CHAOS

CHemicAl compOSition studies of bipolar PN

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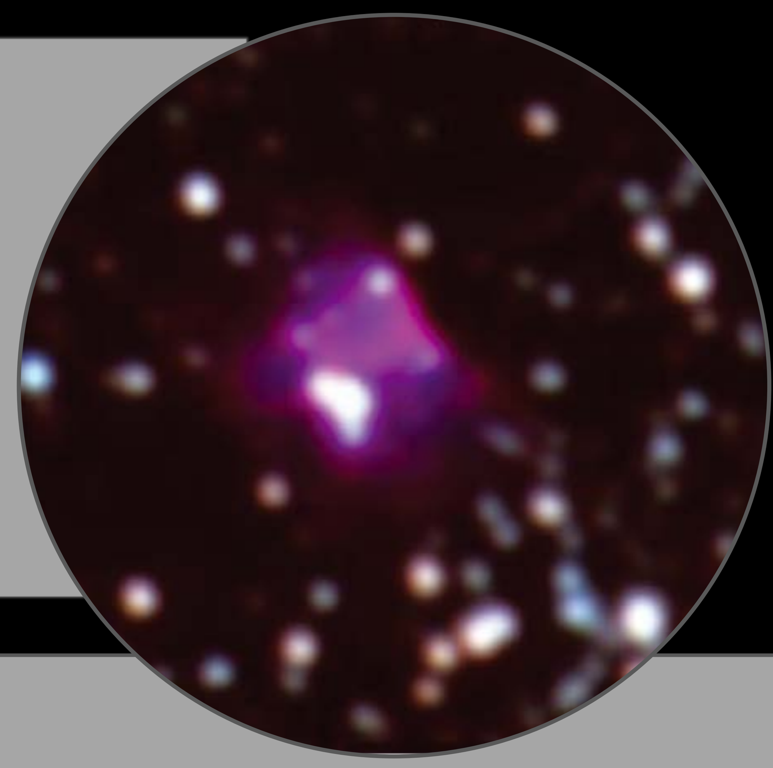
INTRODUCTION

PHR 1315-6555 (PN G305.3-03.1) is a bipolar planetary nebula (PN) with a either a singular or binary central star, which is to be confirmed. This object is an excellent candidate for membership of an open cluster, ESO 96-SC04, meaning that its distance from us can be accurately determined, which is quite rare for a PN. Nowadays, this is the only one case of a confirmed PN that associated with a Galactic open cluster. We have decided to investigate the chemical composition of this particular PN, because available data making it a valuable didactic tool for us to learn to use Cloudy.



METHODS

Using both Cloudy v17.01 and Pine, we have calculated the predicted abundances for PHR 1315-6555 based on different models. For Cloudy, both the blackbody shape and the Rauch SED grid have been employed in the simulation of the chemical composition of the nebula. We have based our studies on the Parker et al. 2011 MNRAS paper and also on unpublished data as inputs to generate the abundance predictions that appeared to be consistent with a Type I PN classification. The emitted spectrum, as well as the ionization structure, of this nebula are also studied. We have used a temperature of 110,000 K for the PN, and also a hydrogen density of 100 cm^2, for the modelling. The PN is assumed to exhibit a closed geometry, have a radius on the order of 10^{18} cm, and with an electron density of 160 cm^2.

RESULTS

Our results indicate that the Rauch reproduces the observables better than the blackbody as expected for Central Stars of Planetary Nebulae (CSPNe) that are described by non-LTE atmospheres. Both atomic oxygen and helium intensities increase at the outer edges of the nebula as the hot ionizing source affects mostly its inner parts driving the production of ionized species. The ionic behaviors of the hydrogen, helium, and oxygen elements towards the ionization front as modeled by Cloudy follow the expected patterns. This should occur somewhere before the temperature cutoff of about 4000 K.

