In [1]:
```
####################
### Project DSC530###
####################

# This project is to analyze Exoplanets database from exoplanet.eu and answer my question:
# Are the ellipses perimeters influenced by the exoplanet detection methods?

# Exoplanets are beyond our solar system.
# When I started to code this project, there were 4082 exoplanets observations.

# I did the dataset search on exoplanet.eu.
# exoplanet.eu is an astronomy website founded in Paris with an Extrasolar Planets database which is constantly updated
with new findings.
# This database has 129 columns or variables.
# This is a database that constantly is being updated with new observations.
# I will use the PyvO database as my dataset and will query exoplanets tables.
# PyvO lets find and retrieve astronomical data available from archives that support standard IVOA virtual observatory
 service protocols.

# To connect to exoplanet.eu database, I will use an API.
# The API was developed by the Virtual Observatory (VO).
# I will create an engine for connecting to the database.
# After connecting to the database, I will be able to extract the data with SQL instructions.
```

In [2]:
```
# Required Packages,

import pyvo
import math
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import thinkstats2 as ts2
import thinkplot as tp
import statsmodels.formula.api as smf

# I created this package which has functions required in this project
import dsc530 as dsc
```

In [3]:
```
# When I use a SQL to access remote data of the Virtual observatory (VO), the result is stored in a proprietary object,
TAPResults.
# TAPResults is a container holding a table of matching catalog records. It is defined in Data Access (pyvo.dal), an af
filiated package for the astropy package.

# I will work with pandas dataframe throughout the analysis, so I will have to make some conversions:
# 1. Convert initial TAPResults object to astropy table,
# 2. Convert astropy table object to numpy array,
# 3. Convert the numpy array to Pandas dataframe.
# I coded a function called, "ConvertDataframe" in my dsc530 package.
# This function converts a pyvo.dal.tap.TAPResults object by a pandas dataframe.

# Number of exoplanets observations:

sql = ('SELECT COUNT(*) AS total'
       '  FROM exoplanet.epn_core')

exoplanet_num = dsc.ConvertDataframe(sql)
print('Exoplanets discovered: {0}'.format(exoplanet_num.total[0]))
```

```
Exoplanets discovered: 4093
```

In [4]:
```
# This is the codebook of exoplanets database,

sql = ('SELECT * '
       '  FROM tap_schema.columns'
       ' WHERE table_name = \'exoplanet.epn_core\'')
codebook = dsc.ConvertDataframe(sql)
codebook
```

Out[4]:

	table_name	column_name	description	unit	ucd	
0	b'exoplanet.epn_core'	b'granule_uid'	Internal table row index Unique ID in data ser...	b''	b'meta.id'	b''
1	b'exoplanet.epn_core'	b'granule_gid'	Common to granules of same type (e.g. same map...	b''	b'meta.id'	b''
2	b'exoplanet.epn_core'	b'obs_id'	Associates granules derived from the same data...	b''	b'meta.id'	b''
3	b'exoplanet.epn_core'	b'dataproduct_type'	The high-level organization of the data produc...	b''	b'meta.code.class'	b'Epn.dataPr
4	b'exoplanet.epn_core'	b'target_name'	Standard IAU name of target (from a list relat...	b''	b'meta.id;src'	b'Epn.Target
5	b'exoplanet.epn_core'	b'target_class'	Type of target, from enumerated list	b''	b'meta.code.class;src'	b'Epn.Target
6	b'exoplanet.epn_core'	b'time_min'	Acquisition start time (in JD)	b'd'	b'time.start'	b''
7	b'exoplanet.epn_core'	b'time_max'	Acquisition stop time (in JD)	b'd'	b'time.end'	b''
8	b'exoplanet.epn_core'	b'time_sampling_step_min'	Sampling time for measurements of dynamical ph...	b's'	b'time.interval;stat.min'	b'Epn.Time.T
9	b'exoplanet.epn_core'	b'time_sampling_step_max'	Sampling time for measurements of dynamical ph...	b's'	b'time.interval;stat.max'	b'Epn.Time.T
10	b'exoplanet.epn_core'	b'time_exp_min'	Integration time of the measurement, lower limit.	b's'	b'time.duration;obs.exposure;stat.min'	b'Epn.Time.T
11	b'exoplanet.epn_core'	b'time_exp_max'	Integration time of the measurement, upper limit	b's'	b'time.duration;obs.exposure;stat.max'	b'Epn.Time.T
12	b'exoplanet.epn_core'	b'spectral_range_min'	Spectral range (frequency), lower limit.	b'Hz'	b'em.freq;stat.min'	b'Epn.Spectr
13	b'exoplanet.epn_core'	b'spectral_range_max'	Spectral range (frequency), upper limit	b'Hz'	b'em.freq;stat.max'	b'Epn.Spectr
14	b'exoplanet.epn_core'	b'spectral_sampling_step_min'	spectral sampling step, lower limit.	b'Hz'	b'em.freq.step;stat.min'	b'Epn.Spectr

	table_name	column_name	description	unit	ucd	
15	b'exoplanet.epn_core'	b'spectral_sampling_step_max'	spectral sampling step, upper limit	b'Hz'	b'em.freq.step;stat.max'	b'Epn.Spectr
16	b'exoplanet.epn_core'	b'spectral_resolution_min'	Sectral resolution, lower limit.	b'Hz'	b'spect.resolution;stat.min'	b'Epn.Spectr
17	b'exoplanet.epn_core'	b'spectral_resolution_max'	Sectral resolution, upper limit	b'Hz'	b'spect.resolution;stat.max'	b'Epn.Spectr
18	b'exoplanet.epn_core'	b'c1min'	Right Ascension (ICRS), lower limit.	b'deg'	b'pos.eq.ra;stat.min'	b'Epn.Spatia
19	b'exoplanet.epn_core'	b'c1max'	Right Ascension (ICRS), upper limit	b'deg'	b'pos.eq.ra;stat.max'	b'Epn.Spatia
20	b'exoplanet.epn_core'	b'c2min'	Declination (ICRS), lower limit.	b'deg'	b'pos.eq.dec;stat.min'	b'Epn.Spatia
21	b'exoplanet.epn_core'	b'c2max'	Declination (ICRS), upper limit	b'deg'	b'pos.eq.dec;stat.max'	b'Epn.Spatia
22	b'exoplanet.epn_core'	b'c3min'	Distance from coordiate origin, lower limit.	b'm'	b'phys.distance;stat.min'	b'Epn.Spatia
23	b'exoplanet.epn_core'	b'c3max'	Distance from coordiate origin, upper limit	b'm'	b'phys.distance;stat.max'	b'Epn.Spatia
24	b'exoplanet.epn_core'	b's_region'	ObsCore-like footprint, valid for celestial, s...	b''	b'phys.outline;obs.field'	b''
25	b'exoplanet.epn_core'	b'c1_resol_min'	Resolution in the first coordinate, lower limit.	b'deg'	b'pos.resolution;stat.min'	b'Epn.Spatia
26	b'exoplanet.epn_core'	b'c1_resol_max'	Resolution in the first coordinate, upper limit	b'deg'	b'pos.resolution;stat.max'	b'Epn.Spatia
27	b'exoplanet.epn_core'	b'c2_resol_min'	Resolution in the second coordinate, lower limit.	b'deg'	b'pos.resolution;stat.min'	b'Epn.Spatia
28	b'exoplanet.epn_core'	b'c2_resol_max'	Resolution in the second coordinate, upper limit	b'deg'	b'pos.resolution;stat.max'	b'Epn.Spatia
29	b'exoplanet.epn_core'	b'c3_resol_min'	Resolution in the third coordinate, lower limit.	b'm'	b'pos.resolution;stat.min'	b'Epn.Spatia
...	...	...	...	...	...	...
99	b'exoplanet.epn_core'	b'albedo_error_min'	Geometric albedo error min	b''	b'phys.albedo;stat.error.min'	b''

