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Caesium vapour capture experiments using POCO CZR-2 graphite

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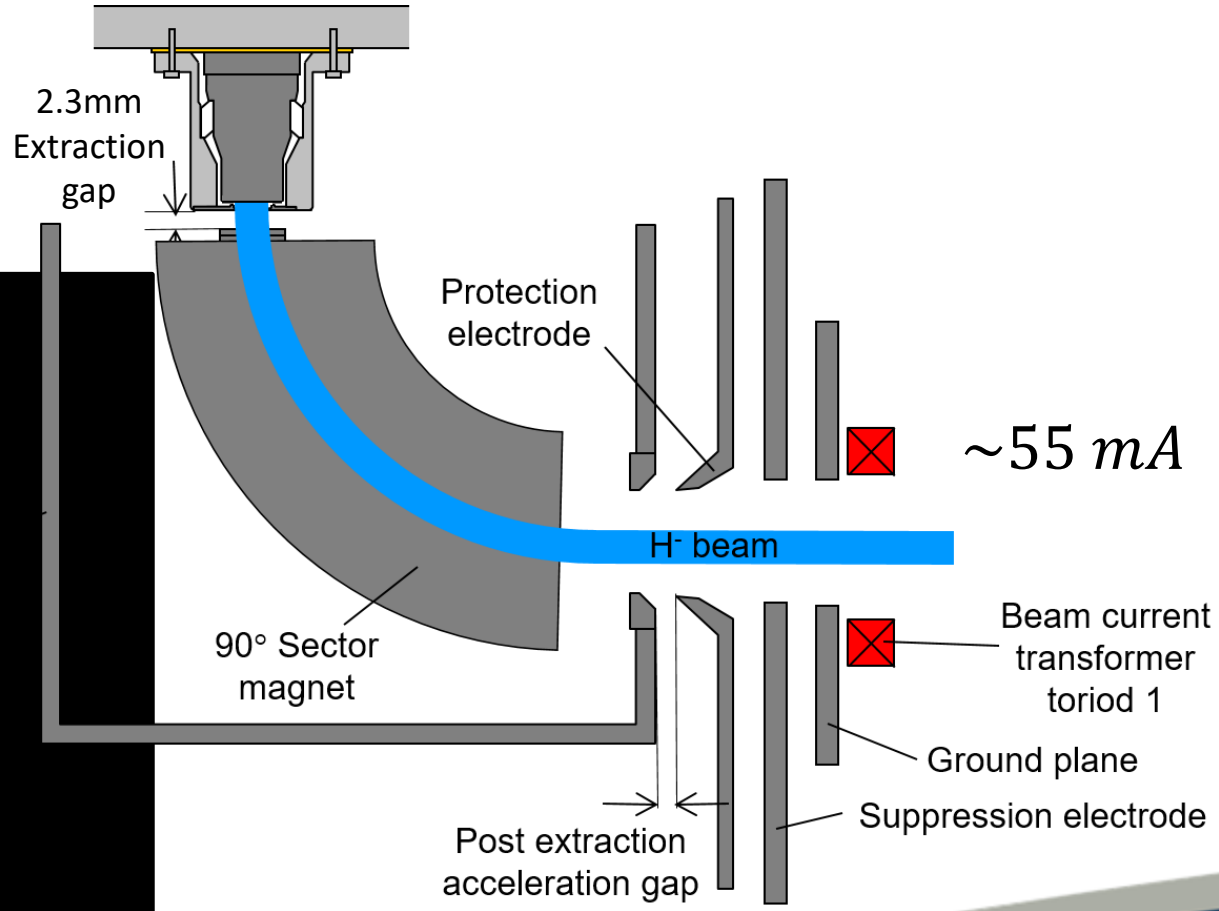
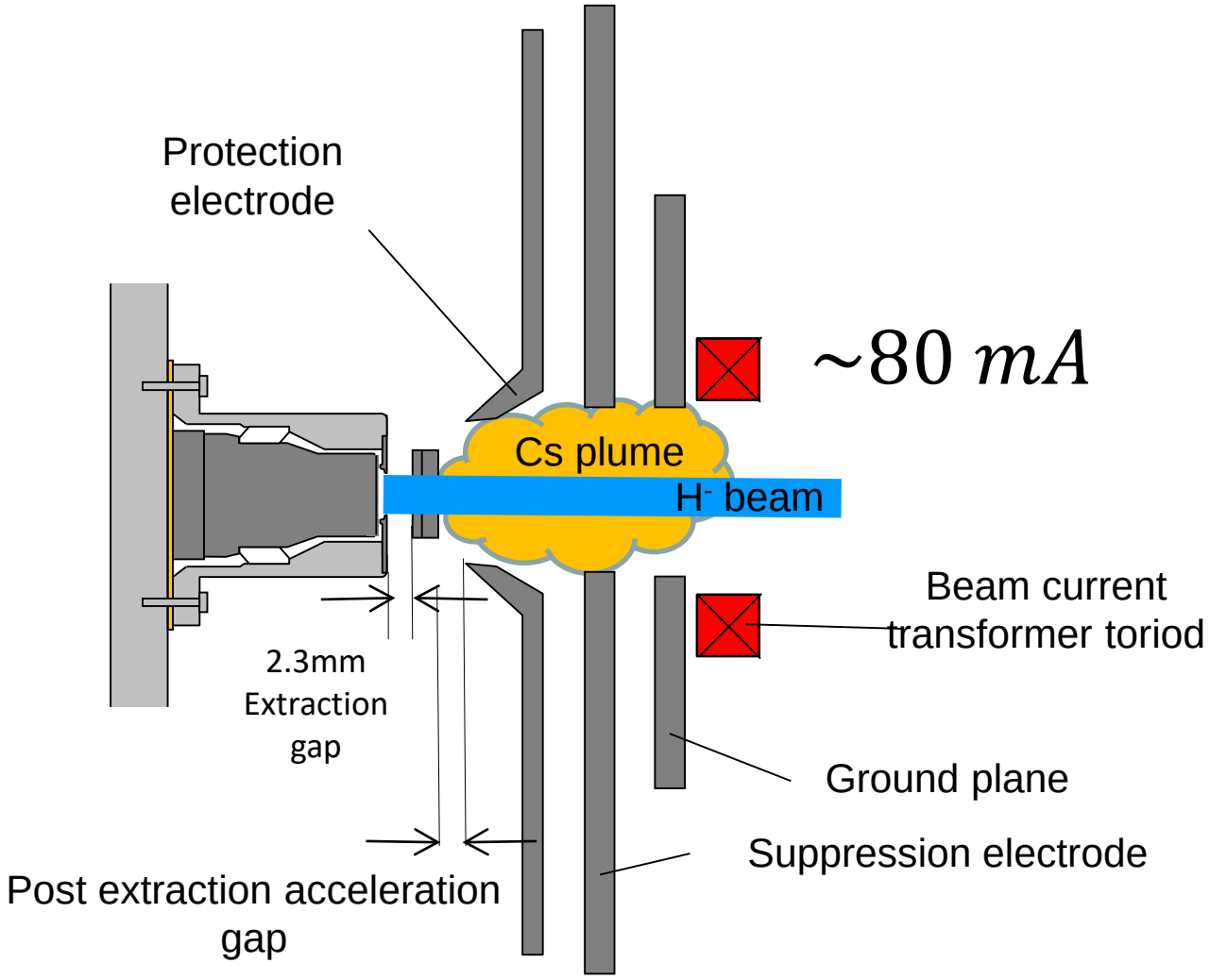
Current operational source on ISIS

refrigeration,
power insulation, etc.



Current operational source on test stand



Keeping all operating settings the same, but removing the cold box:

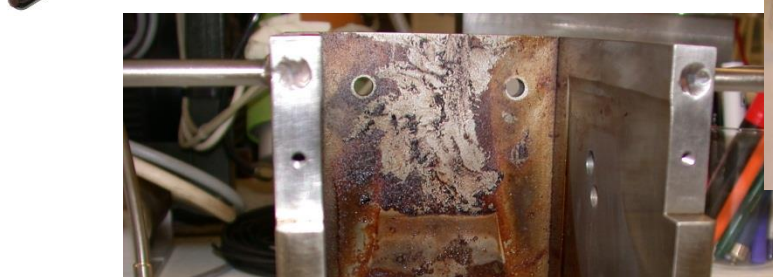
$$\sim 55\ \mathrm{mA} \rightarrow \sim 80\ \mathrm{mA}$$

