THE SERENDIP III 70 CM SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

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Abstract

We employed the SERENDIP III system with the Arecibo radio telescope to search for possible artificial extraterrestrial signals. Over the four years of this search we covered 93% of the sky observable at Arecibo at least once and 44% of the sky five times or more with a sensitivity of $\sim 3 \times 10^{-25}$ W m$^{-2}$. The data were sent to a $4 \times 10^6$ channel spectrum analyzer. Information was obtained from over $10^{14}$ independent data points and the results were then analyzed via a suite of pattern detection algorithms to identify narrow band spectral power peaks that were not readily identifiable as the product of human activity. We separately selected data coincident with interesting nearby G dwarf stars that were encountered by chance in our sky survey for suggestions of excess power peaks. The peak power distributions in both these data sets were consistent with random noise. We report upper limits on possible signals from the stars investigated and provide examples of the most interesting candidates identified in the sky survey. This paper was intended for publication in 2000 and is presented here without change from the version submitted to ApJS in 2000.

keywords:

1. Introduction

Early radio searches for extraterrestrial intelligence used dedicated telescope time to search for emission from nearby stars (see Tarter 1991 for a partial listing, and Tarter 2001 for a full listing of these searches). This type of search became increasingly difficult to carry out at major facilities because of a general reluctance to devote dedicated telescope time to such projects, which though interesting, are acknowledged to have a low probability of success. In addition, sky surveys were carried out which scanned substantial portions of the sky. The Berkeley SERENDIP project (Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations) solved the dedicated telescope time problem by using data obtained simultaneously with ongoing astronomical research. This program began over twenty years ago (Bowyer et al. 1983) and has continued to the present day with ever increasing sensitivity and an ever-widening set of search parameters.

Other sky surveys using dedicated telescopes have been, and are continuing to be, carried out. The Ohio State program (Dixon 1985) was the earliest sky survey; this project is now terminated. The Harvard search (Leigh & Horowitz 1997) has also been terminated. The Argentinian search (Lemarchand et al. 1997), and the Australian search (Stootman et al. 1999) continue. Targeted searches of nearby stars have been initiated by the SETI Institute (Tarter 1997) using substantial amounts of dedicated telescope time which were obtained in return for a substantial financial contribution to the telescope upgrade which was carried out after the conclusion of the SERENDIP III observations.

We discuss our sky survey search for artificial extraterrestrial signals with the SERENDIP III system (Bowyer et al. 1997) and the Arecibo telescope. Although the search was a sky survey, nearby solar-type stars inevitably fell within the beam pattern of the telescope in the course of these observations. As part of the analysis of the SERENDIP III data, we have separately investigated the data from observations of the sky coincident with these nearby stars. Although our integration times for individual targets are relatively short (as compared, for example, with the SETI Institute targeted search), our sensitivity is still substantial because of the large collecting area of the Arecibo telescope and the outstanding receivers that are available for use with this instrument.

We report the results of our sky survey and provide upper limits on possible signals from stars in this paper.

2. Observations and Analysis

The SERENDIP III data were obtained with the National Astronomy Ionosphere Center’s radio observatory in Arecibo, Puerto Rico with a 430 MHz receiver. Data collection began in April, 1992 and ended in October, 1998.

The feed used for SERENDIP III was located at the opposite carriage house from the primary observer’s feed. This resulted in three observation modes. In the first, representing about 45% of the observing time, the primary observer’s feed was tracking a point on the sky. This resulted in the SERENDIP III beam moving across the sky at roughly twice the sidereal rate. In the second, representing about 40% of the observing time the feeds were stationary, resulting in motion at the sidereal rate. In the third, representing about 15% of the observing time, the SERENDIP III feed was tracking a point on the sky.

Power spectra were generated by the SERENDIP III four million channel spectrum analyzer which had a 1.7 second integration period and a 0.6 Hz frequency resolution (2.5 MHz instantaneous band coverage). The sensitivity achieved in a 1.7 second integration at our typical system temperature of 45 K was $3 \times 10^{-25}$ W m$^{-2}$. This bin size is wide enough to encompass Doppler frequency drifts caused by the Earth’s motions plus reasonable accelerations of a hypothetical transmitter’s reference frame. The receiver’s entire 12 MHz band was processed in 2.4 MHz steps taking about 8.5 seconds to complete a single sweep. The SERENDIP III fast Fourier transform based hardware is described in detail by Werthimer et al. (1997).