	table_name	column_name	description	unit	ucd	
100	b'exoplanet.epn_core'	b'albedo_error_max'	Geometric albedo error max	b''	b'phys.albedo;stat.error.max'	b''
101	b'exoplanet.epn_core'	b'mass_detection_type'	mass detection type 1: detected by radial velo...	b''	b'meta.id'	b''
102	b'exoplanet.epn_core'	b'radius_detection_type'	radius detection type 1: detected by radial ve...	b''	b'meta.id'	b''
103	b'exoplanet.epn_core'	b'mass_sin_i'	mass function of the orbit inclination express...	b'"jupiterMass"'	b'phys.mass'	b''
104	b'exoplanet.epn_core'	b'mass_sin_i_error_min'	mass function of the orbit inclination error min	b'"jupiterMass"'	b'phys.mass;stat.error.min'	b''
105	b'exoplanet.epn_core'	b'mass_sin_i_error_max'	mass function of the orbit inclination error max	b'"jupiterMass"'	b'phys.mass;stat.error.max'	b''
106	b'exoplanet.epn_core'	b'k'	Velocity Semiamplitude K	b'm.s-1'	b'spect.dopplerVeloc'	b''
107	b'exoplanet.epn_core'	b'k_error'	Velocity Semiamplitude K error	b'm.s-1'	b'spect.dopplerVeloc;stat.error'	b''
108	b'exoplanet.epn_core'	b'alternate_name'	planet alternate name	b''	b'meta.id'	b''
109	b'exoplanet.epn_core'	b'star_name'	name of host star	b''	b'meta.id'	b''
110	b'exoplanet.epn_core'	b'star_distance'	distance of the star	b'pc'	b'pos.distance'	b''
111	b'exoplanet.epn_core'	b'star_distance_error_min'	Distance of the star error min	b'pc'	b'pos.distance;stat.error.min'	b''
112	b'exoplanet.epn_core'	b'star_distance_error_max'	Distance of the star error max	b'pc'	b'pos.distance;stat.error.max'	b''
113	b'exoplanet.epn_core'	b'star_spec_type'	spectral type of the star	b''	b'src.spType'	b''
114	b'exoplanet.epn_core'	b'mag_v'	V magnitude of a host star	b''	b'phot.mag;em.opt.V'	b''
115	b'exoplanet.epn_core'	b'mag_i'	I magnitude of a host star	b''	b'phot.mag;em.opt.I'	b''
116	b'exoplanet.epn_core'	b'mag_j'	J magnitude of a host star	b''	b'phot.mag;em.IR.J'	b''
117	b'exoplanet.epn_core'	b'mag_h'	H magnitude of a host star	b''	b'phot.mag;em.IR.H'	b''
118	b'exoplanet.epn_core'	b'mag_k'	K magnitude of a host star	b''	b'phot.mag;em.IR.K'	b''
119	b'exoplanet.epn_core'	b'star_metallicity'	Decimal logarithm of the massive elements (Â« ...	b''	b'phys.abund.Z'	b''

	table_name	column_name	description	unit	ucd	
120	b'exoplanet.epn_core'	b'star_mass'	Mass of a host star	b'solMass'	b'phys.mass'	b''
121	b'exoplanet.epn_core'	b'star_radius'	Radius of a host star	b'solRad'	b'phys.size.radius'	b''
122	b'exoplanet.epn_core'	b'star_sp_type'	Spectral type of a host star	b''	b'src.spType'	b''
123	b'exoplanet.epn_core'	b'star_age'	Age of a host star	b'Gyr'	b'time.age'	b''
124	b'exoplanet.epn_core'	b'star_teff'	Effective temperature of a host star	b'K'	b'phys.temperature.effective'	b''
125	b'exoplanet.epn_core'	b'detected_disc'	(direct imaging or IR excess) disc detected	b''	b'meta.info'	b''
126	b'exoplanet.epn_core'	b'ra'	Right ascension of the host star	b'deg'	b'pos.eq.ra'	b''
127	b'exoplanet.epn_core'	b'dec'	Declination of the host star	b'deg'	b'pos.eq.dec'	b''
128	b'exoplanet.epn_core'	b'external_link'	Link to a web page providing more details on t...	b''	b'meta.ref.url'	b''

129 rows × 15 columns

In [5]:
```
# I will work with these variables:

# 1. mass: planetary mass.
# 2. period: orbital period around the star.
# 3. detection type: method used to discover the exoplanet
# 4. semi major axis: the semi-major axis is half of the longest diameter of an ellipse.
# 5. semi minor axis: [derived variable] minor semi-axis is a line segment that is at right angles with the semi-major
 axis and has one end at the center.
# 6. eccentricity: the eccentricity is a measure of how much an ellipse is squashed. This is the shape of the ellipse.
# 7. star distance: distance to a host star.
# 8. ellipse: [derived variable] total ellipse perimeter.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       ROUND(mass, 2) AS mass,'
       '       TRUNCATE(period) AS period,'
       '       detection_type AS detection,'
       '       semi_major_axis,'
       '       semi_major_axis * SQRT(1 - POWER(eccentricity, 2)) AS semi_minor_axis,'
       '       eccentricity,'
       '       UPPER(star_name) AS star,'
       '       star_distance,'
       '       star_teff AS star_temp'
       '  FROM exoplanet.epn_core'
       ' WHERE (1 - POWER(eccentricity, 2)) >= 0')

exoplanets = dsc.ConvertDataframe(sql)
exoplanets.head()
```

Out[5]:

	exoplanet	mass	period	detection	semi_major_axis	semi_minor_axis	eccentricity	star	star_distance	star_temp
0	b'11 COM B'	NaN	326.0	b'Radial Velocity'	1.29	1.255110	0.231	b'11 COM'	110.599998	4742.0
1	b'11 UMI B'	NaN	516.0	b'Radial Velocity'	1.54	1.535064	0.080	b'11 UMI'	119.500000	4340.0
2	b'14 AND B'	NaN	185.0	b'Radial Velocity'	0.83	0.830000	0.000	b'14 AND'	76.400002	4813.0
3	b'14 HER B'	NaN	1773.0	b'Radial Velocity'	2.77	2.574519	0.369	b'14 HER'	18.100000	5311.0
4	b'16 CYG B B'	NaN	799.0	b'Radial Velocity'	1.68	1.217599	0.689	b'16 CYG B'	21.410000	5766.0

In [6]:
```
# Variables into the pandas dataframe,

print('Variables: {0}'.format(exoplanets.columns))
```

```
Variables: Index(['exoplanet', 'mass', 'period', 'detection', 'semi_major_axis',
       'semi_minor_axis', 'eccentricity', 'star', 'star_distance',
       'star_temp'],
      dtype='object')
```

In [7]:
```
###########################
##detection type variable##
###########################

# detection type is the method used to discover exoplanets,

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       detection_type AS detection'
       '  FROM exoplanet.epn_core'
       ' WHERE detection_type IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)

print('{0} variable'.format(exoplanets.columns[1]))
```

```
detection variable
```

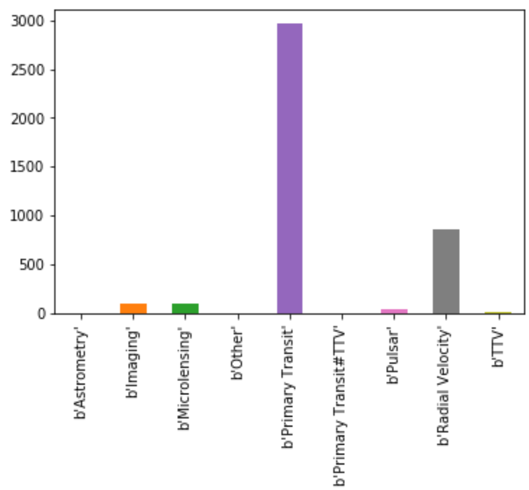
In [8]:
```
# Explore some observations of the detection type variable,

vdetection = exoplanets['detection']
print(vdetection.head())
```

```
0    b'Radial Velocity'
1            b'Imaging'
2    b'Radial Velocity'
3    b'Radial Velocity'
4    b'Radial Velocity'
Name: detection, dtype: object
```

In [9]:
```
# calculate frequency of exoplanet detection types,

fq_detection = exoplanets.detection.value_counts().sort_index()
print(fq_detection)
```

```
b'Astrometry'              1
b'Imaging'               107
b'Microlensing'          100
b'Other'                   5
b'Primary Transit'      2967
b'Primary Transit#TTV'     2
b'Pulsar'                 41
b'Radial Velocity'       861
b'TTV'                     9
Name: detection, dtype: int64
```

In [10]:
```
# Histogram of detection variable,

fq_detection.plot.bar()
plt.show()

# The most used method to find exoplanets is 'Primary Transit'
# primary transit is when a planet passes in front of its host star.
```



In [11]:
```
#################
##mass variable##
#################

# mass variable is the planetary mass.
# The exoplanets mass is expressed in jupMass.
# For example, an exoplanet with 21 jupMass is equivalent to 21 Jupiters.
# Jupiter is the largest planet in the solar system.
# Jupiter is so big that over 1,300 Earths could fit inside of it.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       mass'
       '  FROM exoplanet.epn_core'
       ' WHERE mass IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)

print('{0} variable'.format(exoplanets.columns[1]))
```

```
mass variable
```

In [12]:
```
# Explore some observations of the mass variable,

vmass = exoplanets['mass']
print(vmass.head())
```

```
0    21.0
1    14.0
2    32.0
3    13.0
4    20.0
Name: mass, dtype: float32
```

