December, 06th 2018, CORIA, Rouen (France)

Why Thermographic Phosphors can be useful to Fire Applications ?

Pradip Xavier

Associate Professor

Energy & Propulsion Dept. (INSA)

Reactive Flows Dept. (CORIA)

Recent Motivations

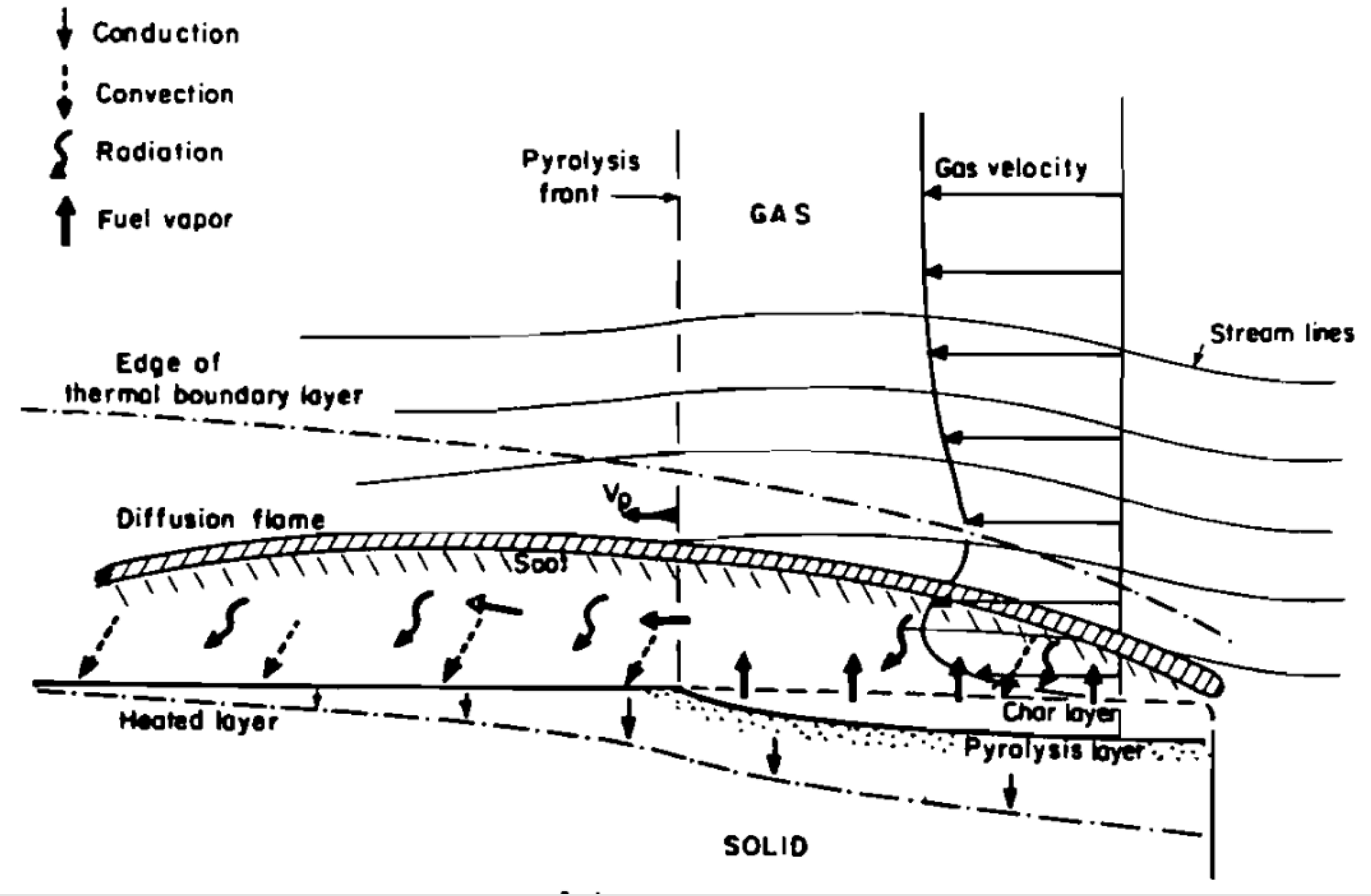
Grenfell Tower

Evening Standard

California wildfires

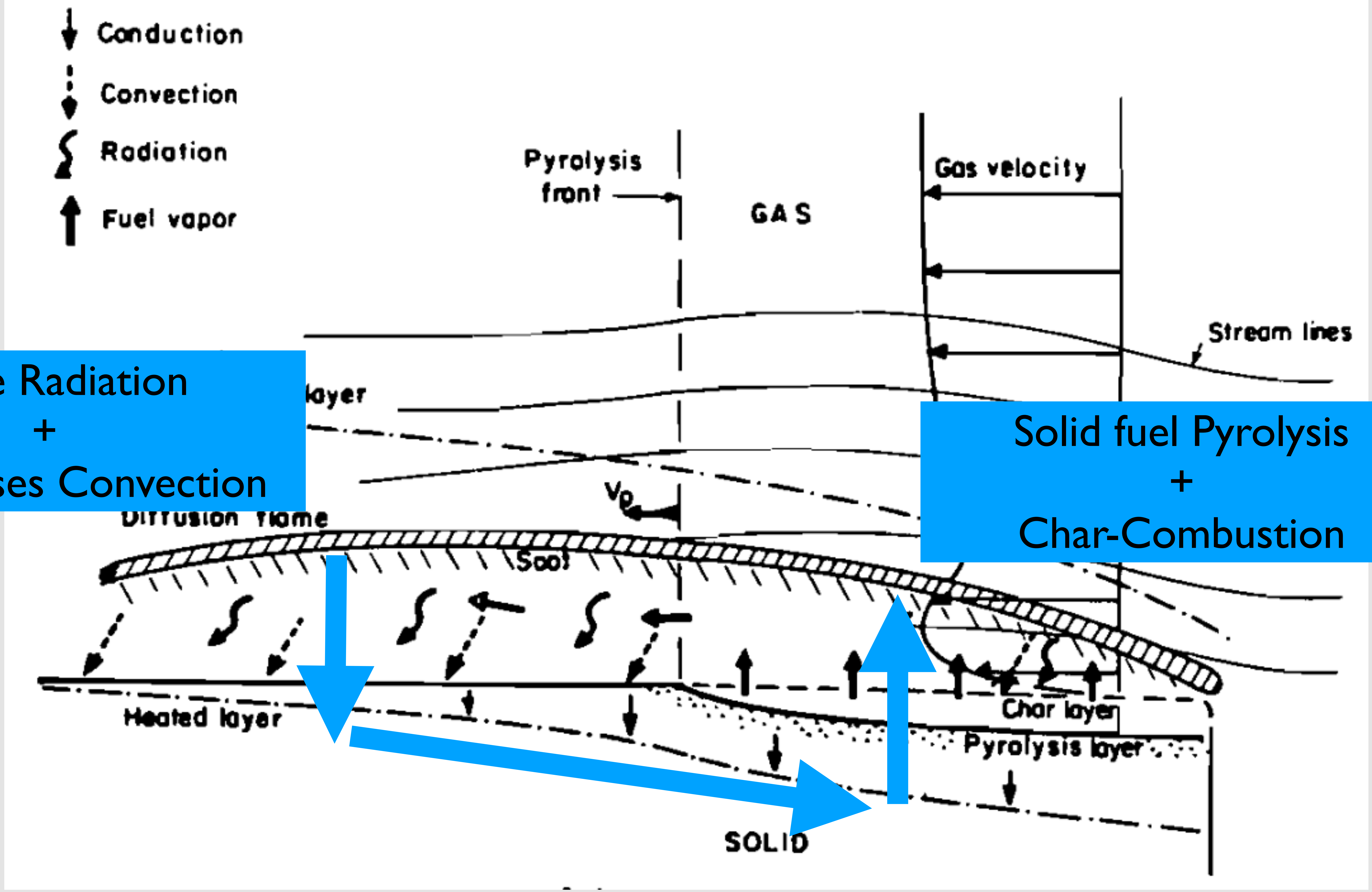
ABC News

Flame Spread & Surface Temperature



Fernandez-Pello, Combust. Sci. Technol. 39:119-134, 1984

Flame Spread & Surface Temperature

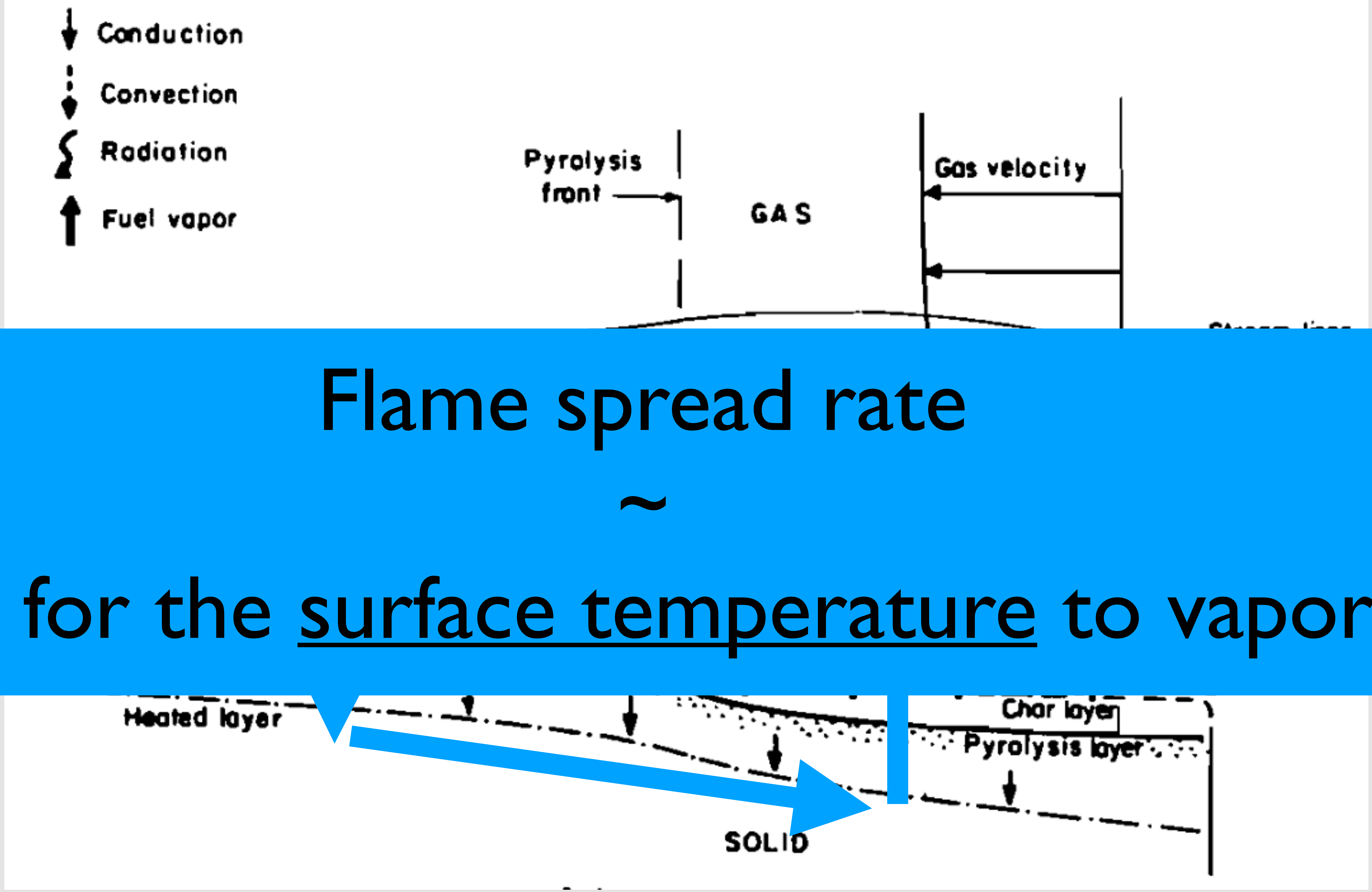


Flame Radiation
+
Burnt Gases Convection

Solid fuel Pyrolysis
+
Char-Combustion

Fernandez-Pello, Combust. Sci. Technol. 39:119-134, 1984

Flame Spread & Surface Temperature



Flame spread rate

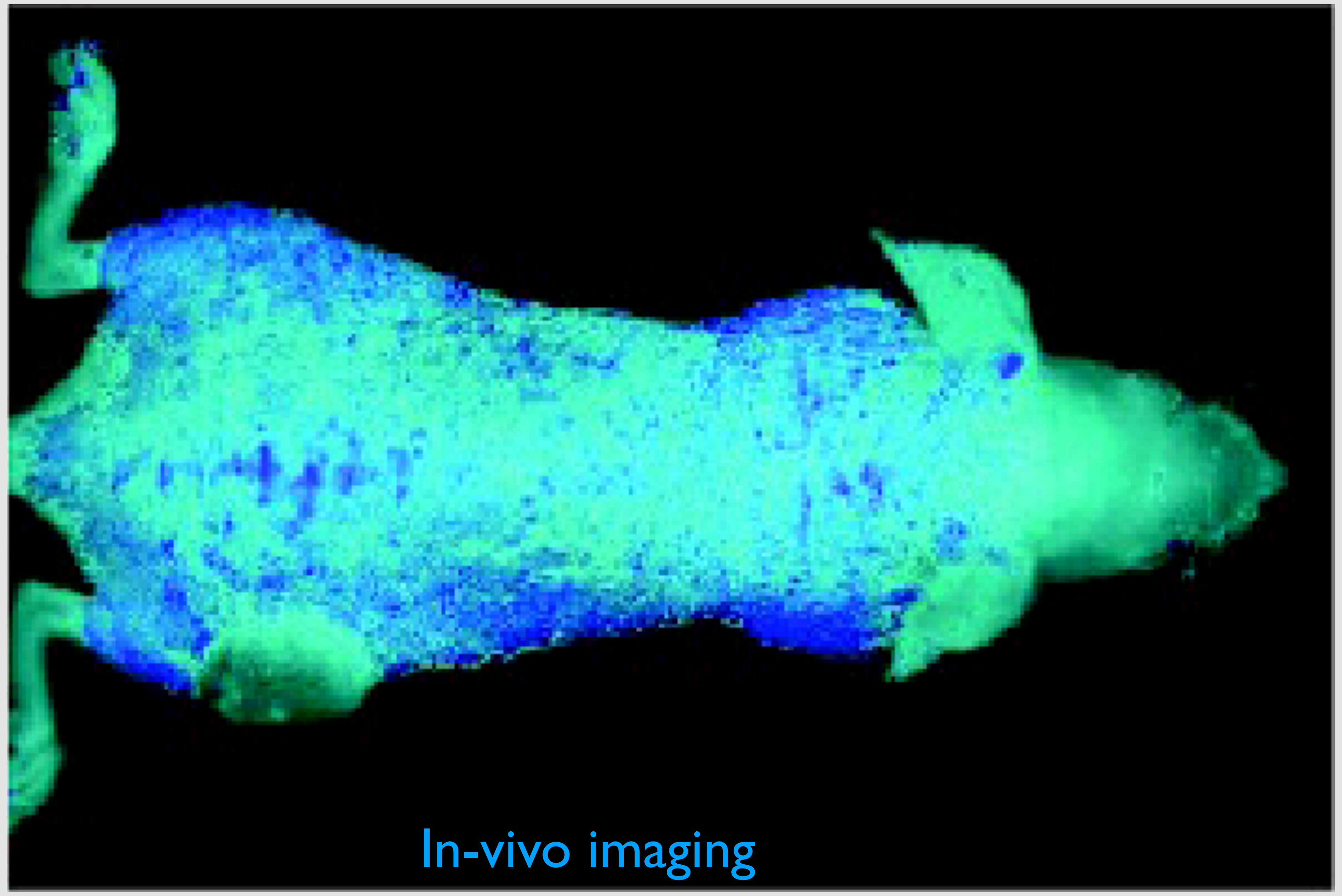
~

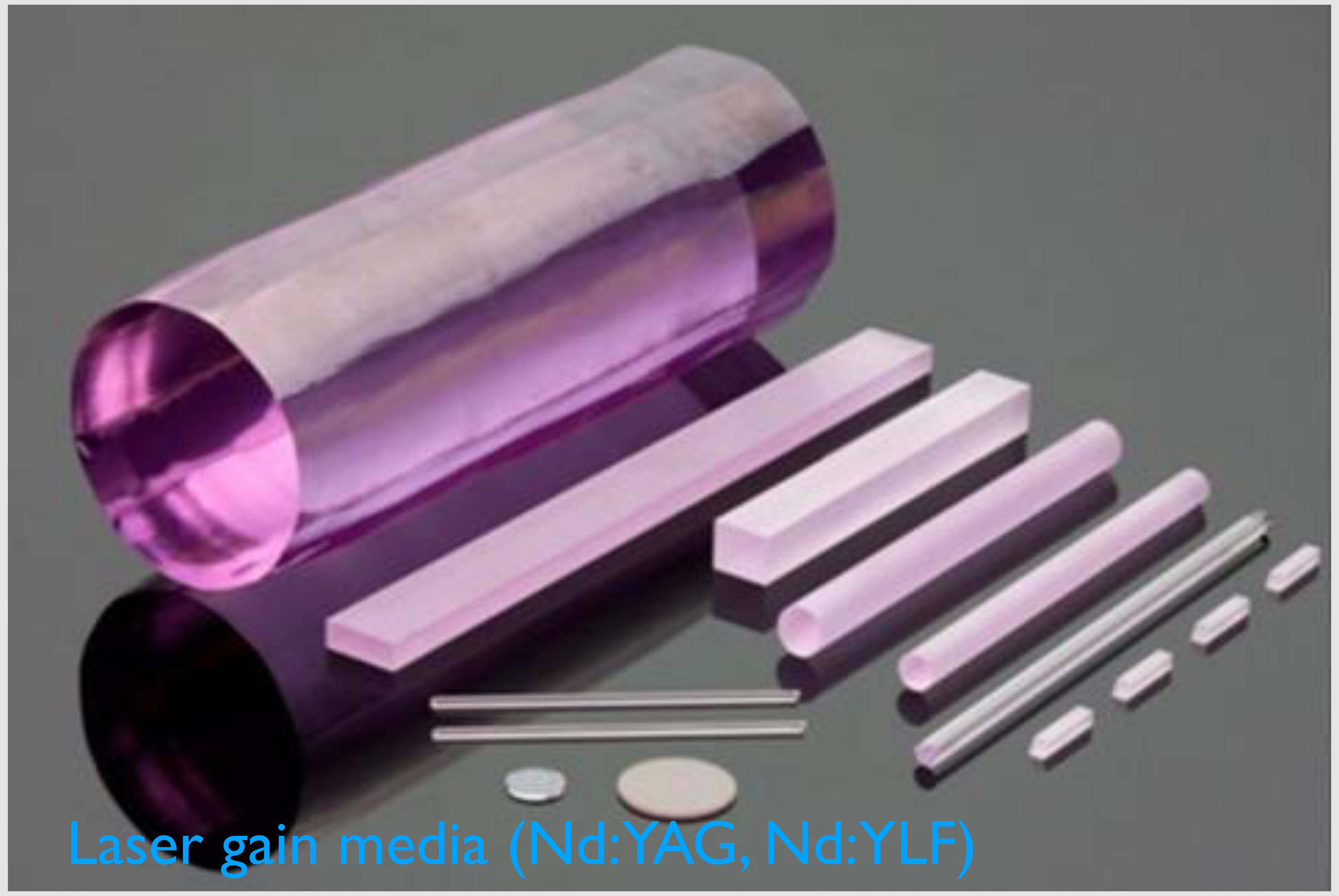
Time for the <u>surface temperature</u> to vaporize

Fernandez-Pello, Combust. Sci. Technol. 39:119-134, 1984

Thermographic Phosphor & Surface Temperature

Phosphors are everywhere





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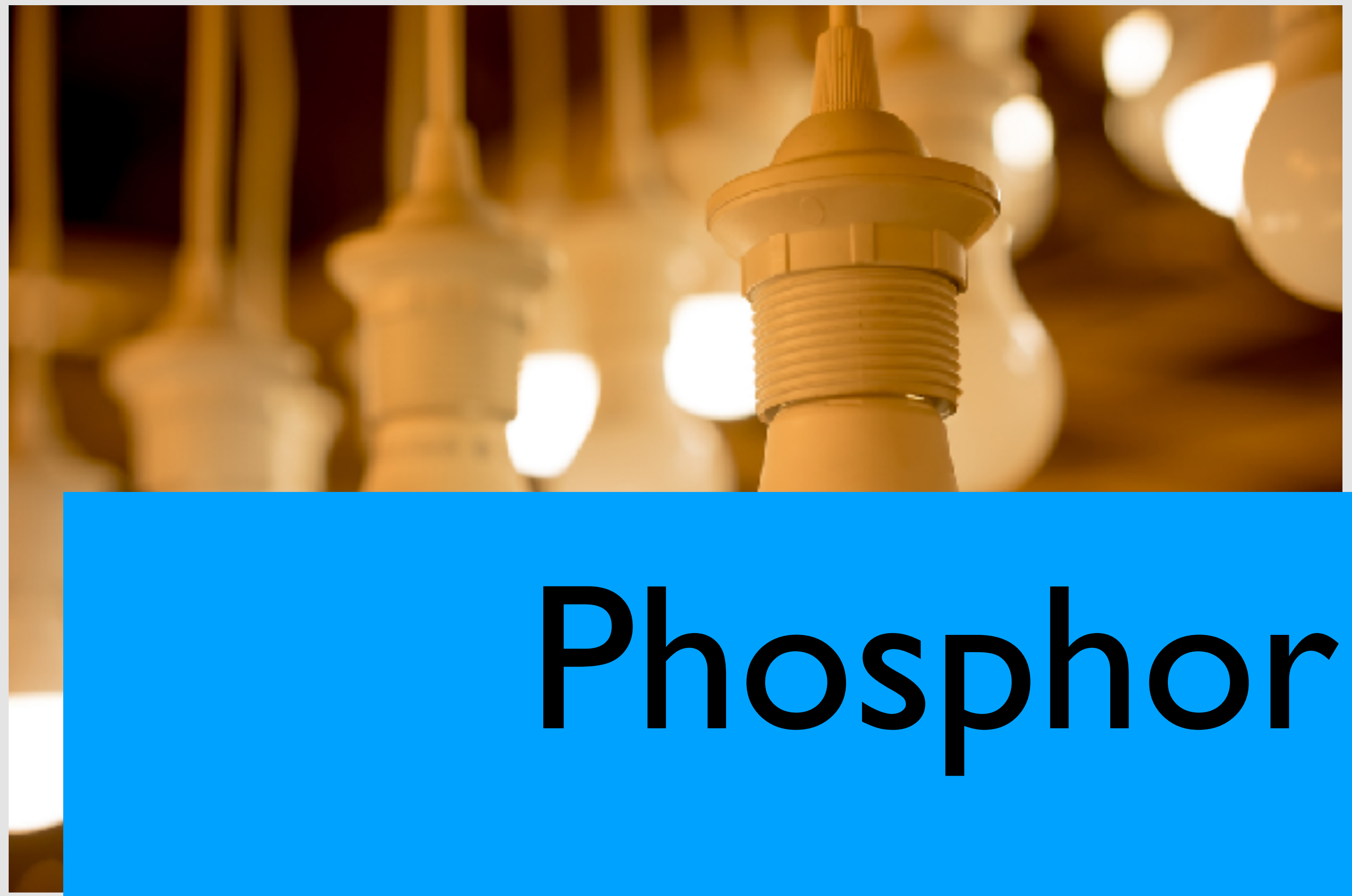
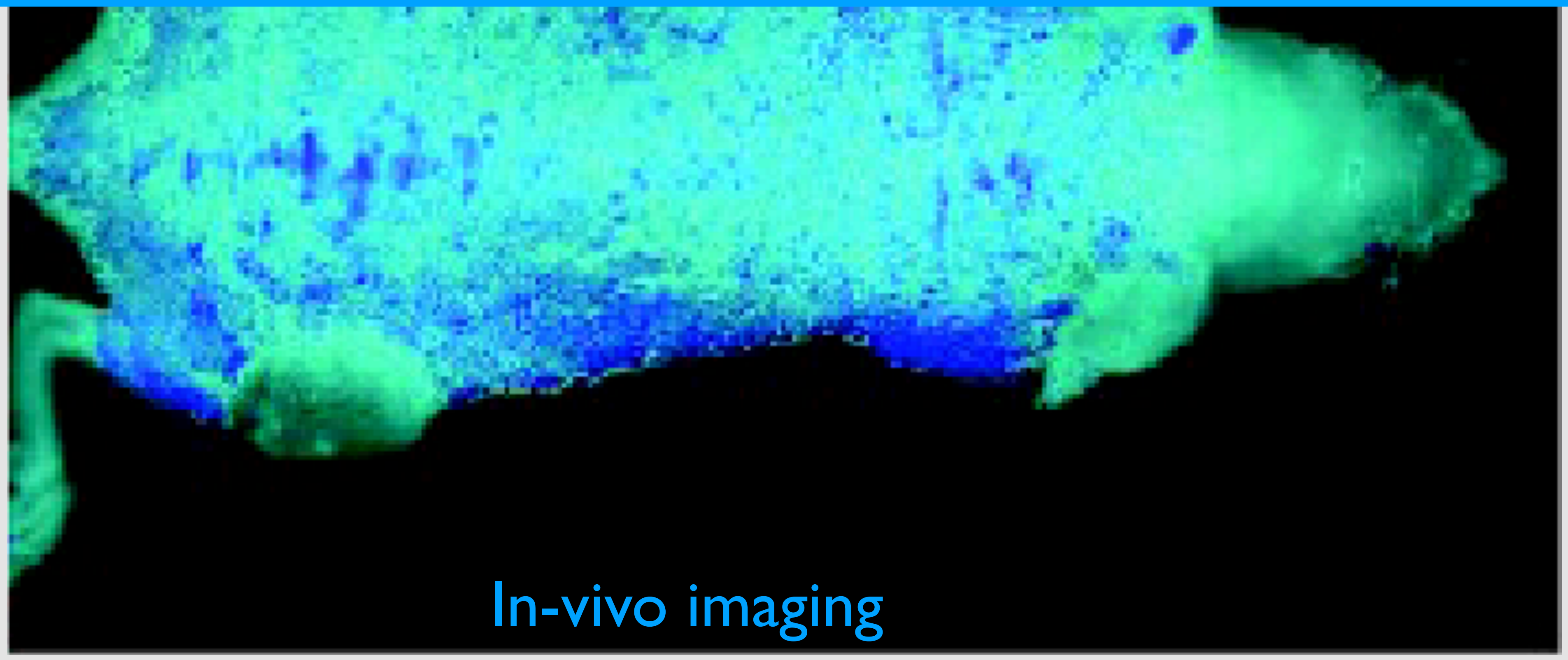


Glow bracelets

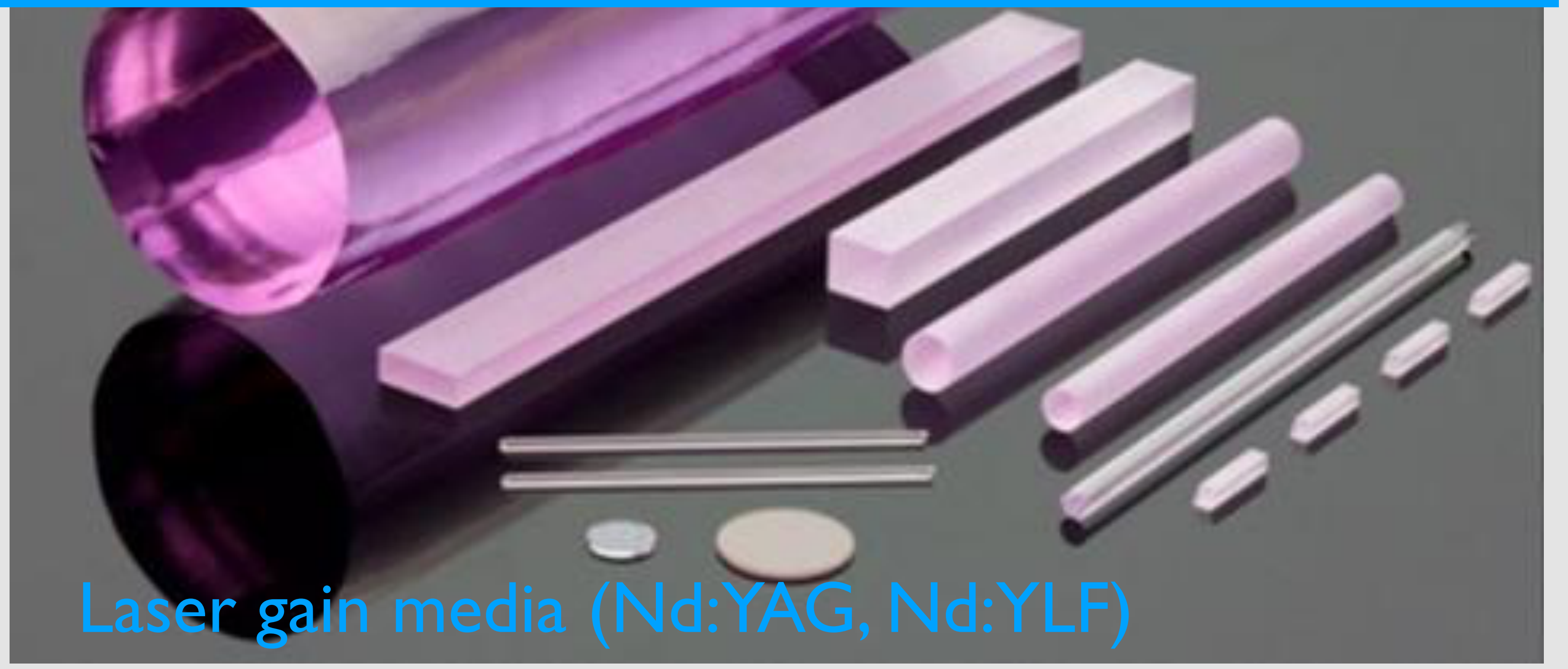
Phosphor particles = light converters

~

Photoluminescence process



In-vivo imaging



Laser gain media (Nd:YAG, Nd:YLF)

Valeur et al., J. Chem. Edu., 2011
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Thermographic Phosphors (TP), what?

Phosphor powder

high-melting point
non-reacting

$Mg_4FGeO_6:Mn$

Brübach et al., Prog. Ener. Combust. Sci. 39:37-60, 2013
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Chemical bonding

Binder + Phosphor + Air-brush
~ 10-200 μm, ~ 1W/m²/K

Insulation !

(Sol-Gel method, Physical vapor deposition, Chemical vapor deposition)

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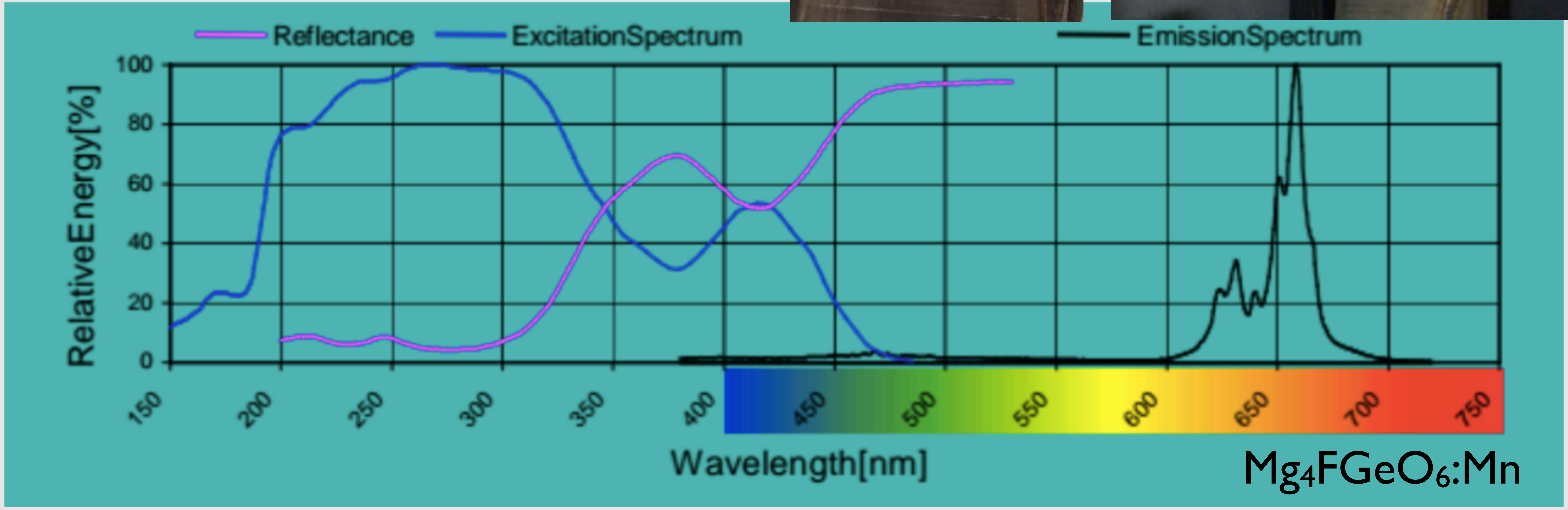
How do we extract temperature ?



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Some Theory …

Inorganic crystals → $YAG:Dy^{3+}$ ← Rare earth ions / Metal transition ions

Allison et al., Rev. Sci. Instrum. 68(7), 1997
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Inorganic crystals

Rare earth ions
Metal transition ions

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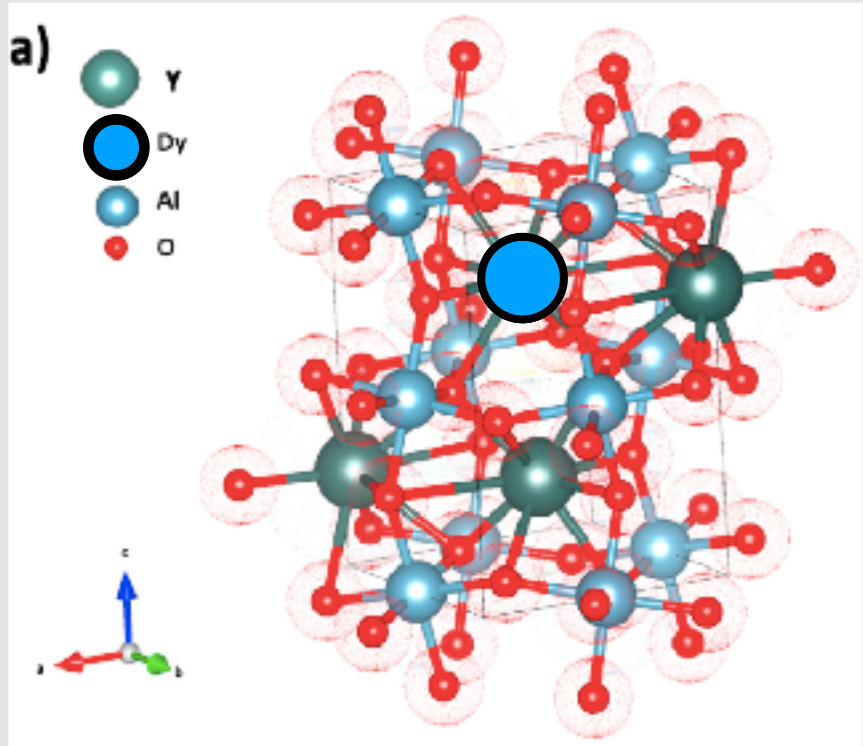

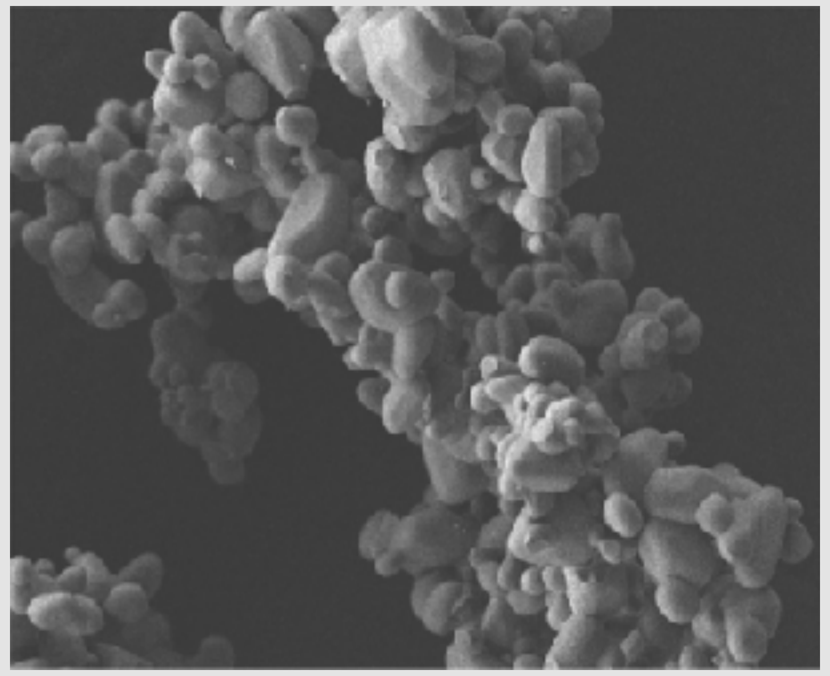

Scanning electron microscope

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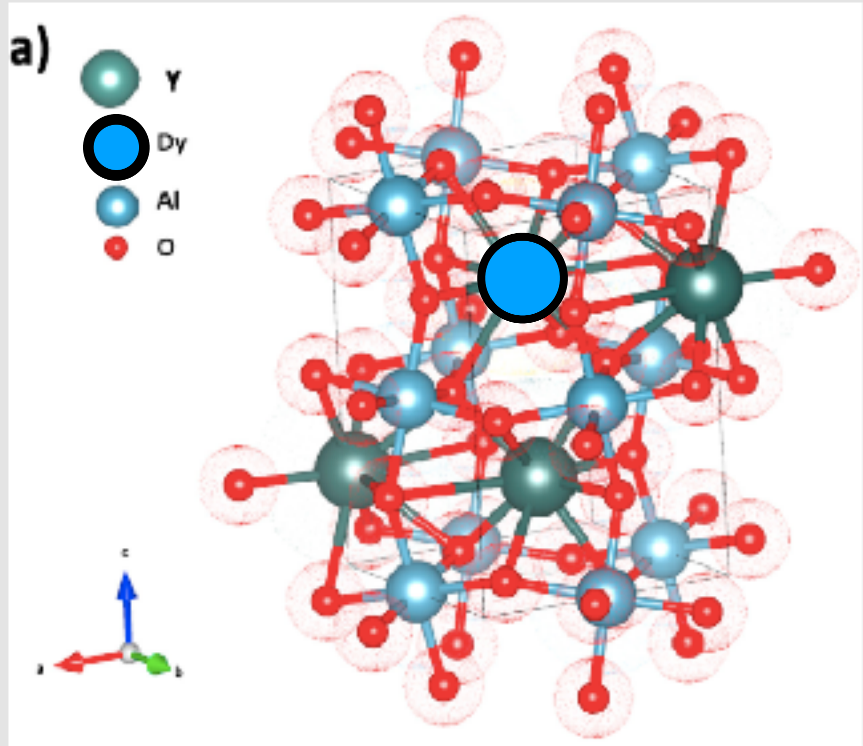

