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

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Objectives:

Previously this task accomplished two main 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.

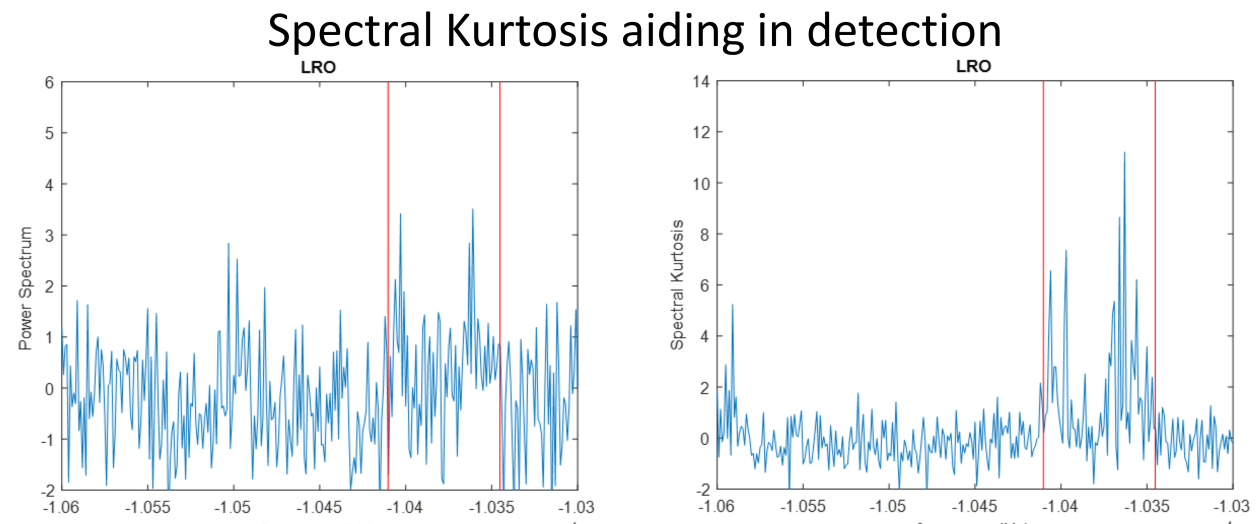
The 4th year, we added an objective to increase the sensitivity of the existing cis-lunar space debris radar to accommodate the detection of 1-m or smaller targets at lunar distances. Since we cannot change the physical characteristics of our existing bistatic setup, we will be focusing on signal processing techniques to increase the radar sensitivity.

Approach and Results:

Investigate a number of different signal processing techniques to increase the sensitivity of our current detection capability:

- Implemented a software polyphase filter bank (PFB) to channelize the data for better performance. Conventional GSSR processing includes a Fast Fourier Transform (FFT). When FFT is applied, the input signal is affected from two major drawbacks: leakage and scalloping loss. The leakage results when signal/clutter occupies more than one output frequency bin. The PFB technique helps minimize both leakage and scalloping loss. The PFB produces a flat response across the channel and provides excellent suppression of out-of-band signals.
- Investigated the use of polarimetric observables to improve the detection of satellites in cis-lunar space. Current techniques rely on detection of single-handed polarization channels (LCP and RCP). Borrowing polarimetric techniques from radio astronomy, we formed all 4 Stokes polarization parameters using I/Q digital samples. Combining both polarizations improved detection via first Stokes parameter. But to benefit from the other Stokes parameters will require the two channels to be phased up very precisely. A celestial source with known polarization ratios can be used to calibrate this phase in the future.
- Investigated the use of spectral kurtosis (kurtogram) as a denoising tool. Kurtograms can distinguish non-stationary signals (positive), stationary (near zero), and harmonic signals (negative). This allowed for better detection of smaller signals. Kurtograms are useful as a supplementary tool in detection. Unfortunately, while the echo signal in kurtogram is stronger, other clutter and interfering signals are also stronger as well.
- Implemented an orbit fit to aid in detection search. Using a model elliptical orbit (that can be from known real objects or simulated), we correlate the relevant segment of orbit with the data set to find the minimum mean square error. A sample trial search for Chandrayaan-1, unfortunately, the did not find Chandrayaan-1. Orbit fit can be applied in combination with other techniques.
- Refine operations by incorporating the use of the radio science's Open Loop Receiver (OLR) into our CSDR operations. This allowed for easier real-time displays to respond and assess during the observation.

