Exoplanets in ecospheres

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Finding the size of ecospheres surrounding stars

The main purpose of this lesson is to pick those exoplanets, that move around their stars inside ecospheres of those stars. Let's assume $r_0 = 0.72$ au (average distance between Venus and the Sun) and $r_1 = 1.52$ au (average distance between Mars and the Sun) mark the edges of Solar System's ecosphere. Then the minimal limit of the ecosphere around a star should be calculated with the use of the following formula:

$$r_{min} = r_0 \frac{R_*}{R_\odot} \left(\frac{T^*_{eff}}{T^\odot_{eff}} \right)^2 \tag{1}$$

and the maximal:

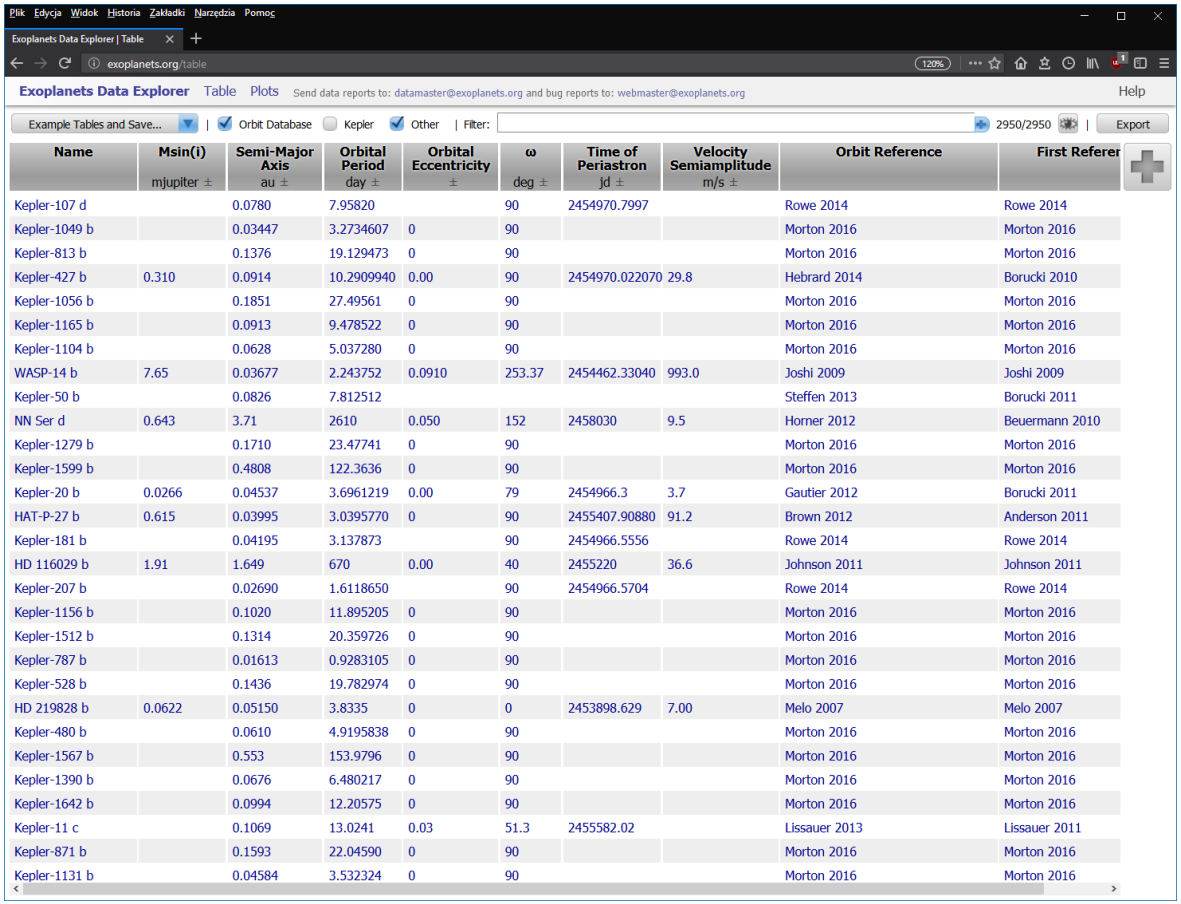
$$r_{max} = r_1 \frac{R_*}{R_\odot} \left(\frac{T^*_{eff}}{T^\odot_{eff}} \right)^2 \tag{2}$$

