A PROJECT TO BUILD AN 8.4GHz RADIO TELESCOPE Volume VI

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Contents *(continued from volume V)*

Note: page numbers herein are not referenced to previous volumes

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12.0 DETECTION OF OUR FIRST SPACECRAFT: STEREO-A

While several different spacecraft have been unsuccessfully searched for with the telescope the first spacecraft that has been successfully detected using this 8.4 GHz telescope was Stereo-A. Stereo-A is one of a pair of spacecraft, Stereo-A and Stereo-B, that were launched from the Cape Canaveral Air Force Station on the 25th of October, 2006 to study the structure and evolution of solar storms as they emerge from the sun. The mission for Stereo-B ended in 2018 but Stereo-A is still operating today, well beyond its design lifetime. Details regarding the Stereo mission can be obtained from https://solarsystem.nasa.gov/missions/stereo/in-depth/.

The Stereo-A spacecraft transmits nominally on a frequency of 8443.5185 MHz, depending upon mission adjustments and aging of spacecraft components. The actual frequency received by an observer on the Earth will be Doppler shifted due to the relative velocity between the observing telescope and the spacecraft. The NASA/JPL Horizons database provides current ephemeris information for the spacecraft and the K5SO_Tracking_v9_Horizons-Linux program is able to access that database to obtain current information on Stereo-A. Further, the “DSN Now” website, https://eyes.nasa.gov/dsn/dsn.html, provides real-time status information of the large DSN dishes so that it is possible to ascertain whether any given spacecraft is being currently accessed and what some of the details are regarding the communications, such as power level received and data rate being used.

Today I noticed that DSS-25, a 34m dish at the Goldstone USA facility, was being used to communicate with Stereo-A and the signal strength received by DSS-25 from Stereo-A was reported as -118 dBm at 8.44 GHz. Thus, if our 8.4GHz telescope were operating optimally with the 4.6m dish (which it isn’t yet, of course!) and our receiving system were comparable in sensitivity performance with the DSS-25 telescope (which is doubtful too!), we might expect to detect Stereo-A at a power level of (4.6m/34m)^2 = 0.018 = -17 dB lower than DSS-25, or -118dBm -17dB = -135 dBm. Our 8.4GHz telescope is, in fact, able to detect such a signal, as evidenced by the following even though the telescope is not yet operating optimally with regard to front-end sensitivity and dish illumination by the feed system.

A screenshot of the SpectraVue display of the SDR-14 output shows transmissions from the Stereo-A spacecraft being received at approximately 8443.571 MHz by our telescope, 53 Khz higher than the rest frequency of 8443.518MHz, with the shift due principally to Doppler effect. The SpectraVue display is shown below.

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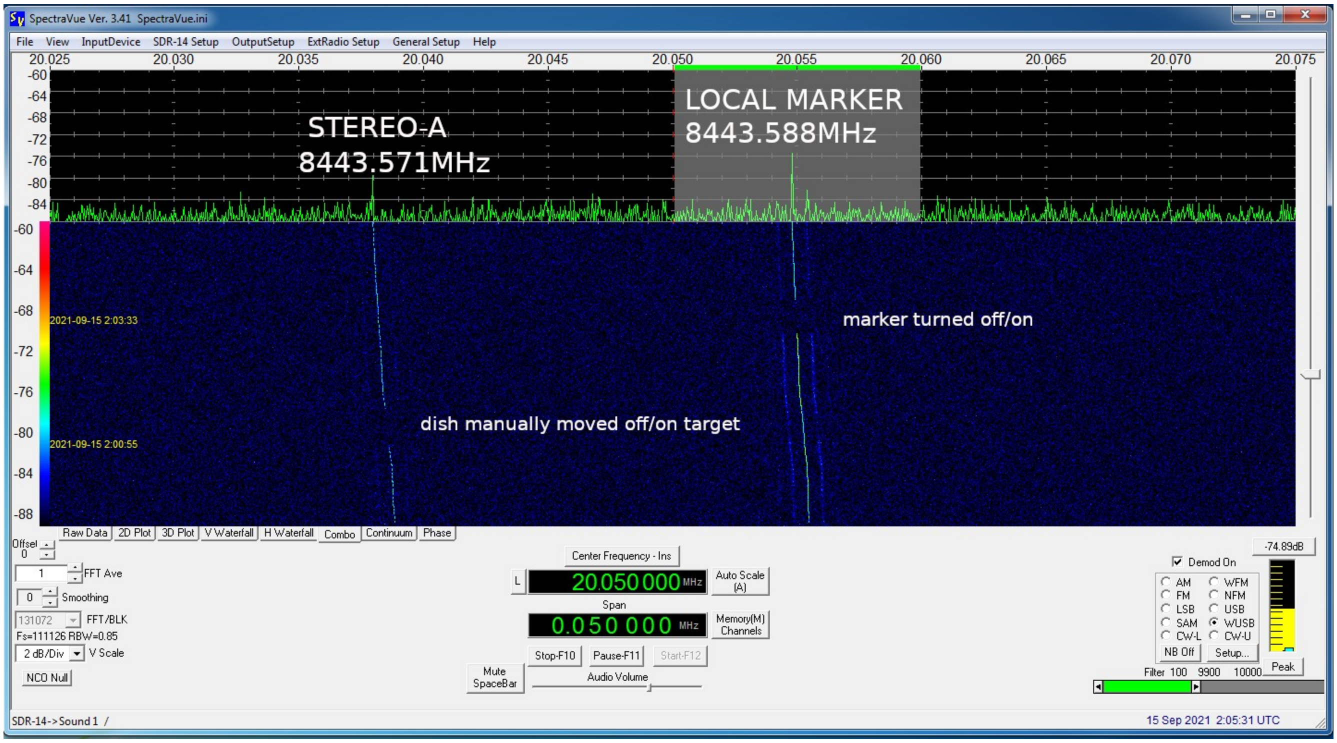

Figure VI-1. Transmissions from the Stereo-A spacecraft detected at approximately 8443.571 MHz as shown on the SpectraVue display using the SDR-14 to receive the 2nd IF frequency of the telescope.

