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AN OPTICAL/INFRARED OUTBURST IN THE EXCITING SOURCE OF HH 7–11

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ABSTRACT

We report on an outburst of SVS 13—the exciting source of Herbig-Haro objects 7–11. According to our CCD archives and recently obtained CCD images, the brightness at 6740 Å of this source increased by around 2.5 mag sometime between 1988 December and 1990 September. Since then, the source has been constantly brightening by 0.06 mag per month. A similar outburst was observed in *V*, *R*, and *I*, although the amplitudes decrease with increasing wavelength throughout the infrared from $\Delta H \sim 1.9$ mag to $\Delta N \sim 0.35$ mag. In our optical spectra, taken in 1989 November and 1990 November, we find emission lines typical of a strong-emission T Tauri or Herbig-Ae star. Infrared spectra around 2.3 μm obtained in 1986 October and 1990 December show no changes in the equivalent widths of the CO emission band heads $v = 2–0$ and $v = 3–1$. We conclude that this outburst, as far as we can ascertain, is similar to those observed in some T Tauri stars (e.g., EX Lupi), but—at least thus far—is definitely not of the FU Orionis type.

Subject headings: stars: individual (SVS 13) — stars: pre–main-sequence

1. INTRODUCTION

The Herbig-Haro (HH) objects 7–11 are among the best-studied examples of their class (e.g., Strom et al. 1986; Solf & Böhm 1987). The outflowing and shock-heated gas which gives rise to HH 7–11 is most probably provided by the IR-source SVS 13 (Strom, Vrba, & Strom 1976), which has a luminosity of $\sim 66\ L_\odot$ (Cohen, Harvey, & Schwartz 1985). HH 7–11 are, however, not the only indications of a very energetic mass outflow from this source: in addition to HH emission, one observes shock-excited H_2 emission (e.g., Hartigan, Curiel, & Raymond 1989), high-velocity CO gas (e.g., Liseau, Sandell, & Knee 1988; Koo 1990), and high-velocity H I gas (Lizano et al. 1988).

Eislöffel, Mundt, & Ray (1989) have started a long-term project to study the proper motions of HH objects and HH jets with the help of deep CCD images. HH 7–11 is one of the objects in their program. On a CCD frame from 1990 September, we discovered a brightening of SVS 13 in the red wavelength region by ~ 2.5 mag relative to the frame from 1988 December. This brightening was also recognized by Mauron & Thouvenot (1991) when they compared their CCD frames from 1990 December with those of Strom et al. (1986). Such outbursts are very rare events among pre–main-sequence stars (e.g., Herbig 1989) and probably result from instabilities in the surrounding accretion disk. In order to understand such a unique event, we initiated a campaign at several observatories to follow the outburst at optical/IR wavelengths with the help of photometric and spectroscopic observations. In this *Letter*, we report on the main results of this campaign.

2. OBSERVATIONS

The optical CCD photometry has been mainly carried out at the 3.5 m telescope at Calar Alto (Spain) using an RCA 15 μm CCD chip. Additional CCD frames were taken during 1991 at the ESO/MPI 2.2 m telescope on January 13–18, the ESO-NTT 3.5 m telescope on February 9 and the Calar Alto 1.23 m telescope on July 10. In addition to the data obtained after 1990 September, we found several CCD frames in our archives taken through a [S II], Hα, and/or *I* filter and dating from 1983 January, 1986 December, and 1988 December. The narrow band [S II] and Hα filters have typical bandwidths (FWHM) between 70 and 100 Å. As discussed below, the [S II] images provide essentially continuum fluxes of SVS 13 at the central wavelength of the [S II] filter (≈ 6740 Å).

Infrared photometry was obtained at both the Palomar 5 m telescope (on 1991 January 1) and the ESO 1 m telescope on La Silla, Chile (on 1991 January 28). SVS 13 was observed in the *J*, *H*, *K*, *L*, and *M* bands at both telescopes and additionally in the *N* band at the 5 m telescope. Within the usual errors, the same results were obtained at both telescopes.

