Response to NASA Request for Information (RFI)

NASA's Artemis II Orion One-Way Doppler Measurements Tracking

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Submitted by:
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Table of Contents

Table of Contents

1. Introduction / Overview

This document presents the Deep Space Exploration Society's (DSES) response to NASA's Request for Information (RFI) titled "NASA's Artemis II Orion One-Way Doppler Measurements Tracking." DSES is a non-profit organization dedicated to advancing radio science, radio astronomy, and deep-space tracking through amateur-professional collaboration. This response outlines DSES's technical capabilities, experience, and potential contributions to NASA's Artemis II tracking initiatives.

For more information see the DSES web site at https://dses.science.

2. Organizational Capabilities

DSES operates a 60-foot parabolic radio telescope and associated communications facilities located near Haswell, Colorado. DSES has a demonstrated capability of receiving and analyzing deep-space signals. Our volunteer technical teams includes professionals from the aerospace, telecommunications, and scientific communities. We have experience in signal detection, Doppler tracking, and radio astronomy projects.

3. Technical Approach or Concept

Our proposed participation involves utilizing the DSES 60-foot dish and associated signal processing systems to support one-way Doppler measurements during Artemis II mission operations. DSES can provide raw Doppler data, time-stamped frequency measurements, and analysis products suitable for comparison with NASA's tracking data. We are prepared to coordinate with NASA centers for data exchange protocols, calibration procedures, and observation scheduling.

4. Submission Criteria for DSES:

a) Specifications regarding the functional performance metrics of the DSES ground station.

The Deep Space Exploration Society (DSES) 60-foot antenna, located near Haswell Colorado, is a parabolic dish with the following physical and geometric parameters:

Aperture Characteristics

Parameter	Symbol	Value	Notes
Antenna Type	—	Prime-focus parabolic reflector	Alt-azimuth mount
Diameter	D	60 ft (18.29 m)	Rim-to-rim diameter

Parameter	Symbol	Value	Notes
Focal Length	f	6.71 m (22 ft)	Measured mechanically
f/D Ratio	f/D	0.367	Typical for deep parabolas
Aperture Area	$A = \pi D^2/4$	≈ 263 m²	Geometric collecting area
Estimated Efficiency	η	0.55–0.69	Depends on feed and alignment
Surface RMS accuracy	—	≈ 2–3 mm	Suitable up to ~10 GHz operation
Mount Type	—	Az–El	Manual or servo tracking capable
Feed support	—	3-leg truss feed with adjustable focus	Currently supports S-band, X-band

Derived Parameters

- Effective Aperture (A_e): $A_e = \eta A \approx 0.69 \times 263 = 181.5\ m^2$
- Gain (at 2.2165 GHz): $G = \eta(4\pi A/\lambda^2) \Rightarrow G \approx 3.16\times10^5$ (50.5 dBi)
- Half-Power Beamwidth (HPBW): $\theta_{3dB} \approx 70\lambda/D = 70 \times (0.1353/18.288) \approx 0.52°$

Summary

- Dish Diameter: 18.3 m (60 ft)
- f/D Ratio: 0.37
- Aperture Efficiency: ~0.6
- Effective Area: ~158 m²
- Beamwidth (at 2.2 GHz): ~0.52°
- Gain: ~51 dBi

The DSES ground station gain-to-noise temperature ratio (G/T): The operating frequency is assumed to be 2216.5 MHz, the receiver noise figure is about 1.0 dB, and the system temp is about 180K.

$G/T\ (dB/K) = G_{ant}\ (dBi) - 10\log_{10}(T_{sys})$
Gain(ant) @ 69% efficiency = 51 dB
$G/T = 51 - 10\log_{10}(96.7\ K)$
$G/T = 51 - 19.9 = 31.1\ dB/K$

Time and Frequency Reference (TFR): The DSES ground station TFR system consists of a late model HP5065A Rubidium Vapor Frequency standard with 5MHz and 1PPS outputs and digital clock. It is trained (not steered) by data collected on a dedicated computer from a GPS receiver and a Time Interval Counter (TIC) that is analyzed by a Python program. After training, the TFR is expected to have a frequency error on the

order of +/- 2e-12. This is the same system that was developed by one of our volunteers for NASA's Very Long Baseline Interferometry (VLBI) and VGOS radio telescopes. During the mission the TFR will be run open loop to avoid introducing steering artifacts, but the frequency error will be continuously measured so that even that small error can be removed from the results in post processing the data if desired.

A performance estimate for a well-adjusted HP 5065A:

- At $\tau = 1$ s, Allan deviation might be on the order of 1×10^{-12} to few $\times 10^{-12}$
- At $\tau = 10$ s, it might drop to a few $\times 10^{-13}$
- At $\tau = 20$ s, perhaps in the low 10^{-13} range

So, for the interval 1 to 20 seconds, a rough estimate might be ADEV(τ) ≈ between 1 and 3 parts in $\times 10^{-12}$ at 1 s, falling to between 1 and 5 parts in 10^{-13} at 10 to 20 seconds.

