In [32]:

```
# Other packages
from astroquery.gaia import Gaia
import astropy.units as u
from astropy.io import fits
from astropy.coordinates.sky_coordinate import SkyCoord
from astropy.units import Quantity
from astroquery.simbad import Simbad
import os
import time
import warnings
warnings.filterwarnings('ignore')
import matplotlib.pyplot as plt
from matplotlib.pyplot import cm
import numpy as np
import pandas as pd
from glob import glob
from astropy.io import ascii

# Curve fitting
from scipy.optimize import fmin
from scipy.optimize import curve_fit
from scipy.signal import find_peaks

%matplotlib inline
plt.style.use('default')
plt.rcParams['figure.figsize'] = (15, 9)
plt.rc('font', family='sans-serif')
plt.rc('axes', labelsize=20)
plt.rc('axes', labelweight='bold')
plt.rc('axes', titlesize=22)
plt.rc('axes', titleweight='bold')
plt.rc('axes', linewidth=4)
plt.rc('xtick',labelsize=18)
plt.rc('ytick',labelsize=18)
# bold symbols
# plt.rc('text', usetex=True)
# plt.rcParams['text.latex.preamble'] = [r'\boldmath']
```

Problem 1

In [17]:

```
bc03_models = ascii.read('bc03_models.txt')
bc03_models
```

Out[17]: *Table length=4771*

WAVE	LUM1	LUM10	LUM100	LUM1000	LUM5000	LUM10000
float64	float64	float64	float64	float64	float64	float64
3400.0	0.0312783	0.0120089	0.00104499	0.000109306	1.432e-05	6.78195e-06
3400.78	0.0311214	0.012052	0.00102177	0.000107551	1.4226e-05	6.75832e-06
3401.57	0.0312522	0.0122631	0.00101318	0.000103973	1.39435e-05	6.62804e-06
3402.35	0.0313686	0.0123845	0.00101097	9.99131e-05	1.35252e-05	6.41025e-06

WAVE	LUM1	LUM10	LUM100	LUM1000	LUM5000	LUM10000
3403.13	0.0313466	0.0123375	0.00101234	9.61526e-05	1.30177e-05	6.15075e-06
3403.92	0.0312484	0.012252	0.00102121	9.31796e-05	1.2489e-05	5.96055e-06
3404.7	0.0312424	0.0121545	0.00102427	9.16673e-05	1.21851e-05	5.81448e-06
3405.48	0.0312688	0.0120859	0.00102324	9.14053e-05	1.20233e-05	5.67934e-06
3406.27	0.0312632	0.0120198	0.00101669	9.15303e-05	1.19122e-05	5.55208e-06
3407.05	0.0311945	0.0119456	0.00100434	9.12223e-05	1.17664e-05	5.4287e-06
...	...	...	...	...	...	...
10176.0	0.000659013	0.00241996	0.000248923	8.75406e-05	2.98996e-05	1.94551e-05
10178.4	0.000658759	0.00241903	0.000248798	8.74202e-05	2.98874e-05	1.94485e-05
10180.7	0.0006582	0.00241882	0.000248743	8.74602e-05	2.989e-05	1.9452e-05
10183.1	0.000657646	0.00241862	0.000248689	8.74999e-05	2.98925e-05	1.94555e-05
10185.4	0.000657087	0.00241841	0.000248634	8.75399e-05	2.9895e-05	1.9459e-05
10187.8	0.000656522	0.0024182	0.000248579	8.75804e-05	2.98976e-05	1.94626e-05
10190.1	0.000655969	0.00241799	0.000248525	8.76201e-05	2.99001e-05	1.94661e-05
10192.5	0.000655404	0.00241778	0.00024847	8.76605e-05	2.99026e-05	1.94696e-05
10194.8	0.000654845	0.00241758	0.000248415	8.77006e-05	2.99051e-05	1.94731e-05
10197.2	0.000654286	0.00241737	0.00024836	8.77407e-05	2.99077e-05	1.94766e-05

