First Light Report
for
Little Thompson Observatory's
21cm Hydrogen Line
Radio Telescope

12 March 2017

Summary:
This report provides evidence of the first observation of celestial objects using the 21 cm hydrogen line (HI) radio telescope. The first radio star detected was the sun. These measurements allowed confirmation of the antenna pointing direction. The second object detected was the northern arm of the Milky Way galaxy

Overview:
The HI radio telescope operates by detecting faint radio emissions from neutral hydrogen in the universe. Neutral hydrogen occasionally emits a photon at 21.11 cm wavelength or 1,420.405752 MHz. This emission is subject to Doppler shift. Increased line-of-sight densities of hydrogen increase the level of emission along a given look direction. The sun also emits radio noise at this frequency.

Telescope Design and Engineering:
The LTO HI radio telescope used an offset feed dish of 3.8m effective diameter which at 21cm results in a beam of about 3 to 4 degrees. This dish was used for satellite communication and is re-purposed for radio astronomy, was installed by LTO volunteers in July 2016 and pointed south at an elevation of about 42 degrees. The dish is shown in Figure 1.

Figure 1: The assembled hydrogen line radio telescope dish located south of the Little Thompson Observatory. This dish is manufactured by Prodelin and has an effective aperture of 3.8 meters.

The feed is a 12” diameter metal dish and a half wave perimeter loop antenna mounted ¼ wavelength above the plate. The feed was constructed by the students and volunteers at the Berthoud High School amateur radio club W0BHS in the 2016 school year and is shown in Figure 2.

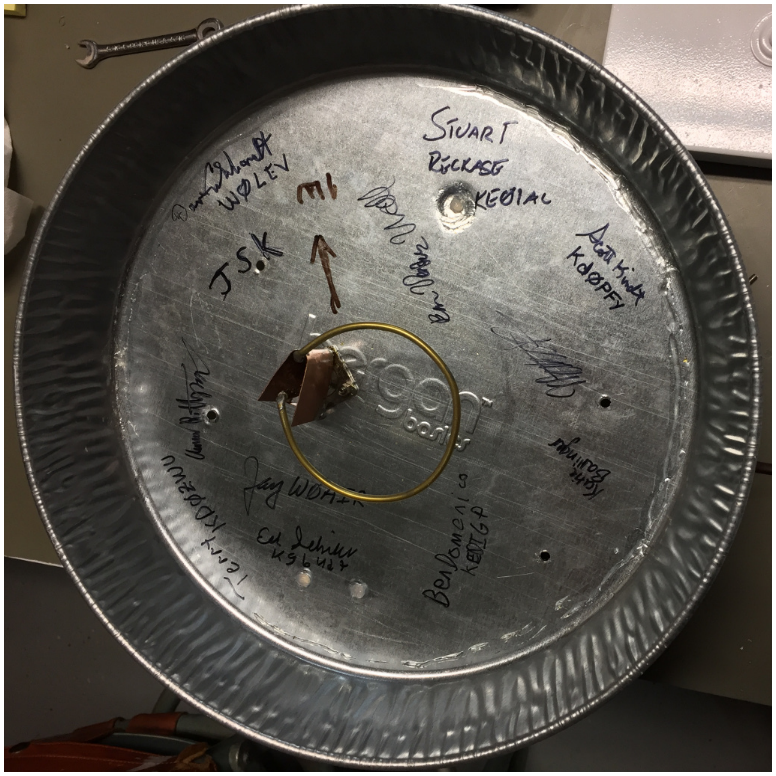

Figure 2: The internal details of the LTO HI telescope feed point. The active element is the loop in the center of the pan. The 12" diameter metal pan acts as a secondary reflector. It is signed by the members of W0BHS radio club who helped in the construction.

The preamplifier configuration at the feed point is a replica of the Haystack Small Radio Telescope, with the addition of a 1000 MHz high pass filter between the antenna and the first amplifier. This was absolutely necessary to avoid saturation of the first stage amplifier by nearby transmitters at 900 MHz. This unavoidably increases the noise figure from 0.5 dB to 1.13 dB, with a gain of 21.5 dB, confirmed by bench measurements. The internals of the preamp are shown in Figure 3 and a block diagram in Figure . This noise figure corresponds to a minimum system temperature of 86K according to this reference:
{http://www.rfcafe.com/references/calculators/noise-figure-temperature-calculator.htm}

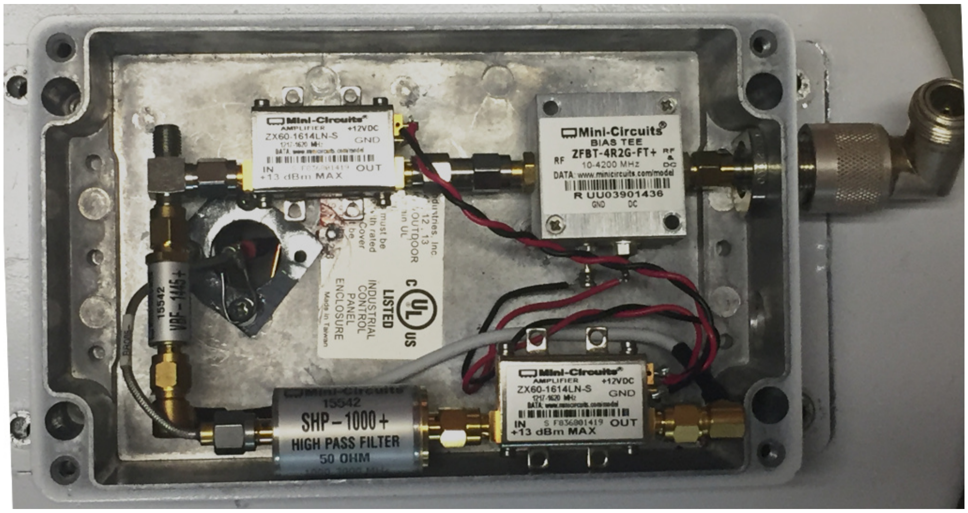

Figure 3: The internal details of the feed point electronics for the HI radio telescope.