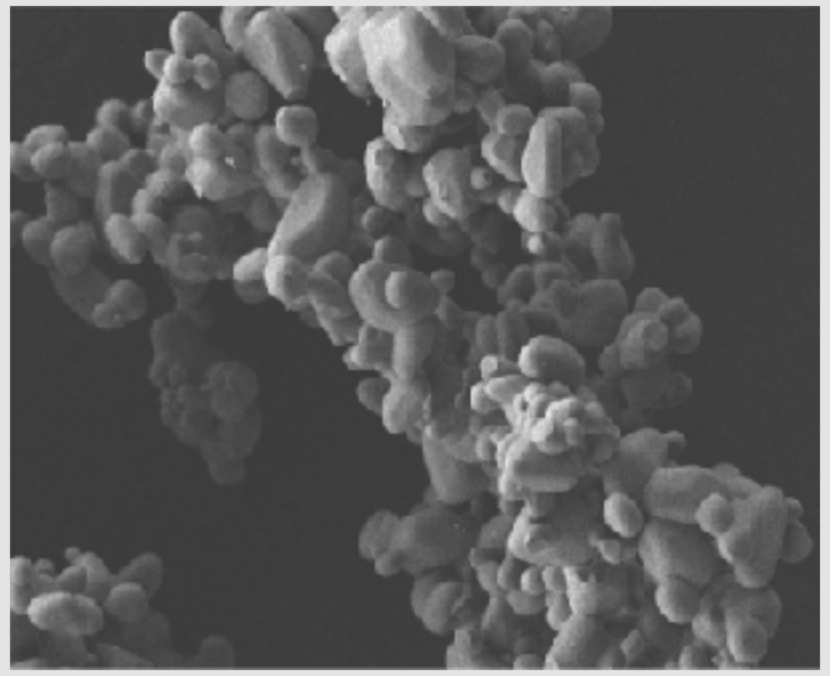

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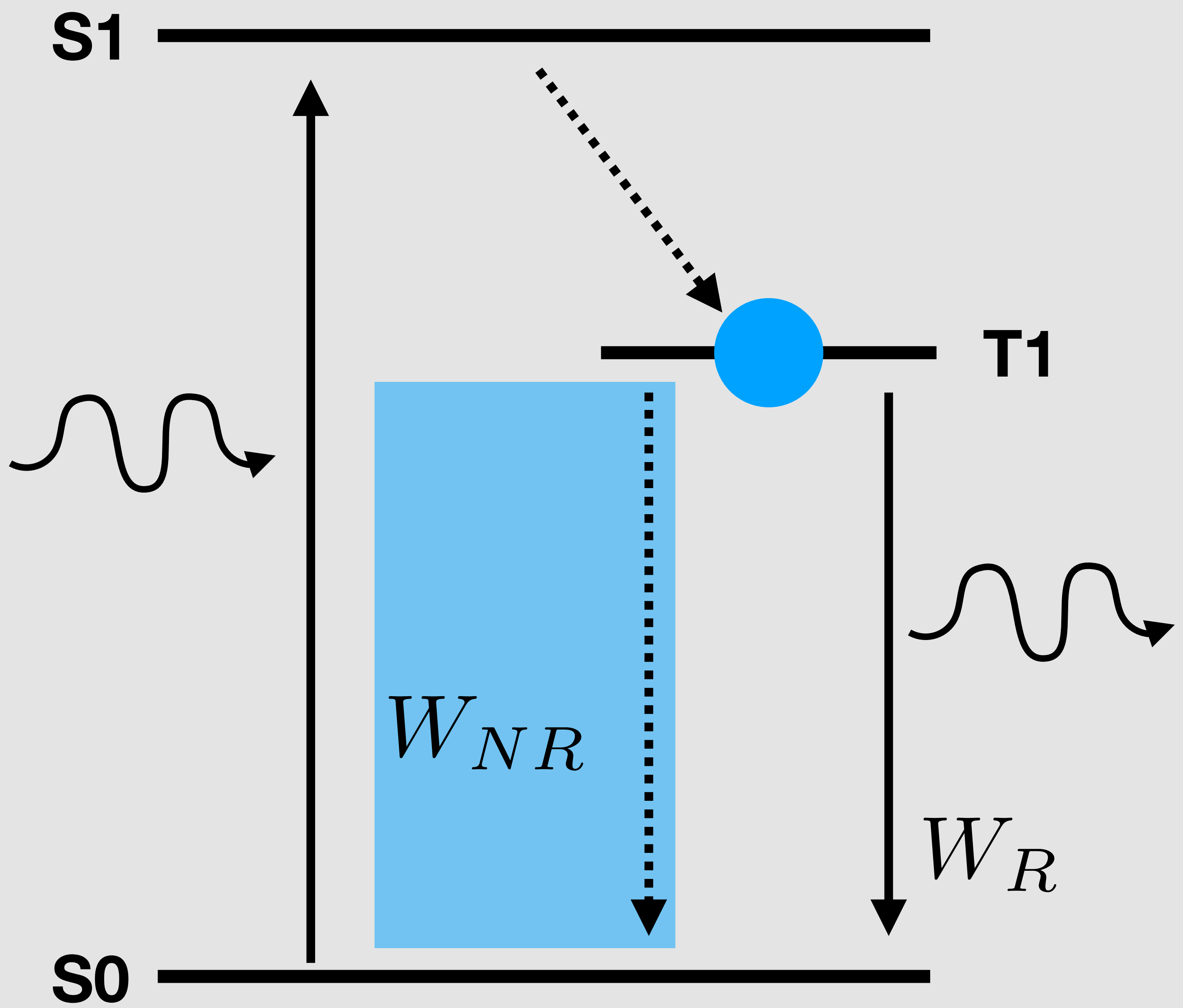

Simplified Jablonski diagram

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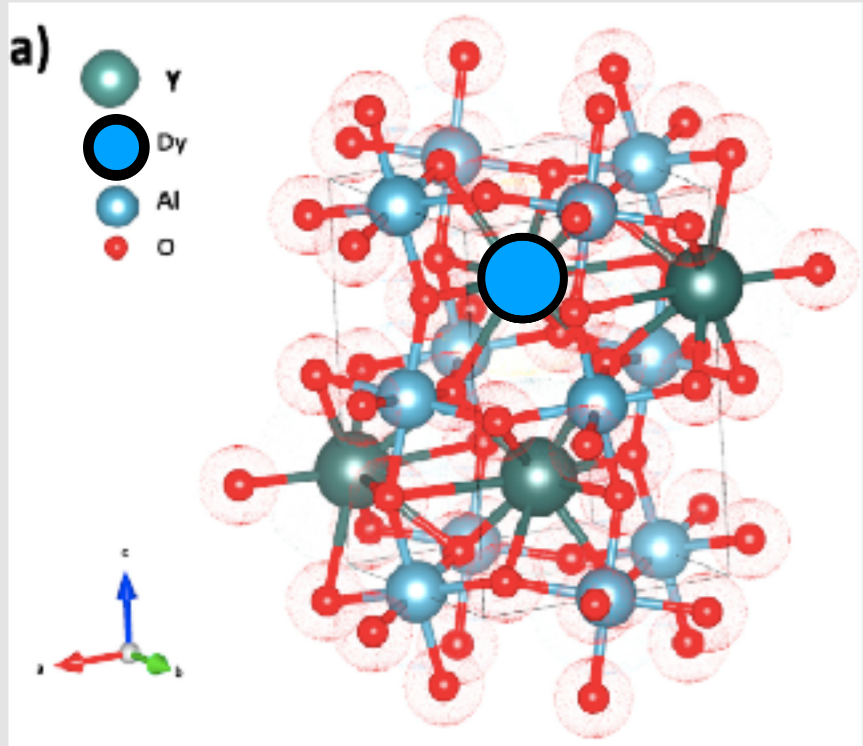

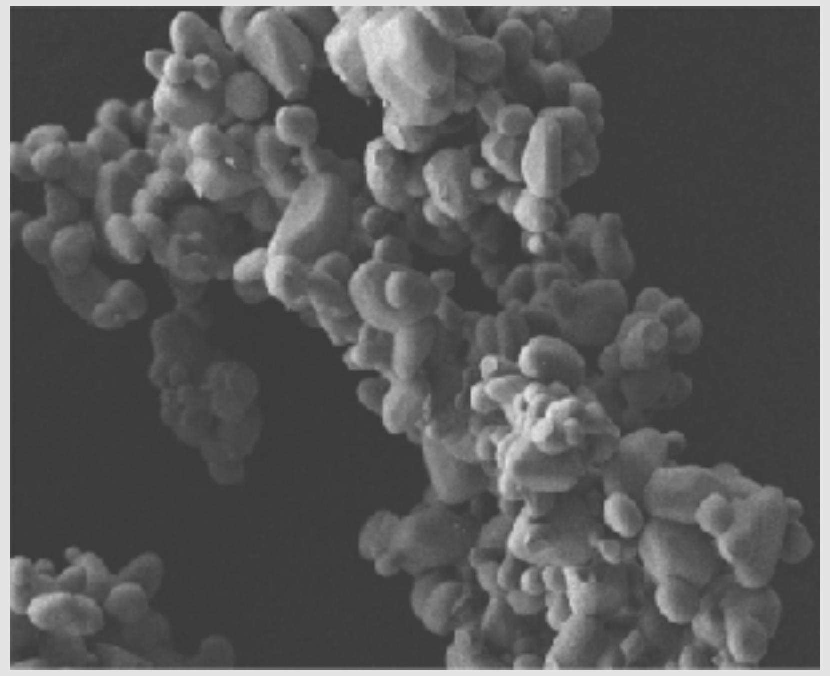

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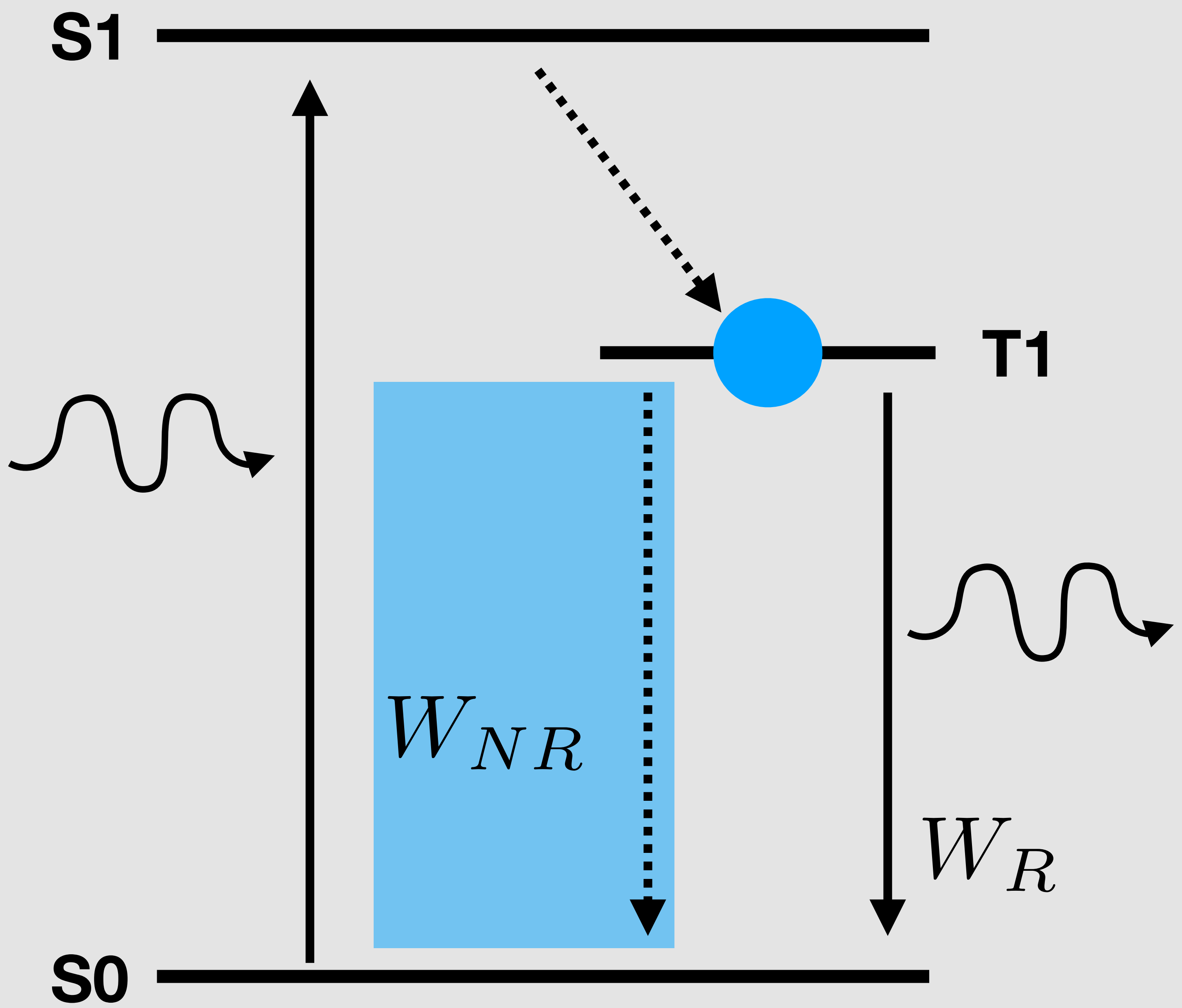

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Non-radiative emission is temperature dependent

$$\tau = \frac{1}{W_R + W_{NR}}$$

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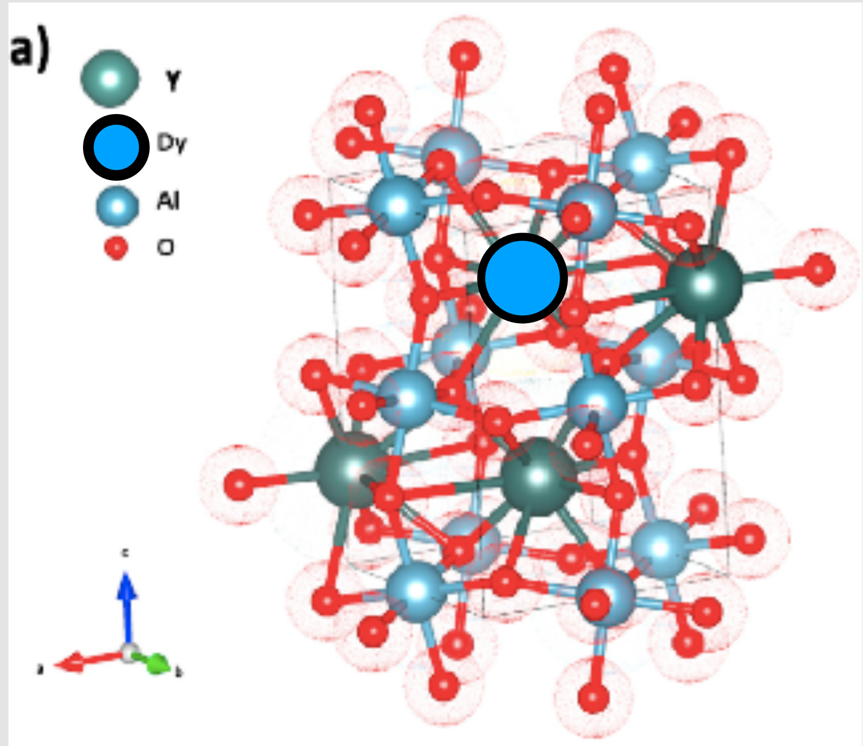

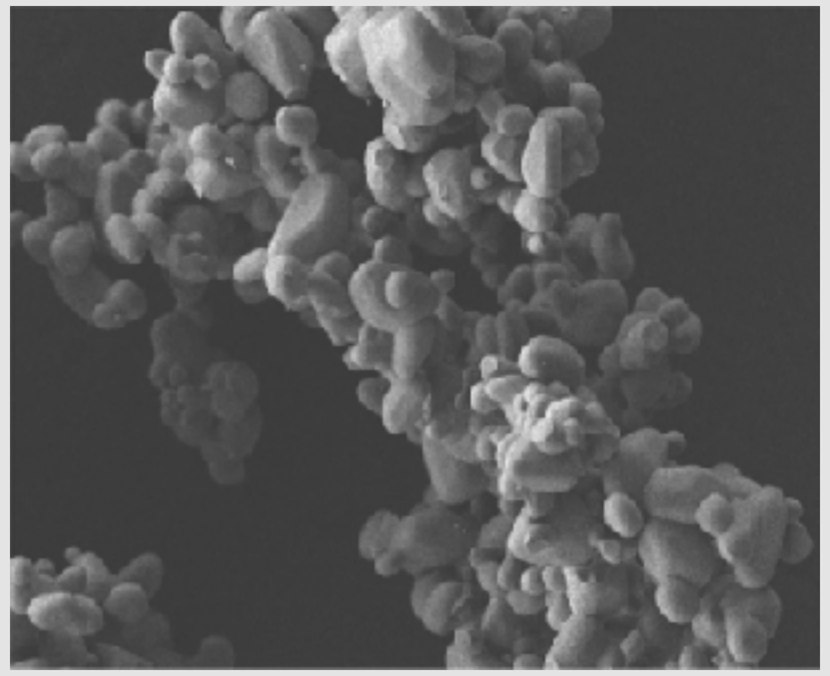

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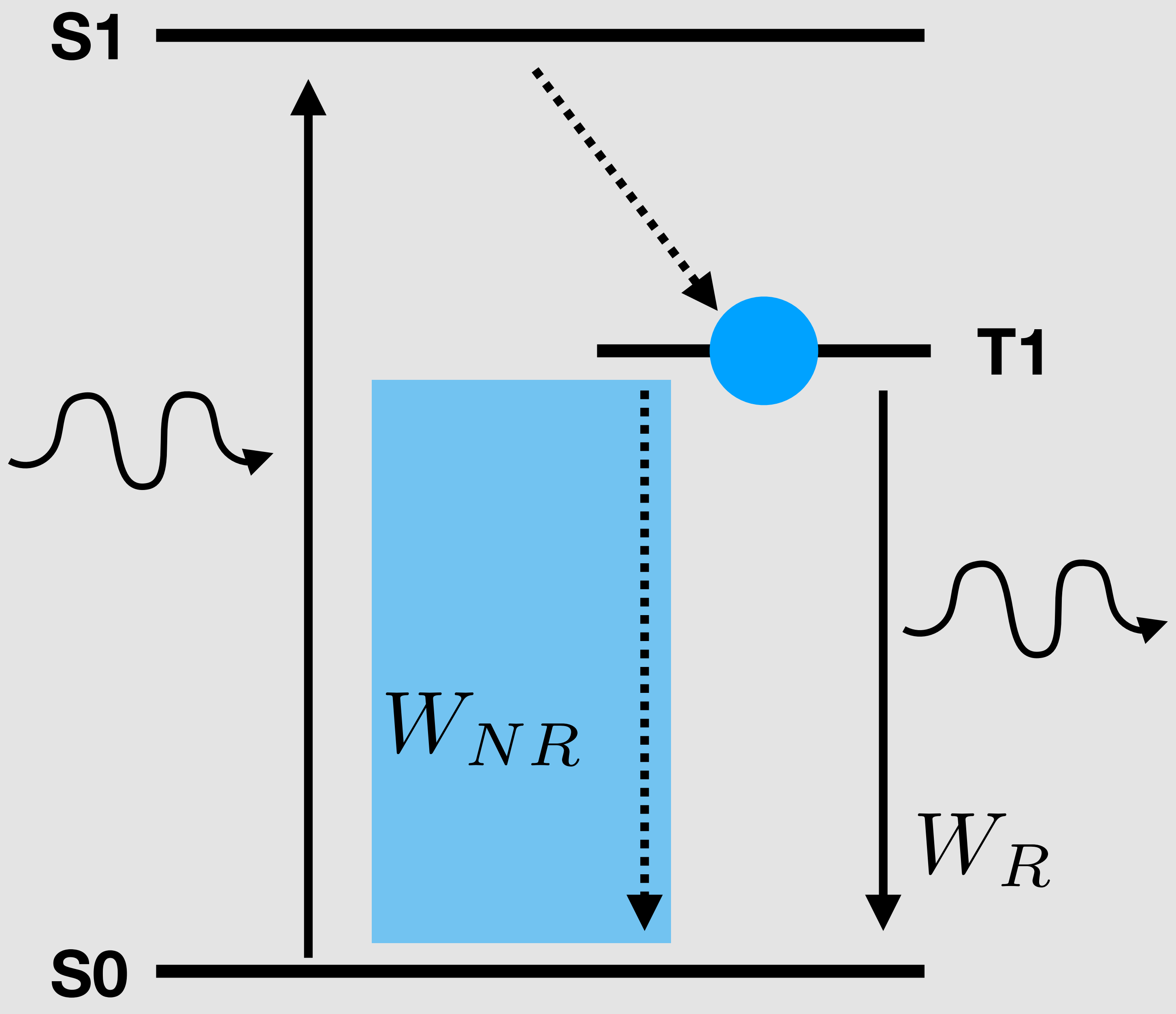

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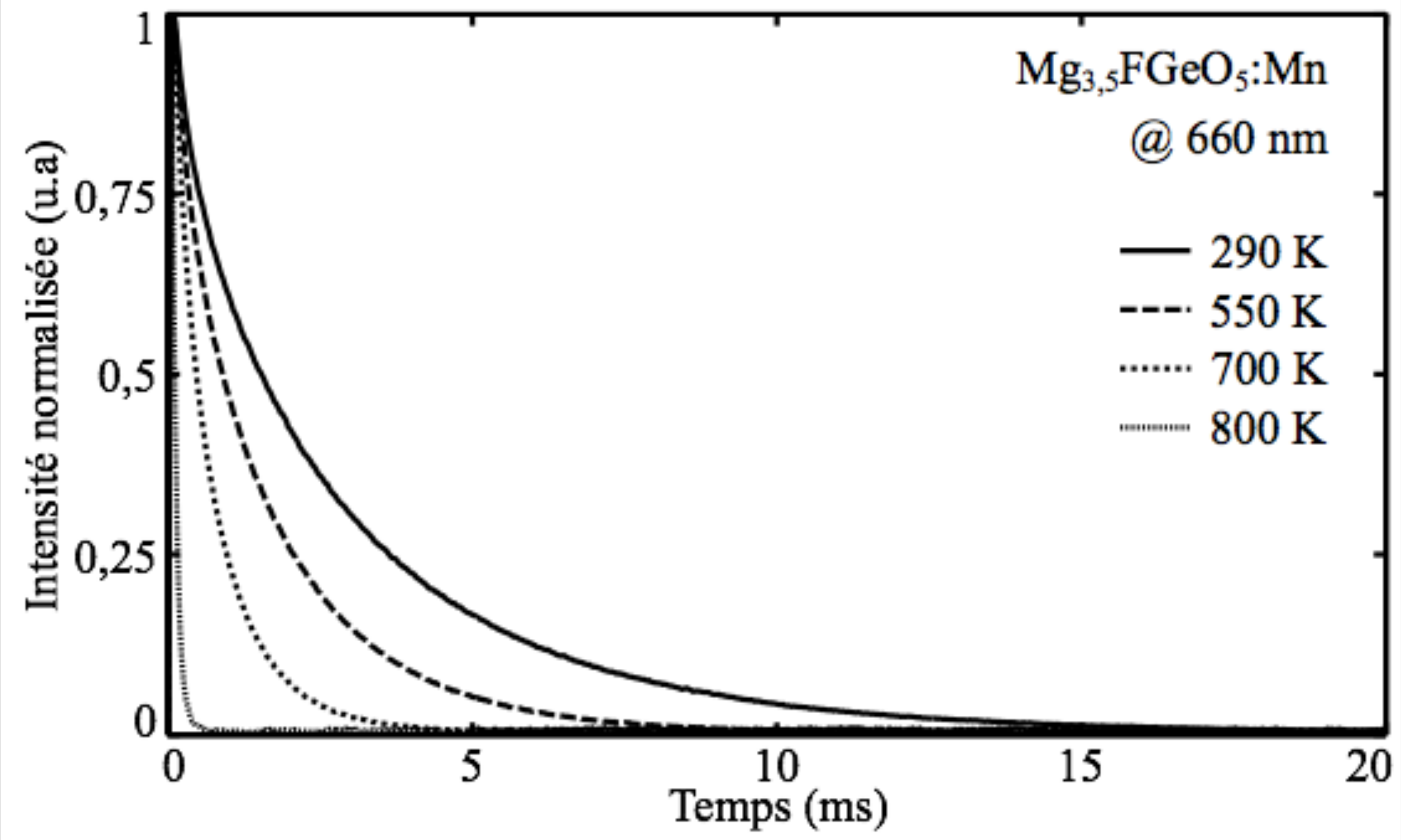

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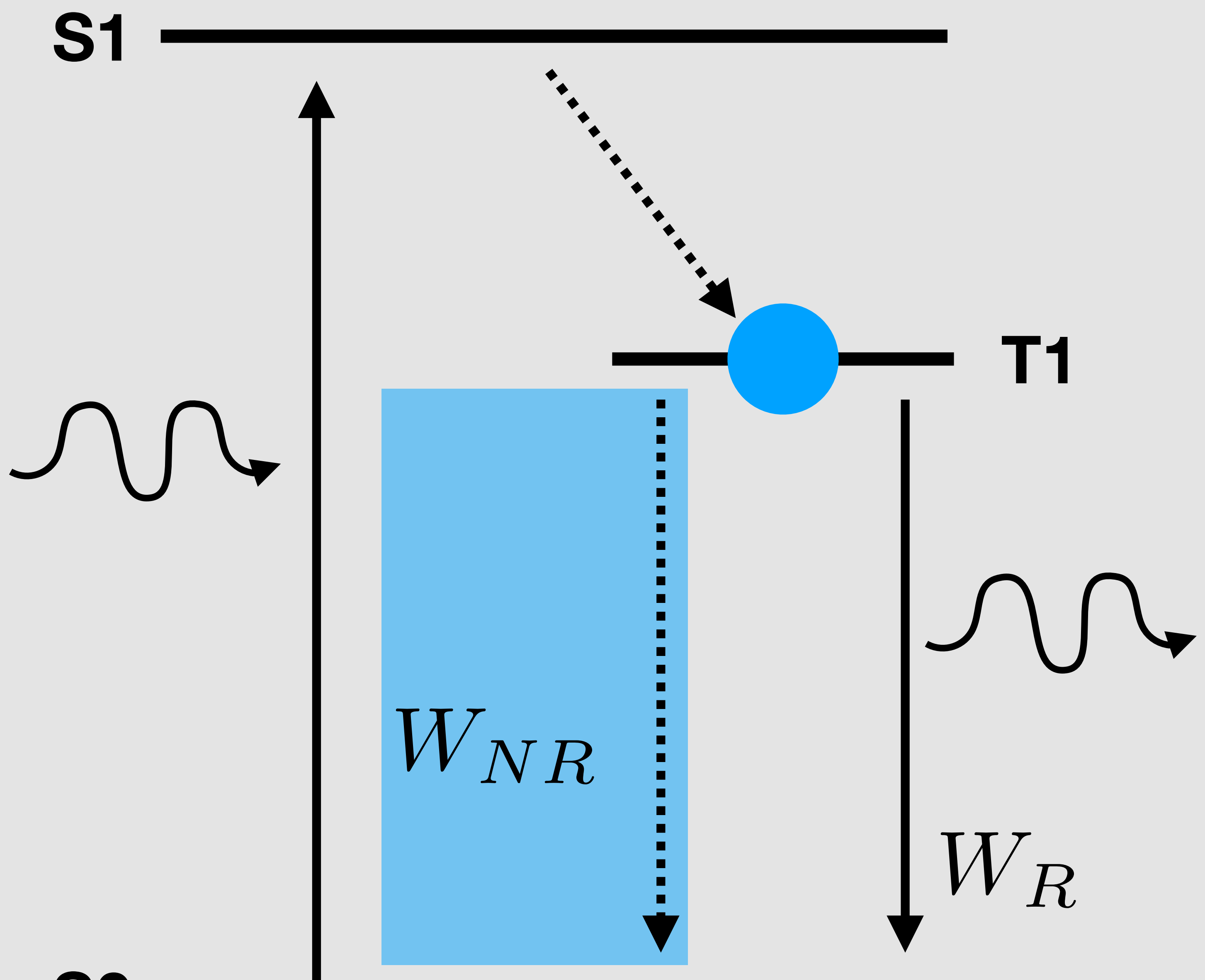

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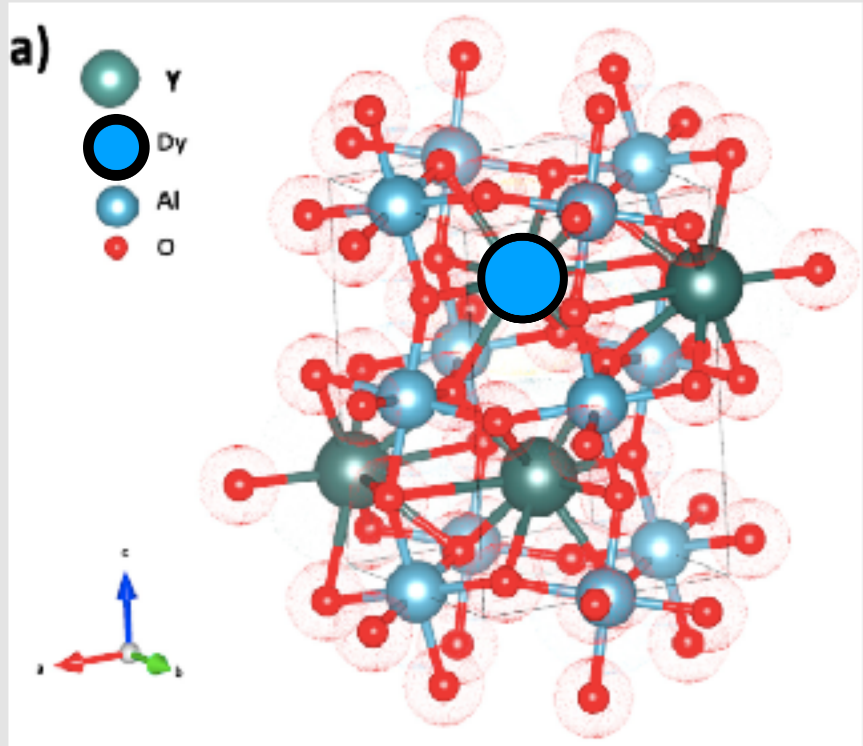

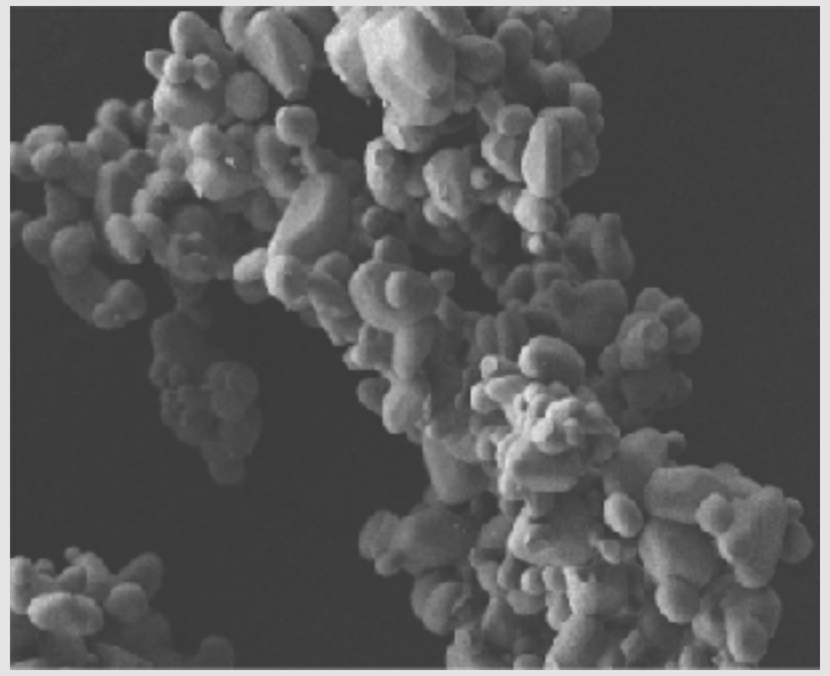

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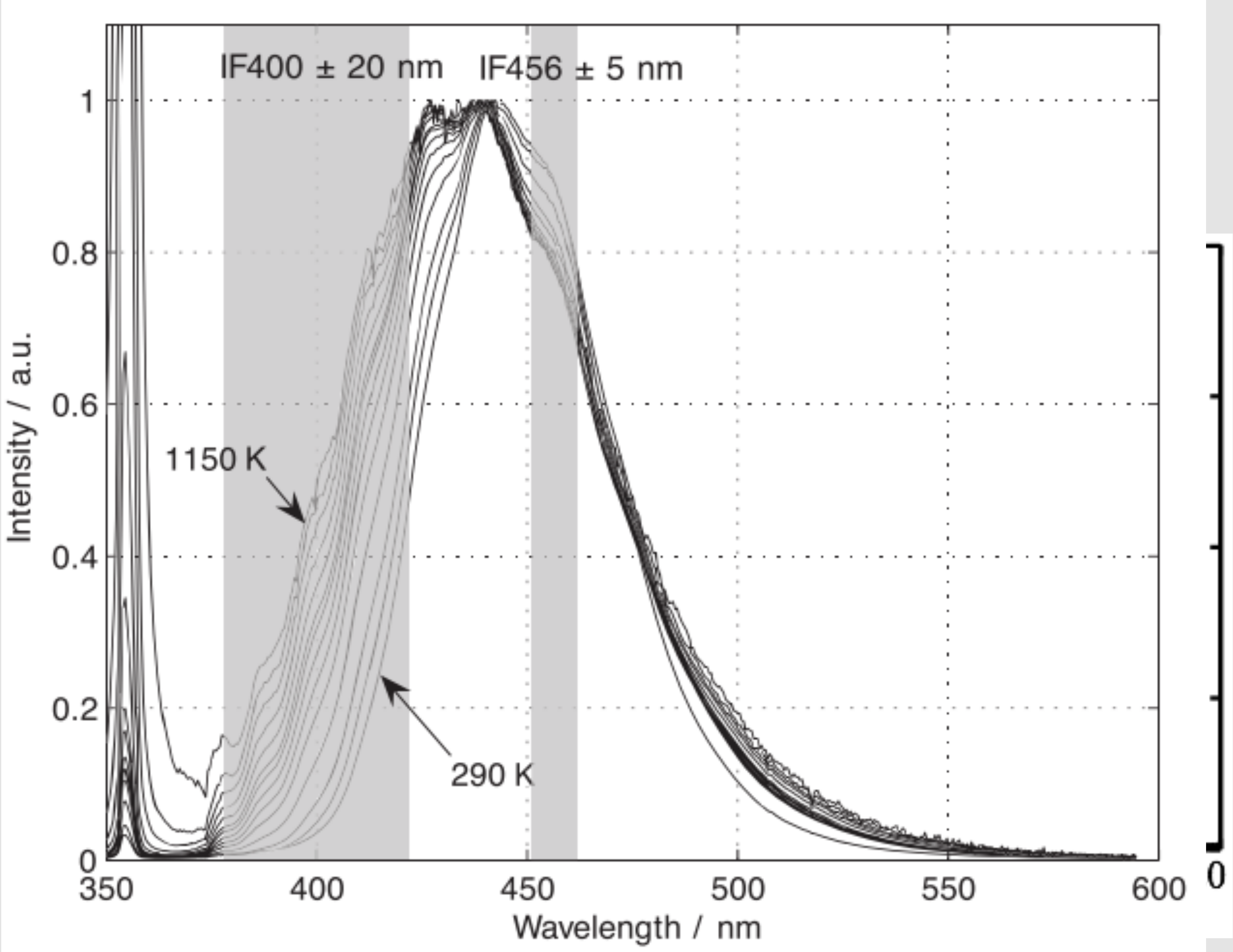

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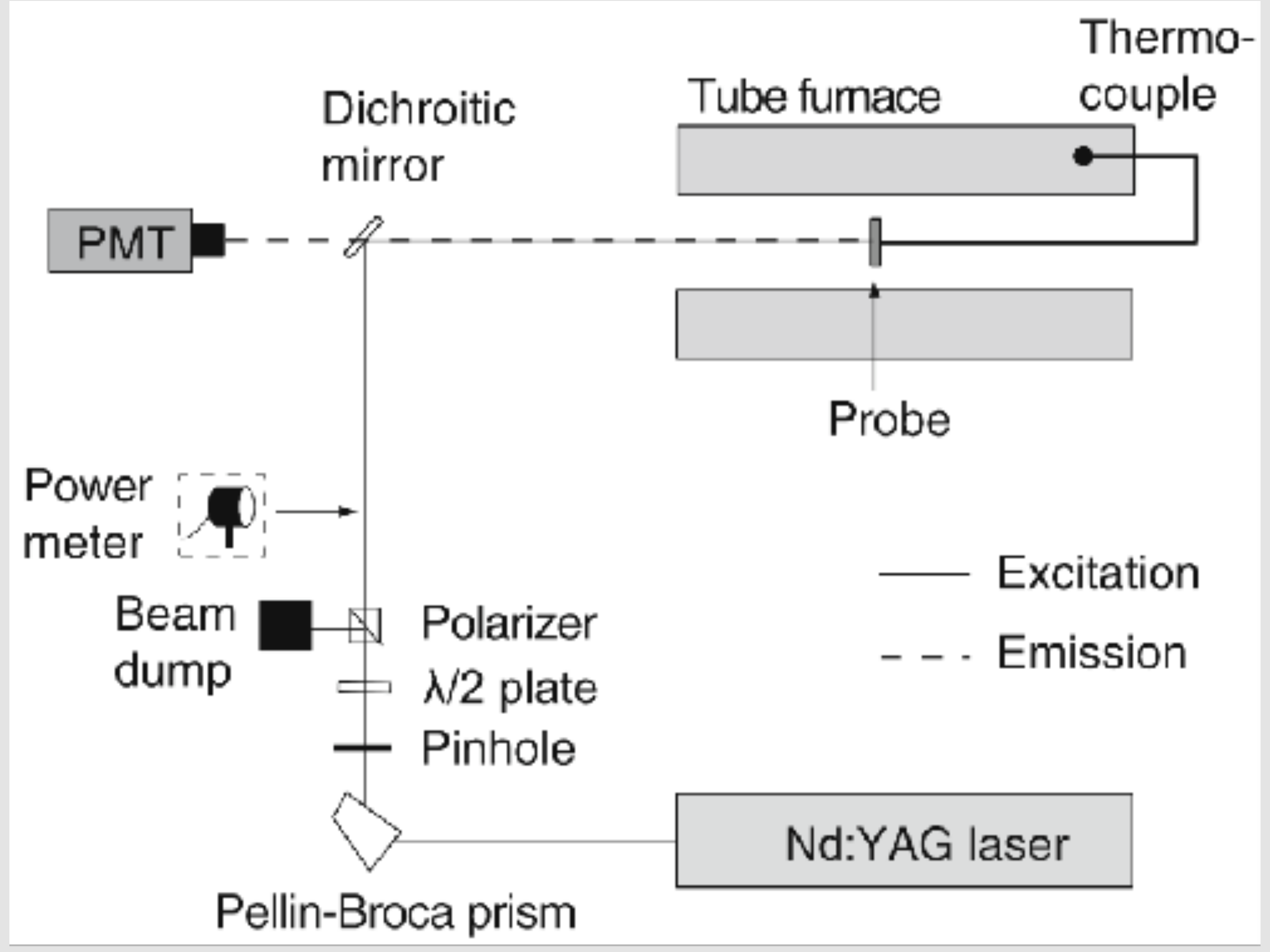
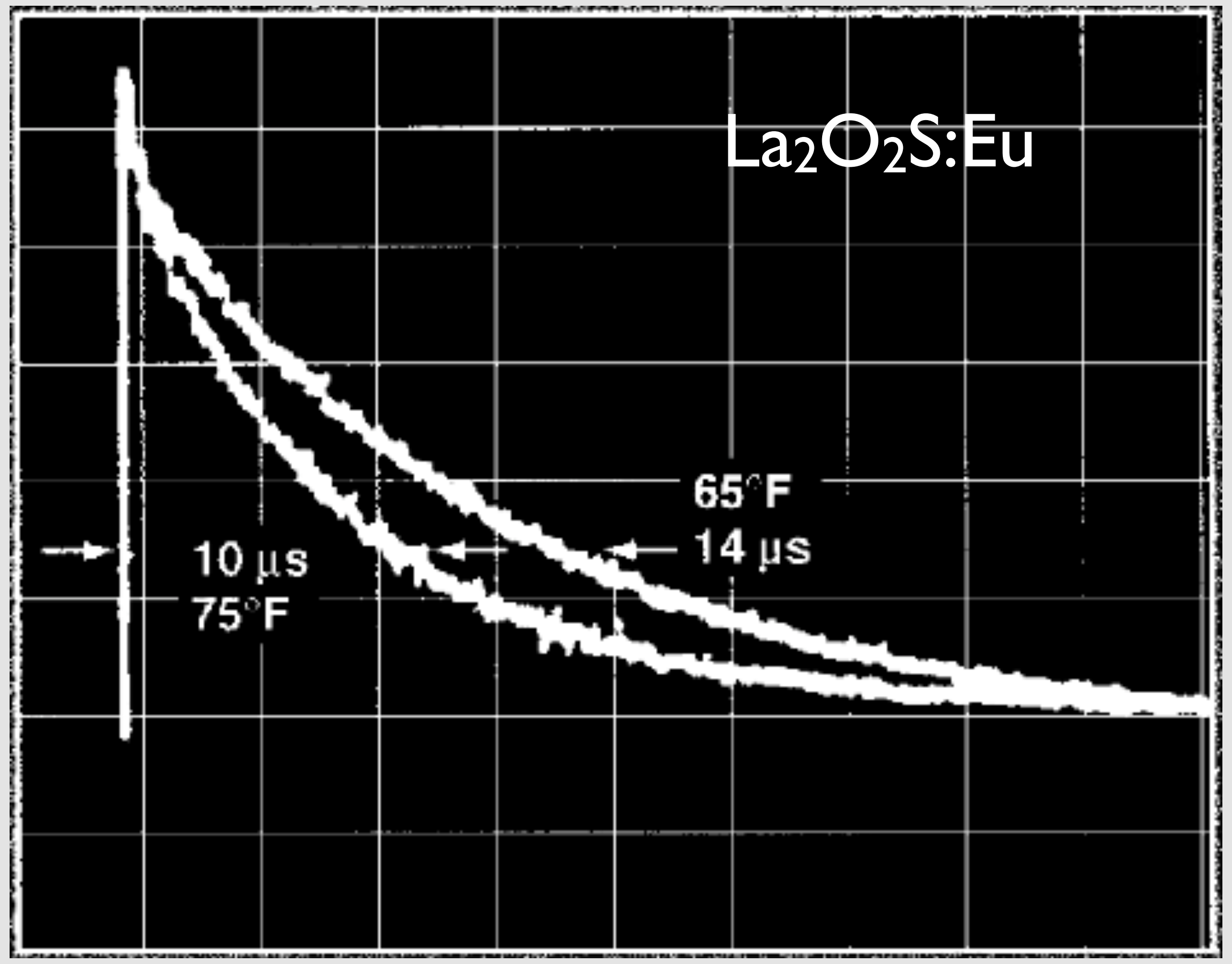
… Applied to Time-Resolved Domain





