2003: The Journal of Astronomical Data 9, 3.

The CTIO nova survey: data

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Received November 11, 2003; accepted December 21, 2003

Abstract

We present 198 optical postoutburst spectra in digital form for 27 novae (23 classical, 4 recurrent). Broad wavelength coverage (between 320 and 1600 nm) has been emphasized at the expense of spectral resolution although the latter has been sufficient to resolve the emission lines. For many of the novae, the temporal coverage has been adequate to document the progressive evolution of the emisison line spectra from the earliest stages at maximum light, dominated by premitted transitions, to the later stages when nebular forbidden lines predominate. Brief descriptions of the spectral evolution for each object are given, and light curves are displayed.

Keywords: novae: shells, novae: decline, cataclysmic variables

1 Introduction

Williams et al. (1991) and Williams, Phillips & Hamuy (1994) have presented the results of the Cerro Tololo Nova Survey, consisting of the qualitative analysis of optical postoutburst spectra of novae, and the establishment of a classification system which defines phases in spectral evolution in therms of the characteristics of the stronger emission lines. While the quoted studies present a large selection of graphical displays of nova spectra, the present paper summarizes and slightly extends the findings of the Cerro Tololo Inter-American Observatory (CTIO) nova survey, and gives the data (as fits and ascii files) for 198 spectra that were taken in this project.

*Operated by AURA, Inc. under cooperative agreement with the National Science Foundation

2 Observations

Observations were carried out from 1987 June to 1994 June with the CTIO 1, 1.5 and 4 m telescopes, depending on the brightness of the novae and the instrumentation available. Observations were normally made during nights preassigned to the program, except for novae in the month following the outburst. At this stage, the spectra evolve on a time scale of days, and therefore require frequent coverage.

The 1-m telescope is dedicated to spectroscopy with the 2D-Frutti two-dimensional photon-counting detector (an S-25 photocathode). Generally, a 300 lines mm^{-1} grating was employed, yielding a typical wavelength coverage of 330 – 720 nm with a resolution of 0.5 nm (FWHM). On some occasions a higher dispersion grating (831 lines mm^{-1}) was used, producing a wavelength coverage of 280 nm at a resolution of 0.3 nm.

With the Cassegrain spectrograph of the 1.5-m telescope, a GEC CCD was employed with a fluorescent coating that extends the detector response to below the atmospheric cutoff. The widest wavelength coverage (460 nm) was always attempted by using low dispersion gratings (158 lines mm^{-1}) providing a resolution of 1.6 nm. In order to achieve full coverage over the useful range of sensitivity (320 – 1100 nm), observations were taken sequentially with two different grating tilts.

On the 4-m telescope we also used a coated GEC CCD together with low dispersion gratings (158 lines mm^{-1}). The corresponding wavelength coverage and resolution were 310 nm and 1.1 nm, respectively. A spectral coverage of 320 – 940 nm was achieved with two grating settings.

A typical sequence of observations consisted of several (2 – 4) narrow-slit exposures of the nova (slit size corresponding to $5''$ at the 1 m, $3''$ at the 1.5 m, and $2''$ at the 4 m telescope) in order to obtain the best spectral resolution. The nova observations were bracketed in time with HeAr comparison lamp exposures. 3 – 5 spectrophotometric standards from the list of Taylor (1984) were also observed during the night with a wide slit in order to provide flux calibration. Each CCD or 2D-Frutti image was divided by a normalized flat-field image obtained during daytime. Spectra for all objects were extracted and sky-subtracted, linearized in wavelength, corrected for atmospheric extinction using the mean extinction curve for CTIO given by Stone & Baldwin (1983), and then flux-calibrated using the sensitivity curve obtained for that night from the spectrophotometric standards. Thus any long-term time-dependent effects in instrument response are eliminated. Although the absolute flux-levels of the novae may be uncertain due to non-photometric conditions, the relative spectrophotometry of the novae is accurate to better than 5%, except shortward of 350 nm where atmospheric refraction becomes pronounced.

The blue and red spectra of each object were generally obtained on either the same night or on two successive nights. Although the weather conditions were not always photometric, both spectra were combined in all cases. When either spectral evolution or nonphotometric weather caused flux differences between the two spectra in the overlap region (630 – 650 nm), the weaker spectrum was multiplied by an arbitrary factor to bring the continuum strength into agreement with the stronger spectrum.

Table 1 lists the observed objects with photometric characteristics, as well as orbital information (Ritter & Kolb 2003), Table 2 lists the times of observation (dates and Julian day numbers), and the names of the two times 198 files (which, in addition, carry the extension .fits or .ascii depending on data type).

The following discussion summarizes and extends the description of the spectral evolution of 24 novae, as given in Williams et al. (1991) and Williams, Phillips & Hamuy (1994), and also supplements it with light curves. These were constructed with data taken from the AAVSO, AFOEV, and VSOLJ databases, the IAU Circulars, and additional sources. The

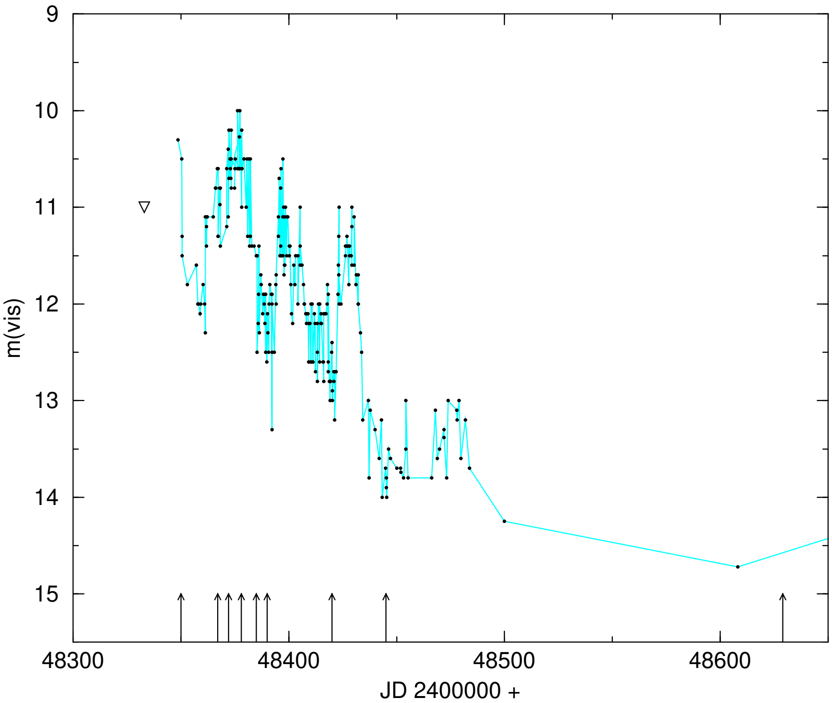

Figure 1: The visual light curve of V868 Cen. Data were taken from A. Jones (private communication), the IAU Circulars, and the AAVSO archive. The inverted triangle indicates an upper limit. Arrows indicate the times when spectra were taken (also in subsequent figures showing nova light curves).

light curves are by no means definitive and should only serve as a rough guide for the brightness evolution. Sometimes very discrepant points were omitted, averages were carried out, or rough zero point shifts were applied to convert photographic magnitudes into visual ones. Rapid fluctuations exhibited in some novae are most likely due to the inhomogeneity of photometric data.

3 Novae observed

3.1 V868 Cen = Nova Cen 1991

V868 Cen was discovered by W. Liller on 1991 April 2 at a photographic red magnitude of $m_r = 8.7$ (IAUC 5230). Our first spectrum on April 3 (JD 2448350) demonstrated that the nova was quite red. Also, early *UBVRI* photometry yielded a $V - R = 1.5$, so the visual brightness at discovery was likely to have been of the order of $m_v = 10.2$. The only prediscovery nondetection places the nova fainter than $m_r = 11$ on March 17, so visual maximum could have occurred some 2 weeks before discovery. This uncertainty together with the paucity of photometric observations between 1 and 3 weeks after outburst cause t_2 and t_3 to be poorly determined: it is unclear whether the nova reached maximum brightness during the first or the second maximum, and the "ragged" character of the light curve makes the determination of the moment uncertain at which the magnitude dropped below the limits of $m = 12$ and 13. Assuming that the second brightness peak is the true maximum, the t_2-time is about 13^{d}, which is indicative of a fast nova (even the assumption of the first peak being the true maximum would yield a similar result). It has already been noted by Downes, Duerbeck and Delahodde (2001) that strong fluctuations may lead to absurd results if Payne-Gaposchkin's (1957) prescription of speed-class determination is followed too closely. Concerning the t_3-time, various assumptions yield t_3-values between 43 and 95 days, with an "average" $t_3 \sim (70 \pm 15)^{\mathrm{d}}$. Thus V868 Cen should be classified as a medium-fast nova.

The early spectra of V868 Cen were characterized by an unusually strong, red continuum, with correspondingly weak emission lines. The strongest lines were of the Balmer series and Fe II multiplets, therefore the object is an "Fe II" nova. The continuum gradually weakened in strength with respect to the optical emission lines, and disappeared by early 1992 (JD 2448622). It is unlikely that the continuum emanated from the secondary star; the flux distribution appeared to be either that of a thermal continuum or due to high reddening.

The spectral evolution was typical for that of an "Fe II" nova. The low ionization lines in the far-red were quite strong, especially lines of N I and C I in addition to the normal O I 8446 and Ca II infrared triplet. [O I] 6300 was the first of the optical forbidden lines to appear, as is normally the case for "Fe II" novae, several weeks after discovery. About 1991 May 1 (JD 2448378), V868 Cen experienced a second maximum, which was comparable to its original brightness at discovery one month earlier, and possibly slightly higher. At this time the continuum strengthened more than the lines and the latter became slightly broader. The Balmer and Fe II lines also developed moderately strong P Cygni absorption features in response to the second outburst, although they had not been present at the first maximum; however, the general nature of the spectrum remained the same. The increased line widths and appearance of absorption at the time of the second maximum demonstrates that the line emission and absorption must have originated in gas which was ejected at the time of the second outburst.

Following the second maximum, the nova spectrum evolved slowly, in a manner typical of "Fe II" novae. With the exception of the appearance of strong [O I] 6300, 6364, little spectral evolution took place through 1991 June, and the far-red lines remained especially strong. Between 1991 July 7 (JD 2448445) and 1992 January 7 (JD 2448629), when the object reappeared behind the Sun, it developed very strong auroral lines of [O III] 4363, [N II] 5755, and [O II] 7325, in addition to strong [O III] 5007 and [N II] 6584. The far-red lines remained moderately strong, although O I 8446 had become weaker than Hβ. Its evolution from the early permitted spectrum to the forbidden-line phase serves as a classic example of the development of the "standard" forbidden-line spectrum of an "Fe II" class nova with a rich line spectrum.

3.2 V394 CrA

V394 CrA is a recurrent nova. Its second outburst was discovered by W. Liller on 1987 August 2 (IAUC 4428), although prediscovery patrol images by both Liller and R.H. McNaught established that 1987 July 29 was the date of maximum brightness in the visible, at $m_v \sim 7.2$. Like the majority of recurrent novae, V394 CrA is very fast.

Spectra were obtained within the first month of the decline, during which time only permitted lines were present. Initially, very broad Balmer lines and nitrogen transitions were prominent (the latter almost certainly due to continuum fluorescence from the postoutburst white dwarf radiation). By August 18 (JD 2447026), the lines had sharpened considerably and He II 4686 was quite strong, with only H and He lines present.

A more extended record of the spectral development has been given by Sekiguchi et

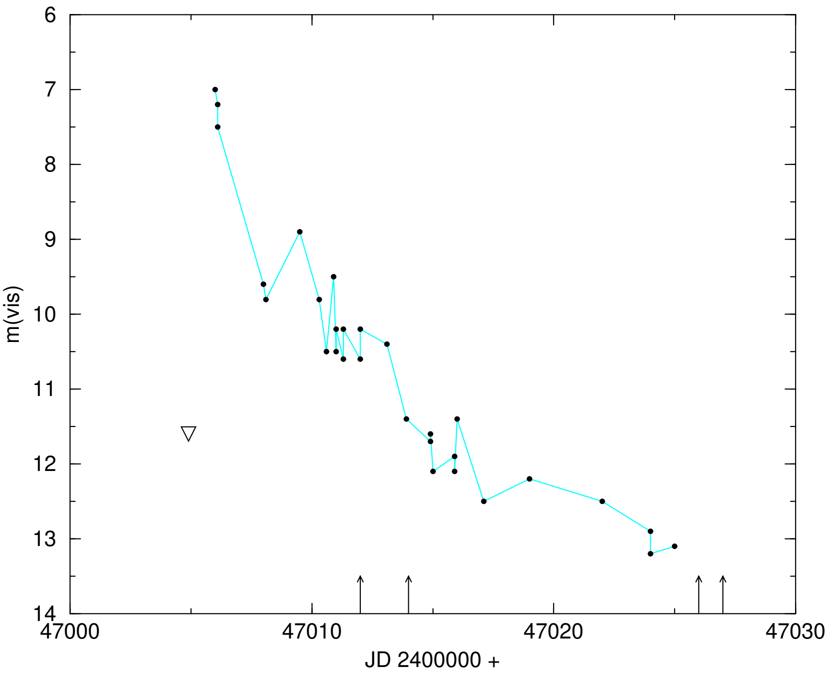

Figure 2: The visual light curve of V394 CrA. Data were taken from the IAU Circulars, the AAVSO and the VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

al. (1989), who found that the line spectrum eventually faded into the continuum without displaying any forbidden lines. In this sense, the spectral evolution was very similar to that of the recurrent nova U Sco.

3.3 V838 Her = Nova Her 1991

This nova was discovered independently by both M. Sugano and G. Alcock on 1991 March 25, near maximum brightness (IAUC 5222). Visual maximum occurred around March 24.8 at $m_v = 5.4$. Prediscovery nondetections indicate that the nova must have been fainter than $m = 10$ on March 23.8 (IAUC 5226, 5265). The nova declined in brightness very rapidly, it is one of the fastest declines recorded for a nova.