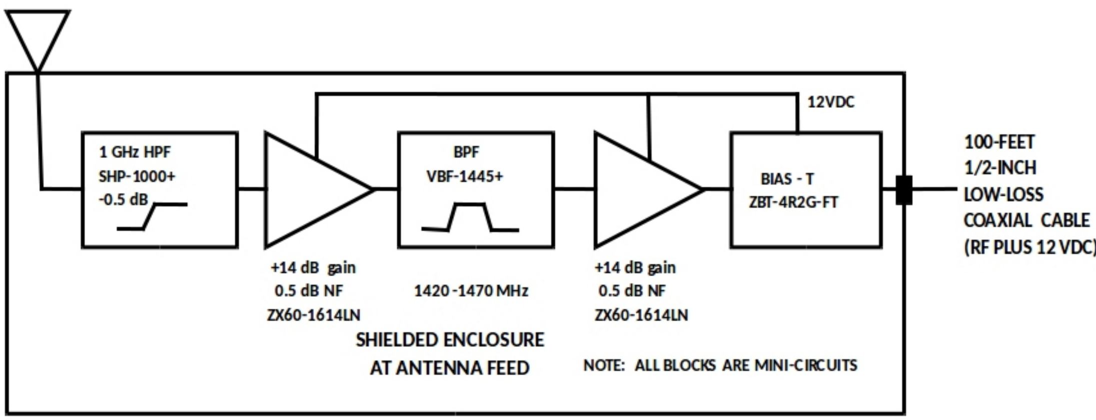

Figure 4: Block Diagram for LTO HI telescope feed point electronics. Gain and noise figures are approximate.

In this first light configuration, the preamp was powered through the feed line by a bias tee and a bench power supply. An additional amplifier of approximately 18dB of gain was needed inside the observatory to bring signals up to the level that can be properly received by the Airspy software defined receiver. These components are simply sitting on a shelf near The receiver was set to 1418 MHz and upper side band demodulation bandwidth of 3 kHz. The Airspy receiver is operated by SDR# software, the digital audio is sent via a program called VB-Cable to Radio Sky Pipe II software for data recording. Data are saved in the native RSP2 visual basic data file format.

Engineering tests of this configuration indicate that the internal noise received noise with the disconnected preamp is about 630 counts (arbitrary voltage units) and nominal received values are around 3000 counts, providing about 14 dB of external signal above internal receiver noise. These signals appear to be free of man-made interference.

First Observations:
Continuous data collections was started on the afternoon of 16 February 2017 and has continued without interruption through the beginning of March. The first 7 days of data are displayed in Figure 5.

Some explanations of the axis of these plots is necessary. The data themselves are statistical representations of the Radio Sky Pipe software output at 1 minute intervals. The software is set to record about 8 samples per second and record these to a data file. We have written a simple, object oriented program in FORTRAN90 to read these data files and perform statistics on the raw data over a specified period of time. This code is called "driftscan-rsp". In all these cases, about 540 raw data points taken over 60 seconds are analyzed. A probability distribution function is computed and the most probable amplitude value, or mode of the distribution is used as the signal estimator. The titles of the plots indicate the estimator is the median, and while the mode and median are numerically close in value, the actual detector is the mode of the distribution.

