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Robiatul Muztaba[1,*], Hakim L. Malasan[1,2,3] and Akira Arai[4]

[1] Department of Atmospheric and Planetary Sciences, Institut Teknologi Sumatera, Lampung 35365, Indonesia
[2] Astronomy Division and Bosscha Observatory, Institut Teknologi Bandung, Bandung 40132, Indonesia
[3] ITERA Astronomical Observatory, Institut Teknologi Sumatera, Lampung 35365, Indonesia
[4] Koyama Astronomical Observatory, Kyoto Sangyo University, Motoyama, Kamigamo, Kita-ku, Kyoto, Kyoto 603-8555, Japan

[*] Email: robiatul.muztaba@sap.itera.ac.id

Abstract. Novae V5668 Sgr spectra that have been observed at Bosscha Observatory on June 12, June 23 and August 15, 2015 using the NEO-R1000 spectrograph attached to the C-11 telescope showed that it has been entered the nebular phase. We will present the results of photoionization modelling using CLOUDY from observations of the Novae V5668 Sgr. The results of this modelling show that the spectrum profile matches fairly to the observations. Emission line features such as Hα, [O I] λ 6300, 6364 Å, [O II] λ 7320 Å, [O III] λ 5007 Å, [N II] λ 5755 Å, and Fe II λ 4924, 5169, 5317, 6149 Å on the observed spectra are also well formed and represented by the model.

1. Introduction

Novae is an explosion that occurs in the close interacting binary system as a result of accretion material by primary component of a compact star (White Dwarf - WD) from the secondary star (the general stars at the main-sequence and late-type giant stages). The average orbital periods are <16 hours. The process of the occurrence of Novae depends on the conservation of angular momentum, the material accreted through the Lagrangian point forms a new layer with hydrogen rich around the primary star. The mass transfer process will result in the formation of accretion disc around the compact star or the WD. The ejected mass can reach ~$2 \times 10^{-4} M_{\odot}$ with particle velocity of ~300–1300 km s^{-1}. The layer degenerates when the based layer temperature rises to ~$2 - 3 \times 10^8$ K [1], resulting in a CNO combustion reaction that takes place very quickly, while the pressure is constant and triggers an explosion or ejecting material in all directions which is also referred to as thermonuclear reactions (Thermonuclear Runaway - TNR) [2,3]. The detailed theory about TNR or Novae outburst has been described in several articles [4,5,6]. The general amplitude of Novae outburst can reach ~7 to 15 magnitudes in 1-2 days and the peak luminosity can be as high as $10^4 - 10^5 L_{\odot}$.

   In this paper, we discuss Novae V5668 Sgr (Novae Sgr 2015 #2; PNV J18365700–2855420) discovered on 2015 March 15.634 UT (JD 2,457,097.134, which we take to be day zero) by John Seach and review of observation results in 2015 at Bosscha Observatory. Furthermore, we discuss the photoionization modelling using CLOUDY of the spectroscopic data of Novae V5668 Sgr. CLOUDY [7,8] is an astrophysical plasma code that uses a given density and an input spectral energy distribution (SED), e.g. stars, active galactic nuclei, etc., to calculate various physical processes and predict the

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spectrum as the radiation interacts with gas and dust of known composition and geometry. The CLOUDY can be used to simulate 1-D models of Novae spectra. Finally, the result of the photoionization model plays the most important role in generating the emission line spectra. This is essential for investigating how the spectral emission line intensities change under different physical conditions.

2. Result of optical spectroscopic observations

In 2015, spectroscopic observations of Novae V5668 Sgr were carried out using the Celestron-11 Telescope (f/10) combined with a low-resolution spectrograph NEO R-1000 (spectral coverage $\lambda\lambda$ 3548-7977 ÅÅ, and resolution, $R = \lambda/\Delta\lambda = 1000$, slit width of 65 μm, a grating with 600 grooves/mm) and CCD ST-8 XME (1530×1020 pixels, 9 micron/pixel, on-chip binning of 1×2) at Bosscha Observatory, Lembang, Indonesia [9]. From the observations, we obtained 3 spectra of Novae V5668 Sgr. The spectra at 12 June, at 23 June and at August 15, 2015 seen in Figure 1 were distributed nicely along light curve from AAVSO database. The clean spectra which have been calibrated for each observation date are displayed in Figure 2. The spectra indicated that it is entering the nebular phase and according to Wiliams [10] the spectrum of V5668 Sgr included in Fe II type. Expansion velocity of this Novae has been measured from its P-Cygni profile in Hß of the blue spectra on 12 June. The expansion velocity was determined to be 2087 ± 179 km/s [11].

