Asymmetric Planetary Nebulae 5
(Ebrary, Cambridge, USA),
A.A Zijlstra, I. McDonald, eds.

The planetary nebula NGC 7009 and its central star

Celia Fierro

Instituto de Astronomía, Apartado Postal 70-264, 04510 México D.F., México

L. Georgiev, A. Peimbert, C. Morisset, A. Arrieta

Stellar evolution models predict that the chemical composition in the atmosphere of stars in the post-AGB has been enhanced in C and N. The aim of this work is to use the planetary nebula NGC 7009 as a test of the stellar evolution models, by making simultaneous models of the nebula and its central star; the parameters obtained through models are supported by the semi-analytical study of the nebula. This type of work yields a self-consistent model of the whole object imposing more observational constraints to models.

THE PLANETARY NEBULA NGC 7009 AND ITS CENTRAL STAR

CELIA FIERRO[1], LEONID GEORGIEV[1] , ANTONIO PEIMBERT[1], CHRISTOPHE MORISSET[1] & ANABEL ARRIETA[2]
[1]INSTITUTO DE ASTRONOMIA, UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO [2]UNIVERSIDAD IBEROAMERICANA

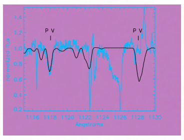
The aim of this work is to study the planetary nebula NGC7009, by making simultaneous models of the nebular spectrum and its central star; the parameters obtained through models are supported by the semi-analytical study of the nebula. This type of work yields a self-consistent model of the whole object imposing more observational constraints to models than studies that are restricted to the CS or the IR. Diffuse x-ray emission has been detected in NGC7009. We find evidence that this x-ray emitted by the CSPN produces super ionization of the stellar wind.

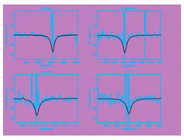
Central Star

The parameters of the central star were determined using the stellar atmospheres code CMFGEN (Hillier & Miller, 1998). The model with the best fit to the observations in UV and optical is shown in the figures.

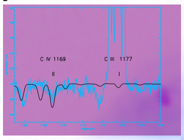
Assuming that the amount of phosphorus in the stellar atmosphere does not change with stellar evolution the P V 1118 line was used to obtain T_{eff} =60 000 K.

Note that the nebular emission hides the P V 1128 line.

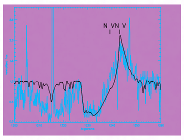




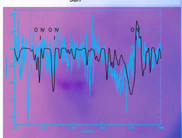
Adjusting the Balmer lines we obtained log g= 4.77



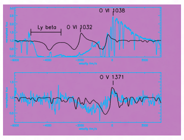
Log (C/O)+12 = 7.0 was obtained from the C IV 11691 doublet. The C III 1167 line is hidden by the nebular emission.



The N V 1128 line was reproduced with V_{wind}= 2 750 km/s, log (N/H) +12 = 7.0, and mass loss rate = 5×10^{-9} M_{sun}/ yr.



Log (O/H)+12 = 8.0 was determined from the O IV 1339 and 1343 lines. But this value is only an lower limit.



T_{eff} > 80 00 K is required to reproduce the O VI 1032 and 1038. The terminal velocity of the wind for this lines is 3150 km/s while other P-Cygni lines are reproduced with V_{wind} =2750 km/s.

This effect was found in NGC 6543 and was attributed to oxygen super ionization by X-rays (Georgiev, et al., 2008). The O V 1371 line shows the same profile as OVI 1032, so we conclude that OV and OVI in NGC7009 are affected by super ionization.

Table 1. Stellar Parameters

Teff = 60 000 K	V_{WIND}= 2750 km/s
Log g = 4.77	M_{dot}= 5 x10-9 M_{SUN}/yr
M = 0.68 M_{SUN}	log (C/H) + 12 = 7.0
L =2500 L_{SUN}	log(N/H) + 12 = 7.0
R =0.421 R_{SUN}	log(O/H) + 12 = 8.0
	log (Fe/H)+12 =7.0

Planetary Nebula

OBSERVATIONS

The optical observations were obtained with an echelle spectrograph mounted on the 2.1 m telescope of the Observatorio Astronomico Nacional in San Pedro Martir, BC, Mexico in August 2003 and August 2004. The nebular spectrum obtained has good S/N (see the figure in the bottom).

