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SAM FALCONER

How to spot an alien megastructure

Intelligent extraterrestrials may have built vast power plants, known as Dyson spheres, around stars. The search for their telltale glow is hotting up, finds **Mordechai Rorvig**

THERE comes a point at which any advanced alien civilisation worth its salt has to dismantle a neighbouring planet for spare parts. This isn't an act of vandalism, you understand, but rather a precursor to building an enormous solar power plant that surrounds its entire host star. What else would an ambitious alien society do to continue its expansion? How else would it meet its ever-increasing demand for energy?

This scenario, or something like it, is the founding principle of the search for alien megastructures, which in this case would look something like dark embers when viewed through infrared telescopes. The search began in 1960, when physicist Freeman Dyson proposed it as a way of finding alien life. More than 60 years later, the hunt for Dyson spheres, as they are now known, remains a minority sport among those involved in the search for extraterrestrial intelligence (SETI), an enterprise that has focused primarily on listening for radio signals from other worlds.

But astronomers are still prospecting for evidence of alien engineering. In particular, they have been working to put the pursuit of Dyson spheres on a rigorous scientific footing. Now, they are poring over the most precise cosmic cartography ever produced to try to find stars that could be surrounded by swarms of solar panels and distinguish them from naturally occurring infrared herrings. They are already narrowing down candidates. They have even begun to think seriously about the final hurdle: how to tell the difference between an infrared herring and a genuine alien megastructure.

Dyson's original proposal was quite broad. In a one-page paper, he suggested simply that advanced extraterrestrial civilisations, should they exist, would be likely to convert the light from their stars into energy on an epic scale, leaving observational clues for those who cared to look. Since then, others have developed the argument. Jason Wright, an astrophysicist at Pennsylvania State University, for instance, concluded in a 2014 paper that "long-lived civilizations with large energy supplies might... be expected to rely almost entirely upon starlight for their energy needs".

In terms of engineering, theorists say there are no serious obstacles to building giant solar power plants around stars. "There is nothing really weird about the physics of a Dyson sphere," says Anders Sandberg at the Future of Humanity Institute at the University of Oxford. Any such structure probably wouldn't be a simple monolithic sphere. More likely, a Dyson sphere would consist of a collection of orbiting solar panels that only partially cover the star.

In any case, there would be clear observational signatures for astronomers here on Earth. Dyson spheres would inevitably give off heat and energy that would make them extremely difficult to conceal. Indeed, Dyson sphere hunters need only make one key supposition – that the structure would get warmed by starlight to a moderate temperature, somewhere above the background temperature of space. All warm matter produces an infrared glow, and a massive megastructure would produce a great deal of it. The structure would therefore effectively reprocess incoming starlight into outgoing infrared light, creating a substantial excess of infrared light compared with what you would see from the same star uncovered.

In 1960, Dyson thought these megastructures would stick out because strong sources of infrared light seemed rare in space. The first proper surveys of the cosmos at this wavelength began with the Infrared Astronomical Satellite (IRAS), a space telescope launched in 1983. The problem was that it revealed a teeming multitude of objects radiating in the infrared. Some were stars that are bigger and brighter than our sun. Others were stars surrounded by clouds of gas and dust, which become heated and radiate infrared light – just like a Dyson sphere would. The implications for the search for Dyson spheres were confounding. "The huge and unexpected abundance of infrared sources made the search harder than people thought it would be," says Wright.

Spectral signatures

Richard Carrigan was among the first to try to sort through the clutter, completing a landmark search in 2009. A particle physicist at the Fermi National Accelerator Laboratory near Chicago, Carrigan pored over the spectroscopic data from IRAS. Like a prism, spectroscopy splits the light from a source into its constituent wavelengths, telling a remarkably full tale about the nature of the object that emitted the light. He identified a handful of stars with the sorts of spectral signatures one would expect if they were surrounded by Dyson spheres. ›

One star looked particularly promising. In the end, however, it was impossible to distinguish it from an ordinary type of star called a red giant. These are old, bright and emit a great deal of infrared. Worse, they are often shrouded by dust, meaning they mimic a Dyson sphere's optical dimness. Carrigan didn't see signs of dust in his candidate's signature, but that only sufficed to make it an unusually undusty red giant. "Not anything you'd say eureka about," he says.

The experience was instructive, though. It demonstrated the difficulty in distinguishing a Dyson sphere from a natural phenomenon that has a similar spectral signature. Many of these phenomena turn out to be associated with stellar age: newborn stars form within a cocoon of dense gas and dust, for example, while old stars can blow out a dense shell of carbon dust that looks a bit like a megastructure. For Dyson sphere searchers, the full list of mimics is long and sobering. "Confirming whether something is really due to extraterrestrial intelligence and not just some very unusual astrophysics, it's hard," says Erik Zackrisson, an astronomer at Uppsala University in Sweden who is heading the largest ever Dyson sphere search.

