EXPLORING OUR SOLAR SYSTEM WITH CUBESATS AND SMALLSATS: A NASA/JPL PERSPECTIVE

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ABSTRACT

We are on the threshold of a new era in robotic exploration of our solar system, one in which Cubesats and Smallsats will play an important role. As NASA's lead center for robotic solar system exploration, JPL has a strategic interest in these new capabilities that enable scientists to expand our knowledge of how our solar system formed, how it works, and even how life originated.

JPL's two MarCO spacecraft are currently being prepared for launch along with the InSight Discovery mission in May of this year. This first pair of interplanetary Cubesats will make their way independently to Mars and provide a relay capability for the InSight lander back to Earth. Lunar Flashlight and Near Earth Asteroid Scout, two Cubesats that are currently under development, will form part of the 'swarm' of Cubesats escorted into lunar orbit by NASA's EM-1 mission – the first launch of its new SLS rocket.

This paper will provide an overview of these and other Cubesat and Smallsat mission developments at JPL.

1. INTRODUCTION

In earlier papers ([1], [2]) the author argued that deep space Cubesats and Smallsats are on the verge of exponential growth, as seen for Cubesats in low Earth orbit. There is growing interest within the Space and Earth Science community for such missions [3]. The growth in terrestrial Cubesats and Smallsats is driven by the push towards constellations, which may consist of multiple elements that each yield unique measurements that collectively serve one higher objective [4], or of similar elements that offer significantly enhanced temporal resolution ([5], [6]), consistent with recently expressed requirements from the Earth science community [7]. It is also clear that miniaturization of many key spacecraft technologies across a broad front will have a profound effect on future deep space exploration [8], and projecting out into the far future, perhaps even on interstellar exploration [9]. It is these kinds of projections that stimulate interest within NASA and at JPL in Cubesat and Smallsat missions.

2. NEAR-TERM MISSIONS

JPL's two MarCO spacecraft are currently being prepared for launch along with the InSight Discovery mission in May of this year (Figure 1). This first pair of interplanetary Cubesats will make their way independently to Mars and provide a relay capability for the InSight lander back to Earth [10]. They will validate several key technologies that were qualified for flight under JPL's INSPIRE project, including the IRIS Radio, and the Sphinx Command and Data Handling System [11]. The reflectarray antenna that will be used on MarCO for the X-Band data relay back to Earth can trace its heritage to the reflectarray antenna demonstrated as far back as just last year on the

ISARA spacecraft in low earth orbit (see section 3 of this paper). Lunar Flashlight ([12], [13]) and Near Earth Asteroid Scout [14], two Cubesats that are currently under development, will form part of the 'swarm' of Cubesats escorted into lunar orbit by NASA's EM-1 mission – the first launch of the new SLS rocket.

