Experimental Validation of Molecular Transport Model

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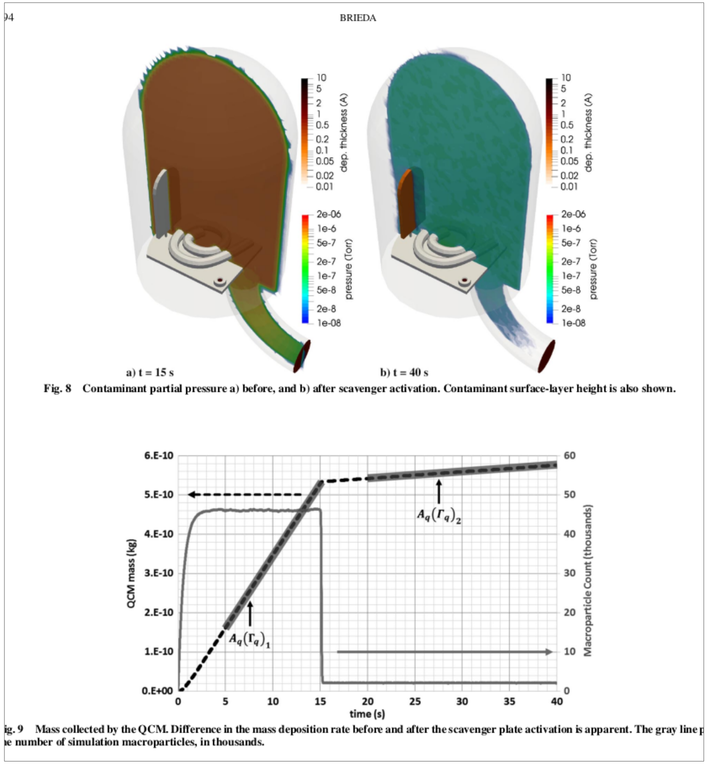
Motivation

- PIC-C developed Contamination Transport Simulation Code (CTSP) is a particle-based computer code for modeling evolution of molecular and particulate contamination (Brieda, L. AIAA JSR, 2018)
  - Supports detailed surface geometry, external forces, inter-molecular collisions, and (currently in development) translating surfaces
  - Used in support of various NASA missions including MMS, GOES-R, TESS, and JWST
- **Question that often comes up: how is the code validated?**
  - **Answer: not as well as we would like! The 2018 paper considered analytical problems and "numerical experiments"**
  - The main issue is the lack of experimental data
  - Data collected at NASA mainly in support of flight projects.
  - Possible export control limitations, but also an overly complex setup. If discrepancy, due to a code bug or failing to account for some piece of MGSE or detailed surface geometry?

Public releasable data with simple experimental set up clearly needed!



Brieda, L. AIAA JSR, 2018

Motivation

- In Spring 2020, had opportunity to join USC as a part-time lecturer in the Astronautics Department to teach scientific computing (and soon, computational plasma physics)

Offered access to a laboratory space!

- Collaborating with my M.Sc. advisor Prof. Joe Wang, and his grad students:
  - **Prof. Joseph Wang:** a professor of astronautics and aerospace & mechanical engineering (ASTE/AME) at USC. Prior to joining USC in 2008, he was a principal staff member at JPL and an aerospace engineering professor at Virginia Tech. Focus on **plasma** and **dust charging** applications.
  - **Elana Helou**: a PhD candidate in ASTE department, research focusing on **triboelectric charging** of **lunar dust** and interaction with space suit materials
  - **Jeff Asher**: a PhD candidate in ASTE, research focusing on experimental testing and numerical analysis of **ionic electrospray thrusters**. Also working as a part-time staff at JHU APL Space Exploration Sector.
  - **Robert Antypas:** former doctoral student focusing on plasma thrusters, currently working at AFRL

Besides offering access to data collection for V&V , this effort also introduces students to the world of contamination control, could lead to a unique program at USC!

USC Department of Astronautical Engineering (ASTE)

From Assoc. Chair, Mike Gruntman, ASTE MS Director

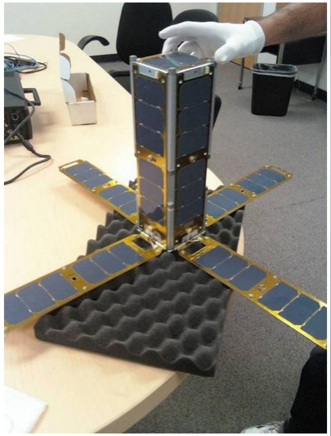
- Unique pure-space-engineering department (established in 2004)
- Built upon astronautical specialization, started in 1995
- Full set of degrees in **Astronautical Engineering (ASTE)**

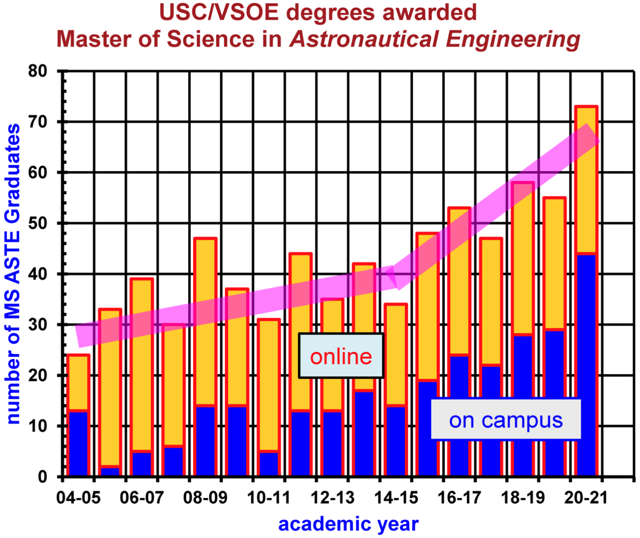
- ❑ Bachelor of Science (BS)
- ❑ Bachelor of Science Minor
- ❑ Master of Science (MS)
- ❑ Engineer
- ❑ PhD
- ❑ Graduate Certificate

MS ASTE degrees awarded annually: 57 during last 5 years

- Among largest national programs in space engineering on Master's level

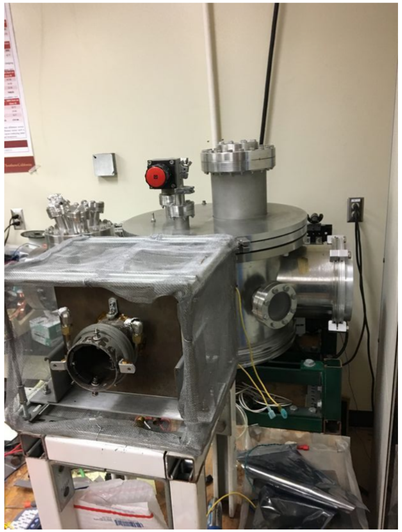
Mission; to provide forefront research and education in astronautical (space) engineering



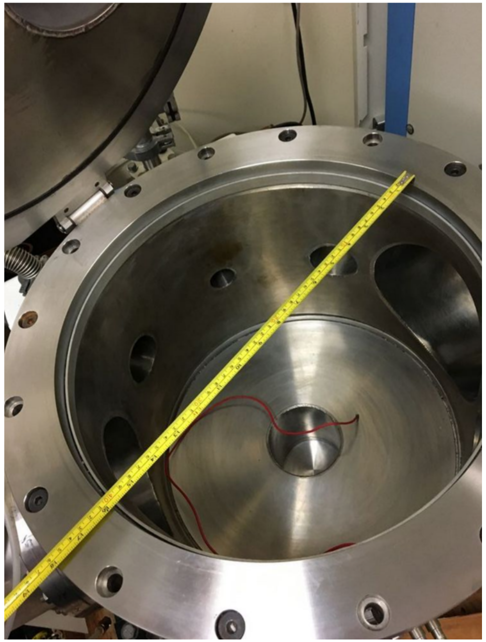


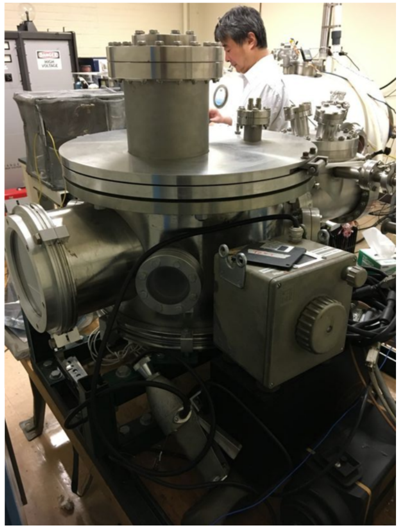
Vacuum Chamber

- The lab contained a small top loader 40 cm diameter vacuum chamber, sitting idle
  - Started working with students to hook up a **roughing pump**, **ion and convectron pressure sensors** and **gauges**, **electrical feed throughs**, **power supply**
  - Spent much time cleaning the chamber, chamber previously used for arc discharge cathode erosion research, various metallic fragments



