PROCEEDINGS OF SCIENCE

Classical Novae as Cataclysmic Variables

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Historically, Classical Novae (CNe) have been considered as a sub-class of Cataclysmic Variables (CVs). Yet it is now clear that a CN explosion is an event in the lifetime of a CV.
In this talk, I compare the current knowledge on CN progenitors with the larger population of CVs, with particular emphasis on their distances, in the context of the current and future projects like Gaia or LSST.

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1. Introduction

Classical novae (CNe) are thermonuclear explosions occurring on the surface of a white dwarf (WD) which is accreting mass from a Roche-lobe filling main sequence star. For a complete review, refer to [3]. The binary system in which a CN occurs is a cataclysmiic variable (CV) and they are described in detail in [27].

For a long time, CNe have been described as a sub-class of CVs, as a purely phenomenological approach was taken and CNe responded well to the "cataclysmic" part of the name of CVs. Nevertheless, our current understanding of the nova phenomenon (e.g. [28]) makes it clear that a nova explosion is an event in the lifetime of a CV. In fact, according to the best scenario at hand (the so-called "hybernation scenario", [20]), after a nova explosion, the system is found in high mass-accretion state due to the irradiation of the hot WD. Eventually, after the WD cools down, the secondary detaches from the Roche lobe and the system enters a phase of "hybernation" which can last tens of thousands of years (and dominates the evolutionary time scale of these objects). Eventually, accretion resumes at a low rate. This scenario is currently at the centre of the debate on nova evolution.

Several authors have provided tentative classification schemes for novae. In general terms, novae can be defined "fast" or "slow" depending on the a specific time scale. This time scale is tipically the time needed to fade n magnitudes from maximum and it is referred as t_n. A typical value of t_2 (time to fade 2 magnitudes from maximum) of $\sim$12 days is a typical threshold between "fast" and "slow" novae. [24] have proposed a classification based on the shape of the light curve. It is evident that a high cadence (less than a day) is required to get a good estimation of the time when the maximum light is achieved and to derive all the photometric characteristics of the light curve (t_1,t_2,t_3, and, of course, the shape of the light curve). It is worth mentioning that, despite the vast differences that can arise between different shapes of light curves, [10] found that t_2 and t_3 follow a (mostly) linear relation.

[28] proposed a spectroscopic classification scheme which also provided a physical explanation of the nova phenomenon. In short, [28] find that novae can be classified as either "Fe II" or "He/N" class. In the former, the spectrum shows (other than Balmer lines), Fe II lines and the emission lines show P Cygni profiles with expansion velocities smaller than $\sim$2500 km/s. "Fe II" novae tend to have a slow photometric evolution. The spectra of "He/N" class show (other than the Balmer lines) lines of He and N (hence the name) with saddle-shaped profiles and expansion velocities larger than $\sim$2500 km/s. In this case, the photometric evolution is fast. In the last decade, several observations have led to the need of reassessing this classification scheme.

2. Searches for Old Novae

According to the aforementioned hybernation scenario ([20]), a CV which underwent a nova explosion in the last century or so must show high mass accretion rate. This property has been used by several authors to identify novae which have exploded in the last century and derive the current properties of the binary (see [10]).

As it will be shown after, the arrival of the data from the Gaia mission is giving a significant push to the study of CVs (e.g. [17]). In particular, [1] provides an interesting recipe for the identification of CVs using Gaia data which has a great potential when applied to novae.

Another way to identify an old nova, even ignoring that the nova has indeed exploded, is to search for a shell of ejected material around a known CV. This strategy has been successfully adopted by several authors. Again, this is reviewed in [10].

A remarkable otucome of the search for CVs which underwent a nova explosion is their period distribution (which was already discussed in [10]). As predicted by the hybernation scenario ([20]), most novae are found above the period gap (i.e. $P_{\rm orb} > 3$ hours).

3. Sky distribution of Novae

Fig.1 shows the distribution in the sky of different types of CVs as well as novae. It is easy to notice that novae are clustered along the plane of the Milky Way while CVs (regardless of their mass-accretion rate) are observed to be all over the sky. This is clearly an observational bias and it was already commented in [9].