The amount of Doppler shift of +53 KHz from the rest frequency of Stereo-A is in good agreement with that predicted by the K5SO_Tracking_v9_Linux-Horizons tracking program, which predicted a +61 KHz Doppler shift given the unknowns regarding aging of frequency components of the spacecraft and possible DSN operator commands sent to the spacecraft that might have shifted the transmit frequency of the spacecraft somewhat. The local marker generator was momentarily turned off then on to confirm the identity of the marker signal in the display. Similarly, the dish was momentarily moved off target then back on target to confirm that the signal attributed to Stereo-A was actually from Stereo-A. The marker signal was due to a -50 dBm signal from an HP83620A microwave generator applied to an 18" diameter off-center-fed dish mounted on the control room outside wall and pointed at the backside of the 4.6m dish located about 150' away. The slight instability in frequency of the marker signal detected is due entirely to instability of the local oscillator within the LNBF of the feedhorn.

The tracking program display at near the time of the above display image is shown below.

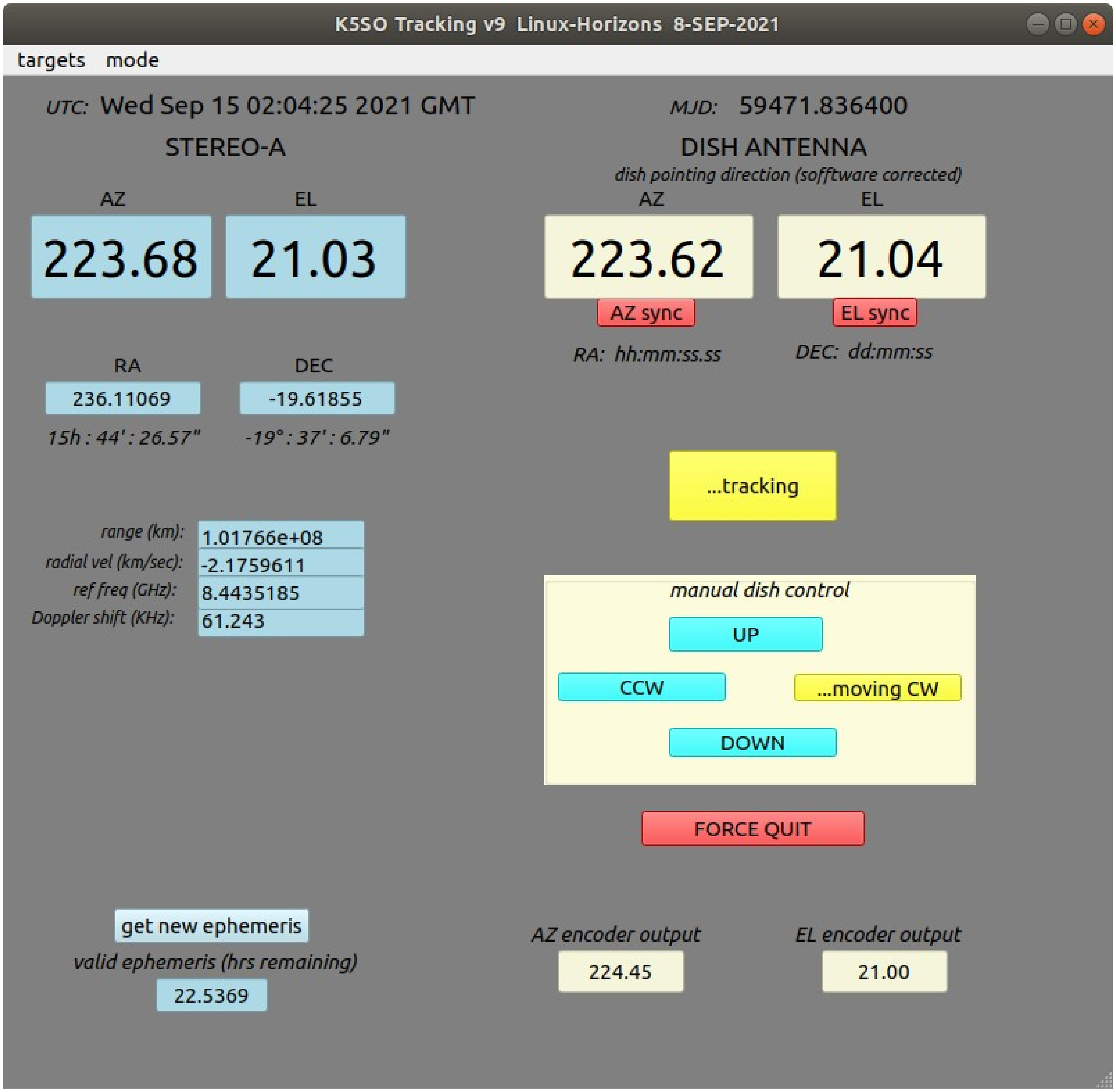

Figure VI-2. Display of the tracking program being used to track the Stereo-A spacecraft at an instant near the time of the SpectraVue display shown in the previous figure.

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According to the tracking program using the Horizons database for ephemeris information, Stereo-A during the time of the observation was located about 101 million kilometers from Earth. This agrees with the ‘DSN Now’ information obtained at the same time. The ‘DSN Now’ screenshot is shown below indicating that the received signal strength from Stereo-A at DSS-25 was about -118 dBm, as mentioned earlier.

