ASTR232, Fall 2019
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Homework # 4

Problem 1a

In each of the six spectra, measure the fluxes of the folowing lines: Hα, Hβ, [O III]λ4363, [O III]λ5007, [N II]λ6583, [S II]λ6716, and [S II]λ6731.

Solution

We report the line fluxes for the spectra we analyzed using IRAF:

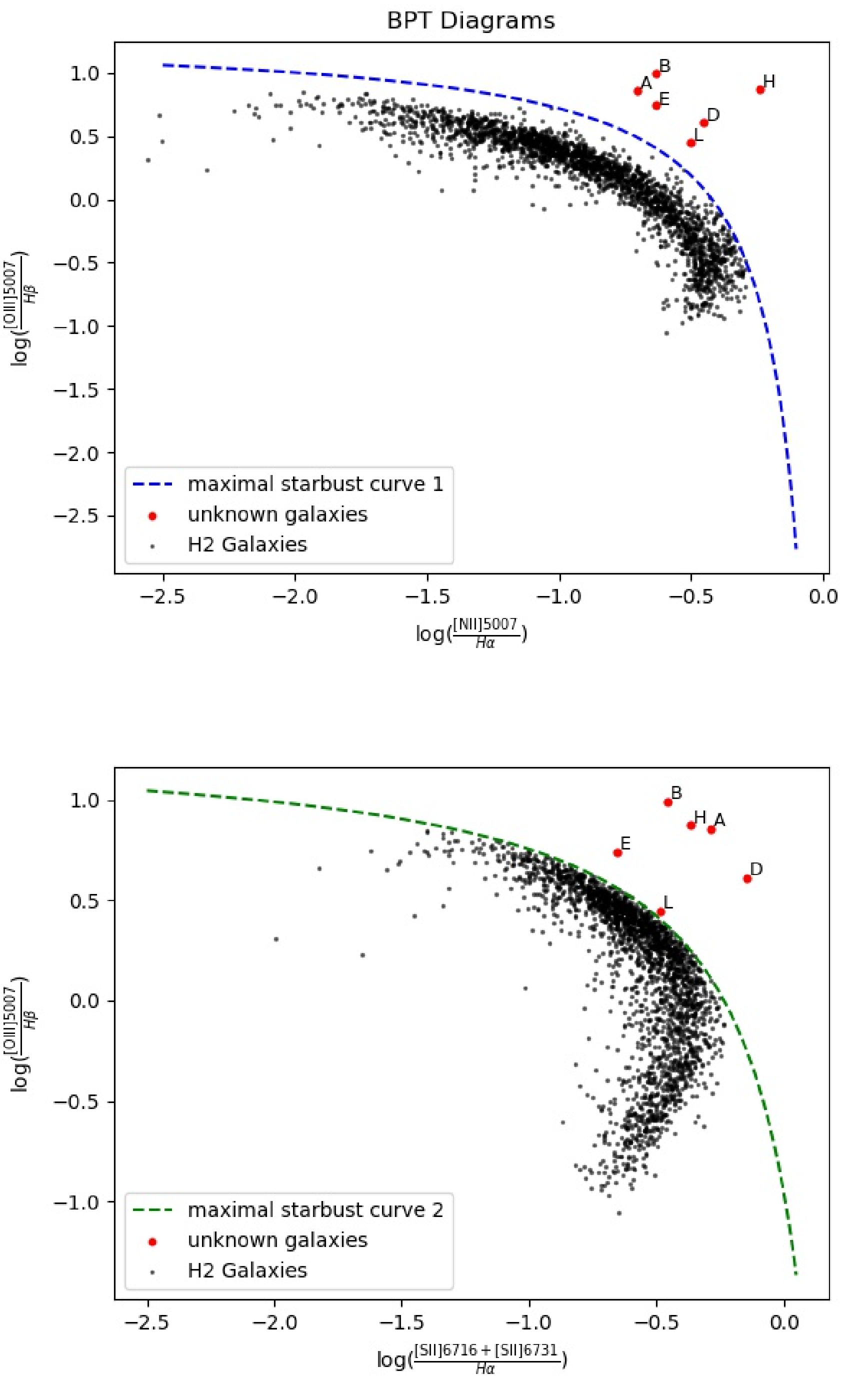
galaxy spectra	h-alpha	h-beta	[OIII]λ4363	[OIII]λ5007	[OI]λ6300	[NII]λ6583	[SII]λ6716	[SII]λ6731
A	306.7	84.61	11.78	609.1	46.02	60.87	89.54	68.65
B	1187.0	306.70	50.93	3020.0	217.40	278.10	234.30	181.40
D	2964.0	764.30	55.39	3131.0	837.20	1051.00	1214.00	898.00
E	3011.0	924.30	88.36	5096.0	92.04	699.90	336.60	335.60
H	4774.0	1104.00	83.79	8282.0	375.90	2757.00	1051.00	1006.00
L	7361.0	2077.00	102.7	5818.0	423.50	2324.00	1301.00	1124.00

