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Spectroscopic analysis of the planetary nebula NGC 1501

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Abstract. The spectrum of the planetary nebula NGC 1501 is reported. It was divided into different regions in order to point out the variations in the measured temperature, density, and chemical abundances. The data were corrected for extinction with the purpose of obtaining the intrinsic values.

1. Introduction

A planetary nebula is the expanding shell of gas around a white dwarf progenitor, with a mass lower than 5 solar masses. Its formation is due to the fact that the star is not heavy enough to ignite the carbon fusion. The star contracts in order to maintain its hydrostatic equilibrium; its temperature increases making the surrounding gas expand. The planetary nebula NGC 1501 surrounds a Wolf-Rayet star at a distance of 1500 pc.

2. Observational Data

The spectra were taken with the Boller & Chivens spectrograph mounted at the 1.22-m telescope of the Asiago Astrophysical Observatory. Three images with exposure time of 300, 900 and 900 s were processed and combined together.

3. Work Description

Using the software ds9, the spectrum of the nebula was divided along the spatial-axis into 8 sections of 10 pixels each plus a central one of 8 pixels containing the continuum of the star.

By using the software IRAF, the flux of the gas emission lines necessary to analyze NGC 1501 was measured for each one-dimensional spectrum (see Table 1). The plot of the intensity versus the wavelength shows the peak of each emission line. We calculated the flux fitting a Gaussian function. This measurement allowed us to derive the average temperature, density, and chemical abundances. In the external regions of the nebula there are weaker fluxes that are more difficult to detect; because of this, many important emission lines could not be measured.

Table 1. Measured fluxes of the emission lines

Region	flux Hα erg cm^{-2} s^{-1}	flux Hβ erg cm^{-2} s^{-1}	flux HeI5876 erg cm^{-2} s^{-1}
4n	1.33e-15	1.9e-16	—
3n	2.46e-14	4.01e-15	8.29e-16
2n	4.55e-14	7.98e-15	1.44e-15
1n	3.46e-14	5.98e-15	9.46e-16
1s	3.75e-14	6.69e-15	1.04e-15
2s	4.19e-14	7.18e-15	1.2e-15
3s	1.78e-14	3.48e-15	5.3e-16
4s	6.9e-16	1.51e-16	—
Region	flux HeII4686 erg cm^{-2} s^{-1}	flux [NII]6548 erg cm^{-2} s^{-1}	flux [NII]6584 erg cm^{-2} s^{-1}
4n	—	3.48e-17	3.77e-17
3n	1.11e-15	4.11e-16	1.28e-15
2n	2.98e-15	6.42e-16	2.12e-15
1n	4.19e-15	6.76e-16	1.28e-15
1s	3.73e-15	5.57e-16	1.23e-15
2s	2.61e-15	6.12e-16	1.83e-15
3s	1.0e-15	2.94e-16	9.07e-16
4s	—	3.39e-17	4.06e-17
Region	flux [SII]6716 erg cm^{-2} s^{-1}	flux [SII]6731 erg cm^{-2} s^{-1}	flux [OII]3727 erg cm^{-2} s^{-1}
4n	—	—	—
3n	2.4e-16	2.62e-16	6.93e-16
2n	3.57e-16	3.62e-16	1.33e-15
1n	1.7e-16	2.15e-16	7.88e-16
1s	2.38e-16	2.36e-16	9.35e-16
2s	3.45e-16	3.46e-16	1.1e-15
3s	1.89e-16	1.85e-16	7.34e-16
4s	—	—	—
Region	flux [OIII]4959 erg cm^{-2} s^{-1}	flux [OIII]5007 erg cm^{-2} s^{-1}	flux [OIII]4363 erg cm^{-2} s^{-1}
4n	8.44e-16	2.63e-15	—
3n	1.74e-14	5.36e-14	2.84e-16
2n	3.38e-14	1.04e-13	5.24e-16
1n	2.43e-14	7.49e-14	5.31e-16
1s	2.74e-14	8.36e-14	3.92e-16
2s	3.07e-14	9.37e-14	6.22e-16
3s	1.51e-14	4.53e-14	2.23e-16
4s	6.38e-16	1.81e-15	—

