Cloudy Tutorial Report

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Cloudy is an open source code that simulates different astrophysical conditions and synthesises the spectra of a cloud in such conditions[a]. In this report, we see the results obtained from Cloudy simulations of a planetary nebula (PNe) and a broad line region (BLR) cloud.

I. PLANETARY NEBULA

A planetary nebula (PNe) is formed at the dying stages of Sun-like stars as they lose their outer envelopes, leaving behind a central white dwarf. In this simulation, we model the irradiating source, the white dwarf, as a blackbody of temperature 10^5 K and luminosity 10^{38} erg (Eddington limit for one solar mass). The nebula is modelled as a sphere. The inner radius is set at 10^{18} cm and with hydrogen density 10^5 cm^{-3}. This is input to Cloudy as below:

```
blackbody, T=1e5 K
luminosity total 38
radius 18
hden 5
sphere
abundances primordial #for no abundances i.e. default solar abundances
iterate
save overview "pn.ovr" last
save continuum "pn.con" units microns last
```

A. Spectra

In the later stages of a Sun-like star, as the envelope swells, the composition of it changes due to dust formation. We can clearly observe this with the presence of a blackbody bump between 10 and 100 microns in the planetary abundance spectrum and not in the solar abundance spectrum (Fig: 1a & 1c). The spectrum for an interstellar medium (ISM) abundance (Fig: 1b) is similar to the PNe abundance, which is expected as they are composed of matter from dying stars like these. Were the star massive and ended as a nova, there would be no dust but strong emission lines (Fig 1d - modeling it to be irradiated by a white dwarf). For primordial composition, we see comparatively weak emission lines. But it is unlikely, Sun-like stars could be formed with such a composition as metals are important in the cooling process that leads to formation of intermediate mass stars. Hence, we expect primordial stars to be massive and have nova type explosions.

B. Gas Temperature

We observe an increase in gas temperature with decrease in metallicity (Fig: 2). This is expected as metals are important in the cooling process of clouds. At 10^{14} cm, the temperature steadily declines, as we move away from the central source. The simulation is carried on until gas kinetic temperature falls to 4×10^3 K. It is noted that for primordial abundance, which has negligible metallicity, the gas temperature maintains a plateau at 7×10^3 K and the simulation is carried out until the radius 10^{18} cm.

