Automated Hyperspectral Pyrometry of Floating Zone Growths

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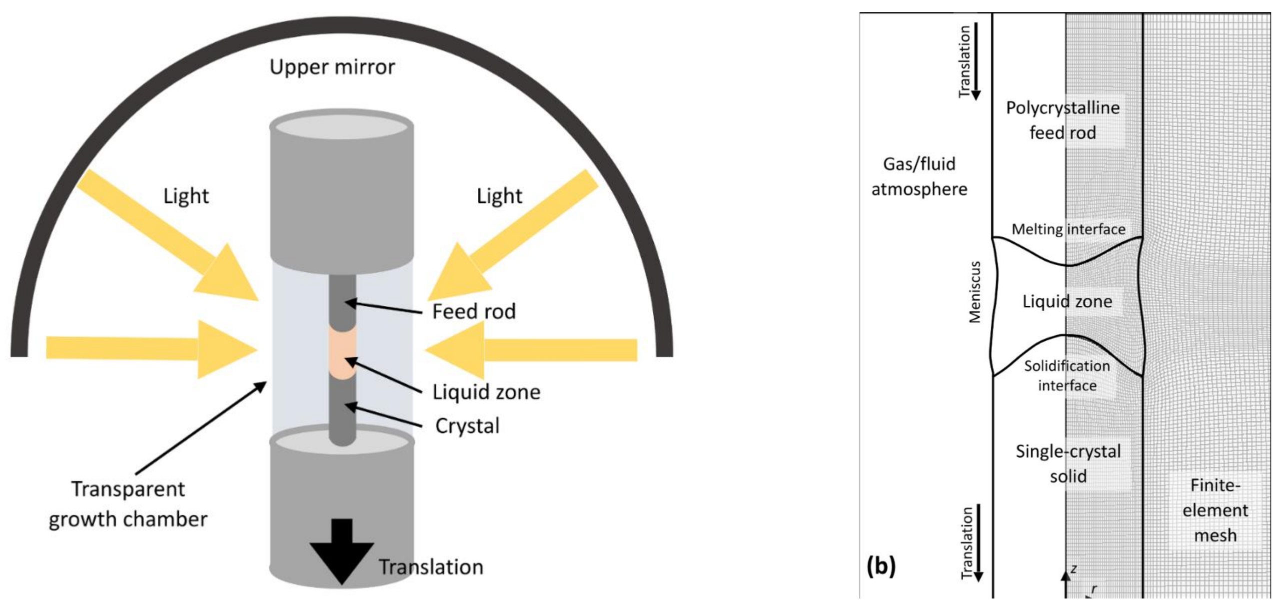
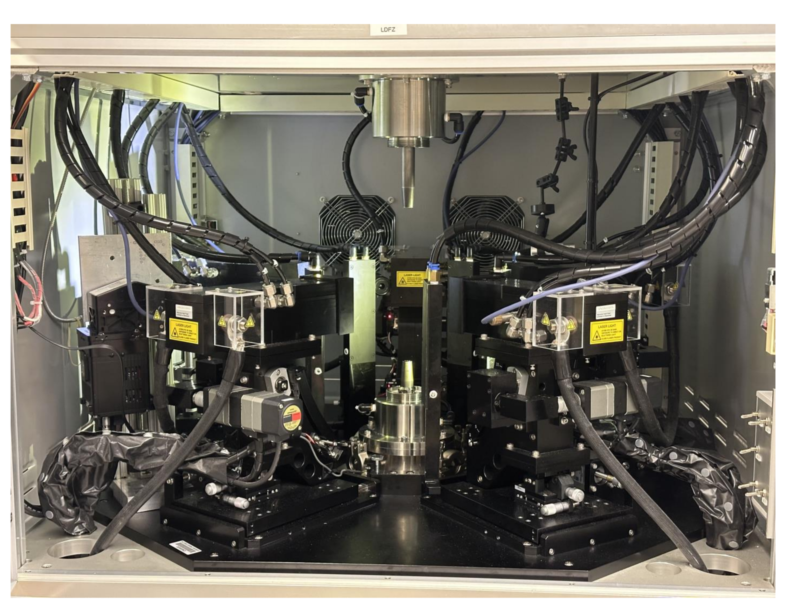
Introduction

- The **floating zone technique** is a popular bulk crystal growth technique for many reasons, including the ability to quickly synthesize small crystal samples and not needing a container in contact with the sample during growth.
- The tips of a crystal rod and a feed rod are heated and joined to form a **floating molten zone** from which a single crystal is extracted [1]

