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Novae: an historical perspective

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1.1 Introduction

Nova, abbreviated from *stella nova*, means *new star* (the plural form is [stellae] novae). Although the Merriam-Webster dictionary indicates its etymological origin to be in New (Renaissance) Latin, the term is in fact found in C. Plinius Secundus, *Naturae Historia*, Book 2, chapter XXIV, written around AD 75 (Pliny, 1855)

> *Idem Hipparchus . . . novam stellam in aevo suo genitam deprehendit; eiusque motu, qua die fulsit, ad dubitationem est adductus, anne hoc saepius fieret moverenturque et eae, quas putamus adfixas*
>
> The same Hipparchus discovered a 'new star' that appeared in his own time and, by observing its motions on the day on which it shone, he was led to doubt whether it does not often happen, that those stars have motion which we suppose to be fixed

although the somewhat obscure text would also permit an identification with a meteor or comet.

Because of the Aristotelian doctrine of the immutability of the *translunar* regions, such an object in the stellar regions would not fit into Aristotle's world view, and other objects now known to be translunar, such as comets, were considered to be atmospheric objects and logically discussed in his book on meteorology (and meteors do indeed belong in that book!). Tycho Brahe was among the first to measure accurately the daily parallaxes of the new star of 1572 and the comet of 1577. His result of immeasurably small parallaxes was a fatal blow to the Aristotelian view of the immutability of the spheres.

1.2 Definition of novae and related stars

The Merriam-Webster dictionary defines a nova as a star that suddenly increases its light output tremendously and then fades away to its former obscurity in a few months or years. This is still modelled after Newton's definition (1726; English translation in Newton, 1729)

> *Hujus generis sunt stellæ fixæ, quæ subito apparent, & sub initio quam maxime splendent, & subinde paulatim evanescunt*
>
> Of this kind are such fixed stars as appear on a sudden, and shine with a wonderful brightness at first, and after vanish by little and little

Classical Novae, 2nd edition, ed. Michael Bode and Aneurin Evans. Published by Cambridge University Press.

(*Principia Mathematica*, 3rd edn, lib. 3, prop. 42, at the end of probl. 22). Hardly any change of definition had occurred at the beginning of the twentieth century (Newcomb 1901, p. 127):

> A distinguishing feature of a star of this class [of new or temporary stars] is that it blazes up, so far as is known, only once in the period of its history, and gradually fades away to its former magnitude, which it commonly retains with . . . little or no subsequent variation

And almost the same definition, with first hints on classification, is given by Clerke (1903), p. 275:

> A temporary star is a variable that rises sheer from profound obscurity to a single maximum. The maximum may be prolonged or multiple, but it must be essentially one. The occurrence of a second independent outburst would at once relegate the object to the category of irregular variables. The distinction is perhaps arbitrary, but we can only investigate by dividing.

Until the twentieth century, there was no discrimination between novae and supernovae: because of the poorly known absolute magnitudes and remnants of supernovae, these objects were counted among the novae. From 1917 onwards, serendipitous discoveries of novae in spiral nebulae, mainly by G. W. Ritchey, H. D. Curtis and others, which were soon followed by systematic searches, indicated two distinct groups. An early summary is given by Shapley (1917), who lists nine novae (and two supernovae) in spirals and discusses the implications for the 'island universe' hypothesis, but points out the difficulty of reconciling the findings with 'van Maanen's measures of internal proper motions' of spirals. Such proper motions have long been proven to be illusory. In 1917, however, the cosmic role of the nebulae was unclear, and comparison with Galactic objects was daring. Only believers in the extragalactic nature of nebulae drew the correct conclusions concerning novae and supernovae, e.g. Curtis (1917) in a study which was almost contemporary with that of Shapley.

S Andromedae (the 'nova' of 1885 in M31) and also Z Cen (the 'nova' of 1895 in NGC 5253) were strange outliers, which rivalled their host galaxy in brightness. Lundmark (1920) was the first to speak about *giant novae*, soon followed by Curtis (1921) in what became known as the *Great Debate*: 'It seems certain . . . that the dispersion of novae in the spirals, and probably also in our galaxy may reach at least ten absolute magnitudes, as is evidenced by a comparison of S And with the faint novae found recently in this spiral. A division into two magnitude classes is not impossible.' Lundmark (1927) called the supernovae *upper-class Novae*, Baade (1929) *Hauptnovae*, Hubble (1929) *exceptional novae*, Lundmark (1933) *super-Novae*, and again Lundmark (1935) *upper-class Novae* or *super-Novae*. Practically simultaneously, Baade and Zwicky (1934) proposed to designate the luminous stellar explosions *supernovae*.

