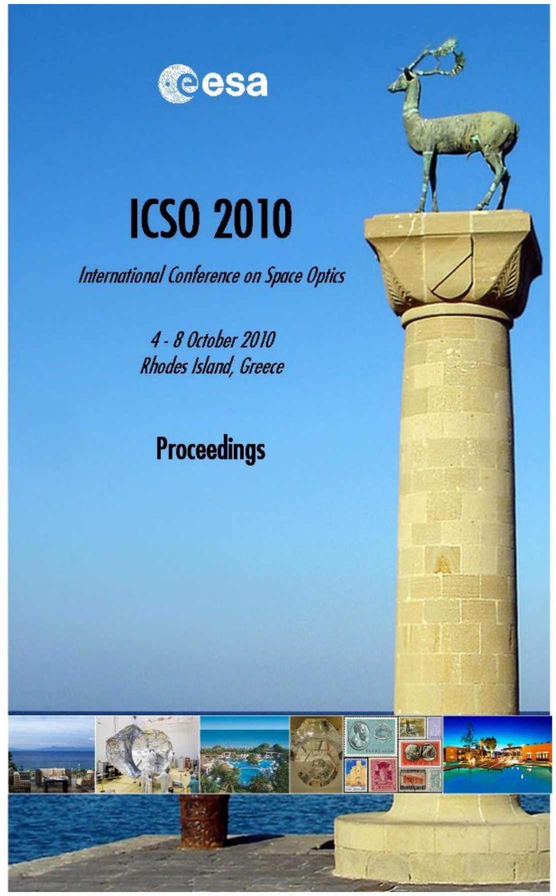
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010



Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny,
Nikos Karafolas, Proc. of SPIE Vol. 10565, 105650G · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309207

LIDAR TECHNOLOGY FOR MEASURING TRACE GASES ON MARS AND EARTH

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INTRODUCTION

Trace gases and their isotopic ratios in planetary atmospheres offer important but subtle clues as to the origins of a planet's atmosphere, hydrology, geology, and potential for biology. An orbiting laser remote sensing instrument is capable of measuring trace gases on a global scale with unprecedented accuracy, and higher spatial resolution that can be obtained by passive instruments.

For Earth we have developed laser technique for the remote measurement of the tropospheric CO2, O2, and CH4 concentrations from space. Our goal is to develop a space instrument and mission approach for active CO2 measurements. Our technique uses several on and off-line wavelengths tuned to the CO2 and O2 absorption lines. This exploits the atmospheric pressure broadening of the gas lines to weigh the measurement sensitivity to the atmospheric column below 5 km and maximizes sensitivity to CO2 changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of O2 column use a selected region in the Oxygen A-band. Laser altimetry and atmospheric backscatter can also be measured simultaneously, which permits determining the surface height and measurements made to thick cloud tops and through aerosol layers.

We use the same technique but with a different transmitter at 1.65 um to measure methane concentrations. Methane is also a very important trace gas on earth, and a stronger greenhouse gas than CO2 on a per molecule basis. Accurate, global observations are needed in order to better understand climate change and reduce the uncertainty in the carbon budget. Although carbon dioxide is currently the primary greenhouse gas of interest, methane can have a much larger impact on climate change. Methane levels have remained relatively constant over the last decade but recent observations in the Arctic have indicated that levels may be on the rise due to permafrost thawing. NASA’s Decadal Survey underscored the importance of Methane as a greenhouse gas and called for a mission to measure CO2, CO and CH4. Methane has absorptions in the mid-infrared (3.3 um) and the near infrared (1.65 um). The 3.3 um spectral region is ideal for planetary (Mars) Methane monitoring, but unfortunately is not suitable for earth monitoring since the Methane absorption lines are severely interfered with by water. The near infra-red overtones of Methane at 1.65 um are relatively free of interference from other atmospheric species and are suitable for Earth observations. The methane instrument uses Optical Parametric Generation (OPG) along with sensitive detectors to achieve the necessary sensitivity. Our instrument generates and detects tunable laser signals in the 3.3 or 1.65 um spectral regions with different detectors in order to measure methane on Earth or Mars. For Mars, the main interest in methane is its importance as a biogenic marker.

