EDUZONE: International Peer Reviewed/Refereed Multidisciplinary Journal (EIPRMJ), ISSN: 2319-5045
Volume 11, Issue 1, January-June, 2022, Impact Factor: 7.687, Available online at: www.eduzonejournal.com

Study on the characteristics of exoplanets: Review

Sanjana Gupta[1], Ishan Kaushal[1], S. Majal Shiny[1], Janani Kavi Priya V S[2]

[1]Graduate Research Trainee, Department of Research and Development, ASTROEX RESEARCH ASSOCIATION, Deoria-274001, India
[2]Research Supervisor, Department of Research and Development, ASTROEX RESEARCH ASSOCIATION, Deoria-274001, India

ABSTRACT

Since the discovery of the first exoplanet 51 Pegasi in 1995, thousands of exoplanets have been discovered till date. They have been found orbiting around almost every type of known star including pulsars, binaries, and neutron stars. Compared to the planets of our solar system, these exoplanets possessed a wide range of masses, sizes, orbits, and other physical and chemical characteristics. The major classification of the exoplanets includes Gas Giants, Neptune-Like, Super-Earths Terrestrial types, however, studies suggest that a lot of other types of exoplanets are also present. In this paper, we review the characteristics which include masses, compositions, and orbital parameters of major types of exoplanets, and try to find the relationship between these prominent characteristics of exoplanets.

Keywords: Exoplanets, Mass, Composition, Orbit, Size.

INTRODUCTION

There is no accepted standard definition for exoplanets by the IAU. An exoplanet or extrasolar planet is a planet outside the Solar System. The first possible evidence of an exoplanet was noted in 1917 but was not recognized as such. The first confirmation of detection occurred in 1992. So, in this paper, at first, we will be exploring some possible definitions of exoplanets as described by scientists. The IAU's Working Group on Extrasolar Planets (WGESP) [1] has agreed to the following statements:

1. Objects with true masses below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) that orbit stars or stellar remnants are "planets" (no matter how they formed). The minimum mass/size required for an extrasolar object to be considered a planet should be the same as that used in our Solar System.
2. Substellar objects with true masses above the limiting mass for thermonuclear fusion of deuterium are "brown dwarfs", no matter how they formed or where they are located.
3. Free-floating objects in young star clusters with masses below the limiting mass for thermonuclear fusion of deuterium are not "planets", but are "sub-brown dwarfs" (or whatever name is most appropriate).

We can expect this definition to evolve as our knowledge improves. The minimum planetary mass is therefore the mass sufficient for self-gravity to overcome rigid body forces and for clearing the neighborhood around the object's orbit. In other words, an object can be considered a planet if it is capable to influence dynamically the evolution of other bodies in its vicinity, sculpting their orbital distribution. This criterion has the advantage that the question of the evolution of other bodies in the neighborhood can be addressed through theoretical calculations or numerical simulations [2]. Note, however, that this definition of the lower limit relies on a dynamical criterion, which has been written with the architecture of the Solar System in mind. In the future, it might need to be adapted to extrasolar systems showing different architectures, e.g., with very eccentric orbits. The upper mass limit of the 2003 definition has been controversial [3], and various proposals have been made to alter it. Some researchers prefer definitions based on formation mechanism; although this has aesthetic appeal, it is highly impractical given the difficulty in determining the formation process of most bodies that might be reclassified by this change. The deuterium burning criterion should not be understood as a criterion linked to the formation mechanism. Some researchers have proposed increasing the boundary to around 25

Jupiter masses (M_{Jup}). Finally, the Organizing Committee decided to keep the current mass limit at the thermonuclear fusion of deuterium. This limit corresponds roughly to 13 Jupiter mass, with some dependence on the metallicity [4].In this paper we studied the properties of newlydiscovered exoplanets TOI-700d and TOI-700c by TESS satellite. We found both planets are in orbital resonance and dueto this they are in tidal locking with each other. We found their orbital resonance period as 7:3 and synodic period as 27.951days presented by Ankit et.al [87].

METHODOLOGY

There are several criteria for classifying exoplanets. Most studies focus on a single criterion of categorization, however, most recognized exoplanet types have more than one criterion for their nomenclature. In this paper, we aim to evaluate the various categorization basis for all of the major exoplanet kinds and provide a thorough list of exoplanet categories.

1. On the Basis of Mass, Size, and Composition

1.1 Sub-Earth

A sub-Earth is a planet that is significantly less massive than Earth and Venus [5]. This category encompasses Mercury and Mars in the Solar System. Sub-Earth exoplanets are among the most difficult to discover due to their small size and mass, which produces the lowest signal. Also known as subterran planets or mercurian planets, they have masses ranging from 0.01 to 0.5 Earth masses. Nonplanetary classifications below 0.01 Earth masses are dwarf planets or hypo-Earths. As a result, it is the seventh most massive or the least massive class of planet [6].

1.1.1 Discovery

Despite the challenges, one of the first exoplanets discovered was a sub-Earth orbiting the millisecond pulsar PSR B1257+12. The smallest known of such planets is WD 1145+017 b, which is 0.15 Earth radii in size, or slightly smaller than Pluto. WD 1145+017 b is a dwarf planet because it orbits within a cloud of dust and gas [7]. The finding of sub-Earths by the Kepler space telescope opened up the world of sub-Earths. Kepler detected the first three sub-Earths around the star Kepler-42 on January 10, 2012.

1.1.2 Characteristics

Because of their low gravity and weak magnetic fields, sub-Earths frequently lack large atmospheres, enabling stellar radiation to erode their atmospheres. Sub-Earths have brief periods of geologic activity due to their tiny sizes, and unless there are large tidal forces when circling near to the parent star. Sub-Earths near their host stars may also have quite big cores [5]. Sub-Earths are rocky because they are too tiny to retain significant amounts of gases like gas giants. Sub-Earths have shorter periods of geologic activity than mid-Earths and super-Earths due to their smaller mass and inability to store heat in their innards like mid-Earths and super-Earths. Despite their smaller size, meteors, comets, and asteroids pound the surface of sub-Earths more often than the surfaces of larger planets due to their generally thinner atmospheres due to their lower gravity. Thinner atmospheres do not burn up the object as rapidly as heavier atmospheres. As a result, sub-Earths have several impact craters on their surfaces. As a result, crater planets would be a prevalent feature of sub-Earths [6].

1.1.3 Occurrence Rates

As of June 2014, Kepler has 45 confirmed planets that are smaller than Earth, with 17 of them being smaller than 0.8 $R_{\oplus}$. In addition, there are over 310 planet candidates with an estimated radius of $< 1R_{\oplus}$, with 135 of them being smaller than 0.8 $R_{\oplus}$ [5] [8]. There are an estimated 177 billion sub-Earths in our galaxy alone, making it the second most abundant mass class of planet. This indicates that sub-Earths account for 216 % of our galaxy's 820 billion planets [6].

1.1.4 Formation and Migration Theories

The following mechanisms might result in the development of sub-Earths during the last phases of planet formation [5]:
1. as the in-situ outcomes of constructive and destructive planetary embryo collisions and scattering
2. from embryos that migrated inward because of gravitational torques imposed by the protoplanetary disc ("Type-I migration")
3. by gravitational scattering

4. evaporation of larger bodies

After developing at greater orbital distances, sub-Earths may potentially travel to closer orbits. The minimal mass of a planet capable of migrating to a short-period orbit is related to the distance in the disc at which ice condenses, commonly known as the snow line. This distance grows in proportion to star brightness and hence stellar mass. The same study found that planets tend to scatter to shorter orbital distances around low-mass stars, implying that low-mass stars may often contain observable Sub-Earths [9].

1.2 Terrestrial

The title “Terrestrial planet” and “Telluric planet” are taken from the Latin words for Earth (Terra and Tellus), as these planets have an Earth-like structure. Terrestrial planets have radii ranging from half to twice the size of Earth. Our solar system’s terrestrial planets include Earth, Mars, Mercury, and Venus. Super-Earths are exoplanets that are at least twice the size of Earth [10].

1.2.1 Discovery

There are 187 confirmed discoveries of Terrestrial planets according to NASA [10]. Gliese 876 d and OGLE-2005-BLG-390Lb were discovered in 2005 as the first planets circling a main-sequence star and showing evidence of being terrestrial planets. Gliese 876 d orbits the red dwarf Gliese 876, which is 15 light-years away and has a mass seven to nine times that of Earth with an orbital period of only two Earth days. OGLE-2005-BLG-390Lb is around 5.5 times the mass of Earth and circles a star in the constellation Scorpius about 21,000 light-years distant.

1.2.2 Characteristics

Terrestrial planets have a solid planetary surface, which distinguishes them from bigger gaseous planets. They have a solid or liquid surface and are mostly composed of rock, silicate, water, and/or carbon. Although these planets may have a gaseous atmosphere, it is not a defining trait. Depending on the presence of an erosive liquid and/or tectonic activity, terrestrial planets can feature surface formations such as canyons, craters, mountains, volcanoes, and others. Secondary atmospheres are produced by volcano outgassing or comet impact debris on terrestrial planets [10].

