PrettyPlotsGWStrainEtc

April 10, 2018

1 Excerpts of GWStrainPlotsSNR for pretty plots for poster and paper

```
In [1]: # Started WEG  20180408.
        # See the gwtools.py which has utility and strain functions in it
        # and ExopDBase notebook that can download a new csv exop database.
```

2 References

P. Amaro-Seoane et al. "Triplets of supermassive black holes: astrophysics, gravitational waves and detection," MNRAS 402 2308-2320 (2010).

P. C. Peters and J. Mathews, "Gravitational Radiation from Point Masses in a Keplerian Orbit," Phys. Rev. 131 (1963) 435-440.

Michele Maggiore, "Gravitational Waves. Volume 1: Theory and Experiments," Oxford Univ. Press, 2008.

Shane Larson, "Sensitivity Curves for ..." http://www.srl.caltech.edu/~shane/sensitivity/

Neil Cornish and Travis Robson, "The construction and use of LISA sensitivy curves," https://arxiv.org/abs/1803.01944

```
In [2]: import sys, os
        import numpy as np
        import urllib as ul
        import pandas as pd
        import gwTools as gwt
        import matplotlib.pyplot as plt
        %matplotlib inline
        import scipy as sp
        import scipy.interpolate as spint
        import seaborn as sea
```

2.1 For some pretty print advice from Astro colleagues and online pointers.

2.2 From https://matplotlib.org/users/customizing.html

If following is in Matplotlib config dir (run matplotlib.get_configdir()), or maybe in ~/.config/matplotlib create mpl_configdir/stylelib/presentation.mplstyle with

axes.titlesize : 24

axes.labelsize : 20

lines.linewidth : 3
lines.markersize : 10
xtick.labelsize : 16
ytick.labelsize : 16
Then use in the script plt.style.use('presentation')

In [3]:
```
print( plt.style.available )
#plt.style.use('ggplot')
```

```
['_classic_test', 'dark_background', 'ggplot', 'seaborn-notebook', 'seaborn-paper', 'seaborn-tic
```

In [4]:
```
if 0:
    plt.rcParams.update({'axes.titlesize' : 24})
    plt.rcParams.update({'axes.labelsize' : 20})
    plt.rcParams.update({'lines.linewidth' : 3})
    plt.rcParams.update({'lines.markersize' : 10})
    plt.rcParams.update({'xtick.labelsize' : 16})
    plt.rcParams.update({'ytick.labelsize' : 16})
```

In [5]:
```
# https://matplotlib.org/users/customizing.html
# The font.size property is the default font size for text, given in pts.
# 10 pt is the standard value.
#
#font.family         : sans-serif
#font.style          : normal
#font.variant        : normal
#font.weight         : medium
#font.stretch        : normal
# note that font.size controls default text sizes.  To configure
# special text sizes tick labels, axes, labels, title, etc, see the rc
# settings for axes and ticks. Special text sizes can be defined
# relative to font.size, using the following values: xx-small, x-small,
# small, medium, large, x-large, xx-large, larger, or smaller
#font.size           : 10.0
#font.serif          : DejaVu Serif, Bitstream Vera Serif, New Century Schoolbook, Centu
#font.sans-serif     : DejaVu Sans, Bitstream Vera Sans, Lucida Grande, Verdana, Geneva,
#font.cursive        : Apple Chancery, Textile, Zapf Chancery, Sand, Script MT, Felipa,
#font.fantasy        : Comic Sans MS, Chicago, Charcoal, Impact, Western, Humor Sans, xk
#font.monospace      : DejaVu Sans Mono, Bitstream Vera Sans Mono, Andale Mono, Nimbus M
```

In [6]:
```
# Plot defaults.
params = {'font.size': 24.0,
          'legend.fontsize': 'x-large',
          'figure.figsize': (16, 10),  # (14,10)
         'axes.labelsize': 'x-large',
         'axes.titlesize':'x-large',
         'xtick.labelsize':'x-large',
         'ytick.labelsize':'x-large'}
```

```
#aa = 18.0
#params = {'legend.fontsize': aa,
#           'figure.figsize': (14, 10),
#          'axes.labelsize': aa,
#          'axes.titlesize': aa,
#          'xtick.labelsize': aa,
#          'ytick.labelsize': aa}
plt.rcParams.update(params)
#print(mpl.rcParams)
savePlot = False
```

2.3 Read the dbase saved in GWStrainPlotsSNR or other method.

```
In [7]: thisDir = os.getcwd()  # This is the /python subdirectory.
        csvDir = thisDir + '/../dbases/'  # Will the /../ work on non-Unices?
        pixDir = thisDir + '/../pix/'
        csvFileName = csvDir + 'exopP_20180408_141319.csv'

        print('Using database file ' + csvFileName)
        with open(csvFileName, 'r') as ifile:
            print(ifile.readline(), '\n', ifile.readline() )  #Print a couple of lines and reset

            ifile.seek(0);

            dbData = pd.read_csv(ifile)  # Read in the whole file to a Panda Dataframe, handles
            #ifile.close()  # Should close when you leave the "with."
```

```
Using database file /home/gabella/Documents/astro/exop/exoplanetsMath/python/../dbases/exopP_201
pl_hostname,pl_letter,pl_discmethod,pl_orbper,pl_orbsmax,pl_orbeccen,pl_bmassj,st_dist,st_mass,r

 HD 142022 A,b,Radial Velocity,1928.00000000,3.030000,0.530000,5.10000,35.87,0.99,2014-05-14,27.
```

```
In [8]: dbData.head(5)
```

```
Out[8]:    pl_hostname pl_letter    pl_discmethod    pl_orbper  pl_orbsmax  \
        0  HD 142022 A         b  Radial Velocity  1928.000000      3.0300
        1     HD 39091         b  Radial Velocity  2151.000000      3.3800
        2  HD 137388 A         b  Radial Velocity   330.000000      0.8900
        3      GJ 3021         b  Radial Velocity   133.710000      0.4900
        4     HD 63454         b  Radial Velocity     2.818049      0.0368

           pl_orbeccen  pl_bmassj  st_dist  st_mass   rowupdate  st_plx
        0       0.5300      5.100    35.87     0.99  2014-05-14   27.88
        1       0.6405     10.270    18.21     1.10  2014-07-23   54.92
        2       0.3600      0.223    38.45     0.86  2014-05-14   26.01
        3       0.5110      3.370    17.62     0.90  2014-05-14   56.76
        4       0.0000      0.398    35.80     0.84  2015-03-26   27.93
```

