PyCloudy, a tool to manage Cloudy

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PyCloudy: what for?

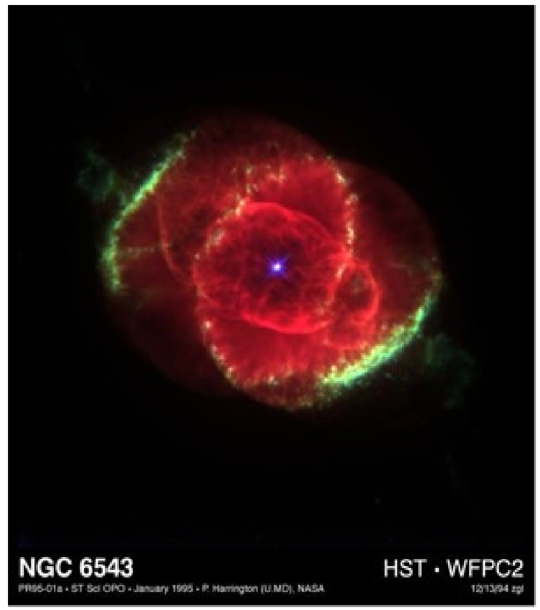
- History, need for 3D code
- Site, forum, pip, manual
- Examples:
  - Inputs/outputs
  - grids
  - 3D nebulae
  - 3MdB (Mexican Million Models database)
  - Changing atomic data

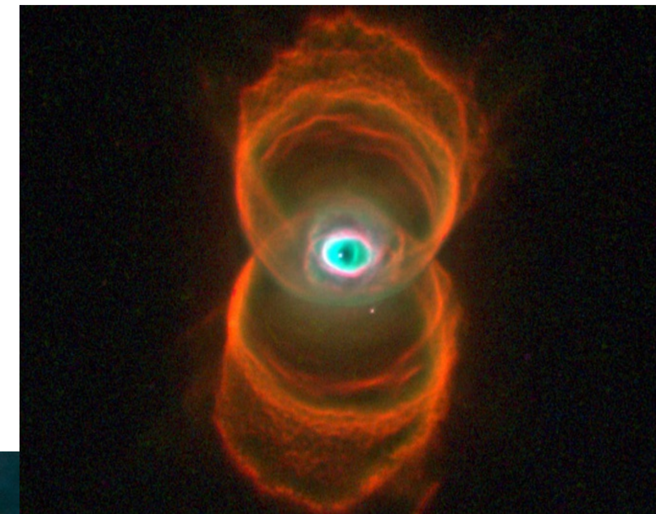
Why 3D ?

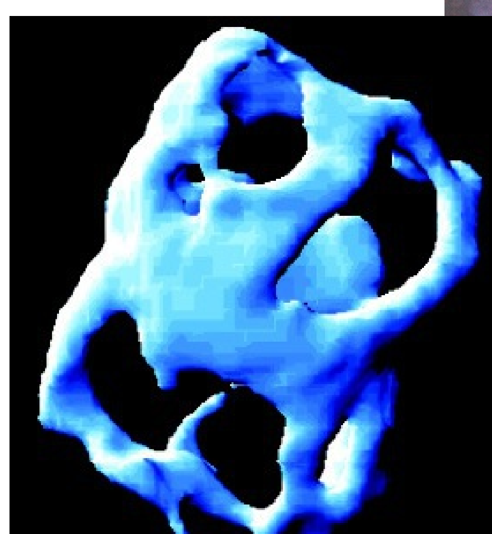
- As we all know, PN are spherical, and HII regions plan parallels :-)

Not O nor //

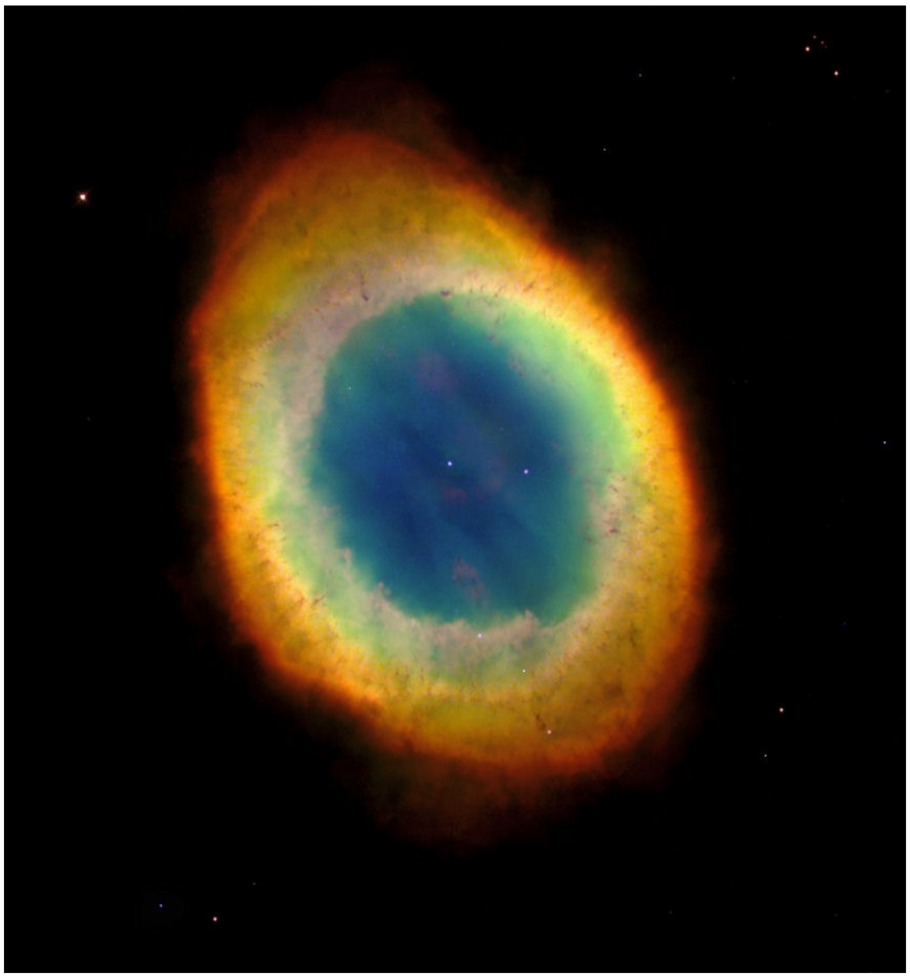

NGC 2346
Hubble Heritage
PRC99-37 • Space Telescope Science Institute • Hubble Heritage Team (AURA/STScI/NASA)


NGC 6543
HST • WFPC2
PR95-01a • ST ScI OPO • January 1995 • P. Harrington (U.MD), NASA
12/13/94 zgl





