National Aeronautics and Space Administration

Cis-lunar Space Debris Radar and Advanced Signal Processing for GSSR

Principal Investigator: Clement Lee (332); Co-Investigators: Nereida Rodriguez Alvarez (332), Joseph Jao (332), Yu-Ming Yang (332), Walid Majid (332), Kamal Oudrhiri (332), Charles Naudet (335), Marina Brozovic (392)

Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Cis-Lunar Space Situational Awareness - Strategic Initiative Leader: Joseph Lazio

Objectives:

1.) Development of Cis-lunar space debris radar (CSDR):

- establish the capability to detect and collect data (size, Doppler, range) on objects (mini-moons, lost spacecraft, small asteroids, etc.) out in cis-lunar space.
- define the limitations and requirements for the standardized use of the cis-lunar SDR detection technique in the future (size and velocity of the debris impact on detection capability, best geometrical configurations).

2.) Cis-lunar space target improved characterization by applying Advanced Signal Processing:

- Develop innovative advanced processing solutions that improve detection of targets in the cis-lunar space.
- Apply developed solutions to NEO in general, not just cis-lunar space, expanding the applicability of these techniques to regular tracks.

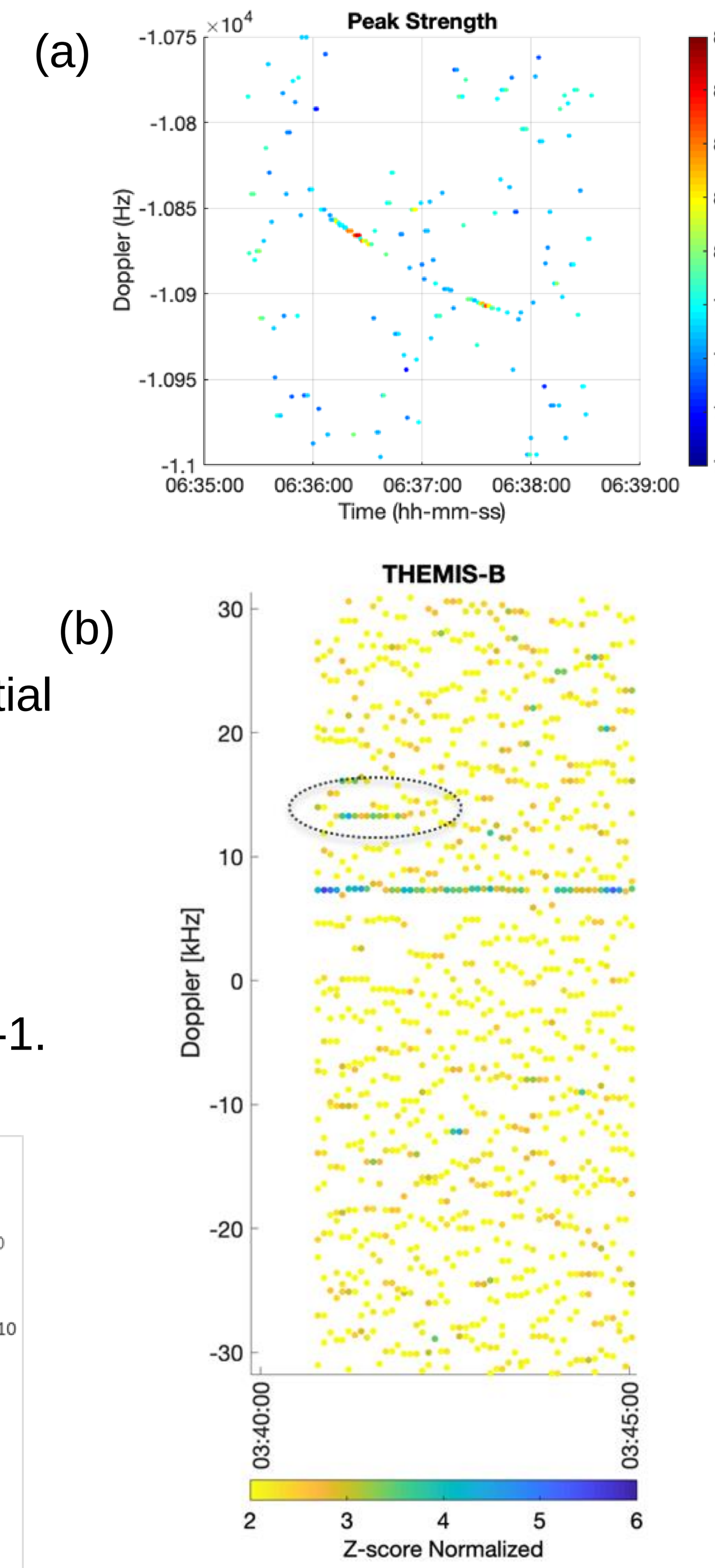

Figure 2. Peak Tracking: CW detection of (a) LRO at lunar south pole with DSS-14 and DSS-25; (b) THEMIS-B DSS-14 to GBT.