The other groups of cataclysmic variables, the U Gem and the novalike stars, were usually counted among the common variable stars, as the above remark by Clerke (1903) testifies. *Novae* (to avoid the old-fashioned expression *temporary stars*) were for a long time treated distinctively from the variables, as still exemplified in the review articles in the *Handbuch der Astrophysik* (Ludendorff, 1928; Stratton, 1928). On the other hand, Shapley (1921) already argued that differences between novae and other types of variables were not irreconcilable, and he mentioned the recurrent novae RS Oph, V1017 Sgr and T Pyx, as well as the symbiotic stars RX Pup and Z And which share photometric and/or spectroscopic characteristics with novae.

Lundmark's (1935) study is not only important because it gives an early description of the properties of supernovae. It offers, for the first time, a tripartition of the novae as follows: *upper-class Novae*, or *super-Novae*, with M_{max} at -15, and a frequency of 1 per 50 years in the Milky Way, *middle-class Novae*, or *ordinary Novae*, with M_{max} at -7, and a frequency of 50 per year, and finally the *lower-class Novae*, or *dwarf Novae*, with M_{max} at $+3$ or $+4$.

Lundmark's dwarf novae are not yet completely synonymous with the modern dwarf novae: he had in mind objects like WZ Sge that, at that time, had shown only single outbursts. They were thus clearly separated from SS Cyg and U Gem stars with recurrent outbursts, which were counted among the 'plain' variable stars. Lundmark already speculated that a star has to go several times through the nova stage and that the average interval should be of the order of 400×10^6 years, and also he mentions the repeated outbursts of T Pyx and RS Oph.

According to our present knowledge, Lundmark's *dwarf novae* show the same outburst and structural characteristics as the U Geminorum stars, and thus the terms are nowadays used synonymously. In recent years, Lundmark's group of rarely outbursting large amplitude objects has also been labelled WZ Sge stars (Bailey, 1979) or Tremendous Outburst Amplitude Dwarf novae (TOADs; Howell & Szkody, 1995).

1.3 Theories of novae until the mid twentieth century

The breakthrough in modern nova theory was initiated with Schatzman's (1951) finding that ^{3}He is a trigger of thermonuclear runaways (TNR), and Walker's discovery of the binarity of DQ Her (Walker, 1954). Kraft's series of articles showed that binarity appeared to be a common property of cataclysmic variables in general and novae in particular (Kraft, 1963, 1964), and his idea of explosive hydrogen burning on the surface of the degenerate blue component (Kraft, 1963) was revived by Paczyński (1965). Thus all theoretical research before 1950–1960 should be considered 'historic' or perhaps more properly, 'pre-historic', since basically no references to pre-1950 theoretical articles (unless they also deal with outburst observations) are found in recent papers. Nevertheless, I will give a short overview, which is mainly based on the review chapter 'Old and new attempts to explain novae' in Stein's (1924) book.

Thirteen theories are already quoted in Riccioli's *Almagestum Novum* of 1651, although only a handful of eruptive objects had been found up to that time, or at least studied in some detail (the new stars of 1572 and 1604, P Cyg of 1600, and Mira Ceti, which was also first announced as a new star). The theories appear quite bizarre to modern eyes, and the reader is referred to Riccioli (1651) or Stein (1924) for details.

Later theories with more physical flavour were proposed by Newton (1726) and Maupertuis (1732, 1768). Maupertuis imagined stars highly flattened by rotation, surrounded and 'deranged' by massive planets in highly eccentric orbits of high inclination – an early hint of the existence and properties of extrasolar planets. Newton (1726; English translation 1729) suggested another mechanism which, with hindsight, has an even more pertinent flavour:

> *Sic etiam stellæ fixæ, quae paulatim expirant in lucem & vapores, cometis in ipsas incidentibus refici possunt, & novo alimentae accensæ pro stellis novis haberi*

> So fixed stars, that have been gradually wasted by the light and vapours emitted from them for a long time, may be recruited by comets that fall upon them; and from this fresh supply of new fuel those old stars, acquiring new splendor, may pass for new stars

(*Principia Mathematica*, 3rd edn, lib. 3, prop. 42). Old stars accreting fuel (albeit from comets, not from a stellar companion): an idea that would only bear fruit over 200 years later!

