1. INTRODUCTION

We have obtained sequences of high-resolution ($R = 48,000$) optical spectra of a number of novae in the months following their outbursts with the Fiber-fed Extended Range Optical Spectrograph (FEROS) echelle spectrograph on the ESO La Silla 1.5 and 2.2 m telescopes. These spectra are a rich source of information about the outburst and ejecta. Their primary limitation lies in the fact that because of fiber transmissivity they do not extend below 3900 Å, where the primary signatures of He/N or "neon" novae occur, and few of our spectra were obtained in the fainter decline stage more than 5–8 months after the outburst because of the moderate apertures of the telescopes, thus failing to sample the later nebular stages of the ejecta.

The spectral evolution of several of the novae in our survey, viz., V382 Vel/99, SMC 2001, LMC 2002, and V5114 Sgr/04 have already been discussed in detail in earlier papers in this series (Della Valle et al. 2002; Mason et al. 2005; Ederoclite et al. 2006). FEROS is a bench-mounted fiber-fed instrument with a fixed format (Kaufer et al. 2000), so except for different intensity signal-to-noise ratios that vary because of differing object brightness and exposure times, the quality of the nova spectra displayed in the above papers is typical of the data for all of our objects. We are currently analyzing these data, and we discuss here initial results of the analysis of absorption lines that we have found to appear in the early decline phase of the majority of the novae we have observed.

2. THE SPECTROSCOPIC DATA

Our present targets consist of Galactic and Magellanic Cloud novae that were discovered in the interval from late 2003 to early 2006 that were observable from the southern hemisphere. An ESO target of opportunity program was activated to obtain FEROS spectra periodically through the early decline months. It was generally not possible to get spectra at regular intervals because of factors such as weather and commitment of the telescopes to large blocks of observing time for dedicated programs. Still, we were successful in acquiring series of spectra for many novae that reveal all the significant changes in line strengths, profiles, and continuum from the initial P Cygni-type spectrum at maximum light to the later forbidden emission line stage of the diffuse ejecta. Table 1 lists the novae for which we have FEROS spectra together with various characteristics of the novae, and the date and time from maximum visible brightness when each of the spectra were acquired.

The observing program was very straightforward. After a discovery announcement we incorporated every observable Galactic nova into our program. We estimated exposure times based on the reported visible brightness of the novae, normally taking three exposures that ranged from 60 to 1800 s each that allowed us to median filter the exposures in the data reduction process. Standard stars were observed to determine the instrument response function (IRF) for flux calibration. Although the FEROS IRF is stable, the relative flux calibration of many of our spectra lacks precision because of the poor sky conditions that prevailed during some of the exposures, and because of the absence of an atmospheric dispersion corrector (ADC). FEROS lacked an ADC before 2005 March, hence spectra taken before that date could be affected by flux losses at wavelengths outside the interval 4000–6000 Å, exacerbated by telescope tracking errors. Wavelength calibration was done using standard lamps and procedures, resulting in a wavelength scale that is extremely stable and accurate to within 0.02 Å, based on the measured wavelengths of interstellar absorption features in the different orders.

The spectral evolution of novae has been well documented and is understood in terms of the evolving conditions in the expanding ejecta. Initially a photosphere forms in the optically thick expanding gas, which becomes less dense and optically thin as it flows outward. The initial continuum and P Cygni line profiles from the expanding gas gradually decline and evolve to a weaker continuum with increasingly prominent emission lines. The properties
of the broad absorption features observed near maximum light were studied long ago by Payne-Gaposchkin (1957) and McLaughlin (1960), who documented the evolution of broad H i Balmer, Fe ii, and Na i profiles that consisted of “multiple absorption systems” whose [expansion] velocities tend to increase with time” and that often “break up into smaller velocity components.”

Changing spectral characteristics are very evident in our high-resolution spectra, and we show several outstanding examples of the time evolution of the absorption associated with the Na i D lines in Figure 1. Near maximum light many novae show several Na i D absorption systems. The features appear with negative radial velocities, usually larger than 400 km s$^{-1}$ from the binary velocity, as defined by the subsequent forbidden emission lines, and they evolve blueward with time. The absorption features tend to broaden and sometimes break up into discrete kinematical components as they are accelerated outward, gradually weakening in time. New Na D doublet absorption features occasionally appear with lower expansion velocities. Corresponding absorption in the Balmer and Fe ii lines shows similar behavior, although less pronounced than the D lines because they are dominated by stronger emission components.