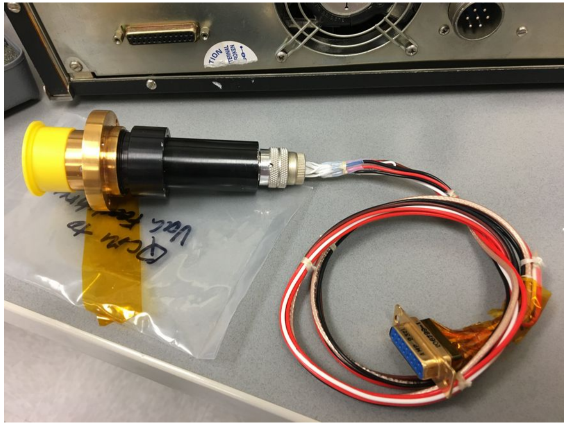
This talk summarizes on-going effort to build up a contamination transport facility.
Testing generally limited to about 6 hours per week due to limited on-site time.

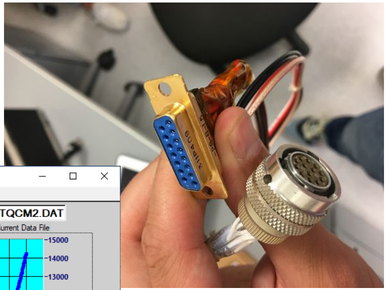


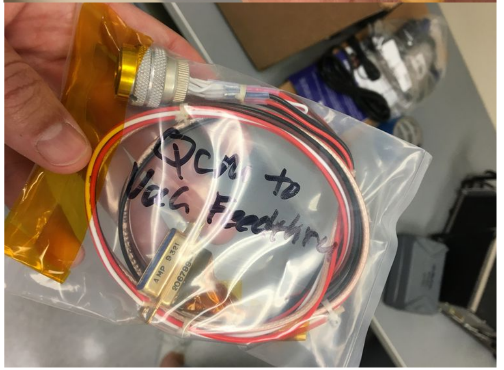


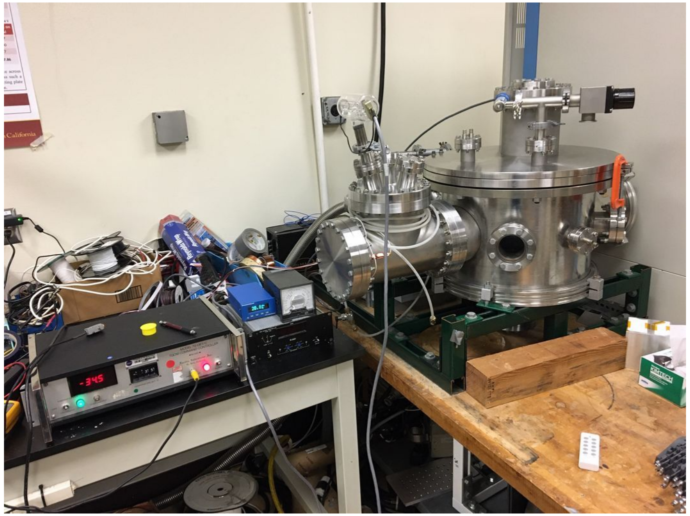
Faraday QCM

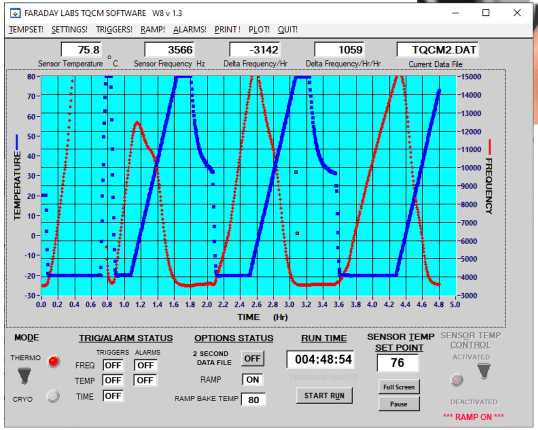
- NASA GSFC loaned a Faraday TQCM along with the controller
- **Install in the chamber significantly delayed by COVID shutdown**
- Post shutdown, spent months looking for options to connect the QCM as QCM to chamber harness not found, only to reappear on its own later
- Finally in May 2021 got the first QCM "sign of life" under vacuum, but then no testing over summer break





