

Nucleus

Electrons

SiO₂
O=Si=O
 Linear - 180°
 A type of covalent molecule

SO₂
O=S=O
 Trigonal planar
 120°
 A type of covalent molecule

SO₂
O=S=O
 Bent
 120°
 A type of covalent molecule

H₂O
H-O-H
 Bent
 105°
 A type of covalent molecule
 Bonds p
 Molecule p

Absorption

Emission

Cloudy

- ◆ **Accurate simulation of physical processes at the atomic & molecular level**
 - “universal fitting formulae” to atomic processes fail when used outside realm of validity, and are not used
- ◆ **Assumptions:**
 - energy is conserved
 - (usually) atomic processes have reached steady state
- ◆ **Limits:**
 - Kinetic temperature $2.7 \text{ K} < T < 10^{10} \text{ K}$
 - No limits to density (low density limit, LTE, STE)
 - Radiation field 10 m to 100 MeV

Simultaneous solution of

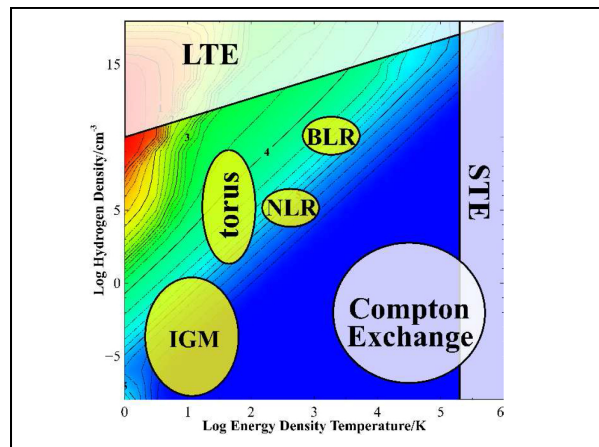
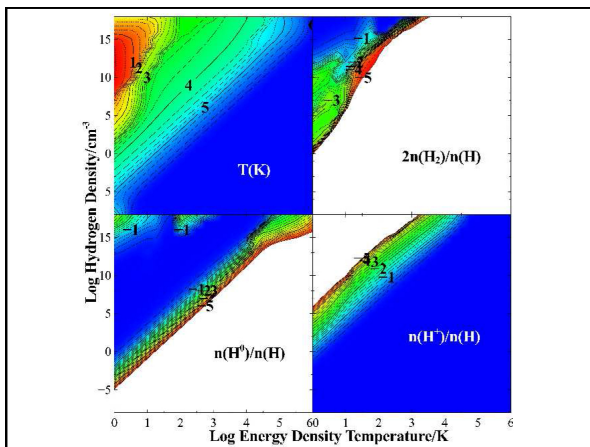
- ◆ **Gas ionization**
 - From ionization balance equations
- ◆ **Chemistry**
 - Large network based on UMIST
- ◆ **Gas kinetic temperature**
 - Heating and cooling
- ◆ **Grain physics**
 - Charging, CX, photoejection, quantum heating
- ◆ **The observed spectrum**
 - Radiative transport

Cloudy and its physics

- ◆ Osterbrock & Ferland 2006, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*, 2nd edition (AGN3)
- ◆ Ferland+2013, Rev Mex 49, 137, *The 2013 Release of Cloudy*
- ◆ Ferland 2003, ARA&A, 41, 517, *Quantitative Spectroscopy of Photoionized Clouds*

Some applications to astronomy

- ◆ Hamann & Ferland, ARA&A, 37, 487, *Elemental Abundances in Quasistellar Objects: Star Formation and Galactic Nuclear Evolution at High Redshifts*
- ◆ Ferland 2001, PASP, 113, 41, *Physical Conditions in the Orion H II Region*
- ◆ And the ~200 papers that cite its documentation each year

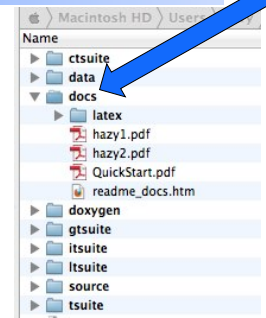


Open source since 1978

- ◆ All versions, all data, on svn at nublado.org
- ◆ You are most welcome to help!