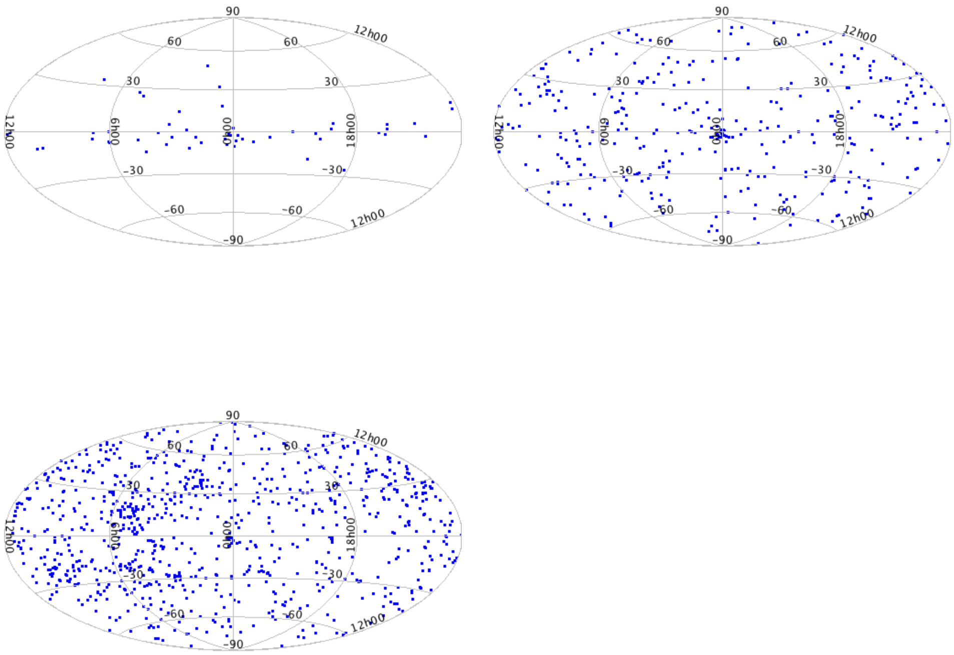

Figure 1: Spatial distribution of novae and CVs in Galactic coordinates. The upper-left panel shows the distribution of novae, the upper-right panel shows high mass-accretion rate CVs and the lower-left panel shows low mass-accretion rate CVs. Data from [18]

4. The Distance of Novae

In order to study the distance distribution of any kind of objects, it is important to recall the definition of absolute magnitude:

$$M_\lambda = m_\lambda - 5\log(d) + 5 - A_\lambda$$

where M_λ is the absolute magnitude in band λ, m_λ is the apparent magnitude in the same band, A_λ is the interstellar absorption in that band and d is the distance in parsecs.

While the measurement of the apparent magnitude is (almost) trivial, certainly the most challenging aspect is the determination of the interstellar absorption.- [23] provide accurate determination for a sample of CNe observed with the International Ultraviolet Explorer (IUE).

4.1 How to use Gaia's parallexes

The determinatoin of distances of novae has been a complex matter for many years. Yet, the situation has changed dramatically thanks to the Gaia mission ([12]). This is an astrometric mission of the European Space Agency. It hosts three instruments: an astrometric instrument, two "photometers" (which, in fact, are low resolution spectrographs with $R = \frac{\lambda}{\delta\lambda} \sim 40$) and a radial velocity spectrograph (a high resolution spectrograph, $R = \frac{\lambda}{\delta\lambda} \sim 11500$, covering the region of the Ca triplet, 845-872 nm). The second data release of Gaia ([13]) provided parallaxes for over 1 billion objects. Yet, it is important to keep in mind that the numbers reported in the archive are mostly a parametrisation of a probability distribution function ([15]) and they should be used as such. The same authors warn against the use of distance as inverse of the parallax in the case the parallax error is larger than 20%. [2] provide distances to almost all sources contained in Gaia DR2, using a model of Milky Way tp apply to the parallaxes. Both parallaxes and distances are easily accessible via TOPCAT ([25]).

The Gaia distances can be compared with distances obtained in other methods. Such comparison is beyond the scope of this paper. A good work in this sense can be found in [19].

