EGU26-16125, updated on 10 Nov 2026
https://doi.org/10.5194/egusphere-egu26-16125
EGU General Assembly 2026
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Millimeter-Wave Atmospheric Radiometry via Nonlinear Optical Upconversion

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The monitoring of the Earth's atmospheric composition requires very sensitive satellite-based measurements that detect the thermal radiation emitted in the millimeter-wave and sub-THz spectral region by the constituent gas molecules. For example, much-needed vertically-resolved global ozone profile observations covering both day and night conditions are currently being made by instruments such as the Microwave Limb Sounder on board the EOS-Aura satellite. Traditionally, such radiometers have a large form factor, high power requirements, require advanced electronics and often have a cooled front-end resulting in high mission costs.
Here we present early results from a novel idea to circumvent the cryogenic requirement, thereby decreasing the payload size, weight, and power (SWaP) requirements and making the radiometers suitable for deployment as passive limb sounders on CubeSats.
Our design converts the atmospheric thermal emission (at 100 GHz – 1 THz) into the optical domain (e.g., infrared - approximately 200 THz). The up-converted signals can be referenced and radiometrically interpreted to measure the temperature of the emitting area.
Having these atmospheric signatures in the infrared domain enables the use of ultra-low-noise optical detection techniques (such as filtered single photon counters or optical heterodyning with a quiet reference laser) that are not available at microwave frequencies. Optical detection methods avoid the fundamental added noise associated with phase-insensitive microwave amplification, with noise instead dominated by optical shot noise and conversion efficiency. On top of that, most of the required components can be integrated into a compact modular device which reduces the footprint dramatically and will allow the device to be packed onto a cost-efficient CubeSat platform.
In order to convert electromagnetic radiation from one spectral region to another, we use a second-order optical nonlinear process. To achieve sufficient efficiency of photon up-conversion, high-quality crystalline microresonators are found to be an ideal system that is consistent with the small footprint we aim for. These electro-optic upconverters can be designed to target the specific emission frequencies of molecules in the atmosphere and detect their weak microwave signatures at ambient temperature with a sensitivity projected to be comparable to direct microwave receivers. The initial results presented here are focused frequency ranges that can be used for

detection of ozone, as recent studies indicate that it is more important than ever to monitor the recovery of the ozone layer, but the same principle could later be expanded to the detection of other atmospheric species.