ICES 2015

Vented detector housings for use in the Mars atmosphere

Ian M. McKinley

Jose I. Rodriguez

July 15, 2015

Jet Propulsion Laboratory

California Institute of Technology

Motivation

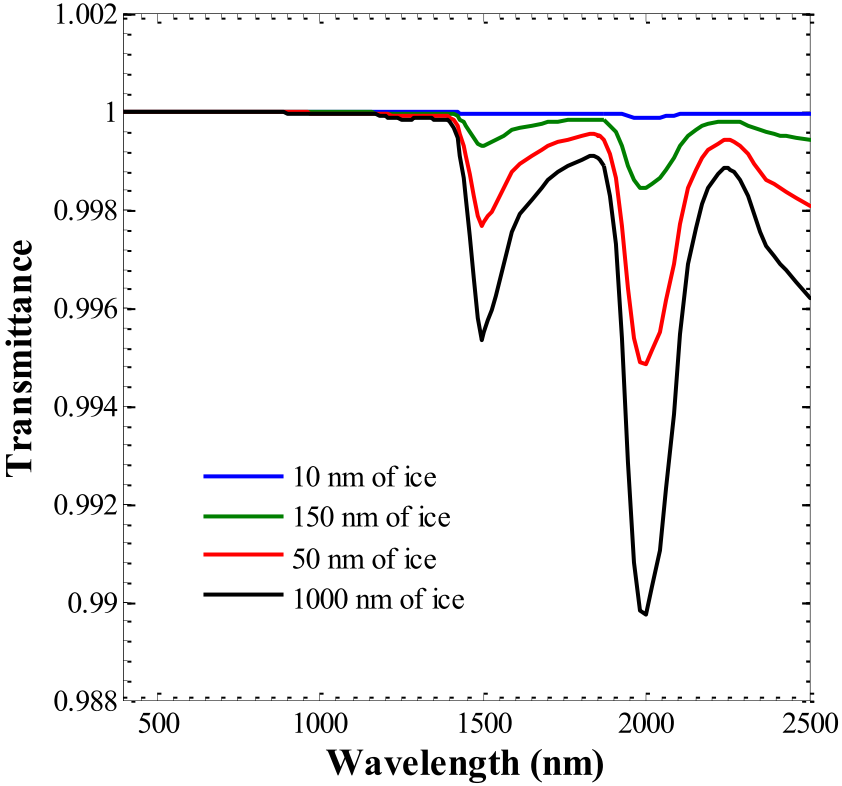
ICES 2015

- Spacecraft traveling to Mars experience three different environments
  - Earth: ~750 Torr, ~2000 parts per million by volume (ppm_v) water
  - Space: ~10^{-6} Torr, ~0 ppm_v
  - Mars: ~2-12 Torr, ~500 ppm_v
- Infrared detectors need to be cooled to cryogenic temperatures (<180K)
  - The presence of water vapor leads to ice layer forming on detector
    - Ice prevents incoming light from reaching the detector
- Hermetic sealed vacuum enclosures eliminate water contamination
  - Require thick, heavy walls to survive the conditions of Earth, space, and Mars.
  - Too heavy for mass constrained cryogenic instruments such as those on the end of robotic arms
- A potential alternative to vacuum enclosures are ones with thinner walls that implement vents
  - Must provide a sufficient barrier to ice layer growth on detector
  - Must be able to equalize pressure during launch
- This study investigates the feasibility of vented enclosures in Mars atmosphere

Vented enclosure requirements

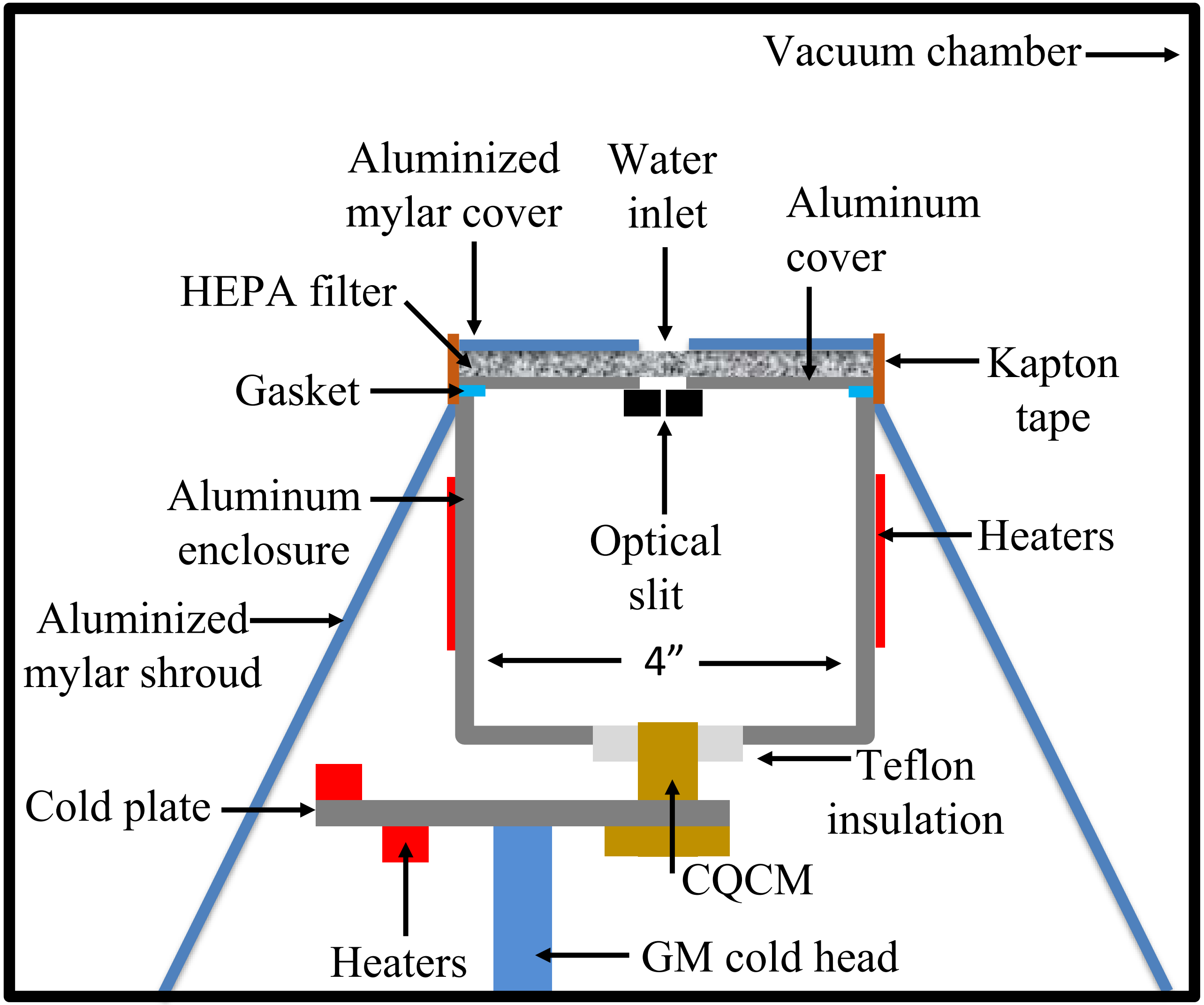
ICES 2015

- Water contamination:
  - Ice layer transmissibility of ice thickness >0.995 in range 400 to 2500 nm
    - Ice layer transmittance estimated by ignoring reflections and knowing the thickness and absorption index of ice [1]
    - Ice optical properties vs wavelength given by Warren and Brandt [2]
  - Detector operates for 6 hours per day [3]
- Venting:
  - Tolerate a pressure decay rate of -4.4 kPa/s for at least ten seconds [4]
  - Safety factor of 2 [5]



[1] Kitamura et al. **Applied Optics**, 46, 2007.
[2] Warren and Brandt. **J. of Geophysical Research**, 113, 2008.
[3] Johnson et al. **AIP Conf. Proc. 1573**, 2014.
[4] Scialdone. *Optical Systems Contamination and Degradation,* 1998.
[5] Musgrave et al. *Safety Design for Space Systems,* 2009.

