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The Outburst of the Very Fast Nova Aql 2009 (V1722 Aql)

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ABSTRACT. Absolute spectrophotometry, high-resolution echelle spectroscopy, and $BVR_{\rm C}I_{\rm C}$ photometry were obtained to monitor and study the outburst evolution of Nova Aql 2009. When discovered, it was setting near evening twilight, and this prevented the observations from extending past the optically thick phase. The evolution has been particularly smooth, with the V-band maximum being reached on 2009 December 17.2 at 9.90 mag. The B-band maximum preceded the $I_{\rm C}$-band maximum by 1 day, consistent with an initial fireball expansion. The reddening is high, $E_{B-V} = 1.35$, and the distance is $d = 5.0$ kpc, for a height above the Galactic plane of $z = 180$ pc. The decline times of $t_2^V = 7.0$ and $t_3^V = 16.0$ days qualify Nova Aql 2009 as a very fast nova. The minimum outburst amplitude (set by the magnitude limit of preoutburst SDSS-II survey images) has been $\Delta R_{\rm C} \geq 12.5$ mag. The spectral evolution has been typical of a Fe II-type nova, with an ejecta expansion velocity of ~915 km s^{-1}. The combination of a very fast decline with a slow ejection velocity sets Nova Aql 2009 apart from the bulk of other novae. The evolution in absolute intensity of the various emission lines was derived, and the time of their maximum flux determined. The Fe II emission reached its maximum value before t_2^V, Hα around t_2^V, and O I 8446 (excited by Bowen fluorescence from Lyβ) halfway between t_2^V and t_3^V. The oxygen mass in the ejecta is calculated to be $2 \times 10^{-5}\ M_\odot$ from analysis of [O I] lines.

Online material: color figure

1. INTRODUCTION

Nova Aql 2009(V1722 Aql) was discovered by Nishiyama & Kabashima (2009) on unfiltered CCD frames exposed on 2009 December 14.40 UT. They estimated the object to have a brightness of 10.9 mag and a position of $\alpha = 19^{\rm h}14^{\rm m}09.73^{\rm s}$, $\delta = +15°16'34.7''$ (equinox 2000.0). Spectroscopic confirmation was provided on the following day by Kinugasa et al. (2009) and Munari & Valisa (2009), who classified the object as a Fe II-type nova, characterized by a FWHM of 1000 km s^{-1} for the emission component of the P Cygni profiles of Balmer emission lines. Strong interstellar lines suggested a high reddening. CCD photometry by Munari et al. (2009) indicated that the nova was discovered while on the rise toward maximum. Corelli (2009) noted that nothing was visible at the astrometric position of the nova on a Digitized Sky Survey plate (limiting red mag to approximately 21.5). Very little else has been published about this nova.

In this article we report on our intensive $BVR_{\rm C}I_{\rm C}$ photometric and spectroscopic monitoring of the evolution of this nova. When discovered, it was setting near evening twilight. The approaching solar conjunction limited the observations to the first three weeks past maximum, by which time the nova had declined by more than 3 mag and its ejecta were still optically thick.

2. OBSERVATIONS

$BVR_{\rm C}I_{\rm C}$ photometry of Nova Aql 2009 was obtained with three telescopes: a 30 cm Meade RCX-400 f/8 Schmidt-Cassegrain equipped with a SBIG ST-9 CCD camera and Omega + Custom Scientific photometric filters (code R030 in Table 1); a 20 cm Celestron C8 f/10 with a Starlight SXV-H9 CCD camera and Custom Scientific photometric filters (code R150 in Table 1); and a 6 cm Takahashi refractor feeding light to a SBIG ST-8XME CCD camera with Astrodon photometric filters (code BSM in Table 1). The photometry was corrected for instrumental color equations. Landolt (1983, 1992) standard stars were used to calibrate reference stars surrounding the nova. These reference stars were then used by all three instruments.

TABLE 1

Our Photometry of Nova Aql 2009

HJD	V	$B-V$	$V-R_C$	$V-I_C$	Telescope
2455181.241	10.324	1.478	....	....	R150
2455181.542	10.198	1.494	0.901	1.794	BSM
2455182.195	10.130	1.646	0.966	1.923	R030
2455182.539	9.958	1.701	0.978	1.921	BSM
2455183.194	10.076	1.740	1.118	2.160	R030
2455183.546	10.246	1.703	1.124	2.244	BSM
2455184.542	10.698	1.518	1.192	2.363	BSM
2455185.199	10.822	1.344	1.175	2.377	R030
2455185.543	11.103	1.301	1.268	2.478	BSM
2455186.194	11.189	1.275	1.292	2.474	R030
2455191.190	12.074	1.160	....	....	R150
2455193.186	12.339	1.109	....	....	R150
2455193.214	12.307	1.102	1.669	2.594	R030
2455195.206	12.482	1.089	1.734	2.629	R030
2455200.195	13.090	1.021	....	2.788	R030
2455203.191	13.186	......	....	....	R150

The BVR_CI_C data that we obtained for Nova Aql 2009 are given in Table 1.