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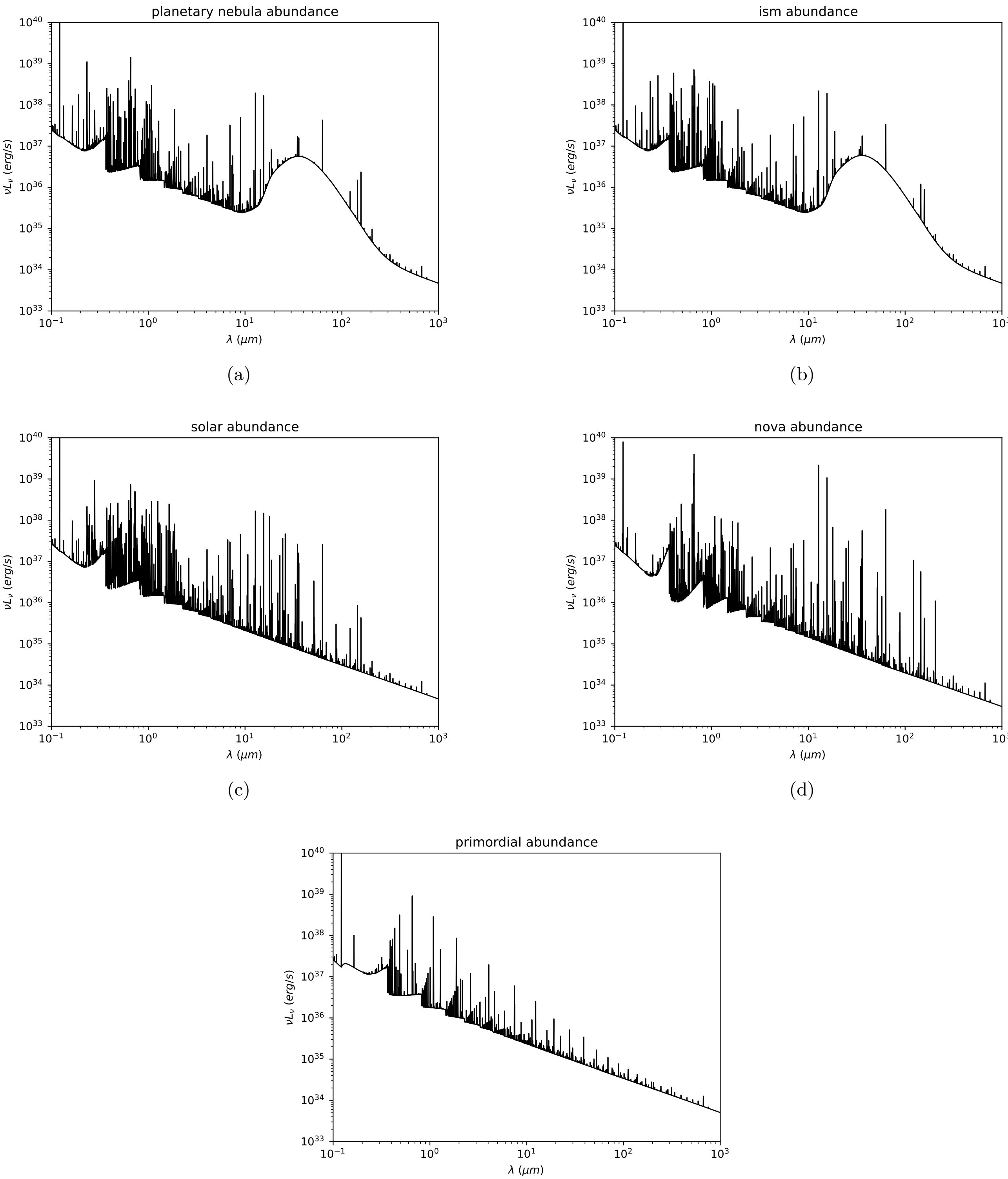
[a] `https://gitlab.nublado.org/cloudy/cloudy`



(a) (b) (c) (d) (e)

FIG. 1: Spectra of a PNe for different abundances in the infrared and optical region

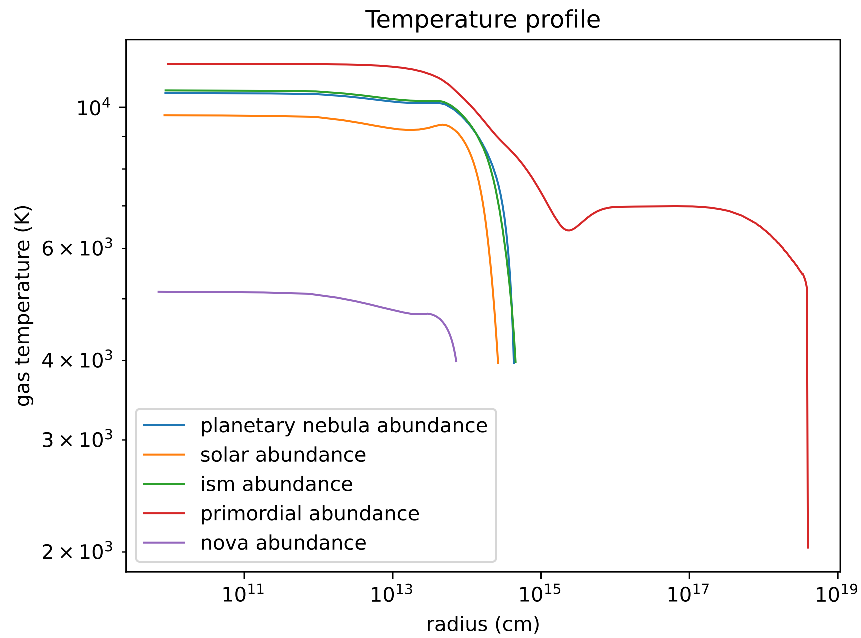


FIG. 2: Temperature profile for different abundances

II. BROAD LINE REGION

In the model of active galactic nuclei (AGN), the central supermassive black hole is surrounded by a torus and clouds (Fig: 3). In this simulation, we see the spectrum of a cloud in the broad line region (BLR) which is closer to the central supermassive black hole. In Cloudy, we provide the following input:

```
table power law
phi(H) 18.5
hden 10
stop column density 22
iterate to convergence
print last iteration
save overview "blr.ovr" last
save continuum "blr.con" units microns last
```

We model the radiation source as a central active nuclei giving a power law continuum and the flux of H ionising photons is $10^{18.5}$ cm^{-2}s^{-1}. Since the cloud is comparatively small and does not surround the central nuclei like a PNe, we do not use the 'sphere' command.

