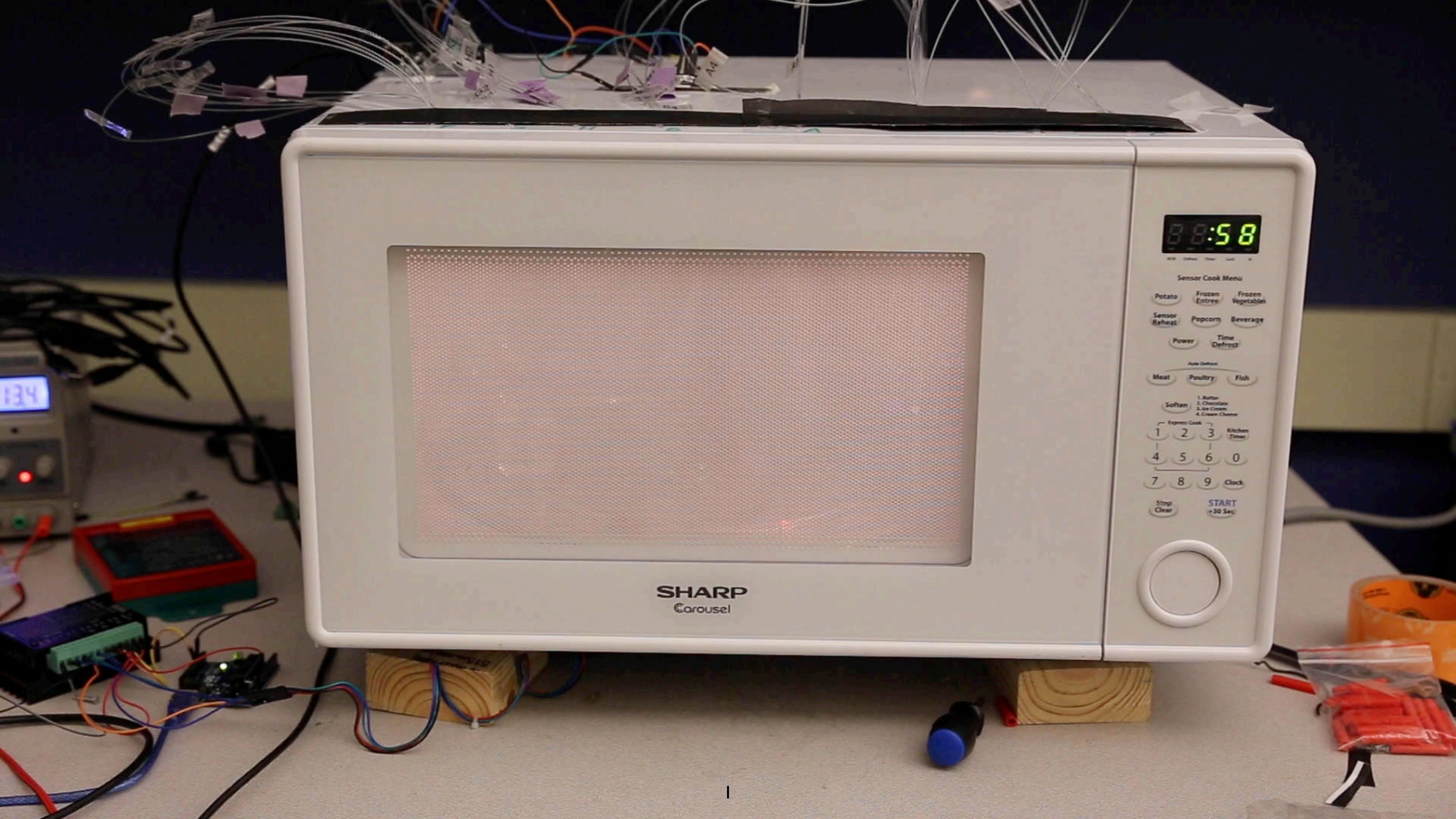
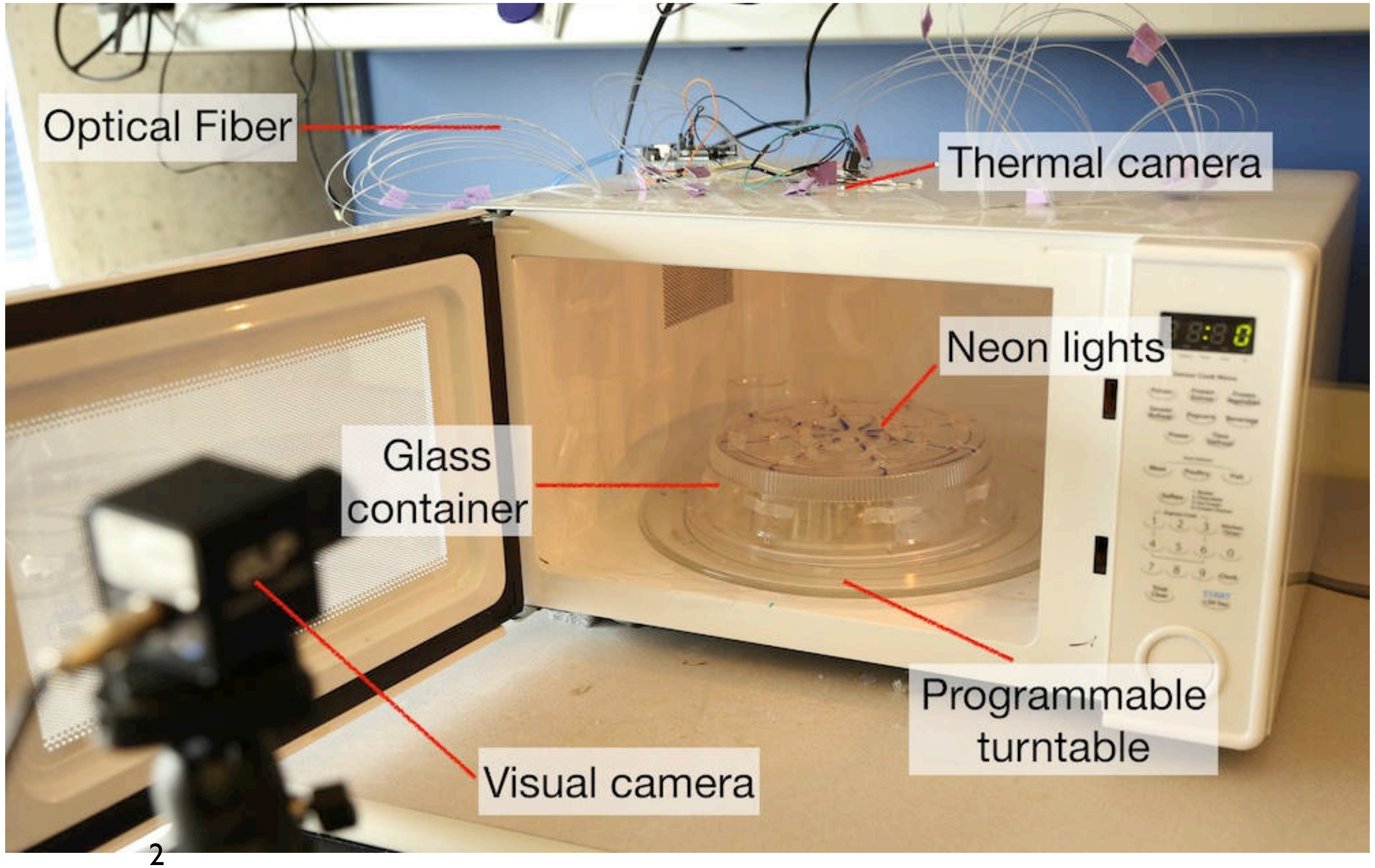

SHARP
Carousel
Sensor Cook Menu
Potato
Frozen Entree
Frozen Vegetables
Sensor Reheat
Popcorn
Beverage
Power
Time Defrost
Meat
Poultry
Fish
Soften
Kitchen Timer
Clock
Stop Clear
START +30 Sec

Software Defined Cooking (SDC) using a microwave oven

Haojian Jin
Jingxian Wang
Swarun Kumar
Jason Hong

Carnegie Mellon University



Cooking is the **application of heat** to ingredients to transform them via chemical and physical reactions

Jeff Potter. Cooking for Geeks: Real Science, Great Hacks, and Good Food.

Cooking is the application of heat to ingredients to transform them via chemical and physical reactions

SDC = programmable heating

heat the food in a software-defined thermal trajectory (recipe).

Jeff Potter. Cooking for Geeks: Real Science, Great Hacks, and Good Food.

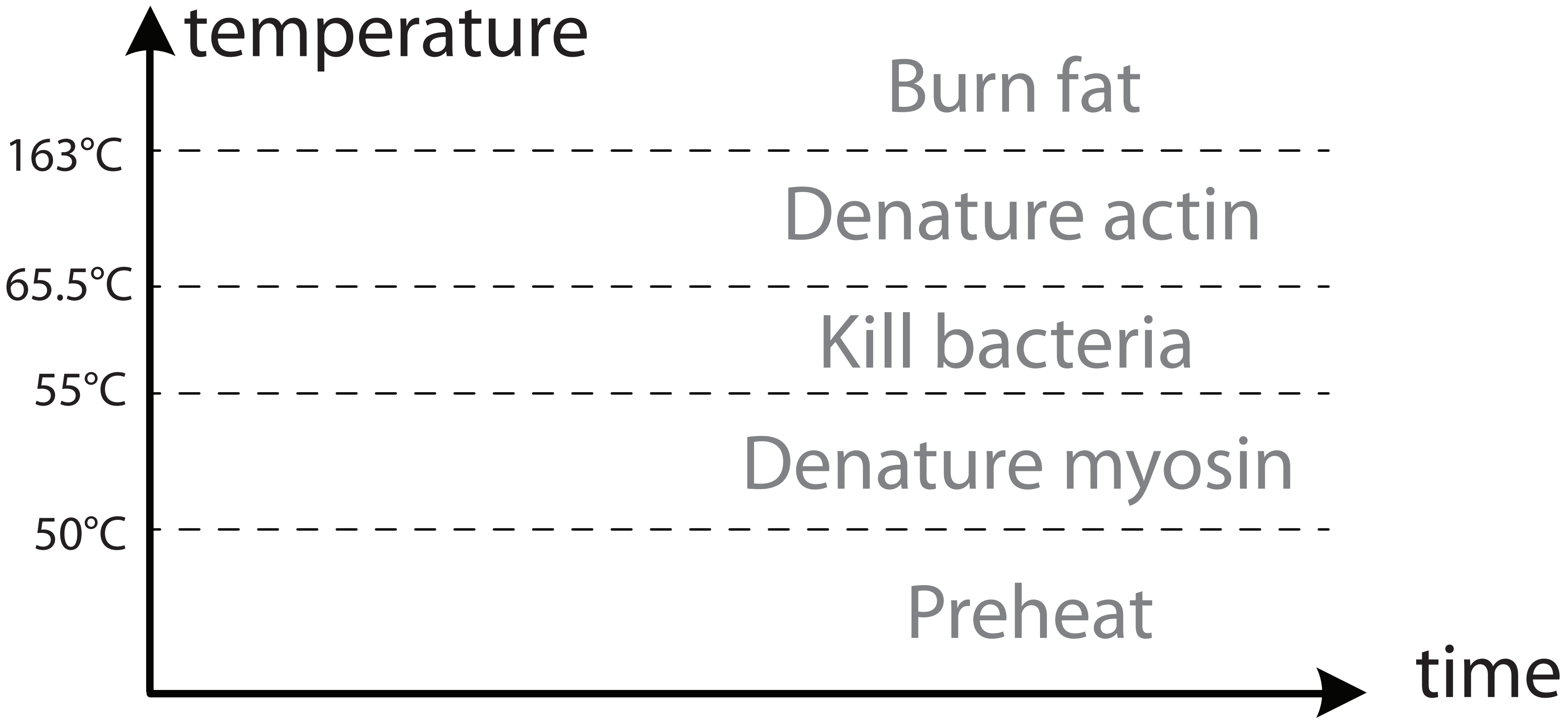

overcooking the fat,
without burning the meat.
https://www.huffpost.com/entry/bacon-mistakes-how-to-cook_n_3111706

Software-defined Cooking Recipe

Cooked = Temperature x Time x Space

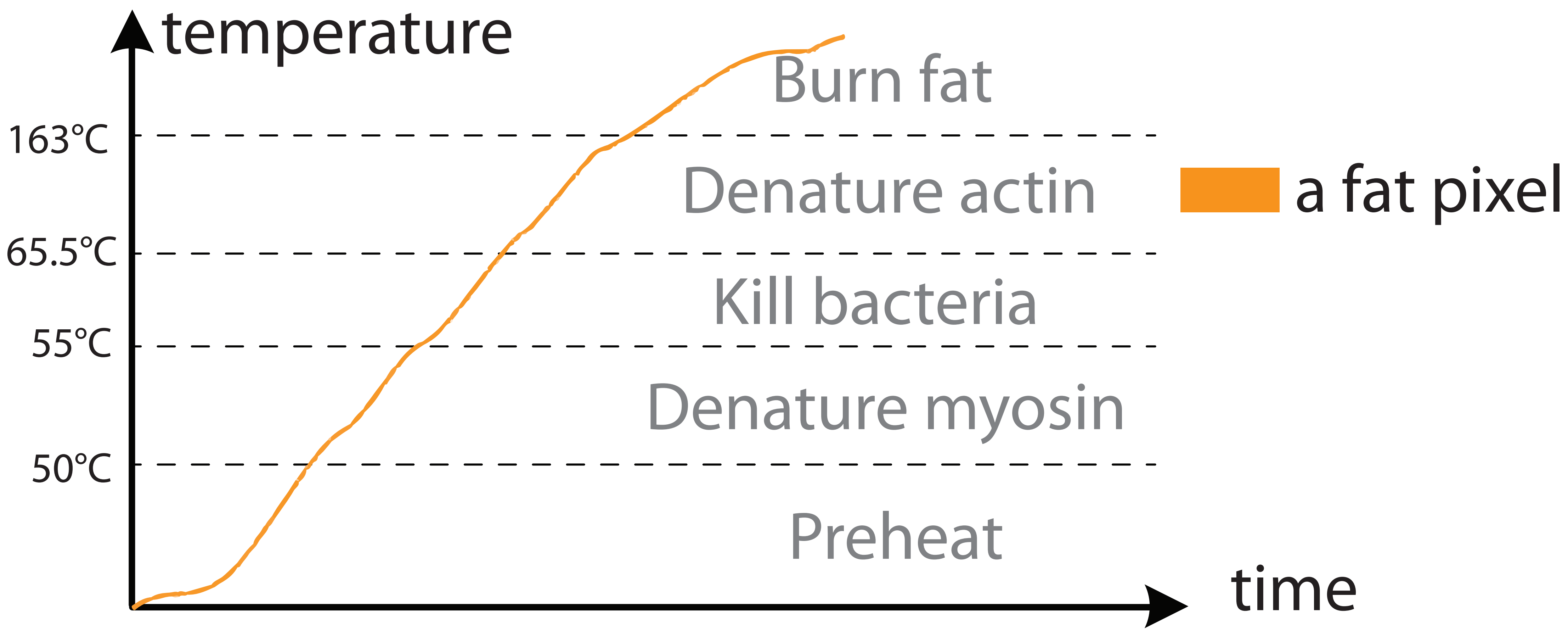
Software-defined Cooking Recipe

Cooked = Temperature x Time x Space



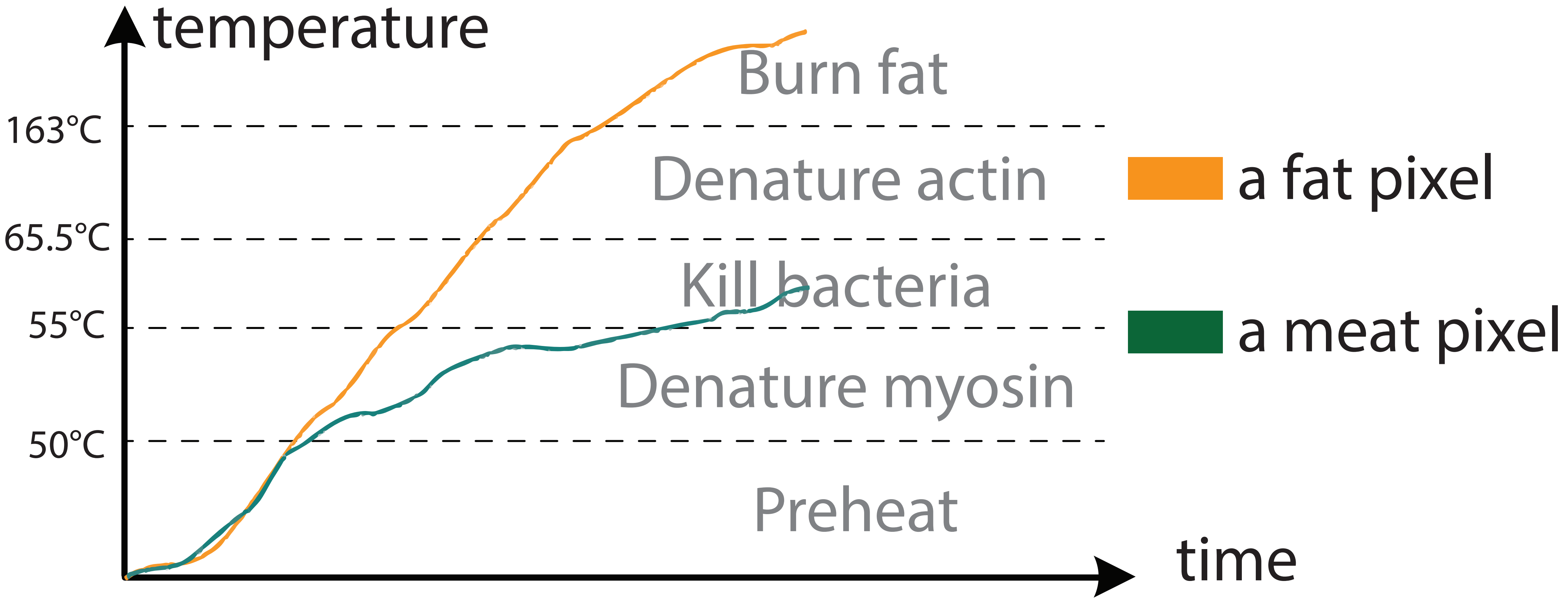
Software-defined Cooking Recipe

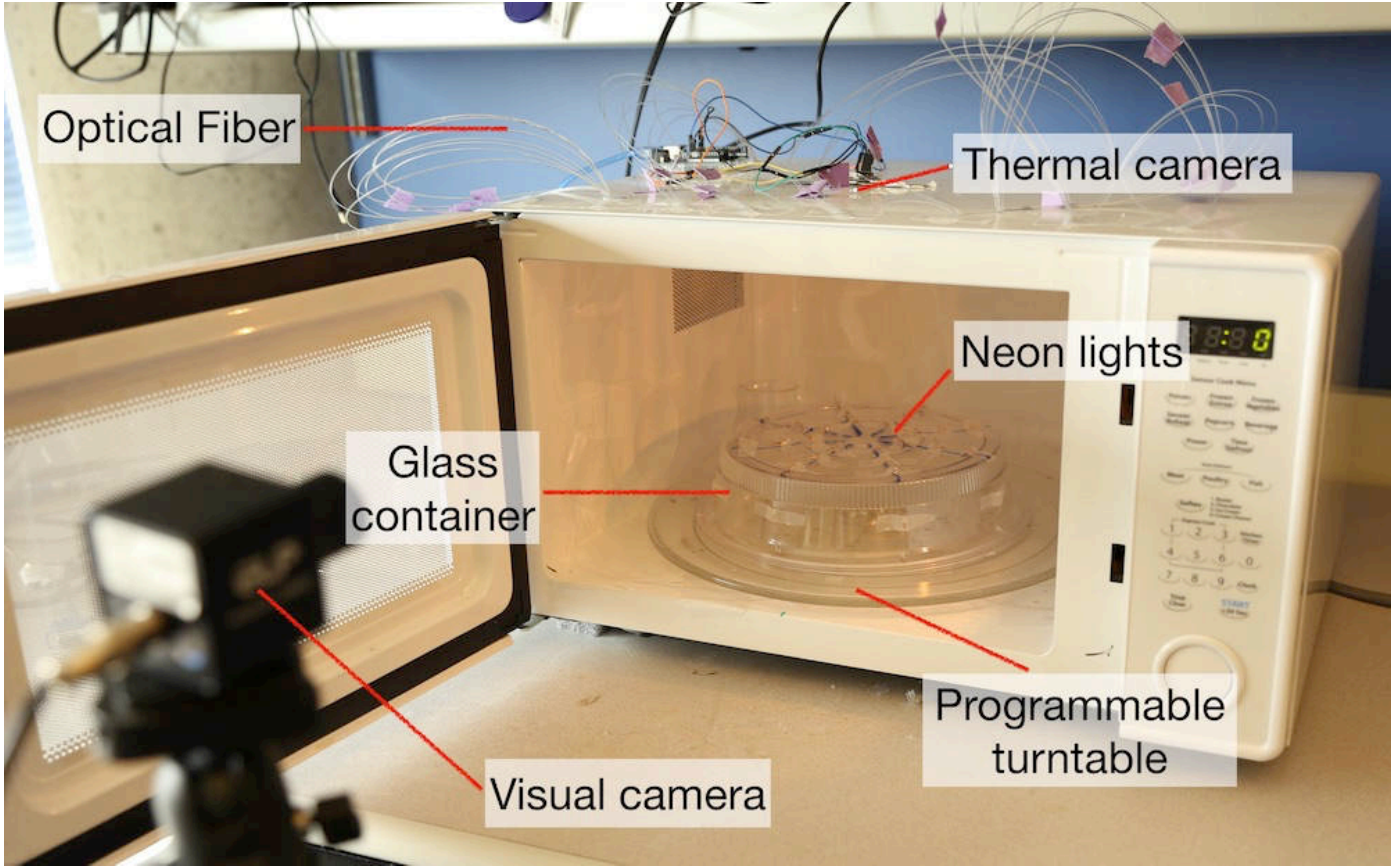
Cooked = Temperature x Time x Space



Software-defined Cooking Recipe

Cooked = Temperature x Time x Space





SDC (software-defined cooking): a novel low-cost **closed-loop** system that can **sense** and **control** heating at a **fine-grained** resolution.

We have a demo booth!

