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Novae in the Local Group of galaxies

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Abstract. I review the current status of the stellar population assignment for novae. Nova observations in the Local Group of galaxies point out the existence of two classes of novae: i) *disk Novae*, mainly associated with the stellar population of the *disk/spiral arm* and characterized by a fast photometric evolution and ii) *bulge Novae* which originate in the *thick-disk/bulge* stellar population and they are marked by a slow photometric decay. Recent X-ray surveys on M31 support this scenario.

Key words. Stars: Cataclysmic Variables – Stars: Novae

1. Introduction

The concept that novae can be classified into two classes of objects, i.e. fast and bright 'disk novae' and slow and faint 'bulge novae', was elaborated in the early 90's by Duerbeck (1990) and Della Valle et al. (1992, 1994), Della Valle & Livio (1998). The former author demonstrated that nova counts in the Milky Way do not follow an unique distribution (Fig. 1), the latter authors showed that the rate of decline, which traces the mass of the WD associated with the nova system (e.g. Shara 1981; Livio 1992), correlates with the height above the galactic plane (Fig. 2) of the Mily Way. Fig. 1 shows that nova counts follow two different trends. Dashed and dotted lines are the predictions from simple disk, $\rho(z) = \alpha \times \rho_{\circ} \exp(-|z|/z_{\circ})$, and bulge ($\rho \sim 10^{0.6}$) nova population models [with $\rho_{\circ} = 125$pc $A_V = 1$mag/kpc^{-1}, M_V(max)= -9, $\rho_{\circ} = 10^{-10}$ pc^{-3} yr^{-1} and $\alpha \lesssim 0.1$, (see Patterson 1984; Della Valle & Duerbeck 1993; Duerbeck 1984; Naylor et al. 1992)].

2. Novae from disk or bulge stellar population?

Starting from 40's, nova stars in the Milky Way have received different stellar population assignment. For example, McLaughlin (1942, 1945, 1946) pointed out the existence of a strong concentration of novae towards the galactic center, which implies a "bulge" classification. On the other hand Kukarkin (1949), Kopylov (1946) and Plaut (1965) indicate the existence of a concentration of novae also towards the galactic plane and thus they classified novae as belonging to the 'disk population'. Minkowski (1948, 1950) and Payne-Gaposchkin (1957) showed that the galactic longitudes of novae and planetary nebulae (PNe) have similar distributions and therefore novae, like PNe, belong to Pop II stellar population. Baade (1958) assigned novae to the

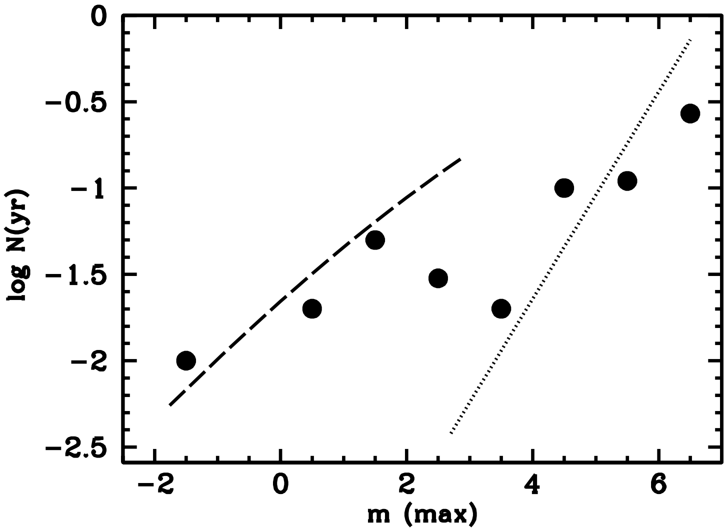

Fig. 1. Theoretical and observed number of novae. Filled circles: observed rate; dashed line: calculated number counts for a disk population; dotted line: expected slope for a bulge population. Adapted from Della Valle (2002)

old Pop II stellar population because of the occurrence of a few ones (e.g. T Sco 1860) in very old stellar population systems, such as the Globular Clusters. Iwanowska (1962) suggested that novae are a mixture of Pop I and Pop II objects, while Patterson (1984) proposed that novae belong to an 'old disk' population. Ciardullo et al. (1987) and Capaccioli et al. (1989) found that most M31 novae were produced in the bulge. Della Valle & Duerbeck (1993), after comparing the cumulative distributions of the rates of decline of novae occurred in M31, LMC and Milky Way (Fig. 3), found that galactic and M31 distributions are indistinguishable, whereas M31 and LMC distributions are different at $\gtrsim 99\%$ significance level. Since the speed class of a nova depends on the mass of the underlying white dwarf (e.g. Shara 1981; Livio 1992), systematic differences in the distributions of the rates of decline indicate the existence of physical differences between LMC and M31 (or Milky Way) novae. This scenario received some observational weight from Tomaney & Shafter (1992) who found that novae belonging to the bulge of M31 are spectroscopically different from novae observed in the neighborhood of the Sun (i.e. novae occurred in the disk of the Milky Way).

