ACHIEVING VISIONARY PLANETARY SCIENCE GOALS WITH DEEP SPACE CUBESATS

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Deep Space CubeSats in Perspective

Some of the very first (**Fig. 1** *below*) interplanetary deep-space cubesat missions are currently in development!

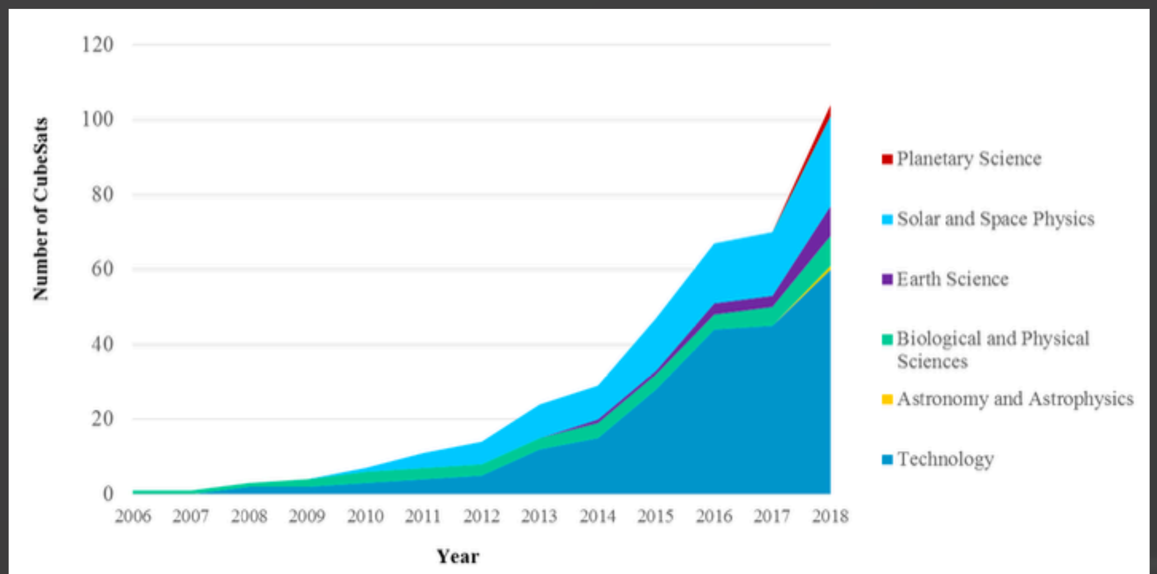


Fig. 1: Cumulative graph of the 104 NASA and NSF-funded CubeSat spacecraft launched and planned through 2018. The first deep-space planetary science CubeSats will be flown in 2016 – 2018 [1].

- A recent NRC study on all CubeSats launched through 2015 indicates that 67 percent of them have been considered successful in orbit, i.e., they achieved full success (33 percent) or partial success (34 percent) criteria (Figure 2).

