Journal of Physics Special Topics
An undergraduate physics journal

A1_6 The Planet Phaeton

A. McCulloch, N.Carr, J. Harrison, J. Whitaker

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 13, 2022

Abstract

Whilst the main theory of the asteroid belt's origin is left over remnants from when the protoplanetary disc formed our Solar System, one theory is a destroyed planet: Phaeton. This paper aims to explore the characteristics of such a planet formed of the asteroids in the main belt. It is found to have a density of 2188.8 kg/m^3, a radius of 6.4×10^5 m, orbital period of 1620.2 days, and an eccentricity of 0.2.

Introduction

The asteroid belt between Mars and Jupiter contains millions of asteroids of a total mass, M, equating to 2.4×10^{21} kg [1]. It shows us a frozen stage of planetary creation, where material had come together into planetesimals and embryo planets but hadn't yet formed into a planet. It was likely due to Jupiter's migration that the belt was created in place of an additional planet in the Solar System. By looking at the properties of the asteroids, we will be exploring characteristics of a planet that could have been created from them.

Density

The main belt is filled with three main types of asteroids: 75% carbonaceous (C-type) with density 1,700 kg/m^3 [2], 17% silicaceous (S-type) with density 3,000 kg/m^3 [3], 7% metallic (M-type) with density 3,000-8,000 kg/m^3 [4][5], however, Ceres (a dwarf planet within the belt with density 2,080 kg/m^3), outsizes all others by being a quarter of the total mass of the belt [6]. Taking this into account, we spread out the percentages of asteroid types in the belt as such: Ceres 25%, C-type 56%, S-type 13%, and M-type 6%. Per these ratios and the densities previously stated, the average density, ρ, of Phaeton is equal to 2188.8 kg/m^3.

Radius

To calculate the radius of a planet with this density, two equations are needed:

$$V = \frac{M}{\rho} \tag{1}$$

where V is volume, M is mass, and ρ is density, and,

$$V = \frac{4}{3}\pi r^3 \tag{2}$$

where r is radius.

Combining Eq. (1) and (2) and rearranging for r,

$$r = \left(\frac{3M}{4\pi\rho}\right)^{\frac{1}{3}} \tag{3}$$

Eq. (3) can then be used, with M and ρ stated previously, to find a radius of 6.4×10^5 m for Phaeton.

Orbit

The asteroid belt sits between 2.2 and 3.2 AU from the Sun, so these values were used for the perihelion, R_p, and aphelion, R_a, of the orbit, respectively, to account for the elliptical nature of all the Solar System's planet's orbits. The semi-major axis, a, is, therefore, 2.7 AU (half the distance of 2.2 + 3.2). Using Kepler's Law of Periods,

$$T^2 = \left(\frac{4\pi^2}{GM}\right) a^3 \tag{4}$$

where T is the time period, G is the gravitational constant, and M is the mass, Phaeton's orbital period is calculated to be 1620.2 days, or 4.4 years.

Since we assumed an elliptical orbit for Phaeton based on the stretch of space the asteroid belt inhabits beyond the Sun, the eccentricity, e, of the orbit can be calculated. Kepler's Law of Orbits gives us the equation:

$$R_a = a(1 + e) \tag{5}$$

and rearranged for e, we get an eccentricity of 0.2 for Phaeton's orbit.

Composition

Due to the nature of the asteroids, mentioned previously in the Density section of this paper, Phaeton would be largely carbonaceous and siliceous, with a high water content thanks to Ceres (which is thought to be 25% water [3]). It would have nickle and iron, most likely in the core due to differentiation during formation, however likely not enough for a magnetosphere. Since Ceres has a very thin atmosphere, Phaeton also would, possibly made mostly of water vapour from the same processes theorised for Ceres: ice volcanoes or surface sublimation [3].

Life?

Whilst the planet never formed, organic material detected by NASA's Dawn [3] suggests the possibility for life in the waters of Ceres, so a larger planet could have hosted microbial life, or perhaps, more advanced life.

Conclusion

The planet Phaeton, orbiting the Sun at 2.2-3.2 AU between Mars and Jupiter, would have a radius of 6.4×10^5 m, which is an order of magnitude smaller than Pluto, rendering it the smallest planet in the Solar System (it would not be a dwarf planet as, despite its small size, it's orbital neighbourhood would be clear since all asteroids are a part of the planet). From the asteroid compositions stated earlier, it would likely be a fairly barren planet, with little atmosphere and no magnetosphere to protect the rocky surface from solar radiation, but, with liquid water beneath its crust, it could still harbor life.

Despite it being commonly accepted that the asteroid belt is a remnant of the time when the Solar System formed, there is still a possibility that Phaeton was real, and the characteristics presented here may be representative of a planet, torn asunder by a cataclysmic collision early in its life, of which today we only see the ghostly remains.

References

[1] Pitjeva, E.V. (2018). "Masses of the Main Asteroid Belt and the Kuiper Belt from the Motions of Planets and Spacecraft." *Solar System Research.* 44 (8-9): 554-566

[2] `https://dbpedia.ord/page/C-type_asteroid` [Accessed 03 November 2022]

[3] P. Vernazza et al. (2021) VLT/SPHERE imaging survey of the largest main-belt asteroids: Final results and synthesis. *Astronomy & Astrophysics* 54, A56

[4] `https://en.wikipedia.org/wiki/M-type_asteroid` [Accessed 03 November 2022]

[5] `https://www.space.com/16105-asteroid-belt.html` [Accessed 25 October 2022]

[6] `https://solarsystem.nasa.gov/planets/dwarf-planets/ceres/in-depth/` [Accessed 25 October 2022]