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V 605 Aquilae – a Star and a Nebula with No Hydrogen

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Three planetary nebulae are known with hydrogen-poor central nebulosities and WR-type central stars: A 30, A 78 and A 58. While the former have been discussed extensively in the literature, the latter remained spectroscopically unknown until 1983. Its story, however, begins much earlier.

In 1920 Max Wolf found a $10^{m}_{.}4$ star on photographic plates taken in 1919. The object had been invisible before 1917; it disappeared in 1923. In 1921, Lundmark took spectra of the suspected nova. These had no resemblance with spectra of any of the known evolutionary states of novae, they looked like those of carbon stars. Decades later, the region around the star, now designated V 605 Aql, was inspected. Abell (1966) found a faint old planetary nebula and entered it as number 58 into his catalogue, Herbig (1971) noticed a very faint starlike object near the centre of A 58 and suggested that this was the remnant star of V 605 Aql.

Our own story of V 605 Aql and A 58 starts in 1983, when I joined H. Duerbeck in his spectral survey of faint old novae with the Calar Alto 2.2-m telescope. The central star of A 58 was not visible on the telescope monitor. However, we had just recorded another unseen old nova, V Per, because it had appeared somewhere along the long slit with which the unwidened spectrum was taken. Thus, the long slit was placed across the planetary nebula in various positions. When it lay exactly across the centre, as deduced from the pattern of spectra from neighbouring stars, a central point-like emission spectrum appeared in addition to the emission lines of the extended planetary nebula. The central nebulosity showed no hydrogen, only strong [OIII] and moderately strong [N II] lines, slightly blueshifted with respect to the planetary emission lines (Seitter 1985a).

An EFOSC spectrum taken for us with the ESO 3.6-m telescope by P. Angebault in 1986 shows the spectra of *three* objects: lines of the planetary nebula and the central nebula and stellar emission lines superimposed on a weak continuum of red magnitude 22.3 (Seitter 1987).

Follow-up observations were obtained on July 1/2, 1987, again with the EFOSC at the ESO 3.6-m telescope. A slit width of 1″ was chosen in order to clearly separate the [N II] 658.4, 654.8 nm lines at a dispersion of 23 nm/mm. The mean spectra obtained in the blue and red/near infrared regions are shown in Figures 1 to 4. In all spectra, contributions from the night sky and the planetary nebula are removed. The subtraction of the latter rests on the assumption that the strengths of the nebular lines towards the northern part of the PN do not differ from those superimposed on the central nebula. This seems to be justified from the appearance of the hydrogen lines in the two-dimensional spectra, where no differences are noticed between the two regions (see Figs. 2 and 3 in Seitter 1985b).

The result is striking as seen in Figure 4: no trace of Hα is found between the nitrogen lines. The central nebula of A 58, which also appears to be the remnant nebula of the nova-like outburst of the central star V 605 Aql in 1917, is the foremost candidate for a nebula entirely free of hydrogen.

The central star of the two nebulae exhibits a strong C IV 580.6 blend, besides marginal lines of He II 468.6, O V and O VI. The broad C IV feature with a FWHM of 2,300 km/s and a total width of 4,400 km/s suggests that this star is of WR type, as are the central stars in A 30 and A 78. An additional similarity of the three objects is the presence of cool dust. Extended dust shells of 140 K were derived for both A 30 and A 78 (Cohen and Barlow 1974) while the IRAS data indicate a point source of 170 K for A 58.

The central object of A 58 is interesting not only because of its extreme properties but also because the outburst was observed photometrically and spectroscopically. This puts severe constraints on any theory trying to explain the observed phenomena.

Following earlier suggestions (e.g. Iben et al. 1981 for A 30 and A 78, and Pottasch 1985 for A 58) the central stars of all three PNs are candidates for post helium shell flash evolution. The central nebulae in A 30 and A 78 have kinematic ages of a few thousand years. If the central stars reached their observed positions in the H-R diagram during the same time interval, one finds fair agreement with evolutionary computations. V 605 Aql, on the other hand, has reached a magnitude comparable to its pre-outburst brightness after less than 70 years.

