DataScienceProject_Exoplanets

November 30, 2020

1 NASA Confirmed Exoplanets - Data Analysis

This project will take a look at how Earth compares to the exoplanets (planets not within our solar system) confirmed by NASA in their Confirmed Exoplanets dataset, and some of the interesting potential relationships between the data collected.

Disclaimer: This project makes use of jupyter-contrib-nbextensions: Python Markdown, to allow markdown cells to communicate important variables. Sometimes this extension requires mardown cells to be re-ran individually (shift+Enter), once the variables are calculated.

1.1 Data Collection and Preparation

[1]:
```
import pandas as pd
import math as math
import numpy as np
pd.options.display.max_columns = None

import matplotlib
import matplotlib.pyplot as plt
%matplotlib inline
```

[2]:
```
import requests
import json

resp = requests.get('https://exoplanetarchive.ipac.caltech.edu/cgi-bin/nstedAPI/
↪nph-nstedAPI?table=exoplanets&format=json')

nasa_discovered_exoplanets = resp.json()

fout=open("nasa_discovered_exoplanets.json", "w")
json.dump(nasa_discovered_exoplanets, fout)
fout.close

nasa_discovered_exoplanets = pd.DataFrame(nasa_discovered_exoplanets)
nasa_discovered_exoplanets
```

[2]:
```
    pl_hostname pl_letter        pl_name pl_discmethod  pl_controvflag  \
0    Kepler-138         c   Kepler-138 c       Transit               0
```

```
1      Kepler-138         d   Kepler-138 d       Transit              0
2      Kepler-139         b   Kepler-139 b       Transit              0
3      Kepler-139         c   Kepler-139 c       Transit              0
4      Kepler-140         b   Kepler-140 b       Transit              0
…             …       …            …           …             …
4296  Kepler-1514         c  Kepler-1514 c       Transit              0
4297  Kepler-1698         b  Kepler-1698 b       Transit              0
4298  Kepler-1699         b  Kepler-1699 b       Transit              0
4299  Kepler-1700         b  Kepler-1700 b       Transit              0
4300  Kepler-1701         b  Kepler-1701 b       Transit              0

      pl_pnum   pl_orbper  pl_orbpererr1  pl_orbpererr2  pl_orbperlim  \
0           3   13.781300       0.000100      -0.000100           0.0
1           3   23.088100       0.000900      -0.000800           0.0
2           2   15.771044       0.000037      -0.000037           0.0
3           2  157.072878       0.001720      -0.001720           0.0
4           2    3.254270       0.000008      -0.000008           0.0
…         …         …             …             …            …
4296        2   10.514100            NaN            NaN           0.0
4297        1    1.210700            NaN            NaN           0.0
4298        1    3.490820            NaN            NaN           0.0
4299        1  234.239000            NaN            NaN           0.0
4300        1  169.134000            NaN            NaN           0.0

      pl_orbpern  pl_orbsmax  pl_orbsmaxerr1  pl_orbsmaxerr2  pl_orbsmaxlim  \
0              9         NaN             NaN             NaN            NaN
1              7         NaN             NaN             NaN            NaN
2              4       0.127             NaN             NaN            0.0
3              4       0.586             NaN             NaN            0.0
4              4       0.045             NaN             NaN            0.0
…            …          …             …              …             …
4296           2         NaN             NaN             NaN            0.0
4297           2         NaN             NaN             NaN            0.0
4298           2         NaN             NaN             NaN            0.0
4299           2         NaN             NaN             NaN            0.0
4300           2         NaN             NaN             NaN            0.0

      pl_orbsmaxn  pl_orbeccen  pl_orbeccenerr1  pl_orbeccenerr2  \
0               2          NaN              NaN              NaN
1               2          NaN              NaN              NaN
2               1          NaN              NaN              NaN
3               1          NaN              NaN              NaN
4               1          NaN              NaN              NaN
…             …           …               …              …
4296            0          NaN              NaN              NaN
4297            0          NaN              NaN              NaN
4298            0          NaN              NaN              NaN
```

4299	0	NaN	NaN	NaN
4300	0	NaN	NaN	NaN

	pl_orbeccenlim	pl_orbeccenn	pl_orbincl	pl_orbinclerr1	\
0	NaN	3	NaN	NaN	
1	NaN	3	NaN	NaN	
2	NaN	0	NaN	NaN	
3	NaN	0	NaN	NaN	
4	NaN	0	NaN	NaN	
…	…	…	…	…	
4296	0.0	0	NaN	NaN	
4297	0.0	0	NaN	NaN	
4298	0.0	0	NaN	NaN	
4299	0.0	0	NaN	NaN	
4300	0.0	0	NaN	NaN	

	pl_orbinclerr2	pl_orbincllim	pl_orbincln	pl_bmassj	pl_bmassjerr1	\
0	NaN	NaN	1	0.00620	0.00602	
1	NaN	NaN	1	0.00201	0.00212	
2	NaN	NaN	0	NaN	NaN	
3	NaN	NaN	0	NaN	NaN	
4	NaN	NaN	0	NaN	NaN	
…	…	…	…	…	…	
4296	NaN	0.0	0	NaN	NaN	
4297	NaN	0.0	0	NaN	NaN	
4298	NaN	0.0	0	NaN	NaN	
4299	NaN	0.0	0	NaN	NaN	
4300	NaN	0.0	0	NaN	NaN	

	pl_bmassjerr2	pl_bmassjlim	pl_bmassn	pl_bmassprov	pl_radj	\
0	-0.00352	0.0	4	Mass	0.107	
1	-0.00122	0.0	3	Mass	0.108	
2	NaN	NaN	0	None	0.262	
3	NaN	NaN	0	None	0.302	
4	NaN	NaN	0	None	0.144	
…	…	…	…	…	…	
4296	NaN	0.0	0	None	0.118	
4297	NaN	0.0	0	None	0.096	
4298	NaN	0.0	0	None	0.140	
4299	NaN	0.0	0	None	0.259	
4300	NaN	0.0	0	None	0.198	

	pl_radjerr1	pl_radjerr2	pl_radjlim	pl_radn	pl_dens	pl_denserr1	\
0	0.006	-0.006	0.0	9	6.2	5.8	
1	0.007	-0.007	0.0	8	2.1	2.2	
2	0.051	-0.051	0.0	3	NaN	NaN	
3	0.062	-0.062	0.0	3	NaN	NaN	