1.2.3 Occurrence Rates

Approximately half of the stars with temperatures similar to our Sun might have a rocky planet capable of hosting liquid water on its surface [11]. An extrapolation to longer periods gives the frequency of terrestrial planets in the habitable zones of FGK stars as $\eta_{\oplus} \approx (34 \pm 14)\%$, thus about one-third of FGK stars are predicted to have at least one terrestrial, habitable-zone planet [12]. It was discovered that 11 ± 4% of Sun-like stars have an Earth-sized planet that receives one to four times the stellar energy as Earth. It was also discovered that the occurrence of Earth-sized planets increases with orbital period (P), within equal intervals of log P up to ∼ 200 days. Extrapolating, it is found that $5.7^{+1.7}_{-2.2}\%$ of Sun-like stars harbor an Earth-sized planet with orbital periods of 200–400 days [13]. There are two regions with planet abundance. One corresponds to planets with radii between 0.5 and $1.5R_{\oplus}$inside of 0.2 AU, the other corresponds to planets with radii between 1.5 and 3 RL beyond 0.5 AU. The relative occurrence rates in the outer high occurrence zone beyond 0.5 AU are approximately ten times greater than those in the inner region within 0.2 AU. This suggests that terrestrial planets in the habitable zone of FGK stars are more numerous than those in close-in orbits. The region with planetary radii between 1.5 and 3.0 $R_{\oplus}$ and orbital semi-major axes between 0.2 and 0.5 AU show occurrence rates that are only about one-tenth of the region beyond 0.5 AU, where the occurrence rates are supposed to be lower as the detection efficiency is much lower there.

1.2.4 Formation Theories

Terrestrial planets emerge from the solid component of circumstellar discs through a sequence of dynamical stages. First, kilometer-sized planetesimals are most likely formed by a mix of sticky collisions, chaotic solid concentration, and gravitational collapse from micron-sized dust grains in the narrow disc midplane. Second, planetesimals combine to produce protoplanets the size of the Moon to Mars, commonly known as “planetary embryos.” Full-sized terrestrial planets eventually form from protoplanets and planetesimals. This last stage of accretion lasts roughly 10-100 Myr and is heavily influenced by gravitational perturbations from any gas giant planets that are forced to develop more quickly during the disk’s 1-10 Myr lifespan. The bulk compositions and volatile (e.g., water) contents of terrestrial planets are determined at this last stage, depending on their feeding zones and the amount of radial mixing that occurs. The mass and surface density profile of the disc, as well as perturbations from giant planets and binary partners, are the key elements that impact terrestrial planet formation. According to simple accretion models, low-mass stars should generate tiny, dry planets in their habitable zones [14].

1.2.5 Subtypes

Several possible classifications for Terrestrial planets have been proposed [15].

- Silicate planet: A solid planet, similar to Venus, Earth, or Mars, with a silicon-based rocky mantle and a metallic (iron) core.
- Carbon planet (or "diamond planet"): A hypothetical type of planet with a metal core surrounded by mostly carbon-based materials. If the metal concentration is high, they may be classified as a form of a terrestrial planet. There are no carbon planets in the Solar System, although there are carbonaceous asteroids such as Ceres and 10 Hygiea. It's unclear if Ceres has a rocky or metallic core.
- Iron planet: A theorised solid planet that is nearly completely composed of iron and so has a higher density and a smaller radius than other solid planets of equivalent mass. Mercury in the Solar System has a metallic core that accounts for 60–70 % of its planetary mass and is sometimes called an iron planet,[16] but its surface is made of silicates and is iron-poor. Iron planets are predicted to develop in high-temperature areas around stars, such as Mercury, and if the protoplanetary disc is iron-rich.
- Icy planet: A form of a solid planet with a volatile ice surface. Most planetary-mass moons (such as Titan, Triton, and Enceladus) and many dwarf planets (such as Pluto and Eris) in the Solar System have this composition. Because of its surface ice, Europa is frequently called an icy planet, although its greater density implies that its interior is primarily rocky. Such planets can have internal saltwater seas and cryovolcanoes releasing liquid water (i.e. an internal hydrosphere, similar to Europa or Enceladus); they can have a methane or nitrogen atmosphere and hydrosphere (like Titan). A metallic core, such as that found on Ganymede, is conceivable.
- Coreless planet: A hypothesised sort of solid planet made of silicate rock but lacking a metallic core. Although there are no coreless planets in the Solar System, chondrite asteroids and meteorites are abundant. Ceres and Pallas contain mineral compositions that are comparable to carbonaceous chondrites, albeit Pallas is substantially less hydrated. Coreless planets are predicted to develop farther away from the star, where volatile oxidising material is more plentiful.

1.3 Super-Earth

Super-Earths are potentially rocky planets subsequent accretion of gaseous envelopes that have a mass greater than the Earth. They are larger than-terrestrial sizes. Masses of super-Earths point to the less challenging detection of these objects compared to the detection of Earth-sized planets [17] [18].

1.3.1 Discovery

Aleksander Wolszczan and Dale Frail found the first super-Earths in 1992, near the pulsar PSR B1257+12. The system's two outer planets have masses roughly four times that of Earth. In 2005, a team led by Eugenio Rivera identified the first super-Earth orbiting a main-sequence star. It is named Gliese 876 d because it circles Gliese 876. It has an estimated mass of 7.5 Earth masses and an orbital period of around 2 days. Because of its closeness to its host star, Gliese 876 d may have a surface temperature of 430–650 kelvin, making it too hot to support liquid water [19].

1.3.2 Characteristics

Super-Earths may have physical and dynamical characteristics similar to those of Earth whereas, unlike terrestrial planets, they are relatively easier to detect. Because of their sizes, super-Earths can maintain moderate atmospheres and possibly dynamic interiors with plate tectonics. They also seem to be more common around low-mass stars where the habitable zone is at closer distances. The first super-Earth was discovered by using the technique of microlensing [20]. In contrast to hot Jupiters that rarely have a comparably sized companion, Super-Earths frequently occur in multiple-planet systems. Super-Earths are planets of between 1 and about 10 Earth masses. Super earth means larger than our Earth. They might be more suitable for life than our Earth. Super earth with the composition of hydrogen and helium are of low densities and those with water and silicon are of high densities. Super-Earths of up to 1.5 Earth radii are likely to be ocean planets or rocky planets with a thin atmosphere. The semimajor axes of the majority of super-Earths are smaller than 0.2 AU and their eccentricities range from 0 to 0.4. Studies also suggest that super-Earths may have dynamic interiors and be able to develop and maintain moderate atmospheres–two conditions that would render super-Earths potentially habitable if their orbits are in the habitable zones of their host stars [21].

1.3.3 Occurrence Rates

Observations have revealed that super-Earths are the most abundant type of planets in the inner systems.

1.3.4 Formation Theories

Planets form in protoplanetary disks surrounding their infant stars. Since the birth and growth of planets are tightly related to their forming environment, it is essential to understand the planet formation processes by studying the physical and chemical conditions of protoplanetary disks. A large number of young protoplanetary disks have been observed and extensively studied in the literature [22]. The study of planet formation is a highly multiscale and multi-physics subject. The increase in the size of a planetary body varies by more than 17 orders of magnitude, from (sub)micron-sized (dust grain) to > 104 km (super-Earth/gas giant planet). It results in different physical mechanisms operating at different length scales and in different stages of growth and evolution. We categorize the planetary bodies into four characteristic size objects: µm-sized dust grains, millimeter/centimeter (mm/cm)-sized pebbles, 100- km-sized planetesimals, and larger than 1000- km sized protoplanets /planets. The final planets are either rocky-dominated terrestrial planets/ super-Earths or gas-dominated giant plan. In the current theory, planets grow out of material orbiting within a circumsolar disk of gas and dust.

As the gaseous disk dissipates, these planets:
(i) clear out material along their orbits, and,
(ii) migrate radially to a more stable orbit [23].

There are two general orbital locations suggested for the formation of Super-Earths. Either they formed in situ with no significant migration or else they formed similarly to giant planets, outside the snow line in the protoplanetary disk and then migrated inwards [24]. Generally, the formation of Super-Earths falls into two categories: In the first, resonance capture is prevented due to turbulence in the disk or by large eccentricities of the migrating planets, which could be due to the mutual gravitational stirring by the super-Earths among each other. In the second category of solutions, planets are efficiently captured into resonance. Still, they escape on timescales that are shorter than the migration timescale between neighbouring resonances due to overstable librations or the resonance chains are broken after the disk dispersal phase due to mutual gravitational stirring of the planets, leading to one to two collisions before establishing long term dynamical stability [17].

Disc model

The evolution of the protoplanetary disc was long thought to be driven by viscous evolution. However, recent more detailed simulations have revealed that the transport of angular momentum can be carried by disc winds, but viscous disc evolution could still be consistent with observations. As the disc evolves, it cools down and with it the disc’s aspect ratio decreases, resulting in a decrease in the pebble isolation mass in time. Additionally, the position of the water-ice line moves inwards in time and comes close to 1 AU. This property is not unique to the here used disc model but is a common outcome of disc evolution models that include viscous heating. The here used disc model is thus a representative of typical viscous disc models, making our results wider applicable. Additionally, a comparison to a passively heated disc model, as there has been a recent debate if viscous heating is active in the inner regions of protoplanetary discs is discussed [18]. Forming planetary cores in the absence of any migration or radial drift in the disk, the largest mass a planet or protoplanet can grow to by the accretion of solids [17] [25].

