IAC-04-IAA-1.1.1.06

SEARCHING FOR DYSON SPHERES WITH PLANCK SPECTRUM FITS TO IRAS

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ABSTRACT

Dyson suggested an advanced civilization might capture energy radiating from a star by breaking up planets to form a loose shell surrounding the star. The shell would reradiate energy as an infrared blackbody spectrum with a characteristic temperature of 300 ºK. There have been several searches for partial Dyson Spheres, notably by Jugaku. These searches look for infrared excesses. A recent search of the IRAS database by Timofeev, et al. found examples of Dyson Sphere signatures but recognized the possibility of confusion with circumstellar gas clouds. This search has examined the IRAS database for examples of good blackbody fits in the 150-500 ºK regime. The search has mostly concentrated on cases with no visible associated star. The IRAS 100 μm band was not used because it was subject to wide zodiacal and interstellar cloud variations. Significant signals were required in the other three filter bands. Many sources pass these cuts. Statistical arguments suggest there are less than 25 pure Dyson Sphere candidates that fit a single blackbody spectrum in this sample.

INTRODUCTION

In 1960 Dyson[1] suggested that an advanced civilization inhabiting a solar system might break up the planets into very small planetoids or pebbles to form a loose shell that would collect all the light coming from the star. The shell of planetoids would vastly increase the available habitable area and absorb all of the visible light. The stellar energy would be reradiated at much lower temperature. If the visible light was totally absorbed by the planetoids a pure Dyson Sphere signature would be an infrared object with luminosity equivalent to the hidden star and a blackbody distribution with a temperature corresponding to the radius of the planetoid swarm. For the case of the Sun with the planetoids at the radius of the Earth the temperature would be approximately 300 ºK. The main focus of this investigation has been to look for pure Dyson Spheres. Many of the earlier searches for Dyson Spheres have looked for so-called partial Dyson Spheres where the loose shell only partially obscures the star.

An unambiguous Dyson Sphere signature could be interesting evidence for “cosmic archaeology”, that is signs of intelligent activity elsewhere in the Universe. (The phrase cosmic archaeology is used to distinguish this from “astronomical archeology” used to designate investigations of ancient astronomical texts.) Cosmic archaeology signatures represent a different approach to finding intelligence elsewhere in the Universe. Unlike SETI signals[2] generated as beacons, the creation of a Dyson Sphere signature did not require an active strategy on the part of the originating “civilization”. Lemarchand[3] has reviewed a wide range of other possible signatures of extraterrestrial technological activity. Another example of a possible cosmic archaeology signature is a so-called Kardashev civilization[4]. Annis[5] has searched for so-called Type III Kardashev civilizations by looking for outliers on galactic distributions used to study the Tully-Fisher or L-T scaling relation. An interesting distinction between SETI searches for radio and laser beacons and systematic searches for objects like Dyson Spheres is that no presumption has to be made concerning the intent or motivation of the originating "civilization". In this sense a Dyson Sphere search is more akin to a search for extra solar planets.

There has been a great deal of informal discussion about the engineering of Dyson Spheres[6] as well as Dyson Sphere generalizations sometimes called Astroengineering Constructions or AC. A putative shell formed from Earth at Earth's distance from the Sun would be 4 mm thick, while a shell formed from Jupiter would be 5 m thick at Earth's radius and 0.2 m thick at Jupiter's distance from the Sun. In the correspondence in *Science Magazine* following Dyson's article several writers drew attention to problems associated with constructing a sphere, in particular a rigid sphere. Dyson responded that a rigid sphere was impossible and that what he had in mind was a swarm of objects. For this article the word "sphere" is used to designate any assembly including rings. Another objection is the large energy required to assemble a sphere. Dyson states that his model case would require the output of the Sun for 800 years. Note that a ring (often called a "Ringworld" from the science fiction novels of L. Niven) would require less energy to assemble but would also not be as effective at collecting stellar energy. Seen through the ring a ringworld could shield the host star like a Dyson sphere. Viewed perpendicular to the ring plane it would not have a strong signature. Finally, a non-anthropocentric view is helpful in considering the possible nature of Dyson's swarm. It might well consist of something like a flock of constantly-renewing 100 micron thick photocells powering computer chips!

