Simulating a simple planetary nebula using CLOUDY

Narendra Bhatkar
UID : 229126
Roll No : 17

Department of Physics, St. Xavier's College

Abstract

Planetary nebulae are celestial wonders, offering insights into the late stages of stellar evolution. Understanding their formation, structure, and emission properties is crucial for unraveling the mysteries of the cosmos. In this study, we employ CLOUDY (Cloudy Line and Continuum Radiation Transfer) astronomy code to simulate a simple planetary nebula system. It is a widely used software package in the field of astrophysics and astronomy for simulating the physical and chemical processes occurring in astrophysical environments like planetary nebulae, H II regions, and active galactic nuclei. CLOUDY allows researchers to model the ionization, excitation, and radiative transfer processes in these environments, helping them understand the emission spectra and other properties of celestial objects. However here we will limit our study to understanding how to use cloudy and simulate a simple planetary nebula, commenting on the output obtained.

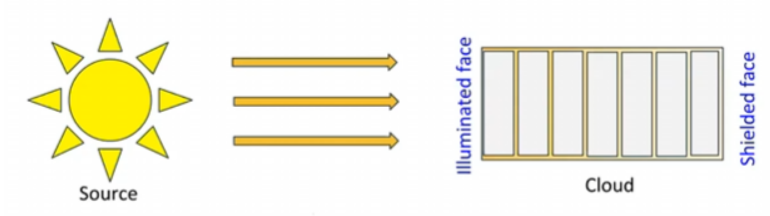
Aim

Simulating a simple planetary nebula using CLOUDY.

Introduction

Nebulae, commonly denoted as celestial entities with a hazy or cloud-like appearing objects in the night sky, are some of the most captivating and enigmatic features of our universe.These astronomical phenomena consist of vast, diffuse clouds of gas, dust, and plasma, and they come in a stunning variety of shapes, sizes, and colors.Nebulae are of utmost significance in the realm of astrophysics, as they fulfil multiple crucial functions. They serve as the primary sites where stars originate, as well as the repositories of stellar remnants resulting from their death.Throughout the history of astronomy, nebulae have inspired curiosity and wonder, and their study continues to unlock the secrets of the universe's past, present, and future.

Numerical simulations enable an understanding of intricate physical situations by employing fundamental principles as a starting point. Cloudy is specifically engineered to fulfill that purpose. This study aims to analyze the physical properties of a non-equilibrium gas, which may be subjected to an external radiation source, and make predictions for the resultant spectrum. CLOUDY is a microphysics code that simulates or replicate the physical conditions found in clouds, spanning a wide range from the intergalactic medium to the AGN , Nebula etc. By specifying the input paramaeters we can obtain information about the physical and chemical composition within that astrophysical environment such as Emission spectra, Tempreature profiles, Ionization structure, Density distribution, Stellar and Radiation Source Properties, Spectral Energy Distributions. The code computes these input parameters which frequently spans a large number of lines, typically reaching hundreds of thousands. A multitude of observable phenomena arise from a limited number of independent variables. Often, the objective is to calculate the values of these independent variables based on empirical data. In this study we will be looking at the variation in the tempreature of the nebula as we move away from the center.



Working

CLOUDY is a computational code in astrophysics that simulates the physical and chemical processes occurring in interstellar and intergalactic environments. Primarily it consists of a radiation source and a gas cloud. The gas is headted and ionized by the radiation field striking the gas from the radiation/central source. The code then solves the that statistical and thermal equations and predict the physical conditions across the cloud.

How does it work?
The code essentially divides the cloud into number of shells called zones where physical properties like ionization, tempreature for each zone is calculated. The transmitted values along with other physical parameters are given to the next zone. The radiation strikes the illuminated side of the cloud and moves towards the shielded side of the cloud and will stop when a stopping criteria is reached. Also the thickness of the zones is decided such that the physical properties across the zones does not change.

We also need to specify the chemical composition of the cloud, ie we need to specify the hydrogen density and the abundance of a particular element in the cloud so the the density of that element can be obtained

$$f(Z) = \frac{n(Z)}{n(H)}$$

where $f(Z)$ is the abundance of the element and $n(Z) and n(H)$ are the densities of the element and hydrogen.

We also need to speccify the cloud geometry.The radius is the distance from the center of symmetry, to a specified point.The depth refers to the spatial separation between the illuminated surface of the cloud and an internal point within the cloud. An open geometry is one where the covering factor is small ie, the central region is visible from all angles where as in closed geometry the gas covers almost all the central source. For our case we will be using the closed geometry as it is assumed in almost all planetary nebulae simulations.

The incident radiation can be catogarized into three types diffused, transmitted and reflected. The relative probability of a photon being scattered back into the incident direction vs being absorbed is very less in case of nebula therefore the diffused fields are far less compared to the incident continumm photons hence incident continumm is the only enery source in the cloud. Reflected radiation is the radiation from continumm and diffused radiation back in the ddirection of the source, this is calculated only in the case of open geometry.

