National Aeronautics and Space Administration

# Towards constraining superheavy dark matter with the Owens Valley Radio Observatory Long Wavelength Array

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## Objectives

1) Estimate the sensitivity to super-heavy dark matter secondary particles interacting on the Moon using the Owens Valley Radio Observatory Long Wavelength Array (OVRO-LWA) radio telescope

2) Derive the requirements for a new digital signal processing back-end in the OVRO-LWA to enable this observation mode.

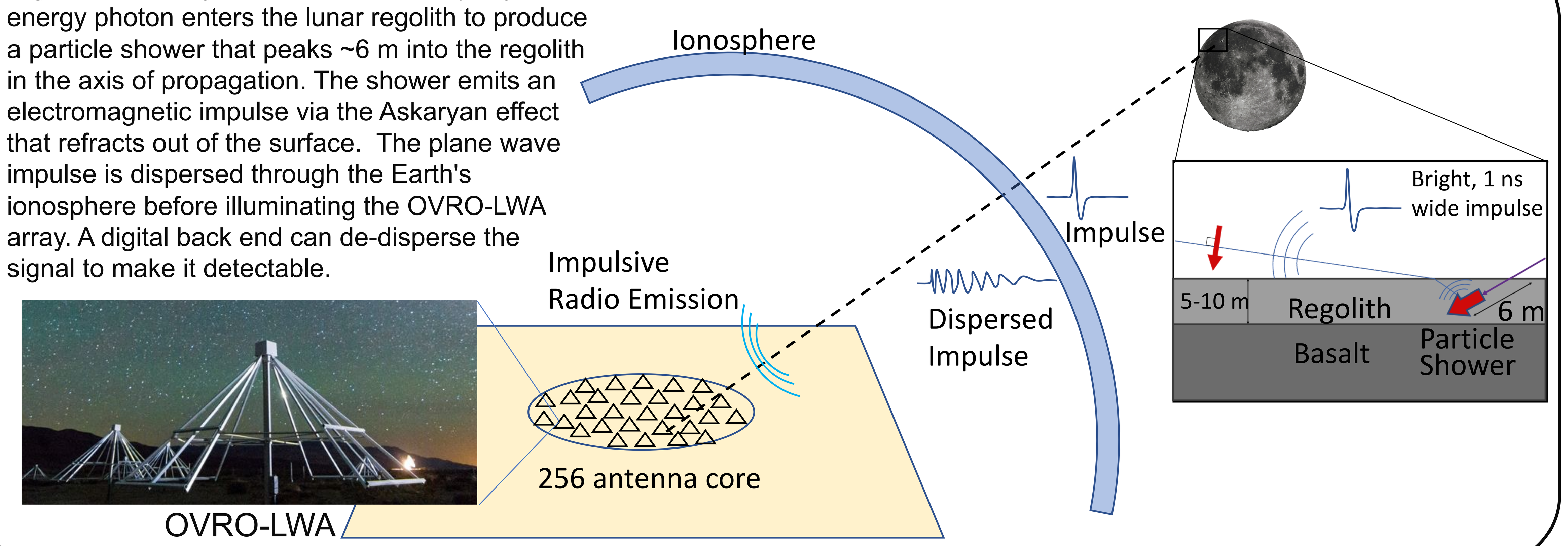
## Background

- Super heavy dark matter (SHDM) particles arise from the hypothesized non-thermal production of massive particles during the early universe.
- SHDM particle annihilate or decay to produce extremely energetic (>$10^{21}$ eV) secondary particles such as photons and neutrinos.

## Approach and Results

- OVRO-LWA array could detect the radio impulsive emission of extremely-high energy particles incident on the Moon (Figure 1).
- Detection requires ionospheric de-dispersion, which can be achieved efficiently (Figure 2).
- OVRO-LWA would use the array core to form a beam on the Moon for triggering. Saving data from outer antennas provides finer localization (<0.1°) (Figure 3).
- An efficient back-end signal processing scheme has been identified to trigger on impulsive transients from the Moon (Figure 4).
- The expected performance of the digital back-end is expected to produce limits that are more than an order of magnitude deeper than the state of the art (Figure 5).