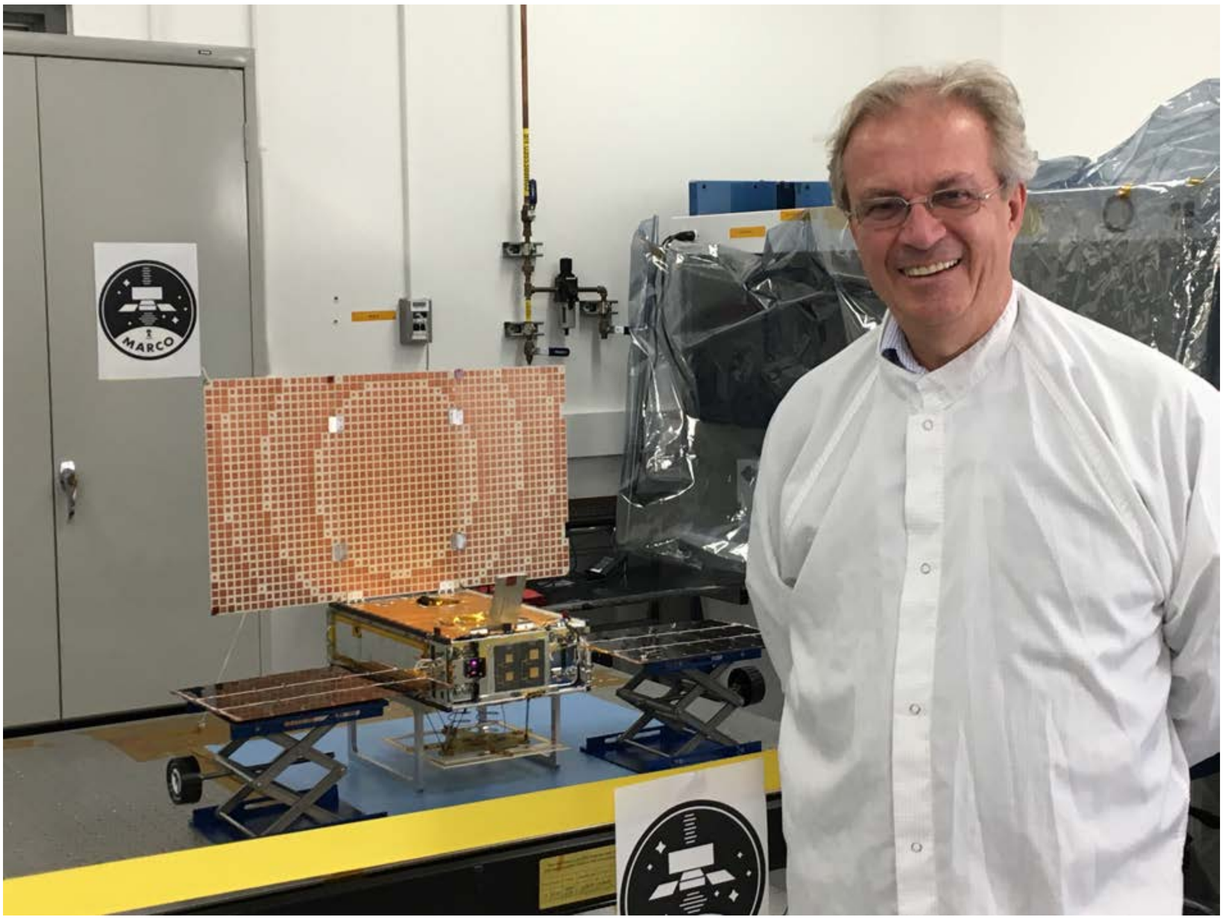

Figure 1: The author standing next to one of the MarCO Cubesats being prepared for flight

3. TECHNOLOGY DEMONSTRATIONS

Technology investments continue to pay off in demonstration missions that serve as a proving ground for capabilities critical to deep space Cubesat and Smallsat missions. Our Deep Space Network-compatible IRIS radio (developed for our INSPIRE Cubesats) is now at TRL-7 and is baselined in the flight system design for several of the EM-1 Cubesats, including Lunar Flashlight and NEAScout. The 3U Integrated Solar Array/ReflectArray (ISARA) Cubesat [15] is currently in low Earth orbit (Figure 2) preparing to demonstrate 100 Mbps downlink capability from LEO.

A critical advantage of Cubesat missions is their short turnaround time, which means that technologies can be demonstrated in flight much faster than on conventional missions, which usually cost more and take much longer to develop. For example, the initial idea behind ISARA, to print a reflectarray surface on the backplane of a deployed solar array, materialized during a concept brainstorming exercise at JPL in November 2011, and was realized as a flight mission in under 6 years. We can trace that back to the initial idea for reflectarray antennas, which has its origins in a publication dating back to 1963 [16]. A similar story can be told for solar sails, which were first incorporated into a JPL engineering study for a deep space mission in the mid-70s, but were not actually flown in space until 2013.

