ENABLING DECADAL SURVEY SCIENCE GOALS FOR PRIMITIVE BODIES USING RADIOISOTOPE ELECTRIC PROPULSION.

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Introduction: The recent report published by the National Research Council "New Frontiers in the Solar System: An Integrated Exploration Strategy" (the “Decadal Survey”) [1] considers the scientific priorities for continuing robotic exploration of the solar system. In addition to the primary missions yet to be implemented, including the return of a cometary samples to Earth, and those in implementation, namely New Horizons to Pluto/Charon and the Juno mission to the Jupiter system, targets for exploration in the outer solar system include Trojan asteroids, Centaurs, other asteroids, comets, and more detailed looks at the moons of Jupiter. In most cases, radioisotope power supplies are enablers for the missions (Juno and the Dawn mission in the Discovery line are solar powered), and propulsion is the significant technical driver. Radioisotope-Electric Propulsion (REP) can enable many of these missions by combining a small (~500 kg dry mass) spacecraft with a focused payload (~50 kg) and advanced radioisotope power sources for a mission cost on the order of that for a New Frontiers mission. REP systems may, in addition, allow extension of the science goals in the Decadal Survey by enabling orbital missions of bodies for which only flyby missions are possible with chemical propulsion. REP systems can also enable an interstellar precursor mission, the subject of a more recent NRC report “Exploration of the Outer Heliosphere and the Local Interstellar Medium” [2]. We consider the generic topic of exploration of low-mass objects: Trojans, Main Belt asteroids, Centaurs, and Kuiper-Belt objects, with REP missions, and discuss the technical breakpoints that drive power and propulsion from solar to radioisotope-enabled. We show how REP can address key Decadal Survey science questions over the next two decades, with an emphasis on the Jovian Trojan asteroids.

The Jovian Trojans: Whilst most bodies in the solar system have undergone some degree of alteration since their formation, the most primitive are found mostly in the region beyond Mars. These include asteroids, comets, small planetary satellites, and objects in the Kuiper Belt and Oort cloud, as well as Pluto and Charon, Triton, and Interplanetary Dust. Such objects have undergone a low degree of chemical and physical alteration since their formation some 4.6 billion years ago from the solar nebula, and therefore can provide unique windows into conditions in the early solar system.

The NAS Decadal Survey recognized that primitive bodies are the principal building blocks of the solar system, and summarized the fundamental science questions relating to them:

- Where in the solar system are the primitive bodies found, and what range of sizes, compositions, and other physical characteristics do they represent?
- What processes led to the formation of these objects?
- Since their formation, what processes have altered the primitive bodies?
- How did primitive bodies make planets?
- How have they affected the planets since the epoch of formation?

Several comets and near-Earth asteroids have now been visited by spacecraft, however, another group of primitive bodies has yet to be the subject of any robotic exploration. These are the Trojan asteroids, which orbit Jupiter at ~5.2 AU, in two elongated clusters around the L4 and L5 Lagrange points. Over 1100 asteroids greater than 15 km in diameter are located near the L4 point, and more than 700 are known near the L5 point. Trojan asteroids may be a possible source for some short-period comets. The Trojan groups contain only low albedo, primarily D-type asteroids, thought to be composed of highly primitive carbonaceous material, and are likely relatively pristine remnants of the early solar system. No known analogs of D-type asteroids exist in the meteorite collection, with the possible exception of the recently discovered Tagish Lake meteorite [3].

The Trojans may yield significant information about the formation and the evolution of the Solar System, including such questions as how they relate to other asteroid groups and the meteorite record, their interior structures, their compositions, organic constituents and isotopic ratios, their collisional histories and role in impact cratering in the Jovian system and elsewhere, and their relationship to comets and icy satellites. At least one Trojan, Patroclus, has been found to have its own moon [4]. It has recently been suggested that the Trojans may have originated as Kuiper Belt Objects which were dynamically disrupted inward to be trapped in Jupiter’s heliocentric orbit [5].

