Ionised gas

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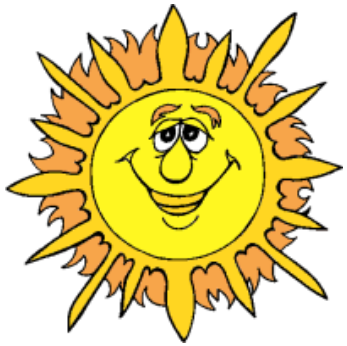
Procesos Radiativos en Astrofísica
Máster en Física Teórica (Astrofísica)

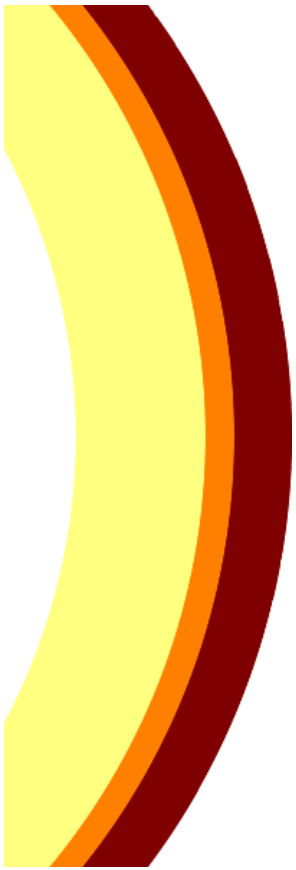
Outline

1. Physics
2. Computing
   - PyNeb
   - Cloudy
3. Hands-on work

Physics

Photoionised nebulae





Astrophysical examples

- HII regions
- Planetary nebulae
- AGN
- Diffuse gas

Atomic physics

Nomenclature

- Chemical elements
  (relative abundance)
- Ions
  (species, ionisation fraction)
- Excitation
  (levels, population)
- Free electrons
  (n_e, T_e)

Emission mechanisms

- Continuum
  - free-free
  - recombination
- Lines
  - recombination
  - collisional/forbidden

Atomic physics

Collisional equilibrium

$$\sum_{j\neq i} n_e n_j q_{ji} + \sum_{j>i} n_j A_{ji} = \sum_{j\neq i} n_e n_i q_{ij} + \sum_{j<i} n_i A_{ij}$$

Two-level atom

$$n_e n_u q_{ul} + n_u A_{ul} = n_e n_l q_{lu}$$

$$\frac{n_u}{n_l} = \frac{n_e q_{lu}}{n_e q_{ul} + A_{ul}}$$

Critical density

$$n_{cr} = \frac{A_{ul}}{q_{lu}}$$

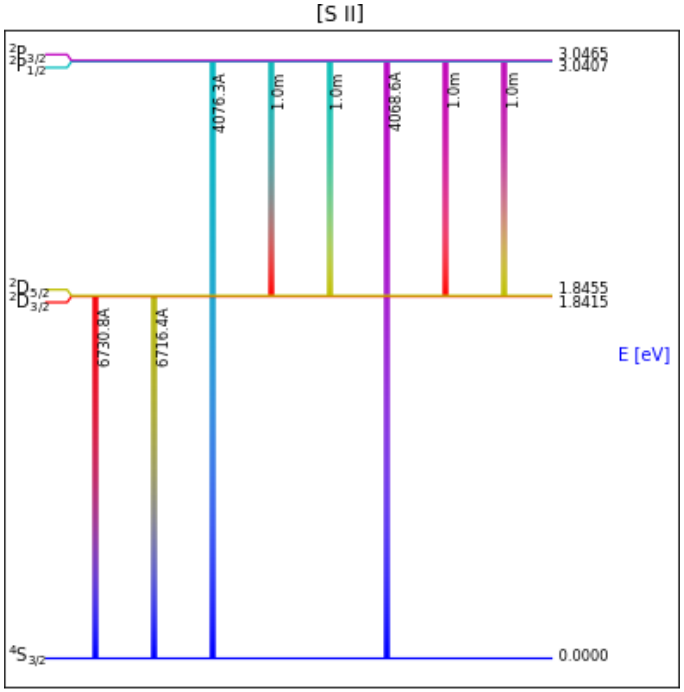
$$n_e \gg n_{cr} \Rightarrow \frac{n_u}{n_l} \simeq \frac{g_u}{g_l} e^{-\frac{E_u - E_l}{kT}}$$