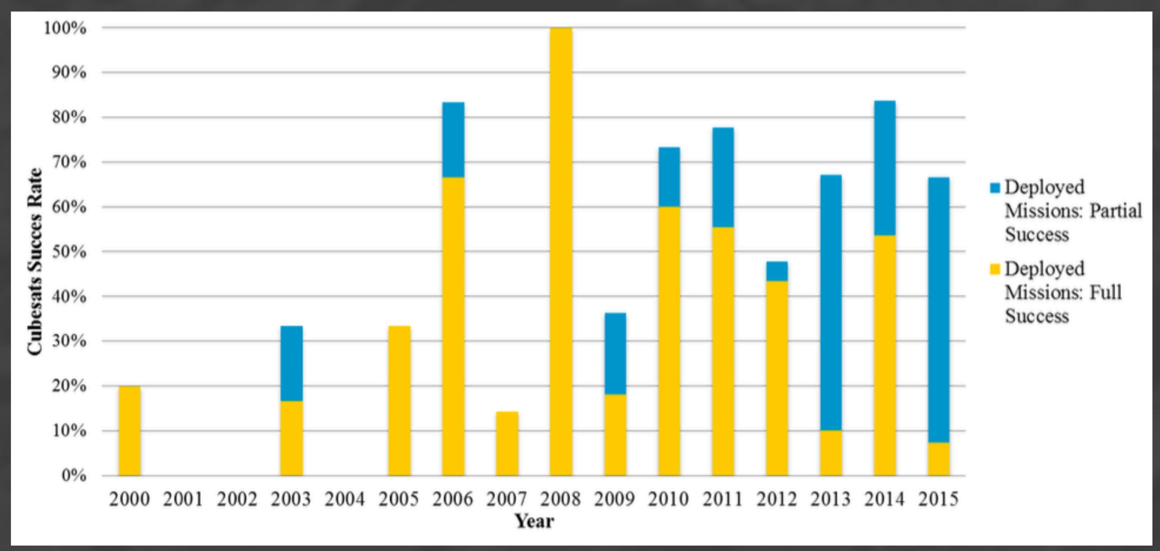


Fig. 2: Partial and full mission success for CubeSats launched from 2000-2015. Full success is nominal operations in-orbit nominally with completion of mission objectives. Partial success is commissioning and taking actions towards achieving primary mission objectives [1].

- NASA Class C/D missions have a ~80 percent success rate
- NASA Class A/B and NOAA operational missions have a ~90 percent success rate.

More recent (2008-2015) CubeSat missions, using a “Fly-learn-refly” approach (i.e. Aerospace Corporation, NSF CubeSat program) have been more successful (71%) then those launched between 2000-2007 (35%) [1].

A recent independent study from U. Munich found similar reliability rates [2].

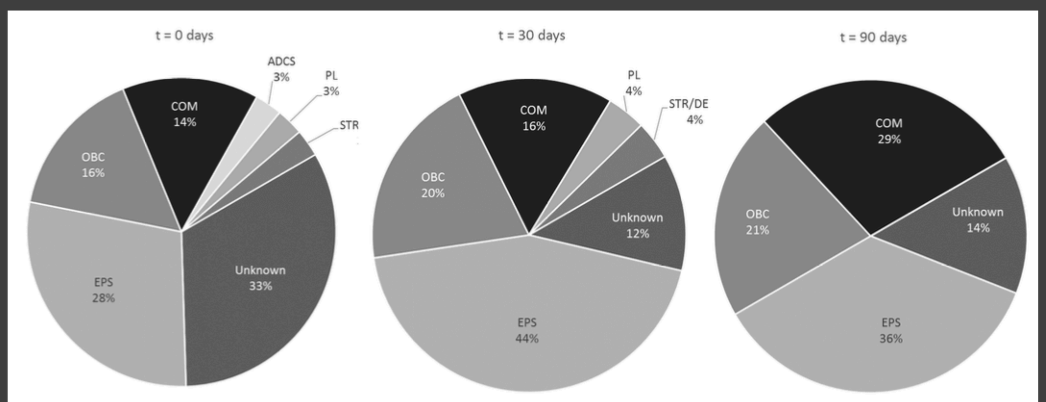


Figure 3: Subsystem contributions to CubeSat failure after ejection (incl. DOA), 30 days and 90 days

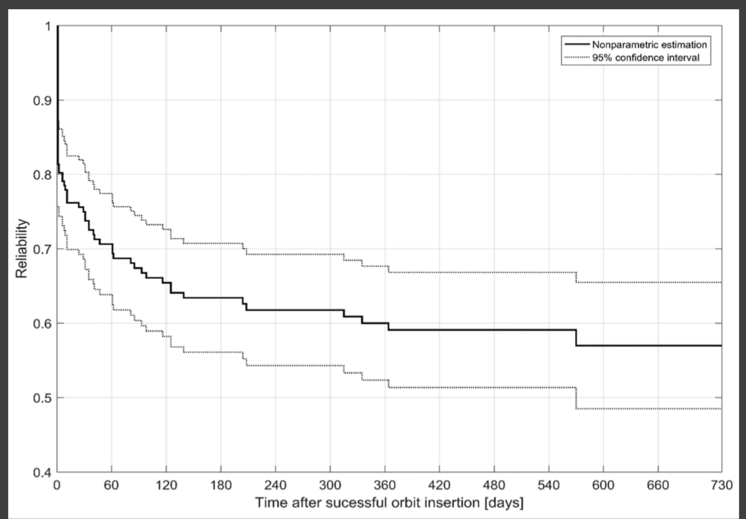


Fig. 4: CubeSat reliability is found to fall around 60% after 2 years in orbit (with 95% confidence interval) [2] http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3397&context=smallsat

