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A Search for Narrow Band 21-cm Wavelength Signals from Ten Nearby Stars

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A search for narrow band radio signals, in the 21-cm wavelength band, possibly generated by other civilizations, has been made in the direction of ten stars. No such signals were found and upper limits to the power of possible transmissions toward the Earth are given.

I. Introduction

The search for artificially generated radio signals originating on planets orbiting nearby stars has often been discussed but no very sensitive experiments aimed at detecting such signals have ever been reported in the scientific literature. Cocconi and Morrison (1959) originally suggested that another civilization desirous of communicating with neighbors in space might use the 21-cm band because the rest frequency of the neutral hydrogen ground-state transition was a naturally occurring standard of which any advanced civilization would be aware. Drake (1961) has reported an experiment to search for such signals, but the details of that experiment were never published in terms of the sensitivity attained.

Troitskii *et al.* (1971) have more recently reported on observations at 927 MHz in the direction of 21 stars but their detection limit was about $2 \times 10^{-21} W/m^2$ in their bandwidth of 13 Hz. This paper reports on the negative results of a search for narrow band radio signals around 1420 MHz in the direction of ten nearby stars, primarily chosen on the basis of their distance and similarity to the Sun and, in two cases, chosen because they may have objects of planetary mass orbiting them.

In justifying an extensive program to search for the radio signals from other civilizations one naturally has to make several assumptions about the likelihood that any given nearby star has a planetary system, that life will have evolved, that it is a technological society and that they would bother to transmit signals toward other planets. Even making favorable assumptions concerning the first three of these categories, it is this author's belief that any detection of signals from another civilization will most likely be an accidental one in the sense that we will pick up signals not meant for us. For this reason it is unlikely, on the basis of our present knowledge of the way we operate on Earth, that a wavelength around 21-cm is the wavelength at which to search because it should be borne in mind that any advanced civilization is also likely to have instituted a series of protected bands for radio astronomy research purposes and might therefore not be transmitting signals in the λ21-cm band at all! However, the present observations were nevertheless made and the most sensitive equipment at this wavelength presently available was used. The results indicate the type of integrations required in order to substantially improve the limits now set to the level of any possible extra-terrestrial transmissions around λ21-cm.

In this paper the λ21-cm hydrogen line profiles toward the ten stars studied are shown. These may be used as zero-epoch profiles for subsequent searches of this nature. Furthermore, examples of the 20 MHz coverage obtained in the direction of two of the stars are also given. The

TABLE I

DETAILS OF THE OBSERVATION ON THE 300-ft TELESCOPE

Star	Position (1950)		Comparison point (1950)		Dates (1971)	Frequency covered (kHz)	Total integration time (min)	Heliocentric velocity of star	Velocity w.r.t. l.s.r.
	Right ascension	Declination	Right ascension	Declination					
Tau Ceti	$1^h\,42^m\,30^s$	$-16°\,11'\,00''$	$1^h\,44^m\,20^s$	$-16°\,30'\,30''$	Oct. 7–21	156	33	−16 km/sec	−26 km/sec
					Oct. 22–25	78	12		
					Oct. 26–31	312	18		
					Nov. 1	625	3		
61 Cygni	$21^h\,04^m\,50^s$	$38°\,30'\,22''$	$21^h\,06^m\,50^s$	$38°\,10'\,47''$	Oct. 4–20	156	69	−64 km/sec	−48 km/sec
					Oct. 21–24	78	18		
					Oct. 25–30	312	28		
					Oct. 31	625	4.6		
Epsilon Eridani	$3^h\,30^m\,34^s$	$-9°\,37'\,15''$	$3^h\,32^m\,20^s$	$-9°\,56'\,45''$	Oct. 7–20	156	36	+15 km/sec	0.7 km/sec
					Oct. 22–30	156	32		
					Oct. 31	625	3.6		