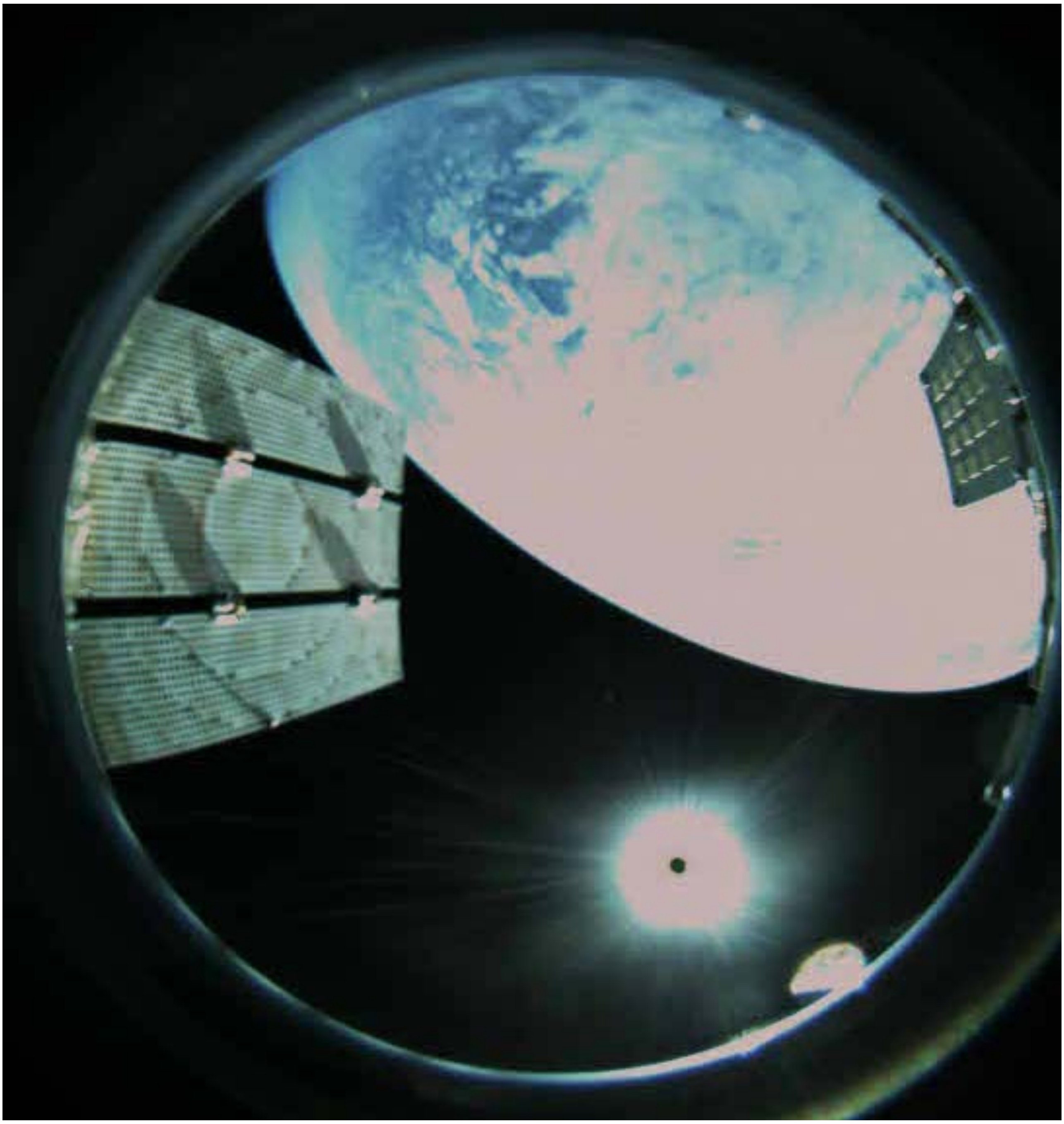

Figure 2: A self-portrait from the fish-eye lens camera on board the ISARA 3U Cubesat, showing the deployed reflectarray (right-hand side) and the smaller feed patch antenna (left-hand side).

