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**APOPHIS PATHFINDER: A MILO SPACE SCIENCE INSTITUTE SMALLSAT
MISSION IN SUPPORT OF SCIENCE AND PLANETARY DEFENSE**

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Introduction: The MILO Space Science Institute (<http://miloinstitute.org>), a nonprofit entity led by Arizona State University (ASU) with support from Lockheed Martin, was formed to provide affordable access to space science missions, especially for new entrants in the realm of deep space robotic science and engineering. MILO's business model is built on the hypothesis that compelling, science-driven deep space missions can be led, organized, and conducted by a consortium of U.S. and international organizations (universities, space agencies, commercial space companies), aided by mentorship and other support from experienced organizations like ASU and Lockheed. MILO members advance their space science mission experience and goals via a three-stage program involving workforce development; payload/spacecraft definition, review, prototyping, testing, and fabrication; and mission operations/data analysis [1]. The "challenge" model, a successful part of numerous innovative/startup development programs, is a fundamental part of MILOs approach to increasing global access to space science and exploration.

As a seed to growing such consortia, MILO has defined an initial set of potential smallsat missions that could be done relatively quickly, at low to modest cost, and that would achieve cutting-edge Decadal quality science. Proposed MILO missions include LunaRide [2], enabling small science payloads to be conducted from a long-range roving vehicle on the surface of the Moon; NEOShare [3], enabling multiple reconnaissance flybys of a diverse population of near-Earth asteroids from a single launch; and Apophis Pathfinder [4], a smallsat flyby mission dedicated specifically to reconnaissance of the Potentially Hazardous Asteroid (99942) Apophis.

Apophis Pathfinder: This MILO mission will launch a pair of smallsats to conduct a flyby precursor investigation to characterize the PHA (99942) Apophis well in advance of its April 2029 extremely close approach to Earth. The spacecraft will be comparable in size and scope to the Janus smallsats developed by the University of Colorado and Lockheed for asteroid exploration [e.g., 5].

(99942) Apophis will make a number of relatively close approaches to Earth before its famous 2029 extremely close encounter, with the closest of these being two precursor approaches at < 0.3 AU in Dec. 2027 and Sept. 2028. The Apophis Pathfinder mission will be targeted for a rideshare launch that will enable the spacecraft to flyby the asteroid during one of these two opportunities.

Science Goals: The MILO Apophis Pathfinder mission will provide initial reconnaissance data to inform, influence planning for, and augment the scientific and Planetary Defense results/implications from other missions to (99942) Apophis in 2029 and beyond, such as NASA's OSIRIS-REx APEx extended mission [6].

Science and Planetary Defense objectives of the Apophis Pathfinder mission include obtaining more precise estimates of the asteroid's mass and density, shape, geology, composition, and orbital parameters than is currently available from optical/near-IR and radar telescopic observations. To achieve these objectives, the Apophis Pathfinder smallsats will carry small and high-heritage payloads like miniaturized optical and thermal-IR cameras [e.g., 7] and a near-IR point spectrometer [e.g., 8], and will implement the first deep-space demonstration of a novel method of determining the mass of sub-km size asteroids using multiple

deployed and optically and/or radio-tracked small spherical "probesats" [9].

Science requirements definition and ultimate payload selection/requirements definition will be led by MILO Institute members, in coordination with scientists and engineers in the MILO Project Office at ASU. Payload integration will be conducted at ASU, Lockheed, and/or MILO member institutions, as appropriate, and launch vehicle integration will be provided by Lockheed and the launch vehicle provider.

Summary: The MILO Institute is seeking to increase U.S. and international participation in the Apophis Pathfinder mission. We are especially interested in involving universities, institutes, companies, and/or space agencies that are looking for relatively low-cost and rapid, non-competitive ways to increase their experience base in deep space sensor and payload development, mission operations, and science data analysis. MILO also offers a variety of workforce development programs for students, early career professionals, and others that are designed as pipelines to help organizations and individuals gain the mentorship and experience needed to move rapidly from science goals to payload definition to deep space mission execution in an affordable and impactful way.

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