Early spectroscopic observations showed very broad (HWZI = 3 300 km s^{-1}), prominent Balmer and Fe II emission with some absorption, and with lines of Na I and N present also (IAUC 5223). Judging from the descriptions of the early spectra (IAUC 5223, 5227) the nova appears initially of the "Fe II" type; however, it then passed briefly through a "He/N" phase before developing forbidden lines, much like the "hybrid" Nova LMC 1988 No. 2 (Williams 1992).

Our first spectrum was obtained on 1991 April 3 (JD 2448350), by which time the first forbidden line, [Ne III] 3869, had just appeared. The lines were still quite broad (HWZI = 3 300 km s^{-1}), with most of them having flat peaks. The strongest non-Balmer lines were those of He I, and the nova would have been classified as a "He/N" nova on the basis of this spectrum, although this date is too long after maximum light for such classification to be valid. By April 25 (JD 2448372) the neon forbidden lines had become very strong, with

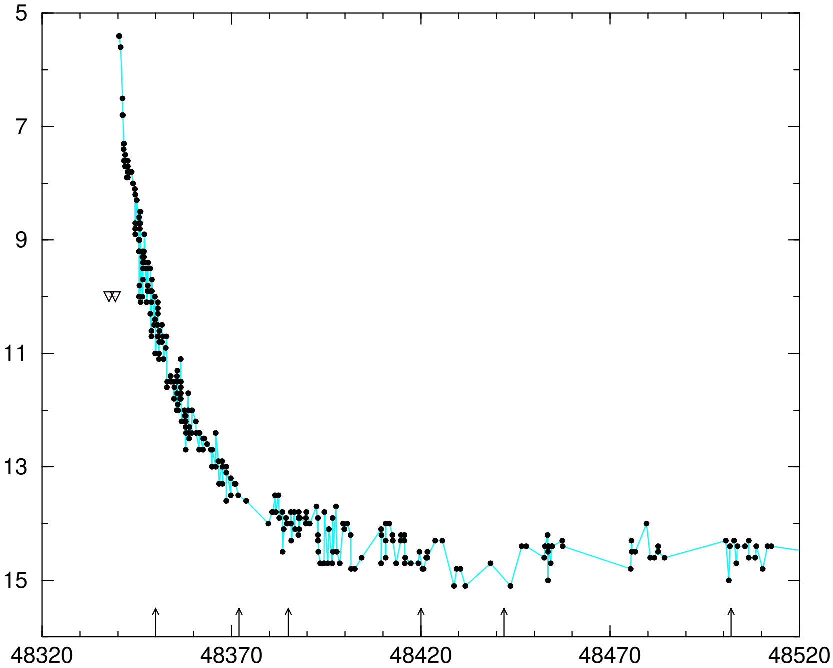

Figure 3: The visual light curve of V838 Her. Data were taken from the IAU Circulars, the AAVSO, AFOEV, and VSOLJ archives. The two inverted triangles indicate upper magnitude limits.

[Ne V] 3426 exceeding Hα + [N II] in flux. Also, an unusually strong [S VIII] 9911 line was present along with other forbidden sulfur lines such as [S III] 6312. By 1991 June 12 (JD 2448420) the neon lines had strengthened further such that they totally dominated the spectrum; however, the level of ionization had decreased and instead of strong [S VIII] there were now prominent lines of [S III] throughout the spectrum. At this point the auroral line of [Ne IV] 4721 was of comparable strength to [N II] + Hα, and the lines were all still very wide and with even flatter line peaks than previously. Our last spectrum was acquired on 1991 September 2 (JD 2448502), after which time the nova passed behind the Sun. When it reappeared the next season, it was too faint to be detected with the 4 m telescope.

Optical spectroscopy between 1991 April 8 and October 31 was reported by Matheson, Filippenko and Ho (1993), optical spectrophotometry (between 1991 March 29 and August 20) and IUE data were presented by Vanlandingham et al. (1996).

3.4 GQ Mus = Nova Mus 1983

The nova was discovered by W. Liller on 1983 January 18. Our spectra cover the time interval 1988 – 1994, when the nova had already dropped by 10 magnitudes in the visual. The spectra of GQ Mus between 1990 and 1994 were analyzed by Diaz et al. (1995). They indicate a central source with a luminosity of 350 $L_{\odot}$ and a temperature of 164000 K, and an ejected mass of 5×10^{-4} $M_{\odot}$.

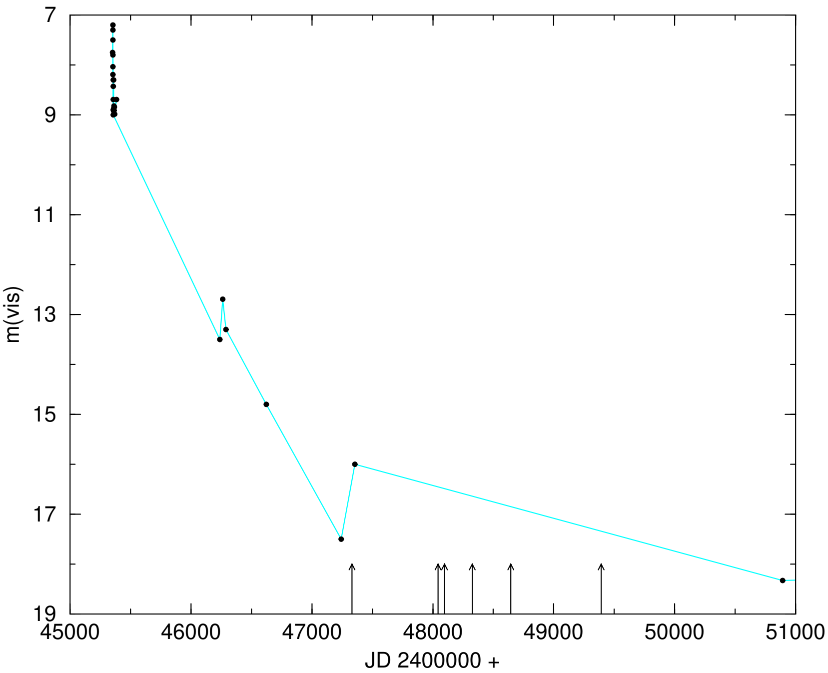

Figure 4: The visual light curve of GQ Mus. The long time base does not permit a resolution of the brightness chages at maximum, which are anyhow incomplete. Data were taken from the IAU Circulars, and the AAVSO archive.

3.5 V2214 Oph = Nova Oph 1988

The discovery of this nova by M. Wakuda was made at about the time of maximum brightness, on 1988 April 10 at $m_v \sim 8.5$ (IAUC 4581, 4582). Prediscovery magnitude estimates show it at magnitude 11.9 at March 24.6 and [11 on March 27. V2214 Oph is a medium-fast nova.

The initial spectra obtained were typical of many novae immediately after outburst, so little spectral evolution may have occurred before our first observation on May 6 (JD 2447288). The early spectra showed strong Balmer lines and Fe II, with the Balmer lines having weak P Cygni absorption components in the blue. Within a month He I lines strengthened, and after 2 months He II and [N II] 5755 appeared, while the Balmer absorption became weak. A temporary absorption event in July is described in detail in Williams et al. (1991).

By 1988 October 4 (JD 2447439) forbidden lines such as [Ne III] and [N II] 5755 appeared and became stronger with time. The ionization steadily increased until in 1990 the [Ne V] lines were far stronger than [Ne III], and the spectrum was rich with [Fe VII] lines. Very little change occurred in the spectrum during 1991/92. The [Ne V] lines remained very strong, as well as [Fe VII] and He II. Other than a slight decrease in the continuum level, the spectrum remained the same as in 1990 May. V2214 Oph is an example of a broad-lined "Fe II" nova which developed a "neon" forbidden spectrum.

Infrared spectroscopy was carried out by Lynch et al. (1989) and Erwin et al. (1992), as well as by Benjamin and Dinerstein (1990). The latter authors found [Si VI] in July-August 1989, indicating a coronal phase. The photometric period indicates a magnetic nova (like V1500 Cyg, GQ Mus, and CP Pup) inside the period gap.

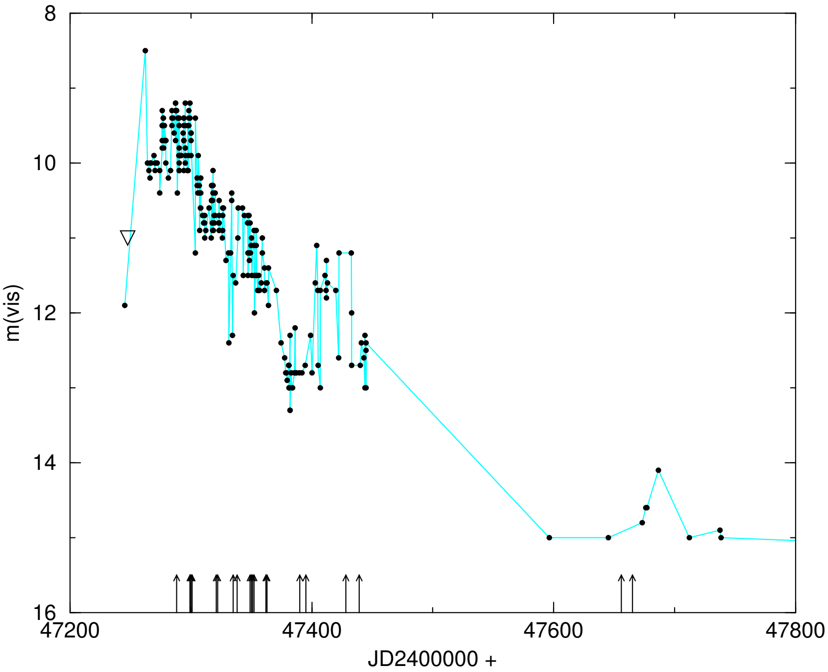

Figure 5: The visual light curve of V2214 Oph. Data were taken from the IAU Circulars, the AAVSO, AFOEV and VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

3.6 V2264 Oph = Nova Oph 1991 No. 1

The nova was discovered by P. Camilleri in Australia on 1991 April 11 when it was approximately $m = 10$ (IAUC 5238). Based on spectra of other stars that were misidentified as the nova, it was variously reported to be either a dwarf nova or a Mira variable, until further spectra confirmed it to be a classical nova (IAUC 5238, 5240, 5243). The nova had not been brighter than $m_v = 12$ on March 23, although a prediscovery patrol photograph showed it at $m_v = 9.8$ on April 9.7 (IAUC 5252), so visual maximum could have occurred during the previous 2 weeks. The decay times of Table 1 are derived by assuming that the latter date is that of maximum light. An earlier, brighter maximum would only lead to a reduction of the decay times, thus V2264 Oph can safely be classified as a fast nova. A photoelectric light curve was presented by Gilmore (1994).

Our initial spectrum was taken on April 20 (JD 2448367), more than 10 days after maximum. Although too far past maximum to make such a determination with certainty, the spectrum was characteristic of that of a "Fe II" nova during the permitted phase, with a strong Fe II multiplet 42, and strong Na I D with a blue absorption component. The usual far-red low ionization lines were prominent with fluorescence-excited lines of Mg II being among the stronger of these. Within three weeks the far-red lines were declining in strength, and [O I] 6300 had appeared. By June the auroral lines [O II] 7325 and [N II] 5755, and the He I lines had become moderately strong, and the red Mg II lines remained prominent. By July 4 (JD 2448442), the Mg II lines had weakened, and forbidden [Ne III] 3869 had emerged. The flux of [Ne III] 3869 steadily increased with time with respect to [O III] 5007, approaching equality in strength around 1991 September 2 (JD 2448502).

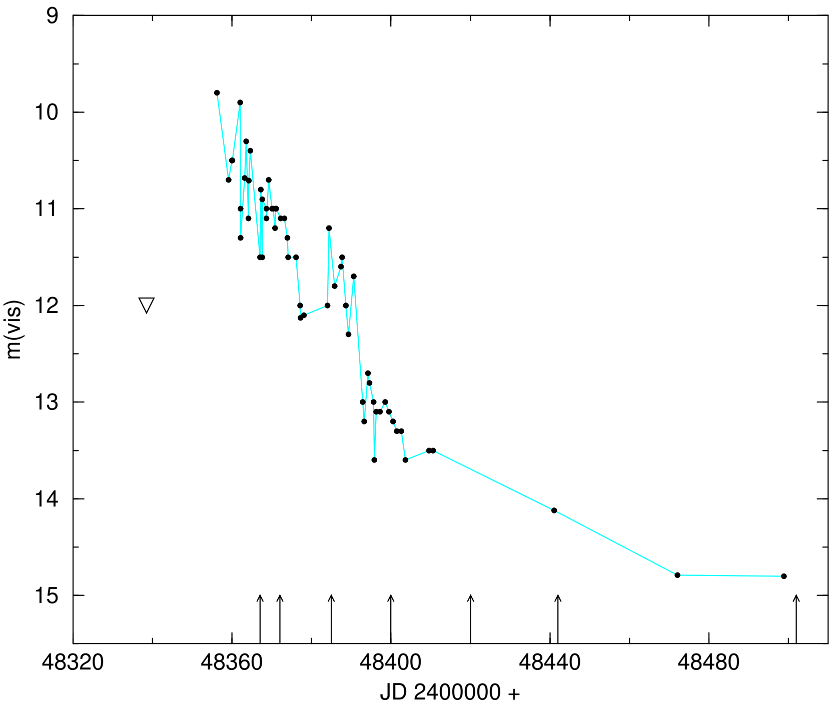

Figure 6: The visual light curve of V2264 Oph. Data were taken from the IAU Circulars, and the AAVSO, AFOEV, and VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

On 1992 March 6 (JD 2448688), after V2264 Oph had reappeared behind the Sun, strong [Ne V] lines had emerged from the spectrum together with other lines such as [Ne IV] and [Fe VII], with the [Fe VII] 6087 profile characterized by double peaks. Two months later, on 1992 May 12 (JD 2448755), the spectra revealed that the double-peaked structure had extended to the [Ne V] and [Ne IV] lines as well. Both the auroral and nebular lines of Ne were stronger than the corresponding oxygen transitions, so V2264 Oph qualifies as a "neon" nova.

