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SEARCH FOR INTERSTELLAR BEACONS AT THE ^{3}HE^{+} HYPERFINE TRANSITION FREQUENCY

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ABSTRACT A search for narrow (>300 Hz) band interstellar beacons was made in the direction of a sample of seven stars showing excess 60 micron fluxes. These "Vega-like" objects may be surrounded by circumstellar disks of material. The stars were observed at their heliocentric velocities using the ^{3}He^{+} hyperfine transition as the assumed beacon transmitting frequency. The ^{3}He^{+} line, the next simplest such transition after 21 cm H I, is a likely choice for an interstellar beacon since a strong, narrow line would be extremely easy to distinguish from naturally occurring ^{3}He^{+} emission. No ^{3}He^{+} beacons were detected. For the narrowest bandwidths sampled, these beacons must have intensities less than 1 Jy (r.m.s.) per channel.

ANOTHER 'MAGIC' FREQUENCY FOR COSMIC BEACONS?

A complete search of the the frequency dimension of the "cosmic haystack" is a daunting possibility for even a ground based *SETI* effort. Even the ambitious NASA Microwave Observing Project (MOP) has compromises in possible frequency and bandwidth coverage. For the next few decades it seems reasonable to continue to make calculated guesses of "magic frequencies" that might be used as interstellar beacons by an ETI wishing to be easily discovered by emerging technologies such as our own. We propose a new beacon—the rest frequency of the "spin flip" transition of ^{3}He^{+}, and report our results for a limited search at that frequency.

There are a variety of reasons why ^{3}He^{+} might be an even better "magic" beacon frequency than the 21 cm hydrogen line. First, the singly ionized, low mass isotope of helium, ^{3}He^{+}, has the next simplest ground

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state hyperfine "spin flip" transition after the 21 cm line of atomic hydrogen. Its frequency is easy to calculate ($\nu_0 = 8.665650\,\mathrm{GHz}$, $\lambda_0 = 3.46\,\mathrm{cm}$; Novick and Cummins 1958). Indeed, it is contained in the early list of Townes (1957) of potential microwave frequency lines. Its abundance in the solar system, with a protosolar value of the ^{3}He/H ratio roughly 2×10^{-5} by number, makes a search for ^{3}He outside the solar system appear difficult but possible (*cf.* Rood, Bania, and Wilson 1984 [RBW]). Moreover, as we discuss below, ^{3}He is astrophysically interesting. Any intelligence that studies interstellar hydrogen would also study ^{3}He.

Beacons transmitting at the ^{3}He$^+$ frequency could be easy to identify for several reasons. (1) Although ^{3}He is abundant as compared to heavier elements, it is not nearly as abundant as atomic hydrogen. Nor is it as ubiquitous: naturally occurring ^{3}He$^+$ is found only in interstellar plasmas. Thus contamination or masking of beacons by natural emission should be minimal. That is, the ^{3}He$^+$ cosmic background from natural processes will be extremely weak. (2) In fact, if associated with an even vaguely earth-like planet, the beacons *would not be inside H*II *regions*! Any strong ^{3}He$^+$ signal detected away from an H II region would almost certainly be artificial. (3) The observed properties of natural ^{3}He$^+$ lines, ~1 MHz widths and ~a few milliKelvin intensities, imply that *anything* much narrower is likely to be artificially produced. Furthermore, for a ^{3}He$^+$ beacon 'narrow' and 'strong' are much wider and less intense by factors of hundreds to thousands than a comparable H I beacon needs to be. (4) Finally, because natural sources of ^{3}He$^+$ radiation are confined to a few directions in the sky 8.665 GHz does not necessarily have to be a protected frequency. Imagine the outcry from radio astronomers if NASA proposed a 10^{12} watt *SETI* transmitter at 1.420 GHz or 1.667 GHz. Would not extraterrestrial radio astronomers do the same? The lobby group for protecting the 8.665 GHz band is likely to be much smaller than that, say for 21 cm, anywhere in the Milky Way. In this way ^{3}He$^+$ is similar to the positronium hyperfine line beacon suggested by Kardashev (1979). However, compared to the 203 GHz positronium line, the 8.7 GHz ^{3}He$^+$ line is more easily accessible from the ground with more primitive receiver technology. Moreover, 8.7 GHz is much closer to the minimum in the cosmic noise background, the "water hole", than is the 203 GHz transition.

