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Ultraviolet Observations of Planetary Nebulae

III. Variability of the Central Star

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Summary. Extensive UV observations of planetary nebulae observed with the Netherlands Astronomical Satellite (ANS) were searched for photometric variations of the central stars. Only five cases of variations were found: IC 418, A 78, He 2–131, NGC 6543 and V-V 1–7. In no case do the variations exceed about 15%. In A 78, He 2–131 and NGC 6543 the variations may have been caused entirely by variations in spectral line intensities, particularly the C IV doublet at 1550 Å. These and IC 418 have Of nuclei. IC 418 shows the maximum variations of about 15%. V-V 1–7 which is probably not a planetary nebula, shows some intriguing variations.

Key words: planetary nebulae — variable stars — ultraviolet photometry — stellar evolution

I. Introduction

Considerable effort has been expended in searching for photometric variations from the nuclei of planetary nebulae in ground based observations. Kohoutek (1966) made use of photographic plates used for the AGK 2 and AGK 3 catalogues, and detected variability in some central stars. Abell (1966) reports photoelectric work on the low surface brightness planetary nebulae discovered by him on 120 cm Palomar-Schmidt plates, most of these central stars are very faint. He gives a list of suspected variables. Bond (1976) has surveyed all the planetary nebulae in the Catalogue of Galactic Planetary Nebulae (Perek and Kohoutek, 1967) which are also in the General Catalogue of Variable Stars (Kukarkin et al., 1969) and his conclusion is that except for four all other objects (including AG Car) are either not planetary nebulae or not variable. The four are:

i) UU Sge-eclipsing variable (Bond, 1976),
ii) K 1–2 (Kohoutek, 1964),
iii) FG Sge (Herbig and Boyarchuk, 1968),
iv) V 605 Aql (Lundmark, 1921; Bidelman, 1971, 1973; Ford, 1971).

However, the central stars FG Sge and V 605 Aql are not classical planetary nuclei.

Several attempts have been made to detect variability on very short time scales (e.g., Lasker and Hesser, 1971), but no photometric variability was detected.

There are theoretical expectations (Rose, 1967; Paczyński, 1975; Stothers, 1977; Härm and Schwarzschild, 1975) that various kinds of pulsational instability may be present in the nuclei of planetary nebulae depending on radius, mass and chemical composition. Variability, if detected, would give us important information on precursors of planetary nebulae and their subsequent evolution.

It should be emphasized that ground based photometric observations are not easy to make or interpret. The central stars are quite faint and generally contribute only a small fraction of the light observed and unless the observations are made with a very small diaphragm the correct stellar magnitude is difficult to deduce. The broad-band photometric observations also include nebular emission lines and this too is a source of uncertainty. Unless a homogeneous set of observations is made, e.g., the same diaphragm size, proper consideration of nebular continuous and line spectra, the same filters, preferably quite narrow, etc., it is difficult to conclude that small observed differences suggest variability. Another important point is that the nuclei of planetary nebulae are very hot stars and photometric variability, if present, would be much more pronounced in the ultraviolet where most of the radiation is emitted. For these reasons we decided to search for variability in the extensive ultraviolet photometric observations (Pottasch et al., 1977a, b; Papers I and II respectively) made of planetary nebulae with the Netherlands Astronomical Satellite (ANS).

We detected variability in a few cases. In Section II the mode of observations is given and various observational limitations are pointed out. Main results are

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discussed in Section III and a brief discussion of these results is given in Section IV.

II. Observations

The description of the telescope etc. is given by Van Duinen et al. (1975). The observations of planetary nebulae are discussed by Pottasch et al. (Paper I and II). In Paper I the value of E_{B-V} has been obtained from the observed ultraviolet data and in Paper II these observations are reported and have been used to obtain L_{Bol} and radii of the central stars. The diaphragm is $150'' \times 150''$ and in most cases contains the star and the entire nebula. There is a slight uncertainty in pointing ($\sim 20''$) and in addition to this there is a jitter ($\sim 20''$) once a pointing has been made. So if the total size of the nebula is $\sim 80''$ or less the star and the nebula are always in the field of view. We would also like to point out that in contrast to the situation in the visual region the nebular contribution in the UV is generally quite small from both theoretical considerations and from our UV observations of "star-free" parts of some of the big nebulae.