Spectroscopic observations of Nova Aql 2009 were obtained with the 0.6 m telescope of the Schiaparelli Observatory in Varese, equipped with a multimode spectrograph (echelle+ single dispersion modes) and various reflection gratings. A journal of the spectroscopic observations is provided in Table 2, where the time is counted from the V-band maximum (see next section). The resolving power of the echelle spectrum is 20,000. The spectroscopic data have been reduced and calibrated in IRAF using standard techniques. The high accuracy of the absolute fluxes has been checked on all spectra by integrating the flux over the B, V, R_C, and I_C bands and comparing it with results from simultaneous or interpolated photometric observations. Differences never exceed 0.1 mag.

3. PHOTOMETRIC EVOLUTION

The photometric evolution of Nova Aql 2009 has been particularly simple. The early discovery enabled good coverage of the phase of maximum brightness, which occurred at different times for the various bands. The light curves in Figure 1 develop particularly smoothly around the time of maximum, and polynomial fits to them provide the following values for the time and brightness level at maximum in the B, V, and I_C bands

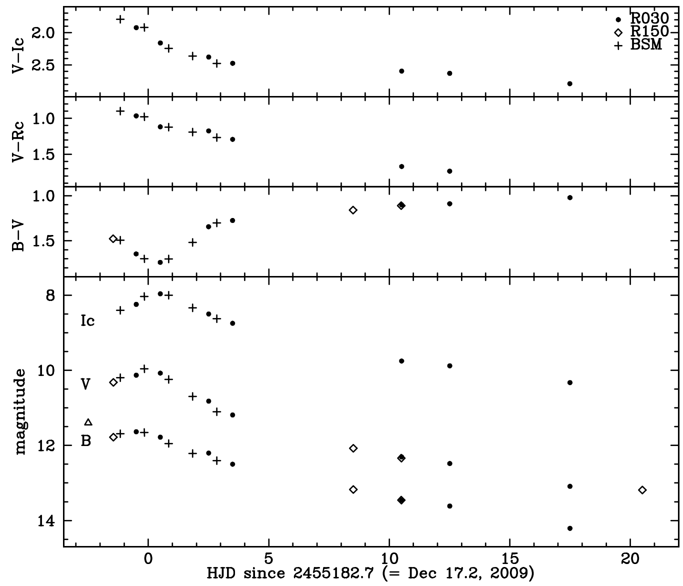

Fig. 1.—Light and color curves of Nova Aql 2009 from our observations in Table 1. The *triangle* at $V = 11.4$ on day -2.49 is from Vollman (2009).

$$t^B_{\max} = 2455182.17 \qquad B_{\max} = 11.78 \tag{1}$$

$$t^V_{\max} = 2455182.70 \qquad V_{\max} = 9.90 \tag{2}$$

$$t^{Ic}_{\max} = 2455183.17 \qquad I_{\max} = 7.92, \tag{3}$$

where the uncertainty for the time is 0.02 days, and that for the magnitude is 0.03 mag. In this article, the time is counted relative to $t^V_{\max}$.

The maximum in the I_C came 1.0 days after that in the B band. This is consistent with expectations. Following Seaquist & Bode (2008), during the initial fireball expansion phase, the flux density emitted by the nova ejecta is

$$f_\nu = B_\nu(\sqrt{A}/D)^2(1 - e^{-\tau_\nu}), \tag{4}$$

where B_ν is the Planck function, A is the projected area of the ejecta, D is the distance, and τ_ν is the free-free optical depth. Inserting the proper expression for τ_ν, and noting that $\sqrt{A}$ is proportional to the radius of the shell of ejecta that grows

TABLE 2

Journal of Spectroscopic Observations

Date	UT	Δt (days)	Exposure time (s)	Dispersion (Å pixel^{-1})	λ range (Å)
2009 Dec 15	18.167	−1.30	900	2.13	3950–8600
2009 Dec 15	18.717	−1.28	1800	0.73	5440–7040
2009 Dec 19	17.733	+2.68	1500	Echelle	4715–8635
2009 Dec 20	17.259	+3.66	2400	2.13	3960–8610
2009 Dec 29	17.317	+12.7	1800	2.13	3960–8610
2010 Jan 06	17.242	+20.7	1200	2.13	3965–8615

linearly in time (as the product of time and expansion velocity), it is possible to express the time (in days) of maximum emission at a given wavelength as