THE ASTROPHYSICAL IMPORTANCE OF ^{3}He

Measurements of the cosmic abundance of ^{3}He have important consequences for cosmology, the chemical evolution of galaxies, and the theory of low-mass stars. The light isotopes ^{2}H, ^{3}He, ^{4}He, and ^{7}Li are all made in the Big Bang. According to the standard model of Big Bang nucleosynthesis, the amount of each of these nuclei produced depends on the average density of baryons in the universe, the rate of expansion of the universe just prior to the era of primordial nucleosynthesis, and details of particle physics such as the number of flavors of light neutrinos (*cf.* Steigman 1990).

Unfortunately none of the crucial isotopes are easy to observe at the present epoch. To complicate matters, it is expected that the abundances of the light isotopes have all evolved due to stellar processing or perhaps other more exotic phenomena. Stars of mass comparable to the Sun should be a prodigious source of ^{3}He (Rood, Steigman, and Tinsley 1976 [RST]). ^{3}He along with, possibly, ^{13}C, are the significant nucleosynthesis products of such stars. Because mass loss by these stars from various processes is the main source of stellar mass input into the ISM in a closed galaxy, a considerable enhancement of the ^{3}He abundance could be expected. Thus, determination of the ^{3}He abundance at a number of locations can give some information on the contribution to galactic chemical evolution of the lower stellar mass component. Finally, under some circumstances ^{3}He abundance patterns can check the canonical assumptions of stellar interior theory (*cf.* Dearborn, Schramm, and Steigman 1986 [DSS]).

IS ANY ^{3}He OUT THERE ANYWAY?

The seemingly straightforward detection experiment, originally proposed by Townes in the 1950's, has in fact required nearly a decade of effort (RBW; Bania, Rood, and Wilson 1987 [BRW]). Our observations to date push the limits of single dish radio spectroscopy. Our work with the engineers at Green Bank has led to improvements in the 140-ft telescope's spectroscopic capability. For the 140-ft telescope at least, it is now possible to measure the wide, weak ^{3}He$^+$ spectral lines rather routinely, albeit with extremely long integration times. Such lines can be observed with at least an order of magnitude more precision than just a few years ago.

We now have excellent ^{3}He$^+$ measurements from a sample of nine galactic H II regions observed from Green Bank (RBW, BRW). The ^{3}He abundances we measure for individual sources are generally a factor of two or more higher than the protosolar value. This result is superficially consistent with the general picture of stellar production of ^{3}He since the formation of the solar system (RST, DSS). However, the fact that there is no apparent correlation of abundance with galactocentric distance or with other indicators of stellar processing suggests that we do not yet fully understand the chemical evolution of ^{3}He.

As part of our ongoing program to study the cosmic abundance of ^{3}He, we have recently begun to conduct ^{3}He$^+$ experiments using the 100 m telescope of the Max Planck Institut für Radioastronomie in Effelsberg. In fact, we have probably detected ^{3}He$^+$ emission from the planetary nebula NGC 3242 during our March 1991 experiment at Effelsberg. The line shown in Figure 1 is extremely convincing!

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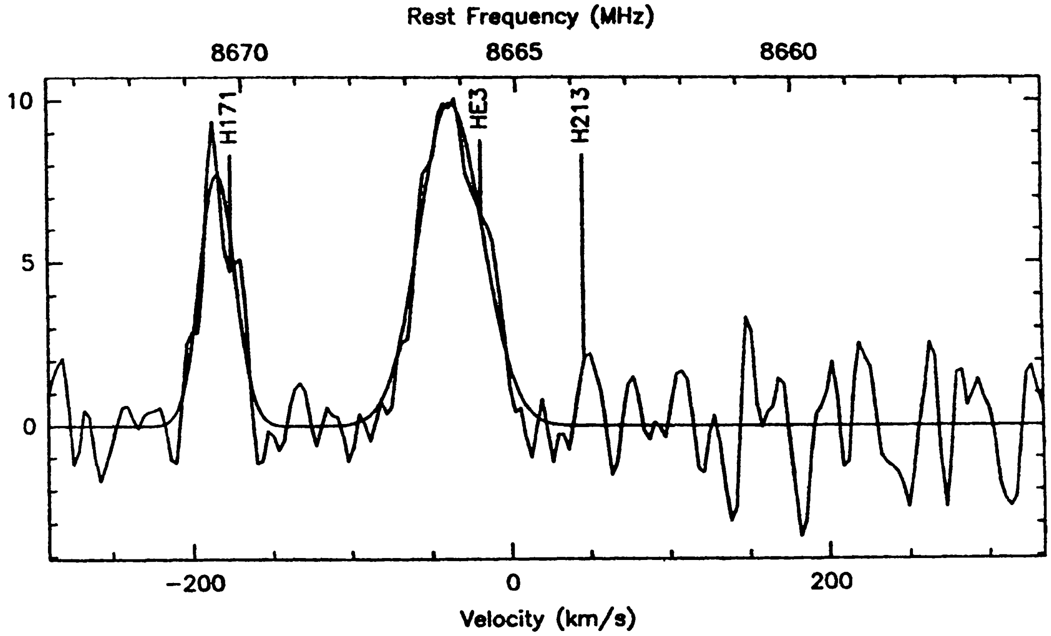

