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ADP Final Technical Report
"CNO Abundance Enrichments in Planetary Nebulae"

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Abstract

This is the final technical report on the project entitled "CNO Abundance Enrichments in Planetary Nebulae," funded through NASA Astrophysics Data Program grant No. NAG5–1432 to ST ScI. This project was initially funded from September 1990 through August 1993. Three no-cost extensions were granted during the period January 1994 through August 1995. The final products of this project are described.

1. Project Goals

The main goal of this project was to analyze the carbon, nitrogen, and oxygen abundance enhancements in planetary nebulae (PNe) that are thought to result from the dredge-up of enriched matter from the interior of the progenitor stars during their asymptotic giant branch (AGB) evolution. The strategy was to re-measure the UV emission line fluxes of various ions from nearly 1000 *IUE* spectra of 100 PNe that had been recalibrated for the *IUE* final archive. These fluxes were to be used in combination with the latest available, ground-based and infrared emission line and continuum fluxes to give a more accurate picture of the ionic abundances in PNe. The strategy was to use simple models to relate ionic to total abundances, and to normalize the abundances to those of Ar and Ne, which are thought to undergo little if any enrichment during the lives of low- to intermediate-mass stars.

The products of this project were to be the analysis of CNO enrichment in planetary nebulae, and an update to the Kaler (1976) catalog of emission line fluxes in planetary nebulae. We performed an extensive review of all observations of PNe in the *IUE* archive, selected all those that had sufficient signal to be useful, and extracted relevant positional, exposure level, and other information for each spectrum. At that time (1991–1992) no spectra had been recalibrated with the Final Archive pipeline system, but we were prepared to process images with similar techniques in an effort to achieve the higher signal-to-noise ratios that were needed for this project.

The success of this strategy depended upon the timely completion by the *IUE* Project of the flux calibrations for the two prime cameras (SWP and LWP), as it became apparent that the new *IUE* flux calibration would be significantly different from the old (IUESIPS)

calibration. While it is generally agreed that the new calibration is better, changes in the calibration translated directly to changes both in the measured emission line fluxes, and to the derived temperatures, which greatly affect the derivation of ionic abundances. Since the revised flux calibration only become available in 1993 for the SWP spectra, and much later for the LWP spectra, we were faced in early 1993 with the difficult choice of delaying our analysis (possibly for years) until the recalibration work was finished, or of refocusing our efforts. Rather than wait, we chose to push ahead with the update to the emission line catalog, and to enhance our nebular analysis software so that it could be distributed to the entire astronomy community. In principle, then, the original project could be completed by any researcher, once the reprocessed *IUE* data were in hand.

2. The Emission Line Catalog

We completed an update of the UV/optical/IR catalog of emission line fluxes for Galactic and extra-Galactic planetary nebulae (Kaler 1976), which includes data from the major astronomical journals and most observatory bulletins, proceedings of meetings, Ph.D. theses, preprints, and private communications. The catalog (hereafter, ELCAT) is thought to be complete through early 1995. ELCAT contains over 68,000 emission line intensities for over 1,000 nebulae, and as such is a very valuable resource for research on planetary nebulae. Unfortunately, it was prohibitively expensive to publish it in hardcopy form. In addition, it is of most use to the research community in machine-readable form. For these reasons the data were reformatted such that they would be easy to ingest with extant tables (or database) manipulation tools, such as those available in MIDAS or the STSDAS/TABLES package.

Kaler, Shaw & Browning (1997) prepared a description of the catalog; the data and ancillary files will appear as part of the AAS CD-ROM series (Vol. 8). As a part of this ADP project, we also made ELCAT available to the community via the Internet through a Web page (http://ra.stsci.edu/elcat/), ftp, and through a Web index of individual nebulae so that researchers can retrieve small subsets of the catalog that are of particular interest to them. Kaler, Shaw & Browning (1997) also provided instructions for retrieving ELCAT via the Internet and interpreting the contents. The catalog will also be given to the NSSDC for inclusion in the Astrophysics Data System.

3. Software: Nebular Analysis Package

To interpret the emission lines from the nebulae in this study, Shaw and Dufour (1995) developed a software package called **nebular** which computes the physical conditions in a low density gas given appropriate diagnostic emission-line ratios; and line emissivities and ionic abundances given appropriate emission line fluxes, the electron temperature (T_e) and density (N_e). The package was an enhancement of the 5-level atom FORTRAN program developed by De Robertis, Dufour, and Hunt (1987), except that many of the atomic parameters were updated or corrected. As well, more diagnostics from a greater set of ions were accommodated, most particularly those in the satellite ultraviolet that are now available through the *IUE* and *HST* archives. The software included a 3-zone nebular model for determining the nebular physical diagnostics and ionic abundances for nebulae that have a simple, stratified structure. The output was compared to published

temperatures, densities, and abundances for several nebulae, and yielded results in good agreement, at least within the uncertainties of the atomic parameters.

When it became clear that this nebular analysis software would be the major product of this ADP project, we re-engineered it to be portable, robust, and easily distributable, while providing a user interface that is simple, powerful, and familiar for most researchers in this field. Another essential feature to support an archival research project like this was the ability to process an almost unlimited number of nebulae automatically, from a simple tables-style input data file, thus making it easy for users to update the emission line fluxes, atomic data, or other ancillary information and re-run the calculations. We chose the IRAF environment to meet these needs, and rebuilt the I/O and many of the internals in IRAF's SPP language.

The **nebular** analysis package is now an IRAF-based utility and consists 7 analysis applications; it is offered through the STSDAS package which is distributed by ST ScI, though users may obtain **nebular** for personal installation if they have IRAF and the TABLES external package. The **nebular** distribution is made up of over 6,500 lines of source code, nearly 50 pages of on-line user documentation, installation instructions, and release notes. The **nebular** analysis software is available to the community at no cost, and is accessible through a World-Wide Web page at http://ra.stsci.edu/nebular/. Two of the applications can be executed over the Web via an HTML form; others may be offered this way in the future.

The package has been presented at two conferences (Shaw & Dufour 1994), and a paper describing its utility in astrophysical investigations was also published (Shaw & Dufour 1995). The software has subsequently been supported through ST ScI (independently of this grant) for over two years, and a number of users world-wide have obtained and made use of it. Additional enhancements to this software are in development (through internal ST ScI funds) to update and extend the atomic data to take advantage of the new, more accurate parameters from the IRON project. This effort will increase the number of supported ions from 22 to 34, includes diagnostics that span a greater range of T_e, N_e, and ionization potential, and will improve the accuracy of the calculations (particularly at extreme T_e) by up to 50%. We believe this package to be a significant contribution to the research community, which was made possible under ADP this grant.

References

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