The ASTERIA Cubesat mission objective is to demonstrate fine pointing for exoplanet detection. ASTERIA is a 6U CubeSat currently in low-Earth orbit, with a payload that consists of a lens and baffle assembly, a CMOS imager, and a two-axis piezoelectric positioning stage on which the focal plane is mounted [17]. ASTERIA is typical of Cubesat projects at JPL in that it is a true collaboration amongst the many partners, with JPL taking the lead role in pulling the mission together. Blue Canyon provided the Attitude Control System, and fine pointing control is achieved by tracking a set of guide stars on the CMOS sensor and moving the piezoelectric stage to compensate for residual pointing errors. Vulcan Wireless produced the telecommunications subsystem, MMA Design LLC the solar arrays, GomSpace the power subsystem and batteries, Spaceflight Industries the flight computer, Ecliptic Enterprises the Focal Plane, Physik Instrumente the piezo stage, and Thermotive the thermal control hardware. In operations, Morehead State University track the spacecraft, and provide the telemetry, and control services to the Mission Operations team at JPL, while MIT perform target selection and analysis of stellar photometry data from ASTERIA.

The ASTERIA spacecraft shown in Figure 3 was delivered lasyt year for integration into the Nanoracks Cubesat Deployer. And then launched to the International Space Station (ISS) with the SpaceX Falcon-9 Crew Resupply Services – 12 (CRS-12) mission on August 14, 2017. The spacecraft was deployed from the ISS on November 20, 2017 to begin the 90-day ASTERIA technology demonstration mission.

Figure 3: The ASTERIA spacecraft is prepared for flight by JPL Electrical Test Engineer Esha Murty (left) and Integration and Test Lead Cody Colley (right)

RainCube [18], planned for launch later this year, will push the bounds of what is possible in terms of instrumentation, as it tests out its compact radar sounder payload. RainCube (Radar in a CubeSat) is sponsored by NASA’s Earth Science Technology Office (ESTO) through the InVEST-15 program. RainCube’s 35.75 GHz radar payload is designed to fit within the 6U CubeSat form factor. This mission will validate a new architecture for Ka-band radars and an ultra-compact lightweight deployable Ka-band antenna in a space environment to raise the technology readiness level (TRL) of the radar and antenna from 4 to 7 within the three year life of the program (see Figure 4). RainCube will also demonstrate the feasibility of a radar payload on a CubeSat platform. The project completed integration and test in February 2018 and was delivered in March 2018. RainCube will be delivered to the ISS on the OA-9 resupply mission (mid-2018) before deployment later in the year.