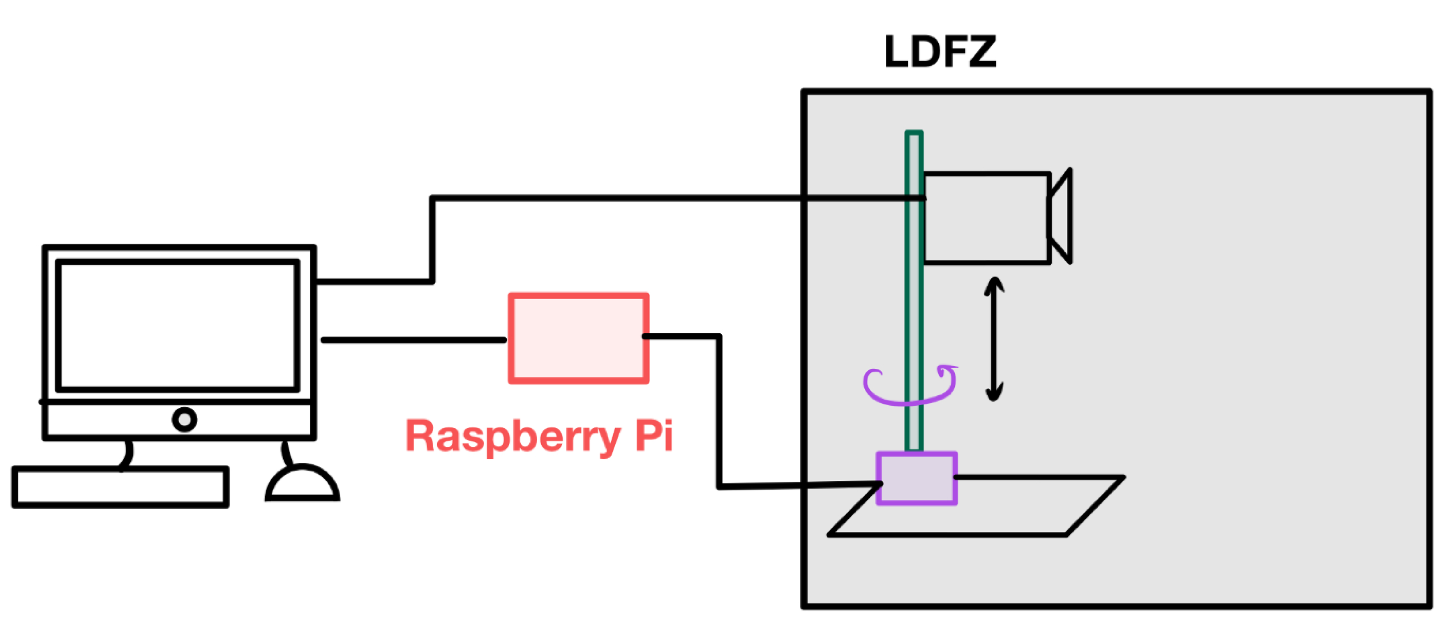


- **Temperature distribution** of the molten zone is a critical parameter in the physics of floating zone growths, so modelling seeks to simulate temperature distribution
- **Experimental data** is needed to inform and validate models, so we **develop infrastructure to collect temperature distribution data** from laboratory floating zone growths
- To measure temperature distribution, we set up a **hyperspectral camera** in the Laser Diode Floating Zone (LDFZ) furnace



Camera Setup

- The camera combines imaging and spectroscopy, measuring a **spectrum for each pixel** in the image
- Camera captures a line rather than a two-dimensional image, so it needs **vertical motion** in the furnace to scan a complete image



Hyperspectral Pyrometry

- Recognizing that heated materials emit **blackbody radiation**, we fit measured spectra to blackbody radiation spectra using **least squares regression** to determine temperature
- A few modifications are needed to the equation from physics theory

$$I_0(\lambda) = \left(\frac{2hc^2}{\lambda^5}\right)\left(e^{\frac{hc}{\lambda k_B T}} - 1\right)^{-1}$$

