# Characterizing the Outgassing of Electronegative Impurities for nEXO

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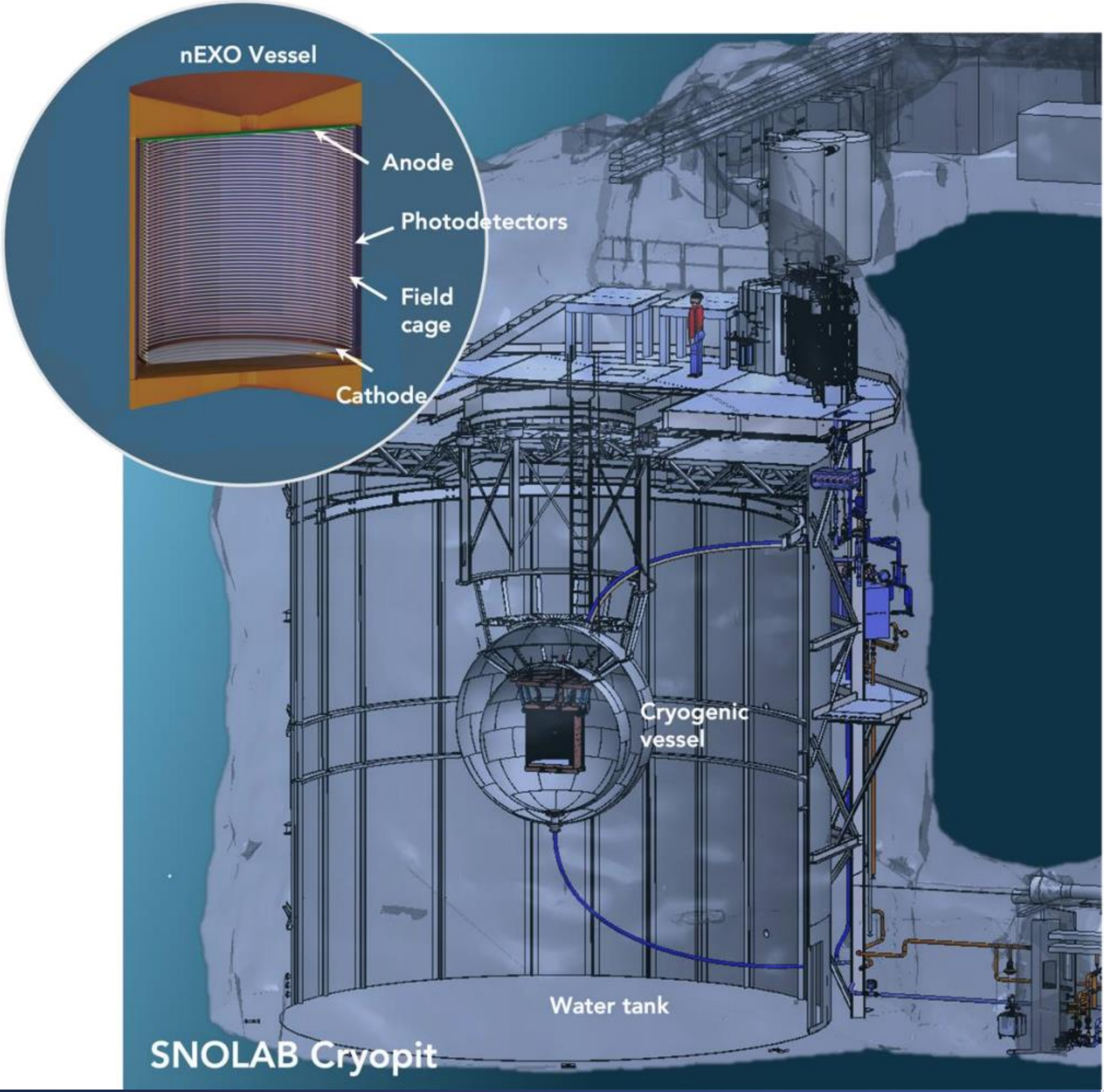
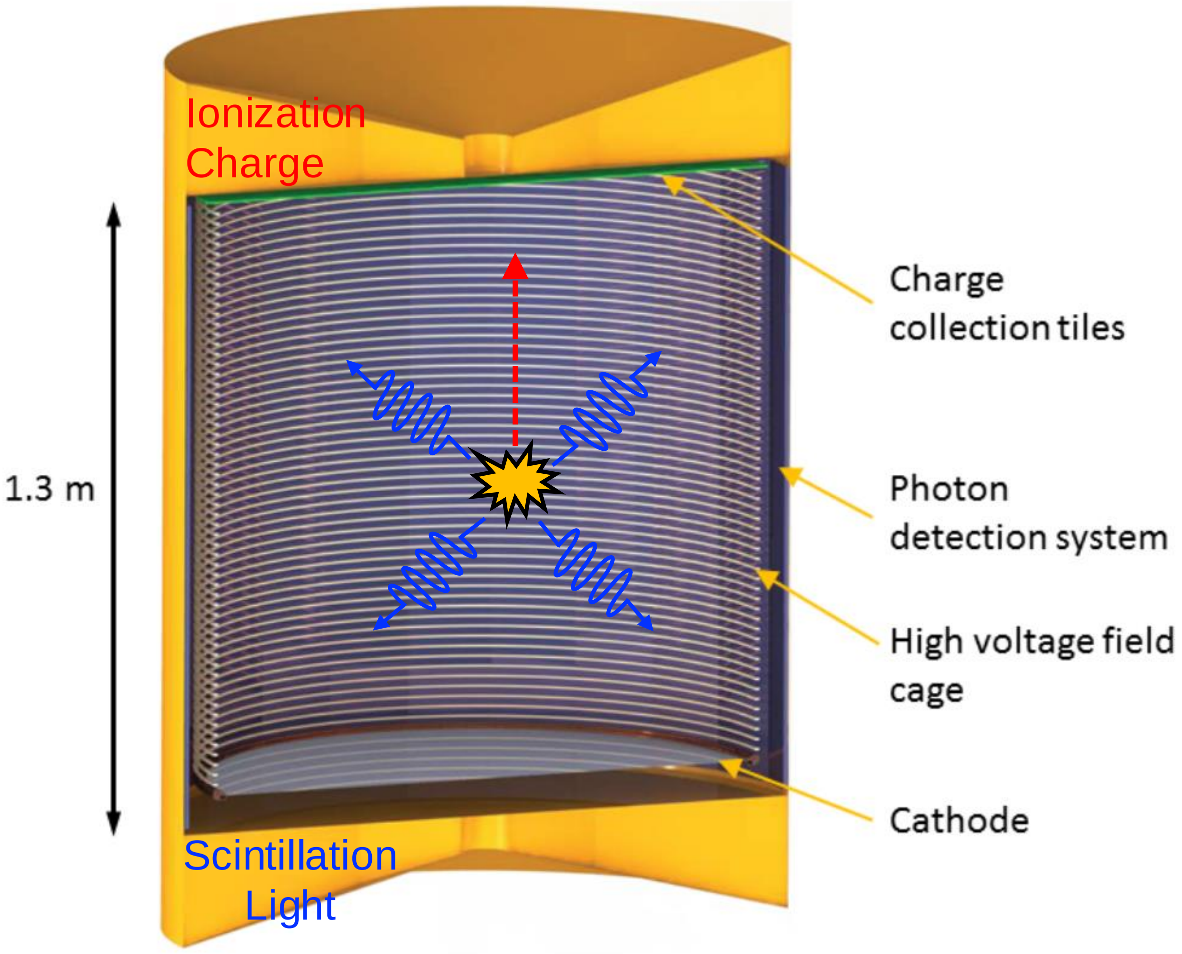
# nEXO Overview

