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THE Hα LIGHT CURVES OF NOVAE IN M31

ROBIN CIARDULLO[1]
Kitt Peak National Observatory, National Optical Astronomy Observatories
ALLEN W. SHAFTER
McDonald Observatory and Department of Astronomy, University of Texas at Austin
HOLLAND C. FORD,[2] JAMES D. NEILL,[1] AND MICHAEL M. SHARA[1]
Space Telescope Science Institute
AND
A. B. TOMANEY
McDonald Observatory and Department of Astronomy, University of Texas at Austin
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ABSTRACT

We present Hα and *B* light curves for 11 M31 novae, four of which were well observed near maximum. These data, along with the Hα light curves of two Galactic novae, demonstrate that a nova's maximum Hα flux occurs days or weeks after its continuum maximum at a monochromatic intensity 1–2 magnitudes above its peak flux in *B*. Moreover, after this maximum is achieved, a typical nova will radiate a third as many photons in Hα as in the entire *B* bandpass. The most interesting part of a nova's Hα light curve, however, is its decline. We find that, regardless of a nova's speed, its Hα decay rate after maximum is almost identical to its decay rate in *B*. Because the effective temperature of the central source is most likely increasing during this time, this behavior suggests that most of a nova's optical luminosity during early decline is continuum emission from the nebula, rather than direct radiation from the central source.

Although the data are limited, we find no correlation of maximum Hα magnitude with nova speed, and no evidence that an Hα maximum magnitude–rate of decline relation exists. However, the Hα emission is still a useful tool for studying the underlying population of nova progenitors. To facilitate such probes, we present the mean Hα lifetimes for novae for a set of limiting magnitudes. These values will enable extragalactic nova rates to be derived from multiepoch Hα surveys.

Subject headings: galaxies: individual (M31) — stars: novae

I. INTRODUCTION

Novae are potentially one of the most useful extragalactic distance indicators. At maximum light, novae can be as bright as $M_B \sim -8$, making them among the brightest objects in de Vaucouleurs's (1978) list of primary standard candles. Moreover, since novae are not exclusively Population I objects, they can be found in uncrowded, dust-free regions of galaxies where no Cepheids or other bright, regular variables exist. Because of this, novae offer a way to obtain distances to the early-type galaxies of Virgo (Pritchet and van den Bergh 1987).

At the present time, however, there are several problems associated with the use of novae as distance indicators. One difficulty is the calibration of novae in our own Galaxy for use as a primary standard candle. Although there are several maximum magnitude–decay rate relations in the literature (McLaughlin 1960; Pfau 1976; de Vaucouleurs 1978; Cohen 1985), the absolute calibration of Galactic novae is treacherous. Direct distance measurements to novae are theoretically possible through the nebular parallax method, but the results are dependent on the geometry of the nova explosion. The shells of many resolved novae are clearly nonspherical, hence two-dimensional models of the mass ejection are necessary (Barden, Rabin, and Wade 1988; Ford and Ciardullo 1988). Furthermore, few Galactic novae are observed at maximum, and the calculations of absolute magnitudes must address the question of interstellar absorption. Because of these uncertainties, the usefulness of the ~ 15 well-observed Galactic novae is limited.

The above difficulties can be avoided by using novae as secondary standard candles and calibrating the light curves in M31. Partial curves in the blue or ultraviolet bandpass exist for almost 300 M31 novae (Hubble 1929; Arp 1956; Rosino 1964, 1973; Rosino *et al.* 1989), and in these homogeneous sets, the broad-band maximum magnitude–decay rate relation has been calibrated quite well. However, an examination of these data reveals the principal obstacle in their use. Novae are relatively rare—the nova rate in M31 is only ~ 30 per year over the entire galaxy (Arp 1956; Capaccioli *et al.* 1989). Furthermore, more than half of these novae have broad-band decay times longer than 2 weeks and are therefore difficult to follow with short observing runs (Capaccioli *et al.* 1989). Hence, in order to use the nova absolute magnitude–decay time relation in distant galaxies, long continuous surveys with large telescopes are needed.

A nova's bright continuum is not its only easily observable property, however. Shortly after maximum light, novae develop strong, broad Balmer emission lines. Within a few

[1] Visiting Astronomer, Wise Observatory, Israel.
[2] Visiting Astronomer, Kitt Peak National Observatory, Operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

days after maximum, Hα becomes much stronger than the continuum, and while the continuum continues to fade, Hα remains bright. This emission has been used to find M31 novae that were weeks or months past maximum (Ciardullo, Ford, and Jacoby 1983; Ciardullo *et al.* 1987, hereafter Paper I).

The longevity of the Hα emission suggests new ways to use novae as standard candles. Whereas on a single deep image of a distant galaxy it may be possible to identify one or two recent novae, with a deep Hα image, many more novae are detectable. Furthermore, the ability to detect a nova's Hα emission long after maximum allows its decay rate to be calculated with only a few observations spaced weeks or months apart. Hence Hα observations of novae may offer significant advantages over *B* in the determination of extragalactic distances.

In Paper I we reported the results of a homogeneous 5 yr Hα nova survey of M31's bulge and discussed the spatial distribution of these objects. Here, we present Hα and *B* light curves for several of our best observed novae, supplementing the observations of the original survey with measurements made from other telescopes. Using these light curves, and the light curves of Nova Cyg 1975 and Nova Cyg 1986, the only Galactic novae with comprehensive spectrophotometry, we will show that a nova's Hα flux usually peaks several days or weeks after its optical continuum maximum, at a monochromatic intensity 1–2 magnitudes above its maximum emission in *B*. Moreover, we will show that when a nova's Hα flux does decline, it does so at a rate approximately equal to the *B* band fade rate. Thus, in the days and weeks after maximum, a nova will emit roughly a third as many photons in a 75 Å bandpass around Hα as it will in the entire *B* bandpass. Unfortunately, we will also show that this property does not appear to be a useful standard candle, as there is no evidence for a maximum magnitude–rate of decline relation. Nevertheless, because Hα surveys do allow the detection of large numbers of novae with relatively little effort, observations in this filter are useful for studying the nova progenitor population. We will therefore calculate the mean Hα lifetime for novae, so that this emission can be used for the determination of extragalactic nova rates.

II. OBSERVATIONS AND REDUCTIONS

Our survey region consisted of a strip along M31's bulge, extending 26$'\!.$3 in diameter along the major axis and 17$'\!.$1 along the minor axis, defined by eight RCA CCD camera fields at the f/7.5 focus of the Kitt Peak No. 1 0.9 m telescope. Observations were taken through three filters, an Hα filter wide enough to include the entire nova emission line (75 Å full width half-maximum), an off-band Hα filter ($\lambda_c = 6194$ Å; FWHM = 347 Å), and a broad-band *B* filter. The exposure times and the details of the observing program are described in Paper I. Except for the initial year of our survey, the Kitt Peak data were collected in two or three short observing runs separated by ~1 month.

To supplement these measurements, data were obtained at two other observatories. Starting in the 1984 observing season, RCA CCD camera frames in *B* and Hα were taken at McDonald Observatory, mostly with the f/13.5 0.8 m telescope. Typical exposure times for these images were 40 minutes for the on-band Hα frames and 5 minutes for *B*. Because of the slower f-ratio, the generally poorer seeing, and the characteristics of the McDonald CCDs, these frames did not go as deep as their Kitt Peak counterparts and could not be used in the nova population study. Instead, the McDonald observations were used primarily to follow novae which were first identified on the Kitt Peak survey frames. The photometry from these frames enabled us to sample several light curves at 1–2 week intervals throughout two observing seasons.