All aspects of the outburst on the Novae are also manifested at various stages in the evolution of Novae spectra. In early-stage after an outburst i.e. the fireball phase, the ionization levels are still low, the novae spectra are generally dominated by permitted and recombination lines such as HI, He I, CI, OI, Fe I and N I. As the ejecta expands with time, the density of the ejecta decreases and layers closer to the central ionizing source are revealed and degrees of excitation and ionization increase with time also called coronal phase. Forbidden and high ionization emission lines are seen at this stage such as [Fe VI], [Fe VII], [Ca V], [Mn XIV] and [Si VI]. Whereas, lines of [Ne III], [O I], [Fe X], [Fe XIV], [Ca XV], [Ni XII], etc. are observed in the nebular phase. Changes in the spectrum of the nebula is evidenced by the broadening of emission lines due to the high speed of development and the formation of an accretion disk. Some of the forbidden lines that often form in the nebular spectrum are N II, O III, and Ne III. The N II λ5755 Å and O III λ4363 Å appear stronger, while the N II λ6548, λ6583 Å and O III λ4959, λ5007 Å appear weaker. The formation of forbidden lines is caused by very high electron densities and low temperatures. The presence of a forbidden line on the Novae envelope identifies a low average temperature, while also showing strong emission line profiles such as Hα, Hβ, He I λ5876 Å, and He II λ4686 Å [12,13].
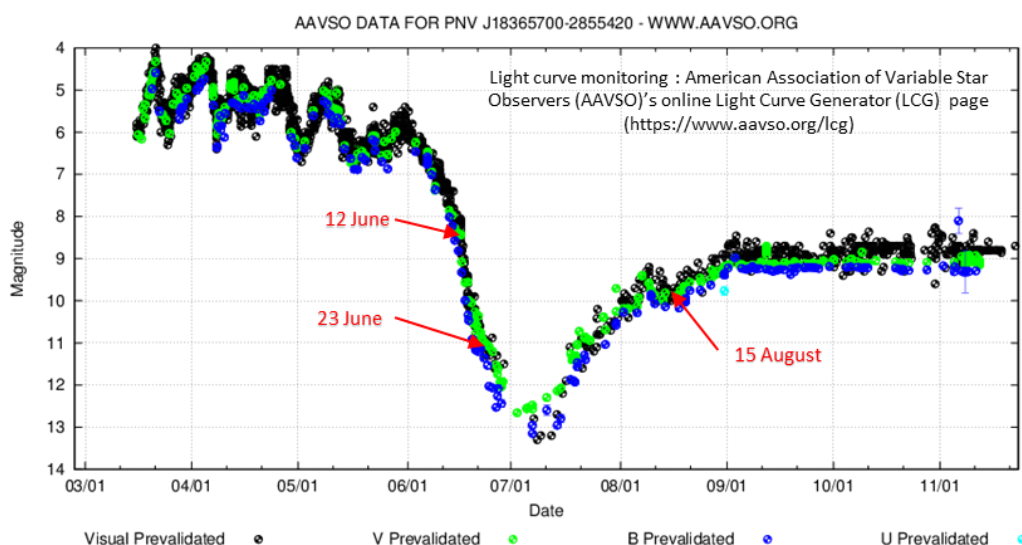

Figure 1. Visual-magnitude light curve of V5668 Sgr from pre-validated AAVSO database. Our observation dates are indicated by red arrows.