Documentation

- ◆ Quick start guide
- ◆ Hazy 1, all commands
- ◆ Hazy 2, description of output, comparison with observations
- ◆ Hazy 3, not compiled, badly out of date, some physics is described there



Quick Start Guide to CLOUDY C13.1

Cloudy & Associates
www.nublado.org
 June 4, 2013

Cloudy & Associates

Photoionization Simulations for the Discriminating Astrophysicist Since 1978

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Welcome to the Cloudy home page!

Cloudy is a spectral synthesis code designed to simulate conditions in interstellar matter under a broad range of conditions.

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Summer school on Cloudy, and the physics and spectroscopy of the interstellar medium Summer 2012 in Lexington. More details on the [Summer School](#) page.

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Introduction to installing Cloudy

This page contains step by step instructions for installing the current stable version of Cloudy. *Hazy*, the code's documentation, the download.

Each version of the code has a set of pages giving updates. The [HotFixes](#) page lists corrections that need to be made to the do source. These are bug fixes that were not included in the version of the code available for download and used to generate the test suite. So the hot fixes should be applied after the test suite has been run and your system validated. A [KnownProblem](#) known problems with that version of the code. The [RevisionHistory](#) page lists improvements.

Cite the code by giving the version number and a reference to the last major review of Cloudy, Ferland et al. (1998; PASP, 11C available [here](#)). An example would be "We used version 05.07b of Cloudy, last described by Ferland et al. (1998)". Then, yes when someone wants to know how an answer was obtained, the version used to obtain it can be retrieved from the old version web site. The [print citation](#) command will print the correct citation for the version you are using.

Setting up this version

- Download** the code, data, and documentation. This creates several directories, Each contains a readme.htm file describing it that directory.
- EditPath** - instructions for how to specify where the data files are located. **Important!** The code will not run if it cannot find
- CompileCode** - how to compile the code using a variety of compilers.
- RunCode** - This explains how to execute the code and run a smoke test.
- MpiParallel** describes how to use the optimize and grid commands on a parallel cluster, using either MPI or a makefile.
- CompileStars** - You must compile some stellar data files if you want to use some of the table star command to include rc continua.
- TestSuite** is a large number of test cases that you should run to confirm that all is well. This is a critical step since it will check your compiler. That directory also contains a group of programs that show how to call the code as a subroutine.

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<https://www.nublado.org/>

Where to go for help

◆ https://groups.yahoo.com/neo/groups/cloudy_simulations/info

Cloudy - plasma simulations

Public Group, 312 members

Welcome to Cloudy - plasma simulations! [New Topic](#)

1 member, 1 message added in the last 7 days

New Messages [See All](#)

Re: Solving Ionization Equations [1 Attachment]
Dear Constantine Di Fe, Aug 8, 2014 at 10:22 AM, constantine@nublado.com...
cloudy differential equations. One possible approach is outlined in Proton...

Solving Ionization Equations
Dear Di or Maxine, I have been trying to solve the ionization equations for a pure hydrogen nebula given by Di and 2.18 in Osterbrock and Ferland's work...

Trending Topics

- change transfer rates...
- SAVE TOTAL OPACITY
- About the Constant Pressure
- Implementing Hard-Media 12
- save optical depth

Members of this group [ds](#)

