



Introduction to CLOUDY

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Outline lectures

Outline (Dec 1)

- CLOUDY introduction
- CLOUDY installation
- a quick CLOUDY run: the input file
- exploration of CLOUDY output
- Q&A

Outline (Dec 2)

- exploration of CLOUDY output
- CLOUDY grid
- exercise
- your future: PhD, post-doc, etc
- Q&A



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My academic journey

- chose humanistic studies for high school
- started studying math at uni, left after 6 months
- worked in bakery and supermarket while playing in a band
- got bored
- moved to Bologna to study astronomy
- after my master degree (thesis with Prof. Pozzi) left for 3 years of travel and work abroad
- came back to Bologna to get a PhD in astrophysics (with Prof. Pozzi and Dr. Vallini)
- during my PhD spent 6 months in Madrid at Centro de Astrobiología, with Dr. Alonso-Herrero
- moved to Madrid for a post-doc at Observatorio Astronómico Nacional, with Dr. García-Burillo
- recently got a permanent position at Observatorio Astronómico Nacional (OAN)



Introduction to CLOUDY

Cloudy is an *ab initio* spectral synthesis code designed to model a wide range of interstellar "clouds", from H II regions and planetary nebulae, to Active Galactic Nuclei, and the hot intracluster medium that permeates galaxy clusters.

Cloudy has been in continuous development since 1978, led by Gary Ferland

Useful links

CLOUDY wiki: <https://gitlab.nublado.org/cloudy/cloudy/-/wikis/home>

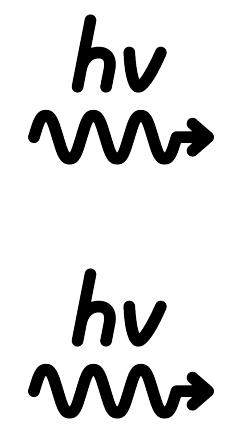
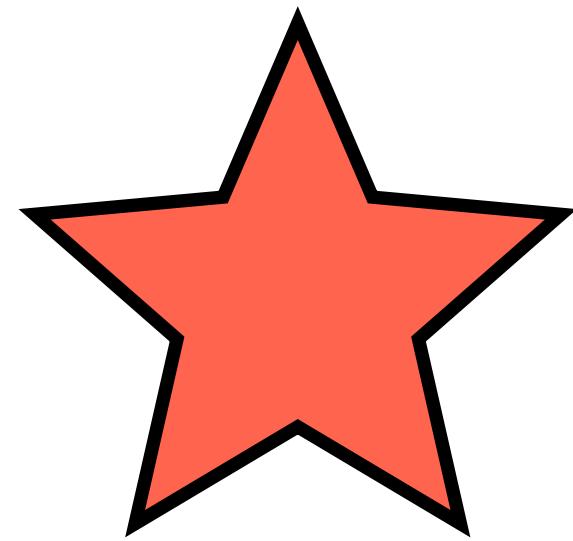
CLOUDY users forum: <https://cloudyastrophysics.groups.io/g/Main>

CLOUDY youtube page: <https://www.youtube.com/@Cloudy-Astroph>

Gary Ferland talking about CLOUDY: <https://youtu.be/q3kKWFKnl8I?si=emp1AE5sGPC8DHxf>

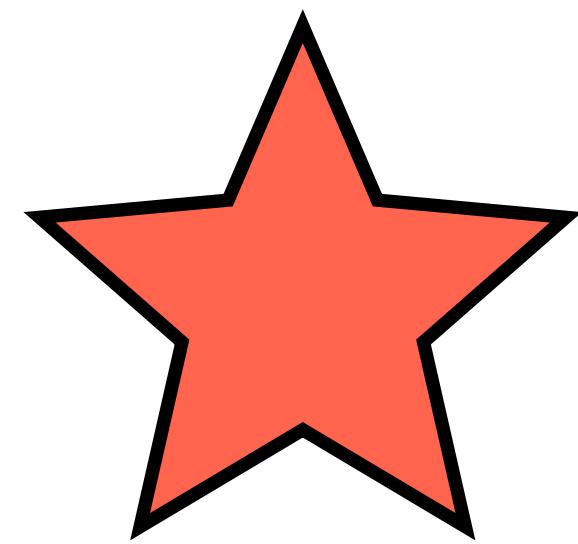
CLOUDY song: https://youtu.be/L-fIO7_HJBo?si=Cybj98m2ULEUheRU 

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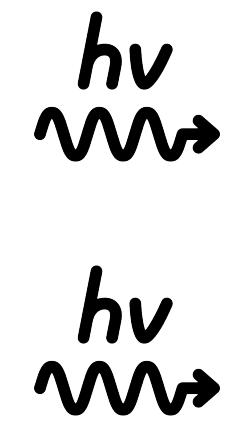


Radiation
source

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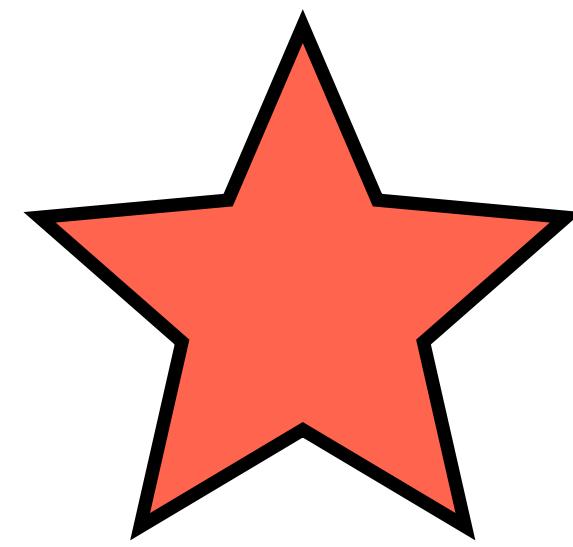