- To account for varying **emissivity of materials** and the camera's **relative scaling** of measured intensity values, we add an emissivity term to our model equation
- Emissivity may also vary with wavelength, so we use a **quadratic approximation** to model this dependence [2]

$$I(\lambda) = \left(a_0 + a_1\lambda + a_2\lambda^2\right) I_0(\lambda)$$

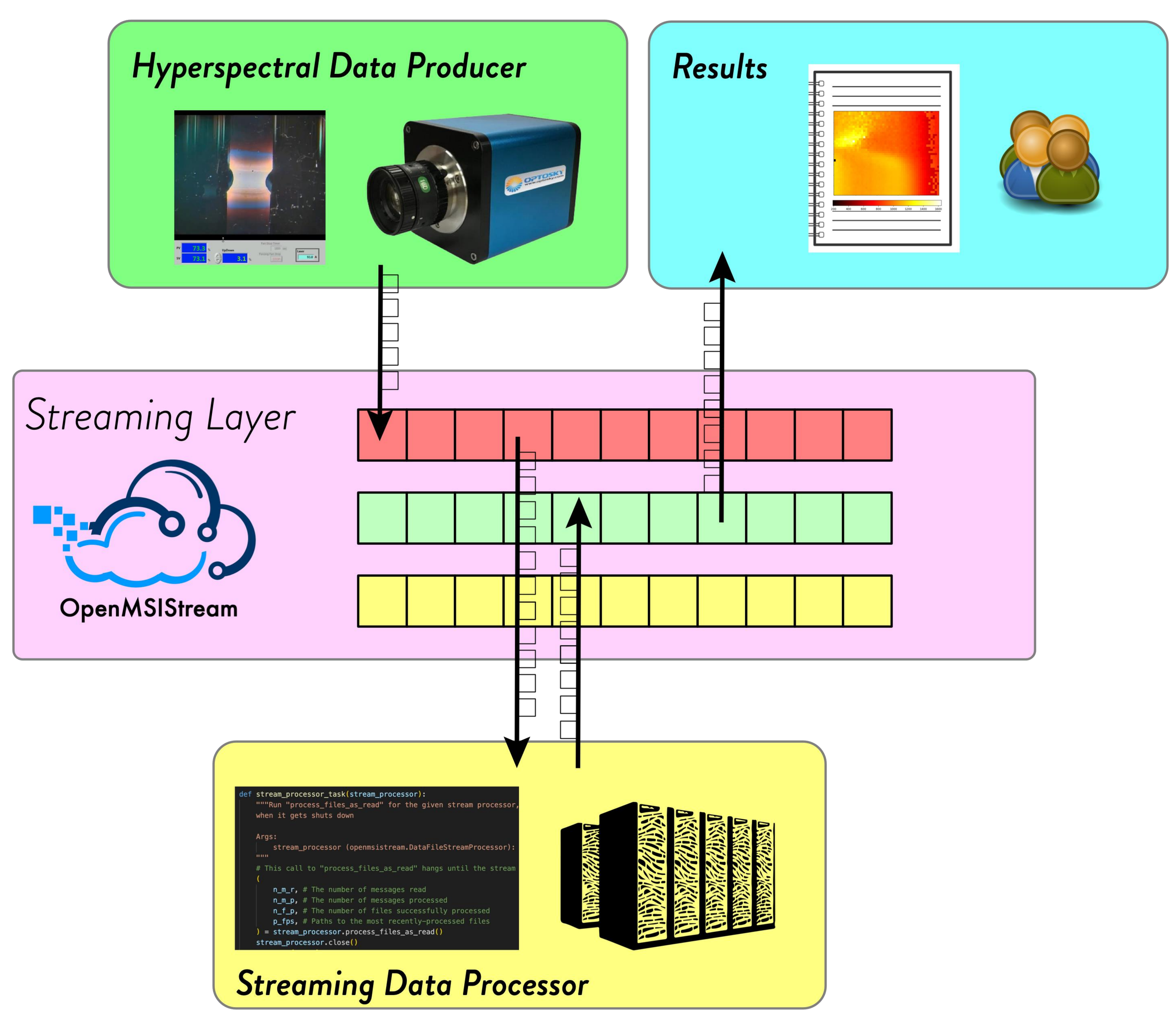
- To account for **stray light** in the image and the camera's **internal correction** of intensity values against background references, we add a constant offset to get the final model equation

$$I(\lambda) = \left(a_0 + a_1\lambda + a_2\lambda^2\right) I_0(\lambda) + \Omega$$