4	0.028	-0.028	0.0	3	NaN	NaN
…	…	…	…	…	…	…
4296	NaN	NaN	0.0	1	NaN	NaN
4297	NaN	NaN	0.0	1	NaN	NaN
4298	NaN	NaN	0.0	1	NaN	NaN
4299	NaN	NaN	0.0	1	NaN	NaN
4300	NaN	NaN	0.0	1	NaN	NaN

	pl_denserr2	pl_denslim	pl_densn	pl_ttvflag	pl_kepflag	pl_k2flag \
0	-3.4	0.0	3	1	1	0
1	-1.2	0.0	3	1	1	0
2	NaN	NaN	0	0	1	0
3	NaN	NaN	0	1	1	0
4	NaN	NaN	0	0	1	0
…	…	…	…	…	…	…
4296	NaN	0.0	0	0	1	0
4297	NaN	0.0	0	0	1	0
4298	NaN	0.0	0	0	1	0
4299	NaN	0.0	0	0	1	0
4300	NaN	0.0	0	0	1	0

	ra_str	dec_str	ra	st_raerr	dec	st_decerr \
0	19h21m31.57s	+43d17m34.7s	290.381547	0.000017	43.292973	0.000017
1	19h21m31.57s	+43d17m34.7s	290.381547	0.000017	43.292973	0.000017
2	18h49m34.07s	+43d53m21.7s	282.391957	0.000017	43.889351	0.000017
3	18h49m34.07s	+43d53m21.7s	282.391957	0.000017	43.889351	0.000017
4	19h09m28.67s	+46d46m05.6s	287.369468	0.000017	46.768213	0.000017
…	…	…	…	…	…	…
4296	19h30m30.59s	+37d51m36.5s	292.627466	0.000017	37.860133	0.000017
4297	19h33m22.80s	+39d15m28.1s	293.344989	0.000017	39.257812	0.000017
4298	19h28m32.96s	+48d55m01.9s	292.137336	0.000017	48.917194	0.000017
4299	19h07m47.93s	+45d21m13.8s	286.949712	0.000017	45.353828	0.000017
4300	19h06m26.13s	+41d53m21.6s	286.608886	0.000022	41.889339	0.000019

	st_posn	st_dist	st_disterr1	st_disterr2	st_distlim	st_distn \
0	2	66.99	0.11	-0.11	0.0	4
1	2	66.99	0.11	-0.11	0.0	4
2	2	395.45	4.26	-4.26	0.0	3
3	2	395.45	4.26	-4.26	0.0	3
4	2	593.80	7.20	-7.20	0.0	3
…	…	…	…	…	…	…
4296	2	379.00	20.87	-18.36	0.0	3
4297	2	223.78	1.20	-1.20	0.0	1
4298	2	NaN	NaN	NaN	NaN	0
4299	2	732.73	8.87	-8.87	0.0	1
4300	2	594.10	6.93	-6.93	0.0	1

	st_optmag	st_optmagerr	st_optmaglim	st_optband	gaia_gmag	\
0	12.925	NaN	0.0	Kepler-band	12.472	
1	12.925	NaN	0.0	Kepler-band	12.472	
2	12.701	NaN	0.0	Kepler-band	12.677	
3	12.701	NaN	0.0	Kepler-band	12.677	
4	12.996	NaN	0.0	Kepler-band	12.941	
…	…	…	…	…	…	
4296	11.690	NaN	0.0	Kepler-band	11.829	
4297	12.914	NaN	0.0	Kepler-band	12.876	
4298	14.678	NaN	0.0	Kepler-band	14.661	
4299	13.685	NaN	0.0	Kepler-band	13.629	
4300	14.566	NaN	0.0	Kepler-band	14.550	

	gaia_gmagerr	gaia_gmaglim	st_teff	st_tefferr1	st_tefferr2	\
0	None	0.0	3841.00	49.00	-49.00	
1	None	0.0	3841.00	49.00	-49.00	
2	None	0.0	5594.00	100.00	-100.00	
3	None	0.0	5594.00	100.00	-100.00	
4	None	0.0	6077.00	136.00	-136.00	
…	…	…	…	…	…	
4296	None	0.0	6251.00	81.98	-87.80	
4297	None	0.0	4945.83	74.17	-52.12	
4298	None	0.0	5214.40	221.45	-133.51	
4299	None	0.0	5885.00	59.00	-34.00	
4300	None	0.0	5116.26	471.94	-60.82	

	st_tefflim	st_teffn	st_mass	st_masserr1	st_masserr2	st_masslim	\
0	0.0	10	0.52	0.06	-0.06	0.0	
1	0.0	10	0.52	0.06	-0.06	0.0	
2	0.0	6	NaN	NaN	NaN	NaN	
3	0.0	6	NaN	NaN	NaN	NaN	
4	0.0	6	NaN	NaN	NaN	NaN	
…	…	…	…	…	…	…	
4296	0.0	3	1.21	0.04	-0.04	0.0	
4297	0.0	2	NaN	NaN	NaN	0.0	
4298	0.0	2	NaN	NaN	NaN	0.0	
4299	0.0	2	NaN	NaN	NaN	0.0	
4300	0.0	2	NaN	NaN	NaN	0.0	

	st_massn	st_rad	st_raderr1	st_raderr2	st_radlim	st_radn	pl_nnotes	\
0	9	0.44	0.02	-0.02	0.0	11	2	
1	9	0.44	0.02	-0.02	0.0	11	2	
2	2	1.30	0.25	-0.25	0.0	6	1	
3	2	1.30	0.25	-0.25	0.0	6	1	
4	1	1.29	0.24	-0.24	0.0	6	1	
…	…	…	…	…	…	…	…	
4296	1	1.22	0.06	-0.05	0.0	3	0	

```
4297          0    0.74        0.02       -0.02        0.0        2          0
4298          0     NaN         NaN         NaN        0.0        1          0
4299          0    1.14        0.01       -0.02        0.0        2          0
4300          0    0.83        0.02       -0.13        0.0        2          0

       rowupdate pl_facility
0     2015-06-17      Kepler
1     2015-06-17      Kepler
2     2014-05-14      Kepler
3     2014-05-14      Kepler
4     2014-05-14      Kepler
…            …           …
4296  2020-09-03      Kepler
4297  2020-09-03      Kepler
4298  2020-09-03      Kepler
4299  2020-09-03      Kepler
4300  2020-09-03      Kepler

[4301 rows x 82 columns]
```

