THE WOW-SIGNAL
AS AN INTERSTELLAR LIGHTHOUSE

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Abstract
This paper describes options and limits of an interstellar lighthouse. Afterwards, this concept is applied to the "Wow"-signal, which was received by Dr. Jerry R. Ehman at the Big Ear Radio Telescope of Ohio State University in 1977. It is shown that all characteristics of a lighthouse beacon are met.
The author suggests a re-observation at slightly adjusted coordinates at an exactly specified time.

Keywords
Wow signal, interstellar beacon, interstellar lighthouse

Translation
This paper has been translated from German to English by the author, who is a non-native-speaker. For any questions or lack of clarity, please contact the author.

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1. Introduction

Lighthouses as long distance signal emitters are known since ancient times.[1] Their focused light beam allows the lighthouse to be seen in a much greater distance compared to an evenly shining light of the same brightness. An observer might still be able to see the beam of focused light for short time intervals, when a continuous light would already be too dim. For an interstellar lighthouse, with the task to call attention to it, a comparable approach seems to be advantageous.

2. Properties of an interstellar lighthouse

The purpose of a lighthouse is, basically, to show the existence of something or someone. A classical lighthouse refers to the existence of a cliff, or a coast. An interstellar lighthouse would tell about the existence of intelligent life. As we know nothing at all about extraterrestrial life, detectability of the lighthouse is even more important. Detectability depends mainly on 4 factors:

- Easy to find nature of the signal (frequency)
- Strength, or brightness, of the signal
- Visibility on the sky (signal not blocked by stars, planets, moons or other matter)
- Frequent possibility of observation

However, there are limits to each of these factors, for the sender as well as for the receiver.

2.1 Nature of the signal (frequency)

Electromagnetic waves of different frequencies are suitable to transport a signal. Academic research on interstellar communication concludes that the radio frequencies between 1420 MHz und 1666 MHz, the „water hole“, are preferable.[2] These two frequencies belong to the emissions of hydrogen (H) and hydroxyl (OH) – water, when mixed. Water is the most important element for life (on earth). More important: This frequency range is the quietest in space. The frequency of hydrogen (1420.405 MHz), which is the most common element in the universe, seems especially attractive. For frequencies below, the "galactic noise" increases rapidly; frequencies above are more and more absorbed by planetary atmospheres.
Recent research on communication frequencies includes optical wavelengths, e.g. (very) short laser pulses. SETI search projects are conducted by the Universities of Harvard and UC Berkeley. An older study done by NASA, however, explains the disadvantages of these frequencies. Besides bad weather issues (clouds), there are physical disadvantages as well: „all laser systems suffer the disadvantage of a higher energy per photon than microwave systems: their effective noise temperature is high.“ [3]
To sum up, the frequencies around 1420.406 MHz (HI-line) seem to be the optimum for an interstellar lighthouse. Space background noise is low, and the frequency can be received at any planet at any weather. Necessary technology (radio telescopes) is established for decades, and is relatively low cost.

[1] See Hoepfner (2003)
[2] See Drake (1998)
[3] Oliver (1971), p. 50

2.2 Strength, or brightness of the signal

A lighthouse should shine as bright as possible. In terms of radio waves: The flux density should be as high as possible. This is usually measured in Jansky, a fraction of watts per square metre per hertz.
Besides pure transmitting power, focusing plays a major role. An isotropic radiator sends its waves evenly to all directions, but the flux density decreases spherically as well. An antenna of 100m diameter, comparable to the radio telescope in Effelsberg/Germany, would focuse the energy in only 1 of 10^7 sky segments instead. The flux in this segment would be higher by the same factor. [4] This consideration shall be examined in more detail later in this paper.
A radio telescope of average size (e.g., the 26m telescope in Hobart/Tasmania) could detect a signal that was sent in 100 LY distance, focused by a 300m antenna, and emitted with 1000 MW (the power of a large power plant). If this imaginary signal would be unfocused, it would need a power of 10^{16} Watt.[5] That is 5 times more than the energy which earth receives from the sun[6]; the amount of energy is many magnitudes higher than any human technology for the foreseeable future.
To sum up, focused radio signals could be sent and received with current human technology. Unfocused signals, however, have technological demands far beyond any reasonable dreams.