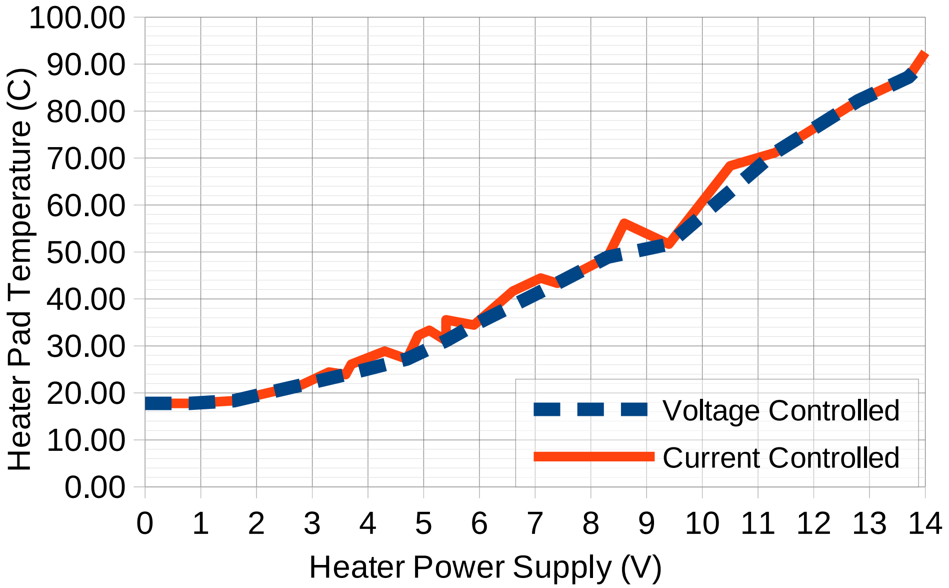


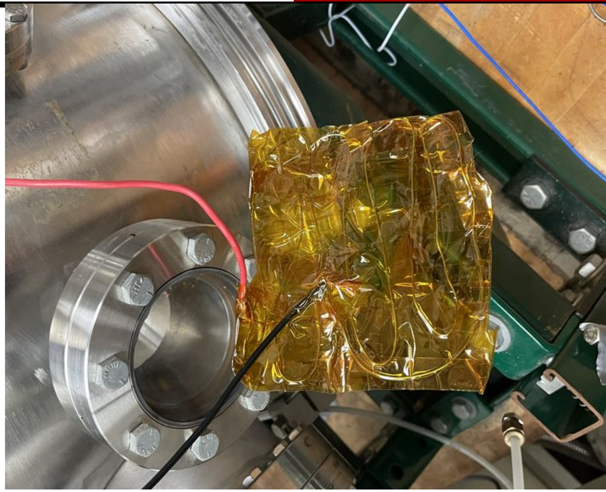


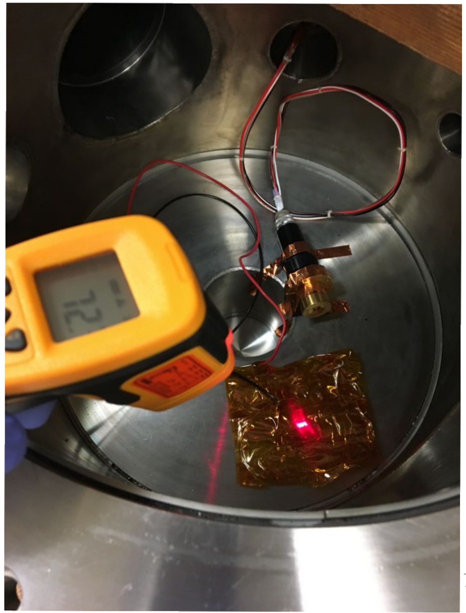


Heater Calibration

- Constructed a heater pad using Nickel Chromium wire and Kapton tape
- At the moment, chamber not instrumented with thermocouples, used a hand-held IR thermometer to create a calibration curve against power supply input voltage
- Calibration performed at atmospheric conditions, possibly underpredicting test values due to lack of convective cooling under vacuum

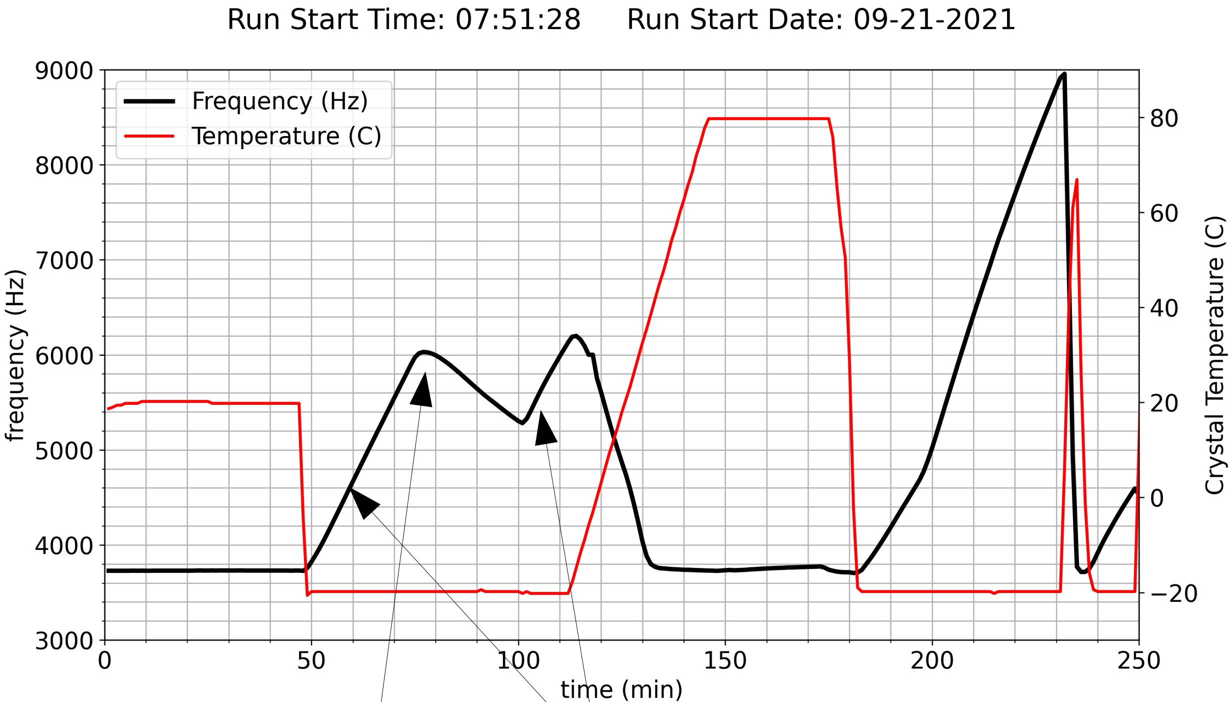


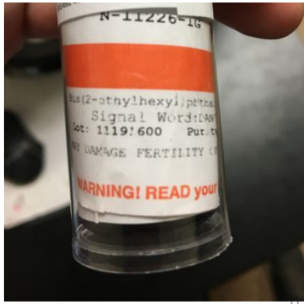




Initial Chamber Characterization

- Figure on right shows QCM data from 9/21 collection
  - Attempted to utilize dioctyl phthalate as a source, John Canham suggestion
  - Difficult to work with due to high viscosity, not obvious how to apply
  - Subsequently used a wire bundle
- Utilizing an **oil-based diffusion roughing pump**, 5.5e-3 Torr pressure, ~3500 Hz baseline QCM rate
- Furthermore, high background contamination load
- Background pressure can be accounted for numerically using schemes such as **DSMC**, but the high contamination loading suggests signal will be lost to noise.





Roughing pump oil clearly affecting QCM collection

Initial Chamber Characterization

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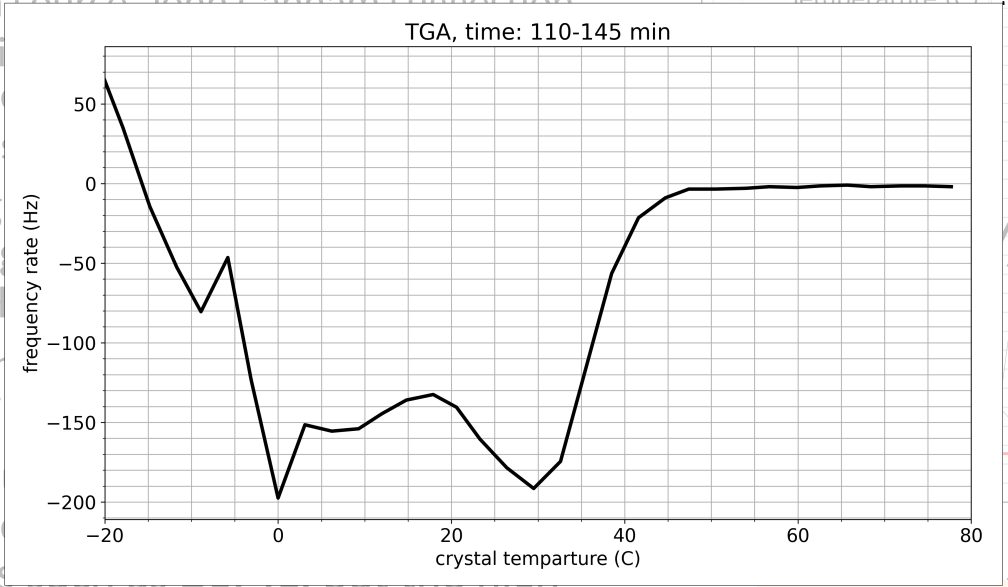
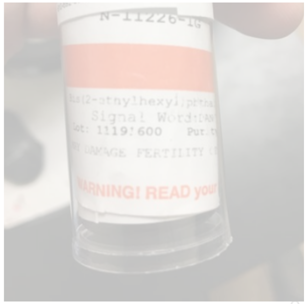
  - Subs…
- Utilizing … **roughing** … ~3500 H…
- Furtherm… contami…
- Backgro… account… schemes such as DCAS, but the high contamination loading suggests signal will be lost to noise.

