We should be looking for small, hot Dyson spheres, new paper argues

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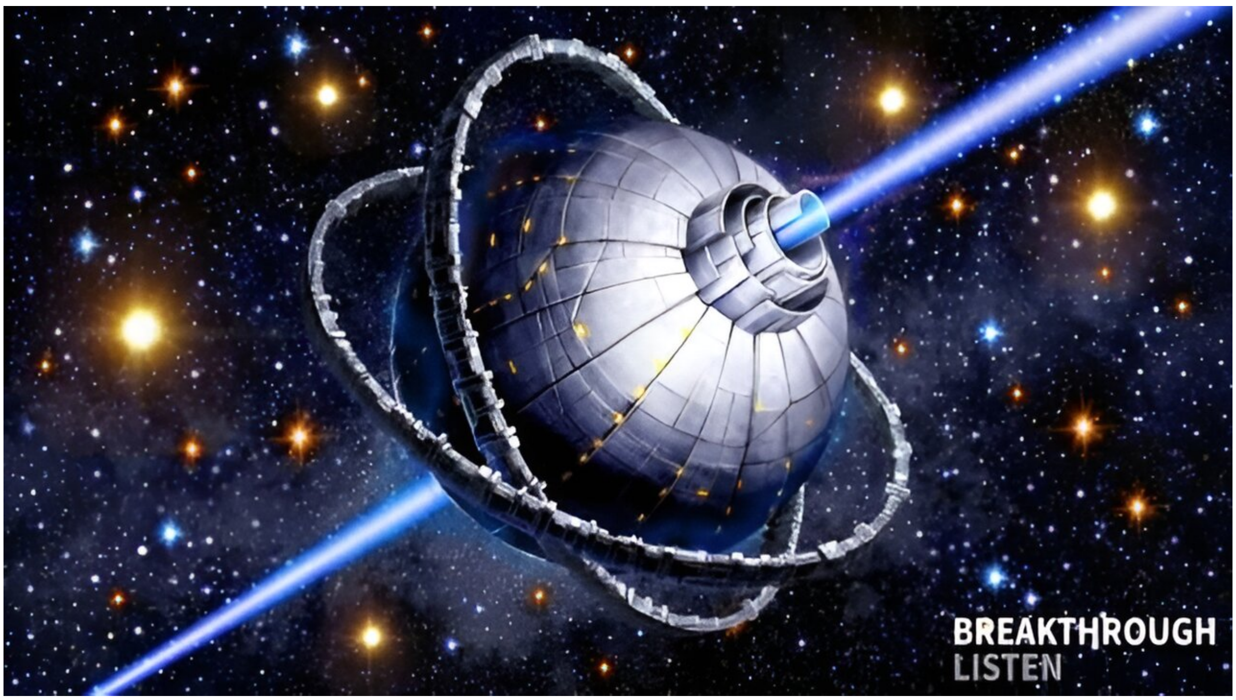

Artist's impression of a Dyson Sphere, a proposed alien megastructure that is the target of SETI surveys. Credit: Breakthrough Listen/Danielle Futselaar

In 1960, legendary physicist Freeman Dyson published his seminal paper "Search for Artificial Stellar Sources of Infrared Radiation," wherein he proposed that there could be extraterrestrial civilizations so advanced that they could build megastructures large enough to enclose their parent star.

He also indicated that these "Dyson spheres," as they came to be known, could be detected based on the "waste heat" they emitted at mid-infrared wavelengths. To this day, infrared signatures are considered a viable technosignature in the Search for Extraterrestrial Intelligence (SETI).

So far, efforts to detect Dyson spheres (and variation thereof) by their "waste heat" signatures have come up empty, leading some scientists to recommend tweaking the search parameters. In a new paper posted to the preprint server *arXiv*, astronomy and astrophysics Professor Jason T. Wright of the Center for Exoplanets and Habitable Worlds and the Penn State Extraterrestrial Intelligence Center (PSTI) recommends that SETI researchers refine the search by looking for indications of activity. In other words, he recommends looking for Dyson spheres based on what they could be used for rather than just heat signatures.

Key to Wright's study is the Landsberg limit, a concept in thermodynamics that represents the theoretical efficiency limit for harvesting solar radiation. This is vital since Dyson's original proposal was largely based on the idea that all life exploits free energy gradients, like photosynthetic life forms that rely on it to produce oxygen gas and organic nutrients. He further argued that technologically advanced life could grow to harness and exploit greater amounts of this energy. However, this ability has an absolute limit: the total energy released from a star (visible light, infrared, ultraviolet, etc.).

