ELEMENTAL ABUNDANCES IN PLANETARY NEBULAE

James B. Kaler
Astronomy Department
University of Illinois

1. ELEMENTAL CLASSIFICATION AND MEAN ABUNDANCES

To date, we have been able to gather information on the abundances of 16 elements, ranging from helium to iron, relative of course to hydrogen, the seventeenth. Of the lightest 26 elements only the lithium, beryllium, boron trio, aluminum, and the quintet of metals from scandium to magnanese have not been treated. The results of decades of labor on galactic planetaries are presented as succinctly as possible in Table 1, where the elements are shown in order of atomic number. I will take as a general approach that He/H and O/H have readily recognizable gradients and variations, and that the other elements either generally vary in concert with oxygen, or are best studied with respect to that atom. Column (2) classifies the element according to its most prominent behavior. The well-studied ratios that are generally constant, for which a true mean can be derived, are designated "C." Those that are probably constant, but which are not well studied, are noted as "c." The four elements with abundances significantly under solar, which are probably depleted from the nebular gas by grain formation, are called "D." The letters "G" and "E" denote those for which vertical galactic gradients and/or enrichment by the parent star have been clearly established.

The mean ratios that I adopt are given in the third column, with the reference sources in the fourth. In some instances, I take the mean from a specific reference, in others it is derived from the various values given by a group of authors. The papers in each of the groups are listed at the end of the table. They consist of: (1) a group headed by Aller; (2) an ultraviolet group, all of which present results derived from the IUE; (3) a set of 4 papers in which iron abundances were studied; (4) a collection in which the three extreme halo nebulae were examined; and finally (5) a general collection. The fifth column of Table 1 gives alternate values where the term "all ref" refers to all the reference groups following the table. Finally, the solar abundances, taken from the compilations in the Aller group, are given in column 6.

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Table 1. Summary of galactic planetary abundances, and references

Ratio (1)	Type (2)	Abundance (3)	Reference (4)	Other (5)	Solar (6)
He/H	G-E	0.08-0.10-0.22	Kaler (1978a,1979)		0.10
O/H	G	0.6(-4)*-6(-4)	Kaler (1980)		7.4(-4)
C/O	E	0.4-4:	Kaler (1981a)	0.4-3(UV group)	0.6
N/O	G-E	0.13-0.2-2	Kaler (1979)		0.12
F/O	c	8.5(-4):	Aller group		5(-5)
Ne/O	C	0.225±0.01	Kaler (1978b)	0.23 (all ref)	0.15
Na/O	c	3.2(-3)	Aller group		2.6(-3)
Mg/O	D	2(-3)	Harrington & Marionni (1981)		5.4(-2)
Si/O	D	1.3(-2)	Aller group		6.0(-2)
P/O	c	4(-4)	Aller group		4.6(-4)
S/O	C	2.7±0.5(-2)	Beck et al.(1981)	2.3(-2)(all ref)	2.3(-2)
Cℓ/O	C	3.3±0.5(-4)	Kaler (1978b)	4.2(-4)(all ref)	4.3(-4)
Ar/O	C	7.0±0.5(-3)	Kaler (1978b)	6.3(-3)(all ref)	5.0(-3)
K/O	c	2.5(-4)	Aller group		1.9(-4)
Ca/O	D	2.6(-4)	Aller group		3.0(-3)
Fe/O	D	2(-3)	iron group		5.1(-2)

* includes extreme halo

C: constant with respect to oxygen -- well studied; c: probably constant with respect to oxygen -- sparsely studied; D: probably depleted; E: enriched by nuclear processes in parent star; G: recognized vertical gradient; G-E: enriched matter compounded by vertical gradient -- 3 values give minimum halo, minimum disk, maximum enriched.

