PLANETARY NEBULAE, AN INTRODUCTORY REVIEW

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The time is long past when we could regard planetary nebulae (PN) as semi-static or even steady state features, anchored in the phase in which we happen to catch them. We must regard them as evanescent phenomena, celestial flowers caught between bud and final loss of petals. Throughout most stages of its existence, a star can be regarded as essentially an equilibrium structure, but a PN and its central star evolve on a time scale comparable with human history.

Two separate developments provide impetus for PN research, a vastly expanded observational data base and important theoretical insights aided and abetted by powerful computers. In addition to optical observations, we have extensive radio-frequency (rf), infrared (IR), and ultraviolet (UV) data. Some 350 PN have been measured in the rf range, a thousand have been detected by IRAS, and photometric data exist in 4 bands for ~300 of these, while some 200 PN have been studied with the IUE.

Observed stellar properties can be mostly summarized by a position, and a high resolution spectral scan, but a PN requires a two dimensional map in several radiations, e.g., [OII], [OIII], Hβ, [NII] and [SII] as obtained, e.g. by Jacoby et al for NGC 40, and NGC 6826. Then we can obtain values of T_ϵ and N_ϵ, N(0+)/N(H+), etc. averaged along a pencil taken through the nebula, and make comparisons with models. The photometric information should be supplemented with velocity measurements, such as those obtained with a Fabry-Perot etalon. The quantity of data involved is tremendous, but the effort is justified for a few objects amenable to detailed theoretical modeling.

New IR and rf techniques supply crucial structural information. With VLA, one can construct continuum isophotic maps, free of effects of interstellar extinction (ISE). Furthermore, by comparing maps from different epochs, we can get nebular angular expansion rates. Spectroscopic measurements give the expansion velocity in km/sec at least in the observers direction; and if one can allow for an increase in the size of the H+ zone as the ionization front invades the neutral zone, the PN's distance can be found. This principle, originally applied to optical data by W. Liller has been used by Masson (1989) to obtain distances and structures of NGC 7027, BD +30 3639 and NGC 6572. Rapid advances in IR technology make it possible to secure high resolution images for many PN. With a 256×256 array and a 2'x2' field one is limited mostly by seeing. We can compare, e.g., images in H_2 with atomic H images from the nearby Brγ line. Also, we hope to get CIII, CIV, and other images in bright PN with the Hubble Space Telescope. Krishna et al (1989) measured X-rays from 8PN - or more accurately from their central stars or "nuclei" (PNN) with the EXOSAT satellite.

Examples of some recent work are: photometric optical data on Hβ, Hα + [NII]. [OIII] and B and V magnitudes for their (PNN) by Shaw and Kaler (1989) for 134 southern objects and measurements of Hβ fluxes in 460 southern PN by Acker et al's (1989). These data are especially valuable for objects of small angular size. Much effort has been devoted to compact and presumably young PN by a number of observers who have obtained optical, IR, and r.f. observations. Zhang and Kwok (1991) compiled energy distributions from 100A to 100 μm for 66 PN. They attempt to separate contributions of nebular continua, lines and dust. Image tube scanners (ITS) and other devices have been used to extend studies of PN spectra to the S. Hemisphere and Magellanic Clouds. Development of high dispersion echelle spectroscopy provides us with high resolution data.

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The Persistent Problem of Planetary Nebular Distances.

A most unsatisfactory feature of the PN problem is our poor knowledge of their distances. The Liller-Masson method promises rich dividends but workers in the field are few. VLA observations are tedious, time-consuming and require great care and patience. For a few precious objects, the spectroscopic parallax method of Kudritzki and his associates can be used, and distance for a few other PNs that are members of binaries or clusters are also obtainable; but for most PNs, many years will be needed to get the necessary VLA observations. Statistical methods have proved disappointing. The Shklovsky method which postulates a uniform mass for all fully ionised PN is confronted by an actual mass range from 0.3 to 1.3 solar masses for PN in the Magellanic Clouds (Dopita & Meatheringham 1991). The Shklovsky method gives a poor determination of the distance of the galactic bulge (Pottasch & Zijlstra 1992).

Evolution and Structure.