2.4 Drop the NaNs

```
In [9]: #  called aData because I expected a bData, etc.
        #
        # {"pl_hostname", "pl_letter", "pl_discmethod", "pl_orbper", \
        # "pl_orbsmax", "pl_orbeccen", "pl_bmassj", "st_dist", "st_mass", \
        # "rowupdate", "st_plx"}
        print('Length all data, dbData ', len(dbData) )
        aData = dbData.copy()

        aData = aData.dropna(axis = 0, how = 'any', subset = ['st_mass'])
        print('Length with st_mass\t', len(aData) )

        aData = aData.dropna(axis = 0, how = 'any', subset = ['pl_bmassj'])
        print('Length with pl_bmassj\t', len(aData) )

        aData = aData.dropna(axis = 0, how = 'any', subset = ['st_dist'])
        print('Length with st_dist\t', len(aData) )

        aData = aData.dropna(axis = 0, how = 'any', subset = ['pl_orbeccen'])
        print('Length with pl_orbeccen\t', len(aData) )

        aData = aData.dropna(axis = 0, how = 'any', subset = ['pl_orbper'])
        print('Length with pl_orbper\t', len(aData) )

        aData = aData.dropna(axis = 0, how = 'any', subset = ['pl_orbsmax'])
        print('Length with pl_orbsmax\t', len(aData) )
```

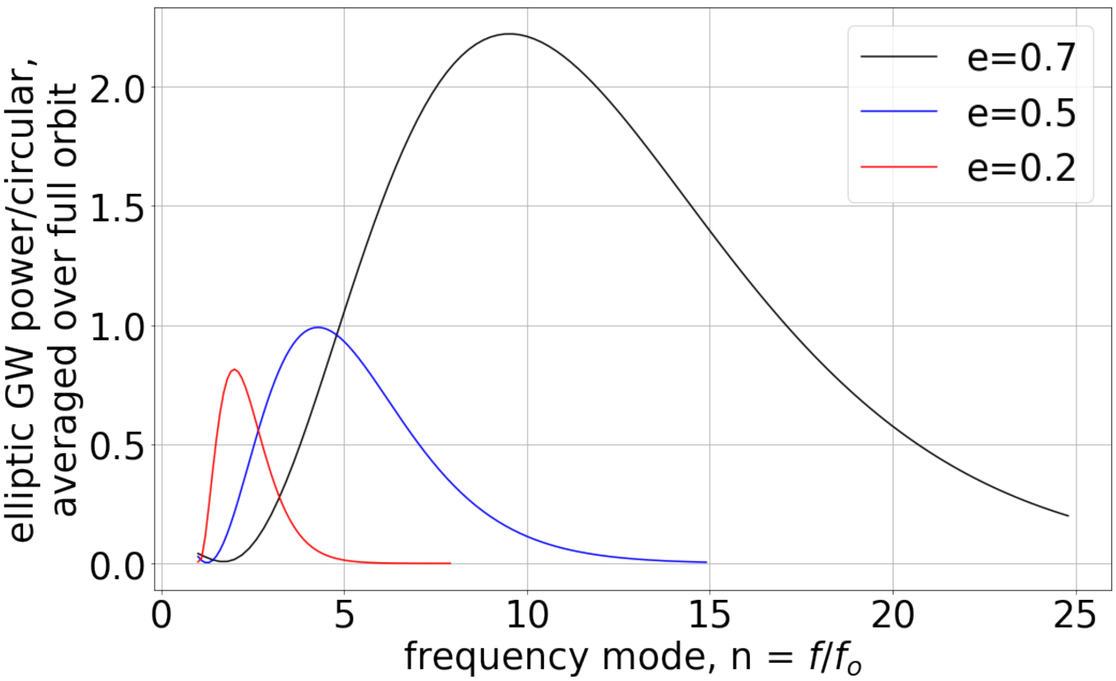
```
Length all data, dbData  3711
Length with st_mass         3418
Length with pl_bmassj         1344
Length with st_dist         1089
Length with pl_orbeccen         933
Length with pl_orbper         933
Length with pl_orbsmax         910
```

2.5 That gets the data in, several plots of just of the functions $g(n,e)$ and $\sqrt(g(n,e))/n$

2.6 The functions/theory

```
In [10]: # Use the gwtools.py definitions.

         afig = plt.figure( )
         ax = afig.add_subplot((111))

         # eccentricities, Peters and Mathews, 0.2, 0.5, 0.7  add 0.9??
         xx = np.arange(1, 25, 0.2)
         yy = gwt.ggSimp(xx, 0.7)
```

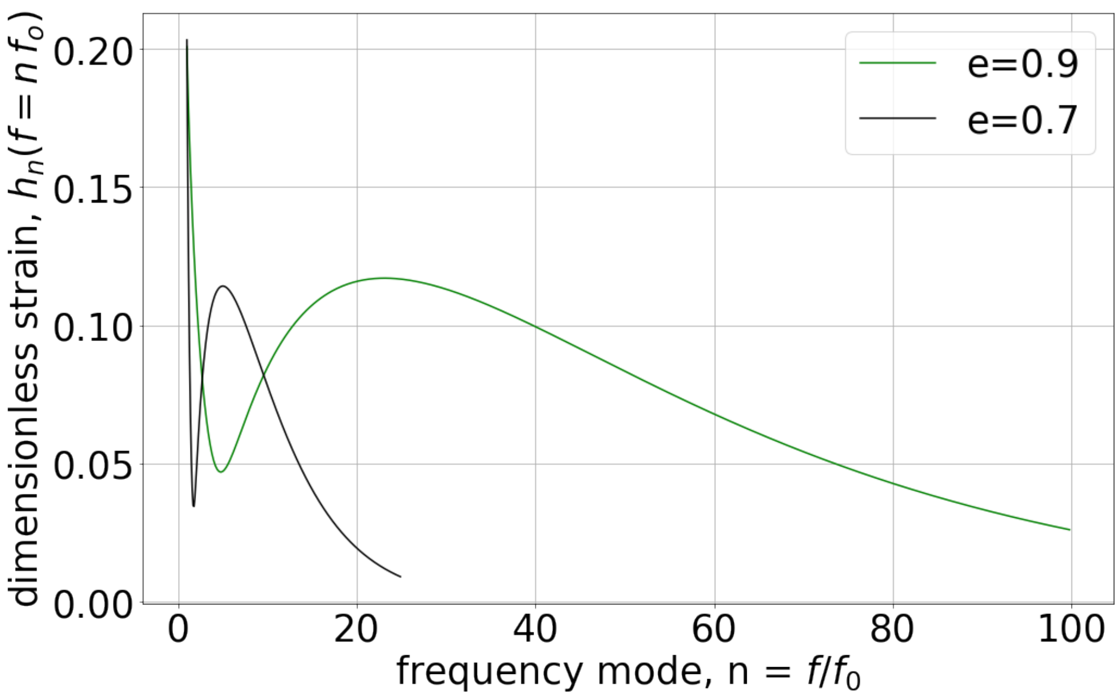
```
ax.set_xlabel('frequency mode, n = $f/f_{o}$')
ax.set_ylabel('elliptic GW power/circular,\naveraged over full orbit')

plt.grid(True)

ax.plot(xx, yy, 'k-', label = 'e=0.7')

x2 = np.arange(1, 15, 0.1)
y2 = gwt.ggSimp(x2, 0.5)
ax.plot(x2, y2, 'b-', label = 'e=0.5')

x3 = np.arange(1, 8, 0.1)
y3 = gwt.ggSimp(x3, 0.2)
ax.plot(x3, y3, 'r-', label = 'e=0.2')

ax.legend()  # AFter the plot calls, to get labels.

if savePlot:
    #plt.savefig('../poster/pix/plot_g_n_e.eps')  # Both eps and svg seem to make good
    plt.savefig('../poster/pix/plot_gne.svg')
```



