THE UV SPECTRUM OF THE CENTRAL STAR OF NGC 40

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This paper presents a preliminary study of the IUE UV spectrum of the planetary nebula NGC 40. Details of the observations are given in Table 1 which were obtained in the low resolution ($\Delta\lambda \sim 6$Å) spectrophotometric mode using both SWP (λλ1150-2000) and LWR (λλ1850-3250) spectrographs. All data were acquired using the large (10"x20") apertures. SWP3076 was taken with the centre of the aperture offset by 7".5N of the central star: all other images were obtained with the slot centred on the nucleus.

The flux calibrated nucleus spectrum is shown in Fig 1 and is seen to be dominated by numerous strong emission lines, similar to those observed in PopI WC stars (Nussbaumer et al. 1981, herinafter NSSW). These arise mainly in the central star since our offset spectrum shows only very weak CIII λ1909 and no other clear nebula features. A comparison of the nucleus spectrum with PopI WC spectra given by NSSW shows a one-to-one correspondance in spectral features consistent with a classification of WC8, albeit with somewhat narrower lines. The observed emission line strengths in NGC 40 are also similar, confirming its visible classification of WC8 (Smith & Aller 1969). This close similarity, despite likely gross differences in the stellar properties of mass, radius and evolutionary status, provides additional support for the picture painted by Smith & Aller (1971) that stellar winds with similar physical and chemical properties can likely arise in widely different types of object (viz the term "WR phenomenon").

Our adopted UV continuum energy distribution for the nucleus of NGC 40 is shown in Fig 2, together with the ANS UV photometry obtained by Pottasch et al. (1978) which lies systematically about 15% higher than the IUE data, reflecting the contamination of the ANS data by emission lines. Also shown in Fig 2 are the IUE spectrophotometric data in our offset image SWP3076 which highlights the negligible contribution to our other IUE data from the nebula emission. An estimation of the expected nebula atomic continuum has been derived using models with T_e = 8000K, $N_e = 1400\ cm^{-3}$, $He^+/H^+ = 0.05$ and no He^{++} (Aller & Czyzak 1979). The model continuum is reddened with $E_{B-V} = 0.4$ and scaled to the observed value of $\log F(H_\beta) = -10.45$ (Pottasch et al. 1978), and multiplied by a

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 453–456.

Table 1: Log of IUE observations of NGC 40. SWP3076 was acquired with the slot (10"x20") offset 7".5N of the central star. All exposures were made on 20:10:1978.

CAM/IMAGE	EXP (s)	P.A.
SWP 3074	480.0	27°
SWP 3075	1200.0	27°
SWP 3076	900.0	27°
LWR 2656	480.0	27°

a factor of 0.2 to estimate the fraction of the nebula entering the IUE large aperture. The expected nebula continuum is also shown in Fig 2, which shows fair agreement with that observed. Clearly evident in Fig 1 and Fig 2 is the presence of a strong interstellar λ2200 band. Using the mean galactic interstellar extinction law given by Seaton (1979) the strength of the λ2200 band gives a colour excess of $E_{B-V} = 0.4$. The dereddened UV continuum energy distribution of the nucleus of NGC 40 is also shown in Fig 2, which is consistent with a blackbody colour temperature of T_{BB} = 30000K. This is close to the nebula HI emission Zanstra temperature of T_z = 27000K derived by Pottasch et al. (1978). We infer that an effective temperature of ~30000K can be applied to the central star and note that this value is close to the T_{eff} recently deduced for PopI WC stars by NSSW and Underhill (1980). Using d = 840 pc (Pottasch et al. 1978), a radius of ~$1R_\odot$ is inferred, giving log $L/L_\odot$ = 2.86.

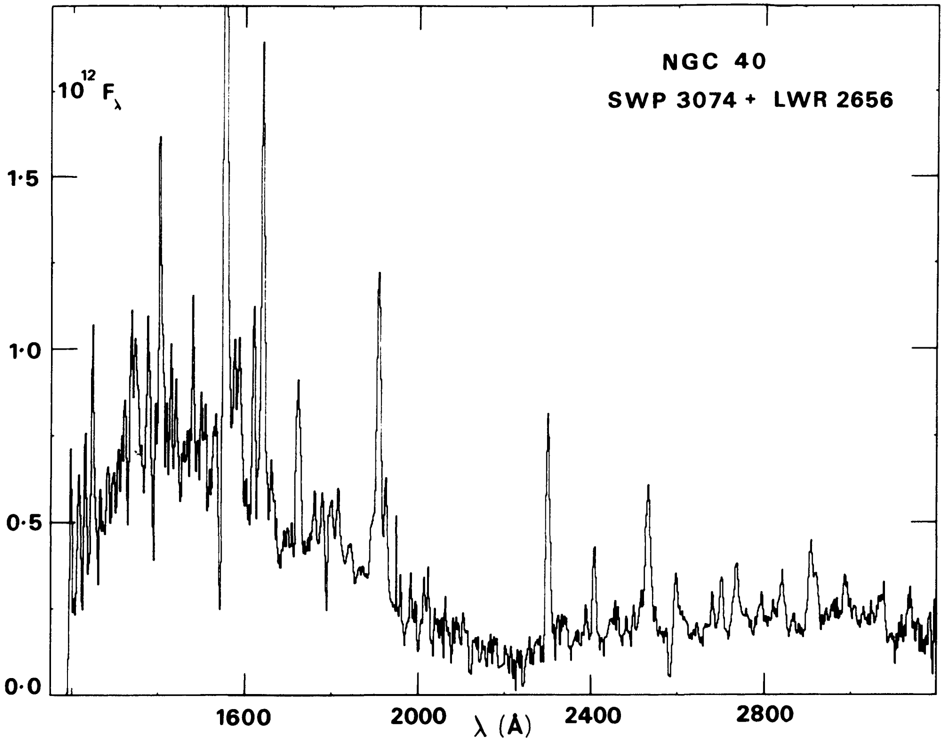
Well defined P-Cygni profiles are seen in CIIλ1335, SiIVλ1393, λ1402 and CIV λ1550, signifying substantial mass loss from the central star. These profiles show displaced absorption edge velocities implying v_∞= 2370 km s^{-1} - a value similar to that found for PopI WC7-8 stars (Willis 1981) again suggesting a similar type of stellar wind in NGC 40 to PopI WC stars. We estimate the mass of the central star using the expression given by Castor, Lutz & Seaton (1981) modified by the use of $v_\infty = 4v_{esc}$ for low mass hot stars (Heap, these proceedings):