The picture of the transformation of an evolving asymptotic giant branch (AGB) star to a PN gradually becomes better defined, but many details and ambiguities remain. As a star ascends the AGB, the mass loss rate increases. Radiation pressure drives the grains away and the mass ejection rate becomes especially large for long period variables with periods greater than 400 days, since radiation pressure drives grains from an extended atmosphere more easily than from a normal one. The mass loss problem appears more tractable for carbon stars. The grains seem to be amorphous rather than graphite. Jura (1991) estimates that in the solar neighborhood half of all stars in the range of 1 to 5 solar masses become C stars, with mass-loss rates between 10^{-7} and 10^{-5} solar masses/yr. A larger fraction of metal-poor stars evolve into carbon stars before they become PN than is the case for metal-rich stars.

If the dying star is sufficiently massive, it becomes surrounded by a thick, warm, dusty envelope. It emits copiously in the IR; hence, the great value of IRAS data. At this stage, the post AGB star has stopped pulsating. The dust cloud is moving into space and what still can be called the "star" migrates to the blue side of the HR diagram. When the envelope mass has fallen to about 0.001 that of the sun, a large mass loss rate can no longer be sustained. The stellar core gradually becomes uncovered and T(*) rises from 5000°K to 30,000°K. The dusty envelope is exposed to high frequency radiation, molecules dissociate, and the gas becomes ionized. All this time the escaping envelope is vanishing into space; and if the stellar spot-light is not turned on fast enough, there will be no PN. If we don't quibble over too many details, this picture is probably generally acceptable. What really happens from the late AGB phase through the proto-PN phase until we get a dusty, shiny, new PN is open to much discussion. The IRAS data have supplied many clues but many questions remain.

Infra-red C stars may evolve unobtrusively into C-rich PN. The OH-IR stars and those with strong 9.7 μm silicate absorption features are expected to produce O-rich PN, but once in a while there is a surprise. Zhang and Kwok (1990) found 6 young PNs that showed both O-rich and C-rich dust features. One of these, SwSt 1 whose PNN exhibits a WC type spectrum, is an O-rich PN. This might be a transition phase where a C-rich photosphere emerges after the O-rich layers escape from the star. Among long-known PN we recall NGC 40 and BD +30° 3639 with WC nuclei and N-rich envelopes with no trace of N in the central star spectrum.

An important clue to the ejection process must be the fact that the dominant symmetry in PN is elliptical or bipolar, a symmetry that can be traced to the central stars. Properties of bipolar pre-PNs are discussed by Mark Morris (1990). They have a thick toroidal ring, so that the outflowing wind, whose velocity depends on latitude, is strongly directed towards the poles. This polar stream (with an average velocity of 100-200 km/sec) moves about ten times as fast as one would expect for a spherical, symmetrical shell driven by radiation pressure on dust grains. The polar streams often exhibit masers and some have ansae along the polar axis, presumably the effect of polar streaming on the AGB envelope. These objects are clearly the antecedents of bipolar and maybe other kinds of PNs with their characteristic topologies and bright line ansae (e.g., Balick 1987).

Bipolar phenomena are common in young PN like Vy2-2 (Miranda & Solf 1991). One striking example is IC 4406. There is a dense, cool, dusty, molecular torus mapped in CO (Sahai et al 1991). The equatorial expansion velocity is about 15 km/sec and four times larger in higher latitudes. The mass of the molecular cloud is at least 0.16 **M**(⊙) and may be much larger. It is a young object with a post-AGB age of less than 10,000 years. Pascoli (1990) has discussed the morphology of bipolar PNs and has set up a classification scheme somewhat similar to that of Balick (1987) and of Sabbadin (1986).

Although bipolar PN possibly may be explained most easily as ejecta from close binaries, nebular statistics do not favor such a hypothesis. There are too many bipolars. Bond and Livio (1990) suggest that PN produced by binaries are most likely ejected at the end of a common envelope phase when the primary star in a wide binary system expands and engulfs the companion, reducing the orbit of the latter. No close binary PN shows double or multiple shells, although half of the planetaries with binary nuclei show butterfly or elliptical features with moderate to extreme density contrasts.

