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Research Note

A list of possible interstellar communication channel frequencies for SETI

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Abstract. Based on the 1420 MHz hydrogen line and the 1667 MHz hydroxyl line and on certain universal mathematically and physically significant scaling factors, a set of 55 possible interstellar communication frequencies for the search for extraterrestrial intelligence (SETI) is derived.

Key words: miscellaneous – planetary systems

1. Introduction

Proposed beacon frequencies in the search for extraterrestrial intelligence (SETI) have generally consisted of naturally occurring lines. These include the 1420 MHz hydrogen line, the 1667 MHz hydroxyl line, and more recently the He^{3+} hyperfine transition at 8.666565 GHz (Bania & Hood 1991) and the 203.385 GHz positronium line (Kardashev 1991).

Since many such beacon frequencies are swamped by natural emission, another approach is to use constants which arise from intelligence and emerging civilisations to define beacon frequencies. It has been argued that such civilisation signature constants (CSC) may be used to scale a fundamental base frequency to new interstellar communication channels (ICC) which could be used for beacons and for subsequent communication (Blair 1986). The ICC should be in a relatively uncontaminated part of the electromagnetic spectrum, particularly in the region of the minimum energy communication band between roughly 1 and 20 GHz. Recently, the number π has been used as a CSC (Blair et al. 1991; Blair et al. 1992) in a search of 176 galactic targets.

Given that hydrogen is the most abundant element in the universe there seems to be little argument that the neutral hydrogen 21 cm line is a good base frequency, but in choosing a CSC care must be taken to avoid anthropocentric bias. The CSC should be non-integer to avoid harmonics of the naturally occurring base frequency. For example π has been chosen based on the early historical discovery of this number and its fundamental role in mathematics and technology. However one cannot be sure how much the choice of such a number, or even the choice of the multiplication rule by which we define ICC $= f_H$ CSC is dependent on a historical accident. The ICC could equally be defined by ICC $= f_H/$CSC. Thus, it is not unreasonable to assume that π^{-1} is as fundamental as π, and an ICC $= f_H/\pi$ could be as significant as $f_H\pi$.

However a minimum energy band for interstellar communication can be determined by galaxy-wide and universal considerations, and would be common to all observers in our galaxy. The low frequency cut off is set by galactic synchrotron radiation noise, and the upper cut off by the quantum limit i.e. the increasing energy per quanta (or energy per bit) as the photon energy increases. The basic assumption here is that a minimum energy principle (or ecology principle) would govern all civilisations sufficiently sustainable to take part in interstellar communication.

Based on the minimum energy argument, we can eliminate the problem of choice between multiplication and division. We choose the CSC and the arithmetic operation such that the ICC occurs in the minimum energy band. Thus, for example, we include $f_H\pi = 4.462336273$ GHz but not $f_H/\pi = 0.452129193$ GHz in Table 1.

However it is impossible to use the minimum energy band restriction to distinguish in this way between say π and 2π, which appear to be equally significant (e.g. the diameter of a circle may be considered to be just as fundamental as the radius). Many other numbers could equally well assume greater significance to different civilisations with different histories. Additional frequencies can also be defined by performing simple arithmetic opera-

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Table 1. Interstellar communication channel (ICC) frequencies based on civilisation signature constants (CSC), the hydrogen line ($f_H = 1.420405751$ GHz) and the hydroxyl line ($f_{OH} = 1.667358$ GHz). The frequencies are arranged in increasing value and do not necessarily reflect the relative ranking in importance

Notes	CSC	CSC value	ICC freq (GHz) based on f_H	ICC freq (GHz) based on f_{OH}
1[p]	1/2	0.5	0.710202876	0.833679
2[p]	$\pi/6$	0.523598776	0.743722712	0.873027
3[s]	$(f_H f_{OH})/(f_H + f_{OH})$		0.767003[a]	
4[p]	Proton/neutron	0.998623479	1.418450532	1.665063
5[p]	Neutron/proton	1.001378419	1.422363665	1.669656
6[s]	$(f_H f_{OH})^{1/2}$		1.538936[a]	
7[s]	$(f_H + f_{OH})/2$		1.543882[a]	
8[p]	$\sqrt{2}$	1.414213562	2.008757077	2.358000
9[p]	$\pi/2$	1.570796327	2.231168136	2.619080
10[p]	Golden mean $(\sqrt{5}+1)/2$	1.618033989	2.298264783	2.697842
11[p]	$\sqrt{3}$	1.732050808	2.460214928	2.887949
12[p]	Deuterium/hydrogen	1.999007511	2.839401764	3.333061
13[p]	2	2	2.840811502	3.334716
14[s]	$f_H + f_{OH}$		3.087764[a]	
15[p]	$\sqrt{5}$	2.236067977	3.176123815	3.728326
16[p]	Feigenbaum α	2.502907875	3.555144740	4.173243
17[p]	Euler's number e $(1+1/n)^n$, $n \to \infty$	2.718281828	3.861063142	4.532350
18[p]	π	3.141592654	4.462336273	5.238160
19[p]	Helium/hydrogen	3.972599637	5.642703371	6.623746
20[p]	$4\pi/3$	4.188790205	5.949781697	6.984213
21[p]	Feigenbaum δ	4.669201609	6.632160818	7.785231
22[s]	$(f_H + f_{OH})e$		8.393412[a]	
23[p]	2π	6.283185307	8.924672545	10.47632
24[s]	$(f_H + f_{OH})\pi$		9.700496[a]	
25[s]	e^2	7.389056099	10.49545778	12.32020
26[s]	πe	8.539734223	12.12988760	14.23879
27[s]	π^2	9.869604401	14.01884285	16.45616
28[p]	Carbon/hydrogen	11.91331331	16.92173874	19.86376
29[p]	4π	12.56637061	17.84934509	20.95264
30[s]	$(f_H + f_{OH})2\pi$		19.400992[a]	
31[s]	e^e	15.15426224	21.52520124	25.26758