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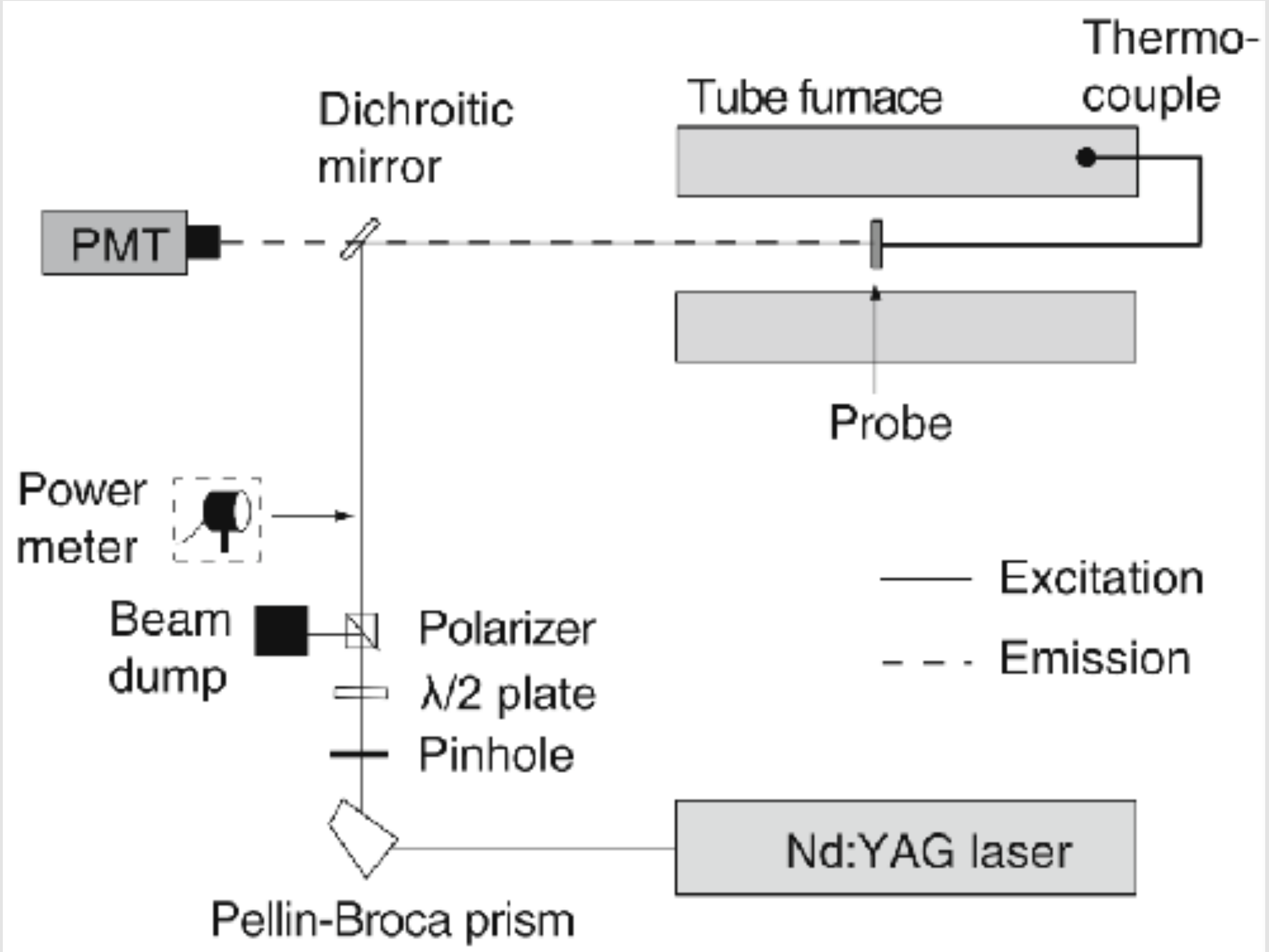
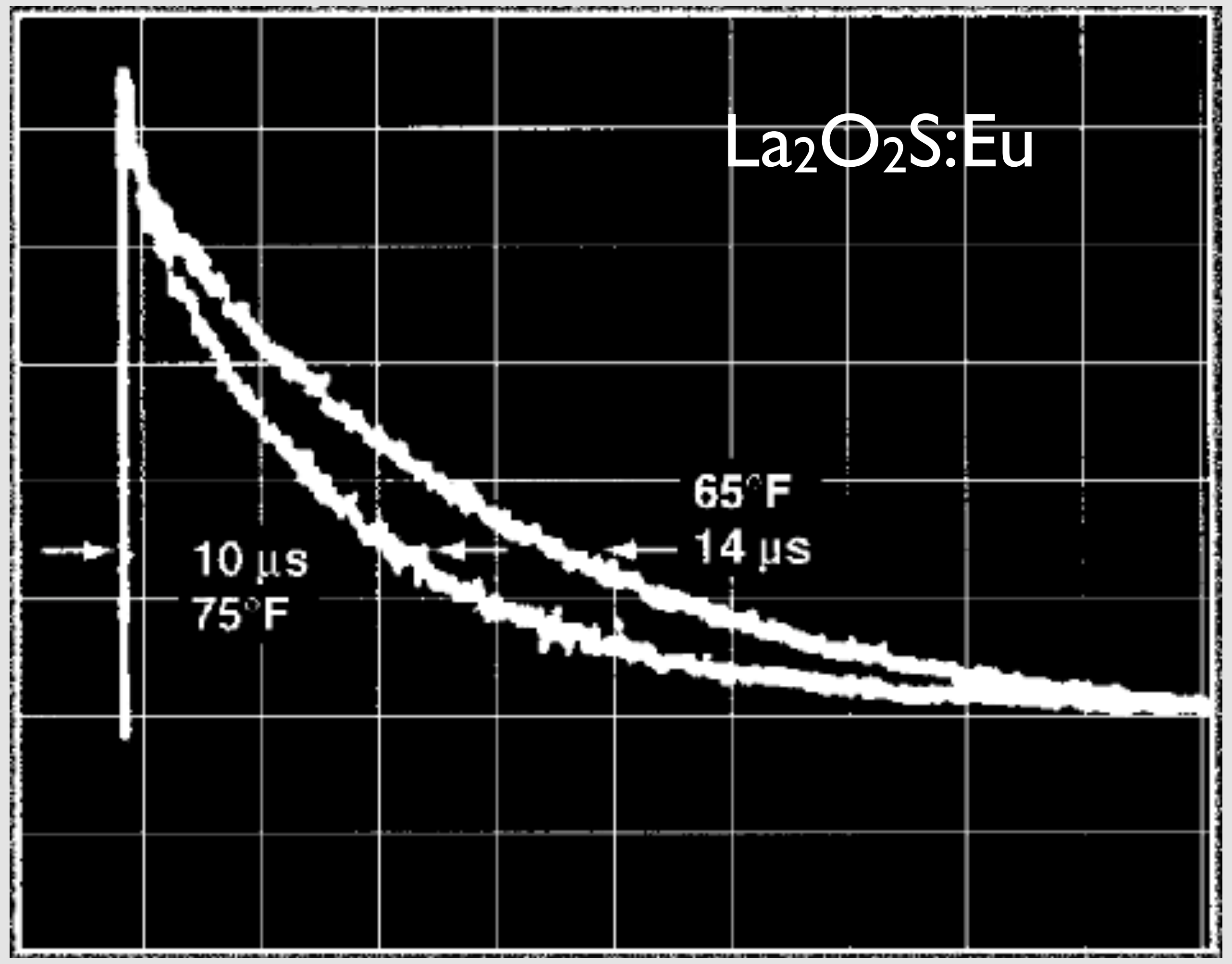


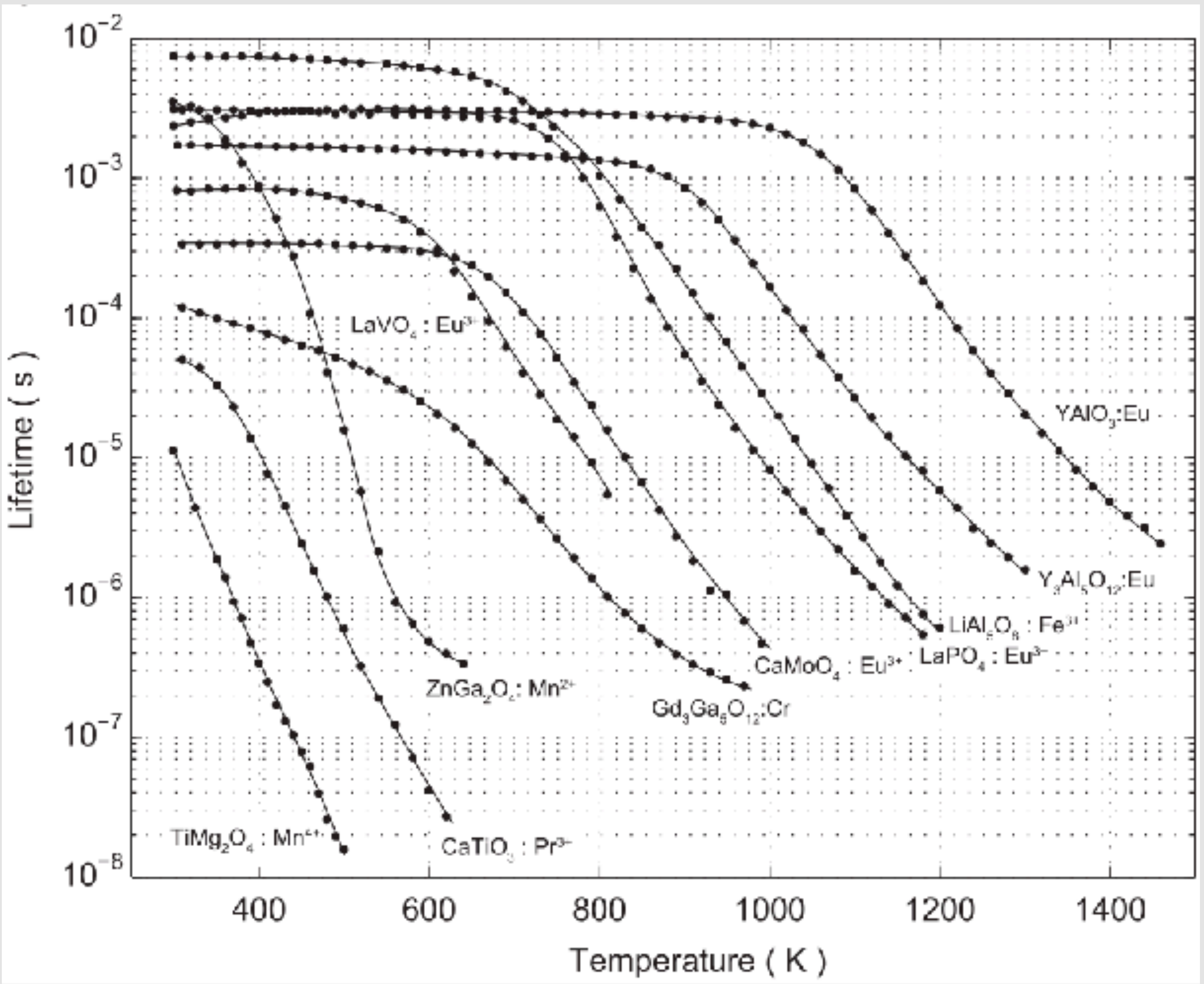


A priori calibration

$$I(t) = I_0 e^{-t/\tau}$$

$$\downarrow$$

$$T = f(\tau) \longrightarrow$$



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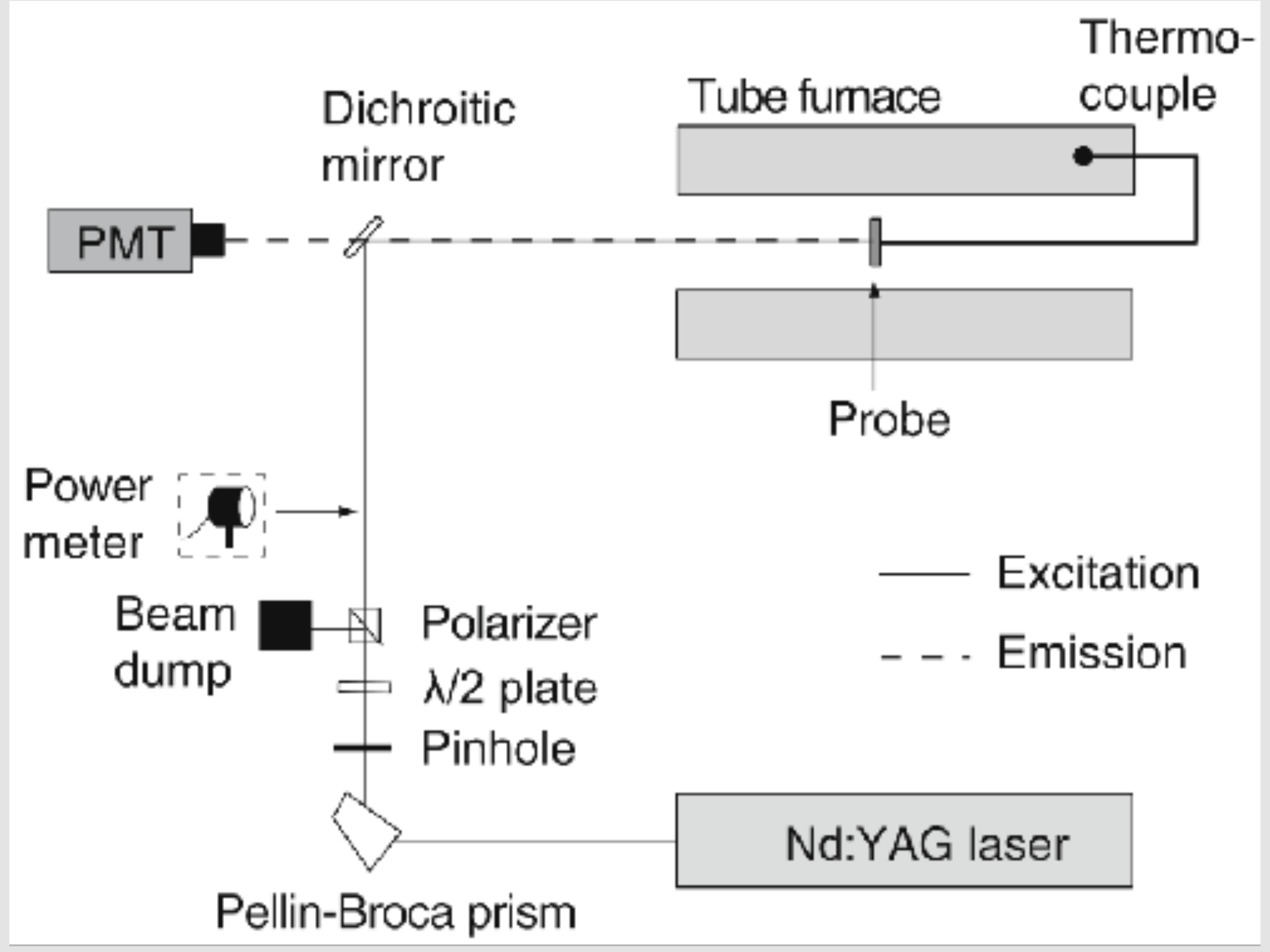

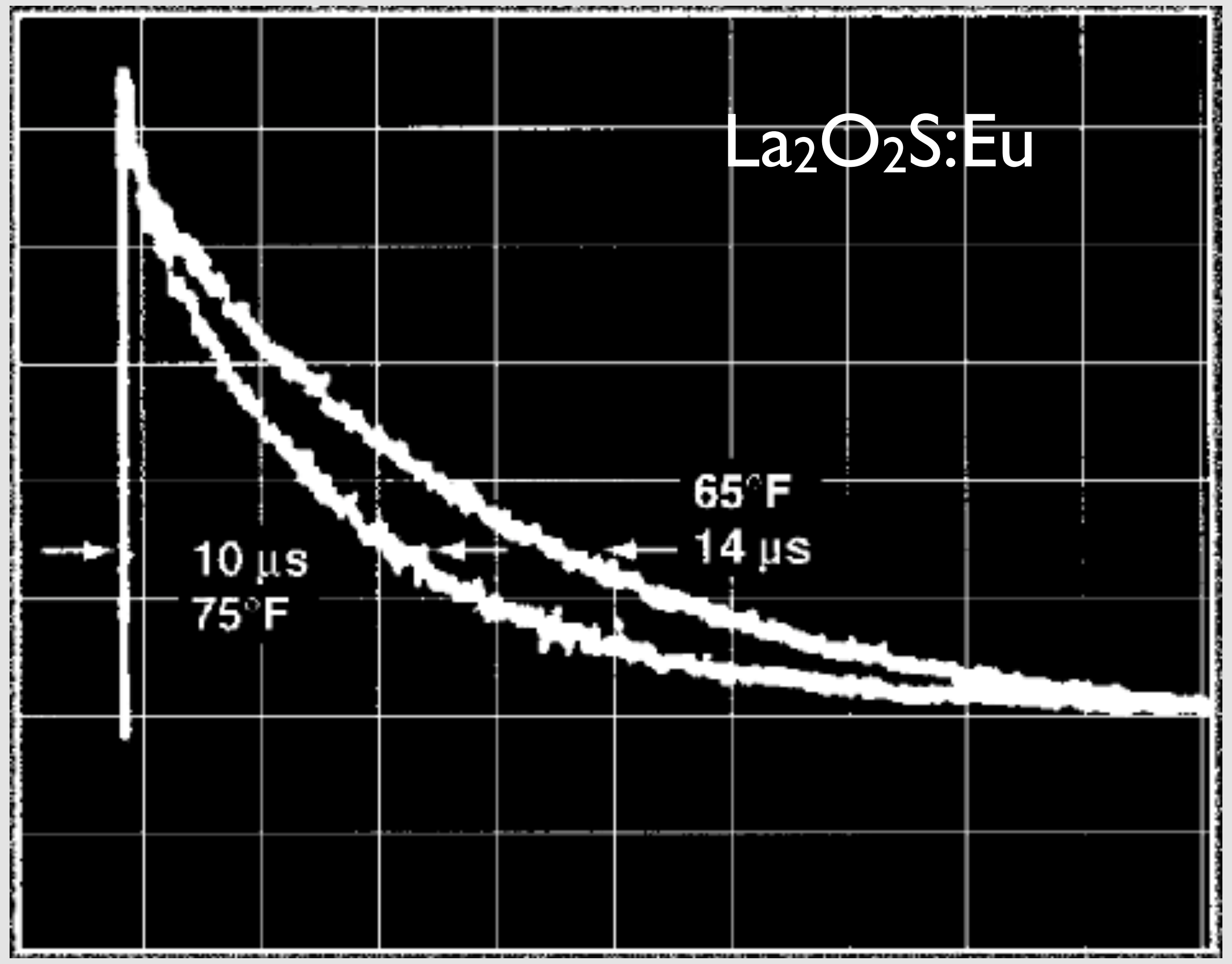

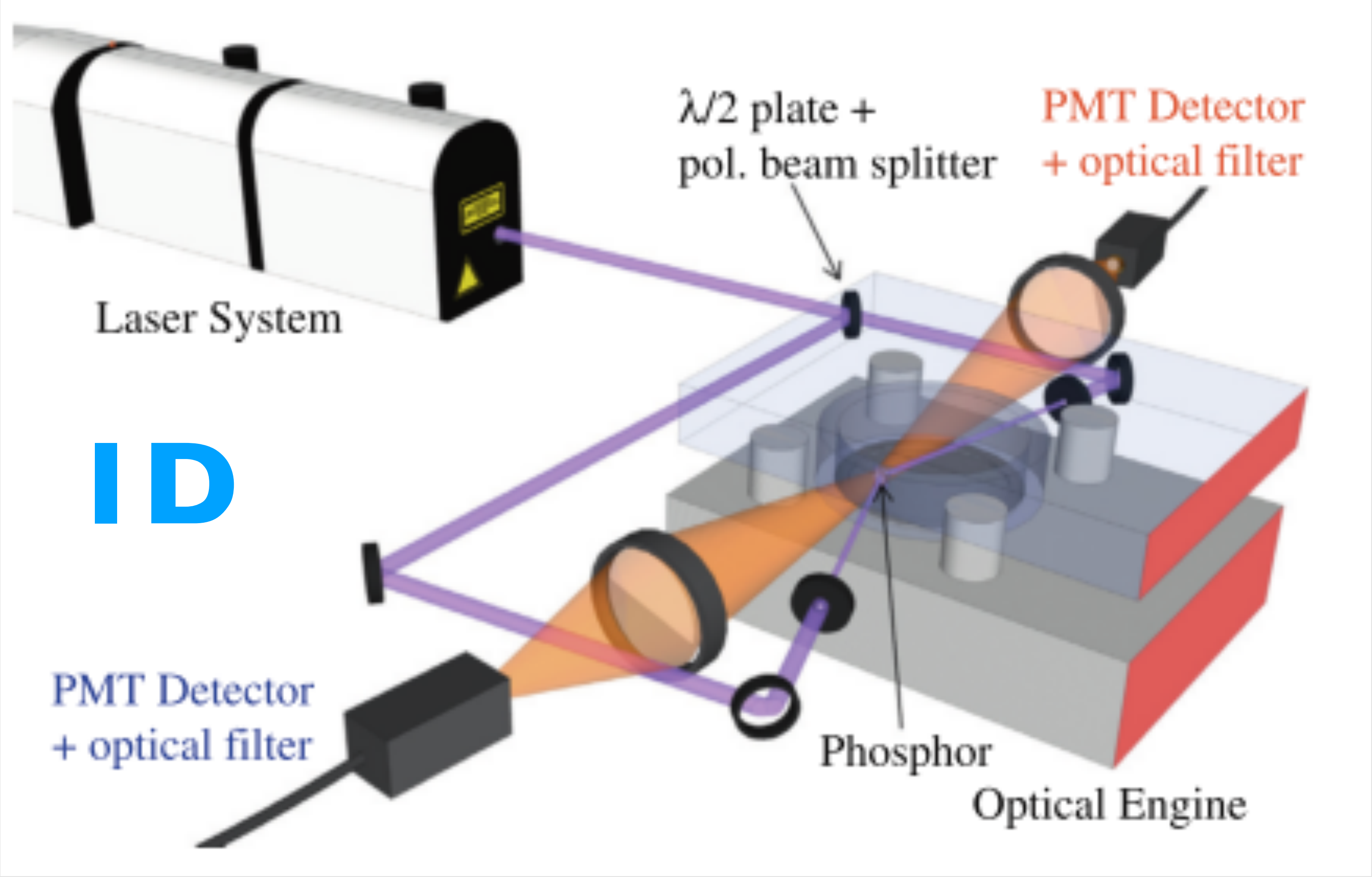

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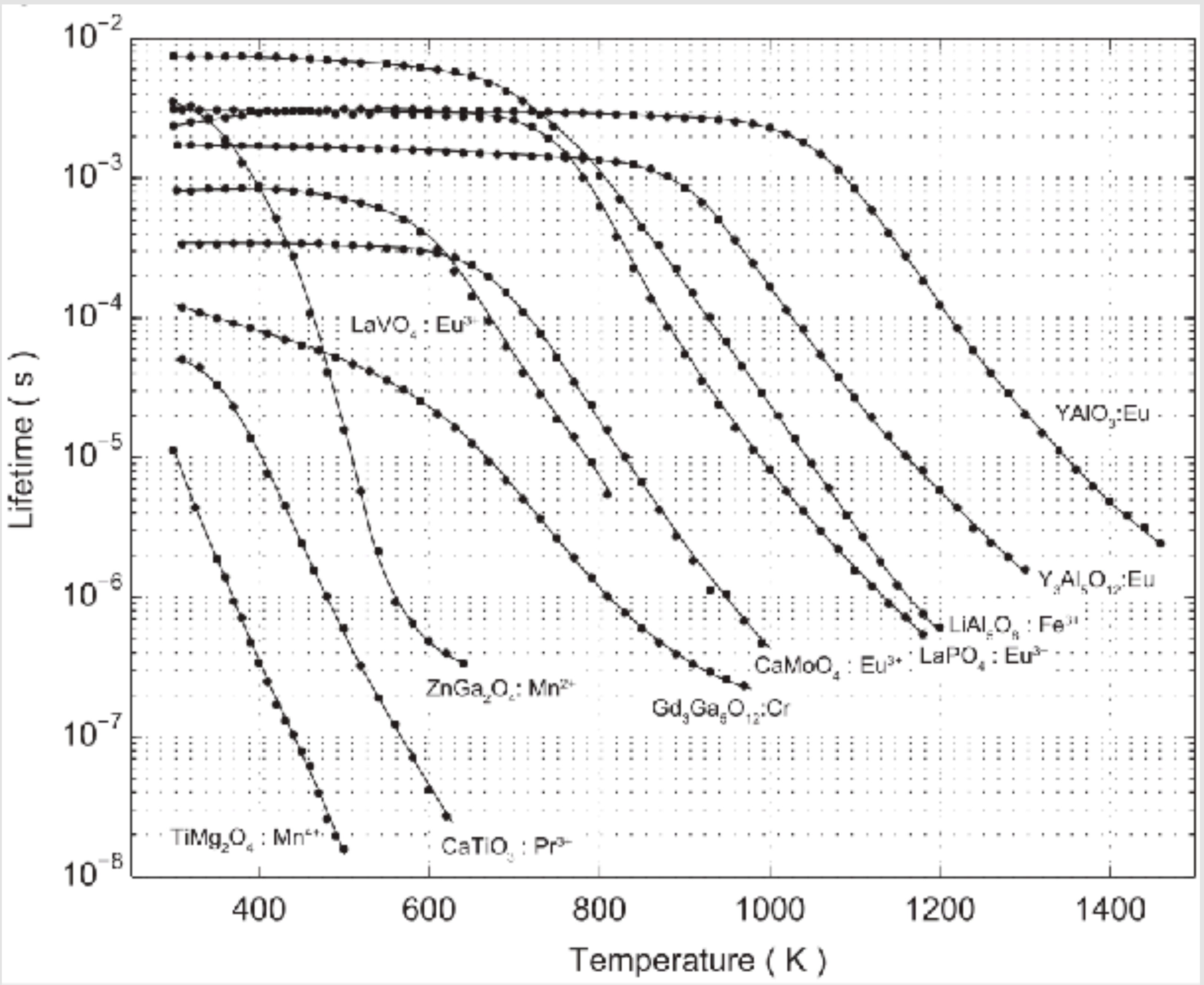

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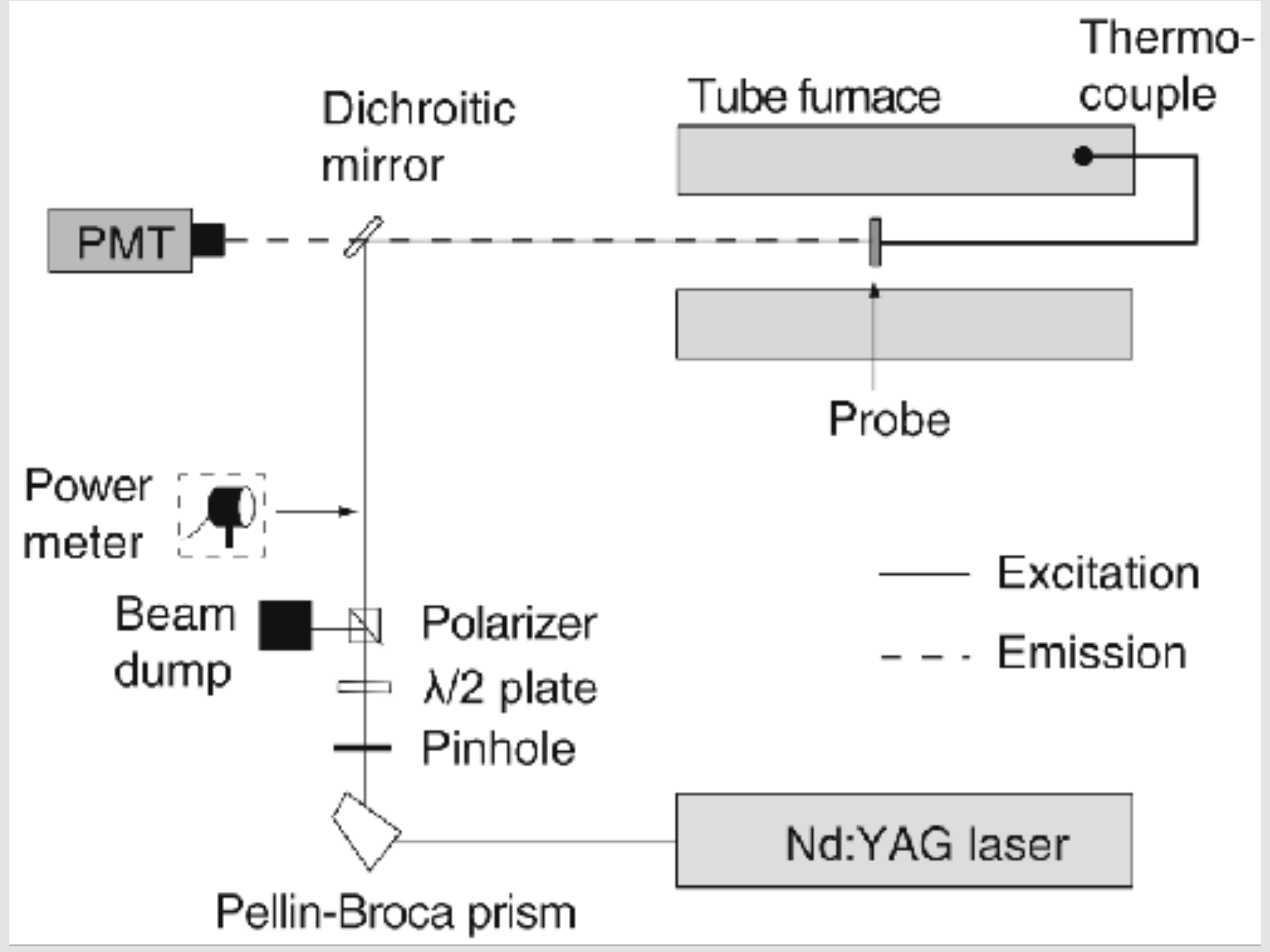

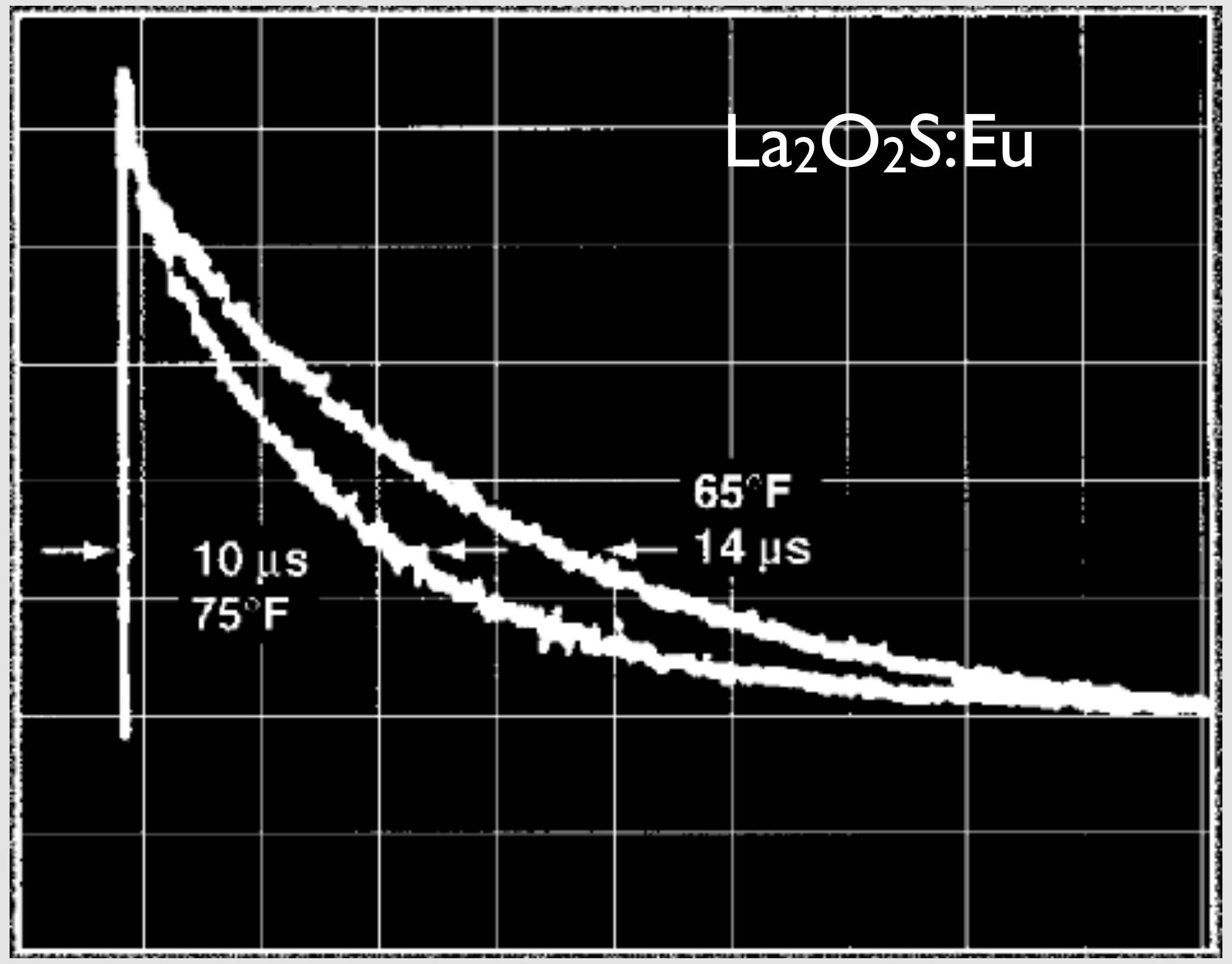

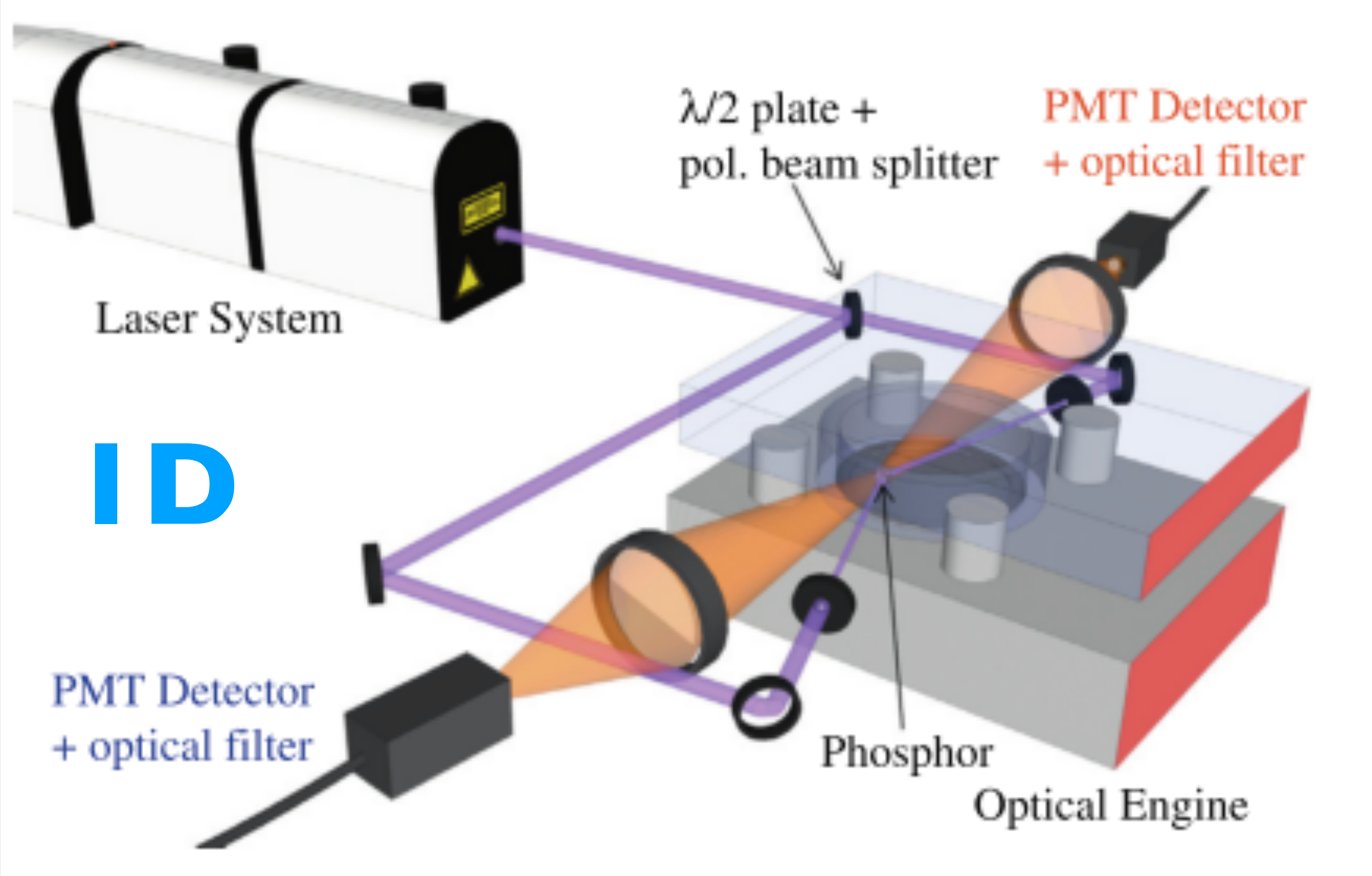

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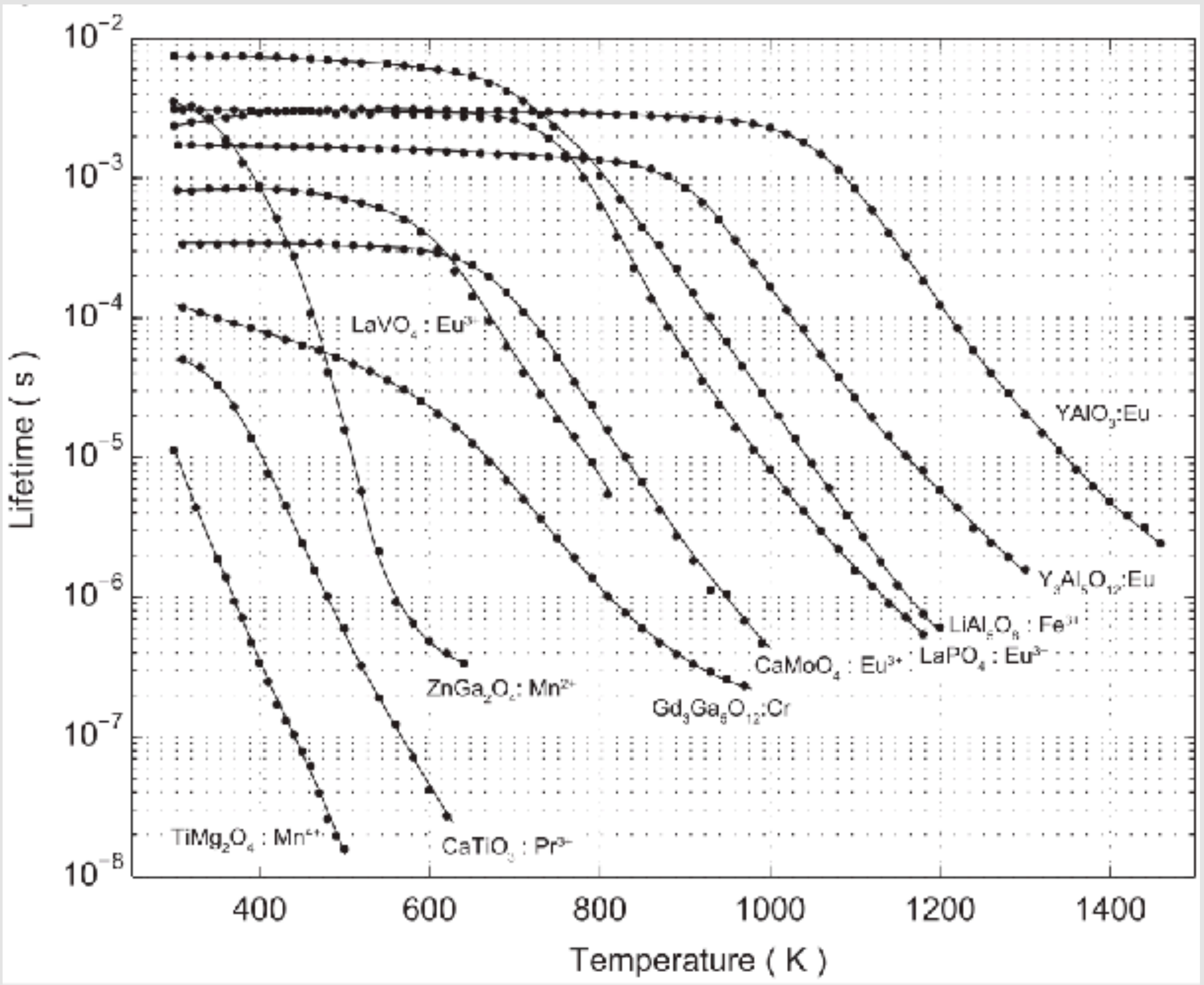

