In [1]:
```
pickles = {}
os.system('ls ../model_spectra/pickles/*.fits > list')
with open('list') as a:
    z = a.read().splitlines()
for line in z:
    f = fits.getdata(line)
    fhead = fits.getheader(line)
    pickles.update({fhead['COMMENT1'].split(' ')[2]:f})

import pickle
pickle.dump(pickles,open('../model_spectra/pickle_models.pkl','wb'))
```

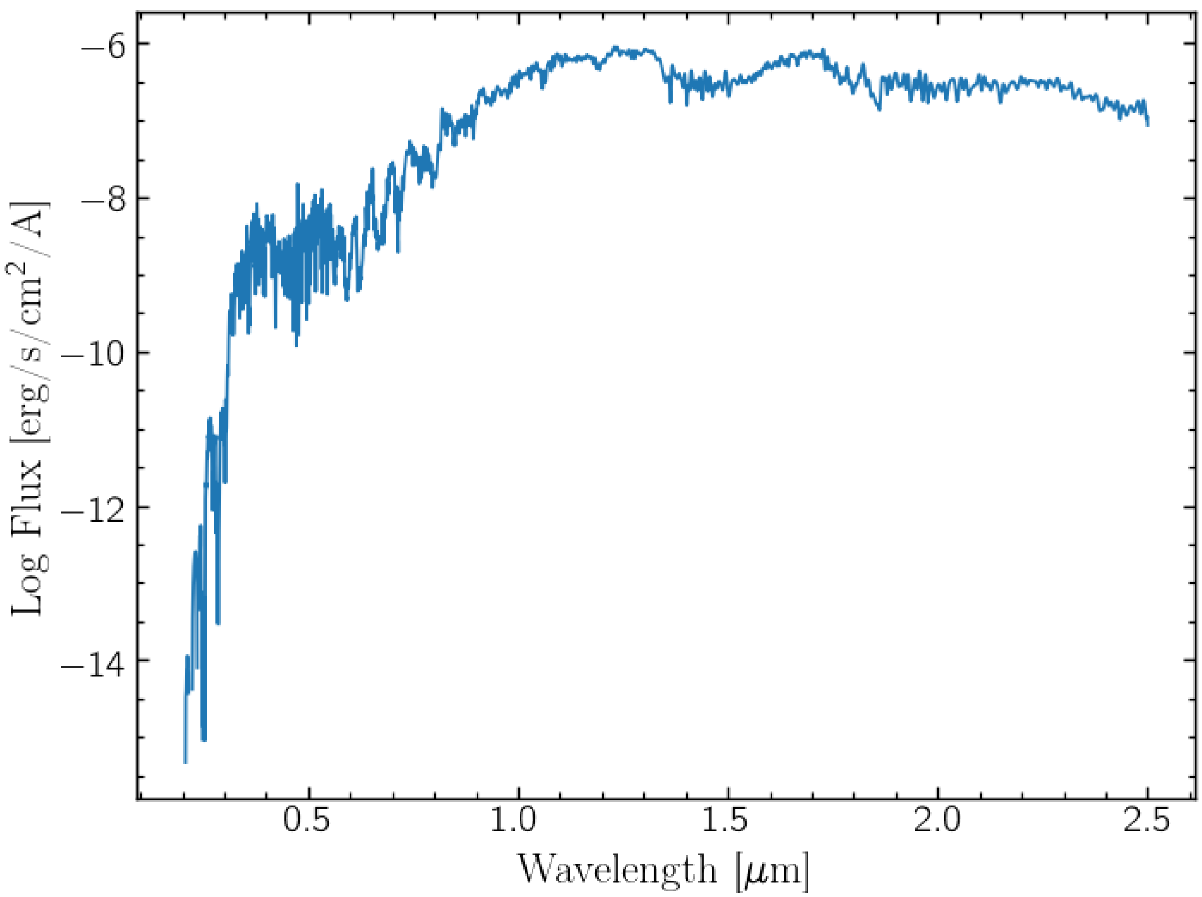
In [2]:
```
spt = [key for key in pickles.keys()]
spt
```

Out[2]:
```
['O5V',
 'O9V',
 'B0V',
 'B1V',
 'B3V',
 'B57V',
 'B8V',
 'B9V',
 'A0V',
 'A2V',
 'A3V',
 'A5V',
 'A7V',
 'F0V',
 'F2V',
 'F5V',
 'F6V',
 'F8V',
 'G0V',
 'G2V',
 'G5V',
 'G8V',
 'K0V',
 'K2V',
 'K3V',
 'K4V',
 'K5V',
 'K7V',
 'M0V',
 'M1V',
 'M2V',
 'M2.5V',
 'M3V',
 'M4V',
 'M5V',
 'M6V',
 'O8III',
 'B12III',
 'B3III',
 'B5III',
 'B9III',
 'A0III',
 'A3III',
 'A5III',
 'A7III',
 'F0III',
 'F2III',
 'F5III',
 'G0III',
 'G5III',
 'G8III',
 'K0III',
 'K1III',
 'K2III',
 'K3III',
 'K4III',
 'K5III',
```

```
'M0III',
'M1III',
'M2III',
'M3III',
'M4III',
'M5III',
'M6III',
'M7III',
'M8III',
'M9III',
'M10III']
```

In [3]:

```
import warnings
warnings.filterwarnings('ignore')
%matplotlib notebook
plt.plot(f['wavelength']*u.AA.to(u.um),np.log10(f['flux']))
plt.xlabel('Wavelength [$\mu$m]')
plt.ylabel(r'Log Flux [erg/s/cm$^2$/A]')
plt.tight_layout()
```



In [4]:

