Detecting Abundance Variations in Planetary Nebulae

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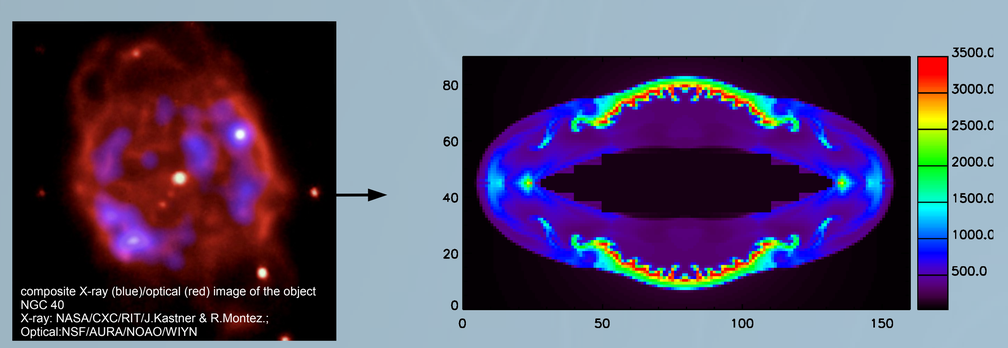
Abstract

Empirical methods of investigating chemical abundances are still widely used as a primary tool to study planetary nebulae (PNe) as well as HII regions. In this work we investigate the capacity of the empirical abundance determination methods to recover pre-defined parameters and abundance variations in a realistically modeled planetary nebula. To perform the test we use a three-dimensional density structure obtained from a hydrodynamical simulation which is fed through a three-dimensional photoionization code. The density structure is an asymmetrical and inhomogeneous elongated closed shell. The input parameters used, such as, ionizing source, density, and chemical abundances are typical values of type I PNe. The model emissivities are projected in the line of sight and emission line maps are generated, which are used to obtain the temperature and density diagnostics. The diagnostics and line emission maps are then used to obtain spatially resolved maps of the abundances. In this work we use the method described above to investigate abundances for two distinct orientations of the density structure and input He abundances. Our results show that for typical signal to noise ratios obtained from long-slit spectroscopy or IFU data, abundance variations can not be detected with the usual empirical method and that artificial abundance variations are introduced.



Context

Chemical abundances in planetary nebulae are important as a tool to study stellar evolution, to estimate effects of internal stellar nucleosynthesis and mixing, study the chemical evolution in the Galaxy and in other nearby galaxies.

The elements for which abundances can be determined by using only optical PNe spectra are: He, O, N, Ne, Ar and S. These elements belong to two classes of chemistry diagnosis: 1- O, Ne, Ar and S abundances to study the chemical composition of the ISM when the progenitor PN central star was born; 2-He and N are used to investigate the present time chemical composition of the nebula and ISM, since these elements are produced by the progenitor star and in the dredged-up episodes, which enrich the PN envelopes. Therefore, in a spatially resolved chemical analysis of PNe, a chemical gradient could be present when the elements under analysis are He and N, and should not be expected in the other elements(Iben & Renzini 1983; Stasinska 2002).

Results for about 20 PNe (mostly Type I) are: a)most are chemically homogeneous and b)a few (NGC 2440, K4-55) show significant abundance variations from one component to another (Perinotto et al. 1994; Guerrero, Stanghellini & Manchado 1995; Corradi et al. 1997; Perinotto & Corradi 1998; Balick et al. 1994; Gonçalves et al. 2003).

Method

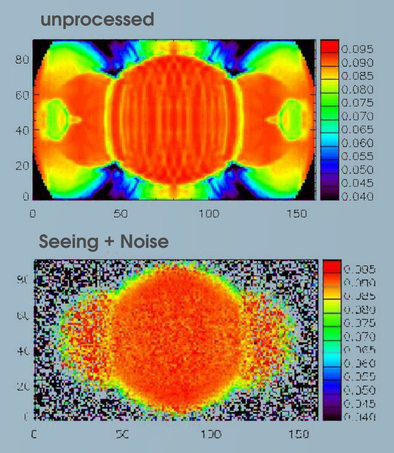
In this work we investigate the possibility of detecting abundance spatial variations using theoretical three-dimensional photoionization models. We explore calculations for two scenarios of a typical Type I PN: 1) with uniform abundances and 2) with an increase of 20% in He in the central regions.

We calculate a full 3D photoionization model using a 2.5D MHD density structure and realistic parameter values for density, chemical composition and ionizing star characteristics (described in Monteiro & Falceta-Goncalves 2011). The photoionization model was obtained with Mocassin 3D. From the model emissivities we obtained projected line emission maps for all typical lines observed in the usual long-slit spectra in the visible region. The maps were processed to add noise to give a signal to noise ratio of about 150 and a 1" seeing to simulate more realistically the observations. The abundances were determined with the usual empirical procedure.

We also investigated two orientation angles as well as an ionizing source as a PG1159 star. The final results are shown in the figures below.

Table 1: Abundances obtained from the total fluxes of the models compared to the input values used.

	Input	*20*	*45*	*A/A0*
He/H	0.14	0.16	0.16	1.14
O/H	4.8e-4	3.7e-4	3.8e-4	0.77
N/H	3.7e-4	5.6e-4	5.6e-4	1.51
S/H	1.1e-5	1.3e-5	1.3e-4	1.18



Total He abundance obtained from the empirical method from maps of the model of Monteiro & Falceta-Gonçalves (2011) which had a UNIFORM abundance distribution input with He/H = 0.09

Conclusions

We have presented a study of the physical conditions and chemical abundances for a set of synthetic spatially resolved data obtained from 3D photoionization models. It is clear from our results that variations are present in the abundance maps obtained from the usual empirical procedure despite the constant abundance input. Results also show some influence of the orientation of the density structure as well as of the ionization structure in the final abundances obtained.

When we simulated real observational conditions, most of the structure seen was washed out. Only hints of major variation structure remained, even though they were not from the original input abundance distribution. The signal to noise ratio required to detect the variations present in the maps used in this work to a one sigma level would be about 2000, which is well above the usual 150-200 in most long slit observations.

Large artificial variations were observed in the abundances obtained from total line fluxes as well as those from emission line maps. The largest discrepancies were seen in the abundances of N where an increase of 50% was seen but variations were also seen in O, with a decrease of 23% and in S with an increase of 18%.

It is clear that the usual empirical procedure is not adequate to investigate spatial variations of abundance and does not recover the original input values. We are currently working on finding possible alternatives that involve only the data and do not require time consuming 3D photoionization modeling although we note that fully self-consistent modeling is still the ideal procedure.

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