Figure 1. Probable detection of ^{3}He$^+$ emission from the planetary nebula NGC 3242. Shown is the 100mspectrum obtained in March 1991. The brightness temperature intensity scale is in milliKelvins. Flags indicate the rest frequencies of ^{3}He$^+$ and the 171η (Δn=7) and 213ξ (Δn=14) recombination lines of hydrogen. Preliminary analysis gives a ^{3}He$^+$/H$^+$ abundance of 2×10^{-3}, which is 100 times larger than the canonical protosolar abundance ratio. *This seems to be the first direct measurement of* $^3He^+$ *enrichment from stellar processing.*

THE SEARCH SAMPLE

Studies of the IRAS point-source catalog (Aumann 1985; Sadakane and Nishida 1986) have identified a sample of 24 nearby stars which are "Vega-like" in terms of their large 60-micron flux excess. These studies identified a population of nearby stars which correlated in position with IRAS point sources. For the objects with 60-micron flux excesses, it was found that spectral type A dominates: 60% of the objects have spectral types between A1 and A5. This may be a selection effect (Sadakane and Nishida 1986). The spectral distribution of these objects is constrained, however. Only three stars have types earlier than A and none is earlier than B9. Altogether, seven stars are later than type G but none is later than K2.

The analysis of these Vega-like sources shows that the data are consistent with the assumption that the 60-micron excess is due to cold material distributed in a ring or toroid about the central star. This conclusion results from modeling (Aumann 1985) as well as observed darkenings

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in six objects which suggest the presence of interstellar disks seen edge-on (Sadakane and Nishida 1986). Such structures are of course evidence for proto-planetary disks. (However, see Aumann [1985] for caveats concerning this interpretation.)

Thus, the IR radiation is assumed to arise from circumstellar dust—basically protoplanetary material. This assumption along with the planetary chauvinism common in the *SETI* community, leads to the conclusion: no planets, thus no ETI. One might wonder why we selected stars with an IR excess as targets of a search for beacons from an advanced civilization.

Rood (1986) has pointed out that such radiation might arise from a truly advanced civilization which lives in space colonies such as those envisaged by Gerald O'Neill (1989). Basically this is a generalization of the concept of "Dyson Spheres" (Dyson 1960). The radiation from Vega could well arise from several earth masses of material assembled into O'Neill colonies, photovoltaic arrays, and the like. The low temperature arises because "hi-tech" civilizations will likely be based on hydrocarbons, graphite, *etc.,* rather than the metals of primitive, planet-bound civilizations. Such an advanced civilization would naturally gravitate (or more precisely anti-gravitate) toward the lower temperature parts of planetary systems where the volatile materials on which their civilization is built will be found in largest abundance.

The following argument leads us to believe that we are far more likely to find such a civilization rather than one bound to terrestrial planets. Consider doing a search for a 1 Hz bandwidth beacon with a sensitivity of 1 Jy (not all that different from our survey or that proposed in the NASA *SETI* MOP Targeted Search). We must remember that it costs the transmitting civilization something to send this message. Let us assume for the sake of an intuitive argument that their civilization is largely confined to a terrestrial planet (*i.e.*, it is a TPC). Furthermore, the TPC buys its power from VEPCO (Vega Electric Power Company) at a cost of \$0.10 kw hr^{-1}, their transmitter efficiency is 100%, and it is at a distance of 100 pc. If they use a 100 m antenna to broadcast a cm-wavelength *directed* beacon their annual power bill would be $\sim 10^6$ \$. A message of a few minutes costs a few dollars—we suppose a calculation similar to this launched Frank Drake onto Project Ozma.