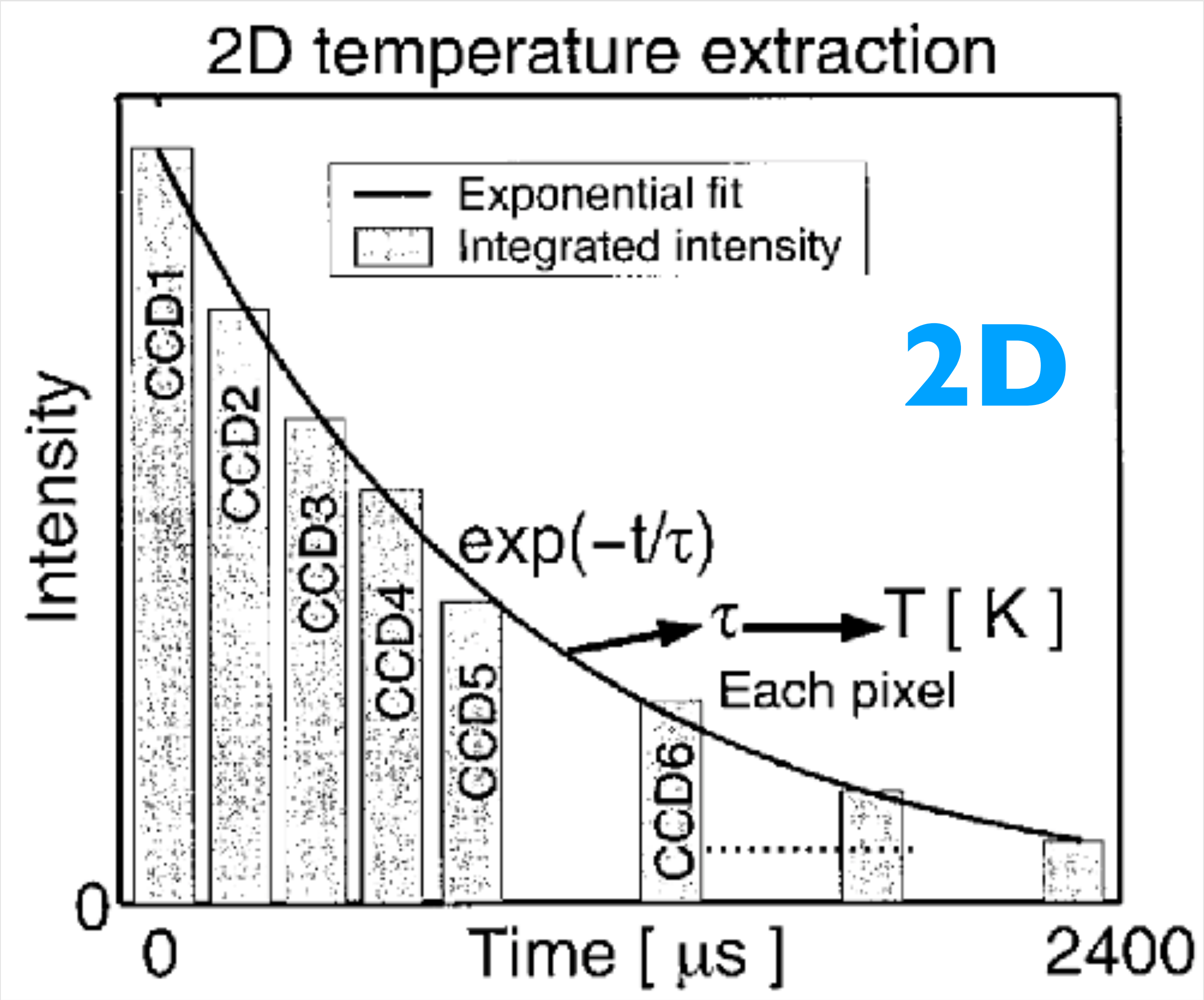

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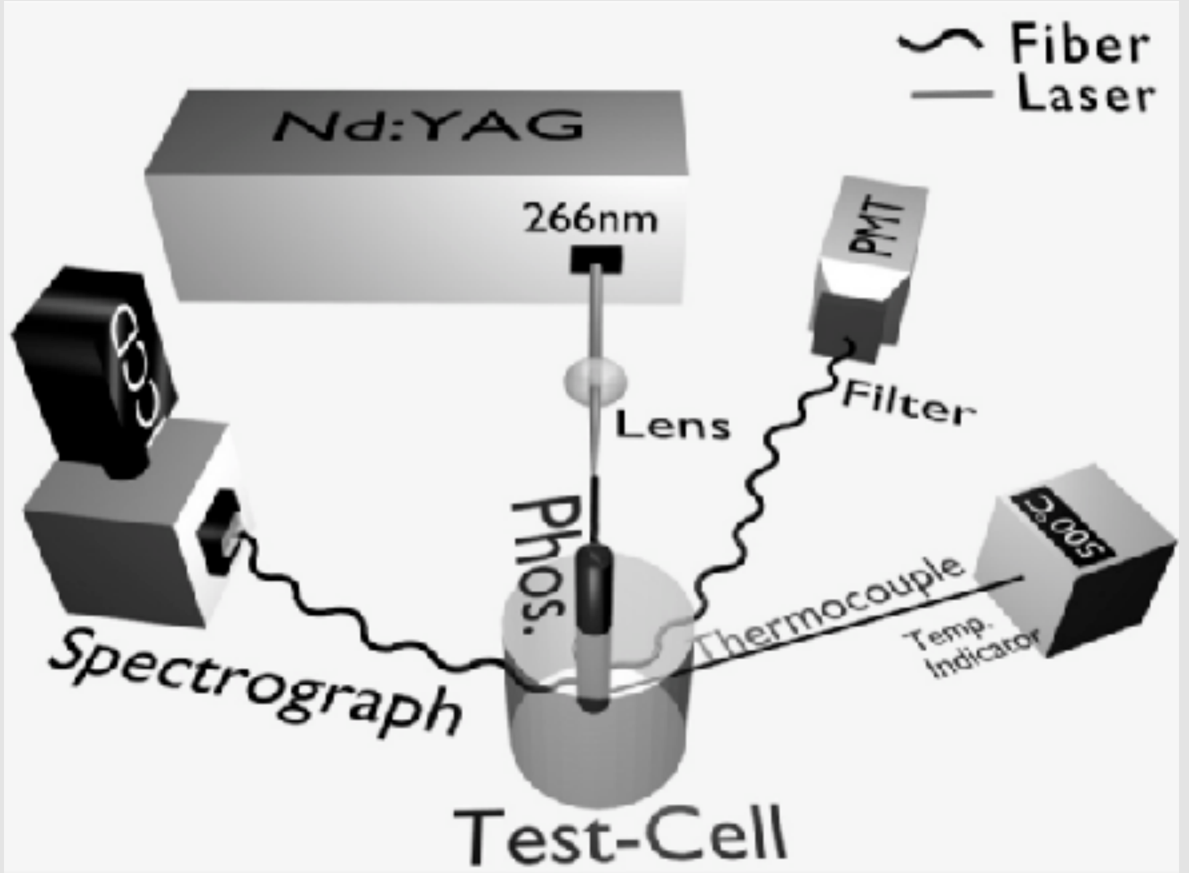
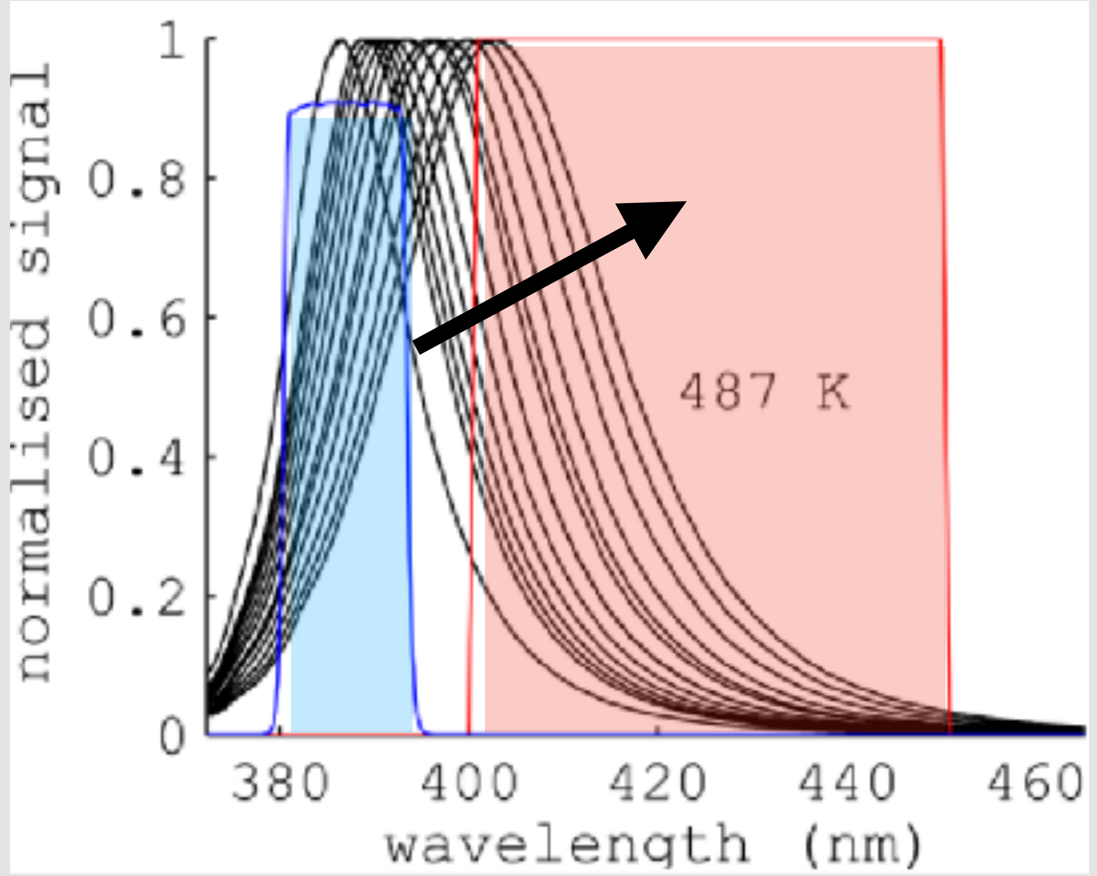
… & Time-Integrated Domain





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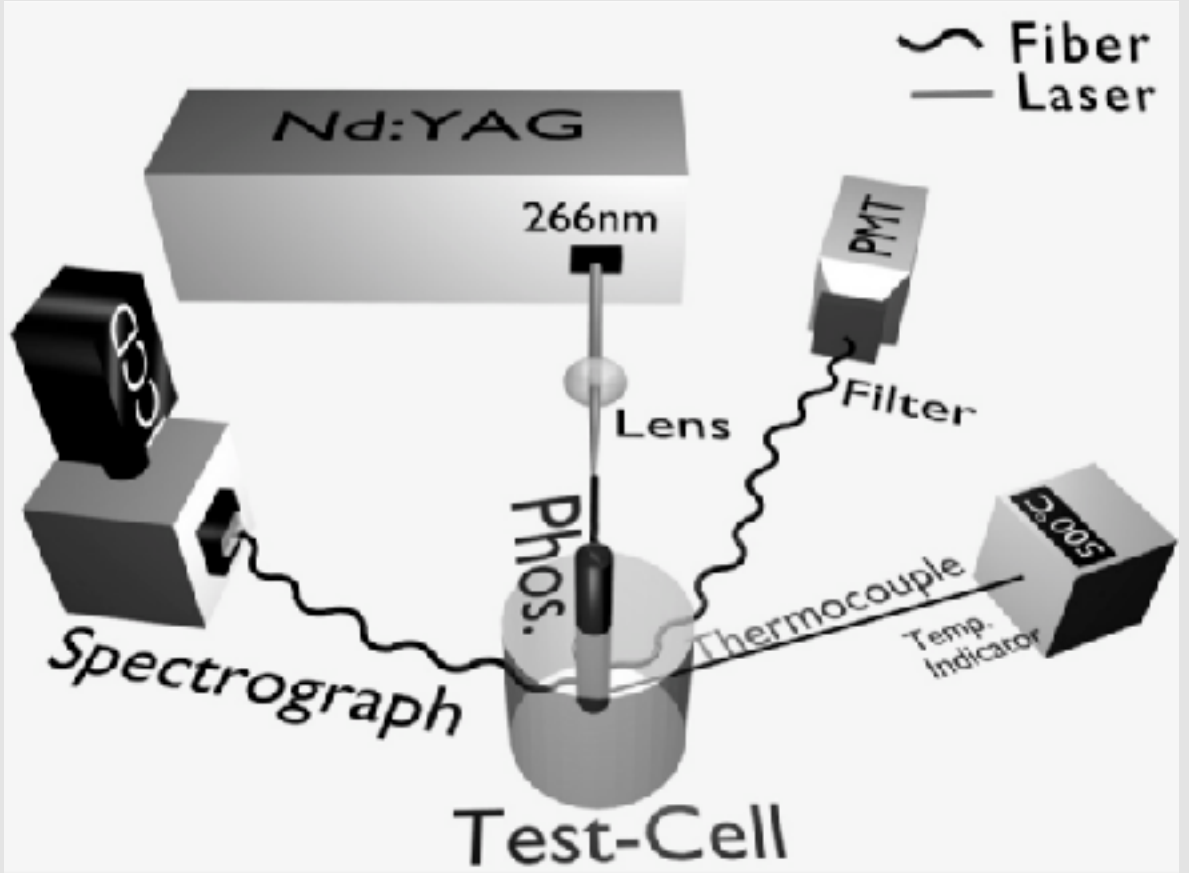
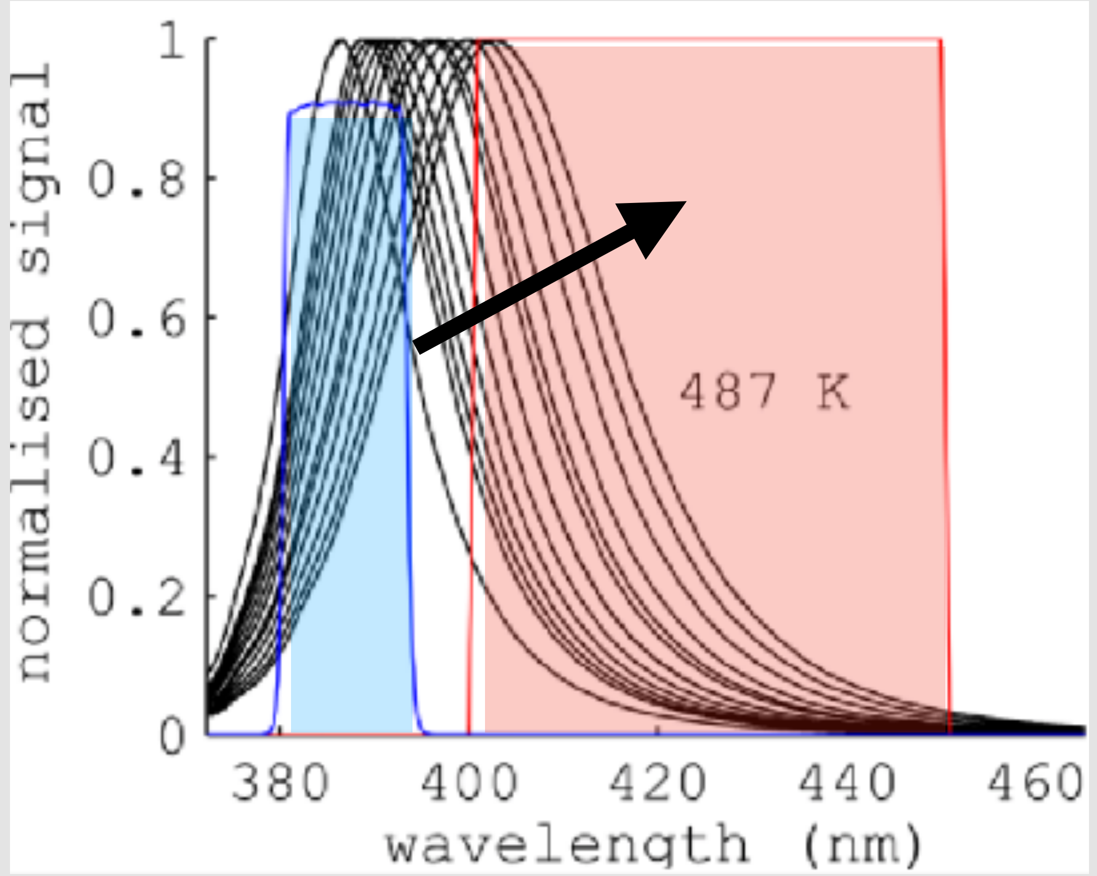




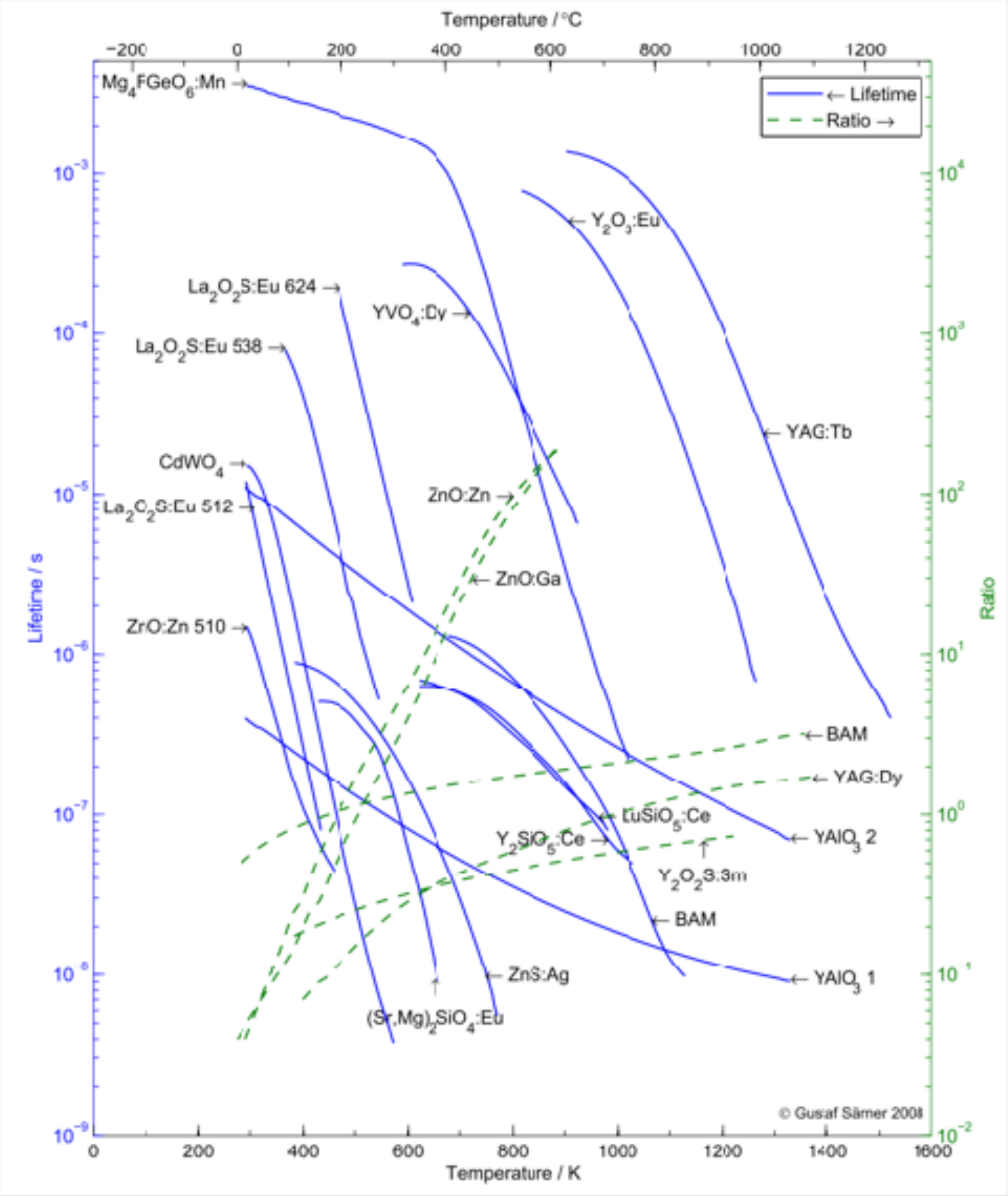
A priori calibration

$$R(T) = I_1/I_2$$

↓

$$T = f(R)$$

→



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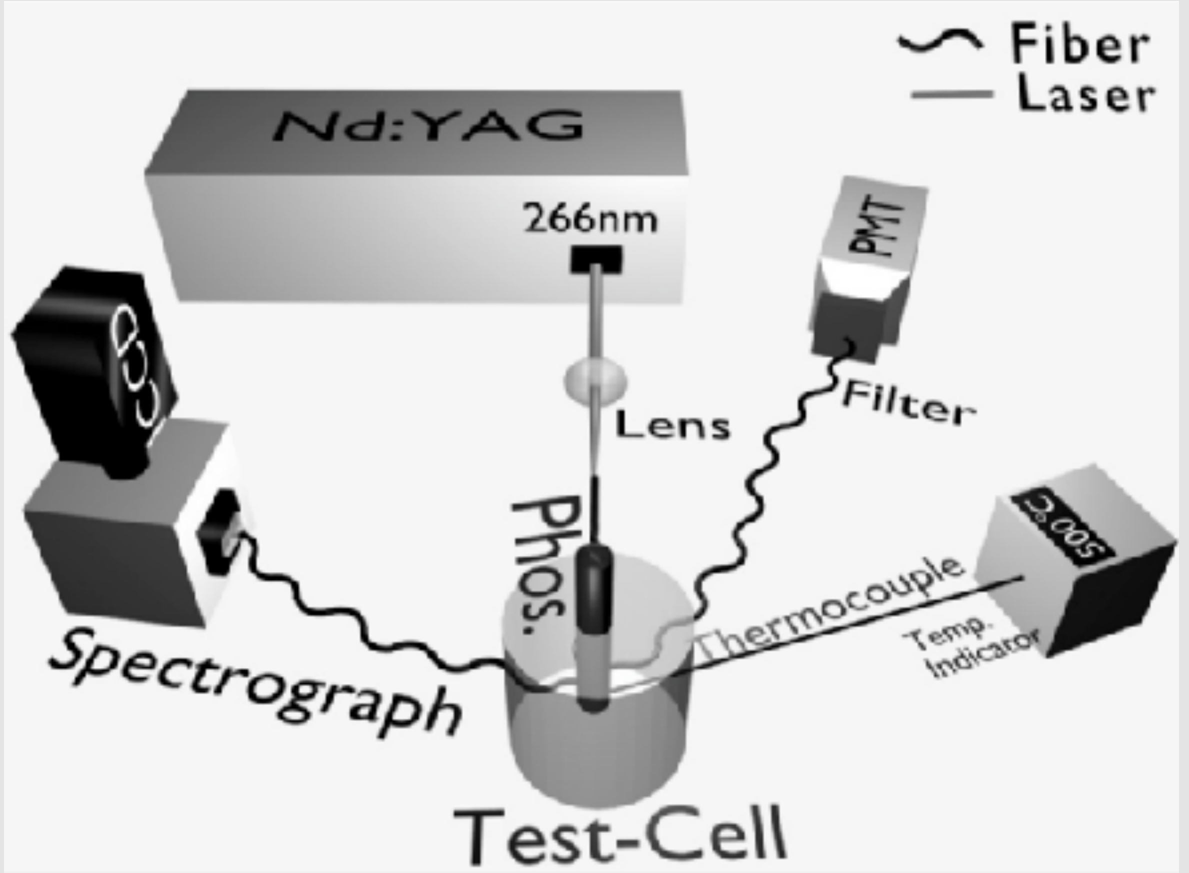

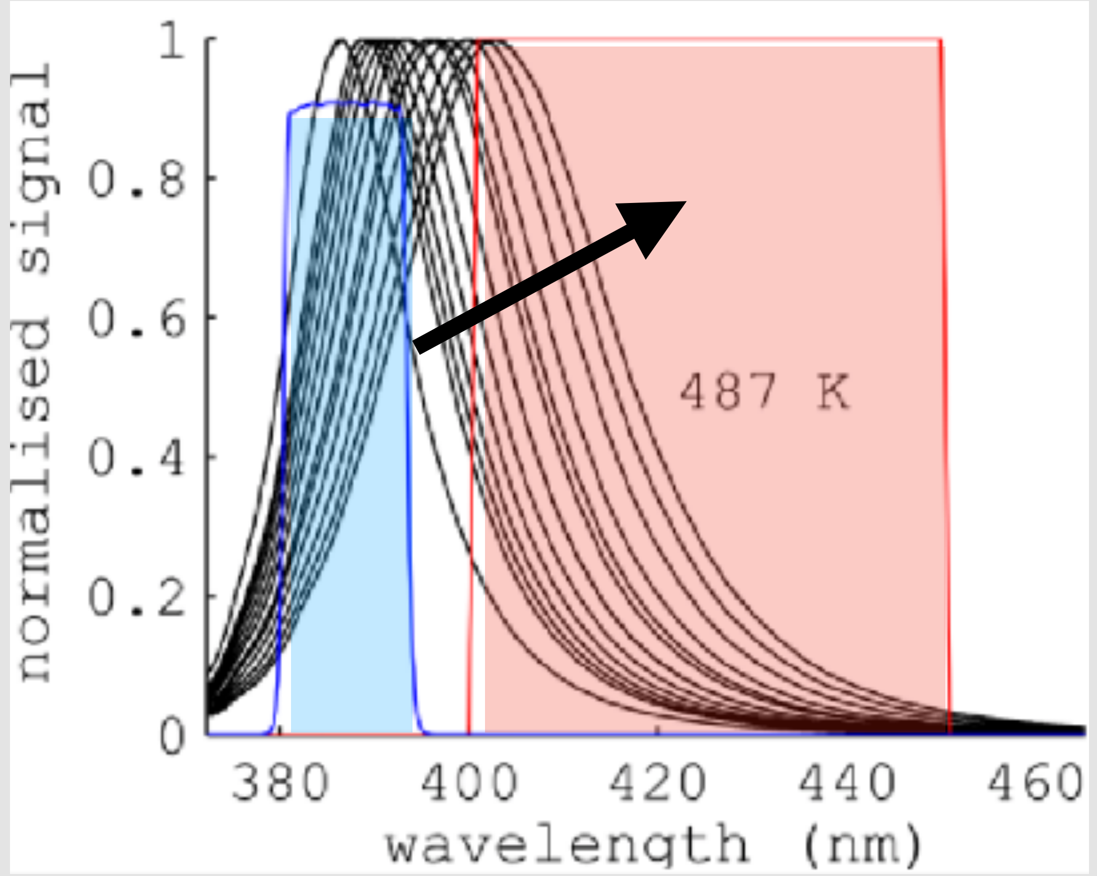

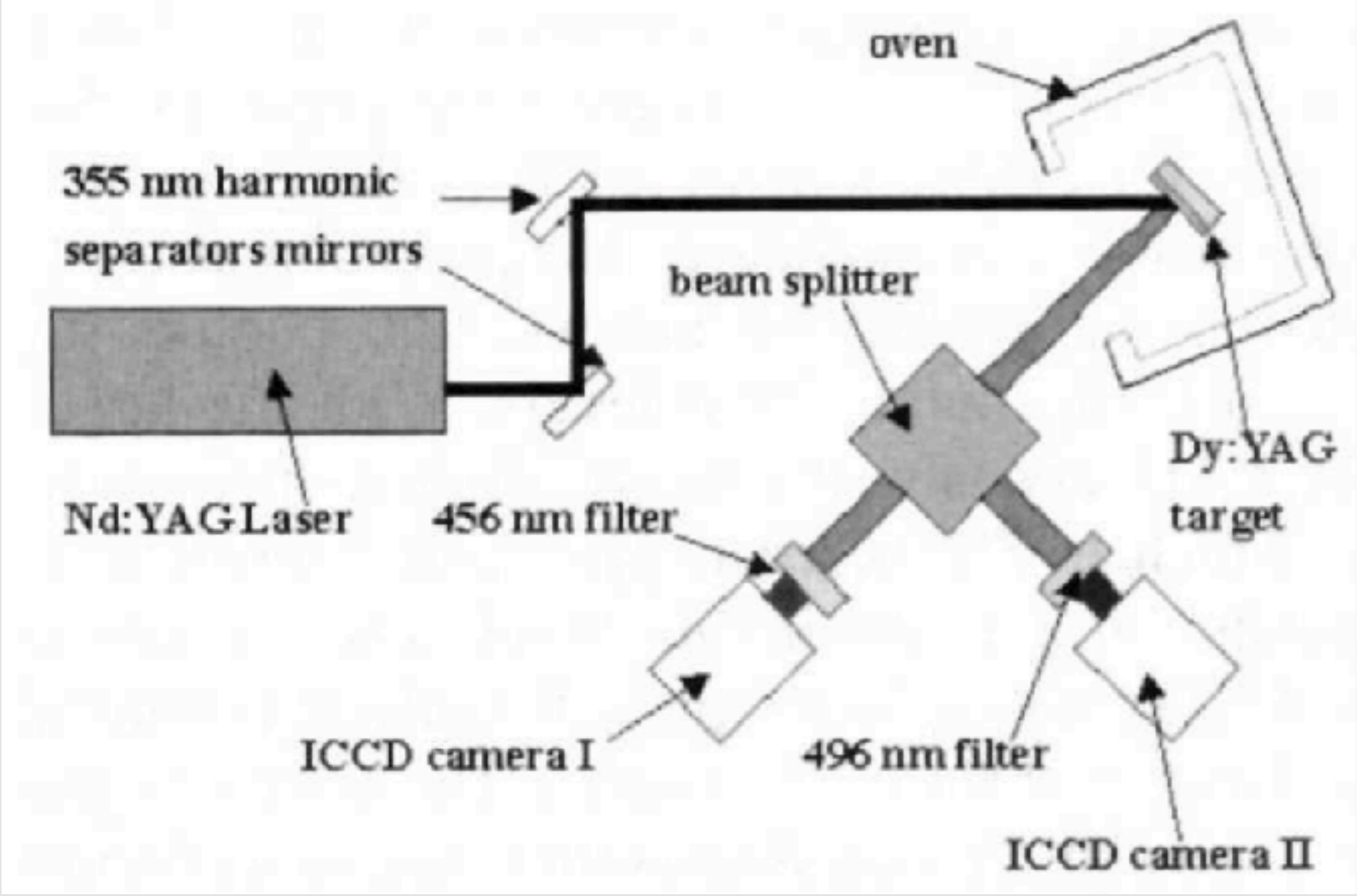

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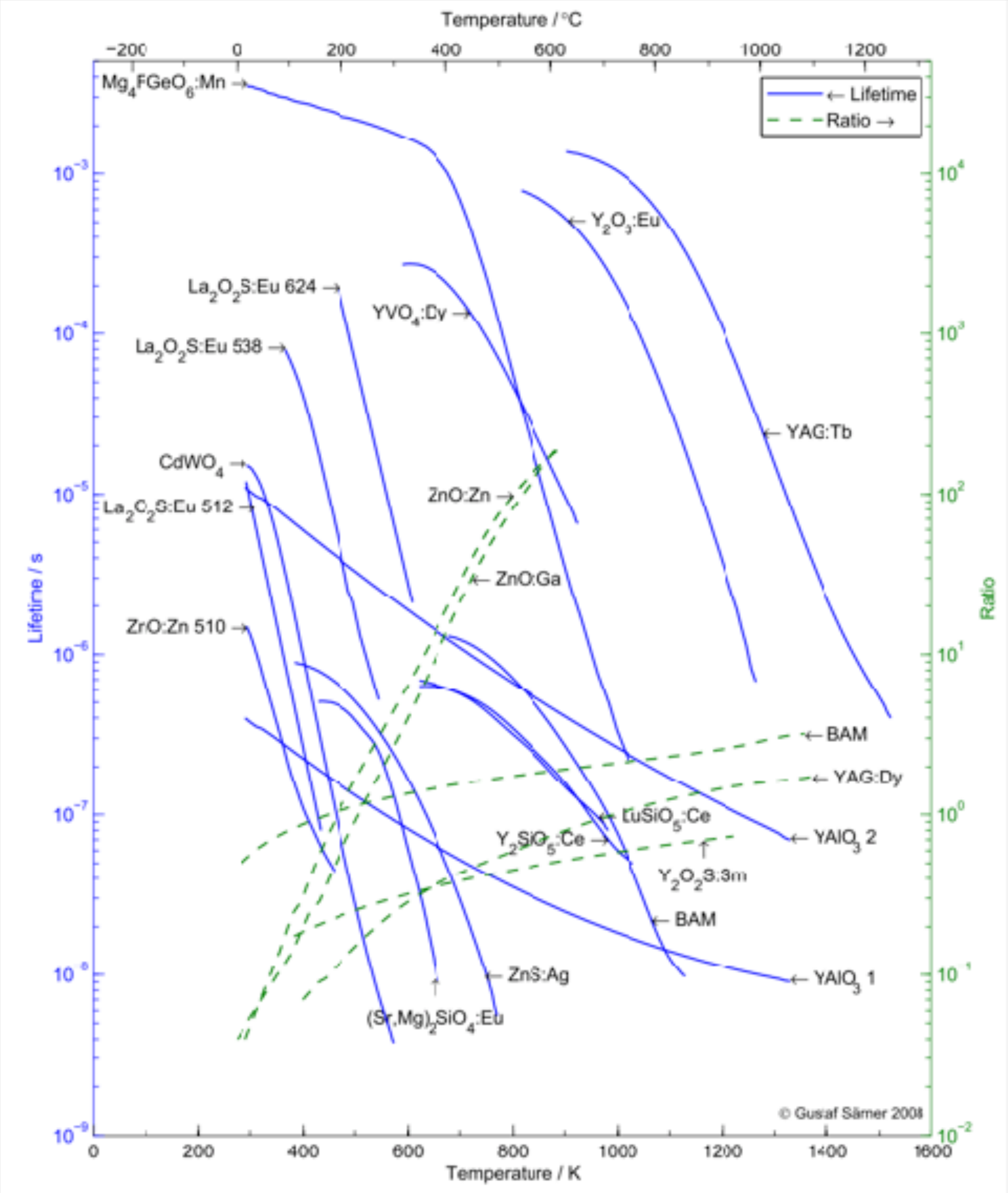

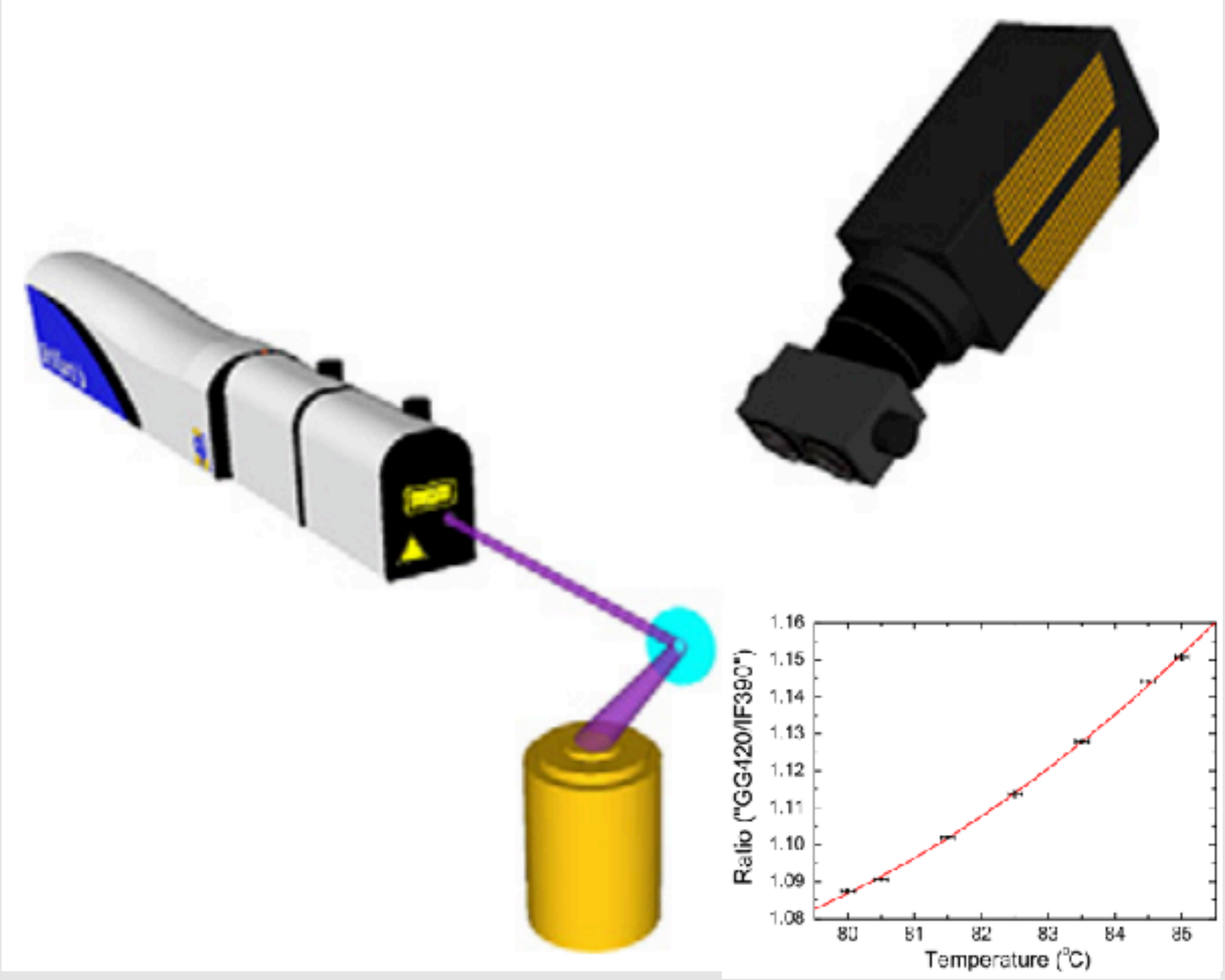

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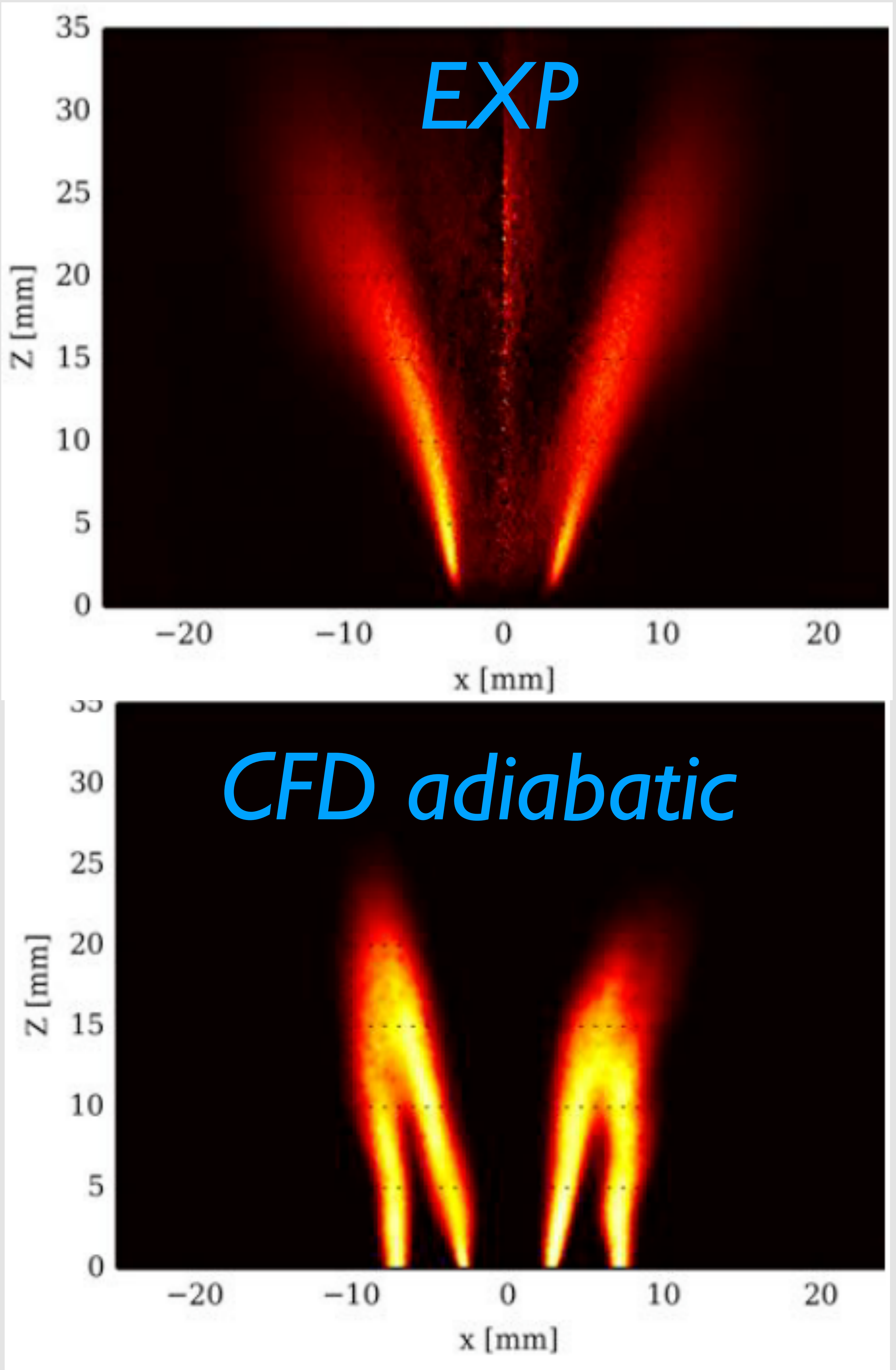
Some applications (1): Gas Turbines



