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UPPER LIMITS FOR CO IN THE OLD GALACTIC NOVAE NQ VULPECULAE, QU VULPECULAE, AND NOVA VULPECULAE 1987 FROM IRAM OBSERVATIONS

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ABSTRACT

We have observed three Galactic novae with the IRAM 30 m telescope at ^{12}CO $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$. We find no evidence for the previously reported emission in NQ Vul and derive strong upper limits for possible CO emission in QU Vul and Nova Vul 1987. There is no evidence for extensive cold molecular material surrounding old novae.

Subject headings: novae, cataclysmic variables — radio lines: molecular: circumstellar

1. INTRODUCTION

Several novae in the past 20 years have been observed to form copious amounts of dust in the early stages of outburst (Gehrz 1988; Bode & Evans 1989). The infrared observations have been made during the first few hundred days of the outburst. Optical light curves of a few classical novae, especially DQ Her, display deep postmaximum transitions that resemble R CrB variations and likely signal the appearance of dust (Gaposchkin 1957; Bode & Evans 1989). In the novae that have shown dust, the initial IR increase appears to roughly coincide with the transition to small optical depth in the ultraviolet (Starrfield & Snijders 1987). There are no reports of any direct detection of the molecular precursor expected to precede the dust condensation, although polycyclic aromatic hydrocarbon emission has been suggested in one nova, N Vul 1987 (Starrfield 1990; R. D. Gehrz 1991, private communication). The presence of such cold material in what are presumed to be optically thin ejecta illuminated by strong ultraviolet sources poses a serious constraint to theories of dust formation. The dust masses typically are a few percent of the total mass of the ejecta. Only a small subset of classical novae seem to show indications of dust formation during outburst so the detection of cold molecular material in the ejecta of those that have formed dust is important.

Albinson & Evans (1989, hereafter AE) have reported a millimeter detection of CO in the dust-forming nova NQ Vul (Nova Vul 1976). This nova was chosen, in part, because of the detection of thermal emission at 4.9 GHz by Bode, Seaquist, & Evans (1987). The ^{12}CO $J = 2 \rightarrow 1$ transition was observed with the 5 m MWO telescope, and AE show a single line with a FWHM ≈ 80 km s^{-1}, and with a peak antenna temperature of 63 ± 17 mK, centered at $+26$ km s^{-1}. Their emission profile, however, covers a substantial fraction of their total velocity bandpass (-180 to $+180$ km s^{-1}) and is quite weak. They do not have a corresponding observation at CO $J = 1 \rightarrow 0$, and they did not observe any other novae.

In their discussion, AE explain the probable mass yielded by their CO detection, greater than 10^{-5} $M_{\odot}$, as arising from cold material accumulated over the course of many individual eruptions of NQ Vul. The system is, however, not a historical recurrent so the time scale for the accumulation of this much mass, nearly the total mass of a single ejection, is quite long. AE estimate that at least 10^4 eruptions are required, taking $\geq 10^6$ yr. On this basis, they argue that the system may be reaching the end of its lifetime.

It is the purpose of this note to show new observations for NQ Vul and two other recent dust-forming novae, taken with the IRAM 30 m millimeter wave telescope, that remove the problems associated with the reported CO detection. We show that there is no emission detected from any of the three novae in our sample at levels more than an order of magnitude less than the AE report.

2. OBSERVATIONS AND RESULTS

Our observations were carried out with the Institut de Radio Astronomie Millimetrique (IRAM) 30 m millimeter wave telescope at Pico Veleta, Spain, on the night of 1991 July 31. Two frequencies were used, 115 GHz [^{12}CO($1 \rightarrow 0$)] and 230 GHz [^{12}CO($2 \rightarrow 1$)]. The beam sizes were $\sim 23''$ and $\sim 12''$, respectively. Both CO transitions were observed simultaneously. The two SIS receivers were aligned to within 2″. Pointing was checked every 2 hours with continuum observations of K3-50A (6.5 Jy at 3.3 mm). Pointing errors were less than 3″ (rms). Total integration times at each frequency were 28 (NQ Vul), 28 minutes (QU Vul), and 20 minutes (Nova Vul 1987). Although the sky was clear during these observations, there was substantial atmospheric water vapor resulting in system temperatures, T_A^*, of 400–600 K (115 GHz) and 700–1100 K (230 GHz). Cold load calibrations were performed every 5–10 minutes, depending on source elevation. Two 512×1 MHz filter banks were used as backends, with velocity resolutions of 2.6 and 1.3 km s^{-1}, respectively. All data are expressed in the main beam temperature scale—the beam efficiencies were 0.60 and 0.45, repectively, for point sources.

