worked with:
Aldair

Total Hours:
~8 hours

ASTR 5490 – Planets
HW #1
Due Thursday, September 7 by 5pm

Please show all work. If you collaborate with other students, write their names at the top of your homework. Please also write the total number of hours you spent on this. Either attach your code and plots to any handwritten solutions or email them separately.

1. (40%) Assume Earth's atmosphere is completely composed of molecular nitrogen N_2 (instead of actual 70%) and has standard values for sea-level pressure $P = 101$ kPa $= 1.01\times10^6$ dyn cm^{-2} and temperature $T = 15\,°C = 288$ K.

   (a) Compute the number density n (in cm^{-3}) and density ρ (g cm^{-3}) of air at sea level. Keep in mind that water density is defined as 1.0 g cm^{-3}.

   (b) Compute the atmospheric scale height H (in km).

   (c) What is the atmospheric density at Laramie's altitude (2,190 m) relative to sea level?

For the subsequent parts, assume Earth's surface is a sphere ($R_\oplus = 6{,}370$ km) and approximate our atmosphere as a step function with constant density n from part (a) and thickness H from part (b). Molecular nitrogen N_2 has a Rayleigh scattering cross section of $\sigma = 5\times10^{-27}$ cm^2 at $\lambda = 550$ nm (green light).

   (d) When looking at stars directly overhead from sea level, what fraction of blue ($\lambda = 400$ nm), green (550nm), and red (700nm) light is scattered out of your line of sight. Ground-based observers should keep in mind that there is non-negligible atmospheric extinction, even when pointing at zenith (airmass = 1).

   (e) When looking at the horizon from sea level, what is the thickness of the atmosphere? Report your answer in *both* km and airmass.

   (f) When looking at the setting sun, what fraction of blue ($\lambda = 400$ nm), green (550nm), and red (700nm) light is received by your eyes. This problem should not only illustrate why sunsets are red but also why it is relatively safe to look at sunsets over the ocean.

2. (20%) Consider a protostellar disk that accretes onto a solar-type protostar with $M_* = 0.6\,M_\odot$ and $R_* = 2\,R_\odot$. Assume the accretion rate $\dot{M} = \dot{M}_{1Myr}\,(t\,/\,1\,Myr)^{-2.5}$ decreases with time according to a power law across t = 0.1 - 10 Myr.

integrals

   (a) Compute the constant $\dot{M}_{1Myr}$ (in $M_\odot$ yr^{-1}), i.e., the accretion rate at 1 Myr, assuming the protostar accretes an additional 0.4 $M_\odot$ (bringing final mass to 1.0 $M_\odot$). You should find it is on the order of ~$10^{-8}\,M_\odot$ yr^{-1} (refer to lecture slide figures).

   (b) How much mass (in $M_\odot$) does the system accrete after t > 1 Myr? Assuming a canonical gas-to-dust ratio of 100, what is the accreted dust mass (in Earth masses $M_\oplus$) after > 1 Myr?

P+C

   (c) What is the total disk luminosity (in $L_\odot$) at *both* t = 1 Myr and 10 Myr?

   (d) At t = 1 Myr, what is the *photospheric* disk temperature at *both* r = 1 AU and 2.7 AU.

For the next two parts, assume the disk mid-plane temperature is four times its photospheric temperature, i.e., $T_{mid} \approx 4T_{eff}$. We'll derive this in a couple weeks.

1AU · 4
2.7AU · 4

   (e) What is the disk mid-plane temperature at t = 1 Myr and r = 1 AU? Keep in mind that dust grain growth into pebbles typically occurs when $T \lesssim 500$ K. This problem should begin to illustrate that *in situ* grain growth at r = 1 AU occurs only after t $\gtrsim$ 1 Myr, when there is insufficient dust remaining in the inner solar system to produce terrestrial planets. The prevailing theory is that dust grain growth into pebbles occurred by t ~ 10^5 yr, mostly at larger separations where the disk was cooler, and then the pebbles migrated inward via viscous drag into the inner solar system, giving a jump start to terrestrial planet formation.

(f) What is the disk mid-plane temperature at t = 1 Myr and r = 2.7 AU? This distance is the canonical snow line, beyond which stickier ice grains can form below T $\lesssim$ 170 K, accelerating grain growth into pebbles and the formation of gas giant planets.