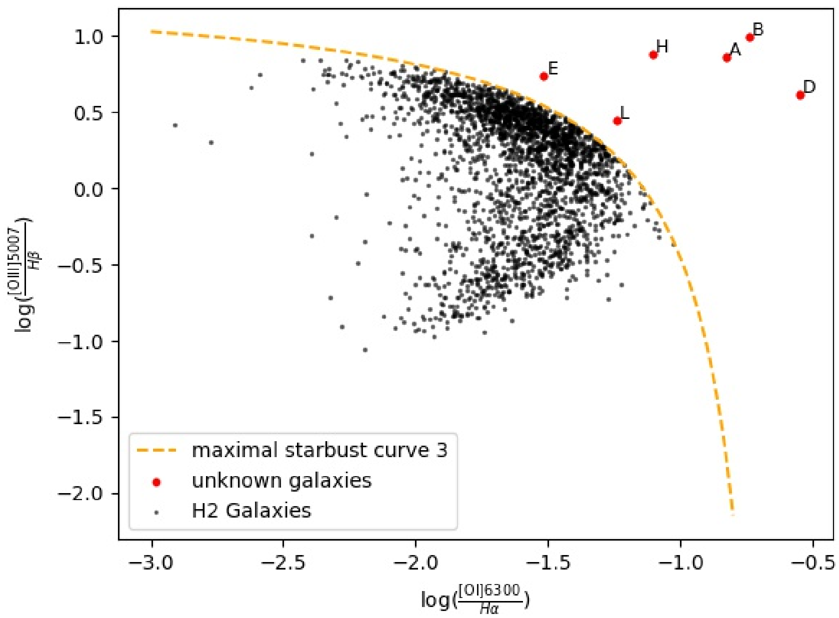
Problem 1b

Construct BPT diagrams for the measured spectra and add points from the `h2.txt` file. Then add maximal starbust curves to the diagrams using equations 1, 2, and 3 in Kewley et al. (2006, MNRAS, 372,961). Finally, classify the objects.

Solution

We plot our line ratios in BPT diagrams, add the line ratios for given H II galaxies and add the maximal starbust curves found in Kewley et. al. (2006). We get the following:


BPT Diagrams
maximal starbust curve 1
unknown galaxies
H2 Galaxies
A
B
E
D
L
H
log([OIII]5007/Hβ)
log([NII]5007/Hα)
maximal starbust curve 2
unknown galaxies
H2 Galaxies
B
H
A
E
D
L
log([OIII]5007/Hβ)
log(([SII]6716 + [SII]6731)/Hα)



