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Fortuitous Observations of Potential Stellar Relay Probe Positions with GBT

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ABSTRACT

Recent theoretical and observational works have investigated the possibility that extraterrestrial intelligence could use the Sun as a gravitational lens in order to aid communication across interstellar distances. Unlike other targeted SETI searches where the drift rate of any artificial extraterrestrial signals may be unknown up to some large upper limit, the drift rates of any solar-system relay probes would be known and set only by the motion of the Earth. One recent work used purpose-designed Green Bank Telescope (GBT) observations to search for signals from a hypothetical communications probe several hundred AU from the Sun at the antipode of the α Centauri AB system. To further aid in the advancement of relay-probe searches, we present a table of 1764 archival GBT observations which fortuitously fall near the positions of hypothetical probes communicating with stars within 100 parsecs and compute the drift rates for these probes.

INTRODUCTION

Following from proposals (e.g., Maccone 1994; Maccone & Piantà 1997; Maccone 2010) that extraterrestrial intelligence (ETI) may use stellar gravitational lenses to magnify communications to or from other stellar systems, Tusay and Huston et al. 2022 performed a targeted search for radio technosignatures opposite Alpha Centauri (α Cen) with the Green Bank Telescope (GBT). Although this search found no evidence for transmissions directed toward the Sun in the 1–3 GHz range, these authors suggested that their method for searching for radio transmissions within the solar system may be useful for future or archival data sets. Specifically, they note that the single, low drift rate of solar system transmitters (approximately only 0.127 Hz s^{-1} in the L band) enables much deeper searches than are computationally feasible to conduct in the general case of transmitters outside the solar system, which have unknown drift rates which could be as large as 200 Hz s^{-1} at 1 GHz (see Sheikh et al. 2019).

To enable further deep searches following the methods laid out in Tusay and Huston et al. 2022, we here present a table of Breakthrough Listen (BTL) observations performed on GBT that fortuitously fall near the antipode of stars within 100 parsecs of the Sun. For each of these observations, we have computed the on-sky coordinates of each of the transmitting and receiving focal lines, as well as the drift rates that should be searched in the corresponding observation band with *turbo*SETI Enriquez & Price (2019) or other software. Abridged results are presented in Table 1, and a summary of our methods is given below. The full table is published in its entirety in a machine-readable format and additionally archived on Zenodo (Palumbo et al. 2023b). The source code used to search for these observations and a Jupyter Notebook with supplemental figures are available on GitHub[1] and archived on Zenodo (Palumbo et al. 2023a).

METHODS

To identify these fortuitous observations, we cross-listed the pointings of the over 45,000[2] publicly available observations conducted by Breakthrough Listen on GBT (Lebofsky et al. 2019) with the positions of stars in the Gaia DR3 catalog (Gaia Collaboration et al. 2016, 2023; Babusiaux et al. 2023). We limit the scope of the search to stars

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[1] https://github.com/palumbom/seti-fortuitous-obs

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within 100 parsecs with Renormalized Unit Weight Error (RUWE) < 1.4. We initially perform a course-grain search neglecting parallax, flagging stars whose antipodes fall within half of one degree of a GBT observation. Following this initial search, we follow the procedure outlined in §1.3.2 of Tusay and Huston et al. 2022 to calculate the coordinates of transmitting and receiving probes as close as 550 AU and as far as infinity, as observed from Earth at the time of the corresponding GBT observation. Observations which contain any portion of either focal line within the FWHM of the observation beam are retained and tabulated. Finally, we calculate the drift rates for each hypothetical probe, assuming (as in §3.1 Tusay and Huston et al. 2022) that the only sources of drift are from the rotational and orbital motions of the Earth. As in Tusay et al. (2022), we recommend searching for signals in some range around this calculated drift rate.

RESULTS

We find 1080 *L*-band observations that contain all or part of either the transmitting or receiving probe focal lines within the beam FWHM, and 684 *S*-band observations. The median fraction of the focal line contained within the observation beam is $\sim$0.36 for both transmitters and receivers. I.e., generally most of the focal line is *outside* the beam FWHM, but it is possible to filter for and prioritize analysis of observations that contain a larger fraction of either focal line. We note that the separation between the focal lines is proportional to the tangential space motion of the target star (i.e., the GBT observation beams may only contain one of the transmitting or receiving focal lines for relay-probe target stars with large proper motions). We find a median drift rate of $\dot{f}_{\rm max} \sim$ -0.113 Hz s^{-1} for *L*-band observations, and $\dot{f}_{\rm max} \sim$ -0.180 Hz s^{-1} for *S* band. These drift rates are comparable to those calculated for α Cen in Tusay and Huston et al. 2022.

At present, the public Breakthrough Listen database does not contain reduced *C*- and *X*-band GBT data. Should these observations become available at a future date, the methods and code applied in this work may be used to identify additional fortuitous observations, although there will be fewer useful observations in these bands because the primary beam is smaller.

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Software: Astropy (Astropy Collaboration et al. 2018), barycorrpy (Wright & Eastman 2014, Kanodia & Wright 2018), Skyfield (Rhodes 2020), Matplotlib (Hunter 2007), NumPy (Harris et al. 2020), Pandas (The Pandas Development Team 2020)

Table 1. Abridged table of GBT observations that fall near the antipodes of stars within 100 pc. On-sky coordinates and maximum drift rates for transmitting probes at 550 AU and infinity are shown. The full table (with URLs for downloading the observation data) is published in its entirety in a machine-readable format and also archived on Zenodo (Palumbo et al. 2023b).