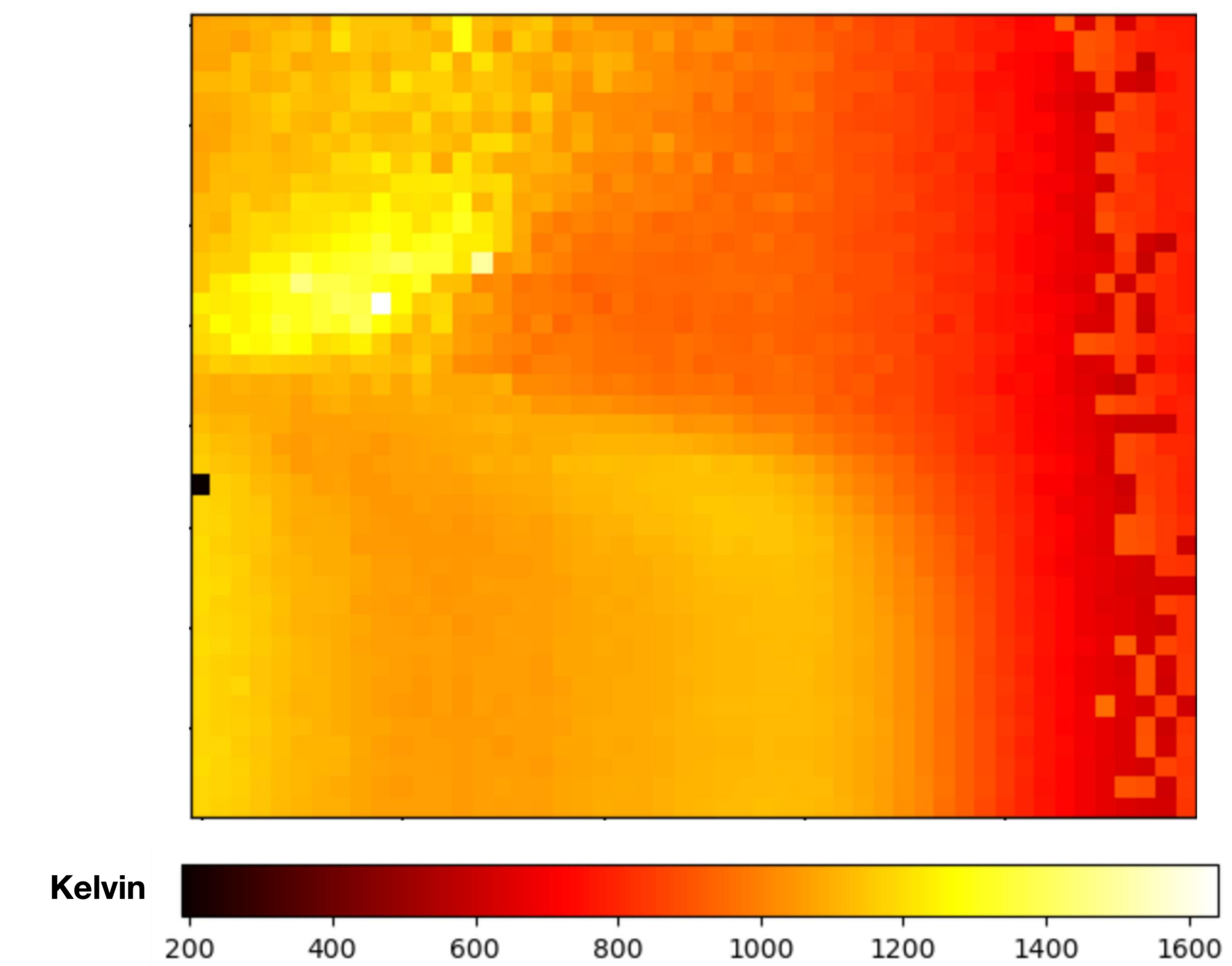
- We fit measured spectra to this equation with parameters a_0, a_1, a_2, Ω and the **desired result T**

Data Streaming

- With data streaming, we **automate the data analysis process** to allow real-time measurement for furnace users and seamless large-scale data collection [3]



Results and Discussion



- This is a processed image of a section of the molten zone. We can see the outline of a section of the molten zone and a detailed temperature distribution
- Aligning the camera and **focusing in on the molten zone** proved to be a non-trivial task
- Testing for the pyrometry method was performed using images not from an active floating zone growth, so adjustments and optimizations may be possible for growths. Future work will investigate these options and more **rigorously validate the method**
- A failed regression produced the dark pixel. Future work will investigate methods to **reduce the failure rate of regressions** and methods to **filter out failed regressions** for future use of the data

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References

[1] Scott S. Dossa and Jeffrey J. Derby. Modeling optical floating zone crystal growth in a high-pressure, single-lamp furnace. Journal of Crystal Growth, 591:126723, 2022.
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[3] Margaret Eminizer, Sam Tabrisky, Amir Sharifzadeh, Christopher DiMarco, Jacob M. Diamond, K.t.Ramesh, Todd C. Hufnagel, Tyrel M. McQueen, and David Elbert. Openmsistream: A python package for facilitating integration of streaming data in diverse laboratory environments. Journal of Open Source Software, 8(83):4896, 2023.