ICARUS 107, 215–218 (1994)

NOTE

A SETI Search of Nearby Solar-Type Stars at the 203-GHz Positronium Hyperfine Resonance

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Received August 27, 1993; revised November 5, 1993

The development of advanced millimeter-wave technology has made it possible to construct low-noise receivers and high-power transmitters comparable to those available at much lower frequencies. This technology, plus certain physical characteristics of the millimeter-wave spectrum, suggests possible advantages for use of this wavelength range for interstellar communications. As a result, a SETI (search for extraterrestrial intelligence) type search has been conducted for narrow-bandwidth signals at frequencies near the positronium hyperfine spectral line (203.385 GHz), a potential natural reference frequency. A total of 40 solar-type stars within 23 parsecs were observed, in addition to three locations near the galactic center. No detections were made at the detection threshold of 2.3×10^{-19} W/m^2 in each of two orthogonal linear polarizations. Future observations will be made with a higher resolution fast Fourier transform spectrum analyzer (FFTSA), which should improve sensitivity by an order of magnitude and reduce required observing time. © 1994 Academic Press, Inc.

I. Introduction. The development of advanced millimeter-wave technology has made it possible to construct low-noise receivers and high-power transmitters comparable to those available at much lower frequencies. This makes a SETI (search for extraterrestrial intelligence) type search at millimeter wavelengths desirable for a number of reasons:

1. The higher gains obtainable for a given antenna size at millimeter wavelengths result in larger transmitted EIRP (effective isotropic radiated power) and thus increase the detectable range (see, for example, Steffes 1993).
2. The effect of the "quantum limit" or "photon noise" on receiver sensitivity is still minimal (less than 15 K) for frequencies below 300 GHz.
3. A spectral marker, or potential communications reference frequency, exists at 203.385 GHz (the hyperfine ground-state spectral line of the lightest artificial atom, positronium; Kardashev 1979).
4. Interstellar scintillation is far less pronounced at millimeter wavelengths than at centimeter wavelengths (Cordes and Lazio 1991).
5. The wide availability of hydrogen maser frequency standards makes it possible to conduct high-spectral-resolution searches (bandwidths less than 1 Hz), comparable to those conducted at centimeter wavelengths.
6. Radio frequency interference (RFI) from Earth-orbiting transmitters is far less severe than at centimeter wavelengths.

While terrestrial atmospheric absorption does handicap such observations, most observatories are sited so as to maintain zenith opacity in clear weather at one optical depth or less, depending on wavelength. Since no previous millimeter-wavelength SETI searches have been reported, we conducted this initial search at the 203.385 GHz positronium hyperfine resonance using the NRAO/Tucson 12-m radio telescope. This is similar to the first centimeter-wavelength SETI search conducted some 33 years previously at NRAO/Green Bank, at frequencies near the hydrogen hyperfine resonance (Drake 1961). The increased gain at higher frequencies makes millimeter-wave SETI very attractive and the existence of a spectral marker at 1.48 mm (203 GHz) is fortuitous. Further, since there is a low abundance of positronium and a small transition probability, the natural line does not contribute significantly to the sky temperature and mask any potential signal. Other reasons for the selection of the positronium hyperfine resonance as the preferred search frequency are detailed by Kardashev (1979).

In this paper, we give the description and results of our observations of 40 solar-type stars and of three regions near the galactic center at frequencies surrounding the 203.385-GHz positronium hyperfine resonance. While no artificial signals were detected, an upper limit on potential signal flux density has been derived, and approaches for quicker, more sensitive searches are presented.

II. Observations. Observations of 40 solar-type stars and three regions near the galactic center were conducted on April 9 and 10, 1993, at frequencies surrounding the positronium hyperfine resonance, measured as 203.8459 ± 0.0012 GHz by Egan *et al.* (1977). The observations were conducted with the 12-m-diameter NRAO millimeter-wave radio telescope located at Kitt Peak, Arizona. (The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.) The purpose of the search was to detect spectrally compact, coherent signals such as targeted beacons or other nearly monochromatic emissions directed toward our Solar System.

