SYMPOSIUM CONCLUSIONS I

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As I am sure you realize I cannot really give you conclusions, I can only give you my own impressions of this conference; George Field will give you his impressions, and you must draw your own conclusions from all that you have heard here.

Dr. Terzian listed a whole series of questions at the beginning of this Symposium, largely having to do with the evolution of stars. They are all questions we certainly would like to answer. Many of the answers however are still obscure and in general I think at a Symposium like this we tend to get the impression that there are a lot of obscurities. However, before getting into the obscurities, I would like to mention a few things we do know. We basically know what planetary nebulae are, that is to say, we know what most of the objects we call planetary nebulae are. And where they fit into the evolutionary picture -- they are shells of gas, photoionized by hot stars in the post red-giant, pre-white dwarf stages of evolution of a fairly abundant type of star, probably in the mass range of 1 to 3 $M_{\odot}$. But there certainly are lots of details that remain.

The distance scale of the planetary nebulae within our galaxy was discussed by Mme. Acker. Her work included the careful collection of a large amount of data -- particularly, selection of planetary nebulae that are Population I-like objects, and attempts to get the most accurate distances for the best cases by kinematic methods, and particularly by interstellar extinction measurements. From these selected cases she derived correction factors to all the existing published distance scales of planetaries, and drew up a list of the best distances which I am sure will be very valuable for future research. Yet, I must confess that the dissimilarities in the appearances of planetary nebulae make me doubt that any single planetary-nebula distance will be determined to better than a factor, say, of two, by magnitude or surface-brightness measurements. This uncertainty makes the space density of planetary nebulae very difficult to determine to a high degree of accuracy. I think that to press arguments that depend on the last decimal place of the space density of planetary nebulae is not really going to work out. I would also say that I think that whenever comparisons are

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made between different kinds of measurements of planetary nebulae, for instance infrared and Lyman α, it is better to compare the measured quantity, flux, than the derived quantity, luminosity. If you insist on reporting luminosity then you should be certain to report the assumed distance scale, and if you compare different luminosities you should be sure to reduce them all to the same distance scale.

It certainly seems that the number of planetary nebulae in our galaxy is in the range between 20,000 to 50,000 nebulae. There seems to be little doubt that the main-sequence star death rate is close to the planetary nebulae formation rate, which in turn is close to the white-dwarf formation rate, all in the solar neighborhood. But the last two rates, at least, are uncertain by a factor of two, and I doubt we will be able to get much more quantitative than that.

There has been tremendous progress in the study of planetary nebulae in other galaxies in the past ten years, or even in the past five years. For the Magellanic Clouds there is a very good list of planetary nebulae which was presented at this meeting, including approximately 100 planetaries in the Large Magellanic Cloud, and approximately 25 in the Small Magellanic Cloud, which is very close to the ratio of their masses. There are excitation differences between the Large Magellanic Cloud and the Small Magellanic Cloud planetaries which are not simply selection effects. There are detailed spectroscopic studies of abundances in the Magellanic Clouds and there are some differences in the abundances between authors, which seem to be at least partly the result of selection. I think that more measurements will be required to get statistics of larger numbers of planetaries in the Magellanic Clouds.

Planetary nebulae have been identified in M31 and four of its companions. There is a strong concentration of planetary nebulae to the center of M31. The number of planetary nebulae in M31 is comparable with the number in our galaxy. The He abundance in planetary nebulae in M32 is normal but seems to be high in NGC 185, although the latter is quite a faint object and more measurements are probably required. There also seem to be real differences between the planetary nebulae in M32 and in NGC 205. In the Fornax dwarf elliptical galaxy a planetary nebula has been discovered which seems to have normal He abundance but lower N and O abundances.

In optical observations there are many spectrophotometric results which have been measured in the last ten years, the best coming very largely from multi-channel, digital, high quantum-efficiency, linear devices. I think these instruments have made possible a tremendous amount of progress in the study of planetary nebulae (as well as other objects). There are already some good two-dimensional systems. We heard some very good results from electronographic cameras, with quantitative results in the form of isophotes and surface brightnesses taken in the light of a single emission line, that can be compared with physical models. The old favorite, photographic plates, still have the capacity for storing lots of data and furnishing a lot of information if they are taken with well-defined filters and are carefully calibrated. We saw a lot of structures at a very faint light level in the faint outer parts of planetary nebulae. In the not too distant future, CCD and TV systems will provide measurements in much greater quantity of the two-dimensional projected structures of planetary nebulae.

Opening up of the ultraviolet spectral region is very important, particularly the spectra of two planetary nebulae showing lines of CIII], C IV, and He II with good spectral resolution. In addition there are filter results for many more planetary nebulae. A lot of the discussion at this Symposium has been about C, and I think that these C III] and C IV lines being observed in the ultraviolet spectra makes this discussion a lot more real.