$$t_{\max}^{\lambda} \approx 0.1\left(\frac{\lambda}{\text{Å}}\right)^{+0.42}\left(\frac{T_{\rm e}}{10^4\ \text{K}}\right)^{-0.27} \times \left(\frac{M_{\rm ej}}{10^{-4}\ M_{\odot}}\right)^{+0.4}\left(\frac{V_{\rm ej}}{1000\ \text{km s}^{-1}}\right)^{-1}, \qquad (5)$$

where the time is counted from the thermonuclear runaway and thus the initial ejection. Inserting the effective wavelengths of the B and I_C bands, and the derived values for the other quantities ($M_{\rm ej} = 2 \times 10^{-4}\ M_{\odot}$, $T_{\rm e} = 5740$ K, $V_{\rm ej} = 915$ km s^{-1}, see later sections), the values $t_{\max}^{Ic} = 7.3$ and $t_{\max}^{B} = 5.7$ days are obtained. Therefore, a delay between the maxima in the two bands of 1.6 days is obtained, which is close to the observed $\Delta t_{\max} = 1.0$ days.

For the sake of discussion, it is interesting to note that equation (5) suggests that the nova ejected the envelope 6.0 days before reaching maximum V-band brightness. A simple parabolic fit to the premaximum V-band light curve of Figure 1, augmented by the Vollmann (2009) $V = 11.4$ point at day -2.49, is fainter than the $B^{\rm lim} \sim 19.5$ and $R_C^{\rm lim} \sim 20.5$ limiting magnitude of the SDSS-II survey (which did not record the progenitor) around day -6.5. Comparing with the peak $R_C^{\rm lim} = 8.98$ reached by Nova Aql 2009, this sets the outburst amplitude to $\Delta R_C \geq 12.5$ mag.

The decline times (in days) of Nova Aql 2009 were

$$t_2^V = 7.0 \qquad t_3^V = 16.0, \qquad (6)$$

which qualifies the nova as a *very fast* one according to the classification criteria summarized by Warner (1995, his Table 5.4). The ratio $t_3^V/t_2^V = 2.29$ is very close to the 2.35 value predicted by the expression that Munari et al. (2008, their eq. [2]) calibrated on the 20 best-studied novae away from the Galactic bulge. The observed decline times and outburst amplitude place Nova Aql 2009 well onto the relation displayed by classical novae, as summarized by Warner (2008, his Fig. 2.3).

4. REDDENING

The medium resolution spectrum of day -1.28 and the echelle spectrum of day $+2.68$ provide a clear view of the interstellar absorption features toward Nova Aql 2009. While strong diffuse interstellar bands (DIBs) are visible at 5780 Å, 5797 Å, 6196 Å, 6204 Å, 6270 Å, and 6614 Å, the dominant interstellar feature is undoubtedly the Na I 5890, 5896 Å doublet. The doublet appears very strong and core-saturated, with each line being a close blend of two marginally resolved components at heliocentric radial velocities -7.5 and $+35$ km s^{-1}. Both components exceed an equivalent width of 0.6 Å, with the red component being ~10% stronger than the blue one. The calibration by Munari & Zwitter (1997) shows that interstellar Na I lines are an excellent tool to measure the interstellar reddening up to $E_{B-V} \leq 0.35$ when the equivalent width is 0.52 Å. Above it, the equivalent width rapidly saturates, being 0.67 Å at $E_{B-V} = 1.0$ and 0.72 Å at $E_{B-V} = 1.5$. The equivalent width of the Na I components at -7.5 and $+35$ km s^{-1} can only place a lower limit $E_{B-V} > 1.1$ on the reddening, which is consistent with the strength of observed DIBs.

The echelle spectrum of day $+2.68$ also covers the interstellar K I doublet at 7665, 7699 Å. The line at 7665 Å is perturbed by telluric O_2 absorption, while the 7699 Å line is unaffected. Munari & Zwitter (1997) show that this line is very useful in high reddening environments, as its equivalent width is on the linear rise with reddening up to $E_{B-V} \geq 2$. On our echelle spectrum, the 7699 Å line cannot be deblended into the same two -7.5 km s^{-1} and $+35$ km s^{-1} components as Na I, probably because the resolving power degrades away from the spectrograph optical axis. The 0.328 Å equivalent width for the two combined components (both optically thin) corresponds to a reddening $E_{B-V} = 1.36$ following the calibration by Munari & Zwitter (1997).

van den Bergh & Younger (1987) derived a mean intrinsic color $(B - V)_{\circ} = +0.23 \pm 0.06$ for novae at maximum, and $(B - V)_{\circ} = -0.02 \pm 0.04$ for novae at t_2. The photometric evolution in Figure 1 and the data in Table 1 show that Nova Aql 2009 was measured at $(B - V) = +1.71$ at maximum, and $(B - V) = +1.16$ at t_2. The corresponding reddenings are $E_{B-V} = 1.48$ and 1.18, for a mean value 1.33, which is essentially identical to the result from the interstellar 7699 Å line. In the rest of this article we will adopt the average value $E_{B-V} = 1.35$ as the reddening affecting Nova Aql 2009.