Lunar Observing
12 Photo Group, 1846 members

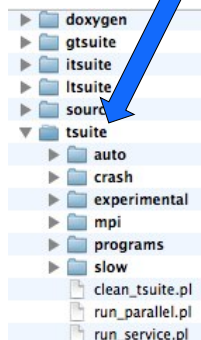
Topics (List as Individual Messages)	Messages	Latest Post
C10.00 Segmentation Fault with GCC 4.6.2 Hello, After upgrading to Fedora16 and the new GCC 4.6.2. C10.00 compiles with no complaints, but segfaults on every model including the smoke test. I have been...	7	Jun 1, 2012 2:02 pm Peter van Hoof peter_van_hoof
compile grain failed. I was trying to compile a new grain with optical constant data, but the extrapolation failed with a message 'something went wrong' in the .out file. What I...	1	May 30, 2012 12:28 pm ef1815
Molecular Hydrogen Reaction Rates Hello, I have been using Cloudy to look at the molecular hydrogen fraction of the ISM at various densities, temperatures etc., however I have run into some...	3	May 30, 2012 11:00 am Gary J. Ferland gary_ferland
PROBLEM DISASTER PROBLEM DISASTER This is in the middle of some experiments, but since the log file has the request to report the problem -- the input file and the log file are here: ...	1	May 19, 2012 12:59 pm notsochaneck
Understanding Compton effects Hi, I'm currently working to extend the capabilities of Knox Long's Pylon radiative transfer code into the X-ray regime. As part of this I'm putting Compton...	3	May 9, 2012 2:47 pm Nicholas Higginbottom nick_soton
Re: beginner	1	May 8, 2012

Running cloudy

- ◆ “run” file contains path-to-cloudy.exe -r \$
- ◆ If file “model.in” contains input, then
- ◆ run model &
- ◆ Produces output “model.out”

The test suite

- ◆ Fully tests the code after any changes
 - “Monitors” allow automatic comparison of current with previous results
- ◆ Provides examples of how to use Cloudy
 - But may include extraneous commands for testing
 - Or backwards compatible
- ◆ Useful examples of how to set up a simulation



The “main output”

- ◆ The *.out file created when code is executed
 - QSG 7.1 & Hazy 2 Chapter 1
- ◆ Gas & grain composition
- ◆ Physical conditions in first and last zone
- ◆ Emission-line spectrum
- ◆ Mean quantities
- ◆ Cloudy is designed to be autonomous and self aware
- ◆ Will generate notes, cautions, or warnings, is conditions are not appropriate.

“Save” output

- ◆ Requested with various “save” commands
 - Hazy 1 Section 16.35 and later
- ◆ The main way the code reports its results

Minimum to run Cloudy

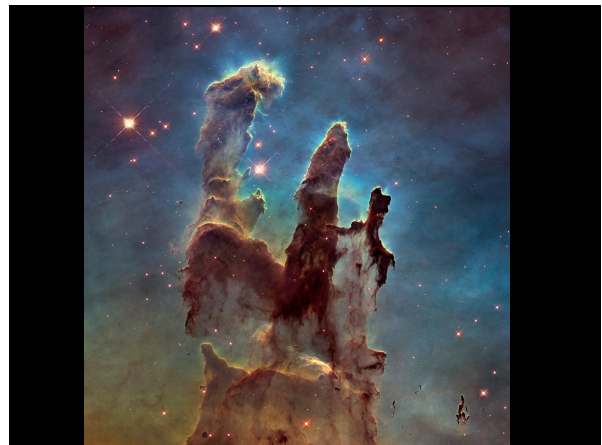
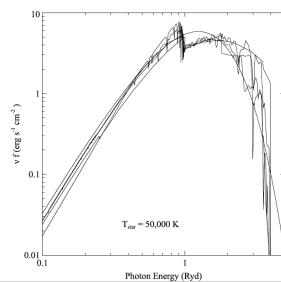
- ◆ **Must specify**
 - SED – shape of the radiation field
 - Flux of photons per unit area
 - Gas density
- ◆ **May specify**
 - Gas composition, grains (grain-free solar by default)
 - Gas equation of state (often constant density)
 - Stopping criterion, often physical thickness

Parameters – the SED shape

- ◆ Quick start guide Chapter 5
- ◆ Hazy 1, Chapters 4, 6

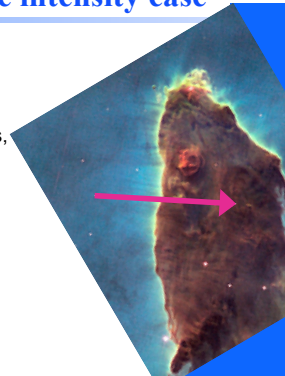
- ◆ Can be specified as a fundamental shape such as a blackbody

- ◆ Generally entered as table of points



SED brightness – the intensity case

- ◆ Specify $\phi(H)$ – flux of photons per unit area
 - The “intensity case”
 - predicts surface brightness, emission per unit area $\text{erg cm}^{-2} \text{s}^{-1}$
 - Inner radius of cloud does not need to be specified