In [13]:
```
# Descriptive characteristics about the mass variable expressed in Earth-size,

# Exoplanet mass expressed in Earth-size,
exoplanets['mass_earth'] = round(exoplanets.mass * 1300)

# Mean, Variance, and Standard Deviation,
mass_mean = exoplanets.mass_earth.mean()
mass_var = exoplanets.mass_earth.var()
mass_std = exoplanets.mass_earth.std()

print('The mass average is {0} Earth-size'.format(round(mass_mean)))
print('Total of mass differences from the mean: {0}'.format(round(mass_var)))
print('Standard deviation is {0}'.format(round(mass_std)))

# Standard Deviation is greater magnitude than mean,
# It can indicate that data are spread out or it has outliers.
# There is a significant difference between mass exoplanets.
```

```
The mass average is 7061 Earth-size
Total of mass differences from the mean: 253579520
Standard deviation is 15924
```

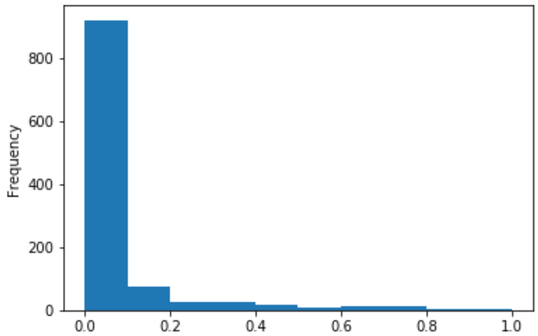
In [14]:
```
# Handle outliers of the mass variable,

# I will use data normalization with the Min-Max method,
exoplanets['mass_earth_MinMax'] = ((exoplanets['mass_earth'] - exoplanets['mass_earth'].min()) / (exoplanets['mass_eart
h'].max() - exoplanets['mass_earth'].min()))
exoplanets.head(10)
```

Out[14]:

	exoplanet	mass	mass_earth	mass_earth_MinMax
0	b'11 OPH B'	21.00	27300.0	0.256410
1	b'1RXS 1609 B'	14.00	18200.0	0.170940
2	b'1RXS J235133.3+312720 B'	32.00	41600.0	0.390720
3	b'2M 0103-55 (AB) B'	13.00	16900.0	0.158730
4	b'2M 0122-24 B'	20.00	26000.0	0.244200
5	b'2M 0219-39 B'	13.90	18070.0	0.169719
6	b'2M 0441+23 B'	7.50	9750.0	0.091575
7	b'2M 1938+46 B'	1.90	2470.0	0.023199
8	b'2M 2140+16 B'	20.00	26000.0	0.244200
9	b'51 PEG B'	0.47	611.0	0.005739

In [15]:
```
# Histogram of normalized mass variable,

exoplanets['mass_earth_MinMax'].plot(kind = 'hist')

# The mass histogram shows that the largest number of exoplanets discovered have a mass between 0.0 and 0.1
# I will calculate the average mass of exoplanets that are in the highest range,

mass01 = round(exoplanets.loc[exoplanets.mass_earth_MinMax <= 0.1].mass_earth.mean())
print('The average mass is {0} Earth-size'.format(mass01))
```

```
The average mass is 1426 Earth-size
```



In [16]:
```
##################
##period variable##
##################

# period is the orbital period around the host star.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       period AS period_days,'
       '       ROUND(period/365, 2) AS period_years'
       '  FROM exoplanet.epn_core'
       ' WHERE period IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)

print('{0} variable'.format(exoplanets.columns[1]))
```

```
period_days variable
```

In [17]:
```
# Explore some observations of the period variable in days and years,

exoplanets.head()
```

Out[17]:

	exoplanet	period_days	period_years
0	b'11 COM B'	326.029999	0.89
1	b'11 OPH B'	730000.000000	2000.00
2	b'11 UMI B'	516.219971	1.41
3	b'14 AND B'	185.839996	0.51
4	b'14 HER B'	1773.400024	4.86

In [18]:
```
# Descriptive characteristics about the period variable expressed in years,

# Mean, Variance, and Standard Deviation,
per_mean = exoplanets.period_years.mean()
per_var = exoplanets.period_years.var()
per_std = exoplanets.period_years.std()

print('The period average is {0} years'.format(round(per_mean)))
print('Total of mass differences from the mean: {0}'.format(round(per_var)))
print('Standard deviation is {0}'.format(round(per_std)))

# Standard Deviation is greater magnitude than mean,
# It can indicate that data are spread out or it has outliers.
# There is a significant difference between period exoplanets.
```

```
The period average is 2 years
Total of mass differences from the mean: 1464
Standard deviation is 38
```

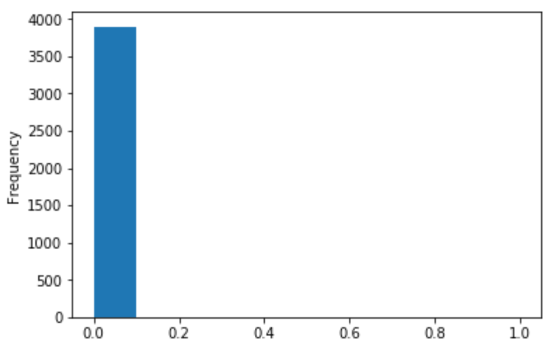
In [19]:
```
# Handle mass outliers,

# I will use data normalization with the Min-Max method,
exoplanets['per_years_MinMax'] = ((exoplanets['period_years'] - exoplanets['period_years'].min()) / (exoplanets['period
_years'].max() - exoplanets['period_years'].min()))
exoplanets.head(10)
```

Out[19]:

	exoplanet	period_days	period_years	per_years_MinMax
0	b'11 COM B'	326.029999	0.89	0.000445
1	b'11 OPH B'	730000.000000	2000.00	1.000000
2	b'11 UMI B'	516.219971	1.41	0.000705
3	b'14 AND B'	185.839996	0.51	0.000255
4	b'14 HER B'	1773.400024	4.86	0.002430
5	b'16 CYG B B'	799.500000	2.19	0.001095
6	b'18 DEL B'	993.299988	2.72	0.001360
7	b'1SWASP J1407 B'	3725.000000	10.21	0.005105
8	b'24 BOO B'	30.350599	0.08	0.000040
9	b'24 SEX B'	452.799988	1.24	0.000620

In [20]:
```
# Histogram of normalized period variable,

exoplanets['per_years_MinMax'].plot(kind = 'hist')

# The period histogram shows that most exoplanets discovered have not very large orbital periods.
# I will calculate the average period of exoplanets that are in the highest range,

period01 = round(exoplanets.loc[exoplanets.per_years_MinMax <= 0.1].period_years.mean(), 2)
print('The average period is {0} years'.format(period01))
```

```
The average period is 1.02 years
```



In [21]:
```
####################
##ellipse variable##
####################

# The ellipse variable is a calculated variable.
# This variable indicates the total ellipse perimeter.
# I have to calculate the ellipse perimeter with semi_major_axis and semi_minor_axis variables, but
# the semi_minor_axis variable does not exist in the database. ALthough,
# the eccentricity variable exists in the database.
# I can calculate semi_minor_axis using eccentricity and semi_major_axis.

# Formula to calculate semi_minor_axis:
# semi_minor_axis [b] = semi_major_axis [a] * SQRT(1 - POWER(eccentricity, 2))

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       semi_major_axis,'
       '       eccentricity,'
       '       semi_major_axis * SQRT(1 - POWER(eccentricity, 2)) AS semi_minor_axis'
       '  FROM exoplanet.epn_core'
       ' WHERE semi_major_axis IS NOT NULL'
       '   AND eccentricity IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)
exoplanets.head()
```

Out[21]:

	exoplanet	semi_major_axis	eccentricity	semi_minor_axis
0	b'11 COM B'	1.29	0.231	1.255110
1	b'11 UMI B'	1.54	0.080	1.535064
2	b'14 AND B'	0.83	0.000	0.830000
3	b'14 HER B'	2.77	0.369	2.574519
4	b'16 CYG B B'	1.68	0.689	1.217599

In [22]:
```
# Exoplanets percentage to which ellipse perimeter can be calculated,

per_data = round((len(exoplanets) * 100) / exoplanet_num.total[0],2)
print('ellipse perimeter can be calculated only in {0}% of exoplanets.'.format(per_data))
```

```
ellipse perimeter can be calculated only in 36.13% of exoplanets.
```