5. DISTANCE

Most relations between absolute magnitude and the rate of decline take the form $M_{\max} = \alpha_n \log t_n + \beta_n$. Using the Cohen (1988) $V - t_2$ relation, the distance to Nova Aql 2009 is 4.9 kpc, and it is 4.8 kpc according to the Schmidt (1957) $V - t_3$ relation. In deriving these distances we have adopted the reddening $E_{B-V} = 1.35$ derived in § 4, and the standard $R_V = 3.1$ interstellar reddening law. According to this law and the intrinsic energy distribution of Nova Aql 2009 at the time of maximum, the extinction in the V band relates to E_{B-V} as $A(V) = 3.746 E_{B-V} + 0.018 E_{B-V}^2 = 5.1$ mag (Fiorucci & Munari 2003).

Buscombe & de Vaucouleurs (1955) suggested that all novae have the same absolute magnitude 15 days after maximum light. The most recent calibrations for it are those of Capaccioli et al. (1989, on M31 novae), and Duerbeck & Downes (2000, on galactic novae), which give $M_{15}^V = -5.69 \pm 0.14$ and $M_{15}^V = -6.05 \pm 0.44$, respectively. The brightness of Nova Aql 2009 15 days after V maximum light was $V_{15} = 12.77$, to which correspond the respective distances of 4.7 and 5.6 kpc.

Taking an average of these four values, the distance to Nova Aql 2009 is $d = 5$ kpc, which will be adopted in the rest of this article. At a galactic latitude of $b = 2^{\circ}.1$ it corresponds to a height above the galactic plane of $z = 180$ pc. della Valle & Livio (1998) found that novae of the Fe II type are distributed over a broad range of z, larger than that of He/N novae, and extending up to 1 kpc.

6. SPECTRAL EVOLUTION

The spectral evolution of Nova Aql 2009 is illustrated in Figure 2. It covers the optically thick phase. The conjunction with the Sun prevented an extension of the monitoring into the nebular phase that was expected to begin a week or so after the last spectrum of Figure 2.

The first spectrum was obtained on day -1.30, well before maximum V-band light. It is characterized by a blackbody distribution with generally weak and blue-shifted absorptions (by ~600 km s^{-1}). A weak P Cygni emission component was visible in the Balmer lines (Hα, Hβ, Hγ), the strongest Fe II multiplets (42, 49), O I (7772 and 8446), and Ca II (far red triplet). Figure 3 displays the Hα P Cygni profile from the medium resolution spectrum of day -1.28. It can be fitted very closely with the combination of 2 Gaussian fits. The absorption component is centered at a heliocentric velocity of -640 km s^{-1}, with an equivalent width of 6.3 Å and a velocity width of 230 km s^{-1}. The emission component is centered at heliocentric velocity of -35 km s^{-1}, with an equivalent width of 18.1 Å, an integrated flux of 7.4×10^{-12} erg cm^{-2} s^{-1}, and a velocity width of 440 km s^{-1} (FWHM 1040 km s^{-1}).

The period during which P Cygni profiles were present was a short-lived one. In fact, on the echelle spectrum for day $+2.68$, the P Cygni absorption of Hα had already disappeared, as had all other photospheric absorptions. On that spectrum, the Hα emission line increased the expansion velocity to 740 km s^{-1} (i.e., the FWHM to 1740 km s^{-1}), the integrated flux to 4.5×10^{-11} erg cm^{-2} s^{-1}, while the radial velocity was constant at -30 km s^{-1}.

Soon after maximum brightness, emission lines became prominent. They were dominated by Balmer series, Fe II (multiplets 27, 28, 37, 38, 42, 46, 48, 49, 55, 57, 58, 73, and 74), O I, Na I, Ca I, Ca II, and Mg II. The excitation of the emission spectrum increased with time, as is normal for novae. On day $+12.7$ Ca II emissions disappeared, and on day $+20.7$, the blend at 4660 Å due to O II, N II, and N III rivaled the Fe II 42 multiplet in intensity. On day $+20.7$, the lines of [O I] and [N II] began displaying a double peaked profile, with a velocity separation of ~980 km s^{-1}. Table 3 presents the integrated absolute flux of the emission lines identified in the spectra for days $+3.66$, $+12.7$, and $+20.7$.