SDC (software-defined cooking): a novel low-cost **closed-loop** system that can **sense** and **control** heating at a **fine-grained** resolution.

Spoiler alert

No Turntable

Default Turntable

high heat

SDC Uniform Heating

SDC Arbitrary Heating

Spoiler alert

No Turntable

Default Turntable

→ high heat

SDC Uniform Heating

SDC Arbitrary Heating

Spoiler alert

No Turntable

Default Turntable

SDC Uniform Heating

SDC Arbitrary Heating

third most popular domestic heating method (after baking and grilling)

Today's Microwave: a **blunt heating** device

reheating leftovers

uneven & **unpredictable** heating

Microwave can only heat food **blindly**

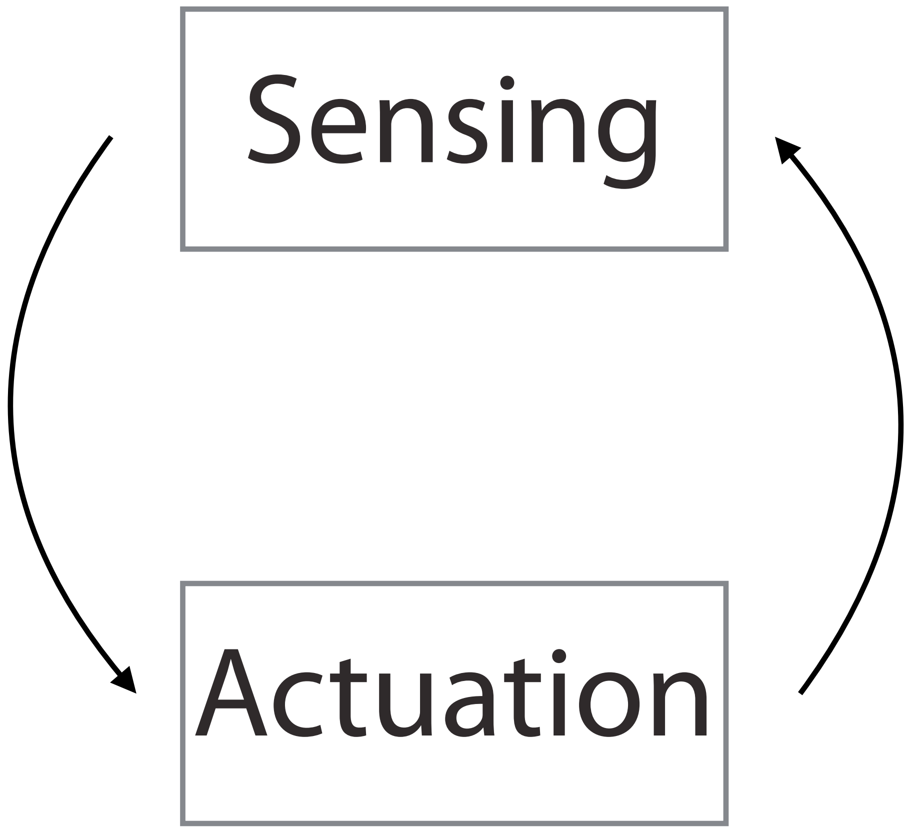
1 Don’t know how much heat each food pixel has absorbed.

2 Have no way to actuate heating on a specific food pixel.

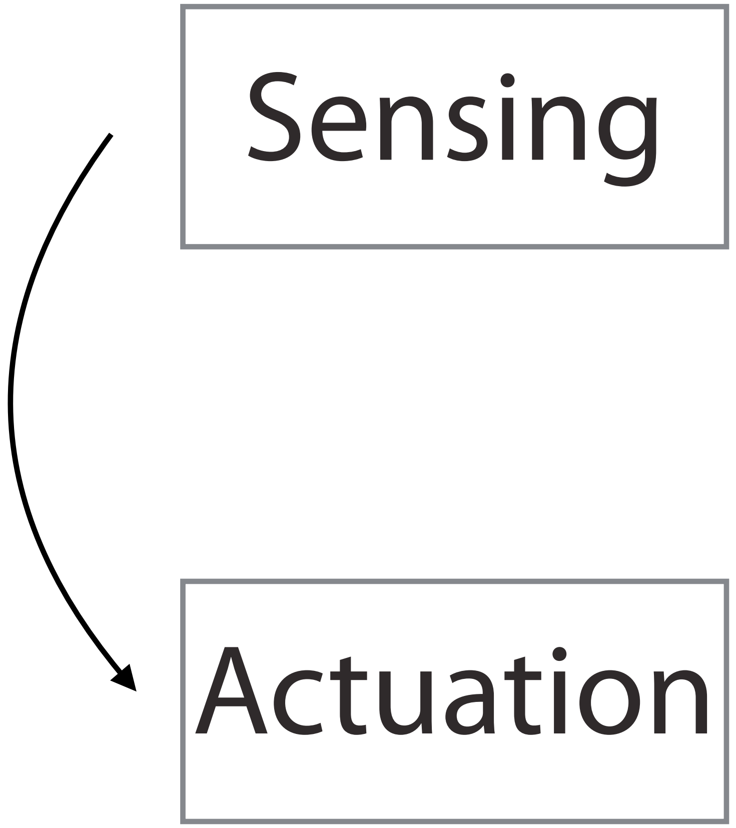
A closed-loop system to heat smartly

1 ~~Don't know how much heat each food pixel has absorbed.~~

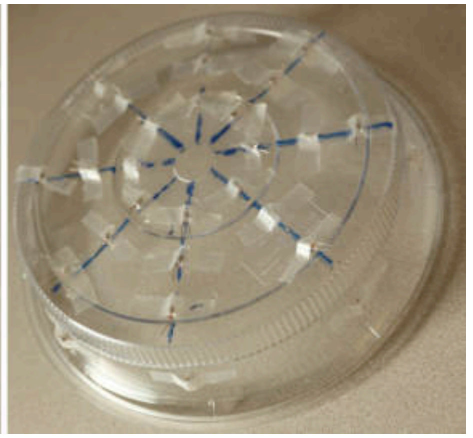
2 ~~Have no way to actuate heating on a specific food pixel.~~

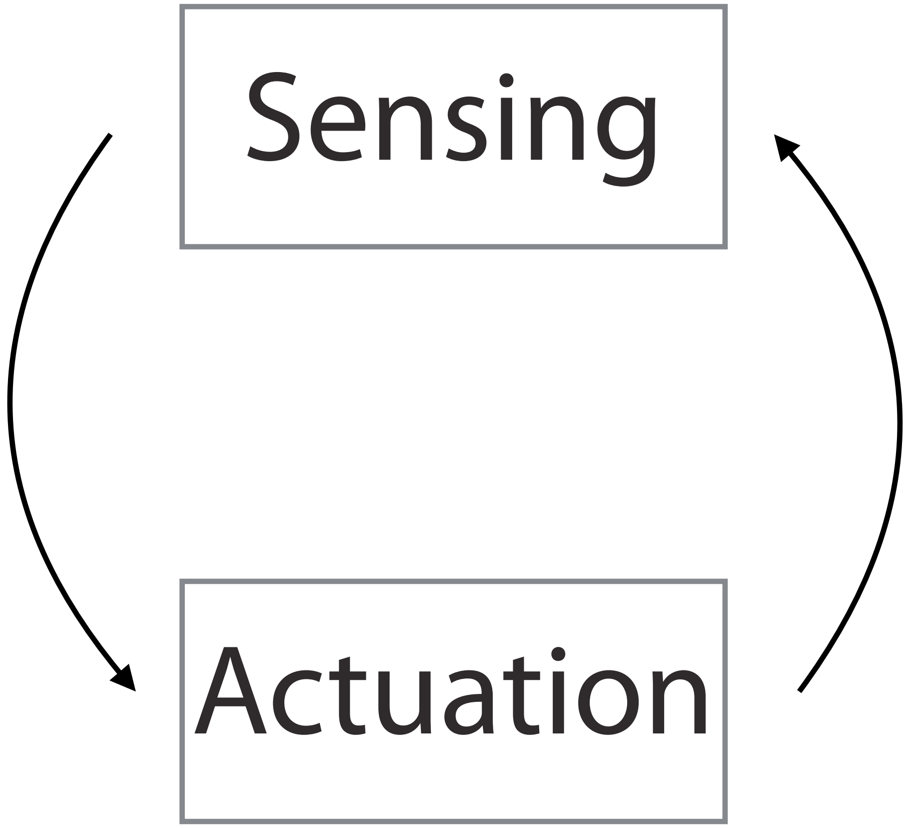


A closed-loop system to heat smartly



A closed-loop system to heat smartly





Heat Sensing

Sensing related work (1)

Most electronics & batteries are **not microwave-safe**.

Sensing related work (2)

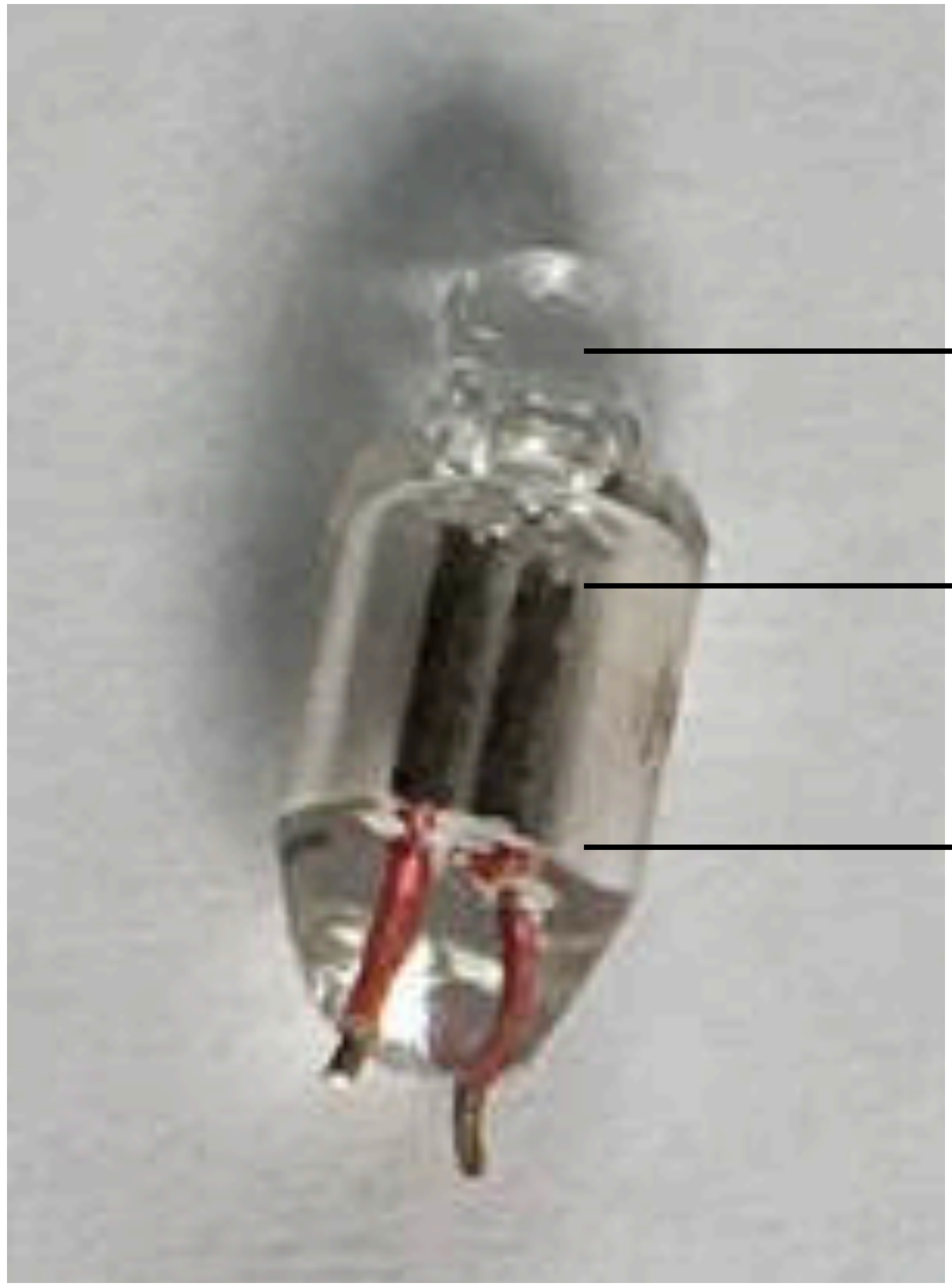
Microwave Synthesis Workstation

8 temperature sensors

$ 86,000+

Specialized microwave-safe sensors are
delicate and expensive.