A revival of this debate occurred at the end of 90's, after Hatano et al. (1997) claim that most M31 novae come from disk. Afterwards Shafter & Irby. (2001) argued that $\sim$ 70% of M31 novae are bulge objects, thus confirming the conclusions of Ciardullo et al. (1987) and Capaccioli et al. (1989). Finally we note that this result is well supported by Darnley et al. (2006) who found that the nova rate in the M31 bulge is about five times larger than that of the disk.

3. The spectroscopic differences between disk and thick-disk/bulge novae

Williams (1992) on the basis of two dozens of MW and LMC novae observed at Tololo

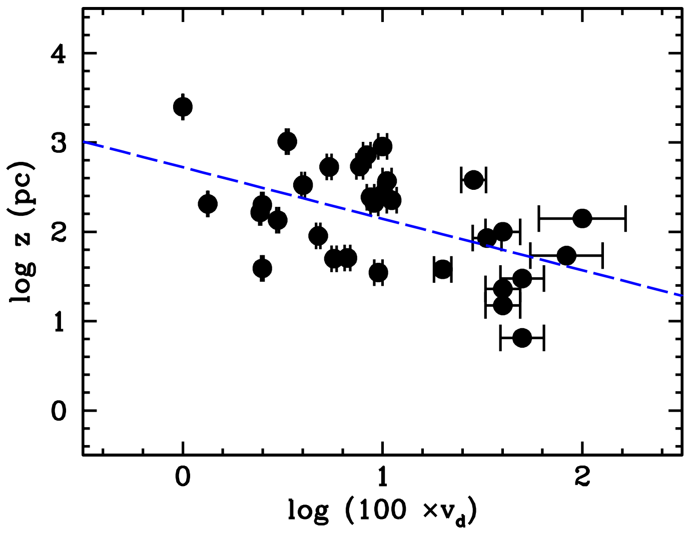

Fig. 2. The relationship between height above the galactic plane, "z" vs. rate of decline, $v_d = 2/t2$. t2 is the time that the nova takes to decrease its brightness by 2 magnitudes from maximum. The sizes of the errorbars in *log z* axis are comparable to the sizes of the dots. Adapted from Della Valle (2002)

Observatory concluded that novae can be broadly divided into two spectroscopic classes: Fe II and He/N novae. The former are characterized by slow spectroscopic evolution with expansion velocities $\lesssim 2500$ km/s (FWZI) and the Fe II lines as the strongest non-Balmer lines in the spectra at early stages. The latter are fast spectroscopically evolving novae, characterized by high expansion velocity ejecta $\gtrsim 2500$ km/s (FWZI) with He and N lines being the strongest non Balmer lines in the emission spectrum near maximum. Hybrid objects (e.g. V1500 Cyg) that evolve from Fe II to He/N are classified as FeII-broad and they are physically related to the He/N rather than to FeII class. In Fig. 4 we have plotted the frequency distribution of the heights "z" above the galactic plane of novae belonging to the fiducial sample studied by Della Valle & Livio (1998).

The histograms show that novae belonging to the He/N class tend to occur close to the Galactic plane with a typical scale height $\lesssim 150$ pc, whereas FeII novae are distributed more homogeneously up to $z \sim 1000$ pc and beyond. A K-S test on the data shows that the two distributions are different at $\gtrsim 95\%$ level. An analysis of Fig. 4 finds that Novae previously classified as 'disk' and 'bulge' objects tend to correspond to the spectroscopic classes introduced by Williams. Indeed about 70% of fast and bright novae belong to the He/N (or FeII-b) class, while the slow and faint ones form the main bulk of Fe II class. For details to explain this behavior see Della Valle (2002).

