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New Nomenclature for Eclipses, Transits and Occultation: Observer Oriented Approach

Mitali Kabra[1], Sudarshan Loya[2]

[1]*Crux View Center, Sagar Trade Center, Jalna Road, Aurangabad*
[2]*Adjunct Professor, Deogiri Institute of Engineering & Management Sciences, Station Road, Aurangabad*

Abstract - *Humans are soon going to inhabit different celestial bodies, one of them being moon. The eclipses on Earth will seem different on the moon. For example, when a Lunar Eclipse occurs on the earth, it will be a Solar Eclipse on the moon. So, even though the celestial arrangement is same, when the observer's position is changed, the entire phenomenon gets changed. Eclipses, transits and occultation are also used by astronomers to find details about celestial bodies. It is important to clearly name the arrangement to explain the syzygy and its meaning. This paper is an attempt to review the current as well as possible new astronomical phenomena and name them precisely keeping the observer's position in mind.*

Scientists have been discovering new, different and quirky systems. So, there may be a possibility of various other types of events occurring, that one may not have even imagined. It is necessary to look into such possibilities from mathematical point of view and name it, so that astronomers can use them to make their mathematical models for exo-planet and exo-moon hunting more precise. A new system is defined in here to name the possible eclipses, transits and occultation, such that any new development can be properly explored and classified. Even though authors have covered a wide range of eclipses and occultations, authors believe this may not be the end of the road.

Key Words: Eclipses, Occultation, Exoplanets, Nomenclature, Syzgy, Observer Oriented.

1. INTRODUCTION

Modern astronomy is filled with many wonders and discoveries of amazing Exoplanets, exomoons and stellar systems which are very different from that of ours [1]–[6]. These discoveries of Exoplanetary system along with their shapes, sizes and orbits shows that universe is filled with stellar systems which cannot be comprehended by any of the human's current analytical or imaginative models. In light of such amazing discoveries, one can wonder not only about the planetary systems; but kind of syzygy they can create. Such arrangements of planets, its natural satellite need to be studied in detail, but before that they need to be classified.

Most people on earth are aware of two kinds of eclipses: Solar and Lunar eclipse [7], [8]. These eclipses have not only shaped our scientific understanding but also our cultural and religious beliefs[9]. But modern day discoveries demand a new classification not just for eclipses but also for transits and occultation. These classifications and nomenclatures need to be observer position dependent as human beings or spacecrafts are no longer bound to earth or just our solar system and in future may observe such phenomena from other bodies. This effort will make the nomenclature universal and usable by future generations.

So, this paper aims to *provide an insight about possible eclipses, transits and other phenomena occurring on celestial bodies, while taking into consideration the position of the observer*. The ideas explained in here are using simple mathematical equations developed from similarity of triangles. Even though dwelling into a more detailed mathematical expression is not possible at this time, the ideas presented here, are very much valid and surely have greater scope.

1.1 Naming from Observer's Point of View:

Many space agencies are planning to create a permanent settlement on the moon by 2035 [10], [11]. The people inhabiting the moon will see the eclipses that occur on earth in a completely different way. In such a scenario, one should take into consideration the position from where the observer may be watching the phenomenon. Because, the eclipses that take place on the earth, are named considering the observer's position to be Earth; so, while discussing eclipses, transits and occultation on other celestial bodies, it is important to identify the observer position.

When there is a lunar eclipse on the Earth, it won't be a lunar eclipse on the Moon. It would be a solar eclipse on the Moon, but to make the observer's position clear, scientists have named it as a *solar eclipse on the moon* [12], [13]. Similarly when there is a solar eclipse on earth, the near side of the moon facing the earth, may see a small black spot moving across the surface of the earth. Though this will not be an eclipse, it will be more of black spot or shadow transiting the earth and hence should be named as ***Self transit (moon on earth)***. *When the shadow of the body* *itself is creating a spot on another celestial body which is visible from the original body, it should be named as self-transit.*

Even though the astronomical arrangement is the same, by changing the position of the viewer, the appearance and viewing of the eclipse is changed. Hence it is important to consider the observer's position, and name the astronomical phenomenon accordingly.

1.2 Planet Transits:

On earth, planetary transits are visible through special equipments [14], [15]. When Venus or Mercury move in front of the sun with respect to earth, they can be seen as a small black dot over sun surface using telescope with solar filters[16]. Such events are called transits and not eclipses [17], [18]. The naming or identification of most transits or eclipses is from earth's point of view. But as explained before, it is important to consider other points of references like Mars, Io, etc. Not just transits, even occultation need to be reclassified based upon observer's point of view.

2. OCCULTATION:

Occultation is a phenomenon which occurs when an object or celestial body passing in front of another object blocks or covers it partially or completely[19], [20]. Occultation is a commonplace occurrence in the night sky on earth with respect to stars or other planets being blocked by the moon [20]–[22]. However, on other planets occultation of one moon by another would be quite a view to behold. Some of these occultation's have been picked by on-board cameras of various space probes on different planets as discussed below [23]–[26]. But before discussing occultation in great detail, one needs to clearly differentiate occultation and transits.

As defined by NASA when a smaller object passes in front of a larger object, such that only a small part of the larger object is blocked, then it should be ***called a transit*** and not an occultation [27], [28]. For the arrangement ***to be called occultation,*** *the body eclipsing the far away celestial object has to be apparently bigger in size from observers point of view* [28], [29]. So when the object closer to the observer has a bigger apparent size as compared to the far away object, the phenomenon will be called occultation. Body in front may or may not cover the entire body behind it or may not be actually bigger than the body behind it, but it just has to appear bigger from the observer's position. If the body in front is appearing smaller from an observer's point of view, the occlusion will be called transit.

But in case of other planets which have multiple moons, the moon close to the planet can be big enough to completely block the other moon behind it and it can be visible by unaided eyes like that happening on planet Mars [19], [25], [28], [30]. Such a phenomenon is called occultation in literature. Although transit and Occultation are used commonly in literature, most of them are defined with respect to earth [20], [27], [31]–[38].

As most of the astronomical studies are done with respect to earth, authors have provided the history of occultation that are regularly observed by scientists [39]–[43]. *Lunar occultation* occurs when the moon is blocking the other celestial body [44]–[46]. It is the most observed occultation and may be observed even from unaided eyes. *Asteroid Occultation* is when an asteroid passes in front of a star with respect to earth [47]. *Planetary Occultation* happens when a planet from the solar system passes in front of other stars with respect to earth [43], [48], [49]. This has been used by scientists to understand the makeup of the planet's atmosphere like that of Pluto even before the spacecraft could have reached there. Lastly, *Artificial Occultation* is when a man-made object is used to block certain objects' visibility to study things in background or at the surface [50].

Scientists in the past have used space probes to see occultation on other planets not just in visible light but also in the UV, IR and radio spectrum [51], [52]. These have helped them to evaluate the ring structure of Saturn as well as shapes and sizes of various objects on other planets [33], [53]–[55]. Occultations of stars by planetary rings, planets, asteroids are called ***Stellar occultation***[52], [55]–[60]. But this definition is confusing. As an asteroid occultation is also an asteroid passing in front of a star and so is stellar occultation. Same with planetary occultation as the planet passes in front of the star.

As the human race is no more limited to the planet earth but trying to colonize other planets which have multiple moons, occultations will be more frequent. Using advance space probe and rovers, astronomers have discovered various other kinds of occultation. Hence it is of utmost importance to classify occultations not just with respect to earth but in common sense which identifies the position of the observer as well as bodies taking part in the occultation.

For example, Mars is an active planet for planetary observation as there are some advanced robotic probes working live on that planet [25], [61]–[63]. As seen by NASA Curiosity rover that On August 1st 2013, Phobos can occult Deimos and block the visibility of Deimos from certain positions on Mars [64]. As Phobos is apparently and actually bigger than Deimos while moving in front of it, such an event is called lunar occultation as observed from Mars as shown in Figure. *When observed from Deimos, Phobos passing in front of Mars will be a lunar transit*. Even on Saturn, a man made space probe Cassini Huygens has observed Saturn's moon Rhea occulted by Dione with respect to probe [65]–[69]. Even though this image does not provide an observation of occultation as viewed from Saturn, it provides evidential support.

Figure 1*:* Lunar occultation of Deimos by Phobos on Mars

The authors are trying to provide a uniform nomenclature to all kinds of occultation and transit. But the nomenclature should be able to differentiate them clearly suggesting the observer position along with bodies involved in the process so as to understand and communicate precisely.