[4]:

```
df = nasa_discovered_exoplanets
df = df.drop(columns = ['pl_letter', 'pl_controvflag', 'pl_orbpererr2',␣
↪'pl_orbperlim', 'pl_orbsmax', 'pl_orbsmaxerr1', 'pl_orbsmaxerr2',␣
↪'pl_orbsmaxlim', 'pl_orbsmaxn', 'pl_orbeccenerr2', 'pl_orbeccenlim',␣
↪'pl_orbincl', 'pl_orbinclerr1', 'pl_orbinclerr2', 'pl_orbincllim',␣
↪'pl_orbincln', 'pl_bmassjerr2', 'pl_bmassjlim', 'pl_bmassprov',␣
↪'pl_radjerr2', 'pl_radjlim', 'pl_denserr2', 'pl_denslim', 'pl_densn',␣
↪'ra_str', 'dec_str', 'st_disterr2', 'st_distlim', 'st_optmaglim',␣
↪'gaia_gmaglim', 'st_tefferr2', 'st_tefflim', 'st_masserr2', 'st_masslim',␣
↪'st_raderr2', 'st_radlim', 'pl_ttvflag', 'pl_kepflag', 'pl_k2flag',␣
↪'ra_str', 'dec_str', 'ra', 'dec', 'st_decerr', 'st_posn', 'st_raerr',␣
↪'st_optmag', 'st_optmagerr', 'st_optband', 'gaia_gmag', 'gaia_gmagerr',␣
↪'pl_nnotes'], axis=1)
```

```
df = df.rename(columns = {'pl_hostname': 'Star name', 'pl_name' : 'Planet␣
↪name', 'pl_discmethod' : 'Discovery method', 'pl_pnum' : 'Number of planets␣
↪in the stellar system', 'pl_orbper' : 'Days in a year', 'pl_orbpererr1' :␣
↪'Days in a year error (+/-)', 'pl_orbpern' : 'Year length number of␣
↪measurements', 'pl_orbeccen' : 'Eccentricity', 'pl_orbeccenerr1' :␣
↪'Eccentricity error (+/-)', 'pl_orbeccenn' : 'Eccentricity number of␣
↪measurements', 'pl_bmassj' : 'Planet mass (compared to Jupiter)',␣
↪'pl_bmassjerr1' : 'Planet mass error (+/-)', 'pl_bmassn' : 'Planet mass␣
↪number of measurements', 'pl_radj' : 'Planet radius (compared to Jupiter)',␣
↪'pl_radjerr1' : 'Planet radius error (+/-)', 'pl_radn' : 'Planet radius␣
↪number of measurements', 'pl_dens' : 'Planet density', 'pl_denserr1' :␣
↪'Density error (+/-)', 'pl_densn' : 'Planet density number of measurements',␣
↪'st_dist' : 'Star distance (in Parsecs)', 'st_disterr1' : 'Distance error (+/
↪-)', 'st_distn' : 'Distance number of measurements', 'st_teff' : 'Star␣
↪temperature', 'st_tefferr1' : 'Temperature error (+/-)', 'st_teffn' :␣
↪'Temperature number of measurements', 'st_mass' : 'Star mass (compared to␣
↪the Sun)', 'st_masserr1' : 'Star mass error (+/-)', 'st_massn' : 'Star mass␣
↪number of measurements', 'st_rad' : 'Star radius (compared to the Sun)',␣
↪'st_raderr1' : 'Star radius error (+/-)', 'st_radn' : 'Star radius number of␣
↪measurements', 'rowupdate' : 'Date of last update', 'pl_facility' :␣
↪'Discovery facility'})


mass_e = round((df['Planet mass (compared to Jupiter)'] / 0.0031463520), 5)
#must round mass_e to 5d.p., as this is the highest accuracy we can quote it␣
↪to, given the planet masses provided are all quoted to an accuracy of 5d.p.

df.insert(13, 'Planet mass (compared to Earth)', mass_e)

year = df['Date of last update'].str.split('-').str[0].tolist()
df.insert(32, 'Year of last update', year)

df
```

[4]:

```
        Star name    Planet name Discovery method  \
0      Kepler-138   Kepler-138 c          Transit
1      Kepler-138   Kepler-138 d          Transit
2      Kepler-139   Kepler-139 b          Transit
3      Kepler-139   Kepler-139 c          Transit
4      Kepler-140   Kepler-140 b          Transit
…             …              …                …
4296  Kepler-1514  Kepler-1514 c          Transit
4297  Kepler-1698  Kepler-1698 b          Transit
4298  Kepler-1699  Kepler-1699 b          Transit
4299  Kepler-1700  Kepler-1700 b          Transit
4300  Kepler-1701  Kepler-1701 b          Transit
```

```
      Number of planets in the stellar system  Days in a year  \
0                                           3       13.781300
1                                           3       23.088100
2                                           2       15.771044
3                                           2      157.072878
4                                           2        3.254270
…                                         …             …
4296                                        2       10.514100
4297                                        1        1.210700
4298                                        1        3.490820
4299                                        1      234.239000
4300                                        1      169.134000

      Days in a year error (+/-)  Year length number of measurements  \
0                       0.000100                                   9
1                       0.000900                                   7
2                       0.000037                                   4
3                       0.001720                                   4
4                       0.000008                                   4
…                            …                                  …
4296                         NaN                                   2
4297                         NaN                                   2
4298                         NaN                                   2
4299                         NaN                                   2
4300                         NaN                                   2

      Eccentricity  Eccentricity error (+/-)  \
0              NaN                       NaN
1              NaN                       NaN
2              NaN                       NaN
3              NaN                       NaN
4              NaN                       NaN
…             …                        …
4296           NaN                       NaN
4297           NaN                       NaN
4298           NaN                       NaN
4299           NaN                       NaN
4300           NaN                       NaN

      Eccentricity number of measurements  Planet mass (compared to Jupiter)  \
0                                       3                            0.00620
1                                       3                            0.00201
2                                       0                                NaN
3                                       0                                NaN
4                                       0                                NaN
…                                     …                              …
4296                                    0                                NaN
```

4297	0	NaN
4298	0	NaN
4299	0	NaN
4300	0	NaN

	Planet mass error (+/-)	Planet mass number of measurements	\
0	0.00602	4	
1	0.00212	3	
2	NaN	0	
3	NaN	0	
4	NaN	0	
…	…	…	
4296	NaN	0	
4297	NaN	0	
4298	NaN	0	
4299	NaN	0	
4300	NaN	0	

	Planet mass (compared to Earth)	Planet radius (compared to Jupiter)	\
0	1.97054	0.107	
1	0.63884	0.108	
2	NaN	0.262	
3	NaN	0.302	
4	NaN	0.144	
…	…	…	
4296	NaN	0.118	
4297	NaN	0.096	
4298	NaN	0.140	
4299	NaN	0.259	
4300	NaN	0.198	

	Planet radius error (+/-)	Planet radius number of measurements	\
0	0.006	9	
1	0.007	8	
2	0.051	3	
3	0.062	3	
4	0.028	3	
…	…	…	
4296	NaN	1	
4297	NaN	1	
4298	NaN	1	
4299	NaN	1	
4300	NaN	1	

	Planet density	Density error (+/-)	Star distance (in Parsecs)	\
0	6.2	5.8	66.99	
1	2.1	2.2	66.99	

2	NaN	NaN	395.45
3	NaN	NaN	395.45
4	NaN	NaN	593.80
…	…	…	…
4296	NaN	NaN	379.00
4297	NaN	NaN	223.78
4298	NaN	NaN	NaN
4299	NaN	NaN	732.73
4300	NaN	NaN	594.10

	Distance error (+/-)	Distance number of measurements	Star temperature \
0	0.11	4	3841.00
1	0.11	4	3841.00
2	4.26	3	5594.00
3	4.26	3	5594.00
4	7.20	3	6077.00
…	…	…	…
4296	20.87	3	6251.00
4297	1.20	1	4945.83
4298	NaN	0	5214.40
4299	8.87	1	5885.00
4300	6.93	1	5116.26

	Temperature error (+/-)	Temperature number of measurements \
0	49.00	10
1	49.00	10
2	100.00	6
3	100.00	6
4	136.00	6
…	…	…
4296	81.98	3
4297	74.17	2
4298	221.45	2
4299	59.00	2
4300	471.94	2

