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Optimizing models in Cloudy

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Optimizing models in Cloudy (1)

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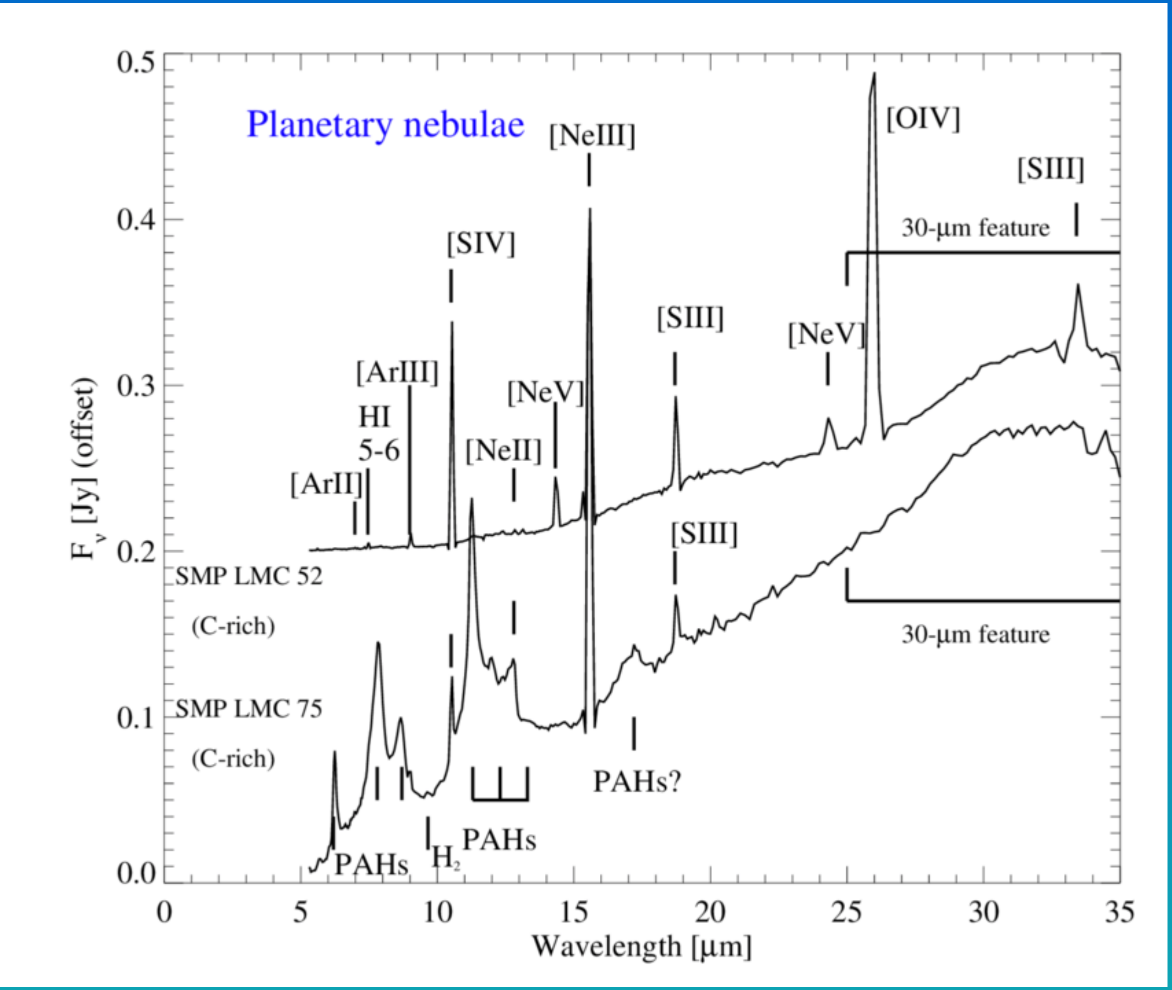
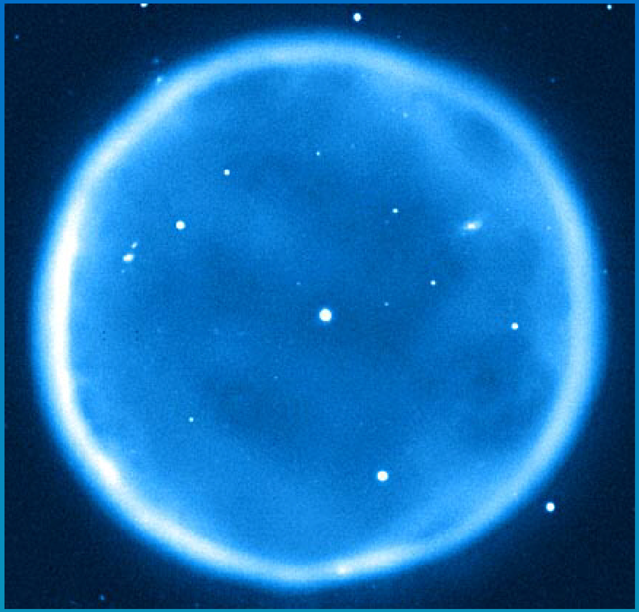
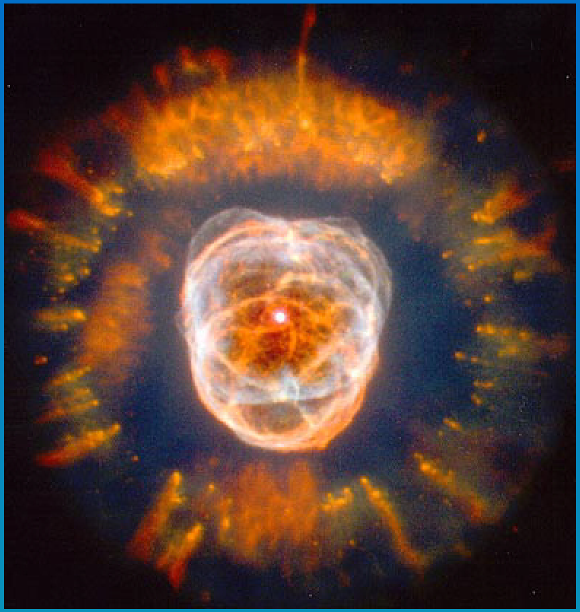