2.1 Nomenclature:

Building upon existing pattern, with slight modifications one can describe the phenomenon precisely from observer location. In the current nomenclature system, it is a common practice to identify transit or occultation by the object in between two bodies. For example, moon is the middle body in lunar occultation. So is the case for other occultations. The only exception is stellar occultation which is named after the star which is occulted by the celestial object in front. But since stellar occultation can also be defined in terms of other occultations, as explained before, authors believe that one should not use the name, stellar occultation anymore.

Following the above example on the Martian planetary system, Phobos occultation of Deimos from Mars, will be named as lunar occultation. But whenever this phenomenon is broadcasted or discussed on earth or any other celestial body, then the name needs to be more precise so that it can specify the celestial bodies taking part in the occultation and their arrangement. Hence, the name should be followed by a bracket, which will specify the celestial bodies taking part in the occultation.

So the name in a generalized way will follow the following pattern-

Type of occultation (The position of the observer -The body that is occulting - The body that is being occulted). The same method can also be applied for already defined occultations and transits with respect to earth. The following list provides examples of various occultations as well as transits, being classified and named as discussed above.

Table 1: Occultation and Transit Classification:

Sr. No	Occultation Type	Example	Nomenclature
1.	Lunar Occultation	1. Phobos between Mars and Deimos and observer at Mars 2. Callisto between Ganymede and Io and observer at Ganymede (Hypothetical arrangement to explain that even one moon can come between two other moons)	1. Lunar occultation (Mars - Phobos - Deimos) 2. Lunar Occultation (Ganymede - Callisto - Io)
2.	Asteroid occultation	1. Asteroid Pallas occulted star Vulpecula as viewed from earth [70] 2. Asteroid 163 Erigone occulted stars Regulus viewed from Earth [71]	1. Asteroid Occultation (Earth - Pallas - Vulpecula) 2. Asteroid Occultation (Earth - 163 Erigone - Regulus)
3.	Planetary Occultation	1. Planet Venus occulting Xi-2 Sagittarii when viewed from earth [72] 2. When Deimos is occulted by Mars from Phobos. 3. Planet TRAPPIST-1 b is occulted TRAPPIST-1 c when viewed from earth [73].	1. Planetary Occultation (Earth - Venus - Xi-2 Sagittarii) 2. Planetary Occultation (Phobos - Mars - Deimos) 3. Planetary Occultation (Earth - TRAPPIST-1 c - TRAPPIST-1 b)
4.	Artificial Occultat	The Sun disk was occulted by Apollo	Artificial Occultation

	ion	Spacecraft when viewed from Soyuz [74].	(Soyuz - Apollo - Sun)
5.	Self-Transit	1. When there is a solar eclipse, the view from the moon will be of a self-transit. 2. Similarly, when Callisto eclipses Jupiter, the view from Callisto will be of self-transit.	1. Self-Transit (Moon On Earth) 2. Self-Transit (Callisto On Jupiter)
6.	Planetary transit	1. When Venus or Mercury move in front of the sun with respect to earth [19] 2. When mercury passes in front of sun with respect to Mars [75]	1. Planetary Transit (Earth - Venus - Sun) 2. Planetary Transit (Mars - Venus - Sun)
7.	Lunar Transit	1. Phobos transiting in front of Sun as viewed from Mars [76], [77] 2. Deimos transiting in front of Sun as viewed from Mars [78]	1. Lunar Transit (Mars - Phobos - Sun) 2. Lunar Transit (Mars - Deimos - Sun)
8.	Artificial Transit	1. The ISS transits the Sun as viewed from Earth [79]	1. Artificial Transit (Earth - ISS - Sun)
9.	Asteroid transit	1. Halley's comet transits the sun when viewed from earth [80] 2. C/1819 N1 transits the sun when viewed from earth [81]	1. Asteroid Transit (Earth - Halley's comet - Sun) 2. Asteroid Transit (Earth - C/1819 N1 - Sun)

3. OTHER KINDS OF ECLIPSES:

Apart from occultations, there are possibilities for new kinds of eclipses that may occur on other planets if not on earth. In recent times, astronomers have discovered different kinds of planetary systems, which are nothing like our own solar system[32]. For example, in the planetary system of Kepler 1625; the planet orbiting Kepler 1625 i.e. Kepler 1625 b is really big compared to anything in our solar system [82]–[84]. Such big planets are commonplace occurrences in other planetary systems as observed in various scientific observations [85], [86]. Keplar 1625 b is supposed to be orbited by a moon Kepler 1625 b I [87], [88]. The astronomers are trying to figure out if the moon has its own moon or there is a different arrangement working on that star [89]–[91]. If this is true, it will give rise to new sets of eclipse and transits.

New astronomical data has found astronomical objects earlier thought to be impossible [92]. On a planetary system having dwarf stars with super Jupiter-like planets orbiting them, they can cast shadows at much longer distances, like the GJ3512 or the WD 1856+534 stellar system [93]–[99]. Can such planets cast an eclipse on another planet? Given the amazing discoveries astronomers are making on a daily basis, no arrangements can be ruled out, just because astronomers haven't observed them yet.

3.1 Eclipses on One Planet by Other Planet:

Eclipses by the moon of a planet on the planet itself are very common, but even a planet can cause an eclipse on another planet. Normally, a planet can only be visible as a bright star from another planet in the night sky, however big the planet can get before it hits the limit of turning into a star or playing tug of war with the original planet [100]. But discoveries of the Exoplanets, their

diameters and the diameter of the star they are orbiting around raise some questions. Discovery of TRAPPIST 1 stellar system recently showed that planets can orbit so close that they can actually appear like the moon from other planets in the same stellar system [101], [102]. Also, when one planet's orbit is too eccentric around a star, on another planet; it can appear slightly bigger than a pointed star in the night sky. Like in the system of HR5183, HD 80606 or HD 20782, the orbit of the respective planet is very eccentric like that of a comet [103]–[107]. Recent simulation done by Kane, S, Blunt and others shows that when viewed from a rocky planet in the habitable zone of the host star, such a planet can appear a little bit bigger like a small ball shaped in the night sky [103], [104].

But to discuss the possibility, one can work with some basic conventions of shadow formation by light. For any shadow to be casted at a large distance, one can use the principle of light and its effect on solid bodies. The light source needs to be smaller with respect to the object and the object should be closer to the source to create a longer shadow when no other light sources are present nearby. So, it is quite clear that Super-Jupiter will have the longest shadow in any stellar system. Further, the shadow of such a super Jupiter can reach even longer, if the host star is a dwarf star which has a diameter comparable to that of super Jupiter. Given that in our solar system, the Sun is too large, the possibility of viewing the sun as a pointed star or small object is fairly small even from very large distances. So to see a planet big enough to cover the sun is quite impossible in our solar system and in most solar systems. But one needs to study other solar systems keeping the above ground rules in mind.

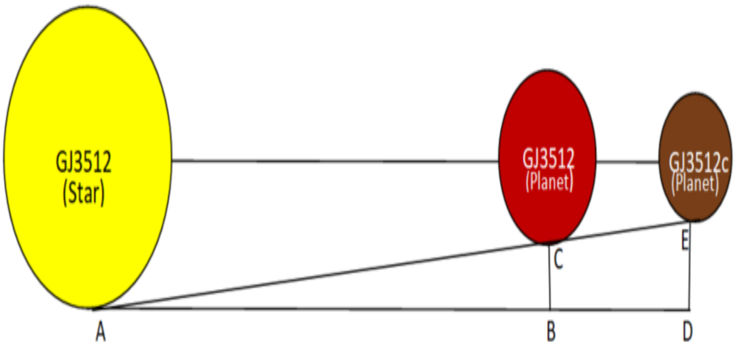

Figure 2*:* Possibility of planet to planet eclipse on imaginary planet in GJ 3512 system*.*

Recently, astronomers have discovered one such system, GJ3512 around 31 light years away from earth; in which the Exoplanet GJ3512b is nearly the same size as the host star [97], [108]. So given the scenario, the shadow cast by GJ3512b will be very large and may reach at distances where other planets can orbit. Astronomers recently discovered second planet orbiting the same star but it is yet to be confirmed by secondary sources. This planet is orbiting at about 1.3 AU from its star. Since the prediction of another planet orbiting the star GJ 3512 is not yet validated, let's assume a hypothetical planet at a distance of 149,600,000 km or 1AU in the same plane as the first planet [109], [110]. And let the planet be called GJ3512ci where 'i' stands for imaginary planet. Performing simple math of triangles to find out the shadow distance, one can check out the possibility of the eclipse on the hypothetical planet by GJ3512ci.

