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A New Review of Old Novae

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Abstract

Novae are certainly very exciting at the time of their eruptions, and there is much work left to be done in understanding all of the details of that part of their existence, but there is also much to be learned by looking at the systems decades, centuries, and even millennia after their peak. I give a brief overview of some of the history and motivation behind studying old novae and long-term nova evolution, and then focus on the state of the field today. Exciting new results are finally starting to shed some light on the secular behavior of post-nova systems, although as is often the case in astronomy, the observations are at times conflicting. As is always the case, we need more observations and better theoretical frameworks to truly understand the situation.

Keywords: novae - dwarf novae - cataclysmic variables - photometry.

1 Introduction

Novae have been observed at least as far back as 134 B.C. (Fontanille 2007), and we continue to observe them and their kin—recurrent novae (RNe), dwarf novae (DNe), and the rest of the cataclysmic variables (CVs)—to this day. Just after discovery, near peak, and for the few weeks following peak, they are quite exciting and tend to receive a good amount of observational coverage from both amateur and professional astronomers. A month or two after peak, however, the number of observations decreases sharply, due to various reasons including limited telescope time and short attention spans among astronomers who understandably want to move on to the next exciting object. Because of this, the long-term, secular behavior of novae is poorly understood. In this conference review, I examine what little we know about novae in the decades, centuries, and millennia following their eruptions and describe efforts to remedy this lack of knowledge and understand how novae fit into the broader context of CV evolution in particular and binary evolution in general.

2 The First Decades

A classical nova (CN) occurs in a CV when enough accreted gas accumulates on the surface of the white dwarf (WD) that a critical temperature/pressure is reached and a thermonuclear runaway is ignited, causing a dramatic brightening of the system, which we see as a nova. Immediately after a nova eruption, two effects compete to affect the brightness of the system. These effects were quantified into the hibernation model originally proposed by Shara et al. (1986) to explain the low observed space-density of novae. Although more recent surveys seem to show that the low numbers of observed novae at the time may have been due to observational limitations and biases, (e.g. Gänsicke et al. 2009), the physical effects described by the hibernation model remain valid and should be investigated. There are two potent effects we must consider. First, the mass ejection during the nova eruption leads to an increase in the angular separation between the accreting WD and its companion star. This leads to a decrease in the accretion rate and therefore the brightness of the star, since the observed brightness is due predominantly to the accretion luminosity. The second effect is that the thermonuclear runaway on the surface of the WD greatly increases its temperature; the hot WD then irradiates the companion star. The companion in turn puffs up, overflows its Roche Lobe more than it was previously doing, and the accretion rate increases, causing the system to get brighter. So the two main observable consequences following a nova eruption act in opposite directions and potentially cancel each other out. The question is which effect dominates, and why.

Collazzi et al. (2009) and Schaefer & Collazzi (2010) obtained the pre- and post-eruption magnitudes of a sample of 25 classical and 6 recurrent novae using a combination of published literature magnitudes, archival plates, and amateur observations. Defining Δm as the average difference between the pre- and post-eruption magnitude values for a given system, $m_{\text{pre}} - m_{\text{post}}$, they found $\Delta m_{\text{avg}} = +0.16$ mag and

$\Delta m_{\rm med} = +0.13$ mag, with $\sigma = 0.42$ mag for the 25 CNe with their 25 observed eruptions. Adding in the 6 RNe, for a total of 44 eruptions, they found $\Delta m_{\rm avg} = +0.03$ mag and $\Delta m_{\rm med} = +0.03$ mag, with $\sigma = 0.43$ mag. Both results are consistent with $\Delta m = 0$, implying that the increase and decrease in the accretion rate after an eruption do in fact cancel each other out in most systems. A textbook example of this is QZ Aurigae, Nova Aurigae 1964, the pre- and post-eruption light curve of which can be seen in Figure 1. QZ Aur has a $\Delta m_{\rm avg} \approx 0.03$ mag, essentially equal to zero.