Spectra were combined with the CLASS data analysis software (Forveille, Guilloteau, & Lucas 1989) and the resolution was degraded by two-channel Hanning smoothing. No baselines were subtracted from the QU Vul and Nova Vul 1987 data and only a linear baseline was removed from the NQ Vul data. In this way there is no chance of obliterating any broad, astrophysically interesting, signal. The spectra are shown in Figures 1–3.

None of the sources were detected. The upper limits are presented in Table 1. For NQ Vul, we offset the beam by 10″ in each cardinal direction. According to measurements by Cohen & Rosenthal (1983) the NQ Vul shell is optically unresolved

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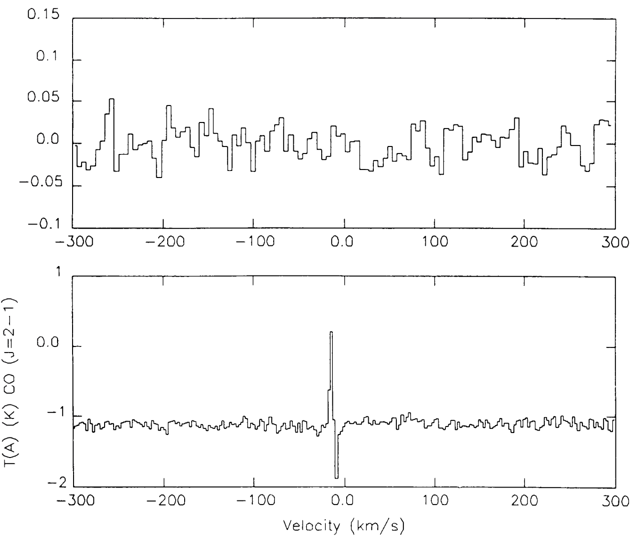

FIG. 1.—Antenna temperature (K) for ^{12}CO 1–0 (*top*) and 2–1 (*bottom*) for NQ Vul. Only a linear baseline has been removed from the data. The local cloud has not been removed from the CO data (see Albinson & Evans 1989).

and so should also be unresolved by the IRAM beam. The reference beam position was varied for all sources by up to 30′ from the source position to make sure that no signal was being subtracted due to the wobbler. It is worth noting here that there is a substantial contribution of an ambient, probably local, molecular cloud to the NQ Vul data. The reference beam data show that the cloud is at least 1° in size. At least two clouds were detected in the various reference positions with heliocentric velocities ranging from −30 to 0 km s^{-1} with antenna temperatures greater than 1 K.

We attribute the reported detection of NQ Vul to baseline fluctuation. Albinson & Evans (1989) used a small telescope, the 5 m MWO, and required several days of observations in order to produce their final spectrum. They also used a smaller bandwidth (256 MHz rather than our 512 MHz), so baseline ripple was harder to detect and remove.

3. EXTINCTION TOWARD HQ VUL FROM CO OBSERVATIONS

There are two clouds along the line of sight to NQ Vul. One must be local because of its large angular extent and small line width but the position of the other is unknown as it is of small angular size. Bohlin, Savage, & Drake (1978) established a correlation between the visual extinction and H$_2$ column density, $N(\mathrm{H_2})/A_V = 0.94 \times 10^{21}$ cm^{-2} mag^{-1} for $A_V < 2$. The visual extinction along the line of sight toward NQ Vul is ∼1.6 mag (Cohen & Rosenthal 1983) so the H$_2$ column density is $\sim 1.5 \times 10^{21}$ cm^{-2}. The extended cloud was always in both the source and reference beams so we cannot accurately measure the CO emission but the integrated intensity is certainly in the range of 5–15 K km s^{-1}. Strong et al. (1988) estimate that the I(CO) intensity to H$_2$ column density conversion factor is $N(\mathrm{H_2}) = 2.3 \times 10^{20} I(\mathrm{CO})$ cm^{-2} K^{-1} (km s^{-1})$^{-1}$. Our measurements give $N(\mathrm{H_2}) \approx (2.3 \pm 1.2) \times 10^{21}$ cm^{-2} so that most of the visual extinction for NQ Vul is probably due to this cloud.