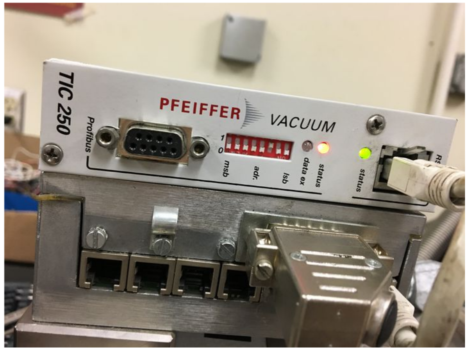


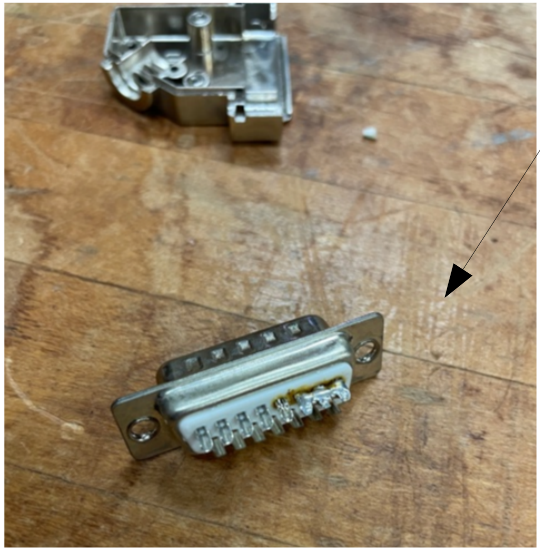


Roughing pump oil clearly affecting QCM collection

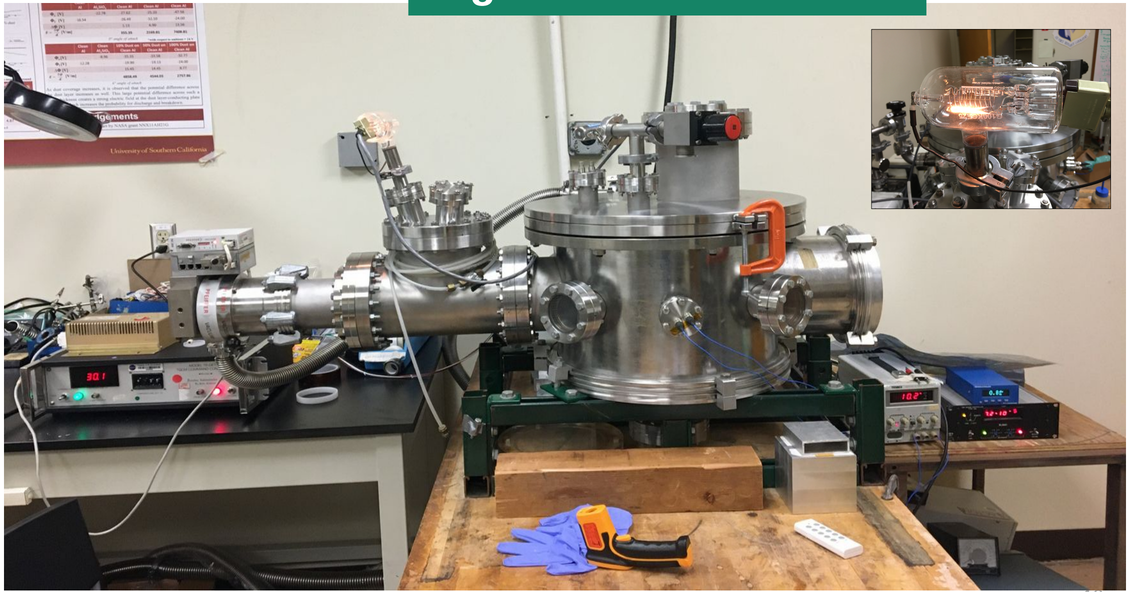
Turbo Pump

- Sourced an used turbo pump off E-Bay
- Required a reducer fitting, long back order from Kurt Lesker, finally arrived 10/7/21
- Turbo subsequently installed, would not turn on.
  - Finally tracked down to a provided connector that apparently is supposed to connect to another controller unit, but in the absence, can be bypassed by bridging pins 2,3,4 to pin 1. Solder missing across pin 4.
  - Only about 15 minutes to pump down to high O(-5) Torr



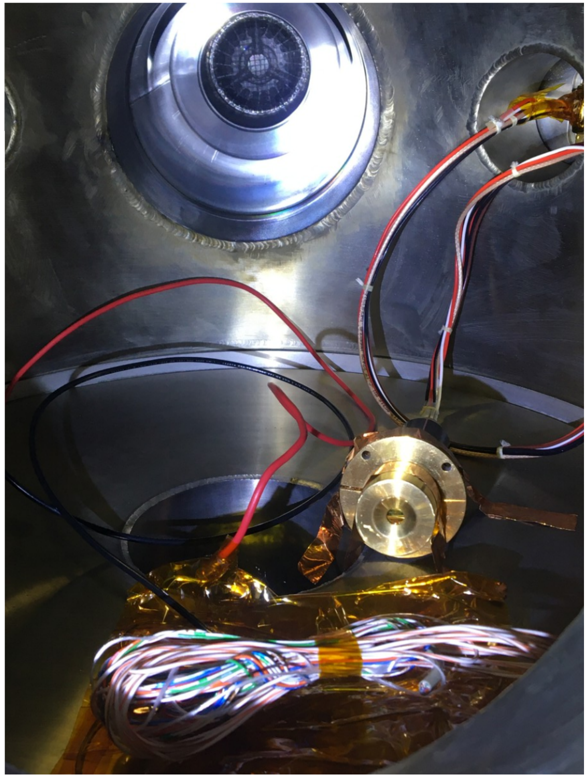


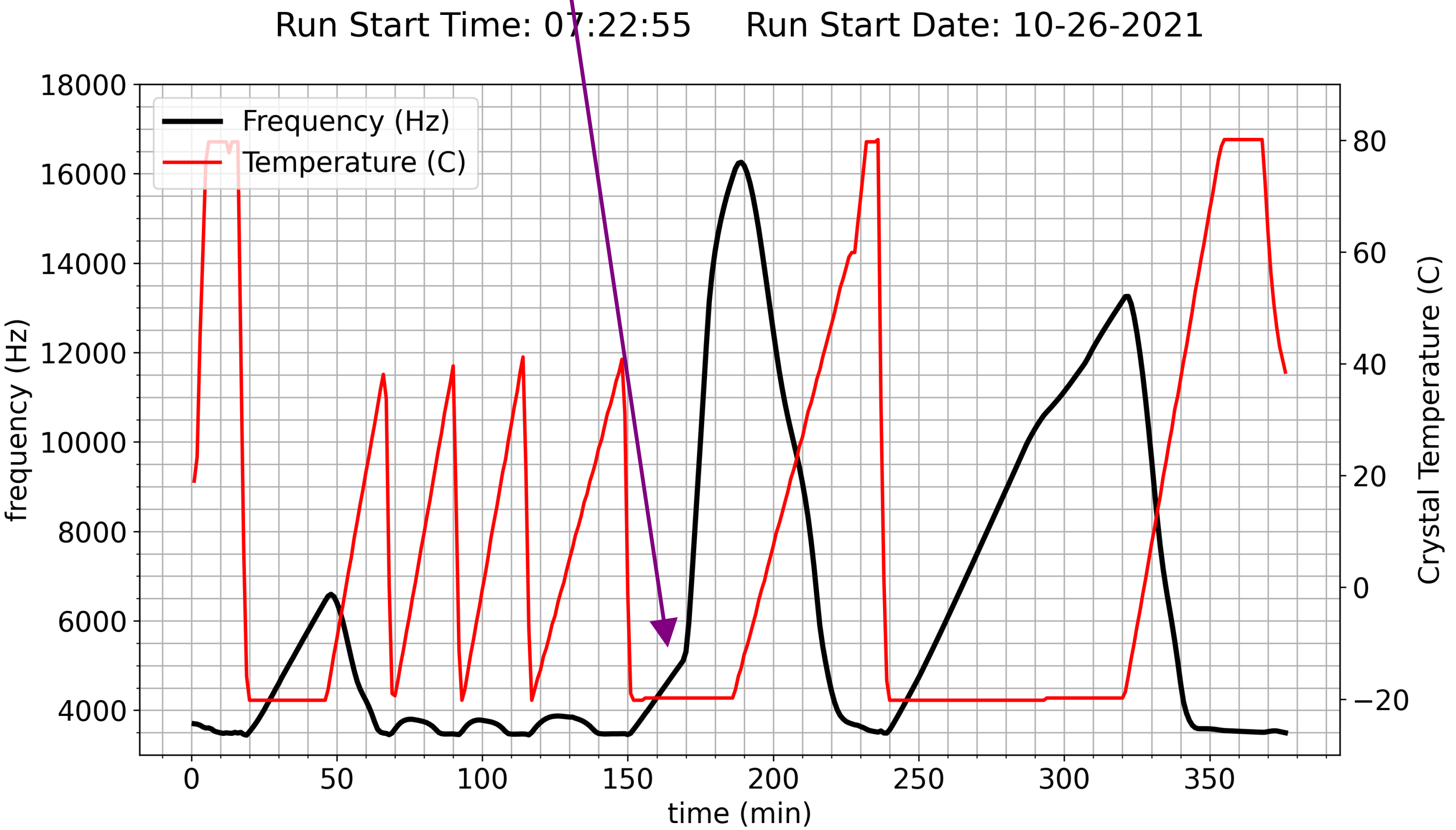
High vac on 10/26/2021!