Spectral Kurtosis aiding in detection



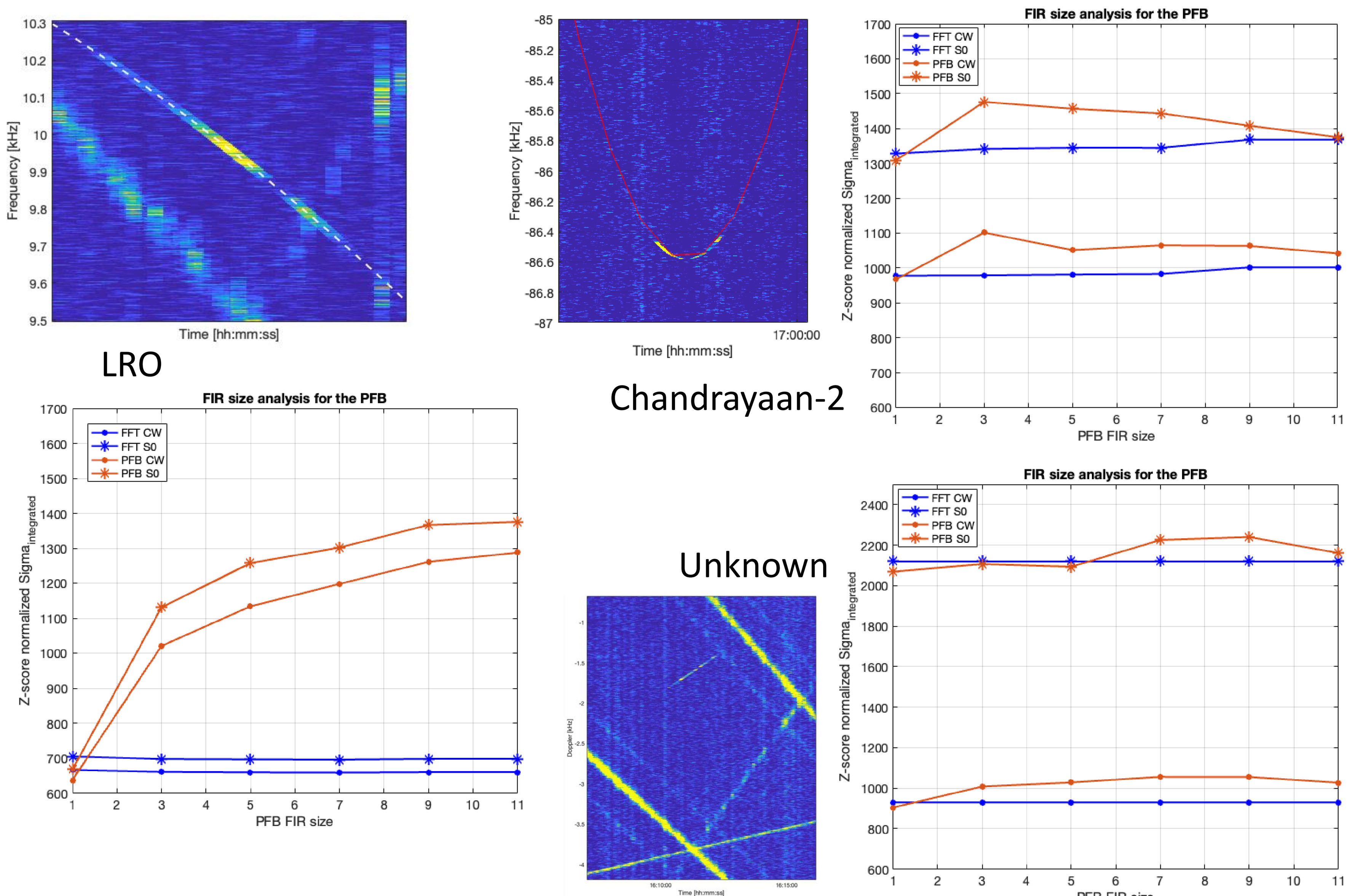
Background:

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.

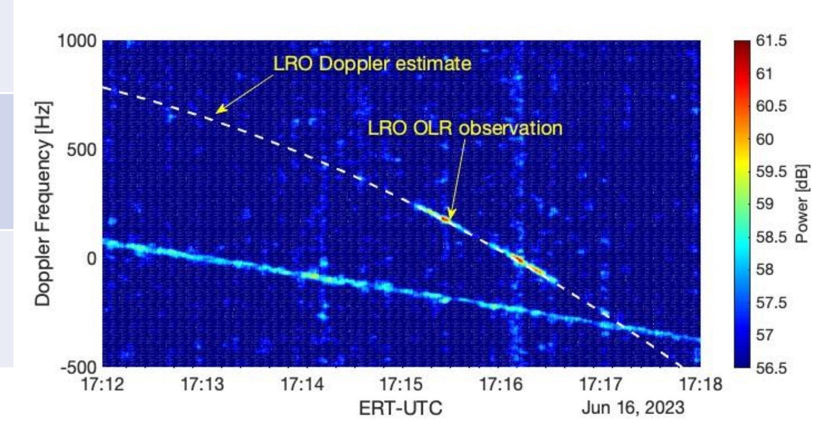
With the new focus to send humans to the Moon, this protection needs to extend to cis-lunar space. GSSR has proven the capability through the detection of the Lunar Reconnaissance Orbiter and lost spacecraft Chandrayaan-1. Small asteroids and debris crossing cis-lunar space may endanger lunar missions.

Z-score normalized sigma levels integrated over the predicted orbit.



	LRO	CH-2	Unknown
FFT CW (standard)	657.87	983.017	929.052
FFT S0 (polarimetric approach)	694.82 (5.62 % improvement)	1344.36 (36.76 % improvement)	2119.93 (128.2 % improvement)
PFB CW (FIR size =7)	1197.86 (82.1 % improvement)	1065.08 (8.35 % improvement)	1055.37 (13.6 % improvement)
PFB S0 (polarimetric approach, FIR size =7)	1301.73 (97.87 % improvement)	1443.48 (46.84 % improvement)	2224.93 (139.5 % improvement)

LRO detection using OLR



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.

Publications:

[1] N. Rodriguez-Alvarez, et.al., "Feed-Forward Neural Network Denoising Applied to Goldstone Solar System Radar Images", Remote Sensing, Feb 2022
[2] C.G. Lee, et.al., "Cis-lunar Space Debris Radar Capability and Feasibility", IEEE Aerospace 2023
[3] Y.-M. Yang, et.al, "Toward the Cis-lunar Target Detection using Deep Space Network and Open Loop tracking Measurements", IEEE Aerospace 2023
[4] C.G. Lee, et al., " Ground-based Cis-lunar Space Debris Radar With GSSR", IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, 2023
[5] Y.-M. Yang, et al., " Background Clutter Impacts On Cis-lunar Target Detection Using Open-loop Tracking Measurements With The Deep Space Network ", IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, 2023

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