In this section, we compare the above results of planetary mass and eccentricity distributions with previous studies and verify the relationship. We also discuss the behavior of planetary distributions in the metal-rich and -poor regions, comparing the observed dataset from the simulation of Mordasini et al. (2012 ).

4.1. Core accretion model

In Mordasini et al. (2012), planets are formed by classical core accretion model, and the final semi-major axes and planetary masses are determined, based on the simulation included the planetary migration in disks and the disk evolution. From our study, the two observed planetary-mass distributions, which were divided by the metal boundary, had different expanses. Then, we discuss each planetary-formation process, comparing the distribution of observed data with that of simulation data. Figure 7 shows that the comparison between the observed data included the selection biases and simulation data cited from Mordasini et al. (2012). The simulation data were also filtered by both selection biases of metal-rich and -poor regions to complete the conditions with the observed data. As the result, the distributions of metal rich regions are very consistence, which can explain that most of gas giants in the metal rich region are formed by core accretion. This is also explained by our results shown in Section ?? because of below interpretation. The interaction between a gas giant and protoplanetary disk possibly makes the eccentricity of planet grow (e.g., Goldreich & Sari 2003 ; Kley & Dirksen 2006). This interaction is concentrated at discrete Lindblad and corotation resonances, which causes the planet's orbit to migrate and open a gap in the disk as the planet mass is large enough. If the viscous coefficient equals to 10􀀀5 , the planet with circular orbit changes to eccentric orbit as the planetary mass is over 3 MJ . The more massive planets make their eccentricity higher until the maximum value 0.25. On the other hand, if a planetary system has two gas giants, the outer planet may prolong the orbital period of the inner planet. These planets' eccentricities grow up in rough inverse proportion to their masses by this orbital interaction (Chiang et al. 2002 ). From the verification of simulation (Ida et al. 2013 ), gas giants and rocky/icy planets emerge, migrate, and undergo dynamical instability in a relatively massive disk, and the perturbation between planets causes orbital crossing, eccentricity excitation, and planetary ejection. Therefore, gas giants formed through core accretion tend to have high eccentricities, which is consistent to our results of eccentricity distribution.

In contrast, the distributions of metal poor regions between the observed data and the simulation data are different. This means that the planetary formation process in metal poor disks differs from in metal rich disks: the planetary formation in metal poor region cannot be explained by only core accretion. On the other hand, the eccentricity of gas giant formed via disk instability ranges from 0 to 0.35 in initial stage, and decreases as the planet mass increases (Boss 2011). Note that the range of semi-major axis is 30 to 70 au. This trend can be also seen slightly in the metal poor region of Figure 5 . However, because it is not clear, there possibly exists other formation processes included core accretion in metal poor regions.

According to the previous studies (e.g., Ribas & Miralda-Escude 2007; Santos et al. 2017; Schlaufman 2018), extrasolar gaseous objects are simply divided into two with a boundary mass of 4MJ and/or a transition of 4 to 10 MJ; while the gas giants lighter than 4 or 10 MJ are likely to be formed via the core accretion process, disk-instability-induced planetary formation occurs beyond 10MJ. However, as discussed above, the upper mass limit of the core-accreted planets which is consistent with the theoretical expectations (e.g., Tanigawa et al. 2007; Mordasini et al. 2012; Tanigawa & Tanaka 2016).

4.2 Beyond the core accretion model

The excess of massive planets orbiting metal-poor stars differs from that expected form the core accretion formation theory in terms of the following two points. While more massive planets are likely to be formed around more metal-rich stars (Mordasini et al. 2012), the mean masses for the intermediate-mass and massive planets clearly increases as the metallicity decreases (Figure 7). In addition, although a continuous decrease in the mass function of massive planets is theoretically predicted (Mordasini et al. 2009), the observation samples orbiting the metal-poor stars are clustered around 1 and 10 MJ (Figure 3). The eccentricities of the massive planets orbiting metal-poor stars also differ from those around metal-rich stars (Figure 6); the eccentricities of the massive planets around the metal-poor stars do not seem to be enhanced through the planet-disk interaction prior to gas dissipation. Thus, the distributions of masses and eccentricities for the massive planets are unlikely in the bottom-up scenarios.

An explanation for the excess massive planets orbiting metal-poor stars is that the disk instability acts in the vicinity of metal-poor stars, because a lower mass limit applies for planets formed via the disk instability mechanism (i.e., corresponding to an order of the Jeans mass (Matsuo et al. 2007; Mayor 2010)). As a result, a sharp increase appears in the planetary mass function around 4 MJ. It is also accepted that planet formation due to disk instability tends to occur in the vicinity of metal-poor stars because the cooling timescale in the disk mid-plane is reduced owing to low disk opacity (Cai et al. 2006; Durisen et al. 2007). The low eccentricities of the massive planets orbiting the metal-poor stars are also consistent with the numerical simulations (Mayer 2010; Mayer et al. 2004) and the eccentricities of four gas giants orbiting HR8799 (Wertz et al. 2017). Note that the four gas giants are located in a region beyond the core accretion model.

4.3 Two planetary formation scenarios

Based on these considerations, we compared the distribution of host star metallicities and companion masses for the 623 common-biased samples with the regions expected from the core accretion and disk instability models (Figure 8). The scarce regions appear in terms of companion mass, one at 0.1 to 4 MJ and one at 20 to 30 MJ. Whereas the former arises from the rapid gas accretion onto the core, the latter represents a gap between binary star and planet formation. In other words, the two regions reflect the lower and upper mass limits of extrasolar gaseous objects that are formed by the planetary formation processes. In fact, the upper mass limit is almost consistent with the theoretical expectations (Tanigawa & Ikoma 2007; Mordasini et al. 2012; Tanigawa & Tanaka 2016).

While the intermediate-mass and massive planets orbiting the metal-rich stars can be explained by the core accretion model, the excess of massive planets is likely to be explained by the top-down model such as gravitational instability instead of the bottom-up scenario. The previous observational studies on dual planetary formation scenarios (Ribas & Miralda-Escude 2007; Santos et al. 2017; Schlaufman 2018) showed that there exists a boundary mass of 4 to 10 MJ in the diagram of host star metallicities and masses for gaseous objects and mentioned that the boundary reflects the transition between the two planetary formations; the upper limit of the core-accreted planets is around 4 MJ. However, we found that the boundary of 4 MJ reflects a population that is likely to be formed via disk instability and expected that planets with masses up to 20-30 MJ can be continuously formed by core-accretion around the metal-rich stars.