WP2outline

March 22, 2018

```
In [1]: from plotting import *
        from CVZ import *
        from JWST_SNR import compute_transmission_SNR
        %matplotlib inline
        # get simulation
        self = loadpickle('pickles/RVInformationGP_Nrvge10')
        #self = loadpickle('pickles/RVInformationGP')

In [2]: # add overheads
        overhead_sec = 30.
        self.tobsGPs_med_N += self.NrvGPs_med_N * overhead_sec / (60*60)

In [3]: # write function that returns indices of planets of interest based on their median obser
        def get_planets(tobs, g, N=0, sort=True):
            tobsinds = np.argsort(tobs[g]) if sort else np.arange(tobs[g].size)
            inds = np.arange(tobs.size)[g][tobsinds]
            return inds if N == 0 else inds[:int(N)]

In [4]: # get K2 targets
        fname = 'input_data/K2planets_Kdwarfs.csv'
        starname, planetname = np.genfromtxt(fname,delimiter=',',skip_header=75,usecols=(1,2),dt
        starnames = np.array(['%s%s'%(starname[i], planetname[i]) for i in range(starname.size)]
        PK2,aK2,rpK2,TeffK2,MsK2,RsK2,JK2 = np.genfromtxt(fname,delimiter=',',skip_header=75,use
        assert PK2.size == starnames.size
        aK2[np.isnan(aK2)] = rvs.semimajoraxis(PK2, MsK2, 0)[np.isnan(aK2)]
        rpK2 *= 11.21
        TpK2 = TeffK2 * np.sqrt(rvs.Rsun2m(RsK2)/(2*rvs.AU2m(aK2)))
        muK2 = np.repeat(2, TpK2.size)
        muK2[rpK2 <= 2] = 30.
        mpK2 = rvs.kg2Mearth(9.8*rvs.Rearth2m(rpK2)**2 / 6.67e-11)
        transmissionK2_ppm = rvs.transmission_spectroscopy_depth(RsK2, mpK2, rpK2, TpK2, muK2)
```

0.1 Measuring the 3σ mass of one temperate Earth-sized planet

```
In [5]: ind = 1451
        inds = np.array([ind])
        print 'Orbital period = %.3f days'%self.Ps_med[ind]
        print 'Planet radius = %.3f Earth radii'%self.rps_med[ind]
```

```
        print 'Planet mass = %.3f Earth masses'%self.mps_med[ind]
        print 'J = %.3f'%self.Jmags_med[ind]
        print 'Stellar effective temperature = %i K'%self.Teffs_med[ind]
```

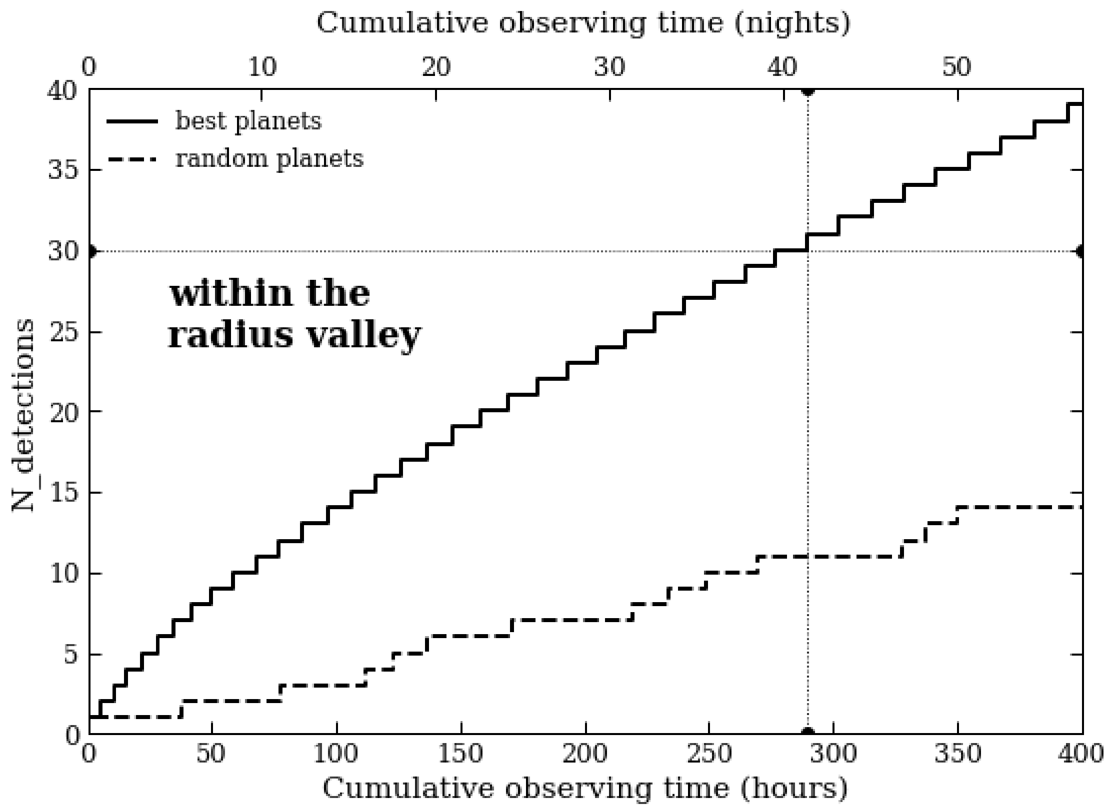
```
Orbital period = 26.300 days
Planet radius = 1.292 Earth radii
Planet mass = 2.660 Earth masses
J = 10.270
Stellar effective temperature = 3284 K
```

```
In [6]: print 'Exposure time = %.2f minutes'%self.texps_med_N[ind]
        print 'RV precision = %.2f m/s'%self.sigmaRV_phot_med_N[ind]
        print 'Median effective RV rms = %.2f m/s'%self.sigmaRV_eff_med_N[ind]
        print 'Median number of RV measurements required = %.1f'%self.NrvGPs_med_N[ind]
        print 'Total observing time = %.1f hours (i.e. %.1f nights)'%(self.tobsGPs_med_N[ind], s
        tobs_WP2 = self.tobsGPs_med_N[ind]
```

```
Exposure time = 10.00 minutes
RV precision = 2.98 m/s
Median effective RV rms = 7.86 m/s
Median number of RV measurements required = 248.8
Total observing time = 43.5 hours (i.e. 6.2 nights)
```