3.7 V2295 Oph = Nova Oph 1993

This object was discovered by P. Camilleri on April 14, 1993, at $m = 9.5$. It reached maximum light of about $9\overset{\mathrm{m}}{.}4$ on April 18. V2295 Oph is a very fast nova.

The first spectrum was taken on April 21 (JD 2449099) when the nova was near maximum light. The Balmer lines and some Fe II lines exhibited P Cygni-profiles. A week later (JD 2449106), the absorption components had vanished, and the same lines appeared as pure emission lines. The fluorescent O I 8446 line almost rivalled Hα in strength. Both these spectra, taken 3 and 10 days after maximum, show a remarkable resemblance to those of V351 Pup about 10 and 30 days after maximum; i.e. V2295 Oph is an "Fe II" nova evolving about 3 times as rapid as V351 Pup. The last spectrum of V2295 Oph, taken June 26 (JD 2440165), showed the poorly resolved [O III] 4959,5007, as well as a fairly strong auroral 4363 line. Again, the resemblance with V351 Pup (1991 December 31) is quite striking, except that in V2295 Oph the ultraviolet [Ne III] and [Ne V] lines are about a factor 20 weaker as compared with the Balmer lines and [O III].

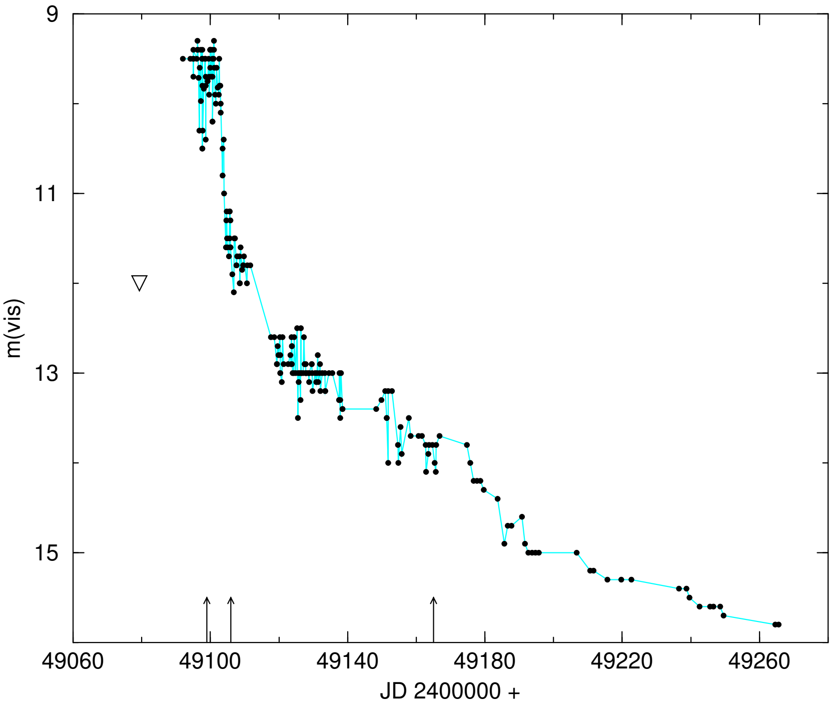

Figure 7: The visual light curve of V2295 Oph. Data were taken from the IAU Circulars, the AAVSO and VSOLJ archives.

3.8 V351 Pup = Nova Pup 1991

In early 1992, P. Camilleri discovered this object on a photograph he had taken on 1991 December 27. This nova was observed to be at $m_v = 6.4$ on December 27.5, having increased to that brightness from fainter than $m_v = 12$ on December 11.5 (IAUC 5422). Although visual maximum could have occurred at any time between these two dates, the brightness at discovery suggests that, in fact, maximum light was probably near the date of the discovery photograph. V351 Pup is a very fast nova. A photoelectric light curve was presented by Gilmore (1994).

The initial spectrum was obtained soon after discovery, on 1992 January 7 (2448629). It shows V351 Pup to be an "Fe II" nova with Balmer line widths on this date of roughly HWZI $\sim$ 2 500 km s^{-1}. As with V2264 Oph which was also an "Fe II" nova, the Mg II transitions were among the stronger of the far-red lines, and N III 4640 had become strong. At the end of January the spectrum had changed little, with [O I] 6300 being stronger and the Balmer and Fe II lines a bit wider. During the next week the spectrum evolved more rapidly, by February 6 (JD 2448659) the Fe II lines had weakened and [N II] 5755 and [O II] 7325 had quickly strengthened, although the N III 4640 feature remained the more intense of the non-Balmer lines.

Subsequent spectra showed a gradual evolution in which the nebular transitions of N, O, and Ne became steadily stronger, as V351 Pup continued to evolve spectroscopically similarly to V2264 Oph (and also V2295 Oph). On 1992 May 12 (JD 2448755), V351 Pup developed [Ne III] and [O III] forbidden lines, with the [Ne III] being stronger, thus resembling V2264 Oph. Therefore, V351 Pup can be classified as yet another "neon" nova.

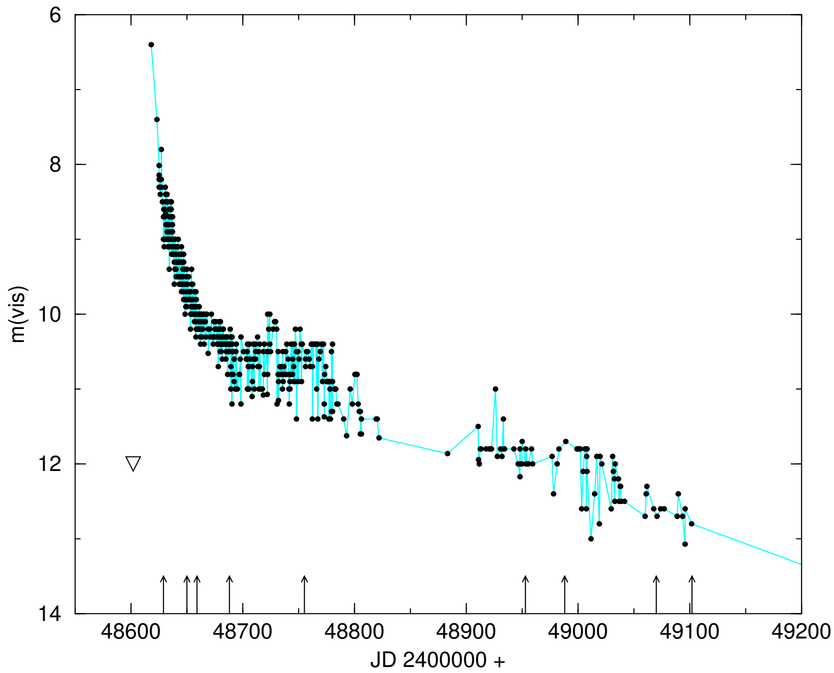

Figure 8: The visual light curve of V351 Pup. Data were taken from the IAU Circulars, the AAVSO, AFOEV and VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

A spectrum taken on 1992 December 31 (JD 2448988) showed that the neon lines remained strong and the level of ionization had increased, as evidenced by the appearance of strong [Ne V] lines, the auroral line of [Ne IV] 4721, [Fe VII], and a possible detection of [Fe X].

A multiwavelength study in the nebular phase was presented by Saizar et al. (1996).

3.9 V3890 Sgr

The recurrent nova V3890 Sgr underwent its 1990 outburst, which was discovered by A. Jones (IAUC 5002) and W. Liller (IAUC 5010). Maximum brightness of $m_v = 8.5$ occurred on April 27 (IAUC 5002, 5004). V3890 Sgr is a very fast nova.

We did not begin to obtain spectra until late May, although previous spectra have been reported by other investigators (IAUC 5006, 5007, 5015, 5019, 5021). It evolved very quickly after maximum, from having predominantly permitted lines to showing high-ionization forbidden lines. In this sense, its spectrum developed very similarly to that of the recurrent nova V745 Sco. Our first spectrum, taken 1990 May 02 (JD 2448014), showed strong coronal lines of [Fe X] 6375 and [Fe XI] 7892, in addition to the very strong O I 8446 line. At this time He I lines and He II 4686 were also prominent, and there is a hint of a component of red continuum from a late-type secondary in the nova system. The latter became increasingly prominent in the following weeks as the continuum from the nova envelope fades. On June 7 (JD 2448050) the [Fe X] was still strong, and other forbidden lines were increasing in strength, notably the auroral lines [N II] 5755 and [O III] 4363, and also nebular lines such as [O III] 5007 and [Ne V] 3426. During the next month, the spectrum underwent a significant change: the previously strong [Fe X], [Fe XI], and O I 8446 lines all disappeared. At

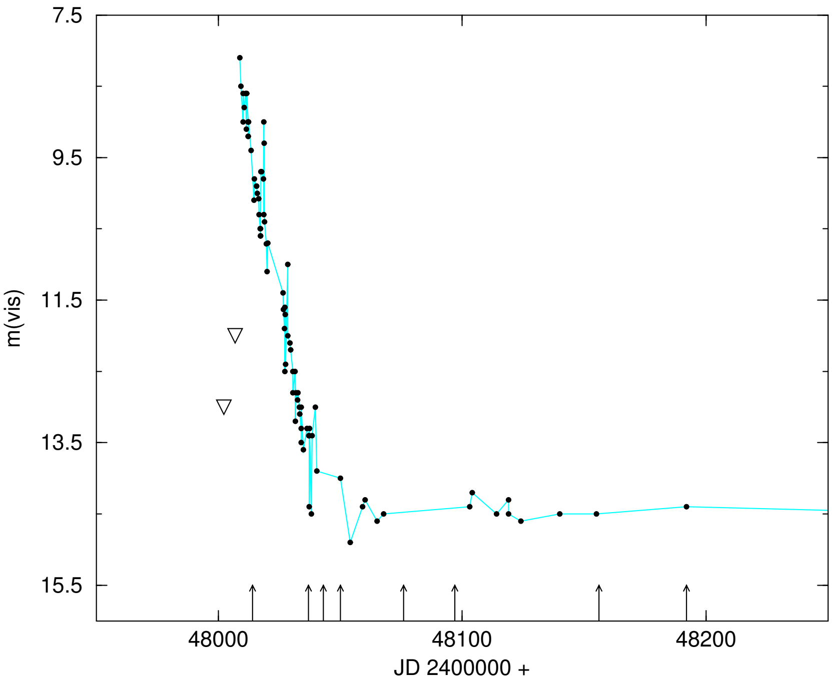

Figure 9: The visual light curve of V3890 Sgr. Data were taken from the IAU Circulars, the AAVSO, AFOEV and VSOLJ archives. The two inverted triangles indicate upper mangitude limits.

the same time, all the other low-to-moderate ionization forbidden nebular and auroral lines, such as [Ne V], [O III], [Fe VII], and [N II] continued to increase relative to the permitted lines. The unusual strengths of [N II] 5755, [O III] 4363, and [Fe VII] 6087 with respect to Hβ are particularly noteworthy in this regard, as is the emergence of the same [Fe II] to [Fe VII] forbidden line spectrum that also appeared in V745 Sco, a similar recurrent nova with a luminous red companion. The V3890 Sgr secondary is also of spectral type M8 III.

By 1991 May 13 (JD 2448390), the emission lines had weakened considerably with respect to the continuum, and the forbidden lines had declined relative to the permitted lines, e.g. [O III] 5007 was now much weaker than Hβ. And, as in V745 Sco, permitted Fe II lines emerged at the time the forbidden lines were weakening with respect to the continuum, raising the possibility that the latter are actually associated with the M giant secondary star. Also notable are the strengths of the He I lines.

Ultraviolet spectroscopy was presented by Gonzalez-Riestra (1992), and optical spectroscopy by Anupama and Sethi (1994).

3.10 V4157 Sgr = Nova Sgr 1992 No. 1

This nova was discovered independently by W. Liller and P. Camilleri on 1992 February 13 at a visual magnitude of roughly $m_v = 7.3$ (IAUC 5451). After discovery both found nondetections of the nova on prediscovery plates which require it to have a brightness of fainter than $m_v = 10$ on February 6 and 7, so visual maximum might have occurred several days before discovery. V4157 Sgr is a very fast nova.

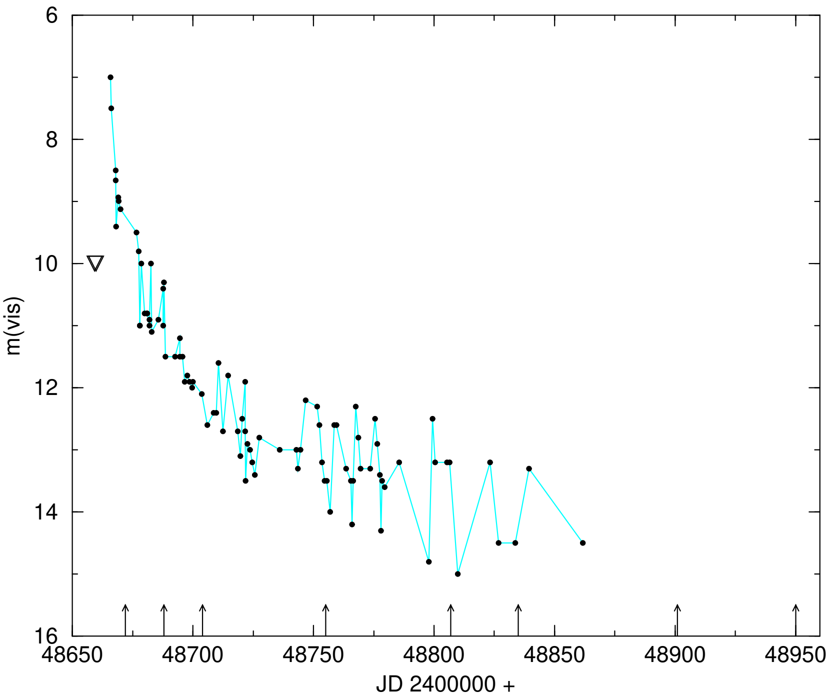

Figure 10: The visual light curve of V4157 Sgr. Data were taken from the IAU Circulars and the AAVSO archive. The inverted triangles indicate an upper magnitude limit.