Adaptive thresholding was achieved by baseline smoothing the raw power spectra with a sliding eight thousand channel local-mean boxcar and searching for channels exceeding 16 times the mean spectral power. These signals were recorded.
SERENDIP III

Figure 1. An illustration for the SERENDIP III data flow showing the steps taken to detect candidate signals. Real-time processing consists of power spectra generation and application of an adaptive threshold to the resulting spectra. Off-line data reduction included RFI rejection techniques, pattern detection, and candidate extraction.

2.1. Off-line Data Reduction

Data were transferred from Arecibo to Berkeley across the Internet where off-line data analysis activities began. Data reduction consisted of removing data taken during periods when the telescope was slewing too fast or too slow for our analysis procedures, followed by the application of a suite of RFI filters.

Excessively rapid telescope slew rates precluded acquisition of accurate positioning information. In addition, during times when the receiver tracks a point on the sky, it is not possible for our analysis programs to differentiate between continuous RFI and a potential signal. Therefore, our first filter was to censor data acquired during periods of rapid telescope movement and periods when the telescope was tracking sky objects. Roughly 15% of the data were removed for this reason.

The next step in data reduction was non-drifting RFI rejection. SERENDIP’s non-drifting RFI rejection algorithms incorporated dynamically adaptive statistical analysis routines that detect spurious signals from terrestrial and near-space sources. Three cluster analysis tests were conducted on each input data file spanning several hours of observation. Signals were rejected if they (1) were detected over broad areas of the spectrum in one or more integration periods (broad spectrum interference), (2) persisted at the same receiver frequency through multiple telescope beams, or (3) persisted in the same channel of the spectrum analyzer.

Broad spectrum interference was identified by the rejection test:

\[ x > 50 \quad \text{and} \quad \frac{\sum x^2}{x} > S \] (1)

where \( d \) is the number of frequency bins (0.6 Hz/bin) between simultaneous events above the threshold and \( x \) is the number of events above threshold in the spectrum. For SERENDIP III, the threshold value was set at \( S = 10^8 \).

RFI rejection algorithm (2) uses a statistical method to determine if several detections at the same observing frequency could be ruled out. If these detections occur with a significantly above-average hit rate, and they continue to occur when our observing beam has moved beyond one beam width (0.17 degrees), we reject the hypothesis of random Poisson events being the cause. Instead we mark these detections as being due to external RFI, and reject them.

RFI rejection algorithm (3) uses the same statistical test as (2) but applies it to hit sequences that have the same intermediate-frequency bin number. In this way it rejects interference generated within the observatory.

Data surviving the first three rejection criteria were further analyzed for RFI that drifts rapidly in frequency and were therefore not rejected by algorithms (2) and (3) above. Figure 2 illustrates SERENDIP’s drifting frequency RFI detection al-
The average event density in frequency-time space was calculated for each data set. Sectors in frequency-time space around each detection (shown as dots in Figure 2) were analyzed to identify sectors having an unusually high number of detections. Sectors containing an excessive number of detections were further analyzed for the presence of drifting signals that persisted through multiple pointings of the telescope beam.

An example of the efficacy of the RFI rejection techniques is shown in Figure 3. Note that after application of SERENDIP’s RFI filters, the remaining data closely approached the number expected from a Poisson noise distribution. Typically, 98% of the RFI was rejected, yet only 1% of the band was lost during RFI removal.

2.2. Pattern Detection

A suite of pattern detection algorithms was employed to detect signal recurrence and telescope beam pattern matching. The primary pattern looked for was recurrence of a signal in frequency over time and position. All data were frequency corrected to the solar system barycenter. Thus, only those signals that displayed the proper Doppler drift relative to the solar system barycenter remained at a nearly constant frequency. If a signal recurred within a defined frequency window, it was tagged as a candidate. We defined frequency windows of two different widths in order to find two different classes of signals.

