# OPTICAL THERMOMETRY OF THERMAL ATOMIC SOURCES FOR NEXT GENERATION NEUTRINO MASS MEASUREMENTS


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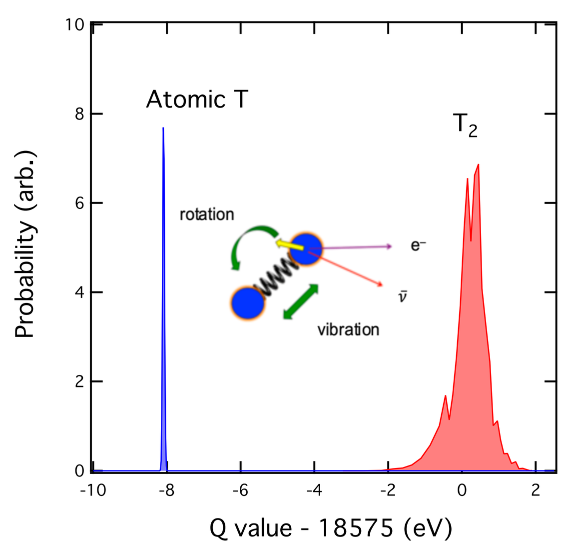
## Atomic Tritium



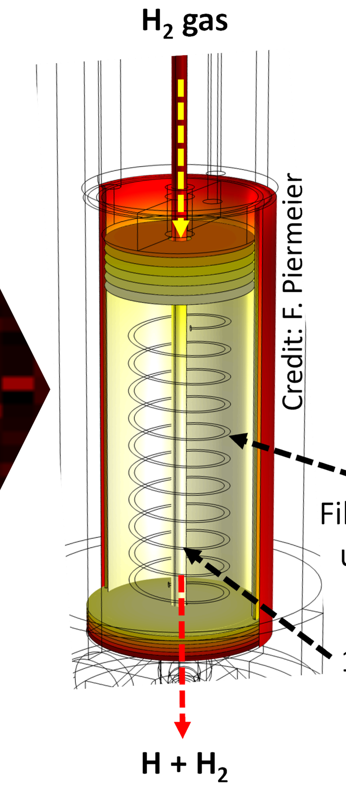

J. Formaggio et al., doi.org/10.1016/j.physrep.2021.02.002

**Atomic density:**
**n(T) ~ $10^{17}$ /m³**

**Ensemble purity:**
**$n(T_2)/n(T) < 10^{-4}$**

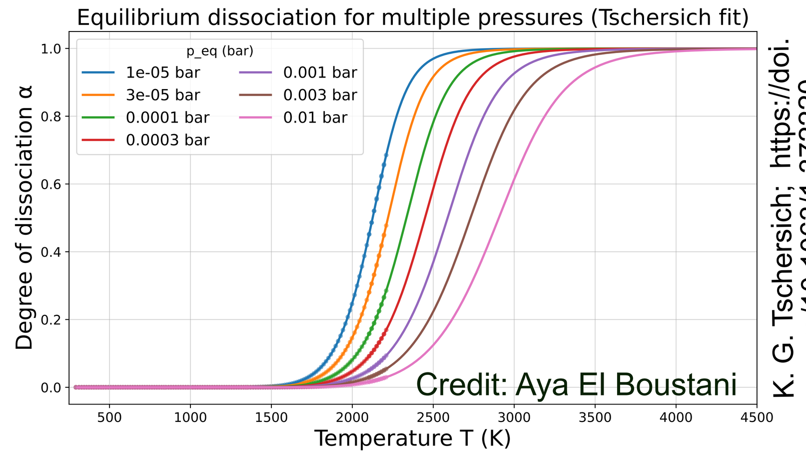
**Project 8** → CRES measurements, 40 meV/c² target sensitivity
**KATRIN++** → Differential measurements, 50 meV/c² target sensitivity

## Thermal Atomic Sources




- Dissociation occurs mainly on the hot capillary walls
- Neutral atomic beam production
- R&D with hydrogen at JGU Mainz
- Tritium testing at Tritium Laboratory Karlsruhe