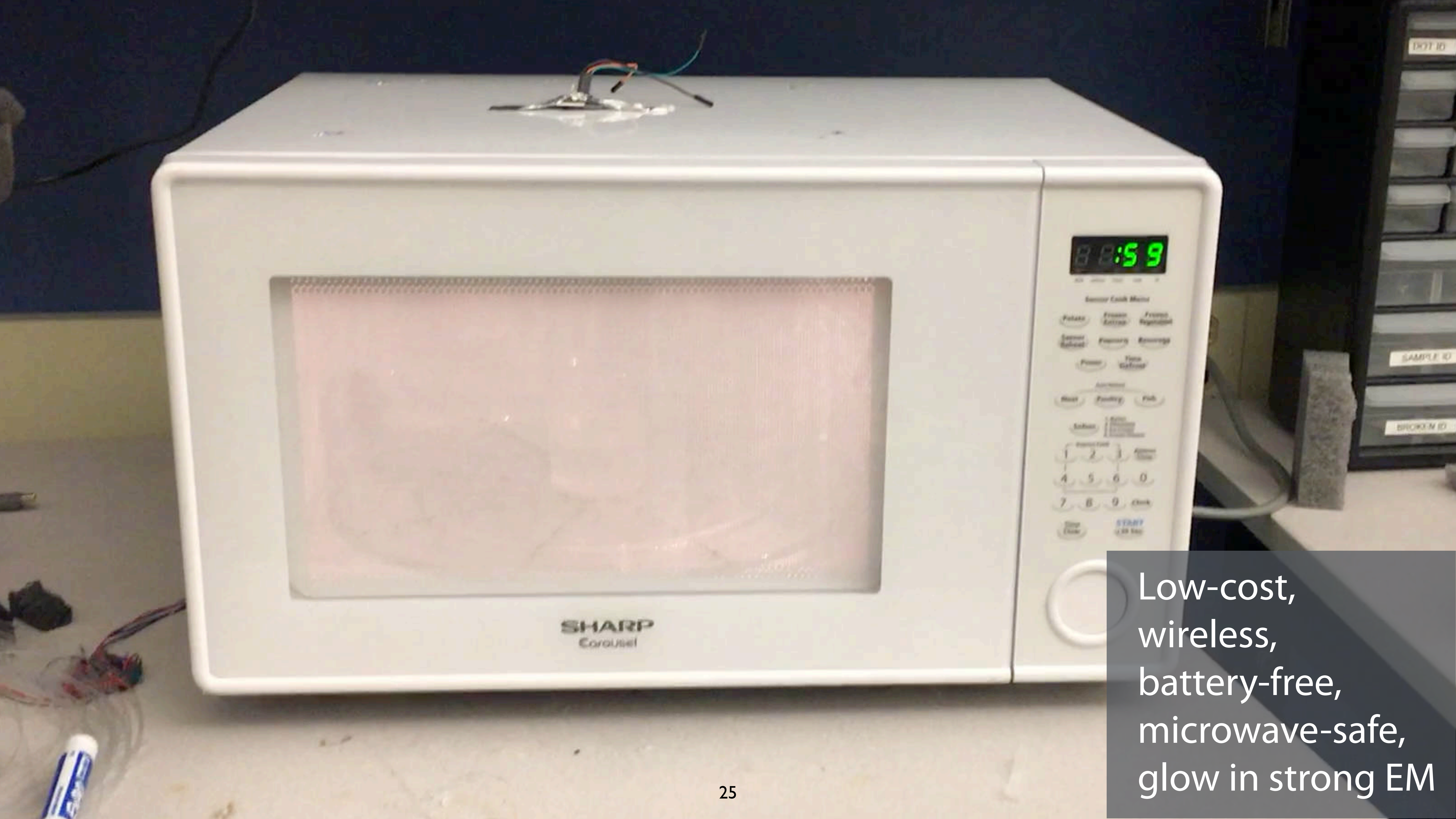
Neon lights



Glass

Electrodes

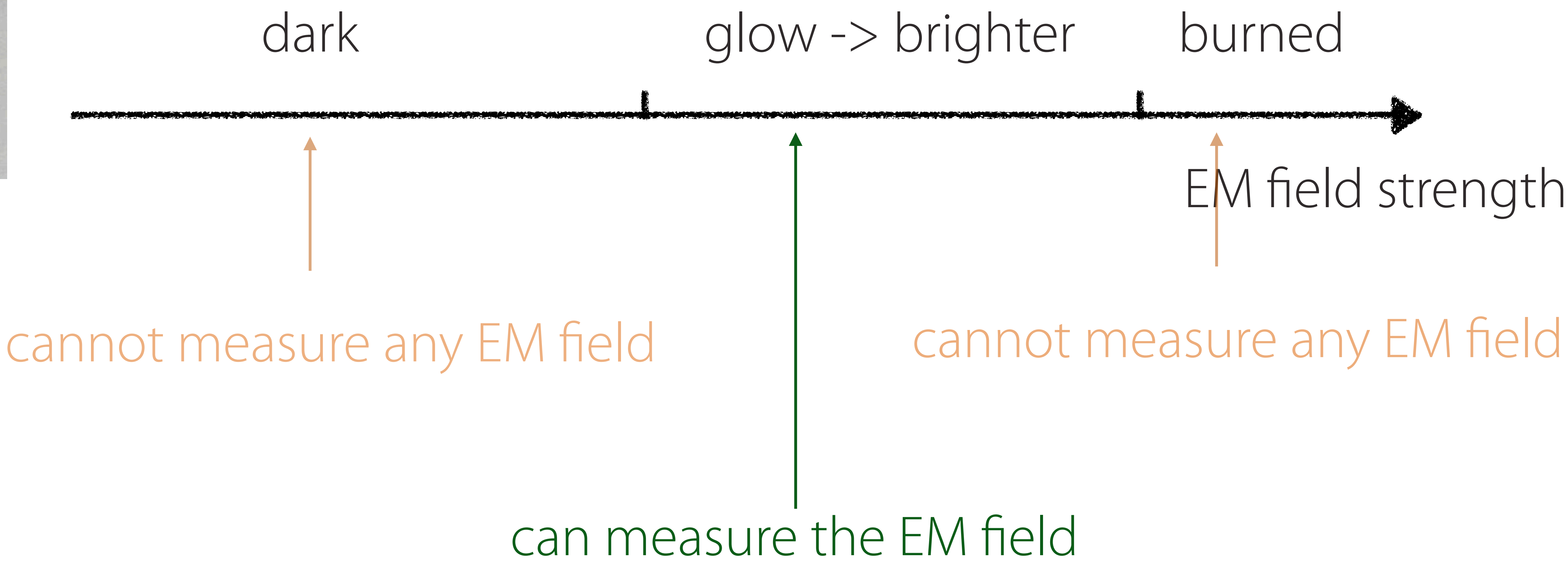
Low-pressure
Neon gas mixture



Low-cost,
wireless,
battery-free,
microwave-safe,
glow in strong EM

Programming EM sensitivity

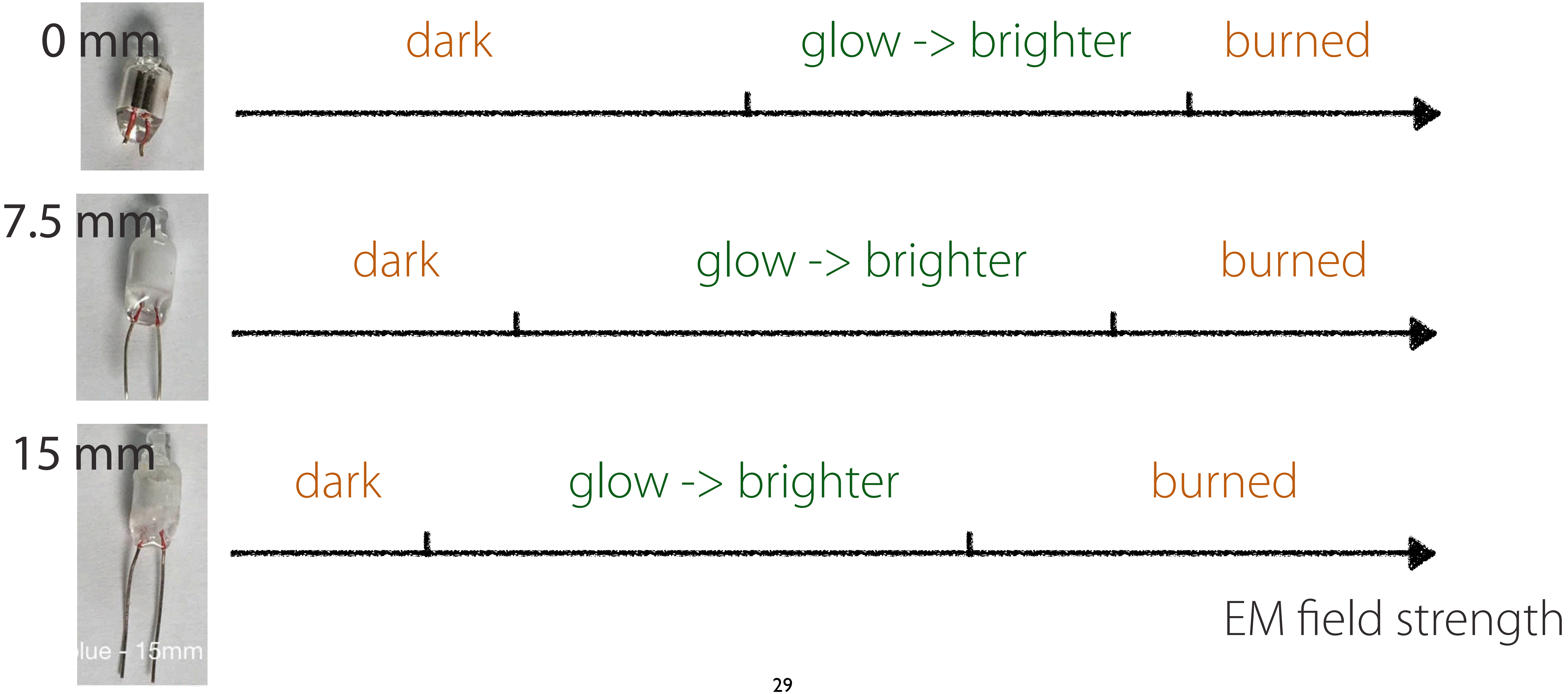
Programming EM sensitivity



Programming EM sensitivity

Wires as the antenna for energy harvesting

Programming EM sensitivity

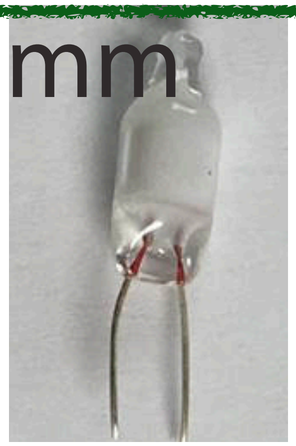


Programming EM sensitivity

0 mm

dark | glow -> brighter | burned

7.5 mm



dark | glow -> brighter | burned

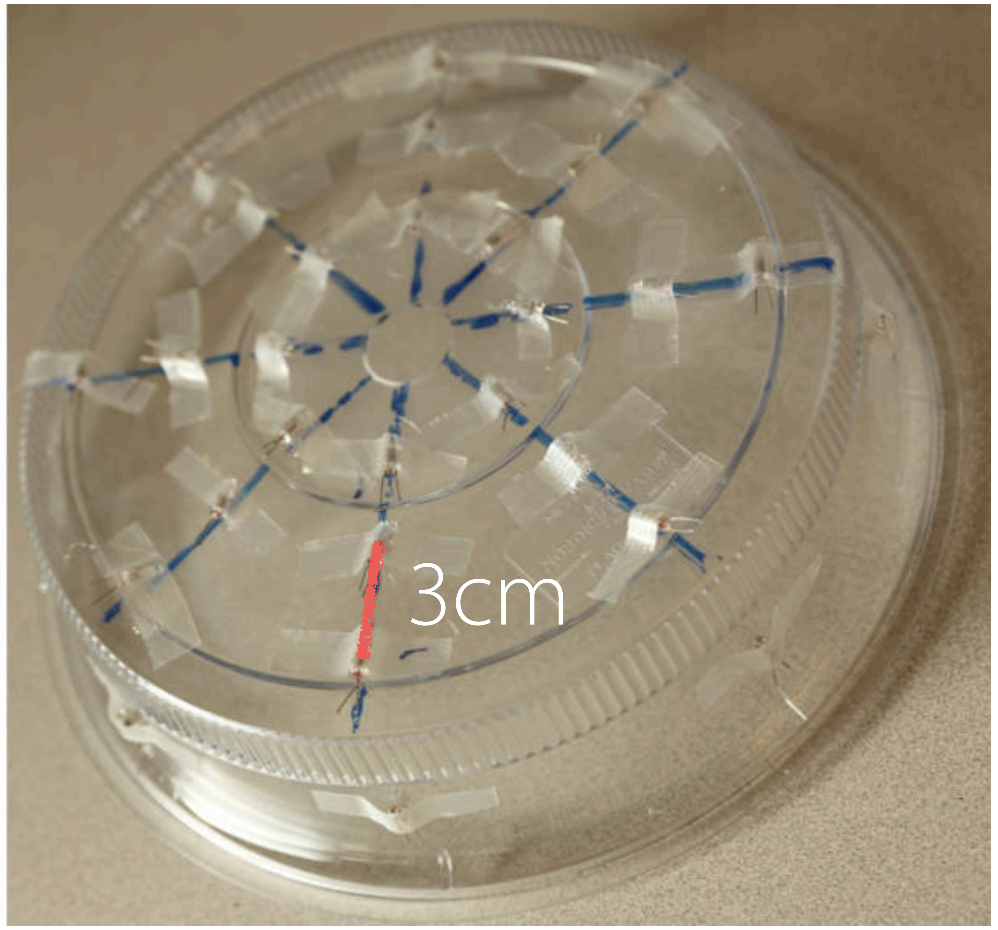
15 mm

dark | glow -> brighter | burned

EM field strength

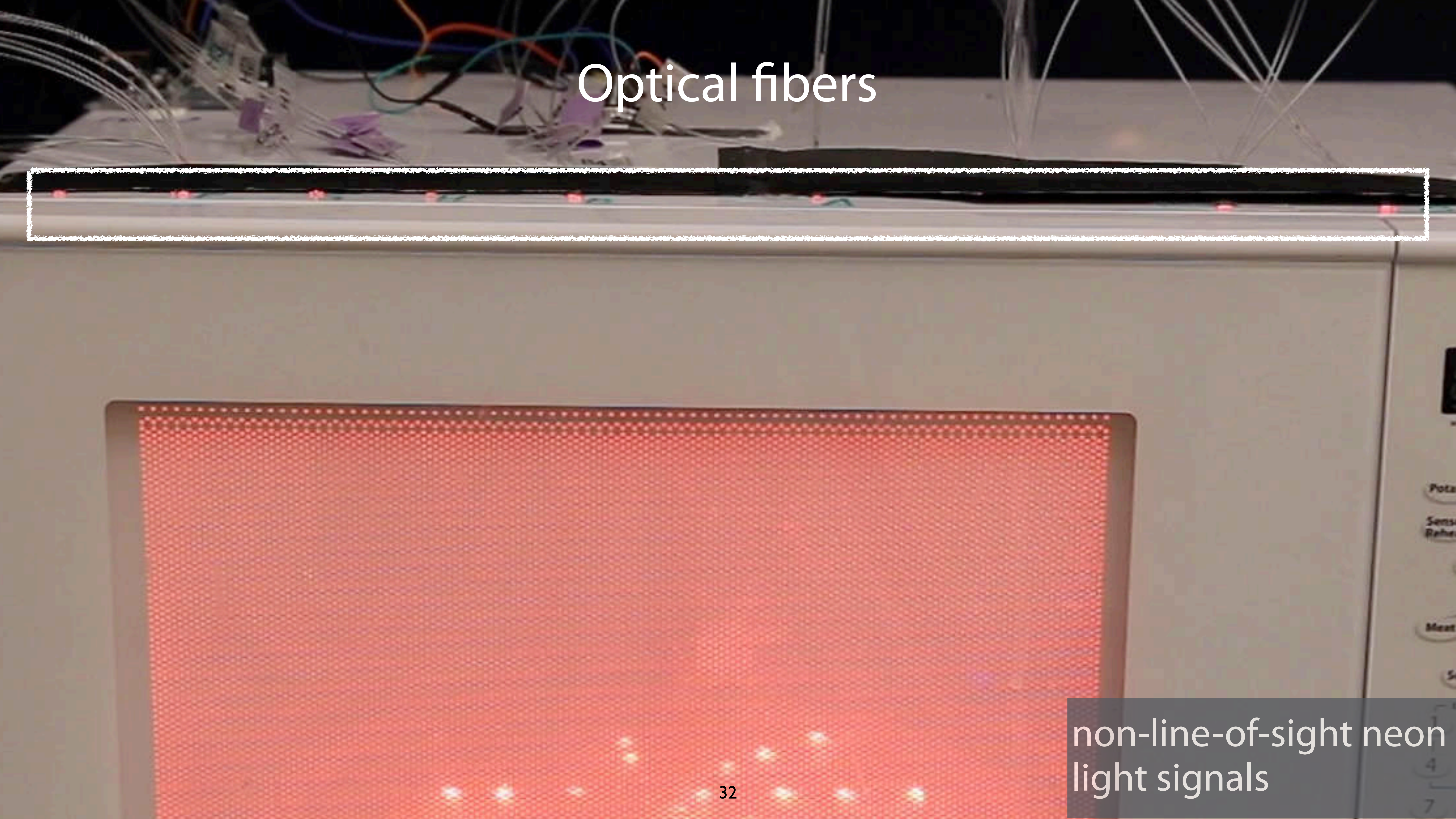
Placement of Neon Lights

turntable with 32 neon lights

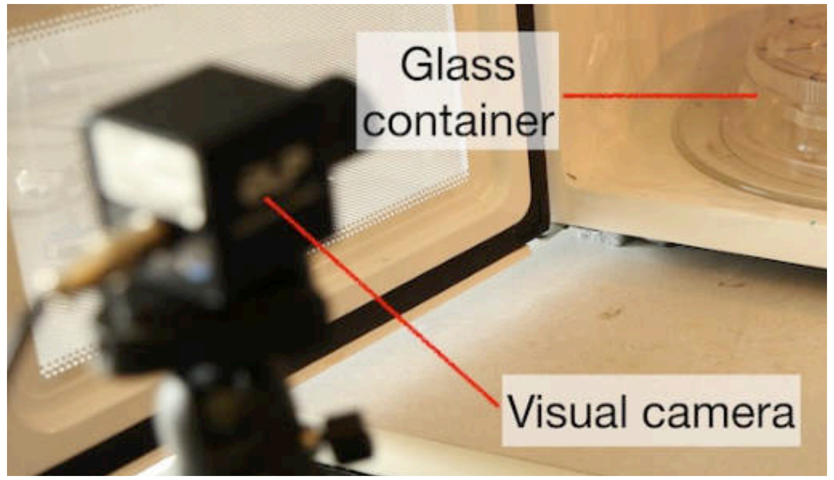


cover with 32 neon lights

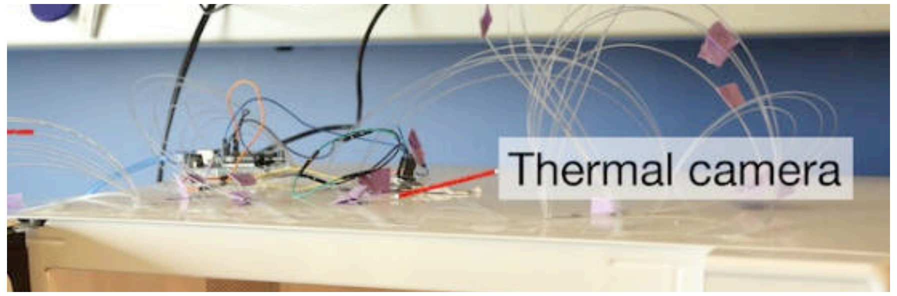
Optical fibers



Sensors



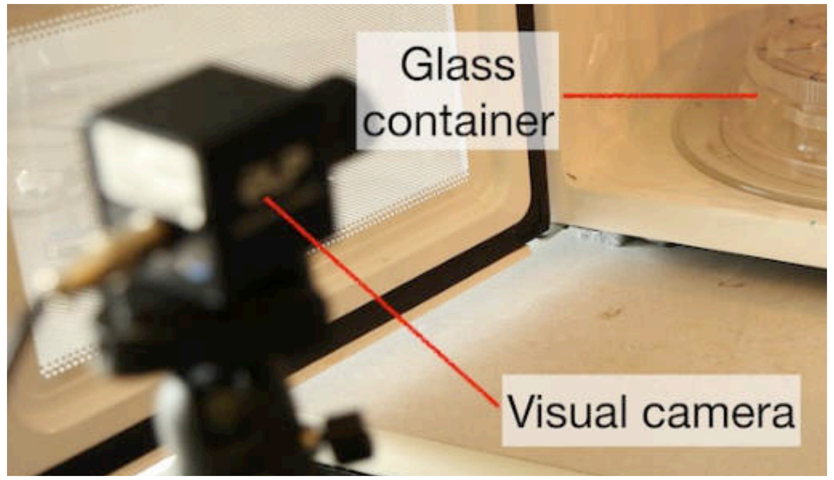
A web cam



A thermal cam

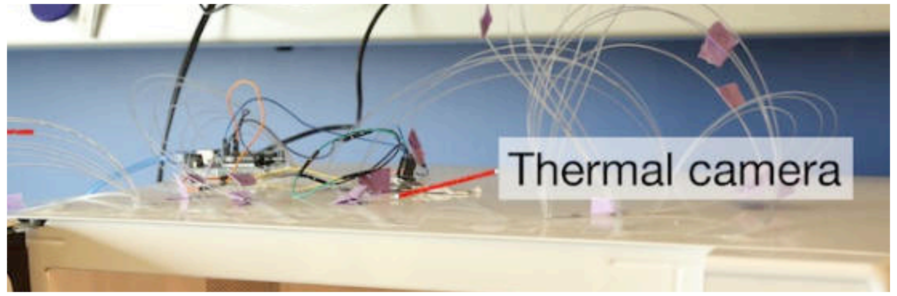
Sensors

Raw data



A web cam

→ 3D EM field



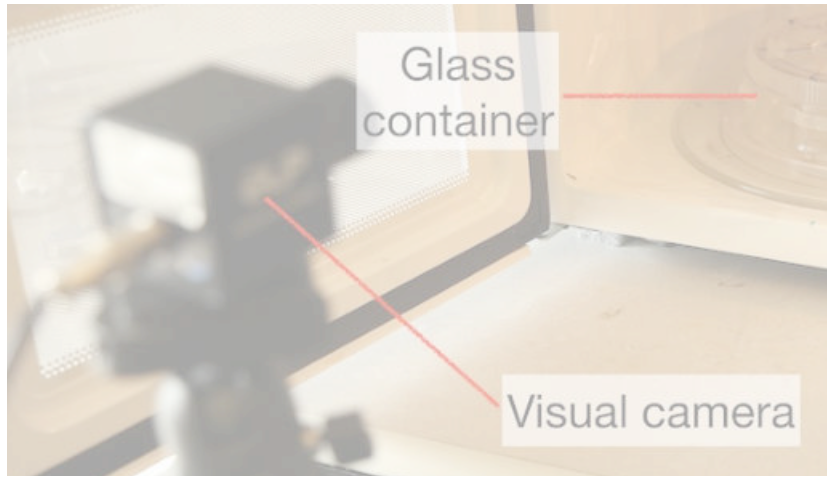
A thermal cam

→ raw temperature

Sensors

Raw data

Output



A web cam

A thermal cam

3D EM field

raw temperature

extended kalman filter

Temperature P

Gradient P'