2.3 Visibility on the sky

A skipper sailing in the dark does not know, where the lighthouse is – otherwise he would have ne need in it. He knows, however, that it is visible, as visibility is a major construction principle. A lighthouse would never send its beam into the land, where no skipper is watching, but always in the direction of the sea.
An interstellar lighthouse would probably be operated in the same way. It would be meaningless to send its beam into the dark voids of space, or into the direction of a cold star without any planets, or to a star which planets would hide behind their sun at the time of arrival. The more knowledge a lighthouse has about its environment, the more precise it will be able to shine.
In order to determine targets of interest for the lighthouse, the available and potentially attainable information about the targets must be analyzed. Even with current technology, humans have detected (large) planets around hundreds of stars. In the near future it might be possible to detect earth-size planets in habitable zones (e.g., using the Keppler space telescope). Further investigations could determine orbit periods, rotation periods (with brightness fluctuations) and potential moons. For the foreseeable future, spectroscopy using advanced telescopes could detect the existence of bio-markers in planetary atmospheres.
These characteristics would be helpful to determine the targets of the lighthouse.

2.4 Frequent possibility of observation

A skipper needs to see the beam of the lighthouse frequently, at least once every couple of minutes. That is possible with a classic lighthouse, which has a strictly defined coast area to illuminate. An interstellar lighthouse, however, faces the problem that space is

[4] See Oliver (1971), p. 55
[5] See Gray/Ellingsen (2002), p. 971
[6] See NASA (2006)

incomparably larger than any coast line. If the interstellar lighthouse shall illuminate many more targets, the length of stay at every position needs to be reduced.
Assuming that potential targets have been analyzed in the way that has been described above, one can roughly estimate the number of targets. For every technology, there are limits: Perhaps spectroscopy can't produce spectra for planets of distances greater than, e.g., 400 LY. This limitation also helps to balance between dwell time and the number of total targets.
Let us assume a limit of 400 LY for the weakest part of technology involved, and a star density of 0.1 stars per cubic parsec. This results in 800,000 candidates in a sphere around the lighthouse. Many of these stars are cold, hot, small or otherwise unattractive, in any way not qualified to harbour planets in a habitable zone for long periods of time. Assuming that 90% of all stars fall into this category, there are 80,000 candidates remaining.
Now the lighthouse might not be active permanently, but need some time to be adjusted for a new target, or have down-time for maintenance. Net up time could be 50%. If the lighthouse now wants to visit every one of its 80,000 candidates once in the period of an earth-year, it can only dwell on every target for 200 seconds.
On the first glance, these minutes seem to be very short. One might be inclined to advice on (much) longer dwell times per target. But that would be unwise, mainly for two reasons:

1. One could tend to build (many) more lighthouses, to illuminate more targets. If one follows this idea down to its very end, one ends up building the isotropic radiator with its disadvantages described before. Surely, more lighthouses would be beneficial, but it seems not be advantageous to invest the available funding in more and more towers.
2. Dwell time per target could be increased, while accepting the reduction in the numbers of targets. Example: Increase dwell time by a factor of 10 to 2000 seconds, and reduce targets by a factor of 10 to 8,000. Each remaining target (e.g., earth) would then be able to receive the signal for 30 minutes instead of 3 minutes, per year. On the other hand, 9 out of 10 targets do not see the lighthouse any more at all. Chances for a random detection of the lighthouse have increased on earth – but if this increase is not tenfold, it was not worth it.

Finally it should be examined how a dwell time of 200 seconds would fit into the technology of radio telescopes. Most observatories use integration times of 10 to 30 seconds.[7] With longer integration times, the signal/noise ratio increases. The ratio decreases when the signal is shorter than the integration time. A dwell time of 200s usually results in several significant data points; a major reduction in dwell time would be disadvantageous.

Lastly, it shall be noted that "more advanced" civilisations might search systematically for signals, and/or show more patients for pauses between signals. Mankind is no desperate skipper who needs a signal every 5 minutes: "Space ship earth" is cruising for a long time already; maybe a silence period of a year seems very reasonable to other potential species.

