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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 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. The nebular He/C/N/O/Ne abundances are similar to the predictions of the AGB star model by [2] for the initially 1.5 $M_{\odot}$ stars with the metallicity $Z = 0.008$.

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 ($T_{\rm eff}$) and surface gravity ($\log g$) When we adopted the model atmosphere for yr 2006 with $T_{\rm eff} = 55\,000$ 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 [Ne III] and [O III]. $T_{\rm eff}$ could be cooler than 55 000 K; we estimated $T_{\rm eff}$ to be 50 500 K using the nebular [O III]/Hβ line ratio. We utilized TLUSTY O-star atmosphere [5] and searched for $T_{\rm eff}$ and $\log g$ to match the observations. We set $T_{\rm eff} = 45\,800$ K and $\log g = 4.55$ cm s^{-2}.

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

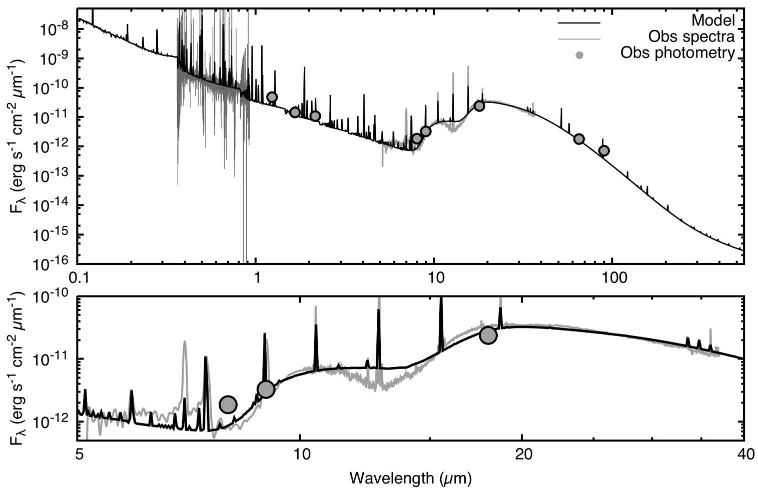

Figure 1. (*upper panel*) Comparison between the CLOUDY model and observational data of Hen3-1357. (*lower panel*) Closed-up plots for mid-IR wavelength. The mid-IR *Spitzer*/IRS spectrum shows the amorphous silicate broad features at 9 and 18 μm. We derived the dust mass of 2.2×10^{-4} $M_\odot$ and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

Table 1. Elemental abundances ($\log_{10}\epsilon(\mathrm{H}) = 12$). 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 $Z = 0.008$.

X	ϵ(X)	[X/H]	Model	X	ϵ(X)	[X/H]	Model
He	11.04	0.11	10.98	Ne	8.09	0.22	8.18
C(RL)	8.09	-0.30	8.06	S	6.71	-0.48	7.16
N(CEL)	7.78	-0.05	7.70	Cl	5.12	-0.38	
N(RL)	7.81	-0.02	7.70	Ar	6.16	-0.39	
O(CEL)	8.65	-0.04	8.36	Fe	5.06	-2.41	
O(RL)	8.79	0.10	8.36				

HST/WFPC2 F487N image taken in 1998. Supposing that the central star was initially 1.5 $M_\odot$ and the current $T_{\rm eff}$ 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.

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