Finally Shafter et. al. (2011) have carried out a spectroscopic surveys on M31 novae and found that $\sim 80\%$ of them belong to FeII class, therefore providing more evidence that most novae in M31 belong to the "bulge" stellar population. Interesting enough the classification in "disk" and "bulge" populations, is further supported by recent XMM/Chandra surveys of M31 (Henze et. al. 2010, 2011) in which the

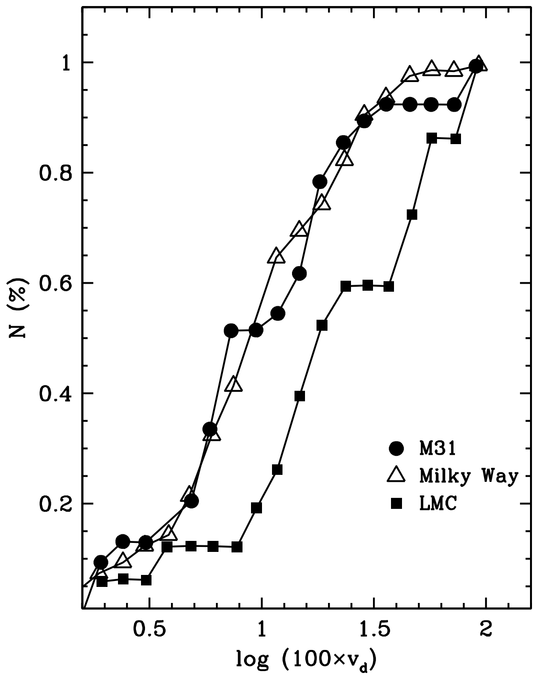

Fig. 3. Cumulative distributions of the rates of decline for M31, LMC and Galaxy (from Della Valle & Duerbeck 1993)

distributions of the effective black body temperatures for "disk" and "bulge" post-novae (see Fig. 5) appear to be statistically different (admittedly at level of $\sim 2\sigma$).

4. The maximum magnitude vs. rate of decline relationship

Fig. 6 reports the maximum magnitude vs. rate of decline relationship for LMC, M31 and Virgo novae. Analysis of these data indicate that the nova production in the LMC mainly consists of fast and bright novae, while the M31 nova population exhibits, in terms of rate of declines, prominent "intermediate" and "slow"components. The same trend is exhibited by novae in Virgo (Pritchet & van den Bergh 1987), in which only the "slow" (and faint) component seems to be present.

This behavior can hardly be explained with the presence of an observational bias. Indeed the brightest novae are detected in the nearest galaxy (LMC) and would be missed in the more distant ones (Virgo). On the other hand, the faintest novae would be missed in the near LMC and detected in the far away galaxies (Virgo). This behaviour is the complete opposite of what one would expect from the action of an observational bias. In fact, these differences in the MMRDs find a simple explanation in the framework of two nova populations scenario: nova systems in disk dominated and

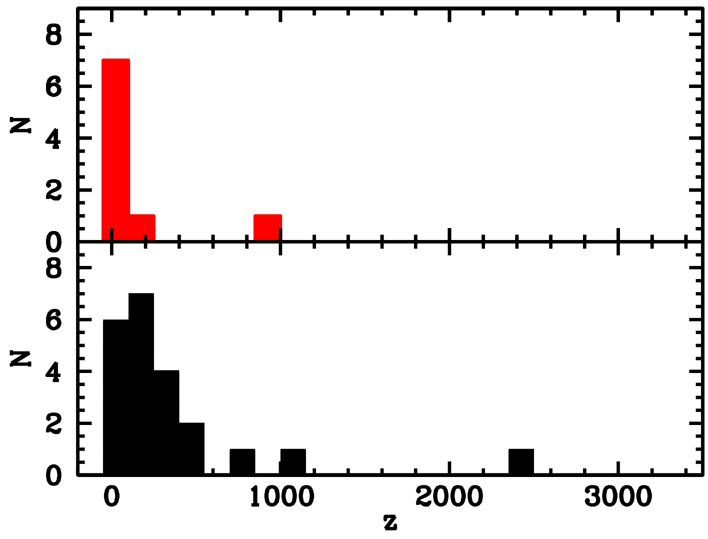

Fig. 4. Frequency distribution of the height above the galactic plane for He/N (and FeII-b) novae (top panel) and FeII novae (bottom panel) Adapted from Della Valle (2002)

