# New Type of Eclipses Possible on Exoplanets

Mitali Kabra[1], Sudarshan Loya[1*]


## ABSTRACT

Modern astronomy is filled with many wonders and discoveries of amazing exoplanets, exo-moons and solar systems which are very different from ours. These discoveries will give rise to new kinds of celestial arrangements which may not be possible on earth because of its neighborhood and a single moon orbiting it. The aim of this paper is to *provide an insight about new possible eclipses occurring on other planets (exoplanets also) and moons, while taking into consideration the position of the observer*. Simple mathematics is used to explain the possibility of these new phenomena, considering the age of the author and their educational background.


## 1. Introduction

Modern astronomy is filled with many wonders and discoveries of amazing exoplanets, exo-moons and solar systems which are very different from ours [1–6]. These discoveries will give rise to new kinds of celestial arrangements which may not be possible on earth because of its neighborhood and a single moon orbiting it. Planetary systems with multiple moons or ring structures can experience eclipses very frequently [7–10]. Similarly exoplanets with planets orbiting close by to their host stars or stars smaller than planets orbiting it will experience very different types of eclipses not studied yet on earth.

The aim of this paper is to *provide an insight about new possible eclipses occurring on other planets (exoplanets also) and moons, while taking into consideration the position of the observer*. Simple mathematics is used to explain the possibility of these new phenomena, because of the age of the author and their educational background. Though the math is basic, it supports the theory and compels to study such syzygy with new understanding.

## 2. Other Kind of Eclipses

New eclipse arrangements covered in this paper are; possibilities of eclipses on one planet by another planet, moon eclipsing another moon and four celestial bodies arranged in one row. Although the mathematical base is provided only for planet to planet eclipse, there is no reason to believe that it cannot be extended to another syzygy suggested before. Further new nomenclature is provided so as to report these occurrences properly in future.

### *Eclipses on One Planet by Other Planet*

Eclipses by the moon of a planet on the planet itself are very common, but current discoveries of the exoplanets, their diameters and the diameter of the star they are orbiting around raise the questions of eclipse of a planet by another planet. Normally, a planet is only visible as a bright star from another planet in the night sky [11]. However when one planet's orbit is too eccentric around a star, or the planets are close to each other they can appear slightly bigger than a pointed star in the night sky. For example, on TRAPPIST 1, HR 5183 b, HD 80606 b, HD 20782 b planets are visible from other planets as round celestial bodies [12–18].

On a planetary system with dwarf stars, if super Jupiter-like planets are orbiting them, they can cast shadows at much longer distances, like the GJ3512 or the WD 1856+534 [19,20]. On such systems, planets orbiting beyond super Jupiter will definitely see the eclipse created by super Jupiter. Although in our solar system the Sun is too large, the possibility of planet to planet eclipse barely exists. However it can definitely be studied for other solar systems and the same is being verified below for the GJ 3512 solar system.

Astronomers have discovered one suitable system around 31 light years away from earth; in which the star (GJ 3512) and the planet orbiting it; are of nearly the same size. In this an exoplanet GJ3512 b is nearly the same size as that of the host star [19,20]. So, the shadow cast by GJ3512b will be very large and may reach at distances where other planets can orbit. Though astronomers' prediction of another planet orbiting the same star GJ 3512 is not yet validated. So assume a hypothetical planet orbiting at the same distance from GJ 3512 as earth is from the sun i.e. 149,600,000 km [21,22]. The planet will 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.

