

New Stars and telescopes: Nova research in the last four centuries

H.W. Duerbeck*

Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium

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This article gives a brief overview of 400 years of research in the field of novae and related stars. Important objects, first applications of various observing techniques, and early ideas of the interpretation of phenomena are listed. Also, the historical evolution of the classification of novae and related stars (supernovae, dwarf novae), as well as their use as distance indicators is discussed.

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1 Introduction: New Stars in history

The understanding of novae – *new stars* – is part of a quest to unravel the structure of the universe. The appearance of a new star – the supernova B Cas of 1572 – shattered the foundations of the established Aristotelian world view of the unchangeable celestial orbs. The discovery of other variable and new stars led to a flurry of interpretations of these objects, listed in detail in Riccioli's (1651) *Almagestum Novum*: with a handful of novae and related stars, there were already 14 theories explaining the phenomenon (see Vol. 2, 177–179, of Riccioli 1651).

2 The pretelescopic supernovae

According to young Tycho Brahe's measurements, the daily parallax of the new star of 1572 (Fig. 1) was definitively smaller than that of the moon, and thus the object belonged to the celestial realm. Tycho's instrument was a sextant – not yet a telescope (cf. Gingerich 2005). Also the last directly observed supernova of the Galaxy, V843 Oph (1604), was observed by Kepler, Galilei and their contemporaries before the invention of the telescope.

3 Novae up to 1900

There was hardly any progress during the next quarter of a millennium, except for the discoveries of a handful of variable stars – mostly periodic and irregular variables (see Clerke 1903). Among the temporary or “new stars”, the – still mysterious – object CK Vul was discovered by Dom Anthelme in 1670, and closely watched by Giovanni Cassini, Johannes Hevelius and others. WY Sge 1783, a classical nova recorded by J.L. d'Agelet as a star and later found missing, was basically overlooked. The luminous

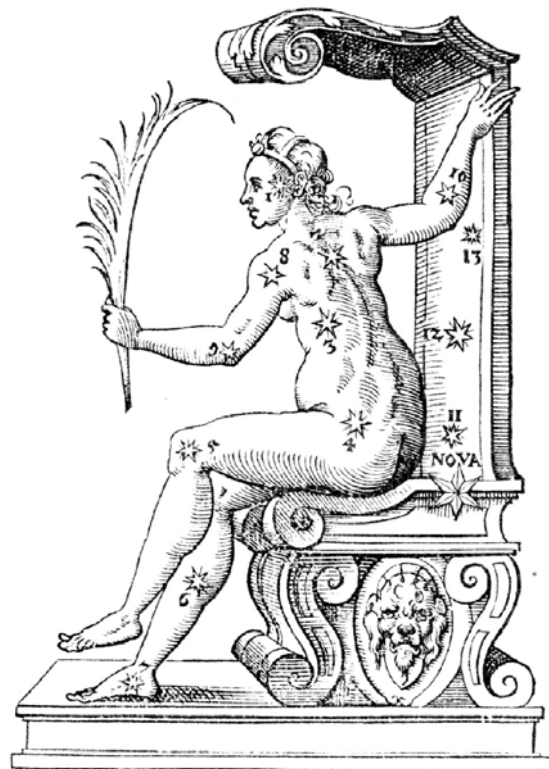


Fig. 1 The new star of 1572 in Cassiopeia (Hagecius 1574).

blue variable P Cyg 1600 was first assumed to be a nova, and η Car, catalogued as a 4th star by Halley in 1677, attracted much interest from John Herschel and his contemporaries when it rose to peak brightness in 1843. V841 Oph 1848, discovered by J.R. Hind, was the last nova before spectroscopy became a regular tool of stellar astronomers.