- Single Phase Time Projection Chamber (TPC)
- 5000 kg of liquid xenon enriched to 90% $^{136}Xe$
- Single drift volume with a 1.3 m drift length
- ~ 6000 mwe overburden (SNOLAB)
- Active water Cherenkov veto outer detector
- Projected Sensitivity: $1.35 \times 10^{28}$ yr at 90% CL



# Signal in nEXO




Scintillation light detected with 7,680 Silicon Photomultiplier channels around the barrel

Ionization electrons drift to the top of the detector to the anode plane

# Electronegative Impurity Screening

Materials in nEXO that come into contact with the Xe must outgas as little electronegative impurities as possible

If there are too many electronegative impurities, the electron lifetime will degrade

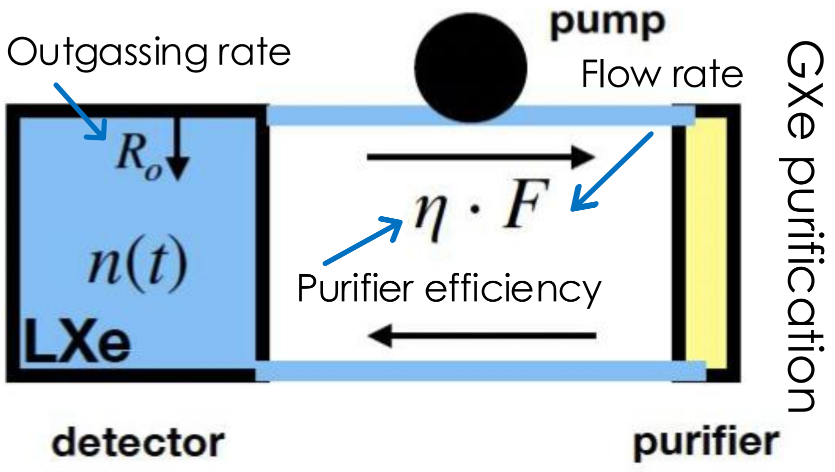
- nEXO's goal lifetime: 10 ms (50 ppt $O_2$ equivalent)
- nEXO's goal outgassing rate: $1.1 \times 10^{-6} \times H \times (F/350$ SLPM) mbar L/s

SL: standard liters of $O_2$ equivalent
$H$: Henry coefficient of LXe/GXe of $O_2$
$F$: detector flow rate

Four main areas to measure:

- Materials in contact with LXe at 170 K
- Materials in contact with GXe at room temperature
- Purifier efficiency
- Leaks to air

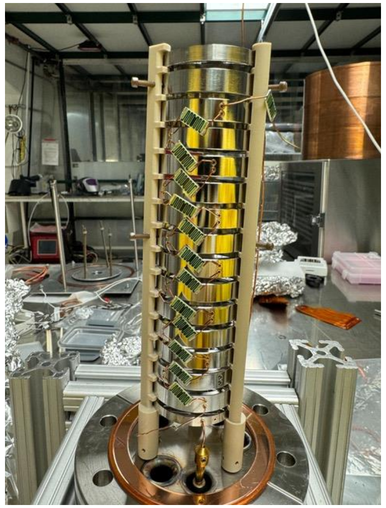
Assumption:
$O_2$ the dominant source of impurity
$O_2$ present in the GXe that gets purified



