Getting to Sedna and Eris Using Solar Electric Propulsion. Edgar A. Bering, III[1], Matthew Giambusso,[1] Alex Parker[2], Mark Carter[3], Jared P. Squire[3], and Franklin R. Chang Díaz[3], [1] University of Houston, Department of Physics, Houston, TX 77204, USA (eabering@uh.edu), [2]Southwest Research Institute, Boulder, CO 80302, USA, [3]Ad Astra Rocket Company, Webster, TX 77598, USA.

Introduction: We explore the capability of solar and hybrid solar-nuclear electric propulsion systems to send spacecraft to Saturn, Neptune and beyond. The purely solar system performs a slingshot pass close to the Sun and uses the high level of available solar energy to produce a sustained burst of high thrust. Enough kinetic energy is provided to the probe to reach Jupiter orbit while still within 0.7-1. AU. This study identifies the important parameters in the propulsion system operation (power level, propellant mass, payload release point, distance of closest approach to the Sun), and scan these parameters to understand and optimize the capabilities of the proposed system. The engine's power rating must match the peak power available when the spacecraft is closest to the Sun. The solar array is assumed to be a planar array rather than a concentrator since it will have to operate near the Sun, where a concentrator would overheat photovoltaic cells.

Saturn and Beyond: The feasibility of using electric propulsion to provide thrust along the transfer orbit until the transfer orbit reaches >5 AU was also examined. The resulting spacecraft speed reaches 60 kps within 1 AU. In order to stop at Saturn, the thruster must retrofire from 1 AU to 5 AU. So far, the best-case Saturn model assumes 30 mT in LEO, and a 5 kps Earth departure velocity from the chemical launch system. The simulation arrives at 1.1×10^6 km from Saturn with a velocity of 3.3 kps. Using chemical SOI, the simulated system delivers an 8.5 mT payload in 4.44 years transit time.

Ice Giants and Beyond. The Ice Giants, Uranus and Neptune, will not be accessible using a Jupiter gravity assist in the late 2020's. Consequently, we modeled these missions using a Saturn gravity assist. An improved, optimized version of the "thrust outward the whole way to Jupiter orbit" model from the previous section was used to reach Saturn. Unfortunately, the two Ice Giants are too far apart to make a dual flyby practical, so we modeled the two missions separately. The Neptune flyby also served as a gravity assist for an Eris flyby and coast to 1000 AU. The Uranus model took 2.8 years and the Neptune model took 3.5 years. The Eris flyby took 9.6 years. This simulation reached 1000 AU in 125 years.

Direct to Eris with Alternate Architectures. We explored alternative architectures using high-power solar-electric boost phases for missions the outer solar system. As a comparison the performance of VASIMR® propulsion, we model a smaller New Horizons-like[i] (~450 kg dry weight, RTG spacecraft power) fast flyby mission of Eris using three HiPEP-like[ii] (670 mN thrust, 7 mg/s flow rate, 39.3 kW power demand) motors and solar array performance based on existing thin-film CIGS arrays (Ascent Solar Large-Scale Bare Module Group, 863 W/kg, de-rated by a factor of 2 to account for degradation and structure). A simple thrust-along-velocity trajectory with an Earth departure speed of zero and no gravity assists can deliver a 450 kg dry weight bus (plus 500kg of solar arrays and support structure) to Eris (at 94 AU) in under 15 years after consuming a total of 300kg of propellant (for a total wet mass of 1250 kg at launch). To explore this concept architecture, we model the trajectory of the spacecraft with a leapfrog integrator on one-day timesteps. The spacecraft begins with a power surplus with respect to the demands of the three motors (~200kW capacity vs. ~120kW demand), but this rapidly reduces as the spacecraft climbs away from the Sun. The spacecraft passes the orbit of Jupiter after just under one year, producing 6400 W of solar power. Thrust continues until propellant is exhausted, and total mission duration depends only weakly on when this occurs. In our non-optimized scenario, cutoff occurs at 2 years into the mission at a heliocentric distance of 13 AU, where the arrays are still generating over 1 kW of power. At this point, the spacecraft jettisons the arrays (switching to RTG power for spacecraft operation) and cruises on a ballistic trajectory to its target, in this case reaching Eris at 94 AU from the Sun (and 16 AU out of the Ecliptic plane) in just under 15 years. This mission duration is comparable to current deep outer solar system flyby mission durations, however the flyby speed at Eris is more than twice current flyby speeds at ~30 km/s. To enable a compelling science mission at Eris under such a flyby architecture, development of larger-aperture instruments would be beneficial to extend the useful range of high-resolution observations and improve the signal-to-noise in the very low light regime at 94 AU.

Sedna. So far, all of the simulations have avoided using a Jupiter flyby. In the late 2020s and 30s, Jupiter will be phased to provide a useful boost for missions to Sedna. We will report on the results of Sedna mission simulations using a Jupiter flyby.

Conclusions: The use of VASIMR® or HiPEP SEP propulsion for missions to the Outer Planets will enable a mission to arrive in half the time required by a chemical propulsion system. It will deliver a spacecraft that is larger and more capable than the one a chemical propulsion system will deliver. If the solar arrays and VASIMR RF generators are retained for the entire mission, one will arrive at Jupiter with a 20 kW power system and the high power RF core of a very capable ice penetrating radar. Finally, we have shown that thrusting outbound all the way to Jupiter orbit will allow getting spacecraft to the Ice Giants even when Jupiter is phased so that a Jupiter-assist flyby is unhelpful.

[i] Stern, S. A. "The New Horizons Pluto Kuiper belt Mission: An Overview with Historical Context," *Space Science Reviews*, Volume 140, 2008.

[ii] Foster, J. E., Haag, T., Patterson, M., Williams, G. J., Sovey, J. S., Carpenter, C., Kamhawi, H., Malone, S., and Elliot, F. "The High Power Electric Propulsion (HiPEP) Ion Thruster," *40th Joint Propulsion Conference and Exhibit*, 2004.