Small Satellite Swarm Observations for Auroral Physics

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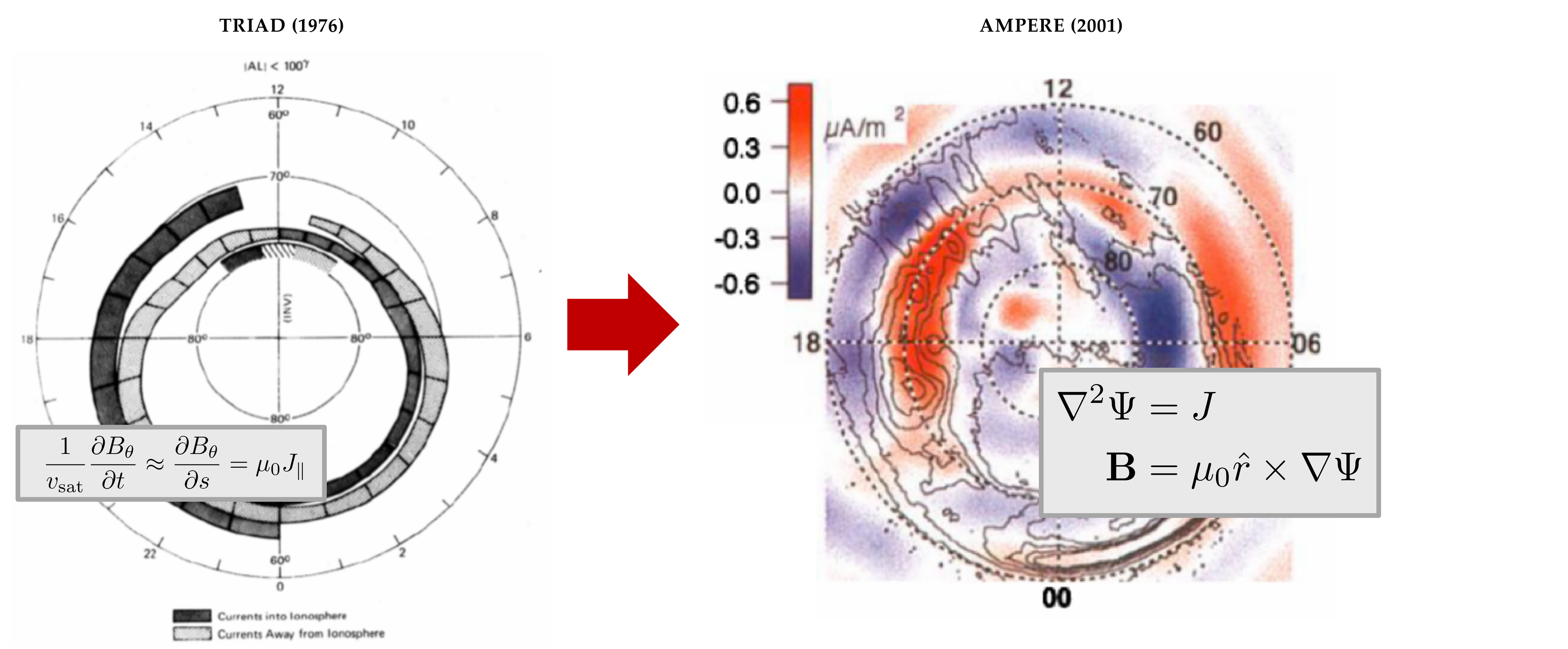
Abstract

Over the past few years Boston University has been developing a small satellite swarm to study the small-scale structure of the aurora. Here we describe show the resulting spacecraft and describe the concept of operations. In addition to the work on the in-house CubeSat, we also show results from collaboration with industry partners that already have satellite constellations on orbit. Auroral structure is visible using attitude magnetometers from a dense constellation of Earth observing CubeSats. This lends hope to possibly using other constellations for added data density of the magnetic environment on orbit, beyond AMPERE's coverage and revisit rate for small-scale phenomena.

