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The role of shocks in the determination of empirical abundances for type-I PNe

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Abstract. We investigate, in the light of new diagnostic diagrams, the role of shocks in the ionization profile of type-I planetary nebulae, and their relation to the empirical derivation of chemical abundances. We apply our technique to two well-known type-I objects: NGC 2440 and NGC 6302. Our results indicate that shocks play a very important role in the spectra of both nebulae and, since the presence of shocks reinforces the flux of low ionization lines, this artificial reinforcement can lead to incorrect chemical abundances, when they are derived through Ionization Correction Factors, at least for type-I PNe.

Keywords. ISM: abundances, planetary nebulae: general, planetary nebulae: individual (NGC 2440, NGC 6302), techniques: spectroscopic

1. Introduction

Despite the growing use of photoionization models to derive chemical abundances of Planetary Nebulae (PNe), empirical abundances derived with the help of Ionization Correction Factors (ICFs) are still very useful for large samples when frequently no information on the central star is available for most nebulae.

This work aims to investigate the role of shocks in the excitation/ionization of type-I PNe, and their relation with the empirical derivation of chemical abundances, using the new diagnostic diagrams developed by Akras & Gonçalves (2016). To perform such diagnostics, an accurate description of the morpho-kinematic structure of PNe is required. This is challenging since these objects can have several morphological types, from the most regular ones, with spherical symmetry, to strongly asymmetrical, multipolar objects.

2. Targets and methodology

We applied the diagnostics to NGC 2440 and NGC 6302, both very well known; the first is multipolar with at least two bipolar components, and the second is bipolar. A whole kind of substructures known as LIS and FLIS (low ionization structures and their fast versions) were already studied in both objects, and were recently linked with shocks, that have a role in the ionization mechanisms. Line flux ratios and density maps from literature were used for both objects. For NGC 2440, velocity fields were obtained from L'opez *et al.* (1998), and from Lago & Costa (2016). For NGC 6302 we used the velocity fields from Szyszka *et al.* (2011), and our own data, derived using coudé spectroscopy.

Akras & Gonçalves (2016) (*loc. cit.*) developed diagnostic diagrams to distinguish photoionization from shocks in PNe, according to the ratio f_{shock}/f_*, where f_{shock} is the flux of ionizing photons due to shocks and f_* is the flux of ionizing photons from the central star. Using the definition of energy flux from shocks, F_{shock}, by

Dopita & Sutherland (1996) and converting it to photon flux f_{shock}, the nebula can be divided in three regions:

- $log(f_{shock}/f_*) > -1$: region excited by shocks
- $-2 < log(f_{shock}/f_*) < -1$: transition region
- $log(f_{shock}/f_*) < -2$: region excited by photoionization

For NGC 2440 we used narrow filter images from Cuesta & Phillips (2000) to build the diagnostic diagrams. For NGC 6302 we used the data from Rauber *et al.* (2014), combined with velocities derived from our own long slit spectra. The values of f_{shock} and f_* were calculated using the formulae by Akras & Gonçalves. Velocity fields are also required to estimate correctly the contribution of shocks. For NGC 2440 they were modelled by Lago & Costa (2016) (*loc. cit.*) and NGC 6302 had its velocity field estimated from our long slit spectra.

The environment where shocks play an important role are those at high velocity regimes (~ 100 km/s), far from the central star, and in the rims of PNe, where there is interaction with the ISM. One of the main consequences is the reinforcement of the low ionization lines in these regions.

3. Results and conclusions

For NGC 2440 we examined points at the peripheral region of the nebula, chosen by morphological criteria, in particular rims and knots, and for NGC 6302 we used points throughout the entire nebula in both lobes.

Results indicate clearly that shocks play a crucial role in the spectra of both nebulae. For NGC 2440, our analysis shows that all points in the peripheral zones lie in the shock regime, with $log(f_{shock}/f_*) > -1$. This raises the hypothesis of interaction of the main nebula with a halo. For NGC 6302 the whole nebula was analysed along the symmetry axis, in steps of 4 arcsecs, and the result shows that many points in the inner part of the nebula lie in the transition zone, with $-2 < log(f_{shock}/f_*) < -1$, while the outer parts are in the shock regime.

ICFs based on line ratios are commonly used to derive elemental abundances in PNe since for most atoms only a few ions are available in the spectra. The presence of shocks reinforces the flux of low ionization lines, and the results discussed above show that, for these nebulae, shocks are present indeed. This artificial reinforcement of low ionization lines can lead to incorrect chemical abundances, when derived through ICFs, at least for type-I PNe.

A comprehensive study of this effect, applied to a larger PNe sample and including all types, ideally a statistically complete sample, would be required to clarify this proposition.

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