Development of a Miniaturized Hollow-Waveguide Gas Correlation Radiometer for Trace Gas Measurements in the Martian Atmosphere. E. L. Wilson[1], E. M. Georgieva[2], G. W. Blalock,[3] C. T. Marx,[4] W. S. Heaps

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Introduction: We present preliminary results in the development of a miniaturized gas correlation radiometer (GCR) for column trace gas measurements in the Martian atmosphere. The GCR is designed as an orbiting instrument capable of mapping multiple trace gases and identifying active regions on the Mars surface.

Gas correlation radiometry is a mature sensing technology on Earth,[1, 2] and with successful miniaturization, it holds promise for trace gas measurements in the Martian atmosphere. The component that most impacts the size of a gas correlation radiometer is the gas correlation cell – the pathlength of which affects the sensitivity of the instrument. 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%).

Here we show methane (CH_4) and formaldehyde (CH_2O) measurements from our prototype GCR that implements a lightweight, 1 mm inner diameter hollow waveguide as the gas correlation cell. This modular instrument technique can be expanded to include measurements of additional species of interest including water vapor (H_2O), deuterated water (HDO), 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/Modular Design: In this design, each trace gas is measured within a self-contained, stackable module. Each module is essentially the same with the exception of the gas and/or gas mixture contained in the hollow wave-guides that act as gas-correlation absorption cells. An optical diagram of an individual module is shown in Figure 1. Incoming sun light that has undergone absorption by the trace gas is focused, modulated with an optical chopper, and re-collimated. Light then passes through a narrow band filter that selects multiple absorption features (lines) of the trace gas (typically in the 2-5 μm region depending on the gas measured). The exact wavelength range of
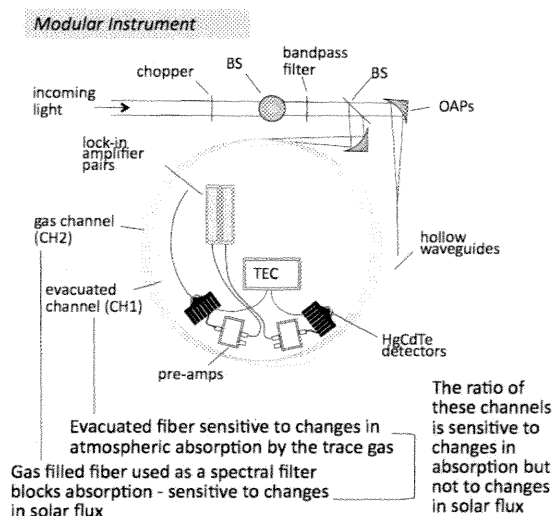

Figure 1. Optical lay-out for a single trace-gas sensing module. A modular design allows for easy addition (or subtraction) of the number and type of trace gases measured to keep pace with changing mission requirements. Abbreviations: OAP (off-axis parabolic mirror), BS (beamsplitter)

the narrow band filter encompasses the maximum number of trace gas lines while minimizing lines from other species that also absorb in this region. 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 chopped. Data is handled and processed through custom Labview software. An AutoCAD image of an individual module is shown in Figure 2.
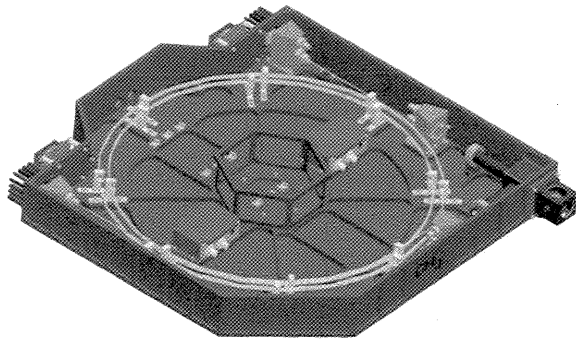
Figure 2. AutoCAD image of a single, stackable module. Components include bandpass filters and pellicle beam-plitters (far right in black), coiled hollow waveguides (silver), combination vacuum/focusing optic housings (orange), detector preamplifiers (purple), and detectors (connected to black heatsinks, far left).

Capabilities and Sensitivity Estimates: The performance of a Mars orbiting version of the hollow-core fiber instrument was simulated assuming a 3 m long, 1 mm inner diameter hollow-core fiber gas correlation cell, a 92.8° sun-synchronous orbit from 400 kmwith a horizontal sampling scale of 10 km × 10 km.[3] The simulation generates a synthetic spectrum for reflected light containing spectral features from the HITRAN database. For each simulation, the total column of the species of interest is perturbed by 1% and the signals are recalculated. We compare the change in the ratio (filled cell to evacuated cell) caused by the perturbation to the detector noise of this ratio. The free parameters of the instrument design (filter bandpass, filter edge slopes, instrument FOV, etc.) are varied in an effort to maximize the response to the species measured.

Initial results indicate that for one second of averaging (3 km displacement along the satellite ground track), a detection limit of slightly better than 1 ppbv is possible for methane and formaldehyde. For water vapor, a detection limit in the low ppb range is achievable and adequate given recent estimates of atmospheric water vapor ranging from 0 to 300 ppm. Because the HITRAN[4] database is intended for evaluating absorption in the Earth's atmosphere (and that some bands found in the Martian atmosphere have been neglected, or are incomplete in this database), specific spectral selections were made using a more complete spectral database of absorption features on Mars.[5]

Capabilities of a four module instrument are summarized in the following table:

Atmospheric species	Methane (CH_4), water vapor (H_2O), 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 estimate	~9kg (for a 4 module instrument)	
Volume estimate	<0.01 m^3	
Power estimate	12 Watts (depending on bus temperature and need for TEC cooling)	
Data rate estimate	<20 Mbits/day	

Conclusions:

This miniaturized gas correlation radiometer implements hollow waveguides for gas correlation cells. Performance simulations 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.

References:

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