The outward acceleration of absorption systems is believed to be driven by a post-outburst wind or radiation from the white dwarf (Kovetz 1998; Kato & Hachisu 2005). As soon as forbidden emission lines emerge from the expanding ejecta the absorption disappears, likely due to both dissipation of the absorbing gas and increasing ionization by the WD wind and radiation. This transition usually occurs over a timescale of less than 2 months and in high-resolution spectra is signaled by an evolution of the broad Na i “D” P Cygni profile to the He i λ5876 emission line. Prior to this transition the bulk of the strong emission feature is to the red of the strong interstellar Na i D absorption, whereas afterward it is to the blue. This morphing of the Na i D → He i λ5876 emission signals a fundamental change in the nova spectrum from a P Cygni absorption spectrum to an emission-line spectrum, and it represents the disappearance of the nova photosphere.

One of the remarkable features of our FEROS spectra is that more than 2/3 of the novae show dozens of well-defined absorption lines near maximum light that have no emission counterpart and that punctuate the spectrum in the early decline period before forbidden emission lines have appeared. Most of the absorption lines are concentrated in the wavelength region 4000–6000 Å and can be identified as low-excitation heavy element transitions. The more prominent systems have relatively narrow lines, e.g., 40 km s$^{-1}$, compared with the strong, broad P Cygni profiles that have widths greater than 10$^5$ km s$^{-1}$, and they therefore are not detected at moderate spectral resolution.

Narrow blueshifted absorption features identified with Fe-peak elements were first observed a century ago in the nova DN Gem/1912 by Stratton (1920) and Wright (1925). McLaughlin (1960, § 4.5) also noted the occasional presence of Ti ii and Cr ii lines in some novae, but he did not mention any analysis or interpretation of these features. They possess a wide range of line widths, and although most of the novae do show the systems for a period of weeks after maximum light before they weaken and disappear, they are prominent in only a few novae which have a system with a small velocity dispersion, i.e., narrow, pronounced lines. Most, and perhaps all, of the transient absorption systems have as one of their strongest lines one of the Na i D absorption doublets that appear in novae at maximum light. The lines are not very deep, typically having residual intensities at line center greater than 70%, and it is the nature and origin of these absorption lines that we focus on here.

3. TRANSIENT HEAVY ELEMENT ABSORPTION SYSTEMS

3.1. Observational Characteristics

During the first weeks after outburst the majority of novae show a continuum with broad P Cygni profiles of H i, Fe ii, Na i, and O i, which is produced by an expanding photosphere of optically thick ejecta from the outburst. Expansion velocities are typically of order (1–2) × 10$^3$ km s$^{-1}$, and the low ionization of the spectral features is due to adiabatic cooling of the ejecta as they expand (Arnett 1979). In the days following the outburst the great majority of novae show strong Na i λ5890,5896 “D doublet” absorption that often has multiple absorption components representing different radial velocities. These normally consist of a strong absorption feature near the blue edge of the broad emission component, having $v_{\text{exp}} > 1500$ km s$^{-1}$, and which is also present.
in the Balmer and Fe II lines. This absorption is the P Cygni component associated with the broad emission from the ejecta.

Additional Na i D absorption doublets are narrower and have radial velocities corresponding to smaller expansion velocities of 400–1000 km s\(^{-1}\). Such systems, several of which are evident in Figure 1, are unambiguously identified from the D-line doublet spacing and relative strengths. Their absorption is usually superposed on the broad Na D emission component. These narrower D-line absorption components of lower expansion velocity originate from the same gas that produces the numerous absorption lines.

Our FEROS data reveal a large number of discrete absorption lines that permeate the spectra in the weeks following outburst and that are not associated with any transitions previously identified in novae. Figure 2 presents a montage of spectra of 10 novae from our survey that show these absorption features, and a diversity of line strengths and widths is evident among the different novae. The spectra are presented roughly in order of decreasing line widths. The radial (expansion) velocities of the systems, relative to the nova binary velocity defined by subsequent forbidden line emission, fall within the range 400–1000 km s\(^{-1}\). The FWHM line widths show a wide range of values between 35 and 350 km s\(^{-1}\), reflecting large variations in internal velocity dispersion of the absorbing gas from nova to nova. The strengths of the absorption lines are such that equivalent widths range from the continuum noise level at the weak end to line center depths that sometime exceed 60% of the continuum intensity for the stronger lines. For a few of the novae in our survey we were successful in obtaining sequences of spectra that show the evolution of the absorption lines, and these are presented in Figure 3.
The lines tend to broaden and move blueward with time before disappearing.

