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The Challenges of Extrasolar Planets

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Abstract

Much has been learned about extrasolar planets in the past 20 years. An overview of the status of the research is presented, addressing exoplanet detection, planet formation and orbit migration, and issues that challenge current theories. Though the observational evidence of extrasolar planets is good in many cases, there are some difficulties in the analysis of the data and limitations of the methods. Extrasolar planetary systems often are very different from our own planetary system. Many known exoplanets are located closer to their stars than Mercury is to the sun. This has prompted development of theories for the migration of planet orbits. Migration theories have challenges in explaining why so many exoplanets have not spiraled into their star and have difficulty explaining exoplanets with orbits that are inclined compared to the equators of their stars. Recent reports from some researchers have expressed concerns that a surprising percentage of transit detections of exoplanets could be due to eclipsing binary stars or brown dwarf stars rather than exoplanets. Another challenge is the large radii of many so-called "hot Jupiters." Known mechanisms may not be adequate to explain the sizes of these planets. Though there is much interest in finding evidence of habitable extrasolar planets, there is still no clear evidence that any exist. The meaning of "habitable zone" is discussed in relation to extrasolar planet research. Extrasolar planets can be understood as being created on the fourth day of the creation week rather than forming from protoplanetary disks.

Introduction

For many years astronomers attempted unsuccessfully to detect evidence of planets orbiting other stars. Then in 1992, an extrasolar planet was found orbiting the pulsar PSR 1257+12 by the use of what is now known as the radial velocity (RV) technique. After some controversy over this discovery, soon there was confirmation of at least two planets orbiting PSR 1257+12 (Wolszczan, 1994), with reason to believe there were more. Since 1992, the technology and methods for detection of extrasolar planets (also known as exoplanets) have improved significantly.

In December 2015, the International Astronomical Union (http://nameexoworlds.iau.org) established

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official names for certain extrasolar planets, including the three planets orbiting PSR 1257+12. The discovery of planets orbiting a pulsar was a major surprise to astronomers. The question of the origin of such a system is still debated today.

There are now significant resources in terms of manpower and equipment that are dedicated to the search for exoplanets. In 2009, the Kepler spacecraft was placed into space in an Earth-trailing orbit. The Kepler spacecraft has dramatically increased the number of possible extrasolar planets known, as well as improved the data available on the objects it observes. Today the NASA exoplanet archive lists 3,373 confirmed exoplanets (NASA, 2016). "Confirmed" indicates that the detection has been confirmed by at least one research team, in addition to the discoverers. Most of these cases are likely to be extrasolar planets, but some are occasionally recategorized as observational errors, brown dwarfs, or other kinds of false positives.

The search for extrasolar planets is strongly motivated by evolutionary ideas and naturalistic assumptions regarding planet formation and the belief that life could evolve on other planets outside our solar system. It is thought that if life evolved on planet Earth, then it could evolve on other planets orbiting other stars, if the exoplanets are habitable. Thus, there is a great interest in finding Earth-like habitable planets orbiting other stars. (In extrasolar planet research, the term "Earth-like" primarily means similar in mass and size.) Statistical estimates based on various observations have been used to gauge the number of exoplanets there could be in in our galaxy. The number of exoplanets in our galaxy (the Milky Way) may be comparable to the number of stars in the galaxy, which implies approximately 100 billion (Clavin, 2012). This is a conservative estimate. The number of exoplanets in our galaxy easily could be double this due to the number of systems with multiple planets. However, this does not mean that life could exist on all these exoplanets.

Prior to the discovery of extrasolar planets 25 years ago, astronomers generally assumed that models of the formation of our own solar system could be used to explain planetary systems that might exist around other stars. But certain key differences were found between our own solar system and the extrasolar planetary systems. First, in many extrasolar systems the planets are so near their stars that the equilibrium temperatures would be too hot for gases to condense onto the planets' cores. Second, exoplanets are not always in "regular" or stable orbits. The orbits of the planets in our system have low eccentricities and low inclinations with respect to one another. Mercury has the most peculiar orbit, with an eccentricity of 0.21, and is tilted seven degrees with respect to the ecliptic, the plane of the earth's orbit. The low eccentricities and inclinations of planets in the solar system make their planet orbits quite stable. But in many exoplanet systems, the orbits are more elliptical than in our system. This makes gravitational interactions possible between planets (if there are multiple planets), and this could lead to the planets altering each other's orbits. Third, many exoplanets orbit so closely to their stars that their spin rates probably are tidally locked, just as our moon is in a tidal lock with Earth. The correct term for this is *synchronous rotation*, which means that the rotation period matches the orbital period. Consequently, this results in one side of an exoplanet always facing the star and the opposite side of an exoplanet always facing away from the star. Fourth, the stars that exoplanets orbit often are not so constant and stable in their energy output as the sun. These characteristics of extrasolar planetary systems have led to changes in planet origins theories. Some of the challenges to planetary science raised by exoplanets have been addressed in new theories, and some challenges are still largely unresolved.

Exoplanet Detection

The detection technique which is applicable to the largest variety of stars is the RV technique (Anderson, 2008; Knutson et al., 2014, Konacki, 2005). This is a spectrographic measurement of the Doppler motion of a star a planet may be orbiting. Due to Newton's third law of motion, the orbit of a planet around a star causes a periodic change in the velocity of the star. This is detected as a component of the star's velocity along Earth's line of sight. If more than one planet is present, there can be more than one superimposed periodic change in the star's radial velocity. As the star's redshift varies, observations over several orbits can sort out these multiple periodicities. It is necessary to rule out other types of variations in the star's light interfering with the measurement.

The RV technique is more effective when the exoplanet is nearer to the star, the exoplanet's mass is greater, or the star's mass is less. The exoplanet's orbit can be determined, assuming there is good data on the star and no complicating observational issues. Thus, the RV technique has a bias toward smaller stars and larger planets. In some systems where the star is more massive and the planet could be small, such a small planet may be more difficult to detect. Finally, if the star is far from Earth, the spectral signal may be weak, and this can limit the method. The RV technique is generally used for relatively nearby stars in our galaxy. Until 2014, there were more discoveries of exoplanets by the RV technique than by any other technique. The RV technique reveals an exoplanet's mass, but not its size (radius).

Since the Kepler telescope spacecraft was deployed in space in 2009, more exoplanets by far have been discovered using the transit photometry technique than any other technique

(Borucki et al., 2009; Steffen et al., 2010). Kepler is not the only instrument that does transit measurements, but it has been the most productive. The Kepler spacecraft has an array of cameras that simultaneously record the brightness of thousands of stars in a large patch of the sky. Sampling star brightness every twenty minutes, Kepler has discovered many variable stars. However, its intended purpose is to detect planets as they pass in front of their stars once each orbit. The transit technique works only if we lie very close to the orbital plane of an exoplanet. Therefore, most extrasolar planets would escape detection by this method. The fact that Kepler has found many exoplanets indicates how common extrasolar planets are.

The transit method reveals an exoplanet's size, but not its mass. However, if we can combine data from a transit measurement and the RV technique, we know both the mass and radius, and the exoplanet's density follows. There have been attempts to probe the atmospheres of exoplanets as they transit. As this technique improves, it may be possible to learn much more about exoplanets than was ever possible with the RV technique. In 2013, there was a failure of part of the pointing mechanism in the Kepler spacecraft. An innovative solution was found that allowed putting Kepler back into use but with certain limitations. The spacecraft must be aligned in a certain orientation in its orbit, and this limits the regions of the sky it can observe. The modification to the spacecraft to allow it to return to service has been called the K2 mission.