Our first spectrum was obtained with the 1 m telescope 1 week after maximum light, on 1992 February 19 (JD 2448672). The nova shows an "Fe II"-type spectrum with line widths of approximately HWZI = 1 800 km s^{-1} and flat-topped profiles which are uncharacteristic of this type of spectrum. Subsequent spectra show that V4157 Sgr followed the normal evolution to the "standard" nebular spectrum that is most common for this class of novae. [N II] 5755 and [O I] 6300 were the first forbidden lines to appear in the spectrum, and by 1992 May 12 (JD 2448755) the spectrum had developed prominent [O III] and [N II] 6584 + Hα lines, with the N and O auroral transitions remaining very strong.

3.11 V4160 Sgr = Nova Sgr 1991

This nova was discovered by P. Camilleri on 1991 July 29 at $m_{pg} = 7$ (IAUC 5313), very near maximum light judging from the brightness and speed of decline. V4160 Sgr is the nova with the most rapid brightness evolution on record. A photoelectric light curve was presented by Gilmore (1994).

Our first spectrum was obtained 3 days after discovery, on 1991 August 1 (JD 2448470). The spectrum is characteristic of the "He/N" class of novae in having the He II 4686/N III 4640 feature as the strongest non-Balmer lines and in having very broad (HWZI = 4 300 km s^{-1}), flat-peaked emission lines. Consistent with the broad emission features which signal a rapidly expanding gas, V4160 Sgr declined in brightness very quickly, as mentioned above. We were not able to obtain our next spectrum until 1 month had passed, on September 2 (JD 2448502), by which time extremely strong broad emission lines of [Ne V], [Ne IV], and [Ne III] had already appeared. The coronal lines [Fe X] 6375 and

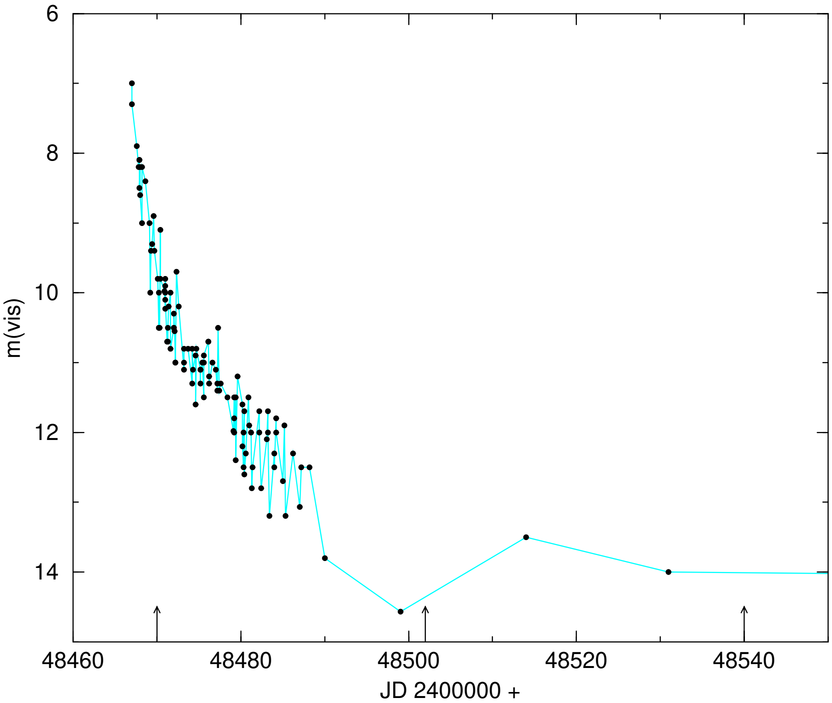

Figure 11: The visual light curve of V4160 Sgr. Data were taken from the IAU Circulars, the AAVSO, AFOEV, and VSOLJ archives.

[Fe XIV] 5303 were also evident at this time, with [Fe X] stronger than [Fe VII], so V4160 Sgr was legitimately in a coronal phase. The spectrum remained roughly the same until October 10 (JD 2448540), although the coronal lines weakened and [O III] 5007 gradually increased in strength relative to [Ne III] 3869, with the lines remaining very wide and flat-topped. Unfortunately, during this time we were not able to obtain spectra in the far-red to determine whether strong forbidden lines of [S VIII] or [S III] formed in V4160 Sgr as they had in V838 Her, which was a "neon" nova very similar to this one. Because of the very rapid decline, acquisition of spectra after 1991 October was not possible.

3.12 V4169 Sgr = Nova Sgr 1992 No. 2

This object was discovered by W. Liller on 1992 July 9 at $m \sim 8.5$, when it was still rising in brightness. Maximum was reached around 1992 July 11. A photoelectric light curve was presented by Gilmore (1994). V4169 Sgr is a fast nova.

A multiwavelength study of this nova was published by Scott et al. (1995), where optical spectroscopy near maximum light (1992 Jul 10 – 21), in 1992 August/September, and 1993 July is reported, which precedes and follows the observations presented here. In addition, high-resolution spectroscopy, scattered UV, IR and Radio observations were carried out.

The first available spectrum (Scott et al. 1995) of July 10 showed a strong continuum with the H lines as P-Cygni profiles, the Fe II lines were hardly seen in emission. Around July 20, the continuum had weakened, and the H and Fe II lines were more pronounced. In the first CTIO spectrum, taken July 31 (JD 2448835), this trend had continued, and a strong [O I] 8446 fluorescence line had appeared, that is markedly present at least until

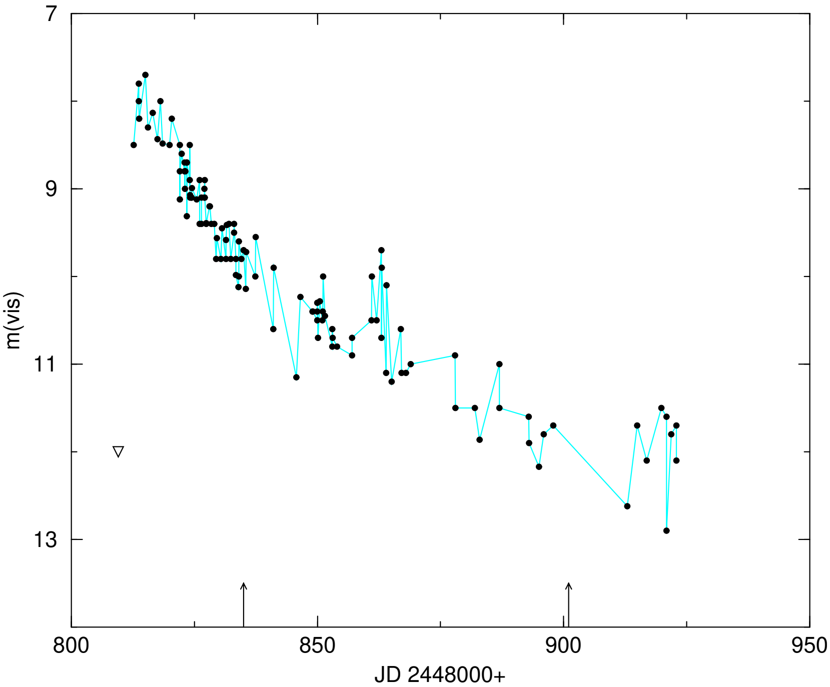

Figure 12: The visual light curve of V4169 Sgr. Data were taken from the IAU Circulars, the AAVSO, AFOEV and VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

October 1992. Blue region spectra of Scott et al. (1995) were taken in late August and late September. The latter shows the emergence of [O III], which is very pronounced in October and in the first half of 1993. The last spectrum of Scott et al. (1995) in 1993 July shows a decline of [O III], but 5007 is still the strongest single line in the visible range. [Fe VIII] is present in spectra taken between 1993 March and July, and exhibits an unusual double-peaked structure.

IR spectra taken by Rossano et al. (1994) in 1992 October showed infrared coronal lines of [S VIII] and [S IX], indicating a high excitation region of low density.

3.13 V4171 Sgr = Nova Sgr 1992 No. 3

This nova was discovered on October 13, 1993 by P. Camilleri, when it was still rising in brightness. Maximum light was reached on 1992 October 14. The light curve, reconstructed from IAUC and VSOLJ data, is that of a very fast nova. A red spectrum taken around maximum is decribed by Stringfellow and Gregg (IAUC 5635), showing strong emission lines of Hα, with the O I and Na I lines showing P-Cygni profiles.

The first CTIO spectrum was taken on 1992 October 27 (JD 2448923), 12 days after maximum. It showed a quite blue continuum superimposed by H and Fe II emission lines. It is characteristic of that of a "Fe II" nova during the permitted phase, with a strong Fe II multiplet 42, and Na I D with a blue absorption component, quite similar to that of V2264 Oph about 10 days after maximum.

On November 22 (JD 2448949), the continuum had faded, and strong H and He I emission

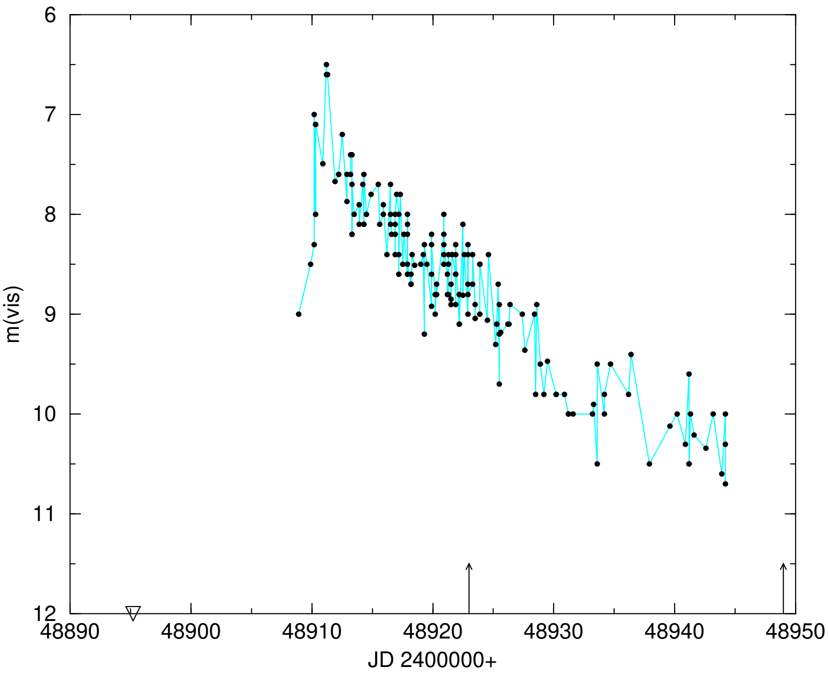

Figure 13: The visual light curve of V4171 Sgr. Data were taken from the IAU Circulars, the AAVSO, AFOEV, and VSOLJ archives.

lines were visible, with [O III] starting to emerge. In March – May 1993 (JD 2449070 – 165), the spectrum is dominated by [O III] emission lines. In the ultraviolet, lines of [Ne III] and [Ne V] had also become strong (although not as prominent as in V2264 Oph), and [Fe VII] was also present.

3.14 V745 Sco

This recurrent nova underwent an outburst that was discovered by W. Liller on 1989 July 30 (IAUC 4820). Maximum light apparently already occurred between July 28 and 30 at $m_v \sim 9.7$ (IAUC 4821). V745 Sco is a very fast nova, like the majority of recurrent novae.

The earliest spectrum, obtained 1989 August 1 (JD 2447740), showed strong broad Balmer lines, with very strong He I 5876 and He II and Fe II also present. The nova experienced a rapid spectral evolution, presumably due in part to a rapidly decreasing envelope density. On August 5 (JD 2447744), He II 4686 was moderately strong, and the coronal [Fe X] 6375 emission was detectable. During the next 2 weeks, the [Fe X] strengthened, and [Fe VII] and [Fe XI] lines appeared, while the Fe II multiplets became weaker. He II 4686 did not decrease in strength in this interval, and the first evidence of a late-type companion appeared in the red. By September 14 (JD 2447784) a significant change in line strengths occurred once again, with the ionization level dropping considerably, such that [O I] 6300 and [O II] 7325 became two of the stronger lines in the spectrum. Relative to the declining nova, the secondary companion became dominant in the red, and based upon the TiO and VO features between 700 and 800 nm, a spectral type of M8 III can be assigned to it.