References to Table 1

(1) Aller group: Aller (1978); Aller and Czyzak (1983); Aller and Keyes (1980)*; Aller, Keyes, and Czyzak (1981)*; Aller, Keyes, Ross, and Czyzak (1980)*; Aller, Keyes, Ross, and O'Mara (1981a)*; Aller, Ross, Keyes, and Czyzak (1979); Aller, Ross, O'Mara, and Keyes (1981)*; Shields, Aller, Keyes, and Czyzak (1981)*. (2) UV group: Aller group marked with *; Harrington, Lutz, and Seaton (1981); Harrington, Lutz, Seaton and Stickland (1980); Harrington, Seaton, Adams, and Lutz (1982); Lutz (1981); Marionni and Harrington (1981); Peña and Torres-Peimbert (1981); Perinotto and Benvenuti (1981); Perinotto, Panagia, and Benvenuti (1980); Pottasch, Gathier, Gilra, and Wesselius (1981); Torres-Peimbert, Peimbert, and Daltabuit (1980); Torres-Peimbert and Peña (1981); Torres-Peimbert, Peña, and Daltabuit (1981). (3) Iron group: Garstang, Robb, and Rountree (1978); Nussbaumer and Storey (1978); Shields (1975, 1978); Shields, Aller, Keyes, and Czyzak (1981); (4) Halo group: Barker (1980a); Hawley and Miller (1978a); Peimbert (1973); Torres-Peimbert and Peimbert (1979); Torres-Peimbert, Rayo, and Peimbert (1981); (5) General: Barker (1978a, 1978b, 1980b); Beck, Lacy, Townes, Aller, Geballe, and Baas (1981); Dinerstein (1980); French (1981); Hawley (1978a); Hawley and Miller (1977, 1978b); Marionni and Harrington (1981); Natta, Panagia, and Preite-Martinez (1980); Peimbert and Torres-Peimbert (1971); Price (1981); Torres-Peimbert and Peimbert (1977).

Single averages of course have little meaning for the 4 elements designated G or E, for which I give minima and maxima. In the case of the G-elements, they represent the mean initial halo and initial extreme disk values, where the three extreme halo objects discussed in this symposium by Barker are included only for O/H. For the E-elements they show the mean initial extreme disk abundance and the maximum observed value caused by stellar enrichment processes. Three numbers - minimum halo, minimum disk, and maximum observed - are given for helium and nitrogen, which exhibit both gradients and enrichments. The G and E elements will be discussed in separate sections below; here we look further at the C and D ratios.

There is a strong body of evidence from the references of Table 1 that neon, argon, chlorine, and sulfur are generally constant with respect to oxygen. There are exceptions, notably the extreme halo objects mentioned above, which generally exhibit depressed neon, argon, and sulfur abundances: see Peimbert's discussion in this volume, and a summary by Torres-Peimbert, Rayo, and Peimbert (1981). The problem of gradients for these element ratios merits further study, as there may be variation within the present observational scatter. The means derived are generally better than the solar determinations, and might logically be included in tables of "solar system values."

The study of flourine, sodium, phosphorus, and potassium is not far enough along really to define an accurate mean, and no data on gradients exist except by analogy with other elements. The four elements designated D do seem to show real deficiencies when compared with the solar ratios, probably caused by depletion of the atoms out of the gas phase into grains. The concept of an average value then means little, since depletion factors certainly vary among nebulae.

2. GALACTIC GRADIENTS

A capsule history of galactic composition gradients: Kaler (1970) found that O/H increased with decreasing radial velocity and distance from the galactic plane; Barker (1978a), however, observed no correlation between his set of objects and galactic kinematics; Torres-Peimbert and Peimbert (1977) noted negative radial gradients in He/H, O/H, and N/O; Peimbert (1973) showed that the extreme halo planetary in M15 was deficient in oxygen, by an order of magnitude; this result was confirmed and the work extended to other elements and to the other two extreme halo nebulae by the "halo group" of references following Table 1; and a series of papers by Kaler (1978a, 1979, 1980, 1981b) re-examined the data with regard to both vertical and radial gradients. The principal results of this series are that: (1) initial He/H increases by about 25% from the general halo (the set of high-velocity nebulae exclusive of the 3 extreme objects), to the extreme disk; (2) N/O increases by very roughly 50% in the same manner; (3) O/H increases steadily from the extreme halo (including the three) to the disk in a recognizable series of steps; (4) S/O is constant.

