Spectroscopic analysis of NGC2346 following hypothesis concerning its central object

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ABSTRACT

The analysis of the planetary nebula is linked to the increasing knowledge of the final phases of stellar evolution. The physical and chemical characteristics of the gas outcoming from the star can be detected from the spectroscopic analysis of the nebular part. These measures can be used to build theoretical models about the main characteristics of the star which has originated the planetary nebula itself. From the outcomes we can understand how to figure out the development phases of pre-white dwarf and whether the centre of the nebula is occupied by one or more objects.

I. INTRODUCTION

Fig. 1: The "butterfly" nebula NGC 2346.

During the rising on the asymptotic branch a star loses mass. When the inner parts get below 0.3 $M_{\odot}$, the most external parts get into resonance and go beyond the escape velocity.
Progressively the star gets rid of the whole envelope, expelled as subsequent layers expanding at high velocity.
This is the planetary nebula phase, during which we can observe the star surrounded by the expelled layers.
At the end of this phase, after the total expulsion of the gas, we have an object with a relatively high density and temperature; the degenerate gas cannot contract anymore: a white dwarf is formed. NGC2346 (Butterfly Nebula) is an astronomic object belonging to this category.
The purpose of our work is to analyse spectroscopically the chemical abundances of the nebular part, aiming at a future use of the obtained information in order to apply it to a model which might indicate temperature and luminosity of the central object.
The resulting chemical abundances proved to be coherent with their values in literature (Walsh 1983).
Once their values were applied to the building model CLOUDY program, the output was contrasting with the spectral class of the central object found in literature and therefore we formulated different hypothesis regarding its nature and structure.

II. OBSERVATIONAL DATA

Name	NGC 2346
Object category	Planetary Nebula
Constellation	Monoceros
Coordinates (2003)	RA:$07^h\ 09^m\ 41^s$ Dec: -00° 48' 56"
Apparent Magnitude	11.7
Redshift	0.000073
Radial Velocity	21.8 km/s
Distance H_o=75 km s^{-1} Mpc^{-1}	≈ 2000 ly (610 pc)

Angular Size	≈ 0.9’
Linear Diameter	0.3 ly
Spectral Class of the central star	A5-V

Tab.1: Data regarding the analysed nebula.

Grating	600 lines/mm
Slit Aperture	3 arcsec
Telescope 122 cm	Cassegrain
Equivalent Focal	19 m

Tab.2: Data regarding the configuration of the spectrograph.

III. WORK DESCRIPTION

The spectra we used were taken from three different parts of the nebula, with three distinct angles. First, we corrected them for bias and flat field. For wavelength calibration we used the emission spectra of a HgAr lamp and of a Ne lamp, while for the conversion from counts into flux we used a comparison spectrum of a spectroscopic standard star with known flux as a function of wavelength.
Finally, we subtracted from the data the contribution given by the sky. We used the IRAF software both for data reduction and analysis.