4. MOLECULAR MASS ESTIMATES FOR NQ VUL, QU VUL, AND NOVA VUL 1987

We follow the presentation given in Albinson & Evans (1989) in order to keep clear the implications of our upper limits on CO emission. The ratio of the MWO and IRAM beam areas is ≈36 (see, e.g., Casoli 1987). Our 1 σ upper limit for the CO $J = 2 \rightarrow 1$ flux is thus a factor of between ≈43 (using 57 mK for the rms upper limit) and ≈100 (using the 22 mK upper limit; see Table 1) lower than that reported by AE. We therefore scale their equation (1) for our $J = 2 \rightarrow 1$ flux upper limit to their equation (1) to obtain a total CO mass of

$$M_{\mathrm{CO}(2-1)} \le 1.1 \times 10^{-8} D_{\mathrm{kpc}}^2 \, T_{\mathrm{ex}} \, e^{16.64/T_{\mathrm{ex}}} \, M_\odot \qquad (1)$$

where D_{kpc} is the distance to NQ Vul in kpc and T_{ex} is the excitation temperature. For a distance of 1.2–1.4 kpc (Duerbeck 1981; Cohen & Rosenthal 1983; Harrison & Gehrz 1991), and assuming a range of excitation temperature, $30 \le T_{\mathrm{ex}} \le 60$ K, we obtain an estimate of the CO mass of $\mathrm{M_{CO}} \le 8.1 \times 10^{-7}\, M_\odot$. The total dust mass derived for NQ Vul 1976 outburst is $M_{\mathrm{grains}} \approx 2 \times 10^{-7}\, M_\odot$ using the estimated dust mass fraction of 10^{-3} (Gehrz 1988; Harrison & Gehrz 1991) and our CO upper limit (using a line width of 80 km s^{-1}) is the same order this dust mass. If the CO abundance is similar to that of molecular clouds [$N(\mathrm{CO})/N(\mathrm{H_2}) \approx 8 \times 10^{-5}$; Irvine, Goldsmith, & Hjalmarson 1990], then the total molecular mass of the ejecta is less than $1.1 \times 10^{-2}\, M_\odot$.

It must be noted, that this CO mass estimate for NQ Vul assumes the line width reported by AE. Assuming that their detection is due to baseline problems, then the CO mass upper limit is uncertain due to the unknown line width and excitation temperature. Cohen & Rosenthal (1983) measured a shell

TABLE 1

UPPER LIMITS FOR CO IN OBSERVED SOURCES

Source	Δv (km s^{-1})	CO 1–0 (mK)	CO 2–1 (mK)	Notes
NQ Vul	2.6	43	57	a,b
NQ Vul	20.8	17	22	b,c
QU Vul	5.2	18	27	a
Nova Vul 1987	5.2	19	30	a

NOTE.—All intensities are in mK rms per channel.

[a] No baseline removed.

[b] Local cloud excluded for rms measurement.

[c] Linear baseline removed from spectra.

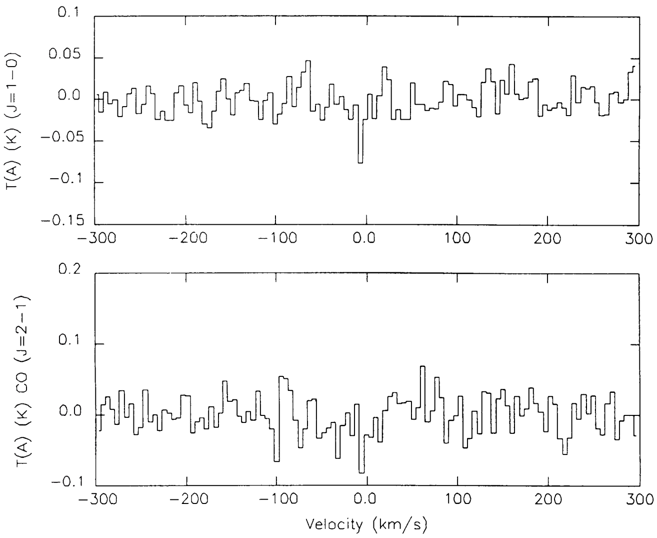

FIG. 2.—Antenna temperature (K) for ^{12}CO 1–0 (*top*) and 2–1 (*bottom*) for QU Vul. No baseline has been removed from these spectra.

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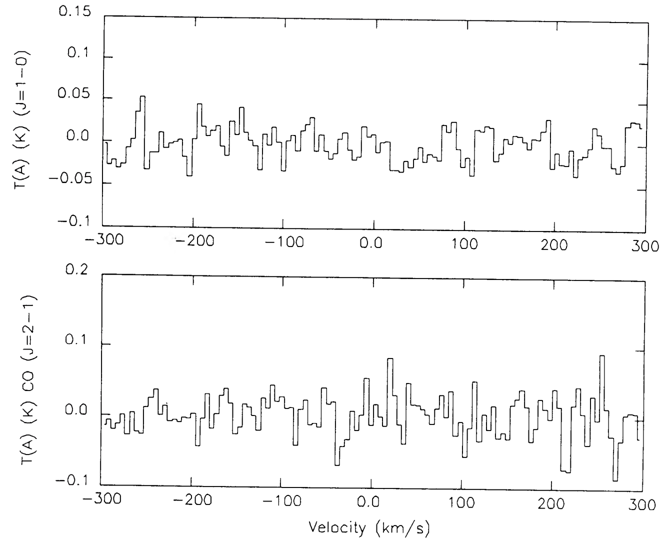

