Nebular kinematics of NGC 7009 and NGC 6543 as tests of possible differences of distribution of permitted and forbidden emission lines

S. Torres-Peimbert\textsuperscript{1}, A. Arrieta\textsuperscript{2}, L. Georgiev\textsuperscript{1}, and M. Richer\textsuperscript{1}

\textsuperscript{1} I. Astronomía, Universidad Nacional Autónoma de México  
silvia.georgiev@astros.uan.unam.mx, richer@astrosen.unam.mx  
\textsuperscript{2} Universidad Iberoamericana, Mexico anabel.arrieta@uia.mx

Summary. One of the open problems in PN research is the abundance discrepancy factor that is obtained from O II lines and [O III] lines. There are two main ideas that have been put forward to explain this difference: (a) variations of temperature in a chemically homogeneous medium (e.g. [1], and references therein) or (b) variations of temperature due to a chemically inhomogeneous medium where there are high density hydrogen-poor condensations of low temperature responsible for most of the recombination line intensities (e.g. [1], and references therein). To try to discriminate among these possibilities, we have examined the possible difference in distribution of the O II and [O III] lines in planetary nebulae. From long slit echelle spectroscopy of NGC 7009 and NGC 6543 we have examined their velocity distribution along the slit on two different positions of each nebula.

Key words: planetary nebulae, NGC 6543, NGC 7009

1 Observations

The observations were performed at the 2.1-m telescope of the Observatorio Astronómico Nacional in San Pedro Martir with the REOSC echelle spectrograph. We have secured long exposures in two different positions centered on the star (Fig. 1) to examine the faint permitted lines of oxygen. The spatial scale along the slit is 0.99\arcsec/pixel, while the velocity resolution is of 10 km/sec/pixel. In each case we have extracted individual spectra along the slit with extraction windows 2 pixels wide. These observations are also presented in [2] for a deep search of highly ionized Fe lines.
2 Position-radial velocity

We can represent the intensity of any line on the position-radial velocity plane, where the stellar continuum contribution has been subtracted with an interpolation scheme at neighboring wavelengths. We have selected a set of lines of different ionization potentials to examine their velocity distribution; they are presented in Figs. 2 and 3. The emission line intensity profiles have been plotted in order of increasing ionization potential. The ionization structure can be clearly appreciated, where the higher potential lines are more centrally located and the velocity distribution varies systematically, in the sense that the lower ionization potential species have higher radial velocities. For better comparison among the position-radial velocity behavior of lines of different intensity they were normalized to maximum intensity and represented on a linear scale.

\[\text{Fig. 1. Location of the slits (i) NGC 7009, P. A. 72°[a] and 172°[b] (ii) NGC 6543: 10°[a] and 43°[b]}\]

3 Oxygen line profiles

In particular, we have selected those oxygen lines that have enough signal to noise ratio to be thus represented (Figs. 4 and 5). The O II lines 4072, 4367, 4649, and 4662 fulfill this criterion. In our echellograms, the nebular lines [O III] 4959 and 5007 are heavily saturated, and cannot be used for comparison. For [O III] we have selected the lines of 4363 and 4931, that are not saturated. However, although the 4931 line is emitted from the same level as 4959 and 5007, and is comparable in intensity to the permitted O II lines, its background is affected by scattered light from the neighboring bright lines in the echellogram, which corrupts its reduction. Thus it cannot be fully corrected for the underlying continuum. For both NGC 7009 and NGC 6543, in both slits we consider that the O II lines show essentially the same velocity structure as 4363 of [O III]. We prepared positional-velocity ratios of O II/[O III] for NGC 7009 to better appreciate their behavior (Fig. 6). To avoid
**Fig. 2.** NGC 7009. Intensity on the position-radial velocity plane along the slit for different emission lines, for positions a (left) and b (right).

**Fig. 3.** NGC 6543. Intensity on the position-radial velocity plane along the slit for different emission lines, for positions a (left) and b (right).
excessive noise we washed out the faint regions. Our figures have been normalized to the mean value of each ratio; in these units the minimum value, maximum value and standard deviations are (0.51, 1.31, 0.14) and (0.70, 1.16, 0.07), respectively.

Fig. 4. NGC 7009. Velocity distribution of O II and [O III] lines for slit positions a (left) and b (right)

Fig. 5. NGC 6543. Velocity distribution of O II and [O III] lines for slit positions a (left) and b (right)

4 Discussion

In NGC 7009 along slit b there is an excess of emission in the O II lines in the central regions, where both 4649 and 4363 lines are faint. These differences can be due to
a lower central temperature, rather than by differences of the velocity distribution. Although we have not yet obtained similar ratios for NGC 6543, from Figs. 5 we also conclude that there are no systematic differences in the velocity diagrams.

In conclusion, we do not find differences in the velocity distribution of the O II and [O III] emitting regions. This result limits the possibility of chemically inhomogeneous condensations as being responsible of the difference in abundance determinations (in contrast to Abell 30, where indeed there are chemical inhomogeneities present in different locations). If indeed these condensations are present in these objects, they have the same velocity distribution. It should be pointed out that [3] have computed the abundances for the central star of NGC 6543 and do not find any difference with the nebular abundance derived from the recombination lines.

References