

## “DOWN TO EARTH” LIMITS ON UNIDENTIFIED AERIAL PHENOMENA

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### ABSTRACT

A recent report by astronomers about Unidentified Aerial Phenomena (UAP) in Ukraine (arXiv:2208.11215) suggests dark phantom objects of size 3–12 meters, moving at speeds of up to 15 km s<sup>-1</sup> at a distance of up to 10–12 km with no optical emission. I show that the friction of such objects with the surrounding air would have generated a bright optical fireball. Reducing their inferred distance by a factor of ten is fully consistent with the size and speed of artillery shells.

## 1. INTRODUCTION

Recently, astronomers in Ukraine reported about Unidentified Aerial Phenomena (UAP) that fall into two categories: bright and dark (Zhilyaev et al. 2022). The dark objects with no optical emission were labeled as “Phantoms”. They were characterized by a size of 3–12 meters and speeds up to  $15 \text{ km s}^{-1}$  at a distance of up to 10–12 km. If real, such objects exceed the capabilities of human-made aircrafts or rockets. Here, I show that the distance of these dark objects must have been incorrectly overestimated by an order of magnitude, or else their bow shock in the Earth’s atmosphere would have generated a bright fireball with an easily detectable optical luminosity.

The interest in UAP stems from their potential non-human origin. Extraterrestrial equipment could arrive in two forms: space trash, similar to the way our own interstellar probes (Voyager 1 & 2, Pioneer 10 & 11 and New Horizons) will appear in a billion years, or functional equipment, such as autonomous devices equipped with Artificial Intelligence (AI). The latter would be an ideal choice for crossing the tens of thousands of light years that span the scale of the Milky Way galaxy and could survive even if the senders are not able to communicate.

It is likely that any functional devices embedded in the Earth’s atmosphere are not carrying biological entities because these would not survive the long journey through interstellar space and its harsh conditions, including bombardment by energetic cosmic-rays, X-rays and gamma-rays (Hoang et al. 2017, 2018; Hoang & Loeb 2020). Interstellar gas and dust particles deposit a kinetic energy per unit mass that exceeds the output of chemical explosives at the speed of tens of  $\text{km s}^{-1}$  characterizing rockets. However, technological gadgets with AI can be shielded to withstand the hazards of space, repair themselves mechanically, or even reproduce given the resources of a habitable planet like Earth. With Machine Learning capabilities, they can adapt to new circumstances and pursue the goals of their senders without any need for external guidance.

As argued by John von Neumann in 1939, the number of such devices could increase exponentially with time if they self-replicate (Freitas 1980), a quality enabled by 3D printing and AI technologies. Physical artifacts might also carry messages, as envisioned by Ronald Bracewell in 1960 (Bracewell 1960; Freitas & Valdes 1985).

## 2. PROPULSION METHODS

In principle, the fastest gadgets could be launched by lightsails, pushed by powerful light beams up to the speed of light (Guillochon & Loeb 2015a). Natural processes, such as stellar explosions (Loeb 2020; Lingam & Loeb 2020) or gravitational slingshot near black hole pairs (Guillochon & Loeb 2015b; Loeb & Guillochon 2016), could launch objects to similar speeds. However, it would be difficult for relativistic payloads to slow down below the escape speed of Earth,  $10^{-4.5}c$ , without having around the same facilities that generated their high initial speeds.

A better suited propulsion technique that was used in all space missions from Earth is chemical rockets. Since rockets carry their fuel, they can navigate to a desired planet and slow down near it.

For a rocket of total mass,  $m$ , and exhaust speed of the ablated gas relative to the rocket,  $v_{\text{exh}}$ , momentum conservation implies:  $m\dot{v} = -\dot{m}v_{\text{exh}}$ , where an overdot denotes a time derivative. The Tsiolkovsky solution to the rocket equation (Tsiolkovsky 2000),  $(m_{\text{initial}}/m_{\text{final}}) = \exp\{(v_{\text{final}} - v_{\text{initial}})/v_{\text{exh}}\}$ , implies that for reasonable fuel-to-payload mass ratio, the final speed  $v_{\text{final}}$  will only be an order of magnitude larger than the exhaust speed. For typical chemical propellants with  $v_{\text{exh}}$  of order a few  $\text{km s}^{-1}$ , this tyranny of the rocket equation explains why all human-made spacecraft reached a speed limit of tens of  $\text{km s}^{-1}$  or  $\sim 10^{-4}c$ . Interestingly, this speed is comparable to the escape speed from the Earth’s orbit around the Sun,  $v_{\text{esc}} \sim 42 \text{ km s}^{-1}$ , making it possible for humanity to launch probes to interstellar space by taking advantage of the motion of the Earth around the Sun at  $v_{\text{initial}} \sim 30 \text{ km s}^{-1}$ . Chemical propulsion may not be sufficient for probes to escape from the habitable zone around dwarf stars, like the nearest star Proxima Centuari (Loeb 2018; Lingam & Loeb 2018).

