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On the possible existence of two classes of progenitors for classical novae

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Abstract. In a 'fiducial sample' of classical novae for which the distances are established independently of the maximum magnitude vs. rate of decline relationship, novae with $t_2 \leq 12$ days are found to be concentrated at low heights above the galactic plane. At the same time, low amplitude and slow novae are found to extend all the way to $z \simeq 1000$ pc. This is consistent with the statistics of extra-galactic novae. We discuss how the distribution of novae of different speed classes may indicate that the progenitors of classical novae belong to two different classes.

Key words: stars: cataclysmic variables – novae – white dwarfs – magnetic fields – galaxy: stellar content

1. Introduction

The idea that novae may arise from two different populations is receiving support from a number of recent works. Dürbeck (1990) postulates the existence of two different kinds of nova populations in order to understand better the fact that in the Galaxy the fast and bright novae are located in the disk while the slow and faint novae belong to the bulge. The evidence for the existence of disk and bulge novae with different properties becomes even more compelling when we consider the results of nova surveys on extragalactic systems such as the LMC (Graham 1979), M33 (Della Valle 1988) and M31 (Capaccioli et al. 1989).

As shown by Ciardullo et al. (1987), and Capaccioli et al. (1989), novae in M31 are mainly produced by the bulge. These authors estimate that the contribution of the disk to the entire nova production of M31 is no larger than 15–20 %. On the other hand, the high values of the specific nova rate (defined as number of novae per year per unit of luminosity of the host galaxy) for bulgeless galaxies such as M33 and LMC (Della Valle 1992), imply *a fortiori* an efficient nova production in the disk. A direct consequence of the two-populations hypothesis is that the 'average' nova of the LMC is expected to be faster and brighter than the 'average' nova of M31. The comparison between the observed distributions of the maximum magnitude *vs.* rate of decline (MMRD) for the LMC and M31 confirms this idea. Capaccioli et al (1990) and Dürbeck (1990), noted also that the percentage of fast and luminous novae in the LMC is $\sim 30\%$, compared to $\sim 10\%$ in M31. This result becomes even more significant when we consider the fact that selection effects do not favor the discovery of fast novae, which may be missed because of their fast declines. This is illustrated comparing the results of the major nova searches for M31: from the analysis of about 1000 plates covering a time of ≥ 30 years, Rosino (1964, 1973) and Rosino et al. (1989) were able to infer a specific rate 0.02 for fast novae, smaller by a factor $\simeq 3$ than that obtained by Arp's continuous patrolling (1956). On the other hand Capaccioli et al. (1990) derived a frequency of 0.3 for the very fast novae in the LMC. The set of observations considered by the latter authors was inhomogeneous and randomly distributed in the last 50 years (with the only exception being the Graham's surveys, 1979), so the value they give is a lower limit for the frequency of fast novae in the LMC. *Differences between the distribution of the rates of decline of the LMC and M31 nova population are therefore real and not due to selection effects.*

In order to examine the question of whether the two-nova-populations hypothesis holds also inside our galaxy we carried out a study of the distribution of the amplitudes and speed class of the galactic novae and examined how it varies with the longitude and with the distance z from the galactic plane.

2. The distribution of novae of different speed classes

According to the classification of Payne-Gaposchkin (1957), very fast novae are those with t_2 shorter than 10 days, in terms of rate of decline, 'v_d', (mag day^{-1} from the time of the outburst till t_2, i.e. $v_d = 2/t_2$) corresponding to $\langle \log (100 \times v_d) \rangle \geq 1.3$. The probability density function (PDF) of the rate of decline for 93 recent galactic novae (the sample used in the statistical work of Della Valle, 1988) is presented in Fig.1: one can see that $\simeq 85$ % of the objects fall around two sharp peaks, at $\langle \log (100 \times v_d) \rangle = 0.95$ and at $\langle \log (100 \times v_d) \rangle = 1.4$. The value $\langle \log (100 \times v_d) \rangle = 1.2$ is approximately the boundary between the two groups.

In order to analyze how the distributions vary with the galactic longitude we perform the following exercise: we plot in Figs.