0.2 Measuring the 5σ mass of the 30 'best' planets within the radius valley

```
In [7]: Nf1 = 30
        scale = (.327/.189)**2  # 3 -> 5 sigma
        g = (self.rps_med >= 1.5) & (self.rps_med <= 2.5) & (self.decs_med > -15)
        tobs = np.append(0, np.cumsum(np.sort(self.tobsGPs_med_N[g]*scale)))
        tobs2 = np.append(0, np.cumsum(self.tobsGPs_med_N[g]*scale))
        Ndet= np.arange(tobs.size)
        fig = plt.figure(figsize=(9,6))
        ax1 = fig.add_subplot(111)
        ax1.plot(tobs, Ndet, 'k-', lw=2, drawstyle='steps', label='best planets')
        ax1.plot(tobs2, Ndet, 'k--', lw=2, drawstyle='steps', label='random planets')
        ax1.axhline(Nf1, ls=':', lw=.8), ax1.axvline(tobs[Ndet==Nf1], ls=':', lw=.9)
        tobs_WP2 = np.append(tobs_WP2, tobs[Ndet==Nf1])
        ax1.set_xlim((0,4e2)), ax1.set_ylim((0,40)), ax1.legend(loc='upper left', fontsize=12)
        ax1.set_xlabel('Cumulative observing time (hours)'), ax1.set_ylabel('N_detections')
        ax1.text(.08, .6, 'within the\nradius valley', transform=ax1.transAxes, fontsize=18, wei
        ax2 = ax1.twiny()
        ax2.set_xlim((0,4e2/7)), ax2.set_xlabel('Cumulative observing time (nights)', labelpad=1

Out[7]: ((0, 57.142857142857146), <matplotlib.text.Text at 0x1a11392690>)
```

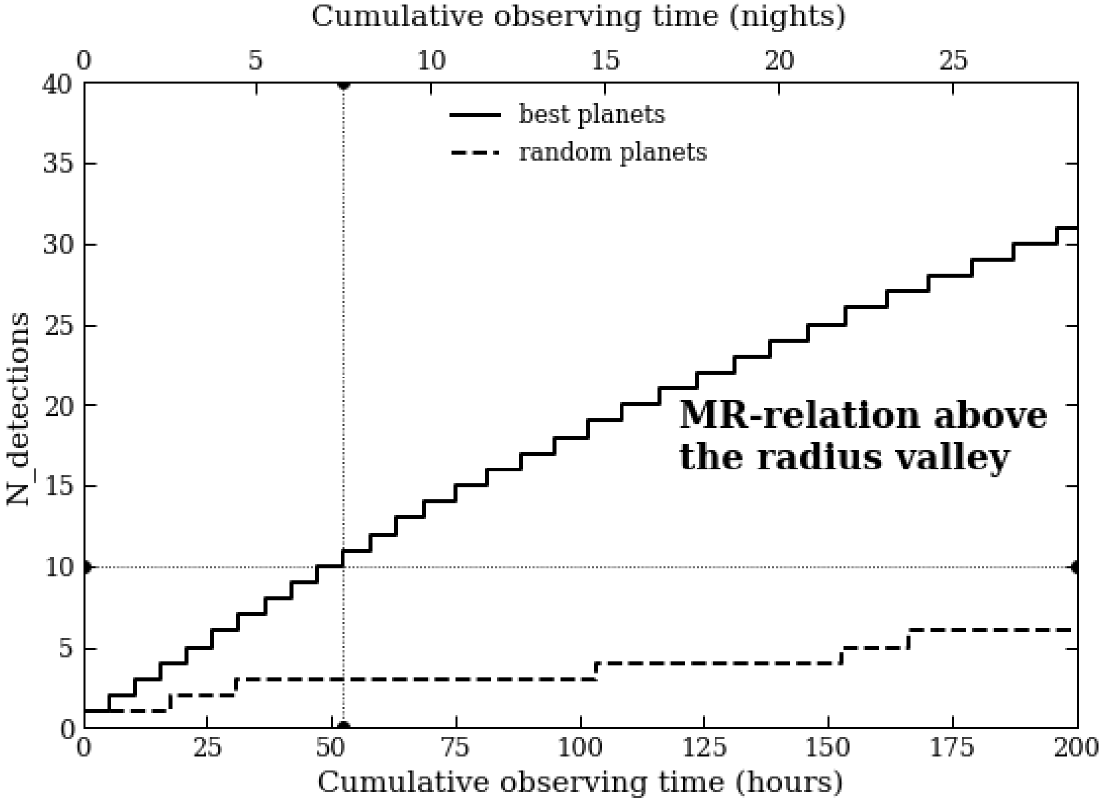



```
In [8]: # save TOI indices
        inds = np.append(inds, get_planets(self.tobsGPs_med_N, g, Nf1))
```