After an observational gap of 8 months, a spectrum taken 1990 May 25 (JD 2448037)

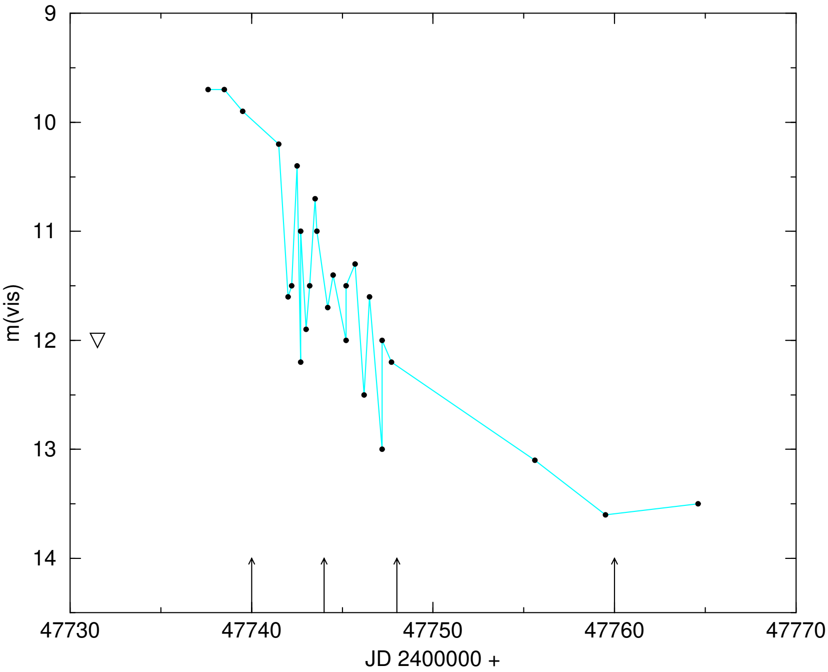

Figure 14: The visual light curve of V745 Sco. Data were taken from the IAU Circulars, the AAVSO, AFOEV, and VSOLJ archives. The inverted triangle indicates an upper magnitude limit.

showed that the [N II] and [O II] auroral transitions were still strong, and the line widths had decreased to the point where [N II] 6584 could be resolved from Hα. In addition, a rich array of forbidden Fe lines had appeared. At this time, the spectrum was very slowly changing with time.

Since 1990 May the emission spectrum weakened considerably, especially the lines with respect to the continuum. The strongest forbidden line, [O III] 5007, virtually disappeared, and the entire flux level of the nova dropped, including the flux of the M giant secondary. The same phenomenon was observed in V3890 Sgr, where the TiO and VO bands of the secondary star gradually diminished in brightness with time. It seems apparent that the nova outburst does affect the giant secondary stars so that they become considerably more luminous immediately after outburst, and then steadily decline in flux. The relative strengths of the absorption features in the secondary do not change during the decline, and therefore the effective temperature must remain roughly constant as the luminosity decreases, i.e. the secondary becomes fainter through a decrease in the effective photospheric radius.

The most notable aspect of the evolution of the spectrum is that by 1992 April 4 (JD 2448717) the emission-line spectrum was once again dominated by the permitted Fe II transitions that characterized the early spectra immediately after outburst. The fact that the flux of the He I 5876 is also strong during this time may indicate that the He I line originates in the chromosphere of the giant secondary. The same behavior is seen in V3890 Sgr, a system that has evolved very similarly to V745 Sco.

Optical spectroscopy of V745 Sco was also presented by Sekiguchi et al. (1990b) and Duerbeck (1989).

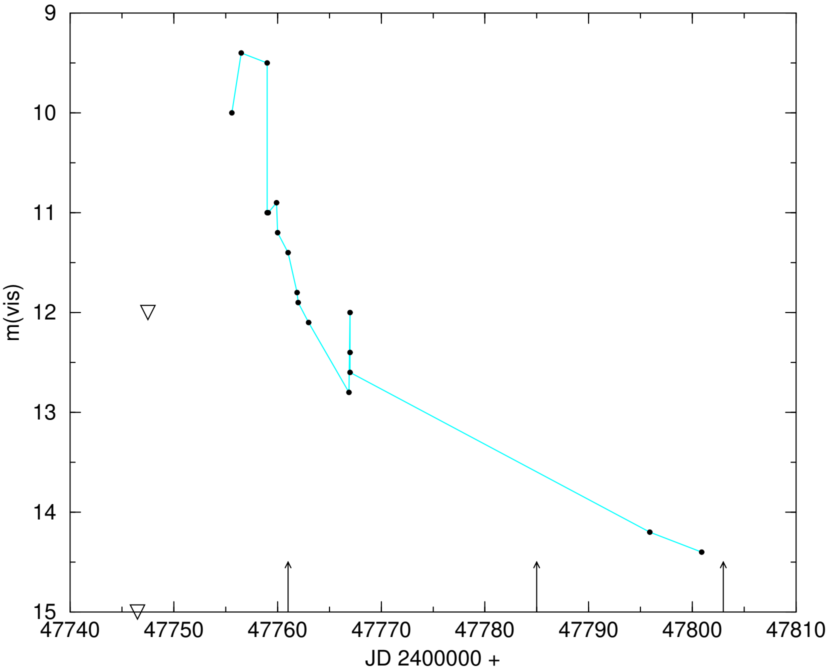

Figure 15: The visual light curve of V977 Sco. Data were taken from the IAU Circulars, and the VSOLJ archive. The inverted triangle indicates an upper magnitude limit.

3.15 V977 Sco = Nova Sco 1989 No. 2

V977 Sco was discovered on 1989 August 17 near maximum light by W. Liller (IAUC 4836). Prediscovery photographs by both Liller and R.H. McNaught (IAUC 4838) confirm that maximum light occurred on August 18 at $m_v \sim 9.5$. V977 Sco is a very fast nova.

A spectrum taken 1989 August 22 (JD 2447761), several days after outburst, revealed low-excitation permitted lines, including Fe II, O I, and Ca II. The wavelengths longward of Hα contained a wealth of heavy element lines, including Mg II multiplets which were probably excited by resonance fluorescence of Lyβ. Almost a month later, on September 15 (JD 2447785), the auroral transitions of [N II] and [O II] were present, but the excitation was still so low that He I lines were only marginally detectable. On 1989 October 3 (JD 2447803), the auroral transitions became stronger, and the ionization level was higher, as evidenced by the definitive appearance of He I lines. By 1990 February 23 (JD 2447946), nebular lines and He II 4686 were becoming strong, and the increasing level of ionization continued until 1990 June 7 (JD 2448050), as the higher ionization [Fe VII] 6087 line also became increasingly stronger. During this period, O I 8446 slowly decreased in strength.

In the years 1991-92, the strengths of the forbidden lines increased with respect to the Balmer lines. The spectrum was of moderate-to-high ionization, with [O III] 5007 very strong and [Fe VII] 6087 and [S VIII] 9911 also prominent. Even [Ne V] 3426 was stronger than Hβ. The fluxes of the auroral lines relative to the nebular lines were greater than one finds in a low-density gas, even stronger than the Balmer lines. In addition, a red continuum appeared in 1991 June and 1992 April (JD 2448419 – 717) that was not present in 1990 June.

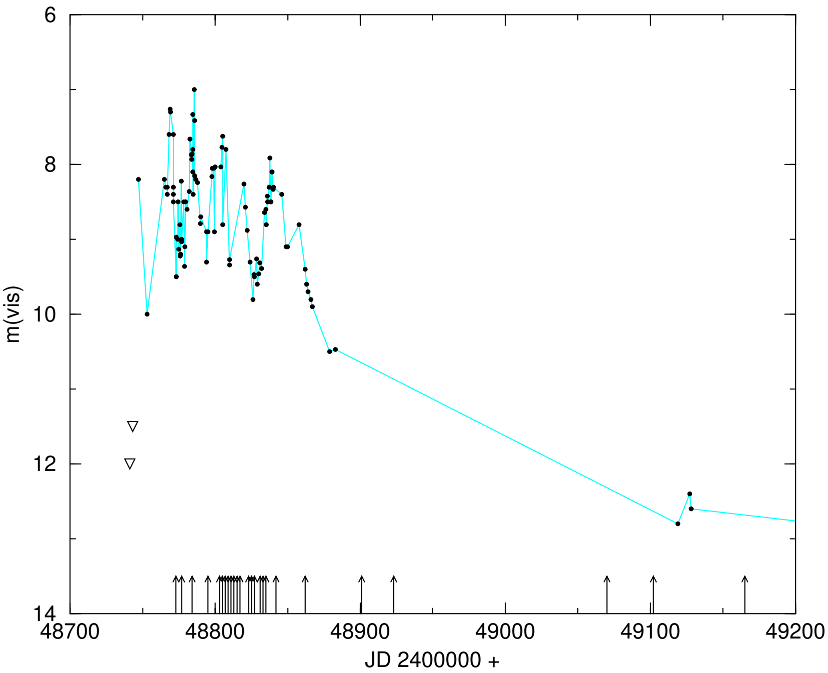

Figure 16: The visual light curve of V992 Sco. Data were taken from the IAU Circulars, the AFOEV and the VSOLJ archives. The two inverted triangles indicate upper magnitude limits.

3.16 V992 Sco = Nova Sco 1992

This object was discovered by P. Camilleri on 1992 May 22 at about 8.2 mag. A photoelectric light curve was presented by Gilmore (1994). The decline is characterized by a short t_2-time and a long t_3-time: while the early rapid decline makes it – by Payne-Gaposchkin's definition, which is based on the t_2-time – a very fast nova, its subsequent more leisurely decline, as well as its spectral evolution, clearly indicate that this is a medium fast (or perhaps even slow) nova.

Our first spectrum, taken 1992 May 30 (JD 2448773), showed a continuum with superimposed emission of Balmer and Fe II lines. V992 Sco is a member of the "Fe II" class. The following spectra, taken in intervals of a few days, hardly showed any changes. On June 21 (JD 2448795), the emission was flanked by a blueshifted absorption component, which remained almost unchanged until July 5 (JD 2448809). The absorption vanished in the following three spectra (July 7 – 11), and re-emerged in the spectra of July 19 and 21, and remained pronounced until August 7 (JD 2448842). Confronting the emergence of absorption with features in the light curve, it is noted that absorption (or an increase in strength of absorption) occurs when the visual light curve rises in brightness: an optically thick shell passes through the photosphere and subsequently makes it grow. On August 27 (2448862), after the light curve had began its definite decline, O I 8446 fluorescence started to appear. After the seasonal gap, when the nova had dropped by more than 5 magnitudes in visual brightness, [O III] and [N II] lines started to dominate the spectrum. They increased in strength until the last spectrum, which was taken 1993 June 26 (JD 2449165).

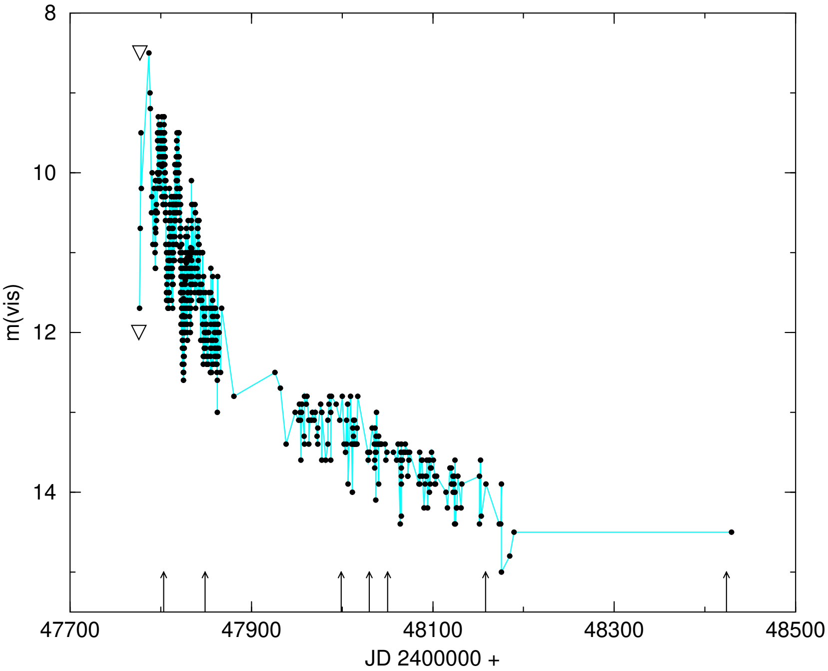

Figure 17: The visual light curve of V443 Sct. Data were taken from the IAU Circulars, the AAVSO and the VSOLJ archives. Two inverted triangles indicate upper magnitude limits.

3.17 V443 Sct = Nova Sct 1989

The initial observation of V443 Sct was made by P. Wild on 1989 September 20 at a brightness of $m_{pg} = 10.5$ (IAUC 4861), although a subsequent search of photographs by McNaught (IAUC 4862) and by Wenzel (IAUC 4868) revealed that visual maximum probably occurred on 1989 September 18 at $m_v \sim 9.5$, or perhaps even a few days earlier. V443 Sct is a very fast nova.

The initial spectrum, taken on 1989 October 3 (JD 2447803), 2 weeks after maximum, featured strong Balmer and Fe II lines, in addition to Na I D with a P Cygni profile. In the near-IR, strong O I 7773 and 8446, together with other permitted lines of Ca II, N I, and C I occurred, in addition to the same Mg II multiplets that were observed in V977 Sco. On November 18 (JD 2447849), 2 months after outburst, strong forbidden lines had appeared, including the auroral lines [N II] 5755 and [O II] 7325. After a 5 month hiatus in data, the spectrum of 1990 April 17 (JD 2447999) showed many more nebular lines emerging, although the auroral lines of [O II], [N II], and [O III] remained unusually strong. The spectrum remained essentially unchanged through 1990 September 23 (JD 2448158), with the exception of the emergence of moderately strong [S III] $\lambda\lambda$9069,9531 lines.

In the years 1991 and 1992, the level of ionization did not change much, judging from the relative strengths of [N II] 5755 and [Fe VII] 6087. The line emission became noticeably weaker, and a faint continuum was evident. The auroral transitions remained strong, and the spectral development of V443 Sct was similar to that of V977 Sco between 1989 and 1992.