I. Introduction

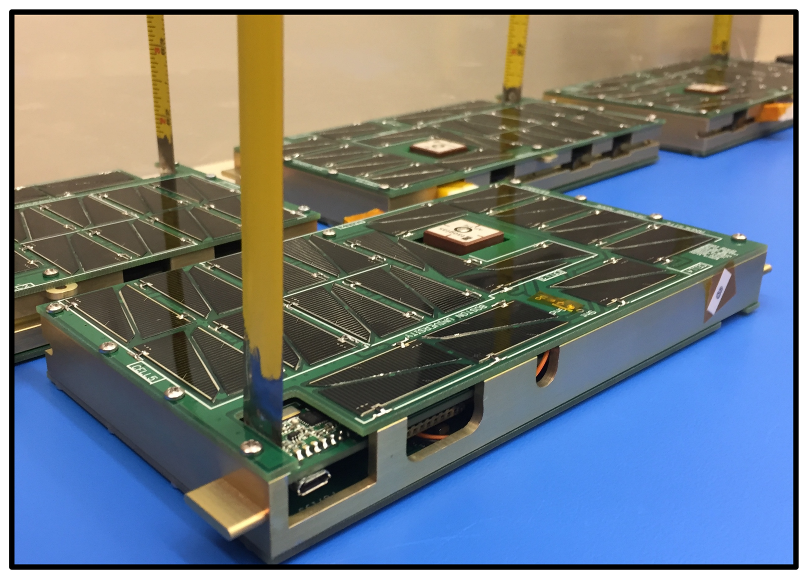
The science need for a dense multi-spacecraft architecture arises from the spatial nature of the auroral structure [Stasiewicz et al., 2000]. The electrical current systems driving the aurora are caused by an intricate interaction between Earth's magnetic field and the solar wind. When the currents strike the atmosphere, their structure imposes a footprint seen as the northern and southern lights. The lights are modulated by plasma wave phenomena that connect ionosphere the magnetosphere, a fundamental research area in space physics. Through Ampere's law we see that those currents which are mainly parallel to the Earth's natural dipole magnetic field manifest in a local magnetic perturbation.



The AMPERE project (**example above right**) demonstrated the scientific efficacy of a space based sensor network, as well as the efficacy of low-quality sensors when deployed in a network configuration [Clausen et al., 2012]. The analysis method of Waters et al. [2001] involved first mapping the data from 66+ satellites to a vector potential estimate of the global perturbation magnetic field. That representation simplified to a direct relation between a fit of the magnetometer samples δB at each satellite point to a global scalar potential $\Psi(r, \theta, \phi)$ represented by spherical harmonics and a Poisson equation for current density. This moved beyond the classic approach of a single time series mapped to a spatial derivative and has been recognized as the path forward for data assimilative techniques [Knipp et al. 2014].