In the currently accepted model, basically due to Kwok, there is first the leisurely red giant wind with a velocity of about 5 km/sec and mass loss rate from 10^{-8} to 10^{-9} **M**(⊙)/yr which is followed by the superwind with a velocity of 10km/sec and a mass loss rate between 10^{-4} and 10^{-6} **M**(⊙)/yr. This phenomenon occurs at the OH-IR star phase and results in expulsion of the AGB envelope. Then, as the hot core is exposed, the very fast wind ($v \sim 2000$km/sec) appears with a mass loss rate of 10^{-7} to 10^{-8} solar masses per year. This wind can compress the previously ejected shell. Giant PN haloes are often interpreted as the remnants of a giant red envelope as buffeted by the superwind.

In the scenario of Kahn and Breitschwerdt (1990), the H+ gas accelerates the sluggishly moving neutral shell producing Rayleigh Taylor instabilities that can cause fragmentation of the shell. They conclude that this model can explain such phenomena as the bright inner ring, low ionization knots, and faint surrounding halo. The knots are regarded as transient features in a dynamical evolution. Much work remains to be done to really understand the vast differences between the smoothness of the Owl Nebula, NGC 3587, and NGC 7293 with its numerous small (~200 astr. units) ansae, presumably cold blobs (Dyson et al 1989). Some PNs show extremely intricate morphologies and kinematics. An example is Abell 78, whose chemical composition is a function of the distance from the PNN. The outflow is non-isotropic and collimated (Pismis 1989).

Fast winds from the central star were suggested 60 years ago by the Wolf-Rayet profiles in the spectra of NGC 40 and BD +30° 3639, but meaningful measurements were possible only with the IUE. Actual mass loss measurements depend on fundamental stellar parameters and are difficult to make (e.g., Cerruti Sola & Perinotto 1989). They give loss rates of 1.4 to 6.3 x 10^{-9} **M**(⊙)/yr for a sample of 5 well-observed PN. Sometimes, as in the PNN of Abell 78 (Kaler et al 1988), where $V \sim 2700$ km/sec, d**M**/dt = 4x10^{-9} **M**(⊙)/yr, the pattern is quite complex; there exists evidence for rebound shocks.

Can these winds affect the physical state as well as the dynamics of the PN? Apparently, they can. Analyses of the wispy giant halo of NGC 6543 by conventional diagnostics suggested an unlikely chemical composition difference between this envelope and the main ring. The discordance is removed if one supposes that a small fraction of the wind energy is expended exciting the halo (Middlemass et al 1989).

Very high excitation NGC 6302 which shows lines of 5 and 6-fold ionized silicon presents an even more dramatic case. Although a PNN with an unlikely temperature of 450,000° could explain the general level of excitation, Lame and Ferland (1991) found that a strictly photo-ionization model would not work in detail, while ionization in a post shock gas at T = 2,000,000°K plus radiation from a PNN at T = 200,000°K could explain the entire spectrum. Could coronal lines be observed in this PN?

Theoretical Nebular Models

Improving knowledge of nebular evolution and morphology now suggests we build better theoretical models. Heretofore, most PN models have been static structures although some workers, most notably Tylenda and Harrington, have investigated effects of time-dependent changes. Bobrowsky and Zipoy (1989) calculated spherically symmetrical kinematical models with a brisk stellar wind in which a molecular shell is exposed to a star that is turned on over a period of 100 to 1000 years. They treat it as a hydrodynamical problem with equations of motion, momentum and energy conservation, and dissipation of energy by the excitation of forbidden lines, etc. all taken into account. Energy input is primarily by photoionization of H although the influence of a stellar wind is also considered. Aware of advances in IR spectroscopy, they include H_2 emission predictions, as well as those of familiar ionic lines. Comparison with observations will require high-quality data. Observationally, one can estimate v(r) from line profiles of H, HeI, HeII, OIII, etc. by Sabbadin's method.

An attempt to explain the PN forms has been made by Icke et al (1992). They start with an intermediate mass star in its final evolutionary stages where it exhibits a slow, dense aspherical wind which is responsible for the toroidal ring. This stage is followed by a fast spherically symmetrical wind from the core. An extremely complicated hydrodynamical code is required to execute the calculations. Their attempt to explain the evolving shapes and morphologies - especially elliptical and butterfly formations, but not ansae - seems to be successful. Effects of different density distributions are most dramatic. The Icke et al theory needs to be extended to include radiative effects and to predict the spectrum. With a sufficiently powerful computer, the task is horrendously difficult but not intractable.