Heat Actuation

Actuation related work

turn table for **blind** rotation

non-uniform and **unpredicatable**

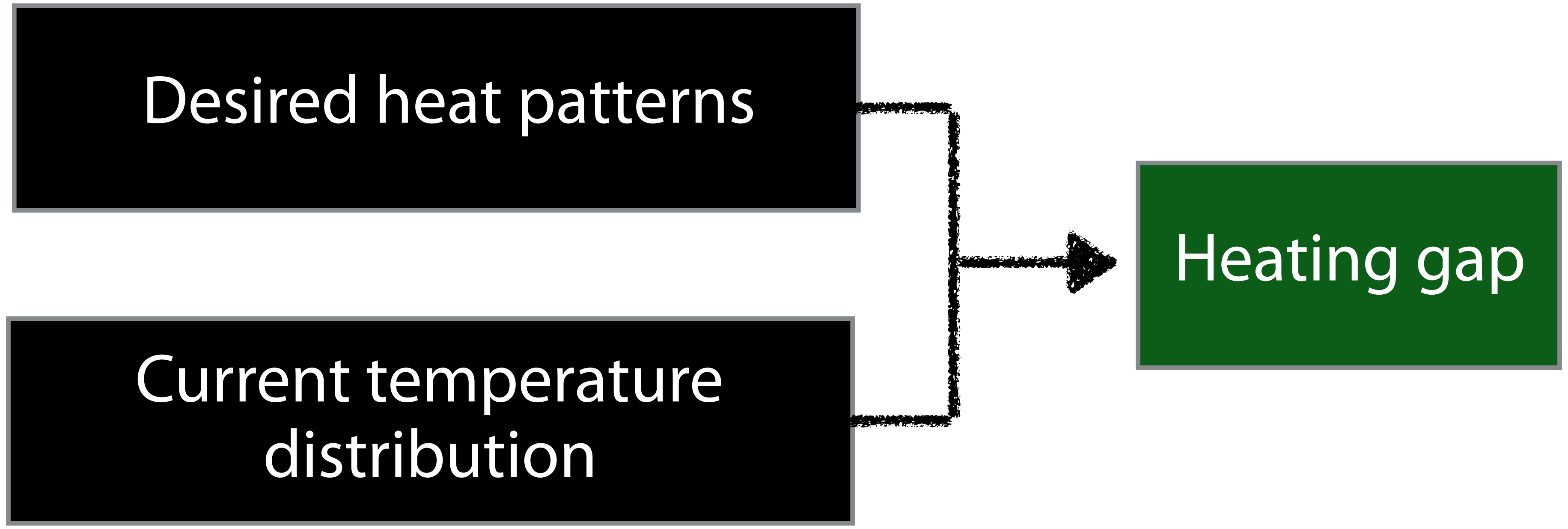
A closed-loop turntable

Desired heat patterns from software-defined recipes

Current temperature distribution from Sensors

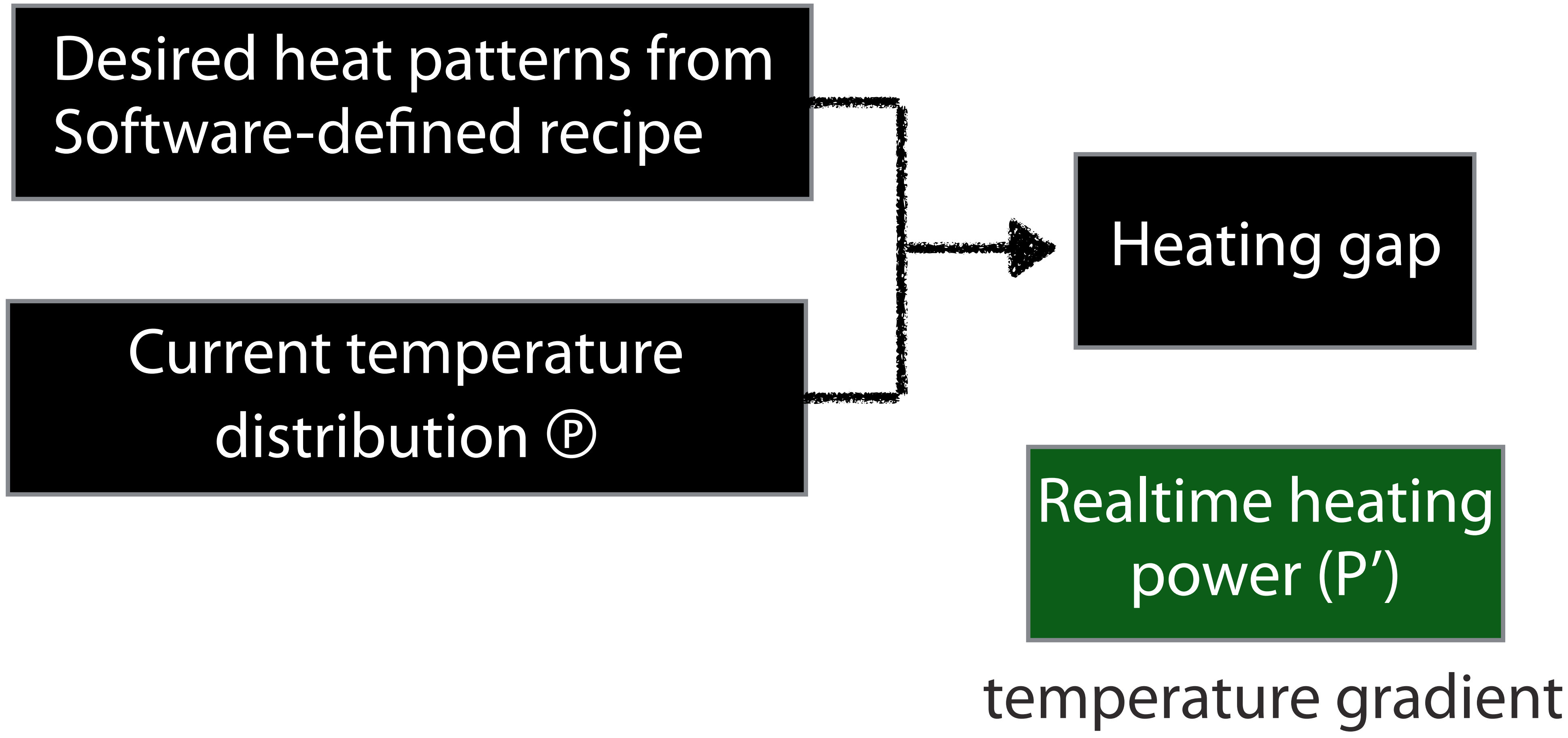
at time t

A closed-loop turntable



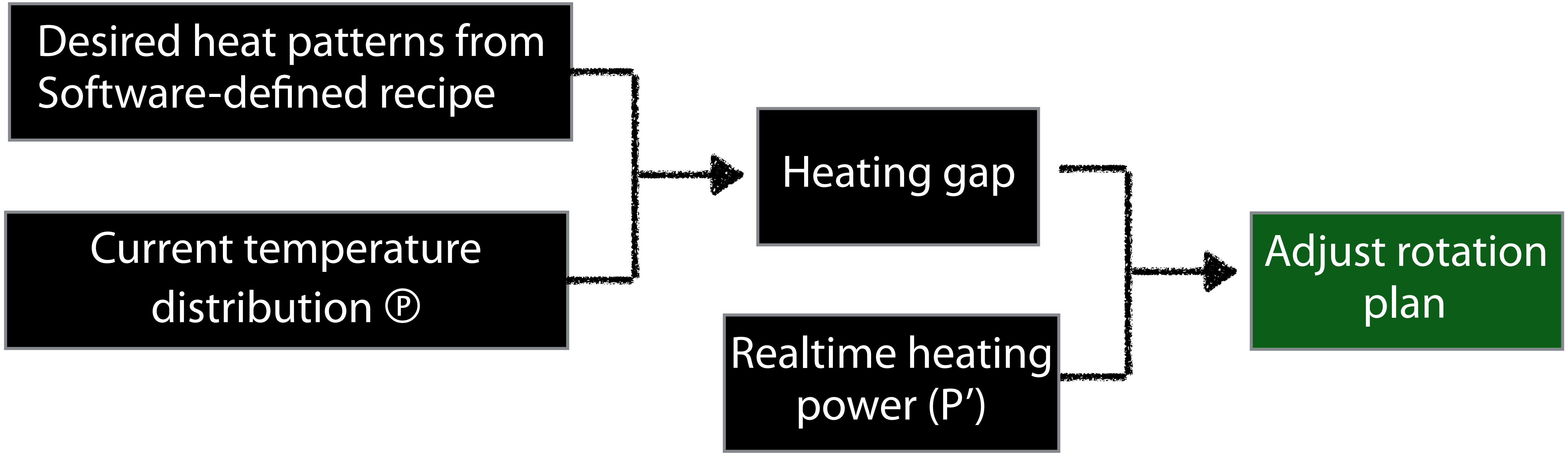
at time t

A closed-loop turntable



at time t

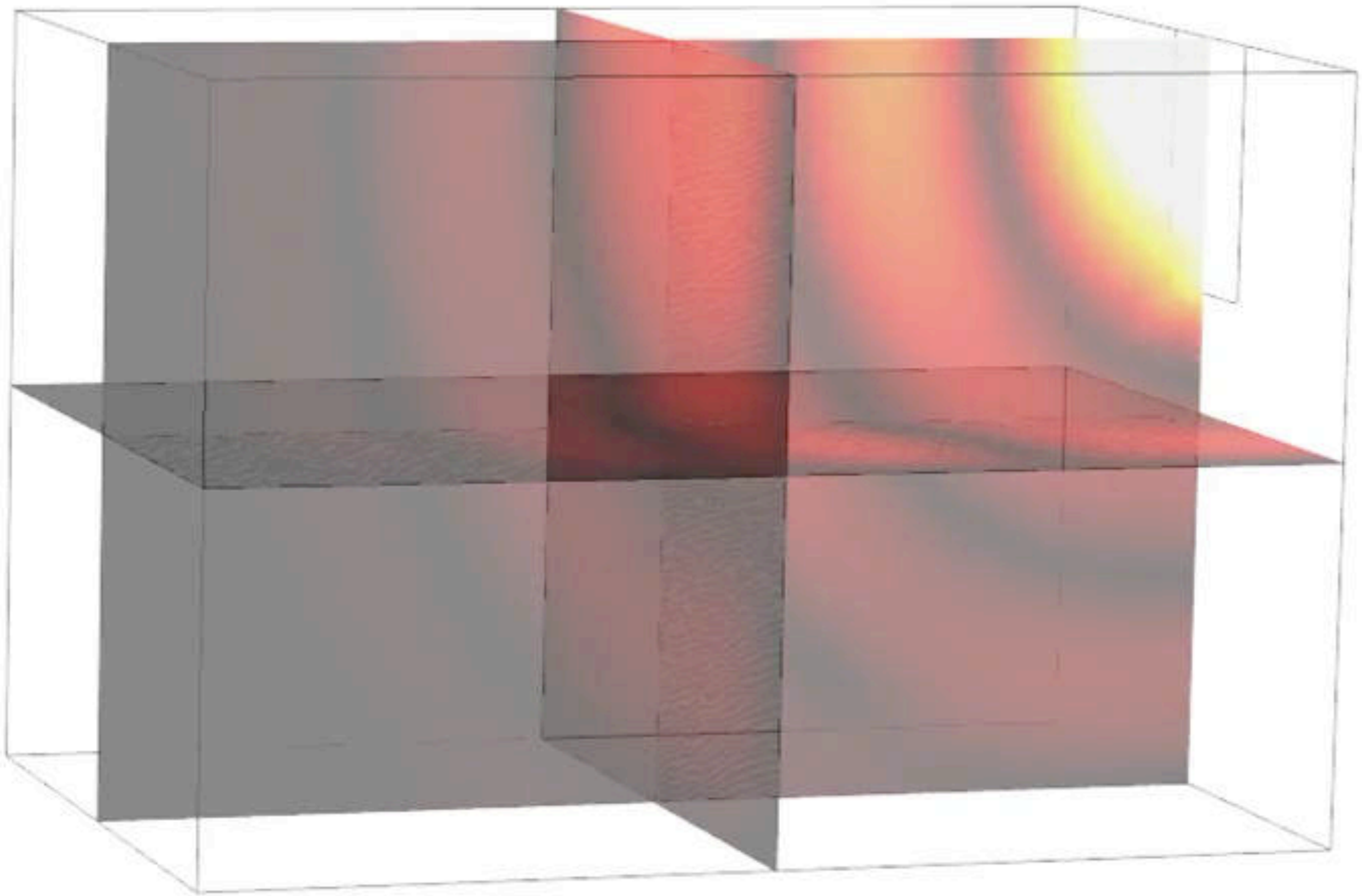
A closed-loop turntable



temperature gradient

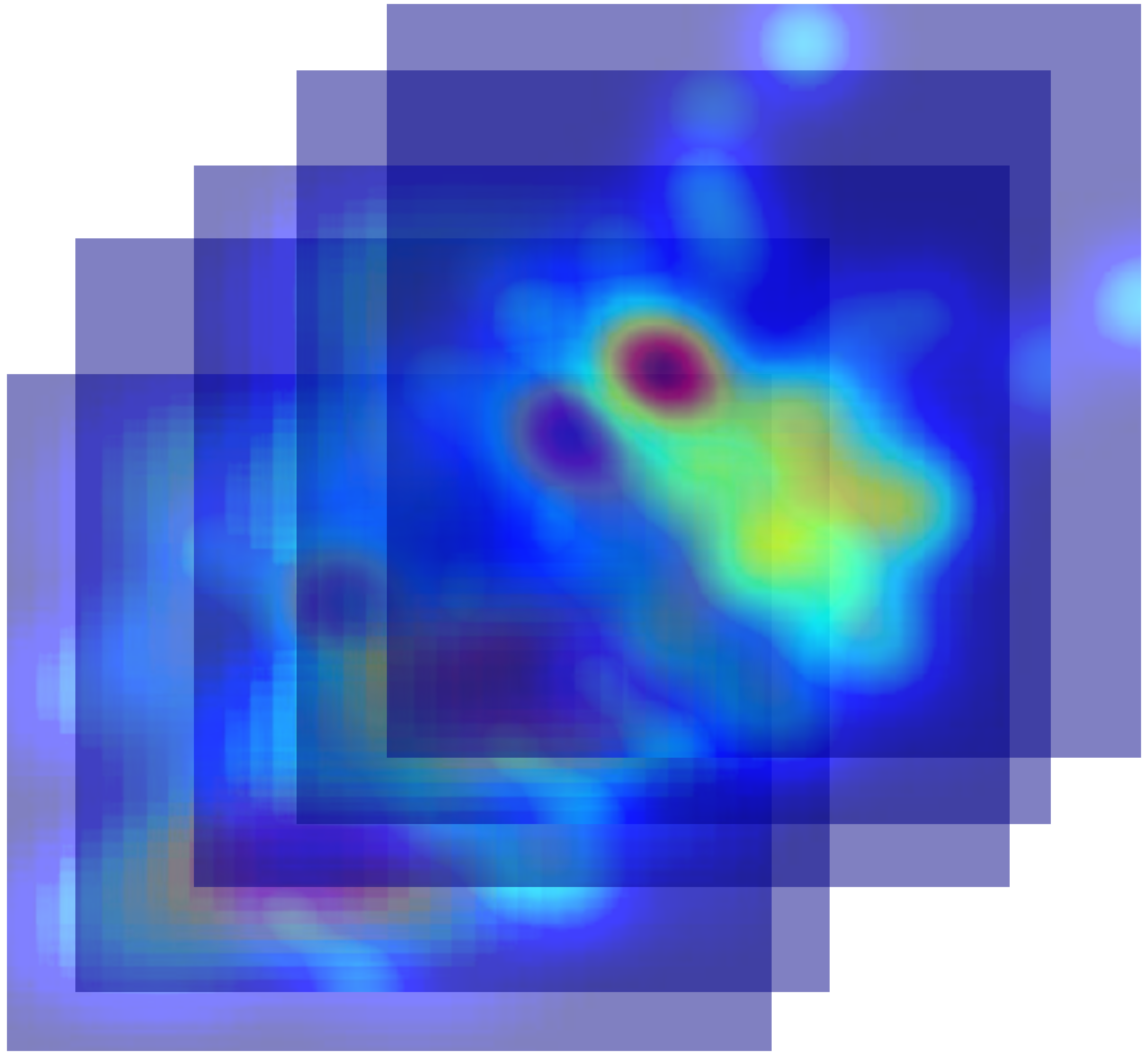
at time t

Heating patterns from 3D standing waves



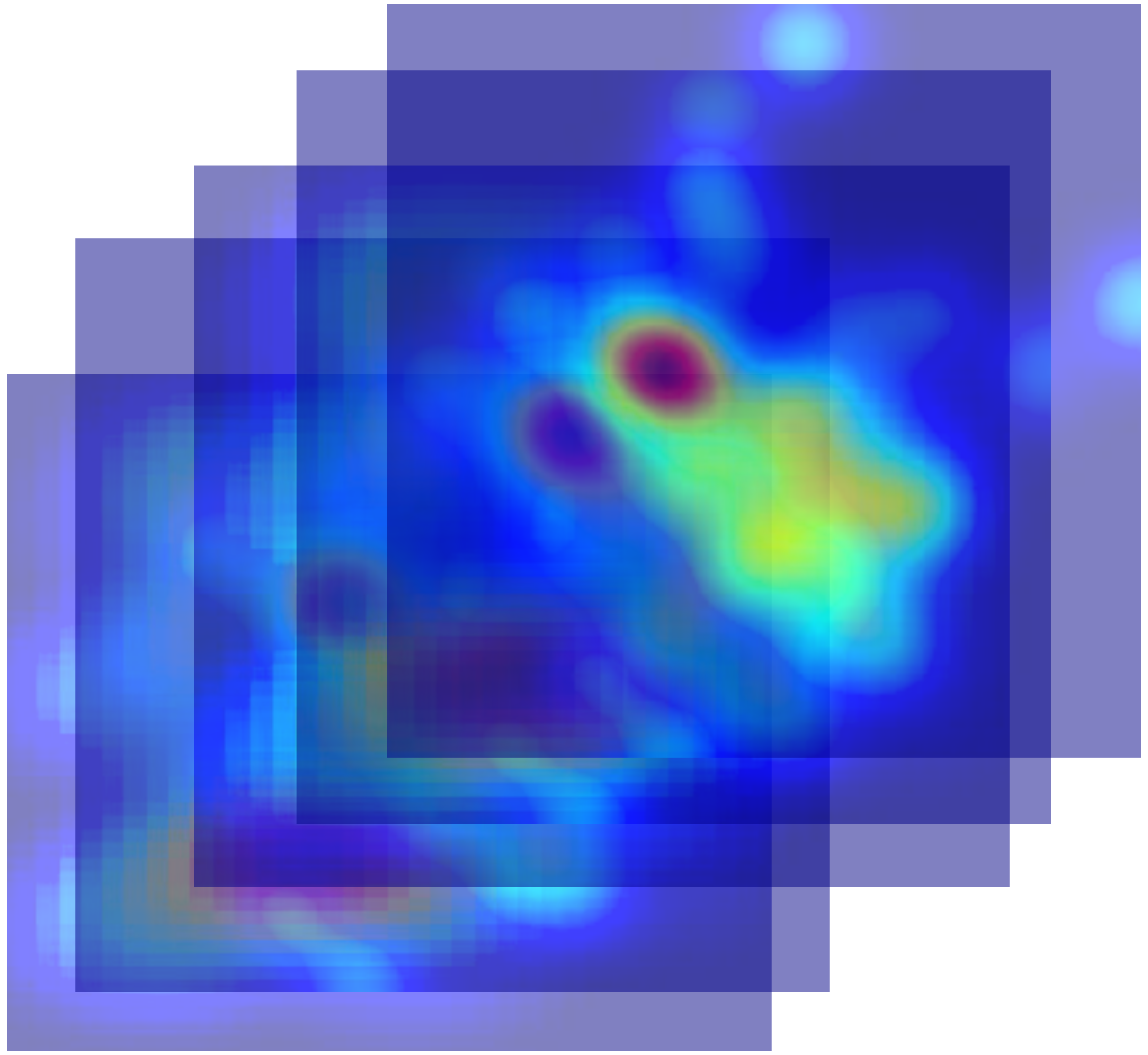
Microwave cannot heat individual pixels independently.

Determining the rotation plan



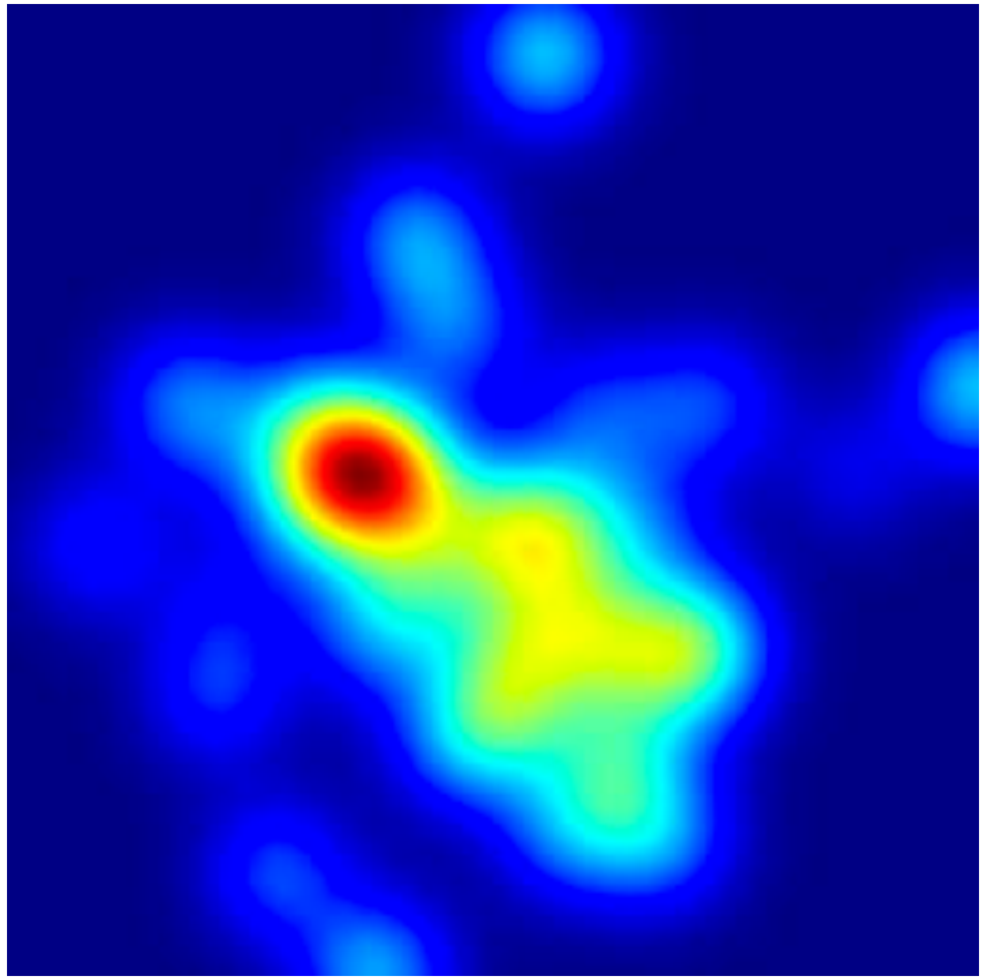
Realtime heating power (P’)

Determining the rotation plan



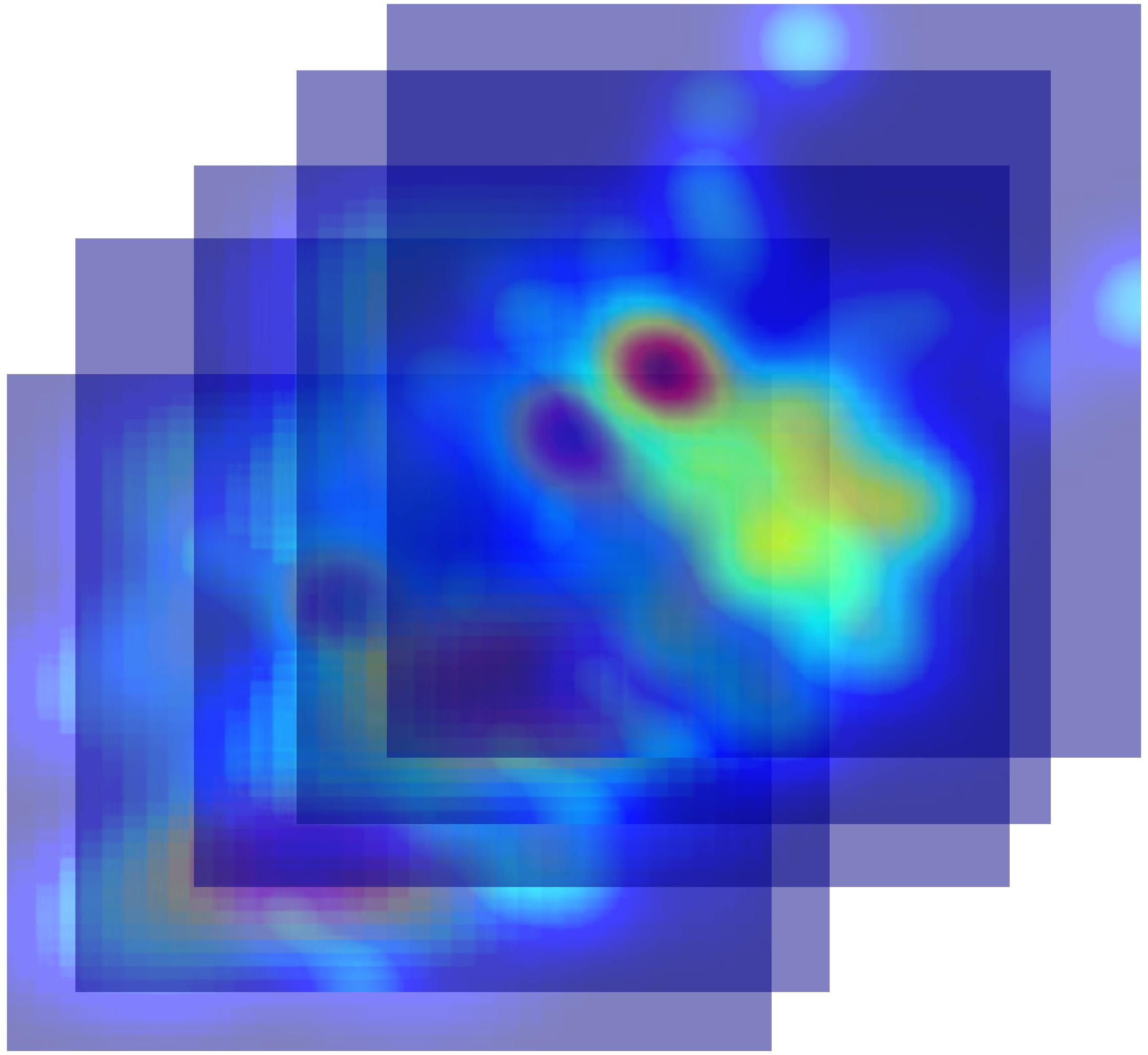
Realtime heating power (P')

=



Heating gap

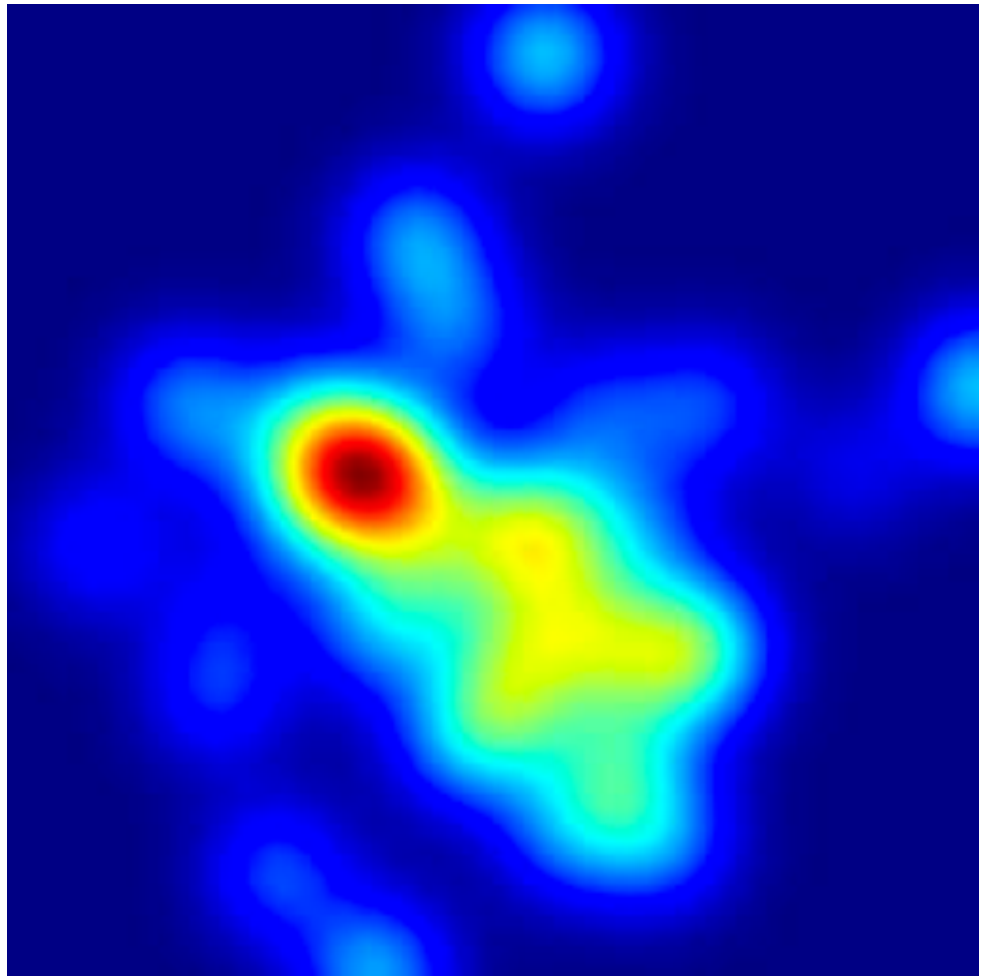
Determining the rotation plan



Realtime heating power (P')