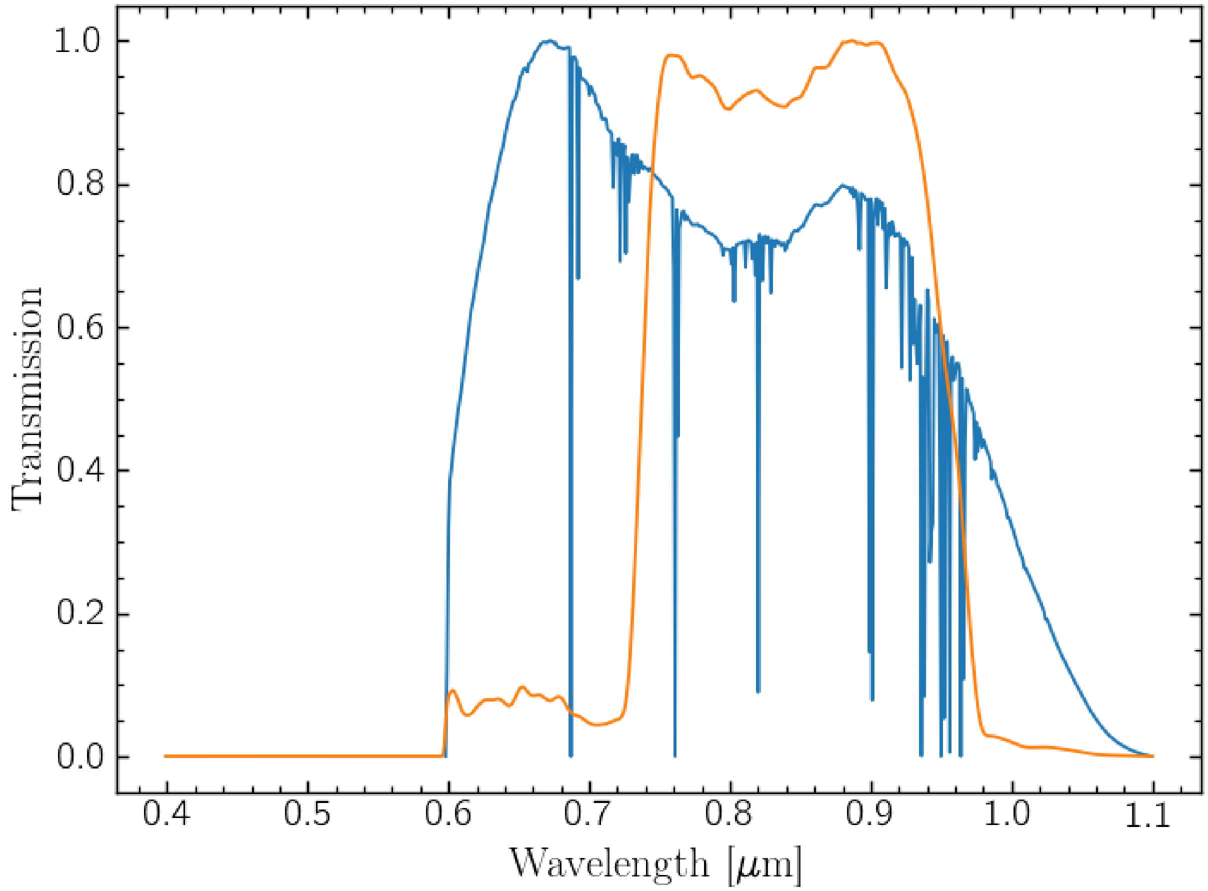
```
f6535 = pd.read_table('../filter_curves/magaox_wfs-open_bs-65-35_atm.da
                      names=['wavelength [m]','transmission'], delim_whites
f6535['wavelength [nm]'] = f6535['wavelength [m]']*u.m.to(u.nm)
f6535['normalized transmission'] = f6535['transmission']/np.max(f6535['

fhair = pd.read_table('../filter_curves/magaox_wfs-open_bs-halpha-ir.da
                      names=['wavelength [m]','transmission'], delim_whites
fhair['wavelength [nm]'] = fhair['wavelength [m]']*u.m.to(u.nm)
fhair['normalized transmission'] = fhair['transmission']/np.max(fhair['
fhair
```

Out[4]:

	wavelength [m]	transmission	wavelength [nm]	normalized transmission
0	3.990000e-07	0.000000e+00	399.0	0.000000e+00
1	4.000000e-07	1.471580e-09	400.0	7.498994e-09
2	4.010000e-07	1.882230e-09	401.0	9.591616e-09
3	4.020000e-07	1.715430e-09	402.0	8.741624e-09
4	4.030000e-07	3.365860e-09	403.0	1.715202e-08
...	...	...	...	...
697	1.096000e-06	2.995650e-05	1096.0	1.526547e-04
698	1.097000e-06	2.358150e-05	1097.0	1.201685e-04
699	1.098000e-06	1.770760e-05	1098.0	9.023579e-05
700	1.099000e-06	1.305950e-05	1099.0	6.654963e-05
701	1.100000e-06	0.000000e+00	1100.0	0.000000e+00

702 rows × 4 columns

In [5]:
```
%matplotlib notebook
plt.plot(f6535['wavelength [m]']*u.m.to(u.um),f6535['transmission']/np.
plt.plot(fhair['wavelength [m]']*u.m.to(u.um),fhair['transmission']/np.
plt.xlabel('Wavelength [$\mu$m]')
plt.ylabel('Transmission')
plt.tight_layout()
```



In [6]:

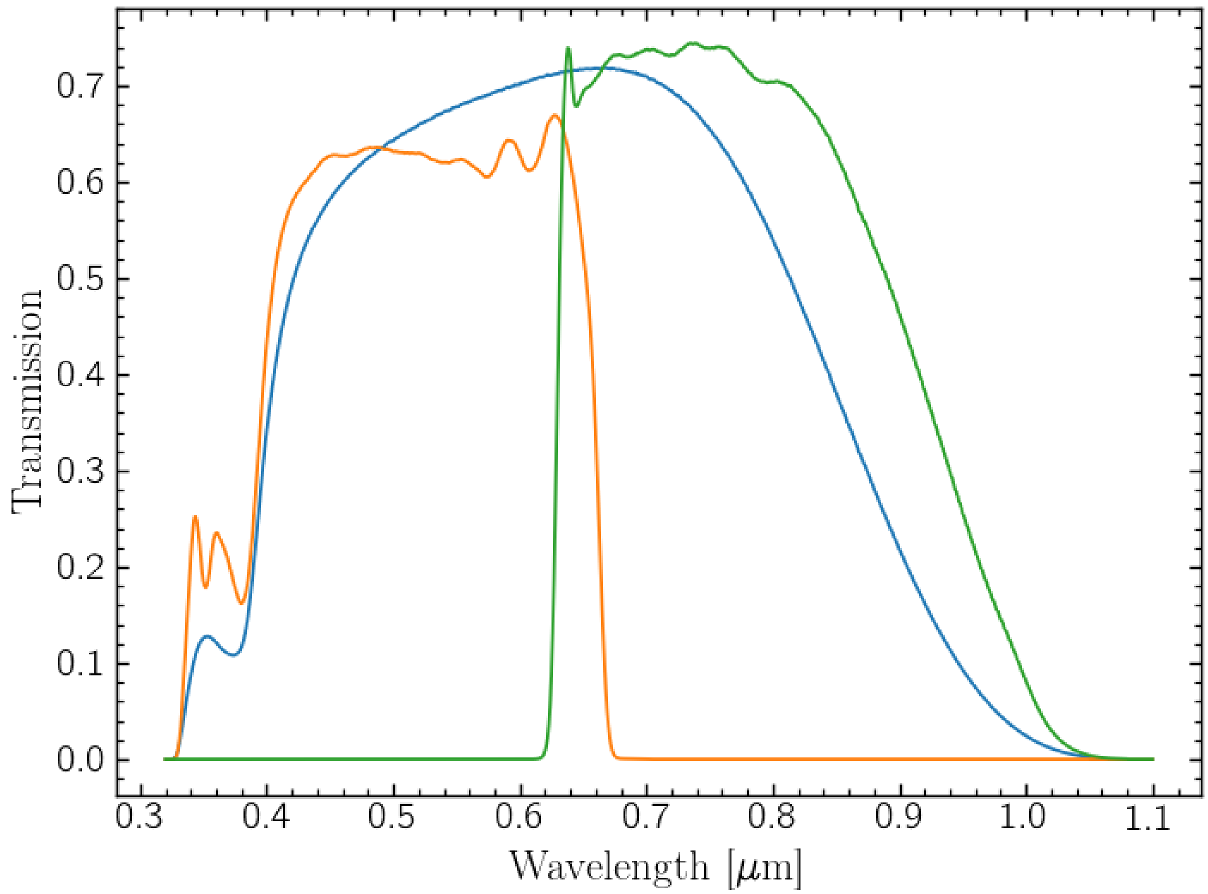
```
g = pd.read_table('../filter_curves/GaiaEDR3_passbands_zeropoints_versi
                  names=['wavelength [nm]','G','eG','BP','eBP','RP','eR
ind = g.loc[np.where(g['BP']==99.99)[0]]
g['BP'].loc[np.where(g['BP']==99.99)[0]] = 0
g['RP'].loc[np.where(g['RP']==99.99)[0]] = 0
g['G'].loc[np.where(g['G']==99.99)[0]] = 0
g
```

Out[6]:

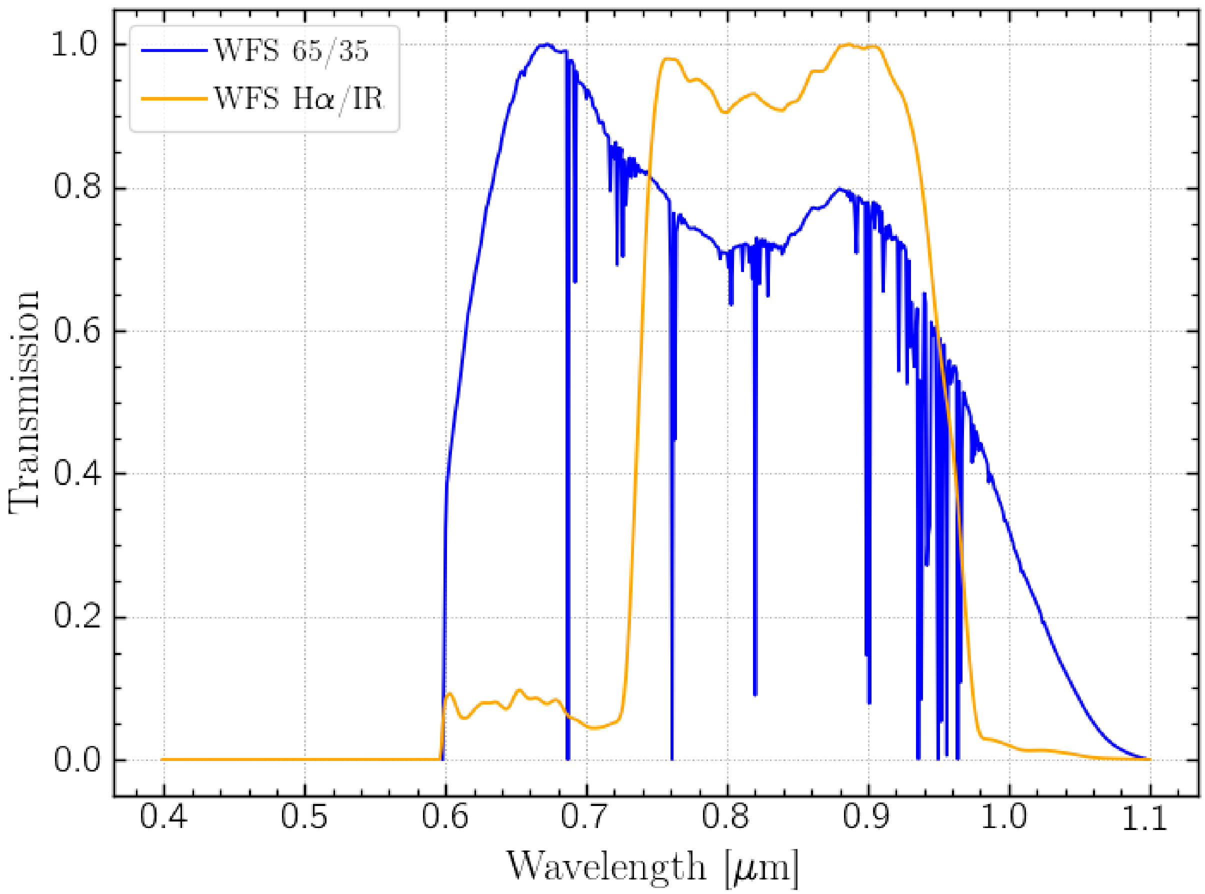
	wavelength [nm]	G	eG	BP	eBP	RP	eRP
0	320.0	2.373670e-08	2.341033e-11	0.0	99.99	0.0	99.99
1	321.0	1.577744e-07	1.540369e-10	0.0	99.99	0.0	99.99
2	322.0	9.085548e-07	8.780532e-10	0.0	99.99	0.0	99.99
3	323.0	4.780723e-06	4.573254e-09	0.0	99.99	0.0	99.99
4	324.0	2.394281e-05	2.266986e-08	0.0	99.99	0.0	99.99
...	...	...	...	...	...	...	...
776	1096.0	0.000000e+00	9.999000e+01	0.0	99.99	0.0	99.99
777	1097.0	0.000000e+00	9.999000e+01	0.0	99.99	0.0	99.99
778	1098.0	0.000000e+00	9.999000e+01	0.0	99.99	0.0	99.99
779	1099.0	0.000000e+00	9.999000e+01	0.0	99.99	0.0	99.99
780	1100.0	0.000000e+00	9.999000e+01	0.0	99.99	0.0	99.99