II.A. OBSERVATIONAL APPROACH. Since we assume that the potential transmissions are targeted, any Doppler shifts due to planetary motion at the transmitting locations are assumed to be corrected, relative to a stable reference frame by the transmitting civilization. (Obviously, our knowledge of the motions of planets within distant Solar Systems is currently nonexistent.) However, there is still the question as to which stable reference frame the transmissions would be referenced. The obvious choices would be the frame of the transmitting star system,

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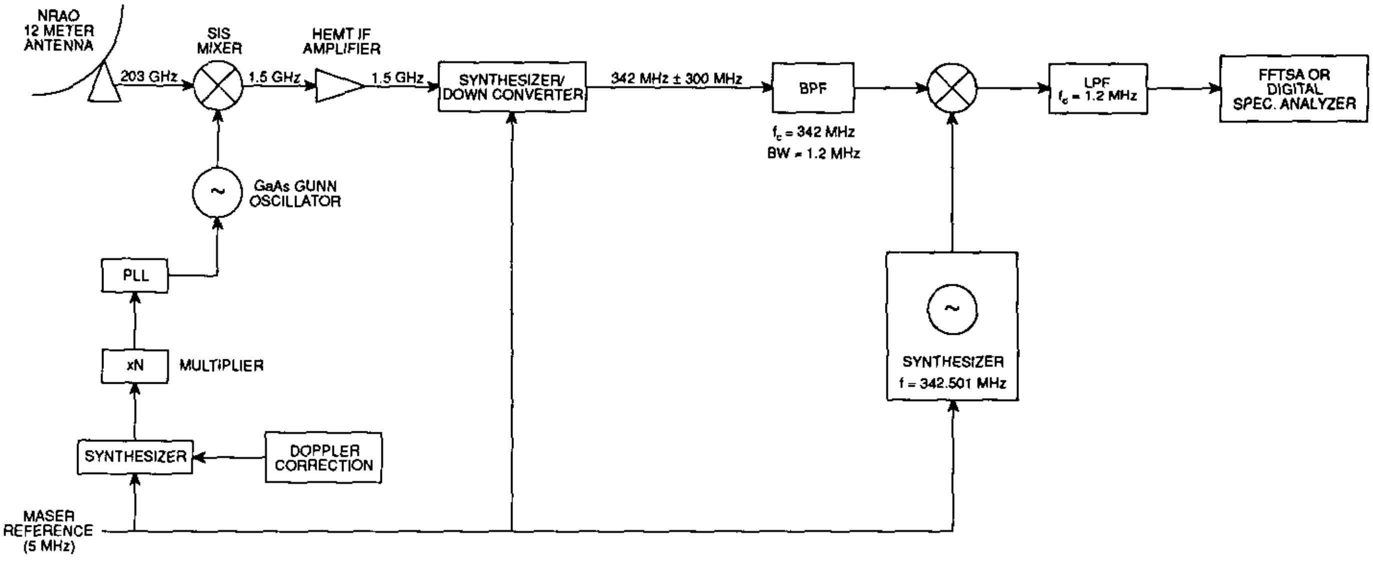

FIG. 1. Block diagram of system used for 203-GHz search narrowband signals.

the local standard of rest (LSR), or our Sun (heliocentric). We chose the third (heliocentric), based on the assumption that a civilization capable of targeting a transmission toward our Solar System would be able to estimate the radial velocity of our star and would correct for it. While referencing to LSR was our second choice, the variability of its definitions by other civilizations would likely add to the overall uncertainty. Even if the transmitting civilization were to reference to our Solar System, there is an inherent uncertainty in estimates of radial velocity, which would be reflected in the transmitted frequency. As a result, we observed a 5-MHz-wide spectral window centered at the 203.3849-GHz positronium hyperfine resonance, adjusted to a heliocentric rest frame (i.e., heliocentric ±3.7 km/sec).

II.B. EQUIPMENT CONFIGURATION. All observations were conducted with the NRAO 12-m Cassegrain antenna. Dual, orthogonal linearly polarized SIS receivers were used, exhibiting system noise temperatures of 600 and 1000 K, respectively. Recent realignment of the reflector surface panels resulted in an overall aperture efficiency of over 32%, providing an effective aperture of 37 m^2 at the operating wavelength of 1.5 mm. Since the antenna beamwidth is extremely narrow (approximately 30 arcsec), and because none of the target stars are strong emitters at this wavelength, normal tracking techniques involving signal peaking were not used. However, the demonstrated open-loop tracking accuracy of this telescope is of 10 arcsec (see Jewell 1990). In addition, a collinear optical telescope is connected to a video display in the control room which verifies the pointing to the majority of the targets, which are visible with a moderate optical telescope.

