A multiwavelength study of the Stingray Nebula; properties of the nebula, central star, and dust

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A multiwavelength study of the Stingray Nebula; properties of the nebula, central star, and dust

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Abstract. We performed a detail chemical abundance analysis and photo-ionization modeling of the Stingray Nebula (Hen3-1357, Parthasarathy et al. 1993[1]) to more characterize this PN. We calculated nine elemental abundances using collisionally excited lines (CELs) and recombination lines (RLs). The RL C/O ratio (0.20) indicates that this PN is O-rich, which is supported by the detection of the broad amorphous silicate features at 9 and 18 μm By photo-ionization modeling, we investigated properties of the central star and derived the gas and dust masses. The nebular elemental abundances, the core-mass of the central star, and the gas mass are in agreement with the AGB model for the initially 1.5 $M_\odot$ stars with the $Z = 0.008$.

1. Nebular elemental abundances
We performed a chemical abundance analysis using the MPG ESO 2.2-m/FEROS 0.36-0.9 μm high-dispersion spectrum taken on 2006 April and the Spitzer/IRS spectrum taken on 2005 March. The result is summarized in Table 1. The RL C/O ratio (0.20) indicates that this PN is O-rich, which is supported by the detection of the broad amorphous silicate features at 9 and 18 μm By photo-ionization modeling, we investigated properties of the central star and derived the gas and dust masses. The nebular elemental abundances, the core-mass of the central star, and the gas mass are in agreement with the AGB model for the initially 1.5 $M_\odot$ stars with the $Z = 0.008$.

2. Physical properties of the central star and the dusty nebula
Using the photo-ionization code CLOUDY [3], we investigated properties of the central star and the dusty nebula by fitting the near-UV FEROS to the Far-IR AKARI/FIS data.

Effective temperature ($T_{\text{eff}}$) and surface gravity ($\log g$) When we adopted the model atmosphere for yr 2006 with $T_{\text{eff}} = 55 000$K and $\log g = 6.0$ cm s$^{-2}$ by [4] and the distance of 1.6 kpc [4], CLOUDY overestimated the fluxes of higher excitation lines such as [NeIII] and [OIII]. $T_{\text{eff}}$ could be cooler than 55 000K; we estimated $T_{\text{eff}}$ to be 50.500 K using the nebular [OIII]/Hβ line ratio. We utilized TLUSTY O-star atmosphere [5] and searched for $T_{\text{eff}}$ and $\log g$ to match the observations. We set $T_{\text{eff}} = 45 800$K and $\log g = 4.55$ cm s$^{-2}$.

Distance We calculated the post-AGB age of $\sim 379 D_{\text{kpc}}$ yrs using the expansion velocity (21 km s$^{-1}$, from the Hβ line) and the nebula’s outer radius (1.7") measured from the

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Figure 1. (upper panel) Comparison between the CLOUDY model and observational data of Hen3-1357. (lower panel) Closed-up plots for mid-IR wavelength. The mid-IR Spitzer/IRS spectrum shows the amorphous silicate broad features at 9 and 18 µm. We derived the dust mass of $2.2 \times 10^{-4} M_\odot$ and the temperature 50-176 K (grain radius $a = 0.01$-0.25 µm and $a^{-3.5}$ size distribution).

Table 1. Elemental abundances ($\log_{10} \epsilon(H) = 12$). The fourth and eighth columns are the predictions of the AGB star model by [2] for the initially 1.5 $M_\odot$ stars with the $Z = 0.008$.

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<th>X</th>
<th>$\epsilon(X)$</th>
<th>[X/H]</th>
<th>Model X $\epsilon(X)$</th>
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<td>0.10</td>
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</table>

HST/WFPC2 F487N image taken in 1998. Supposing that the central star was initially 1.5 $M_\odot$ and the current $T_{\text{eff}}$ is ~45 000-55 000 K, the post-AGB age is ~1000-3000 yrs from the predictions of [6]. Thus, we estimated the distance of 2.7-6.7 kpc. Here we set 5 kpc.

Result We compare the observed SED plots and the SED predicted by the model in Figure 1. The calculated gas mass (0.07 $M_\odot$) and the core-mass (0.62 $M_\odot$) are consistent with [2], who predict that the initially 1.5 $M_\odot$ stars with $Z = 0.008$ will eject ~0.09 $M_\odot$ during the last thermal pulse and end as ~0.63 $M_\odot$ stars.

References