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2 and 3 the PDF of respectively log ($100\times v_d$) and the outburst amplitude for two subsets: novae at galactic longitude $-40^o \leq l \leq +40^o$ and novae at $40^o < l < 320^o$. Fig. 2 shows that fast (and bright) novae tend to cluster around the direction of galactic anti-center, whereas the slower (and fainter) ones are in the direction of the galactic center. In Fig. 3 one notices a clear predominance of large outburst amplitude novae toward the galactic anti-center and of small amplitude novae towards the galactic center, in qualitative agreement with the relationship amplitude vs. t_2 (Warner, 1987). Due to the higher stellar density in the direction of the galactic center, we cannot exclude that this result may be partially produced by erroneously identified faint pre- or ex-novae.

This 'exercise' shows that the spatial position of galactic novae seems to be linked with the physics of the phenomenon.

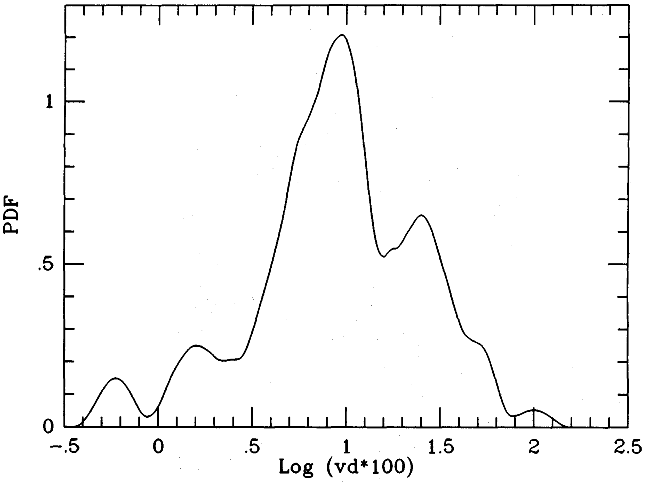

Fig. 1. The Probability Density Function (PDF) of the rate of decline of 93 galactic novae (sample from Della Valle, 1988)

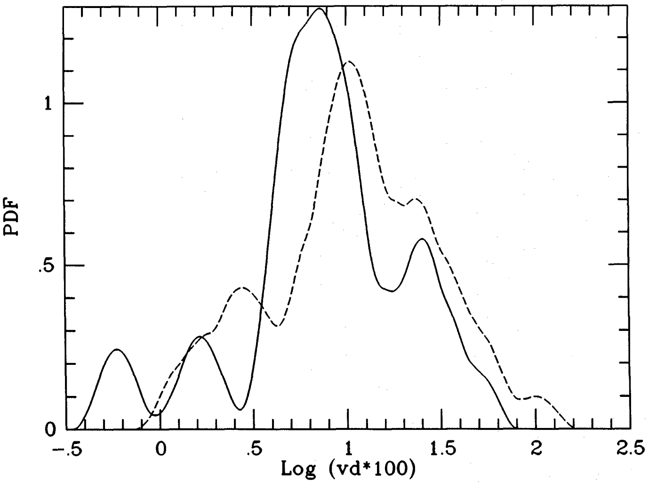

Fig. 2. The PDF of the decline rate for novae from the sample of Fig. 1 at galactic longitude $-40^o \leq l \leq +40^o$ (solid line) and novae at $40^o < l < 320^o$ (dashed line)

