The planetary nebula NGC 7009 and its central star

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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.
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 is UV and optical is shown in the figure.

Assuming that the amount of phosphorus in the stellar atmosphere does not change with stellar evolution the P V 1128 line was used to obtain T eff = 25 000 K.

Note that the nebular emission hides the P V 1118 line. But this value is only an lower limit.

The nebular emission shows the same profile as OVI 1032, so we conclude that O V and O VI in NGC7009 are ionized by UV radiation. O VI 1032 is produced in the ionization region where O V is produced.

The N V 1128 line was reproduced with F V = 2 750 km s, log (V/A) = 12.7, and mass loss rate = 5×10^{-10} M_{\odot}/yr.

The effect found in NGC 7043 and was attributed to oxygen super ionization for XMM-Newton (Georgiev et al., 2009). The O V 1238 the shows the same profile as O VI 1232, as we conclude that O V and O VI in NGC1039 are ionized by thermal excitation.

\begin{equation}
T = 80 000 \text{ K} = \text{desired}
\end{equation}

The model of the central star atmosphere was used as an input to the photoionization code Cloudy (Ferland et al., 1998). A preliminary PN model was obtained assuming a distance to NGC7009 +70 Kpc.

The high ionization species is constructed adding a cool component (T eff = 4 000 K) and intermediate ionization species were constructed adding the slices with 52 < [O III] /[O II] < 62.

The slit (13" x 3") was divided into slices of about 1.825 km s. The model of stellar atmosphere imposing more observational constraints to models than studies that are restricted to the C O or the IR, diffuse emission has been detected in NGC7009. We find evidence that this x-ray emitted by the CSSP produces super ionization of the stellar wind.

Table 1. Stellar Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High</th>
<th>Medium</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>T eff (K)</td>
<td>32 450</td>
<td>28 500</td>
<td>25 000</td>
</tr>
<tr>
<td>log g (cgs)</td>
<td>5.50</td>
<td>5.50</td>
<td>5.50</td>
</tr>
<tr>
<td>L (L_{\odot})</td>
<td>0.050</td>
<td>0.050</td>
<td>0.050</td>
</tr>
<tr>
<td>M (M_{\odot})</td>
<td>3.50</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>V f (ms^{-1})</td>
<td>2540</td>
<td>2540</td>
<td>2540</td>
</tr>
<tr>
<td>[O III]/[O II]</td>
<td>0.040</td>
<td>0.040</td>
<td>0.040</td>
</tr>
<tr>
<td>[Ne II]/[H I]</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>[S II]/[H I]</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Line</th>
<th>High</th>
<th>Medium</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne [II]</td>
<td>1.50</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Ne [III]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [IV]</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Ne [V]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [S II]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [Cl III]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [Ar IV]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [O II]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ne [O III]</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The X-ray emitting plasma probably originates in the stellar wind.

\begin{equation}
\text{nebulosum = } 10^{2} \text{ pc} \text{ cm}^{-3}
\end{equation}

The CMFGEN models were run on an AMD64 computer financed by grant PAPIIT IN-123003 from UNAM (Mexico). The CMFGEN code is available as a free software from the authors.

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

The model of the nebular atmosphere was used as an input to the photoionization code Cloudy (Ferland et al., 1998). A preliminary PN model was obtained assuming a distance to NGC7009 +70 Kpc.

The high ionization species was constructed adding a cool component (T eff = 4 000 K) and intermediate ionization species were constructed adding the slices with 52 < [O III] /[O II] < 62.

The slit (13" x 3") was divided into slices of about 1.825 km s. The model of stellar atmosphere imposing more observational constraints to models than studies that are restricted to the C O or the IR, diffuse emission has been detected in NGC7009. We find evidence that this x-ray emitted by the CSSP produces super ionization of the stellar wind.

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