where R_* and $R_\odot$ are respectively the radius of a star around which an exoplanet revolves and of the Sun, and T^*_{eff} and $T^\odot_{eff}$ are respectively the effective temperature[1] of a star and the Sun. For the Sun we should assume $T^\odot_{eff} = 5772$ K. We assume that an exoplanet is inside the ecosphere if $r_{min} \leq a \leq r_{max}$ is true, where a is the average distance between an exoplanet and its star (the semi-major axis).

[1] Effective temperature of a star is the temperature that an black body has to have in order to emit the same amount of energy as this star.

Exoplanet catalogue

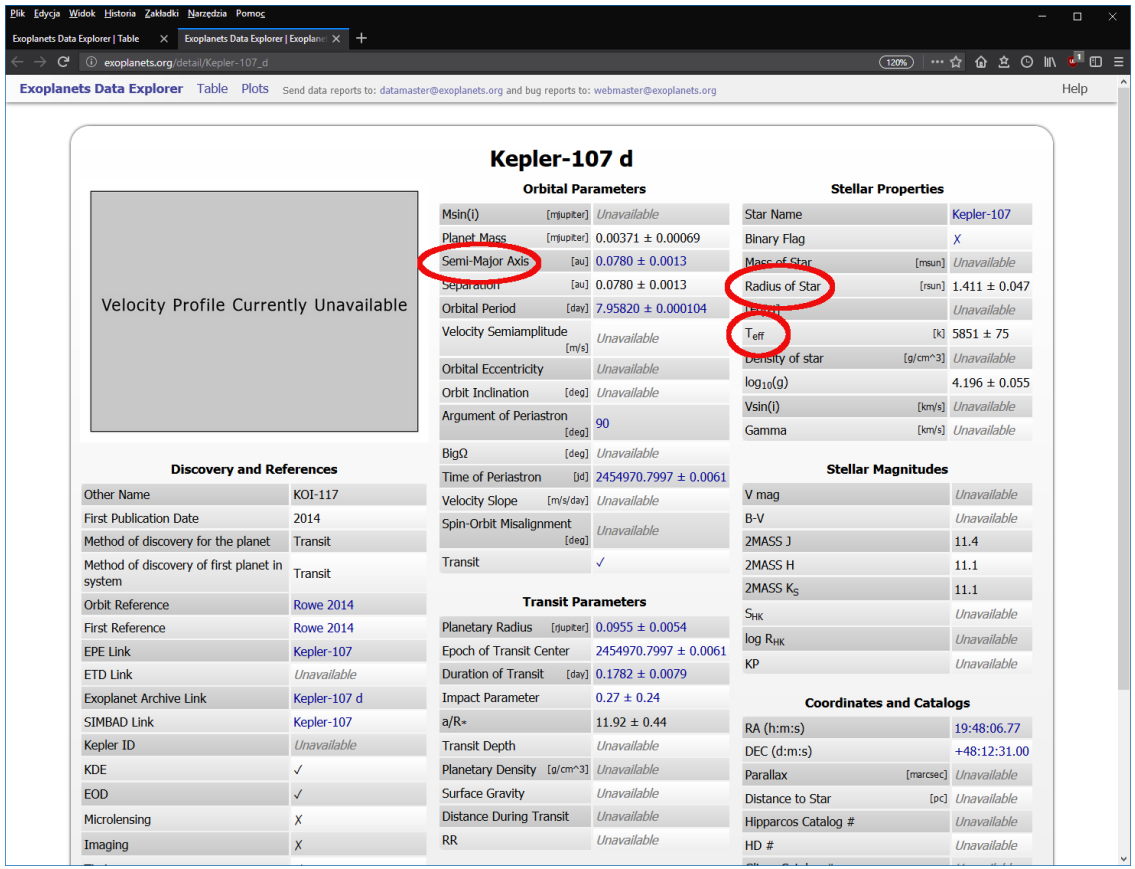
Link to the catalogue: `http://exoplanets.org/table`. After clicking on the preceding link the following view appears, where an exoplanet's name is given in the first column. By clicking on the "**Name**" button we can sort the exoplanets by their names. The "**Filter**" button allows us to filter exoplanets by their names.