Central Stars of Planetary Nebulae

The fundamental parameters required for PNN are their temperatures (which require spectrophotometric measurements) and their luminosities (which require a knowledge of their distances). Magellanic Cloud data, when they can be acquired, are thus particularly useful. The chief limitation is imposed by object faintness and PN size.

The pattern of evolution seems well established by the work of Paczynski, of Schönberner, and of Wood and Faulkner. During the hydrogen burning phase, the initial evolution from the post-AGB stage is at constant luminosity. When the envelope becomes too small, H burning suddenly ceases and the main energy source becomes gravitational contraction. The luminosity now declines and the star begins to cool towards the white dwarf (WD) stage. Stars that burn He in their shells fade more slowly. The rate of evolution depends on the core mass. Below 0.57 $\mathbf{M}(\odot)$, a small decrement in the mass results in a large decrement in L. Very old PN, such as NGC 7293, may contain degenerate, essentially WD stars.

Theory gives an evolutionary time scale. If the PN distance is known, then from the measured rate of expansion in km/sec and the present angular size of the nebula one can deduce a dynamical age. McCarthy et al (1990) found significant discrepancies, e.g., the kinematical age of NGC 7009 was 7000 years, while its evolutionary age was only 1740 years. For a few PN, the kinematical age was less than the evolutionary age. They suggested that the discrepancy could be explained by having a small amount of residual envelope material remaining after the superwind mass-loss phase.

Accurate distances are necessary to resolve the problem of PNN masses. Most of them are generally regarded as falling in the mass range 0.55 to 0.60, although Kaler, Shaw and Kwitter (1990) find a much wider distribution with about 40% of their sample having masses in excess of 0.7 and 15% in excess of 0.8 **M**(⊙). From a sample of PNN for which they could get T(eff), log g, and spectroscopic parallaxes, Napiwotzki and Schönberner found masses in the rage 0.55 to 0.60 **M**(⊙) for stars for which Kaler et al had obtained much higher values.

Considerable justification appears to exist for Zanstra temperatures when they are properly interpreted. Jacoby and Kaler (1989), concerned with investigations of optically thick PN with a view to applications to galaxy distance determinations, measured Hβ and HeII 4686 fluxes to establish the UV fluxes for PNN shortward of 912A and 228 A respectively. You assume a V magnitude and get $T_z(H)$ and $T_z(He^+)$ as a function of V, defining a V (cross-over) such that $T_z(H) = T_z(He^+)$. The method can be calibrated on galactic PN for which the actual V(PNN) can be measured. If the PNN has a dense wind or powerful corona, the HeII Zanstra temperature could be falsified, at least in principle. For galactic PN, T(eff) can be found from model nebular parameters required to reproduce the observed spectrum.

Molecules and Dust

Molecular gas provides the link connecting AGB stars, post-AGB stars, proto-PN, and PN themselves. They supply important probes to evolutionary history and clues to complex morphologies, enabling us to investigate nebular stratification and dense clumps (10^4 to 10^5 atoms/cm^3) which cast shadows protecting fragile molecules from destruction by UV radiation. A PN starts out as a molecular cloud, typically between 0.1 and 1 solar mass, and of non-uniform density. It becomes exposed to the intense UV radiation of a defunct star, which destroys by photoionization most of the molecules present in the proto-PN. The molecular cloud erodes away as it is penetrated by UV quanta. In dense clumps where the density of H_2 molecules can attain $10^4/cm^3$, fragments like CN and HCN can persist (Howe et al 1992). CO is the hardiest of molecules. It is found in a number of mostly young, disk population PN with high N/O ratios and massive progenitors (Huggins & Healy 1989).