Radiation
source

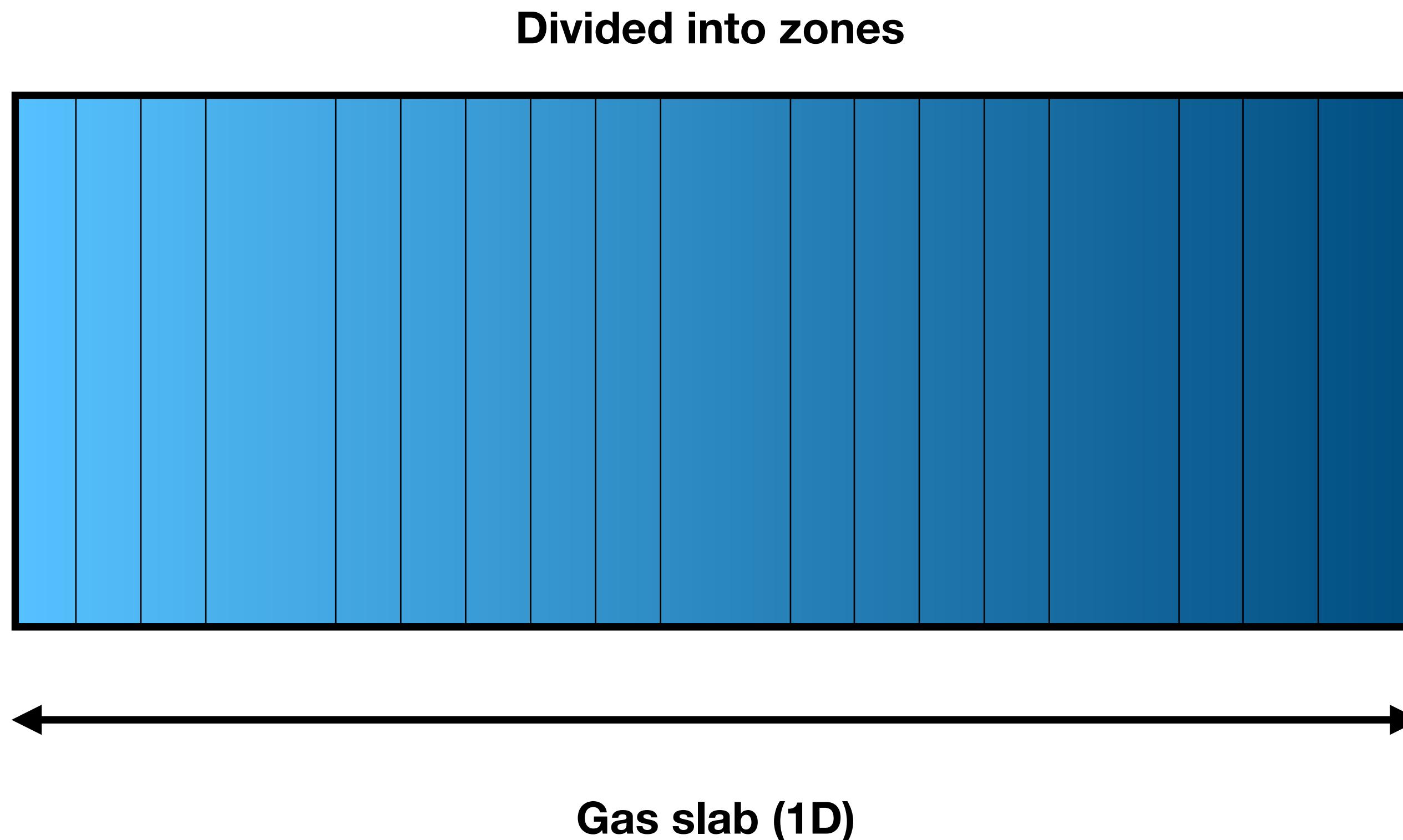
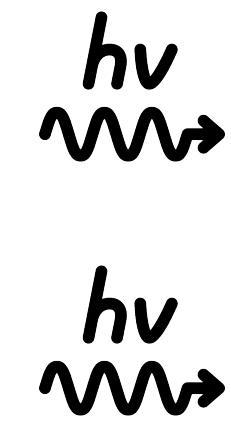


Gas slab (1D)