CO2 MEASUREMENTS AND AIRBORNE INSTRUMENT DESCRIPTION

Our CO2 instrument uses tunable fiber laser transmitters allowing simultaneous measurement of the absorption from a CO2 absorption line in the 1570 nm band [7] and O2 extinction in the oxygen A-band, and aerosol backscatter in the same measurement path. It directs the narrow co-aligned laser beams from the instrument's lasers toward nadir, and measures the energy of the laser echoes reflected from land and water surfaces. The lasers are a MOPA architecture using tunable diode seed lasers and fiber amplifiers, and have spectral widths much narrower than the gas absorption lines. The gas extinction and column densities for the CO2 and O2 gases are estimated from the ratio of the on- and off-line signals via the differential optical absorption technique. Pulsed laser signals and time gating are used to isolate the laser echo signals from the surface, and to exclude photons scattered from clouds and atmospheric aerosols. The 1570 nm CO2 band is well suited for this measurement. It is largely free from interference, and is within the spectral range of high power lasers and sensitive photon counting detectors. Our technique uses several on- and off-line wavelengths tuned to the gas absorption line. The choice of wavelengths allows us to weigh the measurement sensitivity to the atmospheric column below 5 km and maximizes sensitivity to CO2 changes in the boundary layer where variations caused by surface sources and sinks are largest. Simultaneous measurements of O2 column are performed using a frequency doubled 1530 nm fiber amplifier source to reach selected region in the Oxygen A-band at 765 nm.

The instrument has flown on two different aircraft, a Lear-25 jet operated by NASA Glenn Research Center, and a DC-8. The Lear-25 was initially chosen primarily for its high altitude capability (> 45000 ft) that allows us to fly above most clouds and demonstrate the sensitivity of the sensor and its low operating costs. The airborne instrument uses a narrow linewidth wavelength tunable pulsed laser transmitter allowing simultaneous measurement of the absorption from a CO2 absorption line in the 1572 nm band and surface height and aerosol backscatter all in the same path. It directs the narrow co-aligned laser beam toward the custom nadir port of the aircraft, and measures the energy of the laser echoes reflected from land and water surfaces.

The wavelength of single laser is swept across the CO2 line in 20 or 30 steps per scan, at a scan rate of 450 Hz. The time-and wavelength resolved laser back-scatter is collected by the telescope, detected by a photomultiplier and recorded by a photon counting timing system with 1 second integration time. The receiver uses a 20 cm diameter commercial telescope. The gas extinction and column densities for the CO2 are obtained from a retrieval algorithm that fits the observed scan while accounting for atmospheric temperature, pressure, and water vapor. Laser altimetry and atmospheric profiles are also measured simultaneously, which permits determining the surface height and measurements made to thick cloud tops and through aerosol layers.

During the fall 2008 and summers of 2009 and 2010 we made measurements of atmospheric CO2 absorption from the aircraft to the surface during several flights. We flew over northern and southern Ohio, Nebraska, Illinois, Virginia, North Carolina, California, and Nevada. Fig. 1 shows the sensor and the Lear-25 during our Fall 2008 campaign. Several flights were also made over the US Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) site in northern Oklahoma. These flights covered a variety of land surface types, water surfaces and through thin clouds, broken clouds and to cloud tops. Most, but not all, of our flights used a “stair-stepped” pattern, i.e. increasing or decreasing flight altitude over a box or rectangle of several tens of kilometers. These flights were also coordinated with DOE investigators who flew an in-situ CO2 sensor on a Cessna aircraft inside the CO2 Sounder flight pattern – but at much lower altitudes. In this presentation we will be reporting on the results of our airborne campaigns.

Fig. 1 (left) The NASA Glenn Lear-25 carrying our airborne precursor CO2 lidar instrument during December 2008. (right) Photograph of the interior of the Lear aircraft showing the fall 2008 version of the instrument, with (left to right) the receiver telescope assembly, the laser and electro-optics rack and the electronics/computer rack.

METHANE MEASUREMENTS FOR EARTH AND MARS

On Earth the need to measure Methane is related to its potentially large impact on climate change. Although the exact nature and magnitude of any future climate change is difficult to accurately model and predict, its potential consequences can be dramatic and have major global implications. It is therefore extremely important to understand the mechanisms and driving forces behind climate change (e.g. the increase in green-house gases) and assess the potential impact on the globe. Methane survives for a shorter time in the atmosphere than Carbon Dioxide but its impact on climate change can be more than 20 times. Methane levels have remained relatively constant over the last decade around 1.78 parts per million (ppm) but recent observations indicate that levels may be on the rise.

