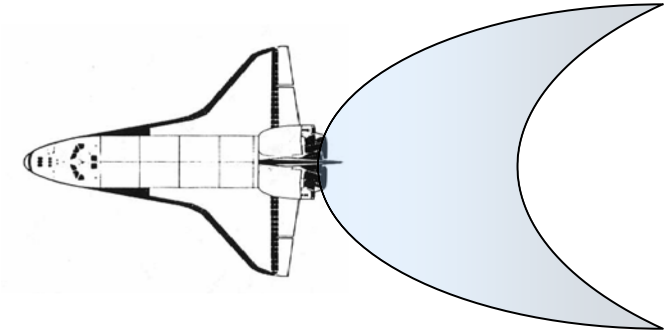
PREDICTIONS OF OBSERVATIONS OF SHUTTLE ENGINE FIRINGS

AMOS 2005 TECHNICAL CONFERENCE



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Outline

- Introduction
- Chemical Mechanisms
- Source and Apparent Signals
- Instrumentation
- Conclusions and Future Work

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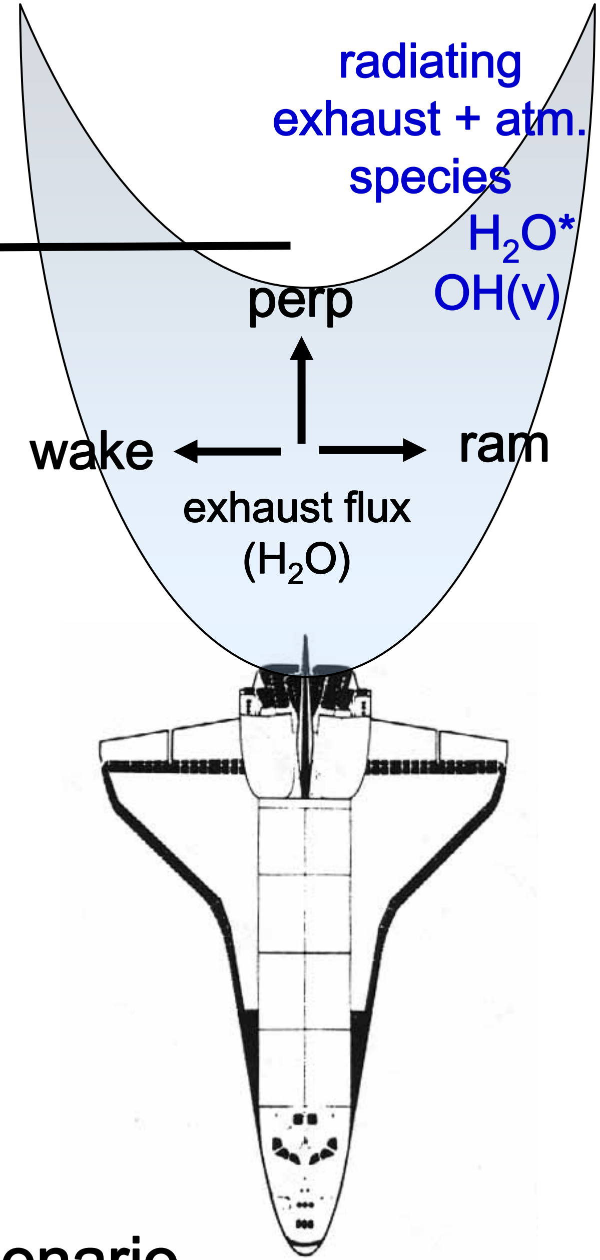
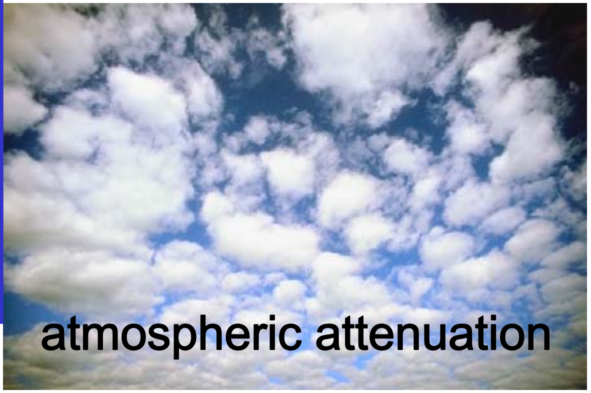
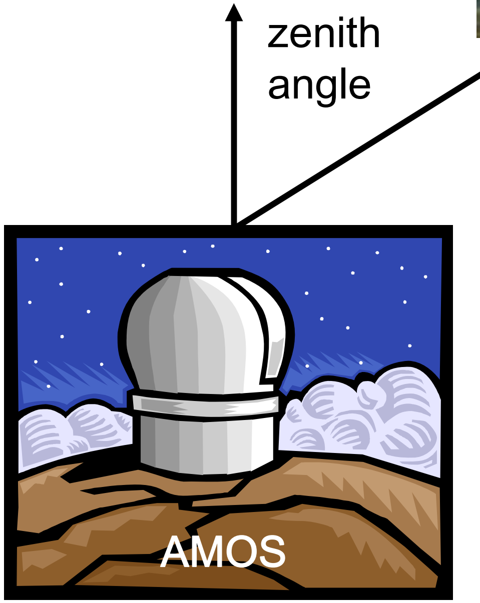
Observation Scenario