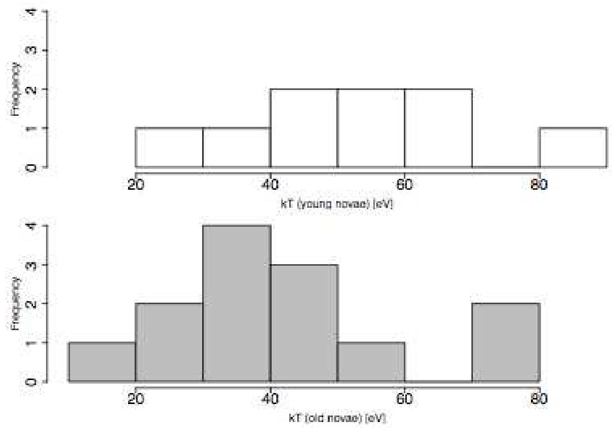

Fig. 5. Distribution of effective (black body) temperature kT for young novae (white/upper panel) and old novae (grey/lower panel). From Henze et. al. (2011)

bulgeless galaxies (such as LMC) are associated with more massive WDs, then resulting in faster and intrinsically brighter nova events (Truran & Livio 1986).

5. Conclusions

Photometric, spectroscopic and X-ray observations of galactic and extragalactic novae

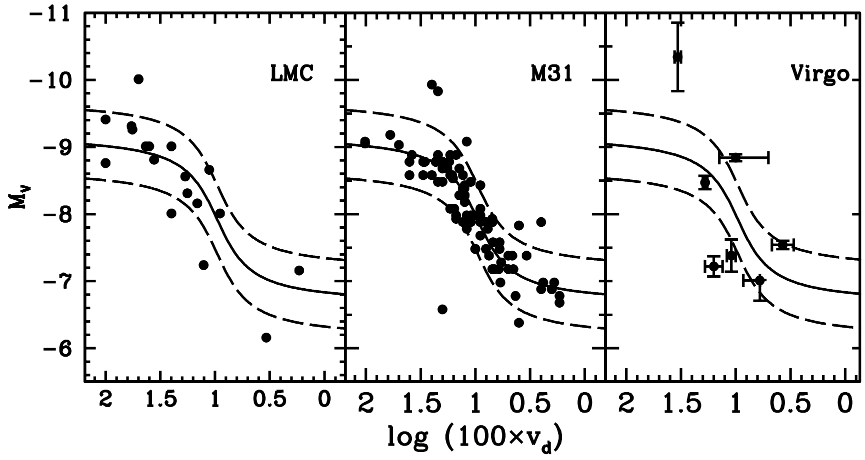

Fig. 6. The MMRD relationships for LMC, M31 and Virgo nova populations. The solid line indicates the best fit (from Della Valle & Livio 1995). Upper and lower dashed curves are located at $\pm 3\sigma$. Adapted from Della Valle (2002)

strongly suggest that nova stars are drawn from two different kinds of stellar populations. In particular:

i) analysis of nova properties inside the Milky Way supports the existence of two nova populations: "disk" and "bulge" novae.

The 'average' *disk nova* is a fast decay nova whose lightcurve exhibits a bright peak at maximum $M_V \gtrsim -9$ (t2 $\lesssim 13^d$ or t3 $\lesssim 20^d$) a smooth early decline and belongs to the He/N (or Fe IIb) spectroscopic class. The progenitor is preferentially located at < 150pc above the galactic plane and should be preferentially associated with massive WD, $M_{WD} \gtrsim 1$ $M_\odot$.

The "average" bulge nova is a slow evolving nova whose lightcurve exhibits a fainter peak, $M_V \sim -7.2$ (t2 $\gtrsim 13^d$ or t3 $\gtrsim 20^d$), often characterized by multiple maxima, dust formation and maximum standstill. It belongs to the Fe II spectroscopic class. The progenitors extend up to 1000 pc from the galactic plane and are likely to be related to a Pop II stellar population of the galactic thick-disk/bulge. They are likely associated with less massive WDs, $M_{WD} \lesssim 1M_\odot$.

ii) analysis of the MMRD relationship for LMC, M31 and Virgo novae confirm the existence of systematic differences in the distributions of the rates of decline of the respective nova populations. Most novae in the LMC are bright and fast and therefore (on average) associated with massive WDs while fast novae in M31 are $\lesssim 25\%$. The two distributions are different at $\gtrsim 99\%$ c.l.

iii) some of the differences between "disk" and "bulge" novae described in this paper have been theoretically explained (see Kolb 1995; Starrfield et al. 1998; Kato 1997).

iv) the apparent existence of a scant group ($\lesssim 5\%$) of super-bright novae which deviate systematically by $\sim$ 1 mag from the MMRD may be a real effect Della Valle (1991). One possible explanation is that a *"super-nova"* explosion might occur at the end of the life of a CV (Iben & Tutukov 1992), (see also Iben & Livio 1993). Schwartz et al. (2001) suggest that the metallicity may be the driving parameter to account for this deviating behavior.

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