In this set of papers, I contended that radial gradients could not be perceived from the planetaries; that since the majority of nebulae at large radial distances are population II, the radial gradients are only apparent, and are reflections of the vertical gradients. Peimbert (1978) and Peimbert and Serrano (1980), however, claimed to detect radial gradients from a homogeneous set of objects. The vertical gradients in N/O, He/H, and O/H seem to be in little doubt. Almost certainly, the radial gradients are present, as witnessed by the work on diffuse nebulae by, for example, Peimbert, Torres-Peimbert and Rayo (1978), Talent and Dufour (1979), and Hawley (1978b). But it is unclear as to whether they can be detected in planetaries at the present time. For helium and nitrogen, the issue is in addition confused by enrichment processes that are, like population types, related to stellar mass. We need a much larger statistical sample to resolve the problem fully. The very high O/H ratio found by Price (1981) in a bulge planetary provides an interesting direction towards future research.

Another point of contention involves the heavier elements. While Kaler (1981b) claimed constancy for S/O, Hawley and Miller (1978a) and Torres-Peimbert and Piembert (1979) indicated a large deficiency in the extreme halo nebula Ha 4-1, which I saw as a possible ionization effect. Yet the papers of the halo group of references indicate similar deficiencies in neon and argon, for which constancy is assumed in the previous section. These nebulae seem genuinely different, and the "C" indication in Table 1 should for now exclude the 3 planetaries of the extreme halo.

3. ELEMENT ENRICHMENT

It is now very clear that the by-products of nuclear burning find their way into the nebula, having been injected into the hydrogen envelope of the parent AGB star before nebular lift-off. Peimbert and Torres-Peimbert (1971) found nitrogen to be commonly overabundant in planetaries, and Kaler (1974) saw that helium could be heavily enriched. The results are far from complete on carbon, but there is strong evidence that enrichment takes place. This phenomenon gives us a superb opportunity to examine internal processes in stars, and to test the general theories of mass loss and the late stages of stellar evolution. In principle, it should be possible to infer the mass of the parent star from the degree of element enrichment, and thereby possible to relate current properties of nebulae and central stars to initial properties.

The prevailing theoretical view is that element enrichment proceeds in a succession of three convective dredge-up stages, detailed for us by Becker and Iben (1979, 1980, hereafter BI) and Renzini and Voli (1981, hereafter RV), following discoveries and ideas by Iben (1964, 1972, 1975), Iben and Truran (1978), and Perinotto and Renzini (1979). The first stage takes place on the first ascent of the red giant branch, the second for stars over ~ 3 $M_\odot$ on the AGB, and the third during the thermally pulsing phase of AGB evolution. In the first stage, N is increased, in the second He and N, and in the third, He and C, while in the absence of other processes the net N abundance goes down.

The theoretical predictions of element overabundances can be readily tested with the observations. Peimbert (1978) pointed out that high enrichment rates of nitrogen and helium went together in his type I nebulae, which are derived from the more massive stars of the galactic disk. Kaler, Iben, and Becker (1978) then showed that nitrogen and helium abundances were generally correlated, in numerical agreement with the theory through the first two dredge-up stages, the observed correlation terminating in the type I objects. However, both BI and RV demonstrate that the agreement is not good after the calculations for third dredge up are included: theoretical N/O changes little with increasing He/H, while the observed steadily increases. And Kaler (1981a) noted that C/O did not climb with He/H in accord with BI's theory. Either third dredge-up does not work as predicted, or as pointed out by BI and RV, the excess carbon is reconverted to nitrogen; BI also invoked grain formation to deplete gaseous carbon.

This review affords us with a good opportunity to look at an improved version of the correlations, and a simultaneous examination of N/O, C/O, and He/H, to see whether or not we can find a consistent set of calculations, and make a choice as to the true theoretical scenario. I have revised and improved the abundance determinations from the previously published values (Kaler 1978a, 1979, 1981a) as follows:

Helium. All of the interference filter measurements made of He/H at Illinois were corrected for temperature shifts of the filters, which on the average produced both increases and decreases on the order of 10%. The new values were then re-averaged with He/H derived from the other good data, particularly from Barker (1978c), Torres-Peimbert and Peimbert (1977), and Aller and Czyzak (1979, 1983).