The internal accuracy of the observations is very high once the corrections due to changes in sensitivity have been made. For example, for several planetary nebulae observations made a day apart, 6 months apart/one year apart, all give the same results within about 1–2%. Another factor which makes the observations very reliable is the small width and rectangular nature of the band passes for the five channels. The channels are centered at wavelengths (with full-widths given in parentheses): 1550 Å (150 Å), 1800 Å (150 Å), 2200 Å (200 Å), 2500 Å (150 Å) and 3300 Å (100 Å). In addition, there is a narrower channel at 1550 Å with a full width of 50 Å. The main purpose of this channel is to see whether the C IV doublet at 1550 Å is in emission or absorption. The ratio of 1550 Å channel observations with the wide filter to 1550 Å observations with the narrow filter, hereafter called 1550 W/1550 N, should be 2.78 if the spectrum is smooth. If the ratio is less than 2.78 then "net emission" is implied, and "net absorption" is implied if the ratio is more than this number.

It should be pointed out that due to the constraints on the satellite orbit we can, in general, observe an object only for about two days in six months (the higher the absolute value of ecliptic latitude the longer is the possible duration), so we can investigate variations over only ~5 min, hours, a day or six months or one year. Also, not all objects were observed the same number of times.

In many cases the positions of the central stars/nebulae were known accurately to only 1′. In such cases due to pointing accuracy and jitter the central star/nebula was not always in the field of view all the time. When later the accurate positions were used the observed flux changed upwards by a small factor. All such changes have been excluded from this discussion.

Other possible sources of error in observations should be mentoined.

i) As mentioned earlier the positional uncertainty of the spacecraft is about 20″ and once a position is attained there is a subsequent jitter which is also of the order of 20″. This can cause two problems: a) if there is a star unrelated to the nebula near the edge of the field, it may come in the field of view and go out in an unpredictable manner. This would cause apparent variation. A careful search was made and except for a case to be discussed later, no other cases were apparent; b) since this is a grating instrument this motion causes a slight change in the wavelength dependence of the band passes which because of the rectangular nature of the band passes is only about 5–10 Å. For stars in general this is no problem but if there is a strong spectral line in emission near the edge of the band pass, the line may be observed part of the time and may not be observed part of the time. It is unlikely that any of the variations reported in this paper could be due to this effect.

ii) Most of the observations were made in the offset mode, i.e., 32 s on object then 16 s on sky 5′ away. For "one" observation this was repeated 5–10 times. If there is a star at an offset position this would give wrong values for the fluxes for the nebula. All cases were carefully examined. In the variations reported only one such case (to be discussed later) was found.

Another limitation in our investigation is the flux sensitivity of the observations. Depending on integration time etc. the absolute sensitivity f_λ is (within about a factor of two) $5\,10^{-14}$ erg/cm^2/s/Å. For a small variation to be meaningful we have taken the lower limit as 5–10 times this number. Putting it another way, in general, we can detect a 10% variation in a $V = 13\overset{m}{.}0$ unreddened O7V star without great difficulty.

Finally, we wish to point out that if, after taking account of all the above observational limitations, variability is detected it would be essentially due to the photometric variations of the central star and not due to nebular variations. Due to constraints imposed by light travel time and recombination time considerations the nebulae are not expected to vary over time scales reported in this paper. Also as pointed out earlier the nebular contribution to the observed light in UV is much less than the contribution in the visual, therefore if there were to be any variations in nebular light in UV, such variations would be much more pronounced in the visual and no such ground based variations have been reported. The variations reported in this paper refer to the *total* light observed and the percentages would be a lower limit to stellar variability since the nebular contribution (which is not variable) has not been taken out.

