

INFLUENCE OF WALL TEMPERATURE ON COMBUSTION INSTABILITIES

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Daniel MEJIA
IMFT
dmejia@imft.fr

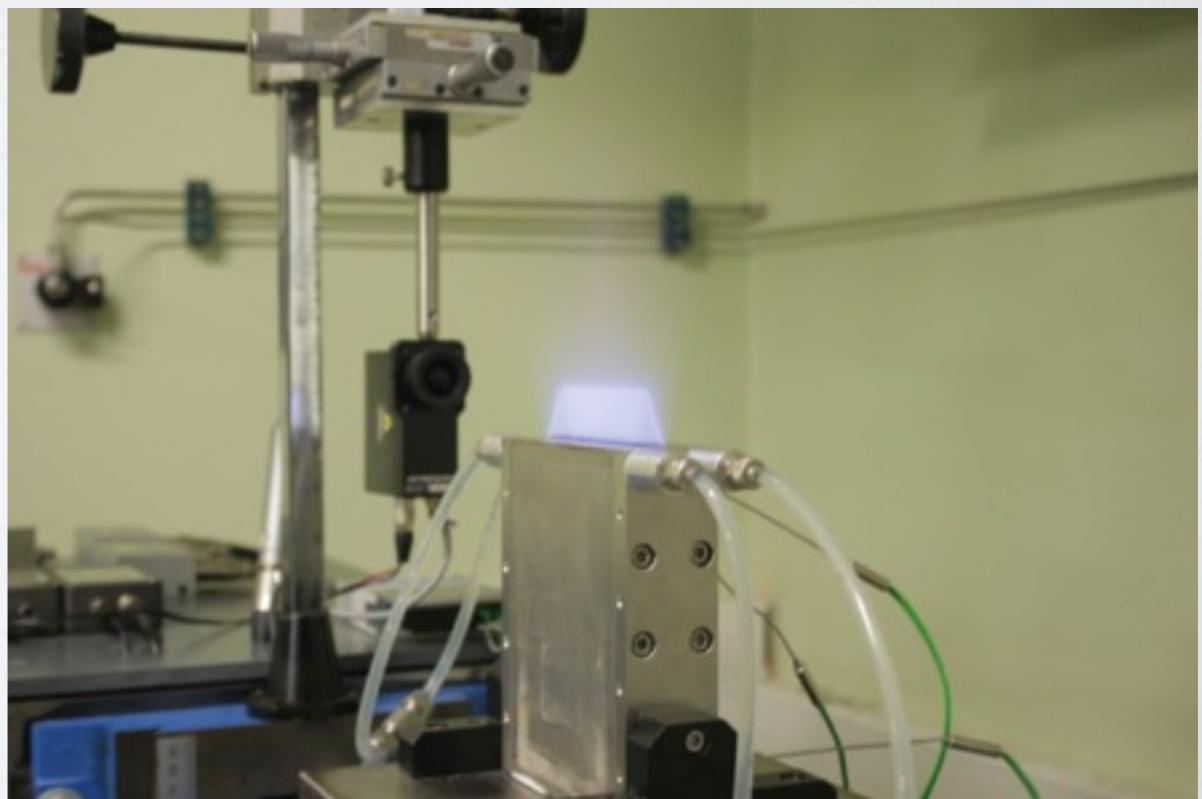


Advisers:

R. BAZILE, L. SELLE, B. FERRET and T. POINSOT.

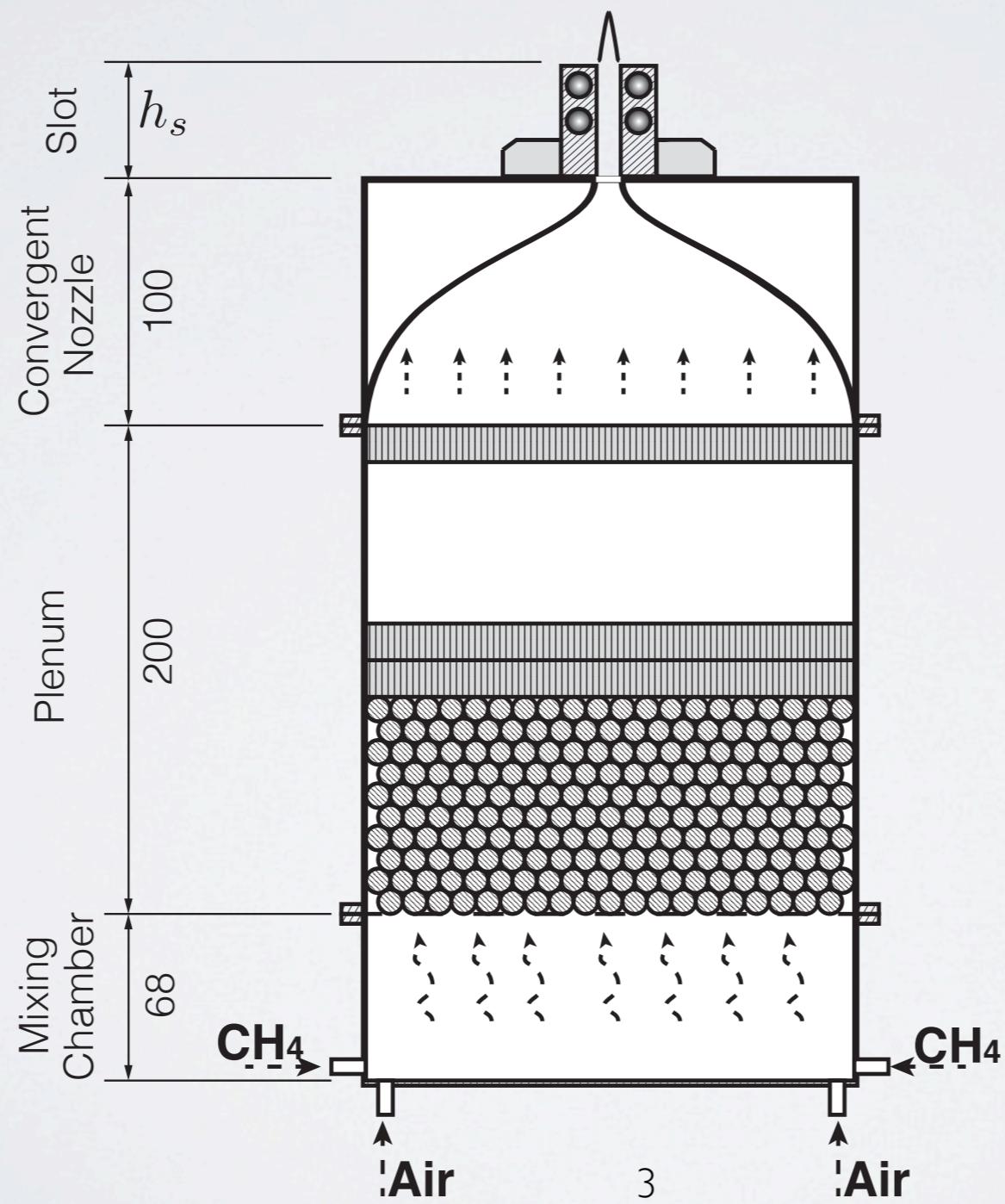
WHAT DO WE STUDY ?

- ❖ Experimental combustion,
- ❖ gaseous fuel,
- ❖ premixed laminar flame,
- ❖ 2D slot burner; wedged flame
- ❖ thermo-acoustic instabilities,
- ❖ impact of wall-temperatures interaction on flame dynamics



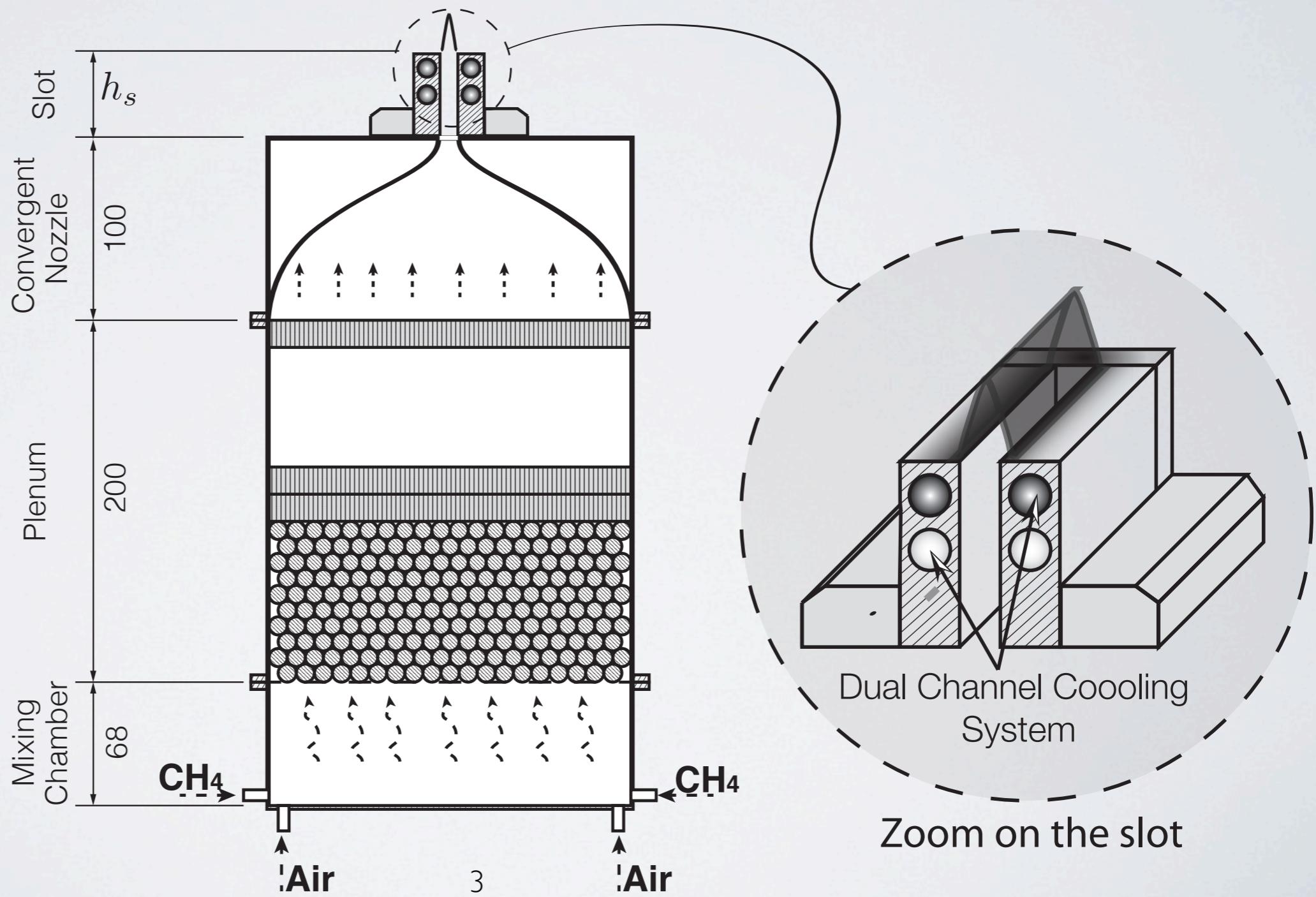
EXPERIMENTAL SET-UP

Bunsen burner, Helmholtz resonator



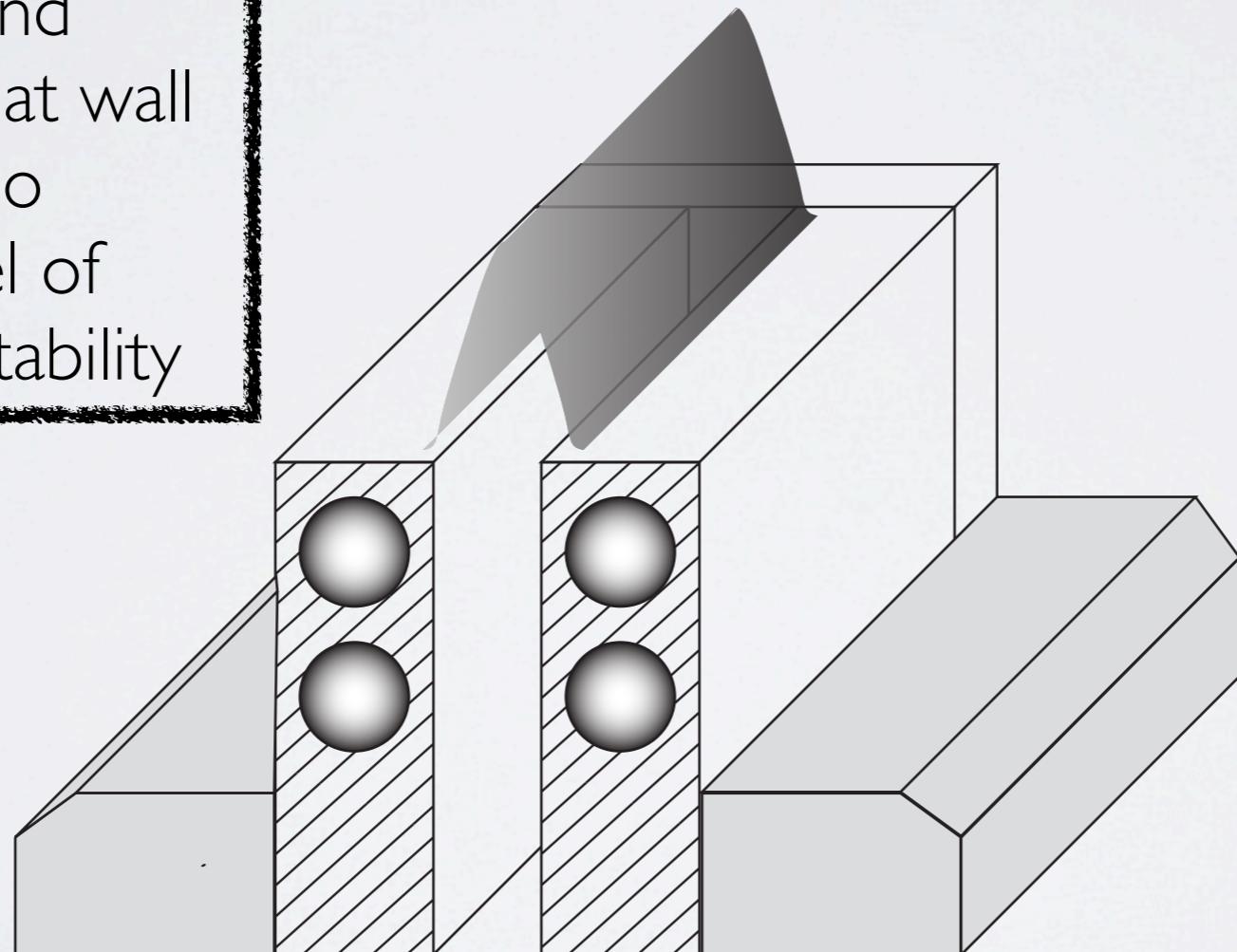
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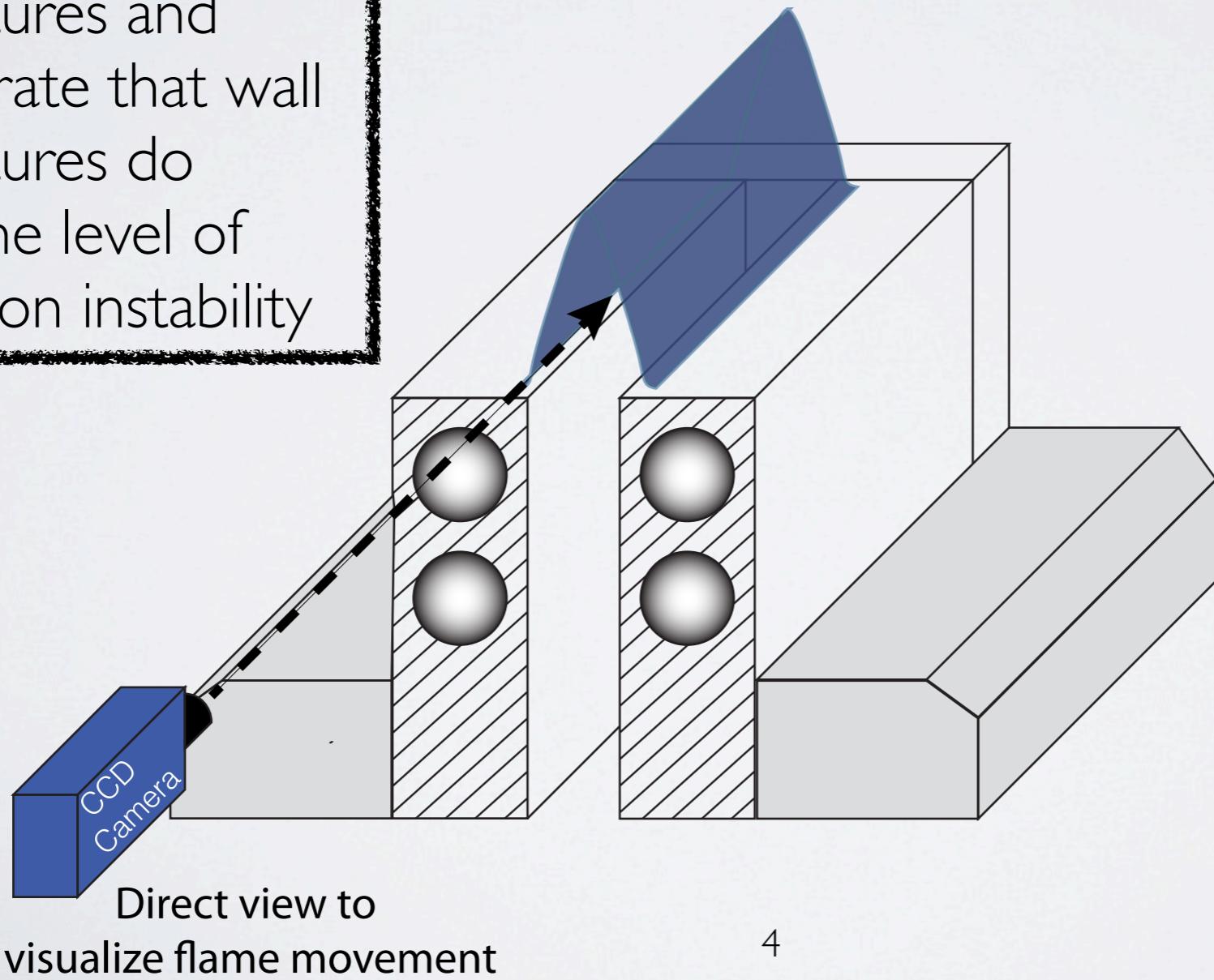
EVIDENCE OF WALL TEMPERATURE ON CI's ?