In summary, chemical propulsion allows escape from the habitable zone of Sun-like stars and enables slowing down near a destination. The Ukrainian report suggests objects with comparable speeds of up to  $15 \text{ km s}^{-1}$ .

Devices which need to refuel would favor a habitable planet where liquid water or combustible organic fuel are available. Planets can be identified from a distance as they transit their star or through direct imaging (Winn 2023). Once an Earth-like planet is targeted, an interstellar device can plunge into its atmosphere. In principle, a multitude of tiny devices can be released from a mothership that passes near Earth.

At  $v_{\text{final}} \sim 10^{-4}c$ , a probe would cross twice the distance of the Sun from the Milky-Way center within a time of  $\sim 0.5 \text{ Gyr}$ . The fraction of all Sun-like stars that host Earth-like planets in their habitable zone is in the range  $\sim 3\text{--}100\%$  (Zink & Hansen 2019; Hsu et al. 2020; Bryson et al. 2021). This implies that self-replicating probes could reach  $\sim 10^{10}$  habitable planets around Sun-like stars in less than a billion years.

Since most stars formed more than a billion years before the Sun (Madau & Dickinson 2014), it is possible that other technological civilizations predated ours by the amount of time needed for their devices to reach Earth. Here, I point out that any supersonic motion of such devices through the Earth’s atmosphere would inevitably be accompanied by optical emission.

### 3. UNAVOIDABLE OPTICAL EMISSION

An object with a frontal cross-sectional area  $A$ , moving at a supersonic speed,  $v$ , must create a bow shock in the Earth’s atmosphere and dissipate a mechanical power,

$$P \approx \frac{1}{2}A\rho_a v^3 = 1.5\text{TW}(A/10 \text{ m}^2)(\rho_a/0.3 \text{ kg m}^{-3})(v/10 \text{ km s}^{-1})^3, \quad (1)$$

where  $\rho_a$  is the ambient air density which depends on elevation, normalized here by its value at an elevation of 10 km.

Data on meteors shows that the fraction of the kinetic power which is radiated away in the optical band is  $\sim 10\%$  (see equation (1) and figure 2 in [Brown et al. \(2002\)](#)), implying an optical luminosity,

$$L_{\text{opt}} \approx 150\text{GW}(A/10\text{m}^2)(\rho_a/0.3 \text{ kg m}^{-3})(v/10 \text{ km s}^{-1})^3. \quad (2)$$

For a path length  $\ell$ , this luminosity will persist over a period of time,  $\sim 1\text{s} \times (\ell/10 \text{ km})/(v/10 \text{ km s}^{-1})$ .

#### 4. CONCLUSIONS

I conclude that the reported speeds and sizes of the ‘‘Phantom’’ objects ([Zhilyaev et al. 2022](#)), would have generated fireballs of detectable optical luminosity at their suggested distances, and so these objects could not have appeared dark. However, if the Phantom objects are ten times closer than suggested, then their angular motion on the sky corresponds to a physical velocity that is ten times smaller,  $v \sim 1.5 \text{ km s}^{-1}$ , and their inferred transverse size would be  $\sim 0.3\text{--}1.2$  meters, both characteristic of artillery shells.

The phantom objects were reported as dark. Their minimal cross-section for blocking light inevitably implies that they must interact with air molecules.

Since  $L_{\text{opt}} \propto A \times v^3$ , the fireball luminosity scales with inferred distance to the 5th power, and is reduced to a modest level of a few MW. If the artillery shells have a frontal diameter of only 10 cm, then  $L_{\text{opt}} \sim 10 \text{ kW}$ , which at a distance of  $\sim 1 \text{ km}$  would appear extremely faint.

The luminous and variable object at an inferred altitude of  $\sim 1,170 \text{ km}$  which was detected through two-site observations above Ukraine ([Zhilyaev et al. 2022](#)), is likely a satellite.

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