Observation of Atomic Oxygen in the Mesosphere and Thermosphere of Earth with the THz Heterodyne Spectrometer GREAT

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Abstract— **Atomic oxygen governs photochemistry and energy balance of the mesosphere and lower thermosphere of the Earth. Its concentration is extremely difficult to measure with remote sensing techniques since it has only few optically active transitions. Current indirect measurements involve photochemical models and the results are not always in agreement, particularly when obtained with different instruments. In addition, altitudes above 100 km are not covered by these methods. We report on direct measurements of the 4.7-THz fine-structure transition of atomic oxygen at 4.7448 THz using the German Receiver for Astronomy at Terahertz Frequencies on board the Stratospheric Observatory for Infrared Astronomy. Our measurements agree well with atmospheric models and satellite observations below 100 km.**

I. INTRODUCTION

Atomic oxygen is a main component of the mesosphere and lower thermosphere (MLT). The photochemistry and the energy balance of the MLT are governed by atomic oxygen. In addition, it is a tracer for dynamical motions in the MLT. Atomic oxygen is generated through photolysis of molecular oxygen by UV radiation. It is an important component with respect to the photochemistry of the MLT because it fuels exothermic reactions [1]. Furthermore, it is important for the energy budget of the MLT, because CO_2 molecules are excited by collisions with atomic oxygen and the excited CO_2 molecules radiate in the infrared and cool the MLT. This means that global climate change can also be observed in the MLT, where the increasing CO_2 content leads to a cooling and shrinking of the MLT [2]. An accurate knowledge of the global distribution of atomic oxygen and its height profile as well as diurnal and annual variations are therefore essential for understanding the photochemistry and the energy budget of the MLT.

Atomic oxygen is difficult to measure with remote sensing techniques. Concentrations can be inferred indirectly from the oxygen air glow or from observations of OH, which is involved in photochemical processes related to atomic oxygen. Such measurements have been performed with several satellite instruments such as SCIAMACHY, SABER, WINDII, and OSIRIS. However, the methods are indirect and rely on photochemical models and assumptions such as quenching rates, radiative lifetimes, and reaction coefficients. The results are not always in agreement, particularly when obtained with different instruments.

We have explored an alternative approach, namely the observation of the $^3P_1 \rightarrow {}^3P_2$ fine-structure transition of atomic oxygen at 4.7 THz (63 µm) using the German Receiver for Astronomy at Terahertz Frequencies (GREAT) on board of SOFIA, the Stratospheric Observatory for Infrared Astronomy. GREAT is a heterodyne spectrometer providing high sensitivity and high spectral resolution [3]. This method enables the direct measurement without involving photochemical models to derive the atomic oxygen concentration [4].

II. RESULTS

The night-time measurements have been performed with GREAT during a SOFIA flight along the west coast of the US. The GREAT heterodyne spectrometer relies on a hot-electron bolometer as mixer and a quantum-cascade laser (QCL) as local oscillator (LO). It has a single-sideband noise temperature of 2200 K and an intermediate bandwidth ranging from 0.2 to 2.5 GHz. The backend spectrometer is a digital fast Fourier transform spectrometer. Its channel spacing is 76.3 kHz. The spectral resolution is ultimately limited by the emission linewidth of the QCL LO, which is Gaussian-shaped with 6 MHz FWHM [5].

A measured spectrum (black lines) is shown in Fig. 1. Several fits (blue, red, and green lines) based on concentration profiles and temperature profiles from the semi-empirical model NRLMSISE-00 are shown as well. In Fig. 1a the atomic oxygen concentration is 120 or 80% of the nominal value (100%). In Fig. 1b the temperature profile has been changed by ±5%. In this case large deviations occur at the peak of the line and in Fig. 1c the peak of the nominal concentration profile is shifted by ±5 km. Again, large deviations occur at the peak.

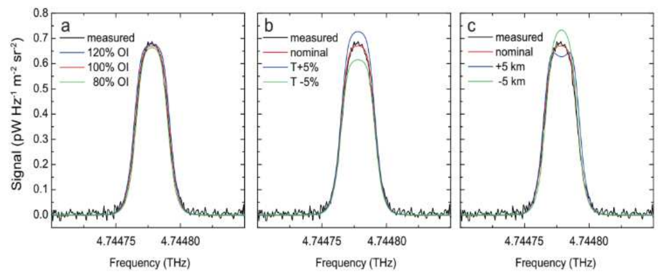

Fig. 1: Measured emission of atomic oxygen (black lines) and modeled emission profiles for various parameters (for details see text).

Based on such spectra the concentration profile of atomic oxygen has been derived. The grey area in Fig. 2 indicates the range of profiles, which are compatible with the measured GREAT spectrum (±1σ uncertainty). Using data obtained from the NRLMSISE-00 model and from the satellite instrument SABER a reference concentration profile of atomic oxygen in the MLT has been determined (Fig. 2, main part). It should be noted that the SABER atomic oxygen concentration reaches only up to about 100 km and that these data are indirectly determined, because SABER relies on optical measurements of OH in combination with photochemical models. The agreement between the SABER/NRLMSISE-00 concentration profile and the GREAT concentration profile is very good. Also, the emission profile calculated with the SABER/NRLMSISE-00 reference concentration profile of atomic oxygen agrees very well with measured emission profile (red line and black lines in the inset in Fig. 2).

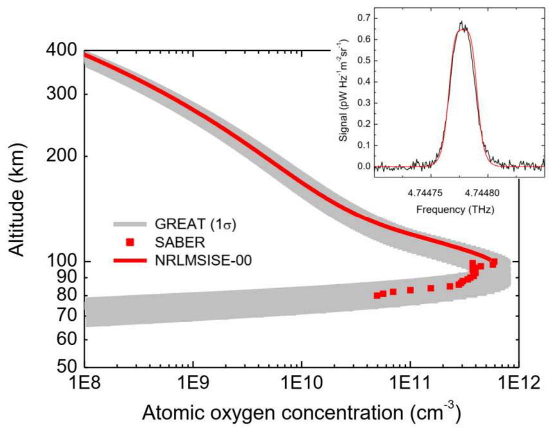

Fig. 2: Concentration of atomic oxygen at various altitudes. The red squares are measurements from a satellite and the red line is a predicted curve using the semi-empirical NRLMSISE-00 model. The inset displays the measured (black) and calculated (red) emission profile of the 4.7-THz transition.

III. SUMMARY

The first spectrally resolved, direct measurement of atomic oxygen in the MLT through its fine-structure transition at 4.7 THz is presented. The measurements enable to derive the concentration profile of atomic oxygen in the MLT. It is an important step towards a conclusive understanding of the photochemistry, energy balance, and dynamics of the Earth atmosphere. This will be substantiated once the large amount of atomic oxygen data, which has been obtained with SOFIA, is completely analyzed. The measurements demonstrate that THz heterodyne spectroscopy is a powerful method for atmospheric science. Beyond that, with the current progress in THz technology balloon-borne and space-borne heterodyne spectrometers become feasible.

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