that x = 1.35 for Salpeter law). Although this value is in good agreement with the result of Mateo, we feel that more elaborate work, particularly under outstanding seeing conditions, has to be carried out before we can state that the mass function slope of a metal-poor population is different or not from the value found for normal metallicity Pop I objects currently ≃2.0 (e.g. Tarrab, 1982, Lequeux 1979) for the *upper* main sequence.

A large potential lies in the many still unstudied young Magellanic Cloud clusters in understanding the morphology of the IMF and the evolution of massive metal poor stars. However, very careful observations, reductions and the availability of evolutionary tracks for a wide range of parameters are necessary to use it. If these conditions are fulfilled, then ground-based observations of the upper mass function will not be superseded by the HST whose resolving power is definitely necessary for fainter magnitudes.

Also other clusters should be studied, because NGC 330 is not one of the easiest objects to work with, although being often presented as the prototype of young blue populous globular clusters in the SMC.

6. Conclusions

The study of the young globular clusters in the Magellanic Clouds is rich in hopes, because it is the most direct check available for the theory of stellar evolution of massive stars with non standard metallicities. In particular, it gives some evidence on what could have been the early evolution of galactic globular clusters. However, the distance of over 60 kpc of these clusters make quantitative work difficult, in particular because of the confusion of stellar images at this distance. In the future, other corrections are to be applied to the photometry than a simple "completeness" factor. Stars which are "lost" are probably affecting the luminosity of other stars of the field, and most visual binaries, when observed in the solar neighbourhood, are seen as single stars in the SMC or LMC. The Hubble Space Telescope will drastically change the prospects in a few years, but this is not an excuse for doing nothing in the meantime.

References

Alcaíno, G., Alvarado, F.: 1988, *Astron. J.* **95,** 1724.
Carney, B.W., Janes, K.A., and Flower, P.J.: 1985, *Astron. J.* **90,** 1196.
Eggen, O.E.: 1987, *Astron. J.* **92,** 393.
Elson, R.A.W., Fall, S.M. and Freeman, K.C.: 1988, STScI preprint No. 292.
Lequeux, J., Peimbert, M., Rayo, J.F., Serrano, A., Torres-Peimbert, S.: 1979, *Astron. Astrophys.* **80,** 155.
Maeder, A. and Meynet, G.: 1988, *Astron. Astrophys.*, submitted.
Mateo, M.: 1988, *Astrophys. J.* **331,** 261.
McClure, R.D., VandenBerg, D.A., Smith, G.H., Fahlmann, G.G., Richer, H.B., Hesser, J.E., Harris, W.E., Stetson, P.B., Bell, R.A.: 1986, *Astrophys. J.* **307,** L49.
Melnick, J.: 1987, *Astron. Astrophys. Suppl.* **71,** 297.
Richtler, T., Spite, M., Spite, F.: 1988, submitted to *Astron. Astrophys.*
Robertson, J.W.: 1974, *Astron. Astrophys. Suppl. Ser.* **15,** 261.
Spite, M., Cayrel, R., Francois, P., Richtler, T., and Spite, F.: 1986, *Astron. Astrophys.* **168,** 197.
Stetson, P.B.: 1987: *Publ. Astron. Soc. Pac.* **99,** 191.
Tarrab, I.: 1982, *Astron. Astrophys.* **109,** 285.
Yoshii, Y., Saio, H.: 1986, *Astrophys. J.* **301,** 587.

The Nebular Stage of Nova GQ Muscae: Physical Parameters from Spectroscopic Observations

J. KRAUTTER, Landessternwarte Heidelberg-Königstuhl, F.R. Germany, and
R.E. WILLIAMS, Cerro Tololo Inter-American Observatory, La Serena, Chile

Nova GQ Muscae 1983, a classical nova which had its maximum in January 1983, might already be familiar to the readers of the *Messenger,* since it was already twice the subject of articles in this journal. E. Oliva and A. Moorwood (1983, *The Messenger* **33,** 30) reported on infrared CVF spectrophotometry carried out within the first four weeks after maximum. J. Krautter, K. Beuermann, and H. Ögelman (1985, *The Messenger* **39,** 25) described the results which were obtained from coordinated observations from X-rays to the infrared regime carried out in 1983 and 1984. Apparently, these authors had some foreboding, since they closed their article with the words ". . . This, *at present,* concludes the story of Nova Muscae 1983." In fact, that was not the end of the story of Nova GQ Muscae: since then, exciting results of new observations of GQ Muscae have been obtained which provide the justification to again write an article about this nova for the *Messenger.*

