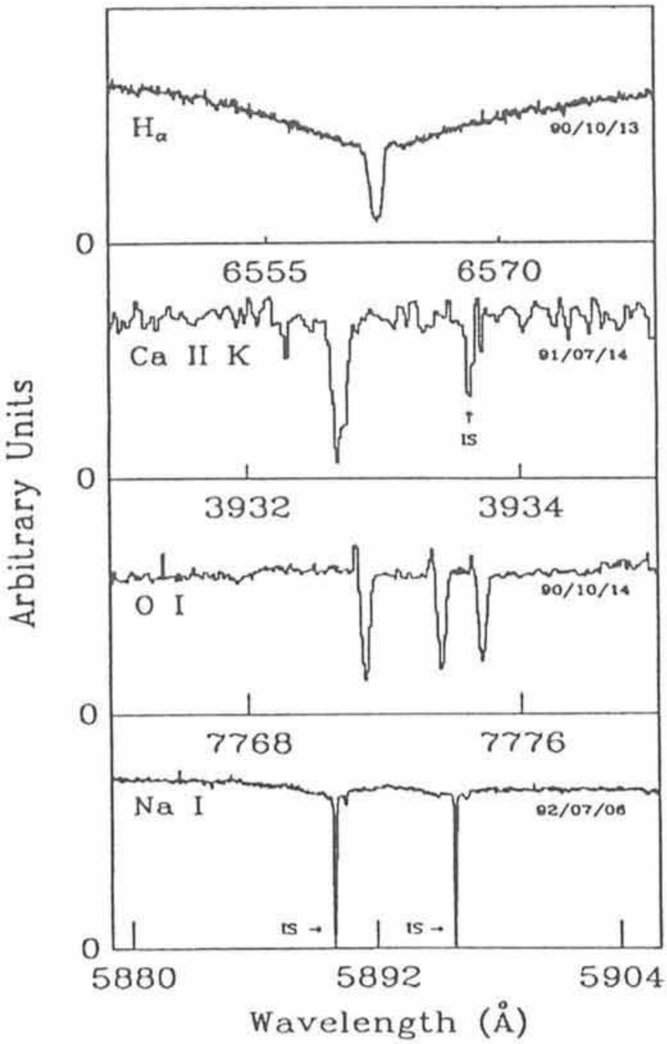
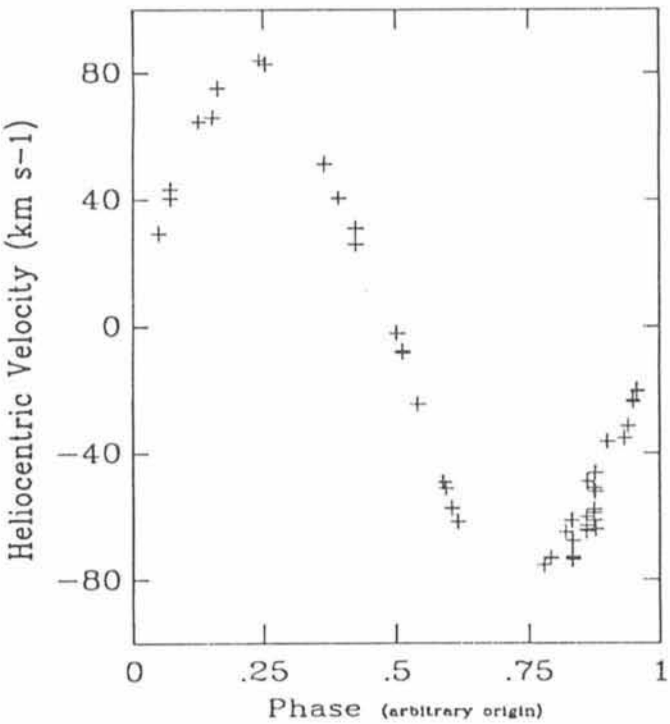


Figure 1: *Examples of high-resolution spectra of TY CrA with lines of Hα, Ca II K, O I, Na I. Narrow absorption lines are observed, and there is a narrow core at the bottom of the Hα line; see the text. They are all variable in velocity except those of IS origin (indicated with an arrow). Note the narrow absorption feature and the broader absorption in the Na I line.* ◀

Figure 2: *Heliocentric velocities of all observed narrow lines (FWHM ≤ 50 km s^{-1}), folded in phase with a period of 2.888777 days.* ▼



8 km s^{-1}. Since we are dealing with an eclipsing binary system, this means that the true rotational velocity of this B7 star is close to this value: but such a value does not fit with the rotational velocity expected for a 3 $R_\odot$ object, if the rotational and 2.9-day orbital motions are synchronized (55 km s^{-1}).