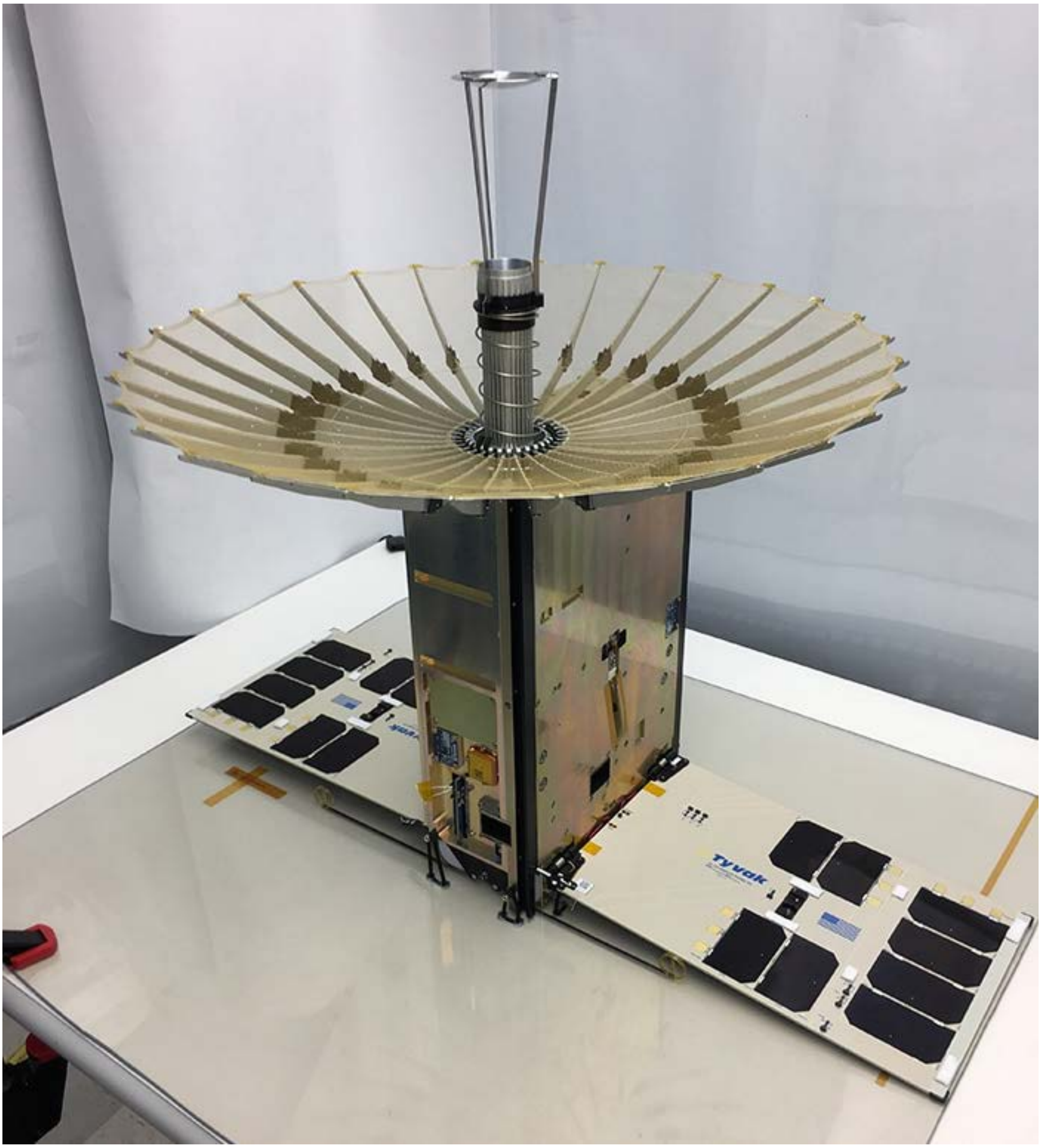

Figure 4: The 6U RainCube spacecraft in Integration and Test, with the solar panels and Ka-band radar antenna deployed

4. MISSION CONCEPTS UNDER STUDY

Recent mission concept studies continue to push the boundaries of the science that is possible with Cubesats and Smallsats. Cupid's Arrow, one of 19 concepts funded under NASA's Planetary Science Deep Space SmallSat Studies call, has as its central idea a Smallsat probe that skims through the atmosphere of Venus to sample the noble gases and their isotope ratios. Free-flying (similar to MarCO) and ride-along architectures are seen to be feasible. Marking the end of the Cassini mission, we recently studied a "Saturn Swarm' of Cubesats that would hitch a ride with whatever mission follows Cassini to explore the ocean worlds Titan and Enceladus, for example.

We are presently funded by NASA to develop a mission concept called SunRISE - a swarm of Cubesats that together form an HF radio interferometer for observing Coronal Mass Ejections from our Sun.

