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Authors	DELLA VALLE, Massimo, Duerbeck, H. W.
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Study of nova shells

I. V1229 Aquilae (1970): nebular expansion parallax and luminosity

M. Della Valle[1,2] **and H.W. Duerbeck**[1,3]

[1] European Southern Observatory, La Silla, Casilla 19001, Santiago 19, Chile
[2] Dipartimento di Astronomia, Università di Padova, Italy
[3] Astronomisches Institut, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

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Abstract. The maximum magnitude – rate of decline (MMRD) relation of classical novae is briefly reviewed, and attention is drawn on superluminous and subluminous novae. Such objects play an important role when the MMRD relation is applied to small or magnitude-limited samples of novae. Direct imaging tance, reddening and luminosity are derived. With $M_V = -6.7$, V1229 Aql is 1^m fainter than predicted by the MMRD.
V1229 Aql is 1m fainter than predicted by the MMRD.

Key words: stars: novae – stars: individual: V1229 Aql – stars: distances

1. Introduction

The quest for luminosities of novae at maximum light is of continuing actuality, since novae are often used as distance indicators of galaxies in the Local Group (see Jacoby et al. 1992 for a review) and beyond, out to the distance of the Virgo Cluster (Pritchet & van den Bergh 1987). Their use as distance indicators is based on the relationship between the absolute visual or photographic magnitude at maximum and the rate of decline (henceforth MMRD), the latter normally being the time, measured in days, which the nova takes to drop two magnitudes from maximum.

Main problems associated with the use of novae as distance indicators are:
(1) to determine the shape and zero point of the MMRD,
(2) to ascertain the universality of the MMRD,
(3) to estimate the amount of intrinsic cosmic scatter, which at faint levels of luminosity may induce considerable errors in fitting the MMRD to data points because of Malmquist bias.

The problems connected with the determination of the shape of the MMRD and its zero point were reviewed recently by Capaccioli et al. (1989, 1990). By comparing the properties of the nova populations in M31, LMC and in the Galaxy, the authors were able to conclude that within $0\overset{m}{.}25$ the MMRD appears to be a universal relation. Differences between the nova populations of M31 and the LMC concern only the frequency of occurrence of fast and slow novae (Duerbeck 1990; Della Valle 1992), but do not affect the zero point of the MMRD.

The determination of intrinsic scatter is problematic, since the scatter due to observational errors is always superimposed upon cosmic scatter. Both are difficult to disentangle, especially if one uses objects in the Galaxy, where interstellar extinction influences the magnitudes of novae to a varying extent, which is not easy to correct. Furthermore, the large area that has to be surveyed for the discovery of galactic novae often causes delayed discoveries, making the estimate of the apparent magnitude at maximum difficult.

A suitable route to surmount these problems is to study the MMRD derived from a sample of novae all placed at the same distance and, at least on the average, suffering extinction to the same extent, e.g. novae in M31 or in the LMC. Due to the small uncertainty currently estimated for distances to galaxies of the Local Group (≈ 10 %, according to van den Berg 1990) the dispersion of the relationship should mainly reflect the intrinsic scatter of the relation.

In a discussion of those novae in the Galaxy, M31, and the LMC, for which most reliable data are available, Della Valle (1991) showed that ≈ 90% of them are found inside a δm-strip of $\pm 0\overset{m}{.}5$ ($\pm 3\sigma$). The contribution to the scatter due to photometric errors is ≈ 10%, a further ≈ 10% originates from the $0\overset{m}{.}2$ uncertainty affecting the distance modulus of M31. All this leads to a number of consequences:
(1) the MMRD relation has an intrinsic dispersion of $\approx 0\overset{m}{.}4$.
(2) 'anomalous' objects make up 10%; they are almost equally distributed above or below the strip, and deviate from the mean relation by $\approx 6\sigma$ on the average ($1\sigma = 0\overset{m}{.}17$, according to Capaccioli et al. 1990).
(3) the existence of superbright novae casts doubts on the applicability of the MMRD as a distance indicator when the sample includes only a few objects.