5. Old novae distance distribution

A cross-match between CVs and the aforementioned Gaia distances is comparatively easy task and the result is shown in Fig.2. While both high and low mass-accretion CVs have a distribution peaked at about 500 parsecs (the origin of this distribution is beyond the scope of this paper), it can be seen that few novae have distances below 500 pc and the distribution has a comparatively long tail towards very high distances. Combining this result with the sky distribution, it is clear that novae are observed at much larger distances than CVs which have not yet been observed to harbour a nova explosion. This is due to the large brightness of novae at maximum with respect to CVs.

6. Novae as distance indicators.

The standardisation of the absolute magnitude of CNe is a very tempting effort. In particular, considering the success of the period-luinosity relation for Cepheids and the relation between the maximum magnitude and the light curve time scale of supernovae Ia.

PoS(GOLDEN2019)025

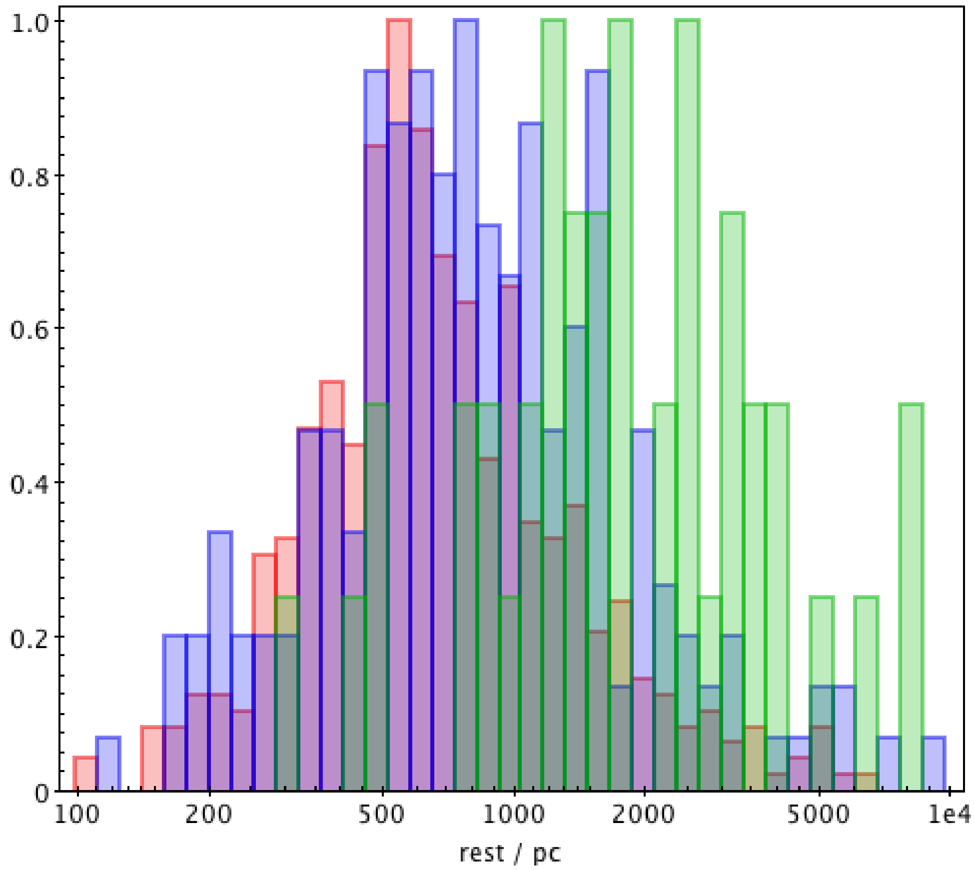

Figure 2: Distance distribution of low mass-accretion CVs (red histogram), high mass-accretion CVs (blue) and CNe (green). All distances are derived from [2]

Several authors (e.g., [5], [6], [7] and [11]) have investigated this possibility and gave some sort of parametrisation, following the pioneering work of [30] suggesting a relation between the maximum magnitude and the rate of decline (hence, the relation is referred to as "MMRD"). Yet, the scatter of this relation is disturbingly large. This is shown in the left panel Fig.3. The data are from the excellent recollection of [23]. The difficulty of reconciling the observations with one model is evident. [14] have shown the existence of a population of fast and faint novae which poses a clear threat to the possibility of using the MMRD. These data are shown in the right panel of Fig.3. [21], using HST observations of M87, showed a similar trend. Of particular relevance, this last work emphasizes that this fast and faint population of novae is predicted by models ([26]).