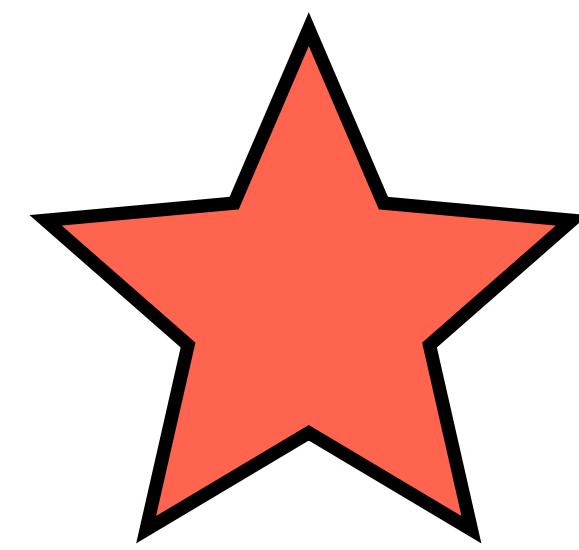
Introduction to CLOUDY



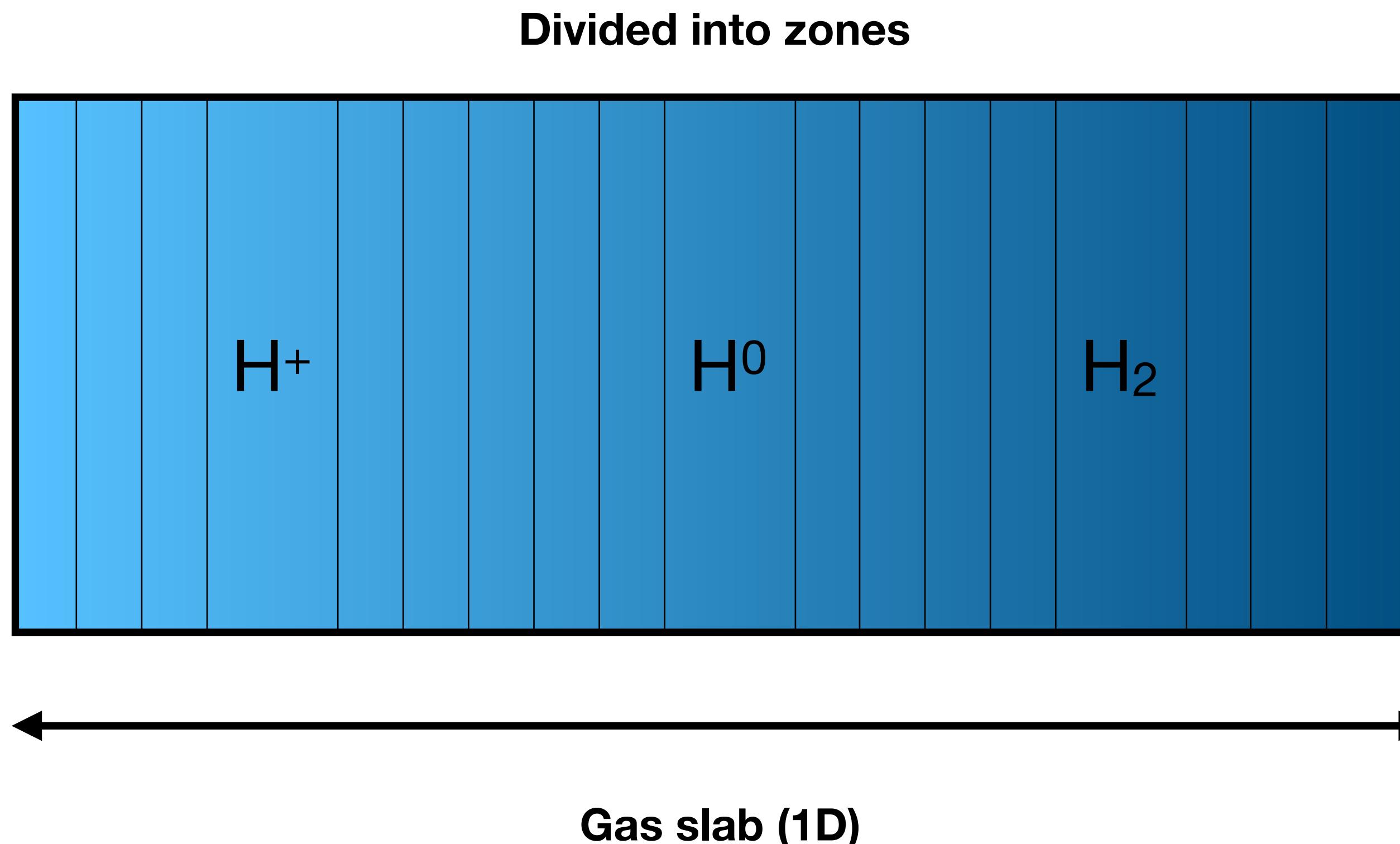
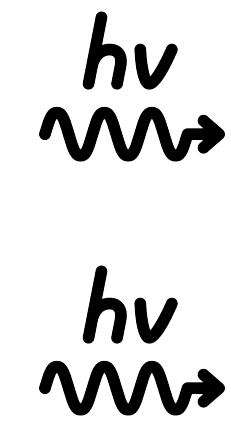
Radiation
source



