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SETI at the spin flip line frequency of positronium

R. Mauersberger[1,2,3], **T.L. Wilson**[1], **R.T. Rood**[4], **T.M. Bania**[5], **H. Hein**[6,7], **and A. Linhart**[1,8]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[2] Radioastronomisches Institut der Universität Bonn, Auf dem Hügel 69, D-53121 Bonn, Germany
[3] Steward Observatory, The University of Arizona, Tucson, AZ 85721, USA
[4] Department of Astronomy, University of Virginia, Charlottesville, VA 22903, USA
[5] Department of Astronomy, Boston University, Boston, MA 02215, USA
[6] IRAM, Avenida Divina Pastora 7-9, Núcleo Central, E-18012 Granada, Spain
[7] Submillimeter Telescope Observatory, The University of Arizona, Tucson, AZ 85721, USA
[8] Institut für Weltraumsensorik, DLR, Rudower Chaussee 5, D-12489 Berlin, Germany

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Abstract. A directed search for extraterrestrial intelligence (SETI) has been carried out using the IRAM 30m telescope. Following a suggestion by Kardashev (1979), the search was conducted at the spin-flip line of the lightest atom, namely positronium, at 203 GHz. Most of the 17 targets are mature stars with excess infrared radiation, which might be the waste heat of a power-rich technological civilisation. The rest frame of the cosmic background radiation was chosen as the velocity frame. The spectral resolution used was 9.7 kHz. From the noise level, which was determined by the limited telescope time and weather conditions, the upper limit for the power of artificial omnidirectional transmitters at the positronium line frequency is of order 10^{15} W. The relevance of this non-detection is discussed.

Key words: search for extraterrestrial intelligence — mm-lines — cosmic background radiation — spectral lines

1. Introduction

From the Drake equation, one can deduce that the search for extraterrestrial intelligence (SETI) is promising only if the typical lifetime of an intelligent, technologically advanced civilization is very long (i.e. > millions of years). A beacon being broadcast for communication with extraterrestrial intelligences (CETI) by such a civilization should have signal properties which make it easy for a primitive technological civilization (i.e. us) to detect. It would probably be very narrow in bandwidth. Further it would be at a frequency which is easy for us to guess. This kind of reasoning motivated Cocconi & Morrison (1959) to first suggest SETI, and Drake (1960) to carry out the first of ~ 50 subsequent searches (see e.g. the compilation by Tarter 1985).

A number of "magic frequences" have been proposed for SETI. Most of these are at frequencies where radiotelescopes of the 1960s and 1970s would operate well, namely at centimetric and decimetric wavelengths (e.g. in the so-called water hole between the OH and H I lines at 18 and 21 cm). The maximum of the distribution of the cosmic background radiation has been proposed as a search frequency (Gott 1982, Vallée 1990). This will, however, probably never be determined as accurately as atomic or molecular spectral lines and therefore requires a large search bandwidth. One specific advantage of using narrowband radiation for broadcasting is that this need not be modulated in a sophisticated way to be detectable, as would be the case for a broadband broadcasting signal. One disadvantage of most magic frequency searches done to date is that they have been at frequencies broadly useful to radio astronomy, particularly OH and H I. Just as these frequencies are in protected bands here, the ET radio astronomers would fight to prevent broadcasts. (Any reader doubting this should propose with a straight face a 10^{12} W 1420 GHz transmitter to a group of radio astronomers.) Kardashev (1979) proposed as a beacon the hyperfine line of the lightest atom, positronium, at 203.385 GHz. While this line is the analog of the 21 cm line of H I, no strong narrow line emission from natural sources is expected to blend with the signal or to raise the ire of local radio astronomers. Kardashev (1979) and Steffes (1993) point out the merits of searches at mm-wavelengths. The spin flip lines of ^{3}He$^+$ (Bania & Rood 1993) or muonium (Rood

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Send offprint requests to: R. Mauersberger, Steward Observatory

& Bania 1995) are also possible beacon frequencies with limited or no interest to radio astronomers.

One factor that has made many previous beacon searches less attractive is that we had no knowledge of the reference frame in which the signals were being broadcast. Either one had to guess a frame or to sacrifice sensitivity by searching in frequency. We (and presumably "they") know now a universal frame, namely that of the cosmic background radiation (Smoot et al. 1992). We have adopted the suggestion of Rood & Bania (1995) who propose that SETI searches be conducted in that frame, to which they refer as the "Frame of God" or FOG. This nomenclature followed the precedent established by COBE investigator G. Smoot in describing structures in the microwave background, e.g., Wilford (1992). The large motion of the Earth relative to the FOG ($\sim 360\,\mathrm{km\,s^{-1}}$) assures that many earlier searches, e.g. the search for signals at 203 GHz conducted by Steffes & DeBoer (1994), would have failed purely on this basis. The band width of the META survey (Horowitz & Sagan 1993), the now-defunct NASA SETI project and its successor Project Phoenix are the only examples of which we are aware which allowed an investigation in the FOG.