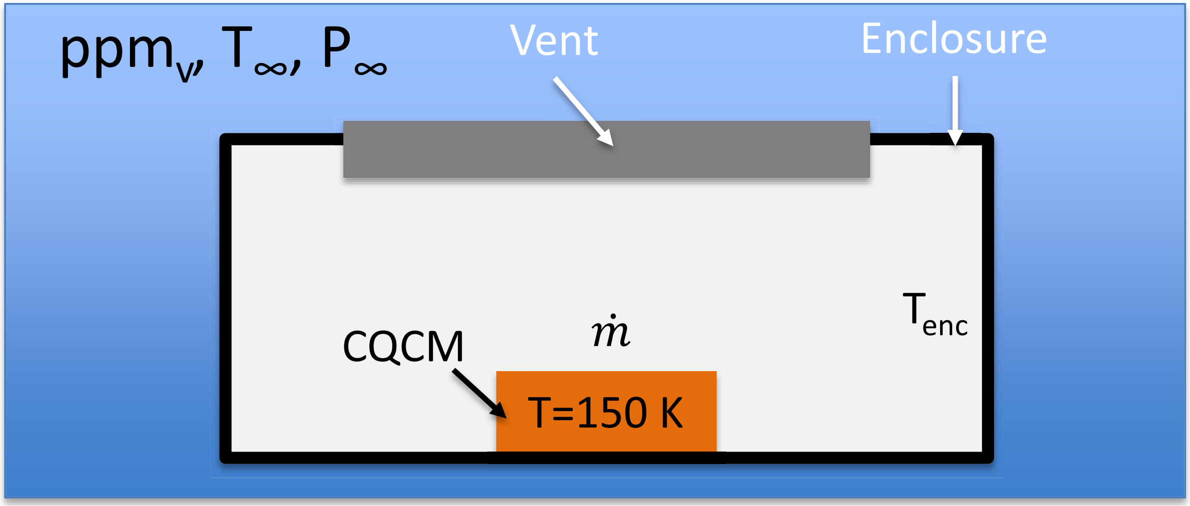
Test apparatus



Not to scale

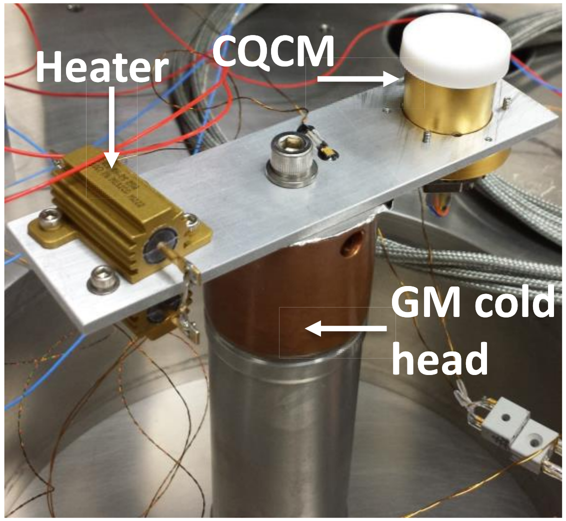
Test procedure

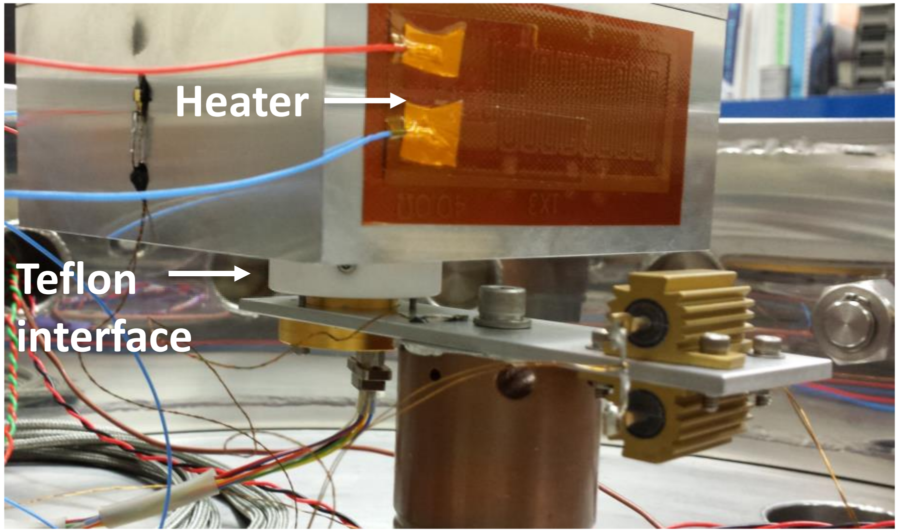
- Vent configuration assembled
- Vacuum chamber pumped to ~10^{-6} torr while enclosure and CQCM held for 12 hours at 333 K and 338 K, respectively
- CQCM cooled and held for 4 hours at 150 K
- Enclosure cooled to 300 K and chamber backfilled with Matheson Air Zero gas
  - Mass collection rate <5 ng/min and ppm_v <10
- Water vapor added from second chamber to achieve ~700 ppm_v
- Temperature and pressure held for 16 hours
  - Water vapor collected and ppm_v decreased to ~150