0.3 Extending the MR relation with 10 planets with $r_p \in [2.5, 4] R_\oplus$

```
In [9]: Nf2 = 10
        g = (self.rps_med > 2.5) & (self.rps_med <= 4) & (self.decs_med > -15)
        tobs = np.append(0, np.cumsum(np.sort(self.tobsGPs_med_N[g]*scale)))
        tobs2 = np.append(0, np.cumsum(self.tobsGPs_med_N[g]*scale))
        Ndet= np.arange(tobs.size)
        fig = plt.figure(figsize=(9,6))
        ax1 = fig.add_subplot(111)
        ax1.plot(tobs, Ndet, 'k-', lw=2, drawstyle='steps', label='best planets')
        ax1.plot(tobs2, Ndet, 'k--', lw=2, drawstyle='steps', label='random planets')
        ax1.axhline(Nf2, ls=':', lw=.8), ax1.axvline(tobs[Ndet==Nf2], ls=':', lw=.9)
        tobs_WP2 = np.append(tobs_WP2, tobs[Ndet==Nf2])
        ax1.set_xlim((0,2e2)), ax1.set_ylim((0,40)), ax1.legend(loc='upper center', fontsize=12)
        ax1.set_xlabel('Cumulative observing time (hours)'), ax1.set_ylabel('N_detections')
        ax1.text(.6, .4, 'MR-relation above\nthe radius valley', transform=ax1.transAxes, fontsi
        ax2 = ax1.twiny()
        ax2.set_xlim((0,2e2/7)), ax2.set_xlabel('Cumulative observing time (nights)', labelpad=1
```

Out[9]: ((0, 28.571428571428573), <matplotlib.text.Text at 0x1a15ba1650>)

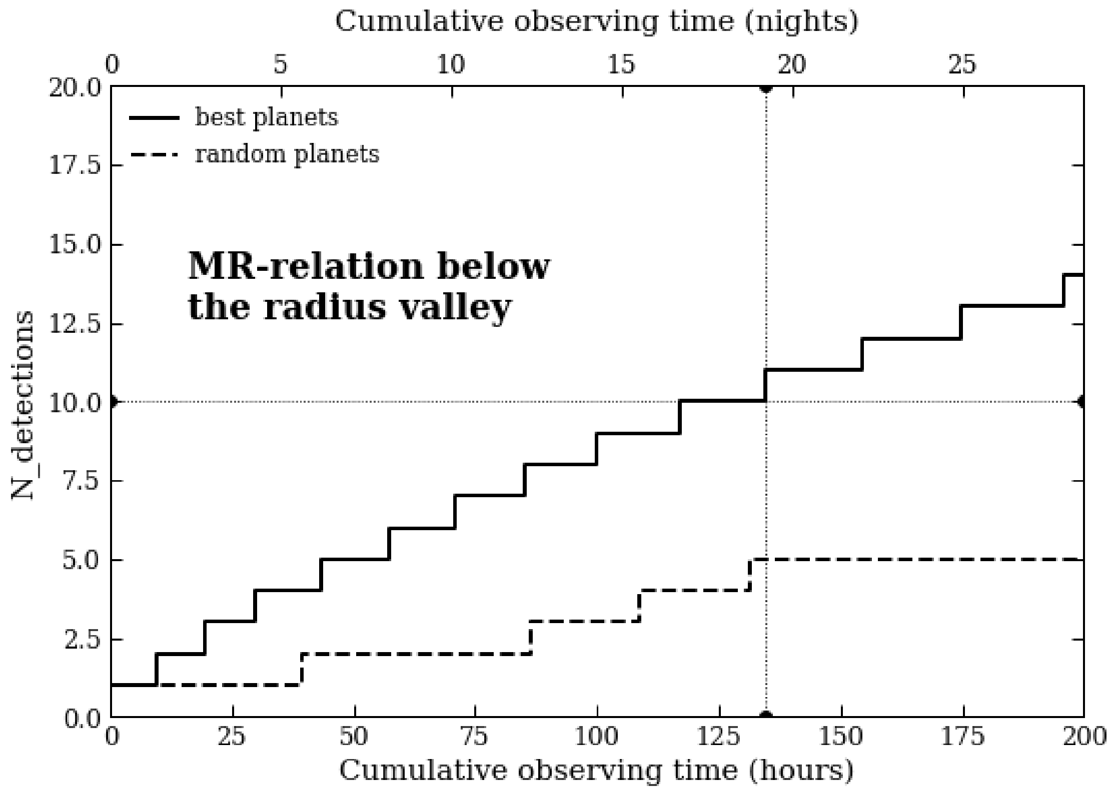



```
In [10]: inds = np.append(inds, get_planets(self.tobsGPs_med_N, g, Nf2))
```

0.4 Extending the MR relation with 10 more planets with $r_p < 1.5R_\oplus$

```
In [11]: Nf3=10
         g = (self.rps_med < 1.5) & (self.decs_med > -15)
         tobs = np.append(0, np.cumsum(np.sort(self.tobsGPs_med_N[g]*scale)))
         tobs2 = np.append(0, np.cumsum(self.tobsGPs_med_N[g]*scale))
         Ndet= np.arange(tobs.size)
         fig = plt.figure(figsize=(9,6))
         ax1 = fig.add_subplot(111)
         ax1.plot(tobs, Ndet, 'k-', lw=2, drawstyle='steps', label='best planets')
         ax1.plot(tobs2, Ndet, 'k--', lw=2, drawstyle='steps', label='random planets')
         ax1.axhline(Nf3, ls=':', lw=.8), ax1.axvline(tobs[Ndet==Nf3], ls=':', lw=.9)
         tobs_WP2 = np.append(tobs_WP2, tobs[Ndet==Nf3])
         ax1.set_xlim((0,2e2)), ax1.set_ylim((0,20)), ax1.legend(loc='upper left', fontsize=12)
         ax1.set_xlabel('Cumulative observing time (hours)'), ax1.set_ylabel('N_detections')
         ax1.text(.08, .63, 'MR-relation below\nthe radius valley', transform=ax1.transAxes, fon
         ax2 = ax1.twiny()
         ax2.set_xlim((0,2e2/7)), ax2.set_xlabel('Cumulative observing time (nights)', labelpad=
```