A plethora of theories explaining the nova phenomenon appeared at the end of the nineteenth century, especially after the discovery and spectroscopic study of nova T Aur (1892). These were mainly 'collisional' theories, e.g. collisions between two stars, collisions of two meteor streams, or the interaction of a star with an interstellar cloud, where the brightness increase was explained by friction. The latter concept, first put forward by W. H. S. Monck (an

Irish amateur astronomer who also anticipated the Hertzsprung – Russell diagram), was elaborated in a series of papers by Seeliger (1886, 1892) and influenced nova theory for a long time.

Parallel to this, there were attempts to explain the spectroscopic phenomena – fruitless ones explaining line shifts by pressure effects, and in the long run fruitful ones explaining them by the ejection of a shell from the star (Pickering, 1894; Pike, 1929).

While the phenomenological explanation of a nova outburst – the ejection of a gas shell – was securely established by the interpretation of spectra of RR Pic (Hartmann, 1925) at the latest, the cause of the outburst remained fairly obscure, although structural considerations (Biermann, 1939) and nuclear reactions (Schatzman, 1951) were suggested to play a role. Only after the binary nature and the structure of the companions had been clarified could a clearer view of the phenomena be achieved, and hydrodynamic models be developed (e.g. Sparks, 1969).

1.4 Pre-telescopic discoveries, observations and catalogues

Most pre-telescopic discoveries of novae were made in the Far East. From at least as early as 200 BC, officials at the imperial Chinese court maintained a systematic watch on the sky for any unusual celestial events, a habit that spread to Korea around the time of Christ, and in the sixth century AD to Japan. The main motive for celestial observation was astrological.

Historical records from these countries contain references to three main types of ‘temporary stars’: *xingbo* (‘bushy stars’), *huixing* (‘broom stars’) and *kexing* (‘guest stars’ or ‘visiting stars’); and in addition *liuxing* (‘flowing stars’). While the first two almost invariably refer to comets, *liuxing* refers to meteors. In principle, *kexing*, used to describe fixed star-like objects, may be interpreted as encompassing novae and supernovae. However, there are reports about moving *kexing*, and about those that later developed tails; thus caution is warranted when interpreting guest stars as stellar outbursts.

Stephenson and Green (2002) give a detailed overview of Chinese, Korean and Japanese sources, as well as of Far Eastern celestial cartography, including lists of *lunar lodges* (called *mansions* in other publications), and also mention early European and Arab sources.

The earliest compilation of reports of such temporary stars was by the Chinese scholar Ma Dualin in the thirteenth century AD, who listed events from the Han dynasty (from 206 BC onward) to his own time; it has been edited by Biot (1843a,b). Other lists were given by Humboldt (1850) and Zinner (1919). Lundmark (1921) made the first detailed study of the stars in Ma Dualin’s list. Important anthologies of Far Eastern reports of comets and guest stars (with English translations of the records) are the following:

(1) Ho Peng Yoke (1962): Chinese, Japanese and Korean sources up to AD 1600;
(2) Ho Peng Yoke and Ang Tian-Se (1970): Chinese sources AD 1368–1911;
(3) Li Qibin (1988): Chinese sources of guest stars only. Based on Zhuang Weifeng’s and Wang Lixing’s 1987 *Zhongguo Gudai Tianxiang Jilu Zongji* (A unified table of ancient Chinese records of celestial phenomena), he lists 53 ‘guest stars’ between 532 BC and AD 1604, with one additional phenomenon in the fourteenth century BC.

Modern catalogues of Far Eastern sources were made by Hsi Tsê-tsung (1958) and Hsi Tsê-tsung and Po Shu-jen (1966). As for European and Near Eastern sources, the reports are scarce and unreliable; a list of Newton (1972) has been scrutinized by Stephenson (1975), who found that a ‘new star’, seen in 1245 AD and recorded by the chronicler Albertus of Stade, could be identified with the planet Mars – and, parenthetically, the same identification was already made by Lundmark (1933). This tells a great deal about the quality of at least some of the European chronicles.