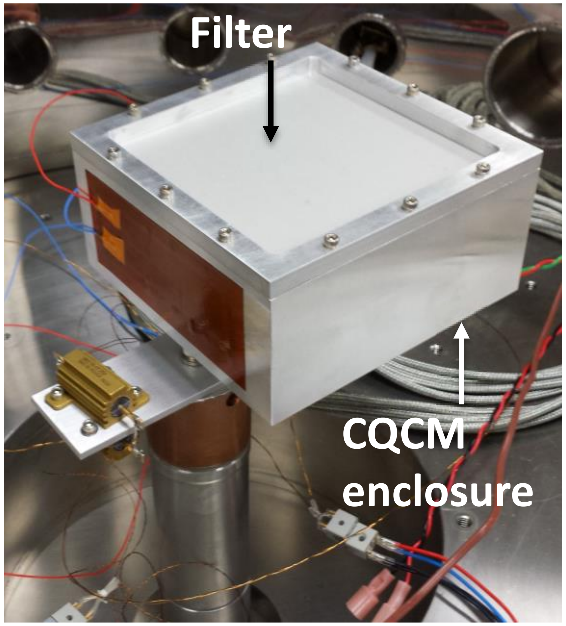


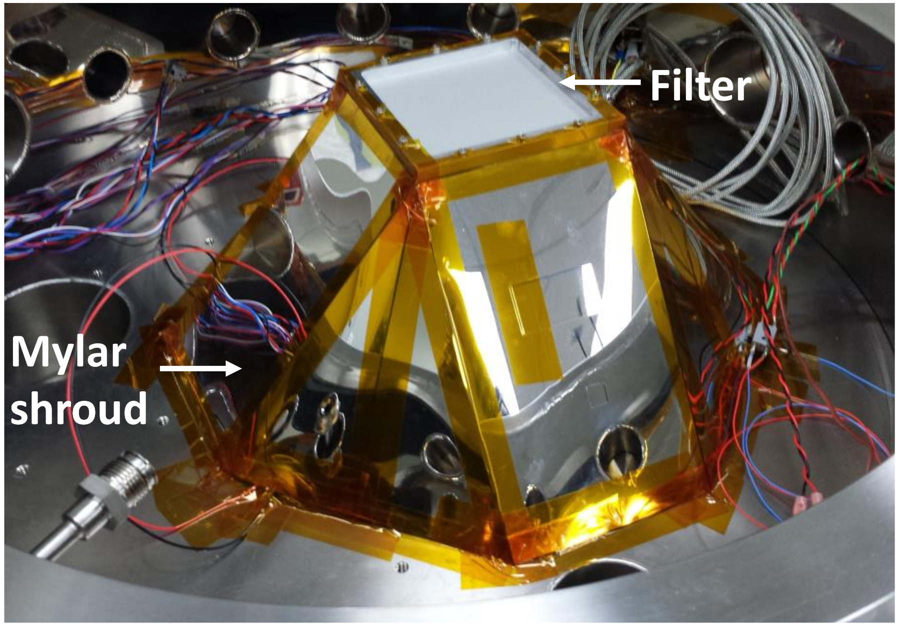
Apparatus

ICES 2015

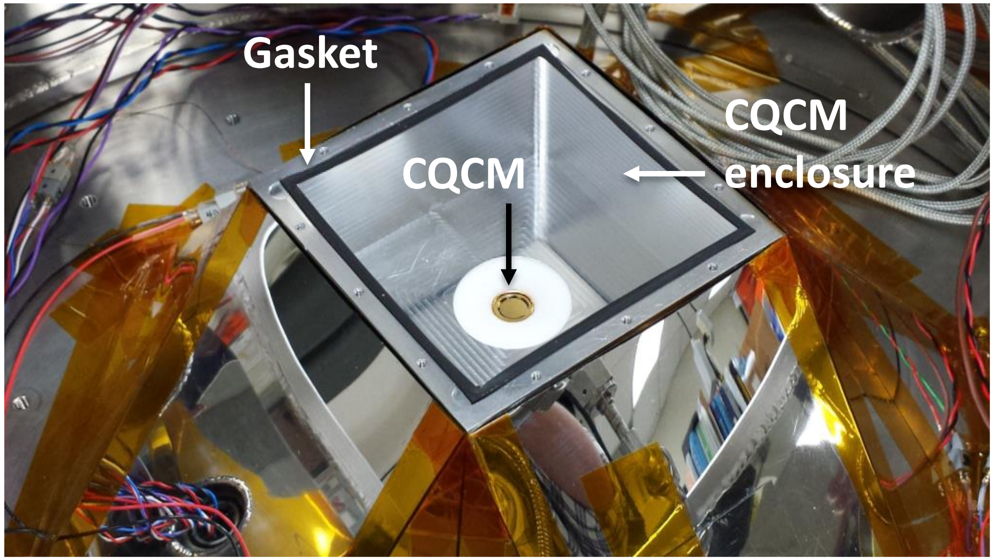




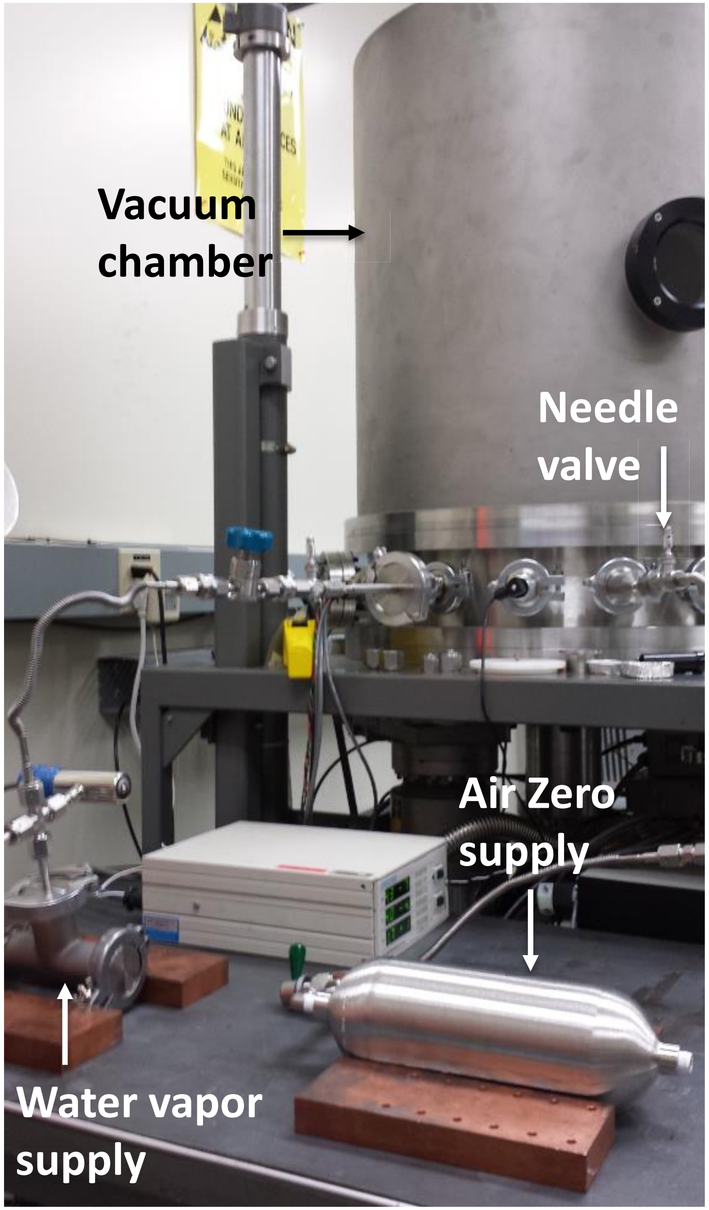




Apparatus


Gasket
CQCM
CQCM enclosure

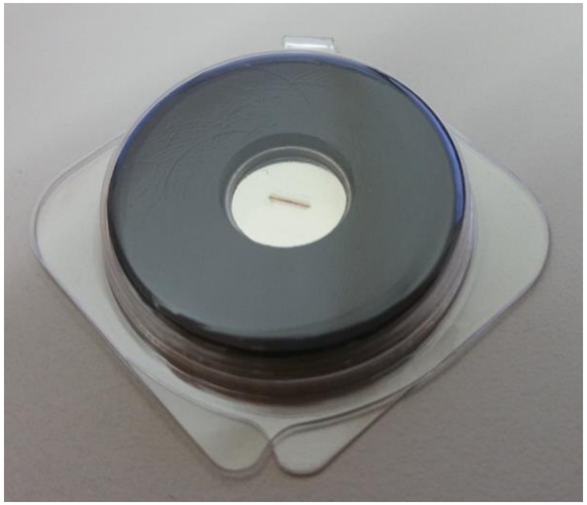

Data acquisition
Data logging
QCM readings
QCM plot


Vacuum chamber
Needle valve
Air Zero supply
Water vapor supply

Vent materials

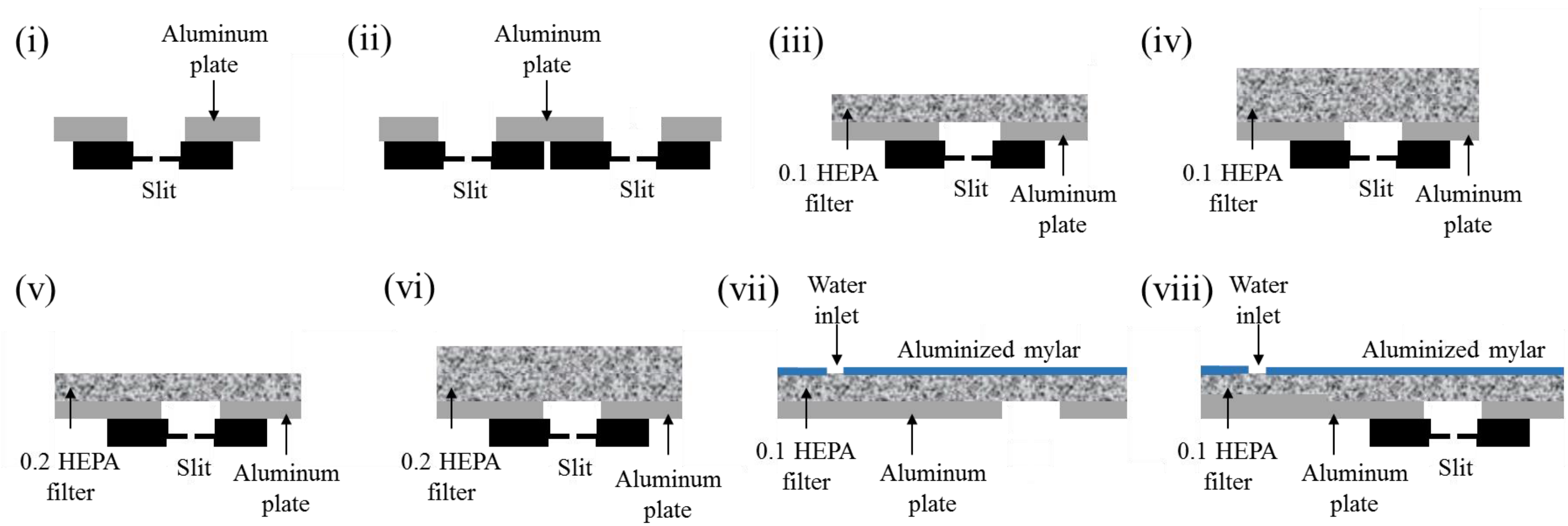
- HEPA filters:
  - Mott Corp. sintered porous metal filters provide particulate protection
  - Qualified and flown on the MER and MSL mission
  - Two grades of filter tested
    - Designed to capture particles down to 0.2 µm and 0.1 µm
    - Porous metal plates approximately 1 mm thick with a 100 mm side length
- Optical slits:
  - National aperture standard precision air slit
  - 25 µm long and 3 mm wide
  - 300 series stainless steel

http://www.mottcorp.com/media/images/sheet.jpg



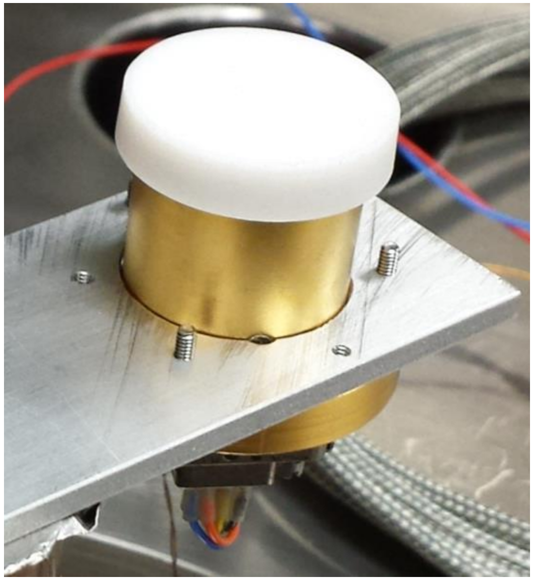
Vent configurations

i. A single optical slit
ii. Two optical slits in parallel
iii. One optical slit in series with 1 mm thick 0.1-grade HEPA filter
iv. One optical slit in series with 2 mm thick 0.1-grade HEPA filter