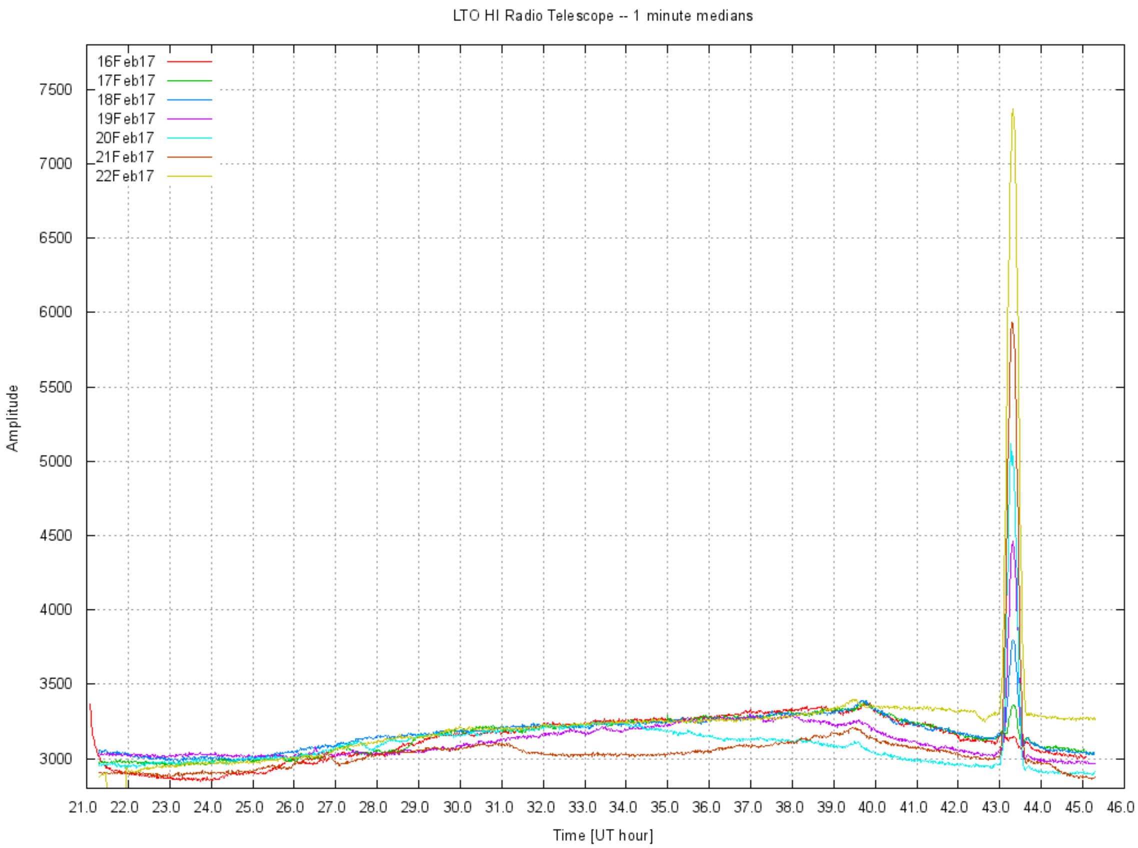

Figure 5: First 7 days of drift scans from the LTO HI radio telescope.

The horizontal axis is time in hours Universal Time. The scale [21-46] comes from the Radio Sky Pipe format for representing time, when the data files are started each day, and the hack used in the gnuplot plotting software used to generate these plots. A more intuitive and robust handling of time stamps is expected in the near future. The vertical axis is amplitude in arbitrary, uncalibrated voltage units.

The most obvious feature of Figure 5 is the sharp increase in amplitude between 43 and 44 hours, which is 19-20 UT or 12-13 hours MST. This section of the plot is enlarged in Figure 6, which shows a signal in approximately constant local time which increases in intensity from day to day, with a peak around 12:18 MST. The time axis major tics are at 5 minute spacing. This signal is the sun passing through the beam of the radio telescope. On 16Feb, the sun barely made it into the lower portion of the beam. On each successive day, as the sun increases it's peak elevation angle at local solar noon by about 0.4° per day, it climbs higher into the antenna beam, mapping out the antenna beam in azimuth every day and elevation from day to day. Close inspection of Figure 6 also reveals that the peak appears a little bit earlier each day, which is consistent with local noon at LTO coming about 7 to 8 seconds earlier each day at this time of year.

See Appendix A.

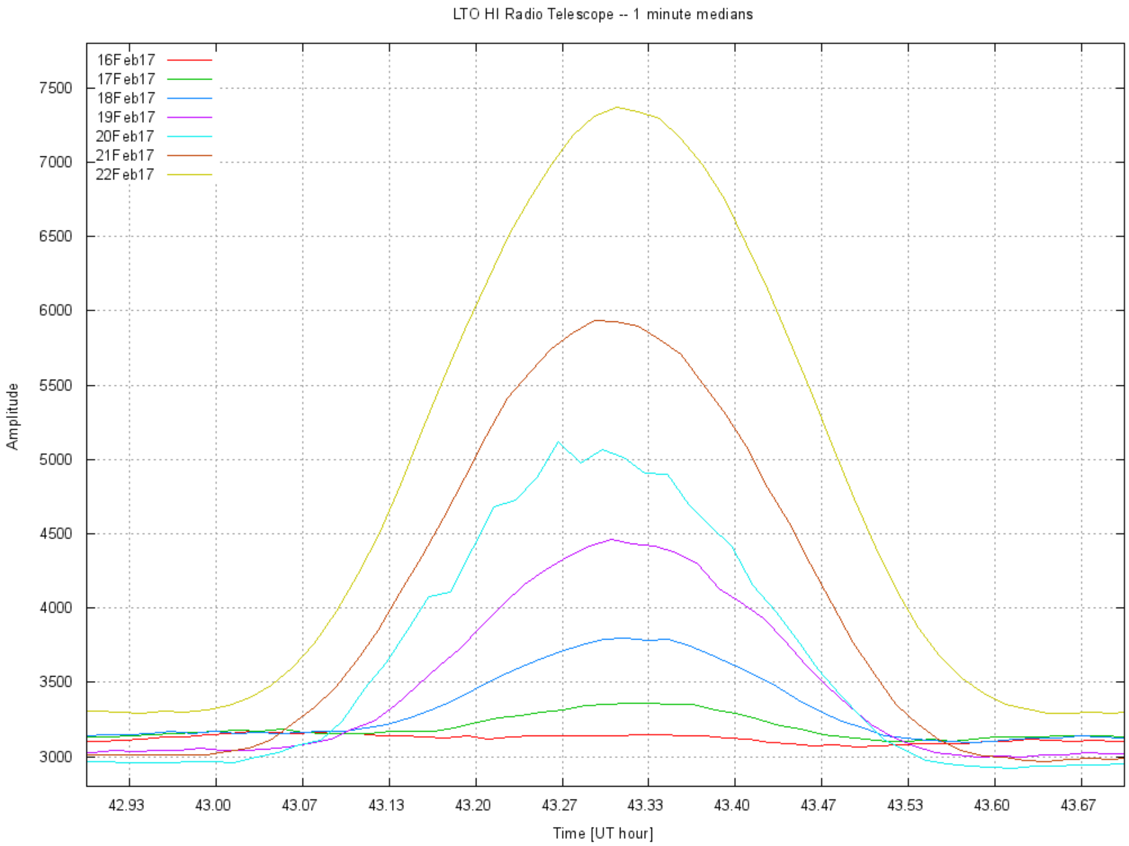

Figure 6: Response of the LTO HI telescope to solar noise 16-22 February 2017

On 27 February 2017, the LTO HI telescope received the maximum signal from transit of the sun. This is shown in Figure 7. The peak output of the telescope occurred at 12:18 MST. Using the solar calculator at NOAA {https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html} and using the location of the LTO dish at approximately 40.299535° N by 105.084387° W, the position of the sun at this time is elevation 41.83° and azimuth 181.47°. This should be the direction of the peak of the beam of the LTO HI radio telescope.