3. (40%) Model the SED of the protoplanetary disk in #2 face on. In addition to the disk, model the pre-MS star as a blackbody with $R_* = 2\ R_\odot$ and $T_{*,\mathrm{eff}} = 5{,}000$ K.

(a) First compute the luminosity L_* of the pre-MS star (in $L_\odot$).

(b) Create a 1D wavelength vector of length 999,901 with separation $\Delta\lambda = 10$ Å and spanning 1,000 Å = 0.1 μm to 10^7 Å = 1,000 μm = 1 mm.

(c) Compute the stellar luminosity spectral density $L_{*,\lambda} = \pi\, B_\lambda(T_{*,\mathrm{eff}})\, 4\pi R_*^2$ (in erg s^{-1} $Å^{-1}$). The first factor of π derives from converting the Planck blackbody intensity into flux density, and the factor of $4\pi R_*^2$ derives from integrating across the surface area of the star. Convert $L_{*,\lambda}$ into units of $L_\odot$ $Å^{-1}$. As a consistency check, you can numerically integrate across all wavelengths to confirm that the total luminosity is $\int L_{*,\lambda}\, d\lambda = L_*$ that you found in part (a).

(d) Plot the SED of the star. The x-axis should be λ (in Å or μm) and the y-axis should be $\lambda L_{*,\lambda}$ (in $L_\odot$). Both axes should be logarithmic. You should find that the stellar SED peaks at $\lambda L_{*,\lambda} = 1.6\ L_\odot$ near $\lambda = 0.73$ μm. The advantage of plotting the SED ($\lambda L_{*,\lambda}$ versus λ) is that you can immediately see that the total luminosity of the star is ~2 $L_\odot$.

(e) Create a 1D radius vector of length 2,000 with separation $\Delta r = 0.05$ AU spanning 0.05 AU to 100 AU, the typical radius of protostellar disks. The area of the annulus centered at each r_i is simply $A(r_i) = 2\pi r_i \Delta r$.

(f) Considering the protoplanetary disk at t = 1 Myr from #2, compute the photospheric temperature $T_{\mathrm{eff}}(r_i)$ at each radius r_i. The flux density (in erg s^{-1} cm^{-2} $Å^{-1}$) at each radius r_i is $F_\lambda(r_i) = \pi B_\lambda(T_{\mathrm{eff}}(r_i))$. Multiplying by the area $A(r_i)$ gives the luminosity spectral density (in erg s^{-1} $Å^{-1}$) at each radius: $L_\lambda(r_i) = A(r_i)\, F_\lambda(r_i)$. Convert this luminosity spectral density $L_\lambda(r_i)$ into units of $L_\odot$ $Å^{-1}$ for each radius r_i. Finally, sum the luminosity spectral density from all annuli to get the total disk luminosity spectral density: $L_{\mathrm{disk},\lambda} = \Sigma_i\, L_\lambda(r_i)$. Overplot the SED of the disk on top of the stellar SED. You should find that the disk dominates the SED beyond $\lambda > 6$ μm. What class of YSO is this object? Does the ratio L_{disk}/L_* inferred from the SED match expectations given your computed value of L_{disk} in part 2c?

(g) Repeat part (f) with a t = 10 Myr protoplanetary disk where $\dot{M}$ is 2.5 orders of magnitude smaller. At what wavelengths does the disk dominate the SED? What class of YSO is this?

(h) Repeat part (f) with a gap (no radiation) across r = 0.2 – 5 AU. Describe the overall SED of the disk. What kind of disk is this?

1. (40%) Assume Earth's atmosphere is completely composed of molecular nitrogen N_2 (instead of actual 70%) and has standard values for sea-level pressure $P = 101$ kPa $= 1.01\times10^6$ dyn cm^{-2} and temperature $T = 15°C = 288$ K.

(a) Compute the number density n (in cm^{-3}) and density ρ (g cm^{-3}) of air at sea level. Keep in mind that water density is defined as 1.0 g cm^{-3}.

(b) Compute the atmospheric scale height H (in km).