An understanding of the continuum emission sources at the Novae became an important role in determining physical parameters from observations and photoionization model using CLOUDY. Furthermore, the assumptions regarding the envelope are transparent or impermeable to the continuum source. This can be seen from the decline in Balmer. The first term of the Balmer series is the most sensitive to the presence of absorbent atoms, so to determine the envelope transparent or impermeable can use the ratio of continuum intensity approaching the Balmer around the Hβ line, see Table 1. Continuum intensity (a) and Balmer decrement (b).
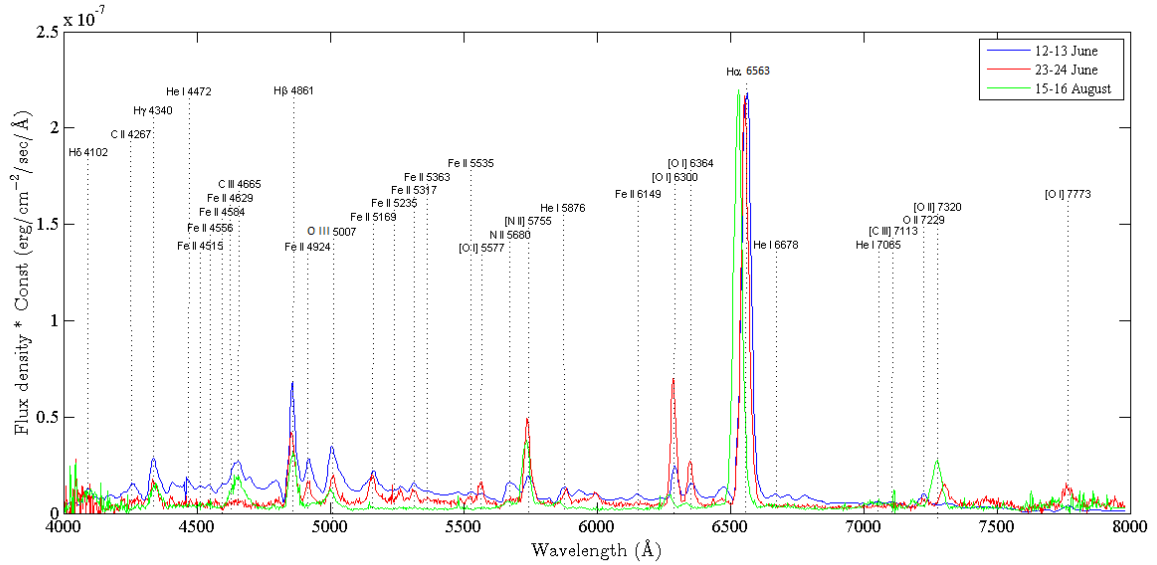

Figure 2. Low-resolution spectra evolution of V5668 Sgr obtained at Bosscha Observatory (Muztaba et al., 2015)

Table 1(a). Continuum intensity

Λ	Line ID	12-06-15				23-06-15				15-08-15			
		$I_{0\,Gauss}$ X 10^{-8}	I_0 I(Hβ) =100	Ic	Δ%	$I_{0\,Gauss}$ X 10^{-8}	I_0 I(Hβ) =100	Ic	Δ%	$I_{0\,Gauss}$ X 10^{-8}	I_0 I(Hβ) =100	Ic	Δ%
4340.47	H I	83.2	71.4	108.5	34	9.37	45.6	64.1	29	4.77	58.9	94.3	38
4363.21	[O III]	58.2	50.0	74.5	-33	10.3	50.0	69.2	-28	4.05	50.0	78.3	-36
4685.68	He II	5.72	4.9	5.6	-13	-	-	-	-	-	-	-	-
4861.33	H I	116	100.0	100.1	0	20.6	100.0	100.1	0	8.09	100.0	100.2	0
4958.92	[O III]	37.4	32.1	29.9	7	2.71	13.2	12.4	6	1.07	13.2	12.2	8
5006.85	[O III]	108	93.1	83.7	11	7.86	38.2	35.0	9	3.11	38.4	34.0	13
5754.57	[N II]	35.3	30.3	16.5	84	21.0	102.3	62.2	64	9.88	122.1	61.5	99
5875.65	HeI	22.0	18.9	9.6	98	4.37	21.2	12.2	75	8.66	10.7	5.0	116
6548.06	[N II]	-	-	-	-	-	-	-	-	-	-	-	-
6562.82	H I	925	794.4	277.6	186	135	656.2	278.5	136	0.73	903.2	277.0	226
6583.39	[N II]	-	-	-	-	-	-	-	-	-	-	-	-
6716.5	[S II]	6.59	5.7	1.8	208	-	-	-	-	-	-	-	-
6730.7	[S II]	-	-	-	-	-	-	-	-	-	-	-	-