Before we discuss our new observations, we want to shortly summarize the most important results from the early phases. GQ Muscae, which had a visual brightness V ≈ 7.0 mag at maximum, is a moderately fast classical nova: t_3, the time for a decrease by 3 magnitudes from maximum brightness, was about 40 days. The outburst amplitude was more than 14 mag, one of the largest outburst amplitudes ever observed for novae. The lightcurve was somewhat unusual for a fast nova, since the visual magnitude remained nearly constant at a level of 3.5 mag below maximum brightness for a period of about 11 months (April 83 to March 84). It should be mentioned that no indication for dust formation, which quite often happens in novae of this type, was found.

The spectroscopic observations during the early phases showed a pronounced overabundance of nitrogen relative to carbon and oxygen, and there was an indication of a He/H overabundance. However, no abundance of any metal relative to H or He could be determined. The line profiles were very complex; during the early phases the usual P Cygni absorption systems (principal, diffuse enhanced, and Orion system) with velocities of the absorption components up to –2000 km/sec were found as well as up to 4 emission components. The distance was found to be D = 4.8 ± 1 kpc. This allowed a lower limit for the luminosity around maximum of about one Eddington luminosity to be derived, assuming a 1 $M_\odot$ white dwarf.

Of special interest were the X-ray observations carried out with EXOSAT, since GQ Muscae was the first classical nova from which X-ray radiation was observed during the outburst or decline from outburst. Since no spectral energy distribution could be determined, two