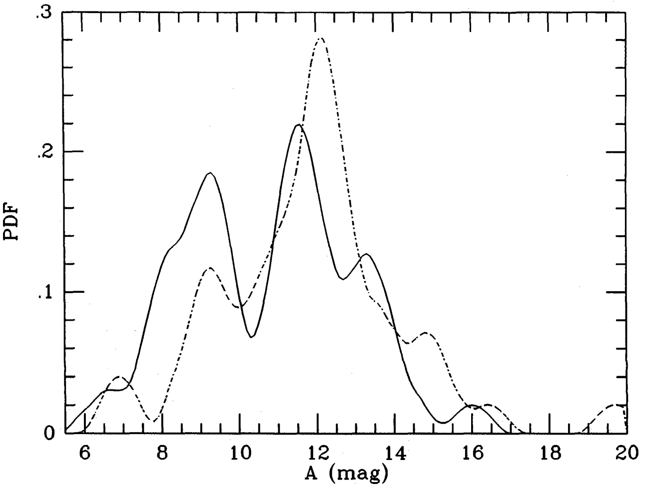

Fig. 3. The PDF of the outburst amplitudes novae from the sample of Fig. 1 at galactic longitude $-40^o \leq l \leq +40^o$ (solid line) and novae at $40^o < l < 320^o$ (dashed line)

3. The fiducial sample

The major difficulty in defining a statistically meaningful nova sample is an accurate determination of the distances and of the heights, z, above the galactic plane. The z-distribution obtained with the well known formula :

$$z = 10^{[0.2(m-M+5-A)]} \times \sin b \qquad (1)$$

(where b is the galactic latitude) is hampered by the very poor knowledge of the absorption which affects most of the galactic novae and is most severe for novae in the galactic disk. Moreover, the determination of the distance through the maximum magnitude vs. rate of decline relationship produces, in view of Eq. (1), an obvious correlation between z and the rate of decline. For these reasons we restrict presently our analysis to the 'fiducial sample' of 19 objects, obtained by Cohen and Rosenthal (1983) and Cohen (1985). This approach has a twofold advantage: i) the distance to each nova was obtained from nebular parallaxes, not from the rate of decline; ii) the strengths of the interstellar lines inferred by the spectra provide a direct measure of the absorption for each object.

After analyzing the frequency distribution of the rate of decline for the novae of the 'fiducial sample', (col. 4 of Table 1), we notice a gap at $\langle \log\,(100 \times v_d) \rangle = 1.2$ corresponding to $t_2 \simeq 13$ days (see Fig. 4). We shall assume the latter value to be the highest for an object to be included in the fast nova class.

The histogram in Fig. 5 presents the frequency distribution of the galactic novae of the 'fiducial sample' relative to log z. The plot shows that six out of the seven fast novae in the sample are found inside the $0 \leq z \leq 100$ pc strip, while most of the slow ones are found in the range $100 \leq z \leq 1000$ pc. *It is difficult to understand how such a distribution could be due to selection effects since there is no obvious mechanism to prevent the discovery of fast (and bright) novae at high z* - although we cannot exclude the possibility that the number of faint (and slow) novae in the range $z \simeq 0 - 100$ pc may be reduced by the absorption.

A Kolmogorov–Smirnov test (e.g. Press et al. 1986) performed on the 'fiducial sample' supports the existence of two distributions characterized by different $\langle z \rangle$ and different absolute magnitudes

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Table 1. Fiducial sample

Nova	log z	t_2	log (100 × v_d)
V1229 Aql	2.35	18	1.05
V500 Aql	2.96	20	1.00
V603 Aql	0.81	4	1.70
T Aur	1.59	80	0.40
V476 Cyg	2.58	7	1.46
V1500 Cyg	0.0	2.4	1.92
HR Del	2.31	≥ 150	0.12
DQ Her	2.13	67	0.47
V446 Her	2.00	5	1.60
V533 Her	2.73	26	0.89
DK Lac	2.57	19	1.02
CP Lac	1.37	5	1.60
GK Per	1.93	6	1.52
RR Pic	2.30	80	0.40
CP Pup	1.17	5	1.60
FH Ser	1.83	42	0.68
XX Tau	2.86	24	0.92
RW UMi	3.40	200	0.00
LV Vul	1.55	21	0.98