Procedure

1. Install the CLOUDY software into the system.

   In order to simulate the code Cloudy needs to be able to deduce the following information,(The central star is a cooling white dwarf)

   - Brightness and geometry of the radiation field striking the cloud.
   - Total hydrogen density present.
   - Composition of the gas and whether grains are present.
   - Thickness / radius of the cloud.

2. Provide the input parameters to the code using a script file.

   Here we have used the following parameters as inputs,

   - Blackbody
     Here we have approximated the radiation field as a hot black body equal to T = 1e5 K. The blackbody input specifies the shape of incident raddiation.
   - Luminosity
     This specifies the radiation field striking the cloud. In case of Luminosity the geometry assumed is closed geometry hence the luminosity and the inner radius df the cloud both are mentioned. Where as if instead Intensity was given as an input command then the open geometry is assumed where only the flux of radiation striking the cloud is specified.

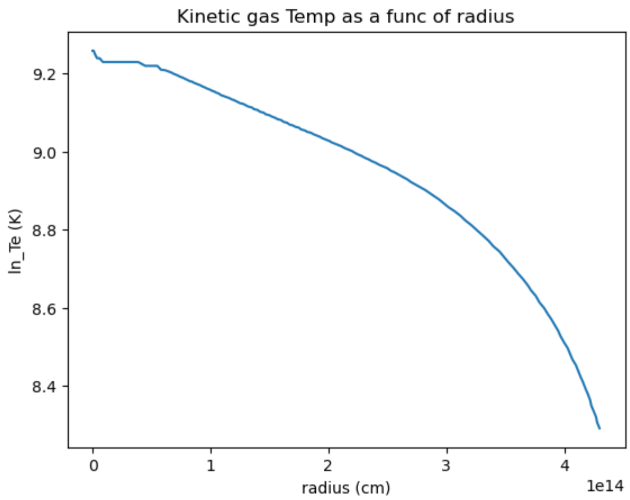
- hden
  This command sets the hydrogen number density (hden) to 5, indicating the density of hydrogen nuclei in the region. A typical hydrogen density measured is of the order 5.
- geometry
  sphere geometry tells the code that the geometry is closed. The shell can either stay the same or get bigger. The shell is thought to be growing quickly enough by default that lines coming out of the shell's lit side don't touch the gas on the other side of the central hole.
- abundance
  Abundances sets the number of occurrences of each element to the amount shown on the line. If there are no numbers but a keyword is given, the composition is set to a default. Here we have no assumed the abundance of a particular element so all will have their default values.

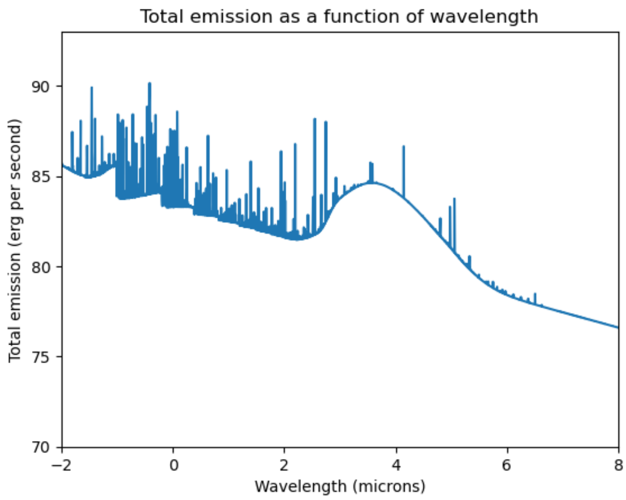
3. When the code is executed we need to check whether the code has run properly, for that we need to see that the "cloudy exited OK" command is present at the end of the output file.
4. Along with the output file two more files are obtained in which the .ovr provieds the overview of all the elements and tempreatures values of the simulation and the .con file provides continumm output values.

Results and Conclusion

From the obtained output files we are interested in the variation of kinetic tempreature of gas as a function of radius and the total emission as a function of wavelength. From the graph we can see that as we move away from the central source the tempreature starts decreasing therefore the more we move inside the cloud more the tempreature profile decreases.

From the emission Vs wavelength graph we see that the emission decreases as wavelength increases but there is a suddeb bumb in the curve approximately near 30 microns probably due to thermal dust emission. Perhaps the radiation due to the central source has warmed the dust preset in nebula causing to peak near 30 microns.





bibliography

1. https://gitlab.nublado.org/cloudy/cloudy/-/wikis/home
2. Extragalactic Astronomy and Cosmology, Peter Schneider
3. Quick Start Guide to CLOUDY C23, A brief introduction to cloudy, Cloudy and Associates, www.nublado.org
4. Code