AN INTRODUCTION TO "CLOUDY"

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WHAT IS CLOUDY?

- Cloudy is a spectral synthesis code created by Gary Ferland that has been developed and improved over the last 40 years. The code website URL is: https://nublado.org/
- The most recent version is called C17.01, and it is discussed in this paper: https://arxiv.org/abs/1705.10877
- Cloudy models the interaction of radiation with the interstellar medium to predict the physical conditions in the gas and its emitted spectrum

WHAT CLOUDY NEEDS TO RUN

To create a physically consistent model, Cloudy must be able to determine the number and energy distribution of photons striking the face of a cloud with known composition and geometry.

THE CLOUDY DOCUMENTATION

- The full operation of Cloudy is described in the code's documentation:
- Quick Start Guide – basic info on running Cloudy and understanding output
- Hazy 1 – a complete list and description of all input commands
- Hazy 2 – a complete description of the output generated by Cloudy
- Hazy 3 – simulation physics, out of date, refer to ISM textbook "AGN2".

RUNNING CLOUDY

- Cloudy is controlled by a series of input commands, entered in the *input block*.
- If the code has sufficient information to run, then Cloudy generates the *output block*.
- To the right is an example of a planetary nebula input file (model.in):

- **title Planetary Nebula**
  - (gives a title on output)
- **radius 17**
  - (log of inner radius in cm)
- **hden 4**
  - (log of hydrogen density)
- **blackbody temp=100000 lumin=38**
  - (temperature, log of luminosity in ergs/sec)
- **filling factor 0.3**
  - (fraction of geometry that is filled)
- **Sphere**
  - (radiation field allowed to interact with other side)
- **print last iter**
  - (print results from last zone, 1st zone is always printed)

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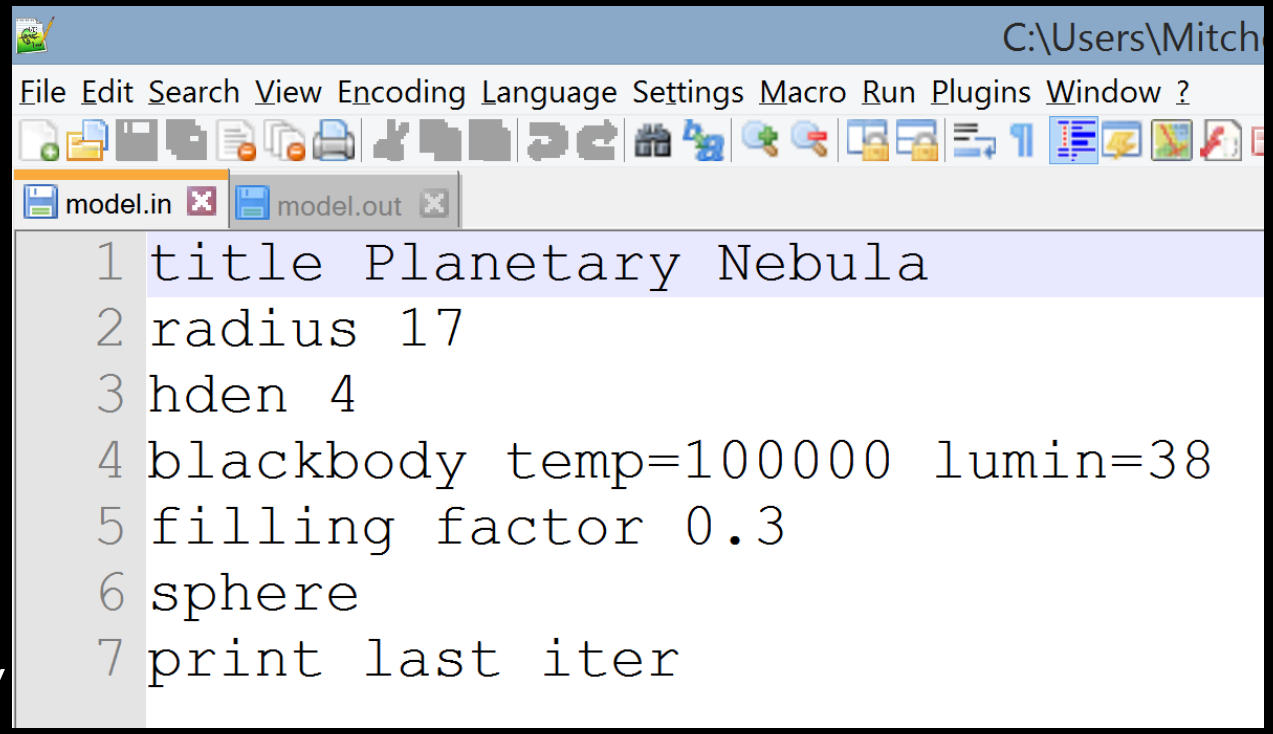