2.7 Plot $\sqrt{g(n,e)}/n$ proportional to h_n dimensionless

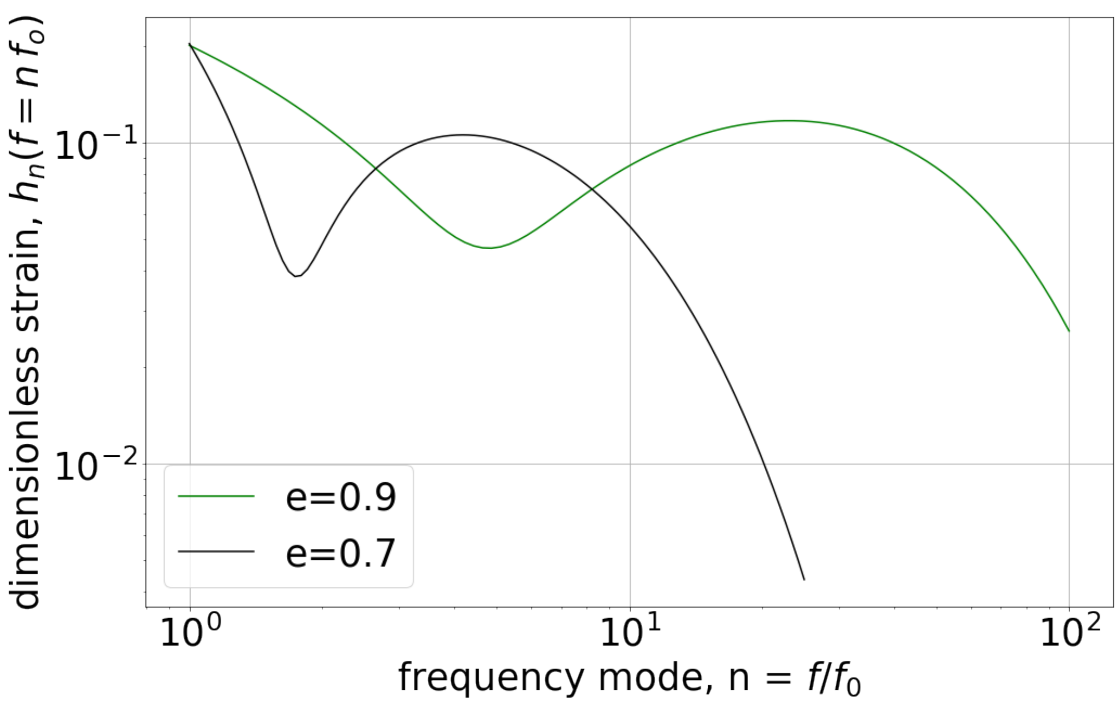
```
In [11]: # Use the gwtools.py definitions.
```

```
afig = plt.figure( )
ax = afig.add_subplot((111))

# eccentricities, Peters and Mathews, 0.2, 0.5, 0.7  add 0.9??
xx = np.arange(1, 100, 0.2)
yy = [ np.sqrt(uu)/nn for nn, uu in zip(xx, gwt.ggSimp(xx, 0.9) ) ]

ax.set_xlabel('frequency mode, n = $f/f_{0}$')
ax.set_ylabel('dimensionless strain, $h_{n}(f = n\,f_{o})$')

ax.plot(xx, yy, 'g-', label = 'e=0.9')

x2 = np.arange(1, 25, 0.1)
y2 = [ np.sqrt(uu)/nn for nn, uu in zip(xx, gwt.ggSimp(x2, 0.7) ) ]
ax.plot(x2, y2, 'k-', label = 'e=0.7')

plt.grid(True)
ax.legend()  # AFter the plot calls, to get labels.

if savePlot:
    #plt.savefig('../poster/pix/plot_g_n_e.eps')  # Both eps and svg seem to make good
    plt.savefig('../poster/pix/plot_h_as_gne.svg')
```




```
In [12]: # Use the gwtools.py definitions.
```

```
afig = plt.figure( )
ax = afig.add_subplot((111))

# eccentricities, Peters and Mathews, 0.2, 0.5, 0.7  add 0.9??
xx = np.linspace(np.log10(1), np.log10(100), 100)
xx = np.power(10,xx)
yy = [ np.sqrt(uu)/nn for nn, uu in zip(xx, gwt.ggSimp(xx, 0.9) ) ]

ax.set_xlabel('frequency mode, n = $f/f_{0}$')
ax.set_ylabel('dimensionless strain, $h_{n}(f = n\,f_{o})$')

ax.loglog(xx, yy, 'g-', label = 'e=0.9')

#x2 = np.arange(1, 25, 0.1)
x2 = np.linspace(np.log10(1), np.log10(25), 100)
x2 = np.power(10,x2)
y2 = [ np.sqrt(uu)/nn for nn, uu in zip(xx, gwt.ggSimp(x2, 0.7) ) ]
ax.loglog(x2, y2, 'k-', label = 'e=0.7')

plt.grid(True)
ax.legend()  # AFter the plot calls, to get labels.

if savePlot:
    #plt.savefig('../poster/pix/plot_g_n_e.eps')  # Both eps and svg seem to make good
    plt.savefig('../poster/pix/plot_h_as_gne_loglog.svg')
```