Here, left hand side circle is the star GJ3512, middle one is the planet GJ3512b whereas on the right hand side is the imaginary planet GJ3512ci.

Point A is at the circumference of the star GJ 3512.

Point B is the location of GJ 3512b from the star position

Point C is the circumference of the GJ351b

Point D is the location of GJ3512ci from the star position.

Point E is on the circumference of GJ3512ci

Radius of GJ3512 = 0.166 *Radius of Sun ~= 115500 km [111]	(1)
Radius of the GJ3512b = 1.27 *Radius of Jupiter~= 88800 km	(2)
Orbital Radius of GJ3512b = 0.338 AU = 0.338 * 149600000= 50565000 km	(3)
Distance of GJ512ci from GJ3512b = Distance from Earth from Sun = 1AU	(4)

Since ∆ABC is similar to ∆ ADE by AA test, one can write the ration of lengths are equal.

AB:AD::BC:DE	(5)
0.338/1=(115500-88800)/DE	(6)
DE= 1*26700/0.338	(7)
DE = 79000 km.	(8)

From Equation (8), the value DE is 79000 km, i.e. smaller than the radius of GJ3512 which is 115500 as shown in equation (1).Therefore, the light has not yet crossed the midpoint of GJ3512ci. Thus the shadow of the super Jupiter planet GJ 3512b can reach the planet in the Umbra region itself. In such a scenario, there is a possibility of having a planet - planet eclipse.

Another interesting example is of the stellar system WD 1856+534, a white dwarf star about 80 light years away from earth. This stellar system has a planet WD1856b which is about 10.4 times the radius of earth [94], [95], [112]. Comparing the radius of the planet and star will suggest that the planet's diameter is bigger than that of its host star.

Radius of WD1856 star = 0.013 * Radius of sun = 0.013*695700 ~=9044km	(9)
Radius of WD1856b = 10.4 *Radius of earth = 10.4*6378 ~= 66000 km	(10)

Hence the planet can virtually block the star and cast a shadow long enough that any other planet in the system will definitely experience a planet to planet eclipse.

Even though the above two examples are based upon an imaginary second planet, soon astronomers may find out a stellar system that exists with multiple planets. Hence, a proper naming system of such eclipses will be needed based upon the host star and two planets involved.

Apart from the above scenario where the two planets have separate orbits, a stellar system can exist, where two planets orbit each other with Barycenter somewhere between them. Like, there are stellar systems with two stars orbiting each other commonly called a double star system [113], [114]. Also, in our own solar system, Pluto and Charon are referred to as binary planetary systems [115]. So, it is highly possible to detect a stellar system where one will be able to detect two planets orbiting each other as binary systems. In such a scenario, it will be even more possible to have one planet eclipsing another planet due to their proximity and orbital motion. Following figure illustrates the same in a simple possible way.

Figure 3*:* Possibility of planet to planet eclipse on an imaginary dual planet system like Pluto and Charon.

3.2 Eclipses on One Moon by another Moon:

There are other kinds of eclipses, in which one can see some evidence in our solar system. One of them is the eclipse of a moon by another moon. As discussed earlier, both moons of Mars can cause occultation with respect to Mars (Phobos-Deimos occultation) and also they have transited the sun with respect to Mars individually [116]. That means both the moon may also come in a straight line with respect to the Sun.

Various telescopic images prove that all four Galilean moons of Jupiter can create solar eclipses on Jupiter [117]–[121]. Out of the four main Galilean moons, the largest two moons Ganymede and Callisto are having approximately the same inclination i.e. 0.204 and 0.205 respectively [122]–[124]. Since both the moons are orbiting in the same plane and they can both eclipse Jupiter, that means Callisto can also eclipse Ganymede, when they are both passing in front of Jupiter at the same time in a straight line.

Some unpublished sources have claimed to have seen Io casting shadows on another moon Ganymede [125]–[127]. Although there are multiple reports of these, authors have not yet found any published source on the same, but just one article in newspaper[128]. But this gives credence to the above theory.

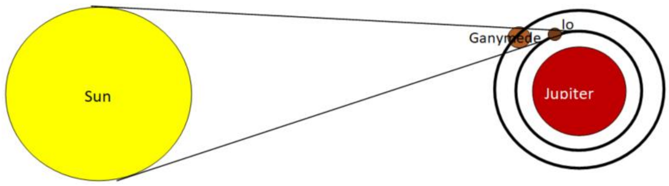

Figure 4*:* Possibility of Io eclipsing Ganymede (both moon of Jupiter) as claimed in paper Washington Post

Not just on the moons of Jupiter, but such an eclipse can occur on other planets where the moons are orbiting around the planets very near to their ecliptic plane. For example, moons of Uranus namely Ariel and Umbriel are going around at very small angles to the ecliptic plane [123], [129], [130]. ***Authors do understand that the Uranus axis is tilted and the moon of Uranus can never come in a straight line along with the sun to cause any eclipse.*** But in special case, if there is a planet like Uranus, whose axis is not tilted and has moons similar to Umbriel and Ariel, moving in same plane and about same distance from the planet, it is very likely to cause a moon eclipsing another moon. Just to figure out the possibility of the same, authors are employing simple math on the triangles as shown in figure.

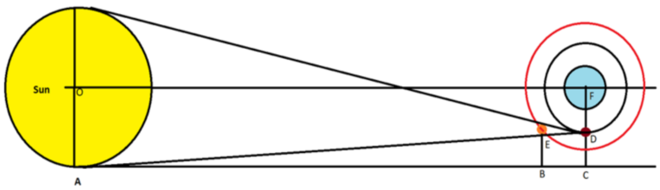

Figure 5*:* Top view of the solar system with the Sun, Uranus and its two moons Ariel and Umbriel in a system where Uranus is not tilted.

Point A is at the circumference of the star i.e. our Sun.

Point B is the location of Uranus Moon Umbriel on the tangent of the sun circumference

Point C is at the location of Uranus Moon Ariel on the tangent of the sun circumference

Point D is the location of Ariel on side of Uranus when facing the Sun

Point E is the location of the Umbriel in front of Ariel

Radius of Sun ~= 696340 km *[131]*	(11)
Radius of the Ariel ~= 1158 km *[132]*	(12)
Radius of Umbriel ~= 1170 Km *[133]*	(13)
Semi Major axis distance of Ariel from Uranus ~=191020 Km	(14)

Distance of Uranus from Sun = 2954100000 Km	(15)
Semi Major axis distance of Umbriel from Uranus ~=266300 Km	(16)

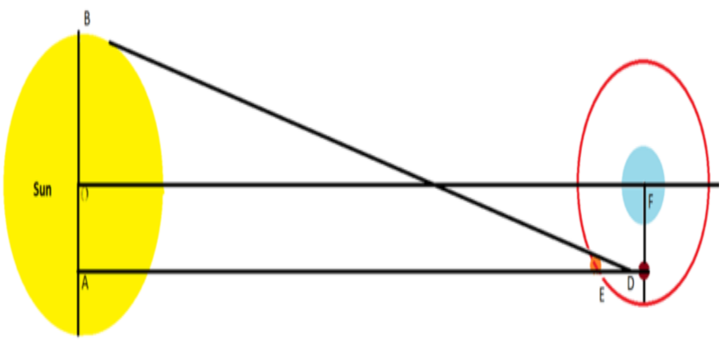

Figure 6*:* Ariel Eclipse of Umbriel in an imaginary system where Uranus is not tilted

From the above discussion one can figure out the position of the Uranus moon Umbriel from Ariel by considering the right angle triangle DEF.

In triangle DEF, ∟EDF is right angle and hence by Pythagoras Theorem, one figure out the distance DE as DF is semi major axis distance of Ariel from equation (14) and EF is semi major axis distance of Umbriel from equation (16).

DE=√(EF2 - DF2) = √(2663002 - 1910202) = 185545 km	(17)

Considering the ***Error! Reference source not found.***, the shadow of Uranus moon Umbriel will be shortest from the light coming from the opposite hemisphere of the Sun. Hence, the figure was modified to check if the shadow of the Umbriel will ever reach Ariel.

From , △DCE and △DBA are similar. Hence their sides have to be in equal ratio.

AB= Radius of Sun + Distance of Ariel from Uranus

EC=Radius of Umbriel - 1170 Km from equation (13)

AE=Distance of Sun from Umbriel is it in line with Sun and Ariel. So, AE will be Distance of Sun from Uranus - Distance of Ariel from Umbriel from equation (17).