The first nova observed spectroscopically was Nova (T) CrB of 1866 by William Huggins (Fig. 2), in collaboration with William A. Miller (Huggins 1866). It is now known to

* Corresponding author: hduerbec@vub.ac.be

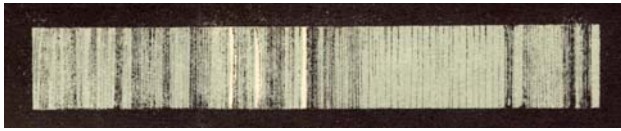


Fig. 2 The visual spectrum of Nova CrB 1866, as observed by Huggins and Miller. From a special insert of *Astronomische Nachrichten* (Huggins 1866).

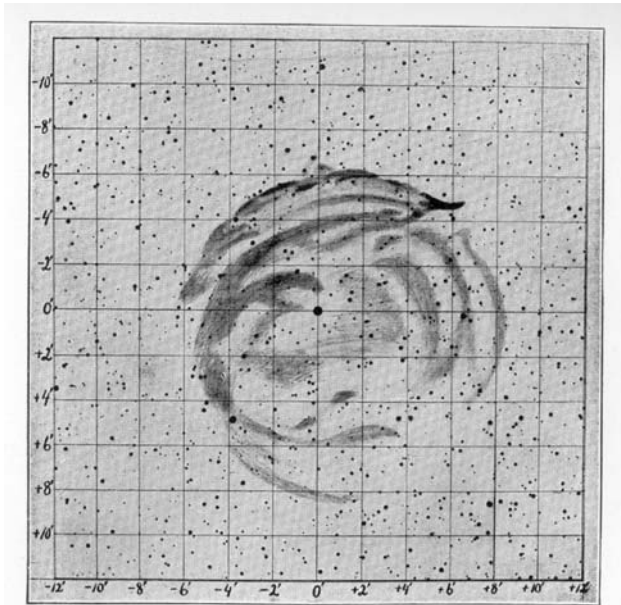


Fig. 3 The light echo around Nova GK Per 1901, observed by Ritchey (1901).

be a recurrent nova. This was followed by the fast nova Q Cyg (1876), and the slow nova T Aur (1892). Besides W. Huggins, Hermann Carl Vogel (1841–1907) and Wilhelm Oswald Lohse (1845–1915) analyzed the spectra of the latter two objects and developed the first, very crude theoretical models.

Visual brightness estimates of variable stars had become a standard practice by then, mainly thanks to the activity of Argelander and his disciples. But more important was certainly the Harvard College Observatory sky patrol, the systematic photographic monitoring of the northern (and soon also the southern) sky. It not only led to many discoveries of novae, but also to reconstructions of light curves of novae before they were actually discovered – as was the case, e.g., with T Aur. In addition, the active involvement of amateur astronomers in variable star work (through the AAVSO and other organisations) provided an important data base for investigations of novae. In the 20th century, a lot of important objects were studied, and our understanding of the nova outburst was revolutionized.

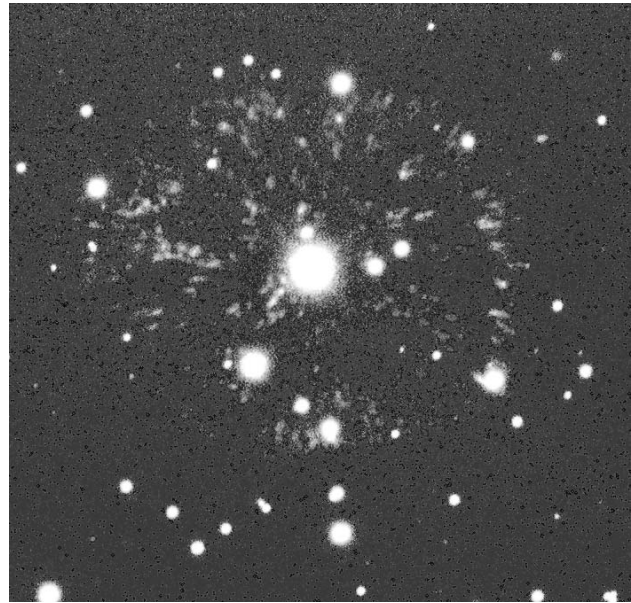


Fig. 4 The shell around GK Per, taken in 1994 with the WIYN 3.5-m telescope (credit: NOAO/AURA/NSF; copyright WIYN Consortium, Inc., all rights reserved).