Table 1(b). Balmer Decrement

Balmer Decrement		12-06-15			23-06-15			15-08-15		
n	Line	MV[1]	TV[2]	DV[3]	MV[1]	TV[2]	DV[3]	MV[1]	TV[2]	DV[3]
3	Hα	7.94	2.86	2.77	6.56	2.86	2.78	9.03	2.86	2.76
4	Hβ	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	Hγ	0.71	0.47	1.08	0.46	0.47	0.64	0.59	0.47	0.94

[1]MV = Measured Value
[2]TV = Theoretical Value
[3]DV = Dereddened Value

3. Result of photoionization model with CLOUDY

In this research, we primarily interested in Novae characteristics in the nebular phase, where the results of observations are available in Section 2. Hence, we use the observed spectra to outline the set of associated parameters to construct photoionization model and, furthermore, to generate synthetic spectra of Novae V5668 Sgr. The set of parameters are envelope radius (R_{env}) of the ejected shell, thickness of ejected shell (ΔR), source luminosity (L) & H-density (n_H), as shown in Table 2.

Furthermore, we consider a clumpy medium with the filling factor of 1.0 and radius of the ejecta's envelope (R_{env}), thickness of ejecta (ΔR), Blackbody temperature of the central source (T_{BB}) from Rauch atmospheric table with $T \geq 100000K$ and Power-law for disk temperature between $5000 \leq T \leq 20000$, luminosity of the central source (L), and hydrogen density (nH).

We succeeded in modeling the three spectrums of observations on 12 June, 23 June, and 15 August 2015. The first modeling results can be seen in Figure 3 which is shown by the blue line for the results from modelling, and by the red line for the observational data, Figure 4 shows the chi-square along ionization parameters, and Figure 5 to show residuals resulted from fitting the observed spectra by model.

Table 2. Some of the parameters that explain the physical condition of the shell from nebular spectra of Novae V5668 Sgr, as set of the parameter limitation to model with CLOUDY

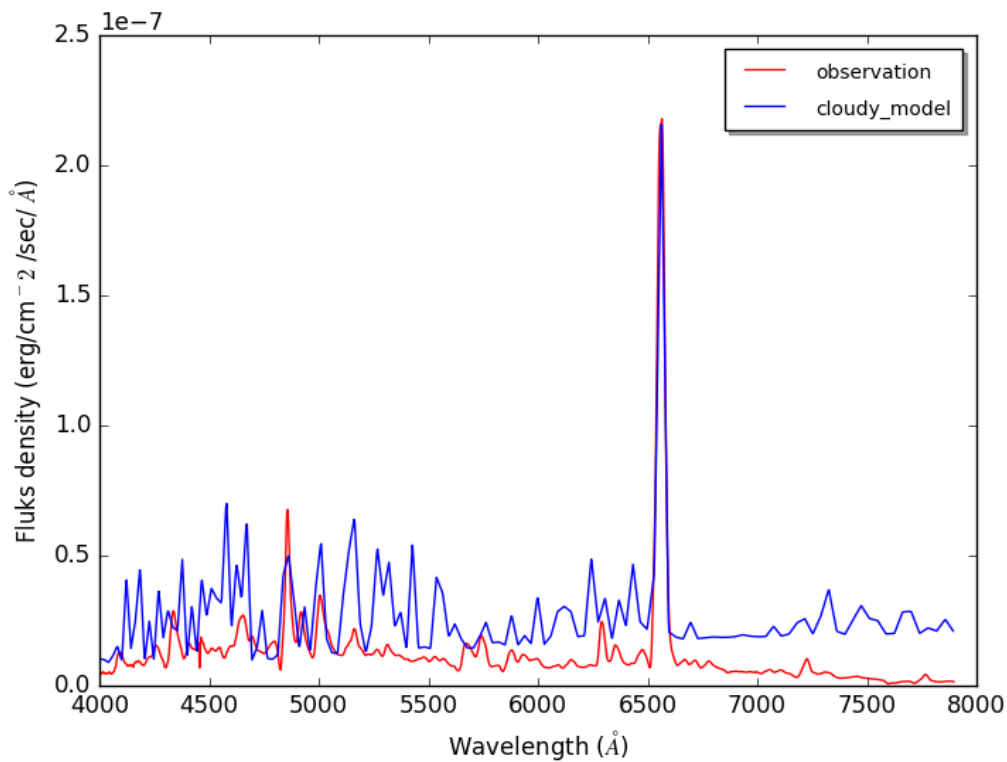| Novae Parameters	12-06-15	23-06-15	15-08-15
T_{eff} (K)	6509.23	5789.41	5719.87
L (erg/s)	3.73 x 10^{42}	3.8 x 10^{41}	6.7 x 10^{41}
log L	42.57	41.58	41.83
T	0.73	0.646	0.574
T(e) (K)	26388	15528	15339
v_{exp} (km/s)	2087	789.66	854.46
R_{env} (cm)	1.70 x 10^{15}	6.89 x 10^{14}	9.38 x 10^{14}
log R_{env}	15.23	14.84	14.97
Thickness ΔR	1.70 x 10^{13}	6.89 x 10^{12}	9.38 x 10^{12}
Log dR	13.23	12.84	12.97
n(e) (cm^{-3})	3.59 x 10^8	1.84 x 10^7	7.28 x 10^6
log n(e) (cm^{-3})	8.55	7.27	6.86
n(H) (cm^{-3})	1.08 x 10^{11}	3.15 x 10^8	4.09 x 10^{12}
log n(H)	11.03	8.5	8.61