We show a naturally unstable experiment with controlled wall temperatures and demonstrate that wall temperatures do change the level of combustion instability



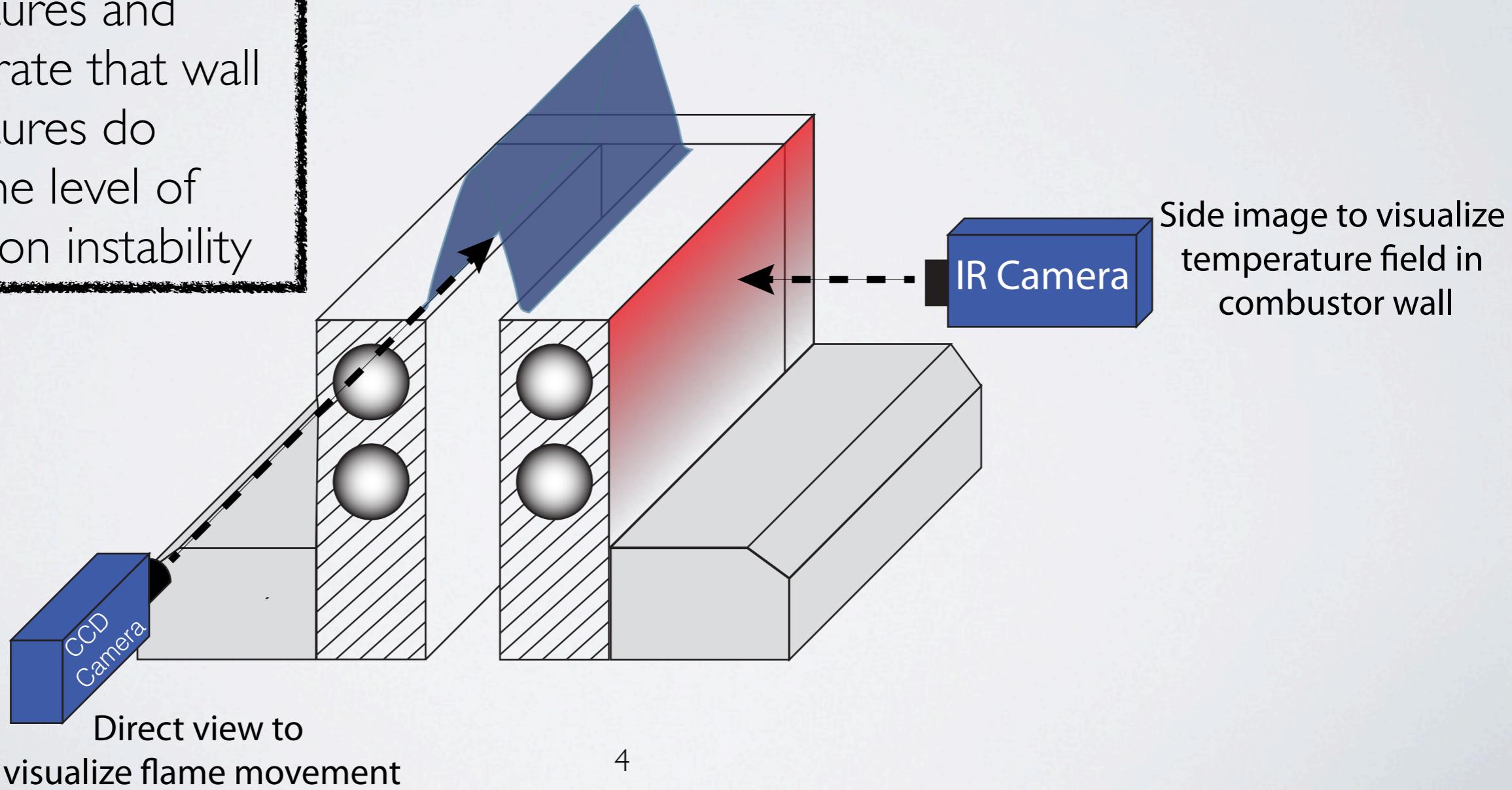
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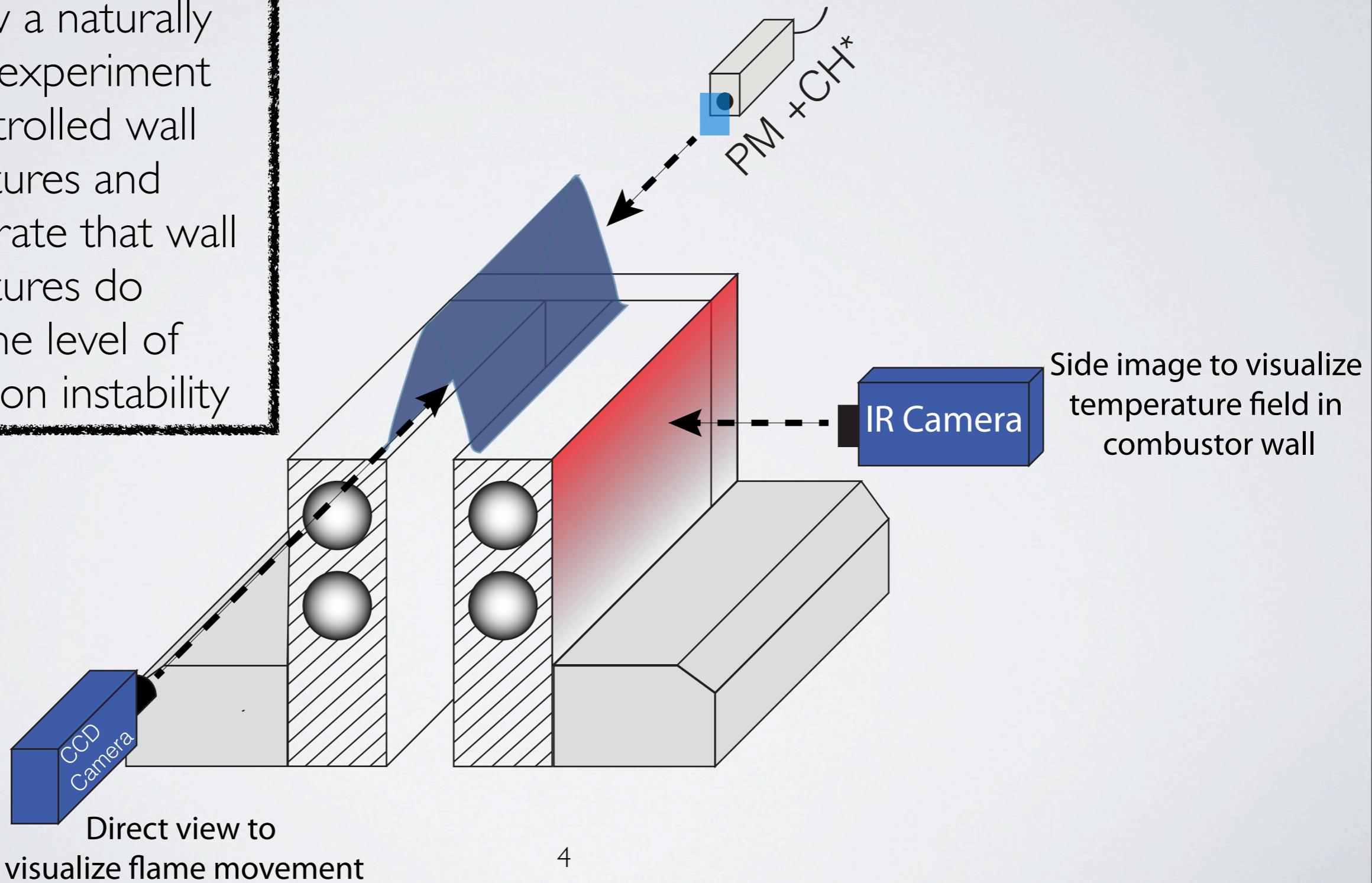
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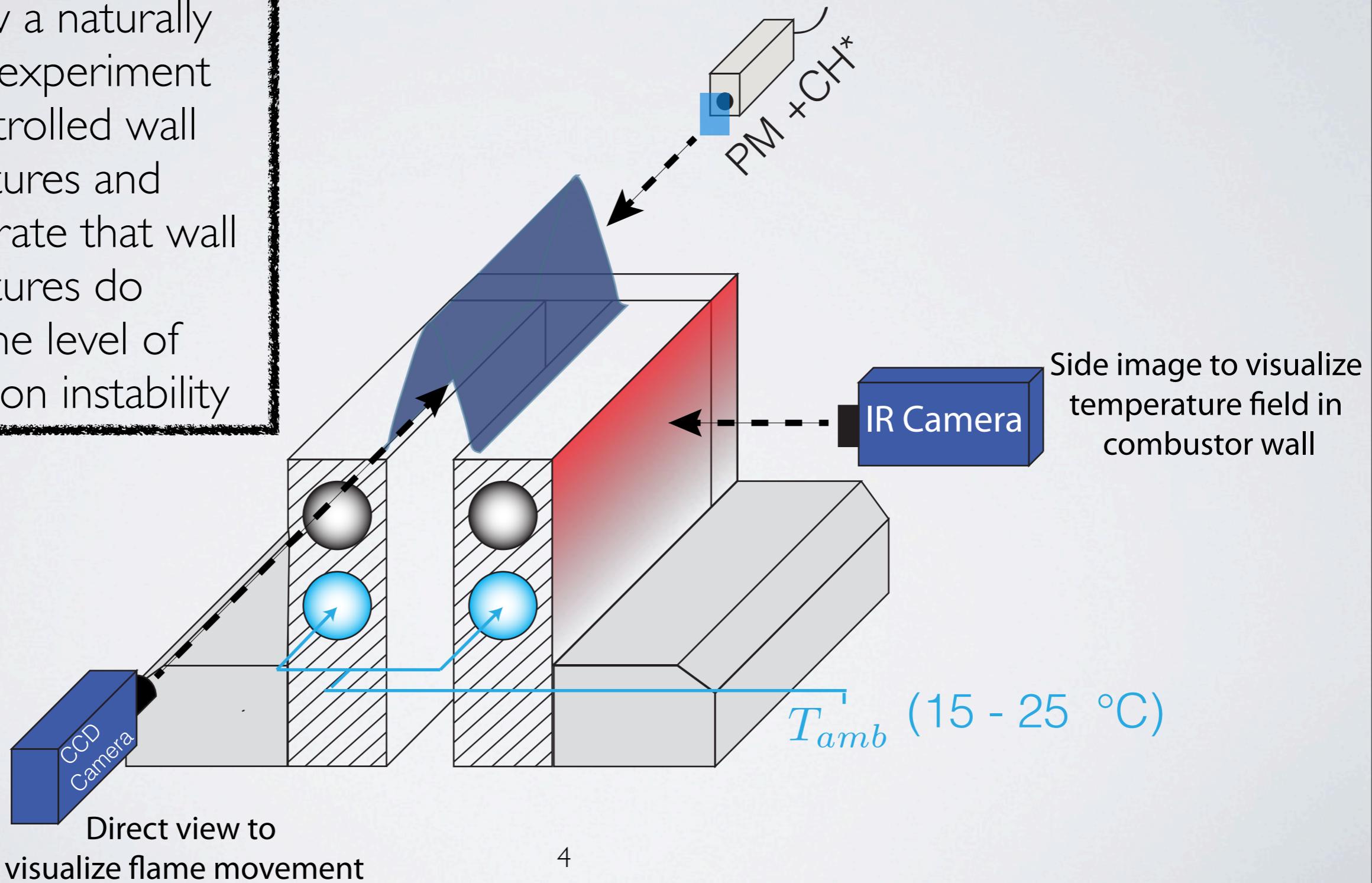
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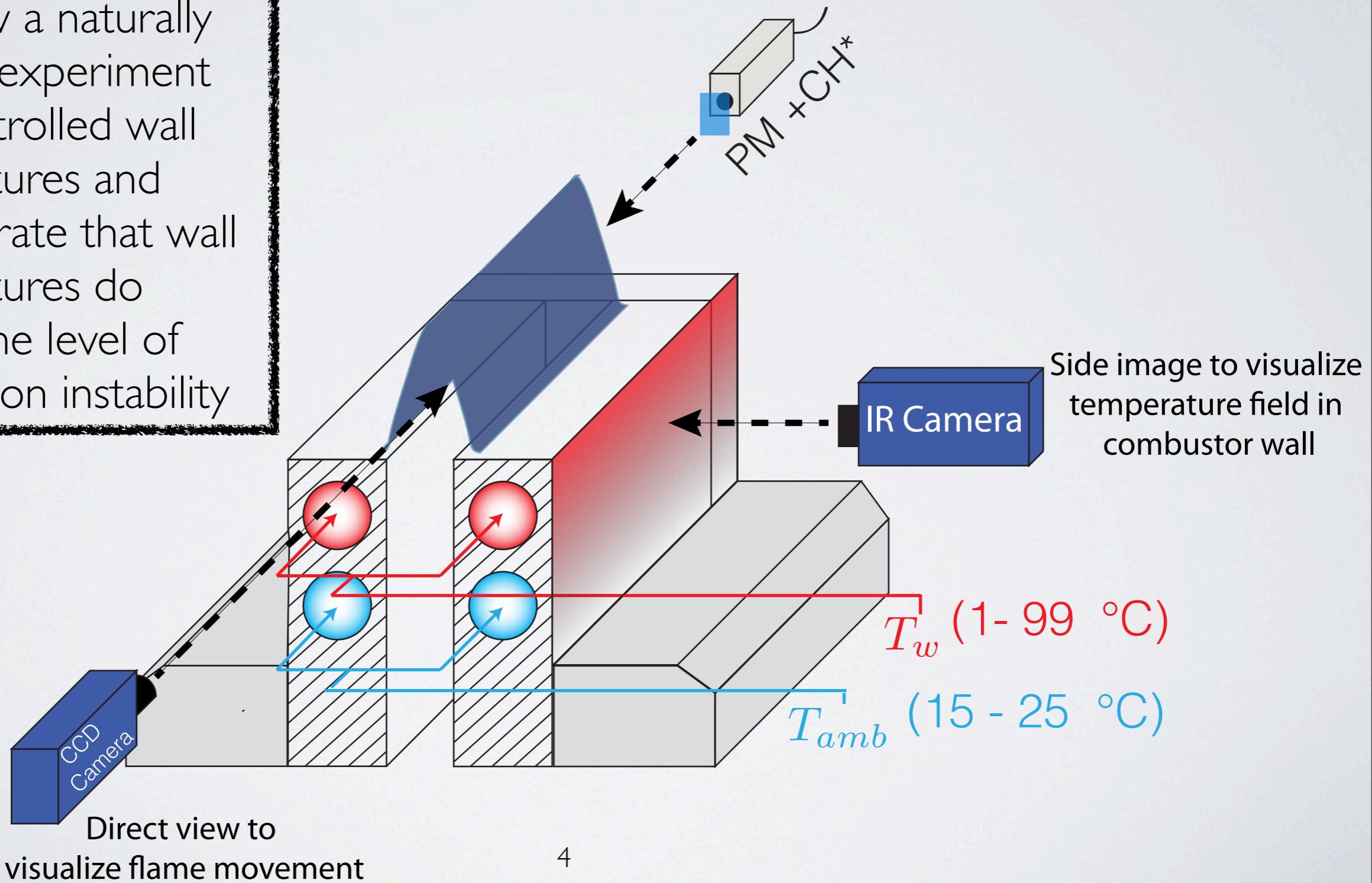
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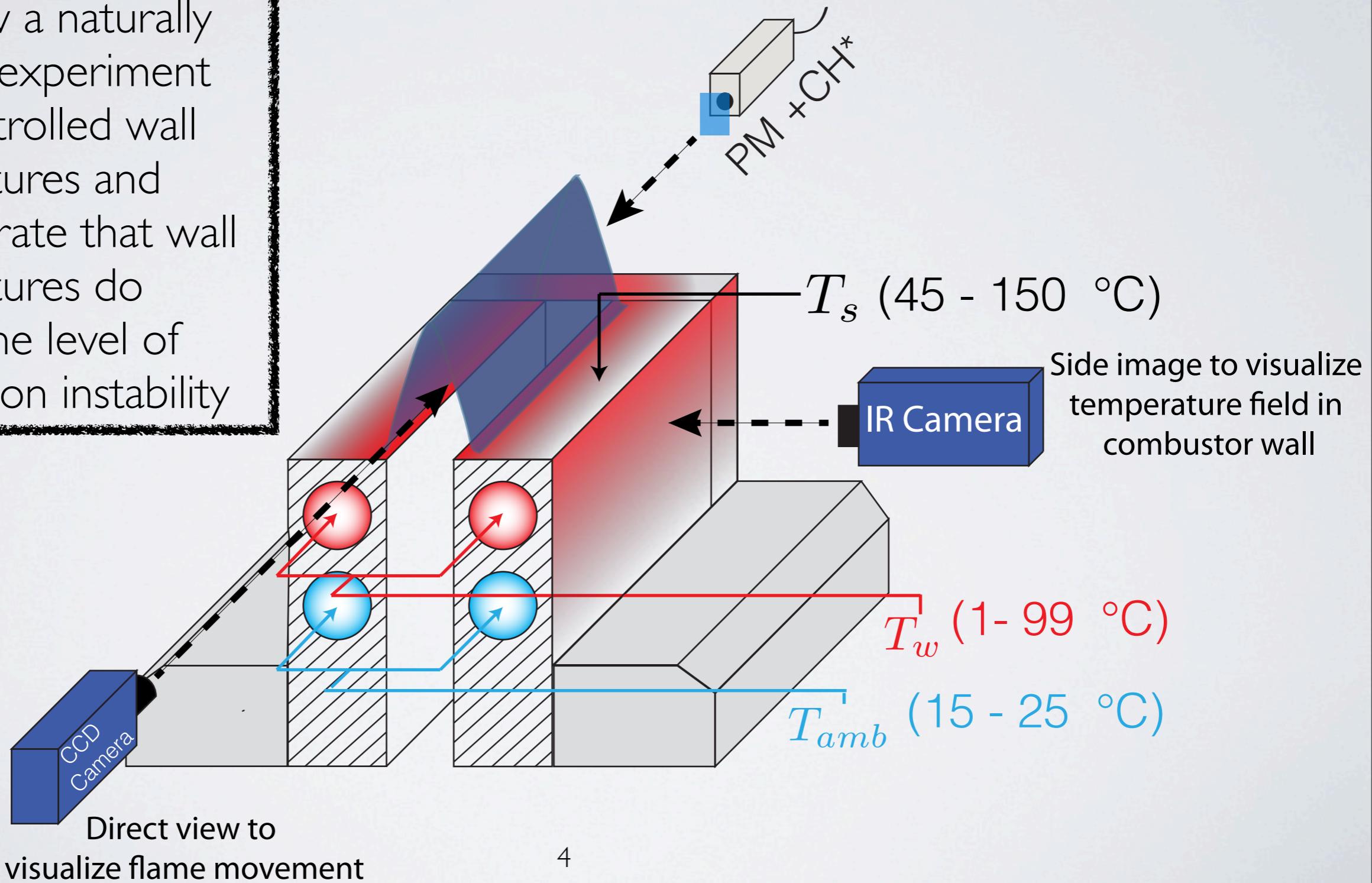
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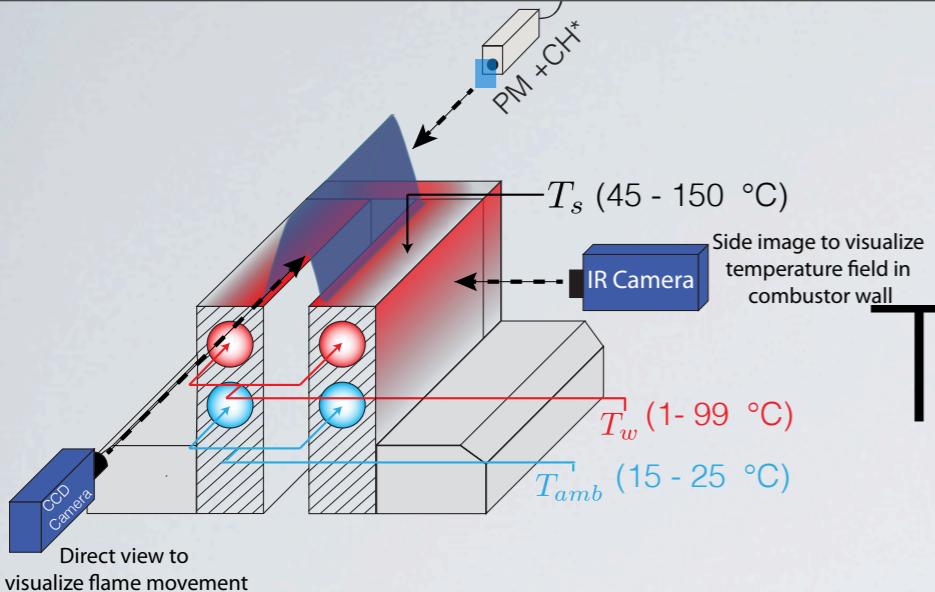
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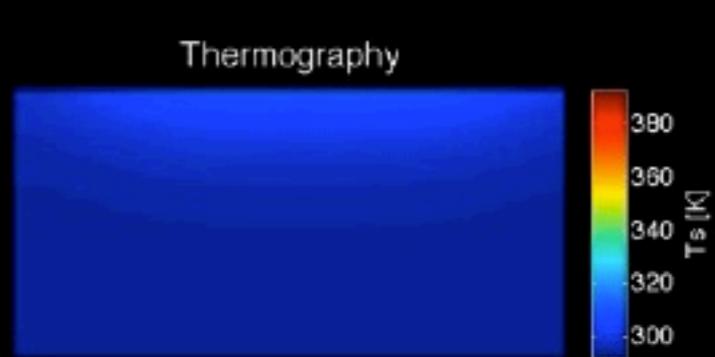
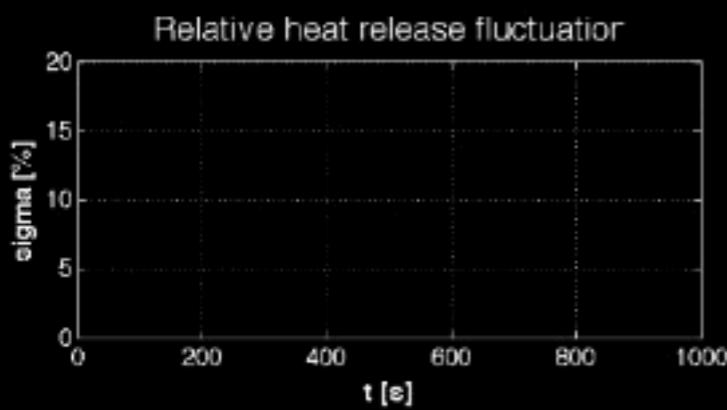
Laminar Premixed Flame

$\phi = 0.92$
 $U_b = 1.6 \text{ m/s}$
 $P = 0.96 \text{ bar}$
 $T_{fg} = 293 \text{ K}$

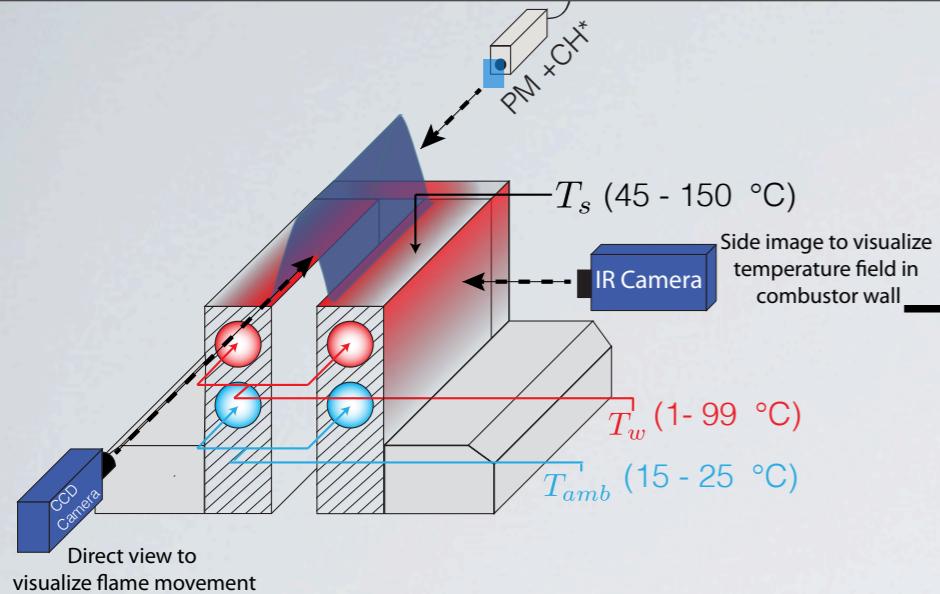
Cooling System : **OFF**



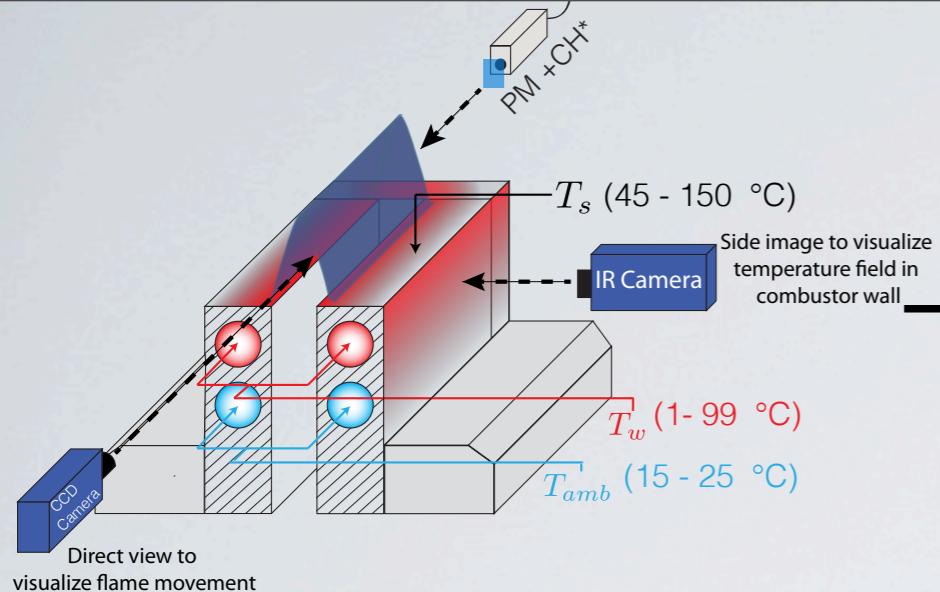
► 1X



EVIDENCE OF WALL TEMPERATURE ON CI's ?



