

Feasibility study of a satellite-borne terahertz heterodyne spectrometer for the retrieval of atomic oxygen and temperature in the Earth's atmosphere

P. B. Hansen^{1,2}, M. Wienold¹, H.-W. Hübers^{1,2}

¹German Aerospace Center (DLR), Institute for Optical Sensor Systems, Berlin, Germany

²Humboldt Universität zu Berlin, Department of Physics, Berlin, Germany

Atomic oxygen is one of the main species in the mesosphere and lower thermosphere (MLT) of the Earth's atmosphere. Thus, atomic oxygen and the local temperature plays an important role for the energy balance in the MLT region. By remote sensing of the emission from the atomic oxygen fine-structure transitions at 2.06 THz and the 4.74 THz, atomic oxygen concentration profiles and neutral temperature profiles of the atmosphere can be derived. By resolving the line profile, heterodyne spectroscopy enables access to layers of the atmosphere for which the oxygen line is saturated. The first spectrally resolved measurements of the 4.74-THz line of atomic oxygen in the atmosphere were performed with the heterodyne spectrometer GREAT on board of the airborne astronomical observatory SOFIA [1]. Based on the experiences from GREAT, the heterodyne spectrometer OSAS-B was developed as a balloon-borne instrument dedicated to the measurement of atomic oxygen in Earth's atmosphere [2].

In this study, we investigate the feasibility of a satellite-borne heterodyne spectrometer for the retrieval of atomic oxygen concentration and temperature in the MLT. Compared to airborne observations, a satellite instrument has the advantage of a limb observation geometry which facilitates the retrieval. A satellite instrument also has the advantage of a fast and almost global coverage.

For investigating the feasibility of such an instrument, we use the vertical density and temperature profiles provided by the NRLMSIS 2.0 atmosphere model to simulate 2.06 THz and 4.74 THz emission spectra as measured by a satellite. We then apply retrieval algorithms for the atomic oxygen concentration and temperature and compare the retrieved profiles to the reference, i.e. the original NRLMSIS 2.0 profiles. We consider the scenario of a satellite in a circular orbit at an altitude of 500 km and an inclination of 8°. The emission spectra are simulated using radiative transfer under the assumption of local thermodynamic equilibrium.

By considering two separate heterodyne receivers with sensitivity of 11,000 K and 25,000 K noise temperature for the 2.06 THz and 4.74 THz lines, respectively, and data accumulated over 100 seconds of measurement time, corresponding to a ground track of 700 km, we can retrieve a vertical temperature profile from 100 km altitude to 300 km altitude with 5 % relative uncertainties and an atomic oxygen concentration profile from 120 km to 300 km with 5 % relative uncertainties. From 100 km to 120 km the uncertainty in the atomic oxygen concentration is higher and within 25 %.

[1] Richter, H. et al. Commun Earth Environ 2,19 (2021), doi: 10.1038/s43247-020-00084-5

[2] Wienold, M. et al. 48th IRMMW-THz, Montreal, Canada (2023), doi: 10.1109/IRMMW-THz57677.2023.10299165