For our survey we have made the transformation to the FOG using the dipole anisotropy direction and amplitude given by Kogut et al. (1993). The error in the measurement produces an error of $\sim 2-3\,\mathrm{km\,s^{-1}}$ depending on direction and our total bandwidth easily covers the error in computing v_{FOG}.

2. The targets

A beam transmitting an omnidirectional signal is very energy consuming. Directed beacons would be much less expensive, but could only be employed by nearby ETI who know or strongly suspect our presence. There is certainly a tradeoff between numbers of directions, number of potential targets, beacon duty cycles etc., but on the whole we feel more comfortable contemplating omnidirectional beacons than wondering why a civilization has picked just us as a broadcast target.

Our detection limits below are in the range of 10^{15} W, not that different from many earlier searches. Following Rood & Bania (1995) we note that such a broadcast power should be compared to the total current power use on Earth (in all forms) of 4×10^{12} W and the 2×10^{17} W rate that Solar energy falls on the Earth. It is clear that SETI broadcasts which we could detect are vastly beyond the resources of a civilization similar to ours and probably beyond the capabilities of any planetary civilization. The only civilisations which might find a detectable omnidirectional beacon to be "cheap" are those which have spread throughout their planetary system and are making use of a large portion of their central star's luminosity as suggested by Dyson (1960). Rood & Bania (1995) hypothesize that such civilizations would be a hybrid of the Dyson model and the space colonies proposed by O'Neill (1974, 1975) and producing a large amount of waste heat emitted in the infrared. They hypothesize that the preferred materials of such a civilization will be hydrocarbon polymers and the like, and thus that the civilizations will reside in the cooler parts of their planetary system where the appropriate raw materials are most abundant. These Dyson/O'Neill civilizations could well have power resources of say $10^{-4}\,L_{\odot}$, or 10^9 times the power resources of our civilization.

Auman (1985) and Sakadane & Nishida (1986) have found from the IRAS catalog a number of nearby stars with a strong $60\,\mu$m excess radiation. Our target list was compiled from the review by Backman & Paresce (1993). We have excluded stars thought to be "young" like β Pic. The bulk of these stars have spectral type G to A; the prototype is Vega (α Lyrae). While the more conservative explanation of the IR excess is that it is caused by a dusty circumstellar envelope or disk, our hope was that it may be due to the waste heat of a Dyson/O'Neill civilization. Note, however, that in a recent survey, which includes several of our target stars, Jugaku et al. (1995) have not found any candidates for stars surrounded by Dyson spheres. In addition to affording SETI beacons which we could detect, a Dyson/O'Neill civilization might find non-relativistic interstellar colonization not to be as ridiculously expensive as conventionally thought (e.g., von Hoerner 1962). Hence we do not restrict our target list to stars with lifetimes long enough to have evolved an indigenous population.

Our target list also includes conventional SETI targets, nearby solar type stars with age comparable to the Sun (all of the stars with HD catalog numbers). A few such stars also have IR excesses (τ Cet, ϵ Eri). The white dwarf, WD2326 (Giclas 29-38), was included because of the strange nature of its IR excess (Zuckerman & Becklin 1987).

3. The search and its results

The observations were carried out in June 1994 using the IRAM 30-m Telescope (Baars et al. 1987). At the observed frequency of 203 GHz the telecope's beam is $13''$ (FWHP) wide, and the beam-efficiency is 0.48. The intensity calibration was established using a chopper-wheel method. All intensities are given on a Rayleigh-Jeans main-beam brightness temperature scale. In this scale, 1 Kelvin corresponds to 4.9 Jy. The telescope was equipped with an SIS receiver, which was tuned so that the response to the image sideband was suppressed by 7dB. In general, two backends were used simultaneously, namely a filterbank of 512×1 MHz wide channels and a three-level autocorrelator with 3584 channels and a channel spacing of 9.7 kHz, yielding a total bandwidth of 35 MHz, corresponding to a total velocity coverage of $52\,\mathrm{km\,s^{-1}}$. From continuum scans through nearby pointing calibrators, we estimate that the pointing accuracy of our observations is correct within $3''$. For the spectral line observations, a nutating subreflector

