References and Notes

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6. Four-fifths of the fish fauna in the Cow Branch formation is shared with the Lockatong formation and three-fifths with the Chinle formation.
7. The possible presence of *Glyptolepis platysperma* implies Middle Keuper age, possibly late Carnian, whereas the presence of *Zamites powellii* and *Dechellyia* seems to collaborate a Chinle correlation.
8. The age for the Chinle formation is based on palynological work by B. Cornet (in preparation) and R. E. Dunay, and M. J. Fisher [*Rev. Palaeobot. Palynol.* **17**, 197 (1974)]. The age of the Lockatong formation is based on a typical late Carnian palynoflora, which is dominated by *Patinosporites densus* and *Triadispora* spp. recovered from the upper part of the formation; *Camerosporites pseudoverrucatus* is also present [see B. Cornet, in *Geobotany*, R. C. Romans, Ed. (Plenum, New York, 1977), pp. 165–172].
9. The owners of this locality wish its exact location to remain unpublished; therefore, a code is used here, the key to which is recorded in the archives of the Peabody Museum of Natural History of Yale University (YPM).
10. F. B. Van Houten, in *Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guidebook of Excursions*, S. Subitzky, Ed. (Rutgers Univ. Press, New Brunswick, N.J., 1969), pp. 313–347.
11. On the basis of the skull, vertebral column, and pes, the new reptile is asigned to the family Tanystropheidae, suborder Prolacertiformes, of the order Eosuchia. This reptile is described in detail by P. E Olsen, *Postilla*, in press.
12. Reptiles occur with a density of about 37 per square meter, whereas fish occur at 10 per square meter in unit b of cycle CB1-2.
13. YPM 7500 and 7627.
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15. All the specimens (including YPM 7553, 7573, and 7574) are very difficult to prepare; the only characters visible at this time are large rhombic ganoid scales, a hemiheterocercal caudal fin, ossified ring centrums, and a long mandible. Other fish genera present are *Turseodus* sp. (YPM 7457 and 7476), *Semionotus brauni* (YPM 7479, 7481, and 7901, *Diplurus newarki* (YPM 7516), and *Synorichthys* sp. (YPM 7576).
16. Specimens are preserved as silvery compressions with almost no relief and can be examined only under a wetting liquid such as glycerol.
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20. The larger conchostracan is identical to W. Bock's *Howellisaura (Howellites) princetonensis* [*J. Paleontol.* **27**, 62 (1953)], which P. Tasch synonymizes with *Cyzicus* [in *Treatise on Invertebrate Paleontology*, R. C. Moore, Ed. (Geological Society of America, Boulder, Colo., 1969), pp. R128–R191)].
21. The smaller CB1 conchostracan is preserved without relief or detail. The resemblance to *Palaeolimnadia* [P. E. Raymond, *Bull. Mus. Comp. Zool. Harv. Univ.* **96**, 218 (1946); J.-C. Gall, *Mem. Serv. Carte Geol. Alsace Lorraine* **34**, 1 (1971)] is based only on gross form and size.
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26. Peaks of reptile density occur at 1.0, 4.8, 7.0, and 30.5 cm above the base of unit b of cycle CB1-2, but even in these thin zones reptile skeletons are found through several "varves," a possible indication that these fluctuations represent changes in the density of locally living reptile populations.
27. Most common conifer at cycle CB1-2; the leaves are variable, almost spherical to elongate, 1 to 3 mm long.
28. Similar cycles occur in the Early Jurassic East Berlin formation (Newark supergroup) [J. F. Hubert, A. A. Reed, P. J. Carey, *Am. J. Sci.* **276**, 1183 (1976)], the Devonian Caithness Flagstones of Scotland [C. B. Crampton, R. G. Carruthers, J. Peach, N. B. Flett, E. M. Anderson, [*Geol. Surv. G. B. Mem. Geol. Surv. Scot.* (1914)], and the Eocene Green River formation of Wyoming [W. H. Bradley, *U.S. Geol. Surv. Prof. Pap. 158E* (1929), p. 87]. These types of cycles may, like the cycles of the Lockatong formation, be produced by climatic changes governed by the precession cycle. Since such control has been plausibly argued for the Pleistocene glacial periods as well [J. D. Hays, J. Imbrie, N. J. Shackleton, *Science* **194**, 1121 (1976)], climatic control of this sort may be characteristic of the entire Phanerozoic.
29. That is, the Late Triassic in addition to the Early Jurassic is about 35 million years.
30. Similar to *D. exile* (Brauns) Nathorst, but each arm of the rachis possesses about 25 pinnae.
31. A single ovuliferous scale comparable to plate 4, figure 1 of K. Mägdefrau, *Geol. Bl. Nordost Bayern* **13**, 95 (1963).
32. *Stachyotaxus*-like foliage, much smaller than *Pagiophyllum* sp. C.
33. Superficially resembles *Stachyotaxus elegans* Nathorst.
34. Associated foliage and possible seed cones.
35. Associated seeds and foliage; seeds differ from *D. gormanii* Ash in that they have numerous veins in lanceolate lamina; *Equisetosporites* pollen, possibly produced by this type of plant, is occasionally found in Carnian strata of the Newark supergroup [see S. R. Ash, *Palaeontology* **15**, 598 (1972)].
36. Isolated leaves, 6 to 14 cm long, tapering at both ends, with about 21 parallel veins.
37. Most common cycadophyte at cycle CB1-2, frequently present as isolated pinnae and large fragments of fronds [see S. R. Ash, *Palaeontogr. Abt. B Palaeophytol.* **149**, 139 (1975)].
38. One leaf with a characteristic surface pattern of "bumps"; the leaf is 4.5 cm long and 2.2 cm wide, tapering proximally and blunt distally.
39. Data for the Taylorsville group and subsurface units are from R. Weems, in preparation; I. W. Marine and G. E. Siple, *Geol. Soc. Am. Bull.* **85**, 311 (1974).
40. Adapted from B. Schaeffer, *Bull. Am. Mus. Nat. Hist.* **135**, 285 (1967); *ibid.* **99**, 29 (1952).

