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Photoionization modeling of the Galactic planetary nebulae Abell 39 and NGC 7027

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Abstract: The main aim of this project is to examine the line ratio of some elements relative to Hβ of planetary nebulae Abell 39 and NGC7027. We used CLOUDY C3.1 codes to obtain the line ratios relative toH_β, electron temperatures and ionization structures of both high and low species of helium, nitrogen, oxygen, neon, Sulphur and argon. To have the best fit models we included carbon abundances that were neglected. We obtained a good fit to the observations and calculated for most of the emission-line fluxes in our photoionization model. We also determined temperature of electrons in the absence and presence of carbon abundances on these two planetary nebulae moreover we have tried to show the ionization structure of both lower and higher species of elements.

Key Words: H II regions, Planetary nebulae, Abell 29, Abundances, NGC7027

1. Introduction

Planetary nebulae (PNe) are physically similar to HII regions, in that both consist of gas ionized by a hot star. They have similar visible-wavelength spectra consisting mainly of recombination lines of hydrogen and helium together with forbidden lines of ionized oxygen, nitrogen, neon and sulfur. The central star of a planetary nebula is usually hotter than that of an HII region, with a surface temperature in the range 50,000 - 100,000 K rather than 25,000 - 50,000 K; the higher stellar temperatures mean that many more highly excited ions are formed. The status of the chemical composition of PNe envelopes is more complex. Some constituents have not been changed and reflect the state of the gas out of which the progenitor of the PN was formed, 10^8 year ago or more. Other elements, such as carbon and nitrogen, have had their abundances strongly affected by nucleosynthesis and mixing processes in the progenitor, and therefore probe the evolution of intermediate mass stars [1].

In general Planetary nebulae (PNe) are the final products of many stars with masses below ~ 8 $M\odot$. This evolutionary stage occurs after the asymptotic giant branch (AGB) phase, if the star reaches a temperature high enough to ionize the circumstellar gas (the AGB external envelope ejected through a stellar wind) before it dilutes into the interstellar medium [1]. The ionized gas contains valuable information on the nucleosynthesis processes occurring inside the AGB stars (because some elements are produced in the interior of these stars and then carried to the surface) and on the chemical composition of the environment where the star was born (since other elements remain unchanged during the life of the star) [2].

We applied CLOUDY codes developed by [3] version. This is a widely used plasma/molecular photoionization code that predict the thermal, ionization and chemical structures of clouds, ranging from intergalactic to the high-density local-thermodynamic equilibrium limit, and their spectra [4]. Then, this computation is performed in a spherical geometry and at each radius from the central ionizing source, the electron temperature, the electron and ions densities, and the line emissivities are determined by solving the ionic and thermal equilibrium equations. Since, as will be discussed later, we will need to consider the greatest extremes of conditions, some of the nebulae considered below have very high oxygen abundances and CLOUDY has always been designed to simulate metal-rich environments [5].

Our ultimate aim is to examine the line ratio of some elements relative to Hβ and to compare with the measured values and observed given by [6]. We also try to determine temperature fluctuations at the given parameter. To do so we will need to consider the greatest extremes of conditions; some of the nebulae considered below have very high oxygen, nitrogen and carbon abundances.

The paper is organized as follows. Section 2 presents models and its parameters. In Section 3 We describe our photoionization model and the derived results in section 2. Our final conclusion is stated in Section 3.

2. Models and Its Parameters

Previously this was done with a model described in [6] to constrain the distance to individual PNe, utilizing the physical PN radius to compare lines ratio of some of ions with the observed. But in this work we are assumed few models parameters which are the same except the chemical abundances of the major elements, hydrogen density and the filling factor, the central star has a blackbody spectrum, the nebula is spherically symmetric [7] and dust or grains are neglected. The construction of models nebulae, using the numerical technique are given below.

The principal parameters of the nebulae gas the mean density and its distribution, usually taken to be uniform at n(H) = 100 cm^{-3} , and filling factor, ε, which is varied freely but in this work we assumed as unity. The main reason for using exactly the same parameters is to be able to distinguish between the causes of any discrepancies between our models results. However, in case of carbon abundances, it was neglected in the previous model. But, carbon is the second most abundant heavy-element in the Universe after oxygen. It is an important source of opacity and energy production in stars as well as a major constituent of interstellar dust and organic molecules [8].

