MINIATURIZED HOLLOW-WAVEGUIDE GAS CORRELATION RADIOMETER (GCR) FOR TRACE GAS DETECTION IN THE MARTIAN ATMOSPHERE.

E. L. Wilson[1], E. M. Georgieva,[2] and H. R. Melroy[3],
[1]NASA Goddard Space flight Center, Code 694, B33, F226, Greenbelt, MD 20771, Emily.L.Wilson@nasa.gov
[2]University of Maryland Baltimore County, Baltimore, MD 21250
[3]The George Washington University, Department of Chemistry, Washington, DC 20052

Introduction: Gas correlation radiometry (GCR) has been shown to be a sensitive and versatile method for detecting trace gases in Earth's atmosphere [1, 2]. Here, we present a miniaturized and simplified version of this instrument capable of mapping multiple trace gases and identifying active regions on the Mars surface.[3] Reduction of the size and mass of the GCR instrument has been achieved by implementing a lightweight, 1 mm inner diameter hollow-core optical fiber (hollow waveguide) for the gas correlation cell. Based on a comparison with an Earth orbiting CO_2 gas correlation instrument, replacement of the 10 meter multipass cell with hollow waveguide of equivalent pathlength reduces the cell mass from ~150 kg to ~0.5 kg, and reduces the volume from 1.9 m x 1.3 m x 0.86 m to a small bundle of fiber coils approximately 1 meter in diameter by 0.05 m in height (mass and volume reductions of >99%)[4, 5]. This modular instrument technique can be expanded to include measurements of additional species of interest including nitrous oxide (N_2O), hydrogen sulfide (H_2S), methanol (CH_3OH), and sulfur dioxide (SO_2), as well as carbon dioxide (CO_2) for a simultaneous measure of mass balance.

Instrumental Design: The miniaturized GCR has been designed as a modular instrument with a single module for each trace gas measurement. The current configuration contains four stacked modules (Figure 1) for simultaneous measurements of methane (CH_4), formaldehyde (H_2CO), water vapor (H_2O), and deuterated water vapor (HDO). The modules are self-contained, and fundamentally identical; differing by the bandpass filter wavelength range and gas mixtures inside the hollow-waveguide absorption cells. Figure 2

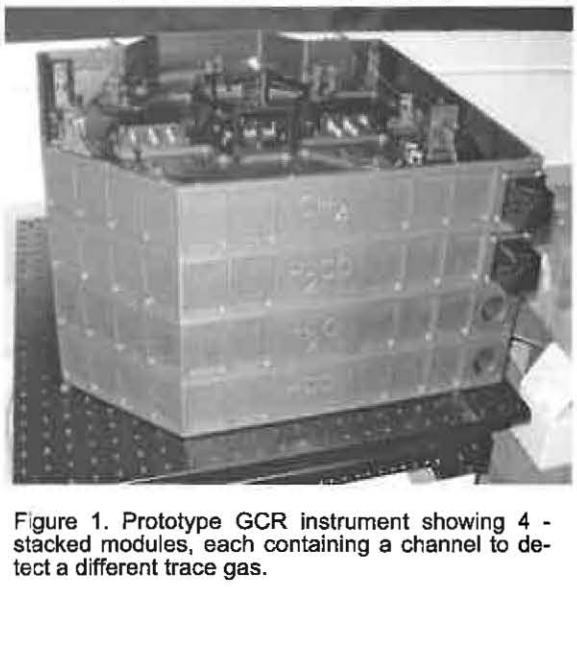

Figure 1. Prototype GCR instrument showing 4 - stacked modules, each containing a channel to detect a different trace gas.