In [23]:
```
# I will calculate the ellipse perimeter using semi_major_axis and semi_minor_axis.
# I will use Ramanujan's formula which is more accurate:

# h = POWER(semi_major_axis - semi_minor_axis, 2) / POWER(semi_major_axis + semi_minor_axis, 2)
# ellipse = math.pi * (semi_major_axis + semi_minor_axis) * (1 + ((3 * h) / (10 + SQRT(4 - (3 * h)))))

# Calculate h,

exoplanets['h'] = pow(exoplanets.semi_major_axis - exoplanets.semi_minor_axis, 2) / pow(exoplanets.semi_major_axis + ex
oplanets.semi_minor_axis, 2)
exoplanets.head()
```

Out[23]:

	exoplanet	semi_major_axis	eccentricity	semi_minor_axis	h
0	b'11 COM B'	1.29	0.231	1.255110	1.879232e-04
1	b'11 UMI B'	1.54	0.080	1.535064	2.576476e-06
2	b'14 AND B'	0.83	0.000	0.830000	7.156889e-32
3	b'14 HER B'	2.77	0.369	2.574519	1.337796e-03
4	b'16 CYG B B'	1.68	0.689	1.217599	2.546601e-02

In [24]:
```
# Calculate ellipse parameter,

exoplanets['ellipse'] = round(math.pi * (exoplanets.semi_major_axis + exoplanets.semi_minor_axis) * (1 + ((3 * exoplane
ts.h) / (10 + np.sqrt(4 - (3 * exoplanets.h))))), 2)

# ellipse perimeter is in AU = 92,96 million miles.
# An astronomical unit (AU) is the average distance between the Earth and the Sun.
# The length of Earth's trajectory around the sun is 584 million miles, that is,
# its ellipse perimeter is 6.28 AUs.

exoplanets.head()
```

Out[24]:

	exoplanet	semi_major_axis	eccentricity	semi_minor_axis	h	ellipse
0	b'11 COM B'	1.29	0.231	1.255110	1.879232e-04	8.00
1	b'11 UMI B'	1.54	0.080	1.535064	2.576476e-06	9.66
2	b'14 AND B'	0.83	0.000	0.830000	7.156889e-32	5.22
3	b'14 HER B'	2.77	0.369	2.574519	1.337796e-03	16.80
4	b'16 CYG B B'	1.68	0.689	1.217599	2.546601e-02	9.16

In [25]:
```
# Descriptive characteristics about the ellipse variable expressed in AUs,

# Mean, Variance, and Standard Deviation,
ellipse_mean = exoplanets.ellipse.mean()
ellipse_var = exoplanets.ellipse.var()
ellipse_std = exoplanets.ellipse.std()

print('The ellipse average is {0} AUs'.format(round(ellipse_mean, 2)))
print('Total of mass differences from the mean: {0}'.format(round(ellipse_var)))
print('Standard deviation is {0} AUs'.format(round(ellipse_std, 2)))

# Standard Deviation is greater magnitude than mean,
# It can indicate that data are spread out or it has outliers.
# There is a significant difference between mass exoplanets.
```

```
The ellipse average is 8.26 AUs
Total of mass differences from the mean: 1137
Standard deviation is 33.72 AUs
```

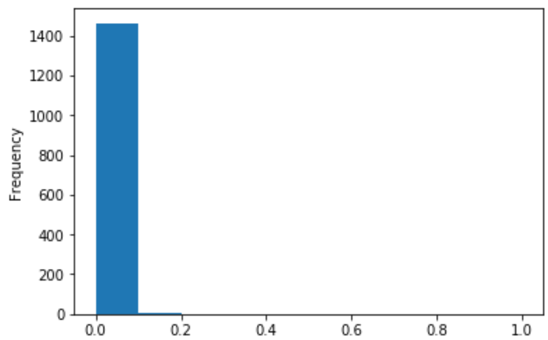
In [26]:
```
# Handle outliers of ellipse variable,

# I will use data normalization with the Min-Max method,
exoplanets['ellipse_MinMax'] = ((exoplanets['ellipse'] - exoplanets['ellipse'].min()) / (exoplanets['ellipse'].max() -
exoplanets['ellipse'].min()))
exoplanets.head(10)
```

Out[26]:

	exoplanet	semi_major_axis	eccentricity	semi_minor_axis	h	ellipse	ellipse_MinMax
0	b'11 COM B'	1.290	0.231	1.255110	1.879232e-04	8.00	0.011064
1	b'11 UMI B'	1.540	0.080	1.535064	2.576476e-06	9.66	0.013369
2	b'14 AND B'	0.830	0.000	0.830000	7.156889e-32	5.22	0.007205
3	b'14 HER B'	2.770	0.369	2.574519	1.337796e-03	16.80	0.023280
4	b'16 CYG B B'	1.680	0.689	1.217599	2.546601e-02	9.16	0.012674
5	b'18 DEL B'	2.600	0.080	2.591667	2.576476e-06	16.31	0.022600
6	b'24 BOO B'	0.190	0.042	0.189832	1.948246e-07	1.19	0.001610
7	b'24 SEX B'	1.333	0.090	1.327590	4.134078e-06	8.36	0.011564
8	b'24 SEX C'	2.080	0.290	1.990615	4.821753e-04	12.79	0.017714
9	b'2M 2140+16 B'	3.530	0.260	3.408598	3.061295e-04	21.80	0.030221

In [27]:
```
# Histogram of normalized ellipse,

exoplanets['ellipse_MinMax'].plot(kind = 'hist')

# The ellipse histogram shows that the largest number of exoplanets discovered have not a big trajectory around the su
n.
# I will calculate the average ellipse of exoplanets that are in the highest range,

ellipse01 = round(exoplanets.loc[exoplanets.ellipse_MinMax <= 0.1].ellipse.mean(), 2)
print('The average ellipse is {0} AUs'.format(ellipse01))

# The Earth's trajectory around the sun is 6.28 AUs,
# most of the discovered exoplanets and with known ellipses,
# revolve around their host star faster than Earth around the Sun.
```

```
The average ellipse is 5.68 AUs
```



In [28]:
```
##########################
##star distance variable##
##########################

# This is the distance of the star from Earth.
# Because the star distance is in pc = 3.26 light years,
# I will create a derived variable 'dis_ly' to calculate the star distance in light years.

sql = ('SELECT UPPER(star_name) AS star,'
       '       UPPER(target_name) AS exoplanet,'
       '       star_distance AS dist_pc,'
       '       ROUND((star_distance * 3.26), 2) AS dist_ly'
       '  FROM exoplanet.epn_core'
       ' WHERE star_distance IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)

print('There are {0} stars with known distances'.format(len(exoplanets)))
exoplanets.head()
```

```
There are 2914 stars with known distances
```

Out[28]:

	star	exoplanet	dist_pc	dist_ly
0	b'11 COM'	b'11 COM B'	110.599998	360.56
1	b'11 OPH'	b'11 OPH B'	145.000000	472.70
2	b'11 UMI'	b'11 UMI B'	119.500000	389.57
3	b'14 AND'	b'14 AND B'	76.400002	249.06
4	b'14 HER'	b'14 HER B'	18.100000	59.01

In [29]:
```
# The farthest star discovered to date,

faraway = exoplanets.loc[exoplanets.dist_ly == exoplanets['dist_ly'].max()]
faraway = faraway.reset_index(drop = True)
faraway = faraway.loc[:, ['star', 'dist_ly']]

print('The farthest star is {0} to {1} light years'.format(faraway['star'][0], faraway['dist_ly'][0]))

# The milky way is 100,000 light years across.
# Therefore, there are not exoplanets discovered in other galaxies.
```

```
The farthest star is b'XTE J1751-305' to 35860.0 light years
```

In [30]:
```
# Exoplanets that belong to that distant star,

exoplanets.loc[exoplanets.star == faraway['star'][0]].exoplanet
```

Out[30]:
```
2865    b'XTE J1751-305 B'
Name: exoplanet, dtype: object
```

In [31]:
```
# The closest star discovered to date,

closeStart = exoplanets.loc[exoplanets.dist_ly == exoplanets['dist_ly'].min()]
closeStart = closeStart.reset_index(drop = True)
closeStart = closeStart.loc[:, ['star', 'dist_ly']]

print('The closest star is {0} to {1} light years'.format(closeStart['star'][0], closeStart['dist_ly'][0]))
```

```
The closest star is b'PROXIMA CENTAURI' to 4.22 light years
```

In [32]:
```
# Exoplanets that belong to that close star,

exoplanets.loc[exoplanets.star == closeStart['star'][0]].exoplanet
```

Out[32]:
```
2659    b'PROXIMA CENTAURI B'
2660    b'PROXIMA CENTAURI C'
Name: exoplanet, dtype: object
```

