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PyNeb
a python library to study
the Interstellar Medium

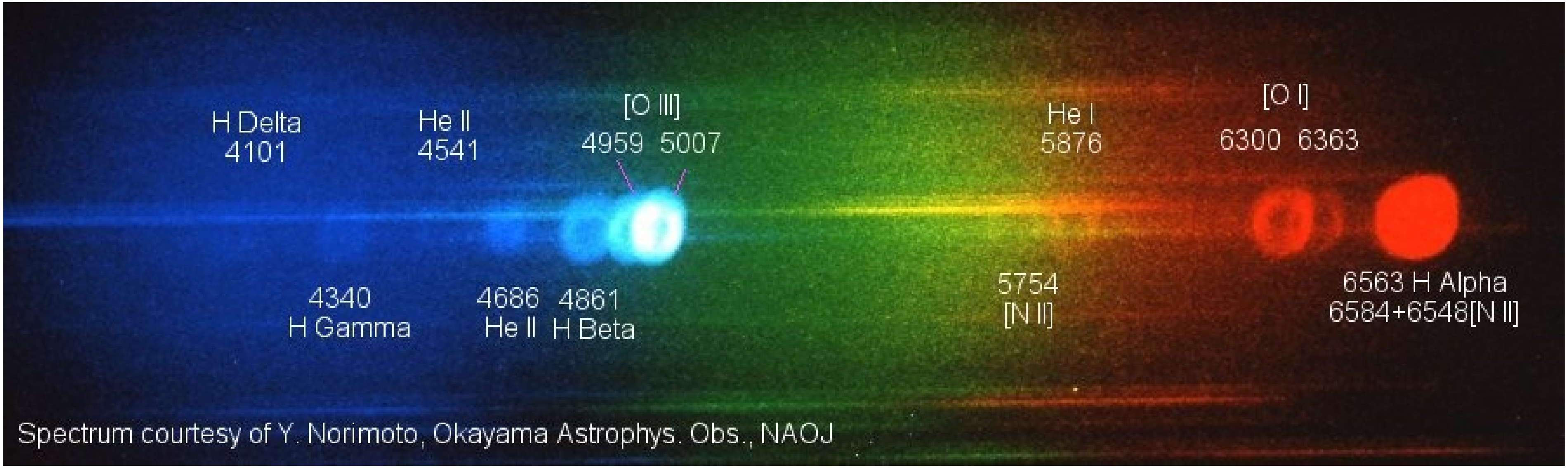
Summary

- Interstellar Medium for dummies
- Pyneb ecosystem
- Comment on some notebooks

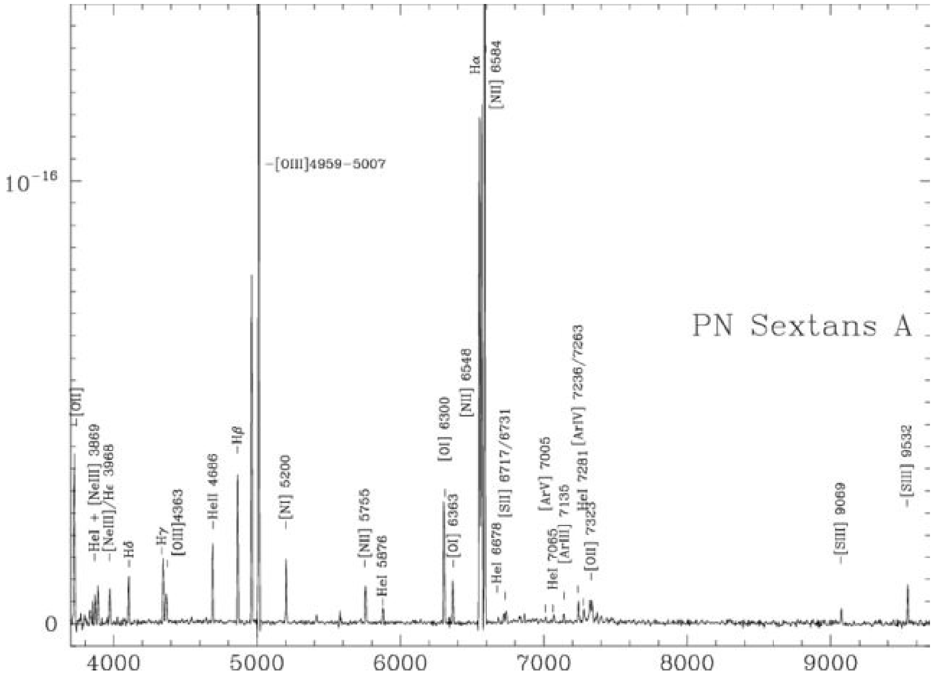
Interstellar Medium

- By ISM, I mean the **ionized gas.**
- Only H^+. No H^0 nor H_2.
- Examples :
  - HII regions
  - Planetary nebulae
  - Wolf-Rayet bubbles