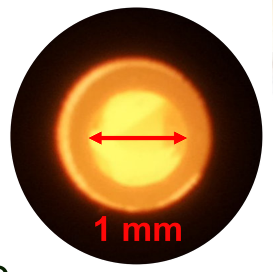
$$\alpha(p,T) = \sqrt{\frac{K_p(T)}{4\frac{p_{equ}}{p^0} + K_p(T)}}$$



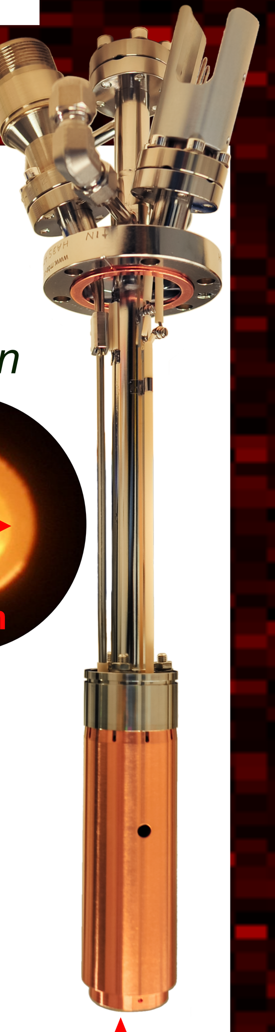

K. G. Tschersich: https://doi.org/10.1063/1.372220

## Challenges

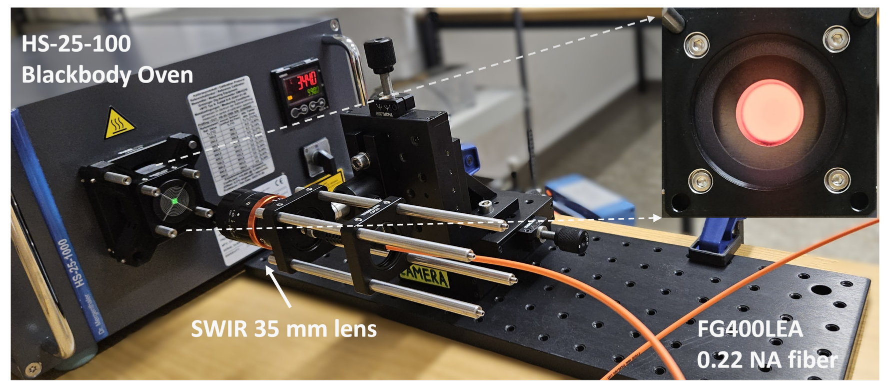
*Temperature measurements are important for atomic fraction measurements!*

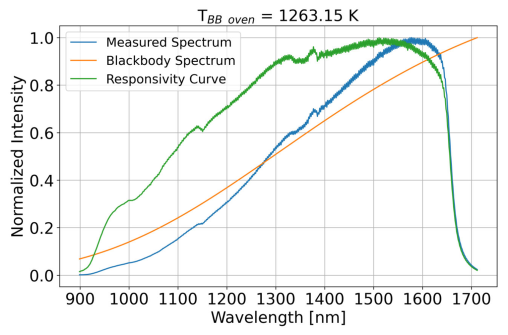



- **A suitable sensor must:**
  - operate at high temperatures (no direct contact)
  - be vacuum-compatible with a low outgassing rate
  - be tritium compatible
- **Source temperature drifts with thermal cycling:**
  - High measurement accuracy and repeatability needed