Because the temperature determination is difficult for a star which displays just one well-defined line, the bolometric

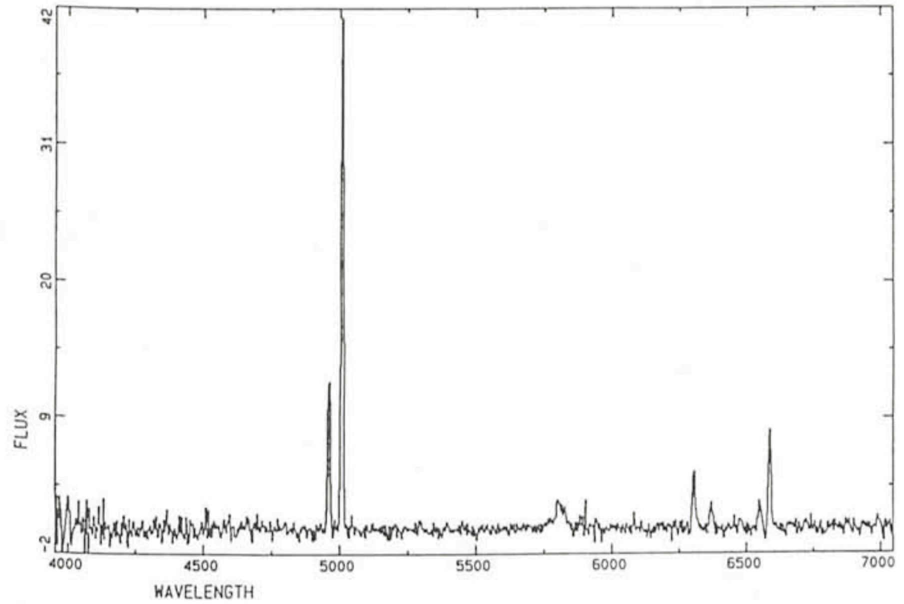

Figure 1: *The nebular remnant of V 605 Aql in the blue spectral region and the superimposed stellar C IV blend at 580.6 nm.*

correction for V 605 Aql remains doubtful. Similarly, any correction for dust absorption in the nebula is merely guesswork. With T = 100,000 K (70,000 K is the Zanstra temperature from the extremely weak He II 468.6 lines in both nebulae relative to the visual stellar continuum) and A_v = 4 at the distance of 3.5 kpc, the luminosity obtained for the central star at its present stage is L = 300 $L_\odot$. It places the object in the H-R diagram in a position which central stars of 0.6 $M_\odot$ reach thousands of years after a late final helium shell flash (Iben et al. 1981). This is more than two orders of magnitude longer than the time which V 605 Aql has actually taken to reach the place computed with the above assumptions. Even a higher mass star would still need much longer than a few tens of years. Observationally, V 605 Aql is an explosive phenomenon, but dynamical evolution has so far not been included in the computations of final helium shell flashes (Schönberner 1987).

The measured radial velocity of the central nebula relative to the PN is 60 km/s, somewhat larger than the 25 km/s observed for the central blobs of A 30. In an explosive event, where the star had no time to adjust to a quasi-stable configuration and the ejected matter escaped directly from the high density central star, a low velocity indicates that the original velocity did not exceed the escape velocity very much and that only a small percentage of the total outburst energy went into kinetic energy. In this respect V 605 Aql differs from classical novae but resembles planetary nebulae (Seitter 1985b).

The C-type spectrum of V 605 Aql during outburst shows that the star was hydrogen-poor two years after light maximum. The extremely low temperature (other outburst objects, like novae or symbiotic stars, generally have A- to F-type spectra during their coolest stages) indicates a very large extent of the stellar quasi-photosphere (locus of optical depth = 1) and/or high opacity in the extended shell or wind. This is supported by the high mass found for the remnant nebulosity from the analysis of the nebular spectrum.

The remnant nebula shows strong lines only of heavy elements. Three ionization stages of oxygen are observed. The [O III] 500.7, 495.9 lines are the strongest lines found in the spectrum. The near infrared [O II] and the red [O I] lines are weaker. The [N II] 658.4, 654.8 lines are next in strength to [O III]. The auroral lines of both ions are very week so that the simultaneous solution for electron temperature and electron density is somewhat uncertain. [NE III] and [A III] lines are seen only in the 1986 spectrum.

The best results for the central nebula with the present data are T_e = 14,000 K and $N_e = 5 \cdot 10^4$ cm^{-3}, those for the planetary nebula are T_e = 12,800 K (derived from [N II]) and N_e = 230 cm^{-3} (derived from the radius/mass relation for PNs given by Pottasch, 1980, the volume and the mean ionic weight per electron). Direct determinations of electron densities from the [S II] lines yield contradictory results from the 1986 and the 1987 spectra. This is attributed to high noise, especially in the 1987 spectra. The results of 1986 also contradict those obtained from the 1987 simultaneous solution. In view of the very faint magnitude (21^m) of the unresolved central nebulosity only a series of long exposures can supply more reliable data. The mass of the central nebula derived from the above data is $M = 5 \cdot 10^{-2} M_\odot$ (upper limit, assuming a filling factor of 1), as compared to $M = 10^{-2} M_\odot$ derived from the light curve data.

Only coarse abundance estimates are possible at this time. This is largely due to the weakness of helium and other diagnostic lines.