III. Main Results

The ANS observations of 39 planetary nebulae detected at 3 or more channels have been discussed by Pottasch et al. (Paper II). These nebulae were observed a total number of about 300 times. Of all these extensive observations and within the constraints discussed in Section II we do not find any photometric variations of more than about 15%. Only five objects showed detectable variations: IC 418, NGC 6543, A 78, He 2–131, and V-V 1–7. These are discussed below.

Individual Objects

IC 418

Of all the objects studied the nucleus of IC 418 shows the maximum amount of variations (Fig. 1). The percentage variation becomes greater with decreasing wavelength, as should be the case for a hot object. The nebula is always in the field of view. (From these observations the nebular contribution has not been taken out). The observations show that significant variations occur over 5^h duration suggesting changes in the bolometric luminosity of more than 15%. There are not enough observations to determine a period (if one exists). The internal accuracy of each measurement is generally better than 0.5%. The photometric variations are such that they may well be impossible to detect at V but persistent and accurate observations at ~3300 Å should be useful.

From our observations, it appears likely that there are spectroscopic changes also associated with photometric variations—the ratio of 1550 W/1550 N (implying "net absorption") is also variable. The central star is an O7f star (Heap, 1977) and we recommend spectroscopic monitoring of the object to see any variability. Wilson and Aller (1954) suspected variations in spectroscopic features in spectrograms taken on two different occasions.

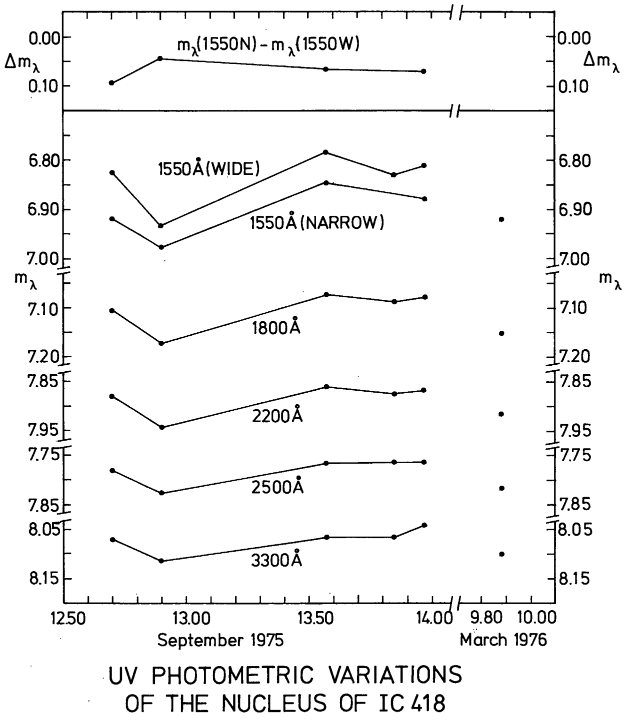

Fig. 1. Photometric variations of IC 418 in different ANS channels as a function of time in U.T. (in fraction of a day). The nebula was observed six times during Sept. 12–13, 1975 and one time on March 9, 1976. The errors are of the order of the size of the dots. The nebula is very small and the variations refer only to the star. The monochromatic magnitudes are calculated using $m_\lambda = 0^m0$ for $3.62\,10^{-9}$ erg/cm^2/s/Å for all the channels. 1550 Å Wide and 1550 Å Narrow refer to cases when the wider band pass (150 Å) or the narrower band pass (50 Å) is used at 1550 Å. The observations show that there is "net absorption" at 1550 Å. In the top part the colour $\Delta m_\lambda = m_\lambda$ (1550 Å Wide) $- m_\lambda$ (1550 Å Narrow) is plotted and shows that there are spectroscopic changes accompanying the photometric changes