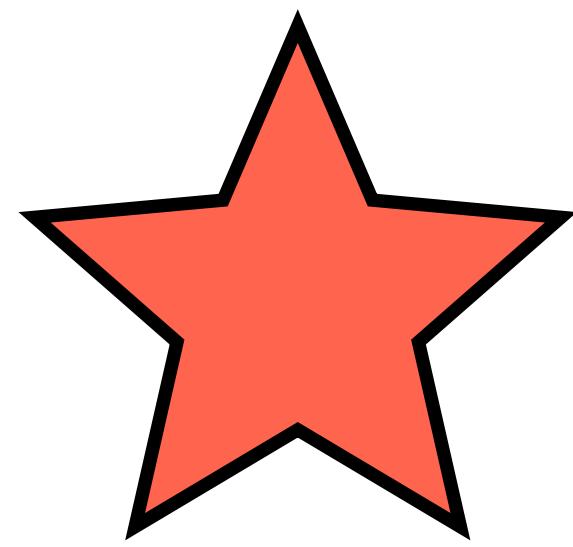
Introduction to CLOUDY



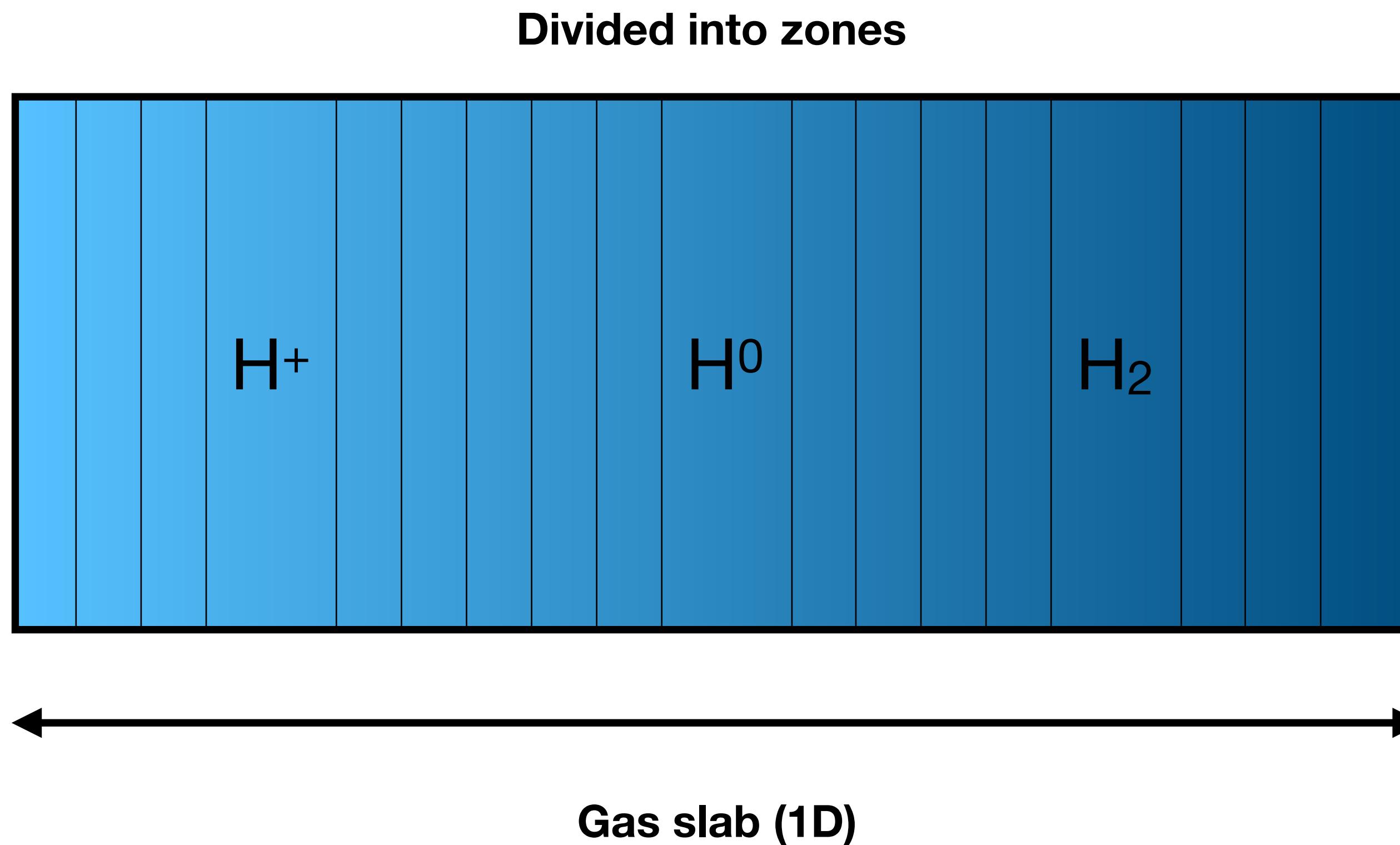
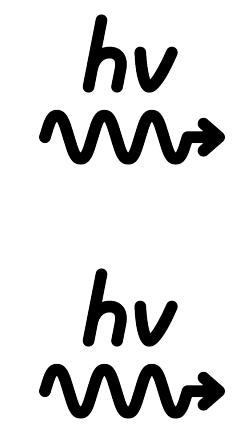
Radiation
source



