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A Passive SETI in Globular Clusters at the Hydroxyl and Water Lines

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We describe an indirect or "passive" SETI in 25 globular clusters, observed for astronomical reasons at the water and hydroxyl lines. No beacon signals were found in a sample of up to 10^7 stars and upper limits to the maximum EIRPs of beacons were 10^{16}–10^{21} W. Ways of enhancing the value of other astronomical spectral line observing programs for SETI purposes are discussed.

INTRODUCTION

The search for extraterrestrial intelligence (SETI) has only recently experienced growth in the number, type, and completeness of its surveys (Verschuur, 1973; Bridle and Feldman, 1980; Dixon and Cole, 1977; Horowitz, 1978). The problem, in part, arises from a practical dilemma: SETI should be done with the greatest possible effectiveness while placing a minimum of time and financial constraints on facilities primarily devoted to astronomical observations.

A promising remedy is to "piggy-back" by conducting an indirect or "passive" SETI in which conventional astronomical observations provide data pertinent to an extraterrestrial life search. We demonstrate the utility of a passive SETI from observations done on globular clusters at the hydroxyl (OH) and water (H_2O) spectral line wavelengths. Subject to various assumptions, this leads to an estimate of the maximum effective isotropic radiated power (EIRP) which any beacons transmitting at these wavelengths could be using. We estimate that as many as 10^7 galactic stars were included in this survey. Ways of using other astronomical spectral line observations for SETI surveys are discussed.

METHODS AND MOTIVATIONS

Many long-period variable stars (LPVs) exhibit maser emission at the 1.35-cm H_2O and 18-cm OH spectral lines (see, for example, Dickinson, 1978). Several LPVs have been found in globular clusters (Sawyer Hogg, 1973), and this has motivated a few high-sensitivity searches for these "stellar masers" in globular clusters (Cohen and Malkan, 1979; Dickey and Malkan, 1980; Bowers *et al.*, 1979). Thus many globular clusters have been observed at H_2O and OH line wavelengths.

There are several reasons for choosing globular clusters for SETIs. In brief, we note the following:

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(1) Although disruption of planetary orbits is expected to be severe in some globular clusters, a simple calculation of such disruption reveals that for typical values of densities of stars in cluster cores, planetary orbits of about 1-AU radius may remain unperturbed by neighboring stars for greater than 10^9 years. If such planetary systems remain unperturbed for the lifetime of the globular cluster, then planets which are propitious for intelligent life may have been extant for up to 10^{10} years. There may be a better chance of encountering civilizations of Type I, II, or III technologies (Kardashev, 1964) in some globular clusters than in many other parts of the galaxy.

(2) As population II objects, globular clusters may seem dubious locations for metal-rich, life-bearing planetary systems. However, some globular clusters (including several in this survey) have metallicities which are 10 to 100% of solar values.

(3) The proximity of globular cluster stars to one another may encourage interstellar radio contact.

(4) Since a large fraction of each cluster's stars fall within the field of view of the antenna, a substantial number of stars may be observed simultaneously.

It is reasonable to assume that ETIs may set up beacons transmitting at wavelengths at or near these water and hydroxyl lines. For example, near 1 cm, spectral linewidths experience a minimum of broadening (Drake and Helou, 1980) so any narrow bandwidth signals at such wavelengths would have the least amount of degradation of signal strength. Similarly, from 15 to 25 cm, the broad but distinct minimum in the cosmic background noise forms another wavelength region where a signal may best be propagated (see Oliver, 1973). At 1.35 and 18 cm, respectively, the H_2O and OH lines stand out as wavelength signposts of these two special wavelength regions, often referred to as the two "water holes." These water holes may be good wavelength regions at which to transmit narrow bandwidth beacon signals. We refer to such hypothetical beacons as "OH beacons" and "H_2O beacons," respectively.

Fortuitously then, searches for OH and H_2O stellar masers in globular clusters constitute passive SETIs since astronomical observations are made at the same wavelengths one may use in a direct SETI, and in a type of astronomical object which has the potential for being the location of intelligent life. We may extract information of interest to SETI directly from the astronomical observations.

Our observations were done at the Arecibo and Haystack Observatories. Procedures and the astronomical results may be found in Cohen and Malkan (1979), and Dickey and Malkan (1980). Bowers *et al.* (1979) have kindly provided the results of their OH studies at the Parkes Observatory. These three astronomical surveys constitute a data base from which it is possible to do a SETI analysis. In brief, no spectral features, natural or otherwise, were evident in the three astronomical surveys. Some general parameters of these surveys are listed in Table I.

