https://aniketdashpute.github.io/TSF/

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Thermal Spread Functions (TSF): Physics-Guided Material Classification

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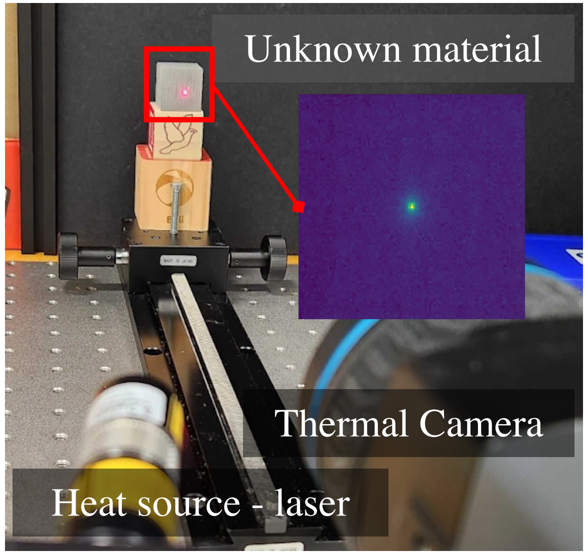
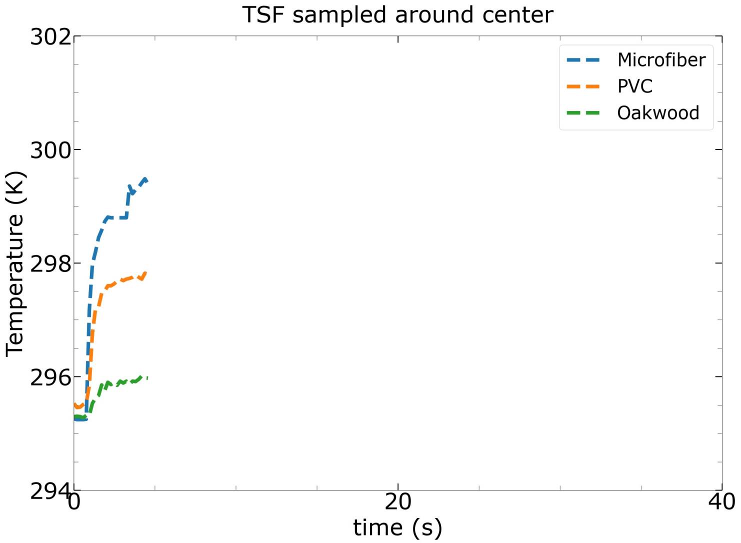
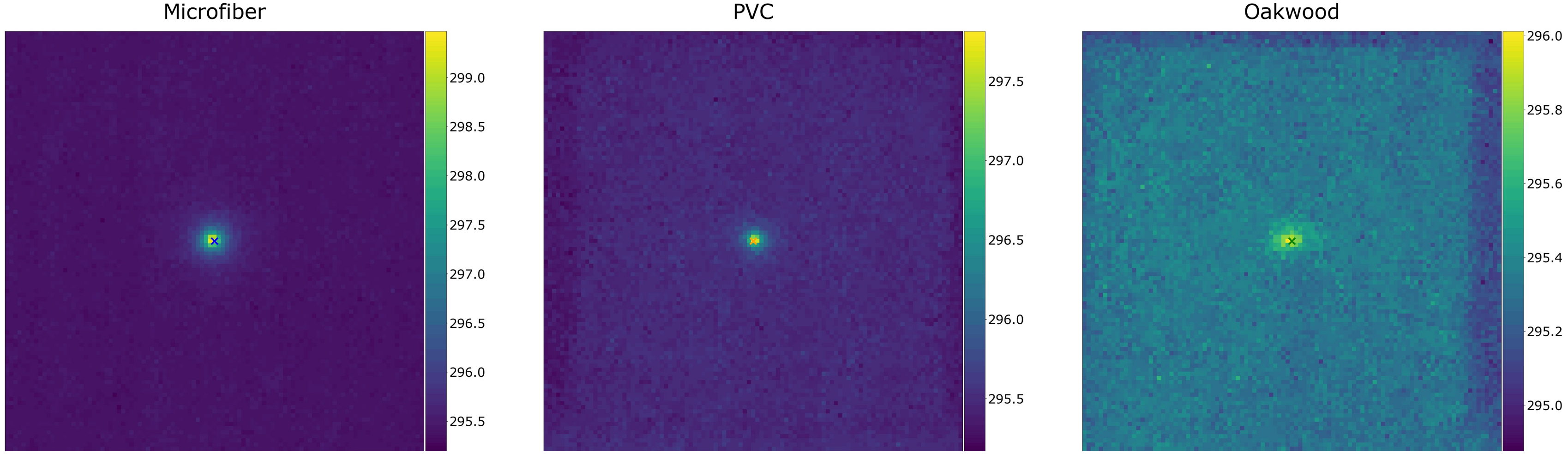
TUE-AM-156