The first of our two optical CCD spectra was obtained on 1989 November 6 using the Faint Object Spectrograph on the University of Hawaii 88 inch (2.2 m) telescope. The 600 l mm^{-1} grating in combination with a 4."7 slit gave an effective spectral resolution of ~ 10 Å. The spectrum covers the region between 6400 and 8800 Å. The second optical CCD spectrum, which is of much higher spectral resolution, is a long-slit spectrogram and was obtained on 1990 November 19 using the Cassegrain Twin Spectrograph of the Calar Alto 3.5 m telescope. The 830 l mm^{-1} grating was used in second order, providing a dispersion of 26 Å mm^{-1}. The effective resolution with a 2" slit was ≈ 0.7 Å (or ≈ 35 km s^{-1}). The 2$^{\rm h}$ spectrum covers the region between 6400 and 6800 Å.

Infrared spectra around the $v = 2–0$ and 3–1 bands at 2.3 μm were obtained on 1990 December 17 on the NASA Infrared Telescope Facility using CGAS, a cooled grating spectrograph with a 32 element linear array as a detector. The resolving power of these observations is ~ 1200 with an aperture size of 2ʺ7. The spectrum was corrected for atmospheric extinction and calibrated by dividing it by a spectrum of the hot star HR 1165.

3. RESULTS

3.1. *Photometry*

Two [S II] images of the HH 7–11 region taken in 1986 December and 1990 November are shown in Figure 1 (Plate L1). They demonstrate that SVS 13 underwent a major outburst during this period. Most CCD frames in our archive are [S II] and Hα narrow-band images that we have taken in the course of a project to measure proper motions of knots in jets and HH objects (Eislöffel, Mundt, & Ray 1989). These archival data, together with data obtained after we discovered the outburst in 1990 September, allow us to describe this event in more detail.

Differential photometry against field stars obtained from these narrow-band frames is shown in Figure 2*a*. The major outburst of SVS 13 (around 2.5 mag) occurred between 1988 December and 1990 September. However, between 1986 December and 1988 December there was already a rise of ~ 0.2 mag. Since the photometric data are sparse, it is not clear whether this is just the beginning of the major outburst or a slight variability of SVS 13 (see, e.g., variations in K before the outburst as shown in Fig. 2). From 1990 September, when we detected the outburst, until 1991 July, the last observation of our monitoring program so far, SVS 13 showed a further increase by 0.6 mag, which is also indicated in the broad-band data described below.

We note that the photometric variations in the [S II] and Hα frames are not due to a change of the emission-line strengths but of the continuum itself: the equivalent widths W_λ in our spectra described below and in the one by Goodrich (1986) are too small to explain the observed changes in brightness. We find W_λ([S II]) to contribute always less than 5% of the total observed flux in our [S II] filter. The Hα line, while contributing $\sim 30\%$ to the total flux in the Hα filter, shows changes of its equivalent width which introduce a scatter of only 0.1 mag or less in our differential photometry.

TABLE 1

BVRI PHOTOMETRY OF SVS 13

Date	B	V	R	I	Reference
1983 Oct or 1984 Jan	...	...	...	19.0	1
1984 Oct 21	...	23.8:	20.3:	...	2
1990 Nov 14	22.92	20.50	...	16.05	...
1990 Dec 19	...	...	18.0	15.4	3
1991 Jan 17	22.84	20.22	18.12	16.03	...
1991 Feb 9	...	...	...	15.94	...
1991 Jul 10	...	...	...	15.74	...

REFERENCES.—(1) Visual estimate from I image in Strom et al. 1986; (2) Goodrich, 1986; (3) Mauron & Thouvenot, 1991.

A summary of the *BVRI* photometry available for SVS 13 is given in Table 1. The outburst behavior described above for the [S II] and Hα differential photometry is generally also seen in the broad-band data, although these data are much more sparse and of poorer photometric quality. The approximate outburst amplitudes in these colors were $\Delta V \sim 3.3$ mag, $\Delta R \sim 2.2$ mag and $\Delta I \sim 2.9$ mag between 1984 (Goodrich 1986; Strom et al. 1986) and 1990 November. In order to support relative photometry from future frames or, possibly, frames available in other archives, we have carried out *BVRI* photometry for field stars near SVS 13 (see Fig. 3 [Pl. L2] and accompanying Table).