A block diagram of the observing system is shown in Fig. 1. In order to be sensitive to signals transmitted over interstellar distance, extremely narrow channel bandwidths are necessary. Two types of multichannel spectrum analyzers were developed. The first was a 32,000-channel fast Fourier transform spectrum analyzer (FFTSA) which used an 8-bit analog-to-digital converter in conjunction with a 64-k-point complex FFT computed and displayed using MATLAB software on a 386-based personal computer. By using a Hamming window and a 2-MHz sampling rate, individual channel resolution bandwidths of approximately 32 Hz were obtained. The total instantaneous bandwidth was 1 MHz (1 kHz–1.001 MHz), and the total time to sample, compute, and display each spectrum was approximately 45 sec. Because of the narrow channel bandwidths involved, all local oscillators were locked to a maser reference signal obtained from the neighboring VLBA facility so as to maintain frequency stabilities of 10^{-12} or better. The second spectrum analyzer was a Tektronix 2710 digital storage spectrum analyzer, which analyzed the same 1-kHz–1.001-MHz range as the FFTSA. Nine individual spectra were taken and averaged, each with a resolution bandwidth of 3 kHz and a video bandwidth of 30 Hz. The resulting averaged 1-MHz-wide spectrum had an equivalent noise bandwidth, B, of 100 Hz in each spectral bin and took approximately 100 sec to measure, average, and display. Since both systems analyzed only a 1-MHz-wide spectrum, the receiver local oscillator was stepped so as to allow taking of five individual 1-mHz-wide spectra, giving a total bandwidth of 5 MHz. The entire process was repeated for the orthogonal polarization as well. The local oscillator system also provided Doppler corrections for earth motion relative to the heliocentric reference frame.

Unfortunately, the FFTSA (which was the more sensitive and more rapid of the two systems) was irreparably damaged by the carrier responsible for transporting it to NRAO/Tucson. As a result, all measurements were conducted with the slower, less sensitive conventional spectrum analyzer. The detection threshold for this system was calculated from the relation

$$F_{\min} = kTB(C/N)_{\min}/A_{\mathrm{eff}}, \tag{1}$$

where $F_{\min}$ is the minimum detectable flux density (w/m^2), k is Boltzman's constant (1.38×10^{-23} J/K), T is the system noise temperature, B is equivalent noise bandwidth (Hz), $(C/N)_{\min}$ is the minimum carrier-to-noise ratio required so as not to produce an excessive false alarm rate from thermal noise (we chose 5 dB for our observation), and A_{eff} is the effective area of the receiving antenna, which has been corrected both for possible antenna mispointing and for the opacity from the terrestrial atmosphere. At the operating frequency of 203.385 GHz, the corrected effective area can be expressed as

$$A_{\mathrm{eff}} = e^{-\tau/\sin \mathrm{EL}}\, P\, (37\ \mathrm{m}^2), \tag{2}$$

where τ is the zenith opacity at the operating frequency inferred from measurements of a 225-GHz tipping radiometer located at the observatory, EL is the elevation angle of the target, and P is the pointing error loss, which at worst case (10 arcsec error) equals 0.73. Thus, in our