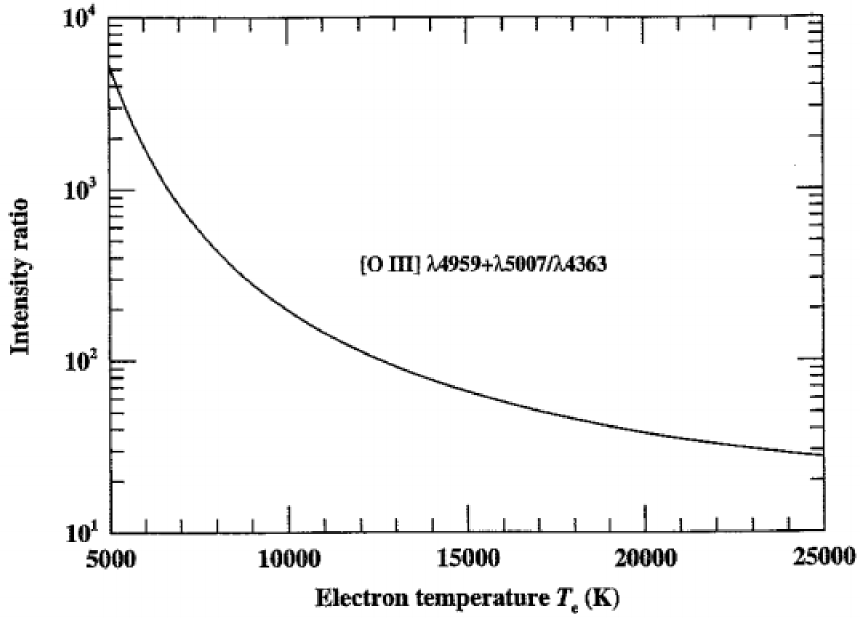
A galaxy can be classified as an AGN if it lies above the maximal starburst curve. Thus, because the galaxies lie above the curves in all three BPT diagrams, we conclude that they are all AGNs.

Problem 1c

Using [O III] and [S II] measurements and the plots from lecture slides, estimate the electron temperature and density for each object. Be as accurate as possible.

Solution

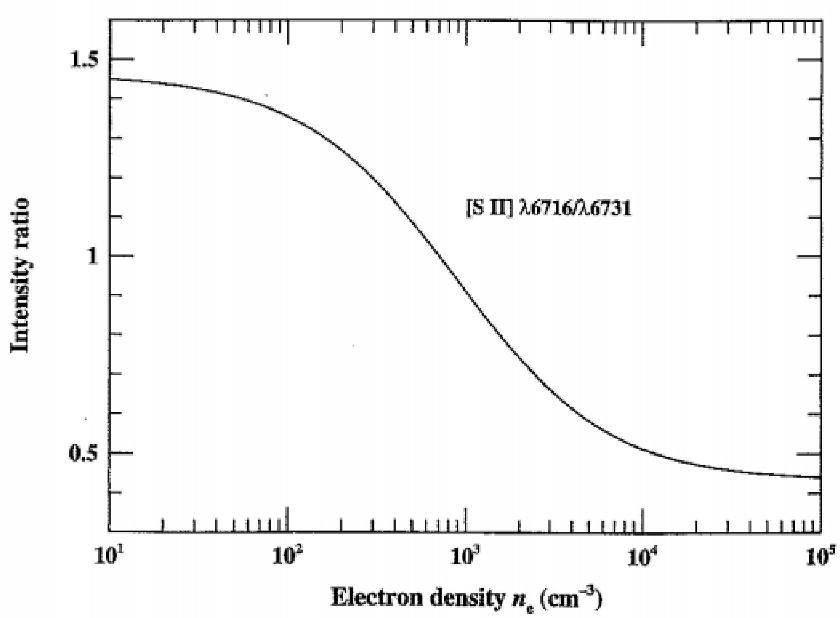
To measure the electron temperature, we need to measure the intensity of the [OIII]$\Big(\dfrac{\lambda 4959 + \lambda 5007}{\lambda 4363}\Big)$ line ratio and compare it to the following plot:



We compute [OIII]$(\lambda4959 + \lambda5007)$ by assuming that it is equal to $\frac{4}{3}$([OIII]$\lambda5007$) (since we did not measure the [OIII]$\lambda4959$ line). Dividing it by the [OIII]$\lambda4363$ line, we get the following line ratios along with their electron temperature (which we found after getting the ratios):

galaxy spectra	[OIII]$(\lambda4959 + \lambda5007/\lambda4363)$	Electron Temperature T_e (K)
A	68.94	15200
B	79.06	14000
D	75.36	14000
E	76.89	14000
H	131.78	9000
L	75.53	14000