Background:

The Goldstone Solar System Radar (GSSR) has proven to be essential in:

- Tracking Near-Earth Objects (NEO): United States annual expense in tracking NEO that pose a hazard in potential to impact the Earth is ~$4 million.
- Providing NASA (Office of Safety and Mission Assurance) with exclusive orbital debris data in Low Earth Orbit (LEO) via Goldstone's Orbital Debris Radar (ODR) for the safety of astronauts and spacecraft operating in that region of space.

With the new focus to send humans to the Moon, this protection needs to extend to cis-lunar space. GSSR has proven the capability through the detection of the Lunar Reconnaissance Orbiter and lost spacecraft Chandrayaan-1. Small asteroids and debris crossing cis-lunar space may endanger lunar missions.

Approach and Results:

1.) <u>Cis-lunar SDR:</u>
Using existing infrastructure, hardware, and software and the proven LEO ODR technique:

- we investigated the feasibility of a CSDR by extending LEO ODR out to cis-lunar space: SNR analysis, waveform design, applications, etc.
- detection of smaller objects near the moon evolved the waveform design back towards traditional continuous wave (CW) waveforms. (Fig.1)
- we developed a peak tracking methodology, that scans the spectrum of the data in the frequency domain with adjustable window sizes to find peaks (Fig.2).

