Classical and Recurrent Novae

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Abstract The physical nature and principal observational properties of novae are reviewed. Suggested improvments to optical photometry and discovery strategies are discussed. Nova eruptions occur in close binary systems, in which a white dwarf (WD) steadily accretes material on its surface from a lower mass cool companion. The accreted envelope is in electron degenerate conditions and grows steadily in mass with time, until a critical amount is accreted (which is inversely related to the WD mass). At that point, a fast evolving thermo-nuclear runaway starts burning hydrogen, in a short flash lasting about a hundred seconds, which is terminated by the violent ejection into the surrounding space (at a speed in excess of the escape velocity) of the whole accreted envelope (or a sizeable fraction of it). The nova is discovered only when, several hours or a few days later, the expansion and cooling of the fireball ejecta make them emit profusely at optical wavelengths; the later decline in brightness is regulated by interplay between dilution of the ejecta into surrounding space, gas and dust opacities, and temperature/luminosity of the central WD when the ejecta eventually become optically thin. The time interval between consecutive outbursts from the same nova is usually (far) longer than recorded history, but for a small number of objects (named recurrent novae) it is short enough that more than one outburst has been observed for them.

1. Introduction

For centuries, the term *nova* simply meant the unexpected appearance of a *new star* in the sky, fixed with respect to the other stars (to distinguish it from planets and comets), that after some time usually vanished from view. Now we know that quite different types of object can emerge from obscurity, sometimes briefly, as the result of completely different physical processes, like supernovae of various types, pre-main-sequence young objects of the FU Ori variety, very evolved objects undergoing late thermal pulses as displayed by V4334 Sgr (Sakurai's Object), cataclysmic variables in outburst, enigmatic events like V838 Mon (widely celebrated for its light-echo), and obviously the classical novae.

From an observational point of view, a *classical nova* (hereafter *nova* for short) is a stellar outburst characterized by a rapid rise toward maximum brightness (a matter of hours or days), a large amplitude in the optical ($8 \leq \Delta\,\mathrm{mag} \leq 16$), mass ejected at high velocity (from a few hundreds to a few thousands km sec^{-1}, as indicated by the very wide emission lines and/or largely blue-shifted absorption components in P Cyg profiles), post-maximum optical spectra evolving toward increasing excitation and ionization, and nebular conditions usually prevailing during advanced decline (that is, forbidden emission lines dominating the spectra). For the vast majority of novae, only one outburst has been observed in historical times. However, a few novae (like the celebrated U Sco, RS Oph, or T CrB) have undergone more than one outburst. They are called *recurrent novae*. It is believed that, should the monitoring time extend for hundreds or thousands of years, all novae would be seen to erupt again (and again). About 500 galactic novae are known. Duerbeck (1987) presented an accurately researched catalog and atlas of essentially all novae that erupted before 1986, which also included finding charts especially useful for old objects, long returned to quiescence conditions. Accurate coordinates, basic information, and finding charts for more recent novae were provided by Downes and Shara (1993) and Downes *et al.* (1997, 2001, 2005).

2. A model nova

Cataclysmic variables (CVs) and novae are believed to be the same binary systems, in which a low mass cool companion transfers material via Roche lobe overflow to a more massive white dwarf (WD). The orbital periods are a few hours long, and the orbital separations are on the order of the Sun's radius. During the hundreds or thousands of years spent away from nova outbursts, the material lost by the companion goes to form an accretion disk before terminating its journey by piling up on the surface of the WD (if the WD is strongly magnetized, the formation of an accretion disk is prevented and the material flows onto the WD via the magnetic poles). The accretion disk is prone to instabilities that cause regular, low amplitude bright phases termed CV-type outbursts (unfortunately, they are also called *dwarf* nova outbursts, a confusing terminology and another example of the irresistible attraction of astronomers for inapt terminology when better alternatives would be at hand). SS Cyg is a famous CV, whose accretion disk every two months goes through a CV-type outburst that brightens the system from $V = 12$ to $V = 8$. This cycle has continued uninterrupted since when SS Cyg was discovered in the late nineteenth century; (a wonderful AAVSO historical light curve covering about 110 years of observations and every outburst since discovery has been presented by Cannizzo and Mattei 1998).