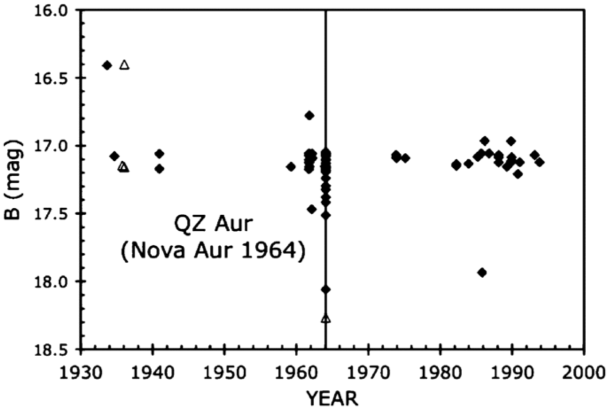

Figure 1: QZ Aurigae, Nova Aurigae 1964, is a textbook example of the findings of Collazzi et al. (2009), who showed that for nearly all novae, the pre- and post-eruption magnitudes are identical, and that on average $\Delta m = m_{\rm pre} - m_{\rm post}$ across all nova eruptions is consistent with 0. Figure reproduced with permission from Collazzi et al. (2009).

There are of course a few systems that do not follow the trend. Christened the V1500 Cyg Stars by Schaefer & Collazzi (2010) after their prototype system, these stars show large positive Δm values years-to-decades after their eruptions have ended, i.e. they return to a quiescence that is brighter than their pre-eruption quiescence value. There are eight systems that fall in this category, with Δm values ranging from 3.01 to > 4.96. The underlying physical mechanism causing this phenomenon is not well understood but it has been postulated that all of the systems are magnetic, either polars or intermediate polars. The magnetic field funnels the accreting material onto a small portion of the WD surface, leading to sustained nuclear burning, which irradiates the companion for a much longer time period than after a normal nova eruption and again causes an increase in the accretion rate and correspondingly the brightness of the system. This theory addresses the basics of the observations, but needs more thorough computational work to confirm its validity.

Neeley & Schaefer (private communication) examined seven old novae that had a large number of magnitudes in the literature covering the decades since their eruptions. Taking all seven together, they found an average decline of 1.4 mags per century, in line with the hibernation model, which predicts an average decline of 1 mag per century. Johnson et al. (2013) examined one of the systems, V603 Aquilae (Nova Aquilae 1918) in much greater detail and found an overall decline in brightness of 0.44 ± 0.04 mags per century since 1938, again as expected from the hibernation model. The light curve for V603 Aql showing this decline can be seen in Figure 2. This average behavior, however, hides the unusual behavior of a few systems among the more vanilla ones, including novae that appear to have undergone state changes, as well as at least one system (Q Cygni) that is getting brighter on a secular timescale (Schaefer, private communication).

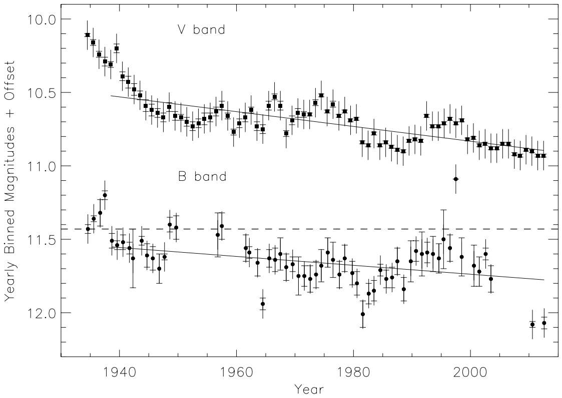

Figure 2: This yearly binned light curve for V603 Aquilae (Nova Aquilae 1918) clearly shows a secular fading in both $B-$ and V-band, as predicted by the hibernation model. The calculated decline rate for V603 Aql is 0.44 ± 0.04 mags per century. Figure reproduced with permission from Johnson et al. 2013.

The variety of behaviors seen when looking at even just a small number of systems indicates that a full survey is necessary to understand what is actually happening to post-nova CVs. I am embarking on a project to examine a much larger sample of post-nova systems in an attempt to obtain complete statistics on what novae do in the decades and centuries following their eruptions. I am working to combine historical magnitudes from archival plates and the published literature with a modern magnitude survey of all galactic novae. The bulk of the plate magnitudes will come from the collection of the Harvard College Observatory, which has ~500,000 plates dating back to the 1890s and ranging from B=14 to B=18 in limiting magnitude. Although at this point, much of the work done using the Harvard plates must be completed by hand, the observatory has embarked on a scanning project known as DASCH (Digital Access to a Sky Century at Harvard) led by Josh Grindlay. Eventually, the entire plate collection will be scanned and available digitally, which should provide an efficient way to study the long-term behavior of many systems, including novae.