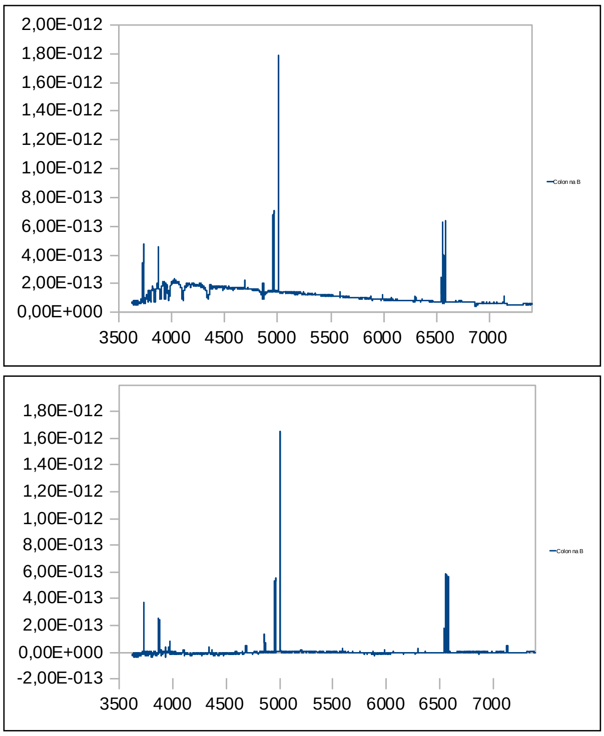

Fig.2: One-dimensional spectra of NGC2346. In the first spectrum there is the contribution of the central star, in the second spectrum the star contribution is subtracted. In abscissa we have Å in ordinate erg/cm^2/s/Å.

In Fig. 2 the two spectra represent the nebula emission respectively with and without the contribution of the central star. For the graphic representation of the above mentioned spectra we used the EXCEL program.
After that, it was necessary to correct the spectrum due to the presence of the interstellar medium. In fact, the ratio between the Hα and Hβ fluxes usually follows the Balmer decrement with value 2.86. In our analysis, we noticed an alteration of the above mentioned ratio, with a 4.9 value: this is due to the partial absorption of the emitted radiation, especially at short wavelengths, given by dust and gas in between the nebula and us.

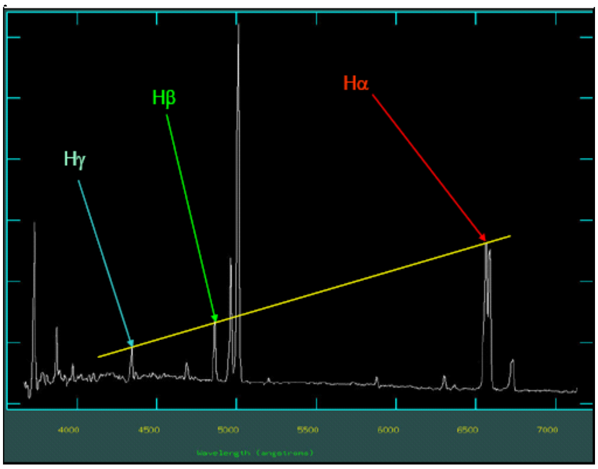

Fig.3: Balmer decrement.

Therefore, we calculated a conversion factor which allowed us to get to the true ratios between the fluxes. In our analysis, this factor is calculated in the following way (I = intrinsic flux and F = observed flux):

$$I(H\alpha)/I(H\beta) = 2.86$$

$$F(H\alpha)/F(H\beta) = 4.9$$

$$I(H\alpha)/I(H\beta) = F(H\alpha)/F(H\beta)\ 10^{-0.4297*E(B-V)}$$

$$E(B-V) = 0.544$$

$$c = \log(I(H\beta)/F(H\beta)) = 1.4436*E(B-V)$$

$$c = \log(I(H\beta)/F(H\beta)) = 0.78$$

Given this value of c it is possible to find the correction in the visual magnitude of the Hβ through:

$$A(V) = c / 0.4657$$

This variation in magnitude can be extended to all the wavelengths through a dereddening procedure based on the Cardelli, Clayton, and Mathis (1989) reddening curve

$$A(\lambda) = A(V) \cdot D(\lambda)$$

This type of correction is one of IRAF functions, so we could get the true fluxes of all the lines and the corrected flux ratios normalized to Hβ.

In Tab. 3 the measured fluxes and the corrected flux ratios normalized to Hβ are reported. The fact that Hα/Hβ gives 2.88 guarantees the reliability of the obtained result. The estimated error on the fluxes is around 10^{-14} erg/cm^2/s.