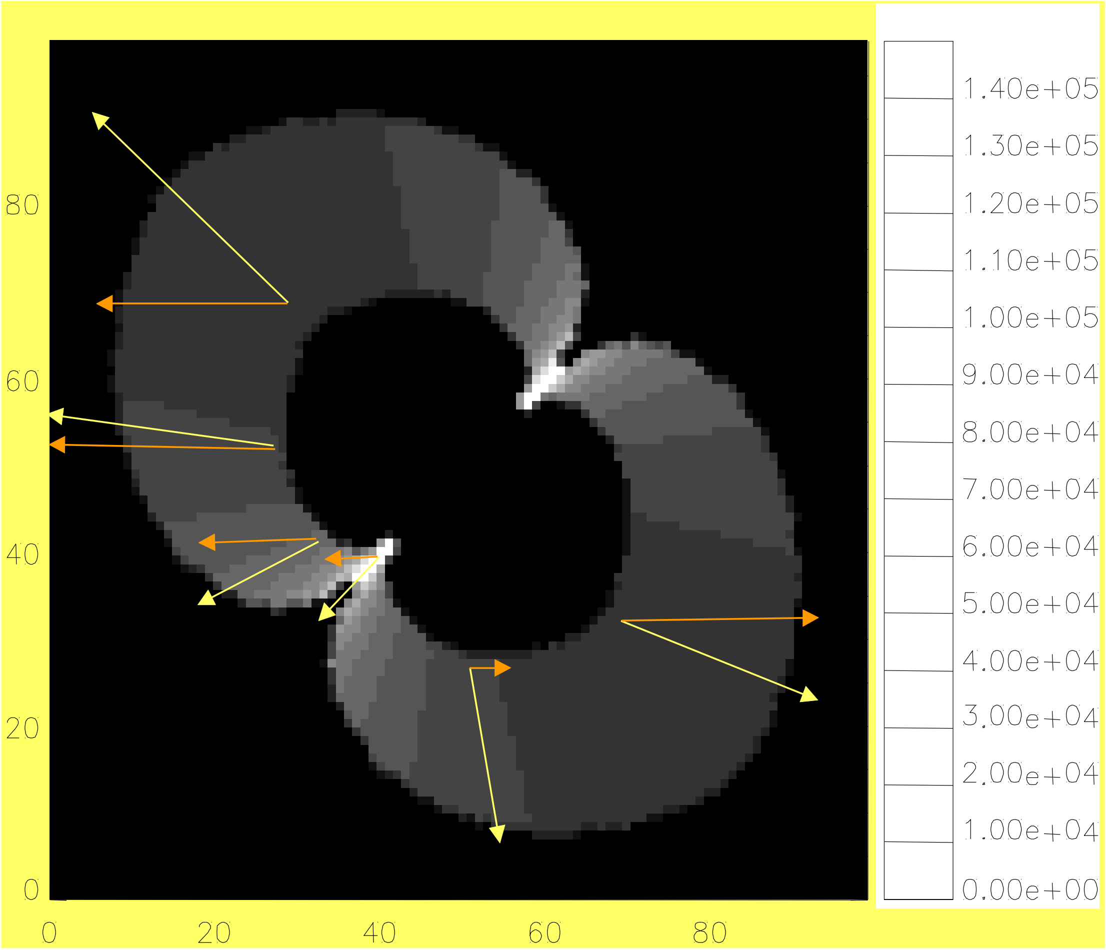
Aperture effects



- Color = dominating emission line.
- Position : different line ratios.

Velocity field

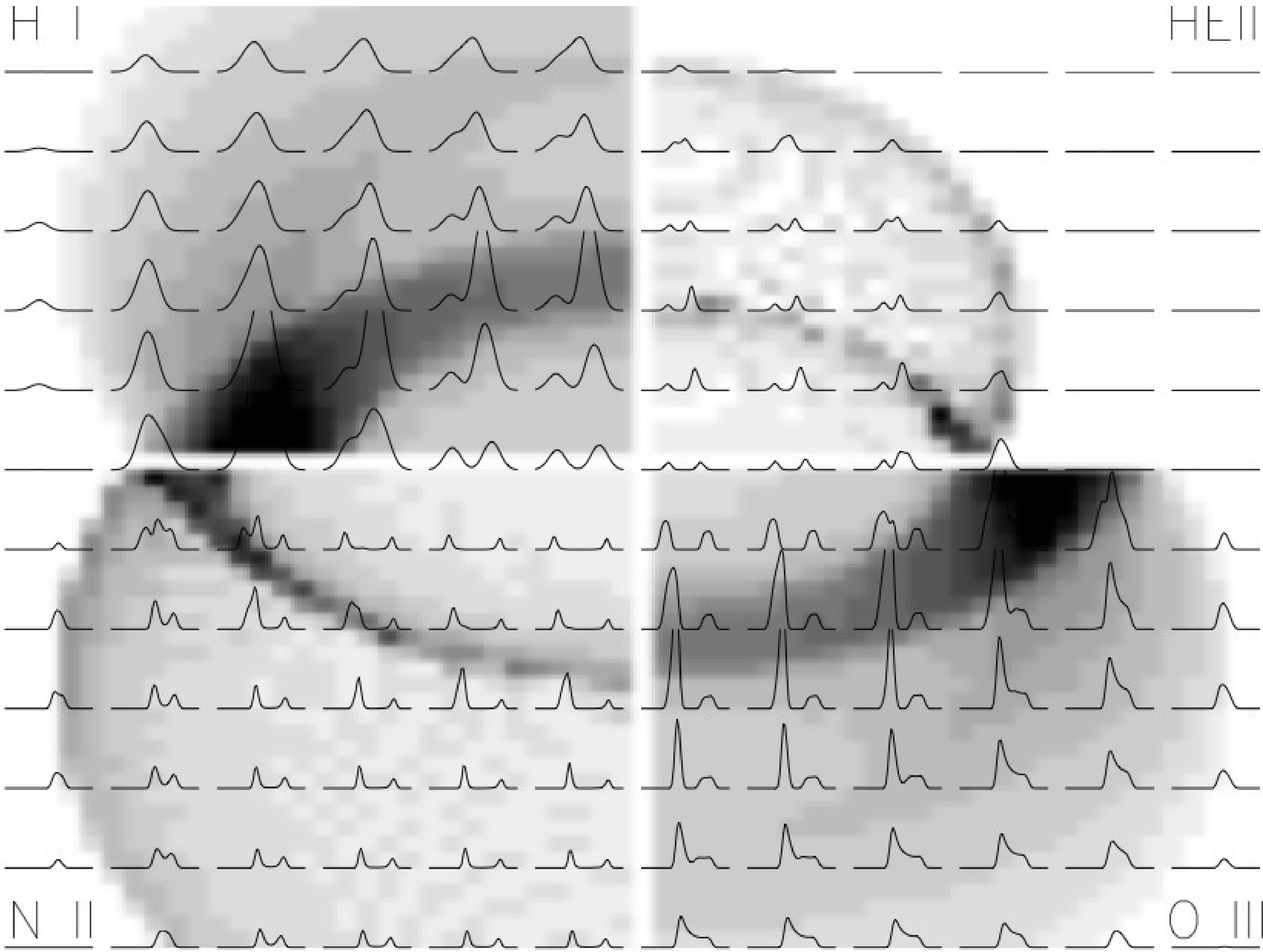
- Velocity field : line-of-sight component projection.



MODELLING OF ASYMMETRIC NEBULAE. II. LINE PROFILES

Revista Mexicana de Astronomía y Astrofísica, **42**, 153–166 (2006)

C. Morisset[1] and G. Stasińska[2]



MODELLING OF ASYMMETRIC NEBULAE. II. LINE PROFILES
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PV-diagrams