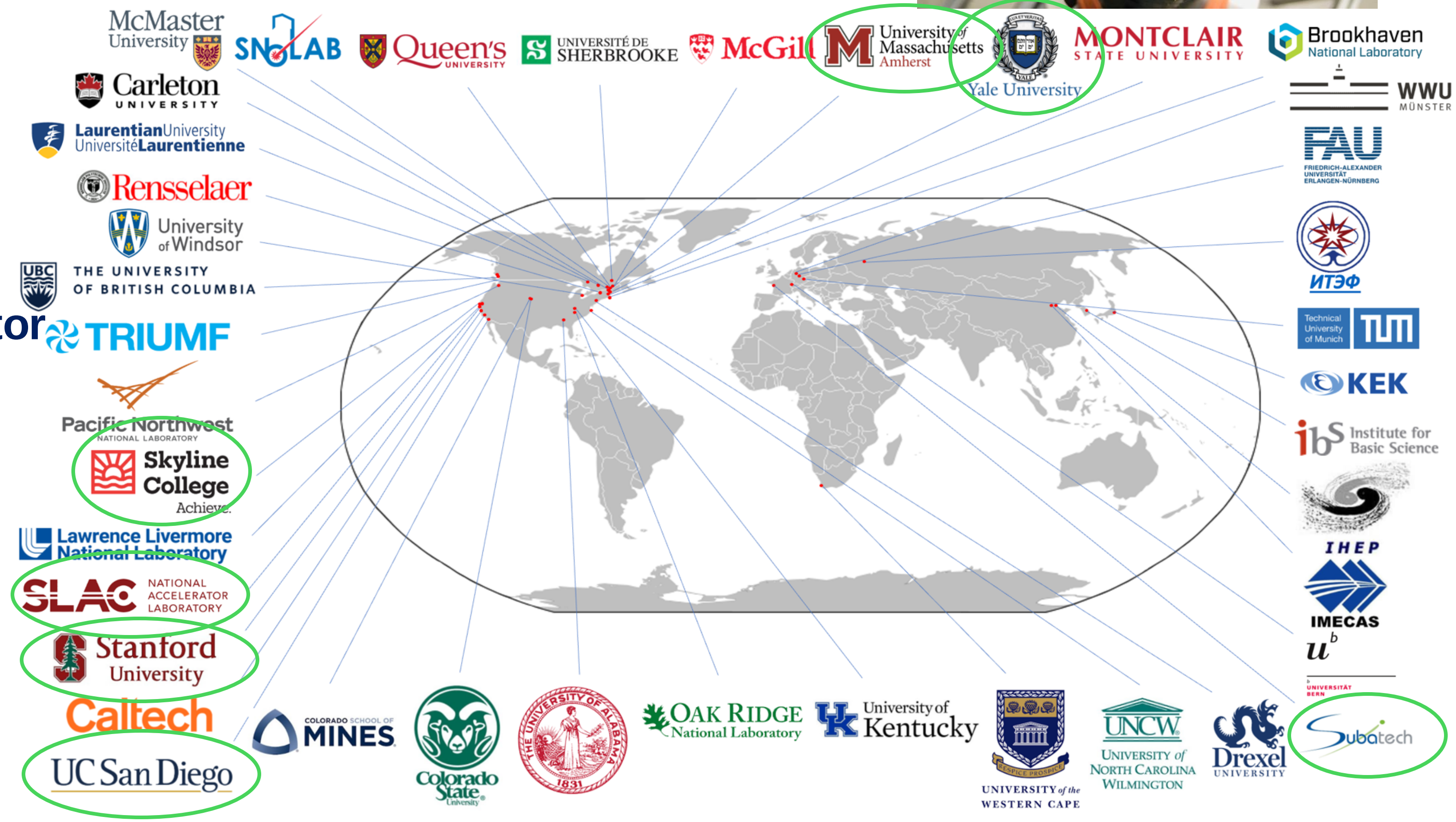
# Electronegativity Subgroup

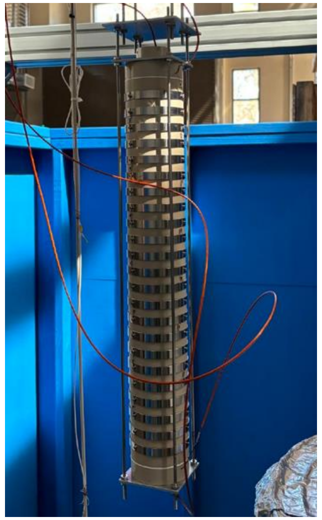
nEXO

SLAC Purity Monitor



Stanford Purity Monitor

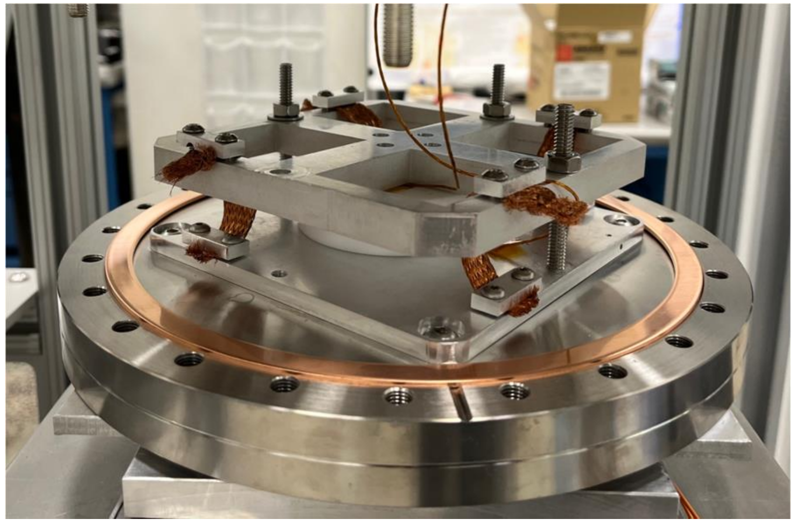


UCSD Purity Monitor

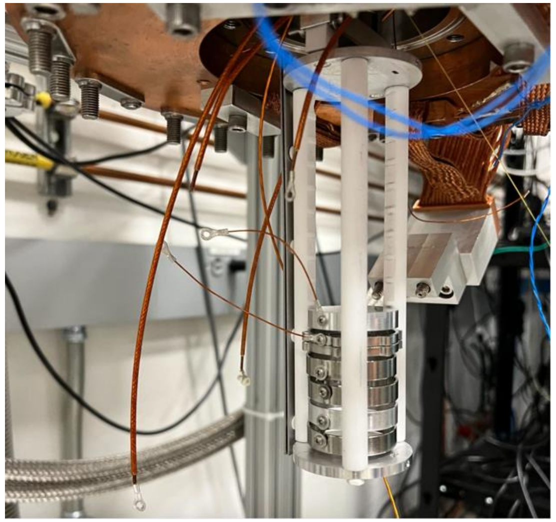
# Electronegativity Measurements at Yale

## Yale Outgassing Setup



Test samples in vacuum at warm temperatures
Measure outgassing rate with RGA while system warms

## Yale Purity Monitor



Test samples in LXe
Measure electron drift
Measure outgassing rate with RGA while system cools

# Outgassing Measurements

We have run a campaign of measurements in the outgassing setup of common samples used in LXe detectors

- Record measurements of sample temperature and partial pressure from 20C - 60C

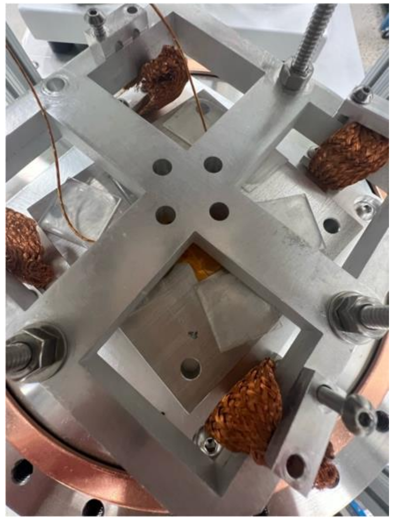
Samples measured:

- PTFE
- Masterbond EP29LPSP Epoxy tiles from Stanford (E. Angelico)
- VESPEL

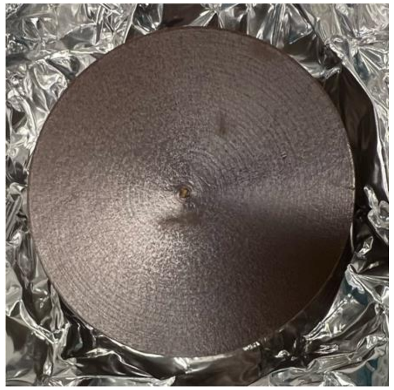
Goal: Try to successfully predict the effect these samples will have on LXe purity using vacuum data only

PTFE

Epoxy



VESPEL



# Vacuum Outgassing Model

After initial pumping, the outgassing rate of a particular gas follows the diffusion equation:

Gas Concentration

$$J = D(T)\left(\frac{\partial c(x,t)}{\partial x}\right)_{x=0}$$

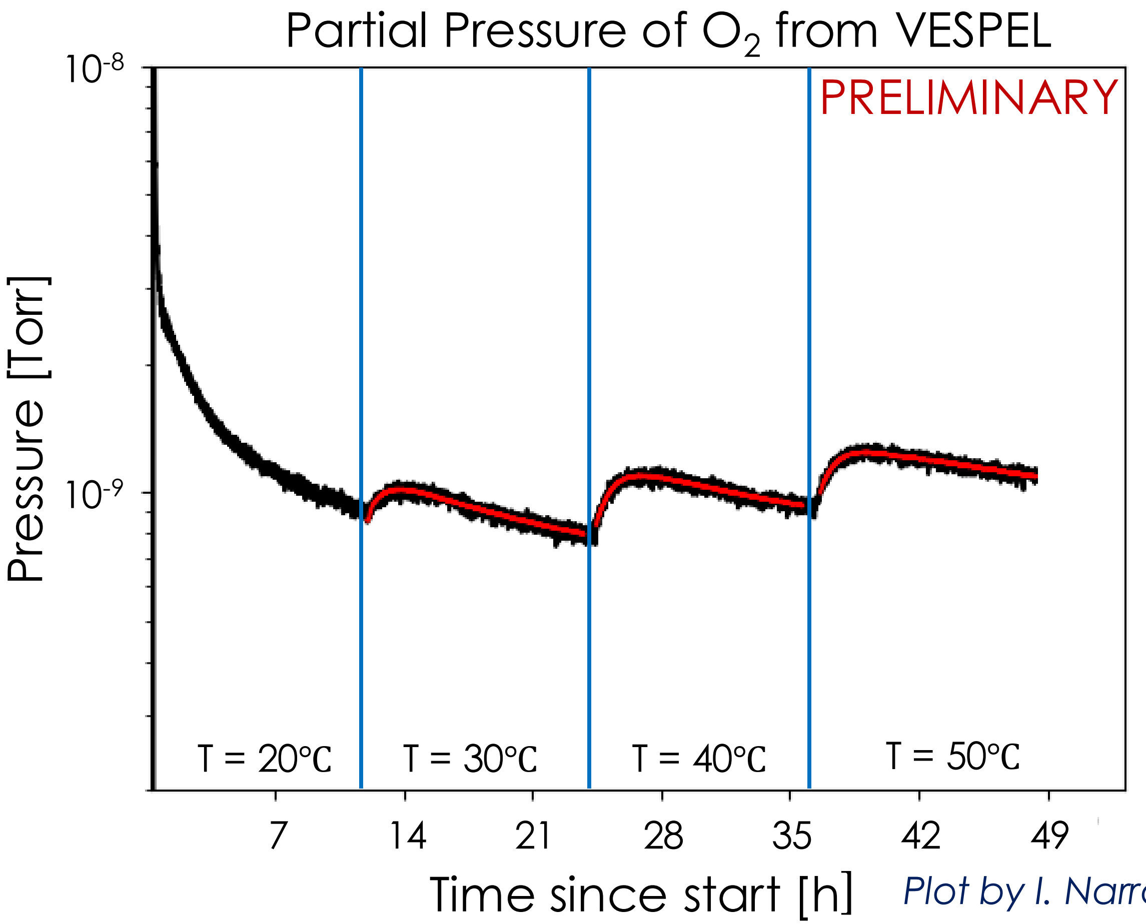
Diffusion Constant

Activation Energy

$$D(T) = D_0 \cdot e^{-\frac{E_a}{k_B T}}$$

Extract material properties, $E_a$ and $D_0$ by fitting the data to the model

Test the hypothesis that $D_0$ and $E_a$ are predictive of the behavior in LXe conditions



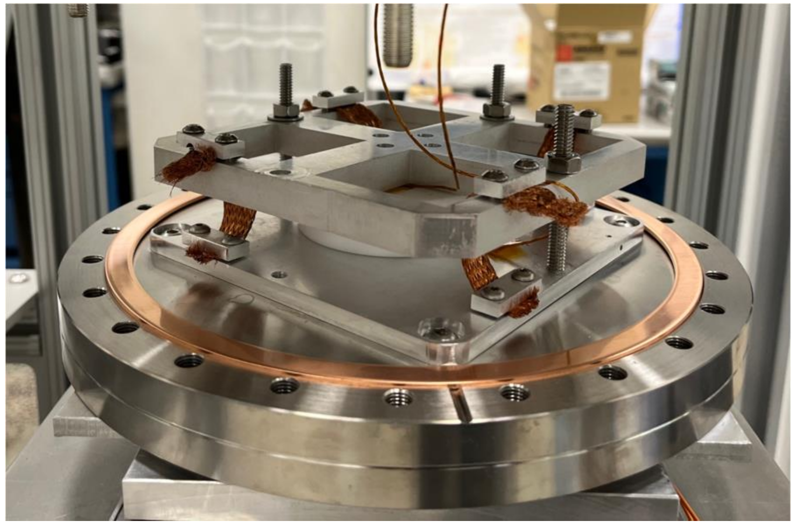

*Plot by I. Narra*

Short timescale approximation: $J = c_0\sqrt{\frac{D}{t}}$

# Electronegativity Measurements at Yale

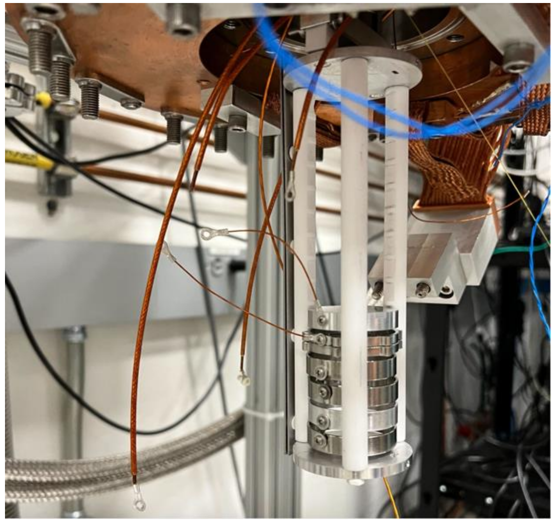
nEXO

## Yale Outgassing Setup



Test samples in vacuum at warm temperatures
Measure outgassing rate with RGA while system warms

## Yale Purity Monitor



Test samples in LXe
Measure electron drift
Measure outgassing rate with RGA while system cools