Due to this we try to incorporate carbon with other chemical abundances which were found in the previous models. It was explained by [9] excitation nebulae carbon is as an important as oxygen in cooling the gas. Therefore, we have an additional set of nebular parameters is the chemical composition of the gas usually taken to be two fold of the solar value of C and N and three fold values of O elements given in) [10]. This is due to oxygen abundance has been traditionally used as a proxy for the metallicity in ionized nebulae because oxygen is the element for which more reliable abundances can be obtained. Bright emission lines from two of its ionization states, O^+ and O^{++}, can be easily measured in optical spectra, and the correction for the contribution of higher ionization states is large only for PNe of very high excitation [2]. Because of the abundances ratio of C/O<1, C/O=0.36 it is oxygen dominant PNe. When oxygen is more abundant than carbon, oxygen rich grains, such as silicates and oxides, will be formed. But in this work we neglect the impacts of such grains.

The chemical composition of these PN envelopes is expected to be quite different from that in interstellar clouds or the circumstellar envelopes of AGB stars, because of the extreme physical conditions. The gas in PNe is exposed to very strong ultraviolet radiation fields from the evolving central stars, and probably too violent shocks generated by fast stellar winds. The envelopes thus provide unique environments for the study of chemistry under these extreme conditions, and the molecular abundances should provide useful diagnostics of processes which play important roles in the evolution of the nebulae. But in this work we try to neglect the shocks and the molecular abundances effect to study the line ratios, temperature of electrons and ionization fraction of elements [11].

The abundances of rest elements are taken from the solar values which are shown in Table1. For each of these baseline models, we calculate results for temperature of electrons and its fluctuation with the ionization structure of the primary elements and the line ration with respect ofH_β.

Table1. Solar Compositions [10]

Element	ϵ
C	8.39
N	7.92
O	8.66
Ne	7.84
S	7.16
Ar	6.18

Note: -Abundances given as$\epsilon = 12 + \log(\frac{X_i}{H})$.

We have tried to refine the nebular parameters iteratively to provide the best match against the observations and calculated values by [6]. Therefore, we have taken the values of effective temperature and the luminosity which is given by [6]. The models that are developed here have some differences with the models that were developed by [6], by its hydrogen number density, filling factor and the chemical composition of some of elements.

3. Results and Discussions

In Table 2 we give the input values for the observables used for the modeling, together with the resulting model predictions calculated by [6]. As can be seen from this table, not all the lines present in the spectra are predicted by cloudy, most notably the higher Balmer lines of hydrogen and helium lines. The resulting physical parameters for the nebulae are given in the same Table 2 in column 7. The hydrogen density shown in this table is the constant density within the sphere.

Since photoionization models for Active galactic nuclei (AGN) in which the gas had a central ionizing source and spherical symmetry. Previous analyses, based upon [6] and observations have revealed a multitude of emission lines of shown in column 4 for Abell 39 and NGC 7027 given in column 5 and 6 respectively. Therefore, in this model we consider the impacts of the symmetry and other parameters given in section 2 and shown in column 2 and 3. The result is shown describe the line ratios of lines with the observed and the parameter. that the line ratios for some specific elements like $H_{\gamma}\lambda4340$ in all cases the result agree with the observed result, for [Ne] $\lambda3869$, the ratios is almost has similar values, for $H_{\alpha}\lambda6563$, the line ratio has small ratio relative to other elements. In some of lines, the presence and the absence of carbon does not affect the line ratios, likes$H_{\gamma}\lambda4340$, [Ar III]$\lambda4740$ and$H_{\alpha}\lambda6563$. The agreement between the $[H_{\gamma}]\ \lambda4340$ with the model developed previously and this new model is particularly good.

Fig 1-2 shows the electron temperature with distance from the source profiles of Abell 39 and NGC7027 PNes. For NGC7027 shown in Fig 1, PNe, electron temperature is slightly above when the carbon abundances is omitted in the simulation relative to the presence. It also shows that the rate of decaying of electron temperature when the carbon abundances omitted from the simulation, it can extends to a distance of 0.9 pc. Near to the source, in both cases the electron temperature drops and rises slowly to have peak values. For Abell 39, shown in Fig 2, the temperature profiles extend to 1.6 pc for in the absence of carbon abundances. The peak temperatures for Abell 39 are greater than NGC7027. The temperature falls sharply and raises slowly to reaches peak value and the curve of temperature in the absence of carbon abundances are slightly higher than the presence of carbon abundance.