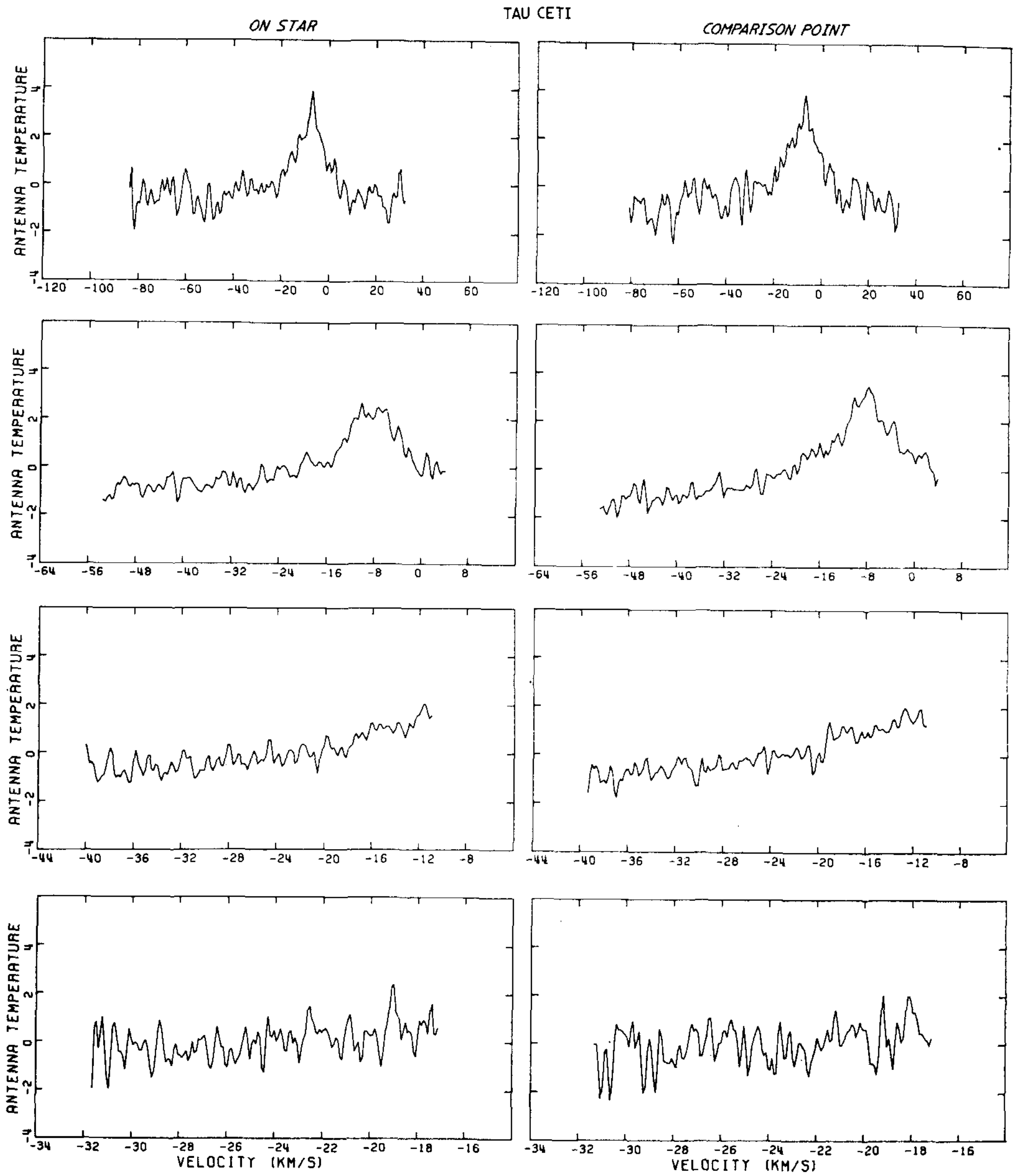


FIG. 1. Data obtained with the 300-ft telescope in the direction of Tau Ceti and a comparison point 20 min of arc away (observed simultaneously) with a range of bandwidths. Velocities are with respect to the local standard of rest, with regard to which the stellar radial velocity is −26 Km/sec.

experiment was performed at various times with both the 300 ft telescope (where observations were fitted in as part of a more extensive program to study galactic neutral hydrogen clouds) and the 140 ft telescope of the National Radio Astronomy Observatory in Green Bank, West Virginia.

I estimate that in the present series of experiments a 5-min integration is equivalent to about 4 days of integration for the equipment used as part of Project Ozma by Drake (1961).

II. THE 300-ft TELESCOPE DATA

The 300-ft radio telescope was used to observe three stars with a feed tracking a

