The OHIO Concept: Refinements on a Design for Satellite-Based Measurements of Stratospheric OH

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ABSTRACT

The OH Interferometer Observations (OHIO) concept is an option for the generalized far infrared Fabry-Perot instrument, optimized for satellite-based measurement of the OH radical in the earth's stratosphere with the simplest possible instrument configuration. This paper gives refined design parameters for OHIO. The design presented uses entirely existing, demonstrated technology, does not require stored cryogens, and concentrates on thermal emission measurements of OH, the one stratospheric species which can be measured uniquely and well in the far infrared from a satellite. Measurements are of the $F_1, 7/2^+ \rightarrow F_1, 5/2^-$ transition at 118.455 cm^{-1} (84.42 μm), which has been demonstrated to be the best spectral feature for atmospheric measurements of OH. The current design parameters, including realistic values for Fabry-Perot transmission, detector performance, and filtering required to suppress radiation passed in the higher orders of the grating monochromator, are demonstrated to be within a comfortable margin of providing what is required for global measurements of OH. Thus, we should soon be able to demonstrate a working model for a potential satellite instrument.

1. INTRODUCTION

Current atmospheric measurement strategies by both NASA and ESA include the development of a technique to measure the global climatology of stratospheric OH, because of its central importance in stratospheric ozone balance. It is now firmly established that the far infrared is the spectral region of choice for making remote sensing measurements of OH,[1] with several measurement techniques currently under consideration. OHIO is an instrument concept that is being developed in an effort to provide the capability to make such OH measurements with a simple instrument using modest satellite resources. OHIO is intended to focus on OH measurements, operating in synergy with other satellite instruments which measure the remaining chemical species that are necessary to provide a full picture of stratospheric photochemistry.

The main features of the OHIO concept and the underlying issues of atmospheric spectroscopy have been discussed in detail in reference 1, hereafter referred to as Paper I. The present paper updates the OHIO concept, to take into account further development of the instrument design. It is demonstrated that current design parameters, using existing Fabry-Perot technology and an existing high-T_c YBaCuO bolometer detector operating at $\sim$85 K,[2] comfortably provide the necessary sensitivity for global OH measurements, making OHIO a viable option for satellite-based OH measurements.

2. ATMOSPHERIC SPECTROSCOPY OF OH

As reviewed in Paper I, the optimum choice for remote sensing measurement of stratospheric OH using a Fabry-Perot instrument or a Fourier transform spectrometer is the $F_1, 7/2^+ \rightarrow F_1, 5/2^-$ emission line of the $^2\Pi$ ground state at 118.455 cm^{-1} (84 μm). This choice is based on considerations of line intensity and power, and lack of interference; heterodyne instrument efforts concentrate on the $F_1, 5/2^- \rightarrow F_1, 3/2^+$ transition at 83.869 cm^{-1} because of the lower frequency and the availability of a good candidate for a local oscillator, a CO_2 laser-pumped far infrared laser line of CH_3OH.

It is worth reiterating in this paper that the underlying atmospheric spectroscopy for OH, and particularly for the 118.455 cm^{-1} line, is in a very mature state. Neither uncertainties in molecular parameters or in knowledge of interfering species will contribute significantly to the error budget for satellite-based measurements.

3. INSTRUMENTAL UPDATE

OHIO employs a Fabry-Perot spectrometer of the SRON type,[3] which includes a grating monochromator for order selection. For optimum use in OH measurements we have taken into account recent improvements in metal mesh design and production,[4] and in space qualified far infrared Fabry-Perot design, which allows for a resonator of 50 mm diameter (a = 25 mm).[5]

The major area for improvement of the OHIO measurement system is the increase in the amount of energy from the selected OH line available for detection. Substantial improvement in the throughput of the Fabry-Perot may be gained by optimizing the choices of spectral resolution and acceptance angle, α, given the spectroscopic constraints of the 118 cm^{-1} line. In Paper I we selected a resolving power of 10,000 with a 50 mm aperture and $\alpha = 1\times10^{-2}$ rad, to give a throughput of 6.17×10^{-7} m^2 sr. The throughput can be increased while taking two things into consideration: (1) The constraint on throughput due to incoherence is relaxed when the resolving power is lowered. For the 118 cm^{-1} line of OH a resolving power, $\mathcal{R}$, of 4240, corresponding to a resolution (FWHM) of 0.028 cm^{-1}, still provides for excellent measurement of the line and the adjacent wings while avoiding interference and keeping the continuum contribution within reasonable levels (see Paper I, Figure 2). This resolving power can readily be obtained with present technology,[3,4] with a finesse, $\mathcal{F}$, of 45, operating in 133rd order, a gap, d, of 5.6 mm, and a throughput corresponding to the Jacquinot criterion,[6] $\alpha = \sqrt{2/\mathcal{R}_0}$. This gives an acceptance angle of 1.83×10^{-2} radian. In the terminology of Vaughan,[7] this corresponds to a choice of the ratio, u, of the rectangular phase scanning function to the half-value width from the finesse of $u = 1$. The resolving power of 4240 is then given by $\mathcal{R}/\mathcal{R}_0 = (1+u^2)^{-1/2}$, where $\mathcal{R}_0 = 6000$ from the product of the order and the finesse. The choice of $u = 1$ also corresponds to a luminosity factor, representing signal lost through lack of coherence due to finite throughput, of 0.5. (2) The walk-off loss is negligible for $a/d\alpha \geq 200$;[7] for our choice of parameters, $a/d\alpha = 244$. The final throughput is then the product of the factors from aperture, acceptance angle, and luminosity, 1.0×10^{-6} m^2 sr.

