Group 3: Using Cloudy to Explore Ionization fractions and Cooling rates

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Outline (remove this later)

- intro to cloudy (1-2 slides)
- ionization fraction team (3 slides)
  - ionization fraction for different elements (C, O)
  - different incident spectra -- compare them (hm05, hm12, sb99)
  - grid model comparison
- cooling rates (3 slides)
  - ionization fraction * cooling coefficient = cooling rate
    - explain why hden doesn't change ionization fraction
    - temp determines the ionization frac, and the tail end of the maxwell distribution, so changing hden doesn’t change
  - carbon cooling rate curve
  - oxygen cooling rate curve

What is Cloudy?

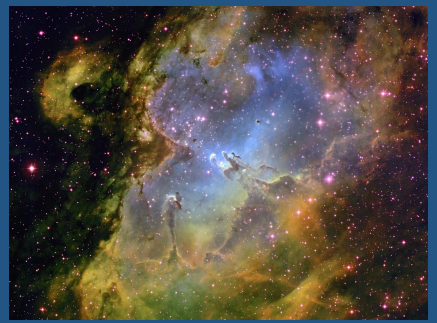
- Cloudy is a computer programme with the ability to compute the physical conditions of diffuse gas.
- It simulates and predicts thermal, ionization and chemical structure of gaseous clouds.
- Added functionality:
  - Predict features of absorption and emission in output spectra for verification
- Extremely flexible; freedom to change and constrain parameters:
  - Redshift
  - Neutral hydrogen density
  - Metallicity
  - Geometry

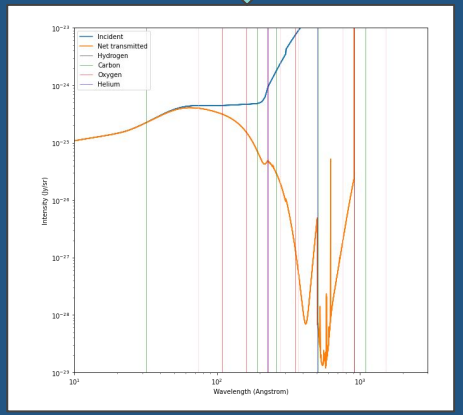
Running cloudy (How does it work?)

Starting Cloudy
Cloudy needs a few things before predicting conditions in a cloud.

What is needed?
- Number density (hden)
- Abundances (metals)
- Geometry (Stop H column density)
- Commands to govern output

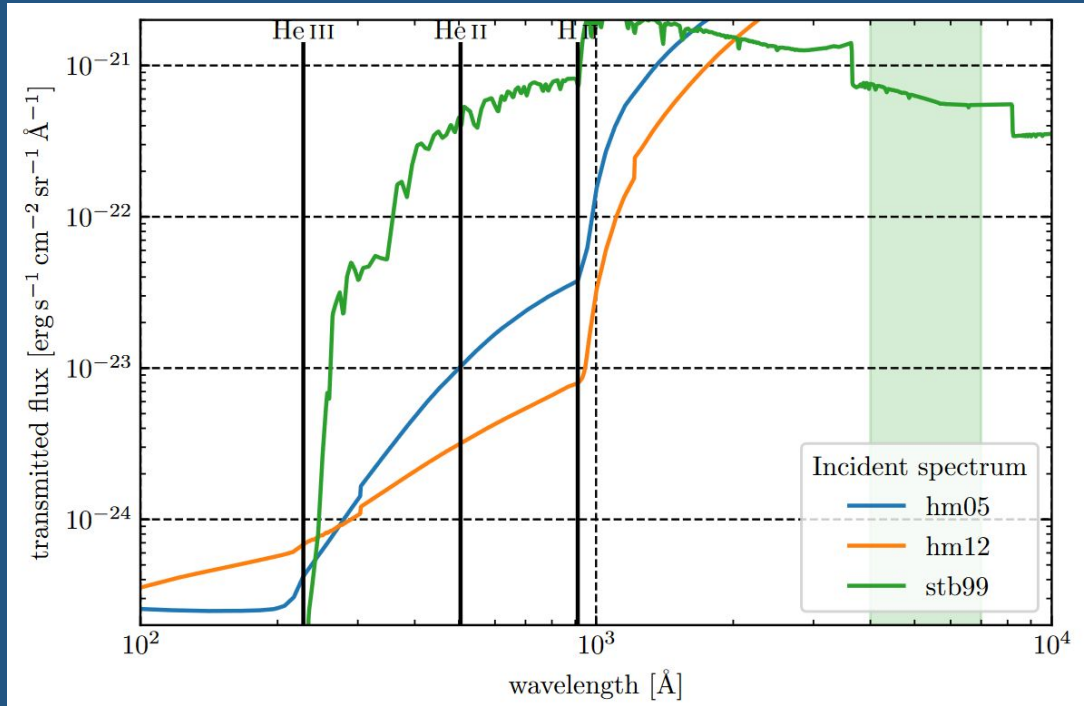
Output
- Cloudy Model with physical conditions
- Output spectra