Some basic properties of the evolution of the emission line spectrum of Nova Aql 2009 are presented in Figure 4. In this figure, fluxes corrected for reddening are used. The top panel of Figure 4 displays the measured expansion velocity. It is derived from the width (corrected for instrumental resolution) of the Hα emission line (obtained, as usual, as $\sigma = \mathrm{FWHM}/2.355$ of the Gaussian fit). The width is observed to rise from 440 on day

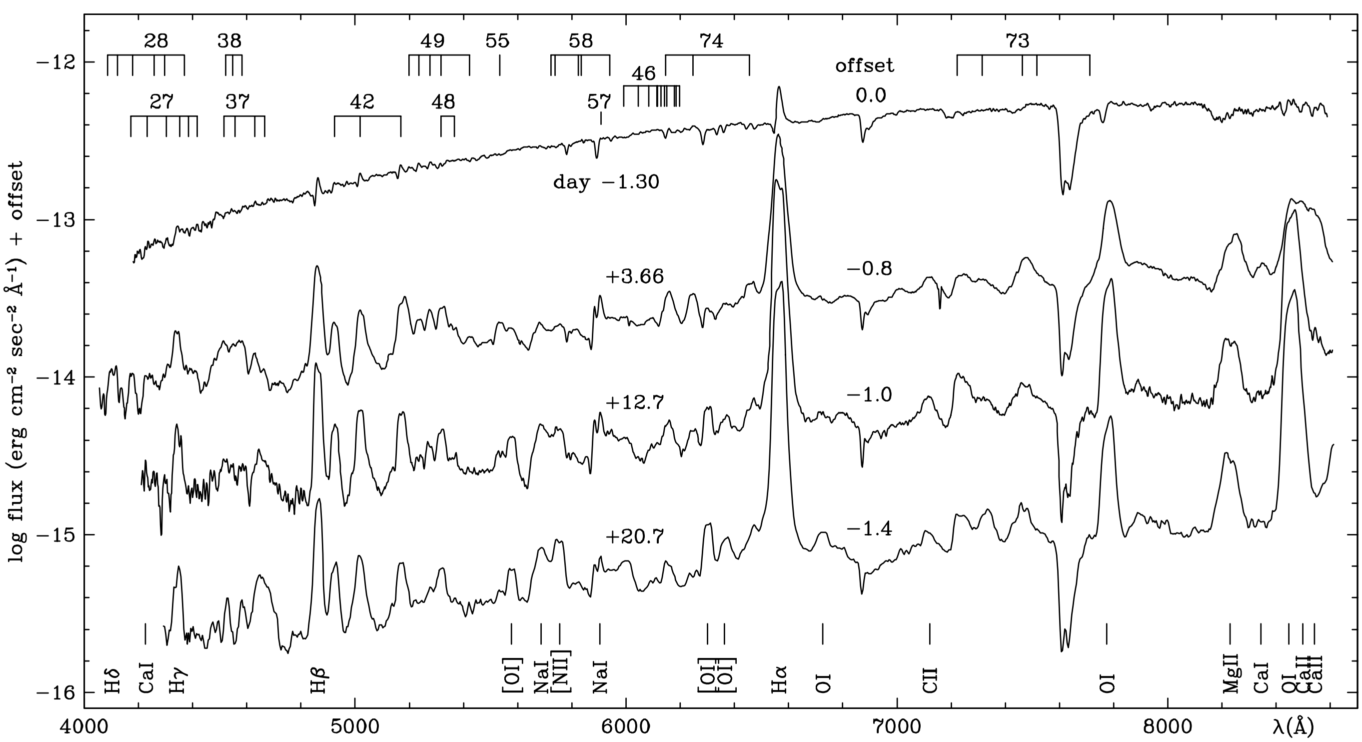

FIG. 2.—Spectral evolution of Nova Aql 2009. The ordinates are in logarithm of the flux to emphasize visibility of weak features. The *comb markings* label member lines from the numbered Fe II multiplets. The spectra are shifted for clarity by the indicated offsets.

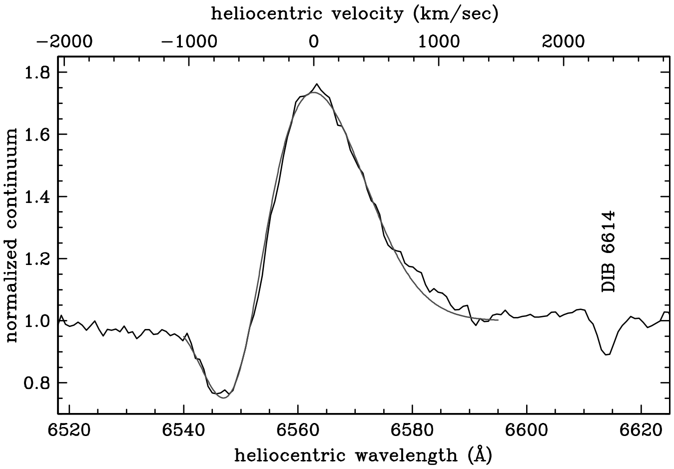

FIG. 3.—High-resolution Hα profile of Nova Aql 2009 for day -1.30. The P Cygni profile is well fit by the combination of two Gaussian fits as described in the text. See the electronic edition of the *PASP* for a color version of this figure.

