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INTERSTELLAR OBJECTS FROM BROKEN DYSON SPHERES

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ABSTRACT

Without extensive maintenance, Dyson spheres will inevitably disintegrate by asteroid impacts over billions of years. The resulting fragments would appear as anomalous interstellar objects, potentially sharing the unusual shape of 'Oumuamua or the unusual material strength of the first two interstellar meteors, IM1 and IM2.

1. INTRODUCTION

Every year, a 2-meter space rock hits Earth and releases an amount of energy similar to the Hiroshima atomic bomb (Brown et al. 2016). The explosion energy of 6×10^{20} ergs is equivalent to the average electric power consumption worldwide, a few Terra-Watt, for twenty seconds.

The likelihood of an impact is proportional to the area of the target. Similar rocks pass within a sphere delineated by the orbit of the Earth around the Sun a few billion times each year.

It is therefore not surprising that an asteroid of twice this size passed 3,589 kilometers above the surface of Earth as recently as January 26, 2023 (IAU MPC, MPEC 2023-B72:2023 BU). The asteroid 2023 BU, was spotted by Gennadiy Borisov, who is also known for discovering the first interstellar comet in 2019, named 2I/Borisov (Guzik et al. 2020).

Here, I examine the implications of the above impact statistics to the search for extraterrestrial intelligence (SETI).

2. STAPLEDON-DYSON SPHERES

In 1937, Olaf Stapledon published the novel "Star Maker", in which he imagined the use of a technologically-manufactored shell of matter to tap the energy output of a host star. The concept was subsequently formalized by Freeman Dyson (Dyson 1960), who reasoned that as the energy needs of humanity will steadily increase, our civilization might aspire to tap all the energy output of the Sun. Dyson proposed a shell of orbiting structures that would intercept and collect the solar luminosity. This so-called Dyson sphere would emit infrared radiation to balance the heat deposited on it by sunlight.

The balance of radiation from the stellar surface by emission from a spherical shell at a larger radius,

$$L_\star = 4\pi\sigma R_\star^2 T_\star^2 = 4\pi\sigma R_{ds}^2 T_{ds}^2, \tag{1}$$

yields the Dyson sphere temperature,

$$T_{ds} = 395\ \mathrm{K} \left(\frac{T_\star}{T_\odot}\right) \left(\frac{R_\star}{R_\odot}\right)^{1/2} \left(\frac{R_{ds}}{1\ \mathrm{au}}\right)^{-1/2}, \tag{2}$$

where $L_\star$, $R_\star$ and $T_\star$ are the stellar luminosity, radius and effective temperature of the star, with solar values of $L_\odot = 4 \times 10^{33}$ erg s^{-1}, $R_\odot = 7 \times 10^{10}$ cm and $T_\odot = 5780$ K, and the associated Dyson sphere parameters of R_{ds} and T_{ds}. The peak wavelength of blackbody emission from the Dyson sphere is given by,

$$\lambda_{\mathrm{peak}} = 7.3\ \mu\mathrm{m} \left(\frac{T_\star}{T_\odot}\right)^{-1} \left(\frac{R_\star}{R_\odot}\right)^{-1/2} \left(\frac{R_{ds}}{1\ \mathrm{au}}\right)^{1/2}, \tag{3}$$

with an observable flux density at a distance of $d_\star$,

$$\frac{L_\star \lambda_{\mathrm{peak}}}{4\pi d_\star^2 c} = 7.8 \times 10^{-2}\ \mathrm{Jy} \left(\frac{L_\star}{L_\odot}\right)^{3/4} \left(\frac{R_{ds}}{1\ \mathrm{au}}\right)^{1/2} \left(\frac{d_\star}{1\ \mathrm{kpc}}\right)^{-2}. \tag{4}$$

This infrared signal could flag a Dyson sphere in contrast to the natural optical emission by Sun-like stars. So far, searches for related infrared signatures from stars or galaxies did not find evidence for Dyson spheres but only for emission by natural dust (see references in Wright (2020)).