AB= AO+OB = 696300+191020 = 887320 Km	(18)
AE= AD-ED = 2954100000 - 185545 = 2953914455 Km	(19)

AB/CE=AD/DE	(20)
887320/ 585=AE+DE/ DE	(21)
1516.8DE-DE=AE (AE is Distance of Sun from Umbriel = 2,953,914,455)	(22)
DE ~= 1,948,750 Km	(23)

However the Ariel and Umbriel are at an inclination of 0.260 and 0.205 degrees from the Uranus plane respectively. Calculating the offset of the moon from the center line by using trigonometry ratios.

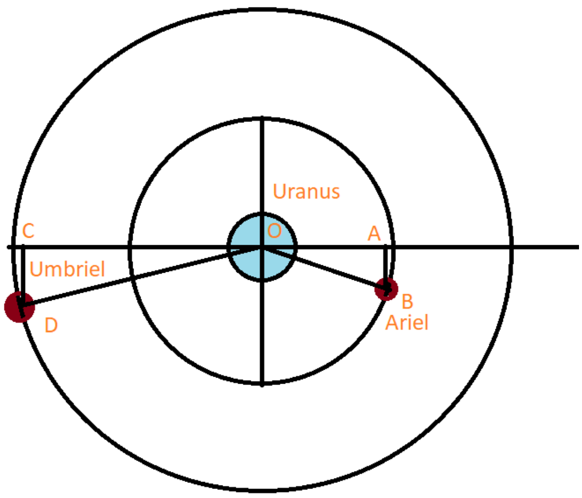

Figure 7*:* Exaggerated view of Arial and Umbriel tilt with respect to ecliptic plane in an imaginary system where Uranus is not tilted.

In the **Error! Reference source not found.**, the inclination of Ariel and Umbriel is exaggerated to make a point that the moons may not be at the center line. The goal here is to find the offset i.e. CD and AB to see if they are out of the shadow cast by the front moon Umbriel on Ariel.

From the above figure, △ODC and △OBA are right angle triangles at ∠OCD and ∠OAB respectively. Since the hypotenuse is known in both the cases i.e. semi major axis distance from Uranus and the angle of inclination is known as discussed above, one can figure out the offset by using Trigonometric Sin function.

CD = OD SIN(COD) = 266300* sin(0.205) = 952.8 Km	(24)
AB = OB SIN(AOB) = 191020* sin(0.260) = 866.8 Km	(25)

Since both the distances are nearly within a range of 100 Km which is way less than the radius of both moons i.e. about 575 Km one can see that the moon-moon eclipse is possible. The shadow of Umbriel i.e. 1948750 Km from equation (23) is about 10 times the distance between Umbriel and Ariel i.e. 185545 Km from equation (17). Hence it is quite possible that even with the offset the Uranus moon Umbriel may eclipse the moon Ariel.

Though this is ***not possible*** due to the tilted orbit of Uranus, it suggests that such possibility can exists and may occur on other planetary systems. Also, in other stellar systems, there may be higher possibilities of such moon-moon eclipses given that the moon sizes are bigger and the star size is smaller.

3.3 Nomenclature:

Abovementioned eclipses need to be defined based upon the celestial bodies involved in the phenomenon. On Earth, eclipses are defined with respect to earth's observation of celestial bodies and named by the object which is not visible to the observer on earth. During lunar eclipse, Moon is not visible and so is the case with sun during the solar eclipse. However to avoid confusion, new eclipses should be described in same way as occultation and transits were named above.

In case of one planet eclipsing another planet, it should be named as Planetary Eclipse by adding a bracket, clearly describing the observer position, body causing the eclipse. Here there is no need to mention the third body as it will be source of light which will be the host star.

There can be two types of the planetary eclipses depending on the observer's position: when the observer is on the planet that is eclipsing the other one, the eclipse will seem like the lunar eclipse on the earth, but it won't be a lunar eclipse as the eclipse is of a planet. Such eclipses should be called as Planetary eclipse. The second type is when the observer will be on the planet that is being eclipsed. It will be like the solar eclipse on the earth, so can be named as Planetary Solar Eclipse.

The format of the name is: Planetary eclipse (observer position - the second body in the arrangement). So: On the stellar system GJ3512, the eclipse taking place will be named as, Planetary Solar Eclipse (GJ3512ci-GJ3512b) if the observer is on GJ3512ci, and if the observer is on GJ3512b, it will be called Planetary Eclipse (GJ3512b-GJ3512ci). Similarly, in the case of WD1856+534 eclipses will be, Planetary Solar Eclipse (any planet, if found - WD1856+534 b) or Planetary Eclipse (WD1856+534 b - any planet, if found).

Similarly, in the case of Lunar Eclipse of one moon by another moon, when the observer is on the moon that is eclipsing, it will be called Lunar Eclipse only. When the observer is on the moon that is being eclipsed, it can be named as Lunar Solar Eclipse. In the case of Io eclipsing Ganymede, observers from Ganymede will call it lunar Eclipse (Ganymede-Io) and observers from Io will call it Lunar Eclipse (Io - Ganymede).The same format can be followed in other systems also.

4. FOUR CELESTIAL OBJECTS IN ONE LINE:

As discussed before, the Curiosity rover observed that Phobos can occult Deimos and both moons can transit the sun independently and that they all (Mars, Phobos, Deimos and Sun) can come together in a straight line. This phenomenon will be called a transit and not an eclipse as the moons of Mars are not big enough to cast a shadow. But if on some other planet or Exoplanets, where the moons are big enough to cast a shadow, it is quite possible given the range of Exoplanets astronomers have discovered [134]. Like that happened and reported on the planet Jupiter where Ganymede is casting shadow on Europa, while the shadow of both is being casted on Jupiter at the same time[128].

There may be a possibility of seeing multiple bodies aligning in the same line, big enough to cast shadows which will create an observation far beyond the explanation of today's terminology. These kinds of eclipses need to be further classified and studied. One can classify these types of eclipses on the basis of different arrangements of celestial bodies involved in the eclipses. Since, the discussion is about eclipses, alignment of small bodies which cannot cast long enough shadows like asteroids, rings, etc. are neglected.

4.1 Sun Moon –Moon Planet Syzgy:

Even though astronomers have not seen Sun-Deimos-Phobos-Mars alignment, having four bodies in a straight line that can create an eclipse is surely possible. As suggested by the paper Washington post, Jupiter's moons Ganymede and Callisto can cast shadow on Europa or Io. Astronomers have discovered eclipses by all the moons on the planet individually. But since they all have nearly the same small inclination angle (about 0.205), the possibility of two moons coming in a straight line increases [135], [136]. For a person standing on Jupiter at the right time and right position can see a solar eclipse of two moons occurring simultaneously. So while Callisto will be casting a shadow on Jupiter, Ganymede or Europa can come in between and provide an appearance of multiple Solar eclipse. As the moon near the planet moves faster compared to moons away from the planet, it is quite possible; Ganymede or Europa can come in between and add another layer of shadow.

Figure 8: Four body alignment creating multiple body eclipse as imagined on Jupiter.

However for the above possibility, both the moons need to be of appropriate sizes to cast shadows long enough to reach the planet surface.

4.2 Sun Moon Planet Moon Syzgy:

On a planet with multiple moons, it is quite possible that on one side of the planet; solar eclipse will be going on, while from the other side, there can be a lunar eclipse happening on another moon. The possibility of the sun, both moons and the planet coming in a straight line is quite obvious. On the planet, there cannot be a single site from where one can observe both the solar eclipse and lunar eclipse simultaneously. From the moon behind the planet, one may never see the second moon in front of the planet and observes the Sun, moon and planet in a straight line. Same is true for the moon in between the sun and the planet. At no single site on the moon, can one see the sun; planet and the other moon align in a straight line. For example, in the Jupiter planetary system, its moon Io and Europa can have such an alignment. Since the possibility of such an event is rare to be visible from a single point on any of the body, there is no immediate need for naming such an event. If discovered in future, the names will be pretty obvious based upon other names given in the sections below.

4.3 Sun Planet Moon Moon Syzgy:

It is a possibility that the Sun, the Planet, and its two moons can come in a straight line leading to two solar eclipses, when observed from the last moon. It is quite possible that while a solar eclipse is going on, when viewed from one moon, another moon orbiting closer to the planet can come in between planet and moon. This will create a four body eclipse when viewed from the first moon. For example, when observed from Jupiter's moon Callisto, Jupiter can block the sun and cast a shadow on Callisto. But at the same time, Ganymede at nearly the same inclination can come in between Jupiter and Callisto further creating an amazing view of multiple bodies aligning at the same time. In this arrangement, the first moon is covered by the shadow of the planet, and the second moon is covered by the shadow of both the first moon and the planet.

