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A NEW METHOD TO DERIVE AN EMPIRICAL LOWER LIMIT ON THE MASS DENSITY OF A UFO

Abraham Loeb[1]

[1] *Head of the Galileo Project, Astronomy Department, Harvard University, 60 Garden St., Cambridge, MA 02138, USA*

ABSTRACT

I derive a lower limit on the mass of an Unidentified Flying Object (UFO) based on measurements of its speed and acceleration, as well as the infrared luminosity of the airglow around it. If the object's radial velocity can be neglected, the mass limit is independent of distance. Measuring the distance and angular size of the object allows to infer its minimum mass density. The *Galileo Project* will be collecting the necessary data on millions of objects in the sky over the coming year.

1. INTRODUCTION

Any object moving through air radiates excess heat in the form of infrared airglow luminosity, L. The airglow luminosity is a fraction of the total power dissipated by the object's speed, v, times the frictional force of air acting on the object. The radiative efficiency depends on the specific shape of the object and the turbulence and thermodynamic conditions in the atmosphere around it (Zel'dovich & Raizer 1967). If the object accelerates, then this friction force must be smaller than the force provided by the engine which propels the object. The net force equals the object's mass, M, times its acceleration, a.

In conclusion, one gets an unavoidable lower limit on the mass of an accelerating object. The object's mass must be larger than the infrared luminosity from heated air around it, divided by the product of the object's acceleration and speed. In other words:

$$M > \frac{L}{|v \times a|} \quad . \tag{1}$$

This limit provides an elegant way to constrain the minimum mass of Unidentified Flying Objects (UFOs), also labeled as Unidentified Anomalous Phenomena (UAPs; see Watters et al. (2023) for an overview). To turn the inequality into an equality, one needs to know the detailed object shape and atmospheric conditions around the object.

The first *Galileo Project* Observatory at Harvard University (Loeb & Laukien 2023) collects data on $\sim 10^5$ objects in the sky every month. A comprehensive description of its commissioning data on $\sim 5 \times 10^5$ objects was provided in a recent paper (Dominé et al. 2024). The data includes infrared images captured by an all-sky *Dalek* array of eight uncooled infrared cameras placed on half a sphere (Loeb & Laukien 2023; Watters et al. 2023).

2. METHOD

Within the coming month, the *Galileo Project*'s research team plans to employ multiple *Dalek*s separated by a few miles, in order to measure distances to objects through the method of triangulation.

The heated air's infrared flux, f, and distance, R, can be combined to infer the luminosity, L, through the relation:

$$L = 4\pi f R^2 \quad . \tag{2}$$

The angular velocity, $(d\theta/dt)$, times the distance, R, provides the transverse component of the full velocity vector, $\mathbf{v}$, which can be combined with the time derivative of the distance, (dR/dt), to get the total speed,

$$v = \left\{ \left[R\left(\frac{d\theta}{dt}\right)\right]^2 + \left(\frac{dR}{dt}\right)^2 \right\}^{1/2} \quad . \tag{3}$$

The time derivative of the velocity vector provides the acceleration vector, $\mathbf{a} = (d\mathbf{v}/dt)$.

Remarkably, in the special case where the radial speed is negligible, $|dR/dt| \ll R|d\theta/dt|$, I find that the lower limit on the object's mass is independent of distance,

$$M > \frac{4\pi f}{|(d\theta/dt) \times (d^2\theta/dt^2)|} \quad . \tag{4}$$

The physical size of the object can be derived as the product of its angular size times its distance, $(\Delta\theta)R$. The minimum mass could then be used to derive the minimum mass per unit volume, or mass density ρ, of the object.

3. DISCUSSION

If the measured velocity and acceleration of a technological object are outside the flight characteristics and performance envelopes of drones or airplanes, then the object would be classified by the *Galileo Project*'s research team as an outlier. In such a case, it would be interesting to calculate the minimum mass density of the object. If the result exceeds normal solid densities, then the object would qualify as anomalous, a UAP. Infrared emission by the object would be a source of confusion, unless the object is resolved and the emission from it can be separated from the heated air around it.

All flying objects made by humans have a volume-averaged mass density $\langle\rho\rangle$ which is orders of magnitude below 22.6 g cm^{-3}, the density of Osmium - which is the densest metal known on Earth. A UFO with a higher mass density than Osmium would have to carry exotic material, not found on Earth.

By summer 2025, there will be three *Galileo Project* observatories operating in three different states within the U.S. and collecting data on a few million objects per year. With new quantitative data on infrared luminosities, velocities and accelerations of technological objects, it would be possible to check whether there are any UFOs denser than Osmium.

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