Properties of nine gas giant planets and their possible formation

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Abstract. This conference paper examines the properties and formation of several exoplanets and gas giants in our solar system. Specifically, this paper focus on HD 80606 b, WASP-14 b, HD 189733b, Saturn, HAT-P-26b, Jupiter, HR 8799 b, HR 8799 c, and HD 149026b. The paper will display 5 theories of formation of gas giants and the physical characteristics of the 9 gas giants, such as mass, radius, and temperature, as well as their atmospheric composition. Additionally, this paper will make analysis to explore the possible path of formation of these planets, using their formation mechanism, location in their respective systems, and the potential influence of their host star. Through this analysis, the paper aims to deepen our understanding of the diversity of exoplanets and the factors that shape their formation and evolution.

Keywords: HD 80606 b, WASP-14 b, HD 149026b, giant planet, formation mechanism.

1. Introduction

The search for exoplanets has revealed a plethora of diverse and intriguing worlds beyond our solar system. In this conference paper, we focus on several gas giants, namely HD 80606 b, WASP-14 b, HD 189733b, Saturn, HD 219134b, Jupiter, HR 8799 b, HR 8799 c, and HD 149026b. These planets offer a range of physical and atmospheric properties, such as their mass, radius, temperature, and atmospheric composition, which provide valuable insights into the diversity of exoplanetary systems. Furthermore, the study of these gas giants enables us to better understand their formation and evolution in general. By comparing and contrasting their formation mechanisms, location in their individual systems, and the potential influence of main sequence stars in their systems, we can develop a more comprehensive understanding of the complex processes that give rise to these fascinating worlds. Through this analysis, we aim to contribute to the ongoing exploration of exoplanetary systems and the quest for understanding our place in the universe.

The plan of this paper is as follows: 1. Introduction. 2.Brief concepts of the five theories of formation of gas giants. 3.Data displacement and Comparison. 4.Comparison of formation of the nine gas giants. 5.Conclusion.

2. Brief concepts of the 4 theories of formation of gas giants

2.1. High eccentricity migration model

The high eccentricity migration model is a theory of gas giant planet formation that proposes that gas giants can form through a process of gravitational interactions with other planets or objects in the protoplanetary disk. According to this model, a gas giant can form initially at a large distance from its host star, and then be perturbed into a highly eccentric orbit through interactions with other planets or objects in the system. As the gas giant orbits close to the host star, it can heat up and lose some of its gas through atmospheric escape, resulting in a smaller, more compact planet. The high eccentricity model is able to explain the existence of some gas giant planets that have highly eccentric orbits [1].

2.2. Core accretion model

The core accretion model is a widely recognized theory of formation that proposes gas giants form through the accumulation of solid materials in the protoplanetary disk. According to this model, gas giants begin as small, solid cores that form through the agglomeration of small particles in the disk. As the core grows, it can start to attract gas from the surrounding disk through its gravity, leading to the formation of a thick atmosphere. The core accretion model is able to explain many of the observed properties of gas giants, such as their large masses, thick atmospheres, and the prevalence of gas giants around stars with high metallicity. However, the model is not without its limitations and challenges, such as the difficulty of forming gas giants in the inner regions of protoplanetary disks, where the supply of gas is limited [2].

2.3. Pebble accretion model

The pebble accretion model is a relatively new theory of gas giant planet formation that proposes that gas giants form through the accretion of pebble-sized particles in the protoplanetary disk. According to this model, gas giants begin as small, solid cores that form through the agglomeration of small particles in the disk. Once the core reaches a critical mass, it can start to accrete pebbles, which are small particles of rock and ice that are abundant in the outer regions of the disk. The pebbles can then stick together and form larger planetesimals, which can grow into gas giants through the accretion of gas from the surrounding disk. The pebble accretion model is able to explain many of the observed properties of gas giants, such as their large masses, the prevalence of gas giants around stars with low metallicity, and the formation of gas giants in the outer regions of protoplanetary disks [3-4].

2.4. Disk instability model

The disk instability model is a theory of gas giant planet formation that proposes that gas giants can form through the gravitational collapse of a dense region in the protoplanetary disk. According to this model, gas giants begin as clumps of gas and dust that form due to the gravitational instability of the disk. These clumps can then collapse under their own gravity, leading to the formation of gas giant planets. The disk instability model is able to explain the existence of gas giant planets that have large masses and are located far from their host stars [5].

2.5. In-situ formation model

In-situ formation model: This theory proposes that hot Jupiters form in place, close to their host stars, through rapid gas accretion during a short-lived period of high gas densities in the protoplanetary disk. This theory can explain the observed properties of some hot Jupiters, but it requires a high rate of gas accretion, which is not well-understood [6].

3. Data displacement and analysis of possible path of formation

Table 1. Data of the 9 gas giants [7-12].

	Mass (MJup)	Radius (RJup)	Eccentri-city	Orbital period (days)	Surface temperature (K)	Semi-major Axis (AU)
HD 80606b	4.1641	1.1032	0.93183	111.44	400-1400	0.460
WASP-14 b	7.341	1.281	0.087	2.244	2800	0.036

Table 1. (continued).