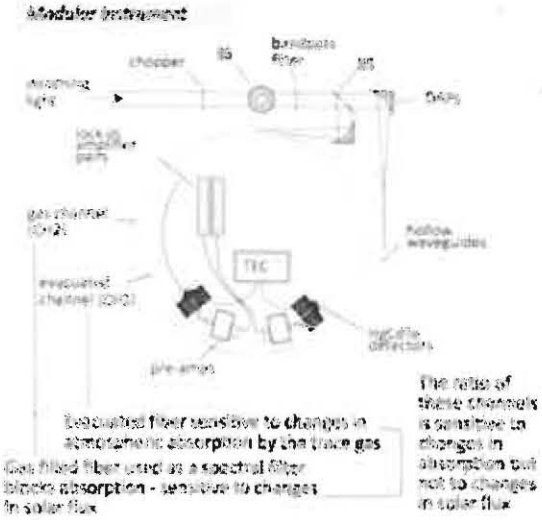

Figure 2. Optical layout of a single module of the gas correlation radiometer.

shows the optical layout of a single module. In this design, incoming sunlight that has undergone absorption by the trace gas is focused, modulated with an optical chopper, and re-collimated. That light is then passed through a narrow band filter that selects multiple absorption features (lines) of the trace gas in the 2-5 μm region. The wavelength range of the bandpass filter is selected to include the maximum number of lines of the trace gas of interest while excluding lines from interfering gases and other spectral features. After passing through the bandpass filter, light is split into two channels with a pellicle beamsplitter. In the first channel, a sample of the trace gas is enclosed in a 6 meter length hollow waveguide and is used as a spectral filter – effectively blocking atmospheric absorption by that species so that this channel is only sensitive to changes in solar flux. The second channel is either evacuated, or contains a relevant mixture of interfering species and is more sensitive to changes in atmospheric absorption by the trace gas. The ratio of these channels is sensitive to changes in absorption of the trace gas but not to changes in solar flux. Use of

duplicate hollow core fibers both reduces etalon and fringing effects in the ratio, and removes interferences by absorption features at adjoining or overlapping wavelengths. Light in each channel is focused onto HgCdTe detectors. Signals are processed through lock-in amplifiers referenced to the frequency of the optical chopper. Data is handled and processed through custom Labview software.

Relevance and Capabilities: Identifying active regions in the Martian atmosphere is key to identifying future locations for lander and sample retrieval missions – and ultimately identifying whether these gases originate from geological sources such as gas seeps, active volcanism and serpentization reactions, or from the presence of extant life. Figure 3 identifies several pathways that may account for methane and formaldehyde production in the Martian atmosphere adapted from Atreya and Wong [6, 7] Isotopic ratios of water vapor will offer insights into the history, age, and depth of water.

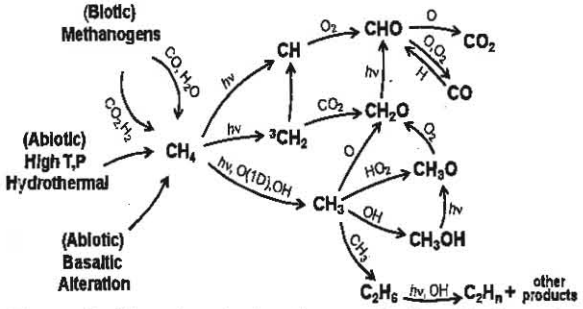

Figure 3. Key chemical pathways in the Martian atmosphere, adapted from Atreya and Wong. Right: Capabilities of the four-module instrument.

Expected capabilities of the four module instrument in a Mars orbit are summarized in the table in Figure 4. These assume one second of averaging and 3 km displacement along the satellite ground track.

Atmospheric species	Methane (CH_4), water vapor (HDO, deuterated water vapor (HDO), ethane (C_2H_6), formaldehyde (CH_2O), nitrous oxide (N_2O), hydrogen sulfide (H_2S), methanol (CH_3OH), sulfur dioxide (SO_2), carbon dioxide (CO_2)
Instrument field of view	10 km x 10 km footprint
Sample Detection limits	Methane (CH_4), formaldehyde (CH_2O) ~ 1 ppb Water vapor <1 ppm
Mass allowable	~9kg (for a 4 module instrument)
Volume estimate	<0.01 m³
Power estimate	12 Watts (depending on bus temperature and need for TEC cooling)
Data rate estimate	<20 Mbit/day

Figure 4. Capabilities of the four-module instrument.

