Assessing the likeliness of a planetary system having an exoplanet able to disrupt the orbit of exo-plutoids

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Introduction

On the 19th of October, 2017, an interstellar object was detected by scientists for the first time[1]. Called ‘Oumuamua, many factors about this foreign object were of high interest to the scientific community. This includes the fact that it was highly elongated, with theories on its shape ranging from it being shaped like a long cigar with a 10:1 ratio of height/ length, to it being unbelievably wide and thin as a millimeter[2]. Another anomaly connected to the interstellar object was that it was able to achieve non-gravitational acceleration despite the fact that it was not a comet. It is decidedly not a comet due to its lack of a tail and no obvious star system of origin[2]. This raised the question of ‘Oumuamua’s makeup to the scientific community as they attempted to understand how such anomalies could have occurred. One idea was that the object could have been an asteroid made of a highly porous material that gave the object a mean density much lighter than air[3]. Another idea is that the object was a large chunk of frozen hydrogen4. Some even made the assertion that the object was an artificially made solar sail created by interstellar intelligence[2]. All these ideas have flaws in some ways, as both porous material and hydrogen ice would lose much structure upon being too close to the sun, and there has never as of yet been any evidence to suggest that life can come into existence at all beyond Earth, let alone life with the ability and will to create interstellar objects. One idea that therefore seems much more viable is the idea by Desch and Jackson, where they considered the possibility that ‘Oumuamua was a piece of an exo-planet similar to Pluto, that was rich in N2 ice5. This would allow the object to experience non-gravitational acceleration via outgassing from the heat of the sun. It would also explain the strange shape as melting from the sun on one side of the chunk could have been the cause of uneven ice removal. Overall this theory makes much sense as an explanation regarding the anomalies present in the object, however, Desch and Jackson’s backing of the statistical likeliness of this nitrogen iceberg appearing within our solar system is based upon the presumption that our planetary system is “typical” compared to others6. This may not be true. This is of high importance to the applicability of Desch and Jackson’s paper as they assert the idea that in order for a piece of a Pluto-like exoplanet to reach interstellar space and therefore have a high likeliness of reaching our solar system, an exoplanet similar in distance from its star to Neptune would need to exist so that objects within an “exo-Kuiper Belt” would have their orbits fully disturbed enough for ejection6. This study seeks to understand if the existence of planets as far away as Neptune exist to a large enough degree throughout the universe that the expulsion of fragments similar to the proposed nitrogen ice model of ‘Oumuamua from other systems is as likely as Desch and Jackson assert.

Discovered exo-planets capable of N2 iceberg ejection

Within their paper, Desch and Jackson assert the fact that our solar system likely produced high quantities of nitrogen Icebergs that have been sent into interstellar space by the disrupting gravitational pull of a migrated Neptune, which not only causes collisions that would break up the objects within the Kuiper belt so that they would become more ‘Oumuamua sized, but also removes them from their orbit so that they may travel into interstellar space. The location of the exo-Kuiper belt, and therefore the planet that disrupts its orbit, must be a certain distance away from the sun so that the Nitrogen can reach a frozen state. The objects within the solar system range highly in their temperatures, however, it is only Pluto and the other Kuiper Belt Objects that have the low temperature available to cause nitrogen to freeze. Nitrogen freezes at 63 kelvin, and Pluto maintains a temperature of approximately 47 K7,8. Neptune itself, despite causing the disruption of many plutoids and overlapping Pluto's orbit, has a temperature of 72 K, most likely due to the greenhouse effect[1]0. This means that for a planet to exist that is suitable to disrupt objects with nitrogen ice, in a star similar to our own, that planet must exist roughly at the distance from the sun that Pluto is and at the far end of Neptune's orbit. This is about 30 Astronomical Units away from that type of star9. Of course, as far as stars go, ours is pretty luminous, so in order to approximate the temperature of exoplanets with stars different from our own, the following equation will be utilized:

$$T = \left[\frac{Lsun(1-a)}{16\sigma\pi}\right]^{1/4} \times 1/\sqrt{d}$$

(11)

Where **T** is the temperature in Kelvin of the planet, **Lsun** is the luminosity of that planet's sun, **a** is the albedo of the planet, **d** is the distance in meters of the planet from its sun, and σ is the Stefan-Boltzman constant. This equation does not account for the greenhouse effect, however, due to the fact that the greenhouse effect serves mainly to cause planets to become hotter, it does not need to be included while taking this conservative measure. The lowest luminosity recorded of a star with a system within 10 parsecs is Teegarden's Star with 0.00073 L , or 2.79444 x 10ˆ23 Watts[12]. The highest albedo ever recorded in an exoplanet was 0.8 in LTT 9779 b[13]. Yet even given these extremes, a planet must be at least 0.235835 astronomical units away from its star in order to be cold enough to allow nitrogen to freeze on its surface.