1 RICE 2 Northwestern University 3 The University of Arizona

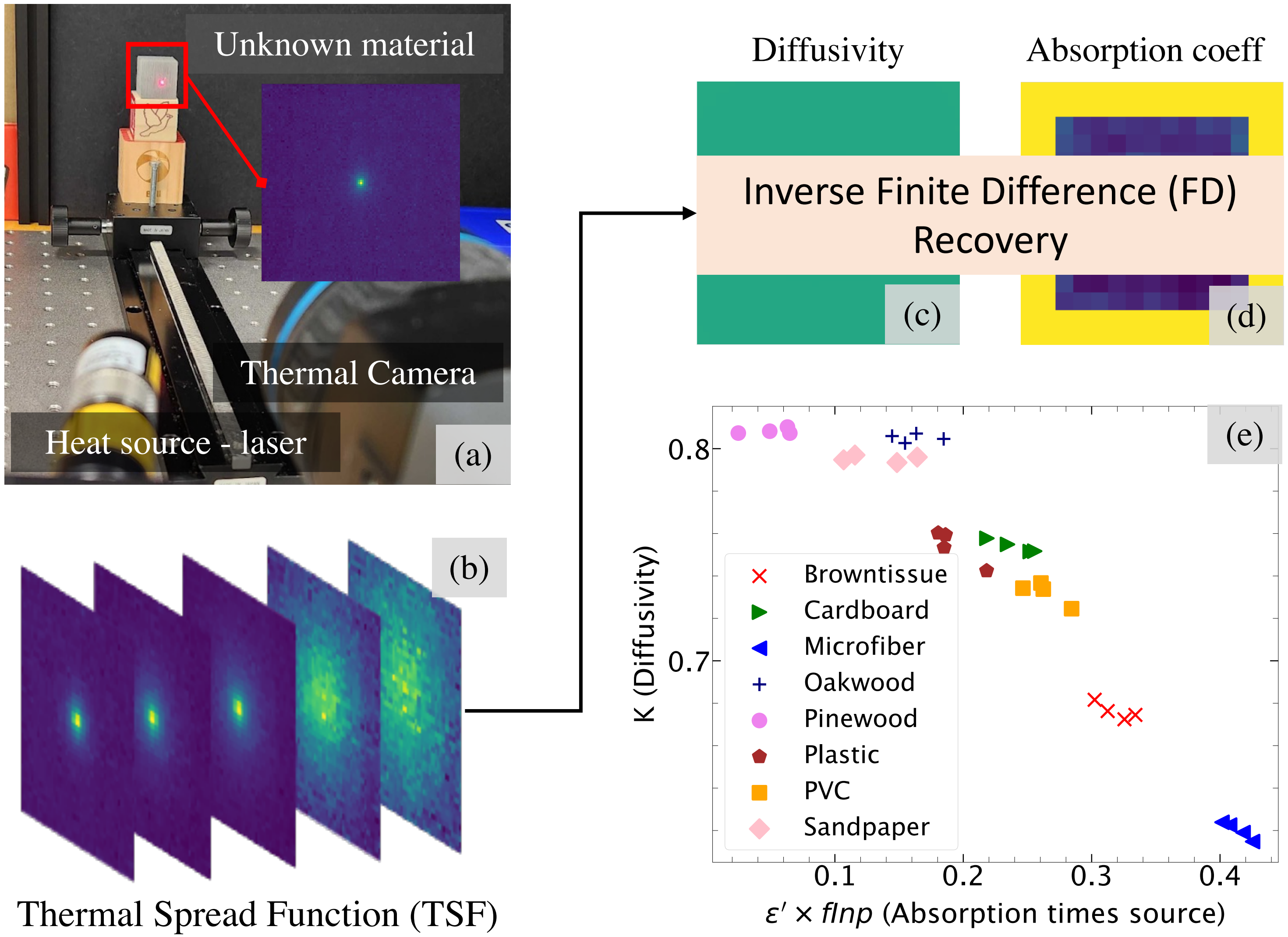
Heating & Cooling - Unique Plots!







Thermal Spread Functions



Material Classification - Current practices

BRDF and Color/NIR based Classification
Require large labeled datasets, Not robust enough

Figure 1: A typical photograph from a wood sample in the a) visible b) NIR part of the spectrum. The colorant is transparent to the NIR and intrinsic texture is observed.

Wang, Oliver, Prabath Gunawardane, Steve Scher, and James Davis. "Material classification using BRDF slices." In 2009 IEEE Conference on Computer Vision and Pattern Recognition, pp. 2805-2811. IEEE, 2009.

Salamati, Neda, Clément Fredembach, and Sabine Süsstrunk. "Material classification using color and NIR images." In Proc. IS&T;/SID 17th Color Imaging Conference (CIC), no. CONF. 2009.

Current practices

Spectral Imaging
Only surface nature of material identified

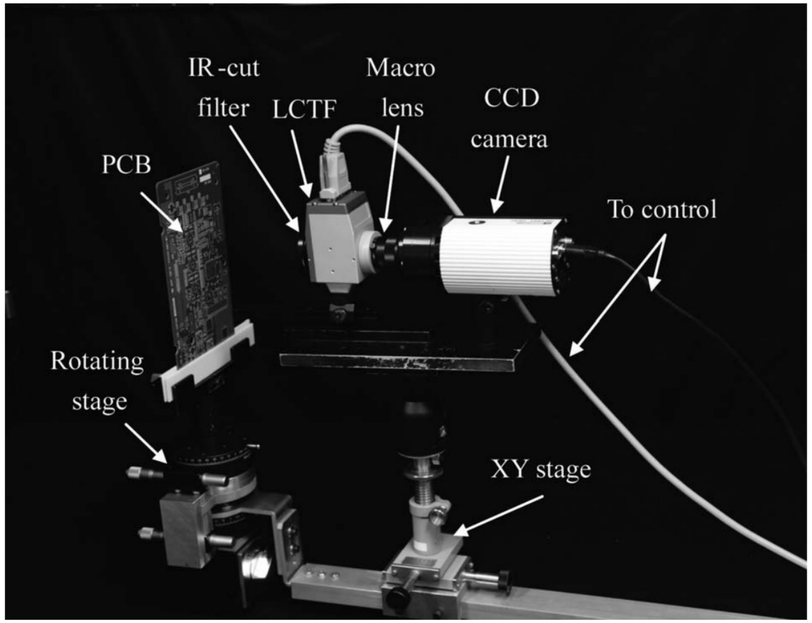


Fig. 1 The proposed spectral imaging system.