-1.30 to 915 km s^{-1} on day $+3.66$, and then slowly declining to 780 km s^{-1} by day $+20.7$. The initial rise is connected with the expansion of the ionization front through the ejecta, reaching progressively outer, faster moving gas.

The very fast decline rate and low expansion velocity set Nova Aql 2009 apart from the majority of other novae. della Valle & Livio (1998) have shown that expansion velocity correlates with the t_2, and that Fe II novae concentrate at slow decline rates and expansion velocities while He/N novae at fast decline rates and expansion velocities. Figure 5 reproduces Figure 2 of della Valle & Livio (1998) with the addition of Nova Aql 2009. Compared to the nova sample of della Valle & Livio (1998), Nova Aql 2009 equals the fastest decline rate observed among Fe II novae ($t_2 = 7$ days for V476 Cyg), but its low expansion velocity places it clearly aside from the rest of the sample.

The bottom panel of Figure 4 compares the evolution of the flux in the Hα, O I 8446, and Fe II (multiplet 42) emission lines to that integrated through the V band. In the initial phases, the flux in the emission lines is orders of magnitude lower than in the continuum. Then, while the flux in the continuum declines, the flux in the emission lines rapidly increases. The Fe II emission reaches its maximum value before t_2^V, Hα around t_2^V, and O I 8446 halfway between t_2^V and t_3^V. At its maximum, Hα alone radiated nearly as much energy as the entire V band, and subsequently declines in pace with the continuum.

The intensity of the O I 8446 Å emission line under normal recombination, optically thin conditions should be appreciably weaker than the O I 7772 line, with 0.6 times its flux. On day -1.30, the ratio was 0.4. However, as the middle panel of Figure 4 shows, the O I 8446 line rapidly gained in intensity, becoming far stronger than O I 7772: 6.9 times stronger by day $+20.7$. The inversion in intensity between the two O I lines is usually associated with fluorescence pumped by absorption of hydrogen Lyβ photons, as first pointed out by Bowen (1947).

TABLE 3

INTEGRATED ABSOLUTE FLUXES (IN erg cm^{-2} s^{-1}) OF EMISSION LINES IN OUR SPECTRA OF NOVA AQL 2009

$\lambda_\circ$	Line[a]	Day +3.66	Day +12.7	Day +20.7
4101.7	Hδ	7.89E-13		
4176.1	Fe II 27+28	9.14E-13		
4226.7	Ca I	1.70E-13		
4245.5	Fe II 27+28	1.14E-12		
4300.0	Fe II 27+28	9.22E-13		
4385.4	Fe II 27	1.38E-12		
4340.5	Hγ	2.23E-12	8.38E-13	3.03E-13
4523.0	Fe II 37+38	3.58E-12	5.20E-13	1.29E-13
4578.9	Fe II 37+38	1.66E-12	2.40E-13	1.15E-13
4641.2	Fe II 37+38	1.47E-12	7.94E-13	7.06E-13
4861.3	Hβ	8.94E-12	3.32E-12	1.22E-12
4923.9	Fe II 42	2.41E-12	1.12E-12	3.97E-13
5018.4	Fe II 42	3.74E-12	1.82E-12	5.50E-13
5126.5	Fe II 35	2.52E-13		
5169.0	Fe II 35+42	3.40E-12	1.63E-12	4.31E-13
5234.6	Fe II 49	2.16E-12	3.73E-13	
5276.0	Fe II 49	2.18E-12	3.80E-13	
5316.3	Fe II 49	3.31E-12	9.05E-13	2.69E-13
5362.9	Fe II 48	1.61E-12	2.27E-13	
5425.3	Fe II 49	6.85E-13		
5534.9	Fe II 55	1.05E-12	2.63E-13	
5577.4	[O I]	1.11E-12	6.37E-13	2.07E-13
5685.7	Na I	1.39E-12	1.30E-12	6.31E-13
5754.8	[N II]	1.34E-12	1.13E-12	6.42E-13
5824.4	Fe II 58	5.87E-13		
5892.9	Na I	1.59E-12	7.19E-12	1.86E-13
5909.4	Fe II 57	1.22E-12	4.12E-13	1.00E-13
5941.4	Fe II 58	5.12E-13	6.04E-13	
5991.4	Fe II 46	1.72E-12	6.28E-13	3.43E-13
6084.1	Fe II 46	5.96E-13		
6150.7	Fe II 46+74	3.15E-12	9.12E-13	2.27E-13
6247.6	Fe II 74	2.54E-12	3.70E-13	
6300.2	[O I]	6.88E-13	8.76E-13	6.08E-13
6363.9	[O I]	6.19E-13	5.90E-13	3.63E-13
6456.4	Fe II 74	1.85E-12	1.13E-12	6.92E-13
6562.8	Hα	9.02E-11	8.13E-11	4.38E-11
6726.3	O I	3.24E-13	3.67E-13	3.09E-13
7120.5	C II	3.55E-12	1.65E-12	3.30E-13
7233.6	Fe II 73+C II	3.84E-12	2.77E-12	8.98E-13
7313.4	Fe II 73	3.97E-12	1.96E-12	8.81E-13
7470.0	Fe II 73	7.05E-12	2.18E-12	1.05E-12
7773.8	O I	2.63E-11	1.69E-11	5.27E-12
8230.3	Mg II+N I	1.57E-11	8.28E-12	3.82E-12
8342.6	Ca I	2.20E-12		
8446.5	O I	2.15E-11	6.46E-11	4.91E-11
8498.0	Ca II	1.93E-11		
8542.1	Ca II	1.99E-11		

