SMALLSAT INNOVATIONS FOR PLANETARY SCIENCE MISSIONS.

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Introduction: As NASA continues to look for ways to fly smaller planetary missions such as SIMPLEX, MoO, and Venus Bridge, it is important that spacecraft and instrument capabilities keep pace to allow these missions to move forward. As spacecraft become smaller, it is necessary to balance size with capability, reliability and payload capacity. Ball Aerospace offers extensive SmallSat capabilities matured over the past decade, utilizing our broad experience developing mission architecture, assembling spacecraft and instruments, and testing advanced enabling technologies. Ball SmallSats inherit their software capabilities from the flight proven Ball Configurable Platform (BCP) line of spacecraft, and may be tailored to meet the unique requirements of Planetary Science missions.

We present here recent efforts in pioneering both SmallSat and instrument miniaturization through mission design and implementation. Ball has flown several missions with small, but capable spacecraft. We also have demonstrated a variety of enhanced spacecraft/instrument capabilities in the laboratory and in flight to advance autonomy in spaceflight hardware that can enable some small planetary missions.

Small Spacecraft: The Ball Small Satellite bus is a fully capable, configurable spacecraft in a compact form factor. With a mass of less than 110 kg and a volume of 61 × 71 × 71 cm, it is fully compliant with ESPA ring single port secondary launch requirements (Figure 1). The spacecraft is three-axis stabilized with precision attitude knowledge (0.02°) and control (0.03° to 0.10°) to meet the demands of a planetary science mission. The bus provides data, command and telemetry interfaces for up to four science payloads, each with data transfer rates of up to 2.0 Mbps. Available total payload mass is up to 70 kg (more if the ESPA reclassification values or ESPA Heavy class is used [1]) with 100-200 W total available payload power (at 1 AU) in a volume of 49 × 67 × 45 cm. An optional solar electric propulsion (SEP) module offers up to 1.5 km/s of ΔV [2].

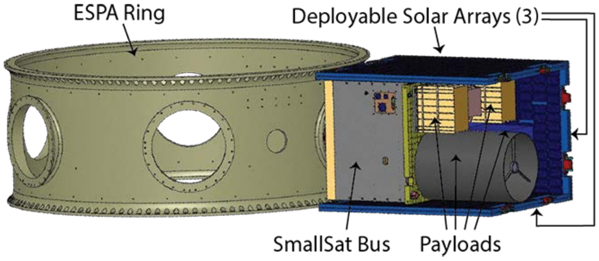

Figure 1. The Ball Small Sat is ESPA ring compatible

Bus Heritage: Two Ball SmallSat busses have flown in low Earth orbit: STPSat-2 (Figure 2(*l*)) and STPSat-3, launched in 2010 and 2013, respectively, both from a Minotaur IV. To date, both spacecraft are still in operation providing nominal performance. A third SmallSat bus has been delivered for the NASA STMD Green Propellant Infusion Mission, and is scheduled to launch from an ESPA ring aboard a Falcon 9 Heavy (Figure 2(*r*)). Finally, a fourth bus is currently in development for the NASA Small Explorer Mission, IXPE.

Figure 2. STPSat-2 (left) and GPIM (right) Small Sats

Miniaturized Science Instrumentation: With a small spacecraft bus comes the need for science instrumentation with significantly less size, weight and power than their traditional mission couterparts. Through a mix of internal research and development and NASA funding, Ball is focusing instrument miniaturization in four key areas described below.

(1) Off the Shelf Components. Our NanoSAGE (Stratospheric Aerosols and Gases Experiment) instrument development uses existing, miniaturized components to build a robust, cubesat compatible sensor small enough to fit within a 1.5U (10 × 10 × 15 cm) instrument payload section. Simple optics feed a commercial spectrometer and utilize the spacecraft to perfrom spatial scans.

(2) State of the Art Calibration. Ball is developing a low volume, highly accurate radiometric calibration approach for the Compact Infrared Radiometer in Space (CIRiS) mission (Figure 3). The advanced carbon nanotube sources and uncooled microbolometer Focal Plane Arrays (FPAs) in the CIRiS instrument will be demonstrated in low earth orbit on a 6U cubesat (12 × 24 × 36 cm). [3][4][5]

(3) Cross-Technology Infusion. Ball is developing a highly miniaturized microwave radiometer utilizing advances in Photonic Integrated Circuits (PICs).