Haptic Sensing
Invasive - can change the scene

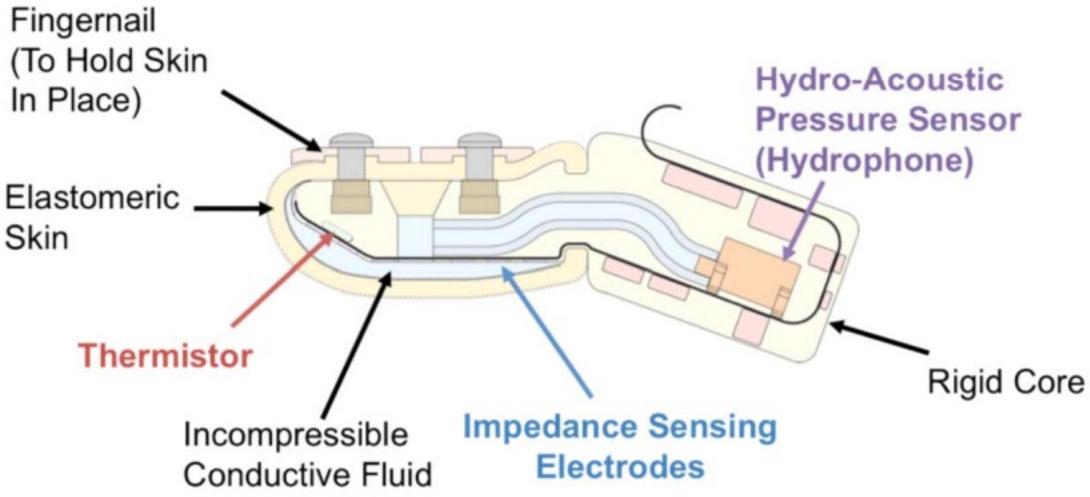
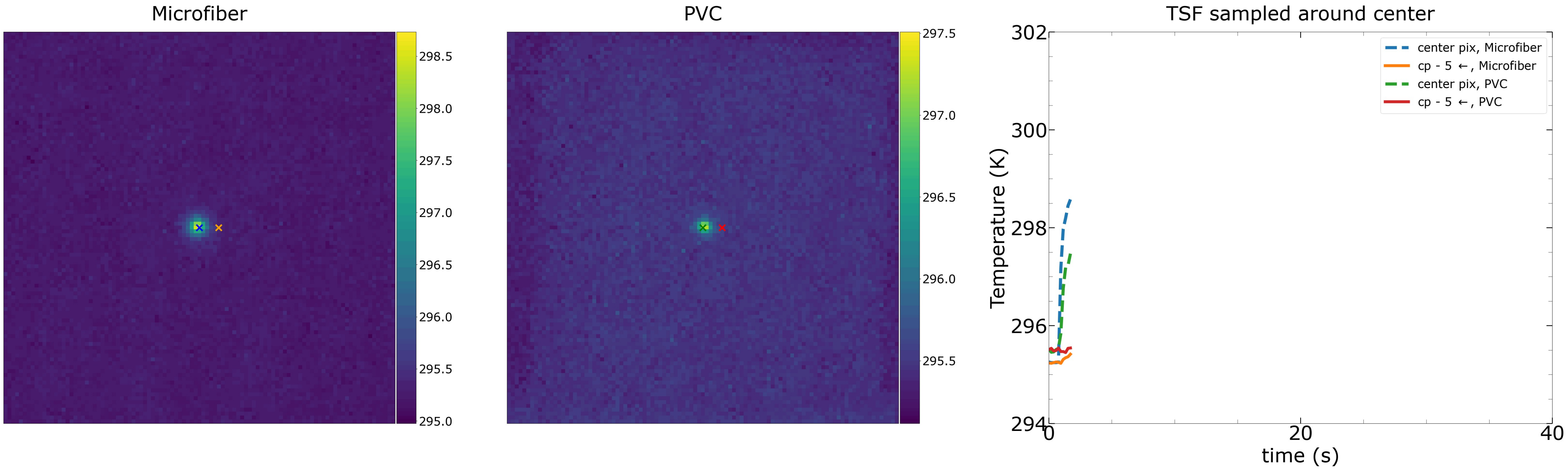


Fig. 1. Cross Section View of BioTAC Fingertip Tactile Sensor

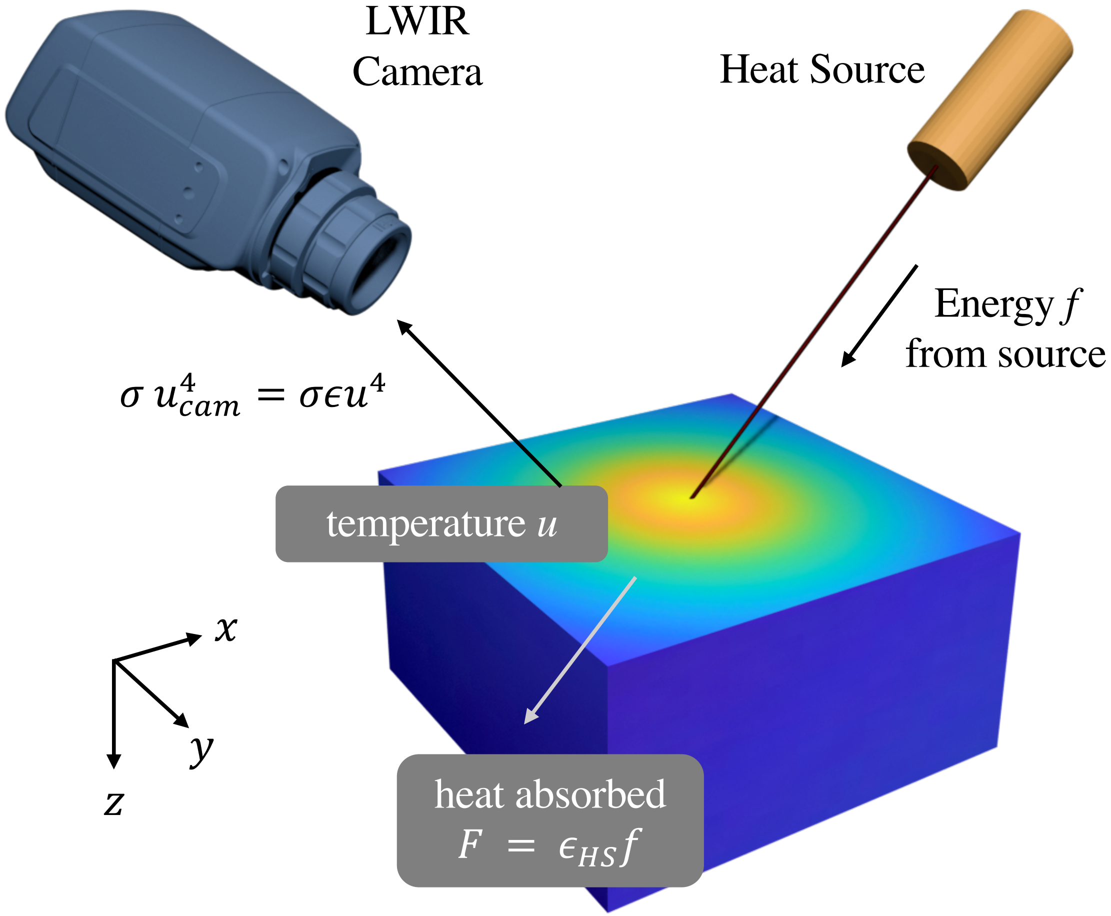
Ibrahim, Abdelhameed F., Shoji Tominaga, and Takahiko Horiuchi. "Spectral imaging method for material classification and inspection of printed circuit boards." *Optical Engineering* 49.5 (2010): 057201.