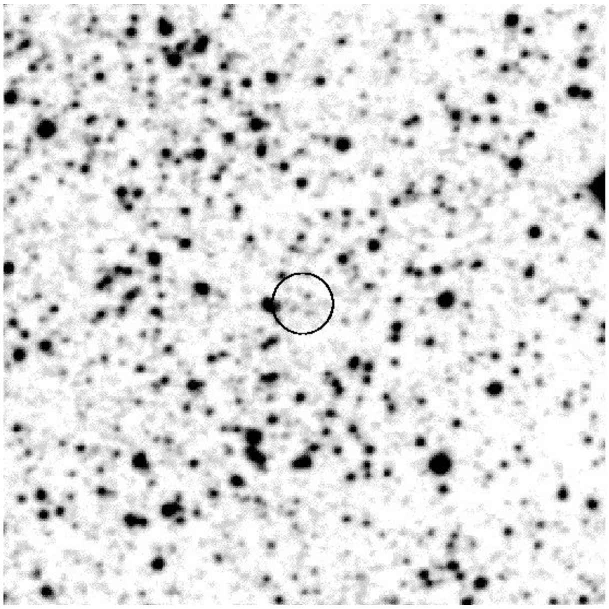

Figure 3: This finder chart for V906 Ophiuchi (Nova Ophiuchi 1952) from the online version of the Catalog and Atlas of Cataclysmic Variables (Downes et al. 2001), showing the location of the nova eruption. There are at least three stars equally near the middle of the identifying circle, any of which could be the quiescent counterpart of the nova, or the actual counterpart could be a fainter star that is not easily detected in this relatively shallow image. There are many nova systems with finder charts as (un)clear as this one, which necessitates photometric and spectroscopic follow-up to identify the proper counterpart before any information can be obtained about its secular brightness history.

One big challenge in this endeavor is identifying the quiescent counterpart of the nova eruption. Although the eruptions are bright and, after detection, easy to identify, once the systems have faded, it becomes much more difficult. The positions and finder charts given for novae are often unclear, with multiple stars, or none at all, visible at the marked location, an example of which can be seen in Figure 3, which shows the V906 Ophiuchi finder chart given in the online version of the Downes et al. (2001) Catalog and Atlas of Cataclysmic Variables. Deep, multi-color images of the fields are required first, to identify blue stars which are more likely to be CVs. If in fact hibernation is correct and most novae spend their decades post-eruption fading in brightness, the practice of identifying the counterparts is more challenging, because they are fainter than they were before the eruption, and will continue to fade. When imaging is not enough to identify post-eruption nova counterparts, spectroscopy is required as well. The team of Tappert, Schmidtobreick, Ederoclite, and Vogt is currently in the middle of a dedicated effort to identify the counterparts of old novae using a combination of photometry and spectroscopy. Tappert, Schmidtobreick, and Ederoclite also have papers in this proceedings, so I will leave the details of their work to them.

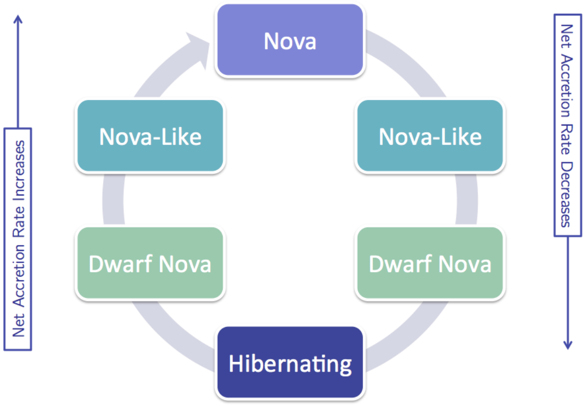

Figure 4: The expected cycle of a CV both pre-and post-nova eruption according to the hibernation model. Before and after the nova, the system would be classified as a nova-like CV, with a high accretion rate but no known eruptions. As the accretion rate falls off post-eruption, the system transitions through a series of other types of CVs, from nova to nova-like to dwarf-nova (perhaps multiple types of dwarf novae), before eventually settling into a state of hibernation in which the accretion essentially goes to zero. After a long period of time during which only gravitational radiation is actively moving the stars close together again, the companion once again overflows its Roche Lobe, accretion restarts at a low level, and the system moves up the left side of the figure, returning to dwarf nova and then nova-like states before likely undergoing another classical nova eruption tens of thousands of years after the first.