[a] Fe II lines include the multiplet number.

For the Lyβ fluorescence to be effective, the optical depth in Hα should be large, presumably owing to the population of the $n = 2$ level by trapped Lyα photons. The $F_{8446}/F_{\mathrm{H}\alpha}$ flux ratio under optically thin, low ionization conditions and typical

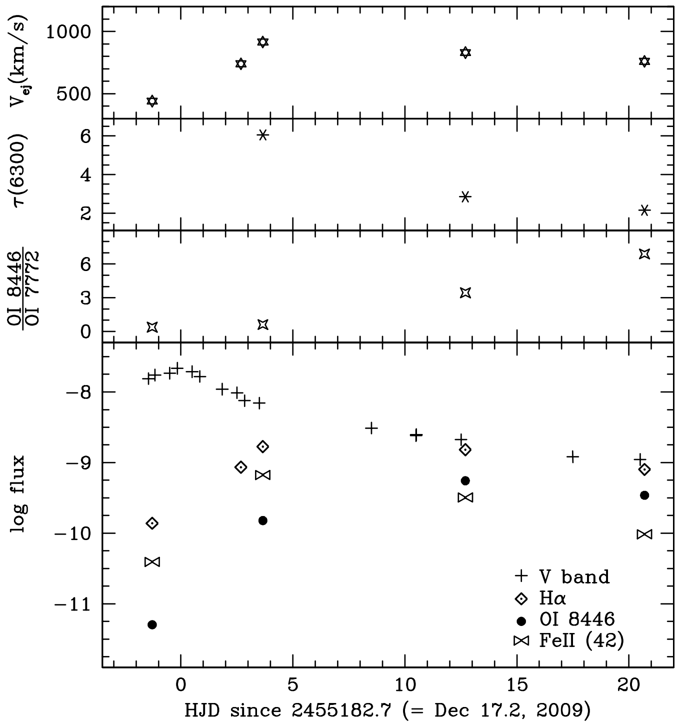

FIG. 4.—From *top* to *bottom*: Expansion velocity from Hα emission line; optical depth in the [O I] 6300 Å emission line; flux ratio of the O I 8446 and 7772 Å emission lines; integrated flux of Hα, O I 8446 Å, and Fe II emission lines (sum of the three components of multiplet 42), and of the V band. All values are corrected for reddening.

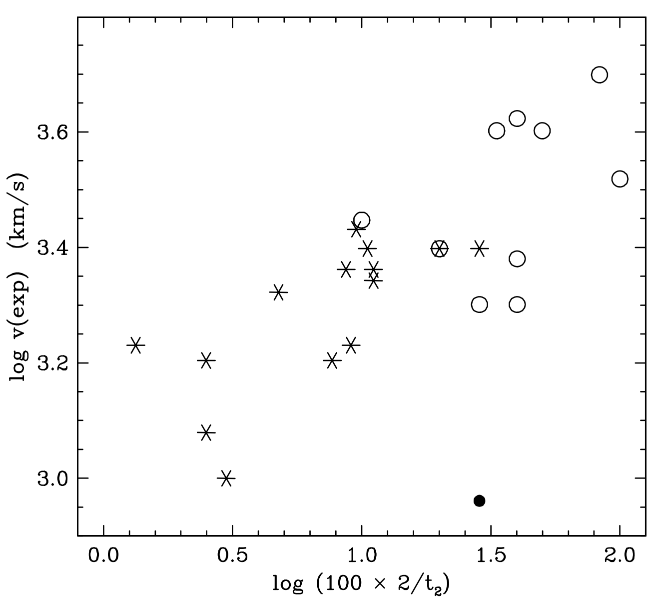

FIG. 5.—Relationship between the rate of decline and average expansion velocity at early stages. *Open circles:* Fe II novae; *asterisks:* He/N novae (from della Valle & Livio 1998); *filled circle* Nova Aql 2009.

nova chemical abundances is quite low, ~10^{-3} (Strittmatter et al. 1977). The evolution of the $F_{8446}/F_{\mathrm{H}\alpha}$ flux ratio for Nova Aql 2009 can be derived from the bottom panel of Figure 4. It evolved from 0.04 on day -1.30, to 0.43 of day $+20.7$. It confirms a very large optical depth in Hα, in agreement with the ejecta being predominantly neutral and dense at that time.

