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Abstract

The Oort Cloud was hypothesised in 1950 but has lost popularity as a research topic. This literary research summarises the most notable articles and simulations on the Oort Cloud with an analysis on the outdated simulations and assumptions. Finally, this research conflates the hypothesised values of Oort Cloud parameters to calculate the required specifications of instrumentation needed to image an Oort Cloud Object, and a rough budget is proposed of $5 million to launch a 35 km interferometer.

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A LITERARY ANALYSIS OF THE OORT CLOUD: SUMMARISING ITS HISTORY AND PROPOSING A MISSION TO IMAGE OORT CLOUD OBJECTS

By

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A Literary Analysis of the Oort Cloud: Summarising its History and Proposing a Mission to Image Oort Cloud Objects

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The Oort Cloud was hypothesised in 1950 but has lost popularity as a research topic. This literary research summarises the most notable articles and simulations on the Oort Cloud with an analysis on the outdated simulations and assumptions. Finally, this research conflates the hypothesised values of Oort Cloud parameters to calculate the required specifications of instrumentation needed to image an Oort Cloud Object, and a rough budget is proposed of $5 million to launch a 35 km interferometer.

I. INTRODUCTION

The Oort Cloud (OC) is a hypothetical shell around our solar system comprised of icy objects. These objects become known as comets when they fall into our solar system (henceforth called the inner solar system to differentiate between the region occupied by Oort Cloud objects (OCOs) and the region containing the planets). Currently, little is known for certain about these comets. By studying the Oort Cloud itself, we will discover their origins, their behaviour, and what they show about the formation of our solar system. In consequence, it may be hypothesised that other star systems have their own OCs. This makes it even more imperative to understand the characteristics required to form an OC and how it dictates the development of planets within the system. Although the Oort Cloud has been hypothesised and modelled occasionally, there remains significant research to improve simulations and eventually obtain physical evidence of its existence.

II. HISTORY OF THE OORT CLOUD

In 1950, Jan Oort theorised a cometary cloud surrounding our solar system as the source of observed long-period comets (LPCs). The orbits of the comets can be used to calculate characteristics including their perihelion distance and semimajor axis; recent simulations found these values to be > 10 AU and $\geq 20,000$ AU, respectively [1]. These values place the comets' origin at approximately 100,000 AU or 1.6 light years from the sun. Consequently, we have yet to send any probes to investigate the comets in their home cloud. We have yet to reach the inner boundary of the cloud with the farthest missions launched: Voyager 1 is 159 AU from the sun at the time this paper was written [2]. Reaching the OC will require dedicated financial and scientific effort.

III. LITERARY RESEARCH

The Oort Cloud lies beyond the limits of our current technology which makes it impossible to research directly (for the next several decades at least, that is). Verifying the hypotheses with physical evidence then shifts to imaging OCOs from on or near Earth.

Previous explorations into OCOs have defined the boundary for the cloud itself. Orbits of comets observed from Earth evidence two categories of comets distinguished by the distance of their origins [1]. 10,000 to 20,000 AU is labelled the inner Oort Cloud which leaves 20,000 to 100,000 AU as the outer Oort Cloud. It is worth noting, though, that this boundary between inner and outer OC is not concretely defined [1]. The threshold between inner and outer OC is set by comet behaviour rather than a distinct location in space. Hills distinguishes inner OC comets by their release into the inner solar system in bursts [3]. Outer OC comets fall into our observational reaches routinely and in smaller groups. The calculations of observed comets' orbits in each group dictate semimajor axes of 10,000 to 20,000 AU for comet showers (the inner OC). Thus, the boundary between inner OC, where comets deploy due to stellar perturbation in bursts between long intervals, depends on available data with which to calculate the comets' semimajor axes.

Our understanding of the Oort Cloud is limited greatly by the low number of observations available for research. Yet, Dones et al employed the rate at which comets are discovered to theorise the population of the outer OC. They compared the rate at which comets at a specific semimajor axis and perihelion distance theoretically enter Earth's orbit with the rate of comets observed within Earth's orbit, which resulted in hypothesising an outer OC containing $3.3 * 10^{11}$ comets [1]. Dones et al then applied their theoretical population to a model of comets' absolute magnitude to yield both a theoretical average mass of an outer OCO and a mass of the region of the OC itself. From their research, we may assume that outer OCOs are approximately $4 * 10^{16}$ g each, contributing to an overall mass of $2 * 10^{28}$ g. Dones et al did not investigate the inner OC to the same level.