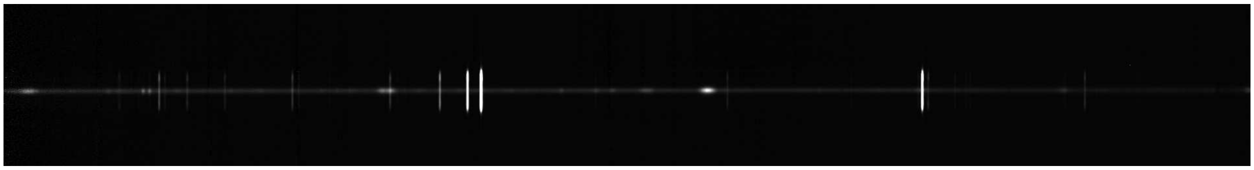

Fig. 1. Spectrum of the planetary nebula NGC 1501.

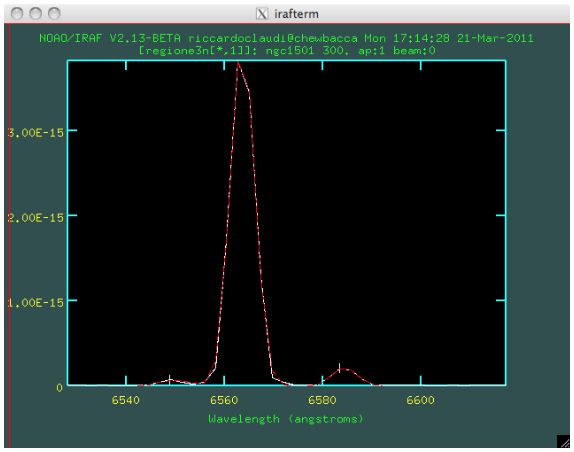

Fig. 2. Example of an emission line fitted with a Gaussian curve.

We corrected our measurements for interstellar extinction by using Cardelli's equation:

$$\frac{I(H\alpha)_{int}}{I(H\beta)_{int}} = \frac{I(H\alpha)_{obs}}{I(H\beta)_{obs}} 10^{-0.1386\,A_v} \tag{1}$$

Knowing that the value of the intrinsic ratio corresponds to 2.86, it was possible to calculate A_v. Using this value each line could be corrected:

$$I(\lambda)_{int} = I(\lambda)_{obs} \cdot 10^{0.4\,A_v\,c(\lambda)} \tag{2}$$

There is a specific $c(\lambda)$ coefficient for each line:

Ion	Wavelength (Å)	c(λ)
[OII]	3727	1.53917
[OIII]	4363	1.33812
[HeII]	4686	1.22194
[Hβ]	4861	1.16427
[OIII]	4959	1.13427
[OIII]	5007	1.12022
[HeI]	5876	0.92773
[NII]	6548	0.82006
[Hα]	6563	0.81775
[NII]	6584	0.81451
[SII]	6716	0.79417
[SII]	6731	0.79183

In particular [OIII] and [SII] were used to find out the effective temperature and density of the analyzed region respectively.

Using the [SII] $\frac{I(6716\text{Å})}{I(6731\text{Å})}$ ratio for a set of temperatures, the density can be obtained, and using the [OIII] $\frac{I(5007\text{Å})+I(4959\text{Å})}{I(4363\text{Å})}$ ratio for a set of densities, the temperature can be measured. Therefore, by using an iterative method, a temperature around 10^4K was chosen to get an approximate density. The obtained density was then used to have an approximate temperature. This method was applied until the values converged, giving the correct result.

Region's name	Temperature	Density [e cm^{-3}]
4n	—	—
3n	11000K	900
2n	10700K	650
1n	12000K	150
1s	10400K	600
2s	11800K	600
3s	10400K	550
4s	—	—