$$j = n_u A_{ul} \propto \rho$$

$$n_e \ll n_{cr} \Rightarrow \frac{n_u}{n_l} \simeq \frac{n_e q_{lu}}{A_{ul}}$$

$$j = n_l n_e q_{lu} \propto \rho^2$$

Plasma diagnostics



Electron density

- Similar energy
- Different n_{cr}

Electron temperature

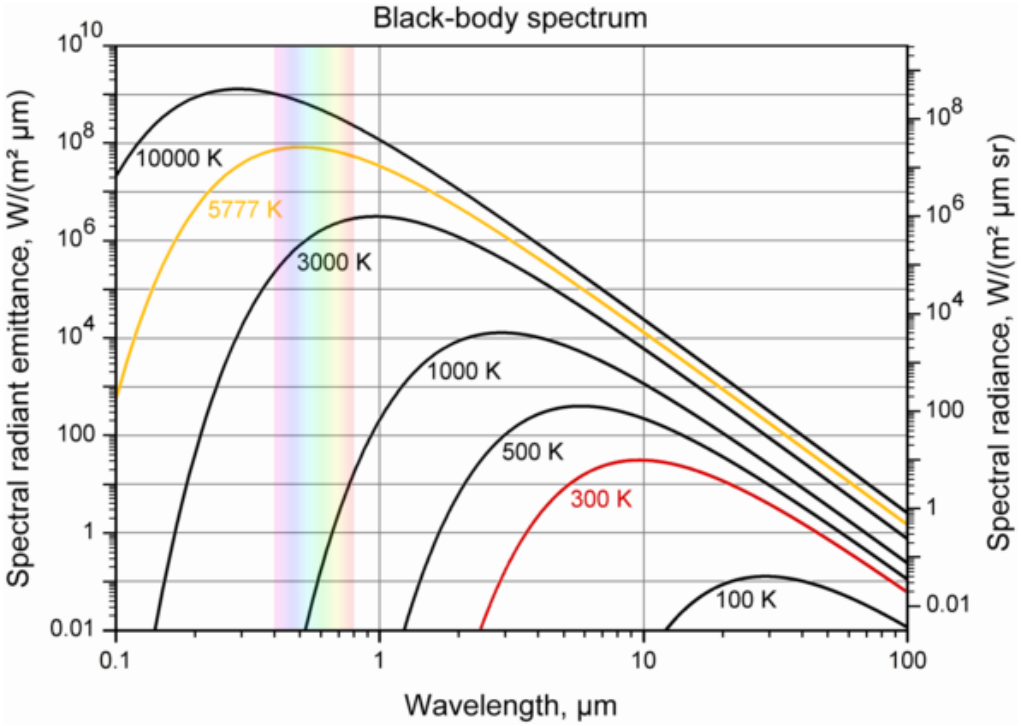
- Different energy
- Away from n_{cr}

Relative abundances

$$\frac{n(A)}{n(B)} = \frac{F(\lambda_A)}{F(\lambda_B)} \frac{j(\lambda_B|n_e, T_e)}{j(\lambda_A|n_e, T_e)}$$

- Ionisation correction factors (ICF)

Radiation field



Main parameters

- Normalisation (flux)
- Spectral shape (hardness)

Einstein coefficients

$$n_u(A_{ul} + B_{ul}J) = n_l B_{lu} J$$

Computing

PyNeb

A&A 573, A42 (2015)
DOI: 10.1051/0004-6361/201323152

Astronomy & Astrophysics

PyNeb: a new tool for analyzing emission lines

I. Code description and validation of results

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Received 29 November 2013 / Accepted 29 September 2014

Luridiana et al. (2015)

http://research.iac.es/proyecto/PyNeb

https://github.com/Morisset/PyNeb_devel

PyNeb classes

Atom / RecAtom

- Atomic data
- Level populations
- Line emissivities

Observation

- Line intensities
- Extinction

Diagnostics

- Density
- Temperature
- Abundances

Cloudy

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **110**:761–778, 1998 July

Invited Review

CLOUDY 90: Numerical Simulation of Plasmas and Their Spectra

G. J. FERLAND,[1] K. T. KORISTA,[1,2] D. A. VERNER,[1] J. W. FERGUSON,[1,3] J. B. KINGDON,[1,4] AND E. M. VERNER[1]
Received 1998 January 19; accepted 1998 March 3

Ferland et al (1998, 2013, 2017)

https://www.nublado.org/

Cloudy

Incident radiation

- SED shape
- Intensity/luminosity
- Geometry

Control commands

- Stopping criterion
- Model grids

Gas

- Initial density
- Temperature?
- Abundances
- Dust
- Other components

Hands-on work

Cloudy Summer School

https://github.com/Morisset/Cloudy_Summer_School