QCM Looking at Sample

- First set of experiments considered QCM looking at a wire bundle source
- Performed series of measurements involving chamber repress and pump down to demonstrate **repeatability**
- Can clearly observe increase in outgassing with heater activation (10 V)





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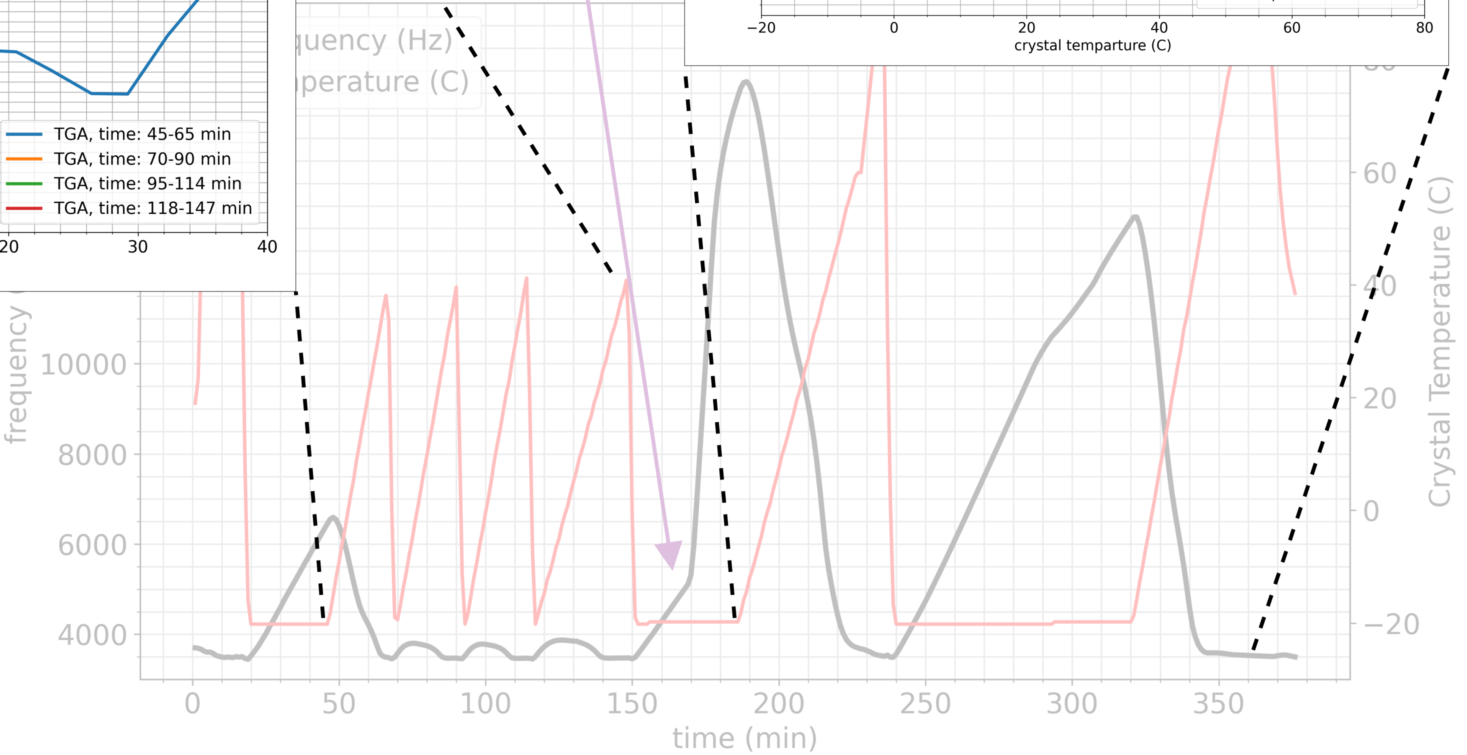
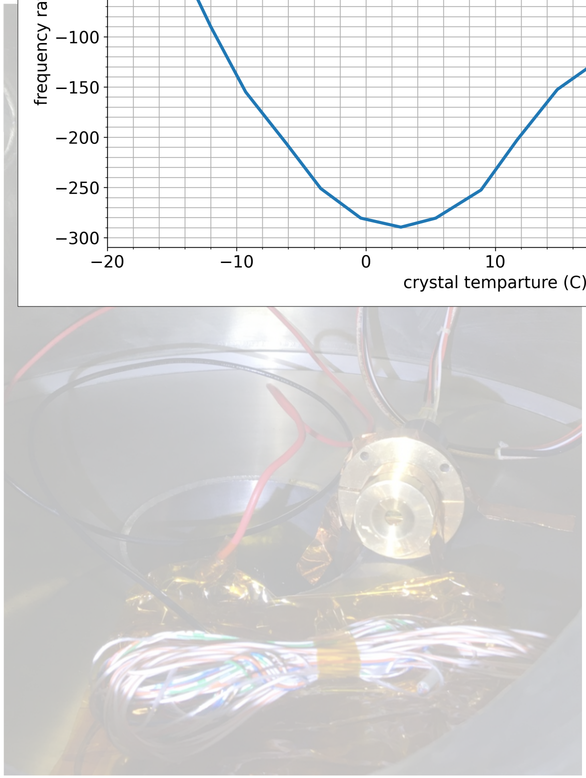
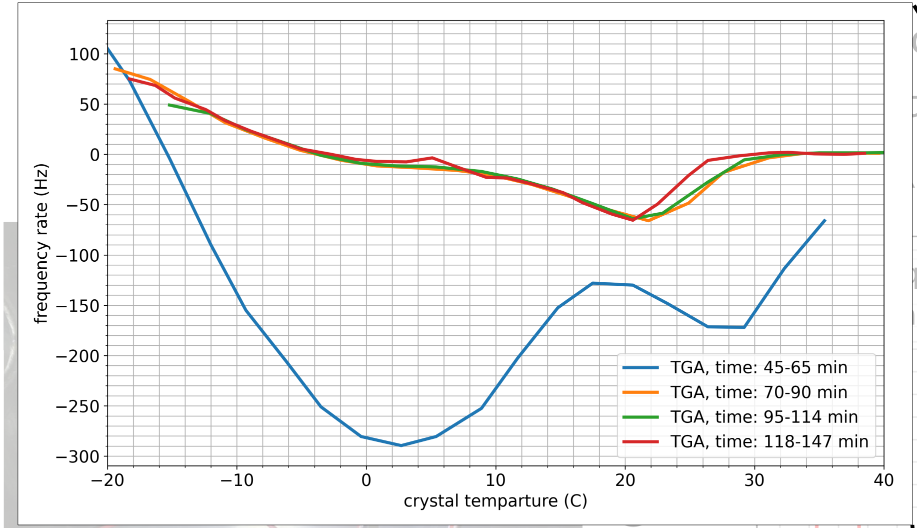
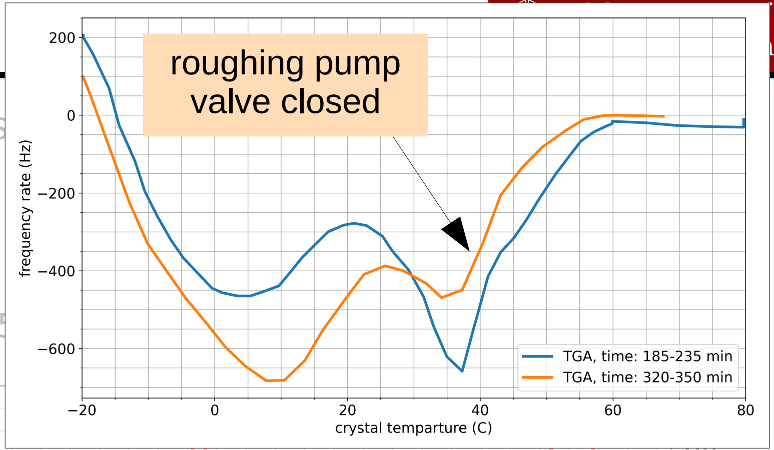
chamber repress and
th heater activation
un Start Time: 07:22:55