Line	Wavelength	Measured Flux erg/cm2/s	Corrected F/ Hβ
[OII]	3727	1.870E-12	11.4055
[NeIII]	3869	5.053E-13	2.91692
	3968	1.659E-13	0.91949
Hε	3968	5.809E-14	0.32172
Hδ	4102	1.072E-13	0.5587
Hγ	4340	1.831E-13	0.82101
[OIII]	4363	4.783E-14	0.20913
He I	4471	3.854E-14	0.15993
Hβ	4861	2.921E-13	1.00000
[OIII]	4959	9.028E-13	2.95072
[OIII]	5007	2.716E-12	8.69036
NII	5755	4.364E-14	0.10766
He I	5876	7.731E-14	0.18053
[OI]	6300	1.648E-13	0.34939
[OI]	6363	4.823E-14	0.10447
[ArI]	6548	9.607E-13	1.89953
Hα	6563	1.438E-12	2.88309
[NII]	6584	3.014E-12	6.01149
HeI	6679	2.588E-14	0.05130
[SII]	6717	7.299E-14	0.14123
[SII]	6731	6.011E-14	0.11824
He I	7065	2.471E-14	0.04159
[ArIII]	7136	1.705E-13	0.29639
[OII]	7321	3.751E-14	0.06355
[OII]	7331	3.515E-14	0.05852
[ArIII]	7752	4.91E-14	0.07503
[SIII]	9069	7.542E-14	0.08951
[SIII]	9531	1.897E-13	0.21152

Then, we measured the fluxes of the lines [OIII] and [SII], which are useful indicators respectively of temperature and electron density. After that, thanks to the IRAF TEMDEN program, we assessed these two values. The procedure consists in providing the program with an initial value for the temperature; then, the TEMDEN program calculates the value of the density on the basis of the temperature we provided. Then, we continued with the calculations inserting step by step the found values of T and N_e until we got to a convergence of the values; in our case the program provided:

T = 18800 K

N_e = 150 cm^{-3}

For the calculations of ionic abundances, we applied some formulas that can be found in Pagel et al. (1989). These allowed us to figure out the ratios between the found ions, using the obtained data concerning the temperature and electron density of the nebula.

$$12+\log(O^+/H^+) = log\frac{3726+3729}{H\beta}+5{,}890 + \frac{1{,}676}{t_2} - 0{,}40 log t_2 + \log(1+1{,}35x)$$

$$\log(O^+/N^+) = log\frac{3726+3729}{6548+6584} - 0.307 + \frac{0.726}{t_2} + 0{,}02 log t_2 + log\frac{1+1{,}35x}{1+0{,}116x}$$

$$\log(O^{++}/Ne^{++}) = log\frac{4959+5007}{3869} - 0{,}215 - \frac{0{,}355}{t} - 0{,}13 log t$$

$$12+\log(S^+/H^+) = log\frac{6717+6731}{H_\beta} + 5{,}423 + \frac{0{,}929}{t_2} - 0{,}28 log t_2 + \log(1+1{,}39x)$$

$$12+\log(S^{++}/H^+) = log\frac{9069+9532}{H_\beta} + 5{,}863 + \frac{0{,}665}{t} - 0{,}22 log t$$

$$\log(O^{++}/H^+) = log\frac{4959-5007}{H_\beta} + 6{,}174 + \frac{1{,}251}{t} - 0{,}55 log t$$

where:

t = electron temperature of the interstellar medium in units of 10^4 *K* $\equiv$ *t[OIII]*

$$\boldsymbol{t_2^{-1} = 0{,}5(t^{-1}+0{,}8)}$$
$$\boldsymbol{x = 10^{-4} n_e t_2^{-1/2}}$$

where n_e is the electron density in cm^{-3}.
From the ionic abundances we got the total chemical abundances multiplying the obtained values and the real ratios.
The abundances are consequently given by the following formulas (Perinotto et al. 2004):

$$\frac{N(S)}{N(H)} = \frac{N(S^+)}{N(H^+)} \times \frac{N(O)}{N(H)} \times \frac{N(H^+)}{N(O^+)}$$

$$\frac{N(N)}{N(H)} = \frac{N(N^+)}{N(H^+)} \times \frac{N(O)}{N(H)} \times \frac{N(H^+)}{N(O^+)}$$

$$\frac{N(O)}{N(H)} = \frac{N(O^+)}{N(H^+)} + \frac{N(O^{++})}{N(H^+)}$$

The planetary nebula NGC 2346 is characterised by an irregular shape similar to a butterfly. In order to build a model we had to imagine it as a sphere. Furthermore, we took a black body spectrum as emission spectrum of the star situated in the centre of the nebula.