In [18]:

```
filter_curves = fits.open('filter_curves.fits')
# print(filter_curves.info())
# filter_curves[0].header
# u_filt = filter_curves['U'].data
# # u_filt
# age_model = bc03_models.colnames[1:]
```

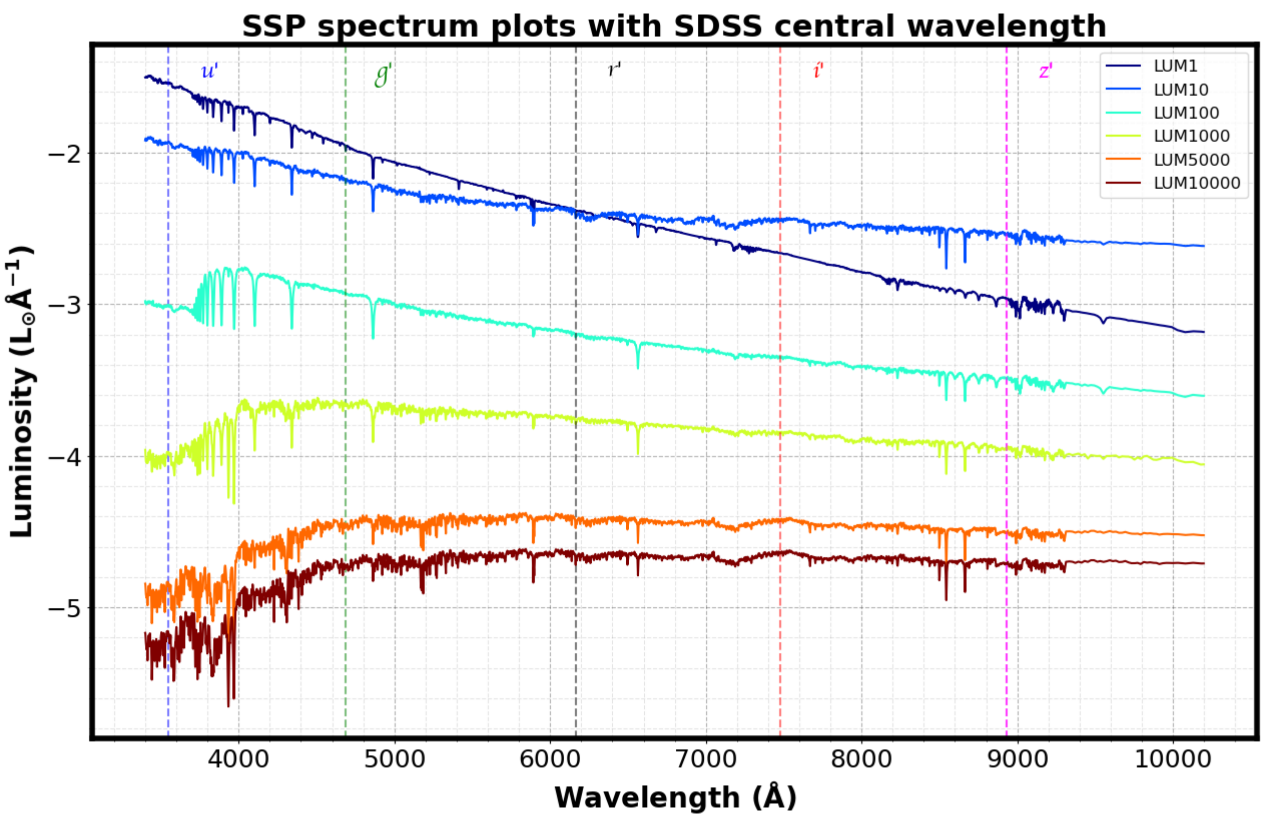
Central SDSS wavelength obtained from: SDSS-III Filters