Send offprint requests to: H.W. Duerbeck, Münster address.

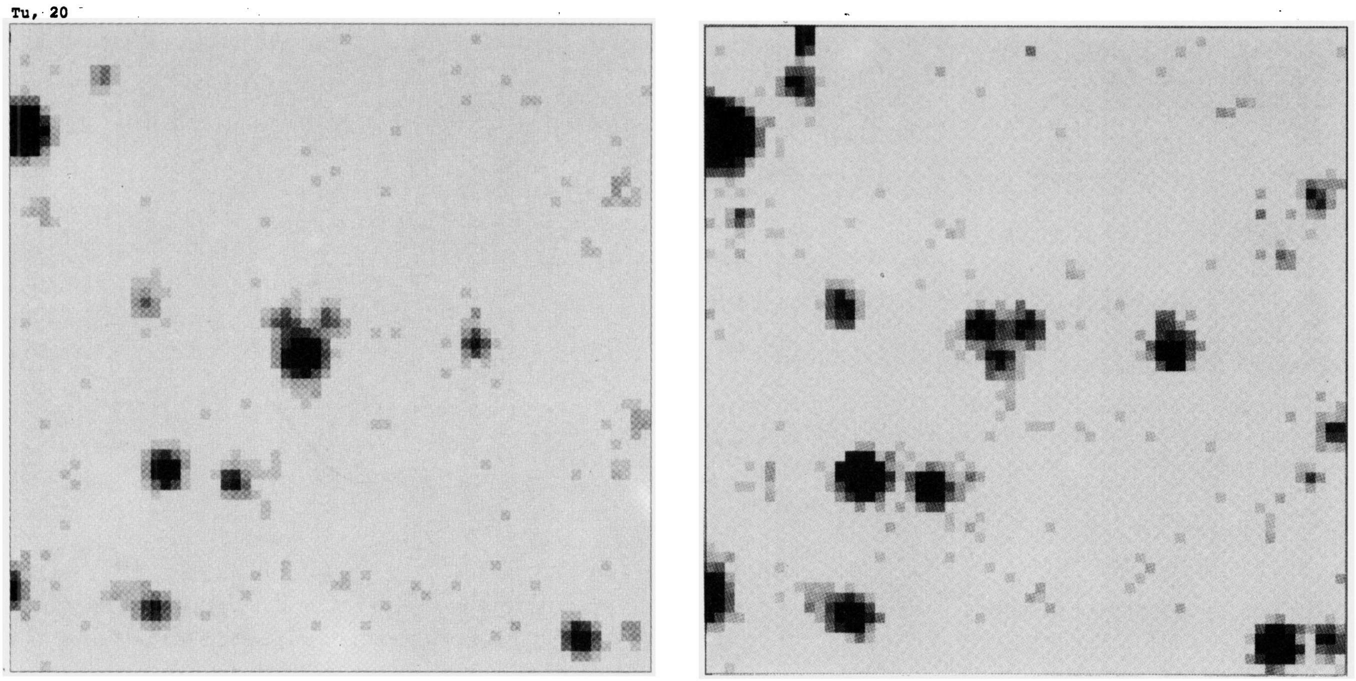

Fig. 1. Hα-on (left) and Hα-off (right) direct images of V1229 Aql, taken with EFOSC-1 attached to the ESO 3.6-m-telescope. North is up, east to the right. The scale is $0\stackrel{''}{.}60$/pixel

The objects above the strip may define a 'fair' homogeneous class of superbright novae, systematically brighter by one magnitude than the absolute magnitude expected by their rate of decline. Since the superbright nova LMC 1991 (Della Valle 1991) is also the first recognized extragalactic neon nova (Starrfield 1992), one may associate neon novae (or a subgroup of them) with these superbright events.