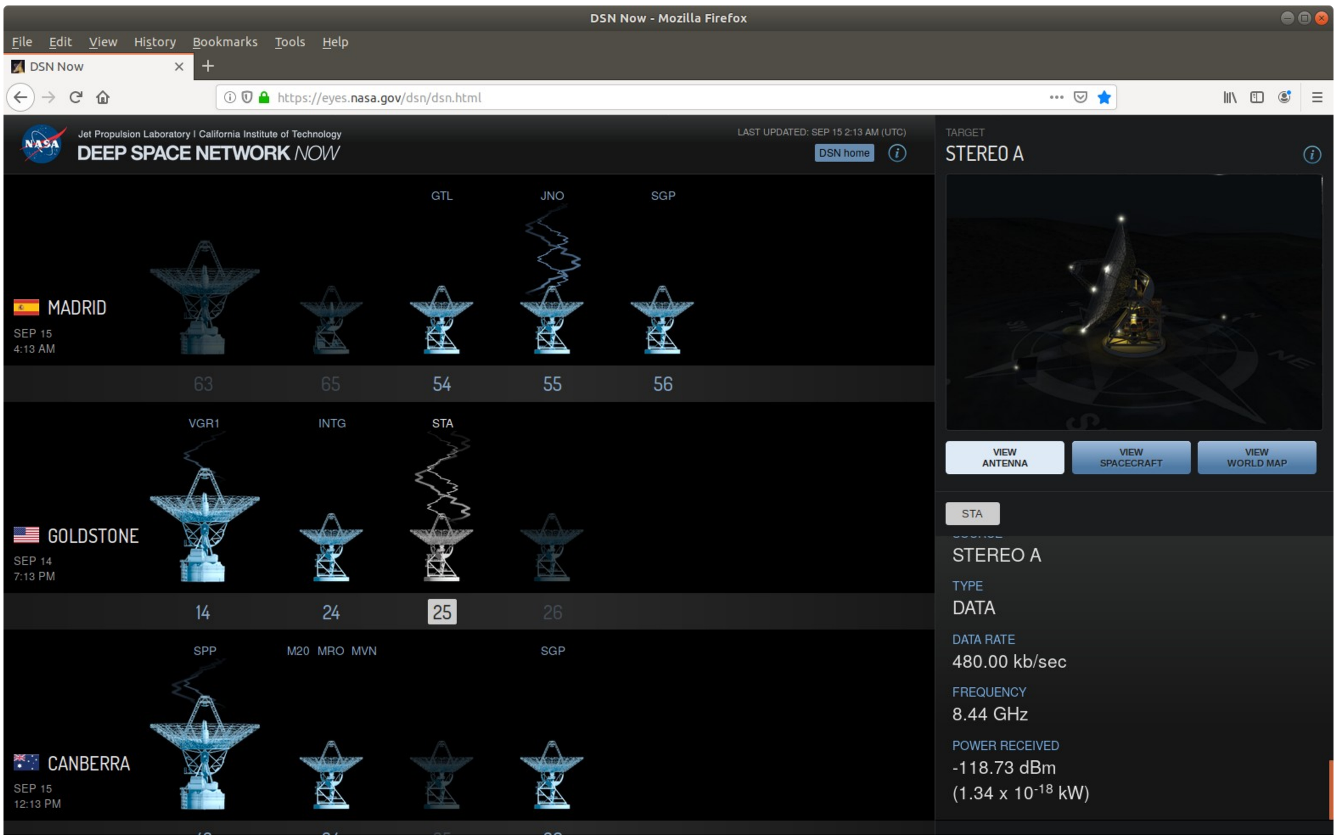

Figure VI-3. Display of the “DSN Now” website at the time of our Stereo-A detection. It shows that DSS-25 was transmitting and receiving from Stereo-A at the time and the received signal power level detected by DSS-25 was about -118 dBm. A data rate of 480 kb/sec was in use.

Although the signal strength of Stereo-A detected by our telescope was quite variable during tracking the signal typically showed about 9 dB above the averaged baseline noise level. It is expected that by making improvements in the illumination of the dish by the feed system signal levels can be improved, perhaps significantly. Nonetheless, this detection shows that the 8.4GHz telescope is moderately sensitive and is able to detect emissions from Stereo-A at least. It is clear that the improvements made with respect to pointing accuracy have been worthwhile and the modifications to the tracking program to include use of the Horizons database have significantly helped in detecting emissions from our first spacecraft.

13.0 DETECTION OF THE MARS RECONNAISSANCE ORBITER

The Mars Reconnaissance Orbiter (MRO) was launched on 12 August 2005 from the Kennedy Space Centre in Florida, USA. The MRO is currently operating. One of its principle functions is to relay communications between Earth and spacecraft and ground probes on and around Mars. I believe we have detected transmissions from the MRO today, even though none of the DSS dishes were shown to be actively communicating with it according to the 'DSN Now' website during our detection. Nevertheless, the detected signal moved in accordance with the Doppler shift predictions obtained using the relevant ephemeris obtained from the Horizons database, which is strong supporting evidence that the emissions were from the MRO. The figure below shows a screenshot of the MRO detection which was obtained at 15SEP2021 19:42_02 UTC.