We have systematically identified the lines in the richest absorption systems, which are those belonging to LMC 2005 and V378 Ser/05, both of which have numbers of clearly detected lines that far exceed any of the other systems we have observed. The radial velocities derived for the Na i D absorption lines in each nova were used to correct the observed absorption wavelengths to rest values, and identifications were sought for each radial velocity that resulted in a consistent set of transitions expected from a diffuse gas. We found that reasonable identifications for the great majority of lines generally resulted from one of the Na D radial velocities, usually that corresponding to the sharper Na D absorption system. The large majority of the
absorption lines can be identified as low-excitation Sc\,\textsc{ii}, Ti\,\textsc{ii}, V\,\textsc{ii}, Cr\,\textsc{ii}, and Fe\,\textsc{ii} transitions. We refer to these absorption line systems which have observable lifetimes of order 2–8 weeks as transient heavy element absorption (THEA) systems.

The novae LMC 2005 and V378 Ser/05 possess the strongest THEA systems partly due to the high signal-to noise ratio (S/N) of their spectra, but also because the absorbing gas in these two novae has the smallest velocity dispersions of all our objects, resulting in the narrowest lines among the novae sample. LMC 2005 has by far the largest number of absorption lines of all the systems we have detected. Almost every line that we have identified in the other novae is present in the LMC 2005 spectra. The absorption lines identified in LMC 2005 therefore serve as a master list of the transitions we observe in THEA systems. A
detailed spectrum of LMC 2005 is shown in Figures 4 and 5 together with line identifications over the wavelength region 4000–5500 Å. Although the relative line strengths vary between different novae, and with time in each nova, this system, whose radial (expansion) velocity with respect to the nova system is \(-435 \text{ km s}^{-1}\), may be taken to be representative of THEA systems in novae. Note that a few lines have not been identified. Whether they belong to a system of another radial velocity or to an element with low solar abundance which happens to be enhanced, or simply have not been observed yet in the lab is not clear.

All of the identified THEA lines originate from levels of low excitation potential, with \(\chi_{\text{exc}} < 4 \text{ eV}\), in singly ionized species. The lines are those that arise from a solar composition gas of low excitation conditions, i.e., the same transitions that occur in the spectra of late-type stars.

The statistics of the THEA systems are as follows: of the 15 novae observed near maximum light in our survey and listed in Table 1, 12 of them were observed to have transient heavy element absorption lines for at least one epoch. We have marked the dates of each of the spectra in Table 1 with an asterisk for those epochs where heavy element absorption lines were observed. Because of different S/Ns and sampling epochs of our spectra the statistics are consistent with every nova having a THEA system at some epoch. Interestingly, the three novae in our sample for which heavy element absorption lines were not detected in spite of our good temporal coverage with high S/N spectra, V382 Vel/99, V1187 Sco/04, and V5115 Sgr/05, are the three novae showing the most rapid declines in brightness. It may be that by the time of our first spectra of these objects at +7, +9, and +6 days, respectively, the THEA gas had already dissipated.

3.2. Excitation Temperature

The relative strengths of the absorption lines originating from levels of different excitation potential of the same ion can be used to derive the excitation temperature of the gas at various epochs as it is accelerated. It is of interest to determine whether heavy element absorption disappears because \(T_{\text{exc}}\) drops below the heavy elements condensation temperature \(T_{\text{cond}} \approx 1500 \text{ K}\) due to depletion onto dust. The best lines to use for this exercise are those that have good S/Ns, appear to be unblended, which are not too strong, i.e., possibly saturated, and which originate on levels of widely differing excitation potential. We focused attention on lines for which other members of the same multiplet were also observed so we could verify that the relative equivalent widths were those expected from the log \((gf)\) values as a validation of the \(f\)-values and the equivalent width measurements. A list of the transitions we have used in our analysis of temperature and abundances, together with their measured equivalent widths, line widths, and \(f\)-values is given in Table 2.