Out[11]: ((0, 28.571428571428573), <matplotlib.text.Text at 0x1a15cca590>)




```
In [12]: inds = np.append(inds, get_planets(self.tobsGPs_med_N, g, Nf3))
```

0.5 Measuring 5σ masses of TOIs amenable to transmission spectroscopy

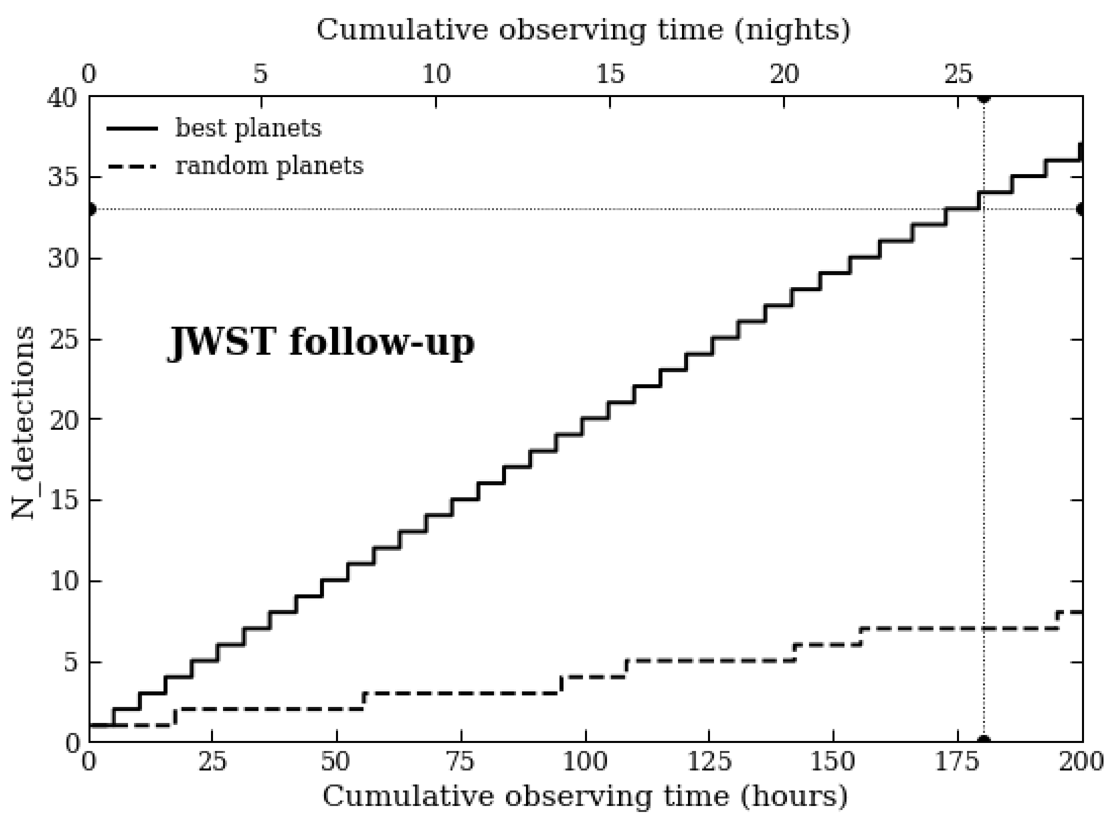
```
In [13]: # set number of WP2 nights available for RV follow-up
         transmission_spec_nights = 0
         trappist1_nights = 0
         total_nights = 100 - transmission_spec_nights - trappist1_nights
         tobs_remaining = total_nights*7. - tobs_WP2.sum()
```

Potential JWST targets must have $SNR_{transmission} \geq 10$, and $\delta > -15$ deg.

```
In [14]: gjwst = (np.in1d(np.arange(self.nstars), inds, invert=True)) & (compute_transmission_SN
         tobs = np.append(0, np.cumsum(np.sort(self.tobsGPs_med_N[gjwst]*scale)))
         tobs2 = np.append(0, np.cumsum(self.tobsGPs_med_N[gjwst]*scale))
         Ndet= np.arange(tobs.size)
         fig = plt.figure(figsize=(9,6))
         ax1 = fig.add_subplot(111)
         ax1.plot(tobs, Ndet, 'k-', lw=2, drawstyle='steps', label='best planets')
```

```
ax1.plot(tobs2, Ndet, 'k--', lw=2, drawstyle='steps', label='random planets')
Njwst = int(Ndet[abs(tobs-tobs_remaining) == np.min(abs(tobs-tobs_remaining))])
tobs_WP2 = np.append(tobs_WP2, tobs_remaining)
ax1.axhline(Njwst, ls=':', lw=.8), ax1.axvline(tobs_remaining, ls=':', lw=.9)
ax1.set_xlim((0,np.ceil(tobs_remaining/1e2)*1e2)), ax1.set_ylim((0,np.ceil(Njwst/1e1)*1
ax1.set_xlabel('Cumulative observing time (hours)'), ax1.set_ylabel('N_detections')
ax1.text(.08, .6, 'JWST follow-up', transform=ax1.transAxes, fontsize=18, weight='semib
ax2 = ax1.twiny()
ax2.set_xlim((0,np.ceil(tobs_remaining/1e2)*1e2/7)), ax2.set_xlabel('Cumulative observi
```

```
Out[14]: ((0, 28.571428571428573), <matplotlib.text.Text at 0x1a1526ad90>)
```




```
In [15]: inds = np.append(inds, get_planets(self.tobsGPs_med_N, gjwst, Njwst))
         print 'We detect %i random potential JWST targets in %.1f hours (i.e. %.1f nights)'%(Nj
```

```
We detect 33 random potential JWST targets in 180.0 hours (i.e. 25.7 nights)
```