781 rows × 7 columns

In [7]:
```
%matplotlib notebook
plt.plot(g['wavelength [nm]']*u.nm.to(u.um),g['G'])
plt.plot(g['wavelength [nm]']*u.nm.to(u.um),g['BP'])
plt.plot(g['wavelength [nm]']*u.nm.to(u.um),g['RP'])
plt.xlabel('Wavelength [$\mu$m]')
plt.ylabel('Transmission')
plt.tight_layout()
```

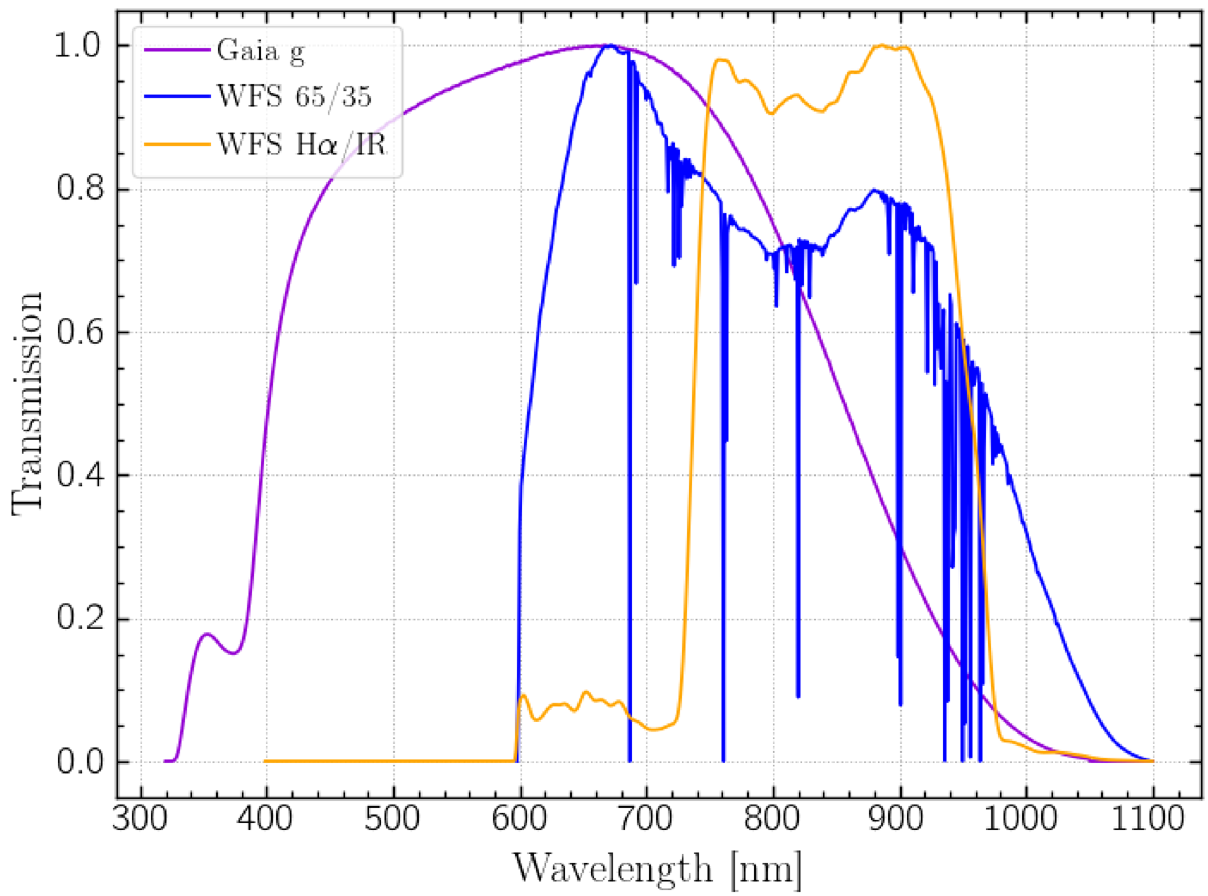


In [8]:
```
directory = '/Users/loganpearce/Dropbox/Uarizona/research/filter_curves

%matplotlib notebook
#plt.plot(g['wavelength [nm]']*u.nm.to(u.um),g['normalized G'], label='
plt.plot(f6535['wavelength [m]']*u.m.to(u.um),f6535['normalized transmi
plt.plot(fhair['wavelength [m]']*u.m.to(u.um),fhair['normalized transmi
plt.xlabel('Wavelength [$\mu$m]')
plt.ylabel('Transmission')
plt.legend(fontsize=15,loc='upper left')
plt.tight_layout()
plt.grid(ls=':')
plt.savefig('../MagAO-X_public/WFS-curves.png')
plt.savefig(directory+'WFS-curves.png')
```