Filter	Central Wavelength
u	3551 Å
g	4686 Å
r	6166 Å
i	7480 Å
z	8932 Å

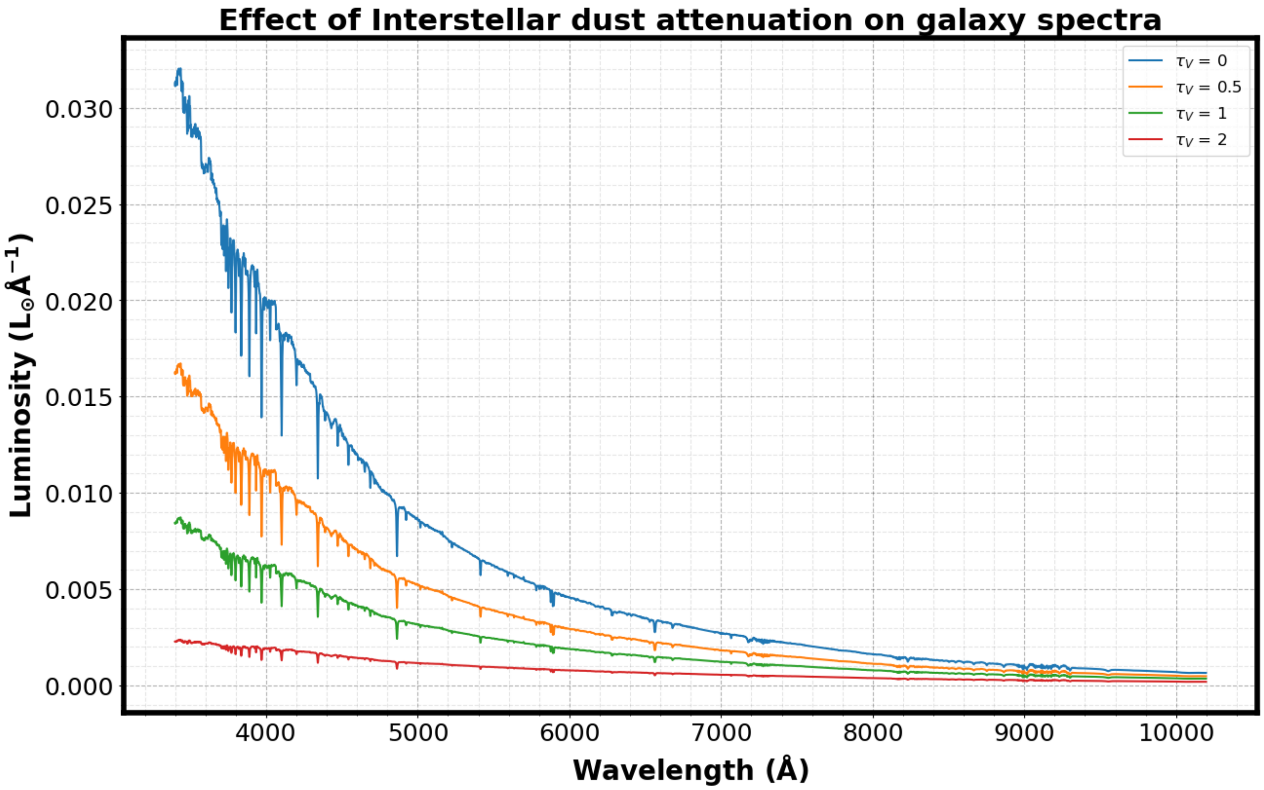
In [23]:

```
age_model = bc03_models.colnames[1:]
SDSS_wav = [3551, 4686, 6166, 7480, 8932]
colors = ['blue', 'green', 'black', 'red', 'magenta']
filter_names = ["u'", "g'","r'", "i'", "z'"]
color2=iter(cm.jet(np.linspace(0,1,len(age_model))))
```

```python
for i in range(0, len(age_model)):
    c=next(color2)
    plt.plot(bc03_models['WAVE'], np.log10(bc03_models[age_model[i]]), label=age
    plt.axvline(SDSS_wav[i-1], ls = '--', color=colors[i-1], alpha=0.5)
    plt.title('SSP spectrum plots with SDSS central wavelength')
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
    plt.text(SDSS_wav[i-1]+200, -1.5, filter_names[i-1], fontfamily='cursive', f

    plt.legend(fontsize=12)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1)
```