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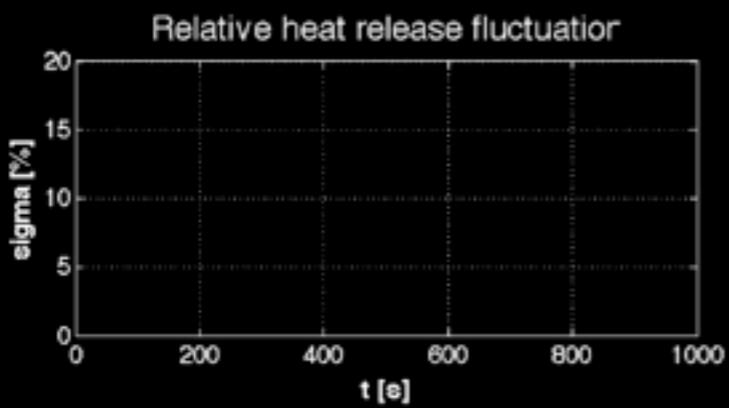
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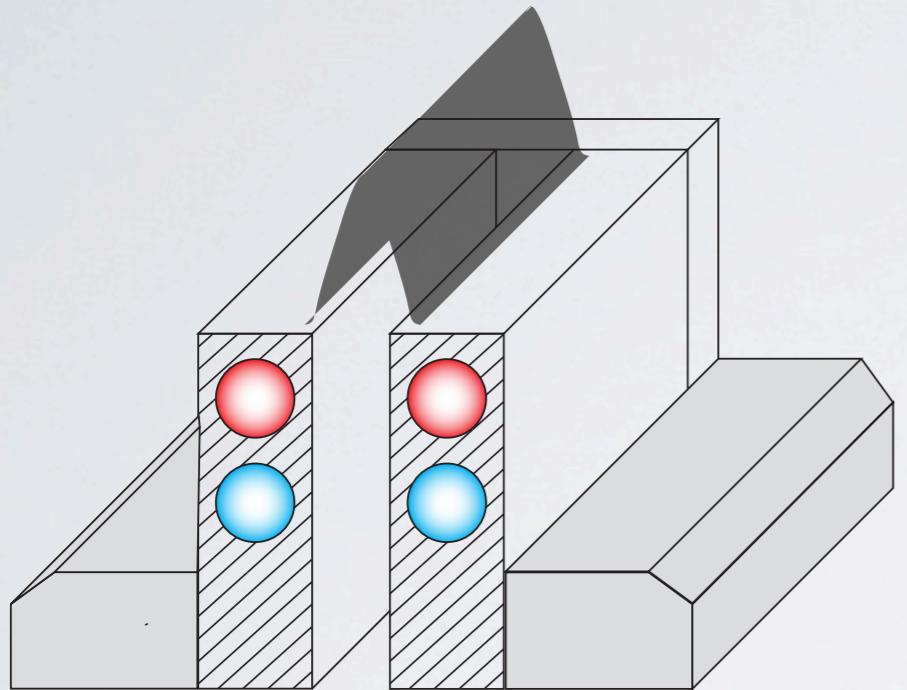
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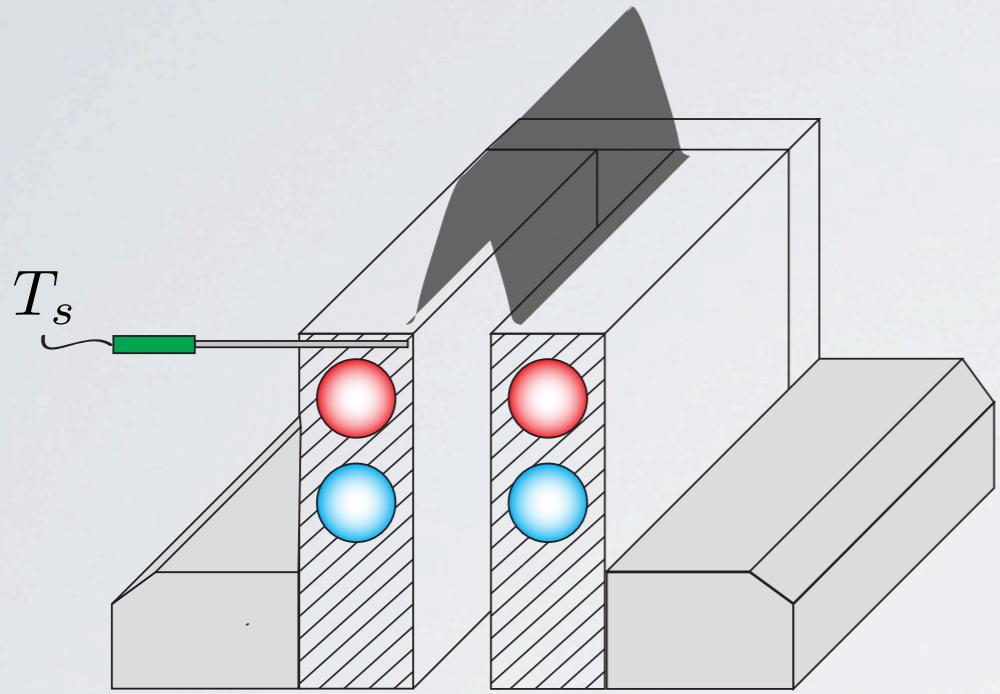
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EXPERIMENT

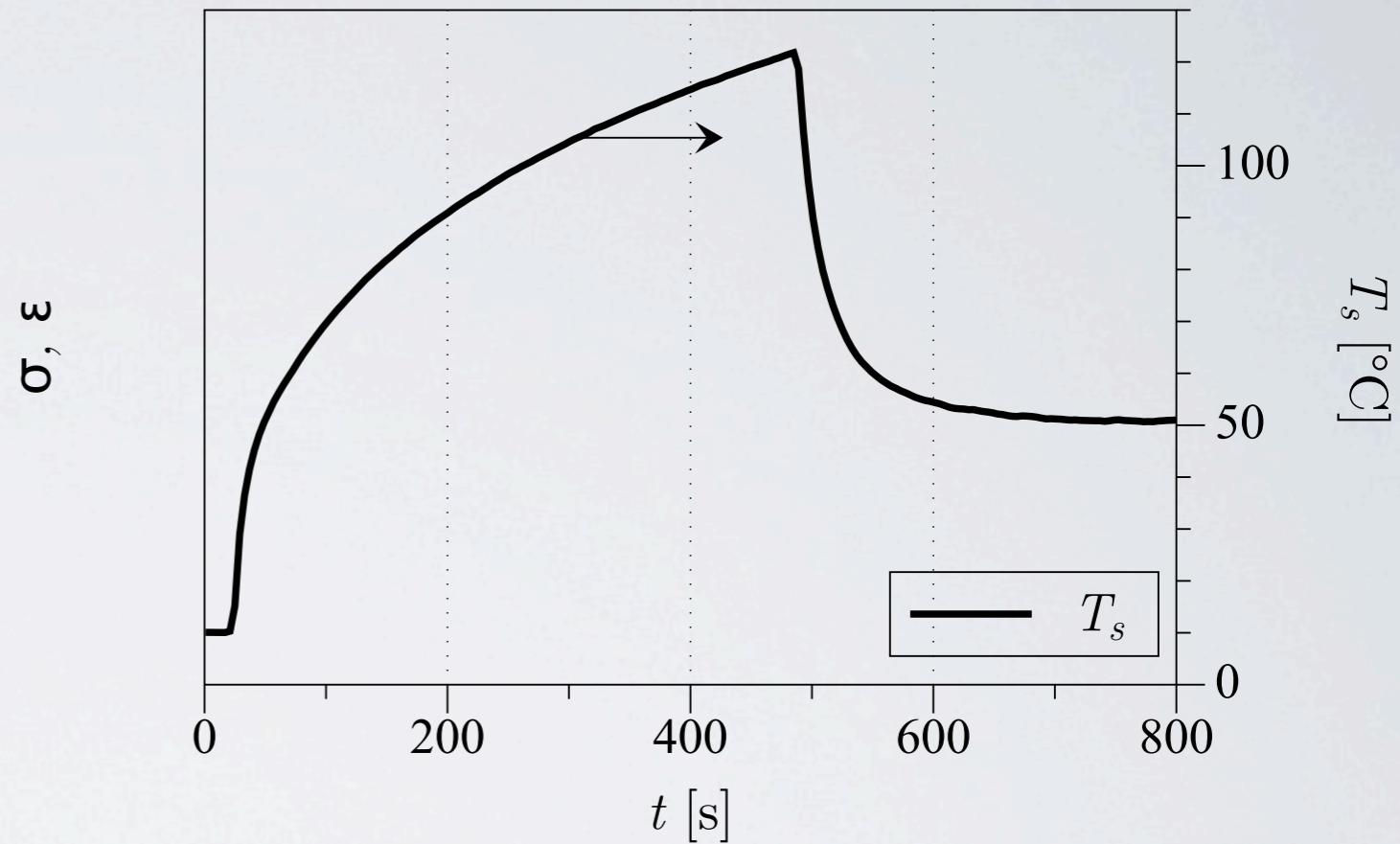


EXPERIMENT

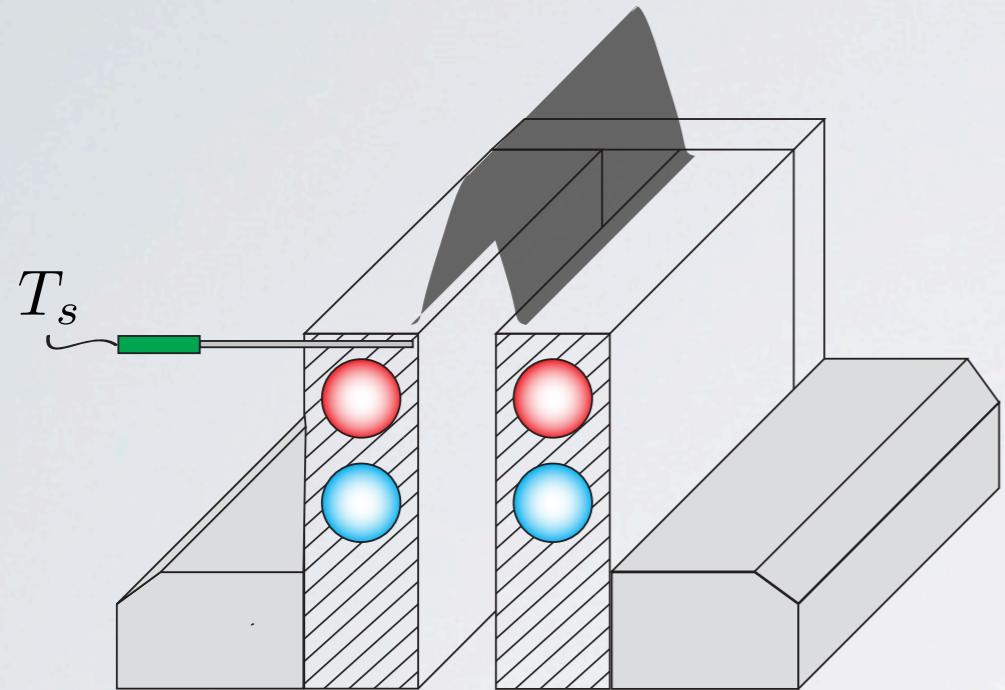


Slot Temperature (Thermocouple)

T_1

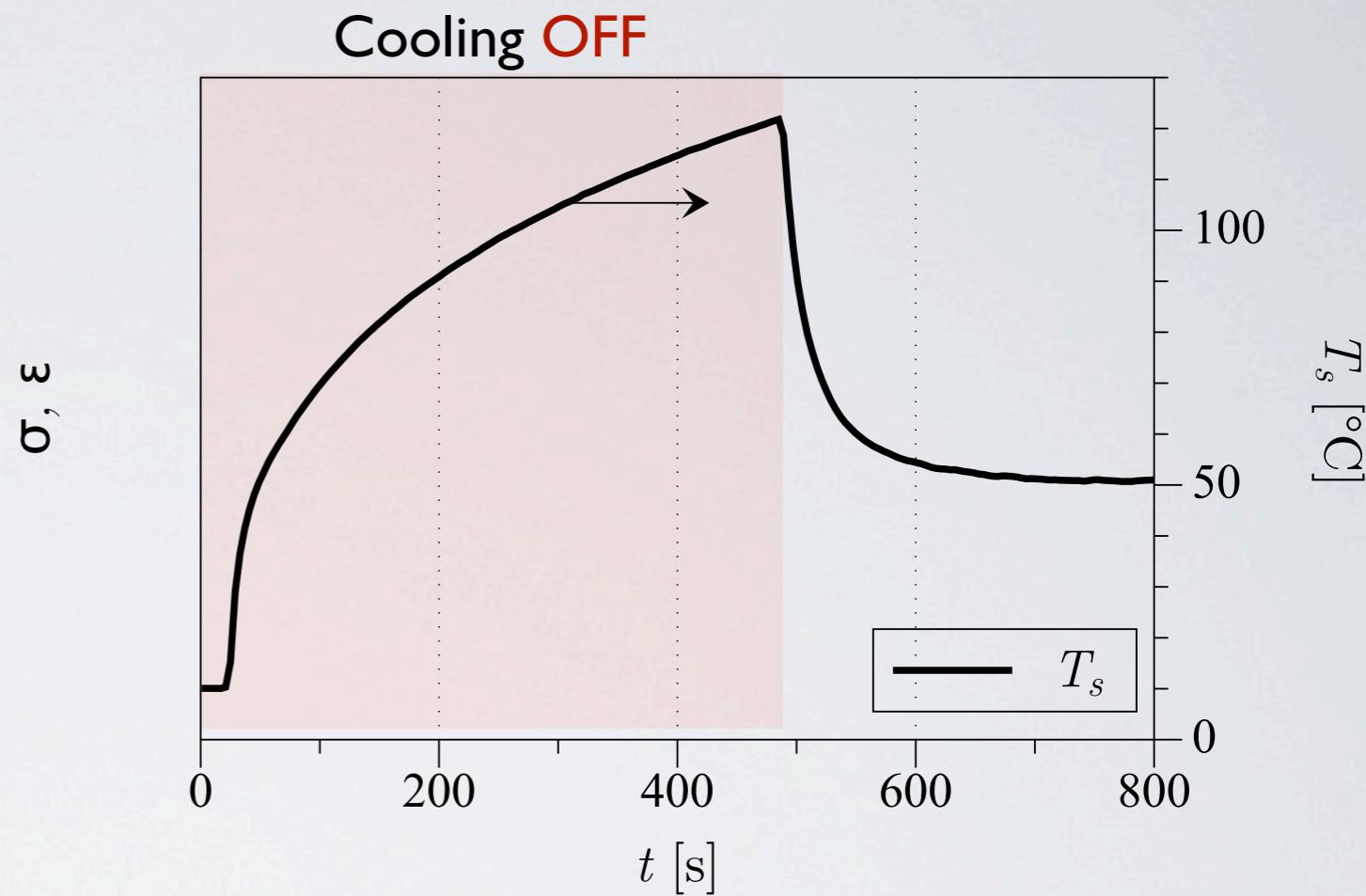


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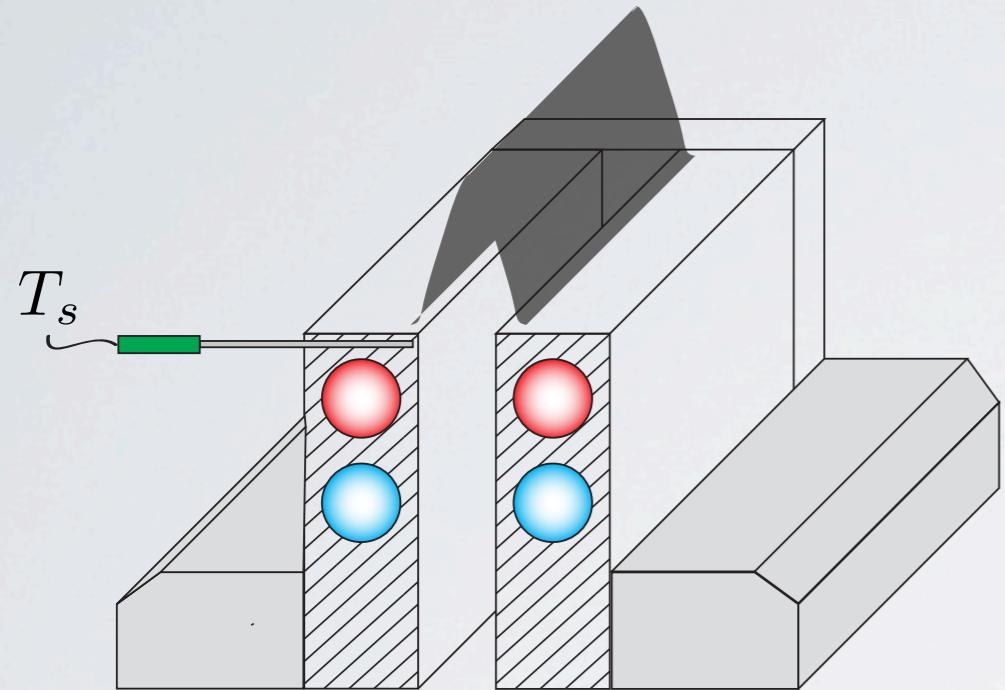