Table 1.1. *Catalogue of pre-telescopic Galactic novae and supernovae*

Date	Source	Type	Dur	cl	RA	Decl	CS	Li	Notes
−14th century	C							01	
−531 spring	C	star	–	5	20 50	−10	01	02	
− 203 Aug–Sep	C	po	10 d	5	14 20	+20	02		
− 133 Jun–Jul	C	k'o	–	4	16 00	−25	03	03	HK Sco
− 76 Oct–Nov	C	k'o	–	4	11 10	+75	04	04	
− 75 May–Jun	C	chu	–	5	01 40	+25	05		
− 47 May	C	k'o	–	4	18 40	+25	06		SN??
− 46 Jun–Jul	C	k'o	–	4	04 00	+65	07		
− 4 Mar–Apr	C	hui	>70 d	2	20 20	−15	08	05	
+ 61 Sep 27	C	k'o	70 d	2	14 10	+35	09		
+ 64 May 3	C	k'o	75 d	2	12 20	−05	10	06	SN??
+ 70 Dec–Jan	C	k'o	48 d	1	09 40	+25	11	07	
+ 85 Jun 1	K	k'o	–	5		+65	12		
+ 101 Dec 30	C	k'o	–	4	09 40	+25	13	08	
+ 107 Sep 13	C	k'o	–	4	06 30	+10	14	09	
+ 123									HK Oph
+ 125 Dec–Jan	C	k'o	–	4	17 10	+10	15	10	
+ 126 Mar 23	C	k'o	–	5	12 00	+10	16	11	
+ 126	C							12	Aqr
+ 173									HK Cen
+ 185 Dec 7	C	k'o	600 d	1	14 20	−60	17	13	SN
+ 222 Nov 4	C	k'o	–	4	12 30	0	18	14	
+ 247 Jan 16	C	hui	156 d	2	12 30	−20	19		
+ 290 Apr–May	C	k'o	–	4		+65	20	15	
+ 304 Jun–Jul	C	k'o	–	4	04 20	+15	21	16	
+ 329 Aug–Sep	C	po	23 d	5	12 30	+55	22		
+ 369 Mar–Apr	C	k'o	150 d	1		+65	23	17	HK ? SN??
+ 386 Apr–May	C	k'o	90 d	1	18 30	−25	24	18	HK Sgr SN??
+ 389									HK Aql
+ 393 Feb–Mar	C	k'o	240 d	1	17 10	−40	25	19	HK Sco SN?
+ 396 Jul–Aug	C	star	>50 d	2	04 00	+20	26	20	SN??
+ 402 Nov–Dec	C	k'o	60 d	2	11 10	+10	27		
+ 421 Jan–Feb	C	k'o	–	4	11 30	−15	28	21	
+ 437 Jan 26	C	star	–	5	06 40	+20	29	22	SN??
+ 483 Nov–Dec	C	k'o	–	5	05 30	0	30		SN?
+ 537 Jan–Feb	C	k'o	–	4		+65	31		
+ 541 Feb–Mar	C	k'o	–	4		+65	32	23	
+ 561 Sep 26	C	k'o	–	4	11 30	−15	33	24	
+ 641 Aug 6	C	po	25 d	5	12 20	+20	34		
+ 684 Dec–Jan	J	po	14 d	5	03 40	+25	35		
+ 722 Aug 19	J	k'o	5 d	3	01 00	+60	36		
+ 829 Nov	C	k'o	–	4	07 50	+15	37	25	
+ 837 Apr 29	C	k'o	22 d	3	07 00	+10	38	26	
+ 837 May 3	C	k'o	75 d	1	12 10	+5	39	27	
+ 837 Jun 26	C	k'o	–	5	18 00	−25	40		
+ 877 Feb 11	J	k'o	–	4	23 50	+20	41		
+ 891 May 12	J	k'o	–	4	16 50	−20	42		
+ 900 Feb–Mar	C	k'o	–	5	17 00	+10	43	28	SN??
+ 911 May–Jun	C	k'o	–	4	17 10	+15	44	29	
+ 926 Apr 20	C							30	
+ 945									HK Cep/Cas
+ 1006 Apr 3	ACEJ	k'o	>2 yr	1	15 10	−40	45	31	SN
+ 1011 Feb 8	C	k'o	–	4	19 20	−30	46	32	
+ 1012									HK Ari