Grubby cold box

Operational source

RF ion source

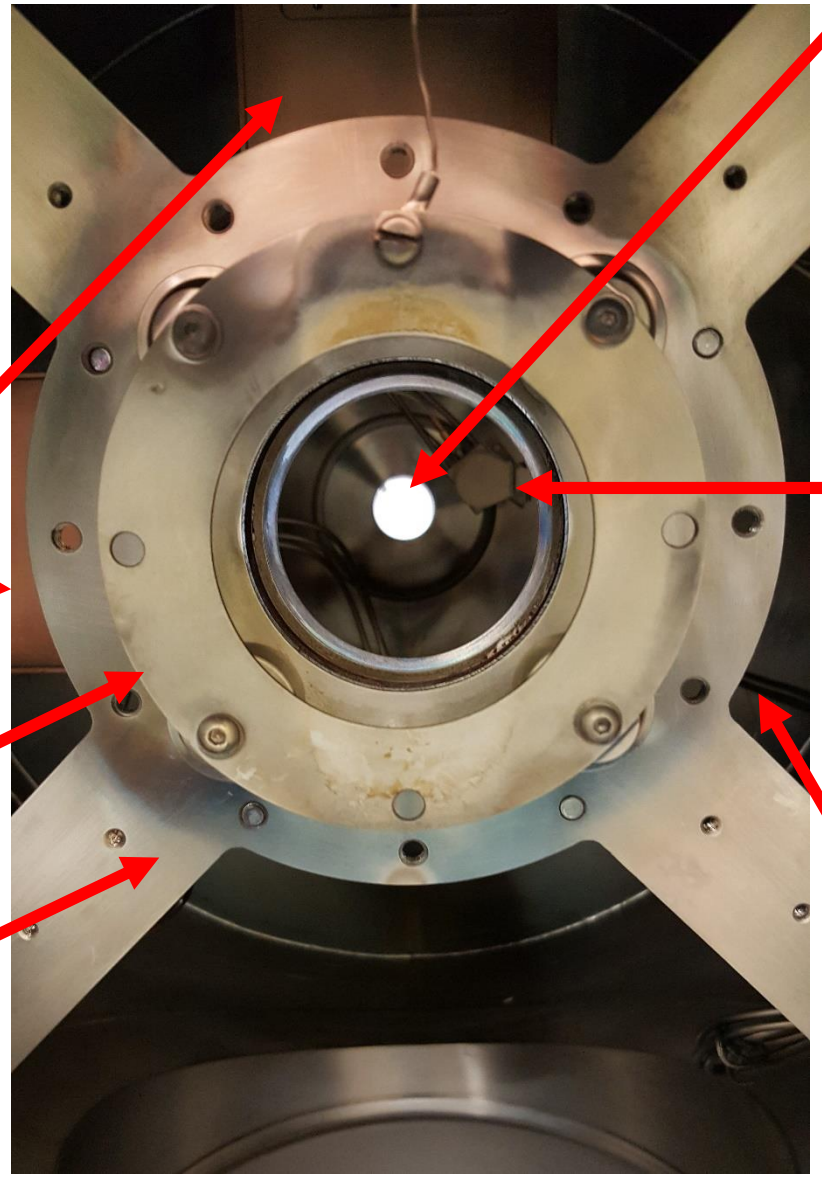
2X source



Require new caesium capture mechanism!

Vessel for Extraction and Plasma Source Analyses (VESPA)

View from ion source



Caesium diagnostics: QCMs

- Quartz Crystal Microbalance:
  - Measures mass deposit on surface from shift in resonant frequency

Δm Δf

using the Sauerbrey relation: $\Delta f \propto -\Delta m$

- Calculates the accumulation rate in the vessel

Time resolution $\sim 1s$ $\rightarrow$ doesn't distinguish caesium escaping during or between pulses

Caesium diagnostics: Spectrometer

- Broadband spectrometer:
  - Simultaneously measures intensity of several wavelengths using a prism and array of CCD chips

Only captures information during plasma pulses

Time resolution $\sim 500\ \mu s$ $\rightarrow$ doesn't reveal structure of pulse