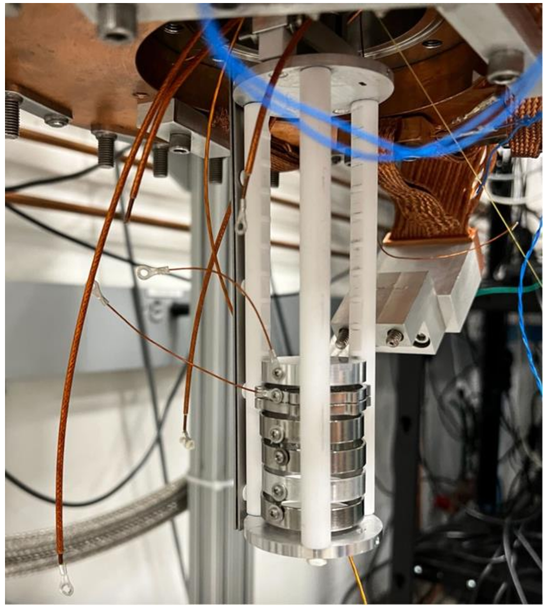
# Yale Purity Monitor

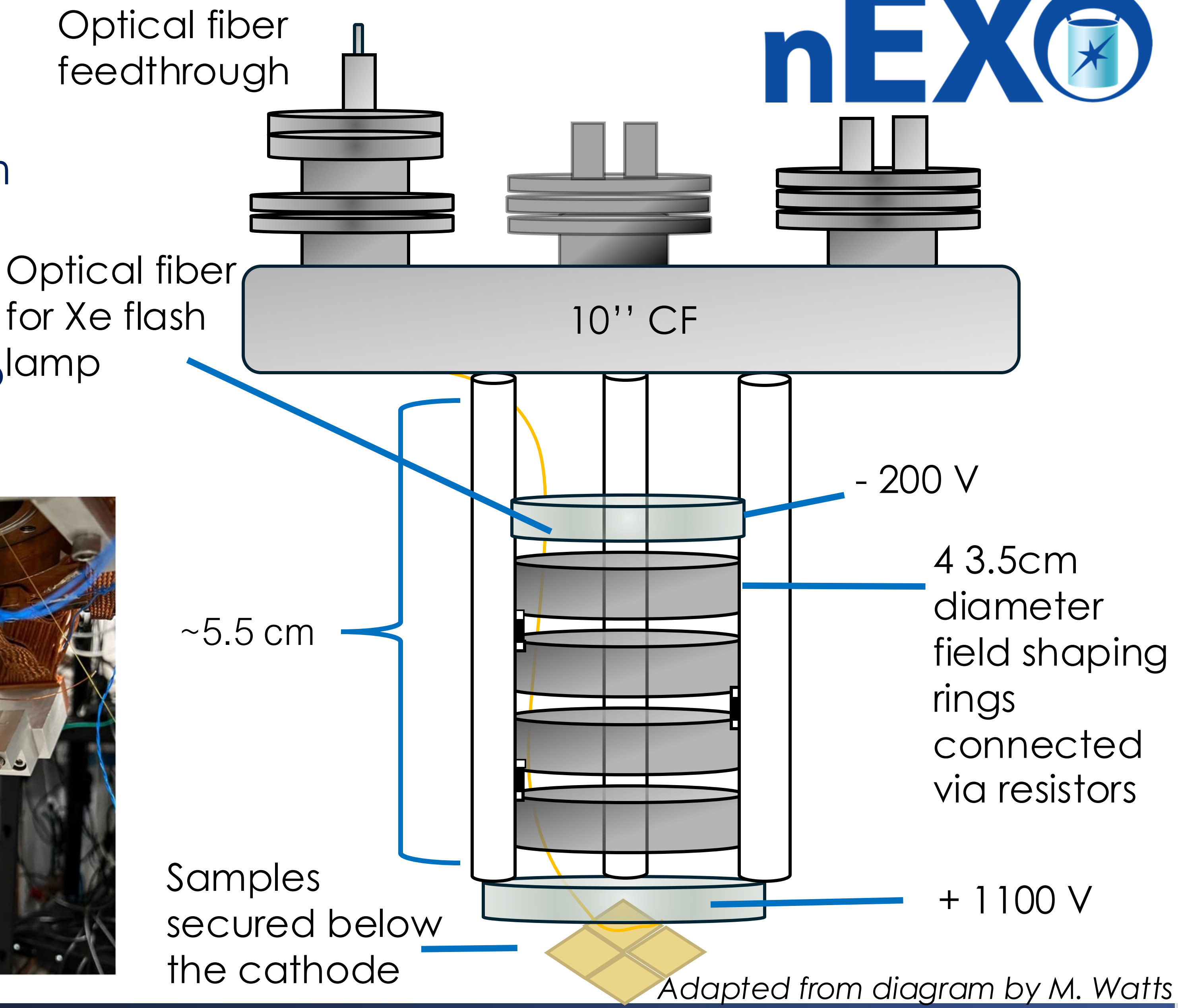
Collect outgassing data as the system cools down to LXe temperatures (~165K)

Gather electron drift waveform data from both the cathode and anode to determine if the charge amplitude decreases over time

Samples measured:

- Masterbond EP29LPSP Epoxy tiles from Stanford (E. Angelico)
- PTFE






*Adapted from diagram by M. Watts*

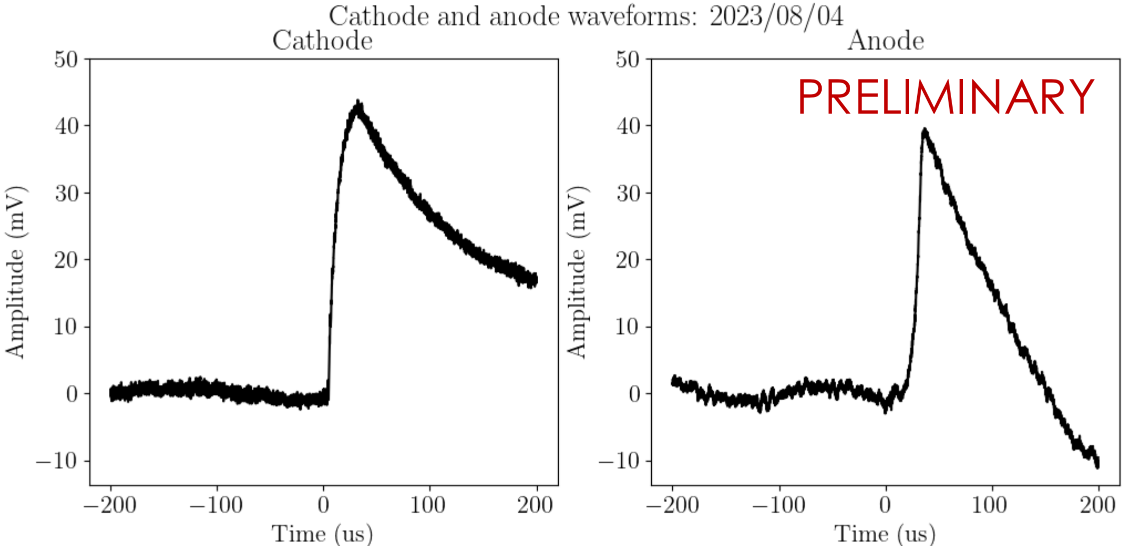
# Initial LXe Measurements

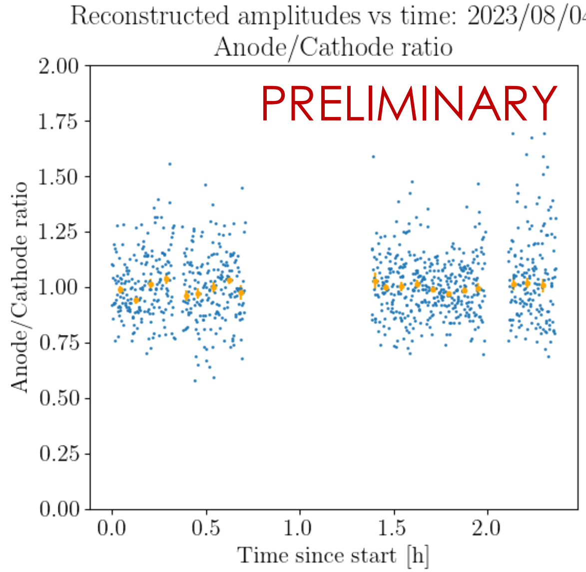
Measure electron drift data in LXe (no samples present) to determine baseline purity of the system before samples are introduced

Calculate the ratio of the anode signal to the cathode signal

- Anode/Cathode ratio remained at ~1 for the duration of the measurement
- Measured an upper limit of the outgassing rate of $1.5 \times 10^{-10}$ SLPM
  - >2 orders of magnitude below nEXO's requirement: $6.6 \times 10^{-8} \times \mathrm{H}$ SLPM
  - Have the capability of measuring samples with low outgassing rates

SL: standard liters of $O_2$ equivalent
$H$: Henry coefficient of LXe/GXe of $O_2$