1. *Crux View Center, Sagar Trade Center, Jalna Road, Aurangabad, Maharashtra*
* *Corresponding Author* ✉ *skloya31@gmail.com*

*Available online: 25 January, 2023*

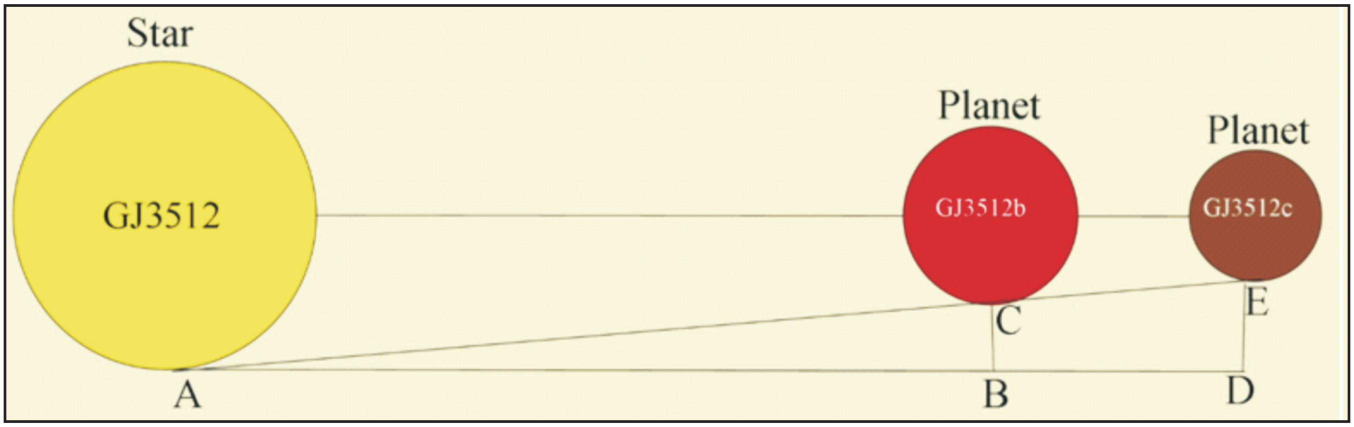


***Figure 1:*** *Possibility of planet to planet eclipse on possible planet in GJ 3512 system*

The 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. Identifying various points on the drawing:

Point A at the circumference of the star.

Point B location of GJ 3512b

Point C at circumference of the GJ351b

Point D location of GJ3512ci.

Point E at circumference of GJ3512ci

| | |
|---|---|
| Radius of GJ3512 = 0.166 *Radius of Sun ~= 115500 km [23] | (1) |
| Radius of 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 GJ3512 = Distance of Earth from Sun | (4) |

Since △ABC is similar to △ADE by AA test, one can write:

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

Since the value DE is 79000 km, smaller than the radius of GJ3512 about 115500, the shadow has not yet crossed the midpoint of GJ3512ci. Thus the shadow of the super Jupiter can reach the other planet, giving a possibility of planet - planet eclipse.

Another example is of the solar system WD 1856+534, a white dwarf star with radius 9044 km traveling about 80 light years away from earth. It has a planet WD1856b which has a radius about 10.4 times that of earth i.e. 63780 km [24–26]. As calculated, the planet's diameter is bigger than that of the star. Hence the planet can 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, it is just a matter of time before astronomers may find out such a solar system exists. Apart from the above scenario, there can exist a solar system, where two planets orbit each other with barycenter somewhere between them and eclipse each other. As, in our own solar system, Pluto and Charon are often referred to as binary systems because of their size comparison [27].

### *Moon Moon Eclipse*

Apart from a planet eclipsing another planet, a moon can also eclipse another moon and one can see some evidence of it in our solar system. Some unverified sources have