As a passive SETI, these three astronomical surveys were sensitive to narrow-bandwidth beacons, with wavelengths at or near the OH and H_2O lines, which were transmitting directionally at the Earth one light travel time ago. It is possible that any such beacons would employ a slow information rate, causing transmission to cease for a time on the order of the observing periods. The following analysis assumes that H_2O and OH beacons would be detected, subject to the search sensitivities and/or the beacons' radiated powers, if they existed in these globular clusters.

To analyze the astronomical results for SETI, we note that there are two observational parameters which determine the coverage and sensitivity of the search: the Doppler radial velocity range, and the upper limit to antenna temperature (taken here as three times the rms noise in the spectrum)—T_a.

With an estimate of T_a, the limit to the

TABLE I

GENERAL OBSERVATIONAL PARAMETERS

Search	Cohen and Malkan (1979)	Dickey and Malkan (1980)	Bowers *et al.* (1979)
Line	22,235.08 MHz, 1.35 cm H_2O	1,667.359 and 1,665.402 MHz, 18 cm OH	1,612.231 MHz, 18 cm OH
Telescope	Haystack	Arecibo	Parkes
Field of view (arcmin^2)	1.4	9.6	94.1
A_e (m^2)	160	20,000	1,700
Polarization	Linear	Dual circular	Dual circular
Resolution of spectrometer (kHz)	65	9.5	4.5
Number of globular clusters	8	15	8
ϵ	6.6×10^{19}	8.1×10^{16}	4.4×10^{17}

maximum beacon EIRP is easily found. This is given by (see, for example, Drake, 1960)

$$\mathrm{EIRP}_{\max} = (4\pi D^2 kBT_a/A_e), \qquad (1)$$

where

$\mathrm{EIRP}_{\max}$ is beacon power (W)
D is the beacons's distance (m),
k is Boltzmann's constant (W m^{-2} K^{-1}),
B is frequency resolution (Hz),
T_a is antenna temperature (K),
A_e is the effective aperture of receiving antenna (m^2).

Taking D in kiloparsecs and combining the other quantities we rewrite

$$\mathrm{EIRP}_{\max} = \epsilon D^2_{\mathrm{kpc}} T_a \qquad (2)$$

where the values for ϵ are given in Table I.

The Doppler radial velocity coverage addresses a salient question: what specific wavelengths are best for OH and H_2O beacon transmissions? We may assume that an intelligent extraterrestrial civilization will take some action to cause its beacon signal to be distinguished easily from any natural emission; one way of doing this is to transmit at a wavelength such that the radial Doppler velocity, with respect to the OH or H_2O line rest wavelengths, is not compatible with the dynamics of stellar masers or globular clusters. Globular clusters commonly have a radial velocity dispersion of 20 km sec^{-1} centered around the systemic radial velocity of the center of mass. And stellar masers exhibit double-peaked velocity groups (Dickinson, 1978), with the stellar radial velocity in the middle, with separations of 20 and 40 km sec^{-1} for H_2O and OH masers, respectively. Hence any natural emission of stellar masers associated with globular clusters should evince velocities of up to 20 and 30 km sec^{-1} from the systemic velocity of the center of mass, for H_2O and OH, respectively. A logical choice for a beacon wavelength is one with a resultant radial Doppler velocity which is outside of these limits. Field stellar masers which coincidentally fall along the line of sight could meet this criterion, but these may be identified by an obvious optical counterpart. We submit that a spectral feature at, for example, a velocity of ±50 km sec^{-1} from the systemic center of mass velocity may not be natural in origin. In any case, other OH and H_2O beacon wavelength schemes are possible and the large observed velocity range includes them.

RESULTS AND DISCUSSION

In Table II we have taken the astronomical data and listed the results of interest to a SETI. These include the velocity coverage, T_a, $EIRP_{max}$, systemic velocities of clusters' center of mass, and distances to the clusters. This constitutes a sample of 25 globular clusters, 6 of which have some overlap of coverage at OH and H_2O. While a direct SETI may strive for a larger survey with more wavelength coverage, we note several important points from these results.

A large number of stars have been included in this survey. With the Dickey and Malkan (1980) search, about 80–90% of each cluster's stars fell within the antenna's field of view. This percentage is close to 100% for the Bowers *et al.* (1979) search, and 50% for the Cohen and Malkan (1979) search. Hence a total of about 10^7 stars have been observed by Dickey and Malkan (1980) and Bowers *et al.* (1979) and about 10^6 stars by Cohen and Malkan (1979). If, as in the solar neighborhood (Oliver and Billingham, 1972), 25% of these stars are of the spectral types most conducive to life, i.e., types F, G, and K, then this passive SETI is the most comprehensive ETI search of the Milky Way at these wavelengths. The result—no OH or water beacons were detected in a sample of up to 10^6 F, G, and K stars.

