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HOPKINS ULTRAVIOLET TELESCOPE OBSERVATIONS OF NOVA CIRCINI 1995 AND NOVA AQUILAE 1995

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ABSTRACT

We observed Nova Cir 1995 and Nova Aql 1995 with the Hopkins Ultraviolet Telescope during the Astro-2 space shuttle mission in 1995 March. The spectra cover the wavelength range from 820 to 1840 Å with a spectral resolution of about 3 Å, extending the ultraviolet wavelength coverage of novae to the region between Lyα and the Lyman limit for the first time. The Nova Cir spectrum contains many broad carbon, nitrogen, and oxygen emission lines thoughout the HUT wavelength range. We approximate its extinction, and fit absorption by the Lyman and Werner bands of molecular hydrogen to find an H_2 column density of $\log N(H_2) = 20.7$ cm^{-2}. We calculate electron temperatures and abundances in the nova shell. The abundances are substantially nonsolar. The broad asymmetric line profiles in the Nova Aql spectrum show that this nova has not evolved as quickly as Nova Cir. The Nova Aql spectrum is significantly reddened, with little flux detected below Lyα. A series of three spectra taken over 10 days shows dramatic changes in the ultraviolet line strengths and profiles as the shell evolves.

Subject headings: novae — stars: individual (Nova Circini 1995, Nova Aquilae 1995)

1. INTRODUCTION

A nova outburst occurs when matter accreted by a white dwarf from a cool companion star undergoes a thermonuclear runaway. Accurate abundance information is important as a diagnostic of this thermonuclear runaway, and of the initial conditions which produce the runaway. Enhanced carbon, nitrogen, and oxygen (CNO) abundances are necessary in fast novae for thermonuclear runaway to produce an ejected shell at the observed velocities. (See Starrfield 1989 and Livio & Truran 1994 for discussions of abundances in novae.) Ultraviolet observations play a critical role in these abundance determinations, as many of the CNO recombination and intercombination lines lie in this wavelength range.

In this Letter, we examine far-ultraviolet observations of Nova Cir 1995 and Nova Aql 1995. Nova Cir was discovered on January 27 by Liller et al. (1995), at a visual magnitude of 7.2; it was fainter than magnitude 12.0 on January 12. AAVSO observations show a decline to magnitude 9.2 after about 20 days, implying that it is a moderately fast nova. Nova Aql was discovered February 7 by Nakano & Takamizawa (1995), at a magnitude of 8.1, and it was fainter than magnitude 12 on 1994 October 23. Its visual magnitude declined by 2 mag after about 32 days.

2. OBSERVATIONS

Nova Aql 1995 and Nova Cir 1995 were observed approximately 1 month after their respective outbursts with the Hopkins Ultraviolet Telescope (HUT). HUT operated aboard the space shuttle *Endeavour* for 14 days in 1995 March as part of the Astro-2 mission. The telescope consists of a 0.9 m mirror and a prime-focus spectrograph with a first-order spectral range of 820–1840 Å and 2–4 Å resolution. Davidsen et al. (1992) describe the instrument in detail as flown on the Astro-1 mission. For Astro-2, several improvements were made to the telescope which increased the effective area considerably (Kruk et al. 1995).

Nova Cir was observed on March 12.51 for 2696 s. Nova Aql was observed three times during the mission, on March 4.85, 6.37, and and 14.50 for 310, 790, and 1498 s. The observations of Nova Aql took place in orbital day, but the observation of Nova Cir included 1200 s in orbital night, when airglow was minimal. The novae were both visible in the HUT slit jaw camera which made them straightforward to acquire. All of the observations were made with a 20″ diameter aperture except for the first Nova Aql observation, which was made with a 32″ diameter aperture. Pointing was stable for all of the observations.

The data have been reduced with a specialized package of IRAF[1] tasks developed at The Johns Hopkins University. The tasks correct for detector pulse-persistence effects, dark count, and scattered light, and perform wavelength and flux calibrations. Details of the calibration are discussed in Kruk et al. (1995). The spectrum obtained from the total Nova Cir observation is shown in Figure 1, and the three Nova Aql spectra are shown in Figure 2. The spectra of both novae show broad (≈2000 km s^{-1} FWHM) lines of carbon, nitrogen, oxygen, and helium. The Nova Cir observation includes substantial emission below Lyα. Nova Aql appears to be heavily reddened. There was no emission detected from Nova Aql below Lyα. The fluxes in each line above a linear fit to the local continuum were integrated using the IRAF "splot" routine and are listed in Table 1 for Nova Cir. The lines are fitted well by single Gaussians, and we list the FWHM of this single Gaussian fit in the table.