The envelope accreted on the surface of the WD is in *electron degenerate* conditions, an unusual state of matter characterized by the fact that the pressure is not related to the temperature. In normal experience, you heat up something and it reacts by expanding: to lift a balloon, you raise the temperature of the air it contains and the resulting increase in pressure swells the balloon, which begins to ascend following Archimedes's principle (the density of the hot air in the balloon is lower than that of the cooler outside air). We write this by saying that its *equation of state* is $P \propto \rho T$, that is, the pressure is proportional to density times temperature. For electron degenerate material the equation of state modifies to $P \propto \rho^{\alpha}$, that is, there is no more dependence on temperature. Let's turn back to our nova in the making. With passing time, the envelope of material accreted on the surface of the WD steadly grows in mass until a critical value is reached (which is inversely related to the WD mass). When this occurs, the hydrogen present in the envelope starts to be burned via the CNO cycle, whose energy production rate (ε_N) is extremely sensitive to temperature: $\varepsilon_N \propto T^{18}$. The energy released by the nuclear burning heats up the envelope which however cannot react by expanding (its pressure is independent of temperature), and in turn the rise in temperature increases the nuclear energy production rate, that is, a circular argument. The temperature in the envelope rises exponentially out of control; (the envelope is experiencing a *thermo-nuclear runaway* or TNR). In a matter of few tens of seconds, it reaches the *Fermi temperature* (of the order of 350 million Kelvin) at which point the electron degeneracy is suddenly removed and the equation of state instantaneously reverts to that of ordinary gas ($P \propto \rho T$): the envelope can now react to its extremely high temperature by expanding. The expansion is so violent that the envelope is actually ejected into the surrounding space at a speed exceeding the escape velocity, and it will never return. The resulting drop in temperature first slows down and then effectively stops the TNR. A few minutes were enough to ignite the TNR, let it develop, and stop it. At this stage the nova has not been discovered yet: it will become visible only hours/days later when the fireball of the expanding ejecta has grown in size enough and its surface temperature as declined to about 10,000 K to shift the peak of radiated energy from the initial γ- and X-rays to the optical range.

When SS Cyg undergoes such a TNR and the consequent resulting nova outburst (maybe tomorrow, maybe a thousand years from now), it will rise in brightness so much that it will probably become, for days/weeks, the brightest star of the whole sky, rivalling or surpassing Vega and Sirius. But do not worry: a few months later SS Cyg will be back to quiescence and in a few decades more, it will resume its CV-type, ~60-day cycle outbursts, for the fun of future enthusiastic observers!

3. Some statistics on novae

3.1. Where they appear

Novae do not appear randomly on the sky, but they concentrate along the Milky Way and in particular in its central regions. There are eighty-eight constellations on the sky, but no nova has ever been observed in over twenty-two of them, most notably Hydra, Ursa Major, Pegasus, and Draco that together cover an area of 4,800 square degrees, or about 12% of the whole sky (the statistics in this review are based exclusively on official International Astronomical Union (IAU) data, in particular *IAU Circulars* and *CBET*s). A list of the constellations arranged according to the number of novae they produced is given in Table 1. Sagittarius, with its 114 novae, leads the group.

Sagittarius is however favored by being a large constellation (867 square degrees). To assess the productivity of the various constellations, it is better to refer to the number of novae which appeared there, per unit area, essentially dividing the data in Table 1 by the constellation area. The results are given in Table 2, expressed as the number of novae appearing in the given constellation over an area of 100 square degrees. The small Scutum (covering just 109 square degrees on the sky; only Circinus, Sagitta, Equuleus, and Crux being smaller) now stands out as where the concentration of novae is the highest (therefore, Scutum would be a good target to image if your are considering starting to look for novae yourself !).

3.2. How bright they are

The distribution of novae in terms of magnitude at maximum and of outburst amplitude (that is, the difference in magnitude between quiescence and outburst maximum) is presented in Figure 1 (panels a and d). The data are rather heterogeneous (coming from old blue-sensitive photographic plates, visual estimates, unfiltered CCDs, properly calibrated BVRI observations, and so on; when the information is available, they refer to the actual maximum brightness, but sometimes only the brightness at the time of discovery is known).

The distibution of magnitude at maximum looks like a Gaussian distribution peaking around magnitude = 8.7. Such a distribution suggests that most of the novae peaking to magnitude 8 or brighter have indeed been discovered. Conversely, the majority of those reaching only magnitude 11 or 12 pass unnoticed. However, the number of Galactic novae does not increase indefinitely toward fainter magnitudes (contrary to the case of supernovae, where fainter magnitudes means larger volumes of space and greater numbers of host galaxies): the size of our Galaxy is limited and the novae are intrinsically very bright objects. Let's take for example Figure 2, which summarizes the distribution in magnitude of the ninety-five novae discovered in the Andromeda galaxy (M31) over the five-year interval 2007–2011 (an average of ~20 novae per year): the distribution peaks between 17.0 and 17.5 in R_C, corresponding to a peak $M(R_c)=-7.3$ magnitude in the absolute magnitude distribution. The discovery of real faint novae in the central bulge region of M31 is no doubt adversely biased; nonetheless the peak of the distribution in Figure 2 seems well established observationally. A $M(R_c)=-7.3$ magnitude Galactic nova would appear to us shining at

$$R_c = M(R_c) + 5 \log d - 5 + A_R = -12.3 + 5 \log d + A_R \qquad (1)$$

where d is the distance expressed in parcsecs and A_R is the amount of interstellar extinction in the R_C band (which relates to E_{B-V} reddening as $A_R = 2.6 \times E_{B-V}$). At a distance of 3 kpc and an extinction $A_R = 1.6$ magnitude, our $M(R_c) = -7.3$ nova would shine at a comfortably $R_c = 6.7$ magnitude. Even pushing it to the center or our Galaxy ($d = 8.5$ kpc, $A_R \approx 5$ mag.), it would still score $R_c \approx 12.3$, well within the observing capability of amateur telescopes (provided their focal length is long enough to discern the nova among the myriads of similarly bright stars crowding the views of telescopes aimed at the center of the Galaxy).