In addition, for a 46 night stretch in the late summer of 1986, our survey region was monitored nightly in *B* and Hα with an RCA CCD camera at the f/8 focus of the Wise Observatory (Israel) 1 m telescope. Because the plate scale and field size of this telescope/detector combination were similar to that of the Kitt Peak survey telescope, the CCD exposure times, typically 15 minutes in Hα and 10 minutes in *B*, were also chosen to be similar. Although the median ~3″ seeing restricted the limiting magnitude of these frames, the continuous coverage allowed the observation of novae at outburst.

The data from the Wise and McDonald Observatories were reduced in a manner similar to that described in Paper I. Raw magnitudes were calculated within apertures of the order of the seeing full width half-maximum using the DAOPHOT photometry package (Stetson 1987). These magnitudes were then placed on a standard system by scaling the nova measurements to measurements made of the photometric field stars defined in Paper I. This technique enabled the observations of five telescopes and eight CCDs to be combined without significant systematic errors.

The dates of coverage from Kitt Peak, McDonald, and Wise Observatories are summarized in Table 1. Table 2 supplements the Kitt Peak magnitude measurements tabulated in Paper I by presenting the magnitudes of newly identified novae, and by combining all the nova observations for objects recorded at

TABLE 1

SUMMARY OF OBSERVATIONS

Run	Year	Beginning UT Date	Number of Nights	Telescope	CCD
1	1982	Sep 13	14	Kitt Peak 0.9 m	RCA 1
2	1983	Sep 10	6	Kitt Peak 0.9 m	RCA 2
3	1983	Oct 10	5	Kitt Peak 0.9 m	RCA 1
4	1984	Sep 2	4	McDonald 0.8 m	Red RCA
5	1984	Sep 19	3	McDonald 0.8 m	Blue RCA
6	1984	Oct 1	2	Kitt Peak 0.9 m	RCA 1
7	1984	Oct 20	3	McDonald 0.8 m	Blue RCA
8	1984	Nov 1	3	Kitt Peak 0.9 m	RCA 1
9	1984	Nov 16	5	McDonald 0.8 m	Blue RCA
10	1984	Nov 21	4	McDonald 0.8 m	Blue RCA
11	1985	Sep 3	8	McDonald 0.8 m	Blue RCA
12	1985	Sep 11	5	Kitt Peak 0.9 m	RCA 3
13	1985	Sep 25	3	McDonald 0.8 m	Blue RCA
14	1985	Oct 4	5	McDonald 0.8 m	Red RCA
15	1985	Oct 13	4	Kitt Peak 0.9 m	RCA 3
16	1985	Oct 23	3	McDonald 0.8 m	Blue RCA
17	1985	Nov 7	2	McDonald 0.9 m	Blue RCA
18	1985	Nov 21	2	McDonald 0.9 m	Blue RCA
19	1986	Aug 16	46	Wise 1 m	RCA
20	1986	Oct 4	5	Kitt Peak 0.9 m	RCA 3
21	1986	Nov 21	4	Kitt Peak 0.9 m	RCA 1
22	1987	Oct 2	1	McDonald 0.8 m	RCA 2
23	1987	Oct 27	1	McDonald 0.8 m	RCA 2
24	1987	Nov 10	2	McDonald 0.8 m	RCA 2
25	1987	Dec 12	2	McDonald 0.8 m	RCA 2
26	1988	Jan 29	1	McDonald 2.1 m	RCA 2
27	1988	Feb 11	1	McDonald 2.1 m	RCA 2
28	1988	Mar 6	1	McDonald 2.1 m	RCA 2
29	1988	Aug 21	1	McDonald 2.1 m	RCA 2
30	1988	Sep 29	1	Kitt Peak 0.9 m	RCA 1
31	1988	Oct 31	1	Kitt Peak 0.9 m	RCA 3
32	1988	Nov 2	1	McDonald 0.8 m	RCA 2
33	1988	Dec 29	2	Kitt Peak 0.9 m	RCA 1
34	1989	Jan 17	1	McDonald 2.1 m	TEK 1

TABLE 2

M31 Nova Magnitudes

Nova	Observatory	J.D. (+2440000)	$m_{H\alpha}$	J.D. (+2440000)	B
15	McDonald	5944.84	16.32	...	...
	McDonald	5947.86	16.28	...	...
	McDonald	5961.85	16.79	...	...
	Kitt Peak	5973.68	16.75	5973.69	20.15
	Kitt Peak	5974.74	16.85	5974.75	20.48
	McDonald	5993.65	17.37	...	...
	Kitt Peak	6004.64	17.26	6004.67	...
	Kitt Peak	6005.86	17.36	...	...
	Kitt Peak	6006.89	17.31	6006.87	...
19	McDonald	6311.90	16.29	6311.89	18.91
	Kitt Peak	6318.77	16.12	6318.76	19.26
	Kitt Peak	6320.81	16.24	...	...
	Kitt Peak	6322.94	16.28	6322.92	19.64
	McDonald	6332.76	16.86	...	...
	McDonald	6333.93	17.07	...	...
	McDonald	6341.89	17.63	...	...
	McDonald	6343.89	17.36	...	...
	McDonald	6343.92	17.36	...	...
	McDonald	6344.89	17.41	...	...
	McDonald	6344.91	17.63	...	...
	Kitt Peak	6350.90	17.63	6350.88	20.75
	Kitt Peak	6353.93	17.72	6353.91	20.76
	McDonald	6361.85	18.01	...	...
20	Kitt Peak	6318.77	17.30	6318.76	20.53
	Kitt Peak	6320.81	17.52	...	...
	Kitt Peak	6321.71	17.44	6321.73	20.22
	Kitt Peak	6322.94	17.37	6322.92	20.27
	McDonald	6332.80	17.68	6332.79	19.85
	McDonald	...	...	6335.93	19.94
	McDonald	6343.92	17.20	...	...
	McDonald	6344.91	17.09	...	...
	McDonald	...	...	6345.79	20.24
	Kitt Peak	6350.90	16.97	6350.88	19.82
	Kitt Peak	6353.93	16.97	6353.91	19.98
	Kitt Peak	6707.90	18.48	6707.92	21.43
	Kitt Peak	6708.67	18.59	...	...
24	Kitt Peak	6320.95	17.64	6320.96	21.54
	Kitt Peak	6353.68	17.77	6353.75	...
	McDonald	...	...	6361.89	19.34
	McDonald	6362.90	18.20	...	...
25	McDonald	...	...	6341.85	17.63
	McDonald	...	...	6343.76	17.77
	McDonald	...	...	6343.76	18.39
	McDonald	...	...	6344.73	17.90
	McDonald	...	...	6344.74	18.05
	McDonald	...	...	6345.74	18.03
	McDonald	...	...	6345.74	19.09
	Kitt Peak	6350.76	16.32	6350.77	19.52
	Kitt Peak	6350.94	16.00	6350.92	18.48
	Kitt Peak	6351.73	16.20	6351.71	18.51
	Kitt Peak	6351.95	16.16	6351.94	18.61
	Kitt Peak	6353.71	16.43	6353.73	18.81
	Kitt Peak	6353.96	16.53	6353.95	19.65
	McDonald	6361.79	16.95	...	...
26	McDonald	...	...	6345.73	19.31
	Kitt Peak	6350.76	16.47	6350.77	17.60
	Kitt Peak	6350.94	16.40	6350.92	17.56
	Kitt Peak	6351.95	16.12	6351.94	17.56
	Kitt Peak	6353.71	15.73	6353.73	17.26
	Kitt Peak	6353.96	15.91	6353.95	17.47
	McDonald	6361.68	14.86	6361.67	17.53
	McDonald	...	...	6361.67	17.86
	McDonald	6361.74	14.76	6361.74	17.49
	McDonald	...	...	6362.62	17.56
	McDonald	...	...	6362.65	17.84
	McDonald	6362.67	14.78	6362.67	17.76
	McDonald	...	...	6375.62	18.80
	Asiago	...	...	6376.43	18.2
	Asiago	...	...	6376.45	18.2
	McDonald	6376.62	15.15	6376.61	18.98
	Asiago	...	...	6378.46	18.3
	McDonald	6389.69	15.67	...	...
	McDonald	6390.59	15.62	...	...
27	Kitt Peak	6350.86	15.84	6350.85	16.07
	Kitt Peak	6353.90	14.49	6353.89	15.59
	McDonald	6360.89	13.88	...	...
	McDonald	6361.79	14.08	...	...
	McDonald	6362.70	13.99	...	...
	McDonald	6362.74	14.09	...	...
28	Kitt Peak	6350.90	18.78	6350.88	20.55
	Kitt Peak	6353.93	18.26	6353.91	18.99
	McDonald	6362.90	17.75	...	...
29	Wise	6696.33	18.30	6696.32	19.18
	Wise	6697.35	17.54	6697.34	18.47
	Wise	6700.24	17.02	6700.23	18.24
	Kitt Peak	6706.78	16.54	6706.81	18.54
	Kitt Peak	...	...	6707.96	18.52
	Kitt Peak	6710.72	16.60	6710.71	18.53
31	Wise	6692.45	16.78	6692.44	17.73
	Wise	...	...	6694.28	16.95
	Wise	6695.56	15.93	6695.52	17.84
	Wise	6696.25	16.02	6696.24	17.56
	Wise	6697.26	16.01	6697.25	17.52
	Wise	6699.25	15.68	6699.24	17.85
	Wise	6701.28	15.68	...	...
	Kitt Peak	6707.85	16.31	6707.89	20.36
	Kitt Peak	6710.92	16.47	6710.91	19.79
	Kitt Peak	6758.62	16.97	6758.61	...
	Kitt Peak	6778.56	17.35	...	...
32	Wise	6658.47	16.45	...	...
	Wise	6659.48	16.45	...	...
	Wise	6660.41	16.64	...	...
	Wise	6661.46	16.51	...	...
	Wise	6662.41	16.42	...	...
	Wise	6662.42	16.52	...	...
	Wise	6663.40	16.52	...	...
	Wise	6664.40	16.55	...	...
	Wise	6665.44	16.42	...	...
	Wise	6666.44	16.53	...	...
	Wise	6667.44	16.49	...	...
	Wise	6668.44	16.64	...	...
	Wise	6669.45	16.42	...	...
	Wise	6670.44	16.55	...	...
	Wise	6671.29	16.67	...	...
	Wise	6672.28	16.90	...	...
	Wise	6673.28	16.27	...	...