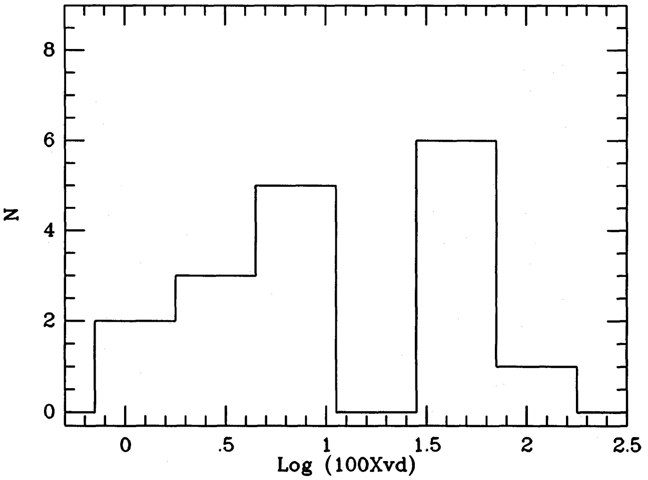

Fig. 4. Histogram showing the distribution of the rate of decline for the galactic novae of the "fiducial sample"

at maximum (Tab. 2) at a high significance level (probability less than 0.01). In the first column of Tab. 2 we report the $\langle z \rangle$ of the distribution. In the second the standard deviation of the mean, in the third the average absolute visual magnitudes at maximum for fast and slow novae and in the fourth the related standard deviation of the mean. Finally we present (fifth column) the number of objects used for the statistical analysis.

Table 2. Data for fast and slow novae

	$\langle \log z \rangle$	$\sigma/\sqrt{N}$	$\langle M_v \rangle$	$\sigma/\sqrt{N}$	N
fast	1.41	0.32	–9.31	0.21	7
slow	2.38	0.16	–7.53	0.39	12

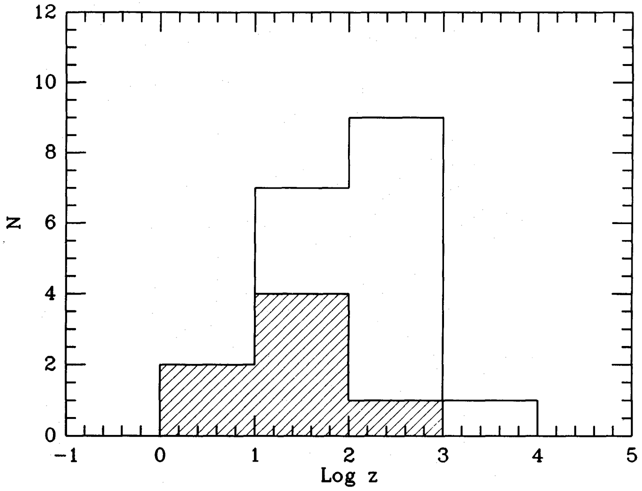

Fig. 5. Histogram showing the frequency distribution as a function of log(z) for slow novae from the "fiducial sample" (unshadowed area) and fast novae of the "fiducial sample" (the shadowed area)

4. Discussion

Although definite conclusions are certainly limited by the available statistics, our analysis indicates the following points:

a) The probability density function of the rate of decline and amplitude outburst for 93 galactic novae shows a bimodal distribution, lending support to the idea that galactic novae may arise from two different populations.

b) The fiducial sample of galactic novae shows a bimodal distribution of the number of objects vs. the height above the plane, z, and vs. the average magnitude at maximum. In particular, fast novae, mainly located at $z < 100$ pc, are associated with the disk, whereas slow novae all the way up to $z \leq 1000$ pc, are associated with the galactic bulge.

c) This result is consistent with the observations of novae in extragalactic systems such as M31 and the LMC. The differences in the ratio of the density of fast and slow novae observed in the LMC and M31 nova populations, can easily be accounted for by assuming a division into two distinct classes of novae.

d) The analysis of the 'fiducial sample' of galactic novae and that of the M31 and LMC nova population shows therefore a difference between 'disk' and 'bulge' novae, which may imply a difference in the nature of the progenitors.

Since the difference between the high z and the low z groups manifests itself in the brightness at maximum and speed class, we must seek possible explanations for this bimodal distribution in the physical parameters which determine the speed class. The three most important factors in the determination of the speed class are: i) the white dwarf mass, ii) the enrichment by heavy

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elements, and possibly iii) the strength of the magnetic field. Of these, the enrichment by heavy elements is not an independent parameter because it is determined by the mixing processes (see Kovetz & Prialnik 1985, Livio & Truran 1991). Because of the very few abundance determinations that have been possible so far in the ejecta of nova systems, we shall not discuss this point.