**Figure 1:** from right to left, an extremely-high energy photon enters the lunar regolith to produce a particle shower that peaks ~6 m into the regolith in the axis of propagation. The shower emits an electromagnetic impulse via the Askaryan effect that refracts out of the surface. The plane wave impulse is dispersed through the Earth's ionosphere before illuminating the OVRO-LWA array. A digital back end can de-disperse the signal to make it detectable.



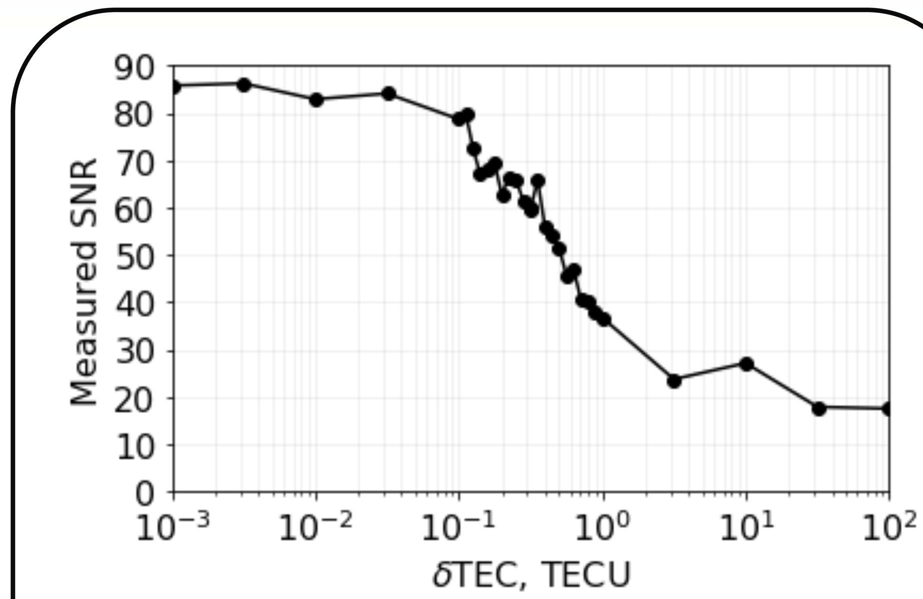
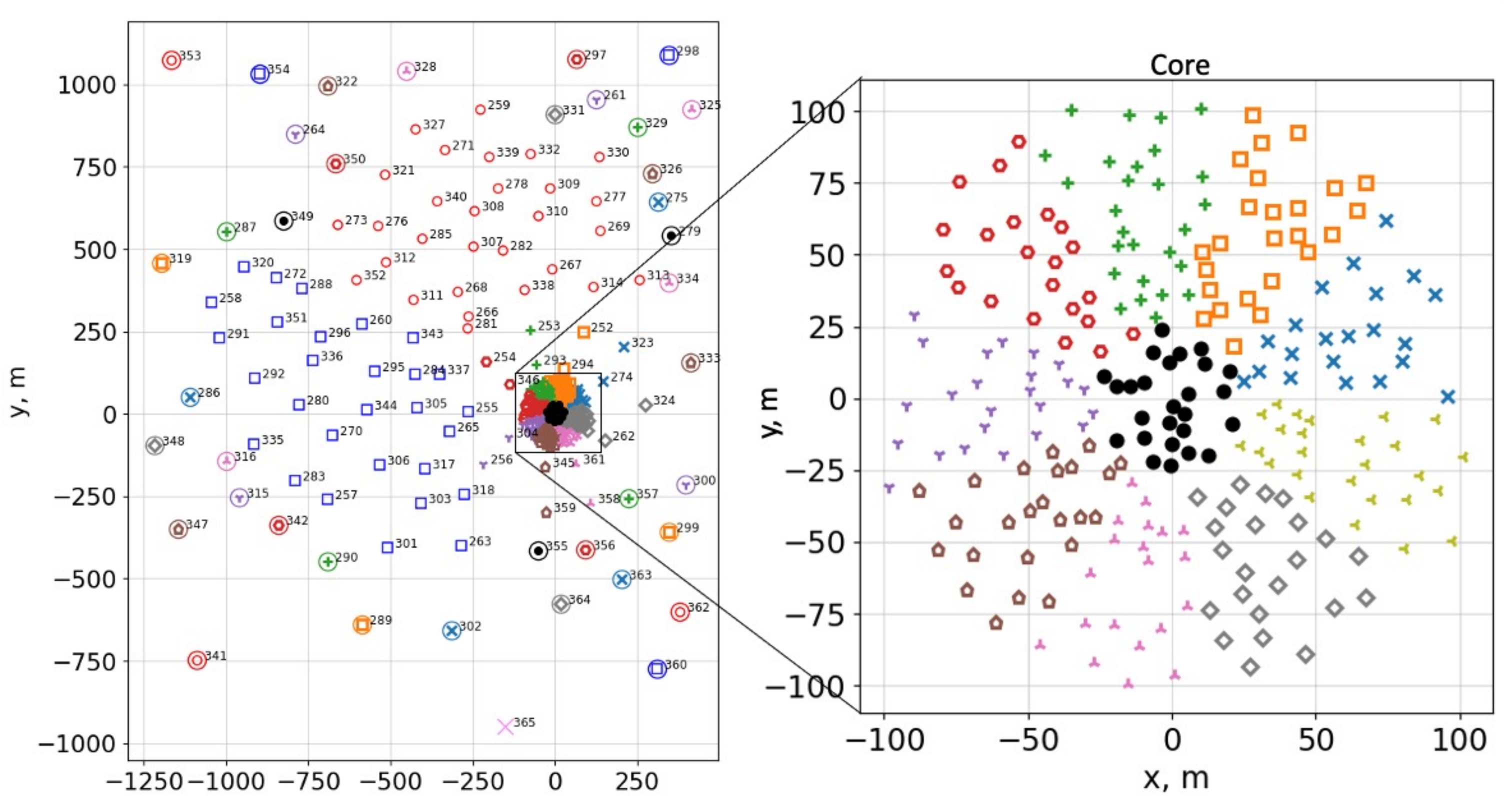