Shuttle engine firing observation scenario. Engine exhaust, consisting mostly of H_2O, interacts with O-atom in the atmosphere to produce internally excited species, OH(v) and H_2O*. The radiative decay of these excited species is attenuated by the atmosphere and observed from AMOS in the 2-5 μm region.



atmospheric wind (O-atom)





Chemical Mechanisms

- Signal is due to two major chemical mechanisms

$$O(^3P) + H_2O(X,{}^1A_1) \rightarrow OH(X,{}^2\Pi) + OH(X,{}^2\Pi)\ ,\ \Delta H = +16.9\ \text{kcal mol}^{-1}, \qquad (1)$$

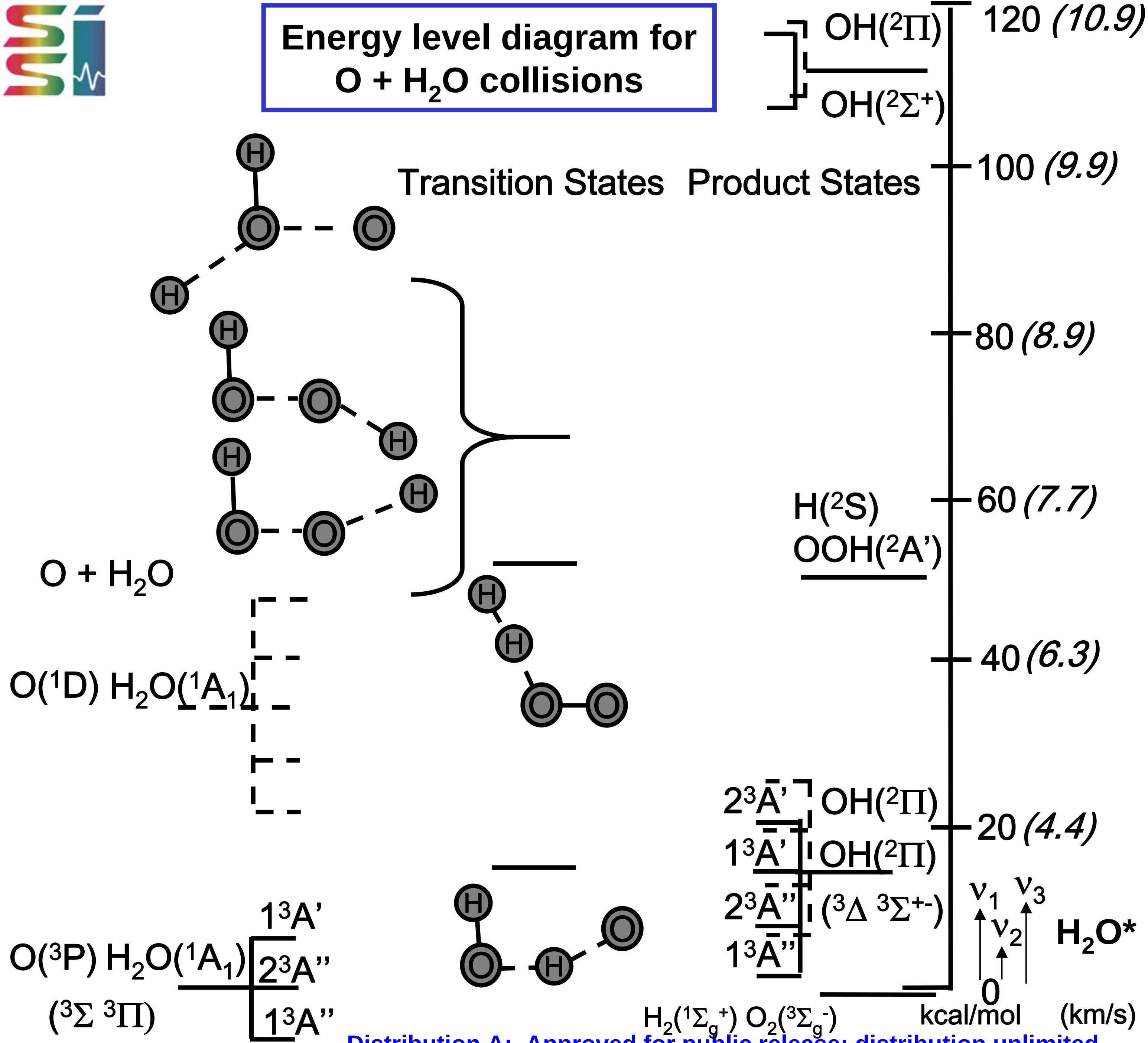
$$O(^3P) + H_2O(X,{}^1A_1,\ (\nu_1\nu_2\nu_3,JK)) \rightarrow O(^3P) + H_2O(X,{}^1A_1(\nu_1'\nu_2'\nu_3',J'K')). \qquad (2)$$

- Single collision models for total signal

$I_{\Delta\lambda}^{space} \approx \left[\frac{\sigma^*}{\sigma_{tot}}\right] N_{H_2O} T_{\Delta\lambda}$ = (Photon efficiency) * (H_2O engine flux) * (atmospheric transmittance) = # photons per second