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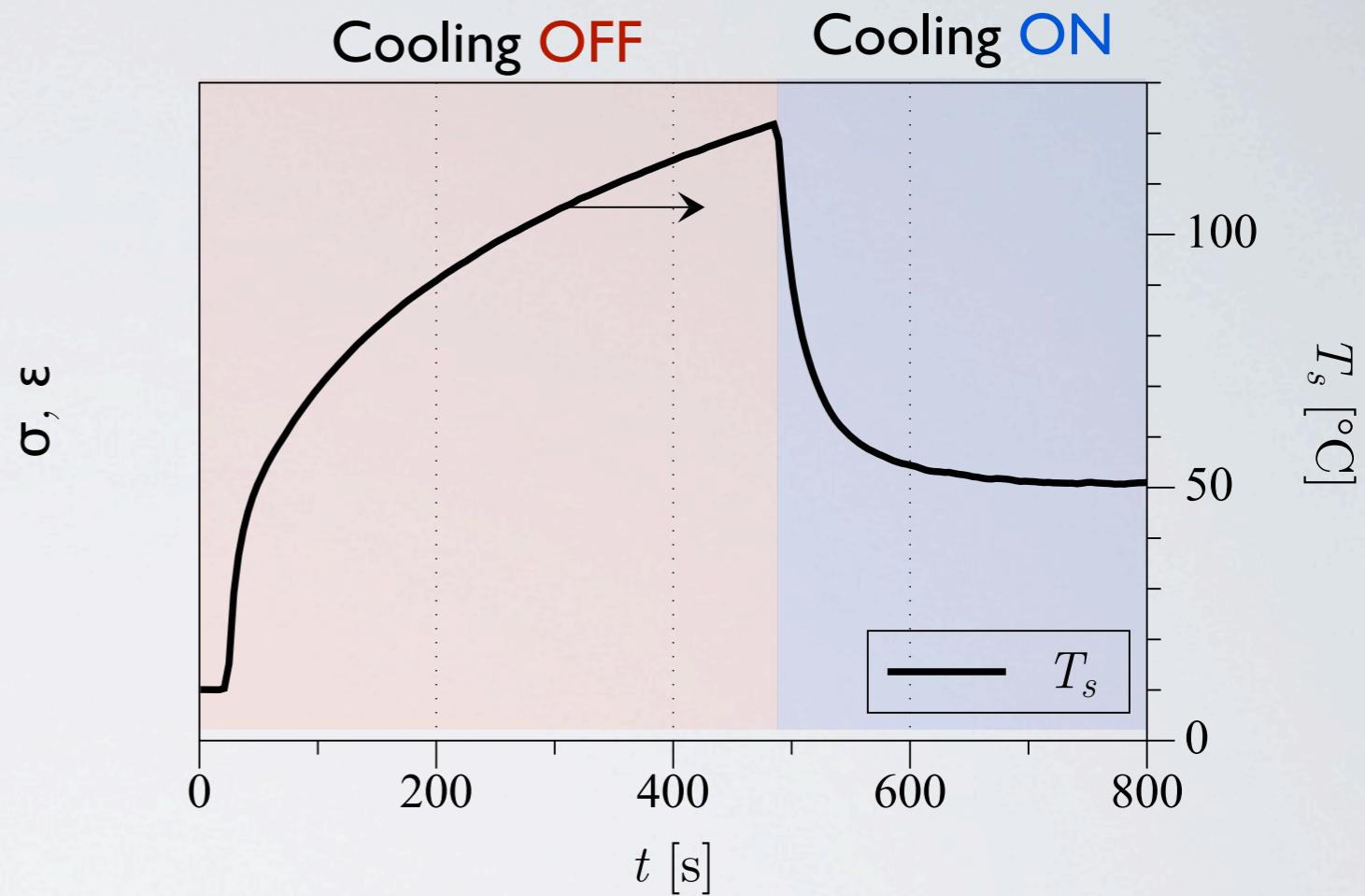


EXPERIMENT

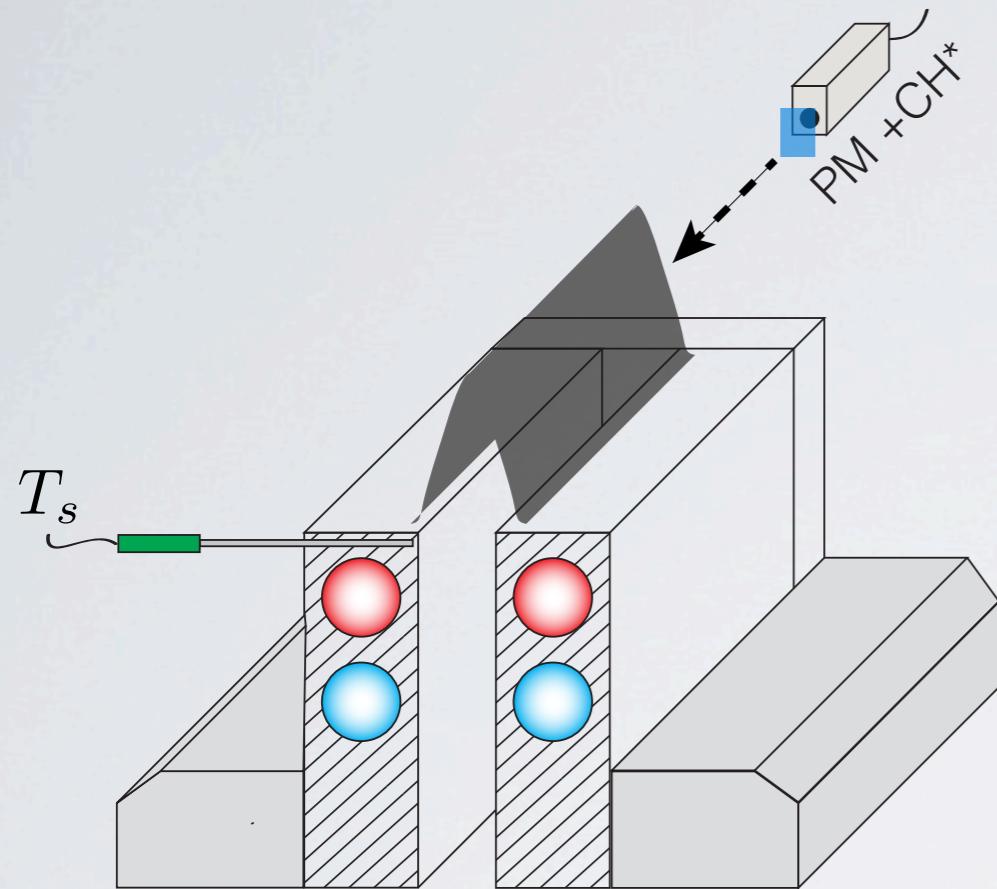


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EXPERIMENT

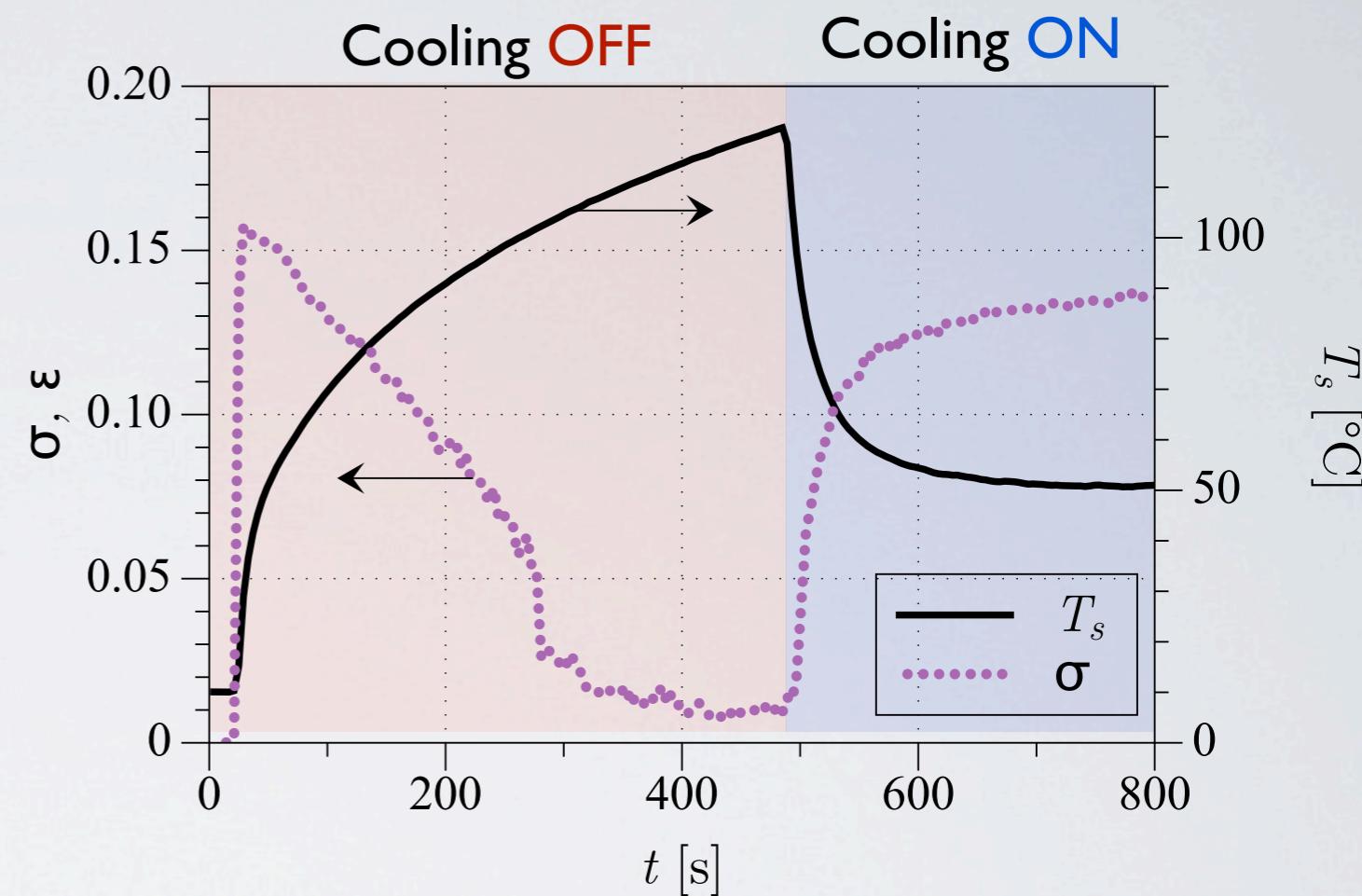


Slot Temperature (Thermocouple)

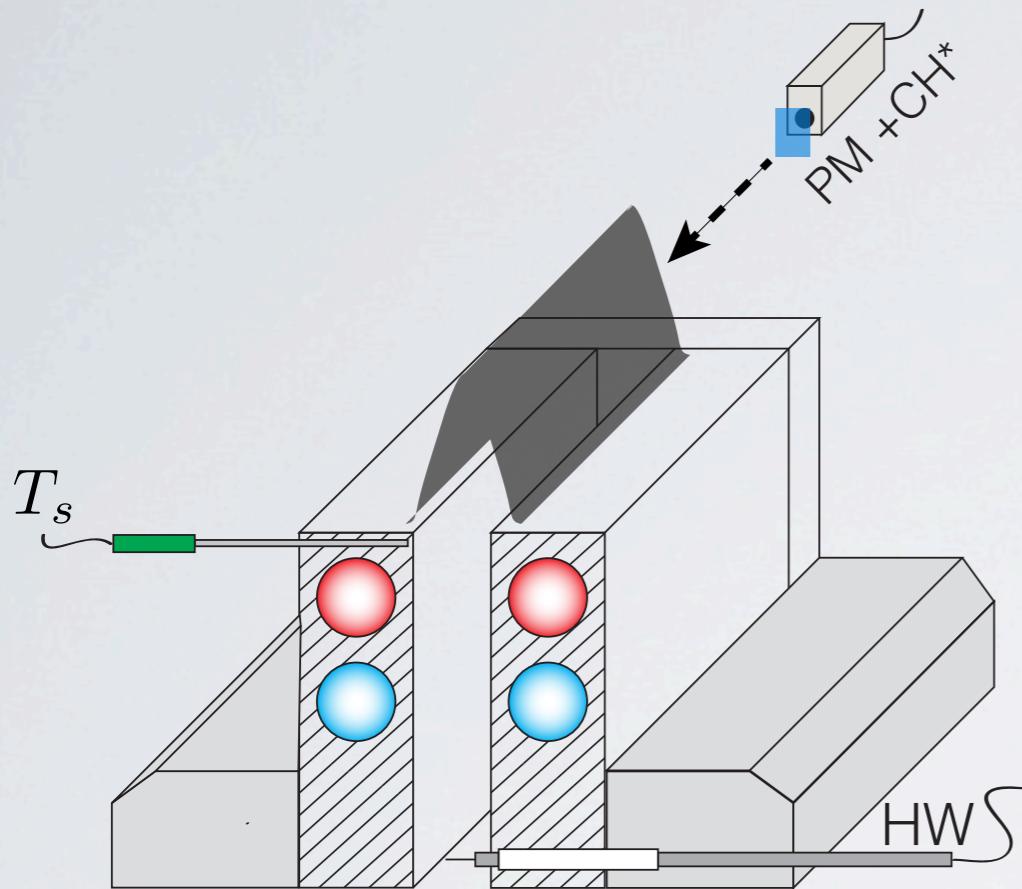
T_1

Heat release fluctuation magnitude
(Photomultiplier + CH* filtre)

$$\sigma = \frac{I_{CH^*}^{rms}}{\bar{I}_{CH^*}}$$



EXPERIMENT



Slot Temperature (Thermocouple)

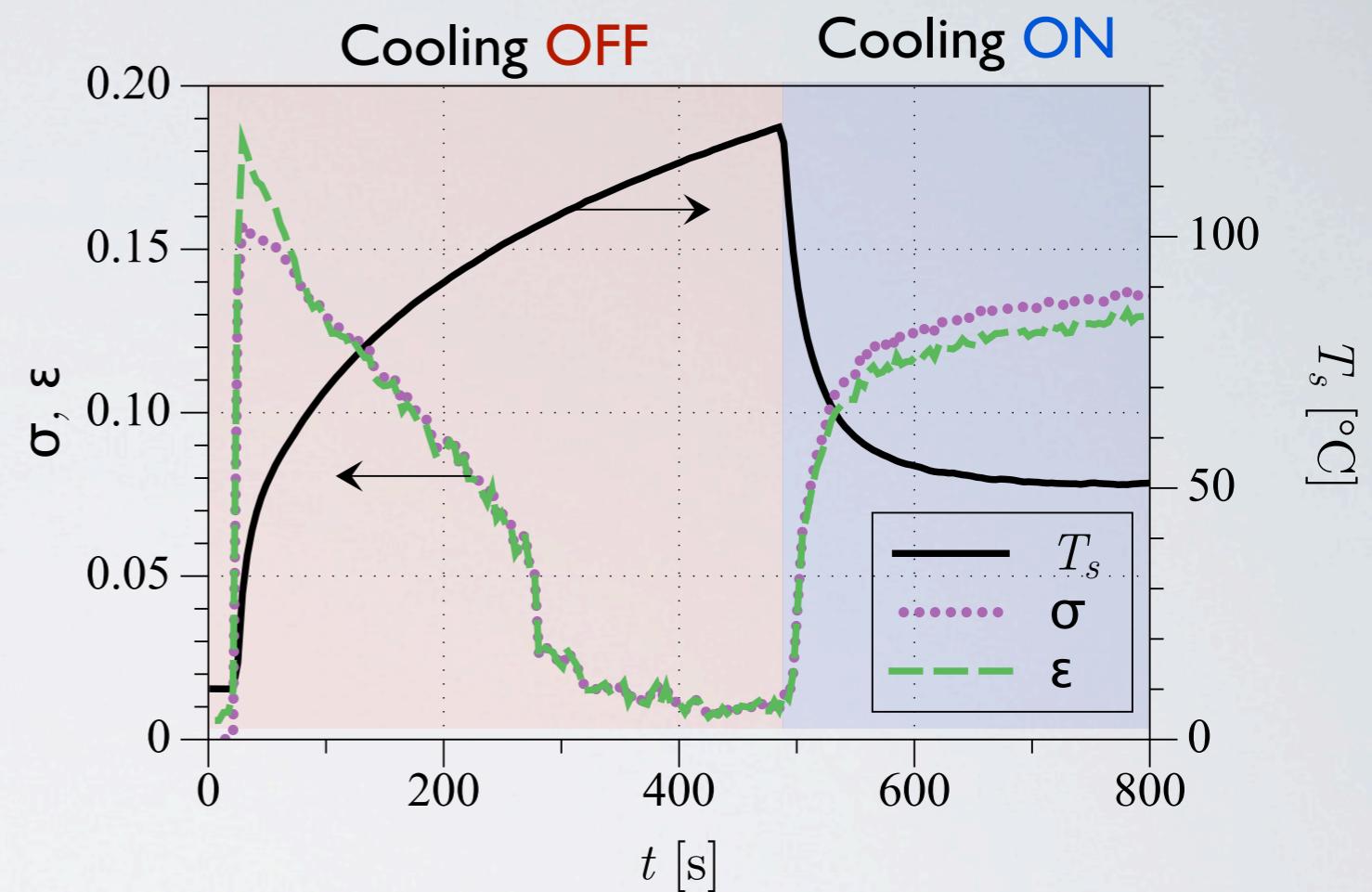
$$T_1$$

Heat release fluctuation magnitude
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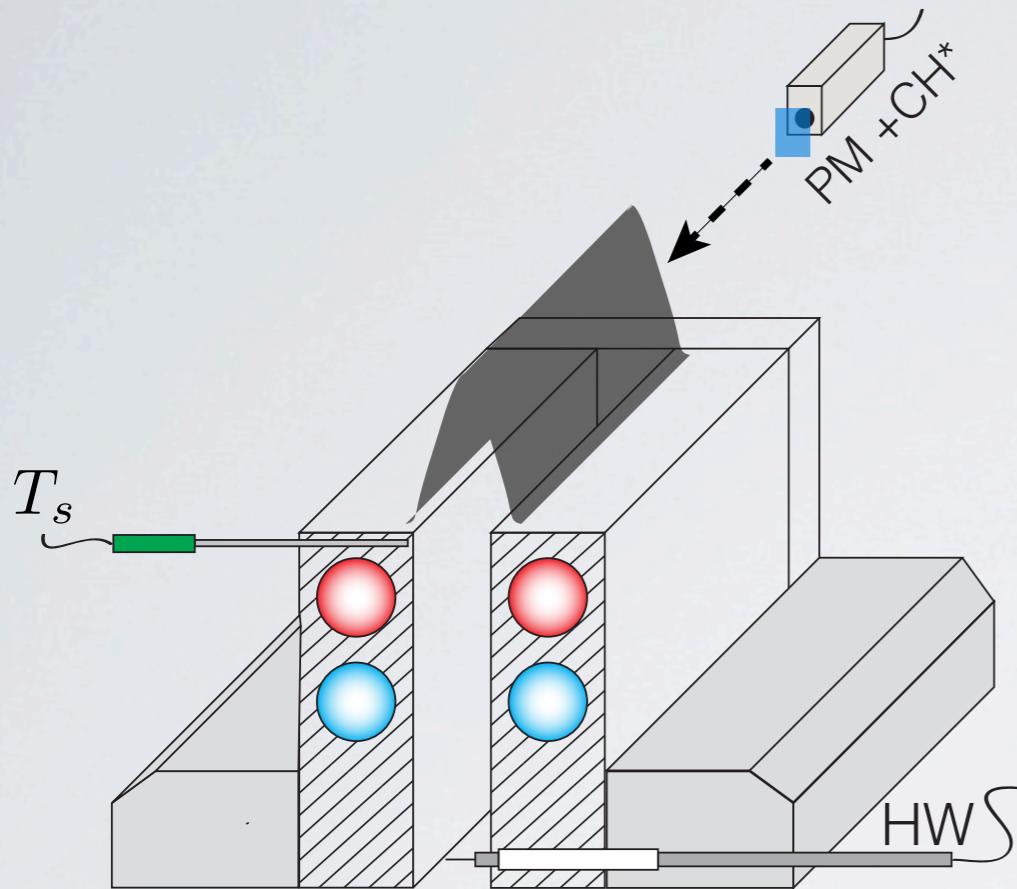
$$\sigma = \frac{I_{CH^*}^{rms}}{\bar{I}_{CH^*}}$$

Velocity fluctuation magnitude (Hot wire)

$$\varepsilon = \frac{v_1^{rms}}{\bar{v}}$$



EXPERIMENT



Slot Temperature (Thermocouple)