=

a knapsack problem



Heating gap

Optimization details => Paper

Spoiler alert

No Turntable

Default Turntable

SDC Uniform Heating

Spoiler alert

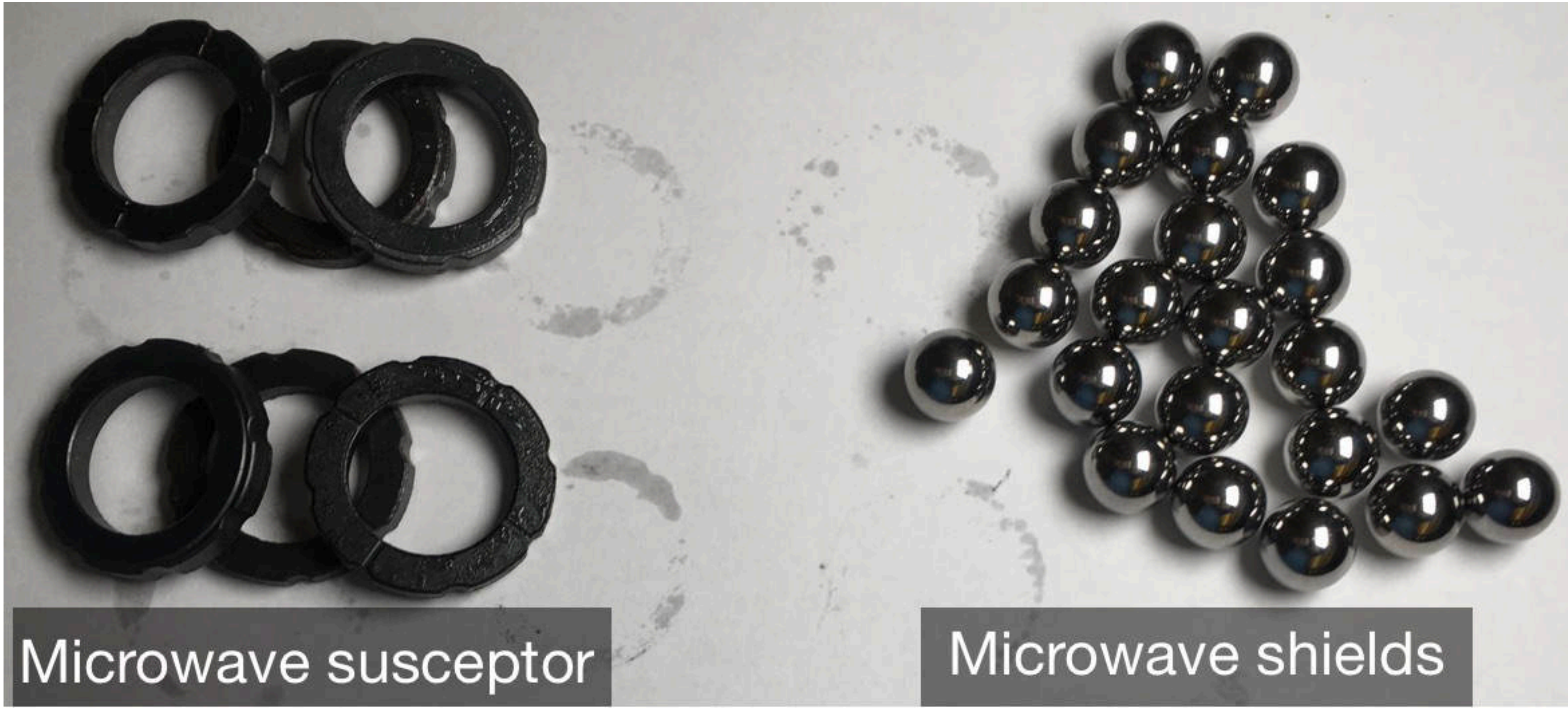
No Turntable

Default Turntable

SDC Uniform Heating

SDC Arbitrary Heating

Microwave accessories



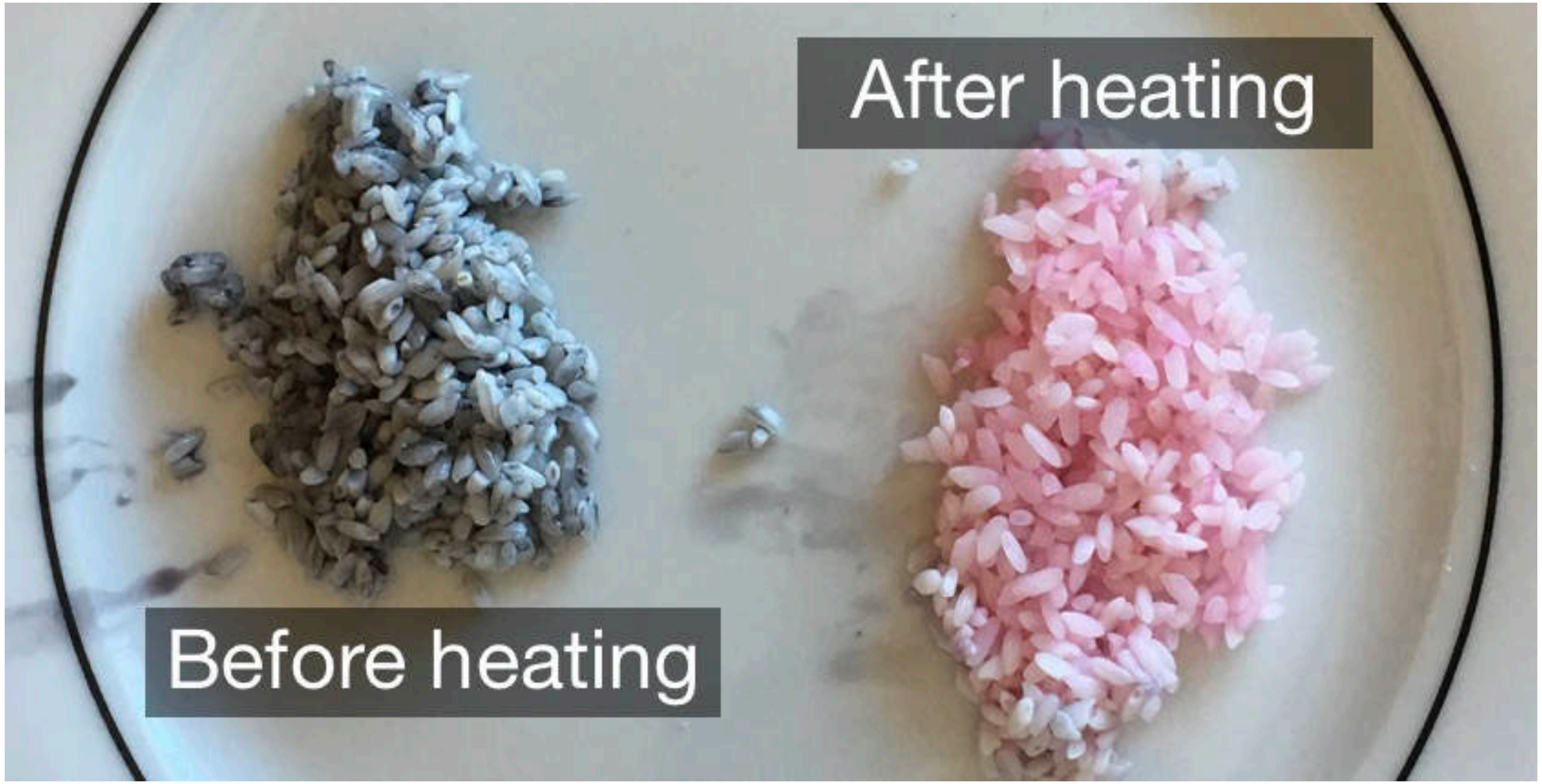
Details => Paper

patterned microwave susceptor

ensure **coverage** through SDC

Evaluation

Evaluation apparatus



thermal-chromatic pigment + rice

reusable

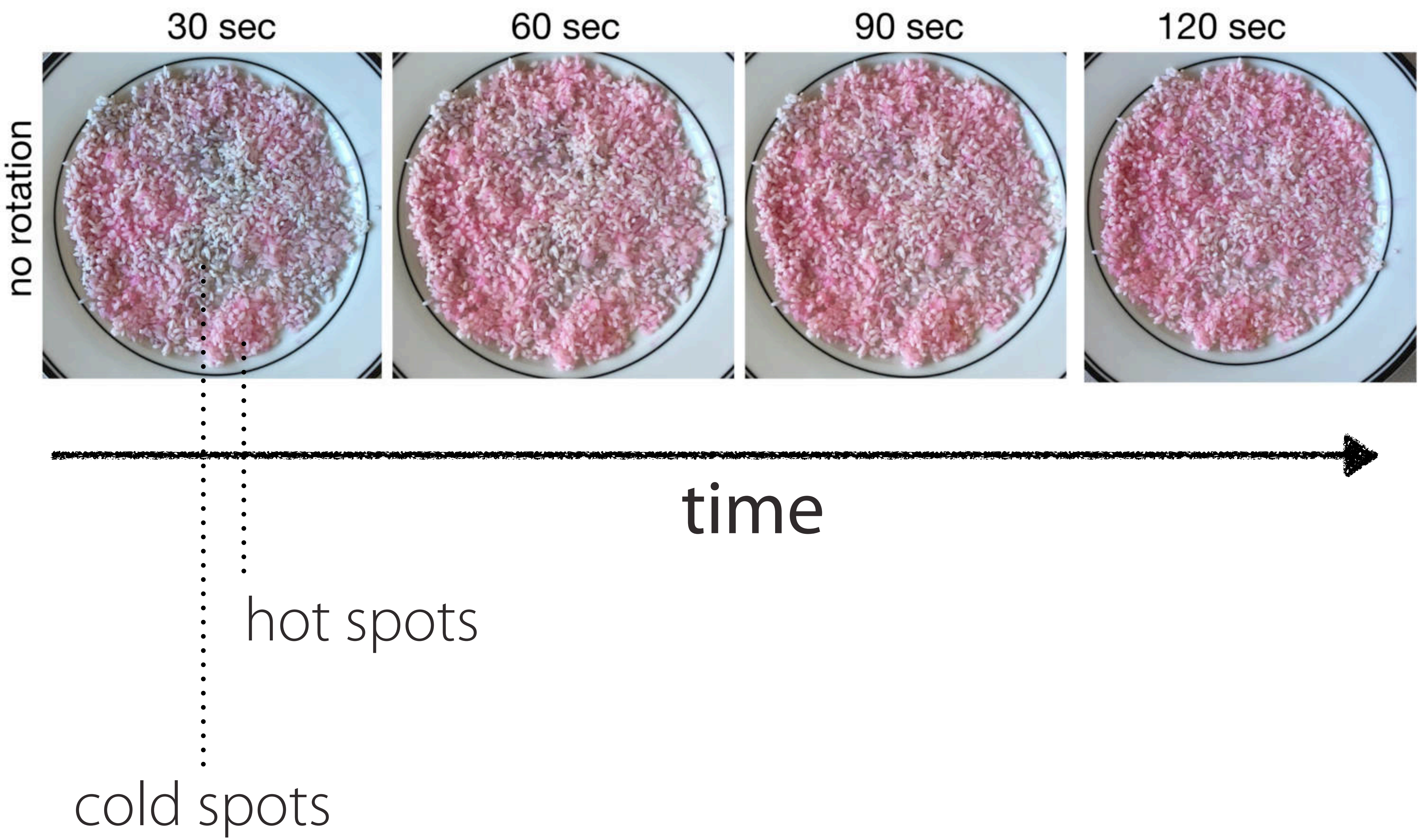
turn pink if p > 31℃

The room temperature is at 20℃.

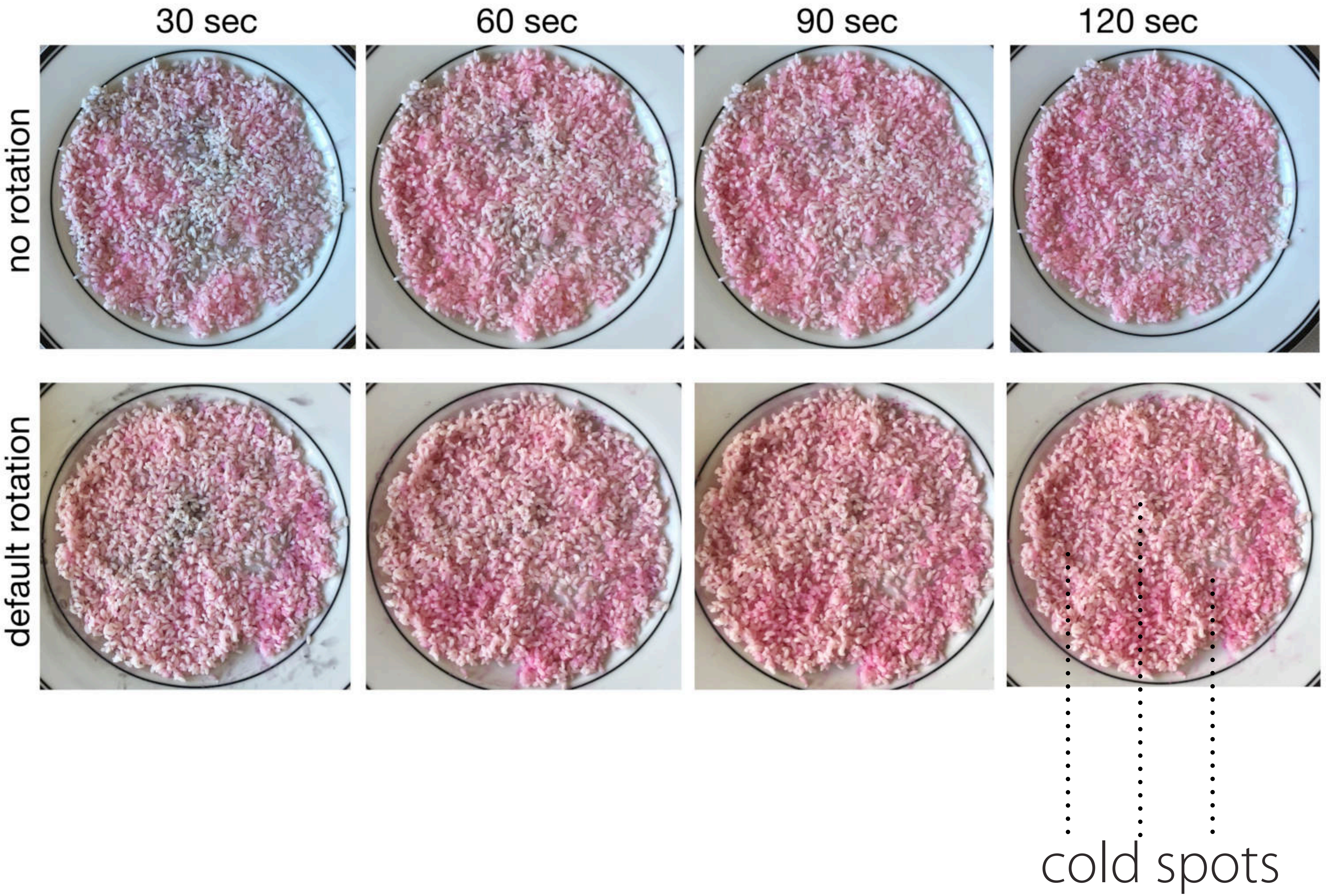
Uniform heating

heat the rice in a plate **uniformly** to 60℃ in 2 minutes.

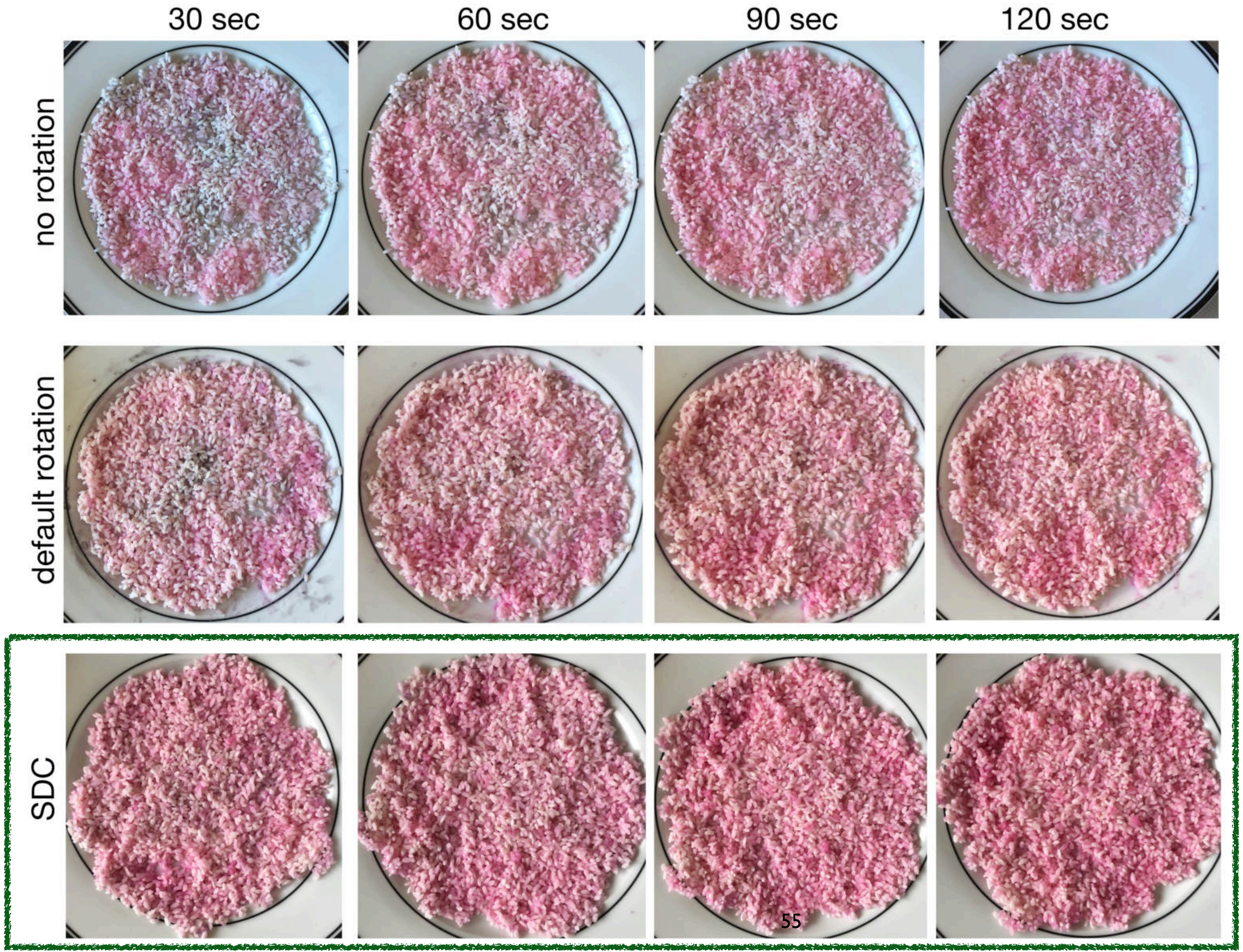
Baselines: microwave oven w/o turntable



Uniform Heating



Uniform Heating



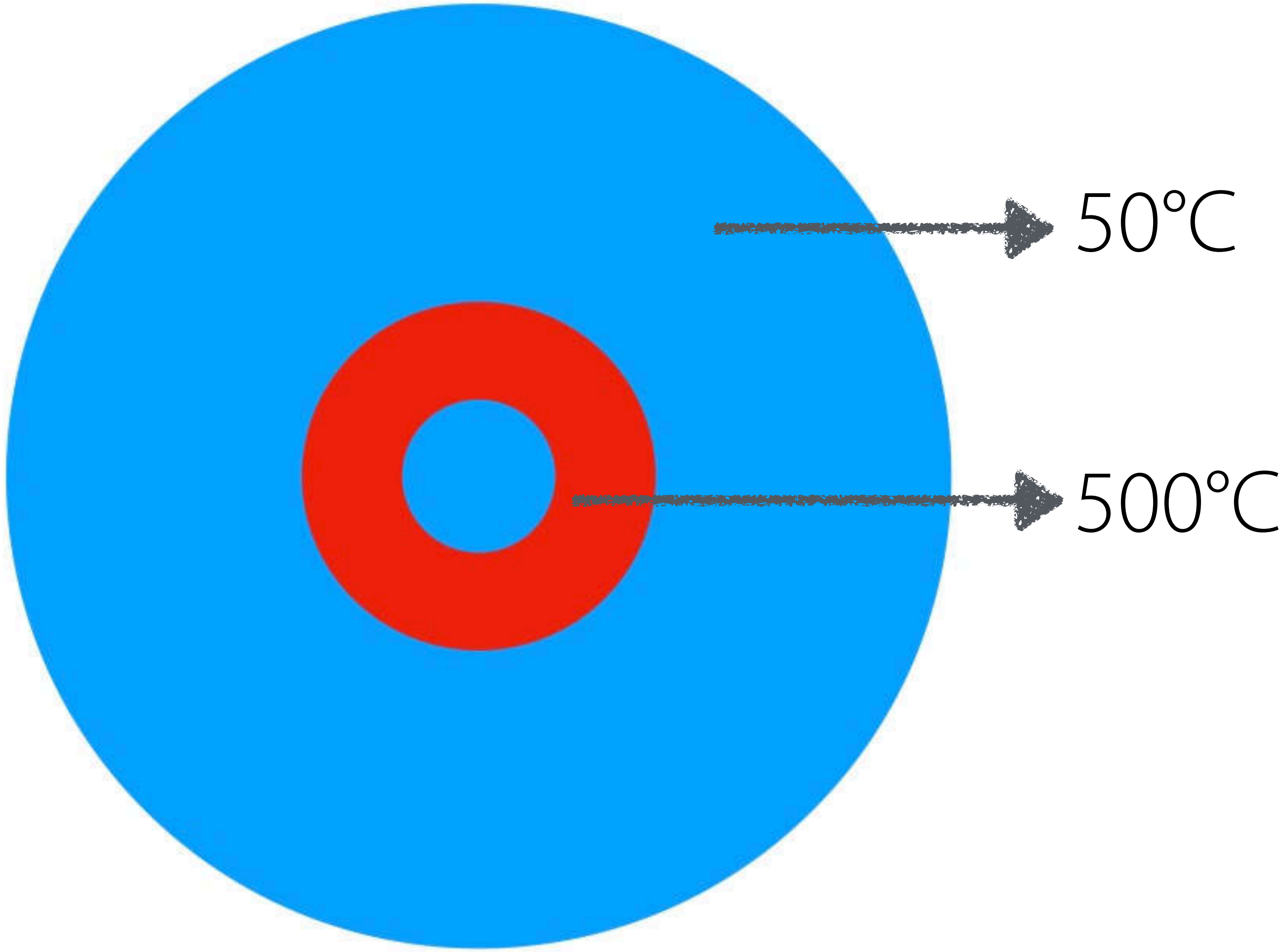
Uniform Heating

Uniform heating

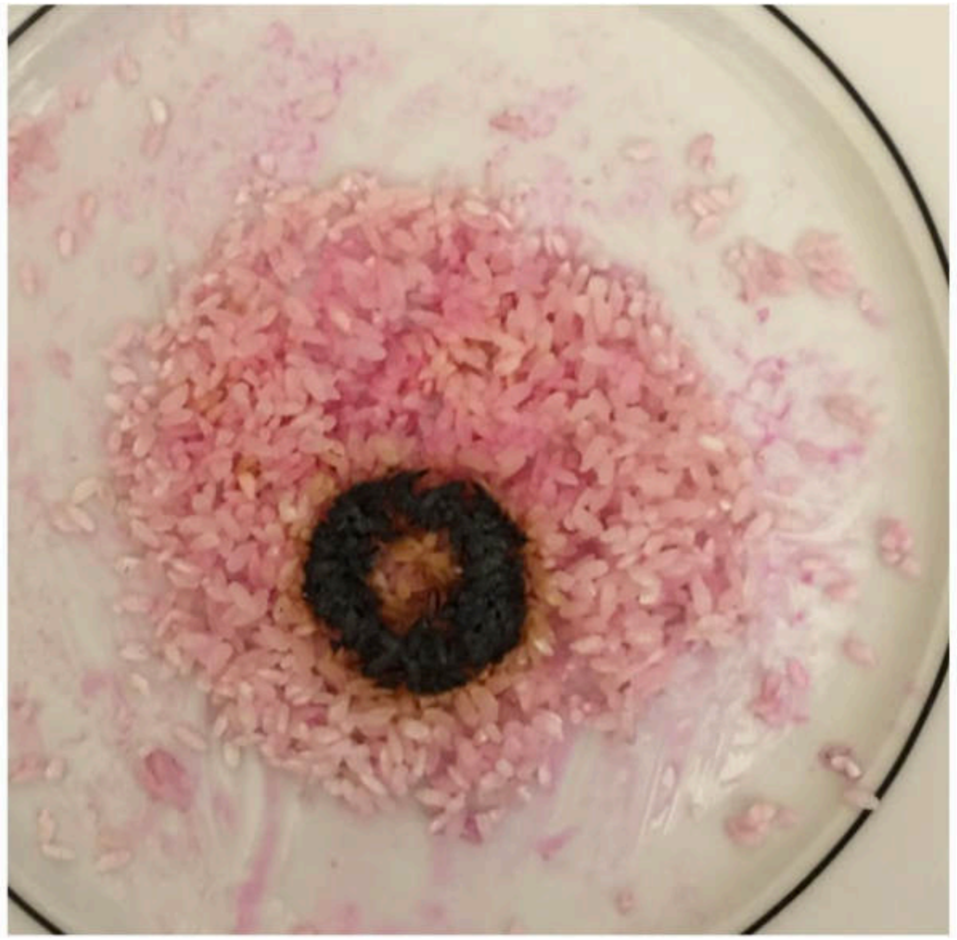
improve the **thermal heating uniformity** by **633%** compared to microwaves with a blind turntable.