TABLE 2—*Continued*

Nova	Observatory	J.D. (+2440000)	$m_{H\alpha}$	J.D. (+2440000)	B
	Wise	6674.29	16.35	...	...
	Wise	6675.29	16.49	...	...
	Wise	6676.40	16.56	...	...
	Wise	6677.29	16.35	...	...
	Wise	6678.30	16.32	...	...
	Wise	6681.32	16.43	...	...
	Wise	6683.26	16.41	...	...
	Wise	6687.27	16.30	...	...
	Wise	6688.40	16.42	...	...
	Wise	6689.35	16.38	...	...
	Wise	6690.37	16.47	...	...
	Wise	6692.45	16.24	...	...
	Wise	6695.56	16.57	...	...
	Wise	6696.25	16.42	...	...
	Wise	6697.26	16.43	...	...
	Wise	6699.25	16.62	...	...
	Wise	6701.28	16.37	...	...
	Kitt Peak	6707.85	16.43	6707.89	19.91
	Kitt Peak	6710.92	16.42	6710.91	19.82
	Kitt Peak	6758.62	16.38	6758.61	20.11
	Kitt Peak	6778.56	16.46	...	...
	McDonald	7070.77	17.08	...	...
	McDonald	7095.71	16.94	...	...
	McDonald	7109.87	16.87	...	...
	McDonald	7110.69	17.12	...	...
	McDonald	...	...	7121.71	20.9
	McDonald	7141.77	17.22	...	...
	McDonald	7142.65	16.96	...	...
	McDonald	7189.63	17.42	...	...
	McDonald	7202.61	17.48	...	...
	McDonald	7226.62	17.39	...	...
	McDonald	7394.70	17.89	...	...
	Kitt Peak	7433.80	17.87	...	...
	Kitt Peak	7433.81	17.94	...	...
	Kitt Peak	7433.82	17.60	...	...
	Kitt Peak	7465.74	17.87	...	...
	Kitt Peak	7465.75	17.96	...	...
	McDonald	7467.61	17.63	...	...
	Kitt Peak	7526.66	18.30	...	...
	Kitt Peak	7525.67	17.88	...	...
	McDonald	7543.65	18.28	...	...
36	Kitt Peak	7433.84	15.81	...	...
	Kitt Peak	7433.85	15.78	...	...
37	Kitt Peak	7433.70	17.99	...	...
	Kitt Peak	7433.71	17.94	...	...
	Kitt Peak	7465.67	18.34	...	...
	Kitt Peak	7465.68	18.28	...	...
38	Kitt Peak	7433.89	16.95	...	...
	Kitt Peak	7433.90	16.92	...	...
39	Kitt Peak	7433.76	18.56	...	...
	Kitt Peak	7433.77	18.34	...	...
	Kitt Peak	7465.72	18.57	...	...
	Kitt Peak	7465.73	18.81	...	...
40	Kitt Peak	7525.66	17.71	...	...
	Kitt Peak	7525.67	17.42	...	...

multiple observatories. The coordinates of novae discovered subsequent to Paper I are presented in Table 3.

Following Paper I, the Hα magnitudes have been referred to the magnitude of Vega through a 75 Å Hα filter, with 0.0 mag = 1.50×10^{-7} ergs cm^{-2} s^{-1}. We note, however, that these magnitudes do not always correspond directly to the total emitted flux in the line. Three factors cause a discrepancy. If the expansion velocity of a nova shell is greater than $\sim$1700 km s^{-1}, then the Hα emission from the object will overfill the 75 Å wide filter and cause us to underestimate the total flux. Such a condition exists only for the very fastest novae. More commonly, if the velocity of a nova's ejecta is greater than $\sim$800 km s^{-1}, Hα and [N II] lines λλ6548, 6584 will become hopelessly blended. This effect will be most important in the latter stage of nova evolution, when the object has faded by several magnitudes and is entering its nebular phase. Finally, a nova at maximum is a continuum object, hence narrow-band filter measurements during this time measure the photospheric continuum, not the emission line. However, as evidenced by our success in discovering novae by comparing on-band and off-band Hα frames (Paper I), it does not take long for Hα emission to totally dominate the bandpass. Thus, during most of a nova's early decline, our Hα magnitudes are a fair representation of the true flux emitted in Hα.