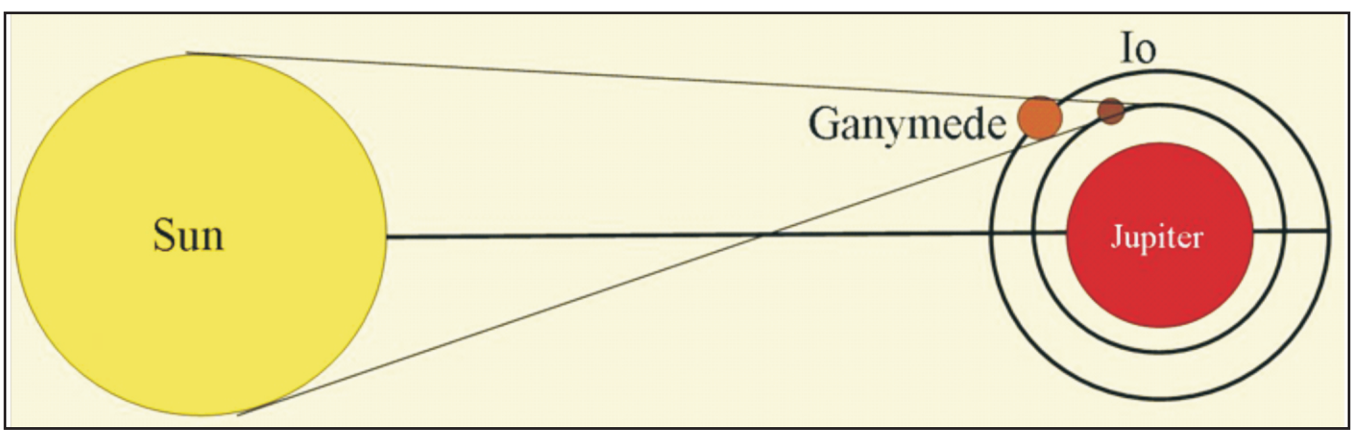


***Figure 2:*** *Possibility of Io eclipsing another Ganymede (both moon of Jupiter) as claimed in paper Washington Post*


***Figure 3:*** *Possibility of Io eclipsing another Ganymede (both moon of Jupiter) as claimed in paper Washington Post*

claimed to have photographed Io casting shadows on another moon Ganymede [28–30]. Although multiple reports have identified it, authors are yet to find any scientific publication verifying it, apart from one article in newspaper [31]. But various telescopic photography has proved that all four Galilean moons can create solar eclipses on Jupiter [32–36]. Out of the four main Galilean moons, the largest two moons Ganymede and Callisto are having nearly the same inclination i.e. 0.204 and 0.205 respectively [37–39]. This means Callisto can also eclipse Ganymede.

**Four Celestial Objects in One Line**

Even though astronomers have not yet seen Sun-Ganymede-Io-Jupiter alignment, having four bodies in a straight line that can create an eclipse is surely possible [40]. As suggested by the paper Washington post, Ganymede and Callisto can cast shadow on Europa or Io, which in turn can eclipse Jupiter [31]. For a person standing on Jupiter at the right time can see a solar eclipse of two moons occurring simultaneously. So while Callisto will be creating a solar eclipse on Jupiter, Ganymede or Europa can come in between and provide an appearance of multiple solar eclipses. As the moon near the planet moves faster compared to moons away from the planet, it is quite possible that, when a solar eclipse of Callisto is going on the planet Jupiter, Ganymede or Europa can come in between and add another layer of shadow.

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. There can be multiple kinds of four body eclipses like Sun-moon-moon-planet eclipse as suggested earlier or Sun-moon-planet-moon or Sun-planet-moon-moon eclipse.

## 3. Naming

Since such eclipses are not visible from earth, a proper nomenclature is required to identify these eclipses anywhere in the universe. This will help in communicating the idea and identifying the type of eclipse occurring. Keeping the observer position in mind, authors suggest the following format of nomenclature:

Type of eclipse [either Planetary orLunar] (celestial arrangement or syzygy in linear fashion)

In the case of the solar system GJ3512, the eclipse can be named as, Planetary Eclipse (GJ3512b-GJ3512ci) and that in the case of WD1856+534 will be, Planetary Eclipse (WD1856+534b-[any planet, if found]). Similarly for the moon-moon eclipse, it will be named as Lunar Eclipse (Callisto-Ganymede).

