Searching for Partial-Dyson Spheres

Al Globus Dana Backman Fred Witteborn

January 21, 2003

1 Abstract

A neighboring star orbited by a very large number of space colonies may exhibit spectral signatures distinguishable from the dust and debris associated with natural stellar processes. These signatures, which depend only on thermodynamics and chemistry, may be detectable by current or soon-to-be operational instruments, making the existence of a very large civilization of orbital space colonies surrounding a nearby star a testable hypothesis. We describe the beginnings of a search of online astronomical databases to detect such civilizations.

2 Introduction

Assume

1. there is no technological short-cut to the laws of thermodynamics, as we know them
2. our civilization continues to expand for perhaps a million years, a small fraction of the lifetime of a star
3. we start building orbital space colonies in the next thousand years or so

In this case, we might be observable to a civilization orbiting a nearby star possessing instruments similar to what we have today. Turning this around, if civilizations similar to ours a million years hence are present in our stellar neighborhood, we may be able to observe them with current or soon-to-be deployed instruments. Specifically, a star orbited by a very large number of space colonies would have reduced visible brightness because of absorption of energy by the orbiting objects. This energy would be reradiated at longer wavelengths by the relatively cool colonies. From a great distance, this energy would appear as excess infrared energy from the star. Such a star may be described as a Partial-Dyson Sphere (PDS). Freeman Dyson [Dyson 1959, Dyson 1966] proposed artificial structures completely enclosing a star, but such structures are gravitationally unstable. However, sufficiently large numbers of orbital colonies around a star would partially block and convert a star's energy. If n% of a star's energy is blocked, we may say that this star is an n% PDS. Given instruments that can detect an n% PDS, the existence of such civilizations, at least in our stellar neighborhood, becomes a testable hypothesis.

The search for extraterrestrial intelligence (SETI) has been dominated by the attempt to detect radio signals on the assumption that other civilizations will attempt deliberate communications and/or that their communication systems are inefficient. While it is true that our present radio frequency communication systems are inefficient in the sense that much of the signal does not reach the intended recipients but is rather broadcast into space, this inefficiency is a function of our current technology and is unlikely to last more than a few centuries or millenia. As a fraction of the multi-billion year life of a star, this is an insignificant length of time. Thus, even if we point our radio telescopes in the right direction, we are unlikely to happen to be at the right time. By contrast, the signatures this paper proposes for detecting PDS should last millions or even billions of years, although only orbital, not planetary, civilizations will emit these signals.

3 Infrared Excess

One approach to detecting a PDS is to look for the infrared emissions produced by artificial thermal radiators. Assuming there is no work-around to our laws of thermodynamics, colonies must absorb a star's energy (or produce new energy), use it and reject the heat to deep space. The heat must be rejected at temperatures below utilization temperatures. The higher the temperature the more efficient the heat rejection. For water based life, therefore, the temperature of the heat rejection systems can be assumed to be in the range 273-373K (the temperature of liquid water). Thus, a PDS star's energy output curve should be somewhat different than a purely natural solar system, with a small artificial peak in the 10-30 micron range. The height of the peak is related to the completeness of the PDS. Once a star with such an infrared excess is found, it is necessary to distinguish between the infrared excess of space colonies and naturally occurring dust or debris. There are two approaches to this discrimination: the temperature range of the source and the age of the star. Infrared spectroscopy provides the most obvious tool for distinguishing between natural and artificial emission of radiation. Debris clouds associated with planet formation contain dust grains with spectroscopic features of silicates and aerosols. Dust ejected from evolved stars will show such features as well as molecular features from hydrocarbons. We would expect that the emission spectrum from an artificial radiator would be black and featureless near its peak (10-30 micron), since that is the most efficient way to dump the waste heat. Recall that on our solar-powered satellites, there is a radiator that must eject at low temperatures, most of the energy absorbed by the solar cells. This is a consequence of the second law of thermodynamics. Second, dust is usually associated with younger stars. If our star develops a PDS it will have taken at least 5 billion years. Thus, a reliable means for determining the age of stars would help distinguish

PDS from dust.

The literature contains at least two attempts to find an infrared excess associated with a PDS.