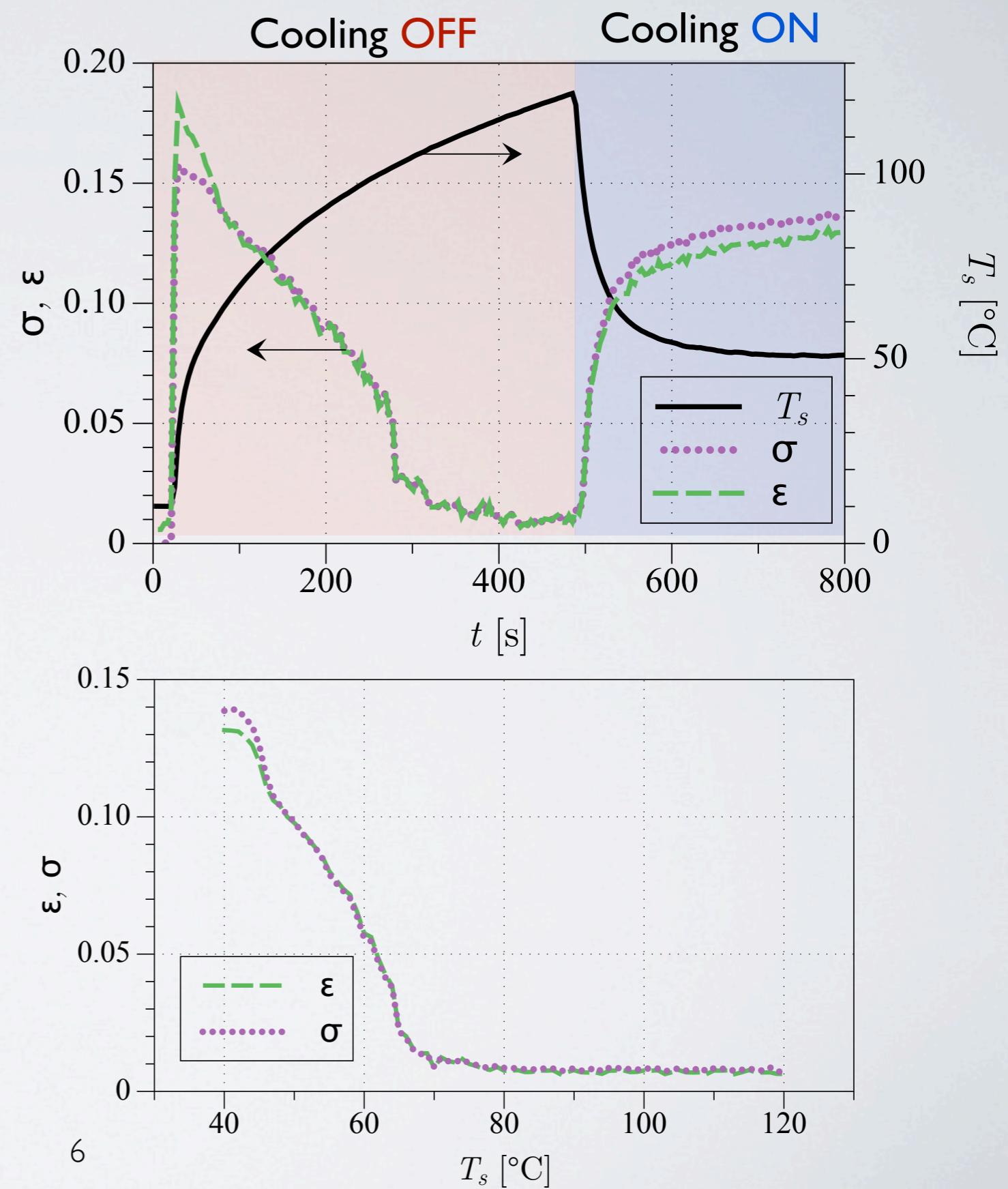
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Heat release fluctuation magnitude
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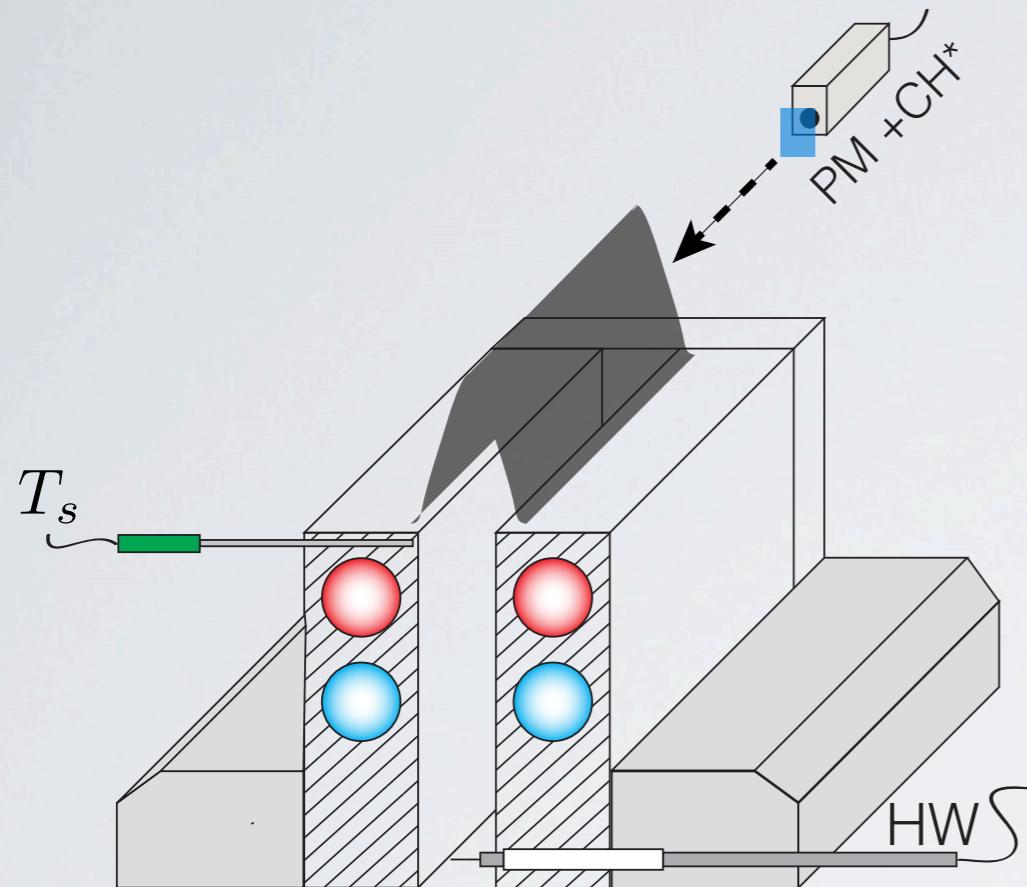
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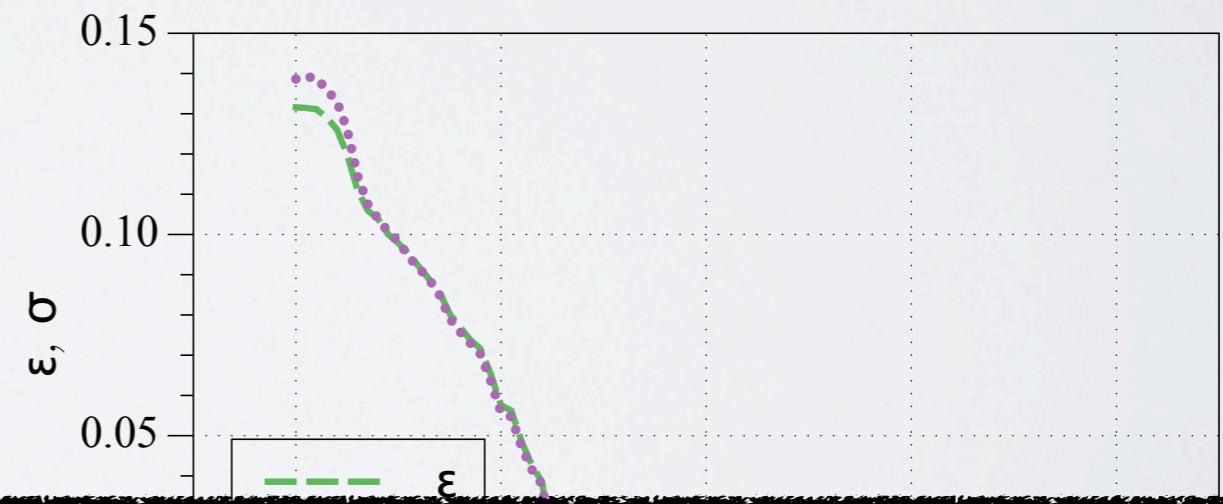
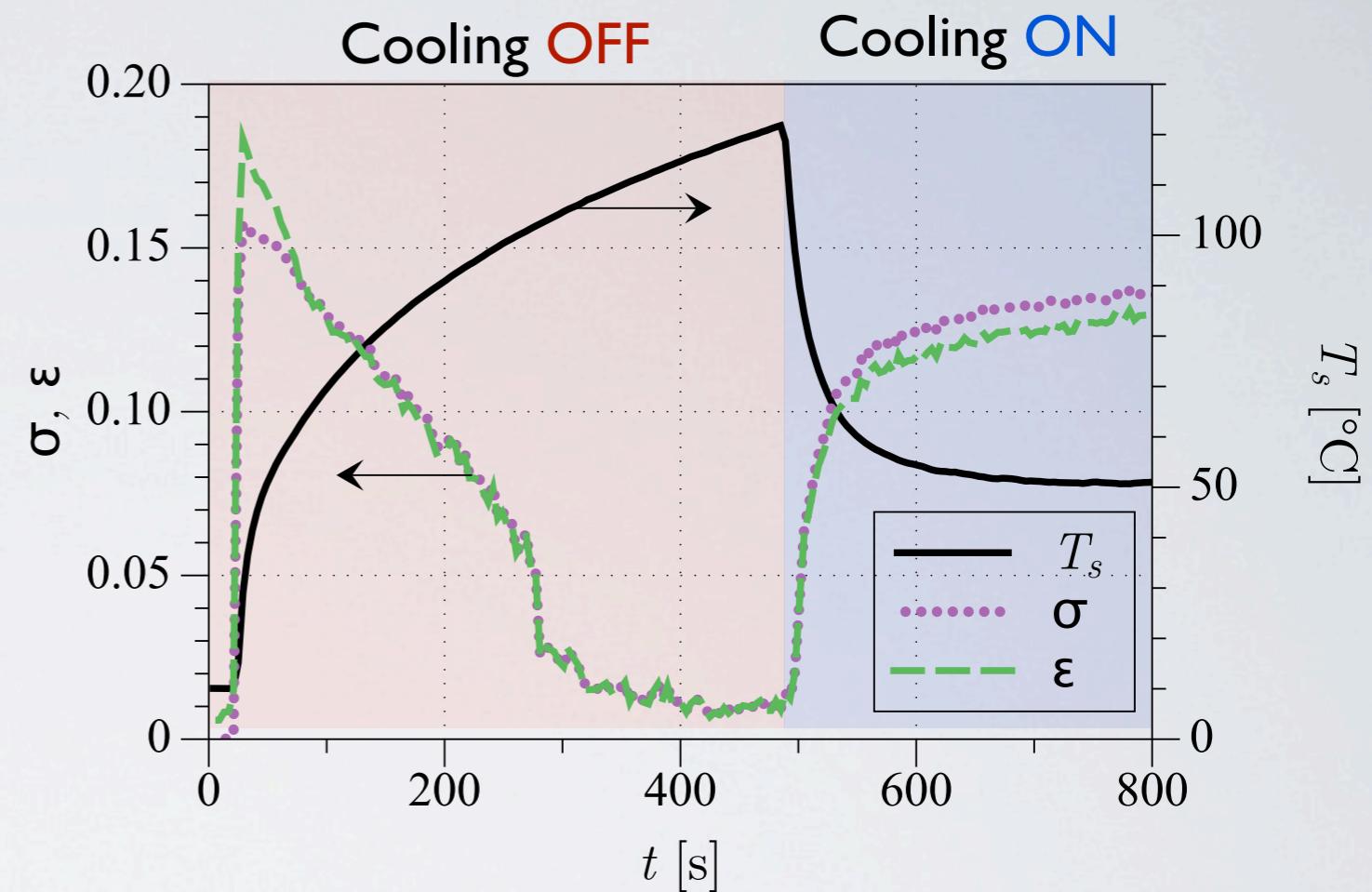


Slot Temperature (Thermocouple)

$$T_1$$

Heat release fluctuation magnitude
(Photomultiplier + CH* filtre)

$$\sigma = \frac{I_{CH^*}^{rms}}{\bar{I}_{CH^*}}$$



The flame natural instability can be suppressed increasing T_s by only 30 K.

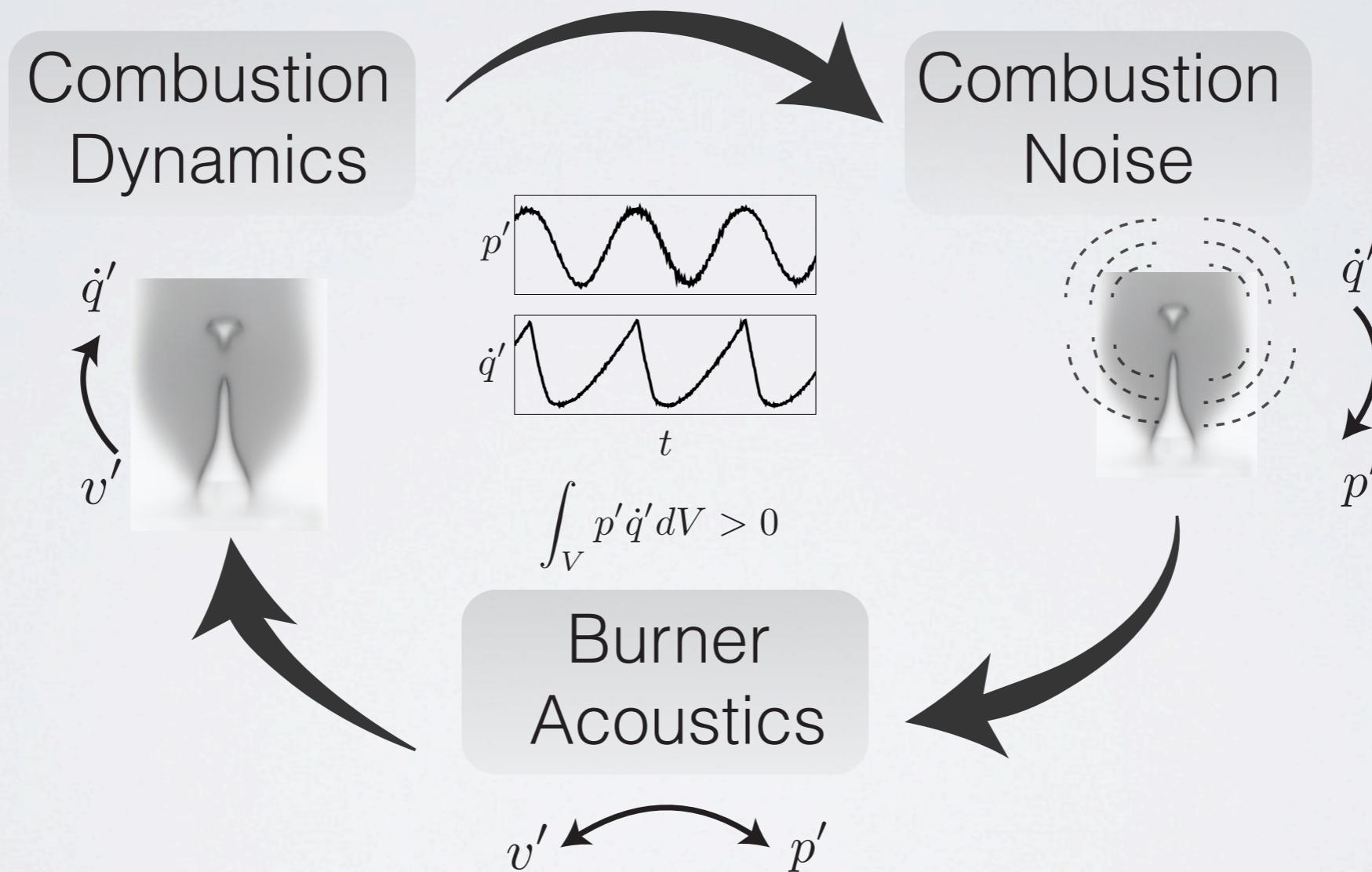
LITERATURE REVIEW

- The coupling between wall temperatures and thermoacoustics is known from experimentalists in laboratories but also in industry
- some studies address the problem indirectly:
 - ◆ Rook (2002, 2003),
 - ◆ Preetham (2004),
 - ◆ Schmitt (2007),
 - ◆ Kaess (2008),
 - ◆ Noiray (2008),
 - ◆ Altay (2009),
 - ◆ Kornilov (2009),
 - ◆ Duchaine (2010),
 - ◆ Kedia (2011),
 - ◆ Cuquel (2013),
 - ◆ Hong (2013),
- but no studies address it directly.

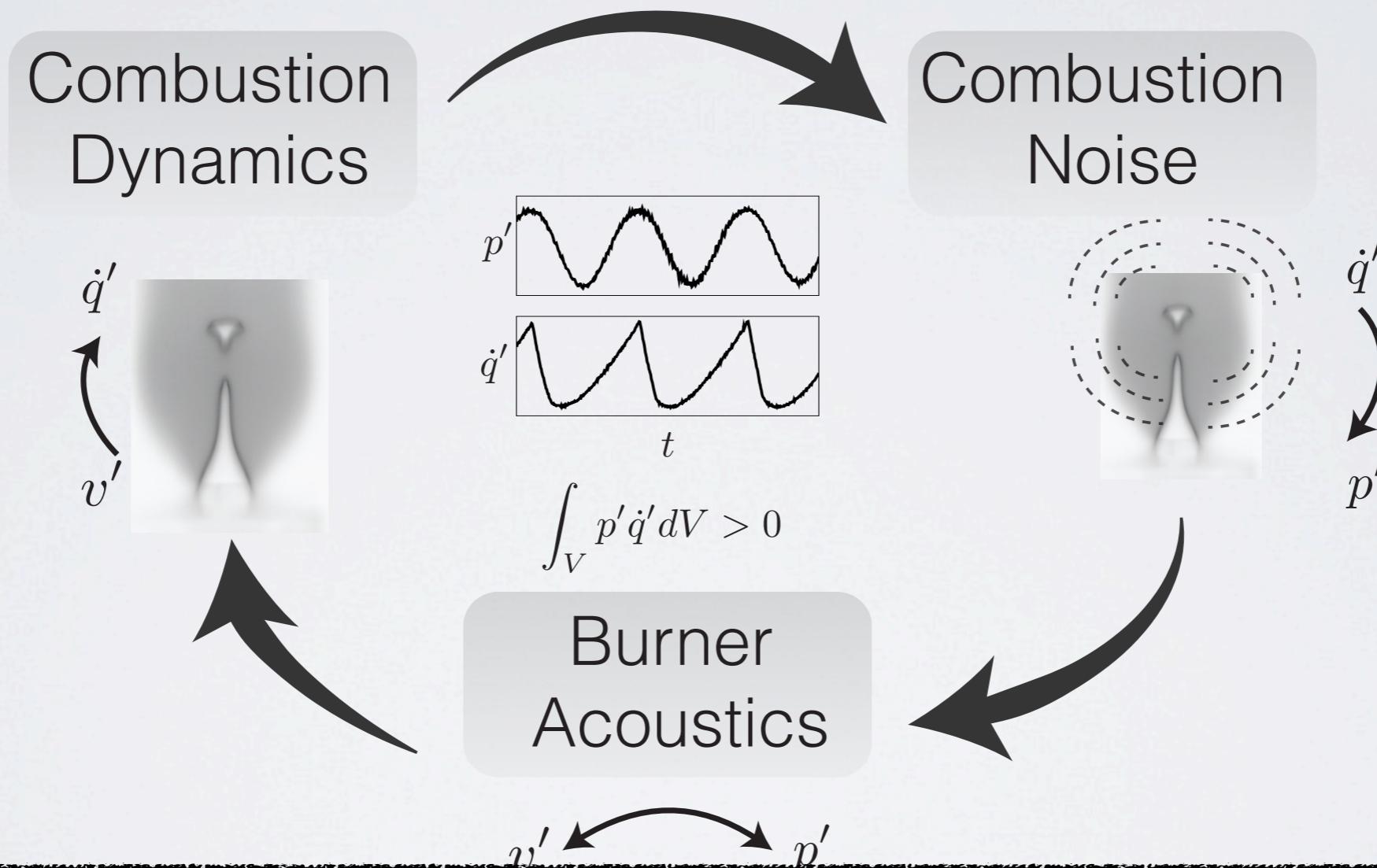
OBJECTIVES

- Understand and anticipate when combustors will be submitted to acoustically coupled combustion instabilities.
- Quantify the influence of the combustion chamber wall temperature on combustion instabilities

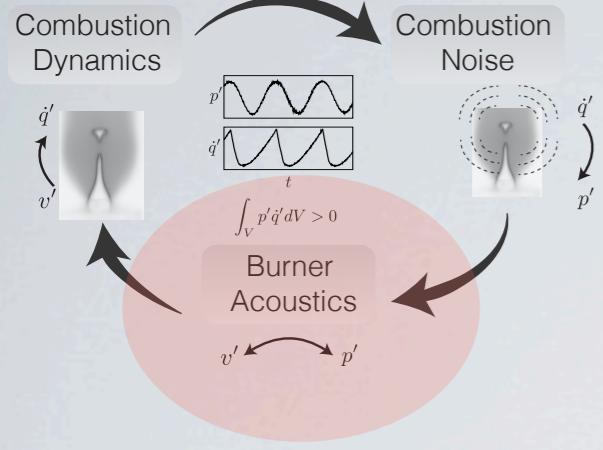
THERMO-ACOUSTIC INSTABILITY



THERMO-ACOUSTIC INSTABILITY

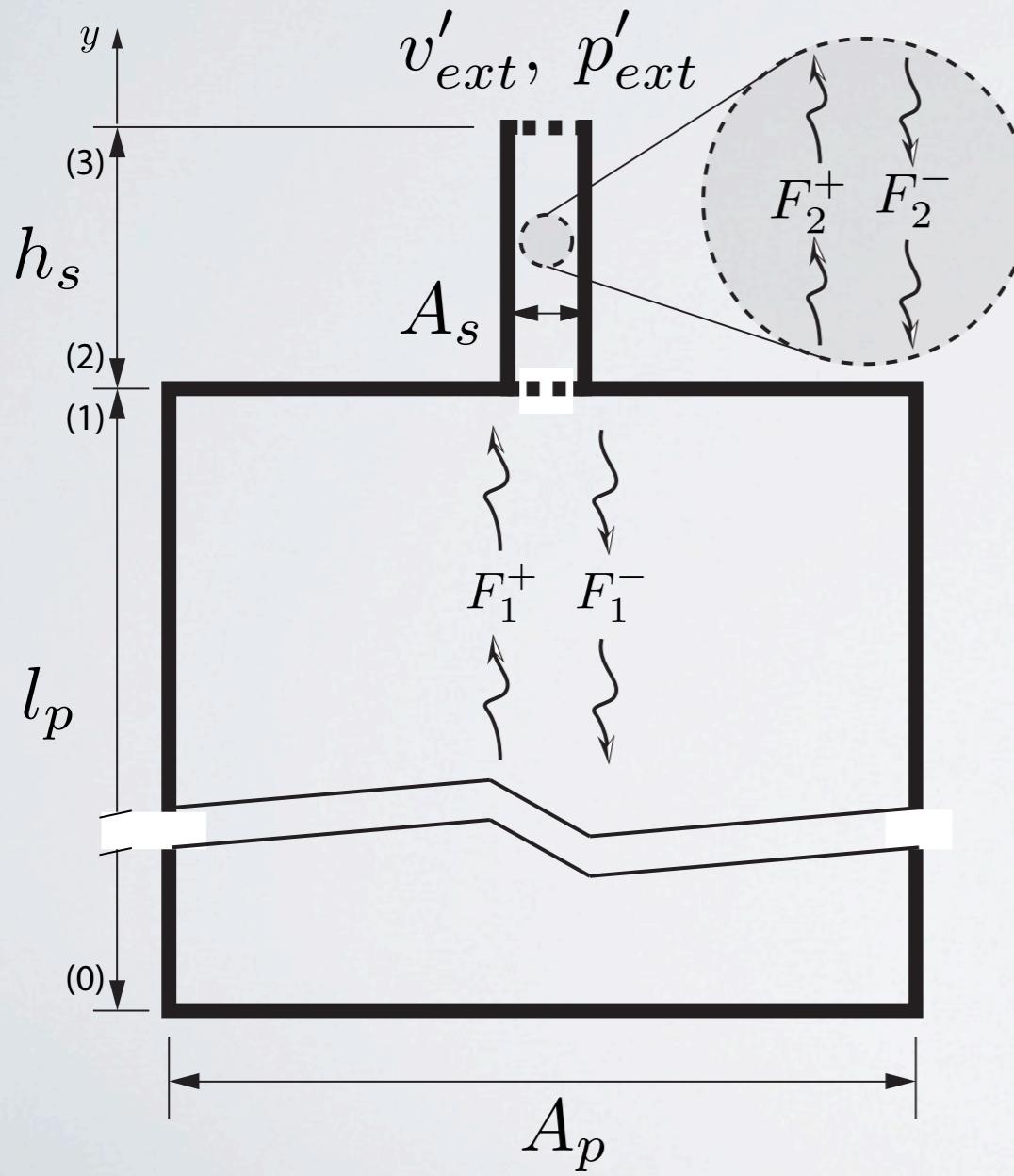


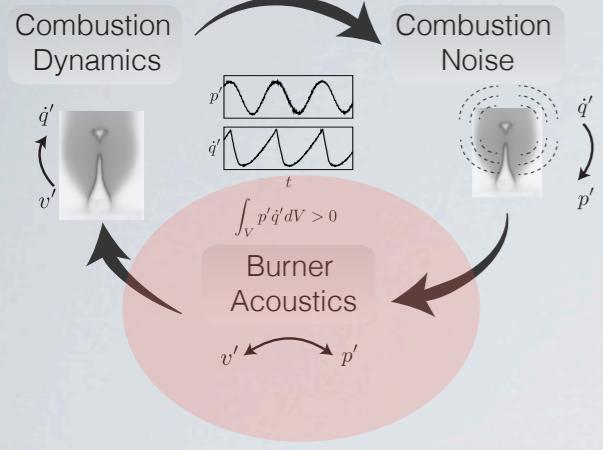
In order to understand and predict combustion instabilities we need a model !