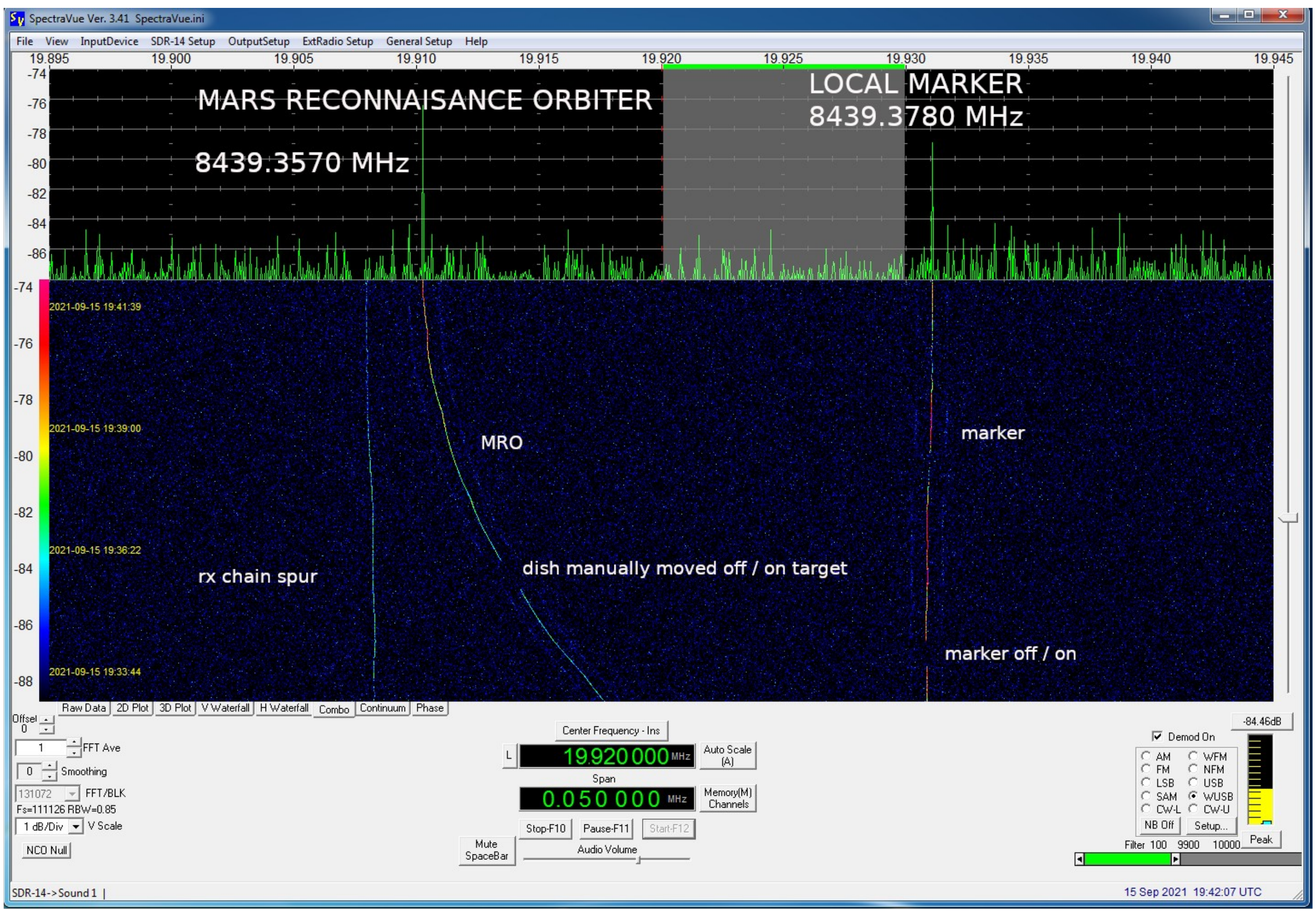

Figure VI-4. Detection of MRO, seen moving in frequency in accordance with the predicted Doppler shift for an Earth observer at my location for the spacecraft as it orbits Mars.

The tracking information at about the same time as the screenshot above was taken is shown below:

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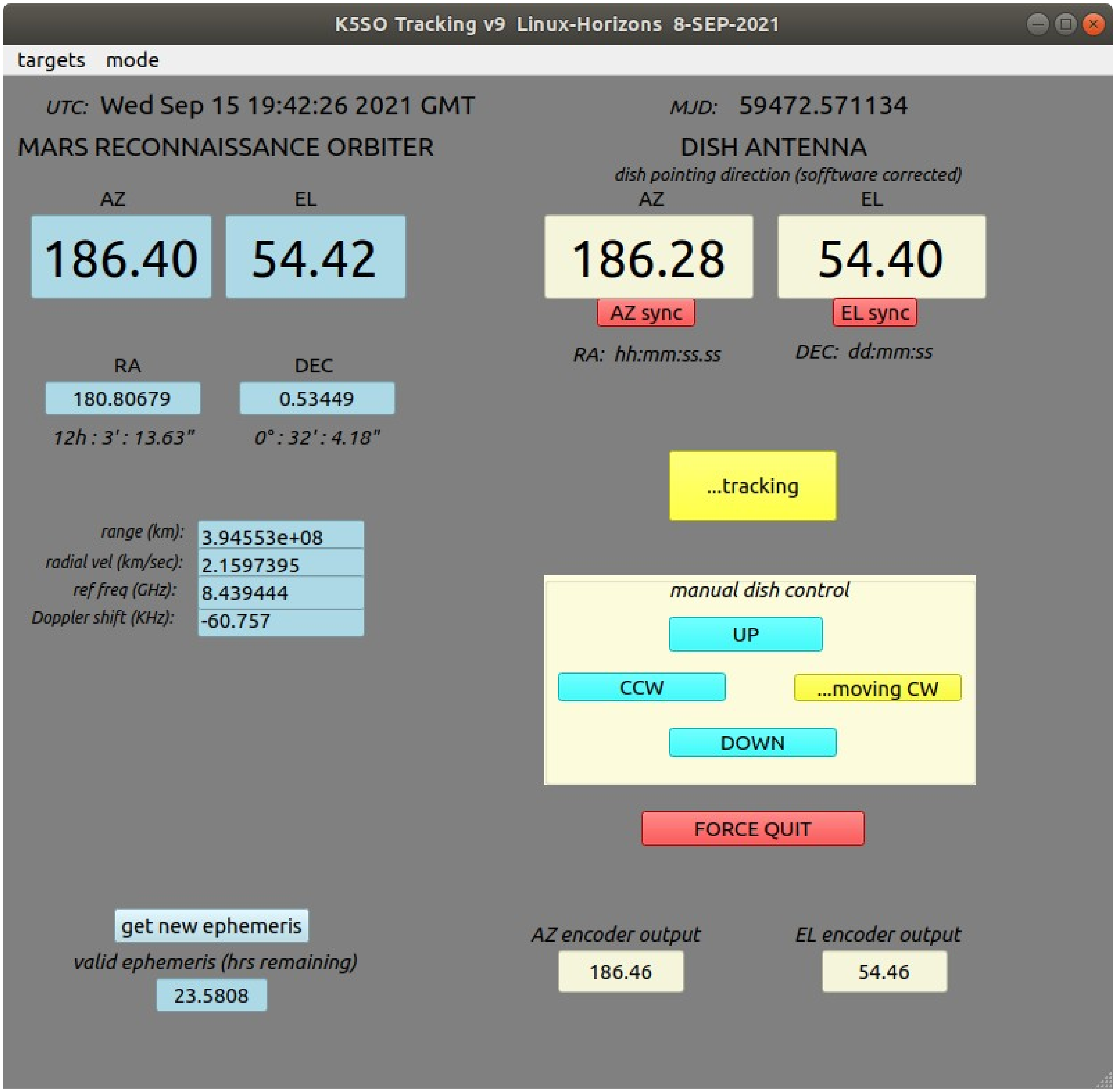

Figure VI-5. Screenshot of the tracking program at about the same time as the screenshot in the previous figure was taken. The tracking program screenshot shows the information obtained from the Horizons ephemeris.

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A quick check of other possible spacecraft positions and the associated predicted Doppler shifts did not immediately reveal any other viable candidate. A verification that our observation is in fact a detection of the MRO has been received by us from an experienced amateur DSN observer who has detected MRO emissions hundreds of times. This is a gratifying result for us, being new to spacecraft detections ourselves at this stage.

14.0 DETECTION OF THE JUPITER MISSION "JUNO" SPACECRAFT

The mission to Jupiter named "Juno" was launched on August 5, 2011 with the goal to improve our understanding of the solar system's beginnings by revealing the origin and evolution of Jupiter, according to the NASA Juno mission website:

https://www.nasa.gov/mission_pages/juno/overview/index.html.

Specifically, according to the website, the tasks for the Juno spacecraft are to:

Determine how much water is in Jupiter's atmosphere, which helps determine which planet formation theory is correct (or if new theories are needed)

- Look deep into Jupiter's atmosphere to measure composition, temperature, cloud motions and other properties
- Map Jupiter's magnetic and gravity fields, revealing the planet's deep structure
- Explore and study Jupiter's magnetosphere near the planet's poles, especially the auroras – Jupiter's northern and southern lights – providing new insights about how the planet's enormous magnetic force field affects its atmosphere.

The spacecraft uses a 2.5m dish for communications with Earth on a reference frequency of 8404.1358 MHz at a power level of 25 watts.