FIG. 3.—Antenna temperature (K) for ^{12}CO 1–0 (*top*) and 2–1 (*bottom*) for Nova Vul 1987. No baseline has been removed for these spectra.

expansion velocity of 705 km s^{-1} at Hα for NQ Vul. Optically thin emission from a uniform expanding shell should have a double-peaked profile, depending on the velocity field in the ejecta and the thickness to radius ratio, so we would expect to have detected the emission with the large bandwidth at 115 GHz and possibly at 230 GHz, as well although this would depend strongly on the line profile. Thus, the maximum upper limit to the mass of CO is 8×10^{-6} $M_{\odot}$ calculated from the 115 Hz line by doubling the rms noise over the entire bandwidth and assuming an excitation temperature of 50 K.

For QU Vul and Nova Vul 1987, we are limited in what we can say by uncertainties in the distance. Given the null detections, however, the overall conclusion to be drawn is that we do not presently have any molecular material present in the shells of these novae. In general, once the shells become optically thin, the ejecta are flooded by strong UV from the white dwarf. This dilute radiation field may not be sufficient to completely sputter the grains, but likely dissociates any molecular gas that happens to be present. The bulk of the luminosity from the central source comes out at wavelengths shorter than 1100 Å, the shortward limit of *IUE* spectra. In addition, the presence of coronal emission in QU Vul soon after the transition to the nebular stage supports the idea that the CO would have been dissociated unless very well screened by the dust. However, the optical depth in dust this late in the outburst is negligible.

Many old novae have been detected with the *IRAS* satellite (Harrison & Gehrz 1988, 1991, 1992). Most of these detections, however, can be explained by combinations of optically thick free-free continuum and fine structure and coronal line emission. There is little evidence for dust continua even for those novae that appear to have produced copious amounts of dust during eruptions. In particular, Harrison & Gehrz (1991) attribute the 25 μm flux of NQ Vul to [O IV] and [Ne V] and the 60 and 100 μm fluxes to cirrus confusion while for QU Vul, the 12 μm flux is attributed to fine structure lines (Harrison & Gehrz 1988). Our results for CO are in accord with these results.

5. SUMMARY

We have observed three old novae, NQ Vul, QU Vul, and Nova Vul 1987 at CO $J = 1 \rightarrow 0$ and $J = 2 \rightarrow 1$ and find that there is no evidence for any detectable molecular material. The apparent problem posed by the high inferred mass from the previous CO observations is therefore removed.

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REFERENCES

Albinson, J. S., & Evans, A. 1989, MNRAS, 240, 47P (AE)
Bode, M. F., & Evans, A., eds. 1989, Classical Novae (New York: Wiley)
Bode, M. F., Seaquist, E. R., & Evans, A. 1987, MNRAS, 228, 217
Bohlin, R. C., Savage, B. D., & Drake, J. F. 1978, ApJ, 224, 132
Casoli, F. 1987, Ph.D. thesis (astrophysique) Paris VII
Cohen, J. G., & Rosenthal, A. J. 1983, ApJ, 268, 689
Duerbeck, H. W. 1981, PASP, 93, 165
Forveille, T., Guilloteau, S., & Lucas, R. 1989, Continuum and Line Analysis Single-Dish Software, Version 4.0, Grenoble: IRAM
Gaposchkin, C. P. 1957, The Galactic Novae (New York: Dover)
Gehrz, R. D. 1988, ARA&A, 26, 377
Harrison, T. E., & Gehrz, R. D. 1988, AJ, 96, 1001
———. 1991, AJ, 96, 587
———. 1992, AJ, 103, 243
Irvine, W. M., Goldsmith, P., & Hjalmarson, Å. 1990, in Interstellar Processes, ed. D. J. Hollenbach & H. A. Thronson, Jr. (Dordrecht: Kluwer), 561
Starrfield, S. 1990, in Evolution in Astrophysics: *IUE* in the Era of New Space Astronomy Missions, ed. E. Rolfs (ESA SP-310), 101
Starrfield, S., & Snijders, A. 1987, in Exploring the Universe with the *IUE* Satellite, ed. Y. Kondo (Dordrecht: Kluwer), 377
Strong, A. W., et al. 1988, A&A, 207, 1