Notes for Table 1

[p] and [s]	Indicate primary and secondary channels
[a]	Although in the f_H column these frequencies are based on both f_H and f_{OH}.
1 and 13	The number 2 is of fundamental importance in inverse square laws and in being the basis of binary digital computation and communication.
2 and 20	The volume of a sphere in flat space-time is $4/3\pi(\text{radius})^3$ or $\pi/6(\text{diameter})^3$.
3, 6, 7, 14, 22, 24, and 30	These are various simple permutations on the two base frequencies and CSCs.
4	Proton (1.007276455 u) to neutron (1.008664904 u) mass ratio.
5	Neutron to proton mass ratio.
10	Golden mean may, at first, appear to be too anthropomorphic, (being related to aesthetics for humans) but does occur in nature and in mathematics in the Fibonacci series.

Table 1 (continued)

12, 19 and 28	These are nuclear mass ratios based on deuterium (2.013553199 u), helium (4.001506080 u) and carbon (12.000000000 u). (Most likely they will be a carbon based life form).
16, 17, 18, 21, 25, 26, 27 and 31	Any emerging civilisation will eventually discover the importance of π, e, α and δ in mathematics and nature.
18 and 23	The circumference of a circle is 2π radius or π diameter.
29	The area of a sphere is $4\pi(\text{radius})^2$ or $\pi(\text{diameter})^2$.

tions on a *pair* of base frequencies. The natural pair seem to be $f_{\rm H}$ (for reasons described above) and the hydroxyl line $f_{\rm OH}$ (being related to water which is essential for life as we know it). While $f_{\rm OH}$ has four values, the line at 1667 MHz is in theory the strongest, and is probably the best choice. (Pumping conditions in galactic OH masers do not make this the strongest observed line however.)

2. List of interstellar communication channels

The two sets totalling 55 ICC frequencies are given in Table 1. Of these, 48 are obtained using the CSC method discussed above. The other seven use the base frequencies $f_{\rm H}$ and $f_{\rm OH}$ alone or in combination with a CSC. One other violates the integer avoidance argument and is the simplest frequency which can be derived from $f_{\rm H}$ alone, namely $2f_{\rm H}$. The number 2 is of fundamental importance in inverse square laws and in being the basis of binary digital computation and communication. This has the disadvantage, as noted above, that receiver harmonic distortion could create interference from natural sources of $f_{\rm H}$, but in practice this may not be enough reason to avoid investigating this line.

The list is not exhaustive, but specifies a set of frequencies worth special examination. It is useful to divide the ICCs into primary and secondary channels. The primary channels use a minimum of operations to define their value. Secondary ICCs are based on an additional operation (such as $e^2 f_{\rm H}$, or $(f_{\rm H}+f_{\rm OH})\pi$). 40 of the ICCs listed here are primary channels.

Clearly there are other possibilities for the CSCs and for the base frequencies. The three other hydroxyl lines at 1612, 1665 and 1720 MHz could provide additional base frequencies. Another possibility is a sequence of CSCs to provide a set of parallel channels widely spaced in frequency within the minimum energy band. For example, sequences of frequencies based on Prime numbers, or on square roots of integers or on increasing roots of an integer e.g. 2, etc. Such sequences while costing more in energy, would increase the likelihood of detection and reduce ambiguities associated with single ICCs.

Note that the ICC cannot be exactly defined in that Doppler corrections can never a priori be fully accounted for at the precision one would like to achieve. The cosmic microwave background reference frame is the most universal choice in which to broadcast a beacon (Blair et al. 1992). However, present inaccuracies in the known direction and amplitude of the dipole anisotropy and the recently observed scale length independent anisotropy means that this provides only an approximate reference frame. This means that a receiver bandwidth $\Delta f/f \sim 10^{-5}$ is required to ensure that a receiver is within a specified ICC frequency. Thus typically one requires a 100 kHz bandwidth (at 10 GHz) within which a sensitive search should have better than 1 Hz resolution. This bandwidth is still 10^{-5} of the search band required if ICC frequencies are not assumed, and allows use of general purpose spectrum analysers and simpler data processing.

3. Conclusions

While "the aliens" may either be arbitrary, or enormously more abstract in their frequency selection than we imagine, it seems reasonable that we should credit them with the intelligence to match their beacon frequencies to those that a typical young technological civilisation might choose.

It is worth noting that:

(i) The set of *simply* defined ICCs is comparatively small.

(ii) To be useful a CSC needs to be known to an accuracy of 10^{-5} as discussed above.

(iii) Although expressed in base 10, the CSCs listed are independent of units of measurement (as they are ratios of quantities or pure numbers) and have significance in any base system.

(iv) If any directed beacons do exist on relatively nearby stars, they are likely to be strong, since the energy requirements are very reasonable (Blair et al. 1991; Blair et al. 1992).

(v) The effort involved in either an all sky or targeted survey of predetermined beacon frequencies is vastly less than that of an all sky survey across the entire 1–20 GHz band.

(iv) Even if the probability of the ICC hypothesis being correct is low, the time and effort involved in searching possible ICC frequencies is very small (10^{-8}) compared with that of an all-frequency search, such as the NASA Microwave Observing Program (Tarter & Klein 1991).

(vii) The recent discovery of very strong Methanol masers at 6.668 GHz indicates that even very strong beacons could easily have been overlooked by radio-astronomy (Macleod et al. 1992).

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