TABLE 3

New M31 Nova Positions

Nova	Year	α(1975)	δ(1975)	No. Obs.
Nova 36.....	1988	$0^h41^m40^s.1$	41°04′43″	3
Nova 37.....	1988	0 41 40.4	41 10 29	4
Nova 38.....	1988	0 41 12.1	41 4 3	2
Nova 39.....	1988	0 41 50.5	41 7 32	4
Nova 40.....	1988	0 41 7.2	41 8 49	2

III. THE Hα LIGHT CURVES

Although the best way to detect novae in other galaxies, may be with direct images through an Hα filter, a quantitative understanding of a nova's Hα light curve is extremely difficult. While theoretical models have successfully reproduced the continuum emission from several Galactic novae (see Starrfield 1989 and references therein), calculations involving nova Balmer emission have yet to be done. (Some time-dependent complications which must be considered are the hardening of the radiation field, the high density and variable clumpiness of the ejecta, the time-dependent propagation of the ionization fronts, the changing speed and intensity of the nova wind, and contamination of the Hα emission by [N II] λλ6548, 6584.) Therefore, for the present, the investigation of nova evolution in Hα must be done empirically, using both Galactic and extragalactic objects.

Since 1970 $\sim$40 Galactic novae have been observed in outburst, but less than 10 have been observed spectrophotometrically, and only Nova Cyg 1975 (V1500 Cyg) and Nova Cyg 1986 (V1819 Cyg) have reasonably complete spectrophotometry throughout their decline. According to the observations of Ferland, Lambert, and Woodson (1986), the Hα emission from Nova Cyg 1975 reached a maximum of 5.90×10^{-8} ergs cm^{-2}

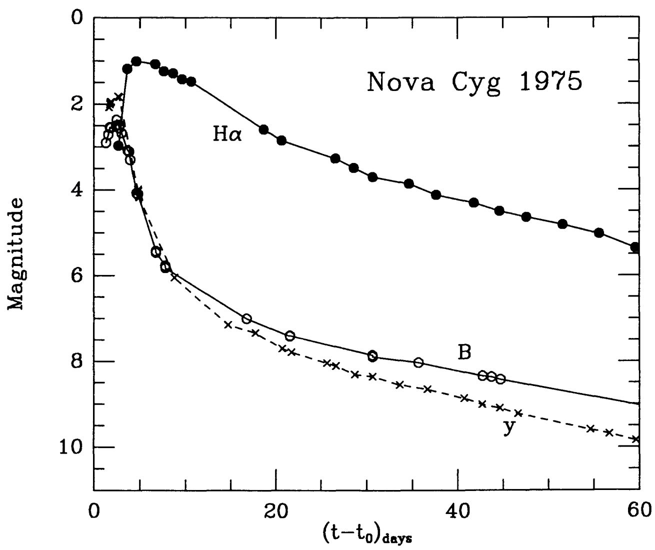

FIG. 1.—The observed *B*, *y*, and Hα light curve of Nova Cyg 1975 during the first 2 months of outburst (t_0 = 1975 Aug 28.5 = JD 2,442,653.0). The *B* magnitudes have been taken from the photometry of Young *et al.* (1976) and Williamon (1977), the Strömgren *y* photometry comes from Lockwood and Millis (1976), and the Hα points are derived from the spectrophotometry of Ferland, Lambert, and Woodman (1986). In this fastest Galactic nova on record, the Hα emission peaked 2 days after the broad-band maximum. Six days after maximum, more photons were being recorded in Hα than in the entire *B* filter. Note the similarity in the decay rates of Hα and *B* after this time.

s^{-1} 2.26 days after maximum light (Young *et al.* 1976). In the next two weeks, during the phase labeled by McLaughlin (1960) as early decline, the nova's *B* luminosity faded by 4.5 mag (Williamon 1977), but its Hα flux only declined by 1.5 mag. At this stage, the observed fluxes contained in the *B* filter and in Hα were approximately the same. Past this point, the decay rates of Hα and *B* were similar, with Hα declining slightly more rapidly. If we adopt Ferland's (1977) value of $E(B-V) = 0.50$ for the differential extinction to Nova Cyg and a Seaton (1979) reddening law, then during this phase, the true $B-$ Hα color of the object was ~ 3.5 and the blue continuum to Hα flux ratio was $\nu f_\nu(B)/f(\mathrm{H}\alpha) \sim 8$. In other words, during early decline Nova Cyg 1975 emitted roughly as many photons in Hα as in the entire *B* filter. The *B* and Hα light curves for the early stages of Nova Cyg 1975's outburst are reproduced in Figure 1.

Nova Cyg 1986, although much slower, behaved in a similar manner. The light curve of Andronov *et al.* (1988) shows that the object attained a maximum photographic magnitude of ~ 9 on 1986 Aug 9, then began a slow, oscillating decline similar to that of Nova Pictoris 1925 (RR Pic). The spectrophotometry of Whitney and Clayton (1989), however, shows that the nova's Hα maximum did not occur until 2–3 weeks later, when a peak flux of $\sim 2.8 \times 10^{-10}$ ergs cm^{-2} s^{-1} was achieved. After this maximum, the decay rates of the continuum and Hα were roughly the same. If we adopt a differential reddening of $E(B-V) = 0.35$ to the object (Whitney and Clayton 1989), the application of Seaton's (1979) reddening curve implies that during this phase of decline $\nu f_\nu(B)/f(\mathrm{H}\alpha) \sim 25$.

Although these two objects do not by any means represent all novae, the observations of M31 suggest that the above light curves are typical. In the course of our nova survey, we were able to obtain complete coverage of only two novae: Nova 26 in 1985 and Nova 31 in 1986. However, nine other objects were well observed including two which were detected at outburst (Nova 6 in 1982 and Nova 29 in 1986). Figures 2 and 3 display the most complete light curves. A summary of the derivable properties for all the novae is listed in Table 4.

Nova 26 is one of the two novae with a well-sampled light curve. On JD 2,446,345, the object was just barely visible on a *B* image taken at McDonald Observatory; five days later, it was probably past its maximum of $B \approx 17$ and on its way down. The Hα maximum did not occur until ~ 2 weeks later, when the $B-$ Hα color was ~ 2.9. Assuming a foreground

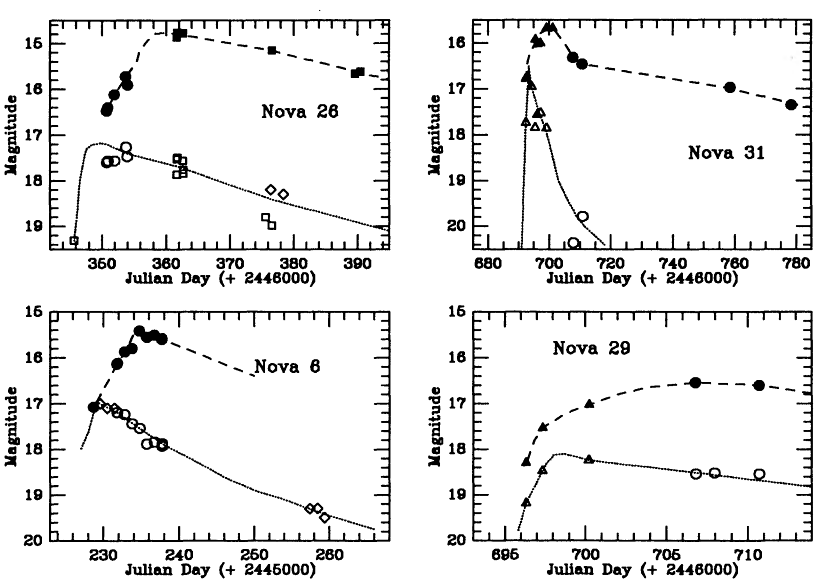

FIG. 2.—The light curves of four M31 novae at outburst. The solid points are Hα magnitudes; the open figures are measurements in *B*. Circles represent observations taken at Kitt Peak, squares are from McDonald Observatory, triangles from the Wise Observatory, and diamonds are photographic magnitudes from the Asiago 1.82 m telescope (Rosino *et al.* 1989). From these four novae and Nova Cyg 1975, there appears to be little correlation between the speed of a nova and its maximum Hα brightness.

