Final Technical Report for NASA Grant NAG 5-3403

A Detailed Investigation into the Use of Planetary Nebulae as Standard Candles

Grant Period: 9/15/96 - 9/14/98
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January 19, 2000

This program represents the continuation of NASA Grant NAG W-3159 "A Detailed Investigation into the Use of Planetary Nebulae as Standard Candles." The grant was originally awarded in 1992 under the Long-Term Space Astrophysics Program, which was administered by NASA headquarters; NAG 5-3403 covers the final year of the project. The program's goal was to understand the physics underlying the [O III] $\lambda5007$ planetary nebula luminosity function (PNLF) and evaluate its accuracy as an extragalactic distance indicator.

A list of papers supported in part by this grant, or the parent grant NAG W-3159, is given at the end of this report; people supported in the course of the project were the P.I., and assistants R. McMillan, and J. Feldmeier.

Work under the grant concentrated in two areas. The first major goal was to extensively test the PNLF method to find its limits. We did this performing yet another internal test of the method in the core galaxies of the Fornax Cluster, performing external comparisons of PNLF distances with distances derived from Cepheids and the Surface Brightness Fluctuation method (SBF), and, in general, examining the PNLF in as many different galactic environments as possible, including the disks of late-type spirals. Because of the difficulty distinguishing planetary nebulae (PNe) from H II regions, and because spiral galaxies have uneven internal extinction, the process of identifying "statistical" samples of PNe in these objects is extremely complicated. Nevertheless, by using the ratio of [O III] $\lambda5007$ to Hα as a diagnostic, we were able to effectively discriminate PNe from most H II regions, and apply the method to systems such as NGC 300, M101, M51, and M96. Surprising, our results show that the method works just as well in spiral galaxies as it does in ellipticals; the effect of population age and internal extinction on the PNLF is minimal. Our results demonstrate that the PNLF is the best tool presently available for uniting the Pop I (Cepheid, Tully-Fisher, SN Ia) and Pop II (SBF, D_n-σ) extragalactic distance scales.

The second goal of this research was to determine theoretically, why the PNLF is such an excellent standard candle. To do this, we collaborated with Roberto Méndez of the University of Munich and performed Monte Carlo simulations on synthetic populations of planetary nebulae. Our study showed that, in old and intermediate-age populations, the PNLF cutoff is insensitive to age, but the PNLF cutoff does shift to brighter magnitudes in star-forming systems. Unfortunately, this conclusion was quickly contradicted by our PNLF measurements in nearby spirals. To resolve this discrepancy, we turned to PNe in the Local Group galaxies of M31 and the Large Magellanic Clouds. By performing detailed analyses on the PN spectra, we showed that overluminous PNe do exist in star-forming galaxies. However, the increased mass loss associated with these Type I PNe, coupled with their faster evolutionary rates, cause them to be embedded in clouds of circumstellar extinction. In other words, although some PNe formed by young populations are intrinsically bright, these objects always appear faint due to extinction. The bright end of the PNLF is therefore dominated by PNe from older progenitors. This effect, along with the previously known invariance of the PNLF to metallicity, explains why the method works as well as it does.

Aspects of this work were presented at a number of conferences, and in colloquia at such institutions as Northwestern, Columbia, Stanford, Colorado, Arizona State, Ohio State, Michigan State, Ohio University, and the University of California at Santa Cruz.

Papers Supported by NASA Grants NAG W-3159 and NAG 5-3403

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