UNDERSTANDING THE EVOLUTION OF THE SOLAR SYSTEM. Maria T. Zuber[1], David E. Smith[1], Erwan Mazarico[2], Antonio Genova[1], Gregory A. Neumann[2], [1]Dept of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 (smithde@mit.edu, zuber@mit.edu, genova@mit.edu); [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt MD 20771 (erwan.m.mazarico@nasa.gov, gregory.a.neumann@nasa.gov).

Introduction: The evolution of the solar system encompasses the history of the sun, planets, and all the components of the solar system. The forces that produced this evolution are also those that will determine the future of the solar system. A mission concept that measures the changes in scale and rotation of the solar system within our galaxy would be significant accomplishment. Further, we believe such a mission could be achieved with a small constellation of SmallSats.

At the center, and the most important force in this evolution, is the Sun that radiates both electromagnetic and particle radiation resulting in a small but not insignificant loss of its mass. This loss changes the scale of the solar system and the revolutionary motion of all the planets and bodies of the solar system.

Mission Concept: A constellation of SmallSats distributed at host planets within the solar system with the ability to measure the timing of signals between them could obtain within a few years the rate at which the host planets are receding from the sun, thereby providing a measure of the loss of solar mass. Further, if the measurements form a set of closed triangles, and the measurements are two-way between spacecraft, the rotation of the solar system in inertial space could also be obtained.

The effect of a loss of solar mass on a planetary body is to increase the orbital radius and to decrease the orbital velocity, the latter a result of the conservation of angular momentum. For a steady-state rate of mass loss planetary distances increase linearly such that the greater the planetary distance the larger the effect, suggesting that a measurement to the most distant planets, such as Pluto, would be the preferred measurement, ignoring technical difficulties. However, the effect of the change in orbital velocity is much larger for the inner planets because their orbital velocities are greater than those of the outer planets, suggesting that measuring the change in orbital position of the inner planets, such as Mercury would be preferable. Thus the optimum measurement is between a fast moving inner planet and a “rapidly” expanding outer planet orbit, such as Jupiter.

The current best estimate of the rate of mass loss by the sun [1, 2, 3] from the combined effects of the conversion of hydrogen into helium in the solar interior and the loss from the solar wind and solar eruptions is ~10^{-13} solar masses/year. This decrease in mass causes the orbits of planetary bodies in heliocentric orbits to expand because of the weaker gravitational pull of the sun. The expected solar mass loss translates to ~1.5 cm/year/AU increase in planetary orbital radii (~14 cm/yr for Saturn), and ~9 cm/year/AU in orbital velocity (~15 cm/yr for Mercury). Thus the distance between Mercury and Jupiter is expected to increase by nearly 30 cm/yr with an approximate quadratic increase with time.

A single line measurement, such as Jupiter to Mercury, is in principle, able to make the measurement of expansion but it could be confused with other changes in the orbits of the 2 planets. A much stronger approach is to involve at least 3 planets such that the observations form a closed triangle providing both range and angle measurements. All three bodies are affected by a mass change in a similar way but a perturbation of the position of one planet would change the distances to the other 2 planets and therefore not satisfy the constraints imposed by a solar mass change in scale and velocity of all three bodies. This was the basis of the simpler concept behind the Trilogy proposition by [3, 4] that suggested the measurements around the triangle formed by Earth, Venus, and Mars could provide rate of expansion today over just a few years, with the technologies presently available.

If the measurements between the planets are made in both directions, and if the measurements form a triangle then the system may be able to determine the rotation of the solar system in an inertial frame. The total distance around the network in one direction will differ from the other direction as a result of the Sagnac effect [5], which predicts the two distances will differ if the system is rotating within the inertial reference frame. The possible difference could be large enough to measure and provide an estimate of the rotation of the solar system within the galaxy.

Technology: The critical component of the concept is the ability to measure accurately (cm level) the distance between planetary bodies, typically several AU apart. With physical size and power in mind a laser ranging system seems the most viable approach, although nothing precludes the observations being made at radio frequencies. An asynchronous transponder [6] appears to be the most viable approach in which two one-way measurements of range are made simultaneously but asynchronously between 2 laser terminals. Measurements at the centimeter level have been demonstrated between Earth and the Moon on the LRO [7, 8] and LADEE [9] missions and the physical size of the laser terminal on LADEE indicates that such a system could fit into a SmallSat design, or even a Cubesat. Further, laboratory experiments at both NASA GSFC and NASA JPL indicate that distances of several AU are possible at the desired accuracy with optical systems today.

The locations of the laser terminals at the host planets are spacecraft in orbit around each planet of the network, although a terminal on the surface could perform the same function at solid planets, but not at Venus or any of the gas giants. Measurements between the spacecraft would be used to determine the orbits of the spacecraft around the host planets and hence the actual location of the planets themselves at accuracy levels comparable to the range accuracy. Placing the SmallSats at the host planets need not require a special launch but could be deployed as secondary payloads on future science missions to almost any planetary body.

Interpretation of Results: The minimum number of host planets is 3, creating a single triangle. But with the addition of a fourth planet the number of triangles increases to 4, and to 10 for 5 planets, improving the quality of the results by probably an order of magnitude; and their robustness to system failure. With increased accuracy comes the ability to investigate any time dependence in the loss of solar mass that might occur on decadal time scales, such as the 11 or 22-year solar cycle, and possibly providing insight into the relative magnitudes of the EM and particle radiation, the latter being much less understood, of solar mass loss. Understanding how the solar system is currently evolving and the implications for the Sun, its interior, and the motions of the planets are a major scientific endeavor.

References:

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