All PN with strong H_2 emission are N-rich objects with equatorial toroidal structures and faint bipolar extensions (Webster et al 1988). In NGC 2440 where T(★) ~ 350,000, V(wind) ~ 2000 km/sec, d**M**/dt ~ $3x10^{-7}$ **M**(⊙)/yr, the v = 1-0 S(1) line of H_2 which is strong in the position of the two intense clumps (Reay et al 1988) appears to be excited by winds. In most PN, excited H_2 is distributed the same as in the Hα + [NII] images. Emitting molecules lie in or close to the transition region between the neutral and ionized H gas. Generally it is believed that vibrational and rotational transitions of H_2 arise from thermal emission from a gas shocked by a brisk stellar wind. However, Dinerstein et al (1988) found strong lines in Hb12 originating from v = 1, 2, and 3 vibrational levels. These must be produced by fluorescence, not by thermal excitation. The dust/gas mass ratio which varies from PN to PN averages much less than in the ISM. Lenzuni et al (1989) suggest dust grains evolve during a PN's evolution, their size and total mass declining as the nebular radius increases. Perhaps they are ablated by the wind. Hydrogenated amorphous carbon grains appear to contribute to a diffuse emission band extending from 5500-8200A (Furton and Witt 1992).

Physical Processes

Progress in the interpretation of PN spectra depends on availability of accurate atomic parameters whereby we can investigate detailed physical processes, establish nebular diagnostics, determine abundances and examine evolutionary developments. Many references are listed by Aller (1990) and in the excellent review article by Peimbert

(1990). The great importance of the primordial helium abundance has stimulated much work on the He spectrum. The metastability of the 2^3 S and 2^1 S levels, which behave somewhat like pseudo ground levels, mandate attention to many collisional and radiative effects: Peimbert & Torres-Peimbert (1987), Clegg & Harrington (1989).

Accurate electronic collision strengths and A-values have long been required for nebular diagnostics; but in turn, PN data provides checks on these very same atomic data. Important contributions have been made by Seaton and his associates in London and by the Belfast group, including F.P. Keenan, C. T. Johnson, A. E. Kingston, V. M. Burke, D. J. Lennon, K. M. Aggarwal, E. Barrett, and C. D. McKeith.

The OIII Bowen fluorescent mechanism seems to play a role in many astrophysical sources: the solar chromosphere, interacting binaries, the x-ray source Sco X-1, and active galactic nuclei; but the lines are studied in PN with a minimum of interference. Studies by O'Dell et al (1992) and others show that charge exchange with OIV can be important and emphasize the need for detailed quantitative theoretical and observational work.

On the other hand, NIII lines, such as 4097, 4103, 4634, and 4640, long popularly attributed to the NIII Bowen fluorescent mechanism cannot thus arise (Kastner & Bhatia 1991). Ferland (1992) finds that direct continuum fluorescence gives an intensity prediction for 4634 in good agreement with the observations; this line may serve as a direct probe of the stellar continuum in the 374A region, thereby providing a check on model PNN atmospheres.

Chemical Abundances

The results of many investigations indicate the following: (1) There is a large scatter in the C,N,O abundances among galactic disk PNs. The N-rich (Peimbert's type I) constitute a distinct class, but there also exists C-poor objects where the C/O ratio < 0.1 of the solar value. Some C-rich PN also exist. (2) The disk <O/H> is about a half the solar value. In some PN, such as NGC 6537, the (p,O) cycle may convert O to N. Some of the discordance may be blamed on grain formations or T_ϵ fluctuations. (3) He and N are enhanced in Type I PN and C in many objects. Ne and heavier elements were not affected by nucleogenesis in PN progenitors. Some elements, such as Ca and Fe, are tied up in grains. (4) The Ne/O ratio is remarkably stable, ~0.17 by numbers. (5) The N/O ratio is constant up to a core mass **M**(PNN) of about 0.65. Thereafter, it seems to rise with core mass for awhile or at least with T(PNN). N was produced more copiously in massive stars. (6) Comparison of C/H, O/H, and N/H ratios in PNs with red giants show many facets of similarity but some differences suggesting that the PN material may come from subsurface layers of AGB stars. (7) The CNO cycle and He burning produce most of the C and N in PN. O, largely, and all heavier elements come from the interstellar medium at the epoch of formation of the progenitor stars; the lower the metallicity and mass of the progenitor stars, the lower the N abundance.

Broad surveys of abundances carried out by R. B. C. Henry (1989), Perinotto (1991), and by Henry et al (1989), and by Dopita and Meatheringham (1991) in the Magellanic Clouds show that the C/H, N/H, O/H. and He/H correlations and anti-correlations follow expectations of nucleogenesis theory, at least qualitatively, although improvements in theories of element building are needed.