The average magnitude of discovered novae has not significantly changed over the last eighty years, since photographic emulsions substituted for the eye as detector in patrol searches (Figure 1c). What has been continously improving is instead the frequency of nova discoveries, as illustrated in Figure 1b. From about 2.5 novae per year on average at the beginning of the twentieth century, it rose to about 4 during 1980–1990. The surge to about 8 novae per year over the last 5 to 10 years is undoubtedly connected to the widespreading use of sensitive CCDs as detectors and electronic blinking of images. Figure 1b suggests we are currently on a steep rise, and the number of novae discovered per year should appreciably increase during the next 5 to 10 years.

3.3. Who discovers them

Table 3 lists the most prolific nova discoverers, nearly all of them amateur astronomers, a group of highly motivated and dedicated people led by William Liller, who works from Viña del Mar, in Chile. He has for a long time recorded sky images with a 35-mm camera, an 85-mm lens, Kodak Technical Pan 2415 film, and an orange filter, and then made use of a homemade, 25-power stereo viewer. One eye looks at the new sky photograph, while the other at an archival image. If a candidate nova appears in one image but not the other, that prompts further investigation and confirming observations. Such an eye inspection is equivalent to blinking on a computer monitor electronic images taken with CCDs. Their dropping costs, the ever-increasing area of their detectors, and the real-time inspection of their images allowed by electronic blinking (either via automated software or eye inspection on a computer monitor), are making DSLR cameras the primary tool for current nova hunters. The discovery of novae will presumably remain, for a long time, a business reserved for amateurs: professional telescopes are too inefficient to cover large areas of the sky at bright limiting magnitudes night after night.

4. The light curve

A schematic light curve for a nova is shown and described in Figure 3. With the increasing number and quality of photometric observations, the great diversity among the observed light curves is increasingly evident, to the point that speaking of a *typical* light curve for novae is losing its meaning. Many examples of light curves of novae have been presented, among others, by Payne-Gaposchkin (1957), Kiyota *et al.* (2004), and Strope *et al.* (2010), the latter offering also a new morphological classification scheme.

After the initial rapid rise (a matter of just a few hours in very fast novae like U Sco), the nova goes through a maximum optical brightness phase that can be anything from an immediate rebound toward decline, to a smooth and well-behaved round phase, or a series of erratic ups-and-downs on top of a flat plateau, or a second and equally well-behaved maximum, and so on. A non-exhaustive compilation of observed behaviors at maximum brightness is shown in Figure 4. Then, past maximum phase, the decline toward quiescence sets in, and it is usually characterized by two phases: a faster one, when the ejecta are still optically thick (the central source cannot be seen from outside) and that lasts until the nova has declined by 3–4 magnitudes from maximum, and then a slower one, when the ejecta become optically thin (the whole body of them becomes directly exposed to the hard ionizing radiation emanating from the central star, and the latter is visible from outside the ejecta).

The time when the transition from optically thick to optically thin conditions occur in the ejecta also marks in some novae the onset of transient events perturbating an otherwise smooth decline, either dust formation or (semi-periodic) oscillations. Dust grains can form in the ejecta, and the resulting dust obscuration can dim by several magnitudes the brightness of the nova. After a maximum is reached, the obscuration by dust progressively reduces and, after a while, the nova resumes the decline path it would have followed in the absence of dust formation. The dilution of the dust grains caused by the ongoing expansion of the ejecta is the main reason for the end of the obscuration phase. The radiation absorbed in the optical heats up the dust grains which re-emit it at longer wavelengths, and the nova appears several magnitudes brighter at infrared wavelengths (thus, during the dust phase, the infrared light curve is a mirror image of the optical light curve). With the transition from optically thick to optically thin conditions in the ejecta, oscillations of various types may be seen in several novae. They can be either of the type making the nova look temporarily fainter (like for instance V2467 Cyg / N Cyg 2007) or brighter (as in V2468 Cyg / N Cyg 2008 No. 1). These oscillations can either appear irregular in both phase and amplitude, or follow a regular, sinusoidal-like pattern. One of the novae showing the most spectacular set of oscillations was GK Per (N Per 1901). They started when the nova was 3.5 magnitude down from maximum brightness, and lasted several months; at least 20 oscillation cycles were counted, with peak-to-valley amplitudes ranging from 1.0 to 1.5 magnitudes. A generally agreed physical explanation for the oscillations does not yet exist, though various models have been suggested.

5. The spectrum

The spectra of novae, right at maximum brightness, are dominated by an underlying hot continuum with only relatively weak emission lines, sometimes only Hα being visible in emission. All absorption lines show large negative radial velocities, indicating that they are forming in a rapidly expanding medium. As soon as the nova begins to decline, the emission lines rapidly get progressively stronger than the continuum. This is the combined effect of the underlying continuum declining in intensity while, for some time, the emission lines increase in their absolute flux. After the transition from optically thick to optically thin ejecta has been completed, the underlying continuum essentially vanishes, and nearly all the flux recorded from the nova comes from emission lines only.