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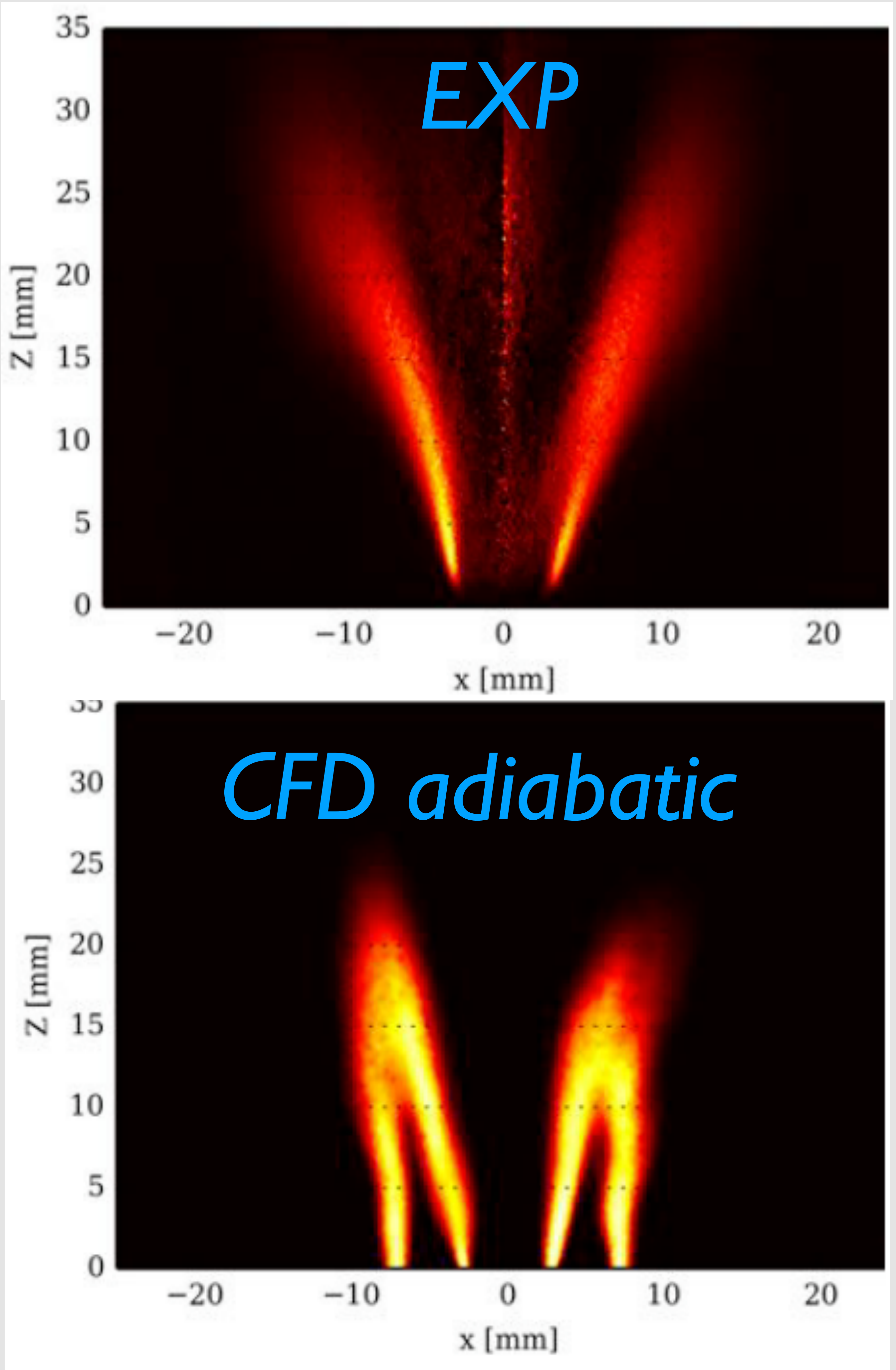
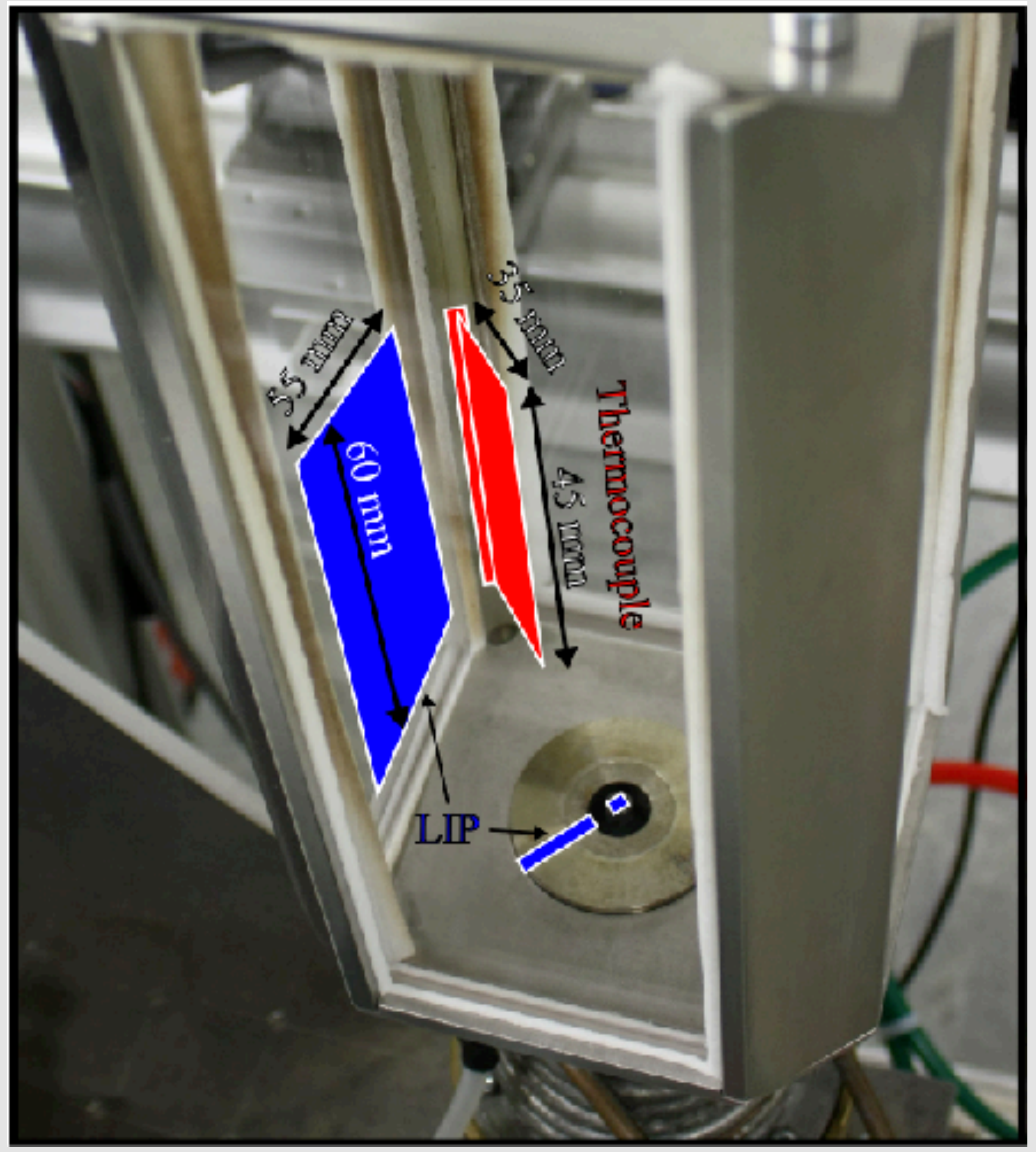
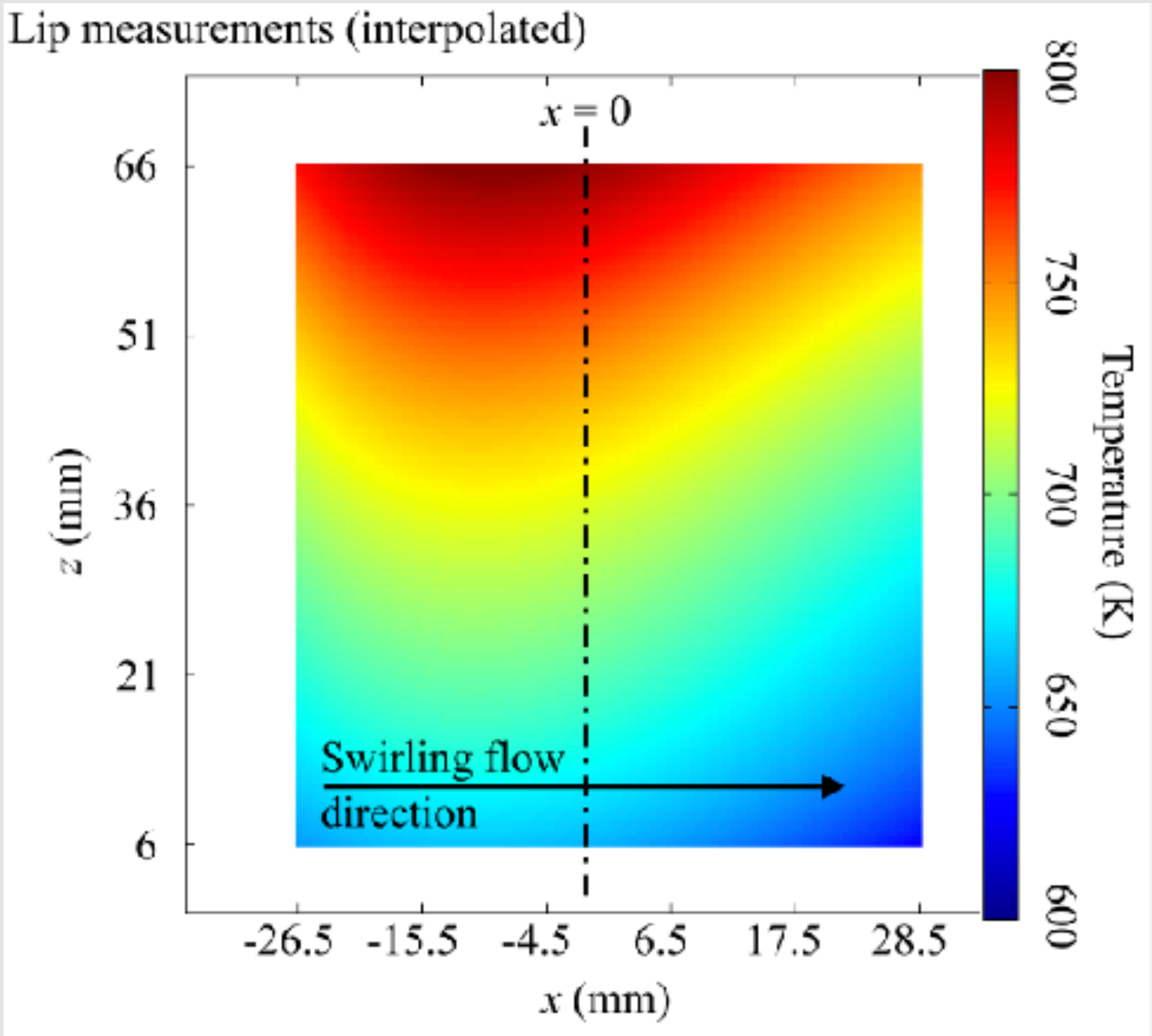


Thermal boundary conditions





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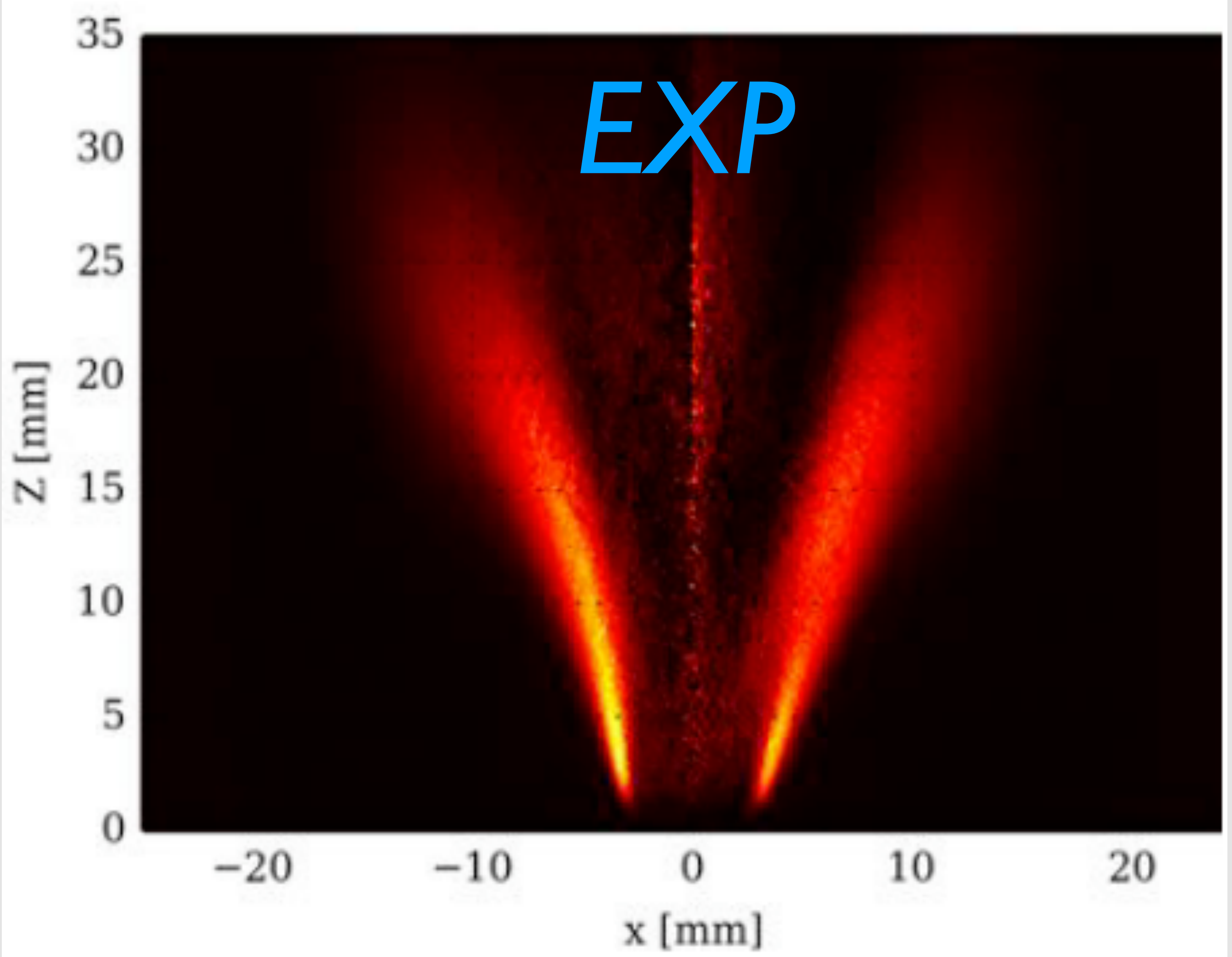
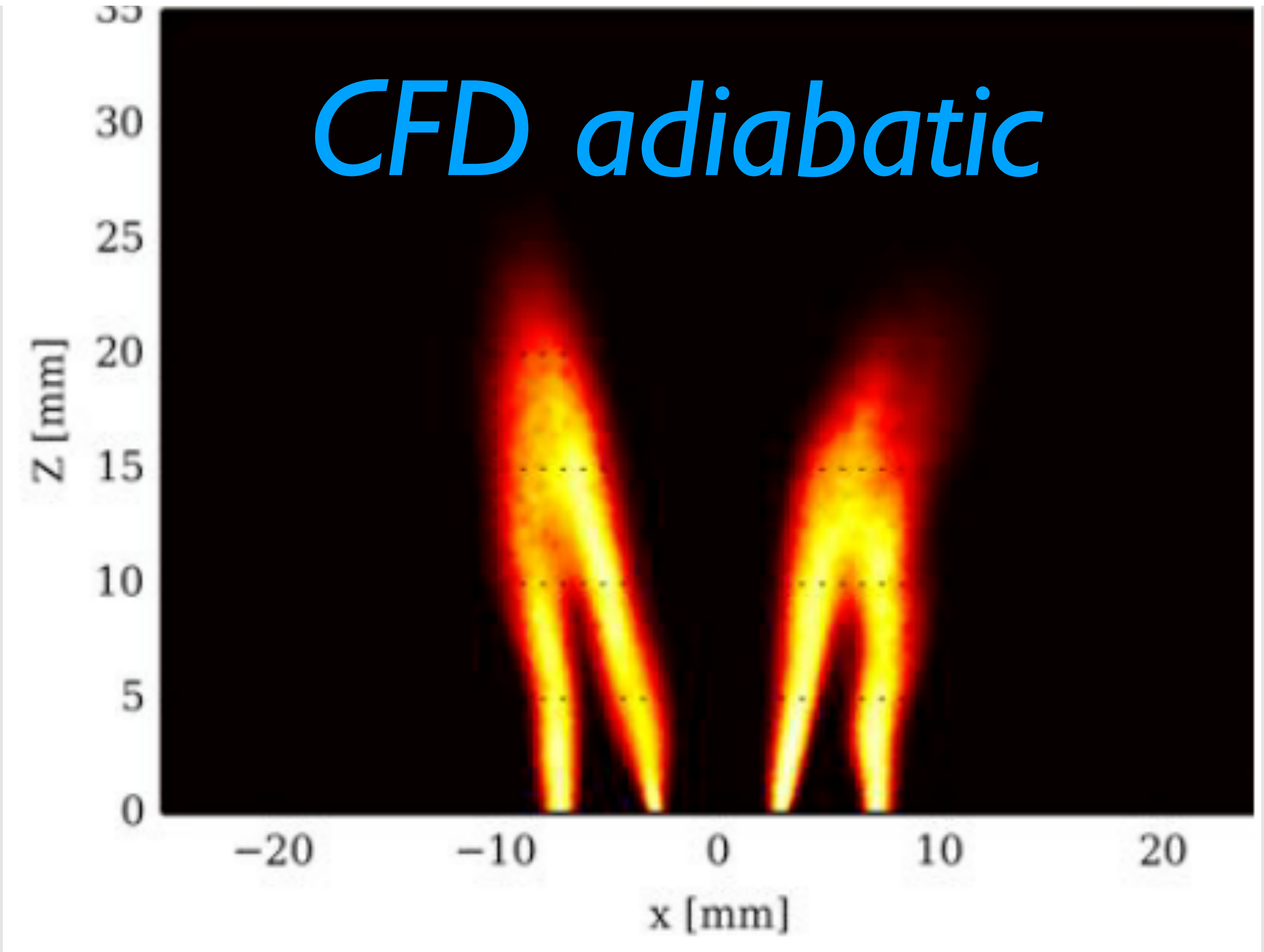
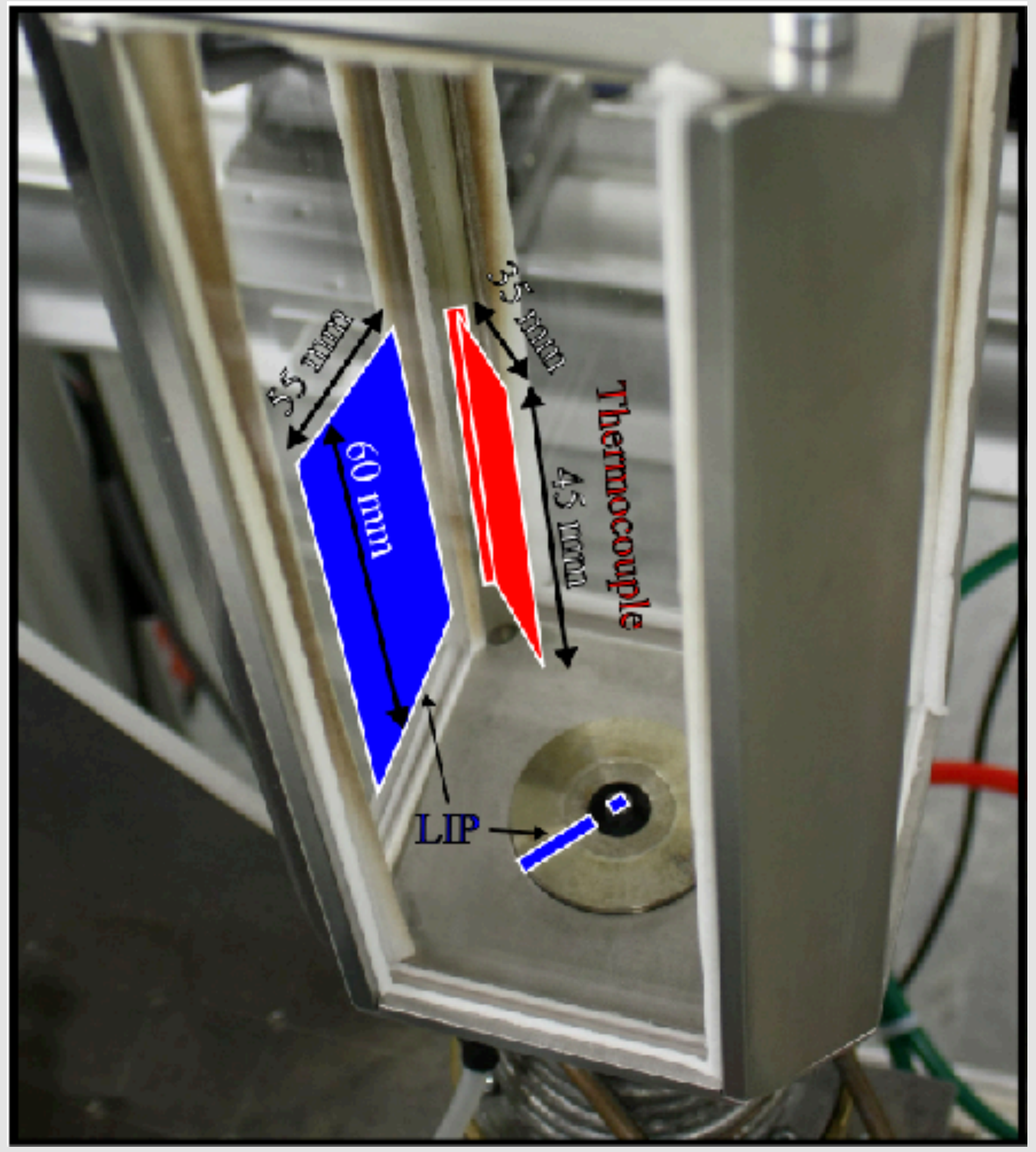
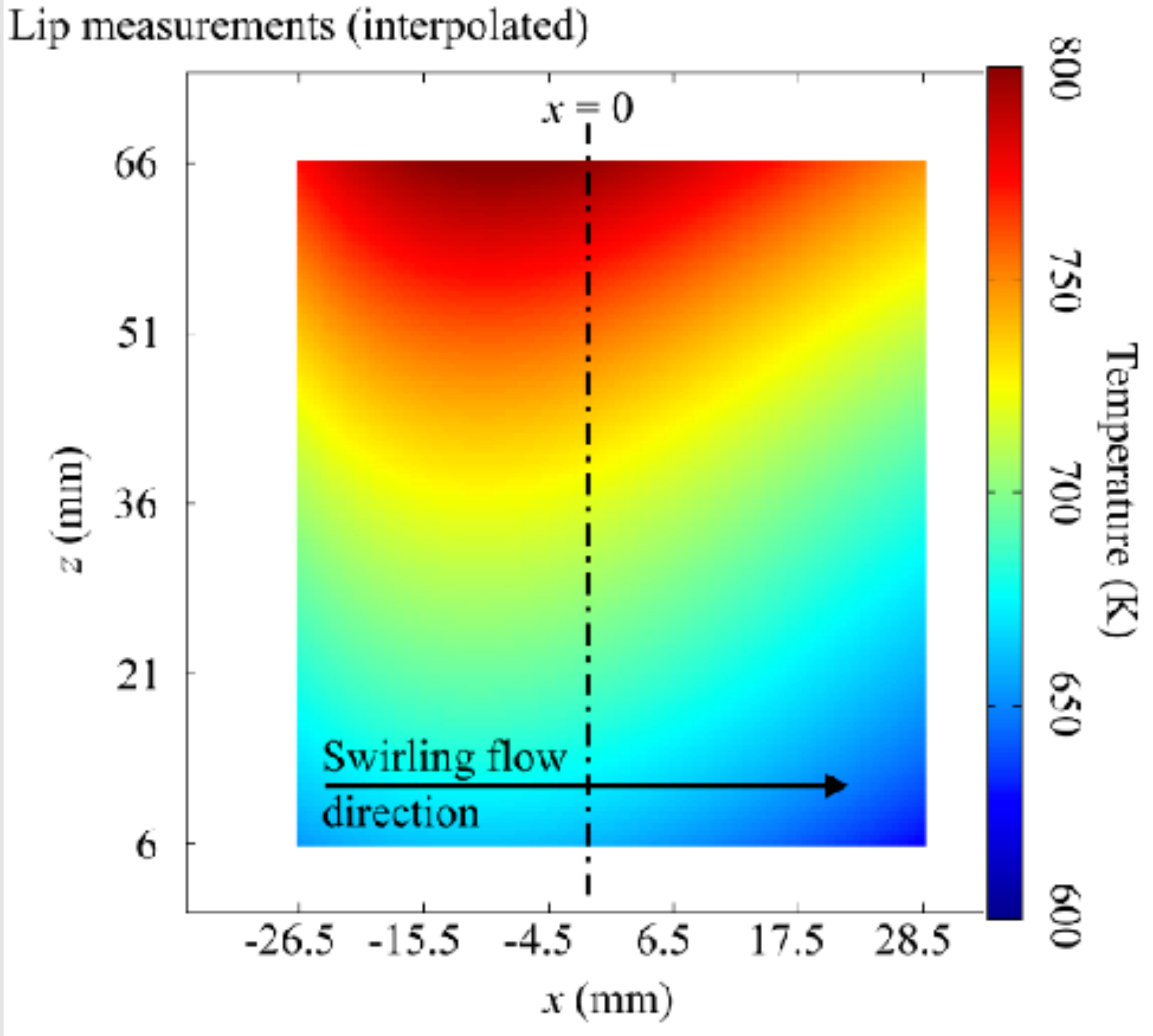
Some applications (1): Gas Turbines

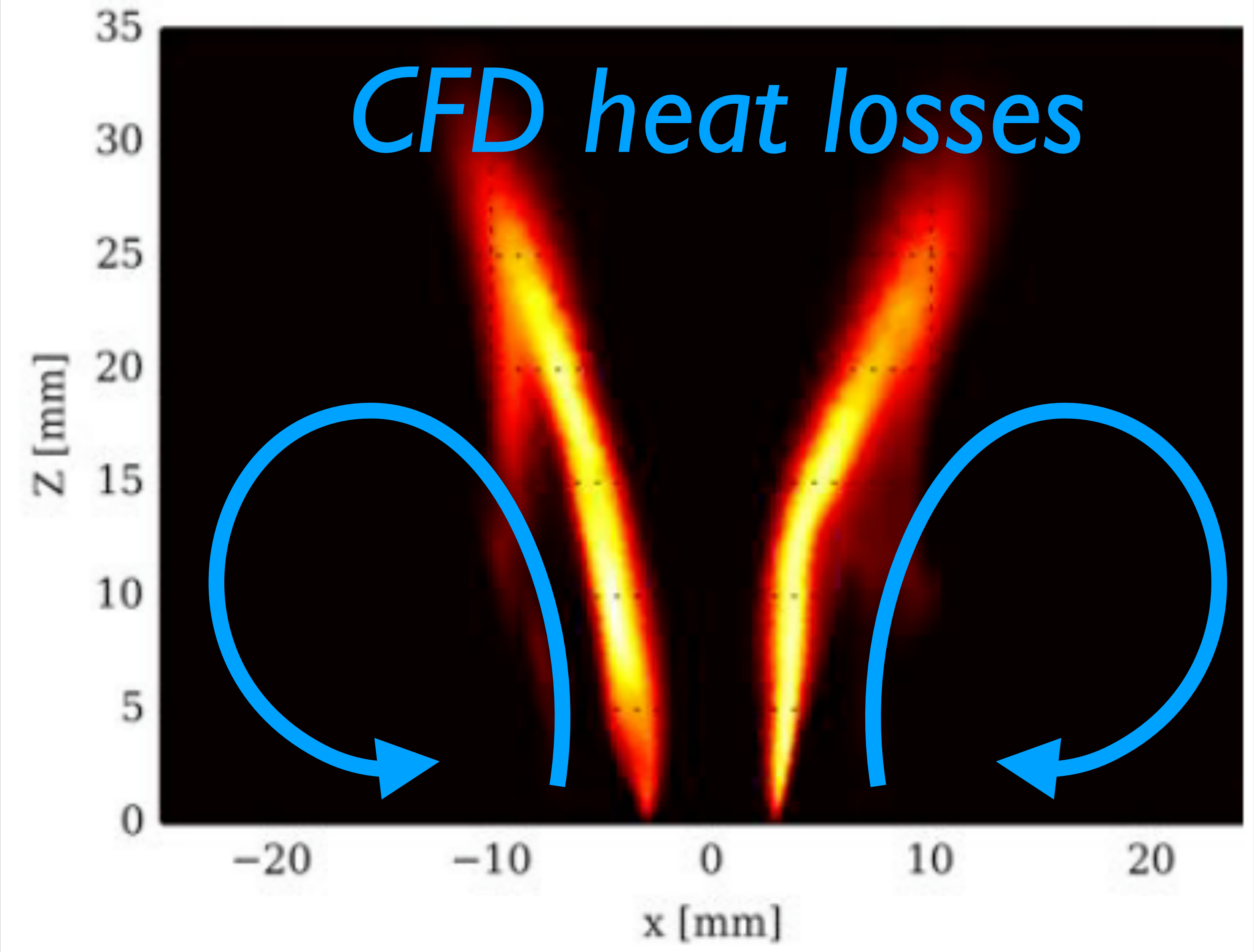




Thermal boundary conditions



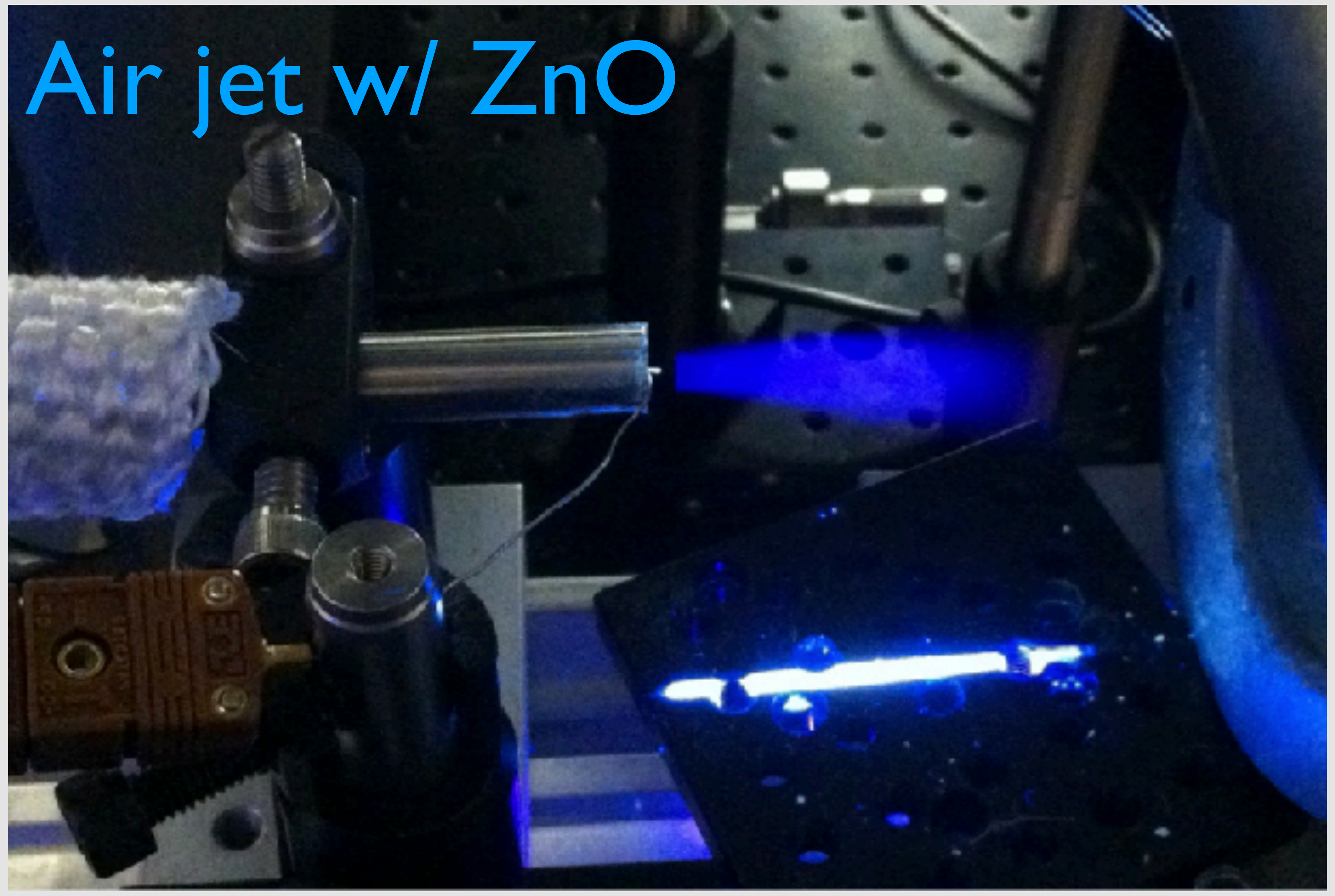




Guiberti Thesis, ECP, 2015
Feist et al., Proc.Inst. Mech. Eng 217:193-200, 2005
Seyfried et al., AIAA J. 45:1966-71, 2007
Nau et al., ASME GT75293, 2018

Cooled burnt recirculation = Enthalpy losses

Many applications (2): Gas-phase Thermometry



Abram et al., Appl. Phys. 111:155-160, 2013
Schreivogel et al., Heat Mass Transfer 103:390-400, 2015
Abram et al., Prog. Ener. Combust. Sci. 64:93, 2018

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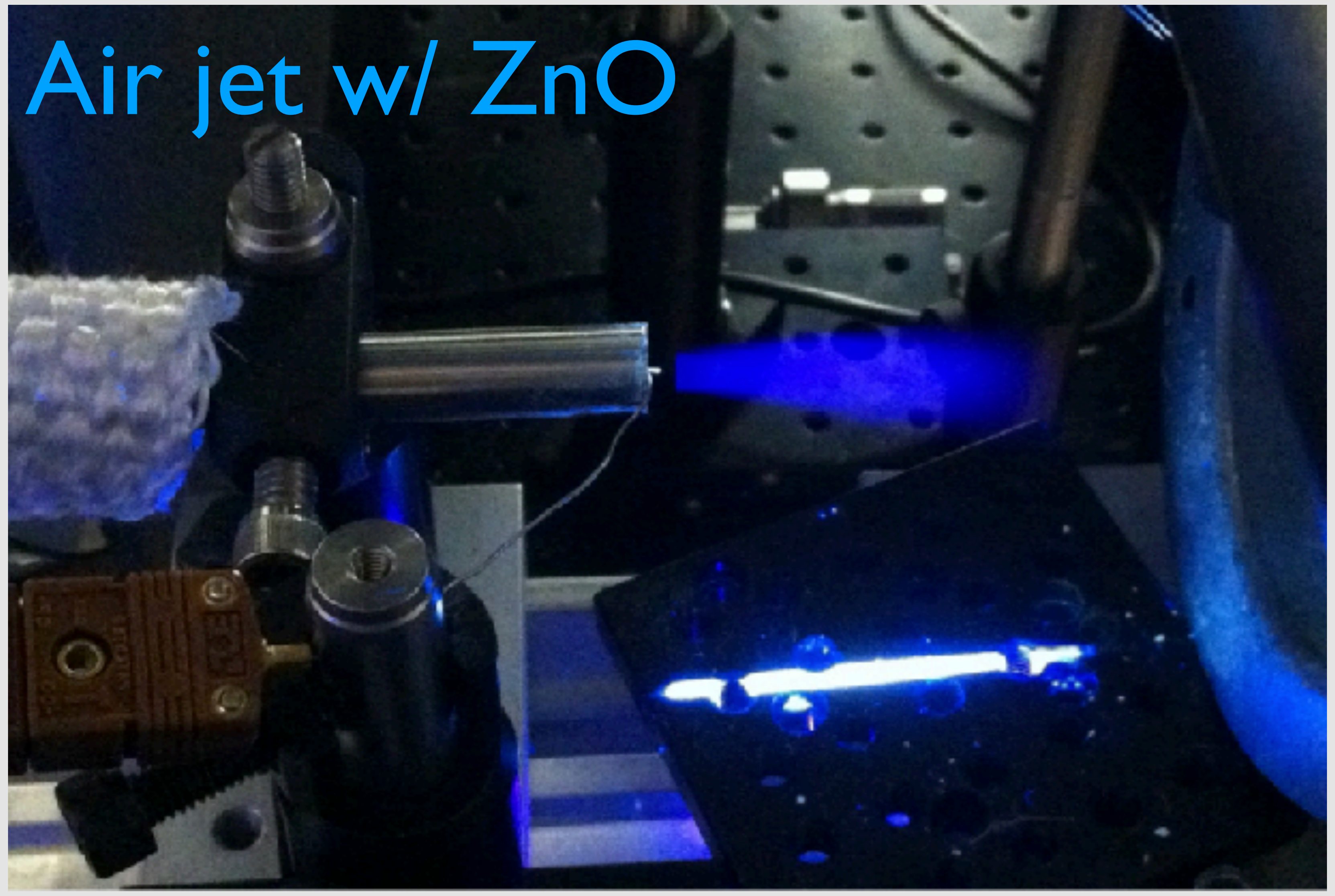