v. One optical slit in series with 1 mm thick 0.2-grade HEPA filter
vi. One optical slit in series with 2 mm thick 0.2-grade HEPA filter
vii. 1 mm thick 0.1-grade HEPA filter with offset inlet and outlet by 76 mm
viii. 1 mm thick 0.1 HEPA with offset in/outlet in series with one optical slit



Mass collection rate

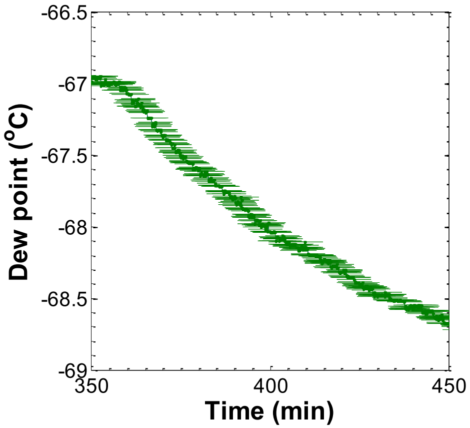
- QCM Research: MK18 CQCM
  - Active area: A=1 cm^2
- Measure difference in vibrating frequency (ΔF) of two piezoelectric crystals
- Crystal sensitivity:
  - $S = \frac{2F^2}{C\rho} = 5.0918x10^8 \ \frac{Hz\ cm^2}{s}$
    - Transverse wave velocity: $C = 3.3369x10^5 \ \frac{cm}{s}$
    - Fundamental frequency: F=15 MHz
    - Density of crystal: $\rho = 2.6485 \ \frac{g}{cm^3}$
- Mass:
  - $m = \frac{A\Delta F}{S}$

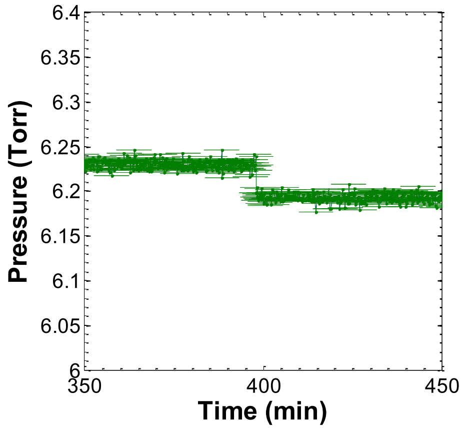


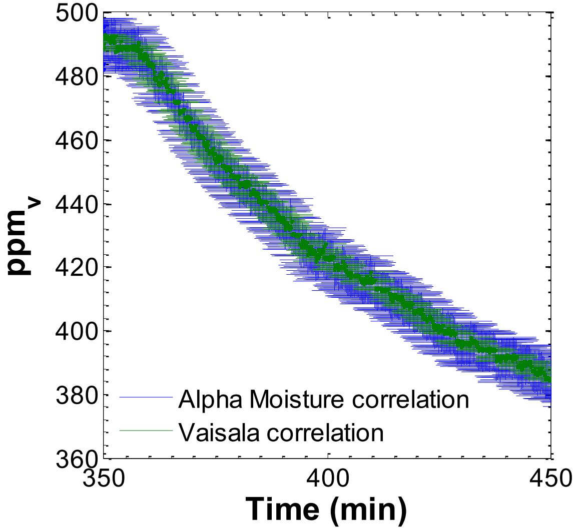
Parts per million by volume

ICES 2015

- Computation of the ppm_v of water vapor in the vacuum chamber
  - Measure the dew point T_{dp} using an Alpha Moisture dew point sensor
  - Measure the pressure using a Granville-Phillips pressure sensor







- Use correlations to calculate ppm_v:
  - Vaisala (-70 to 0°C):

