An interpretation of exoplanet masses and orbital radii with a theoretical model of gas giant formation

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About 4000 exoplanets have been detected and their statistical properties such as mass and orbital distributions become clear. However, the origin of these distributions is still uncertain. In this study, applying a recent core accretion model to data ofexoplanets, we clarify whether it is possible to explain the observed distributions ofmasses and orbital radii, and in what protoplanetary disk they can be explain.
We adopt the following theoretical model of gas giant formation in this study. We use the model of Tanigawa & Tanaka (2016) for the mass growth rate (i.e., the gasaccretion rate onto a planet) and the latest model of Kanagawa et al.(2018) for the planetary migration speed. Those are reliable because of their consistency with severalresults of hydrodynamic simulations. For simplification, interactions among multiple planets are ignored. Since the growth rate and the migration speed of a planet areproportional to the disk surface density nearby, a model for global evolution of protoplanetary disk is also necessary. We adopt self-similar solutions of viscous accretion disks. In the model of the disk surface density, we also include the effect of gas depletion due to the planetary gas capture. Furthermore, we also take account of disk dissipation due to the photoevaporation. Then the rate of disk dissipation due to the photoevaporation is a parameter.
From this model, we obtained evolution curves on the plane of the planet mass and orbital radius (Figure 1). The evolution curves are also expressed in an analytical form. Since both the growth rate and migration speed of a planet are proportional to the disk surface density nearby, the curves do not depend on the detail of the disk model. In Figure 1, we also plotted data of exoplanets. Masses of gas giants are clustered around 2 Jupiter mass (or 0.2% of the central-star mass). Such exoplanets do not migrate much during their formation. Even for the largest exoplanet (of which mass is 2% of the star mass), its orbital radius is reduced moderately (to 1/10). Many gas giants are located at around 2AU from their stars. This can be explained as solid cores are easily formed near snow lines of disks at ~3AU.
The termination of growth of each gas giant planet is mainly determined by the initial disk mass and the disk dissipation rate due to photoevaporation. Thus for a given disk dissipation rate, we can obtain initial disk masses corresponding to each planetary masses. Figure 2 plots the distribution of the initial disk masses obtained from the masses of exoplanets with our theoretical model. We find that the peak of our initial disk mass distribution agrees with the most common disk mass in observations (~0.02 solar masses, Andrews et al. 2010) if the disk dissipation rate is set to be ~3×10^{-9} solar mass per year.

Keywords: Exoplanet, giant planet, protoplanetary disk

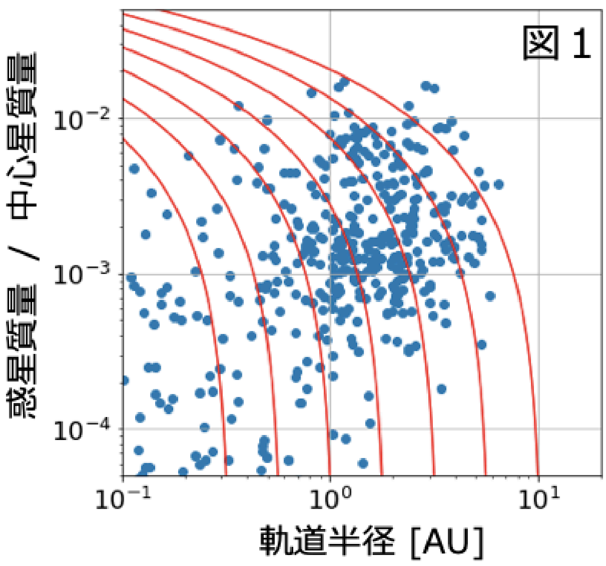
図 1
10^{-2}
10^{-3}
10^{-4}
惑星質量 / 中心星質量
10^{-1}
10^{0}
10^{1}
軌道半径 [AU]

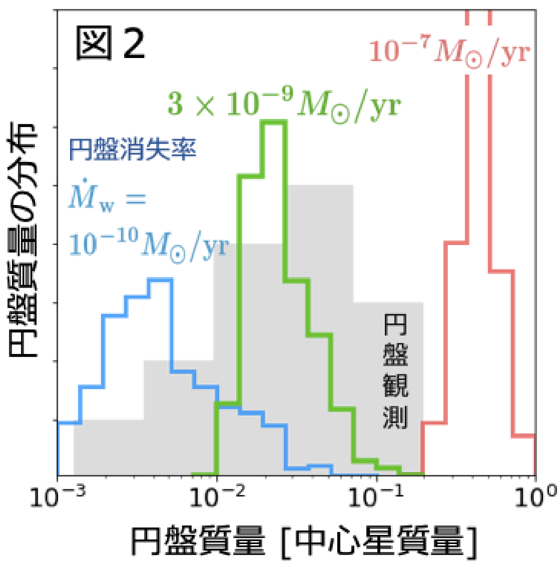
図 2
$10^{-7} M_\odot/\mathrm{yr}$
$3 \times 10^{-9} M_\odot/\mathrm{yr}$
円盤消失率
$\dot{M}_\mathrm{w} =$
$10^{-10} M_\odot/\mathrm{yr}$
円盤観測
円盤質量の分布
10^{-3}
10^{-2}
10^{-1}
10^{0}
円盤質量 [中心星質量]