The maximum EIRPs also have interesting ramifications. Beacons arising from Type II, Type III, and advanced Type I civilizations would have easily been detected. We can only speculate, however, whether this represents an actual lack of such technologically sophisticated civilizations in the globular clusters of this search, or if the choice of observing parameters excluded any detections.

OTHER PASSIVE SETIs

We have demonstrated that a passive SETI can emerge from astronomical observations. Since it seems unlikely that many more direct SETIs will be done until radio observatory facilities place a major emphasis on this type of research, we discuss aspects of astronomical data taking which make it easier to extract passive SETI information.

A passive SETI should create few, if any, new requirements or restrictions on the observational methods. Yet in cases where the astronomical objectives allow some versatility in the choice of observing parameters, the following are to be preferred:

(1) Special attention should be placed on regions with high densities of stars: galactic clusters, the Galactic Plane and Center, and external galaxies. This allows many stars to be surveyed simultaneously.

(2) For a noise reduction technique, frequency switching rather than position switching should be used because this increases the wavelength coverage. Obversely, if the astronomical observations cover a large wavelength range with good wavelength resolution, position switching doubles the sky coverage.

(3) In addition to the 21-cm hydrogen line other atomic transition lines should be explored by passive SETIs at the long-wavelength (15–25 cm) water hole. Hydrogen, helium, and carbon recombination lines are good choices, helping to fill in the overall wavelength coverage. The "center of mass" OH–H line at 18.137 cm (Drake and Sagan, 1973) may be observed in this way. Other molecules which are important to life (for example, glycine; see Brown *et al.*, 1979) have transitions near the water lines and hence may be just as inviting for SETI work.

We do not envision the need for any data reduction techniques which are not typical for the analysis of astronomical spectral

TABLE II

SUMMARY OF PASSIVE SETI RESULTS

Cluster (NGC or other)	Distance (kpc)	Central velocity (km sec^{-1})	22 GHZ H_2O			1667 MHZ OH			1665 MHZ OH			1612 MHZ OH		
			Velocity range (km sec^{-1})	T_a (3σ) (°K)	EIRP$_{max}$ (w)	Velocity range (km sec^{-1})	T_a (3σ) (°K)	EIRP$_{max}$ (w)	Velocity range (km sec^{-1})	T_a (3σ) (°K)	EIRP$_{max}$ (w)	Velocity range (km sec^{-1})	T_a (3σ) (°K)	EIRP$_{max}$ (w)
104	4.6	−30	—	—	—	—	—	—	—	—	—	−90 → +60	0.071	6.6E17
121	<60	<154	—	—	—	—	—	—	—	—	—	+70 → +250	0.075	1.2E20
419	<60	<154	—	—	—	—	—	—	—	—	—	+70 → +250	0.15	2.4E20
5024	16.7	−112	—	—	—	−450 → −225	0.082	1.8E18	−802 → −577	0.098	2.2E18	—	—	—
						−225 → 353	0.041	9.2E17	−577 → +1	0.049	1.1E18			
						353 → 578	0.082	1.8E18	+1 → 226	0.098	2.2E18			
5053	13	?	—	—	—	−278 → −53	0.250	3.4E18	−630 → −405	0.344	4.7E18	—	—	—
						−53 → 506	0.125	1.7E18	−405 → 173	0.172	2.4E18			
						506 → 750	0.250	3.4E18	173 → 398	0.344	4.7E18			
5272	8.8	−154	−280 → −50	0.053	2.7E20	−492 → −267	0.08	5.0E17	−844 → −619	0.086	5.4E17	—	—	—
						−267 → 311	0.04	2.5E17	−619 → −41	0.043	2.7E17			
						311 → 536	0.08	5.0E17	−41 → 184	0.086	5.4E17			
5466	14	127	—	—	—	−211 → 14	0.166	2.6E18	−563 → −338	0.168	2.7E18	—	—	—
						14 → 592	0.083	1.3E18	−338 → 240	0.084	1.3E18			
						592 → 817	0.166	2.6E18	240 → 465	0.168	2.7E18			
5904	6.7	49	—	—	—	−288 → −63	0.078	2.8E17	−640 → −515	0.088	3.2E17	—	—	—
						−63 → 515	0.039	1.4E17	−515 → 163	0.044	1.6E17			
						515 → 740	0.078	2.8E17	163 → 388	0.088	3.2E17			
5927	7.2	−93	—	—	—	—	—	—	—	—	—	−190 → −10	0.109	2.5E18
6205	6.3	−241	—	—	—	−578 → −353	0.116	3.7E17	−930 → −705	0.122	3.9E17	—	—	—
						−353 → 225	0.058	1.9E17	−705 → −127	0.061	2.0E17			
						225 → 450	0.116	3.7E17	−127 → 98	0.122	3.9E17			
6356	12.1	31	−60 → 110	0.053	5.1E20	—	—	—	—	—	—	—	—	—
6388	14.3	87	—	—	—	—	—	—	—	—	—	0 → 140	0.09	8.1E18
6426	17	?	—	—	—	−398 → −173	0.13	3.0E18	−398 → −173	0.150	3.5E18	—	—	—
						−173 → 525	0.065	1.5E18	−173 → 525	0.075	1.8E18			
						525 → 750	0.13	3.0E18	525 → 750	0.150	3.5E18			
6553	3.3	−27	−100 → 50	0.071	5.1E19	—	—	—	—	—	—	−190 → 140	0.109	5.2E17
6712	5.7	−131	−200 → −40	0.035	7.5E19	—	—	—	—	—	—	—	—	—
6749	5	?	—	—	—	−398 → −173	0.25	5.1E17	−398 → −173	0.24	5.0E17	—	—	—
						−173 → 525	0.125	2.5E17	−173 → 525	0.12	2.4E17			
						525 → 750	0.25	5.1E17	525 → 750	0.24	5.0E17			
6760	4.4	?	−280 → −110	0.053	6.7E19	−398 → −173	0.206	3.2E17	−398 → −173	0.196	3.0E17	—	—	—
						−173 → 525	0.103	1.6E17	−173 → 525	0.098	1.5E17			
						525 → 750	0.206	3.2E17	525 → 750	0.196	3.0E17			
6779	8.9	−145	−230 → −60	0.042	2.2E20	−483 → −258	0.108	6.9E17	−835 → −320	0.132	8.5E17	—	—	—
						−258 → 320	0.054	3.5E17	−320 → −32	0.066	4.2E17			
						320 → 545	0.108	6.9E17	−32 → 193	0.132	8.5E17			