Within ten parsecs of this solar system, there exist about 500 stars, around 60 of which have planetary systems[1]4. 103 exo-planets are shared between these 60 stars[1]5. 31 of these are over 0.235835 AU away from their stars. A star with 0.01 L luminosity will be hot enough to ensure nitrogen does not freeze to a distance of 0.87286 AU. 19 of the 31 planets are either too distant from their star or have a star with too little luminosity to be within this range and therefore may possibly be in the freezing temperature of nitrogen. These 19 planets are cataloged and their calculated temperatures are listed in Table 1.

Planet Name	Distance from Star (au)	Calculated Temperature (k)
Epsilon Eridani b	3.53	76.18
GJ 15 A c	5.4	31.01
Epsilon Indi A b	11.5	37.15
Tau Ceti f	1.33	134.8
Wolf 1061 d	0.47	92.89
GJ 9066 c	0.88	38.02
GJ 687 c	1.165	65.86
GJ 832 b	3.56	39.60
HD 219134 d	0.237	274.2
HD 219134 g	0.3753	217.9
HD 219134 h	3.11	75.68
HD 192310 c	1.18	134.9
GJ 849 b	2.32	51.03
GJ 849 c	4.95	34.95
GJ 433 c	4.819	36.40
GJ 3512 b	0.337	63.76
GJ 3512 c	1.292	33.83
GJ 1151 c	0.5714	59.04
GJ 680 b	10.138	21.99

Table 1 (information gathered from NASA public sources)

This means that of the around 500 stars within 10 parsecs, only 9 stars (not including Sol) have been proven to have planets existing within the range of their stars where nitrogen is able to freeze. This does not even include the concept of the greenhouse effect, which could easily serve to cause many of these planets to become much hotter.

It is understood that planets are more likely to be detected when they are much closer to their star's orbit (though they are also easier to detect in less luminous stars), so this statistic should not be taken as infallible evidence that planets able to cause N2 fragment ejection are highly unlikely to exist, but rather that there is simply very little current evidence to suggest that these planets are present within the galaxy at the degree to which our solar system has them[1]6. Therefore, the assertion that our solar system is typical in its ability to eject nitrogen icebergs is not fully represented by our current data on exo-planetary systems.

Likeliness of the migration of Neptune

Previous data within this paper has been to point out the fact that there is little contemporary evidence to make the assertion that our solar system is typical for the galaxy in its ability to send nitrogen iceberg fragments into interstellar space, however, due to the detection of exoplanets being more likely based on the closeness of the planet to its star, the data is admittedly somewhat biased. This section, therefore, aims to prove through models of stellar systems that the migration of Neptune (which caused the removal of large amounts of KBOs) is rare as far as planetary systems go.

The migration of Neptune into farther reaches of the solar system is believed to be due to the stress between it and Jupiter's and Saturn's orbits, with the large mass difference between them causing Neptune to be pushed far out towards the current location of the Kuiper belt[1]7. Jupiter is nearly 19 times more massive than Neptune, and Saturn is nearly 6 times more massive than Neptune[1]8. This all means that the migration of Neptune was heavily reliant on the large mass differences between it and the two gas giants. These large mass differences are mostly nontypical for planetary systems, however. The most common planetary system type is the "similar" type, where the planets are all similar to each other in mass[1]9. If this were to occur, that would mean that the mass difference between the planets would not be large enough to have Neptune migrate as highly as it had, meaning it would be unlikely to disrupt the Kuiper belt as significantly[2]0. The following equation is the parameters set for a system to be classified as "similar" in structure:

$$|C_S(M)| \leq 0.2$$

(19)

Where $\mathbf{C_s}$ is defined by the following equation regarding $\mathbf{q}$ as the mass ($\mathbf{M}$) of the planets:

$$C_S(q) = \frac{1}{n-1} \sum_{i=1}^{i=n-1} \left(\log \frac{q_{i+1}}{q_i} \right).$$

(19)

This means that for an eight-planet system, the average difference in mass between planets would be less than 2x rather than the much higher differences seen between Jupiter and Saturn compared to Neptune. This, therefore, means that our solar system, due to its peculiarity in planetary architecture, is uncommon in its ability to have planets migrate to the extent at which they are able to eject high amounts of debris into interstellar space, as the mass difference between the planets would not generate the force required to do so.

This once again points to a peculiarity of our solar system unseen in others, however, while the planet's temperature peculiarity is based more on physical, though biased evidence, this peculiarity is based upon frameworks which are applicable to all systems within the galaxy without requirement of currently unobtainable measuring systems.