In [24]:
```python
def L_dusty(tau_V, L_0, wave):
    tau_wav = tau_V * (wave/5000)**(-0.7)
    return L_0 * np.exp(-tau_wav)

for i in (0, 0.5, 1, 2):
    LUM1_dusty = L_dusty(i, bc03_models[age_model[0]], bc03_models['WAVE'])
    plt.plot(bc03_models['WAVE'], LUM1_dusty, label=r'$\tau_V$ = {}'.format(i))
    plt.title('Effect of Interstellar dust attenuation on galaxy spectra')
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
#     plt.text(SDSS_wav[i-1]+200, -1.5, filter_names[i-1], fontfamily='cursive',

    plt.legend(fontsize=12)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1)
```



Problem 2

In [6]:

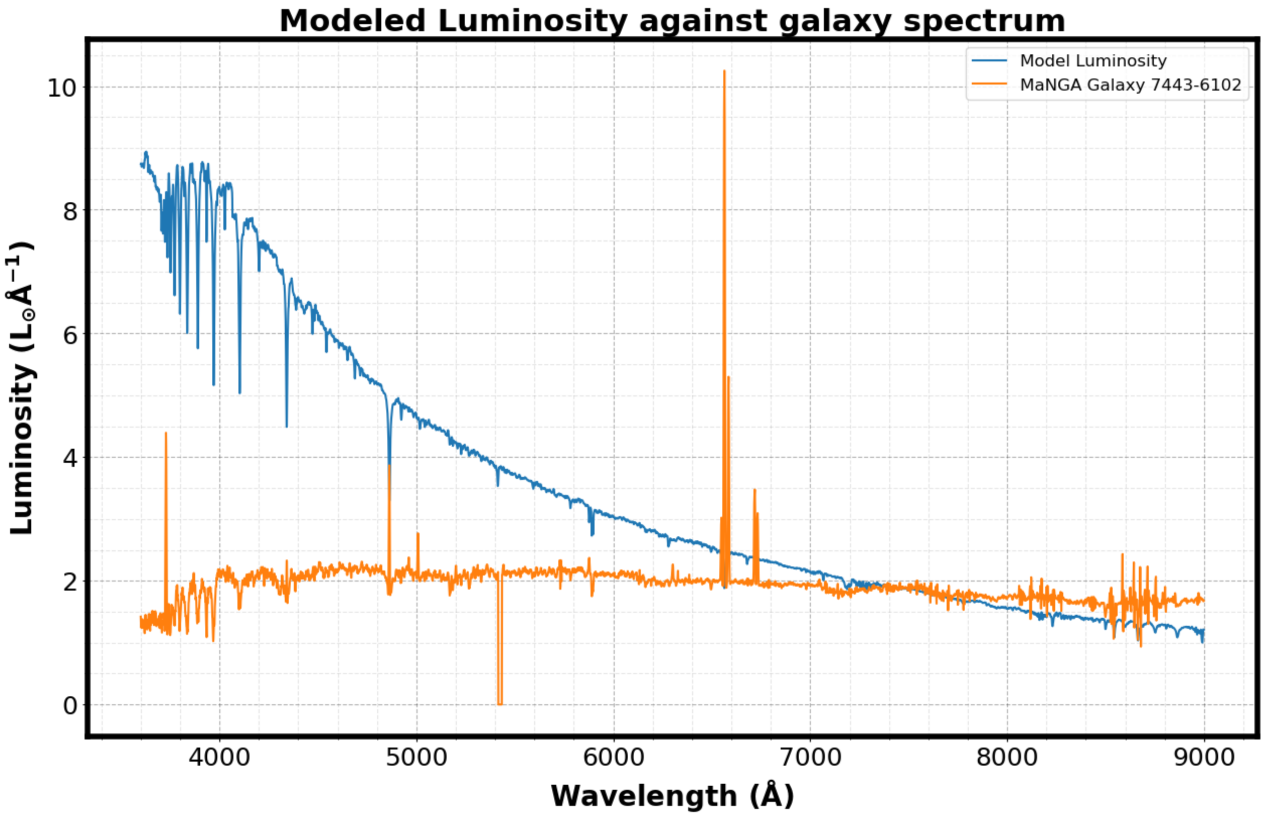
```
from ipywidgets import interact, interactive, fixed, interact_manual, FloatSlide
import ipywidgets as widgets
import matplotlib.pyplot as plt, random
from IPython.display import display
```