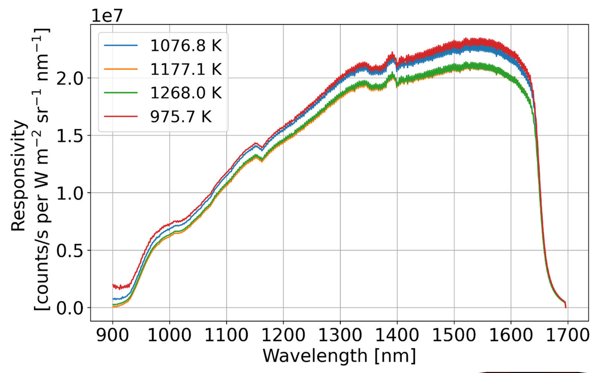


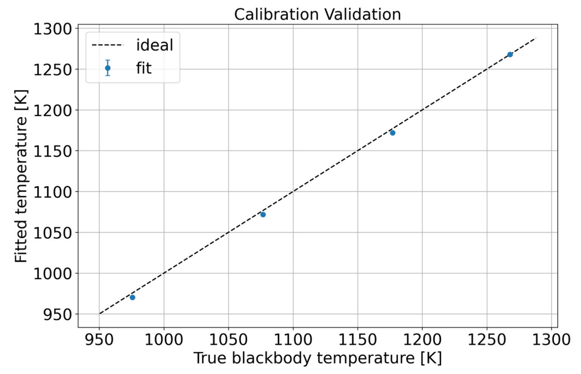

## 2. Optical Responsivity Calibration



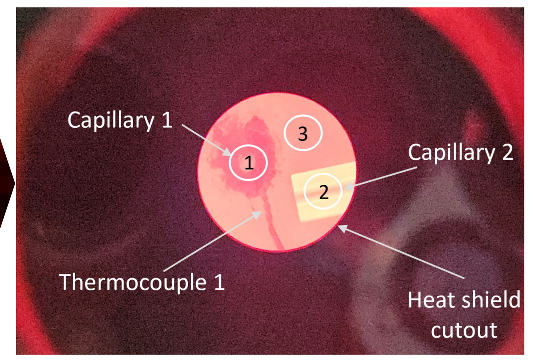

Pixel response scales non-linearly with light intensity → Temperature fit error ± 0.5%



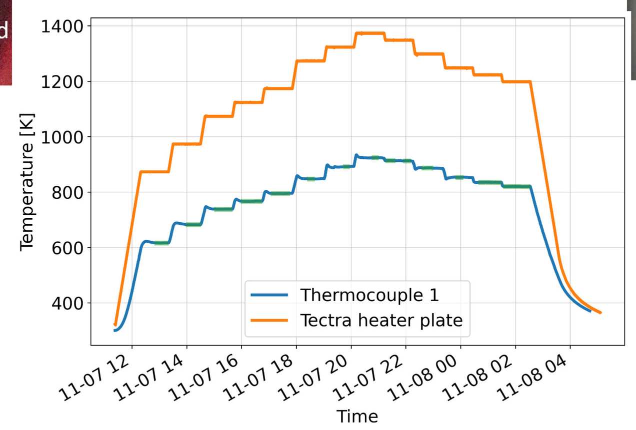

## 3. Emissivity Modeling

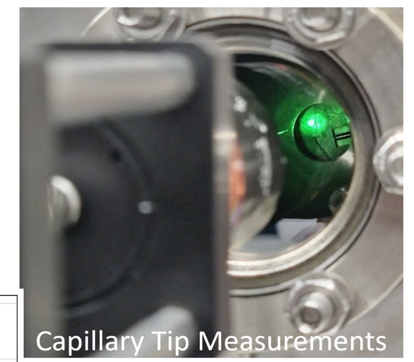
- Dedicated emissivity measuring setup built @ TLK
- Two unused W capillaries mounted on a sample heater ($T_{max}$ = 1500 °C)
- W capillary: 1.5 mm outer diameter, in vacuum