NGC 6543

The nucleus has been classified as O3feq by Heap (1977) and as O7+WR by Aller (1975). Changes in line intensities and profiles have been reported by Aller (1967). Due to its fortuitous location extremely close to the north ecliptic pole this object was observed 28 times with the ANS. It is quite bright and the observations are of high photometric accuracy. The maximum variations in the observations are at 1550 Å and only about 5%. All other channels also show variations in the same sense as at 1550 Å but smaller in magnitude. The low resolution UV spectrum obtained with the TD-1 satellite has been published by Boksenberg et al. (1975). It is a rich emission line spectrum with the C IV doublet at 1550 Å in emission in some sort of "absorption trough". Our 1550 W/1550 N ratio is 2.70 implying small amount of "net emission". A power spectrum analysis was attempted of our observations but no periodicity was obtained. We think the variations observed are real even though small in magnitude. The variations occur in durations of less than 24 h and may be due to changes in emission line strengths.

A 78

Our observations show a change of about 15% in both the 1550 W and 1550 N channels. The variation in the 1800 channel is only about 5%. The ratio of 1550 W/1550 N = 2.47 implying reasonable "net emission". The visual spectra are discussed by Greenstein and Minkowski (1964) who classify it as O5fek, i.e., the star shows mixture of absorption and emission lines with emission lines being stronger than the absorption lines and interstellar K line present. They also report variable C IV. Of lines and strong C IV $\lambda\lambda$5801–12 emission. In light of their spectroscopic observations we interpret our photometric observations to show strong C IV λ1550 Å doublet in emission whose intensity varies in less than 24 h. The variations in other channels are much weaker and could be also due to spectroscopic changes only. A 78 is one of the nuclei suspected by Abell (1966) of photometric variability.

Table 1a. ANS UV observations of V–V 1–7 in different channels

Date and time (in UT)	$m_\lambda(0^m.0=3.62$ erg/cm²/s/Å)		3.62 10^{-9} erg/cm²/s/Å)			
	1550 Å (Narrow)	1550 Å (Wide)	1800 Å	2200 Å	2500 Å	3300 Å
1975 Oct 24.711	—	8.268	8.106	8.484	8.473	8.392
1976 Apr 21.277	—	8.419	8.179	8.513	8.529	8.445
1976 Apr 21.335	8.401	—	8.138	8.502	8.524	8.399
1976 Apr 21.875	8.303	—	8.066	8.451	8.433	8.343
1976 Apr 22.001	8.467	—	8.181	8.536	8.586	8.472

(Internal errors are of the order of 1% except for 1550 N where they are of the order of 2%)

Table 1b. ANS Intrinsic colours $(m_\lambda - V)_0$ (from Wu and Wesselius, 1976)

Channel MK Sp type	1550 Å	1800 Å	2200 Å	2500 Å	3300 Å
A0 V	−0.39	−0.51	−0.34	−0.05	+0.09
A1 V	+0.07	−0.25	−0.07	+0.19	+0.19

Table 1c. ANS "average" interstellar extinction curve (Van Duinen et al., 1976)

Channel	1550 Å	1800 Å	2200 Å	2500 Å	3300 Å
$\frac{E_{\lambda-V}}{E_{B-V}}$	5.03	4.80	6.56	4.19	2.04

Table 1d. Ground based *UBV* photometry of V–V 1–7

Observer	*U*	*B*	*V*
Kostjakova et. al. (1968)	8.20	8.41	8.31
Kohoutek and Wehmeyer (1975)	8.289	8.239	8.184
Shao and Liller (1970)	8.43	8.25	8.21

He 2–131

The nucleus of He 2–131 has been classified by Heap (1977) as O7(f)eq and the stellar lines show P Cygni profile. Our observations showed about 15% variations only at 3300 Å and 1550 Å in two sets of observations six months apart. A careful examination showed that during some observations there was a 9th magnitude K0 star at the offset position and when its existence is taken into account the variation at 3300 Å disappears. The variation at 1550 Å does not have a similar explanation because "dark" measurements were also made in addition to the offset "sky" measurements and there is no net signal from the "sky" position at 1550 Å. In light of this and the P Cygni nature of stellar lines we think the variation at 1550 Å is real and requires changes in the strength and profile of the C IV doublet at 1550 Å over time scales of six months. The ratio 1550 W/1550 N is 3.21 and implies strong "net absorption"; this ratio for main sequence O stars is only about 3.1.