The Sun-moon-moon-planet phenomena creates two solar eclipses from the same position on the planet and hence named as **Twin Solar Eclipses.** For example Twin Solar Eclipse on Jupiter (Callisto-Io). In the Sun-planet-moon-moon arrangement, the solar eclipse is created by both the moon and the planet. 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.

## 4. Conclusion

When astronomers discovered other planets like Pluto, they designated them with new terminology of dwarf planets. Similarly, with the discovery of different types of exoplanets and exomoons orbiting various kinds of big or small stars may result in different kinds of eclipses or transits being observed in future. So it is necessary to start with their identification and classification. Such scenarios may provide a perspective about the motion of planetary systems in the future.

Modern technology recently identified more moons for Jupiter and Saturn. The same will be true in future for exo-planets also. Since astronomers have discovered exoplanets of various shapes, sizes that orbits around different kinds of stars, discovery of the exo-moon will further add spice to the entire viewing profile. Based upon various observations till now, authors have extrapolated some scenarios and have tried to classify various eclipses. Even though authors have tried to cover a wide range, authors don't think that this will be the final frontier. There are many more different events yet to be observed or named, but given that such scenarios are possible mathematically, it is a matter of time before scientists observe them. Also, with the technological changes and advancement, such alignment will be broadcasted live in future from other planets as fast as possible to create awareness among a space enthusiastic community of human beings. Hence identifying and naming them becomes even more important.

In this paper the authors have tried to take the observer's position in each of the existing and common astronomical arrangement into account, reviewed them and have tried to redefine it keeping it in mind. This will be of great importance in the future as with the discussion of human settlement on Mars and the moon taking precedence, it is necessary to understand that different astronomical phenomena when seen from different positions, look different. Astronomers use various techniques to find new exoplanets and most of the time, they use mathematical models to fit the date to define the planets. These suggestions on possible eclipses or occultations may help them fine tune their model and help them with better definition of the planet size and orbit.