In [10]:

```
g['normalized G'] = g['G']/np.max(g['G'])
g['normalized BP'] = g['BP']/np.max(g['BP'])
g['normalized RP'] = g['RP']/np.max(g['RP'])

%matplotlib notebook
plt.plot(g['wavelength [nm]'],g['normalized G'], label='Gaia g',color='
plt.plot(f6535['wavelength [nm]'],f6535['normalized transmission'], lab
plt.plot(fhair['wavelength [nm]'],fhair['normalized transmission'], lab
plt.xlabel('Wavelength [nm]')
plt.ylabel('Transmission')
plt.legend(fontsize=15,loc='upper left')
plt.tight_layout()
plt.grid(ls=':')
plt.savefig('../MagAO-X_public/WFS-Gaia-curves.png')
plt.savefig(directory+'WFS-Gaia-curves.png')
```



In [11]:

```
# Determine step sizes for each filter set:
dl_f6535 = np.mean([f6535['wavelength [nm]'][i+1] - f6535['wavelength [
              for i in range(1,len(f6535['wavelength [nm]'])-1)])
dl_fhair = np.mean([fhair['wavelength [nm]'][i+1] - fhair['wavelength [
              for i in range(1,len(fhair['wavelength [nm]'])-1)])
dl_g = np.mean([g['wavelength [nm]'][i+1] - g['wavelength [nm]'][i]
              for i in range(1,len(g['wavelength [nm]'])-1)])

# Determine effective wavelength:
GaiaG_lambda0 = np.sum(g['wavelength [nm]']*g['normalized G']* dl_g)/ \
                np.sum(g['normalized G']* dl_g)
GaiaBP_lambda0 = np.sum(g['wavelength [nm]']*g['normalized BP']* dl_g)/
                np.sum(g['normalized BP']* dl_g)
GaiaRP_lambda0 = np.sum(g['wavelength [nm]']*g['normalized RP']* dl_g)/
                np.sum(g['normalized RP']* dl_g)
f6535_lambda0 = np.sum(f6535['wavelength [nm]']*f6535['normalized trans
                np.sum(f6535['normalized transmission']* dl_f6535)
fhair_lambda0 = np.sum(fhair['wavelength [nm]']*fhair['normalized trans
                np.sum(fhair['normalized transmission']* dl_fhair)
```

In [12]:

```
dl_f6535 = np.mean([f6535['wavelength [nm]'][i+1] - f6535['wavelength [
              for i in range(1,len(f6535['wavelength [nm]'])-1)])
dl_fhair = np.mean([fhair['wavelength [nm]'][i+1] - fhair['wavelength [
              for i in range(1,len(fhair['wavelength [nm]'])-1)])
dl_g = np.mean([g['wavelength [nm]'][i+1] - g['wavelength [nm]'][i]
              for i in range(1,len(g['wavelength [nm]'])-1)])
dl_g,dl_f6535,dl_fhair
```

Out[12]:

```
(1.0, 0.9999999999999998, 1.0)
```

In [13]:

```
k = fits.getdata(z[0])
k_wavenm = k['wavelength']*u.AA.to(u.nm)

from scipy.interpolate import interp1d
spl = interp1d(k_wavenm, k['flux'])

F_lambda0_g = spl(GaiaG_lambda0)
F_lambda0_bp = spl(GaiaBP_lambda0)
F_lambda0_rp = spl(GaiaRP_lambda0)
F_lambda0_f6535 = spl(f6535_lambda0)
F_lambda0_fhair = spl(fhair_lambda0)

# Colors:
GaiaG_to_f6535 = -2.5*np.log10(F_lambda0_g) - (-2.5*np.log10(F_lambda0_
GaiaG_to_fhair = -2.5*np.log10(F_lambda0_g) - (-2.5*np.log10(F_lambda0_
GaiaBP_RP = -2.5*np.log10(F_lambda0_bp) - (-2.5*np.log10(F_lambda0_rp))
print(GaiaBP_RP, GaiaG_to_f6535, GaiaG_to_fhair)
```

```
-1.7532864681297404 -0.913168607991345 -1.1443593022930152
```

In [14]:

```
from scipy.interpolate import interp1d

G6535_colors = np.array([])
GHaIR_colors = np.array([])
BPRP_colors = np.array([])

for SpT in spt:
    k = pickles[SpT]
    k_wavenm = k['wavelength']*u.AA.to(u.nm)

    from scipy.interpolate import interp1d
    spl = interp1d(k_wavenm, k['flux'])

    F_lambda0_g = spl(GaiaG_lambda0)
    F_lambda0_bp = spl(GaiaBP_lambda0)
    F_lambda0_rp = spl(GaiaRP_lambda0)
    F_lambda0_f6535 = spl(f6535_lambda0)
    F_lambda0_fhair = spl(fhair_lambda0)

    # Colors:
    GaiaG_to_f6535 = -2.5*np.log10(F_lambda0_g) - (-2.5*np.log10(F_lamb
    GaiaG_to_fhair = -2.5*np.log10(F_lambda0_g) - (-2.5*np.log10(F_lamb
    GaiaBP_RP = -2.5*np.log10(F_lambda0_bp) - (-2.5*np.log10(F_lambda0_

    G6535_colors = np.append(G6535_colors, GaiaG_to_f6535)
    GHaIR_colors = np.append(GHaIR_colors, GaiaG_to_fhair)
    BPRP_colors = np.append(BPRP_colors, GaiaBP_RP)

p_wfs = pd.DataFrame()
p_wfs['SpT'],p_wfs['Gaia BP-RP'],p_wfs['G - 65/35 color'],p_wfs['G - Ha
                G6535_colors, GHaIR_colors
p_wfs
```