1. Jugaku, Noguchi, and Nishimura have searched numerous stars with a 1.26 m infrared telescope in Japan and examined IRAS [IRAS] data looking for a 10-20 micron infrared excess. They claim that the sensitivity of the instruments should be sufficient to detect a 1% PDS. No candidates have yet been found [Jugaku, Noguchi, and Nishimura 1995, Jugaku and Nishimura 1991, 1997, 2000].

2. Slysh [Slysh 1985] examined the IRAS data for 100% PDS candidates, specifically 0507+528 P05, 0453+444 P03, 0536+467 P05, and 0259+601 P02, without finding a candidate. He noted that G 357 .3-1.3 [Gautier et al. 1984] is a strong source with a 220K blackbody spectrum and claims this is a good 100% PDS candidate, however the temperature is suspiciously low. Slysh notes that it is difficult to distinguish a 100% PDS from circumstellar dust shells around an evolved red giant.

We note that circumstellar dust shells surrounding evolved giants are now easy to distinguish, thanks to improvements in infrared spectroscopy and in parallax measurements. High resolution spectra of even very thick dust shells reveal molecular lines expected from either carbon-rich or oxygen-rich atmospheres. In addition, the Hipparchos data provides distance measurements or lower limits that provide an easy distinction between the relatively low luminosity main-sequence stars that could host colonies, and the very large, short-lived giant stars.

As new instruments become available, a search of greater sensitivity becomes possible. For example, the Space Infrared Telescope Facility [SIRTF] is expected to launch soon. We may examine the capabilities of this instrument for PDS detection by assuming a cloud of individual space colonies orbiting in a belt where equilibrium $T = 300K$. Assume the colonies would not be confined to the same orbital plane because that limits the number of colonies and also makes them shadow each other. If they are distributed about an ecliptic mid-plane the orbits must be inclined to the ecliptic, i.e. each individual colony will oscillate vertically about the mid-plane as it orbits the star. This oscillation should not have a large amplitude otherwise the colonies would have large velocities relative to each other and it would be difficult to move personnel and supplies between colonies. Traffic control problems also suggest small colony-colony relative velocity dispersion is desirable.

Assuming the belt of colonies has a vertical extent $\approx 1/1000$ of their stellar orbital radius, i.e. 150,000 km at 1 AU, the cross-velocities between colonies will be $V_{orb}/1000 \approx 30 meters/sec$. Further, assume the belt is filled with colonies to the point that the "optical depth" for a ray from the star to infinity would be no more than 0.1, i.e. viewed from a given colony, at most 10 percent of the sun is blocked by other colonies.

wavelength (microns)	total F_{nu} from colonies relative to G2 photosphere (%)
15	7
24	16
70	33

Table 1: Infrared emission from colonies relative to host star.

Following from these assumptions about 'vertical' extent of the colony swarm and upper limit on mutual shadowing, the total cross-sectional area of all the colonies around a solar-type star would be: $2\pi \times 10^{-4} AU^2$, or $1.4 \times 10^{19} m^2$, which is 10^5 times the land area of Earth. The total bolometric luminosity of stellar radiation intercepted by the colonies and re-radiated in the IR would be $5 \times 10^{-5} L_{sun}$. The contrast to the star at specific wavelengths is found in table 1.

To detect the IR excess from the colonies with 5-sigma precision and do it in 500 sec integration time, the pre-launch sensitivities for SIRTF imply the stellar photosphere must be brighter than 2.3 mJy at 24 microns. For a solar-type star this means distance less than 120 pc. 24 microns appears to be the best compromise between rising relative flux from the 300 K colonies vs. decreasing relative sensitivity of SIRTF.

4 Temperature/Luminosity Anomaly

Another approach to finding an n% PDS, albeit with high n, is to search for main sequence stars with low luminosity relative to other main sequence stars of the same temperature. A main sequence star's mass determines its temperature and therefore its absolute magnitude. If the distance to a star is accurately known, its absolute luminosity can be calculated from its apparent brightness. The European Hipparchos satellite [Hipparchos] calculated very accurate distance to nearby stars using parallax. We have extracted 299 stars from the Hipparchos catalogue that exhibit low luminosity relative to other stars with similar temperatures. The stars were selected to have:

$$p \geq 20 \quad (1)$$

$$T_c = \frac{7300}{B - V + 0.73} \quad (2)$$

$$T_c \leq 8000 \quad (3)$$

$$M_h \leq 27.31 - 0.002149 T_c \quad (4)$$

$$M_h \geq 17.805 - 0.001681 T_c \quad (5)$$

where p is the Hipparchos parallax, $B-V$ is from the Hipparchos catalogue, and M_h is the Hipparchos (absolute) magnitude based on apparent magnitude and the Hipparchos distance. T_c is the temperature as calculated from $B-V$. B-V is the difference between the magnitudes of an object in the B (blue, centered at 450 nanometers) and V (visual, centered at 550 nanometers) passbands defined by astronomers. One measures the B and V magnitudes of a target object with respect to a network of standard stars. The B and V magnitudes are each logarithmic expressions of flux reaching the Earth from an object, thus $B-V$ is a difference of two logarithms, representing the ratio of fluxes received from the object at 450 versus 550 nm wavelength. $B-V$ is sometimes called the color, or color index, of an object. The (counter-intuitive) definition of the magnitude scale means that increasing $B-V$ means more flux at 550 relative to 450 nanometers, thus an object with $B-V=0.63$ (this is the Sun's color index) appears redder than an object with $B-V=0.00$ (the star Vega, which is blue-white to the eye). In fact Vega is the fiducial object, $T=9700K$, its color defines $B-V=0.00$. Blackbodies and stars cooler than Vega have positive color indices and hotter objects have negative color indices. There is a 1-1 mapping of blackbody temperatures to $B-V$ color index values expressed by equation 2.

We have attempted to exclude degenerate stars (e.g. white dwarfs and other high-density stars) with eq. 4. Eq. 5 eliminates most normal and all giant stars. Eq. 3 eliminates hot stars, even on the main sequence, because we do not expect them to live long enough for intelligent life to develop. Eq. 1 limits the sample to stars with accurately measured distances. The stars that appear in Fig. 2 could be there for a variety of reasons. Some might have unusually strong sunspot activity. Others may, like beta Pictoris, be young stars partially obscured by the debris of planet formation. Some might be brown dwarfs. If there are (thick) partial Dyson spheres, however, they will also be present in this portion of the HR diagram. Detection of the expected infrared excess from a PDS is a far more sensitive approach, but this alternative (examining anomalously faint stars) method may identify candidates otherwise overlooked. Further examination by spectroscopy would then be needed to distinguish natural processes from colonies.

5 Conclusion

With the advent of internet accessible archives of astronomical data, such as the Hipparchos catalogue and the IRAS database, it is possible to design computer searches for candidate PDSs. With new, more powerful infrared instruments becoming available, such as SIRTF, pledged to put their data on the net, new opportunities for inexpensive, computerized search for PDS will become possible. Combined with a search for passive signatures of large scale orbital civilizations, we now have a testable hypothesis that can lead the quantification of an upper limit to the density x size of any PDS in our stellar neighborhood.

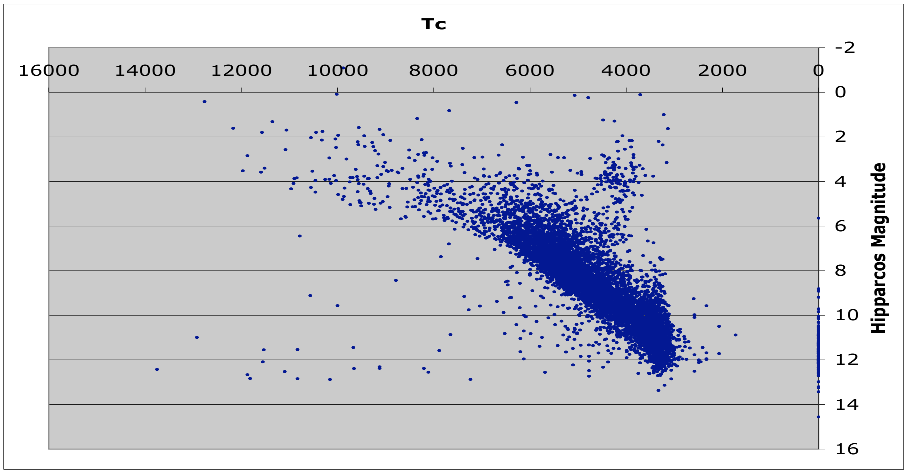

Figure 1: All of the stars from the Hipparchos catalogue that satisfy eq. 1, plotted as a Hertzsprung Russell diagram.