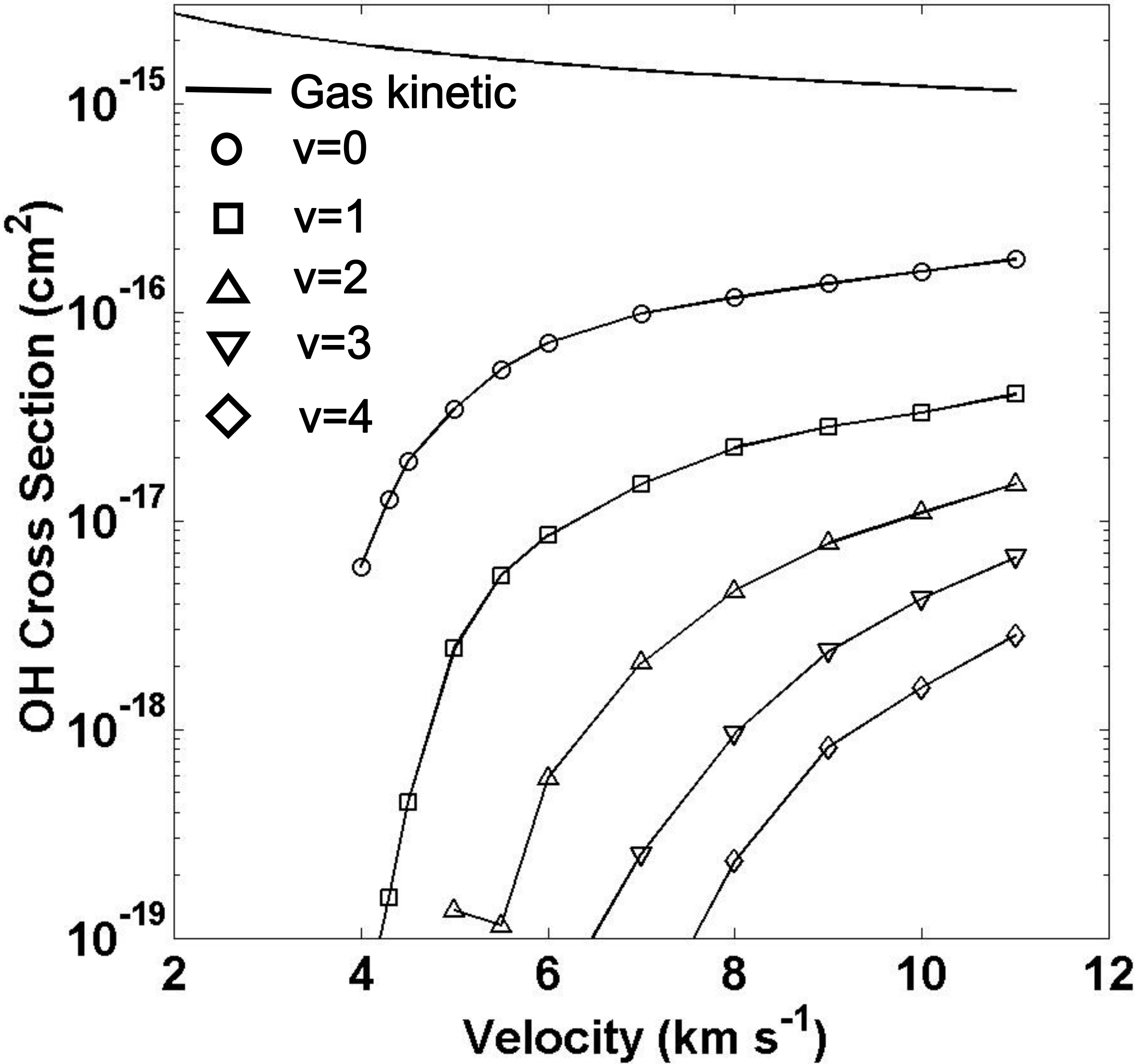
$$\left[\frac{\sigma^*}{\sigma_{tot}}\right] = \frac{1}{\sigma_{tot}} \sum_{species} \sum_{v=1} v\,\sigma_v^{species}$$