41. We are grateful to the owners of the CB1 site for permission to excavate and for their help during the fieldwork. We also thank the following for their help in the excavation of the site, other field assistance, discussions on the subject, or criticisms of the manuscript: D. Baird, R. Broumbough, F. Carpenter, J.-C. Gall, C. H. Gover, W. Hartman, J. Hubert, G. E. Hutchinson, J. I. Johnson, P. H. Knappenberger, A. J. Litt, N. G. McDonald, A. R. McCune, J. H. Ostrom, K. Padian, S. P. Rachootin, J. Rodgers, R. Salvia, B. Schaeffer, P. Thayer, and K. Waage. This work was made possible by grant BMS 74-07759 from the National Science Foundation to K.S.T.

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A Search for Ultra-Narrowband Signals of Extraterrestrial Origin

Abstract. *Nearly 200 nearby stars similar to the sun were observed at the 21-centimeter neutral hydrogen wavelength (in the heliocentric frame) with a bandwidth of 1 kilohertz and a resolution of 0.015 hertz, using the Arecibo 305-meter antenna. At this resolution the effects of terrestrial interference are so slight that the detection limit of 4×10^{-27} watt per square meter was set by receiver noise alone. No evidence of artificial signals was found.*

A search for extraterrestrial intelligence (SETI) has been carried out at the National Astronomy and Ionosphere Center (NAIC) at Arecibo, Puerto Rico, based on a particular set of assumptions about the probable nature of signals that might be received. Although these ideas are not new (*1*, *2*), the survey itself was several orders of magnitude more sensitive than any SETI activity previously reported (*3*).

Briefly stated, this is the assumed scenario.

1) A narrowband acquisition beacon is transmitted near the neutral hydrogen frequency (21 cm, 1420 MHz); extremely narrow bandwidths would provide the simplest means of achieving a high signal-to-noise ratio, as well as suggesting the presence of artificial signals. The logic for this choice of frequency, originally put forth by Cocconi and Morrison (*4*), still seems strong, in spite of subsequent arguments: hydrogen is the simplest and most abundant atom in the universe, its hyperfine transition results in a single line, which constitutes the most abundant photon in the universe, and that line falls near the frequency of minimum background noise.

2) The beacon is directed at individual "interesting" targets, rather than being transmitted omnidirectionally; the presumption is that a superior knowledge of the processes of stellar and planetary evolution and of the evolution of life allows the transmitting civilization to reduce its list of targets to a relatively small number. This assumption is required for the last step, which follows.

