Asteroseismology of Planetary Nuclei

Howard E. Bond[1], Steven D. Kawaler[2], Robin Ciardullo[3] and Worldwide Collaborators

[1]Space Telescope Science Institute; [2]Iowa State University; [3]Pennsylvania State University

Introduction

The first two pulsating planetary-nebula nuclei (PNNs), those of K 1-16 and Lo 4, were discovered by Grauer & Bond (1984) and Bond & Meakes (1990). They are nonradial multiperiodic g-mode pulsators, with typical periods near 25–31 min and low amplitudes (up to $\sim$0.05–0.1 mag). These PNNs have extremely high temperatures ($T_{\rm eff} > 100,000$ K), and are hydrogen-deficient with high abundances of C and O. Their spectra and pulsational properties are very similar to those of the pulsating GW Vir (PG 1159−035) white dwarfs.

In an effort to find more pulsating PNNs, we used CCD cameras on 0.9- and 1.5-m telescopes at Kitt Peak National and Cerro Tololo Interamerican Observatories to survey most of the known hot, hydrogen-deficient central stars for low-amplitude variability. We have subsequently organized a world-wide photometric campaign on one of our newly discovered pulsating PNNs.

This poster paper reports results of both of these programs.

The Photometric Survey

During the CCD photometric survey we searched for low-amplitude pulsations in 29 hot, hydrogen-deficient PNNs. We discovered six new pulsators (the PNNs of NGC 246, 1501, 2371-2, 2867, 5189, and 6905), bringing the total number known to nine (including K 1-16, Lo 4, and the recently discovered RX J2117.1+3412). In addition, there are four known PG 1159 white-dwarf pulsators, along with the pulsating PNN-like field O VI star Sand 3. Details of the survey are reported in our survey paper, which has now been published (Ciardullo & Bond 1996). All of the PNN pulsators have "O VI" or "PG 1159"-type spectra, and most or all of them show amplitudes and periods that are variable on timescales of months or less, in contrast to the more stable PG 1159 white-dwarf pulsators.

The NGC 1501 Global Campaign

As a follow-up to the survey, we obtained CCD photometry of the nonradially pulsating O VI central star of the PN NGC 1501 from five observatories around the world, over a two-week interval in 1991 November.

The figure shows a collection of nightly light curves of NGC 1501 (from the earlier survey work described above). The amplitudes of the variations are occasionally as large as $\sim$ 0.1 mag, but typically they are lower, and sometimes the variations even disappear for appreciable intervals due to destructive interference between individual pulsation modes. Typical timescales of the variations are about 20-30 min.

From the campaign photometry we have identified 10 independent pulsation periods in the nucleus of NGC 1501, ranging from 5235 s down to 1154 s. Additional modes, not present during the campaign, were identified in the earlier survey data plotted in the figure. The resulting list of pulsation modes reveals that most or all of them are split into triplets

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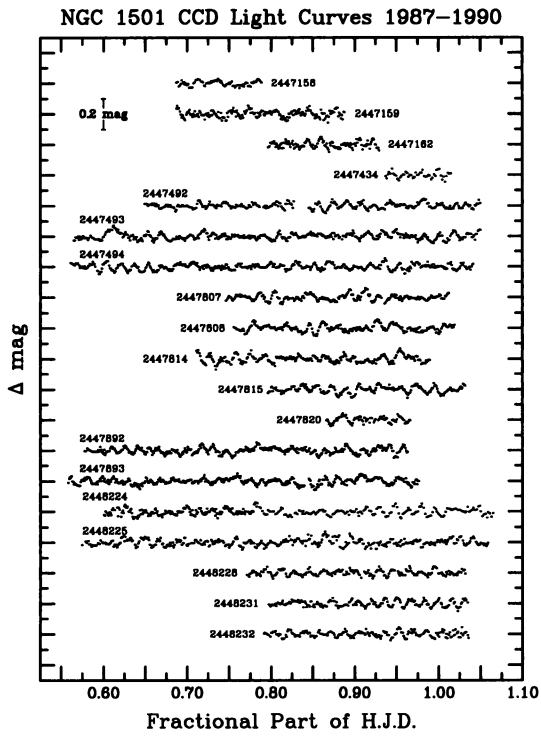

Figure 1: A collection of nightly CCD light curves for the central star of NGC 1501 (see Ciardullo & Bond 1996 for details).

(although all three components are not always present for each mode) with a common *frequency* splitting of $\pm 4.95\ \mu$Hz. This is almost certainly a rotational splitting, corresponding to a stellar rotation period of 1.17 days.

The $m = 0$ modes (i.e., the central frequencies of the triplets) show a common *period* spacing of 22.3 sec (or integer multiples thereof). Based on the models of Kawaler & Bradley (1994), this period spacing implies a stellar mass of $0.55 \pm 0.03 M_{\odot}$. Full details, including the names of all participants, will be published in the 1996 December AJ.

These results demonstrate the power of asteroseismology in revealing fundamental properties of central stars of planetary nebulae. We are now analyzing data from a seismological campaign on Sand 3, and hope to conduct further worldwide campaigns on other objects in the future.

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