Table 1.1. *continued*

Date	Source	Type	Dur	cl	RA	Decl.	CS	Li	Notes
+ 1035 Jan 15	C	star	–	5	01 20	+05	47		
+ 1054 Jul 4	CJ	k'o	660 d	1	05 40	+20	48	33	SN
+ 1065 Sep 11	C	k'o	–	4	09 20	−25	49	34	
+ 1069 Jul 12	C	k'o	11d	3	18 10	−35	50	35	
+ 1070 Dec 25	C	k'o	–	4	02 40	+05	51	36	
+ 1073 Oct 9	K	k'o	–	4	00 10	+05	52		
+ 1074 Aug 19	K	k'o	–	4	00 10	+05	53		
+ 1087 Jul 3	C		–					37	SN?
+ 1138 Jun–Jul	C	k'o	–	4	01 50	+20	54	38	
+ 1139 Mar 23	C	k'o	–	4	14 10	−10	55	39	
+ 1163 Aug 10	K	k'o	–	4	17 30	−20	56		
+ 1166 May 1	C							40	
+ 1175 Aug 10	C	po	5 d	5	15 40	+50	57		
+ 1181 Aug 6	CJ	k'o	185 d	1	01 30	+65	58	41	SN?
+ 1203 Jul 28	C	k'o	9 d	3	17 10	−40	59	42	HK Sco SN??
+ 1224 Jul 11	C	k'o	–	4	17 10	−40	60	43	
+ 1230									HK Oph
+ 1240 Aug 17	C	k'o	–	5	17 10	−40	61	44	
+ 1244 May 14	C							45	SN?
+ 1248	C							46	SN?
+ 1264									HK Cep/Cas
+ 1356 May 3	K	k'o	–	4	05 50	+30	62		
+ 1388 Mar 29	C	star	–	5	00 10	+20	63	47	OE
+ 1399 Jan 5	K	k'o	–	4	18 50	−20	64		
+ 1404 Nov 14	C	star	–	5	19 50	+30	65	48	OE SN?1408
+ 1430 Sep 9	C	star	26 d	4	07 30	+05	66	49	OE SN??
+ 1431 Jan 4	C	star	15 d	5	04 50	−10	67	50	OE SN?
+ 1437 Mar 11	K	k'o	14 d	3	16 50	−40	68		
+ 1460 Feb–Mar	V	star	–	5	11 30	−15	69		
+ 1489 Nov 23	C								OE
+ 1497 Sep 20	C	(star)						51	
+ 1572 Nov 8	CEK	k'o	480 d	1	00 20	+65	70	52	HK Cas,OE SN
+ 1584 Jul 11	C	star	–	5	16 00	−25	71		HK Sco,OE
+ 1592 Nov 28	K	k'o	450 d	1	01 20	−10	72		
+ 1592 Nov 30	K	k'o	120 d	1	00 50	+60	73		
+ 1592 Dec 4	K	k'o	90 d	1	00 00	+60	74		
+ 1604 Oct 8	CEK	k'o	360 d	1	17 30	−20	75	53	HK Oph;OE SN

Date: − refer to years BC, with 0, −1, −2 . . . = 1, 2, 3 . . . BC etc.; + refer to years AD.
Source: A = Arab lands, C = Chinese, E = European, J = Japanese, K = Korean, V = Vietnamese.
Type: k'o = kexing (guest star); po = xingbo (bushy star); hui = huixing (broom star); chu = chuxing (the 'candle star').
Dur = duration: duration of visibility (in days or years).
cl = class: 1 . . . 5 decreasing reliability of being a supernova; Stephenson (1976) suspects that class 3 objects are mainly novae, while in classes 4 and 5, the contamination by comets may be significant.
Coordinates RA, Decl.: Right ascension and declination refer to equinox 1950.0.
CS and *Li*: Number in the catalogues by Clark and Stephenson (1977) and Li Qibin (1988).
Notes: occurrence in the lists of Humboldt (1850), pp. 220 et seq. (= HK), and of Ho Peng Yoke and Ang Tian-Se (1970) (= OE). Humboldt sometimes gives the constellation, which is indicated in three-letter-abbreviation; the classification of an object as a true, likely or possible supernova (SN/SN?/SN??) is based on Li Qibin's (1988) fuzzy classification.