Another method, which is a variation on the transit technique, is transit timing variations (TTV). This method carefully determines whether transits start in a strictly periodic manner (Steffen et al., 2010; Xie, 2013; Barros et al., 2014). In some systems, this method can be used to verify other techniques. For example, if a system has more than one transiting planet (which is rare), it can cause variation in the transit timings. Or if an exoplanet orbits a binary star, there may be variations in the transit timing because the stars are moving. Note that in most cases even if a star has multiple planets, it may be that only one of the exoplanets has the proper orbit alignment and distance from the star to allow a transit measurement from Earth.

Direct imaging is becoming a more commonly used technique for detecting exoplanets. Direct imaging most often is attempted in the infrared part of the spectrum, because the difference in brightness between planets and their stars is least in the infrared. Furthermore, an occulting disk normally is employed to block the light of the star (Marois et al., 2008). If the light of the star can be sufficiently well characterized, it can be cancelled out, leaving the infrared glow of nearby planets in the image. This method allows direct observation of the motion of the exoplanets. The NASA exoplanet archive shows 42 cases of confirmed exoplanets detected with this method as of September 2, 2016.

Another method is gravitational microlensing. This uses an effect from general relativity in which a foreground star is used as a lens to image a much more distant star. The foreground star would be the star hosting the exoplanet. This technique can be used to detect exoplanets for stars much more distant, but it requires such precise alignment of the two stars that it is unlikely to ever happen again. The mass of the exoplanet can be roughly estimated, but determination of the orbit is very uncertain. There are some confirmed exoplanets using this technique.

Other methods used occasionally are eclipse timings of eclipsing binary stars, orbital-brightness modulation, pulsar timing, and pulsation timing from non-pulsar stars. In orbital-brightness modulation, light reflecting off the exoplanets causes variations in the star's light. There are a few pulsars with exoplanets. Pulsar pulse timings are a very good means of detecting planets orbiting them, because pulsars have extremely regular periods, so any motion of the pulsars due to orbiting planets shows up easily. Some variable stars have periods regular enough that this technique can be used to detect orbiting planets using the same method. Table 1 shows the number of confirmed extrasolar planets from various techniques as of September 2, 2016 (NASA, 2016).

Planet Formation and Migration

Planet formation theories start with a flattened disk of gas and dust around a newly formed star. This protoplanetary disk is supposed to be material that failed to amalgamate into the star. Presumably, the disk and star have the same composition, except that the disk may have a lower proportion of hydrogen and helium than the star has. Small particles of dust can collide and stick together. It is known from experiments that small particles (up to about 1 mm) can stick together due to static charge and other effects, but there has never been an adequate explanation of how solid rocky objects could grow to become sizable objects, such as 1 km in size. This is important, because computer simulations often start with model objects of 1 km diameter because simulations cannot effectively simulate objects growing to this size. The process of solid objects growing is often referred to as "accretion." But the dynamics of particles of different sizes and compositions colliding in a material medium is a complex mix of processes. If one assumes the planetesimal objects start at approximately 1 km diameter, then gravity may pull them together if they do not have too much velocity. But it is well known that even objects smaller than this 1 km size tend to break each other apart in collisions. The following extended quote from Halliday, 2003 (p. 516) explains the problems with small objects combining to make larger objects:

Table 1. Confirmed Exoplanets by Detection Method.

Detection Method	Number Confirmed
Transit Photometry	2664
Radial Velocity	593
Direct Imaging	42
Microlensing	39
Transit Timing	14
Eclipse Timing (Binary stars)	8
Orbital Brightness Modulation	6
Pulsar Timing	5
Pulsation Timing (non-Pulsars)	2
TOTAL	**3,373**

Table 1. Number of extrasolar planets listed in the NASA Exoplanet Archive (http://exoplanetarchive.ipac.caltech.edu/index.html) as of Sept. 2, 2016. Of the 2,664 transit detections above, 2,427 of these were with the Kepler telescope.

> Laboratory experiments on sticking of dust have been reviewed by Blum (2000), who concluded that sticking microscopic grains together with static and Van der Waals forces to build millimeter-sized compact objects was entirely feasible. However, building larger objects (fist- to football pitch-sized) is vastly more problematic. Yet it is only when the objects are roughly kilometer-sized that gravity plays a major role. Benz (2000) has reviewed the dynamics of accretion of the larger of such intermediate-sized objects. The accretion of smaller objects is unresolved.

The process of accretion is something all planetary origin theories depend on, and yet there is no explanation for the physics of it, except for the formation of small dust particles millimeters to centimeters in size. Another group of authors examine the issue and give the following comments while discussing the early stages of the formation of our solar system (Montmerle et al., 2006, pp. 75–76):

> The growth from dust grains to kilometer-size planetesimals is still unexplained. … The simulations assume rocky objects, but it is still unclear how a puffy pile of dust becomes a solid rock.

In the early stages of the growth of planet cores, the key process is random collisions. This is usually referred to as "oligarchic growth." Once a planet core grows to a certain critical mass, estimated as about 10 Earth masses, then gravity is expected to be able to capture and add other material to the planet core in a rapid fashion. This is known as the "runaway" growth stage because it is believed both gases and solid material can rapidly accumulate on a planet's core in this period (Montmerle et al., 2006). A planet the size of Jupiter or Saturn must accumulate most of its mass in less than about 5 million years according to this scenario. If it does not accumulate its mass in this runaway stage, it never will, because the protoplanetary disk will dissipate. The original disk of gas and dust is essentially replaced with many planetesimals. The planetesimals have formed by the same accretion process assumed to form the larger planet cores. Planetesimals are solid objects made up of a variety of minerals, ice, and some organics believed to be very much like today's asteroids.

Smaller planets are thought to require longer times to form than larger planets. The size of planets is understood to be related to the density, thickness, and other properties of the disk. Rocky planets such as Earth or Mars are thought to form from random collisions of objects, often referred to as "planetary embryos." Planetary embryos are objects larger than planetesimals, possibly as large as Earth's moon, which could be made up of rock or ice. In several million years, a disk of dust would dissipate, leaving planetesimals and planet embryos.

The formation of planets is understood to be very dependent on the properties of the protoplanetary disk and other planets (or stars) present in the system. The properties of the star greatly affect the process as well. Near the star, the equilibrium temperature may be too high for gases to condense. Near some stars, even some metals may boil away from planets. Planet orbit migration has come to be an accepted process in planetary science. Orbit migration was first considered as a means of allowing planets to form at a greater distance from the star than where they are observed today. This allowed more material to be available to accumulate on them in the early stages. For example, a planet could form at perhaps 4 or 6 A.U. from its star and then migrate inward. When the disk was depleted in some systems, planetary migration would stop. However, today there are believed to be multiple types of planet migration scenarios possible. Planet migration has been related to spiral density wave theory and planet-planet orbit interactions so that migration either can be inward toward the star or outward. Orbit migration has not really been observed except in the sense of cases where we can see that a planet has a decaying orbit, or perhaps a resonant relationship exists with another planet that could affect it in a predictable manner over a few years of observations. But orbit migration theory often involves planets moving very significant distances, perhaps as much as 5 or 10 A.U. in some cases. This kind of large-scale orbit change has not been observed.