Photometry at K (Fig. 2*b*), where most of our IR data are available, shows that the IR flux of SVS 13 also increased during the outburst, but only with an amplitude of $\Delta K \sim 1.2$ mag, i.e., much smaller than in the optical. The data apparently indicate a slight variability of up to 0.5 mag already during the decade before the outburst, as mentioned above. In Figure 4, two spectral energy distributions (SED) constructed from broad-band photometry are shown: the dashed line delineates a "mean" pre-outburst SED about a decade before the outburst, which we have put together from various sources in the literature, while the continuous line delineates the SED as of 1991 January. For convenience, the *IRAS* fluxes are also shown. We measured an increase of ~ 3 mag in the optical, as already mentioned, and of $\Delta J \sim 2.5$ mag, $\Delta H \sim 1.9$ mag,

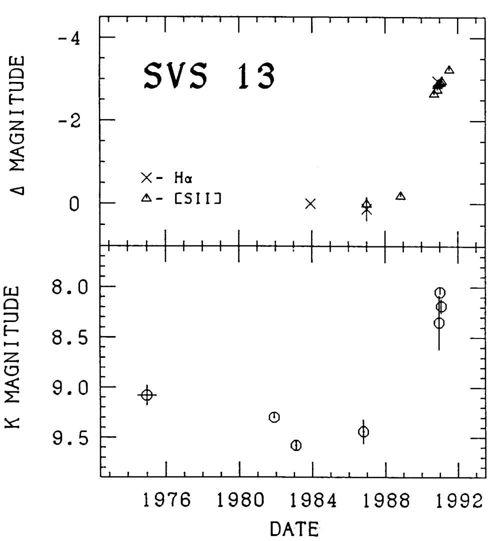

FIG. 2.—Optical photometry of SVS 13 in [S II] and Hα narrow-band filters and infrared photometry at K.

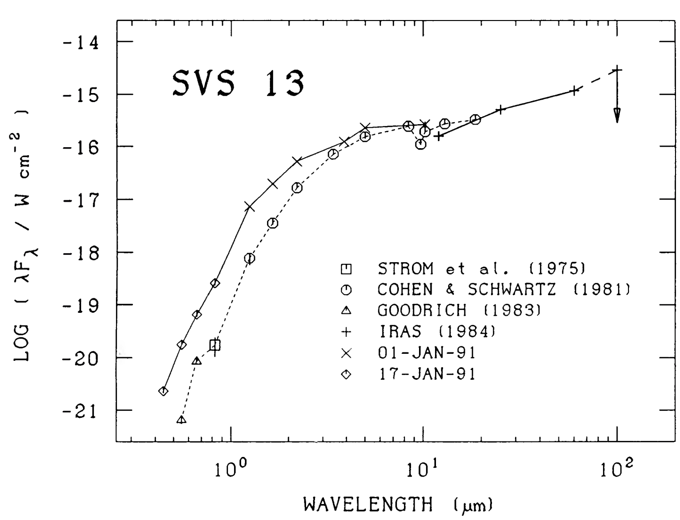

FIG. 4.—Spectral energy distributions of SVS 13 before and during the outburst.