0.6 Summary of WP2 time allocations and planet populations

```
In [16]: labels = ['1 temperature Earth-sized planet','%i planets within the radius valley'%Nf1,
         for i in range(tobs_WP2.size):
```

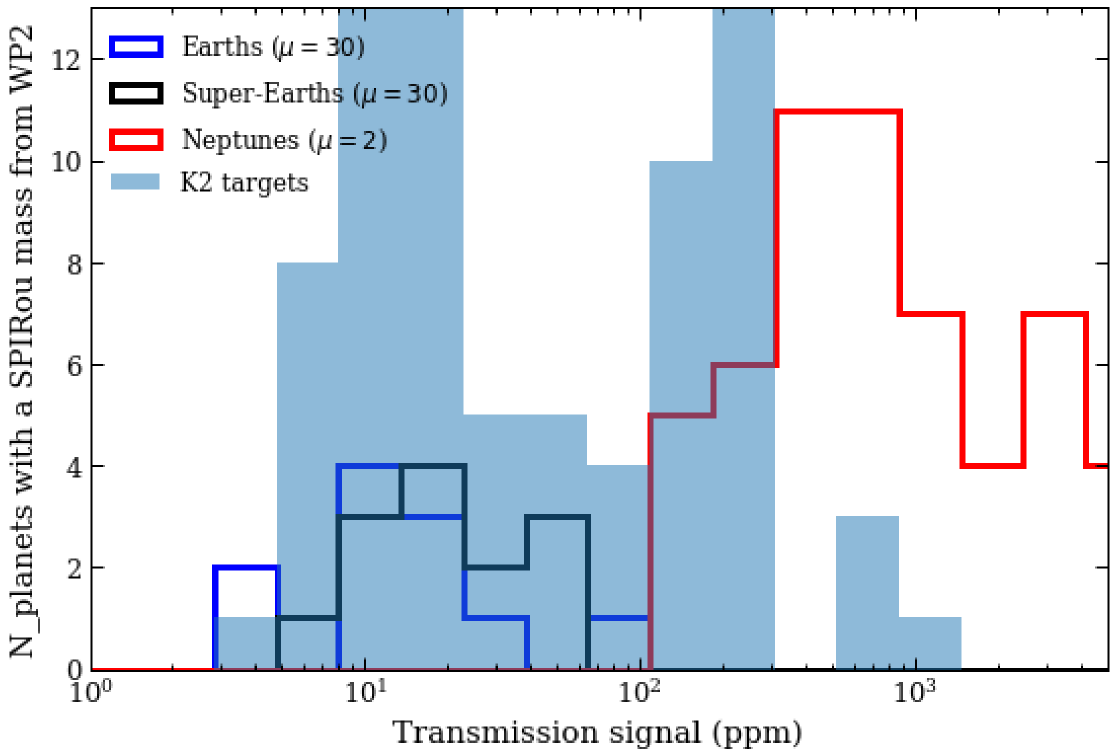
```
        print 'Measuring %s requires %.1f hours (i.e. %.1f nights).'%(labels[i], tobs_WP2[i
    print 'Total observing time for %i TESS targets = %.1f hours (i.e. %.1f nights)'%(inds.
    print '\nTransmission spectroscopy is allocated %.1f hours (i.e. %.1f nights)'%(transmi
    print 'Monitoring of the TRAPPIST-1 system is allocated %.1f hours (i.e. %.1f nights)'%
    tot_time = tobs_WP2.sum() + (transmission_spec_nights+trappist1_nights)*7
    print '\nTotal observing time for WP2 = %.1f hours (i.e. %.1f nights)'%(tot_time, tot_t
```

```
Measuring 1 temperature Earth-sized planet requires 43.5 hours (i.e. 6.2 nights).
Measuring 30 planets within the radius valley requires 289.5 hours (i.e. 41.4 nights).
Measuring 10 planets above the radius valley requires 52.4 hours (i.e. 7.5 nights).
Measuring 10 planets below the radius valley requires 134.5 hours (i.e. 19.2 nights).
Measuring 33 JWST follow-up planets requires 180.0 hours (i.e. 25.7 nights).
Total observing time for 84 TESS targets = 700.0 hours (i.e. 100.0 nights)

Transmission spectroscopy is allocated 0.0 hours (i.e. 0.0 nights)
Monitoring of the TRAPPIST-1 system is allocated 0.0 hours (i.e. 0.0 nights)

Total observing time for WP2 = 700.0 hours (i.e. 100.0 nights)
```

In [17]:
```
fig = plt.figure(figsize=(9,6))
ax1 = fig.add_subplot(111)
g1 = (np.in1d(np.arange(self.nstars), inds)) & (self.rps_med <= 1.5)
ax1.hist(self.transmission_ppm[g1], bins=np.logspace(0,4.3,20), histtype='step', color=
g3 = (np.in1d(np.arange(self.nstars), inds)) & (self.rps_med <= 2) & (self.rps_med > 1.
ax1.hist(self.transmission_ppm[g3], bins=np.logspace(0,4.3,20), histtype='step', color=
g2 = (np.in1d(np.arange(self.nstars), inds)) & (self.rps_med > 2)
ax1.hist(self.transmission_ppm[g2], bins=np.logspace(0,4.3,20), histtype='step', color=
ax1.hist(transmissionK2_ppm, bins=np.logspace(0,4.3,20), histtype='stepfilled', alpha=.
ax1.set_xscale('log'), ax1.set_xlim((0,5e3)), ax1.legend(loc='upper left', fontsize=12)
ax1.set_xlabel('Transmission signal (ppm)'), plt.ylabel('N_planets with a SPIRou mass f
ax1.set_ylim((0,13))
```