Table 1. Observing log and results

	α_{1950}	δ_{1950}	$v^{a}_{\rm Hel}$	d	Spectr. type	Date	$t_{\rm int}$	$T_{\rm SYS}$	$T^{b}_{\rm RMS}$	L^{c}
	h m s	° ′ ″	km s^{-1}	pc		6/94	min.	K	mK	10^{15} W
HD004614	0 46 03.0	57 33 06	215.5	5.9	G0V+dM0	15	4	2600	2800/250	<2.9
						20	4	550	590/62	<0.6
δ Cas	1 22 33.2	59 58 32	190.5	19	A5III-IVv	15	8	1710	1300/71	<14
						19	8	980	730/80	<7.8
HD010307	1 38 44.0	42 21 48	244.4	11	G1.5V	16	60	1700	485/32	<1.7
						20	4	520	580/59	<2.1
τ Cet	1 41 39.5	−16 11 24	265.4	3.6	G8V	20	4	650	710/59	<0.27
ϵ Eri	3 30 31.5	−9 37 34	144.9	3.3	K2V	20	4	560	600/66	<0.19
ψ5-Aur	5 43 08.0	43 37 48	−8.3			15	8	1010	770/52	
						19	8	690	520/53	
DM-23	9 39 59.0	−23 41 24	−327.5	12	F9IV	15	4	2990	3100/151	<2.6
β UMa	10 58 50.6	56 39 04	−165.5	19	AIv	15	16	1240	665/42	<7.1
						19	8	650	500/54	<5.3
β Leo	11 46 29.1	14 51 01	−339.2	12	A3V	15	4	1680	1850/114	<7.3
HD159222	17 30 13.0	34 18 18	50.1	20	GVv	16	4	5440	5340/380	<63
Gal. Center	17 42 26.6	−28 55 00	23.7	8500		16	28	5590	5330/-	$<10^{7}$
Vega	18 35 15.4	38 44 22	130.0	8.1	A0Va	15	12	520	330/36	<0.63
HD176051	18 55 09.0	32 50 12	158.8	17	F9V	17	12	1680	1030/78	<8.8
HD193664	20 17 02.0	66 41 36	144.6	15	G3V	16	8	2490	1810/110	<12
						20	4	660	730/71	<4.8
δ Equ	21 12 02.9	9 47 58	320.6	15	F5V+G0V	16	16	6000	3200/120	<21
HD217014	22 55 00.0	20 30 00	356.7	13	K1III	16	16	2310	1240/88	<6.0
						20	4	700	760/73	<3.8
WD2326	23 26 16.0	4 58 30	367.0	14	DAV4^{d}	16	16	2360	1330/98	<7.7
						20	4	694	760/70	<4.3

a) corresponding to $v_{\rm FOG} = 0\,{\rm km\,s^{-1}}$
b) with 10 kHz wide channels/ with 1 MHz wide channels
c) From the 5σ RMS in 10 kHz wide channels and assuming an omnidirectional beam.
d) in the scheme of Sion et al. (1983)

switched the telescope beam between the source to be observed and positions 4′ in azimuth on the sky. The time of either phase was 2 seconds.

This project served as a backup program for a regular astronomical observing project when the astronomical sources were below the horizon or when cloudy weather did not allow astronomical observations. While a part of the observations were done under very good weather conditions, with an effective system temperature of around 600 K, some of the observations were done under mediocre atmospheric conditions. In that case, the system temperatures were much higher.

A list of the observed sources, with their coordinates, and the heliocentric velocities at which the narrowband spectrometer was centered, the distances and spectral types (see Hoffleit 1982) as well as the observing dates, the system temperatures and integration times is given in Table 1. The velocities correspond to $v = 0\,{\rm km\,s^{-1}}$ in the FOG. From the error given by Kogut et al. (1993) for the amplitude of the dipole anisotropy of the cosmic background radiation, the uncertainty of the velocity is $\sim 3\,{\rm km\,s^{-1}}$, and it is very probable that any emission at $v_{\rm FOG} = 0\,{\rm km\,s^{-1}}$ is contained in our spectrometer band.

The RMS noise as measured in the narrowband and in the broadband spectrometer are listed in Table 1. With neither resolution was a signal detected at the positronium frequency stronger than expected from the system noise. Also in the Fourier transforms of the spectra, no features were detected.

We have converted our RMS limits of the flux density, S, to 5σ limits to the total emitted power of an omnidirectional broadcast beam at the distance of our target stars (Table 1) using

$$L = 1.2\,10^{8}\,{\rm W}\frac{S}{\rm Jy}(\frac{d}{\rm pc})^{2}\frac{\Delta\nu}{\rm Hz}. \qquad (1)$$

The limits we obtain, scatter by an order of magnitude around a value of 10^{15} W.

