 2005 March (*dotted line*). It can also be seen that the equivalent width of the emission component decreased by about 50% between 2004 March and November, although by 2005 March the equivalent width was back at the outburst level. The Paγ and Paδ lines exhibit a similar trend. A possible explanation for the dramatic decrease in these lines, particularly the blueshifted absorption, is that the wind decreased substantially during the 8 months between 2004 March and November.

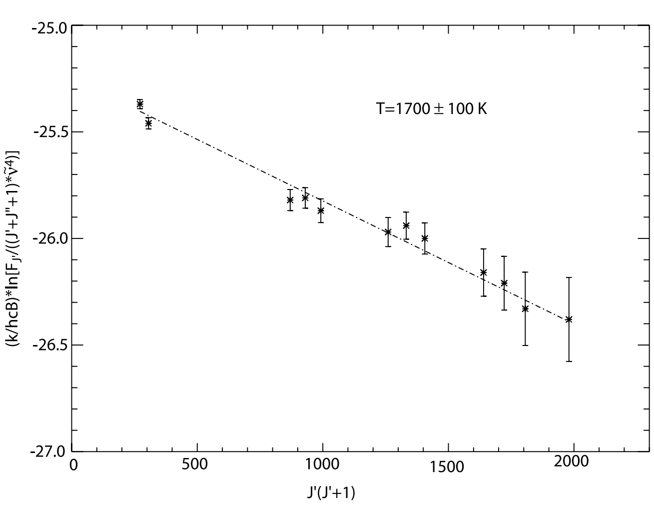

FIG. 4.—Excitation diagram of the ^{12}CO (1–0) emission lines observed on 2004 July 31. The fit to the high-*J* lines is linear and gives a rotation temperature of 1700 ± 100 K, somewhat lower than the ~2500 K derived from 2004 February observations.

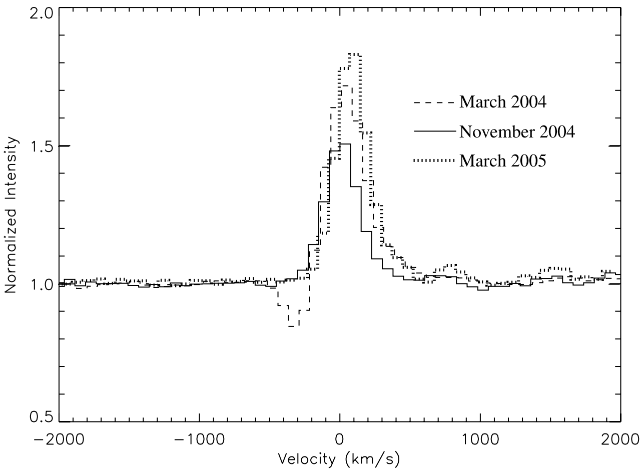

FIG. 5.—Velocity profile of the H I 5–3 (Paβ) line in 2004 March (*dashed line*) and November (*solid line*) and 2005 March (*dotted line*). Note the emission feature has decreased by about 50% between the 2004 March and November and increased in strength again relative to the continuum between 2004 November and 2005 March. The blueshifted absorption was no longer evident after 2004 March (the 3 σ upper limit has decreased by a factor of ~3).

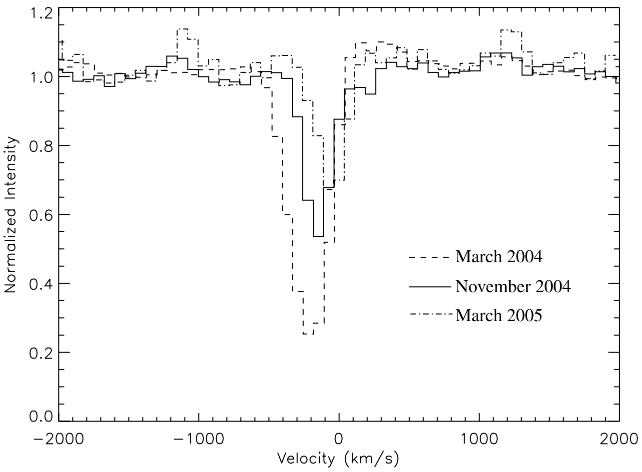

FIG. 6.—He I 1.0830 μm velocity line profile in 2004 November (*solid line*), 2004 March (*dashed line*), and 2005 March (*dot-dashed line*). The emission component and the higher velocity blueshifted components are not present in 2004 November or 2005 March.