The most convenient catalogue of pre-telescopic novae and supernovae is that given by Stephenson (1976), reprinted in Clark and Stephenson (1977). I have edited it for the purpose of the present volume (Table 1.1) by adding objects from Li Qibin's (1988) more complete survey, which is, however, restricted to Chinese sources. Li Qibin's (1992) maps give a good impression of the 'error circles' of the listed coordinates. It may serve as a first guide to look for interesting objects, but consultation of primary and secondary sources is strongly recommended.

1.5 Modern discoveries, observations and catalogues

The plethora of nova discoveries, starting around 1892 with the discovery of T Aur, was based on the beginning of systematic monitoring of the sky by photographic means. The stations of Harvard College Observatory, both in the northern and southern hemispheres, were later followed by stations in Germany, Russia and elsewhere. After the cessation of systematic sky patrols by the Harvard Observatory in the early 1950s, quite a number of novae were found during objective prism surveys from the 1950s to the 1970s. Since the 1970s, an increasing percentage of novae have been discovered by amateurs. They first visually checked 'stellar patterns' in selected regions by means of binoculars. From about the mid 1970s, photographic and later CCD monitoring became common practice, so that most of the discoveries nowadays are made on films and CCDs. Since the 1980s, discoveries of classical novae have almost totally become a domain of amateur astronomers. A first instructive, although by now somewhat dated, introduction to 'nova hunting' is given by Liller and Mayer (1985).

An overview of early catalogues of novae and variable stars is given by Hagen (1921). Many lists of novae are found in books and articles of novae and variable stars (e.g. in Payne-Gaposchkin, 1957); of course, novae are also included in the General Catalogue of Variable Stars (GCVS; Kholopov, 1985), whose most recent version can be found on the web:

http://www.sai.msu.su/groups/cluster/gcvs/gcvs/

This includes a query form which allows searches for objects of a specified type of variability.

Among those nova catalogues that include finding charts, we should mention Duerbeck (1987), Bode and Evans (1989), Downes and Shara (1993) and Downes *et al*. (1997). For the most up-to-date information, the reader is referred to the electronic data base

http://icarus.stsci.edu/∼downes/cvcat/

(Downes *et al*., 2001), which gives the status as of early 2006, and is also available on CD (Downes *et al*., 2005).

1.6 Photometric and spectroscopic properties of novae

1.6.1 Classification of nova light curves

It goes without saying that novae, from the beginning, were accepted as unique objects. Contrary to most other variable stars, whose light variations often showed similarities that permitted them to be sorted into various classes (Mira stars, cepheids, eclipsing binaries . . .), each carefully studied nova exhibited unique characteristics, fluctuations, pulsations, deep brightness drops etc. After sufficient material was collected, in the 1930s, suggestions of light-curve classes were proposed. Almost simultaneously, and probably independently, Lundmark (1935) and Gerasimovic (1936) proposed very similar schemes. Gerasimovic introduced two principal groups, (I) slow novae and (II) flashing novae. The first group was subdivided into four subgroups according to the degree of slowness, from permanent novae (P Cyg) through very slow novae (η Car) to slow ones (RR Pic, DQ Her), while the second group was subdivided into fast novae without and with a brightness recovery (V 603 Aql and T CrB, respectively). Lundmark formed five groups arranged according to speed and additional characteristics: flash novae proper (T CrB), flash and oscillation novae (V603 Aql), wave novae (T Aur), wave-oscillation novae (P Cyg) and 'jump novae' whose light curve resembled 'the temperature curve of a malaria patient', for which he could only cite examples in M31 (Novae 26, 38, 40, 53).

After a number of years, another scheme was suggested by Woronzow-Weljaminow (1953), building upon the previous ones. Calling the fast 'flash' novae R (for rapid), and the slow novae S, he added subclasses such as o (for oscillation), d (for depression), and s (for enhanced slowness). Thus his types were Rs (CP Pup), Ro (GK Per), Rd (T CrB), Ss (V841 Oph), So (RR Pic), Sd (DQ Her) and Sss (RT Ser).