The challenge is to weed out these mimics, and we already have a few ideas of how it can be done. Though IRAS was revolutionary for its time, it couldn't tell how far away the infrared sources it detected were: it only measured brightness, not distance. A star that seemed bright in infrared could just be a star that was nearby, rather than an unusually infrared bright Dyson sphere. Conversely, an optically dim-seeming star could just be far away, rather than having its visible light blocked by a megastructure. Carrigan realised that measuring the distance to a candidate would help pinpoint its identity.

"The idea is to release a list of interesting objects for the whole SETI community"

But distance can also help to identify stars that are less likely to have dust in the first place. The distance to a star can be used to deduce its true intrinsic brightness, or luminosity. This in turn correlates with its age; old stars like red giants burn bright, for instance. Age then speaks to the presence of dust – which is more common around very young or very old stars. Through this chain of reasoning, Zackrisson and his colleagues figured, we can identify middle-aged "main sequence" types of stars that are less likely to be mistaken for dusty impersonators.

The recent releases of data from the European Space Agency's Gaia space telescope give Dyson sphere prospectors exactly what they need to narrow their search. Gaia was launched in 2013. Its mission is to measure the distances to more than a billion stars in the Milky Way and beyond. In the process, it has identified precisely the main sequence stars SETI researchers are looking for – the least dusty candidates. All of which explains why Zackrisson and his team are so keen to make use of the Gaia data, which has been released in three tranches so far, the latest coming in December 2020.

Fresh search

Zackrisson's first study using Gaia results came out in 2018. He and his colleagues looked for stars that seemed too dim in visible light for their distance, suggesting they might be shrouded. The distance was given by Gaia, with an independent estimate of dimness acquired from ground-based telescopes. The trouble is that spectroscopic data takes a long time to collect. Gaia won't be providing much of it, and that limits the number of stars you can scour for signs of Dyson spheres with this approach.

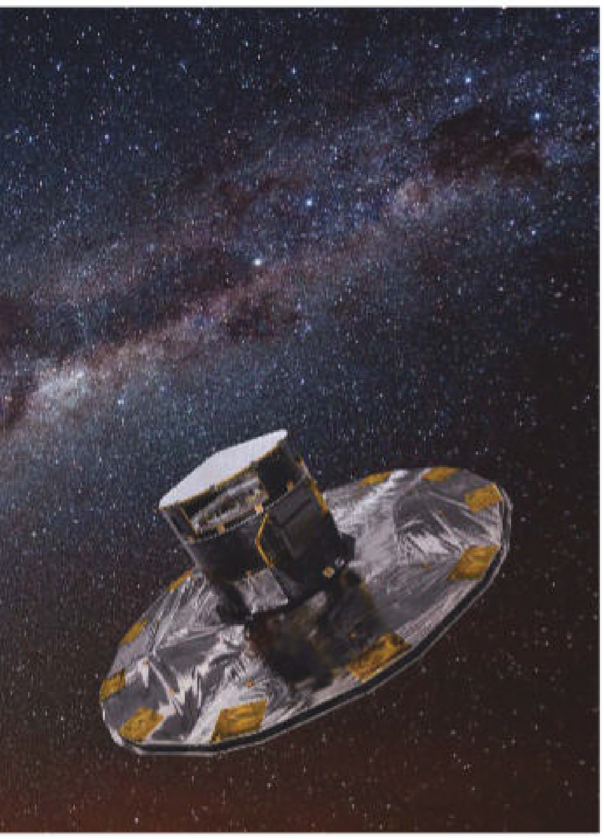
Now, Zackrisson, along with Wright and others, is experimenting with a new method that allows them to scour many more stars. The researchers are combining the Gaia data set with observations from the Wide-field Infrared Survey Explorer (WISE) space telescope, launched in 2009 as a kind of supercharged successor of IRAS. They are focusing on undusty main sequence stars, readily identifiable thanks to Gaia, and looking exclusively for infrared brightness over and above what you would typically expect, rather than combing through the details of each star's spectroscopy. "While they are on the main sequence, you don't expect them to have a very strong infrared excess," says Zackrisson.

Their first goal is to estimate the possible prevalence of Dyson spheres in the galaxy. To do this, the researchers take every main sequence star from the Gaia/WISE data set and look at how its infrared emissions would change if it was surrounded by a Dyson sphere that covers a given percentage of its surface. A sphere with a more complete swarm of solar installations would build up more heat and therefore generate more infrared light. Zackrisson and his team then compare these emission signatures with the actual emissions from stars in the Milky Way to see how many match. This way, they can calculate the prevalence of possible Dyson spheres with various covering fractions.