For two optically thin transitions originating from levels \(i\) and \(j\) of the same ion, it is straightforward to show that the excitation temperature can be written

\[
T_{\text{exc}} = \chi_{ij} \left[ k \ln \left( \left( W_{ij} W_{ji} \right)^{1/2} \right) \right]^{-1},
\]

where \(W_{ij}\) is the equivalent width of the absorption line from level \(j > i\), \(\chi_{ij}\) is the difference in excitation potential of levels \(j\) and \(i\), and \(g_i, f_i,\) and \(\lambda_i\) are the statistical weight, \(f\)-value, and wavelength of the transition from level \(j\) upward.

Although the majority of novae in our survey display a THEA system in at least one epoch of observation, the best system for...
which we have good data with high S/N and unblended lines to
determine the excitation temperature and relative abundances
of the absorbing gas with some confidence is that of LMC 2005.
Its absorption system shows little change over the interval of
6 weeks during which it was detected (see Fig. 3), and we se-
lected the 2005 December 5 epoch for detailed analysis. The
same-ion line pairs that best satisfy the requirements for analysis
in this nova are (1) Ti\textsuperscript{ii}\,\lambda\lambda4012.37 (\chi_{\text{exc}} = 0.6\text{ eV}) and 4163.64
(\chi_{\text{exc}} = 2.6\text{ eV}); (2) Sc\textsuperscript{ii}\,\lambda\lambda4415.56 (\chi_{\text{exc}} = 0.6\text{ eV}) and
5526.81 (\chi_{\text{exc}} = 1.8\text{ eV}); and (3) Fe\textsuperscript{ii}\,\lambda\lambda4491.40 (\chi_{\text{exc}} = 2.8\text{ eV})
and 6416.92 (\chi_{\text{exc}} = 3.9\text{ eV}). Using the measured equivalent
widths given in Table 2 with f-values from the Kurucz\textsuperscript{6}
compilation we derive values for the excitation temperature of
T_{\text{exc}} = 8573 (Sc\textsuperscript{ii}), 9766 (Ti\textsuperscript{ii}), and 11822 (Fe\textsuperscript{ii}) K for the primary
THEA system of LMC 2005. Not surprisingly for systems in
which absorption is observed from levels \leq 3\text{ eV above the
ground state an excitation temperature of 10^4 K is found,
characteristic of the kinetic temperatures of H\textsc{ii} regions. This
temperature for the outer diffuse circumbinary gas is higher than that
normally associated either with dust formation or with the ex-
panding photosphere of novae ejecta, where T_{\text{phot}} < 5000 K
(Warner 1995; Hauschildt et al. 1997). The relatively warm
temperature may be a relic of photoionization from the hot white
dwarf in the time immediately prior to the outburst.

3.3. Element Abundances

Our spectral resolution of 48,000 (6 km s\textsuperscript{-1}) easily resolves
the absorption lines in the heavy element systems, which all have
line widths of FWHM > 35 km s\textsuperscript{-1} at every epoch of the systems

\textsuperscript{6} R. Kurucz 2008, http://cfa-www.harvard.edu/amp/ampdata/kurucz23/sekur.html.

Fig. 4—Continued

\[ W_i = \pi e^2 / (m_e c^2) N_i \alpha_i^2 f_i, \]  

where \( N_i \) is the column density of absorbers in the lower level \( i \)
of the transition. We have taken the measured equivalent widths and oscillator strengths of lines in Table 2 together with an
assumed temperature of \( T_{\text{exc}} = 10^4 \text{ K} \) to calculate the column densities of the parent ions of the THEA lines in LMC 2005. The absorption originates from levels having a range of different ex-
citation potentials; therefore we assume a Boltzmann distribu-
tion for the column densities of the levels to compute the total ion
column density, \( N_{\text{ion}} \), for each ion, and this quantity is what is
shown in the final column of Table 2. The average of values de-
termined for each ion have then been taken to determine the rela-
tive abundances of the heavy elements, assuming the fraction
of singly ionized species to be the same for all elements, and these
results are given in the bottom row of Table 3. The abundances
are shown relative to Fe, which has been arbitrarily normalized to
the solar value with respect to H. Because H absorption is highly
saturated in our spectra, the Fe/H abundance cannot be deter-
mined from our spectra.
The column densities for the transient system in LMC 2005 can be used to calculate a rough mass estimate for the absorbing gas. If one assumes (1) a radius of 30 AU for the system; (2) a covering factor of ~30% for the gas, since it is seen in most novae; (3) a solar Fe/H ratio; and (4) a column density of \(10^{18}\) cm\(^{-2}\) for Fe\(\text{ II}\) in a typical nova, the mass of the THEA system is of order \(10^{-5}\) \(M_\odot\). This is at the low end of the mass required in nova calculations to initiate the thermonuclear outburst on a WD (Starrfield et al. 2005; Yaron et al. 2005), although most of the mass may be ejected from the system and does not accrete onto the WD. This estimate is very approximate, of course, but it does indicate that mass ejection episodes by the secondary star could be the dominant form of mass transfer even over long periods of time in cataclysmic variable systems.