A number of searches for Dyson Spheres have been made in the past and a few candidates have been identified but discounted for various reasons. Sagan and Walker[7] carried out an early analysis of the possibility of detecting a Dyson Sphere. They showed that a search out to 1000 pc was feasible even with sixties technology but that the possible confusion with natural signatures could require searches for other artifacts of intelligence such as radio signals associated with a candidate source. Jugaku and colleagues have carried out a series of searches for partial Dyson Spheres[8]. Typically they use the 2.2 μm K band as an indicator of the photospheric radiation of a star hosting a partial Dyson Sphere and then look for an infrared excess in the IRAS infrared satellite 12 μm band (IRAS – "Infrared Astronomical Telescope", see following sections). A 1 mag difference would arise if the Dyson Sphere covered 1% of the host star. The measured differences are characteristically less than 0.3 mag which is consistent with measurement errors. They selected a set of 1774 stars from the Woolley catalog nearer than 25 pc and found 458 with matches in the 12 μm IRAS band. They have looked at 384 of these stars for infrared excesses. With the exception of a few cases discussed in their 1990 article they have found no sources with excesses suggestive of a partial Dyson Sphere covering as much as 1% of the host star.

Slysh[9] and Timofeev at al.[10] have used the IRAS database for a different approach. Slysh notes that the flux density in Jy at the maximum of a Dyson Sphere spectrum is:

$$S_{\max} = \frac{35}{T}\left(\frac{D}{1\,kpc}\right)^{-2}\left(\frac{L}{L_0}\right) \qquad (1)$$

where T is the temperature of the Dyson Sphere, D is the distance to the source, L and L_0 the luminosities of the source and the Sun. He estimates that all Dyson Spheres with temperatures from 50 to 400 ºK within 1 kpc of the sun should have been detected. The Timoreev search looked at a population of IRAS sources in the 110-120 and 280-290 ºK temperature range as established by Kardashev and others and did Planck blackbody fits to the four IRAS bands at 12, 25, 60, and 100 µm. They fitted by minimizing

$$q = \sum_j \left(\frac{F_{appj} - F_{Sj}}{\max} \right)^2 \qquad (2)$$

where F_{appj} is an approximation flux for the blackbody spectrum in the jth band, F_{Sj} is an observational flux, max is the largest value from the two sets of fluxes, and j runs over the four bands. Note that no Planck spectrum correction is made on the four measured fluxes. Sylsh identified one possible Dyson Sphere candidate, G357.3-1.3. The Timofeev at al. search identified 10 or so candidates but ruled out most of them, often on the basis of associations.

More recently several other searches have been conducted for partial Dyson Spheres. Globus et al.[11] have searched by looking for a temperature/luminosity anomaly due to the fact that the luminosity of a star surrounded by a partial Dyson sphere would be lowered compared to a naked star of the same temperature. Conroy and Werthimer[12] have searched by constraining the Jugaku infrared excess technique to older stars using a list of 1000 nearby older stars compiled by Wright and Marcy. Using older stars eliminates thick dust clouds around young stars. They also correlate with the rich K band near-infrared ground based data from 2MASS. They have found 33 candidates in the 12 µm IRAS band with 3 σ excesses from the mean.

REQUIREMENTS FOR A DYSON SPHERE SEARCH

To identify a Dyson Sphere it is necessary to differentiate it from other objects with similar signatures. There are three principal signatures for a pure Dyson Sphere. One is luminosity similar to an ordinary main sequence star. A second is an infrared distribution that is a pure Planck spectrum. The third is the absence of an optically visible star. The third requirement can be relaxed for a partial Dyson Sphere.

For a partial Dyson shell only partly covering a star it might be possible to determine the stellar distance by stellar red shift analysis and thereby estimate the luminosity of the star and the surrounding Dyson Sphere. Unfortunately it is not straightforward to determine the luminosity of an infrared object with a Planck distribution at an unknown distance from the observer unless the object is close enough so that the shell has a finite and observable size. Possible indirect techniques to determine the distance to a Dyson Sphere include association with a known cluster like the galactic center or the Pleiades or by finding a Dyson Sphere that is a member of a binary star system.

A fair fraction of stars are in multiple star systems. A binary system consisting of a pure Dyson Sphere and an ordinary star with a separation smaller than the resolving capability of the infrared telescope would appear as a partial Dyson Sphere. In that situation, a pure Dyson Sphere might be distinguished by looking for full eclipses from a disk several AU in diameter, much more longer than corresponding Jupiter-sized eclipses. Resolvable cases could be identified by looking for companion stars near the pure Dyson Sphere candidate. A problem is that without a distance determination for the Dyson Sphere there are typically too many normal star candidates nearby.