Nebular spectroscopy



Emission lines in ISM

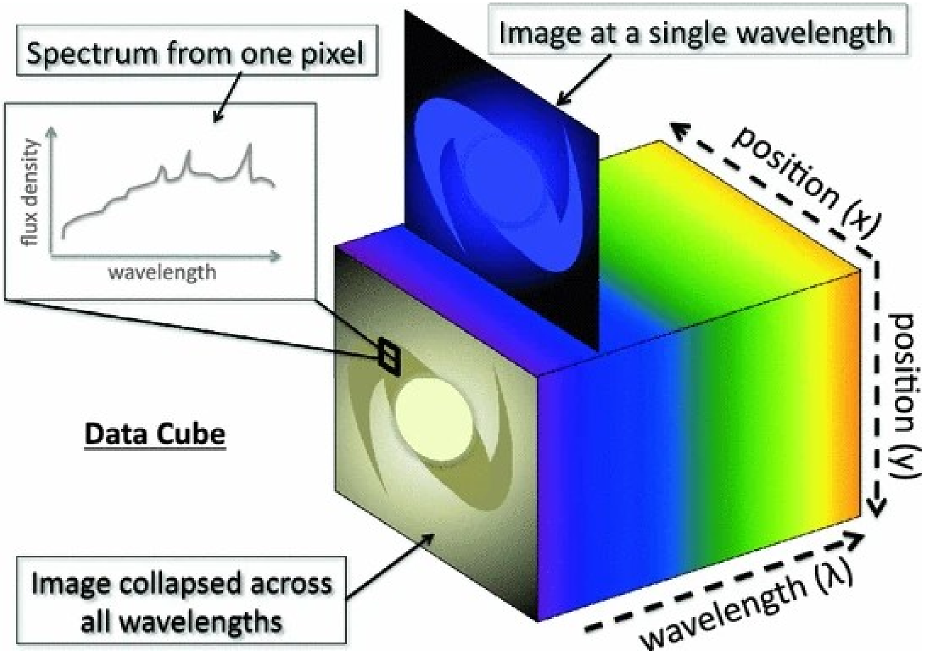


Magrini+04

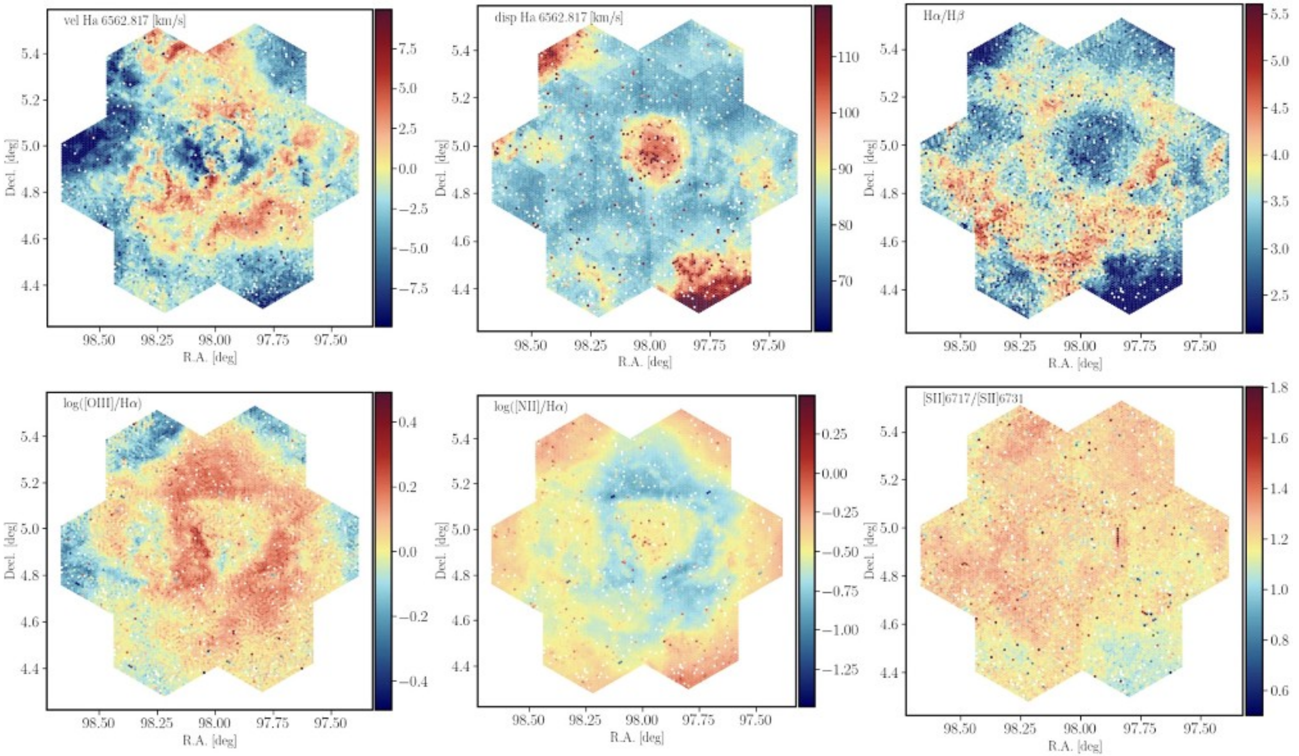
- Spectra are dominated by lines in emission.
- They are emitted by ions: H^+, He^+, N^+, O^+, O^{++}, Ne^{++}, S^+, S^{++}
- Their analysis are used to determine:
  - Physical conditions (Te, ne),
  - Chemical composition

Integral Field Units (IFUs) = 3D spectroscopy

- IFUs are spatially resolved spectra covering a whole region of the sky.
- CALIFA, MANGA, SIGNALS, SDSS V LVM surveys.