Because energy must be conserved, Freeman Dyson reasoned that some of this energy must be expelled from the Dyson structure as waste heat. Leveraging advances in infrared astronomy, a burgeoning field in Dyson's time, astronomers could theoretically measure the energy used by an advanced civilization by looking for this heat. To date, only three all-sky mid-infrared studies have been conducted, including the Infrared Astronomical Satellite (IRAS), Wide-field Infrared Survey Explorer (WISE), and AKARI.

"Traditionally, we look for infrared emission from stars to see if they have orbital material warm from the starlight," Wright told Universe Today via email. "If it is not the kind of star that typically has material orbiting it, then we can look more closely to see if the material looks like dust or something else." However, all searches that have been attempted to date have been somewhat hampered by the fact that there is no underlying theory of what the waste heat would look like since the properties of a Dyson sphere's materials remain unknown.

Several theoretical models have been proposed by astrophysicists (including Wright himself) for what their thermal signatures might look like, but these have been rather simple and based on numerous assumptions. These include the spherical symmetry of the shell and its orbital distance from the star while failing to predict typical temperatures, radiative interactions, or optical depths of the material. This raises another vital concept Wright considered, which has to do with the purpose of the Dyson structure (what "work" does it perform?), from which inferences about its material properties can be made.

Dyson acknowledged that capturing a star's energy was merely one possible motivation for building such a megastructure. For example, several SETI researchers have proposed that a Dyson structure could be used as a stellar engine that could move stars (a Shkadov thruster) or as a massive supercomputer (a Matrioshka brain). Like its namesake, a Matrioshka brain has a nested structure, where the inner layer absorbs direct sunlight and the outer layers exploit the waste heat from the inner layer to optimize computational efficiency.

Moreover, Wright addressed the engineering challenges of building such a structure. Whereas Dyson focused on the laws of physics as the sole basis for the existence of megastructures, Wright also considered the engineering practicalities involved. From this, he ventured that civilization might be motivated to gradually build sections of a sphere to gradually increase their habitable volume around a star. With all of this in mind, Wright applied the thermodynamics of radiation to Dyson spheres as computation machines and what the observable consequences would be.

He concluded that there is little to no advantage in creating nesting shells and that the optimal use of mass would favor smaller, hotter Dyson spheres. Furthermore, he indicated that there would be observable differences between "complete" Dyson spheres (fully assembled around a star) and those still in progress. As Wright explained:

"Contrary to the expectations of some authors that Dyson spheres would be extremely large and cold to maximize their efficiency, I find that for a fixed mass budget, the optimum configuration is actually for very small, hot spheres that capture most but not all of the light that escapes. [W]e might expand our search parameters to temperatures well above 300K (a bit hotter than Earth) because work extraction of starlight is more efficient closer to the star, where things are hotter."

These findings could help inform future searches for Dyson structures, which are unfortunately limited at the moment. A notable exception is the work of astrophysics Ph.D. student Mathias Suazo (University of Upsalla) and his colleagues at Project Hephaistos. Suazo presented their work back in June as part of the 2nd Annual Penn State SETI Symposium, where he explained how the project scientists combined data from the ESA's Gaia Observatory, Two Micron All Sky Survey (2MASS), and NASA's Wide-field Infrared Survey Explorer (WISE) to narrow the search for thermal signatures that could indicate the presence of megastructures.

The combined data revealed roughly 5 million possible candidates within a volume measuring ~1,000 light-years in diameter. After creating a "best fit" model based on temperature and luminosity profiles that eliminated possible natural sources, Suazo and his team winnowed the list to 20 viable candidates. These sources will likely be subject to follow-up observations by next-generation telescopes in the near future. Meanwhile, the search continues, and while it has produced no definitive evidence of megastructures, the possibility remains.

As Dyson famously said when addressing the possible motivations for such engineering. "My rule is, there is nothing so big nor so crazy that one out of a million technological societies may not feel itself driven to do, provided it is physically possible." If only a handful of advanced civilizations have committed to mega-engineering projects in our galaxy, we'll sniff them out sooner or later.

More information: Jason T. Wright, Application of the Thermodynamics of Radiation to Dyson Spheres as Work Extractors and Computational Engines, and their Observational Consequences, *arXiv* (2023). [DOI: 10.48550/arxiv.2309.06564](https://doi.org/10.48550/arxiv.2309.06564)

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