Energy level diagram for O + H_2O collisions



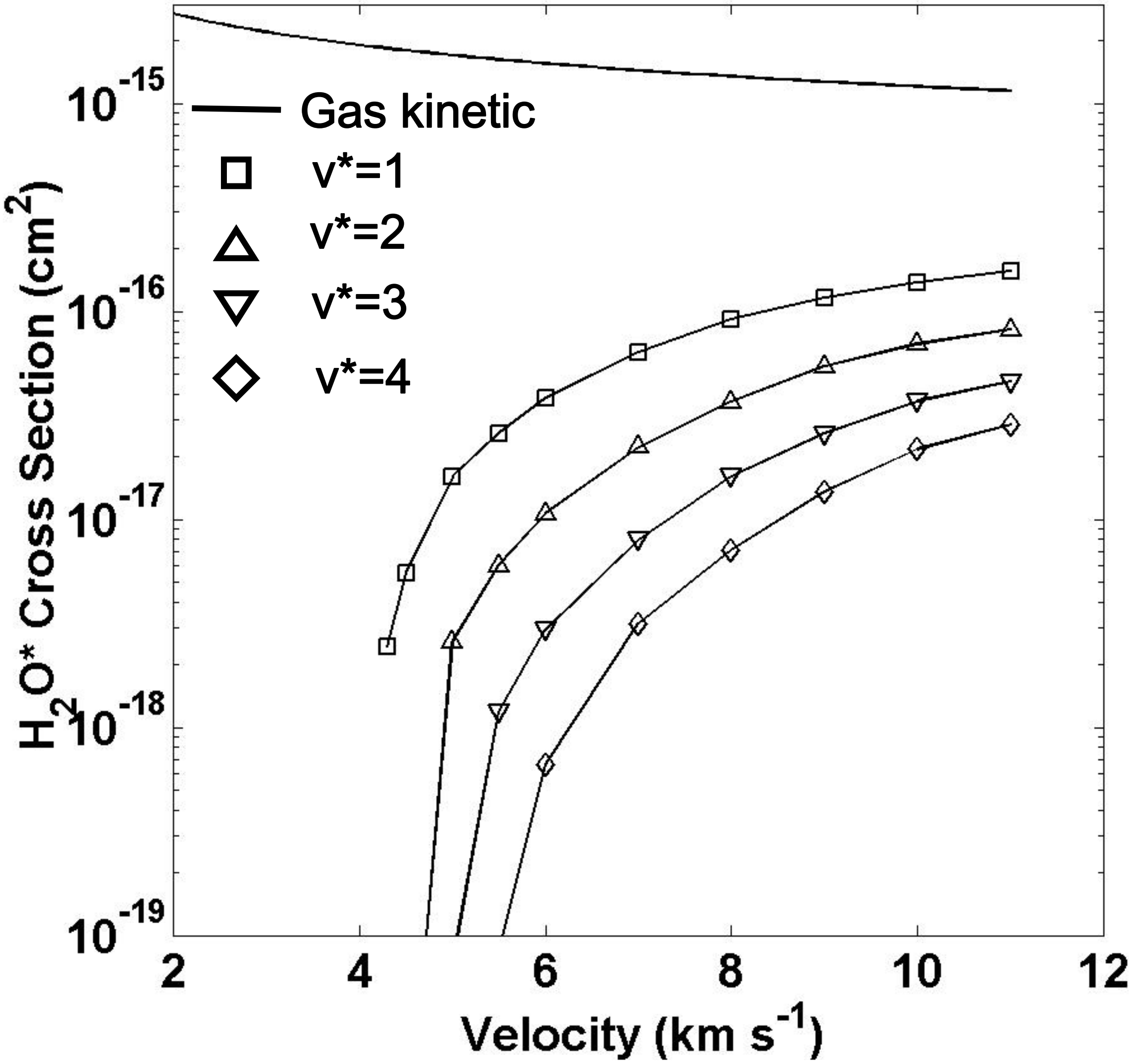
Cross sections for the reaction, O + $H_2O \rightarrow OH(v) + OH(v)$, as a function of collision velocity

$O + H_2O \rightarrow OH(v) + OH(v)$



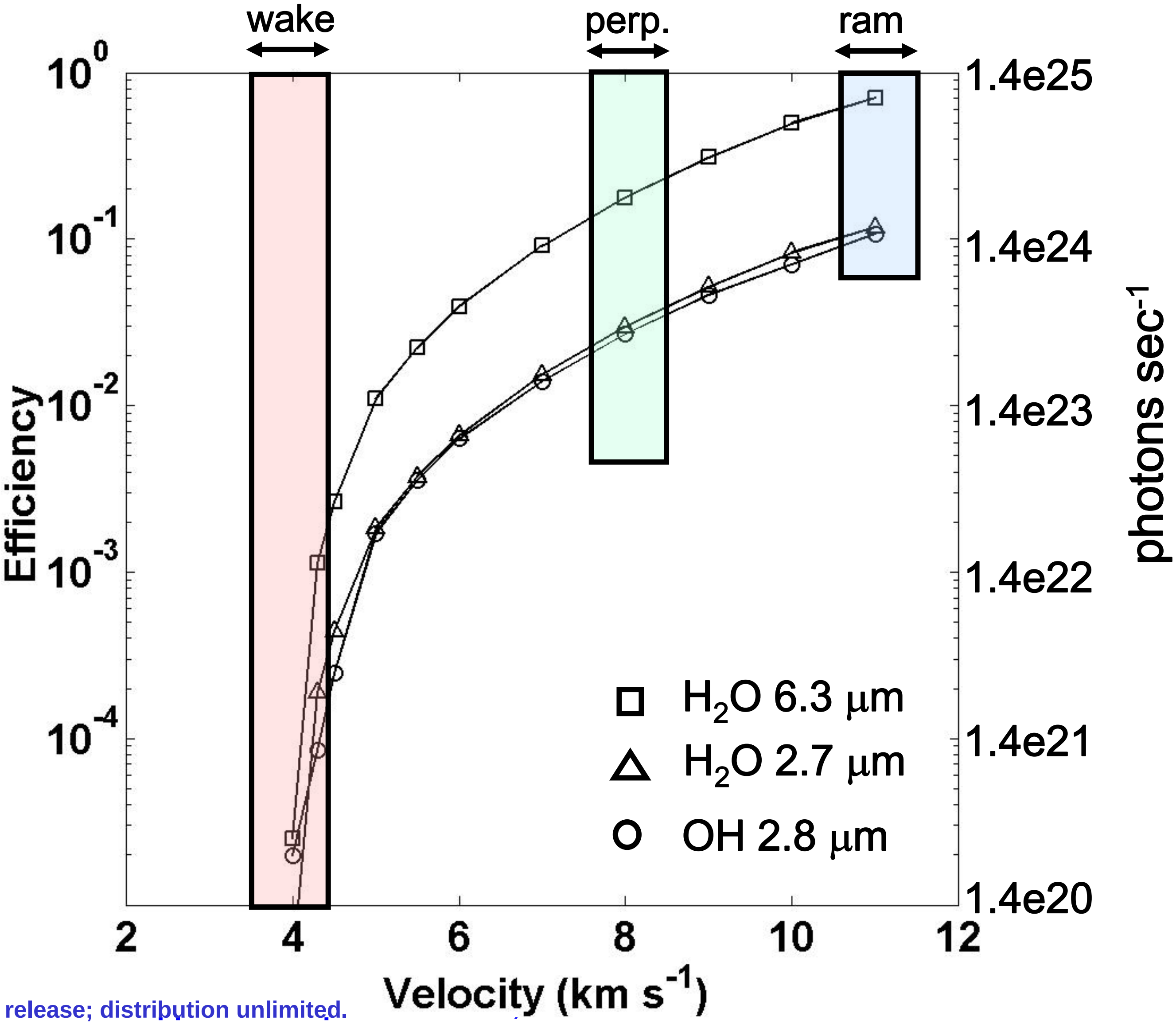
Cross sections for the reaction, $O + H_2O \rightarrow O + H_2O^*$ as a function of collision velocity