For Mars, the need to measure methane is primarily driven by the search for life. Methane is a strong biogenic marker but it could also be produced by geochemistry. Finding and localizing the sources of methane on Mars is of primary importance for future Mars missions. The Martian atmosphere is well suited for trace gas measurements using lasers. The average surface pressure is ~7 mbar, which minimizes pressure broadening and results in narrow linewidth absorption lines.

At Goddard Space Flight Center (GSFC) we have developed a LIDAR system that we believe will be suitable for both Mars and Earth applications. The transmitter for the methane LIDAR uses optical parametric generation (OPG). A single frequency Nd:YAG laser (pump) is combined with an amplified seed diode laser operating at the wavelength of choice and directed through a non-linear crystal which generates the mid or near infrared radiation. The infra-red beam is then directed through a cell or to an open path and then onto an IR detector. The seed wavelength is scanned over the methane absorption and a computer digitizes the detector signal. We initially targeted a set of three methane lines at 3270.40 nm. These lines have very strong line strengths and are not interfered with by CO2, the major atmospheric constituent on Mars. They are closely spaced together and provide a unique spectroscopic signature for Methane. Fig. 1 shows a scan of the 3270.40 nm Methane lines in a cell. The pressure was 2.06 Torr and the Methane concentration was 2.9%. The agreement between the expected absorption as calculated from the 2004 HITRAN database and the OPA systems is excellent. The same system has been used to generate 1.65 um radiation for the earth application simply by changing the seed laser. Fig. 2 shows a scan of the 1650.96 nm Methane lines in a cell. The pressure was 200 Torr and the Methane concentration was 100%.

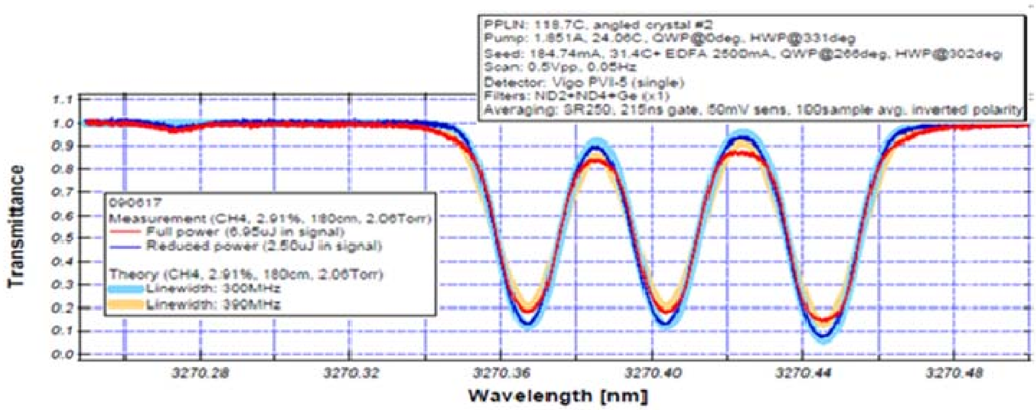

Fig. 2. Scan of Methane lines at 3270.40 nm using the GSFC OPG system.

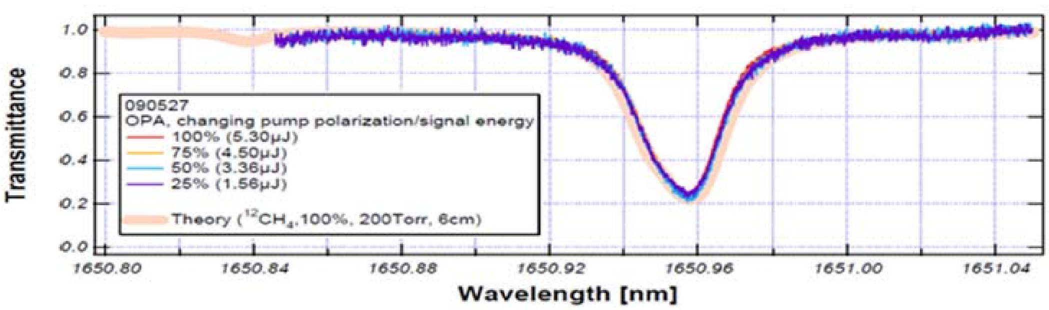

Fig. 3. Scan of Methane lines at 1650.96 nm using the GSFC OPA system.

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