By simulating for different hydrogen densities (Fig: 4), we see that the emission lines vary and intensity of lines do not increase with H density in all cases. While 10^8 cm^{-3} is the lower limit for BLR, the appearance of recombination continuum occurs only for a density of 10^{10} cm^{-3}.

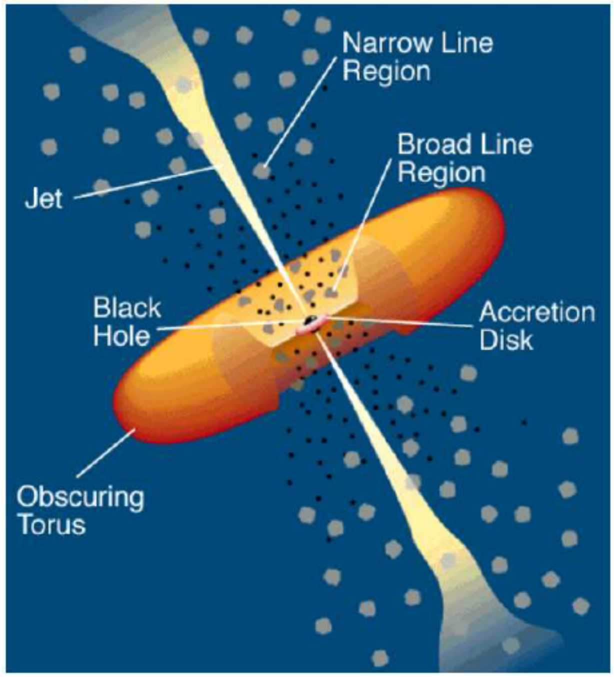


FIG. 3: AGN unification model. Credits: Urry and Padovani (1995)

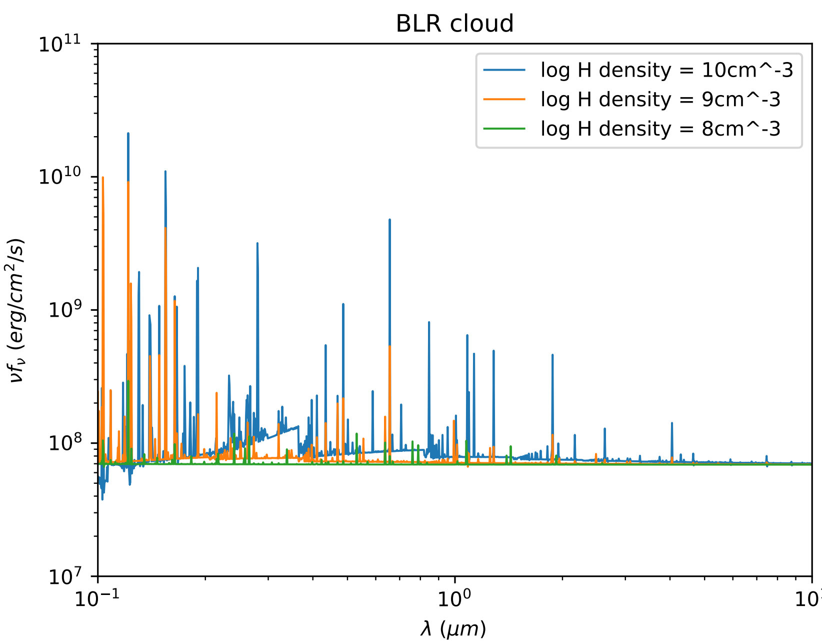


FIG. 4: Spectra of a BLR cloud for different H densities in the infrared region