Kerr, Emmett, T. Martin McGinnity, and Sonya Coleman. "Material classification based on thermal properties—A robot and human evaluation." *2013 IEEE International Conference on Robotics and Biomimetics (ROBIO)*. IEEE, 2013.

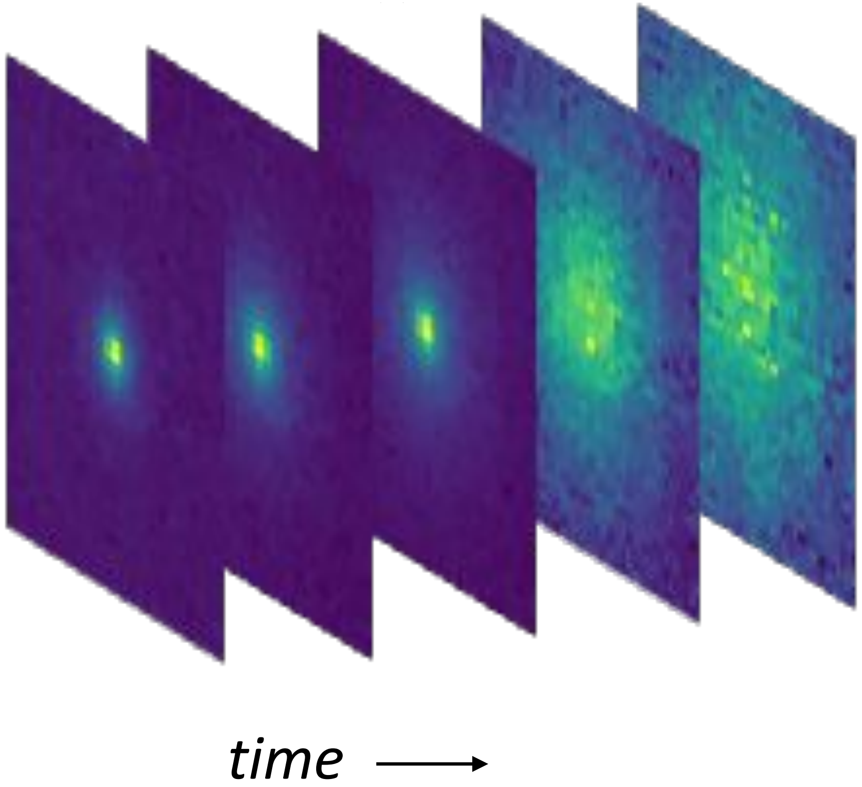
How are we solving it?



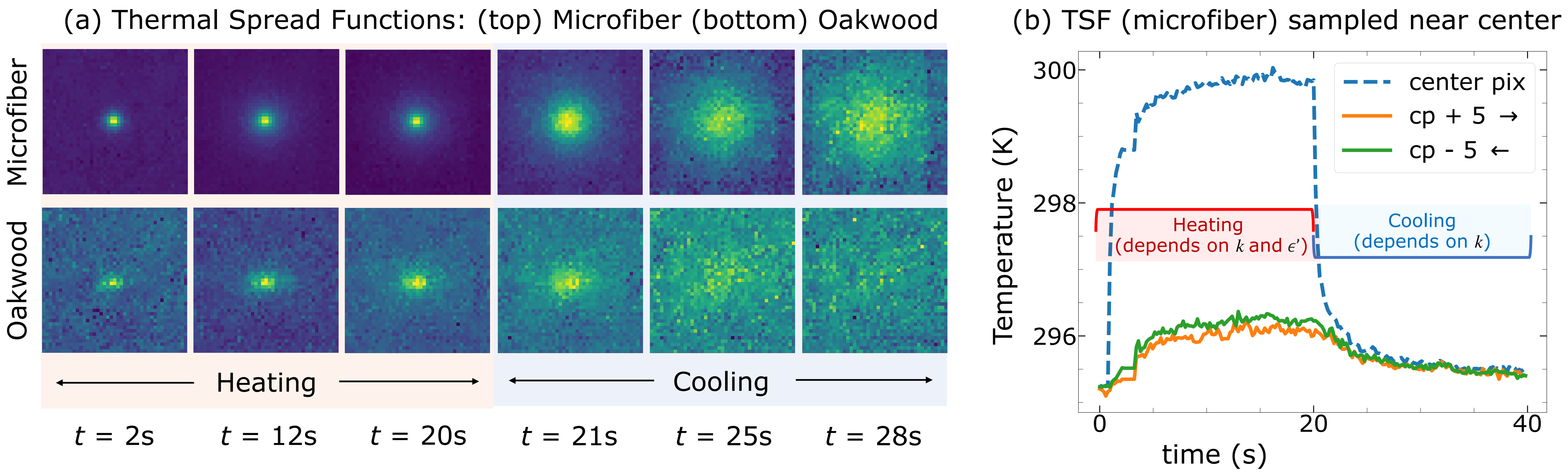
Thermal Spread Functions



Stack of thermal images showing the transients



Thermal Spread Functions



How does it work?