4 Nova Per 1901, Nova RR Pic 1925, Nova Her 1934

The first nova of the 20th century was also one of the most spectacular ones. Nova GK Per was a bright, very fast nova with oscillations in the later stages of the light curve. It showed a light echo (Fig. 3), which was investigated by Ritchey (1901) and others. In the 1980s, the old observations were studied again. Almost at the same time, the echo of Supernova 1987a in the LMC was observed; another spectacular phenomenon of this type was the echo around the red eruptive variable V838 Mon (2002). Even a present-day light echo of Tycho's supernova of 1572 was recorded with modern instrumentation (Krause et al. 2008).

GK Per was also the first nova for which the evolution of its shell of ejected material, discovered in 1916 (Ritchey 1918), was studied in detail, both by direct imaging (Fig. 4), visual, and UV spectroscopy.

But GK Per had additional surprises in store: spectra taken during the decline showed not only the “nebulium lines” λ 4363, 4959, 5007 Å, later identified with forbidden lines of [O III], but also the strong lines of [Ne III] 3869, 3968 Å (Sidgreaves 1901). Thus it belongs to the class of “neon novae” that were identified as a separate class only in 1985.

Another famous nova was RR Pic (1925), a slow nova that erupted in the southern sky. Spectra were taken by Johannes Hartmann, who submitted one of the shortest papers in the field, a telegram sent from Buenos Aires 1925 November 26 (Hartmann 1925): *RR Pic. Nova-Problem gelöst. Stern bläht sich auf, zerplatzt.*¹ In contrast to this,

¹ Nova problem solved: star expands, and bursts.

there exists the thorough spectroscopic study of RR Pic by Harold Spencer Jones (1931), a monograph comprising almost 550 quarto pages.

An even more detailed study was carried out for DQ Her (1934). An atlas was compiled that documents the spectral changes of the star from its maximum all into the deep minimum, that was obviously caused by dust formation (Stratton & Manning 1939). DQ Her is also famous for its “equatorial ring and polar blobs”-shaped nebular shell, which is a characteristic of many slow novae. The stellar remnant, the “exnova” was the first discovered eclipsing binary in a nova system (Walker 1954).

Other notable novae were discovered in the last third of the 20th century, among them the very slow nova HR Del (1967) and the bright and fast nova V1500 Cyg (1975). Other novae became famous because of the close monitoring in other wavelength regions or with special telescopes: V1668 Cyg (1978) with IUE, GQ Mus (1983) with Exosat, V1974 Cyg (1992) with HST.

5 Classification of novae

Novae – also called temporary stars among the early authors – are a group of objects that were first kept separate from the many other types of “regular” and “irregular” variables. In the *Handbuch der Astrophysik* of the 1920s, variables and novae were assigned different chapters, and present-day readers will find it strange that U Gem stars (i.e. dwarf novae) and novae were assumed to be quite different objects in the past. But the study of novae at minimum stage, as well as the finding that some novae exhibit repeated outbursts, helped to remove the dividing line between variable and temporary stars.

Ritchey and Curtis in 1917 discovered that novae can appear in spiral nebulae. First examples were S And and Z Cen – both today recognized as extragalactic supernovae –, but other fainter ones were also found. In 1920, Lundmark (Fig. 5) noted the discrepancy, argued that objects in the brighter group had a higher luminosity than the well-known novae in our Galaxy, and coined them *giant novae*. Curtis in 1921 accepted the division and talked about two magnitude classes, and in 1927, Lundmark called the brightest species *upper class novae*. In 1929, both Baade and Hubble independently accepted the existence of the brighter class and coined the objects *Hauptnovae* and *exceptional novae*. In 1933, it was Lundmark again who named them *super-novae*, a term picked up and propagated by Baade and Zwicky in 1934.