In [7]:

```
manga_7443_6102 = ascii.read('manga_7443-6102.txt')
# manga_7443_6102

# Removing the wavelength offset
bc03_offset = bc03_models[(bc03_models['WAVE']>=min(manga_7443_6102['WAVE'])) &
```

In [40]:

```
def L_model(c1, c2, c3, c4, c5, tau_v):
    model = ((c1*bc03_offset['LUM1'] + c2*bc03_offset['LUM100']
             + c3*bc03_offset['LUM1000'] + c4*bc03_offset['LUM10000'])
             * (c5*np.exp(-tau_v *(bc03_offset['WAVE']/5000)**(-0.7))
               )
            )
    return model

plt.plot(bc03_offset['WAVE'], L_model(50,200,10,20,20,1), label='Model Luminosit
plt.plot(manga_7443_6102['WAVE'], manga_7443_6102['LUMINOSITY'], label='MaNGA Ga
plt.title('Modeled Luminosity against galaxy spectrum')
plt.xlabel('Wavelength $\mathbf{(\AA)}$')
plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
plt.legend(fontsize=12)
plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
plt.minorticks_on()
plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1);
```



In [33]:

```
def series(c1, c2, c3, c4, c5, tau):
    plt.plot(bc03_offset['WAVE'], L_model(c1,c2,c3,c4,c5,tau), label='Model Lumi
    plt.plot(manga_7443_6102['WAVE'], manga_7443_6102['LUMINOSITY'], label='MaNG
    plt.title(r'Fitting Model to observed Galaxy Spectrum (Focused on 3000-4000
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
    plt.legend(fontsize=12)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1)
    plt.xlim(3500, 5000)
    plt.ylim(0,4)
    plt.show();
    return()
interact(series, c1 = (1,1000,1), c2 = (1,10000,5), c3 = (1,10000,5), c4 = (1,10
```

Best Values: c1: 3, c2: 36, c3: 420, c4:50, c5:101, tau=2.0

Values that also gave good fit:

```
c1: 4, c2: 1151, c3: 6471, c4:9906, c5:6, tau=2.0

c1: 8, c2: 1196, c3: 2761, c4:2676, c5:8, tau=2.0

c1: 3, c2: 71, c3: 180, c4:820, c5:100, tau=2.0
```

In [36]:

```
def series(c1, c2, c3, c4, c5, tau):
```

```
    plt.figure(figsize=(15,9))
    plt.plot(bc03_offset['WAVE'], L_model(c1,c2,c3,c4,c5,tau), label='Model Lumi
    plt.plot(manga_7443_6102['WAVE'], manga_7443_6102['LUMINOSITY'], label='MaNG
    plt.title('Fitting Model to observed Galaxy Spectrum (Overall)')
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('A$\mathbf{(\lambda) / A_v}$')
    plt.legend(fontsize=12)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1);
    plt.show()
    return()
interact(series, c1 = (1,500,1), c2 = (1,500,1), c3 = (1,500,1), c4 = (1,500,1),
```