Introduction to CLOUDY

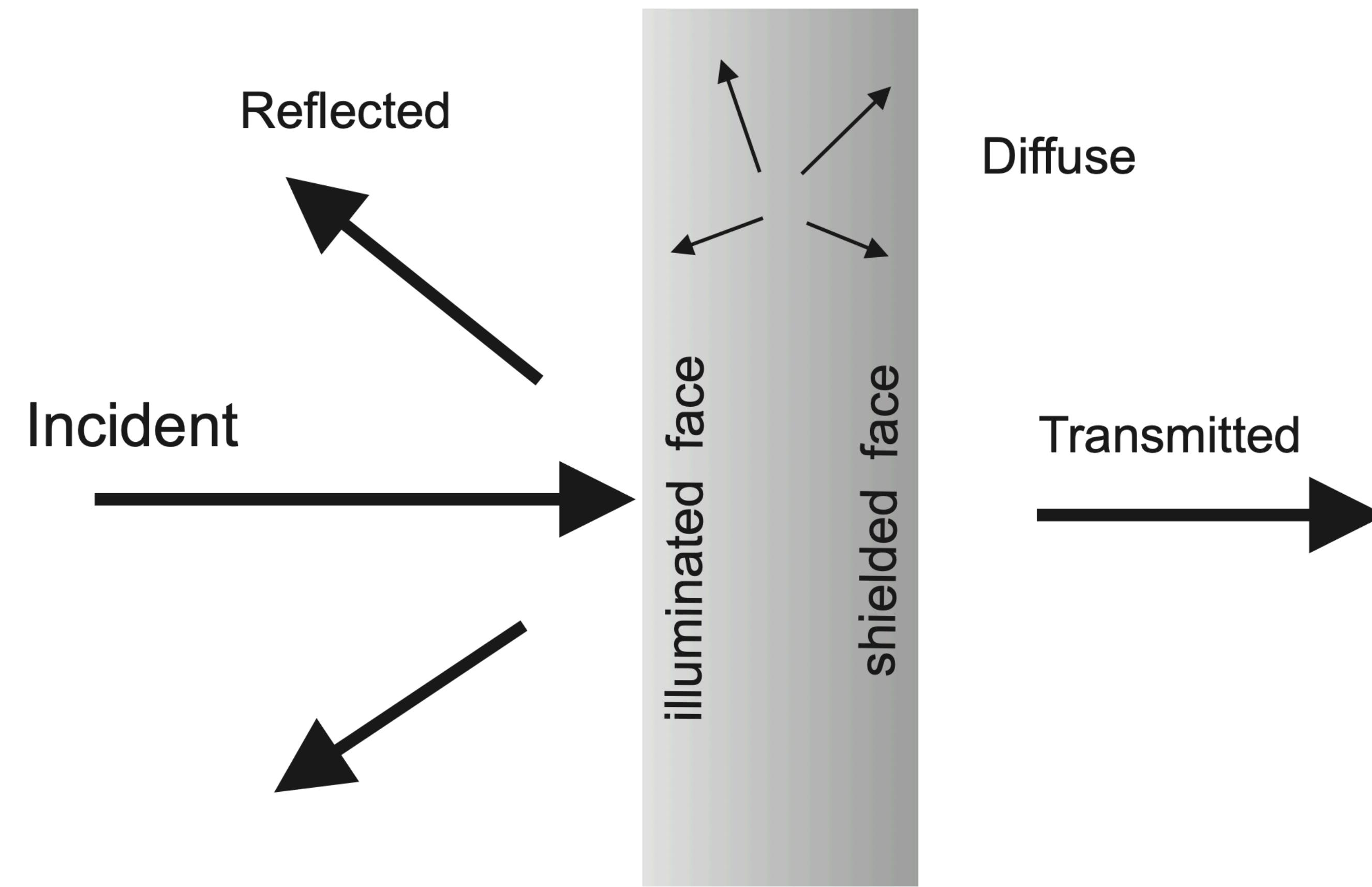


Radiation source

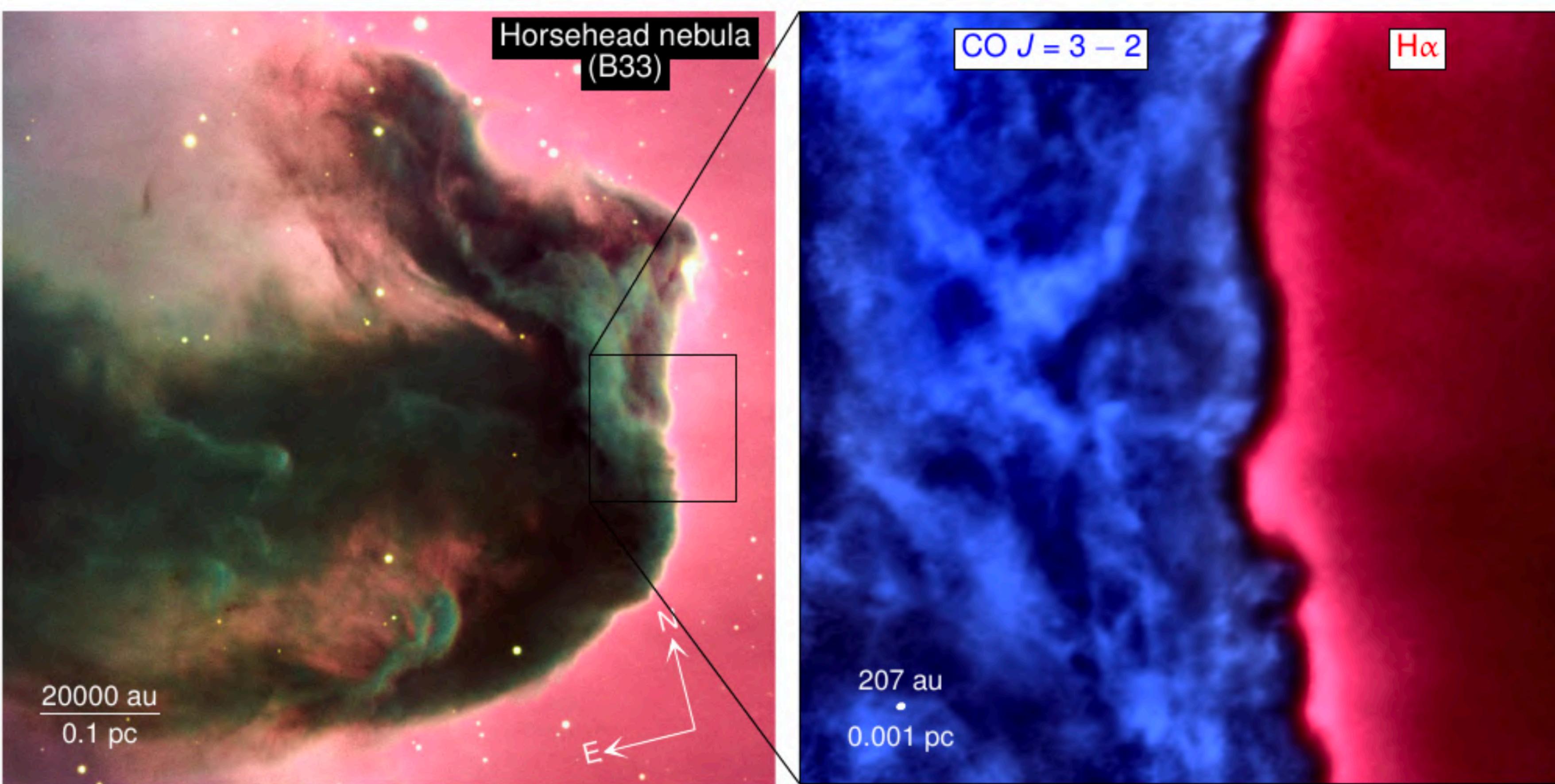


Introduction to CLOUDY

in CLOUDY words (from Hazy 1):

