Evolving ChipSats to support Lunar Network Science at Scale. R. P. Quigley¹, J. C. Govern², and D. B. J. Bussey²

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Overview: We have developed a ChipSat that can survive the high-g loads associated with a hard landing on the Moon. We are investigating the utility of these devices to conduct inexpensive widespread network science on the Moon. These ChipSats can be dropped off in orbit, survive impact with the lunar surface, and collect large data sets of interest.

Background: Our plan is to refine ChipSat designs for future planetary missions that could benefit from the low cost and broad spatial and temporal resolution data collection capabilities of ChipSats. We believe ChipSats could be used to efficiently characterize broad swaths of the lunar landscape to support exploration, ISRU, STEM education, and enable network science at varying scales across multiple disciplines.

Additionally, we are looking at a number of use cases for ChipSat-based systems that can cost-effectively characterize other bodies in the Solar System. One example would be performing surveys of the asteroid belt, or outer planet moons as a precursor for larger science or exploration missions. In conjunction with a transportation/logistics provider, we could execute these survey missions and generate data of significant value for NASA and similar organizations. Developing capabilities and deploying systems in the lunar environment would provide a jumping-off point for these broader programs.

ChipSat History / Organizations / Missions: ChipSats, as the name suggests, pack the basic functions of a satellite onto a platform the size of a small microchip. The concept was first introduced in 1999 by the Aerospace Corporation, and Cornell has been developing ChipSats since 2010 and achieved TRL 8 via multiple orbital missions (104 deployed in 2019). The University’s work represents the leading edge of decades’ worth of effort to miniaturize space systems. Building off this, New Ascent has developed a line of Suborbital ChipSats that can be delivered to altitudes above 100 km, and function both during descent and on the ground. Figure 1 shows the Spark vBeta suborbital ChipSat which has been used to collect atmospheric data and has survived multiple ground impacts.

Many use cases have been proposed and researched by organizations that include: NASA, APL, Draper Laboratory, Sandia National Lab, University of Surrey, University of Strathclyde, Brown University, Carnegie Mellon University, and International Space University. Notable space missions include:

- **MISSE-8** (2011): ISS experiment that included 3 ChipSats. Demonstrated in-space survivability for 3 years in LEO.
- **KickSat-1** (2014): First flight of 3U deployer with 104 ChipSats.
- **Venta-1** (2017): ChipSat hosted payload demonstrated comms at 1500 km.

The next planned space mission is **Alpha** (late 2024), a CubeSat that will deploy a light sail experiment carrying 4 kapton-substrate ChipSats that will demonstrate operational functions for future sail systems.

Another exciting use case is for the Breakthrough Starshot Initiative, which envisions propelling a chain of ChipSat-controlled solar sails at 20% of the speed of light on a 20-year mission to Alpha Centauri to gather and return images of the planets in that solar system.

Figure 1. New Ascent’s Spark vBeta ChipSat

ChipSat Platform Capabilities: ChipSat platforms include subsystems that are analogous to those of their larger cousins, and have seen a steady increase in performance over the last 10 years due to advances in microcontrollers and other technologies. While existing designs have been optimized for low size and mass, these can be traded for increased utility without sacrificing the cost benefits of the platform.

Mechanical: Board size has varied from 36 x 36 mm up to 25 x 100 mm employing square and rectangular form factors using both silicon and kapton substrates. Mass is on the order of 5-10 g with silicon and has been reduced to 2 g with kapton.

Power: ChipSats for orbital applications have used solar cells, generating from 20 to 300 mW. Suborbital and terrestrial ChipSats have had hybrid (solar cell + storage) or storage-only architectures. The power bus is
typically regulated to 3.3 V, aligned with the input required by most MCUs and PCB-scale sensors. Energy storage has been achieved using ultracapacitors and lithium polymer batteries. Average power draw has varied based on the sensor suite, but is typically under 50 mA; peak power draw has been in the range of 100 – 200 mA for higher performing designs.

