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Photoionization Models of Chemically Inhomogeneous Planetary Nebulae

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Abstract. We have constructed photoionization models of NGC 6153, M 2-36, and M 1-42. These planetary nebulae show large differences, both, in the CNO and Ne abundances as derived from recombination lines and collisionally excited lines, as well as, in the electron temperature determined from Balmer jump and [OIII] lines. The model nebulae have low mass (about 1% of the total nebular mass) inclusions where the CNO and Ne abundances are enhanced by a factor of 200 or so.

We have constructed photoionization models in order to account for principal findings of Liu et al. (2000, 2001) in their observational studies of some planetary nebulae. These findings are as follows. First, the CNO and Ne abundances derived from optical recombination lines are significantly higher than the abundances from optical and UV collisionally excited lines. Second, the electron temperature determined from the Balmer jump is significantly lower than that from optical forbidden line ratios (e.g. [OIII]). Third, the differences in the abundances and in the temperatures are strongly correlated.

The nebula in our models has two components. The first component is the main nebula which is spherically symmetric, constant density, with more or less standard abundances that match collisionally excited lines. The second component consists of low mass inclusions (blobs, filaments) uniformly distributed inside the main nebula. In the inclusions the CNO and Ne abundances are significantly enhanced. Two kinds of models have been considered regarding the inclusions. In the first one the density in the inclusions results from an assumption that the inclusions are in pressure equilibrium with the main nebula. In the second case the density in the inclusions is constant across the nebula and is treated as a free parameter. The whole nebula is in the ionization and thermal equilibrium with the radiation from the central star.

The models have been constructed for three planetary nebulae, i.e. NGC 6153, M 1-42 and M 2-36. In these nebulae the above mentioned observational effects are exceptionally strong. According to Liu et al. (2000, 2001) the abundances of CNO and Ne derived from recombination lines are 5–20 times higher than the values deduced from collisionally excited lines. The electron temperature from the Balmer jump is 2500–5500 K lower than the [OIII] temperature.

All the observational data used to constrain the models have been taken from Liu et al. (2000, 2001). We have attempted to fit intensities of all important lines in the UV, optical and infrared, including recombination multiplets of CNO and Ne, and the Balmer jump strength.

The first kind of models, i.e. inclusions in pressure equilibrium with the main nebula, is able to satisfactorily account for the observations only in the case of M 2-36. The main problem of this kind of models in the case of the two other nebulae concerns the [NeIII] 15.6 μm line. When the models fit the rest of the observational constraints (including optical [NeIII] and NeII lines) they predicte [NeIII] 15.6 μm by a factor of 2.5 (NGC 6153) and 6 (M 1-42) stronger than observed. Also [NeII] 12.8 μm is too strong in the models. The point is that the highly enriched inclusions tend to be significantly cooler and thus significantly denser (pressure equilibrium) than the main nebula. In our models the density in the inclusions is typically 10^4 cm^{-3} (compared to 1-2 10^3 cm^{-3} in the main nebula). At this density the infrared lines of [NIII] and [OIII] are significantly suppressed collisionally and the cooling goes primarily through the infrared lines of [NeIII] and [NeII]. As a result the Ne infrared lines are very strong and the electron temperature in the inclusions is 1000–2000 K in our models (below 1000 K emissivity of the Ne lines decreases exponentially and the cooling is not able to balance the heating).

When the assumption of pressure equilibrium is relaxed the models can be fitted to the observations of NGC 6153 and M 1-42 provided that the density in the inclusions is close to that in the main nebula, i.e. 2×10^3 cm^{-3} and 1×10^3 cm^{-3} in NGC 6153 and M 1-42, respectively. At these densities the collisional deexcitation of [NIII] 57 μm and [OIII] 52, 88 μm is unimportant and the electron temperature in the inclusions can fall well below 1000 K. In our models fitting the observations of NGC 6153 and M 1-42 it is as low as 250–500 K. At these temperatures the emissivities of the [NeII] and [NeIII] lines are significantly reduced which allows to fit the models to the observations.

The abundances in the inclusions in our models fitting the observations are (by number): C/H=0.02-0.05, N/H=0.04-0.13, O/H=0.07-0.15, Ne/H=0.008-0.035. When compared to the abundances in the main nebula the mean enhancement in the inclusions is of factor 70, 250, and 300 in M 2-36, NGC 6153, and M 1-42, respectively. The mass of the inclusions compared to the mass of the whole nebula is 0.8% in the case of NGC 6153 and M 2-36 and 2% in M 1-42. Discussion of the results can be found in the invited paper by Tylenda in this volume.

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