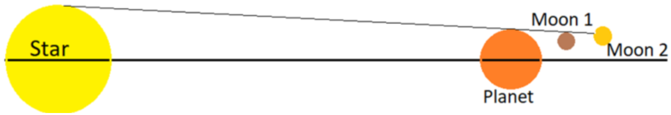

Figure 9: Four body Eclipse with planet eclipsing two moons.

Similarly on Pluto, when looking from Nix or Styx, both Pluto and Charon can come in between the moon and the sun. The four bodies may be in alignment for a small time, but it will be a sight to look out for.

Even though a wide range of new eclipses are discussed in here, authors don't think that these will be the final frontier. There are many more different phenomena yet to be observed or named, but if it is possible physically or mathematically, it is a matter of time before scientists observe them.

4.4 Nomenclature:

Continuing with the same format discussed earlier; following nomenclature is suggested for describing four body eclipses to avoid any confusion. The names are given with respect to view from the last body as the body in the middle will have eclipses similar to one discussed earlier.

In any of the cases discussed, the observer from the last body is going to observe two solar eclipses created by two different bodies and hence it can be named as **Twin Solar Eclipses.** However, it is also essential to identify on which planet or moon the eclipse is taking place and the arrangement of celestial bodies. Hence the following nomenclature:

On the planetary system Jupiter, the arrangement of Sun, Callisto, Ganymede and Jupiter should be represented as a Twin Solar Eclipse on Jupiter (Callisto-Ganymede).

On the planetary system of Pluto, when the arrangement of Sun, Pluto, Charon and Nyx come into play, it can be called as Twin Solar Eclipse on Nyx (Pluto- Charon). The same can be used for other planetary systems also without changing the convention.

3. CONCLUSIONS

The discovery of different types of Exoplanets and exomoons orbiting various kinds of big or small stars may result in different, new and interesting kinds of eclipses or transits being observed in future. So it is necessary to do their identification and classification. Such scenarios may provide a perspective about the motion of planetary systems in the future. Since astronomers have discovered exoplanets of various shapes, sizes that orbits around different kinds of stars, discovery of the exomoons will further add spice to the entire viewing profile.

So based upon various observations till now, authors have extrapolated some scenarios and try to classify various eclipses, occultations and transits. With the technological advancement, these phenomena will be broadcasted live in future from other planets as fast as possible to create awareness among the space enthusiastic community. Hence identifying and naming them is important.

REFERENCES

[1] A. Cassan *et al.*, "One or more bound planets per Milky Way star from microlensing observations," *Nature*, vol. 481, no. 7380, pp. 167–169, Jan. 2012, doi: 10.1038/nature10684.

[2] E. A. Petigura, A. W. Howard, and G. W. Marcy, "Prevalence of Earth-size planets orbiting Sun-like stars," *Proceedings of the National Academy of Sciences*, vol. 110, no. 48, pp. 19273–19278, Nov. 2013, doi: 10.1073/pnas.1319909110.

[3] F. J. Ballesteros, A. Fernandez-Soto, and V. J. Martínez, "Diving into Exoplanets: Are Water Seas the Most Common?," *Astrobiology*, vol. 19, no. 5, pp. 642–654, May 2019, doi: 10.1089/ast.2017.1720.

[4] M. Benisty *et al.*, "A Circumplanetary Disk around PDS70c," *ApJL*, vol. 916, no. 1, p. L2, Jul. 2021, doi: 10.3847/2041-8213/ac0f83.

[5] Z. Zhang, M. C. Liu, Z. R. Claytor, W. M. J. Best, T. J. Dupuy, and R. J. Siverd, "The Second Discovery from the COCONUTS Program: A Cold Wide-orbit Exoplanet around a Young Field M Dwarf at 10.9 pc," *ApJL*, vol. 916, no. 2, p. L11, Aug. 2021, doi: 10.3847/2041-8213/ac1123.

[6] P. Brennen and K. Walbot, "Exoplanet Exploration," *Exoplanet Exploration*. https://exoplanets.nasa.gov/what-is-an-exoplanet/overview/

[7] B. Brewer, *Eclipse: History. Science. Awe*, Third edition. Seattle, Wash: Earth View, 2017.

[8] P. Harrington, *Eclipse!: The What, Where, When, Why, and How Guide to Watching Solar and Lunar Eclipses*. Wiley, 1997.

[9] D. Steel, *Eclipse: the celestial phenomenon that changed the course of history*. Washington, DC: Joseph Henry Press, 2001.

[10] H. H. Schmitt, *Return to the Moon: Exploration, Enterprise, and Energy in the Human Settlement of Space*. New York, NY: Springer New York, 2006. Accessed: Jul. 27, 2021. [Online]. Available: http://www.myilibrary.com?id=114135

[11] D. G. Schrunk, B. L. Sharpe, B. L. Cooper, and M. Thangavelu, *The moon: resources, future development, and settlement*. Berlin; Chichester: Springer : Praxis, 2007. Accessed: Jul. 27, 2021. [Online]. Available: https://liverpool.idm.oclc.org/login?url=http://dx.doi.org/10.1007/978-0-387-73982-3

[12] D. Bolles, "A Solar Eclipse on the Moon," *Lunar Eclipse*, 2021. https://science.nasa.gov/science-news/science-at-nasa/2005/20apr_lunareclipse

[13] R. Nemiroff and J. Bonell, "A Solar Eclipse from the Moon," *Astronomy Picture of the Day*, 2014. https://apod.nasa.gov/apod/ap140407.html

[14] M. Perryman, *The Exoplanet Handbook:*, 2nd ed. Cambridge University Press, 2018. doi: 10.1017/9781108304160.

[15] S. B. Howell *et al.*, "The K2 Mission: Characterization and Early Results," *Publications of the Astronomical Society of the Pacific*, vol. 126, no. 938, pp. 398–408, Apr. 2014, doi: 10.1086/676406.

[16] J. Lankford, *History of astronomy: an encyclopedia*. 2011.

[17] B. Dunbar, "When Planets Transit," *When Planets Transit*. https://www.nasa.gov/feature/when-planets-transit

[18] D. Sellers, *The transit of Venus: the quest to find the true distance of the sun*. Leeds: MagaVelda Press, 2001.

[19] G. F. Chambers, *A Handbook of Descriptive and Practical Astronomy*. 1861.

[20] H. Karttunen, *Fundamental astronomy*. Berlin; New York: Springer, 2007. Accessed: Jul. 27, 2021. [Online]. Available: http://site.ebrary.com/id/10230128

[21] B. O'Leary, "Frequencies of Occultations of Stars by Planets, Satellites, and Asteroids," *Science*, vol. 175, no. 4026, pp. 1108–1112, Mar. 1972, doi: 10.1126/science.175.4026.1108.

[22] J. L. Elliot, "Stellar Occultation Studies of the Solar System," *Annu. Rev. Astron. Astrophys.*, vol. 17, no. 1, pp. 445–475, Sep. 1979, doi: 10.1146/annurev.aa.17.090179.002305.

[23] JPL Caltech, "Curiosity Observes Phobos Eclipse: Sol 2359," *Curiosity Observes Phobos Eclipse: Sol 2359*, 2019. https://mars.nasa.gov/resources/22392/curiosity-observes-phobos-eclipse-sol-2359/

[24] B. Dunbar, "Rare Triple Eclipse on Jupiter," *Rare Triple Eclipse on Jupiter*. https://www.nasa.gov/centers/goddard/multimedia/largest/triple_eclipse.jpg.html

[25] B. Dunbar, "Curiosity Rover," *Curiosity Rover*, Mar. 04, 2020. https://www.nasa.gov/mission_pages/msl/index.html

[26] M. McAuley, "PhotoJournal," *Photo Journal of Mars*, Mar. 04, 2020. https://photojournal.jpl.nasa.gov/targetFamily/Mars

[27] P. K. Seidelmann, United States Naval Observatory, and Great Britain, Eds., *Explanatory supplement to the Astronomical almanac*, Rev. ed. Mill Valley, Calif: University Science Books, 1992.

[28] A. young, "Transits and Occultations," *Eclipse 101*. https://eclipse2017.nasa.gov/transits-and-occultations

[29] D. M. Popper, "Transit or occultation?," *Astrophys Space Sci*, vol. 45, no. 2, pp. 391–396, Dec. 1976, doi: 10.1007/BF00642673.

[30] Herodotus, A. D. Godley, Herodotus, and Herodotus, *Herodotus*, vol. 7, 7 vols. in The Loeb classical library, no. 117–120, vol. 7. Cambridge, Massachusetts: Harvard University Press, 1990), 1981.