TABLE I
Observation List

Name	RA (1950)	Dec (1950)	Distance (pc)	Radial Velocity (km/sec)	Spectral Type	Elevation At Start of Observation
GL 34 A	$00^h46^m03^s$	+57°33.1'	5.94	+ 8.2	G3 V	50°.4 r[a]
GL 34 B	$00^h46^m03^s$	+57°33.1'	5.94	+ 10.5	K7 V	50°.4 r
GL 71	$01^h41^m45^s$	-16°12.0'	3.50	- 17.0	G8 Vp	40°.6 r
GL 124	$03^h05^m27^s$	+49°25.4'	10.82	+ 49.5	G0 V	67°.3 r
GL 135	$03^h16^m30^s$	-03°01.4'	15.58	+ 22.5	G1.5 V	54°.5 r
GL 160	$04^h02^m22^s$	+21°52.5'	17.39	+ 23.9	G5 V	70°.7 r
GL 177	$04^h45^m21^s$	-17°01.5'	12.67	+ 21.7	G1 V	39°.3 s
GL 178	$04^h47^m07^s$	+06°52.5'	7.51	+ 24.4	F6 V	64°.9 s
GL 188	$05^h04^m30^s$	+18°34.8'	17.01	+ 20.6	G4 V	76°.2 r
GL 197	$05^h15^m37^s$	+40°03.4'	14.39	+ 66.5	G2 IV-V	69°.5 s
GL 198	$05^h16^m37^s$	-18°10.9'	15.70	+ 40.3	G0 V	28°.3 s
GL 202	$05^h21^m30^s$	+17°20.3'	15.34	+ 38.1	F8 Ve	53°.7 s
GL 245	$06^h43^m08^s$	+43°37.8'	15.10	- 23.9	G0 V	62°.7 s
GL 262	$07^h00^m20^s$	+29°25.4'	17.06	+ 25.4	G4 V	53°.8 s
GL 302	$08^h16^m01^s$	-12°27.7'	12.61	+ 30.5	G7.5 V	45°.8 s
GL 368	$09^h45^m22^s$	+46°15.3'	13.28	+ 5.0	G0.5 Va	42°.3 s
GL 387 A	$10^h14^m30^s$	+23°21.5'	16.45	+ 37.5	F8 Vbw	42°.8 s
GL 392 A	$10^h24^m59^s$	+49°03.2'	19.27	- 6.8	F9 V	39°.1 s
GL 434	$11^h38^m25^s$	+34°29.0'	8.62	- 5.9	G8 Ve	63°.3 s
GL 451 A	$11^h50^m06^s$	+38°04.7'	8.62	- 99.1	G8 VI	76°.2 r
GL 475	$12^h31^m22^s$	+41°37.7'	8.72	+ 6.6	G0 V	61°.5 s
GL 484	$12^h42^m38^s$	+39°33.0'	15.75	+ 80.7	G0 V	52°.3 s
GL 502	$13^h09^m32^s$	+28°07.9'	8.35	+ 5.1	G0 V	56°.0 s
GL 504	$13^h14^m18^s$	+09°41.1'	13.48	- 27.4	G0 V	48°.4 s
GL 547	$14^h20^m42^s$	+01°28.5'	17.27	- 18.9	G1 V	44°.1 s
GL 549 A	$14^h23^m30^s$	+52°04.9'	14.28	- 11.4	F7 V	55°.7 r
GL 564	$14^h48^m02^s$	+24°07.0'	14.35	- 2.7	G2 V	50°.2 r
GL 566 A	$14^h49^m05^s$	+19°18.4'	6.71	+ 2.2	G8 Ve	60°.5 r
GL 566 B	$14^h49^m05^s$	+19°18.4'	6.71	+ 3.1	K4 Ve	60°.5 r
GL 598	$15^h44^m01^s$	+07°30.5'	11.92	- 68.5	G0 V	54°.0 r
GL 602	$15^h50^m57^s$	+42°35.4'	17.39	- 56.4	F9 V	73°.9 r
GL 611 A	$16^h03^m13^s$	+39°17.4'	12.48	- 60.0	G8 V	43°.9 s
GL 616	$16^h12^m54^s$	-08°14.3'	15.36	+ 12.0	G1 V	37°.7 r
GL 632	$16^h34^m28^s$	+79°53.7'	22.32	- 16.9	dG3	40°.9 r
GL 641	$16^h50^m27^s$	+00°04.5'	16.53	+ 45.4	G8 V	37°.6 s
GL 651	$17^h01^m12^s$	+47°08.4'	16.18	- 47.3	G8 V	44°.9 s
GL 672	$17^h18^m47^s$	+32°31.9'	13.57	- 79.1	G2 V	71°.3 r
GL 779	$20^h01^m51^s$	+16°56.0'	16.61	+ 4.8	G1 V	37°.1 s
GL 788	$20^h17^m02^s$	+66°41.6'	13.72	- 4.6	G5 V	48°.7 s
GL 882	$22^h55^m00^s$	+20°30.0'	17.12	- 33.7	G4 V	78°.5 r

[a] "r" refers to a rising object while "s" refers to a setting object.

worst case observation (T = 1000 K, EL = 37.6°, τ = 0.23 optical depths), the minimum detectable flux density was 2.3 × 10^{19} W/m^2.