In [33]:
```
# Descriptive characteristics about the distance variable,

dist_mean = exoplanets.dist_ly.mean()
dist_var = exoplanets.dist_ly.var()
dist_std = exoplanets.dist_ly.std()

print('The average distance is {0} light years'.format(round(dist_mean)))
print('Total of distances differences from the mean: {0}'.format(round(dist_var)))
print('Standard deviation is {0}'.format(round(dist_std)))

# Standard Deviation is greater magnitude than mean,
# It can indicate that data are spread out or it has outliers.
# There is a significant difference between farthest stars and closest stars.
```

```
The average distance is 2043 light years
Total of distances differences from the mean: 10690559
Standard deviation is 3270
```

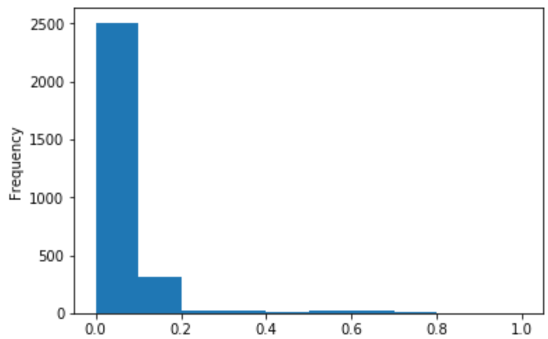
In [34]:
```
# Handle outliers of distance variable,

# I will use data normalization with the Min-Max method,
exoplanets['dist_ly_MinMax'] = ((exoplanets['dist_ly'] - exoplanets['dist_ly'].min()) / (exoplanets['dist_ly'].max() -
exoplanets['dist_ly'].min()))
exoplanets.head(10)
```

Out[34]:

	star	exoplanet	dist_pc	dist_ly	dist_ly_MinMax
0	b'11 COM'	b'11 COM B'	110.599998	360.56	0.009938
1	b'11 OPH'	b'11 OPH B'	145.000000	472.70	0.013066
2	b'11 UMI'	b'11 UMI B'	119.500000	389.57	0.010747
3	b'14 AND'	b'14 AND B'	76.400002	249.06	0.006828
4	b'14 HER'	b'14 HER B'	18.100000	59.01	0.001528
5	b'16 CYG B'	b'16 CYG B B'	21.410000	69.80	0.001829
6	b'18 DEL'	b'18 DEL B'	73.099998	238.31	0.006529
7	b'1RXS 1609'	b'1RXS 1609 B'	145.000000	472.70	0.013066
8	b'1SWASP J1407'	b'1SWASP J1407 B'	133.000000	433.58	0.011975
9	b'24 BOO'	b'24 BOO B'	100.000000	326.00	0.008974

In [35]:
```
# Histogram of normalized distance,

exoplanets['dist_ly_MinMax'].plot(kind = 'hist')

# The distance histogram shows that the largest number of stars discovered are close to Earth.
# I will calculate the average distance of stars that are in the highest range,

dist01 = round(exoplanets.loc[exoplanets.dist_ly_MinMax <= 0.1].dist_ly.mean())
print('The average distance is {0} light years'.format(dist01))
```

```
The average distance is 1194 light years
```



In [36]:
```
##############################################################
### Probability Mass Functions (PMF)#########################
##############################################################
### Compare two scenarios in the exoplanets data using PMF###
##############################################################
```

In [37]:
```
# I will select exoplanets discovered with the Primary Transit method.
# Primary Transit is when a planet passes in front of its host star.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       detection_type AS detection,'
       '       ROUND(mass) AS mass,'
       '       ROUND((star_distance * 3.26)) AS dist_ly'
       '  FROM exoplanet.epn_core'
       ' WHERE detection_type IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)
```

In [38]:
```
# Convert detection categorical variable to codes,

exoplanets['detection_cat'] = exoplanets.detection
exoplanets.detection_cat = pd.Categorical(exoplanets.detection_cat)
exoplanets['detection_cat'] = exoplanets.detection_cat.cat.codes
exoplanets.head()
```

Out[38]:

	exoplanet	detection	mass	dist_ly	detection_cat
0	b'11 COM B'	b'Radial Velocity'	NaN	361.0	7
1	b'11 OPH B'	b'Imaging'	21.0	473.0	1
2	b'11 UMI B'	b'Radial Velocity'	NaN	390.0	7
3	b'14 AND B'	b'Radial Velocity'	NaN	249.0	7
4	b'14 HER B'	b'Radial Velocity'	NaN	59.0	7

In [39]:
```
# Filter exoplanets discovered with the Primary Transit method,

transit = exoplanets[exoplanets.detection_cat == 4]
print('{0} exoplanets discovered with the Primary Transit method.'.format(len(transit)))
transit.head()
```

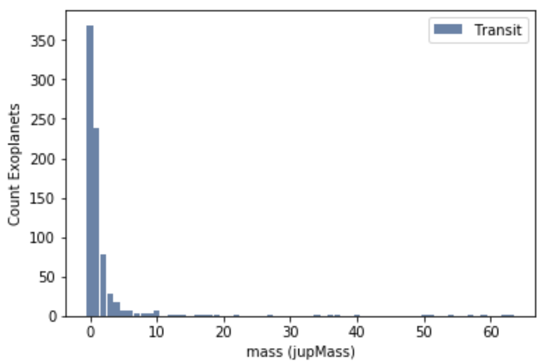
2967 exoplanets discovered with the Primary Transit method.

Out[39]:

	exoplanet	detection	mass	dist_ly	detection_cat
9	b'1SWASP J1407 B'	b'Primary Transit'	NaN	434.0	4
30	b'38 VIR B'	b'Primary Transit'	NaN	NaN	4
39	b'55 CNC E'	b'Primary Transit'	0.0	40.0	4
54	b'AD 3116 B'	b'Primary Transit'	54.0	608.0	4
65	b'BD+20 594 B'	b'Primary Transit'	0.0	496.0	4

In [40]:
```
# Histogram of mass variable in the Primary Transit method,

hist_mass = ts2.Hist(transit.mass, label = 'Transit')
print(hist_mass[0])
tp.Hist(hist_mass)
tp.Config(xlabel = 'mass (jupMass)', ylabel = 'Count Exoplanets')
```

369

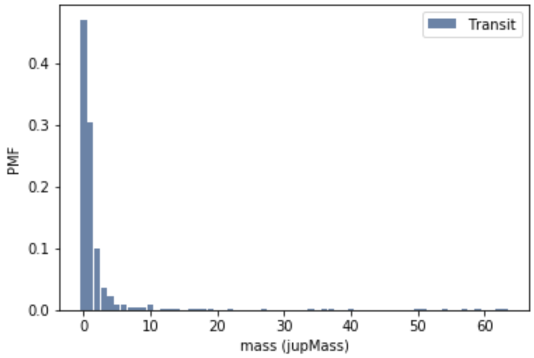


In [41]:
```
# Normalize the distribution.

# I will divide by the total count of mass:

count_mass = hist_mass.Total()
pmf_mass = hist_mass.Copy()
for x, freq in hist_mass.Items():
    pmf_mass[x] = freq / count_mass
```

In [42]:
```
# Example,
# What is the probability of discovering an exoplanet with the Primary Transit method whose mass is 1 Jupiter?

print('Probability {0}% of discovering an exoplanet with 1 Jupiter mass with the Primary Transit method.'.format(round
((pmf_mass[1] * 100), 2)))
```

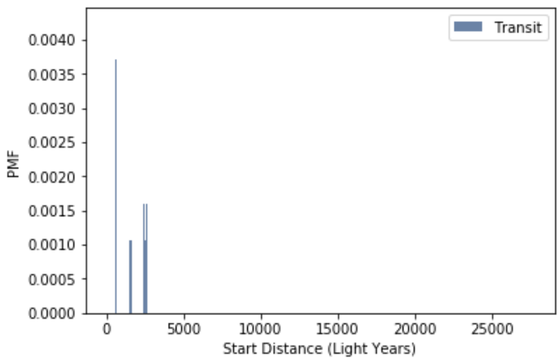
Probability 30.45% of discovering an exoplanet with 1 Jupiter mass with the Primary Transit method.