[31] N. Nigro, *Knack night sky: decoding the solar system. from constellations to black holes*. 2010. Accessed: Aug. 31, 2020. [Online]. Available: http://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=4427158

[32] F. Mullally *et al.*, "PLANETARY CANDIDATES OBSERVED BY *KEPLER* . VI. PLANET SAMPLE FROM Q1–Q16 (47 MONTHS)," *ApJS*, vol. 217, no. 2, p. 31, Apr. 2015, doi: 10.1088/0067-0049/217/2/31.

[33] J. E. Colwell, L. W. Esposito, R. G. Jerousek, M. Sremčević, D. Pettis, and E. T. Bradley, "CASSINI UVIS STELLAR OCCULTATION OBSERVATIONS OF SATURN's RINGS," *The Astronomical Journal*, vol. 140, no. 6, pp. 1569–1578, Dec. 2010, doi: 10.1088/0004-6256/140/6/1569.

[34] R. G. French *et al.*, "Uranian ring orbits from earth-based and Voyager occultation observations," *Icarus*, vol. 73, no. 2, pp. 349–378, Feb. 1988, doi: 10.1016/0019-1035(88)90104-2.

[35] T. D. Robinson, L. Maltagliati, M. S. Marley, and J. J. Fortney, "Titan solar occultation observations reveal transit spectra of a hazy world," *Proceedings of the National Academy of Sciences*, vol. 111, no. 25, pp. 9042–9047, Jun. 2014, doi: 10.1073/pnas.1403473111.

[36] A. J. Kliore, "Radio Occultation Observations of the Ionospheres of Mars and Venus," in *Geophysical Monograph Series*, J. G. Luhmann, M. Tatrallyay, and R. O. Pepin, Eds., Washington, D. C.: American Geophysical Union, 2013, pp. 265–276. doi: 10.1029/GM066p0265.

[37] J. E. Westfall and W. Sheehan, *Celestial shadows: eclipses, transits, and occultations*. in Astrophysics and space science library, no. 410. New York ; Heidelberg: Springer, 2015.

[38] A. Stern and D. J. Tholen, Eds., *Pluto and Charon*. in Space science series. Tucson: University of Arizona Press, 1997.

[39] D. W. Dunham *et al.*, "The size and shape of (2) Pallas from the 1983 occultation of 1 Vulpeculae," *The Astronomical Journal*, vol. 99, p. 1636, May 1990, doi: 10.1086/115446.

[40] A. Dudhia, "SATELLITE REMOTE SENSING | Temperature Soundings," in *Encyclopedia of Atmospheric Sciences*, Elsevier, 2003, pp. 1985–1998. doi: 10.1016/B0-12-227090-8/00355-9.

[41] S. A. Stern, J. Wm. Parker, and C. B. Olkin, "Pluto, Charon, and the Kuiper Belt Objects," in *Treatise on Geophysics*, Elsevier, 2007, pp. 541–564. doi: 10.1016/B978-044452748-6.00169-3.

[42] N. Emelyanov, "Obtaining astrometric data from observations of mutual occultations and eclipses of planetary satellites," in *The Dynamics of Natural Satellites of the Planets*, Elsevier, 2021, pp. 239–276. doi: 10.1016/B978-0-12-822704-6.00012-1.

[43] S. Seager, R. Dotson, and Lunar and Planetary Institute, Eds., *Exoplanets*. in The University of Arizona space science series. Tucson : Houston: University of Arizona Press ; In collaboration with Lunar and Planetary Institute, 2010.

[44] R. Nather and D. Evans, "Photoelectric Measurement of Lunar Occultations. I. The Process," *The Astronomical Journal*, vol. 75, no. 5, p. 575, 1970.

[45] P. Scheuer, "On the Use of Lunar Occultations for Investigating the Angular Structure of Radio Sources," *Aust. J. Phys.*, vol. 15, no. 3, p. 333, 1962, doi: 10.1071/PH620333.

[46] J. Africano, D. Evans, and F. Fekel, "Photoelectric measurements of lunar occultations. VIII," *The Astronomical Journal*, vol. 81, no. 8, p. 575, 1976.

[47] P. Tanga and M. Delbo, "Asteroid occultations today and tomorrow: toward the GAIA era," *Astronomy & Astrophysics*, vol. 474, no. 3, pp. 1015–1022, 2007.

[48] J. N. Winn, "Transits and Occultations," *arXiv:1001.2010 [astro-ph]*, Sep. 2014, Accessed: Aug. 30, 2021. [Online]. Available: http://arxiv.org/abs/1001.2010

[49] D. Charbonneau, T. M. Brown, D. W. Latham, and M. Mayor, "Detection of Planetary Transits Across a Sun-like Star," *The Astrophysical Journal*, vol. 529, no. 1, pp. L45–L48, Jan. 2000, doi: 10.1086/312457.

[50] C. J. Copi and G. D. Starkman, "The Big Occulting Steerable Satellite (BOSS)," *ApJ*, vol. 532, no. 1, pp. 581–592, Mar. 2000, doi: 10.1086/308525.

[51] K. C. Freeman and G. Lynga, "Data for Neptune from occultation observations," *ApJ*, vol. 160, p. 767, May 1970, doi: 10.1086/150468.

[52] W. B. McKinnon, "Introduction to 'Pluto, Charon, and the Kuiper Belt Objects': Pluto on the Eve of the New Horizons Encounter," in *Treatise on Geophysics*, Elsevier, 2015, pp. 637–651. doi: 10.1016/B978-0-444-53802-4.00210-4.

[53] J. E. Colwell, L. W. Esposito, and M. Sremčević, "Self-gravity wakes in Saturn's A ring measured by stellar occultations from Cassini," *Geophys. Res. Lett.*, vol. 33, no. 7, p. L07201, 2006, doi: 10.1029/2005GL025163.

[54] M. M. Hedman, P. D. Nicholson, and H. Salo, "EXPLORING OVERSTABILITIES IN SATURN'S A RING USING TWO STELLAR OCCULTATIONS," *AJ*, vol. 148, no. 1, p. 15, Jun. 2014, doi: 10.1088/0004-6256/148/1/15.

[55] J.-H. Yee, R. J. Vervack, and R. Demajistre, "The Stellar Occultation Technique: Past Achievements, Recent Developments, and Future Challenges," in *Occultations for Probing Atmosphere and Climate*, G. Kirchengast, U. Foelsche, and A. K. Steiner, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2004, pp. 261–273. doi: 10.1007/978-3-662-09041-1_23.

[56] C. C. Porco and D. P. Hamilton, "Planetary Rings," in *Encyclopedia of the Solar System*, Elsevier, 2007, pp. 503–518. doi: 10.1016/B978-012088589-3/50031-1.

[57] J. L. Ortiz, B. Sicardy, J. I. B. Camargo, P. Santos-Sanz, and F. Braga-Ribas, "Stellar occultations by Trans-Neptunian objects: From predictions to observations and prospects for the future," in *The Trans-Neptunian Solar System*, Elsevier, 2020, pp. 413–437. doi: 10.1016/B978-0-12-816490-7.00019-9.

[58] B. Sicardy *et al.*, "The dynamics of rings around Centaurs and Trans-Neptunian objects," in *The Trans-Neptunian Solar System*, Elsevier, 2020, pp. 249–269. doi: 10.1016/B978-0-12-816490-7.00011-4.

[59] A. R. Cooray, J. L. Elliot, A. S. Bosh, and L. A. Young, "Stellar Occultation Observations of Saturn's North-Polar Temperature Structure," *Icarus*, vol. 132, pp. 298–310, 1998.

[60] J. L. Ortiz *et al.*, "The size, shape, density and ring of the dwarf planet Haumea from a stellar occultation," *Nature*, vol. 550, no. 7675, pp. 219–223, Oct. 2017, doi: 10.1038/nature24051.

[61] "AT WORK ON MARS," *Mars*, Mar. 2021. https://www.jpl.nasa.gov/topics/mars

[62] Institute of Electrical and Electronics Engineers, IEEE Systems, Man, and Cybernetics Society, IEEE Reliability Society, and International Council on Systems Engineering, Eds., *Systems engineering the Curiosity Rover: A retrospective*. Piscataway, NJ: IEEE, 2013.