## 5. References


1. Brennen, P.; Walbot, K. Exoplanet Exploration https://exoplanets.nasa.gov/what-is-an-exoplanet/overview/.
2. Ballesteros, F. J.; Fernandez-Soto, A.; Martínez, V. J. Diving into Exoplanets: Are Water Seas the Most Common? Astrobiology , 19 (5), 642–654.
3. Cassan, A.; Kubas, D.; Beaulieu, J.-P.; Dominik, M.; Horne, K.; Greenhill, J.; Wambsganss, J.; Menzies, J.; Williams, A.; Jørgensen, U. G.; Udalski, A.; Bennett, D. P.; Albrow, M. D.; Batista, V.; Brillant, S.; Caldwell, J. A. R.; Cole, A.; Coutures, Ch.; Cook, K. H.; Dieters, S.; Prester, D. D.; Donatowicz, J.; Fouqué, P.; Hill, K.; Kains, N.; Kane, S.; Marquette, J.-B.; Martin, R.; Pollard, K. R.; Sahu, K. C.; Vinter, C.; Warren, D.; Watson, B.; Zub, M.; Sumi, T.; Szyma@ski, M. K.; Kubiak, M.; Poleski, R.; Soszynski, I.; Ulaczyk, K.; Pietrzy@ski, G.; Wyrzykowski, Ł. One or More Bound Planets per Milky Way Star from Microlensing Observations. Nature , 481 (7380), 167–169.
4. Petigura, E. A.; Howard, A. W.; Marcy, G. W. Prevalence of Earth-Size Planets Orbiting Sun-like Stars. Proc. Natl. Acad. Sci., 110 (48), 19273–19278.
5. Benisty, M.; Bae, J.; Facchini, S.; Keppler, M.; Teague, R.; Isella, A.; Kurtovic, N. T.; Pérez, L. M.; Sierra, A.; Andrews, S. M.; Carpenter, J.; Czekala, I.; Dominik, C.; Henning, T.; Menard, F.; Pinilla, P.; Zurlo, A. A Circumplanetary Disk around PDS70c. Astrophys. J. Lett., 916 (1), L2.
6. Zhang, Z.; Liu, M. C.; Claytor, Z. R.; Best, W. M. J.; Dupuy, T. J.; Siverd, R. J. The Second Discovery from the COCONUTS Program: A Cold Wide-Orbit Exoplanet around a Young Field M Dwarf at 10.9 Pc. Astrophys. J. Lett., 916 (2), L11.
7. Stephenson, F. R. Historical Eclipses and Earth's Rotation
8. JPL Caltech. Curiosity Observes Phobos Eclipse: Sol 2359.
9. Dunbar, B. Rare Triple Eclipse on Jupiter https://www.nasa.gov/centers/goddard/multimedia/largest/triple_eclipse.jpg.html.
10. Whitemell, C. Solar Eclipses on Jupiter Due to the Third Satellite (Ganymede). J. Br. Astron. Assoc. , 6, 424–426.
11. Chen, J.; Kipping, D. Probabilistic Forecasting of the Masses and Radii of Other Worlds. Astrophys. J. , 834 (1), 17.
12. Barnett, A. 10 Things: All About TRAPPIST-1 https://solarsystem.nasa.gov/news/335/10-things-all-about-trappist-1/.
13. Brennen, P. Largest batch of Earth-size, habitable zone planets https://exoplanets.nasa.gov/trappist1/#Poster.
14. Kane, S. R.; Blunt, S. In the Presence of a Wrecking Ball: Orbital Stability in the HR 5183 System. Astron. J. , 158 (5), 209.
15. Blunt, S.; Endl, M.; Weiss, L. M.; Cochran, W. D.; Howard, A. W.; MacQueen, P. J.; Fulton, B. J.; Henry, G. W.; Johnson, M. C.; Kosiarek, M. R.; Lawson, K. D.; Macintosh, B.; Mills, S. M.; Nielsen, E. L.; Petigura, E. A.; Schneider, G.; Vanderburg, A.; Wisniewski, J. P.; Wittenmyer, R. A.; Brugamyer, E.; Caldwell, C.; Cochran, A. L.; Hatzes, A. P.; Hirsch, L. A.; Isaacson, H.; Robertson, P.; Roy, A.; Shen, Z. Radial Velocity Discovery of an Eccentric Jovian World Orbiting at 18 Au. Astron. J., 158 (5), 181.
16. Fossey, S. J.; Waldman, I. P.; Kipping, D. M. Detection of a Transit by the Planetary Companion of HD 80606. Mon. Not. R. Astron. Soc. Lett. , 396 (1), L16–L20.
17. Hidas, M. G.; Tsapras, Y.; Street, R. A.; Ramaprakash, A. N.; Mislis, D.; Schmitt, J. H. M. M.; Steele, I.; Barros, S. C. C.; Pollacco, D.; Ayiomamitis, A.; Antoniadis, J.; Nitsos, A.; Seiradakis, J. H.; Urakawa, S. An Ingress and a Complete Transit of HD 80606 b. Mon. Not. R. Astron. Soc. , no-no.
18. O'Toole, S. J.; Tinney, C. G.; Jones, H. R. A.; Butler, R. P.; Marcy, G. W.; Carter, B.; Bailey, J. Selection Functions in Doppler Planet Searches. Mon. Not. R. Astron. Soc. , 392 (2), 641–654.
19. Lopez-Santiago, J.; Martino, L.; Míguez, J.; Vázquez, M. A. A Likely Magnetic Activity Cycle for the Exoplanet Host M Dwarf GJ 3512. Astron. J., 160 (6), 273.
20. Wang, Y.-H.; Perna, R.; Leigh, N. W. C. Giant Planet Swaps during Close Stellar Encounters. Astrophys. J. , 891 (1), L14.