There are uncertainties in the abundances due to assumptions in the analysis and it is hard to quantify all of them. They involve (1) an assumed mean temperature of \(T_{\text{exc}} = 10^4\) K for all the ions; (2) \(f\)-values for a number of transitions which are difficult to determine experimentally and therefore have been computed from theory; (3) assuming the fraction of singly ionized species to be the same for all the heavy elements; and (4) no selective gas depletion among any of the elements due to condensation into dust. With regard to the latter two points, not only is the gas temperature much higher than \(T_{\text{cond}}\), but the condensation temperatures of all of the heavy elements we have observed are similar, and should not lead to differences in relative depletions. In addition, the ionization potentials of the first three stages of the elements we observe are all quite similar, so the relative abundances of the singly ionized species should not be very different from those of the elements.

Taken together we estimate that the uncertainty in the calculated abundance for any one of the THEA ions could be an order of magnitude. There is a clear pattern among the group of elements having atomic numbers less than Fe, viz., Sc, Ti, V, and Cr, which all have abundances relative to Fe that are appreciably above solar values. This systematic result gives some credulity to the idea that (Sc, Ti, V, Cr)/Fe abundances may be enhanced above solar values in the pre-outburst circumbinary gas. We are not aware of any nucleosynthesis scenario that explains this general abundance pattern we find for the THEA systems. Because the errors in our analysis may be large, the important question of abundances must be addressed by further study of more of these systems in future novae.

### 3.4. Interpretation

The apparent lower limit to the expansion velocities of the absorption systems of ~400 km s\(^{-1}\) may be related to the escape velocity of the secondary star in the sense that gas ejected below a certain velocity is likely to fall back into the binary system. The high-velocity limit to the accelerated systems is dictated by the WD post-outburst wind or radiation field. The gradual weakening of the absorption may be due to dissipation of gas by the accelerating wind or to an increase in ionization caused by interaction with the accelerating wind and radiation.

Are the metal systems produced in the outburst, or have they been produced prior to it and originate in gas whose accretion may have been the cause of the outburst? Given that at maximum light most novae show evidence of Na I D absorption systems having expansion velocities in the range 400–1000 km s\(^{-1}\), it is possible that the outburst has produced these systems in the days between the thermonuclear runaway and maximum visible luminosity. However, inasmuch as the prominent Balmer, Fe II, and Na I D P Cygni features at maximum light originate in the more rapidly expanding outburst ejecta, the fact that the lower velocity
heavy element absorption lines are superposed on the P Cygni emission features, as is clearly seen for the Hγ emission component in most of the spectra in Figure 2, requires that the THEA systems originate outside of the photosphere. Thus, the heavy element systems, which have lower expansion velocities than the outburst ejecta, must pre-exist the outburst.

Since most THEA systems experience outward acceleration, yet they are located outside the outburst ejecta, it raises the question as to what the accelerating mechanism is. Since the ejecta are located inside the transient systems, the WD wind would not be expected to have reached the outer THEA gas. A possible acceleration mechanism might be γ-rays emitted by proton-capture reactions associated with the outburst. Or, the ramp up to the outburst may have produced a WD wind resulting from the very high surface temperature, and this wind interacts with the THEA gas. A mechanism must also be invoked to account for the acceleration of the outburst ejecta, since the P Cygni absorption components of the strong Balmer and Fe ii lines also show a steady migration to bluer wavelengths, as can be seen for the broad Hγ P Cyg absorption components in Figure 3. Whatever the mechanism is, it is clear that a substantial fraction of the outer heavy element absorption systems experience acceleration after the outburst.

