OBSERVATIONS AND SIMULATIONS OF NOVA VUL 1984 #2: A NOVA WITH EJECTA RICH IN OXYGEN, NEON, AND MAGNESIUM

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ABSTRACT

Nova Vul 1984 #2 has been observed with the IUE Satellite from December 1984 through November 1987 and we expect to be able to observe it with the IUE Satellite for at least another two years. These spectra are characterized by strong lines from Mg, Ne, C, Si, O, N, and other elements. Data obtained in the ultraviolet, infrared, and optical show that this nova is ejecting material rich in oxygen, neon, and magnesium.

1. *Introduction*

Novae occur in cataclysmic binary systems in which a Roche lobe filling secondary is losing hydrogen-rich material through the inner Lagrangian lobe onto a white dwarf primary. Theoretical studies show that the accumulating shell of hydrogen on the white dwarf is unstable to a thermonuclear runaway and simulations of this phenomena reproduce many of the observed features of a nova explosion (Starrfield, Truran, and Sparks 1978; Sparks, Starrfield, and Truran 1978; Gallagher and Starrfield 1978; Starrfield 1986, 1987; Starrfield, Sparks, and Truran 1985; 1986; Starrfield, Sparks, and Shaviv 1987). The models further imply that the energetics of the outburst, and thus the type of nova, is not only sensitive to the abundances of the intermediate mass elements, but also depends on other factors such as the mass of the accreted shell, white dwarf mass, and accretion rate (Truran 1982; Starrfield 1986, 1987; Shaviv and Starrfield 1987).

In addition, as a direct result of IUE observations of previous novae such as V693 CrA (Williams et al. 1985) and V1370 Aql (Snijders et al. 1987), we were able to show that there were two classes of novae: those in which the outburst occurs on a carbon-oxygen white dwarf and those in which the outburst occurs on an oxygen-neon-magnesium white dwarf (Starrfield, Sparks, and Truran 1986).

The third nova to show the characteristics of an oxygen-neon-magnesium white dwarf was Nova Vul 1984 #2. *However, unlike the previous novae, it is a slow* nova that has declined from a maximum visual magnitude of ~+5 to ~+12 in the last 3.5 years. This has allowed us to follow its outburst both in the optical and in the ultraviolet.

In addition, X-ray data were obtained early in the outburst with Exosat which indicated that as early as 1985 there was a hot source in the system radiating at a temperature of about 3 x 10^5K. This high a temperature is fully expected by the numerical modeling (Starrfield, Sparks, and Truran 1986) and was observationally confirmed by infrared observations of coronal lines (Greenhouse et al. 1987). In addition, other infrared studies found that this nova formed silicate dust, which implies an overabundance of oxygen with respect to carbon (Gehrz et al. 1986), and showed strong infrared evidence for enhanced neon (Gehrz et al. 1986). All of these data warrant continued observations of this nova.

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We are also continuing to model this outburst in order to learn more about outbursts that occur on oxygen, neon, magnesium white dwarfs. Further work on this nova is required since our published studies of outbursts on oxygen, neon, and magnesium white dwarfs only produced "fast" outbursts (Starrfield, Sparks, and Truran 1986). We are currently improving our hydrodynamic stellar evolution code in order to calculate new simulations of this nova. These improvements include the effects of accretion energy on the evolution, elemental diffusion between the accreted material and the white dwarf, and a large nuclear reaction network with new rates.

2. Observations of the Outburst

In Figures 1, 2, and 3, we show SWP and LWP images of Nova Vul 1984 #2 on June 24, 1985 (the LWP image was obtained on July 2, 1985); September 11, 1986; and November 15, 1987. These spectra are not the only ones that we have obtained but were chosen to represent the changes that have occurred in this object over time. The spectrum shown in Figure 1 was taken just after the nebular lines began to appear and the spectrum shown in Figure 3 is the latest spectrum that we have obtained. Table 1 gives the lines, their identification, when known, and whether or not they were present on a given date.

It is clear from the lines that are present that this is a "neon" nova. It has virtually the same elements and ions as found in both Nova V693 CrA (Williams et al. 1985) and Nova V1370 Aql 1982 (Snijders et al. 1987). The primary indicators are the strength and simultaneous presence of [NeIV] 1602Å and [NeIV] 2422Å. We also note that [NeV] 3346Å, is one of the strongest lines in the spectrum. Note that at the same time as these spectra were taken, Gehrz et al. (1986) reported that [NeII] 12.8mm was strong. The great strength of these multiple ionization states of neon, all occurring at the same time, strongly argue for its enhancement in this nova. The strength of the magnesium and oxygen lines also argues that these elements are overabundant. All of the fluxes have been determined for these spectra and the analysis is presently in progress. We note that the presence of all of the forbidden neon lines, both in the ultraviolet and the optical, plus the forbidden oxygen lines will allow us to solve for the electron density and temperature simultaneously.