The first class (Class I) consists of signals with no frequency drift in the barycentric frame. If transmitted from a planet, such a signal must contain a Doppler correction, and therefore would be a deliberately beamed message. For such signals, the chief cause of potential frequency drift arises from our lack of knowledge of the source’s exact position on the sky. We use the direction of the beam center to approximate the source position, and obtain an approximate compensating frequency drift by projecting our antenna’s diurnal and annual acceleration onto that nominal line of sight. Due to our beam’s size (0.17 degrees), this drift rate uncertainty can shift an ideal signal by as much as 120 Hz. Consequently, our compensated signal class defined a candidate as any set of signals that recurred within a band whose width \( f_\sigma = 120 \text{ Hz} \).

The second class (Class II) consists of signals containing significant Doppler acceleration. Radio leakage from a transmitter on a planet will significantly drift in frequency over time spans of minutes to months. Here, signal sets were allowed a frequency deviation \( f_\sigma = 50 \text{ kHz} \). The width of this band was derived assuming a transmitter whose acceleration was as great as the Jovian cloud tops.

Multiple detections in a given transit were examined to determine if the observed power as a function of time matched the telescope’s Gaussian beam pattern. Such a finding would suggest that the signal emanated from a point source on the sky.

2.3. Candidate Merging and Ranking

The output of SERENDIP’s suite of pattern detection algorithms was a collection of statistically interesting events. These data sets were then examined to identify candidate locations for signals of interest. A candidate was defined as a one beamwidth area on the sky that was identified by one or more pattern detection algorithms. A candidate is fully described by one or more records in the candidate database, each of which is the result of detection by a single algorithm. In addition, celestial objects such as nearby stars, globular clusters, and known planetary systems are entered into the candidate database to check for coincidence with candidates identified by the other algorithms described herein.

Candidates are ranked by two methods. First, each candidate record was given an algorithm specific score. Second, we asked how many algorithms detected the candidate. Here we considered coincidence with an interesting celestial object to be counted as an “algorithm”.

Figure 2. Schematic illustration of SERENDIP’s drifting RFI detection algorithm. Sectors of frequency-time space around each detection were analyzed for signals that exhibit time-coherency and persistence over multiple pointings of the telescope’s beam.

Figure 3. Data from a period of severe interference (top). Each dot represents a high power signal detection by the SERENDIP instrument. After RFI filtering (bottom) the number of hit remaining approaches that expected from a Poisson distribution, as would be expected in a white-noise environment.
To determine the score in the case of multiple transit detections, we calculated the relative probability of our detections occurring from noise, given the number of detections in the candidate area, the number of times we have observed the candidate area, the number of frequency bins searched by the algorithm, and the actual frequency separation of the detections. The relative probability is given by

$$P = \frac{n_c^{\nu_d}}{n_d! \left( \frac{F_{\text{tot}}}{F_{\text{win}}} \right)^{(n_d - 1)}} \left[ \frac{\Delta f + f_\sigma}{f_\sigma} \right]$$

where:

- $n_c$ is the total number of events logged at any frequency in the candidate area,
- $n_d$ is the number of detections within $F_{\text{win}},$
- $F_{\text{win}}$ is the frequency window searched for events,
- $F_{\text{tot}}$ is the total SERENDIP band observed,
- $\Delta f$ is the maximum frequency separation for the detection set,
- $f_\sigma$ is the expected frequency variance as explained in section 2.3.

In searches for either Class I or Class II signals, the lower the numerical rating in this algorithm, the more promising the candidate.

To calculate the score in the case of beam pattern matching in a single transit across the telescope’s Gaussian beam, we first determined the best fit Gaussian to the data. The relative score is then given by

$$P_G = A_G \cdot Q(\chi^2 | \nu)$$

where $A_G$ is the amplitude of the best fit Gaussian, and $Q(\chi^2 | \nu)$ is the $\chi^2$ probability function. In this case, the higher the numerical rating, the more promising the candidate.

The data from the most promising candidates were independently scrutinized for RFI contamination by three researchers and those surviving this evaluation constitute the list of most interesting candidates. Our top candidates from our signal detection algorithms and their scores are given in Table 1.