BURNER ACOUSTICS

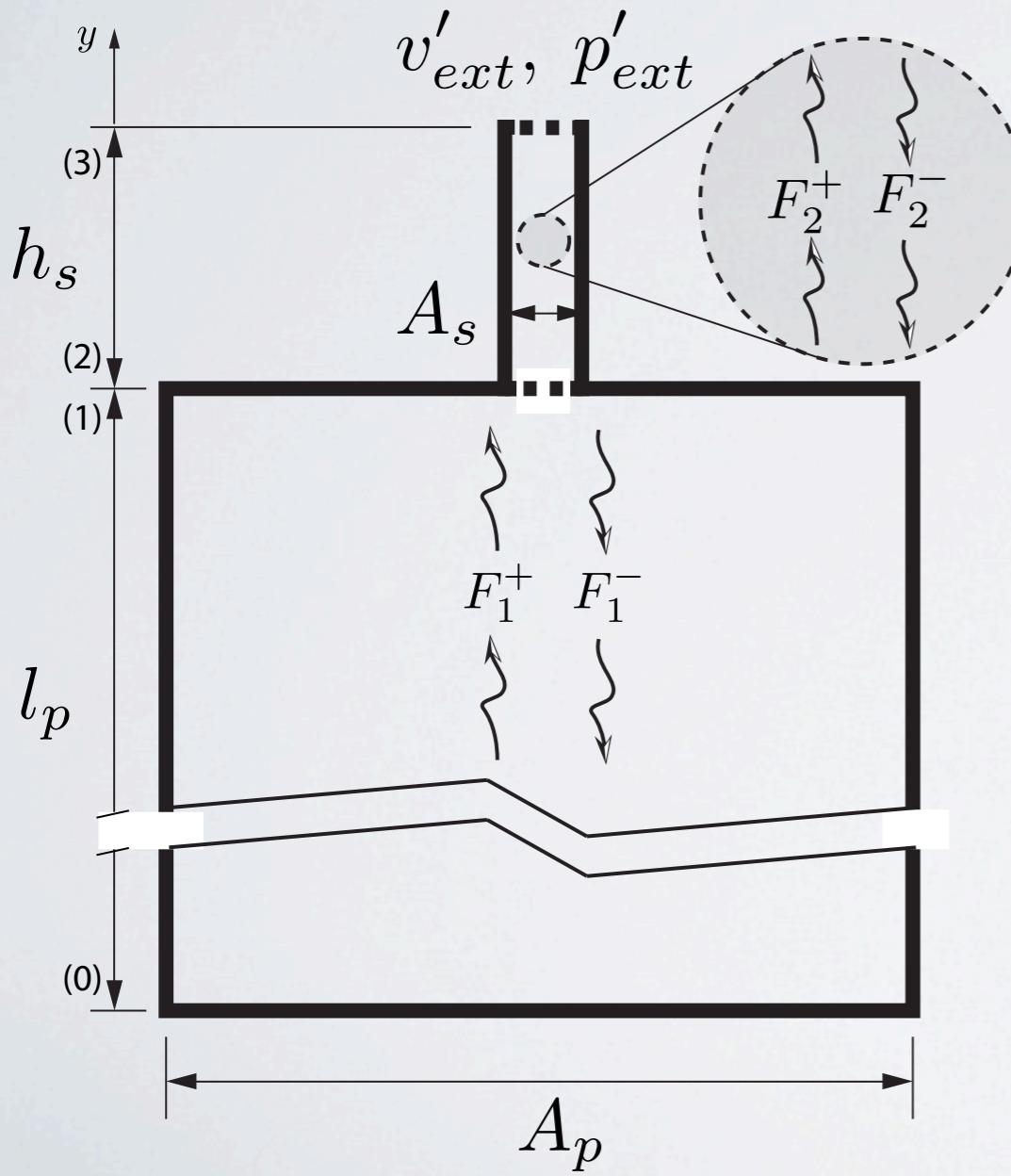
Helmholtz resonator





BURNER ACOUSTICS

Helmholtz resonator

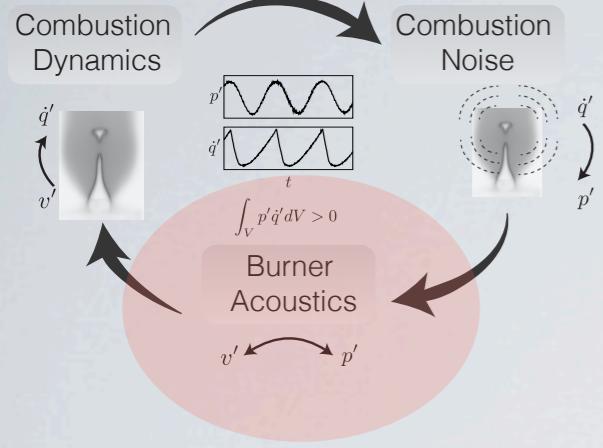


Wave equation

$$\nabla^2 p' - \frac{1}{c^2} \frac{\partial^2 p'}{\partial t^2} = 0$$

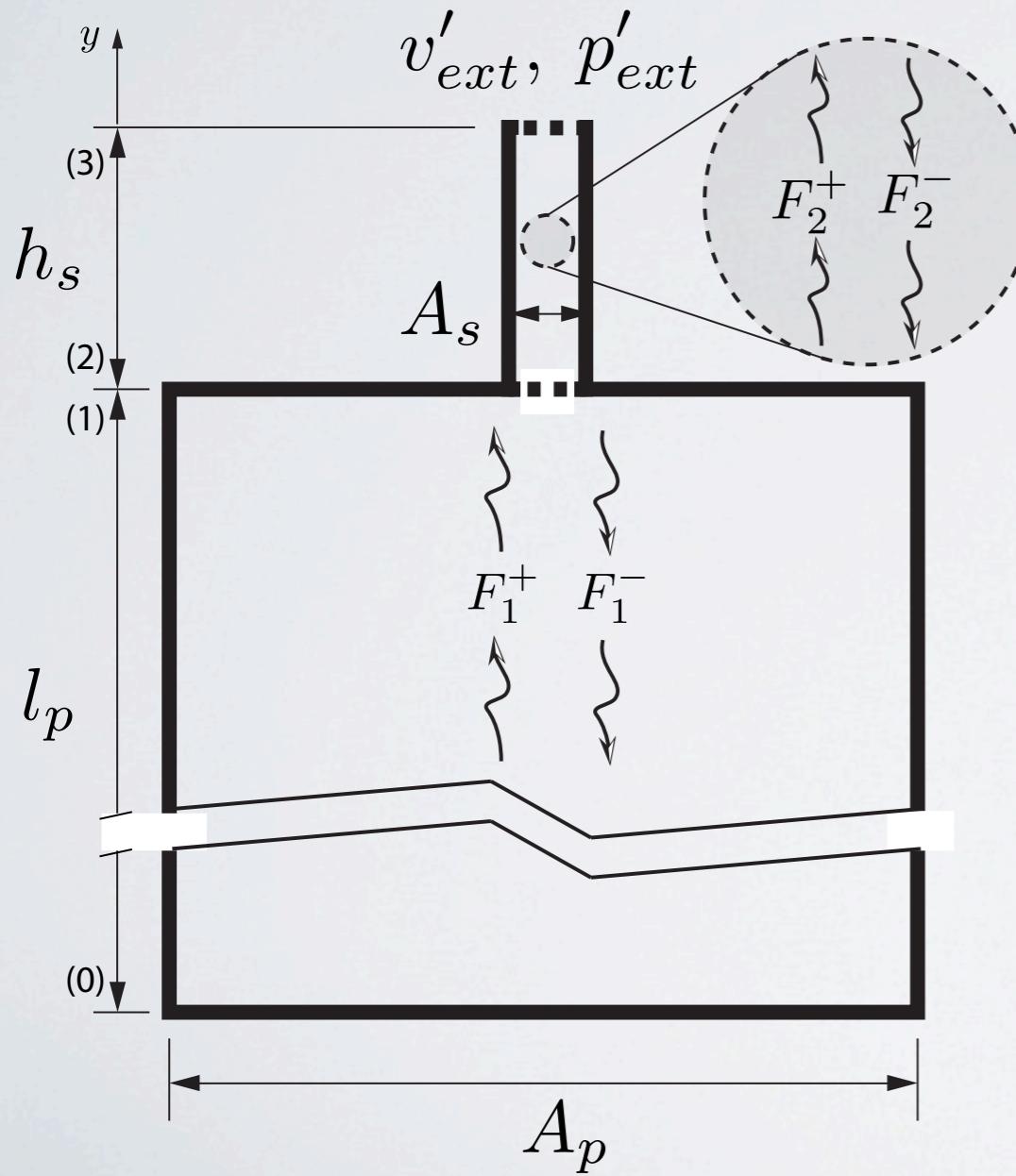
$$p'(y, t) = F^+ e^{i(ky - \omega t)} + F^- e^{i(-ky - \omega t)}$$

$$v'(y, t) = \frac{1}{\rho c} \left(F^+ e^{i(ky - \omega t)} - F^- e^{i(-ky - \omega t)} \right)$$



BURNER ACOUSTICS

Helmholtz resonator



Wave equation

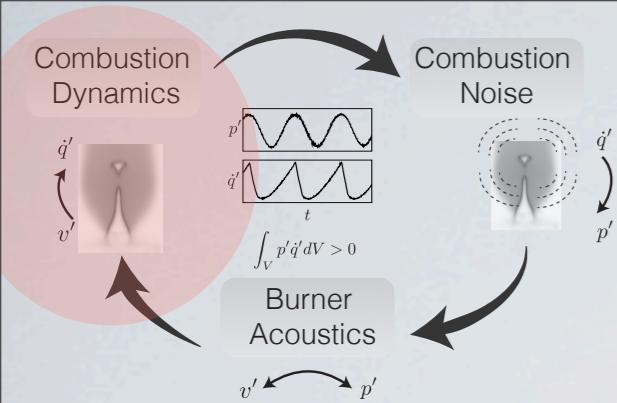
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$$v'(y, t) = \frac{1}{\rho c} \left(F^+ e^{i(ky - \omega t)} - F^- e^{i(-ky - \omega t)} \right)$$

Acoustic networks of compact elements

$$\frac{d^2 p'_0}{dt^2} + 2\delta \frac{dp'_0}{dt} + \omega_0^2 p'_0 = \omega_0^2 p'_{ext}$$

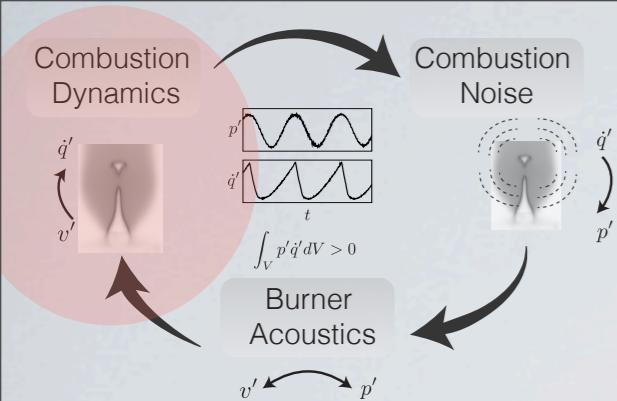


COMBUSTION DYNAMICS

Modèle $n - \tau$

$$\dot{q}' = n [v'_1]_{t-\tau_c}^*$$

★ Crocco (1951)

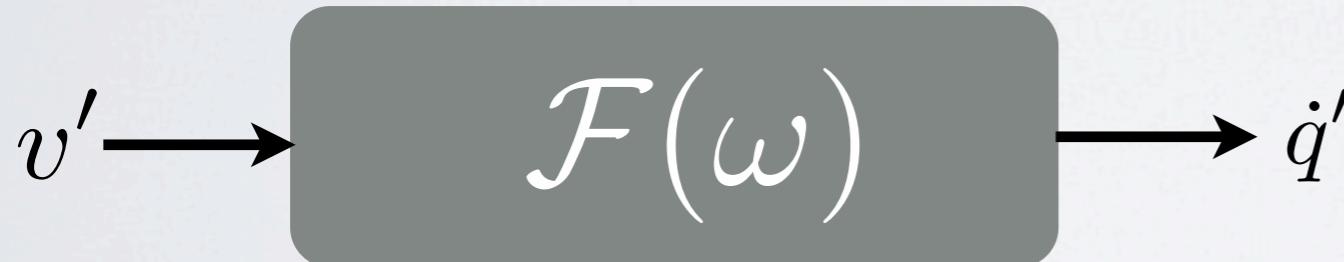


COMBUSTION DYNAMICS

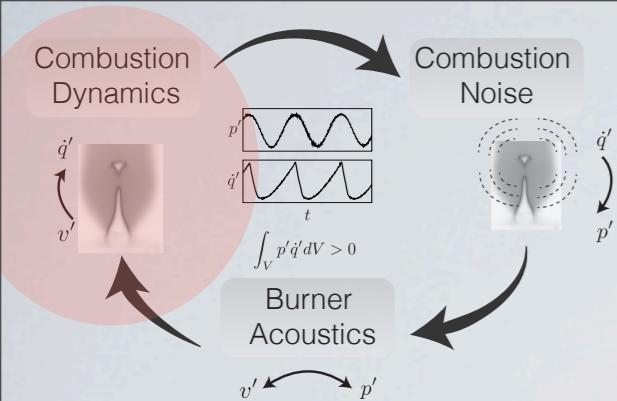
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Flame Transfer Function approach



★ Crocco (1951)



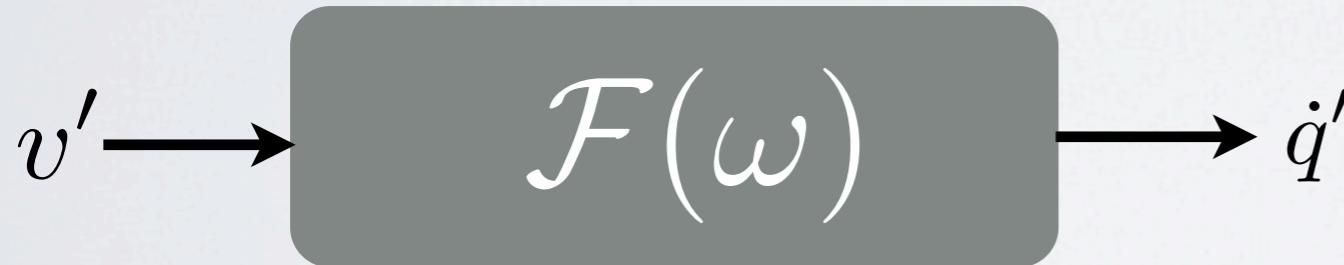
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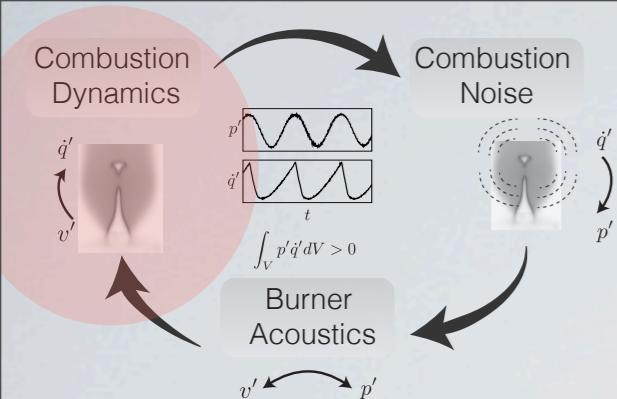
$$\dot{q}' = n [v'_1]_{t-\tau_c}^*$$

$$\mathcal{F}(\omega) = \frac{\dot{q}' / \bar{\dot{q}}}{v'_1 / \bar{v}} = \frac{\mathcal{A}' / \bar{\mathcal{A}}}{v'_1 / \bar{v}}$$

Flame Transfer Function approach



★ Crocco (1951)



COMBUSTION DYNAMICS

Modèle $n - \tau$

$$\dot{q}' = n [v'_1]_{t-\tau_c}^*$$

Flame Transfer Function approach

$$v' \rightarrow \mathcal{F}(\omega) \rightarrow \dot{q}'$$

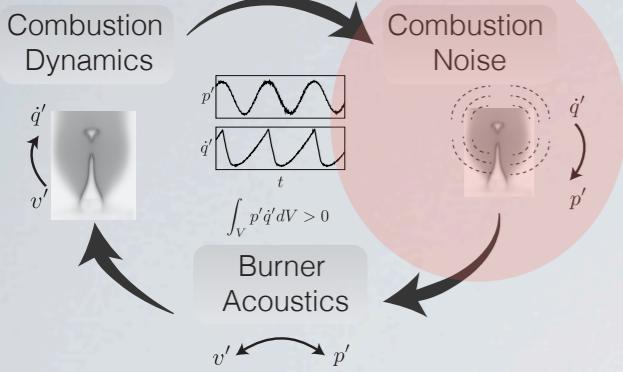
$$\mathcal{F}(\omega) = \frac{\dot{q}' / \bar{q}}{v'_1 / \bar{v}} = \frac{\mathcal{A}' / \bar{\mathcal{A}}}{v'_1 / \bar{v}}$$

$$\mathcal{G} = |\mathcal{F}(\omega)|$$

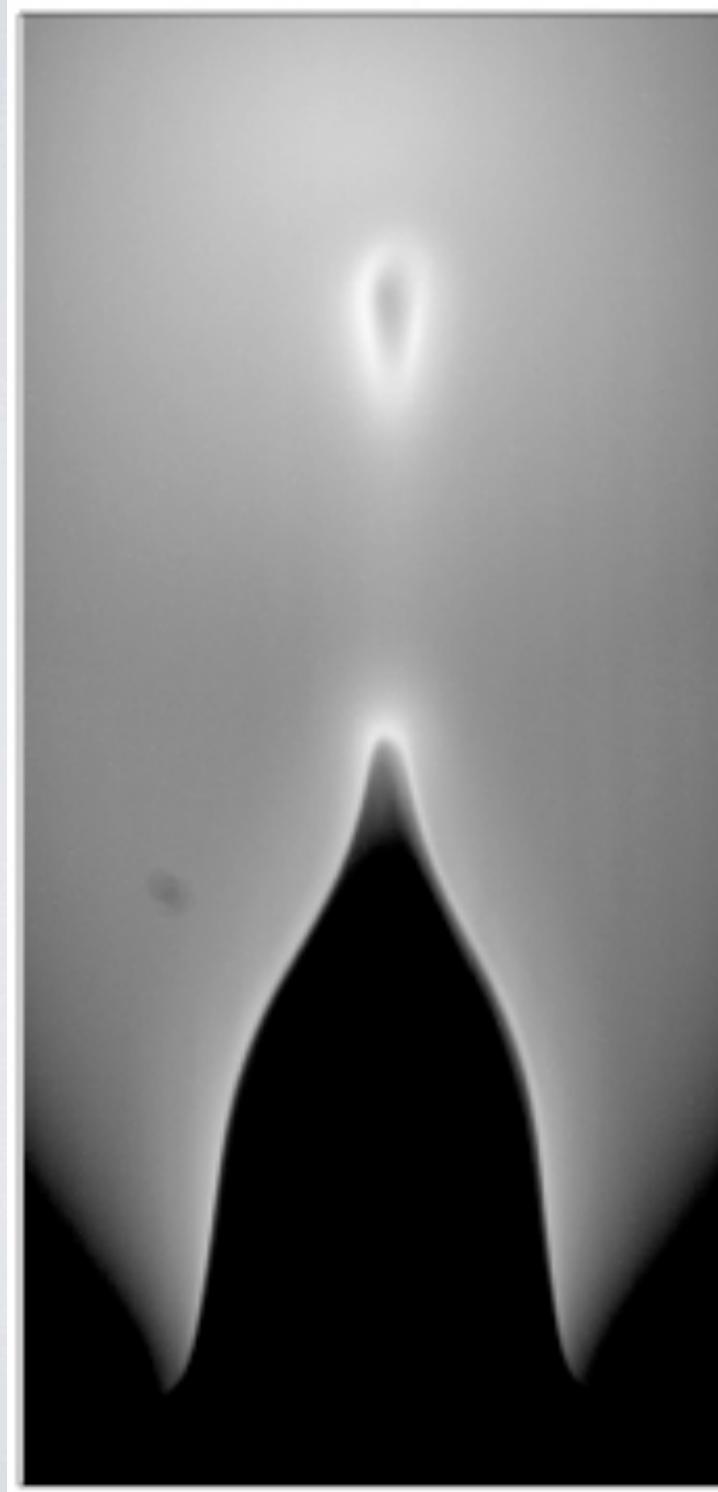
$$\varphi = \arg[\mathcal{F}(\omega)]$$

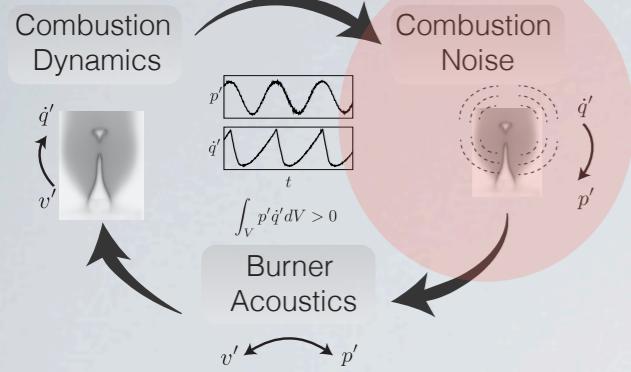
$$\mathcal{F}(\omega) = \mathcal{G}(\omega) e^{i\varphi(\omega)}$$