[7] The Big Ear Telescope has used 10s during its discovery of the Wow signal. Gray/Ellingsen used 30s in their search at the Wow coordinates with the Tasmania Hobart 26m telescope. Gray/Marvel even used 10 minutes in their re-observation when using the (much more sensitive) Very Large Array (VLA).

3. Application of the framework to the Wow signal

In this chapter, the described framework shall be applied to the so-called "Wow" signal. It was detected by Dr Ehman on August 15th 1977 at the Big Ear Radio Telescope of Ohio State University (disassembled in 1998). The signal was received during 72s dwell time of the telescope at one point in the sky. It matched all characteristics of a long distance (>300,000km) signal. The second receiver at the telescope, which dwelled 155s before or after the first one at the same position in the sky, only received noise. Thus, the signal either ended (or began), or changed its frequency. It was only detected in the second of 50 channels, each of 10 KHz width, at 1420.456 MHz (±5 KHz).

3.1 Frequency of the signal

The detected frequency was 50 KHz (±5) higher than the HI-line at 1420.406 MHz. That translates into a Doppler drift of +10.6 km/s [+9.5...+11.7] into the direction of the receiver.
In the previous chapter, it was theorized that the lighthouse might have knowledge about the receiving planet, e.g. the length of its year and day period. Furthermore, the movement of its planets and of the host star might be known as well. The corresponding Doppler drift could then be compensated. That might not be an easy task, as a signal for a 200 LY distance would be on its way for 200 years, requiring precise forecasts for all parameters for the same period. Orbit periods and speed vectors would need to be known with great precision, to create exact forecasts. The Wow signal had a small, but significant positive Doppler drift of ~11 km/s relative to the HI-line, thus 4 possibilities can be derived:

- Wow was not a lighthouse signal
- Perfect Doppler drift compensation was not possible, e.g., due to technical limits
- Perfect Doppler drift compensation was no goal (e.g., one signal for several receivers that have different drifts)
- The Doppler drift of +11 km/s was used designedly

At first glance, a perfect compensation seems to be attractive: The receiver would know that it was an artificial message designated for him and nobody else. So to speak, the frequency itself would contain content already, without any modulation to transport other information.

On the other hand, the information that it was an artificial message for a designated receiver could be transported with other (receiver's) frequencies as well. Suppose the Wow signal would have been received at exactly 1420.4588 MHz, which is a drift of 52,94 KHz from the HI-line, or a vector of 11.186 km/s. This frequency is within the error margins of the Wow signal, so it could well have been the "real" frequency, e.g. having a bandwidth of 1 Hz. What would the meaning of these 11.186 km/s be? Possibly a coincidence, but it is the escape velocity of our planet earth.

As the exact frequency of the Wow signal is unknown, no further speculation should be made. It should be noted, however, that the Wow signal could well be a lighthouse signal in terms of its frequency.

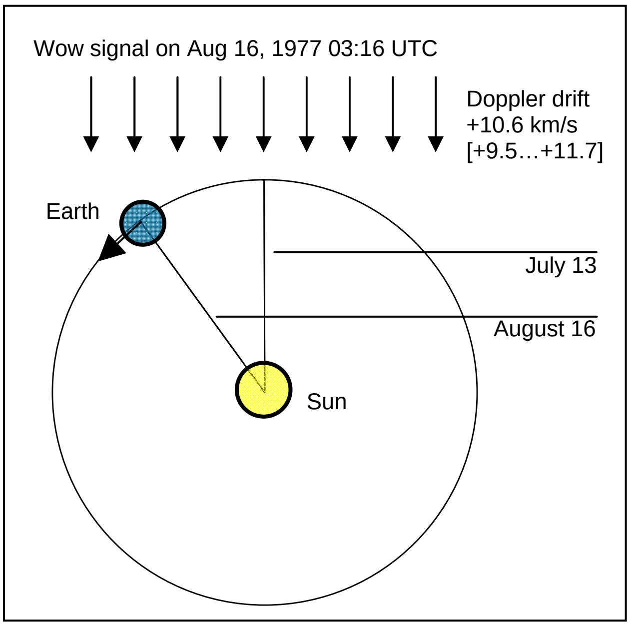
3.2 Strength, or brightness of the signal