Figure 3 and 4 shows the ionization structure of elements for low and higher species of PNe nebulae, NGC7027. For the lower ionization species, H II is dominating from the center of the star to a distance of 0.5 pc. The electron temperature continuously drops until the ionization of N^{+} and O^{+} rises and higher than H^{+}. Since, they are cooling agents. The ionization structure of S^{+} is still going to rise throughout the region as the other elements are peak.

For higher ionization species shown in Figure 4, shows that H^{++} is dominated from the center of the source to 0.16 pc. Beyond this distance the other ions have a high ionization fraction. The ionization structure of O^{4+} is dominated than N^{4+}. For the distance 0.16 pc to 1 pc both Ar^{++} is higher than S^{++}. They are falling at different rate and S^{++} decaying faster than Ar^{++}.

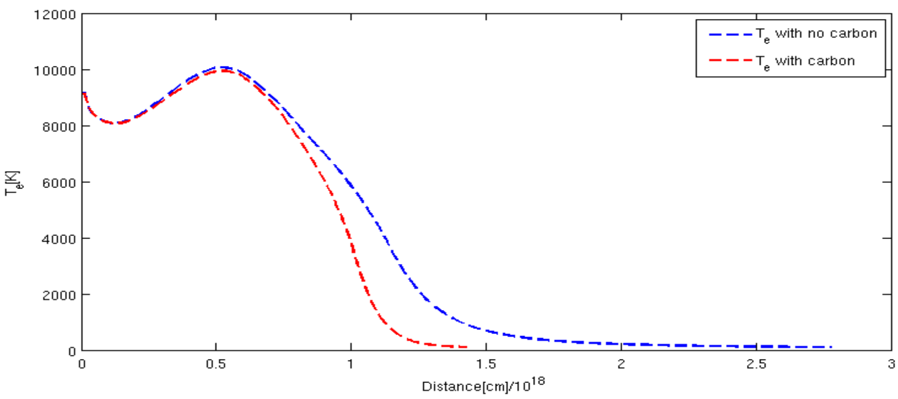

Figure 1. The electron temperature profile of NGC7027 PNe with carbon and no carbon abundances.

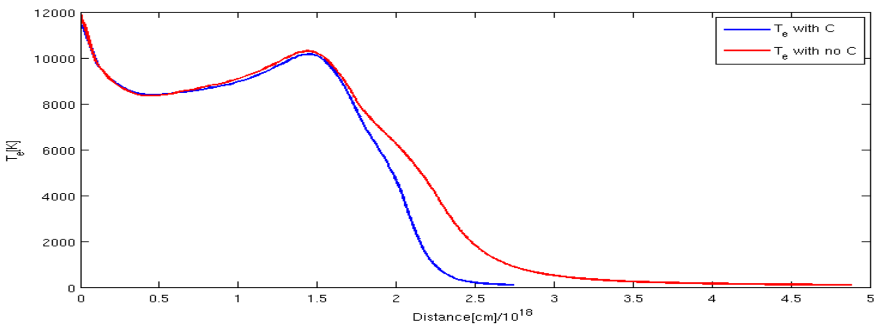

Figure2. The electron temperature profiles of Abell 39 PNe with and with no carbon abundances.

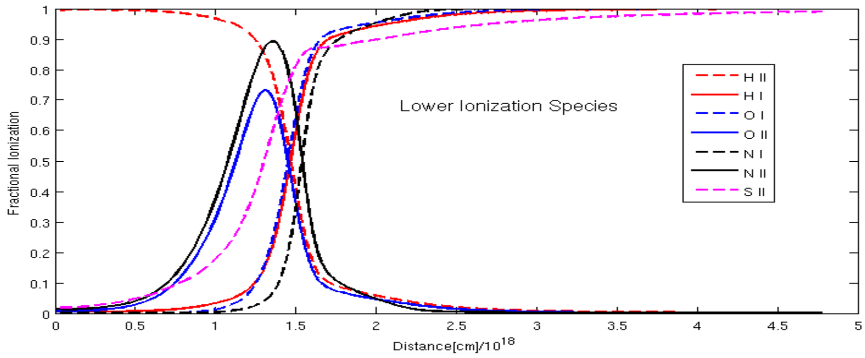

Figure 3. The ionization Structure is derived from CLOUDY C13.1 of NGC7027 planetary nebulae of the lower ionization species of H, O, N and S for the model shown in this paper.