Concerning the white dwarf mass, theoretical calculations have established that the more massive the white dwarf is, the brighter the nova at maximum and - in the absence of magnetic fields - the faster (Starrfield et al. 1985, Kovetz & Prialnik 1985, Kato & Hachisu 1989, see Livio 1992 for a discussion). Thus, the results of the present work could indicate that nova systems containing more massive white dwarfs are concentrated, on the average, closer to the disk. Also pointing in this direction is the result of the statistical study of the novae in the bulge of M31 of Tomaney & Shafter, 1992, that found no O-Ne-Mg novae (thought to occur on massive O-Ne-Mg white dwarfs). It is interesting to investigate whether there exists independent evidence suggesting that CV's that are closer to the disk contain more massive white dwarfs than CV's at high latitude. Recently, Dobrzycka & Howell (1992) determined (although with obvious uncertainties) that the mass of the white dwarf in PG0917+344, which is at $z \simeq 300$ pc, is $M_{WD} \simeq 0.3 M_{\odot}$. Szkody & Howell (1991) found the mass of the white dwarf in DV UMa (a system at $z \simeq 390$ pc) to be $M_{WD} \simeq 0.40$-$0.43\ M_{\odot}$. More generally, Szkody & Howell (1992) found that the orbital period distribution of the high galactic latitude CV's has a higher proportion of systems below the period gap. Such system, on the average, are believed to contain less massive white dwarfs (e.g. Ritter et al. 1991). We should point out, however, that exceptions do exist, like the recurrent nova T Pyx which is a high z object, but whose outbursts can be explained as thermonuclear runaways only if the system contains a very massive white dwarf (Webbink et al. 1987).

Concerning the issue of the magnetic fields, Orio et al. (1991, 1992) found that if the white dwarf is not very massive ($M \simeq 0.9\ M_{\odot}$), but has a magnetic field $B \geq 10^6$ Gauss, a magnetically driven wind from the optically thick envelope can accelerate mass loss by centrifugally accelerating matter, thus turning even what would have been a slow nova into a fast one. The magnetic field according to this model influences the rate of decline and the velocity of the ejecta, but not the magnitude at maximum, causing a spread in the MMRD relationship. The above authors and Livio (1992) discuss also observational evidence that the known AM Her or intermediate polar novae belong to the class of fast or very fast novae. For instance, V1500 Cyg, the fastest nova ever recorded, is an AM Her system (Chlebowski & Kaluzny 1988, Stockman et al. 1988). Incidentally, this object had also a very large outburst amplitude and remarkably it belongs, together with V603 Aql and CP Pup that also show signatures of AM Her systems (Diaz & Steiner, 1989, and 1991, Udalsky & Schwarzenberg-Czerny 1989), to the novae at lowest z that appear in our 'fiducial sample'. Two out of three intermediate polars of the sample, DQ Her and GK Per (King et al. 1979), are at intermediate height above the galactic plane. V533 Her is the only 'suspected' magnetic system found at high z in the fiducial sample. Due to the still poor statistics on magnetic nova systems we cannot regard this, however, as definitive evidence. The possible correlation between the strength of the white dwarf's magnetic field and z is not entirely clear. We do note, however, that for single white dwarfs, Sion et al. (1992) found that magnetic degenerates as a subgroup have remarkably low space motions compared to the non-magnetic subgroup, and they are likely therefore to belong to the disk. Whether the stratification of nova system according to the magnetic nature of the white dwarf is statistically significant or not can only be clarified with more good quality data on magnetic nova candidates (optical photometry, polarization measurements and X-ray observations).

The bimodality in the nova distribution may represent the dependence of the nova speed class on the white dwarf mass, its magnetic field or both. Because of the implications that the distribution has for the physics of the phenomenon, it is important to improve the statistical significance of the findings of the present work.

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