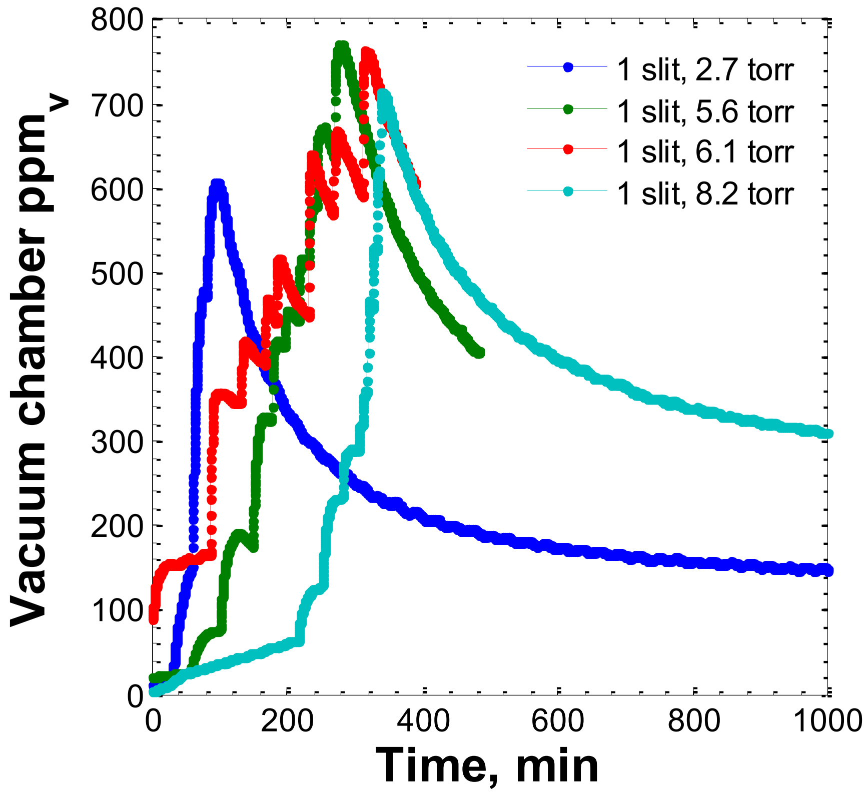
$$ppm_v = 10^6 \frac{P_w}{P - P_w} \qquad P_w = 100\left(6.114742 \times 10^{\frac{9.778707 T_{dp}}{T_{dp}+273.1466}}\right)$$

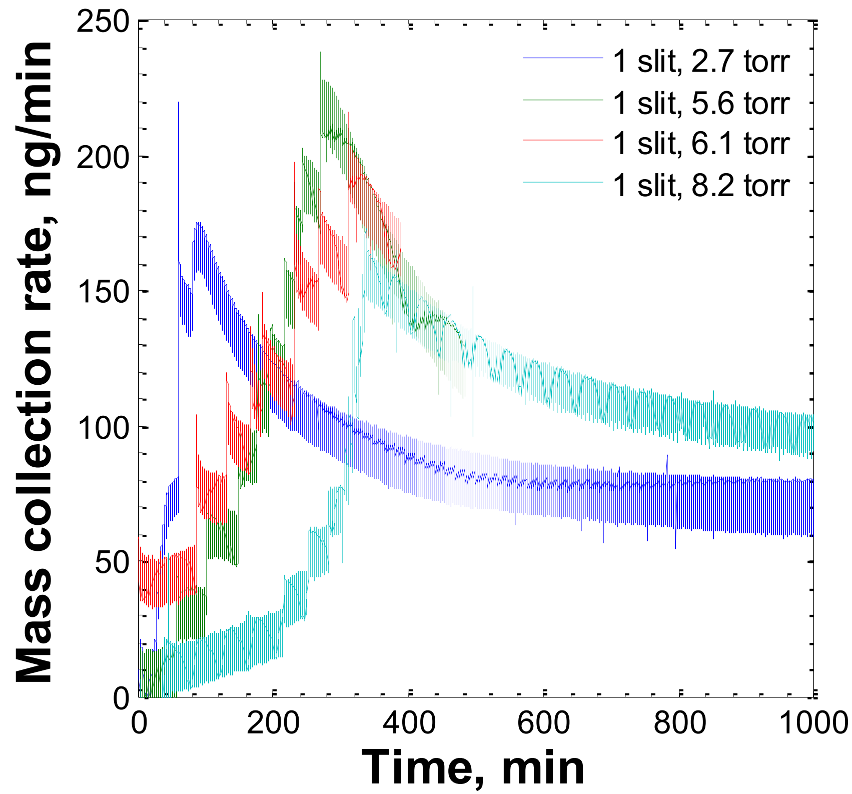
  - Alpha moisture:

$$ppm_v = 10^6 \frac{\exp[\ln(611.2) + 22.46 T_{dp}/(272.62 + T_{dp})]}{P}$$

Single slit temporal data

- PPM_v computed from dew point sensor measurement and total pressure
- Film thickness rate measured by CQCM

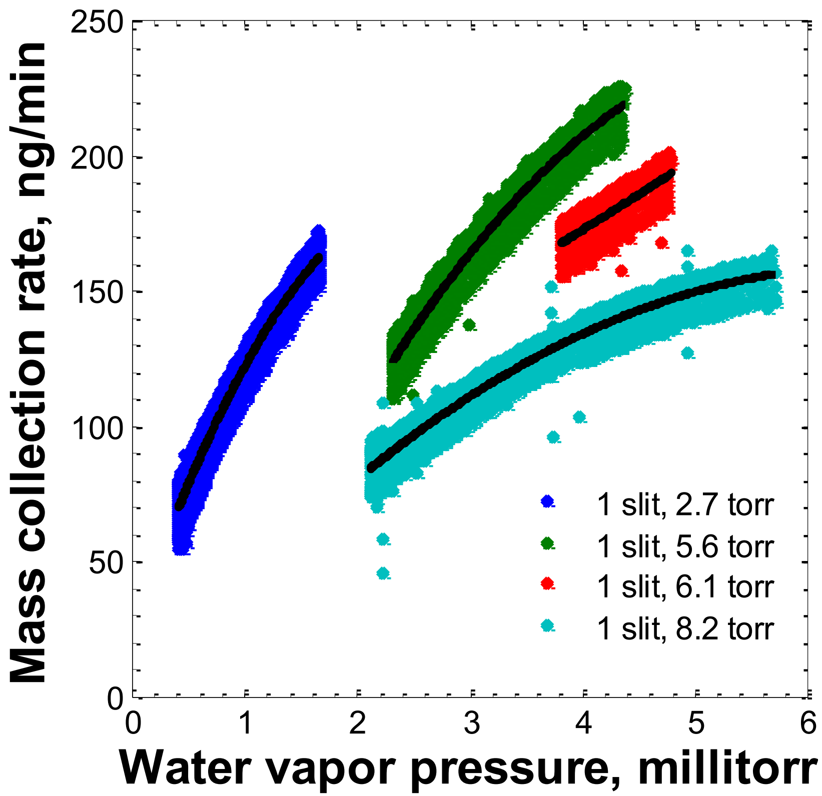


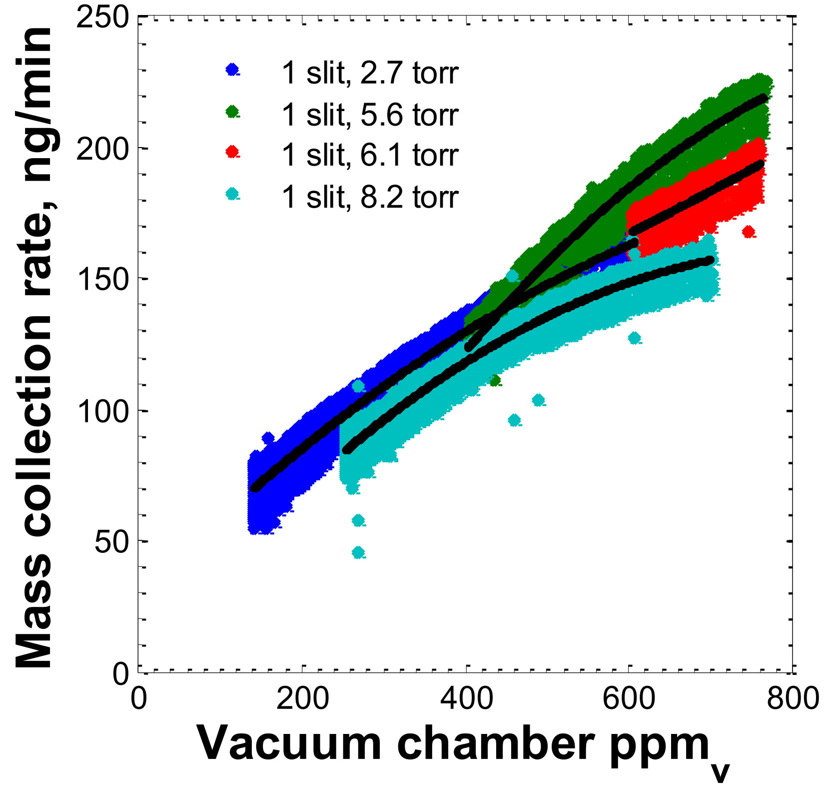


Mass collection rate single slit

ICES 2015

- Scatter in data due to 0.1 K error in temperature control
  - Eliminated with second order polynomial fit