The Big Ear Radio Telescope's sensitivity was comparable to that of a traditional 52.5m-dish.[8] Due to its construction it was much cheaper than other, more "professional" telescopes of its time. Still, it was capable of receiving the Wow signal with a signal to noise ratio of >30. Due to the technological progress during the last 30 years, especially in electronics, it is possible to receive a signal comparable to Wow using a 3.7m radio telescope.[9]
Therefore, the Wow signal was definitely strong enough to fulfil the brightness criteria of an interstellar lighthouse.

3.3 Visibility on the sky

A signal that arrives when earth is behind the sun would be worthless. A lighthouse with minimum knowledge about its receiver would send its signal in a way that makes it receivable. For the Wow signal, this criteria was met, as shown in graph 1.

Graph 1: Schematic 2D plot of earth's position on its orbit when Wow was received



Source: Created by the author

3.4 Frequent possibility of observation

In the previous chapter, it has been argued that long silent periods (months, years) between short (minutes) dwell times per target would be a reasonable approach for an interstellar lighthouse. Reflecting this matter, 3 questions should be discussed:

1. Should there be discrimination in dwell time between the targets, based on their attractiveness?
2. How long should the silence period exactly be?
3. What exact dwell time should be used?

[8] See www.bigear.org, visited March 4th, 2010
[9] See http://www.setileague.org/articles/calibwow.htm, visited March 14th 2010

3.4.1. Discrimination in dwell time

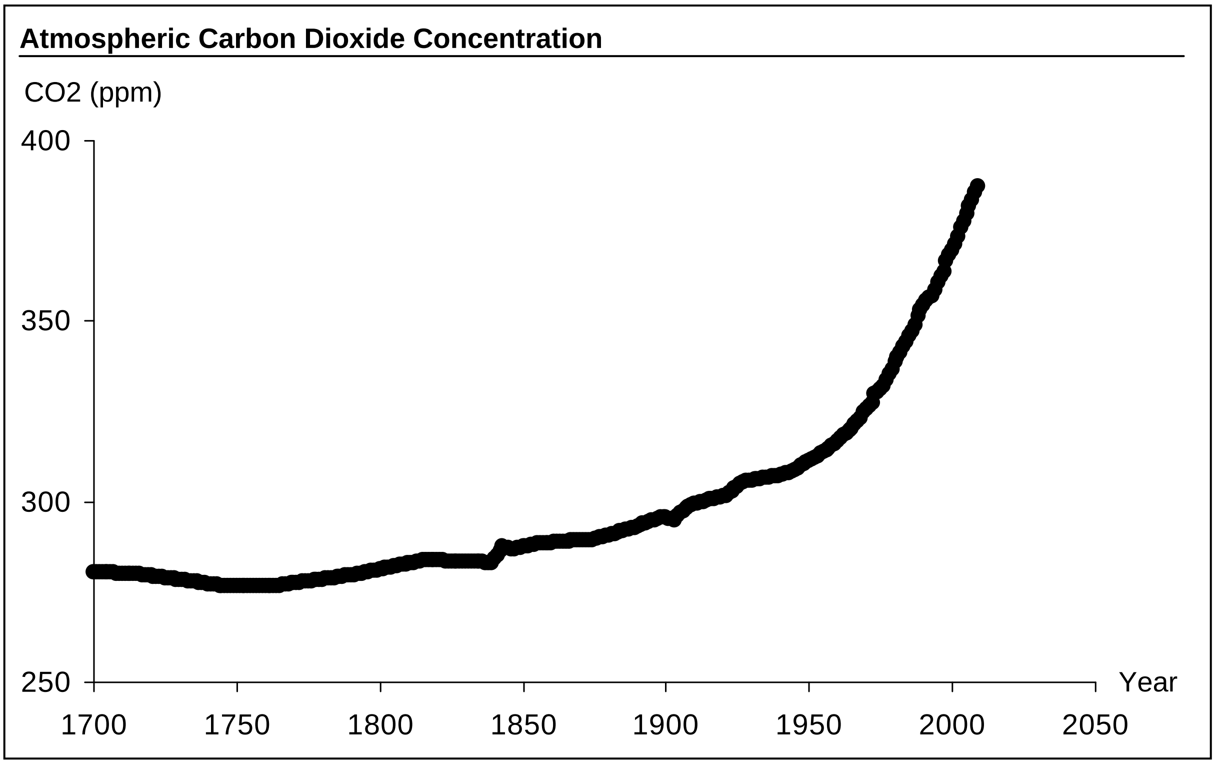
Discriminating between targets due to their different attractiveness seems to be unfair only on the first glance. More detailed analysis shows that discrimination can be a very useful variable in pursuing the lighthouse's goal: Maximize the chances to be seen.