The Nova Aql line profiles are highly asymmetric and

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[1] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., (AURA) under cooperative agreement with the National Science Foundation.

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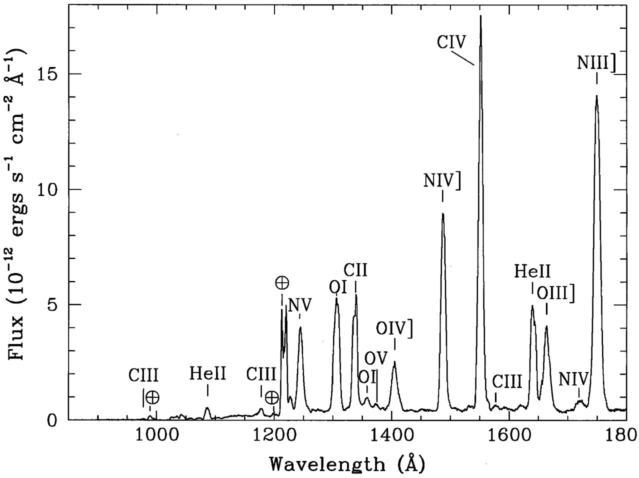

FIG. 1.—Observed HUT spectrum of Nova Cir 1995. ⊕ denotes emission from terrestrial airglow.

TABLE 1

EMISSION LINES IN THE HUT SPECTRUM OF NOVA CIRCINI 1995

λ_{obs} (Å)	Line ID	F_{obs}[a]	F_{corr}[b]	FWHM (km s^{-1})
977............	C III	3:	9	1800
1085............	He II	85:	162	2000
1177............	C III	55:	64	2200
1227............	N I[c]	131:	175	1800
1243............	N V[c]	800	1052	2400
1305............	O I[c]	914	1103	2700
1336............	C II	983	1147	1900
1357............	O I[c]	156:	178	2600
1371............	O V	61:	69	2000
1404............	O IV]	530	583	2500
1486............	N IV]	1657	1741	1800
1550............	C IV	3019	3086	1600
1577............	C III	38:	39	...
1640............	He II	1000	1000	1800
1664............	O III]	1063	1060	2300
1720............	N IV	86:	86	...
1750............	N III]	3657	3638	2100

[a] Observed fluxes are given relative to He II λ1640 = 1000 = 5.58 × 10^{-11} ergs cm^{-2} s^{-1}. Errors are ±10%, or 30% if marked with a colon.

[b] Fluxes are corrected for interstellar extinction, using a CCM curve with $R_V = 3.1$ and $E_{B-V} = 0.11$. The corrected He II λ1640 flux is 1.16 × 10^{-10} ergs cm^{-2} s^{-1}.

[c] From the night portion of the observation, which was less contaminated by airglow.

variable with time. Some lines are characterized by a broad shoulder, extending as much as 2500 km s^{-1} from line center. The profiles of individual lines differ significantly. For example, N III] λ1750 shows a large blue wing, while N IV λ1486] shows a large red wing, and N V λ1240 is relatively symmetric. We note that if the red bump on N IV] λ1486 is also N IV, it is redshifted by ~1800 km s^{-1}; if this feature is due to another ion, its identification is unknown. The centroids of the lines shift to shorter wavelengths with time, indicative of varying optical depth effects in the nova shell as it evolves toward a nebular state. As the shell expands and thins, more of the line becomes visible. Table 2 lists the total flux and centroid for each line in the three observations. From ratios of various ions of the same element, it appears that the ionization level increases with time. The emission at 1412 Å has not been seen before in novae. Its position corresponds to a component of the O IV λ1404 line redshifted by 1700 km s^{-1}, although we cannot explain the absence of similar structure in other strong lines (with the possible exception of N IV] λ1486). An alternative is N I λ1412, but the absence of N I λ1227 does not support this identification. We list the feature separately in Table 2 since its peak is apparently resolved.

