Space Environmental Electrical Power Subsystem (SEEPS)

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Introduction
The space environment presents numerous hazards (energetic particles, radiation, debris, plasmas, etc.) that are traditionally viewed as threats to spacecraft. The current research effort – the Space Environmental Electrical Power Subsystem (SEEPS) – seeks to harness these dangers to provide a novel source of power for spacecraft. The research campaign seeks to identify sources of energy in the space environment and develop the requisite technology to harness it. Here, we present an overview of the concept and future steps in the research campaign.

State of the Art Spacecraft Power
Spacecraft are currently powered by photovoltaic (PV) cells or radioisotope thermoelectric generators (RTGs). PV cells work amazingly well in the inner solar system, but are easily damaged by debris or charging environments. RTGs have been the only source suitable for long duration missions beyond Jupiter, but are becoming scarce and are ill-suited for small spacecraft applications or distributed sensing missions.

The need for SEEPS
Measurements of the space plasmas often require knowledge of spatial gradients in properties. This requires taking multiple measurements at different spatial locations at the same instant in time. Often, the spatial scales of interest are on the order of km, not cm. Traditional, monolithic spacecraft architectures are not able to accomplish this mission.

Distributed spacecraft architectures (e.g. Cluster II, THEMIS) have successfully performed these measurements by flying several (4-5) spacecraft in formation. Taken to the extreme, swarms of tiny CubeSats and ChipSats could perform numerous measurements simultaneously. While feasible in Earth orbit, this becomes difficult to impossible with current PV or RTG technology beyond Earth orbit.

The Space Environment presents
- Radioisotope thermoelectric generators (RTGs): PV cells are insufficient to accomplish the mission. RTGs have been the only source suitable for long duration missions beyond Jupiter, but are becoming scarce and are ill-suited for small spacecraft applications or distributed sensing missions.

Wireless Power Transmission
NASA has experimented in the past with wireless power transfer (laser & RF) between spacecraft and between the ground and spacecraft. These architectures share features with proposed SEEPS missions:
- Distributed sensor networks, without conventional power sources
- Centralized processing and communications
- Low power spacecraft operations

RF Harvesting
In Earth orbit, a 1 ng particle impacts at a rate of 1/day/m². A piece of debris or micrometeoroid impacting spacecraft at orbital speeds (v ~ 10 km/s) can vaporize and ionize both itself and portions of the spacecraft chassis, forming a plasma. As the plasma expands, an electromagnetic pulse (EMP) is emitted [1].

EMPs may contain a significant fraction of the impactor’s kinetic energy (for a 1 ng particle, travelling 10 km/s, KE ~0.1 J). Freely flying sensors, deployed in a dusty environment (vicinity of an asteroid, comet, ring system) could capture a portion of this energy to measure and transmit data.

Plasma Transformer
Plasmas are inherently dynamical and unstable and currents can be set up by imposing electromagnetic fields. Though plasmas are initially quasineutral, the flow of plasma can be briefly split into ion and electron components with magnetic fields. If the resulting current varies rapidly, significant voltages will be created in the spacecraft due to Faraday’s law, inducing currents. With the proper geometry and rectifying circuitry, this could be harnessed directly.

Spacecraft Charging
Bodies immersed in a plasma build up a net charge due to the relative flux of electrons to ions at the surface. Depending on the geometry, lighting conditions, and plasma properties, the spacecraft potential can differ considerably from the ambient potential by tens of V in sunlight to negative kV in eclipse.

Passive electron emitters decrease this discrepancy by expelling electrons with large electric fields generated at sharp geometrical features [2]. This creates a current from the spacecraft chassis/surface to the emitter. Interrupting this current with a load or battery is a possible source of power in the space environment.

Future Work
In Autumn 2018, SEESS is conducting a series of experiments at NASA Ames Vertical Gun Range (AVGR), a light gas gun used to accelerate microparticles to large velocities. In addition to the primary dusty plasma research goals, we are developing a sensor to simultaneously quantify the RF emission spectrum from the resulting EMP and demonstrate that energy storage in these impacts is feasible.

We are funded to simulate through 2019 to begin more intensive research beyond the feasibility study presented here. In particular:
- Use PIC simulations to demonstrate plasma transformer operation
- Develop an EM solver to determine the spectral energy content of the hypervelocity impact EMPs
- Use public domain charging codes to determine IV curves for representative spacecraft
- Place bounds on energy content of regions of interest

Later, we plan to choose one technology and develop a prototype SEEPS to test in ground-based experiments. Prototype flight units will follow.

Conclusions
Current spacecraft power sources are insufficient to accomplish the broad range of scientific questions remaining in planetary science. We intend to develop a system to harness the energy within the space environment; using the EMPs emitted from debris impacts, currents in the plasma, or from spacecraft charging. This will enable large distributed sensing missions in the outer planets and open up interstellar space to exploration.

Acknowledgments
Sean Young would like to thank the guidance of Prof. Sigrid Close and Dr. Nicolas Lee for the many helpful insights and ideas they provided and to the NASA for funding the work for 2018-2019.

Bibliography

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