ESA/ATG MEDIALAB; BACKGROUND: ESO/S. BRUNIER

Artist's impression of the Gaia satellite, which helps us hunt alien engineering

Initial results, presented last year by Zackrisson's colleague Matías Suazo showed that Dyson spheres covering 90 per cent of their star seem to occur around at most 1 in 10,000 stars in the Milky Way. The results served as proof of the principle for this sort of analysis. Well, sort of. Closer attention revealed something of a hiccup in that the candidates that they identified weren't main sequence stars after all, let alone Dyson spheres: Gaia had been tricked by binary star systems and other stellar objects like planetary nebulae, which can be closer or further than they appear. But Suazo is in no doubt that, as the team analyses the data more closely, such wrinkles will be ironed out.



The next stage is to whittle down however many possibilities the team ends up with to the most promising. One way to do this is by scrutinising the spectroscopic information for each star of interest, which provides a wealth of insight on the presence and nature of dust. If a star is surrounded by a common form of dust known as polycyclic aromatic hydrocarbon (PAH) dust, for instance, then ultraviolet light is absorbed and re-emitted at specific infrared wavelengths, says planetary astronomer Carey Lisse at Johns Hopkins University Applied Physics Laboratory in Maryland. See extra light at those wavelengths and you know there is PAH dust.

Crucially, a smooth distribution of light over many wavelengths indicates an absence of dust – and the possibility that the star in question is surrounded by a Dyson sphere. “An optically thick Dyson sphere or swarm should be spectrally featureless,” says Lisse.

It is going to be extremely difficult to rule out every natural explanation for what appears to be a vast solar plant around a star. “This is a problem for many types of SETI,” says Zackrisson. But he expects his highly targeted search to generate at least 100 to 1000 potential candidates, all of which will have to be further scrutinised to see if they can be explained with natural phenomena. “We will have our list of weird objects at the end of the day, and I think it will be substantial,” says Zackrisson.

The idea is that follow-up spectroscopy observations will be able to tease out the answers to many questions, including a candidate’s shape, temperature and material composition – including the presence or absence of dust. The precision with which these questions can be addressed will be enhanced by the upcoming James Webb Space Telescope (JWST) – that is, if Dyson sphere searchers can gain precious observing time. “If we find an interesting candidate, we will need to argue that it is interesting enough for JWST regardless of its nature,” says Wright.

But even the best spectroscopy will have trouble making an indisputable ruling. Nowhere in the wavelengths is it likely to state unequivocally ALIENS WERE HERE. The only way to know for sure if there is an artificial megastructure around a star would be to detect an alien radio signal coming from it. Zackrisson’s team plans to hand its list of candidates to radio SETI colleagues for follow up observations. “The idea is to release a list of interesting objects for the whole SETI community,” says Zackrisson.

Then again, there remains the possibility that we might actually see an alien structure, rather than rely on infrared inferences. Interferometers, which combine the light from multiple telescopes to enhance resolution, have already demonstrated the ability to take startling images of faraway solar systems. The Atacama Large Millimeter/submillimeter Array (ALMA) interferometer in northern Chile has revealed natural megastructures around nearby stars with high clarity, such as phenomena known as debris disks – left over from planet formation.

Using earlier instruments, “all the disks would look like blobs”, says Mark Wyatt at the University of Cambridge. Now, with ALMA, disks have been clearly observed as vast belts of rocky debris, like the rings of Jupiter, but a thousand times larger. Would a Dyson sphere look truly distinctive? “It’s harder to say,” says Wyatt. “We don’t know what those look like.”

Wright, Zackrisson and Lisse recently argued that the search for Dyson spheres has matured to the point that the biggest obstacle is now funding. There is precious little money devoted to such pursuits. But there are signs this is beginning to change. Last year, NASA awarded its first ever grant to search for non-radio alien “technosignatures”, including solar arrays on the surface of exoplanets.

When it comes to finding Dyson spheres, no one is under any illusions about the scale of the challenge. “It’s going to continue to be hard for a long time,” says Zackrisson. And yet as they learn more about the natural phenomena that can shroud stars, astronomers are building up a formal framework by which they could, should the opportunity ever present itself, objectively distinguish between a mere dusty shroud and an alien megastructure. ■

Traces of technology

Glowing megastructures aren’t the only “technosignatures” alien civilisations might leave behind

POLLUTANTS

Intelligent extraterrestrials are likely to have transformed their planet with industry. SETI researchers have proposed that we could look for their non-natural waste products such as chlorofluorocarbons (CFCs), which can persist in the atmosphere for tens of thousands of years.

PARTICLE COLLIDERS

If intelligent aliens are curious about the fundamental forces of nature, they might have built a particle collider that makes our Large Hadron Collider look puny. A black-hole-powered accelerator, for instance, would produce super-high-energy neutrinos, particles that could be detected from Earth.

APOCALYPSE

Any advanced alien civilisation runs the risk of destroying itself, and the fallout might be visible to distant observers. Nuclear bombs would release flashes of gamma rays, but they would be fleeting and the resulting dust would be hard to distinguish from that produced by an asteroid strike.

Mordechai Rorvig is a science writer based in Massachusetts