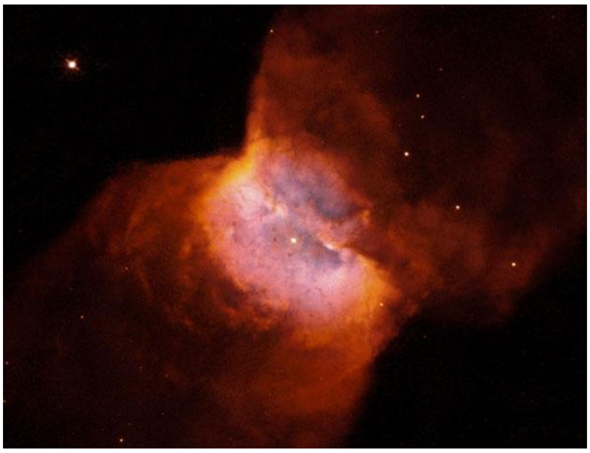

Fig.4: Image of NGC 2346.

The model elaboration, carried out through the Cloudy program, is based on entering five free parameters:

1. Black-body temperature (T);
2. Luminosity (L);
3. Electronic density (Ne);
4. Dimensions (r);
5. Chemical abundances;

We obtained the values of these parameters through different methods.
We calculated the electron density of NGC2346, equal to 150 cm^{-3}, with the IRAF program that elaborated the previously collected data.
As dimensions of the nebular part, we used three data: internal radius, external radius and depth of the nebular shell.
The external radius was calculated using simple trigonometric relation:

$$R = d \cdot \sin \alpha/2 \approx d \cdot \alpha/2$$

where d refers to the distance between Earth and the nebula (613.5 pc), while R is the external radius and α (0.9′) the visual angle. Therefore, the external radius is about $2.5 \cdot 10^{17}$cm. The value of the internal radius (r), on the contrary, estimated through the observation of images of the nebula seems to be about 1/10 of the external one (i.e. $2.5 \cdot 10^{16}$ cm).
The chemical abundances were chosen to be equal to the solar ones.
On the contrary, for the other two parameters of temperature and luminosity, we defined a range within which we made them variable.
We got the models allowing the logarithm of the luminosity (in erg/sec) to vary from a minimum value of 32 to a maximum of 39.
Since the continuum of the spectrum was comparable to the one emitted by an A5 V spectral class star we initially made the hypothesis that the central object, source of ionization of the nebular gas, had a temperature of 10000 ~ 15000 K , but then, the values of the chemical abundances obtained by the CLOUDY program at those temperatures were completely different from the values obtained analysing the real spectrum. We realised that the star could not be the one we initially expected.
Therefore, we decided to change the temperature of the black-body from 50000 K to 150000 K with intervals of 10000 K.
Among the about eighty models we made, it was necessary to find out the one closest to the experimental values.
To carry out this work, first of all we calculated the difference between each experimental abundance and its corresponding item in each model (deviation). While calculating the deviation it was easy to find out the most appropriate model: the one with the minimum deviation. The model we obtained gave us the values of the unknown parameters: temperature and luminosity.

IV. RESULTS

N(O+)/N(H+)	2.6E-04
N(O++)/N(H+)	6.3E-05
N(S+)/N(H+)	1.8E-07
N(S++)/N(H+)	5.6E-07
N(O++)/N(Ne++)	1.57
N(O+)/N(N+)	5.06
N(O+++)/N(H+)	1.6E-04

Tab.4: Ionic abundances.