SDSS V LVM Survey



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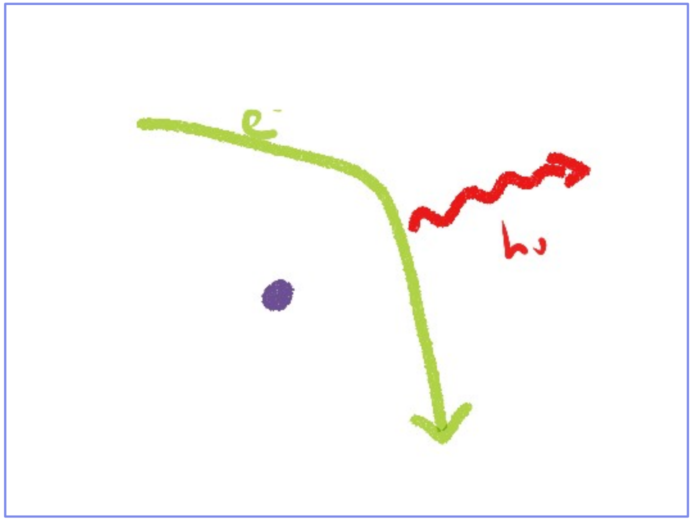
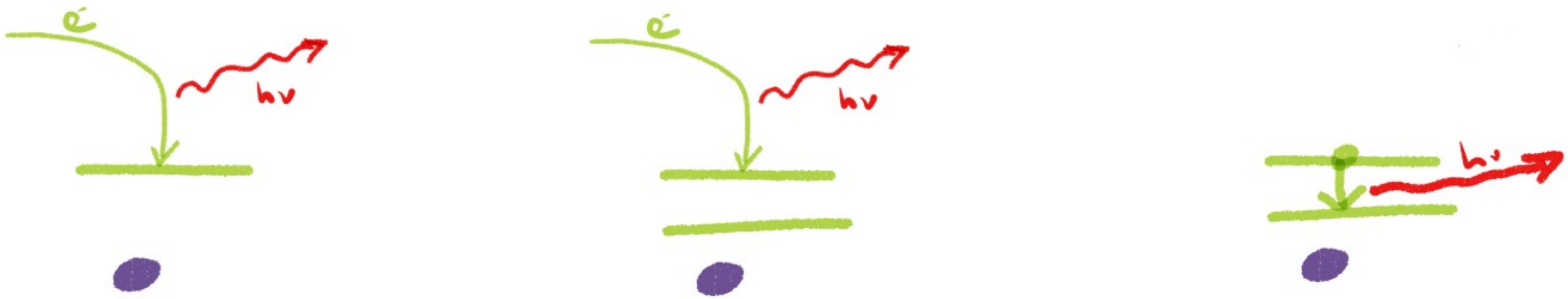
Light production in nebulae

- **Free-free** (Bremsstrahlung)



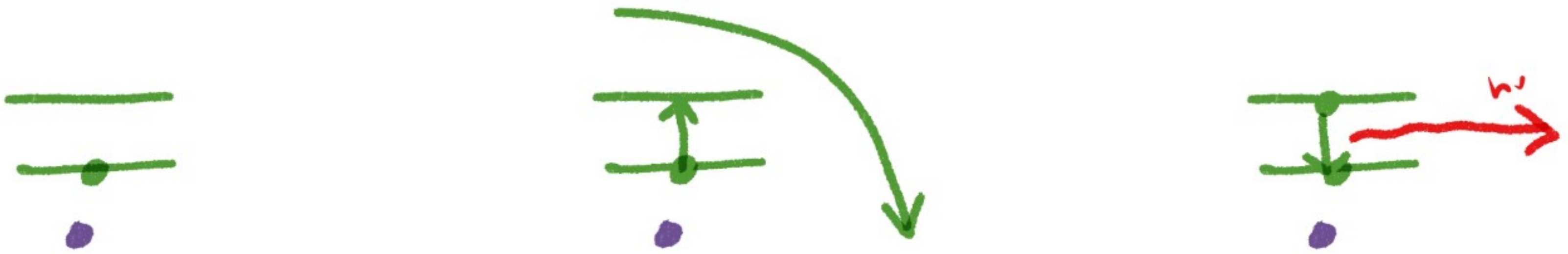
Light production in nebulae

- **Recombination** (radiative), followed by cascade.
- Main H and He emission process.
- Works better at low temperature: $\epsilon \propto \frac{1}{T_e}$



Light production in nebulae

- **Collisional excitation**, followed by cascade.
- Main metal emission process.
- Works better at high temperature: $\epsilon \propto \frac{e^{-\frac{h.\nu}{k.Te}}}{\sqrt{Te}}$



Light production in nebulae

- Free-free, free-bound, <u>bound-bound</u> : this latest leads to emission <u>lines</u>.
- If transition is « forbidden » (i.e. upper level is meta-stable), **non-radiative** collisional de-excitation occurs at high **densities**.
- Other processes exist :
  - Dielectronic recombination
  - Charge exchange
  - Fluorescence/Phosphorescence

PyNeb

- Correct from reddening correction (effect of selective attenuation by dust on the line of sight).
- Compute line emissivities as function of temperature and density.
- Invert problem solving : deduce T_e and n_e from line ratios, produce T_e-n_e diagnostic diagrams.
- Compute ionic abundances.
- Compute total elemental abundances.
- Easy change of atomic data and compare effects.
- Can follow uncertainties among the pipeline using Monte Carlo methods.
- Use of Machine Learning (scikit-learn) accelerator when MC and/or IFUs are used.

