1993A&A...267L..19P

Astron. Astrophys. 267, L19–L22 (1993)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

SAO 244567: a post-AGB star which has turned into a planetary nebula within the last 40 years*

M. Parthasarathy[1], **P. García-Lario**[2], **S.R. Pottasch**[3], **A. Manchado**[4], **J. Clavel**[5], **D. de Martino**[5], **G.C.M. Van de Steene**[3], **and K.C. Sahu**[3]

[1] Indian Institute of Astrophysics, Bangalore – 560034, India
[2] Laboratorio de Astrofísica Espacial y Física Fundamental, Apartado de Correos 50727, E-28080 Madrid, Spain
[3] Kapteyn Astronomical Institute, Postbus 800, NL-9700 AV Groningen, The Netherlands
[4] Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain
[5] IUE Observatory, Villafranca Satellite Tracking Station, Apartado de Correos 54065, E-28080 Madrid, Spain

Received June 25, accepted July 24, 1992

Abstract. SAO 244567 (Hen 1357 = CPD -59^{0}6926 = IRAS 17119–5926) is an IRAS source with far infrared colours and flux distribution similar to those of planetary nebulae. The IUE ultraviolet spectra obtained in July, 1988 and April 1992 show nebular emission lines and also the changes in the spectra suggest the formation of the planetary nebula and the rapid evolution of the central star. The optical spectrum of this star obtained by Henize around 1950 shows only the Hα line in emission, while the most recent one, obtained in 1990 shows strong forbidden emission lines corresponding to a low excitation and young planetary nebula. The IUE ultraviolet spectra show evidence for the presence of stellar wind and mass loss. The stellar lines show P-Cygni type profiles and the terminal velocity of the stellar wind is $\sim$ – 3000 km s^{-1}. The spectral type of the central star is $\sim$O8 V. The presence of a detached cold dust shell (125 K), high galactic latitude and abundances suggest that SAO 244567 has recently evolved from a low or intermediate mass progenitor star which has ejected its outer envelope during the AGB stage of evolution and is rapidly evolving towards hotter spectral types.

Key words: Planetary nebulae - SAO 244567 - early-type-stars - emission lines - infrared stars - mass loss - UV radiation

1. Introduction

From the analysis of the IRAS Point Source Catalogue a new class of stars were detected. These stars have circumstellar dust shells with far infrared colours and flux distribution similar to the dust shells of planetary nebulae (PNe) and most of them show A, F, G and K supergiant-like spectra in the optical region (Parthasarathy and Pottasch, 1986; Lamers et al. 1986). Parthasarathy and Pottasch (1986) interpreted these dust shells as the result of severe mass loss during their AGB stage of evolution. It is likely that these objects are a in a hitherto unseen post AGB phase of the stellar evolution.

The AGB phase of evolution of low and intermediate mass stars is terminated by the ejection of most of the hydrogen rich outer envelope resulting in a PN (Iben and Renzini, 1983). The post-AGB stars detected by IRAS extend from non-variable OH/IR stars to M, K, G, F and A supergiant-like stars with circumstellar dust shells. This sequence appears to represent the evolution of the post-AGB stars towards hotter spectral types (Parthasarathy, 1990; García-Lario, 1992). A few B-type peculiar emission line stars also show far infrared colours similar to those of known PNe (Parthasarathy and Pottasch, 1989) and are probably evolving into the early stages of PNe. The duration of the transition phase (from the tip of the AGB to young PNe) is relatively short as evident from the case of SAO 244567 on which we report here. Initially considered as a transition object (Parthasarathy and Pottasch, 1989), the analysis of the optical and ultraviolet spectra show that it has now become a new low excitation planetary nebula.

2. Observations

SAO 244567 (CPD -59^{0}6926 = Hen 1357 = IRAS 17119-5926) is a high galactic latitude star (l^{II} = 331^0, b^{II} = -12^0), originally classified as a B or A emission line star by Wackerling (1970) and Henize (1976). Kozok (1985a,b) made UBV photometry in 1980 and derived $V = 10.95$, $B - V = -0.043$, $U - B = -0.884$, $E(B - V) = 0.18$, $V_0 = 10.37$, $(B - V)_0 = -0.22$, $M_v = -3.4$ and $d = 5.6$ kpc. Hill et al. (1974) made UBV photometry of SAO 244567 in 1968-1970 and found V = 10.75, B-V = -0.02 and U-B = -0.89. They found the spectral type to be B3e. Kilkenny and Hill (1975) give the radial velocity to be +44 km s^{-1} with a standard error of 5 km s^{-1}. On the basis of IRAS data Parthasarathy and Pottasch (1989) deduced that SAO 244567 is a post-AGB star evolving towards hotter spectral types. García-Lario (1992) made near infrared photometry obtaining $J = 11.37$, $H = 11.97$ and $K = 11.38$.

