# A small satellite with a dual-frequency heterodyne spectrometer for the detection of atomic oxygen in the atmosphere of Earth


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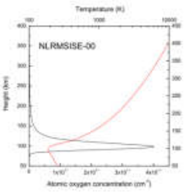
## 1. Scientific motivation

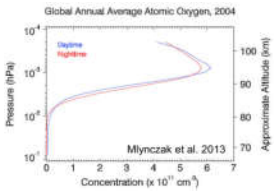
Atomic oxygen is the dominant species in the mesosphere and lower thermosphere (MLT) of Earth's atmosphere. An accurate knowledge of the global distribution of atomic oxygen and its height profile as well as diurnal and annual variations are therefore essential for understanding the photochemistry and the energy budget of the MLT. Atomic oxygen is

- generated through photolysis of molecular oxygen or ozone by ultraviolet radiation from the sun,
- responsible for almost all of the radiative cooling of the MLT through exothermic chemical reactions and infrared radiative cooling,
- radiated via the fine structure transitions from the lowest excited state, $^3P_1$, into the ground state, $^3P_2$, at 4.74 THz (63.2 µm),
- extremely difficult to measure directly with remote sensing techniques, because it has not many optically active transitions.

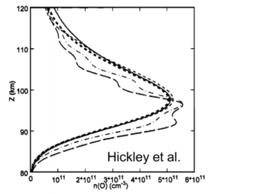
As a first step towards realization, a small satellite study for OSAS (Oxygen Spectrometer for Atmospheric Science) has been performed based on Concurrent Engineering methods.




Calculated atomic oxygen concentration and temperature in the MLT. It extends from about 60 km to well above 300 km but with more than 90% concentrated between 85 km and 125 km altitude.




Measured global annual average of the atomic oxygen concentration measured with SABER/TIMED [1].




Because of the long lifetime of atomic oxygen in in the $^3P_1$ state of up to a few hours it can be transported over large distances before it releases its energy. Therefore it can be used as tracer for dynamical motions such as gravity waves [2].

## 2. Mission concept

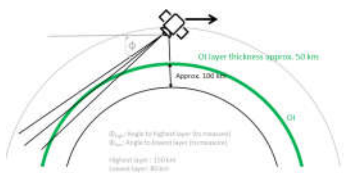
### Mission Objectives

- Measure the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz in the atmosphere of the Earth.
- Determine the global distribution of atomic oxygen in the MLT by observation of at least one of the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz.
- Detect gravity waves in the MLT by observation of at least one of the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz.
- Measure the wind speed in the MLT observation of at least one of the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz.
- Demonstrate for the first time a THz heterodyne receiver for frequencies above 2 THz in space.

**Secondary objectives**

- Measure the global temperature profiles in the MLT by observation of the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz.
- Demonstrate for the first time a THz quantum-cascade laser in space.
- Measure the fine-structure transitions of atomic oxygen at 4.75 THz and 2.06 THz in selected astronomical objects with low spatial resolution.

### Principle of operation



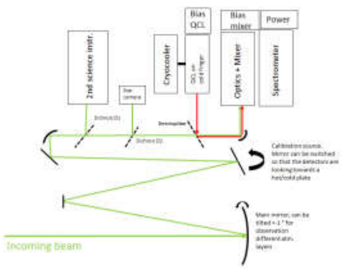

To measure the height distribution of the fine-structure transition of atomic oxygen the limb-sounding method will be applied. To do so the instrument is pointed towards tangent points of atmospheric layers at different heights.

### Global coverage

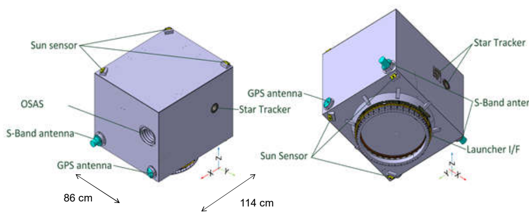
Visualisation of the 575 km orbit with covered areas after one day (green).

To provide complete mapping of the Earth plus characterization of particular areas of interest, the spacecraft design allows the observation of the MLT at different local times during the time of the mission. Therefore, a high inclination low earth orbit, preferably a sun synchronous orbit, is intended as initial orbit. The baseline orbit allows for creating a global map of the atomic oxygen distribution within four weeks.

## 3. Science payload

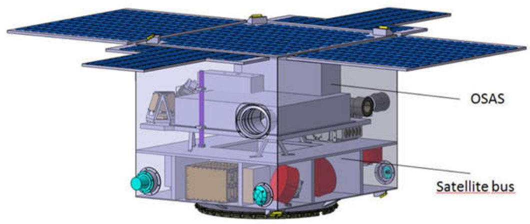



- The proposed science payload is a dual frequency heterodyne spectrometer.
- The low-frequency channel is centered at the 2.06 THz fine-structure transition of atomic oxygen and the high-frequency channel is centered at its 4.74-THz fine-structure transition.
- The low-frequency channel has a Schottky diode mixer with a multiplied microwave oscillator as local oscillator (LO). The high-frequency channel is based on a Schottky diode mixer and a quantum-cascade laser as LO. The backend is a digital fast Fourier spectrometer.





Scheme of the satellite and the optical bench with payload. The footprint of the bus plate is 930 mm x 800 mm.




- A total mission duration of 24 months is planned.
- In case of a SSO a propulsion system adapts the orbit to observe the MLT at different local times.
- Five solar array panels will provide up to 260 W electrical power required by the entire spacecraft for the mission.
- The total mass of the spacecraft has been estimated at approx. 240 kg including 50 kg payload.
- The dimensions in the launch configuration of the satellite are 1.14 m x 0.86 m x 0.89 m and in flight configuration, 2.36 m x 2.22 m x 0.82 m.

Deutsches Zentrum für Luft- und Raumfahrt


[1] Mlynczak, M. G., L. A. Hunt, et. al., Atomic oxygen in the mesosphere and lower thermosphere derived from SABER: Algorithm theoretical basis and measurement uncertainty, J. Geophys. Res., vol. 118, 5724–5735 (2013).
[2] P. Hickley et. al, Secular Variations of atomic oxygen in the mesopause region Induced by transient gravity wave packets, Geophysical Research Letters, vol. 27, 3599-3602 (2000).