Nitrogen. The major improvement was to add in the N/O ratios derived by observers in the UV group of references of Table 1, and to include the new data by Aller and Czyzak (1979, 1983).

Carbon. This element provides an especially difficult problem. Only one line is extensively observed in the optical, recombination λ4267 CII, and serious errors can be made in extrapolating C/O from an ionic C^{2+}/O abundance, even with the use of models. Better results should be had from the ultraviolet data, where the collisionally excited lines are presumably better understood, and where up to 3 ions can be observed. But the UV analyses have other severe difficulties. The energies of the excited levels are so high that the derived abundances are extremely sensitive to the adopted electron temperature. Kaler (1983a) shows that $T_e(C^{2+})$, derived from λ1909 CIII] and λ4267 CII and the currently accepted atomic parameters, averages 1500 K less than T_e[OIII], and a change of only 1000 K can lead to a factor of two change in abundance. In addition, there is a problem with absorption of the UV line photons by dust (Harrington, Lutz and Seaton

1981). Generally, the optical data give abundances significantly higher than the UV, where differences could be ascribed to a combination of the above problems, in addition to inadequate atomic data, particularly from the recombination cascade analysis.

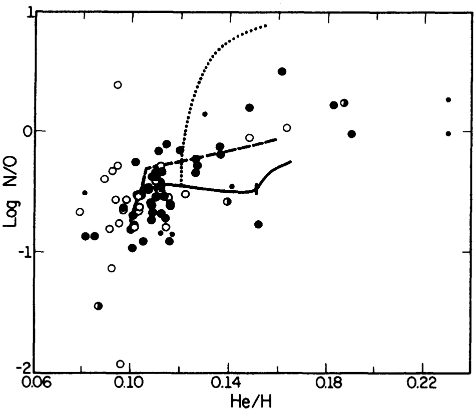
I approached the problem (Kaler 1981a) by deriving relative C/O ratios from λ4267 CII, an adopted ionization curve, and an empirical correction for electron density, followed by a scaling of the results to those derived from the UV. That way, we could look at a larger statistical sample that should on the average be accurate, albeit with large individual errors. The method assumes that errors in the UV results, caused largely by uncertain electron temperatures, average out in the scaling process. The wealth of new UV carbon abundances now available allows a significant rescaling of the above optical C/O ratios. From comparison with the results of the UV group (Table 1), the Kaler (1981a) C/H and C/O ratios should be raised by a factor of 1.6, or 0.2 in the log. In addition, I have codified the technique into analytic expressions:

$$\log C/H = -3.15 + 0.14 \log t + \log I_c(\lambda 4267) + 0.4465E + 0.6124E^2 + 0.469 \log x \qquad (1a)$$

$$\log C/H = 114.73 + 0.14 \log t + \log I_c(\lambda 4267) - 49.66 \log T_* + 5.211 \log T_*^2 + 0.469 \log x, \qquad (1b)$$

where equations (1a) and (1b) are to be used for nebulae with and without He II lines respectively. In the above, $t = 10^{-4}\,T_e$ (electron temperature), I_c is the intensity of λ4267 CII $[I(H\beta) = 100]$ corrected for reddening, $E = He^{2+}/He$, T_* is the central star temperature, and $x = 10^{-4}\,N_e/\sqrt{t}$, where N_e is the electron density. The final improved abundances were derived from these equations, and include some new data from the references of Table 1. The resultant C/H (or when combined with O/H, the C/O) are still smaller than C^{2+}/H calculated directly from λ4267 and recombination theory, demonstrating the persistent problem between the optical and UV.