More quantitative results => Paper

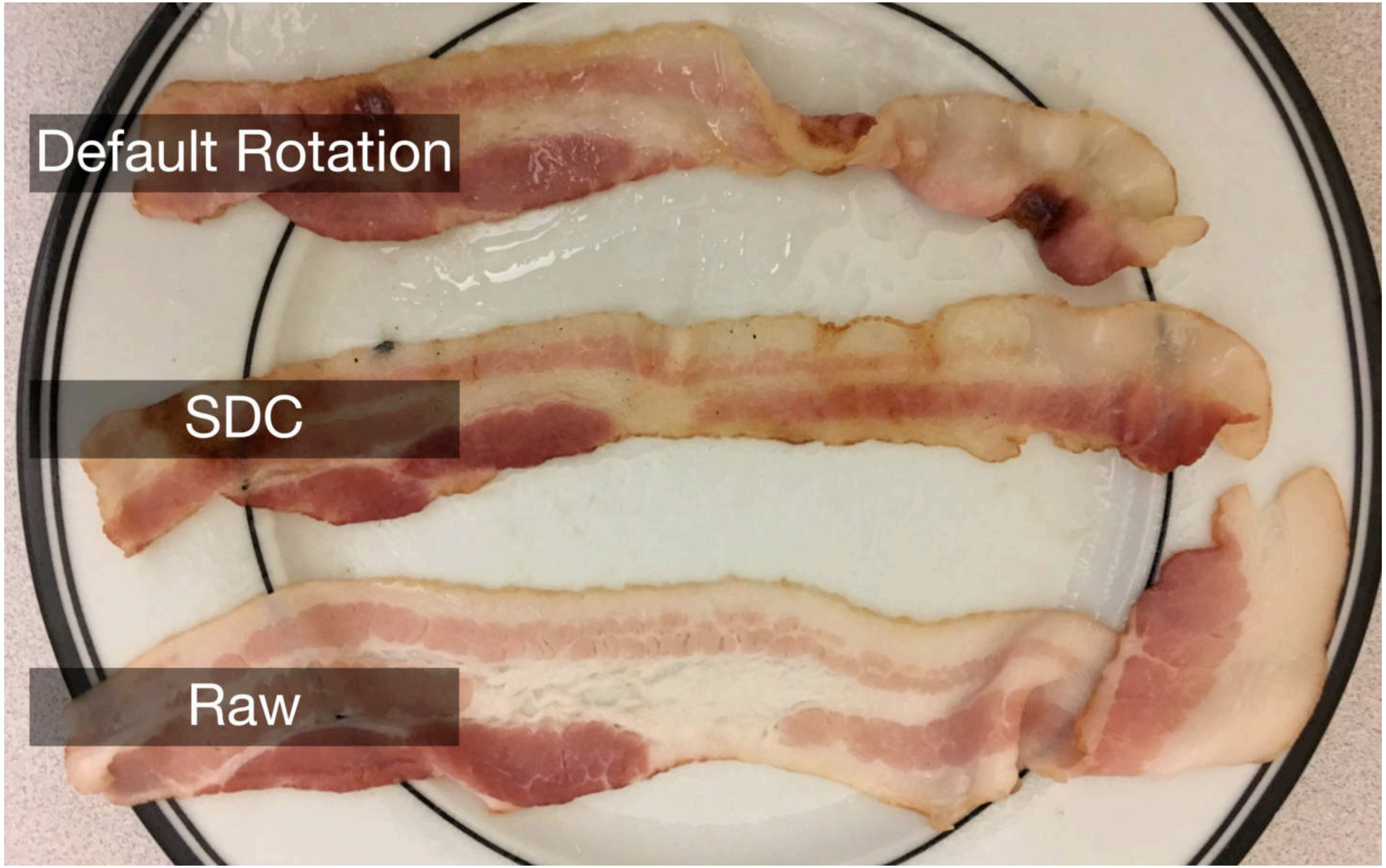
Arbitrary heating



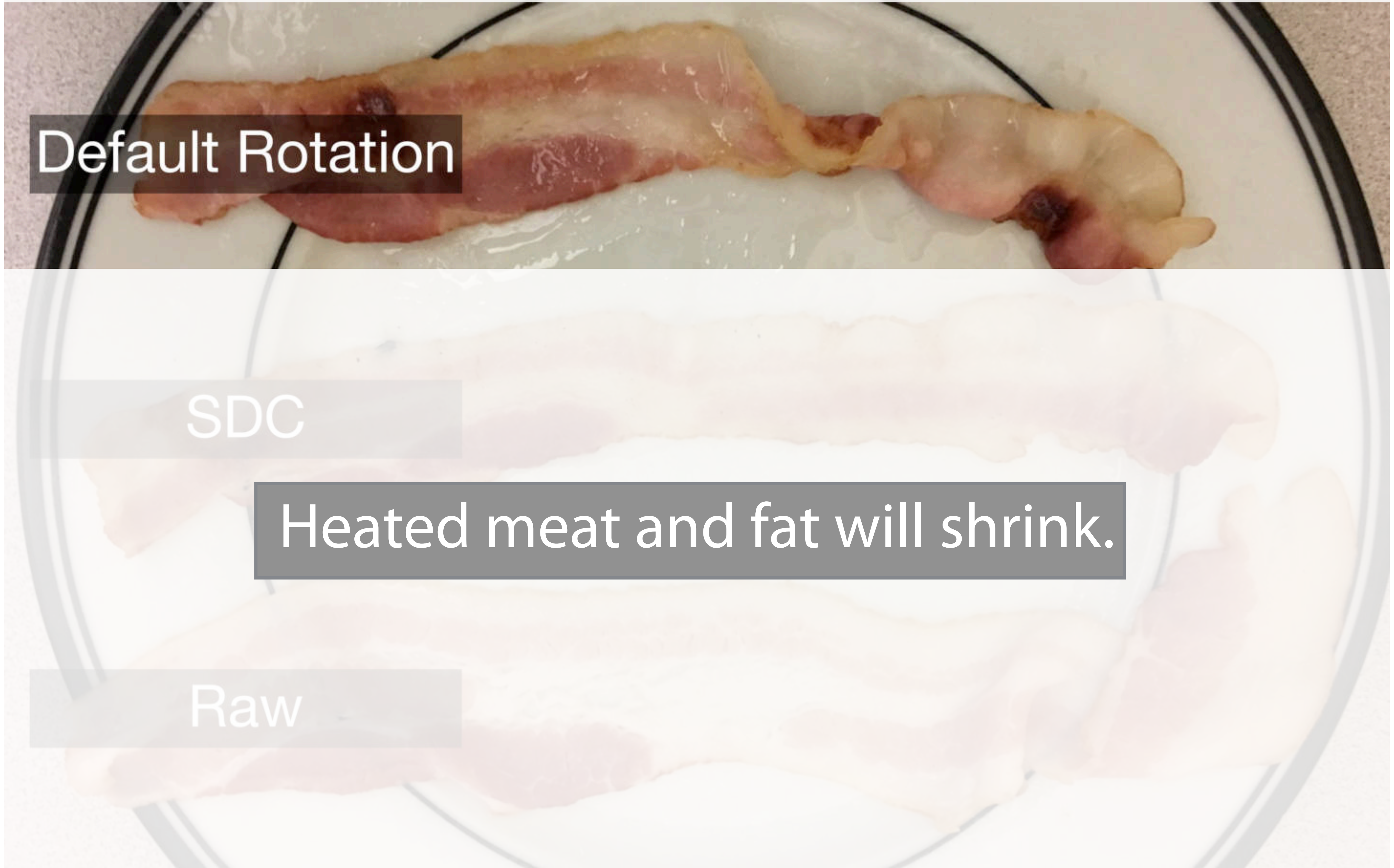
with a microwave susceptor ring



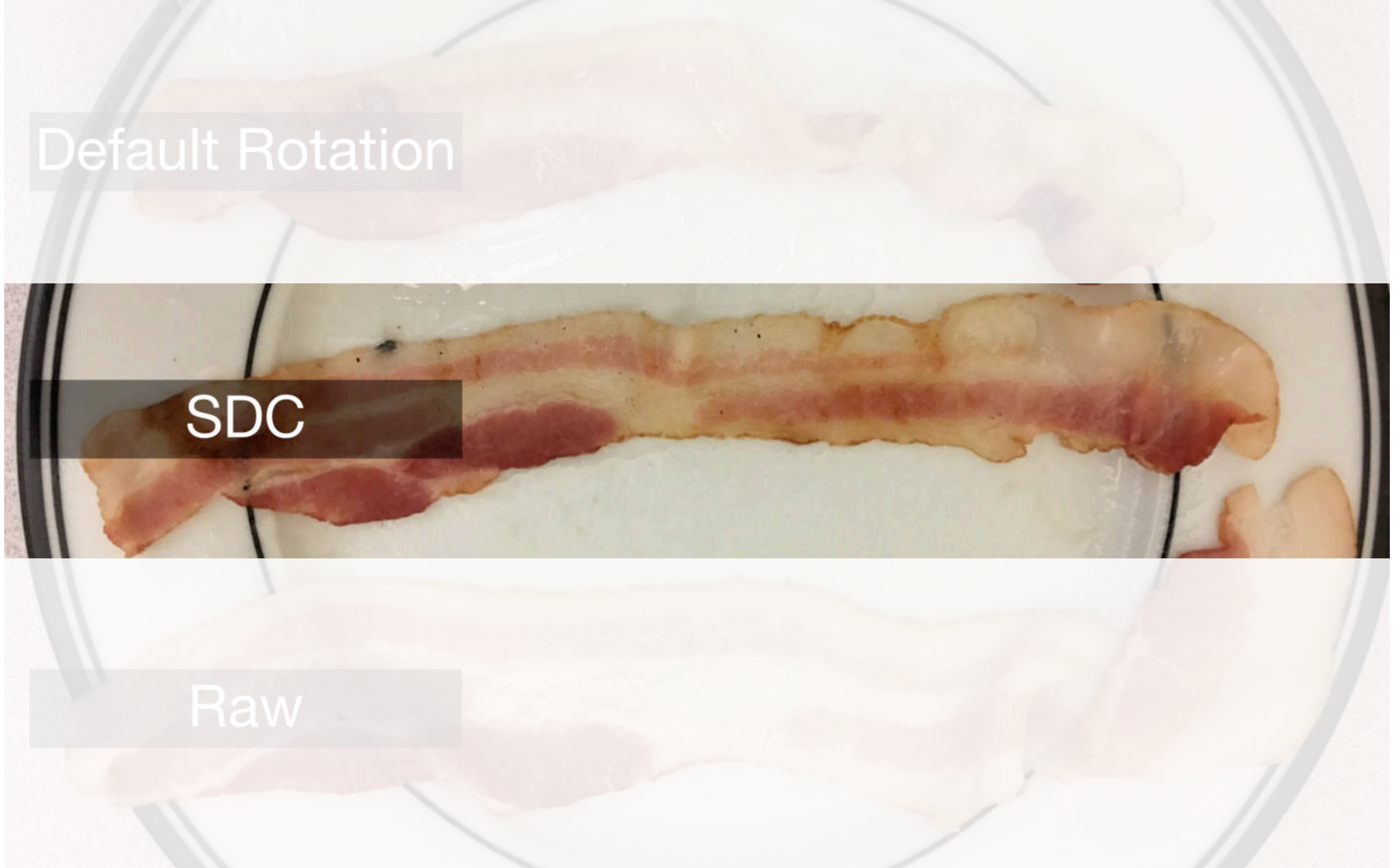
App: Cooking bacon



App: Cooking bacon



App: Cooking bacon



More apps => Paper

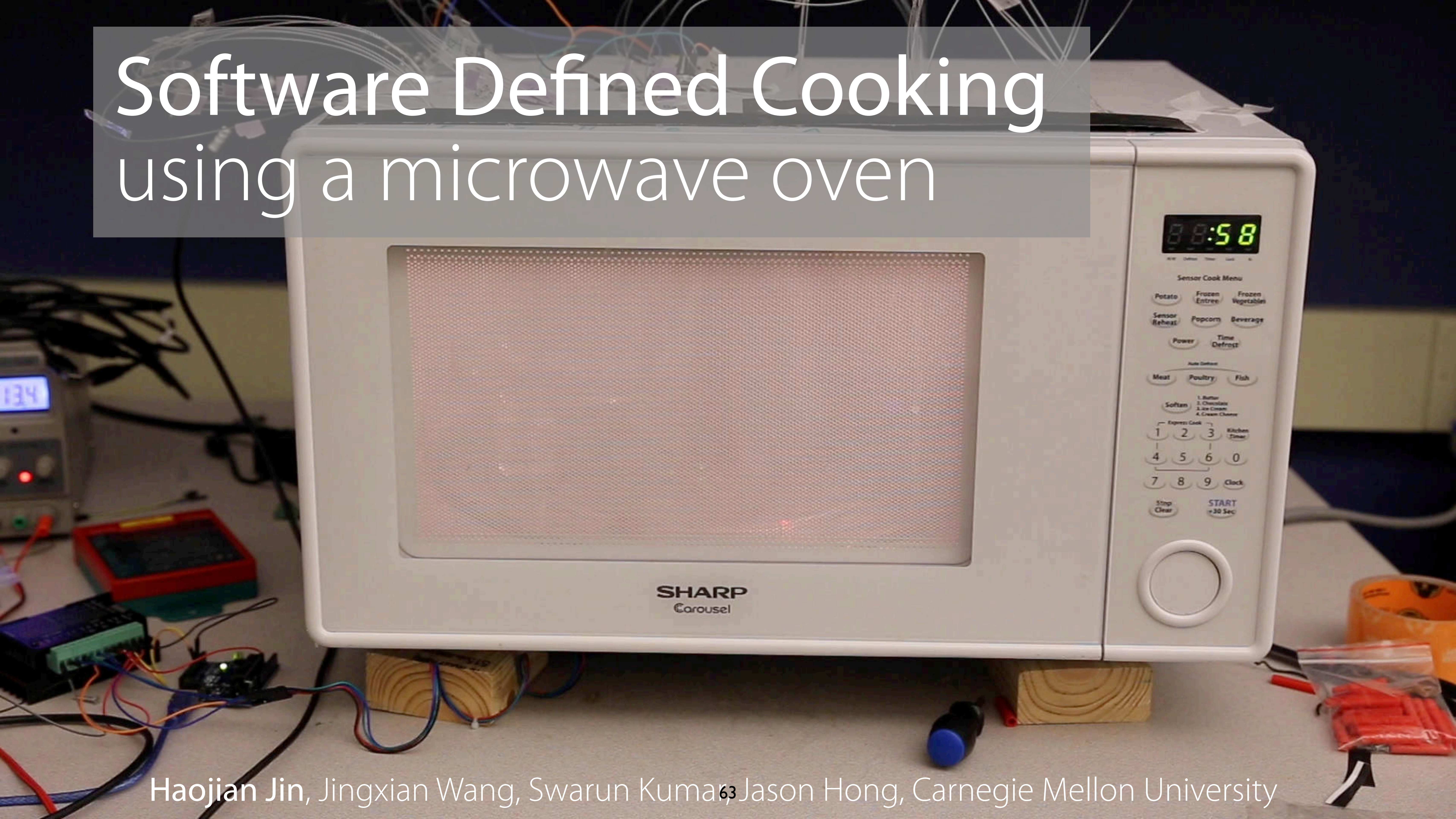
Limitations

1. SDC cooking is slower.
2. Some heating patterns might be infeasible.
3. Not sure if it's more delicious. :-)

Future work

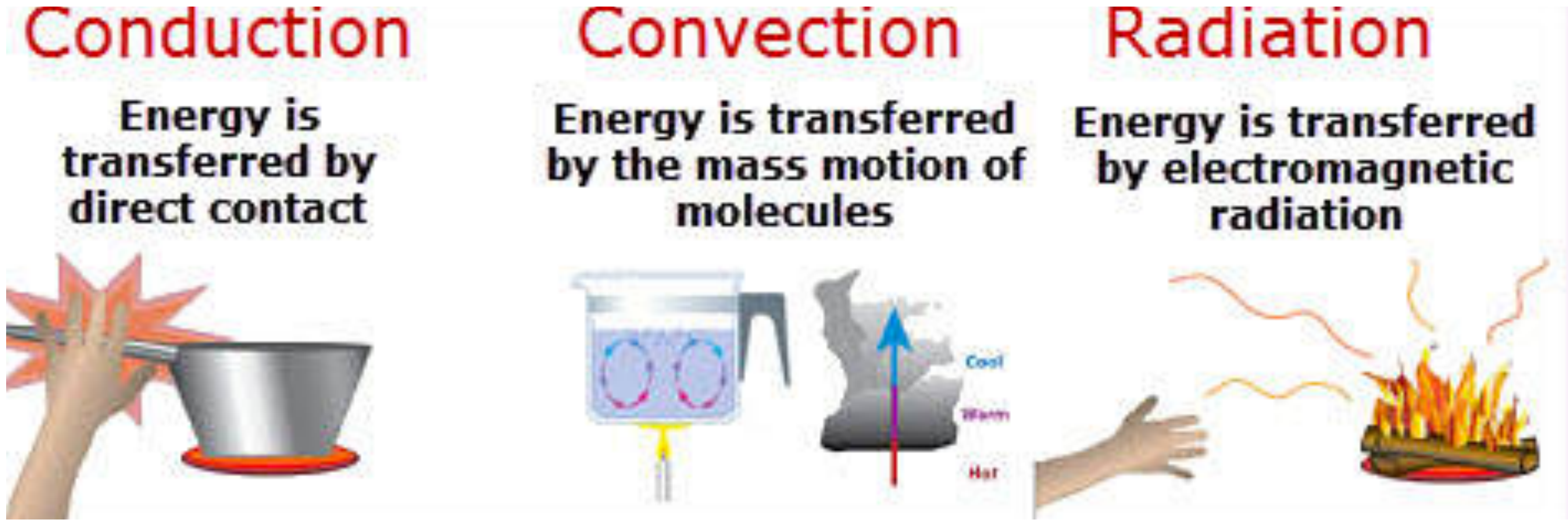
1. 6 DoF turntable
2. Higher frequency microwave + beamforming
3. Replacing neon lights with rectifiers

Software Defined Cooking using a microwave oven



Haojian Jin, Jingxian Wang, Swarun Kumar, Jason Hong, Carnegie Mellon University

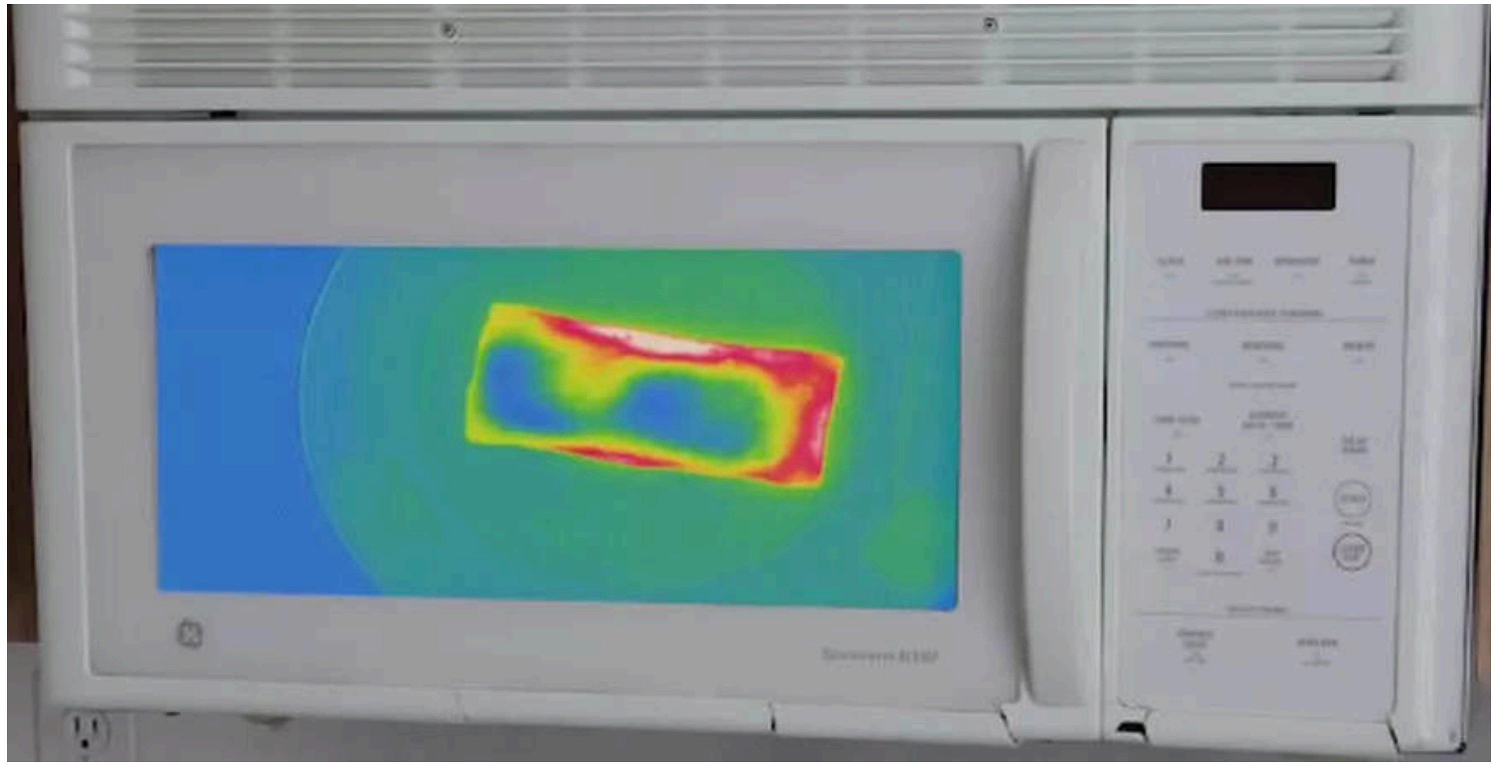
Why Microwave?