Figure 3. The observed and modelled spectra for observation of June 12, 2015.
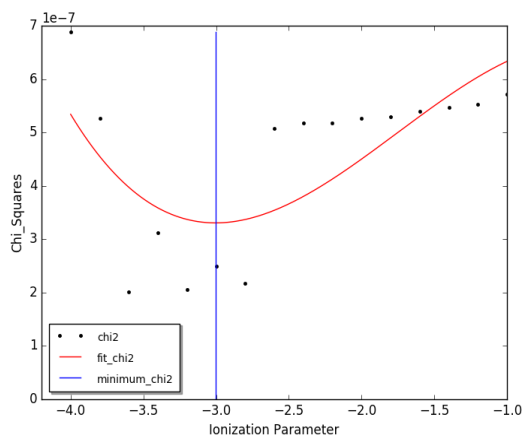

Figure 4. The chi-square values as function of the ionization parameter are marked by a black dot, and the fitting uses a third-order polynomial curve by a red line. The minimum value for the chi-square is marked by the blue line.
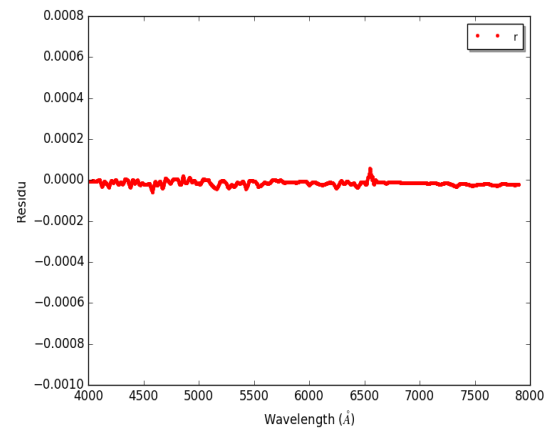