Influence of the incident spectrum on the ionization properties

- Changing the hardness i.e. slope of the incident SED affects the continuum of the
- We ran models with different incident spectra:
  - Haardt&Madau05
    - Table for $0 < z < 9.479$
    - Accounts for quasars and galaxies
  - Haardt&Madau (2012)
    - Table for $0 < z < 15.93$
    - No QSO contribution considered here
  - Starburst99
    - Table for stellar atmospheres
- Explore the spectral regions close to the ionization edges of various species

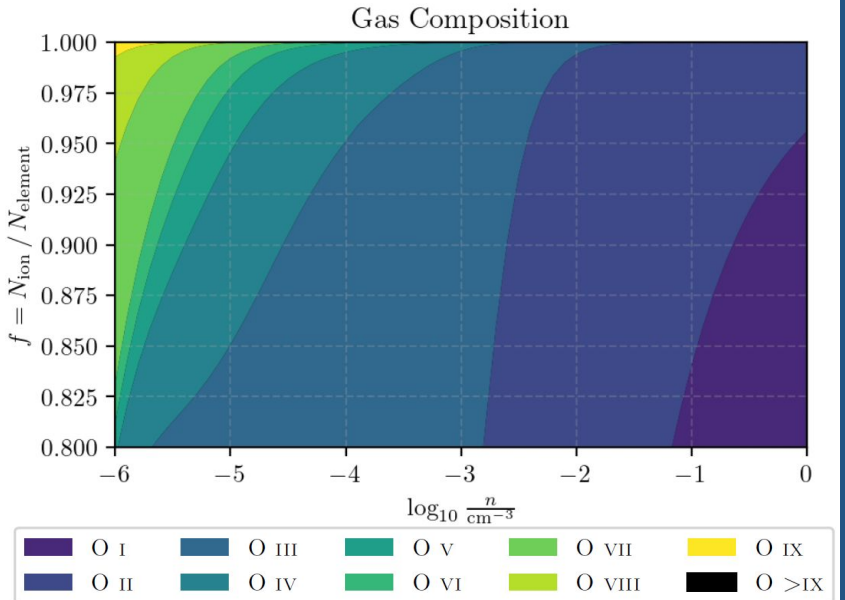


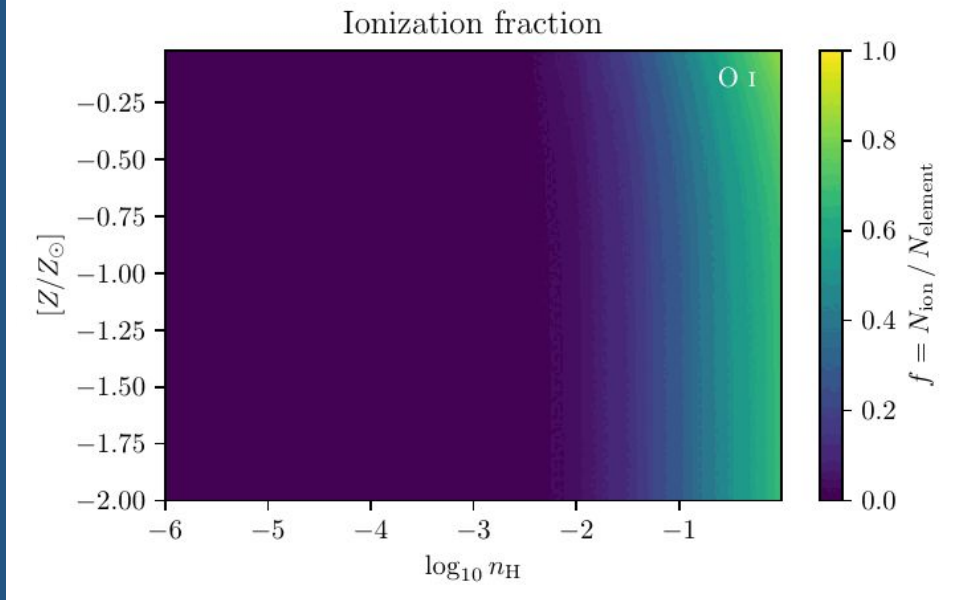
Running a Grid with Cloudy

... in order to explore the parameter space

n_H N_{HI} $[Z / Z_\odot]$

- Ionization fraction is affected by the incident spectrum
- In the case of photoionization, the ion fraction depends on the number density
- Ionization fraction does not strongly depend on the metallicity