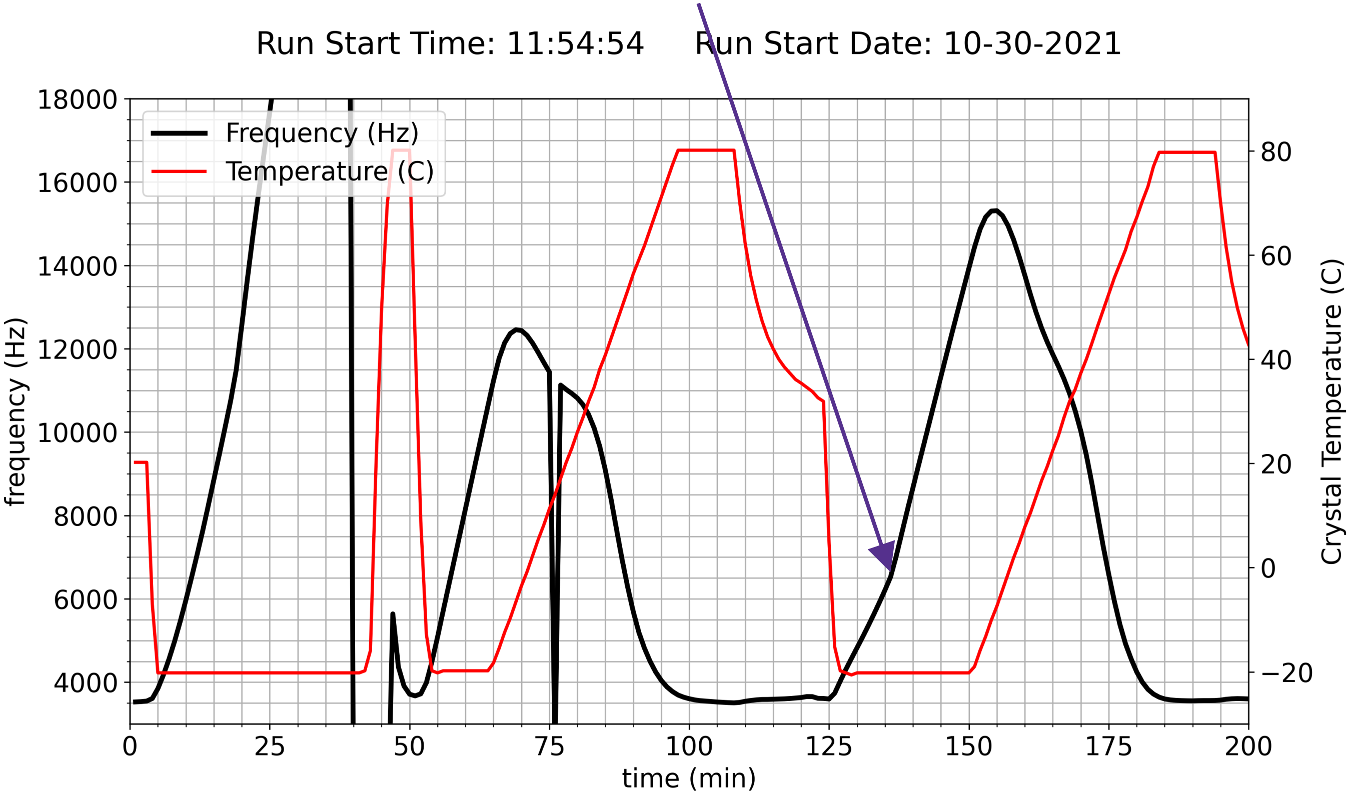






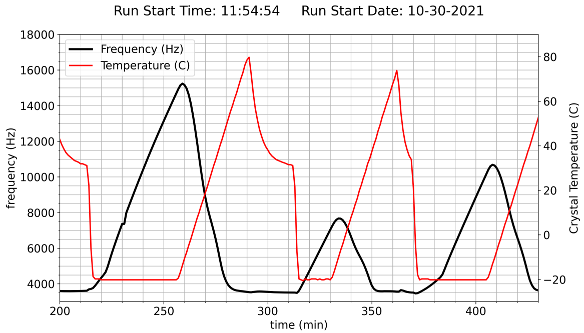
Chamber Background

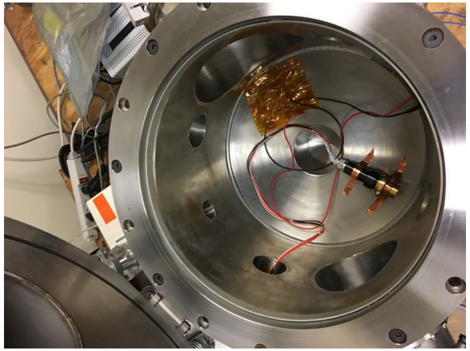
- Subsequently removed test harness and performed similar set of pump downs
- Observing reduced increase in outgassing rate with heater activation
- Increased deposition at lower pressures / with turbo pump activated

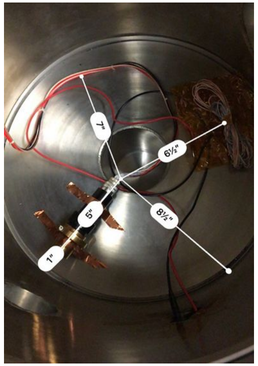


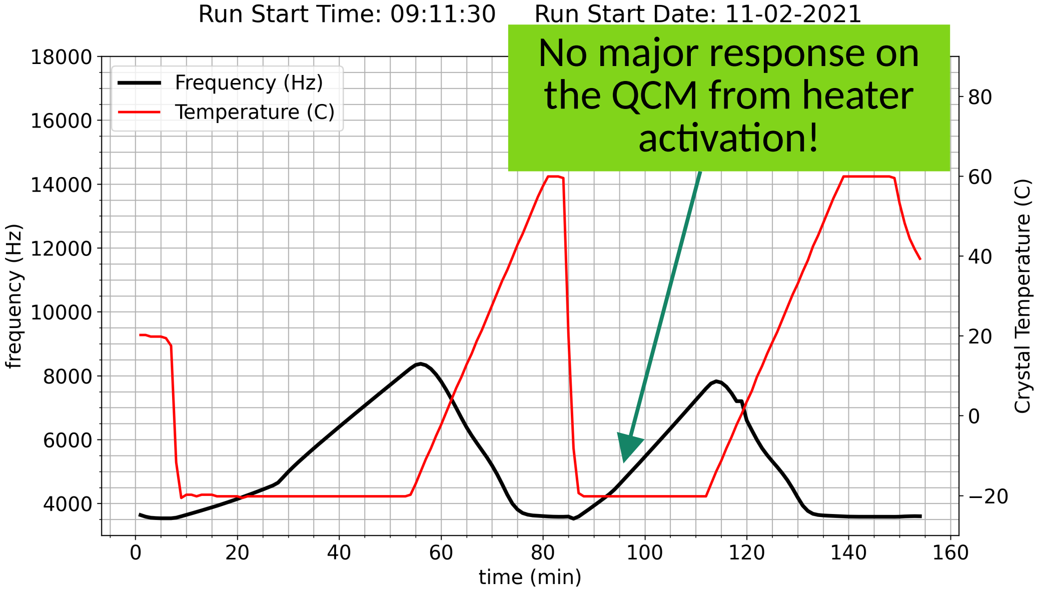
Facing Wall

- Next performed two experiments with QCM facing the wall with and without the wire bundle
- Goal is to simulate line-of-sight vs. outside line-of-sight configurations
- Future work may include baffles or bakeout boxes