We then use the following plot to compute electron density:



Computing the [SII](λ6716/λ6731) ratio, we get the uncorrected electron density. We then apply the correction, which is needed since the above plot assumes a temperature of 10^4 K. To correct, we use the uncorrected n_e and multiply by $(\frac{10^4}{T_e})^{0.5}$. Thus, we get:

galaxy spectra	S2(6716/6731)	electron density(cm-3) uncorrected	electron density(cm-3) corrected
a	1.304297	180	145.999279
b	1.291621	180	152.127766
d	1.351893	100	84.515425
e	1.002980	700	591.607978
h	1.044732	700	737.864787
l	1.157473	350	295.803989

Problem 2

For any object classified as an AGN, calculate the luminosity of the Hβ line. Then, using $\epsilon = 10^{-2}$, estimate the radius (in pc) and mass (in $M_\odot$) of the narrow line region.

Solution

To get the luminosity of the Hβ, we use

$$L_{H\beta} = 4\pi \mathrm{d}^2 \mathrm{F}_{H\beta} \tag{1}$$

Converting distances to centimeters, we produce the following luminosities for the spectra:

galaxy spectra	luminosity$_{H\beta}$(erg/s)
A	1.1×10^{38}
B	1.5×10^{39}
D	3.13×10^{38}
E	4.04×10^{39}
H	1.25×10^{39}
L	4.2×10^{39}

After finding $L_{H\beta}$, we can calculate the radius of the narrow line region (NLR) using the following equation:

$$\mathrm{R_{NLR}} = \left(\frac{3\mathrm{L_{H\beta}}}{4\pi\alpha_{\mathrm{H\beta}}\mathrm{h}\nu_{\mathrm{H\beta}}\mathrm{n_e^2}\epsilon}\right)^{\frac{1}{3}} \tag{2}$$

where $\alpha_{\mathrm{H\beta}} = \frac{\alpha_{\mathrm{tot}}}{8.5} = \frac{2.59\times10^{-13}}{8.5}$, h=$6.626 \times 10^{-27}$ erg/sec, $\nu_{\mathrm{H\beta}} = \frac{c}{\lambda} = \frac{2.99\times10^{10}}{4.86\times10^{-5}}$, and $\epsilon = 10^{-2}$.

Plugging in the values listed along with the luminosity and corrected electron density, we get:

galaxy spectra	$\mathrm{R_{NLR}}$(pc)
A	32.5
B	75.18
D	65.87
E	42.25
H	24.67
L	68.11

Finally, we use the following equation to solve for the mass of the NLR:

$$\mathrm{M_{NLR}} = \left(\frac{\mathrm{m_p L_{H\beta}}}{\alpha_{\mathrm{H\beta}}\mathrm{h}\nu_{\mathrm{H\beta}}\mathrm{n_e}}\right) \tag{3}$$

Here, we have a $\mathrm{m_p} = 1.67 \times 10^{-24}$g. Plugging in our luminosity and corrected electron density, we produce the following masses in solar masses:

galaxy spectra	$M_{NLR}(M_{\odot})$
A	5183.7
B	66819.6
D	24966.3
E	46128.8
H	11449.2
L	96608.4