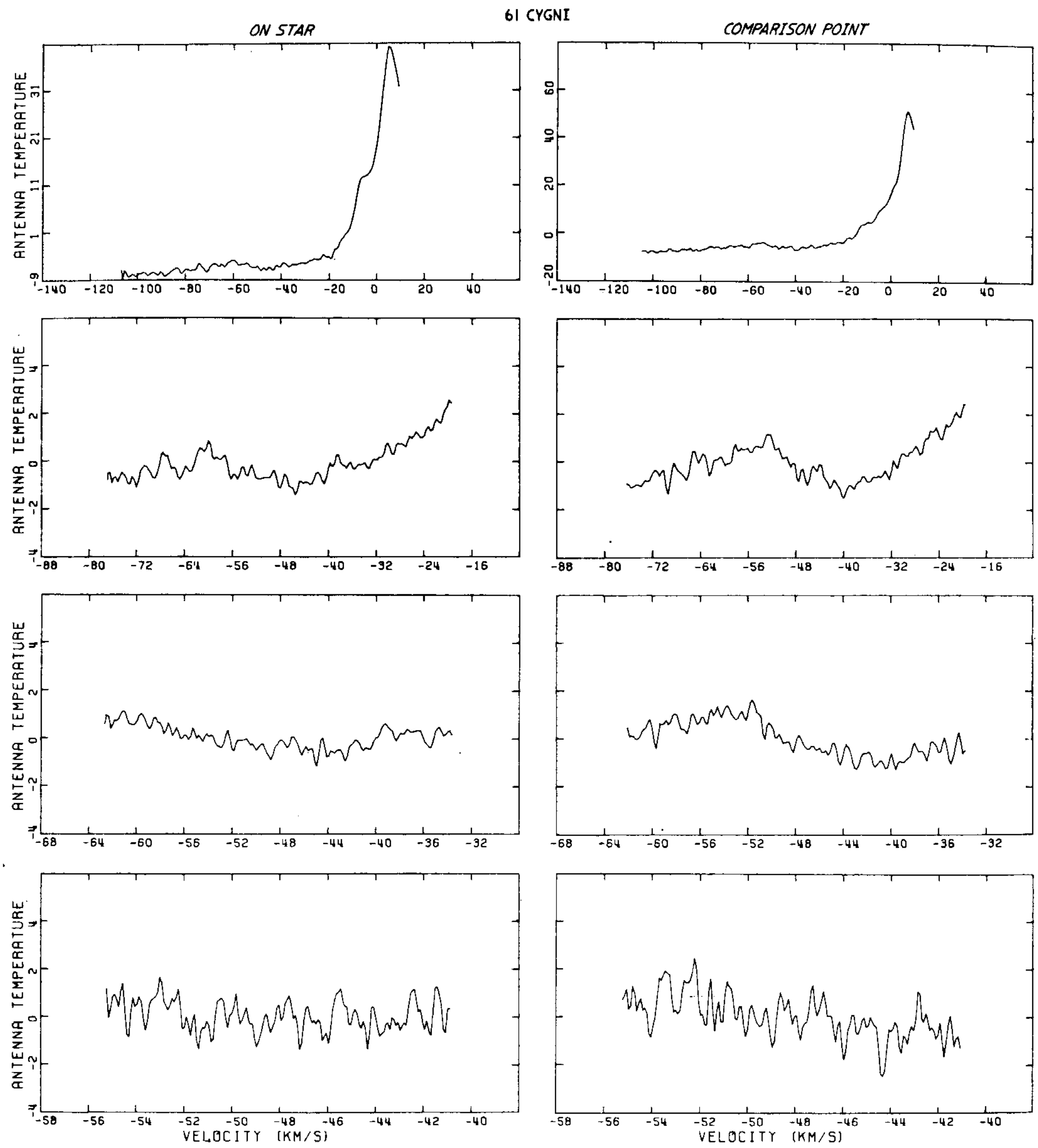


FIG. 2. Data obtained with the 300-ft telescope in the direction of 61 Cygni and its comparison point. The radial velocity of the star is −48 Km/sec.

star for 4 min each day for about a month. A comparison feed tracked a position 20 min of arc away from the star at the same time. The signals were sent through two parametric amplifiers whose system temperatures were 110°K and fed into each of two 192 channel digital spectrometers. The overall bandwidth of the 192 channel receivers were variously set to cover 130, 65, 32 and 16 km/sec centered about the velocity of the star with respect to the local standard of rest. (1 km/sec ≡ 4.74 kHz at this wavelength.) For the narrowest bandwidth observations the presence of signals at the velocity of the star would have been revealed. However, if the alien transmitter were broadcasting at a frequency corresponding to the laboratory frequency on their planet, and if their planet has an orbit similar to that of the Earth around the Sun then their signals would have been Doppler shifted out of the narrowest bandpasses used in this experiment. The narrowest bandwidth I used gave a channel width of 0.49kHz.

The observations of these three stars were fitted into an extensive observing program at 21-cm during which galactic neutral hydrogen clouds were being studied. Other stars were not included because they would have interfered with the routine observations of the main observing program and even for these three stars it was not possible to track each of them for the maximum time allowed by the tracking feed system of the 300-ft telescope.

In Table I the observations made with the 300-ft telescope are summarized. A total of 2hr of data are available on 61 Cygni, 66 min on Tau Ceti and 71min on Epsilon Eridani. While tracking the star and its comparison point, profiles were recorded every 10sec of time and examined separately to see if any signals greater than the peak-to-peak noise in this interval (4K) were present. None were found. The observations in the direction of any particular star with a particular bandwidth were subsequently added together in order to improve the chances of detecting a weak continuous signal which might have a very narrow frequency structure. The results of some of these integrations are shown in Fig. 1 for Tau Ceti, in Fig. 2 for 61 Cygni and in Fig. 3 for Epsilon Eridani. The data for both signal and comparison feeds are shown and have been smoothed a little, using a Haning weighting function to reduce the noise level. The plots are given in terms of antenna temperature and the conversion to brightness temperature may be made using an aperture efficiency of 0.6 for the stars around -9 to $-16°$ declination and 0.75 for the star at declination 38°.

No signals of the order of 1K or greater were found in any of the observations on these three stars. This converts to an upper limit of 1kW/Hz for the power of a transmitter on a 300-ft diameter telescope beamed at the Earth from a distance of 10 light years. Therefore, in the narrowest band data we would have detected a 500-kW transmission (see below). Very roughly one can also state that the limit of detection was about 10^{-26} W/m^2/Hz, or 5×10^{-24} W/m^2 for the narrowest band observations for Tau Ceti and 61 Cygni, or nearly three orders of magnitude below the levels set by Troitskii *et al.* (1971) at 927MHz.