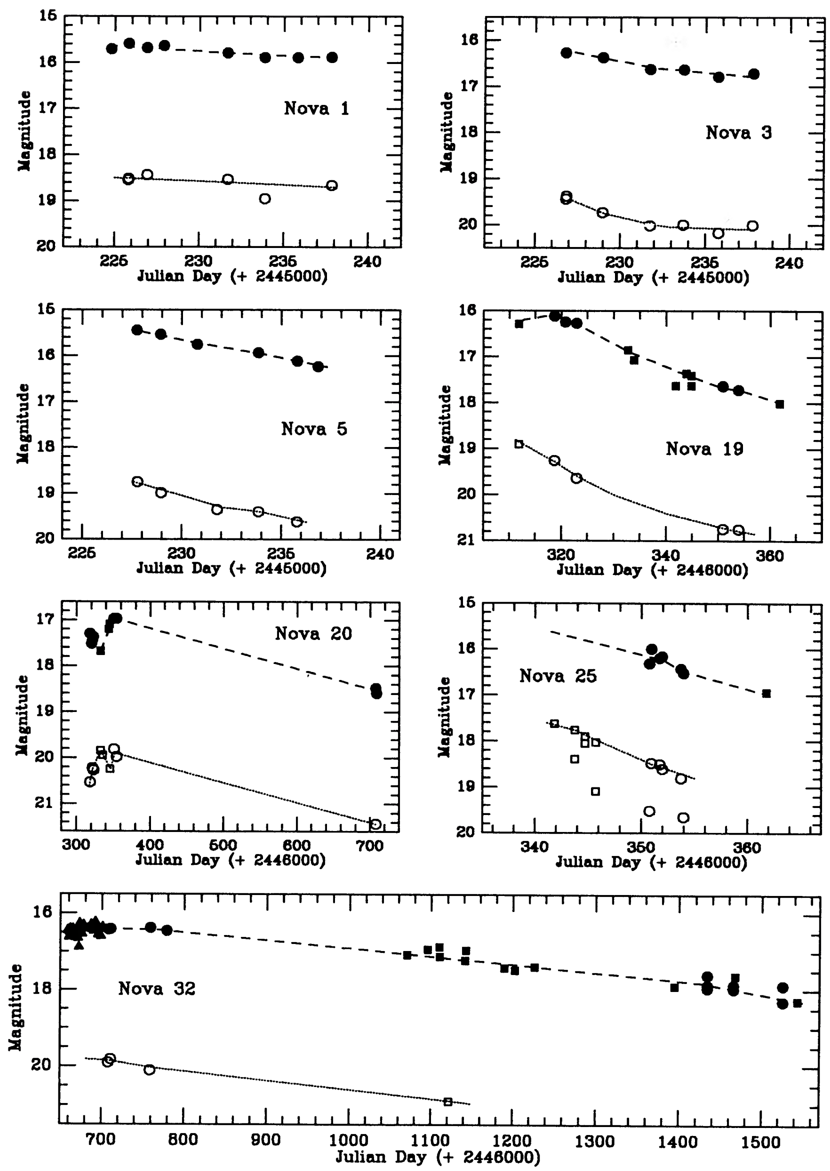

FIG. 3.—The light curves of seven M31 novae observed days or weeks after outburst. The solid points are Hα magnitudes; the open figures are measurements in *B*. Circles represent observations taken at Kitt Peak, squares are from McDonald Observatory, and triangles were taken at the Wise Observatory, Israel. Remarkably, when Hα is in decline, it parallels the *B* light curve, regardless of the object's speed or absolute magnitude.

differential extinction of $E(B-V) = 0.11$ to the bulge of M31 (McClure and Racine 1969), this color implies roughly half as many photons were emerging in Hα as in the *B* filter (a blue continuum to Hα flux ratio of ~ 15). Once past maximum the Hα fade rate of 0.029 mag per day was very similar to the implied *B* fade rate of 0.037 mag per day, which is typical for a moderately fast nova.

Nova 31, the other well-surveyed object, was much faster. The complete coverage around maximum shows that, in the continuum, the nova quickly rose to a maximum $B \lesssim 16.9$, but then faded by over 3 magnitudes within 3 weeks. In Hα, however, the nova remained bright. The data from the Wise Observatory show that the Hα maximum occurred a little over a week past continuum maximum, at a time when *B* had already faded by a magnitude. Despite the rapid decline in *B*, the Hα fade rate, as determined from post-maximum Kitt Peak data was ~ 0.013 mag per day, slower than that of Nova 26. Both the shapes of the light curves and the large $B-\mathrm{H}\alpha$ color are similar to that seen in Nova Cyg 1975.

Despite the lack of coverage in their later stages of evolution, the light curves of Nova 6 and Nova 29 are also instructive for studying the behavior of novae near maximum light. Nova 6 was a fast nova observed at outburst at both Asiago Observatory (Rosino *et al.* 1989) and Kitt Peak. The Hα maximum of this object occurred ~ 5 days after its *B* maximum, when the dereddened $B-\mathrm{H}\alpha$ color was ~ 2.0. Judging from its maximum *B* luminosity, Nova 29 was much slower, but both the time delay between the Hα and *B* maxima and the nova's $B-\mathrm{H}\alpha$ color at Hα maximum were similar to that of Nova 6. (A comparison of Nova 29's position with a $B-\lambda 6200$ color map of M31's bulge [Ciardullo *et al.* 1988] does show that the nova is projected on dust lane, but its $B-\mathrm{H}\alpha$ color at outburst does not indicate an extreme amount of extinction.) Interestingly, Nova 29 must have faded rather rapidly, since 40 days

TABLE 4

PROPERTIES OF M31 NOVA LIGHT CURVES

Nova	At Outburst Maximum Magnitude B_{max}	$H\alpha_{max}$	Baseline (days)	During Optical Decline $\nu f_\nu(B)/f(H\alpha$	Rate (mag/day) B	$H\alpha$	Comment
Nova 1	...	...	13	15.3	0.023	0.022	
Nova 2	...	...	13	...	...	...	Constant during coverage
Nova 3	...	...	11	8.8	0.063	0.046	
Nova 4	...	...	10	38.4	...	...	In decline, but irregular
Nova 5	...	...	9	8.0	0.102	0.084	
Nova 6	17.0	15.42	31	24.2	...	0.080	
Nova 7	< 15.9	< 14.4	31	..	...	...	Bright and irregular
Nova 8	...	...	33	10.6	...	...	Constant during coverage
Nova 9	...	...	33	...	...	0.045	
Nova 10	...	...	5	26.6	0.150	0.167	Possibly irregular
Nova 11	< 16.0	< 14.3	...	...	...	...	Observed near maximum
Nova 12	...	...	2	15.3	...	...	
Nova 13	< 16.9	< 15.0	...	...	...	...	Observed just after maximum
Nova 14	...	...	2	8.8	...	...	
Nova 15	...	...	62	8.0	...	0.017	
Nova 16	...	...	33	12.7	...	...	Constant during coverage
Nova 17	...	...	2	...	...	...	
Nova 18	...	...	4	22.1	...	...	
Nova 19	...	...	50	10.6	0.044	0.046	
Nova 20	...	...	390	12.7	0.0043	0.0044	Irregular, slow decline
Nova 21	< 18.5	< 17.3	...	...	...	...	Observed as continuum source
Nova 22	...	...	33	...	...	...	Irregular
Nova 23	...	...	31	...	...	0.013	
Nova 24	...	...	42	...	...	0.011	
Nova 25	...	...	45	22.1	0.094	0.074	
Nova 26	17.26	14.76	29	14.0	0.037	0.029	Full coverage
Nova 27	< 15.6	< 13.9	...	...	...	...	Observed near maximum
Nova 28	< 19.0	< 17.7	...	...	...	...	Observed as continuum source
Nova 29	18.24	16.54	4	32.0	...	...	
Nova 30	...	...	...	...	...	...	
Nova 31	16.95	15.68	71	...	...	0.013	Rapid initial decline in B
Nova 32	...	...	867	8.0	...	0.0018	Extremely slow
Nova 33	...	...	...	...	...	...	
Nova 34	...	...	...	...	...	...	
Nova 35	...	...	2	...	...	...	
Nova 36	...	...	...	...	...	...	
Nova 37	...	...	32	...	...	0.011	
Nova 38	...	...	...	...	...	...	
Nova 39	...	...	32	...	...	...	Constant during coverage
Nova 40	...	...	...	...	...	...	