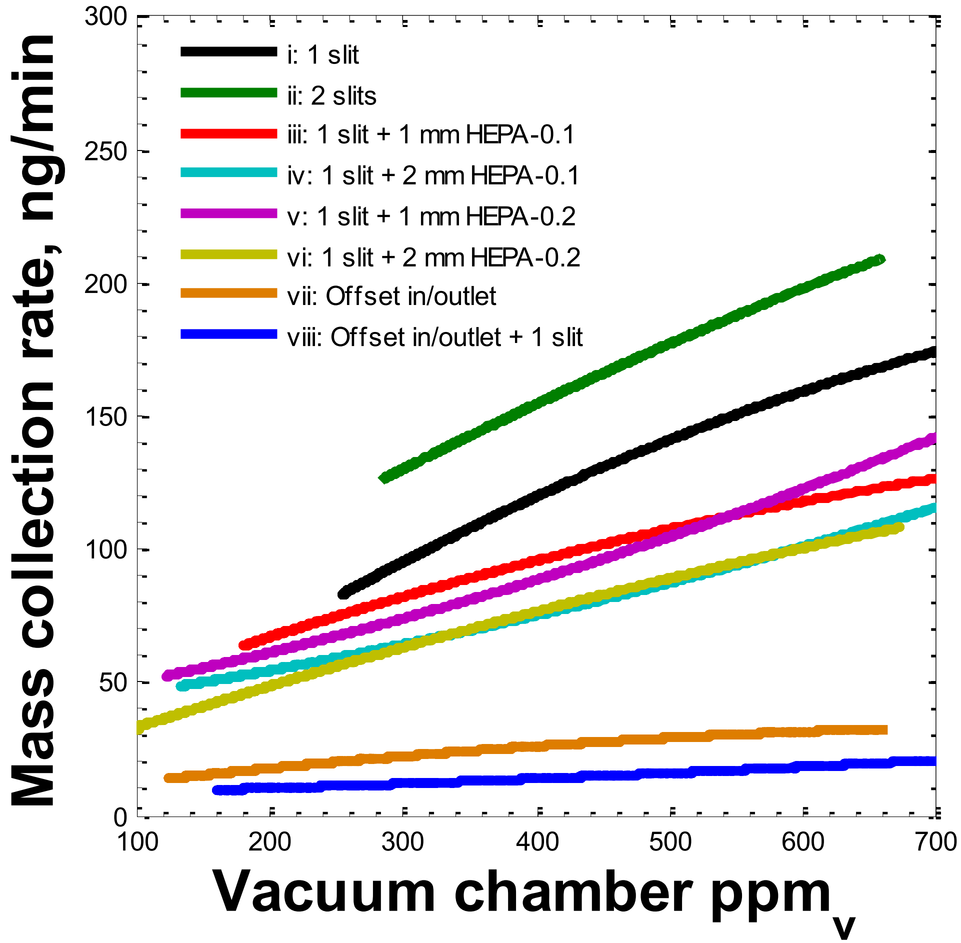


Mass collection rate vs. ppm$_v$ is nearly independent of total pressure

Mass collection rate

ICES 2015

- Second order polynomial fits shown
- Total pressure range: 2.7 to 8.2 Torr

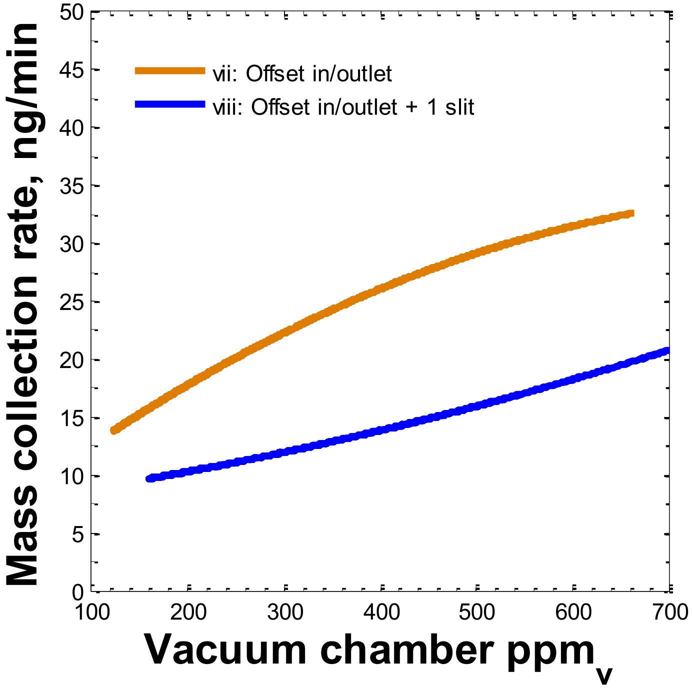


- Mass collection rate of 2 slits was less than double 1 slit
- Mass collection rate vs. ppm$_v$ independent of HEPA filter grade
- Maximum mass collection rate of configuration vii: 35 ng/min

Water contamination requirement

ICES 2015

- Convert mass collection rate ($\dot{m}$) to film thickness rate ($\dot{L}$)
  - $\dot{L} = \frac{\dot{m}}{\rho A_d}$
  - Density of ice at 160 K: $\rho = 930\ \mathrm{kg/m^3}$
  - CQCM measurement area: $A_d = 1\ \mathrm{cm^2}$
- Six hours of ice collection
- Transmittance of ice must exceed 0.995 for wavelengths between 450 and 2000 nm



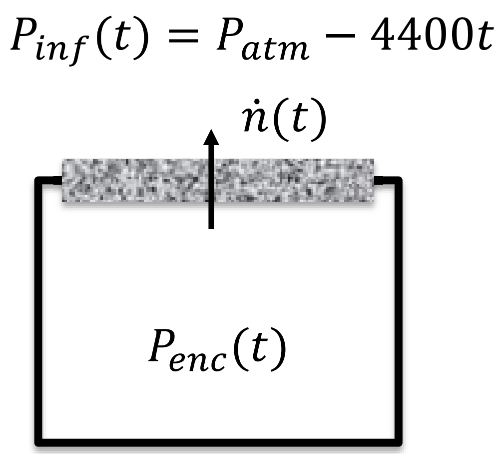
Vent config.	Max $\dot{m}$ (ng/min)	Max $\dot{L}$ (nm/min)	L after 6 hrs (nm)	Min transmittance
iv/vi	116	1.25	449	0.9954
vii	33	0.35	128	0.9987
viii	21	0.23	81	0.9998