This can be shown in a simplified example. Let us assume 2 stars each having a planet in its habitable zone. Both are in a distance of 200 LY from the lighthouse, both have similar orbit periods, rotation periods, and moons. The only difference shall be the spectroscopic image of their atmospheres. Both show clear traces of carbon dioxide based life. However, on one of the planets, a rapid increase of the CO_2-content in its atmosphere has occurred during the last 100 years. Even more, Chlorofluorocarbon rocketed during the last 30 years. Now, should the lighthouse illuminate both planets equally? Definitely not: The lighthouse should favour the planet that shows clear markers of intelligent, technologically advanced life (CFCs in the air), without completely neglecting the other planet.

What does earth look like for a lighthouse in 200 LY distance? Yet, it looks like the less interesting of the two planets in our example. Mankind started burning fossil fuels in noteworthy amounts in the 1850s (see graph 2). Due to the limited speed of light, this information will be received at the lighthouse from 2050 on. If the lighthouse reacts immediately, its signal could be received on earth in the year 2250. For CFCs, it would be the year 2370.

It seems to be clear that earth is currently no tier-1 target for signals.

Graph 2: Change of atmospheric CO_2 concentration 1700 – 2009.



Source: Chart created by the author, data from Earth Policy Institute, http://www.earth-policy.org/datacenter/xls/indicator8_2010_4.xls

3.4.2 How long should the silence period exactly be?

If Wow was a lighthouse signal, the main question must be: When will it signal us again? Following the arguments in this paper, nothing should be random, but follow calculations to maximize detection probability. For instance, no signal should arrive at a star which planets hide behind their sun. Hence: What is the most likely interval of a potential Wow lighthouse?
As humans, we have no information about other species and their logical approaches. We can only use our own thinking patterns. Let us use yet another little example to illustrate human logic.
Consider yourself travelling Europe by train. At a random station, the train stops. We look out of the window and suddenly see a pretty woman. She looks up, and the following eye contact and her smile tell us to get out of the train and ask her out. Unfortunately, in this very moment the doors close and the train drives on. As we have the luxury of being on holiday, we decide to get out of the train at the next station and go back. Just an hour later we arrive at the point she had been. However, she is gone. Perhaps she didn't have the time to wait? Now we consider our next steps. How could we possibly meet her again? There is no other place we would know of to look for her. It must be the one platform of this station. Still, we can't stand here and wait for a long time. We need time off for maintenance, food and sleep. When should we come back? That's an easy question. Humans follow patterns. They get up at the same time, and they take the same train to work every day. It seems logical that the maximum probability to meet the woman is exactly one day later, at the exact same place. That would be more likely than any other time (Wednesday 3:40AM?) or place (Rome?).
In the search for another occurrence of the Wow signal, this is not a totally new idea. However, the assumptions were focused on shorter periods (up to 24hrs) and centred on the lighthouse's possible home planet and its day length:

- Big Ear Radio Telescope has observed the Wow coordinates for ~ 100 times, dwelling 72s each time. That is a total of 2 hours.
- At the 26m Tasmania Hobart Telescope, 6 observations each lasting 14 hours were made by Gray and Ellingsen.[10] This took place in March, April and October 1999. The total was 84 hours.
- Gray and Marvel used the Very Large Array (VLA) to search for very weak signals at the Wow coordinates. Several observations of up to 22 minutes were made, totalling 1 hour of observation time.[11]