past maximum its B continuum could not be detected at Asiago, and 60 days after outburst, its Hα emission was invisible on the Kitt Peak frames.

The light curves shown in Figure 3 demonstrate the behavior of Hα at later stages of nova evolution. Though the fade rates of the seven novae vary dramatically, from the rapid rate of ~0.08 mag per day seen in Nova 5 and 25 to the extremely slow decay of 0.67 mag per year observed for Nova 32 (see Cowley and Starrfield 1987 and Tomaney and Shafter 1990 for spectra of this object), in none of these cases is there a statistically significant difference between the B and Hα decay rate. Though none of these objects was recorded at outburst, and thus their ages are not known, there appears to be no relationship between the observed Hα magnitude and rate of decline. On both short and long time scales, however, the evidence is clear that the Hα and B magnitudes are well correlated.

When considered together, these 11 objects present a coherent picture of the behavior of novae in Hα. When a nova first goes off, the Hα and B light rise in unison until the B maximum is achieved. At this point, the object's $B - H\alpha$ color of ~0.5 represents the continuum emission of its A or F type photosphere, which is radiating at or near the critical Eddington luminosity for the progenitor white dwarf plus red dwarf. Shortly after this maximum, the gas which is being expelled from the system becomes optically thin in the continuum, and the nova's broad-band emission begins to decline, while an Hα emission line starts to develop. For a short period of time which is extremely well correlated with the nova's speed, B and Hα go their separate ways: the broad-band B luminosity drops, while Hα continues to increase. In the case of Nova Cyg 1975, which is the fastest nova in the sample and the fastest nova on record, the increase in Hα lasted only 2 days past maximum light; for the slower Nova Cyg 1986 and M31 Nova

29, the Hα emission intensified for over 2 weeks. After this maximum, however, the Hα light curve turns over and the emission begins to decay at a rate almost equal to the decline in B. During a nova's decline, its mean $B - \mathrm{H}\alpha$ color is $\sim 2.7 \pm 0.6$, a number which translates into a blue continuum to Hα flux ratio of 17 ± 10. The intrinsic scatter in this relation is real: a comparison of the $B - \mathrm{H}\alpha$ nova colors with the underlying color of the galaxy, as measured from the $B - \lambda 6200$ color map of Ciardullo *et al.* (1988), shows no systematic trend.

The key to understanding a nova's behavior in Hα lies in understanding its slow decline, which parallels that of the B continuum. Upon outburst, the central engine of a nova maintains a constant bolometric luminosity near its Eddington limit for weeks or months. However, as matter is ejected in the nova explosion, the photosphere of the object shrinks in radius, and as a result, the effective temperature of the central source increases from ~ 8000 K at optical maximum, to $\sim 200{,}000$ K (Bath and Shaviv 1976; Bath 1978; Prialnik, Shara, and Shaviv 1978, 1979; Gallagher and Starrfield 1978). This flux redistribution decreases the amount of energy radiated in the optical, but produces a large increase in the number of emitted UV and EUV photons. However Hα, which is a product of photoionization from UV photons, does not undergo a similar increase. Instead, a nova's Hα flux fades at the same rate as its B continuum. Out of our sample of 40 novae, 13 were observed in both B and Hα at multiple epochs during decline. All of these objects, regardless of magnitude or speed class, behaved in a like manner: after Hα maximum, the B and Hα decay rates were the same. This property was also observed in Nova Cyg 1975 (cf. Fig. 1) and Nova Cyg 1986. If the bolometric luminosity of a nova is indeed constant during this phase, then it is exceedingly difficult, if not impossible, to achieve this coupling if the B luminosity comes from the central remnant and the Hα emission emanates from the envelope.

There are several possible solutions to this problem. The first, and simplest, is to hypothesize that the B filter bandpass is dominated by nebular emission lines, and hence the recorded B magnitudes do not reflect the level of the continuum. There is some truth to this: during the latter stages of nova evolution, the lines which fall in the B filter, Hβ, Hγ, Hδ, [O III] λλλ4363, 4959, 5007, the λ4640 blend, and several Fe II lines, can emit a total flux comparable to that of Hα. However, in most novae, the observed ratio of B to Hα flux is ~ 3 times stronger than this value. Moreover, as discussed below, for novae in early decline, steep Balmer decrements are the rule and forbidden line emission is suppressed by high nebular densities. Additional evidence attesting to the relative unimportance of emission lines in the B band comes from Strömgren y photometry of Nova Cyg 1975 (Lockwood and Millis 1976). As displayed in Figure 1, between optical maximum and $t \approx 30$ days, there is no significant difference between the nova's decay rate in y and B. Since no emission lines exist in the 200 Å wide y filter, this fact demonstrates directly that B is indeed recording the object's continuum. The effect of emission lines in the B bandpass can be seen in the divergence of the y and B light curves at later times, but significantly, it is the y light curve which better reflects the emission in Hα.

A relatively easy way of coupling a nova's B and Hα emission is to postulate that both the Hα emission line and the optical continuum are produced in the expanding nebula. If this is the case, the similarity in the two light curves is a natural consequence of the nebula physics and the relative intensities of the continuum and Hα line is a probe of the electron temperature of the nebula (Osterbrock 1974). Unfortunately, although there is no problem in fitting the continuum shape with nebular emission—the optical flux distribution of Nova Her 1960 (Meinel 1963) and Nova Her 1963 (Chalonge *et al.* 1965), and the infrared spectrum of Nova Cyg 1975 (Gallagher and Ney 1976) have all been fitted with simple one component nebular emission models—the observed blue continuum to Hα ratio is much too large for this explanation. In the 13 best observed declining novae of Table 4, and in Nova Her 1960 (Meinel 1963), Nova Cyg 1975 (Ferland, Lambert, and Woodman 1986), and Nova Cyg 1986 (Whitney and Clayton 1989), $\nu f_\nu(B)/f(\mathrm{H}\alpha)$ never got below 8 and were observed to be as high as 38. In a Case B recombination nebula with electron temperatures less than 20,000 K, however, a number closer to 1 is expected. Now it may be possible to change this ratio by assuming additional sources of continuum emission, such as a coronal line region (Ferland, Lambert, and Woodman 1986), but it is difficult to lock this independent emission to Hα in every object. Furthermore, as noted by McLaughlin (1960) and Gallagher and Starrfield (1976), there is a correlation between the color temperature of a nova and its visual magnitude—as a nova fades, its color becomes bluer. This can most easily be explained in terms of an increasing effective temperature for the central source. Indeed, models in which most of a nova's luminosity comes from a thermonuclear runaway on the central remnant have been extremely successful at reproducing bolometric and optical light curves (e.g., Sparks, Starrfield, and Truran 1978; Starrfield, Sparks, and Truran 1985) near maximum. If the observed optical continuum actually emanates from the expanding envelope, then a new explanation must be found to explain why a nova's optical light fades while its bolometric luminosity remains constant. In addition, the photometric observations of Nova Cyg 1975 by Patterson (1978) add an additional complication to the nebula emission model. While in outburst, Nova Cyg 1975 displayed a ~ 3 hr photometric period which almost certainly originated with the central binary. Thus, at least in this one object, some of the optical continuum must have come from the core of the system rather than the nebula.