Finally, Lundmark (1935) suggested a three-fold separation of “novae” into upper-class novae (or super-novae, like S And), middle-class novae (ordinary novae, like GK Per), and lower-class novae (dwarf novae, like WZ Sge). Gerasimovic (1934) was the first to coin the expression “classical novae” for the second group (minus those by them filed away as recurrent novae). This expression was revived in the 1970s by Brian Warner. Note that Lundmark’s “dwarf



Fig. 5 K. Lundmark (left) visiting Steward Observatory, Arizona, in the 1930s. The director of Steward Observatory and pioneer of dendrochronology, A.E. Douglass, is to the right (photograph by Edwin F. Carpenter).

novae” do not refer to today’s large group of “dwarf novae”, i.e. repeatedly erupting stars like U Gem, Z Cam, or VW Hyi: he had in mind the rarely erupting, “subluminous” objects like WZ Sge – i.e. those which show quite rare outbursts, and large amplitudes (as compared with other dwarf novae). They usually also show superhumps, but this detail was not yet known to Lundmark – the low luminosity was his only criterion.

6 Nova speed classes and light curve types

Classical novae show a bewildering variety of light curve forms. The light curve may rise and fall very rapidly, and the mass loss be quite instantaneous; this goes together with a simple “decay light curve” (which is also observed in most supernovae). Oscillations may occur in the latter part of the decay. Other, more slowly evolving novae show a prolonged maximum light, with either small fluctuations or several marked maxima. In the later stages of the outburst, a noted minimum with a partial recovery of the light curve may also occur – the signature of dust formation in an ejected shell of material.

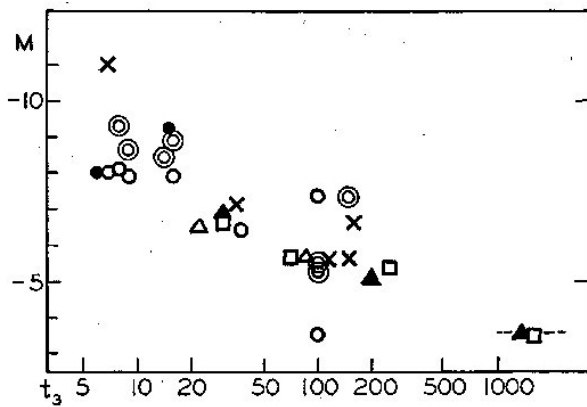


Fig. 6 The absolute magnitude- t_3 -time relation of McLaughlin (1945). Absolute magnitudes based on expansion parallaxes (double circles), interstellar line strengths (open circles), and membership in globular clusters (solid circles), galactic rotation (crosses), the Sagittarius clouds (squares), Large Magellanic Cloud (open triangle) and M31 (solid triangles) were used for the calibration.

A first attempt to classify novae was according to the “speed” of development. Gerasimovic (1936), McLaughlin (1939, 1945), Bertaud (1951) and Payne-Gaposchkin (1957) defined such speed classes, which are mainly based on a “decay time” of the light curve, i.e. the time it takes until the brightness drops by 2 or 3 magnitudes from maximum light. An intercomparison of speed classes as defined by the various authors can be found in Duerbeck (2008). Light curve types, irrespective of their decay time, were introduced by Woronzow-Weljaminow (1953) as well as by Duerbeck (1981); it can be noted that a fast brightness evolution goes together with a smooth light curve; slowly evolving novae may have a variety of light curve forms.

The photometric behavior of novae at minimum was neglected for a long time; it was simply assumed that a faint star erupts and then returns to its original brightness. Until the 1950s there were only a few amateurs who kept a regular watch on “exnovae” (for a summary, see Duerbeck 1992).