The spectrum of a nova around maximum and early decline can be either of the *FeII* or the *He/N* type, and an example of them is shown in Figure 5 (note that the ordinate scales are in logarithm of the flux to enhance visibility of the weak features). A FeII-type nova displays, in addition to hydrogen Balmer emission lines, many permitted emission lines from FeII, especially from multiplets 27, 28, 37, 38, 42, 48, 49, 73, 74. Conversely, a He/N-type nova, in addition to Balmer lines, will display emission lines from helium and nitrogen but not from FeII.

The early classification of a nova spectrum is important because it will set the stage for what to expect next in its evolution. In comparison with FeII-type, He/N novae usually decline faster, show larger expansion velocities (that is, broader emission lines), and eject a lower amount of mass. While FeII novae appear to belong to an older stellar population, heavily concentrated toward the bulge of the Galaxy, He/N novae show a lower concentration toward the center of the Galaxy and are instead more concentrated along the disk of the Galaxy, suggesting a younger parental stellar population and more massive WDs. All FeII novae display a nebular spectrum during their advanced decline, while a few He/N novae sometimes do not. An example of a nebular spectrum is shown in Figure 6 (note how the flux of the continuum in between the emission lines is almost null). Conversely, only He/N may display coronal emission lines (lines of extremely high ionization such as [FeX] 6375, [FeXI] 3987, 7892, [FeXIV] 5303, [NiXIII] 5114, [NiXV] 6702, [ArX] 5532, [ArXI] 6915, all seen during the 2006 outburst of RS Oph).

Amateur spectroscopic observations can provide both a confirmation and a classification (FeII or He/N types) of candidate novae, and then follow their early post-maximum evolution. A 60-cm telescope equipped with a spectrograph working at dispersions from 2 to 4 Ångstroms/pixel can do that for novae brighter than V = 11. The exceptional intensity of the Hα emission line in nearly all novae allows one to follow the evolution of its profile (frequently multi-peaked and with P Cyg absorption components varying with time) for a long time into the decline. A spectrograph working at 1 Ångstrom/pixel on a 60-cm telescope can easily observe and resolve the Hα profile for novae down to $V = 12$ magnitude.

6. Hints about observing novae

Amateur astronomers are already providing fundamental photometric data on novae. However, significant improvements, easy to implement, are still possible, and some of them are suggested in this concluding section.

6.1. Discovery

Most amateurs carry out their patrols for novae and discover them on unfiltered CCD images. It would be advisable to carry out the search with well-known photometric filters instead. The on-line AAVSO Photometric All-Sky Survey (APASS) provides suitable Jonhson *BV* and Sloan $g'r'i'$ comparison stars down to 16th magnitude anywhere on the sky. Cousins' R_c, I_c magnitudes can be easily obtained from the following relations calibrated on APASS data:

$$\begin{aligned} R_c &= r' - 0.095 \times (g' - i') - 0.141 \\ I_c &= i' - 0.055 \times (g' - i') - 0.364 \\ (R{-}I)_C &= 0.894 \times (r' - i') + 0.212 \end{aligned} \qquad (2)$$

for APASS fields south of the equator, while for APASS fields north of the equator they are:

$$\begin{aligned} R_c &= r' - 0.065 \times (g' - i') - 0.174 \\ I_c &= i' - 0.044 \times (g' - i') - 0.365 \\ (R{-}I)_C &= 0.918 \times (r' - i') + 0.198 \end{aligned} \qquad (3)$$

There is very little to lose if the observations are carried out, for example, in the standard R_c Cousins or Sloan r' bands: the sensitivity of most CCDs peaks there; they include the emission of the strong Hα line; and the background sky brightness is lower there than at bluer wavelengths. The discovery images will be the only ones covering that part of the light curve, that is, the critical phases preceding or around optical maximum, but if they were not obtained in a proper photometric system it will be very difficult to extract solid physical information from them. Frequently, the un-filtered photometry is unavoidably ignored in subsequent analysis and modeling.

6.2. Maximum brightness

It happens too frequently that a nova is rapidly forgotten after the initial discovery. While the discovery is surely personally rewarding and an important contribution to the field, accurate photometric monitoring (especially in the *B* and *V* bands) of the nova while it is passing through maximum brightness, is vital to fix fundamental quantities like the exact time of maximum, its brightness and its color. From the $B-V$ color the reddening and extinction will easily follow. The *B* and *V* magnitudes exactly 15 days past maximum constrain the distance to the nova. Knowing the exact *B* and *V* magnitudes at maximum brightness will allow one to define the fundamental quantities t_2 and t_3 in both bands (that is, the time required for the nova to decline by 2 and 3 magnitudes, respectively). From t_2 and t_3 the distance to the nova can be derived, and many other parameters (like the mass of the ejecta, the mass of the WD, or when the optically thin phase will begin) can be constrained. In most cases, by the time professionals can access a telescope and turn it to a recently discovered nova, it will be already past maximum, and a fundamental piece of information would be lost if not provided by amateurs.