### 2.4. Investigation of Possible Signals from Nearby G-Dwarf Stars

We investigated the data obtained from nearby G-dwarf stars that were observed by chance in our sky survey with the rationale that these were especially interesting candidates. In this effort, we used the Center for Astrophysics list of G-dwarf stars within (roughly) 100pc of the Sun (Latham 1999) as listed on their web site as of August 1999\(^1\). We identified those stars in this list visible with the Arecibo telescope (i.e. stars between $-2^\circ$ and $+38^\circ$). We then searched the SERENDIP III position data set and identified stars in the list that fell within the half power beam width of the Arecibo antenna during our observations.

Of the 516 stars in the CFA list that are observable with the Arecibo telescope, 494 had been observed at least once, and 439 had been observed multiple times. In Figure 4, we show a histogram of the number of separate times each star in the CFA G-dwarf subset was observed in the SERENDIP III search. No narrow band excess power beyond that expected for random noise was detected from these stars.

In Table 2 we provide the HD number of the observed stars, their distances as obtained from the Hipparcos catalogue, and the upper limits to the irradiated power at the star.

### 3. CONCLUSIONS

We have carried out an extensive search with the world’s largest telescope for evidence of radio emission produced by an extraterrestrial intelligence. We were able to carry out this search using this unique facility because of the non-intrusive character of our observing program. A major challenge in our search (and in all other searches for extra terrestrial intelligence) is the problem of false signals produced as a result of human activity. We developed a variety of techniques to deal with this problem and demonstrated their robustness. This shows that a non-intrusive collateral data collection technique such as ours is viable.

Given the extensive character of our search we found many signals of potential interest. A prioritization scheme was developed to identify the most promising of these signals. These

\(^1\) [http://cfa-www.harvard.edu/~latham/gdwarf.html](http://cfa-www.harvard.edu/~latham/gdwarf.html)
Table 1
Most Interesting Candidates

| R.A. (hours) | Dec (deg) | Sky Separation (deg) | Frequency (MHz) | Max. Freq. Separation (Hz) | # of Obs. | # of Times Detected | Score by Algorithm | Coincident Object |
|-------------|-----------|----------------------|----------------|-----------------|----------|---------------------|-------------------|-------------------|
| 0.67        | 28.1      | 0.1                  | 429.600        | 6               | 6        | 2                   | 91.084            | GJ 1019           |
| 0.96        | 7.8       | 0.1                  | 426.839        | -               | 1        | 1                   | 43.17             |                   |
| 2.13        | 26.9      | 0.1                  | 431.959        | 17              | 20       | 3                   | 1.801             |                   |
| 4.59        | 27.0      | 0.1                  | 434.603        | 30              | 13       | 3                   | 0.632             |                   |
| 5.13        | 2.1       | 0.2                  | 435.009        | 46467           | 4        | 2                   | 79.371            | 22.68             |
| 8.15        | 9.0       | 0.1                  | 435.089        | -               | 1        | 1                   | 26.93             | GJ 299            |
| 10.23       | 18.5      | 0.2                  | 430.059        | 79              | 34       | 3                   | 20.525            |                   |
| 14.32       | 25.9      | 0.2                  | 427.350        | 72              | 8        | 3                   | 0.250             |                   |
| 23.09       | 26.8      | 0.1                  | 429.973        | 27              | 21       | 3                   | 2.529             |                   |

1 Maximum frequency separation between multiple observations
2 Number of times SERENDIP III observed this point in the sky
3 Three different scoring algorithms:
   Algorithm 1: Doppler compensated signal class (120Hz max frequency window) (see eq. 2); smaller is more remarkable
   Algorithm 2: Non-Doppler compensated signal class (50kHz max frequency window) (see eq. 2); smaller is more remarkable
   Algorithm 3: Gaussian beam fit (see eq. 3); larger is more remarkable

were examined in more detail. In the end, no extraterrestrial signals were identified. We do not find this surprising nor discouraging given our lack of knowledge as to appropriate source locations, frequencies and time periods that an intentional extraterrestrial signal may be employing.
We are continuing our search.