Gas accretion

Planetary cores of a few Earth masses could in principle start to undergo gas accretion, which would allow them to increase their mass well above the pebble isolation mass, which is why the maximum mass is set to 10 Earth masses as planets close to this mass could start runaway gas accretion. However, the gas accretion process is hindered by recycling flows of the gas that penetrate the Hill sphere of the planets, making gas accretion onto planets of just a few Earth masses tough. In addition, the envelope contraction depends on the opacity within the envelope. It was suggested that the opacity in the inner disc might be larger than in the outer disc, implying that planets in the inner regions do not grow to gas giants [17] [18].

Protoplanetary disc evolution

The structure of the protoplanetary disc sets the pebble isolation mass and has thus great influence on the formation of Super-Earths. The viscous disc model used here follows the decrease in the disc’s accretion rate over time following observations. This decrease in the disc's accretion rate over time can be explained by viscous evolution. In addition, the viscous evolution models find a very similar reduction in the disc's accretion rate and thermal structure over time. Thus, discs that generate enough viscous heating should follow similar structures and evolutions [18].

Planet migration and resonant systems

Due to the interactions with the gaseous protoplanetary disc, planets migrate through it. Planetary migration for bodies of a few Earth masses happens on timescales shorter than the disc lifetime and is directed mostly inwards. In regions with steep radial gradients of entropy, migration can be directed outwards, if the viscosity is high enough. This is the case in the viscosity-dominated disc model and planets of a few Earth masses can migrate outwards. Multiple planets piling up at close distances to each other, increase their eccentricity through mutual interactions.

However, this increase in eccentricity reduces the co-rotation torque and thus outward migration and chains of planets migrate inwards. The migration of the forming planets is ultimately stopped at the inner edge of the disc, where the planets can pile up in chains of resonant planets. The migration speed of the planets sets in which resonance the planets are finally trapped because migrating planets can skip weaker resonances easier if the migration speed is large [18].

Planet composition

A recent analysis of the Kepler data has revealed that close to Super-Earth could be predominantly of rocky composition. A planetary embryo accreting pebbles interior to the water ice line will by construction have no water ice content. Planets forming exterior to the water ice line might have instead a large water ice content, potentially inconsistent with the observations. This implies that planets forming in the outer disc and then migrating inwards after their formation is complete, might have masses that match the observations, but their composition would be dominated by ice instead of rock. However, some super-Earths might contain a significant water ice fraction, implying that these planets must have formed in the outer parts of the protoplanetary disc and then migrated inwards.

However, the studies showed that planetary embryos growing exterior to the water ice line form systems with only water-rich planets, due to the fast growth of icy pebbles in the outer disc. This thus implies that some fraction of the super-Earths must form in the inner regions of the protoplanetary disc [18].

1.4 Mega-Earth

A mega-Earth is a suggested term for a huge terrestrial exoplanet 10 times the size of Earth. Mega-Earths are far larger than super-Earths which have masses of 5–10 Earth.

1.4.1 Discovery

The name "mega-Earth" was popularised in 2014 after Kepler-10c was discovered to be a Neptune mass planet with a density far larger than that of Earth, albeit it has now been confirmed to be a normal volatile-rich planet weighing slightly less than half that mass. In 2017, a more thorough investigation utilising data from numerous telescopes and spectrographs revealed that Kepler10c is more likely to be approximately $7.4M_{\oplus}$, indicating that it is a typical volatile-rich mini-Neptune rather than a mega-Earth [26]. Discovered in the C4 field of the Kepler K2 mission is a sub-Neptune-sized planet (2.23R), BD + 20594b (K2-56b). Using radial velocity measurements, it is found that this planet has a mass of 16.3ML. In other words, it is estimated to have an unusually large average density of 8.10665 $\mathrm{g/cm^{-3}}$. As a primarily presumed rocky world, BD + 20594b can be classified as a mega-Earth [27].

1.4.2 Characteristics

These planets are more massive than 10M, making them giants. Despite being this massive, these planets are found to be terrestrial rather than gas giants. Their interior structure is detailed as follows: Rocky cores enveloped by atmospheres. Their core might be engulfed by a silicate mantle, followed by a layer of ices of high-pressure forms if they are icy worlds [27].

1.4.3 Formation and Migration Theories

Planets with solid surfaces up to thousands of Earth masses may be able to develop around big stars like B-type and O-type stars with 5–120 solar masses if the protoplanetary disc contains enough heavy elements.

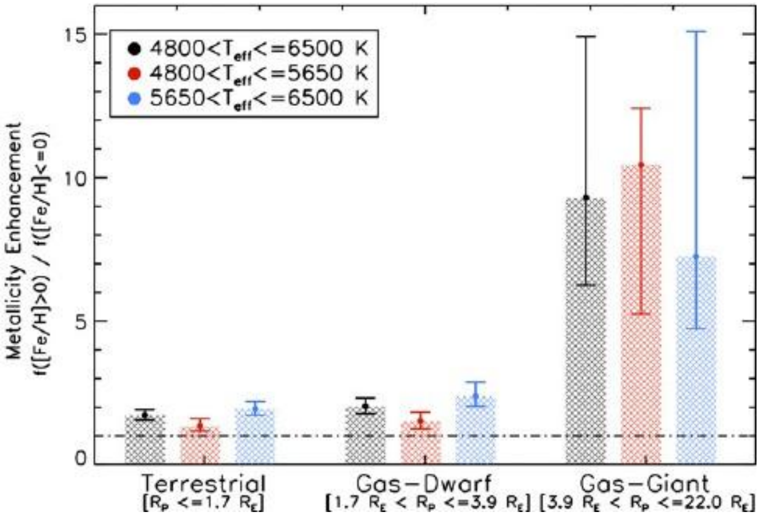

Figure 1: Relative planet occurrence rate as a function of planet size [29]

Furthermore, these stars contain significant UV radiation and winds that might photoevaporate the gas in the disc, leaving just the heavy metals which might lead to the formation of such a planet [28]. Mega-Earths are more likely to be formed via accretion in gas giant less-systems or massive protoplanetary disks. It can be theoretically concluded that if the inward passage of gas giants can be switched around on time, mega-Earths could form in the protoplanetary disks of said systems. This is derived based on Batygin and Laughlin's theory. It is also believed that, when rocky cored planets enclosed by dense gases undergo mass loss via photoevaporation caused by high energy stellar radiation, the result is a giant terrestrial-like planet [27]. Figure 1 shows the relative planet occurrence rate as a function of planet size. Here, the relative planet occurrence rate is defined as the ratio of the planet occurrence rate for metal-rich stars (high metallicity stars) to metal-poor stars (low metallicity stars). The (horizontal) dotted line indicates that the ratio is unity i.e., the relative planet occurrence rate is independent of metallicity. The relative planet occurrence rates for gas giant planets (having a radius between, $3.9R_{\oplus}$ and $22R_{\oplus}$), gas-dwarf planets (having a radius between $1.7R_{\oplus}$ and $3.9R_{\oplus}$), and terrestrial planets (having a radius less than equal to $1.7R_{\oplus}$) are all considerably higher than the unity which indicates that the planet–metallicity correlation is universal for the planet irrespective of its size. The study found a universal planet–metallicity correlation: gas-giant planets and gas-dwarf planets and terrestrial planets occur more frequently in metal-rich stars. However, the rate of occurrence was relatively higher in the case of Gas Giants. The study is further divided into different effective temperature ranges, one with 4800 K $<T_{eff} \leq$ 5650K, and the other one with 5650K $<T_{eff} \leq$ 6500K. This graphical analysis suggests that, for smaller planets, the metallicity dependence of the planet occurrence rate is weaker for stars with lower T_{eff} than for stars with higher T_{eff}. The dependence of the planet occurrence rate on metallicity decreases with the decrease in the planet size. For terrestrial and gas-dwarf planets, the relative planet occurrence rate for stars with higher effective temperatures (indicated in blue colour) is higher than for stars with lower effective temperatures (indicated in red colour). However, the study needs more observations in the future to confirm or refute the conclusions.

1.5 Mini-Neptune

A Mini-Neptune (also known as a gas dwarf or transitional planet) is a planet that is less massive than Neptune but has a thick hydrogen-helium atmosphere and likely contains deep layers of ice, rock, or liquid oceans comprised of water, ammonia, a combination of both, or heavier volatiles [30].

1.5.1 Discovery

Kepler-66b and Kepler-67b were the first Mini-Neptune planets discovered in the year 2013 in the open star cluster called NGC 6811 located about 3,300 light-years from Earth.