$O + H_2O \rightarrow O + H_2O^*$



Photon production efficiency per collision and total source signal in photons s^{-1} as a function of velocity for PRCS engine firings.

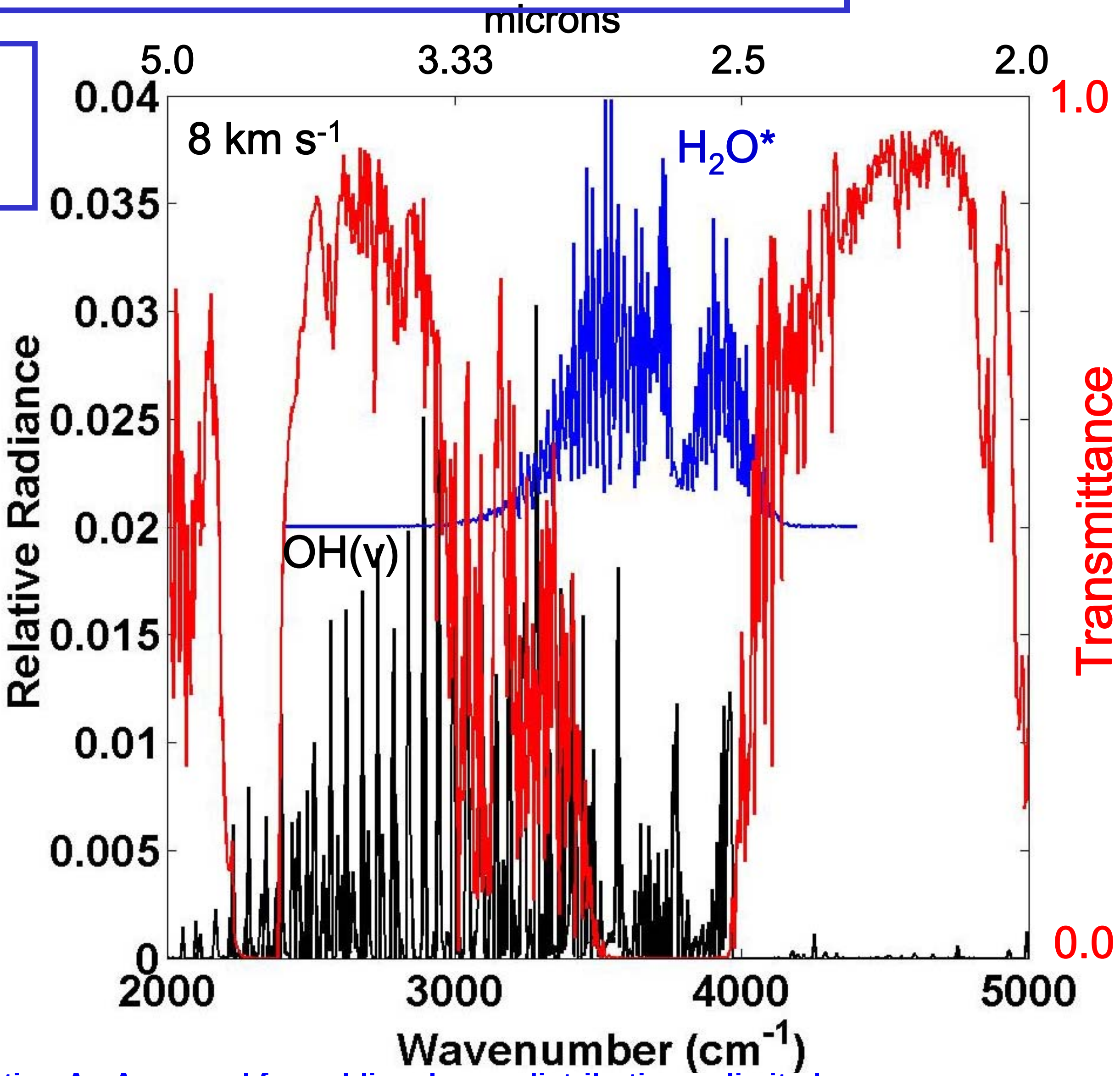
The H_2O^* contribution has been split into H_2O 2.7 μm and H_2O 6.3 μm contributions. The OH(v) contribution is here called 'OH 2.8 μm'. The OH 2.8 μm and H_2O 2.7 μm curves contribute to the 2-5 μm pass-band.