**Figure 2:** Pulse SNR as a function of TEC error (delta-TEC) in the de-dispersion template using our algorithm. The input pulse has an SNR of 100. Beyond a δTEC of 0.1 TECU the pulse peak SNR degrades rapidly while below this value the pulse peak SNR is held relatively constant.

**Figure 3:** Left: antenna layout for the OVRO-LWA 352 antenna upgrade. Right: zoomed-in view of the core of the array. The symbols on each antenna location indicate the FPGA to which the signals are routed.



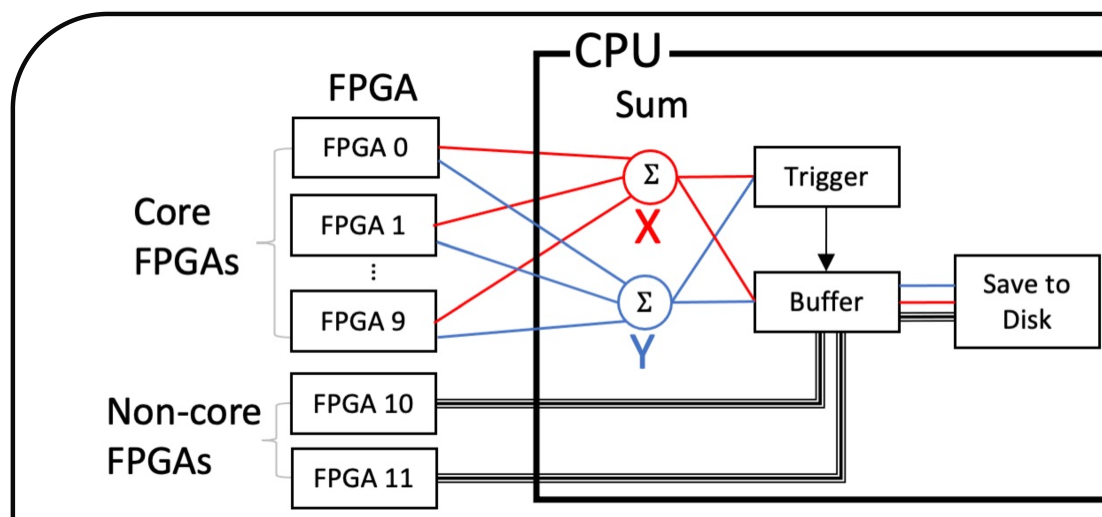




**Figure 4:** Core antennas are routed to FPGAs 1-9 applying real-time beamforming to each polarization (X in red and Y in blue). Beamformed signals are routed to a CPU for further beamforming and de-dispersion. The system triggers if the de-dispersed beamformed waveform exceeds an SNR of 5. FPGAs 10 and 11 (not containing core antennas) are saved when triggered for higher-resolution pointing on the Moon.