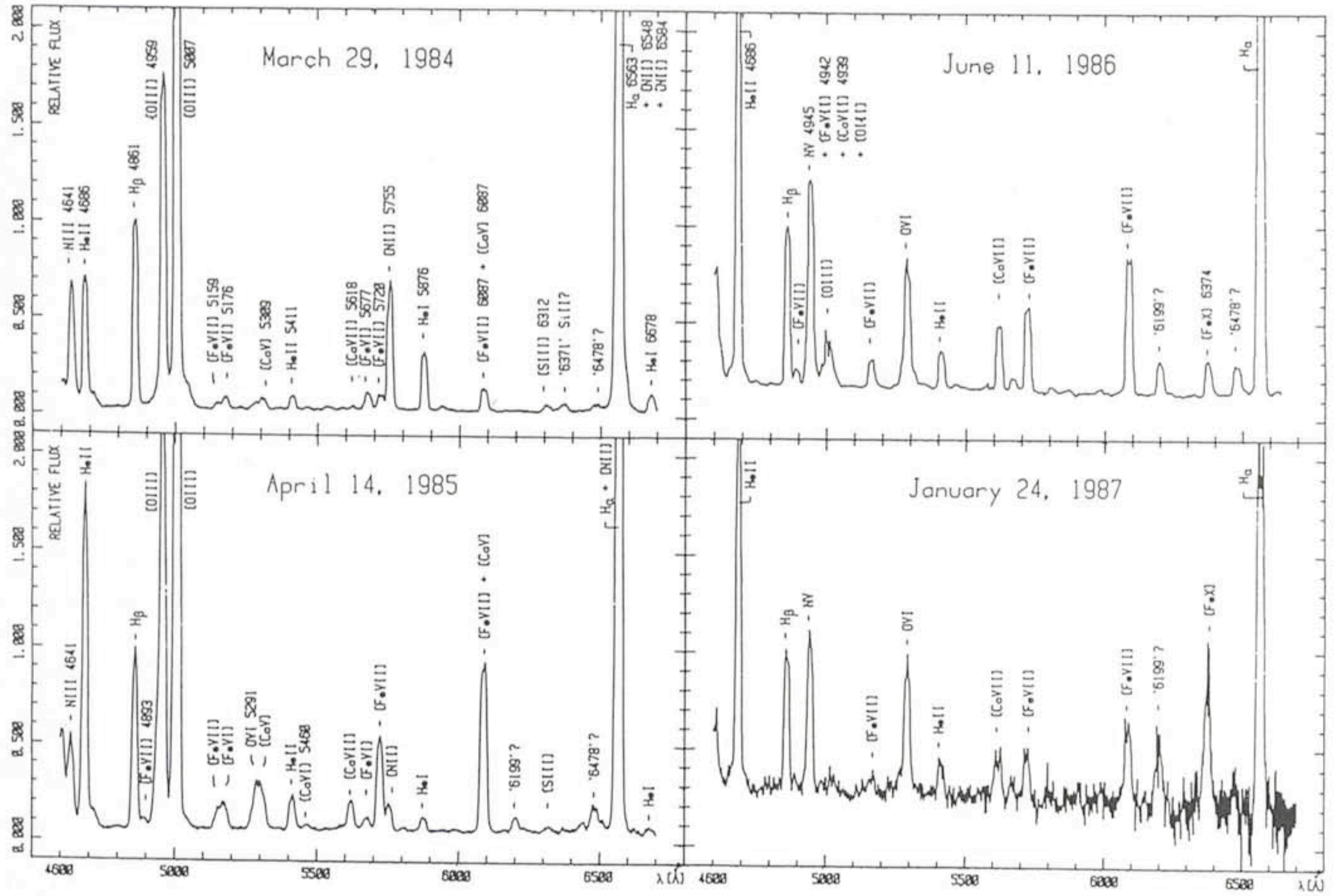

Figure 1: *A series of spectra of Nova GQ Muscae 1983 from March 1984 to January 1987. The fluxes are given in relative units. The strongest lines are not shown in full intensity. From Krautter and Williams (submitted to* Astrophys. J.*).*

possible explanations were given at the time: either a shocked shell of circumstellar gas emitting 10^7 K thermal bremsstrahlung radiation or a white dwarf remnant emitting blackbody radiation of several hundred thousand K at about one Eddington luminosity. However, there were arguments which strongly favoured the latter mechanism (Ögelman, Krautter, Beuermann, 1987, *Astron. Astrophys.* **177,** 110).

We shall come back to the X-ray emission mechanism at the end of this article.

Spectroscopic Observations During the Nebular Stage

We now turn to our spectroscopic observations, carried out in irregular intervals during the nebular phase from 1984 to 1988. Most observations in the optical spectral range were performed using the ESO 1.5-m, 2.2-m, and 3.6-m telescopes on La Silla. Low and medium resolution spectrograms were obtained with the Cassegrain Boller & Chivens spectrographs and recorded with IDS or CCD detectors. Two spectra were obtained with the 1-m and 4-m telescopes of the Cerro Tololo Inter-American Observatory and recorded with a 2D-frutti photon counting detector. UV spectra were obtained with IUE using, in all cases, the facilities of the ESA Villafranca satellite tracking station.

Figure 1 shows a representative series of low resolution ($\Delta\lambda \approx 7$ Å) spectra taken in March 1984, April 1985, June 1986, and January 1987. The spectra are displayed in the range 4600 Å–6700 Å, and the fluxes are given in relative units. Note that the strongest emission lines are not shown in full strength; they have been cut in order to show weak lines on a reasonable scale.

The spectrum from March 29, 1984 (upper left) is shown in full scale in Krautter et al. (1985, *The Messenger* **39,** p. 29).

The general character of the spectra did not change during this period; they are dominated by strong emission lines superposed on a weak continuum. However, since the emission line fluxes continuously decreased while the continuum flux remained about constant, the average equivalent widths decreased from 1984 to 1988. All lines are very broad and have half widths at zero intensity of about 800 km/sec which reflect the velocity of the expanding envelope. Due to the low resolution, only two emission components can be distinguished.