1.5.2 Characteristics

A Mini-Neptune is a gas planet with a rocky core and a thick envelope of hydrogen, helium, and other volatiles, with a total radius of 1.7 to 3.9 Earth radii ($1.7 - 3.9 R_{\oplus}$). Theoretical investigations of such planets are based on what we know about Uranus and Neptune. It would be categorised as an ocean planet instead [31] if it lacked a dense atmosphere. The predicted dividing line between a rocky and a gaseous planet is between 1.6 and 2.0 Earth radii [32]. Planets with larger radii and particular masses are mostly low-density and require an extensive atmosphere to explain their masses and radii at the same time, and observations show that planets larger than about 1.6 Earth radii and more massive than about 6 Earth masses contain significant amounts of volatiles or H–He gas, most likely acquired during formation [30] [33]. Such planets appear to have a diversity of compositions that is not well-explained by a single mass-radius relation as that found for denser, rocky planets [34] [35] [36] [37] [38] [39]. The lowest limit for mass varies greatly for various planets depending on their composition; the dividing mass can range from 1 to 20 $M_{\oplus}$. Smaller gas planets and planets closer to their star will lose atmospheric mass faster than bigger planets and planets further out. If a low-mass gas planet has the correct temperature, it can have a radius similar to that of a gas giant. Despite being only slightly larger, Neptune-like planets are much uncommon than sub-Neptunes. This "radius cliff" divides sub-Neptunes (radii less than 3 Earth radii) from Neptunes (radii more than 3 Earth radii). This is hypothesised to occur because, when gas is accreting, the atmospheres of planets of that size reach the pressures necessary to drive hydrogen into the magma ocean, stopping radius increase. Once the magma ocean is saturated, radius expansion can resume. Planets with enough gas to attain saturation, on the other hand, are considerably rarer since they require a lot more gas.

1.5.3 Occurrence Rates

Planets sized between Earth and Neptune radii ($1R_{\oplus} - 4R_{\oplus}$) are very common in our galaxy. In general, it is found by Venturini and Helled [40] that the chances for Mini-Neptunes to form are relatively higher in enriched atmospheres. Venturini and Helled found the occurrence rate of Mini-Neptune for certain conditions. In the case of pebble accretion, the occurrence rate is very low without envelope enrichment. But for envelope enrichment and pebble masses 50 and 200 $M_{\oplus}$ the occurrence rate is as high as $10-80\%$, and for farther distances (~ 30 AU) the occurrence rate of Mini-Neptunes formed via pebble accretion is higher than via planetesimal accretion. Whereas for the latter the occurrence rate is higher around a semi-major axis of ~ 5 AU [40].

1.5.4 Formation Theories

The creation of a planet in the core accretion concept begins with the building of a solid core made of heavy elements, followed by the binding of a gaseous envelope. When the mass of heavy elements is equivalent to the mass of H–He, this is referred to as the crossover mass (which happens at the time t_{cross}), a very fast stage of gas accretion occurs if the gaseous disc is still extant, and the planet becomes a gas giant [41] [42]. When the accretion of solids is primarily in the form of planetesimals (0.1–100 km size objects), there is an intermediate stage of growth in which the protoplanet's gravitational influence region is depleted of solids, but the accretion luminosity is sufficient to sustain the envelope's growth at a slow rate (the so-called phase-2 by Pollack et al.) [42]. In this scenario, phase-2 is generally the longest (on the order of 106 years), hence the planet's mass at this time is critical to the probability of producing a mini-Neptune. Pollack et al's traditional core accretion model has a formation timeframe of several million years. Subsequent research has shown that the long formation timescale problem can be overcome by incorporating various processes/assumptions such as planetary migration, specific conditions of planetesimal sizes, the opacity of the envelope, and the replenishment of scattered planetesimals from the embryo's feeding zone [42] [43] [44] [45] [40]. Consideration of pebble accretion with typical sizes of ~10 cm yields an alternate scenario that overcomes the lengthy creation duration in the core accretion hypothesis [46]. Because pebbles move at Keplerian speeds and are tiny, they encounter a severe headwind from the sub-Keplerian gas, resulting in orbital degradation. This results in a stream of pebbles that may be efficiently accreted by the protoplanet due to gas friction, which considerably slows them down [46] [47]. The accretion rates of solids in the pebble accretion case are typically high ($\sim 10^{6}$–$10^{5} M_{\oplus} yr^{1}$) for low-turbulent disks during the entire growth. This stops when the protoplanet perturbs the disk's structure, producing pressure bumps that hinder pebble accretion when the protoplanet has a mass of $\sim 20 M_{\oplus}$ [47]. Many studies have focused on the formation of mini-Neptunes in situ and found that most of the exoplanets with radii between 1 and 4 $R_{\oplus}$ have periods of less than 50 days, but it might also be due to observational bias. All studies of this type concluded that gas accretion inside the ice line during the disk's lifetime is very rare [48]. Still, even beyond the snowline, the acquisition of a gaseous envelope of 10 % of the planet's mass or higher requires very specific disk conditions [48]. The creation of low-mass, gas-rich planets are difficult to grasp in the context of the conventional core accretion model, in which all solids are believed to sink to the core since protoplanets begin to accrete significant volumes of gas only when the core reaches a critical mass of $\sim 10M_{\oplus}$ [42]. Besides finding that mini-Neptunes can form from pebbles at 20 AU as described above, Venturini et al. [40] also find that mini-Neptunes can form from km-sized planetesimals closer in at 5 AU in 83% of systems. Mini-Neptunes should be able to develop readily in several places with these two forms of accreted material for a variety of atmospheric features.

1.6 Gas Giant

James Blish, a science fiction writer, created the phrase "gas giant" in 1952, and it was initially used to apply to all massive planets. Gas Giants are exoplanets that are largely made up of hydrogen and helium.

1.6.1 Discovery

Jupiter and Saturn are the Gas Giants first discovered by man. People knew about Jupiter and Saturn since ancient times, but the first proper observation was made by Galileo using his telescope.

1.6.2 Characteristics

Jupiter and Saturn are essentially enormous hydrogen and helium spheres with minor additions from heavier elements and complicated molecules. Many known exoplanets have similar mass and radius to our gas giants, and they most likely have similar bulk structures. The atmosphere of such an object is a thin outer area defined as the region above the radiative-convective boundary, which can be on the scale of kilobars for the most heavily irradiated planets and occurs in the neighbourhood of ~ 1 kbar in gas giants. One of the most important structural issues for many of the known gas-giant planets is whether or not they have cores in their centres [49]. The pressure on these planets is so strong that stuff is not in gaseous form for the majority of their volume. Except for the top layers of the atmosphere, all stuff is most likely past the critical point, when there is no distinction between liquids and gases. A more realistic phrase would be "fluid planet". Jupiter possesses metallic hydrogen at its core, but the majority of its volume is made up of hydrogen, helium, and traces of other gases above their critical points. At less than unit optical depth, the observed atmospheres of all three planets are relatively thin compared to their radii, stretching just around one percent of the way to the core. As a result, the visible sections are gaseous.

1.6.3 Formation and Migration Theories

The presence or lack of cores is of relevance because it impacts the formation mechanism of planets, whether through the process of accreting gas or gravitational instability of the protoplanetary gas disc [49]. Gas giants may form in the gas-rich debris disc that surrounds a newborn star. A seed is provided by a core formed by collisions between asteroids and comets, and when this core reaches a sufficient mass, its gravitational attraction rapidly draws gas from the disc to create the planet. At disc radii, $r > 100$ AU, gas giant planets are expected to form in situ due to disc instability, although core accretion with gas capture remains the dominating formation mode for $r > 100$ AU. Mass loading during the mass accretion phase can push discs toward fragmentation conditions at large r. Massive, stretched discs can break up into clusters ranging in size from a few to tens of Jupiter masses.

1.6.4 Subtypes

In theory, gas giants may be classified into five separate groups based on their predicted physical atmospheric features, and hence their appearance: ammonia clouds (I), water clouds (II), cloudless (III), alkali-metal clouds (IV), and silicate clouds (V). Jupiter and Saturn are both classes I. Hot Jupiters are class IV or V.

1.7 Super-Jupiter

A super-Jupiter is a gas giant exoplanet that is larger than Jupiter.

1.7.1 Discovery

There were 180 known super-Jupiters by 2011, some hot and others cold [50].

1.7.2 Characteristics

Size Despite being more massive than Jupiter, they stay around the same size as Jupiter, up to 80 Jupiter masses. This means that their surface gravity and density increase in direct proportion to their mass. Because of gravity, the increasing mass compresses the planet, preventing it from growing larger.[50]. Because of their greater gravity and hence greater gravitational contraction, several of these planets are smaller than Jupiter. Gravitational contraction happens when the planet's powerful gravity drags its surface inwards, shrinking it. Super-Jupiters have radii of 1.5 to $2R_J$ after formation, depending on their mass, with more massive super-Jupiters having bigger radii. More massive super-Jupiters have smaller radii than lower mass super-Jupiters about five billion years after their creation, since more massive planets shrink quicker than lower-mass planets, intensifying their gravity and causing them to shrink even faster. About two-fifths of all super-Jupiters are smaller than Jupiter, while others are the same size or slightly bigger. However, some lower mass hot super-Jupiters are significantly larger due to bloating of the outer layers of gas caused by the star's heat. The gravity of super-Jupiters compresses gases to the point that some of them are denser than Earth, the densest planet in our solar system. Some high mass super-Jupiters have densities approaching 20 g/cm^3, making them roughly four times denser than Earth [6].

Interior

Super-Jupiters have no solid surface and are gaseous, yet they contain rock/iron cores surrounded by three layers of the mantle. Because of their heavier gravity and higher densities, super-Jupiters have internal pressures that are even greater than Jupiter's. In the top mantle or lower atmosphere, there is a supercritical fluid (gas and liquid phases combined) hydrogen-helium mixture, liquid metallic H-He in the intermediate mantle, and solid metallic H-He in the lower mantle. As we go deeper, pressure increases, thus the lower mantle exerts more pressure than the upper mantle, which is why the hydrogen-helium combination becomes more compact and metallic as we go deeper [6].