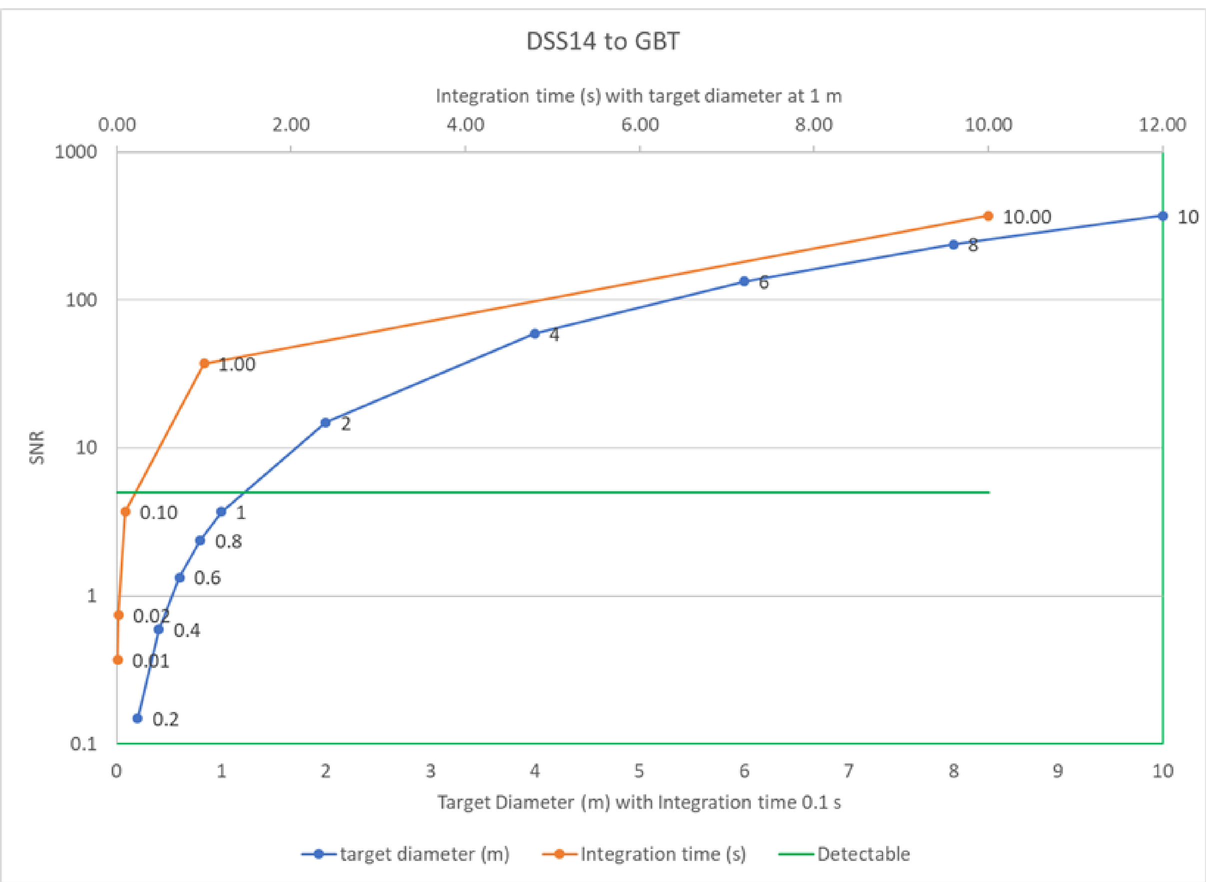

Figure 1. Sample of the SNR analysis. Several test bistatic experiments were conducted using DSS-14 transmit to various receive antennas, DSS-13, GBT, DSS-25

2.) <u>Advanced Signal Processing:</u>
To address objectives:

- we continued and completed the study of denoising techniques applied to past NEO tracks. Block-matching and 3D filtering (BM3D) and Feedforward Neural Network (FFNN) denoising techniques were studied and compared to standard GSSR signal processing results. The most effective is FFNN.
- FFNN denoising could be used for enhancing detection of weaker targets or detections with smaller dishes [1], (Fig. 3)
- We applied denoising to cis-lunar object Telstar-401 measured with CSDR.
- We started study on the use of a Polyphase Filter Bank (PFB) scheme to replace the standard Fast Fourier Transform (FFT): test on cis-lunar track on LRO (Fig. 4)