V–V 1–7 (=VV 68)

The nature of this object has been recently investigated in detail by Kohoutek and Wehmeyer (1975) who have concluded that it is not a planetary nebula at all. The main arguments are two: i) the nebula is visible only on the blue POSS (Palomar Observatory Sky Survey) print and not on the red POSS print and ii) in their ground based photometry and spectroscopy there is no trace of a hot star. Our UV observations are given in Table 1a. In Table 1b we have given the ANS intrinsic colours for A0 V and A1 V stars (Wu and Wesselius, 1976) and in Table 1c is reproduced the ANS "average" interstellar extinction curve (Van Duinen et al., 1976). The ground based photoelectric photometric observations are combined in Table 1d. Our observations show that even in the UV the observations are quite consistent with the star HD 62001 = BD −18° 1967, the central star, as being A0.5 V with $E_{B-V}=0.06$ as deduced by Kohoutek and Wehmeyer (1975). However, as is quite evident from Table 2a, the UV observations show definite variations, even if we disregard the differences in various ground based observations. There are two possible causes of variations in UV observations: 1) that there is a blue star at the edge of the $2\frac{1}{2}\times2\frac{1}{2}'$ field of view which comes in and goes out of the field. A comparison of the red POSS print and the blue POSS print shows that a star about 70″ southwest, being somewhat brighter in the blue print than in the red, is the only possible candidate. In that case we predict that star to be early or middle B. If by photometry and/or spectroscopy it turns out to have a spectral type A or later then we have to come to the second alternative; 2) either a) the star HD 62001 itself is variable, or b) there is another, and optically much fainter star hidden in the overexposed image of HD 62001, which is a variable and is a B star or hotter, or c) HD 62001 forms an eclipsing binary with a hot star which contributes about 10% light at 3300 Å and 15–20% at 1550 Å. It should be emphasized that the "variations" occur in a duration of about 3 h, and if alternative c) is correct, it would mean the star which is eclipsed is very small. This is also the case in novae. In this case then the observed shell would be a remnant of a nova explosion. The data are not adequate to warrant further speculation and we suggest that some more observations be made. The possibility that it may be a reflection nebula (Kohoutek and Wehmeyer, 1975) appears unlikely to us since reflection nebulae do not form such nice shells.

IV. Discussion and Conclusions

The UV observations of planetary nebulae obtained with the ANS present a homogeneous and sensitive set of data to study the photometric variability of the nuclei of these objects. No variations of more than about 15% were found in spite of very extensive observations. The satellite orbit causes limitations as discussed earlier and we could have, in general, detected variations over 5–10 min, h, a day, a six month or one year interval only. Our observations place some constraint on irregular, periodic, and secular variations even though the theories seem to have predicted such variations (see, e.g., Stothers, 1977).

The only definite variations reported in this paper are in nuclei showing emission lines with Of characteristics. No sdO or other nuclei showed any detectable variations. In A 78, NGC 6543 and He 2–131 the variations may be entirely spectroscopic in origin with particularly the C IV doublet at 1550 Å changing in strength since the variations are considerably more pronounced at 1550 Å than at other channels. Aller (1968), Wilson and Aller (1954) have suggested that spectroscopic changes in Of nuclei are due to changes in the atmospheric structure of these stars. Similar changes are observed in Population I Of stars also. In IC 418 the variations seem to require both spectroscopic and photometric variations. It is of considerable interest that IC 418 has a nucleus which is probably very close to the main sequence on its leftward journey in the H–R diagram and may be exhibiting variations due to effects suggested by Stothers (1977) and Härm and Schwarzschild (1975).

V-V 1–7 is probably not a planetary nebula at all. But if the variations reported in this paper are indeed due to a star not apparent in POSS prints, it becomes a very intriguing object and further observations should be made to clarify its nature.

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