Thermodynamics and storms

Due to their greater gravity, these planets tend to produce more heat from their interiors than Jupiter. More heat equals more activity! As a result, super-Jupiters have more severe storms and stronger winds than Jupiter. Over millions of years, storms get more ferocious and wind becomes stronger as planets continue to generate more heat due to increased gravitational contraction induced by planet shrinking [6].

1.7.3 Occurrence Rates

It is believed that our galaxy has 46 billion super-Jupiters, making it the least abundant mass class of planets. This means that 56% of our galaxy's 820 billion planets are super Jupiters [6].

1.7.4 Formation and Migration Theories

These planets may form from two different avenues, namely the standard core accretion scenario, and giant impacts between massive planets or planet embryos. This latter process is likely to yield very metal-enriched and thus very dense massive planets, with a finite eccentricity, as a result of planet scattering [51].

2. On the Basis of Mass, Composition, and Orbit

2.1 Hot Super-Earth

A class of rocky exoplanets is found to have significantly high apparent temperatures due to their close-in orbits. They are termed, "Hot super-Earths".

2.1.1 Characteristics

Their masses and/or radii are similar to terrestrial planets, making them rocky. As a result of their very close-in orbits, the apparent temperature of these planets is so high, that their rocky surfaces should melt or even vaporize in such conditions, at least on their tidally locked side. Hence, it is clear that they have prominent temperature variations between their tidally-locked side and night side [52].

2.1.2 Hot Super-Earth Desert

Within the 2.2 - 3.5 $R_\oplus$ range, and incident fluxes, $F > 650\ F_\oplus$, a complete lack of exoplanets is observed. This region is termed the "Hot-Super-Earth desert". It is found that planets in this radii range are volatile-rich. Hence, if their orbits are too close, theoretically these planets lose their envelopes due to photoevaporation. This could explain the scarcity of these Hot-Super-Earths [53].

2.2 Hot Neptune

A hot Neptune, sometimes known as a Hoptune, is a kind of giant planet with a mass equivalent to Uranus or Neptune that orbits near to its star, usually within less than one AU.

2.2.1 Discovery

Gliese 436 b, an exoplanet around 33 light-years away, was the first hot Neptune found with confidence in 2007. With an orbital period of 19 hours and an atmospheric temperature of over 1700 degrees Celsius, LTT 9779 b is the first ultra-hot Neptune identified. Because it is so near to its star and has a mass roughly twice that of Neptune, its atmosphere should have dissipated into space, necessitating an extraordinary explanation [54] [55]. In 2021, a candidate planet somewhat larger than Neptune was discovered around Vega. It circles Vega, an A-class star, every 2.43 days and, if verified, would be the second-hottest 13 planet in the record, with a temperature of almost 2500 degrees Celsius [56].

2.2.2 Characteristics

Because of their closeness to their parent stars, hot Neptunes transit their star at a considerably faster pace and have a far greater likelihood of doing so than planets of the same mass in broader orbits. This enhances the likelihood that they will be discovered using transit-based observation approaches.

2.2.3 Occurrence Rates

Morton & Johnson [57] claimed that more than 90% of Kepler planetary candidates are very likely real planets. Based on this fiducial lower limit, Howard et al. [58] performed detailed statistical studies on the Kepler planetary candidates. After corrections for the alignment probability, these authors derived an occurrence rate of 13 ± 1% for planets with radius $2 \leq R_p \leq 4R_\oplus$, orbiting G and K dwarfs in $P < 50$ days. Bonomo et. al. considered planets with $2 \leq R_p \leq 4R_\oplus$ and $1.2 \leq P \leq 17.0$ days and choose the same bins of planetary radius and orbital period as Howard et al. Integrating between 1.2 and 17.0 days, they got an occurrence rate of 5.5 ± 0.5% [59]. For orbital period $P > 10$ days, the planet frequency $\frac{dNp}{(d\ \log P\ )}$ for "Neptune-size" planets ($R_p = 4{-}8R_\oplus$) increases with the period as $\propto P^{0.7\pm0.1}$. Within an orbital period of 250 days, the occurrence rate of Neptune-Like planets was found to be 7 % [60].

2.2.4 Formation Theories

In 2004, the first theoretical investigation of how Hot Neptunes may develop was conducted [61]. If Hot Neptunes originated ex-situ, that is, by migrating to their current positions while developing, they might have a lot of frozen volatile substances and amorphous ices. Otherwise, if they originated in situ, their heavy element inventory should be constituted of refractory materials [30]. Regardless of how they formed, Neptune-Like planets should have substantial proportions (by mass) of gases, notably hydrogen and helium, which also make up the majority of their volume [62] [63]. Standard disk models show that at the distances where Hot Neptunes have been found [64] [65], the temperature is 600 – 2000 K (depending on the stellar type). Although the presence of solid material cannot be counted out at these distances, the temperature is too high to anticipate a significant amount of it to form huge solid cores. More probable, huge planets like this develop at far greater distances from the star, then move inwards. Theory and numerical simulations have demonstrated that developing protoplanets can suffer orbital migration, moving a long distance from their birth location [66] [67] [68] [69]. Planetary migration is a natural result of the nebula's tidal interaction. For protoplanets, the most likely form of migration is inward in a quasicircular orbit [68] [69] [70] [71]. The stellar magnetosphere and tidal interaction with the star prevent the planets from collapsing onto the star.

2.3 Cold Neptune or Ice-Giant

These planets are mostly made up of heavier elements than hydrogen and helium, such as oxygen, carbon, nitrogen, and sulphur. The word “ices” in astrophysics and planetary science refers to volatile chemical substances with freezing points above around 100 K, such as water, ammonia, or methane, which have freezing values of 273 K (0°C), 195 K (-78°C), and 91 K (-182°C), respectively.

2.3.1 Discovery

Astronomers found Neptune, the eighth planet circling the Sun, during the night of September 23-24, 1846 [72]. The finding was obtained based on mathematical estimates of its expected position as a result of observed deviations in Uranus’ orbit. Beyond the snow line, which is the distance from a star beyond which water remains frozen during planetary formation, cold Neptune mass worlds are anticipated to be the most frequent type of planet. The snow line in our solar system is roughly 2.7 times Earth’s distance from the Sun, putting it in the centre of our solar system’s main asteroid belt [73]. Uranus was the first ice giant discovered in 1781 by William Herschel.

2.3.2 Characteristics

They have no solid surfaces and are largely made up of gases and liquids. The ice giants are mostly made up of heavier elements other than hydrogen and helium. Based on the number of elements in the cosmos, the most likely elements are oxygen, carbon, nitrogen, and sulphur. Although ice giants have hydrogen envelopes, they are substantially smaller in size. They make up less than 20% of their total mass. Their hydrogen also never reaches the depths required for the pressure required to produce metallic hydrogen. These envelopes, however, limited view of the interiors of the ice giants, and hence information on their composition and development. Because of their vast diameters and limited thermal conductivities, planetary interior pressures and temperatures can reach several hundred GPa and several thousand kelvins (K).

2.3.3 Formation Theories

Core Accretion

Because they lack huge gaseous envelopes, ice giant planets are less bound by protoplanetary disc life periods. Ward et al., [74], have also investigated the formation of ice giant planets in situ by embryo migration to the inner protoplanetary disc limit. Because collision time scales grow with increasing distance and therefore orbital period, the accumulation process in the outer solar nebula is considerably slower than in the zone of gas giant planets. Furthermore, the decreased surface density of solids inhibits development even further. The embryos have eccentric orbits owing to reciprocal contacts; hence ice giant planets cannot develop in the classic core accretion model [75].

Disk Instability

Extreme ultraviolet radiation (EUV) from big stars may photoevaporate the gas beyond a radius of roughly 10 AU in protoplanetary discs in timeframes as brief as $\sim 10^5$ yr [76] in areas of high-mass star formation. Once the disc gas is removed, the outermost protoplanets are exposed to EUV radiation and assuming they do not contract to planetary densities in less than $\sim 10^6$ yr [77], their gaseous envelopes will be photoevaporated, leaving behind the cores formed by sedimentation and coagulation of their dust grains. EUV photo evaporation of most of the gaseous envelopes of the outermost three protoplanets may leave behind cores with partial gaseous envelopes, resulting in planets with structures similar to Uranus and Neptune [78].

2.4 Hot Jupiter

Hot Jupiters are a kind of gas giant exoplanet thought to be physically similar to Jupiter but with extremely short orbital periods of less than 10 days.

2.4.1 Discovery

The study of these planets traces back to almost the commencement of exoplanet studies (in the 1990s), with the discovery of 51 Peg b, a Jupiter-mass planet by Mayor and Queloz using the radial velocity method [79]. 51 Peg b is 10 times closer to its star than Mercury is to the sun. This discovery called for the revision of planet formation theories, as all the theories until then are derived akin to our solar system model. This also led the scientific community to venture into the study of exoplanets with profound interest [80]. 51 Peg b stunned the world, because of its unusually low orbital period. But very soon, many such worlds were discovered, paving the way for the study of 'Hot Jupiters'. Hot Jupiter detections continuously increased with the detection of planet HD 209458b five years after the discovery of 51 Peg b, by transit method [79]. It takes several decades to observe multiple orbits of Jupiter analog planets using the radial velocity method, on the contrary, Hot Jupiter orbits were observed multiple times within weeks [80].