Figure 5. Residual results from the observation and modelled spectra

The second modelling results displayed in Figure 6 is shown by the blue line, while red line represent observed spectra, Figure 7 shows the chi-square along ionization parameters, and Figure 8 to show residuals resulted from fitting the observed spectra by model
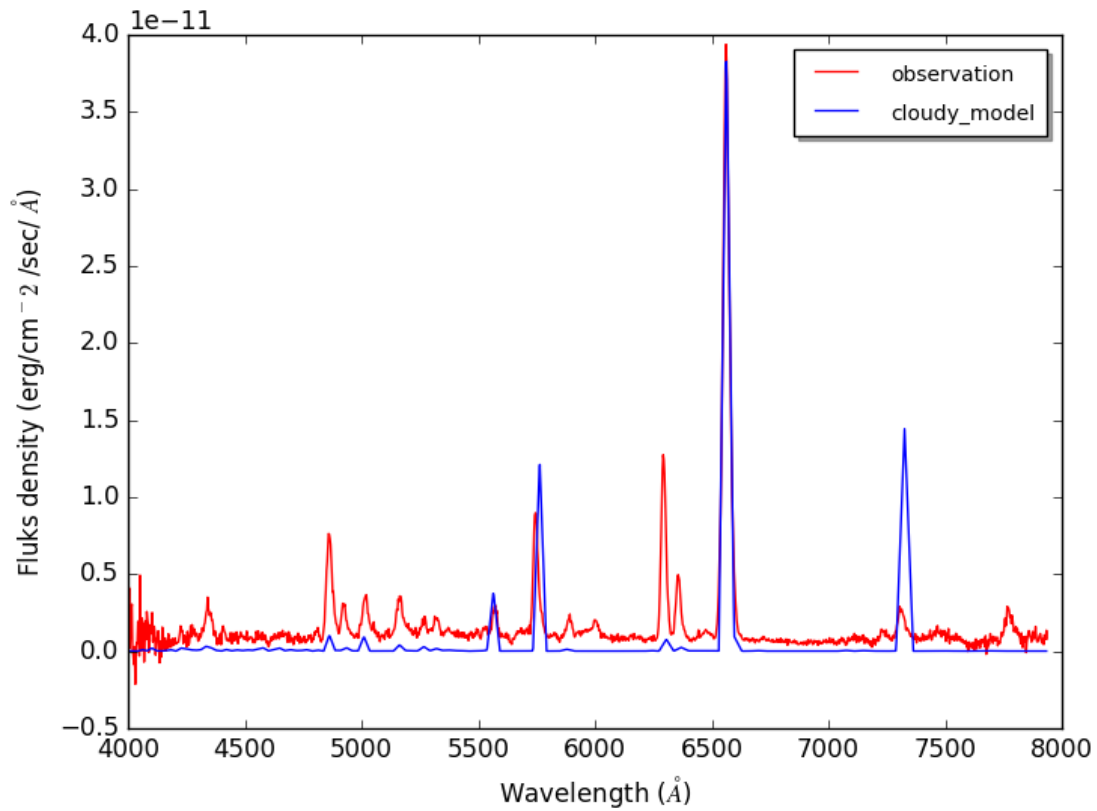
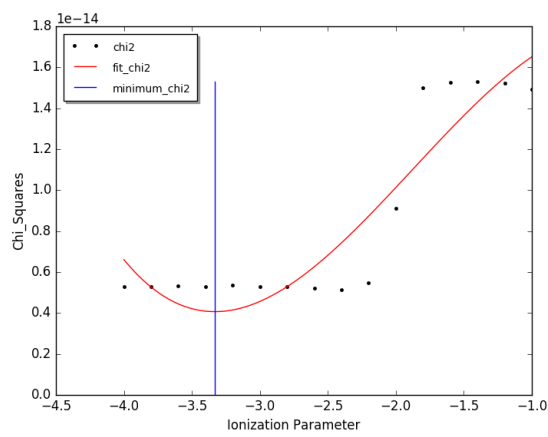**Figure 6.** The observed and modelled spectra for observation of June 23, 2015.
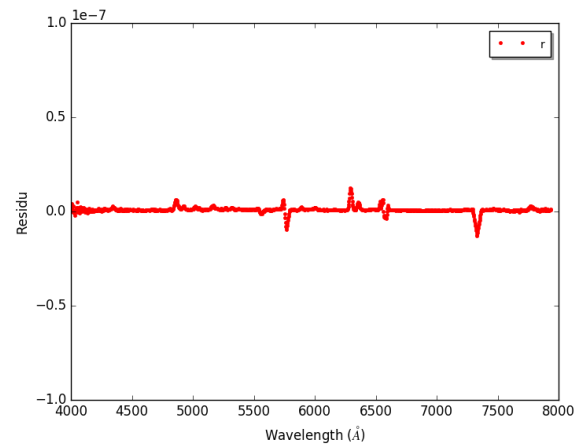