Caesium capture requirements

- Capture ~ 5 g in a month
- Ideally minimise ancillary equipment

→ chemical capture

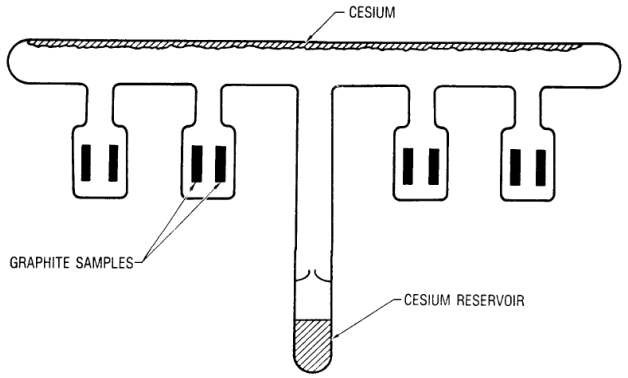
→ graphite

used in caesium clocks

comes in different grain sizes and porosities

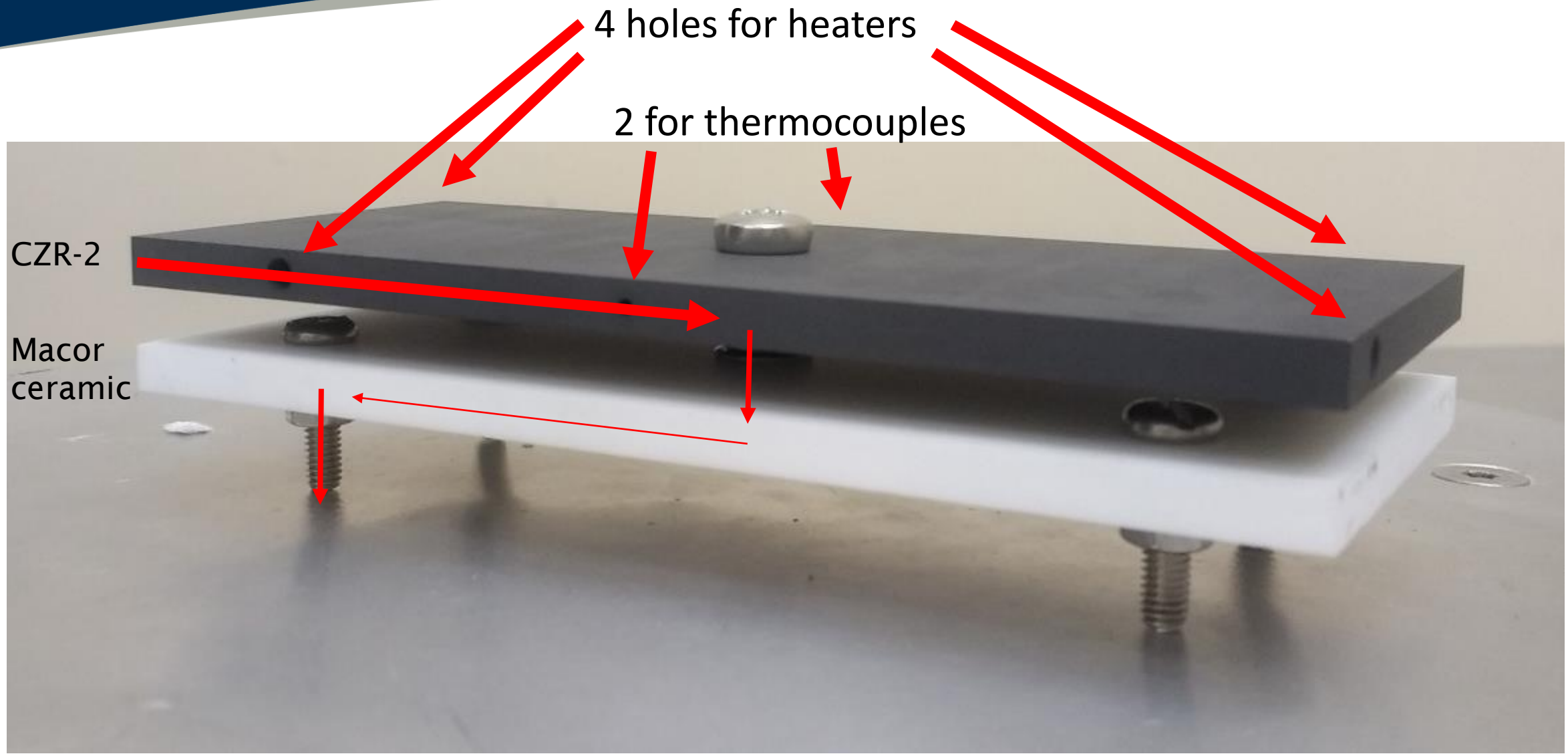
Graphite design

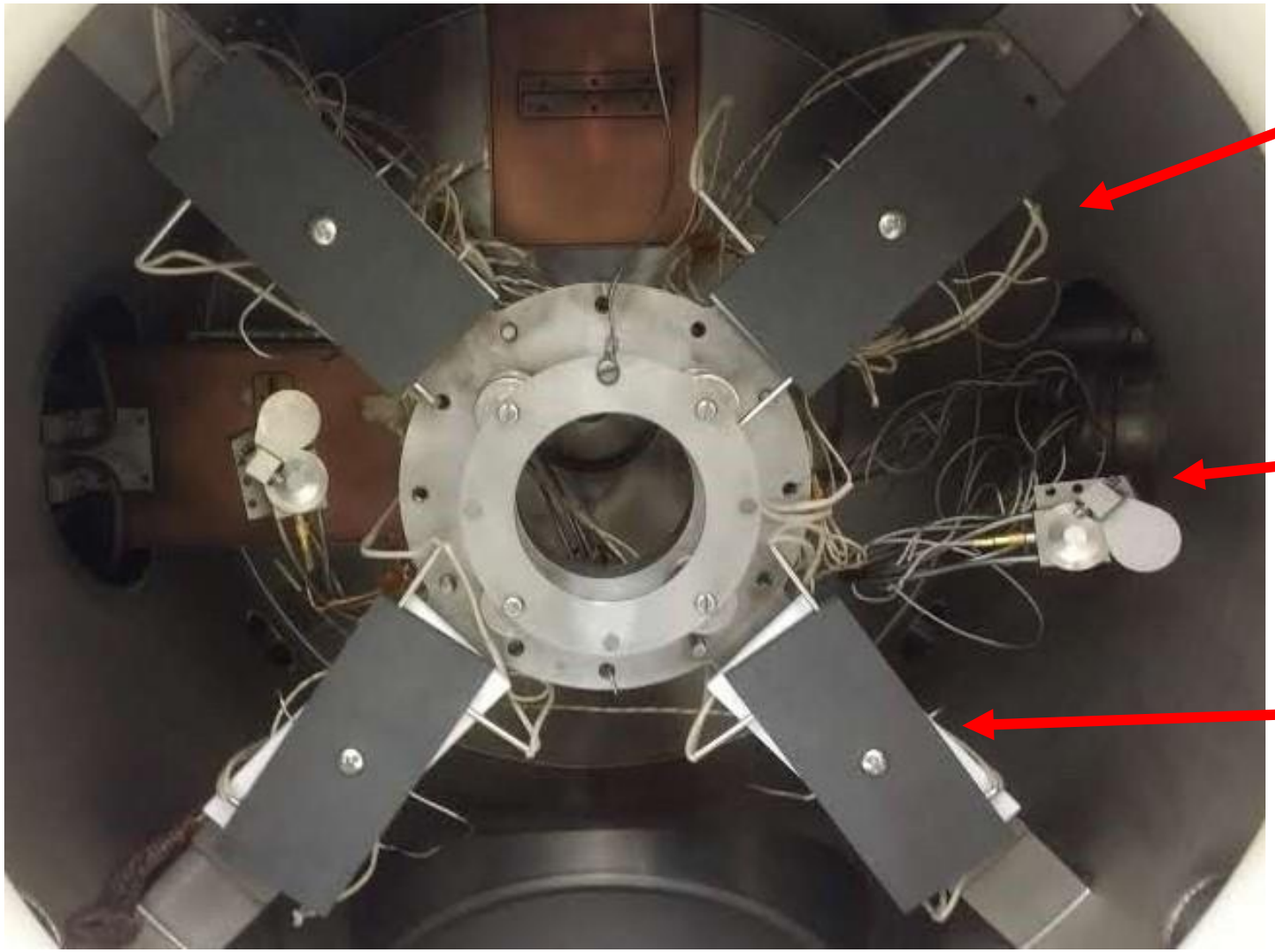
- Bhaskar et al (‘88) found POCO CZR-2 graphite to be most effective, capturing 20% its own mass



- Want to bake in situ, and heat to experiment at various temperatures

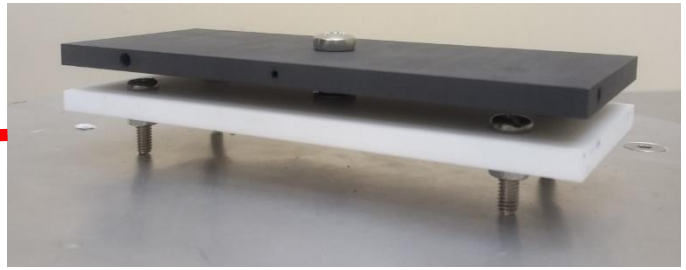
- ANSYS to ensure sufficient thermal isolation to hold 500 °C without too much heating to the rest of the vessel


4 holes for heaters
2 for thermocouples
CZR-2
Macor
ceramic



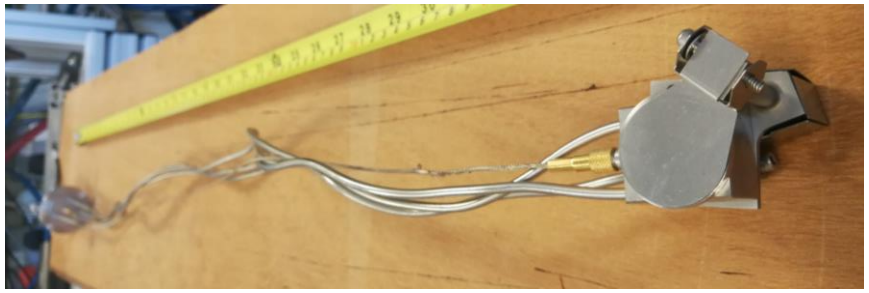
‘Firerod’ heaters operate up to 350 °C

QCMs



Graphite design (2)

- Heaters are in series pairs to provide some redundancy
- Redundant thermocouple on each block also minimises need to open vessel
- With current set up cannot be sure QCMs and optical fibre return to the exact same position after opening and closing vessel

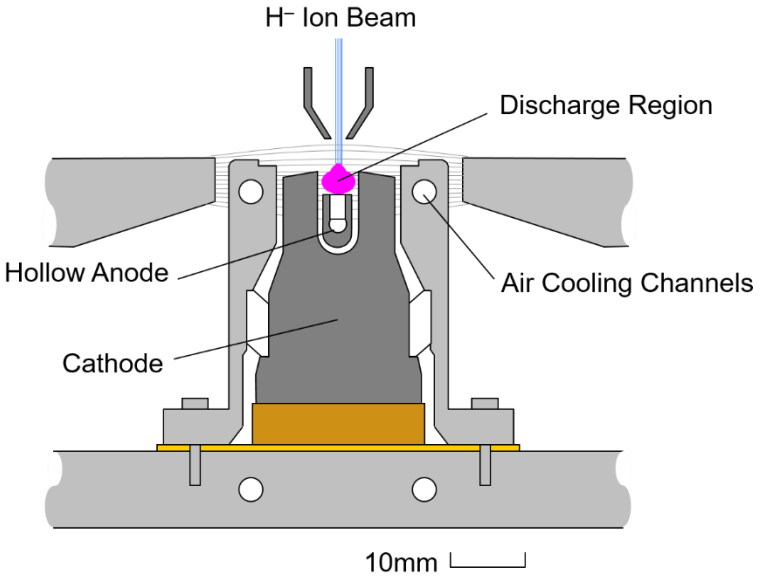


Comparison with/without graphite

- Currently cannot compare absolute values with and without graphite
- Can see changes to data as graphite temperature is changed
- Must distinguish if changes are caused within source or by graphite
- Set of experiments to characterise effect of source changes on QCM and spectrum readings.

Characterising experiments

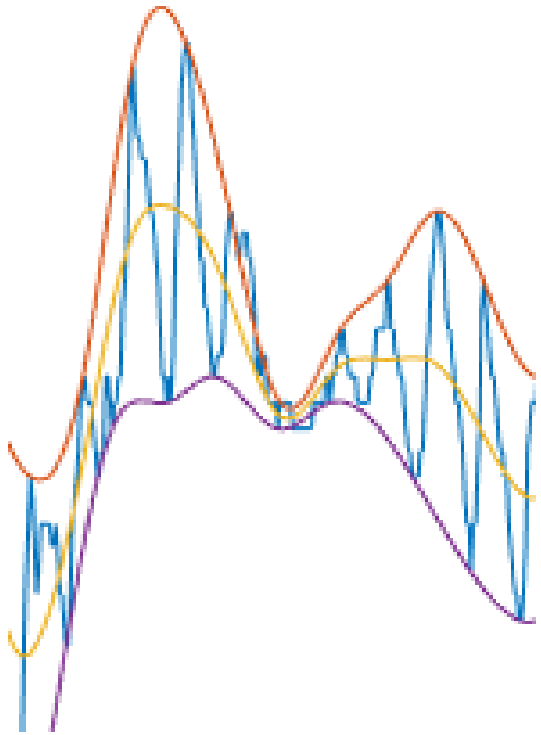
- 3 key independent variables on the source, with typical operating settings:
  - Oven temperature (159 °C)
  - Air flow (10.5 L/min) (Source cooling)
  - Discharge current (55 A)



- 3 experiments: run the source and change only one parameter

Preparing QCM data

- Thickness is measured every second
- Accumulation rate is calculated
- Smoothed by taking:
  - a moving mean of 30 previous points
  - the mean of the peak envelope



- Normalised to first 100 points in an experiment

Interpreting QCM data

- Accumulation rate depends on:
  - Deposition rate
  - Evaporation rate

→ sensitive to changes in distribution of caesium and temperature of the crystal

$1\ s$ time resolution → dominated by caesium escaping between pulses, and (possibly) from vessel surfaces

Preparing spectrometry data

- H_α recorded with 300 μs integration time to avoid saturation
  - Didn't go to plan
- H_β, Caesium lines 852 nm, recorded with 1500 μs integration time
- Smoothed by taking:
  - a moving mean of 30 previous points
- Normalised to first 100 points in an experiment

Interpreting spectrometry data

- Assuming electron collisions are the only cause of emission:

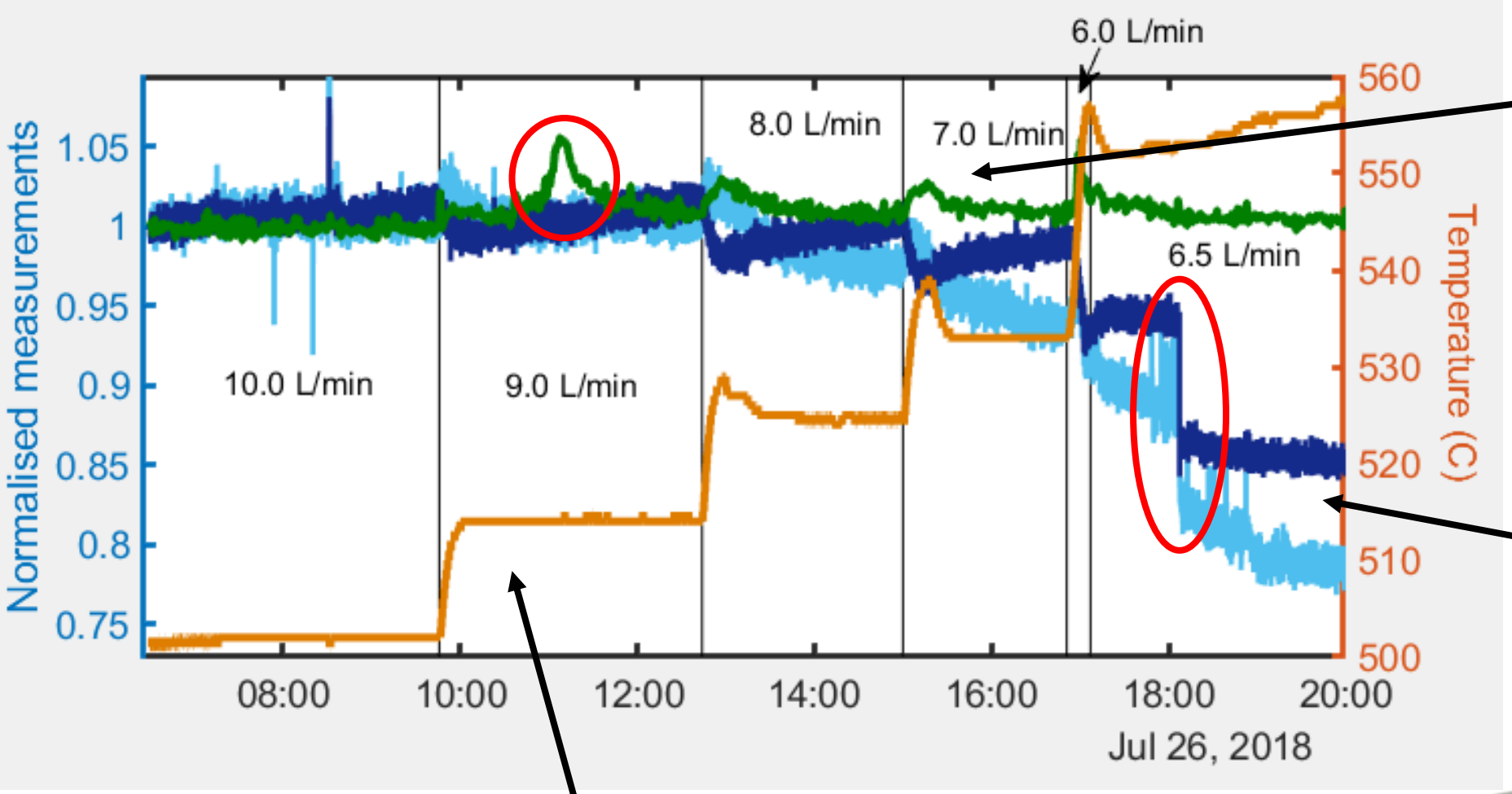
$$I \propto n_e n_i < \sigma(v) v >$$

n_e - electron density
n_i - species density
v – electron velocity
$\sigma(v)$ - cross section as function of velocity

$\frac{I_{H\alpha}}{I_{H\beta}} = \frac{<\sigma(v)v>_{H\alpha}}{<\sigma(v)v>_{H\beta}}$ increases with electron energy, proxy for voltage between anode and cathode if only primary electrons collide

$$\frac{I_{Cs\ 852\ nm}}{I_{Cs\ 894\ nm}} = \frac{<\sigma(v)v>_{Cs\ 852\ nm}}{<\sigma(v)v>_{Cs\ 894\ nm}} \approx constant$$

Air Flow: Oven at 159 °C



QCM rate and Cs line increase in bumps, tailing off

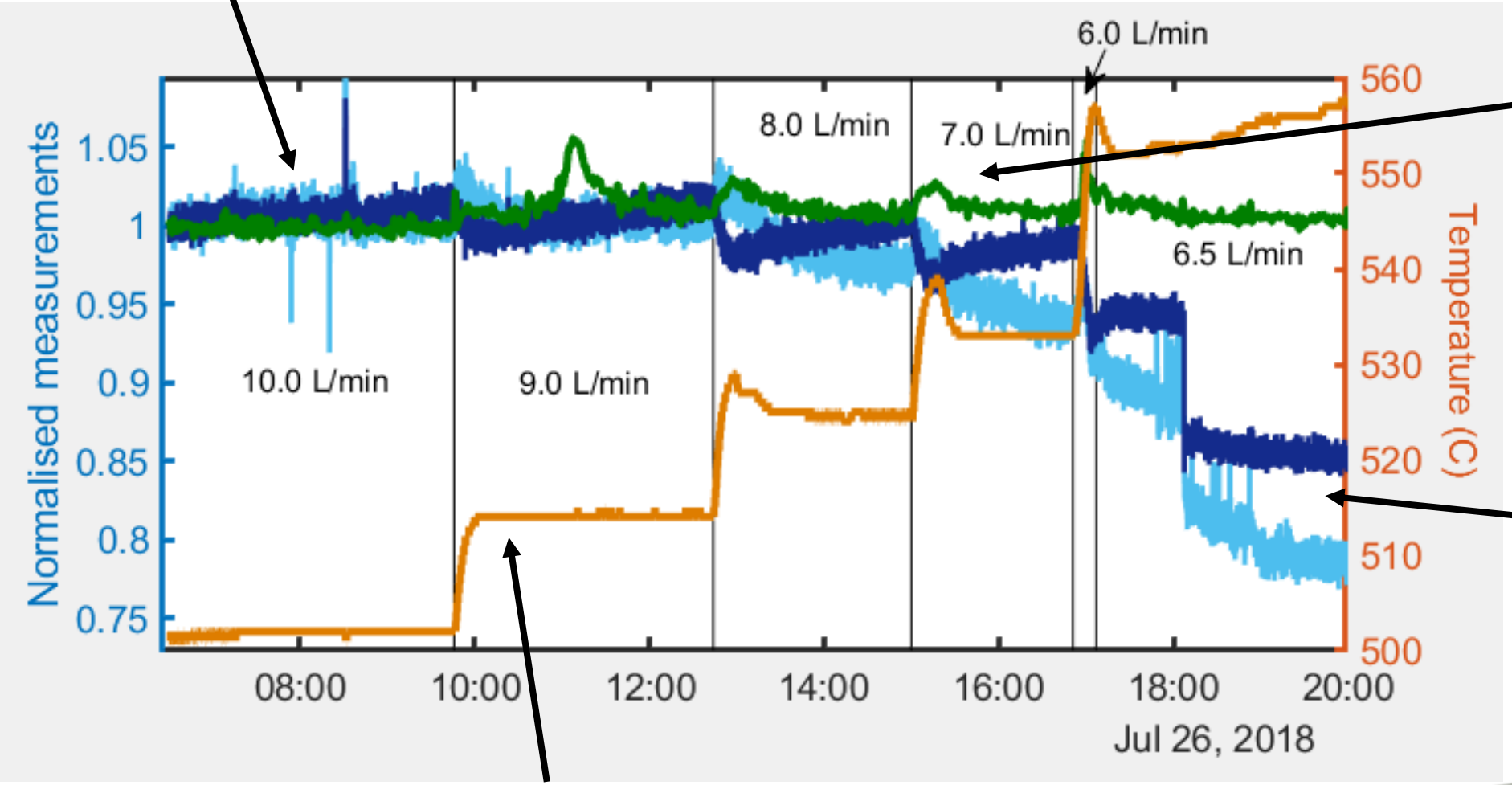
Cathode Temp
QCM Rate
Hβ
Cs 852 nm

Cs and Hβ decrease overall

Cathode temperature increases in steps

Air Flow: Oven at 159 °C (2)