In addition to the beam direction, the data in Figure 7 can be used to compute the beamwidth of the antenna and feed configuration. The blue horizontal line represents values that are 3 dB below the peak of the curve, as highlighted by the green horizontal line. The lines are at 9644 and 6701 counts respectively. The location where the blue line interests the red data curve are at UT times 19.147 and 19.450 hours, for a difference of 0.303 hours. With the drift scan rate of 15.0 degrees per hour, the half power full beamwidth is 4.55°. This does not correct for the fact that the sun is not a point source, but approximately 0.5° width and a non-uniform illuminator because it is a spherical radiator. An approximate correction of 0.4° on each side of the scan brings the beamwidth to 3.75°. This compares well to a theoretical value of 3.2° for a 3.8m dish at 21cm wavelength.

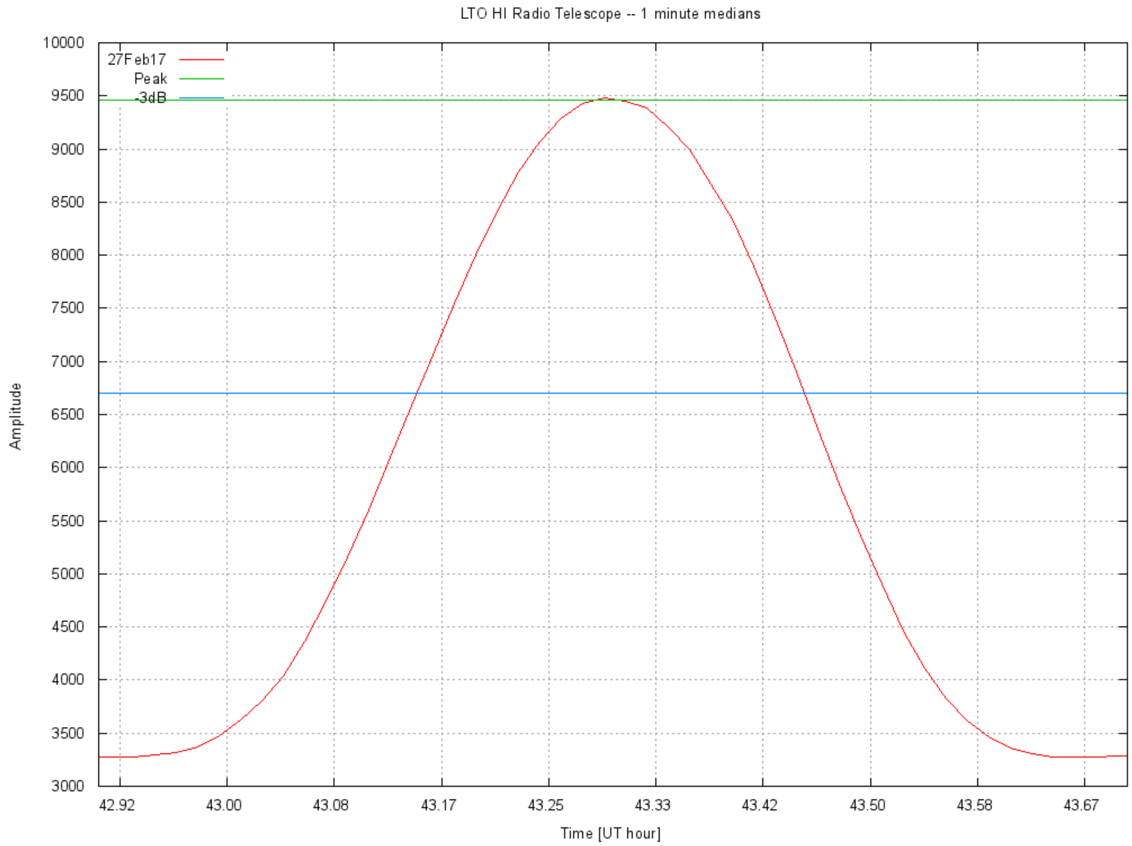

Figure 7: Receiver output of LTO HI radio telescope for 27Feb17 which showed the maximum day to day signal from the sun at local noon. These data allow to compute the azimuth, elevation and beamwidth of the dish and feed.

Re-plotting the data in Figure 1 to enhance the visibility of the non-solar data results in Figure 8. It is reassuring that there are no obvious spikes or sudden jumps in these lower level data. We feel that that the telescope is largely free of man-made interference at this time. There is an interesting feature in the data that show up around 39-40 hours (15-16UT) and this feature seems to drift in local time from day to day. However, unexplained shifts in the baseline signals from day to day make it difficult to determine if this shift corresponds to the -4 minutes per day of sidereal time.