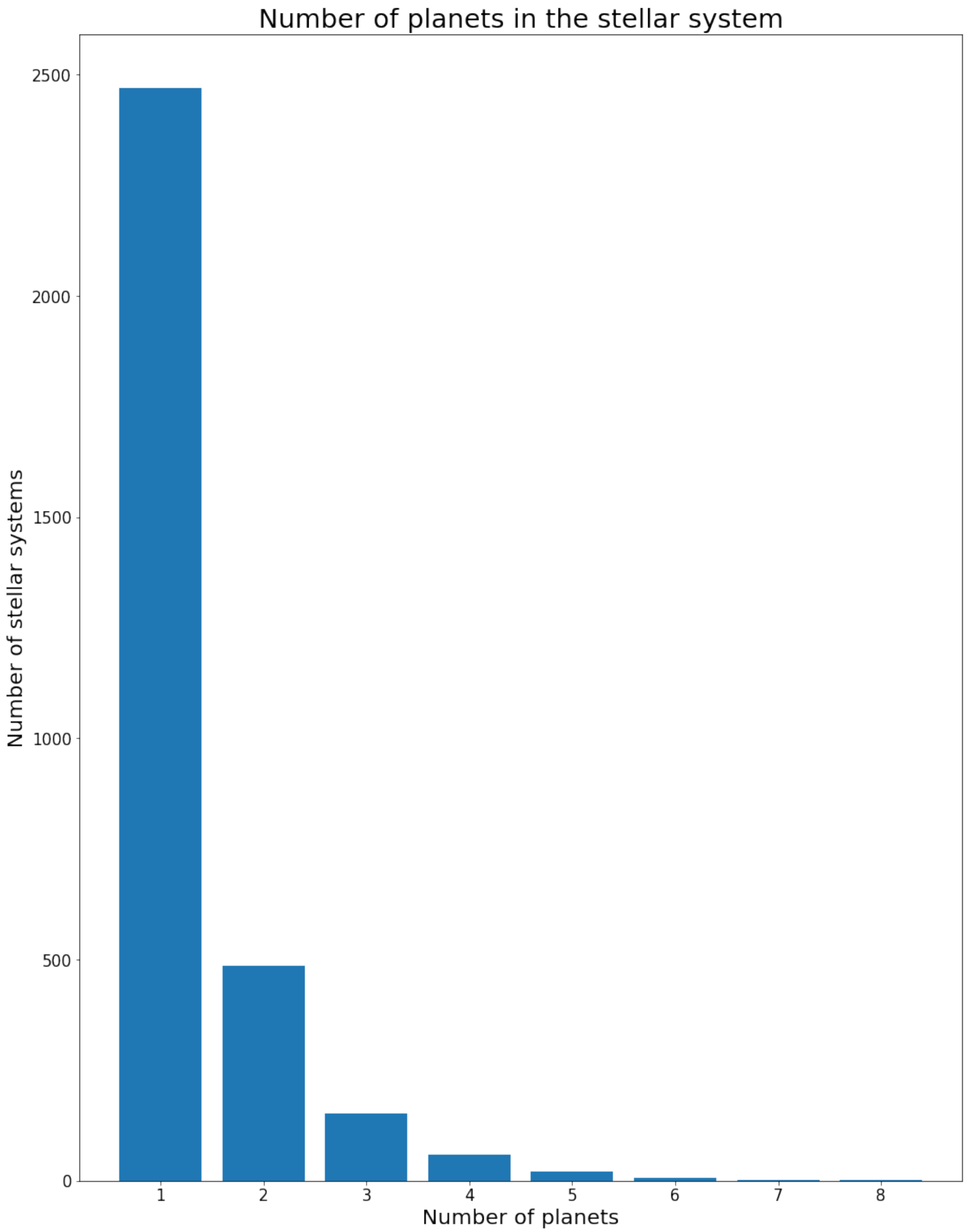
	Star mass (compared to the Sun)	Star mass error (+/-) \
0	0.52	0.06
1	0.52	0.06
2	NaN	NaN
3	NaN	NaN
4	NaN	NaN
…	…	…
4296	1.21	0.04
4297	NaN	NaN
4298	NaN	NaN
4299	NaN	NaN

```
4300                                   NaN                    NaN

      Star mass number of measurements  Star radius (compared to the Sun)  \
0                                     9                               0.44
1                                     9                               0.44
2                                     2                               1.30
3                                     2                               1.30
4                                     1                               1.29
…                                   …                                 …
4296                                  1                               1.22
4297                                  0                               0.74
4298                                  0                                NaN
4299                                  0                               1.14
4300                                  0                               0.83

      Star radius error (+/-)  Star radius number of measurements  \
0                        0.02                                  11
1                        0.02                                  11
2                        0.25                                   6
3                        0.25                                   6
4                        0.24                                   6
…                       …                                   …
4296                     0.06                                   3
4297                     0.02                                   2
4298                      NaN                                   1
4299                     0.01                                   2
4300                     0.02                                   2

     Date of last update Year of last update Discovery facility
0             2015-06-17                2015             Kepler
1             2015-06-17                2015             Kepler
2             2014-05-14                2014             Kepler
3             2014-05-14                2014             Kepler
4             2014-05-14                2014             Kepler
…                    …                   …                …
4296          2020-09-03                2020             Kepler
4297          2020-09-03                2020             Kepler
4298          2020-09-03                2020             Kepler
4299          2020-09-03                2020             Kepler
4300          2020-09-03                2020             Kepler

[4301 rows x 34 columns]
```

Here I have filtered and cleaned the dataset. With use of the Data Column Definitions Documentation, I use the dataframe 'drop' method to delete data that may not be relevant to the analysis I want to undertake on the dataset, and at the same time give more readable names to the relevant data. Any data that appears irrelevant to the current analysis has been kept in for potential future analyses. I also created two new columns to make some data more useful for comparisons and visualisations in analysis: ‘Planet mass (compared to Earth)’ and ‘Year of last update’.