★ Crocco (1951)

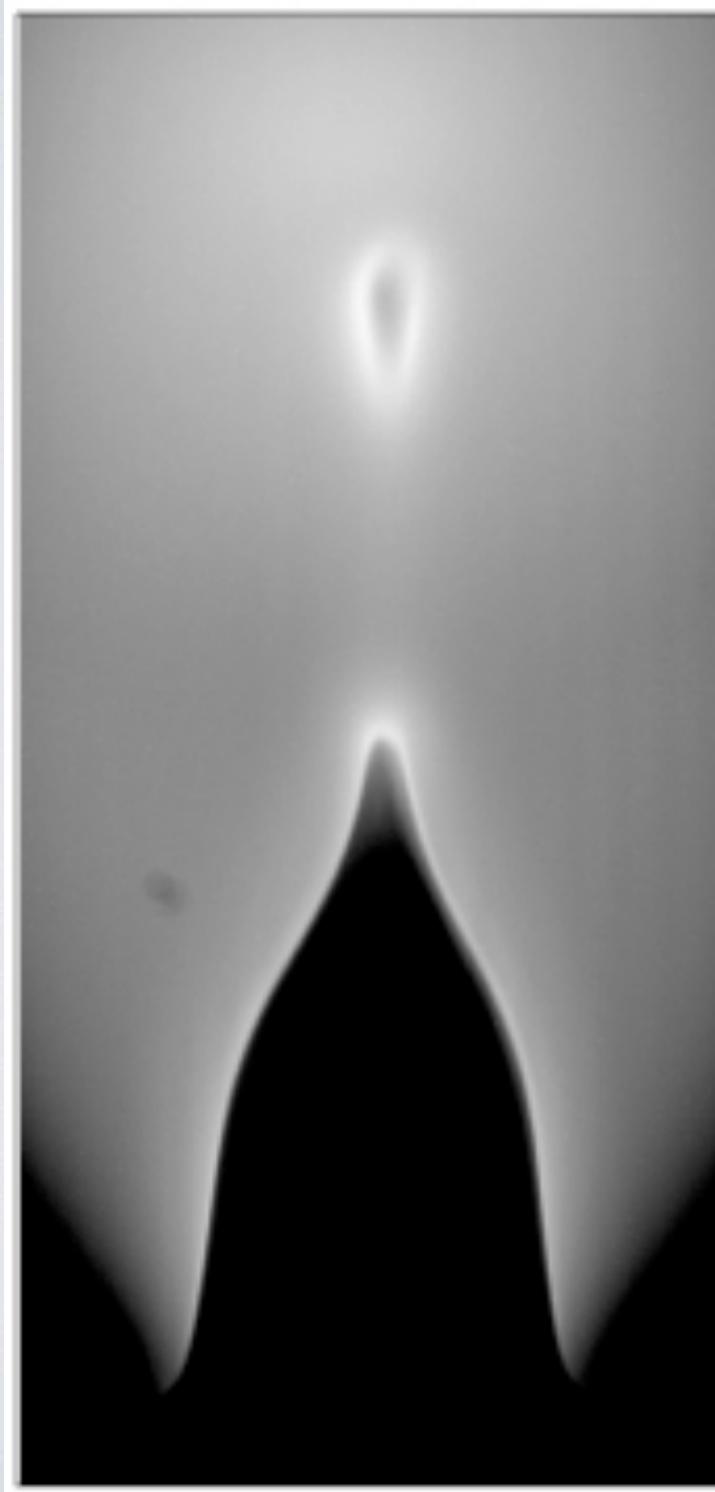


COMBUSTION NOISE



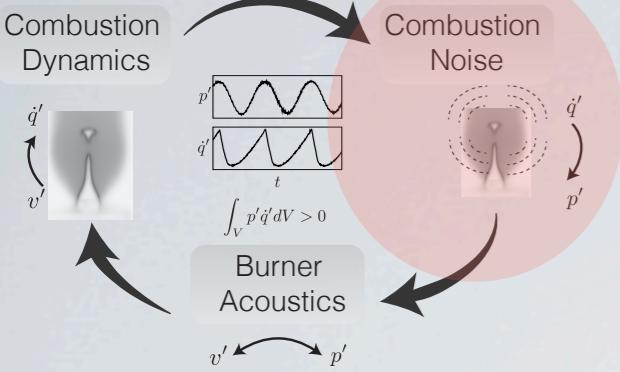


COMBUSTION NOISE

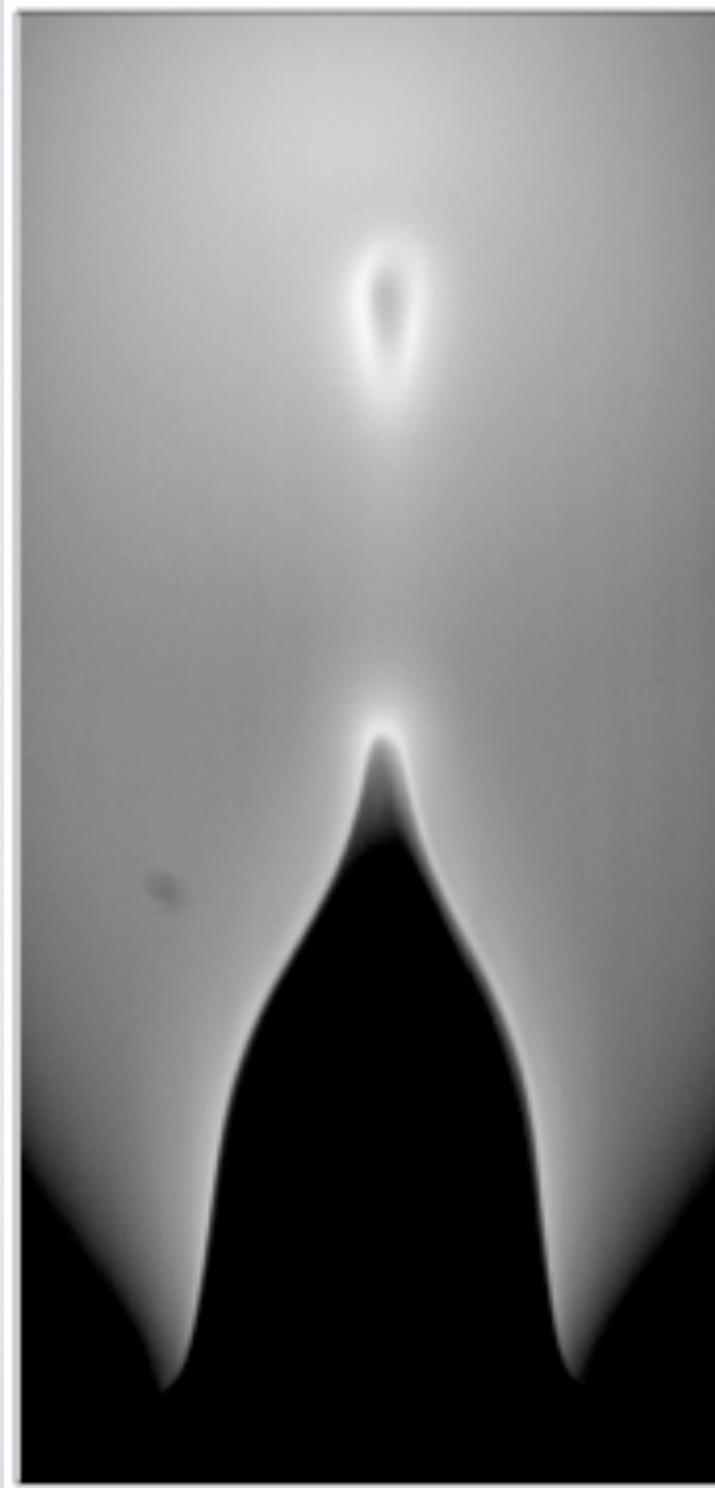


$$p'(\mathbf{x}, t) = \frac{\gamma - 1}{4\pi|\mathbf{x}|c^2} \int_V \frac{\partial \dot{q}}{\partial t}(\mathbf{x}_0, t - \tau_{ac}) dV(\mathbf{x}_0) \star$$

★ Strahle (1971)



COMBUSTION NOISE

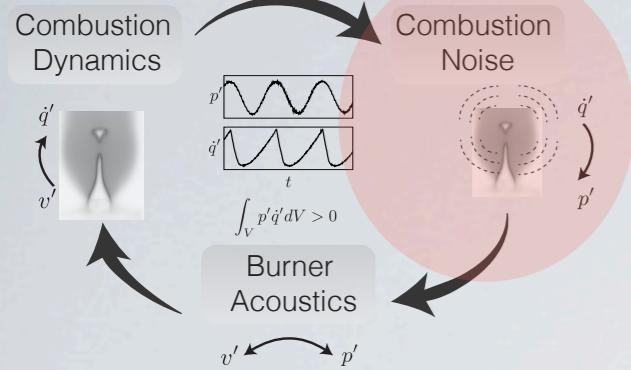


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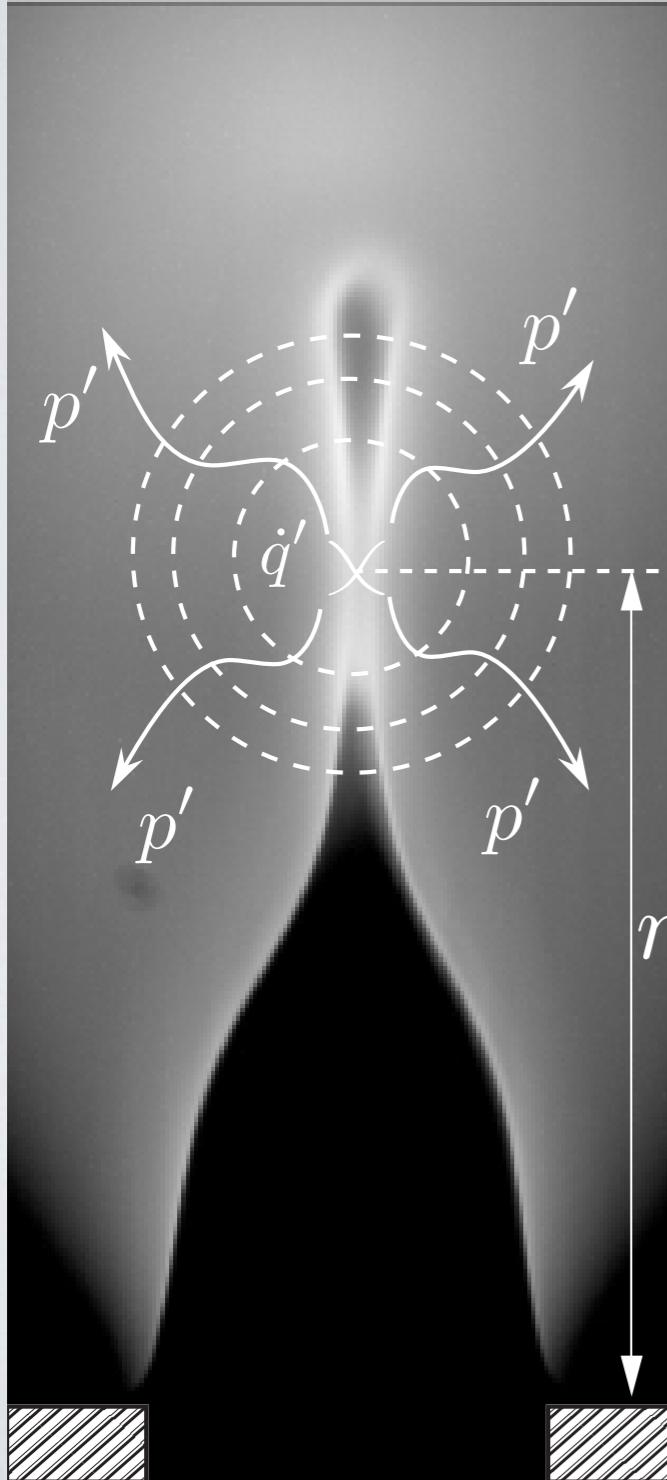
- Compact flame,
- Perfect premixed combustion,

$$\int_V \dot{q} dV = \int_A \rho Y_F s_D(-\Delta h_f^0) dA$$

★ Strahle (1971)



COMBUSTION NOISE



$$p'(\mathbf{x}, t) = \frac{\gamma - 1}{4\pi|\mathbf{x}|c^2} \int_V \frac{\partial \dot{q}}{\partial t}(\mathbf{x}_0, t - \tau_{ac}) dV(\mathbf{x}_0) \star$$

- Compact flame,
- Perfect premixed combustion,

$$\int_V \dot{q} dV = \int_A \rho Y_F s_D (-\Delta h_f^0) dA$$

- Stretch and curvature are ignored,
- isobaric flame,

$$p'_{ext}(t) = \frac{\rho(E-1)s_L}{4\pi r} \left[\frac{dA'}{dt} \right]_t \diamond$$

★ Strahle (1971)
◊ Clavin and Siggia (1991)

DISPERSION EQUATION

Combustion
Dynamics

Combustion
Noise

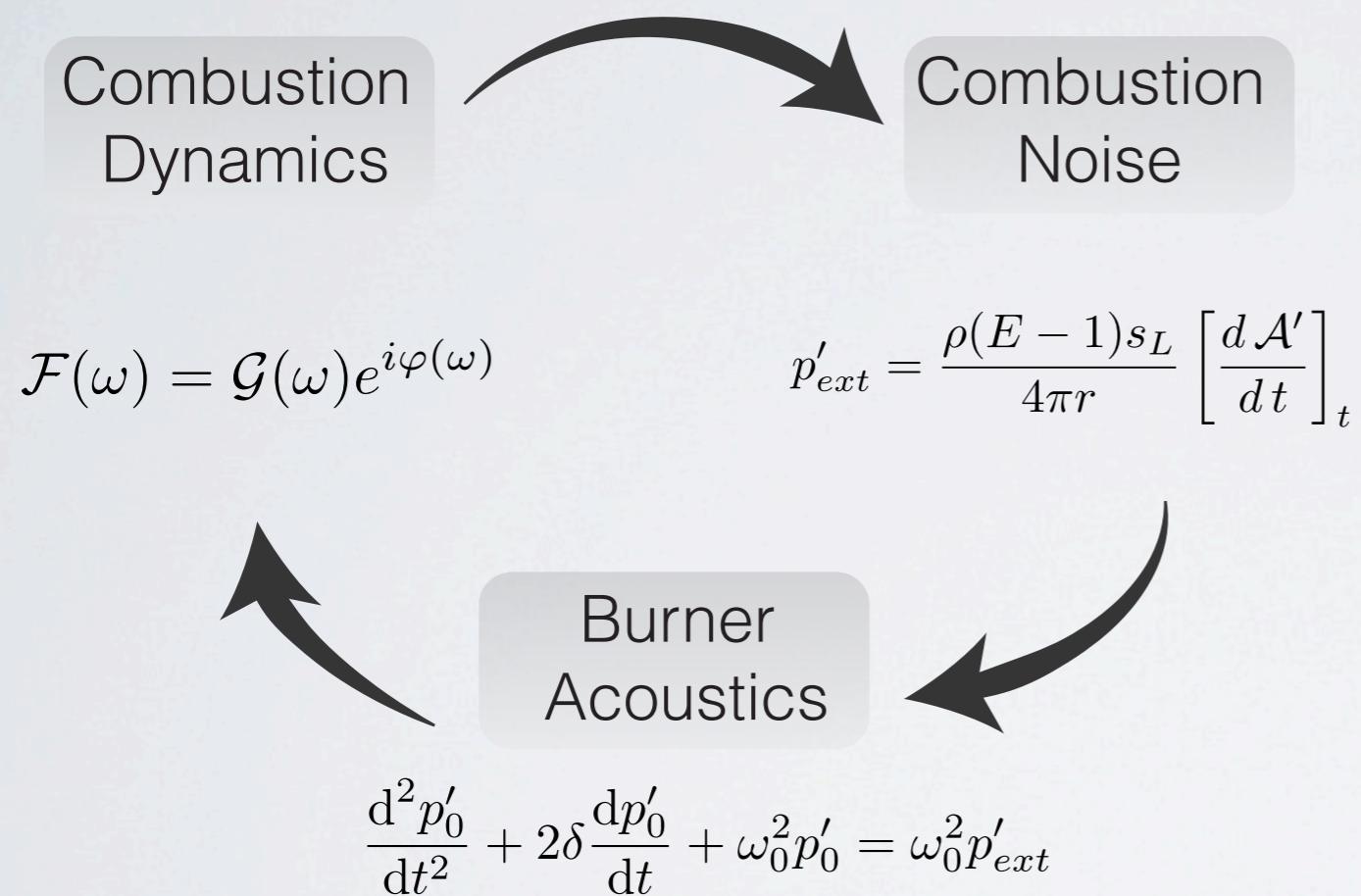
$$\mathcal{F}(\omega) = \mathcal{G}(\omega)e^{i\varphi(\omega)}$$

$$p'_{ext} = \frac{\rho(E-1)s_L}{4\pi r} \left[\frac{d\mathcal{A}'}{dt} \right]_t$$

Burner
Acoustics

$$\frac{d^2 p'_0}{dt^2} + 2\delta \frac{dp'_0}{dt} + \omega_0^2 p'_0 = \omega_0^2 p'_{ext}$$

