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FINAL TECHNICAL REPORT

NASA Research Grant NAG 5-855

ULTRAVIOLET OBSERVATIONS OF CLOSE-BINARY AND PULSATING NUCLEI OF PLANETARY NEBULAE

WINDS AND SHELLS AROUND LOW-MASS SUPERGIANTS

THE CLOSE-BINARY NUCLEUS OF THE PLANETARY NEBULA HFG 1

A SEARCH FOR BINARY NUCLEI OF PLANETARY NEBULAE

UV MONITORING OF IRREGULARLY VARIABLE PLANETARY NUCLEI

and

THE PULSATING NUCLEUS OF THE PLANETARY NEBULA Lo 4

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Although one grant number, NAG 5-855, was used throughout the 1986-91 interval, the research was actually based on a total of eight individual research proposals covering six different projects. These were the following:

- Ultraviolet observations of close-binary and pulsating nuclei of planetary nebulae (1987).
- Winds and shells around low-mass supergiants (1986-89; Co-Investigator: Andrea Dupree, Center for Astrophysics).
- The close-binary nucleus of the planetary nebula HFG 1 (1988).
- A search for binary nuclei of planetary nebulae (1988-89 and 1991).
- UV monitoring of irregularly variable planetary nuclei (1990).
- The pulsating nucleus of the planetary nebula Lo 4 (1990).

The following briefly summarizes highlights of the research results supported by NAG 5-855.

1. *Binary Nuclei of Planetary Nebulae.* A large fraction of our effort was devoted to several aspects of binary central stars in planetary nebulae. Most of our *IUE* observations were aimed at searching for additional examples of such binaries.

The search program consisted of obtaining low-dispersion UV spectra of central stars whose optical spectra are dominated by late-type stars. If these cool stars have hot companions responsible for ionizing the nebulae, they might be detectable with *IUE*.

Several objects, including Abell 14, Abell 19, H 3-75, HtWe 12, IC 2120, and Sh 2-71, failed to show such hot companions. These negative results are still of interest, since they indicate either that the true central star is extremely faint (and thus of very high mass and/or temperature), or that the cool star *is* the central star, caught in a transient "born-again" red-giant phase. We believe that the latter, more exciting, possibility is likely for at least some of the objects, and thus we believe that we have provided observational support for a theoretically predicted transient phase in the very late evolution of low-mass stars. (Further discussion of these objects is given in reference 15 in the bibliography below.)

Our *IUE* spectra of the central star of the planetary nebula LoTr 1 showed it to have a spectacular UV continuum. Optical observations show only a cool late-type star with the Ca II H and K lines in emission, but the *IUE* spectra show that the cool star has a companion with an effective temperature in excess of 100,000 K. Ground-based photometry revealed a 6-day modulation, with an amplitude of $\sim$0.1 mag, which we tentatively attribute to starspots on the cool star which produce photometric variations as the star rotates with a 6-day period.

As discussed in the paper by Bond and Livio (ref. 10) and in refs. 14-15, we believe LoTr 1 and two similar objects (Abell 35 and LoTr 5) constitute a new class of binary planetary nuclei, consisting of a late-type star seen in the optical band, and an extremely hot companion responsible for ionizing the nebula. We propose that the cool stars, although classified as giants, are actually main-sequence stars that are still out of thermal equilibrium after emerging from a common envelope.

Another planetary nucleus, K 2-15, also appears to have a UV continuum that is too hot to be due to the optical star, and thus we believe that we have detected a hot companion. Analysis of its spectrum is continuing.

2. *Other variable planetary nuclei.* We also carried out *IUE* observations of a pulsating central star, that of Lo 4, in an attempt to detect a high-velocity wind that had been associated with the only other pulsating nucleus known at that time, that of K 1-16. The *IUE* spectra, however, show no strong evidence for such a wind in Lo 4. We also used *IUE* for spectroscopic monitoring of the central star of IC 418, which shows irregular variability in its optical brightness, while a collaborator (R. Ciardullo, Pennsylvania State University) obtained simultaneous ground-based photometry. Analysis of these data continues.

3. *Low-Mass Supergiants.* Progress reports on this project have been presented by Co-Investigator A.K. Dupree (Center for Astrophysics) (see refs. 3 and 9 in the publication list below). The aim is to investigate the nature of high-galactic-latitude supergiants, typified by the F-type supergiant 89 Herculis. Our *IUE* spectra do appear to indicate that high-latitude A- and F-type supergiants may be surrounded by nebular shells, on the basis of observations at the Mg II lines. This would support the view that these objects are low-mass post-AGB stars, rather than normal high-mass supergiants formed at, or ejected to, large distances from the galactic plane. Dr. Dupree is taking the lead in further analysis of these objects, and is obtaining additional data on 89 Herculis during *IUE* time allocated to her as Principal Investigator.

4. *Other IUE-related research.* During the grant period, we also carried out collaborative research on blue-straggler stars (ref. 1), and collaborated on a study of 0950+13 (ref. 4). The latter object is a very large planetary nebula discovered several years ago by the PI. *IUE* and ground-based spectra show the central star to be a hot ($\sim$70,000 K) DA white dwarf, surrounded by a compact nebular shell which is unresolved from the ground. Based on the *IUE* and ground-based observations, we were able to propose successfully for followup imaging with the *Hubble Space Telescope,* and these indicate that the hot white dwarf is accompanied by a close stellar or substellar companion.

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