---

*Based on observations made with the IUE satellite, VILSPA, Madrid, and the European Southern Observatory, La Silla.
Send offprint requests to: M. Parthasarathy

1993A&A...267L..19P

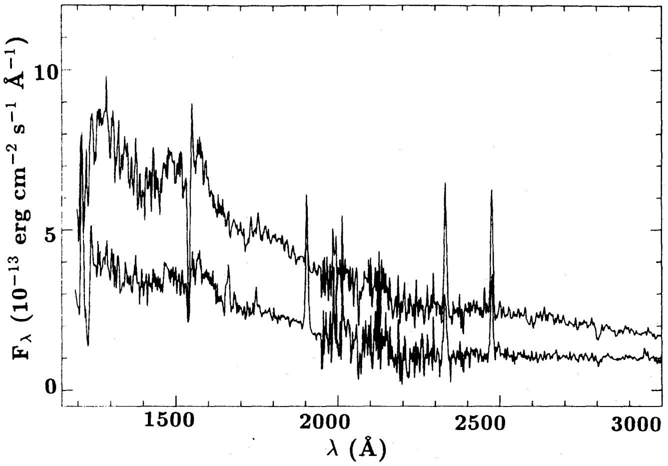

Fig. 1. IUE low resolution spectra of SAO 244567 (top: SWP 33955 + LWP 13715, July 21, 1988; bottom:: SWP 44459 + LWP 22874, April 23, 1992). Note that continuum flux in April 1992 has decreased and the intensity of CIII] 1909 Å has increased significantly.

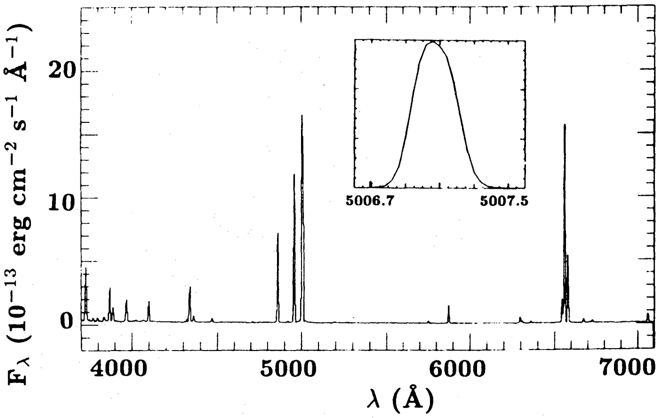

Fig. 2. Low resolution optical spectrum of SAO 244567 taken in June 1990 with the 1.5m ESO telescope at La Silla (Chile) The insert shows the high-resolution [OIII] 5007 Å profile

The J excess was attributed to the presence of ionized material in the circumstellar envelope. This excess is found in known PNe and is due to the presence of the strong He I triplet at 1.083 μm.

The ultraviolet observations were made using the IUE satellite from Villafranca Satellite Tracking Station. The low resolution spectra (6 Å) were obtained through large aperture using the SWP and LWP cameras on July 21, 1988 and April 23, 1992 and are shown in Fig. 1.

We also obtained an optical spectrum of this source in June 1990, using the 1.5m ESO telescope at La Silla (Chile). We used the Boller & Chivens Spectrograph attached to the Cassegrain focus and an RCA CCD detector, with a spectral range between 3700 and 7100 Å and an effective spectral resolution of 4.8 Å. The exposure times range from 10 minutes to only 1 second to avoid saturation in some of the brightest emission lines, obtaining a very high S/N ratio. This spectrum is shown in Figure 2.

A high-resolution spectrum ($\lambda/\delta\lambda \simeq 60,000$) around 5010 Å, covering the [OIII] 5007 Å and the HeI 5015 Å lines, was obtained in May 1991, using the ESO 1.4m Coudé Auxiliary Telescope and the Coudé Echelle spectrograph. The observed [OIII] profile (shown as an insert in Fig.2 with the corected wavelength scale) and the HeI profile both give $V_{rad} = 13 \pm 2$ km s^{-1}. The Gaussian best fit to the observed profile has a width of 16 km s^{-1}, suggesting that the V_{exp} of the ionised shell is ~ 8 km s^{-1}.

