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Stuart R. Pottasch Planetary Nebulae*

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The monograph at hand surveys the current status of research on planetary nebulae. These most fascinating celestial objects have more and more been riveting the attention of observers and theorists alike.

A new review of the subject is long overdue. What monographs have been available were published in the fifties and sixties. Since that time, thanks to progress in observing techniques, planetary nebula studies have advanced far ahead: they have been extended from the visual spectral region of the "invisible" domains—the far infrared, the radio-frequency range, and, stepping outside the earth's atmosphere, even the far ultraviolet and x-ray regions. Some very interesting, indeed fundamental discoveries have been made and have gained no less interesting theoretical interpretations. One example is the finding that planetary nebulae emit excess far-infrared radiation, attributable to thermal emission by dust grains. Perhaps the most noteworthy outcome of the past 20 years of study is the conclusion that planetaries play a very special role in stellar evolution and in the evolution of the Galaxy as a whole.

All these matters have not hitherto been treated in the astronomical review literature with the completeness they deserve. Investigators have long felt the need to unify the accumulated information on planetary nebulae and the recent observational results, and to consider the theoretical analyses from an integrated standpoint. This need has now largely been satisfied with the publication of Pottasch's monograph.

The author, Stuart R. Pottasch, is a leading specialist on planetary nebulae; he has long been recognized both for his theoretical work and for the part he has taken in pioneering new observations of these objects, both at radio frequencies and from space. In his monograph Pottasch brings together the results of the past few decades and treats them in a unified manner, updating them as much as possible. Many of the findings presented in the book have been obtained by the author himself.

The first of the 11 chapters recounts in lively and interesting style the story of how planetary nebulae were discovered and their spectra studied. A general explanation is given of the morphology of planetaries, and their special forms are described. This chapter is illustrated with recent photographs of typical nebulae, taken in various wavelength bands, and the distinctive characteristics of each nebula and its central star are set forth.

In Chapter II, on the distribution of planetary nebulae in the Galaxy, the author first discusses the methods of discovering planetaries—from inspection of photographs or from their spectrum or on plates taken through filters. The distribution of the nebulae in galactic coordinates l, b is examined in detail—both the whole population of planetaries and individual groups (nebulae in the solar neighborhood, nebulae located near the galactic center). In particular the author considers how the distribution depends on the angular size of the nebulae. In the Galaxy the planetaries form a layer with an effective half-thickness of about 300 pc. Studies of planetary radial velocities and proper motions are discussed, as is the velocity dispersion of these objects.

From his analysis of the kinematics and distribution of planetary nebulae in the Galaxy, the author concludes that two age groups are present: old Population II nebulae near the galactic center or in the halo, and younger nebulae representing intermediate Population I or the disk population. The chapter closes with a section on extragalactic planetaries—their discovery and distribution in other galaxies. Comparisons are drawn between the properties of the planetary nebulae in other galaxies and in our own.

Chapter III interprets the emission lines in the spectrum of planetary nebulae and discusses their chemical composition. The author concisely surveys the "classical" topics of nebular emission theory: the basic mechanisms responsible for the permitted and forbidden emission lines and the principal methods of determining chemical abundances. He then turns to such more novel questions as dielectronic recombination and self-absorption in the hydrogen spectrum.

The general percepts of constructing model nebulae to determine their chemical composition are explained. Abundances are given for a number of elements found in particular nebulae, and the differences between certain categories of nebulae are described. Some heavy elements (argon, oxygen) are underabundant in nebular belonging to the galactic halo, while nebulae close to the galactic plane exhibit enhanced N, C, He abundances.

In similar fashion Chapter IV discusses the continuum emission of planetary nebulae. The principal mechanisms are described: hydrogen free—free and recombination emission, the helium recombination continuum, hydrogen two-photon emission, and also helium two-photon emission, which becomes significant in the far-ultraviolet continuum of planetary nebulae. The techniques and results of observing the continuum in different parts of the spectrum are set forth: in the visual, the ultraviolet, and the radio range. This last form of emission, the radio continuum, is considered most fully of all; it offers good prospects for evaluating nebular physical parameters.

Chapter V is devoted to an especially difficult problem—determining the distances of planetary nebulae. At least 10 basic methods are available, both for individual distances and statistically. The distances derived by different methods are compared, and the accuracy of the methods and their range of applicability are assessed. Included in this chapter are topics closely related to distance determination: interstellar extinction and the ways to

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measure it, the number density of planetaries in space, methods of determining their mass and their formation rate. In the Galaxy there are $5 \cdot 10^{-8}$ nebulae per cubic parsec in the solar neighborhood, and $3 \cdot 10^{-6}$ near the galactic center. One may infer that one or two planetary nebulae are born annually in our Galaxy; the total population is 20,000 to 50,000.