Out[17]:

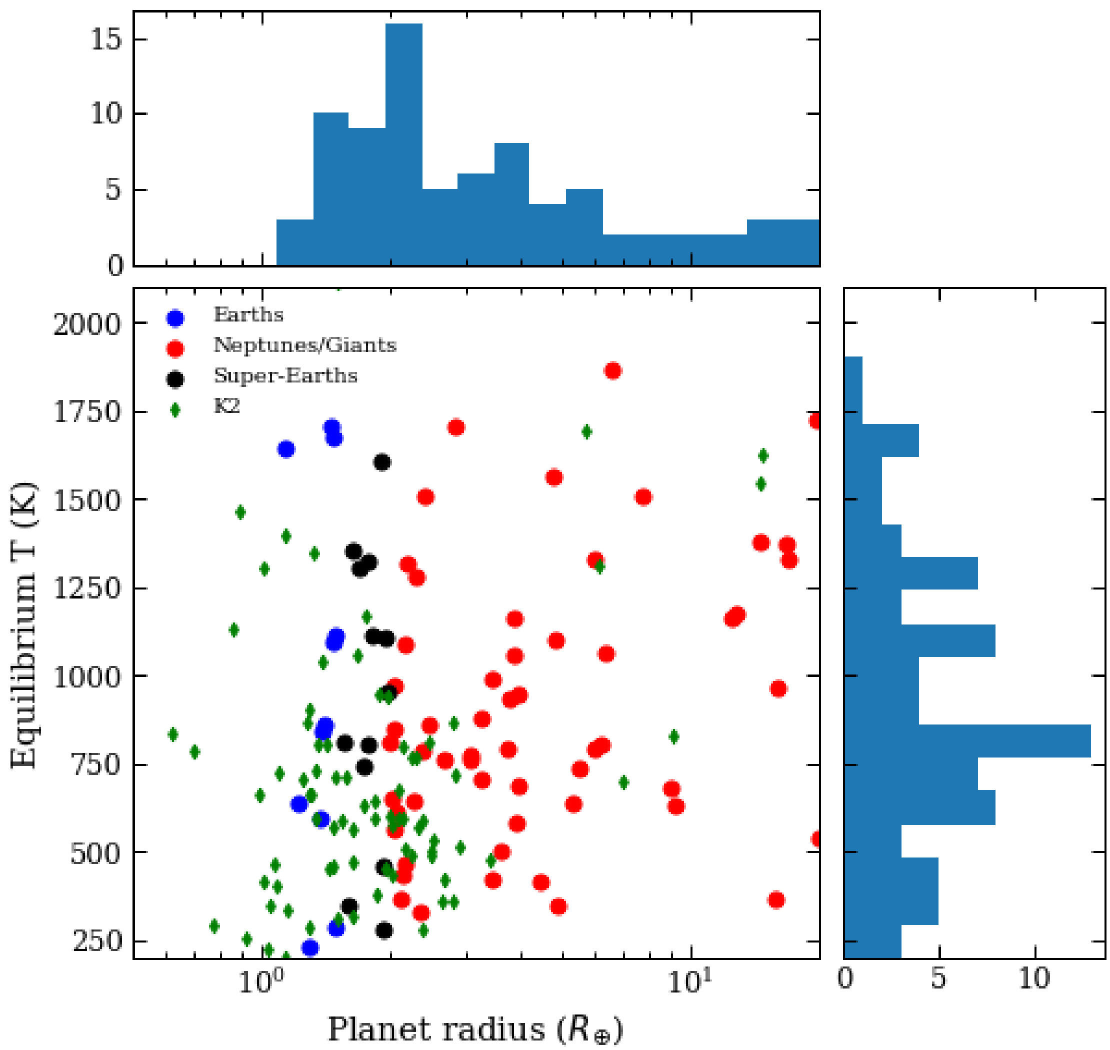
(0, 13)