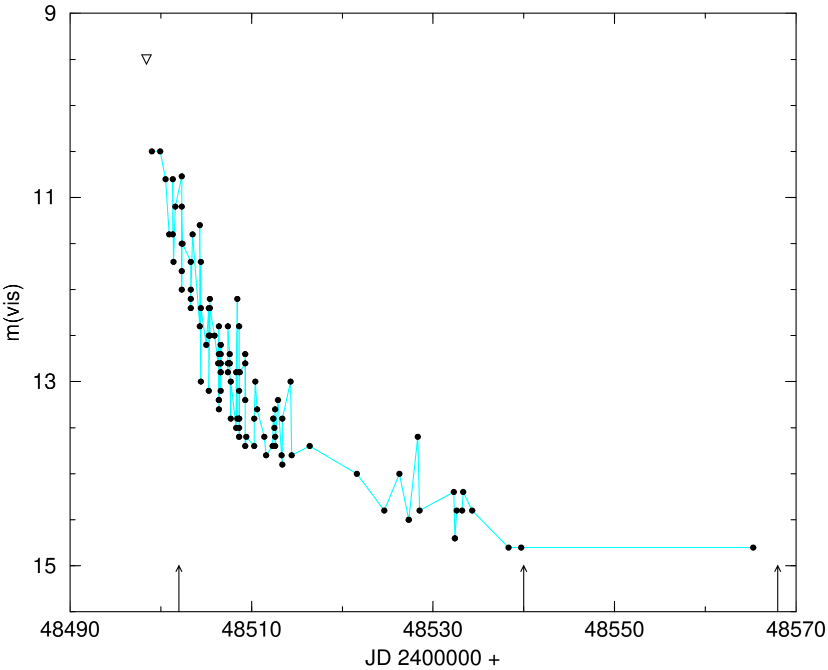

Figure 18: The visual light curve of V444 Sct. Data were taken from the IAU Circulars, and the AAVSO archive. The inverted triangle indicates an upper magnitude limit.

3.18 V444 Sct = Nova Sct 1991

This object was found by P. Camilleri on 1991 August 30.5 at $m = 10.5$ (IAUC 5331), while it had been fainter than 9.5 half a day before, and nondetections on prediscovery photographs require it to have been fainter than $m = 12$ on August 8. V443 Sct is a very fast nova.

Our first spectrum, taken on 1991 September 2 (JD 2448502), three days after discovery, showed the nova to be of the "Fe II" class with quite broad lines, viz. HWZI = 3 000 km s^{-1} for the Balmer lines. P Cygni absorption components were present for the Balmer, Fe II, and Na I D lines. The nova declined in brightness fairly quickly. However, given the relative faintness of the nova at discovery and its apparently moderately fast rate of decline, it is very likely that visual maximum occurred during the week before discovery. Since the rates of decline in brightness of fast novae near maximum usually change not much within 2-3 mag of maximum unless dust forms, uncertainties in the dates of visual maximum should not have a large effect in the value of t_3.

As with V4160 Sgr, we were not able to get a second spectrum of V444 Sct until more than a month after discovery. By 1991 October 10 (JD 2448540), the He I lines had become very strong, and both the He I and Balmer lines appeared to have line profiles consisting of a broad base on which was superimposed a narrower core. Very broad forbidden lines of [Ne V], [Ne III] 3869, and [O III] 5007 had also appeared, as had the N III/He II blend. One month later, on November 7 (JD 2448568), the emission lines had become narrower and [Ne V] 3426 and He II 4686 had become very strong. As is usually the case with novae whose initial line widths (HWZI) exceed 2 500 km s^{-1}, V444 Sct developed a "neon" nova forbidden-line spectrum. Given the considerable strength of the high ionization lines,

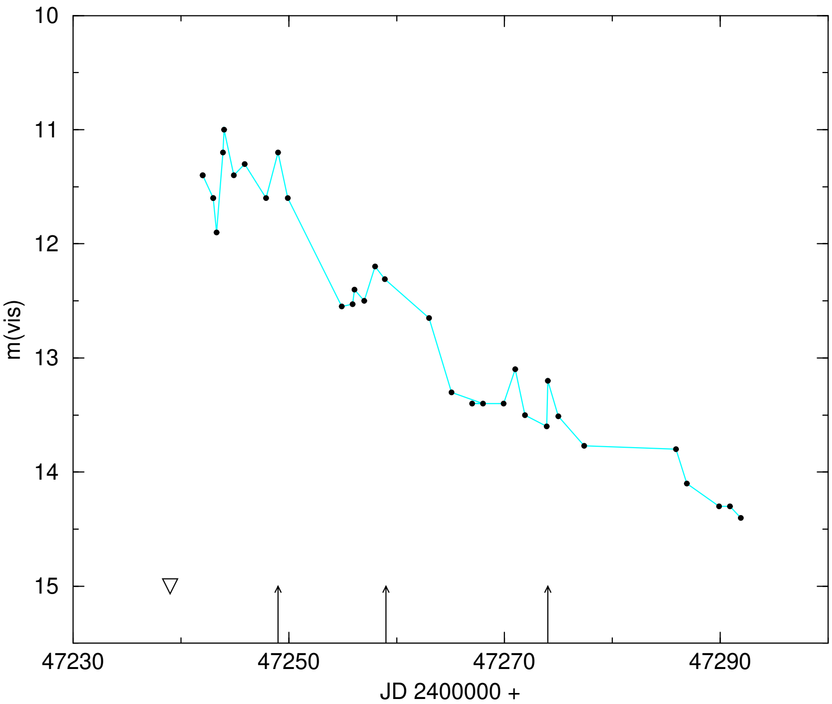

Figure 19: The visual light curve of Nova LMC 1988 No. 1. Data were taken from the IAU Circulars. The inverted triangle indicates an upper magnitude limit.

the absence of [Fe VII] 6087 was notable since it is usually strong in such novae. A final weak spectrum obtained on 1992 April 4 (JD 2448714) showed [O III] and [Ne III] to have increased in strength relative to [Ne V], and the H and He lines to be very weak. The coronal line of [Fe X] also appeared in that last spectrum, signalling that the nova had entered a very high ionization phase.

3.19 Nova LMC 1988 No. 1

This nova was discovered by G. Garradd in March 1988 and reached a maximum brightness of $m_v \sim 11.2$ on 1988 March 23 (IAUC 4568, 4569). N LMC 1988 No. 1 is a fast nova.

We obtained spectra in the first month following outburst, during which time the spectrum did not evolve in a dramatic fashion. As is typical of many novae during maximum, the Balmer lines dominated the spectrum in the visible, accompanied by low-ionization lines of Fe II, Na I, O I, and the Ca II infrared triplet. A number of these lines had blue absorption components. By April 22 (JD 2447274), the O I 8446 and Fe II lines had increased in strength relative to Hβ, and the forbidden lines [O I] 6300, [O I] 5577, and [N II] 5755 had appeared above the continuum. Presumably the strong Hα feature observed consisted of an unresolved, perhaps dominant, [N II] 6584 component. Due to observational constraints, no further data were obtained to document the nebular stage.

A multiwavelength study of the early evolution was carried out by Schwarz et al. (1998).

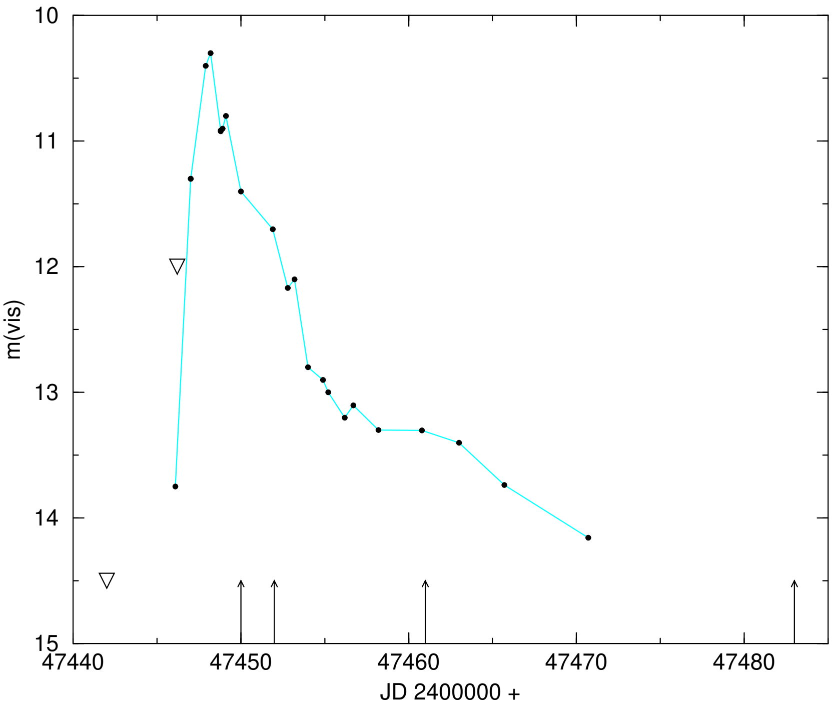

Figure 20: The visual light curve of Nova LMC 1988 No. 2. Data were taken from the IAU Circulars; a prediscovery magnitude is given by Kurochkin (1988). The two inverted triangles indicate lower magnitude limits.

3.20 Nova LMC 1988 No. 2

Also discovered by G. Garradd, this nova was found on 1988 October 13 with $m_v \sim 10.5$ (IAUC 4663, 4664, 4666). N LMC 1988 No. 2 is a very fast nova.

Our spectra show it to have been dominated initially by broad Balmer lines with narrow, blueward absorption components, and Fe II emission. As is frequently the case, Na I D was also present with a P Cygni profile. Two weeks after maximum, the N II multiplets 3, 21, and 24, which may have been excited from resonance fluorescence of the $3d^3P^o$ state via scattering of $\lambda529$ radiation, became stronger, and remained so until our final spectrum on November 17 (JD 2447483). This is one of the few novae we have observed in which the line profiles became more flat-topped with time. In spite of the high expansion velocities of the envelope ($\sim 10\,000$ km s^{-1}), no forbidden lines appeared within the first month after outburst.

Optical spectroscopy of N LMC 1988 No. 2 was also carried out by Sekiguchi et al. (1989).

3.21 Nova LMC 1990 No. 1

This nova was discovered by G. Garradd on 1990 January 16 on a patrol photograph at an apparent brightness of $m_{pg} \sim 11.5$ (IAUC 4946), where no object had been apparent on January 3. Subsequently, W. Liller found from searching his own PROBLICOM exposures that the nova was already in outburst at this brightness on January 14 (IAUC 4961), thus having achieved maximum on this date, or earlier. N LMC 1990 No. 1 is thus a very fast

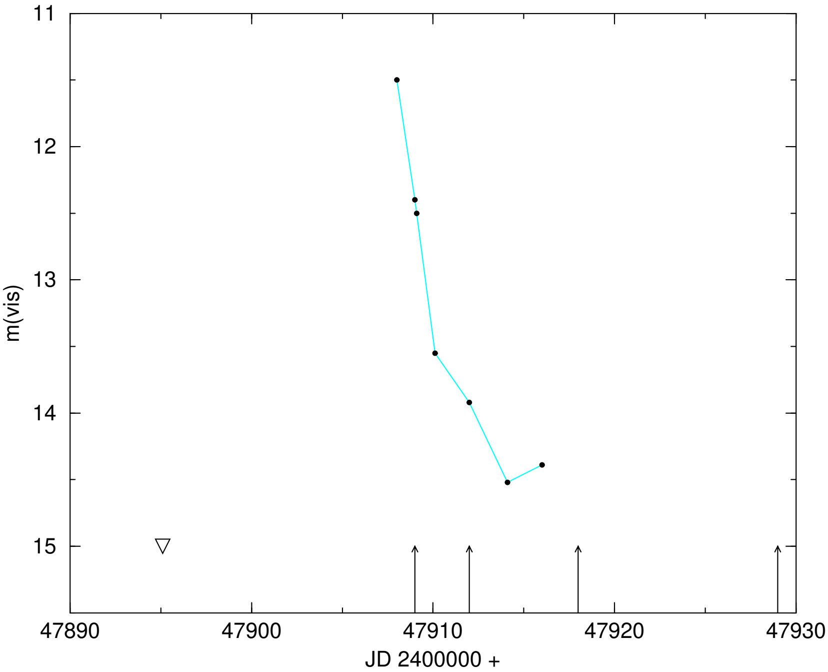

Figure 21: The visual light curve of Nova LMC 1990 No. 1. Data were taken from the IAU Circulars. The inverted triangle indicates a lower magnitude limit.

nova, one of the most rapid ones on record.

Our first observations of 1990 January 17 and 20 (JD 2447909/912) showed that the spectrum was very similar to that of Nova LMC 1988 No. 2, in having very broad Balmer lines with N III 4640 and N II 5001. However, unlike Nova LMC 1988 No. 2, this nova evolved very rapidly, developing strong forbidden lines within 2 weeks of discovery. In particular, both [Ne III] 3869 and [Ne V] 3426 were strong on January 26 (JD 2447918) and had become stronger than Hβ by February 6 (JD 2447929). The fact that [O III] 5007 was weak in comparison to the strong [Ne III] line almost certainly indicates that the neon abundance is very high. Thus "neon" novae are not just peculiar to our Galaxy, but also exist in the LMC.

Elemental abundances have been derived by Vanlandingham et al. (1999).

3.22 Nova LMC 1990 No. 2

This recurrent nova was discovered by W. Liller on 1990 February 14 in outburst with $m_{pg} \sim 11.2$, and based on positional coincidence it is very likely to be the same nova that was observed in outburst in the LMC in 1968 (IAUC 4964). The light curve is quite fragmentary, nevertheless, the object can securely be classified as a very fast nova.

We succeeded in obtaining a single spectrum in the visible on 23 February (JD 2447946), which featured prominent Balmer lines and a very strong He II 4686 line. The lines had narrow cores with broad wings.

UV spectra were obtained by Shore et al. (1991) using the IUE. Additional optical spectra were taken by Sekiguchi et al. (1990a) around the time of the CTIO observation.