More fully than in the introduction, Chapter VI takes up to the morphology of planetary nebulae and their expansion and mass loss. Various models and attempts at morphological classification are discussed. The author remarks that models give a very incomplete picture of the process of mass ejection in a nebula. The morphology of some of the most interesting individual objects is examined in this chapter. Special attention is given to the halo structure in nebulae. The problem of stellar wind and its influence on the nebula is considered.

Chapter VII, the lengthiest, is also one of the most important, as it deals with the temperature of the central stars, the nuclei of planetary nebulae. First the author gives an up-to-date classification of central stars according to their spectrum; their most significant characteristics are then discussed. The basic principles are outlined for constructing a model atmosphere for a central star, as is necessary if its effective temperature is to be determined.

Thoroughly explained in this chapter are the chief methods for evaluating the temperature of a central star: the Zanstra methods, the Stoy procedure based on the energy balance in the nebula, and the method that relies on the ionization equilibrium for various elements in the nebula.

Comparing the temperatures derived by different methods, and analyzing the factors responsible for the differences, Pottasch concludes that the Zanstra hydrogen temperatures $T_Z(H)$ are closer to the true effective temperature of the star than are the helium temperatures $T_Z(He)$. He is inclined to attribute the disparity to imperfections in the model stellar atmospheres. Incidentally Pottasch as a rule obtains very high temperatures for the central stars, often in excess of $(1-2) \cdot 10^5$°K and in some cases as great as $5 \cdot 10^5$°K. Other researchers have criticized these results.

Chapter VIII surveys a comparatively new topic in the physics of planetary nebulae—their infrared and millimeter-wavelength radiation. Considered in the first sections is the excess infrared continuum emission ($1 < \lambda < 100\ \mu$, with a peak at 30–40 μ) and its interpretation as the thermal emission of dust. The distribution of this radiation in a nebula is then examined, as are the possible mechanisms for heating the dust grains: Lyman-α emission in the nebula, the emission of other resonance lines, and the ultraviolet radiation of the central star.

Along with the continuum radiation, this chapter describes the infrared emission lines and broad bands. Observations of molecular hydrogen in the near-infrared spectrum of planetary nebulae are reported, as well as carbon monoxide emission in the millimeter range.

The next two chapters of the monograph are devoted to a cardinal problem: the evolution of planetary nebulae and their central stars. Pottasch takes the principal steps of planetary evolution in reverse order.

Chapter IX begins by considering how a planetary nebula will evolve once it has been ejected from the parent star. A detailed Hertzsprung–Russell diagram is compiled for the central stars of many nebulae, so that one can follow the evolutionary track of a star from the time the envelope is thrown off to the white dwarf stage. The evolution of the nebular envelope during this same interval is described. Theoretical models are compared against the observational data, and the basic properties of white dwarfs are summarized.

In Chapter X a less well-explored stage is traced: the evolution of the progenitor red giant from the main sequence of the planetary nebula phase. Several groups of stars belong to the cool-giant class, including Mira variables as well as OH/IR masers; these are discussed as possible progenitors. Their basic properties are reviewed (galactic distribution, kinematics, mass loss, formation rate), and examples of protonebular objects are cited. The chapter closes with a general scenario or qualitative evolutionary picture of the whole planetary nebula phenomenon.

Chapter XI, the last, considers how planetary nebulae will influence the interstellar medium. Several possible effects are examined: 1) enrichment of the medium with new matter; 2) as a source of ionizing radiation; 3) injection of kinetic energy into the medium. The author concludes that planetaries, along with novae, supernovae, and Wolf–Rayet stars, are especially significant as conveyors of material to the interstellar medium, enriching it with nitrogen, carbon, and helium, and contributing mass. In the final analysis planetary nebulae represent a link in the chain of galactic evolution.

Pottasch's whole monograph is a most valuable and much needed one. It reviews the fundamental problems in planetary nebula physics from timely points of view. The author emphasizes the latest observational results and theoretical questions of current importance.

Containing many diagrams, pictures, and tables of numerical data, the book will be useful in practical research on planetary nebulae. Not only will specialists in nebular physics find it helpful, however, but also scientists in related fields as well as graduate and undergraduate students working in broad areas of astrophysics and stellar astronomy.

The main drawback of the book, in our opinion, is the omission of the customary literature citations in context, hampering use of the material. References instead are assembled at the end of each chapter, and author limiting himself to the most recent papers and to literature of historical interest. Nevertheless this shortcoming by no means impairs the overall value of the monograph as a very complete and up-to-date survey. A Russian-language edition would be highly desirable.

*A study of Late Stages of Stellar Evolution. Astrophysics and Space Science Library, Vol. 107. D. Reidel Publishing Company, Dordrecht, 1984. ix + 322 pp.

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