High Resolution Observations

When we finally obtained in April 1985 (two days before the second spectrum in Figure 1) high resolution spectra ($\Delta\lambda \approx 0.2$ Å) using the Echelle spectrograph CASPEC attached to the 3.6-m telescope, we were rather surprised by the line profiles we saw. As an example, Figure 2 shows a tracing of the [O III] $\lambda\lambda$ 4959, 5007 emission lines: as many as at least 22 different emission components can be distinguished! All the small peaks in the emission lines are real emission components and not noise, since they show up in both [O III] lines. The line profiles of the other emission lines in the CASPEC spectra have the same general structure, i.e., the same line width and the same radial velocities of the individual components. There are, however, variations in the relative fluxes of the emission components: For instance, in the [O III] the blueshifted components are on the average stronger than the redshifted ones, whereas the Balmer and the [Fe VII] lines have a more symmetric structure. These line profiles clearly show that the ejection of the expanding envelope of GQ Mus was anything but spherically symmetric. The individual emission components appear to be emitted by individual blobs of

TABLE 1: *T_e and n_e at different dates.*

Date	T_e [K]	log N_e
Apr 1984	14500	7.5
Apr 1985	18000	6.9
Jan 1986	17500	6.6
Jan 1987	≤25000	6.0

material. Such "blobs" can be seen on direct images of old nova shells which are close enough to be spatially resolved. Nice examples are presented in a recent article by H. Duerbeck (1987, *The Messenger* **50,** 8). Because of its larger distance (4.8 kpc) the shell of Nova Muscae should now have an apparent diameter of only 0.3 arcsec and cannot be spatially resolved. The minor differences in the emission characteristics of different lines may be due to different excitation conditions and/or slightly different chemical abundances in the individual blobs.

We should not forget to mention that the high resolution spectra allowed us to determine the wavelengths of the emission lines with a much higher accuracy than is possible from medium or low resolution spectra. On the basis of the CASPEC spectra we could remove some uncertainties in the line identifications; for instance, we are now sure that coronal lines like [FeX] λ 6374 were not present in April 1985 (more about coronal lines later).

Element Abundances and Physical Parameters in the Expanding Shell

Emission line ratios can be used to derive physical parameters of the expanding shell, particularly n_e, T_e, chemical abundances, and the mass of the shell. One has to keep in mind, however, that the derived numbers are mean values for the entire expanding shell. As we have seen, there could be slight variations from blob to blob. Unfortunately, only a limited number of lines can be used for diagnostic work. Because of the large line widths many lines are heavily blended with other lines and, hence, no reliable fluxes can be determined. Striking examples are the [NII] λλ 6548, 6584 lines, which are hopelessly merged with the strong Hα line. Since the line profiles are very complex and vary from one species to the other one, deconvolution procedures can be applied in a limited way only. Table 1 shows T_e and n_e for those epochs at which the (quasi-)simultaneous UV and optical data allowed us to derive numbers for these quantities. The kinetic temperature T_e at the gas in the expanding shell was determined using the line ratio of NV λ 1240/NIII λ 1719, both in the UV range. These lines are formed by different processes – NV by collisional excitation, NIV by dielectric recombination – and have, therefore, different temperature dependences. In order to calculate the electron density, we used the line ratios of the collisionally excited forbidden [OIII] λλ 4363, 4959, 5007 lines which are found in the optical spectral range. The relative intensities of these lines depend on T_e and n_e. Using T_e as calculated from the UV spectra, we obtain a unique value for n_e. In January 1987 (and later on) both NIV λ 1719 and the [OIII] lines had become too weak to be used for diagnostic work. Hence, we extrapolated n_e from the earlier values and determined an upper limit for the temperature from [FeVII] line ratios.

Of special importance is the knowledge of the chemical composition of the shell. In order to understand why, we have to shortly review the basic ideas of the 'thermonuclear runaway model' (hereafter TNR model) which very successfully describes the general features of the nova outburst. For those readers who are interested in more details of this model we refer to reviews by e.g. Starrfield and Sparks (1987, *Astr. Spac. Sci.* **131,** 379) or Truran (1982, in: *Nuclear Astrophysics,* ed. Barnes, Clayton, Schramm, Cambridge) who have done the basic work of the TNR model.