3 The Centuries to Millennia Following Eruption

In addition to the long-term fading of a post-nova system, another prediction of the hibernation model is that a system should undergo state changes, passing through various other types of CVs on its way into and out of hibernation (Shara et al. 1986). It is expected to be a cycle such as that depicted in Figure 4, in which a system changes state as the accretion rate changes. Immediately post-eruption, the system should appear as a nova-like variable, eventually transitioning to a dwarf nova, and then finally going into hibernation proper when the accretion essentially stops. After a time period that could be on the order of thousands of years, gravitational radiation will grind down the system, return it to contact, and restart the accretion, propelling the system back through the cycle from dwarf nova to nova-like and eventually back to another nova eruption. This is another testable prediction of the hibernation theory.

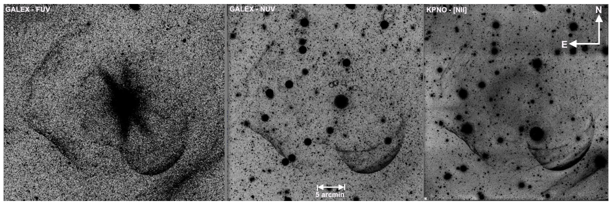

Figure 5: Three images of the classical nova shell surrounding the dwarf nova Z Camelopardalis; from left to right they are in Far-UV (1516 Å) and Near-UV (2267 Å) from GALEX and in [NII] from the KPNO 4m telescope. Shell expansion has not yet been detected, but an upper limit of 0.17" per year, corresponding to a velocity no greater than 138 km s^{-1} has been placed on the expansion of the shell by Shara et al. 2012b. The nova eruption of Z Cam is quite possibly associated with a guest star recorded by Chinese astronomers in 77 B.C. (Johansson 2007). Figure reproduced with permission from Shara et al. 2012b.

At this time, we have regular post-eruption observations of novae going only approximately one century past their eruptions, for old novae with good coverage on the Harvard plates. There are two systems in which both classical and dwarf nova eruptions have been observed. GK Persei (Nova Persei 1901) was the first system in which this behavior was observed, when dwarf nova eruptions began approximately 50 years after the CN eruption. The second system is V1017 Sagittarii, which was considered to be recurrent for many years, but upon closer examination it was realized that V1017 Sgr had a DN eruption first, in 1901, followed by a CN eruption in 1919, followed by future DN eruptions, starting back up again in 1973 (Webbink et al. 1987). This state change occurs on a much faster timescale than predicted by the hibernation model.

The century of data from Harvard is an excellent resource, but is not, however, the limit of how far forward—or backward, depending on your perspective—we can look. Thus far there are two systems currently known to be dwarf novae around which very old nova shells have been discovered. The first was Z Cam, originally discovered by Shara et al. (2007), and followed up with better observations of the shell published in Shara et al. 2012b; Figure 5 shows three of those images, the Near- and Far-UV images from GALEX (1516 Å and 2267 Å, respectively), and the [NII] optical emission image taken at the Kitt Peak 4-m telescope. Shell expansion has been undetectable thus far, with an upper limit of 0.17" per year, corresponding to an expansion velocity no greater than 138 km s^{-1}. It is likely that the nova eruption that caused the shell was recorded as a guest star by Chinese astronomers in 77 B.C. (Johansson 2007).

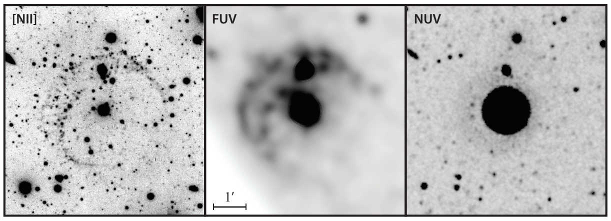

Figure 6: Three images of the classical nova shell surrounding the current dwarf nova AT Cancri; from left to right they are in [NII] from the KPNO 4m telescope, Far-UV (1516 Å) and Near-UV (2267 Å) from GALEX. AT Cancri is the second dwarf nova, after Z Cam, which has had a classical nova shell detected around it. Figure reproduced with permission from Shara et al. 2012c.