The Pleadies at 125 pc is a useful cluster of about 1200 objects that subtend a large field of roughly four square degrees or approximately 10^{-4} of the sky. The Pleiades would contain about 25 members of a randomly distributed sample of 250,000 objects scattered across the sky. Thus association with a nearby cluster will be a useful tool for less than 0.1% of the objects in a sample. The galactic center may be a more tempting target.

A number of objects can be confused with a Dyson Sphere[13]. Some possibilities for misidentification include late type stars with shells such as C stars or “Myra” variables.

Very thick dust clouds occur when there is an extreme phase of mass loss. Since this is a fast process these are apparently rare. In addition for a thick cloud of dust one sees an agglomeration of blackbody spectra for many different temperatures. Very young stars or protostars are typically in situations where there is a lot of dust and a lot of star formation. An example is Orion. Brown dwarf temperatures are generally higher than those expected for Dyson Spheres. Planetary nebula might be confused with Dyson Spheres with temperatures in the 200 ºK region. Globus et al. note that dust clouds from planetary formation will contain spectroscopic features of silicates, aerosols, and hydrocarbons. Further, the age of a star can help to distinguish a cloud from a partial Dyson Sphere since a dust cloud will be young while a Dyson Sphere is expected to be near an old star.

IRAS

For a comprehensive search it is useful to have a whole sky survey. This rules out point and shoot satellite instruments like the Spitzer Telescope and NICMOS (the Near Infrared Camera and Multi-object Spectrograph on Hubble). In addition, the search instrument needs to be sensitive to temperatures ranging from roughly 100 to 600 ºK. The wavelengths associated with this interval span 10 to 100 μm. Ground-based infrared telescopes are ruled out for this regime because of the high sky background. This eliminates the sensitive, whole sky, ground-based 2MASS survey as the principle search tool because it only goes out to 2.17 μm. Finally good angular resolution is useful to rule out associations with nearby stars.

The IRAS[14] database is the best existing resource available to address these three requirements. The IRAS satellite flew in 1983. It identified 250,000 infrared point sources and scanned 98% of the sky. These sources were measured with four filters centered at 12, 25, 60, and 100 μm. This is almost ideal for a Dyson Sphere search. One of the principle motivations of the IRAS program was an investigation of cosmic dust. Partly as a result of that the lens of the telescope had a diameter of only 60 cm so that the angular extent of a “point source” is O(1 minute). The positional reconstruction error is quoted as about 2" to 6" in-scan and about 8" to 16" cross-scan. The sensitivity was O(0.5 Jy) for the 12, 25, and 60 μm bands and 1 Jy for the 100 μm band.

The 2MASS[15] survey with nearly 500 M sources is both much more sensitive and precise in the near infrared. Each of the two 2MASS telescopes had a mirror diameter of 1.3 m. The positional reconstruction error is 0.5". However a blackbody source centered on the 12 μm IRAS band must be at least 10 Jy to register in the 2MASS 2.17 μm band. This is a factor of order ten times higher than the minimum IRAS sensitivity. If the two sources can be correlated one can take advantage of the better 2MASS angular resolution and pointing accuracy.

One of the findings illuminated by IRAS was the significant presence of emission in the 100 μm band on a wide range of angular scales from so-called infrared cirrus due to interstellar dust. This is frequently noticed when comparing Planck distributions fits to the 12, 25, and 60 μm bands. For a large fraction of the cases the 100 μm band is riding well above the blackbody distribution. For this reason, the 100 μm band was not used for blackbody fitting.

The IRAS database includes flux quality factors, FQUAL(i), for each of the bands with values ranging from 3 for a high quality case to 1 for an upper limit. For this analysis sources were not used if they had only an upper limit in any one of the 12, 25, or 60 μm bands. This cut left a sample with 19572 sources. Note that this choice limits the range of temperatures that can be observed. For example, a high temperature source visible in the 2MASS bands and the IRAS 12 μm band might have a small value in the IRAS 25 and 60 μm bands.

THE SEARCH

A feature of IRAS is the possibility of fitting the bands with a Planck distribution to

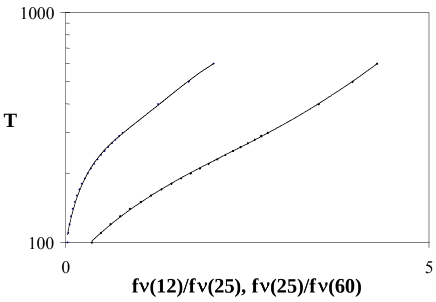

Fig. 1: IRAS flux density ratios. The left line is the 12/25 case, the right one is 25/60. The lines are fits with fourth order polynomials.