Novae below the main relation are an assortment of inhomogeneous objects. They possibly comprise heavily obscured normal novae like A4 in M31 (Arp 1956) and Nova LMC 1951 (Buscombe & de Vaucouleurs 1955), or objects like R48 and R79 in M31, which were suggested by Rosino (1973) to be two outbursts of the same recurrent nova (it is interesting to note that the recurrent nova in the LMC is also underluminous). Finally we note the presence of intrinsically faint well-investigated galactic novae like HR Del ($\approx 1\stackrel{\mathrm{m}}{.}65$ below the main relation), or V1668 Cyg ($1\stackrel{\mathrm{m}}{.}8 \pm 0\stackrel{\mathrm{m}}{.}5$ below the main relation) (Friedjung 1992; Duerbeck et al. 1980).

More and better data on novae are urgently needed to provide a a secure statistical footing of these trends. We have started a project to improve the statistics of distances and luminosities based on nebular expansion parallaxes. Besides a preliminary study of the luminosity of FH Ser (Duerbeck 1992), the first paper deals with a little-known, fainter twin of FH Ser, also discovered in 1970: Nova V1229 Aql.

2. Past and present observations of V1229 Aql

V1229 Aql was discovered by Honda (1970) on 1970 April 14.787 (UT) at about magnitude 7. Several prediscovery photographs indicate that the outburst took place after April 8. Photographs taken April 12.76 and 12.77 show the nova at $m_{\mathrm{vis}} = 6.5 - 6.7$. For the following discussion, we will assume April 12.0 and $6\stackrel{\mathrm{m}}{.}5$ as time and visual magnitude at maximum.

B and V light curves and medium-resolution spectroscopy are reported by Ciatti & Rosino (1974). The light curve is that of a quite fast nova (t_2 = 19d, t_3 = 32d as derived from the V light curve). The apparent photographic magnitude at minimum on the Palomar prints (Duerbeck 1987) yields an outburst amplitude of $\approx 12\stackrel{\mathrm{m}}{.}5$, which is normal for such a fairly fast nova. In mid-May a noticeable brightness drop set in, and in early June infrared dust emission was observed (Geisel et al. 1970). The light curve shape resembles very much the well-studied nova FH Ser.

On April 15.79, radial velocities of absorption lines of -600 km s^{-1} were measured on high-resolution spectra (Tsuji 1970). Two days later, the width of the Hβ emission was 1540 km s^{-1} (Cowley 1970). Nine to twelve days after maximum, Ciatti & Rosino observed two absorption systems with -745 and -1420 km s^{-1}. 20 days after outburst, the emission bands had split into two components, a weaker blue one with -311 ± 12, a stronger red one with $+371$ km s^{-1}. Due to the weakening of the continuum, absorption velocities of -1280 and -2180 km s^{-1} are somewhat uncertain. One month after outburst, the emission components had reached equal strength, and the absorption had almost disappeared. Between May and July, the nova went through the nebular stage, and Ciatti & Rosino reported a fading of the redshifted components – a fact that can easily be explained by the abovementioned dust formation. The blueshifted lines had an average velocity of -1000 km s^{-1} at this stage.

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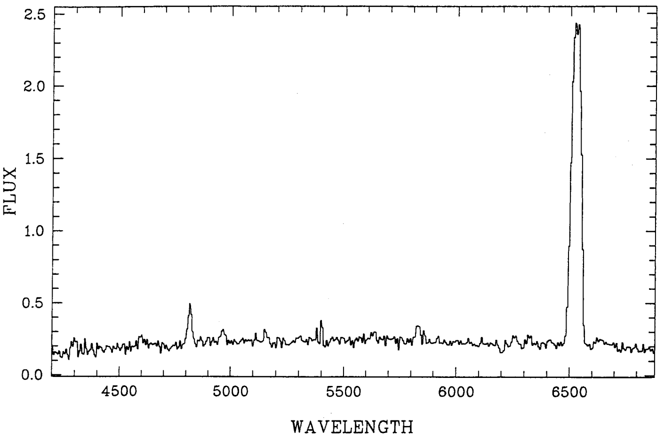

Fig. 2. Low resolution spectrum of V1229 Aql, taken with EFOSC-I at the ESO 3.6m-telescope, covering the range 3800-7200 Å