Name	Msin(i) mjupiter ±	Semi-Major Axis au ±	Orbital Period day ±	Orbital Eccentricity ±	ω deg ±	Time of Periastron jd ±	Velocity Semiamplitude m/s ±	Orbit Reference	First Referer
Kepler-107 d		0.0780	7.95820		90	2454970.7997		Rowe 2014	Rowe 2014
Kepler-1049 b		0.03447	3.2734607	0	90			Morton 2016	Morton 2016
Kepler-813 b		0.1376	19.129473	0	90			Morton 2016	Morton 2016
Kepler-427 b	0.310	0.0914	10.2909940	0.00	90	2454970.022070	29.8	Hebrard 2014	Borucki 2010
Kepler-1056 b		0.1851	27.49561	0	90			Morton 2016	Morton 2016
Kepler-1165 b		0.0913	9.478522	0	90			Morton 2016	Morton 2016
Kepler-1104 b		0.0628	5.037280	0	90			Morton 2016	Morton 2016
WASP-14 b	7.65	0.03677	2.243752	0.0910	253.37	2454462.33040	993.0	Joshi 2009	Joshi 2009
Kepler-50 b		0.0826	7.812512					Steffen 2013	Borucki 2011
NN Ser d	0.643	3.71	2610	0.050	152	2458030	9.5	Horner 2012	Beuermann 2010
Kepler-1279 b		0.1710	23.47741	0	90			Morton 2016	Morton 2016
Kepler-1599 b		0.4808	122.3636	0	90			Morton 2016	Morton 2016
Kepler-20 b	0.0266	0.04537	3.6961219	0.00	79	2454966.3	3.7	Gautier 2012	Borucki 2011
HAT-P-27 b	0.615	0.03995	3.0395770	0	90	2455407.90880	91.2	Brown 2012	Anderson 2011
Kepler-181 b		0.04195	3.137873		90	2454966.5556		Rowe 2014	Rowe 2014
HD 116029 b	1.91	1.649	670	0.00	40	2455220	36.6	Johnson 2011	Johnson 2011
Kepler-207 b		0.02690	1.6118650		90	2454966.5704		Rowe 2014	Rowe 2014
Kepler-1156 b		0.1020	11.895205	0	90			Morton 2016	Morton 2016
Kepler-1512 b		0.1314	20.359726	0	90			Morton 2016	Morton 2016
Kepler-787 b		0.01613	0.9283105	0	90			Morton 2016	Morton 2016
Kepler-528 b		0.1436	19.782974	0	90			Morton 2016	Morton 2016
HD 219828 b	0.0622	0.05150	3.8335	0	0	2453898.629	7.00	Melo 2007	Melo 2007
Kepler-480 b		0.0610	4.9195838	0	90			Morton 2016	Morton 2016
Kepler-1567 b		0.553	153.9796	0	90			Morton 2016	Morton 2016
Kepler-1390 b		0.0676	6.480217	0	90			Morton 2016	Morton 2016
Kepler-1642 b		0.0994	12.20575	0	90			Morton 2016	Morton 2016
Kepler-11 c		0.1069	13.0241	0.03	51.3	2455582.02		Lissauer 2013	Lissauer 2011
Kepler-871 b		0.1593	22.04590	0	90			Morton 2016	Morton 2016
Kepler-1131 b		0.04584	3.532324	0	90			Morton 2016	Morton 2016

Parameters of exoplanets and stars necessary to find the size of an ecosphere

By clicking on an exoplanet's name (left column) we get to see the following view, where red ellipses mark placements of parameters needed to determine the size of an ecosphere and whether or not the planet is inside it.



Red ellipses mark correspondingly:

1. Exoplanet's semi-major axis a expressed in au.
2. Radius of a star, $R_\odot$, expressed as a multiple of the Sun's radius.
3. Star's effective temperature, T^*_{eff}, expressed in Kelvins.