1.2 Data Analysis

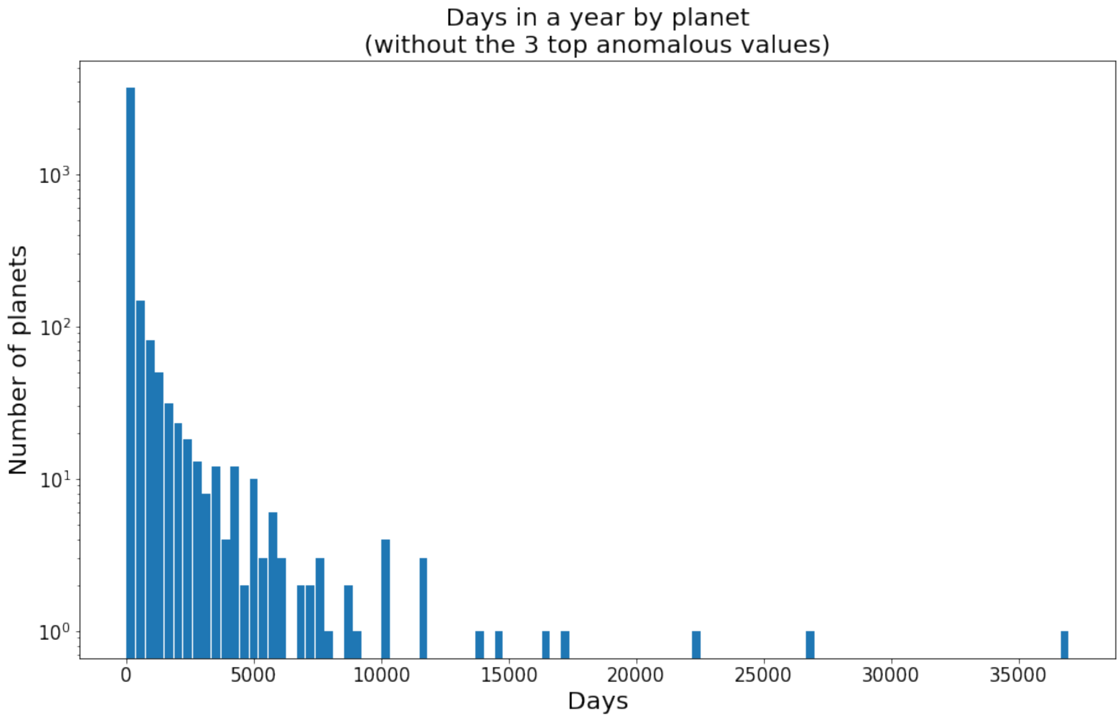
[5]:
```
s2 = df.groupby(['Number of planets in the stellar system']).size()

plt.figure(figsize=(15,20))
plt.title('Number of planets in the stellar system', fontsize=25)
plt.ylabel('Number of stellar systems', fontsize=20)
plt.xlabel('Number of planets', fontsize=20)
plt.tick_params(labelsize=15)


count=s2.index.min()
index=0

for i in s2.values: #clean up required as stellar systems will be represented␣
 ↪by multiple planets.
    i = i/count
    count = count+1

    s2.values[index] = i
    index=index+1

plt.bar(s2.index, s2.values)

sum = 0
for x in s2.index:
    sum += x*s2[x]
mean_planets= sum/s2.sum()


one_planet_percentage=round(s2[1]/s2.sum()*100,3)
eight_planets_integer=s2[8]
eight_planets_percentage=round(s2[8]/s2.sum()*100,3)
```

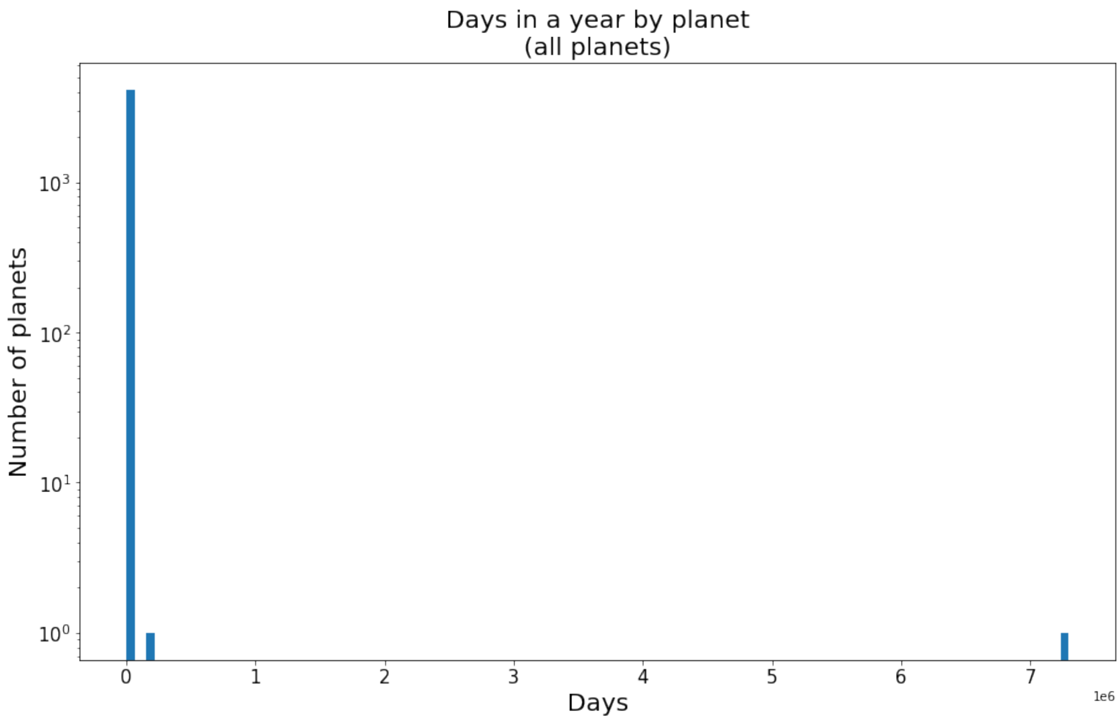


The above bar chart shows the number of planets per system discovered. The average number of planets in a stellar system is {{round(mean_planets, 5)}}, with {{one_planet_percentage}}% of stellar systems having just 1 planet. Interestingly, this makes our own solar system an extreme outlier. Our solar system contains 8 planets, a trait shared only by {{eight_planets_integer}} other system(s), {{eight_planets_percentage}}% of discovered stellar systems.

```
[6]: s3 = df['Days in a year']
s3=s3.dropna()

mean=round(s3.mean(), 6)
# print(s3.std())

largest_1 = int(s3.values[s3.values==max(s3.tolist())])
s4 = s3.drop(s3.index[s3.values==max(s3.tolist())])
largest_2 = int(s4.values[s4.values==max(s4.tolist())])
s4 = s4.drop(s4.index[s4.values==max(s4.tolist())])
largest_3 = int(s4.values[s4.values==max(s4.tolist())])
s4 = s4.drop(s4.index[s4.values==max(s4.tolist())])

new_mean=round(s4.mean(), 6)


fig, axs = plt.subplots(2)
plt.subplots_adjust(hspace=0.25)

plt.subplot(211)

plt.title('Days in a year by planet\n(without the 3 top anomalous values)',␣
 ↪fontsize=20)
plt.ylabel('Number of planets', fontsize=20)
plt.xlabel('Days', fontsize=20)
plt.tick_params(labelsize=15)
s4.hist(bins=100, figsize=(15,20), grid=False, rwidth=0.9, log=True)

plt.subplot(212)

plt.title('Days in a year by planet\n(all planets)', fontsize=20)
plt.ylabel('Number of planets', fontsize=20)
plt.xlabel('Days', fontsize=20)
plt.tick_params(labelsize=15)
s3.hist(bins=100, figsize=(15,20), grid=False, rwidth=0.9, log=True)


## comparisons to Earth

ten_percent = 365.25/10

s_comp=s3.drop(s3.index[s3.values<365.25-ten_percent])
s_comp=s_comp.drop(s_comp.index[s_comp.values>365.25+ten_percent])

num_shorter = s3.values[s3.values<365].size
percentage_shorter = round(num_shorter/s3.size*100, 4)
```

```
num_longer = s3.values[s3.values>365].size
percentage_longer = round(num_longer/s3.size*100, 4)
```