Several facts point to the secondary star as the origin of the THEA gas: (1) expansion velocities of \( \sim 400 - 1000 \) km s\(^{-1}\) are more characteristic of the secondary star escape velocity than the much higher WD escape velocity, and (2) it seems improbable that the heavy elements, which do not participate in the nuclear reactions of the nova outburst, are from the WD because they are expected to selectively diffuse into the WD interior. That said, one cannot absolutely rule out the WD as the origin of the THEA gas. Indeed, even if the source of the heavy element gas is mass loss by the secondary star, that material could have been transferred to it by the WD during the earlier common envelope stage. On balance, we interpret the high fraction of novae that exhibit expanding THEA gas at maximum light to be indicative of circumbinary gas ejected by the secondary star prior to the outburst, possibly episodically.

The fact that multiple Na i D line and THEA absorption systems are common suggests that there may be episodes of mass loss in the secondary star, presumably due to structural changes associated with its evolution in the close binary system, e.g., pulsations or instabilities. A fraction of the ejected gas is likely not to escape the binary system, but rather fall back onto the stars from dissipation of angular momentum in turbulent interactions, and the accreted gas may well be sufficient to trigger the outburst(s) on the WD. There has long been a debate as to the cause of secondary outbursts only weeks after the initial nova outburst. Mass ejection episodes from the secondary star could initiate this activity, in addition to being the cause of well-documented post-eruption brightness variations of several magnitudes amplitude observed in many old novae, such as GK Per/1901 and V1017 Sgr/1919 (Warner 1995). Whatever the cause, secondary maxima do require an explanation for the rather short interval of weeks between the initial and secondary outbursts that follow the much longer interval of years of quiescence that has preceded the initial primary outburst. With the outer layers of the WD still hot from the initial outburst, a second episode of mass ejection from the secondary star provides additional pressure, heating, and fresh H to fuel another \( p \)-capture episode in the WD outer layers that
produces renewed energy generation in the degenerate gas in a matter of days rather than centuries.

We present a schematic diagram showing the possible geometry of the different ejecta components of novae at outburst in Figure 6 that is consistent with the observations reported here. A mass ejection episode by the secondary star in a short-period binary system results in some fraction of gas being lost from the system (THEA gas; in red), primarily in the binary plane but with eventual diffusion out of the plane. Some gas does not escape the system (in red) and accretes onto the WD, triggering the nova outburst. The outburst results in the high-velocity ejection of the outer layers of the WD (in black) that gives rise to the photosphere with its strong continuum and P Cygni profiles, and which overtakes the outer, slower moving THEA gas. For an assumed lifetime of the THEA gas of roughly 1 month and a velocity difference between the THEA and ejecta gas of $10^3$ km s$^{-1}$, the collision between the two gaseous components, which terminates the transient absorption system, takes place at a distance of order 10–100 AU from the two stars. We note that the disappearance of the heavy element absorption lines occurs around the time that the early “permitted” P Cygni spectral phase changes to the “auroral” forbidden emission phase (Williams et al. 1991), so this transition may be facilitated by the interaction between the two gaseous systems.

There is every indication that novae ejecta are very inhomogeneous. Old resolved nova shells, such as T Pyx (Shara et al. 1997) show extremely inhomogeneous, clumpy structure. The Na D absorption lines in novae are always observed to be saturated inasmuch as the doublet ratio of equivalent widths is closer to 1:1 than the 2:1 ratio of the f-values. However, the central depths of the D doublet never approach zero intensity as is expected for a saturated line. This requires the D-line absorbing gas to incompletely cover the continuum radiation source. The same is true of the THEA gas: some of the strengths of Ti ii and Sc ii lines do not correspond to the ratio of their (admittedly uncertain) f-values, indicating some saturation. However, the residual intensity of the lines exceeds 70%. This suggests that the THEA gas has a covering factor of less than 0.5. Thus, both the WD ejecta and THEA gas must be very clumpy.

The existence of two separate interacting gas systems might explain both the X-ray emission observed after nova outbursts (Krautter 2002) and the large variations in the characteristics of dust in novae, some of which show virtually no observable evidence for dust formation, whereas others show strong optical absorption and an appreciable fraction of the post-outburst luminosity radiated in the IR by dust (Gehrz 1988; Bode & Evans 1989). The ejecta are cooler than the outer THEA gas due to their rapid adiabatic expansion. The nova ejecta are also likely to be more dense, so dust formation is most likely to occur in the ejecta, e.g., in pockets where the gas temperature drops below the condensation temperature. Dust will form where proper conditions occur, but it would likely be destroyed by the heating that results when the two gas systems collide. Thus, the determining factor of the extent to which dust does or does not form in a nova may depend on whether the conditions for dust formation in the WD ejecta occur before it collides with the outer layer of THEA gas.