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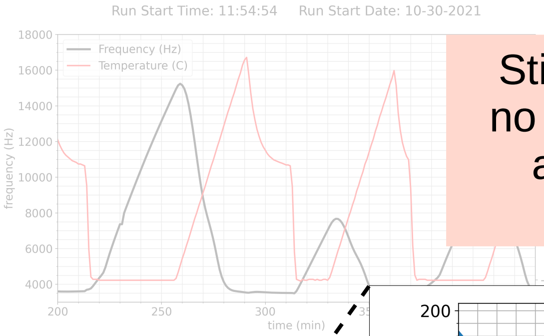
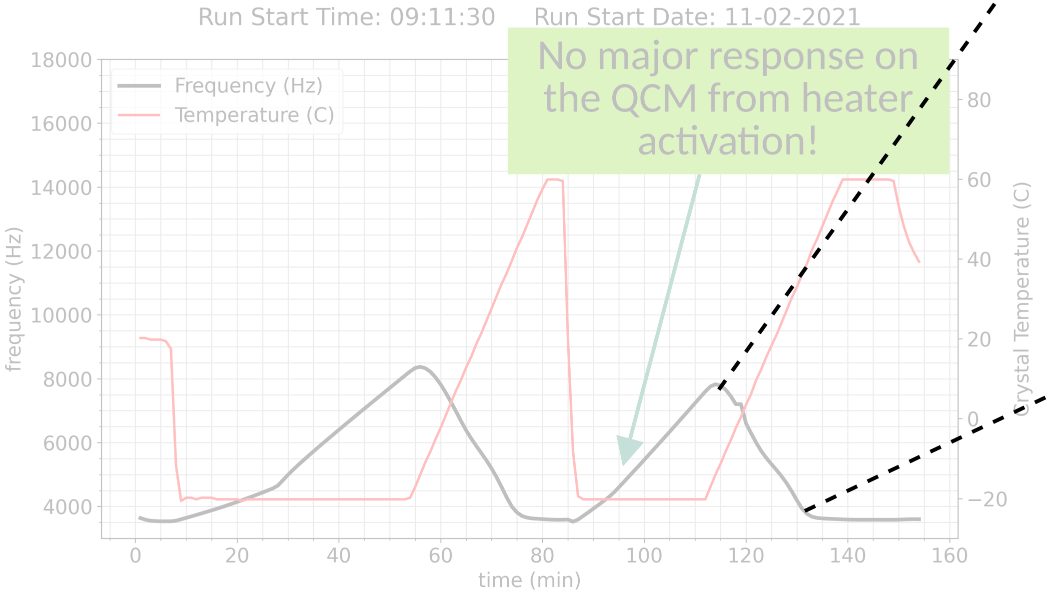
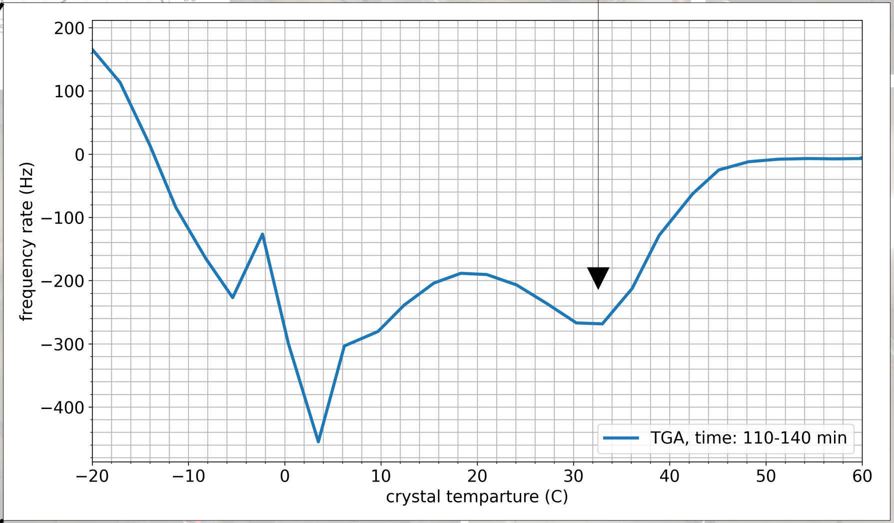
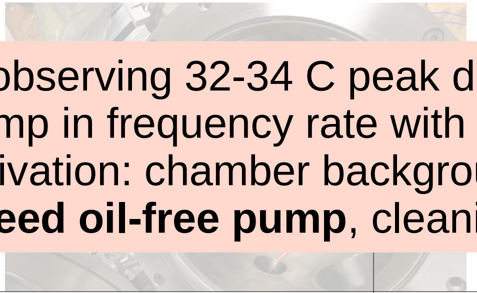


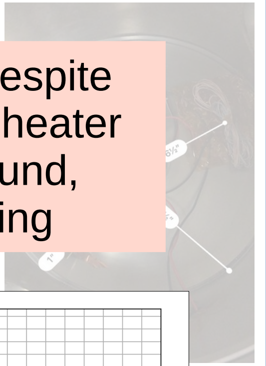
Still observing 32-34 C peak despite no jump in frequency rate with heater activation: chamber background, **need oil-free pump**, cleaning

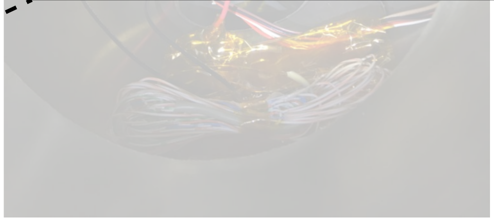


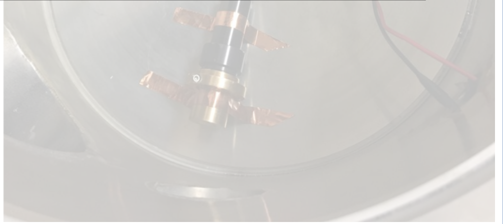
No major response on the QCM from heater activation!