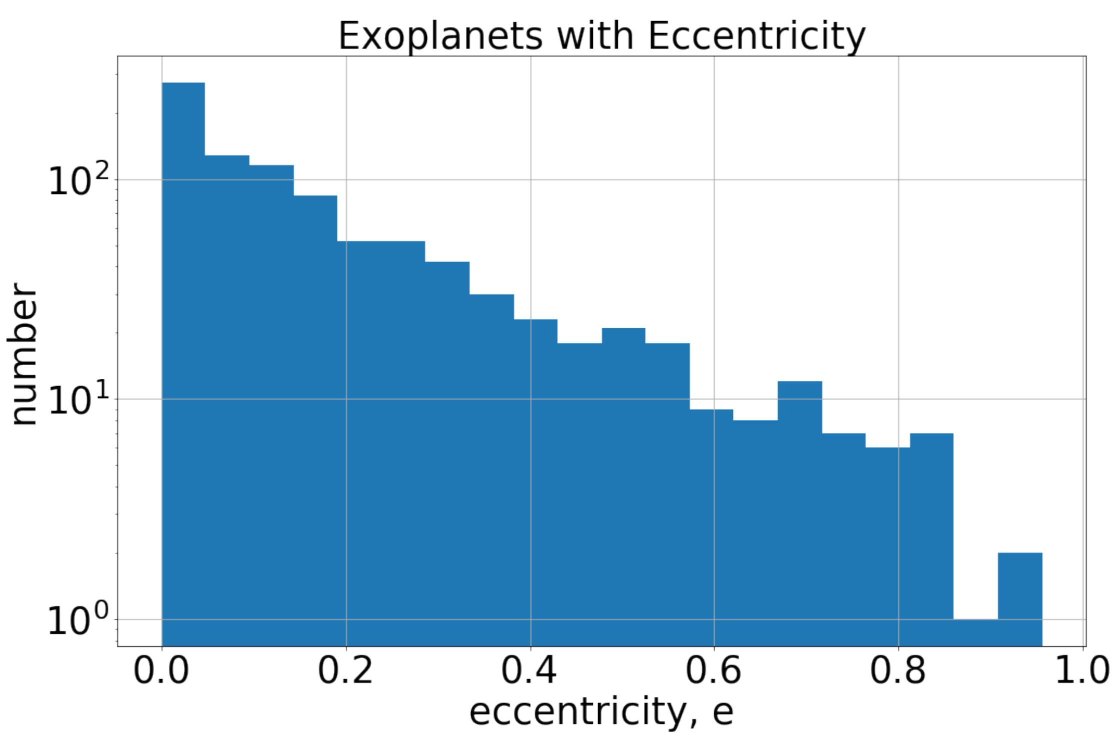


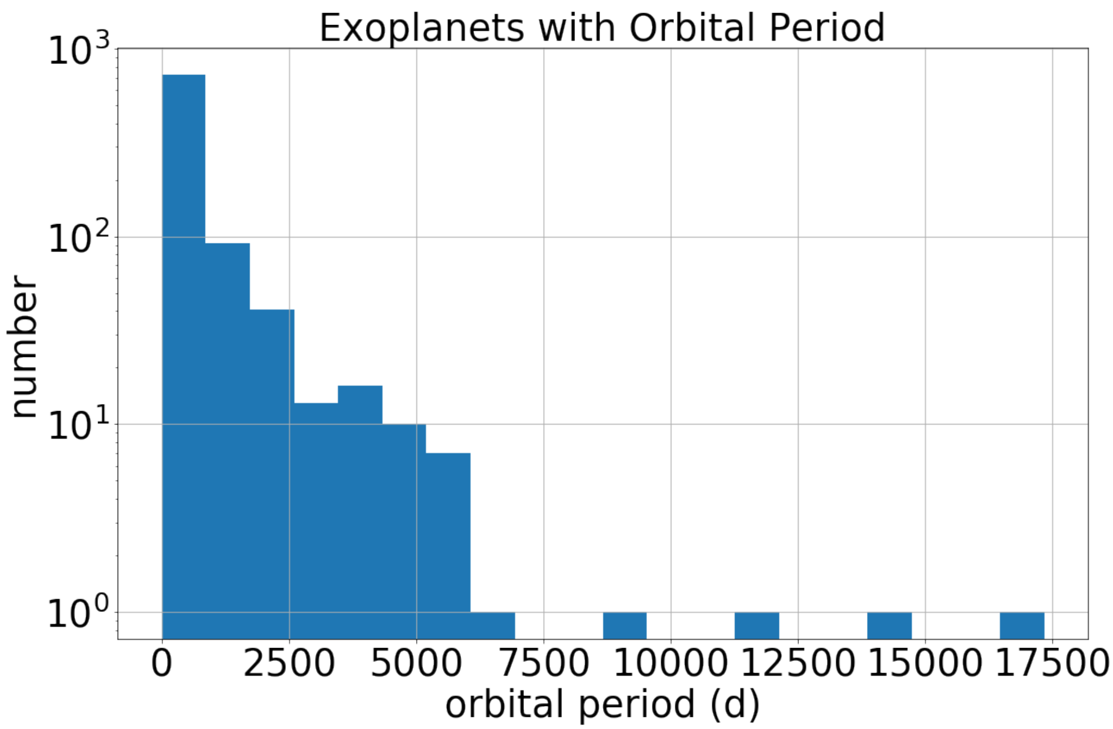
2.8 Histograms of NASA Archive, AFTER the filter

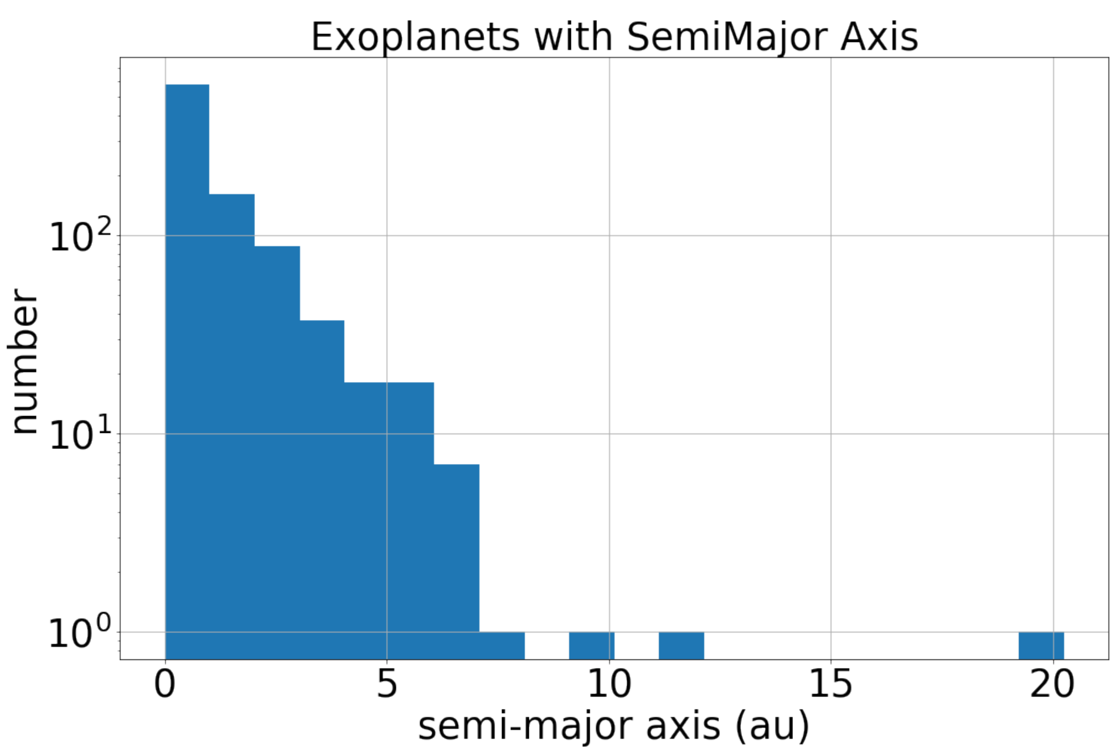
2.9 A list of the columns to histogram, from ExopDBaseHistos notebook

