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The quality of spectral lines in planetary nebulae

Quality control lines

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Abstract. We estimated a series of uncertainties generated in the reduction process of the planetary nebulae spectra obtained from the 2.15m CASLEO telescope in Argentina. We also proposed to add to the usual line ratios of spectra quality control the He I $\lambda4471/\lambda5876$, $\lambda6678/\lambda5876$ and He II $\lambda5412/\lambda4686$ ratios. Moreover, we emphasize that this quick spectral quality control can be applied not only for planetary nebulae but also to H II regions.

Resumo. Neste trabalho estimamos uma série de incertezas oriundas do processo de redução de espectros de nebulosas planetárias obtidos com o telescópio de 2.15 m CASLEO, na Argentina. Também propomos adicionar às razões de linhas usuais de controle da qualidade espectral, as razões He I $\lambda4471/\lambda5876$, $\lambda6678/\lambda5876$ e He II $\lambda5412/\lambda4686$. Além disso, enfatizamos que esse rápido teste da qualidade espectral poder ser aplicado não apenas às nebulosas planetárias, mas também às regiões H II.

Keywords. Instrumentation: spectrographs – planetary nebulae: general – Methods: data analysis

1. Introduction

In H II regions and, particularly, in planetary nebulae (PNe), there are certain emission lines whose ratios do not depend on the physical properties (for example T_e or n_e) of the object. These lines can be called *quality control lines*, since they serve to quickly evaluate the quality of the spectra obtained. The collection of spectroscopic data necessarily generates series of uncertainties, though they are rarely detailed in the literature. We estimated these uncertainties −from the data acquisition all the way to the measurements of the emission line fluxes−, for the same lines in all spectra of each object. The procedure was done using data of the REOSC-DS spectrograph, which is mounted at the 2.15m CASLEO telescope in Argentina. In addition to the usual quality control lines ([O III] and [N II]), we also analyzed the He I $\lambda4471/\lambda5876$, $\lambda6678/\lambda5876$ and He II $\lambda5412/\lambda4686$ ratios.

2. Observational sample

The observations were carry out during five consecutive nights. Six standard flux PNe were observed. They were taken from Dopita & Hua (1997) (see Table 1).

We selected the 300 g/mm grating with a 2.5 arcsec width slit. The position angle of the slit was set in 90° for all objects, also in the case of the flux standard stars. These last objects were observed with a 6 arcsec slit. The reduction procedures (performed with IRAF) included image trimming, flat fielding, wavelength calibration, sky subtraction, flux calibration and dereddening.

Table 1. List of observed objects.

Objects	PN G	Exposure [s]	Number of spectra
Hb 4	003.1+02.9	600	21
He 2−34	274.1+02.5	1100	15
He 2−86	300.7−02.0	800	18
He 2−123	323.9+02.4	700	16
He 2−182	325.8−12.8	200	18
StWr 4−10	336.9+08.3	1500	18

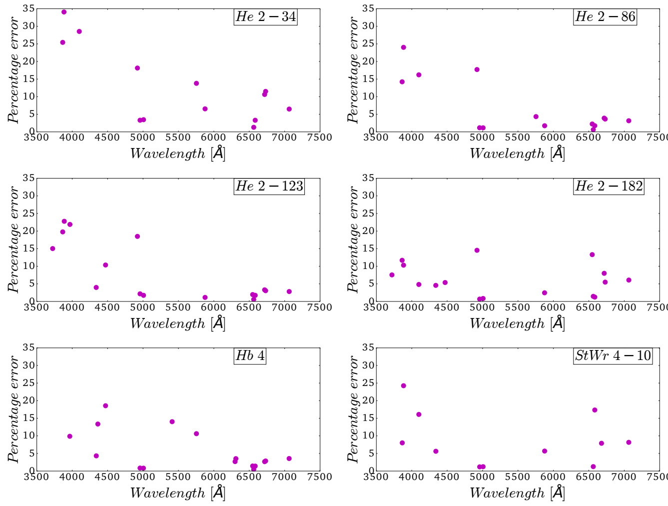

Figure 1. Uncertainties obtained for the six flux standards PNe.

3. Measurement uncertainties

We took into account combined uncertainties due to the observations, reductions, wavelength and flux calibrations and reddening correction. Then, the fluxes of 15 emission lines of each spectra were measured for determining the mean flux and its standard deviation. In Figure 1 we can see the results.

Another source of uncertainty is the measurement process itself. In this case we did an experiment asking to 19 other astronomers to measure the same six emission lines in one specific spectrum. Thus we computed the mean flux and, with the standard deviation, the percentage error between the different measurements. The results can be seen in Table 2: for lines with a

Table 2. Results from the different measurements of the flux.