Out[14]:

	SpT	Gaia BP-RP	G - 65/35 color	G - Ha/IR color
0	O5V	-1.753286	-0.913169	-1.144359
1	O9V	-1.759123	-0.876533	-1.122929
2	B0V	-1.691478	-0.858265	-1.115505
3	B1V	-1.576876	-0.816744	-1.074639
4	B3V	-1.522363	-0.769310	-0.973999
...	...	...	...	...
63	M6III	2.861989	1.167731	1.838463
64	M7III	3.690518	1.445635	2.439192
65	M8III	4.309958	1.565400	2.786293
66	M9III	4.147218	1.428649	2.673833
67	M10III	4.413303	1.540157	3.102000

68 rows × 4 columns

In [15]:
```
dwarfs = [i for i in p_wfs['SpT'] if 'V' in i]
giants = [i for i in p_wfs['SpT'] if 'III' in i]

dwarfs_colors = [p_wfs['G - 65/35 color'][i] for i in range(len(dwarfs)
giants_colors = [p_wfs['G - 65/35 color'][i] for i in range(len(dwarfs)
dwarfs_gaia_colors = [p_wfs['Gaia BP-RP'][i] for i in range(len(dwarfs)
giants_gaia_colors = [p_wfs['Gaia BP-RP'][i] for i in range(len(dwarfs)

dwarfs_colors2 = [p_wfs['G - Ha/IR color'][i] for i in range(len(dwarfs
giants_colors2 = [p_wfs['G - Ha/IR color'][i] for i in range(len(dwarfs

```

In [16]:
```
spt_letter_conv = {'O':0,'B':1,'A':2,'F':3,'G':4,'K':5,'M':6}

spt_numbers = np.array([])
for s in spt:
    letter = s[0]
    number = spt_letter_conv[letter]

    type_number = np.float(s[1]) / 10

    spt_numbers = np.append(spt_numbers,number + type_number)

spt_numbers[-1] = 7.0
spt_numbers[5] = 1.6
spt_numbers_dwarfs = spt_numbers[range(len(dwarfs))]
spt_numbers_giants = spt_numbers[range(len(dwarfs),len(spt_numbers))]
spt_numbers_dwarfs,spt_numbers_giants
```

Out[16]:
```
(array([0.5, 0.9, 1. , 1.1, 1.3, 1.6, 1.8, 1.9, 2. , 2.2, 2.3, 2.5, 2.7,
        3. , 3.2, 3.5, 3.6, 3.8, 4. , 4.2, 4.5, 4.8, 5. , 5.2, 5.3, 5.4,
        5.5, 5.7, 6. , 6.1, 6.2, 6.2, 6.3, 6.4, 6.5, 6.6]),
 array([0.8, 1.1, 1.3, 1.5, 1.9, 2. , 2.3, 2.5, 2.7, 3. , 3.2, 3.5, 4. ,
        4.5, 4.8, 5. , 5.1, 5.2, 5.3, 5.4, 5.5, 6. , 6.1, 6.2, 6.3, 6.4,
        6.5, 6.6, 6.7, 6.8, 6.9, 7. ]))
```

In [17]:

```
p_wfs['SpT Number'] = spt_numbers
p_wfs.to_csv('GaiaG_WFS_color_conversion.csv',index=False)
p_wfs.to_csv(directory+'GaiaG_WFS_color_conversion.csv',index=False)
p_wfs
```

Out[17]:

	SpT	Gaia BP-RP	G - 65/35 color	G - Ha/IR color	SpT Number
0	O5V	-1.753286	-0.913169	-1.144359	0.5
1	O9V	-1.759123	-0.876533	-1.122929	0.9
2	B0V	-1.691478	-0.858265	-1.115505	1.0
3	B1V	-1.576876	-0.816744	-1.074639	1.1
4	B3V	-1.522363	-0.769310	-0.973999	1.3
...	...	...	...	...	...
63	M6III	2.861989	1.167731	1.838463	6.6
64	M7III	3.690518	1.445635	2.439192	6.7
65	M8III	4.309958	1.565400	2.786293	6.8
66	M9III	4.147218	1.428649	2.673833	6.9
67	M10III	4.413303	1.540157	3.102000	7.0

68 rows × 5 columns

In [18]:
```
p_wfs[:len(dwarfs)].to_csv('GaiaG_WFS_color_conversion-dwarfs.csv', ind
p_wfs[:len(dwarfs)]
```