EXAMINING THE OUTPUT

File Edit Search View Encoding Language Settings Macro Run Plugins Window ?

model.in | model.out

```
                                                 Cloudy 17.01
                                               www.nublado.org

                    ****************************************17Jun01****************************************
                    *                                                                                    *
                    * title Planetary Nebula                                                             *
                    * radius 17                                                                          *
                    * hden 4                                                                             *
                    * blackbody temp=100000 lumin=38                                                     *
                    * filling factor 0.3                                                                 *
                    * sphere                                                                             *
                    * print last iter                                                                    *
                    *                                                                                    *
                    ************************************************************************************



NOTE Setcon: continuum has zero intensity starting at  7.9913e+01 Ryd.
 1027 cells in the incident continuum have zero intensity.  Problems???

          8228CellPeak1.79E+00   Lo 3.04e-09=  29.98m   Hi-Con:7.13E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.00 MeV
          L(nu>1ryd):  37.9510   Average nu:2.176E+00   L( X-ray):  27.6722   L(BalC):  37.0172     Q(Balmer C):  47.8589
          Q(1.0-1.8):  47.9252   Q(1.8-4.0):  47.9690   Q(4.0-20):  47.0417   Q(20--):  37.0070     Ion pht flx:1.498E+13
          L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  35.4329   Alf(ox):   0.0000     Total lumin:  38.0000
          log L/Lsun:   4.4170   Abs bol mg:  -6.3000   Abs V mag:   0.0378   Bol cor:  -6.3378     nuFnu(Bbet):  35.5356
          U(1.0----):4.998E-02   U(4.0----):2.922E-03   T(En-Den):4.328E+01   T(Comp):9.580E+04     nuJnu(912A):1.978E+02
          Occ(FarIR):7.298E-06   Occ(H n=6):7.837E-13   Occ(1Ryd):9.120E-15   Occ(4R):6.292E-17     Occ (Nu-hi):0.000E+00
          Tbr(FarIR):3.508E-09   Tbr(H n=6):3.432E-09   Tbr(1Ryd):1.439E-09   Tbr(4R):3.980E-11     Tbr (Nu-hi):0.000E+00

                                                 Gas Phase Chemical Composition
      H : 0.0000  He: -1.0000  Li: -8.6904  Be:-10.5800  B : -9.2097  C : -3.6108  N : -4.0701  O : -3.3098  F : -7.5200
```

CLOUDY OUTPUT

- First, Cloudy will print the code version number, and the input commands:

```
                                    Cloudy 17.01
                                  www.nublado.org

*****************************************17Jun01*********************************
*                                                                               *
* title Planetary Nebula                                                        *
* radius 17                                                                     *
* hden 4                                                                        *
* blackbody temp=100000 lumin=38                                                *
* filling factor 0.3                                                            *
* sphere                                                                        *
* print last iter                                                               *
*                                                                               *
*********************************************************************************
```