The problem: we have observations (typically a spectrum) and want to derive properties of the object from that. Image credit: Matsuura et al., 2014, MNRAS 439, 1472.

Optimizing models in Cloudy (2)





- There are several ways to model the data, here we discuss optimizing the model with Cloudy.
- Images: from left to right – Abell 39, NGC 2392, NGC 6302. These nebulae show increasing levels of complexity in their morphology, yet we have to assume they all are spherical!
- Modeling bipolars can be difficult as the nebula is usually optically thick in the EDE but optically thin in the polar directions.

Optimizing models in Cloudy (3)

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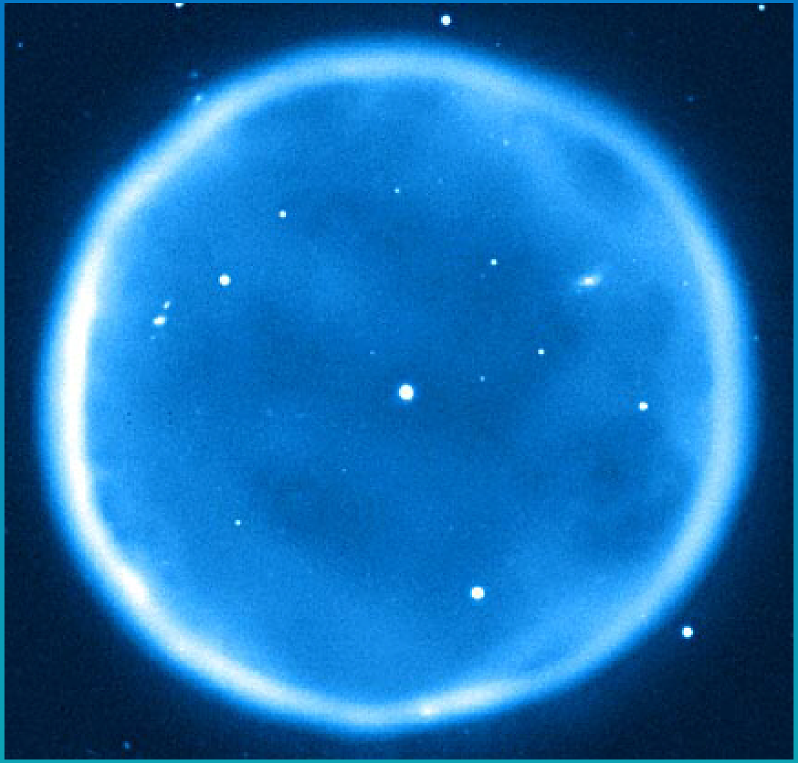

Parameters:

- Central star – T_{eff}, L_* (choose SED grid)
- Nebula – R_{in}, $n_H(r)$, set outer radius with stop command
- Composition – abundances, grains

Optimizing models in Cloudy (4)

What observables do we need?

