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A full Earth orbit as viewed from Venus

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Abstract

The Earth has been monitored from Venus orbit in both reflected sunlight and thermal emission with the VIRTIS instrument on Venus Express. The spectra, obtained between April 2007 and October 2008, show clear evidence of some of the most abundant gases in the planet's atmosphere, namely O_2, CO_2, CH_4, and H_2O. From Venus orbit, the Earth is seen within a limited range of phase angles ~0-46^o, which means that the fraction of the Earth's illuminated disk is always ~80% or more. We have set out to interpret the collected spectra and their relevance in the context of the prospective characterization of an Earth-twin orbiting a Sun-like star in a remote solar system.

1. Introduction

The search for habitable worlds beyond our Solar System is a major topic in current astrophysics. Missions such as COROT and Kepler are providing a census of exoplanets, some of them reaching sizes of even less than one Earth. In the near future, CHEOPS and TESS will expand further those statistics. Subsequently, the best candidates for characterization will be investigated with the James Webb Space Telescope and the upcoming generation of 30-m (and larger) ground-based telescopes.

In preparation for such efforts, there has been a significant amount of work dedicated to investigate the spectral signature of Earth-like planets in transmission spectroscopy [1-2, and refs. therein] and in reflected light [3-5]. Since Earth is so far the only known inhabited planet, much of this effort has focused on conditions relevant to the present-day Earth.

2. Venus Express and VIRTIS

Venus Express is ESA's prime mission to our neighbouring planet [6]. The spacecraft was launched in November 2005 and arrived at Venus in April 2006. Soon after, the spacecraft was stabilized into an eccentric, 24-h orbit around the planet. Since then, the mission payload instruments have been reporting a substantial amount of data back to Earth, which has resulted in a significant advance in our understanding of Venus.

VIRTIS-M is the double-channel mapping spectrometer of the VIRTIS instrument on Venus Express [7]. The visible and infrared channels of VIRTIS-M provide moderate-resolution spectroscopy (resolving power of 100–200) over 432 spectral bands each, for wavelengths ranging from 0.3 to 1.1 micron and from 1 to 5 micron, respectively. With the scanning mirror fixed, the instantaneous field of view (IFOV) of the instrument is 0.25x64 mrad^2, or 0.25x0.25 mrad^2 for each of the 256 pixels along the slit.

Besides its routinely operations, Venus Express has conducted observations of other objects. Starting in April 2007 and through to October 2008, the spacecraft was periodically commanded to observe the Earth with the VIRTIS instrument. From Venus orbit the Earth occurs as a sub-pixel target lacking any spatial resolution. Observations were conducted over nearly 40 orbits, and thus the collected data span a broad range of seasonal conditions and land/ocean configurations. As Venus is an inner planet, the Sun-Earth-Venus phase angle is always smaller than 46^o, which entails that the Earth's disk appears always illuminated at the ~80% or more.

3. Relevance of the VIRTIS spectra

The VIRTIS spectra of the Earth constitute a unique dataset for the investigation of the signatures in the Earth's disk-integrated spectrum. As seen in Fig. 1, the VIRTIS spectra show clear evidence of gases such as O_2, CO_2, CH_4, and H_2O. These molecules exhibit strong electronic and vibrational absorption bands in the range of wavelengths investigated with VIRTIS. We are particularly interested in the bands' depths, which are principally determined by the molecule's atmospheric concentration, but also in the bands' variability. The Earth is a complex system that exhibits non-uniform surficial features and cloud patterns. Some of that complexity is expected to cause variability in the features of the reflection spectrum.

4. Ongoing work

We are investigating the Earth spectra obtained with the VEx/VIRTIS instrument over a total period of more than one year. The ultimate goal of this effort is to characterize the Earth's spectrum, with special emphasis laid on its variable features. To assist with the in-detail analysis of the spectra, we have adapted the XtraRT model [8], that produces spectra of reflected sunlight and thermal emission for a plane-parallel, stratified atmosphere.

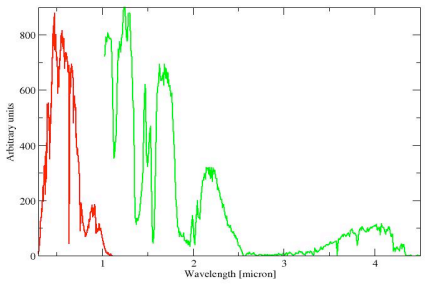

Figure 1: VIRTIS-M spectra of the Earth. In red, data from the visible channel (0.3-1 micron). In green, data from the IR channel (1-5 micron). The spectrum is dominated by absorption bands of O_2, CO_2, H_2O and CH_4. Thermal radiation becomes significant longwards of 3 micron.

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