CLOUDY OUTPUT

- Next, Cloudy prints information on the radiation field and gas composition:

```
NOTE Setcon: continuum has zero intensity starting at  7.9913e+01 Ryd.
 1027 cells in the incident continuum have zero intensity.  Problems???

      8228CellPeak1.79E+00   Lo 3.04e-09=  29.98m   Hi-Con:7.13E+06 Ryd   E(hi):7.35E+06Ryd     E(hi):     100.00 MeV
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      Q(1.0-1.8):  47.9252   Q(1.8-4.0):  47.9690   Q(4.0-20):  47.0417   Q(20--):  37.0070     Ion pht flx:1.498E+13
      L(gam ray):   0.0000   Q(gam ray):   0.0000   L(Infred):  35.4329   Alf(ox):   0.0000     Total lumin:  38.0000
      log L/Lsun:   4.4170   Abs bol mg:  -6.3000   Abs V mag:   0.0378   Bol cor:  -6.3378     nuFnu(Bbet):  35.5356
      U(1.0----):4.998E-02   U(4.0----):2.922E-03   T(En-Den):4.328E+01   T(Comp):9.580E+04     nuJnu(912A):1.978E+02
      Occ(FarIR):7.298E-06   Occ(H n=6):7.837E-13   Occ(1Ryd):9.120E-15   Occ(4R):6.292E-17     Occ (Nu-hi):0.000E+00
      Tbr(FarIR):3.508E-09   Tbr(H n=6):3.432E-09   Tbr(1Ryd):1.439E-09   Tbr(4R):3.980E-11     Tbr (Nu-hi):0.000E+00

                                                Gas Phase Chemical Composition
    H :  0.0000  He: -1.0000  Li: -8.6904  Be:-10.5800  B : -9.2097  C : -3.6108  N : -4.0701  O : -3.3098  F : -7.5200
    Ne: -4.0000  Na: -5.6696  Mg: -4.4597  Al: -5.5302  Si: -4.4597  P : -6.4949  S : -4.7352  Cl: -6.7190  Ar: -5.6003
    K : -6.8794  Ca: -5.6402  Sc: -8.8297  Ti: -6.9788  V : -8.0000  Cr: -6.3298  Mn: -6.5406  Fe: -4.5498  Co: -7.0799
                                           Ni: -5.7496  Cu: -7.7905  Zn: -7.4001
```

CLOUDY OUTPUT

- This is followed by physical and simulation information, and ***warnings***:

```
####  1  Te:1.551E+04 Hden:1.000E+04 Ne:1.201E+04 R:1.001E+17 R-R0:7.520E+13 dR:1.504E+14 NTR:  6 Htot:6.413E-16 T912: 1.00e+0
Hydrogen      1.49e-04 1.00e+00 H+o/Hden 1.00e+00 8.31e-12 H-    H2 4.37e-19 3.30e-13 H2+ HeH+ 2.98e-14 Ho+ ColD 6.71e+13 4.51
Helium        2.31e-06 2.06e-02 9.79e-01 HeI 2s3S 5.02e-08 Comp H,C 4.10e-22 6.64e-23 Fill Fac 3.00e-01 Gam1/tot 1.00e+00
He singlet n  2.26e-06 3.85e-13 2.94e-20 4.55e-20 2.04e-20 4.44e-20 He tripl 5.02e-08 2.83e-17 2.10e-19 7.87e-19 1.55e-19
Pressure      NgasTgas 3.57e+08 P(total) 4.93e-08 P( gas ) 4.93e-08 P(Radtn) 0.00e+00 Rad accl 1.99e-05 ForceMul 2.23e+03
Texc(La)      3.78e+03 T(I con) 4.32e+01 T(D con) 6.17e+00 T(U tot) 4.32e+01 nT (c+d) 1.19e+07 Prad/Gas 0.00e+00 Pmag/Gas 0.00
Molecules     CH/Ctot: 7.96e-21 CH+/Ctot 5.19e-18 CO/Ctot: 1.66e-28 CO+/Ctot 6.45e-27 H2O/Otot 3.71e-34 OH/Ototl 3.87e-21
Lithium       7.87e-06 8.75e-02 8.98e-01 1.44e-02 Berylliu 1.10e-05 1.32e-03 9.97e-01 1.25e-03 0.00e+00 sec ion: 4.85e-14
  Planetary Nebula
  Calculation stopped because lowest Te reached. Iteration 1 of 1
  The geometry is a thick shell.
C-Continuum zero at some energies.
 !Charge transfer H => H+ reached 1480.3% of the local H ionization rate.
 !AGE: Cloud age was not set.  Longest timescale was 2.90e+09 s = 9.20e+01 years.
 !The CMB was not included.  This is added with the CMB command.
 !The radiation pressure jumped by 675% at zone 49, from 2.63e-09 to 2.12e-10 to 2.28e-10
  Charge transfer heating reached 2.13% of the local heating.
  Destruction of He 2TriS reached 3.7% of the total He0 dest rate at zone 1, 1.5% of that was photoionization.
  The density is too low to l-mix the lowest H  I collapsed level.  More resolved levels are needed for accurate line ratios.
  The density is too low to l-mix the lowest He I collapsed level.  More resolved levels are needed for accurate line ratios.
  Non-collisional excitation of [O III] 4363 reached 0.96% of the total.
  Grains were not present but might survive in this environment (energy density temperature was 4.33e+01K)
  The continuum optical depth at the lowest energy considered (3.045e-09 Ryd) was 1.477e+04.
  The ratio of radiation to gas pressure reached 8.26e-02 at zone 49.  Caused by Lyman alpha.
```