Code

```
'''
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HW4
10 - 11 - 19
'''

#importing required packages
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

#importing csv with spectral line data for 6 galaxies
spectra_lines = pd.read_csv('spectra_lines.csv',index_col=False)
#importing line ratio data for HII galaxies
h2 = pd.read_csv('C:/Users/Gilberto/Documents/Wesleyan/senior_year/
    fall_term/ASTR232/hw4/hw4_zip/hw4_moodle/h2.txt',sep='\s+',
    index_col=False)

spectra_lines_latex = spectra_lines.to_latex(index=False)
#print(spectra_lines)

#computing line ratios for spectra_lines file:
spectra_lines['log([OIII]5007/h-beta)'] = np.log10(spectra_lines['[
    OIII]5007'] / spectra_lines['h-beta'])
spectra_lines['log([NII]6583/h-alpha)'] = np.log10(spectra_lines['[
    NII]6583'] / spectra_lines['h-alpha'])
spectra_lines['log([SII]6716 + [SII]6731/h-alpha)'] = np.log10( (
    spectra_lines['[SII]6716'] + spectra_lines['[SII]6731'] ) /
    spectra_lines['h-alpha'])
spectra_lines['log([OI]6300/h-alpha)'] = np.log10(spectra_lines['[OI
    ]6300'] / spectra_lines['h-alpha'])

#convert the names column into a lst
spectra_lst = list(spectra_lines['galaxy_spectra'])
spectra_lst = [string.upper() for string in spectra_lst]

#plot 1

for i,spectra in enumerate(spectra_lst):
    x_coord = spectra_lines['log([NII]6583/h-alpha)'].iloc[i]
    y_coord = spectra_lines['log([OIII]5007/h-beta)'].iloc[i]
```

```
    plt.scatter(x_coord,y_coord,color='red',s=10)
    plt.text(x_coord+0.01,y_coord+0.01,spectra,fontsize=9)

plt.scatter(spectra_lines['log([NII]6583/h-alpha)'],spectra_lines['
    log([OIII]5007/h-beta)'],s=10,color='red',label='unknown
    galaxies')
plt.scatter(h2['N2/Ha'],h2['#O3/Hb'],color='k',s=2,alpha=0.5,label='
    H2 Galaxies')
plt.ylabel(r'$\log(\frac{[\mathrm{OIII}]5007}{H\beta})$')
plt.xlabel(r'$\log(\frac{[\mathrm{NII}]5007}{H\alpha})$')

x = np.linspace(-2.5,-0.1,1000)
plt.plot(x, [(((0.61 / (b-0.05))) +1.3) for b in x], linestyle = '--
    ',color = 'blue',label='maximal starbust curve 1' )

plt.legend()
plt.title('BPT Diagrams')
plt.savefig('bpt1.jpg')
plt.close()


#plot 2

for i,spectra in enumerate(spectra_lst):
    x_coord = spectra_lines['log([SII]6716 + [SII]6731/h-alpha)'].
        iloc[i]
    y_coord = spectra_lines['log([OIII]5007/h-beta)'].iloc[i]
    plt.scatter(x_coord,y_coord,color='red',s=10)
    plt.text(x_coord+0.01,y_coord+0.01,spectra,fontsize=9)

plt.scatter(spectra_lines['log([SII]6716 + [SII]6731/h-alpha)'],
    spectra_lines['log([OIII]5007/h-beta)'],s=10,color='red',label='
    unknown galaxies')
plt.scatter(h2['S2/Ha'],h2['#O3/Hb'],color='k',s=2,alpha=0.5,label='
    H2 Galaxies')
plt.ylabel(r'$\log(\frac{[\mathrm{OIII}]5007}{H\beta})$')
plt.xlabel(r'$\log(\frac{ [\mathrm{SII}]6716 + [\mathrm{SII}]6731 }{
    H\alpha})$')

x1 = np.linspace(-2.5,0.05,1000)
plt.plot(x1, [(((0.72 / (x-0.32))) +1.30) for x in x1], linestyle =
    '--',color = 'green',label='maximal starbust curve 2' )

plt.legend()
#plt.title('BPT Diagram')
```

```python
plt.savefig('bpt2.jpg')
plt.close()

#plot 3

for i,spectra in enumerate(spectra_lst):
    x_coord = spectra_lines['log([OI]6300/h-alpha)'].iloc[i]
    y_coord = spectra_lines['log([OIII]5007/h-beta)'].iloc[i]
    plt.scatter(x_coord,y_coord,color='red',s=10)
    plt.text(x_coord+0.01,y_coord+0.01,spectra,fontsize=9)

plt.scatter(spectra_lines['log([OI]6300/h-alpha)'],spectra_lines['
    log([OIII]5007/h-beta)'],s=10,color='red',label='unknown
    galaxies')
plt.scatter(h2['O1/Ha'],h2['#O3/Hb'],color='k',s=2,alpha=0.5,label='
    H2 Galaxies')
plt.xlabel(r'$\log(\frac{[\mathrm{OI}]6300}{H\alpha})$')
plt.ylabel(r'$\log(\frac{[\mathrm{OIII}]5007}{H\beta})$')


x2 = np.linspace(-3,-0.8,1000)
plt.plot(x2, [(((0.73 / (a+0.59))) +1.33) for a in x2], linestyle =
    '--',color = 'orange',label='maximal starbust curve 3' )

plt.legend()
#plt.title('BPT Diagram')
plt.savefig('bpt3.jpg')
plt.close()


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########### 1c ##############
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### temperature ###

# to measure the 4959 + 5007 line, assume = 4/3 * 5007. Thus,
spectra_lines['(4959+5007)/4363'] = ((4/3)*spectra_lines['[OIII]5007
    '])/spectra_lines['[OIII]4363']
```

```
spectra_lines['T_electron(K)'] = [15200,14000,14000,14000,9000,14000]

### density ###
spectra_lines['S2(6716/6731)'] = spectra_lines['[SII]6716'] / spectra_lines['[SII]6731']


spectra_lines['electron_density(cm-3)_uncorrected'] = [180,180,100,700,700,350]
spectra_lines['electron_density(cm-3)_corrected'] = spectra_lines['electron_density(cm-3)_uncorrected'] * (10**4/spectra_lines['T_electron(K)'])**(0.5)

#print(spectra_lines)

spectra_lines_latex = spectra_lines[['galaxy_spectra','S2(6716/6731)','electron_density(cm-3)_uncorrected','electron_density(cm-3)_corrected']].to_latex(index=False)


##############################
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########### 2 ###############
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###luminosity calculation ###

names = ['fits_file','num1','num2','num3','distance','dist_unit']
distances = pd.read_csv('C:/Users/Gilberto/Documents/Wesleyan/senior_year/fall_term/ASTR232/hw4/hw4_zip/hw4_moodle/distances.txt',sep='\s+',index_col=False,skiprows=1,names=names)

distances['dist(cm)'] = distances['distance'] * 3.086e24 #convert Mpc to cm
spectra_lines['lum_h-beta(erg/s)'] = spectra_lines['h-beta']*10**(-17) * distances['dist(cm)']**2 * 4 * np.pi

### radius calculation ###