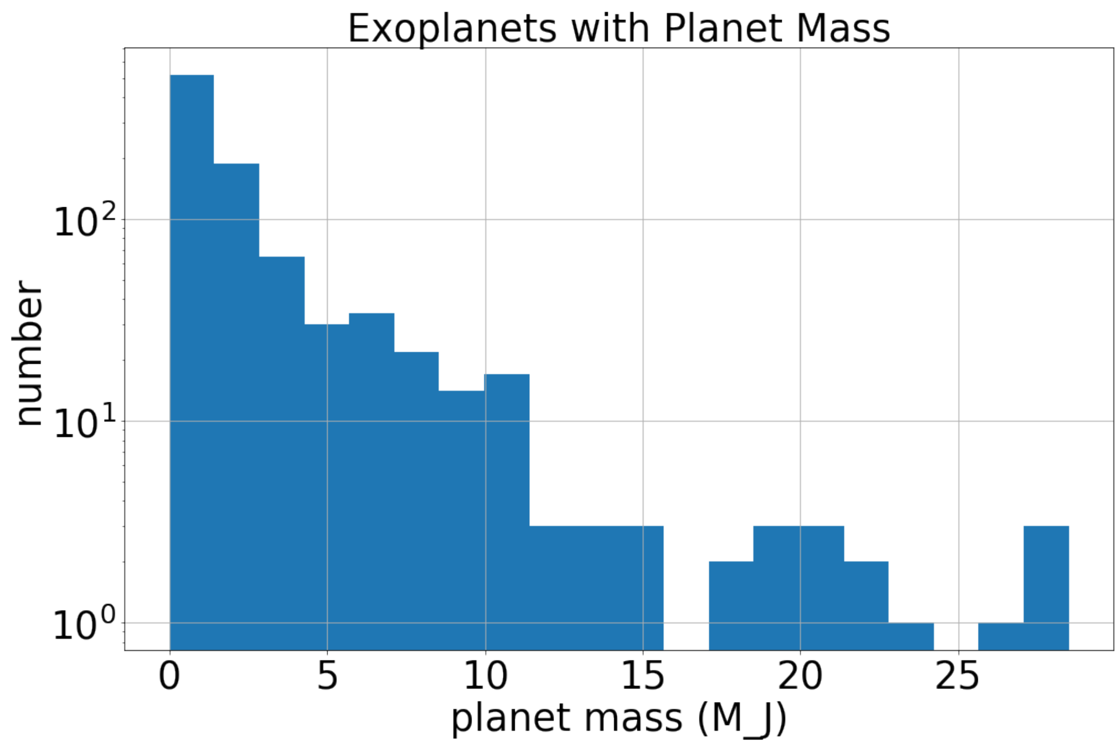
```
In [13]: histCols = ['pl_orbeccen', 'pl_orbper', 'pl_orbsmax', 'pl_bmassj', 'st_dist', 'st_mass'
         titles = ['Eccentricity', 'Orbital Period', 'SemiMajor Axis', 'Planet Mass', 'Stellar D
         xlabels = ['eccentricity, e', 'orbital period (d)', 'semi-major axis (au)', 'planet mas
                    'stellar distance (pc)', 'stellar mass (M_sol)']
```

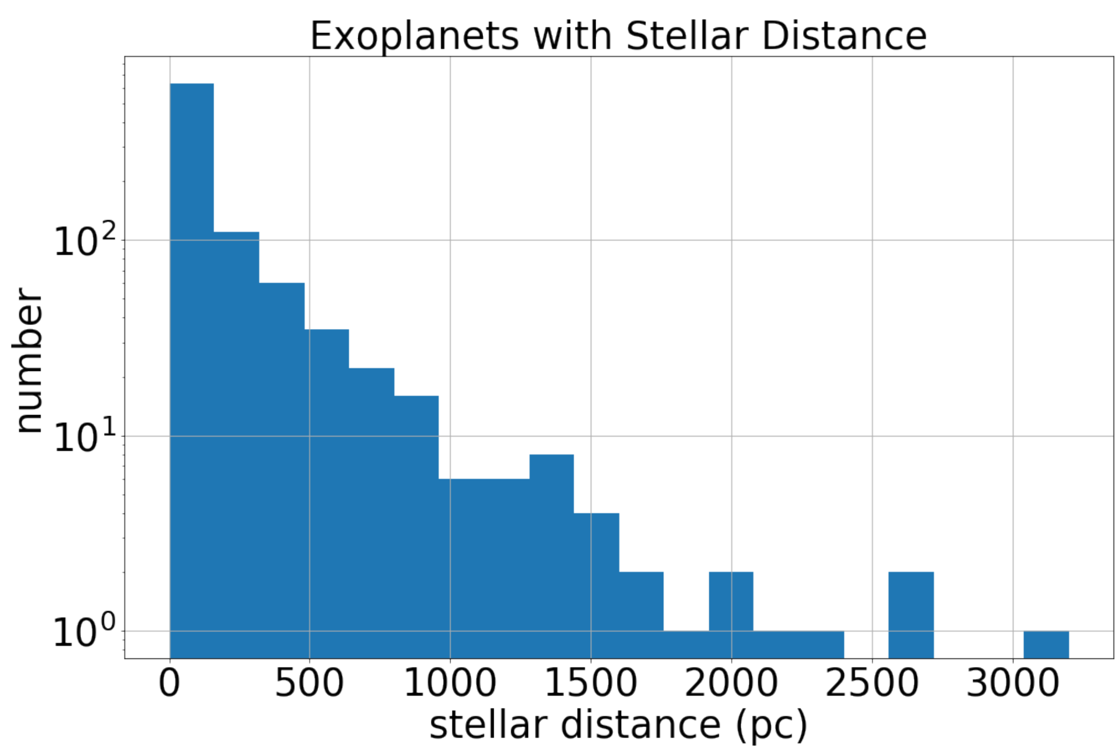
```
In [14]: figs=[]
         axs=[]
         for icol, ititle, ixlabel in zip(histCols, titles, xlabels):
             # time to get fancy
             afig = plt.figure( )
             figs.append( afig )
             ax = afig.add_subplot((111))
             axs.append( ax )
             aData.hist(icol, ax=ax, bins=20)
             ax.set_title('Exoplanets with ' + ititle)
             #ax.set_xscale('log')
             ax.set_yscale('log')
             ax.set_ylabel('number')
             ax.set_xlabel(ixlabel)
             if savePlot and ititle == 'Eccentricity': # Save the figure
                 plt.savefig('../poster/pix/exopEccenHisto.svg') # LibreOffice import SVG histos
                 plt.savefig('../poster/pix/exopEccenHisto.png') # PNGs seem okay, SVGs continue
             plt.show()
```