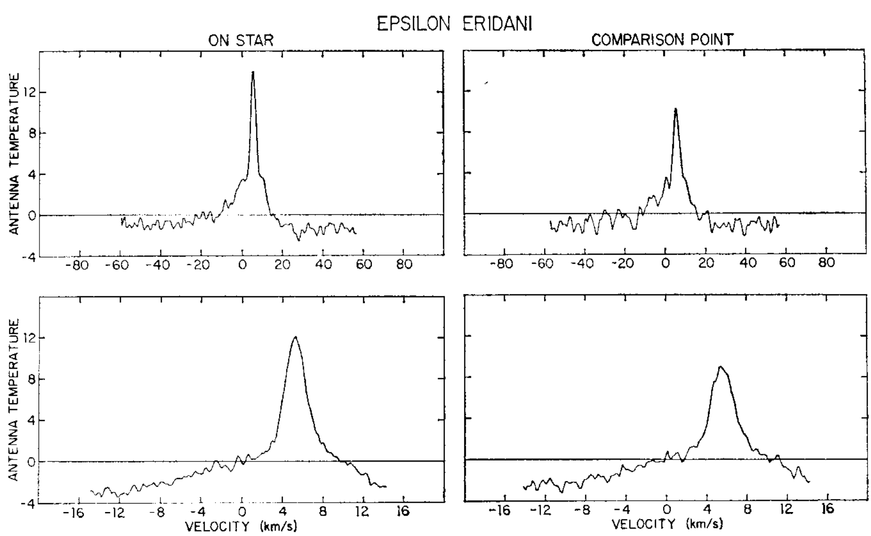


FIG. 3. Data obtained with the 300-ft telescope in the direction of Epsilon Eridani. The radial velocity of the star is +0.7 Km/sec.

III. The 140-ft Telescope Data

Narrow band observations in the direction of HD 165341 (70 Oph) were performed on June 25 and 26, 1972. In Fig. 4a the results of two 50-min integrations in the direction of this star are shown while in Fig. 4b one of these profiles is plotted so as to show the full height of the hydrogen line. The receiver used was a cooled parametric amplifier (system noise temperature 48K) combining with the Mk II, 384 channel digital spectrometer. The bandwidth used was 6.9kHz per channel and the peak-to-peak noise in a 50-min integration was 0.1°K. We can say that no narrow band signal of the order of 0.07°K was seen in a 350km/sec range about the local hydrogen profile in a 100-min integration. The velocity of the star is 10.7km/sec with respect to the local standard of rest.

A limit of 0.07K converts to 0.25 flux units on the 140-ft telescope (ie, $1.7 \times 10^{-23}\,W/m^2$ in our bandwidth) which, in turn, allows us to set a limit of 3 Megawatts for an alien transmitter radiating anywhere in the 2.3MHz bandwidth seen in Fig. 4, from a 100-m diameter telescope beamed at the Sun (see below) from a distance of 5pc.