Additional transmission factors must be included to obtain the final optical performance. The first of these is due to Fabry-Perot transmission. With a currently-available system, the transmission at 84μm for resolving power = 10,000 and finesse = 75 (thus operating in approximately 133rd order) is 40%.[4] The peak transmission is given by $P = (1 - A/(1-R))^2$, where A is the power absorptance and R is the reflectance, and the finesse by $\mathcal{F} = \pi\sqrt{R}/(1-R)$. By going to a system with lower finesse (from 75 to 45), and assuming that the absorption loss can be kept at least as low, we can increase the peak transmission to 60%. Optics losses, including the diffraction grating, are not severe in the far infrared; 90% transmission is a reasonable goal for inclusion of these effects. The greatest unknown for overall transmission is the result of the need to include blocking filters to reduce contributions from higher orders of the grating. This need was addressed in general in Paper I. Using FIRS-2 balloon-borne far infrared measurements and atmospheric calculations with the SAO radiative transfer code[8] we have determined that the contributions from higher orders start to become appreciable in 4^{th} order (21 μm) and become severe in 5^{th} order (17 μm) and higher. Filter transmission curves supplied by Infrared Laboratories, Inc. indicate that a filter composed of diamond powder on 0.15 mil polyethylene will supply the necessary blocking while allowing transmission of greater than 70%; this level of transmission is confirmed by experience at SRON using reststrahlen reflectors in series with scatter filters. The product of these various transmission factors is 38% transmission. The inclusion of the system transmission then gives an overall effective system throughput of 3.9×10^{-7} m^2 sr.

The OHIO instrument optics need to be re-scaled from the dimensions given in Paper I, to account for the increased étendue, but there are no fundamental changes.

The baseline detector remains a high-T_c YBaCuO bolometer.[1] A device operating at ~85 K, with measured NEP of 1.5×10^{-12} W $Hz^{-1/2}$ has recently been produced,[2] compared with the NEP of 1.6×10^{-11} W $Hz^{-1/2}$ available for consideration in Paper I.[9] The spectrometer and detector are cooled to below 90 K using a combination of radiative cooling and a Stirling cycle refrigerator.

4. RETRIEVAL AND MISSION STUDIES

The minimum scanning strategy remains the same as that given in Paper I. Briefly, this consists of OH measurements at 5 km intervals from 25-45 km, taking 3 measurement points at each elevation angle - on line and to either side - for a total of 15 integration times per limb-scan. The detected power for typical OH concentrations with the refined instrument characteristics is given in Table 1.

We require measurements of the OH power at each elevation angle to at least a signal to noise ratio of 10 in order to make significant retrievals of OH concentration profiles and to avoid having feedthrough effects in the onion-peeling process dominate the error budget. Based on experience with OH profile retrievals at the Smithsonian Astrophysical Observatory, significantly greater uncertainties will not permit meaningful determinations of OH below 30 km. In order to detect the lowest power levels, 1.3×10^{-11} W, in 15 s, corresponding to sampling at 12° in latitude,[1] a detector NEP of 5.1×10^{-12} W $Hz^{-1/2}$ is required. This compares with the value of 1.5×10^{-12} W $Hz^{-1/2}$ that has been produced.[2] Thus we have met our goal of a concept for a simple, lightweight OH instrument that will operate from a satellite without stored cryogens by a comfortable margin.

TABLE 1. OH Power and Continuum Results

z_{tan} (km)	OH Power W m^{-2} sr^{-1}	Detected Power W	Continuum Height[a]	Detected Continuum W
25	3.4×10^{-5}	1.3×10^{-11}	7.7×10^{-2}	1.3×10^{-11}
30	4.6×10^{-5}	1.8×10^{-11}	2.1×10^{-2}	3.5×10^{-12}
35	4.9×10^{-5}	1.9×10^{-11}	6.1×10^{-3}	1.0×10^{-12}
40	4.5×10^{-5}	1.7×10^{-11}	1.7×10^{-3}	2.9×10^{-12}
45	3.5×10^{-5}	1.4×10^{-11}	4.5×10^{-4}	7.4×10^{-14}

[a]Normalized to a 250 K blackbody.

5. DISCUSSION

OHIO is at present in the conceptual stage. It combines elements of Fabry-Perot/grating spectrometer design[3] with current progress in Fabry-Perot resonator design[5] and metal mesh fabrication.[4] In the coming year we intend to combine these elements in the laboratory in order to refine the detailed optical design (especially that of the image slicer) and finalize the choices for short-wavelength filtering. At that stage we would be prepared for a test of a balloon-borne version of the instrument. The laboratory and balloon test phases of OHIO will be carried out with the most appropriate detectors currently available. This will hopefully include a flight-ready version of the high-T_c YBaCuO bolometer. Otherwise, the optical instrument development will proceed in advance of anticipated detector development and a 4 K photoconductor detector will be used during the initial test phases.

Various approaches are being considered to increase the sensitivity margin of the OHIO concept even more, in order to allow for measurement on a shorter geophysical scale and over a larger altitude range. These include the possibility of increasing the size of the Fabry-Perot (difficult at present because of limitations in the size of high-quality meshes that can be produced), the use of multiple etalons, and the possibility of spatial multiplexing to increase the number of detectors for a single etalon. In the current paper we have concentrated on the optimization of the simplest system, because of the desire to produce an instrument that meets our goals of simplicity, reliability, relatively low cost, and modest requirements for satellite resources.

Acknowledgements

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6. REFERENCES

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