Gaia Source ID	BTL Obs. Index	BTL Target Name	Obs. RA (Deg.)	Obs. Dec (Deg.)	GBT Band	Transmitter RA (Deg.)	Transmitter Dec. (Deg.)	Drift Rate (Hz. s^{-1})
6271993076526910464	63387	HIP11993	38.661254	24.892810	L	38.732818	24.883105	-0.093817
						38.672031	24.879817	-0.093766
6663357265409042432	63389	HIP35136	108.958754	47.238879	L	108.990300	47.285813	-0.039768
						108.989509	47.329705	-0.039721
4941589401397099520	63658	HIP67301	206.884092	49.313058	L	206.771482	49.264359	-0.075849
						206.892484	49.300907	-0.075897
4635422588982400000	63927	HIP58619	180.317471	79.087481	L	179.975006	78.965903	-0.013479
						180.116056	79.060475	-0.013381
6046860717776728064	64065	HIP22394	72.303663	24.802969	L	72.266266	24.758930	-0.093574
						72.154052	24.746215	-0.093849
4388385484686595584	64116	HIP24819	79.805746	-3.604719	L	79.937530	-3.582100	-0.135286
						79.834927	-3.590775	-0.135472
4277764337081333248	64491	HIP30026	94.774912	-2.930873	L	94.759386	-2.904232	-0.120225
						94.659057	-2.911064	-0.120132
4522099086610737664	64521	HIP30469	96.088250	-16.453229	L	96.071975	-16.394715	-0.092729
						95.968025	-16.406852	-0.092584
6903714561687742464	64560	HIP43557	133.068671	8.061674	L	133.187956	8.034219	-0.105528
						133.122065	8.039665	-0.105462
2923751192356546048	65087	HIP91101	278.742825	24.905171	L	278.692154	24.903548	-0.137134
						278.804633	24.905045	-0.137261
1737510503994354944	65155	HIP43994	134.380754	-7.267147	S	134.429833	-7.241820	-0.163270
						134.349024	-7.245100	-0.163157
6895086934462357504	65181	HIP44984	137.442821	11.563898	S	137.422818	11.573928	-0.119212
						137.344402	11.592111	-0.119027
5256731149306974208	65387	HIP108938	331.053250	59.866936	L	331.084013	59.853584	-0.082885
						331.204519	59.785483	-0.083151
5338096006212083712	65399	HIP113853	345.848654	60.445412	L	345.904474	60.405766	-0.087267
						345.980544	60.326140	-0.087523
6884240247958763520	65561	HIP45170	138.070329	14.996946	S	138.179029	14.975271	-0.188972
						138.095473	14.999137	-0.188943
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

REFERENCES

Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., et al. 2018, AJ, 156, 123, doi: 10.3847/1538-3881/aabc4f

Babusiaux, C., Fabricius, C., Khanna, S., et al. 2023, A&A, 674, A32, doi: 10.1051/0004-6361/202243790

Enriquez, E., & Price, D. 2019, turboSETI: Python-based SETI search algorithm, Astrophysics Source Code Library, record ascl:1906.006. http://ascl.net/1906.006

Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016, A&A, 595, A1, doi: 10.1051/0004-6361/201629272

Gaia Collaboration, Vallenari, A., Brown, A. G. A., et al. 2023, A&A, 674, A1, doi: 10.1051/0004-6361/202243940

Harris, C. R., Millman, K. J., van der Walt, S. J., et al. 2020, Nature, 585, 357, doi: 10.1038/s41586-020-2649-2

Hunter, J. D. 2007, Computing in Science & Engineering, 9, 90, doi: 10.1109/MCSE.2007.55

Kanodia, S., & Wright, J. 2018, Research Notes of the American Astronomical Society, 2, 4, doi: 10.3847/2515-5172/aaa4b7

Lebofsky, M., Croft, S., Siemion, A. P. V., et al. 2019, PASP, 131, 124505, doi: 10.1088/1538-3873/ab3e82

Maccone, C. 1994, Journal of the British Interplanetary Society, 47, 45

Maccone, C., & Piantà, M. 1997, Journal of the British Interplanetary Society, 50, 277

Maccone, C. a. 2010, Acta Astronautica, 67, 526, doi: 10.1016/j.actaastro.2010.03.012

Palumbo, M., Wright, J. T., & Huston, M. J. 2023a, palumbom/seti-fortuitous-obs: v0.1.0, v0.1.0, Zenodo, doi: 10.5281/zenodo.8361381

Palumbo, M. L., Wright, J. T., & Huston, M. J. 2023b, Fortuitous Observations of Potential Stellar Relay Probe Positions with GBT - Results Data Table, Zenodo, doi: 10.5281/zenodo.8357446

Rhodes, B. 2020, Skyfield: Generate high precision research-grade positions for stars, planets, moons, and Earth satellites, 1.17

Sheikh, S. Z., Wright, J. T., Siemion, A., & Enriquez, J. E. 2019, ApJ, 884, 14, doi: 10.3847/1538-4357/ab3fa8

The Pandas Development Team. 2020, pandas-dev/pandas: Pandas, latest, Zenodo, doi: 10.5281/zenodo.3509134

Tusay, N., Huston, M. J., Dedrick, C. M., et al. 2022, AJ, 164, 116, doi: 10.3847/1538-3881/ac8358

Wright, J. T., & Eastman, J. D. 2014, PASP, 126, 838, doi: 10.1086/678541