obtain a temperature and an estimate of the error. This requires use of at least three of the bands. The more usual technique for obtaining a temperature is to use a color-color determination. Each ratio of bands gives a putative Planck temperature T(ij) based on the assumption that the spectral distribution of the source is a single black body. Figure 1 shows the relationship between temperature and the flux density ratios taken from the IRAS Explanatory Supplement. The points have been fitted with an arbitrary fourth order polynomial to provide temperature estimators for the analysis. This search has concentrated on the temperature region from 150 to 500 °K so the polynomial was fitted for the region 100 to 600 degrees °K. The polynomial is:

$$Te_l = c_0 + \sum_k c_{kl} (f_a / f_b)^k \qquad (3)$$

where Te_l is the estimated temperature for each of the two flux ratios (12/25, 25/60) and c_{kl} are the fitting constants. For the 12/25 set the constants are $c_{01} = 98.0$, $c_{11} = 433.1$, $c_{21} = -386.0$, $c_{31} = 240.2$, $c_{41} = -47.0$ while for the 25/60 ratio they are $c_{02} = 78.0$, $c_{12} = 61.3$, $c_{22} = 13.2$, $c_{32} = -7.20$, $c_{42} = 1.724$.

For this search sources were only retained if the two estimated temperatures lay between $100 \leq T_e \leq 600$ °K. This cut left 4685 sources. The estimator function is not single valued so that sources with f(12)/f(25) > 2.04 were eliminated since T was actually greater than 600 degrees for these cases. With two pairs of bands one can compare these putative temperatures to see if they agree. In practice there will be an error associated with each determination so that some estimation of error is needed to establish that the spectrum is due to a single blackbody distribution. As noted earlier in general the T(12/25) determination will often be better than the T(25/60) determination due to the possible contamination of Zodiacal light or cirrus in the 60 μm band.

The second approach followed a technique suggested in Timofeev et al. A least squares array was formed over the sources for temperatures T_m

$$LSQ_n(T_m) = \sum_k \left(\frac{\left(F_{nk} / K_{km} - a_{nm} P_{km}\right)}{\sigma_{km}^2} \right)^2 \qquad (4)$$

where F_{nk} are the IRAS non-corrected fluxes (in Janskys) for each of the n sources, K_{km} are the Planck color corrections from the IRAS Supplement, a_{nm} is the fitting parameter, P_{km} is the temperature-dependent Planck distribution per unit frequency, and σ_{km} is a weight. The LSQ is formed as the sum over the k index for the 12, 25, and 60 μm bands. This was determined for each source to get $LSQ_n(T_m)$ and an uncertainty.

To carry out the fits the algorithm was used to form a table for all the sources over a temperature range m from 100 to 550 °K in 50 degree increments. A $Tmin_n$ temperature was the fitted to the minimum. This algorithm results in some alias banding in the scatter plots related to the array temperatures. The temperature range of the sample reported here was limited to $150 \leq T \leq 500$ °K after the algorithm was applied.

For the fits shown here $\sigma_{km} = \sqrt{P_{km}}$. This weight was used rather than some estimate of error on the measured F_{nk} because the F(60) band could ride high due to cirrus, etc. Several other parameters in the IRAS database could potentially give indications of the error in forming blackbody least squares distributions. These include TSNR(k), the signal to noise ratio for a band, and RELUNC(k), the relative flux uncertainty. While these variables relate to

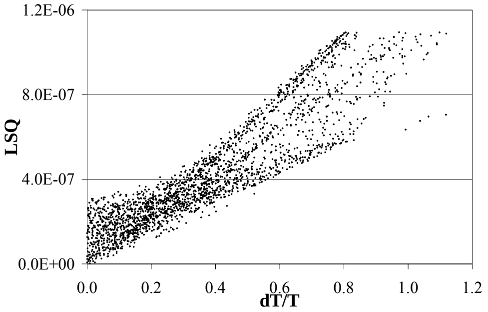

Fig. 2: Least squares vs dT/T as determined from color fits.

measurement uncertainty, they do not address the systematic problem presented by the presence of cirrus. Cirrus variables in the IRAS database were also not used in the first data selection discussed in this paper because they degrade the full sky coverage. No cut has been made on proximity to other sources. By doing this partial Dyson spheres are not ruled out. The IRAS database also includes the variables VAR, an indicator of source variability. VAR was not used as a cut since a Dyson Sphere might be eclipsing a nearby companion in a multiple star system.