**Avionics:** Initial designs used MCUs operating at 16-48 MHz; current designs employ dual core 133 MHz ARM Cortex MCUs. Integrated, external chip, and SD card flash memory types from 32 kB to 16 GB have been used to store application and sensor data. Interfaces include I2C, SPI, UART, and USB.

**Guidance, Navigation, and Control:** GNC sensors employed include IMUs, lights sensors, and GPS receivers. Currently under test is a 9-axis IMU with an integrated processor that outputs orientation (Euler angles, quaternion), angular velocity, and linear acceleration at 100 Hz. Later ChipSats have employed an integrated torque coil in tandem with light sensors to point solar cells at the sun.

**Firmware:** Firmware for operations typically employs the C language, often with real-time programming architectures. CircuitPython-based education applications are under development to make the platform more accessible for K-12 students.

**Communications:** NASA Gold Codes, various FSK implementations, and the LoRa protocol have been used at the 437 MHz and 915 MHz ISM bands. Data rates (range dependent) from 100 bps to 27 kbps have been demonstrated. Unobstructed, line-of-sight links have been closed at up to 1500 km; obstructed ground-to-ground links have closed at 4-5 km. ChipSat-to-ChipSat networked communications have been tested in a lab setting.

**Sensors:** Early ChipSats integrated only basic GNC sensors (IMU, light), while later suborbital and terrestrial designs incorporated GPS and atmospheric sensors (temperature, pressure, humidity). Candidate sensors for future missions would ideally have a PCB-scale size and mass, low average power draw, and generate data for storage or transmission at average rates of <1 kB per second. That said, higher-performance use cases should not be ruled out; FPGA architectures for on-board image processing and similar applications have been conceptualized.

**Lunar Science ChipSat Systems:**

**System Elements and ConOps:** A Lunar Science ChipSat system would include:

- **ChipSats.** Collects data to support the scientific investigation. Derived from current platforms and optimized to support a mission-specific sensor suite. Anywhere from one to thousands could be deployed across an area of interest in one or multiple deployment events.

- **ChipSat Dispenser Mechanism.** Deploys ChipSats as required by the investigation. Could be a small, concentrated area or a large survey across thousands of square kilometers. Deployment from orbit, during descent, from a stationary lander, or dispersion via rover or human on the surface are all viable methods.

- **Base/Receiver Station.** Receives ChipSat transmissions and stores, processes, and/or forwards data as required by the investigation. Could be in orbit or on the lunar surface.

**Benefits/Advantages:**

- **Enables True Network Science.** Adaptable deployments to achieve investigation-specific spatial and temporal data resolution.

- **Low Cost.** Current ChipSats cost <$200 each.

- **Massive Scalability.** Low size and mass enable large scale deployments of potentially up to tens of thousands of sensors.

- **Data Redundancy.** Multiple sensor deployments in a given area increase data reliability and hedge against sensor failure in the harsh lunar environment.

- **Rapid Development Cycles:** 3-month typical design/build/test cycle for PCB-scale embedded systems.

**Technology Challenges:** A number of challenges need to be addressed through terrestrial R&D and in-situ testing to evolve ChipSat systems into viable and valuable tools for lunar science.

- **ChipSat platform ruggedization for lunar environment survival**

- **Sensor g-ruggedization to allow for orbital, descent, and other deployment types that involve lunar surface impact**

- **Sensor miniaturization to allow for integration with a ChipSat-scale platform**

- **Power generation and storage approaches compatible with the lunar environment and a range of investigations**

- **Lunar Geolocation for ChipSats via a Lunar Navigation System or determination of relative locations using techniques like Time Difference of Arrival (TDoA)**

- **Lunar night survival to enable longer duration investigations**

**Potential Lunar Science Opportunities:**

- **Temperature Mapping**

- **Magnetic Field Mapping**

- **Mineral & Resource Characterization**

- **Seismology**

**Conclusion:** We are excited to explore with the planetary science community how ChipSats can be used to enable broad network science.