The procedure to derive abundances is to first estimate the He/H ratio for the planetary nebula using the equations given by Miller (1987), then to determine the relative strengths of the heavy elements in both nebulae, taking into account the different column heights and filling factors of the central and the planetary nebula. Using for the column heights the ratio 1/10 as derived from the angular sizes (with an upper limit for the unresolved central nebula) and for the filling factors the ratio 10/1 (a guess as good as any other) no correction factor is needed. Then, adopting the

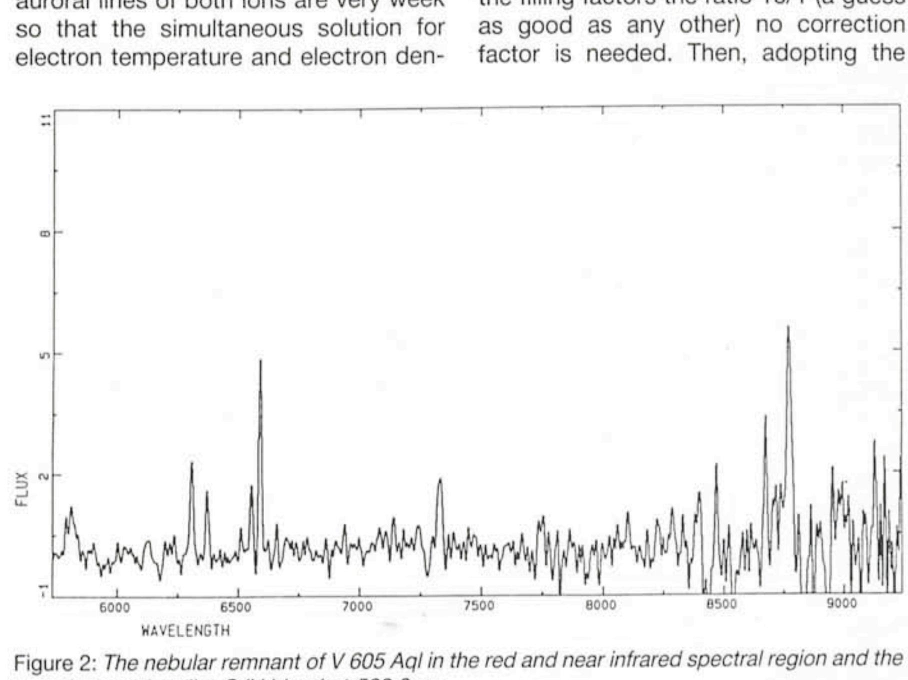

Figure 2: *The nebular remnant of V 605 Aql in the red and near infrared spectral region and the superimposed stellar C IV blend at 580.6 nm.*

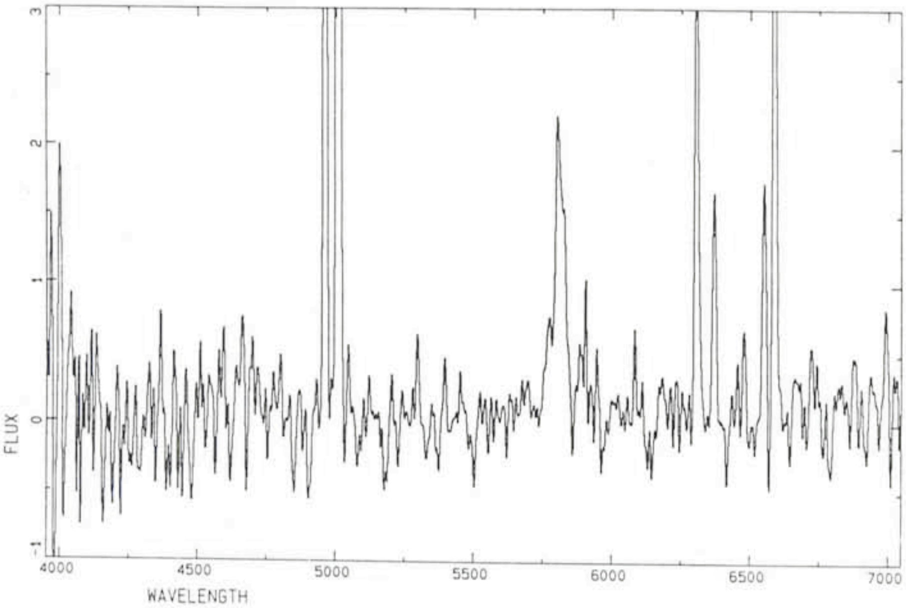

Figure 3: *The strongest feature of the central star, the C IV blend at 580.6 nm, seen as broad line near the centre of the spectrum.*