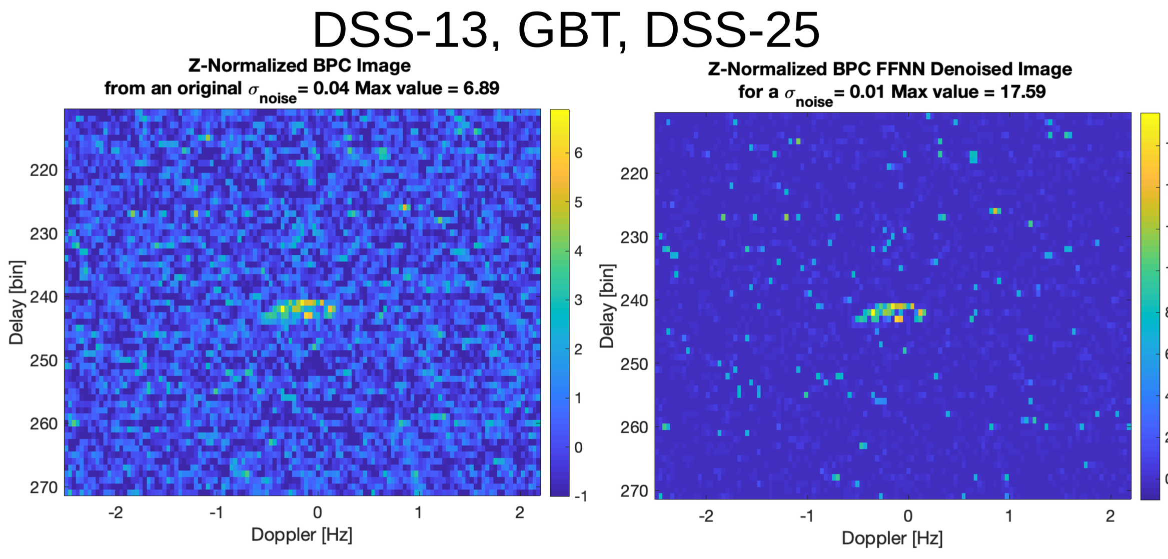

Figure 3. Sigma-level on 2017 WX12 data: (a) original (6.89); and (b) FFNN-denoised (17.59)

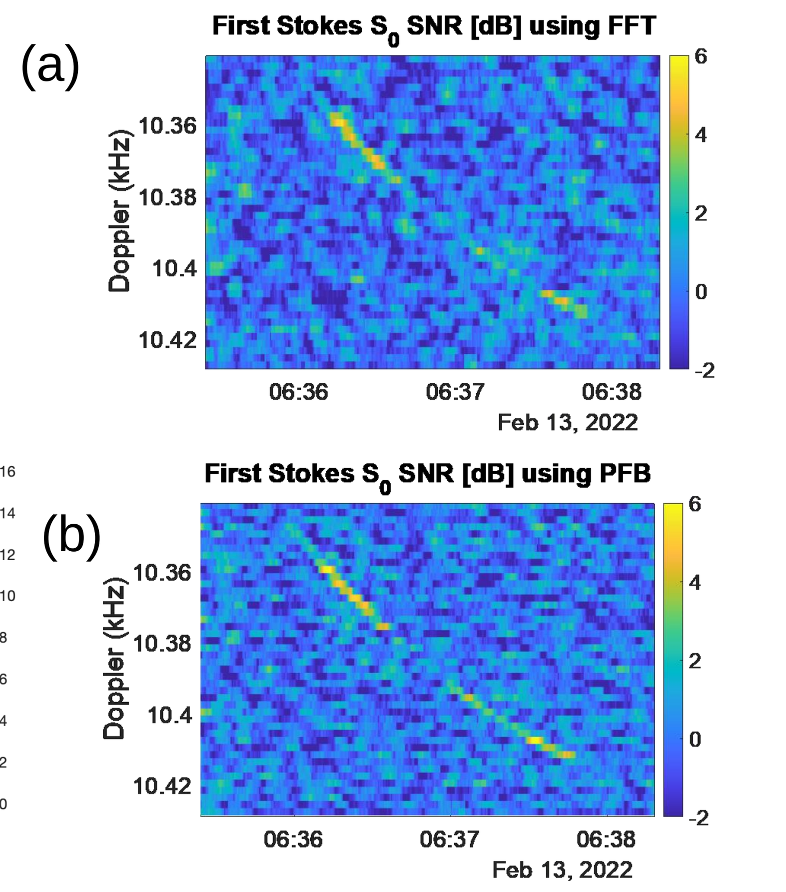

Figure 4. Processing Scheme: (a) FFT; (b) PFB

Significance/Benefits to JPL and NASA:

1. Cis-lunar SDR blindly radar-based detection of objects will bring a valuable capability for NASA to monitor debris in cis-lunar space and will provide valuable data for potential hazards for future missions to the moon.
2. Enhancing the GSSR observational capabilities with new signal processing techniques can enable a better detection of cis-lunar bodies.
3. Both objectives will help JPL become the lead in the capability to monitor the cis-lunar space and provide NASA with valuable data to ensure safety of a spacecraft crossing cis-lunar space.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#22-5337
Poster Number: RPC#R20045

Publications:

Rodriguez-Alvarez, N.; Jao, J.S.; Munoz-Martin, J.F.; Lee, C.G.; Oudrhiri, K. Feed-Forward Neural Network Denoising Applied to Goldstone Solar System Radar Images. *Remote Sens.* 2022, *14*, 1643. https://doi.org/10.3390/rs14071643

PI/Task Mgr. Contact Information:

Email: clement.g.lee@jpl.nasa.gov