SEARCHING FOR DYSON SPHERES WITH GAIA

E. Zackrisson[1], A. Wehrhahn[1] and A. Korn[1]. [1] Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden

Partial Dyson spheres may manifest themselves as optically subluminous stars for which the parallax distance and the spectroscopically inferred distance are discrepant. Based on this criterion, the Gaia telescope will in coming years allow for a Dyson-sphere search that is complementary to searches based on excess flux at mid/far-infrared wavelengths. A limited search of this type is also possible at the current time, by combining Gaia parallax distances with spectroscopic distances from ground-based surveys like RAVE or GALAH.

Partial Dyson spheres without infrared excess

Searching for indirect signatures of extraterrestrial technology (e.g. astroengineering, interstellar propulsion mechanisms, industrial pollution in the atmospheres of exoplanets) serves as an interesting alternative to the classical, signal-based approach to SETI (the Search for Extraterrestrial Intelligence), since the former makes no assumption on the willingness of distant civilizations to communicate over interstellar distances. In a seminal paper, Dyson [6] suggested that extremely advanced civilizations could harvest the radiation energy of their host stars by completely or partially enshrouding these objects in shell-like structures, plausibly consisting of large numbers of light-absorbing satellites constructed out of material from dismantled planets. Such *Dyson spheres* would make a significant fraction of the stellar radiation energy available for powering habitats in parts of the planetary system that might otherwise not be able to sustain life, for vessel propulsion, for supercomputing or other project with immense power requirements (e.g. [1],[13],[15]). Advanced civilizations that can harness energy on this scale are usually referred to as Kardashev type II civilizations [10]. Previous searches for individual Dyson spheres (e.g. [14,16,9,4]) have been based on the waste heat signature that these objects are expected to display at mid/far-infrared wavelengths. For partial Dyson spheres, however, the Gaia mission [7] offers an alternative route to detection. While the parallax method should be able to provide an accurate distance to a star surrounded by a partial Dyson sphere, a spectroscopic or spectrophotometric distance based on the apparent brightness of the object at optical or near-infrared wavelengths is expected to overestimate its distance. With future data releases, both distance estimates can be obtained from Gaia data, but even with Gaia data release 1 [8], it is possible to carry out a search of this kind by combining the parallax distances provided by the Tycho-Gaia Astrometric Solution (TGAS) with the spectroscopic distances from groundbased surveys like the Radial Velocity Experiment (RAVE) [11] or GALAH [12]. Candidates for Dyson spheres identified this way can also be tested for mid/far-infrared excess through a comparison of the predicted and observed fluxes at 3.4-22 micron in the WISE survey [17]. The primary advantage of this method, however, is that it can be used even if the waste heat signature is much smaller than usually assumed (high-ν, low-γ civilizations in the formalism of [18]), either because the energy absorbed is transmitted in some non-isotropic/non-thermal/non-photonic way or somehow stored through the conversion from energy to matter. Excess radiation at wavelengths beyond 22 micron can also be detected in the all-sky surveys provided by the Infrared Astronomical Satellite (IRAS) or Planck, but the sensitivity of these surveys do not allow for competitive constraints unless the Dyson sphere temperature is <50 K, which would correspond to a Dyson sphere with an implausibly large radius (see [18] for a discussion).

Gaia detection limits

Assuming that the light-collecting satellites of the Dyson sphere obscure optical/near-infrared light as grey absorbers (i.e. in a way that is independent of wavelength), a partial Dyson sphere could reveal itself as an anomalously underluminous star with a parallax-based distance ($D_{parallax}$) that is significantly smaller than the spectroscopically inferred one (D_{spec}). The ratio of the two distances, $D_{parallax}/D_{spec}$ is then related to the Dyson sphere covering fraction as: $f_{cov} = 1 - (D_{parallax}/D_{spec})^2$. Given the typical errors on these distance estimates, this method can realistically only single out partial Dyson spheres with very high covering fractions (at least $f_{cov} > 0.5$). As an example, consider the case where TGAS parallaxe distances from Gaia data release 1 are combined with spectroscopic distances from RAVE data release 5. Most of the ≈200,000 stars which are common to both catalogs have distance errors much too large to be useful for this analysis, but searches among subsets of objects with the highest-quality data and fits could still be fruitful. Our analysis indicates that there are some ≈8000 stars in the combined sample for which very few spurious $f_{cov} \geq 0.7$ interlopers would be expected on statistical grounds given the quoted errors. Further cuts can be made to exclude objects which are very young (potentially obscured by debris disks), which have left the main sequence (for which RAVE distances are known to be more unreliable; e.g. [2]) or for which the stellar parameters favored by the RAVE and the alternative RAVE-on [5] analysis are inconsistent. For the best-fitting stellar parameters provided by RAVE, the PARSEC isochrones [3] – on which the RAVE fits are based – also provide the predicted WISE fluxes of these stars. A comparison to the observed WISE flux may then reveal any infrared excess associated with waste heat emission from the Dyson sphere at wavelengths 3.4-22 micron.

Due to parameter degeneracies, the complicated error distributions of the spectroscopic distances and the limited wavelength range of the RAVE spectra, one must however consider the possibility that the fitting routine in rare cases may converge on solutions that provide acceptable spectral fits yet catastrophically incorrect distance estimates. Interesting candidates should therefore be scrutinized further through spectroscopic follow-up observations that sample different wavelength intervals. Curiously, a casual search in the combined Gaia/RAVE data indicate that there are a couple of objects for which the fits appears perfectly acceptable, yet the discrepancy in distance estimates indicates $f_{cov} \approx 0.7$ (implying that they would be ≈1.3 magnitudes fainter than expected). None of these stars display any excess flux within the range of infrared wavelengths covered by WISE. These objects are now targeted by follow-up observations as part of Project Hephaistos[1], a SETI endeavor devoted to the search for signatures of astroengineering both in the Milky Way and beyond.

Additional Information:

(A) Questions 1 and 3

(B) While the primary search will based on the Gaia catalog (~1 billion objects), auxiliary data from other large databases (SDSS, 2MASS, WISE, Pan-STARRS) can be used to further investigate the properties of interesting candidates.

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