Typical Planetary Science Mission Features:

- Longer duration
- Higher power
- Larger ΔV
- Larger spacecraft mass driven by science and engineering requirements
- Higher cost associated with lower acceptable project risk

Pre-existing spacecraft technologies developed for near-Earth missions must be modified and adapted for use in deep space planetary science missions. These include:

- Propulsion
- Communications
- Power systems (fault protection)
- Operational simplicity (lower cost)

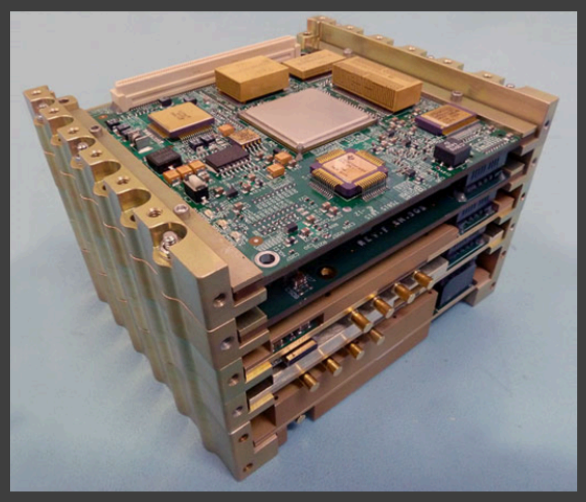
Conventional vs. Electric Propulsion

	Conventional	Electric
Propellant mass	Large mass	Small mass
Mission duration	Long	Very long

- High energy trajectories require large mass of chemical propellant;
- Electric propulsion uses less mass, takes much longer

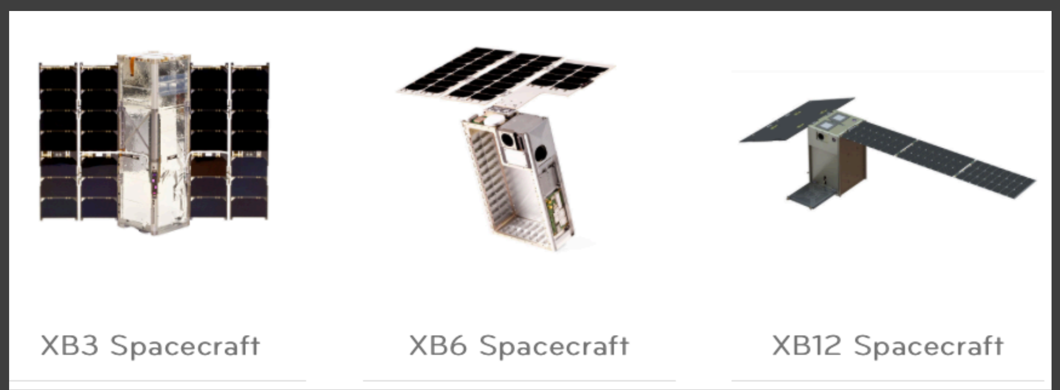
Mission design considerations for long durations
- Hardware reliability
- Operations costs
- Reducing mass by using electric propulsion creates very long mission duration and ops expense

Comms/Power/Instrumentation



JPL IRIS radio is capable of deep-space communication via the DSN at:
- Cis-lunar and lunar space via patch antennas (LunaH-Map, Lunar IceCube, BioSentinal – SLS EM-1)
- Mars via a reflector array (MarCO – Insight) [3,4]

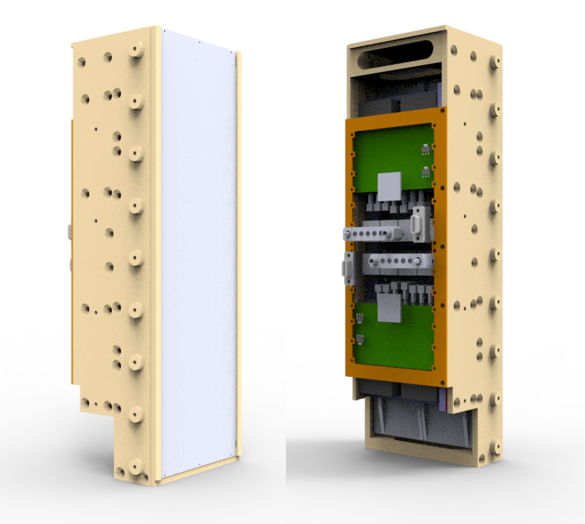
Blue Canyon Technologies is developing 3-12U CubeSat including power systems (<6W bus power; 25-100Whr storage), C&DH, FSW, comms, and orbit lifetime in LEO of >3.5 years [5]