Some caesium ‘reservoir’ exists on the source surfaces



Caesium fills first the plasma, then vessel, and temporarily increased rate

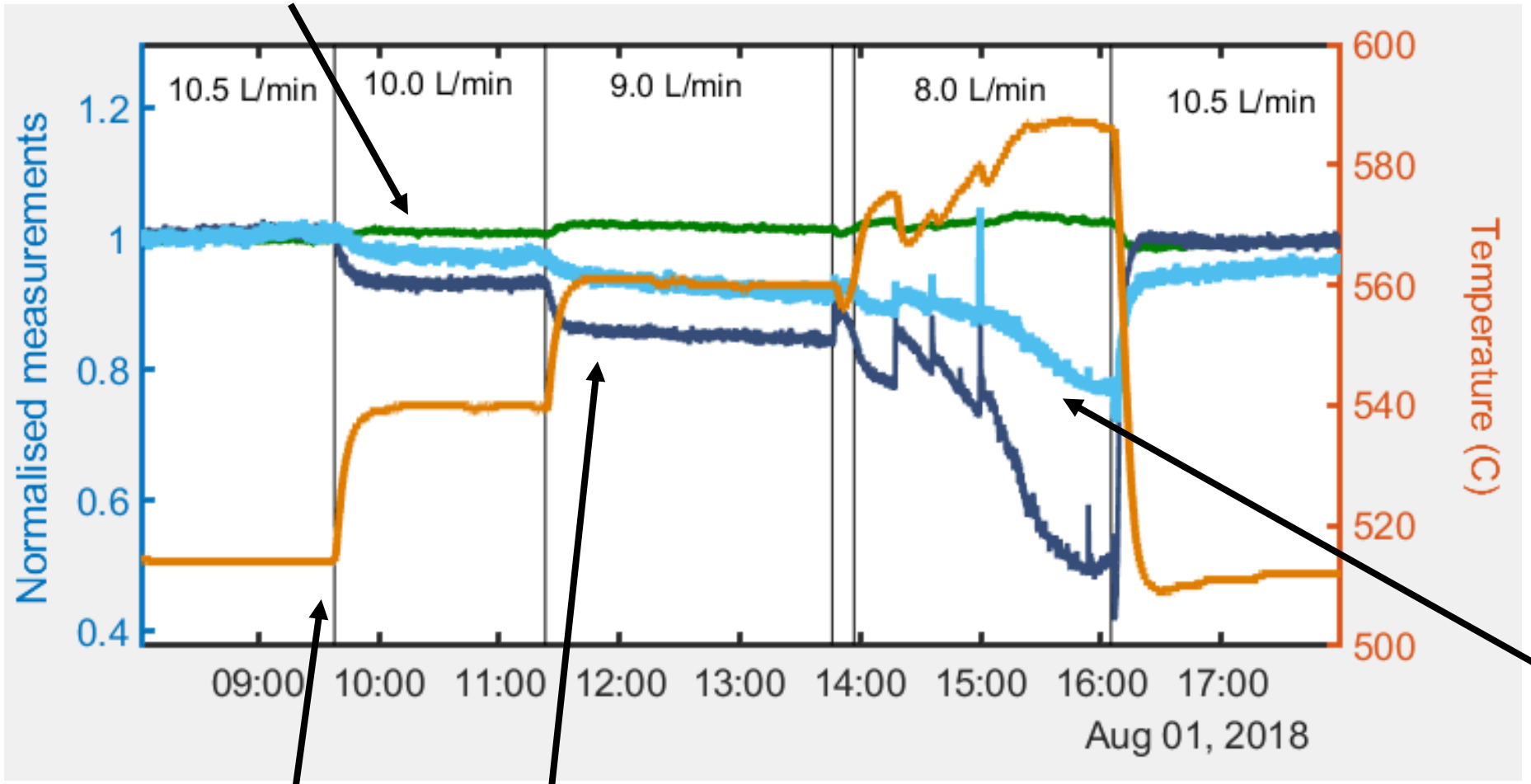
Cathode Temp
QCM Rate
$H\beta$
Cs 852 nm

Less caesium is available so signal drops
e^- energy **increases** so cross sections drop

Temperature change shifts equilibrium size of the reservoir

Air Flow: Oven at 171 °C

QCM increase in steps



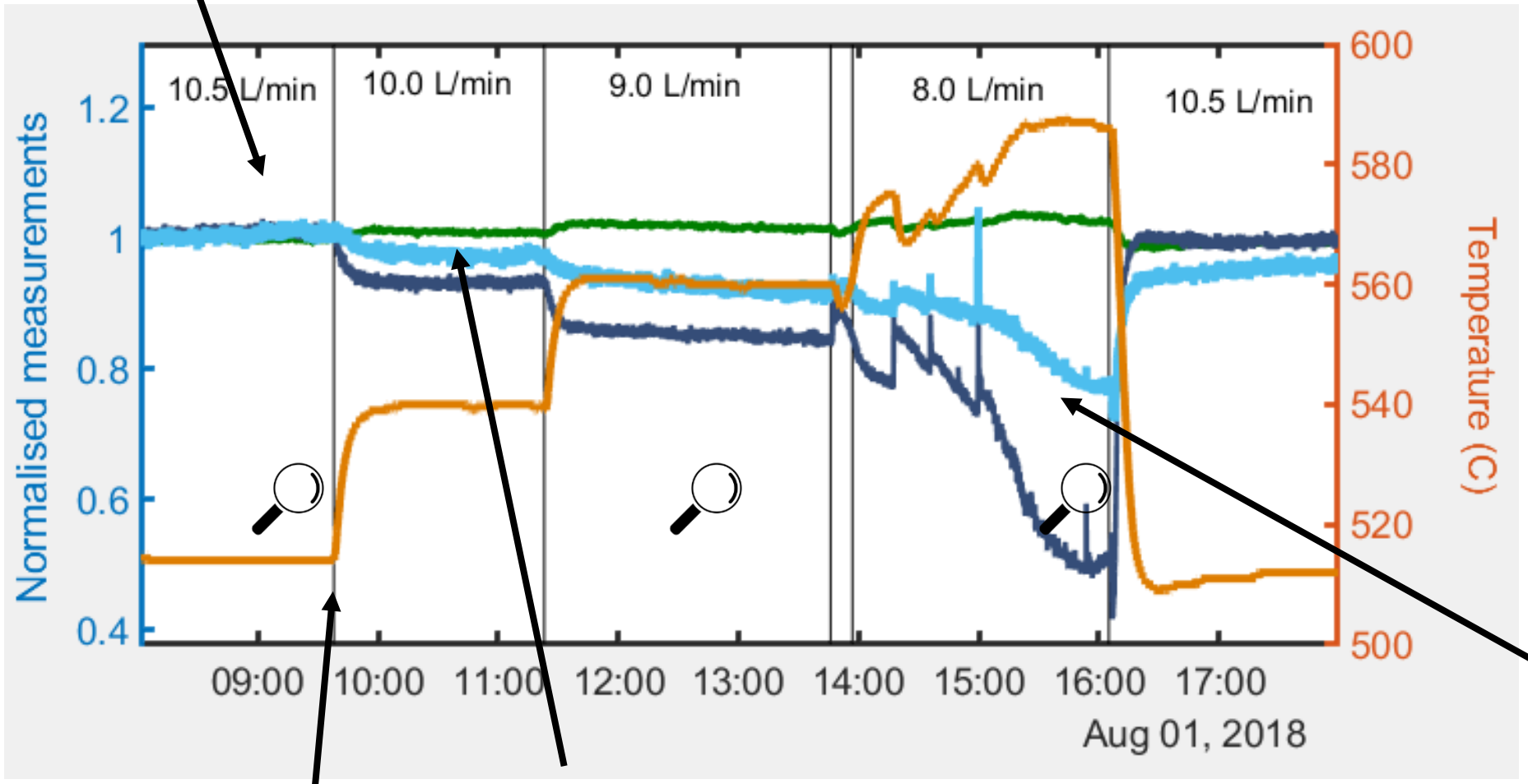
Stability is lost

Cathode temperature increases in steps

Cs and Hβ decrease in steps

Some caesium ‘reservoir’ exists on the source surfaces

Air Flow: Oven at 171 °C

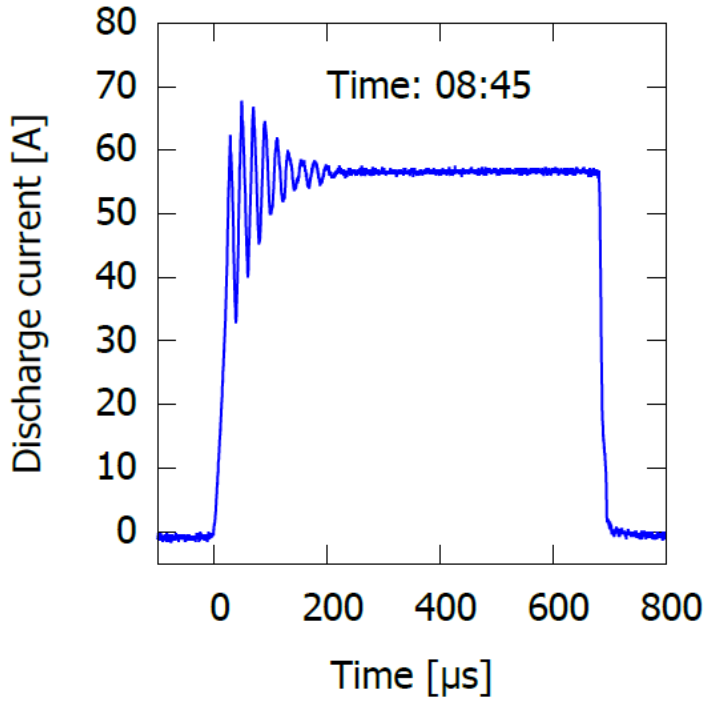


Reservoir is nearly depleted

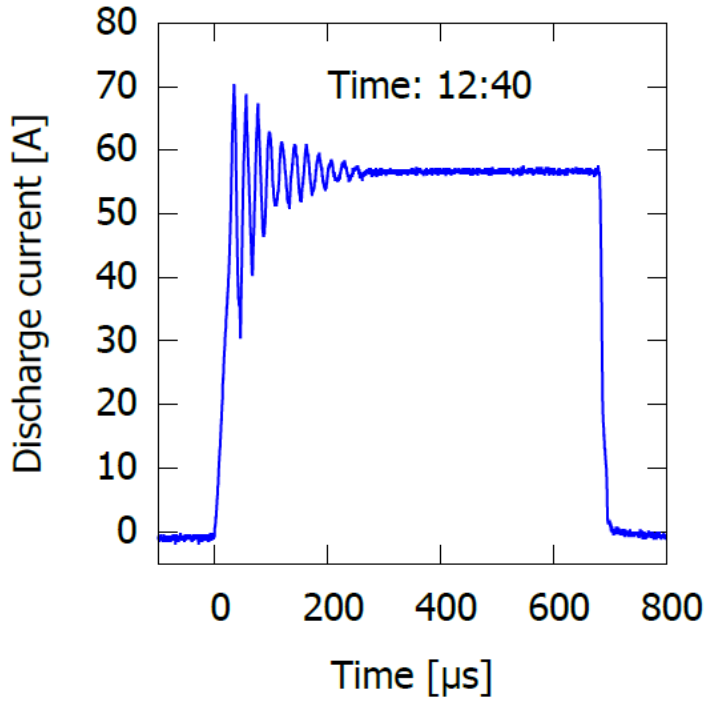
Reservoir is replenished more rapidly, so drop off is much slower