Element	PyNeb	Rauch SED	BB	PN	Type I	non-Type I	Solar
He	11.10	11.00	11.00	11.18	11.11	11.05	10.93
N	8.17	8.26	8.26	8.20	8.72	8.14	7.78
O	7.95	8.64	8.64	8.26	8.65	8.69	8.66
Ne	7.72	8.04	8.04	7.73	8.09	8.10	7.84
S	6.87	7.00	7.00	6.97	6.91	6.91	7.14
Ar	5.84	6.43	6.43	5.80	6.42	6.38	6.18
log(N/O)	0.22	-0.39	-0.39	-0.06	0.07	-0.55	-0.88
log(Ne/O)	-0.23	-0.60	-0.60	-0.53	-0.56	-0.59	-0.82
log(S/O)	-1.08	-1.64	-1.64	-1.29	-1.74	-1.78	-1.52
log(Ar/O)	-2.11	-2.21	-2.21	-2.46	-2.23	-2.31	-2.48

Table 1. Chemical abundances between spectrum based on model using, PyNeb (de-reddening process), Rauch SED, BB shape and PN model (Parker et al. 2011). For comparison, the abundances for Type I and non-Type I PN are taken from Kingsburgh & Barlow (1994) and solar abundances from Asplund, Grevesse & Sauval (2005).