(c) What is the atmospheric density at Laramie's altitude (2,190 m) relative to sea level?

a)
$$\rho = \frac{\mu m_H P}{kT} \qquad 1\,\text{dyn} = 1\,\frac{\text{g cm}}{\text{s}^2}$$

amu to grams

$$\rho = \frac{28.01\,(1.67\cdot10^{-24}\,\text{g})(1.01\cdot10^{6}\,\frac{\text{g}}{\text{cm s}^2})}{1.38\cdot10^{-16}\,\frac{\text{cm}^2\text{g}}{\text{s}^2\text{K}}\,(288\,\text{K})}$$

$$\rho = \frac{4.72\cdot10^{-17}\,\frac{\text{g}^3\text{cm}^3}{\text{mol s}^2}}{3.97\cdot10^{-14}\,\frac{\text{cm}\cdot\text{g}}{\text{s}^2}}$$

$$\rho = .0012\,\frac{\text{g}^{\cancel{3}2}\text{cm}^{\cancel{3}2}}{\text{mol}\,\cancel{\text{s}^2}}\,\frac{\cancel{\text{s}^2}}{\cancel{\text{cm}}\cdot\cancel{\text{g}}}$$

$$\boxed{\rho = .0012\ \text{g cm}^{-3}}$$

$$n = \frac{\rho}{\mu m_H}$$

$$n = \frac{.0012}{28.01\cdot1.67\cdot10^{-24}}\;\frac{\text{g}}{\text{cm}^3}\cdot\frac{1}{\text{g}}$$

$$\boxed{n = 2.56\cdot10^{19}\ \text{cm}^{-3}}$$

b)
$$H = \frac{kT}{\mu m_H g}$$

$$H = \frac{1.38\cdot10^{-16}\,\frac{\text{cm}^2\text{g}}{\text{s}^2\text{K}}\,(288\,\text{K})}{28.01\,(1.67\cdot10^{-24}\,\text{g})\cdot980\,\frac{\text{cm}}{\text{s}^2}}$$

$$H = \frac{3.97\cdot10^{-14}\,\frac{\text{cm}^2\text{g}}{\text{s}^2}}{4.58\cdot10^{-22}\,\frac{\text{g m}}{\text{s}^2}} \rightarrow$$

$$8.67\cdot10^{5}\,\frac{\text{cm}^{\cancel{2}}\cancel{\text{g}}}{\cancel{\text{s}^2}}\cdot\frac{\cancel{\text{s}^2}}{\cancel{\text{g cm}}} \qquad \boxed{H = 8.67\ \text{km}}$$

c)
$$\rho = \rho_0 \exp\left(\frac{-z}{H}\right)$$

$$\rho = \exp\left(-\frac{2.19\ \text{km}}{8.67\ \text{km}}\right)$$

$$\boxed{\rho = 78\%\ \text{of sea level}}$$

For the subsequent parts, assume Earth's surface is a sphere ($R_\oplus = 6{,}370$ km) and approximate our atmosphere as a step function with constant density n from part (a) and thickness H from part (b). Molecular nitrogen N_2 has a Rayleigh scattering cross section of $\sigma = 5\times10^{-27}$ cm^2 at $\lambda = 550$ nm (green light).

(d) When looking at stars directly overhead from sea level, what fraction of blue (λ = 400 nm), green (550nm), and red (700nm) light is scattered out of your line of sight. Ground-based observers should keep in mind that there is non-negligible atmospheric extinction, even when pointing at zenith (airmass = 1).

(e) When looking at the horizon from sea level, what is the thickness of the atmosphere? Report your answer in *both* km and airmass.

(f) When looking at the setting sun, what fraction of blue (λ = 400 nm), green (550nm), and red (700nm) light is received by your eyes. This problem should not only illustrate why sunsets are red but also why it is relatively safe to look at sunsets over the ocean.

$n = 2.56\cdot10^{19}$ $\qquad H = 8.67$ km

$\sigma_{N_2} = 5\cdot10^{-27}$ cm^2 @550nm

d = 12740 km

d)

blue (400nm) → $1.79\cdot10^{-26}$ → 33% scattered

green (550nm) → $5\cdot10^{-27}$ → 11%

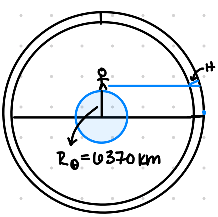
red (700nm) → $1.91\cdot10^{-27}$ → 4.2%