Both [14] and [29] suggest that an extra parameter may be required to completely make sense of the MMRD. Fig.4 shows an attempt to search for such extra parameter. The different types of light curve (following the types defined in [24]) do not seem to account for the scatter in the distribution. The spectroscopic type (as defined by [28]) despite being dominated by Fe II novae, seems to have most of the He/N and hybrid novae as fast objects. This is somewhat expected as it comes from the definition of the classification.

[19] suggested that, if needed, the MMRD can be replaced by the assumption that all novae have an absolute magnitude at maximum of -7.0 ± 1.4 mag.

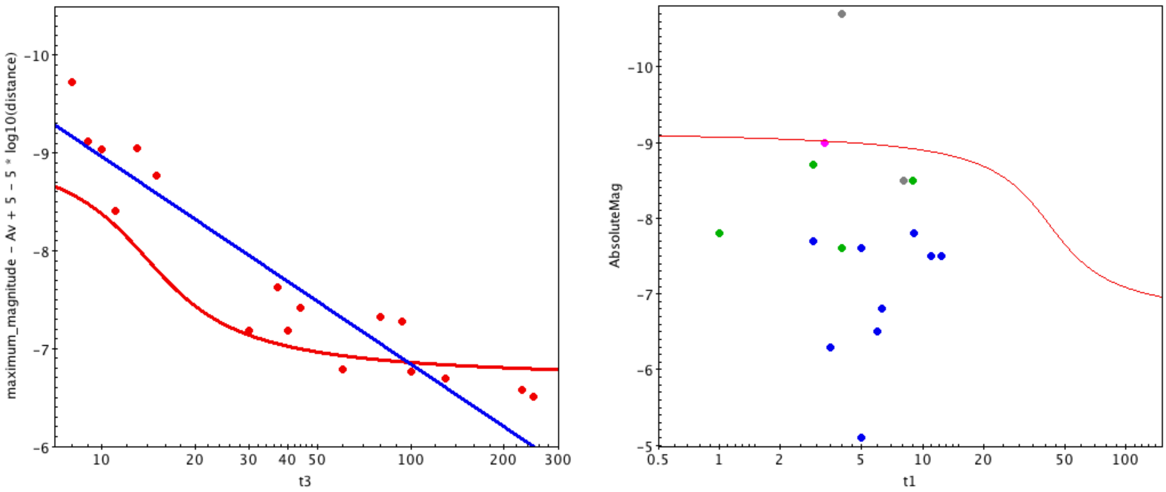

Figure 3: The right panel shows the MMRD obtained using the data from [23]. Overplotted are the fits by [6] and from [23] themselves. **In the left panel**, the data from [14] are shown. The different colours refer to different galaxies. Considering the low number statistics it is hard to draw conclusions on if the spread is indeed due to differences in the nova phenomenon as such or in novae occurring in different environments.

