Galaxies (Structure, Dynamics and Evolution)
Programming Assignment - 1

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Submitted by

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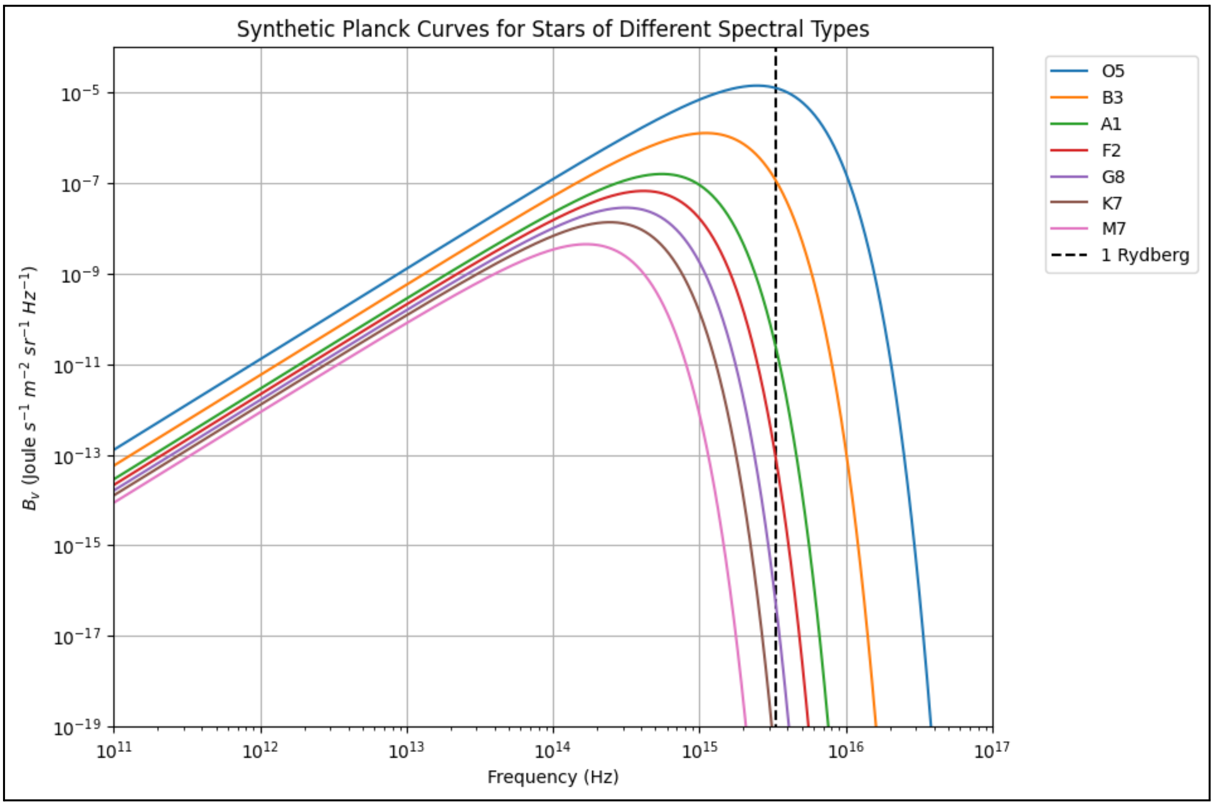
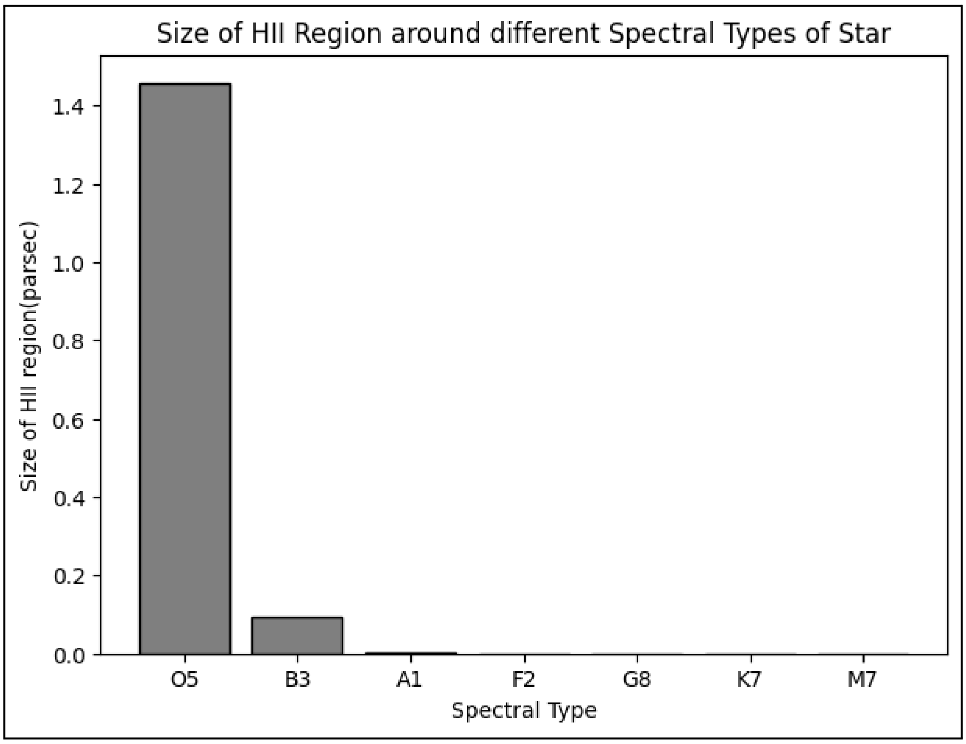
1. Plot of synthetic Planck function showing the intensity of radiation emitted by stars of spectral type O, B, A, F, G, K, and M.



