NEXT GENERATION LASER RANGING AT FUTURE LANDING SITES. J. G. Williams[1], D. G. Currie[2], and D. H. Boggs[1], [1]Jet Propulsion Laboratory, California Institute of Technology (Pasadena, CA 91109-8099, USA, James.G.Williams@jpl.nasa.gov), [2]University of Maryland (College Park, MD, USA, currie@umd.edu).

Introduction: Lunar Laser Ranging (LLR) provides information on lunar geophysics and geodesy, physics, and terrestrial geodesy [1]. Modern ranges are fit with a weighted rms residual of 9 mm. Part of this scatter is due to the finite size of the retroreflecting arrays. Ranging to larger (10 cm) single Next Generation Laser Ranging (NGLR) corner cubes can reduce this scatter [2].

Five lunar sites have retroreflecting arrays composed of multiple small corner cubes. The position of the Earth in the lunar sky varies about ±0.1 radians in longitude and latitude (optical librations). The finite size of the arrays with the optical librations cause the ranges of individual photons to scatter by several cm about the mean range. NGLR corner cubes would make this geometric scatter zero.

Robotic Commercial Lander Payload Service (CLPS) and Lunar Geophysical Network (LGN) missions, plus manned Artemis missions will land on the Moon during the next decade. These missions can carry NGLR corner cubes.

Simulations: We considered existing data plus 6 yr of simulated data to (NGLR) corner cubes at Mare Crisium (CRS) in the northeast, plus sites in the northwest (NW), southwest (SW), and south pole (SP). There were 9 combinations of reflectors: the 4 sites separately (plus existing data), 3 pairs of the non-polar sites, the 3 non-polar sites together, and all 4 sites together. The 4 range accuracy levels are: 1) no improvement over existing accuracies (very pessimistic), 2) expected accuracies with existing ranging equipment and data analysis model, 3) 1.5 mm scatter that would require improvements in equipment and model, and 4) sub-mm scatter that would require large improvements in equipment and model.

Results: The earliest result from a new reflector is its position. 1 or 2 months of data yield 3-dimensional submeter accuracy positions with respect to the center of mass and principal axes. The use of the existing reflector locations for lunar geodesy is described in [3].

Compared to uncertainties from existing data analyses, major improvements would be made in the displacement Love numbers h_2 and l_2. One or more southern sites are most helpful since the existing LLR sites are equatorial and north of the equator.

For 3 non-polar sites with level 2 ranges the improvement is a factor of 2 whereas all 4 sites give a factor of 4 improvement.

The improvements in horizontal Love number l_2 is similar to vertical Love number h_2 but not identical.

Lunar science parameters include tidal energy dissipation at several periods, dissipation at the fluid-core/solid-mantle boundary (CMB), and flattening of the CMB. For $\beta=(C-A)/B$ and $\gamma=(B-A)/C$, where $A<B<C$ are the lunar principal moments of inertia, parameter β is aided by a large north-south spread and γ is aided by a large east-west spread. SW and SP aid the former and CRS and NW or SW aid the latter.

There are also parameters for the equivalence principle and gravitational constant times mass (GM) of Earth+Moon. The former needs improved range accuracy for a strong improvement in uncertainty.

Summary: Placing 10 cm corner cubes at widely separated CLPS, LGN, and Artemis sites would reduce uncertainties of science parameters including displacement Love numbers h_2 and l_2, tidal dissipation at several frequencies, fluid-core/solid-mantle boundary (CMB) dissipation and flattening, and moment of inertia combinations β and γ. Submeter accuracy coordinates of a new reflector would be available with 1 or 2 months of data. Other benefits include gravitational physics equivalence principle and geodetic precession; Earth science including terrestrial tidal dissipation, ranging station positions and motions, the orientation of the Earth in space: the precession and obliquity rates and nutations; and astronomical constants with GM(Earth+Moon).

Acknowledgments: LLR stations at McDonald Observatory, Texas; Observatoire de la Côte d'Azur, France; Haleakala Observatory, Hawaii; Apache Point Observatory, New Mexico; Matera, Italy; and Wettzell, Germany provided the LLR data that make analyses possible. LLR data are available from the Crustal Dynamics and International Laser Ranging Service at https://cddis.nasa.gov/Data_and_Derived_Products/SLR/Lunar_laser_ranging_data.html. The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National (80NM0018D0004). sponsorship acknowledged and at the University of Maryland, College Park.

References: [1] Müller J. et al. (2019) J. Geod., 93, 2195. [2] Currie D. G. et al. (2013) Nuclear Physics B (Proc. Suppl.), 243-244, 218. [3] Wagner R. V. et al. (2017) Icarus, 283, 92.