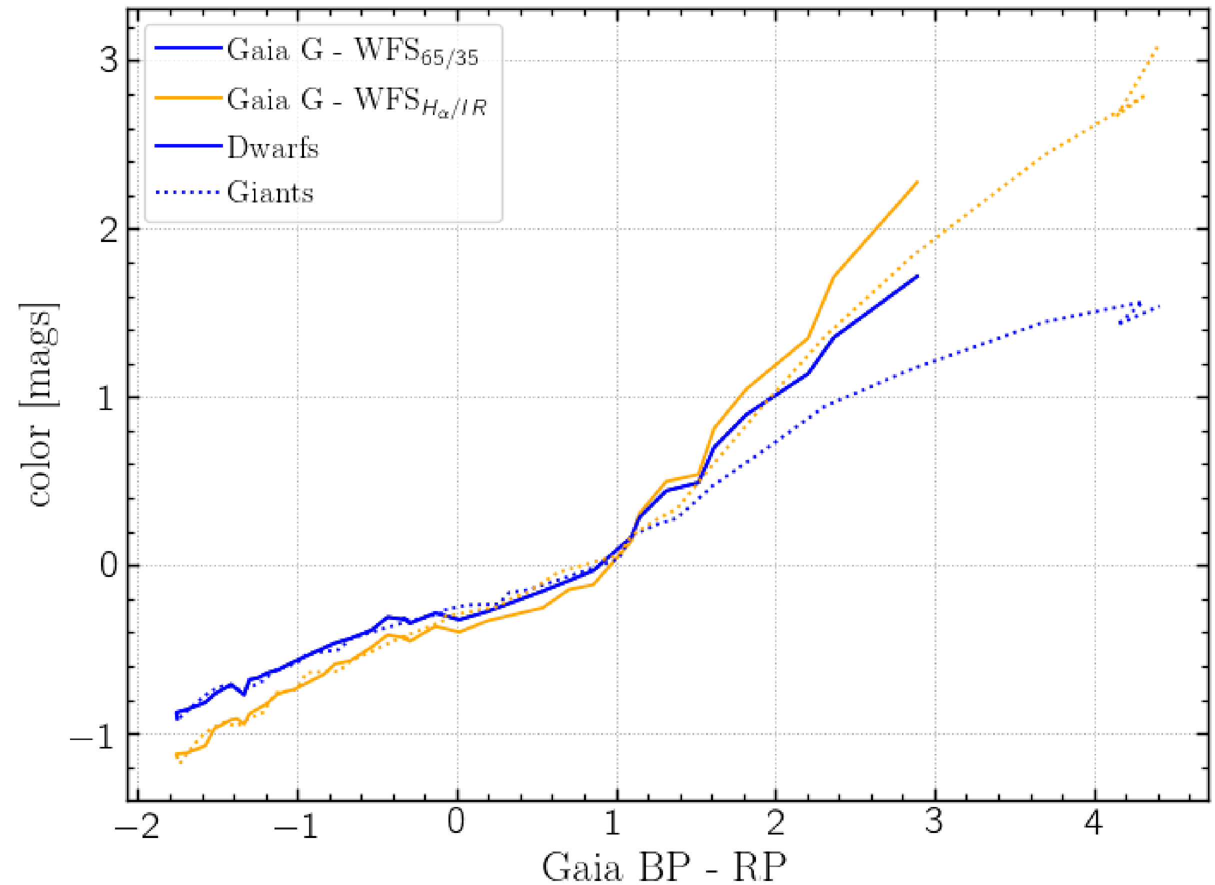
Out[18]:

	SpT	Gaia BP-RP	G - 65/35 color	G - Ha/IR color	SpT Number
0	O5V	-1.753286	-0.913169	-1.144359	0.5
1	O9V	-1.759123	-0.876533	-1.122929	0.9
2	B0V	-1.691478	-0.858265	-1.115505	1.0
3	B1V	-1.576876	-0.816744	-1.074639	1.1
4	B3V	-1.522363	-0.769310	-0.973999	1.3
5	B57V	-1.414522	-0.708785	-0.919704	1.6
6	B8V	-1.378287	-0.738685	-0.913619	1.8
7	B9V	-1.333443	-0.770971	-0.945338	1.9
8	A0V	-1.299172	-0.680670	-0.882710	2.0
9	A2V	-1.243093	-0.669132	-0.853022	2.2
10	A3V	-1.188863	-0.640910	-0.822082	2.3
11	A5V	-1.122917	-0.624290	-0.766289	2.5
12	A7V	-1.019593	-0.573833	-0.738065	2.7
13	F0V	-0.835827	-0.493682	-0.651311	3.0
14	F2V	-0.764432	-0.463906	-0.588959	3.2
15	F5V	-0.667340	-0.436827	-0.568548	3.5
16	F6V	-0.534392	-0.387383	-0.488193	3.6
17	F8V	-0.432657	-0.309275	-0.415122	3.8
18	G0V	-0.306904	-0.325406	-0.435026	4.0
19	G2V	-0.333389	-0.318766	-0.433490	4.2
20	G5V	-0.292217	-0.345564	-0.452592	4.5
21	G8V	-0.133017	-0.284652	-0.363772	4.8
22	K0V	0.016583	-0.324673	-0.398000	5.0
23	K2V	0.196112	-0.274918	-0.330736	5.2
24	K3V	0.540885	-0.154610	-0.253983	5.3
25	K4V	0.704193	-0.093564	-0.145960	5.4
26	K5V	0.857385	-0.032463	-0.117300	5.5
27	K7V	1.097466	0.166133	0.142296	5.7
28	M0V	1.145770	0.282430	0.304490	6.0
29	M1V	1.316385	0.442299	0.497946	6.1
30	M2V	1.518757	0.490685	0.539141	6.2
31	M2.5V	1.617733	0.700961	0.814714	6.2
32	M3V	1.820338	0.895735	1.048387	6.3
33	M4V	2.207078	1.138602	1.350243	6.4