We get paranoid when considering directed beacons—why are *they* sending a message to *us*? We feel that it is much more reasonable to consider omnidirectional beacons. The annual power bill in this case would be $\sim 10^{12}$ \$! That sounds pretty expensive, and we doubt that any TPC government would make such an appropriation to broadcast to "who knows what?" Indeed the power use of such a transmitter, $\gtrsim 10^{12}$ watt, amounts to about 2% of our current global gross power use—it is truly expensive for a mere TPC to do.

We argue that any other TPC would reach the same conclusion. Solar energy falls on the Earth at a rate of 1.76×10^{17} watts. We will refer to this unit of power as *total wattage intercepted: terrestrial* or the "twit". Now, no matter what pollutionless form of energy production might be invented, the second law of thermodynamics demands that the ultimate pollution of waste heat be dumped into the planetary environment. Current thinking is that altering the Earth's energy input by a small fraction of a twit would place the climate in severe jeopardy. A Greenhouse warming of 3 C, viewed as a crisis by many, amounts to trapping 40 *milli*twits in the lower atmosphere. Basically, any TPC is forever doomed by thermodynamics to be a subtwit civilization. If we consider a 5 microtwit *SETI* transmitter to be ridiculously expensive, so will they.

For a civilization to play the *SETI* broadcast game they must have vastly more energy resources than any TPC. By necessity they must be dispersed, and the *bulk* of the enterprise of the civilization must be in space. Such a civilization might grow to use a substantial fraction of their star's output. (This fraction is argued by Dyson and Kardashev to be close to 1; we would argue for 10^{-5}.) The Vegans are observed to be using power at a rate of 0.3 megatwit. Perhaps a 5 microtwit *SETI* transmitter would be a frivolous expense to them.*

For our search for ^{3}He$^+$ beacons, we observed a stellar sample taken from these objects with 60-micron excesses. Our hope is that some of these are advanced civilizations rather than protoplanetary dust. Although our survey sample was defined by the stars' infrared emission properties, we in fact chose our targets from this sample by the simple criterion that they fitted into available LST slots during this epoch of our ^{3}He$^+$ experiments toward galactic H II regions.

The properties of the stars in our sample are summarized in Table 1. Most of these data are taken from the *Catalog of Bright Stars* (Hoffleit 1982). Listed are the star names, equatorial positions (epoch 1950.0), heliocentric stellar velocities, spectral types, and distance from the Sun from trigonometric parallaxes. Several of our objects are in multiple star systems and four are either known or suspected spectroscopic binaries. (Sadakane and Nishida conclude that the frequency of multiple stars in the 60-micron excess sample is identical to that found for the general stellar population found within 5 pc of the Sun.)

THE SURVEY

The survey was conducted 31 August and 1 September 1988 using the 140-ft telescope of the National Radio Astronomy Observatory in Green Bank, West Virginia. For the beacon search, we used the two-channel (orthogonal linear polarizations) maser/upconverter receivers which had typical system temperatures on cold sky of 50 K. We observed in total power mode, taking spectra 6 minutes on and 6 minutes off source in the manner described in RBW. Except for Vega which was observed twice (on 31 August and 1

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* What a civilization considers frivolous is certainly a matter of conjecture. A cruising jumbo jet uses power at a rate in the 100's of picotwit range. Our society tolerates astronomers flying around in the Kuiper Observatory or Presidential aides flying around the world—activities many would consider frivolous. Hence for us the difference between ridiculously expensive and frivolous is only about a factor of 10,000.