[63] "Mars Curiosity Rover," *Mars*, Mar. 2021. https://mars.nasa.gov/msl/home/

[64] T. Greicius and N. Hartono, "Before and After Occultation of Deimos by Phobos," *Before and After Occultation of Deimos by Phobos*, Mar. 2021. https://www.jpl.nasa.gov/images/before-and-after-occultation-of-deimos-by-phobos

[65] P. M. Schenk, R. N. Clark, C. J. A. Howett, A. J. Verbiscer, J. H. Waite, and R. Dotson, Eds., *Enceladus and the icy moons of Saturn*. in The University of Arizona space science series. Tucson: The University of Arizona Press in collaboration with Lunar and Planetary Institute, Houston, 2018.

[66] A. Barnett, "Occulting Enceladus," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/resources/14283/occulting-enceladus/

[67] A. Mallama and B. Krobusek, "Eclipses of Saturn's moons," *J. Geophys. Res.*, vol. 101, no. E7, pp. 16901–16904, Jul. 1996, doi: 10.1029/96JE01604.

[68] J. Elliot, “Lunar occultation of Saturn. I. The diameters of Tethys, Dione, Rhea, Titan, and Iapetus,” *Icarus*, vol. 26, no. 4, pp. 387–407, Dec. 1975, doi: 10.1016/0019-1035(75)90107-4.

[69] M. Dougherty, L. Esposito, T. Krimigis, and M. K. Dougherty, *Saturn from Cassini-Huygens*. Dordrecht London: Springer, 2009.

[70] F. W. Price, *The planet observer's handbook*, 2nd ed. Cambridge ; New York: Cambridge University Press, 2000.

[71] D. Dunhan, “The International Occultation Timing Association 24th Annual Meeting at Mt. Cuba Observatory, Greenville, Delaware,” in *International Occultation Timing Association*, Greenville, Delaware, 2006.

[72] J. L. Hilton, P. K. Seidelmann, and C. Liu, “Analysis of ancient Chinese records of occultations between planets and stars,” *The Astronomical Journal*, vol. 96, p. 1482, Oct. 1988, doi: 10.1086/114900.

[73] R. Luger, J. Lustig-Yaeger, and E. Agol, “Planet–Planet Occultations in TRAPPIST-1 and Other Exoplanet Systems,” *ApJ*, vol. 851, no. 2, p. 94, Dec. 2017, doi: 10.3847/1538-4357/aa9c43.

[74] G. M. Nikolskiy, A. I. Simonov, I. S. Kim, R. T. Guila, and M. D. Jenness, “Artificial solar eclipse: Experiment MA-148,” *In its Apollo-Soyuz Test Proj*, vol. 1, pp. 85–99, 1977.

[75] T. Greicius, “Mercury Passes in Front of the Sun, as Seen From Mars,” *Solar Sytem*, Mar. 2021. https://www.jpl.nasa.gov/news/mercury-passes-in-front-of-the-sun-as-seen-from-mars

[76] S. C. Stähler *et al.*, “Geophysical Observations of Phobos Transits by InSight,” *Geophys. Res. Lett.*, vol. 47, no. 19, Oct. 2020, doi: 10.1029/2020GL089099.

[77] R. D. Lorenz *et al.*, “Scientific Observations With the InSight Solar Arrays: Dust, Clouds, and Eclipses on Mars,” *Earth and Space Science*, vol. 7, no. 5, May 2020, doi: 10.1029/2019EA000992.

[78] R. Park, “Horizons System,” *Solar System Dynamics*, Spetmeber 2021. https://ssd.jpl.nasa.gov/?horizons

[79] G. I. Redfern, “International Space Station and Satellites,” in *Astrophotography is Easy!*, in The Patrick Moore Practical Astronomy Series. Cham: Springer International Publishing, 2020, pp. 305–310. doi: 10.1007/978-3-030-45943-7_16.

[80] “The Transit and Tail of Halley's Comet,” *Nature*, vol. 83, no. 2121, pp. 501–502, Jun. 1910, doi: 10.1038/083501c0.

[81] “The Understanding of Their Physical Nature,” in *Comets*, Dordrecht: Springer Netherlands, 2005, pp. 39–75. doi: 10.1007/1-4020-3495-4_3.

[82] A. Teachey and D. M. Kipping, “Evidence for a large exomoon orbiting Kepler-1625b,” *Sci. Adv.*, vol. 4, no. 10, p. eaav1784, Oct. 2018, doi: 10.1126/sciadv.aav1784.

[83] A. Teachey, D. Kipping, C. J. Burke, R. Angus, and A. W. Howard, “Loose Ends for the Exomoon Candidate Host Kepler-1625b,” *AJ*, vol. 159, no. 4, p. 142, Mar. 2020, doi: 10.3847/1538-3881/ab7001.

[84] A. S. Hamers and S. F. Portegies Zwart, “Catching a Planet: A Tidal Capture Origin for the Exomoon Candidate *Kepler* 1625b I,” *ApJ*, vol. 869, no. 2, p. L27, Dec. 2018, doi: 10.3847/2041-8213/aaf3a7.

[85] C. R. Kitchin, *Exoplanets: finding, exploring, and understanding alien worlds*. in Astronomers' universe. New York: Springer, 2012.

[86] “Astronomers Directly Image Massive Star's ‘Super-Jupiter,’” *Universe*, 2012. https://www.nasa.gov/topics/universe/features/super-jupiter.html

[87] R. A. Moraes and E. Vieira Neto, “Exploring formation scenarios for the exomoon candidate Kepler 1625b I,” *Monthly Notices of the Royal Astronomical Society*, vol. 495, no. 4, pp. 3763–3776, Jul. 2020, doi: 10.1093/mnras/staa1441.

[88] K. Rodenbeck, R. Heller, M. Hippke, and L. Gizon, “Revisiting the exomoon candidate signal around Kepler-1625 b,” *A&A*, vol. 617, p. A49, Sep. 2018, doi: 10.1051/0004-6361/201833085.

[89] L. Kreidberg, R. Luger, and M. Bedell, “No Evidence for Lunar Transit in New Analysis of Hubble Space Telescope Observations of the Kepler-1625 System,” *ApJ*, vol. 877, no. 2, p. L15, May 2019, doi: 10.3847/2041-8213/ab20c8.

[90] D. Forgan, “The habitable zone for Earthlike exomoons orbiting Kepler-1625b,” *arXiv:1810.02712 [astro-ph]*, Nov. 2018, Accessed: Sep. 14, 2021. [Online]. Available: http://arxiv.org/abs/1810.02712

[91] A. Teachey, D. M. Kipping, and A. R. Schmitt, “HEK. VI. On the Dearth of Galilean Analogs in *Kepler* , and the Exomoon Candidate Kepler-1625b I,” *AJ*, vol.

155, no. 1, p. 36, Dec. 2017, doi: 10.3847/1538-3881/aa93f2.

[92] Y. Alibert and W. Benz, "Formation and composition of planets around very low mass stars," *A&A*, vol. 598, p. L5, Feb. 2017, doi: 10.1051/0004-6361/201629671.

[93] C. E. O'Connor, B. Liu, and D. Lai, "Enhanced Lidov–Kozai migration and the formation of the transiting giant planet WD 1856+534 b," *Monthly Notices of the Royal Astronomical Society*, vol. 501, no. 1, pp. 507–514, Dec. 2020, doi: 10.1093/mnras/staa3723.

[94] P. Brennen, "WD 1856+534 b," *EXOPLANET CATALOG*, 2020. https://mars.nasa.gov/msl/home/

[95] F. Lagos, M. R. Schreiber, M. Zorotovic, B. T. Gänsicke, M. P. Ronco, and A. S. Hamers, "WD 1856 b: a close giant planet around a white dwarf that could have survived a common envelope phase," *Monthly Notices of the Royal Astronomical Society*, vol. 501, no. 1, pp. 676–682, Dec. 2020, doi: 10.1093/mnras/staa3703.

[96] G. Laughlin, "The world that came in from the cold," *Science*, vol. 365, no. 6460, pp. 1382–1383, Sep. 2019, doi: 10.1126/science.aay7775.

[97] J. Lopez-Santiago, L. Martino, J. Míguez, and M. A. Vázquez, "A Likely Magnetic Activity Cycle for the Exoplanet Host M Dwarf GJ 3512," *AJ*, vol. 160, no. 6, p. 273, Nov. 2020, doi: 10.3847/1538-3881/abc171.

[98] R. Alonso *et al.*, "A transmission spectrum of the planet candidate WD 1856+534 b and a lower limit to its mass," *A&A*, vol. 649, p. A131, May 2021, doi: 10.1051/0004-6361/202140359.