Heat Equation with external heat source

Absorption/Emission coefficient

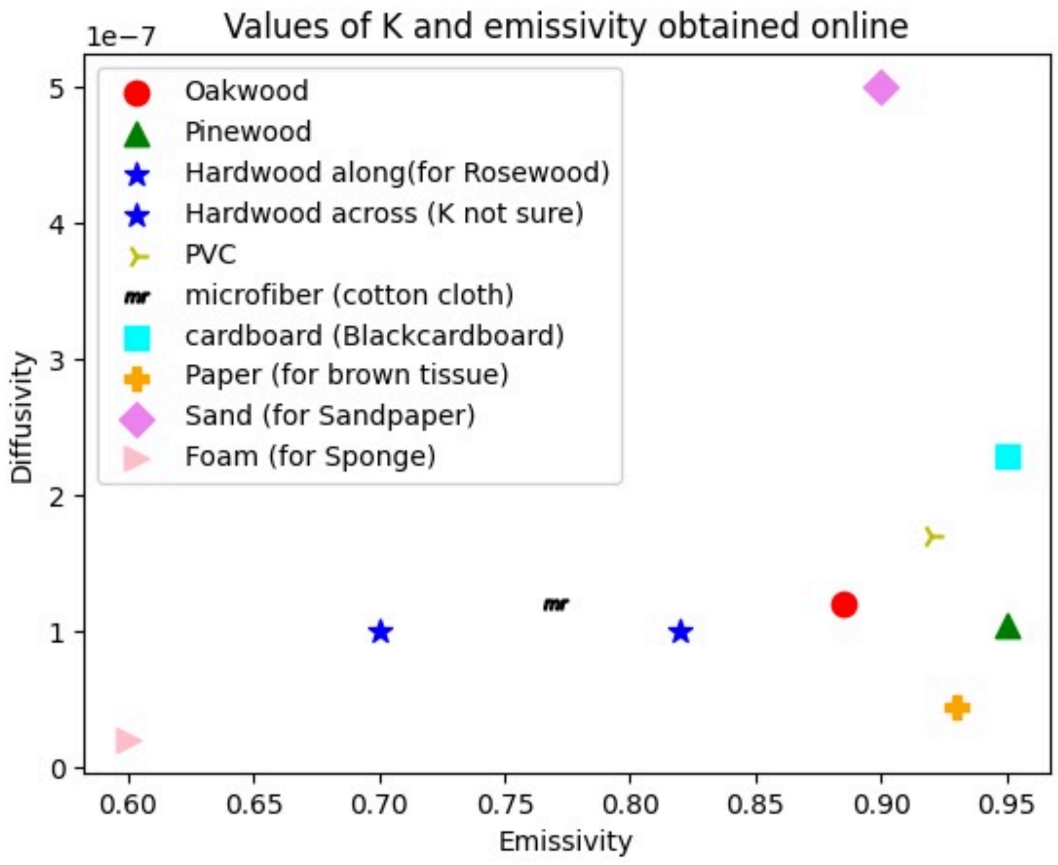
$$u_t = k \cdot u_{xx} + \epsilon' \cdot f$$

Diffusivity

External Heat Source

Notations: $u_t = \frac{\partial u_C}{\partial t}, \quad u_{xx} = \frac{\partial^2 u_C}{\partial x^2}$

Real values of diffusivity and emissivity



Source: https://material-properties.org/

How do we solve this?

Heat Equation with external heat source

$$u_t = k \cdot u_{xx} + \epsilon' \cdot f$$

Absorption/Emission coefficient (ϵ')

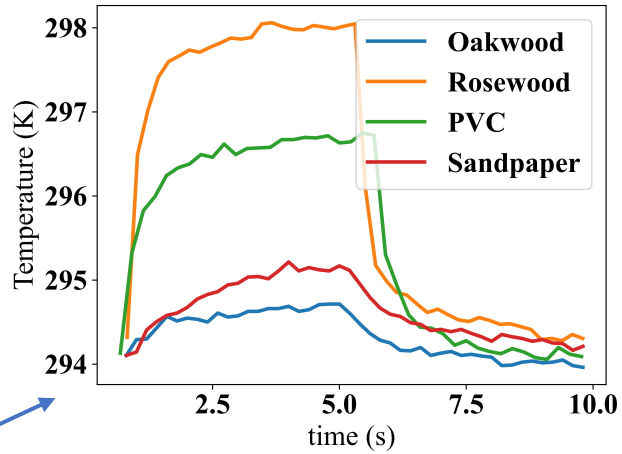
Diffusivity (k)

External Heat Source (f)

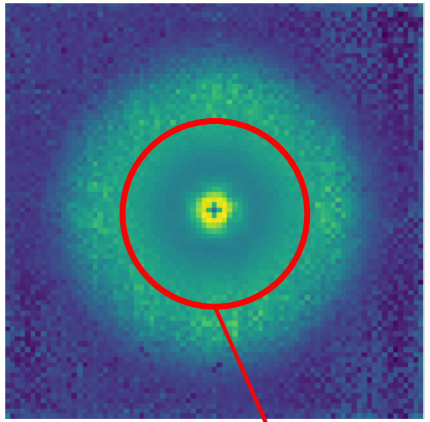
Notations: $u_t = \frac{\partial u_C}{\partial t}, \quad u_{xx} = \frac{\partial^2 u_C}{\partial x^2}$