In addition to the ultraviolet data, we have also obtained infrared and optical data on this nova. The infrared data has been discussed and reviewed by Gehrz (1988). The data show that this nova formed silicate grains and is currently exhibiting coronal line emission. In figures 4 and 5, we show optical spectra obtained by one of us (RMW) at the 1.8m Perkins Reflector of the Ohio Wesleyan and Ohio State Universities at the Lowell Observatory. The spectra are numbered from the beginning of the outburst. Note the strong emission from [Ne III] which is still present even very late in the outburst. There are also coronal lines present in the optical spectra.

3. Discussion

As already mentioned in Starrfield, Sparks, and Truran (1986), the presence of an oxygen, magnesium, neon white dwarf in a close binary system is an important constraint on our theories of stellar evolution. First, the calculations of single star evolution show that in order for a star to survive carbon burning its mass on the main sequence must exceed about $8M_{\odot}$ to $10M_{\odot}$. Second, for it to end up as a member of a nova system requires that it had to evolve as a single star for much of its life before its radius reached to the point where it interacted with the secondary. At this point, it had to have lost most of its main sequence mass (if it had not lost it already) which carried away most of the angular momentum of the binary. Because it was in a binary, it lost all of the remaining hydrogen and helium layers and, possibly, some of the carbon burning layer. However, the differences in the ejected carbon abundances of V693 CrA, V1370 Aql, and V1500 Cyg suggest that the amount of carbon lost is variable. On the other hand, hot hydrogen burning will produce a significant amount of carbon from oxygen.

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TABLE 1

LINE ID (Å) ION	DATE 1	2	3	4
1216 Lyα	p	p	p	p
1240 NV	p	p	p	p
1304 OI	p			
1335 CII	p		p	
1371 OV	p			
1397 SiIV			p	
1402 OIV]	p	p		p
1486 NIV]	p	p	p	p
1549 CIV	p	p	p	
1575 [NeV]		p		p
1602 [NeIV]	p	p	p	p
1640 HeII	p	p	p	p
1663 [OIII]	p	p	p	p
1750 NIII]	p	p	p	p
1806 [MgVI]			p	
1814 SiII	p			p
1846 ?			p	p
1857 AlIII		p	p	
1892 Si III]	p	p		
1909 CIII]		p	p	
2326 CII]				p
2422 [NeIV]		p	p	p
2510 [MgVII]		p	p	
2604 [AlVI]			p	p
2629 [MgVII]	p			
2670 AlII]	p	p	p	p
2800 MgII	p	p	p	p
2835 OIII		p		p
2929 [MgV]		p	p	p
2974 [NeV]			p	p
3047 OIII		p	p	p
3133 OIII	p	p	p	p
3251 ?		p	p	p
3346 [NeV]	p	p	p	p

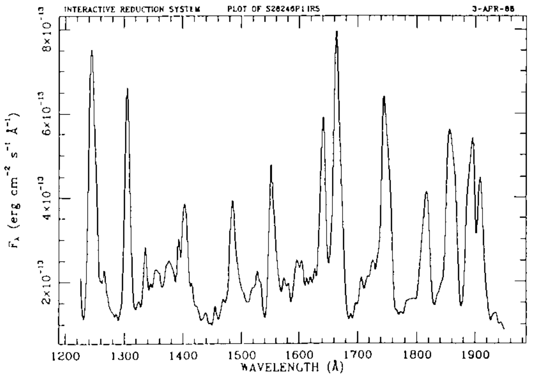

Figure 1a. The SWP spectrum was obtained on June 24, 1985 at a time when the magnitude of the nova was +10. It is a 24 minute exposure. Lyα was present at all times but is too strong to show on the same plot. Note that the flux scaling is different in all of the plots.

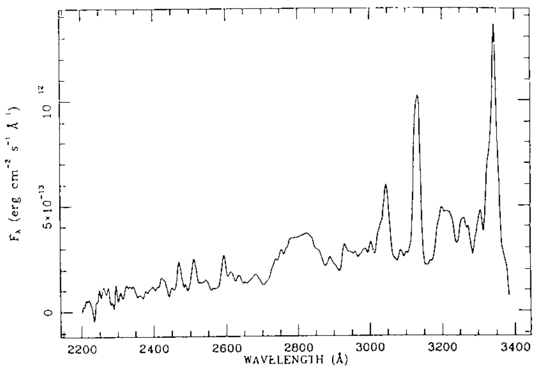

Figure 1b. The LWP spectrum was obtained on July 2, 1985 and is a 4 minute exposure. Note that six months after discovery this slow nova still shows a cool continuum. The strong line at 3346Å is either [Ne V] or [Ne III]. Mg II 2800Å is very overexposed.

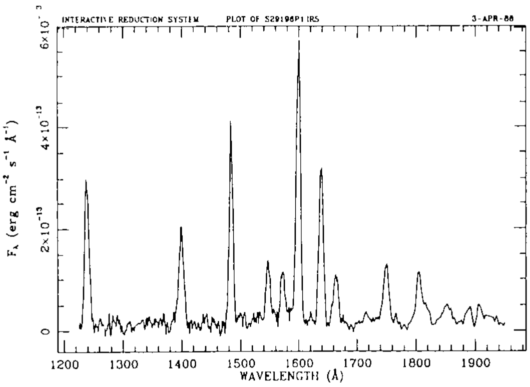

Figure 2a. The SWP spectrum was obtained on September 11, 1986. The nova had declined to 11.4 and this was a 38 minute exposure. The strong line at 1602Å is [Ne IV].