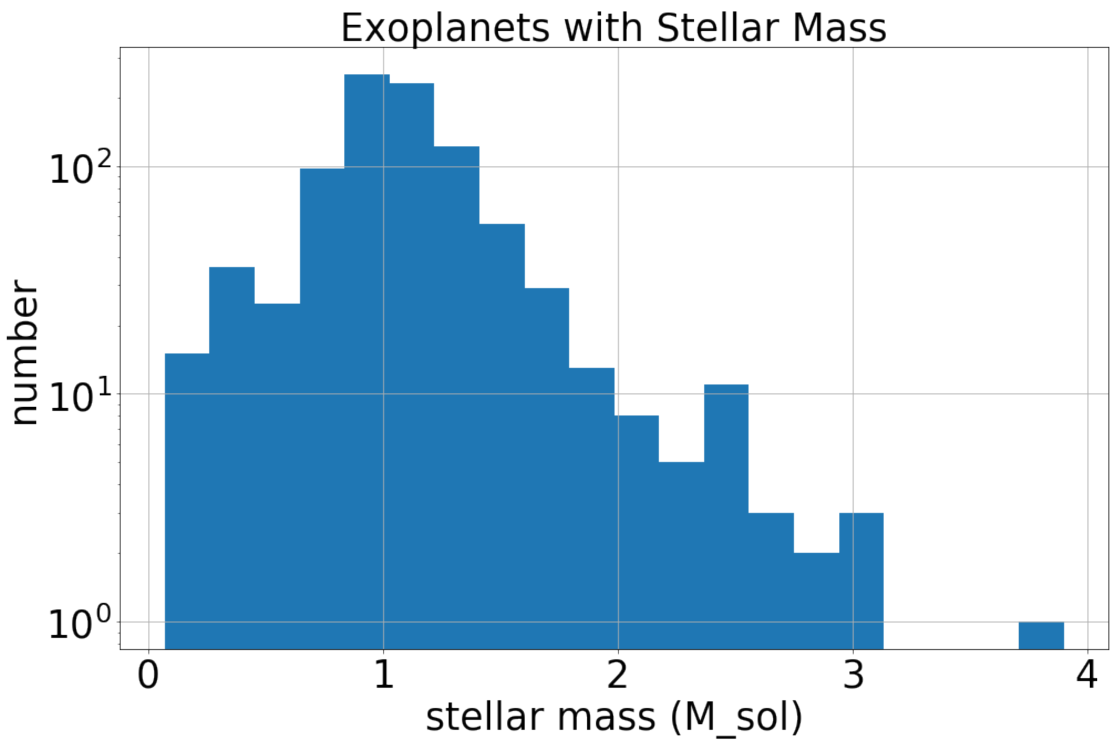



Exoplanets with Orbital Period
10^3
10^2
10^1
10^0
number
0
2500
5000
7500
10000
12500
15000
17500
orbital period (d)


Exoplanets with SemiMajor Axis
10^2
10^1
10^0
number
0
5
10
15
20
semi-major axis (au)


Exoplanets with Planet Mass
number
10^2
10^1
10^0
0
5
10
15
20
25
planet mass (M_J)


Exoplanets with Stellar Distance
number
10^2
10^1
10^0
0
500
1000
1500
2000
2500
3000
stellar distance (pc)



2.10 Chirp mass histo

In [15]:
```
# Some scipy.constants for comparison mostly.
from scipy.constants import speed_of_light, gravitational_constant, c, G, pi

massSun = 1.989e30; #(*kg *)
massJ = 1.898e27; #(* kg *)
massE = 5.972e24; #(* kg *)
massJe = massJ/massE; #(* Jupiter mass is 317.9 earth masses *)
massJs = massJ/massSun; #(* relative to the sun's mass *)

pc = 30.86e15; #(* meters, parsec *)
au = 149.6e9; #(* meters, astron unit *)

cee = 299792458.0; #(* meters/s, speed of light *)
print('Compare my cee ', cee, ' and scipy.constants ', speed_of_light)
cee = speed_of_light # Use the scipy.constants one.
secsYear = 365.24*24.0*3600.0; #(* s, number of seconds in a year *) # What do astronom
secsDay = 24.0*3600.0; #(* s, number of seconds in a day *)

bigG = 6.67408e-11; #(* SI Gravitational constant, m^3/kg/s *)
```

```
print('Compare my bigG ', bigG, ' and scipy.constants ', gravitational_constant)
bigG = gravitational_constant

rscon = 2*bigG*massSun/(cee*cee) #(* 2955.43 m, solar mass Scharzschild radius *)
lunits = bigG*massSun/(cee*cee) #(* meters per solar mass, units of G=c=1, no factor
#of 2 as in Schwarzschild radius *)
masscon = lunits; #(* m, G Msol/c^2, for 1 solar mass *)
powercon = cee**5/bigG  #(* 3.628e52 W, c^5/G, W/unit since P is dimensionless in G=c=1
energycon = (cee**4)/bigG  #(* 1.210e44 J/m, c^4/G *)
```

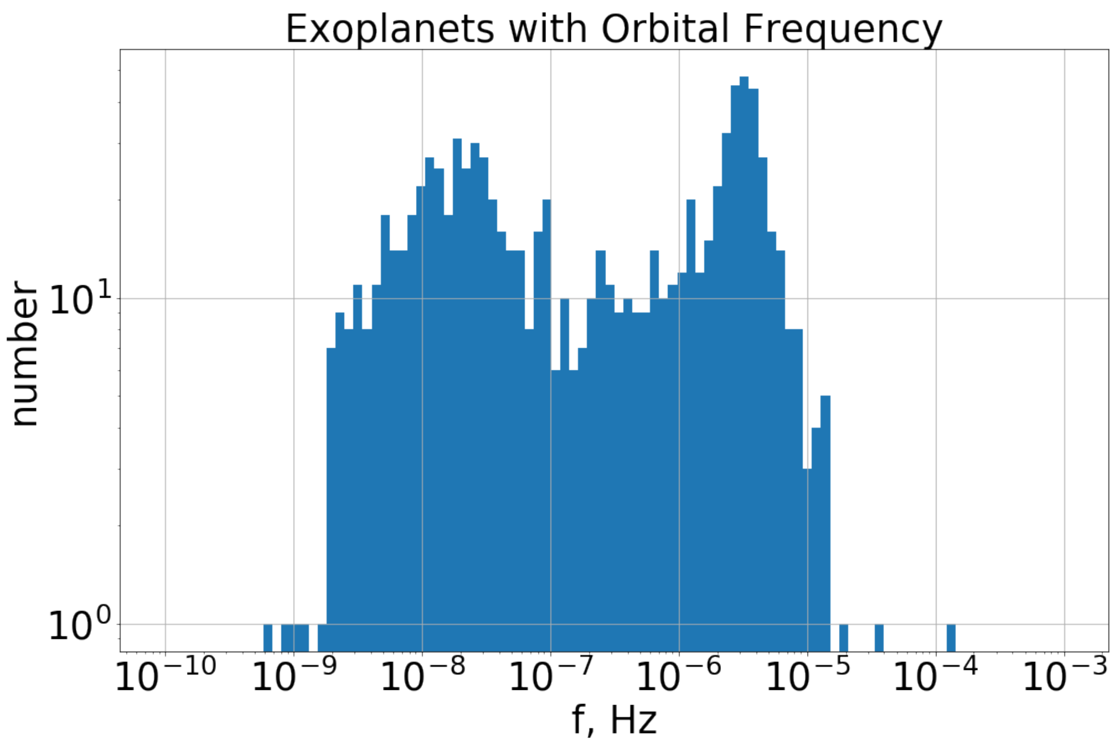
```
Compare my cee  299792458.0  and scipy.constants  299792458.0
Compare my bigG  6.67408e-11  and scipy.constants  6.67408e-11
```