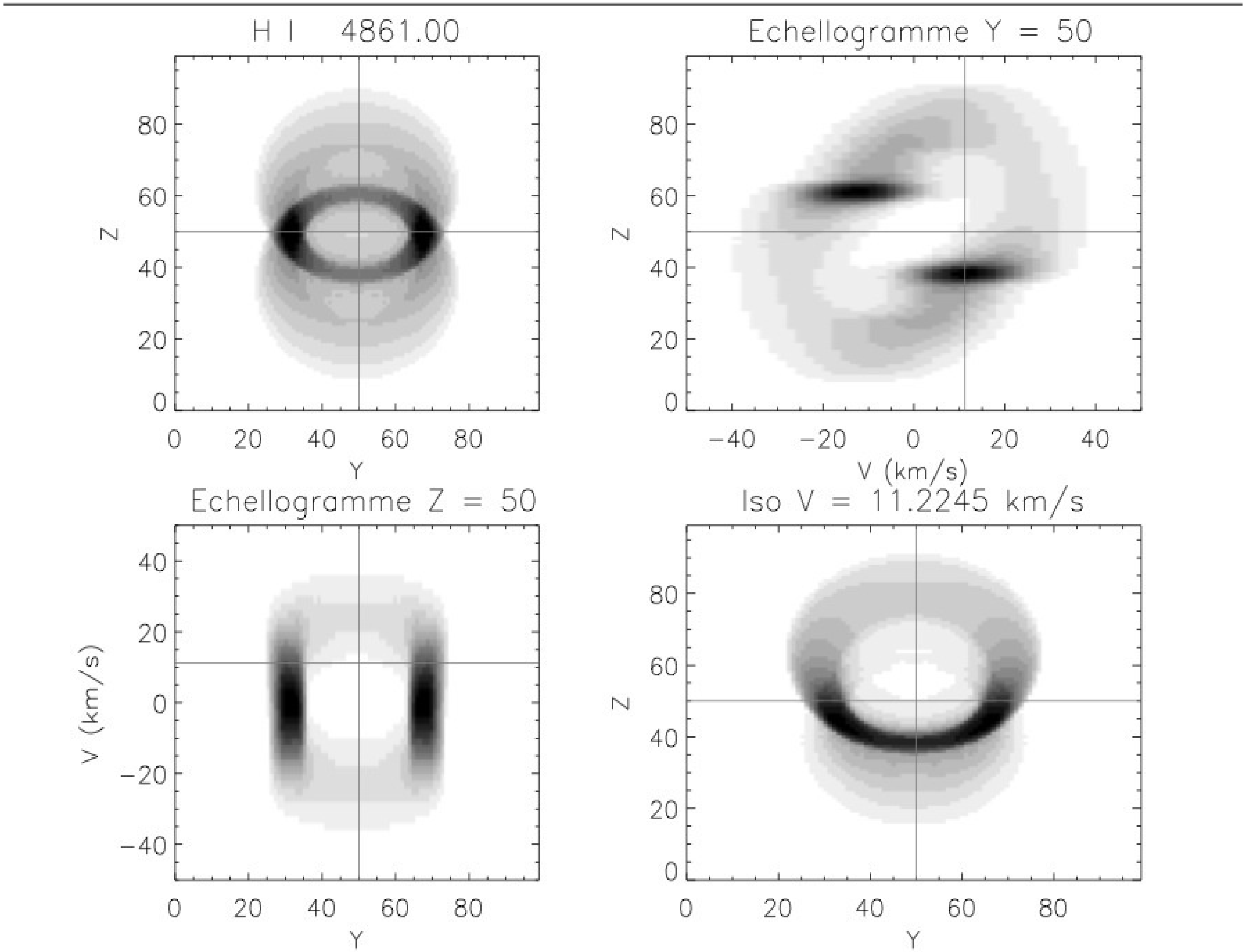
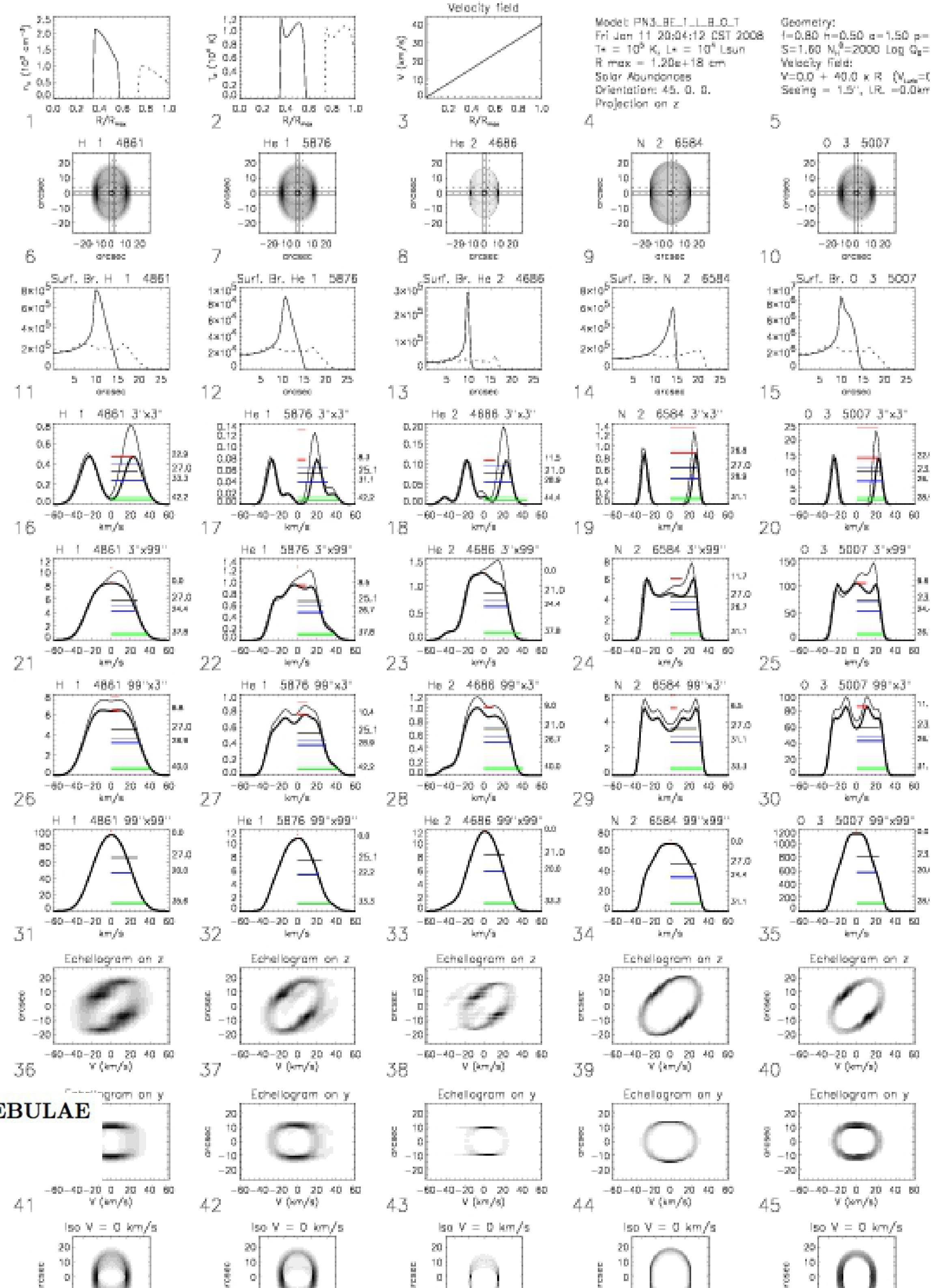


Fig. 10. PV diagrams obtained for the bipolar nebula presented in § 3.1. Upper left: surface brightness image for Hβ with the 2 slits used for the forthcoming PV diagrams, Upper right: PV diagram obtained for a narrow vertical slit crossing the center of the nebula, Lower left: PV diagram obtained for a narrow horizontal slit crossing the center of

AN ATLAS OF SYNTHETIC LINE PROFILES OF PLANETARY NEBULAE

C. Morisset[1] and G. Stasińska[2]

Revista Mexicana de Astronomía y Astrofísica, **44**, 171–180 (2008)