II.C. TARGETS. A total of 40 stars were observed, in addition to three locations near the galactic center. The 40 stars were selected from a list of solar-type stars (F6 through K7 dwarfs, luminosity class 5) within 23 parsecs of earth, which was provided by D. Latham and G. Torres (private communication). These stars are listed in Table I, together with information on position, distance, radial velocity, spectral type, and the elevation above the horizon when the observation of that star commenced. (A typical obvservation lasted approximately 25 min.)

In addition to observations of the target stars, observations were made of three sites at and near the galactic center from where 511-keV emission had been detected (see for example, Leahy 1991; or Ligenfelter and Ramaty 1989). Note that 511 keV corresponds to the electron–positron annihilation energy). Because of the short lifetime of positronium (approximately 10 nsec), the broadening of any natural positronium hyperfine emission would be substantial (at least 100 MHz). As a result, observations of the galactic center region were conducted using a 256-channel, wide-band (2 MHz per channel) filter bank. Detection of emission at the positronium hyperfine resonance is highly unlikely, however, due to the vastly stronger annihilation process.

III. *Results, conclusions, and suggestions for future work.* No detections of coherent emission at the level of 2.3 × 10^{-19} W/m^2 or higher were made in our search of 40 target stars in the frequency range from 203.3834 to 203.3884 GHz (referenced to a heliocentric rest frame). Likewise, as expected, no incoherent emissions due to the positronium hyperfine resonance were detected from observations at the galactic center. We note that had our FFTSA not been destroyed in shipment, a factor of 3 sensitivity improvement would have been achieved. Additionally, the FFTSA could have been "clocked down" to run in a high-resolution mode, providing an additional factor-of-10 sensitivity improvement in selected bands (8×10^{-21} W/m^2).

Although no signals were detected, the conduct of such millimeter-wavelength SETI searches should not be abandoned. As with the initial microwave searches conducted by Drake (1961), this observation has set an initial reference point from where more complete and more sensitive searches can be conducted. The substantial improvement and relatively low-cost of FFTSA systems will make it possible to conduct more complete searches in shorter periods of time. Likewise, the improvements in receiver sensitivity and antenna performance at millimeter wavelengths will make searches at dramatically improved sensitivity levels possible. Finally, the measurements conducted showed a very low "false-alarm" level. This was, of course, due to the absence of RFI at these short wavelengths and a minimum of scintillation. As a result, we expect that this spectral range will hold potential in the search for extraterrestrial intelligence for many years to come.

ACKNOWLEDGMENTS

The authors are deeply grateful to Dr. W. Whitfield Smith, Mr. David Lashley, and Mr. Richard Tatem of Georgia Institute of Technology for their assistance in the preparation and conduct of this observation. We are also extremely grateful to the staff and operators at NRAO/Tucson–Kitt Peak, Arizona, for their tireless help, especially Drs. Robert Freund and Philip Jewell, whose efforts in bringing some level of functionality back to our damaged equipment were truly heroic. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation. Support for this work was received from the High Resolution Microwave Survey (HRMS) Project of the National Aeronautics and Space Administration under Grant NAG2-700 from NASA Ames Research Center.

REFERENCES

CORDES, J. M., AND T. J. LAZIO 1991. Interstellar scintillations and SETI. *Astrophys. J.* **376,** 123–135.

DRAKE, F. D. 1961. Project Ozma. *Phys. Today* **14,** 40–46.

EGAN, P. O., V. W. HUGHES, AND M. H. YAM 1977. Precision determination of the fine structure interval in the ground states of positronium. IV. Measurement of positronium fine structure density shifts in noble gases. *Phys. Rev. A* **15,** 251–260.

JEWELL, P. R. (Ed.) 1990. *Users Manual for the NRAO 12m Millimeter-Wave Telescope.* National Radio Astronomy Observatory, Tucson.

KARDASHEV, N. S. 1979. Optimal wavelength region for communication with extraterrestrial intelligence: $\gamma = 1.5$ mm. *Nature* **278,** 28.

LEAHY, D. A. 1991. Discovery of a nonthermal radio source associated with the galactic center 511 keV annihilation-line source. *M. Not. R. Astron. Soc.* **251,** 22.

LIGENFELTER, R. E., AND R. RAMATY 1989. The nature of the annihilation radiation and gamma ray continuum from the galactic center region. *Astrophys. J.* **343,** 686–695.

STEFFES, P. G. 1993. The potential for millimeter-wave SETI. *Third Decennial USA–USSR Conf. SETI—A.S.P. Conf. Ser.* **47,** 367–371.