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

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 poster presents the work on the Planetary Nebula M 2-4 on which we are developing our approach to the 3D modeling.

As an observing tool we have used the VLT FLAMES instrument, with the Argus Integral field Unit (IFU), as part of programme 077.D-0679. This instrument is capable of high spectral resolution necessary for resolving individual line profiles (see Table 1).

For modeling we are using Cloudy_3D [1], an IDL library which provides a quick tool to produce pseudo 3D photoionization models.

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.

Band	Resolution	Wavelength range [Å]	Lines of interest
L2	10200	3960- 4560	Interstellar reddening correction, ionizing source properties
L3	12000	4500-4760	
H6	32000	4540-4760	He II
H8	32000	4920-5400	[OIII]
H13	36000	6120-6400	[O I]
H15 N	28000	6470-6790	Hα, [SII] density ratio

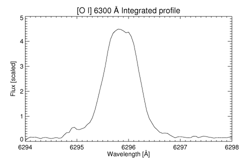

Figure 1: In case having no spatial information, and considering that the integrated profile of the low-ionization line OI 6300A is reasonably symmetrical, it could be presumed that the nebula is spherical symmetric. However, this is far from being the case, as demonstrated below from IFU data (see Figs.2 & 3).

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 contain one spectrum. The main advantage of IFS is that we are not constrained to only one (or a few) slit orientation on the nebula. We can put many synthetic slits (Figure 2.), or we can produce channel maps (see Figure 3.)

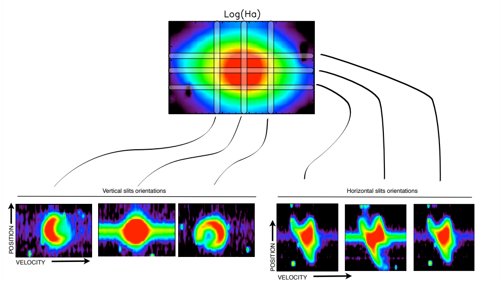

Figure 2: This illustration presents flexibility of IFU spectroscopy. The central panel is a log of integrated flux in Hα, the usual way we would discover and classify the morphology of the the nebula . In this case ellipsoidal nebula.
The smaller tails are PV diagrams in [O I] 6300 Å line, along minor and major axis. The nebula looks also drastically different depends on which axis of the nebula the P-V diagram was produced.

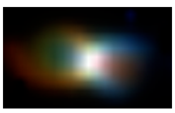

Figure 3: This image presents RGB color composite of three channel maps of [SII] 6731 Å line profile. Each channel corresponds to 5 km/s bin, green channel corresponds to the center of the profile, blue and red channels to correspond to adjacent blue- and red- shifted wings of line.

The Cloudy_3D (C3D) photoionization code

In our approach we firstly analyzed data cubes using IDL to create channel maps and P-V diagrams along different axes (see figure 2 and 3). 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 NEBU [4] and Cloudy [5] to have a good idea about the properties of ionization source. After that we could start work with Cloudy_3D.

The Cloudy 3D is an IDL library which allows one to construct pseudo 3D photoionization model of a cloud of gas [1]. The user needs to define morphology as an IDL-callable function of ϕ, ϑ. Usual Cloudy input needs to be provided; some parameters like inner density can change with ϕ, ϑ . Base on this input C3D will create typical self-contained Cloudy input files. Then Cloudy is called n times where n is number of different rays. The cloudy 1D models are interpolated in 3D, creating data cube. In the final step the resulting data cube can be rotated along three axes, and the velocity can be added, and finally the data cube can be projected on the plane. The last step can be repeated for different rotation angles and velocities without need to recalculated 1D Cloudy models.

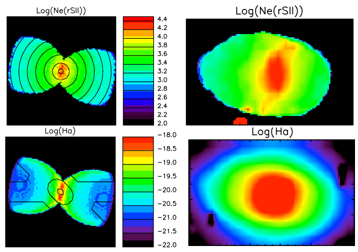

Figure 4: Here we compare C3D model (left) with observed data (right). The electron density map (upper row) was created based on [SII] 6716/6731 ratio, Hα emissivity is presented in the lower row. One of the problems of the current model is that it is difficult to reproduce Hα emission simultaneously with high velocity components and low surface intensity components visible in PV diagrams on Figure 2.

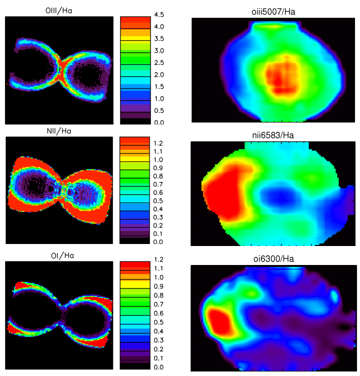

Figure 5: Here we contrast intensity maps for velocity channel V = 0 ± 5 km/s for modeled (left) and observed nebula (right). Three different ionization stages are displayed, O^{++} , N^{+} and O^{0} which trace different parts of the nebula.

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 size of the nebula.

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

[1] Morisset, 2006, Planetary Nebulae in our Galaxy and Beyond, IAUS #234 ; [2] Ruffle et al., 2004, Angular diameters, fluxes and extinction of compact planetary nebulae, MNRAS, 353,796R ; [3] Steffen, W., López, J.A., 2006, Morpho-kinematic modeling of gaseous nebulae with SHAPE, RevMexAA 42, 99 ; [4] Pequignot & Tsamis, 2005, Astronomy and Astrophysics, v.430, p.187 ;c [5] Ferland, G. J. Korista, K.T. Verner, D.A. Ferguson, J.W. Kingdon, J.B. Verner, & E.M. 1998, PASP, 110, 761

Acknowledgments

CS is grateful to Daniel Pequignot for his hospitality and support during his September 2009 visit as well as to Christophe Morisset and UNAM staff for hospitality and financial support during his Nov/Dec 2009 visit where most of this work has been done.