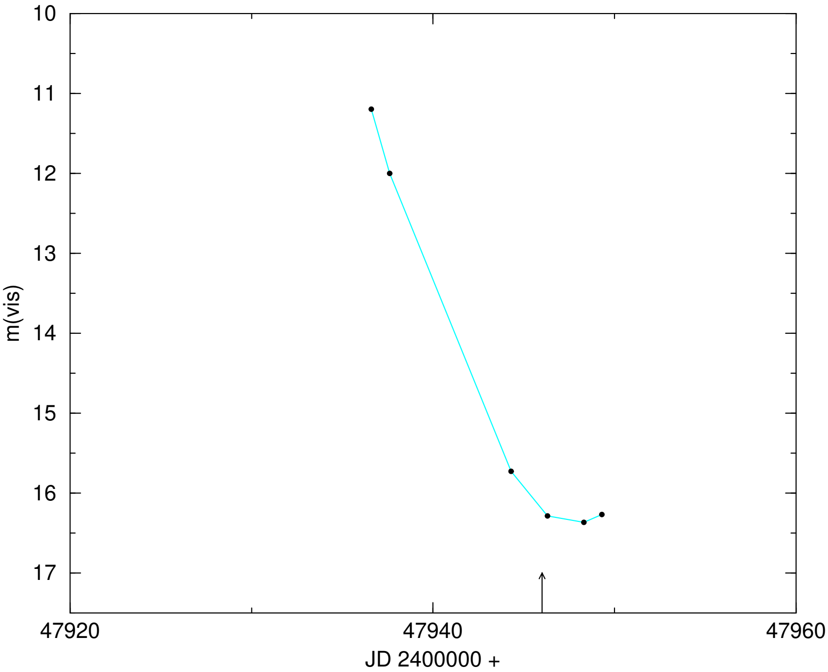

Figure 22: The visual light curve of Nova LMC 1990 No. 2. Data were taken from the IAU Circulars, and from Sekiguchi et al. (1990b).

3.23 Nova LMC 1991 No. 1

The nova was found by W. Liller on 1991 April 18 at a brightness of $m_v = 12$ (IAUC 5244). The discovery occurred well before maximum brightness, and the light curve and spectral evolution have been well documented both before and after visual maximum. Visual observations showed that the nova steadily increased in brightness until maximum light was reached at $m_v \sim 8.8$ on April 23.8, at which point its luminosity well exceeded the Eddington luminosity for a 1 $M_\odot$ white dwarf (IAUC 5250, 5253, 5257). The decline from visual maximum was very fast. A photoelectric light curve was presented by Gilmore (1994).

The initial spectrum, taken on April 20 (JD 2448367), showed prominent Balmer and Fe II lines which were relatively narrow, with HWZI = 2 100 km s^{-1}, and having strong, narrow P Cygni absorption features characteristic of an “Fe II” nova. The far-red lines were not very strong at this stage, and the lines were superimposed on a strong thermal-like continuum which peaked near 380 nm. On April 25 (JD 2448372), near maximum light, the spectrum was qualitatively the same except that all the lines were considerably broader. The far-red lines were dominated by C I, N I, and O I transitions, most having blueward absorption components.

In the following two weeks the spectrum changed completely. By May 8 (JD 2448385) the continuum had virtually disappeared as had the absorption components, and N III, He I and [N II] emission lines were emerging, together with a very strong O I 8446. The spectrum was clearly evolving to the nebular phase; however, the LMC was poorly placed in the sky for further observations at this time. The next spectrum was not obtained until 1991 September 2 (JD 2448502), when the forbidden nebular spectrum was already well developed. [O III] 5007 dominated the spectrum, and [O III] 4363 was impressively strong. In general, the

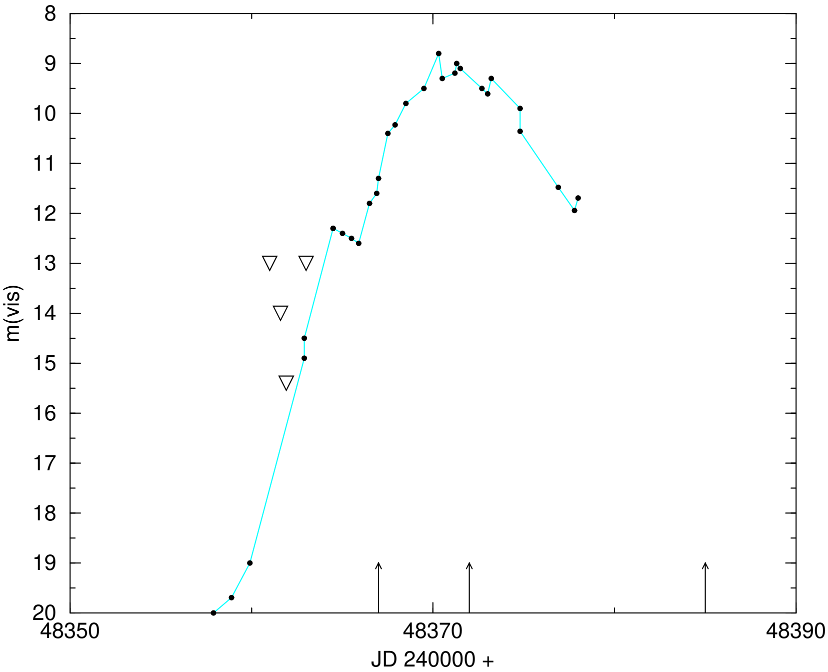

Figure 23: The visual light curve of Nova LMC 1991 No. 1. Data were taken from the IAU Circulars. Inverted triangles indicate lower magnitude limits.

emission spectrum at this time fits well within the description of the "standard" nebular spectrum to which the majority of "Fe II" novae evolve. Over the next months, the basic spectrum changed little although it did develop higher ionization with steady increases in the fluxes of lines such as [Ne V] 3426 and O VI 5292, and even though the lines were not very broad, they still had jagged and flat, rather than sharp, line peaks. Repeated attempts to get spectra after 1992 February failed because of the faintness of the nova.

A multiwavelength analysis of N LMC 1991 was presented by Schwarz et al. (2001).

3.24 Nova LMC 1992

The object was discovered by W. Liller on 1992 November 11 at $m_r = 10.7$. The decline from maximum was very fast. A photoelectric light curve was presented by Gilmore ((1994).

The first spectrum was taken on 1992 November 27 (JD 2448954). Besides the Balmer lines, Fe II multiplet lines were seen in emission, and it is very likely that we deal with an "Fe II" nova. O I 8446 was already enhanced by fluorescence, and equalled Hβ in strength. On December 18 (JD 2448975), [O III] and also [N II] 5755 appeared (the [N II] nebular lines are blended with Hα) and remained present until the last spectrum, taken 1993 March 23 (JD 2449070). This is remarkable since the auroral transitions of [O III] and [N II] remain strong and surpass Hβ in strength.

3.25 Various objects

Besides the above objects, the CTIO nova survey comprises a few spectra of V1419 Aql and V705 Cas. Since observations of these objects have been presented and discussed extensively in the existing literature, no additional information is given here.

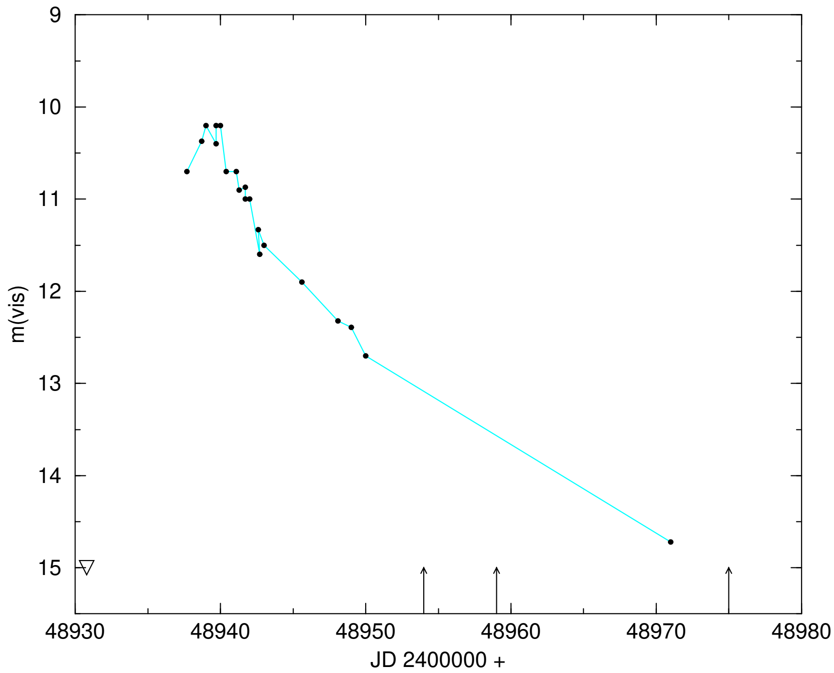

Figure 24: The visual light curve of Nova LMC 1992. Data were taken from the IAU Circulars.

4 Summary

We presented 198 spectra of classical and recurrent novae, taken at various phases of their spectral evolution, from maximum light to the nebular stage. A major part of them was used to establish the CTIO classification system (Williams et al. 1991, Williams 1992), and thus the digital spectra may serve as useful templates for future attempts of classifying nova spectra.

Acknowledgments

We are happy to acknowledge the important contributions of the many people, and especially Bill Liller, who are actively engaged in projects to discover new novae. We have also benefited from the professionalism of the CTIO mountain observer support crew who have provided many instrument set-ups for us on short notice.

We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research. Thanks are also to VSOLJ for kindly allowing their data to be available in the VSNET web pages. This research has made also use of the AFOEV database, operated at CDS, France. Special thanks are due to Albert Jones who put his long series of estimates of V868 Cen at our disposal.

Part of this work has been supported by "IUAP P5/36" Interuniversity Attraction Poles Programme of the Belgian Federal Office for Scientific, Technical and Cultural Affairs, and the Flemish Ministry for Foreign Policy, European Affairs, Science and Technology, under contract BIL 01/2.

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Table 1. Novae and their photometric characteristics (numbers in brackets indicate estimated or extrapolated values, numbers with colons uncertain values).

Object (year)	m(max)	speed class	t_2 (days)	t_3 (days)	orbital period (days)
V868 Cen (1991)	10.2	MF	(13)	70:	
V394 CrA (1987)	7.2	VF(rec)	3	5	0.7577:
V838 Her (1991)	5.4	VF	1.2	3.5	0.297635
GQ Mus (1983)	(7)	F	18	40	0.059365
V2214 Oph (1988)	8.5	MF	45	73	0.117515
V2264 Oph (1991)	(9.8)	F	20	36	
V2295 Oph (1993)	9.4	VF	8.5	21	
V351 Pup (1991)	(6.4)	VF	9.5	25	0.1182
V3890 Sgr (1990)	8.5	VF(rec)	7.7	12.2	
V4157 Sgr (1992)	(7.3)	VF	3.5	12	
V4160 Sgr (1991)	7	VF	2	3	
V4169 Sgr (1992)	7.7	F	18	40	
V4171 Sgr (1992)	6.6	VF	6	18	
V745 Sco (1989)	9.7	VF(rec)	8	12	
V977 Sco (1989)	9.5	VF	5.5	10.5	
V992 Sco (1992)	7.4	MF	9	81.5	0.15358
V443 Sct (1989)	8.5	VF	5	21	
V444 Sct (1991)	10.5	VF	6	10.5	
N LMC 1988/1	11.2	F	20	24.5	
N LMC 1988/2	10.3	VF	5.3	10	
N LMC 1990/1	(11.5)	VF	2	6	
N LMC 1990/2	(11.2)	VF(rec)	(3)	(4.5)	
N LMC 1991/1	8.8	VF	5.7	7.7	
N LMC 1991/2	10.2	VF	8.5	15.5	

Table 2. Nova spectra.

Object	Date	Date (JD)	Spectrum	Filename
V1419 Aql	1993 Jun 26	2449165	v1419aql.a.26jun93	v1419aqa
V705 Cas	1994 Feb 19	2449493	v705cas.a.19feb94	v705casa
	1994 Feb 23	2449497	v705cas.b.23feb94	v705casb
	1994 Feb 24	2449498	v705cas.c.24feb94	v705casc
V868 Cen	1991 Apr 03	2448350	v868cen.a.03apr91	v868cena
	1991 Apr 20	2448367	v868cen.b.20apr91	v868cenb
	1991 Apr 25	2448372	v868cen.c.25apr91	v868cenc
	1991 May 01	2448378	v868cen.d.01may91	v868cend
	1991 May 08	2448385	v868cen.e.08may91	v868cene
	1991 May 13	2448390	v868cen.f.13may91	v868cenf
	1991 Jun 12	2448420	v868cen.g.12jun91	v868ceng
	1991 Jul 07	2448445	v868cen.h.07jul91	v868cenh
	1992 Jan 07	2448629	v868cen.i.07jan92	v868ceni
	1992 Mar 06	2448688	v868cen.j.06mar92	v868cenj
	1992 Jul 31	2448835	v868cen.k.31jul92	v868cenk
	1993 Jan 30	2449018	v868cen.l.30jan93	v868cenl
	1993 Mar 23	2449070	v868cen.m.23mar93	v868cenm
	1993 Apr 24	2449102	v868cen.n.24apr93	v868cenn
V394 CrA	1987 Aug 04	2447012	v394cra.a.04aug87	v394craa
	1987 Aug 06	2447014	v394cra.b.06aug87	v394crab
	1987 Aug 18	2447026	v394cra.c.18aug87	v394crac
	1987 Aug 19	2447027	v394cra.d.19aug87	v394crad
	1987 Aug 26	2447034	v394cra.e.26aug87	v394crae
V838 Her	1991 Apr 03	2448350	v838her.a.03apr91	v838hera
	1991 Apr 25	2448372	v838her.b.25apr91	v838herb
	1991 May 08	2448385	v838her.c.08may91	v838herc
	1991 Jun 12	2448420	v838her.d.12jun91	v838herd
	1991 Jul 04	2448442	v838her.e.04jul91	v838here
	1991 Sep 02	2448502	v838her.f.02sep91	v838herf
GQ Mus	1988 Jun 09	2447322	gqmus.a.09jun88	gqmusa
	1990 May 31	2448043	gqmus.b.31may90	gqmusb
	1990 Jul 24	2448097	gqmus.c.24jul90	gqmusc
	1991 Mar 10	2448326	gqmus.d.10mar91	gqmusd
	1992 Jan 22	2448644	gqmus.e.22jan92	gqmuse
	1994 Feb 07	2449391	gqmus.f.07feb94	gqmusf
V2214 Oph	1988 May 06	2447288	v2214oph.a.06may88	v2214opa
	1988 May 17	2447299	v2214oph.b.17may88	v2214opb
	1988 May 18	2447300	v2214oph.c.18may88	v2214opc
	1988 May 19	2447301	v2214oph.d.19may88	v2214opd
	1988 Jun 08	2447321	v2214oph.e.08jun88	v2214ope
	1988 Jun 09	2447322	v2214oph.f.09jun88	v2214opf
	1988 Jun 22	2447335	v2214oph.g.22jun88	v2214opg
	1988 Jun 25	2447338	v2214oph.h.25jun88	v2214oph
	1988 Jul 06	2447349	v2214oph.i.06jul88	v2214opi
	1988 Jul 07	2447350	v2214oph.j.07jul88	v2214opj
	1988 Jul 08	2447351	v2214oph.k.08jul88	v2214opk
	1988 Jul 09	2447352	v2214oph.l.09jul88	v2214opl
	1988 Jul 19	2447362	v2214oph.m.19jul88	v2214opm
	1988 Jul 20	2447363	v2214oph.n.20jul88	v2214opn
	1988 Aug 21	2447395	v2214oph.p.21aug88	v2214opp

Table 2 (continued). Nova spectra.