On August 23, 1972 observations were

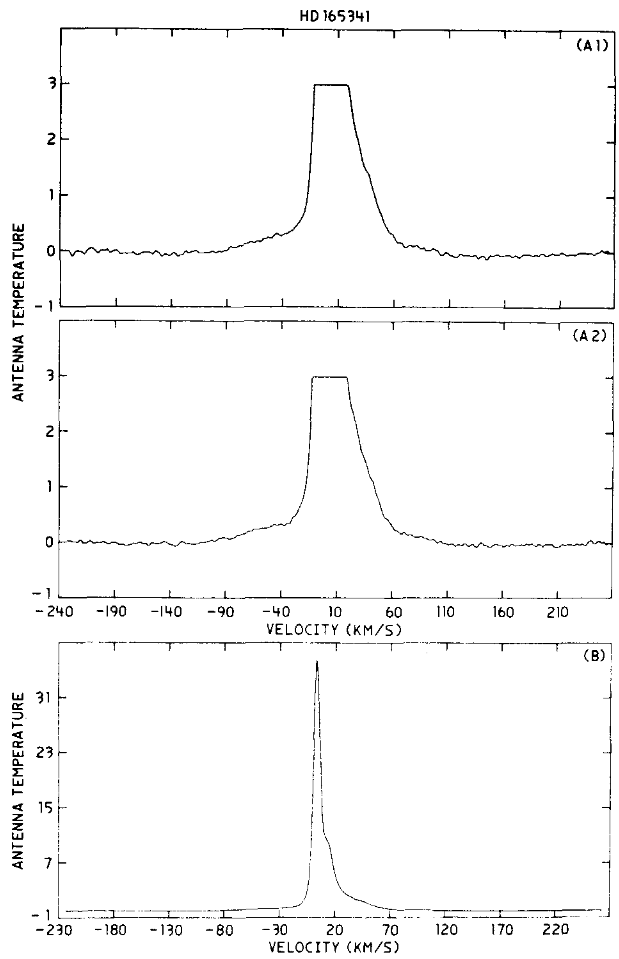


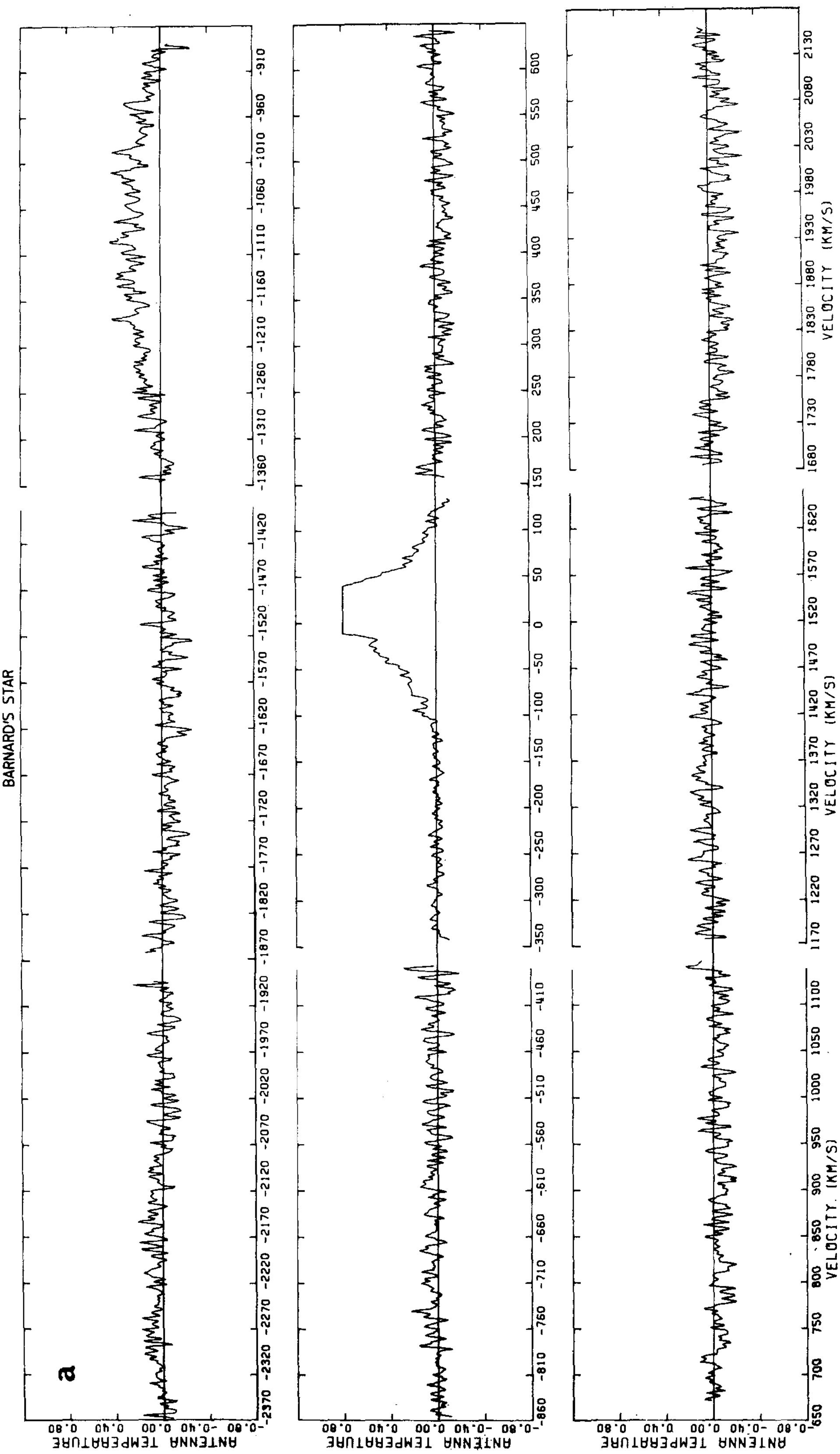
Fig. 4. Data obtained with the 140-ft telescope in the direction of HD 165341 (70 Oph). A1 and A2 are two dependent 50-min integrations and B shows the same data as A2 with the scale altered to include the full hydrogen emission line.

TABLE II

Name	HD	Type	Distance (parsecs)	α 1950	δ 1950	l	b	Radial velocity of star: Heliocentric (km/sec)	Radial velocity of star: l.s.r. (km/sec)	Detection limit $(T_a)^+$	Velocity interval (l.s.r.) (km/sec)	Power limit (Megawatts)[a]
				h m s	° ′ ″							
Barnard's Star	—	M5	1.83	17 55 24	4 24 34	30.8	13.9	−108	−90	0.12	−340 to 135	0.665
										0.20	−2380 to 2160	1.109
Wolf 359	—	M8	2.38	10 54 12	7 20 37	244.1	56.3	+13	+9.3	0.15	{−250 to 50; 10 to 250}	1.407
										0.20	−2270 to 2270	1.876
L-726-8	—	M6	2.42	1 36 24	−18 13 00	175.1	−75.7	+29	+19.3	0.30	−2270 to 2270	2.909
LAL 21185	95735	M2	2.52	11 00 31	36 21 46	184.7	65.5	−86.5	−84.3	0.15	{−250 to −100; 30 to 240}	1.577
										0.30	−2270 to 2260	3.155
Ross 154	—	M6	2.85	18 46 42	−23 52 57	11.4	−10.3	−4	7.5	0.30	−2270 to 2270	4.035
Ross 248	—	M6	3.16	23 39 24	43 55 08	110.0	−16.9	−81	−73	0.12	{−250 to −50; 20 to 240}	1.984
										0.30	−2270 to 2270	4.960
EPS ERI	22049	K2	3.31	3 30 34	−9 37 15	195.8	−48.1	+15	0.7	0.30	−2270 to 2270	5.426
61 (Cyg(A-B)	201092	K3-K5	3.40	21 04 50	38 30 22	82.3	−5.9	−63.5	−48.2	0.15	{−270 to −30; 20 to 190}	2.871
										0.30	−2320 to 2230	5.743
TAU CETI	10700	G8	3.75	01 42 30	−16 11 00	173.5	73.3	−16.2	−26.1	0.30	−2290 to 2250	6.986
70 Oph (A-B)	165341	K1-K5	5.04	18 02 54	02 30 30	29.8	11.8	−7	+10.7	0.07	−232 to 255	2.944

+ By inspections of data (≈ peak-to-peak noise).