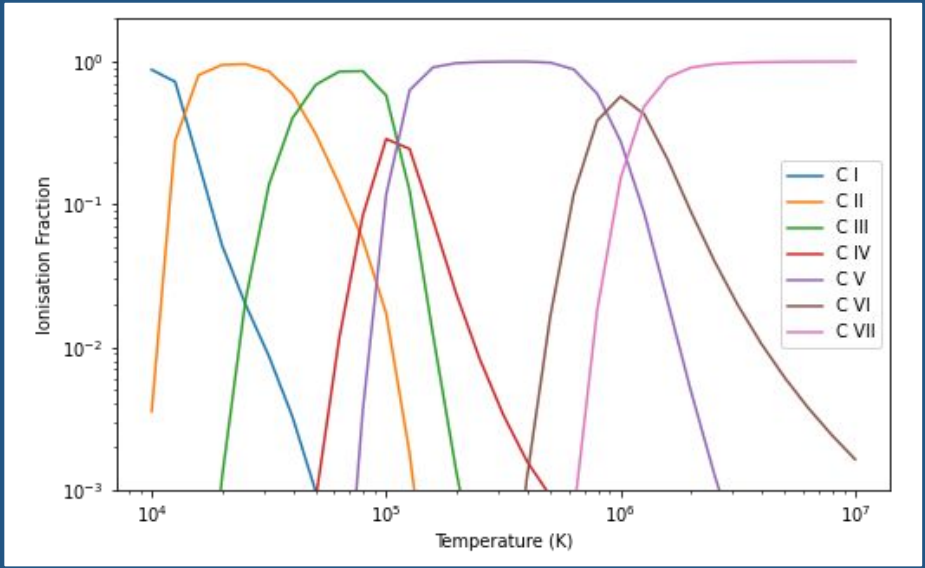


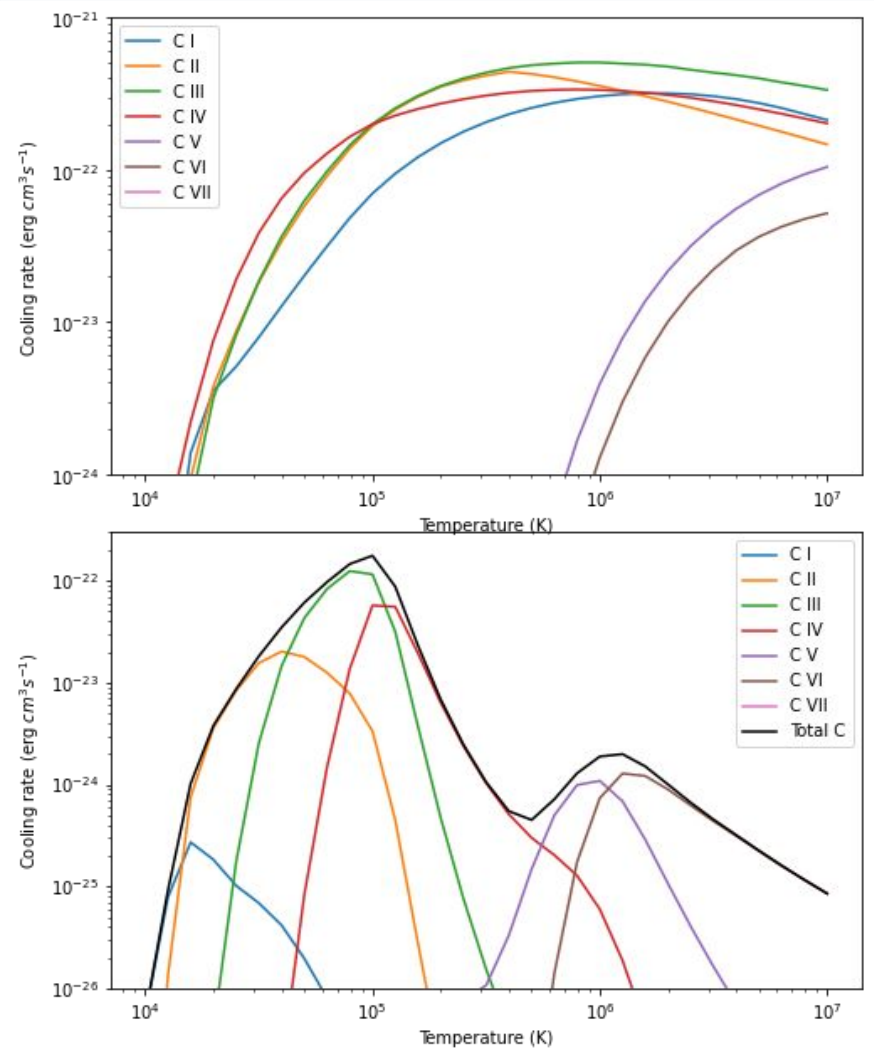
Cooling efficiency (Λ) of elements

- Λ = ionization fraction * cooling rate per volume [erg cm^{-3} s^{-1}] / n^2
- Ionization fraction (from only collisions)
  - Does not depend on the number density of the gas
  - Depends on the gas temperature