Line λ (Å)	S/N	Mean flux	RMS	Percentage error
4100	15	11.09	0.58	5.3
4340	40	28.87	0.64	2.2
4861	135	100	-	-
4959	720	371.01	6.03	1.6
6563	2230	421.27	8.64	2.1
6717	50	9.23	0.48	5.2

Table 3. Percentage errors obtained with different methods. The λ6717 Å line represents the case of deblending, which generated higher errors.

Line λ (Å)	S/N	Experiment	Gonzalez-Delgado
4100	15	5.30	4.39
4340	40	2.20	2.93
4861	135	-	1.54
4959	720	1.60	0.56
6563	2230	2.10	0.20
6717	50	5.20	1.02

high S/N about 2% of the uncertainties are due only to the measurement process.

We decided to compare our results with another way to estimate the uncertain, in this sense we used the Gonzalez-Delgado et al. (1994) (see equation 1), where σ_l is the error in the line flux, σ_{cont} represents the standard deviation in a continuum window near the emission line measured, N is the number of pixels used in measuring the line flux, EW is the line equivalent width, and Δ is the dispersion in Å pixel^{-1}. Results are shown in Table 3.

$$\sigma_l = \sigma_{cont} \sqrt{N} \left(1 + \frac{EQW}{N\Delta}\right)^{0.5} \equiv \sigma_{G-D} \qquad (1)$$

Therefore, the criterion adopted for the uncertainties was:

$$S/N \leq 40 \rightarrow \sigma_{new} = \sigma_{G-D}\ ;\ S/N > 40 \rightarrow \sigma_{new} = 3\sigma_{G-D} \qquad (2)$$

4. Characterization of the *quality control lines*

Using the criterion adopted above, we were able to assign an error to the measurements for these 6 PNe and another 18 (whose spectra were taken in the same way and observatory, but in previous years). Then we measured the He I line ratios, with respect to Hβ = 100, and compared with the values from Girard et al. (2007) and Górny et al. (2009). The results obtained can be seen in Figure 2. For the He II ratio we used our values and the Girard et al. (2007) ones (see Figure 3).

5. Conclusions

Our detailed analysis allows to point out the following conclusions:

- The flux calibration clearly depends on the lines S/N ratio and the uncertainties are as follows: for $S/N \gtrsim 40 \rightarrow$ from 3% to 8%; and for $S/N \lesssim 40 \rightarrow$ between 15% and 35%.
- We now have a criterion of uncertainties valid for spectra taken by CASLEO with the 300 g/mm grating: $3\sigma_{G-D}$ ($S/N > 40$) and σ_{G-D} ($S/N \leq 40$).
- The improved method to evaluate the quality of the spectra should be based on the line ratios:

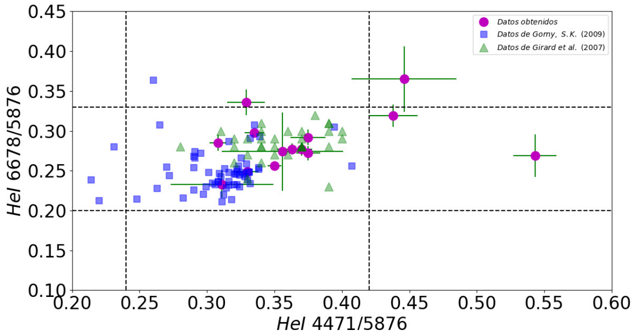

Figure 2. Results obtained for He I and expanded using other works. The dashed lines are the 2σ errors and the error bands are calculated using the adopted criterion (eq. 2).

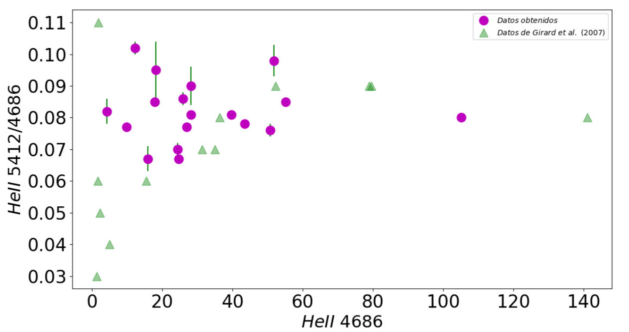

Figure 3. Results obtained for He II and expanded using the Girard et al. (2007) data. The error bands are calculated using the adopted criterion (eq. 2).

1. [*N II*] $\lambda(6583)/\lambda(6548)$ = 2.92 ± 0.32 (Acker et al. 1989),
   [*O III*] $\lambda(5007)/\lambda(4959)$ = 3.01 ± 0.23 (Acker et al. 1989)
2. *He I* $\lambda(4471)/\lambda(5876)$ = 0.33 ± 0.05 and $\lambda(6678)/\lambda(5876)$ = 0.27 ± 0.03
3. *He II* $\lambda(5412)/\lambda(4686)$ = 0.08 ± 0.02.

We also remark that the last two line ratios were not used before aiming the spectra quality control and are the main contribution of our work.

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