The Brackett lines tell a different story. On the three nights of observations, they did not show blueshifted absorption, nor did their equivalent widths change significantly over the course of the observations. It has been noted that Brγ line luminosities of the classical T Tauri stars are well correlated with the disk accretion luminosities of those stars (Muzerolle et al. 1998) via the relation $\log(L_{\rm acc}/L_\odot) = (1.26 \pm 0.19)\log(L_{\rm Br}/L_\odot) + (4.43 \pm 0.79)$. If we assume that the same relation holds for V1647 Ori, we measure a Brγ line flux of $\sim 9 \times 10^{-17}$ W m^{-2} in 2004 November and 1.6×10^{-16} W m^{-2} in 2005 March. If we correct for 14 mag of visual extinction (Rettig et al. 2005; Briceño et al. 2004; Vacca et al. 2004) using the extinction correction method of Rieke & Lebofsky (1985) and Cardelli et al. (1989) with $R_v = 5$, the fluxes are $\sim 5 \times 10^{-16}$ and $\sim 9 \times 10^{-16}$ W m^{-2}, respectively. Assuming a distance of 400 pc to V1647 Ori, we infer accretion luminosities of 14 and 30 $L_\odot$ in 2004 November and 2005 March, respectively. Using the relation $\dot{M} = L_{\rm acc}R_{\rm acc}/GM_*$ and assuming a stellar mass of 0.5 $M_\odot$ and $R_{\rm acc} = 3\ R_\odot$, we derive disk accretion rates of $\sim 3 \times 10^{-6}\ M_\odot$ yr^{-1} in 2004 November and $\sim 6 \times 10^{-6}\ M_\odot$ yr^{-1} in 2005 March, in good agreement with the values cited earlier by Vacca et al. (2004) and the model presented by Muzerolle et al. (2005).

3.4. He I

Several changes are noted for the helium lines. The $2\ ^1S$–2^1P 2.058 μm line, which was observed as blueshifted absorption by Vacca et al. (2004), was not detected in 2004 November or 2005 March.

The He I $2s\ ^3S \rightarrow 2p\ ^3P$ absorption line at 1.0830 μm was present on all dates. The lower level of this transition is a metastable state that is primarily populated by recombination following photoionization by the extreme UV continuum. It has been observed toward six accreting T Tauri stars (Edwards et al. 2003), where it was found that the line usually penetrates to a depth of >50% into the continuum. In most T Tauri sources, the line is primarily observed in absorption and sometimes exhibits a P Cygni profile. Dupree et al. (2005) observed the He I 1.0830 μm absorption line toward classical T Tauri stars TW Hya and T Tau. Both objects exhibit a strong P Cygni profile and the spectra are interpreted to indicate the presence of hot winds. However, for weak T Tauri star V827 Tau the line was absent (Edwards et al. 2003), implying that disk accretion is connected to the presence of He I 1.0830 μm absorption. Edwards et al. (2003) interpreted the He I line profiles to be due to the geometry of the inner wind, where high-velocity outflowing gas is produced. In this scenario, the redshifted emission component may be occulted by the star and accretion disk, leaving a predominantly blueshifted absorption in many sources.

These observations suggest that if the outbursting source V1647 Ori has a hot inner accretion disk with outflowing gas, the He I line should be observed with a strong blueshifted component. The lack of emission may be due to occultation by the star and accretion disk. In addition, we would expect the line to have been stronger during the outburst and weaken with time as the outflow decreases.

This is indeed what has been observed. The blue component of the He I 1.0830 μm absorption line decreased in equivalent width from 8.9 to 3.9 Å between 2004 March and November (see Fig. 6). In March, the blueshifted wing extended to greater than -500 km s^{-1}, whereas in November, the blueshifted absorption only extended to roughly -300 km s^{-1}. This velocity is greater than that associated with the blueshifted H I lines, which may be due to optically thick H I lines sampling slower moving outflowing gas farther from the star. The weak redward emission component (P Cygni profile) suggested by the 2004 March data was not evident in 2004 November or 2005 March. This would seem to imply that the hot, high-velocity wind has slowed substantially since the outburst.

3.5. Ca II

On 2004 March 21 and April 17, Walter et al. (2004) observed the 0.8498, 0.8542, and 0.8662 μm Ca II emission lines. They reported a ~2 : 2 : 1 line ratio for the triplet, similar to the pattern often seen in T Tauri and Herbig Ae/Be stars (Hamann & Persson 1992a, 1992b). In 2004 November, the Ca II lines (see Fig. 1*a*) had approximately the same equivalent widths (to within 15%), giving a ratio of ~1 : 1 : 1, in agreement with Vacca et al. (2004). The 2005 March data are also consistent with a ~1 : 1 : 1 ratio. The reason for this variability is unclear.

4. CONCLUSION

Arguments have been put forth that V1647 Ori is an FU Orionis–type object (FUor), typified by a brightening of up to 5 mag and a slow decline over a period of 5–10 decades (Hartmann & Kenyon 1996). Ábrahám et al. (2004) claimed that the SED resembled those of other FUors, and Briceño et al. (2004) suggested that spectroscopic characteristics and luminosity indicated an FU Ori event. Reipurth & Aspin (2004), on the other hand, argued that the MNO resembles an EXor, characterized by repeated outbursts with shorter durations. Recent photometry by (Kóspál et al. 2005) indicate a decay time of about two years, much shorter than the decay timescales for FUors but somewhat longer than that for EXors.