Another possibility is that the narrow lines originate in a circumstellar shell (CS) that surrounds the primary component. In fact, these narrow lines are very similar to the ones observed for the A-type main-sequence star βPictoris, which are clearly due to CS gas. TY CrA's spectrum is more similar to that of βPictoris than to those of usual Herbig stars. This may indicate that this star is more evolved than the latter objects, perhaps very near the end of its pre-Main-Sequence evolution. Further observations are needed to pursue the investigation of this possibility.

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Atomic Processes and Excitation in Planetary Nebulae

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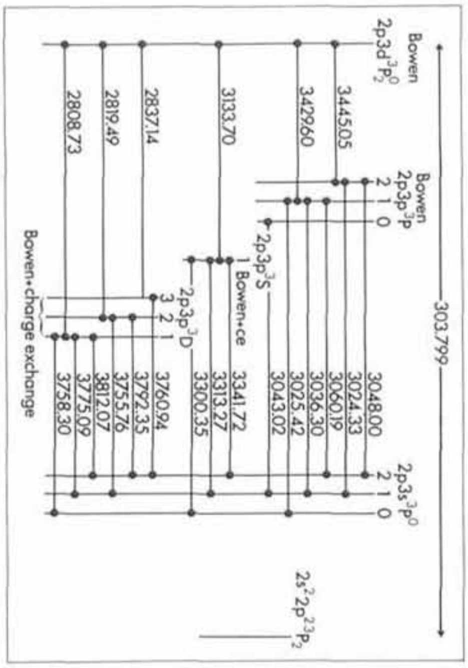
Introduction

Owing to their relatively simple geometry and physical conditions, Planetary Nebulae (PNe) are potentially an ideal laboratory to study various atomic processes important in gaseous nebulae. O III Bowen fluorescence lines, excited by the ultraviolet pumping of the $2p^2\ ^3P_2$–$2p3d\ ^3P^o_2$ line of O III at 303.799 Å by the He II Lyα line at 303.780 Å (Bowen 1934, 1935), are observed in a variety of astrophysical sources, as diverse as PNe, Seyfert galaxies, the Sun, and X-ray binary and burster sources (Schachter et al. 1989, 1990, 1991; Sternberg et al. 1988 and the references therein). These lines are interesting because they provide a powerful diagnostic probe of the physical environment in which they appear. Charge transfer (CT hereafter) of O^{3+} ions in collisions with hydrogen atoms, $O^{3+} + H^0 \rightarrow O^{2+} + H^+$ populates excited states of O^{2+} (Dalgarno, Heil and Butler 1981, DHB hereafter), and con-



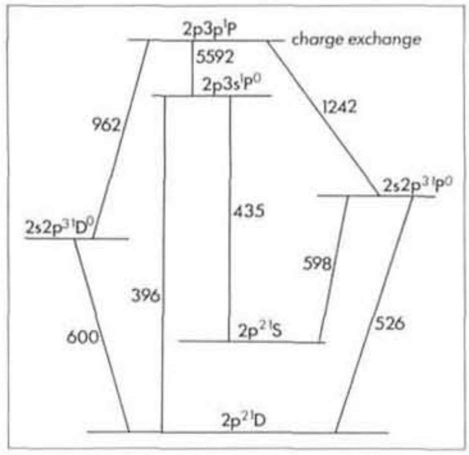


Figure 1: *We show the energy level diagrams for most of the relevant transitions in the optical domain arising from Bowen fluorescence and charge exchange mechanisms.*

tributes significantly to the Bowen cascade from the ^3D state in some planetary nebulae. CT also populates the singlet state 2p3p ^{1}P which provides an allowed transition at 5592 Å (DHB; Dalgarno and Sternberg 1982). Figure 1 provides an abbreviated description of the relevant energy levels. Charge transfer is an important process in determining the ionization equilibrium and now is a standard ingredient in models of gaseous nebulae.