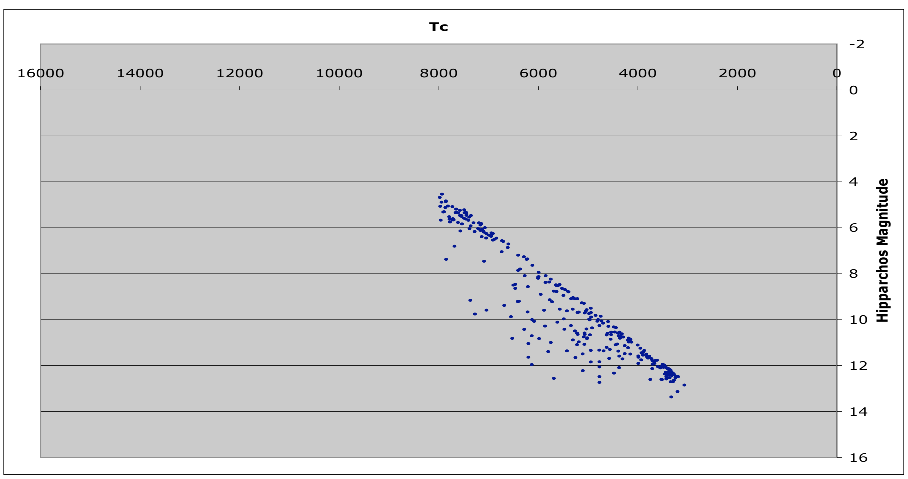

Figure 2: All of the stars from the Hipparchos catalogue that satisfy eq. 1-5. These are candidates for further evaluation.

6 Acknowledgements

Thanks to Bonnie Klein for reviewing this paper.

7 References

[Dyson 1959] Freeman J. Dyson "Search for Artificial Sources of Infrared Radiation," *Science*, volume 131, page 1667.

[Dyson 1966] Freeman J. Dyson "The Search for Extraterrestrial Technology," in R. E. Marshak, editor, *Perspectives in Modern Physics: Essays in Honor of Hans Bethe*. New York: John Wiley & Sons 1966.

[Gautier et al. 1984] T. Gautier et al., *A*p J. (Letters), volume 278.

[Hipparchos] http://archive.ast.cam.ac.uk/hipp/

[IRAS] http://space.gsfc.nasa.gov/astro/iras/iras_home.html

[Jugaku and Nishimura 1991] Jugaku, J., and Nishimura, S. "A Search for Dyson Spheres Around Late-Type Stars in the IRAS Catalog," in *Bioastronomy: The Search for Extraterrestrial Life*, J. Heidemann and M. J. Klein (Eds.), Lecture Notes in Physics 390, pp. 295-298. Berlin: Springer-Verlag.

[Jugaku, Noguchi, and Nishimura 1995] Jun Jugaku, Kunio Noguchi, and Shiro Nishimura, "A Search for Dyson Spheres Around Late-Type Stars in the Solar Neighborhood," *P*rogress in the Search for Extraterrestrial Life, G. Seth Shostak editor, ASP Conference Series, Volume 74, 1995, pages 381-385.

[Jugaku and Nishimura 1997] Jugaku, J., and Nishimura, S. "A Search for Dyson Spheres Around Late-Type Stars in the Solar Neighborhood. II," No. 161 in IAU Colloquium, pp. 707-709. Bologna: Editrice Compositori.

[Jugaku and Nishimura 2000] Jugaku, J., and Nishimura, S. "A Search for Dyson Spheres Around Late-Type Stars in the Solar Neighborhood. III," in G. Lemarchand and K. Meech, eds. *A New Era in Bioastronomy*, vol. 213 of ASP Conference Series. San Francisco: Astronomical Society of the Pacific.

[SIRTF] http://sirtf.caltech.edu

[Slysh 1985] V. I. Slysh, "A Search in the Infrared to Microwave for Astroengineering Activity," *T*he Search for Extraterrestrial Life: Recent Developments, M. D. Papagiannis, editor, IAI, 1985, pages 315-319.