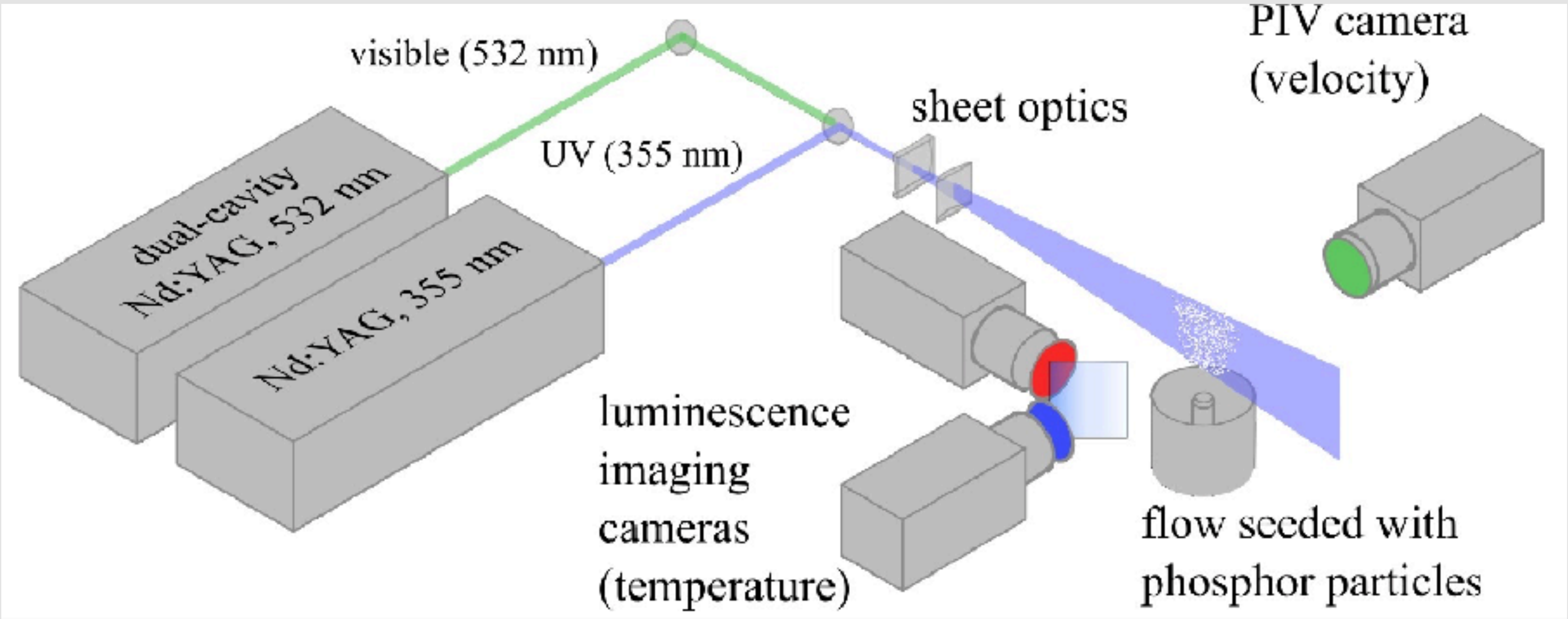

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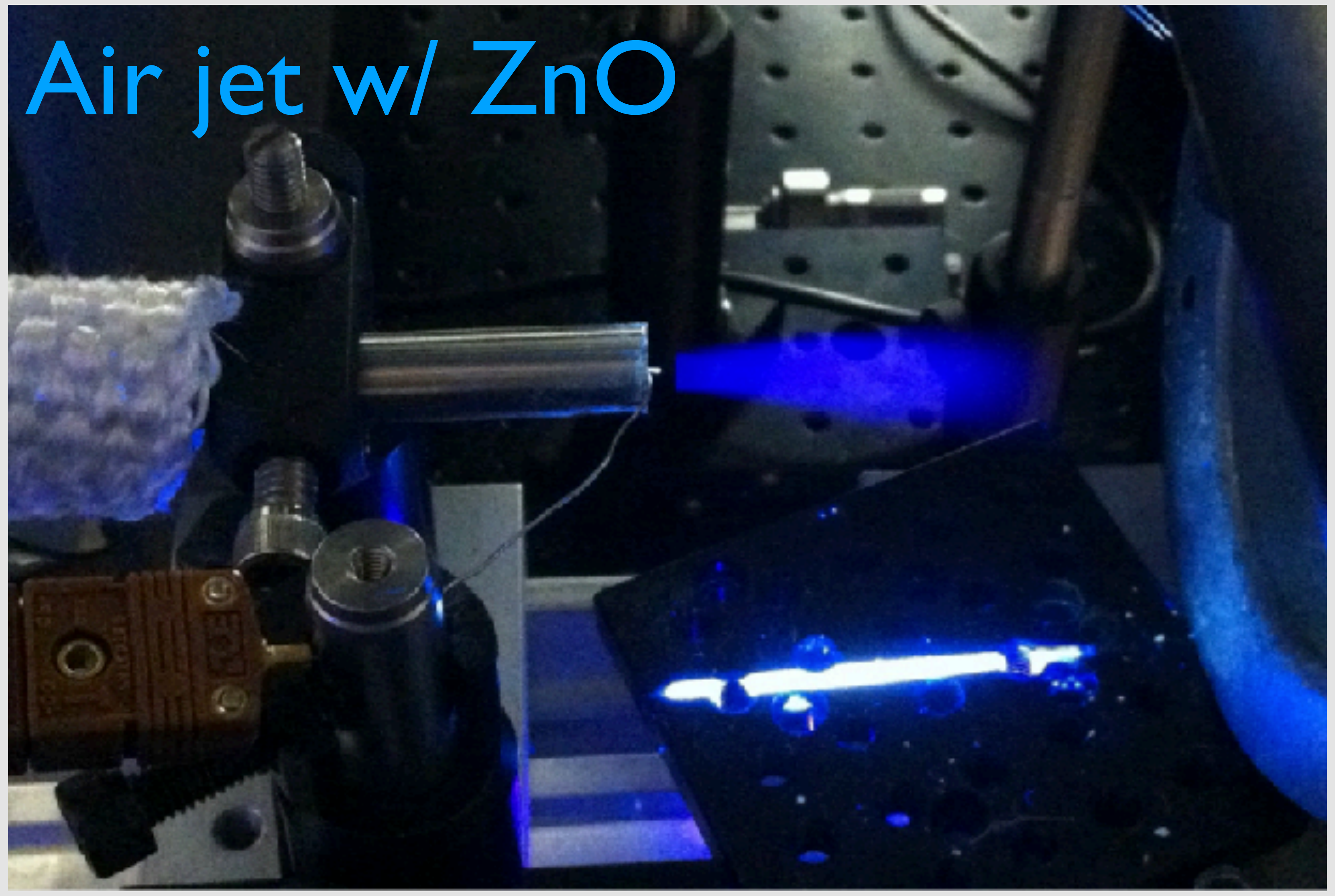
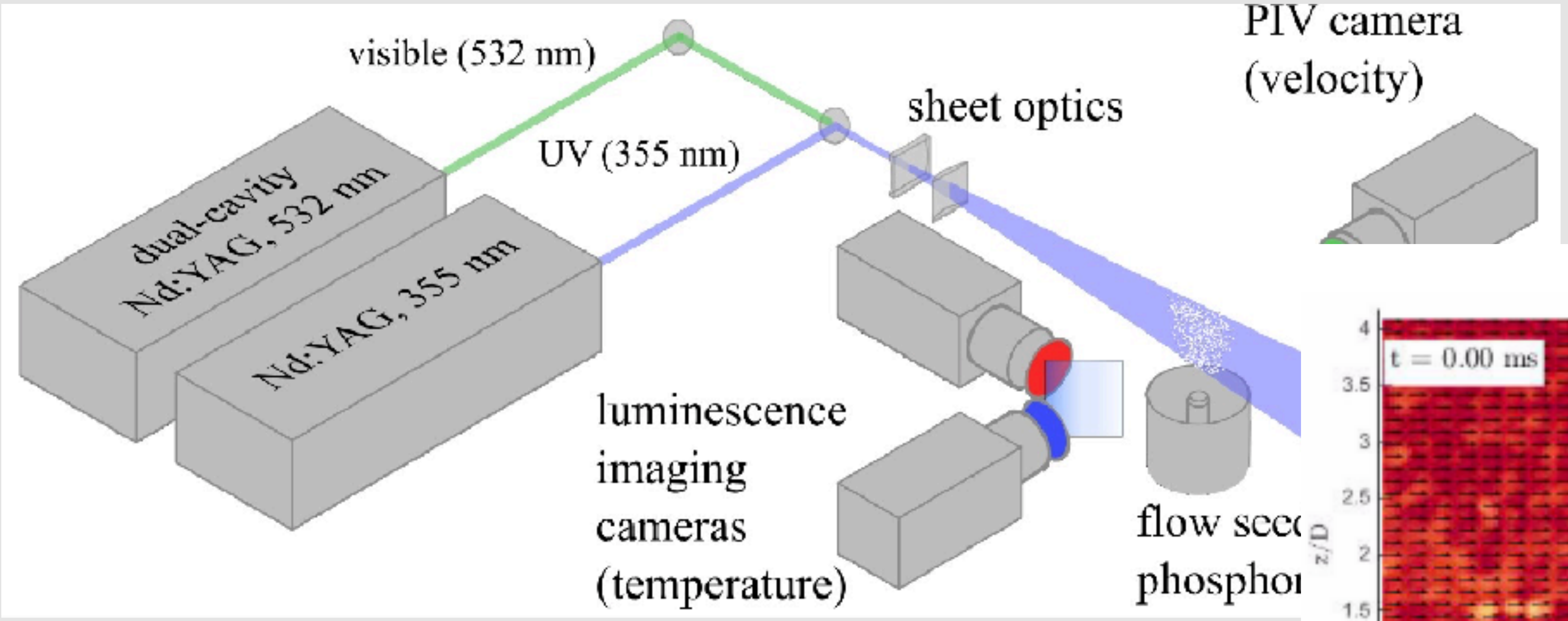
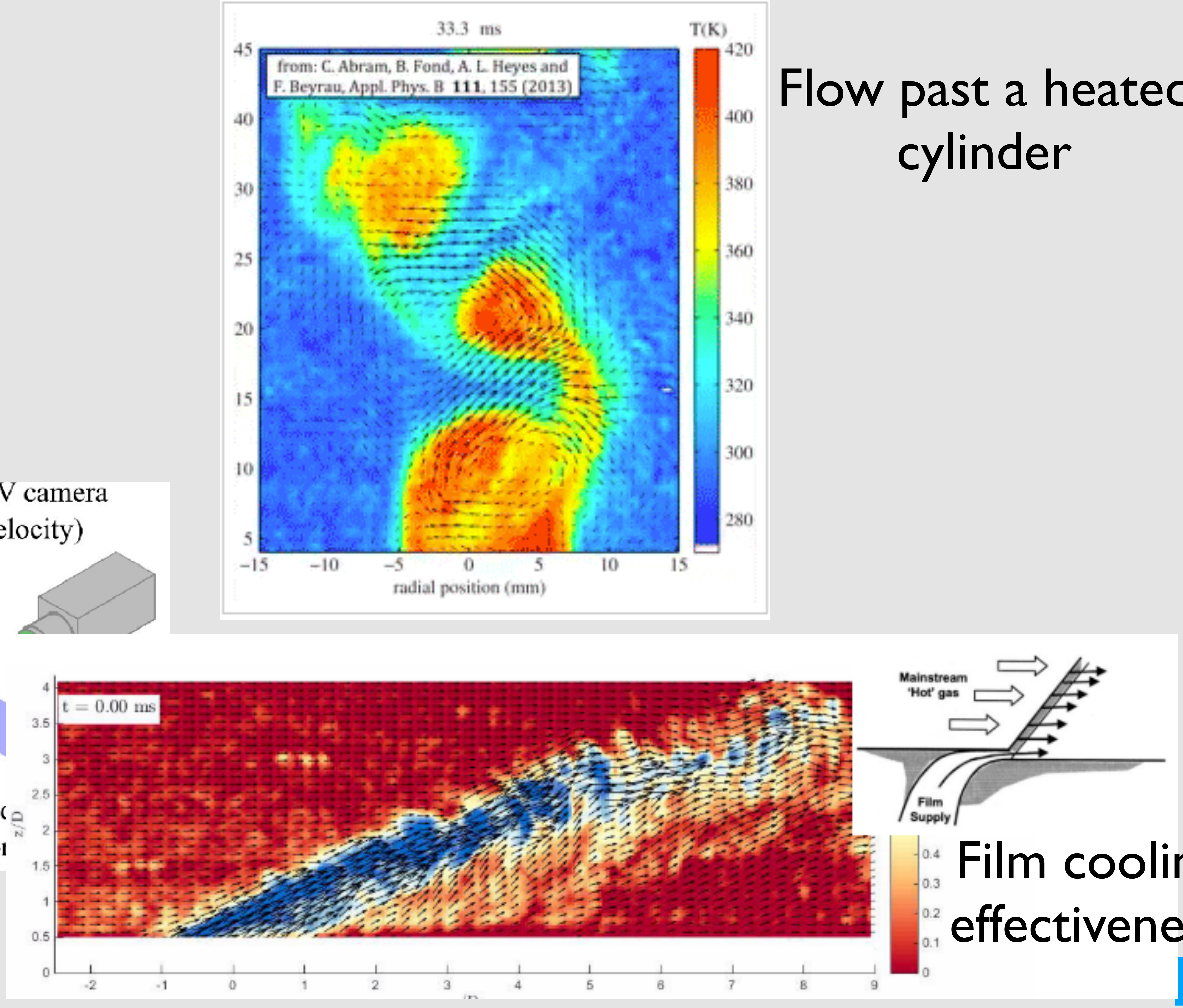
Many applications (2): Gas-phase Thermometry







Flow past a heated cylinder

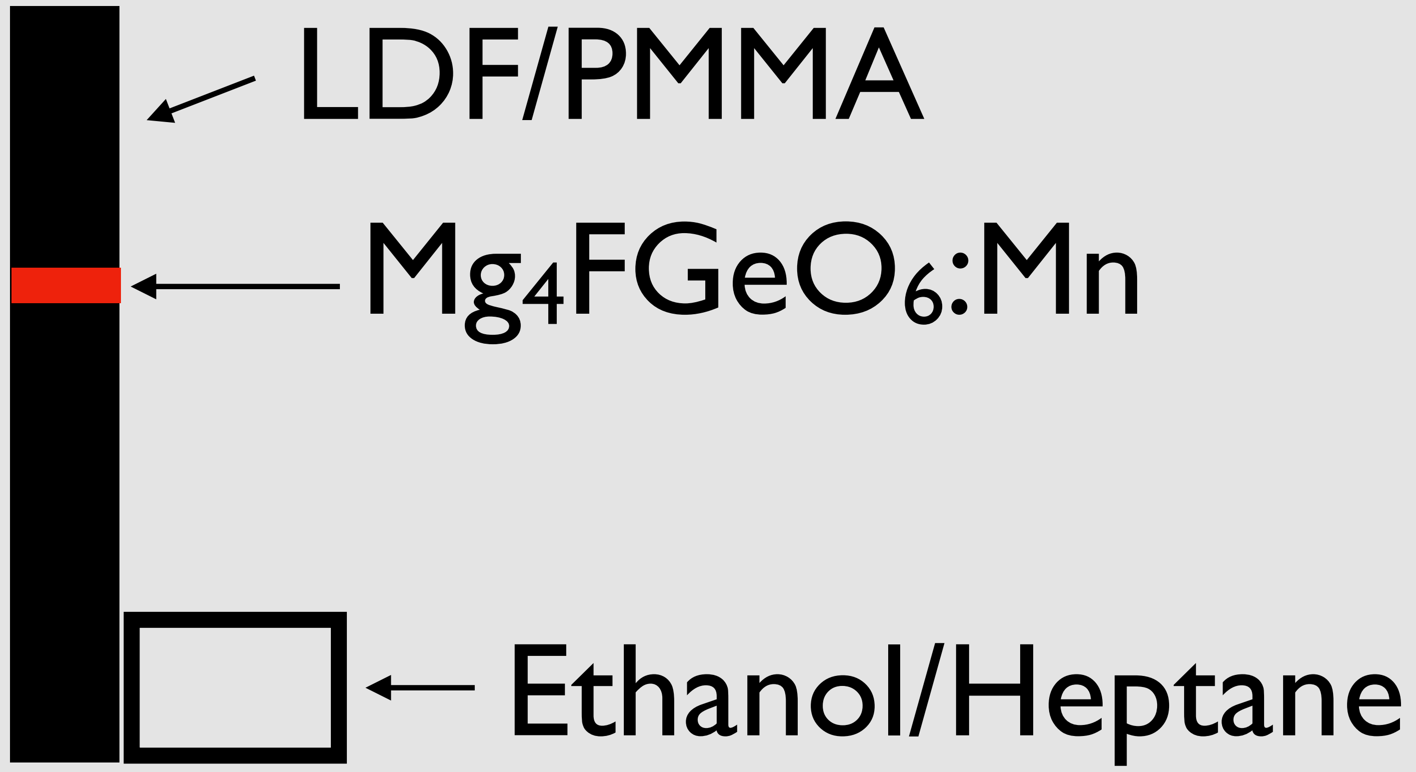
Film cooling effectiveness

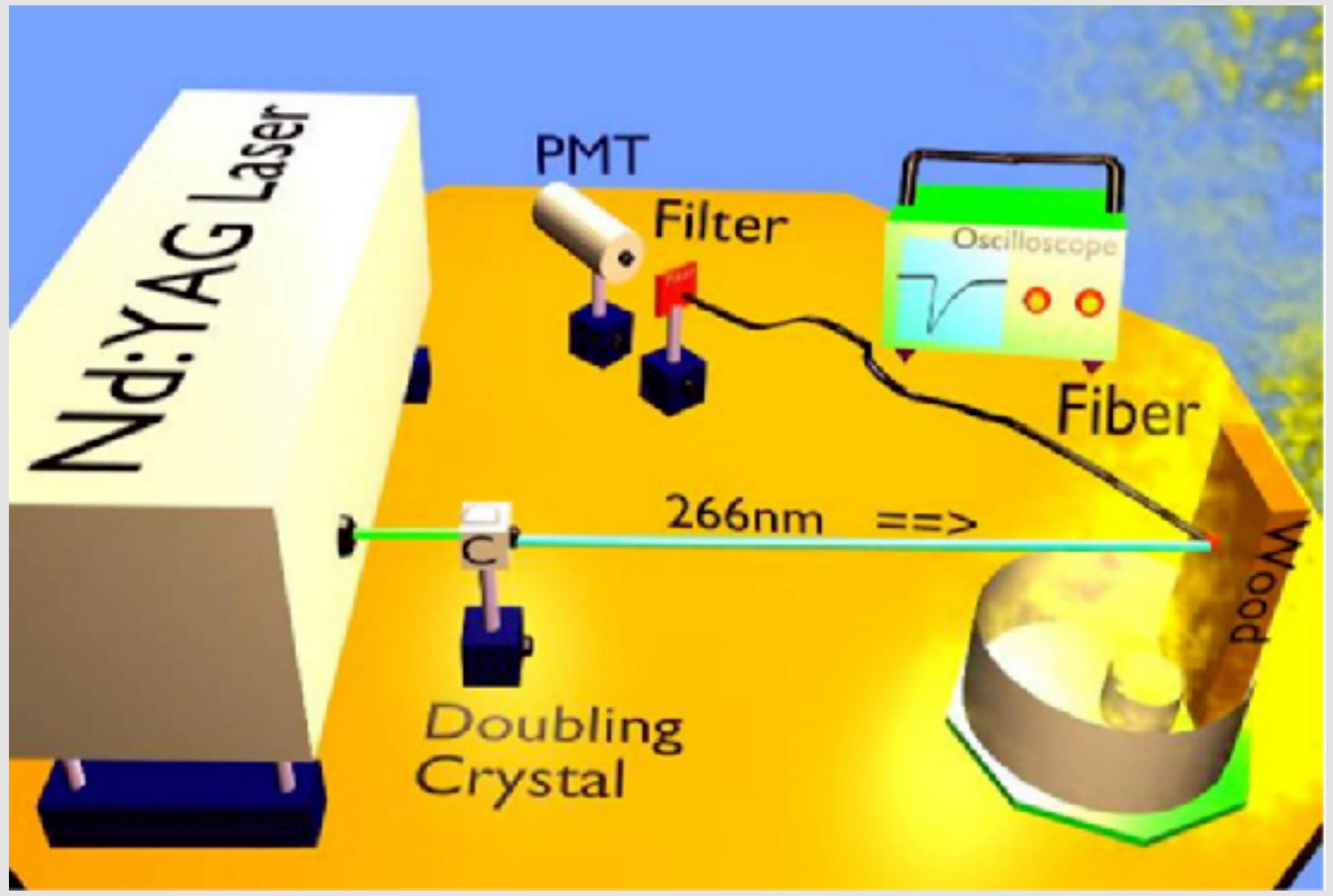
Abram et al., Appl. Phys. 111:155-160, 2013
Schreivogel et al., Heat Mass Transfer 103:390-400, 2015
Abram et al., Prog. Ener. Combust. Sci. 64:93, 2018

Valencia et al., GDR Feux 2015

Fire applications

Flame Spread - 1D





Interferences w/ flame emission
Soot issues

Omrane et al., Fire Saf. Sci. 7:141-152, 2003

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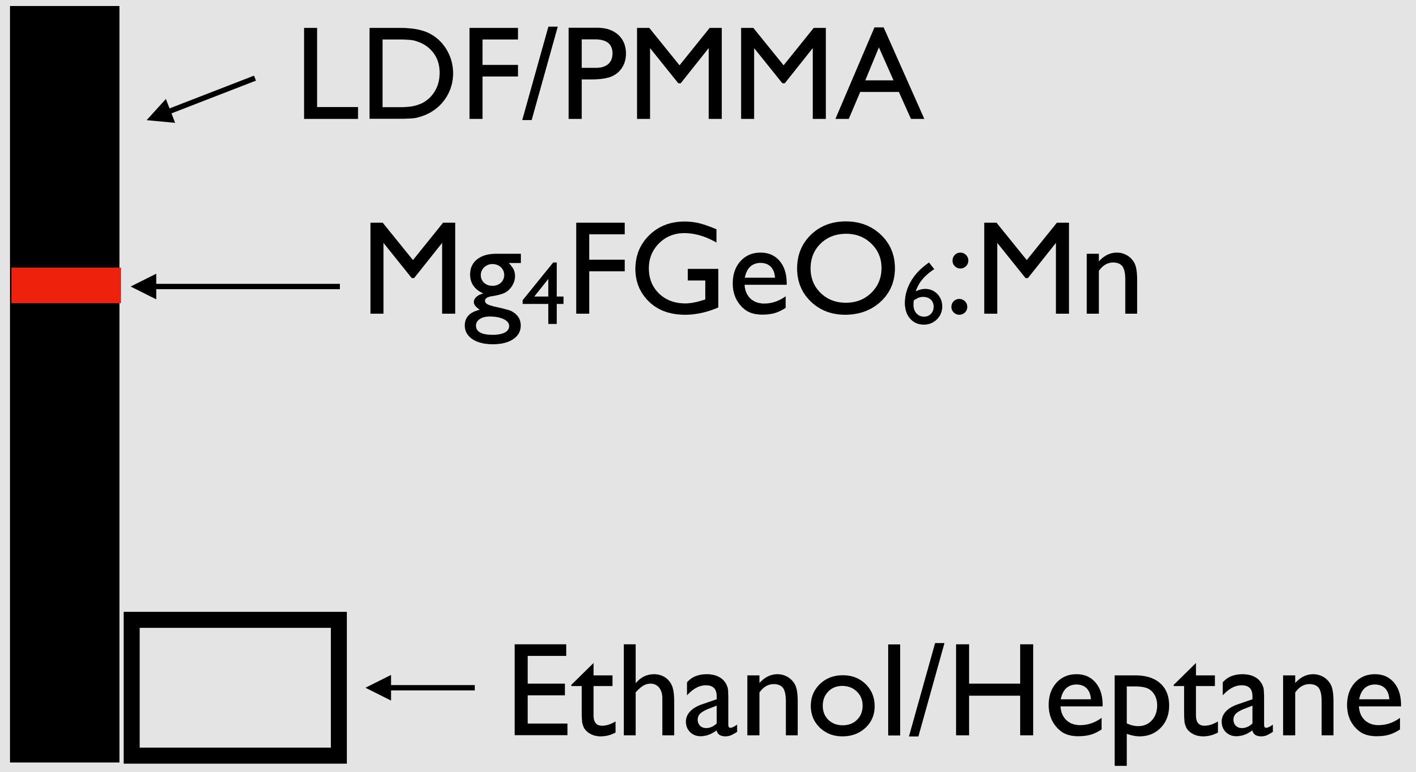

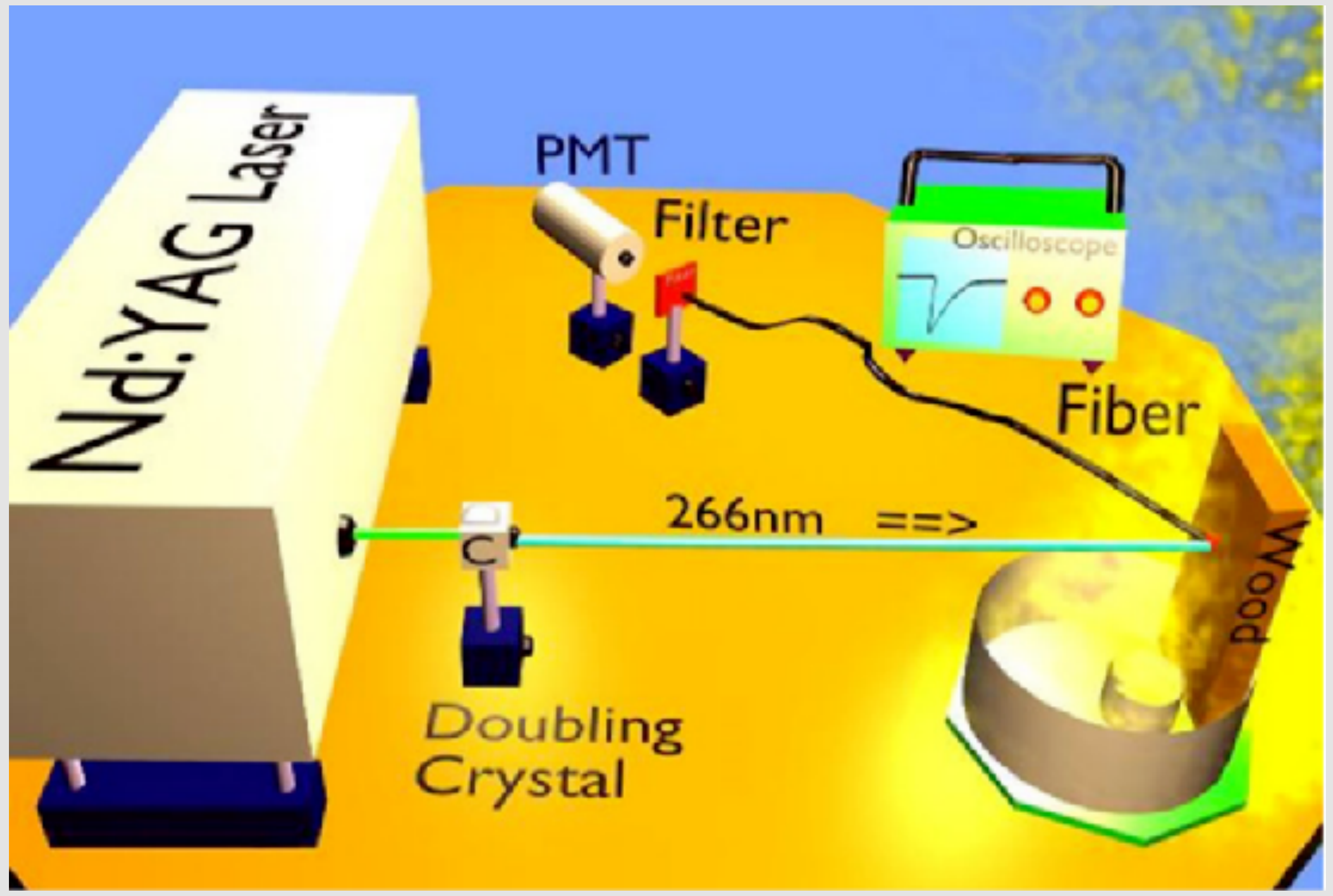

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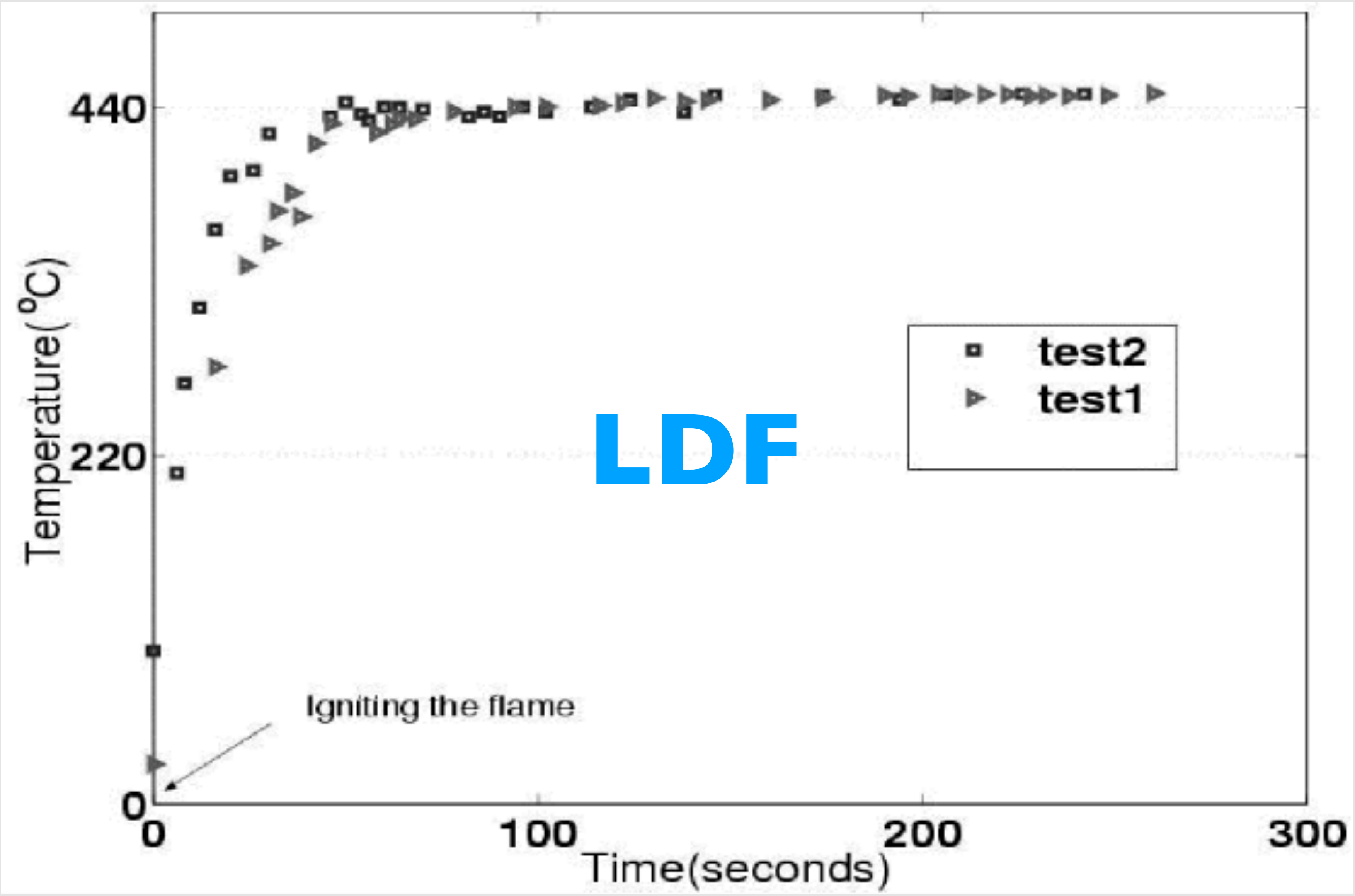

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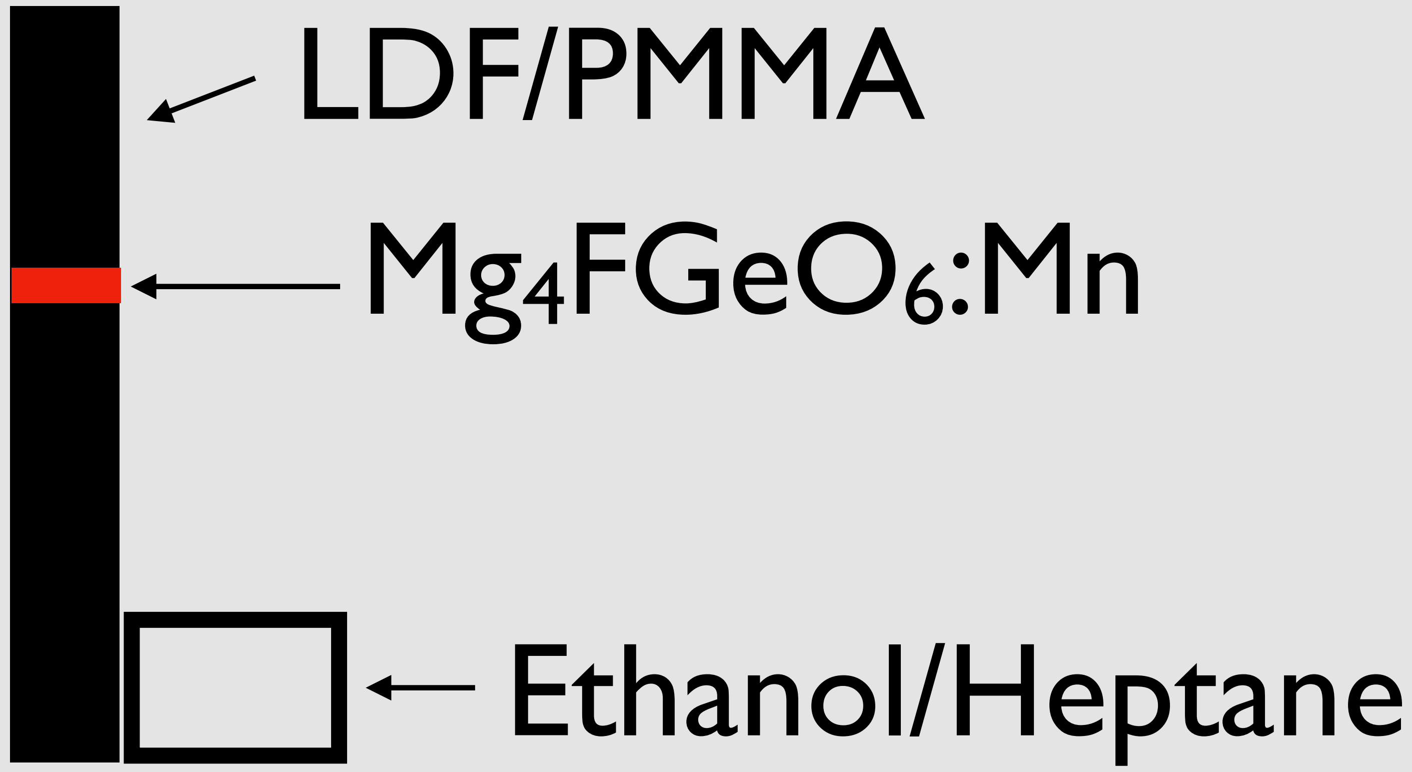
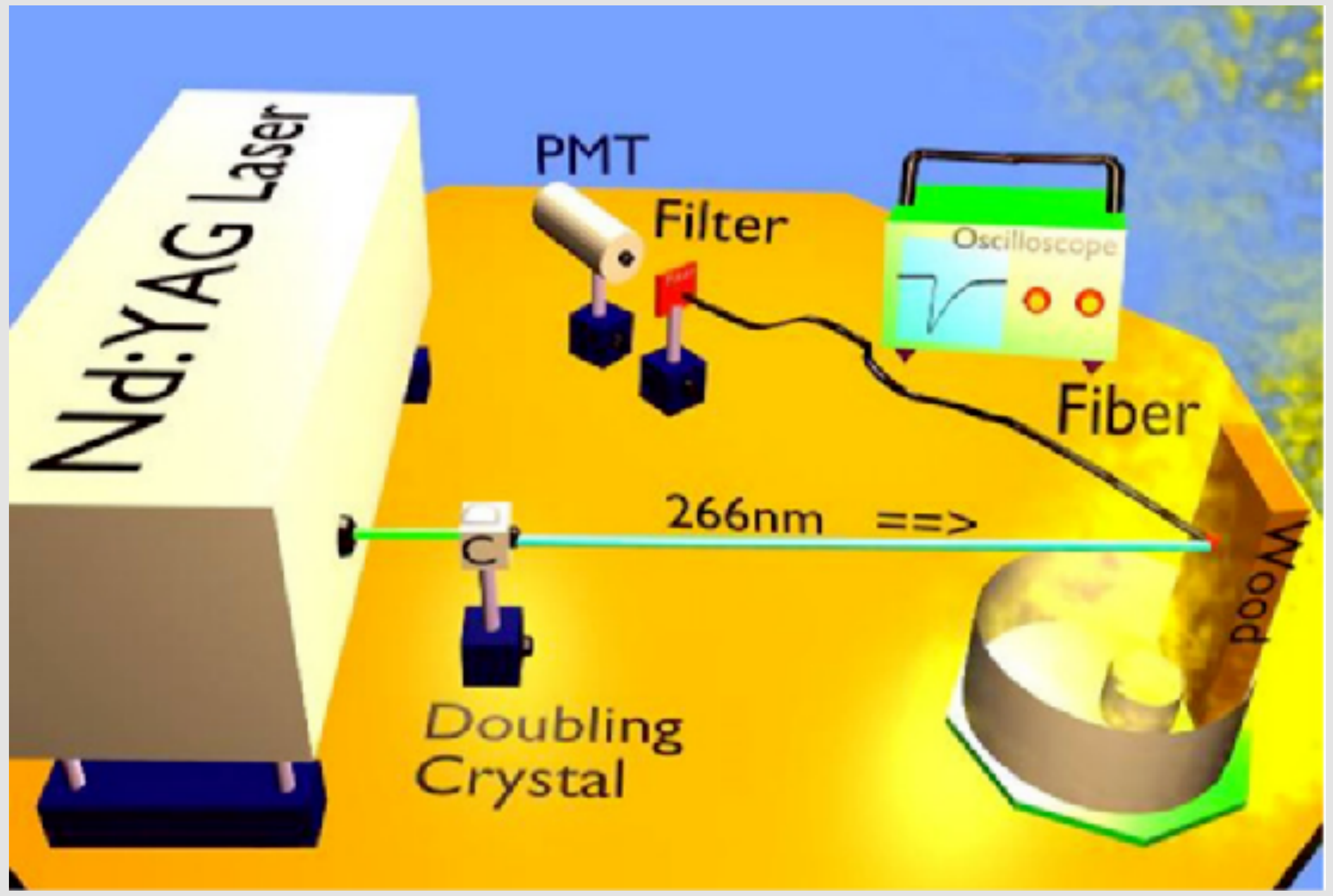
Flame Spread - 1D