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Stars observed with SERENDIP III

| HD number | Distance (pc) | Upper Limit (log10(Watts)) |
|-----------|---------------|----------------------------|
| 101       | 38            | 12.7                       |
| 377       | 40            | 12.8                       |
| 531E      | 70            | 13.2                       |
| 531W      | 70            | 13.2                       |
| 700       | 59            | 13.0                       |
| 1832      | 41            | 12.8                       |
| 4903      | 53            | 13.0                       |
| 5035      | 39            | 12.7                       |
| 6715      | 33            | 12.6                       |
| 7047A     | 40            | 12.7                       |
| 8009A     | 65            | 13.2                       |
| 8009B     | 65            | 13.2                       |
| 8262      | 26            | 12.4                       |
| 8523      | 60            | 13.1                       |
| 8574      | 44            | 12.8                       |
| 8648      | 45            | 12.9                       |
| 9091      | 46            | 12.9                       |
| 9224      | 43            | 12.8                       |
| 9472      | 33            | 12.6                       |
| 9670      | 37            | 12.7                       |
| 9986      | 26            | 12.4                       |
| 10126     | 34            | 12.6                       |
| 10844     | 54            | 13.0                       |
| 11045     | 58            | 13.1                       |
| 11130     | 27            | 12.4                       |
| 11850     | 33            | 12.6                       |
| 12235     | 31            | 12.5                       |
| 12783     | 48            | 12.9                       |
| 13357A    | 49            | 12.9                       |
| 13357B    | 49            | 12.9                       |
| 13382     | 33            | 12.6                       |
| 13483     | 34            | 12.6                       |
| 13836     | 37            | 12.7                       |
| 13997     | 34            | 12.6                       |
| 14082B    | 39            | 12.7                       |
| 14305     | 34            | 12.6                       |
| 14348     | 62            | 13.1                       |
| 14651     | 40            | 12.8                       |
| 14874     | 59            | 13.1                       |
| 15632     | 42            | 12.8                       |
| 16086     | 54            | 13.0                       |
| 16397     | 36            | 12.7                       |
| 17674     | 47            | 12.9                       |
| 17820     | 65            | 13.2                       |
| 18144     | 29            | 12.4                       |
| 18330     | 39            | 12.7                       |
| 18702     | 32            | 12.6                       |
| 18774     | 66            | 13.2                       |
| 19019     | 23            | 12.3                       |
| 19308A    | 43            | 12.8                       |
| 19445     | 39            | 12.7                       |
| 19518     | 41            | 12.8                       |
| 19902     | 42            | 12.8                       |
| 19962     | 38            | 12.7                       |
| 20165     | 22            | 12.2                       |
| 20477     | 52            | 13.0                       |
| 21183     | 75            | 13.3                       |
| 21663A    | 46            | 12.9                       |
| 21774     | 50            | 13.0                       |
| 22309     | 45            | 12.9                       |
| 23314     | 49            | 12.9                       |
| 24040     | 47            | 12.9                       |
| 24053     | 33            | 12.6                       |
| 24206     | 179           | 14.1                       |
| 24496     | 21            | 12.2                       |
| 24552     | 45            | 12.9                       |
| 24702     | 47            | 12.9                       |
| 25285     | 65            | 13.2                       |
| 25682     | 46            | 12.9                       |
| 25825     | 47            | 12.9                       |
| 26749     | 36            | 12.7                       |
| 26756     | 46            | 12.9                       |
| 26767     | 45            | 12.9                       |
| 26913     | 21            | 12.2                       |
| 26923     | 21            | 12.2                       |
Table 2 — Continued