CLOUDY OUTPUT

- The input is printed again, followed by **intrinsic** and **emergent** line strengths:
- The format is: *line label, wavelength (A or m)*, flux (cgs), and *ratio relative to* $H\beta$

Emission Line Spectrum. Constant Density Model. Closed geometry. Iteration 1 of 1.
Luminosity (erg/s) emitted by a shell with full coverage.

Intrinsic line intensities

general properties.....				H 1	3.48198m	33.264	0.0020	Ca 5	4.15739m	33.819	0.0072
Inci	0	38.000	109.9358	H 1	19.0565m	33.455	0.0031	Ca 5	5309.11A	33.645	0.0049
TotH	0	37.627	46.6179	H 1	11.3055m	33.349	0.0025	Cl 2	14.3639m	33.000	0.0011
TotC	0	37.627	46.5803	H 1	8.75760m	33.228	0.0019	Cl 2	8578.70A	33.495	0.0034
BFH1	0	37.538	37.9240	H 1	7.50599m	33.067	0.0013	Cl 3	5537.87A	33.981	0.0105
BFHe	0	36.806	7.0319	H 1	6.77008m	32.967	0.0010	Cl 3	5517.71A	33.685	0.0053
TotM	0	36.054	1.2458	H 1	4.84633m	33.065	0.0013	Cl 3	3342.80A	33.305	0.0022
CT H	0	35.571	0.4091	H 1	27.7955m	33.125	0.0015	Cl 4	20.3197m	33.722	0.0058
H FB	0	36.314	2.2659	H 1	16.2045m	33.039	0.0012	Cl 4	11.7629m	34.049	0.0123
HFBc	0	36.314	2.2659	Ca A	303.784A	36.666	5.0995	Cl 4	7530.54A	33.670	0.0051
H 1c	0	36.363	2.5371	Ca A	256.317A	35.952	0.9849	Cl 4	8045.62A	34.033	0.0119
He 1c	0	36.146	1.5383	Ca A	243.027A	35.524	0.3671	Fe 4	3094.96A	33.931	0.0094
Al 3c	0	34.359	0.0251	Ca A	237.331A	35.215	0.1805	Fe 4	2835.74A	35.556	0.3955
Ar 2c	0	33.704	0.0056	Ca A	234.347A	34.973	0.1033	Fe 4	2829.36A	35.293	0.2159

TIPS ON THE CLOUDY OUTPUT

- There are a variety of SAVE commands in Cloudy
- These allow you to control the main output, and save additional files
- See Hazy 1, Chapter 16 (C17.01) for further information on SAVE options
- Be careful with linear vs. logarithmic quantities, and check the output!
- Make sure it says “Cloudy exited OK” at the end of your model!