In [43]:
```
# PMF histogram of mass variable in the Primary Transit method,

tp.Hist(pmf_mass)
tp.Config(xlabel = 'mass (jupMass)', ylabel = 'PMF')
```

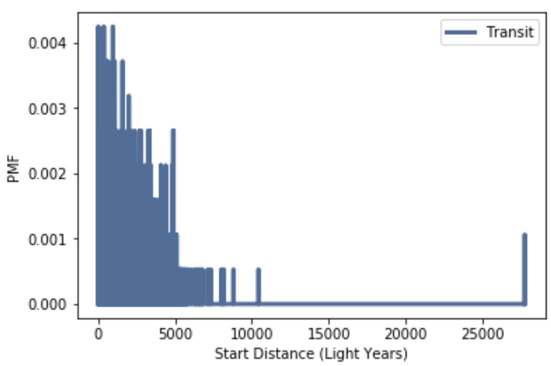


In [44]:
```
# PFM of star distance in the Primary Transit method,

pmf_dist_ly = ts2.Pmf(transit.dist_ly, label = 'Transit')
```

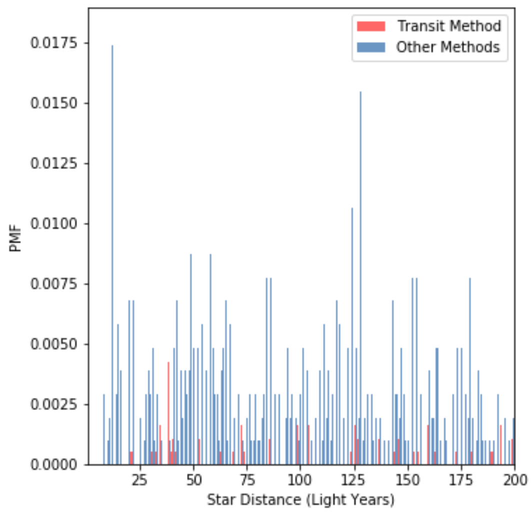
In [45]:
```
# Histogram of star distance in the Primary Transit method,

tp.Hist(pmf_dist_ly)
tp.Config(xlabel = 'Start Distance (Light Years)', ylabel = 'PMF')
```



In [46]:
```
# PMF Histogram of star distance in the Primary Transit method,

tp.Pmf(pmf_dist_ly)
tp.Config(xlabel = 'Start Distance (Light Years)', ylabel = 'PMF')
```

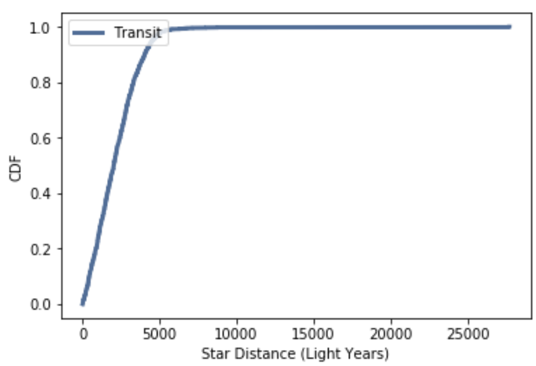


In [47]:
```
# PMF Histogram of star distance in the Primary Transit method and other methods,

other_methods = exoplanets[exoplanets.detection_cat != 4]

transit_pmf = ts2.Pmf(transit.dist_ly, label = 'Transit Method')
otherMethods_pmf = ts2.Pmf(other_methods.dist_ly, label = 'Other Methods')

width = 0.5
axis = [1, 200, 0, 0.019]

tp.PrePlot(2, cols = 2)
tp.Hist(transit_pmf, align = 'right', width = width, color = 'red')
tp.Hist(otherMethods_pmf, align = 'left', width = width)
tp.Config(xlabel = 'Star Distance (Light Years)', ylabel = 'PMF', axis = axis)
```



In [48]:
```
###############################################
###Cumulative Distribution Function (CDF)###
###############################################
```

In [49]:
```
cdf_dist = ts2.Cdf(transit.dist_ly, label = 'Transit')
tp.Cdf(cdf_dist)
tp.Config(xlabel = 'Star Distance (Light Years)', ylabel = 'CDF', loc = 'upper left')
```



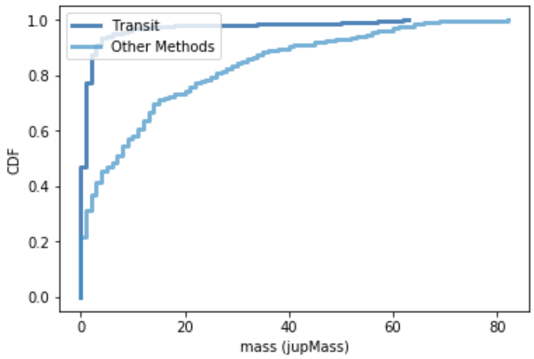
In [50]:
```
# Get the probability that corresponds to star distances.
# For example, What is the probability that start distances are less 5,000 light years in the Primary Transit method?

print('{0}% of star distances are less than or equal to 5000 light years in the Primary Transit method.'.format(round((
cdf_dist.Prob(5000) * 100), 2)))
```

```
97.71% of star distances are less than or equal to 5000 light years in the Primary Transit method.
```

In [51]:
```
# Average star distance in the Primary Transit method,

print('The median is {0} light years in the Primary Transit method.'.format(round(cdf_dist.Value(0.5))))
```

```
The median is 2034.0 light years in the Primary Transit method.
```

In [52]:
```
# visualize two distributions,
#   1. Primary Transit detection method
#   2. Other detection methods

transit_cdf = ts2.Cdf(transit.mass, label = 'Transit')
othermethods_cdf = ts2.Cdf(other_methods.mass, label = 'Other Methods')

tp.PrePlot(2)
tp.Cdfs([transit_cdf, othermethods_cdf])
tp.Config(xlabel = 'mass (jupMass)', ylabel = 'CDF')

# Large exoplanets are more likely to find them with the Primary Transit detection method.
```



In [53]:
```
# For example,
# Exoplanets with 20 jupiter-mass have a high probability of beging found with the Primary Transit detection method.

print('{0}% probability of finding exoplanets with 20 jupiter-mass in the Primary Transit detection method.'.format(rou
nd(transit_cdf.Prob(20), 2) * 100))
print('{0}% probability of finding exoplanets with 20 jupiter-mass in other methods.'.format(round(othermethods_cdf.Pro
b(20), 2) * 100))
```

```
98.0% probability of finding exoplanets with 20 jupiter-mass in the Primary Transit detection method.
74.0% probability of finding exoplanets with 20 jupiter-mass in other methods.
```

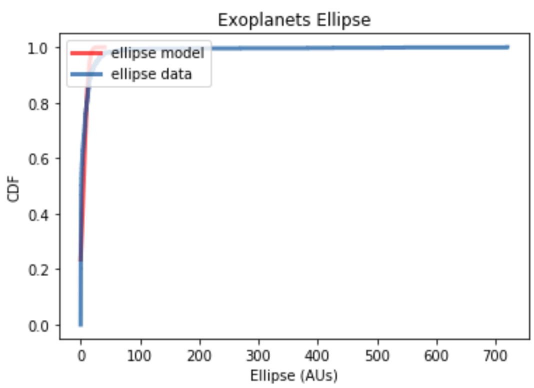
In [54]:
```
#############################
###Analytical Distribution###
#############################
```

In [55]:
```
# I will use the ellipse (perimeter) variable,
# ellipse perimeter is in AU = 92,96 million miles.
# The length of Earth's trajectory around the sun is 6.28 AUs.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       semi_major_axis,'
       '       eccentricity,'
       '       semi_major_axis * SQRT(1 - POWER(eccentricity, 2)) AS semi_minor_axis'
       '  FROM exoplanet.epn_core'
       ' WHERE semi_major_axis IS NOT NULL'
       '   AND eccentricity IS NOT NULL')

exoplanets = dsc.ConvertDataframe(sql)

exoplanets['h'] = pow(exoplanets.semi_major_axis - exoplanets.semi_minor_axis, 2) / pow(exoplanets.semi_major_axis + ex
oplanets.semi_minor_axis, 2)
exoplanets['ellipse'] = round(math.pi * (exoplanets.semi_major_axis + exoplanets.semi_minor_axis) * (1 + ((3 * exoplane
ts.h) / (10 + np.sqrt(4 - (3 * exoplanets.h))))), 2)
```

In [56]:
```
#Create and fit the ellipse model.

# Estimate ellipse parameters: mean, variance, and standard deviation,
# Trimming outliers: p is the fraction of values to trim off each end.

vellipse = exoplanets.ellipse.dropna()
ellipse_mean, ellipse_var = ts2.TrimmedMeanVar(vellipse, p = 0.04)

print('Ellipse average {0} AUs'.format(round(ellipse_mean, 2)))
print('Ellipse variance: {0}'.format(round(ellipse_var, 2)))

ellipse_std = np.sqrt(ellipse_var)
print('Standard deviation is {0} AUs'.format(round(ellipse_std, 2)))
```