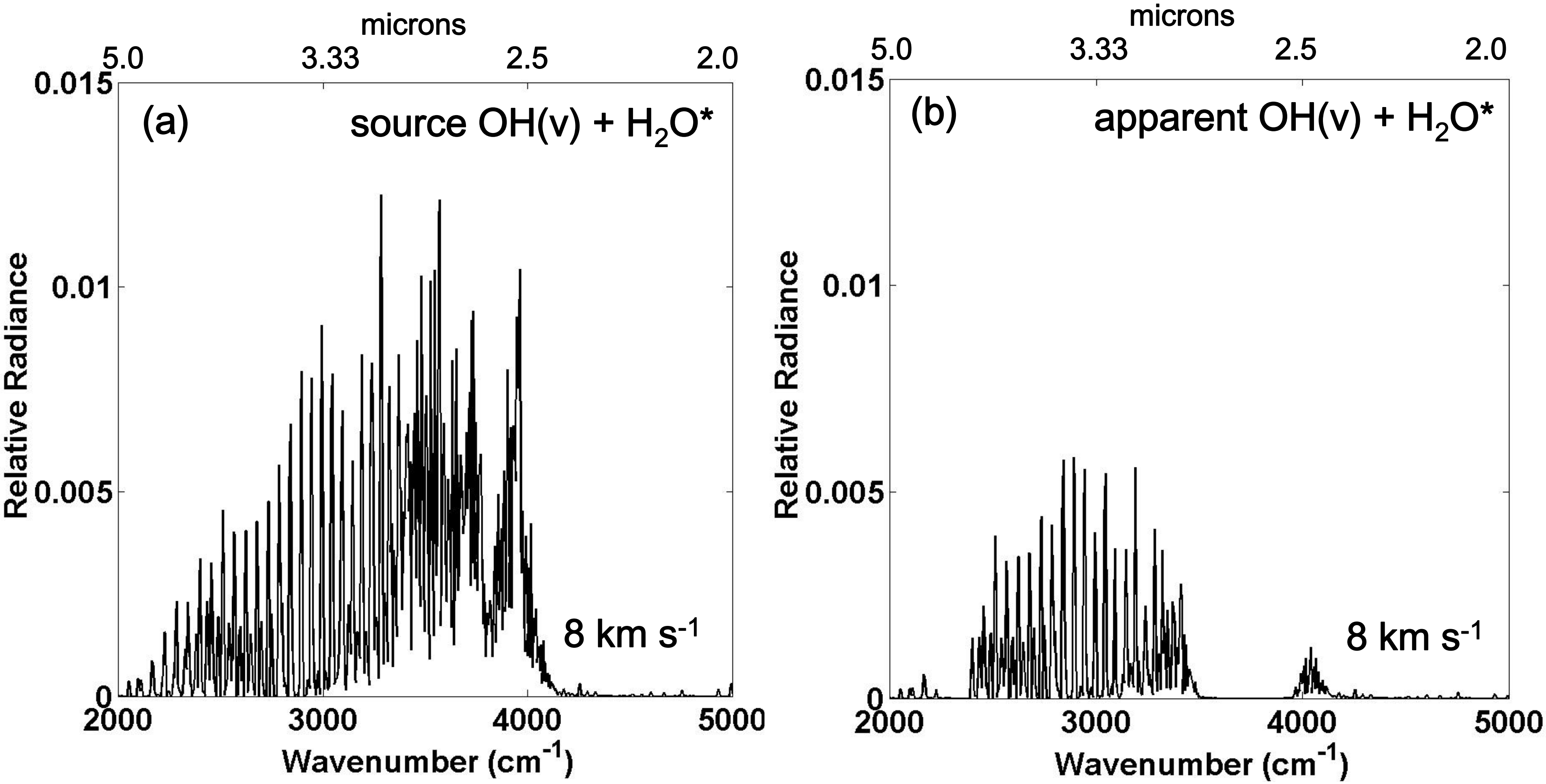
Normalized spectral radiance from OH(v) (black curve) and H_2O^* (blue curve) at 8 km s^{-1} relative collision velocity.

Source and Apparent Signals

The OH(v) and H_2O^* curves have been separately normalized to 1.0 and the H_2O^* curve displaced for clarity. The atmospheric transmittance for a 60 degree zenith look angle from AMOS is shown in red. Spectral resolution is 5 cm^{-1}.