Though the theories of planet orbit migration have received much attention in the scientific literature, such theories still have serious limitations and problems. The most serious problem may be that if a planet begins migrating inward, it tends to fall into the star. Scientists want to show how a planet migrating inward could migrate over a timescale that is longer than the time for the disk to dissipate. This would allow the planet to migrate inward until the disk dissipates. However, in scenarios planets migrate too rapidly and fall into the star before the disk dissipates (Hasegawa and Ida, 2013). A timescale on the order of 10^5 years is often estimated for the migrating planet to spiral into the star, but this depends on the system. This problem has been referred to as the "death spiral."

Migration theories are thus lacking in clarifying mechanisms that would stop the planet from spiraling into the star. There are two main types of migration that have received attention in the research, known as Type I and Type II (Plavchan and Bilinski, 2013; Hasegawa and Ida, 2013). In Type I migration, the disk is very massive compared to the mass of the planet, so that the planet's migration does not have a great effect on the disk. In Type II migration, the mass of the planet is greater, and the disk material is significantly affected by it. In Type II migration, a gap usually is opened in the disk due to absorption of gas and dust by the migrating planet. Both Type I and Type II migration scenarios involve the formation of density waves that can exist around the planet. The density wave can theoretically push the planet forward in the right conditions, making it spiral outward, or slow its motion, causing it to spiral inward. Spiraling inward is considered more common and is focused on more in the research to try to explain the many so-called "hot Jupiters" that exist close to their star.

As an example of a typical "hot Jupiter" type exoplanet, we can consider object Kepler-74. This exoplanet was referred to as KOI-200b, when it was first detected from a Kepler spacecraft transit measurement in 2012 (Hebrard et al., 2013). (The letters "KOI" refer to "Kepler Object of Interest.") The Kepler-74 designation was used after it was confirmed. It was confirmed by radial velocity measurements from two high-precision spectrographs, SOPHIE (in France) and HARPS-N (in Spain) (Hebrard et al., 2013). Kepler-74 orbits an F8V-class star with a mass estimated at 1.40 + 0.14, -0.11 solar masses and an estimated radius of 1.51 ± 0.14 solar radii. Kepler-74 is estimated to have a mass of 0.68 ± 0.09 times the mass of Jupiter (M_{Jup}) and a radius of 1.32 ± 0.14 compared to Jupiter (R_{Jup}). The star is estimated to have an effective temperature of 6,050 ± 110 Kelvin. The planet's orbital period is 7.34 days, and the eccentricity of its orbit is estimated to be 0.287 ± 0.062 (Hebrard et al., 2013). For comparison, Mercury in our solar system has an orbital period of 87.97 days and an eccentricity of 0.206. Kepler-74 is similar to many other cases of exoplanets.

An ongoing debate among exoplanet researchers continues over the question of how so many planets can migrate from some distance inward until they are very close to the star and then stop migrating. Several mechanisms for stopping migration have been considered (Plavchan and Bilinski, 2013; Nagasawa and Ida, 2011). The mechanism with the most promise is sometimes referred to as dynamical tides. The dynamical tide is the tidal force created by the star on the planet as a function of distance. If a planet has an orbit that is significantly eccentric (preferably more than Kepler-74), when it is at its point of closest approach to the star (periastron), tidal forces are greater than when it is at its farthest point (apastron). This tidal force tends to circularize planetary orbits as planets migrate closer toward their stars. Migration ought to cease once an orbit is sufficiently circular. Exoplanets close to their stars usually do not have significant eccentricities. Compared to other hot Jupiters, the eccentricity of Kepler-74 is somewhat high for a planet so near its star.

However, dynamical tides consider only half of the tidal physics. Some researchers may believe dynamical tides solve the migration problem in many cases. But even if an exoplanet's orbital eccentricity is close to zero, it can still spiral into the star. This is due to the tidal bulge raised by the planet on the star. When a planet is very close to the star, in many cases the planet may revolve more rapidly than the star rotates. The tidal bulge on the star induced by the planet may cause the planet to lose orbital energy and spiral inward. In addition, planets near their stars sometimes lose significant mass from the star pulling gases off the planet. The rotation rate of the star and the size of the planet are significant factors in how the tidal forces affect the planet. The exoplanet can either spiral inward and be absorbed by the star or spiral outward to a more stable orbit in some cases. However, some researchers have argued that rather than looking for a mechanism for "saving planets" from spiraling into their star, perhaps they do not stop (Jackson et al., 2009). Perhaps tidal destruction is more common than halted migration. I find this line of argument to be more realistic, but more observations of these exoplanets over time and analysis of their dynamics are required to be more certain. Even if many of the hot Jupiters do spiral into their stars, it may require millions to billions of years. However, some exoplanets would spiral into their stars in only several hundred thousand years. These are only estimates arrived at from computer simulations.

Challenges to Current Theories

There are several ongoing challenges to current theories of extrasolar planetary systems listed below. All these issues are topics of great interest today in extrasolar planet research. They also give hints of possible advantages of a young-age creation view over an old-age naturalistic perspective. A creationist view can allow for supernatural formation of exoplanets in the creation week. Also in a creation approach, our own solar system becomes special in being a stable system that allows for life on Earth.

- Retrograde or high inclination exoplanet orbits
- False positives in transit measurements
- Gas planets whose radii are too large for their mass and distance from the star
- Problems with the habitability of exoplanets

High Inclinations of Exoplanet Orbits

In April 2010, the Royal Astronomical Society and the European Southern Observatory put out a press release announcing that six exoplanets were orbiting their stars in a retrograde direction, opposite the direction their stars spin (RAS/ESO, 2010). This was determined from transit observations. (These six cases have designations of WASP-2b, WASP-5b, WASP-8b, WASP-15b, WASP-17b, and WASP-33b.) One of the scientists involved, Andrew Cameron, professor from the University of St. Andrews in Scotland, made the statement, "The new results really challenge the conventional wisdom that planets should always orbit in the same direction as their star's spin" (RAS/ESO, 2010).

The evidence for high inclinations and some retrograde orbits among exoplanets comes from an observational technique known as the Rossiter-McLaughlin (RM) measurement (Bouchy et al., 2008; Fabrycky and Winn, 2009; Lund et al., 2014). The RM measurement examines an effect at the edges of the disk of the star as it is observed. On one side, the redshift will be greater because the surface of the star is moving away from the observer. On the other side of the star, the red shift will be less because the surface of the star moves toward the observer. This produces a predictable distortion in the redshift that allows estimating an angle that can be related to the spin axis of the star. An observer sees only a projection of the actual angle the star makes with the planet's orbit, not the actual angle. This projected angle is referred to as λ (lambda). The projected angle λ is what is measured in an RM determination. It is a projection of the actual angle between the star's spin axis and a line normal to the planet's orbit.

The actual angle between the star axis and the planet orbit is known as the stellar obliquity, and it is designated by ψ. The two angles λ and ψ are in two different planes (Fabrycky and Winn, 2009; Lund et al., 2014). Determination of ψ requires developing a detailed model of the star, such as from the changes due to stellar spots or from a technique known as asteroseismology. In asteroseismology, stellar oscillations are analyzed in terms of a sum of oscillation harmonics over time. An asteroseismology model can be compared to similar models of other stars and then applied to the star in question. The result is a model of the spectrum of the star as a function of its rotation. This allows determination of the star's obliquity.