# Epoxy Measurements

See a very small signal with epoxy present

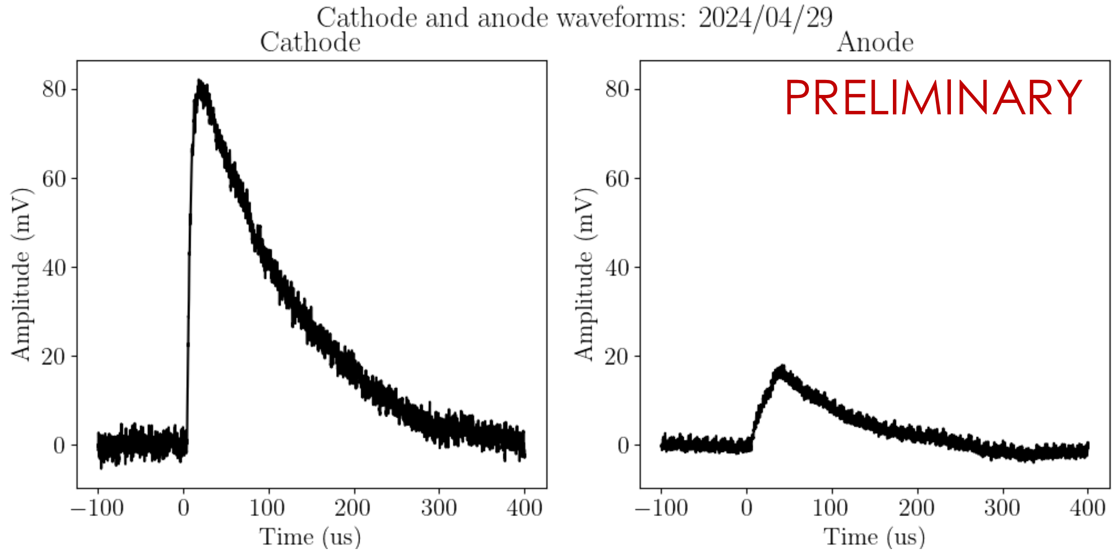
- Anode/Cathode centered at ~0.25

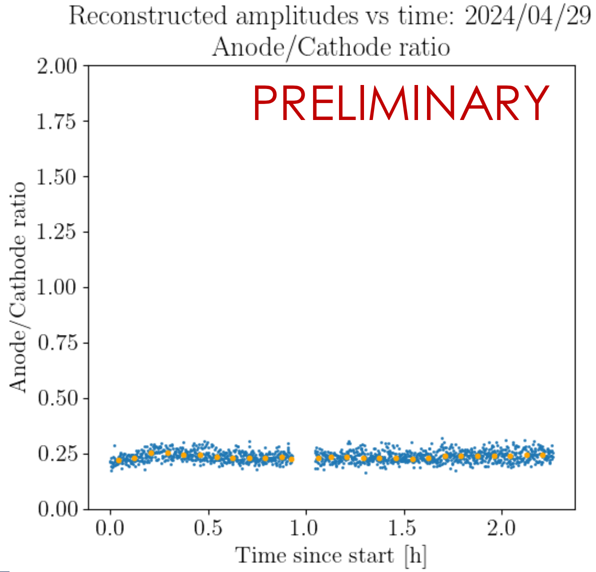
Saw no improvement after purifying for ~1.5 h

- Recirculation timescale ~2 h

In EXO-200, this epoxy did not have a noticeable effect on the electron lifetime

- Could be due to differences in preparation
- Still expect improvement after purifying

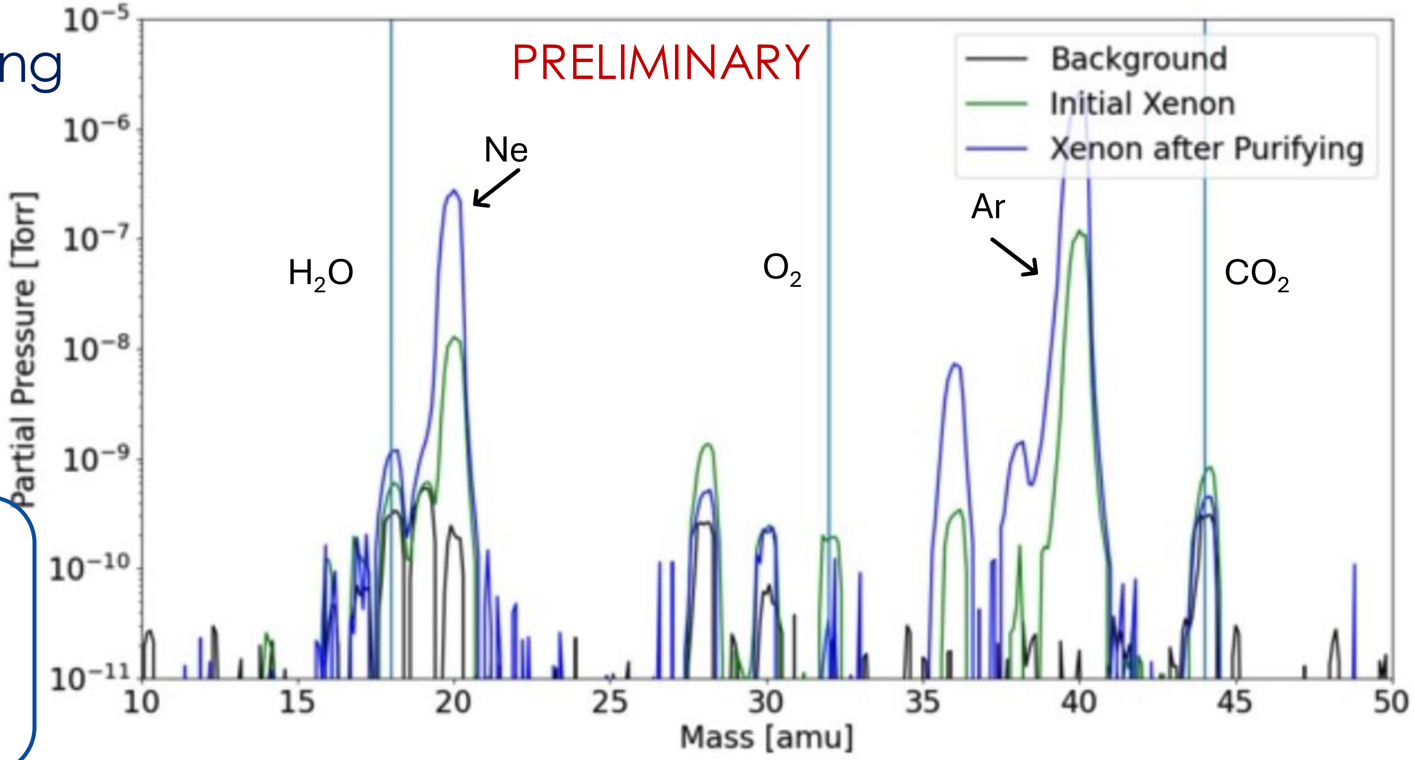


# Cold Trap

Measure partial pressure of evaporated gases in the Xe with an RGA
- One background scan before introducing Xe
- One scan with Xe
- One scan after purifying Xe for ~2 h

Anode/Cathode remained agnostic to $O_2$ levels throughout the run




Is $O_2$ the dominant cause of electron lifetime degradation? Are the electronegative impurities volatile?

# Summary

nEXO

- Yale has two procedures to characterize the outgassing rates of candidate materials for nEXO
  - Vacuum outgassing
  - LXe purity monitor
- Working to determine whether the low Xe purity with the epoxy present is due to $O_2$ and how this could affect nEXO
  - Plan to inject $O_2$ into the purity monitor to investigate cause
- Electronegativity Subgroup is ramping up a measurement system to assess TPC materials

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@nexoexperiment

# Thank You!

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-2139841.