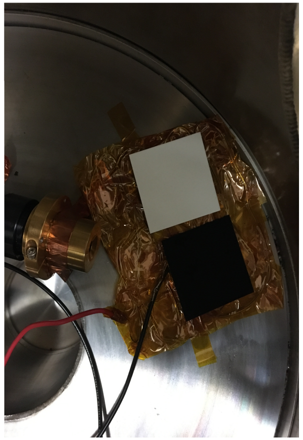


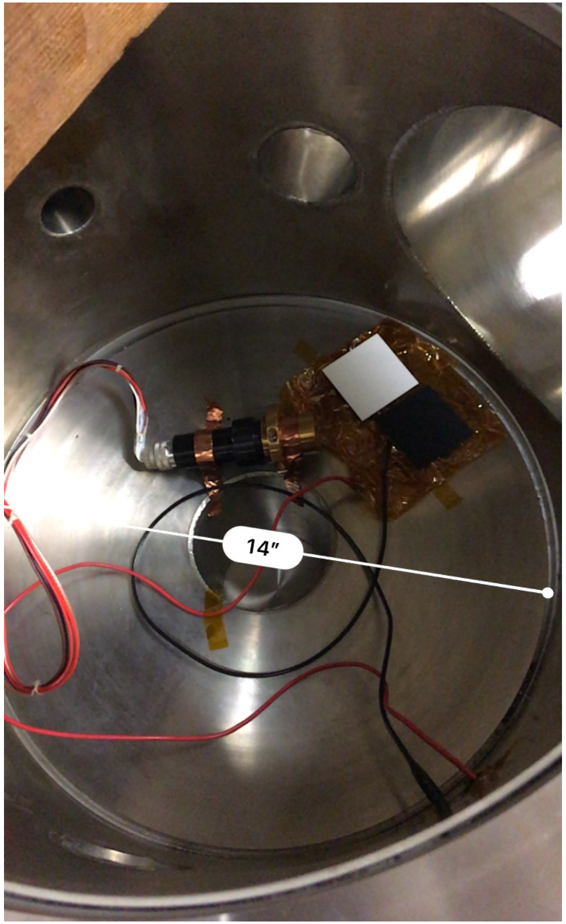


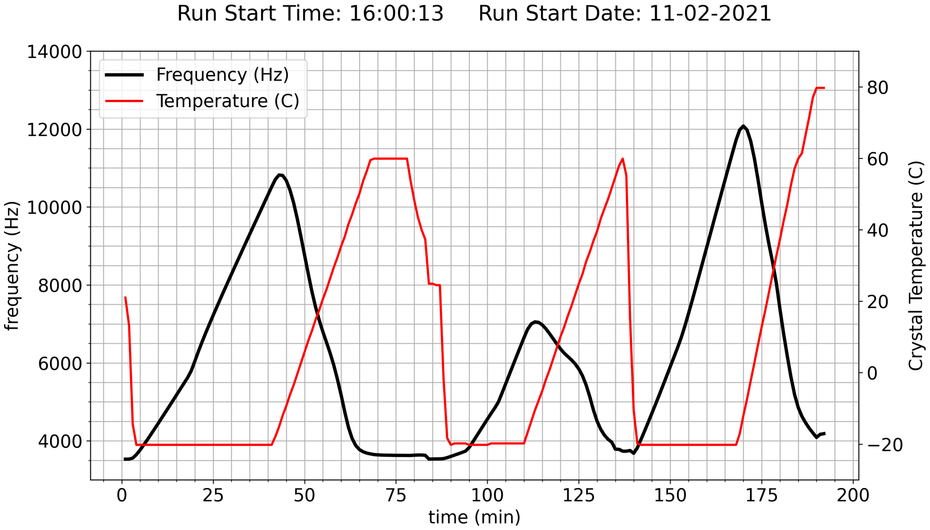


Additional Testing with GSFC provided samples

- Obtained samples from Goddard and Aerothreads, including Z307 black paint, Z93 white paint, MLI with built-in vents
- Analysis still pending
- Future work will also consider the use of a high voltage power supply to study possible arcing or charging of outgassed materials and / or electrostatic transport

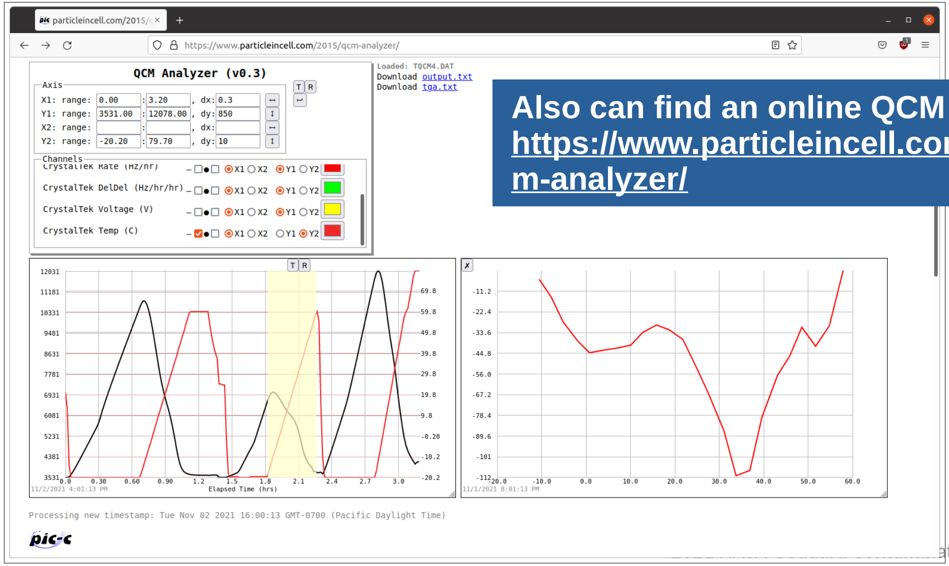




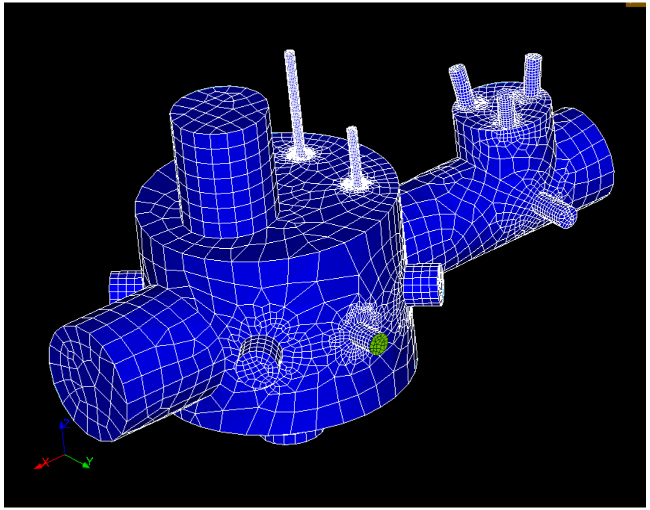


Numerical Study

- **Observed data to be used for code validation**
- Generated detailed surface mesh of the chamber, analysis still pending
  - Simulation will consider a model of the wire bundle, along with the QCM crystal
  - Will utilize temporal variation of QCM crystal temperature to predict time-dependent sticking, with TGA data used to set sticking coefficients
  - DSMC will be used to model rarefied gas flow environment achieved without the turbo pump
- **Data Availability**
  - Data and simulation input files uploaded to https://www.particleincell.com/2021/usc-outgassing

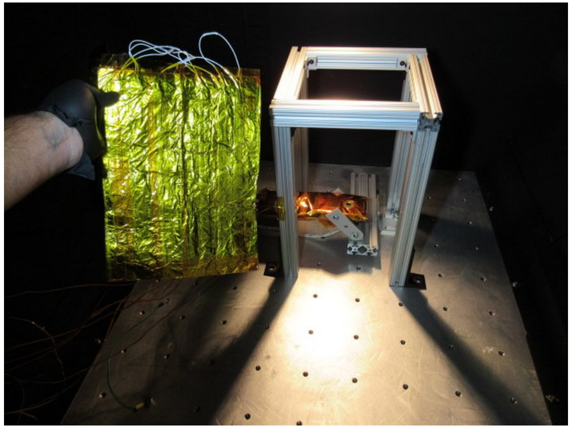


Also can find an online QCM analyzer, https://www.particleincell.com/2015/qcm-analyzer/



Summary and Future Work

- In final stages of building up a small vacuum facility at USC Dept. of Astronautical Engineering for rarefied gas / contamination transport basic science research studies
  - Rapid pump down, about 10 minutes to reach O(-5) Torr
  - Secondary goal is to introduce USC ASTE student population to spacecraft TVAC testing and contamination control practices



- GSFC provided QCM used to characterize outgassing with and without a turbo pump, comparison with preliminary simulations
- Future work: **clean chamber**, replace roughing pump with an **oil-free** variant, install **RGA**, install **thermocuples**, install **high-voltage power supply** for charging/plasma discharge studies, complete parallel study using an external partner **TVAC chamber**
- Looking for collaboration opportunities!
  - Contact: *lubos.brieda@particleincell.com*, *brieda@usc.edu*

- Acknowledgements:
  - George Meadows at NASA/GSFC for providing the QCM and offering useful practical information; GSFC JWST CC team (Eve Woolridge, Kelly Henderson, Mike Woronowicz) for facilitating the equipment loan, Alfred Wong and Aleks Bogunovic for providing material samples, John Canham and Rob Studer for providing practical information on sample source materials