RM measurements have been done only for a limited number of exoplanet systems. Data in Figure 1 come from a catalog of exoplanet transit data from Keele University, UK (Southworth, 2016). In this catalog, there were 166 exoplanets listed for RM measurements. Those which included both the λ and ψ angles were just 20 out of 166 as of September 2, 2016. Of these 20, four data points were of exoplanet HAT-P-07, and two were of HAT-P-11 (Table 2). The other 14 data points were each of different exoplanets (see Table 2). The chart shows the estimated actual obliquity angle on the vertical axis and the projected angle along the horizontal axis. The numeric values above each point show the angle ψ. In Figure 1, the points labeled 106 and 97 are the two HAT-P-11 measurements. This shows HAT-P-11 as being in a near polar orbit around the star, moving in a slightly retrograde manner. The data points labeled with 101 and 87 are two of the HAT-P-07 measurements. HAT-P-07b is also in a near polar orbit. The two HAT-P-07 data points on the graph had an error in ψ too small for the error bars to display. Some data points have a large amount of uncertainty, and the reported error varies significantly from one exoplanet to another. Four data points show a ψ value comparable to or less than the obliquity of our sun in our own solar system. The other 16 data points show a

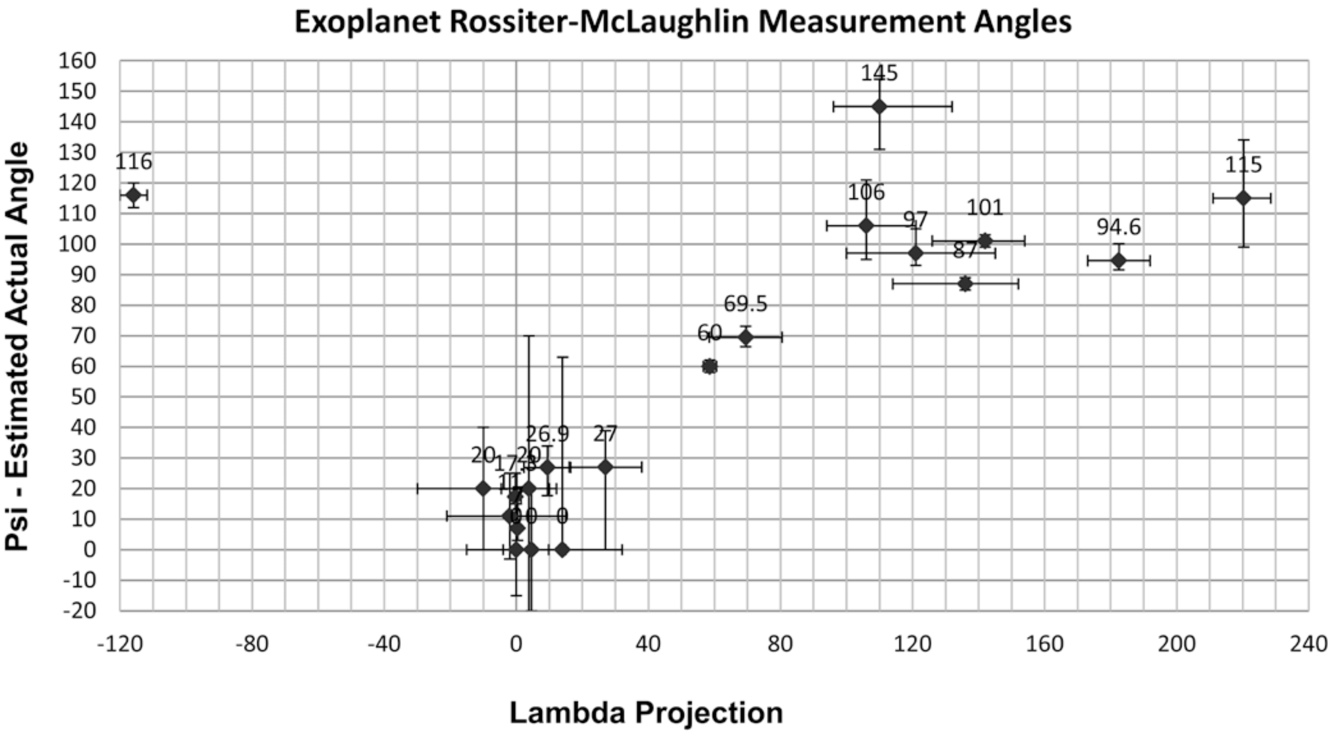

Figure 1. Chart showing exoplanet data from 20 RM measurements of 16 stars using data presented in Table 2. The estimated actual stellar obliquity angle ψ is plotted versus the projected angle λ. Numbers above the data points are the angle ψ in degrees.

higher ψ value than in our system. There appear to be two clusters of data points, one cluster at the lower angles and one at the higher angles. This trend has been noticed by exoplanet researchers, and it is often attributed to two different migration mechanisms. Though there is need for more RM measurements and perhaps more asteroseismology analysis for the exoplanet stars, the implied inclinations of the exoplanet orbits have been a challenge for planetary scientists. High inclinations of the exoplanet orbit compared to the star's axis are not explicable as due to the "traditional" process of planets forming from a protoplanetary disk.

The inclination of exoplanet orbits compared to the spin axes of their host stars is generating significant research today. In our own solar system, the orbits of all the planets are measured by the ecliptic plane, which is defined by Earth's orbit. Our sun's spin axis is tilted slightly over 7° compared to the ecliptic. This has been a challenge for models of the formation of our own solar system. In the traditional nebular hypothesis for the formation of our solar system, the spin energy of the star and the orbital motion of the planets must initially come from the spinning protoplanetary disk. This would make the orbits of the planets initially lined up with the equator of the star, and their orbital motion would be in the same sense as the spin of the star. This is accepted for extrasolar planetary systems as well, except that orbit migration is thought to explain how planets might exist today in different orbits than those that they initially formed in. Today, because planet orbit migration is considered to be common, it is thought that many systems may have had some planets spiral into their star and some other planets that may have been ejected out of their systems.

Type I and Type II migration described above are two forms of disk migration. In these models, the mass of the disk is primarily responsible for the migration of planets. Disk migration does not provide a mechanism to make planet orbits significantly tilted compared to the spin axis of the star.

Other theories for planet orbit migration have been proposed that are often referred to as planet-planet scattering. Planet-planet scattering is thought to explain highly inclined or retrograde exoplanet orbits. If a planet orbit changes in disk migration, it must happen early, in the first several million years of the

Table 2. Exoplanet data plotted in Figure 1.