Example of an analysis

Planet Kepler 107-d revolving around the Kepler 107 star[2]

For this object we have $a = 0.078$ au; for its star $T^*_{eff} = 5851\mathrm{K}$ and its radius $R_* = 1.411 R_\odot$. We leave out measurement uncertainties for the sake of these calculations. From the first formula we know the minimal limit of the ecosphere

$$r_{min} = 0.72\ \mathrm{au} \frac{1.411 R_\odot}{1 R_\odot} \left(\frac{5851\mathrm{K}}{5772\mathrm{K}}\right)^2 = 1.04\ \mathrm{au} \tag{3}$$

and from the second one the maximal limit

$$r_{max} = 1.52\ \mathrm{au} \frac{1.411 R_\odot}{1 R_\odot} \left(\frac{5851\mathrm{K}}{5772\mathrm{K}}\right)^2 = 2.20\ \mathrm{au} \tag{4}$$

Thus we concluded that the ecosphere around Kepler 107 star is between 1.04 au and 2.22 au away from its centre. Planet Kepler 107-d is at the average distance of 0.078 au from the star, which means it is way closer to it than the ecosphere.

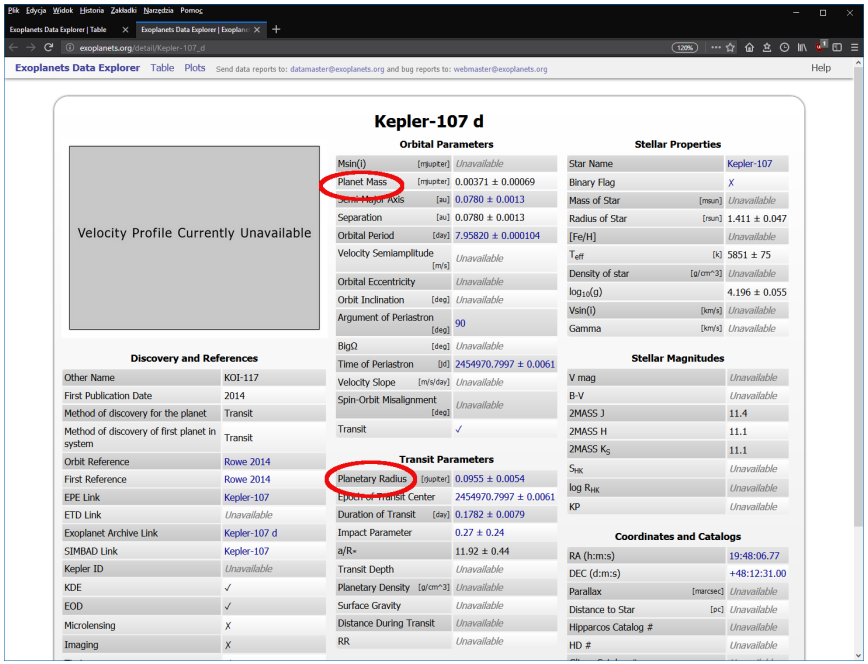
[2] Names of this exoplanet and the star come from NASA's space telescope Kepler looking for terrestrial extrasolar planets. We know 4 planets revolving around the star Kepler 107, they are called Kepler 107-b, Kepler 107-c, Kepler 107-d and Kepler 107-e. All planets discovered by Kepler telescope are named analogically, starting with the letter b.

Materials for the extended version of the lesson

Having exoplanets inside ecospheres we can now focus o finding those Earth-like (terrestrial) ones, assuming the following limitations for chosen exoplanets:

1. More restrictive limitations: $0.5R_\oplus < R_p \leq 1.5R_\oplus$ and\or $0.1m_\oplus < m_p \leq 5m_\oplus$
2. Less restrictive limitations: $0.5R_\oplus < R_p \leq 2.5R_\oplus$ and\or $0.1m_\oplus < m_p \leq 10m_\oplus$

Where R_p and $R_\oplus$ are respectively radius of the planet and of the Earth, m_p and $m_\oplus$ are respectively mass of the planet and of the Earth. However, it's worth noting that for not all planets this data is available.



Red ellipses mark respectively:

1. Planet mass, m_p, expressed as a multiple of Jupiter's mass.
2. Planetary radius, R_p, expressed as a multiple of Jupiter's mass.

In the calculations we have to assume Jupiter's mass as 317.83 masses of Earth, however Jupiter's radius as 10.517 times Earth's radius.