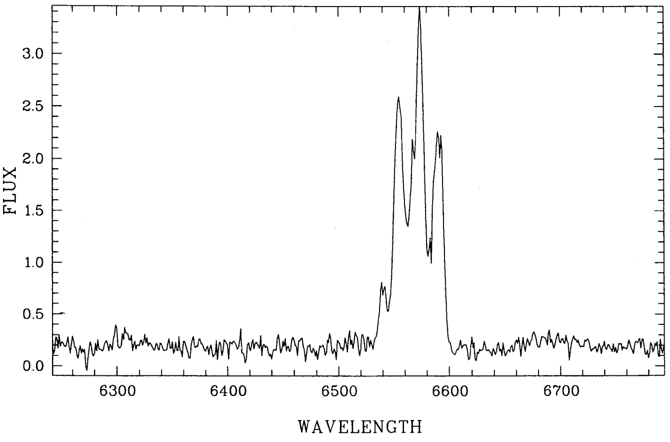

Fig. 3. Spectrum of V1229 Aql, taken with EFOSC-II at the ESO/MPI 2.2 m telescope, covering the range 6200-6700 Å

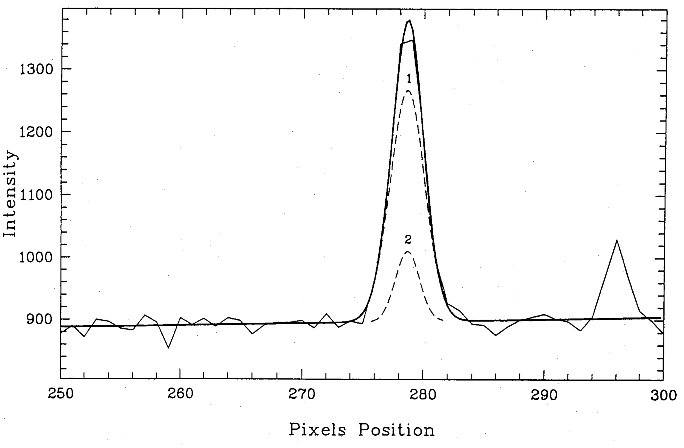

Fig. 4. Subtraction of the stellar continuum (2) from the Hα profile, yielding the nebular profile (1)

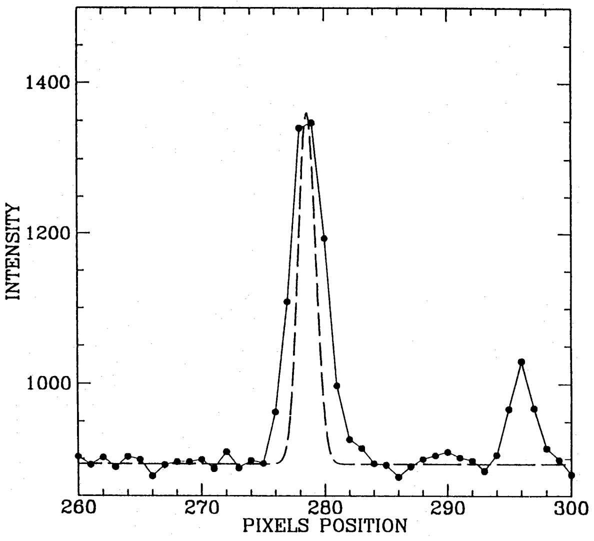

Fig. 5. The nebular profile of V1229 Aql, as compared to a point spread function

For a determination of the nebular expansion parallax, knowledge of the expansion velocity of the shell is of paramount importance. However, in this case (as in many others) it is difficult to choose from the above data 'the' expansion velocity of the shell that became visible later. This problem will be addressed in Sect. 3.2.

A first visibility of the shell was reported by Cohen (1985) who found a radius of 0.7″ in 1984, from which an expansion rate of 0.05″ yr^{-1} is derived. She assumed an expansion velocity of 575 km s^{-1}, based on spectrographic observations of the nebular Hα emission at the time of the direct observation of the shell, an apparent visual magnitude at maximum of $6^{\mathrm{m}}\!.5$, an interstellar extinction $A_V = 1.2 \pm 0.5$ (a 'rough guess', as stated by the author), and derived an $M_V = -6.6$.