Image Based 2D Analysis

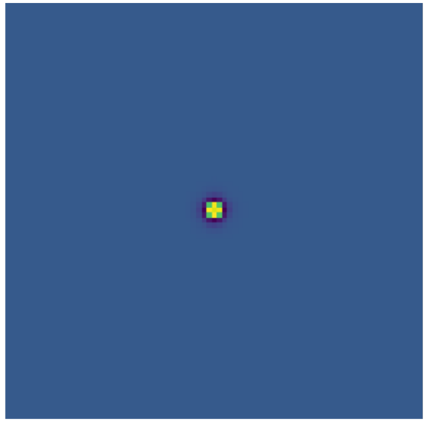
Take time derivative of these curves



Diffusivity k



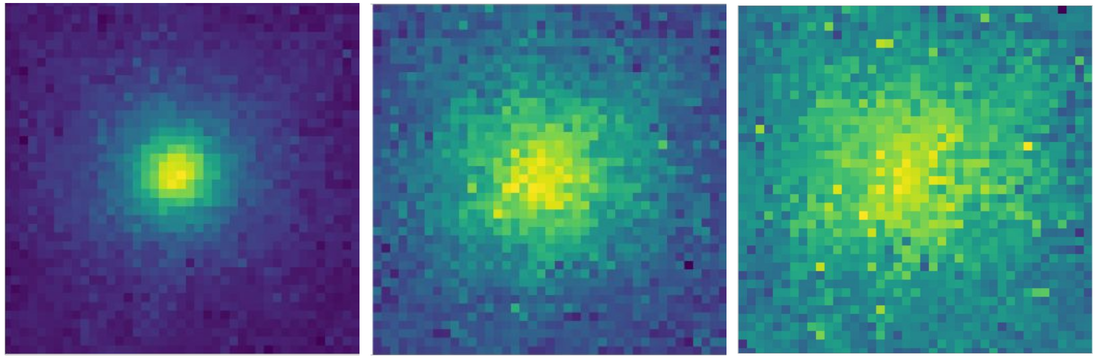
Absorption ϵ'