Below I demonstrate that if Dyson spheres existed to serve their civilizations for a limited time, most of them would have disintegrated within billions of years in the absence of extensive maintenance. In that case, their ejected fragments could appear as interstellar objects (Siraj & Loeb 2022a).

3. BROKEN DYSON SPHERES

Rigid Dyson spheres are not easy to maintain. In compliance with Newton's iron sphere theorem, a perfectly spherical and rigid shell is not subjected to any net gravitational force from a star interior to it, regardless of whether it is centered on the star. However, the shell experiences destructive differential forces across its surface, and its material strength must be high in order to prevent deformation. The required tensile strength, Π, is given by:

$$\Pi \approx \frac{GM_\star \rho_{ds}}{2R_{ds}} = 3.6 \times 10^6 \text{ MPa} \left(\frac{M_\star}{M_\odot}\right) \left(\frac{\rho_{ds}}{7.9 \text{ g cm}^{-3}}\right) \left(\frac{R_{ds}}{1 \text{ au}}\right)^{-1}, \tag{5}$$

where $\rho_{\rm ds}$ is normalized by the solid density of iron. The derived value is an order of magnitude above the tensile strength of graphene, $\Pi_{gr} = 1.3 \times 10^5$ MPa.

To circumvent the material strength challenge, Robert Forward proposed a tiled structure (Forward 1991), with each component functioning as a solar sail for which the star's gravity is exactly balanced by by the star's outward radiative push, thus maintaining a fixed position without orbiting the star. The force balance reads (Loeb 2022a):

$$\frac{L_\star}{2\pi R_{ds}^2 c} = \frac{GM_\star \Sigma_{ds}}{R_{ds}^2}, \tag{6}$$

where the mass per unit area of the light sail components is given by,

$$\Sigma_{ds} = 1.5 \times 10^{-4} \text{ g cm}^{-2} \left(\frac{L}{L_\odot}\right) \left(\frac{M_\star}{M_\odot}\right)^{-1} . \tag{7}$$

4. IMPLICATIONS FOR SETI

If a Dyson sphere disintegrated by asteroid impacts over time, then its fragments could have been ejected by gravitational kicks from planets out of the host planetary system.

Interstellar fragments of a broken Dyson sphere could potentially share the unusual shape and light sail characteristics of the interstellar object 1I/'Oumuamua (Loeb 2022b; Bialy & Loeb 2018), or the unusually high yield strength ($\gtrsim 10^2$ Mpa, larger than the value of iron meteorites) exhibited by the first and second interstellar meteors, IM1 and IM2 (Siraj & Loeb 2022b). The planned expedition to retrieve the fragments of IM1 (Siraj et al. 2022) and the subsequent analysis of the fragments composition, could potentially test this hypothesis.

Irrespective of its architecture, maintenance of a Dyson sphere is extremely challenging since the structure will be punctured by a few billion human-size asteroids every year for a planetary system that resembles the Solar system. Over a few billion years, the structure would have holes of a few meters in size every hundred meters. Interestingly, the estimated size of 1I/'Oumuamua was about a hundred meters (Mashchenko 2019), potentially dictated by the asteroid bombardment rate of an old Dyson sphere in a Sun-like planetary system.

Small holes would be more abundant. The holes would cover a significant fraction of the Dyson sphere surface from bombardment by micrometeorites on sub-centimeter scales. This impact statistics is currently measured empirically, as JWST is being hit by a dust-sized particle every month. Without repair, a billion-year old Dyson sphere would resemble a fishing net which lets a substantial fraction of the starlight out.

In summary, once a civilization abandons its Dyson sphere this technosignature is expected be punctured by micrometeorites and lose its functionality on a timescale much shorter than the lifetime of the host star. Studies of the composition of interstellar objects offers a new way to constrain the abundance of broken Dyson spheres, irrespective of their age and deteriorated infrared characteristics.

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