Figure 7. Similar to Figure 4

Figure 8. Similar to Figure 5

The third modelling results displayed in Figure 9 is shown by the blue line, while red line represent observed spectra, Figure 10 shows the chi-square along ionization parameters, and Figure 11 to show residuals resulted from fitting the observed spectra by model
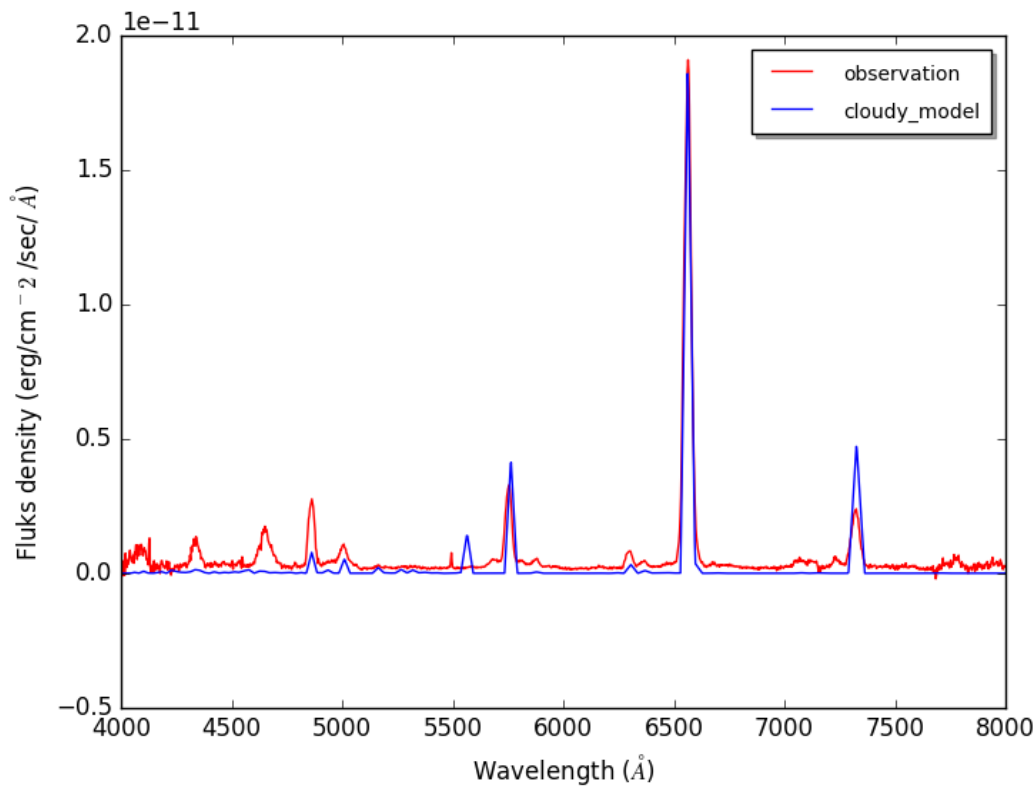
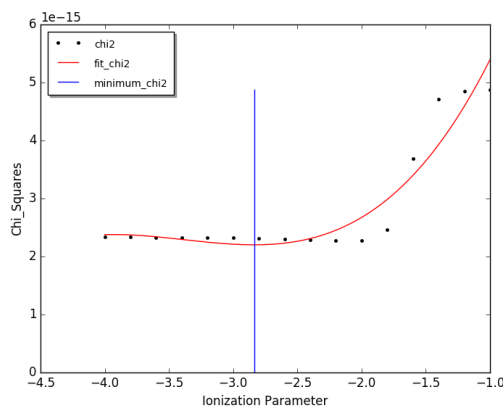**Figure 9.** The observed and modelled spectra for observation of August 15, 2015.
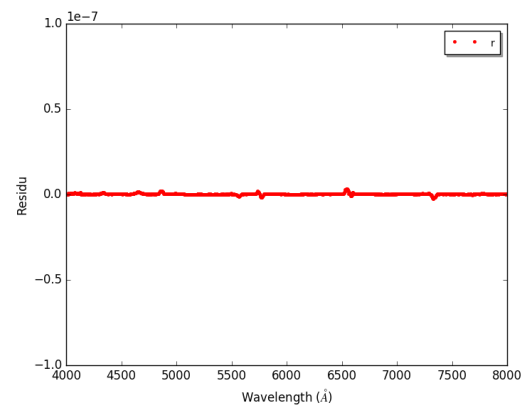