2.11 Orbital frequency

In [16]:
```
# append orbital frequency in Hz!
orbFreqs = []
for irow in range(len(aData)):
    aa = 1.0/( aData['pl_orbper'].values[irow]*secsDay )
    orbFreqs.append( aa )


aData['orbFreqs'] = np.array(orbFreqs)
```

In [17]:
```
# time to get fancy
afig = plt.figure( )

ax = afig.add_subplot((111))

# Log plot need even bins in Log-Space??
binmin = 1e-10
binmax = 0.001
nbins = 100
mybins = np.logspace(np.log10(binmin), np.log10(binmax), (nbins+1))


aData.hist('orbFreqs', ax=ax, bins=mybins)
ax.set_title('Exoplanets with Orbital Frequency')
#ax.set_xscale('log')
ax.set_yscale('log')
ax.set_ylabel('number')
#ax.set_ylim( (0.7, 2000) )
ax.set_xscale('log')
ax.set_xlabel('f, Hz')

if savePlot:
    plt.savefig('../poster/pix/exopOrbFreqsHisto.svg')
```

```
    plt.savefig('../poster/pix/exopOrbFreqsHisto.png')
plt.show()

#Print the max orb freq
print( 'Round trip time for LISA lasers along leg ', (2.0*2.5e9)/cee, ' secs,  and freq
      cee/(2.0*2.5e9), ' Hz.' )
print( 'Orbital frequency in Hz, NOT with GW modeset yet ', np.max( aData['orbFreqs'].v
```

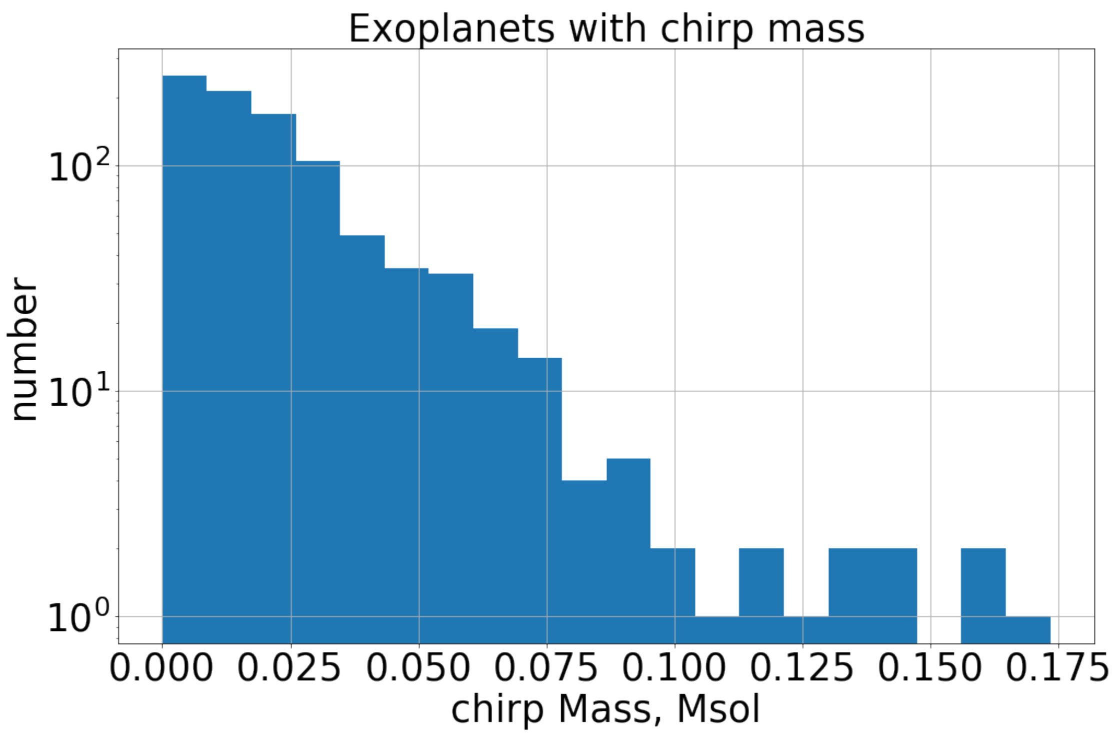



```
Round trip time for LISA lasers along leg  16.6782047599076  secs,  and frequency of  0.05995849
Orbital frequency in Hz, NOT with GW modeset yet  0.00012759946497772808
```

2.12 Chrip Mass histo

```
In [18]: # append chirp mass to
         chirpMs = []
         for irow in range(len(aData)):
             m1 = aData['st_mass'].values[irow]*massSun
             m2 = aData['pl_bmassj'].values[irow]*massJ
             aa = (m1*m2)**(3/5)/(m1+m2)**(1/5)/massSun
             chirpMs.append( aa )

         aData['chirpMassMsols'] = np.array(chirpMs)
```

```
In [19]: # time to get fancy
         afig = plt.figure( )

         ax = afig.add_subplot((111))

         aData.hist('chirpMassMsols', ax=ax, bins=20)
         ax.set_title('Exoplanets with chirp mass')
         #ax.set_xscale('log')
         ax.set_yscale('log')
         ax.set_ylabel('number')
         ax.set_xlabel('chirp Mass, Msol')
         if savePlot:
             plt.savefig('../poster/pix/exopChirpMHisto.svg')
             plt.savefig('../poster/pix/exopChirpMHisto.png')
         plt.show()
```



2.13 Append the rows I need for the modeset and GW freqs histo

```
In [20]: # Actually append n_min, n_max, numpy array of GW strains h.
         # In the Mathematica JustStrainPlots.nb, about 40% down, calc hhVfreq first time.

         hhmodesCol = []  # Setup a list of the hhmodes that will be appended to the dataframe.
         modesCol = []    # The modes set acually used for the calculation, int(modeMin) to int(
         freq0Col = []    # Collect the orbital frequency that was used.
```

```
for irow in range(len(aData)):
    # Calculate the SI parameters needed by the strains and the strain "front coefficie

    orbeccen = aData['pl_orbeccen'].values[irow]
    modeMax = gwt.aNmax( orbeccen )  # The "max" mode number where g(n,e) returns to 1/
    modeMin = gwt.aNmin( orbeccen )  # Either 1 for e>0 or 2 for e=0.
    #
    m1 = aData['pl_bmassj'].values[irow]*massJ
    m2 = aData['st_mass'].values[irow]*massSun
    smax = aData['pl_orbsmax'].values[irow]*au
    dL = aData['st_dist'].values[irow]*pc
    freq0 = 1.0/( aData['pl_orbper'].values[irow]*secsDay )
    # Amaro-Seoane Eqn. (9)...common terms.
    frontCoeff = np.power(bigG,5/3.)/cee**4 * 2 * np.sqrt(32/5.) * np.power( gwt.chirpM
    np.power((2*np.pi*freq0), 2/3.)/dL
    if irow > 6 and irow < 10:
        print('irow is ', irow, ' ,frontCoeff is ', frontCoeff, ' pl_orbeccen is ', orb

    # Now loop over the GW modes and calc the dim-less strain and the modes used.
    hhmodes = [ frontCoeff* np.sqrt( gwt.ggSimp(uu, orbeccen) )/uu for uu in range(int(
    modes = [ uu for uu in range(int(modeMin), int(modeMax)+1)  ]

    # Append to the list.
    hhmodesCol.append( hhmodes )
    modesCol.append( modes )
    freq0Col.append( freq0 )

#Append the hhmodesCol to the dataframe, for ease of getting at the other attributes.
aData['freq0'] = freq0Col
aData['modes'] = modesCol
aData['hhmodes'] = hhmodesCol

aData.head(3)
```

```
irow is  7  ,frontCoeff is  4.6311021600204593e-26  pl_orbeccen is  0.03
irow is  8  ,frontCoeff is  2.169114619938696e-26  pl_orbeccen is  0.41
irow is  9  ,frontCoeff is  2.5108674723286658e-25  pl_orbeccen is  0.638
```

```
Out[20]:   pl_hostname pl_letter    pl_discmethod  pl_orbper  pl_orbsmax  pl_orbeccen  \
         0  HD 142022 A         b  Radial Velocity     1928.0        3.03       0.5300
         1     HD 39091         b  Radial Velocity     2151.0        3.38       0.6405
         2  HD 137388 A         b  Radial Velocity      330.0        0.89       0.3600

            pl_bmassj  st_dist  st_mass   rowupdate  st_plx      orbFreqs  \
         0      5.100    35.87     0.99  2014-05-14   27.88  6.003150e-09
         1     10.270    18.21     1.10  2014-07-23   54.92  5.380788e-09
```