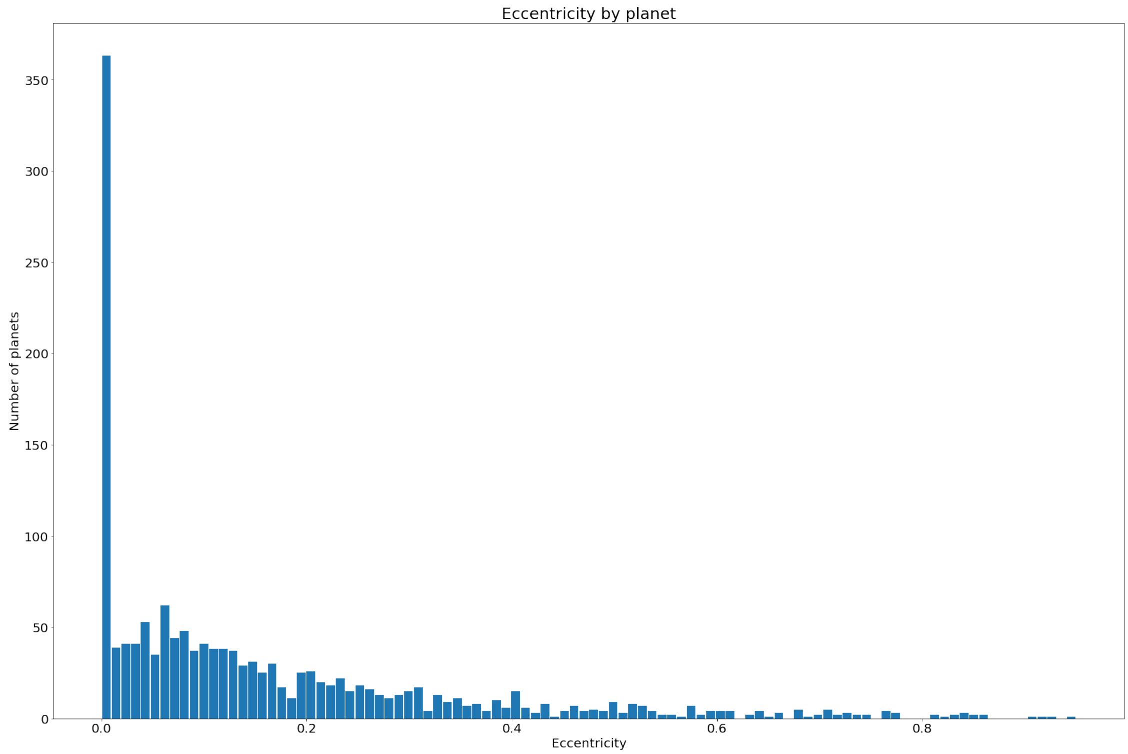


The data on days in a year by planet is uniquely interesting, as there are a small number of extremely high values that skew the whole data. The three largest day counts are {{largest_1}}, {{largest_2}} and {{largest_3}}. When these extremely high values are included the average days in a year for the exoplanets of the dataset is {{mean}} days, but when these anomalies are excluded from the calculations, the average days in a year for the exoplanets is {{new_mean}} days. Therefore, to properly characterise and visualise the data, some anomalous results have been removed for one of the visualisations.

The number of planets with a similar year lenth to Earth (+/-10% of 365.25 days) is {{s_comp.size}}. {{percentage_shorter}}% of planets have shorter years than Earth, whilst {{percentage_longer}}% of planets have longer years. So, despite an Earth year being only about {{round(365.25/mean,3)}} times the average year length, an Earth year is still longer than about {{round(percentage_shorter,1)}}% of planet years.

[7]:
```
### Earth's eccentricity varies between 0.0034 and 0.058
s5 = df['Eccentricity']
s5=s5.dropna()

eccentricities_similar_to_earth = np.sum(s5.between(0.0034, 0.058, inclusive =␣
↪True))
eccentricities_smaller_than_earth = np.sum(s5<0.00339)
eccentricities_larger_than_earth = np.sum(s5>0.0581)
eccentricities_zero = np.sum(s5.equals(0))

num_eccentricities_recorded = s5.size

percentage_similar_to_earth = round(eccentricities_similar_to_earth/
↪num_eccentricities_recorded*100, 3)

mean_eccentricity = round(s5.mean(), 5)

plt.title('Eccentricity by planet', fontsize=25)
plt.ylabel('Number of planets', fontsize=20)
plt.xlabel('Eccentricity', fontsize=20)
plt.tick_params(labelsize=20)

s5.hist(bins=100, figsize=(30,20), grid=False, rwidth=0.9)
```

[7]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7fdb4acc2940>
```



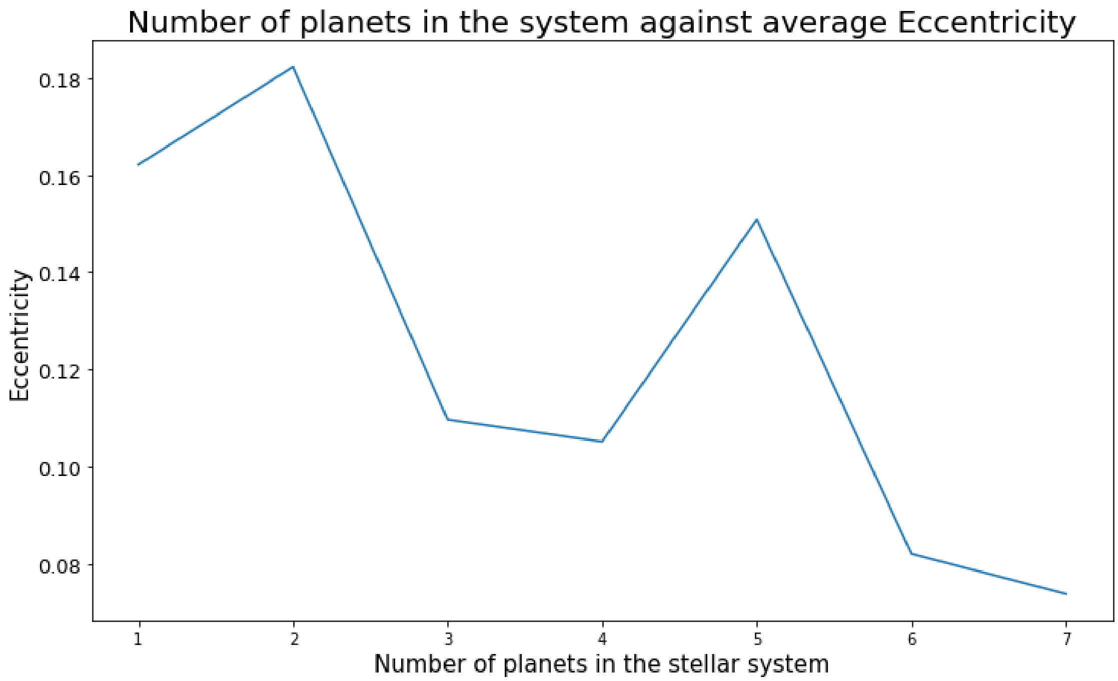
According to the Wikipedia page on 'Orbital Eccentricity' the Earth's eccentricity varies between 0.0034 and 0.058 over hundreds of thousands of years. Note that eccentricity determines the amount by which an orbit around another body deviates from a perfect circle. An eccentricity of 0 implies an orbit with a perfect circle. Eccentricity has a range of 0 <= e < 1.

The average eccentricity of an exoplanet's orbit is {{mean_eccentricity}}, about {{round(mean_eccentricity/0.0580,2)}} times larger than Earth at it's 'most eccentric'. {{percentage_similar_to_earth}}% of the exoplanets have similar eccentricity in their orbit as Earth (between 0.0034 and 0.0580).

There are {{eccentricities_zero}} planets with an orbital eccentricity of 0, hence there are {{eccentricities_zero}} planets whose orbits are perfect circles.

[8]:
```
df.groupby(['Number of planets in the stellar system'])['Eccentricity'].mean().
 ↪plot(y='Eccentricity', figsize=(12,7))