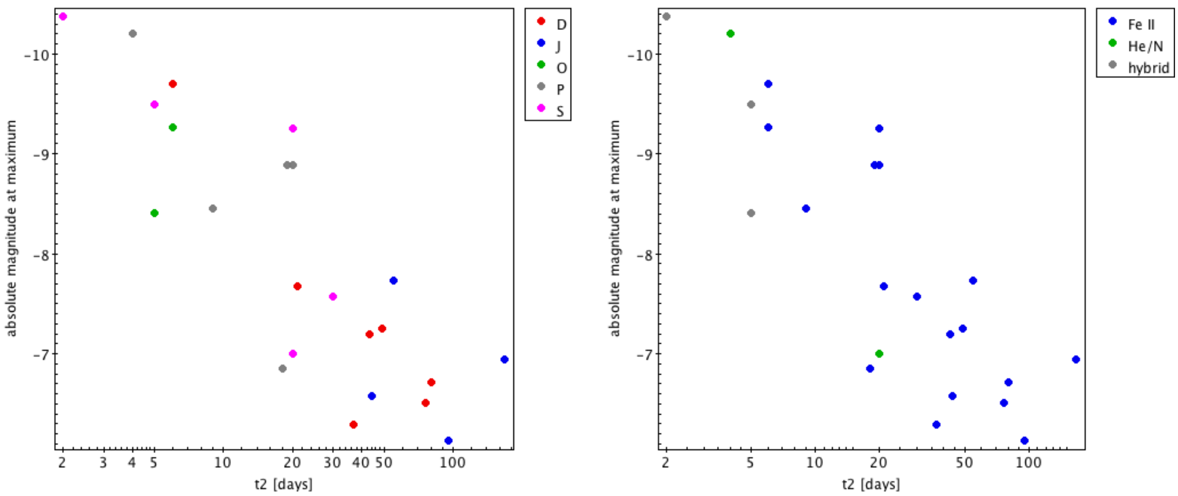

Figure 4: The left panel shows the MMRD . Data are from [16] and [8].

It is finally worth mentioning an alternative methodology, first explored by [4]: all novae have the same absolute magnitude ∼15 days after maximum light. Unfortunately, since the seminal paper, few authors have followed this path. Nevertheless, recently, this claim has been supported by new observations of novae in M87 with HST ([22]).

7. Conclusions

The current automatic all-sky surveys are providing a fantastic sample on which we will be able to test our knowledge of the nova phenomenon in the future. Our understanding of novae is unprecedented, yet still full of flaws. It has taken decades to stop saying that “novae are a sub-class of cataclysmic variables". It is clear that any complete understanding of novae is intimately related to a complete understanding of CVs and vice-versa.

While determining the basic characteristics of individual objects is a significant, valid and worthy effort, the use of novae as distance indicators seems to be reaching a dead end or, at least, a moment of careful reflection. There are valid arguments both in favour and against the MMRD. Unfortunately, the observational evidence is heterogeneous and it is difficult to put it in a common framework. Different authors use different time-scales (normally t_2 or t_3 but, more recently, even t_1 has been used). Yet, the most complicated aspect is the use of different photometric filters. While most works, in the 20th century were based on the V filter of the Johnson photometric system, many works of the last two decades are based on either Sloan filters (mostly, g and r) or the HST F606W filter. Fig.5 shows the response function of these filters. It is clear that these filters are nothing alike and cover different spectral regions. In particular, as we are interested in the maximum magnitude, the Hα line will be recorded differently in these filters. It is worth noting that the Johnson V is also sensitive in the Hα and it is certainly affected by it. This highlights the complexity of deriving conclusions in the midst of such an heterogeneous dataset.

With the rise of a new approach towards astronomical data, there is a possibility to use the current data on the MMRD not anymore in a deterministic manner but with a probabilistic approach. If one considers the data filling the plot of the MMRD, one can say that there is a certain probability of a nova with some t_n to have an absolute magnitude of M. This is doable as long as the MMRD plane is filled with spectroscopically confirmed novae, whose distance and interstellar absorption is well constrained and when the light curve is well sampled in a given filter.

For the years to come, a standard approach to nova observation is required. Considering their use in most wide-field surveys, the use of the Sloan filters seems the most obvious choice. Unfortunately, LSST will saturate at magnitude ~ 16. Yet, many high-cadence projects (with smaller telescopes) are being planned, which will be able to complement these data.

Acknowledgments

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References

[1] Abril J., Schmidtobreick L., Ederoclite A., López-Sanjuan C., 2019, arXiv, arXiv:1912.01531

[2] Bailer-Jones C. A. L., Rybizki J., Fouesneau M., Mantelet G., Andrae R., 2018, AJ, 156, 58

[3] Bode, M. & Evans, N. *Classical Novae, 2nd Edition*, Cambridge University Press, Cambridge, 2008