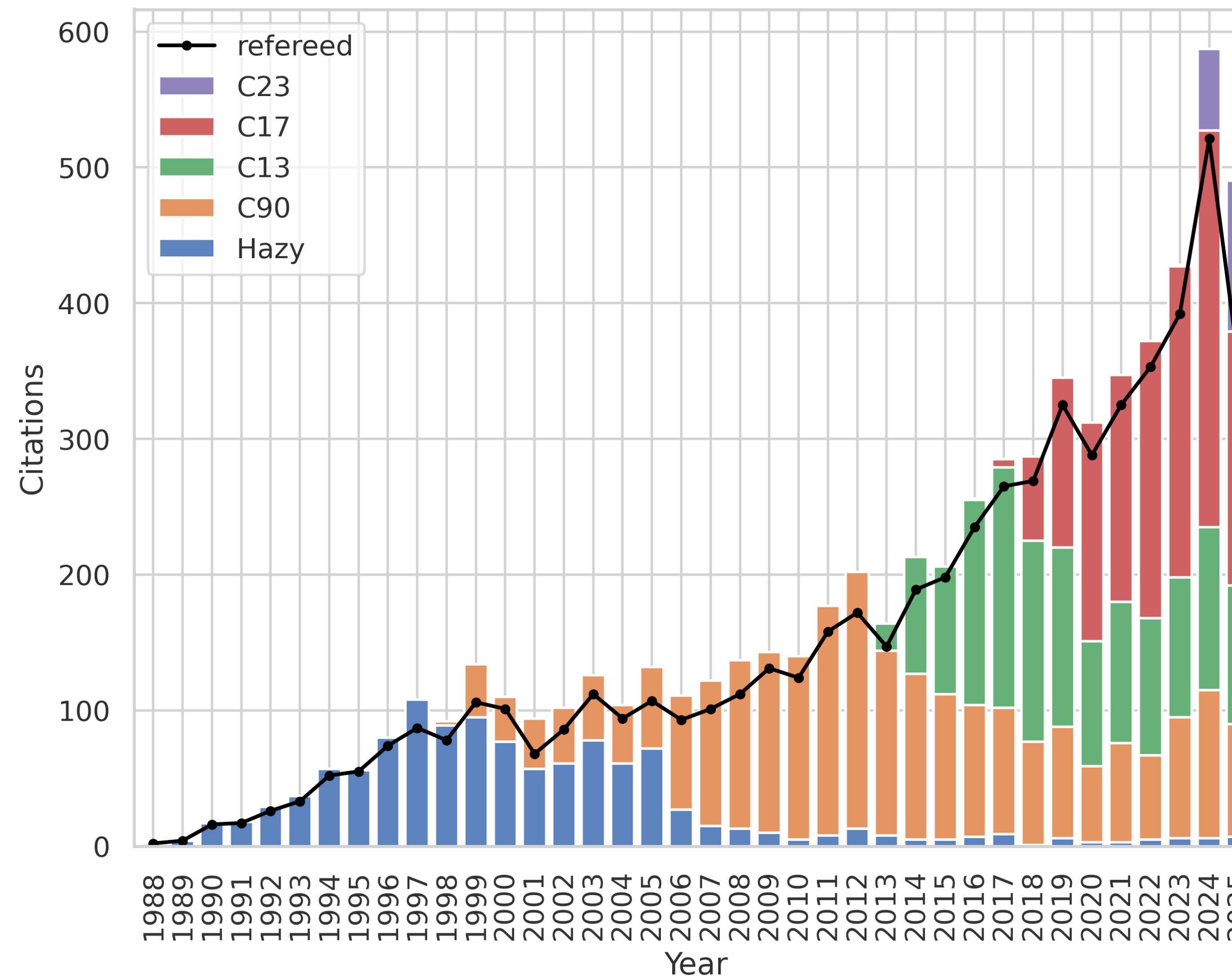


Introduction to CLOUDY



Hernández-Vera et al. (2023)

Introduction to CLOUDY



How to run CLOUDY

1. Prepare a clean folder “cloudytest”
2. Within it, create a “cloudytest.in” text file
3. Edit “cloudytest.in” (next slide)
4. Run with path/to/source/cloudy.exe cloudytest.in
5. Wait...
6. Check the output files (within the same “cloudytest” directory)

CLOUDY input file 101

Input file

It is a text file with extension .in

Incident radiation

Intensity case

We need to specify intensity/luminosity + shape (i.e. SED)

Specify intensity [erg / s / cm²]

Luminosity case

Specify luminosity [erg / s] + specify cloud distance [cm]

Cloud density

We will see constant density (in cm⁻³) simulations

Cloud composition

How much C/O? Which metallicity? Do we want dust?

Stopping criteria

When should the simulation stop?

PDR input file (1/2)

```
set save prefix "pdr_test"
```

every saved file (except .out) will have this prefix

```
table star "sfr1_kroupa.ascii" age=1e6 years
```

this is the incident SED of a stellar population
(obtained with the starburst99 code)

```
intensity -2.8, range 0.44 to 1 Ryd
```

intensity $G_0=1$, since $G_0 = 1.6 \times 10^{-3}$ erg / s / cm²
normalized between 6 and 13.6 eV

```
hden 4
abundances ISM no grains
grains ISM
metals and grains linear 1
```

gas+dust density, composition, and metallicity
hden 4 means constant 10^4 cm⁻³
abundances and grains are better split
metals and grains scale the abundances

PDR input file (2/2)

```
turbulence 1 km/s  
cosmic rays background  
no grain molecules
```

turbulence affects the shielding and pumping of lines
cosmic rays are important for molecular chemistry
no grain molecules avoid condensation onto grains

```
stop temperature off  
stop column 23  
set nend 5000  
iterate to convergence
```

stop temperature default is 4000K
column density $\text{NH} = 10^{23} \text{ cm}^{-2}$ to see CO lines
nend = number of zones (default 1400)
iterate to convergence sets max=7 iterations

```
save last overview ".ovr"  
save last continuum ".cont"  
save last pdr ".pdr"  
save last lines zone cumulative emergent ".emis"  
CO 2600.05m      # CO(1-0)  
CO 1300.05m      # CO(2-1)  
...
```

last means last iteration
files will be named with the save prefix
after save lines we need to list lines

XDR input file

table xdr

AGN SED truncated between 1-100 keV
to isolate the effect of X-rays

intensity 0.0, range 147 to 735 Ryd

intensity is $F_x = 10^0 \text{ erg / s / cm}^2$
normalized between 2 and 10 keV

```
hden 4
abundances ISM no grains
grains ISM
metals and grains linear 1
turbulence 1 km/s
cosmic rays background
no grain molecules
stop temperature off
stop column 23
set nend 5000
iterate to convergence
save last overview ".ovr"
save last continuum ".cont"
save last pdr ".pdr"
save last lines zone cumulative emergent ".emis"
```

all subsequent commands are same as PDR

CLOUDY output files

main output (.out)