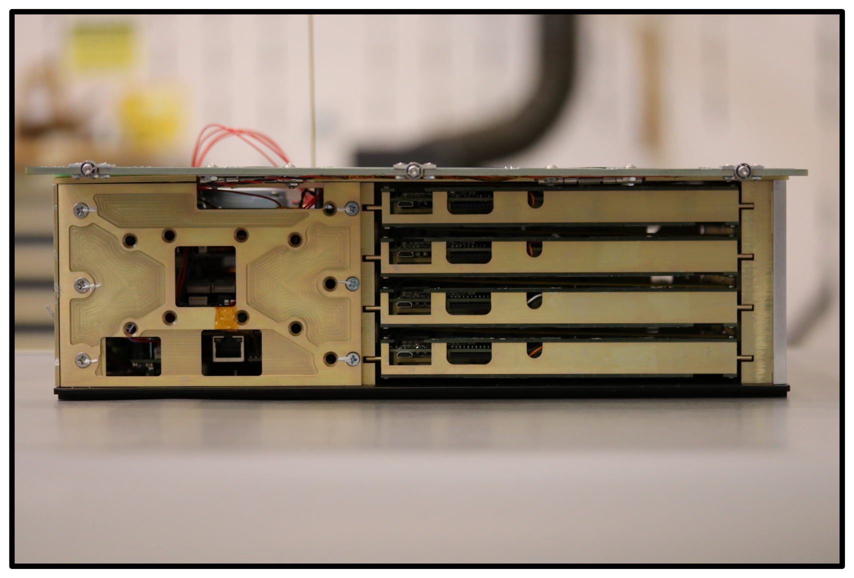
II. ANDESITE

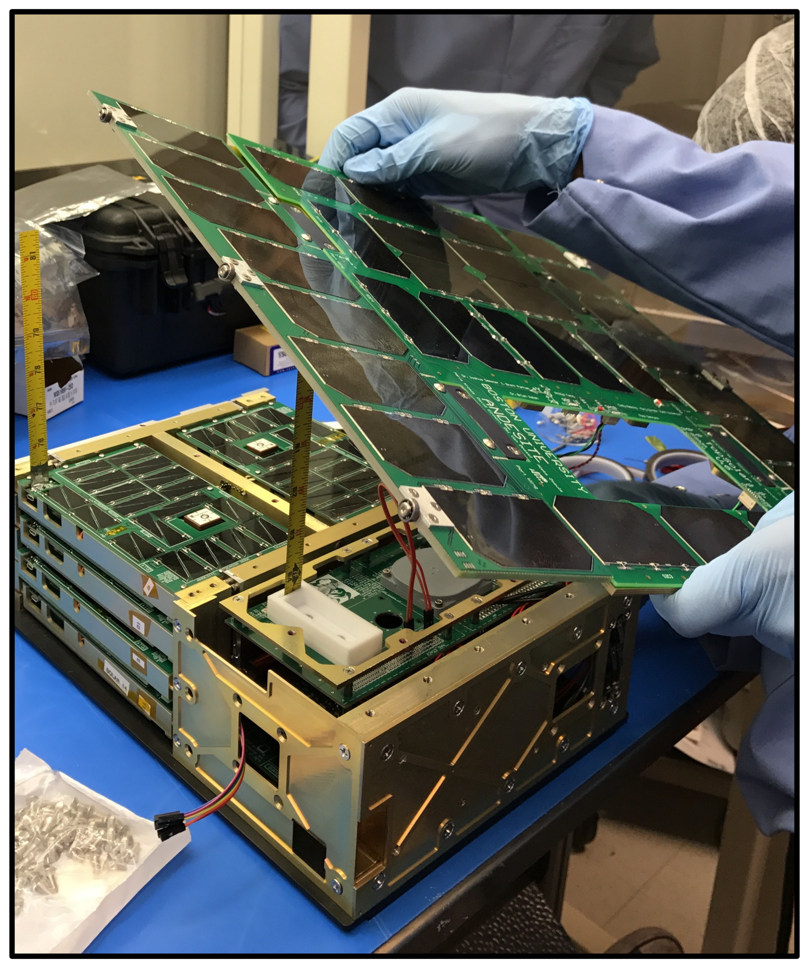
With modern low-cost systems, multiple spacecraft can fly through the same auroral event, moving toward a better decoupling of any space-time ambiguity. ANDESITE's mission is to sample in such a way that the integral form of Ampere's law can be used to directly estimate the currents. This is accomplished with a swarm of eight closely spaced picosatellites (**right**) deployed from a larger 6U mothership (**below**).



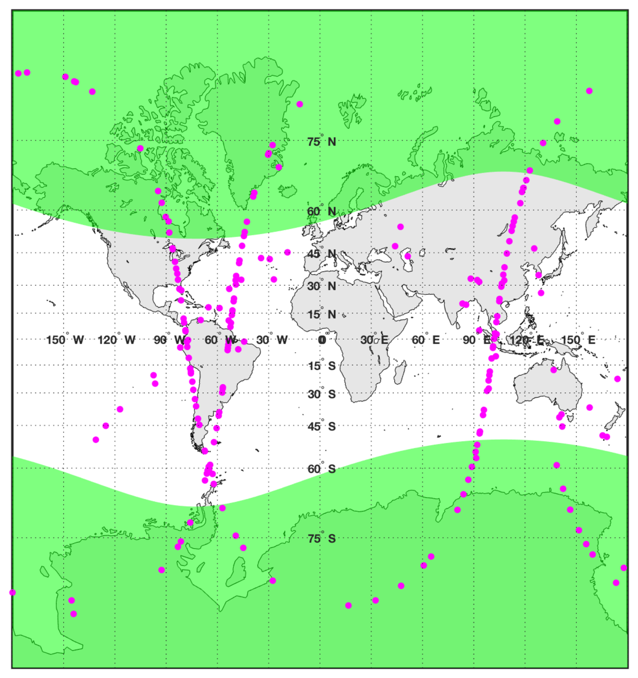
This design acts as a cheap pathfinder mission for operation model. The system is a proof of concept for creating and managing a small swarm. With the short-duration mission, the design can include risk acceptance of parts without space heritage up to the failure of individual satellite nodes as long as "enough" of the nodes work to provide a spatially diverse sampling. The program also relies on a novel duplex radio from Nearspace Launch's EyeStar line. The simplicity of the command and control path and the low urgency of data downlink is ideal for such a device, providing near-constant access to the spacecraft with no need for a ground station.