A better way of explaining the covariance of Hα with B comes from considering one of the most obvious characteristics of a nova's post-maximum spectrum: its steep Balmer decrement. Most novae in early decline have Balmer decrements that are much larger than predicted by Case B recombination. In Nova Cyg 1975, the reddening corrected Hα/Hβ ratio rose to ~ 9 within 3 weeks of outburst, and remained above ~ 6 for over a year (Ferland, Lambert, and Woodman 1986). Similarly steep decrements have been observed in a host of other novae, including Nova Her 1960 (Meinel 1963), Nova Sct 1975 (Gallagher 1978), Nova Sgr 1982 (Mazeh *et al.* 1985), Nova Cyg 1986 (Whitney and Clayton 1989), and five M31 novae (Ciardullo, Ford, and Jacoby 1983; Cowley and Starrfield 1987). The reason for these large line ratios is the optical thickness of the nova shell to Balmer photons. Shortly after outburst, extremely high optical depths in Hα ($\tau \gtrsim 1000$) are not uncommon in the expanding nebula of a nova. Strittmatter *et al.* (1977) demonstrated that the strong O I λ8446 emission seen throughout the first 48 days of Nova Cyg 1975 was the result of resonance-florescence of $2p\ ^3P_2$–$3d\ ^3D^o$ λ1025.77 by Lyβ λ1025.72 (Bowen 1947), and, as pointed out by Grandi (1980), this mechanism only works if the gas is optically thick in Hα. (If the nebula is optically thin in Hα, then Lyβ can be removed by decaying into Hα + Lyα.) Strong O I emission has also been seen in the post-maximum spectra of Nova Sct 1975 (Gallagher 1978), Nova Sgr 1982 (Iijima and Rosino 1983), and Nova Vul 1984 No. 2 (Andrillat and Houziaux 1985), confirming the frequency of the phenomena. In such cases, Balmer self-absorption produces steep Balmer decrements in virtually all nebula with electron densities between $10^8 \le n_e \le 10^{12}$ (Drake and Ulrich 1980). Ferland, Lambert, and Woodman's (1986) measurement of the strength of [O III] λ4363 relative to [O III] λ5007 + λ4959 shows that 6 weeks after outburst, the electron density of Nova Cyg 1975 was certainly in this range (cf. Osterbrock 1974; Filippenko and Halpern 1984) and the general absence of strong forbidden lines in the post-maximum spectra of novae (McLaughlin 1960) suggests that such high densities are not uncommon. Thus, there is strong evidence that novae contain a region where Hα is trapped by its high optical depth.

This being the case, a new avenue exists to explain the covariance of Hα with the continuum. If a nova shell is optically thick in Hα, then its emission in the Balmer lines can be several magnitudes smaller than predicted by the Case B scenario due to self-absorption in the lines (Canfield and Puetter 1981). The strength of the continuum is then no longer a problem, since the nebular emission can dominate the flux emitted from the central source without generating huge line fluxes. The variation of Hα with the continuum is then a natural consequence of the nebular physics of a high-density, optically thick zone. Furthermore, if the Hα optical depth reaches $\tau_{\mathrm{H}\alpha} \sim 2000$, as it appears to have done in Nova Cyg 1975 (Strittmatter *et al.* 1977), the nova shell can become optically thick in the Balmer continuum as well, thus shielding our view of the central engine in the near-ultraviolet and, in the reprocessing, strengthening the optical and IR continuum even more.

If the above scenario is correct, the following picture of a nova outburst emerges. When a nova first goes off, its spectrum is that of an expanding photosphere, and consequently, the luminosity of the object reflects its size. Eventually, as the density of this photosphere decreases, the central source becomes optically thin in the continuum, and the luminosity increase is halted. (In a few exceptional objects with super-Eddington emission, such as Nova Cyg 1975, a rapid decrease in brightness may also occur at this point.) The region immediately surrounding this photosphere, however, is still very optically thick in the Balmer lines, and the temporary increase in Hα luminosity immediately after continuum maximum reflects the extra expansion of this "Hα photosphere." As the eruption continues and the mass injection rate decreases, the density throughout the wind drops and the Hα photosphere moves inward. It is this contraction which produces the observed decline in the Hα and continuum emission fluxes.

Work in two areas would improve our understanding of nova outbursts. First, detailed models of the physical processes occurring in thick winds powered by a photosphere evolving at approximately constant luminosity are needed. Comparison of such models with the present observations would give new insights into the physical processes which take place during the ejection of a nova envelope. Second, more observations in the ultraviolet are required during a nova's early decline. After maximum, the effective temperature of the central remnant increases from ~8000 K to ~200,000 K. If the flux from this source is not overwhelmed by emission from the Hα photosphere, this change should be detectable with ultraviolet telescopes, such as *IUE* (or the *HST*). Unfortunately, the *IUE* nova observations to date appear to be either of a relatively cool photosphere, or an extremely hot central remnant. Ultraviolet observations during several stages of a nova's early decline are needed in order to try and fill in the gap.

IV. Hα LIGHT CURVES AS A DISTANCE INDICATOR

Because there are well-defined relationships between a nova's maximum B magnitude and its rate of decline (de Vaucouleurs 1978; Cohen 1985; van den Bergh and Pritchet 1986), it is tempting to try and find a similar relationship involving its Hα emission. Unfortunately, the present data suggests that no such relationship exists. Although only four M31 novae have both their speed and Hα maximum recorded, the light curves of these objects, along with that of Nova Cyg 1975 and Nova Cyg 1986, imply that there is no correlation between a nova's rate of decline and its maximum Hα magnitude. For instance, although Nova 26 and Nova 6 both declined by 2 magnitudes in ~25 days, Nova 26, the slower nova, attained an Hα magnitude almost 0.7 mag brighter than Nova 6. The two fastest novae in our study, Nova 31 and Nova Cyg 1975, both declined by three B magnitudes within 3 weeks, but while Nova Cyg's Hα flux decreased by 2 magnitudes within a month, this same decay in Nova 31 took over 3 months. At the other end of the spectrum, Nova 29, an apparent slow nova, got no brighter than $m_{\mathrm{H}\alpha} = 16.5$ but faded from view within 60 days. Nova 32, however, was first detected at $m_{\mathrm{H}\alpha} = 16.5$ and remained visible for over 2 yr. All this evidence leads to the conclusion that there is no correlation between a nova's speed and its maximum Hα flux.