[a] In the 7-kHz bandwidth radiated from a 100-m telescope at the star.


BARNARD'S STAR
a
VELOCITY (KM/S)
ANTENNA TEMPERATURE

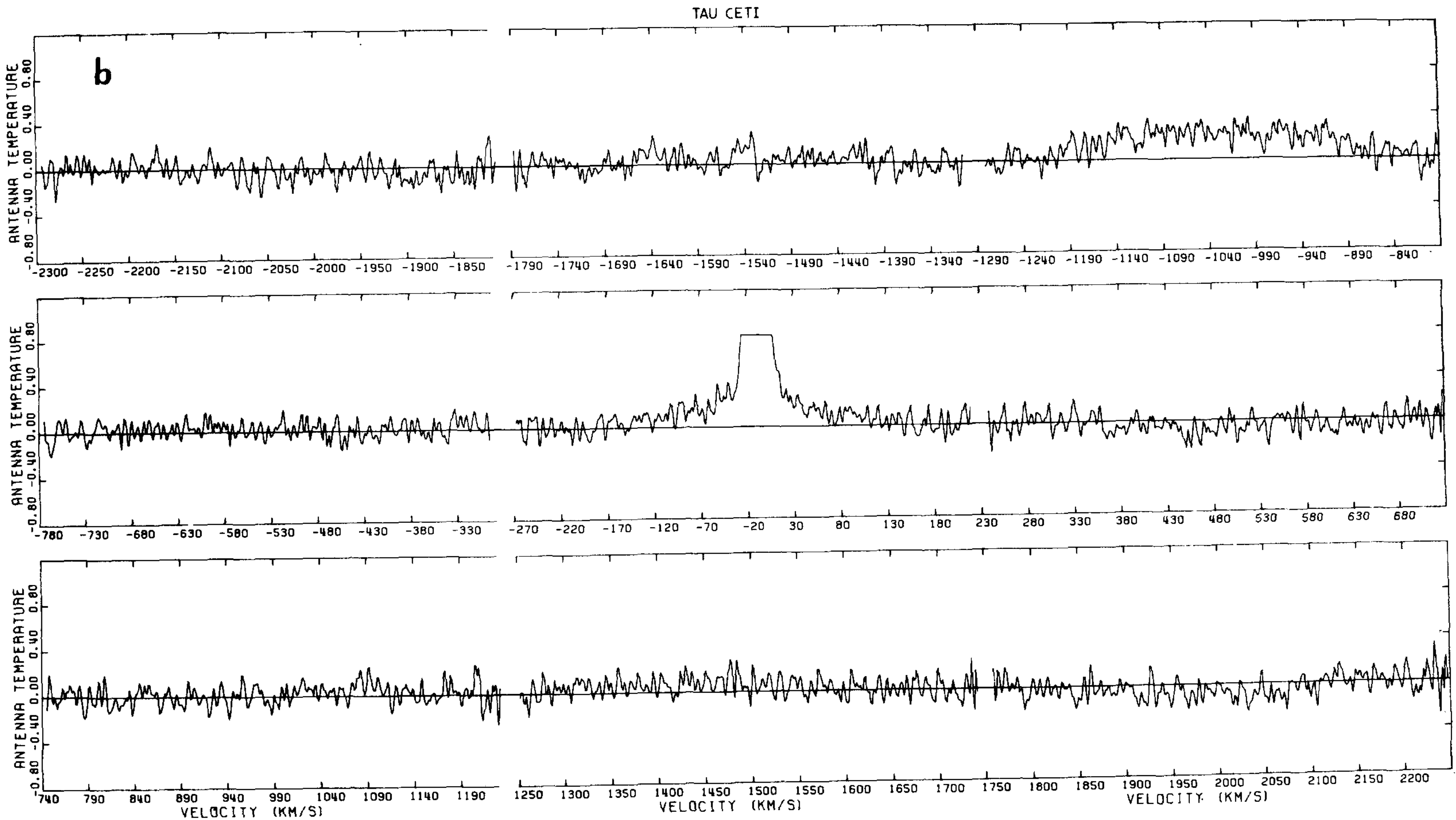


FIG. 5. Data obtained with the 140-ft telescope in the direction of Barnard's star and Tau Ceti. The integration time was 5 min except in the central portion of the coverage on Barnard's star. Gaps in the data reflect regions of the spectrum where edge effects in the spectrometer were larger than the noise level.

made in the direction of the other eight stars listed in Table II. A 20-MHz frequency range centered about the hydrogen line rest frequency was observed in the direction of each star, although small gaps occurred in this coverage, due to edge effects in the digital correlator profiles. The receiver used was the cooled parametric amplifier and the 20MHz was covered with a channel bandwidth of 7.2kHz. The observations were made by setting the spectrometer so that the 384 channels covered a total bandwidth of 2.5MHz and the receiver was frequency switched to two reference frequencies, centered 2.5MHz above and below the signal band. After a five minute integration the central frequency and reference frequencies were shifted by 2.4MHz. This meant that a positive going signal in the signal band on one local oscillator setting would be expected to appear negative going on an adjacent setting because it was then likely to be in the reference band. However, no such signals were detected. Sometimes a further five minute integration was done around the velocity of the star and, in the case of Barnard's star, a total of 20min was obtained at the central velocity setting.