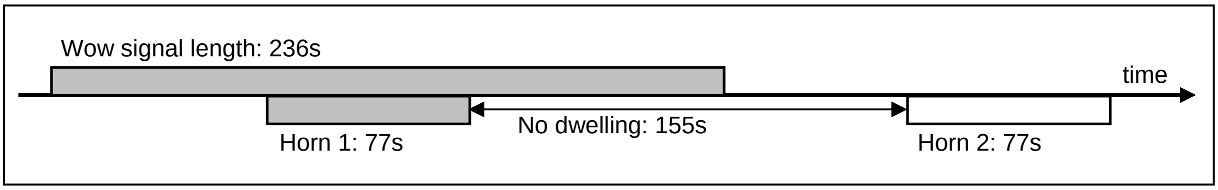
These observations, especially the ones by Gray and Ellingsen (2002), exclude a signal of a period length shorter than a few days. What other logical period could a Wow lighthouse use? There is only one remaining: 1 earth year. After one sidereal year, earth would be at the exactly same position on its orbit again (see graph 1). The perfect time and place for a rendezvous.

[10] See Gray/Ellingsen (2002)
[11] See Gray/Marvel (2001). In section 4.4 of this present paper, some deficits of the observations by Gray/Marvel will be shown.

3.4.3 What exact dwell time should be used?

The Wow signal was only received in one of two receivers for its observation time of 72 seconds, but not in the other receiver which dwelled on the same coordinates 155s before or afterwards. Thus, the signal length is unknown. Theoretically, the signal could have been very long, and just ended (or begun) in the 155s between the two observations. Equally, it would be possible to have lasted the minimum of 72s, or any time between these two limits.
If Wow was a lighthouse signal, the lighthouse would be free in its decision about the signal length. Thus, it seems logical to use a signal length with some meaning, and not a random length. As the lighthouse could know orbit length and rotation period of the receiver, these numbers could be used to define the signal's length. Earth turns 365.24 times (days d) during one (1) cycle around the sun. Signal length could be a fraction of this time, e.g., $1/d^2$ of a year. That would be 236 seconds. As shown in graph 3, such a length would fit well into observation data.

Graph 3: How a signal length of 236 seconds would fit into the Wow observation



Source: Created by the author

4. Summary of results and suggestions for re-observation

In this paper, criteria for a signal of an interstellar lighthouse were developed. For the Wow signal, all criteria were met. This does not imply that Wow was a lighthouse signal, but it shows that it could have been one. The conclusions from this paper can easily be falsified by re-observing the Wow coordinates. This will be done using the 26m Tasmania Hobart Radio Telescope on August 16th, 2010. In this chapter, the parameters for the observation shall be discussed.

4.1 Length of observation

Wow was detected for 72 seconds, and this paper proposes a signal length of 236 seconds. Thus, an observations of a few minutes at the right time will suffice. A 10 minutes observation has been scheduled.

4.2 Time of observation

Following the argument of this paper, Wow would reoccur once a year. As we know nothing about the sender, we have to use earth's year as a basis. During history, human cultures have developed different calendars to measure the length of a year, based on Venus, the moon or the sun.[12] Today's western calendar uses the tropical year for reference.
From an astronomy perspective, the sidereal year seems to be a much better guess. The sidereal year is the time after which earth has returned to the same location in space, when

[12] See Bennet et. al. (2009), chapter 3

fixed stars are the basis. The sidereal year is ~ 20 minutes longer than the tropical year; the difference is present in the 26.000 years lasting precession.
Using the sidereal year, the next possibility for a re-observation would be August 16th, 2010 on 14:18 UTC. That is exactly 33 sidereal years (each lasting 31558149.54 seconds) after the detection of the Wow signal on August 16th, 1977, 03:16 UTC.
At this time, Wow coordinates will be visible in the sky from Hobart/Tasmania

4.3 Frequency and bandwidth

Wow was detected at 1420.456 MHz, which is also suggested for the re-observation. A bandwidth of at least ±5 KHz should be covered as well. That would include frequencies such as 1420.4588 MHz (Doppler drift 11.186 km/s, escape velocity) mentioned in the previous chapter.

