

3–12.5  $\mu\text{m}$  SPECTROSCOPY OF V705 CASSIOPEIAE (NOVA CASSIOPEIAE 1993)DAVID K. LYNCH,<sup>1</sup> RAY W. RUSSELL,<sup>1</sup> ROBERT C. KELLOGG,<sup>1</sup> AND ANN. L. MAZUKSpace and Environment Technology Center, The Aerospace Corporation-M2/266, P.O. Box 92957, Los Angeles, California 90009  
Electronic mail: david.lynnch@aero.org

MARTHA S. HANNER

Jet Propulsion Laboratory, Pasadena, California 91109  
Electronic mail: msh@scn2.jpl.nasa.gov

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## ABSTRACT

Infrared spectroscopy of the moderately fast nova V705 Cassiopeiae (Nova Cassiopeiae 1993) between 3 and 13  $\mu\text{m}$  approximately 367 days after visual maximum revealed a strong infrared excess dominated by two thermal-like continua and three emission features at  $3.38 \pm 0.05$ ,  $4.6 \pm 0.05$ , and  $11.27 \pm 0.07$   $\mu\text{m}$ . Their full width at one half maximum above the local continuum were 0.22, 0.30, and 0.36  $\mu\text{m}$ , respectively. No emission from the central star was detected. We tentatively identify the 4.6  $\mu\text{m}$  feature as being the fundamental vibrational lines of CO. The 3.4  $\mu\text{m}$  feature is almost certainly due to the C–H stretching mode in organic molecules, while the 11.3  $\mu\text{m}$  is still somewhat of a mystery, although SiC cannot be ruled out. From our analysis we find that the absolute visual magnitude at maximum  $M_v(\text{max})$  was near  $-7$ , the extinction was about 2.8 mag, and the distance was  $1250 \pm 290$  pc. © 1997 American Astronomical Society. [S0004-6256(97)02104-3]

## 1. INTRODUCTION

Nova Cassiopeiae 1993 was discovered by Kanatsu on 1993 December 7 (Kanatsu 1993) at  $\alpha = 23^{\text{h}} 39^{\text{m}} 22.3^{\text{s}}$ ,  $\delta = +57^{\circ} 14' 22.55''$  (1950) ( $l^{\text{II}} = 113.66$ ,  $b^{\text{II}} = -4.10$ ). Figure 1 shows the light curve based upon visual magnitude estimates compiled by the AAVSO (Mattei 1996). We adopted 1993 December 13.0 UT as the time of maximum brightness and the definition of day 0 in this light curve as well as on compiled by Granslo *et al.* (1996). The nova reached maximum brightness  $m_v \approx +6.0$  on about December 18 and underwent a classical visual decline very similar to that of NG Vulpeculae (Ney & Hatfield 1978). On about day +60 the visual brightness began dropping rapidly and by day 68 had decreased by more than five magnitudes. At the same time the IR brightness had begun to soar, a sure sign of dust formation (Shore *et al.* 1994). From its visible light curve, Nova Cass 1993 appeared to have been normal and unremarkable. In the infrared, however, it shows a number of interesting spectral features. In this paper we report thermal IR spectroscopy of Nova Cassiopeiae 1993 and discuss the spectral features observed in terms of dust composition and discuss the nova's optical color and brightness in terms of its distance and reddening.

<sup>1</sup>Visiting Astronomer, Infrared Telescope Facility, operated by the University of Hawaii under contract from the National Aeronautics and Space Administration.

## 2. OBSERVATIONS AND DATA REDUCTION

Nova Cassiopeiae 1993 was observed on 1994 December 14.3 UT (367 days after maximum) with the Aerospace spectrograph (Hackwell *et al.* 1990) on the 3 m Infrared Telescope Facility (IRTF) using a 3 arcsec aperture and a 18 arcsec N-S chop. The spectral coverage was 3–14  $\mu\text{m}$  with a resolution of about 0.1  $\mu\text{m}$ . Nineteen spectra were recorded over an air mass range from 1.40 to 1.84, each with a 200 s integration time. The intermediate calibration stars  $\beta$  Peg,  $\alpha$  Tau were ultimately tied to  $\alpha$  CMa whose brightness we adopted as  $m = -1.40$  at all wavelengths. Atmospheric extinction corrections were made in the usual manner.