7 Novae as distance indicators

Lundmark was also a pioneer in using novae as distance indicators, especially for extragalactic systems. His distance estimates of the Andromeda nebula based on novae, and published between 1925 and 1927, range between 300 and 430 kpc, and are in hindsight somewhat better than the 1925 distance estimate of Hubble, based on Cepheids (285 kpc). McLaughlin (1942, 1945), proposed magnitude-lightcurve decline relations (Fig. 6) which were frequently calibrated in subsequent decades. Besides coarse comparisons of these relations with those of nearby galaxies, they have rarely been used for extragalactic distance determinations. One of the few attempts was carried out by van den Bergh (1988), who compared nova light curves in M31 with those of (ground-based) light curves of novae in the Virgo cluster,

and derived from this very sparse material a Hubble constant of $72 \pm 14 \text{ km s}^{-1} \text{ Mpc}^{-1}$. A recent study by Ferrarese et al. (2003) using HST observations has revealed quite a lot of unexpected discrepancies in speed classes when nova populations in different galaxies are compared. This distance indicator should be used with care, until we understand differences in nova populations much better.

8 Spectral classifications

The Harvard spectral classification did not cover the changing spectroscopic appearance of novae in outburst; the type Q was assigned to any star with a peculiar spectrum. In 1922, the International Astronomical Union expanded this to a sequence Qa, . . . , Qz. Based on extensive studies by D.B. McLaughlin, the IAU replaced this hardly used system with another one running from Q0 to Q9, with detailed descriptions on absorption and emission line systems (see Hearnshaw 1986 for details).

In the 1990s, the availability of digital, flux-calibrated spectra of novae from early to very late stages has led to another classification (Williams et al. 1991; Williams 1992), with the two major groups of Fe II- and He/Ne-novae. The classification system also permits a detailed description of the features seen in the evolution of an outburst.

9 Novae as binary stars

In 1954, Walker (1954) discovered eclipses in DQ Her. Two years later he found rapid periodic light variations in DQ Her, which were identified with the rotation of a magnetized white dwarf. A systematic search by Kraft (1964) finds that many novae and related stars are close binary systems, some showing eclipses. By 1975, there was a general agreement that novae, novalike stars and dwarf novae show a similar underlying structure. In the following decades, it was attempted to fit the various types of cataclysmic binaries into a general scheme, in which a classical nova system by a variation of the accretion rate can turn into a dwarf nova or even a *hibernating system* with interrupted mass transfer. Such a *hibernation scenario* was proposed by Shara et al. (1986), but our knowledge of space densities, recurrence rates etc. of novae and cataclysmic binaries is still too poor to put firm constraints on this suggestion. The discovery of an ancient nova shell around the dwarf nova Z Cam (Shara et al. 2007) is at least a convincing proof of the close relation between novae and dwarf novae.

10 Theories

After the first discoveries of variable and new stars, first steps towards a classification of variables were made, and reasons for variability were figured out. Riccioli in his *Almagestum Novum* (1651) already mentioned fourteen theories. Newton’s idea that novae are stars recruited by comets

that fall onto them (1726) is an early example of an “accretion” theory. In the following decades Maupertuis (1732) elaborated on the idea that novae are rapidly rotating (and thus flattened) stars that are deranged by planetary companions. In the 19th century, first ideas of stellar evolution enter the scene: Zoellner (1865) indicated that stars are the fourth evolutionary state of a celestial body, the period of eruptions.

The spectroscopic studies of T Aur triggered a plethora of explanations for the observed light curves: the collision between two stars, the collision of two meteor streams, the interaction of a star with an interstellar cloud, whereby the brightness increase is caused by friction.

Attempts to explain the spectroscopic phenomena – the violet displaced absorption spectrum, and the spectrum of bright lines – were also made. Pickering (1894) and Pike (1929) explained the spectrum by the ejection of a shell from the star.

While the phenomenological explanation of a nova outburst – the ejection of a gas shell – was securely established by the interpretation of the spectrum of RR Pic (Hartmann 1925), the cause of the outburst remained obscure. A dramatic change in stellar structure (Biermann 1939) and nuclear reactions (Schatzman 1951) were evoked. Only after the binary nature and the structure of the components had been clarified, a clearer view was obtained (Kraft 1963), and hydrodynamic models for explosive hydrogen burning in degenerate surface layers of white dwarfs could be developed (Sparks 1969).