# Motivation

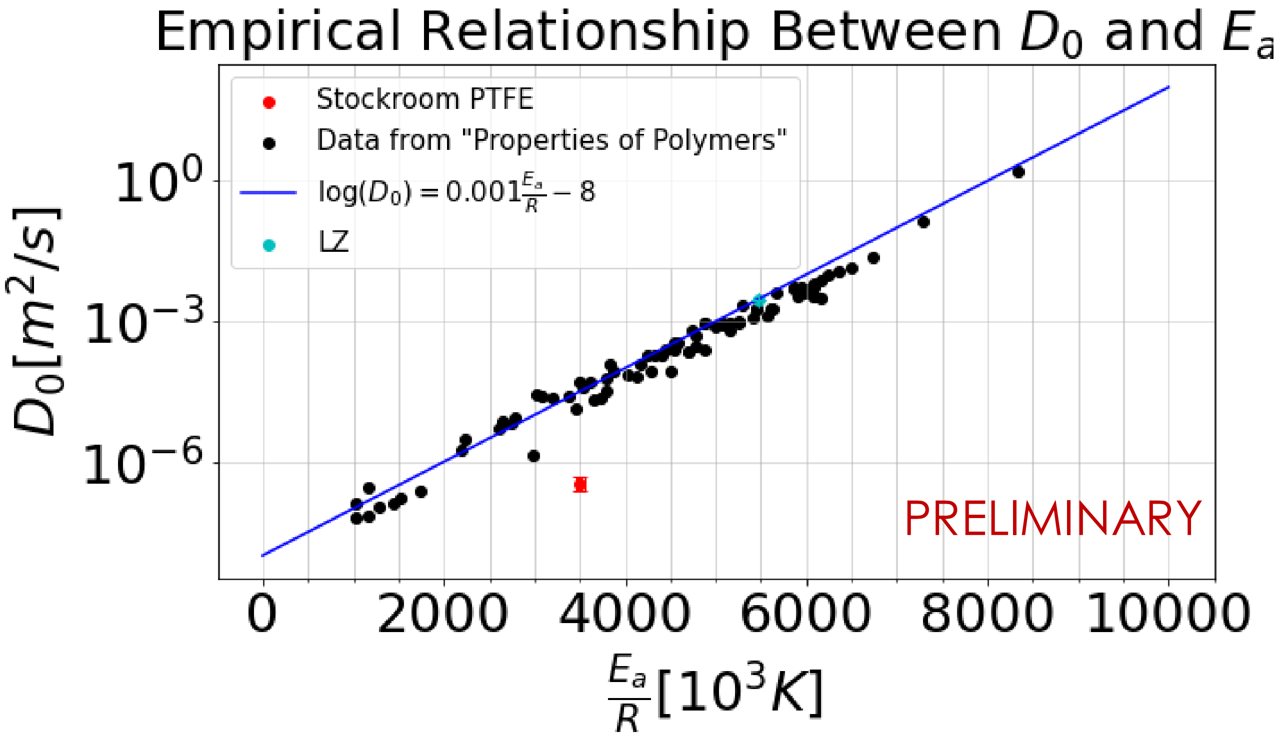
- Important to quantify how candidate detector materials will affect the electron lifetime
- Certain porous materials will diffuse atmospheric gases into LXe, and electronegative species will attract drifting electrons
  - Need to determine which materials do so and how to minimize this to reach our 10 ms goal

# Relationship of $D_0$ and $E_a$

Validate the diffusion parameter results by comparing their relationship

- Empirically shown that $D_0$ and $E_a$ follow a linear relationship for all polymers
- Our results should fall on this line

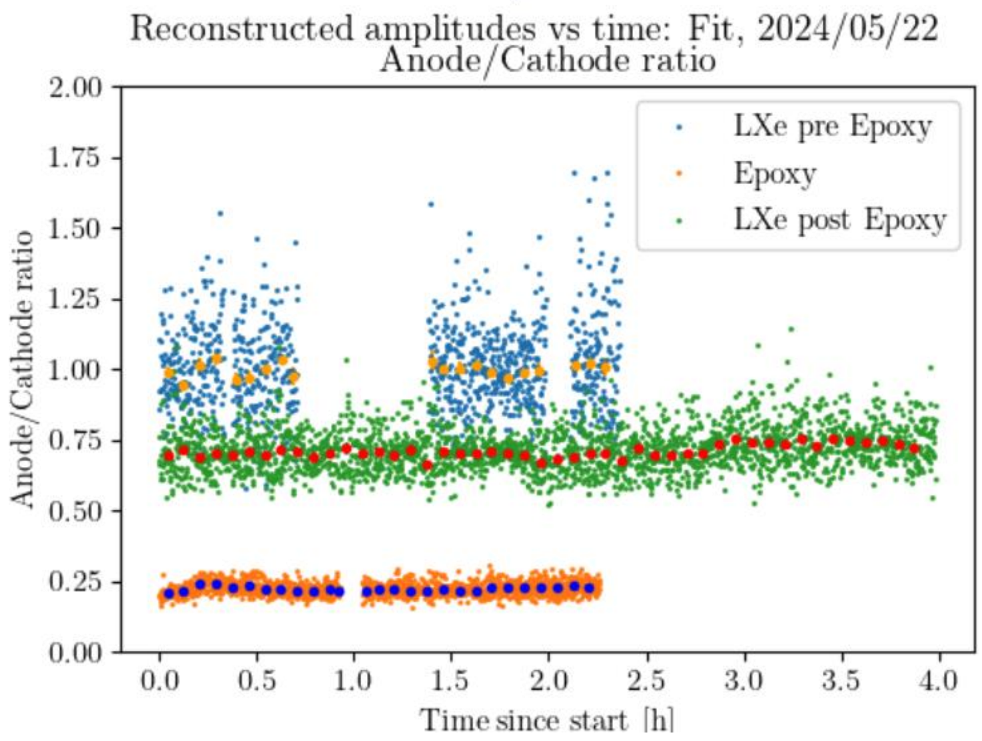
Challenge: High degeneracy in parameter space of $D_0$ and $E_a$, so the fits do not always converge towards the proper values



# LXe Background Post Epoxy

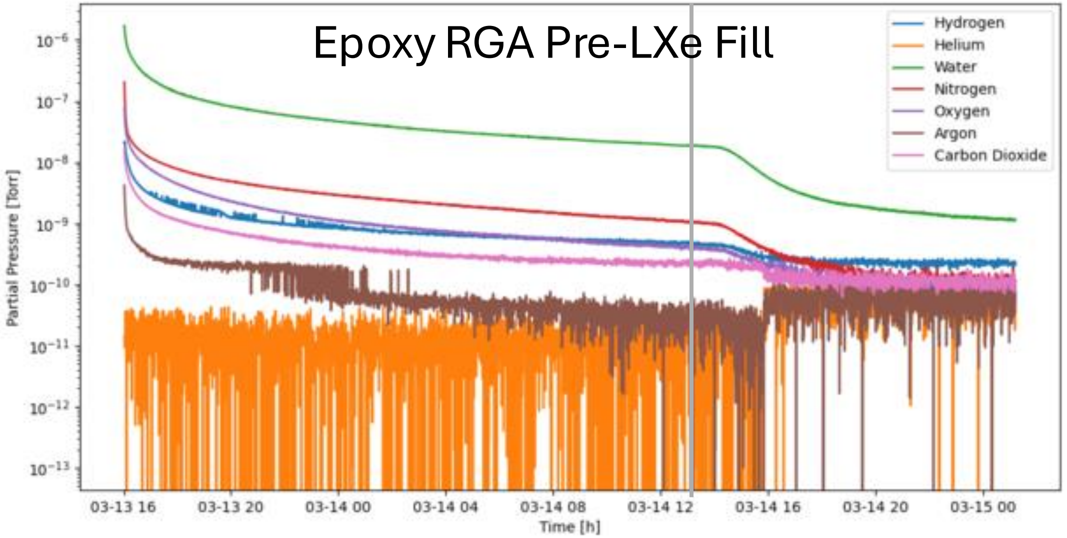
Removed epoxy and saw worse Anode/Cathode in pure LXe than before