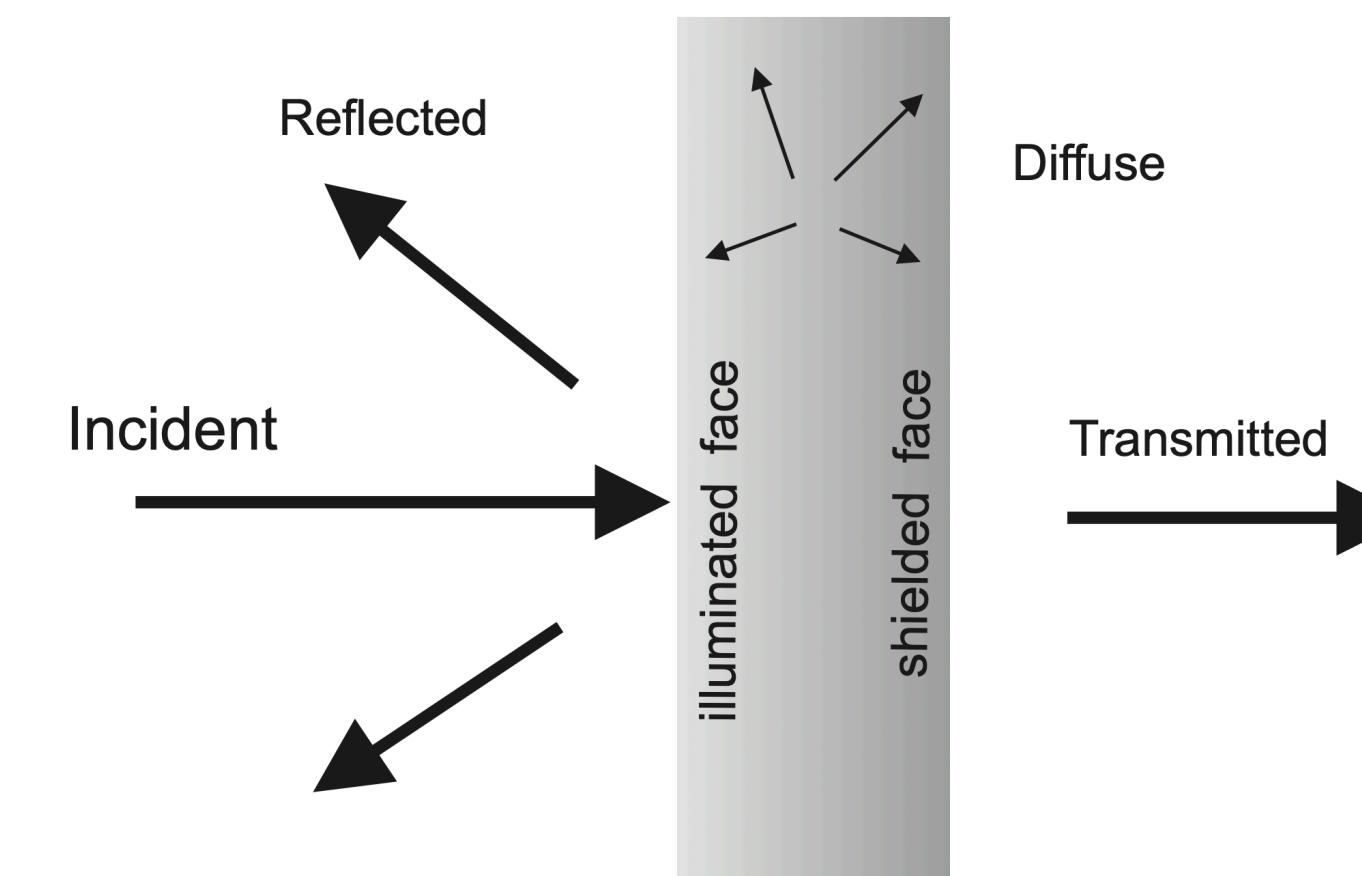
- the only default output file
- gives a lot of informations about the run
- lists warnings, failures, cautions, notes

CLOUDY output files

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- intrinsic continuum: to check the input SED
 - total continuum: transmitted + reflected
 - default units: Rydberg

continuum (.cont)



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continuum (.cont)

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- total continuum: transmitted + reflected
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overview and PDR (.ovr .pdr)

- first column of both: cloud depth [cm]
- ovr contains temperature and ion. fractions
- pdr contains column density and G0

CLOUDY output files

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overview and PDR (.ovr .pdr)

- first column of both: cloud depth [cm]
- ovr contains temperature and ion. fractions
- pdr contains column density and G0

lines cumulative emergent (.emis)

- first column: cloud depth [cm]
- every other column: line flux [$\text{erg}/\text{s}/\text{cm}^2$]

Explore CLOUDY results with Python

First, we create a **python virtual environment**.

Choose a directory

Open terminal in that directory and execute line by line:

```
python3 -m venv cloudy_day
source cloudy_day/bin/activate
which pip  ### output should be path/to/cloudy_day/bin/pip
pip install --upgrade pip
pip install jupyter ipython ipykernel
python -m ipykernel install --user --name=cloudy_day
pip install numpy pandas matplotlib seaborn scipy
```