If needed, the Alan Deviation and related measurements for the HP 5065A can be documented as one of our volunteers has a precision time and frequency lab with an independent reference and a 53100A Phase Noise Test Set.

Additional relevant ground station performance characteristics:

b) Expertise in the capture and consistent monitoring of the Orion signal and/or similar S-band signals.

DSES routinely tracks and monitors radio astronomy targets, including pulsars and magnetars. We have a team dedicated to the development and maintenance of the tracking hardware and software for the 60-foot dish. We can track a wide variety of celestial objects, including the moon. Our ability to steer the dish is easily within the parameters of the mission.

In 2022, the Deep Space Exploration Society (DSES), in cooperation with the Japan Aerospace Exploration Agency (JAXA) and the University of Tokyo, attempted to track the Japanese OMOTENASHI CubeSat, which was deployed from NASA's Artemis I mission. Although the effort was ultimately unsuccessful due to the spacecraft failures, it demonstrated DSES's capability and initiative in attempting to follow the Artemis I trajectory using an open loop tracking method.

c) Ability to generate and document one-way Doppler tracking data.

The system design that DSES will use for the Artemis II mission includes a feed mounted low noise amplifier and a high-quality software defined radio (SDR), probably an Ettus Research B210 or equivalent. The precision frequency reference (TFR), described above, is fed up a fiber optic link from the control room to the SDR at the feed to ensure that all measurements are synchronized to that reference. Resulting data is returned to the control room via another fiber optic link and is processed by a computer into the desired format and sent to NASA over our new fiber optic internet connection.

d) Proficiency to deactivate ground station transmission functionalities, ensuring zero radiation towards Orion.

DSES has a variety of feeds for the 60-foot dish in stock and under development covering frequency bands from 380MHz to over 8GHz. All of these except for the 1296 MHz feed are designed for receive only operation, mostly for radio astronomy. They are designed with low noise preamplifiers mounted in the feed, so transmissions are impossible. The design we are considering for Artemis II includes the use of a receiver module also at the feed point with data sent to the control center over a fiber optic data link. Thus, there will be no possibility of transmissions from DSES during the Artemis II mission.

e) Tracking data format compatibility and the proficiency to send this information to NASA.

- Tracking data will be compliant with the CCSDS Tracking Data Message (TDM) international standard as defined by the Consultative Committee for Space Data Systems (CCSDS) for exchanging tracking and navigation data between space agencies, ground stations, and spacecraft operators as defined by CCSDS 503.0-B-2 Tracking Data Message (Blue Book), Issue 2, June 2020 available at https://ccsds.org/Pubs/503x0b2c1.pdf.
- DSES has a variety of Windows and Linux computers available to format the data and programmers proficient in Python, C, C++, and GNU Radio to develop whatever interfaces are needed. Recently, DSES has installed a fiber optic interface to our internet service provider. We are subscribed to 75Mbps bi-directional service but, if necessary DSES can increase that service to a data rate over 1Gbps on short notice.
- CCSDS Section 3.1.5 states “It shall be possible to exchange a TDM either as a real-time stream or as a file.” Now that DSES has a fiber optic interface to the internet, either or both transmission methods can be supported.
- The total volume of data collected is a function of the specific CCSDS message types recorded, the sampling rate at which the data are acquired, and the file segmentation strategy, which dictates the number of headers and metadata sections required. A preliminary estimate indicates that Doppler data sampled once per second, with each record comprising approximately 60 characters, would generate on the order of 32 megabytes over a six-day mission duration. The computer system designated for use by DSES is equipped with a minimum of one terabyte of solid-state storage, providing ample capacity for all anticipated onsite data recording requirements.

f) Geodetic WGS84 Information for the DSES 60-foot antenna:

- Station Name: DSES

- East Longitude: -103° 09′ 22.98″ (-103.15638)
- Geodetic Latitude: 38° 22′ 51.09″ (38.380858)
- Height: 4298 ft (1.310 km)

5. Additional Required Supplemental Information:

DSES routinely measures Doppler offsets during radio astronomy measurements of pulsars and magnetars. We do not, however, have experience of one-way Doppler tracking during past launch and/or trajectory sequences. Some of our volunteer scientists and engineers do have experience in this area from their commercial work for NASA and/or defense contractors. The same is the case regarding conducting spacecraft RF signal tracking and furnishing Doppler tracking for celestial assets positioned beyond GEO.

As stated above, the DSES feed that will be used for Artemis II prevents any possibility of uplink radiation by design. DSES will also place large warning sign(s) in the control center to assure that all operators are aware of this restriction during the Artemis II mission.

6. Feedback and Recommendations

DSES recommends considering the inclusion of qualified amateur and non-profit deep-space tracking organizations as part of NASA's extended ground-based observation network. Collaboration at this level enhances resilience, public engagement, and data diversity for mission analysis. We also suggest establishing standardized interfaces for frequency reference data and metadata to streamline data fusion.

Note: This information is provided for planning purposes only and may be shared within NASA for evaluation of potential collaboration opportunities.