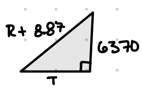
$$\tau = n\sigma z$$

$$\sigma = 5\cdot10^{-27}\,\text{cm}\left(\frac{\lambda}{5.5\text{E}-5}\right)^{-4}$$

$$1 - e^{-\tau}$$

e)





$T^2 + 6370^2 = 6378.87$

$T^2 = 113082.48$

$T = 336.28$ km

$T^2 = 6378.87^2 - 6370^2$

$\boxed{= 336.28\ \text{km or } 38\ \text{airmasses}}$

f)

blue → $1.79\cdot10^{-26}$ → $\tau = n\sigma z$ → 0%

red → 19%

green → 1.4%

2. (20%) Consider a protostellar disk that accretes onto a solar-type protostar with $M_* = 0.6\,M_\odot$ and $R_* = 2\,R_\odot$. Assume the accretion rate $\dot{M} = \dot{M}_{1Myr}\,(t\,/\,1\,Myr)^{-2.5}$ decreases with time according to a power law across t = 0.1 - 10 Myr.

(a) Compute the constant $\dot{M}_{1Myr}$ (in $M_\odot\ yr^{-1}$), i.e., the accretion rate at 1 Myr, assuming the protostar accretes an additional 0.4 $M_\odot$ (bringing final mass to 1.0 $M_\odot$). You should find it is on the order of $\sim10^{-8}\ M_\odot\ yr^{-1}$ (refer to lecture slide figures).

(b) How much mass (in $M_\odot$) does the system accrete after t > 1 Myr? Assuming a canonical gas-to-dust ratio of 100, what is the accreted dust mass (in Earth masses $M_\oplus$) after > 1 Myr?

(c) What is the total disk luminosity (in $L_\odot$) at *both* t = 1 Myr and 10 Myr?

(d) At t = 1 Myr, what is the *photospheric* disk temperature at *both* r = 1 AU and 2.7 AU.

For the next two parts, assume the disk mid-plane temperature is four times its photospheric temperature, i.e., $T_{mid} \approx 4T_{eff}$. We'll derive this in a couple weeks.

(e) What is the disk mid-plane temperature at t = 1 Myr and r = 1 AU? Keep in mind that dust grain growth into pebbles typically occurs when $T \lesssim 500$ K. This problem should begin to illustrate that *in situ* grain growth at r = 1 AU occurs only after $t \gtrsim 1$ Myr, when there is insufficient dust remaining in the inner solar system to produce terrestrial planets. The prevailing theory is that dust grain growth into pebbles occurred by $t \sim 10^5$ yr, mostly at larger separations where the disk was cooler, and then the pebbles migrated inward via viscous drag into the inner solar system, giving a jump start to terrestrial planet formation

) What is the disk mid-plane temperature at t = 1 Myr and r = 2.7 AU? This distance is the canonical snow line, beyond which stickier ice grains can form below $T \lesssim 170$ K, accelerating grain growth into pebbles and the formation of gas giant planets.

$$0.4 = \dot{M}_{1myr} \int_{.1}^{10} (t/1myr)^{-2.5}\, dt$$

a) $\boxed{\dot{M}_{1Myr} = 1.9E-8}$

b) $$dM = \int_1^{10} \dot{M}_{1myr}\,(t/1myr)^{-2.5}\, dt$$

a) $\boxed{M = 0.012\ M_\odot}$

b) $3996.36\ M_\oplus / 100$

$\boxed{39.96\ M_\oplus}$

c) $$L_{disk} = \frac{GM_*\dot{M}}{2R_*}$$

$L_{disk}(1) =$

$$\frac{6.67\cdot10^{-8}\frac{cm^3}{g\,s^2}(.6\cdot2E33\,g)(1.21E18\,\frac{g}{s})\cdot}{2(2\cdot7E10\ cm)}$$

$3.46E32\ \frac{cm^2 g}{s^3}$ aka erg/s

$\boxed{=.09\ L_\odot}$

$L_{disk}(10) =$

$$\dot{M} = 1.9E-8\,(10/1)^{-2.5} = 6E-11$$

$$\frac{6.67\cdot10^{-8}\frac{cm^3}{g\,s^2}(.6\cdot2E33\,g)(3.81E15\,\frac{g}{s})}{2(2\cdot7E10\ cm)}$$