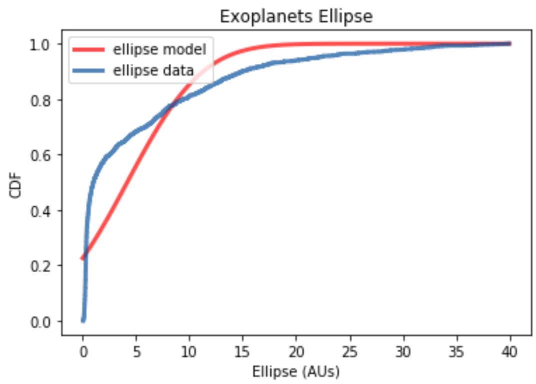
```
Ellipse average 4.75 AUs
Ellipse variance: 43.23
Standard deviation is 6.58 AUs
```

In [57]:
```
# Plot the ellipse model,

# Up to 40 AUs,
ellipse_xs, ellipse_ps = ts2.RenderNormalCdf(ellipse_mean, ellipse_std, low = 0, high = 40)
tp.Plot(ellipse_xs, ellipse_ps, label = 'ellipse model', color = 'red')

# plot the data

cdf = ts2.Cdf(vellipse, label = 'ellipse data')

tp.PrePlot(1)
tp.Cdf(cdf)
tp.Config(title = 'Exoplanets Ellipse',
          xlabel = 'Ellipse (AUs)',
          ylabel = 'CDF')

# This is the CDF and the model.
# It seems that the ellipse model doesn't fit the data well.
# I will take the segment between 0 and 40AUs
```



In [58]:
```
# Filter ellipse variable between 0 and 40AUs,

exoplanets1 = exoplanets[exoplanets.ellipse <= 40]
```

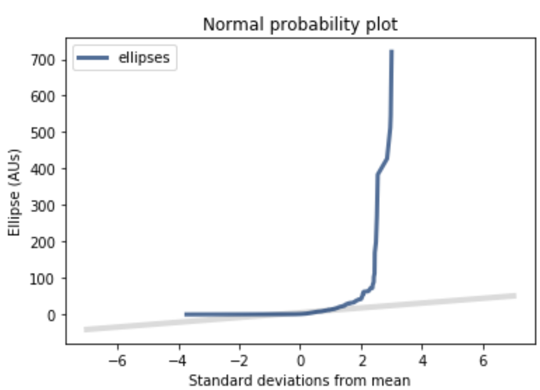
In [59]:
```
# re-plot the ellipse model,

vellipse = exoplanets1.ellipse.dropna()
ellipse_mean, ellipse_var = ts2.TrimmedMeanVar(vellipse, p = 0.04)
ellipse_std = np.sqrt(ellipse_var)

ellipse_xs, ellipse_ps = ts2.RenderNormalCdf(ellipse_mean, ellipse_std, low = 0, high = 40)
tp.Plot(ellipse_xs, ellipse_ps, label = 'ellipse model', color = 'red')

cdf = ts2.Cdf(vellipse, label = 'ellipse data')
tp.PrePlot(1)
tp.Cdf(cdf)
tp.Config(title = 'Exoplanets Ellipse',
          xlabel = 'Ellipse (AUs)',
          ylabel = 'CDF')

# In the CDF and the model, the ellipse model doesn't fit the data well.
```



In [60]:
```
# Normal probability plot for exoplanets ellipses,

# Estimate ellipse parameters: mean, variance, and standard deviation,
# Trimming outliers: p is the fraction of values to trim off each end.

vellipse = exoplanets.ellipse.dropna()
ellipse_mean, ellipse_var = ts2.TrimmedMeanVar(vellipse, p = 0.04)
ellipse_std = np.sqrt(ellipse_var)
print('Standard deviation is {0} AUs'.format(round(ellipse_std, 2)))
```

```
Standard deviation is 6.58 AUs
```

In [61]:
```
# Normal probability plot,

xs = [-7, 7]
fxs, fys = ts2.FitLine(xs, ellipse_mean, ellipse_std)
tp.Plot(fxs, fys, linewidth = 4, color = '0.8')

xs, ys = ts2.NormalProbability(vellipse)
tp.Plot(xs, ys, label = 'ellipses')

tp.Config(title='Normal probability plot',
          xlabel='Standard deviations from mean',
          ylabel='Ellipse (AUs)')

# In the normal probability plot for ellipses,
# we can seen the perimeter of the short ellipses is longer than normal.
# And the perimeter of the long ellipses is longer than normal.
```



In [62]:
```
##########################################
###Correlation and Causation Analysis###
##########################################
```

In [63]:
```
# I will compare two variables, period and ellipse.
# The ellipse variable is a calculated variable.
# This variable indicates the total ellipse perimeter.
# period is the orbital period around the host star.
# I will filter some period outliers of more than 100 years.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       period AS period_days,'
       '       ROUND(period/365, 2) AS period_years,'
       '       semi_major_axis,'
       '       eccentricity,'
       '       semi_major_axis * SQRT(1 - POWER(eccentricity, 2)) AS semi_minor_axis'
       '  FROM exoplanet.epn_core'
       ' WHERE semi_major_axis IS NOT NULL'
       '   AND eccentricity IS NOT NULL'
       '   AND period IS NOT NULL'
       '   AND ROUND(period/365, 2) <= 100')

exoplanets = dsc.ConvertDataframe(sql)

exoplanets['h'] = pow(exoplanets.semi_major_axis - exoplanets.semi_minor_axis, 2) / pow(exoplanets.semi_major_axis + ex
oplanets.semi_minor_axis, 2)
exoplanets['ellipse'] = round(math.pi * (exoplanets.semi_major_axis + exoplanets.semi_minor_axis) * (1 + ((3 * exoplane
ts.h) / (10 + np.sqrt(4 - (3 * exoplanets.h))))), 2)
print(len(exoplanets))
exoplanets.head()
```

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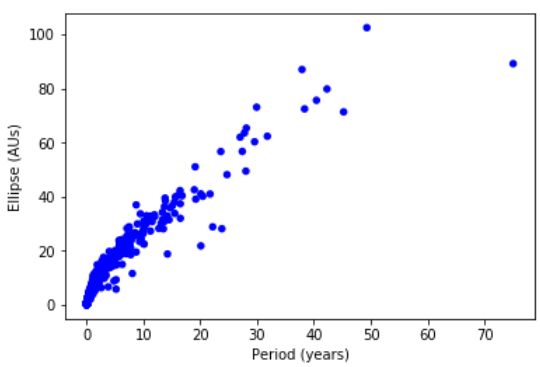
Out[63]:

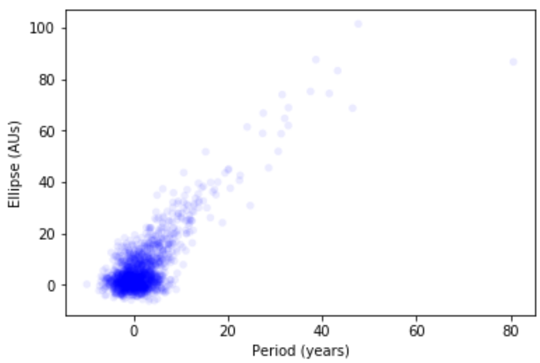
	exoplanet	period_days	period_years	semi_major_axis	eccentricity	semi_minor_axis	h	ellipse
0	b'11 COM B'	326.029999	0.89	1.29	0.231	1.255110	1.879232e-04	8.00
1	b'11 UMI B'	516.219971	1.41	1.54	0.080	1.535064	2.576476e-06	9.66
2	b'14 AND B'	185.839996	0.51	0.83	0.000	0.830000	7.156889e-32	5.22
3	b'14 HER B'	1773.400024	4.86	2.77	0.369	2.574519	1.337796e-03	16.80
4	b'16 CYG B B'	799.500000	2.19	1.68	0.689	1.217599	2.546601e-02	9.16

In [64]:
```
# I will select period and ellipse variables,
vperiod, vellipse = exoplanets.period_years, exoplanets.ellipse
```

In [65]:
```
# Scatter plot with alpha = 1. Each point is fully saturated,

tp.Scatter(vperiod, vellipse, alpha = 1)
tp.Config(xlabel = 'Period (years)',
          ylabel = 'Ellipse (AUs)',
          legend = False)
```



In [66]:
```
# I will use jitter (noise) with normal distribution to improve the visualization,

vperiod = dsc.Jitter(vperiod, 2.9)
vellipse = dsc.Jitter(vellipse, 2.5)

tp.Scatter(vperiod, vellipse, alpha = 0.08)
tp.Config(xlabel = 'Period (years)',
          ylabel = 'Ellipse (AUs)',
          #axis=[140, 210, 20, 200],
          legend = False)

# This scatter version shows the distribution most accurately.
# Zero years means that the period of rotation around the sun is done in less than a year.
# That is, in some months, weeks, or days.
# Zero ellipse means that the distance traveled is less than one AU.
# That is, the distance traveled can be one sixth or less of the Earth's travel.
# In the scatter, I can see that in most of the exoplanets, the distance traveled and the time used is proportional.
```