[4] Buscombe W., de Vaucouleurs G., 1955, Obs, 75, 170

[5] Capaccioli M., Della Valle M., D'Onofrio M., Rosino L., 1989, AJ, 97, 1622

[6] della Valle M., Livio M., 1995, ApJ, 452, 704

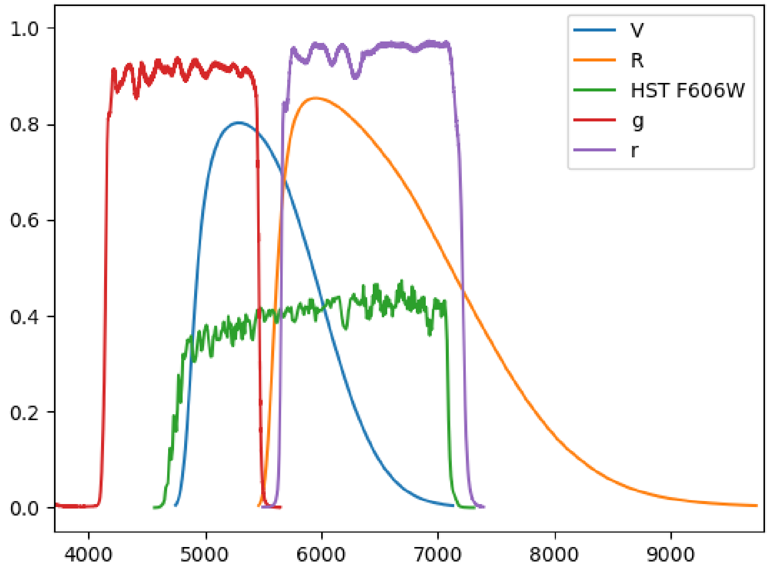

Figure 5: Response functions of the most used filters in photometric studies of novae.

[7] Downes R. A., Duerbeck H. W., 2000, AJ, 120, 2007

[8] Downes R. A., Webbink R. F., Shara M. M., Ritter H., Kolb U., Duerbeck H. W., 2001, PASP, 113, 764

[9] Ederoclite A., Tappert C., Schmidtobreick L., Vogt N., 2011, ASPC, 215, ASPC..447

[10] Ederoclite A., Tappert C., Schmidtobreick L., Vogt N., 2017, in proceedings of "The Golden Age of Cataclysmic Variables and Related Objects IV" PoS(GOLDEN 2017)045 (2017)

[11] Ferrarese L., Côté P., Jordán A., 2003, ApJ, 599, 1302

[12] Gaia Collaboration, et al., 2016, A&A, 595, A1

[13] Gaia Collaboration, et al., 2018, A&A, 616, A1

[14] Kasliwal M. M., Cenko S. B., Kulkarni S. R., Ofek E. O., Quimby R., Rau A., 2011, ApJ, 735, 94

[15] Luri X., et al., 2018, A&A, 616, A9

[16] Özdönmez A., Ege E., Güver T., Ak T., 2018, MNRAS, 476, 4162

[17] Pala A. F., et al., 2019, arXiv, arXiv:1907.13152

[18] Ritter H., Kolb U., 2003, A&A, 404, 301

[19] Schaefer B. E., 2018, MNRAS, 481, 3033

[20] Shara M. M., Livio M., Moffat A. F. J., Orio M., 1986, ApJ, 311, 163

[21] Shara M. M., et al., 2017, ApJ, 839, 109

[22] Shara M. M., et al., 2018, MNRAS, 474, 1746

[23] Selvelli P., Gilmozzi R., 2019, A&A, 622, A186

[24] Strope R. J., Schaefer B. E., Henden A. A., 2010, AJ, 140, 34

[25] Taylor M. B., 2005, ASPC, 29, ASPC..347

[26] Yaron O., Prialnik D., Shara M. M., Kovetz A., 2005, ApJ, 623, 398

[27] Warner B., 1995, *Cataclysmic Variable Stars*, Cambridge University Press

[28] Williams R. E., 1992, AJ, 104, 725

[29] Williams R., 2016, JPhCS, 042001, JPhCS.728

[30] Zwicky F., 1936, PASP, 48, 191

DISCUSSION

JESÚS CORRAL-SANTANA: Have you checked the vertical distribution (z) of different types of CVs? Instead of looking at the distance (d) and galactic distribution (l,b), check z: distance above the Galactic plane. We did it with x-ray binaries and it was surprising.

ALESSANDRO EDEROCLITE: We did not do it and it is an interesting suggestion indeed.

PAULA SZKODY: How did you identify old novae by color?

ALESSANDRO EDEROCLITE: Went to position on sky of novae that have gone off in the last 20-30 years.

ROBERTO RADDI: Does the spatial distribution of old novae or recurrent and dwarf novae depend on their physical properties?

ALESSANDRO EDEROCLITE: It also depends on observational bias

SUMNER STARRFIELD's Comment: MMRD depends on WD mass, WD composition, $\dot{M}$, and metallicity, so MMRD cannot be real.