2.4.2 Characteristics

Gas giant planets like our very own Jupiter and Saturn, but with an orbital period of only a few days are known as 'Hot Jupiters' [79]. Hot Jupiters are Gas giants with masses greater than or equal to 0.25 M_J (0.83 Saturn masses) and orbital periods shorter than 10 days [80].

2.4.3 Occurrence Rates

Upon analyzing the transit and radial velocity surveys, it is found that one in a hundred Sun-like stars harbors a Hot Jupiter planet [79]. In other words, Hot Jupiter is harbored by only 1% of Sun-like stars. Also, their occurrence rate surprisingly drops off around the most abundant star class in the galaxy, M Dwarfs [80].

2.4.4 Formation Theories

In-situ formation

In-situ formation of close-in giant planets is only possible via either Core accretion or Gravitational instability. The core accretion hypothesis states that when a solid core of $\sim 10\ M_\oplus$accretes gas from the nebula giant, planets are formed. Complications associated with Hot Jupiter formations via core accretion are related to core formation, not in the accretion process [80]. The formation of such large cores near the stars has many complications, which are stated as follows:

1. Limited solid availability due to the reduced size of the feeding zones.
2. Disk forbids the merger of numerous smaller cores.
3. At comparatively very lower mass, the radial accretion of pebbles slows down.

Gas conditions are not satisfied closer to the star, to enable formation by gravitational instability [79].

Disk migration

The conditions at farther distances from the host star are more feasible for core accretion and/ or gravitational instability. This may enable the formation of Hot Jupiters at such farther distances [79]. The orbits of these planets eventually reduce from several AU away to hundredths of an AU, making them very close to their stars, as a result of the gaseous protoplanetary disks' torques [80].

High-eccentricity migration

Hot Jupiters may be subjected to inward migrations from their highly elliptical orbits via tidal dissipation, as soon as their gas disk is lost [79]. A perturbing body disrupts the orbit of a Cold Jupiter, resulting in the planet following a highly elliptical orbit. This causes the planet to lose its orbital angular momentum by a factor of ten, which is done by the perturbing body. Next, as a result of planet-star interaction, the orbital energy of Jupiter is tidally dissipated. The orbit is eventually circularized and closed-in by the angular momentum conservation, yielding a "Hot Jupiter" [80].

2.5 Cold Jupiter

Gas-Giants in more distant orbits beyond the snowline are known as Cold Jupiters.

2.5.1 Characteristics

If the orbital distances of giant planets with mass > $0.3M_J$, is farther than 1 AU, they are termed as "Cold Jupiters" [81] [82].

2.5.2 Occurrence Rate

Cold Jupiters ($\gtrsim$ 1 AU), are found to be the most commanding population, being present in around 10% of Sun-like stars [81]. It is found recently that though distant orbit Cold Jupiters are more frequent than close orbit giant planets, they are not as readily detected as giant planets found in orbits close to their stars [83]. It is found that systems harboring Super-Earths also harbor Cold Jupiters three times more than that of Cold Jupiters around other star systems. It means almost 90% of the time, they are tagged along with Super-Earths [81].

2.5.3 Formation Theory

Cold Jupiters are formed in the distant regions, where their cores are gradually formed from planetesimals via accretion. Eventually, after attaining the critical core mass, they become enveloped by gases via runaway gas accretion [81].

3 On the Basis of Mass and Size

3.1 Super-Puff or Cotton-Candy

A super-puff is a form of an exoplanet with a mass just a few times that of Earth but a radius bigger than that of Neptune, giving it an extremely low mean density. They are less substantial and colder than the expanded low-density Hot-Jupiters [84].

3.1.1 Discovery

The individual transit timing variation analyses of Kepler-51b, done by various groups over the years when integrated, showed a mass of just $\sim 2.1\ M_\oplus$, but the transit radii of $\sim 7R_\oplus$, making it a solid Super-Puff. A list of all the Super-Puffs discovered so far is Kepler 51 c, 51d; Kepler 79d, 79e [85].

3.1.2 Characteristics

As the term 'Super-Puffs' clearly states, these planets, despite looking like giants, have extremely low densities. As defined above, this class of planets has radii equivalent to that of gas giants ($\gtrsim 5\ R_\oplus$), and masses similar to Sub-Neptunes ($\lesssim 5\ M_\oplus$). As a result, they have remarkably low mean densities (10^{-1} gcm^{-3}) and higher scale heights (~ 3000 km). These planets also lack strong surface gravity, as an effect of their unusually low densities. Super-Puffs are supposed to undergo superabundant mass loss when photoevaporation happens, even if there is a lack of stellar radiation for photoevaporation to occur their atmospheres should fade off, within thousand years. But the Kepler 51 system is found to be much older than this. In the near-infrared region, Kepler-51b and 51d indicated the flat transmission spectra, or in other terms, no evident spectral line is observed, when observed using the Hubble Space Telescope WFC3. Though it is possible to justify the flat spectra with the presence of cloud or haze, it is merely impossible for current models to support the existence of cloud/haze at such high altitudes. So, Wang and Dei's model for the Kepler-51b proposes a slow hydrodynamic outflow, carrying dust to higher altitudes, resulting in the transit radii as large as $\sim 7R_\oplus$, when observed. This outflow also erases the trace of all the other atmospheric species [85].

3.1.3 Formation and Migration Theories

According to one theory, a super-puff has continual outflows of dust to the top of its atmosphere, therefore the visible surface is dust at the top of the atmosphere. Another theory is that some of the super-puff worlds are smaller planets with massive ring systems [84].

4 On the Basis of Composition

4.1 Hycean World

Hycean is derived from the terms hydrogen and ocean. Hycean worlds are planets that are covered with oceans and have hydrogen-rich atmospheres.

4.1.1 Discovery

K2-18b, a planet considered to be potentially habitable, inspired the study by Madhusudhan et. al. [86], and is now deemed to be a potential Hycean world by the same study.

4.1.2 Characteristics

A recently identified habitable planetary class is composed of water-rich interiors and massive oceans, followed by a Hydrogen-dominant atmosphere. This planetary class is named"Hycean" worlds, to signify their hydrogen and ocean dominance. Lying between rocky Super-Earths and comparatively extensive mini-Neptunes in the density scale and terms of the interior structure, these planets are prime candidates for habitability search. Based on the habitable conditions mentioned by Madhusudhan et. al., [86], for a planetary mass of 10 $M_\oplus$ these planets can have the radii as large as $2.6R_\oplus$ and still, be habitable. They can also possess a maximum equilibrium temperature of $\sim$ 500 K. These results are obtained, based on the assumption that these planets have a rocky Earth-like core, which contributes to at least 10% of their total mass. Unlike Earth-like planets, Hycean planets permit a considerably far-ranging habitable zone.

5 On the Basis of Size

5.1 Mesoplanet

Mesoplanets are objects of planetary mass that are smaller than Mercury, but larger than Ceres. Isaac Asimov invented the phrase. Mesoplanets should have a radius of 500 km to 2,500 km if the size is defined in proportion to the equatorial radius.

CONCLUSION

The primary objective of our paper was to review the different characteristics of exoplanets. We aimed to specify and differentiate various types of exoplanets based on certain parameters. A thorough study of the characterization of exoplanets plays a crucial role in providing the glimpses of formation, evolution, and habitability of these planets and related planetary systems. We also had a comprehensive study on the formation theories and occurrence rates of various types of exoplanets and find that the evolution of most exoplanets starts from the formation of a protoplanetary disc and the gravitation, gas accretion, and other phenomena escalate the further evolutionary processes. In a few cases, these characteristics create a significant distinction between various exoplanets just like masses of sub-Earths, terrestrial planets, gas giants, and super-Earths are greatly different and we can easily identify these planets based on their masses. However, in many instances, these characteristics of different exoplanets may overlap with each other just like a lot of super-Earths and hot Jupiters may have the same range of orbital radius and orbital periods. It is still very difficult to standardize the characteristics of an exoplanet based on these parameters as various characteristics of different exoplanets highly overlap with each other. More observational campaigns and studies are required to make these overlapped zones thinner.

REFERENCES

[1] A. P. Boss, G. Basri, S. S. Kumar, J. Liebert, E. L. Martın, B. Reipurth, and H. Zinnecker, “Nomenclature: brown dwarfs, gas giant planets, and?”, in Symposium-international astronomical union, Vol. 211 (Cambridge University Press, 2003), pp. 529–537.
[2] J.-L. Margot, “A quantitative criterion for defining planets”, The Astronomical Journal 150, 185 (2015).
[3] G. Chabrier, A. Johansen, M. Janson, and R. Rafikov, “Giant planet and brown dwarf formation”, arXiv preprint arXiv:1401.7559 (2014).
[4] D. S. Spiegel, A. Burrows, and J. A. Milsom, “The deuterium-burning mass limit for brown dwarfs and giant planets”, The Astrophysical Journal 727, 57 (2011).
[5] E. Sinukoff, B. Fulton, L. Scuderi, and E. Gaidos, “Below one earth: the detection, formation, and properties of subterrestrial worlds”, Space Science Reviews 180, 71–99 (2013).
[6] Planetstar fandom.