In addition, the time of maximum brightness is a period of unexpected behavior by many novae. Some examples are illustrated in Figure 4. So far, very few novae have been accurately and multi-band monitored through their maxima. Consequently, this phase is still so poorly documented that many theoretical models do not treat it in a way able to account for the observed peculiarities. Providing accurate multi-band monitoring of maximum brightness for a greater number of novae could allow one to search for correlations between behavior at maximum and other parameters of the nova light curve or spectral properties. This in turn would both motivate and constrain theoretical efforts attempting to model peculiar maxima.

6.3. Novae in the center of the Galaxy

Compared to the novae normally discovered by amateurs, those erupting close to the center of the Galaxy will appear fainter (because of the greater distance and larger intervening extinction) and will be harder to spot against their higher stellar density backgrounds. The extremely high stellar densities at the core of the Galaxy suggests that many novae that erupt there go undiscovered every year.

The reason they escape detection lies probably in the use of DSLR cameras for nova patrol. While entirely appropriate to search for novae elsewhere on the sky, their limiting magnitude is too bright and their focal length too short to be able to detect most of the novae erupting in the central regions of our Galaxy.

To discover them, a longer local length and a larger lens than in DSLR cameras seems appropriate. The area to patrol is limited (of the order of 12×12 degrees) and a longer focal length could cover it with a limited number of overlapping images, providing a sufficient spatial resolution to isolate a $V = 12$ magnitude nova from the dense surrounding stellar background. The dividends paid by such a program focused just on novae at the heart of our Galaxy could be high.

6.4. The interesting case of V2672 Oph (Nova Oph 2009)

Nova Oph 2009 (V2672 Oph) reached maximum brightness at $V = 11.35$ on 2009 August 16.5 UT. With observed $t_2(V) = 2.3$- and $t_3(V) = 4.2$-day decline times, it is one of the *fastest* known novae, being rivalled only by V1500 Cyg (Nova Cyg 1975) and V838 Her (Nova Her 1991) among classical novae, and U Sco among the recurrent ones. The line of sight to the nova passes within a few degrees of the Galactic Center, crosses the whole bulge, and ends at a galacto-centric distance larger than that of the Sun. This is probably a record distance and position among known Galactic novae. It is not incidental that, to discover it, K. Itagaki used an $f/3$ 21-cm reflector, providing light gathering power and spatial resolution far in excess than a DSLR camera. On the basis of its many remarkable similarities to U Sco, it is highly probable that this nova is a recurrent one, possibly with a recurrence time as short as that of U Sco (Munari *et al.* 2011), and it should be inserted among the areas to be monitored regularly in the future.

The central region of the Galaxy has been imaged (on films and with CCDs) countless times, especially by amateurs looking for impressive pictures. It is quite possible that other outbursts of V2672 Oph lie unnoticed on such archival images, especially those imaging at red wavelengths. A devoted search is highly encouraged and I would be pleased to be informed (at the e-mail address given above) about the results. A list of negative results (reporting about date, UT, band, focal length, limiting magnitude of the image) would also be relevant to put constraints on the recurrence time scale. Figure 7 identifies the nova on a R_C image obtained close to maximum brightness, and provides magnitudes for reference stars.

6.5. Photometric monitoring

If observers provide only a few photometric points each, to cover the entire light curve of a nova it is necessary to combine data from many different observers. The dispersion of points in such a combined light curve is however so large (up to 1 magnitude) that all details are smeared out. The main reason is that during decline the flux from a nova is mainly concentrated in a few emission lines. Two nearly identical filters can produce drastically different data, if one includes in the transmission profile a strong emission line and the other not. This is what usually happen with the *V* filter, whose steep rising blue transmission edge coincides with the [OIII] 4959, 5007 doublet, usually the strongest emission line during the nebular phase. Figure 6 illustrates the situation.

It is advisable that once an observer begins to observe a nova (the earlier in its evolution the better), they should try to keep focused on it for the longest possible period of time. Their photometric equipment will remain the same through the observing campaign, and the collected data will be self-consistent: all the finer details of the light curve will be visible because it will not be necessary to combine with other external data.

To avoid the strongest emission lines and collect an important measurement of the true continuum underlying them, Stromgren *b* and *y* filters could be used in addition to standard Johnson *B* and *V* throughout the whole light curve. It is true that being narrower they will collect less light and the exposure times will consequently be longer, but this will be counter-balanced by the increasing physical value of the measurements. The following relations

$$y = V - 0.062 \times (B{-}V) + 0.027 \quad (4)$$
$$b = B - 0.469 \times (B{-}V) + 0.060$$
$$(b{-}y) = 0.593 \times (B{-}V) + 0.033$$

provide an useful mean to estimate Stromgren *b* and *y* magnitudes of comparison stars from their APASS *B* and *V* values.