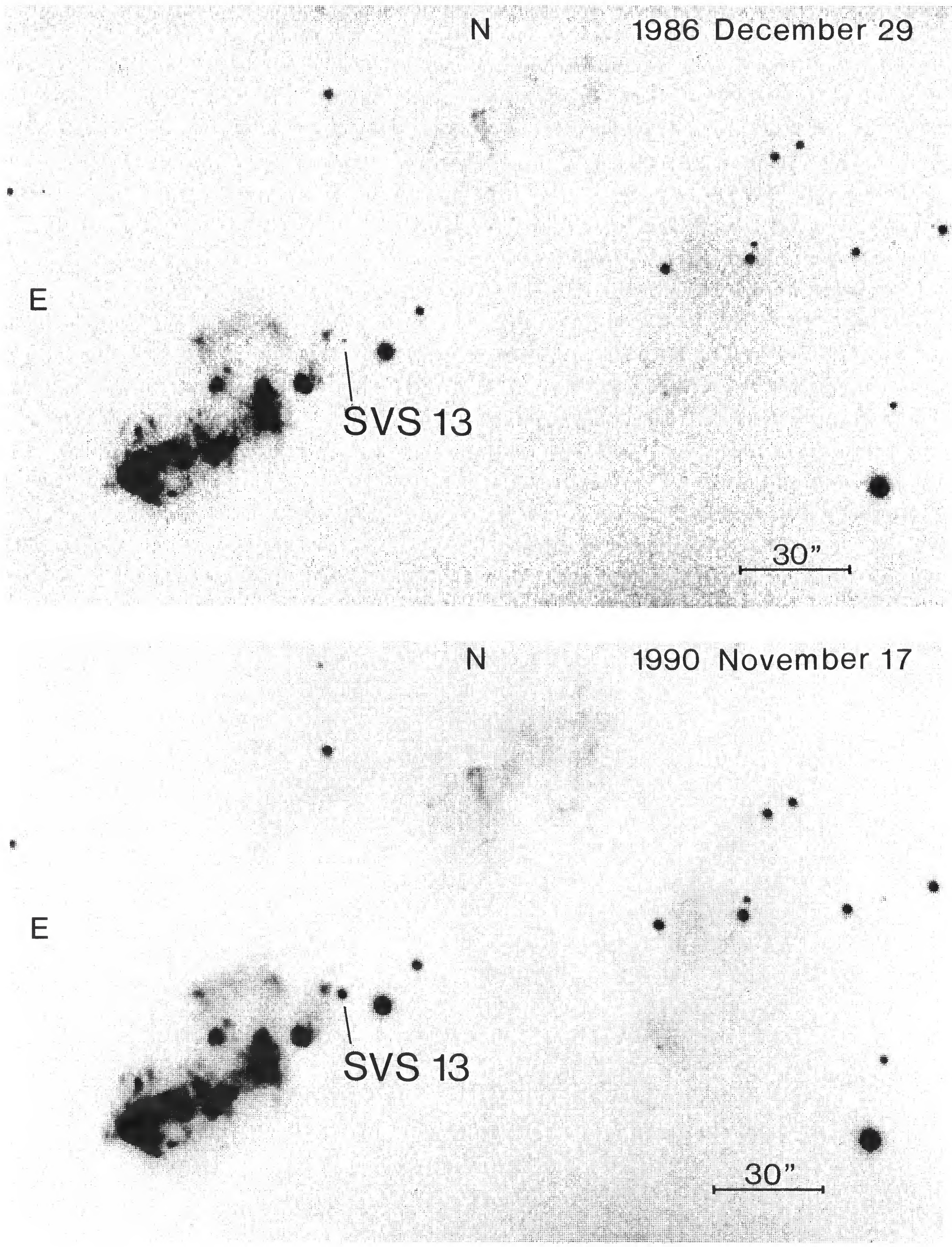

FIG. 1.—[S II] frames of the HH 7–11 region showing SVS 13 on 1986 December 29 before the outburst and on 1990 November 17 during the outburst phase