```

```
#some constants:
alpha_Hb = (2.59e-13)/8.5 # for temp = 10^4
h = 6.626e-27 #erg/sec
nu_Hb = (2.997e10) / (4.86e-5) #cm/sec
epsilon = 10**(-2)

#solving for radius:

spectra_lines['radius_nlr(cm)'] = ((3*spectra_lines['lum_h-beta(erg/s)']) / (4*np.pi*alpha_Hb*h*nu_Hb*epsilon*spectra_lines['electron_density(cm-3)_corrected']**2))**(1/3)
spectra_lines['radius_nlr(cm)'] = ( (3 * spectra_lines['lum_h-beta(erg/s)']) /(4*np.pi*alpha_Hb*h*nu_Hb*spectra_lines['electron_density(cm-3)_corrected']**2 *epsilon) )**(1/3)
spectra_lines['radius_nlr(pc)'] = spectra_lines['radius_nlr(cm)'] * 3.24e-19


### mass calculation ###

#more constants
m_proton = 1.67e-24 #grams

#solving for mass:

spectra_lines['mass_nlr(grams)'] = (m_proton * spectra_lines['lum_h-beta(erg/s)'] ) / (alpha_Hb*h*nu_Hb*spectra_lines['electron_density(cm-3)_corrected'])
spectra_lines['mass_nlr(solar_mass)'] = spectra_lines['mass_nlr(grams)'] / 1.99e33
print(spectra_lines)
```