It is now generally accepted that a nova outburst occurs on the white dwarf component of a close binary system in which the secondary is transferring mass through the inner Lagrangian point into an accretion disk and ultimately onto the white dwarf. The build up of the hydrogen envelope on the white dwarf

TABLE 2: *Element abundances in the ejecta of GQ Mus (mass fractions). For comparison purposes the solar values are also given.*

Element	GQ Mus	Sun
H	0.42	0.77
He	0.38	0.21
C	0.004	0.0034
N	0.12	0.0013
O	0.07	0.0083
"Z"	0.20	0.018

continues to some critical value, whereupon hydrogen burning via the CNO cycle starts and the thermonuclear runaway begins. One of the predictions of the TNR model was that the energetics of the outburst should depend on the abundance of the intermediate mass elements C, N, and O. Fast novae, which undergo a more violent explosion than slow ones, should have strong CNO overabundances. In fact, no fast nova could ever be (theoretically) produced with solar CNO abundances. Therefore, the CNO abundance should be a very critical observational test of the TNR model.

Up to now, reliable abundances for only a handfull of novae (≈ 9) have been available. For the determination of the element abundances in the ejecta of GQ Muscae we used emission lines from both the optical and UV spectral range. The He/H abundance was calculated from recombination lines in the optical spectral range, whereas UV lines were used for the N/He ratio. The mass fractions are given in Table 2, where for comparison purposes the solar values are also shown. He is overabundant with

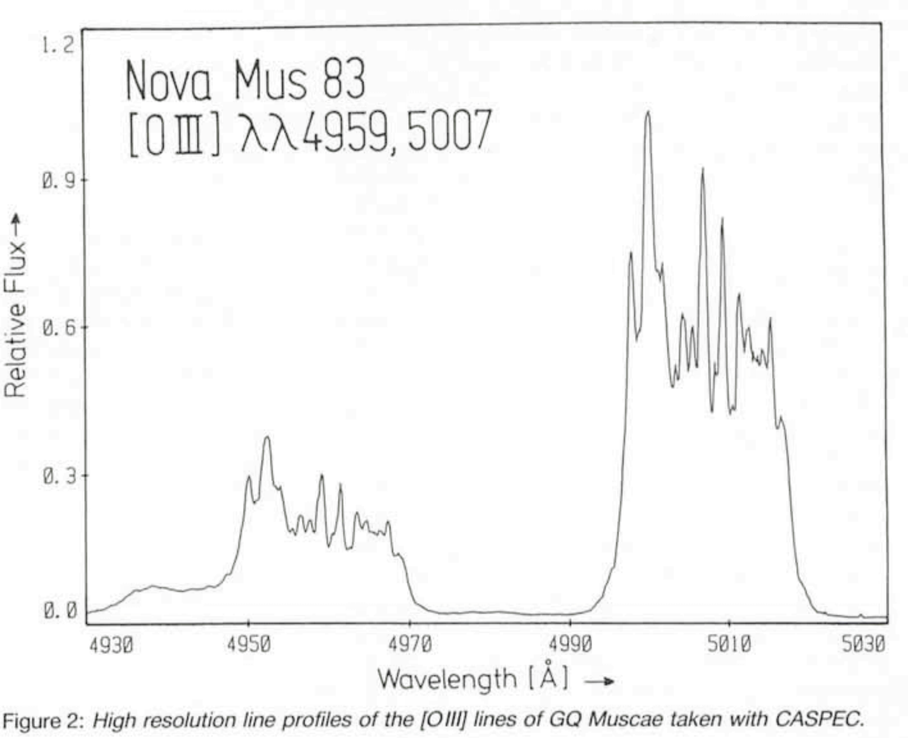

Figure 2: *High resolution line profiles of the [OIII] lines of GQ Muscae taken with CASPEC.*