Since 1986, we have systematically observed the O III Bowen fluorescence and CT lines in a number of high-excitation PNe. Sample spectra of NGC 3242 are plotted in Figure 2. From these data we have obtained a number of interesting results which are summarized below. In addition, we will address the important problem of electron temperature fluctuations in PNe. Details of these results have been given elsewhere (Liu and Danziger 1993a, b; Liu, Danziger and Murdin 1993). Interested readers are referred to those papers.

The Bowen Fluorescence Line Ratios and Evidence for Departure from Pure LS Coupling

The relative intensities of the Bowen fluorescence lines depend only on the radiative transition probabilities, and measurements of these lines give a direct verification of these quantities. The radiative transition probabilities of O III have been calculated by Saraph and Seaton (1980, hereafter SS) and by Luo et al. (1989, hereafter LPSSY). In these approaches LS coupling is assumed. Calculations of O III transition probabilities within the scheme of intermediate coupling are presented by Kastner, Behring and Bhatia (1983, hereafter KBB) and by Kastner and Bhatia (1990, hereafter KB).

Our measurements in the λλ3100 – 4000 wavelength region at resolutions and S/N greater than previously used show:

(1) The observed ratios λ3428/λ3444, λ3299/λ3341, λ3312/λ3341, λ3791/λ3755 and λ3774/λ3757, where each of these pairs of lines in the ratio decay from the same upper level and belong to the same multiplet; thus their ratios depend only on the assumed coupling scheme, and deviate from the predictions of pure LS coupling and are in better agreement with those using intermediate coupling calculated by KBB and KB. Echelle observations of NGC 7009 between λλ3750 – 3800 with a resolving power as high as 40,000 strengthen the conclusion that the discrepancies are not due to blending effects from unidentified lines.

(2) The observed ratio I (λ3133)/I (λ3444 + λ3428) is best reproduced using the transition probabilities from LPSSY and is in disagreement with that predicted by KB. Although the three lines decay from the same upper level, the λ3133 belongs to a multiplet other than that of the λ3444 and λ3428. Therefore, this ratio depends not only on the coupling scheme but also on transition probabilities for the multiplet. Similarly, the observed ratio I(λ3299 + λ3312 + λ3341)/I (λ3133), after the contribution from CT to the λ3299, λ3312 and λ3341 has been corrected, is in best agreement with that predicted by LPSSY. However, there is weak evidence that even in the calculations of LPSSY, the role of depopulation of the 2p3p ^{3}S, ^{3}D levels by cascades has been overestimated by about 5 – 10 %. It appears that the results given by LPSSY represent the best available calculations of O III transition probabilities for these permitted lines.

The Efficiency of the Bowen Fluorescence Mechanism

The fraction of He II photons that are absorbed by the O^{2+} ions and converted to the Bowen fluorescence lines may depend on a number of characteristics of the nebula, including the optical depth of the He II Lyα, the geometry and the thermal and ionizational structure of the nebulae. Photoionization of the residual H^0 and He^0 in the He^{2+} zone as well as dust absorption can also destroy the He II Lyα photons.

The efficiency, R, of the Bowen fluorescence mechanism (BFM hereafter) quantifies the fraction of all those He II Lyα photons created following recombination of He^{2+} ions and electrons which are converted to Bowen fluorescence lines. The value of R can be derived by comparing a Bowen fluorescence line (e.g. O IIIλ3133) and a He II recombination line (e.g. He IIλ4686). The efficiency of the BFM is an important quantity because it provides a unique probe to study the radiative transfer problem of the (extremely optically thick) He II Lyα line. Calculations of R in model PNe and Seyfert galaxies (Weymann and Williams 1969, Harrington 1972, Kallman and McCray 1980) show that R ≈ 0.5, and is insensitive to the input parameters, such as temperature, ionizing source and the resulting ionizing structure.