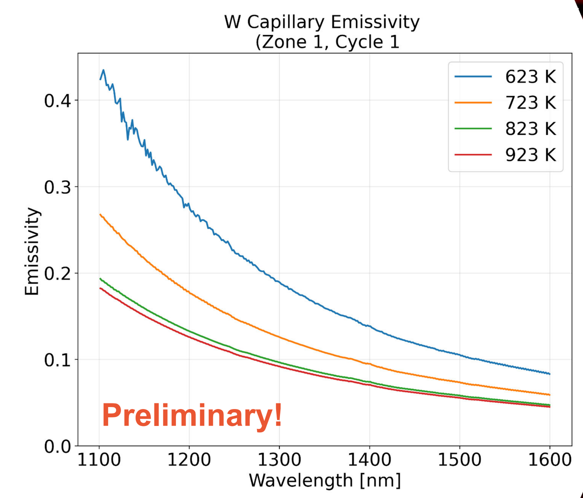



→ 3 measurement zones: (1) standing capillary, (2) side capillary and (3) Mo holder

→ Added two Type C thermocouples to improve zone-specific temperature accuracy



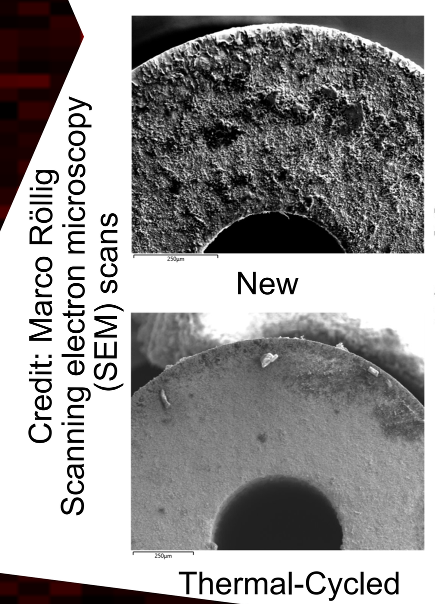



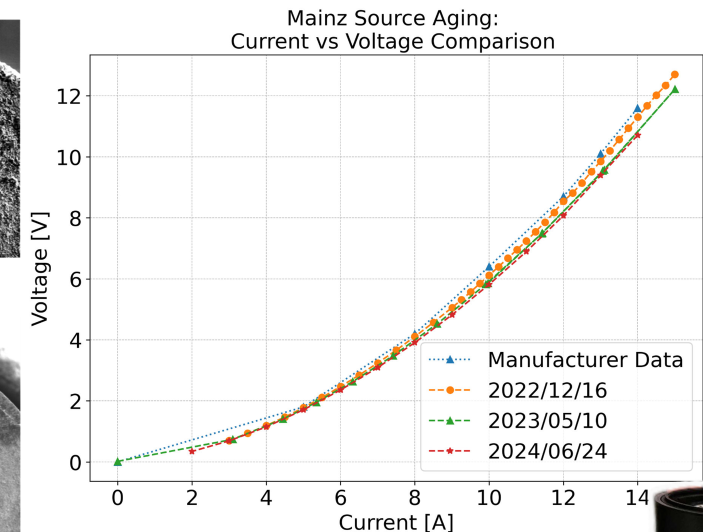




→ Temperature scan measurement to obtain ε(λ, T)

## 4. Thermal Cycling

Thermal cycling alters the capillary surface properties
→ Tungsten emissivity changes with each cycle
→ Source drifts to cooler temperatures
→ 16 temperature scans performed to determine ε(λ, T) changes with source aging