Cupid's Arrow [19] is a small atmospheric probe concept designed to measure noble gases and their isotope ratios in the atmosphere of Venus. The nominal Cupid's Arrow mission assumes that the probe is targeted to Venus and carries a Solid Rocket Motor (SRM) that puts it into orbit around with periapsis below the homopause where noble gases are well mixed within the predominantly CO2-N2 atmosphere. Each sample acquired is then analyzed by a miniaturized Quadripole Ion Trap Mass Spectrometer (QITMS) developed at JPL (see Figure 5). A calibrant tank provides a reference for calibration. Data are transmitted to Earth during the long apoapsis segment of the orbit. The current estimate for the mass of the dry probe is 70 kg, including margins.

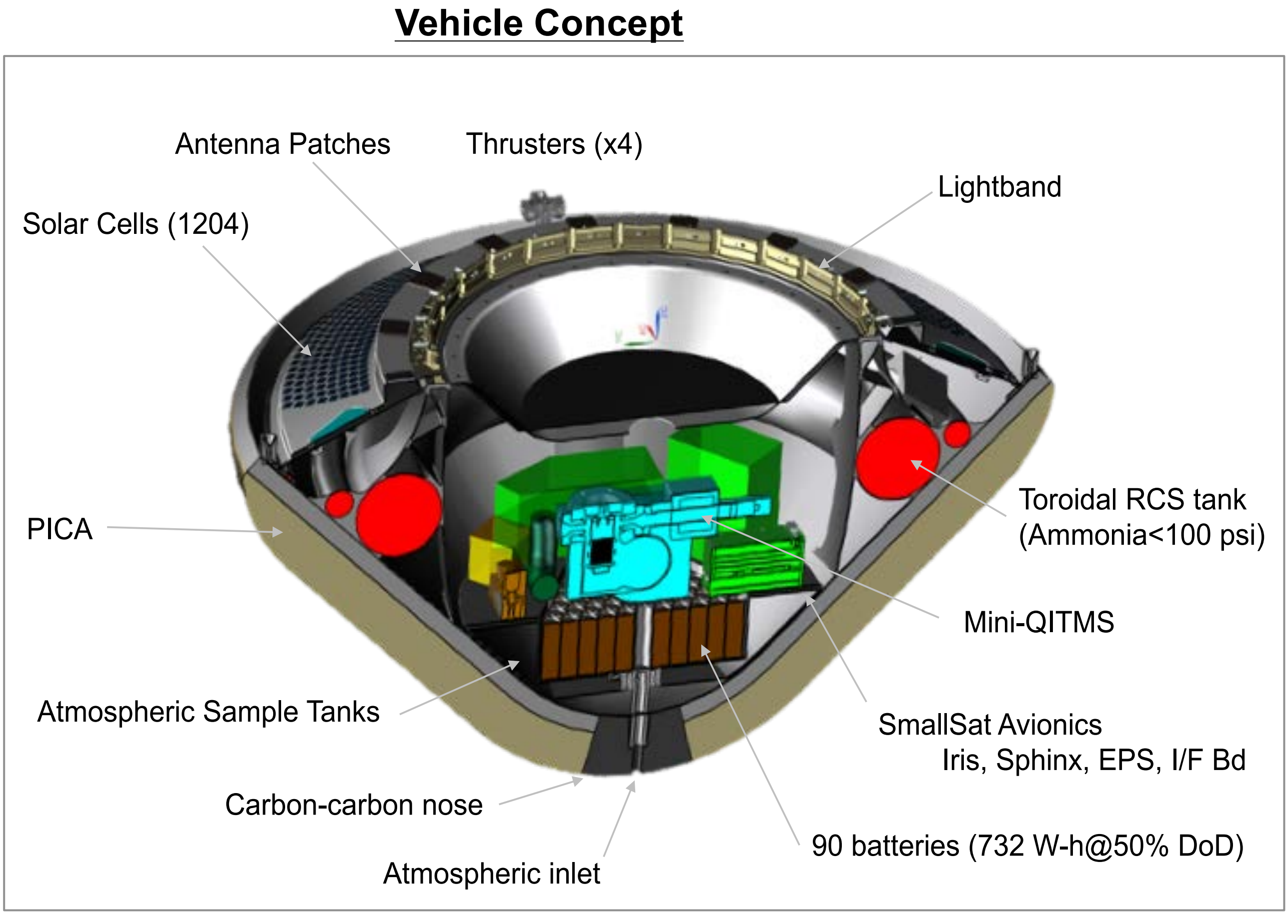

Figure 5: Cut-out depicting the design of the Cupid's Arrow Venus Atmospheric 'skimmer probe'