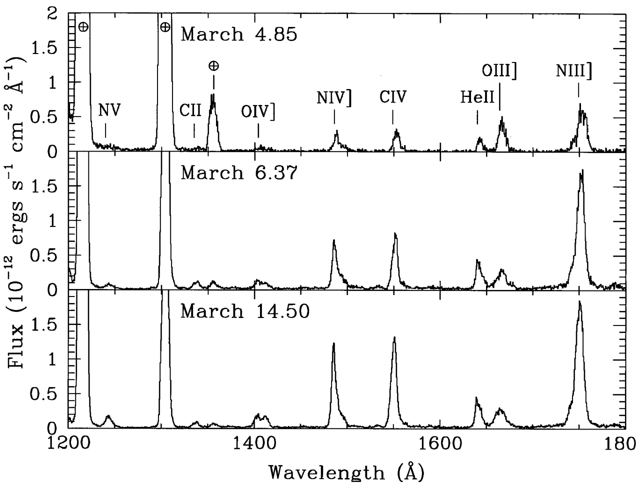

FIG. 2.—Observed HUT Spectrum of Nova Aql 1995 longward of 1200 Å. The spectrum shortward of Lyα appears heavily reddened, with little flux other than terrestrial airglow (which is denoted by ⊕ in the figure).

3. EXTINCTION

The He II recombination lines present in the HUT wavelength range allow us to estimate the extinction to Nova Cir. The observed ratio of He II λ1640/λ1085 is 11.8, while the intrinsic ratio for a Case B plasma with $T_e \simeq 12{,}500$ K, and log (n_e) = 9.0 should be 6.1 (Hummer & Storey 1987). Application of the interstellar extinction curve of Cardelli, Clayton, & Mathis (1989, hereafter CCM) with the average Galactic $R_V = 3.1$, requires an E_{B-V} of 0.11 to achieve this ratio, taking into account interstellar H_2 absorption of the He II λ1085 line as described below. The extinction-corrected fluxes, relative to He II λ1640, are listed in Table 1. The actual extinction curve for the line of sight to the nova may differ from the mean

TABLE 2

EMISSION LINES IN THE HUT SPECTRUM OF NOVA AQUILAE 1995[a]

λ_{rest} (Å)	Line ID	March 4.85		March 6.37		March 14.50	
		λ_{obs}	F_{obs}	λ_{obs}	F_{obs}	λ_{obs}	F_{obs}
1085........	He II	1085	≤70:	1085	≤6:	1085	≤3:
1240........	N V	1244	≤10:	1243.8	90:	1243.4	148
1335........	C II	1339.3	40:	1337.6	80	1337.1	55
1404........	O IV]	1406.0	60:	1403.0	72:	1403.1	140:
1412........	?[b]	1416.5	20:	1411.5	82:	1411.8	120:
1486........	N IV]	1489.2	240	1487.5	580	1486.6	830
1549........	C IV	1553.1	240	1551.5	570	1550.5	970
1640........	He II	1643.0	130	1642.1	330	1641.4	330
1664........	O III]	1666.8	380	1666.3	360	1665.0	360
1749........	N III]	1752.8	800	1751.3	1860	1750.2	2040

[a] The table shows the time dependence of the the flux and the centroid of the emmission lines in the Nova Aql spectrum. The observed flux, F_{obs}, is given in units of 10^{-13} ergs cm^{-2} s^{-1}. Errors are ±15%, or 40% if marked with a colon.

[b] Unidentified line or possible redshifted O IV component; see text.

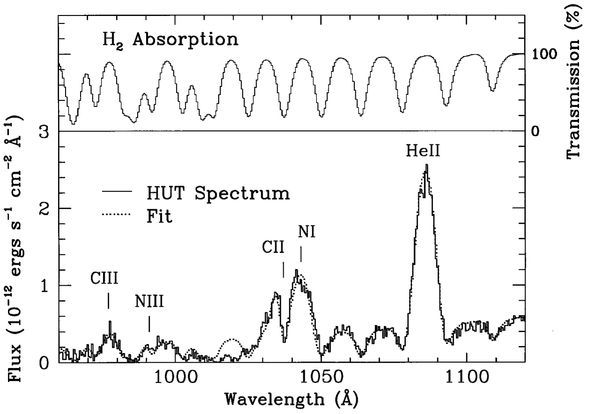

FIG. 3.—Night portion of the extinction-corrected HUT spectrum of Nova Cir 1995 is compared with a fit comprised of a power-law continuum and Gaussian emission lines, absorbed by the H_2 model shown in the upper portion of the figure. The strengths and widths of the Gaussian emission lines used in the model are listed in the text. The H_2 column density used in the fit is $\log N(H_2) = 20.7$ cm^{-2}.