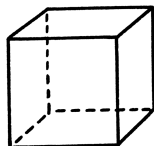
SED brightness – the luminosity case

- ◆ Specify $Q(H)$ – photon luminosity
 - Inner radius of cloud must be specified, since $\phi(H) = Q(H) / 4\pi r^2$
 - predicts emission line luminosities erg s^{-1}

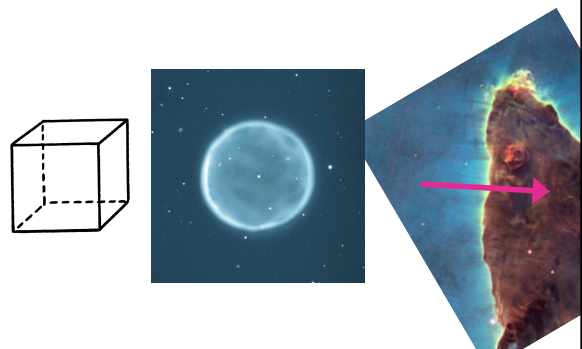


A “unit cell”

- ◆ We will model a cubic cm of matter in many of the atomic calculations
- ◆ A “unit cell”, 1 cm^3
- ◆ Intensity case plus commands
 - Stop zone 1
 - Set dr 0



The three geometries



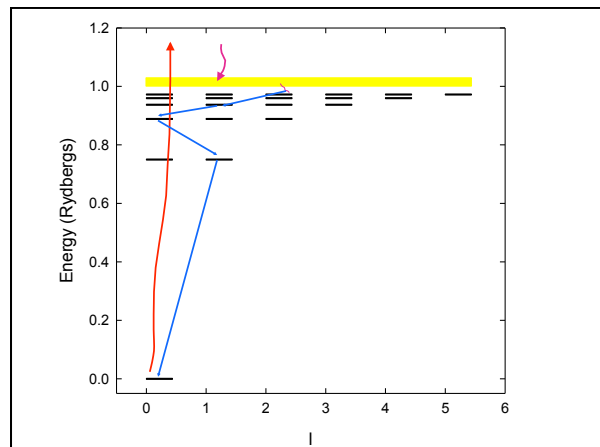
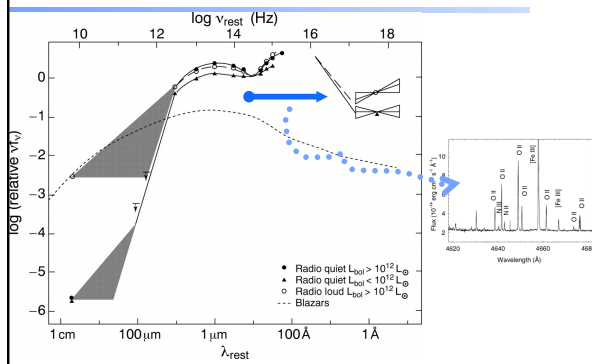
Cloud density, Hazy 1 Chap 8

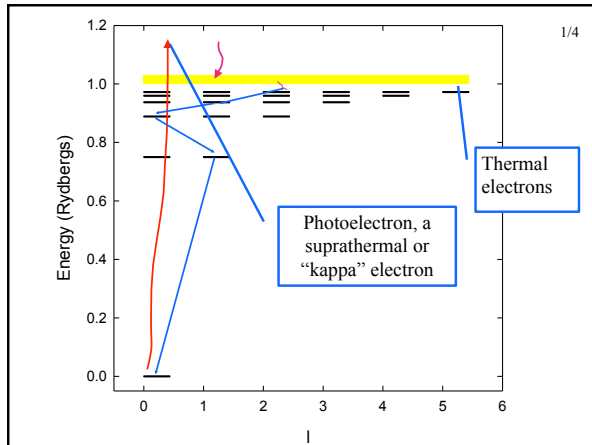
- ◆ “hden” command set H density cm^{-3}
- ◆ Constant density by default
 - the H density is the same across the cloud
- ◆ Other equations of state possible
 - Constant pressure, flows, power-laws