In LEO, Small Sats and CubeSats have changed the paradigm, offering a fast and low cost alternative to traditional space vehicles. These small spacecraft have spawned revolutionizing industries and are performing cutting edge science. This new mission development philosophy has the potential to significantly change the economics of interplanetary exploration and a number of missions are in development that could utilize CubeSat class spacecraft beyond Earth orbit. In a recent study [20] 10 'hitch-hiker' Cubesat and Smallsat concepts were studied that could ride along on NASA's next mission to the Saturn system, following the success of the Cassini mission. The concepts included probes similar to Cupid's Arrow but targeting the atmospheres of Saturn and Titan, orbiting Cubesats to study the magnetosphere and other phenomena at Titan, and finally a 'Ring-Diver' to get the closest possible view of Saturn's famous ring system – see Figure 6.

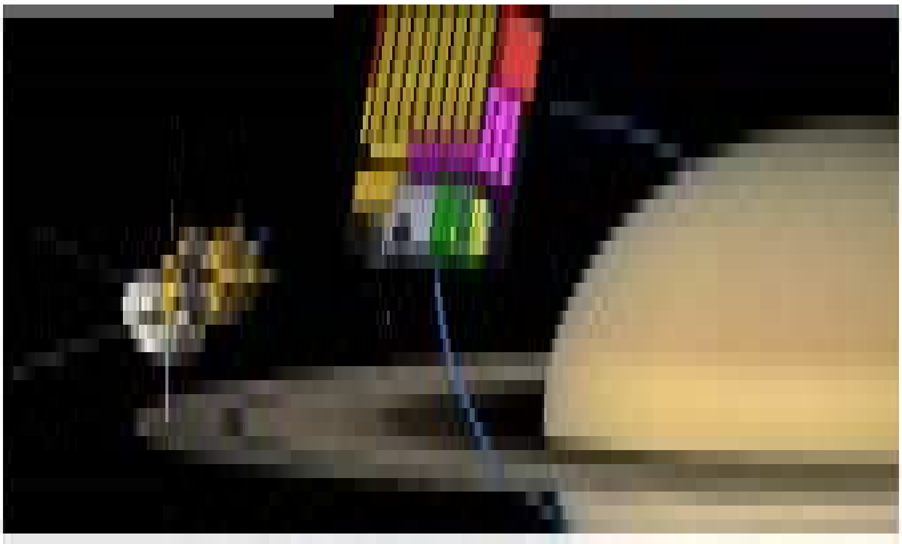

Figure 6: The Saturn Ring Diver Cubesat Mission Concept

The SunRISE mission currently under study consists of a ‘science swarm’ or constellation of 6 Cubesats operating as a synthetic aperture radio telescope to address the critical heliophysics problems of how solar energetic particles are accelerated and released into interplanetary space [21]. Each Cubesat is pointed in the direction of the Sun and carries an HF receiver (Figure 7). Signals collected by the synthetic array are combined on the ground. RF emissions generated by Coronal Mass Ejections are tracked and localized.

