

# Exoplanet mass distribution considering selection factors for transit technique

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## Abstract

Retrieving the mass distribution of exoplanets was performed for photometric observed planets from space- and ground-based surveys. True statistical distribution requires debiasing (correction) of observation selection. Retrieved distribution of transit exoplanets by mass accounts the probability of mass determination and the probability of transit configuration. As a not normalized probability density function (PDF), the corrected (debaised) exoplanet mass distribution can be approximated by the power law:  $dN/dm \propto m^{-2}$ . Minima significances in the retrieved mass distribution have been verified by Kolmogorov-Smirnov test.

## 1. Introduction

Retrieving the mass distribution of exoplanets determines the abundance of planets of various types in the Galaxy. It will verify the planet formation mechanisms. Moreover, the planet mass statistics is not traceable in Solar system, because the number of Solar planets and their diversity are both incomplete. We followed to the catalogue [1] mass distribution of transiting exoplanets. The transiting planets which masses were determined by the radial velocity (RV) surveys are considered. The mass  $m$  is robustly determined if an exoplanet has transit. Statistical mass distribution of transiting planets was taken from the exoplanet catalogue sharply differs from the true, actual distribution, because of the presence and biasing of several factors of observation selection, which we discuss here and do account for them. As the result, the communication shows the refined mass distribution which is close to several distributions, known e. g. from [2, 3]. Directly obtained from [1], two *raw* catalog mass distributions of transit exoplanets known today, are presented in Figure 1. Exoplanet mass distributions are shown, with those, discovered by *Kepler ST* (space telescope) represented by the green (dot) line and those by

ground-based transit surveys and CoRoT – represented by the blue (dashed) line. Taking into account the errors in the measurement of mass, the standard KDE with symmetric Gaussian profile - or asymmetric skew normal profile was used to smooth these distributions, shown by red (solid) line and black (solid) line respectively. Evidently, both distributions should have a similar shape; however, this is clearly not observed by the catalogue obtained dependencies. Evident reason for this discrepancy is the observation selection. We intent to show that both mass distributions well converge when these factors are taken into account.

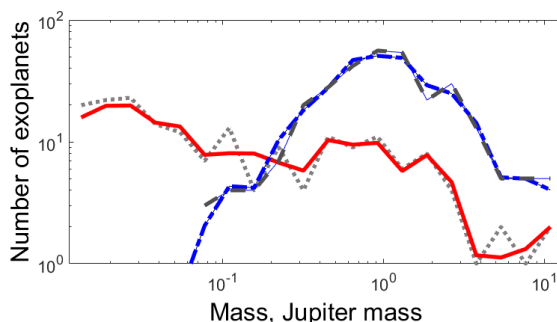


Fig. 1. From catalog [1], the *raw* mass distribution of transit planets. Gray (dot) line shows distribution of Kepler planets with the measured mass, KDE filtered red (solid) line. Gray (dashed) line shows the distribution of transit planets discovered by ground-based surveys and the CoRoT mission. Blue (solid) line accounts for the mass measurements errors.

## 2. The selection factor of mass determination for exoplanets detected by *Kepler ST*

For giant planets, the mass is more easily measured than for small planets (e.g. neptunes and super-earths). The proportion of *Kepler's* planets with a measured mass relative to the total number of *Kepler* planets is close to one in the region of giant planets.

However, this proportion drastically falls down to 2-3% in the region of 0.1-0.3 of the radius of Jupiter ( $r_J$ ). A "mass determination coefficient" denoted by  $k$  was introduced, used to describe the ratio of the number of *Kepler ST* planets with the measured mass to the total number of *Kepler ST* planets in a radii domain. The graph of  $k$  versus the radius in  $r_J$  is shown in Figure 2.

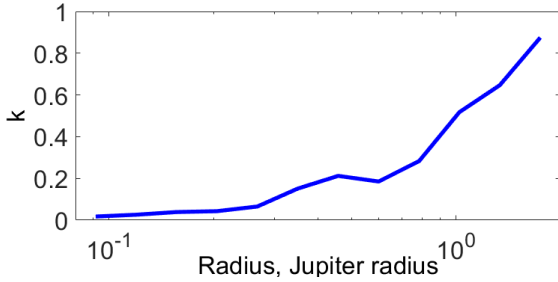


Fig. 2. The "mass determination coefficient"  $k$  versus the radius of *Kepler ST* planet.

### 3. Exoplanets mass distribution corrected for the mass determination and for the probability of transit configuration

To account for the mass determination observation selection factor, we have considered each *Kepler ST* planet with the measured mass as having a statistical weight inversely proportional to  $k$ . The raw (catalogue) mass distribution of *Kepler ST* exoplanets, shown by the red (solid) line in Figure 1, is changed significantly, as shown in Figure 3 (by the red (solid) line). As the first order approximation, the corrected distribution follows a straight line in log-log scale. Therefore, this dependence can be approximated by a power law  $dN/dm \propto m^{-2}$  by the least squares method.

Considering the *factor of mass determination* " $k$ ", the corrected mass distribution of *Kepler ST* planets is shown by the red (solid) line, and that for transit planets discovered by ground-based surveys and CoRoT mission shown by the black (solid) line. Additionally, taking into account the *factor of transit configurations probability*, the corrected mass distribution of *Kepler ST* planets is represented by the magenta (dashed) line and transit planets discovered by ground-based surveys and CoRoT mission shown by the blue (dashed-dot) line. These lines are shown by errorbars considering Poisson criterion  $\sqrt{N}$ . Furthermore, shown is a histogram of *Kepler ST* planets (reciprocal probability  $1/p$ )

demonstrating three *Kepler ST* planets with statistical oscillations. The legend in right-top corner shows the corresponding exponent, if approximated by the power law. For correct statistics of the mass distribution of planets, and also following [4], we added another factor of observational selection, namely, the probability of transit configuration. For ground-based surveys, the observed distribution of transit planets for true masses  $dN/dm$  remains less distorted by observational selection only for planets of the size class of  $r > 0.7 r_J$ . Planets with masses  $m > 0.4 m_J$  have  $r > 0.7 r_J$ . For these planets, the mass determination factor is close to one:  $k = 1_{-0.02}$ , to which we accounted for.

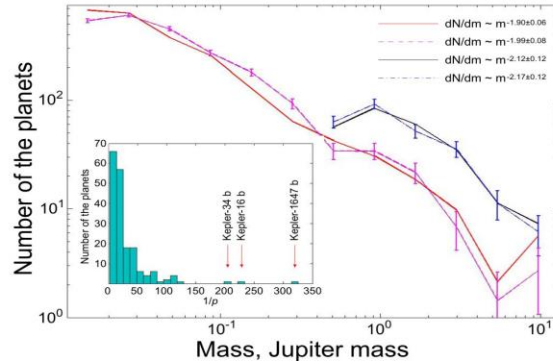


Fig. 3. Mass distribution of transit planets with accounted for observation selection. Details in text.

### Acknowledgements

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