Galactic curve, especially in the far-ultraviolet, and consequently this E_{B-V} value, and our corrected fluxes, are only approximate. The determination of line ratios within the HUT wavelength range, however, does not depend strongly on the shape of the curve to which we fit the He lines. Choosing simply a straight line for the extinction curve gives line ratios, longward of 1000 Å, differing by less than 15% from those determined using the CCM curve. Hence, although care must be taken in combining these observations with those at other wavelengths, the uncertainty in the shape of the extinction curve does not create a significant error in our results. Our estimate of extinction is consistent with that obtained from visual observations. Van den Bergh & Youngh (1987) find that for novae at maximum, $(B - V)_0 = +0.23 \pm 0.06$. Liller et al. give $B - V = 0.38 \pm 0.02$ for Nova Cir near maximum, yielding $E_{B-V} = 0.15 \pm 0.06$.

Strong absorption by molecular hydrogen is observed in the Nova Cir spectrum shortward of 1150 Å. Figure 3 shows this portion of the night HUT spectrum, corrected for extinction as described above. The fit shown in the figure was produced by assuming a power-law continuum over the range of wavelengths shown in the plot, to which was added Gaussian emission lines at the positions of suspected emission. Molecular hydrogen absorption was then applied to this spectral fit, using a grid of models at various column densities as described by Bowers et al. (1995). The models assume a population distribution over rotational levels of the ground vibrational state characterized by a temperature of 80 K, and a Doppler velocity parameter $b = 10$ km s^{-1}, representative of interstellar molecular hydrogen (Savage et al. 1977). The H_2 model used, smoothed to the resolution of the instrument, is shown in the upper portion of the figure, with the scale shown at the right. The Gaussians, continuum, and molecular hydrogen column density were allowed to vary to minimize χ^2, using "specfit" (Kriss 1994). The emission lines at C III λ977, N III λ991, C II λ1037, N I λ1043, and He II λ1085 were found to have respective fluxes of 1.1, 1.0, 9.0, 5.0, and 19.0×10^{-12} ergs cm^{-2} s^{-1}, and FWHM of ~2000 km s^{-1}. The required H_2 column density was $\log N(H_2) = 20.7 \pm 0.3$ cm^{-2}. The fit agrees very well with the data, except near 1017 Å, where an additional absorption appears to be needed. The region from ~1030–1045 has been fitted assuming the presence of C II λ1037 and N I λ1043. The identification of C II λ1037 is probably correct, since assuming the line is dominated by recombination, the C II λ1335 flux predicts a C II λ1037 flux about twice the value used in our fit. The identification of the other line as N I is less certain. Another possibility is O I λ1040, given the strength of the O I λ1304 line; but this would require the line either to be redshifted by about 2 Å or to have a FWHM of ~3000 km s^{-1} to produce a good fit. Nova Aql is considerably more reddened. In the absence of extinction, we would expect a He II λ1085 line flux of 4×10^{-13} ergs cm^{-2} s^{-1} based on the He II λ1640 flux seen in our third observation. The observed flux is 20 times smaller and may actually only be an upper limit due to weak N II airglow emission at λ1085. Assuming this flux is He II, and the CCM curve, $E_{B-V} \geq 0.56$.

TABLE 3

NOVA CIRCINI 1995 ABUNDANCES RELATIVE TO He^{2+}

Ion	$N(X)/N(He^{2+})$	Line[a]
C^{2+}..........	0.17	C II λ1335 (D)
C^{3+}..........	0.013	C III λ1176 (D)
	0.014	C IV λ1549 (C)
	0.012	C III λ1577 (D)
N^{2+}	0.033	N III] λ1749 (C)
N^{3+}	0.039	N IV] λ1486 (C)
N^{4+}	0.023	N V λ1240 (C)
	0.021	N IV λ1719 (D)
O^{2+}	0.011	O III] λ1664 (C)
O^{3+}	0.024	O IV] λ1404 (C)
O^{5+}	0.026	O V λ1371 (D)

[a] Abundances are from the ratio of the indicated line to He II λ1640 assuming population by recombination (D) or collisional excitation (C).