[99] J. A. Johnson *et al.*, "CHARACTERIZING THE COOL KOIs. II. THE M DWARF KOI-254 AND ITS HOT JUPITER," *The Astronomical Journal*, vol. 143, no. 5, p. 111, May 2012, doi: 10.1088/0004-6256/143/5/111.

[100] J. Chen and D. Kipping, "PROBABILISTIC FORECASTING OF THE MASSES AND RADII OF OTHER WORLDS," *ApJ*, vol. 834, no. 1, p. 17, Dec. 2016, doi: 10.3847/1538-4357/834/1/17.

[101] A. Barnett, "10 Things: All About TRAPPIST-1," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/news/335/10-things-all-about-trappist-1/

[102] P. Brennen, "Largest batch of Earth-size, habitable zone planets," *Exoplanet Exploration*, Mar. 2021. https://exoplanets.nasa.gov/trappist1/#Poster

[103] S. R. Kane and S. Blunt, "In the Presence of a Wrecking Ball: Orbital Stability in the HR 5183 System," *AJ*, vol. 158, no. 5, p. 209, Oct. 2019, doi: 10.3847/1538-3881/ab4c3e.

[104] S. Blunt *et al.*, "Radial Velocity Discovery of an Eccentric Jovian World Orbiting at 18 au," *AJ*, vol. 158, no. 5, p. 181, Oct. 2019, doi: 10.3847/1538-3881/ab3e63.

[105] S. J. Fossey, I. P. Waldman, and D. M. Kipping, "Detection of a transit by the planetary companion of HD 80606," *Monthly Notices of the Royal Astronomical Society: Letters*, vol. 396, no. 1, pp. L16–L20, Jun. 2009, doi: 10.1111/j.1745-3933.2009.00653.x.

[106] M. G. Hidas *et al.*, "An ingress and a complete transit of HD 80606 b," *Monthly Notices of the Royal Astronomical Society*, p. no-no, May 2010, doi: 10.1111/j.1365-2966.2010.16744.x.

[107] S. J. O'Toole *et al.*, "Selection Functions in Doppler Planet Searches," *Monthly Notices of the Royal Astronomical Society*, vol. 392, no. 2, pp. 641–654, Jan. 2009, doi: 10.1111/j.1365-2966.2008.14051.x.

[108] Y.-H. Wang, R. Perna, and N. W. C. Leigh, "Giant Planet Swaps during Close Stellar Encounters," *ApJ*, vol. 891, no. 1, p. L14, Mar. 2020, doi: 10.3847/2041-8213/ab77d0.

[109] J. H. Shirley and R. W. Fairbridge, Eds., *Encyclopedia of planetary sciences*, 1st ed. in Encyclopedia of earth sciences series. London ; New York: Chapman & Hall, 1997.

[110] B. Luque and F. J. Ballesteros, "To the Sun and beyond," *Nat. Phys.*, vol. 15, no. 12, pp. 1302–1302, Dec. 2019, doi: 10.1038/s41567-019-0685-3.

[111] P. Brennen, "GJ 3512 b," *EXOPLANET CATALOG*. https://exoplanets.nasa.gov/exoplanet-catalog/7476/gj-3512-b/

[112] A. Merlov, E. Bear, and N. Soker, "A Red Giant Branch Common-envelope Evolution Scenario for the Exoplanet WD 1856 b," *ApJL*, vol. 915, no. 2, p. L34, Jul. 2021, doi: 10.3847/2041-8213/ac0f7d.

[113] P. Brennen, "Orbiting in the Habitable Zone of Two Suns," *Exoplanet Exploration*, 2020. https://exoplanets.nasa.gov/resources/97/orbiting-in-the-habitable-zone-of-two-suns/

[114] W. D. Heintz and W. D. Heintz, *Double stars: Wulff D(ieter) Heintz*. in (Geophysics and astrophysics monographs, no. 15). Dordrecht [usw.]: Reidel, 1978.

[115] I. Asimov and I. Asimov, *Pluto: a double planet?*, A Gareth Stevens Children's Books ed. in Isaac Asimov's library of the universe. Milwaukee: G. Stevens Pub, 1990.

[116] J. F. Bell *et al.*, "Solar eclipses of Phobos and Deimos observed from the surface of Mars," *Nature*, vol. 436, no. 7047, pp. 55–57, Jul. 2005, doi: 10.1038/nature03437.

[117] R. Nemiroff, "Astronomy Picture of the Day," *APOD*, Mar. 2021. https://apod.nasa.gov/apod/ap150206.html

[118] R. Nemiroff, "Astronomy Picture of the Day," *APOD*, Mar. 2021. https://apod.nasa.gov/apod/ap041111.html

[119] C. C. C. Tsang, J. R. Spencer, E. Lellouch, M. A. Lopez-Valverde, and M. J. Richter, "The collapse of Io's primary atmosphere in Jupiter eclipse: IO's ATMOSPHERE IN ECLIPSE," *J. Geophys. Res. Planets*, vol. 121, no. 8, pp. 1400–1410, Aug. 2016, doi: 10.1002/2016JE005025.

[120] G. L. Goodwin and G. J. Hobson, "Atmospheric gravity waves generated during a solar eclipse," *Nature*, vol. 275, no. 5676, pp. 109–111, Sep. 1978, doi: 10.1038/275109a0.

[121] V. Hue *et al.*, "Juno-UVS Observation of the Io Footprint During Solar Eclipse," *J. Geophys. Res. Space Physics*, vol. 124, no. 7, pp. 5184–5199, Jul. 2019, doi: 10.1029/2018JA026431.

[122] P. K. S. (Chair) *et al.*, "[No title found]," *Celestial Mechanics and Dynamical Astronomy*, vol. 82, no. 1, pp. 83–111, 2002, doi: 10.1023/A:1013939327465.

[123] "Planetary Satellite Mean Orbital Parameters," *Solar System Dynamics*, Sep. 2021. https://ssd.jpl.nasa.gov/?sat_elem

[124] S. Musotto, F. Varadi, W. Moore, and G. Schubert, "Numerical Simulations of the Orbits of the Galilean Satellites," *Icarus*, vol. 159, no. 2, pp. 500–504, Oct. 2002, doi: 10.1006/icar.2002.6939.

[125] "MUTUAL EVENTS OF THE GALILEAN SATELLITES IN 2021," *Turn Left at Orion*, 2021. https://www.cambridge.org/turnleft/pages/whats_up_tonight/the_best_2021_galilean_satellite_mutual_events

[126] T. Phillips, "JUPITER MOON MOVIE," *What's up in Space*, 2009. https://www.spaceweather.com/archive.php?view=1&day=18&month=08&year=2009

[127] I. O'Neill, "Amateur Captures Solar Eclipse, By Io… On Ganymede," *Amateur Captures Solar Eclipse, By Io… On Ganymede*, 2009. https://astroengine.com/2009/08/18/amateur-captures-io-eclipse-on-ganymede/

[128] K. Patel, "Watch this 'surreal' Jupiter eclipse that you probably missed," *Washington post*, Washington, D. C., Aug. 21, 2021. [Online]. Available: https://www.washingtonpost.com/weather/2021/08/21/jupiter-transit-moons-mutual-2021/

[129] W. Grundy, L. Young, J. Spencer, R. Johnson, E. Young, and M. Buie, "Distributions of H2O and CO2 ices on Ariel, Umbriel, Titania, and Oberon from IRTF/SpeX observations," *Icarus*, vol. 184, no. 2, pp. 543–555, Oct. 2006, doi: 10.1016/j.icarus.2006.04.016.

[130] S. S. Sheppard, D. Jewitt, and J. Kleyna, "An Ultradeep Survey for Irregular Satellites of Uranus: Limits to Completeness," *AJ*, vol. 129, no. 1, pp. 518–525, Jan. 2005, doi: 10.1086/426329.

[131] A. Barnett, "Our Sun," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/solar-system/sun/by-the-numbers/

[132] A. Barnett, "Ariel," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/moons/uranus-moons/ariel/by-the-numbers/

[133] A. Barnett, "Umbriel," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/moons/uranus-moons/ariel/by-the-numbers/

[134] D. M. Kipping, "Transit timing effects due to an exomoon," *Monthly Notices of the Royal Astronomical Society*, vol. 392, no. 1, pp. 181–189, Jan. 2009, doi: 10.1111/j.1365-2966.2008.13999.x.

[135] A. Barnett, "Callisto," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/moons/jupiter-moons/callisto/by-the-numbers/

[136] A. Barnett, "Ganymede," *Solar System Exploration*, Mar. 2021. https://solarsystem.nasa.gov/moons/jupiter-moons/ganymede/by-the-numbers/