Finally, Duerbeck (1981), having at first overlooked previous attempts in the field, introduced classes A/Ao (rapid novae with smooth light curves, with/without oscillations), Ba/Bb (fairly rapid light curve with some weak/expressed fine structure), Ca/Cb (flat/declining maximum, followed by a marked drop due to dust formation), and D (slow novae with structured light curves). At the same time, he drew attention to the fact that only the novae with A-type light curves have super-Eddington luminosities, while novae of light-curve types B,C and D radiate for an extended time near the Eddington limit; their light fluctuations can be explained by variations in the photospheric radius, i.e. irregularities in mass loss.

1.6.2 Dividing nova light curves: the speed classes

As regards the speed classes, once again it was Gerasimovic (1936) who started to divide novae into several groups. This first attempt does not appear to be well designed; it nevertheless comprises the two groups *slow novae* and *flashing novae*, the latter being more or less synonymous with fast novae. A refinement was made by McLaughlin (1939), who introduced the speed classes: fast, average, slow, RT Ser, as derived from their light-curve decay times t_2 and t_3, the times to decay by 2 and 3 magnitudes respectively. The next step by McLaughlin (1945) was the establishment of a light-curve–luminosity relation, where the group of very fast novae was introduced, and also the question of the existence of subluminous novae (Lundmark's (1927, 1935) *dwarf novae*) was discussed. Finally, the speed classes were slightly redefined on the basis of their t_2-times by Payne-Gaposchkin (1957), and this definition was repeated and thus 'canonized' by Warner (1995, p. 263; see also Chapter 2).

Using a set of light curves from the compilation of Downes, Duerbeck and Delahodde (2001), we derived simple relations between t_2 and t_3, disregarding whether the light curve was based on a visual or blue/photographic passband. For all novae, the relation $t_3 = 1.75t_2$ holds; the slope is, however, dominated by the slow objects. Splitting the sample in two groups, (a) very fast and fast, and (b) moderately fast, slow and very slow objects, according to Payne-Gaposchkin's (1957) classification, yields the conversion rules-of-thumb for (a) $t_3 = 2.10t_2$ and for (b) $t_3 = 1.75t_2$.

In Table 1.2, the boldface numbers are those given by the respective authors, or estimated from their tables and diagrams. Values of t_2 and t_3 missing from their papers were calculated according to the rules-of-thumb given in the previous paragraph, with some generous rounding to define suitable intervals.

It is clearly seen that McLaughlin's (1939) 'fast' is equivalent to Bertaud's (1951) 'rapide', and McLaughlin's (1945) 'very fast' and 'fast' correspond to those of Payne-Gaposchkin

Table 1.2. *Definitions of speed classes of classical novae*

Author	Class	t_2	t_3
Gerasimovic (1936)	flashing		
	slow		
McLaughlin (1939)	fast	< **29**	< **49**
	average	**30–49**	**50–84**
	slow	**50–299**	**85–499**
	RT Ser	> **300**	> **500**
McLaughlin (1945)	very fast	< 7	< **15** (10)
	fast	8–24	**15–45** (30)
	average	25–49	**50–84** (60)
	slow	50–250	**85–449** (200)
	RT Ser	> 570	> **1000**
Bertaud (1951)	rapide		< **50**
	lente		> **50**
Payne-Gaposchkin (1957)	very fast	< **10**	< 20
	fast	**11–25**	21–49
	moderately fast	**26–80**	50–140
	slow	**81–150**	141–264
	very slow	**151–250**	265–440

(1957). McLaughlin's 'average', 'slow' and RT Ser undergo no change between 1939 and 1945, and are summarized under Bertaud's 'nova lente' group. As can be seen by comparing McLaughlin (1945) and Payne-Gaposchkin (1957), there are differences – the latter's 'moderately fast' group has a larger extent than McLaughlin's 'average' group, while Payne-Gaposchkin's 'slow' group has narrower limits than McLaughlin's. Since very slow or RT Ser novae are extremely rare, a suitable classification of such objects is problematic.

Finally, it should be mentioned that the *General Catalogue of Variable Stars* (Kholopov, 1985) divides novae into 'fast' (NA, t_3 < 100 days), 'slow' (NB, t_3 > 150 days) and 'very slow' (NC, more than a decade at maximum light). This somewhat inconsistent classification has never enjoyed extensive use outside the GCVS.

