CLOUDY 3D approach to 3D spectroscopy of PN M 2–4

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In recent years, high-spectral-resolution integral-field-unit spectrographs have become readily available. Such instruments are ideal for study the motion of the ionized component in Planetary Nebulae. However without appropriate tools those observations are excessively difficult to interpret, especially when the nebula is clearly aspherical.

CLOUDY 3D is an IDL library to compute pseudo-3D photoionization models by interpolating between several 1D Cloudy models. It allows one to generate emission line ratio maps, PV-diagrams, channel maps, once an expansion velocity field is given.

It is significantly faster than full 3D photoionization code, thus allow user to explore wide space of free parameters.

We present our attempts to reproduce observed data cubes using CLOUDY 3D.
Cloudy 3D modeling to 3D spectroscopy of the planetary nebula M 2-4

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The Aim of this project

This project was started as an attempt to construct realistic physical and kinematical models of three planetary nebulae from the Milky Way Bulge, namely M 2-4, M 2-8 and Fg 2. We believe that the approach undertaken can improve our understanding of 3D kinematics of planetary nebulae. This nebula was chosen for this project base on its previous classification as ellipsoidal [2].

The observations of M 2-4

This nebula was chosen for this project base on its previous classification as ellipsoidal [2]. Also the integrated line profile does not show clear signs of asymmetry, as shown in Figure 1.

Due to restricted wavelength coverage in high resolution mode, 4 settings are needed in high resolution mode to cover different lines from different ions, and two in low resolution to constrain model parameters. The field of view is 12” x 7”.

Table 1: The summary of settings used to obtain discussed data.

<table>
<thead>
<tr>
<th>Band</th>
<th>Resolution</th>
<th>Wavelength range [Å]</th>
<th>Lines of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2</td>
<td>10300</td>
<td>3960 - 6800</td>
<td>Intermediate reddening correction, line of O3300 is reasonably symmetrical.</td>
</tr>
<tr>
<td>L3</td>
<td>13000</td>
<td>4930 - 7420</td>
<td>Hα, Hβ</td>
</tr>
<tr>
<td>Hβ</td>
<td>32000</td>
<td>4960 - 5600</td>
<td>[OIII]</td>
</tr>
<tr>
<td>Hα</td>
<td>36000</td>
<td>6130 - 6640</td>
<td>[OIII]</td>
</tr>
<tr>
<td>HN</td>
<td>38000</td>
<td>6470 - 6750</td>
<td>[SII]</td>
</tr>
</tbody>
</table>

What is IFU spectroscopy?

The Integral Field Unit spectroscopy is a type of observation where we obtain spatially resolved spectral information about our source, so it’s an image in which each pixel contains information from a small region of the nebula. In the case elliptical nebulae the smaller tails are PV diagrams in [O I] 6300 Å, along minor and major axis.

The Cloudy 3D (C3D) photionization code

In our approach we finally analyzed data cubes using IDL to create channel maps and PV diagrams along different axes (see Figure 3 and 4). Latter we created a nebula in Shape [3] to have a general idea about its morphology and orientation. Also a 1D model was calculated using NEBULUS [4] and Cloudy (5) to have a good idea about the properties of ionization sources. After that we could start work with Cloudy 3D.

The Cloudy 3D is an IDL library which allows one to construct pseudo 3D photionization models of a cloud of gas [1]. The user needs to define morphology and ionizing source properties. In case having no spatial information, and considering that the integrated profile of the line of interest, line of O3300 is reasonably symmetrical, it could be presumed that the nebula is spherical symmetrical. However, this far from being the case, as demonstrated below from IFU data (see Figs 2 & 3).

Conclusions & Future work

This study shows that it is possible to correctly classify the morphology base on IFU observations, even if object is marginally resolved. In contrast, spectroscopic classification may depend on slit orientation while imaging may be limited by seeing, instrument used or time of the observation.

The nebula M 2-4 shows high velocity and low surface intensity morphological structures, and a high density core.

We were able to reproduce with Cloudy 3D general nebular properties of the nebula M 2-4. Especially the stratification of different ionization sectors (see Figure 4). But the fully converged model isn’t there yet.

Literature


Acknowledgments

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