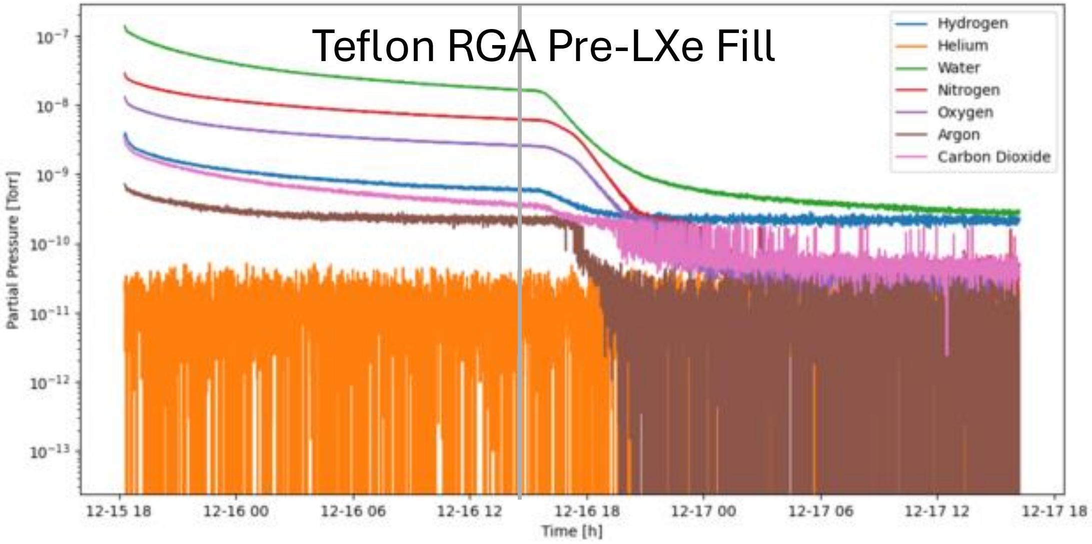
Started cold trap to investigate the trace gas content in the LXe



# Epoxy Pre-fill

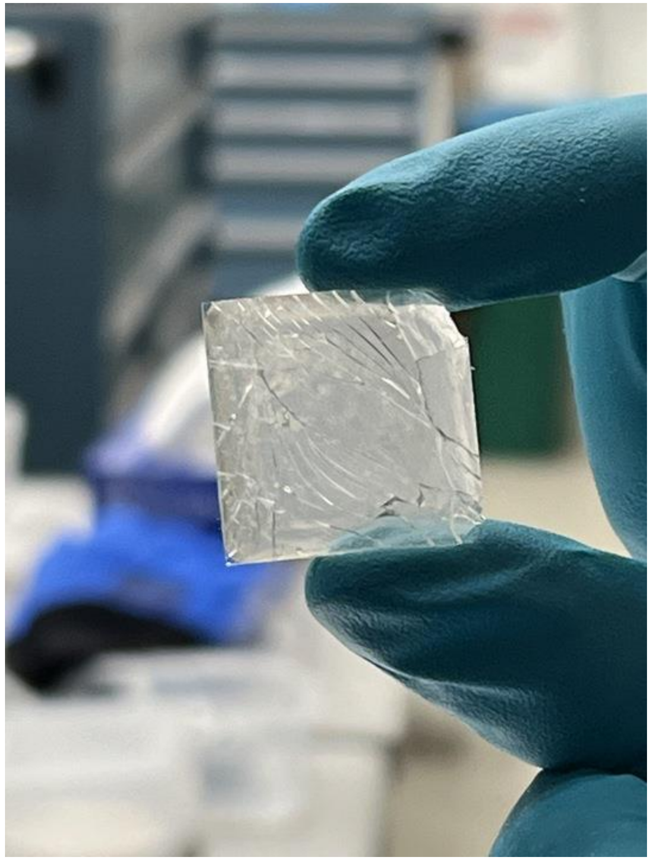
- Vented chamber for ~2 days beforehand
  - Vented chamber for ~1 day for the Teflon
- Partial pressures of the epoxy did not decrease as much as the Teflon
  - Water about an order of magnitude higher
  - $O_2$ went to nearly background levels in the Teflon data, but remained relatively high for the epoxy

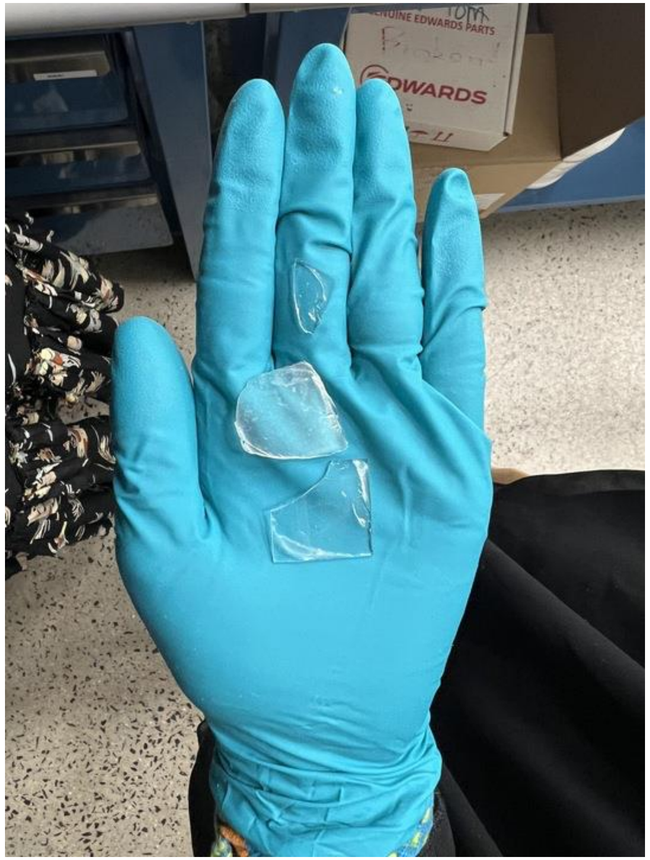


# Another Potential Epoxy Issue

After taking out the epoxy, the tiles were cracked and falling apart, likely due from being exposed to the cold temperatures





# O2 Injection: Is Our Purifier Working?

Assumption: $O_2$ dominant source affecting electron lifetime
Electronegative impurities are volatile and thus will be present in both condensed and evaporated forms in GXe and LXe, respectively

Are these assumptions true?

- Add controllable amounts of $O_2$ using a leak valve
- See if there is an increase in the RGA scans after the injection and whether there is a decrease in Anode/Cathode
- Monitor the $O_2$ levels while purifying and determine whether Anode/Cathode improves

Will provide a better understanding of the situation