- From Cloudy, we obtain
  - Ionization fractions for every ionization state for the element of interest
  - Cooling rate per volume for separate ionization state

Cooling rate: Carbon

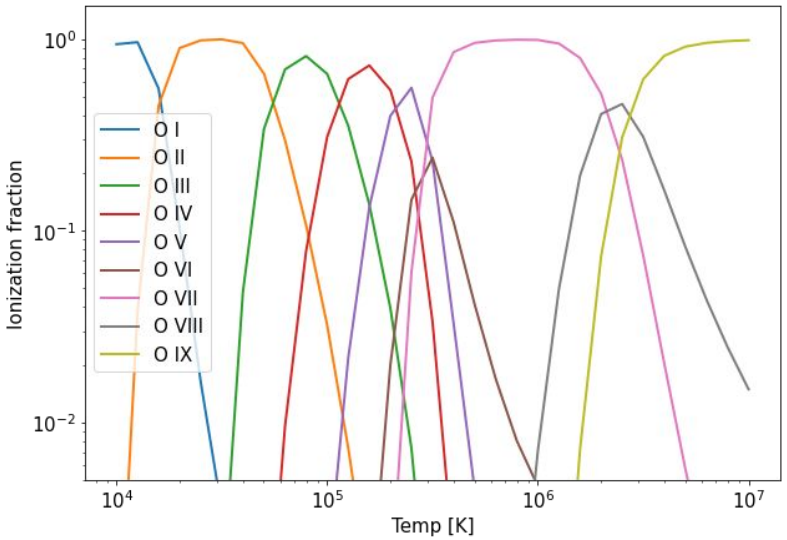
hden = 1 cm^{-3}
Metallicity = 1 (Solar)
Vary temperature between 10^4 and 10^7 K