4. Discussion

Although we present only upper limits to the ETI signals, we do not feel that this is discouraging. Our experiment was limited to a short period of time. We may have just missed the "on" cycle of the broadcast; this might be settled by regular monitoring. Further our observing periods had modest weather conditions and used an instrument dedicated to astronomical observations. Maybe we are in a similar situation as Sir Oliver Lodge, who just after the discovery of radio waves directed a receiver toward the Sun, without detecting its radio emission (Hey 1973); maybe we are not sensitive enough. One specific disadvantage was the coarse spectroscopic resolution, 10^4 Hz. Most astronomers involved in SETI agree that a spectral resolution of 1 Hz would be desirable. (At much lower resolutions, signals may be widened in frequency due to interstellar plasma motions [Horowitz & Forster 1985]). To cover the range of uncertainty of the FOG, such a high resolution spectrometer would have to consist of $\sim 10^7$ spectral line channels, similar to the NASA MCSA (Backus 1993) now being used in Project Phoenix. With such a spectrometer, observations such as those described here would be very worthwhile.

Although "they" might be able to afford the energies necessary to broadcast interstellar signals, they will certainly make an estimate about the required signal strength. If they have experienced a technical evolution which is about as rapid as ours, they might argue that the time from the discovery of radio waves to the development of optimum receivers which reach the quantum limit is negligibly short compared to the lifetime of a civilization. They might expect us a few decades ahead, possessing 10 K receivers, a SETI backend, and a space-born, dedicated, 30-m telescope. In that case they would expect us to be orders of magnitude more sensitive. Despite vast power resources, their politicians, like ours, may be parsimonious in manners such as SETI.

A civilisation able to broadcast CETI beacons might afford interstellar colonialisation making use of radio relay stations. In that case, even serendipitous (i.e. non-directed) searches might be promising, and small mm-wave radio telescopes could be employed for searches or, alternatively, 203 Ghz receivers could be installed off-axis on an existing antenna and operated in parallel with astronomical projects. We also note that searches for very narrow lines would not require such excellent weather conditions as e.g. mm-wave continuum measurements or extragalactic studies. Monitoring a sample of targets would therefore be an ideal backup program for astronomical observations that are sensitive to weather conditions. Thus, future 203 GHz searches need not adversely impact traditional radio astronomical observations.

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References

Aumann, H.H., 1985 PASP 97, 885
Baars, J.W.M., Hooghoudt, B.G., Mezger, P.G., de Jonge, M.J., 1987, A&A 174, 319
Backman, D.E., Paresce, F., 1993, in Protostars and Planets III, eds. E.H. Levy, J.I. Lunine, U. Arizona Press, Tucson, p. 1253
Backus, P.B, 1993, in Third Decennial US-USSR Conference on SETI, ASP Conference Series 47, ed. G.S. Shostak, ASP, San Francisco, p. 323
Bania, T.M., Rood, R.T., 1993, in Third Decennial US-USSR Conference on SETI, ASP Conference Series 47, ed. G.S. Shostak, ASP, San Francisco, p. 357
Cocconi, G., Morrison, P., 1959, Nat 184, 844
Drake, F., 1960, S&T 19, 140
Dyson, F, 1960, Sci 131, 1167
Gott, J.R., in: Extraterrestrials — Where Are They? eds.: M.H. Hart, B. Zuckerman, Pergamon Press, New York, p. 122
Hey, J.S., 1973, The Evolution of Radio Astronomy, Scientific History Publ., New York
von Hoerner, S., 1962, Sci 137, 18
Hoffleit, D., 1982, Catalog of Bright Stars, 4th edition, Yale Univ. Obs., New Haven
Horowitz, P., Forster, J., 1985, IAU-Symp. 112, 292
Horowitz, P., Sagan, C., 1993, ApJ 415, 218
Jukagu, J., Noguchi, K., Nishimura, S., 1995, in: Progess in the Search for Extraterrestrial Life, ASP Conference Series 74, ed.: G.S. Shostak, p. 381
Kardashev, N.S., 1979, Nat 278, 28
Kogut, A. et al. 1993, ApJ 419, 1
O'Neill, G.K., 1974, Phys. Today 27, 32
O'Neill, G.K., 1975, Sci 190, 943
Rood, R.T., Bania, T.M., 1995, in prep.
Sakadane, K, Nishida, M., 1986, PASP 98, 685
Sion, E.M., Greenstein, J.L., Landstreet, J.D., Liebert, J., Shipman, H.L., Wegner, G.A., 1983, ApJ 269, 253
Smoot, G.F., et al., 1992, ApJ 396, L1
Steffes, P.G., 1993, in Third Decennial US-USSR Conference on SETI, ASP Conference Series 47, ed. G.S. Shostak, ASP, San Francisco, p. 367
Steffes, P.G., DeBoer, D.R., 1994, Icarus 107, 215
Tarter, J., 1985, IAU-Symp. 112, 292
Vallée, J.P., 1990, A&A 238, 1
Wilford, J.N., 1992, New York Times, 5 May, C1
Zuckerman, B., Becklin, E.E., 1987, Nat 330, 138

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