$1.09\ \frac{cm^3 g}{s^3}$ or erg/s

$$6E-11\ \frac{M_\odot}{yr}\left(\frac{2E33\,g}{3.15E7\,s}\right)$$

$\boxed{= 2.83E-7\ L_\odot}$

d)

```
2)
Mdot at 1 Myr: 1.899265861962991e-08
Mdot 0.012261372012686202
Photospheric Disk Temp at 1 and 2.7: [100.09522447  47.52154313]
e and f: [400.38089788 190.08617253]
3)
solar luminosities 2.2969175972285583
```

3. (40%) Model the SED of the protoplanetary disk in #2 face on. In addition to the disk, model the pre-MS star as a blackbody with $R_* = 2\ R_\odot$ and $T_{*,\mathrm{eff}} = 5{,}000$ K.

(a) First compute the luminosity L_* of the pre-MS star (in $L_\odot$).

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(d) Plot the SED of the star. The x-axis should be λ (in Å or μm) and the y-axis should be $\lambda L_{*,\lambda}$ (in $L_\odot$). Both axes should be logarithmic. You should find that the stellar SED peaks at $\lambda L_{*,\lambda} = 1.6\ L_\odot$ near $\lambda = 0.73$ μm. The advantage of plotting the SED ($\lambda L_{*,\lambda}$ versus λ) is that you can immediately see that the total luminosity of the star is $\sim 2\ L_\odot$.

(e) Create a 1D radius vector of length 2,000 with separation $\Delta r = 0.05$ AU spanning 0.05 AU to 100 AU, the typical radius of protostellar disks. The area of the annulus centered at each r_i is simply $A(r_i) = 2\pi r_i \Delta r$.

(f) Considering the protoplanetary disk at t = 1 Myr from #2, compute the photospheric temperature $T_{\mathrm{eff}}(r_i)$ at each radius r_i. The flux density (in erg s^{-1} cm^{-2} Å^{-1}) at each radius r_i is $F_\lambda(r_i) = \pi B_\lambda(T_{\mathrm{eff}}(r_i))$. Multiplying by the area $A(r_i)$ gives the luminosity spectral density (in erg s^{-1} Å^{-1}) at each radius: $L_\lambda(r_i) = A(r_i)\, F_\lambda(r_i)$. Convert this luminosity spectral density $L_\lambda(r_i)$ into units of $L_\odot$ Å^{-1} for each radius r_i. Finally, sum the luminosity spectral density from all annuli to get the total disk luminosity spectral density: $L_{\mathrm{disk},\lambda} = \Sigma_i L_\lambda(r_i)$. Overplot the SED of the disk on top of the stellar SED. You should find that the disk dominates the SED beyond $\lambda > 6$ μm. What class of YSO is this object? Does the ratio L_{disk}/L_* inferred from the SED match expectations given your computed value of L_{disk} in part 2c?

(g) Repeat part (f) with a t = 10 Myr protoplanetary disk where $\dot{M}$ is 2.5 orders of magnitude smaller. At what wavelengths does the disk dominate the SED? What class of YSO is this?

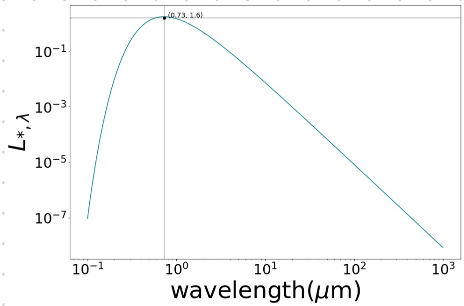
(h) Repeat part (f) with a gap (no radiation) across r = 0.2 – 5 AU. Describe the overall SED of the disk. What kind of disk is this?

$\dfrac{kg\, \cancel{m^2}\, K^4}{s^3\, \cancel{m^2}}$ $K \cdot m$

$\dfrac{kg\, K^5\, m}{s^3}$

$$\boxed{L = 4\pi R_*^2\, \sigma_{SB}\, T_{eff}^4}$$

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{hc}{\lambda k T}\right) - 1}$$



The code below has been mostly debugged and should work, however when timing the for loop it took nearly 20 minutes to go through less than a quarter of its iterations which means to make the desired graphs would take running overnight(which I will do). I just wanted to note that I seem to have fixed the storage issue and can successfully get a 2000x999901 matrix that then sums into one total (graphable) vector. I also added the repeat code for the next two parts with their new variables.