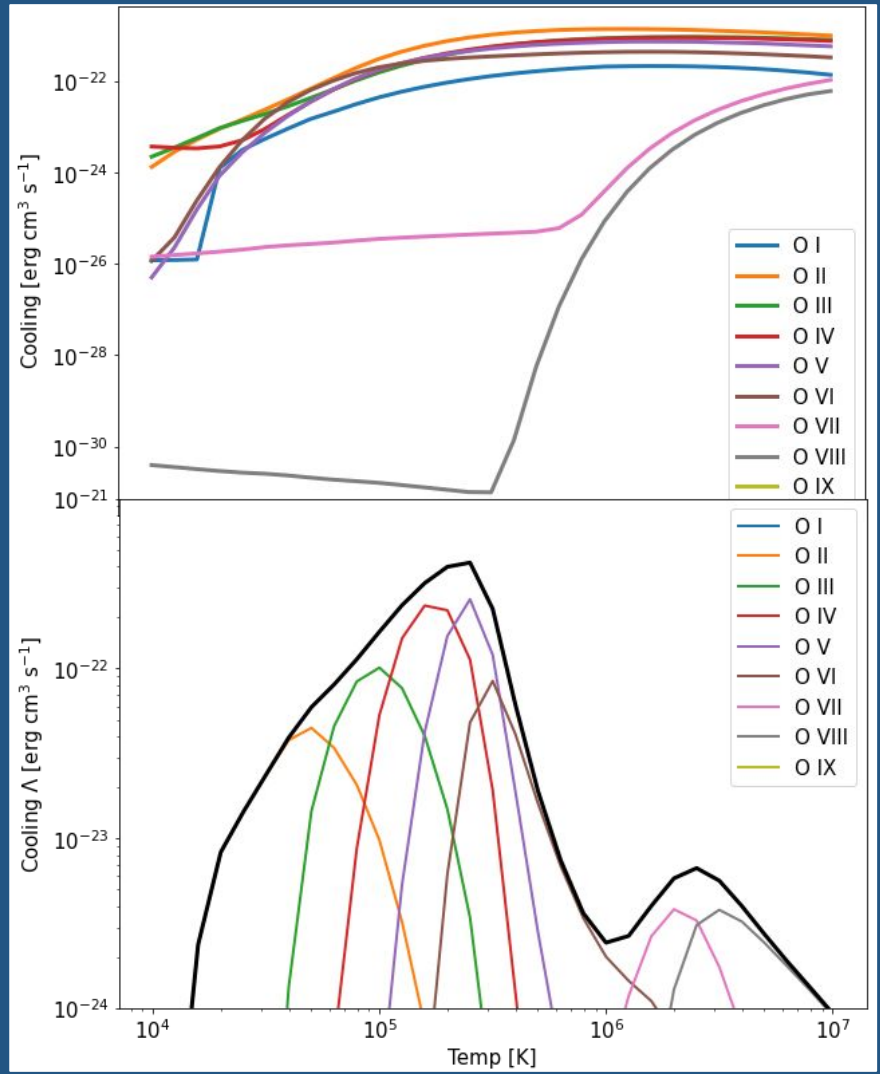




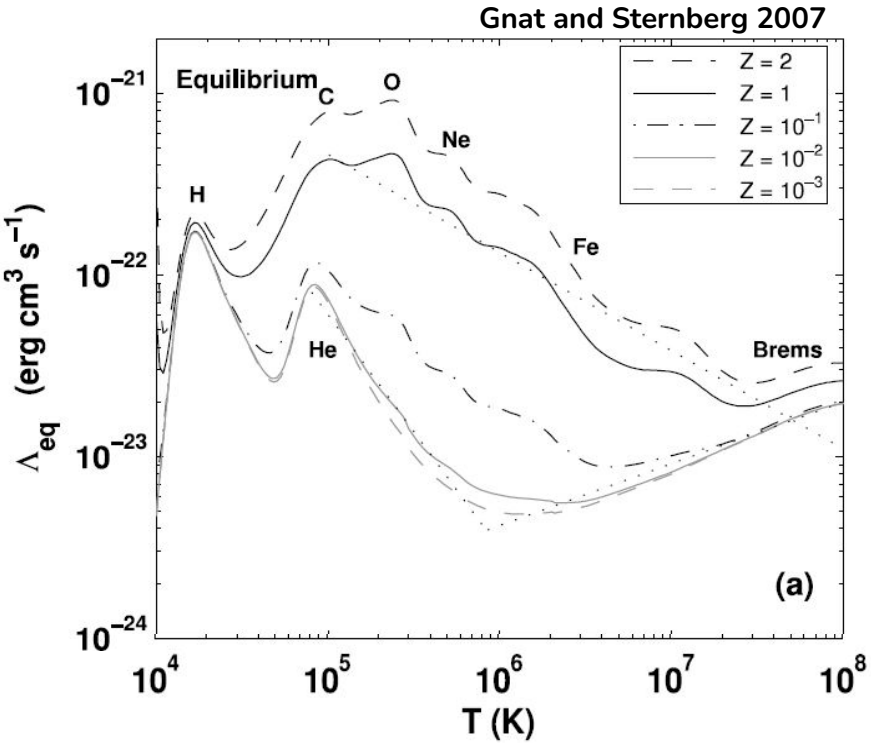
Cooling rate: Oxygen

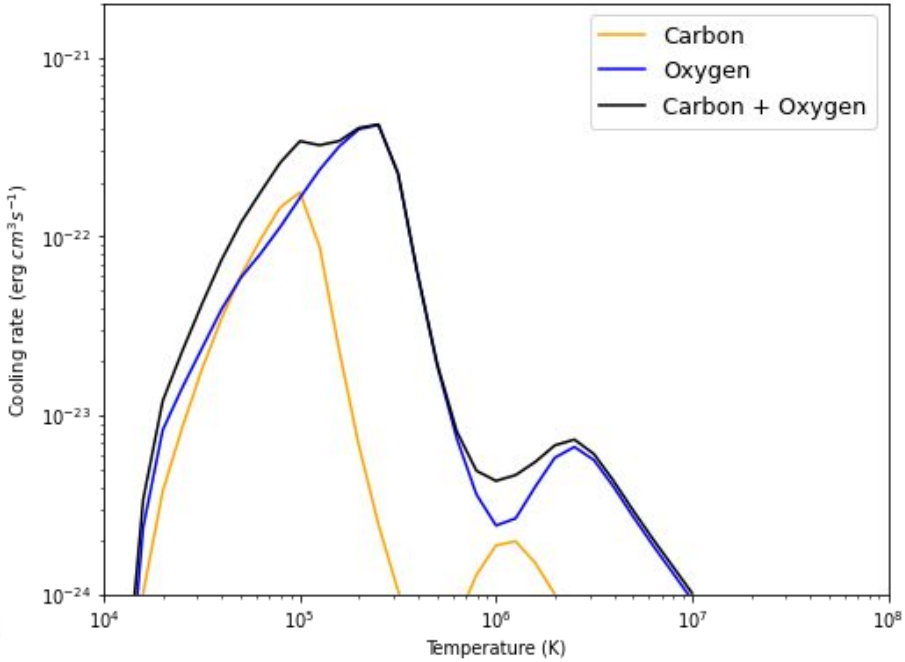
hden = 1 cm^{-3}
Metallicity = 1 (Solar)
Vary temperature between 10^4 and 10^7 K





Cooling efficiency: C+O





Summary

- Cloudy is super fun and easy to use :>
- Cloudy is extremely well-documented! You can get all your questions answered just by reading Hazy1,2,3. (why not foggy, or rainy, hmm...)
    - Knowing which Hazy document is a hurdle to overcome (ctrl+f is your best friend)
- We've managed to:
    - Figure out how different incident spectra used for Cloudy will influence the ionization properties of the predicted output.
    - Replicate theeaks of the (peaks of the) cooling efficiency curve for carbon and oxygen.
- You can do more with Cloudy!