Object	Date	Date (JD)	Spectrum	Filename
	1988 Aug 21	2447395	v2214oph.p.21aug88	v2214opp
	1988 Sep 23	2447428	v2214oph.q.23sep88	v2214opq
	1988 Oct 04	2447439	v2214oph.r.04oct88	v2214opr
	1989 May 09	2447656	v2214oph.s.09may89	v2214ops
	1990 May 18	2447665	v2214oph.t.18may90	v2214opt
	1990 Sep 23	2448158	v2214oph.u.23sep90	v2214opu
	1991 Mar 11	2448327	v2214oph.v.11mar91	v2214opv
	1991 May 09	2448386	v2214oph.w.09may91	v2214opw
	1992 Apr 04	2448717	v2214oph.x.04apr92	v2214opx
V2264 Oph	1991 Apr 20	2448367	v2264oph.a.20apr91	v2264opa
	1991 Apr 25	2448372	v2264oph.b.25apr91	v2264opb
	1991 May 08	2448385	v2264oph.c.08may91	v2264opc
	1991 May 23	2448400	v2264oph.d.23may91	v2264opd
	1991 Jun 12	2448420	v2264oph.e.12jun91	v2264ope
	1991 Jul 04	2448442	v2264oph.f.04jul91	v2264opf
	1991 Sep 02	2448502	v2264oph.g.02sep91	v2264opg
	1992 Mar 06	2448688	v2264oph.h.06mar92	v2264oph
	1992 May 12	2448755	v2264oph.i.12may92	v2264opi
	1992 Jul 29	2448833	v2264oph.j.29jul92	v2264opj
V2295 Oph	1993 Apr 21	2449099	v2295oph.a.21apr93	v2295opa
	1993 Apr 28	2449106	v2295oph.b.28apr93	v2295opb
	1993 Jun 26	2449165	v2295oph.c.26jun93	v2295opc
V351 Pup	1992 Jan 07	2448629	v351pup.a.07jan92	v351pupa
	1992 Jan 28	2448650	v351pup.b.28jan92	v351pupb
	1992 Feb 06	2448659	v351pup.c.06feb92	v351pupc
	1992 Mar 06	2448688	v351pup.d.06mar92	v351pupd
	1992 May 12	2448755	v351pup.e.12may92	v351pupe
	1992 Nov 26	2448953	v351pup.f.26nov92	v351pupf
	1992 Dec 31	2448988	v351pup.g.31dec92	v351pupg
	1993 Mar 23	2449070	v351pup.h.23mar93	v351puph
	1993 Apr 24	2449102	v351pup.i.24apr93	v351pupi
V3890 Sgr	1990 May 02	2448014	v3890sgr.a.02may90	v3890sga
	1990 May 25	2448037	v3890sgr.b.25may90	v3890sgb
	1990 May 31	2448043	v3890sgr.c.31may90	v3890sgc
	1990 Jun 07	2448050	v3890sgr.d.07jun90	v3890sgd
	1990 Jul 03	2448076	v3890sgr.e.03jul90	v3890sge
	1990 Jul 24	2448097	v3890sgr.f.24jul90	v3890sgf
	1990 Sep 21	2448156	v3890sgr.g.21sep90	v3890sgg
	1990 Oct 27	2448192	v3890sgr.h.27oct90	v3890sgh
	1991 May 13	2448390	v3890sgr.i.13may91	v3890sgi
	1992 Apr 04	2448717	v3890sgr.j.04apr92	v3890sgj
V4157 Sgr	1992 Feb 19	2448672	v4157sgr.a.19feb92	v4157sga
	1992 Mar 06	2448688	v4157sgr.b.06mar92	v4157sgb
	1992 Mar 22	2448704	v4157sgr.c.22mar92	v4157sgc
	1992 May 12	2448755	v4157sgr.d.12may92	v4157sgd
	1992 Jul 03	2448807	v4157sgr.e.03jul92	v4157sge
	1992 Jul 31	2448835	v4157sgr.f.31jul92	v4157sgf
	1992 Oct 05	2448901	v4157sgr.g.05oct92	v4157sgg
	1992 Nov 23	2448950	v4157sgr.h.23nov92	v4157sgh
	1993 Mar 23	2449070	v4157sgr.i.23mar93	v4157sgi
	1993 Apr 21	2449099	v4157sgr.j.21apr93	v4157sgj
	1993 Jun 26	2449165	v4157sgr.k.26jun93	v4157sgk

Table 2 (continued). Nova spectra.

Object	Date	Date (JD)	Spectrum	Filename
V4160 Sgr	1991 Aug 01	2448470	v4160sgr.a.01aug91	v4160sga
	1991 Sep 02	2448502	v4160sgr.b.02sep91	v4160sgb
	1991 Oct 10	2448540	v4160sgr.c.10oct91	v4160sgc
V4169 Sgr	1992 Jul 31	2448835	v4169sgr.a.31jul92	v4169sga
	1992 Oct 05	2448901	v4169sgr.b.05oct92	v4169sgb
	1992 Oct 27	2448923	v4169sgr.c.27oct92	v4169sgc
	1993 Mar 23	2449070	v4169sgr.d.23mar93	v4169sgd
	1993 Apr 24	2449102	v4169sgr.e.24apr93	v4169sge
	1993 Jun 26	2449165	v4169sgr.f.26jun93	v4169sgf
V4171 Sgr	1992 Oct 27	2448923	v4171sgr.a.27oct92	v4171sga
	1992 Nov 22	2448949	v4171sgr.b.22nov92	v4171sgb
	1993 Mar 23	2449070	v4171sgr.c.23mar93	v4171sgc
	1993 Apr 24	2449102	v4171sgr.d.24apr93	v4171sgd
	1993 Jun 26	2449165	v4171sgr.e.26jun93	v4171sge
V745 Sco	1989 Aug 01	2447740	v745sco.a.01aug89	v745scoa
	1989 Aug 05	2447744	v745sco.b.05aug89	v745scob
	1989 Aug 09	2447748	v745sco.c.09aug89	v745scoc
	1989 Aug 21	2447760	v745sco.d.21aug89	v745scod
	1989 Sep 14	2447784	v745sco.e.14sep89	v745scoe
	1990 May 25	2448037	v745sco.f.25may90	v745scof
	1990 May 31	2448043	v745sco.g.31may90	v745scog
	1990 Jun 12	2448055	v745sco.h.12jun90	v745scoh
	1991 Jun 12	2448420	v745sco.i.12jun91	v745scoi
	1992 Apr 04	2448717	v745sco.j.04apr92	v745scoj
V977 Sco	1989 Aug 22	2447761	v977sco.a.22aug89	v977scoa
	1989 Sep 15	2447785	v977sco.b.15sep89	v977scob
	1989 Oct 03	2447803	v977sco.c.03oct89	v977scoc
	1990 Feb 23	2447946	v977sco.d.23feb90	v977scod
	1990 Apr 04	2447986	v977sco.e.04apr90	v977scoe
	1990 Apr 17	2447999	v977sco.f.17apr90	v977scof
	1990 May 18	2448030	v977sco.g.18may90	v977scog
	1990 Jun 07	2448050	v977sco.h.07jun90	v977scoh
	1990 Aug 17	2448121	v977sco.i.17aug90	v977scoi
	1991 Jun 12	2448419	v977sco.j.12jun91	v977scoj
	1992 Apr 04	2448717	v977sco.k.04apr92	v977scok
V992 Sco	1992 May 30	2448773	v992sco.a.30may92	v992scoa
	1992 Jun 03	2448777	v992sco.b.03jun92	v992scob
	1992 Jun 10	2448784	v992sco.c.10jun92	v992scoc
	1992 Jun 21	2448795	v992sco.d.21jun92	v992scod
	1992 Jun 29	2448803	v992sco.e.29jun92	v992scoe
	1992 Jul 01	2448805	v992sco.f.01jul92	v992scof
	1992 Jul 03	2448807	v992sco.g.03jul92	v992scog
	1992 Jul 05	2448809	v992sco.h.05jul92	v992scoh
	1992 Jul 07	2448811	v992sco.i.07jul92	v992scoi
	1992 Jul 09	2448813	v992sco.j.09jul92	v992scoj
	1992 Jul 11	2448815	v992sco.k.11jul92	v992scok
	1992 Jul 13	2448817	v992sco.l.13jul92	v992scol
	1992 Jul 19	2448823	v992sco.m.19jul92	v992scom
	1992 Jul 21	2448825	v992sco.n.21jul92	v992scon
	1992 Jul 23	2448827	v992sco.o.23jul92	v992scoo

Table 2 (continued). Nova spectra.

Object	Date	Date (JD)	Spectrum	Filename
	1992 Jul 27	2448831	v992sco.p.27jul92	v992scop
	1992 Jul 29	2448833	v992sco.q.29jul92	v992scoq
	1992 Jul 31	2448835	v992sco.r.31jul92	v992scor
	1992 Aug 07	2448842	v992sco.s.07aug92	v992scos
	1992 Aug 27	2448862	v992sco.t.27aug92	v992scot
	1992 Oct 05	2448901	v992sco.u.05oct92	v992scou
	1992 Oct 27	2448923	v992sco.v.27oct92	v992scov
	1993 Mar 23	2449070	v992sco.w.23mar93	v992scow
	1993 Apr 24	2449102	v992sco.x.24apr93	v992scox
	1993 Jun 26	2449165	v992sco.y.26jun93	v992scoy
V443 Sct	1989 Oct 03	2447803	v443sct.a.03oct89	v443scta
	1989 Nov 18	2447849	v443sct.b.18nov89	v443sctb
	1990 Apr 17	2447999	v443sct.c.17apr90	v443sctc
	1990 May 18	2448030	v443sct.d.18may90	v443sctd
	1990 Jun 07	2448050	v443sct.e.07jun90	v443scte
	1990 Sep 23	2448158	v443sct.f.23sep90	v443sctf
	1991 Jun 16	2448424	v443sct.g.16jun91	v443sctg
	1992 Oct 01	2448897	v443sct.h.01oct92	v443scth
V444 Sct	1991 Sep 02	2448502	v444sct.a.02sep91	v444scta
	1991 Oct 10	2448540	v444sct.b.10oct91	v444sctb
	1991 Nov 07	2448568	v444sct.c.07nov91	v444sctc
	1992 Apr 04	2448714	v444sct.d.04apr92	v444sctd
LMC 1988/1	1988 Mar 28	2447249	lmc88n1.a.28mar88	lmc88n1a
	1988 Apr 07	2447259	lmc88n1.b.07apr88	lmc88n1b
	1988 Apr 22	2447274	lmc88n1.c.22apr88	lmc88n1c
LMC 1988/2	1988 Oct 15	2447450	lmc88n2.a.15oct88	lmc88n2a
	1988 Oct 17	2447452	lmc88n2.b.17oct88	lmc88n2b
	1988 Oct 26	2447461	lmc88n2.c.26oct88	lmc88n2c
	1988 Nov 17	2447483	lmc88n2.d.17nov88	lmc88n2d
LMC 1990/1	1990 Jan 17	2447909	lmc90n1.a.17jan90	lmc90n1a
	1990 Jan 20	2447912	lmc90n1.b.20jan90	lmcn190b
	1990 Jan 26	2447918	lmc90n1.c.26jan90	lmc90n1c
	1990 Feb 06	2447929	lmc90n1.d.06feb90	lmc90n1d
LMC 1990/2	1990 Feb 23	2447946	lmc90n2.a.23feb90	lmc90n2a
LMC 1991	1991 Apr 20	2448367	lmc91.a.20apr91	lmc91a
	1991 Apr 25	2448372	lmc91.b.25apr91	lmc91b
	1991 May 08	2448385	lmc91.c.08may91	lmc91c
	1991 Sep 02	2448502	lmc91.d.02sep91	lmc91d
	1991 Nov 07	2448568	lmc91.e.07nov91	lmc91e
	1992 Jan 07	2448629	lmc91.f.07jan92	lmc91f
	1992 Feb 05	2448658	lmc91.g.05feb92	lmc91g
LMC 1992	1992 Nov 27	2448954	lmc92.a.27nov92	lmc92a
	1992 Dec 02	2448959	lmc92.b.02dec92	lmc92b
	1992 Dec 18	2448975	lmc92.c.18dec92	lmc92c
	1992 Dec 31	2448988	lmc92.d.31dec92	lmc92d
	1993 Jan 30	2449018	lmc92.e.30jan93	lmc92e
	1993 Mar 23	2449070	lmc92.f.23mar93	lmc92f