TABLE I Properties of Survey Target Sources

Source	α (1950.) (hh:mm:ss.s)	δ (1950.) (dd:mm:ss)	V[a] (km sec^{-1})	Spectral Type	D[b] (pc)
β UMa (Merak)	10:58:50.3	+56:39:03	+0.00	AOVa	19
β Leo (Denebola)	11:46:29.5	+14:50:59	+0.00	A3V	12
α CrB (Alphekka)	15:32:34.0	+26:52:49	+2.00	AOV	22
γ Ser	15:54:08.5	+15:48:35	+7.00	F6V	12
σ Her	16:32:28.3	+42:32:17	-11.00	B9V	100
ζ Her	16:39:21.6	+31:41:44	-70.00	GOIV	10
α Lyr (Vega)	18:35:13.9	+38:44:17	-14.00	AOVa	8

[a] Heliocentric stellar velocity

[b] Trigonometric parallax

September), each star was surveyed for $^{3}\mathrm{He}^{+}$ emission with a single total power on/off pair. Altogether, four frequency bands were sampled simultaneously with the autocorrelator, each centered at the heliocentric velocities listed in Table 1. Table 2 lists the total bandwidths sampled, together with other survey information. Each bandwidth was sampled with 256 correlator channels.

The bandwidths we sampled together span a very large range of instantaneous velocity widths and frequency resolution per channel. This flexibility in the Green Bank correlator enhances the power of a *SETI* beacon survey a great deal since we search a lot of parameter space at once. We believe that we have attained a reasonable compromise, searching for narrow-band beacon signals (narrow in the sense discussed above) as well as covering an appreciable range of velocities in the stellar rest frame (see below). In particular, the narrowest channel bandwidth sampled (305 Hz) was ~0.03% of the typical linewidth we observe for natural $^{3}\mathrm{He}^{+}$ emission from galactic H II regions. The r.m.s. sensitivity we reached was 1,005 mJy. The 2.5 MHz total bandwidth spectra gave a sensitivity of 126 mJy for a frequency resolution that was ~0.98% of the typical H II region linewidth.

No $^{3}He^{+}$ emission was detected during our survey down to the r.m.s. limits listed in Table 2. (For Vega, these limits are a $\sqrt{2}$ lower since it was observed each day.)

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IMPLICATIONS FOR SETI

Like any finite SETI beacon targeted search, our survey is fraught with assumptions, both known and unknown, concerning the nature of ^{3}He$^+$ beacons. In the case of our sample, we can identify a few of these issues.

Foremost of these is that an IR excess might be an indication of a power rich civilization. If indeed the IR in all cases arises from dust, any beacons must, in all probability, have been left there by the scientific survey expeditions of some starfaring ETI. Perhaps they would hope to use the 60-micron excess flux as a sort of natural beacon to draw attention to these stellar systems. The ^{3}He$^+$ beacons would then be unambiguously artificial if for no other reason than that ^{3}He$^+$ cannot be naturally produced under the conditions that exist in the disks. This alternative is less probable than finding a power-rich civilization.

TABLE II Sampled Bandwidths and Observed Sensitivities

BW (total) (MHz)	$\Delta\nu$ (kHz ch^{-1})	VW (total) (km sec^{-1})	Δ V (km sec^{-1}ch^{-1})	S$_\nu$(r.m.s.) (mJy)
20.000000	78.125	691.910	2.703	62.8
2.500000	9.766	86.489	0.338	177.7[a]
0.625000	2.441	21.622	0.084	355.3
0.078125	0.305	2.703	0.011	1,004.5

[a]For two receivers the r.m.s. sensitivity was 125.6 mJy.

Given this, then the velocity shift of a beacon with respect to the stellar velocity might not be too important. Certainly our knowledge of the heliocentric stellar velocities is not very accurate at present. (In fact, the velocity we adopted for Merak was plain wrong by $\sim$13 km sec^{-1}.) In any case, ETIs would not in general be tuning their beacons to the heliocentric frame of the solar system. The beacons need not be tuned even to the rest frame of the system. In fact they are probably in orbit and it would add extra information if a beacon were to show an orbital doppler shift. For the solar system, a beacon on the Earth shows a ±30 km sec^{-1} annual shift. This is why we sampled our two independent receivers with 2.5 MHz total bandwidths—these spectra covered over 86 km sec^{-1} total velocity width at, of course, a loss of sensitivity for detecting narrow bandwidth beacons.

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Finally, we note that the sensitivity achieved for our narrowest band measurements is roughly that expected for the MOP all sky survey for similar integration times. Clearly, a search at this frequency is feasible.

In conclusion, we urge that the $^3He^+$ *beacon search be conducted in an early phase of the NASA SETI MOP. Further we suggest that the targeted survey be expanded to include IR excess stars as well as solar stars.*

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Paul Steffes measures the mettle of millimeter wavelengths.

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