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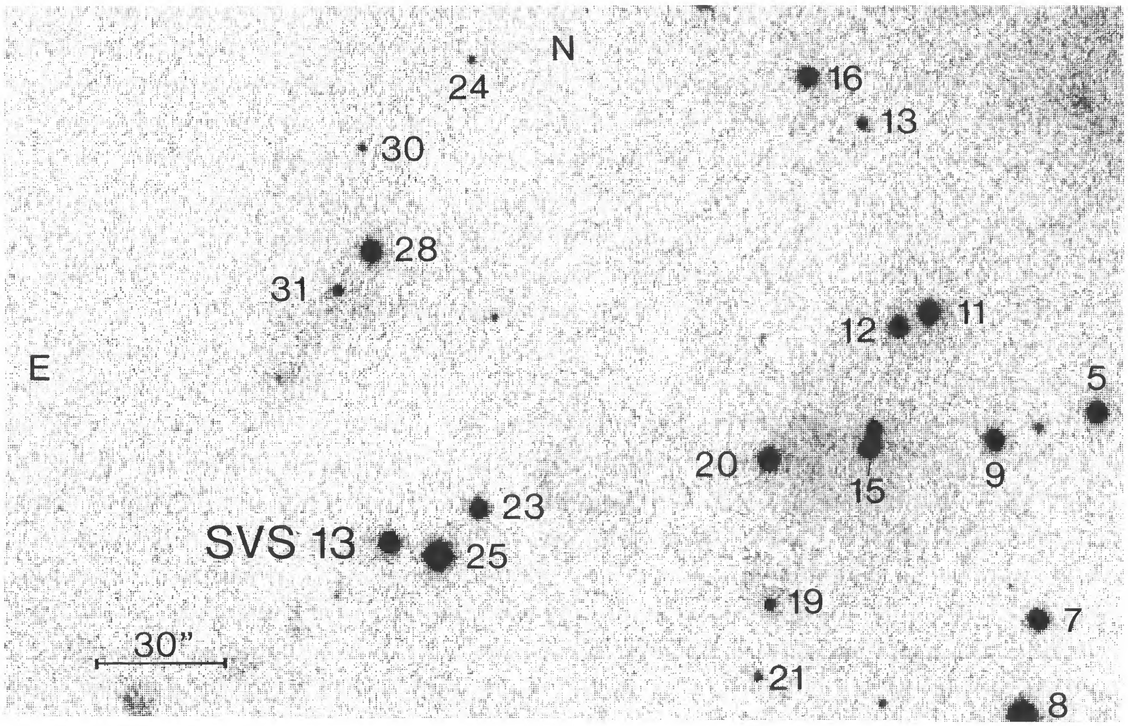

TABLE 2

PHOTOMETRY OF STARS IN THE FIELD OF SVS 13

STAR	B	V	R	I
5	21.01	19.09		15.66 ± 0.05
7	23.36	20.31		16.05 ± 0.16
8	17.24	15.74		14.23 ± 0.24
9	21.48	19.44		15.90 ± 0.07
11	22.29	19.87		15.88 ± 0.05
12	22.83	20.05		16.13 ± 0.15
13				19.13 ± 0.17
15	20.88	18.99		15.71 ± 0.07
16	22.42	20.42		16.37 ± 0.01
19				18.30 ± 0.40
20	23.92	19.86		15.65 ± 0.13
21				19.40 ± 0.40
23	20.79 ± 0.17	18.89	18.00	16.26 ± 0.08
24				20.81
25	17.92 ± 0.00	16.29	15.60	14.31 ± 0.16
28	20.86 ± 0.17	19.14	17.64	15.66 ± 0.02
30				19.70 ± 1.10
31				18.97 ± 0.20

FIG. 3.—I frame of the HH 7–11 region taken on 1990 November 14. The field stars for which we obtained *BVRI* photometry are labeled, and the photometric data are listed Table 2, above. The field star numbers have been adopted from Strom et al. (1986). Stars having entries for which an error is given have been measured at two to four epochs, ~1 month apart. One should be aware that many stars in this field could be young objects showing considerable intrinsic variability.

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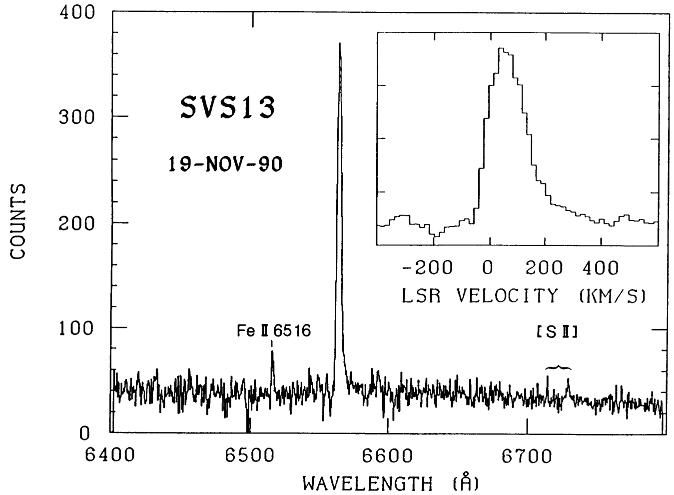

FIG. 5.—High-resolution spectrum of SVS 13 taken in 1990 November. The inserted box shows the Hα line profile.