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Table 1. Number of novae that appeared in the listed constellations, updated to 2012. The constellations that never displayed a nova (such as Ursa Major) are not listed.

Sgr	114	Vul	10	Mus	5	Leo	3	Lup	2	Tau	1	Crv	1
Oph	45	Car	10	Vel	4	CrA	3	Lib	2	Pyx	1	CrB	1
Sco	43	Ser	8	TrA	4	Boo	3	Eri	2	Psc	1	Com	1
Aql	33	Nor	8	Sge	4	Aur	3	Cru	2	Pic	1	CMa	1
Cyg	22	Her	8	Mon	4	Ari	3	Ara	2	Lyr	1	Cha	1
Sct	18	Cir	7	Lac	4	And	3	Vir	1	LMi	1	Cet	1
Cen	14	Per	6	Cas	4	Tri	2	UMi	1	For	1	Cep	1
Pup	11	Gem	6	Ori	3	Pav	2	Tel	1	Del	1	Aqr	1

Table 2. Ranking of the constellations in Table 1 in terms of nova productivity per unit area on the sky (here expressed as the number of novae that appeared over an area of 100 square degrees).

Sct	16.50	Mus	3.61	Gem	1.17	CrB	0.56	Tel	0.40	Cep	0.17
Sgr	13.14	Cru	2.92	Per	0.98	Crv	0.54	UMi	0.39	Tau	0.13
Sco	8.66	Cyg	2.74	Ara	0.84	Pav	0.53	Lib	0.37	Psc	0.11
Cir	7.50	CrA	2.35	Mon	0.83	Del	0.53	Lyr	0.35	Aqr	0.10
Aql	5.06	Car	2.02	Vel	0.80	Ori	0.50	Boo	0.33	Vir	0.08
Sge	5.00	Lac	1.99	Cha	0.76	Aur	0.46	Leo	0.32	Cet	0.08
Nor	4.84	Pup	1.63	Ari	0.68	Pyx	0.45	Com	0.26		
Oph	4.75	Tri	1.52	Cas	0.67	LMi	0.43	CMa	0.26		
Vul	3.73	Cen	1.32	Her	0.65	And	0.42	For	0.25		
TrA	3.64	Ser	1.26	Lup	0.60	Pic	0.41	Eri	0.18		

Table 3. List of the most prolific nova discoverers and the number of novae credited to them (from official International Astronomical Union discovery documentation).

40	W. Liller	9	M. Mayall	7	Y. Nakamura
14	K. Nishiyama	9	P. Camilleri	6	M. Wolf
14	H. Nishimura	8	G. Pojmański	6	D. MacConnell
14	F. Kabashima	8	L. Plaut	6	Y. Kuwano
14	H. Honda	8	A. Cannon	6	C. Hoffmeister
12	G. Haro	7	M. Yamamoto	6	K. Haseda
11	I. Woods	7	J. Seach	6	C. Burwell
11	W. Fleming	7	Y. Sakurai		

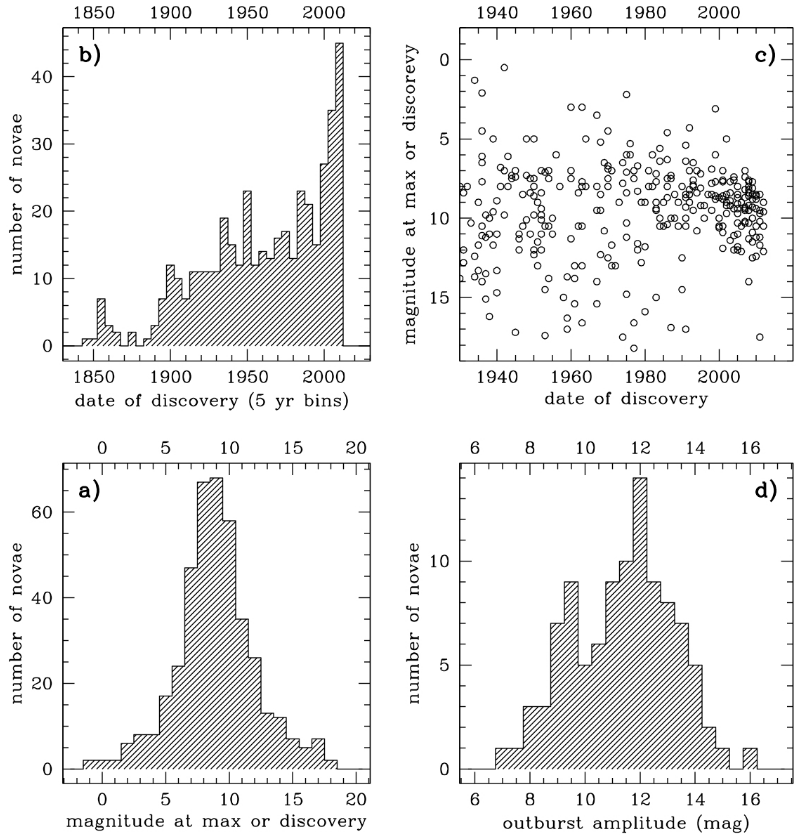

Figure 1. Statistics about Galactic novae updated to 2012: a. distribution in magnitude at maximum (or, when not available, at the time of discovery); b. number of novae discovered, counted in five-year-wide bins; c. brightness of discovered novae as function of time; d. distribution of the amplitude of nova outburst (this panel adapted from Figure 2.3 of Warner 2008).