## 3. THE SPECTRUM

Figure 2 shows the spectrum of the nova taken on 1994 December 14 (day +367). Error bars are  $\pm 1$  standard deviation of the mean based on the scatter in the individual spectra. The spectrum shows three emission features at  $3.38 \pm 0.05$ ,  $4.6 \pm 0.05$ , and  $11.27 \pm 0.07$   $\mu\text{m}$ . Their full width at one half maximum (FWHM) above the local continuum were 0.22, 0.30, and 0.36  $\mu\text{m}$ , respectively and were spectrally resolved (instrumental widths are about 0.11  $\mu\text{m}$  at these positions). The first feature is probably the C–H stretching mode in organic molecules at 3.38  $\mu\text{m}$  a well-known component of novae spectra. Gehrz *et al.* also reported the 3.38  $\mu\text{m}$  feature on days 368 and 418.

The 11.3  $\mu\text{m}$  feature was first reported by Gehrz *et al.* who detected it on 1994 November 15 (day +338), about

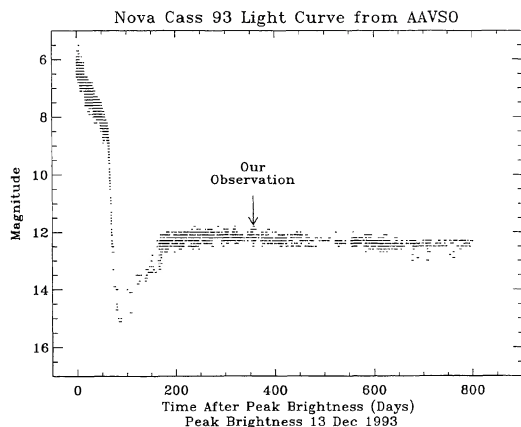


FIG. 1. Light curve of V705 Cassiopeiae (Nova Cassiopeiae 1993) compiled by the American Association of Variable Star Observers (Mattei 1996). We adopted the date of peak brightness as 1993 December 18.0 (JD 2449340). From these data we estimate  $t_2$  and  $t_3$  are 53 and 76 days, respectively.

270 days after the onset of dust formation. Our detection about a month later agrees with Gehrz *et al.*'s flux level although our spectral resolution is not as good. The origin of the feature is somewhat uncertain. It might be tempting to assign the nova's 3.38 and 11.3  $\mu\text{m}$  features to the unidentified infrared bands (Gillett *et al.* 1973). The two bands are often associated with the C-H stretch and C-H out-of-plane bending mode, respectively, of polycyclic aromatic hydrocarbon (PAH) molecules (Allamandola *et al.* 1989). PAHs would also be expected to show the in-plane bending mode near 8.6  $\mu\text{m}$ , and this feature is absent (also noted by Gehrz *et al.* 1995). Owing to the rapid equilibration of vibrational modes, it is hard to understand how the out-of-plane bending mode could be present without the in-plane bending. The identification of individual CO lines in the band by Scott *et al.* (1994) does not rule out the existence of a broad, underlying CO feature. Thus we are left with trying to identify the source of the 11.3  $\mu\text{m}$  feature.

The 11.3  $\mu\text{m}$  feature is suggestive of two other sources. (1) Silicon carbide SiC (Treffers & Cohen 1974; Goebel, *et al.* 1995), and (2) peridotite, dunite and olivine (Salisbury *et al.* 1991). The SiC feature seen in carbon rich environments such as IRC+10216 extends between 10.2 and 12.6  $\mu\text{m}$ , much broader than the one we observed. Even an optically thin cloud of SiC would produce a feature whose FWHM is approximately 0.5  $\mu\text{m}$  (Treffers & Cohen?). A review of carbon stars showing the 11  $\mu\text{m}$  feature (Goebel *et al.* 1995) shows that the feature is about 2  $\mu\text{m}$  wide in these sources. Laboratory spectra of SiC shows a minimum width of about 1  $\mu\text{m}$ . Therefore we do not believe that the 0.07  $\mu\text{m}$  feature we see is due to SiC.