Radio interferometric measurements were made at 6 and 3 cm with the Australian Compact Array in March and April 1991. The source has a radioflux at 6 cm of 63.6 mJy±1.8 mJy and an angular diameter (FWHM) of 1".5. The flux at 3 cm, obtained from a direct fit to the uv-data, is 51±12 mJy.

3. Analysis

3.1. *Spectral type, T_{eff} and interstellar extinction*

The IUE ultraviolet spectra shown in Figure 1 clearly suggest that SAO 244567 is a hot star with an early spectral type. From the spectral features sensitive to the effective temperature and the luminosity (Heck, 1987) and the comparison with the standard stars given in the IUE Low Dispersion Spectra Reference Atlas (Heck et al. 1984) we find it to be very similar to an O8 - O9 V star. This is supported by the equivalent widths of the C IV (1550 Å), Si IV (1400 Å) and N V (1240 Å) doublets (Segikuchi and Anderson, 1987; Abbott et al. 1982), which are found to be 6.1 Å, 2.2 Å and 2.5 Å, respectively. In radiative equilibrium models the N V line is not expected in stars cooler than $T_{eff} = 35000$ K (Abbott et al. 1982). The C IV and N V features in the UV spectrum of SAO 244567 are similar to those observed in other O - B stars with $T_{eff} \sim 35000$ K.

The 2200 Å interstellar reddening feature suggests that the UV flux of SAO 244567 is affected by extinction. Correcting the observed energy distribution using the interstellar extinction law in the UV given by Seaton (1979), we obtain $E(B-V) = 0.20 \pm 0.05$, which is in agreement with the value of $E(B-V) = 0.18$ found by Kozok(1985b). The same result is found from the analysis of the Balmer decrement in the optical low resolution spectrum: $E(B-V) = 0.18 \pm 0.02$. The corrected UV flux distribution has been compared with the UV fluxes of several O - B stars (Kudritzki and Hummer, 1990; Kurucz, 1979). We estimate T_{eff}=37500 K and log $g = 4.0$.

The extinction may also be derived from the ratio of the radio continuum emission to Hβ. Using the measured value of 63 mJy at 6 cm, one would predict an Hβ flux of 1.94×10^{-11} erg cm^{-2} s^{-1}. Since the measured value is 1.1×10^{-11} erg cm^{-2} s^{-1}, the extinction should be E(B-V) = 0.14.

3.2. *Stellar wind*

The N V (1239 - 1243 Å) and C IV (1548 -1551 Å) doublets are blueshifted and show P-Cygni profiles while the N IV 1718 Å line is in absorption. The Mg II 2800 Å absorption feature is relatively broad and high resolution observations may reveal the stellar wind profile. The Si IV (1394 - 1403 Å) and Al III (1855 - 1863 Å) doublets are also blueshifted indicating the presence of a strong stellar wind. The average terminal velocity (v_∞) of this stellar wind, derived from the N V and C IV lines of the 1988 spectrum is found to be $v_\infty = -3060$ km s^{-1}, similar to that found in other central stars (Cerruti-Sola and Perinotto, 1985). The NV/CIV ratio increased in 1992 compared to that of 1988 (Fig. 1), suggesting an increase of ionisation with time. This is also supported by the behaviour of NIV line. The April 1992 IUE spectrum indicates an increase in the stellar wind velocity (–3600 km s^{-1}). Cerruti-Sola and Perinotto found that central stars of planetary nebulae (CSPNe) with $T_{eff} \leq 63000$ K almost always have a wind. They also found that nuclei with larger radii than log $R/R_{\odot} \sim -0.5$ exhibit a wind while a good percentage of those with a smaller radius do not. They suggest that a wind is always present in a CSPN if log $g \leq 5.2$. These results are modified to some extent by the results of quantitative high resolution spectroscopic studies of CSPNe made by Méndez et al. (1988). It is found that the decisive factor is not gravity alone. Objects close to the Eddington limit show winds while objects far from this limit do not, which means that winds in CSPNe are driven by radiation pressure. The presence of a stellar wind in SAO 244567 is qualitatively in agreement with the above results. Using the relation between v_{∞} and T_{eff} of Pauldrach et al. (1988) for different core masses, we obtain a core mass of $M_c \leq 0.546 M_{\odot}$.