The results of the reanalyses are presented in Figures 1 and 2, where log N/O and log C/O are plotted against He/H. In both figures, population I nebulae (see Kaler 1978a) are plotted as filled symbols, population II as open. In Figure 3, the optically derived (scaled) C/O ratios are plotted as circles, the UV-derived ratios as X's. With the improved abundances, the correlation between N/O and He/H is even clearer than before. N/O first increases rapidly with He/H (or may be even independent of He/H), then at He/H ≈ 0.12 it increases at a much slower rate as He/H climbs to a maximum of ≈ 0.20. The C/O ratios, however, show very little trend with He/H: there is too much scatter. Interestingly, the spread for the UV results is the same as that for the optical, implying that if there really is a valid theoretical relationship between C/O and He/H, the two methods are of similar reliability.



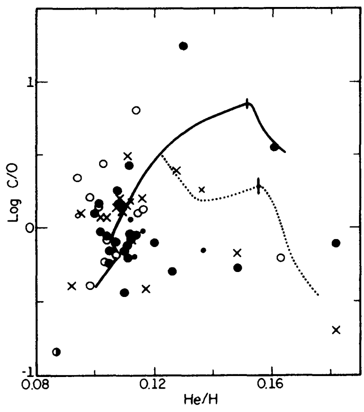


Fig. 1. Log N/O plotted against He/H. Filled symbols: Pop. I; open symbols: Pop. II; solid curve: mean of predicted values from BI and RV through the 3rd dredge-up; dotted curve: RV with envelope burning; dashed curve: BI with conversion of C to N at 1/2 the full rate.

Fig. 2. Log C/O plotted against He/H. The symbols and curves have the same meaning as in Fig. 2. Circles: C/O derived from λ4267 CII; X's: C/O derived from ultraviolet data. The analog to the dashed curve of Fig. 2 lies near the solid curve.

A summary of the theoretical predictions by BI and RV for Population I is shown by the curves in Figures 1 and 2. The solid lines give the average from BI and RV of the abundances expected after all three dredge-up cycles, with no further processes (i.e. excluding RV's burning in the convective envelope). Clearly, the curve in Figure 1 does not fit the well-defined observational relation. If the third dredge-up (which destroys the successful relation demonstrated through the second phase by Kaler, Iben and Becker 1978) is valid then, as BI point out, there must be some mechanism of reconverting the dredged carbon to nitrogen. RV accomplish this by their scheme of envelope burning, which produces the dotted curve, and which fits even more poorly. The best fit is obtained by BI, where they assume that carbon is converted to nitrogen at 1/2 the full rate given by their equation (19), which has little effect on the carbon abundance. This curve, which passes nicely through the points in Figure 1, is similar to, and about 0.1 dex above, the curve through the second dredge-up, and cannot be observationally distinguished from it. Addressing Figure 2, we find that the observations cannot yet distinguish among any of the curves, including that through the second dredge-up (not shown), which is a flat line. Grain formation, as suggested by BI, may certainly be important.

In summary on this topic, the observations will support a theory that incorporates a modest reconversion of carbon back to nitrogen in the convective envelope. Observationally, we must improve the statistics of both the presentations of Figures 1 and 2, the former for comparison with the distribution predicted by an initial mass function, and the latter (for now) to see whether there is any correlation at all. The data, especially in Figure 2, are very strongly affected by observational selection, since we observe only bright nebulae in the UV, or those in the optical with already strong λ4267 CII. Many more observations are needed of λ4267 to reduce the scatter, and to improve the statistics at high He/H. It is particularly important to obtain total CII fluxes free from stratification effects. Theoretically, we need to explain the high He/H ratios that fall beyond the curve, and it would be of great aid if models could be calculated that incorporate the proper physics of C to N conversion during the thermal pulsing phase, in order to avoid the ad hoc assumption used by BI.