2. Table containing the details of star and the HII region around the star

Spectral Type	Surface Temperature (K)	Radius ($R_\odot$)	Hydrogen Ionizing Photon Flux (photons/s)	Size of HII region (parsec)
O5	42000	13.4	1.14×10^{50}	1.456382515
B3	18800	3.8	2.98×10^{46}	0.09306917483
A1	9400	2.1	9.10×10^{41}	0.002910465832
F2	7050	1.4	1.09×10^{39}	0.0003091132744
G8	5310	0.96	2.46×10^{35}	1.88×10^{-05}
K7	4150	0.74	2.76×10^{31}	9.08×10^{-07}
M7	2860	0.2	4.82×10^{22}	1.09×10^{-09}

3. Plot showing the size of the H II region against stellar spectral type.



4. (a) Stars of which spectral type can produce large regions of warm ionized gas?

O and B stars can produce large regions of warm ionized gas. In this case for O5 stars, the size of the HII region is about 1.45 pc, whereas for B3 we are getting 0.09pc.

(b) What will be the rough temperature of the warm ionized plasma, and why?

The temperature range is 6000 K to 10000 K.The kinetic energy of a photoelectron emitted in an ionization event is approximately E_0 = 13.6 eV. This energy will be quickly thermalized among the constituent particles. Electron scattering occurs at a significantly high rate compared with that of recombination, allowing thermalization of the energy. 13.6eV corresponds to a temperature of 10^5 K, which is the expected temperature of the ionized medium. But other cooling processes in the ionized region come into play which lowers the temperature to 10^4 K. Another cooling process is the radiative line cooling, in which an excited atom can get back to the ground state through collisional de-excitation or through spontaneous radiative transition.

(c) What does the presence of bright WIM tell us about star formation in a galaxy?

Hot young massive stars produce a large number of ionizing photons. These ionized photons create the HII region (Warm Ionized Medium (WIM)) around the stars. Since these stars have a very short lifetime, the presence of WIM suggests the possibility of a recent star formation in that location. Star formation rate is therefore estimated by looking at the HII region in a galaxy. Hydrogen recombination produces line emissions such as Hα line, so this line is usually used to calculate the star formation rate.