Given the low number of outbursting objects studied to date, it is difficult to classify V1647 Ori. However, spectroscopic similarities and differences between V1647 Ori and these classes of outbursting young stars can be compared. In particular, it is interesting to note that the FUors studied to date exhibit deep, broad, gas-phase water absorption at 1.4 and 1.9 μm (Mould et al. 1978; Sato et al. 1992), in addition to strong absorption of the CO overtone bandheads near 2.3 μm (Hartmann & Kenyon 1996 and references therein). V1647 Ori, on the other hand, shows no clear evidence of water absorption in the near-infrared (except the 3 μm water ice feature, which is thought to originate in an intervening cloud), and the CO overtone bandheads are in emission. This, coupled with the rapid decline, may indicate that V1647 Ori is not an FUor. However, neither does V1647 Ori fit well with the class of EXors. In particular, the significant variations at maximum that are usually observed toward EXors were not observed in V1647 Ori (Walter et al. 2004). It may be that the classes of outbursting young stars and their spectral characteristics need to be revisited. In particular, further studies of spectral characteristics of outbursting young objects are needed.

We have presented similarities and differences in the infrared (0.8–5 μm) spectra of V1647 Ori between 2004 March, 2004 November, and 2005 March, during and postoutburst, respectively. Drastic changes of the Paschen lines of hydrogen and the absorption lines of He I were noted. In particular, the postoutburst line fluxes and profiles suggest that the outflow has decreased substantially in velocity and magnitude. The highly blueshifted component of the He I lines has disappeared, indicating that the velocity of the outflow decreased by $\sim$100 km s^{-1} in the 8–12 months separating the outburst and postoutburst observations.

The CO emission originating in the hot inner disk decreased in temperature from $\sim$2500 K in 2004 February to $\sim$1700 K in 2004 July. The implication is that the hot inner disk does not extend inward as far as it did during the outburst. This is also consistent with the noted decrease in the HWZI of the P30 line. Further observations are needed to address the issue of replenishment of the inner disk after an outburst event.

For the timescale of these changes, at most we can surmise that the variations observed in the hydrogen and helium lines occur within the first few months after the outburst. Also, higher S/N observations of the CO emission lines are needed to determine the extent to which the temperature and distribution of gas in the inner disk changes prior to, during, and after outbursts. Clearly, outbursting objects need to be monitored consistently on timescales of days to weeks at all wavelengths from the time of the outburst.

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REFERENCES

Ábrahám, P., Kóspál, Á., Csizmada, Sz., Moór, A., Kun, M., & Stringfellow, G. 2004, A&A, 419, L39

Andrews, S. M., Rothberg, B., & Simon, T. 2004, ApJ, 610, L45

Briceño, C., et al. 2004, ApJ, 606, L123

Brittain, S. D., Rettig, T. W., Simon, T., Kulesa, C., DiSanti, M. A., & Dello Russo, N. 2003, ApJ, 588, 535

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Cushing, M. C., Vacca, W. D., & Rayner, J. T. 2004, PASP, 116, 362

Dupree, A. K., Brickhouse, N. S., Smith, G. H., & Strader, J. 2005, ApJ, 625, L131

Edwards, S., Fischer, W., Kwan, J., Hillenbrand, L., & Dupree, A. K. 2003, ApJ, 599, L41

Hamann, F., & Persson, S. E. 1992a, ApJS, 82, 247

———. 1992b, ApJS, 82, 285

Hartmann, L., & Kenyon, S. J. 1996, ARA&A, 34, 207

Kóspál, Á., Ábrahám, P., Acosta-Pulido, J., Csizmadia, S., Eredics, M., Kun, M., & Rácz, M. 2005, Inf. Bull. Variable Stars, 5661, 1

Mallas, J. H., & Kreimer, E. 1978, The Messier Album (Cambridge: Sky)

McLean, I. S., et al. 1998, Proc. SPIE, 3354, 566

McNeil, J. W., Reipurth, B., & Meech, K. 2004, IAU Circ. 8284

Mould, J. R., Hall, D. N. B., Ridgway, S. T., & Hintzen, P. 1978, ApJ, 222, L123

Muzerolle, J., Hartmann, L., & Calvet, N. 1998, AJ, 116, 2965

Muzerolle, J., Megeath, S. T., Flaherty, K. M., Gordon, K. D., Rieke, G. H., Young, E. T., & Lada, C. J. 2005, ApJ, 620, L107

Rayner, J. T., Toomey, D. W., Onaka, P. M., Denault, A. J., Stahlberger, W. E., Vacca, W. D., Cushing, M. C., & Wang, S. 2003, PASP, 115, 362

Reipurth, B., & Aspin, C. 2004, ApJ, 606, 119L

Rettig, T. W., Brittain, S. D., Gibb, E. L., Simon, T., & Kulesa, C. 2005, ApJ, 626, 245

Rieke, G. H., & Lebofsky, J. J. 1985, ApJ, 288, 618

Sato, S., Okita, K., Yamashita, T., Mizutani, K., Shiba, H., Kobayashi, Y., & Takami, H. 1992, ApJ, 398, 273

Vacca, W. D., Cushing, M. C., & Rayner, J. T. 2003, PASP, 115, 389

Vacca, W. D., Cushing, M. C., & Simon, T. 2004, ApJ, 609, 29L

Walter, F. M., Stringfellow, G. S., Sherry, W. H., & Field-Pollatou, A. 2004, AJ, 128, 1872