Water contamination requirement met

Pressure drop prediction

ICES 2015

- Predict the pressure drop across the HEPA filter as a function of time
- External pressure known
  - Typical Launch pressure decay rate:
    - $P_{inf}(t) = P_{atm} - 4400t$ (Pa)
- Mott provides specification for pressure drop [1]:
  - $\Delta P(t) = P_{enc}(t) - P_{inf}(t) = C_1 \frac{\dot{\forall}}{A}$
- Molar flux:
  - $\dot{n}(t) = \frac{P_{enc}(t)\dot{\forall}(t)}{RT}$
- Conservation of moles:
  - $n_{enc}(t) = \frac{P_{atm}\forall_{enc}}{RT} - \int_o^t \dot{n}dt$
- Enclosure pressure is single unknown
  - Yields differential equation to be solved numerically:
    - $\dot{P}_{enc}(t) = -\frac{A}{\forall_{enc}C_1} P_{enc}(t)[P_{enc}(t) + 4400t - P_{atm}]$

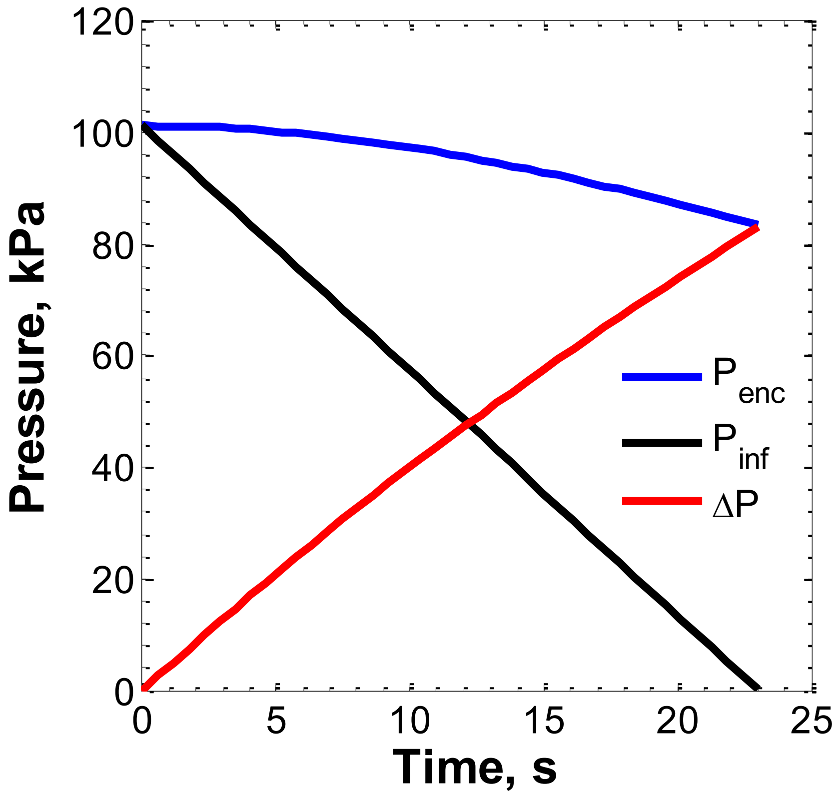


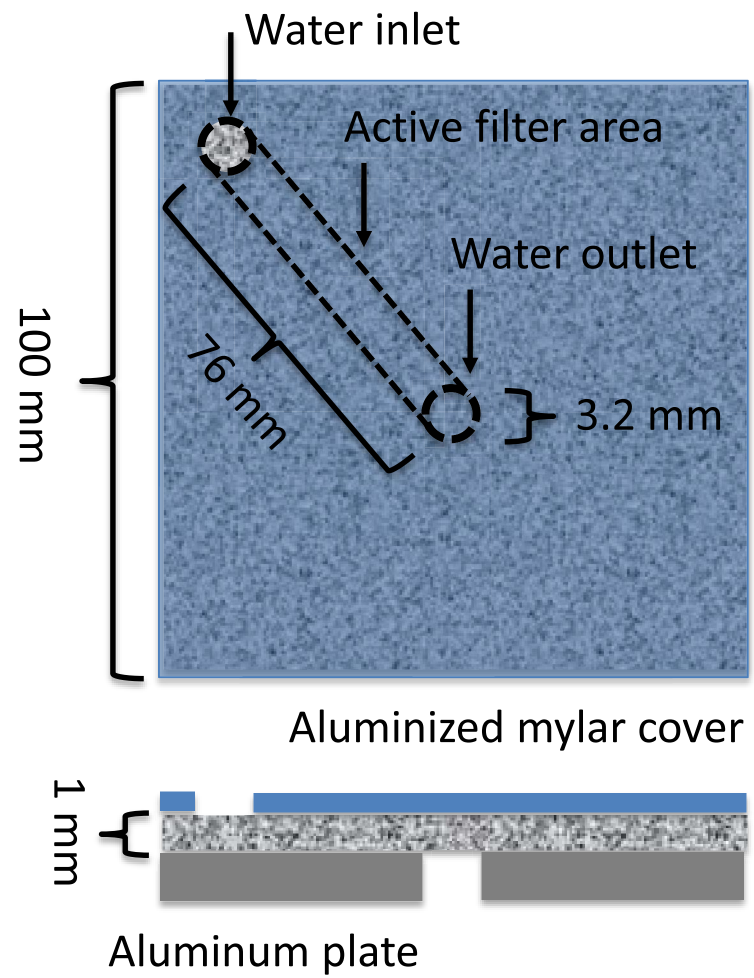
[1] http://www.mottcorp.com/resource/pdf/RS_Perm_all.pdf

HEPA pressure drop prediction

ICES 2015

- Pressure drop across the HEPA filter as a function of time
- 76 mm filter length
- Filter area: 1 mm x 3.2 mm = 3.2 mm^2



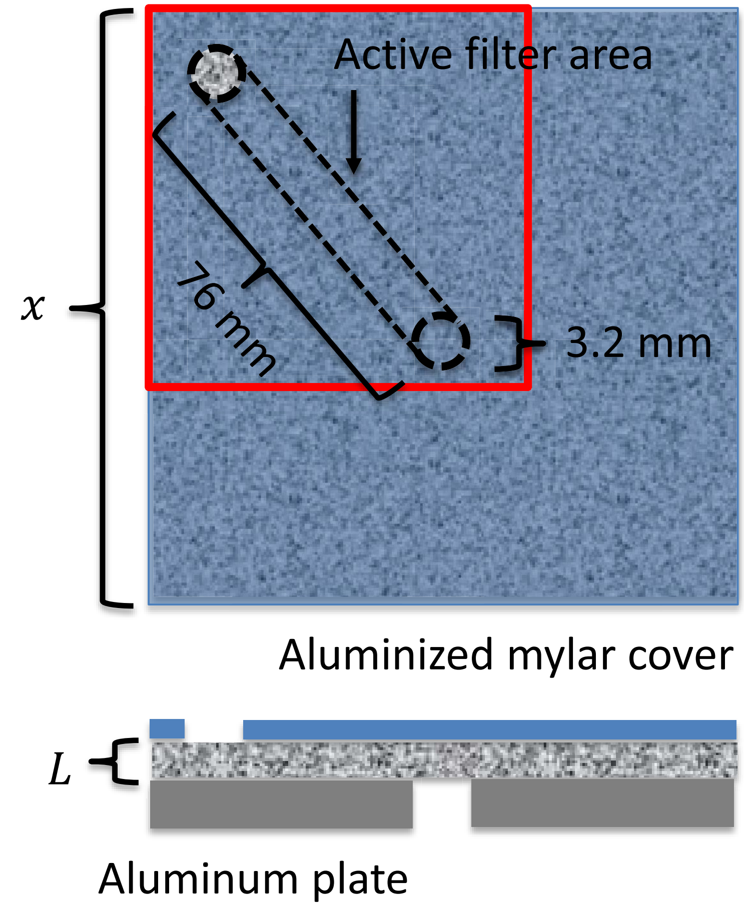


Not to scale

Stress analysis

ICES 2015

- Maximum pressure drop across filter in configuration vii was 82.5 kPa
- The maximum stress in a square panel that is simply supported on all edges and subject to a uniform pressure differential [1]:
  - $\sigma_{max} = \frac{0.281 \Delta P_{max} x^2}{L^2} = 232\ MPa$
- Yield strength of Mott 0.1-grade filters is 221 MPa [2]
- Can reduce side length x from 100 mm to 55 mm and still accommodate active filter area
  - Maximum stress becomes 70.2 Mpa
  - Meets safety requirement of 2