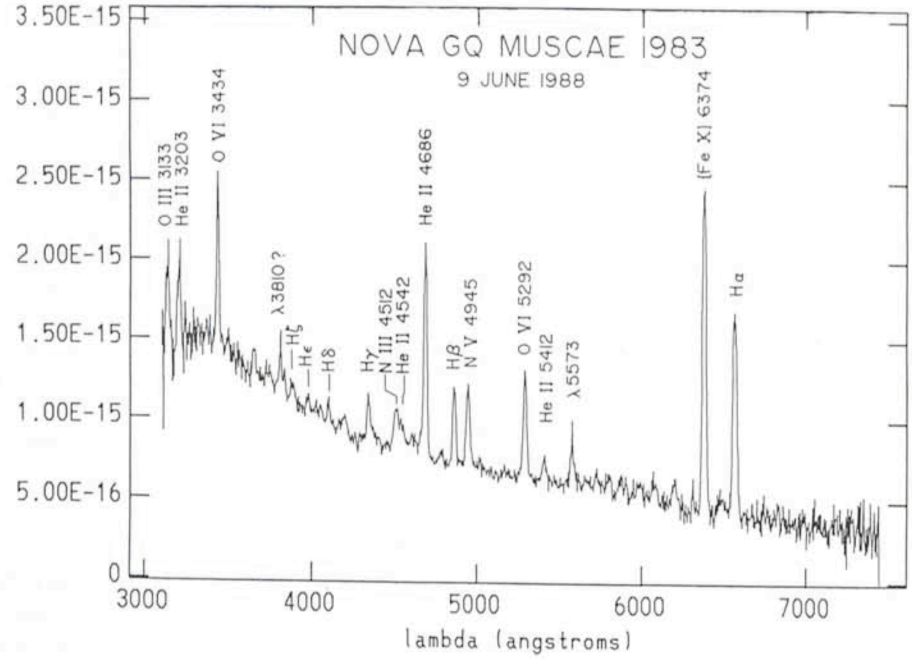

Figure 3: *Spectrum of GQ Muscae taken with the CTIO 4-m telescope and recorded with a 2D frutti photon counting detector. The red [FeX] λ 6374 coronal line is the strongest line in the spectrum which has – to our knowledge – not been found yet in any other astronomical object. From Krautter and Williams (submitted to* Astrophys. J.*).*

respect to H by more than a factor of two. Of the heavy elements, N and O are strongly overabundant, whereas C has about solar abundance. "Z" is about 0.20. We would like to note that the CNO abundances are preliminary numbers only; the final numbers might be subject to slight changes. However, the result is obvious: GQ Mus has a CNO overabundance, just as the TNR model requires for a fast nova.

The Increase of the Ionization of the Optical Spectrum

A very interesting feature of the spectral evolution of GQ Muscae is the continuous increase of the ionization from March 1984 to June 9, 1988 (the date of our last spectrum). Already in March 1984, 14 months after maximum, the general ionization is rather high (upper left part of Figure 1). Apart from the hydrogen Balmer and the HeI recombination lines, all other lines of neutral elements had disappeared at this time. On the other hand, emission lines of rather highly ionized species like [FeVI], [FeVII] and [CaVII] are found. One year later, in April 1985, the ionization had increased. Lines of higher ionization have increased in strength relative to e.g. Hβ, whereas lines of lower ionization like [NII] λ 5755 have decreased. A striking example is the line ratio of [NII] λ 5755 vs. [FeVII] λ 5721. In 1984 [NII] was much stronger, whereas in 1985 the situation was reversed. Also the HeII/HeI ratio had considerably increased. Another 14 months later, in June 1988, the spectral appearance had changed even more: the [OIII] lines had become rather weak, and the [NII], HeI, and even [FeVI] lines had disappeared. On the other hand, the red [FeX] λ 6374 coronal line was present as a relatively strong line. The first sign of this line was found in a spectrum taken 10 months earlier, in August 1985 (not shown in Figure 1). In January 1987, [FeX] was as strong as Hβ and stronger than [FeVII] λ 6087. This increase of the ionization continued for at least 17 more months until June 9, 1988, the date of our last spectrum (Figure 3). [FeX] λ 6374 is now the strongest line in the spectrum – even stronger than Hα. This is extraordinary, as we are not aware of any other astrophysical object which has an [FeX] or any other coronal line of comparable strength!

In order to understand this spectral behaviour, a crucial question must be answered: what is the source of the ionization, collisional ionization or photoionization? The movement of the ejected envelope through the interstellar medium might produce a shock front giving rise to temperatures sufficient to cause very highly ionized species like [FeX]. There are, however, many arguments which exclude any significant shock contribution to the formation of the highly ionized species:

- The kinetic temperature T_e in the ejecta is low at all times (≤ 25,000 K).
- The post-shock temperature of $1.9 \cdot 10^7$ K for an expansion velocity of 800 km/sec would require [FeXIV] λ 5303 to be more intense than [FeX] λ 6374. However, [FeXIV] could not be identified in the spectrum.
- The increase of the ionization state requires a shock whose strength increases with time. There is no plausible explanation, however, why a shock should develop that way.
- The range of ionization is very narrow. In the case of collisional ionization one would expect a much broader range in the ionization.