Non uniformities

$$u_t = k \cdot \Delta u_{xyz} + \epsilon' \cdot f$$

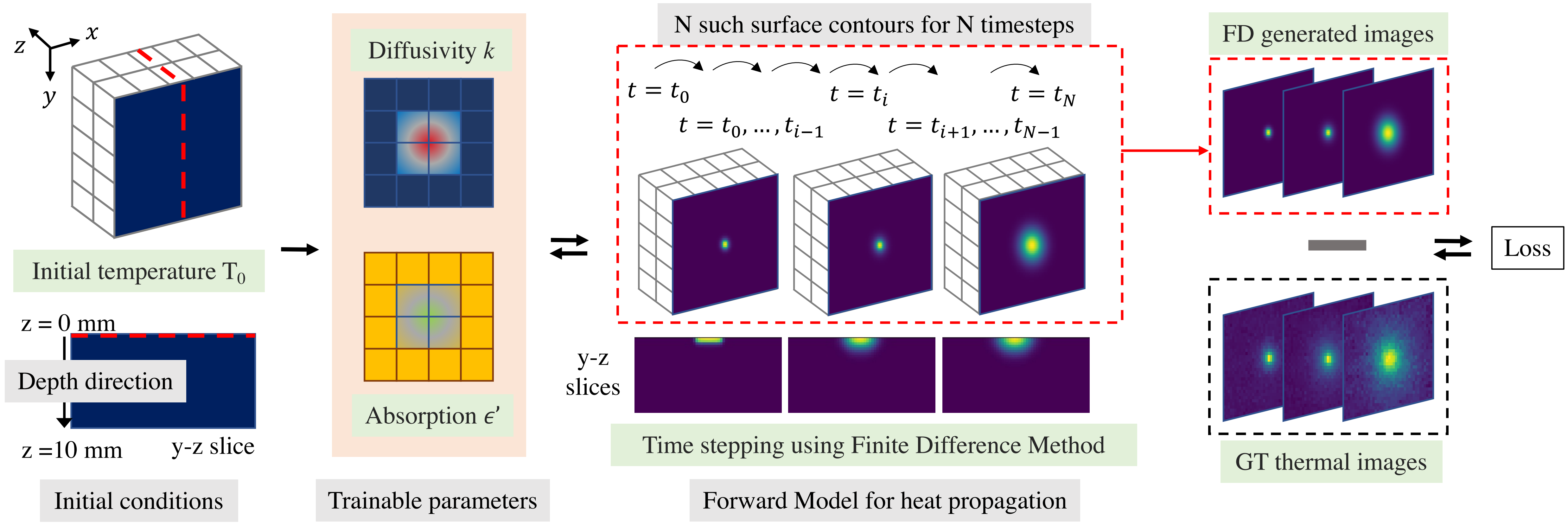
t = 21s t = 24s t = 27s



Take spatial 2D Laplacians of images

* $\Delta u_{xyz} = u_{xx} + u_{yy} + u_{zz}$

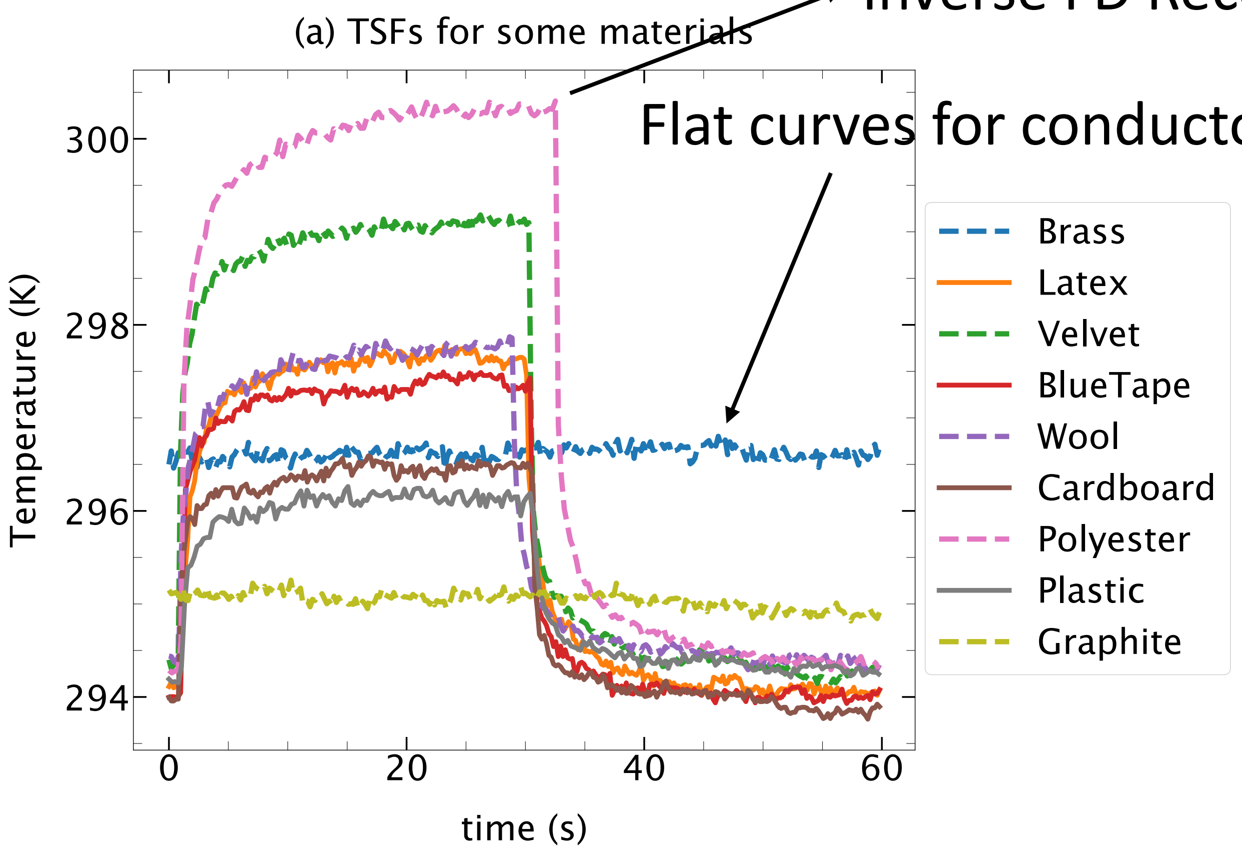
How do we solve it?

