Abstract

Planets are among the most diverse celestial bodies in the Universe. In the Solar System alone, we find four very different representatives of terrestrial planets, two giant planets, two ice giants, several dwarf planets, and many small objects, each of them with special and unique characteristics.

By the end of the twentieth century, modern technologies extended our understanding of planetary systems beyond the Solar System, pushing planetary diversity to a new level. In modern times, planetary science, which can be regarded as an ancient branch of space science, has expanded to include exoplanetary science.

Observationally, the study of exoplanets is challenging. This is primarily due to the faintness of these objects. Therefore, various modern techniques and instruments have been developed to detect planetary objects surrounding different stars, and to measure the basic characteristics of their planets, including mass, radius, and orbital period. Ongoing efforts to detect and characterize exoplanets from Earth and space have led to the detection of thousands of planets in our own Galaxy. Constraining the composition and internal structure is essential for exoplanet characterization.

The internal structure and composition of planets is tightly linked to their formation mechanisms, their birth environment, and their long-term evolution. Nevertheless, it is not possible to deduce the exact formation path and the conditions of the birth environment from the current planetary structure. This is because various formation and evolution scenarios can lead to the same composition and interior. Finding the initial conditions and identifying the key processes that shape planets and planetary systems are essential to understand planets as a class of astronomical objects.

The key objective of planetary science, as a modern scientific discipline, is to understand the formation, structure, and composition of planets inside and outside the Solar System. This thesis focuses on the composition and internal structure of intermediate-mass exoplanets.

First, we perform a statistical analysis to determine the characteristic maximum (threshold) radii for various compositions for exoplanets with masses up to 25 $M_\oplus$. We confirm that most planets with radii larger than 1.6 $R_\oplus$ are not rocky, and must consist of lighter elements, as reported in previous studies. We find that planets with radii above 2.6 $R_\oplus$ cannot be pure water worlds, and must contain significant amounts of hydrogen and helium (H–He). We find that planets with radii larger than approximately 3 $R_\oplus$, 3.6 $R_\oplus$, and 4.3 $R_\oplus$ are expected to consist of 2%, 5%, and 10% of H–He, respectively. We show that the envelope's metallicity, the global mass fraction of H–He, and the distribution of the elements play a significant role in the determination of the threshold radius. We conclude that, despite the degenerate nature of the problem, it is feasible to put limits on the possible range of compositions for planets with well-measured mass and radius.

Second, we explore why larger stars tend to host larger planets. Previous studies have suggested that the planetary radius scales linearly with stellar mass (for planets with radii smaller than 6 $R_\oplus$ and hosts below 1 $M_\odot$). In our study, we investigate whether this inferred relation between planetary size and the host star's mass can be explained by a higher planetary mass, inflation due to the difference in stellar irradiation, or different planetary compositions and structures. Using exoplanetary data of planets with measured masses and radii, we investigate the relations between stellar mass and various planetary properties for G- and K-stars, and we confirm that massive stars tend to host larger, more massive, and hotter planets. However, we find that the differences in planetary masses and temperatures are insufficient to explain the measured differences in radii. In addition, we show that incompleteness of the data cannot explain this trend. We investigate the possibility that planets around more massive stars have higher H–He mass fractions, and we show that such an interpretation can explain the observations. Therefore, we suggest that the larger planetary radii can be explained by the larger fraction of volatiles among planets surrounding larger stars. Our findings imply that planets forming around more massive stars tend to accrete H–He atmospheres more efficiently.

This thesis presents an additional step toward a more complete understanding of planets.