Based on earlier ideas by Eddington (1921) and Grotrian (1937), that matter can be lost from a star through radiation pressure, and a thick wind generates an extended pseudo-photosphere, such a concept was taken up by Finzi (1973) and Bath & Shaviv (1976), who described novae as thermonuclear runaways on white dwarfs that radiate at Eddington luminosity.

11 Multiwavelength studies

11.1 Radio, IR and UV

In 1970, the first multi-frequency data in the radio region of novae were obtained by Hjellming & Wade (1970) with telescopes at NRAO. The shells of HR Del and FH Ser remained optically thick in the radio region until several 100 days after outburst, and then decayed: the radio maximum occurs very much later than the optical one, and depends on the considered wavelength.

FH Ser (1970) was the first nova which was not only observed in the visible, but also in the near infrared, and – sparsely – also in the ultraviolet. It was a DQ-Her-type nova with dust formation, and the wide wavelength coverage made it possible to study the total luminosity of it, and it was discovered that it remained basically constant for an extended time. FH Ser triggered theoretical studies

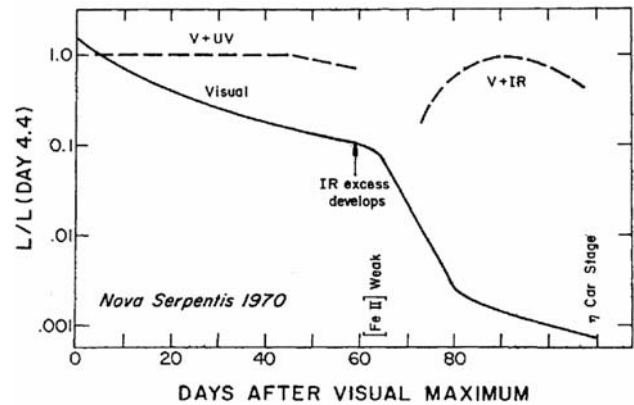


Fig. 7 The luminosity of Nova FH Ser (1970), according to Gallagher & Starrfield (1978).

of “Eddington Novae” in the following years. It was sometimes coined the “rosetta stone” of nova research. Indeed it showed the importance of multi-wavelength studies for the investigation of the nova phenomenon, which came to full maturity with the availability of IUE, the international Ultraviolet Explorer (1978–1996). A complete survey of nova observations by IUE is given by Cassatella, González-Riestra & Selvelli (2004).

The first thorough studies were carried out in 1978 for V1668 Cyg with IUE. It was shown that the total flux from UV to IR remained quite constant at Eddington luminosity.

11.2 X- and γ -ray

X-ray emission was first detected in 1984 in the nova GQ Mus (1983) with Exosat (Oegelman, Beuermann & Krautter 1984). Until now, no positive detection of classical novae in gamma-lines with the available satellites was achieved (Hernanz & José 2005).

12 Outlook

The 20th century has supplied us with a large number of interesting galactic novae (and a nearby extragalactic supernova). The ongoing research on novae and other classes of cataclysmic binaries has by now accumulated in such a way that theoretical models of cataclysmic binary evolution can be tested against observational constraints.

13 Books and conferences

The poorly known books of Cecchini & Gratton (1940) and Woronzow-Weljaminow on Novae (1953, first published 1948) preceded Payne-Gaposchkin’s classical book *The Galactic Novae* (1957). This has been replaced (but not superseded) by the multi-authored book *Classical Novae* (Bode & Evans 1989, 2008).

As concerns conferences on novae, we should mention *Les Novae et les Naines Blanches*, Paris, July 1939

(Shaler 1941), *Colloque international sur les Novae, Novoides et Supernovae*, Obs. Haute Provence, September 1963 (Anonymous 1965), *Novae and Related Stars*, Paris, September 1976 (Friedjung 1977), *Physics of Classical Novae*, Madrid, June 1989 (Cassatella & Viotti 1990), and *Classical Nova Explosions*, Sitges, May 2002 (Hernanz & José 2002). There were many more conferences dealing with cataclysmic variables in general, including novae, which are not listed here.

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