Temperature change shifts equilibrium size of the reservoir

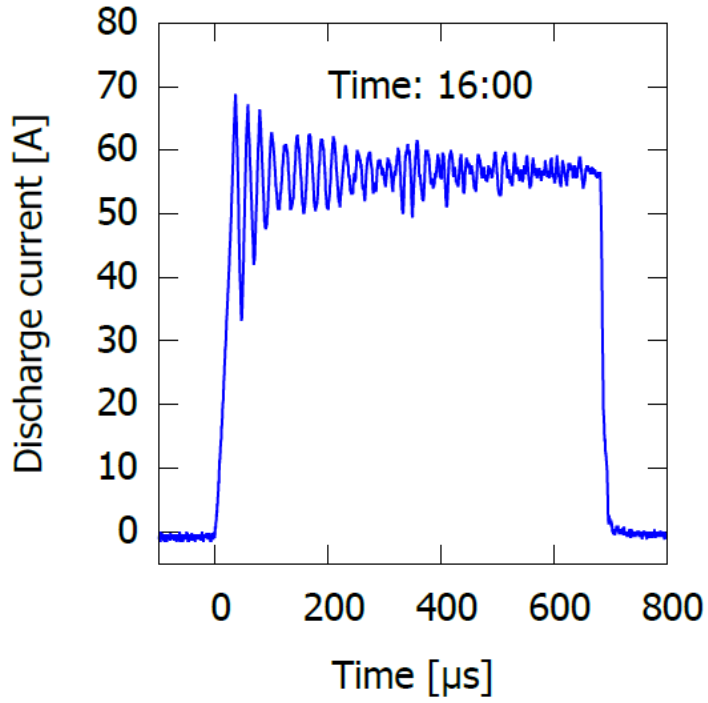
Air Flow: Oven at 171 °C



10.5 L/min



9.0 L/min

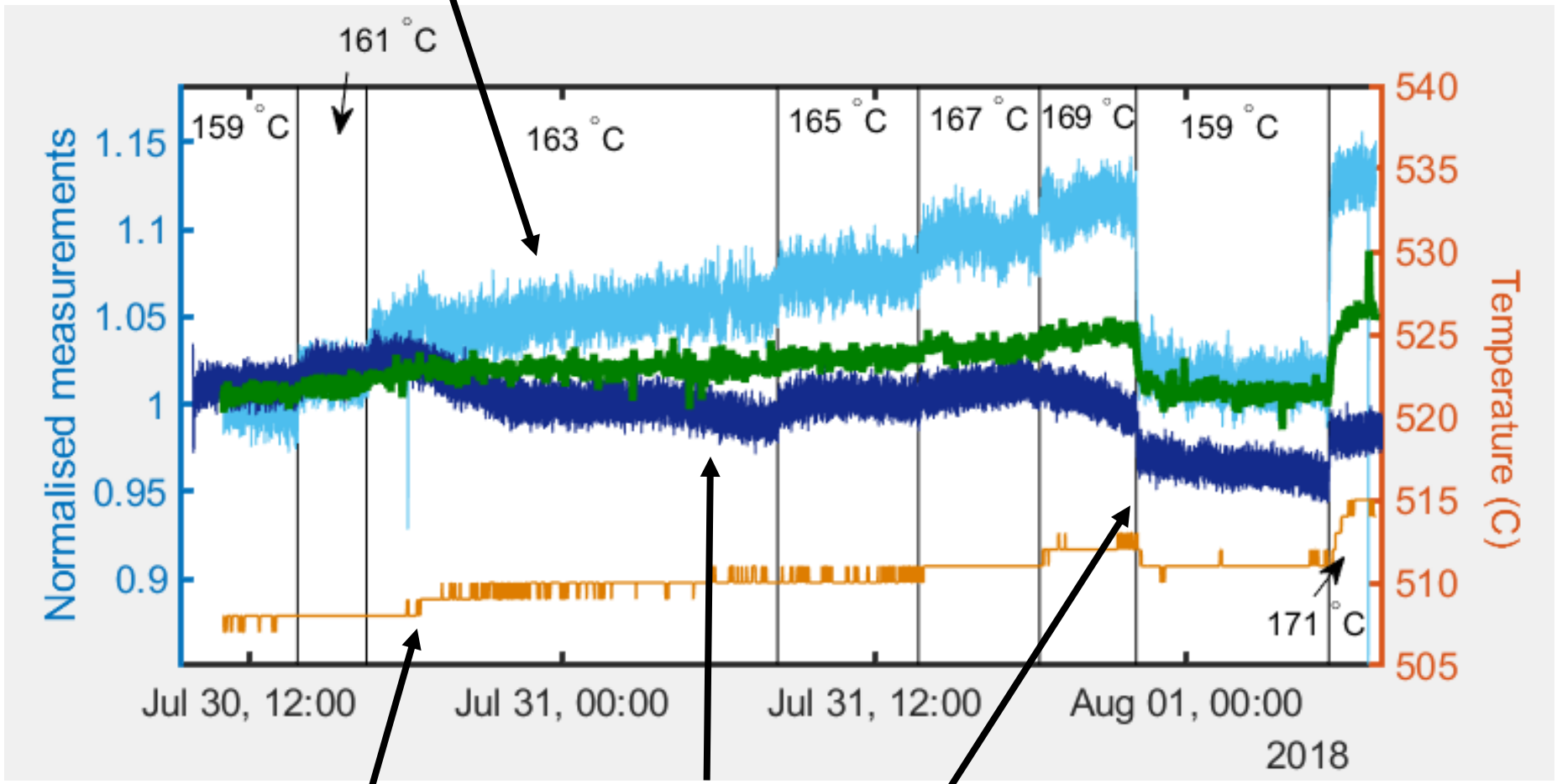


8.0 L/min

Noise appears gradually
as caesium reservoir is depleted

Oven temperature

Caesium line and
QCM increase in steps

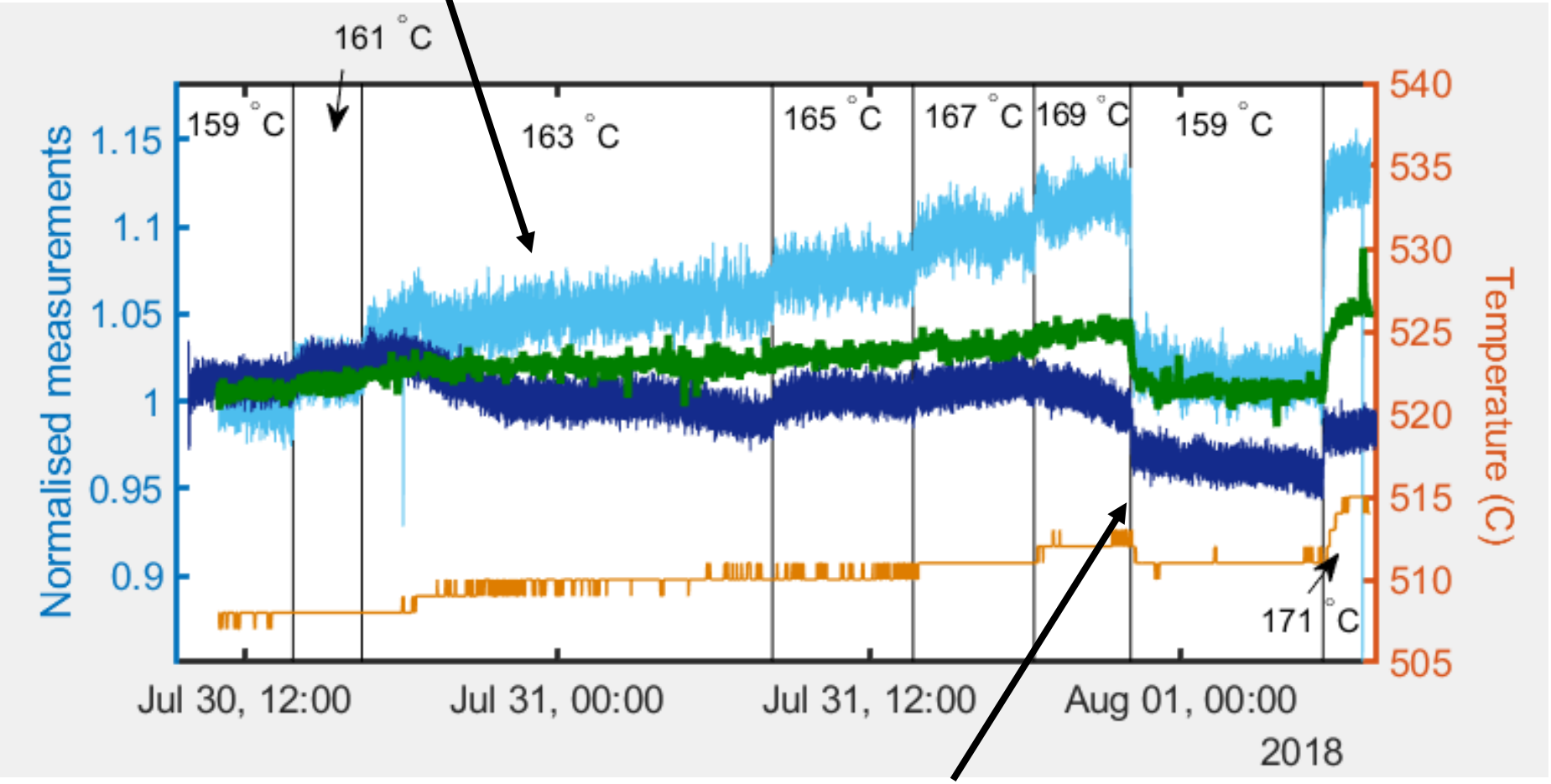


Cathode temperature
doesn't change much

Hβ doesn't display
obvious trend except
at biggest drop