ANDESITE is built, licensed, and awaiting its ELaNa launch currently scheduled in 2018.



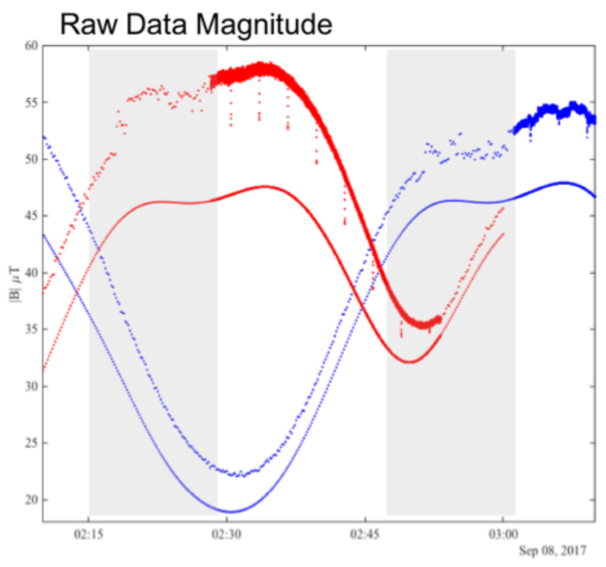


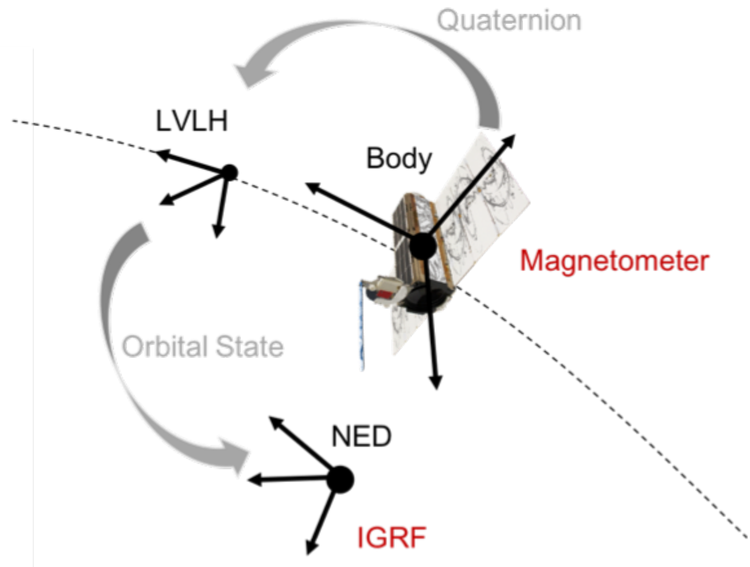
III. Commercial Collaborations

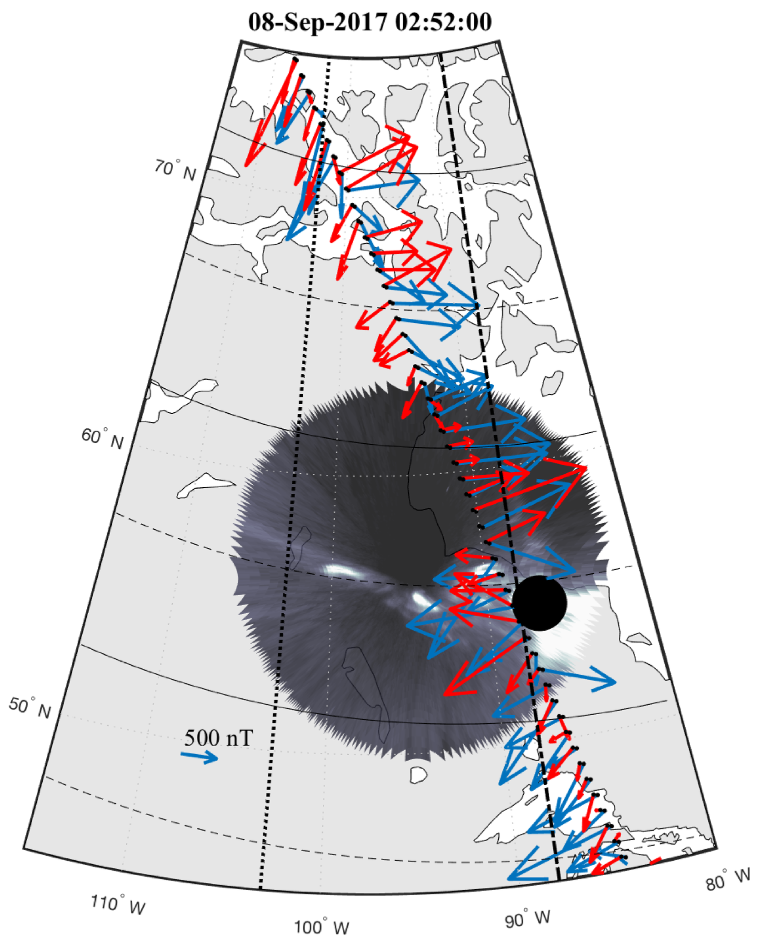


The Planet Labs Inc. constellation currently consists of nearly 200 3U CubeSats using non-propulsive phasing to make an evenly distributed network of earth observing sensors [Foster et al., 2017]. Their main mission is to image the Earths surface at high cadence and coverage and they need precise attitude knowledge to correctly geo-register those images and communicate them down to a ground station. A large part of the constellation uses two orbital planes that are sun-synchronous at 500 km (280 km *lower* than the Iridium constellation) and centered around 10AM and 10 PM, (seen in the **map on the left**). This allows a crossing of the northern auroral oval (**green shaded area**) on the night side at around 9PM and 11PM local time each night. Their capability has been rapidly built by waves of satellite launches, each updating the design to ensure a more robust operation. Satellites used in this poster were part of the Flock 3P launch [Doan et al., 2017], the latest iteration of the spacecraft which included star-trackers to help with attitude knowledge.

In order to make sense of the attitude magnetometer data, it needs to be aligned with geophysical reference frames. Since magnetometers affixed to body of satellite and report data in that frame there needs to be a translation to the coordinate frame of the IGRF model. To accomplish that we use the orbital state and self reported attitude knowledge from the spacecraft. Planet publicly releases ephemerides data with full historical access that are made using internal telemetry data and claim to be accurate to <1 km [Foster et al., 2015]. (http://ephemerides.planet-labs.com)







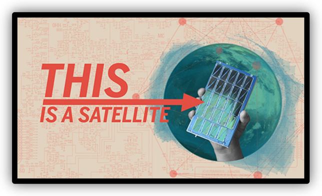