In Fig. 5 the complete data on Barnard's star and Tau Ceti are shown, again with the neutral hydrogen line clipped. Only a straight baseline was taken out of each integration covering 2.5MHz, and the curvature noticeable between −860 and −1360 km sec^{-1} is due to the shape of the receiver bandpass. The data on the other six stars listed in Table II are essentially the same in appearance to that shown for the two stars in Fig. 5.

We conclude that no narrowband signals of the order of 0.30K or greater were seen in the direction of any of these stars.

IV. Limits to the Power of the Alien Transmitters

Let the receiving antenna have a dish diameter of D_r meters. Then the area of this dish is

$$A = 7.85 \times 10^3 \, D_r^2 \text{ cm}^2 \qquad (1)$$

Let the limit of detection in antenna temperature be $L\ (K) \equiv 4.7L$ in flux units on the 140-ft telescope. Therefore the limit of detection in watts (P_L) is given (for the 140-ft) by

$$P_L = 3.717 \, L \, D_r^2 \times 10^{-26} \text{ W/Hz} \qquad (2)$$

If an alien transmitter on a planet R parsecs away is used in conjunction with a 100-m telescope having a beamwidth of 9 min of arc, then the area (B) subtended by this beam at the Earth is

$$B \simeq 4.9 \times 10^{31} \, R^2 \text{ cm}^2 \qquad (3)$$

Therefore the fraction of the power received by the 140-ft telescope is given by A/B and the upper limit to the power radiated at the alien planet is then $P_r = P_L \times B/A$ i.e.,

$$P_r \sim 2.3 \times 10^2 \, R^2 \, L \text{ W/Hz} \qquad (4)$$

In the last three columns of Table II, I list the detection limit (in T_A) for possible signals in the velocity ranges indicated in the second last column. These limits we determined by inspection of the data. In the last column the upper limit to the power being transmitted in the 7-kHz bandwidth by a 100-m dish at the distance of the respective stars is listed. Equation 4 above was used to derive these limits. In order to derive the limit to the flux being received one needs to convert the antenna temperature to brightness temperature by dividing the former by 0.76 for the 140-ft telescope and to get flux units one multiplies this number by 3.64. For example, for the velocity interval around zero velocity on Barnard's star our power limit received is 4×10^{-23} W/m^2 in the 7.2-kHz bandwidth. Alternatively, we can set a limit of 665kW to a transmitter in a 100-m dish on one of the planet's orbiting Barnard's star, which is known to have at least two planets of Jupiter-like mass (van de Kamp and Warren, 1969). The other star thought to have planets is L-726 (Fredrick and Shelus, 1969).

Our power limits for transmitters around the two stars thought most likely to have Earth-like planets, Tau Ceti and Epsilon