Star Name	Effective Star Temperature (Kelvin)	Lambda (X) in degrees	Lambda Error	Psi (Y) in degrees	Psi Error
CoRoT-18	5440	-10	± 20	20	± 20
HAT-P-07	6310	182.5	± 9.4	94.6	+5.5, -3
HAT-P-07	6310	220.3	+8.2, -9.3	115	+19, -16
HAT-P-07	6310	142	+12, -16	101	± 2
HAT-P-07	6310	136	+16, -22	87	± 2
HAT-P-11	4780	106	+15, -12	106	+15, -11
HAT-P-11	4780	121	+24, -21	97	+8, -4
HAT-P-36	5620	14	± 18	0	+63, -0
HD_189733	5050	0.4	± 0.2	7	+12, -4
KELT-17	7474	-115.9	± 4.1	116	± 4
Kepler-13	7650	58.6	± 2	60	± 2
Kepler-17	5781	0	± 15	0	± 15
Kepler-25 c	6270	9.4	± 7.1	26.9	+7, -9.2
Kepler-63	5576	110	+22, -14	145	+9, -14
WASP-19	5460	4.6	± 5.2	0	± 20
WASP-32	6100	-2	+17, -19	11	± 14
WASP-52	5000	3.8	± 8.4	20	± 50
WASP-84	5280	-0.3	± 1.7	17.3	± 7.7
WASP-117	6040	69.5	± 11	69.5	+3.6, -3.1
XO-2	5332	27	± 11	27	+12, -27

Extrasolar planet data for cases plotted in Figure 1. Data obtained from http://www.astro.keele.ac.uk/jkt/tepcat/rossiter.html on Sept. 2, 2016.

formation of the system before the disk of gas and dust dissipates.

One form of migration is where planetesimals cause the migration of the planet. Migration via planetesimals happens after the protoplanetary disk is dissipated but while the planets are still accreting material from colliding planetesimals. This type of migration depends on the existence of a disk (or ring) of planetesimals that is massive enough to affect the planets' orbits. Migration by planetesimals also would not be expected to cause planet orbits to be tilted by large angles. Often planetary scientists seem to simply assume that the 7-degree angle in our own system somehow arose from random collisions in the planetesimal-accretion stage.

Another model for planet migration is where multiple planets form and their mutual gravity pulls them into resonance, so that their orbital periods are close to being whole number ratios of each other. If a system has multiple planets that can cause changes in each other's orbits, this process is considered something that can theoretically continue for long periods of time until something stops the process. If two planets come into a resonance, it is also dynamically possible that they could migrate together. Today a mixture of all these concepts has been applied to our own solar system in the Nice model (Tsiganis et al., 2005) and the Grand

Tack model (Walsh et al., 2011; Walsh et al., 2012). These concepts have been worked out from years of research on extrasolar planetary systems. Thus, scientists have attempted to develop theories that explain both other planetary systems and our own solar system.

One scenario for planet-planet scattering is known as Kozai cycles or Kozai oscillations (Fabrycky and Tremaine, 2007; Plavchan and Bilinski, 2013). The Kozai mechanism was originally developed as an explanation for how binary- and triple-star systems could come to have a near binary pair orbiting each other with a more distant companion star. If there is a star at a greater orbital distance than the binary pair, the distant companion can alter the inclination of the binary pair. The process could apply in some planetary systems where there are either multiple stars or multiple planets or both. It could apply if the system has a star (or a binary pair) that is orbited by a planet and there is another object, more distant and in an eccentric, highly inclined orbit. The distant object could theoretically be either a planet or a star. The distant object being in an inclined eccentric orbit can cause precession and oscillations of the inner planet orbit in this configuration. Over time the inner planet orbit in this scenario would become more eccentric for a time, but then as the planet orbit becomes closer to the inner star, the tidal forces from the inner star would round the orbit of the planet. So early in the Kozai cycles process the outer inclined object would affect the planet more, but later in the process the planet orbit has shrunk and then the tidal forces of the inner binary become more important. Computer simulations have been done of the mechanics of the Kozai cycles process.

The Kozai mechanism would not be applicable in a system with only one planet, but there could be some exoplanet systems where it could apply. There must be at least two objects orbiting a star not too far apart but in different planes if they are to influence each other gravitationally. In computer simulations, the Kozai process can produce planet orbits close to a star (or binary pair) that are highly inclined. Because the Kozai cycle mechanism is a slow process, it would require long periods of time, on the order of 1 or 2 billion years in simulations (Fabrycky and Tremaine, 2007). It is also possible that if a system has multiple planets in similar orbital planes that the planets can prevent the Kozai orbit oscillations. Multiple planets in similar orbital planes tend to stabilize the system, not increase orbital inclinations.

In extrasolar planet research, appeal often is made to the Kozai mechanism as a possibility, but it would not be applicable to many exoplanet systems. However, there are exoplanets in binary- and trinary-star systems. In some extrasolar planet systems, if there is evidence for a high inclination in a planet orbit, researchers sometimes merely assume that there was a distant companion object in an inclined orbit, whether there is observational evidence for such an object or not. If one is not observed, it can be argued that the distant object was ejected during the orbit oscillations of the Kozai process. A more distant exoplanet can be hard to detect, however, and exoplanets in distant orbits rarely undergo a transit. Showing that exoplanet orbits are undergoing a long-term change that is due to the Kozai mechanism would be difficult because we cannot observe the history of the exoplanetary system. The Kozai mechanism may require a distant companion planet that cannot be observed. Thus, the Kozai cycles scenario has limited applicability, even though it is a physically valid mechanism.

The Kozai cycles process generally ends with the exoplanet near its star (or binary pair) in a near circular but inclined orbit. But like other cases of hot Jupiter planets, it could still spiral into the star. The Kozai process attempts to explain how a distant object in a tilted orbit can cause another orbit to tilt. But it raises the unanswered question of how the distant object came to be in a tilted orbit. The Kozai mechanism gives some insight into how a system of multiple planets and multiple stars can change over time. In a creation view, it may be that planet-planet scattering and Kozai cycles do not have time to alter orbits greatly. In a naturalistic or uniformitarian approach to planetary systems, planet orbits must migrate by possibly several astronomical units over millions or billions of years. On the other hand, a creation alternative would be to view the exoplanets as being formed on the fourth day of the creation week at the time the star was formed. Then some limited migration could be possible over a young-age timescale.

Some exoplanet researchers have argued that high orbital inclinations could be related to various complicating observational effects and thus are not valid. One of the effects suggested is differential rotation in the star (Hirano et al., 2012). Stars may have latitude bands that rotate at different speeds, as does our own sun. Though differential rotation is probably common in stars, it is not clear how much it would interfere with transits or determinations of ψ. Another model was proposed suggesting that the outer layers of a star could "decouple" from the interior of the star, causing the star to have two rotation axes (Rogers et al., 2012). The star core and interior would have a different spin axis than the star's outer layers. It is not clear whether known exoplanets provide support for this model.

As more analysis is done of the data, these processes are likely to be either ruled out or better understood and better accounted for in models. The growing list of examples of exoplanets with possible high inclinations are not likely to all be explained away as observational issues. The highly inclined and retrograde exoplanet orbit issue seems to not go away, though better data and analysis is needed to clarify it. Even if no exoplanets were found to have orbit inclinations more than 7°, that would only confirm that exoplanets have the same unexplained problem that has been found in our own system.

False Positives in Transit Measurements

In 2012 and 2013, scientists analyzing Kepler transit data realized that false positive detections with the Kepler spacecraft were much more common than had been expected (Santerne et al., 2012; Santerne et al., 2016). There are systems with eclipsing binary stars that can be almost indistinguishable from a planet transiting the star. One such case could be a brown dwarf that transits the star. Another case could be a blended binary, where a bright star is orbited by a binary pair that is less bright. Another case is known as a grazing binary system in which a dim star just barely overlaps the field of view of the other star. The grazing binary is thought to be the most common of these cases. The problem stems from apparently underestimating the number of eclipsing binary systems that could appear like planet transits.

