Brightness Variability of Planet Nine

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Abstract

In this project, we were interested in exploring the brightness variability of Planet Nine as a function of orbital distance with an added complexity of a potential brightness increase during a storm in its upper atmosphere. Our intention is to provide brightness upper limits to inform observation efforts and increase chances of detection. We found that semi-major axes < 480 AU with small true anomalies will have a minimum apparent magnitude of 24, and a storm system may increase the brightness by a factor of 1.2e-56, providing a planet that is possibly detected in the WISE catalog, and certainly accessible by future JWST instrumentation.

1 Introduction

An additional planet in the solar system, a distant "Planet Nine," has been theorized in several scientific peer reviewed publications as a possible perturbation source for several KBO orbits [1] as well as the culprit behind the induced 6 degree spin-axis tilt of our sun [2]. This planet is hypothesized to be a Neptune or Uranus-sized ice giant residing in the far outer reaches of our solar system, and since detection has so far proved a challenge to observers [3], many parameters are still uncertain. With local ice giants Neptune and Uranus as planetary analogues, we theorized that occasional storm systems, like "Berg" on Uranus [5], may temporarily generate an increase in brightness. We also noted the strong brightness-orbital distance dependence [6]. Exploring these impacts together motivated our early characterization efforts.

2 Methodology

Using Neptune as an analogue, Fortney et al. 2016 [6] suggests leveraging modeled values for Planet Nine with observed quantities of Neptune to provide a first-order understanding of Planet Nine's magnitude in the V-band:

$$V_{p9} = 7.8 + 5log_{10}[(\frac{R_{p9}}{R_{Nep}})^2(\frac{A_{p9}}{A_{Nep}})(\frac{r_{p9}}{r_{Nep}})^4]$$

Brightness is a function of planetary radius R, distance r, and albedo A. Inspired, we took the proposed conditions of $R_{PlanetNine} = 3.46R_{Earth}$ (large H/He envelope)[6] and $r_{PlanetNine} = 700AU$[1] and varied albedo from 0 to 1 to produce Figure 1, showing the 5-magnitude variation that can be induced on the V-band magnitude by altering the albedo of Planet Nine.

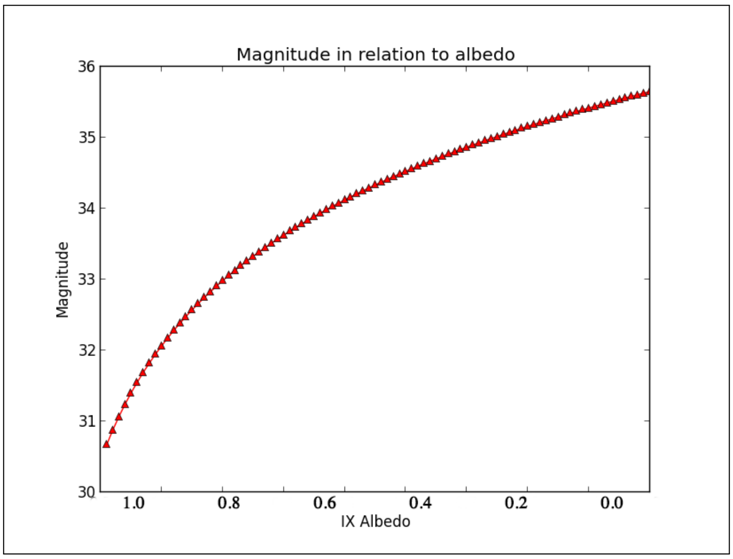

Figure 1: V-band Magnitude in relation to alterations in the albedo of Planet Nine varies from 30.5-35.5 from parameters given in Fortney 2016 [6].

Interesting, however, is our calculated magnitude range (30.5-35.5) by varying albedo is about 8 magnitudes larger than the Fortney 2016 best-guesses

(22-25)[6], which puts their other brightness parameters into question, and motivates a study into varying the orbital distance r, a factor of true anomaly ν and semi-major axis a, to inform which orbits and portions of orbits may be visible for best-case scenario brightnesses.

To go about this, we first solved for distance r using the following equation:

$$r_{P9} = \frac{a(1-e^2)}{1+ecos(\nu)}$$

Eccentricity is taken as $e = 0.6$ [1], and semi major axis a is varied from 300-900 AU [4] and true anomaly ν is varied along a comprehensive range from 0-360 degrees. Results are plotted in Figure 2, which shows different semi major axes and their corresponding distances as reached by their true anomalies. Each peak is a different semi major axis, and the slopes are their variations along true anomaly.