The slit (13" x 3") was divided into slices of about 1"x3". The resulting slices were classified by the degree of ionization determined from the ratio [O III]/[O II] I(4363)+I(4959)+I(5007)/ I(3726) +I(3729). The high ionization spectra was constructed adding slices with 63 < [O III]/[O II] < 75, and the intermediate ionization spectra were constructed adding the slices with 52 < [O III]/ [O II] < 62.

Table 2. Electron densities and temperatures from the optical lines.

		High	Medium
Ne [Ar IV]	I(4711)/I(4740)	7635 + 1270 - 1060	8320 + 1040 - 950
Ne [Cl III]	I(5538)/I(5518)	6940 + 4330 - 2390	5720 + 1890 - 1340
Ne [O II]	I(3729)/I(3727)	2930 + 390 - 320	2540 + 260 - 240
Ne [S II]	I(6731)/I(6716)	5860 + 6680 - 2240	5280 + 2660 - 1390
Te [O III]	I(4363)/I(4959)	9710 + 160 - 180	10250 + 150 - 140
Te [N II]	I(5755)/I(6548)	13550 + 2060 - 1350	13480 + 1100 - 860

MODEL

The model of stellar atmosphere obtained was used as input to the photoionization code Cloudy (Ferland et al.1998). A preliminary PN model was obtained assuming a distance to NGC7009 =0.75 Kpc, spherical symmetry and hydrogen density = 4000 cm^{-3}. Table 3 shows the comparison of the observed intensities in the two regions with those obtained from the photoionization model.

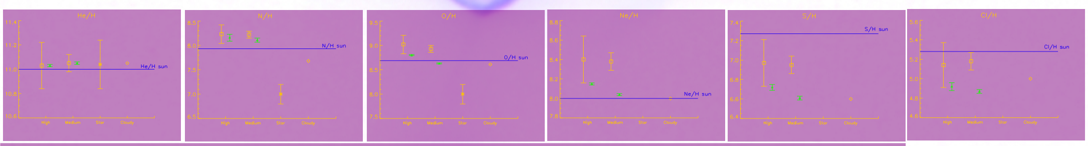
TABLE 3.

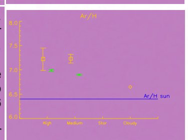
LINE		HIGH	MEDIUM	MODEL
H 1	3835	7.330	4.4010	6.268
H 1	3970	16.570	16.483	14.480
H 1	4102	25.470	26.618	24.960
H 1	4340	49.550	...	50.260
H 1	4861	100.000	100.000	100.000
He 1	3820	1.130	1.258	1.344
He 1	4144	0.350	0.412	0.360
He 1	4388	0.660	0.744	0.654
He 1	4471	5.830	5.860	5.219
He 1	4713	0.710	0.746	0.685
He 1	5876	15.200	16.397	14.340
He 2	4686	28.630	26.532	29.170
C 2	4267	1.000	1.156	1.159
N 2	5755	0.144	0.151	0.109
N 2	6548	1.600	1.825	1.867
N 2	6584	5.210	5.458	5.509
O II	3726	8.060	8.139	15.650
O II	3729	3.790	4.011	7.532
O 3	4363	9.380	9.241	9.977
O 3	4959	534.210	439.677	433.900
Ne 3	3869	122.280	117.159	126.500
Ne 3	3968	36.010	16.483	38.120
S 3	6312	1.220	1.187	1.179
S II	6716	0.540	0.577	0.596
S II	6731	0.940	0.989	1.040
Cl 3	5518	0.380	0.420	0.477
Cl 3	5538	0.520	0.536	0.579
Ar 4	4711	4.940	4.747	4.838
Ar 4	4740	6.040	5.939	5.562