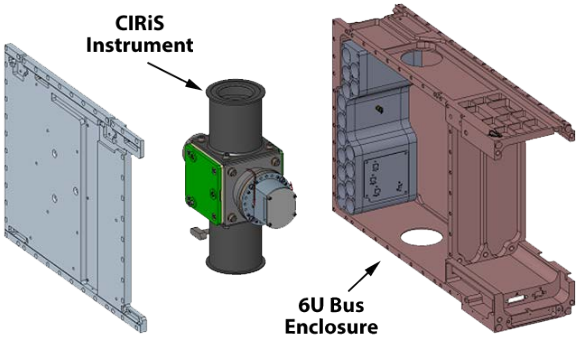

Figure 3. An advanced on-board calibration target enables a low power, uncooled Compact Infrared Radiometer in Space (CIRiS).

Fusing PICs technology with a microwave instrument allows for a significantly greater number of observing channels in an area less than 150 times smaller than existing filters.

(4) Technology-Mission Integration. Simple, focused measurements made in conjunction with existing assets can greatly increase the overall science return. With less complex measurements, sensor performance may be optimized and implemented in extremely small envelopes. To this end, Ball is developing a Compact Hyperspectral Prism Spectrometer (CHPS) [6] and a Reduced Envelope Multispectral Instrument (REMI).[7] These efforts utilize innovative technologies such as step-stare scanning and unique optical designs to create small, low cost instruments to complement and extend existing ongoing missions.

Enabling Advanced Algorithms: With Small Sats possessing more limited resources than their full-sized counterparts, autonomy and selective data collection become important for keeping data storage, data downlink volume and spacecraft commanding to a minimum. Ball has demonstrated a variety of enhanced spacecraft and instrument capabilities in both the laboratory and in-flight to advance autonomy and control for spaceflight hardware. One example of this is the use of Model Predictive Control Algorithms (PCAs). Ball has developed PCAs to provide autonomous instrument operations and spacecraft control to maximize observing opportunities. Using a LIDAR instrument as a sample application, a PCA was developed to autonomously and dynamically steer laser beams to maximize observations of desired features – e.g., waterways on Earth (Figure 4). [8]

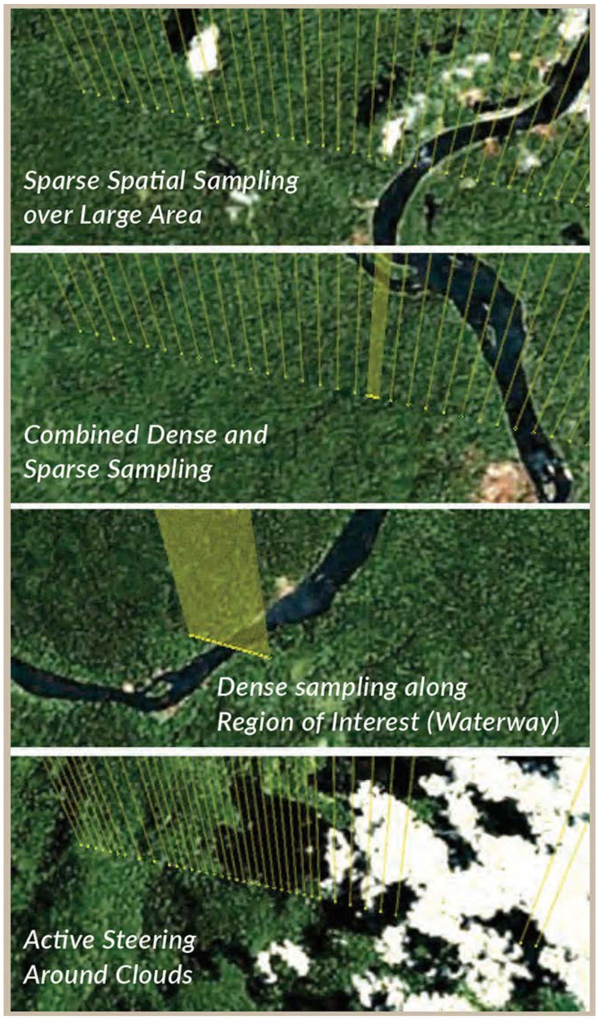

Figure 4. Predictive Control Algorithms can enable smart instrument operations to make selective measurements of regions of interest, thereby reducing operating time and downlinked data volume.

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