plt.title('Number of planets in the system against average Eccentricity',␣
 ↪size=20)

plt.xlabel('Number of planets in the stellar system', size=15)
plt.ylabel('Eccentricity', size=15)

plt.xticks(size=10)
plt.yticks(size=13)
```

[8]: (array([0.06, 0.08, 0.1 , 0.12, 0.14, 0.16, 0.18, 0.2]),
 <a list of 8 Text major ticklabel objects>)

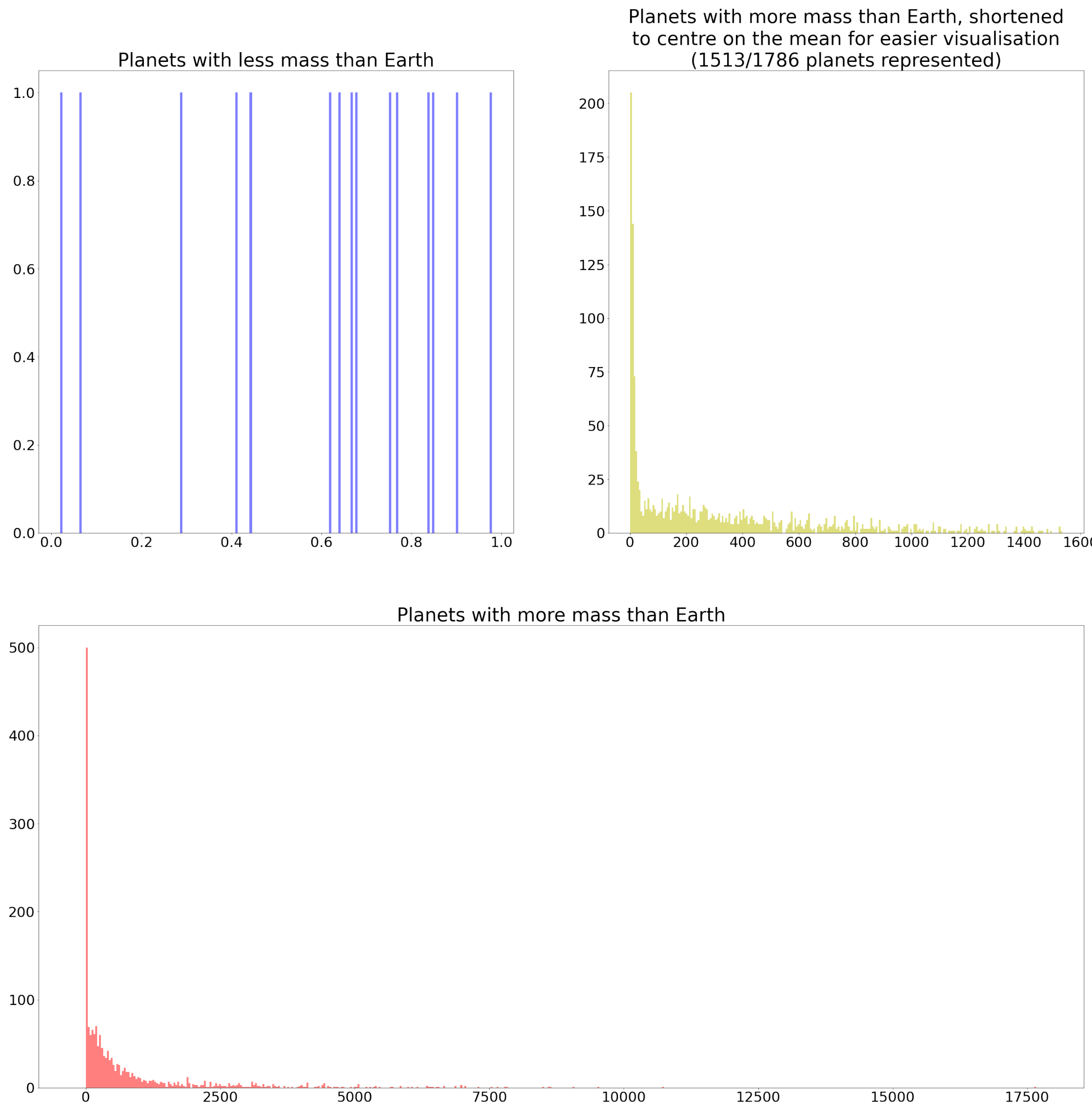


The Wikipedia page on 'Orbital Eccentricity' also mentions that the variability of Earth's eccentricity is 'a result of gravitational attractions among the planets'. This graph attempts to visualise a possible relationship between the number of planets in a system and the orbital eccentricity of a planet in that system. Although it appears as though more planets in a system leads to a lower orbital eccentricity of planets in that system, this is not a conclusion I would be confident in drawing, as there are very few discovered planets that are in 6 and 7 planet stellar systems. There simply is not enough data to draw conclusions on this relationship.

[9]:
```
import matplotlib.gridspec as gridspec

s6 = df['Planet mass (compared to Earth)']

#if(s6.values.notnull):
s6=s6.dropna()
mean=round(s6.mean(), 5)

s7=s6.drop(s6.index[s6.values>1])
s8=s6.drop(s6.index[s6.values<1])

s9=s8.drop(s8.index[s8.values>(s6.mean()*2)])
```

```python
# Create 2x2 sub plots
gs = gridspec.GridSpec(2, 2)

plt.figure(figsize=(40,40))

ax = plt.subplot(gs[0, 0]) # row 0, col 0
ax.set_title('Planets with less mass than Earth', fontsize=40) #title
ax.tick_params(labelsize=30) #labelsize

plt.hist(s7.values, 180, alpha = 0.5, color = ('b'))

ax = plt.subplot(gs[0, 1]) # row 0, col 1
ax.set_title('Planets with more mass than Earth, shortened\nto centre on the␣
 ↪mean for easier visualisation\n('+str(s9.size)+'/'+str(s6.size)+' planets␣
 ↪represented)', fontsize=40) #title
ax.tick_params(labelsize=30) #labelsize

plt.hist(s9, 250, alpha = 0.5, color = 'y')

ax = plt.subplot(gs[1, :]) # row 1, span all columns
ax.set_title('Planets with more mass than Earth', fontsize=40) #title
ax.tick_params(labelsize=30) #labelsize