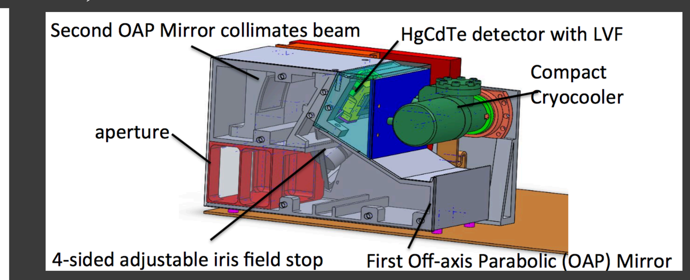


MMA Designs, LLC is developing large deployable solar arrays capable of providing >60W on a 6U CubeSat. The arrays are also gimbaled for peak power tracking (LunaH-Map – SLS EM-1) [6]

Science Instrumentation

Remote sensing instrumentation for deep-space planetary CubeSats is rapidly advancing to achieve high resolution imaging, IR spectroscopy, thermal mapping, and neutron spectroscopy (subset of miniaturized CubeSat science payloads in development below).





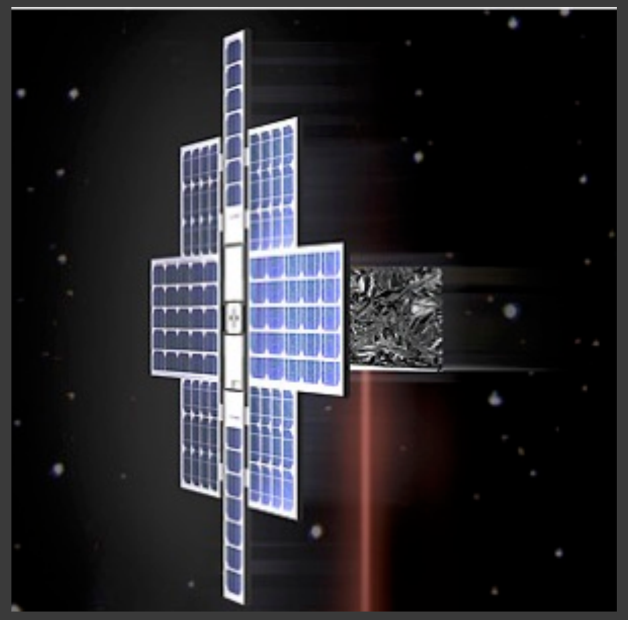


Fig. 7: Top left – 2U Miniature Neutron Spectrometer (Mini-NS) in development for the LunaH-Map mission [7,8]. Top right – BIRCHES IR spectrometer in development for Lunar IceCube mission [9]. Right – Lunar flashlight NIR laser reflectance instrument [10].

Planetary Science CubeSats in 2020 - 2050

- *Launch Opportunities:* Increased launches are necessary to support the “Fly-learn-refly” and “learn-as-you-fly” approach
- *Cost/Risk:* Increased investment now (despite possible failures) can pay off, if a strong commitment is made to the CubeSat platform and design philosophy
- *Mission Design for Planetary Science:* CubeSat rideshare opportunities should increase, but CubeSat platform mission designs should differ from that of larger spacecraft. Acceptance of high-risk/high-reward mission strategies will ensure deep-space CubeSats are a valuable addition to future deep-space rideshare opportunities. Looking to 2020-2050, ~6U CubeSats may focus primarily on high-risk/high-reward mission concepts such as multi-asteroid surveys, soft landers, penetrators or low-altitude orbiters.
- *Key Technology Developments:* Challenges for deep-space CubeSats without a parent spacecraft include management of radiation, power, telecommunications and autonomous navigation. Developments in these technologies will be critical CubeSats to truly become independent deep-space missions. Continued investment by NASA in miniaturized planetary science instruments for CubeSats will enable new mission concepts.

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