## Significance / Benefits to JPL and NASA

- Executing this experiment would result in the deepest limits for the existence of extremely high energy particles.
- Positive detections would be a major discovery.
- Would provide evidence that dark matter is composed of super massive particles forged during the origin of the universe.
- This result would motivate a lunar orbiting mission to map out the directions of arrival of SHDM decay products.

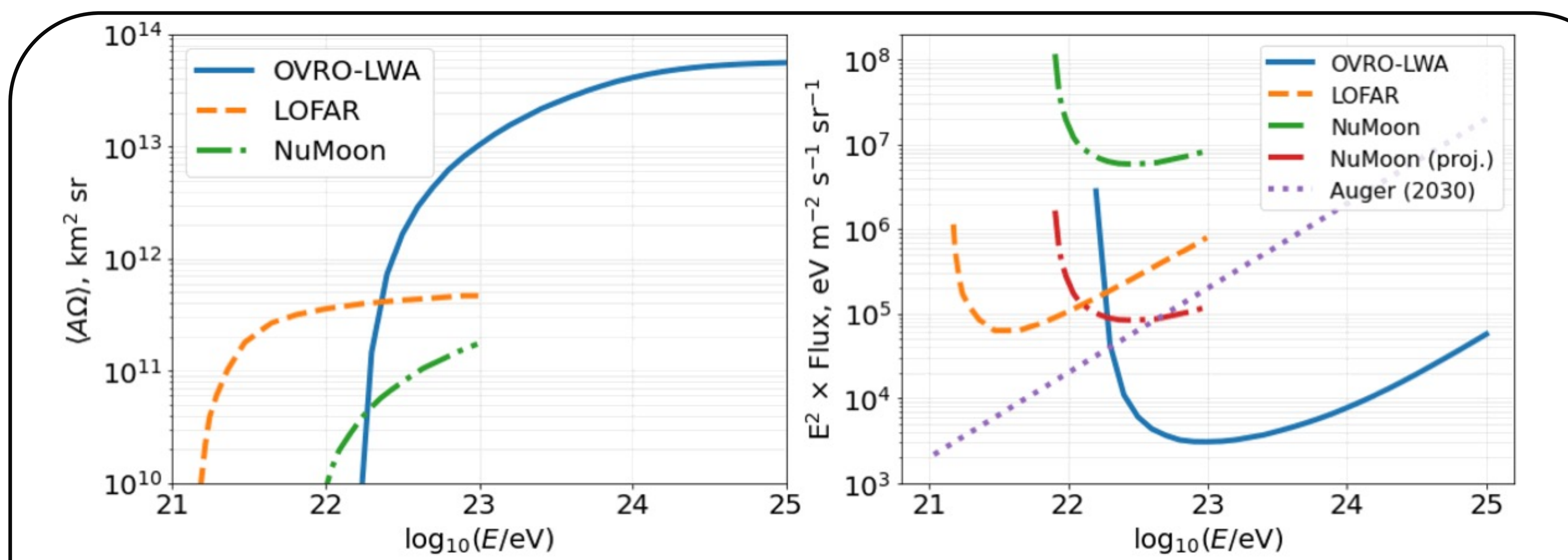



**Figure 5:** Left: Acceptance of OVRO-LWA (this work) compared to LOFAR and NuMoon. OVRO-LWA exceeds LOFAR and NuMoon above ~$2\times10^{22}$ eV with >10x increased sensitivity above $10^{23}$ eV. LOFAR and NuMoon have limited duty cycles (<5%) which wouid give OVRO-LWA another order of magnitude boost in total exposure. Right: limits for OVRO-LWA assuming a total livetime of 1 year on the Moon. Projected limits (labeled "proj." in the legend) for the Pierre Auger Observatory in 2030 and future NuMoon observations are included.

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