The second dwarf nova to have a shell is AT Cancri, shown in Figure 6 in the same three bands as the Z Cam image. Additionally, AT Cancri's shell has knots, as seen more clearly in the Hα + [NII] image in Figure 7. The knots are likely caused by the same Rayleigh-Taylor instabilities that cause the knots in GK Per (Shara et al. 2012a) and T Pyx (Shara et al. 1997, Schaefer et al. 2010, Toraskar et al. 2013).

Most recently, Patterson et al. (2013) have pointed to the star BK Lyncis as a third system that has changed state. Pre-2005, BK Lyn appeared to be a normal nova-like star, with a WD accreting at a relatively high rate, but nothing else special about the system. Starting in 2005, however, and very well defined by 2011 and 2012, BK Lyn transitioned into being an ER UMa-type dwarf nova. (For more details about BK Lyn and the contributions of the excellent observers of the Center for Backyard Astrophysics to this discovery, see Joe Patterson's proceedings paper from this meeting.) BK Lyn is possibly associated with a nova recorded in 101 A.D., and therefore it took approximately 2000 years for it to make its transition, as opposed to just a few decades for GK Per and V1017 Sgr. This is loosely theorized to be due to the large difference in the orbital periods of the systems, with BK Lyn being quite short (107.97 minutes; Patterson et al. 2013) and GK

Per and V1017 Sgr having long orbital periods (1.997 days and 5.780 days, respectively; Pagnotta & Schaefer 2013), but the effect is still not well understood and needs a more solid theoretical grounding.

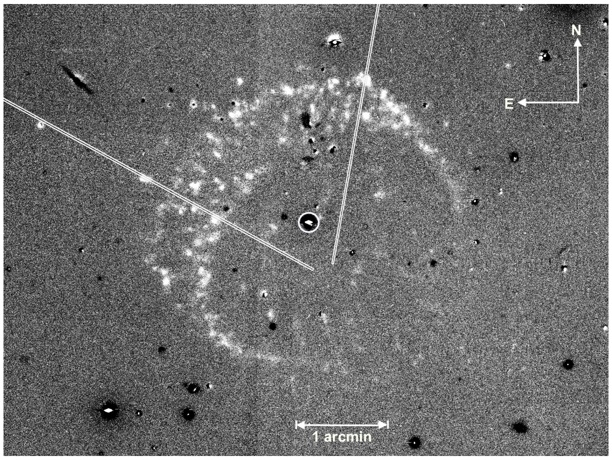

Figure 7: This Hα + [NII] image of the classical nova shell around AT Cancri clearly shows the knots present. The knots are likely caused by Rayleigh-Taylor instabilities and are similar to those seen in GK Per (Shara et al. 2012a) and T Pyx (Shara et al. 1997, Schaefer et al. 2010, Toraskar et al. 2013) Figure reproduced with permission from Shara et al. 2012c

4 Conclusion

With even just a small sample of post-eruption novae for which the long-term behavior has been studied, we see a wide variety of behaviors. Some novae fade, as predicted by the hibernation model; others brighten, in direct opposition to the theory. Some appear to stay at the same magnitude for many decades following their eruption; perhaps they will continue in this fashion, or perhaps a change will set in many years later. A number of systems have been seen to change states, from novae to dwarf novae, on time scales varying from approximately 50 years to approximately 2000 years. Taken all together, the lesson from this review is that the long-term behavior of post-eruption novae is poorly understood, and most certainly in need of more study, both observationally and theoretically.

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DISCUSSION

ED SION: Q Cyg may not be so odd. We found that Nova Oph 1848 (V841 Oph) and DI Lac (Nova Lac 1910) are also accreting at a high rate and probably getting brighter.

ASHLEY PAGNOTTA: Very interesting, and a great example of why we need a large-scale survey of novae to see what's normal and what's not. Thank you for pointing out those two systems.

JAN-UWE NESS: Very encouraging results from historical plates. In addition to the Harvard Plates, smaller historical observatories such as Hamburg may have scanned plates that could fill more gaps. MARINA ORIO and RENE HUDEC made similar comments about smaller observatories including Asiago and Bamburg. RENE HUDEC also commented on his presently-active project to document what exists in current plate archives and help facilities get their collections scanned into a digitally-accessible form.