Using retrieval modelling based on observed LPCs, we have theorised populations, masses, and rates of comet infall. Separately, we have also produced a theory for the formation of the Oort Cloud in accordance to proto-solar system dynamics. From our understanding of proto-planet migration, the current hypothesis for how the Oort Cloud formed states that comets around 3,000 AU from the proto-sun were perturbed by Neptune and Jupiter's orbits to a much greater semimajor axis [3]. Jupiter continued to be a major influence on changing OCO orbits. Thus, we have derived theories for the OC formation and characteristics. Essentially, we know what we expect it to look like, where it to be, and how it behaves. It follows, then, as the natural progression of the pursuit of knowledge, to gain data that improves our hypotheses.

IV. METHOD OF IMAGING

To date, our most advanced attempts at visualising the OC are simulations of the comets over time. While these have assisted in the simplified calculations described above, the simulations' high uncertainty and limited data pool are widely discussed and accepted in every investigation that uses them [4] [1]. Naturally, though, we cannot rapidly acquire more observational data to improve the models given that only approximately 12 new comets per year that reach a perihelion distance of < 3 AU [1]. Dones et al attempted to correct for the small number of objects by simulating the orbits of 27,000 test particles. This model, though, matched only a fraction of parameters defining the Oort Cloud. Notably, the increased test size yielded an inclination of $\approx 123°$ while observed comets have a median inclination of 45°. Additionally, most of the simulated subjects exhibited retrograde motion as opposed to prograde. This opposite motion has great effects on the assumed lifetime of the comet (102,000 years for retrograde comets versus 64,000 years for prograde). A comet's lifetime partially determines its likelihood of being captured into a long-period orbit, and thus a difference in expected lifetime greatly affects the expected population of the Oort Cloud.

In summary, the Oort Cloud cannot be parameterised well without more evidence to confirm the proposed boundaries. To better constrain the Cloud, this research has outlined a telescope capable of imaging an average Oort Cloud Object – an average object was defined as 61 km in diameter and calculated as the average of diameters of known Oort Cloud objects.

V. TELESCOPE DESIGN

Given the large distance to the Oort Cloud and the small diameter of objects, it follows from the equation of resolving angle that a telescope must have an effective diameter of ≥ 35 km. This large diameter cannot be made of a single dish, and thus the telescope must be a radio interferometer compiled of multiple dishes. Additionally, radio interferometers more efficiently image through interstellar and interplanetary dust, the latter of which would interfere with imaging Oort Cloud objects.

Secondly, the proposal includes launching the interferometers to space. This eliminates atmospheric interruption that would further distort images. Additionally, interferometers in space can encompass a larger distance for their effective diameter which would improve the resolving power of the interferometer. Notably, though, the resolving power depends on the imaging wavelength. Currently, the R band has been noted for its wide use in imaging Kuiper Belt objects, according to Dr. Kat Volk from the University of Arizona, but this variable remains under research pending the inclusion of more literature into the bibliography and calculations with various wavelength values.

VI. COMPARATIVE BUDGET

Given the novelty of this proposed telescope, a comprehensive budget cannot be calculated. Instead, the cost of building and launching the interferometer is estimated from reviewing the costs of similar projects.

The Very Long Baseline Array (VLBA) is the largest diameter interferometer to date. It consists of 10 25-meter dishes that span an effective diameter of 8600 km [5]. This ground-based array cost \$85 million to construct [6]. The VLBA showcases the cost of a large interferometer array, but it does not include the complexities of launching a telescope to space. The cost of a space-based mission is exemplified by the most recent and most advanced space telescope to date. The James Webb Space Telescope (JWST) cost approximately \$10 billion to build and launch [7]. Thus, considering the two examples and their differences to the proposed mission, the Oort Cloud interferometer would require an estimated \$5 billion to get into space. This value will be refined once a wavelength is determined and other logistics are selected.

VII. CONCLUSION

The Oort Cloud remains a mostly unresearched, misunderstood mystery in our own solar system. Although it holds key information to the formation of our solar system and stands as an obstacle to travelling to other star systems, missions have not prioritised studying it. Simulations available are outdated and utilise a small number of data points. Further, the limited available data due to the low number of comets released from the Oort Cloud into the inner solar system. To fully understand and characterise the Oort Cloud, empirical evidence can be obtained by imaging the objects. This mission includes launching a 35 km interferometer to low-orbit for a cost of \$5 billion that will then image Oort Cloud objects. With these images, the Oort Cloud can be studied and analysed to depths currently unachievable, and this will further our understanding of our place in space.

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[7] C. Dreier, How much does the james webb space telescope cost? (2021).