The unusual shape and strength of the underlying continuum might suggest a siliceous origin. The 11.3  $\mu\text{m}$  feature coincides with a strong olivine feature but there is no hint of the accompanying 9.7  $\mu\text{m}$  olivine peak. Furthermore, olivine-like structures seen in comets (Bregman *et al.* 1988; Campins & Ryan 1989; Hanner *et al.* 1994) resemble two shoulders that define a trapezohedron-like shape rather than two distinct peaks. The presence of 3.4  $\mu\text{m}$  C-H feature

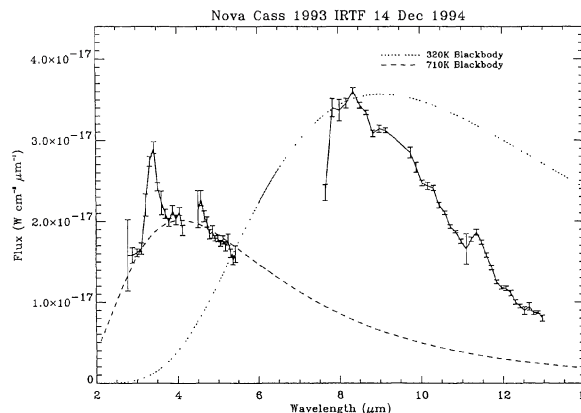


FIG. 2. Spectrum of V705 Cassiopeiae (Nova Cassiopeiae 1993) taken on 1994 December 14.2 (JD 2449701), approximately 367 days after maximum light. Gaps in the spectrum at 4.2 and 6–8  $\mu\text{m}$  are due to terrestrial  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , respectively. Spectral features at 3.4, 4.6, and 11.3  $\mu\text{m}$  are evident, as well as the absence of the 8.6  $\mu\text{m}$  feature. Gray body curves for  $T=320$  and 725 K are shown as a guide to the continuum levels. The infrared excess was quite large, thereby preventing reasonable continuum fits to the 8–12.5  $\mu\text{m}$  data.

would suggest a carbon-rich environments while a silicate feature would suggest an oxygen-rich (i.e., carbon poor) conditions so it is hard imagine how the two could exist simultaneously. We note, however, that spectra containing both carbon-rich and oxygen-rich features have been reported (Little-Marenin 1986; Willems & de Jong 1986). An alternative explanation is that the two features do not originate in the same molecule. Thus the 3.4  $\mu\text{m}$  feature could be the C-H stretch while the 11.3  $\mu\text{m}$  feature could be due to an as yet undetermined species.

The 4.6  $\mu\text{m}$  feature may be due to CO. There are a number of CO bands in this region including  $\nu=1-0R(1)$  at 4.65  $\mu\text{m}$ ,  $\nu=1-0R(0)$  at 4.66  $\mu\text{m}$ ,  $\nu=1-0P(1)$  at 4.67  $\mu\text{m}$ , and  $\nu=1-0P(2)$  at 4.68  $\mu\text{m}$ . There are also two hydrogen lines in the region, Pf  $\beta$  at 4.65  $\mu\text{m}$  and  $\text{H}_2 \nu=0-0S(9)$  at 4.69  $\mu\text{m}$ . Br  $\alpha$  at (4.05  $\mu\text{m}$ ), which is populated directly from above by Pf  $\beta$ , is absent from our spectrum as is Hu  $\alpha$  (12.4  $\mu\text{m}$ ). Thus we feel that hydrogen contributes little if any to the 4.6  $\mu\text{m}$  feature.

The width of the feature (0.30  $\mu\text{m}$ ) would seem to argue for the CO identification (Fig. 3). The overtone bands have been reported previous in novae at 1.6–2.2  $\mu\text{m}$  (Ferland *et al.* 1979) and in this nova by Scott *et al.* (1994). Measurements of the same CO bands in OMC-1 (Geballe & Garden 1987, 1990; Grasdalen *et al.* 1992) show a FWHM of about 0.5  $\mu\text{m}$ , considerably wider than the hydrogen lines. The CO fundamental bands have been reported in both absorption and emission in other astronomical sources. There have also been a number of previous suggestions as to the existence of the 4.6  $\mu\text{m}$  CO in novae shells (Ferland *et al.* 1979; Rawlings *et al.* 1986; Shenavrin *et al.* 1977) based on 5  $\mu\text{m}$  photometry (Gehrz & Hackwell 1988; Gallagher & Ney 1976; Geisel *et al.* 1970; Ney & Hatfield 1978). Merrill (1977) reported a band in NQ Vul that was very similar to the one we observed, although he was unable to identify it. Merrill's spectrum differed from ours in the sense that his showed



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