Download shared folder

https://github.com/federicoesposito/cloudy_unibo_workshop

The screenshot shows a GitHub repository page for 'cloudy_unibo_workshop'. The repository is public, as indicated by the 'Public' badge. The main navigation bar includes 'Pin', 'Watch 0', 'Fork 0', and 'Star 0' buttons. A red arrow points to the 'Code' dropdown menu, which is highlighted with a red box. Below the navigation bar, there are buttons for 'main' (selected), '1 Branch', '0 Tags', 'Go to file', 'Add file', and the 'Code' dropdown. The repository has 1 branch and 0 tags. The commit history shows a single commit from 'federicoesposito' at 'a246ea1' made 25 minutes ago, with 5 commits. The commit details show 'Add files via upload' for 'data', 'docs', 'grid', 'pdr', and 'xdr', and 'Initial commit' for 'README.md'. To the right of the commit list is a detailed description of the repository: 'A two lectures hands-on introduction to CLOUDY. Tailored for astrophysics master students. Made for the 2025-26 ISM course at Unibo'. Below this are links for 'Readme', 'Activity', '0 stars', '0 watching', and '0 forks'. The 'Releases' section indicates 'No releases published' and provides a link to 'Create a new release'. The 'Packages' section indicates 'No packages published'. At the bottom, there is a preview of the 'README' file.

cloudy_unibo_workshop Public

Pin Watch 0 Fork 0 Star 0

main 1 Branch 0 Tags Go to file Add file Code About

federicoesposito Add files via upload a246ea1 · 25 minutes ago 5 Commits

data Add files via upload 25 minutes ago

docs Add files via upload 25 minutes ago

grid Add files via upload 25 minutes ago

pdr Add files via upload 25 minutes ago

xdr Add files via upload 25 minutes ago

README.md Initial commit last week

Readme Activity 0 stars 0 watching 0 forks

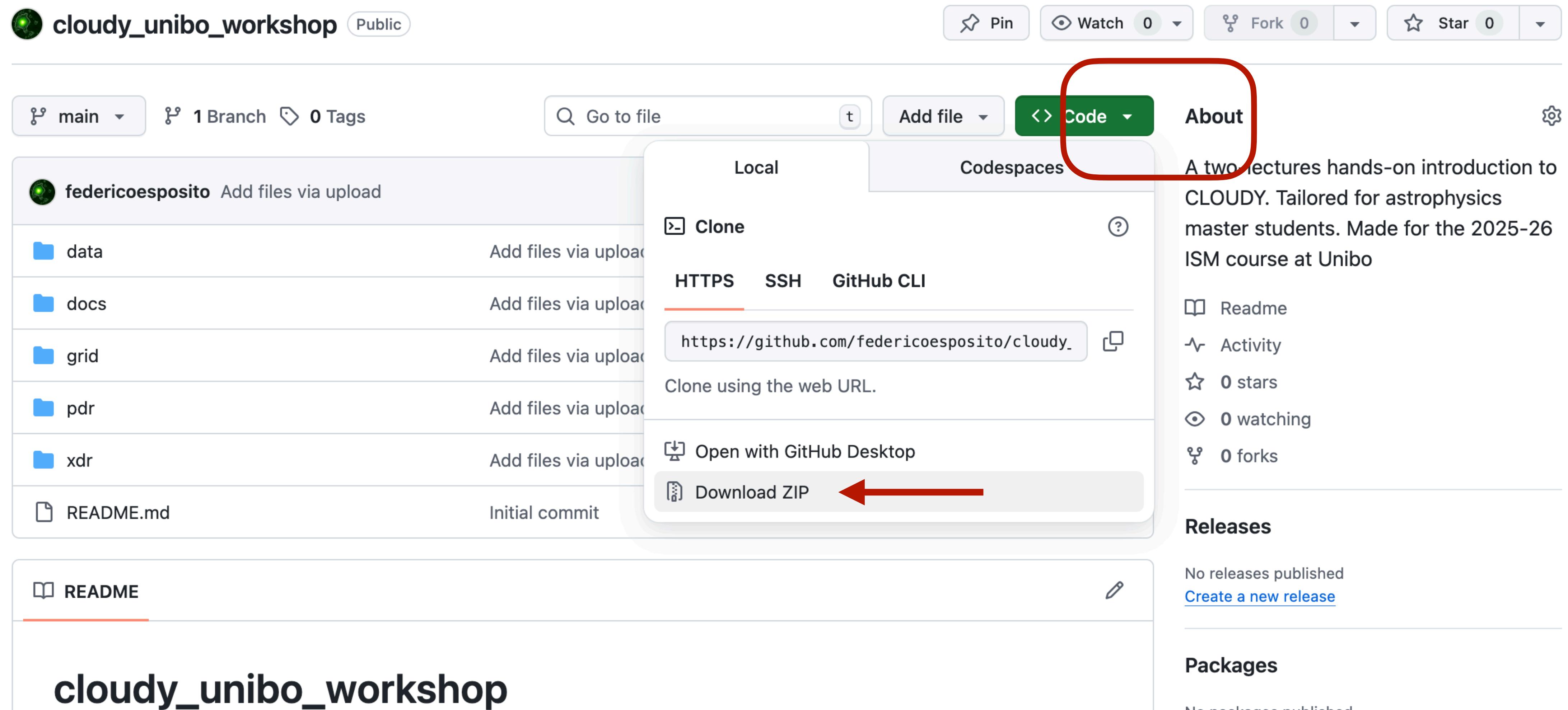
No releases published Create a new release

Packages No packages published

cloudy_unibo_workshop

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The screenshot shows a GitHub repository page for 'cloudy_unibo_workshop'. The repository is public, has 1 branch, and 0 tags. The main branch is selected. The repository was created by 'federicoesposito' and contains files for 'data', 'docs', 'grid', 'pdr', and 'xdr', along with a 'README.md' file. The repository is described as a 'A two lectures hands-on introduction to CLOUDY. Tailored for astrophysics master students. Made for the 2025-26 ISM course at Unibo'. The 'Code' button is highlighted with a red box, and the 'Download ZIP' button is also highlighted with a red arrow pointing to it.

1. Download ZIP
2. Extract the ZIP
3. Move it to your favourite location
4. Rename the main folder 'cloudy_unibo_workshop'

Anonymous questions

Fully anonymous, we will review the questions later / tomorrow

<https://app.sli.do/event/35xx4R47zVRrTUaJQcbxeb>



For direct messages:



f.esposito@oan.es