4. ABUNDANCES AND THE EVOLUTION OF PLANETARY NUCLEI

Here we shall look more specifically at the relations between abundances and the general evolution of central stars. Perhaps the most exciting development in this area was the discovery in two planetary nebulae of embedded zones or knots that consist of nearly pure helium: Abell 30 (Hazard et al. 1980), and Abell 78 (Jacoby and Ford 1982). Both the central stars exhibit strong mass outflow, as indicated by powerful P-Cygni lines (Greenstein 1981, Heap 1979). The stars have evidently removed their entire hydrogen envelopes, and are now releasing matter from the helium rich cores themselves. Iben et al. (1983) suggest that these stars are remnant cores that suffered a final thermal pulse while they were on the cooling track of their initial passage through the log L - log T plane, which forced them to brighten and repeat their earlier evolutionary tracks. Detailed abundance analyses like that of Jacoby and Ford (1982) will provide further superb means for examining stellar evolutionary processes. We do not know how common objects of this sort may be.

On a more general aspect of the subject, Renzini (1979) and Iben and Renzini (1982) predicted that overabundances in planetaries should correlate with the position of the central star on the log L - log T plane, as a consequence of both stellar evolution and dredge-up theories. Stars of high initial mass will produce nuclei of higher core mass, which because of evolutionary time-scales, will be seen generally on their cooling tracks on the lower left of the log L - log T plane; these are the stars that should have enriched their nebulae the most via convective dredge-up. Even if we ignore the time-scale argument, we would expect that central stars of high core mass should have nebulae with high N/O and He/H. And that is indeed what we find. Figure 3, taken from Kaler (1983b), shows the placement on the log L - log T plane of the central stars of large nebulae ($r > 0.175$ pc) with known N/O. The trend is very clear: half the stars with core masses $> 0.6\ M_{\odot}$ have nebular N/O ≥ 1, whereas there are none with core mases $< 0.6\ M_{\odot}$. The true situation may be more complex than predicted, however. Taken at face value, Figure 4 shows a mix of N/O for higher core mass, suggesting that the relations among overabundances, core masses, and initial masses may not be simple and monotonic. This problem is bound up with difficulties in the placement of the stars on the plane, and with the planetary distance scale: see Kaler (1983b) for a detailed discussion.

Finally, we see a strong relationship between overabundances and nebular structure or morphology. Peimbert (1978) noted that the type I nebulae, those with extreme N/O and He/H, "comprise an extreme subset of Greig's (1971) class B," nebulae with a bi-lobed, apparently toroidal structure. This relation is confirmed and broadened by Figure 4, also taken from Kaler (1983b), which shows N/O for the large nebulae plotted against the geometric filling factor, ξ, with only one nebula overlapping with Peimbert's set. This filling factor is a measure of the solid angle with which a nebula appears to surround its star, and is intimately connected with the Greig classification: nebulae with $\xi < 1$ are his class B. Since Kaler (1983b) further shows that the low-ξ nebulae are related to high core mass, the range in N/O for $\xi \approx 0.5$ is analogous to the range seen directly for higher core mass in Figure 3. The nebular abundances show large-scale agreement with theoretical predictions, and general consistency among theories of

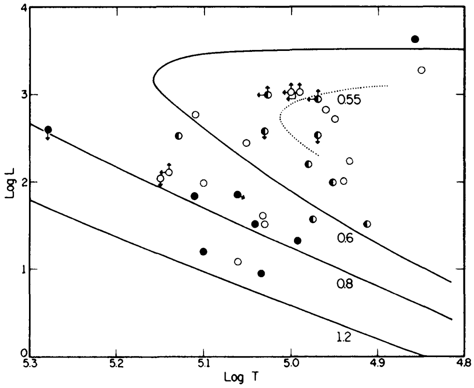


Fig. 3. The central stars of large planetaries (r > 0.175 pc) with known N/O on the log L - log T plane. Open symbols: N/O $\leq$ 0.4; half-filled sybmols: 0.4 < N/O < 1; filled symbols: N/O $\geq$ 1. Solid curves: evolutionary tracks for 0.6, 0.8, 1.2 $M_{\odot}$ from Paczyński (1971); dotted curve: extrapolated track for 0.55 $M_{\odot}$ from Schönberner and Weidemann (1981).