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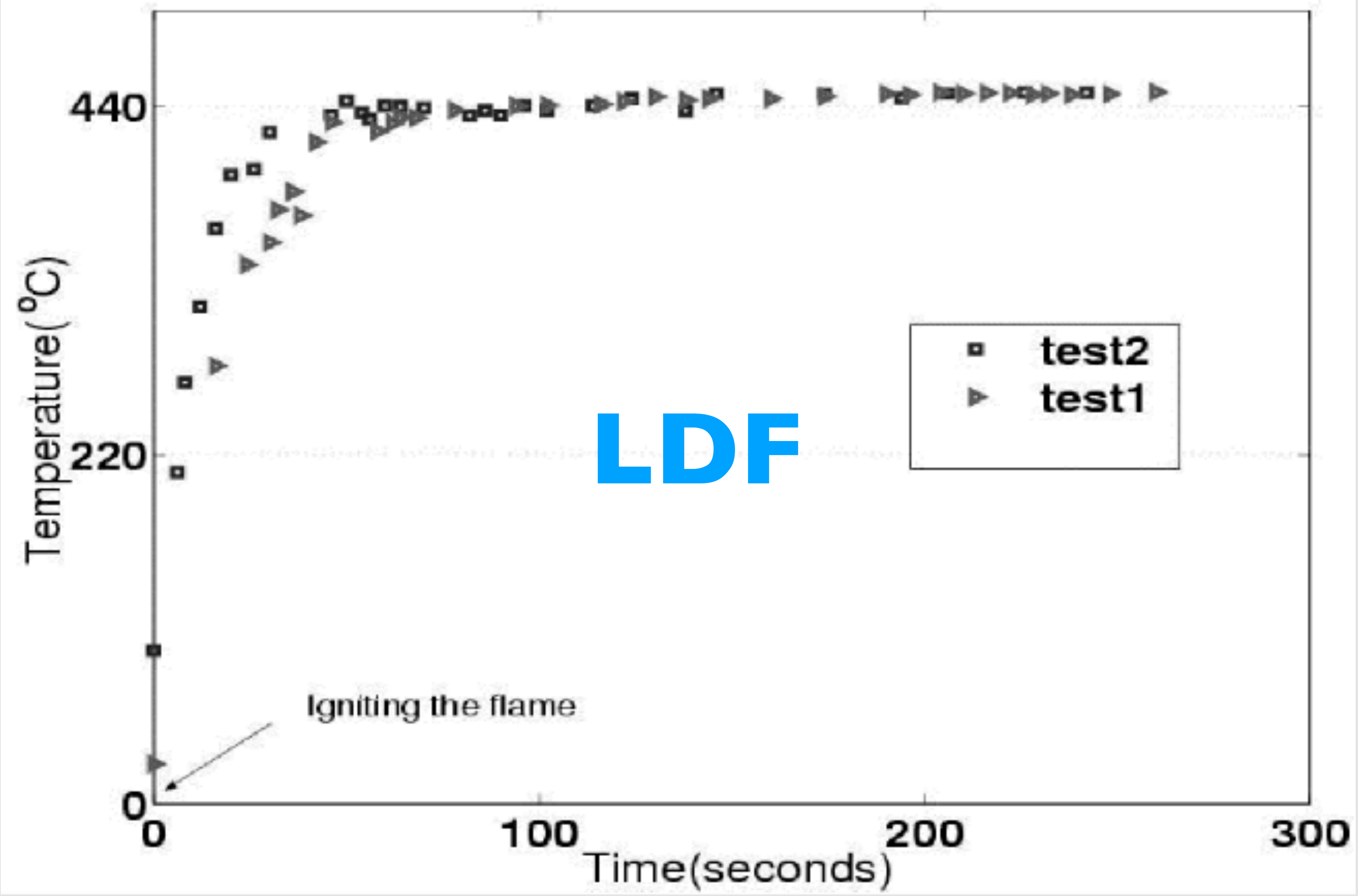
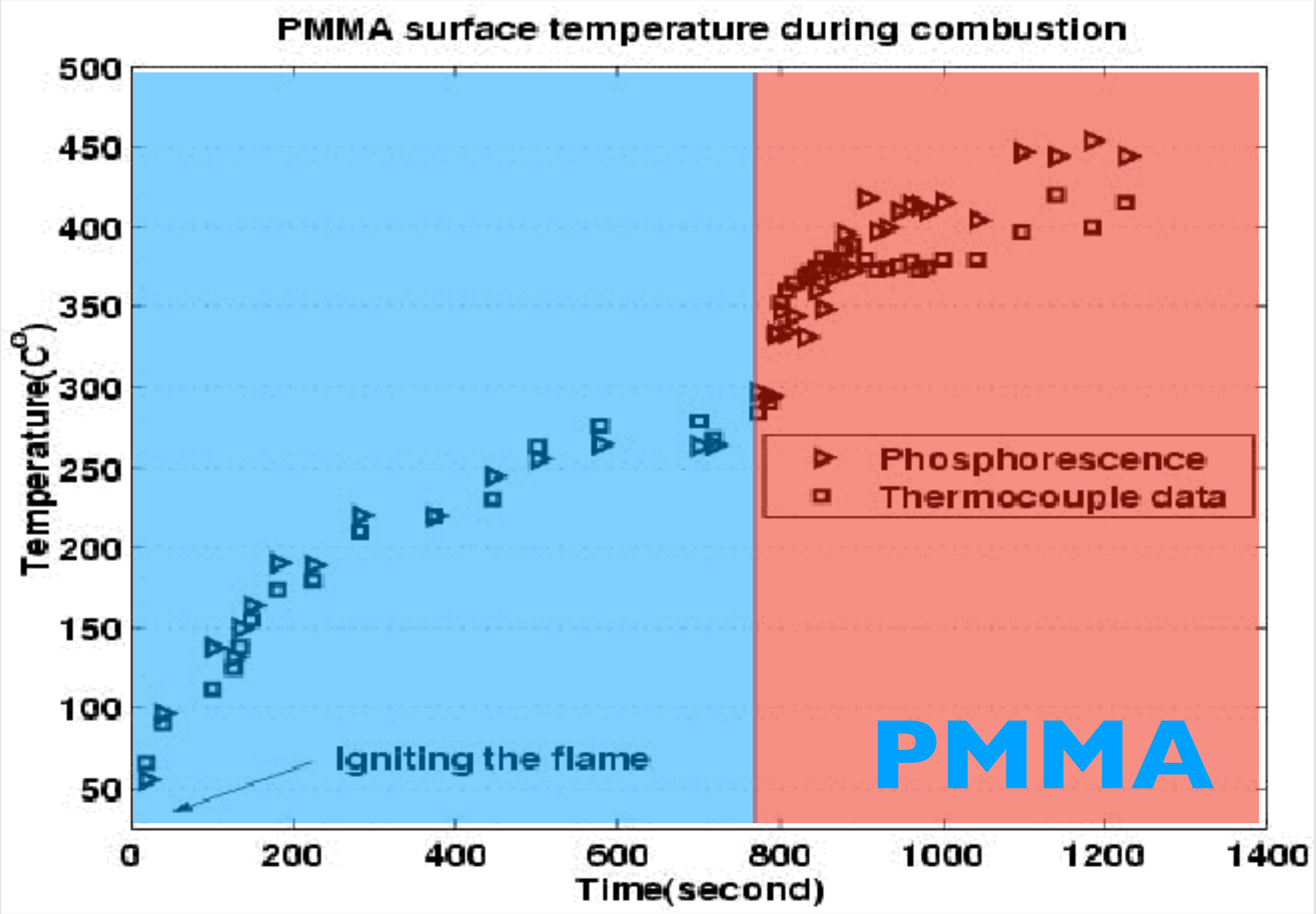
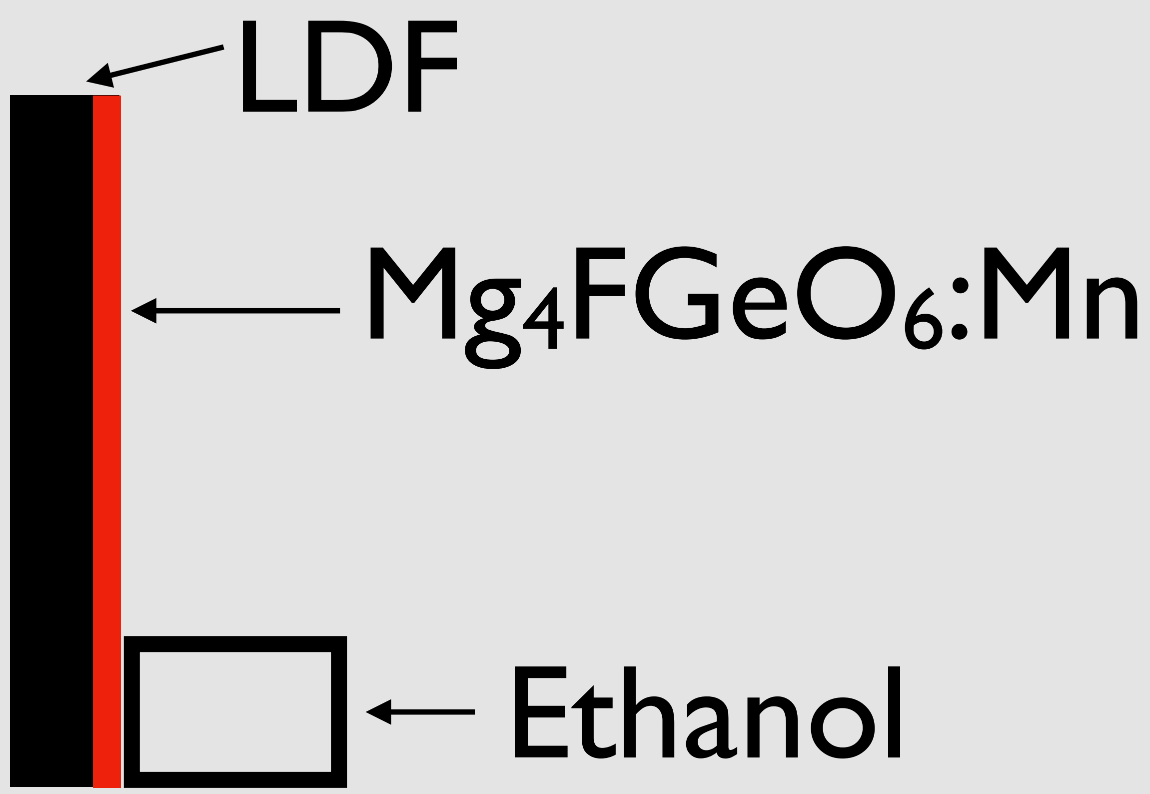
Soot issues

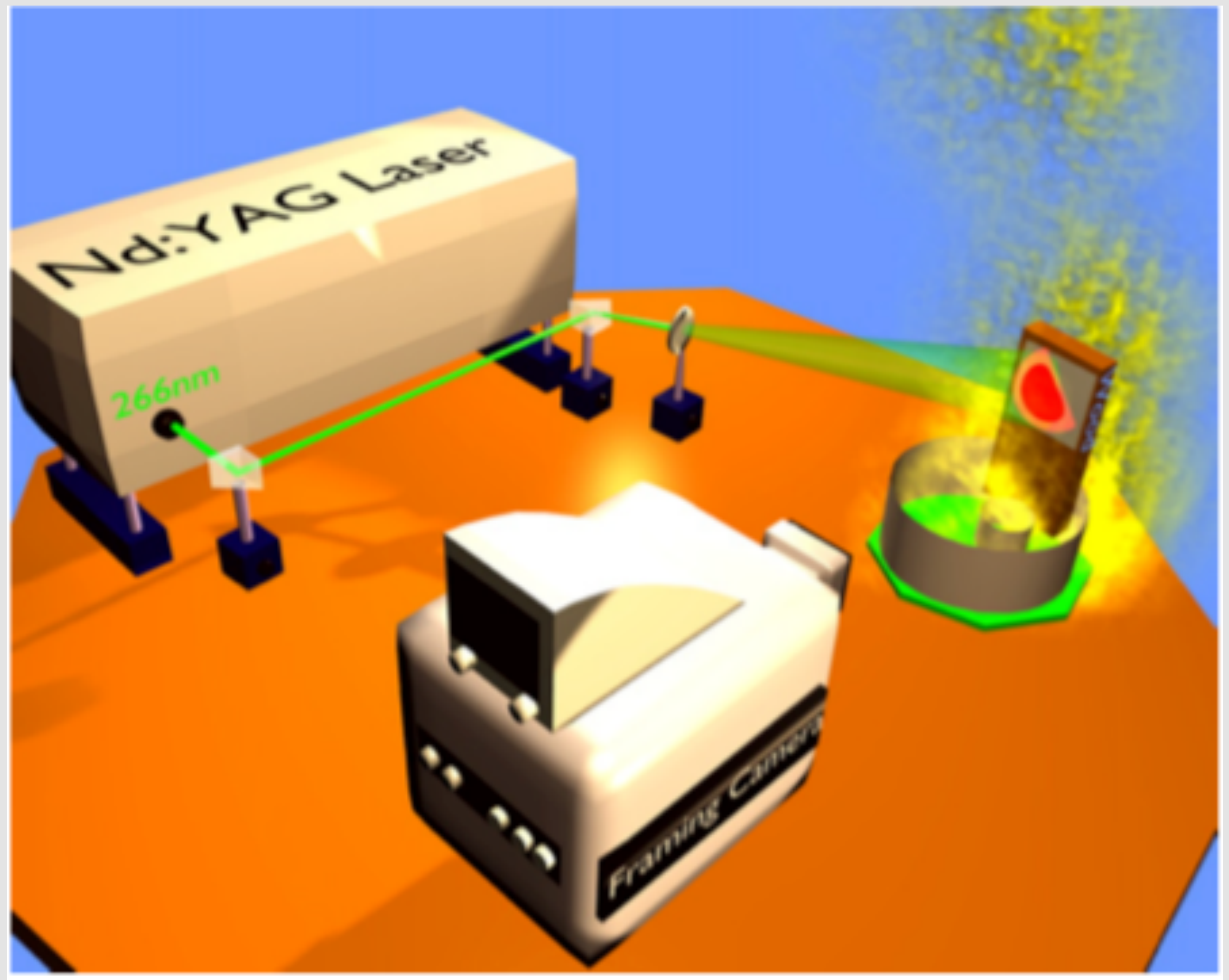




Omrane et al., Fire Saf. Sci. 7:141-152, 2003

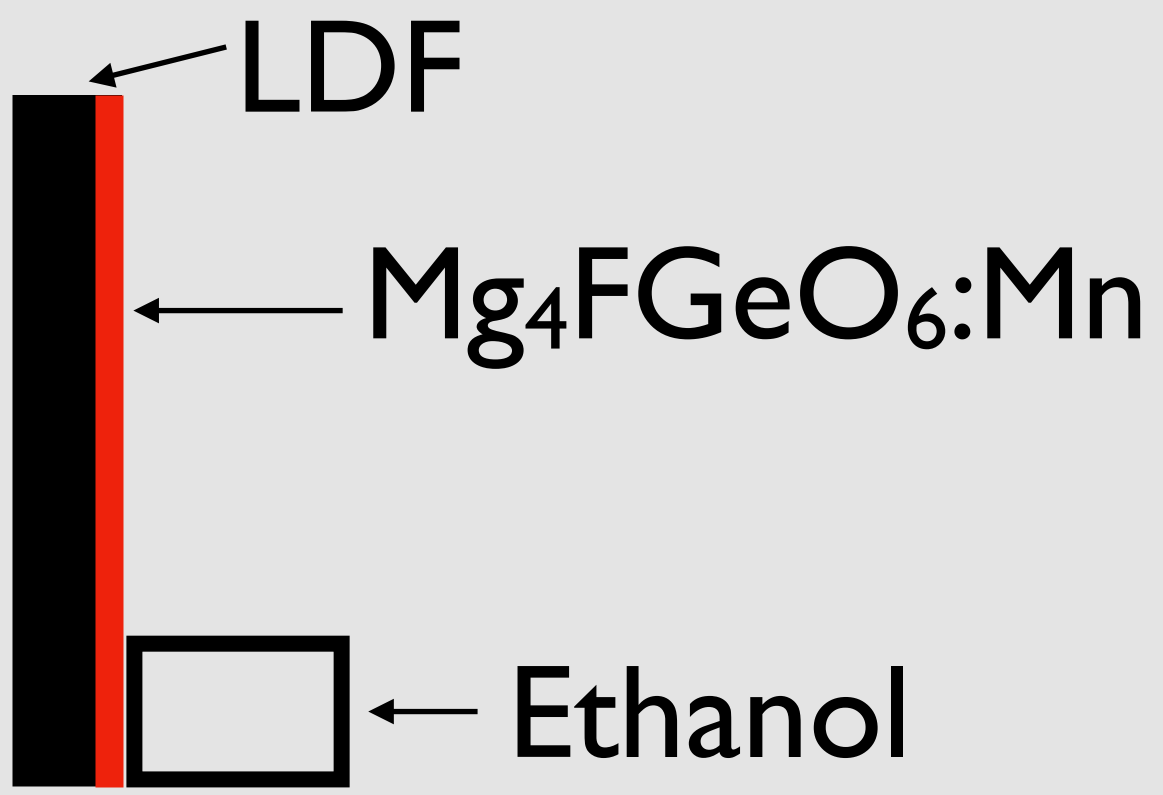
Flame Spread - 2D

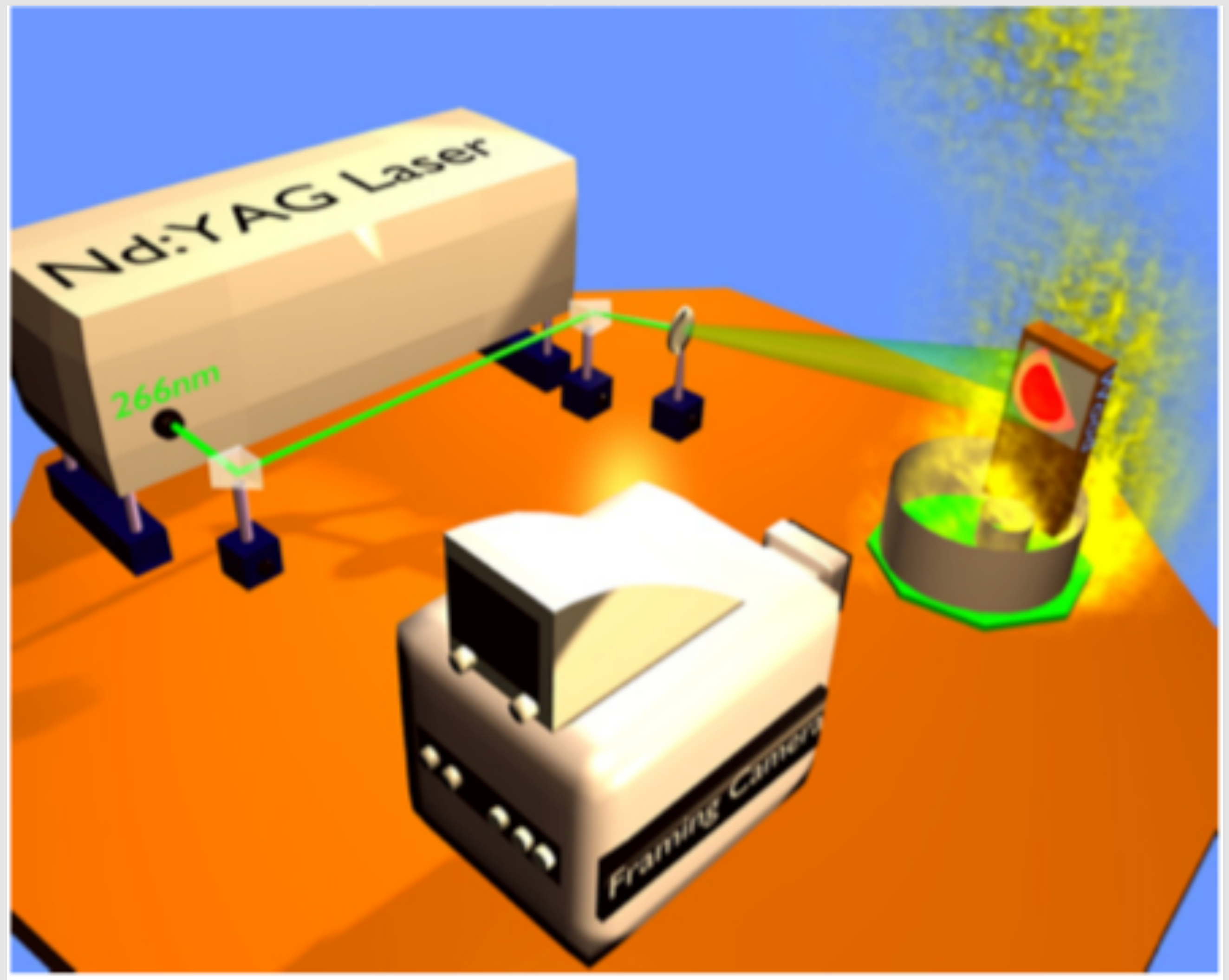


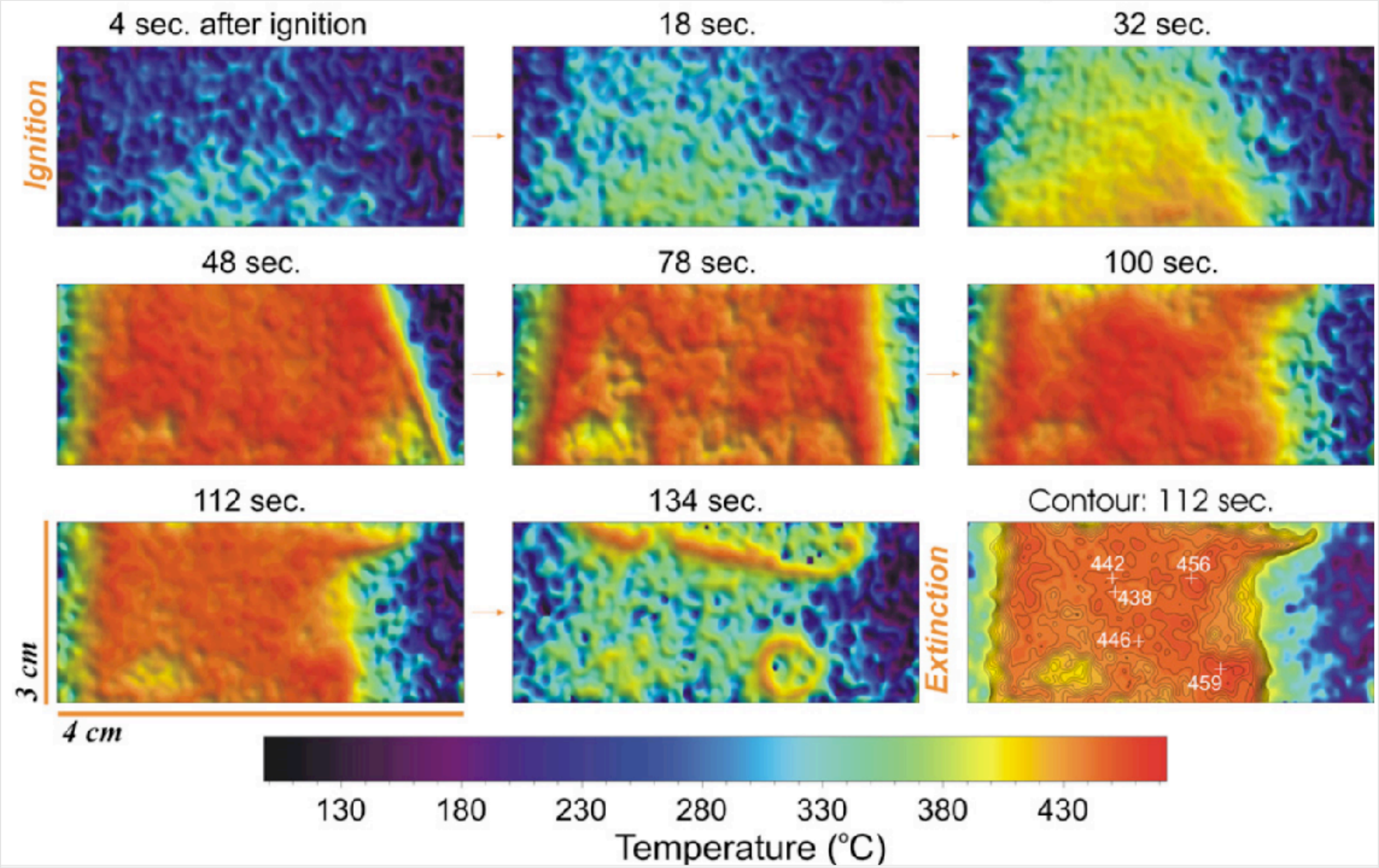


Omrane et al., Proc. Combust. Inst. 29:2653-2659, 2002

Flame Spread - 2D

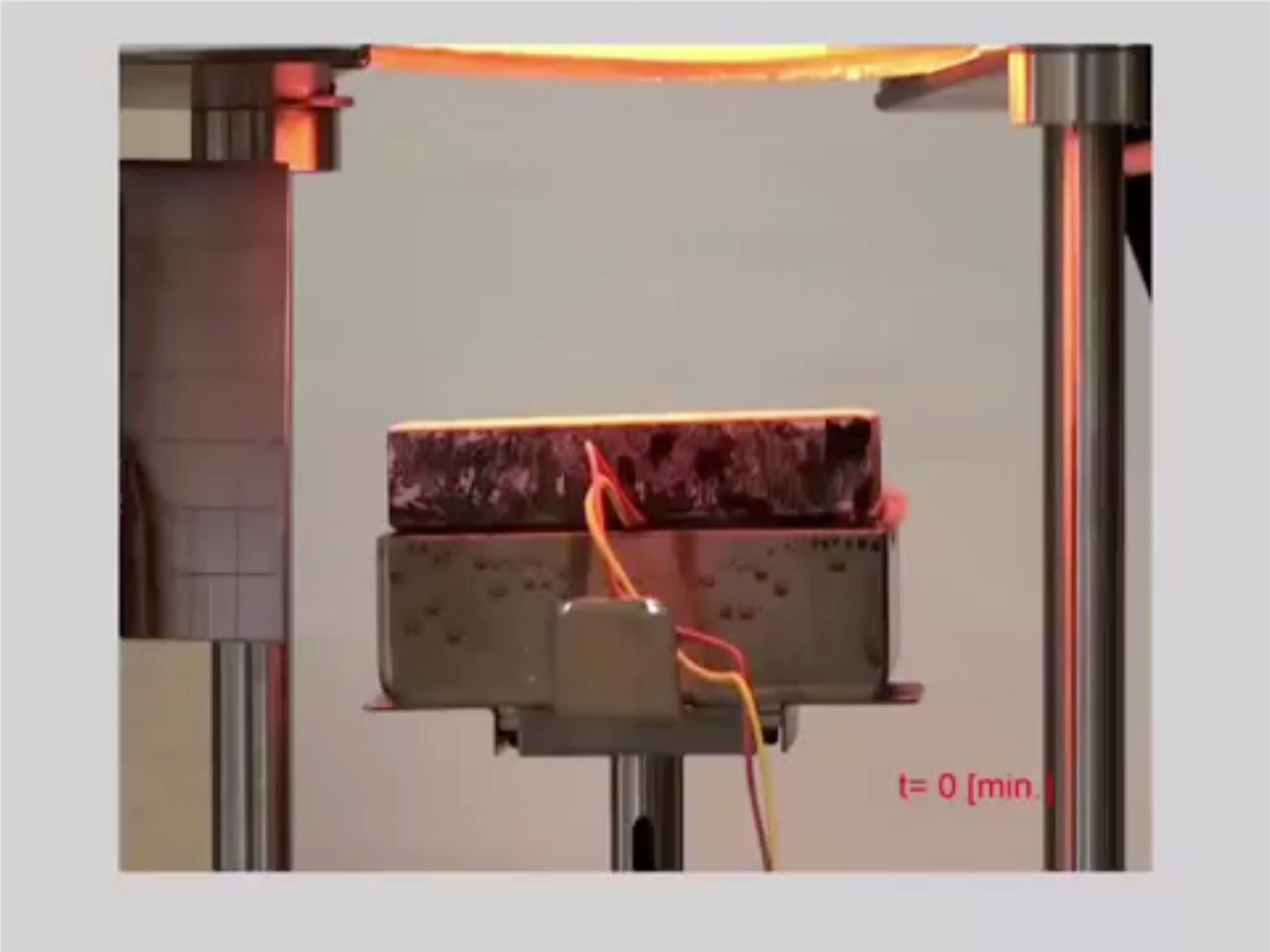


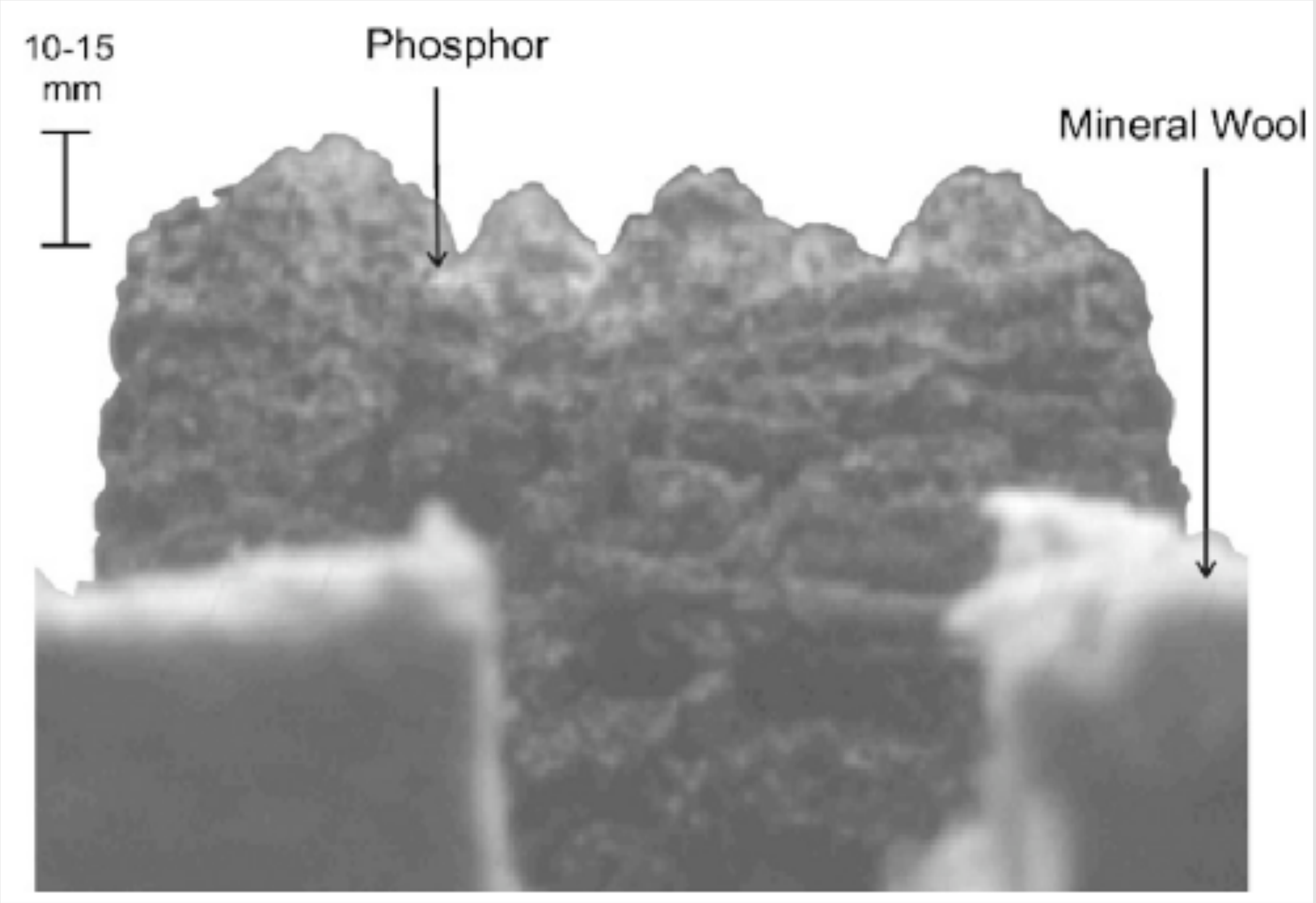




Omrane et al., Proc. Combust. Inst. 29:2653-2659, 2002

Fire Safety & Intumescent Coatings





Bartholmai et al., Fire Mater. 27:151-162, 2003
Omrane et al., Fire Safe. J. 42:68-74, 2007

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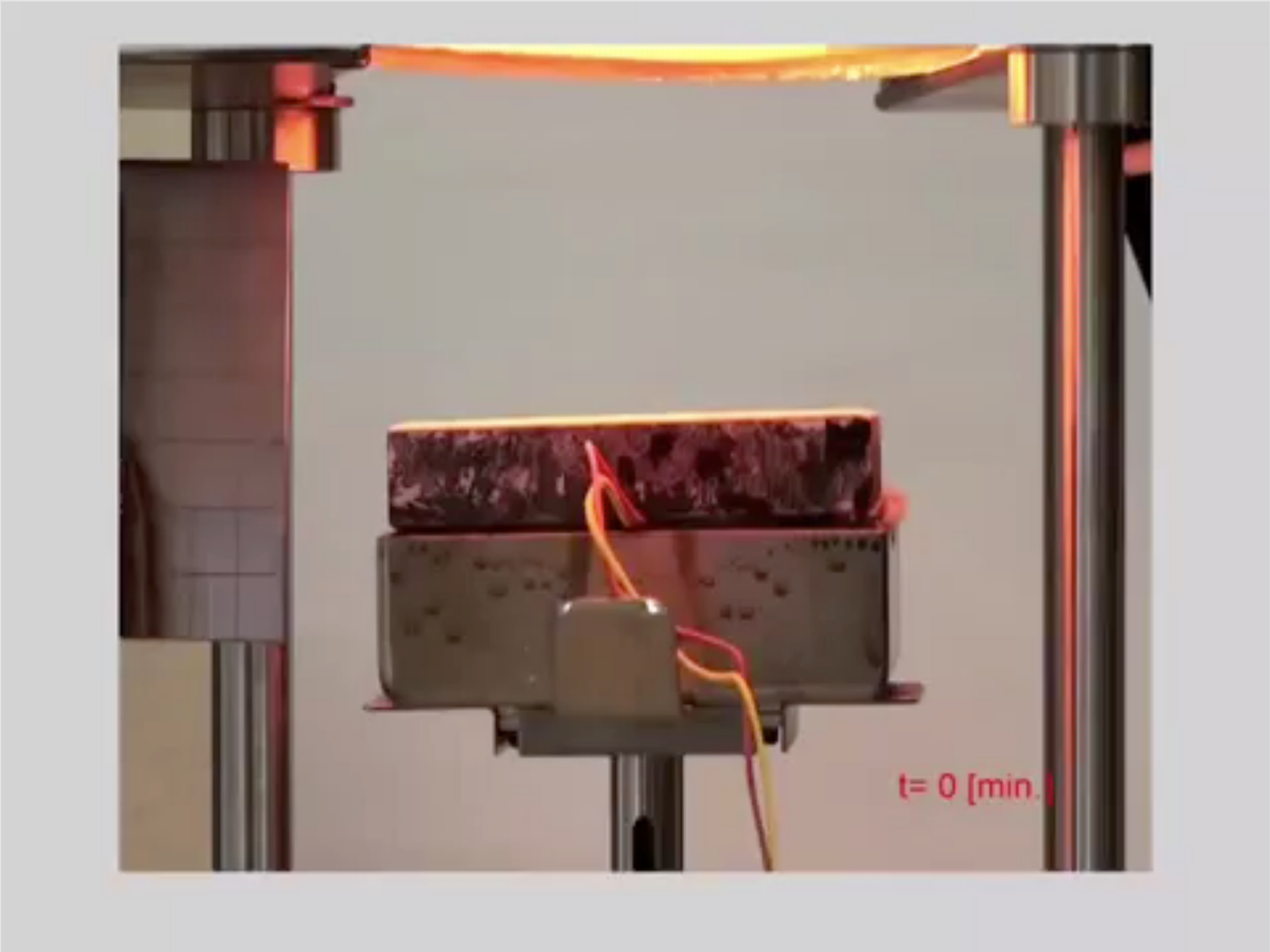

