Planetary Nebulae: An Eye to the Future
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Early results from ChanPLaNS: Mystery of hard X-ray emitting CSPNe†

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Abstract. We are presently using the Chandra X-ray Observatory to conduct the first systematic X-ray survey of planetary nebulae (PNe) in the solar neighborhood. The Chandra Planetary Nebula Survey (ChanPlaNS) is a 570 ks Chandra Cycle 12 Large Program targeting 21 high-excitation PNe within ∼1.5 kpc of Earth. When complete, this survey will provide a suite of new X-ray diagnostics that will inform the study of late stellar evolution, binary star astrophysics, and wind interactions. Among the early results of ChanPlaNS (when combined with archival Chandra data) is a surprisingly high detection rate of relatively hard X-ray emission from CSPNe. Specifically, X-ray point sources are clearly detected in roughly half of the ∼ 30 high-excitation PNe observed thus far by Chandra, and all but one of these X-ray-emitting CSPNe display evidence for a hard (few MK) component in their Chandra spectra. Only the central star of the Dumbbell appears to display "pure" hot blackbody emission from a ∼200 kK hot white dwarf photosphere in the X-ray band. Potential explanations for the"excess" hard X-ray emission detected from the other CSPNe include late-type companions (heretofore undetected, in most cases) whose coronae have been rejuvenated by recent interactions with the mass-losing WD progenitor, non-LTE effects in hot white dwarf photospheres, self-shocking variable winds from the central star, and slow (re-)accretion of previously ejected red giant envelope mass.

Keywords. surveys, X-rays: stars, planetary nebulae: general, stars: white dwarfs

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Summary. A comprehensive survey of PNe is required to test the various explanations put forward to explain the hard X-ray emission detected thus far from CSPNe. The first coherent subsample of solar neighborhood PNe to be surveyed as part of ChanPlaNS are predominately high-excitation, well-studied PNe. Here, we provide a snapshot of preliminary results for these and other X-ray-detected CSPNe. Figure 1, a sample of images of NGC 1514 from the mid-infrared to the X-ray, illustrates the multiwavelength approach we are adopting in studying the ChanPlaNS target PNe. In Figure 2 we display a summary of the median X-ray photon energies and energy ranges for all archival Chandra and ChanPlaNS detections of CSPNe to date. The source median photon energies range from ∼ 0.2 keV (indicative of white dwarf photospheric emission) for the CSPN of NGC 6583 to ∼ 1.0 keV for the X-ray sources associated with the CSPN in the ChanPlaNS target NGC 6445 and the known binary CSPNe within DS 1, HFG 1, and LoTr 5 (Montez

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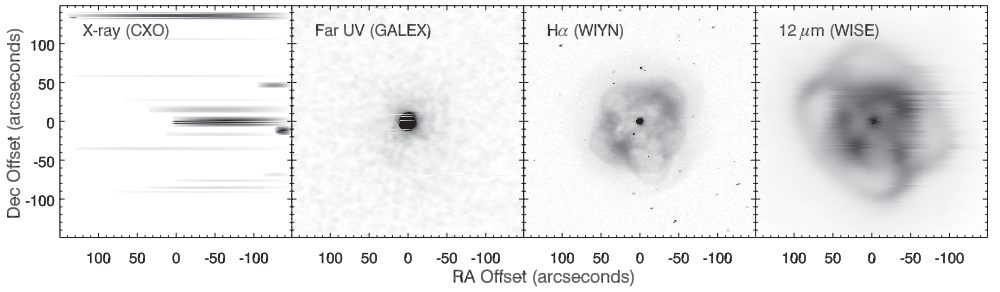

Figure 1. In support of ChanPLaNS, we have started acquiring new and archival multi-wavelength observations for all Chandra target PNe. In this montage, we depict selected multiwavelength observations of ChanPlaNS target NGC 1514. The CXO observation reveals a hard X-ray emitting central star, which may be due to coronal activity at a binary companion. The influence of such a binary companion may also manifest itself in the WISE infrared image, where a set of nested rings were recently discovered that are likely caused by past binary interactions (Ressler *et al.* 2010).

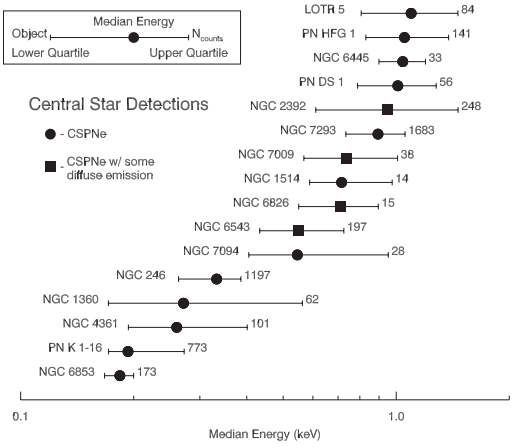

Figure 2. We characterize the X-ray emission from each CSPN by calculating the median energy and energy range of the X-ray photons. The hot white dwarf photosphere can emit X-rays, but only NGC 6853 (Dumbbell Nebula) has a source energy range indicative of such (pure white dwarf photospheric) emission. All other CSPNe show evidence for a hard X-ray excess that requires an additional physical explanation. Such hard X-ray excesses were discovered in three binary CSPNe (LoTr 5, HFG 1, and DS 1) and were attributed to cool companions whose coronae have been rejuvenated by binary interactions (Montez *et al.* 2010). On the other hand, a cool companion to the CSPNe of NGC 7293 (Helix Nebula) has been ruled out (Guerrero *et al.* 2001), suggesting another process is necessary to account for the hard X-ray excess detected in this CSPN. Guerrero (elsewhere in these proceedings) suggests the hard excesses detected from the CSPNe of NGC 7293, NGC 6543, and NGC 2392 are likely due to the self-shocking variable winds of these CSPNe.

et al. 2010). More information on the survey and members of the ChanPLaNS team can be found at the website `http://lama.cis.rit.edu/chanplans/`.

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