[7] S. Rappaport, B. Gary, T. Kaye, A. Vanderburg, B. Croll, P. Benni, and J. Foote, "Drifting asteroid fragments around wd 1145+ 017", Monthly Notices of the Royal Astronomical Society 458, 3904–3917 (2016).
[8] Nasa exoplanet archive.
[9] G. M. Kennedy and S. J. Kenyon, "Planet formation around stars of various masses: the snow line and the frequency of giant planets", The Astrophysical Journal 673, 502 (2008).
[10] Terrestrial, Apr. 2022.
[11] S. Bryson, M. Kunimoto, R. K. Kopparapu, J. L. Coughlin, W. J. Borucki, D. Koch, V. S. Aguirre, C. Allen, G. Barentsen, N. M. Batalha, et al., "The occurrence of rocky habitable-zone planets around solar-like stars from kepler data", The Astronomical Journal 161, 36 (2020).
[12] W. A. Traub, "Terrestrial, habitable-zone exoplanet frequency from kepler", The Astrophysical Journal 745, 20 (2011).
[13] E. A. Petigura, A. W. Howard, and G. W. Marcy, "Prevalence of earth-size planets orbiting sunlike stars", Proceedings of the National Academy of Sciences 110, 19273–19278 (2013).
[14] S. N. Raymond, "Terrestrial planet formation in extra-solar planetary systems", Proceedings of the International Astronomical Union 3, 233– 250 (2007).
[15] Scientists model a cornucopia of earth-sized planets, Apr. 2007.
[16] S. A. Hauck and C. L. Johnson, "Mercury: inside the iron planet", Elements: An International Magazine of Mineralogy, Geochemistry, and Petrology 15, 21–26 (2019).
[17] H. E. Schlichting, "Formation of super-earths", arXiv preprint arXiv:1802.03090 (2018).
[18] B. Bitsch, "Inner rocky super-earth formation: distinguishing the formation pathways in viscously heated and passive discs", Astronomy & Astrophysics 630, A51 (2019).
[19] E. J. Rivera, J. J. Lissauer, R. P. Butler, G. W. Marcy, S. S. Vogt, D. A. Fischer, T. M. Brown, G. Laughlin, and G. W. Henry, "A˜ 7.5 m planet orbiting the nearby star, gj 876", The Astrophysical Journal 634, 625 (2005).
[20] N. Haghighipour, "Super-earths: a new class of planetary bodies", Contemporary Physics 52, 403–438 (2011).
[21] Super-earths.
[22] B. Liu and J. Ji, "A tale of planet formation: from dust to planets", Research in Astronomy and Astrophysics 20, 164 (2020).
[23] S. J. Kenyon and B. C. Bromley, "Formation of super-earth mass planets at 125–250 au from a solar-type star", The Astrophysical Journal 806, 42 (2015).
[24] R. G. Martin and M. Livio, "On the formation of super-earths with implications for the solar system", The Astrophysical Journal 822, 90 (2016).
[25] C. Mordasini, Y. Alibert, C. Georgy, K.-M. Dittkrist, H. Klahr, and T. Henning, "Characterization of exoplanets from their formation-ii. the planetary mass-radius relationship", Astronomy & Astrophysics 547, A112 (2012).
[26] V. Rajpaul, L. A. Buchhave, and S. Aigrain, "Pinning down the mass of kepler-10c: the importance of sampling and model comparison", Monthly Notices of the Royal Astronomical Society: Letters 471, L125–L130 (2017).
[27] P. Fut´o, "Bd+ 20594b: a mega-earth detected in the c4 field of the kepler k2 mission", in 48th annual lunar and planetary science conference, 1964 (2017), p. 1078.
[28] S. Seager, M. Kuchner, C. Hier-Majumder, and B. Militzer, "Mass-radius relationships for solid exoplanets", The Astrophysical Journal 669, 1279 (2007).
[29] J. Wang and D. Fischer, "Revealing a universal planet–metallicity correlation for planets of different sizes around solar-type stars", The Astronomical Journal 149, 14 (2014).
[30] G. D'Angelo and P. Bodenheimer, "In situ and ex situ formation models of kepler 11 planets", The Astrophysical Journal 828, 33 (2016).
[31] E. De Mooij, M. Brogi, R. de Kok, J. Koppenhoefer, S. Nefs, I. Snellen, J. Greiner, J. Hanse, R. Heinsbroek, C. Lee, et al., "Optical to nearinfrared transit observations of super-earth gj 1214b: water-world or mini-neptune?", Astronomy & Astrophysics 538, A46 (2012).
[32] D. C. Fabrycky, J. J. Lissauer, D. Ragozzine, J. F. Rowe, J. H. Steffen, E. Agol, T. Barclay, N. Batalha, W. Borucki, D. R. Ciardi, et al., "Architecture of kepler's multi-transiting systems. ii. new investigations with twice as many candidates", The Astrophysical Journal 790, 146 (2014).
[33] G. D'Angelo and P. Bodenheimer, "Three-dimensional radiation-hydrodynamics calculations of the envelopes of young planets embedded in protoplanetary disks", The Astrophysical Journal 778, 77 (2013).
[34] G. W. Marcy, H. Isaacson, A. W. Howard, J. F. Rowe, J. M. Jenkins, S. T. Bryson, D. W. Latham, S. B. Howell, T. N. Gautier, N. M. Batalha, et al., "Masses, radii, and orbits of small kepler planets: the transition from gaseous to rocky planets", The Astrophysical Journal Supplement Series 210, 20 (2014).
[35] G. W. Marcy, L. M. Weiss, E. A. Petigura, H. Isaacson, A. W. Howard, and L. A. Buchhave, "Occurrence and core-envelope structure of 1– 4× earth-size planets around sun-like stars", Proceedings of the National Academy of Sciences