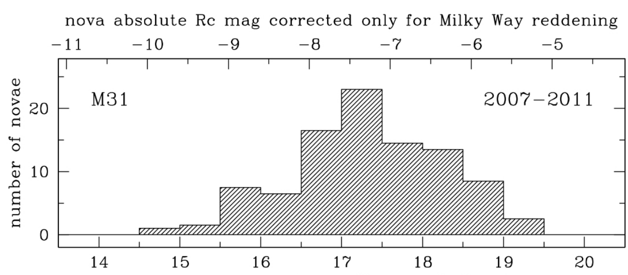

Figure 2. Distribution in R_C magnitude of the 95 novae discovered in M31 over the five-year period between 2007 and 2011.

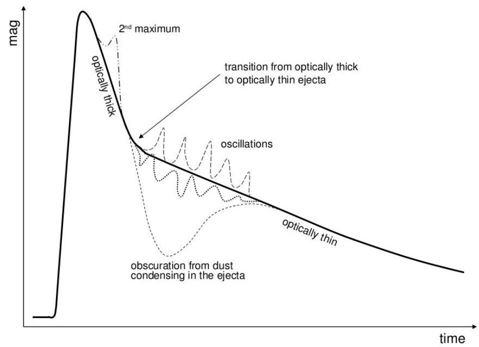

Figure 3. Schematic representation of the optical light curve of a nova. The thicker solid line provides the reference background behavior, the thinner and dashed/dotted lines represent alternative behaviors displayed by some novae.

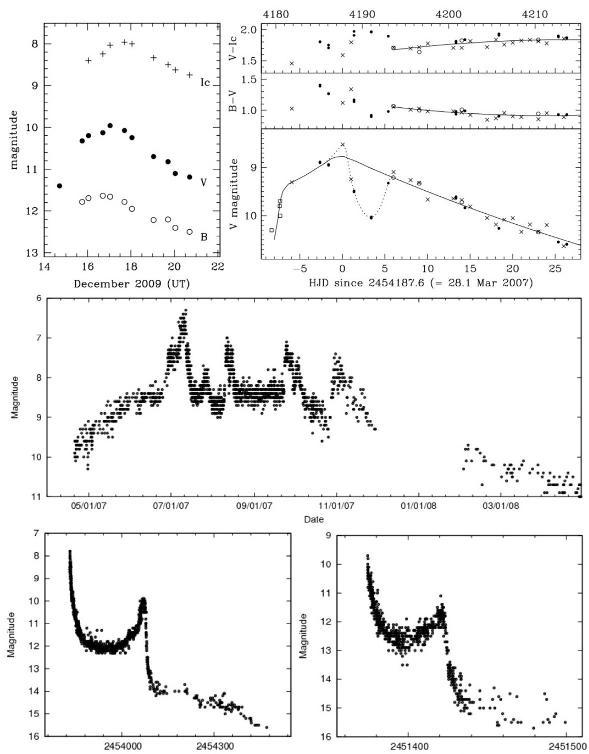

Figure 4. Some examples of the many different behaviors shown by novae around maximum brightness: the textbook smoothness exhibited by V1722 Aql/N Aql 2009 (upper left; Munari *et al*. 2010); the single pulsation-like cycle displayed by V2615 Oph/N Oph 2007 (upper right; Munari *et al.* 2008); the chaotic train of several maxima presented, over a flat plateau, by V5558 Sgr/N Sgr 2007 (center; AAVSO); the second maximum shown by V2362 Cyg/N Cyg 2006 (bottom left; AAVSO); and V1493 Aql/N Aql 1999 No.1 (bottom right; AAVSO).