$\Delta K \sim 1.2$ mag, $\Delta L \sim 0.7$ mag, $\Delta M \sim 0.4$ mag, and $\Delta N \sim 0.35$ mag in the near-infrared. This demonstrates that the outburst amplitude was largest in the optical and decreased continually with increasing wavelength, i.e., SVS 13 became considerably bluer in the outburst phase. The luminosity between 0.45 and 10 μm increased from 7.5 to 10 $L_\odot$.

3.2. *Spectroscopy*

Our high-resolution optical spectrum of SVS 13 taken in 1990 November is shown in Figure 5. Hα, Fe II(40) λ6516 and [S II] $\lambda\lambda$6716, 6730 are in emission, while Fe II(74) λ6456 and Fe II(40) λ26432 are marginally indicated. Our low-resolution spectrum taken in 1989 November covers a region extending further into the red. In addition to the Hα, and [S II] $\lambda\lambda$6716, 6730 lines, [Fe II](14F) λ7155, O I(4) λ8446, and the infrared Ca II triplet around 8500 Å can be seen. In comparison with our spectra, that taken in 1984 October by Goodrich (1986) shows prominent Hα, [S II] $\lambda\lambda$6716, 6730 and [Fe II](14F) λ7155 as well as [O I] $\lambda\lambda$6300, 6363 lines (outside the region covered by our spectra).

Our high-resolution spectrum is of low S/N, but apparently shows a P Cyg profile at Hα (see box inserted in Fig. 5). Such a profile would explain why the emission component is redshifted by $+47$ km s^{-1} and why it clearly shows a steeper gradient along its blue wing compared to its red wing which is much broader and reaches out to about $+300$ km s^{-1}. On the blue side of the emission component, an absorption component at about -200 km s^{-1} may be present. Comparing the equivalent widths W_λ(Hα) of the emission components in our two spectra with that obtained by Goodrich (1986), we find that W_λ(Hα) was identical within the measurement errors on 1984 October and 1989 November [W_λ(Hα) $\sim$ 50 Å], while it decreased somewhat to W_λ(Hα) = 30 Å on 1990 November. At the same time, the [S II] lines seem to have weakened from W_λ([S II]) $\sim$ 5–10 Å to W_λ([S II]) $\sim$ 3 Å, although these values are affected by our poor S/N, particularly in our 1990 November spectrum. The [Fe II](14F) λ7155 line exhibits a much more marked decrease from W_λ([Fe II]) $\sim$ 35 Å in 1984 October (Goodrich 1986) to W_λ([Fe II]) = 7 Å in 1989 November. For the O I(4) λ8446 line and the near-infrared Ca II triplet lines we find within a factor of 2 similar equivalent widths as in the strong-emission T Tauri stars AS 353A and T Tau (Eislöffel, Solf, & Böhm 1990).

An IR spectrum taken in 1990 December is shown in Figure 6, together with one taken in 1986 October (Carr 1989). They cover the range from 2.28 to 2.34 μm and show the CO band heads $v = 2$–0 and $v = 3$–1 in emission in both cases. Between the two observations, the continuum flux as well as the flux in the band heads increased by a factor of $\sim$2.7, leaving the equivalent widths of the band-head emission constant. This continuum flux increase is in good agreement with the rise seen in K.

4. DISCUSSION

According to the data described above, SVS 13 increased in brightness by $\sim$3 mag in the optical and has remained in this high state for at least 10 months. Outbursts of such magnitude and duration among young stellar objects (YSOs) are very rare (see, e.g., Herbig 1989). Herbig (1989) divided YSOs with strong outbursts similar to SVS 13 into two classes, namely the FU Orionis stars (FUORs) and the EXORs (named after EX Lupi, which is the first T Tauri star for which such a major outburst was recognized). The FUORs show typical optical brightness increases of 4–5 mag within 100–1000 days and their high states last at least several decades. Furthermore, they have very characteristic spectroscopic properties (e.g., absorption spectra resembling F- or G-type supergiants, weak Hα emission with very deep and broad blueshifted absorption; e.g., Bastian & Mundt 1985). Although the EXORs show outbursts of similar magnitude as the FUORs, they normally remain at maximum for only a few hundred days and, more important, during maximum their spectra are still dominated by T Tauri–like emission lines.