F) I would assume this to be a class II YSO since its disk dominates its spectrum, I cannot give a confident answer regarding overall luminosity

g) this would be a class III YSO since its age is closer to 10 Myr

h) This is a representation of a gap disk since it has nearly .15 AU of material on the inside and from 5 on on the outside

Astro Code

Corinne Komlodi

Physics Department, University of Wyoming.

(Dated: September 7, 2023)

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Tue Sep  5 14:32:43 2023

@author: corinnekomlodi
"""

import matplotlib.pyplot as plt
import numpy as np
import scipy.integrate as integrate

#question 1 algebra
n = 2.56e19
Z = 336.28e5
sig_r = 1.91e-27
sig_b = 1.79e-26
sig_g = 5e-27

tau_r = n*Z*sig_r
tau_g = n*Z*sig_g
tau_b = n*Z*sig_b
# print(np.exp(-tau_r))
# print(np.exp(-tau_g))
# print(np.exp(-tau_b))

#2
print('2)')
#consider a protostellar disk that accretes onto a solar-type protostar
    with m and r.
```

```python
def eq(x):
    return (x/1)**-2.5

initialM, err = integrate.quad(eq, .1, 10)
finalM = 0.4/initialM
print('Mdot at 1 Myr: {}'.format(finalM/1e6))
#1.9E-8 Msun/yr


initialM1, err = integrate.quad(eq, 1, 10)
print('Mdot {}'.format((finalM)*initialM1))

sb = 5.67e-5 #g s-3 K-4
G = 6.67e-8 #cm3 g-1 s-2
Mstar = 1 * 2e33 #g
Rstar = 2 * 7e10 #cm
Rsun = 1 * 7e10 #cm
Mdot = 1.9e-8 * (2e33/3.15e7) #g s-1
r = np.array([1 * 1.5e13, 2.7 * 1.5e13])  #cm

photoa = (3*G*Mstar*Mdot)
photob = (8*np.pi*sb*Rstar**3)
PhotoTeff = ((photoa/photob)**(0.25))*((r/Rstar)**(-0.75))
print('Photospheric Disk Temp at 1 and 2.7: {}'.format(PhotoTeff))
print('e and f: {}'.format(PhotoTeff*4))



#3
print('3)')
```

```
Rstar = 2 #solar radius
Teff = 5000 #k
sb = 5.67e-5 #W/m2/K4

Luminosity = (4*np.pi*(Rstar*7e10)**2*sb*Teff**4)/3.8e33
print('solar luminosities {}'.format(Luminosity))
#2.3 Solar Luminosities

wavelength = np.arange(1000,10000010, 10) #angstroms
h = 6.67e-27 #cm2 g s-1
c = 3e10 #cm s-2
K = 1.4e-16 #cm2 g s-2 K-1
BTeff = ((2*c**2*h)/((wavelength*1e-8)**5))*(1/(np.exp((h*c)/((
    wavelength*(1e-8))*K*Teff))-1))

StelLumCGS = 4*np.pi**2*BTeff*(Rstar*7e10)**2
stelLum = StelLumCGS/3.8e33

fig, ax = plt.subplots(figsize = (15,10))
ax.set_yscale('log')
ax.axvline(x = .73, color = 'darkgrey')
ax.axhline(y = 1.6, color = 'darkgrey')
ax.set_xscale('log')
ax.plot(wavelength/10000, (wavelength/10000/10000)*stelLum, color = "
    teal")

ax.set_xlabel('wavelength($\mu$m)')
ax.set_ylabel('$L_{*,\lambda}$')
ax.text(.8, 1.7, '(0.73, 1.6)', color = 'k', fontsize = 'x-large')
ax.plot(.73, 1.6, 'ko')
```

```
r = np.arange(.05,100.05, .05)
Teffr = ((3*G*Mstar*Mdot)/(8*np.pi*sb*Rstar**3))**.25*(r/Rsun)**-.75
Bteffa = ((2*h*c**2)/((wavelength*1e-8)**5))

BTeffr = np.array([])
for i in range(0, len(Teffr)):
    loop = (((wavelength*(1e-8))*K*Teffr[i])-1)
    exponent = (np.exp((h*c)/loop))
    bTeffr = Bteffa*(1/exponent)
    BTeffr = np.append(BTeffr, bTeffr)
    print(i)