Composition, Hazy 1 Chap 7

- ◆ Solar, no grains, by default
- ◆ Other standard mixtures possible,
- ◆ Stored in data / abundances

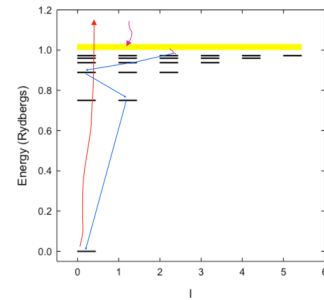
The “primary mechanism” Continuum → emission lines





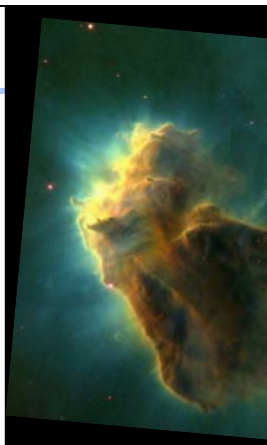
Life history of an Orion electron

- ◆ **H⁰ ground state**
- 1 day
- ◆ **Suprathermal**
- 1 second
- ◆ **Thermal**
- 1 yr
- ◆ **H⁰ excited states**
- 10⁻⁷ s
- ◆ **H⁰ ground state**



Let's model a ...

- ◆ Relatively dense,
 $n_H = 10^4 \text{ cm}^{-3}$
- ◆ ISM cloud
- ◆ One parsec away from an
O6 star
- ◆ O6 star



definitions

- ◆ **Illuminated and shielded face**
- ◆ **Incident, transmitted, emitted, reflected, components of radiation field**
- Hazy 1, section 2.2

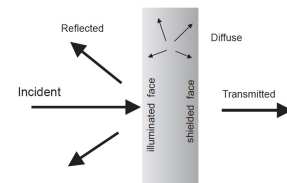
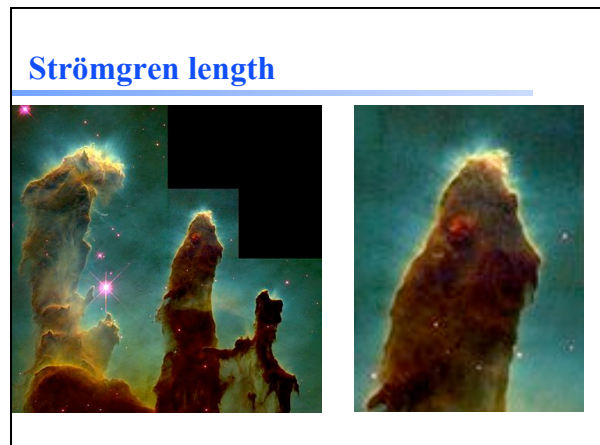
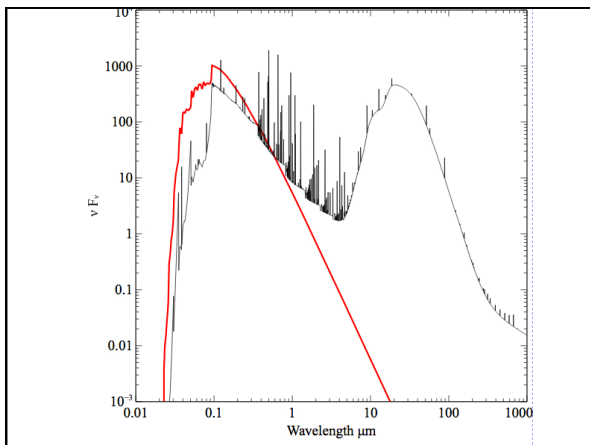
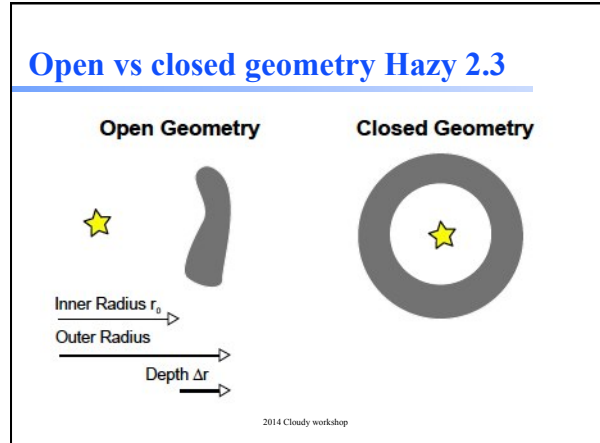
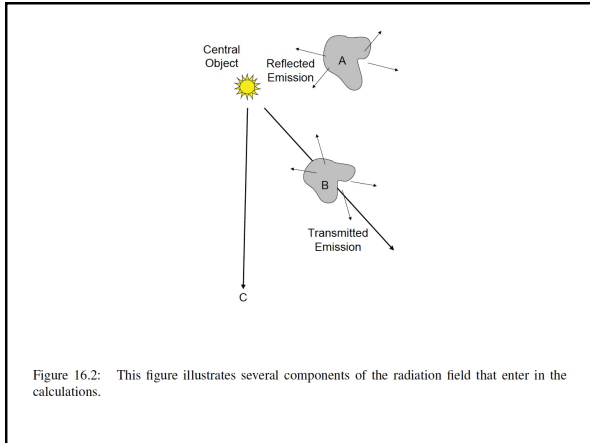
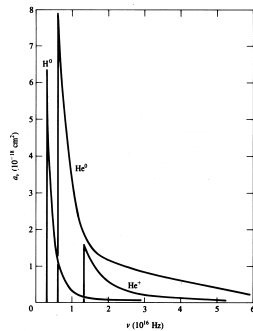