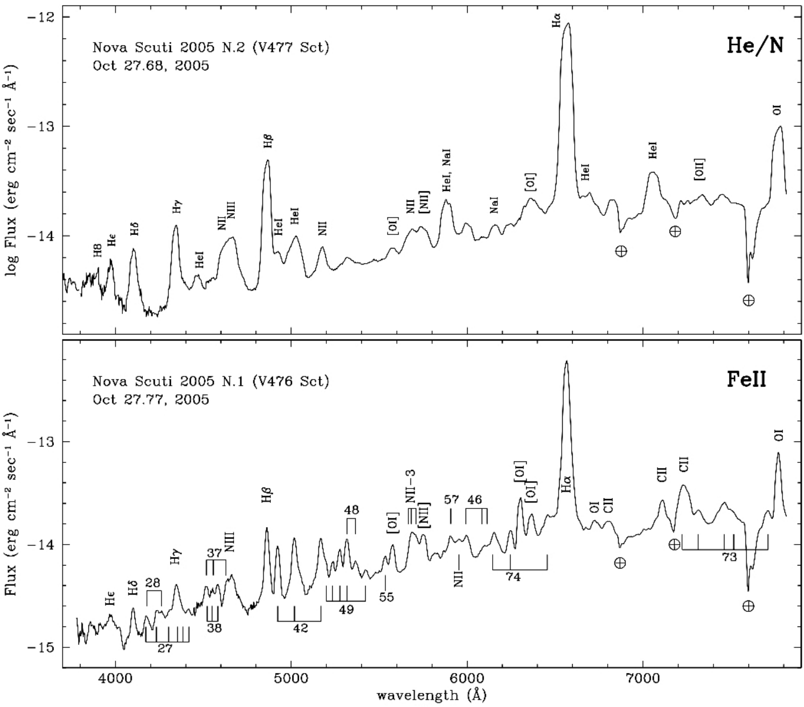

Figure 5. Examples of spectra of FeII and He/N types of novae (around maximum and along the optically thick part of the decline light-curve; Munari *et al.* 2006a, 2006b). To enhance visibility of the weak features, the absolute fluxes on the ordinate scale are plotted in logarithmic units. Major emission lines are identified. Comb-like markings identify FeII lines and the associated number the respective multiplet. Strong telluric absorption bands at 6850, 7160, and 7580 are also marked. Note the larger width of the lines in V477 Sct, tracing a large ejection velocity than in V476 Sct.

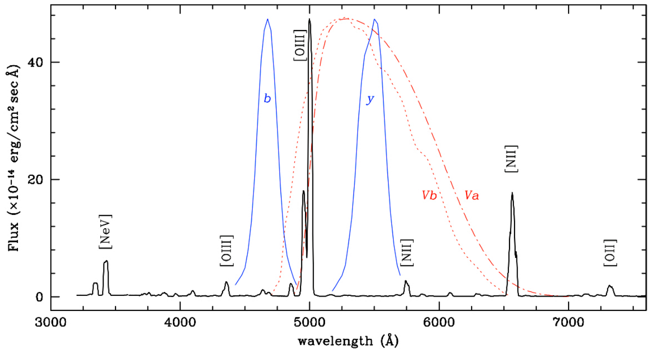

Figure 6. The nebular spectrum of Nova Cir 1995, as observed in 1996. The major forbidden emission lines are identified ([OIII] 4363, 4959, 5007 Å, [NII] 5755, 6458, 6584 Å, [NeV] 3346, 3426 Å, [OII] 7325). The transmission profiles of two commercially available *V*-band filters (labelled *Va* and *Vb*) are overplotted to show their difference in trasmitting the [OIII] 4959, 5007 Å and the [NII] 6458, 6584 + Hα 6563 Å blends (from Munari and Moretti 2012). The transmission profiles of Stromgren *b* and *y* filters are also overplotted. By avoiding the strongest emission lines, they provide a direct measurement of the true continuum emission of the nova.

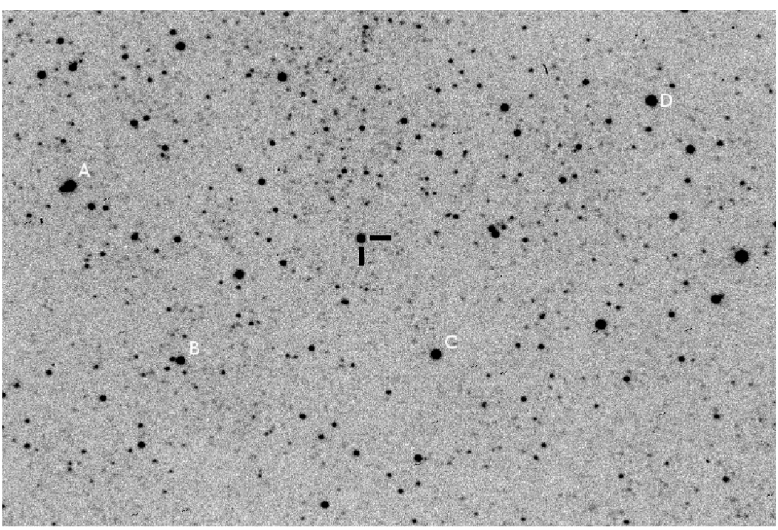

Figure 7. Finding chart for V2672 Oph/N Oph 2009 (J2000: R.A. $17^h\ 38^m\ 19.72^s$, Dec. –26° 44' 13.7") when it was shining at $R_C = 11.64$ a couple of days past maximum. The *V*, *B–V*, $V–R_C$, $V–I_C$ values for the four comparison stars are: 11.250, +2.032, +0.990, +1.991 for A; 12.039, +0.689, +0.300, +0.746 for B; 11.620, +1.518, +0.763, +1.560 for C; and 11.290, +1.814, +0.916, +1.797 for D. 18 × 13 arcmin image courtesy S. Dallaporta (Meade 10-inch + SBIG-ST8).