APPENDIX

Python Code for Stromgen Radius Calculation

```
# Importing necessary libraries
import numpy as np
import scipy
from scipy import constants
from scipy import special
from scipy import integrate
import math
import matplotlib.pyplot as plt

plt.style.use('default')


# Constants

e = constants.e
me = constants.m_e
c = constants.c
pi = math.pi
h = constants.Planck
k = constants.Boltzmann
Ry = constants.Rydberg
Ry_energy = h*c*Ry
Ry_energy_eV = Ry_energy/e
#print("Ry energy (eV) = ",Ry_energy_eV)
Ry_freq = Ry_energy/h
#print("Ry_freq = ",Ry_freq)

pc = 3.0856776 * (10**16) #m

# Setting up numpy arrays with information related to stars
# Such as spectral type, surface temperature and radius
spec_type = np.array(['O5','B3','A1','F2','G8','K7','M7'])
temp = np.array([42000,18800,9400,7050,5310,4150,2860])
Rsun = 696340 * (10**3)
radius = np.array([13.4,3.8,2.1,1.4,0.96,0.74,0.2]) * Rsun


# Code to plot the Planck's function for different temperature
def B(v,T):
   t1 = (2*h*np.power(v,3))/(c**2)
   t2 = 1/(np.exp((h*v)/(k*T))-1)
   return(t1*t2)

v = np.logspace(10,16.6,1000)
fig = plt.figure(figsize = (9,7))
```

```
for i in np.arange(len(temp)):
   plt.plot(v,B(v,temp[i]),label = f"{spec_type[i]}")


plt.xlabel("Frequency (Hz)")
plt.ylabel(r"$B_{v}$ (Joule $s^{-1}$ $m^{-2}$ $sr^{-1}$ $Hz^{-1}$)")


plt.xlim(10**11,10**17)
plt.ylim(10**-19,10**-4)

plt.vlines(Ry_freq,0,10**-4,linestyles='dashed',label = '1 Rydberg')
#B(Ry_freq,42000))

plt.legend(bbox_to_anchor=(1.05, 1.0), loc='upper left')
plt.title("Synthetic Planck Curves for Stars of Different Spectral Types")
plt.xscale("log")
plt.yscale("log")
plt.grid()
plt.show()
```

```
#Calculation of number of photons having energy greater than or equal to
13.6 eV
def calc_NLyman(v,temp,radius):
   return((B(v,temp)*4*pi*(radius**2)*4*pi)/(h*v))

NLyman = np.zeros(len(temp))
for i in np.arange(len(temp)):
   T = temp[i]
   R = radius[i]
   I = integrate.quad(calc_NLyman,Ry_freq,10**16.6,args = (T,R)) #UL =
10**16.6
   I_array = np.array(I)
   #print("I = ",I_array[0])
   print(I_array[0])
   NLyman[i] = I_array[0]
```

```
#Calculation of Stromgen Radius
def calc_Rs(noPhotons):
   alphaH = 3*(10**(-13))*(10**(-2))**3 #m^3 s^-1
   n = 1000/((10**(-2))**3) #m^(-3)
   Rs = ((3*noPhotons)/(4*pi*alphaH*(n**2)))**(1/3)
```

```
    Rs = Rs/pc
    return(Rs)


sizeHII = np.zeros(len(NLyman))

for i in np.arange(len(NLyman)):
    sizeHII[i] = calc_Rs(NLyman[i])
    print(sizeHII[i])

print("sizeHII = ",sizeHII)
```

```
#Plotting the graph between size of HII Region and the spectral types of
the respective star
fig = plt.figure(figsize = (7,5))

plt.bar(spec_type,sizeHII,color = 'tab:gray',edgecolor = 'black')
plt.xlabel("Spectral Type")
plt.ylabel("Size of HII region(parsec)")
plt.title("Size of HII Region around different Spectral Types of Star")
plt.show()
```