Source and apparent (atmospherically attenuated) OH(v) + H_2O^* relative spectral radiance at 8 km s^{-1} relative collision velocity



Normalized spectral radiance from OH(v) (black curve) and H_2O* (blue curve) at 11 km s^{-1} relative collision velocity.

The OH(v) and H_2O* curves have been separately normalized to 1.0 and the H_2O* curve displaced for clarity. The atmospheric transmittance for a 60 degree zenith look angle from AMOS is shown in red. Spectral resolution is 5 cm^{-1}.

microns

5.0

3.33

2.5

2.0

1.0

11 km s^{-1}

H_2O*

Transmittance

OH(v)

0.0

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Source and apparent (atmospherically attenuated) OH(v) + H_2O* relative spectral radiance at 11 km s^{-1} relative collision velocity

microns

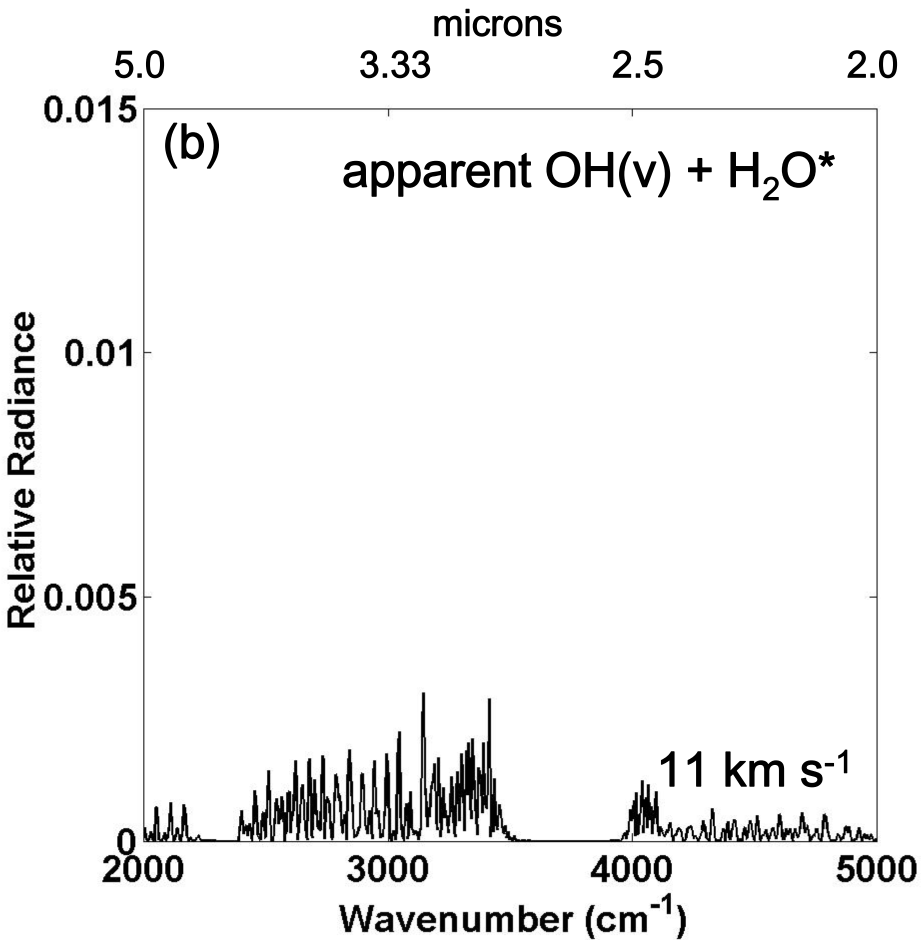
5.0 3.33 2.5 2.0

(a)