The UV flux distribution of SAO 244567 shows a broad and deep absorption feature extending from 1300 to 1500 Å (see Figure 1, top). This absorption feature is present in several young PNe of high surface brightness, and it was attributed to H_2^+ (Heap and Stecher, 1980; Feibelman et al. 1981). This indicates the presence of a molecular envelope around SAO 244567, which is also a characteristic of other young PNe. The April 1992 IUE spectrum indicates that this broad absorption feature has decreased in strength.

3.3. Emission lines: ionic and elemental abundances

In addition to the P-Cygni profiles found in the UV spectra, which are stellar in origin, SAO 244567 shows nebular emission lines due to [OIII] 1660 Å, [NIII] 1750 Å, CIII] 1909 Å, CII] 2326 Å and OII] 2470 Å. The IUE spectrum obtained in April 1992 shows remarkable changes compared to the July 1988 spectrum. The NV 1240 Å has increased in strength. The continuum flux in the UV has decreased by a factor of 2. The CIII] 1909 Å has become very strong. These changes indicate a rapid evolution of the central star and the formation of the nebula. The optical spectrum taken in June 1990 (Fig. 2) clearly shows several forbidden lines, which also indicates the presence of a nebular component. However, this nebula is extremely compact (<2 arcsec). The presence of forbidden emission lines of different elements corresponding to low ionization states, such as [O I] or [N I] and the absence of He II lines clearly shows the low excitation nature of SAO 244567. The intensity of the [O III] 5007 Å line compared to Hα is about 3. The nebular conditions are similar to those seen in Hu 2–1 or IC 418 (Lutz, 1981; Torres-Peimbert et al. 1980; Harrington et al. 1980) which are also probably young PNe. In Table 1 we present the intensities of the emission lines observed in SAO 244567.

The electron density has been estimated from the ratio [S II] 6717 Å / [S II] 6731 Å ($N_e = 10^4 cm^{-3}$), while the electron temperature has been derived from the ratio [O III] 4363 Å / [O III] (4959 + 5007) Å ($T_e = 11000 \pm 250K$). The ratio [N II] 5755 Å / [N II] (6548 + 6584) Å gives a similar result.

The atomic abundances, calculated using the atomic coefficients summarized by Mendoza (1983), are listed in Table 2 together with other relevant physical parameters. Elemental abundances were obtained assuming simple ionization correction factors (Torress-Peimbert and Peimbert, 1977) and are also shown in this Table. We obtain a ratio N (C II) / N (O II) = 1.51, from the C II] 2326 Å and OII] 2470 Å lines, which suggests that SAO 244567 is carbon rich.

Table 1. Line intensity ratios for SAO 244567

Line	Flux* (Hβ=100)	Line	Flux* (Hβ=100)
3727 [O II]	81.2	5007 [OIII]	933
3835 H9, He II	6.0	5199 [N I]	0.6
3869 [Ne III]	49.0	5755 [N II]	1.8
3889 H8	17.2	5876 He I	15.8
3969 [Ne III],Hϵ	32.3	6300 [O I]	4.1
4070 [S II]	1.7	6312 [S III]	1.4
4101 Hδ	24.6	6363 [O I]	2.0
4340 Hγ	46.3	6548 [N II]	23.2
4363 [O III]	8.3	6563 Hα	305
4471 HeI	4.3	6584 [N II]	78.6
4711 [Ar IV]	0.6	6678 He I	4.4
4861 Hβ	100	6717 [S II]	1.5
4921 He I	1.5	6731 [S II]	3.0
4959 [O III]	305	7065 He I	9.0

F(Hβ)* = 1.10×10^{-11}
*Fluxes are dereddened using E(B-V) = 0.18

Table 2. Physical parameters and abundances for SAO 244567

	N(X)/N(H)		
		N_e (cm^{-3})	10^4
O^+(3727)	5.00x10^{-5}	T_e [O III] (K)	11000
O^{++}(4959+5007)	24.4x10^{-5}	T_e [N II](K)	11000
O°(6300)	0.6x10^{-5}	Abundances	
N^+(6548+6584)	1.3x10^{-5}	N(O)/N(H)	30x10^{-5}
Ne^{++}(3967)	8.8x10^{-5}	N(N)/N(H)	6.5x10^{-5}
S^+(6717+6731)	2.20x10^{-7}	N(He)/N(H)	0.103
S^{++}(6713)	2.03x10^{-6}	N(Ne)/N(H)	9.2x10^{-5}
He^+(5876)	0.104	N(S)/N(H)	2.2x10^{-6}
He^+(6678)	0.102		

The He^+ abundance has been estimated from the intensity of the He I lines at 5876 Å and 6678 Å, corrected for collisional effects (Clegg, 1987), obtaining very similar values of 0.104 and 0.102, respectively. Considering the excitation characteristics of SAO 244567, the presence of neutral helium in the nebula is not expected (Torres-Peimbert and Peimbert 1977). Furthermore, the absence of HeII 4686 line suggests that He^{++} is absent. Therefore, we assume that the He^+ abundance is a good estimation for the total helium abundance.