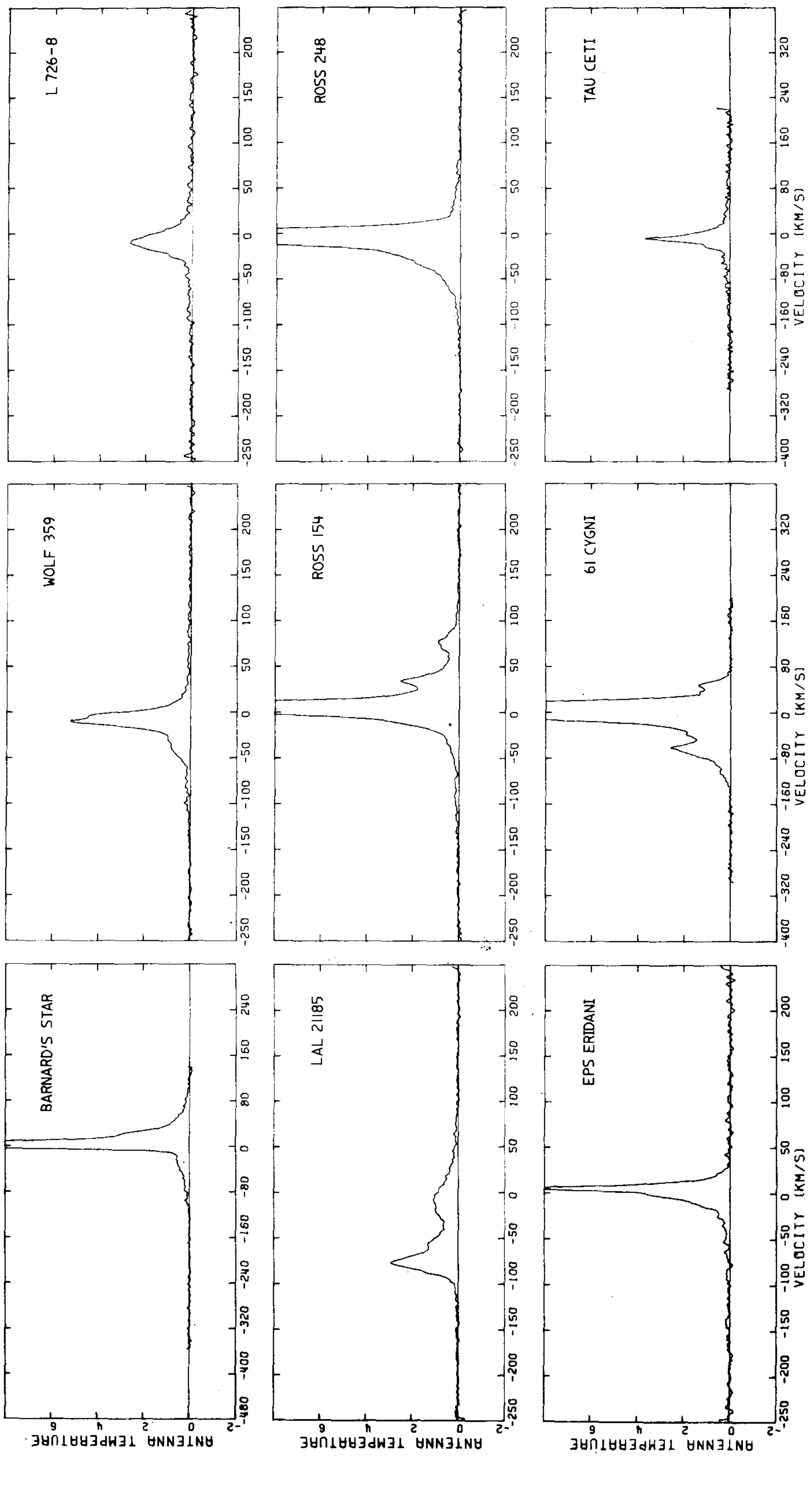


FIG. 6. The 21-cm emission profiles in the direction of each of the stars studied with the 140-ft telescope shown on the same scale.

Eridani, are ~6Megawatts in our bandwidth.

V. Comments on the Hydrogen Line Profiles

In Fig. 6 the 21-cm profiles obtained in the direction of each of the stars are shown drawn to the same scale. Both Figs. 4 and 6 reveal some interesting, but expected, aspects of the neutral hydrogen profiles observed in the direction of the stars.

Ross 154: We observe weak emission with $T_A \sim 0.15$K at $-90 \mathrm{km\,sec}^{-1}$ in the direction of this star ($l = 11°$, $b = -10°$). This is in good agreement with the weak signals around this velocity found by Dieter (1972). This emission is an aspect of the high velocity cloud phenomenon in this part of the sky. (See Verschuur, 1973).

61 Cygni: A weak peak in the emission profile at $-108 \mathrm{km\,sec}^{-1}$ is visible. Comparison with the data of Verschuur (1973) suggest that this would be due to emission from spiral arm γ at a distance of about 13kpc from the Sun at this longitude (82°) and therefore expected. The matter giving rise to this emission would have a z distance of some 1.3kpc.

Ross 248: This profile appears to show emission out to +50, maybe $+70 \mathrm{km\,sec}^{-1}$, which for its location ($l = 110°$, $b = -17°$) is a velocity forbidden on normal models of galactic rotation. However, in view of the wings visible in the profiles on the next two stars we must conclude that this type of signal is probably due to emission in the far out sidelobes of the 140-ft telescope.

Tau Ceti and L-726: These two stars are at latitudes +73° and −76°, respectively, and at about the same longitudes (174°, 175°). Both profiles show weak emission extending to about $\pm 80 \mathrm{km\,sec}^{-1}$ which, if one roughly fits a Gaussian, suggests a broad feature with $T_A \sim 0.1$°K at about zero velocity. It is probable that the emission from other parts of the galactic plane in sidelobes 30 dB down from the main beam would produce just such a signal.

Wolf 359: The profile in Fig. 6 suggests the presence of considerable emission out to $-100 \mathrm{km\,sec}^{-1}$ which is surprising. It may be due to the side lobe problem mentioned above. The emission out to $-50 \mathrm{km\,sec}^{-1}$ is associated with the so-called intermediate velocity matter known to exist near this part of the sky ($l = 244°$, $b = +56°$) although this such emission has not actually been reported for such large longitudes.

HD165341 (70 Oph) = the weak emission out to $-90 \mathrm{km\,sec}^{-1}$ is expected for its position in the sky originating in very distant spiral arms at high z [Verschuur (1973)] although this too may be due to side lobe radiation in view of its low level.

Eps Eridani, Barnard's Star, and LAL 21185: These profiles do not show anything unexpected for their location in the sky.

VI. Conclusions

These data obtained in the direction of ten nearby stars have not revealed the presence of any signals which might be attributed to an artificial source, either on Earth or in the direction of the stars. Substantial further improvement in sensitivity, frequency coverage, and number of stars observed is possible with existing equipment.

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