These broad statistical surveys are invaluable in establishing global patterns, but at some stage we will need more accurate data for individual PN's for which specific nuclear scenarios can be worked out. On the one hand, we need accurate spectrophotometric data over a wide wavelength range and on the other, fairly sophisticated models calculated eventually for an evolving PN. For NGC 7027, I compare 3 abundance estimates as obtained by Keyes et al (1990), Middlemass (1991) and Hyung with similar observational data. We normalize to N(H) = 10,000.

el.	**He**	**C**	**N**	**O**	**Ne**	**Mg**	**S**	**Cl**	**Ar**
K.	1100	6.9	1.3	3.1	1.0	0.26	0.071	0.002	0.021
M.	1000	13.0	1.9	5.5	1.1	0.21	0.086		0.025
H.	1000	8.5	1.8	4.6	0.9	0.20	0.10	0.0028	0.025

For some elements the discordances are still too large. Care must used with the observations. Fluxes of stronger lines often pertain to the integrated PN image, but for weaker lines we often employ a pencil beam through the image (Aller 1990).

Planetary Nebulae in the Galactic Center and in Other Galaxies

Great emphasis has been placed on PN in the galactic center, in the Magellanic Clouds and other galaxies. We give up spatial resolution, accept small fluxes, but have the advantage of dealing with a sample at a known distance, thus avoiding the worst problem in galactic PN research.

Extensive studies by Pottasch and collaborators and by Stasinska et al (1991) suggest that the total number of galactic bulge PNs is about 600-700, <M(PNN)> = 0.593. Pottasch (1990) finds the distance to the galactic center to be in harmony with that found by other methods, somewhere near 7.5 to 7.8 kpc.

Various observers have carefully studied PNs in the Magellanic Clouds: Dopita and Meatherington measured PN masses, constructed HR diagrams for PNN and obtained nebular parameters and chemical compositions. Most of the PNN seem to have been caught on the H burning excursion to high temperatures, their T(eff) agreeing well with T(Zanstra). They find a huge range in PN masses. One of the most interesting objects in the SMC is the X-ray source, N67, investigated by Qinde Wang (1991).

The greatest of PN paradoxes is that although distances of individual local objects are hard to get, these nebulae yet serve as one of the most useful of standard candles for determining the distances of galaxies more remote than 10 Mpc. The reason is that the PN luminosity function is remarkably stable from galaxy to galaxy. The method is insensitive to the color or Hubble type of the host galaxy (Jacoby et al 1990), although metallicity may have a small effect (Ciardullo and Jacoby 1992). With modern methods special filters to isolate the [OIII] lines, etc., a group of PN can be measured in a galaxy, such as M8I, and a luminosity function constructed and compared with that of a nearby galaxy of known distance, such as M31.

Thus planetary nebulae have paid off in a big way. Once regarded only as useful objects for visitors nights and for testing physical theories of atomic processes, they have emerged as a window of the last days of an ordinary star, as probes for stellar nucleosynthesis processes, and lastly, as yardsticks for measuring the nearby universe. The preparation of this summary was aided in part by National Science Foundation grant NSF AST 90-14133 to UCLA.

REFERENCES

Acker, A., Stenholm, B., Tylenda, R. (1989), Astr.& Ap.Suppl., **77**, 487.
Aller, L.H. 1990, PASP, **102**, 1097.
Balick, B. 1987, Astron.J., **94**, 671.
Bobrowsky, M. & Zipoy, D.M. 1989, Ap.J., **347**, 307.
Bond, H.E. & Livio, M. 1990, Ap.J., **355**, 568.
Ciardullo, R. & Jacoby, G. 1992, Ap.J., **388**, 208.
Clegg, R.E.S. & Harrington, J.P. 1989, **239**, 869.