4. Discussion

The survey carried out by Henize (1967, 1976) on LH_{α} plates covered the wavelength region from 4800 to 6800 Å and the dispersion was 450 Å mm^{-1} at Hα. With this resolution he could detect not only the presence of the [O III] lines at 4959 and 5007 Å , but he could also separate [N II] 6584 Å from Hα in several new PNe. However, in the case of SAO 244567, he only reports the presence of the Hα line in emission, with a strength 2, on a scale 5 = very strong and 1 = weak, with no trace of the [O III] and [N II] lines. In the recent spectrum, however, the strength of [O III] 5007 Å is nearly 3 times that of Hα and the present strength of Hα relative to the continuum seems to be considerably higher than that observed 40 years ago. The high resolution [OIII] spectrum indicates an expansion velocity of $\sim$8 km s^{-1}.

The flux at 5500 Å can be obtained from the photometric measurements made in 1980 by Kozok (1985a,b). This gives a value of 1.51 10^{-13} erg cm^{-2} s^{-1} Å^{-1}. From the UV spectrum obtained in 1988 we can also estimate the flux at this wavelength assuming the theoretical ratio F_λ1810 Å / F_λ5500 Å of an O8 V star and we derive a lower value of 4.16 10^{-14} erg cm^{-2} s^{-1} Å^{-1}. Finally, the flux at 5500 Å in the 1990 optical spectrum is $\sim$1.2 10^{-14} erg cm^{-2} s^{-1} Å^{-1}, significantly less than the flux derived in 1980 by Kozok (1985b). The April 1992 IUE spectrum shows that the continuum flux has decreased by a factor of $\sim$2 compared to that observed in July 1988. (The drop in sensitivity of SWP and LWP cameras from 1988 to 1992 (Garhart 1991) is only 3% and 5% respectively). The CPD visual magnitude of this star is 9.3 (Henize, 1976) and in 1980 the V magnitude is 10.95 (Kozok, 1985). The V magnitudes estimated from the IUE FES data are 11.9 in July, 1988 and 11.3 in April, 1992. All the above observations indicate that the star has also become fainter in the optical region.

Using a distance of 5.6 kpc, we estimate the ionised mass to be 0.07 M$\odot$ and the luminosity of the star to be $\sim$3000 L$\odot$. The core mass - luminosity relation (Wood and Zarro, 1981) suggests the core mass to be $\sim$0.55 M$\odot$. The observed rapid evolution and the drop in luminosity are not in agreement with what is expected from the theory for such low core masses. The presence of a stellar wind indicates that post-AGB mass loss may be one of the factors for the rapid evolution into a PN. Although the distance estimate is uncertain, the uncertainty cannot be high. The observed positive radial velocity of 13$\pm$2 km s^{-1} for SAO 244567 lies in the "forbidden region" of the galactic rotation curve. Thus, a kinematic distance estimate is not possible, although it should be noted that anomalous positive radial velocities in this region have been noted for several stars and HII regions near the plane (Kilkenny and Hill 1975). However, if we use a distance of 2 kpc, the luminosity is found to be $\sim$400 L$\odot$, which is much lower than that expected from a post-AGB star. The distance larger than 10 kpc would however make the intrinsic Hβ flux more than that from NGC 7027 which is not likely.

For SAO 244567 we find N/O = 0.22 and He/H = 0.104 which are similar to the values found for type II PN (Perinotto 1991; Kaler and Jacoby 1990; Peimbert and Serrano 1980). These results suggest that the initial main sequence mass of the object is $\lesssim$3M$\odot$.

5. Conclusions

The detached cold dust shell around SAO 244567, with far and near infrared colours similar to those of known PNe, the optical and ultraviolet spectra clearly suggest that this star is a new low excitation PN. SAO 244567 has probably evolved from a low or intermediate mass progenitor star and ejected its hydrogen rich outer envelope, evolving rapidly to hotter spectral types resulting now in a PN. The central star is an O8 V star which shows stellar wind and mass loss. The nebula is carbon rich.