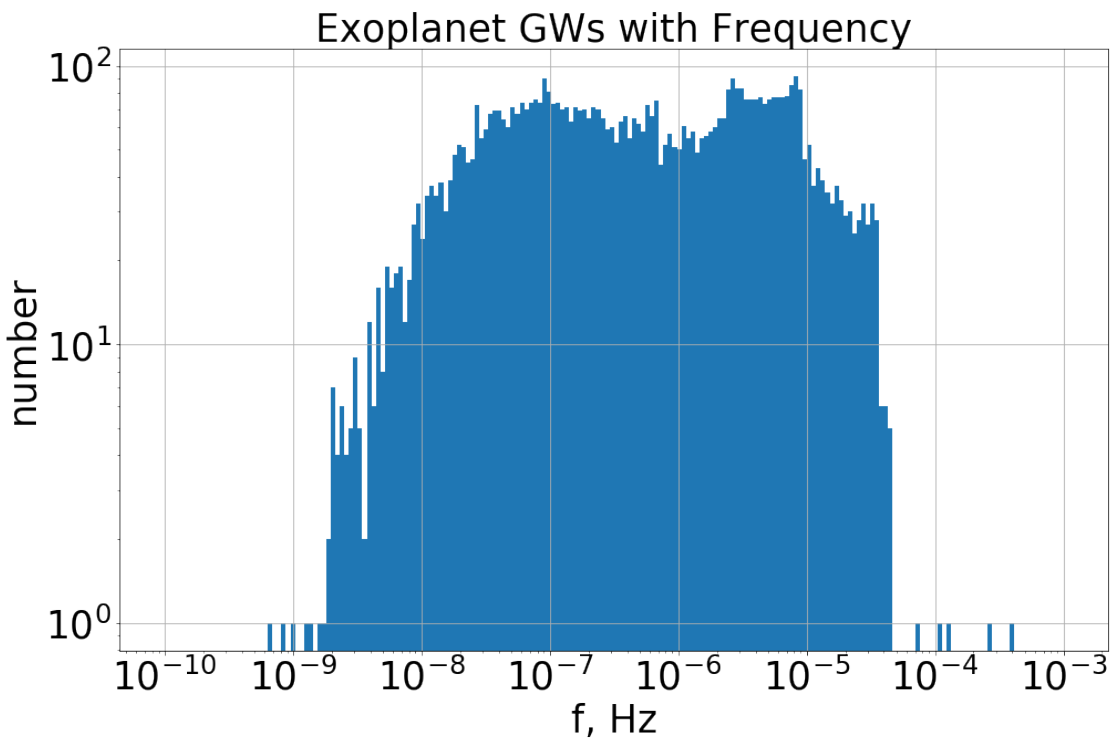
```
2      0.223    38.45     0.86  2014-05-14   26.01  3.507295e-08

   chirpMassMsols         freq0  \
0        0.040754  6.003150e-09
1        0.064644  5.380788e-09
2        0.005896  3.507295e-08

                                               modes  \
0  [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14...
1  [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14...
2                             [1, 2, 3, 4, 5, 6, 7]

                                             hhmodes
0  [1.8702816437643177e-26, 2.1740658908129503e-2...
1  [8.230508420052954e-26, 4.507375225359441e-26,...
2  [1.6721119496253516e-27, 4.481574164761941e-27...
```

2.14 All GW modes freqs histogrammed.

In [21]:
```
# Build the XX and YY's from the modesets and the orbital freq.
# time to get fancy
afig = plt.figure( )

ax = afig.add_subplot((111))

myfreqs = []
for irow in range(len(aData)):
    freq0 = aData['freq0'].values[irow]
    modes = aData['modes'].values[irow]   # a list not np.array
    for im in modes:
        myfreqs.append( im*freq0 )

print(len(myfreqs))

# Log plot need even bins in Log-Space??
binmin = 1e-10
binmax = 0.001
nbins = 200
mybins = np.logspace(np.log10(binmin), np.log10(binmax), (nbins+1))

ax.hist(myfreqs, bins=mybins)

ax.set_title('Exoplanet GWs with Frequency')
#ax.set_xscale('log')
ax.set_yscale('log')
ax.set_ylabel('number')
#ax.set_ylim( (0.7, 10000) )
ax.set_xscale('log')
```

```
ax.set_xlabel('f, Hz')
ax.grid(True)

if savePlot:
    plt.savefig('../poster/pix/exopGWFreqsHisto.svg')
    plt.savefig('../poster/pix/exopGWFreqsHisto.png')
plt.show()

#Print the max orb freq
print( 'Round trip time for LISA lasers along leg ', (2.0*2.5e9)/cee, ' secs,  and freq
      cee/(2.0*2.5e9), ' Hz, and C&R $f_\star$ ', (cee/(2*np.pi*2.5e9)), ' Hz' )
print( 'Max GW frequency in Hz, NOT with GW modeset yet ', np.max( myfreqs ) )
```

```
6312
```




```
Round trip time for LISA lasers along leg  16.6782047599076  secs,  and frequency of  0.05995849
Max GW frequency in Hz, NOT with GW modeset yet  0.00038279839493l8424
```

```
In [22]: aa = gwt.lisa_psd()
         aa([12.3e-3, 1e-8, 1e-6])  # S_n(f) per Hz
```

```
Out[22]: array([3.07258155e-40, 3.94217686e-09, 3.94225804e-21])
```

```
In [23]: np.sqrt( aa([12.3e-3, 1e-8, 1e-6]) )  # sqrt(S_n(f)) per root Hz
```

```
Out[23]: array([1.75287808e-20, 6.27867570e-05, 6.27874035e-11])
```