7. MASS OF THE EJECTA

The [O I] 5577, 6300, 6364 Å lines are among the first forbidden lines to appear in nova spectra, thanks to their high critical densities. The ratio of the 6300, 6364 Å nebular lines under optically thin conditions is 3:1 from their transition probabilities, and it scales with optical depth τ (in the 6300 Å line) as

$$\frac{F_{6300}}{F_{6364}} = \frac{1 - e^{-\tau}}{1 - e^{-\tau/3}}. \quad (7)$$

At typical oxygen abundance, ejected mass, and outflow velocity for a nova, [O I] 6300 Å should become optically thin within the first few days after maximum brightness. Williams (1994) noted how the $6300/6364$ Å flux ratio in novae is almost always lower than 3:1, indicating persistently optically thick conditions in the lines. He proposed that optically thick [O I] lines in novae come from small, very dense, neutral globules embedded in ambient, ionized ejecta and that the globules are internally powered by the decay of the unstable isotopes produced by initial nuclear reactions.

[O I] lines became visible in Nova Aql 2009 for the first time on the day $+3.66$ spectrum, and remained visible on spectra for days $+12.7$ and $+20.7$. The evolution of the optical depth τ_{6300} is illustrated in Figure 4. Following Williams (1994) and Osterbrock & Ferland (2006), the electron temperature in the region of [O I] line formation has been computed from the ratio of the nebular 6300 Å to the auroral 5577 Å line, and the mass of neutral oxygen from the flux in the 6300 Å line and the distance to the nova. The results for the three observing dates are summarized in Table 4. The mass of the ejecta in the form of neutral oxygen has been declining with time, as expected on the basis of an expansion of the ionization front through the ejecta. It seems safe to assume that, at first appearance of [O I] lines, all oxygen in the ejecta was in the neutral form (an assumption that has been verified in detail at least for Nova Cyg 2006 by Munari et al. 2008). Under such conditions, the mass of oxygen directly

TABLE 4

AMOUNT OF NEUTRAL OXYGEN IN THE EJECTA (M_{OI})

Day	$\left(\frac{F_{6300}}{F_{6364}}\right)^{\circ}$	τ_{6300}	$\left(\frac{F_{6300}}{F_{5577}}\right)^{\circ}$	T_e (K)	$F_{6300}{}^{\circ}$	M_{OI} ($M_{\odot}$)
+3.66	1.151	6.05	0.343	5740	1.54E-11	2.22E-05
+12.7	1.539	2.85	0.760	5615	1.96E-11	1.54E-05
+20.7	1.731	2.15	1.623	5025	1.36E-11	1.39E-05

NOTE.—All line fluxes and ratios are corrected for reddening.

relates to the total mass of the ejecta. The mean mass fraction of oxygen in nova ejecta is ~0.11, from a straight average of the summary of values listed in Gehrz et al. (1998), augmented by additional determinations published later. Applying this proportion to the results in Table 4 for day $+3.66$, a total mass of the ejecta of Nova Aql 2009 is obtained as

$$M_{\text{ejecta}} = \frac{M_{\text{OI}}}{0.11} \approx 2.0 \times 10^{-4}\ M_{\odot}. \qquad (8)$$

An oxygen mass of $2.2 \times 10^{-5}\ M_{\odot}$ for the ejecta of Nova Aql 2009, even if somewhat higher than the results summarized by Gehrz et al. (1998) from photoionization studies in the infrared, is compatible with the results obtained on other novae: (a) the mean mass of neutral oxygen derived by Williams (1994) for the 14 novae he studied is 2.5×10^{-5} $(\sigma = 3.1 \times 10^{-5})$ $M_{\odot}$; (b) Nova Cyg 2006, which was characterized by a similar fast decline ($t_2^V = 10$ days) and slow early expansion velocities (1000 km s^{-1}), ejected $6.5 \times 10^{-5}\ M_{\odot}$ of oxygen (Munari et al. 2008; the results from [O I] during early outburst phases being confirmed by photoionization analysis during the advanced nebular stage). It is also worth noticing that the peculiar position occupied by Nova Aql 2009 in Figure 5 could relate to unusual characteristics of its ejecta.

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