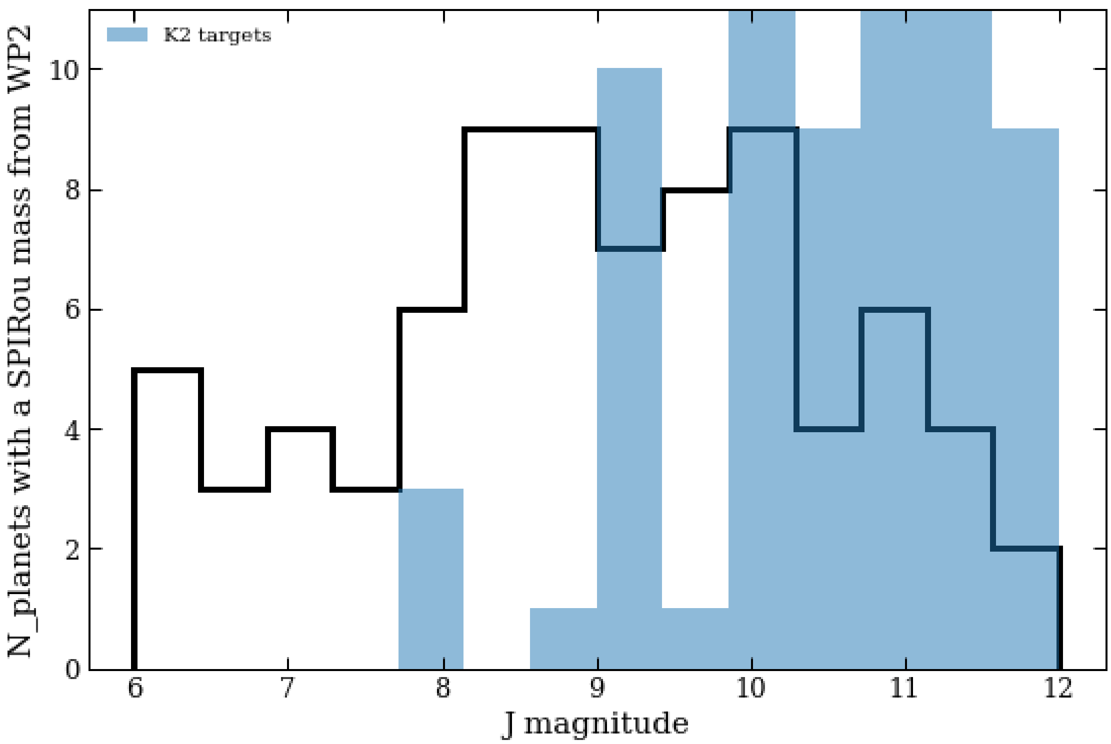

```
In [18]: fig = plt.figure(figsize=(8,8))
         gs = gridspec.GridSpec(7,7)
         ax1 = plt.subplot(gs[2:,:-2])
         ax2 = plt.subplot(gs[:2,:-2])
         ax3 = plt.subplot(gs[2:,-2:])
         ax1.scatter(self.rps_med[g1], self.Tps_med[g1], s=50, c='b', label='Earths'), ax1.set_x
         ax1.scatter(self.rps_med[g2], self.Tps_med[g2], s=50, c='r', label='Neptunes/Giants'),
         ax1.scatter(self.rps_med[g3], self.Tps_med[g3], s=50, c='k', label='Super-Earths')
         ax1.scatter(rpK2, TpK2, s=20, c='g', marker='d', label='K2')
         ax1.set_xlabel('Planet radius ($R_{\oplus}$)'), ax1.set_ylabel('Equilibrium T (K)')
         ax2.hist(self.rps_med[inds], bins=np.logspace(-.3,np.log10(20),20)), ax2.set_xscale('lo
         ax2.set_xticklabels(''), ax1.legend(loc='upper left')
         ax3.hist(self.Tps_med[inds], bins=np.linspace(2e2,2e3,20), orientation='horizontal')
         ax3.set_ylim((2e2,2.1e3)), ax3.set_yticklabels('')
```

Out[18]:

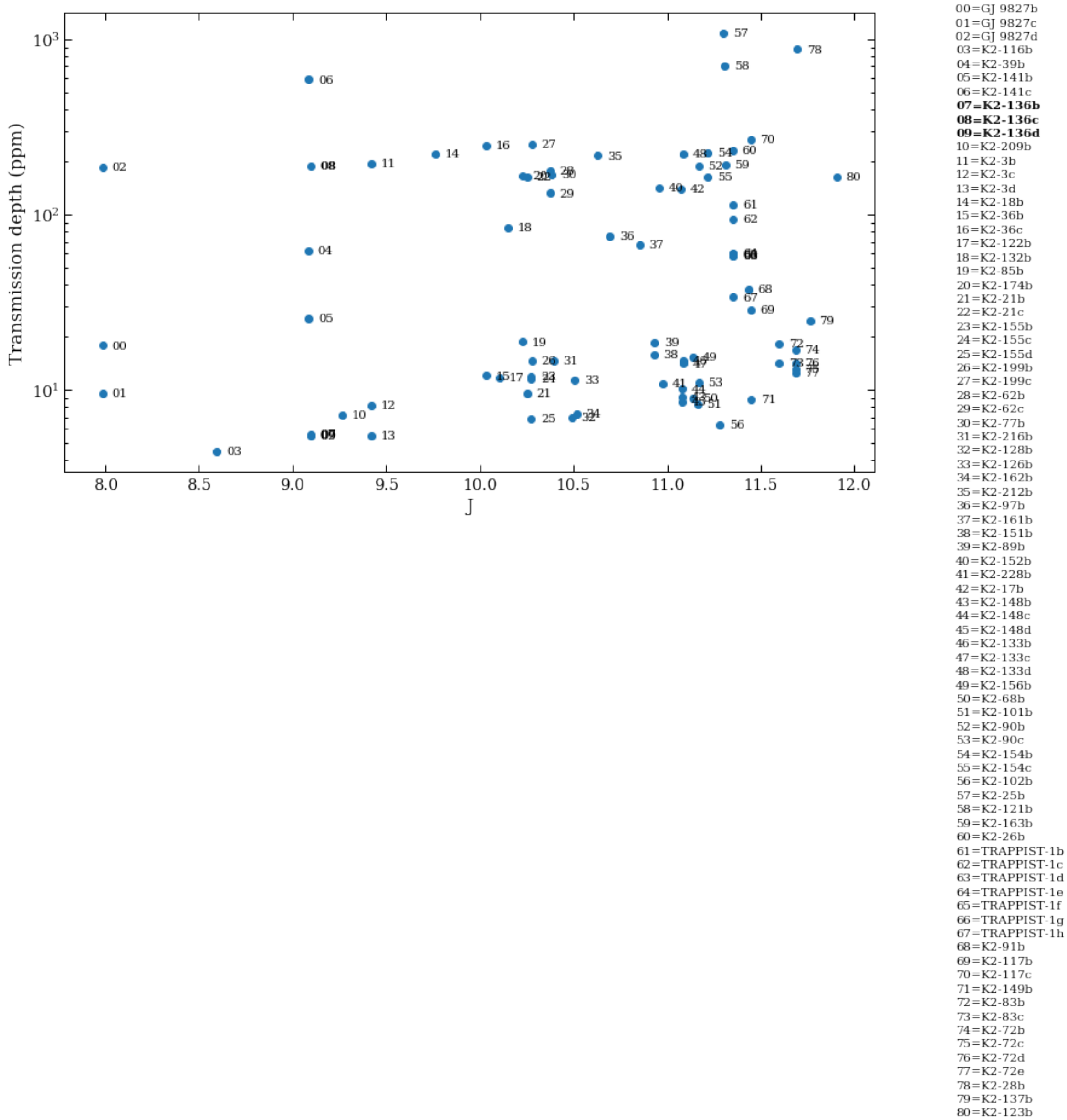
$$((200.0,\quad 2100.0),\quad [])$$




```
In [19]: fig = plt.figure(figsize=(9,6))
         ax1 = fig.add_subplot(111)
         ax1.hist(self.Jmags_med[inds], bins=np.linspace(6,12,15), histtype='step', color='k', l
         ax1.hist(JK2, bins=np.linspace(6,12,15), histtype='stepfilled', alpha=.5, label='K2 tar
         ax1.legend(loc='upper left')
         ax1.set_xlabel('J magnitude'), plt.ylabel('N_planets with a SPIRou mass from WP2'), ax1

Out[19]: (<matplotlib.text.Text at 0x1a160dab50>,
          <matplotlib.text.Text at 0x1a12ca0ed0>,
          (0, 11))
```