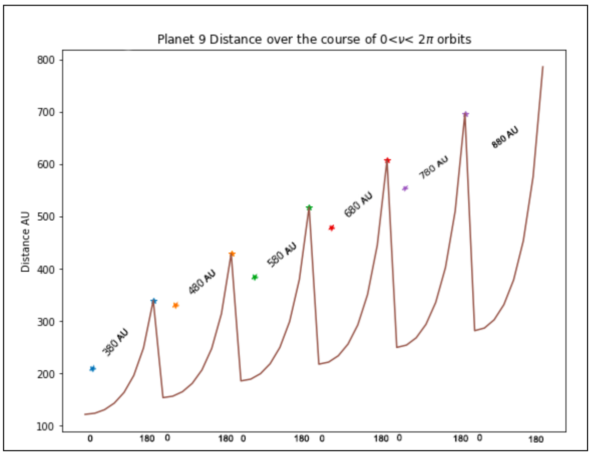

Figure 2: Distance r vs true anomaly ν for a range of semi major axis a.

From these r distances, we then solved for magnitude, using an model albedo of $A_{P9} = 0.75$ [6], and $R_{P9} = 3.46R_{Earth}$ [6].

Figure 3 shows the final range of V -band magnitudes vs distance for various semi-major axes over the course of the orbit. Magnitude increases (so brightness decreases) with increased semi major axis, as is expected. The inverse is also true: smaller semi major axes will lead to a brighter planet, and in order to reach the best-case magnitudes of 22<V<25, current distance r would have to be less than 200AU, which could correspond to orbits of $a < 480$ with small true anomalies. Detection of a planet with these distances and brightnesses is likely given the proper instrumentation, which is discussed further in our Conclusions.

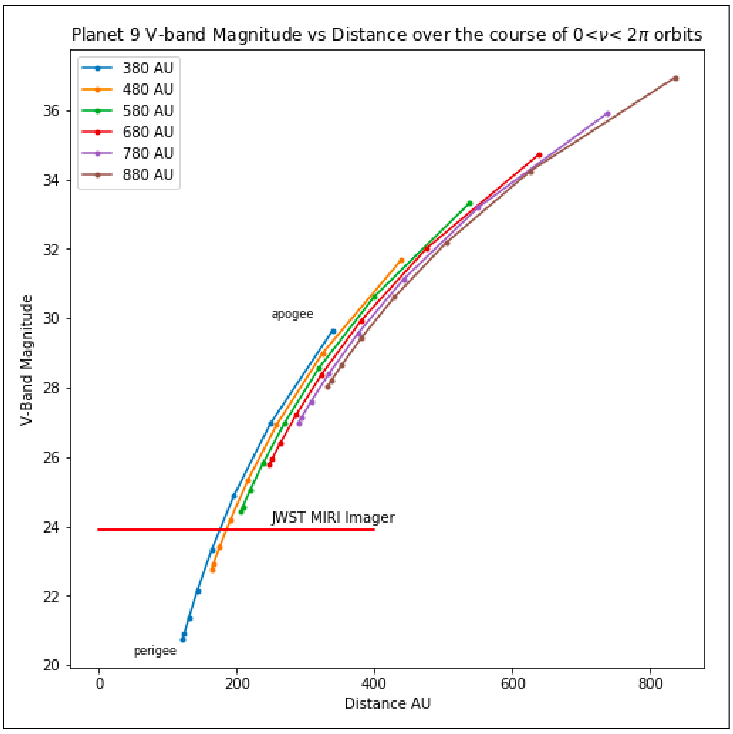

Figure 3: V-band Magnitude as a function of orbital distance r, a function of true anomaly (dots) and semi major axis (colored lines, separated for visibility). Values orbits of $a < 480$ with small true anomalies give $r < 200$AU, which would give a target at this distance a magnitude <24, within the imaging capabilities of JWST.

Another method of exploring brightness variations was to consider the effects of a possible storm on the planet. Going back to Figure 1, factors that can influence the albedo of a planet include but are not limited to: temperature, optical depth, atmospheric composition, density, volume and atmospheric pressure. Of course, boiling a kettle on a distant planet wont really have enough of an immediate effect to really change the albedo significantly enough,[7] however one impressive phenomena of nature that occurs on planets with dense enough atmospheres is storm systems.

The hypothesized properties of Planet Nine seem to coincide with some of the observed properties of Neptune and Uranus [6]. The storm systems present on Uranus and Neptune offer an excellent starting point for modeling variations in the albedo and therefore perceived brightness of planet nine. In particular, there is a certain storm system known colloquially as "Berg" that appears sporadically on the surface of Uranus that can be viewed using the Keck telescope [5].

The equation we start out with to model the brightness is given in the textbook, *Fundamental Planetary Science* [8].

$$B_v(T) = \frac{2hv^3}{c^2}\frac{1}{\exp(hv/kT) - 1}$$

In this equation we can observe that the brightness is a function of both frequency (ν) and primarily temperature. The storm system "Berg" on Uranus has a quite visible variation in pressure from 1.75 to 3.5 bars that is visible in the K'-band and H-Hcont observations.