We observed the shell on a direct CCD frame, exposed for 5 minutes through an Hα filter (Fig. 1a) with EFOSC-I attached to the ESO 3.6m-telescope on July 9, 1992, under fair seeing conditions (better than 1.4″). A 5 minute Hα filter off–band frame was obtained for the subtraction of the continuum (Fig. 1b). A low resolution spectrum, covering the range 3800-7200 Å was also obtained during the same run (Fig. 2).

In order to determine the expansion velocity of the nebula, we obtained with EFOSC-II at the ESO/MPI 2.2 m telescope on July 31, 1992 a spectrum of the region around Hα (5900-7000 Å), with a resolution of ≈ 3.5 Å (Fig. 3).

3. Results

3.1. The direct image

We have first subtracted from the Hα profile the contribution of the continuum, as inferred from the Hα-off-band profile (see Fig. 4), and then deconvolved (Lucy 1974) the pure nebular profile with the point spread function (Fig. 5) in MIDAS environment, both along X and Y directions. Within the limits of the Gaussian approximation, the FWHM of the deconvolved profile, which turns out to be $\langle R \rangle = (1.59 \pm 0.13)''$, is a good estimate of the radius of the nebula. Possible deviations from spherical expansion are smaller than ≈ ±10%.

This result implies an annual expansion rate of $(0.072 \pm 0.007)'' \mathrm{yr}^{-1}$, which compares reasonably well with the value obtained by Cohen (1985).

3.2. The spectral profile of the Hα complex

The red spectrum taken at higher resolution shows a complex Hα-[N II]-blend. The only other remarkable feature is the shape and the intensity of the lines of [O I] 6300, 6365. Their ratio is 1 rather than ≈ 3, which can only be understood if the 6365 line is blended with [Fe X] 6375.

A Gaussian fit routine was used to decompose the multi-component profile of the Hα + [N II] lines that originate in the nova shell. We started from the position of the bluemost feature, which we interpreted as a blueshifted $[\mathrm{N\,II}]_{6548}$ component, and from the redmost feature, which we interpreted as a redshifted $[\mathrm{N\,II}]_{6584}$ component. With these assumptions, the known laboratory wavelengths of all lines, and the known 1:3 ratio of the blue and red [N II] line, we obtained the satisfactory solution listed in Table 1. The radiation of the shell is concentrated in two regions which show a mean radial velocity of ± 340 km s^{-1} relative to the observer.

Table 1. Parameters of the multiple Gaussian fit

comp.	amplitude	position	σ (Å)	area	line
1	0.53	6540.7	4.4	5.83	$[\mathrm{N\,II}]_{6548}$
2	0.72	6555.5	4.4	7.90	$[\mathrm{N\,II}]_{6548}$
3	1.69	6555.5	4.4	18.62	Hα
4	1.90	6570.4	4.4	20.70	Hα
5	1.59	6576.0	4.4	17.53	$[\mathrm{N\,II}]_{6584}$
6	2.17	6590.5	4.4	23.93	$[\mathrm{N\,II}]_{6584}$

The two emission components seem to correspond to those observed already 20 days after outburst. They might originate in certain condensations in the shell (e.g. an inclined equatorial ring), and a direct use of the data as the true expansion velocity must be avoided.

One of the best-studied nova outbursts is that of DQ Her. Spectroscopic observations during outburst are summarized by McLaughlin (1937), and a recent careful discussion of the shell kinematics was made by Herbig & Smak (1992). The latter authors find the shell to be a prolate ellipsoid, seen almost at an inclination angle of 90° (i.e. the equatorial ring is seen edge-on) The expansion velocity of the equatorial region is 384 km s^{-1} that of the polar region 528 km s^{-1}. Due to the favorable inclination, during outburst 'equatorial' velocities were observed. The 'true' expansion velocity at the equator is found in late radial velocity observations of the principal absorption (absorption II according to McLaughlin's nomenclature), and in the widths of the emission bands observed several years after outburst.