In the case we multiply the galaxy spectrum by its 1e6 scale. The variables change to:

    Option 1: c1: 1833101.00, c2: 69058701.00, c3: 273380701.00, c4:
    499999901.00, c5: 101, tau: 2

    Option 2: c1: 20001.00, c2: 10090601.00, c3: 20167601.00, c4:
    50945001.00, c5: 1001, tau: 2

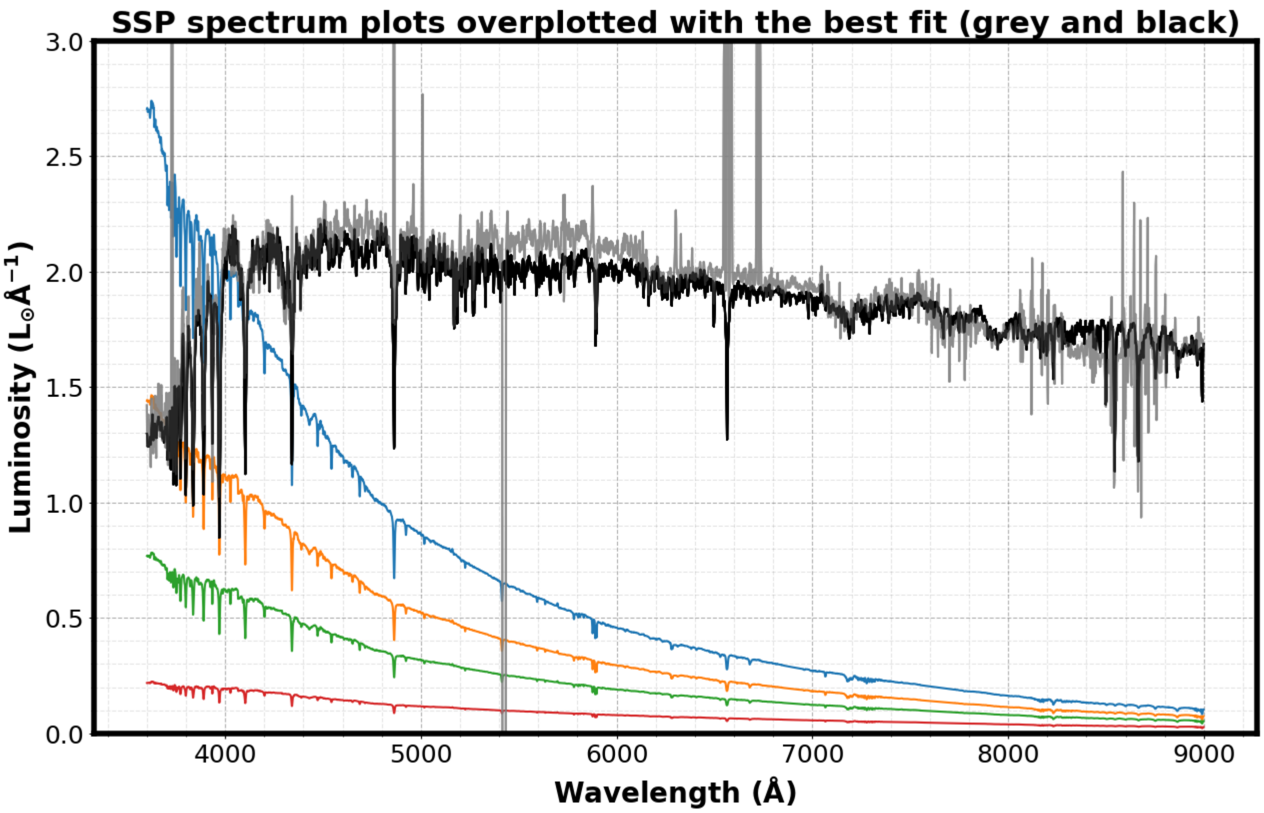
In [38]:

```
def series(c1, c2, c3, c4, c5, tau):
    plt.plot(bc03_offset['WAVE'], L_model(c1,c2,c3,c4,c5,tau), label='Model Lumi
    plt.plot(manga_7443_6102['WAVE'], manga_7443_6102['LUMINOSITY']*1e6, label='
    plt.title('Fitting Model to observed Galaxy Spectrum (Overall)')
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('A$\mathbf{(\lambda) / A_v}$')
    plt.legend(fontsize=12)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1);
    plt.show()
    return()
interact(series, c1 = (1,5e6,1e2), c2 = (1,5e8,1e2), c3 = (1,5e8,1e2), c4 = (1,5
```