- T_{eff} – line emission from ions with different ionization potentials, especially the highest stages are important
- L_* – absolute flux, e.g. Hβ or radio flux, angular diameter
- R_{in} – hottest dust, highest ionization stages, direct observations?
- $n_H(r)$ – density sensitive line ratios, EM, ionization balance
- abundances – line ratios, preferably multiple ionization stages
- grains – dust continuum flux

Note the following:

- You need (many) more observables than free parameters
- Deredden the spectrum and compare to intrinsic
- You need a distance, optimizing this doesn't work well
- Do multiple runs with different initial estimates
- CPU intensive → do parallel runs

Optimizing models in Cloudy (5)

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This script is set up for C13!

```
title NGC 7027
sphere
constant density
cosmic rays background
TABLE STAR RAUCH SOLAR 5.267549 LOG 8.000000 vary
optimize increment 0.2
# optimize range 5.0 5.5
LUMINOSITY 37.494171 LOG range -0.000232 6.866524 vary
optimize increment 0.2
RADIUS= 16.680534 LOG vary
optimize increment 0.2
DLAW 4.519993 1.5 2.895e16 2 0 0 0 0 0 vary
optimize increment 0.2
abundances planetary no grains
ELEMENT HELI ABUNDANCE 10.998940 LOG vary
optimize increment 0.1
ELEMENT CARB ABUNDANCE 9.069492 LOG vary
optimize increment 0.1
# ... snip ...
ELEMENT IRON ABUNDANCE 5.539659 LOG vary
optimize increment 0.1
GRAIN ABUND=-0.459092 LOG "graphite_Om010.opc"  vary
optimize increment 0.2
GRAIN ABUND=0.5455 LOG "ph3n_ab08_10.opc"  vary
optimize increment 0.2
print line flux seen at earth
normalize to "H  1" 4861 scale factor 100
distance 980 linear parsec
# atom H-like levels 20 element hydrogen resolved
# atom H-like levels 15 element helium resolved
# set temperature floor 10 K linear
stop continuum flux 75 micron 463 jansky
stop zone 2000
stop temperature 10 K linear
stop radius 18
iterate
```

Optimizing models in Cloudy (6)

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This script is set up for C13!

```
optimize phymir
optimize tolerance 0.01
optimize iterations 10000
optimize lines
TOTL  1240A   88.8161 0.390
TOTL  1486A   68.0027 0.174
Ne 4  1602A   12.9688 0.300
He 2  1640A   336.0866 0.158
# ... snip ...
O  3 51.80m   11.2634 0.160
N  3 57.21m   1.5435 0.169
O  3 88.33m   1.0633 0.165
O  1 145.5m   1.6377 0.158
C  2 157.6m   3.3543 0.158
CO   216.9m   0.2350 0.015
end
optimize continuum flux at   5.0 micron   11.  jansky 0.20
optimize continuum flux at   6.6 micron   56.  jansky 0.20
optimize continuum flux at  10.  micron  159.  jansky 0.20
optimize continuum flux at  15.  micron  406.  jansky 0.20
optimize continuum flux at  18.  micron  682.  jansky 0.20
optimize continuum flux at  19.  micron  785.  jansky 0.20
optimize continuum flux at  24.  micron 1218.  jansky 0.20
optimize continuum flux at  32.  micron 1500.  jansky 0.20
optimize continuum flux at  37.  micron 1544.  jansky 0.20
optimize continuum flux at  52.  micron  934.  jansky 0.20
optimize continuum flux at  70.  micron  579.  jansky 0.20
optimize continuum flux at  75.  micron  463.  jansky 0.20
optimize radio continuum flux 0.25 cm 4676.4 mJy 0.05
optimize angular diameter 11" 0.10
```

Optimizing models in Cloudy (7)

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Things to look out for:

- Errors on observables also steer the optimization since they affect χ^2.
- So getting realistic errors is important, but difficult. There are many easily overseen sources that often dominate the error: flux calibration, dereddening, aperture correction, atomic data, etc. So keep a minimum of 5 – 10% on line ratios.
- Check Cloudy output for predicted lines that are strong enough to be observed, yet are absent. Use upper limits to prevent this in next run.
- Observed lines may be blended with lines that are not modeled by Cloudy, especially weak lines in very deep spectra.
- Grain properties are often poorly known (such as the size distribution) yet this is important for heating the gas.
- There is mounting evidence for a missing heating source in the PDR. You can use the hextra command or a temperature floor to work around that.
- Check if the model makes physical sense!
- Do multiple runs with different initial estimates.