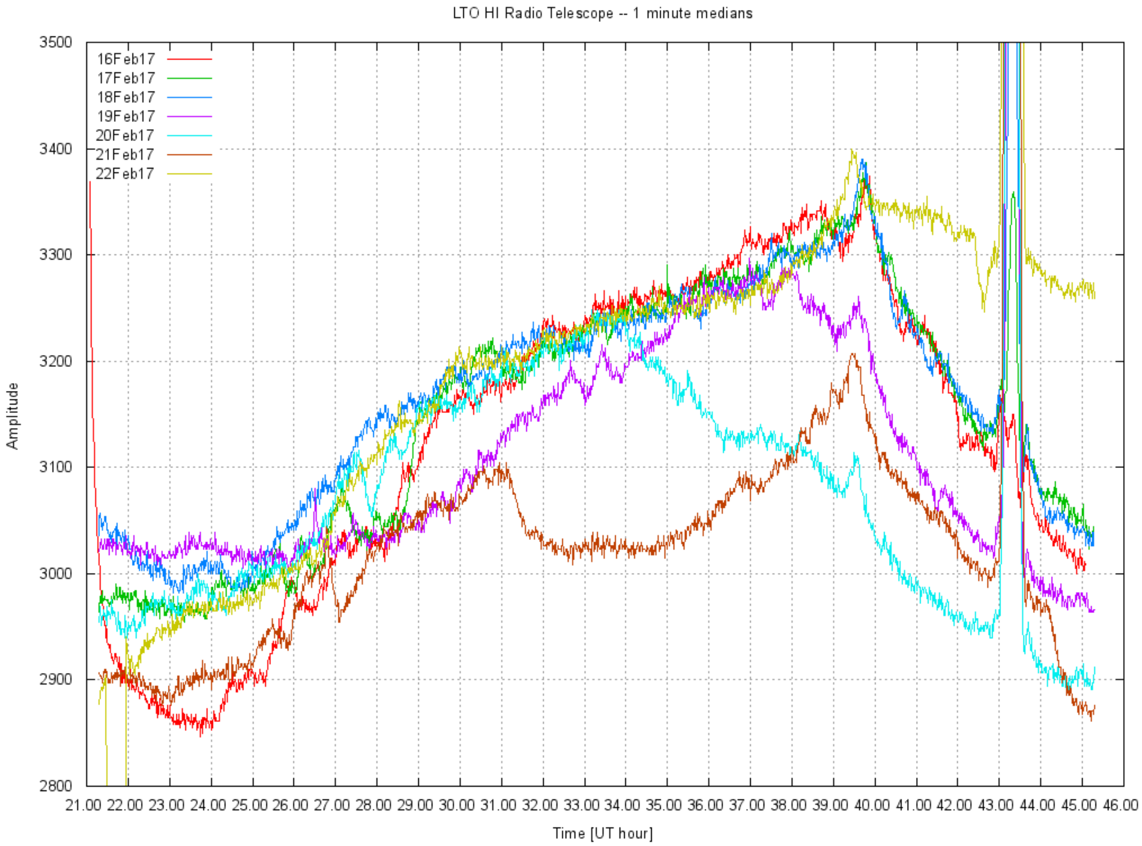

Figure 8: The first 7 days of data with a change in the vertical axis scale to enhance the non-solar signals.

In Figure 9, the first 8 days of drift scans are plotted from 14:30 to 16:30 UT. In this plot, the major time axis tic marks are at 4 minute intervals, to correspond with the difference between UT and sidereal time. Each day of data is plotted with a different offset such that each successive day is plotted an approximately equal distance above the previous day. This is to enhance the visibility of the signal which clearly drifts in UT. Figure 10 adds a black line, drawn by hand, to emphasize the peak of each day’s drift scan and indicate that these peaks are occurring at a constant sidereal time.

The duration of these peaks are some 30 minutes long. This represents about 7.5° of arc, being observed with a beam of 3.75 degrees. This object is larger than the beamwidth, but not by much.

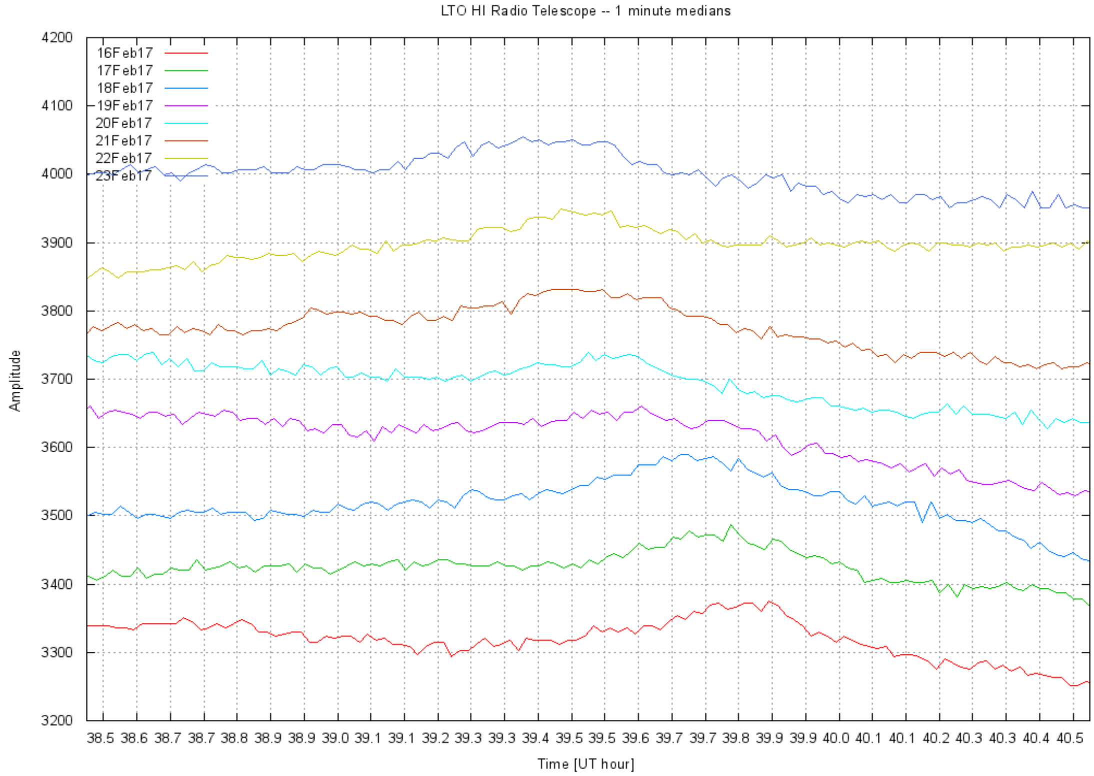

Figure 9: Drift scans for the first 8 days between 14.5 and 16.5 UT with amplitude offsets