The Kepler spacecraft was designed to be sensitive enough to detect the transit of an Earth-sized exoplanet, but this new issue of false positives will raise questions about reliably detecting such planets. There has been great interest in the scientific community in doing transit studies of exoplanets smaller than Jupiter or Saturn. Some have been found that are approximately double Earth's mass. These exoplanets are often referred to as "super-Earths." In some cases, the eclipsing binary possibility can be tested, given the proper analysis. But there are many transiting exoplanets that cannot be verified by the radial velocity technique. The radial velocity technique measures the change in the motion of the star due to the planet. For some transiting exoplanets, the velocity change in the star is too small to reliably detect with any instruments available today. This limits the ability of researchers to clearly show that the decrease in the star's light from Kepler is due to a planet and not an eclipsing star. In some cases, it will become a statistical argument rather than a physical argument to claim that it was an exoplanet that transited the star and not another star transiting the star. Virtually all Earth-sized or super-Earth exoplanets would be in this category. Thus, the problem of false positives from eclipsing binaries is a serious one, and in my opinion, it makes the detection of Earth-sized exoplanets very uncertain.

The false positives problem varies with the planet size and distance from its star. In 2012, Santerne et al. reported that for giant exoplanets with orbital periods of less than 25 days, the percent of likely false positives is 34.8 ± 6.5%. This was after studying a sample of 46 well-chosen transit cases. In 2015, Santerne et al. published updated results saying that as many as 54.6 ± 6.5 % of gas giant planets with orbital periods of 400 days or less could be false positives! This recent effort used a larger sample of Kepler Objects of Interest (KOI). Known false positives were first removed from the KOI list, and then the list was further parred down to those stars bright enough to be verified by the SOPHIE spectrograph (in France), leaving 2,481 KOI objects. Undoubtedly techniques will be refined to address this issue, but creationists should be cautious about accepting all claims of detection of exoplanets, especially for exoplanets orbiting very closely to their stars.

The Size of Gas Exoplanets

Another issue has become a significant ongoing mystery in extrasolar planet research: the sizes of many gas exoplanets near their stars. In recent years, scientists have noticed that many exoplanets near their stars have radii larger than expected in models (Baraffe et al., 2003; Anderson, 2010; Leconte, 2011; Southworth et al., 2014). There are several known effects that can cause a gaseous planet to expand near its star. But the magnitude of the radii for some exoplanets may defy all known mechanisms. The equilibrium temperature of the planet naturally increases as its distance from the star decreases. There is also a heating effect from tidal forces that can heat a planet near its star, known as *tidal dissipation*. Some would argue that tidal effects would heat these planets sufficiently to explain their large radii. But this has not really been shown clearly in tidal dissipation calculations. A recent paper (Martin, Spruit, and Tata, 2011) shows that this seems to require unrealistic values of the quality factor (Q), which is an important parameter in tidal dissipation calculations. The Q value has been estimated for Jupiter and various moons and planets in our own solar system. Estimates of Q frequently use a lower value for the star than for the exoplanet, and they use a value for the planet that is at least a magnitude higher than estimates for Jupiter in our own system. This is questionable because this tends to make the tidal force on the planet by the tidal bulge of the star less. I find it more likely the star would have a higher Q than the exoplanet.

The large radius of exoplanets also presents a time problem, because these planets are believed to form at some distance and migrate inward to near the star, then stop migration and remain stable for many years. As a planet migrates inward close to the star, it comes into synchronous rotation (tidal lock) with the star. At that point, one side of the planet cools very efficiently, because it is always facing away from the star. Though a gaseous planet in this configuration could have very high winds, and it might lose gases to the star, it would cool over long periods of time. But indications are that many of the "hot Jupiters" are hotter than expected from gas models and planet interior models.

However, this problem does not apply to all the exoplanets near their stars. For example, it would not apply to a planet with a high abundance of metals or a planet that is likely to have a large, dense core. An example case was discussed by Baraffe, et. al. in 2003. The following quote eloquently explains the nature of the issue (Baraffe et al., 2003, p. 712):

> In summary, we do not expect irradiation effects alone to explain the large observed radius of HD 209458b. In the same vein, tidal interactions will affect only the early stages of evolution of the planet but will probably be dissipated too rapidly to affect the long-term contraction of the object. Other sources of energy, representing about 100 times the intrinsic luminosity of the planet, seem to be required to explain the observed radius.

Exoplanet HD 209458b, mentioned above, has a mass of approximately 69% the mass of Jupiter, and yet its radius is roughly 30% more than Jupiter. A much more recent paper from Spiegel et al. (2014, p. 12623) made this statement summarizing the problem: "Despite the lack of a consensus mechanism, it is clear that objects must either be quite young or very highly irradiated to have significantly inflated radii." The expression "quite young" is not intended to mean several thousand years as in a young-age timescale. Planetary scientists have recently proposed a solution to the large radius problem by suggesting a collision event could have occurred in these systems (Martin, Spruit, and Tata, 2011). The collision proposed is referred to as a binary merger, and the authors suggest it could have taken place 100 million years ago or less. On the other hand, it would be a very plausible solution to propose that these "puffy" exoplanets have primordial heat that remains from their formation. But this does not fit planet formation models because the heat should have dissipated in billions of years. Thus, a catastrophic event has been proposed that generated a large ring that such an exoplanet could form from. Models of the gas dynamics of exoplanets very close to their stars require more research to clarify the problem. But this issue may be an indication of the young age of these exoplanets. Planetary scientists tend to look for an age in the millions of years to allow the dust ring to dissipate, the planet to form, and then allow the young planet to migrate inward. On the other hand, if these exoplanets were created supernaturally only several thousand years ago, they could still be hot and "inflated" from their formation. This is a tentative interpretation, but it does seem consistent with other evidence from our solar system (Spencer, 2003, 2015a).

The Habitability of Exoplanets

The driving motivation for much of the research on extrasolar planets is to find evidence of habitable planets like Earth. In recent years the technology applied to exoplanet research has improved, and this is driven by a desire to find smaller exoplanets, since it is believed this makes finding a habitable planet more likely. The concept of the "habitable zone" (HZ) has itself undergone refinements over the years. The HZ primarily is defined as the region around a star in which a planet having the proper atmosphere could have liquid water on its surface. How do planetary scientists set about the process of searching for habitable planets? Most of the time, they focus on low-mass dwarf stars. These stars usually have a lower mass than our sun, making it easier to detect even small planets by the RV method. Furthermore, the HZs of such stars are very close to the stars, yielding short orbital periods, making it more likely to observe transits. If both RV and transit measurements are made, we directly can determine the density of a planet. Scientists do not expect life to exist in gas giant planets, thus determining the density is important.

Transits may allow the determination of the major composition of planetary atmospheres (assuming the planets have atmospheres). The general requirements scientists look for on such a rocky exoplanet is that the temperature and pressure conditions on the surface allow for liquid water and that there be carbon dioxide (CO_2) in the atmosphere. Oxygen is not considered essential for life per se, but an atmosphere made up of mostly N_2, H_2O, and CO_2 is considered ideal for plant life to start. Thus, scientists generally look for a reducing atmosphere similar to what they believe Earth's early atmosphere was between about 3 billion and 2.3 billion years ago. Scientists believe it was because of photosynthetic bacteria that Earth's atmosphere switched from a reducing to an oxidizing nature approximately 2.3 billion years ago. Some scientists would consider an atmosphere more like the Earth's or Saturn's moon Titan to be more likely, where the major constituent is N_2 but there is a mixture of many organic gases, with some CO_2.