Radiation is most programmable because electromagnetic wave is **reflective and stackable**.

Why not thermal camera?

Place thermal camera **outside**



1. limited resolution (both spatial and temporal)

2. only measure the effect of heating after-the-fact

Challenges: heat food **blindly**

Sensing

1. limited resolution (both spatial and temporal)

2. only measure the effect of heating after-the-fact

Actuation

3. blind rotation.

4. limited degree of freedom.

Cooking is the **application of heat** to ingredients to transform them via chemical and physical reactions

that improve flavor, reduce chances of food borne illness, and increase nutritional value.

→ leave this space for professional chefs.

Jeff Potter. Cooking for Geeks: Real Science, Great Hacks, and Good Food.

Stochastic knapsack problem

The heat pattern is **non-static** and **unpredictable**.

Many factors can impact heat patterns.

e.g., size, temperature,
texture, material types

A greedy approximation algorithm

Greedy strategy:

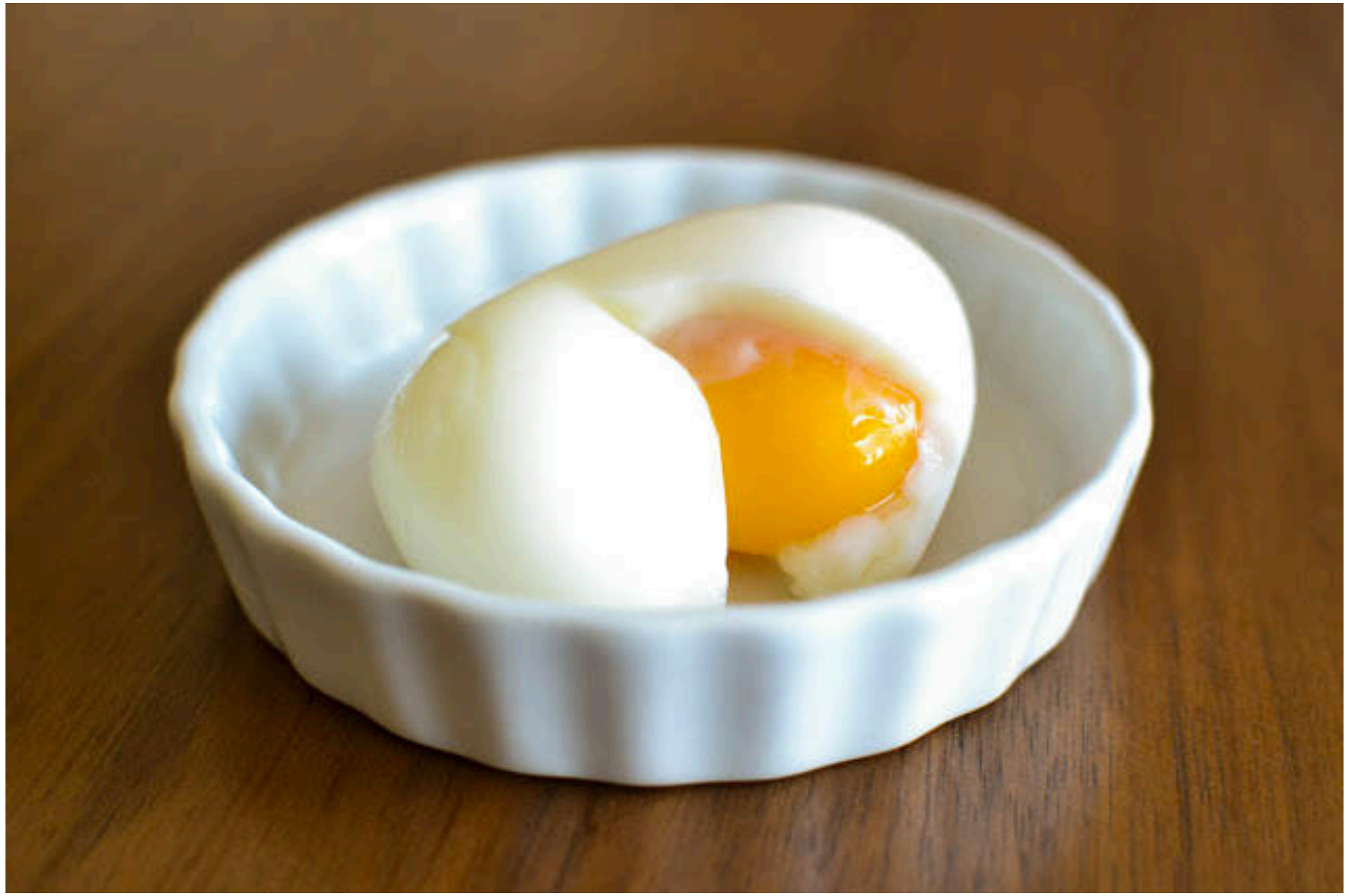
At each step of the journey, heat at the rotation angle **whose temperature gradient is most similar to the current heating gap**.

Solving the Optimization (3)

Cooking is the **application of heat** to ingredients to transform them via chemical and physical reactions that improve flavor, reduce chances of food borne illness, and increase nutritional value.

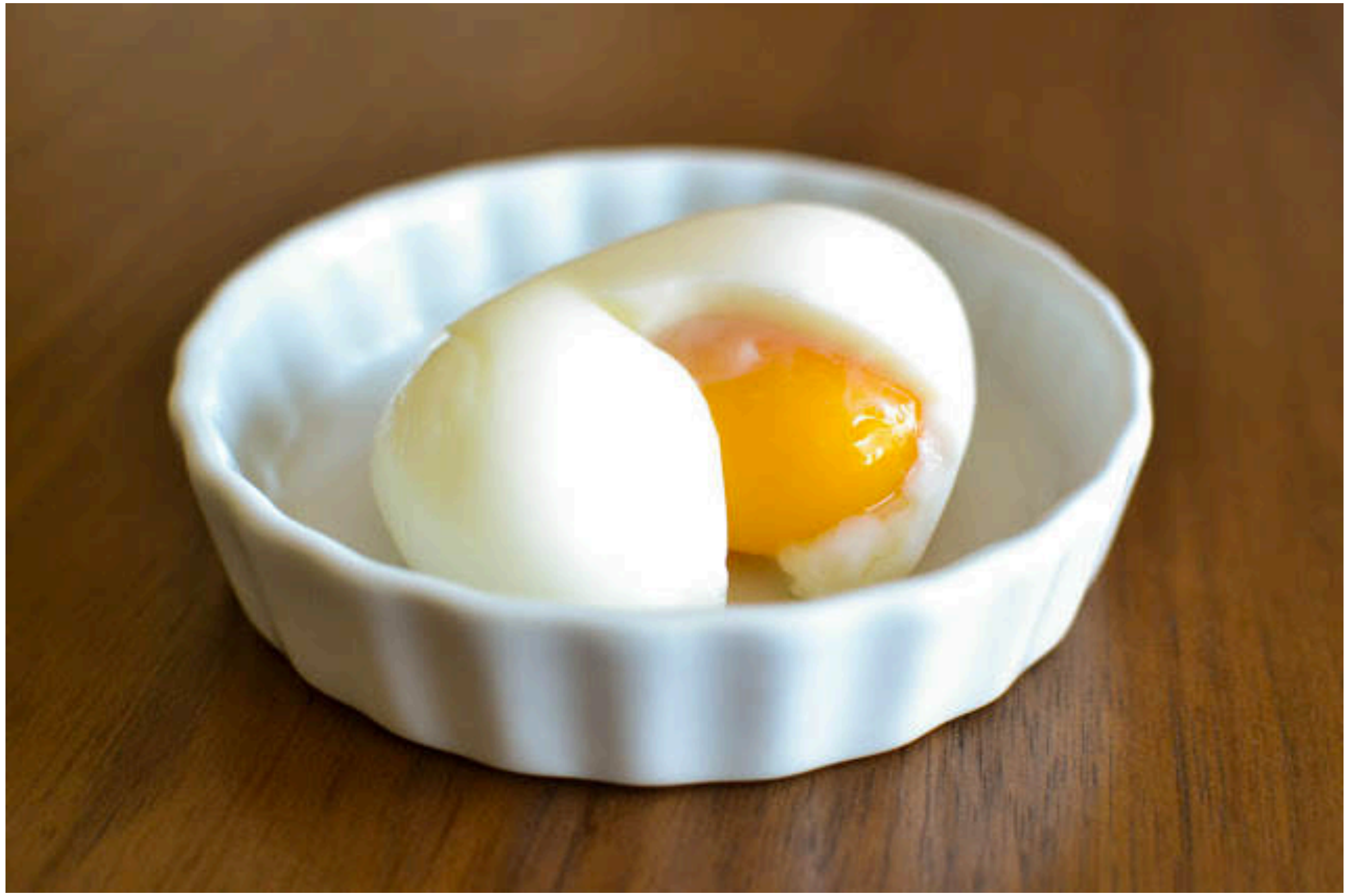
Jeff Potter. Cooking for Geeks: Real Science, Great Hacks, and Good Food.

onsen tamago/hot spring eggs/63°C eggs



Cooked = Temperature x Time

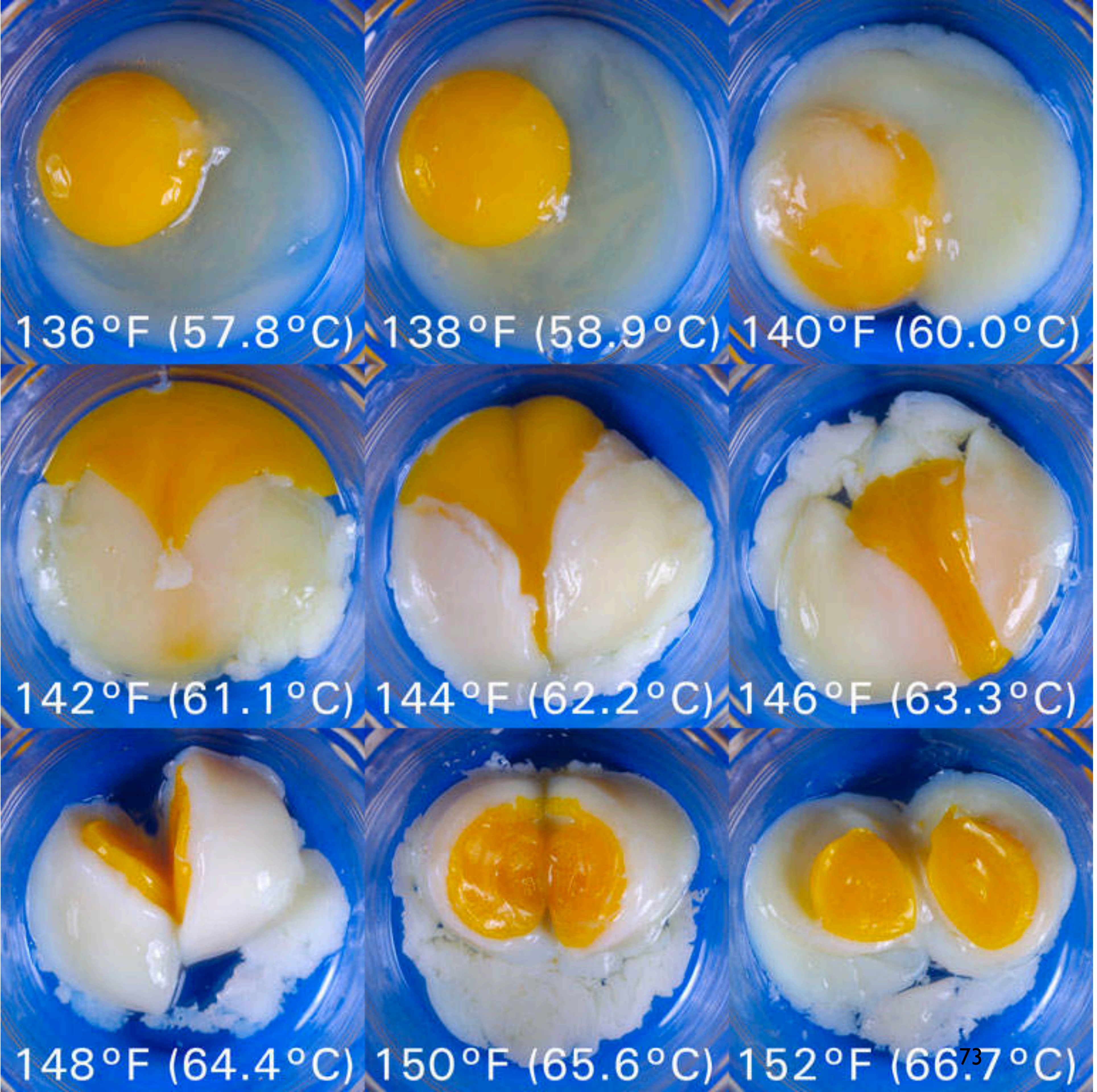
onsen tamago/hot spring eggs/63°C eggs



set the temperature to **145°F (63°C)** and let the eggs cook for anywhere from **45-90 minutes**.

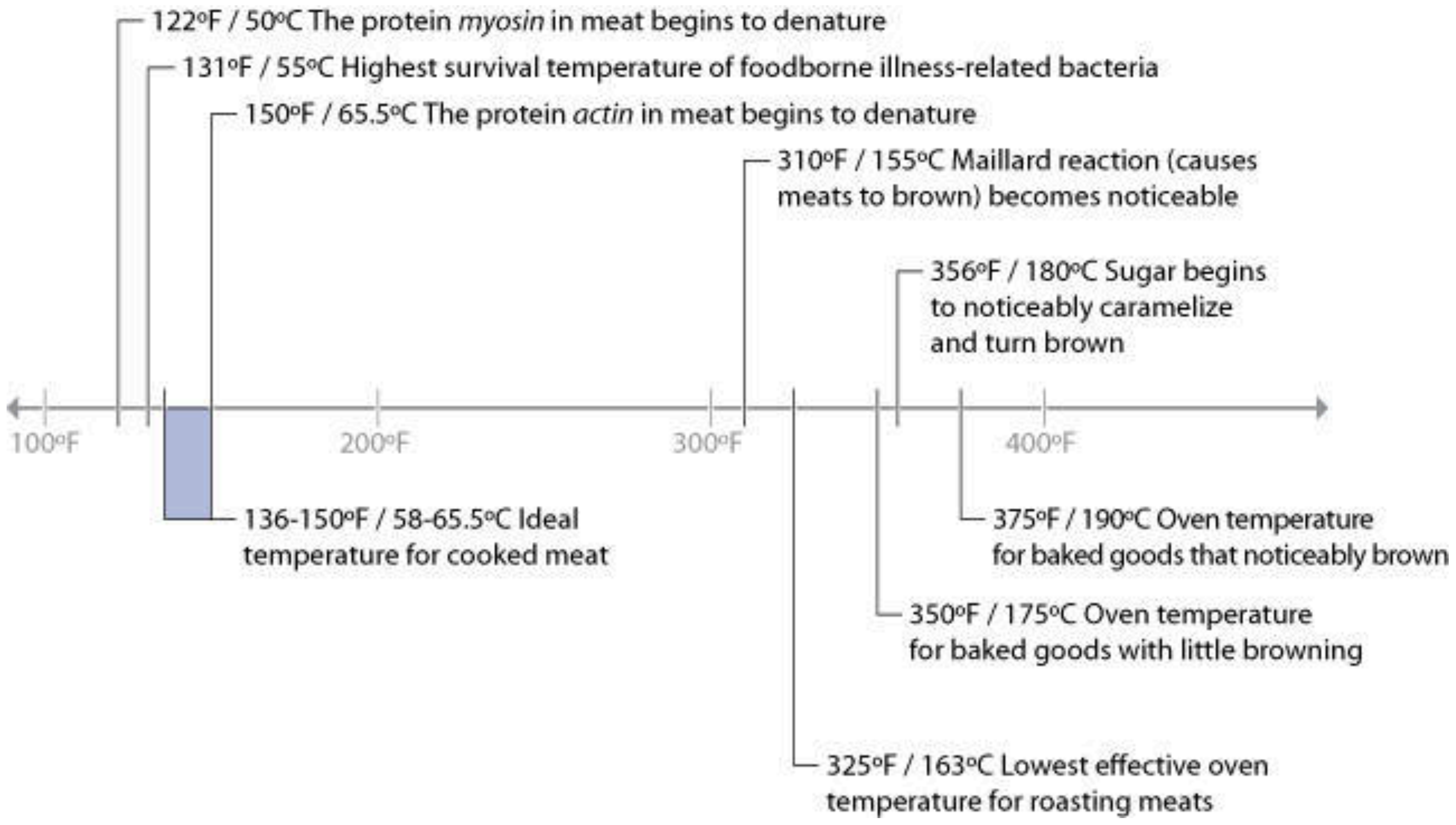
Cooked = **Temperature** x Time

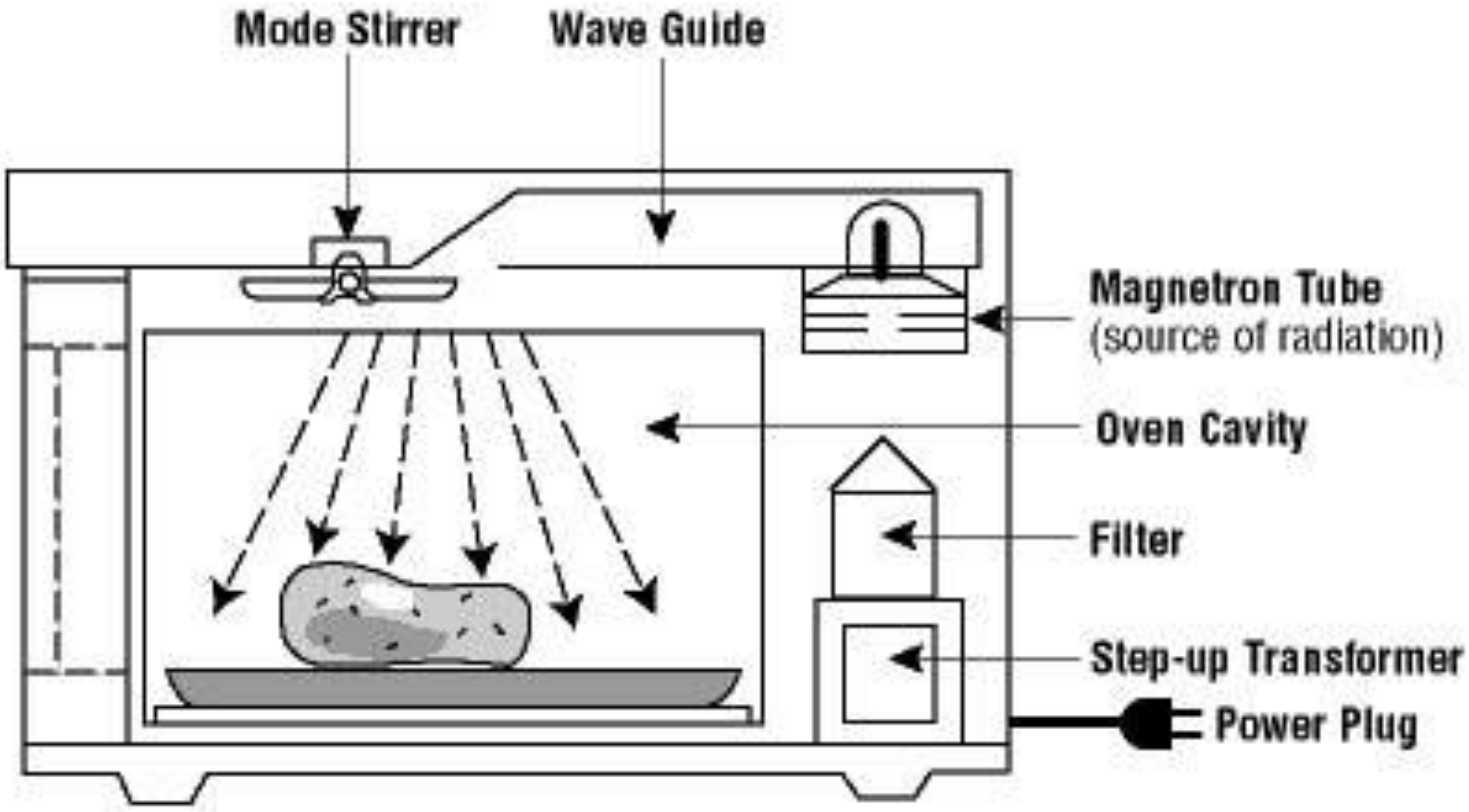
Aki Kamozawa and Alex Talbot
Ideas in Food: Great Recipes and Why They Work: A Cookbook