4.4 Coordinates

Assuming the lighthouse would be within a few hundred LY, star catalogues can be used to define potential sender stars. In graph 4 (page 14), the relatively large field of view of the Big Ear Radio Telescope is shown as the outer red rectangle. Within, there are 6 stars that are brighter than 10mag. For each star, data from satellite Hipparcos is available. The following table shows this data, sorted by the stars' distance to our own sun (G2V), in the Hertzsprung–Russell diagram.

HIP number	Brightness (mag)	Stellar classification	Distance (LY)
95275	9,07	G1V	296
95887	9,42	G3V	543
95865	5,46	K1/K2III	252
95882	8,32	K4III	3624
95412	9,24	B9IV	1087
95604	7,75	A0V	1164

A G1V or a G3V star has a larger chance for planets in a habitable zone than a K-star. For B- and A-stars, planets in habitable zones are unlikely or impossible. Thus, 4 stars of interest remain. Unfortunately, the 2 best candidates are more than 28 arc minutes apart, thus only one of them can be observed with the Hobart Radio Telescope.
After extensive discussions with experts, Hobart will observe candidate number 1; star HIP 95275 (G1V). This was based mainly on the smaller distance of the candidate.
A second telescope could now cover for targets #2 (HIP 95887, G3V), #3 and #4 with one observation, as they are closely together. The author would be very thankful for any support.

Graph 4 (page 14) also shows the area that was examined by Gray/Marvel using the VLA.[13]
Despite the authors' claim that the large field of view of Ohio State was being accounted for, this is not entirely true. The authors correctly mention the HPWB of 40' in declination, but use the centre point of the error margins for the corresponding total field. When using the upper and lower limits of the error bars, the corresponding *possible* field of view is larger, as shown in graph 4. Please note that the true field of view was indeed smaller, but it is unknown which part was included, due to the possible errors of its centre.

[13] Vgl. Gray/Marvel (2001)

From the table above, only star HIP 95412 (B9IV, a sub giant), was covered. The other 5 candidates, especially #1 and #2, lie outside the VLA search. This is especially unfortunate, as the VLA search was designed to find a weak underlying signal. However, in the VLA search, all potential sources for such a signal were excluded by the too narrow field of view.

4.5 Suggestion for re-observation

Hobart will observe candidate #1, HIP 95275 (G1V), using the following (planned) settings:

- Time: August 16th 2010, 14:18 UTC. Duration 10 minutes, if possible begin at 14:13 UTC to cover 5 minutes before and after that exact time
- Frequency: 1420.4588 MHz. If possible with a range of +- 50KHz or more
- Channel width: Something between 1KHz to 10 KHz
- Integration time: 30 seconds or the like, to achieve a reasonable S/N ratio for fluxes of e.g. 60 Jansky
- Coordinates (Y2000.0):
    - RA: 19h23m
    - DE:-26°42'

For candidate #2, star HIP 95887, no observation has been scheduled so far. The author would be thankful for any support. The above settings would be recommended, on this position:

- RA 19h30m
- DE -27°34'

The two K-stars from the table above are relatively close to this location and would also be covered with an amateur telescope.

4.6 Null hypothesis for re-observation

It is assumed that the observation result will show no emission significantly exceeding noise levels, especially no narrowband signal (<10KHz) at high fluxes (e.g. 60 Jansky).

As the time of the observation is assumed to be crucial, it is recommended to install and test the equipment prior to the observation. This will also be done by Hobart/Tasmania, and can also be used to collect a silent data sample for reference, to test the Null hypothesis against.

After the observation, please send your results to the author (michael@jaekle.info). He will collect the data from all observations and inform all participants on the outcomes. In the unlikely event that your data contradicts the Null hypothesis, please call the author at any time at +49 177 1982058 to discuss next steps.

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Graph 4: Map of the Wow field of view (red rectangle), limiting magnitude 13m4. The narrow, vertical bands are the confidence intervals of the focus points of the two receivers. The gray rectangle depicts the area that was covered with the VLA search. The 6 stars which are brighter than 10mag are shown by their HIP numbers.