How common are rocky exoplanets? As of October 1, 2016, the NASA Exoplanet Archive listed 344 cases of confirmed exoplanets that showed both the semimajor axis and the density to be determined. Of these, 49 cases had densities 3.0 g/cm^3 or greater. Note that these 49 would be approximately 1.5% of the total of confirmed exoplanets in Table 1. (For comparison, Earth's moon has a density of 3.34 g/cm^3.) Of these 49, 5 show a density of 14 or more, with the highest as 28 g/cm^3. These high densities are probably suspect, so further research is needed on these cases. Error is not always reported in the density data and when it is, it is highly variable from one determination to another. Also, even if a very small error is reported, there are observational issues or data interpretation issues that could cause large errors, especially in light of the false positives problem discussed above.

How is the HZ defined? One of the best determinations of the HZ is published in Kopparapu et. al., 2013. For our solar system, the HZ is listed by Kopparapu as from 0.99 to 1.70 A.U. This distance range would start just inside Earth's orbit and range out to slightly past the orbit of Mars. There is thought to be some unknown error in this kind of estimate from the effects of clouds in climate models. This range of distances for the HZ is defined based mainly on the greenhouse effect as a function of distance from the star. It is thought that cloud cover tends to expand this range of distances. At the inner boundary of the HZ, water cannot be retained on the surface due to the high temperatures. At the outer boundary, the greenhouse effect is not significant enough to prevent water from freezing. Note that determining the range of distances from a star that would correspond to the HZ depends on making assumptions about the planet having an atmosphere. Often the assumption made for determining the HZ distance range is that the exoplanet has an atmosphere similar to Earth's in density. It has been estimated that if Earth's atmosphere disappeared, the surface would freeze. This shows how critical the nature of a planet's atmosphere is for habitability.

Even if a planet is in the HZ distance range, various effects can render it uninhabitable. First, most of the extrasolar planets studied with transit measurements probably are in tidal lock with their stars. If a planet is in tidal lock, the atmosphere could migrate to the cold side and then freeze out onto the surface. However, it is thought that if the atmosphere is dense enough, it would have a sufficient greenhouse effect and wind circulations to prevent this. A very challenging question would be, how could life find a safe place to live on a tidally locked planet? Such a planet would have extreme conditions on it that would not be very hospitable.

Second, many of the exoplanets are exposed to strong flares from their star, or bursts of ultraviolet or X-rays in some cases. This problem is likely to affect Proxima Centauri b for example, which was detected in August 2016 (Anglada-Escudé, 2016; Clery, 2016; Davenport et al., 2016). The star system Alpha Centuari has two stars referred to as A and B, and Proxima Centauri is thought to be a third star that is more distant but part of the same system. Proxima Centauri is a dwarf star, and it has an exoplanet that has been detected using the RV technique and has been confirmed. Proxima Centauri b orbits its star in 11.2 days, and the mass calculated for it is about 30% more than Earth. Orbital models of the Proxima Centauri system with its planet have been done, but since the RV measurement is the only data available, we cannot be sure of the mass since the RV technique gives only a minimum mass for the planet. Even if we knew its mass, we do not know its size, so the density of Proxima Centuari b is completely unknown. So, it could be more like Uranus or Neptune than Earth. Also, nothing is known of the composition of its atmosphere, or even if it has an atmosphere.

Stellar flares and radiation bursts are often far more intense for many other stars than what we experience from our sun. Our sun is exceptionally stable as a star. Another problem is that the planet could migrate inward to a position near the star early in that system's history, but then the star could boil off the water before life could get started (Spencer, 2015a).

For many of the exoplanets that are thought to be in the HZ for their stars, we know very little about them, because we do not know if they are rocky or gaseous. Large gaseous planets have their own reasons why life would be unlikely. They would have a high gravity and no solid surface, possibly limited water, little availability of light for bacteria, and they may possess ionizing radiation and magnetic phenomena that could destroy bacteria. The study of extrasolar planets shows how special our own planet and our own solar system are in being well suited to life and to our needs as humans.

Conclusions

Extrasolar planets are a very active topic of research in astronomy today. After many refinements of techniques and even special spacecraft being put into space for the observations, there remain many challenges to naturalistic theories on the origin of exoplanets. Experimental evidence for the existence of extrasolar planets is good in many cases, yet the limits of detection methods and the analysis of the data have many inherent challenges. Scientists want to find evidence of Earth-like extrasolar planets, but the primary discovery has been that extrasolar planetary systems are different from our own solar system. In many cases little is known about the exoplanets themselves. Though the Kepler spacecraft has done transit measurements for many exoplanets, there is a significant outstanding problem in that a large percentage of these detections could be false positives due to dwarf stars or eclipsing binary stars.

The existence of extrasolar planets is not in conflict with a biblical worldview, but naturalistic origins theories are. Extrasolar planets are often found to be very close to their star despite an apparent tendency for them to spiral in and be absorbed by the star. This may suggest these planets have not existed long enough to be absorbed by the star. Extrasolar planetary systems are not as safe or stable an environment as our own solar system is from our privileged place on Earth. Planet origins models have been adapted to incorporate the concept that planets can form in one orbit and then migrate to another, very different orbit. In these models, planets can form and fall into their star or be ejected into space. Exoplanets are sometimes found in orbits that are inclined at angles very different from the equators of their stars. This has led to application of models in which multiple planets (or stars) that orbit in different planes can scatter or alter each other's orbits over time. This planet-planet scattering concept presumes a history for these systems that cannot be verified.

Planet origins models assume processes that often cannot be verified by observations. Some exoplanets have also been found with a radius that seems so large that it challenges existing theories. These large "puffy" exoplanets may be explained better as being young objects. Though some exoplanets are within the HZs of their respective stars, usually very little actually is known about these planets. Also, the possibility of liquid water on the surface of an exoplanet does not explain how life could evolve there from nonliving matter. The planet's atmosphere and stellar flares are critical factors that rule out life on many exoplanets. Extrasolar planets are best understood as examples of the variety created by God to demonstrate design in our own solar system. Extrasolar planets could have been created in the creation week on the fourth day only thousands of years ago. Exoplanets could have been created in various orbital configurations in the beginning, rather than forming from a spinning disk of dust and gas.

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References

Anderson, D.R., 2008. WASP-5b: a dense, very hot Jupiter transiting a 12th-mag Southern-hemisphere star. *Monthly Notices of the Royal Astronomical Society* 387:L4-L7.

Anderson, D.R. 2010. WASP-17b: an ultra-low density planet in a probable retrograde orbit. *The Astrophysical Journal* 709(1):159–167.

Anglada-Escudé, Guillem. 2016. A terrestrial planet candidate in a temperate orbit around Proxima Centauri. *Nature* 536:437–440. doi:10.1038/nature19106

Baraffe, I., et. al. 2003. Evolutionary models for cool brown dwarfs and extrasolar giant planets. The case of HD 209458. *Astronomy and Astrophysics* 402:701–712.