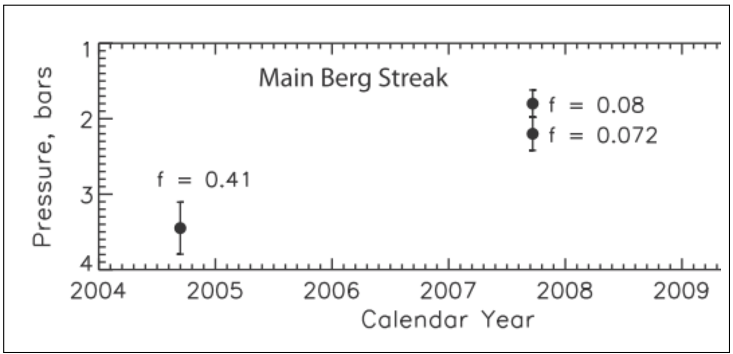

Figure 4: Variation in pressure inferred from observations made of the storm system "Berg" on Uranus [5].

The equation for brightness however does not give pressure as something you may vary. Crudely, using the ideal gas law, we can rewrite this equation so as to give a variation in brightness as a function of pressure. [5]

$$PV = NkT$$
$$T = \frac{PV}{Nk}$$

We can find the volume of the atmosphere by integrating over the atmosphere of a sphere 3.48 Earth radii (which is the hypothesized radius of planet nine) [3] The number of particles can be found from this by modeling the atmosphere as being primarily composed of methane molecules. We substitute the temperature in the brightness equation for pressure to yield the following:

$$B_v(P) = \frac{2hv^3}{c^2}\frac{1}{\exp(hvN/PV) - 1}$$

We can then graph how much this quantity changes as a function of pressure, such as that given to us by the variation in the storm system known as "Berg" on Uranus. Variation in the brightness as a function of pressure is shown in Figure 5, which shows a non-zero change in brightness of 10e-56 due to pressure variations of 1.75-3.5 bar. We found that the 1.75 to 3.5 bar variance can have quite a change on the brightness of the planet, we compared the difference to varying the temperature from 40 to 50K (the range of hypothesized temperatures of the planet) and found that there is actually a greater variance from the alteration of pressure due to a storm system than from this temperature variation.

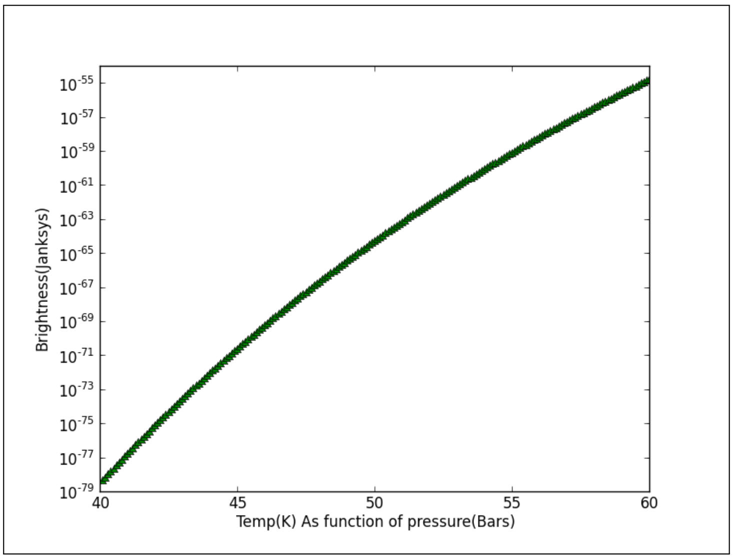

Figure 5: Logarithmic plot of the brightness of planet nine as a function of the variation of temperature as related to the high pressure variation caused by a storm system with about the same magnitude as that found on Uranus.

3 Results and Conclusions

This variation in storm brightness is a non-zero amount, but still incredibly small.If a telescope or instrument with the capability of detecting planet nine made a survey of the night sky during a certain time of the year, would it have to take into account varying storm activity on its surface when taking the data? Surveying the same portion of the night sky during different times of the year when a storm system might be able to affect the brightness of the planet could potentially affect the probability of whether we detect it or not.

Many teams are searching the old WISE catalogs for possible detections of Planet Nine, with no results thus far. However, new instrumentation is on the horizon, and with the assistance of the MIRI instrument on JWST that can detect faint objects up to 24-magnitude, our target with semi major axis less than 480 AU with small true anomalies may well be within observational detection, especially during storm conditions. In the best case scenario, as soon as JWST launches, we may have a planet nine in the solar system once again. Let the hunt continue!

References

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