HD 189733 b	1.138	1.138	0	2.219	1200	0.031
Saturn	0.2994	0.8430	0.054	10759	133	9.53
HAT-P-26 b	0.0585	0.57	0.124	4.234	590	0.0479
Jupiter	1	1	0.048	4,332	35	5.204
HR 8799 b	7	1.2	0	164250	870	68
HR 8799 c	8.3	1.3	0	82145	1090	42.9
HD 149026 b	0.357	0.718	0	2.876	2300	0.042

3.1. HD 80606 b

Shown as Table 1, HD 80606 b orbits its system’s main sequence star with a highly eccentric orbit, meaning that its distance from the star varies greatly over a revolution. It is located very close to its domestic main sequence star during the closest part of its orbit, but then swings out to a distance that is much farther away.

This type of orbit is thought to be the result of a process known as "high-eccentricity migration," in which a gas giant planet forms farther out from its star and then migrates inward due to interactions with other planets or with the protoplanetary disk. In the case of HD 80606b, it is likely that the planet formed farther out from its star and then migrated inward due to interactions with other planets or with the protoplanetary disk, which caused its orbit to become highly eccentric.

Other formation pathways, such as core accretion and disk instability, are less likely to be responsible for the formation of HD 80606 b. This is because these pathways typically result in planets that are either located closer to their host star or have more circular orbits. Core accretion typically results in gas giants forming farther out from their star, but they do not generally migrate inward to the degree seen in HD 80606 b. Disk instability, on the other hand, typically results in gas giants that are located relatively close to their host star and have more circular orbits.

Therefore, based on the characteristics of HD 80606 b, it is most consistent with the high-eccentricity migration theory, and less likely to have formed through core accretion or disk instability. However, it is important to note that our understanding of exoplanet formation is still evolving, and it is possible that new formation pathways may emerge or that our understanding of existing pathways may change over time.

3.2. WASP-14 b

As Table 1 shows, WASP-14 b is a gas giant exoplanet that orbits its system’s main sequence star with a relatively short orbital period of just 2.24 days, and is located relatively close to its system’s main sequence star. It is believed to have formed through a process known as "core accretion," which is one of the two main theoretical pathways for the formation of gas giant planets.

Core accretion involves the slow accumulation of gas and dust onto a solid core, which eventually becomes massive enough to begin accumulating gas more rapidly and grow into a gas giant planet. This process typically occurs relatively far away from the system’s main sequence star, in the colder and more distant regions of the protoplanetary disk.

In the case of WASP-14 b, it is thought that the planet formed through core accretion, as it is not massive enough to have formed through disk instability. Disk instability typically produces more massive planets that are located closer to their host star, which is not consistent with the characteristics of WASP-14 b.

However, it is also believed that the planet may have undergone some migration to its current location. Planetary migration refers to the process by which a planet's orbit changes over time, often as a result of interactions with other planets or with the protoplanetary disk. It is possible that WASP-14 b formed farther out from its host star and then migrated inward to its current location.

Other formation pathways, such as high-eccentricity migration, are less likely to be responsible for the formation of WASP-14 b. This is because high-eccentricity migration typically produces planets with highly elliptical orbits, while WASP-14 b has a relatively circular orbit.

Therefore, based on the characteristics of WASP-14 b, it is most consistent with the core accretion pathway, with the possibility of some migration involved in its formation.

3.3. HD 189733b

As Table 1 shows, HD 189733b is a gas giant exoplanet that orbits its system’s main sequence star with a relatively short orbital period of just 2.2 days, and is located relatively close to its host star. It is believed to have formed through the process of "core accretion," which involves the slow accumulation of gas and dust onto a solid core.

Core accretion is one of the two main theoretical pathways for the formation of gas giants, and is believed to occur relatively far away from the domestic main sequence star, in the colder and more distant regions of the protoplanetary disk.

It is consistent with the characteristics of HD 189733b, which is relatively close to its host star but still located outside of the star's habitable zone.

However, it is also believed that the planet may have undergone some migration to its current location. Planetary migration refers to the process by which a planet's orbit changes over time, often as a result of interactions with other planets or with the protoplanetary disk. HD 189733b is located close enough to its host star that it may have undergone some migration to its current location.

Other formation pathways, such as disk instability and high-eccentricity migration, are less likely to be responsible for the formation of HD 189733b. Disk instability typically produces more massive planets that are located closer to their host star, which is not consistent with the characteristics of HD 189733b. High-eccentricity migration typically produces planets with highly elliptical orbits, while HD 189733b has a relatively circular orbit.

Therefore, based on the current understanding of exoplanet formation, HD 189733b is most consistent with the core accretion pathway, with the possibility of some migration involved in its formation.

3.4. Saturn and Jupiter

Shown as Table 1, both Saturn and Jupiter are gas giant planets located in the outer solar system, beyond the asteroid belt. They are believed to have formed through the process of core accretion, which involves the gradual accumulation of pebble-sized fragments onto a solid core.