Barros, S.C.C., et. al. 2014. SOPHIE velocimetry of Kepler transit candidates X. KOI-142 c: first radial velocity confirmation of a non-transiting exoplanet discovered by transit timing. *Astronomy and Astrophysics* 561:L1.

Borucki, W.J., et. al. 2009. Kepler's optical phase curve of the exoplanet HAT-P-7b. *Science* 325(5941):709.

Bouchy, F., D. Queloz, et. al. 2008. Transiting exoplanets from CoRoT space mission III. The spectroscopic transit of CoRoT-Exo-2b with SOPHIE and HARPS. *Astronomy and Astrophysics* 482:L25-L28.

Clavin, Whitney. 2012. Study shows our galaxy has at least 100 billion planets. http://www.jpl.nasa.gov/news/news.php?feature=3251 (accessed October 2, 2016).

Clery, Daniel. 2016. The exoplanet next door. *Science* 353(6302):857.

Davenport, James R. A., et. al. 2016. MOST observations of our nearest neighbor: flares on Proxima Centauri. *The Astrophysical Journal* (in press) 829(2). https://arxiv.org/abs/1608.06672

Fabrycky, Daniel C., and Joshua N. Winn. 2009. Exoplanetary spin-orbit alignment: results from the ensemble of Rossiter-McLaughlin observations. *The Astrophysical Journal* 696:1230–1240.

Fabrycky, Daniel, and Scott Tremaine. 2007. Shrinking binary and planetary orbits by Kozai Cycles with tidal friction. *The Astrophysical Journal* 669(2):1298–1315.

Halliday, A.N. 2003. The origin and earliest history of the earth. In Davis, A.M. (editor), *Meteorites, Comets and Planets*. Vol. 1 of *Treatise on Geochemistry*, pp. 509–557. Elsevier-Pergamon, Oxford, UK.

Hasegawa, Yasuhiro, and Shigeru Ida. 2013. Do giant planets survive type II migration? *The Astrophysical Journal* 774:146.

Hebrard, G., et. al. 2013. KOI-200b and KOI-889b: two transiting exoplanets detected and characterized with Kepler, SOPHIE, and HARPS-N. *Astronomy and Astrophysics* 554:A114.

Hirano, Teruyuki, et. al. 2012. Measurements of stellar inclinations for Kepler planet candidates. *The Astrophysical Journal* 756:66.

Jackson, Brian, et. al. 2009. Observational evidence for the tidal destruction of exoplanets. *The Astrophysical Journal* 698:1357–1366.

Kopparapu, Ravi Kumar, et. al. 2013. Habitable zones around main-sequence stars: new estimates. *The Astrophysical Journal* 765:131.

Knutson, Heather A., et. al. 2014. Friends of hot Jupiters I. A radial velocity search for massive, long-period companions to close-in gas giant planets. *The Astrophysical Journal* 785:126.

Konacki, Maciej. 2005. An extrasolar giant planet in a close triple-star system. *Nature* 436:230–233. doi:10.1038/nature03856.

Leconte, J. 2011. The radius anomaly in the planet/brown dwarf overlapping mass regime. *The European Physical Journal* 11:03004. doi:10.1051/epjconf/20111103004.

Lund, Mikkel N., et. al. 2014. Asteroseismic inference on the spin-orbit misalignment and stellar parameters of HAT-P-7. *Astronomy and Astrophysics* 570:A54.

Martin, E. L., H.C. Spruit, and R. Tata. 2011. A binary merger origin for inflated hot Jupiter planets. *Astronomy and Astrophysics*, 535:A50.

Marois, Christian, et. al. 2008. Direct imaging of multiple planets orbiting the star HR 8799. *Science* 322(5906):1348–1352.

Montmerle, T., J. Augereau, M. Chaussidon, et al. 2006. Solar system formation and early evolution: the first 100 million years. *Earth, Moon, and Planets* 98(1):39–95.

Nagasawa, M., and S. Ida. 2011. Orbital distributions of close-in planets and distant planets formed by scattering and dynamical tides. *The Astrophysical Journal* 742:72.

NASA. 2016. NASA Exoplanet Science Institute, The NASA Exoplanet Archive, http://exoplanetarchive.ipac.caltech.edu (Accessed September 2, 2016).

Plavchan, Peter, and Christopher Bilinski. 2013. Stars do not eat their young migrating planets: empirical constraints on planet migration halting mechanisms. *The Astrophysical Journal* 769:86. doi:10.1088/0004–637X/769/2/86.

Rogers, T.M., et. al. 2012. Internal gravity waves modulate the apparent misalignment of exoplanets around hot stars. *The Astrophysical Journal* 758:L6.

Royal Astronomical Society (RAS), jointly with the European Southern Observatory (ESO) press release, April 12, 2010. "Turning planetary theory upside down" RAS PN 10/25 (NAM 10). https://www.ras.org.uk/news-and-press/news-archive/157-news2010/1780-turning-planetary-theory-upside-down (Accessed 10/5/2016)

Santerne, A., et. al. 2012. SOPHIE velocimetry of Kepler transit candidates VII. A false-positive rate of 35% for Kepler close-in giant candidates. *Astronomy and Astrophysics* 545:A76.

Santerne, A., et. al. 2016. SOPHIE velocimetry of Kepler transit candidate XVII. The physical properties of giant exoplanets within 400 days of period. *Astronomy and Astrophysics* 587:A64.

Southworth, John, et. al. 2014. High-precision photometry by telescope defocusing—VII. The ultrashort period planet WASP-103. *Monthly Notices of the Royal Astronomical Society* 447:711–721.

Southworth, John. 2016. TEPCat: Rossiter-McLaughlin effect observations of transiting planets. Keele University, UK. http://www.astro.keele.ac.uk/jkt/tepcat/rossiter.html. (Accessed 9/2/2016)

Spencer, Wayne. 2003. Tidal dissipation and the age of Io. In Ivey, Robert L. Jr. (editor), *Proceedings of the Fifth International Conference on Creationism*, pp. 585–595. Creation Science Fellowship, Inc., Pittsburgh, PA.

Spencer, Wayne. 2015a. Exoplanets—habitable or not? *Journal of Creation* 29(2):10–11.

Spencer, Wayne. 2015b. Warm icy moons. *Journal of Creation* 29(3):97–2003.

Spiegel, David S., et. al. 2014. Structure of exoplanets. *Proceedings of the National Academy of Sciences* 111(35):12622–12627.

Steffen, Jason H., et. al. 2010. Five Kepler target stars that show multiple transiting exoplanet candidates. *The Astrophysical Journal* 725:1226–1241.

Tsiganis, K., et. al. 2005. Origin of the orbital architecture of the giant planets of the solar system. *Nature* 435:459–461.

Walsh, Kevin J., et. al. 2011. A low mass for Mars from Jupiter's early gas-driven migration. *Nature* 475:206–209.

Walsh, Kevin J., et. al. 2012. Populating the asteroid belt from two parent source regions due to the migration of giant planets—"The Grand Tack." *Meteoritics & Planetary Science* 47(12):1941–1947.

Wolszczan, Alexander. 1994. Confirmation of Earth-mass planets orbiting the millisecond pulsar PSR B1257 + 12. *Science* 264(5158):538–542.

Xie, Ji-Wei. 2013. Transit timing variation of near-resonance planetary pairs: confirmation of 12 multiple-planet systems. *The Astrophysical Journal* 208:22.