3) The beacon is transmitted at a frequency such that it arrives in our solar system at the laboratory hydrogen-line frequency, thus simplifying our search; the presumption is that a superior technology has given the transmitting civilization accurate observational values of the radial velocity of our sun. [Continued

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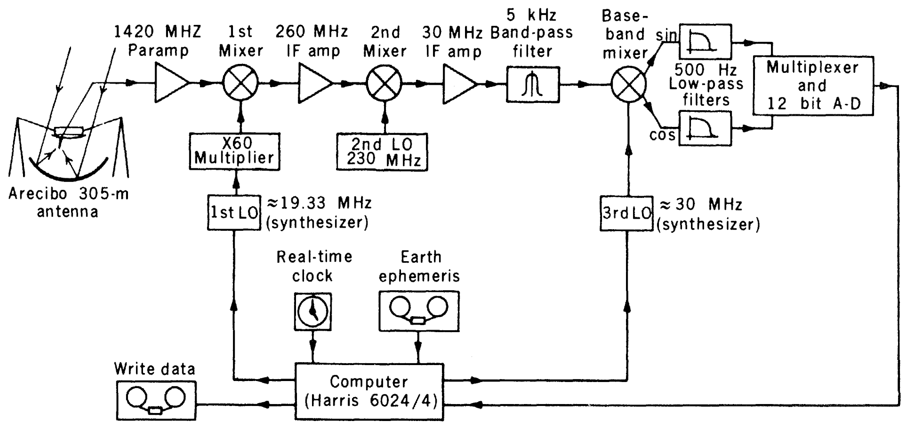

Fig. 1. Computer-controlled data acquisition system for narrowband SETI. Earth ephemeris data are used to synthesize local oscillator (LO) frequencies appropriate for reception of laboratory-frequency 21-cm radiation in the solar system rest frame.

observations could furnish them with the velocity of our solar system's center of mass (barycenter) as well. Both possibilities—laboratory frequency in the heliocentric frame or the barycentric frame—can be investigated simultaneously with modest bandwidth, since the difference amounts to ± 60 Hz, at most, at the hydrogen frequency.] Compensating for the Doppler shift due to the relative motion of the source and target suns is a natural extension of the correction that must be made for the source planet's motion in order to attain extremely narrow bandwidths; the spin and orbital motion of the earth, for instance, introduces Doppler shifts of order 10^5 Hz (at 1420 MHz), with diurnal and annual components.

A search strategy based on these assumptions consists simply of observing likely stars [F, G, and K main-sequence dwarfs (*5*); the sun is a G2 dwarf] at a terrestrial frequency corresponding to the laboratory hydrogen frequency in the heliocentric rest frame. The total bandwidth used should be sufficient to include the "barycentric frequency" (that is, the frequency at our site of a signal that would be received by an observer at the solar system's barycenter at the same frequency as emitted by neutral hydrogen in his frame).

For this search a total bandwidth of 1 kHz was used, with a resolution of 0.015 Hz (65,536 equally spaced frequency bins). The bandwidth limit was dictated by two considerations: (i) the resolution of available frequency synthesizers at Arecibo (0.01 Hz) and the stability of the rubidium-referenced oscillator (short-term $\Delta f/f \simeq 5 \times 10^{-12}$, where f is frequency) set a limit of 0.01 Hz, and (ii) recent calculations (*6*) of the ultimate limit to narrowband interstellar radio propagation—line broadening by multiple scattering from fluctuations in the ionized interstellar medium through which the initially monochromatic signal passes (also responsible for scintillation effects)—suggest that signals received from sources associated with nearby stars ($\lesssim$ 100 parsecs, say) will have minimum bandwidths of order 10^{-2} Hz.

Spectral line observations with a frequency resolution of this order of magnitude require precise control of the receiver frequency, via real-time computer control of the local oscillator (LO) frequencies. The earth's spin alone contributes a Doppler shift at 1420 MHz that changes at the rate of 0.16 Hz/sec for a source at the zenith observed from the equator. Since a frequency resolution of 0.01 Hz requires observations of 100 seconds duration, it is clear that the local oscillator frequency must be updated several thousand times during each observation, a situation not ordinarily encountered during spectral line observations of astronomical radio sources. Curiously enough, this leads to a highly favorable rejection of narrowband signals of terrestrial origin, an interference problem that has plagued previous SETI work: with a resolution of 0.01 Hz, a fixed-frequency terrestrial signal sweeps through 1600 frequency bins in a single 100-second observation (for source and site as above); a short burst of monochromatic terrestrial interference is also spread over many bins because $\Delta f \Delta t \gtrsim 1$, where Δt is the time interval of the burst. Only a narrowband signal that (i) persists for the duration of an observation, and (ii) drifts in frequency in precisely the same manner as the local oscillator, will appear as a narrowband signal in the final spectrum.