Conclusion

In conclusion, the assertion that the planetary system that Earth is a part of is typical of other planetary systems is not entirely backed by the currently discovered catalog of exo-planets, nor the expected models of planetary system architecture within the galaxy. The exo-planets currently discovered display a very low rate of existence far enough away from their star to be able to disrupt the orbits of objects that have high amounts of Nitrogen ice. This does not even take into account the greenhouse effect, which would serve to raise the calculated temperatures of these exoplanets even higher. Of course, it is understood that this collected physical evidence is not an entirely accurate depiction of the degree to which exoplanets exist within the range that Nitrogen ice freezes. This is because the methods used to confirm the presence of exoplanets are more easily able to pick up on planets closer to their stars, and more exposed to their heat. This physical evidence, therefore, is not meant as irrefutable evidence that N2 ice-disrupting planets are extremely rare, instead, it is meant to display the fact that there is simply very limited contemporary evidence suggesting that such planets exist to a high degree. Framework-based evidence regarding the lessened probability of solar systems architecturally similar to ours existing is also able to display the unlikeliness of planets like Neptune being able to migrate to the degree that they did away from the sun, as that migration was based on the high mass differences between Neptune and the two gas giants, Jupiter and Saturn. Due to the fact that "similar" systems are the most common system, where all planets are highly close to each other in mass, this level of difference would be unlikely to occur in most other planet groups, meaning the migration of planets like Neptune would not occur to the degree that it did in our system. This means exo-plutoids would be less affected by that shift, further pointing to the fact that the rate at which our system produces nitrogen icebergs is much higher comparatively. Although this study has provided evidence to weaken the applicability of the Nitrogen iceberg model of 'Oumuamua, it should still be noted that the Nitrogen ice model is still one of the better models for the structure of 'Oumuamua. It is able to explain all the strange properties of the object and its generation is still possible and based on much known evidence. This study has, however, proven that if the Nitrogen model of 'Oumuamua is correct, then, based on current knowledge of planetary systems, the passing of 'Oumuamua through our solar system was a very rare occurrence.

References

1. 'Oumuamua. *NASA*.*https://solarsystem.nasa.gov/asteroids-comets-and-meteors/comets/oumuamua/in-depth* (2019)

2. Avi Loeb.On the Possibility of an Artificial Origin for 'Oumuamua.*Astrobiology*.1392-1399.http://doi.org/10.1089/ast.2021.0193. (2022)

3. Eirik G. Flekkøy *et al* 2019 *ApJL* **885** L41 (2019)

4. Darryl Seligman and Gregory Laughlin 2020 *ApJL* **896** L8 (2020)

5. Jackson, A. P., & Desch, S. J. 1I/'Oumuamua as an N2 Ice Fragment of an exo-Pluto Surface: I. Size and Compositional Constraints.*Journal of Geophysical Research: Planets*,*126*(**5**), e2020JE006706.*https://doi.org/10.1029/2020JE006706*. (2021)

6. Desch, S. J., & Jackson, A. P. 1I/'Oumuamua as an N2 ice fragment of an exo-Pluto surface II: Generation of N2 ice fragments and the origin of 'Oumuamua. *Journal of Geophysical Research: Planets*,**126**, e2020JE006807. https://doi.org/10.1029/2020JE006807. (2021)

7. Solar System Temperatures. *NASA*.*https://solarsystem.nasa.gov/resources/681/solar-system-temperatures/*(2022)

8. S. Gagnon. How cold is liquid nitrogen? *JLab.* https://education.jlab.org/qa/liquidnitrogen_01.html.

9. Planet distance chart. *NASA.* https://www.jpl.nasa.gov/edu/pdfs/ssbeads_answerkey.pdf

10. Greenhouse effects... also on other planets. *European Space Agency.* https://www.esa.int/Science_Exploration/Space_Science/Venus_Express/Greenhouse_effects_also_on_other_planets (2003)

11. N. Strobel. Surface temperature. *Astronomy Notes.* https://www.astronomynotes.com/solarsys/s3c.htm (2022)

12. Star Teegarden's star. *Stellar Catalog.* https://www.stellarcatalog.com/stars/teegardens-star (2019)

13. The extremely high albedo of LTT 9779 b revealed by CHEOPS. *EDP Sciences.* https://www.aanda.org/articles/aa/full_html/2023/07/aa46117-23/aa46117-23.html (2023)

14. Stars, brown dwarfs, and exoplanets within 10 parsecs (version 2). *Gruze.org.* https://gruze.org/10pc/

15. Exoplanet catalog, discovery. *NASA.* https://exoplanets.nasa.gov/discovery/exoplanet-catalog/ (2023)

16. Planet detection methods. *NASA.* https://www.nasa.gov/kepler/overview/planetdetectionmethods (2017)

17. Thommes, E., Duncan, M. & Levison, H. The formation of Uranus and Neptune in the Jupiter–Saturn region of the Solar System. *Nature* **402**, 635–638. https://doi.org/10.1038/45185. (1999)

18. D. Williams. Planetary fact sheet - metric. *NASA.* https://nssdc.gsfc.nasa.gov/planetary/factsheet/ (2023)

19. L. Mishra, Y. Ailbert, S. Udry, C. Mordasisni. Framework for the architecture of exoplanetary systems. *Astronomy and Astrophysics.* **670**. (2023)

20. Kuiper Belt. *NASA.* https://solarsystem.nasa.gov/solar-system/kuiper-belt/in-depth/ *(2021)*