6838	3.1	−80	−100 → 0	0.042	2.7E19	−398 → −173	0.086	6.7E16	−750 → −525	0.116	9.0E16	—	—	—
						−173 → 405	0.043	3.3E16	−525 → 53	0.058	4.5E16			
						405 → 630	0.086	6.7E16	53 → 278	0.116	9.0E16			
7006	34	−348	—	—	—	−700 → −475	0.12	1.12E19	−1052 → −827	0.092	8.6E18	—	—	—
						−475 → 103	0.06	5.6E18	−827 → −249	0.046	4.3E18			
						103 → 328	0.12	1.12E19	−249 → −24	0.092	8.6E18			
7078	9.8	−105	−190 → −10	0.042	2.7E20	−447 → −222	0.07	5.4E17	−799 → −574	0.07	5.4E17	—	—	—
						−222 → 356	0.035	2.7E17	−574 → 4	0.035	2.7E17			
						356 → 581	0.07	5.4E17	4 → 229	0.07	5.4E17			
KRON3	<60	<154	—	—	—		—			—		70 → 250	0.075	1.2E20
LIND1	<60	<154	—	—	—		—			—		70 → 250	0.15	2.4E20
PAL10	8.3	?	—	—	—	−398 → −173	0.19	1.1E18	−398 → −173	0.192	1.1E18	—	—	—
						−173 → 525	0.095	5.3E17	−173 → 525	0.096	5.4E17			
						525 → 750	0.19	1.1E18	525 → 750	0.192	1.1E18			
PAL13	21	?	—	—	—	−360 → −135	0.07	2.5E18	−712 → −487	0.078	3.1E19	—	—	—
						−135 → 443	0.035	1.3E18	−487 → 91	0.039	1.4E18			
						443 → 668	0.07	2.5E18	91 → 316	0.078	3.1E19			

line observations. We stress, however, that beacon signals may be narrow in width and could be variable in intensity and/or polarization; awareness of the possibility of such anomalous lines is the quintessence of a passive SETI approach.

SUMMARY

We have described a passive SETI of globular clusters done at the water and hydroxyl lines. If H_2O or OH beacons exist in these clusters then they must have EIRPs of less than 10^{16}–10^{21} W. No beacons from a sample of about 10^7 galactic stars were evident. We have described ways of making other astronomical spectral line radio observations into useful passive SETIs.

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