21. Encyclopedia of Planetary Sciences, 1st ed.; Shirley, J. H., Fairbridge, R. W., Eds.; Encyclopedia of earth sciences series; Chapman & Hall: London@; New York, 1997.
22. Luque, B.; Ballesteros, F. J. To the Sun and Beyond. Nat. Phys. 201915 (12), 1302–1302.
23. Brennen, P. GJ 3512 b https://exoplanets.nasa.gov/exoplanet-catalog/7476/gj-3512-b/.
24. Lagos, F.; Schreiber, M. R.; Zorotovic, M.; Gänsicke, B. T.; Ronco, M. P.; Hamers, A. S. WD 1856 b: A Close Giant Planet around a White Dwarf That Could Have Survived a Common Envelope Phase. Mon. Not. R. Astron. Soc. , 501 (1), 676–682.
25. Brennen, P. WD 1856+534 b https://mars.nasa.gov/msl/home/.
26. Merlov, A.; Bear, E.; Soker, N. A Red Giant Branch Common-Envelope Evolution Scenario for the Exoplanet WD 1856 b. Astrophys. J. Lett. , 915 (2), L34.
27. Asimov, I.; Asimov, I. Pluto: A Double Planet?''
28. Mutual Events of the Galilean Satellites in 2021 https://www.cambridge.org/turnleft/pages/whats_up_tonight/the_best_2021_galilean_satellite_mutual_events.
29. Phillips, T. Jupiter Moon Movie https://www.spaceweather.com/archive.php?view=1&day=18&month=08&year=2009.
30. O'Neill, I. Amateur Captures Solar Eclipse, By Io…On Ganymede https://astroengine.com/2009/08/18/amateur-captures-io-eclipse-on-ganymede/.
31. Patel, K. Watch This 'Surreal' Jupiter Eclipse That You Probably Missed. Washington post
32. Nemiroff, R. Astronomy Picture of the Day https://apod.nasa.gov/apod/ap150206.html.
33. Nemiroff, R. Astronomy Picture of the Day https://apod.nasa.gov/apod/ap041111.html.
34. Tsang, C. C. C.; Spencer, J. R.; Lellouch, E.; Lopez-Valverde, M. A.; Richter, M. J. The Collapse of Io's Primary Atmosphere in Jupiter Eclipse: IO's ATMOSPHERE IN ECLIPSE. J. Geophys. Res. Planets , 121 (8), 1400–1410.
35. Goodwin, G. L.; Hobson, G. J. Atmospheric Gravity Waves Generated during a Solar Eclipse. Nature , 275 (5676), 109–111.
36. Hue, V.; Greathouse, T. K.; Bonfond, B.; Saur, J.; Gladstone, G. R.; Roth, L.; Davis, M. W.; Gérard, J. @C.; Grodent, D. C.; Kammer, J. A.; Szalay, J. R.; Versteeg, M. H.; Bolton, S. J.; Connerney, J. E. P.; Levin, S. M.; Hinton, P. C.; Bagenal, F. Juno@UVS Observation of the Io Footprint During Solar Eclipse. J. Geophys. Res. Space Phys. , 124 (7), 5184–5199.
37. (Chair), P. K. S.; Abalakin, V. K.; Bursa, M.; Davies, M. E.; Bergh, C. de; Lieske, J. H.; Oberst, J.; Simon, J. L.; Standish, E. M.; Stooke, P.; Thomas, P. C. [No Title Found]. Celest. Mech. Dyn. Astron. , 82 (1), 83–111.
38. Planetary Satellite Mean Orbital Parameters https://ssd.jpl.nasa.gov/?sat_elem.
39. Musotto, S.; Varadi, F.; Moore, W.; Schubert, G. Numerical Simulations of the Orbits of the Galilean Satellites. Icarus , 159 (2), 500–504.
40. Kipping, D. M. Transit Timing Effects Due to an Exomoon. Mon. Not. R. Astron. Soc. , 392 (1), 181–189.


❖ ❖ ❖