plt.hist(s8, 500, alpha = 0.5, color = 'r')

s10=s6.drop(s6.index[s6.values>1.1])
s10=s6.drop(s6.index[s6.values<0.9])
print('Number of planets with similar mass to Earth (+/-10%):' + str(s10.size))

s11=s6.drop(s6.index[s6.values>=3.5])
habitable_gravity = s11.size

plt.show()
```

```
Number of planets with similar mass to Earth (+/-10%):1772
```



The average mass of planets in the dataset is {{mean}} times the size of mass on Earth.

Out of the three measurements of ‘size’: mass, radius and density, I am particularly interested in mass, as the mass of a planet is the only thing that indicates the magnitude of gravity a human would experience on the planet.

An article from Science Alert claims researchers believe a reasonable upper limit of gravity for any planet humans could visit would be between 3 and 4 times that of Earth’s (1g). For the sake of this inquiry we’ll use 3.5g as an upper limit.

With this in mind, there are a total of just {{habitable_gravity}} planets that humans could feasibly walk on, just {{round(habitable_gravity/s6.size*100 , 5)}}% of the recorded exoplanets planets.

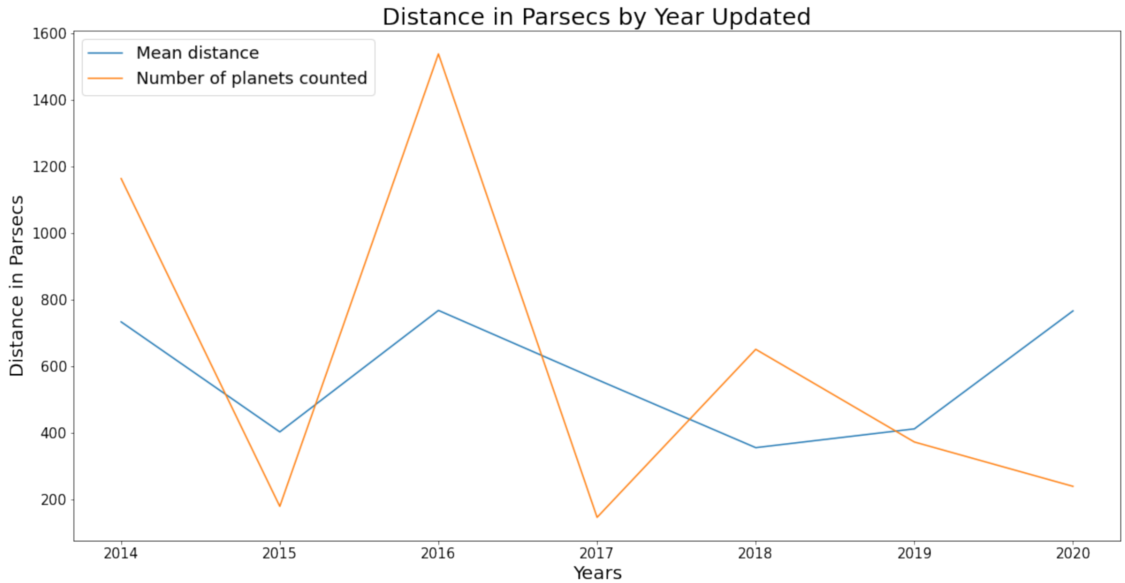
[10]:
```
s12=df['Star distance (in Parsecs)']
s12=s12.dropna()

#speed of light = 299 792 458 m/s
#81.5 - 18 years in seconds (life expectancy Ireland - adult age) = 63.5 years␣
↪in seconds = 2,002,536,000 s
#one parsec in metres = 3.0857x10^16 m

max_distance_metres = 299792458 * 2002536000
max_distance_parsecs = max_distance_metres / (3.0857 *(10**16))

reachable_planets=s12.drop(s12.index[s12.values>=max_distance_parsecs])
reachable_planets_percentage= round(reachable_planets.size/s12.size*100, 2)
```

This is an inquiry into which discovered exoplanets a human could possibly travel to in their lifetime. This is purely theoretical and assumes that the human can travel at maximum speed, the speed of light. It is assumed also that life expectancy is 81.5 (the average life expectancy of an Irish person, ref) and that one can only travel into space once they're 18.

The number of 'reachable' exoplanets in a lifetime is {{reachable_planets.size}}, {{reachable_planets_percentage}}% of discovered planets.

[11]:
```
s12=df['Star distance (in Parsecs)']
s13=df['Year of last update']

s14=df['Star distance (in Parsecs)']
s14.set_index=df['Year of last update'].values

s15 = df.groupby(df['Year of last update'])['Star distance (in Parsecs)'].
↪agg(['mean'])
s16 = df.groupby(df['Year of last update'])['Star distance (in Parsecs)'].
↪agg(['count'])


plt.figure(figsize=(20,10))
plt.title('Distance in Parsecs by Year Updated', fontsize=25)
plt.ylabel('Distance in Parsecs', fontsize=20)
plt.xlabel('Years', fontsize=20)

plt.tick_params(labelsize=15) #labelsize

plt.plot(s15, label='Mean distance')
plt.plot(s16, label='Number of planets counted')
plt.legend(loc="upper left", prop={'size': 18})
```

[11]:
```
<matplotlib.legend.Legend at 0x7fdb4a1ee6d0>
```



The above graph visualises the relationship between the year the planet was updated in the dataset and it's star's distance from us. One could imagine logically that each year that goes by we discover planets that are further and further away. The blue line shows that the mean distance of planets discovered does not seem to increase over time. There is something of a noticeable relationship between the mean distance and the number of planets counted, inferring that more planets discovered does mean planets further away will be discovered. However, there is no indication that we are discovering planets further away as time goes on.

1.3 Summary and Further Analysis

In summary, we have gained much insight into how Earth 'stacks up' to exoplanets discovered so far.

Incredibly, Earth is 1 of just {{eight_planets_integer+1}} known planets inhabiting systems of eight planets.

Whilst Earth years are very short compared to an average planet year, our years are still in the top {{round(percentage_longer)}}% of known planet year lengths.

The eccentricity of Earth's orbit is similar to {{percentage_similar_to_earth}}% of exoplanets, {{eccentricities_zero}} of which have a perfectly circular orbit. But our planet's eccentricity is roughly {{round(mean_eccentricity/0.0580,2)}} times smaller than the average planet, so we're closer to perfect than most!

From the analysed mass data I have deducted that humans could only feasibly walk around on just {{round(habitable_gravity/s6.size*100 , 5)}}% of the discovered exoplanets, assuming they were protected from all external forces other than gravity.

From data on the star distances in Parsecs, and theoretical data on human life expectancy and light speed travel, I have found that theoretically {{reachable_planets_percentage}}% of the discovered planets are reachable in a human's lifetime.

As for further analysis, there is plenty that could be done with the rest of the available data. For example the range of error allowed by each discovery station, to deduce which gives the most accurate measurements, or which discovery method provides the most discoveries. More enquires could also be done into the similarities between our Sun and the stars of the discovered exoplanets.