At least until 1990 December 17, when the IR spectrum shown in Figure 6 was taken, SVS 13 showed no signs of being a FUOR since all optical and IR spectra taken up to that time were characteristic of either a classical T Tauri star or a Herbig-Ae star. The strong Hα emission of SVS 13 [W_λ(Hα) of 30–50 Å compared to $\sim$1 Å in FUORs (see Table 2 in Mundt et al. 1985)], the presence of Fe II λ6516 emission, the strength of the infrared Ca II triplet, and the presence of CO band-head

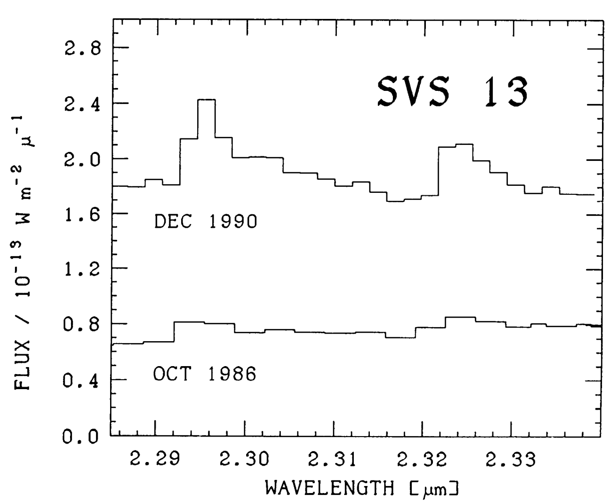

FIG. 6.—IR spectra of SVS 13 taken in 1986 October and 1990 December. The emission lines near 2.295 and 2.325 μm are the CO band heads $v = 2$–0 and $v = 3$–1, respectively.

emission are rather typical of strong emission-line YSOs and are not at all typical of FUORs. Note that the CO band heads are either in absorption or undetectable in all of the FUORs in which these features have been sought (e.g., Mould et al. 1978; Carr, Harvey, & Lester 1987; Carr 1989). Thus, the recent outburst of SVS 13 appears, at least up to the present, to be of the EXOR type, although it cannot be excluded that SVS 13 might develop into a FUOR in the near future.

SVS 13 is the first YSO for which optical and IR fluxes before and after such an outburst are available. These data may provide some clues to the nature of the outburst. One conceivable reason could be a decrease in circumstellar extinction A_V(circ), since a variable A_V(circ) has been considered as the cause of variability in some YSOs (e.g., Gahm 1988). However, the observed variations cannot be explained by a variable A_V(circ) if the circumstellar dust has properties similar to that in the interstellar medium: in that case, 2–3 times smaller variations should be observed for $\lambda \geq 2$ μm. Furthermore, the decreases in equivalent widths of the forbidden lines probably result from an increase in the continuum flux and not from a change in the line flux since the latter are expected to react relatively slowly to the outburst if they are formed far from the star (≈ 100 AU). A more plausible explanation for the outburst and the resulting change of the SED is therefore a physical change in the circumstellar accretion disk. Since the strongest flux increase (by ~ 3 mag) occurred between 0.5 and 1 μm, variations in the disk properties (e.g., in optical thickness) in a temperature regime of ~ 3000–5000 K (i.e., in the innermost part of the disk) could easily explain the optical part of the outburst (see, e.g. Hessman 1991).

There is considerable observational evidence which suggests that outflows from YSOs are variable or even intermittent phenomena (e.g., Mundt, Brugel, & Bührke 1987; Reipurth 1989). Therefore, it is particularly interesting that such a well-studied outflow source like SVS 13 has such a strong outburst. In order to understand these variations, it is very important that the wind properties of SVS 13 close to the source are monitored for the next few decades.

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