To interpret the data we need a good physical model from which predictions can be calculated and compared with observations. In such models it is of course necessary to include all the physical effects that occur. In particular, in planetary nebulae one important physical effect is collisions of electrons with ions, and the collision-strength situation is now much better than it was ten years ago. Much more accurate collision strengths are available for essentially all 2p electron configurations of abundant ions, and the 3p ones are coming along -- approximate collision strengths exist, and accurate ones will soon be available. At the personal level, I am glad to know that for [O II] there is a good hope that including the relativistic effects should lead to a more nearly correct value of the intensity ratio at high densities. The [Fe III] and [Fe VI] collision strengths that were given here are certainly much needed.

There still exists the stubborn problem of the disagreement of predicted intensities of [O II] and [N II] with the observations. All the experts seem to think that high-density optically thick condensations are a large part of the answer. But then the question is how do these condensations survive or how do they continue to form? This is a very important problem. Several people have emphasized the role of filaments in the actual structure of planetary nebulae -- they are there, yet no one understands just why they are. Are the filaments important in dynamics? It seems to me they should be included. And it seems that they will also be important in calculations of the line strengths, although no one has completely reproduced the observed spectrum by using optically thick condensations. The question of why we see [Ne III] in the same places in the outer shell of NGC 6720 where we see [O II] seems very important in really understanding the ionization structure.

Another part of a model planetary nebula is the input star radiation, which has to be calculated from physically correct theory. Complications such as heavy-element opacity, curvature and non-LTE effects all seem to be required and have been included in various model stellar atmospheres. The biggest problem, or the biggest discrepancy between the calculations and the observations seems to be in the number of He^+ ionizing photons, either calculated from the models, or derived from comparisons with Population I stars, which in the visible and near ultraviolet spectral regions seem to have nearly identical spectra.

Both the planetary-nebulae model experts and the stellar-atmosphere model experts seem to regard the stellar radiation held in the far UV as an almost completely adjustable set of parameters, yet it seems to me that we cannot say that we completely understand nebulae until we have actually calculated stellar atmospheres that fit. There is a real need for physical models there. Some new ideas are emerging and were expressed at this conference, particularly the idea of the "leaky shell", and also the idea of a high-temperature corona. Perhaps carbon-rich central star models will have different properties in their far UV spectra.

On the question of abundances, what strikes me is that except in the halo planetaries, there are remarkably small differences in the abundances among difference planetaries. There are a few Population I planetaries with considerably higher He abundances, somewhat enriched in N, and there seems to be a negative gradient outward of the N abundance gradient in the galaxy, although there is a good deal of scatter in the data. The O abundance seems to be normal in planetaries, with perhaps a very small gradient. The C abundance also seems to be high, mostly on the basis of the C III] and C IV lines, although possibly the recombination-line evidence is in that direction too. It does not look as if the material we see in planetary nebulae is enriched in N at the expense of C, but rather that there was more C than normal, which was then partly changed into N. This is quite similar to the situation Kraft and his collaborators are finding in the envelopes of late-type giant stars.

Three halo planetaries were discussed. All of them have normal He abundances. There are normal or high N and Ne abundances in one of them, but O is down, and K 648 the planetary nebula in M15, has the lowest Ne and N abundances.

There is no doubt that there is dust in planetary nebulae and it is extremely important in their radiative properties, yet dust in planetaries was hardly expected ten years ago at the Tatrenska Lomnica meeting.

The H_2 molecules discovered in planetary nebulae are also very important. I believe the question of observing "signatures" that tell something about the type of dust in the infrared spectrum of planetaries is quite important.

I would interject one word of caution -- it seems to me that NGC 7027 is a very good object to observe in the infrared, yet if I had to tell you one planetary nebula which I thought was not typical from the optical point of view, I would name NGC 7027, so I would urge not only measuring it, but also measuring some other planetaries if at all possible.

I think the things we heard this morning about the proto-planetaries and their measurements in the CO lines were extremely exciting and interesting. Again it seems that the progenitors of planetary nebulae have a somewhat high C abundance. Again I would ask a question related to this observation -- should we not compute models of central stars with very high C abundances? What is the spectrum of far ultraviolet ionizing radiation that comes out of such stars?

I confess that it is not clear to me that the objects we heard described as proto-planetaries this morning are the precursors of typical planetary nebulae, but it seems that there is a good chance they are, and they certainly should be studied in detail.

I have said very little about the stars, but I was much impressed by the calculations reported this morning on dynamical instability, and the result that planetary shells may come off in a series of puffs over a time of a few hundred years.

One final impression I would state is that although in the discussion at a symposium like this it is fine to speak "naively", in the end we want to understand planetary nebulae "completely". In principle we should like to be able to start with a star, and follow its evolution and see how the abundances of the elements change, and in the end how it throws off a shell, follow the evolution of the shell hydrodynamically, and understand its complete evolution back to interstellar matter plus a remnant star.