N(O)/N(H)	4.8E-04
N(S)/N(H)	3.3E-07
N(N)/N(H)	9.5E-05

Tab.5: Chemical abundances.

The values of the chemical abundance of Sulphur and Nitrogen agree with the ones obtained by Walsh (1983).
In Tab. 6, we reported the experimental data and the ones referring to the model with the minimum deviation. We can see how the two series are comparable (Fig. 5). We also noticed the presence of two abnormal data corresponding to the emission of [OII] and [NII].
The reason of this difference can be related to the fact that the chemical abundance of the various elements is not uniformly spread. but it varies in relation to the distance from the central star.

Lines	λ	experimental	model	residual
[OII]	3729.36	5.976	2.960	9.0984
[NeIII]	3870.15	2.641	1.650	0.9811
[NeIII] HeI	3968.47	0.977	0.500	0.228
Hδ	4102.01	0.266	0.260	4E-05
Hγ	4341.36	0.529	0.470	0.0035
[OIII]	4364.14	0.249	0.160	0.0079
Hβ	4959.85	3.850	3.640	0.0441
[OIII]	5007.8	11.559	10.950	0.3706
[NII]	5757.16	0.107	0.010	0.0093
HeI	5876.4	0.089	0.090	1E-06
[OI]	6301.15	0.149	0.120	0.0009
[OI]	6365.14	0.060	0.040	0.0004
Hα	6563.59	2.838	2.910	0.0052
[NII]	6584.37	2.602	0.530	4.2912
[SII]	6717.62	0.056	0.460	0.163
[SII]	6731.72	0.056	0.360	0.0923
[ArIII]	7136.26	0.202	0.190	0.0009
[OII]	7321.12	0.033	0.090	0.0032

Tab.6: Comparison between experimental data and with CLOUDY model deviations of minimum variance.

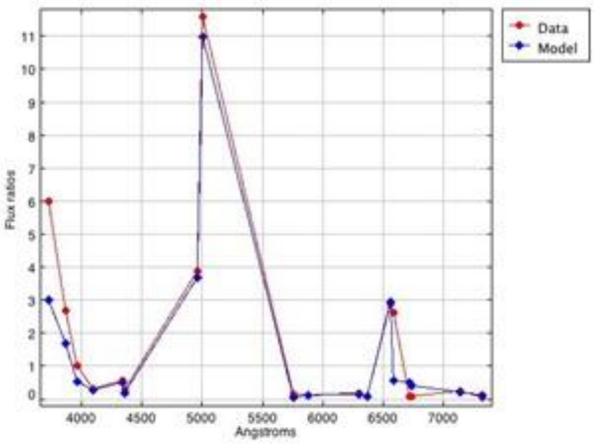

Fig.5: Comparison between the relative intensities of the experimental data and the minor variance model.

The best model gave us for the central source:

$$T = 140000\,K$$

$$L \approx 10^{38}\,erg/s$$

What do these data suggest? First of all we verified that our temperature measurement is in agreement with Walsh (1983).
So what kind of object is the source of the ionization of the nebular gas? A source of about 10000 K (A5 V) cannot justify the nature of the external gas. In literature we found that the central star shows a radial velocity variation typical of a binary system. Therefore, the source of the studied phenomenon is the companion of the central star. This companion might be a star in a pre-white dwarf phase that, probably due to the gravitational field generated by the central star, has lost the external shells as far as it uncovers a very hot core where the He gets burnt.

The peculiar shape like butterfly wings might be explained by the presence of a sort of belt of obscure material influencing the expansion of the nebular gas.
In order to check our proposed explanations, a research on the nebula in UV should be carried out.
In this band the difference of continuum between an A class star and such a hot source would be so clear as to indicate a decisive experimental difference.

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