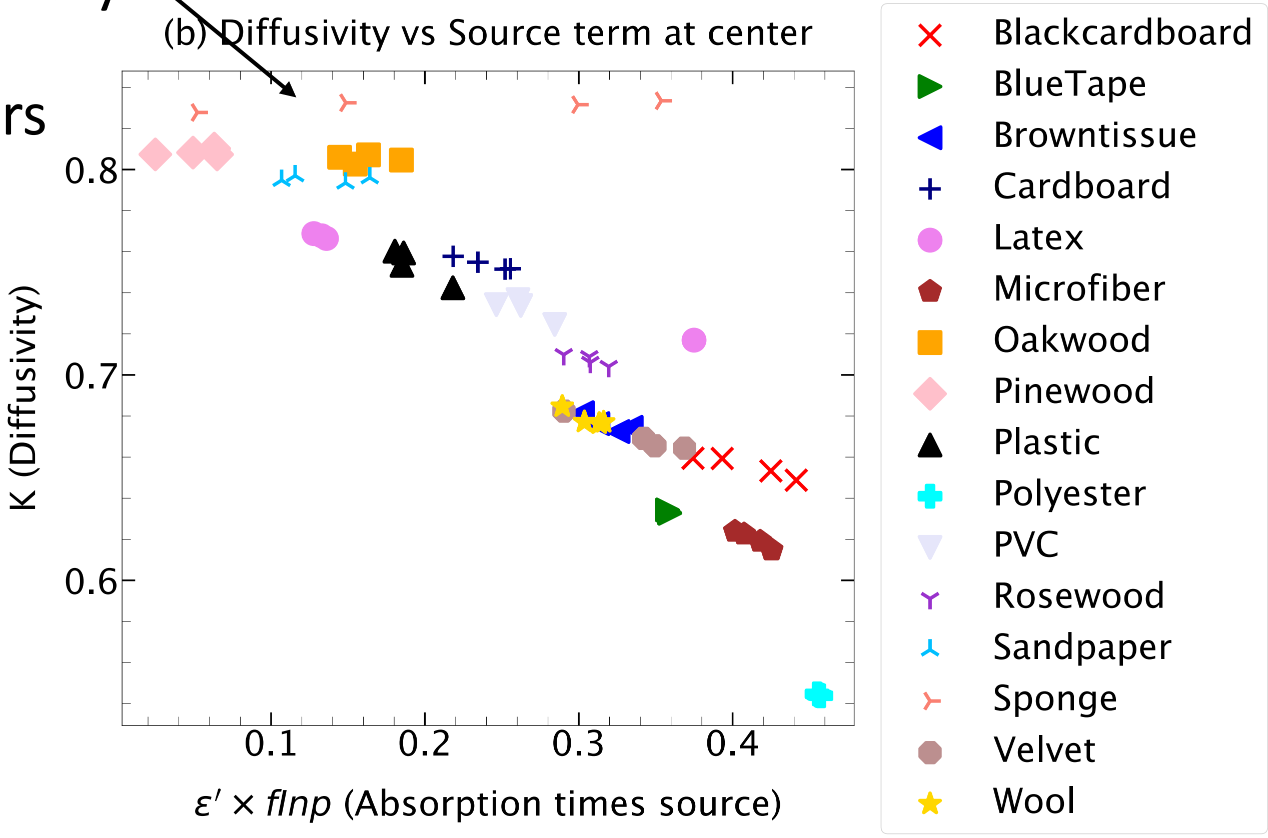


Differentiable Finite Differences (FD) Method for Inverse Heat Problem

Classification and failure cases

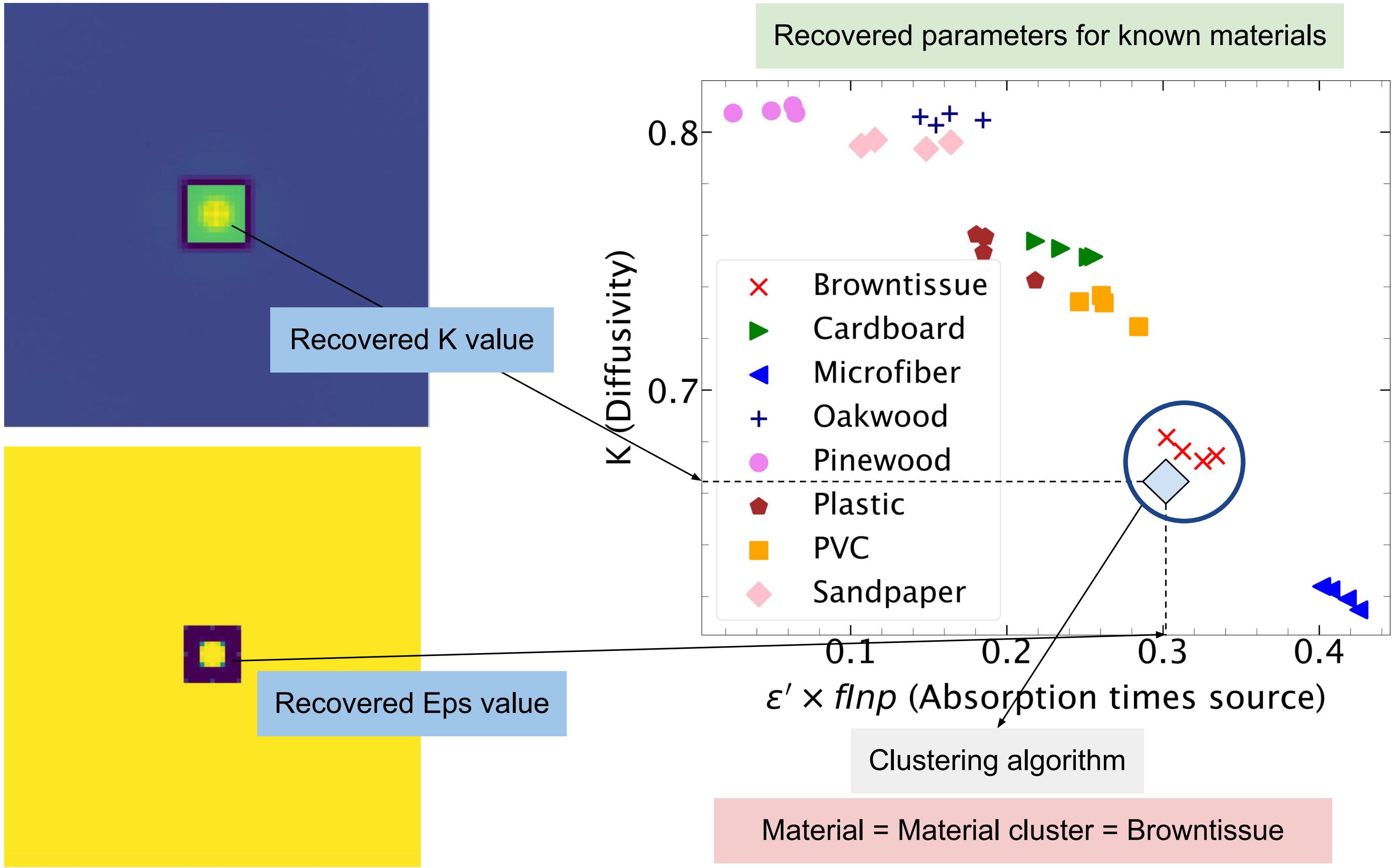
Inverse FD Recovery





TSF plotted at center pixel for nine materials

Classification



Classification Results

(a) Some of the materials used for experiments

	BlueTape	Cardboard	PVC	Pinewood	Plastic	Polyester	Wool	microfiber	Blackcard	Browntiss	Latex	Oakwood	Rosewood	Sandpaper	Velvet	Sponge
BlueTape	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cardboard	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PVC	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinewood	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Plastic	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Polyester	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Wool	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
microfiber	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Blackcard	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0
Browntiss	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	0
Latex	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0
Oakwood	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0
Rosewood	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0
Sandpaper	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
Velvet	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0
Sponge	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2

(b) Confusion Matrix for classification on non-metals

Classification Results

Features	SVC	nuSVC	RF	MLP
2	68.8%	76.6%	**82.8%**	76.6%
18	65.6%	82.8%	**84.4%**	81.2%
50	64.0%	**85.9%**	84.4%	**85.9%**

(a) Comparing accuracies of different classifiers

	BlueTape	Cardboard	PVC	Pinewood	Plastic	Polyester	Wool	microfiber	Blackcard	Browntiss	Latex	Oakwood	Rosewood	Sandpaper	Velvet	Sponge
BlueTape	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cardboard	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PVC	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinewood	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Plastic	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Polyester	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Wool	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
microfiber	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Blackcard	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0
Browntiss	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	0
Latex	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0
Oakwood	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0
Rosewood	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0
Sandpaper	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
Velvet	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0
Sponge	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2

(b) Confusion Matrix for classification on non-metals https://aniketdashpute.github.io/TSF/

Conclusion

- The main contributions of our work are:
  - Observing the Thermal Spread Functions (TSFs) and deriving initial temperature independent thermal factors to uniquely characterize a material
  - Use of Finite Differences (FD) Method to solve the inverse heat problem for recovering parameters related to diffusion, absorption and emission
  - Non-invasively recovering these properties and using them to classify materials