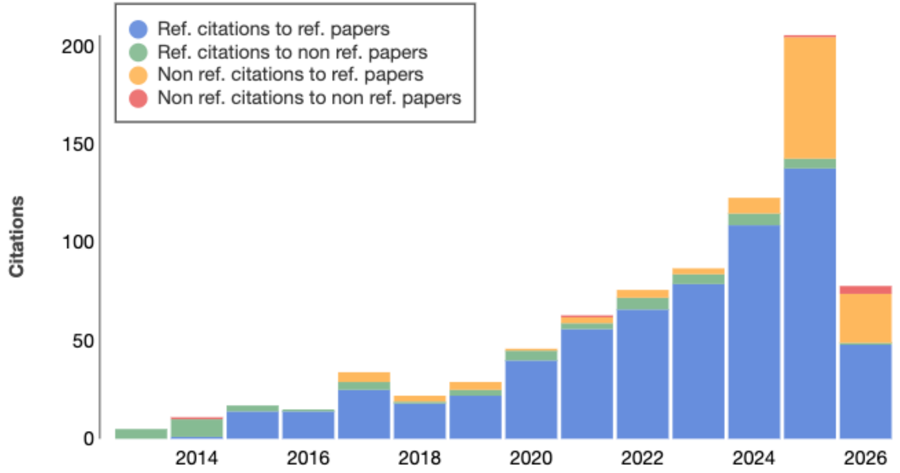
PyNeb ecosystem

- Main github repository:
  - https://github.com/Morisset/PyNeb_devel/
- Documentation:
  - https://github.com/Morisset/PyNeb_devel/tree/master/docs
  - http://morisset.github.io/PyNeb_devel/
- Discussion group, hotline:
  - https://groups.google.com/forum/#!forum/pyneb
- Installed using **pip install -U pyneb**
- Latest version: 1.1.29

PyNeb papers to cite

- Luridiana, V., Morisset, C. and Shaw, R. A., **2013**, A&A, 558, A57 *PyNeb: a new tool for analyzing emission lines. I. Code description and validation of results*
  - http://adsabs.harvard.edu/abs/2015A%26A...573A..42L
- Morisset, C., Luridiana, V., García-Rojas, J., Gómez-Llanos, V., Bautista, M., & Mendoza, C. **2020**, Atoms, 8, 66, *Atomic Data Assessment with PyNeb*
  - https://ui.adsabs.harvard.edu/abs/2020Atoms...8...66M
- Mendoza, C., Méndez-Delgado, J. E., Bautista, M., García-Rojas, J., & Morisset, C. **2023**, Atoms, 11, 63, *Atomic Data Assessment with PyNeb: Radiative and Electron Impact Excitation Rates for [Fe II] and [Fe III]*
  - https://ui.adsabs.harvard.edu/abs/2023Atoms..11...63M

PyNeb's papers citations



810 : total citations for the 4 papers.

PyNeb is a library

- PyNeb is NOT a click-and-publish tool ;-)
- It needs to be included in a python script/notebook as part of a pipeline leading from line intensities to abundances (but not only).
- It requires the user to define receipts on the way they want to deal with the observations:
  - Which lines are used and how is determine the reddening correction?
  - Which lines are used to determine T_e and n_e? Only one, or multiple zones?
  - Which lines are better to determine the ionic abundances?
  - Which ICFs are used to compute the elemental abundances?
- No general receipt exists, it depends on the available observations (wavelength ranges) and their qualities (uncertainties).

PyNeb notebooks

- Introduction to PyNeb
- Using Atom to compute emissivities
- The atomic data
- The Recombination lines
- The extinction correction
- The Observations
- The Diagnostic diagrams and determination of Te-Ne
- The determination of ionic abundances
- ICFs and elemental abundances
- Some examples
- Use of Monte Carlo (Uncertainty estimations) and Neural Network (speed-up Te-Ne determination)