source

OH(v) + H_2O*

11 km s^{-1}



Space Shuttle Plume Measurement Analysis

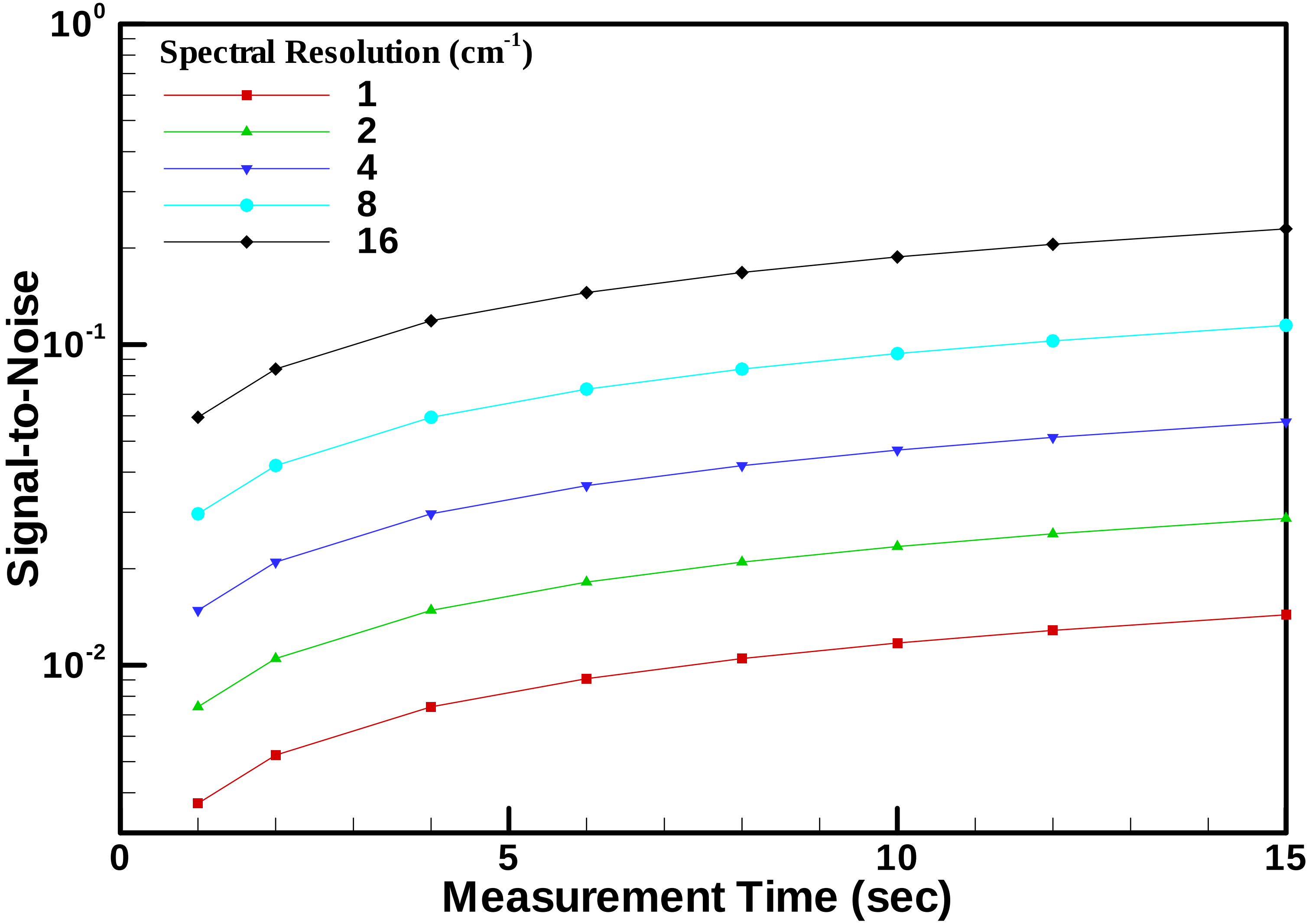
- Utilize Total Signal Calculation to Estimate a Signal-to-Noise for Two Available Spectrometers – 3.76e04 W (11 km/s Case)
- Assume Both Integrable onto AMOS Telescope (Most Likely B37)
- 5 km Diameter Plume at 390 km Altitude and 60 Degree View From Zenith
- Expect Plume Radiance to Fill the FOV (B37 is Only 3 mrad Total)
- Calculate Average Radiance by Dividing by 4π Steradians and Estimated Plume Area

ABB (Bomem) FTIR Spectrometer Spec’s

- Two Simultaneous Non-Imaging Detectors
  - 1- 6 μm InSb, 1.37e-09 RMS NESR at 1 cm^{-1} Resolution
  - 2 - 15 μm MCT, 1.4e-08 NESR at 1 cm^{-1}
  - Currently Use LN2 for Detector Cooling
- 5, 28, 75 mrad Telescopes Available as Attachments
- LN2 Cooled Cold Source
- Weight – 45 kg Nominal
- Scan Rate and Spectral Resolution Specifications:

Resolution (cm^{-1})	16	8	4	2	1
Frame Rate (scans/sec)	64.6	47.8	31.4	18.6	10.3
Maximum Acq Time (sec)	242	163	125	104	95

ABB FTIR InSb Detector S/N Calculations



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Broadband Array Spectrograph System (BASS)

- Aerospace Corporation Sensor (Dave Lynch)
- Wavelength Dispersive System – 2 Prisms
- 116 Total Detectors
- 3 – 13.5 μm Waveband
- Approximately 0.1 μm Resolution (Much Lower Than Desired)
- Noise Equivalent Power: 4.0e-14 W/Sqrt(Hz) (1 Sec Integration)
- Frame Rate: 0.1 – 200 Hz
- Estimate S/N = 1448 Over the 3 – 4.2 μm Region
  - Calculation Not Reviewed by Aerospace Corp. Personnel

Conclusions and Future Work

- Total Signal (Watts) =

(Efficiency in photons per H_2O) (# H_2O from engine s^{-1}) (3.33e3 cm^{-1} / photon) (1.9863e-23 Joules / cm^{-1}) (atmospheric attenuation factor)

8 km s^{-1} → 1.26e4 Watts

11 km s^{-1} → 3.76e4 Watts

- Results compare well with previous observations at 11 km s^{-1}
- OH(v) is the major contributor
- More source signal (and a little more attenuation) at higher velocities
- Need high angle of attack firing to see signal
- ABB FTIR spectrometer not sensitive enough with present configuration
- BASS sensor appears to have required sensitivity but at the expense of low spectral resolution

- Future Work
  - Better $O + H_2O \rightarrow O + H_2O^*$ cross sections
  - Analyze spatial distribution of radiation
  - Additional instrument analysis required