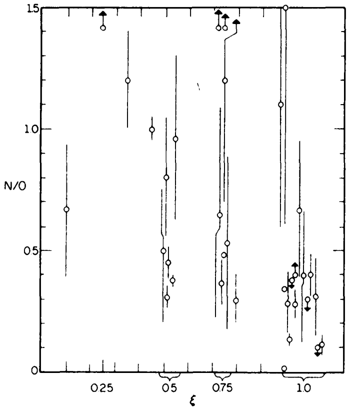


Fig. 4. N/O for large planetaries plotted against ξ, the geometric filling factor, a measure of morphology. Nebulae with $\xi < 1$ are generally Greig class B.

stellar evolution, convective dredge-up, and mass loss. But much more observational and theoretical work is needed before agreement in detail can be attained.

5. EXTRAGALACTIC NEBULAE

No generalized statements comparable to those above can yet be made about abundances in extragalactic planetaries, simply because of the paucity of data and the severe observational selection: only the very brightest nebulae have been observed. The Magellanic Clouds of course are the best studied: see in particular papers by Osmer (1976), Webster (1976), Dufour and Killen (1977), Aller et al. (1981b), and Maran et al. (1982). Results are consistent with those derived from galactic planetaries: O/H is similar to that found in the LMC and SMC diffuse nebulae, and there is a range in He/H and N/O, demonstrating that dredge-up processes are at work. The three nebulae studied by Maran et al. (1982), which show large overabundances in N/O and C/O (the latter particularly in the SMC) relative to the ambient interstellar medium, are shown by Stecher et al. (1982) to have high mass cores ($\approx 1\ M_\odot$), consistent with the galactic objects displayed in Figure 3. Looking farther afield, abundances are available for planetaries in M32 (Jenner, Ford, and Jacoby 1979), the Fornax dwarf (Danziger et al. 1978), and NGC 6822 (Dufour and Talent 1980). The latter again displays large N/O (≈ 5) and He/H (≈ 0.19).

As the observations improve, and as we can probe to fainter nebulae, it will be interesting to see how the correlations between abundance ratios might differ among galaxies, and how the dredge-up processes are influenced by different initial abundances. There are interesting possibilities in the comment by Jenner, Ford and Jacoby (1979) that the planetaries in M32 have consistently stronger [NII] lines than do those in other elliptical galaxies. There is certainly no lack of work, both on other galaxies and in our own, to keep us occupied.

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SEATON: Can we rule out the possibility that C and O are depleted, owing to grains? The interpretation of infrared features (silicates and carbides) rests on the assumption that CO takes all the O for $C/O > 1$, all the C for $C/O < 1$. If that is correct, one might expect depletion.

KALER: That is certainly a possibility, which Becker and Iben invoked to explain the lack of agreement with theory.

PAGEL: How much of the excess nitrogen is a primary nucleosynthesis product? Some extragalactic PN have been found to have enormous overabundances of N relative to surrounding H II regions.

PEIMBERT: Most PN show $N/O < -0.30$ dex and for them it is very likely that most of the excess N is of secondary origin, produced during the first dredge-up episode. For PN of type I, those with $N/O > -0.3$ dex, a substantial fraction of the excess N is of primary origin, typically about two thirds.

TERZIAN: You indicated that several PN have unacceptably high helium abundances. There certainly are severe theoretical difficulties in explaining such high abundances. Is it possible that the observations are wrong?

KALER: Some may be. One nebula is NGC 7293, which the Peimberts have now found to have lower N/O and He/H than previously believed. Another, NGC 6537, has large errors associated with it; but others, such as NGC 6302, are well observed.

ALLER: We are trying to make detailed measurements of N-rich objects like Hu 1-2, NGC 6537, and NGC 6445 to help clarify the nitrogen problem and He/H ratio, which is indeed important. The carbon abundances derived from either λ 4267 or ultraviolet lines cover a wide range, as your slide showed. We find $\langle\log(C/H)\rangle_{4267} - \langle\log(C/H)\rangle_{UV} \approx 0.1$, so the discrepancy between the λ 4267 and ultraviolet results is lowered but not removed.