Taken together, all these arguments lead to the conclusion that the ionization must be due to photoionization from a hot source. The increase of the ionization indicates an increase of the temperature T_* of the ionization source. To get a more quantitative estimate of T_* we have used the HeII/HeI line ratios in order to calculate Zanstra temperatures. We obtained $T_* = 3 \cdot 10^5$ K, $8 \cdot 10^5$ K, and $\geq 1.5 \cdot 10^6$ K for 1984, 1985 and 1986, respectively. These values are approximate and represent upper limits because we have assumed a radiation-bounded sphere. This is still approximately fulfilled in 1985 as the presence of [NII] shows, but in 1986 the deviations might be larger.

For the interpretation of these results we consider the phase of 'constant bolometric luminosity' of the TNR model of the nova outburst. The hydrodynamical calculations show that, during the early hydrodynamic phase, only part (anywhere from 10% to 90%) of the material accreted on the white dwarf has a velocity high enough to be ejected as an expanding envelope. The velocity of the remaining material quickly drops and a hydrostatic equilibrium is established. We now have a configuration with the white dwarf core, an inert He shell and the hydrostatic envelope with a radius of $10^{11}-10^{12}$ cm (the size of a red giant!). On top of the degenerate core, where the temperature is high enough, the hydrogen burning continues hydrostatically at a constant level of roughly one Eddington luminosity. The effective temperature of the whole system exceeds 10^5 K.

In the further evolution, the mass of the envelope decreases. Hydrogen is used up by the thermonuclear reactions and material is ejected by radiation pressure-driven mass-loss. The radius of the envelope decreases. On the other hand, there is a constant production of energy from the shell hydrogen burning which continues as long as some material is left in the envelope. As a result, the effective temperature T_* of the remnant increases with decreasing radius.

But that is exactly what we observe in the case of GQ Muscae! The photoionizing source is the white dwarf remnant whose temperature increases. Of course, the high temperature of the white dwarf also easily explains the X-rays from GQ Muscae. Unfortunately, after the termination of the EXOSAT mission, for several years no X-ray satellite sensitive to soft X-ray radiation has been available for some time and none will be available until the launch of ROSAT. Only very little observational material on the late phases of the classical nova outburst is available yet. Many crucial questions remain: How long does the hydrogen shell burning really last? When does a nova turn off? In the case of GQ Muscae, we have demonstrated how long-term observations of novae in the optical spectral range can help to improve this situation. The observations appear to constitute an important verification of the TNR model of the classical nova outburst.

Violent Activity in the Bright Quasar 3C 273

T. J.-L. COURVOISIER, Observatoire de Genève, Sauverny, Switzerland

Observations of the optical variability in the bright quasar 3C 273 date from long before this source has been found to be a quasar. Almost a century of (mostly photographic) data are available (Angione and Smith, 1985) and display variations on many timescales longer than ~10 days. In more recent years, a programme of multi-frequency observations of the quasar from the radio domain to the X-rays has been conducted. The first results of this programme have been described in the *Messenger* No. 45 (September 1986). In summary, we found variations by a factor ~2 in most observable spectral domains. The typical variability timescale was of the order of one month. The different components of the source varied at different epochs, showing little correlation between them. This complex variability pattern allowed to identify distinct components and showed that most of them must be emitted in regions not larger than about one light-month.

