Laser Limb Sounding Approach for Planetary Atmospheres using Cubesats or SmallSats

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Introduction: We describe an approach for an efficient and sensitive way to map trace gas abundances in planetary atmospheres. The approach uses a pair of small satellites flying in formation, in a circular polar orbit. Each satellite carries several tunable single frequency diode lasers and a sensitive optical detector. The laser beam from each satellite is pointed through the limb of the planetary atmosphere to illuminate the other satellite. Tuning the diode laser's wavelengths through trace gas absorption lines allows the gas abundance in the path to be measured at the other satellite's receiver.

Application for Mars Atmosphere: NASA's 2013 Planetary Science Decadal Survey identified mapping gas abundance in planetary atmospheres as an important goal. This new laser limb sounding approach allows the concentration of many key trace gases (such as CH_4, H_2O, HDO and CO_2) to be measured simultaneously and continuously with very high sensitivity.

Recent observations of Mars [1-3] suggest that CH_4 varies in longitude, latitude, and season, but the details are sparsely measured and are poorly understood. The proposed concept will enable mapping the global atmospheric CH_4 concentrations. The technique also allows probing water isotopic ratios (e.g., D/H), a proxy to sub-surface release and water loss. Earth-based observations show strong variations in the D/H ratio in column water vapor, and aspects of their seasonal changes [4]. Measurements from orbit are expected to provide new insights into the processes that control their distribution and ratio. The targeted gases also vary with altitude and one may vary the limb tangent altitude by changing the spacecraft spacing.

Benefits of Approach: There are several important benefits to this novel approach. Unlike solar occultation, which can measure only during sunrise or sunset events, this approach allows continuous measurements, permitting full planetary mapping from polar orbit, even in darkness. The measurement sensitivity is high because the optical path length through the atmosphere is long (1000's of km). The geometry allows the measurement to be made with modest (10-20 mW) laser power using compact diode lasers and sensitive infrared detector [5].

Measurement Scenario: A mission can be accomplished with two smallsats, or 6U cubesats. After deployment the distance between them is adjusted so that they co-orbit with the primary spacecraft and the optical path between the two cubesats passes through the limb of the atmosphere. Each satellite is 3-axis stabilized and carries a payload consisting of a few small tunable single frequency diode lasers, a receiver lens and an optical detector.

The satellites use body-pointing of their payloads. Once two-way pointing is achieved, repetitively sweeping the diode laser's wavelength through its gas absorption line allows the gas absorption line shapes to be measured at the other satellite's receiver. From the line shape the path-integrated gas abundance can be calculated. The limb-tangent altitude can be varied by changing the distance between the satellites. From a circular polar orbit the measurements allow a global map of the trace gases to be made as the planet rotates. Several gases can be measured simultaneously by using different diode lasers, each emitting at a specific wavelength for each gas.

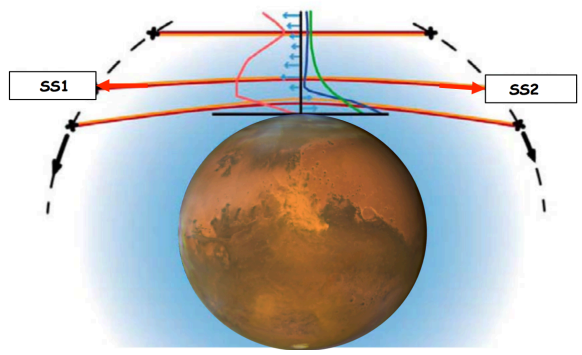

Figure 1. Illustration of the planetary laser limb sounding measurement geometry allowing measurements between two cubesats

Application for Earth's Atmosphere: There are similar benefits from measuring H_2O and HDO globally in the Earth's stratosphere (with the tangent path above the cloud tops) with this approach. Water vapor plays a critical role in the climate system through the direct absorption of infrared radiation and through the formation of cloud and aerosol particles. Reliable long-term climate forecasts require accurate descriptions of the mechanisms that transport water vapor across the tropopause and how this mechanism changes with a changing climate. The isotopic abundance of water vapor is strongly influenced by transport processes, showing large variations depending on the role of deep convection compared to large-scale adiabatic ascent. Measurements of the isotopic abundance of water va-

por (the ratio HDO/H_2O) can be used to quantify the role of convection and constrain the transport processes in global climate models [6].

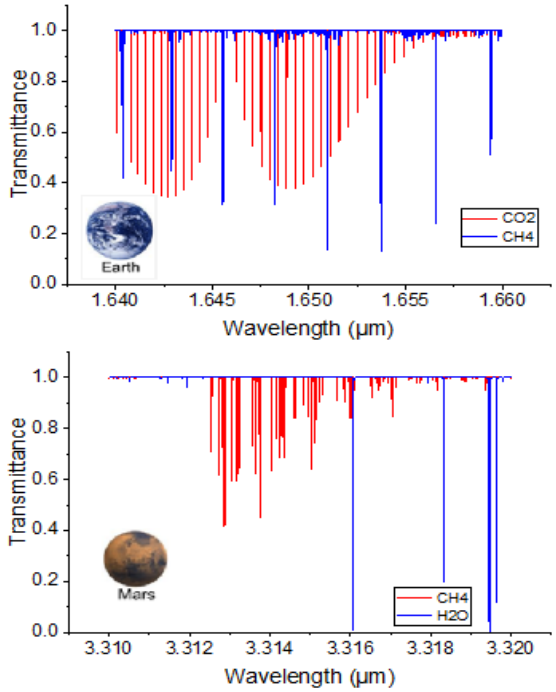

Figure 2. Transmission spectrum through the Earth's (top) and Mars (bottom) atmosphere at 20 km tangent height for candidate gases (CO_2 and CH_4 for Earth and CH_4 and H_2O for Mars).

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