Measurements of R in PNe are presented by Barker (1978) and Likkel and

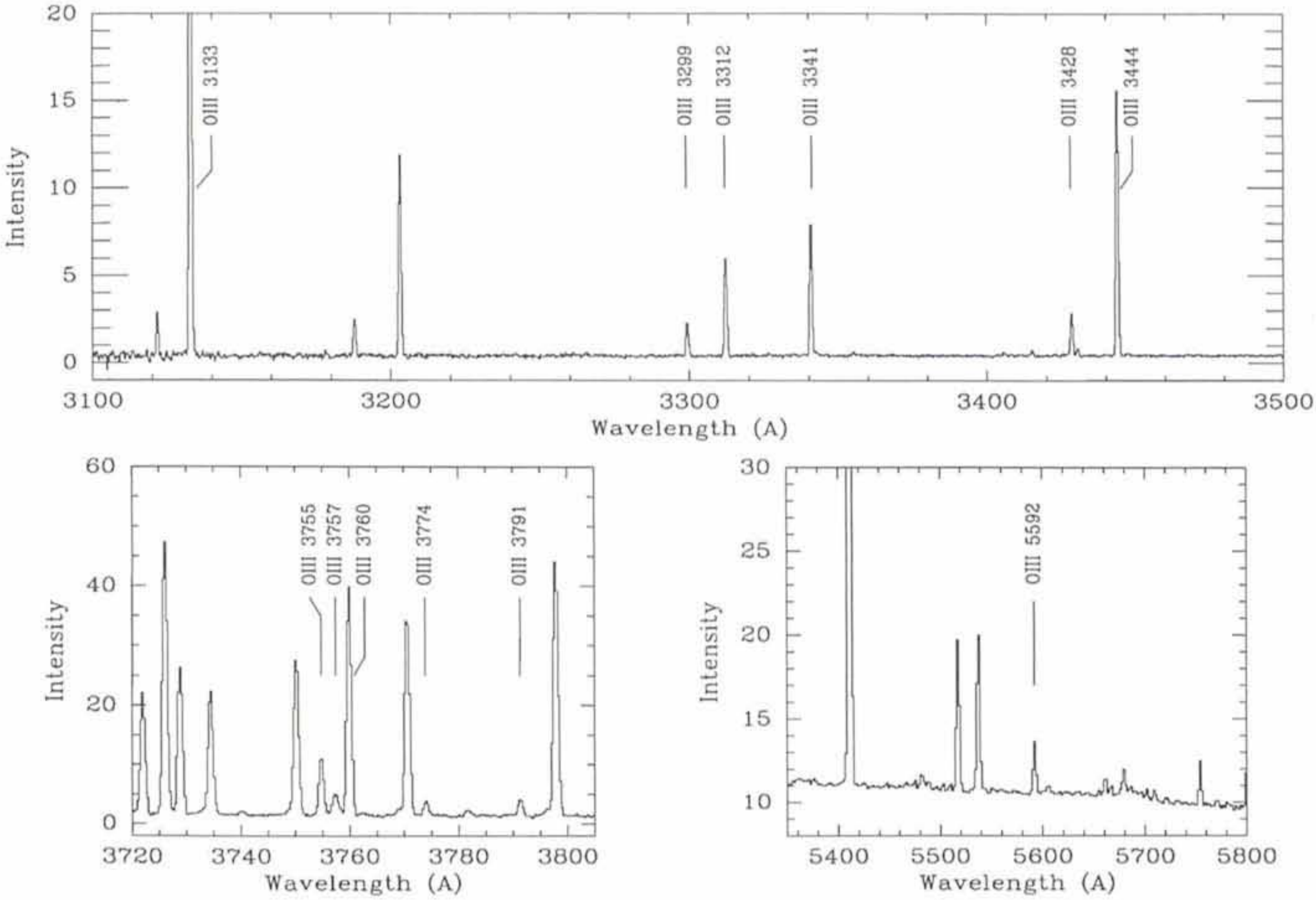


Figure 2: *Integrated spectra of NGC 3242 showing all the O III Bowen fluorescence and charge transfer lines discussed in the paper. The spectra in the blue and UV regions were secured at La Palma in January 1987, using INT 2.5-m + IDS + IPCS and with a spectral resolution of 0.72 Å in FWHM. The one in the yellow region was obtained at ESO-La Silla in January 1991, using ESO/MPI 2.2-m + B&C + CCD. The observed intensities of λ3299, λ3791 and λ5592 relative to Hβ are 0.026, 0.0024 and 0.00064, respectively.*

Aller (1986, hereafter LA). From our new high quality observations, we have derived accurate values of R in 14 PNe, and a wide range is apparent. These new measurements are analysed together with those presented by Barker (1978) and LA. Some new understanding of the Bowen fluorescence efficiencies has been achieved through the correlation of accurately determined efficiencies with other characteristic parameters of the nebulae. It is found that when the expansion velocity of O^{2+} exceeds 28 km/s, the efficiency drops abruptly, a result supported by quantitative considerations. We show that there is a good linear positive correlation between the Bowen efficiencies and the fractional abundances of singly ionized helium and doubly ionized oxygen, as well as a remarkable anticorrelation between the Bowen efficiencies and the electron temperature as first noted by LA. The difference in R between PNe with different morphology types or excited by stars with different spectral characteristics as suggested by LA is however not observed.