3D photoionization codes

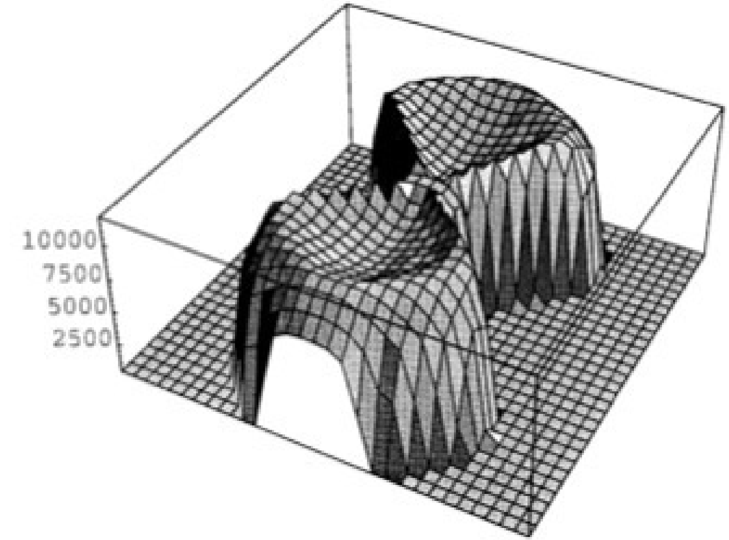
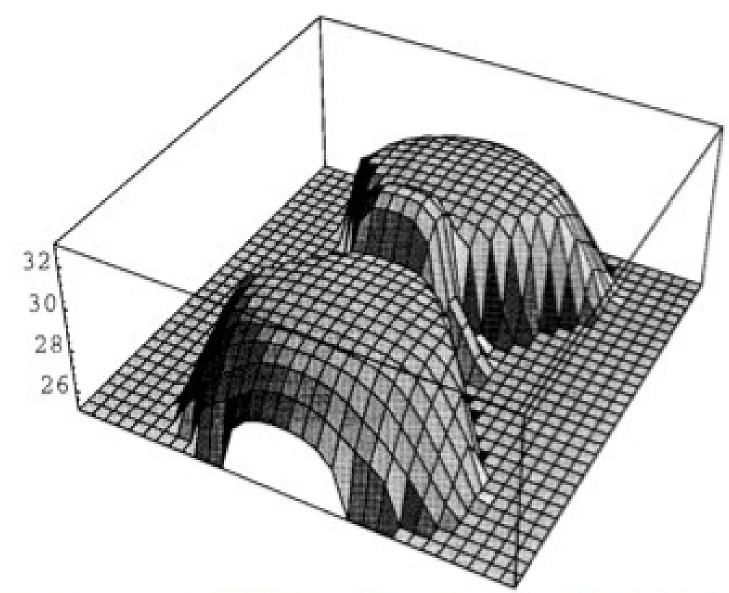


FIG. 1.—Electron temperature in the plane (110" × 110") perpendicular to the torus. The vertical axis gives the temperature (K).

A NEW GENERATION OF PHOTOIONIZATION CODES: THREE-DIMENSIONAL MODELS. THE BIPOLAR PLANETARY NEBULA IC 4406

R. GRUENWALD AND S. M. VIEGAS
Instituto Astronômico e Geofisico/Universidade de São Paulo, Av. Miguel Stefano, 4200, 04301-904, São Paulo, SP, Brazil
AND
D. BROGUIÈRE

THE ASTROPHYSICAL JOURNAL, 480:283–289, 1997 May 1



MORPHOLOGY AND KINEMATICS OF PLANETARY NEBULAE. I. A NEW MODELING TOOL

C. Morisset,[1,2] R. Gruenwald,[2] and S. M. Viegas[2]

The Astrophysical Journal, 533:931–937, 2000 April 20

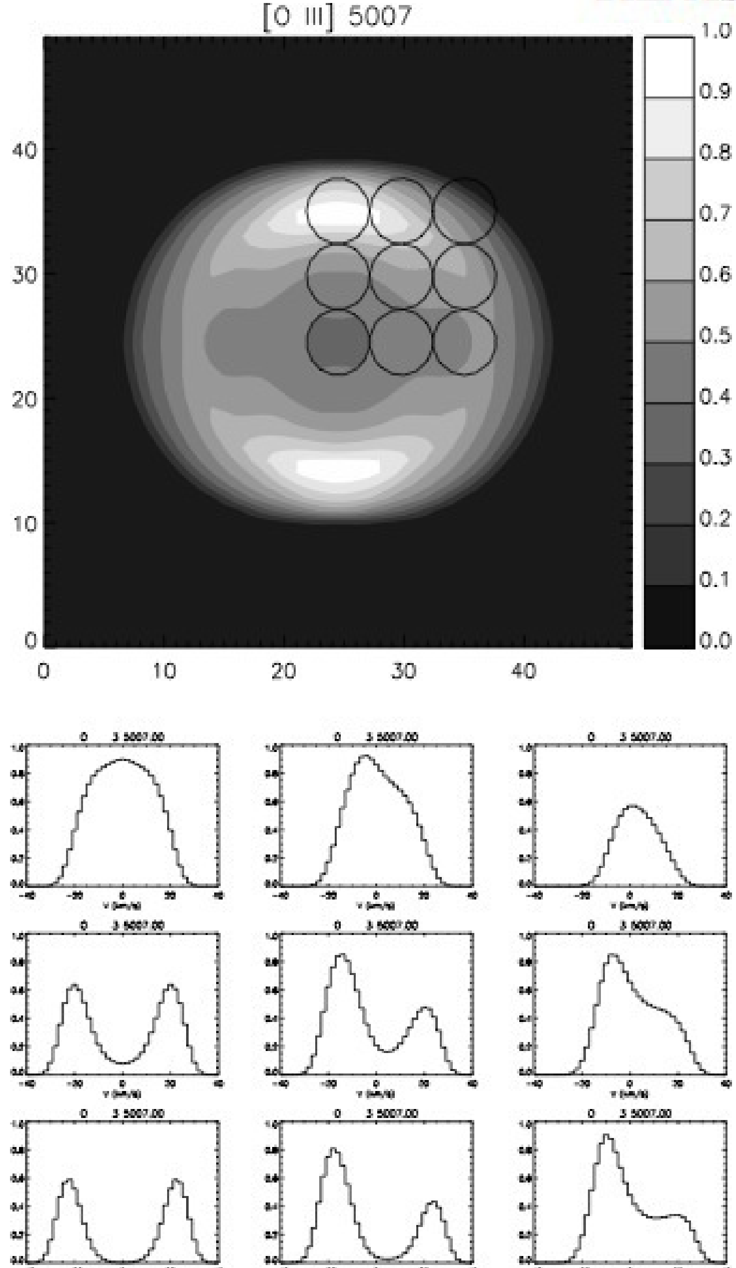


Fig. 4.—*Top*: Size and positions of the aperture used to obtain the [O III] velocity profiles shown in the bottom nine panels for model A1. The