The observations were carried out during January to April 1978, using the 1420-MHz dual circular polarization feed, which gives an effective antenna area of 22,000 m² (68 dB gain). The overall system temperature was ≃ 80°K, with parametric amplifier front ends and dual conversion (260- and 30-MHz intermediate frequencies). Band-pass crystal filters with a bandwidth of 5 kHz at 30 MHz followed the second intermediate frequency amplifier, and, after mixing with the ≃ 30-MHz third LO, the sine and cosine baseband signals from the quadrature mixers were further filtered to 500 Hz with four-pole Butterworth low-pass tunable filters. The resultant signals—a quadrature pair from each of two circular polarizations—were sampled under computer control with an analog multiplexer and 12-bit analog-to-digital converters. The data acquisition scheme is summarized in Fig. 1.

A single observation consisted of 64K (65,536) complex samples at 1-msec intervals from each of two polarizations. The digitized samples were written in real time onto nine-track digital magnetic tape for subsequent analysis. The data acquisition program also controlled the first and third LO's, setting the first LO frequency at the beginning of each observation so that the third LO began at 30 MHz; the third LO was then updated at 20-msec intervals during the observation by computing frequency offsets in real time from a quartic polynomial approximation to accurate earth velocity data obtained from the Lincoln Laboratory planetary ephemeris (*7*).

The off-line analysis program performed a 64K complex fast Fourier transform (FFT) on the digitized quadrature signals, employing a method (*8*) that required only 4K of array size in core and 4K complex FFT's; this was done on a Harris Slash 6 computer, making extensive use of a Floating Point Systems array processor. A 64K complex FFT and computation of power spectrum took approximately 15 seconds, much of which was occupied by peripheral storage (disk) operations.

The resultant power spectrum contained 64K equally spaced frequencies spanning 1 kHz centered on the combined LO frequency (the complex FFT operating on quadrature baseband signals separates the positive and negative baseband frequencies). The frequency resolution was 0.015 Hz per bin. The analysis program looked for large peaks in the spectrum, and displayed the power spectrum (as a raster of 256 × 256 eight-level gray scale pixels, each 4 × 4 dots on a 100 dot per inch electrostatic plotter) of observations containing large peaks. The entire system was tested with a variety of signals added at intermediate frequency and radio frequency stages; in an analysis of 1 minute's data it easily detected narrowband signals with the expected frequency variation 40 dB below noise (in a 1-kHz band), while rejecting fixed-frequency (interference-like) signals at, or even above, the level of the noise.

Observations were made on target stars taken from the Royal Greenwich Observatory (RGO) catalog, which includes all known stars within 25 parsecs (82 light years) (*9*); all F, G, and K stars of luminosity class V (dwarf) or of unknown luminosity class from the RGO list that are not known to be members of multiple star systems and that can be seen with the Arecibo dish ($0° <$ declination $< 38°$) were observed during this search. In addition, the flat-spectrum radio sources 4C05.64 and PKS0735+17 and the unusual pulsars 1913+16 (binary) and 1952+29 (extremely small rate of change of period) were observed. Altogether 185 objects were examined, 60 of them on more than one occasion, during 80 hours of telescope time. Ten 1-minute observations were made in the vicinity of each object, eight at the source position and two displaced from it by ± 2 minutes in right ascension. In no case were extrastatistical narrowband signals detected. Terrestrial interference was not a problem, even during noise-prone daytime observations, confirming the reasoning presented earlier. There were no false alarms and hence no loss of observing time as a consequence of man-made interference. It is a simple matter to calculate the sensitivity of the overall system to narrowband polarized signals. Using the known parameters of the system, one obtains a sensitivity of 4×10^{-27} W/m^2 for a signal-to-noise ratio of 5:1 in each of the eight observations of each source; this is at least two orders of magnitude more sensitive than any previously reported SETI activity and corresponds to a total power incident on the earth's disk of less than a millionth of a microwatt. This can be expressed alternatively as the range at which this system could detect an identical antenna transmitting a 1-MW carrier, say, beamed at our sun. That distance is 370 parsecs, for a signal-to-noise ratio of 5:1 in each 1-minute observation.