Radial velocities observed in a shell which shows an inclination relative to the observer are more difficult to disentangle. Because of the impossibility to obtain already spatially resolved spectroscopy for V1229 Aql, a determination of the inclination angle is not possible. If spherical symmetry is assumed, errors up to ±20% may easily occur, as is seen in the case of DQ Her and from the observed ellipticity of other nova shells.

The most trustworthy expansion velocity of V1229 Aql thus appears to be 745 km s^{-1}, as observed in the course of the outburst. Other measured radial velocities cannot be excluded, and the expansion velocity is uncertain by ±20%. Thus, the range of possible expansion velocities is 500…1000 km s^{-1}, with v_{exp} = **750** km s^{-1} taken as a 'best guess'. A ring expanding with 750 km s^{-1}, seen at an inclination of 27°, would produce maxima at ±340 km s^{-1}, and would have an apparent axial ratio of 0.89, within the error margins of the observed direct image.

3.3. Interstellar extinction

First, the interstellar extinction can be estimated by comparing the observed colours of the nova with the intrinsic colours. It was shown by van den Bergh & Younger (1987) that novae two magnitudes below maximum have an intrinsic $(\mathrm{B-V})_0$ of -0.02 ± 0.04. V1229 Aql, two magnitudes below maximum, had an observed (B − V) of $+0.47 \pm 0.01$ (Nishimura 1971). The derived $E_{\mathrm{B-V}}$ is 0.49 ± 0.05. A similar investigation by Miroshnichenko (1988), isolating a plateau in the colour curves of novae, yields $E_{\mathrm{B-V}} = 0.59 \pm 0.02$. It should be noted that in both methods V1229 Aql was used, among a dozen or more other objects, to calibrate the relations, and that these results are somewhat uncertain.

A second independent estimate of the extinction is based on the comparison of observed and predicted line ratios. Assuming a theoretical ratio $\mathrm{H}\alpha/\mathrm{H}\beta \approx 2.9$ (case B), we derive, from the analysis of the spectrum of Fig. 1, an observed ratio of 6.9 which corresponds to $E_{\mathrm{B-V}} = 0.79$. On the other hand, Whitney & Clayton (1989) have shown that steep values of the Balmer decrement may not be attributed only to the reddening effect, but rather to the excess of intensity of Hα due to optical depth effects. A piece of evidence in this direction comes from the results obtained by Rosino et al. (1991) and Anupama et al. (1992), who were able to show that the ratio $\mathrm{H}\alpha/\mathrm{H}\beta$ of Nova Sct 1989 = V443 Sct is varying with time. However, at very late stages, the ratio should converge to its theoretical value. We shall assume the value of the reddening derived this way as an upper limit for the extinction correction.

The He I ratio $\lambda 5876/\lambda 4471$ (= 2.9) is not sensitive to radiative-transfer effects (Robbins 1968; Ferland 1977), and one can assume that the difference between the observed and the theoretical ratio is due to reddening. Our data yields a ratio $\lambda 5876/\lambda 4471$ of 3.9. With the ratio of total to selective extinction determined by Seaton (1979), we derive $E_{\mathrm{B-V}} = 0.36$. Another value of the reddening toward V1229 Aql can be derived from the $\lambda 6678/\lambda 4471$ ratio. A comparison between the observed ratio of 1.15 and the case B value of 0.78 yields $E_{\mathrm{B-V}} = 0.25$.

Table 2. Summary of reddening determinations

Average of intrinsic colour relations:	0.54
Average of line ratios:	0.47
Average of Na I – E_{B-V} relations:	0.48

Third, from data reported by Cohen (1975) (her Tables 1 and 2), we were able to derive the following empirical relation between the EW of Na I (= 1.2Å) and the reddening, $E_{B-V} = 0.61 \times \mathrm{EW} - 0.08$. The equivalent width of 1.2Å suggests a value of $E_{B-V} = 0.65$. A similar relation, provided by Barbon et al. (1990), yields $E_{B-V} = 0.30$.