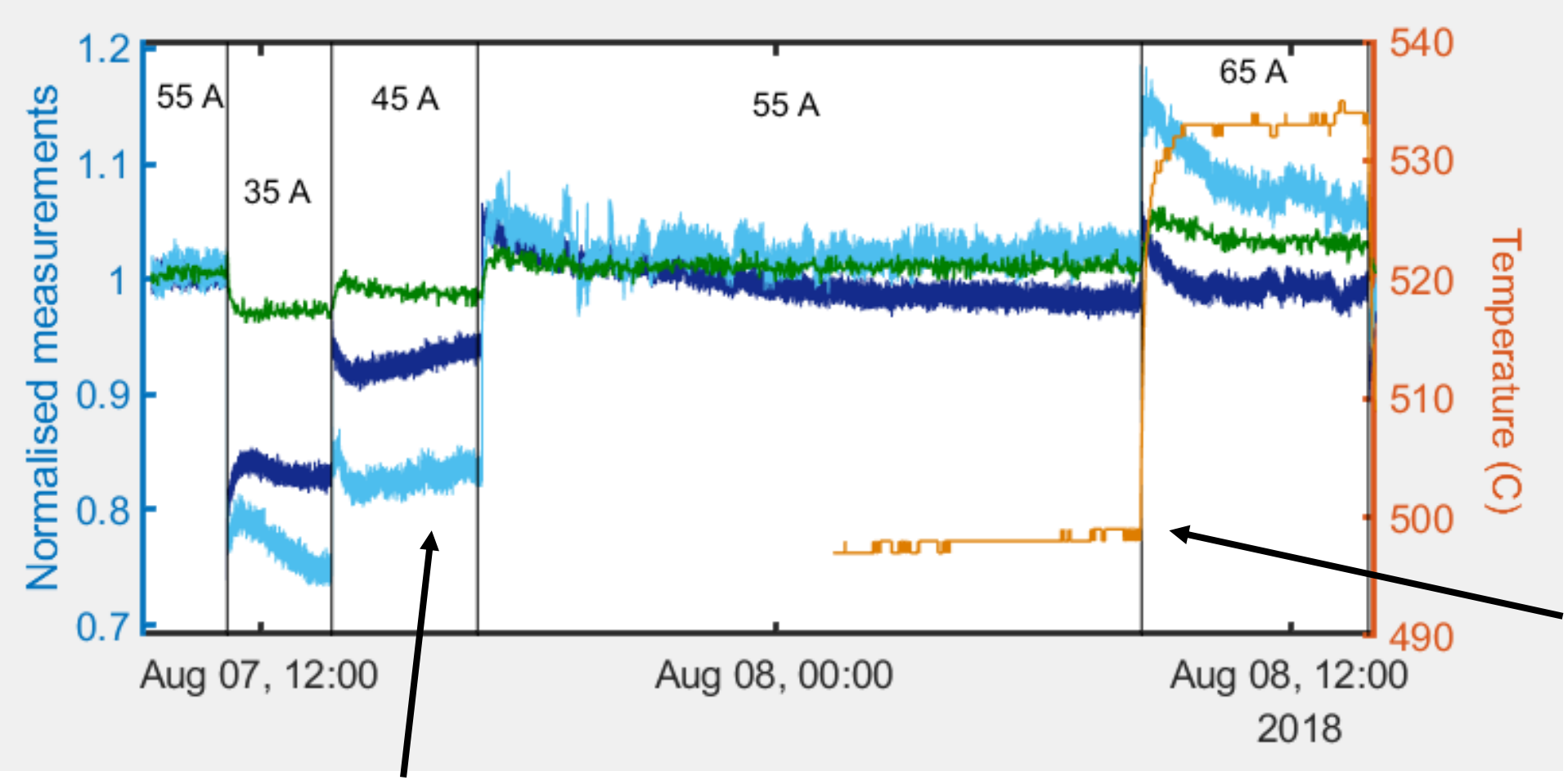
Oven temperature (2)

Caesium delivery rate increased



higher electron energy →lower cross section → Less caesium results in arc voltage increase

Discharge current

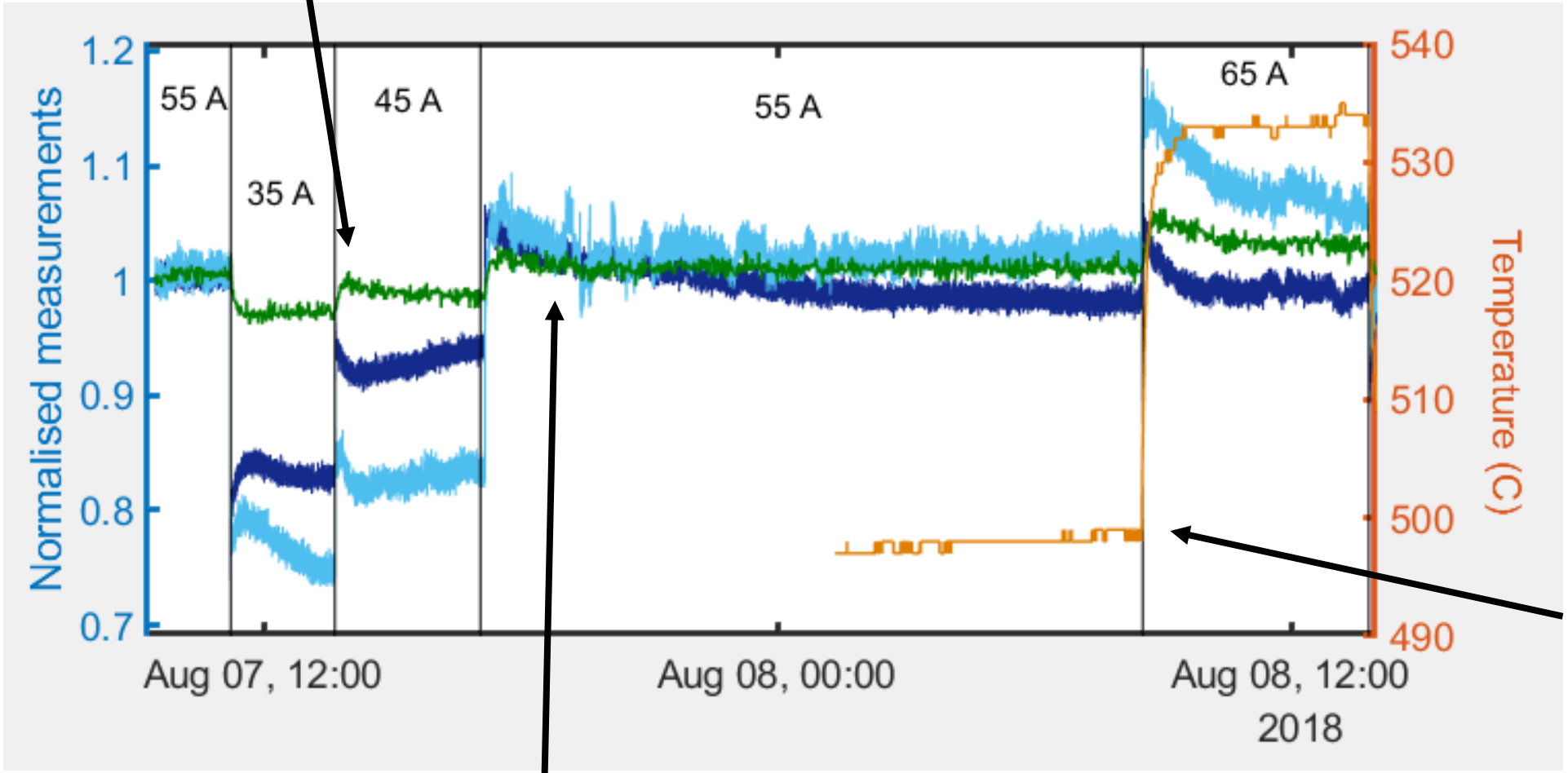


Cathode temperature increases in steps observed but not recorded due to controls network maintenance

Cs line, QCM, and $H\beta$ all increase in bumps, tailing off at increased values

Discharge current (2)