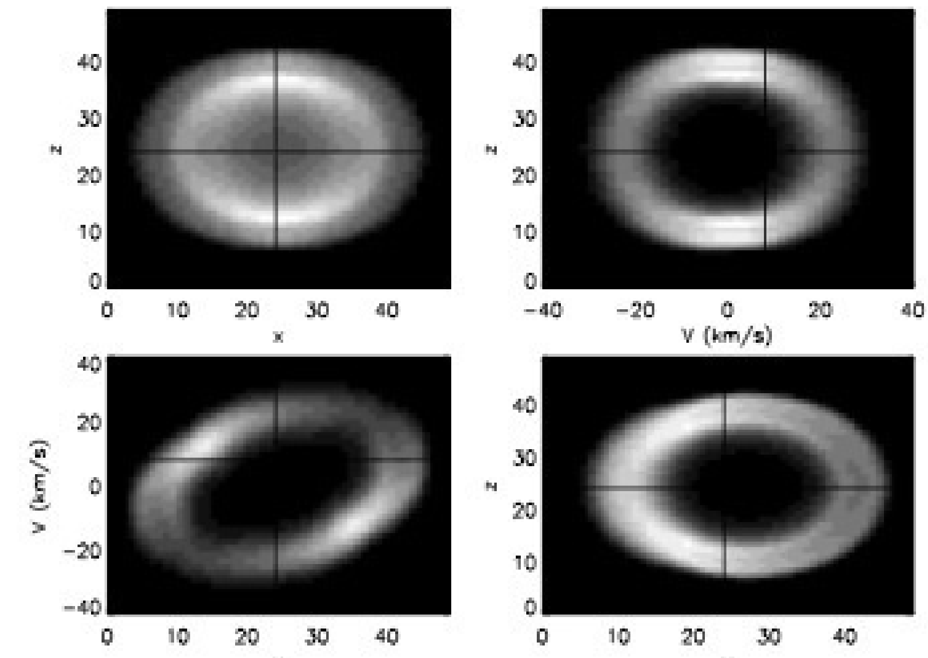
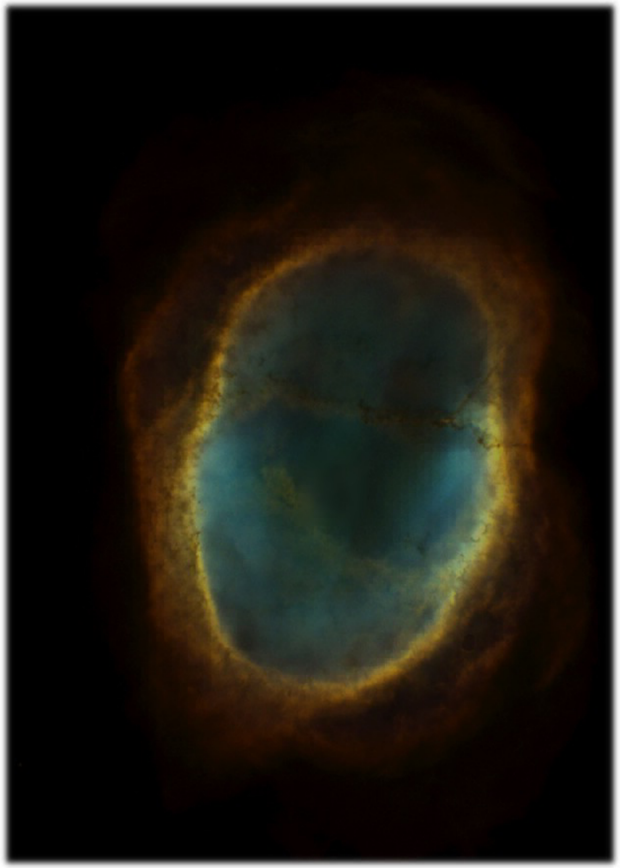


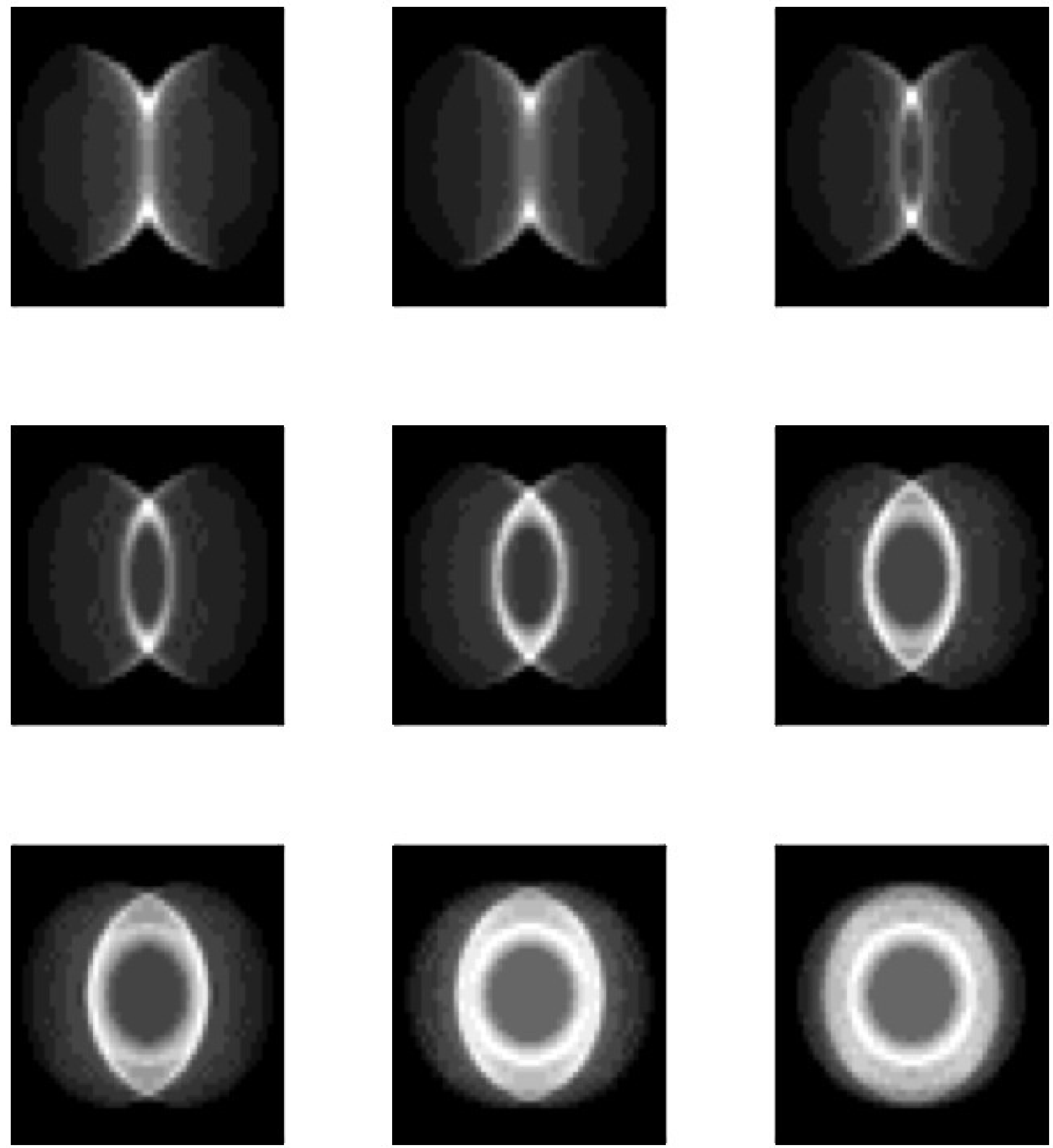
Fig. 5.—[O III] line image (*top left*), P-V diagrams obtained through centered horizontal (*top right*) and vertical (*bottom left*) slits, and iso-velocity contours for $V = 9$ km s^{-1} (*bottom right*). The *z*- and *y*-axes are given in pixels.