4. TYPE Ia SUPERNOVAE

It is widely believed that type Ia supernovae (SNe Ia), like classical novae, may occur in close mass transfer binaries; however, this has proven difficult to establish conclusively. Eclipsing

### TABLE 3

| Relative Abundance | Sc | Ti | V | Cr | Fe | Sr | Y | Zr | Ba |
|--------------------|----|----|---|----|----|----|---|----|----|
| LMC 2005 THEA Abundance (log Fe $\equiv 7.54$) | 4.11 | 5.88 | 5.30 | 6.09 | 7.54 | 2.45 | 3.24 | 3.81 | 2.26 |
| Solar Abundance (Lodders 2003) | 3.15 | 5.00 | 4.07 | 5.72 | 7.54 | 2.99 | 2.28 | 2.67 | 2.25 |
| (THEA System - Solar) | 0.96 | 0.88 | 1.23 | 0.37 | $\ldots$ | $-$0.54 | 0.96 | 1.14 | 0.01 |

Note.—The values of the excitation temperature, $T_{\text{exc}}$, as determined from Sc ii, Ti ii, and Fe ii are 8573, 9766, and 11,822 K, respectively.
systems having periods less than 1 day have been observed in some old novae, but have not been observed in quiescent SNe Ia systems. The lack of such observations for SNe is understandable due to the difficulty of making such a detection in extremely faint extragalactic sources in crowded fields. If SNe Ia are indeed cataclysmic variable systems it is possible that the supernova outburst is triggered by a discrete episode of mass transfer from the secondary star, and that the same heavy element absorption lines observed in novae at the time of maximum might also be present in the spectra of SNe Ia. Patat et al. (2007) have found spectroscopic evidence that they interpret in terms of circumstellar material around SN Ia 2006X.

Because of the higher expansion velocities of SNe Ia compared with those of novae, the principle SNe ejecta are likely to collide with circumbinary gas that gives rise to the heavy element absorption lines sooner after the outburst than observed in novae, perhaps even before SNe maximum light. It would therefore be instructive to acquire high-resolution spectra of SNe Ia as soon after discovery as possible, and preferably before visual maximum. Detection of discrete heavy element absorption systems like those reported here for novae could provide strong evidence that the SNe Ia phenomenon is associated with mass transfer onto a white dwarf. Differences in the characteristics of novae vs. SNe Ia circumbinary absorption systems could reveal important parameters that determine which type of outburst results from mass transfer episodes. In particular, episodic mass transfer involving relatively large amounts of secondary star mass might take place in conditions that enable a WD to exceed the Chandrasekhar limit and collapse in spite of the steady loss of its mass that has been predicted to occur from models of repeated nova outbursts.

5. SUMMARY

High-resolution spectra of novae at the time of outburst reveal many absorption lines that are identified with Fe-peak and s-process elements. The lines originate from warm gas that is expanding outward from the novae at velocities of 400–1000 km s^{-1}, and they gradually weaken and disappear in roughly 2–8 weeks. The gas originates before the outburst, and most likely comes from the secondary star. Most of the heavy elements observed appear to be enhanced with respect to Fe.

If the secondary stars of cataclysmic variables do experience episodic mass loss it is likely that they do so at times that do not lead to an outburst. Confirmation of this scenario could come from observing old nova systems with high-resolution spectroscopy.

![Fig. 6.—Schematic representation of the gas associated with novae near the time of outburst. The red spiral represents material ejected by the secondary star before the outburst, some of which escapes and some of which is accreted onto the white dwarf. The central black sphere represents the ejecta of the white dwarf from the nova outburst. It produces the luminous photosphere and eventually collides with the outer gas from which the transient heavy element absorption systems originate.](image-url)
to see whether THEA systems are detected in novae in quiescence, between outbursts. A large telescope would be necessary to provide the necessary S/N for detection, but a large sample of old novae exists and THEA systems should be observable against the optical continua of cataclysmic variable accretion disks at quiescence. Finally, if Fe-peak elements are found to be enhanced in the THEA systems of the majority of classical novae and the origin of the enhancements is the secondary star, it carries the implication that the nova phenomenon occurs preferentially in CV systems with highly evolved secondaries.

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