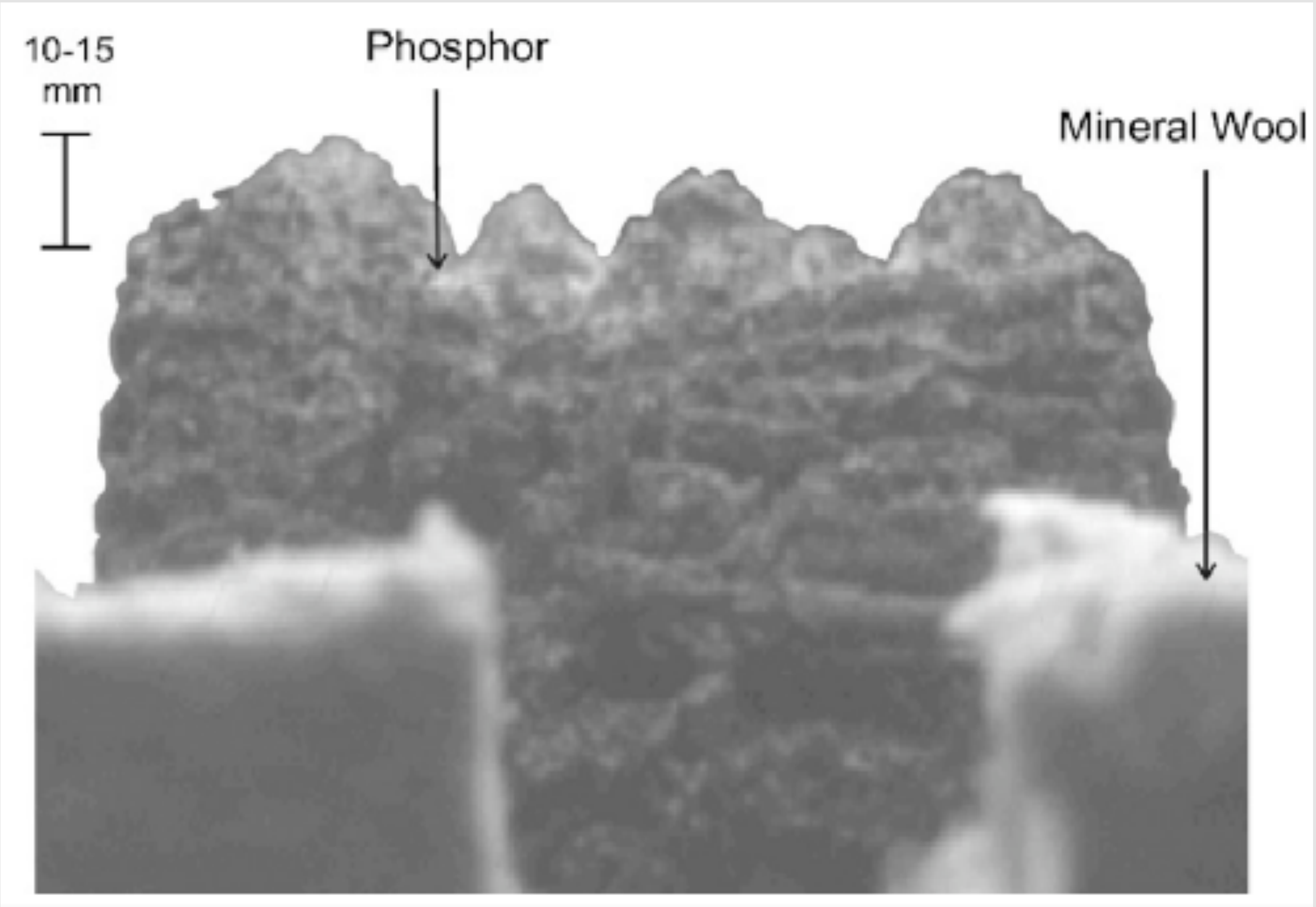

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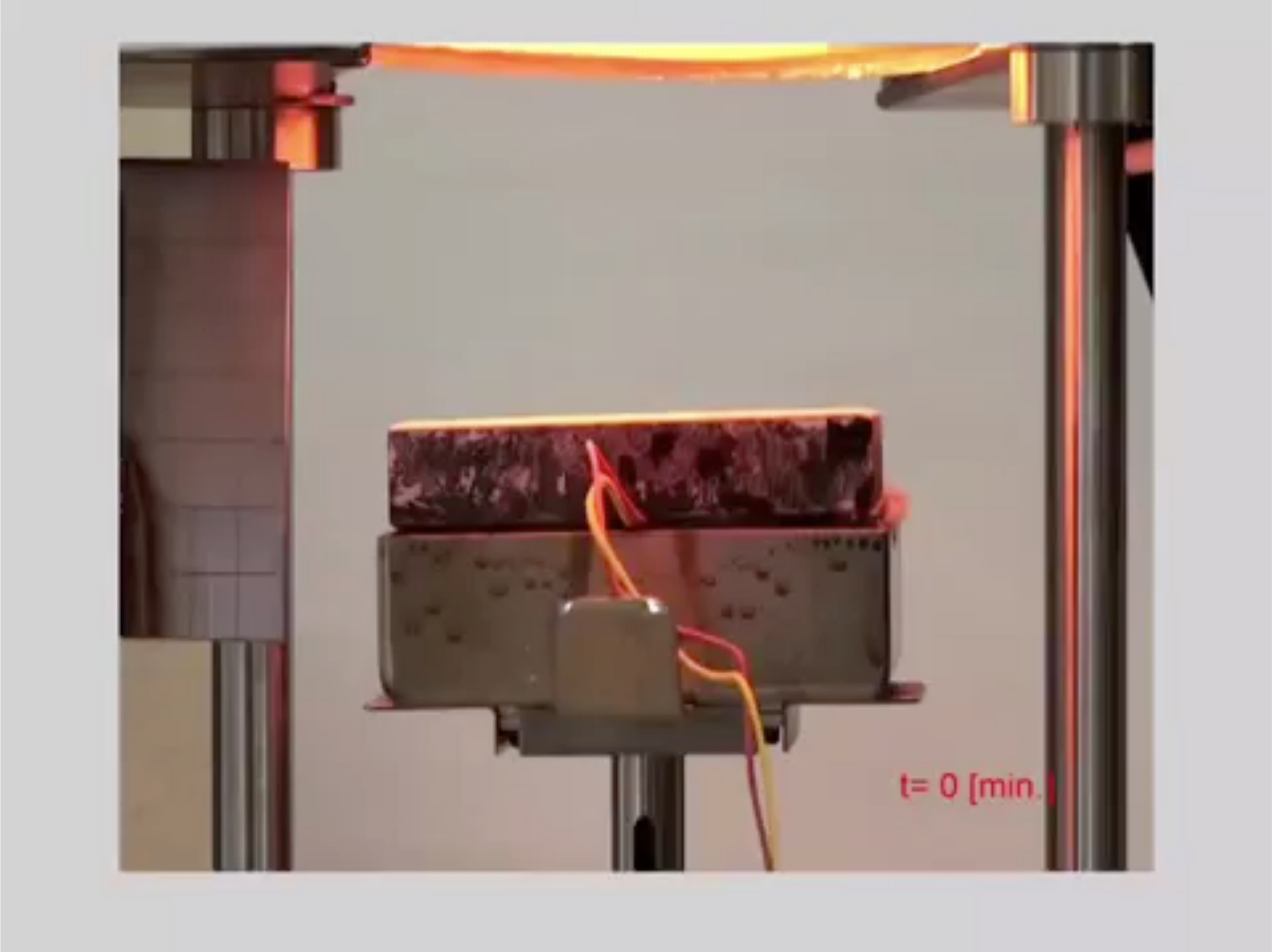
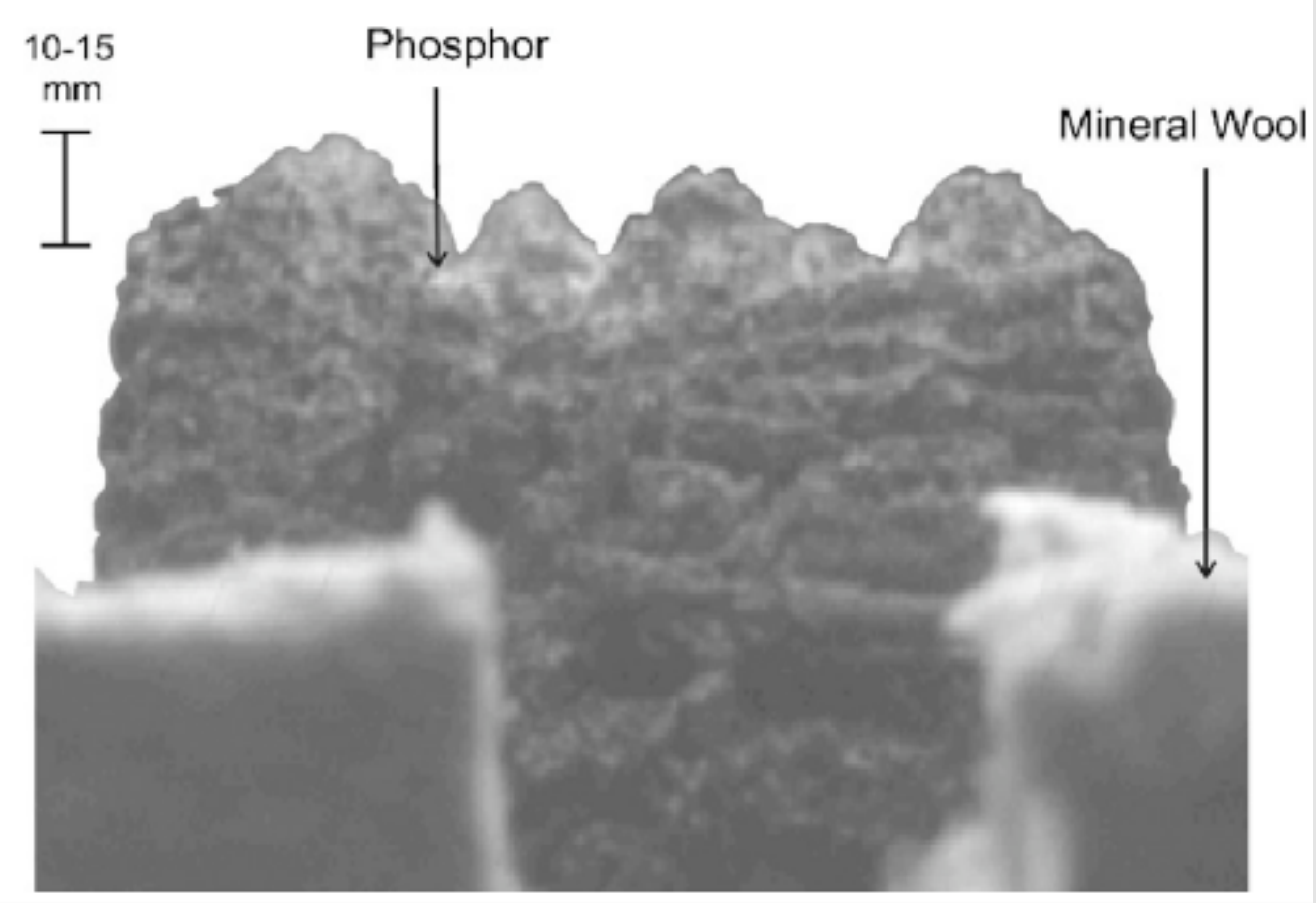
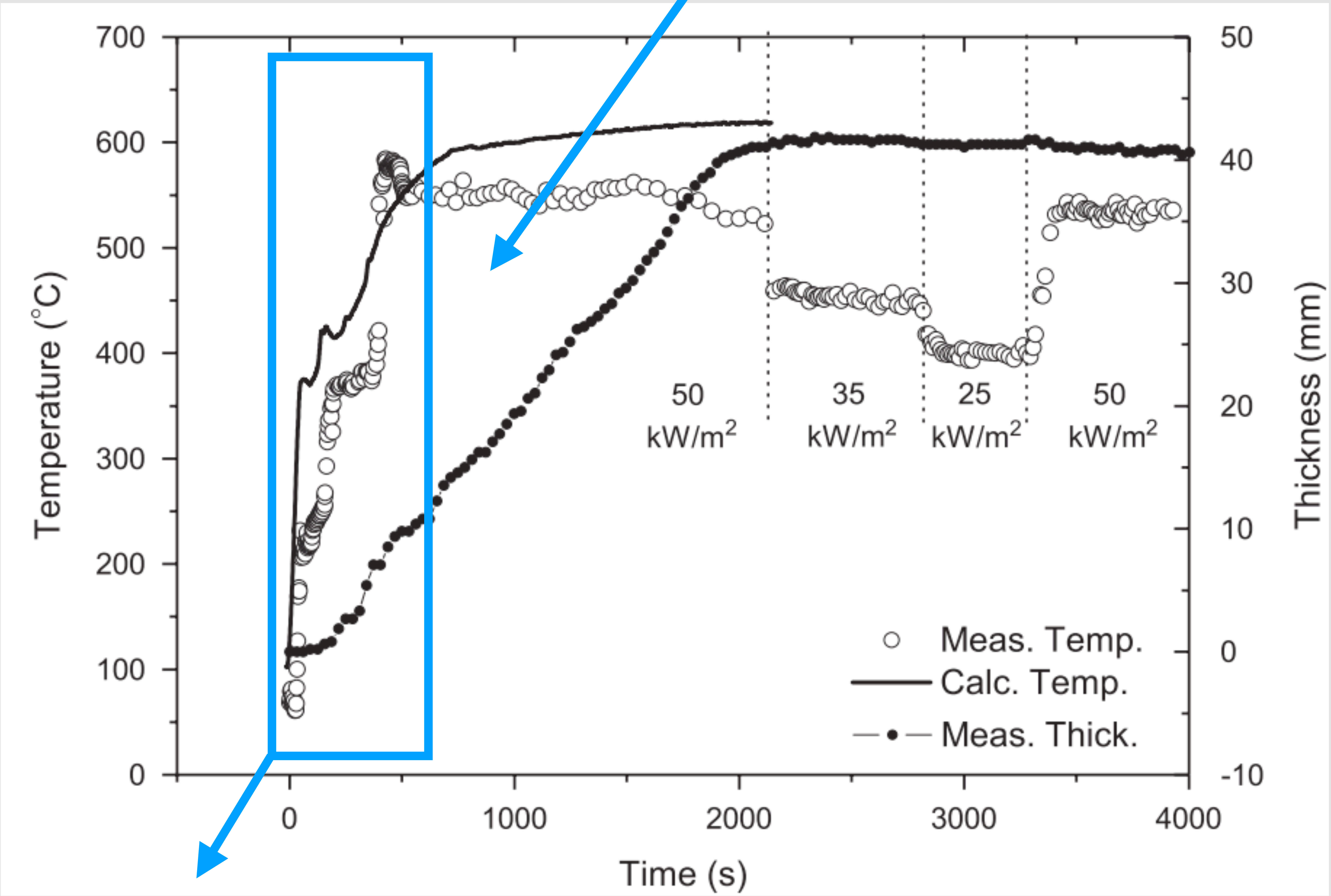




Expansion rate vs. temperature



Theory does not account for endothermic reactions

Bartholmai et al., Fire Mater. 27:151-162, 2003
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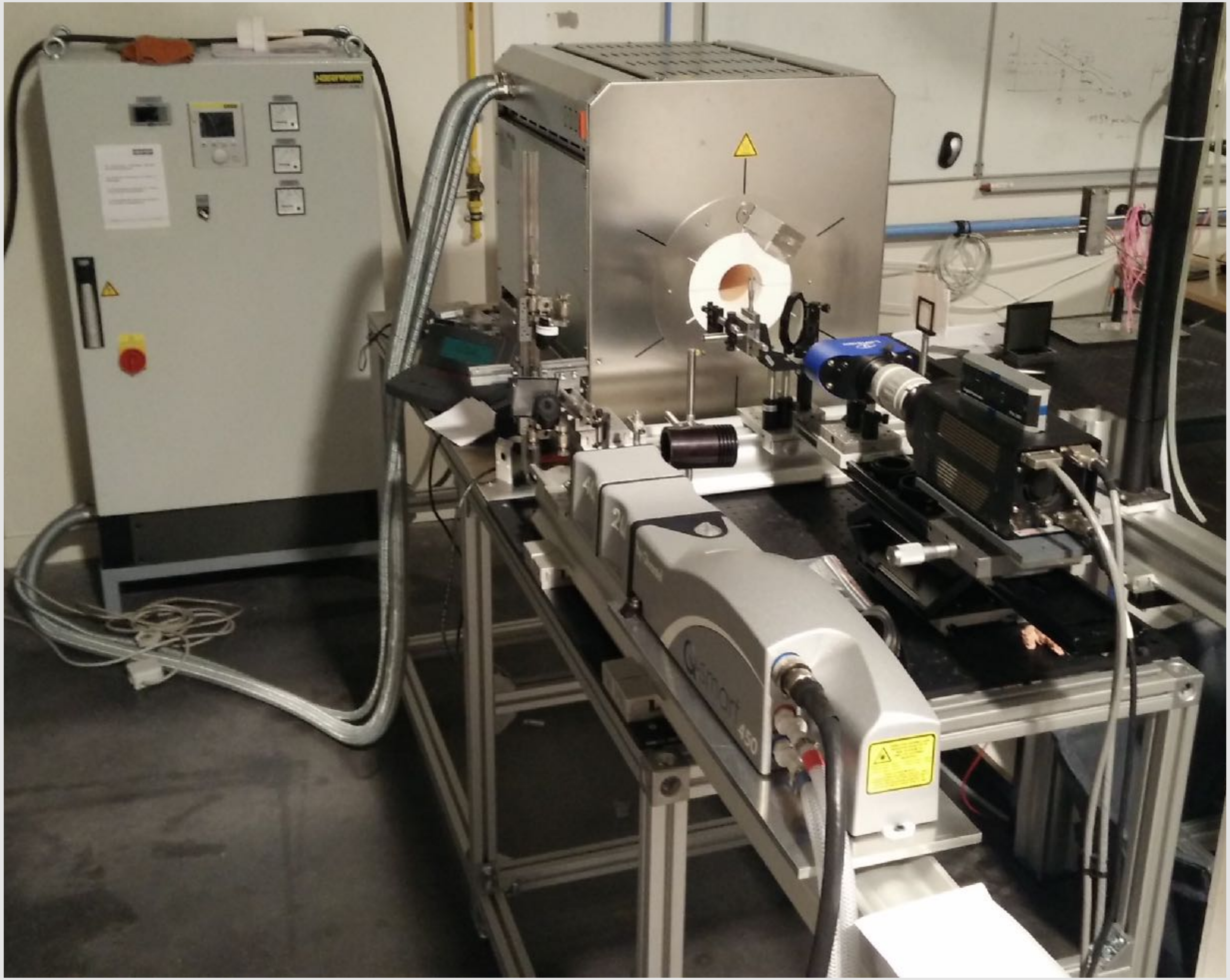
Project ??



Acknowledgments

Prof. Frédéric GRISCH
Prof. Alexis COPPALLE
Dr. Benoît BARVIAU
Dr. Christopher BETRANCOURT
Sylvain PETIT

Dr. Thierry POINSOT
Dr. Laurent SELLE
Sébastien CAZIN
Moïse MARCHAL

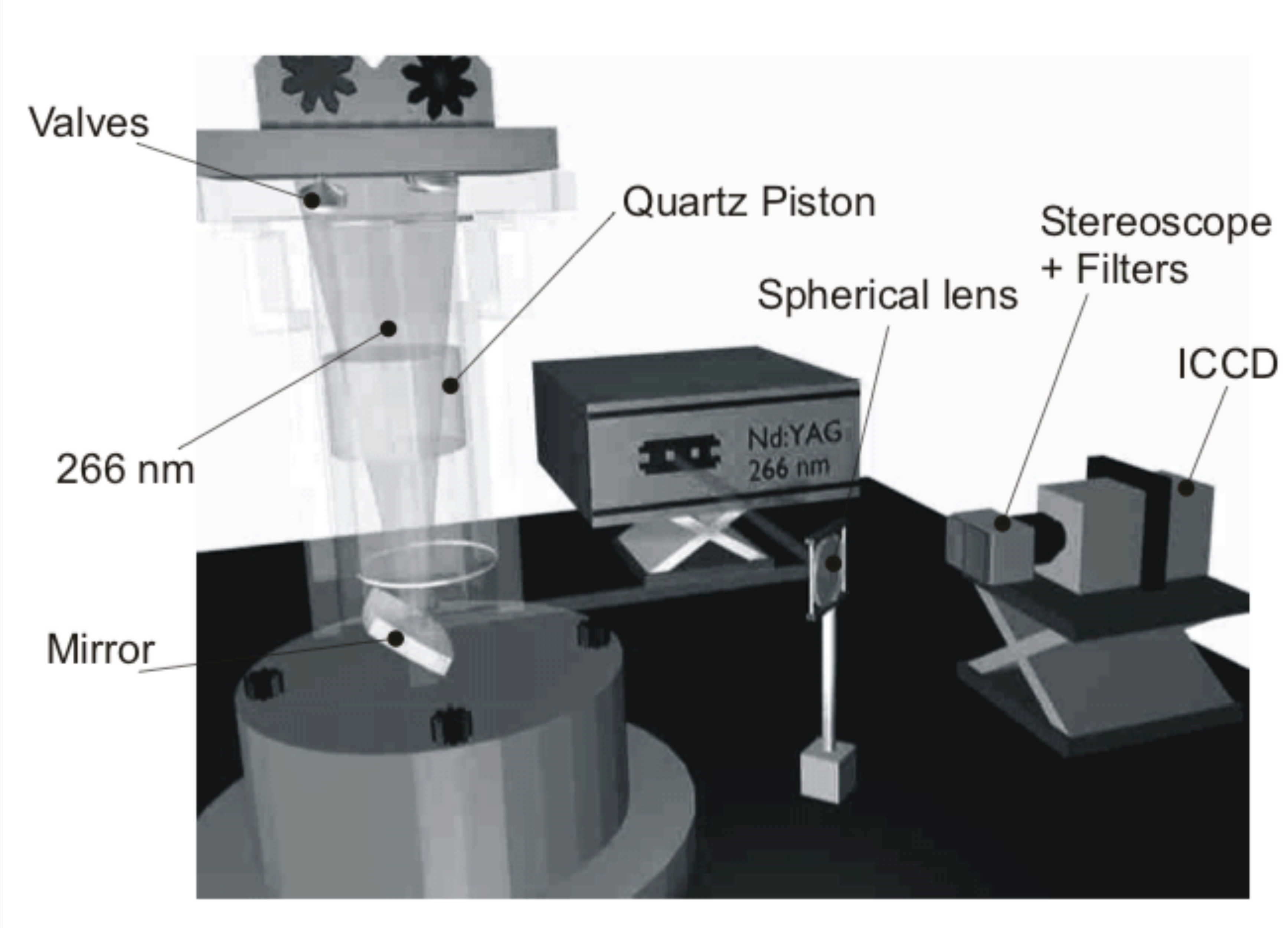
Dr. Benoît FOND
Prof. Frank BEYRAU

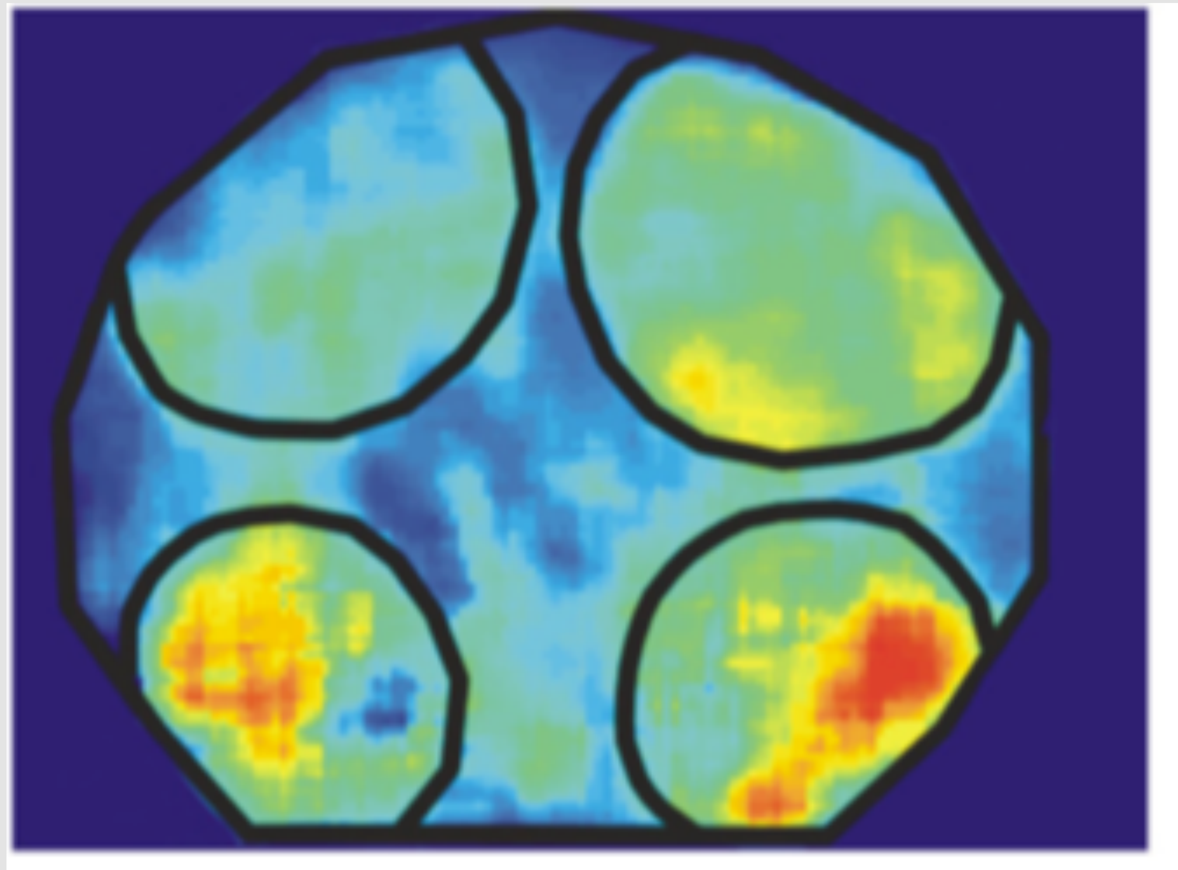
PRECIPUT 2018

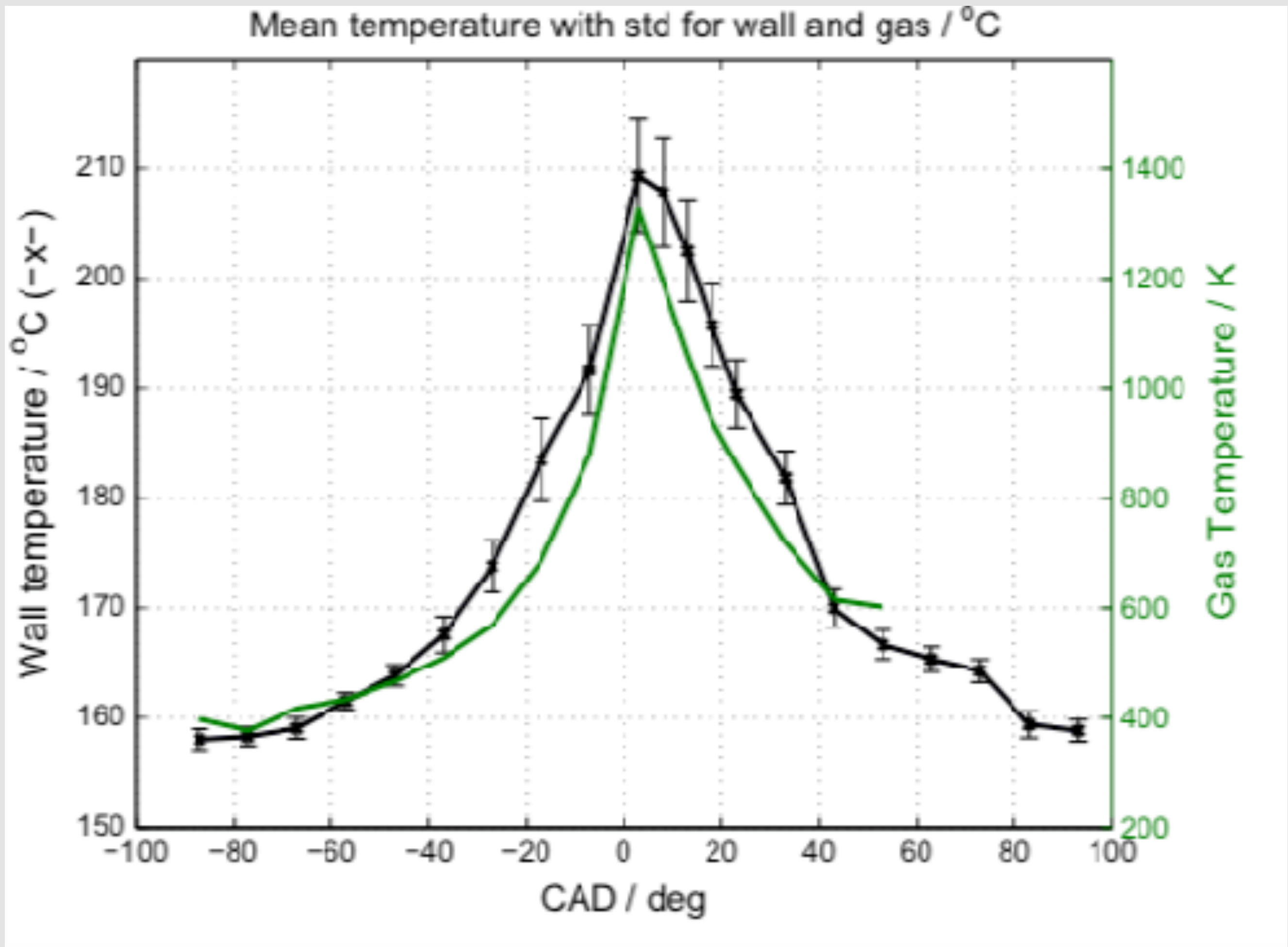
Chaire Industrielle PERCEVAL

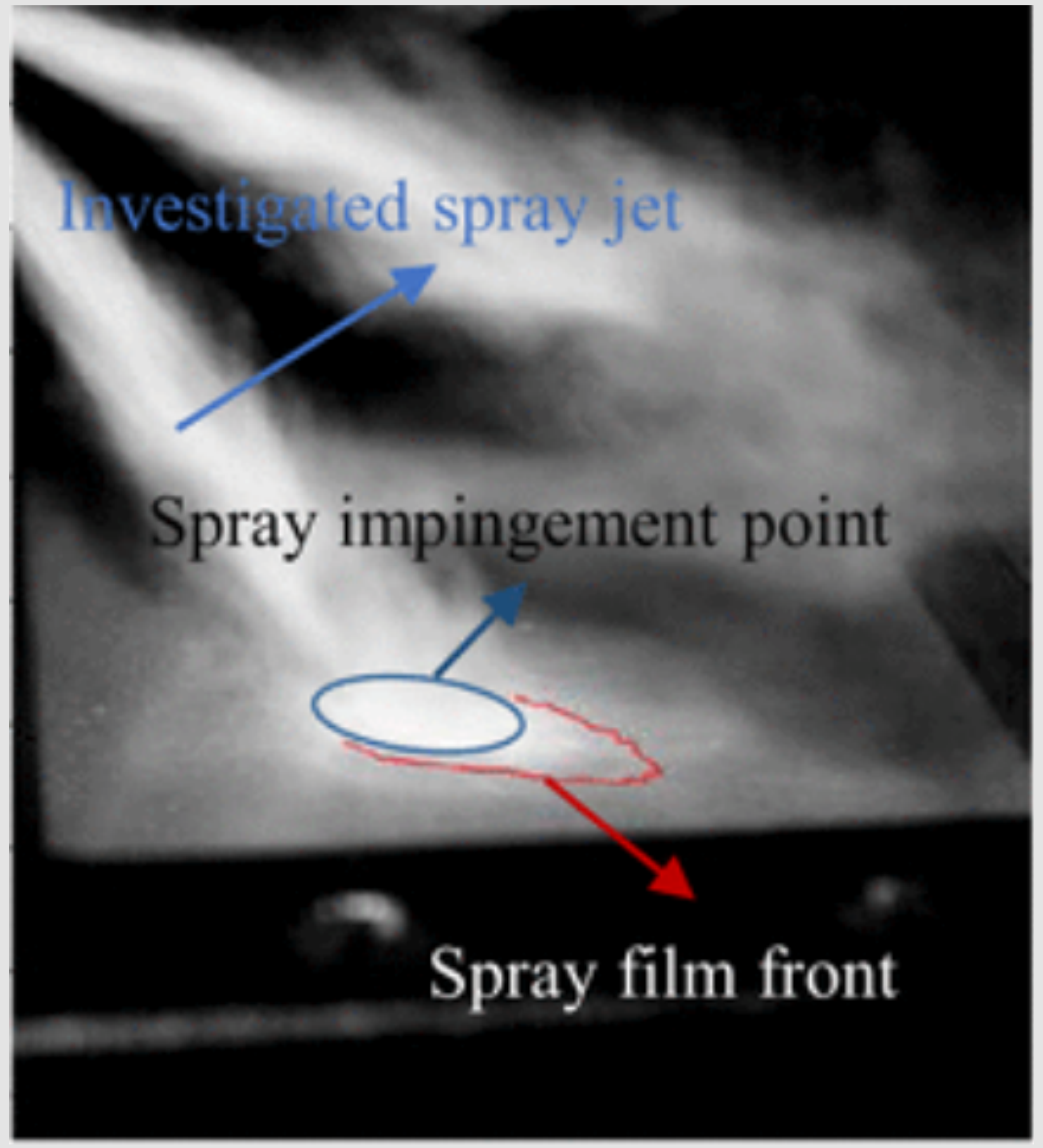
Projet PERCEVAL 2

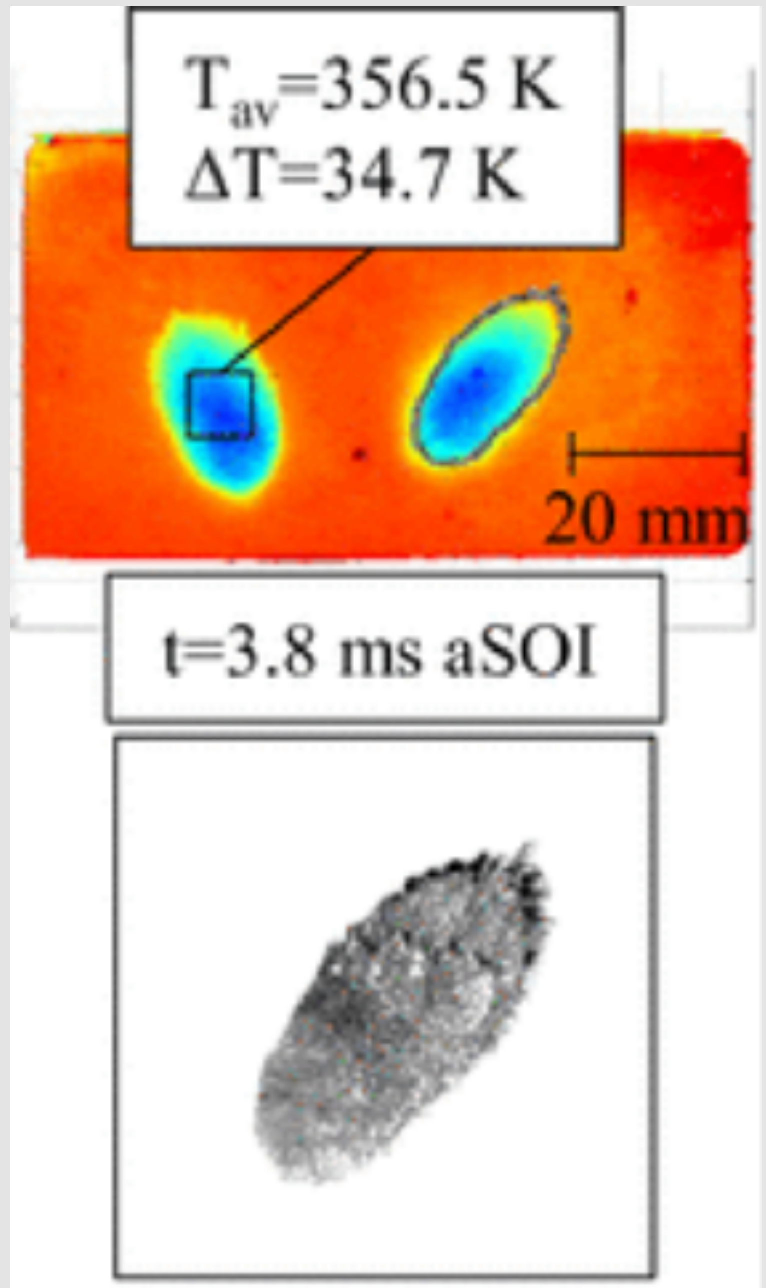
Many applications: Internal Combustion Engines





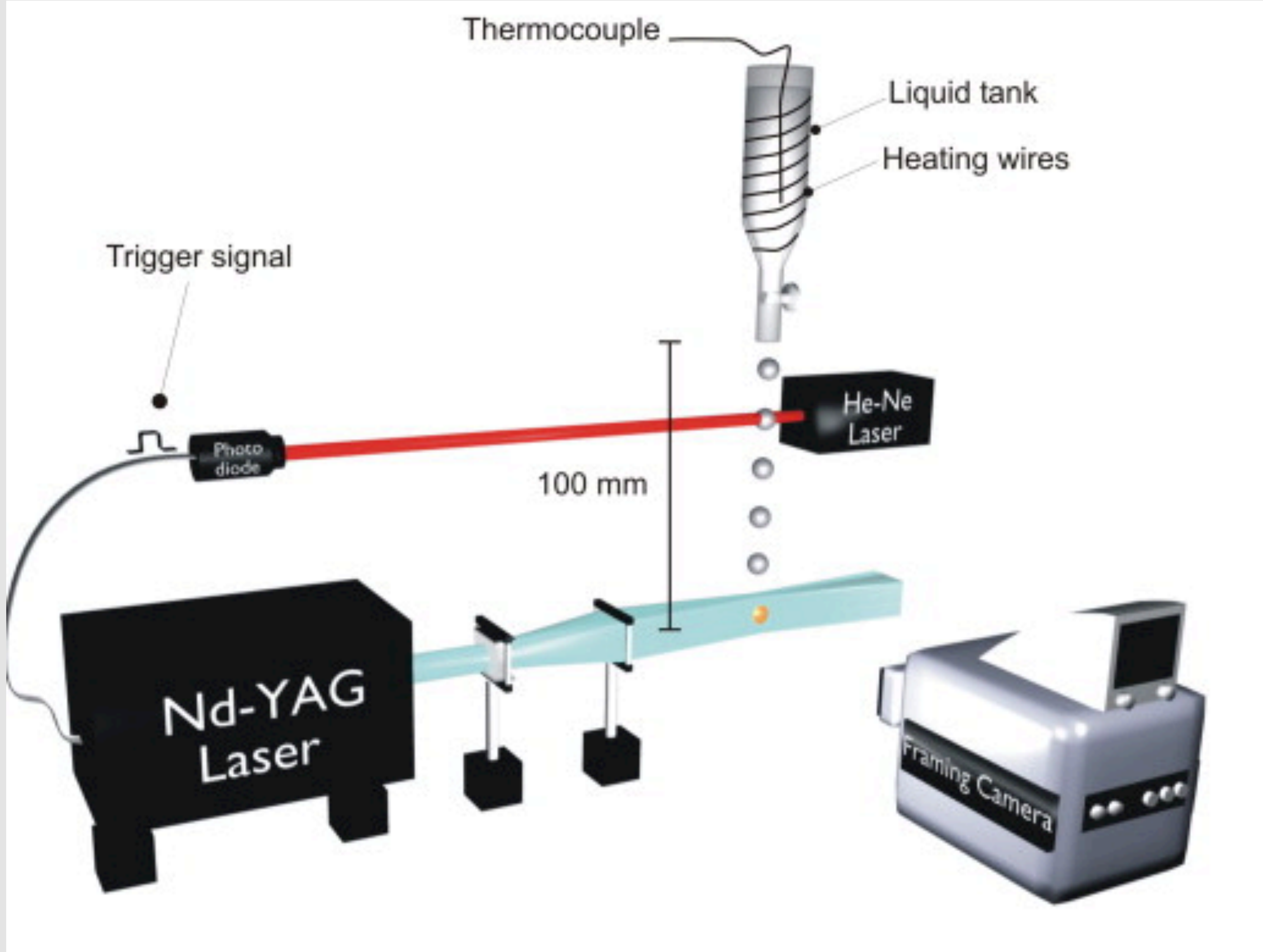


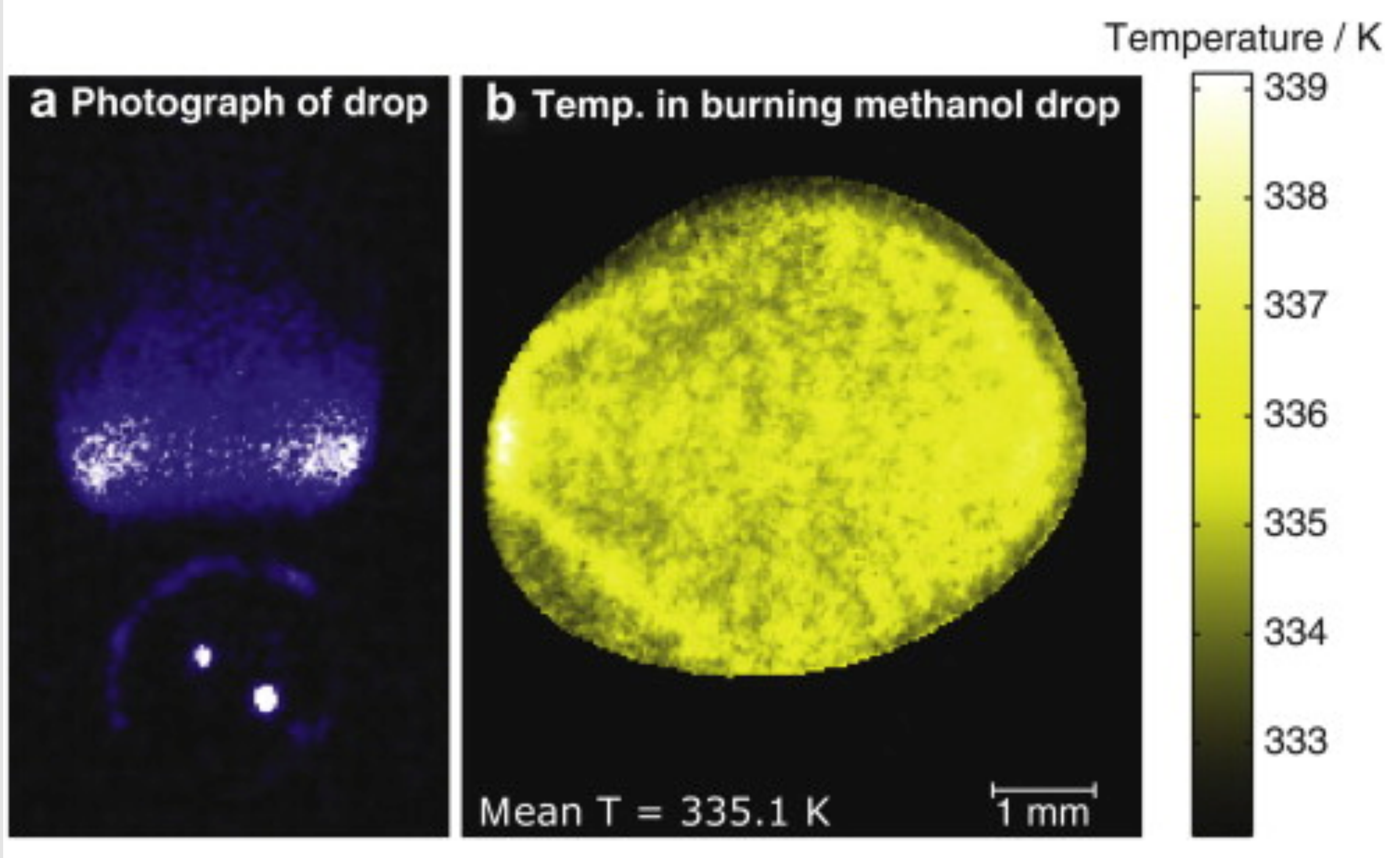


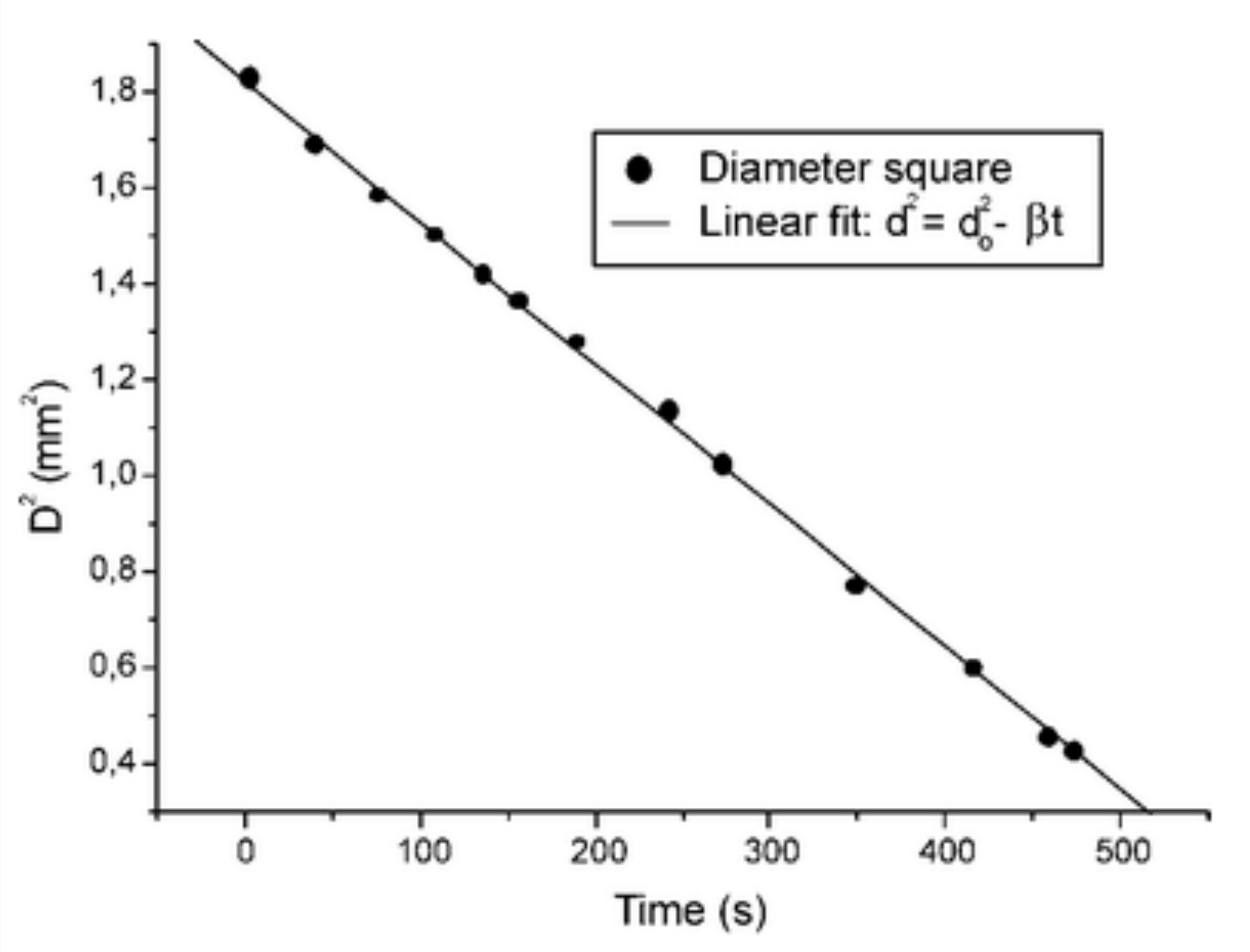


Omrane et al., SAE Tech. 01-0609, 2004
Fuhrmann et al., Appl. Phys. B 106:945-951, 2012
Dragomirov et al., Exp. Fluids 59:42, 2018

Many applications: Two-Phase Flows







Omrane et al., Appl. Opt. 43:3523-3, 2004
Omrane et al., Lab Chip 4:287-291, 2004
Särner et al., Opt. Lett. 33:1327-9, 2008