Obviously, the observations agree only marginally with modelling calculations and there are a number of results not accommodated by the currently available theoretical predictions. To interpret these results, calculations of the efficiency of Bowen conversion based on detailed modelling, taking into account both the thermal and ionization structure of individual nebulae are necessary.

Rate Coefficients for CT Reaction $O^{3+} + H^0 \rightarrow O^{2+} + H^+$

As described in section 1, the CT reaction between O^{3+} and H^0 is a significant source of the excitation of the O III multiplet λ3760 emitted from the ^3D state. Rate coefficients of this process have been calculated by DHB, Gargaud et al. (1989, GMO hereafter) and by Roueff and Dalgarno (1988, RD hereafter). In the calculations of DHB and GMO neither the fine-structure levels of the ground term of O IV 2p $^2P_{1/2,3/2}$ nor those of the product O III are taken into account. Dalgarno and Sternberg (1982) suggest that the CT excitation of the O III 2p3p ^3D_J(J = 1,2,3) levels tends to equalize the fine-structure populations and they assume that the rate coefficients into the individual fine-structure levels of ^3D are equal. This suggestion is not supported by the calculations of RD where the individual fine-structure levels of both the initial O^{3+} ion and the product O^{2+} have been taken into account. They find that the cross-sections increase approximately with the statistical weights of the fine-structure levels, i.e. 2J + 1.

By observing the lines excited only by the BFM and the pure CT line λ5592, we are able to decouple these two processes, which in turn enables for the first time accurate measurement of the relative CT rate coefficient k(2p3p ^3D_J)/k(2p3p ^1P) (J = 1, 2 and 3).

Lines of the multiplets containing λ3760 as well as the λ5592 are generally quite weak and may be contaminated by excitation from processes other than the BFM and CT. One of the possible mechanisms is excitation by dielectronic and radiative recombination. To estimate the contribution from this process, we make use of the O III λ3261, λ3265 and λ3267 lines of multiplet

$2p3p\ ^3D_3 - 2p3d\ ^3F^o_4$. This multiplet has been identified for the first time and measured in most objects studied here. Due to the large orbital angular momentum of the upper levels, these lines are very likely excited only by radiative and dielectronic recombination. This is confirmed by the close agreement found between the ionic abundances of O^{3+} derived from this multiplet with those from the UV collisionally excited lines OIV]λλ1403, 1409 in objects for which measurements of both the UV and the optical lines are available. Another possible mechanism which might excite the lines studied here is fluorescent absorption of stellar UV radiation. However, we show that this process is completely negligible for lines we are interested in.

The derived values of $k(2p3p\ ^3D_J)/k(2p3p\ ^1P)$ are found to be sensitive to the adopted transition probabilities. This is particularly true for the $^3D_3$ level mainly excited by the BFM and in objects of relatively low excitation. CT is found to be more efficient in objects of higher excitation class. When the transition probabilities from LPSSY are adopted, the values of the above ratio found from measurements of different objects have the smallest scatter, giving $k(2p3p\ ^3D_J)/k(2p3p\ ^1P) = 1.44 \pm 0.17$, 1.10 ± 0.13 and 1.03 ± 0.32 for J = 1, 2 and 3, respectively. These values lie somewhere between the predictions of 1.40 and 0.98, independent of J, by DHB and by GMO, respectively, and support the suggestion by Dalgarno and Sternberg (1982) that the charge transfer reaction tends to equalize the fine-structure populations, giving an equal rate coefficient for the three fine-structure levels of 2p3p ^3D. They are certainly inconsistent with the theoretical predictions of RD who find $k(2p3p\ ^3D_J) = 1.4$, 2.2 and 3.1 for J = 1, 2 and 3, respectively, i.e. $k(2p3p\ ^3D_J)$ increases approximately with 2J + 1. It seems to us that $k(2p3p\ ^3D_J)/k(2p3p\ ^1P) = 1.20$, independent of J, would be a good value to adopt for the moment and should be accurate to about 30 %.

Stronger conclusions on the CT rate coefficients than those reached in this work are frustrated by the uncertainties in the available atomic data. Again, more accurate calculations of O^{2+} transition probabilities, especially taking into account the deviation from pure LS coupling are highly desirable.