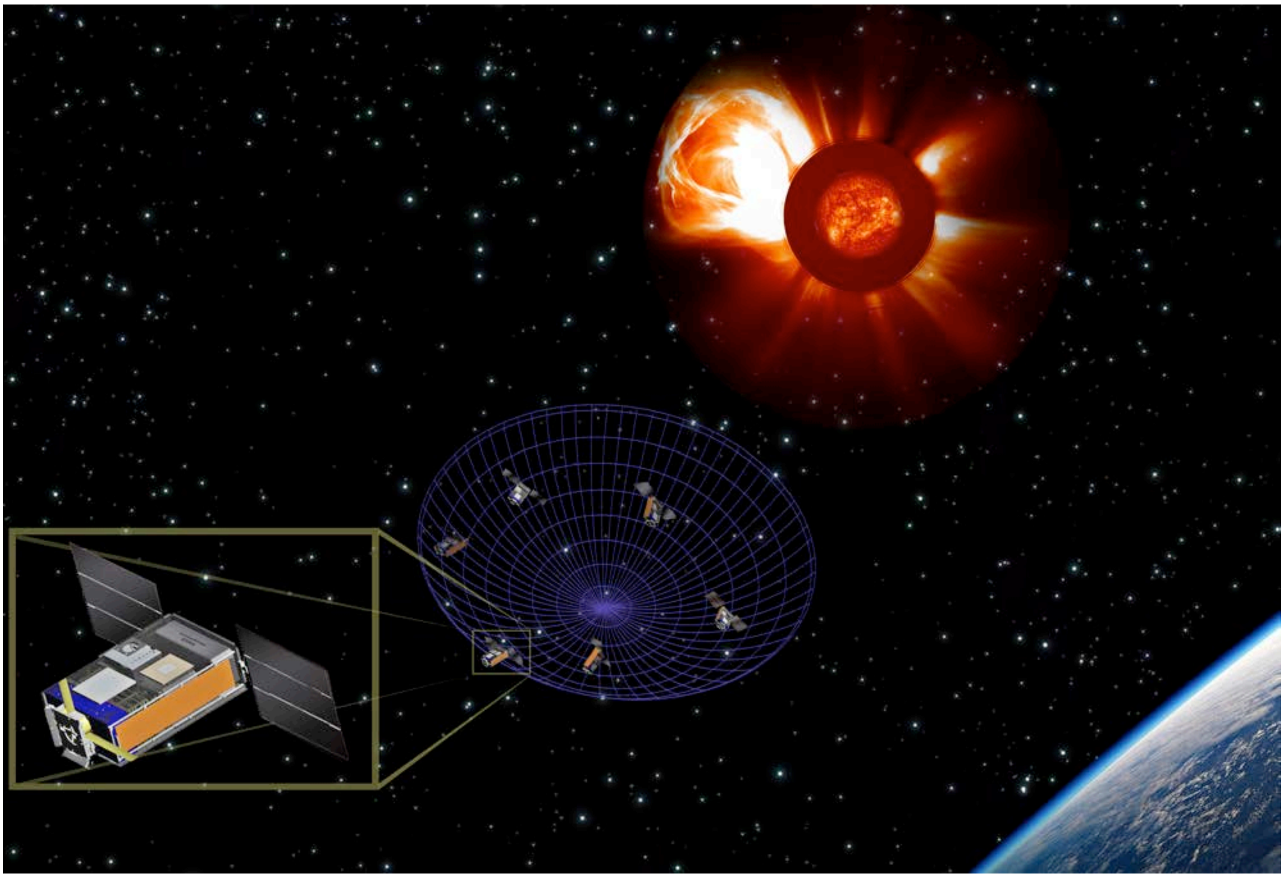

Figure 7: The SunRISE mission concept consists of a constellation of Cubesats which together constitute the first HF radio interferometer in space, focused on the study of radio emissions caused by Coronal Mass Ejections (CMEs).

5. SUMMARY

JPL has multiple Cubesat missions at each stage of development: formulation, implementation and operations. Each is significantly more capable than the Cubesats that were the state-of-the-art just a few years ago. The missions described in this paper are just a subset. More information can be found at [22].

6. ACKNOWLEDGMENTS

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The information presented about future CubeSat and SmallSat mission concepts is pre-decisional and is provided for planning and discussion purposes only. The work described here was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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