Figure 2.1: Several of the radiation fields that enter in the calculations.



Photoionization

- ◆ Highest cross section at lowest photon energies
- ◆ AGN3 Fig 2.2



Make plot of total opacity for zone 1 of H II region

Recombination AGN3

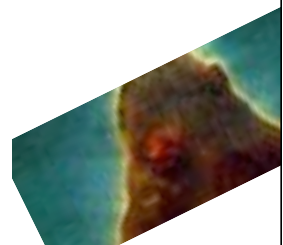
- ◆ Electron and ion recombine, emitting energy
- ◆ Radiative recombination for H and He
- ◆ Dielectronic recombination for heavy element
- ◆ Print arrays command (a debugging tool) will report recombination rates (s^{-1})

Strömgren length

- ◆ Number of ionizing photons entering layer is balance by number of recombinations along it

$$\varphi(H) = n_e n_p \alpha L$$

$$L \propto \frac{\varphi(H)}{n_e n_p \alpha}$$

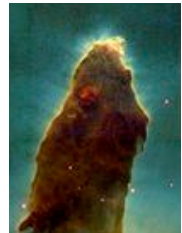


Matter vs radiation bounded



Beyond the H⁺ layer

- ◆ Little H⁺ ionizing radiation gets past the H⁺ layer
- ◆ Deeper regions are atomic or molecular
- ◆ Also cold and produce little visible light
- ◆ Large extinction due to dust



Why did the simulation stop?

- ◆ Make plot of H⁺ fraction vs depth
- ◆ Various stopping reasons given in Hazy 2, Sec 7.6
- ◆ Default is to stop when gas temperature falls below 4000 K, probably a region near the H⁺ - H⁰ ionization front.
 - But is this what you want?

Definitions

- ◆ **Ionization fractions**
 - Fraction of an element in that ionization state
- ◆ **Kirchoff's laws of spectroscopy**
 - Hot transparent gas makes emission lines
 - Cool gas in front of continuum source make absorption lines
 - Warm optically thick makes continuum, perhaps blackbody
- ◆ **Luminosity**
 - Energy emitted per second

Definitions

- ◆ **Emissivity $4\pi j$**
 - Emission per unit volume, per second
- ◆ **Optical depth τ**
 - Number of mean free paths through a medium
- ◆ **Opacity κ**
 - $\tau = \kappa n$
- ◆ **Planck function $B = j/\kappa$**
- ◆ **Rob Rutten's course notes describes this and more**
 - http://www.staff.science.uu.nl/~rutte101/Radiative_Transfer.html