MORPHOLOGY AND KINEMATICS OF PLANETARY NEBULAE. II. A DIABOLO MODEL FOR NGC 3132

H. Monteiro,[1] C. Morisset,[1,2] R. Gruenwald,[1] and S. M. Viegas[1]

The Astrophysical Journal, 537:853–860, 2000 July 10



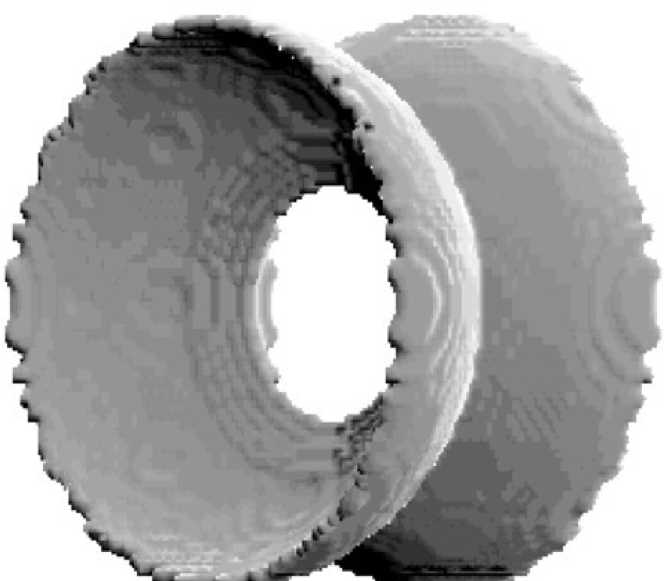


Fig. 4.—Gas distribution for the Diabolo model. Only the denser zone

images from the Diabolo model. From the upper left to the lower right panel, the angle between the axis of symmetry and the sky plane

Och's Monte-Carlo code

Diffuse radiation in models of photoionized nebulae

S.R. Och[1], L.B. Lucy[2], and M.R. Rosa[2,*]

[1] Dr. Remeis-Sternwarte, Astronomisches Institut der Universität Erlangen-Nürnberg, Sternwartstrasse 7, D-96049 Bamberg, Germany,
[2] Space Telescope-European Coordinating Facility, European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany (llucy@eso.org)

Astron. Astrophys. 336, 301–308 (1998)

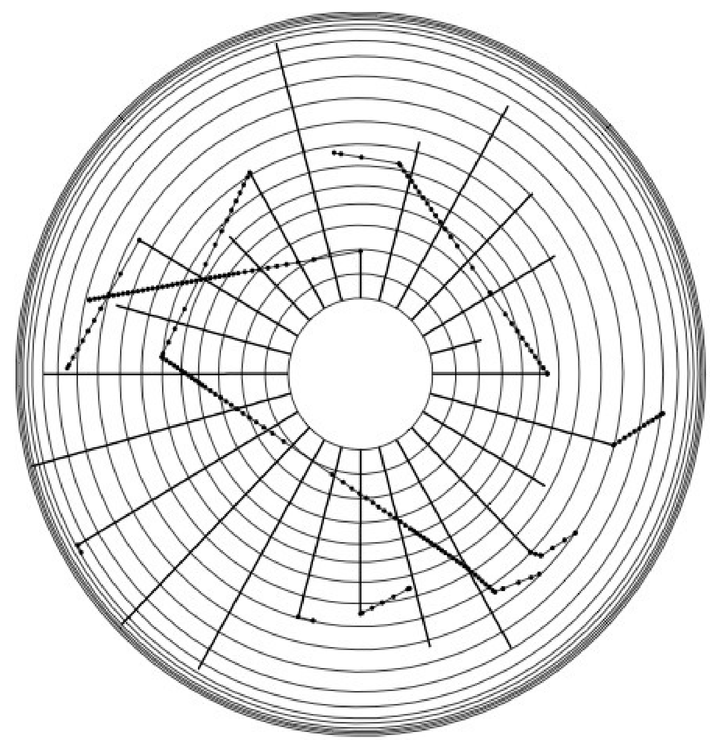


Fig. 1. The random walks for several photon packages starting at the inner nebular radius are plotted. Stellar photon packages are shown as thick lines, while diffuse packages passing reference positions are represented by filled dots (only every fifth radial grid surface is drawn). Once they have turned into non-ionizing packages, they are no longer tracked since they escape immediately.

MOCASSIN: a fully three-dimensional Monte Carlo photoionization code

B. Ercolano,★ M. J. Barlow, P. J. Storey and X.-W. Liu†
University College London, Gower Street, London WC1E 6BT

Mon. Not. R. Astron. Soc. **340,** 1136–1152 (2003)
Mon. Not. R. Astron. Soc. **340,** 1153–1172 (2003)

Three-dimensional photoionization modelling of the planetary nebula NGC 3918

B. Ercolano,[1★] C. Morisset,[2†] M. J. Barlow,[1] P. J. Storey[1] and X.-W. Liu[1‡]
[1]*University College London, Gower Street, London WC1E 6BT*
[2]*Laboratoire d'Astrophysique de Marseille, CNRS, BP 8, 13376 Marseille Cedex 12, France*

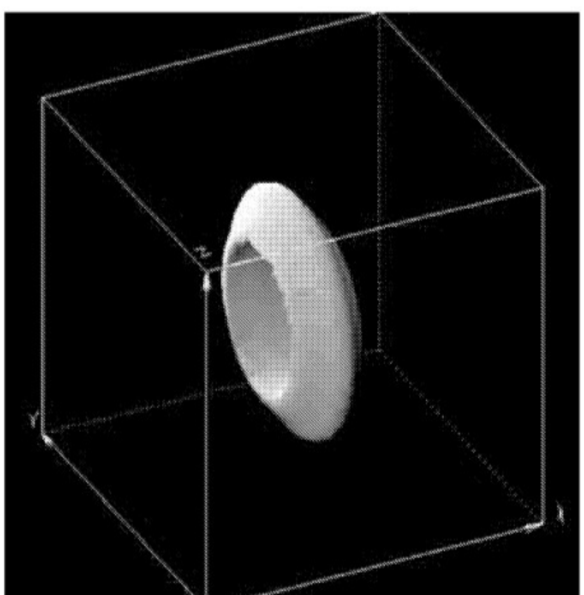
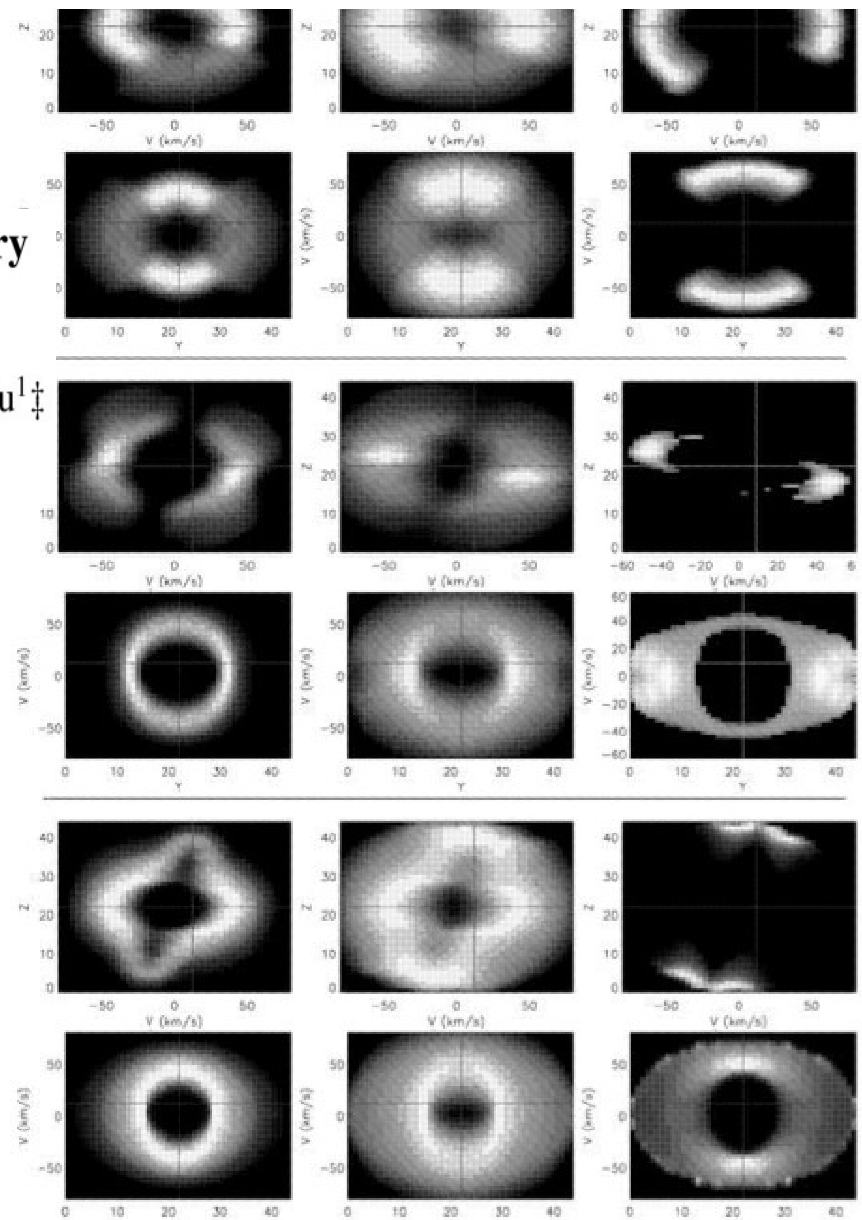