The NAS Decadal Survey recommended four potential missions to study primitive bodies, one of which was a Trojan Asteroid/Centaur Reconnaissance mission. This mission would be equipped with imaging, imaging spectroscopy, radio science and, potentially, other instruments, to make the first explorations of both a Jovian Trojan asteroid and a Centaur, and would have deep ties to understanding the origins of primitive bodies. The Study report notes that the Trojan flyby would sample primitive material from the Jovian accretion region of the nebula; it would also allow an important recalibration of the bombardment flux on objects in the Jovian system, and would offer new insights into space weathering and other processes affecting asteroids, particularly in the main belt. At the time of writing the Study Report, an orbital mission to the Trojans was not deemed feasible.

Exploration of the Trojans using REP: We have been investigating mission concepts that use small electric propulsion engines, ~1 kW radioisotope power, and low-mass spacecraft construction techniques. Our objective is to find practical missions to high-priority targets, with reasonable travel times and a reasonable science payload. The high power-to-mass ratio of planned radioisotope power systems enables New-Frontiers class missions that carry a significant science payload to new destinations. The PARIS (Planetary Access with Radioisotope Ion-drive System) spacecraft take advantage of high-efficiency Stirling radioisotope generators (SRGs) or new thermoelectric converters to provide the power for an electric propulsion system. These low-thrust missions launched to a high C3 are especially effective for exploring objects in shallow gravity wells in the outer solar system. We consider a PARIS mission that can reach the asteroids in less than 5 years, orbit 624 Hektor, the largest of the Jovian Trojans, and go on to orbit at least one other object (Fig. 1; Table 1). The candidate payload for this mission includes wide-field and narrow-field cameras, a UV-Vis-IR spectrograph, gamma-ray and neutron spectrometers, and plasma and energetic particle spectrometers. About 900 W of power are required. The launch mass would be slightly less than 1000 kg. The <5 year trip time is dependent on having the next generation power sources with a specific power of > 8W/kg.

Summary: Radioisotope-electric propulsion (REP) enables a new class of deep space missions. REP spacecraft, launched on medium-class launch vehicles, can orbit or co-orbit bodies beyond Mars with reasonable trip times. REP can deliver ~500 kg spacecraft with ≤ 50 kg science payloads and ~1 kWe of power, and can enable many of the Decadal Survey science goals for primitive bodies for New Frontiers-scale budgets.

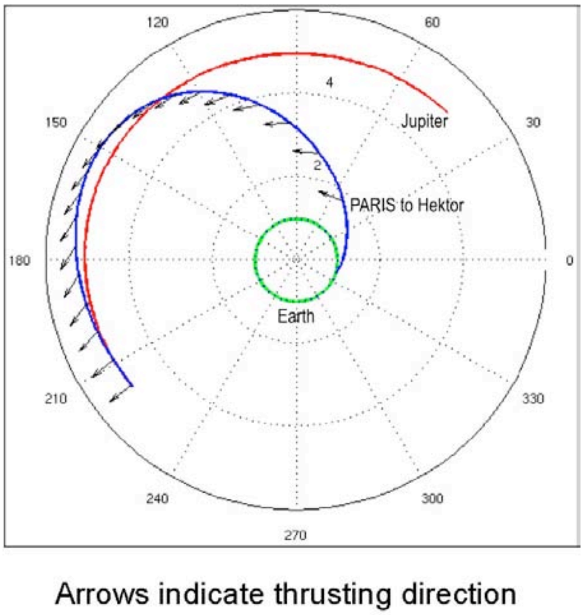

Figure 1: Orbit of REP spacecraft to Trojan asteroid.

Power	8We/kg
Launch Dates	18-Aug-09
Additional Dates	Every 13 months
Arrival Date	1-Nov-14
Travel Time	4.2 yr
Orbit Duration	1 Earth yr at each object
Launch Mass	983 kg
Payload Mass	33 kg
Dry Mass + margin	530 kg
Propellant Mass	453 kg
Launch Vehicle	Atlas V 551/Star 48
C_3	121.6 km²/s²
EP Delta V	8.3 km/s

Table 1: Characteristics of REP spacecraft.

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