In [81]:

```
for i in (0, 0.5, 1, 2):
    LUM1_dusty = L_dusty(i, bc03_offset[age_model[0]], bc03_offset['WAVE'])
    plt.plot(bc03_offset['WAVE'], LUM1_dusty*1e2)

    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
    plt.ylim(0, 3)
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1)

for i in range(0, len(age_model)):
    LUM1_dusty = L_dusty(2, bc03_offset[age_model[i]], bc03_offset['WAVE'])
    plt.plot(bc03_offset['WAVE'], LUM1_dusty)
    plt.plot(bc03_offset['WAVE'], L_model(3,36,420,50,101,2), 'black')
    plt.plot(manga_7443_6102['WAVE'], manga_7443_6102['LUMINOSITY'], 'grey', alp
```

```
    plt.title('SSP spectrum plots overplotted with the best fit (grey and black)
    plt.xlabel('Wavelength $\mathbf{(\AA)}$')
    plt.ylabel('Luminosity $\mathbf{(L_{\odot}\AA^{-1})}$')
    plt.grid(b=True, which='major', color='k', linestyle='--', alpha=0.3)
    plt.minorticks_on()
    plt.grid(b=True, which='minor', color='k', linestyle='--', alpha=0.1)
```



Observations

I observed that when scaling the different SSP constants (c1, c2, c3, c4 & c5) each had an unique effect on the model luminosity. Some of the obervations are listed below:

```
1) The c1 or LUM1 affected mainly the shorter wavelength (4000 -
5000 Angstrom) causing the start of the spectrum to be steeper or
flatter. The spectrums were very sensitive to this variable (small
change would cause significant shift in the modeled spectrum)

2) The c2 or LUM10 acted as a translation variable (shifting entire
curve) up or down.

3) The c3 allowed me to control the mid-wavelengths (5500-7500
Anstrom) and spectrum was not as sensitive to this variable.

4) The c4 moved the tail end part of the spectrum (8000+ Ansgtrom)
and spectrum was not as sensitive to this variable.

5) The c5 acted as a scale factor affecting the overall sensitivity
of modelded spectrum towards rest of the variables. High value of
c5 meant, small changes in each of the c1-c4 have significant
```

```
changes, while a smaller value meant that spectrum was not as
sensitive to the constants. It acted as a scale parameter.

6) The tau (dust attenuation) affected where the overall strength
of each of the absorption and emission features of the spectrum.
Smaller the tau, more significant the features (deeper absoprtion
troughs and emission peaks), while larger the tau, less pronounced
the features.
```

This indicates that each luminosity (LUM1-1000) contributes differently and is depended on specific mass to luminosity ratio. This enables us to estimate distribution of stellar mass and how that affects the overall spectrum of a galaxy. Using these features to estimate the constant value that best fit the model spectrum to actual galaxy spectrum enables us to constrain stellar population/distrubution of the galaxy.

In [85]:

```
print(r'The Stellar mass from option 1 is {:.3e} solar mass'.
      format((3+36+420+50)*101*1e6))
```

```
The Stellar mass from option 1 is 5.141e+10 solar mass
```

Compared to Milky way $\mathbf{5 \times 10^{10}\ M_\odot}$ The mass of this galaxy is very similar coming at about $\mathbf{5.141 \times 10^{10}\ M_\odot}$