Figure 3. Three-dimensional isodensity plot of the dense torus component



MOCASSIN and Cloudy_3D

- MOCASSIN : A full 3D photoionization code, using Monte-Carlo.
- F90 MPI code, running on cluster.
- Few hours to days to run/converge a model (cluster allocation time policies).
- → need for a quick (but not so dirty) code to obtain « pseudo-3D » models
- Cloudy_3D : we're loosing the « full » 3D, but a few minutes to run a model :-)

Cloudy_3D

Modelling of aspherical nebulae – I. A quick pseudo-3D photoionization code

Mon. Not. R. Astron. Soc. **360,** 499–508 (2005)

C. Morisset,[1★] G. Stasińska[2] and M. Peña[1]

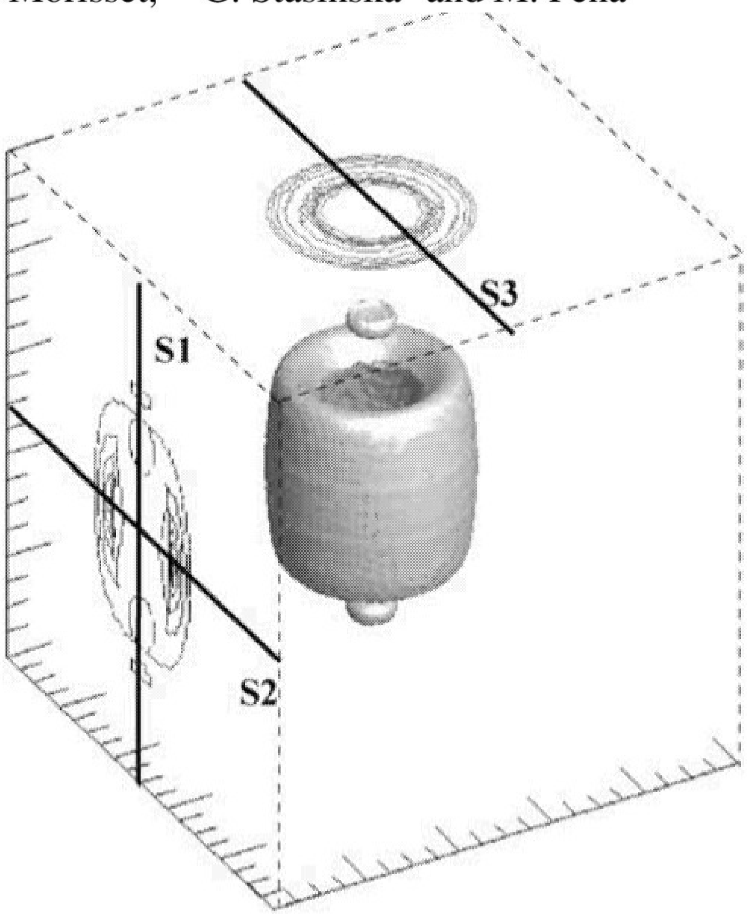
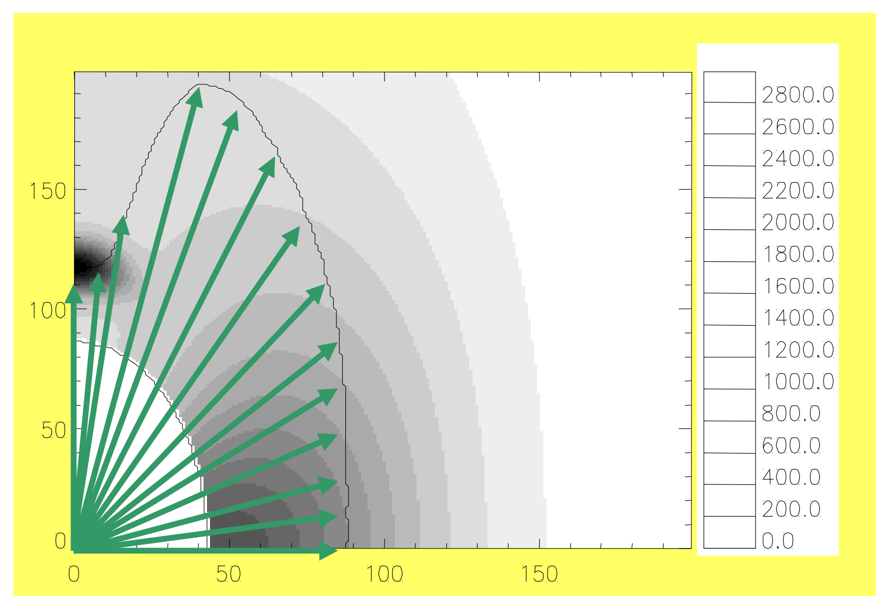


Figure 2. 3D representation of the nebula. An isodensity surface is drawn, showing the equatorial density enhancement and the two polar knots. On the faces we have represented the Hβ surface brightness contours for two orientations of the nebula: on the left side, for the nebula seen with the polar

- Various runs of Cloudy (1D), corresponding to different angles.
- 3D reconstruction in a coordinate cube by interpolation between the 1D runs. IDL package



C3D: faster but limited ?

- Cloudy_3D is not a “full” 3D code. It only considers radial radiation (as a combination of 1D runs)
- Limitation: when no-radial radiation dominates a process (e.g. photoionization)
- Mainly 2 cases:
  - Shadows
  - Multiple stars
- Otherwise: OK

Shadows

Asymmetric Planetary Nebulae III
ASP Conference Series, Vol. 313, 2004
M. Meixner, J. Kastner, B. Balick and N. Soker eds.

Lights in the Shadows, 3D-Modelling Knots with

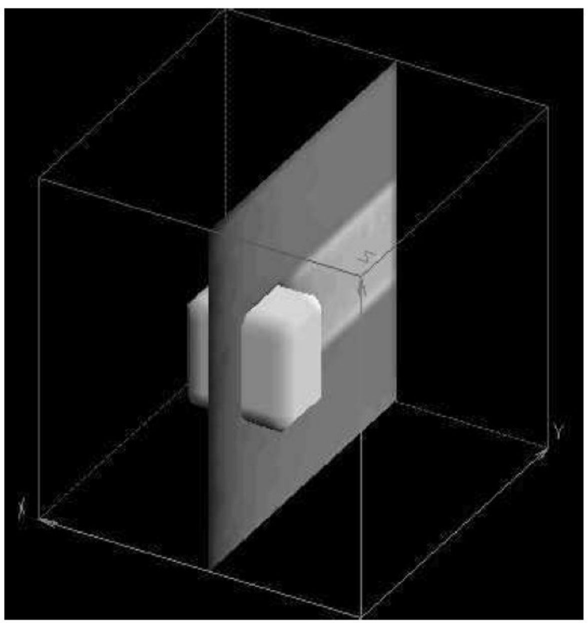


Figure 1. Density distribution of the gas for the model of a Knot. The plane parall ionizing flux is arriving from bottom-left.