In the core accretion model, it is believed that the process begins with the formation of a small solid core, typically made up of heavy elements such as rock and metal. This core then slowly grows in size as it accretes gas and dust from the surrounding protoplanetary disk. Over time, the growing planet becomes massive enough to attract gas directly from the disk, rapidly increasing its size and leading to the formation of a gas envelope.

Saturn and Jupiter are both massive planets, with Jupiter being the largest planet in the solar system. Their large size is thought to be a result of their ability to rapidly accrete gas from the protoplanetary disk, due to their large solid cores. This is consistent with the core accretion model.

Furthermore, both Saturn and Jupiter have many moons, which is also consistent with the core accretion model. In this model, the formation of moons is believed to occur through a similar process of accretion, with smaller particles and debris in the protoplanetary disk coalescing to form moons around the gas giant planet.

Other models for planetary formation, such as disk instability and high-eccentricity migration, are less likely to be responsible for the formation of Saturn and Jupiter. Disk instability is typically associated with the formation of smaller, more massive planets closer to their host star. High-eccentricity migration is typically associated with the formation of gas giants with highly elliptical orbits, which is not consistent with the nearly circular orbits of Saturn and Jupiter.

In summary, Saturn and Jupiter are believed to have formed through the core accretion model of planetary formation, which is consistent with their large size, location in the outer area of our domestic system, and the presence of many moons.

3.5. HAT-P-26b

Shown as Table 1, HAT-P-26b is a relatively small exoplanet located close to its host star. It is believed to have formed through the process of core accretion.

The core accretion model proposes that planets are formed through the gradual accumulation of gas and dust onto a solid core. In this model, it is believed that the process begins with the formation of a small solid core made up of heavy elements such as rock and metal. This core then slowly grows in size as it accretes gas and dust from the surrounding protoplanetary disk.

HAT-P-26b is not massive enough to have formed through the process of disk instability, which is another model for the formation of planets. In the disk instability model, it is believed that planets are formed through the direct fragmentation of the protoplanetary disk. However, this process typically leads to the formation of massive gas giant planets that are much larger than HAT-P-26b.

It's worth noting that HAT-P-26b is also relatively close to its host star, which is another factor that supports the core accretion model. In this model, planets that form closer to their host stars are believed to be smaller and denser than those that form farther away.

Overall, the characteristics of HAT-P-26b, such as its relatively small size and close proximity to its host star, are consistent with the core accretion model of planetary formation. The fact that it is not massive enough to have formed through disk instability also supports this model over other possible formation pathways.

3.6. HR 8799 b & c

HR 8799 b and HR 8799 c are gas giant exoplanets that are part of a system of four planets located relatively far from their host star. They are thought to have formed through the process of disk instability, which is one of the two main models for the formation of giant planets.

In the disk instability model, it is believed that gas giant planets are formed through the gravitational fragmentation of a massive protoplanetary disk. This process can lead to the emergence of more than one massive planets in a relatively short amount of time. The resulting planets may be relatively massive and located at a relatively isolated position from their system's main sequence star, as is the case with HR 8799 b and HR 8799 c.

The fact that HR 8799 b and HR 8799 c are located relatively apart from their host star is consistent with the disk instability model, as it is believed that planets that form farther away from their host stars are more likely to form through this mechanism. Additionally, their relatively high masses and the fact that they are part of a system of four planets are also consistent with the disk instability model.

Overall, the characteristics of HR 8799 b and HR 8799 c, such as their high masses, location distant from their system's main sequence star, and probable migration, are consistent with the disk instability model of planetary formation. The fact that they are not located close to their host star, like hot Jupiters, also supports this model over other possible formation pathways.

3.7. HD 149026 b

As Table 1 shows, HD 149026 b has a mass similar to that of Saturn but is only 0.04 AU away from its host star, completing an orbit in just 2.87 days. This makes it a "hot Saturn" or a "hot Neptune," rather than a hot Jupiter, despite its relatively close orbit to its host star.

One possible explanation for its formation is the "in-situ" formation model, where the planet formed in place close to its host star, rather than migrating inward from a distance. However, this theory is not well-supported by observations, as it is difficult to explain how a planet with such a low mass could form so close to its host star.

Another possibility is that HD 149026 b formed through the core accretion model but experienced significant atmospheric loss due to its close proximity to the host star. This atmospheric loss may have caused the planet's mass to be significantly reduced, making it appear more like a hot Neptune than a hot Jupiter.

Overall, HD 149026 b is an interesting exoplanet that challenges our current knowledge in the field of gas giant formation and evolution. Further observations combined with modeling may be necessary to better understand its origin and properties.

4. Conclusion

In conclusion, the planetary bodies HD 80606 b, WASP-14 b, HD 189733b, Saturn, HAT-P-26b, Jupiter, HR 8799 b, HR 8799 c, and HD 149026b differ in their mass, radius, and period of evolution. These differences suggest that they may have formed through different pathways and in different regions of their respective planetary systems. This paper explored possible pathway of formation of these gas giants with analysis of their properties in the use their formation mechanism, location in their individual systems, and the potential influence of their system's main sequence stars. Through this analysis, the paper aims to deepen the understanding of the diversity of exoplanets and the factors that shape their formation and evolution.

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