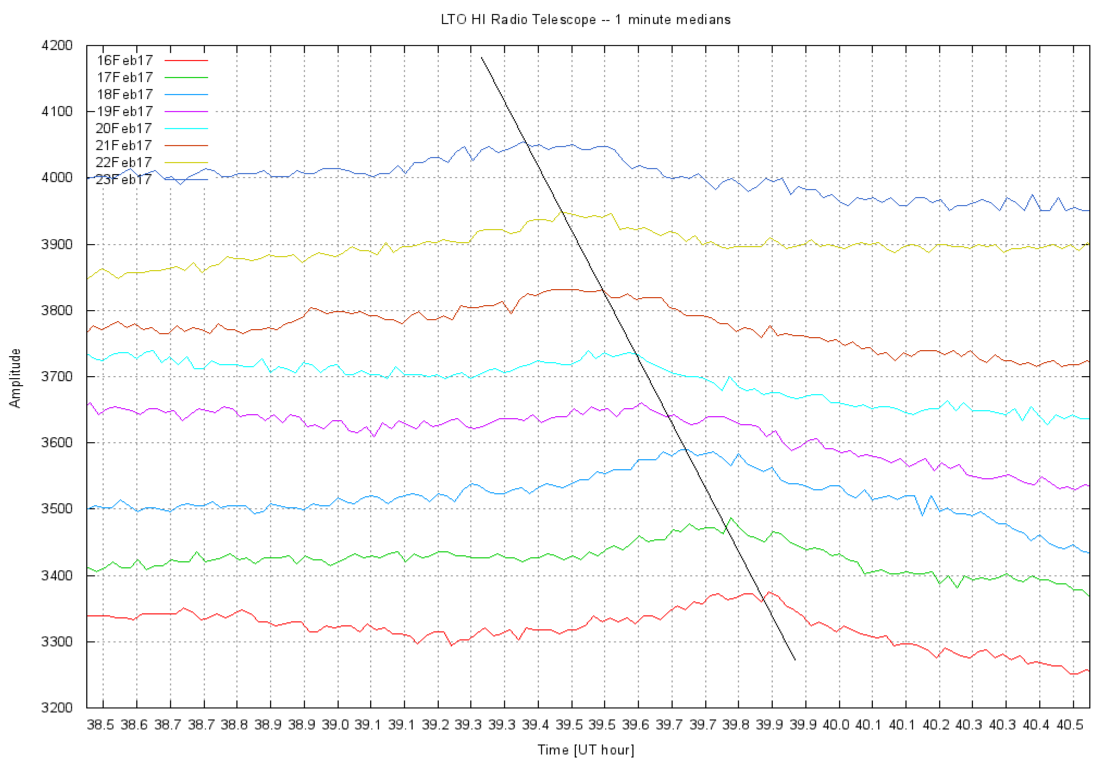

Figure 10: The same data as in Figure 7 with a line drawn to show the peak of each daily signal

The computer program Radio Eyes {http://radiosky.com/radioeyesishere.html} allows comparison of our viewing geometry with known galactic hydrogen line emission maps. Given the beamwidth of the LTO antenna, its location, pointing direction, and time of observation, our look direction can be plotted on the known radio sky. This is shown in Figure 11 for the entire sky. The beam of the LTO antenna for 15UT in the latter half of February is shown, as a blue circle near the middle of the diagram, and it is clearly crossing a known radio emission band.