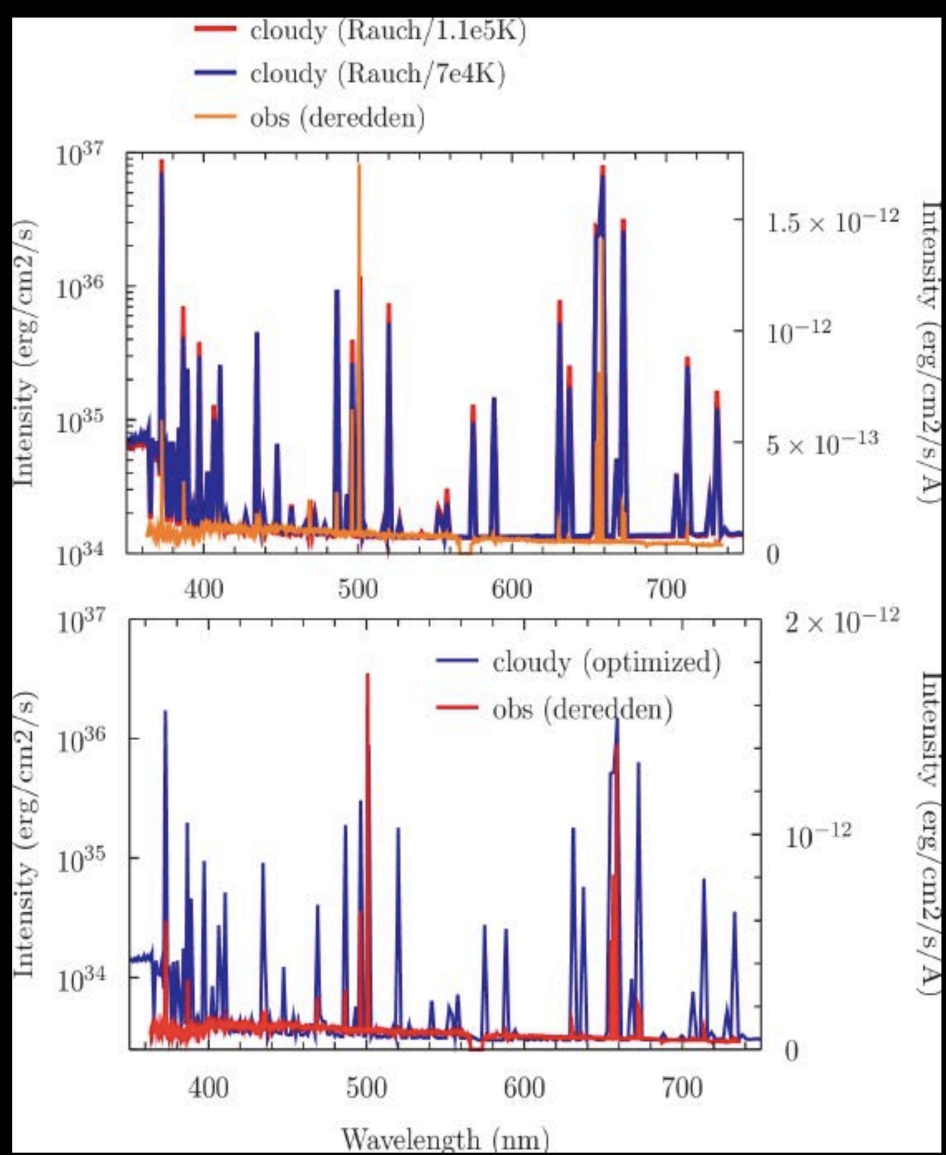


Fig 1.
Top panel: Spectral lines of observed spectra (orange) and simulated spectrum (blue) based on Rauch SED stellar atmosphere with different effective temperatures for the PN central star (blue: 70,000K; red: 110,000K).
Bottom panel: The calculated spectrum (blue) obtained with optimized parameters overlayed with observed emission data (red).