Not to scale

Ventilation requirement met with non-consequential modification

[1] Ugural. *Stresses in Plates and Shells*, 2007.
[2] Mott Corpotation. http://www.mottcorp.com/media/images/sheet.jpg

Summary

- There are feasible HEPA filter configurations to both meet venting requirements during launch and provide sufficient barriers to water vapor mass transfer for water vapor concentrations and total pressures similar to the Mars atmosphere
- Detector could operate at 150 K for six hours before a 140 nm thick film was present on its surface
- Venting requirements for launch could be met with slight modification
- Possible future work:
  - Build a flight-like enclosure with an appropriately-sized HEPA filter and an operating detector
    - Subject the assembly to actual launch pressure decay
    - Repeat tests in this study to measure the effect of ice on the operation of the detector

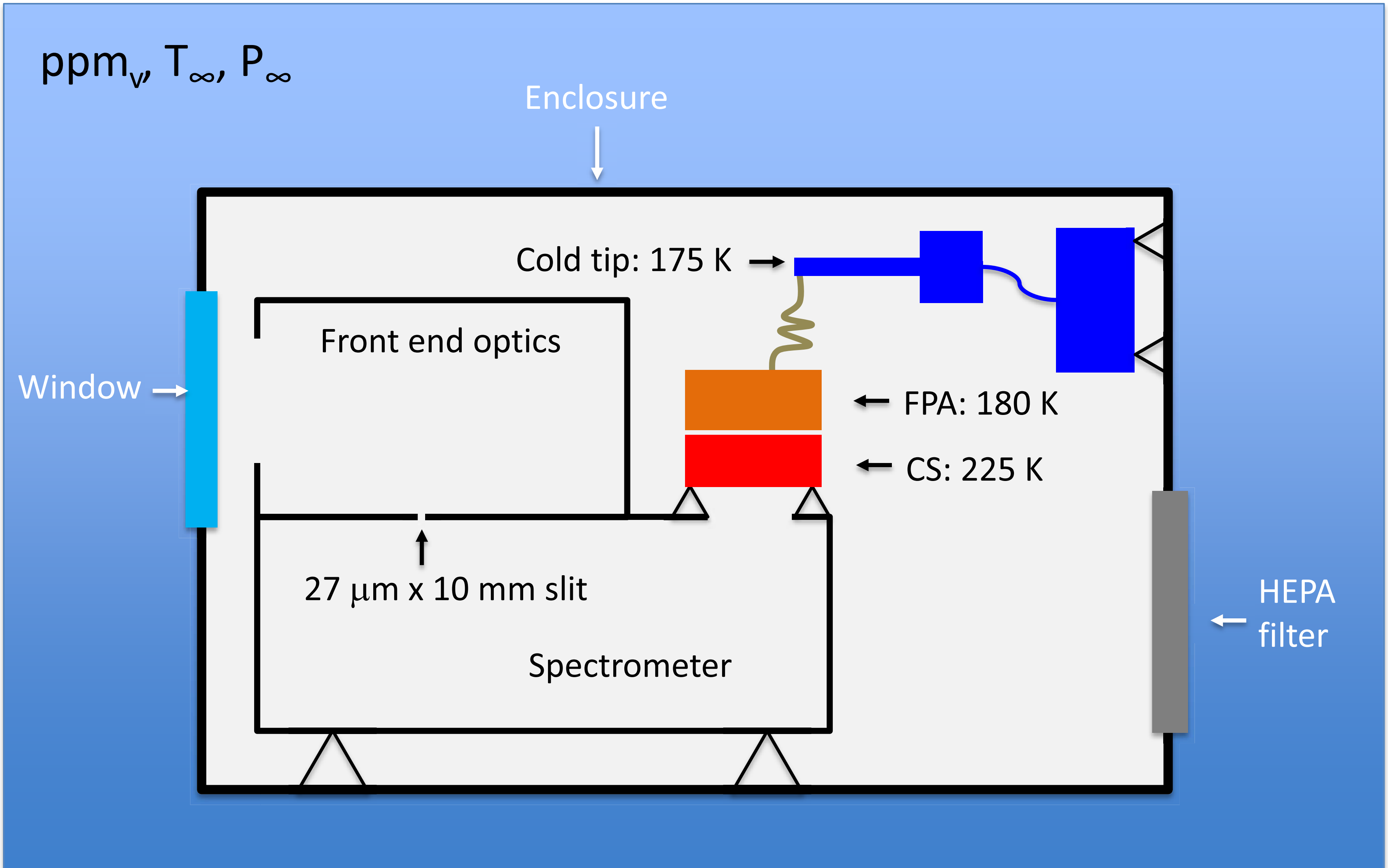
Questions?

THANK YOU FOR YOUR ATTENTION

EXTRA SLIDES

Enclosure geometry

ICES 2015



HEPA filter specs

ICES 2015

http://www.mottcorp.com/resource/pdf/RS_Perm_all.pdf

Media Grade: 0.1 Thickness: 0.039 inches

Material Specifications

Bubble Point, in. of Hg: 7.0 - 9.0
Min Tensile Strength, kpsi: 34.0
Yield Strength, kpsi: 32.0
Young's Modulus, x 10^6 psi: 17.0

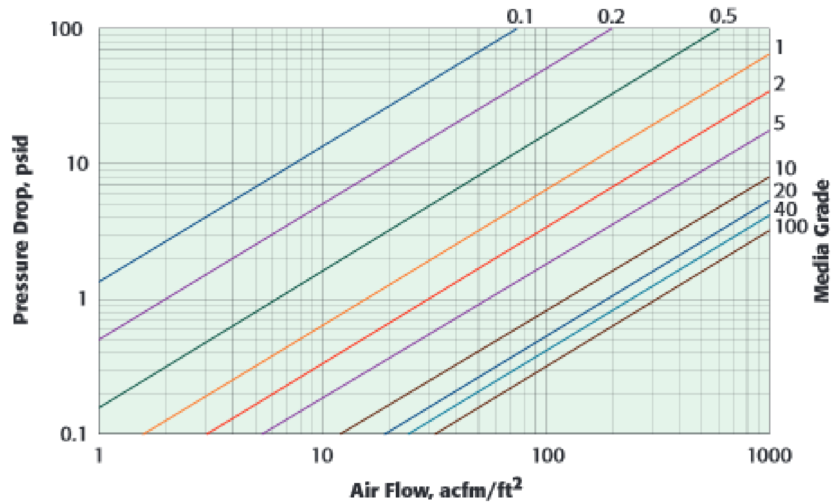
Permeability Coefficient

Liquid, K_L: 270
Gas, K_G: 1900

Liquid: Pressure Drop, psid = (K_L)(Flux, gpm/ft^2)(Visc, cp)(Thck, in.)
Gas: Pressure Drop, psid = (K_G)(Flux, acfm/ft^2)(Visc, cp)(Thck, in.)

Air Flow for Media Grades 0.1 - 100

Note: Rolled sheet samples are of standard thickness



Mott Porous Metal Data Sheet			
Media Grade:	0.2	Issued:	06/22/10
Type:	Rolled Sheet		
Alloy:	316LSS		
Thickness:	0.039 inches		

nover.pdf