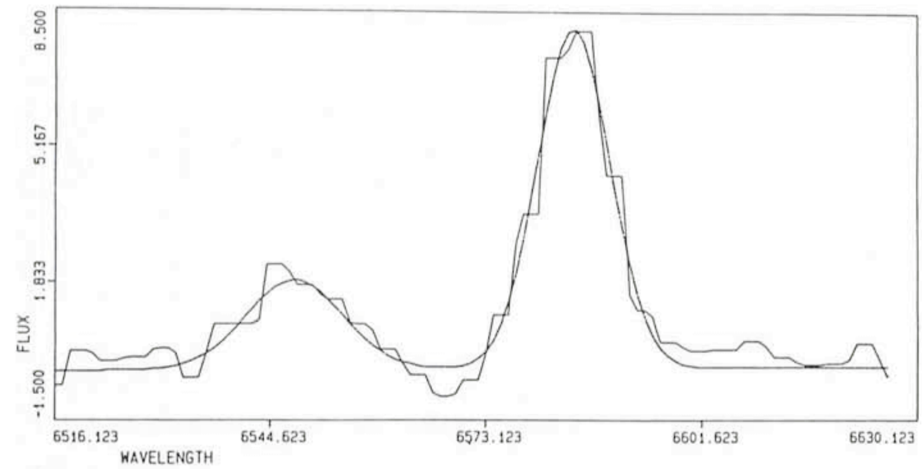

Figure 4: *Tracing and fitted Gaussian profiles to [N II] 658.4, 654.8 nm showing the complete absence of Hα.*

CNO abundance in the PN to be 1 % by number, all data are normalized to the data obtained for the PN. The results are given in Table 1.

The relatively strong nitrogen lines could be the result of incomplete hydrogen burning in the hot CNO cycle after mixing during the early phases of the helium shell flash. At the same time, the absence of hydrogen in both the stellar and the nebular remnant indicates that all H was consumed during this stage.

The large overabundance of oxygen would be the result of the triple alpha process, which is even more efficient in producing O than C as has been shown by Kettner et al. (1982). The abundance of carbon is uncertain because no line was clearly identified. A strong line in the near infrared could be [C I] 8727 but its wavelength is measured too large. Better calibrated spectra are needed to solve the problem. If the presence (and a possible overabundance) of neon can be verified, very hot He-burning is indicated.

Our conclusions are: If V 605 Aql is a final helium shell flash object, then:

- this stage was reached approximately 25,000 years (kinematic age of A 58) after formation of the planetary nebula;
- the time scale of evolution through the final helium shell flash and well back towards the pre-flash stage is of the order of tens of years indicating evolution on a dynamic time scale;
- incomplete CNO cycle- and (possibly hot) He-burning can account for the elemental abundances in the remnant star and the remnant nebula;
- the remnant star shows a strong WC-type wind, possibly instrumental in sustaining the cool dust shell;
- the apparent presence of hydrogen in the central nebula of A 58, as reported by Pottasch et al. (1985), must be attributed to the superimposed PN spectrum. It cannot be excluded from the observing modes described by Jacoby and Ford (1983) that this also accounts for the presence of hydrogen in the central objects of A 30 and A 78.

If there should be noticeable overall differences in the H- and He-contents of final helium shell flash objects as well as in their time scales, one will have to look for the parameters that determine whether a helium shell flash becomes eruptive or not. This might be important not only for the *final* helium shell flashes.

TABLE 1. *Abundance estimates, given in number percentages, for A 58 and for the nebular remnant of V 605 Aql*

Object	H	He	CNO	C	N	O
A 58	79	20	1	not specified		
V 605 Aql	0	93	7	?	≤1	≤6

Acknowledgements

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ESO Book Presented to the Press

The ESO Book "Exploring the Southern Sky" (see the *Messenger* **49,** page 42) was presented to the Press in late September, in Copenhagen and at the ESO Headquarters. A reception was held at the Danish Academy of Sciences on September 21, with participation of representatives from the publisher, RHODOS, and the two foundations which supported the Danish edition, Urania Fonden and Knud Højgaards Fonds. On September 29, the English and German editions were presented by Springer and Birkhäuser Verlag, during a reception at ESO in Garching. On this day, the Press was also allowed to visit the "Remote Control Room" where Mira Véron (Observatoire de Haute-Provence) was observing with the 2.2-m telescope on La Silla.

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The Volcano and the Stars

This beautiful photo of the active Volcán Villarica in central Chile was obtained by ESO astronomer Bo Reipurth in March 1987. The photo was made in bright moonlight, illuminating the top glacier. The stars in the field are in the constellations of Ara and Pavo; η Pav is seen as bright trail near the right edge and η Ara is left of the fiery crater.