Figure 10. Similar to Figure 4

Figure 11. Similar to Figure 5

Photoionization models and spectrum synthetic computed using CLOUDY have given more appropriate results, enabled us to explain quantitatively. Emission lines that emerge from the observed spectra were successfully represented by modeling. However, some emission lines were not formed from modelling, such as the O II line λ7320 on the observation spectrum on June 23 and August 15, 2015. This is because the oxygen line is usually formed from a veil that has a high electron density, n(e) $\geq 10^8$ cm^{-3}. With this high density the collision process becomes very possible to form oxygen lines. O II λ7320Å is a very ionized oxygen line, possibly due to electron density of 1.84×10^7 cm^{-3} and electron temperature of 15528 K on June 23. and electron density of 7.28×10^6 cm^{-3} and electron temperature of 15339 K on August 15 of   as input values into modeling, so it is not possible for the release of these atoms from their bound state.

Table 3. Photoionization from nebular spectra and Fe lines.

Element and Wavelength (Å)	State of ionization	Date Observation	Flux Density ($\times 10^{-8}$)	Ionic Density N(X) ($\times 10^7$ cm^{-3})	Ratio N(X)/N(H) ($\times 10^{-5}$)	Exp. Velocity (km/s)
O I 5577	O	6-12-2015	3.87	0.77	7.07	641.70
	O	6-23-2015	0.0051	0.002	5.84	632.31
O I 6300	O	6-12-2015	45.46	8.99	83.05	607.07
	O	6-23-2015	0.0297	0.011	34.17	562.15
	O	8-15-2015	0.0022	0.0008	2.02	795.07
O I 6364	O	6-12-2015	24.1	4.76	44.03	786.66
	O	6-23-2015	0.0102	0.004	11.79	569.65
	O	8-15-2015	0.00084	0.0003	0.76	852.85
O I 7773	O	6-12-2015	12.5	2.47	22.84	775.97
O II 7229	O+	6-12-2015	25.02	0.27	2.50	771.69
	O+	6-23-2015	0.0032	0.0002	0.51	831.89
O II 7320	O+	6-23-2015	0.0088	0.00044	1.40	848.55
	O+	8-15-2015	0.0096	0.0005	1.24	884.09
O III 5007	O++	6-12-2015	108.4	5.17	47.74	1416.05
	O++	6-23-2015	0.0079	0.0008	2.55	878.11
	O++	8-15-2015	0.0031	0.0003	0.80	1249.91
N II 5680	N+	6-12-2015	34.16	0.49	4.50	1007.81
	N+	8-15-2015	0.00067	0.00003	0.08	980.23
N II 5755	N+	6-12-2015	35.33	0.50	4.65	870.61
	N+	6-23-2015	0.021	0.001	3.31	661.14
	N+	8-15-2015	0.0099	0.0005	1.24	827.76
S II 6716	S+	6-12-2015	6.587	0.015	0.13	585.71
Fe II 4924	Fe+	6-12-2015	38.6	1.20	11.05	839.13
	Fe+	6-23-2015	0.00518	0.00002	0.51	744.42
	Fe+	8-15-2015	0.00008	0.000003	0.006	84.61
Fe II 5169	Fe+	6-12-2015	45.37	1.41	13.0	1371.18
	Fe+	6-23-2015	0.0092	0.00003	0.91	1034.13
Fe II 5317	Fe+	6-12-2015	12.4	0.384	3.55	760.26
	Fe+	6-23-2015	0.0026	0.00008	0.26	652.81
Fe II 6149	Fe+	6-12-2015	11.95	0.37	3.43	903.68

4. Conclusions

Photoionization models and spectrum synthesis using CLOUDY have given more appropriate results of our observations. The results of the modelling show the spectra that match fairly the observations. Emission line features on spectroscopic observations are also formed by modelling, such as Hα, [O I] λ 6300, 6364 Å, [O II] λ 7320Å, [O III] λ 5007Å, [N II] λ 5755Å, and Fe II λ 4924, 5169, 5317, 6149Å. Future work can be extended to detect presence of molecular lines in the ejected shell of Novae. Spectroscopic observations beyond optical range (near infra-red) will be increasingly indispensable.

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