This lack of correlation is consistent with the theoretical idea that the speed of a nova is determined by its metallicity, Z, its envelope mass M_{env}, and its white dwarf mass, M_{wd} (cf. Shara 1989). M_{env} and Z are determined by the accretion history of the white dwarf before eruption, and this may vary from system to system. Thus novae with the same envelope mass but different accretion histories, and hence different envelope Z, can display different speeds. If the Hα flux is mostly determined by envelope mass, then the lack of correlation is understandable.

Despite this discouraging result, the Hα emission from novae can still be useful for extragalactic distance determinations. In order to obtain a distance with a conventional maximum magnitude–rate of decline relation, the continuum of a nova must be followed at least 2 or 3 magnitudes below maximum. For novae in distant galaxies, this observation is extremely difficult and is limited by the bright, rapidly varying background of the parent galaxy. However, as Figure 3 demonstrates, once a nova passes Hα maximum, its B and Hα light curves parallel. Since Hα is much easier to detect during this phase, observations in Hα present an easy way to measure the decline of an undetectable continuum.

There is, of course, a basic limitation to this technique. The correlation between a nova's continuum and Hα flux takes place only after the emission line has fully developed. Any fading which occurs before this time is lost and cannot be recovered with narrow-band observations. Thus for fast novae, such as Nova Cyg 1975 and M31 Nova 31, surrogate measurements in Hα cannot be used in the maximum magnitude–rate of decline relation. Hα observations can, however, be useful for estimating the rate of decline of slower novae, and therefore may be of some use in the determination of extragalactic distances.

V. THE MEAN Hα LIFETIME

Although a nova's Hα emission does not appear to offer an opportunity for extragalactic distance measurements, its high visibility does make it ideal for studying the population of nova progenitors. Paper I noted that there is a strong dependence of nova rate on stellar population; specifically the overwhelming majority of novae in M31 are associated with the bulge. This high rate may be due to some internal property of the bulge (e.g., the age of the population, the mean star density, etc.), or it may be caused by the formation and ejection of close binaries by globular clusters (cf. Paper I). Periodic Hα surveys of nearby galaxies can examine these alternatives.

In order to use Hα observations to calculate extragalactic nova rates, the mean lifetime of a nova in Hα is needed. This number can be estimated from Paper I's M31 bulge survey in two ways. An upper limit to the Hα lifetime of a nova can be found from the light curves of Figures 1–3. Of the best observed novae, the most rapid Hα decline was that of Nova Cyg 1975, which faded 3 magnitudes in 32 days; the slowest decay rate belonged to M31 Nova 32, which remained bright in the emission line for more than 2 yr. If we take the estimated decay rates listed in Table 4 to be representative of the entire nova population and assume that the Hα maximum typically occurs ~1 week after outburst, then the median time for a nova to fade 3 mag in Hα is ~240 days. This value, based on the fragmentary light curves recorded in M31, is an upper limit, since a nova's rate of decline will normally slow with time and our limited coverage selects against the fastest objects. Nevertheless, the 240 day period of detectability gives some idea of the power of Hα measurements for finding recent novae.

Since the purpose of estimating the mean nova Hα lifetime is to measure extragalactic nova rates, a more appropriate method for determining this quantity is to count the number of novae actually observed in the Hα survey and divide by the true nova rate. This technique, which derives from the methodology used by Zwicky (1942) to determine the rate of extragalactic supernovae, requires only that the effective survey time be calculated.

The amount of time sampled by any individual survey frame depends on when the preceding survey took place. If we define the mean nova lifetime, τ_c, to be the length of time a nova remains brighter than m_c, then the time sampled by a single image taken at epoch t_i is

$$T_i = \min\,(t_i - t_{i-1}, \tau_c)\,. \qquad (1)$$

The mean nova lifetime is then derivable from the true nova rate, R, by solving the relation

$$R = \frac{N(m < m_c)}{\tau_c + \sum_{i=2}^{n} T_i}\,, \qquad (2)$$

where $N(m < m_c)$ is the number of novae observed brighter than the critical magnitude identified over n epochs.

Unfortunately, in order to calculate τ_c, the true nova rate within the region must be known. One way to estimate this is to adopt the Capaccioli *et al.* (1989) value of 23.2 ± 4 for the annual nova rate in M31's bulge. When normalized to Walterbos's (1986) value of $B = 5.21$ for the total bulge magnitude,

TABLE 5

MEAN LIFETIMES IN Hα FOR M31 NOVAE

Apparent $m_{\mathrm{H}\alpha}$	Absolute $M_{\mathrm{H}\alpha}$	Number of Novae Observed	Mean Hα Lifetime (days)
15.00.....	9.53	3	$7.3^{-4.8}_{+5.0}$
15.50.....	−9.03	7	$20.4^{-9.1}_{+4.3}$
16.00.....	−8.53	10	$26.1^{-6.3}_{+14.0}$
16.50.....	−8.03	17	$58.0^{-19.1}_{+22.1}$
17.00.....	−7.53	24	$95.6^{-26.4}_{+31.5}$
17.50.....	−7.03	29	$127.6^{-34.1}_{+28.3}$

and scaled to a distance of 710 kpc (Welch *et al.* 1986) and a foreground extinction of $E(B-V) = 0.11$ (McClure and Racine 1969), this estimate implies a luminosity specific nova rate of $\rho_{\mathrm{Bulge}} \approx 24$ yr^{-1} per 10^{10} $L_{B\odot}$. (The Capaccioli *et al.* value of $\rho_{\mathrm{Bulge}} \approx 10$ yr^{-1} per 10^{10} $L_{B\odot}$, which is based on the assumption that there is over a magnitude of internal extinction in M31's bulge, leads to mean Hα lifetimes of well over a year. Although some dust does exist in M31's inner bulge [cf. Ciardullo *et al.* 1988], it is certainly not enough to change the estimated rate of nova production by more than a few percent.) If the bolometric correction applicable to the bulge of M31 is −0.80 (Ciardullo *et al.* 1989), then the bolometric luminosity specific nova rate of M31 is $\rho_{\mathrm{Bulge}} \approx 10$ yr^{-1} per 10^{10} $L_\odot$.

Scaling this rate to the amount of light included in our Hα survey region ($B = 6.00$) gives an effective nova rate of ~11.2 ± 2. Substituting this rate into equation (2) and using the Kitt Peak survey periods listed in Table 1, yields the Hα lifetimes tabulated in Table 5. (The errors associated with the Hα lifetimes reflect only the Poisson statistics of the small number of novae.) The absolute magnitudes presented were derived by again using a distance of 710 kpc (Welch *et al.* 1986), a differential extinction of $E(B-V) = 0.11$ (McClure and Racine 1969), and the interstellar extinction law of Seaton (1979). Because novae fainter than $m_{\mathrm{H}\alpha} \approx 17.3$ were missed within ~20″ of the nucleus, the last entry in Table 5 excludes novae within this region. The overall relationship defined by the table is a featureless power law, with a least-squares relation

$$\log \tau(M < M_c) \approx 5.6 + 0.48 M_c\,, \qquad (3)$$

with τ given in days. By using this relationship and scaling extragalactic surveys to the luminosity sampled in M31, the nova rates for other galaxies can be determined through multi-epoch Hα observations.

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ROBIN CIARDULLO: Kitt Peak National Observatory, P.O. Box 26732, Tucson, AZ 85726

HOLLAND C. FORD, JAMES D. NEILL, and MICHAEL M. SHARA: Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

ALLEN W. SHAFTER: Department of Astronomy, San Diego State University, San Diego, CA 92182

A. B. TOMANEY: Department of Astronomy, University of Texas, RLM 15.308, Austin, TX 78712