4. NOVA CIRCINI ABUNDANCES AND ELECTRON TEMPERATURES

Stickland et al. (1981), Williams et al. (1981), and others have applied assumptions of nebular densities and temperatures to *IUE* spectra of other novae to estimate the abundances present in the ejecta. Andreä, Dreschel, & Starrfield (1994) have shown reasonable agreement between observations and synthetic spectra derived from abundances determined by this method. Neglecting collisional de-excitation, the flux ratio of a recombination line of an ion to a collisionally excited line of the next higher ionization determines the electron temperature. Three such combinations are available for Nova Cir in the HUT wavelength range (see Table 3). Using recombination coefficients calculated by Nussbaumer & Storey (1984), and collision strengths tabulated by Mendoza (1983), we calculate the following electron temperatures, using our extinction corrected fluxes: (C IV λ1549/C III λ1577) → $T_e = 12{,}300$ K, (C IV λ1549/C III λ1176) → $T_e = 12{,}100$ K, and (N V λ1240/N IV λ1719) → $T_e = 12{,}700$ K. We then, assuming $T_e = 12{,}700$ K for N V and ions with similar ionization potentials, and $T_e = 12{,}200$ K for C IV and similar ions, approximate the ratio $N(X)/N(He^{2+})$ for each ion. These values are listed in Table 3. The assumed excitation mechanism, recombination or collisional excitation, is noted for each line. The collisionally excited lines are especially sensitive to the electron temperature through the exponential term, so ions with greatly different ionization potentials than those used in our temperature determinations will have the largest errors. There are also errors associated with our assumptions that the same volume is producing the emission, and that self-absorption may be ignored. Contamination by terrestrial airglow in the ultraviolet data prevents a determination of the $N(\mathrm{He}^{2+})/N(\mathrm{H})$ ratio. Optical spectra are needed to relate these abundances to hydrogen.

Following Andreä et al. (1994), Williams et al. (1985), and others, we make rough approximations for the elemental abundances using ratios of ions with similar ionization potentials:

$$\frac{N(\mathrm{C})}{N(\mathrm{N})} \approx \frac{N(\mathrm{C}^{2+}) + N(\mathrm{C}^{3+})}{N(\mathrm{N}^{2+}) + N(\mathrm{N}^{3+})} = 2.5,$$

$$\frac{N(\mathrm{N})}{N(\mathrm{O})} \approx \frac{N(\mathrm{N}^{2+}) + N(\mathrm{N}^{3+})}{N(\mathrm{O}^{2+}) + N(\mathrm{O}^{3+})} = 2.1.$$

The corresponding solar ratios are 4.8 and 0.12 (Aller 1987), indicating that nitrogen is enhanced relative to carbon in Nova Cir by a factor of 2, and oxygen is underabundant relative to carbon by a factor of 9.

5. SUMMARY

The first detection of a nova in the wavelength range between Lyα and the Lyman limit has been made using the Hopkins Ultraviolet Telescope. The HUT observation of Nova Cir has allowed us to estimate its reddening, H_2 column density, and the electron temperature and abundances in the nova shell. The H_2 column density derived from a fit to the Lyman and Werner band absorption is $\log N(H_2) = 20.7\ \mathrm{cm}^{-2}$. The electron temperature for C IV is 12,200 K, and for N V is 12,700 K. We also estimate the C:N:O ratio to be 5.2:2.1:1, showing considerable enhancement of N above the solar ratio and an oxygen to carbon ratio below solar. The Nova Aql spectrum appears to be heavily reddened below Lyα. The line profiles are broad and asymmetrical, and the ionization level and the intensities in most of the lines increase with time.

We would like to thank everyone who helped make the Astro-2 mission a success, including the mission support personnel at NASA, the crew of *Endeavour*, and our colleagues on the HUT team. Our ability to plan these observations benefitted greatly from the willingness of Steve Shore and Sumner Starrfield to discuss their ongoing *IUE* observations of these novae. We thank Joni Johnson for useful discussions. We would also like to thank Janet Mattei and the members of the AAVSO for their visible light observations throughout the decline of these novae. Support for this work is provided by NASA contract NAS5-27000 to the Johns Hopkins University.

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