$$v_\infty = 4 \left(\frac{2(1-\Gamma)GM}{R_c} \right)^{\frac{1}{2}} \quad : \quad \Gamma = 2.45\times10^{-5} . \frac{(L/L_\odot)}{(M/M_\odot)}$$

which yeilds $M = 0.8M_\odot$.

Since the UV spectrum of NGC 40 clearly resembles closely those of PopI WC stars, we have carried out a preliminary Sobolev analysis of the UV CIII and HeII emission lines to estimate the C/He ratio of the central star in a manner analogous to that performed for WR stars by Willis & Wilson (1978) and Smith & Willis (these proceedings). Details of the modelling will appear elsewhere. The radius of the continuum emitting stellar core is taken as $R_c = 1R_\odot$; that of the representative point in the wind emission line region as $R_p = 4R_\odot$. The wind expansion velocity at R_p is taken as 1500 km s^{-1} and a core temperature of T*=30000K is adopted. Here we have assumed a similar value of R_p/R_c as derived by Smith & Willis for PopI WC stars, since the observed spectra are so similar.

Fig 1: The combined SWP+LWR IUE spectra of the nucleus of NGC 40. Units in the fluxes are erg cm^{-2} s^{-1} $Å^{-1}$.



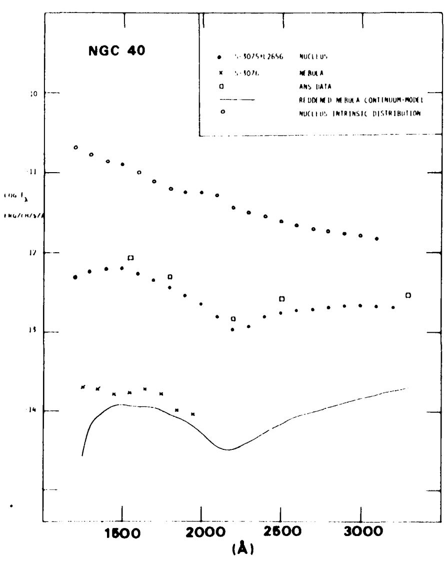


Fig 2:
The estimated UV continuum energy distribution of NGC 40. Aslo shown are the ANS data; the observed IUE offset SWP fluxes; the estimated atomic reddened nebula continuum and the dereddened nucleus continuum.

https://doi.org/10.1017/S007418090002920X Published online by Cambridge University Press

Modelling of the CIII λ1909 and CIII λ2297 lines as a function of N_e and T_e and N(CIII) implies the following best fit values, in which it is assumed that He is the dominant species and is mainly fully ionised:

T_e=30000K: $N_e=8\times10^{10}$ cm^{-3}: N(CIII)=1.8×10^{9} cm^{-3}: N(He)=4×10^{10} cm^{-3}

T_e=40000K: $N_e=2\times10^{10}$ cm^{-3}: N(CIII)=1.3×10^{9} cm^{-3}: N(He)=1×10^{10} cm^{-3}.

giving C/He ratios of respectively 0.13 and 0.39. The models for T_e = 30000K also give good agreement with the observed HeII lines and thus adopting the above values for T_e = 30000K (close to T^*) we can estimate the mass loss rate from the central star as dM/dt $\sim6\times10^{-7}$ $M_\odot$/y. The maximum rate expected from radiation pressure driven wind models ($dM/dt_{max} = L^*/v_\infty c$) is $\sim7\times10^{-9}$ $M_\odot$/y, so our inferred rate for NGC 40 is some 80 times larger. This excess in mass loss rate over the expected radiation pressure limit is also found for PopI WC stars (Barlow, Smith & Willis 1981), where $\dot{M}/\dot{M}_{max}$ is 20-50. Thus again we have a strong similarity between NGC 40 and PopI WC stars. Further we note that the estimated C/He ratio is not only very high, but also quite close to the values of 0.1-0.2 recently calculated by Gabriel & Noels (1981) for theoretical stellar evolution models at the He-burning stage for stars with heavy mass loss such that their outer atmospheres have been stripped to reveal the He-burning products. This suggests that such a stripping may also have occured for the nucleus of NGC 40.

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