Our detection of transmissions from the Juno spacecraft are shown in the SpectraVue screenshot below (zoom in on the image to make it larger and easier to read):

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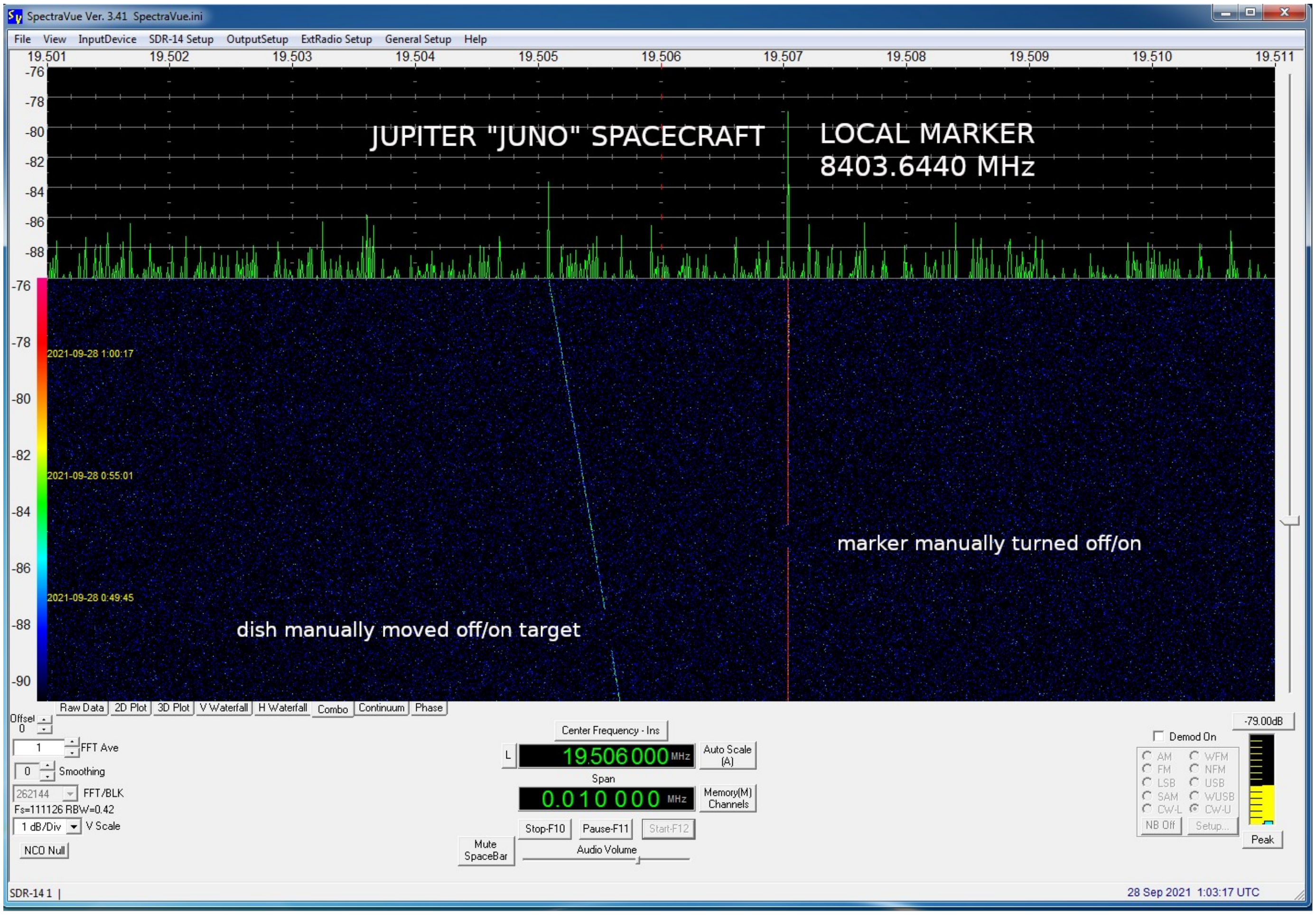

Figure VI-6. Screenshot showing signal transmission from the Juno spacecraft (blue line) and our local marker reference signal (red line). Please use your document viewer zoom feature to enlarge the image.

The nearly simultaneous screenshot of the tracking program is shown below, giving the range, Doppler shift to be expected for the observation, and other relevant data:

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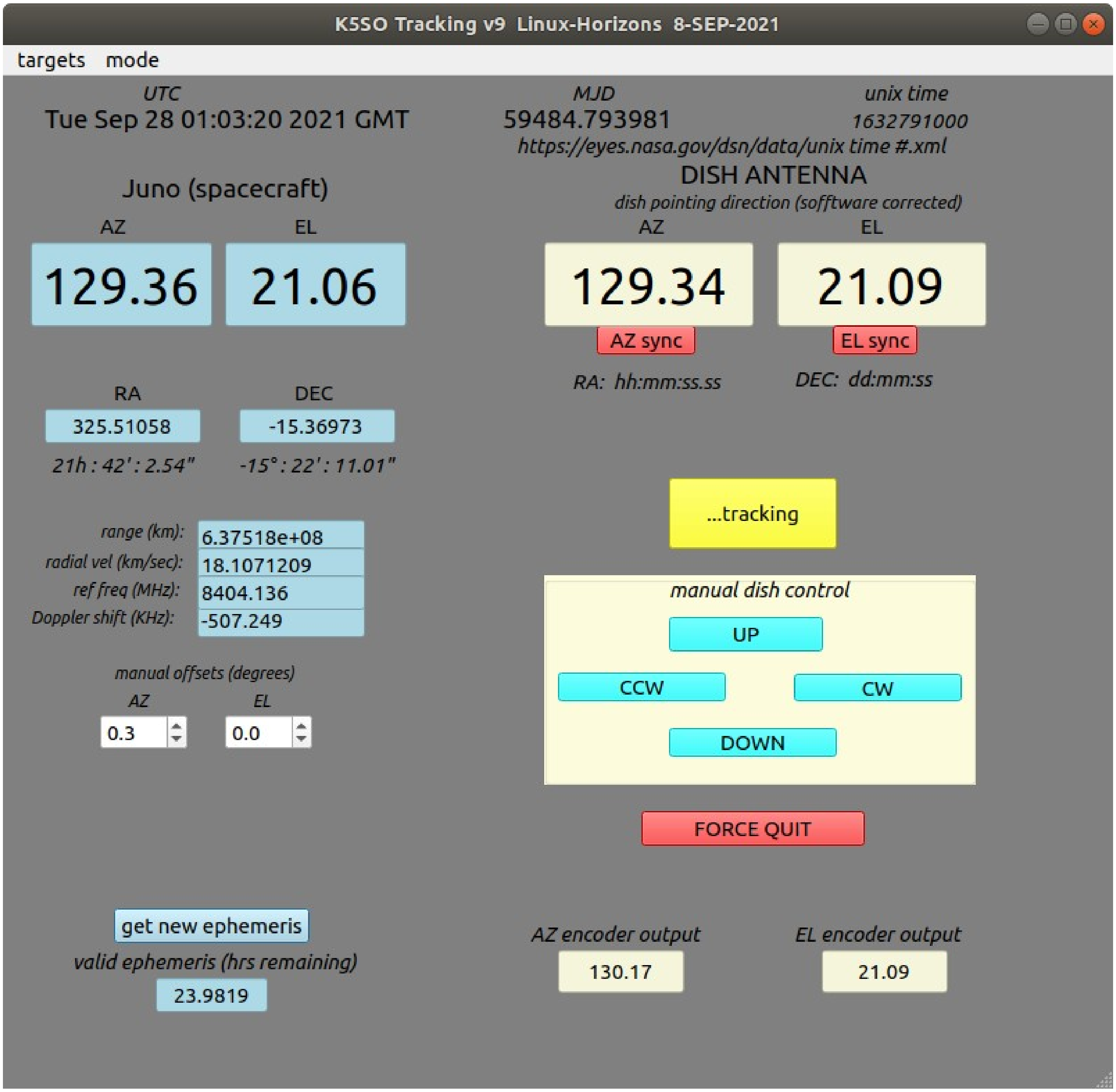