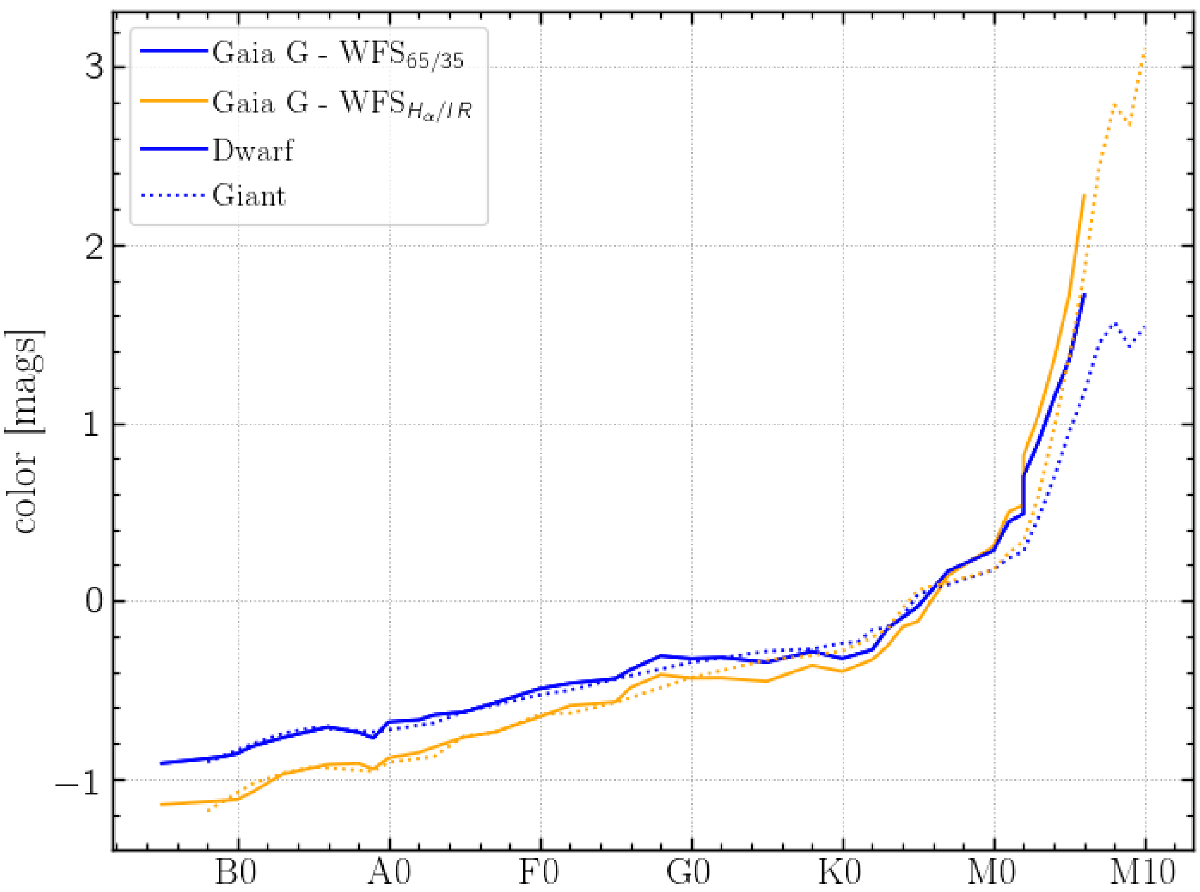
	SpT	Gaia BP-RP	G - 65/35 color	G - Ha/IR color	SpT Number
34	M5V	2.366079	1.351703	1.712598	6.5
35	M6V	2.892390	1.717700	2.277202	6.6

In [19]:

```
%matplotlib notebook
c=['blue','orange']
plt.plot(dwarfs_gaia_colors,dwarfs_colors, color=c[0],label=r'Gaia G -
plt.plot(dwarfs_gaia_colors,dwarfs_colors2,color=c[1],label=r'Gaia G -

plt.plot(dwarfs_gaia_colors,dwarfs_colors, color=c[0],label=r'Dwarfs')
plt.plot(giants_gaia_colors,giants_colors, color=c[0], ls=':',label=r'G
plt.plot(giants_gaia_colors,giants_colors2,color=c[1], ls=':')

#plt.plot(spt_numbers_dwarfs,dwarfs_colors,color=c[0],label='Dwarf')

#plt.ylim(-2.7,1)
#ticks = np.arange(1,7.5,1)
##labels = ['B0','A0','F0','G0','K0','M0','M10']
#plt.gca().set_xticks(ticks)
#plt.gca().set_xticklabels(labels)
plt.ylabel('color [mags]')
plt.xlabel('Gaia BP - RP')
plt.legend(fontsize=15)

#ax1 = plt.gca()
#ax2 = ax1.twiny()
#lims = ax1.get_xlim()
#ax2.set_xlim(ax1.get_xlim())
#ticks = np.linspace(lims[0],lims[1],7)
#labels = ['B0','A0','F0','G0','K0','M0','M10']
#ax2.set_xticks(ticks)
#ax2.set_xticklabels(labels)

plt.tight_layout()
plt.grid(ls=':')
plt.savefig('GaiaG_to_MagAO-X_WFS_color_conversion-ByBPRPcolor.png',dpi
plt.savefig(directory+'GaiaG_to_MagAO-X_WFS_color_conversion-ByBPRPcolo
plt.show()
```


Gaia G - WFS$_{65/35}$
Gaia G - WFS$_{H_\alpha/IR}$
Dwarfs
Giants
color [mags]
Gaia BP - RP
3
2
1
0
−1
−2
−1
0
1
2
3
4

In [20]:
```
%matplotlib notebook
c=['blue','orange']
plt.plot(spt_numbers_dwarfs,dwarfs_colors,color=c[0],label='Gaia G - WF
plt.plot(spt_numbers_dwarfs,dwarfs_colors2,color=c[1],label=r'Gaia G -

plt.plot(spt_numbers_dwarfs,dwarfs_colors,color=c[0],label='Dwarf')
plt.plot(spt_numbers_giants,giants_colors,color=c[0],ls=':',label = 'Gi
plt.plot(spt_numbers_giants,giants_colors2,color=c[1],ls=':')

#plt.ylim(-2.7,1)
ticks = np.arange(1,7.5,1)
labels = ['B0','A0','F0','G0','K0','M0','M10']
plt.gca().set_xticks(ticks)
plt.gca().set_xticklabels(labels)
plt.ylabel('color [mags]')
plt.legend(fontsize=15)

#ax1 = plt.gca()
#ax2 = ax1.twiny()
#ax2.set_xlim(ax1.get_xlim())
#ax2.set_xticks(p_wfs['Gaia BP-RP'])

plt.tight_layout()
plt.grid(ls=':')
plt.savefig('GaiaG_to_MagAO-X_WFS_color_conversion.png',dpi=300)
plt.savefig(directory+'GaiaG_to_MagAO-X_WFS_color_conversion.png',dpi=3
plt.show()
```



In [ ]:

```
1
```