| HD number | Distance (pc) | Upper Limit EIRP (log10(Watts)) |
|-----------|--------------|----------------------------------|
| 54100     | 45           | 12.9                             |
| 54351     | 44           | 12.8                             |
| 54405     | 46           | 12.9                             |
| 54718     | 46           | 12.9                             |
| 55458A    | 25           | 12.4                             |
| 55918     | 38           | 12.7                             |
| 56202     | 53           | 13.0                             |
| 56303     | 41           | 12.8                             |
| 56513     | 35           | 12.7                             |
| 58781     | 30           | 12.5                             |
| 58971     | 43           | 12.8                             |
| 59360     | 41           | 12.8                             |
| 59374     | 50           | 13.0                             |
| 60298     | 39           | 12.7                             |
| 62346     | 51           | 13.0                             |
| 63935     | 50           | 12.9                             |
| 64090     | 28           | 12.5                             |
| 64324     | 35           | 12.6                             |
| 65629     | 32           | 12.6                             |
| 66348A    | 43           | 12.8                             |
| 66485     | 44           | 12.8                             |
| 66550     | 38           | 12.7                             |
| 68168     | 34           | 12.6                             |
| 68284     | 300          | 14.5                             |
| 69056     | 43           | 12.8                             |
| 70571A    | 92           | 13.5                             |
| 70571B    | 92           | 13.5                             |
| 72946     | 23           | 12.3                             |
| 73226     | 43           | 12.8                             |
| 73668A    | 36           | 12.7                             |
| 74011     | 46           | 12.9                             |
| 74156     | 65           | 13.2                             |
| 74567     | 93           | 13.5                             |
| 75302     | 30           | 12.5                             |
| 76218     | 26           | 12.4                             |
| 76261     | 46           | 12.9                             |
| 76349     | 49           | 12.9                             |
| 76752     | 40           | 12.8                             |
| 76765     | 61           | 13.1                             |
| 76780     | 34           | 12.6                             |
| 77024A    | 77           | 13.3                             |
| 77278     | 31           | 12.5                             |
| 77407     | 30           | 12.5                             |
| 78317     | 48           | 12.9                             |
| 78660     | 50           | 13.0                             |
| 79498A    | 49           | 12.9                             |
| 79726     | 48           | 12.9                             |
| 80408     | 39           | 12.7                             |
| 80536     | 51           | 13.0                             |
| 80870     | 45           | 12.9                             |
| 81040     | 33           | 12.6                             |
| 81240     | 59           | 13.1                             |
| 82939     | 38           | 12.7                             |
| 83408     | 58           | 13.1                             |
| 84209     | 72           | 13.3                             |
| 84749     | 47           | 12.9                             |
| 85426     | 61           | 13.1                             |
| 85689     | 45           | 12.9                             |
| 86133A    | 42           | 12.8                             |
| 86133B    | 42           | 12.8                             |
| 86460     | 41           | 12.8                             |
| 86794     | 52           | 13.0                             |
| 87680     | 394          | 12.7                             |
| 88371     | 62           | 13.1                             |
| 88446     | 69           | 13.2                             |
| 88725     | 36           | 12.7                             |
| 89055     | 36           | 12.7                             |
| 89070     | 31           | 12.5                             |
| 89813     | 27           | 12.4                             |
| 90164     | 54           | 13.0                             |
| 90905     | 32           | 12.6                             |
| 91148     | 37           | 12.7                             |
| 91204     | 52           | 13.0                             |
| 93215     | 47           | 12.9                             |
| 94028     | 52           | 13.0                             |
| HD number | Distance (pc) | Upper Limit EIRP (log\(_{10}\)(Watts)) |
|-----------|--------------|-------------------------------------|
| 126246A   | 36           | 12.7                                |
| 126246B   | 36           | 12.7                                |
| 126512    | 47           | 12.9                                |
| 126583    | 34           | 12.6                                |
| 126961    | 41           | 12.8                                |
| 127825    | 58           | 13.1                                |
| 128198    | 68           | 13.2                                |
| 129095    | 50           | 13.0                                |
| 129413A   | 40           | 12.8                                |
| 129814    | 42           | 12.8                                |
| 130268    | 68           | 13.2                                |
| 131179    | 39           | 12.7                                |
| 132973    | 75           | 13.3                                |
| 133161    | 35           | 12.7                                |
| 134066A   | 32           | 12.6                                |
| 134066B   | 32           | 12.6                                |
| 134625A   | 33           | 12.6                                |
| 134625B   | 33           | 12.6                                |
| 135101A   | 28           | 12.5                                |
| 135101B   | 28           | 12.5                                |
| 135792A   | 43           | 12.8                                |
| 136925    | 46           | 12.9                                |
| 138246    | 62           | 13.1                                |
| 138373    | 31           | 12.5                                |
| 138919    | 41           | 12.8                                |
| 139018    | 79           | 13.3                                |
| 139324    | 53           | 13.0                                |
| 139457    | 47           | 12.9                                |
| 139839    | 65           | 13.2                                |
| 140209    | 65           | 13.2                                |
| 140233    | 78           | 13.3                                |
| 140324    | 55           | 13.0                                |
| 140514    | 83           | 13.4                                |
| 140750    | 68           | 13.2                                |
| 141272    | 21           | 12.2                                |
| 141529    | 55           | 13.0                                |
| 142093    | 31           | 12.5                                |
| 142229    | 41           | 12.8                                |
| 142637    | 66           | 13.2                                |
| 143291    | 26           | 12.4                                |
| 144873    | 47           | 12.9                                |
| 145229    | 33           | 12.6                                |
| 145729    | 45           | 12.9                                |
| 146588    | 45           | 12.9                                |
| 146644    | 61           | 13.1                                |
| 147044    | 36           | 12.7                                |
| 147528    | 51           | 13.0                                |
| 147750    | 40           | 12.8                                |
| 148530    | 47           | 12.9                                |
| 148816    | 41           | 12.8                                |
| 149028    | 48           | 12.9                                |
| 149380    | 94           | 13.5                                |
| 149809    | 39           | 12.7                                |
| 150554A   | 45           | 12.9                                |
| 150828B   | 63           | 13.2                                |
| 150933A   | 44           | 12.8                                |
| 152264    | 64           | 13.2                                |
| 153627    | 43           | 12.8                                |
| 153701    | 37           | 12.7                                |
| 154417    | 20           | 12.2                                |
| 154656    | 42           | 12.8                                |
| 154931    | 55           | 13.0                                |
| 155060    | 36           | 12.7                                |
| 155193    | 61           | 13.1                                |
| 155358    | 43           | 12.8                                |
| 155423    | 44           | 12.8                                |
| 156146    | 76           | 13.3                                |
| 156893    | 68           | 13.2                                |
| 156968    | 55           | 13.0                                |
| 157089    | 59           | 12.7                                |
| 157637    | 41           | 12.8                                |
| 158226A   | 69           | 13.2                                |
| 158331    | 51           | 13.0                                |
| 158332    | 30           | 12.5                                |
| 159009    | 37           | 12.7                                |
| 160013    | 42           | 12.8                                |
| 161728    | 63           | 13.2                                |
| 161848    | 38           | 12.7                                |
Table 2 — Continued