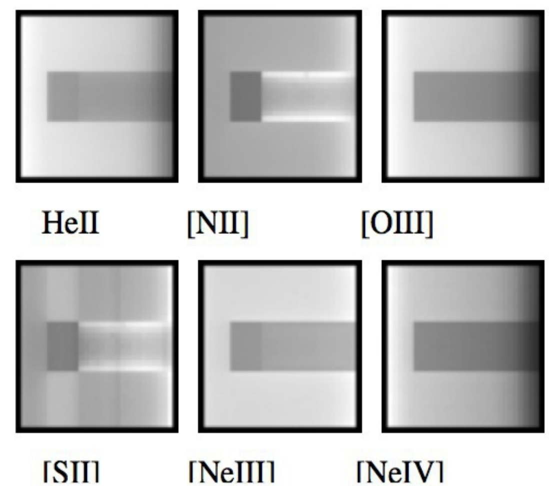


Figure 3. Synthetic images in the sky plane, for some emission lines. The main trends observed in the Helix Knots are reproduced : recombination and forbidden lines from low charged ions are emitted preferentially by the tail.

Multiple stars

The effects of spatially distributed ionisation sources on the temperature structure of H II regions

Astrophys Space Sci (2009) 324: 199–204

Barbara Ercolano · Nate Bastian · Grazyna Stasińska

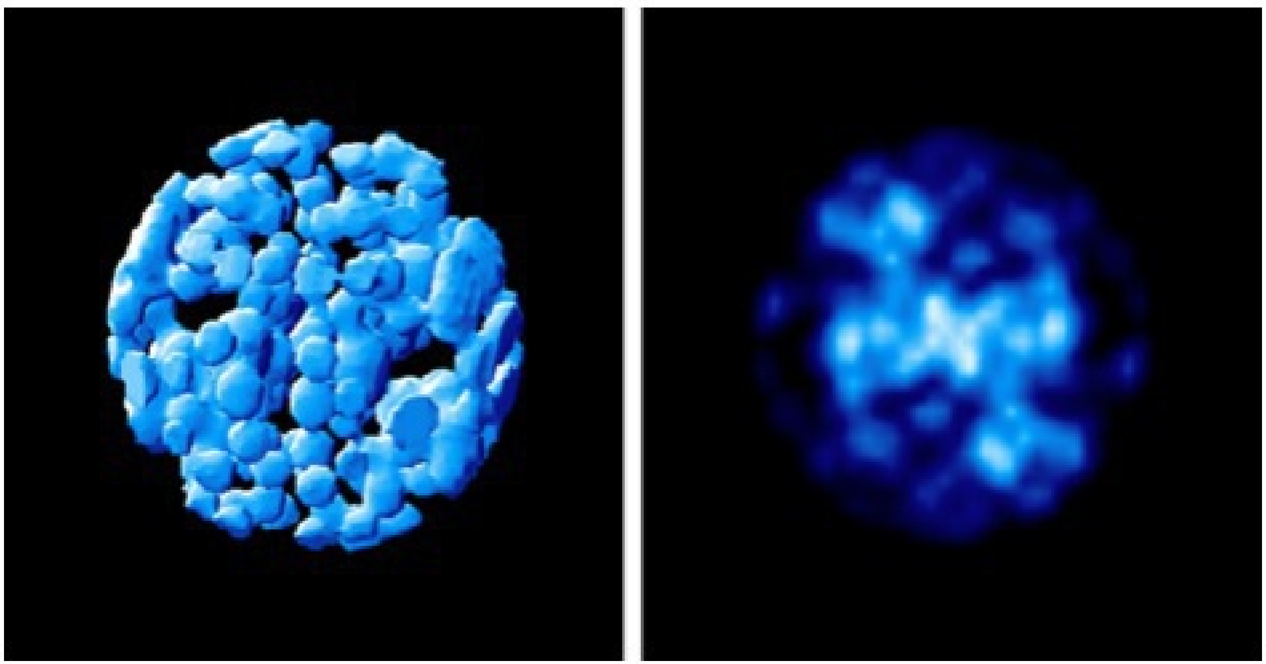


Fig. 1 *The left-hand panel* shows a 3D representation of the Strömgren sphere distribution for case F, plotted as the iso-surfaces where the ionisation fraction of hydrogen is 0.95. *The right-hand panel* shows an average projection map of the ionic abundance of H^+

C3D → pyCloudy

- In 2011, I translated C3D from IDL to python to have all the benefits of python: free language, widely used by the community, very well supported.
- I also took the opportunity to increase the facilities (e.g. parallelisation, a lot of new methods, MdB, ...).

pyCloudy

- PyCloudy is not only a pseudo-3D code, it's more than this.
- It's a python library used to manage the inputs and the outputs of Cloudy.
- It allows to
  - easily run a model and play with the results (including plotting them).
  - easily compute grids of models, running Cloudy in parallel.
  - Compute pseudo 3D models
- It can interact with the 3MdB database.

pyCloudy galaxy on the web

- Site: https://sites.google.com/site/pycloudy/
- Forum: https://groups.google.com/forum/#!forum/pycloudy
- Pip: https://pypi.python.org/pypi/pyCloudy/
- Reference Manual: https://pythonhosted.org/pyCloudy/
- Sources: https://github.com/Morisset/pyCloudy

Installation

- Some libraries are needed for pyCloudy to run:
  - Numpy
  - Matplotlib
  - Scipy
  - Image (to make 3 colors images)
  - Pyneb (to change atomic physics)
  - PyMySQL (to interact with 3MdB, better than MySQL)

Installation of Python

- The best seems to install a full package that comes with everything an astronomer may need. The STSCI team collaborate to such a package named **Anaconda:** https://www.continuum.io/downloads
- It comes with almost everything (even IRAF...)

Using PIP

- Once Anaconda installed, from a terminal, the installation of the remaining libraries and of pyCloudy itself is trivial:
  - pip install pyneb (optionnal)
  - pip install pyCloudy

Managing input and output files

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using_pyCloudy_1.ipynb

Grids of models

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using_pyCloudy_2.ipynb

3D model

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using_PyCloudy_3.ipynb

How to take the aperture size and position into account

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using%20PyCloudy%204.ipynb

Huge grids of models

- Sometimes one needs to compute huge grids of models (from a few 10^3 to 10^6 models...).
- In this case one cannot rely on reading all the output files, it would take tooooo much time and memory (RAM and ROM).
- The solution is to store the results of the models into a database.
- This is the main idea behind 3MdB (Mexican Million Models dataBase).

3MdB

- https://sites.google.com/site/mexicanmillionmodels/

Example of use of 3MdB from pyCloudy

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using%20pyCloudy%20MdB.ipynb

A paper on 3MdB:

http://adsabs.harvard.edu/abs/2014arXiv1412.5349M

Changing atomic data in Cloudy

It is possible to extract from the Cloudy model the electron temperature and density and the ionic fractions to re-compute at each zone of the nebula the emissivities of the lines, using the PyNeb code. This is NOT coherent in the fact that changing the line emissivities change the cooling and then the electron temperature. And only collisional effects are taken into account. But this can nevertheless helps to understand the effect of choosing one set of atomic data or another one in the analysis of a nebula.

https://github.com/Morisset/pyCloudy/blob/master/pyCloudy/docs/Using%20PyCloudy%20with%20PyNeb.ipynb