In [67]:
```
# Computes the covariance of period and ellipse variables,

cov = dsc.Cov(vperiod, vellipse)
print('The covariance between period and ellipse is {0}'.format(round(cov, 2)))
```

```
The covariance between period and ellipse is 50.39
```

In [68]:
```
# Find the correlation between period and ellipse variables,

corr = dsc.Corr(vperiod, vellipse)
print('The correlation between period and ellipse is {0}'.format(round(corr, 2)))

# Both variables have a strong correlation.
```

```
The correlation between period and ellipse is 0.8
```

In [69]:
```
# Find the Spearman correlation between period and ellipse variables,

spearman = dsc.SpearmanCorr(vperiod, vellipse)
print('The Spearman correlation between period and ellipse is {0}'.format(round(spearman, 2)))

# In Spearman's correlation, the correlation is a lower.
```

```
The Spearman correlation between period and ellipse is 0.42
```

In [70]:
```
######################################
###Conduct a test on my hypothesis###
#####################################

# My hypothesis is that there are differences in the ellipses of exoplanets that are discovered by the Primary Transit
 method and other methods.
# The null hypothesis (H_0) is that there is not difference between Primary Transit method and other methods;
# that is, that ellipses perimeter for both groups have the same distribution.
```

In [71]:
```
# I will select exoplanets discovered with the Primary Transit method and others methods.

sql = ('SELECT UPPER(target_name) AS exoplanet,'
       '       detection_type AS detection,'
       '       semi_major_axis,'
       '       eccentricity,'
       '       semi_major_axis * SQRT(1 - POWER(eccentricity, 2)) AS semi_minor_axis,'
       '       period AS period_days,'
       '       ROUND(period/365, 2) AS period_years'
       '  FROM exoplanet.epn_core'
       ' WHERE semi_major_axis IS NOT NULL'
       '   AND eccentricity IS NOT NULL'
       '   AND detection_type IS NOT NULL'
       '   AND ROUND(period/365, 2) <= 100')

exoplanets = dsc.ConvertDataframe(sql)

# Calculate ellipse variable,

exoplanets['h'] = pow(exoplanets.semi_major_axis - exoplanets.semi_minor_axis, 2) / pow(exoplanets.semi_major_axis + ex
oplanets.semi_minor_axis, 2)
exoplanets.head()

exoplanets['ellipse'] = round(math.pi * (exoplanets.semi_major_axis + exoplanets.semi_minor_axis) * (1 + ((3 * exoplane
ts.h) / (10 + np.sqrt(4 - (3 * exoplanets.h))))), 2)

# Convert detection categorical variable to codes,

exoplanets['detection_cat'] = exoplanets.detection
exoplanets.detection_cat = pd.Categorical(exoplanets.detection_cat)
exoplanets['detection_cat'] = exoplanets.detection_cat.cat.codes

# Filter exoplanets discovered with the Primary Transit method and other methods,

transit = exoplanets[exoplanets.detection_cat == 4]
other_methods = exoplanets[exoplanets.detection_cat != 4]
```

In [72]:
```
# First group, Primary Transit method,

transit.head()
```

Out[72]:

	exoplanet	detection	semi_major_axis	eccentricity	semi_minor_axis	period_days	period_years	h	ellipse	detection_cat
14	b'38 VIR B'	b'Primary Transit'	1.820000	0.030	1.819181	825.900024	2.26	5.067059e-08	11.43	4
23	b'55 CNC E'	b'Primary Transit'	0.015439	0.028	0.015433	0.736548	0.00	3.844614e-08	0.10	4
43	b'BD+20 594 B'	b'Primary Transit'	0.241000	0.000	0.241000	41.685501	0.11	5.305501e-32	1.51	4
57	b'COROT-1 B'	b'Primary Transit'	0.025400	0.000	0.025400	1.508960	0.00	1.679174e-31	0.16	4
58	b'COROT-10 B'	b'Primary Transit'	0.105500	0.530	0.089464	13.240600	0.04	6.765466e-03	0.61	4

In [73]:
```
# Other detection methods,

other_methods.head()
```

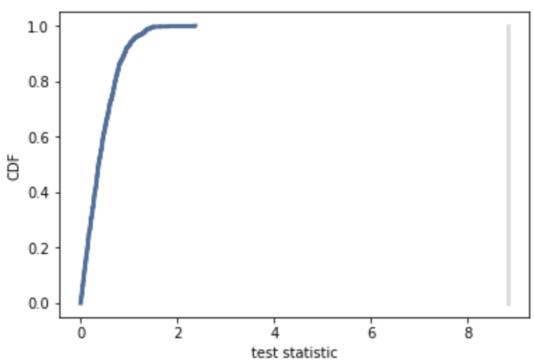
Out[73]:

	exoplanet	detection	semi_major_axis	eccentricity	semi_minor_axis	period_days	period_years	h	ellipse	detection_cat
0	b'11 COM B'	b'Radial Velocity'	1.29	0.231	1.255110	326.029999	0.89	1.879232e-04	8.00	7
1	b'11 UMI B'	b'Radial Velocity'	1.54	0.080	1.535064	516.219971	1.41	2.576476e-06	9.66	7
2	b'14 AND B'	b'Radial Velocity'	0.83	0.000	0.830000	185.839996	0.51	7.156889e-32	5.22	7
3	b'14 HER B'	b'Radial Velocity'	2.77	0.369	2.574519	1773.400024	4.86	1.337796e-03	16.80	7
4	b'16 CYG B B'	b'Radial Velocity'	1.68	0.689	1.217599	799.500000	2.19	2.546601e-02	9.16	7

In [74]:
```
# Permutation test,

#data = transit.ellipse.values, other_methods.ellipse.values
data = other_methods.ellipse.values, transit.ellipse.values
ht = ts2.DiffMeansPermute(data)

print('p-value is {0}'.format(ht.PValue()))

# A small p-value indicates that the observations are inconsistent with the Null hypothesis.
# So we reject the null hypothesis (there is not difference).
# Therefore, there is a significant difference in the ellipse perimeters
# when exoplanets are discovered by the Primary Transit method and other methods.
```

```
p-value is 0.0
```

In [75]:
```
# distribution of the test statistic,

ht.PlotCdf()
tp.Config(xlabel = 'test statistic',
          ylabel = 'CDF')
```



In [76]:
```
#########################
###Regression Analysis###
#########################
```

In [77]:
```
# Ellipse as a function of period,

formula = 'ellipse ~ period_years'
model = smf.ols(formula, data = transit)
results = model.fit()
results.summary()
```

Out[77]:

OLS Regression Results

Dep. Variable:	ellipse	**R-squared:**	0.904
Model:	OLS	**Adj. R-squared:**	0.904
Method:	Least Squares	**F-statistic:**	5763.
Date:	Sat, 16 Nov 2019	**Prob (F-statistic):**	3.04e-314
Time:	15:34:40	**Log-Likelihood:**	-685.25
No. Observations:	616	**AIC:**	1375.
Df Residuals:	614	**BIC:**	1383.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
Intercept	0.5015	0.030	16.613	0.000	0.442	0.561
period_years	3.4247	0.045	75.914	0.000	3.336	3.513

Omnibus:	240.285	**Durbin-Watson:**	1.498
Prob(Omnibus):	0.000	**Jarque-Bera (JB):**	39897.376
Skew:	0.536	**Prob(JB):**	0.00
Kurtosis:	42.412	**Cond. No.**	1.56

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.

In [78]:
```
# Intercep and Slope,

inter = results.params['Intercept']
slope = results.params['period_years']
inter, slope
```

Out[78]: (0.5015045154559239, 3.4246696391721168)

In [79]:
```
# The p-value of the slope estimate,

slope_pvalue = results.pvalues['period_years']
slope_pvalue
```

Out[79]: 3.0393332957e-314

In [80]:
```
# The coefficient of determination,

results.rsquared

# The coefficient of determination explains in a 90% the variability between period and ellipse.
```

Out[80]: 0.9037145023364705

In [81]:
```
# difference in ellipse perimeters between transit method and other methods,

diff_ellipse = transit.ellipse.mean() - transit.ellipse.mean()
diff_ellipse

# The average of the ellipses found in both detection methods is the same.
```

Out[81]: 0.0

In [82]:
```
# Difference in periods between transit method and other methods,

diff_period = transit.period_years.mean() - other_methods.period_years.mean()
diff_period

# With other detection methods, different to Primary Transit method,
# we can find exoplanets with greater orbital periods.
```

Out[82]: -2.8593877005347643