1.6.3 Spectroscopic classification of novae

Two novae which were very thoroughly observed spectroscopically, DN Gem (1912) and DQ Her (1934), were instrumental in the development of spectral classification of novae. The monograph by Stratton (1920) led to the isolation of seven spectral stages of novae, and soon afterwards the International Astronomical Union proposed to expand a preliminary Harvard designation – Q – into a sequence Qa . . . Qc, Qu . . . Qz (Adams, 1923). Another well-observed nova, DQ Her, for which a detailed atlas was prepared (Stratton & Manning, 1939), led another ardent student of novae, D. B. McLaughlin, to divide the evolution of nova spectra into various stages. He divided Harvard class Q into 10 or 11 subclasses (Q0 . . . Q9.5), traversed by a nova in the course of its outburst (McLaughlin, 1938, 1946). In addition, he defined the stages (McLaughlin, 1942b), and presented a sequence of 'synthetic' spectra of a typical nova outburst (McLaughlin, 1944a), showing pre-maximum, maximum and post-maximum spectra at magnitude intervals of about 1, and spectra in the nebular and post-nova stage.

McLaughlin (1944b) was also the first to draw attention to a remarkable difference in the strength of the [Ne III] 3869, 3968 Å lines in the spectra of novae in the nebular stage. Only in the 1980s did this finding lead to the concept of neon novae, i.e. outbursts occurring on massive white dwarfs that show ejecta enriched in O, Mg and Ne.

The refined Q classification of nova spectra never enjoyed widespread use. A more physical classification of nova spectra, which is well suited for modern observations with linear receivers, covering a wide wavelength range, was proposed by Williams *et al.* (1991).

1.6.4 Novae as distance indicators

The occurrence of novae in spiral nebulae spurred interest in determining their absolute magnitude, in order to derive the distances of nebulae. Knut Lundmark was undoubtedly the pioneer of such studies, and he published half a dozen calibrations between 1919 and 1939. His first attempt (Lundmark, 1920) led to a mean absolute magnitude at maximum, $\langle M \rangle = -4.0$. In subsequent papers (e.g. Lundmark, 1923), he gave an absolute magnitude averaged from the results of various methods (trigonometric and secular parallaxes, magnitude of novae near the Galactic centre, and Galactic distribution, compared with B stars). Over the years, his absolute magnitude calibration converged to $\langle M \rangle = -7.0$ (Lundmark, 1941).

When Lundmark terminated his studies, McLaughlin took over. After having investigated light-curve forms and connections between rate of decline and ejection velocities, he started to investigate the luminosities. In addition he started to derive average luminosities of novae, using parallaxes, proper motions, nebular expansion parallaxes, interstellar line strengths and other distance determinations (McLaughlin, 1942a). In his 1942 study, he also obtained an average value of $\langle M \rangle = -7.0 \pm 0.2$, but his most important result was that slow novae are, on the average, 1.8 magnitudes fainter than fast ones. His suggestion that there exists a connection between luminosity and rate of decline, or a ‘life–luminosity relation’, was elaborated three years later, when McLaughlin (1945) published his diagram where he plotted M versus t_3, and also drew attention to a group of dwarf novae – the prototype being WZ Sge – with noticeably fainter absolute magnitudes. This ‘maximum magnitude–rate of decline’ relation has been recalibrated several times in recent decades (see Chapters 2 and 14).

1.7 Novae and related stars

In the *General Catalogue of Variable Stars* (Kholopov, 1985), the novae (split into three hardly used groups according to speed class) are counted among the cataclysmic variables. Other types in this category are the novalike stars, the recurrent novae, the supernovae (Types I and II), the U Gem stars (subdivided into SS Cyg, SU UMa and Z Cam stars), and finally the Z And or symbiotic stars. It was already mentioned that in the beginning of variable star research, novae formed a class of their own, aside from (and even before!) the group of variable stars. Early in the twentieth century the group of novae split into supernovae, novae and dwarf novae, although in the beginning, dwarf novae were not synonymous with U Gem stars in general, but included objects that are now identified as WZ-Sge-type systems with rare outbursts.

The term *classical nova* was possibly first used by Gerasimovic (1934), when he discussed cycle lengths of SS Cyg variables and linked them with T Pyx and classical novae whose