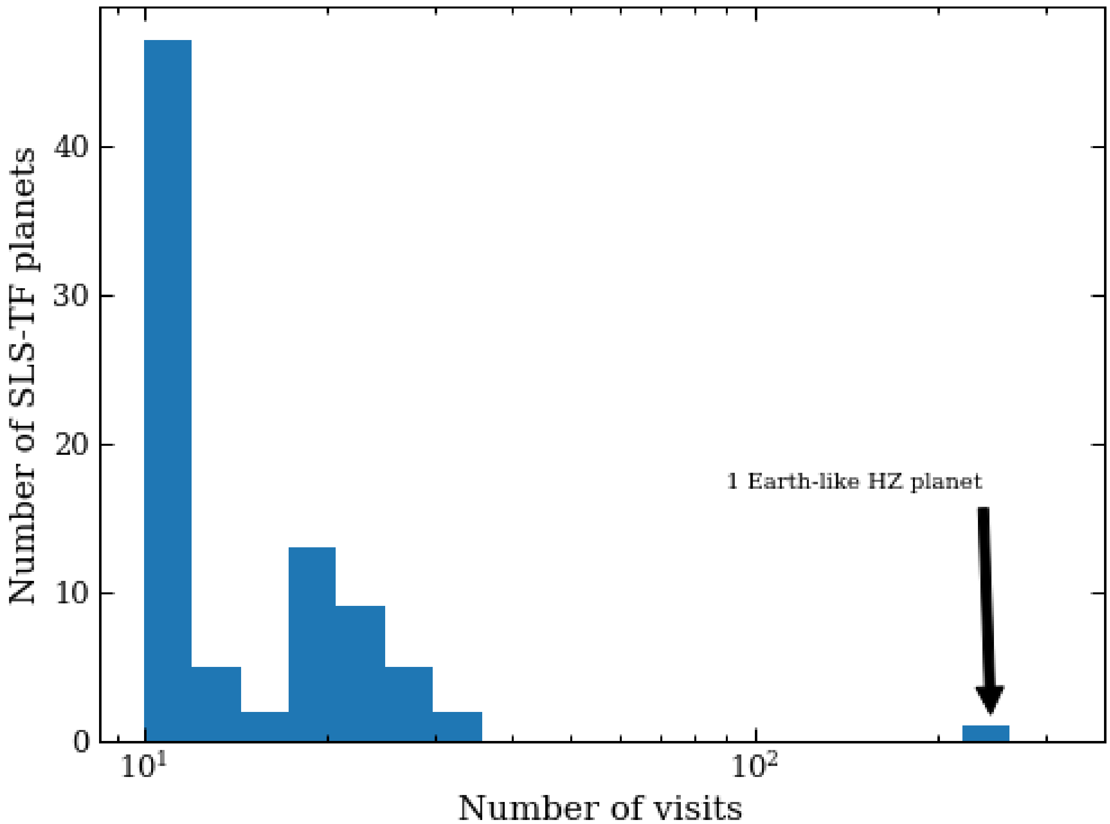



```
In [20]: # K2 targets
         fig = plt.figure(figsize=(12,7))
         ax = fig.add_subplot(111)
         ax.scatter(JK2, transmissionK2_ppm), plt.yscale('log')
         ax.set_xlabel('J'), ax.set_ylabel('Transmission depth (ppm)')
         labels = np.arange(starnames.size)
         for i in range(starnames.size):
             weight = 'bold' if starname[i] == 'K2-136' else 'normal'
             ax.text(JK2[i]+.05, transmissionK2_ppm[i], '%.2d'%labels[i], verticalalignment='cen
             ax.text(1.1, 1-.03*i, '%.2d=%s'%(labels[i], starnames[i]), transform=ax.transAxes,
```




```
In [21]: plt.figure(figsize=(8,6))
         plt.hist(self.NrvGPs_med_N[inds], bins=np.logspace(1,2.5,20)), plt.xscale('log')
         plt.ylabel('Number of SLS-TF planets'), plt.xlabel('Number of visits')
         plt.annotate('1 Earth-like HZ planet', xy=(245,1), xytext=(90,17), arrowprops=dict(face
```

```
Out[21]: <matplotlib.text.Annotation at 0x1a1f65f210>
```



Number of SLS-TF planets
40
30
20
10
0
1 Earth-like HZ planet
10^1
10^2
Number of visits


```
In [ ]:
```