Figure 2 illustrates a typical distribution for LSQ as a function of the quantity

$$dT/T = \frac{2\left(T[12/25]-T[25/60]\right)}{\left(T[12/25]+T[25/60]\right)} \qquad (5).$$

In this plot sources with LSQ > 1.09E-6 have been omitted to leave a sample of 3543 sources. This sample is plotted for IRAS cases with IRAS variable IDTYPE = 0, that is no positional association. This choice rules out partial Dyson Spheres and leaves a sample of 2356 IRAS sources.

The lowest LSQ rises quite fast as dT/T moves away from 0. By dT/T = 0.2 it is almost half of the maximum LSQ at dT/T = 0. Based on that it may be possible to rule out LSQ values greater than 1-2E-7. In any case there is a direct relation between dT/T and LSQ.

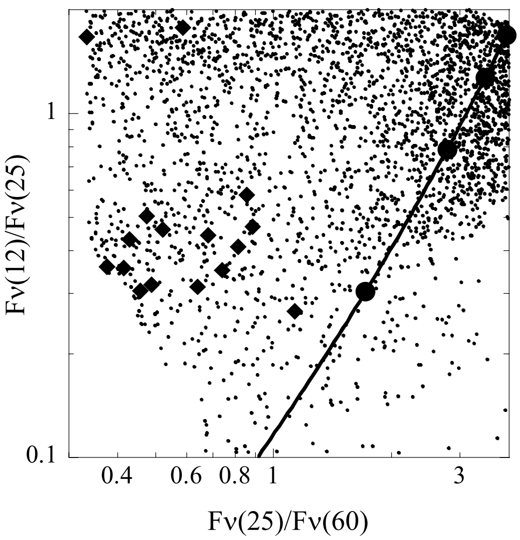

Fig. 3: Color-color plot for the IRAS sample described in the text. The diamonds are extragalactic objects, the dots are sources with no catalog entries. Pure black bodies would lie on the line. The dots along the line are for the blackbody temperatures 200, 300, 400, and 500 °K.

The ratios of the bands can be used to form so-called color-color plots along the lines of the Pottasch et al. investigation of planetary nebulae near the galactic center[16]. Figure 3 illustrates this distribution for the IRAS sample outlined above. The extragalactic objects occupy the same region where they are on Fig. 1 in Pottasch et al. Dyson Spheres should lie along the blackbody line shown in the graph. There is no strong band along the line. The clustering in the top right corner looks similar to the star distribution in Pottasch et al. The tendency for objects to cluster on the blackbody line can be examined by plotting the source frequency as a function of dT/T. This is illustrated in Figure 4. There is no obvious peaking at dT/T = 0 where pure Dyson Spheres should be located. There are about 370 sources with no catalog entry between -0.1 < dT/T < 0.1 so that about 1 out of every 600 IRAS sources passes this test. However, the distribution is statistically flat in the region of dT/T = 0. A 3 σ peak in one bin might require about 25 sources or one in 10,000 of the IRAS sources.

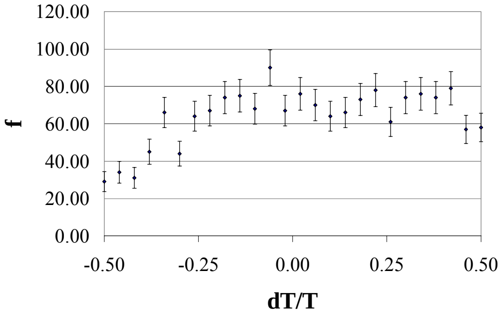

Fig.4: Number of sources with no catalog entries as a function of dT/T.

PROSPECTS AND CONCLUSIONS

This search has not identified an obvious population of Dyson Spheres as might be indicated by a peak in the dT/T distribution or the minimum value of the least squares distributions. This suggests that there may be less than 25 pure Dyson Sphere candidates in the IRAS database.

This analysis has not yet considered the important need to measure the absolute luminosity of the IRAS sources by determining the distance to the source. Once a candidate is identified as a source with a single blackbody spectrum it is either necessary to associate it with a known cluster such as the Pleiades or a multiple star system. Another possibility is to look in the direction of the galactic center and assume sources are 8 kpc away. In the case of a Jugaku Dyson Sphere establishing the source distance is straightforward because the signature is an excess in the infrared tail of the star.

In the future the candidates with small dT/T or LSQ will be examined individually to examine their proximity to other sources and to determine the impact of cirrus. It is hopped that this will either rule out possible candidates or identify likely objects requiring further investigations.

ACKNOWLEDGEMENTS

The author would like to thank J. Annis and C. Beichman for guidance.

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