Table 4

	Ratio	High	Medium	Model
Ne [Ar IV]	I(4740)/I(4711)	1.223	1.251	1.150
Ne [Cl III]	I(5538)/I(5518)	1.368	1.276	1.214
Ne [O II]	I(3729)/I(3727)	0.470	0.493	0.481
Ne [S II]	I(6731)/I(6716)	1.741	1.714	1.745
Te [O III]	I(4363)/I(4959)	0.018	0.021	0.022
Te [N II]	I(5755)/I(6548+6584)	0.021	0.021	0.014

Table 4 presents a comparison of lines ratios for Te and Ne diagnostics of the observed lines with those the model. All the density diagnostics are well reproduced. Temperature from [O III] is best reproduced for the intermediate ionization than for the high ionization region. Temperature from [N II] is not good, This is only a preliminary model. Further work incorporating a 3D model is necessary due to the complicated structure of NGC7009.



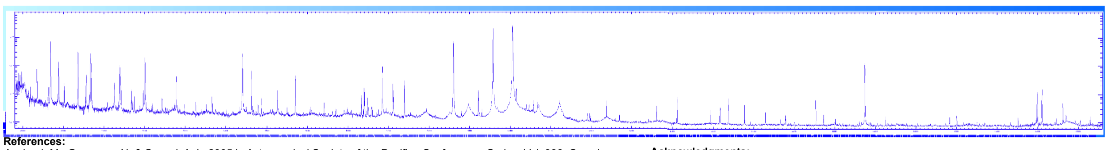


The plots show the comparison of the abundances obtained. The yellow asterisks represent the abundances obtained from the stellar atmosphere model. The green triangles represent the nebular abundances from the observations assuming thermal homogeneity (t^2=0). Yellow squares represent the nebular abundances from the observations assuming thermal inhomogeneity ($t^2 \neq 0$). Yellow diamonds represents the abundances from the photoionization model. Blue line represent the solar value (Asplund, et al., 2005).

The Helium abundance is closer to solar in the nebula and the star. Ne and Ar are enhanced. O is enhanced in the nebula and "depleted" in the star but the O in the star is only a lower limit. The nitrogen has a similar behavior as the oxygen. We need a better determination of oxygen and nitrogen in the star to resolve this discrepancy. S and Cl are depleted. The results agree with predictions of stellar evolution theory; similar behavior was observed in NGC6826 (Fierro et al., in preparation)

Georgiev et al., (2006) in his study of NGC7009 found that the plasma emitting in X-rays is depleted in iron, although whether this plasma is of stellar or nebular origin is uncertain. In this work we find that Fe is depleted in the star. The X-ray emitting plasma probably originates in the stellar wind.

The nebular and stellar abundances agree well, but the results here are only preliminary. In order to obtain the best possible model it is necessary to do more iterations between the nebular and stellar models,



References:

•Asplund, M., Greveese, N. & Sauval, A.J., 2005 in Astronomical Society of the Pacifica Conferences Series, Vol. 336, Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis, ed. T.G. Barnes, III & F.N. Bash.
•Ferland,G.J., Korista,K.T., Verner, D.A., Ferguson, J.W., Kindon, J.B. & Verner, E.M, 1998, PASP,110,761.
•Fierro,C.R., Georgiev, L.N., Peimbert, A. & Morisset, C., The Planetary Nebula NGC6826 and its Central Star (in preparation)
•Georgiev,L.N., Richer, M.G., Arrieta, A. & Zhekov,S.A., 2006, ApJ, 639,185G.
•Georgiev,L.N., Peimbert, M., Hillier, D.J., Richer, M.G., Arrieta, A. & Peimbert, A., 2008, ApJ, 681, 333.
•Hillier, D.J., Millier, D., 1998, ApJ, 496, 407. The treatment of non-LTE line blanketing in spherically expanding out flows.

Acknowledgments:
The UV spectra presented in this work were obtained from the Multimission Archive at the Space Telescope Science Institute (MAST), from The IUE and FUSE Missions.
The CMFGEN models were run on a AMD-64 bit computer financed by grants PAPIIT IN123309 from DGAPA (UNAM, México) . It is a pleasure to acknowledge to José I. Cárdenas and Alfredo Díaz for their computational support.