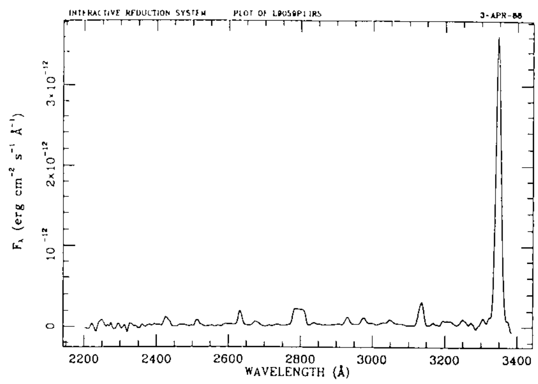

Figure 2b. The LWP spectrum is a 12 minute exposure on the same day as the SWP spectrum. By this time [Ne IV] 2422 is present and strong and the line at 3346Å is definitely [Ne V]. The simultaneous presence of [Ne IV] 1602Å and 2422Å requires that neon be enhanced. Again Mg II 2800Å is very exposed.

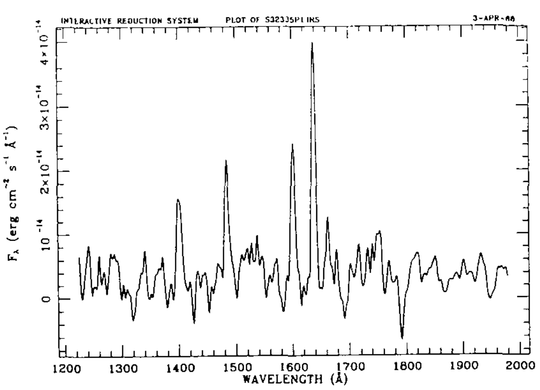

Figure 3a. The SWP spectrum is a 200 minute exposure and the nova has now declined to 13.4. It was obtained on November 15, 1987. [Ne IV] 1602Å has declined markedly since the last SWP spectrum was taken.

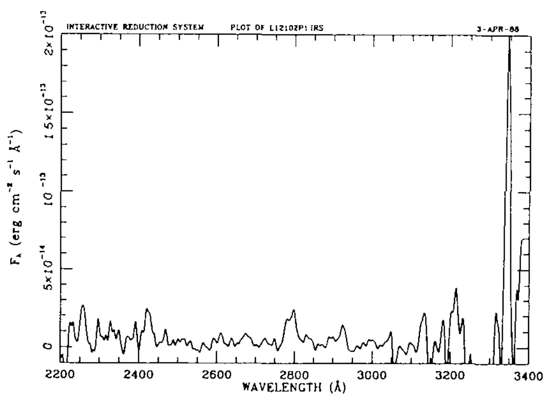

Figure 3b. The LWP spectrum was taken on the same day as the SWP spectrum and is a 40 minute exposure. While the neon lines are still prominent, Mg II 2800Å has virtually disappeared.

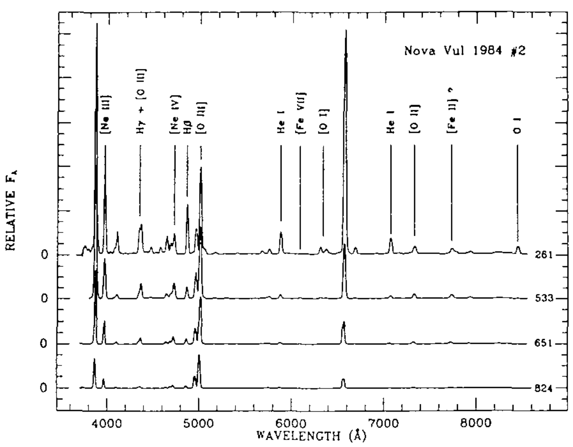

Figure 4. This is a montage of the optical spectra taken by R.M. Wagner. The number on the RHS of each spectrum is the day since outburst. Note how slowly this nova became nebular. The great strength of the neon lines, with respect to the [O III] lines, also argues for non-solar neon abundances.

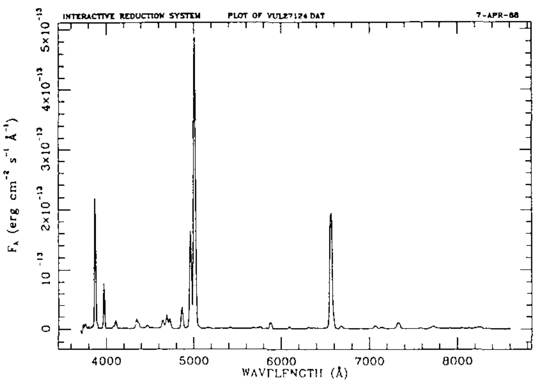

Figure 5. This is the latest optical spectrum of the nova obtained by Wagner. The [NeIV] lines are still present and strong enough to use to determine the density and temperature in the region where [O III] is formed (see text).