Nebular Continuum Emission and Evidence for Temperature Fluctuations

As a by-product of the observations carried out above, we have obtained accurate measurements of the Balmer discontinuity of nebular continuum emission. A spectrum showing the Balmer discontinuity in NGC 3242 is given in Figure 3. The most important application of measured Balmer discontinuities is that they provide information on the electron temperature. Using this method, Peimbert (1971) derived electron temperatures in three planetary nebulae and for several regions in the Orion nebula and found that the temperatures derived in this way were systematically lower than those found from forbidden lines. He attributes this difference to temperature fluctuations in the nebulae and uses their difference to make first-order corrections for the effect of temperature fluctuations on abundance determinations. The physical idea is that the nebular continuum emission originates from recombination processes and weights preferentially low-temperature regions whereas the forbidden lines are excited by electron collisions and weight preferentially high-temperature regions. Thus if there are temperature fluctuations, the electron temperature derived from the Balmer discontinuity, T_e(Bal), will be lower than that derived from the [O III] nebular to auroral line ratio I(λ4959 + λ5007)/I(λ4363), T_e([O III] na). On the other hand, Barker (1978, 1979) derived electron temperatures from observations of the Balmer discontinuity for a number of PN's but found general agreement with those parameters from forbidden lines.

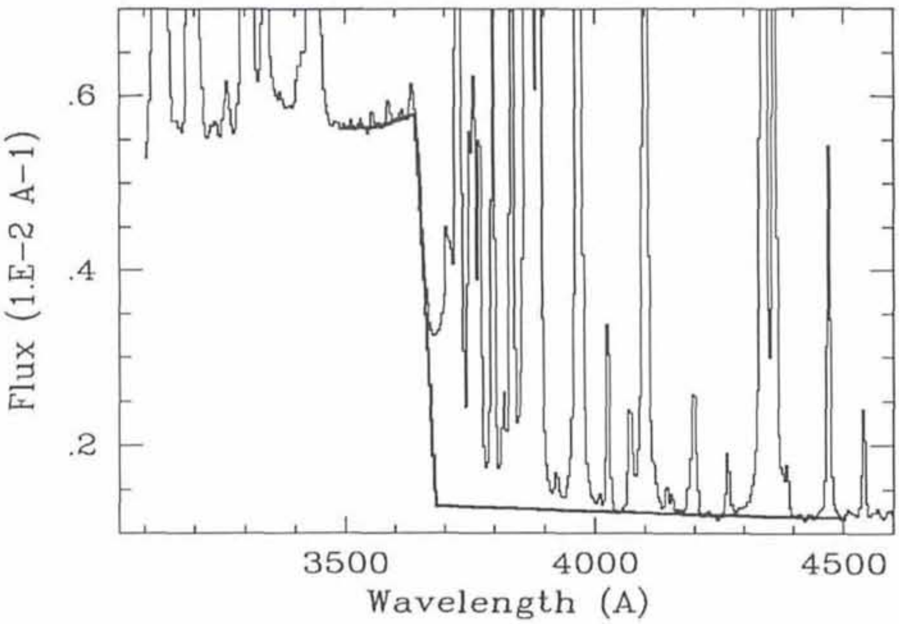


Figure 3: *Integrated spectrum of NGC 3242 showing the Balmer discontinuity at λ3645. The observation was carried out in February 1991 using ESO/MPI 2.2-m + B&C = CCD. The thick line overplotted is a spline fit to the estimated continuum (nebular plus stellar).*

From the new measurements of the Balmer discontinuity, we have derived T_e(Bal) in fourteen PNe. These, together with those presented by Peimbert (1971) and by Barker (1978) are compared to T_e([O III] na). In total there are 34 objects, covering a wide range of excitation class and electron temperature. The data clearly show that T_e(Bal) tends to be lower than T_e([O III] na) for the same objects, with the former on the average about 1500 K lower than the latter, which corresponds to a temperature fluctuation parameter $t^2 = 0.029$ as defined by Peimbert (1967). There are however, a few objects for which T_e(Bal) is considerably lower than T_e([O III] na), leading to values of t^2 as large as 0.10. Excluding these extreme cases, we recommend that $t^2 = 0.030$ may be used as a representative value for most PNe. This value has the effect that composition determinations of PNe assuming a homogeneous temperature may underestimate the metal abundance by about 0.1 dex.