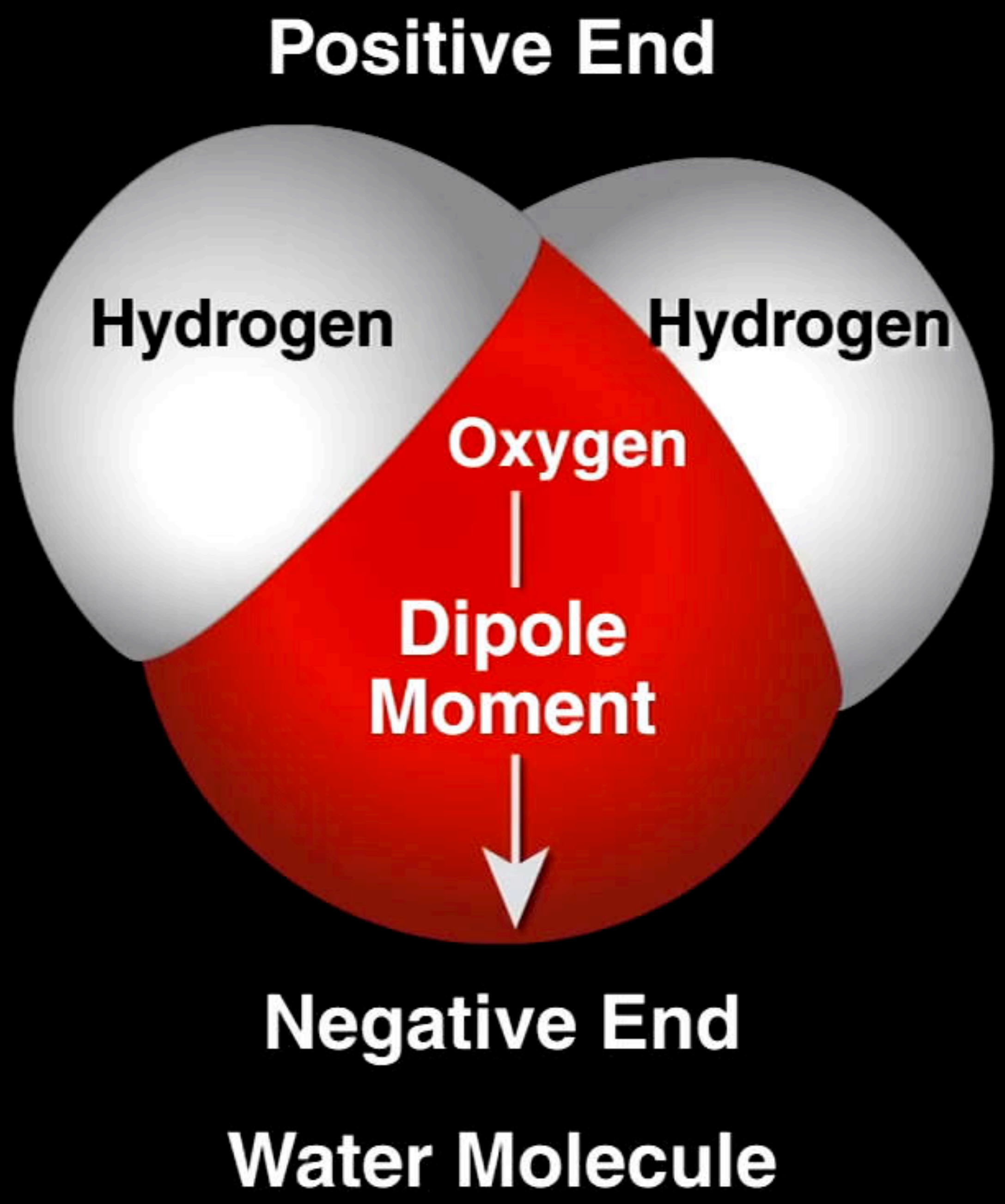
The process of **protein denature** is a function of the temperature & time.

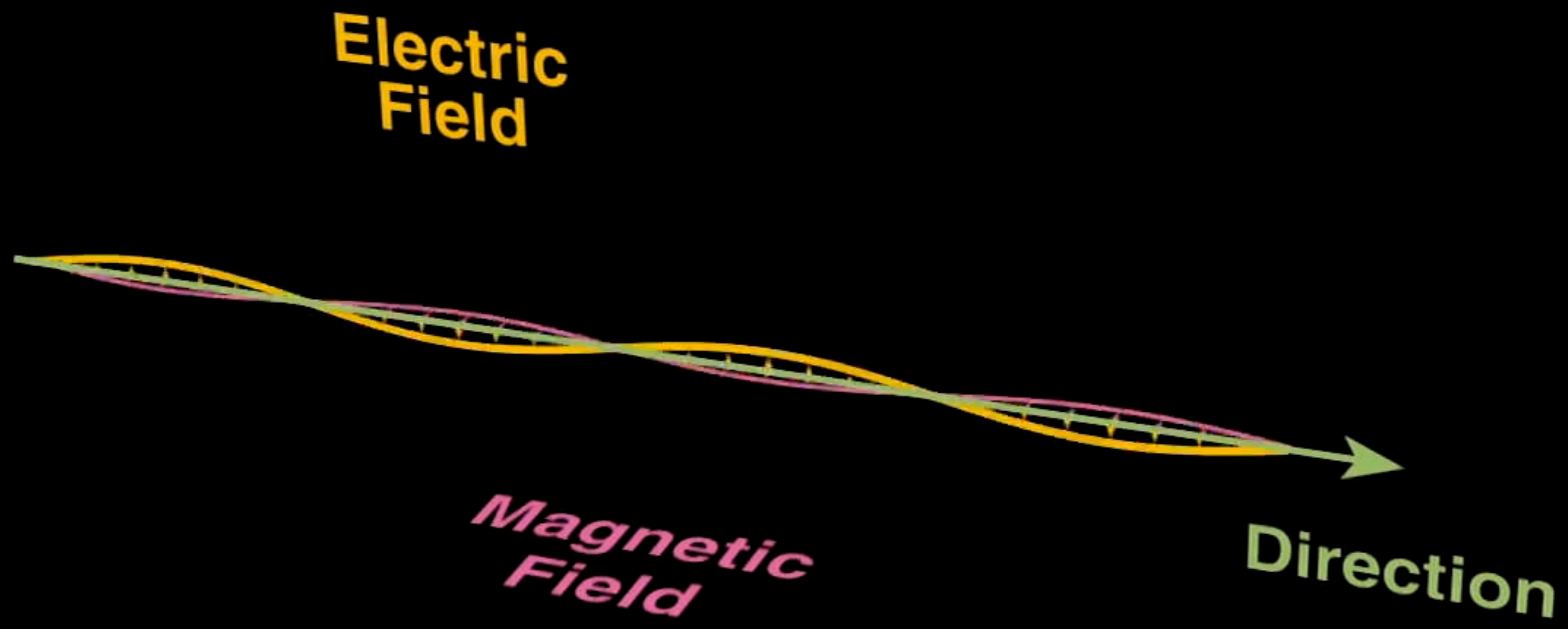
Temperatures of common reactions in food





A microwave oven converts a large electrical input (≈1000W) into microwave energy (2.45 GHz) and heats food using microwave radiation.



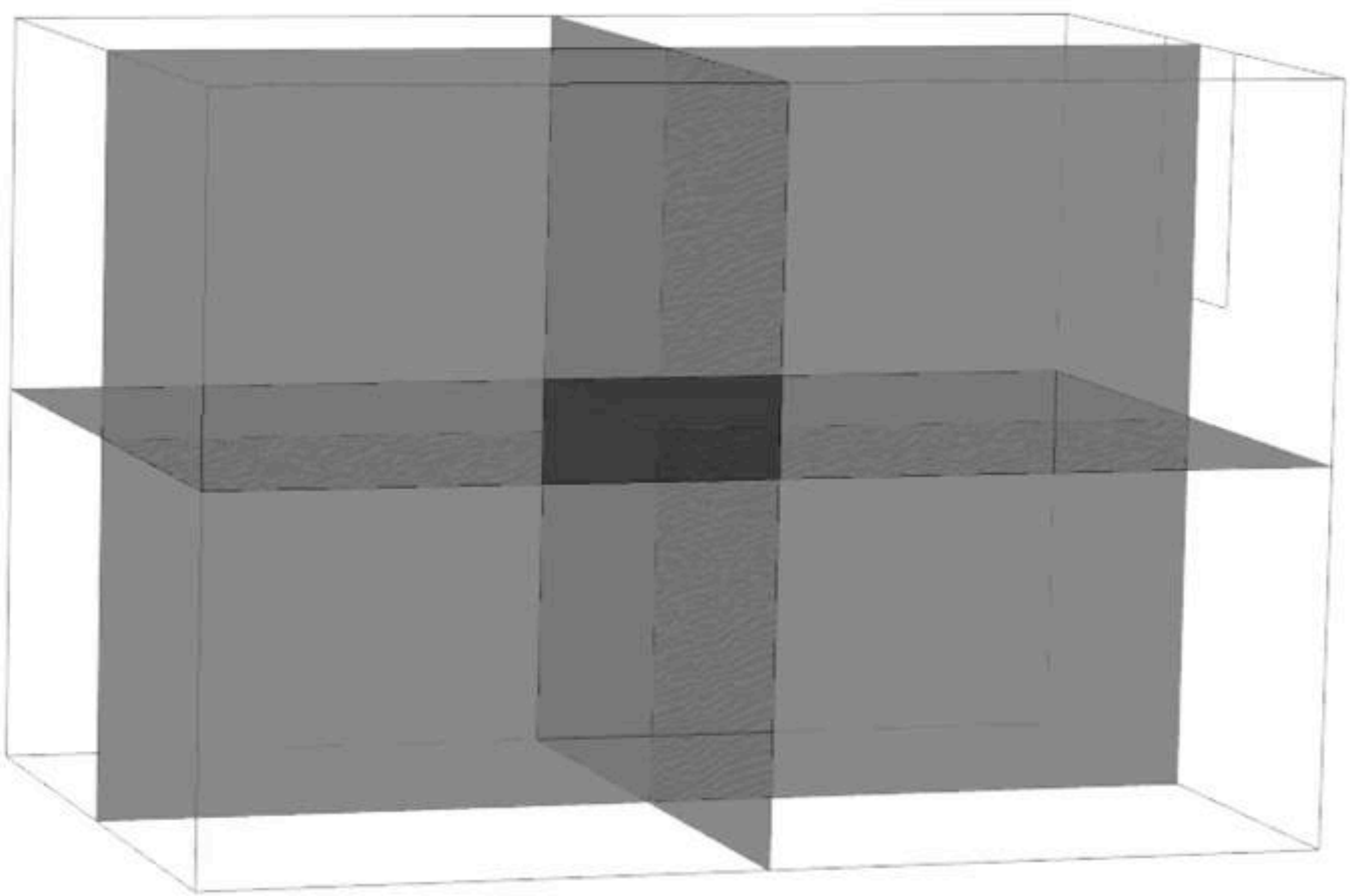


dielectric heating

https://www.youtube.com/watch?v=kp33ZprO0Ck

standing wave

https://www.youtube.com/watch?v=kp33ZprO0Ck



Unpredictable cold/hot spots
Influenced by the content
(shape, surface, temperature, etc.)

3D standing wave

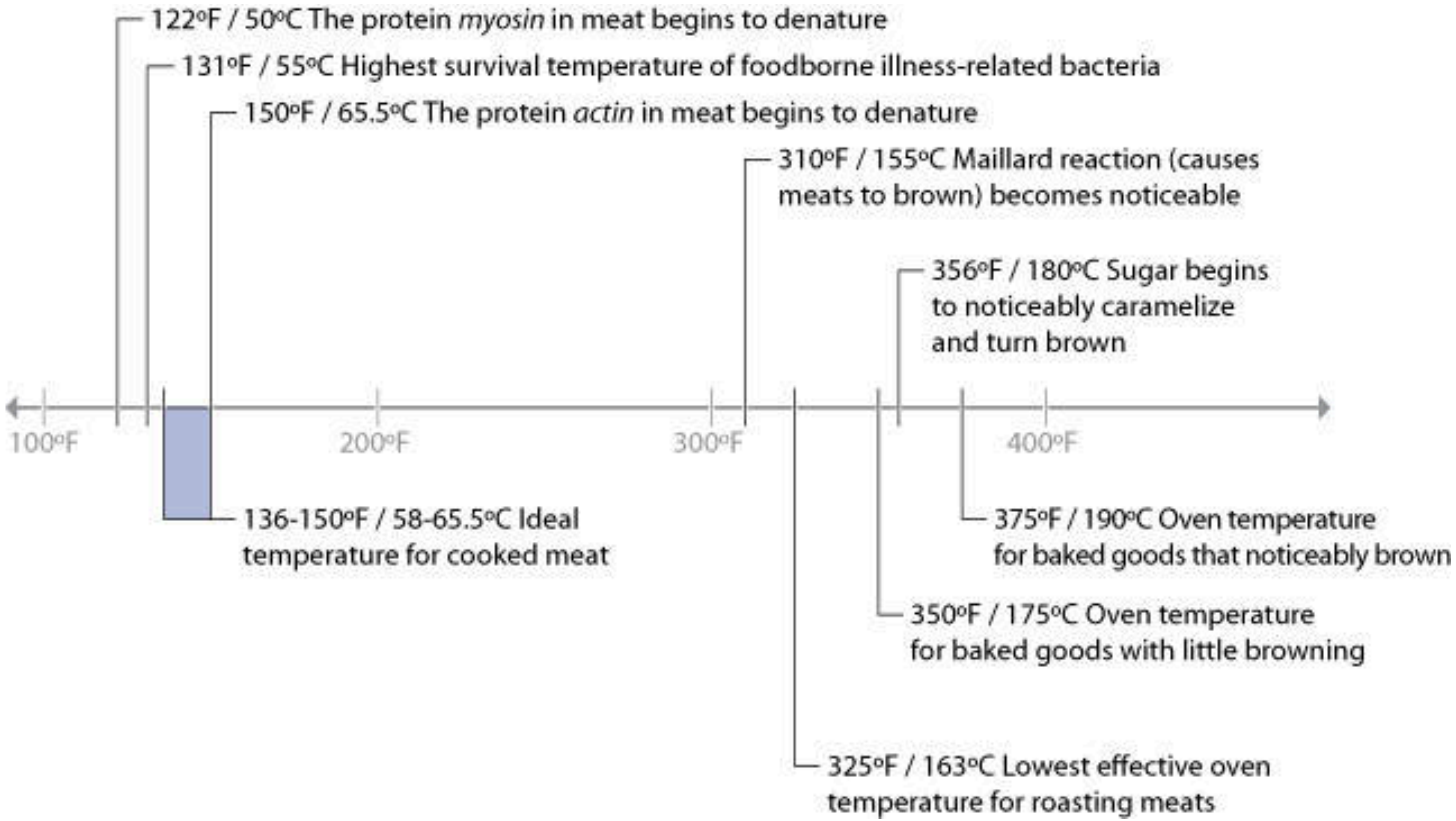
sharp-edged metals
(e.g., forks, most sensors, motors)

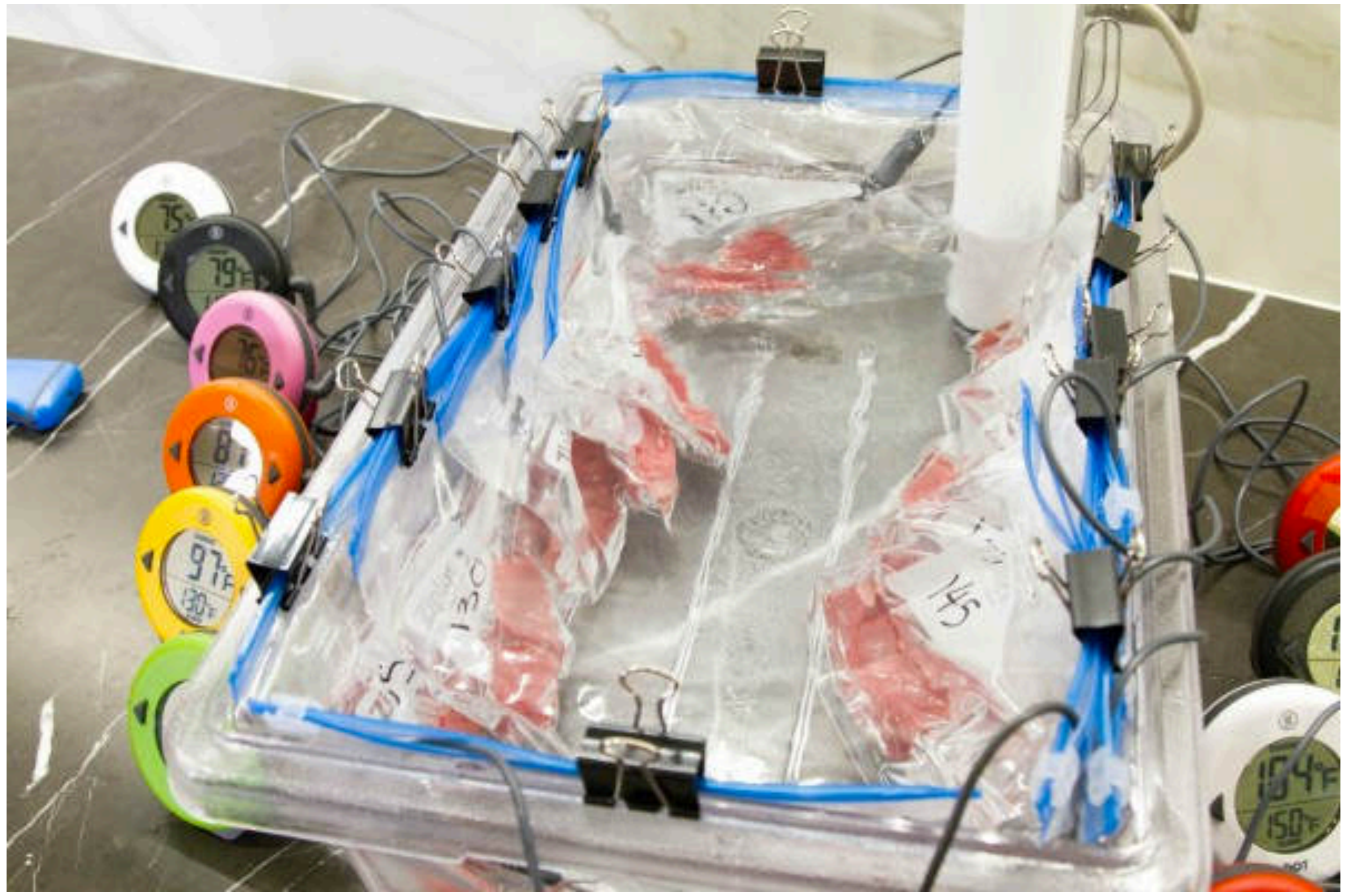
Microwave-safe plastic

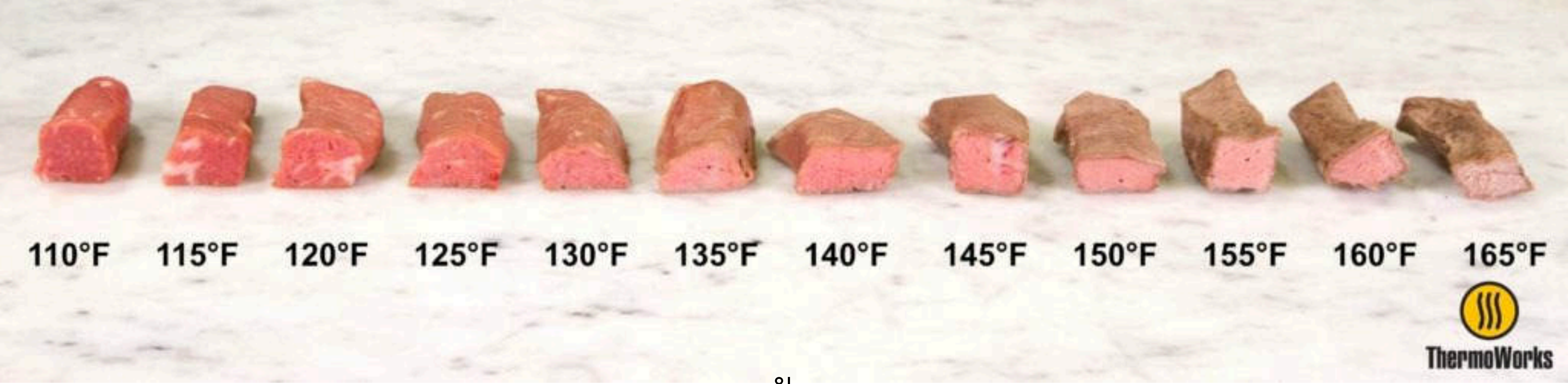
Eggs

….

Microwave is dangerous


122°F / 50°C The protein *myosin* in meat begins to denature
131°F / 55°C Highest survival temperature of foodborne illness-related bacteria
150°F / 65.5°C The protein *actin* in meat begins to denature
310°F / 155°C Maillard reaction (causes meats to brown) becomes noticeable
356°F / 180°C Sugar begins to noticeably caramelize and turn brown
100°F
200°F
300°F
400°F
136-150°F / 58-65.5°C Ideal temperature for cooked meat
375°F / 190°C Oven temperature for baked goods that noticeably brown
350°F / 175°C Oven temperature for baked goods with little browning
325°F / 163°C Lowest effective oven temperature for roasting meats




110°F
115°F
120°F
125°F
130°F
135°F
140°F
145°F
150°F
155°F
160°F
165°F
ThermoWorks