While there is a considerable scatter among the single determinations, the average value $E_{B-V} = 0.50 \pm 0.08$ appears to be well established, leading to $A_v = 1.55 \pm 0.23$.

3.4. Distance and absolute magnitude at maximum

From the decomposed FWZI of the Hα line we derive an expansion velocity of ± 800 km s^{-1}, close to the above value of 750 ± 250 km s^{-1}, derived from spectra taken during outburst. The *latter value*, in combination with the angular expansion rate of the nebula (Sect. 3.1), leads to a distance $d = 2100 \pm 900$ pc. (A previous distance estimate by Duerbeck 1981, based on the strength of the Ca II K line, yielded $d = 1730$ pc.) By assuming $m_v = 6.5$ for the apparent magnitude at maximum and $A_v = 1.55$ for extinction, the absolute magnitude at maximum is $M_v = -6.7$, with extreme values of -7.5 and -5.6.

The bolometric magnitude at maximum is derived after applying a bolometric correction of -0.25, corresponding to a F5 Ia star (Duerbeck 1981), yielding $M_{\mathrm{bol}} = -6.9$ (margins $-5.8 \ldots -7.5$) which is close to the Eddington limit of $M_{\mathrm{bol}} = -7$ for *slow* classical novae (Starrfield 1988).

Inserting $t_2 = 19^d$ into the analytic expression of the MMRD (Capaccioli et al. 1989) yields an expected absolute magnitude at maximum of V1229 Aql of $M_v = -8.1$. To match this value with the magnitude at maximum derived from the nebular expansion parallax would imply that the extinction was underestimated by a factor 2. Six out of seven independent methods used to determine the amount of extinction exclude this possibility, only the Balmer line ratio does lend some support to it. Another way to reconcile the maximum magnitudes is to assume that the value for the expansion velocity was incorrectly chosen. But for the nova being more luminous, i.e. at a distance of 4070 pc, the expansion velocity must be almost 1500 km s^{-1}, a quite unlikely value. Any noticeable deceleration of the expansion rate in the course of the first 22 years after outburst can be safely excluded; normally nova shells hardly show indications of such a deceleration, and if they do (e.g. GK Per, Bode et al. 1988), the spectroscopic appearance of such a shell is different from that of V1229 Aql. We conclude that V1229 Aql is very likely a new member of the group of underluminous novae.

4. Discussion

The results presented in the previous section are of importance to clarify the following three issues:

(1) The presence of novae below the main MMRD seems well established, if we exclude the possibility of serious errors in the extinction estimates. An analysis of Cohen's practically distance-limited sample suggests that ≈ 10% of the galactic novae could be underluminous. Due to their intrinsically faintness they are easily missed during extragalactic nova searches, and therefore they can affect the shape of the MMRD at the faint luminosity level, making the position of the faint shoulder of the relationship somewhat uncertain. Some caution seems in order when comparing the galactic and extragalactic MMRD's to determine extragalactic distances. The existence of intrinsically fainter objects in the galactic sample can led to an overestimate of extragalactic distances.

(2) Sub-luminous objects may be interpreted in terms of outbursts occurring in systems close to the *nova dud line*, i.e. systems with low mass white dwarfs and/or high mass accretion rates, so that the ignition of TNRs would occur only under mildly degenerate conditions (e.g. Livio 1993). HR Del, recently discussed by Friedjung (1992), may be another example of these 'border novae' which marginally satisfy the conditions for a thermonuclear runaway. This sketch is supported by the recent result of Della Valle et al. (1992), who find that novae containing massive white dwarfs are located close to the galactic plane, within a strip of $|z| \leq 100$ pc, whereas HR Del is located at $z = 205$ pc and V1229 Aql at $z = 222$ pc.

(3) Another interesting possibility has been recently pointed out by Orio et al. (1992). According to their model, the existence of a magnetic field can accelerate the process of mass ejection, thus increasing the rate of decline (decreasing t_2) without modifying the absolute magnitude at maximum. In the MMRD-diagram, a nova undergoing a strong 'magnetic driven outflow' would appear systematically fainter than what is expected by its rate of decline.

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