Temporary increase, as before



Expect similar behaviour to air flow tests, superposed with something else

Unsure why QCM settles at new values

Characterisation experiments: Summary

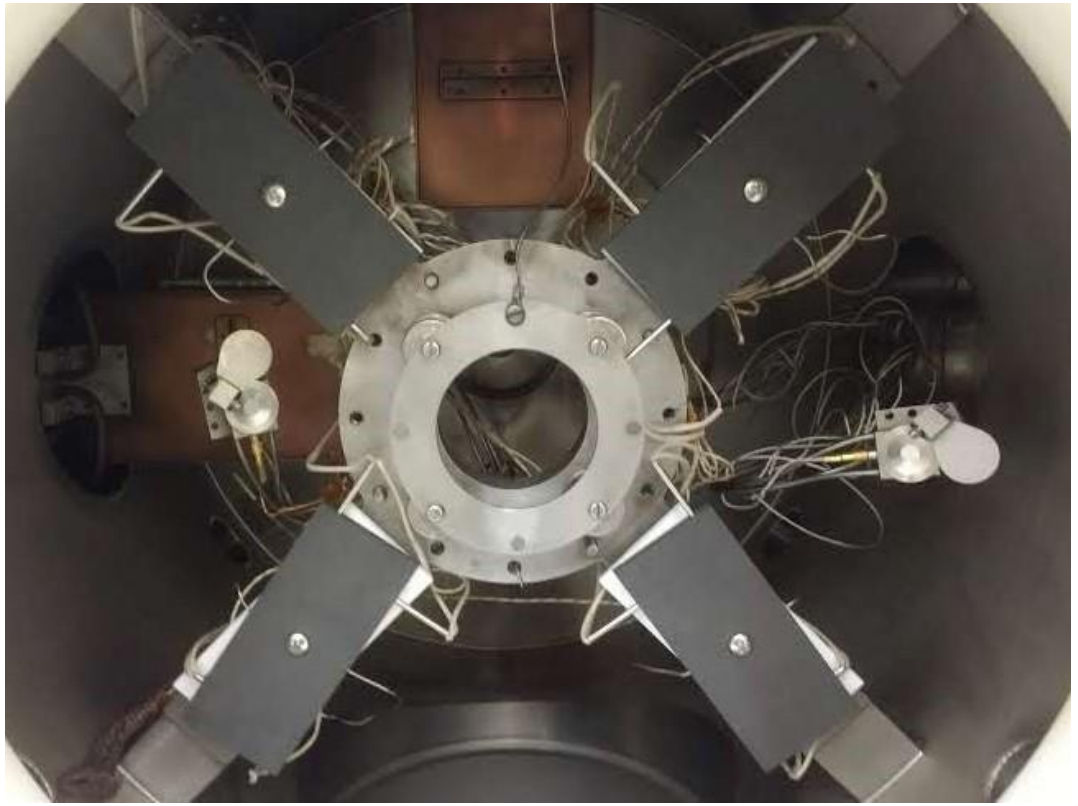
- Have a record of how observables change in response to sudden source changes
- Behaviour partially explained by presence of caesium reservoir
- Still lack understanding:
  - Why accumulation rate changes when oven doesn't
  - When arc voltage increases or decreases
  - When in or out of the pulse caesium leaves the surface and source

Characterisation experiments: Next steps

- Repeat these experiments, tracking hydrogen ratio
- Use more QCMs
- Improve time resolution to see during and between pulses to learn when caesium
  - Escapes the source
  - Evaporates from the surface
- Fix position of QCMs and optics

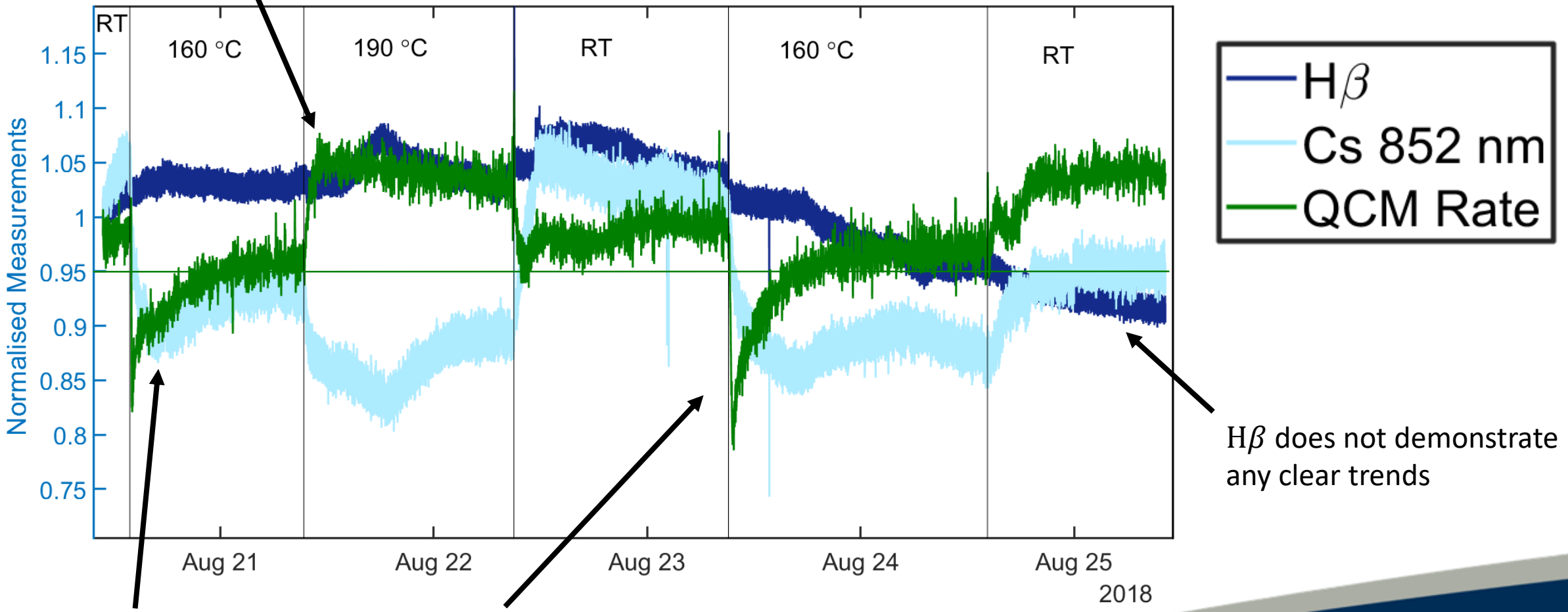
Experiments with graphite

- Baked at 200 °C until changing the temperature had no effect on vessel pressure, indicating end of outgassing (2 days)
- Source started with graphite at room temperature,
  160 °C and 190 °C
- Did not require changes to operational settings



Experiments with graphite

At 190 °C QCM increases higher than at RT
Cs line drops further



Hβ does not demonstrate any clear trends

QCM rate sharply decreases, becoming negative when heated to 160 °C before flattening still lower than at RT

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Graphite experiments: Summary

- QCM accumulation and caesium line are clearly affected

  (Caesium in vessel) (Caesium in plasma)

- Unclear how plasma light can be affected by graphite temperature
  - Related to caesium pressure in the vessel?

- Appears there is a temperature range around 160 °C where gettering occurs

Graphite experiments: Next steps

- As we speak other temperatures are being trialled
- Improve time resolution to observe during pulse
  - Could this help understand why light is affected?
- Fix QCM and optics with frame
- Use more QCMs

Improving time resolution: Ionisation monitor

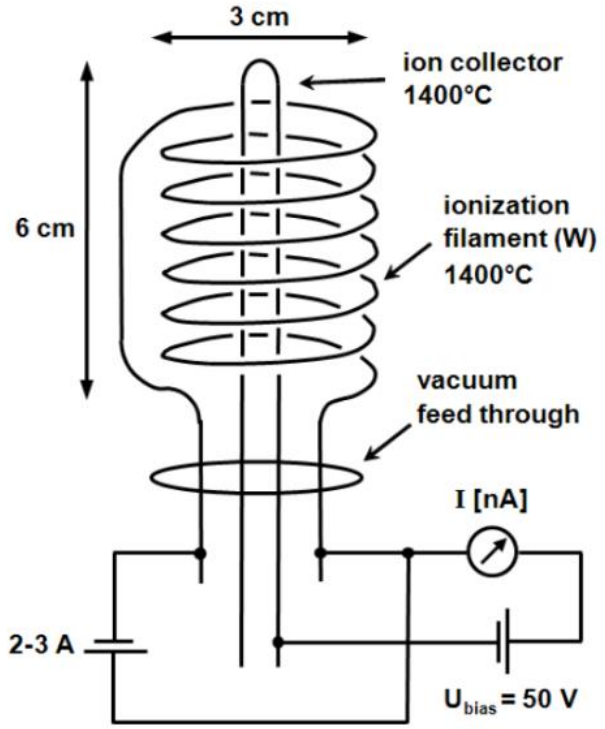

Figure 4.8.: Schematic illustration of a surface ionization detector (SID) consisting of the tungsten ionization filament and the biased ion collector.

- Caesium deposited on the filament is ionized
- The measured current is proportional to the amount of incoming caesium

Gutser R. Experiments and simulations for the dynamics of cesium in negative hydrogen ion sources for ITER N-NBI.

Improving time resolution: Optical kit

- Light collected through optical fibres
- Bandpass filters
- Silicon photomultipliers

Conclusions

- Still very early
- Many unexpected results which don’t yet have explanations
- Exciting early indications that graphite may reduce presence of caesium in the vessel motivate further investigation

Thank you for your attention