The strong spectral changes and the drop in luminosity detected are not expected from theoretical evolutionary models. However, the low luminosity, abundances and the high galactic latitude indicate that the progenitor star is not massive. This star seems to be a part of the "missing link" between post-AGB stars and PNe or proto-PNe. The evolutionary connection between this star and the other high-galactic latitude post-AGB stars (Parthasarathy and Pottasch 1986) needs further study. Some of the post AGB Be or BQ[ ] stars with circumstellar dust shell with far IR (IRAS) colours similar to PN (Parthasarathy and Pottasch 1989) may be evolving rapidly towards PN stage similar to SAO 244567. Monitoring programs are necessary to evaluate these changes.

References

Abbott,D.C., Bohlin,R.C., Savage,B.D.: 1982, *ApJSS*, **48**, 369

Cerruti-Sola, M., Perinotto, M.: 1985, *ApJ*, **291**, 237

Clegg, R.E.S.: 1987, *MNRAS*, **229**, 31P

Feibelman, W.A., Boggess, A., McCracken, C.W., Hobbs, R.W.: 1981, *AJ*, **86**, 881

García-Lario, P.: 1992, *Ph.D. Thesis.* Univ. La Laguna (Spain)

Garhart, M.P.: 1991, IUE NASA Newsletter, **46**, 65

Harrington, J.P., Lutz, J.H., Seaton, M.J., Stickland, D.J.: 1980, *MNRAS*, **191**, 13

Heap, S.R., Stecher, T.P.: 1980, in *The Universe at Ultraviolet Wavelengths*, NASA CP-2171, ed. R.D. Chapman, p. 657

Heck, A.: 1987, in *Scientific Accomplishments of the IUE*, ed. Y. Kondo. (Reidel) p. 121

Heck, A., Egret, D., Jaschek, M., Jaschek, C.: 1984, *Low Dispersion Spectra Reference Atlas*, ESA-SP 1052

Henize, K.G.: 1967, *ApJSS*, **14**, 125

Henize, K.G.: 1976, *ApJSS*, **30**, 491

Hill,P.W., Kilkenny,D., van Breda,I.G.: 1974,MNRAS,**168**, 451

Iben, I., Jr., Renzini, A.: 1983, *Ann.Rev.A&A*, **21**, 271

Kaler, J.B., Jacoby, G.H.: 1990, *ApJ*, **362**, 491

Kilkenny, D., Hill, P.W.: 1975, MNRAS, **172**, 649

Kozok, J.R.: 1985a, *A&ASS*, **61**, 387

Kozok, J.R.: 1985b, *A&ASS*, **62**, 7

Kudritzki, R.P., Hummer, D.G.: 1990, *Ann.Rev.A&A*, **28**, 303

Kurucz R.L., 1979, *ApJ Suppl.*, **40**, 1

Lamers, H.J.G.L.M., Waters, L.B.F.M., Garmany, C.P., Pérez, M. R., Waelkens, C.: 1986, *A&A*, **154**, L20

Lutz, J.H.: 1981, *ApJ*, **247**, 144

Méndez, R.H., Kudritzki, R.P., Herrero, A., Husfeld, D., Groth, H.G.: 1988, *ApJ*, **190**, 113

Mendoza, C.: 1983, *IAU Symp.* **103** on *PN*, p143

Parthasarathy, M.: 1990, *Proceedings of IAU Symp.* **145**, ed. G. Michand, p. 119

Parthasarathy, M., Pottasch, S.R.: 1986, *A&A*, **154**, L16

Parthasarathy, M., Pottasch, S.R.: 1989, *A&A*, **225**, 521

Pauldrach, A.W.A., Puls, J., Kudritzki, R.P., Méndez, R.M., Heap, S.R.: 1988, *A&A*, **207**, 123

Peimbert, M., Serrano, A.: 1980, *Rev. Mex. A&A* **5**, 9

Perinotto, M.: 1991, *ApJSS*, **76**, 687

Pottasch S.R., 1984, *planetary Nebulae*, D. Reidel, p8

Seaton, M.J.: 1979, *MNRAS*, **187**, 73P

Segikuchi, K., Anderson, K.S.: 1987, *AJ*, **94**, 129

Torres-Peimbert,S., Peimbert,M.: 1977, *Rev. Mex. A&A*, **2**, 181

Torres-Peimbert, S., Peimbert, M., Daltabuit, E.: 1980, *ApJ*, **238**, 133

Wackerling, L.R.: 1970, *Mem.RAS*, **73**, 153

Wood, P.R., Zarro, D.M.: 1981, *ApJ*, **247**, 247