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References and Notes

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10. I thank D. Campbell, M. Davis, F. Drake, J. Hagen, and E. M. Purcell for valuable discussions and assistance, and the Arecibo Observatory for hospitality. J. Tarter (NASA Ames Research Center) kindly provided the RGO source coordinates. I received support from the National Astronomy and Ionosphere Center while on sabbatical leave from Harvard University. Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under contract with the National Science Foundation.

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Decomposition of Calcium Carbonate and Organic Carbon in the Deep Oceans

Abstract. *Simple mass-balance calculations indicate that in seawater the calcium variation (ΔCa) correlates with the variation in the titration alkalinity (ΔTA) and the variation in the total carbon dioxide ($\Delta\Sigma CO_2$) or nitrate (ΔNO_3) according to the equations* $\Delta Ca = 0.46288\ \Delta TA + 0.074236\ \Delta\Sigma CO_2$ *and* $\Delta Ca = 0.5\ \Delta TA + 0.53125\ \Delta NO_3$. *The estimated values for* ΔCa *from these equations, which agree with the values obtained from direct measurements, have been used to estimate the ratio of the in situ inorganic to organic carbon fluxes in the oceans. The precise vertical distribution of this ratio is shown for the first time.*

The processes related to the abyssal dissolution of $CaCO_3$ and organic C provide a direct mechanism for the renewal of elements in the sea. They are also responsible for changing, or in fact maintaining in the steady state, the *p*H and buffer capacity of the oceans, and are of fundamental interest in chemical, biological, and geochemical oceanography (*1*). Values for $CaCO_3$ fluxes have been obtained from measurements of dissolved Ca in seawater (*2*). The analysis of dissolved Ca, in the presence of Mg and Sr, to a precision of $\pm$ 0.1 percent, is one of the classic problems in the analytical chemistry of seawater. Furthermore, the high concentration of dissolved Ca in seawater (10.3 mmole/kg for normal seawater at a salinity of 35 per mil) relative to the small changes due to $CaCO_3$ dissolution ($\Delta Ca < 0.1$ mmole/kg) makes the evaluation of Ca fluxes extremely difficult. Nonetheless, several recent papers have reported such analyses [see (*2–4*)].

The dissolution of $CaCO_3$ alone increases the Ca concentration and titration alkalinity (*TA*) in a fixed ratio of 0.5. Several investigators (*2, 4*) have therefore tried to linearly correlate observed Ca concentrations with *TA*; their success has been limited. The ratio is not exactly equal to 0.5 because the decomposition of organic material also changes *TA* but not Ca. Consequently, the ratio of Ca to *TA* is not a constant and one should not expect to find a linear correlation between Ca and *TA*. I examine here some recent chemical data on seawater in an attempt to correlate the Ca variation (ΔCa) with the variation in titration alkalinity (ΔTA) and in total CO_2 ($\Delta\Sigma CO_2$) or nitrate (ΔNO_3), and to estimate ΔCa from the available chemical data.

In seawater, $CaCO_3$ decomposes to form

$$CaCO_3 = Ca^{2+} + CO_3^{2-} \qquad (1)$$

The increases in Ca, *TA*, and ΣCO_2 are 1 mole, 2 equivalents, and 1 mole, respectively, for the dissolution of 1 mole of $CaCO_3$. The decomposition of 106 moles of organic C yields 106 moles of CO_2, 16 moles of HNO_3, and 1 mole of H_3PO_4 according to the Redfield-Ketchum-Richards model (*5*):

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\ O_2 = 106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O \qquad (2)$$

In seawater, CO_2, HNO_3, and H_3PO_4 produced in situ react with CO_3^{2-} (*1, 6*) to form, respectively, HCO_3^-, NO_3^-, and HPO_4^{2-}, and Eq. 2 becomes

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\ O_2 + 124\ CO_3^{2-} = 16\ NO_3^- + HPO_4^{2-} + 230\ HCO_3^- + 16\ H_2O \qquad (3)$$

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