The observed large temperature fluctuations cannot be reconciled with the current models of PNe (cf. Harrington et al., 1982) and some additional mechanisms are required to explain the observations. At the moment, two possibilities can be envisaged. One is that there is an additional source of energy input to the nebulae other than the photoionization, e.g. shock waves produced by stellar winds (Peimbert et al., 1991). Large temperature fluctuations can also be produced if the PNe are very inhomogeneous in chemical composition, such as suggested by the models of NGC 4361 constructed by Torres-Peimbert et al. (1990). Further evidence for an additional heating mechanism other than the photoionization in at least some planetary nebulae is provided by new observations in X-ray carried out with ROSAT. Kreysing et al. (1992) report detection of extended X-ray emission from six planetary nebulae. It appears that these objects tend to have exceptional large temperature fluctuation and belong to a special group in which some unknown process (e.g. shock heating) is playing an important role. This category includes objects such as NGC 2392, NGC 4361, NGC 6543 and J320. Further investigation is required to clarify the problem. It is worth noting that the type of work described above can be accomplished on modest sized telescopes provided there is adequate UV throughput of the system.

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Two New Catalogues of Small Magellanic Cloud Members Coming Soon

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Within the framework of our studies of the stellar populations of the Small Magellanic Cloud (SMC) two extensive surveys – one for carbon stars and one for point-source Hα emission-line objects – were undertaken in the early eighties. For these surveys we introduced an observing technique which turned out to be very efficient for the detection of the SMC OB and blue supergiant stars (Azzopardi and Vigneau 1975), as well as for the identification of the Magellanic Cloud Wolf-Rayet stars (Azzopardi and Breysacher 1979, 1980). Briefly, the surveys combined a IIa-O emulsion with a suitable interference filter in order to restrict the instrumental spectral range to a selected useful spectral domain, according to the type of object to be detected. By reducing the sky background, the interference filter allowed longer exposures hence reaching fainter stars. Furthermore, since the resulting spectra on the plates were very short, the number of overlaps was kept low enough to make the survey of very crowded SMC regions possible.

Due to the relative faintness of the objects we have detected, which are generally located in very crowded fields, accurate positions and clear finding charts are absolutely necessary to facilitate further observations. For this purpose, the equatorial coordinates (equinox 2000.0) of the objects of interest, in both surveys, were inferred from those of several secondary astrometric reference stars. The positions of these stars were themselves computed with reference to the right ascension and the declination of the stars listed in the Perth catalogue and appearing on the ESO Schmidt telescope plate No. 6266. The transformation of very accurate x-, y-coordinates into equatorial coordinates, for all the stars, was done using special astrometry routines written at ESO by R. West. The objects listed in both catalogues were identified on individual finding charts of 2.25 arcmin square. These have been extracted from scans of a glass copy of the Schmidt red plate No. 6266, processed at the ESO Sky Atlas Laboratory by B. Dumoulin using an improved unsharp masking technique in order to reduce the density range of the deep original plate while keeping the fine details of the image. The plate has been scanned by J. Marchal at Nice Observatory with a PDS 1010A microdensitometer linked to a VAX 785 computer. Extensive photographic work has been done by M. Gerbal and H.H. Heyer when preparing each set of finding charts.

SMC Carbon Star Survey

Earlier detections of carbon stars in the Magellanic Clouds were carried out by Blanco, McCarthy and Blanco (1980) and Blanco and McCarthy (1983). Their survey, in the near infrared spectral domain, of 37 SMC sample regions with the Cerro Tololo Inter-American Observatory (CTIO) 4-m telescope equipped with low-dispersion transmission gratings (grisms) resulted in the identification of 860 carbon stars in the Small Cloud. From the carbon star-count isopleths, based on the sample region surface densities found for these stars, Blanco and McCarthy (1983) estimated the total number of the SMC carbon stars to be 2900.

In the mean time, during the 1981, 1983 and 1984 Magellanic Cloud observing periods, an extensive spectral survey for field carbon stars in the SMC was carried out by B.E. Westerlund, J. Breysacher and the author, in order to get the best possible picture of the distribution of these stars. Adopting the Sanduleak and Philip (1977) survey technique in searching for carbon stars (identification of their pronounced C_2 Swan bands at 4735 Å and especially at 5165 Å), we used the ESO 3.6-m telescope equipped with the large-field triplet adaptor (0.78 degree circular field)