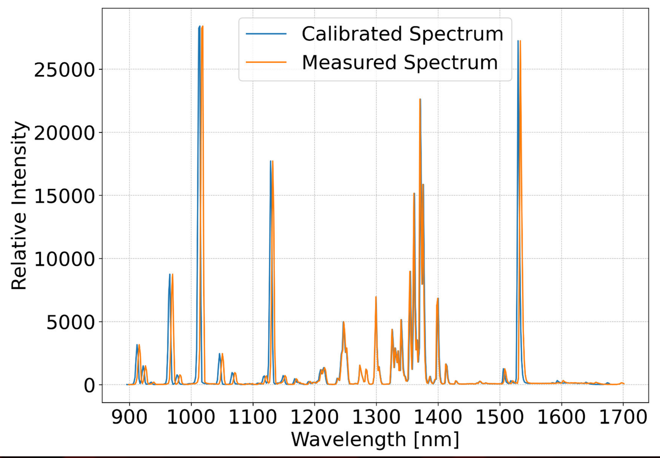


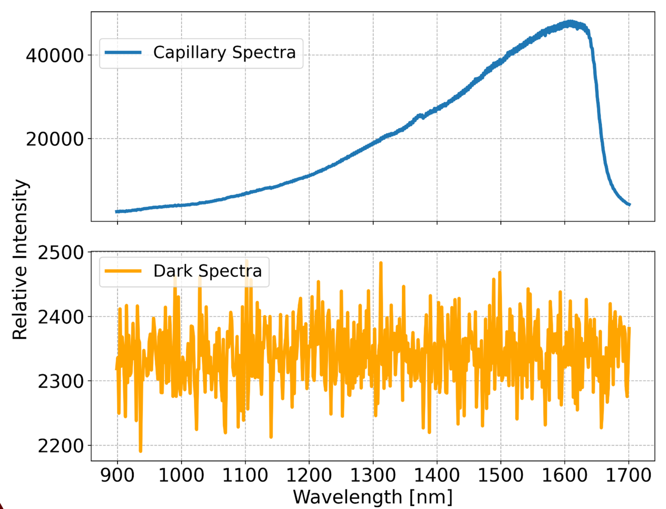

## 1. Wavelength Calibration

of the NIR spectrometer, using an Argon-Mercury calibration source

$$\lambda_p = 895.8 + 1.64\,p + 0.00039\,p^2 + 1.03 \cdot 10^{-6} p^3$$




## How to Measure the Temperature?

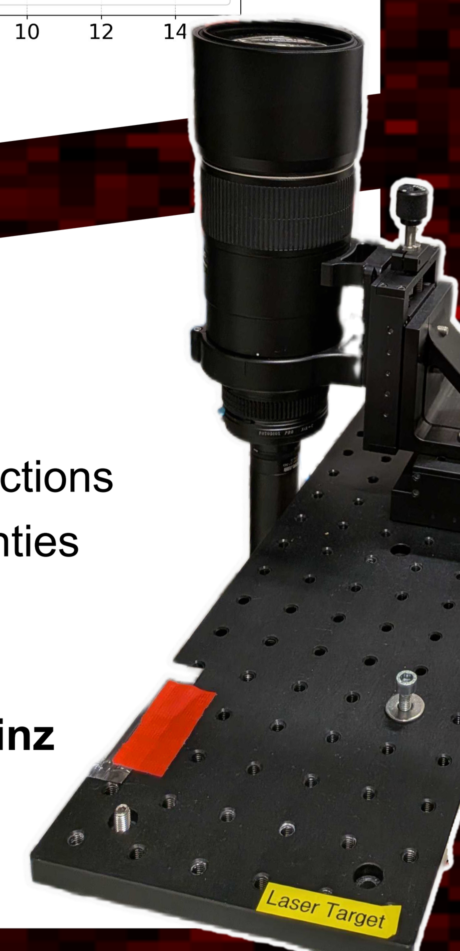



- InGaAs array 512x1 pixel spectrometer
- 900 nm - 1700 nm
- Spectral resolution of 3.75 nm @ 1128.75 nm
- Thermoelectrically cooled to improve SNR

$$L(\lambda,T,\theta,\phi) = K(\lambda)\cdot C(\lambda,\theta,\phi)\cdot \varepsilon_{cap}\left(\frac{2\,h\,c^2}{\lambda^5}\frac{1}{\exp\left(\frac{hc}{\lambda k_B T_{cap}}\right)-1}\right)$$

## 5. Next Steps

- Full tungsten emissivity model:
  - fiber etendue and optical system throughput corrections
  - Non-linearity corrections to reduce fitting uncertainties
  - Thermal cycling evolution
- **Atomic source temperature measurements in Mainz**
- **Obtain source dissociation efficiency!**





**This work has been supported by the Cluster of Excellence Precision Physics, Fundamental Interactions, and Structure of Matter (PRISMA++) and the Research Training Group GRK 2796 funded by the German Research Foundation (DFG).**