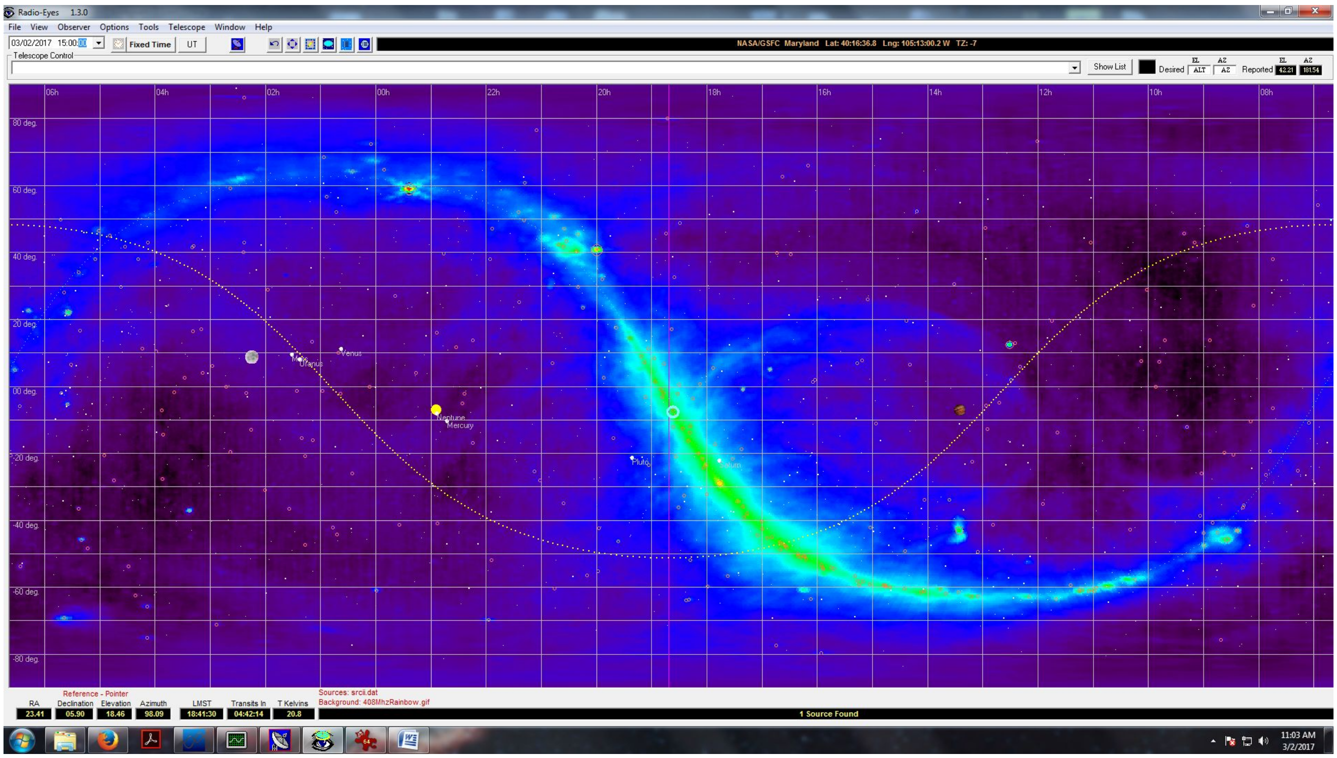

Figure 11: Radio Eyes plot of known radio emissions and the location of the LTO antenna beam at 15UT.

Figure 12 zooms in on the area of interest. This figure clearly shows that we are observing a radio intense region of the Milky Way galaxy that is relatively narrow compared to our telescope beamwidth. This is consistent with our observations.

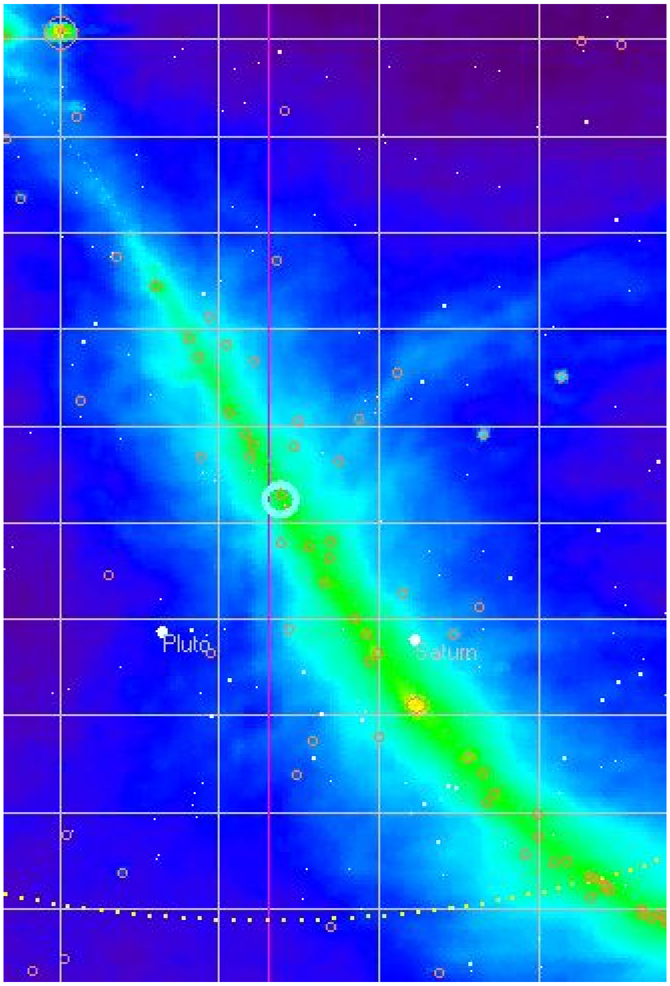

Figure 12: Observation area for LTO HI radio telescope antenna around 15UT in February.

Near Term Objectives:

There are several near term objectives identified by the radio astronomy team as necessary to complete the HI radio telescope and make it contribute to the objectives of LTO. All of these tasks are in the plan for the next 12 months.

System Temperature Investigation – We have made engineering tests to determine the system temperature of the radio telescope. The system temperature, along with antenna size, determines the lower limit on observing faint radio objects. The system temperature seems high. This may be because the entire receiver is not built and functioning. The source of this is still being studied.

Complete Receiver Construction – The parts on hand, plus a suitable local oscillator, need to be incorporated into a physical and electrical housing. This should bring the receiver to full performance.

Antenna Focus – The placement of the feed point and the focus of the dish is still in question, albeit a minor issue based on the data presented in this report. Ideas for determining the focus of the dish involve flying a drone in the main beam and using either a test transmitter or the audio of the drone to more precisely determine the location of the focal point of the dish antenna.

Software Development – The simple ‘driftscan-rsp’ software need to be updated to correctly handle time between Windows/Visual Basic and Linux FORTRAN. Subroutines to level the data from these unknown day to day variations and to map the UT data into sidereal time are needed.

Data Collection and Presentation – Meaningful drift scans take months to years to accumulate enough data to be presented as an image that resembles the radio universe. These data need to be processed meaningfully

Audible Data Presentation – Radio telescope data is highly amenable to audible presentation to the visually impaired or others who learn better through hearing than sight. The meteor radio data are highly engaging in this respect. The HI telescope data need to be modulated into audio frequencies and need to be sped up in time to make a meaningful auditory presentation.

Volunteer Training – The radio astronomy program needs formal documentation and training for the LTO volunteers so as to be better integrated into the overall education objectives of LTO.

Conclusions:

The radio astronomy team believes we have presented data that supports a conclusion that the instrument has received signals both from the Sun and from the Milky Way galaxy. We believe this satisfies the condition of a “first light” observation.

We look forward to completing the receiver, improving its performance.
At this point, the radio astronomy team would like to encourage and solicit other LTO volunteers to participate in the observations and data analysis.