Dinerstein, H., Lester, D., Carr, J., & Harvey, P. 1988, Ap.J., **327**, L27.
Dopita, M. & Meatheringham, S. 1991, Ap.J., **367**, 115.
Dyson, J.E., Hartquist, T.W., Pettini, M. & Smith, L.J. 1989, MNRAS, **241**, 625.
Ferland, G.V. 1992, Ap.J., **389**, L63.
Furton, D.G. & Witt, A.N. 1992, Ap.J., **386**, 587.
Henry, R.B.C. 1990, Ap.J., **356**, 229.
Henry, R.B.C., Liebert, J., & Boronson, T.A. 1989, Ap.J., **339**, 812.
Howe, D.A., Millar, T.J. & Williams, D.A. 1992, MNRAS, **255**, 217.
Huggins, P.J. & Healy, A.P. 1989, Ap.J., **346**, 201.
Icke, V., Balick, B., & Frank, A. 1992, Astr.& Ap., **253**, 224.
Jacoby, G., & Kaler, J.B. 1989, Astron.J., **98**, 1662; Ap.J. **345**, 871.
Jacoby, G., Ciardullo, L., & Ford, H., 1990, Ap.J., **356**, 332.
Jacoby, G., Walker, A.R., & Ciardullo, R., 1990, Ap.J., **365**, 471.
Jura, M., 1992, Astr.Ap.Reviews, **2**, 227.
Kahn, F.D. & Breitschwerdt 1990, MNRAS, **242**, 505; **244**, 521, 526.
Kaler, J.B., Feibelman, W.A., & Henrich, H.F. 1988, Ap.J., **324**, 528.
Kaler, J.B., Shaw, R.A., & Kwitter, K.B. 1990, Ap.J., **359**, 392.
Kastner, S. & Bhatia, A.E. 1991, Ap.J., **381**, L59.
Keyes, C.D., Aller, L.H., & Feibelman, W.A. 1990, PASP, **103**, 59.
Krishna, M., Apparao, V., & Tarafdar, S.P. 1989, Ap.J., **344**, 826.
Lame, N.J. & Ferland, G.J. 1991, Ap.J., **367**, 268.
Lenzuni, P., Natta, A., & Panagia, N., 1989, Ap.J., **345**, 306.
Masson, C.R. 1989, Ap.J., **346**, 243.
McCarthy, J.K., Mould, J.R., Mendez, R.H., Kudritzki, R.P., Husfeld, D., Herrero, A. & Groth, H. 1990, Ap.J., **351**, 230.
Middlemass, D., 1990, MNRAS, **244**, 294.
Middlemass, D., Clegg, R.E.S. & Walsh, J.R. 1989, MNRAS, **239**, 1.
Miranda, L.F. & Solf, J. 1991, Astr.& Ap., **252**, 331.
Morris, M. 1990, From Miras to Planetary Nebulae, ed. M. Mennessier, France, Editions Frontieres, p. 520.
Napiwotzki, R., & Schönberner D. 1990, Toulouse White Dwaric Workshop.
O'Dell, C.R. & Miller, C.O. 1992, Ap.J. **390**, 219.
Pascoli, G. 1990, Astr.& Ap., **232**, 184.
Peimbert, M. 1990, Rep.Prog.Phys., **53**, 159.
Peimbert, M., Torres-Peimbert, S., 1987, Rev.Mex.Astr.Astrofis., **15**, 117.
Perinotto, M. 1991, Ap.J.Suppl., **76**, 687.
Pismis, P. 1989, MNRAS, **237**, 611.
Pottasch, S.R. 1990, Astr.& Ap., **236**, 231.
Pottasch, S.R. & Zijlstra, A.A. 1992, Astr.& Ap., **256**, 251.
Reay, N.K., Walton, N.A., & Atherton, P.D. 1988, MNRAS, **232**, 615.
Sabbadin, F. 1986, Astr.& Ap., **160**, 31.
Sahal, R., Wootten, A., Schwarz, H.E., & Clegg, R.E.S. 1991, Astr.& Ap., **251**, 560.
Shaw, R.A. & Kaler, J.B. 1989, Ap.J.Suppl., **69**, 495.
Stasinska, G., Fresneau, A., Gameiro, G., Acker, A. 1991, Astr.& Ap., **252**, 762.
Wang, Qinde 1991, MNRAS, **253**, 47P.
Webster, B.L., Payne, P.N., Storgy, J. & Dopita, M. 1988, MNRAS, **235**, 533.
Zhang, C.Y. & Kwok, S. 1990, Astr.& Ap., **237**, 479.
Zhang, C.Y. & Kwok, S. 1991, Astr.& Ap., **250**, 179.