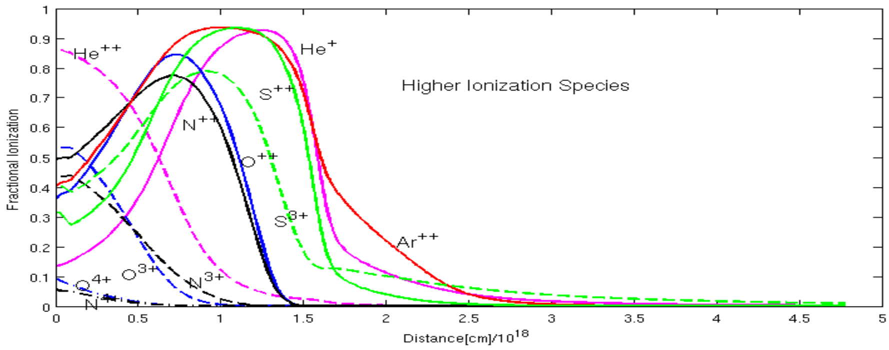

Figure 4. The ionization structure is derived from CLOUDY 13.1 of NGC7027 Planetary nebulae of the higher ionization species of He, O, S, Ne and Ar for the model shown in this paper.

Table 2 Model parameters, observed and calculated model output

Parameters	A 39	NGC7027	Line	$\lambda(\dot{A})$	A39 Obs	A39 Mod	NGC7027 Obs	NGC7027 Mod	This work A39 No(with) C	NGC7027 No(with) C
T_{eff}	160000 K	180000 K	[Ne V]	3426	9.8	8.0	154	139	----	0.59 (0.58)
L ($L_{\odot}$)	1800	7500	[O II]	3727	40	51	21	21	1446.9 (1372.2)	958.89(898.44)
Log(R_{in})	18.2774 cm	18.33	[Ne III]	3869	104	92	126	143	50.79 (125.1)	49.89(47.52)
n_H	100cm^{-3}	100 cm^{-3}	H_γ	4340	48	47	47	48	46.61(46.84)	46.66(46.65)
ϵ	1	1	[O III]	4363	24	20	25	39	4.88(4.6)	8.40(7.96)
Log(He/H)	-1.00	-1.0	He II	4686	95	94	49	62	39.05(38.73)	46.04(46.67)
Log(N/H)	-3.78	-3.78	[Ar II]	4740	4.0	4.5	8.1	8.1	0.12(0.12)	0.67(0.66)
Log(O/H)	-2.86	-2.86	H_β	4861	100	100	100	100	100(100)	100(100)
Log(Ne/H)	-4.16	-4.16	[O III]	5007	1131	957	1397	1345	1083.18(1060.88)	1507.61(1477.05)
Log(S/H)	-5.19	-5.19	[N II]	5755	---	1.4	5.8	7.2	5.87(5.51)	3.8(3.71)
Log(Ar/H)	-5.82	-5.19	H_β	5876	1.9	1.9	10.9	7.5	11.98(12.41)	10.01(10.15)
Log(C/H)	(-3.31)	(-3.31)	H_α	6563	286	278	287	275	295.93(295.53)	294.44(294.47)
			[N II]	6584	12	41	110 118		470.76(445.57)	294.65(282.11)
			[S II]	6724	9.7	11	5.6	5.3		
			[Ar III]	7135	5.8	2.2	5.6 5.3		13.47(12.98)	11.13(10.86)

4. Conclusions

In this paper we have presented the line ratios of some of elements in the presence and absence of carbon abundances for planetary nebulae Abell 39 and NGC7027 and we compared with measured and calculated values given in Table 2 column 5 and 6. For some of lines, the computed and measured values agree with this work. Other lines like [O II]λ3727, the result we obtained in these models is contradicted with the work done in Table 2 column 5 and 6. This is might be due to the abundances of elements and the filling factor. There are also lines like [Ne V]λ3426 and [S II] λ6724 do not exist in this work for both PNes. Since carbon is one of the chemical which is used as cooling agents in planetary nebulae. When the carbon abundances are included in the model, the temperature is lower than the absence.

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