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Dave Eckhardt (WØLEV)
Jay Wilson (WØAIR)

Appendix A – Local Noon variation for LTO

Solar Noon Calendar for Little Thompson Observatory

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	12:03:52	12:13:52	12:12:33	12:04:04	11:57:26	11:58:17	12:04:21	12:06:43	12:00:23	11:49:55	11:43:51	11:49:26
2	12:04:20	12:13:59	12:12:21	12:03:47	11:57:19	11:58:27	12:04:32	12:06:39	11:59:58	11:49:36	11:43:50	11:49:49
3	12:04:48	12:14:06	12:12:08	12:03:29	11:57:13	11:58:37	12:04:43	12:06:34	11:59:38	11:49:17	11:43:50	11:50:13
4	12:05:15	12:14:12	12:11:55	12:03:12	11:57:08	11:58:48	12:04:54	12:06:28	11:59:18	11:48:58	11:43:50	11:50:37
5	12:05:42	12:14:17	12:11:42	12:02:55	11:57:03	11:58:58	12:05:05	12:06:22	11:58:58	11:48:40	11:43:52	11:51:02
6	12:06:08	12:14:21	12:11:25	12:02:38	11:56:58	11:59:09	12:05:15	12:06:15	11:58:38	11:48:22	11:43:54	11:51:27
7	12:06:34	12:14:25	12:11:13	12:02:21	11:56:54	11:59:21	12:05:24	12:06:08	11:58:17	11:48:04	11:43:58	11:51:53
8	12:06:59	12:14:27	12:10:58	12:02:05	11:56:51	11:59:32	12:05:33	12:06:00	11:57:57	11:47:47	11:44:02	11:52:19
9	12:07:24	12:14:29	12:10:43	12:01:48	11:56:49	11:59:44	12:05:42	12:05:52	11:57:36	11:47:31	11:44:07	11:52:46
10	12:07:49	12:14:30	12:10:28	12:01:33	11:56:47	11:59:56	12:05:51	12:05:43	11:57:15	11:47:15	11:44:13	11:53:13
11	12:08:13	12:14:31	12:10:12	12:01:17	11:56:45	12:00:08	12:05:59	12:05:33	11:56:54	11:46:59	11:44:19	11:53:41
12	12:08:36	12:14:30	12:09:56	12:01:02	11:56:44	12:00:20	12:06:06	12:05:23	11:56:33	11:46:44	11:44:27	11:54:08
13	12:08:58	12:14:29	12:09:40	12:00:47	11:56:44	12:00:33	12:06:13	12:05:12	11:56:11	11:46:29	11:44:35	11:54:37
14	12:09:20	12:14:27	12:09:23	12:00:32	11:56:44	12:00:46	12:06:20	12:05:01	11:55:50	11:46:15	11:44:45	11:55:05
15	12:09:42	12:14:24	12:09:06	12:00:18	11:56:45	12:00:59	12:06:26	12:04:49	11:55:29	11:46:01	11:44:55	11:55:34
16	12:10:03	12:14:21	12:08:49	12:00:04	11:56:46	12:01:12	12:06:31	12:04:36	11:55:07	11:45:48	11:45:06	11:56:03
17	12:10:23	12:14:16	12:08:32	11:59:50	11:56:48	12:01:25	12:06:37	12:04:23	11:54:46	11:45:36	11:45:18	11:56:32
18	12:10:42	12:14:12	12:08:15	11:59:37	11:56:50	12:01:38	12:06:41	12:04:10	11:54:24	11:45:24	11:45:30	11:57:02
19	12:11:00	12:14:06	12:07:57	11:59:24	11:56:53	12:01:51	12:06:45	12:03:56	11:54:03	11:45:13	11:45:44	11:57:31
20	12:11:18	12:14:00	12:07:40	11:59:14	11:56:57	12:02:04	12:06:48	12:03:42	11:53:41	11:45:02	11:45:58	11:58:01
21	12:11:35	12:13:53	12:07:22	11:58:59	11:57:01	12:02:17	12:06:51	12:03:27	11:53:20	11:44:52	11:46:13	11:58:30
22	12:11:52	12:13:45	12:07:04	11:58:48	11:57:05	12:02:30	12:06:53	12:03:17	11:52:59	11:44:43	11:46:29	11:59:00
23	12:12:07	12:13:37	12:06:46	11:58:37	11:57:11	12:02:43	12:06:55	12:02:56	11:52:38	11:44:34	11:46:46	11:59:30
24	12:12:22	12:13:28	12:06:28	11:58:26	11:57:16	12:02:56	12:06:56	12:02:40	11:52:17	11:44:26	11:47:03	11:59:59
25	12:12:36	12:13:19	12:06:10	11:58:16	11:57:22	12:03:08	12:06:57	12:02:23	11:51:56	11:44:19	11:47:22	12:00:29
26	12:12:50	12:13:09	12:05:52	11:58:06	11:57:29	12:03:21	12:06:57	12:02:06	11:51:35	11:44:13	11:47:41	12:00:59
27	12:13:02	12:12:59	12:05:34	11:57:57	11:57:36	12:03:33	12:06:56	12:01:49	11:51:15	11:44:07	11:48:00	12:01:28
28	12:13:14	12:12:48	12:05:16	11:57:48	11:57:43	12:03:46	12:06:55	12:01:31	11:50:54	11:44:02	11:48:21	12:01:57
29	12:13:24	12:12:40	12:04:59	11:57:40	11:57:51	12:03:58	12:06:53	12:01:13	11:50:34	11:43:58	11:48:42	12:02:26
30	12:13:34		12:04:40	11:57:33	11:58:00	12:04:10	12:06:50	12:00:55	11:50:14	11:43:55	11:49:04	12:02:55
31	12:13:43		12:04:22		11:58:09		12:06:47	12:00:36		11:43:52		12:03:24

Source: http://www.solar-noon.com/