Improving Nanosatellite Imaging and Atmospheric Sensing with Adaptive Optics

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Measurements of atmospheric temperature, pressure, water vapor, and composition are important to users in the Earth science, defense, and intelligence communities. Nanosatellites (with mass < 10 kg, such as CubeSats) can support miniaturized instruments for atmospheric sounding and characterization. Nanosatellite constellations can improve spatial and temporal weather sensor coverage of Earth and can produce data consistent with the current state of the art at reduced cost compared with larger satellites. Nanosatellites are also used for on-orbit technology demonstrations due to low cost and higher risk posture. We focus on CubeSats as a host platform for instruments and technology demonstrations for atmospheric occultation experiments and coronagraphic direct imaging of exoplanets.

Occultation experiments measure electromagnetic signals received from a transmitter as it passes behind the Earth from the perspective of the receiver. In the neutral atmosphere, the measurements yield profiles of temperature, pressure and in certain configurations, composition. Occultation observations using several near infrared optical wavelengths can measure absorption features to characterize atmospheric species and abundances. Intersatellite optical links are used for these measurements, but transmissions deep in the atmosphere experience scintillation and distortion. Wavefront measurement or control systems could be used to compensate for atmosphere-induced aberrations.

Wavefront control systems are also needed to obtain reflection absorption spectra of exoplanet atmospheres, where photons from the host star are reflected from the planet. A telescope equipped with an internal coronagraph makes high contrast measurements off-axis using high spatial frequency wavefront control systems to correct for speckles, imperfections, and other distortions that would degrade the measurement. High actuator count deformable mirrors (DMs) are needed, and Microelectromechanical systems (MEMS) DMs can provide a cost-effective, compact solution. We describe our design for a nanosatellite platform using a wavefront sensor to characterize the on-orbit performance of MEMS DMs.

We present results from these new approaches to improve atmospheric sounding and characterization missions using nanosatellites. We simulate and experimentally demonstrate a CubeSat wavefront control system using a MEMS DM that can be used to characterize the performance of MEMS DMs, sensitive to ~10 nm motion and up to three times the 1.5 um-stroke of the DMs, which is useful for future applications in both atmospheric near infrared occultation as well as in exoplanet direct imaging space telescopes. These contributions both improve current nanosatellite capabilities and use nanosatellites to advance technologies in future larger systems for atmospheric sounding and characterization of Earth and exoplanets.