111, 12655–12660 (2014).
[36] L. M. Weiss and G. W. Marcy, “The mass– radius relation for 65 exoplanets smaller than 4 earth radii”, The Astrophysical Journal Letters 783, L6 (2014).
[37] L. A. Rogers, “Most 1.6 earth-radius planets are not rocky”, The Astrophysical Journal 801, 41 (2015).
[38] C. D. Dressing, D. Charbonneau, X. Dumusque, S. Gettel, F. Pepe, A. C. Cameron, D. W. Latham, E. Molinari, S. Udry, L. Affer, et al., “The mass of kepler-93b and the composition of terrestrial planets”, The Astrophysical Journal 800, 135 (2015).
[39] B. J. Fulton, E. A. Petigura, A. W. Howard, H. Isaacson, G. W. Marcy, P. A. Cargile, L. Hebb, L. M. Weiss, J. A. Johnson, T. D. Morton, et al., “The california-kepler survey. iii. a gap in the radius distribution of small planets”, The Astronomical Journal 154, 109 (2017).
[40] J. Venturini and R. Helled, “The formation of mini-neptunes”, The Astrophysical Journal 848, 95 (2017).
[41] P. Bodenheimer and J. B. Pollack, “Calculations of the accretion and evolution of giant planets: the effects of solid cores”, Icarus 67, 391–408 (1986).
[42] J. B. Pollack, O. Hubickyj, P. Bodenheimer, J. J. Lissauer, M. Podolak, and Y. Greenzweig, “Formation of the giant planets by concurrent accretion of solids and gas”, icarus 124, 62–85 (1996).
[43] Y. Alibert, C. Mordasini, W. Benz, and C. Winisdoerffer, “Models of giant planet formation with migration and disc evolution”, Astronomy & Astrophysics 434, 343–353 (2005).
[44] Y. Alibert, F. Carron, A. Fortier, S. Pfyffer, W. Benz, C. Mordasini, and D. Swoboda, “Theoretical models of planetary system formation: mass vs. semi-major axis”, Astronomy & Astrophysics 558, A109 (2013).
[45] H. Tanaka and S. Ida, “Growth of a migrating protoplanet”, Icarus 139, 350–366 (1999).
[46] M. Lambrechts and A. Johansen, “Rapid growth of gas-giant cores by pebble accretion”, Astronomy & Astrophysics 544, A32 (2012).
[47] M. Lambrechts, A. Johansen, and A. Morbidelli, “Separating gas-giant and ice-giant planets by halting pebble accretion”, Astronomy & Astrophysics 572, A35 (2014).
[48] E. J. Lee and E. Chiang, “Breeding super-earths and birthing super-puffs in transitional disks”, The Astrophysical Journal 817, 90 (2016).
[49] D. S. Spiegel, J. J. Fortney, and C. Sotin, “Structure of exoplanets”, Proceedings of the National Academy of Sciences 111, 12622–12627 (2014).
[50] C. R. Kitchin, Exoplanets: finding, exploring, and understanding alien worlds (Springer Science & Business Media, 2011).
[51] I. Baraffe, G. Chabrier, and T. Barman, “Structure and evolution of super-earth to super-jupiter exoplanets-i. heavy element enrichment in the interior”, Astronomy & Astrophysics 482, 315– 332 (2008).
[52] J. Tennyson and S. N. Yurchenko, “Laboratory spectra of hot molecules: data needs for hot super-earth exoplanets”, Molecular Astrophysics 8, 1–18 (2017).
[53] M. Lundkvist, H. Kjeldsen, S. Albrecht, G. Davies, S. Basu, D. Huber, A. B. Justesen, C. Karoff, V. Silva Aguirre, V. Van Eylen, et al., “Hot super-earths stripped by their host stars”, Nature Communications 7, 1–8 (2016).
[54] P. Thorley, The first ultra-hot neptune, ltt 9779b, is one of nature’s improbable planets, Sept. 2020.
[55] J. S. Jenkins, M. R. Dıaz, N. T. Kurtovic, N. Espinoza, J. I. Vines, P. A. P. Rojas, R. Brahm, P. Torres, P. Cort´es-Zuleta, M. G. Soto, E. D. Lopez, G. W. King, P. J. Wheatley, J. N. Winn, D. R. Ciardi, G. Ricker, R. Vanderspek, D. W. Latham, S. Seager, J. M. Jenkins, C. A. Beichman, A. Bieryla, C. J. Burke, J. L. Christiansen, C. E. Henze, T. C. Klaus, S. McCauliff, M. Mori, N. Narita, T. Nishiumi, M. Tamura, J. P. de Leon, S. N. Quinn, J. N. Villase˜nor, M. Vezie, J. J. Lissauer, K. A. Collins, K. I. Collins, G. Isopi, F. Mallia, A. Ercolino, C. Petrovich, A. Jord´an, J. S. Acton, D. J. Armstrong, D. Bayliss, F. Bouchy, C. Belardi, E. M. Bryant, M. R. Burleigh, J. Cabrera, S. L. Casewell, A. Chaushev, B. F. Cooke, P. Eigm¨uller, A. Erikson, E. Foxell, B. T. G¨ansicke, S. Gill, E. Gillen, M. N. G¨unther, M. R. Goad, M. J. Hooton, J. A. G. Jackman, T. Louden, J. McCormac, M. Moyano, L. D. Nielsen, D. Pollacco, D. Queloz, H. Rauer, L. Raynard, A. M. S. Smith, R. H. Tilbrook, R. Titz-Weider, O. Turner, S. Udry, S. R. Walker, C. A. Watson, R. G. West, E. Palle, C. Ziegler, N. Law, and A. W. Mann, “An ultrahot Neptune in the Neptune desert”, Nature Astronomy 4, 1148–1157 (2020).
[56] S. A. Hurt, S. N. Quinn, D. W. Latham, A. Vanderburg, G. A. Esquerdo, M. L. Calkins, P. Berlind, R. Angus, C. A. Latham, and G. Zhou, “A decade of radial-velocity monitoring of vega and new limits on the presence of planets”, The Astronomical Journal 161, 157 (2021).
[57] T. D. Morton and J. A. Johnson, “On the low false positive probabilities of kepler planet candidates”, The Astrophysical Journal 738, 170 (2011).
[58] A. W. Howard, G. W. Marcy, S. T. Bryson, J. M. Jenkins, J. F. Rowe, N. M. Batalha, W. J. Borucki, D. G. Koch, E. W. Dunham, T. N. Gautier, et al., “Planet occurrence within 0.25 au of solar-type stars from kepler”, The Astrophysical Journal Supplement Series 201, 15 (2012).
[59] A. S. Bonomo, P.-Y. Chabaud, M. Deleuil, C. Moutou, F. Bouchy, J. Cabrera, A. F. Lanza, T. Mazeh, S. Aigrain, R.

Alonso, et al., "Detection of neptune-size planetary candidates with corot data-comparison with the planet occurrence rate derived from kepler", Astronomy & Astrophysics 547, A110 (2012).
[60] S. Dong and Z. Zhu, "Fast rise of "neptunesize" planets (4–8 r) from p 10 to 250 days—statistics of kepler planet candidates up to 0.75 au", The Astrophysical Journal 778, 53 (2013).
[61] A. Brunini and R. G. Cionco, "The origin and nature of neptune-like planets orbiting close to solar type stars", Icarus 177, 264–268 (2005).
[62] G. D'Angelo, R. H. Durisen, and J. J. Lissauer, "Giant planet formation", Exoplanets, 319–346 (2010).
[63] G. D'Angelo and J. J. Lissauer, "Formation of giant planets", arXiv preprint arXiv:1806.05649 (2018).
[64] R. P. Butler, S. S. Vogt, G. W. Marcy, D. A. Fischer, J. T. Wright, G. W. Henry, G. Laughlin, and J. J. Lissauer, "A neptune-mass planet orbiting the nearby m dwarf gj 436", The Astrophysical Journal 617, 580 (2004).
[65] B. E. McArthur, M. Endl, W. D. Cochran, G. F. Benedict, D. A. Fischer, G. W. Marcy, R. P. Butler, D. Naef, M. Mayor, D. Queloz, et al., "Detection of a neptune-mass planet in the ρ1 cancri system using the hobby-eberly telescope", The Astrophysical Journal 614, L81 (2004).
[66] P. Goldreich and S. Tremaine, "Disk-satellite interactions", Astrophysical Journal 241, 425– 441 (1980).
[67] D. N. Lin and J. Papaloizou, "On the tidal interaction between protoplanets and the protoplanetary disk. iii-orbital migration of protoplanets", The Astrophysical Journal 309, 846– 857 (1986).
[68] W. R. Ward, "Density waves in the solar nebula: diffential lindblad torque", icarus 67, 164– 180 (1986).
[69] W. R. Ward, "Protoplanet migration by nebula tides", Icarus 126, 261–281 (1997).
[70] H. Tanaka, T. Takeuchi, and W. R. Ward, "Threedimensional interaction between a planet and an isothermal gaseous disk. i. corotation and lindblad torques and planet migration", The Astrophysical Journal 565, 1257 (2002).
[71] H. Tanaka and W. R. Ward, "Three-dimensional interaction between a planet and an isothermal gaseous disk. ii. eccentricity waves and bending waves", The Astrophysical Journal 602, 388 (2004).
[72] Discovery of neptune, Apr. 2022.
[73] D. Suzuki, D. Bennett, T. Sumi, I. Bond, L. Rogers, F. Abe, Y. Asakura, A. Bhattacharya, M. Donachie, M. Freeman, et al., "The exoplanet mass-ratio function from the moa-ii survey: discovery of a break and likely peak at a neptune mass", The Astrophysical Journal 833, 145 (2016).
[74] W. R. Ward, "Survival of planetary systems", The Astrophysical Journal 482, L211 (1997).
[75] H. F. Levison, L. Dones, C. R. Chapman, S. A. Stern, M. J. Duncan, and K. Zahnle, "Could the lunar "late heavy bombardment" have been triggered by the formation of uranus and neptune?", Icarus 151, 286–306 (2001).
[76] J. Bally, L. Testi, A. Sargent, and J. Carlstrom, "Disk mass limits and lifetimes of externally irradiated young stellar objects embedded in the orion nebula", The Astronomical Journal 116, 854 (1998).
[77] W. M. DeCampli and A. Cameron, "Structure and evolution of isolated giant gaseous protoplanets", Icarus 38, 367–391 (1979).
[78] A. P. Boss, G. W. Wetherill, and N. Haghighipour, "Rapid formation of ice giant planets", Icarus 156, 291–295 (2002).
[79] J. J. Fortney, R. I. Dawson, and T. D. Komacek, "Hot jupiters: origins, structure, atmospheres", Journal of Geophysical Research: Planets 126, e2020JE006629 (2021).
[80] R. I. Dawson and J. A. Johnson, "Origins of hot jupiters", Annual Review of Astronomy and Astrophysics 56, 175–221 (2018).
[81] W. Zhu and Y. Wu, "The super earth–cold jupiter relations", The Astronomical Journal 156, 92 (2018).
[82] K. Masuda, J. N. Winn, and H. Kawahara, "Mutual orbital inclinations between cold jupiters and inner super-earths", The Astronomical Journal 159, 38 (2020).
[83] R. Burn, M. Schlecker, C. Mordasini, A. Emsenhuber, Y. Alibert, T. Henning, H. Klahr, and W. Benz, "The new generation planetary population synthesis (ngpps)-iv. planetary systems around low-mass stars", Astronomy & Astrophysics 656, A72 (2021).
[84] J. E. Libby-Roberts, Z. K. Berta-Thompson, J.-M. D´esert, K. Masuda, C. V. Morley, E. D. Lopez, K. M. Deck, D. Fabrycky, J. J. Fortney, M. R. Line, et al., "The featureless transmission spectra of two super-puff planets", The Astronomical Journal 159, 57 (2020).
[85] L. Wang and F. Dai, "Dusty outflows in planetary atmospheres: understanding "super-puffs" and transmission spectra of sub-neptunes", The Astrophysical Journal Letters 873, L1 (2019).
[86] N. Madhusudhan, A. A. Piette, and S. Constantinou, "Habitability and biosignatures of hycean worlds", The Astrophysical Journal 918, 1 (2021).
[87] Akash Sharma, Ankit Kumar Mishra, "An Investigational Study on Orbital resonance in TOI-700c and TOI-700dexoplanets''. Transactions on Innovations in Science & Technology 5(2), 2021, pp. 306-308.