In the external regions the emission was too weak to be detected, so it was not possible to obtain temperature and density values in those regions. By using TOPCAT, plots were created in order to show the radial profiles of the temperature and density of NGC 1501. The positive values correspond to the upper regions and the negative ones to the lower regions. The distance was converted from pixels to pc applying the following formula:

$$r[''] = r[px] \cdot scale\left[\frac{''}{px}\right] \tag{3}$$

$$r[pc] = \frac{r['']d[pc]}{206265} \tag{4}$$

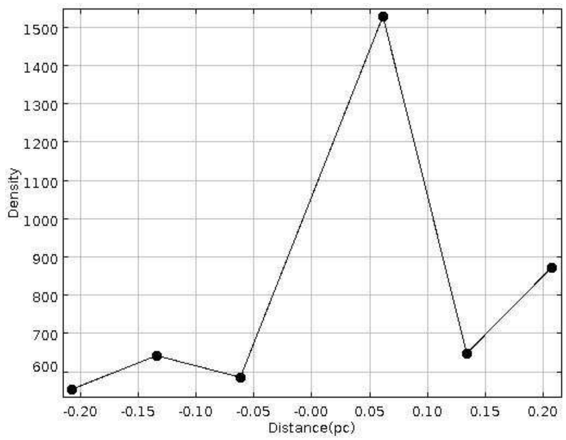

Fig. 3. Radial density profile.

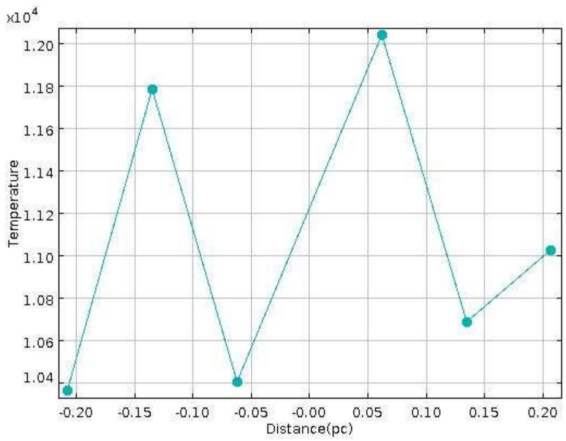

Fig. 4. Radial temperature profile.

It is possible to determine Oxygen and Nitrogen abundances by using the following formulas:

$$12 + \log\left(\frac{OI}{HI}\right) = \log\left(\frac{I_{3727}}{I_{H\beta}}\right) + 5.89 + \tag{5}$$

$$+\frac{1.676}{t_2} - 0.40\log(t_2) + \log(1 + 1.35x)$$

$$12 + \log\left(\frac{OII}{HI}\right) = \log\left(\frac{I_{4959} + I_{5007}}{I_{H\beta}}\right) + 6.174 + \tag{6}$$

$$+\frac{1.251}{t} - 0.55\log(t_2) + \log(t)$$

$$\frac{OIII}{OII + OI} = \left(\frac{I_{4686}}{I_{5876}}\right)0.111t^{-0.13} \tag{7}$$

$$t = \frac{T_e[OIII]}{10^4 K} \tag{8}$$

$$t_2 = T_e[OII] = 0.243 + t(1.031 - 0.184t) \tag{9}$$

$$x = \frac{N_e}{\sqrt{t_2}10^4} \tag{10}$$

$$\frac{O}{H} = \frac{OI + OII + OIII}{HI} \tag{11}$$

$$\log\left(\frac{O}{N}\right) = \log\left(\frac{I_{3727}}{I_{6548} + I_{6583}}\right) - 0.307 + \frac{0.726}{t_2} + \tag{12}$$

$$+0.02\log t_2 + \log\left(\frac{1 + 1.35x}{1 + 0.116x}\right)$$

$$\frac{N}{H} = \left(\frac{O}{H}\right)\left(\frac{N}{O}\right) \tag{13}$$

Region	O/H	O/N	N/H
4n	—	—	—
3n	4.4148e-4	5.1599	8.5559e-5
2n	5.0698e-4	5.2926	9.5790e-5
1n	5.1585e-4	5.2869	9.7571e-5
1s	6.2080e-4	6.1897	1.0029e-4
2s	4.2792e-4	4.8208	8.8765e-5
3s	5.2487e-4	5.3840	9.7485e-5
4s	—	—	—

4. Results

According to the experimental data, it is possible to infer that variations of temperature and density are neither uniform nor regularly changing. It can only be observed that there are high temperatures where there are high densities. From the analysis of the chemical abundances, it is detected a higher presence of Hydrogen than Oxygen and Nitrogen. It can be deduced that the planetary nebula NGC 1501 is not symmetrical.

References

Ercolano, B., Wesson, R., Zhang, Y., Barlow, M. J., De Marco, O., Rauch, T., & Liu, X.-W. 2004, MNRAS, 354, 558