Figure VI-7. Tracking program screenshot taken roughly at the same moment the previous screenshot was taken of the SpectraVue program showing the Juno track in frequency.

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From the above image it can be seen that the radial velocity of the Juno spacecraft in its orbit around Jupiter at the observation time of 28 SEP 2021 01:03:20 UTC was expected to be about 18.107 km/sec receding from our telescope, at a range of about 637.5 million kilometers from us. This velocity results in a negative Doppler shift of about -507 KHz down from the spacecraft transmission frequency of 8404.1358 MHz.

Our reference marker at 8403.6440 MHz is shown in Figure VI-6 . The Juno signal at the time of the screenshot is about 2 KHz lower than our marker signal, or about 8403.6438 MHz. The difference between the observed signal from the spacecraft and the reference frequency of the spacecraft is

$$8403.6438 \text{ MHz} - 8404.1358 \text{ MHz} = -0.492 \text{ MHz} = -492 \text{ KHz}$$

which is only about 15KHz from the expected Doppler shift of about -502 KHz. This is taken as good evidence that the object we are receiving signals from is the Juno spacecraft. This, coupled with the facts that there are no other signals in the detected bandwidth and that the magnitude of the Doppler shift is decreasing at the rate predicted by the Horizons ephemeris during the time of the observation support our claim of detection of the Juno spacecraft.

None of the DSN earth stations were communicating with the Juno spacecraft during our observation unfortunately so additional supporting confirmation data from the DSN sites was not possible to obtain for our observation.

The signal strength from the spacecraft varied from being in the baseline noise of the panadapter display to a level of about 8 dB above the baseline noise level.

This spacecraft detection provides evidence that the sensitivity is reasonable for this 4.6m telescope, I believe. It will be interesting to compare observations of the Juno spacecraft using this telescope when DSN is communicating with it so that we can learn what data rate is being used for the communications. If the data rate is not too high it might be possible for us to decode some of the transmissions from the spacecraft. Whether this will be possible for us remains to be seen at this time. It may turn out that our telescope aperture is too small to permit such decoding.

14.0.1 FREQUENCY STABILITY IMPROVEMENTS TO THE LNBF

Improvements have been made to the telescope since observing the MRO previously in terms of replacing the free-running (drift prone) local oscillator of the LNBF front end with an external phase-locked digital synthesizer instead and Rb-vapor frequency standard module mounted onto the feed horn assembly. At the moment the only frequency-determining component of the telescope that is not locked to either a Rb-vapor frequency standard or a GPSDO frequency standard is the SDR-14 radio used for narrow-band observations such as this spacecraft emission observation. The SDR-14 is known

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to have a several KHz error in terms of it's frequency accuracy, even though its stability is reasonably good. No external reference input is available on the SDR-14 but we may soon modify the SDR-14 to accept an external reference. The new feed horn arrangement being used is shown below:

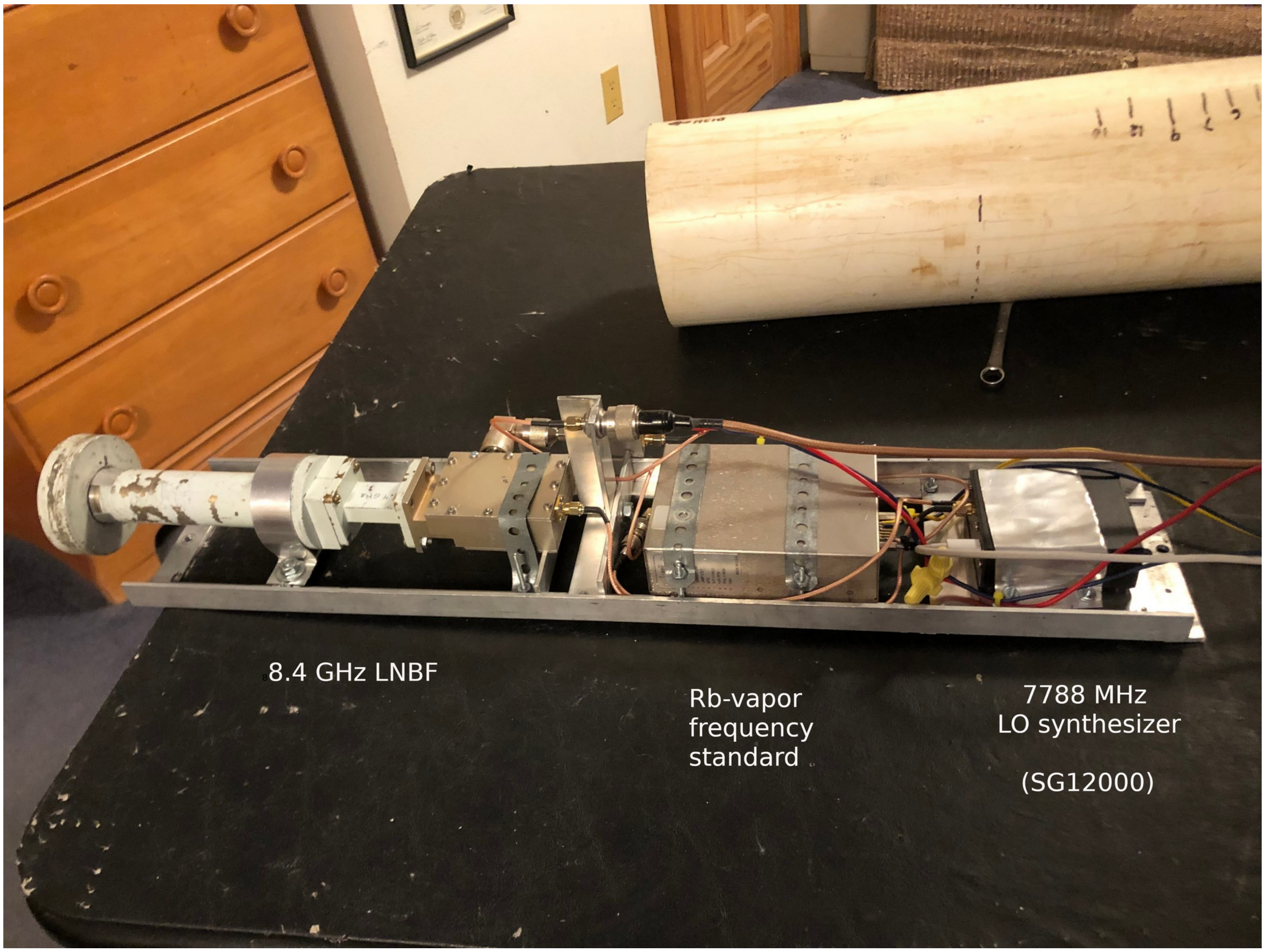

Figure VI-8. Feed horn assembly for the 8.4 GHz telescope.

The Rb-vapor frequency reference is a module that was removed from cell tower service and is similar to modules readily available from a variety of eBay sellers; it provides a 10 MHz reference frequency for the digital LO synthesizer module. The LO synthesizer is an SG-12000 unit available from DS Instruments, USA. The synthesizer produces an external +10 dBm, 7788 MHz LO frequency for the LNBF via the SMA cable shown at the rear of the LNBF assembly. This combination of modules

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provides a stable 8.4 GHz receiver chain resulting in a 650 MHz IF output that is routed from the antenna feed horn location to the telescope control room via 150’ of LMR-600 coaxial cable.

15.0 DETECTION OF THE MERCURY MISSION “BEPI COLUMBO” SPACECRAFT

According to the BepiColumbo mission website, https://sci.esa.int/web/bepicolombo, BepiColombo is Europe's first mission to Mercury. Launched on 20 October 2018, it is on a seven year journey to the smallest and least explored terrestrial planet in our Solar System. When it arrives at Mercury in late 2025, it will endure temperatures in excess of 350 °C and gather data during its one-year nominal mission, with a possible one-year extension. The mission comprises two spacecraft: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (Mio). BepiColombo is a joint mission between ESA and the Japan Aerospace Exploration Agency (JAXA), executed under ESA leadership.

Currently the two spacecraft are still joined together on their way to Mercury. The spacecraft transmits in X-band on any of several frequencies using 24 watts of power optionally into a 1 meter diameter high-gain antenna with 38.5 dB gain, a medium-gain antenna with 21.5 dB gain, or a low-gain antenna with 8 dB gain on any of three X-band frequencies: 8401.297 MHz, 8420.432 MHz, 8439.567 MHz. We located BepiColumbo while it was transmiting on 8420.432 MHz, as shown in the SpectraVue image below collected at 29SEP2021 18:21:22 UTC:

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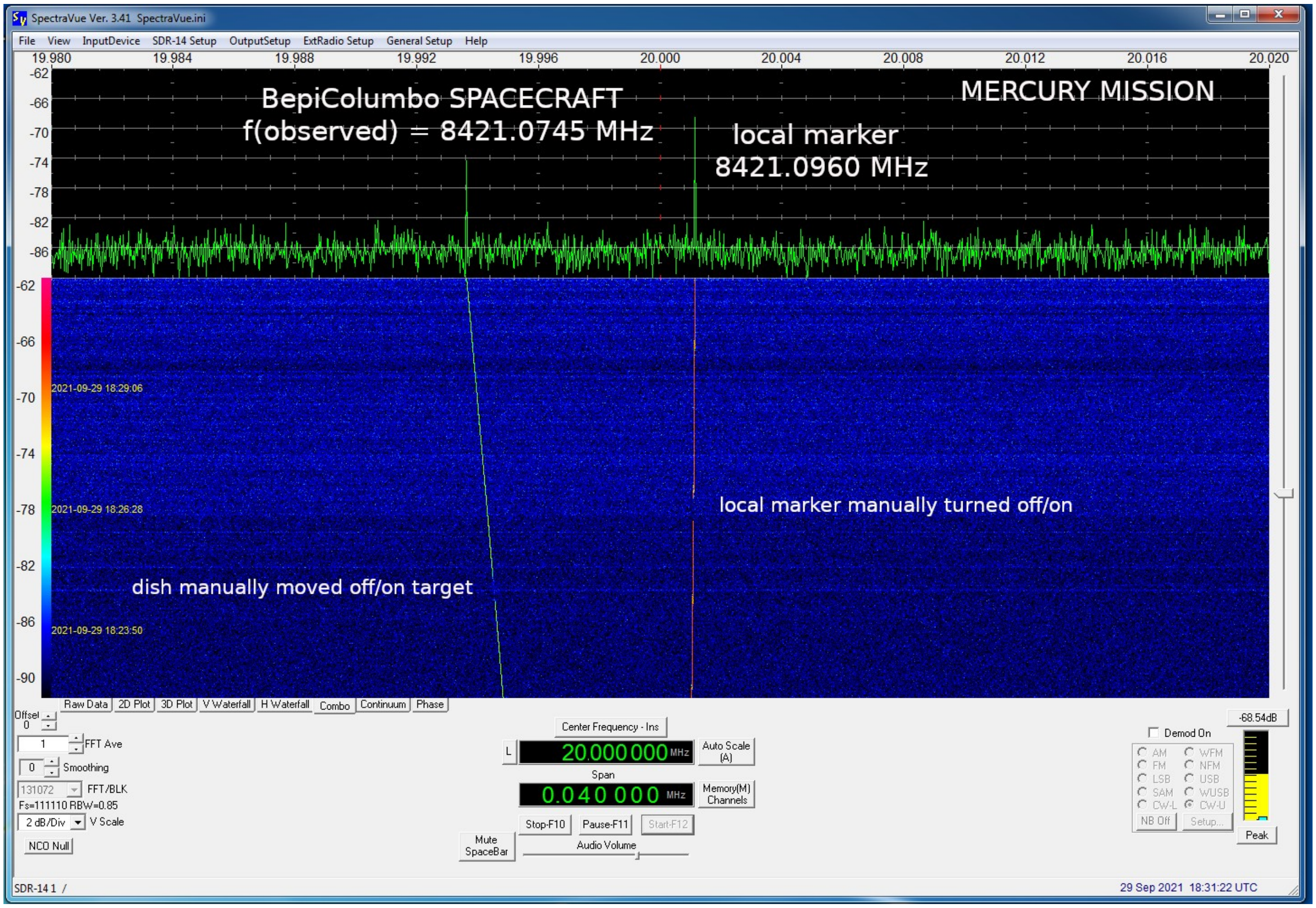