This multi-waveband campaign of observations started in late 1983 and has been pursued during each observing season (December to July) since then. Until now, different types of variability behaviour have been observed each year. Figure 1 illustrates this by showing the V band flux as a function of time since January 1985, when the Swiss telescope on La Silla joined in the programme with regular and precise photometric measurements. A slow flux increase can be seen in 1985, followed by a year of very small variations in 1986. During the observing season which started in December 1986, the UV flux (measured with IUE) decreased by ~40%, the decrease was much less important at longer wavelengths but can still be seen in the figure. The most striking feature of the figure, however, is the change of the behaviour of 3C 273 in February 1988. At this time, which is well within the observing season, the source changed from a state characterized by relatively slow changes to a state of rapid and recurrent flares. The characteristic times were then not of the order of an month as during the previous years, but rather of the order of a day. This violent activity in 3C 273 came at a very appropriate time, when our collaboration was well established and could react rapidly to the observed changes. We were thus able to observe very frequently, even daily for part of the time, in the optical and infrared domains. The observations were performed at the ESO 1-m telescope, the ESO/MPI 2.2-m telescope, the 70-cm Swiss telescope on La Silla, the UK infrared telescope (UKIRT) in Hawaii and with the mm telescope SEST at ESO and JCMT in Hawaii. The results of these observations have been published (Courvoisier et al. 1988). Even with the temporal and spectral sampling that we were able to obtain during the flares, the flux variations were so fast that we could not resolve them satisfactorily.

The period of violent activity lasted from February to April 1988. During this interval, we observed 5 optical maxima separated on average by ~15 days, although 2 of the maxima are separated by 2 days only (Fig. 2). The amplitude of these maxima is of about 30%. The fastest change we observed was a flux decrease of ~15% in 24 hours. This flux decrease corresponds to a change in luminosity in the source of about $-6 \cdot 10^{40}$ erg s^{-2} or to the switching off of ~10 million suns per second for 24 hours (assuming a distance to 3C 273 based on a cosmological model with H_0 = 50 km s^{-1} Mpc^{-1} and a source emitting isotropically).

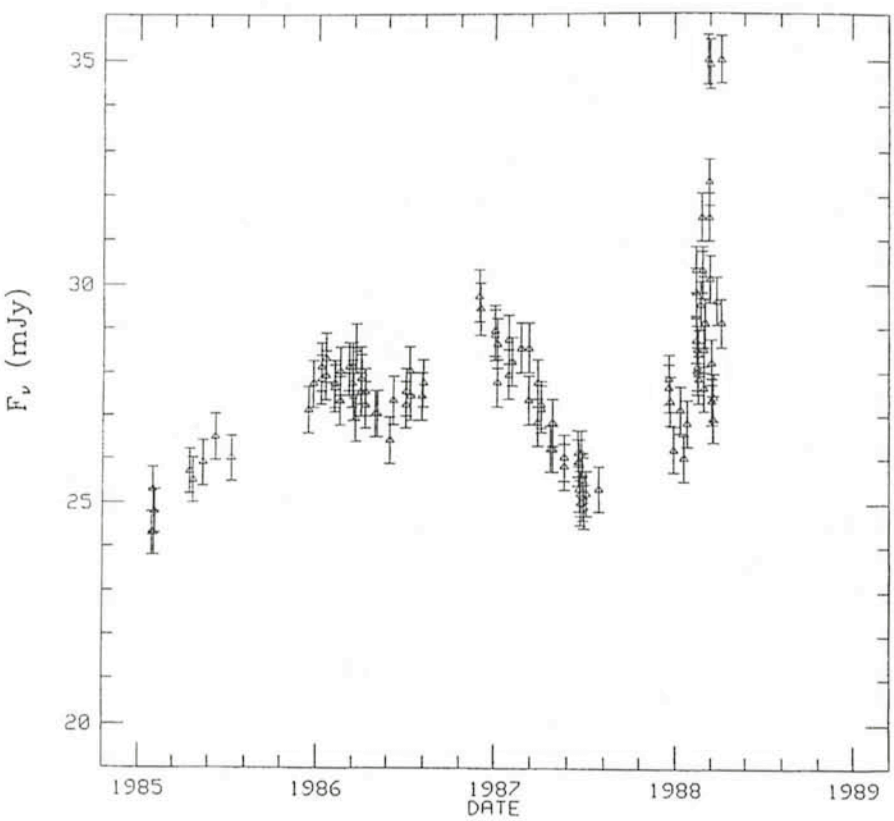

Figure 1: *The V-band light curve obtained with the Swiss telescope on La Silla since early 1985.*