| HD number | Distance (pc) | Upper Limit EIRP (log_{10}(Watts)) |
|-----------|---------------|------------------------------------|
| 209458    | 47            | 12.9                               |
| 209858    | 55            | 13.0                               |
| 209875    | 51            | 13.0                               |
| 210388    | 43            | 12.8                               |
| 210460    | 56            | 13.0                               |
| 210462A   | 54            | 13.0                               |
| 210483    | 49            | 12.9                               |
| 210553    | 45            | 12.9                               |
| 211476    | 31            | 12.5                               |
| 211786    | 42            | 12.8                               |
| 212291    | 32            | 12.6                               |
| 212858    | 55            | 13.0                               |
| 214059    | 80            | 13.4                               |
| 214435    | 49            | 12.9                               |
| 214560    | 55            | 13.0                               |
| 215257    | 42            | 12.8                               |
| 215274    | 45            | 12.9                               |
| 216625    | 44            | 12.8                               |
| 216631    | 43            | 12.8                               |
| 217165    | 44            | 12.8                               |
| 218133    | 38            | 12.7                               |
| 218172    | 74            | 13.3                               |
| 218261    | 28            | 12.5                               |
| 219172    | 46            | 12.9                               |
| 220008    | 87            | 13.4                               |
| 220077    | 77            | 13.3                               |
| 220255    | 52            | 13.0                               |
| 220334B   | 37            | 12.7                               |
| 220773    | 48            | 12.9                               |
| 221477    | 59            | 13.1                               |
| 221822    | 39            | 12.7                               |
| 221851    | 23            | 12.3                               |
| 221876    | 75            | 13.3                               |
| 222033    | 50            | 13.0                               |
| 222941A   | 46            | 12.9                               |
| 223061    | 45            | 12.9                               |
| 223238    | 47            | 12.9                               |
| 224156    | 29            | 12.5                               |
| 225261    | 26            | 12.4                               |