Figure VI-9. Detection of the BepiColumbo spacecraft on its way to Mercury is shown above. Use ZOOM feature of your pdf viewer program to enlarge the image.

The associated dish tracking screenshot taken at approximately the same time as the SpectraVue screenshot with relevant data for the spacecraft position is shown in the figure below.

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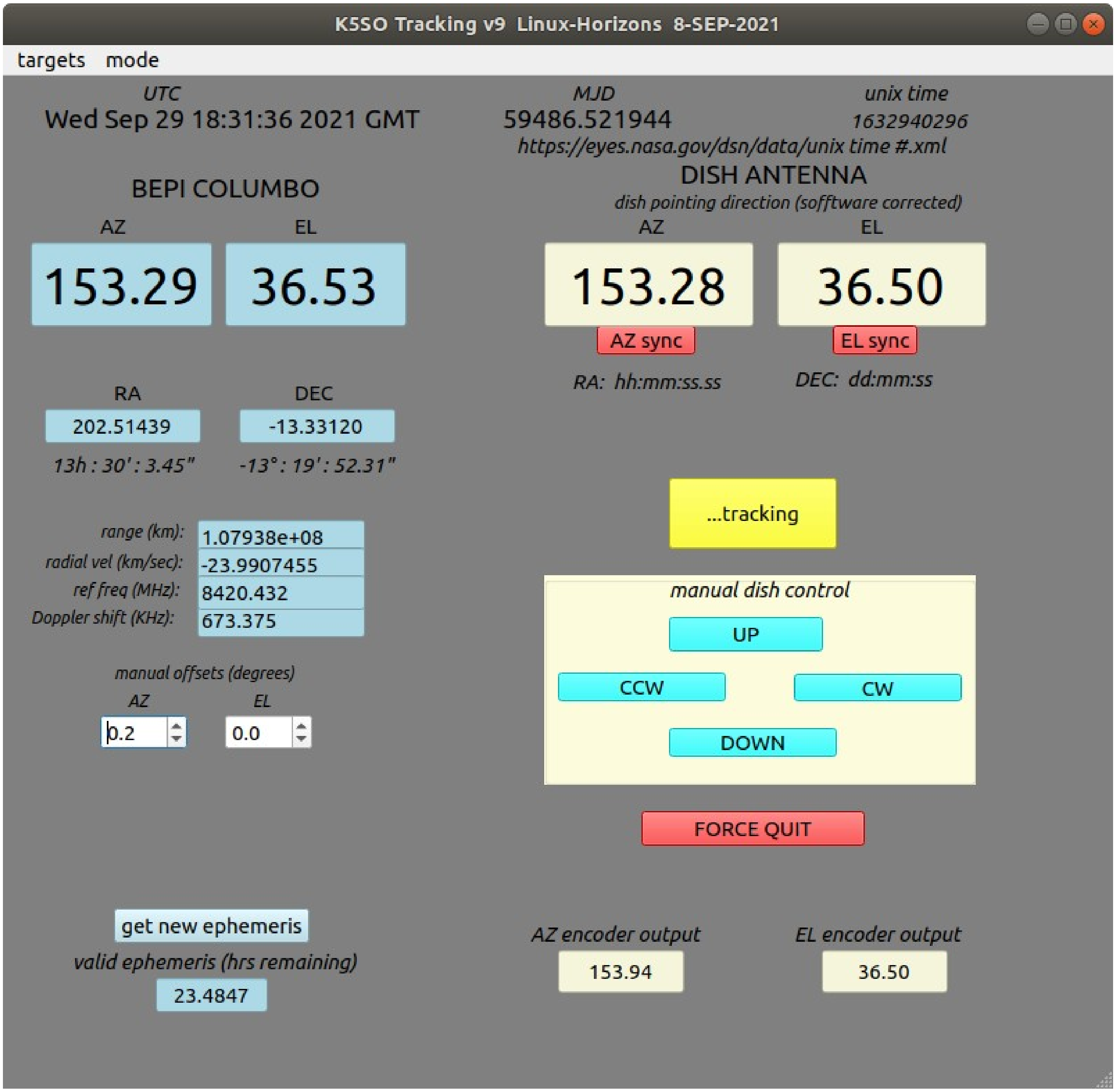

Figure VI-10. Tracking program screenshot showing the range, relative velocity to the telescope, and expected Doppler shift for the BepiColumbo signals.

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The figures above show that during the observation BepiColumbo was at a range of about 107.9 million kilometers from us, coming toward us with a radial velocity component of about 24 km/sec and slowing in terms of its radial velocity toward us in the highly elliptical journey of the spacecraft. The expected Doppler shift at the time the screenshot was collected is about +673 KHz, up from the spacecraft transmit frequency of 8420.432 MHz. We detected the spacecraft transmissions at a frequency of 8421.0745 MHz, yielding an observed Doppler shift of:

Observed Doppler shift = f(obs) – f(ref) = 8421.0745 MHz – 8420.432 MHz = 643 KHz.

in reasonable agreement with the 673 KHz Doppler shift predicted by the Horizons database ephemeris information. In addition, the observed frequency for the spacecraft is decreasing in accordance with the predictions relevant for the observation duration.

The signal strength of the spacecraft remained fairly steady for us at about 12 dB above the baseline noise level at the time of reception when using a 40 KHz bandwidth and an FFT size of 131,072 bins (i.e., about 305 Hz/bin resolution bandwidth).

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