A first pass plotting (**above**) the magnitude of the magnetic field versus the IGRF sampled magnitude using the TLE state immediately shows that more post processing calibration is needed to rectify the measurements. Attitude estimates are provided by Planet in the form of quaternions referenced as rotations from the Local Vertical Local Horizontal (LVLH) reference frame (**schematic above).** A typical Planet satellite is three axis stabilized, with the telescope nadir pointing for the imaging mission.

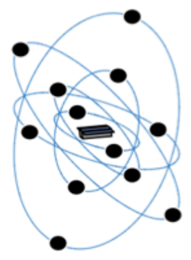
Once the data has been aligned and calibrated against the Earth background field, a high pass filter is applied to smooth out modeling errors, nulling anything with periods 30 minutes or longer. That cutoff is chosen to represent about a third of an orbit with enough buffer to not critically affect small-scale features in the signals. This process is similar to the early AMPERE processing chain ideology. Using IGRF we map the satellite geographic footprint along the field line from the 500 km altitude orbit to the reference altitude of 110 km where we can also correlate magnetometer measurements with an all-sky camera (seen **left).**

The intense solar events in early September 2017 provided a clear picture of the capability of the Planet constellation to resolve events in LEO. With nearly the entire constellation passing through the Birkland currents and a few satellites within them at any moment the spacecraft provide unprecedented revisit rate and coverage of the current system that their orbital planes pass through.

IV. Path Forward.

Satellite sensors should become as commonplace as weather buoys in an ocean. Specialized systems like ANDESITE or a similar controlled formation will push the envelope of resolution. With better miniaturized thrusters, more reliable magnetometers or other plasma instruments, and small GPS receivers, swarms of low-cost sensors can resolve the aurora and other ionospheric phenomena in a way that cannot be accomplished by single-point sensors of past decades. Ultimately, predictive modeling and understanding for the near-space plasma environment must rely on the coverage provided by each new satellite constellation put in orbit, like Planet Labs. Without the denser global networks provided by these large commercial constellations, the degrees of freedom are too many.





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