Preliminary Results: The detection limit for formaldehyde in the lab is slightly better than 3 ppm. This corresponds to a 30 ppb sensitivity in the Martian atmosphere. A change of 0.04 torr of methane is equivalent to an approximate change of 0.5 ppm methane in the Martian atmosphere. These early lab results are shown in Figure 5.

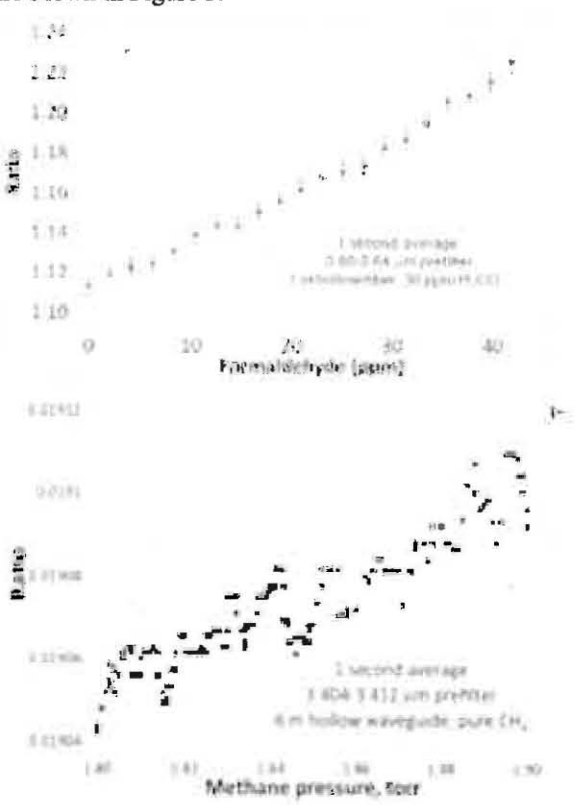

Figure 5. Preliminary lab measurements for formaldehyde and methane.

diometer implements hollow waveguides for gas correlation cells. Preliminary results indicate that a 1 ppb detection limit is possible for both formaldehyde or methane with one second of averaging. With non-optimized components, we have demonstrated an instrument sensitivity equivalent to ~30 ppb for formaldehyde, and ~500 ppb for methane. Custom bandpass filters and 6 m long waveguides are expected to significantly improve these promising results.

Acknowledgements: We would like to thank the NASA Planetary Instrument Definition and Development Program, the Goddard Internal Research and Development Program, and the following people for their advise on this project: Mike Mumma, Paul Mahaffy, John Pearl, Jim Garvin, Geronimo Villanueva, Carl Stahle, Bill Heaps, and Jonathan Rall.

References:

1. Drummond, J.R., et al., *Early Mission Planning for the MOPITT Instrument.* www.atmosp.physics.utoronto.ca/MOPITT/mission.pdf, 1999.
2. Pfister, G., et al., *Effects of a Spectral Surface Reflectance on Measurements of Backscattered Solar Radiation: Application to the MOPITT Methane Retrieval.* Journal of Atmospheric and Oceanic Technology, 2005. **22**: p. 566-574.
3. Wilson, E.L., et al., *A hollow-waveguide gas correlation radiometer for ultra-precise column measurements of formaldehyde on Mars.* Measurement Science and Technology, 2011. **22**(8): p. 085902.
4. Tolton, B.T., et al., *Strawman design for a gas-filter correlation radiometer satellite instrument to measure the atmospheric CO2 column.* Proc. of SPIE, 2004. **5543**: p. 332-337.
5. Tolton, B.T., *A Concept for a Gas-Filter Correlation Radiometer to Remotely Sense the Atmospheric Carbon Dioxide Column from Space.* Journal of Atmospheric and Oceanic Technology, 2004. **21**: p. 837-852.
6. Wong, A.S., et al., *Atmospheric photochemistry above possible martian hot spots.* Advances in Space Research, 2004. **33**: p. 2236-2239.
7. Atreya, S.K., P.R. Mahaffy, and A.-S. Wong, *Methane and related trace species on Mars: Origin, loss, implications for life, and habitability.* Planetary Space Science, 2007. **55**(3): p. 358-369.