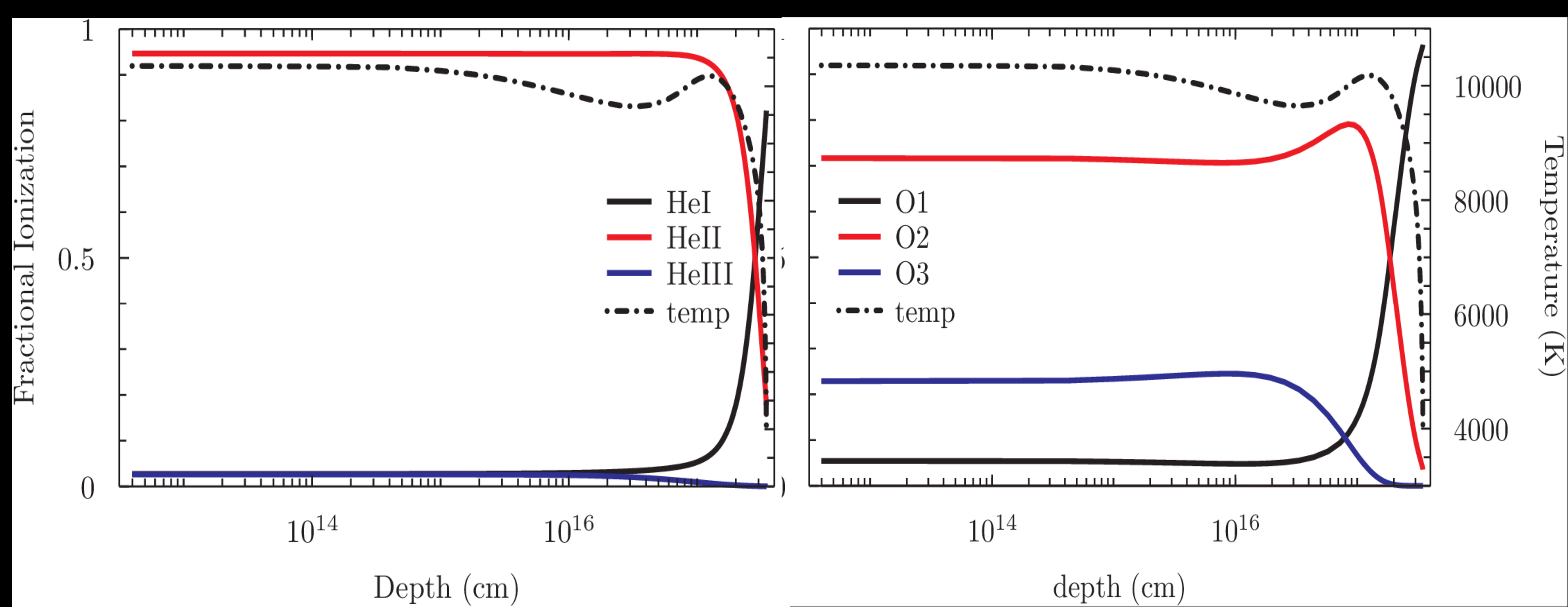


Fig. 2. Fractional ionizations for He and O. Gas kinetic temperature profile is overplotted on both panel (as the dashed lines). The left-hand side of each panel is inner boundary of the nebula. These fractional ionization profiles are constructed using the Rauch H-Ni SED with T_eff of 110,000K.

DISCUSSION

Our studies provide more evidence that the simulated PHR 1315-6555 chemistry is consistent with that of type-I PN in the intermediate-age open cluster ESO 96-SC04. (For more details, please see Table 1.) It can be seen that He abundances from the de-reddened spectrum (obtained using PyNeb) are closer to the values for Type-I PN He abundances than non-Type-I PN. Other elements are calculated to have similar abundances to that predicted by standard models (including blackbody and Rauch H-Ni SED-based ones). Calculated abundances are determined based on observed data obtained using medium-resolution 2.3-m DBS optical spectrum of the PN taken in 2006. For the photoionization modeling, we have opted for the Rauch SED grid rather than simple blackbody "shape" available as a simple command in Cloudy, because such stellar atmosphere data would give us more a realistic model of central star atmospherical conditions. We have applied effective temperature for both SED model with 110,000K and 70,000K from some private studies for two CSPN candidates. Calculated spectra (Figure 2) has been generated using a Rauch SED grid with both values of T_{eff} yielding very similar spectra. To complete our analysis, we have also carried out some opimization of the input parameters using the optimization feature of Cloudy. Primarily, we have varied the input CSPN temperature, the nebular radius, and also the nebular luminosity. About 20 line ratios of the emitted spectrum, together with 3 abudances of He, N, and O relative to the H abundance, as well as the absolute H-beta flux have been employed to constrain the optmization. Using this inverse problem-solving technique, then backwards engineer, we were able to come up with a much higher T_{eff} for the CSPN, of about 1.5E5K, a figure much closer to the Parker paper (2011) value of ~2E5K. Also, a mass of 0.8 solar has been deduced from our simulation, which is a bit bigger than the 0.5 solar stated in the Parker paper (2011). It was also found that a lower luminosity of 1.6 log solar, and a smaller radius of about 17 log cm from the staring values were resulted from the optimization. The new model used based on the optimized values is found to produce self-consistent results, with one check being the H-beta absolute luminosity. The given was 32.8 log (cgs). And, the new model gives a predicted H-beta value of 32.3. Also, Cloudy has indicated that the age of the PN should be at least 13,000 years, somewhwat larger than the 11,000-yar estimate given by the Parker et al. paper (2011).

References:
1. Asplund, M., Grevesse N., Sauval, A. J., 2005, ASP Conf. Ser., **336**, 25
2. Kingsburgh, R. L., Barlow, M. J., 1994, MNRAS, **271**, 257
3. Parker et al., 2011, MNRAS, **413**, 1835

SUMMARY

We have utilized both Cloudy V17.01 and PyNeb to model the chemical compositions of a bipolar planetary nebula (PN), PHR 1315−6555 (PN G305.3− 03.1), and have compared our computed abundances with the model-dependent quantities. The computed data is indicative of a Type I PN, though a more thorough study must be carried out in order to verify this claim. The PN concerned is observed to be oxygen-rich, and should exhibit carbon-suppressing chemistry. We also investigated the ionization structure for different chemical species, the temperature distribution with depth, and finally the spectrum based on two different Cloudy models – one based on a blackbody "shape" assumption and the other using a Rauch SED grid for the PN nuclei. As expected, both models yielded similar results. Moreover, optimization with Cloudy was used to check our original assumptions, from both private studies and published data.