BTeffr = np.reshape(BTeffr, [2000, 999901])
FxDensity = np.pi*BTeffr


for i in range(0, 2000):
    delr = .05
    a_r = 2*np.pi*r[i]*delr
    Lcgs = a_r*FxDensity[i:]


LsolLum = Lcgs/3.8e33
summation = np.sum(LsolLum, axis = 0)

ax.plot(wavelength/1000, summation*wavelength/10000/10000)
fig, ax = plt.subplots(figsize = (15,10))
ax.set_yscale('log')
ax.axvline(x = .73, color = 'darkgrey')
```

```
ax.axhline(y = 1.6, color = 'darkgrey')
ax.set_xscale('log')
ax.plot(wavelength/10000, (wavelength/10000/10000)*stelLum, color = "
    teal")

ax.set_xlabel('wavelength($\mu$m)')
ax.set_ylabel('$L_{*,\lambda}$')
ax.plot(range(1000, 10000010, 2000), summation)

print('e')
Mdot10 = 3.81e15 #g s-1
Mstar = 2 * 6.5e8 #g

Teffr = ((3*G*Mstar*Mdot)/(8*np.pi*sb*Rstar**3))**.25*(r/Rsun)**-.75
Bteffa = ((2*h*c**2)/((wavelength*1e-8)**5))

BTeffr = np.array([])
for i in range(0, len(Teffr)):
    loop = (((wavelength*(1e-8))*K*Teffr[i])-1)
    exponent = (np.exp((h*c)/loop))
    bTeffr = Bteffa*(1/exponent)
    BTeffr = np.append(BTeffr, bTeffr)
    print(i)

BTeffr = np.reshape(BTeffr, [2000, 999901])
FxDensity = np.pi*BTeffr


for i in range(0, 2000):
    delr = .05
```

```
    a_r = 2*np.pi*r[i]*delr
    Lcgs = a_r*FxDensity[i:]


LsolLum2 = Lcgs/3.8e33
summation2 = np.sum(LsolLum2, axis = 0)


fig, ax = plt.subplots(figsize = (15,10))
ax.set_yscale('log')
ax.axvline(x = .73, color = 'darkgrey')
ax.axhline(y = 1.6, color = 'darkgrey')
ax.set_xscale('log')
ax.plot(wavelength/10000, (wavelength/10000/10000)*stelLum, color = "
    teal")

ax.set_xlabel('wavelength($\mu$m)')
ax.set_ylabel('$L_{*,\lambda}$')
ax.plot(wavelength/1000, summation2*wavelength/10000/10000)

print('f)')
#gap between .2 and 5 AU
r = np.append(np.arange(.05,2.05, .05), np.arange(2, 100.05, .05))

Teffr = ((3*G*Mstar*Mdot)/(8*np.pi*sb*Rstar**3))**.25*(r/Rsun)**-.75
Bteffa = ((2*h*c**2)/((wavelength*1e-8)**5))

BTeffr = np.array([])
for i in range(0, len(Teffr)):
    loop = (((wavelength*(1e-8))*K*Teffr[i])-1)
```

```
    exponent = (np.exp((h*c)/loop))
    bTeffr = Bteffa*(1/exponent)
    BTeffr = np.append(BTeffr, bTeffr)
    print(i)

BTeffr = np.reshape(BTeffr, [2000, 999901])
FxDensity = np.pi*BTeffr


for i in range(0, 2000):
    delr = .05
    a_r = 2*np.pi*r[i]*delr
    Lcgs = a_r*FxDensity[i:]


LsolLum3 = Lcgs/3.8e33
summation3 = np.sum(LsolLum3, axis = 0)


fig, ax = plt.subplots(figsize = (15,10))
ax.set_yscale('log')
ax.axvline(x = .73, color = 'darkgrey')
ax.axhline(y = 1.6, color = 'darkgrey')
ax.set_xscale('log')
ax.plot(wavelength/10000, (wavelength/10000/10000)*stelLum, color = "
    teal")

ax.set_xlabel('wavelength($\mu$m)')
ax.set_ylabel('$L_{*,\lambda}$')
ax.plot(wavelength/1000, summation3*wavelength/10000/10000)
```