DISPERSION EQUATION



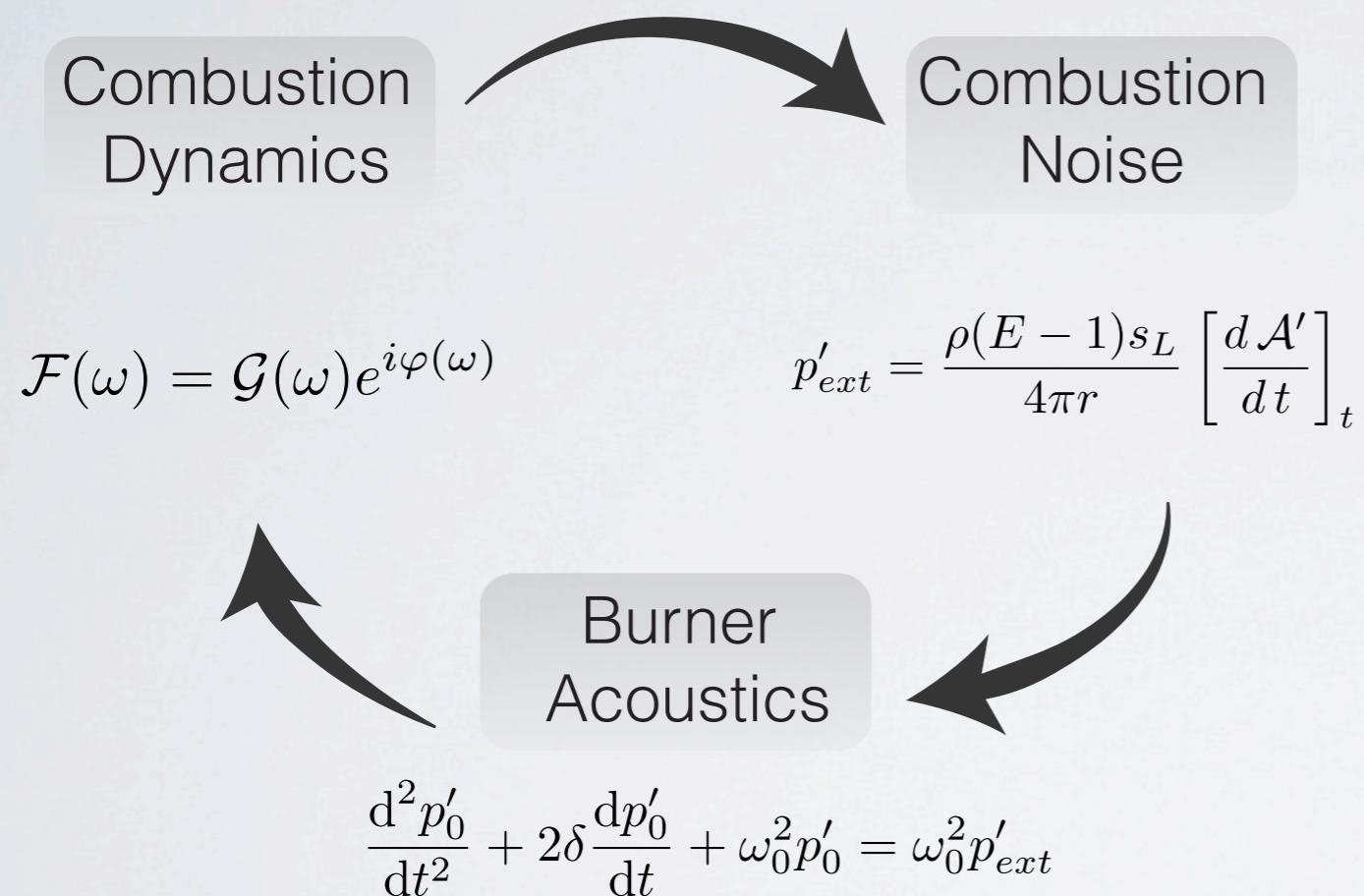
Harmonic perturbations

$$\omega^2 + 2i\delta\omega - \omega_0^2 = -\frac{A_s}{4\pi h_e} \frac{E-1}{r} \omega^2$$

$$\left[1 + C \frac{1}{r} n e^{i\varphi} \right] \omega^2 + 2i\delta\omega - \omega_0^2 = 0$$

$$C = \frac{1}{4\pi} \frac{A_s}{h_e} (E-1)$$

DISPERSION EQUATION



Harmonic perturbations

$$\omega^2 + 2i\delta\omega - \omega_0^2 = -\frac{A_s}{4\pi h_e} \frac{E-1}{r} \omega^2$$

$$\left[1 + C \frac{1}{r} n e^{i\varphi} \right] \omega^2 + 2i\delta\omega - \omega_0^2 = 0$$

$$C = \frac{1}{4\pi} \frac{A_s}{h_e} (E-1)$$

$$\omega = \omega_r + \omega_i$$

$\omega_r \rightarrow$ Frequency of resonance

$\omega_i \rightarrow$ Growth rate

The system will develop combustion instabilities if:

$$\omega_i > 0$$

STABILITY CRITERIA

The system may develop self-induced oscillations when the acoustic energy produced by unsteady combustion is fed into the system.

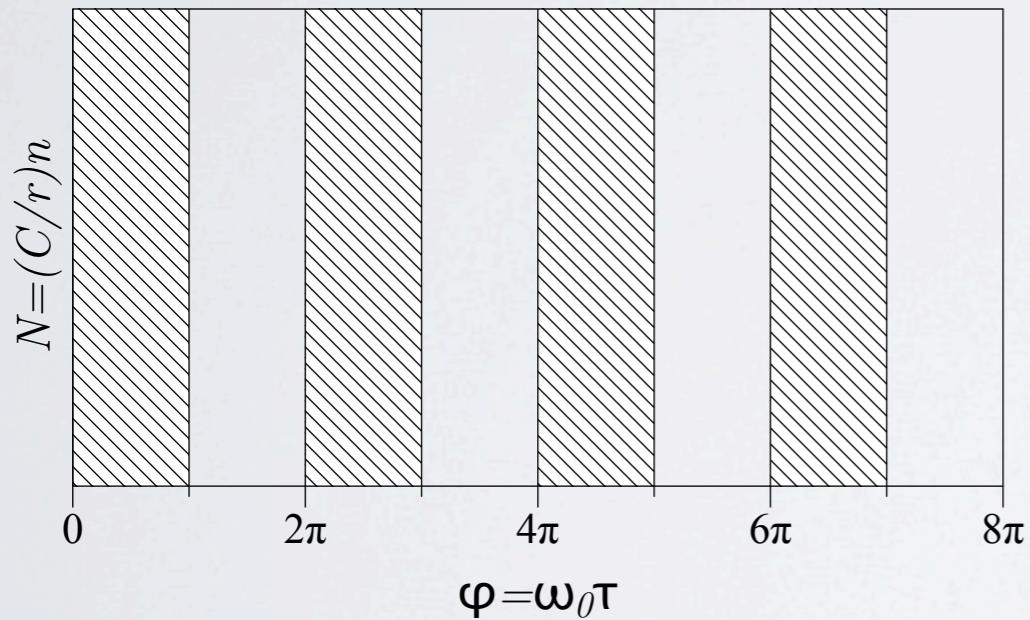
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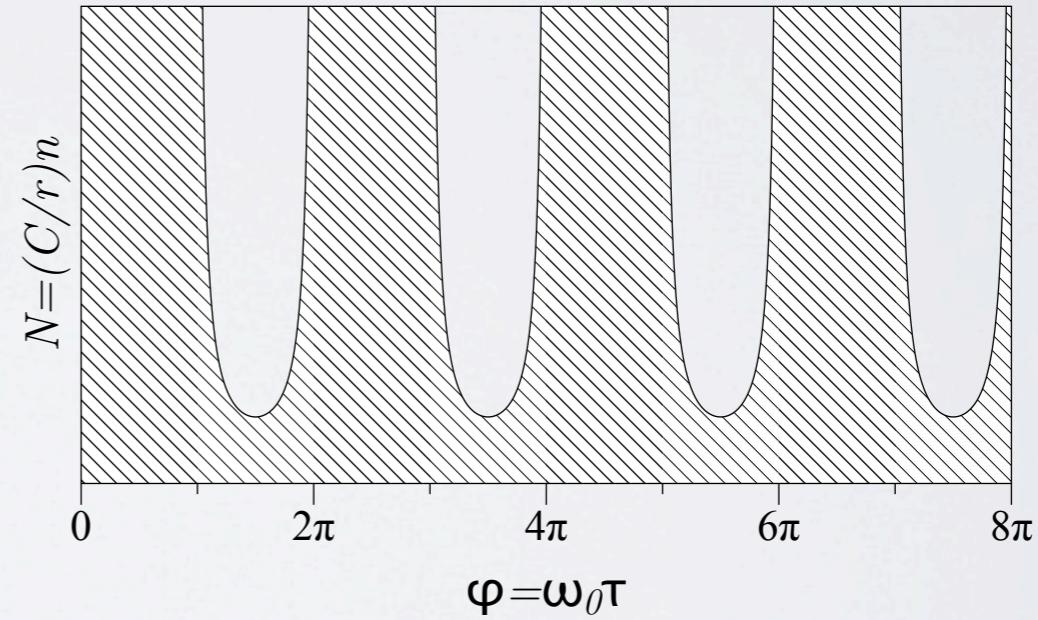
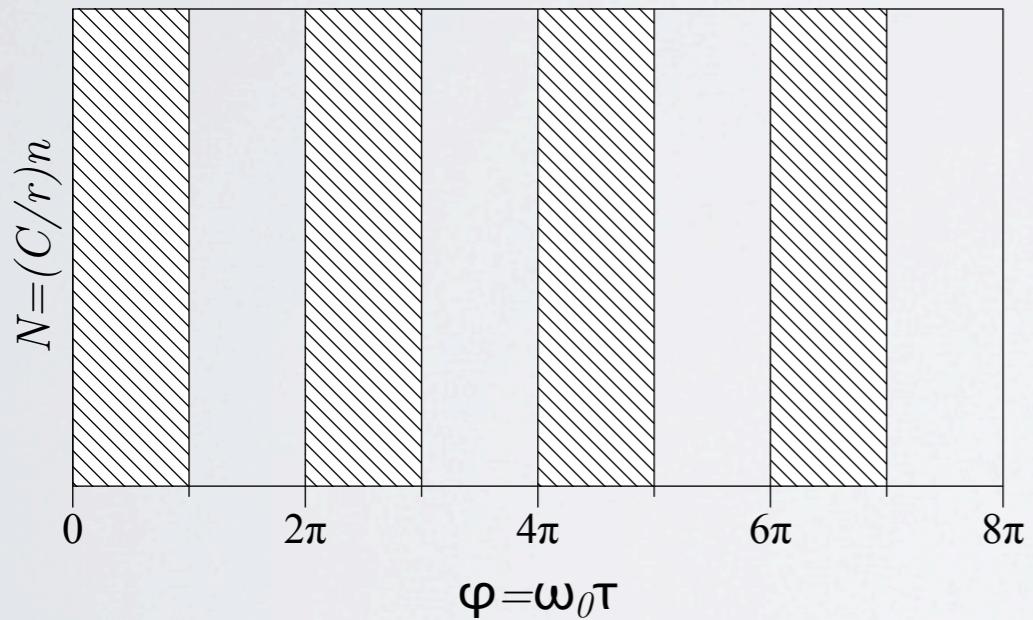
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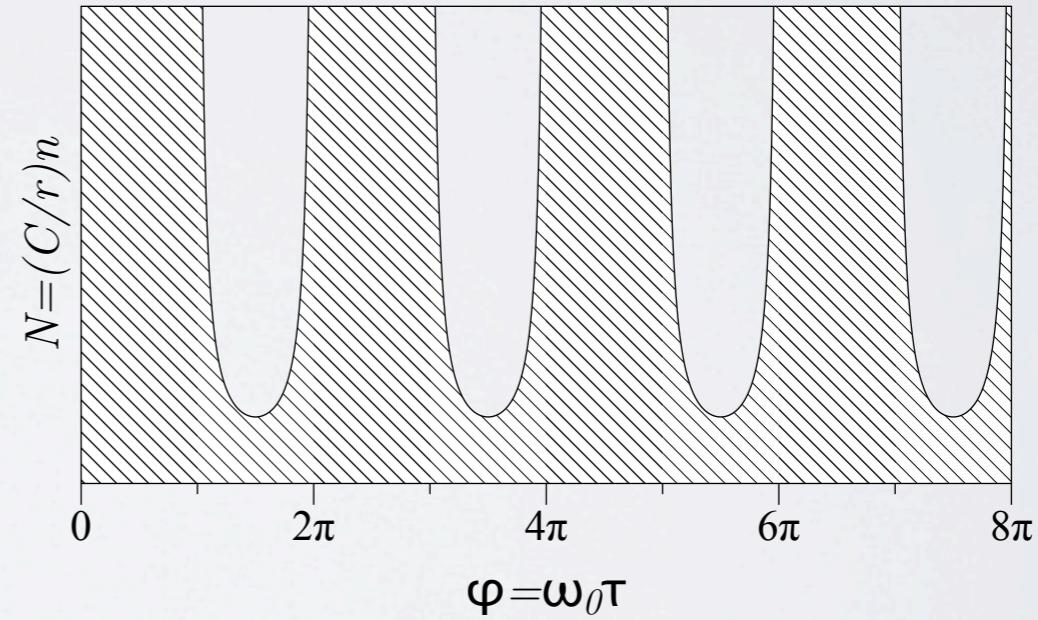
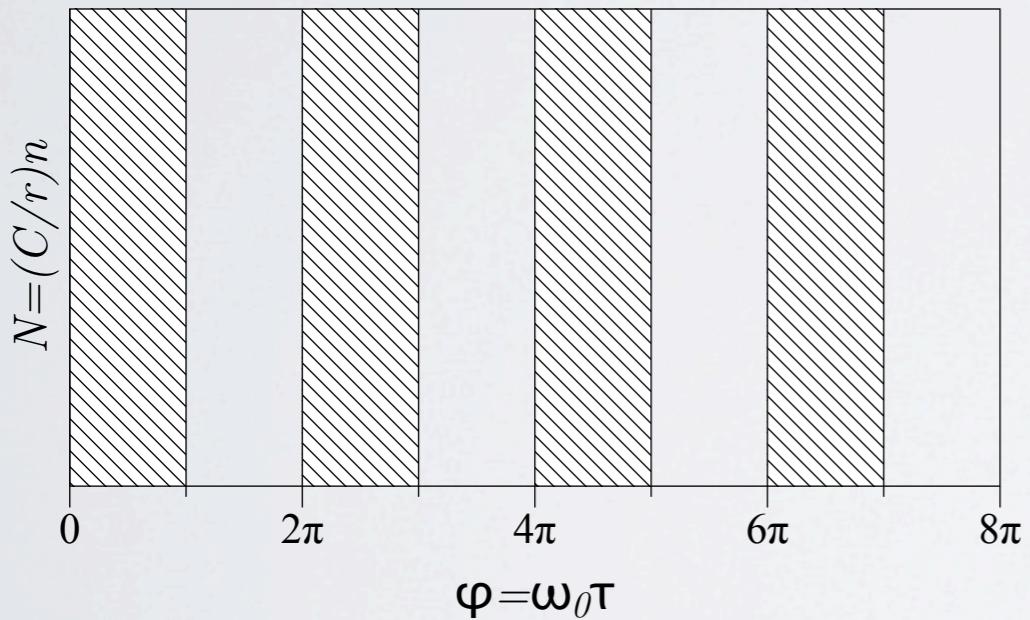
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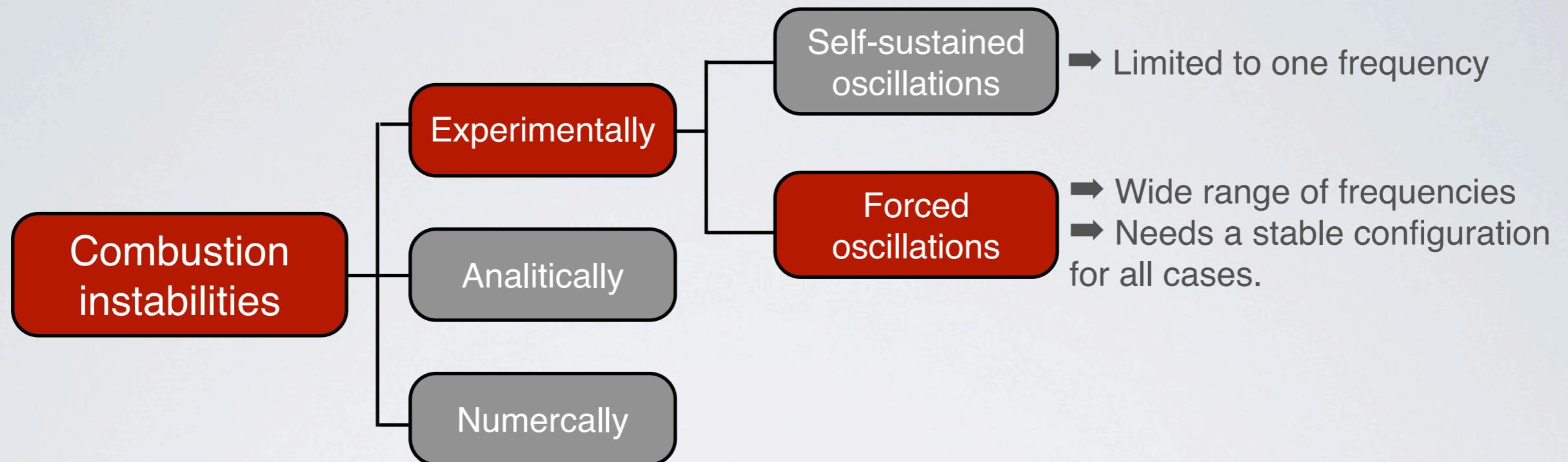
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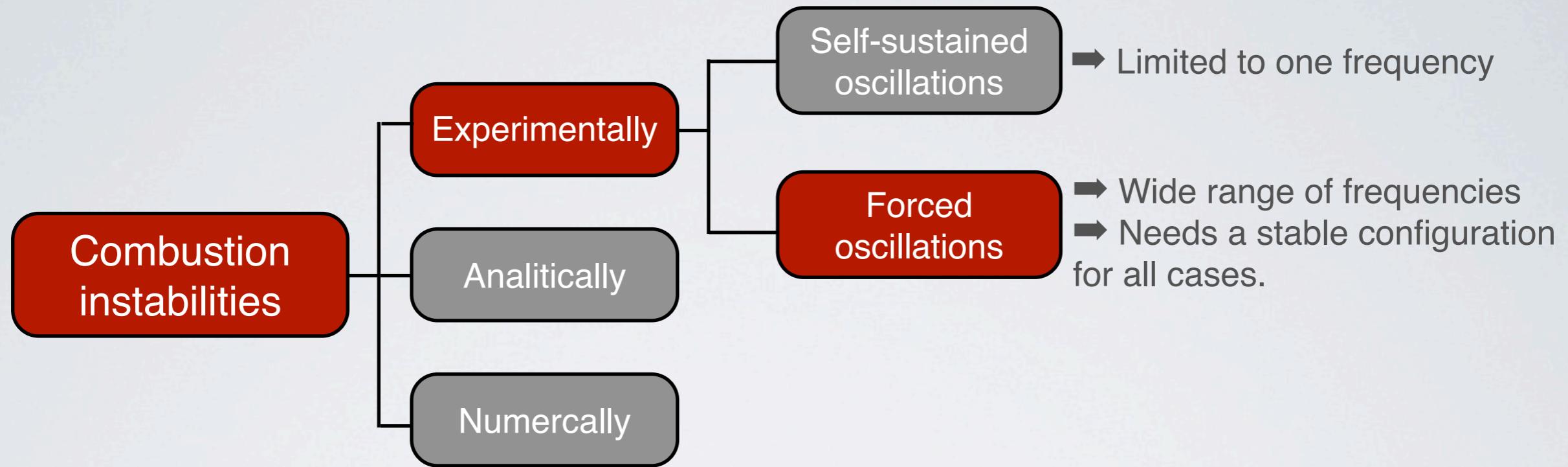


**To solve the problem one needs to determine:
 r, δ, ω_0, n and τ .**

METHODOLOGY

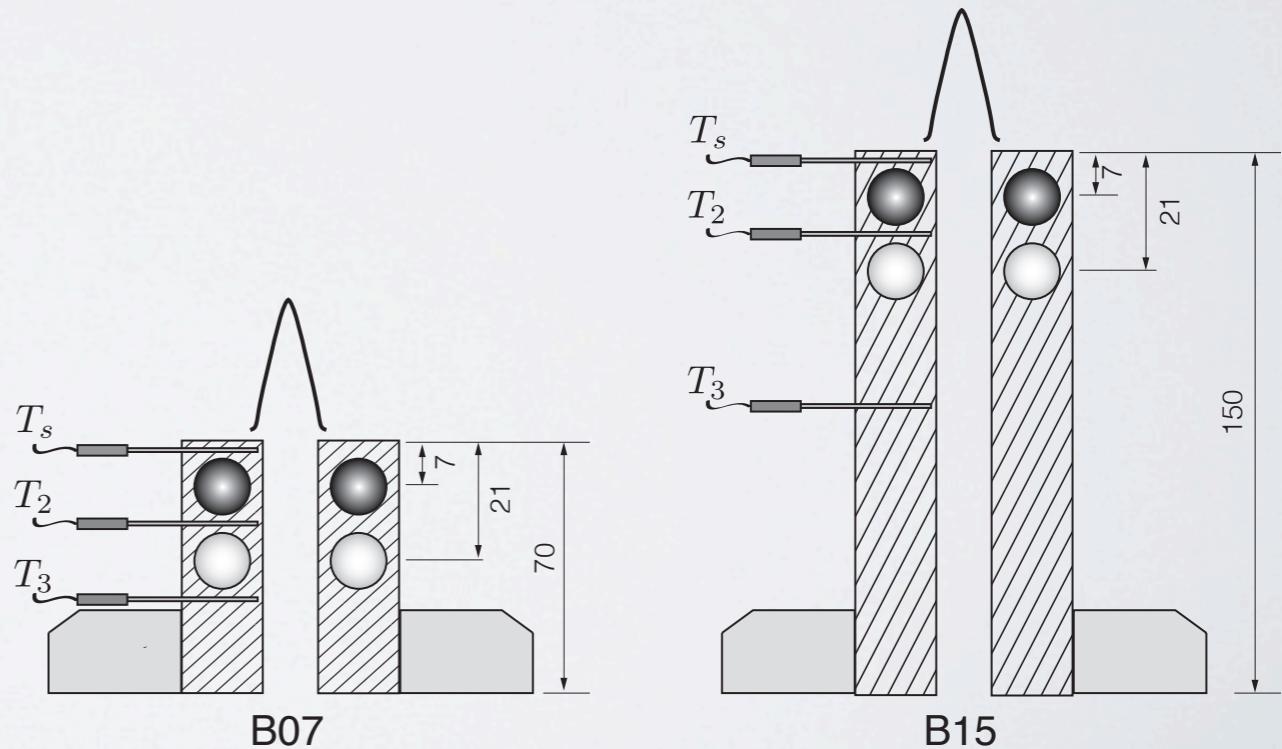


METHODOLOGY

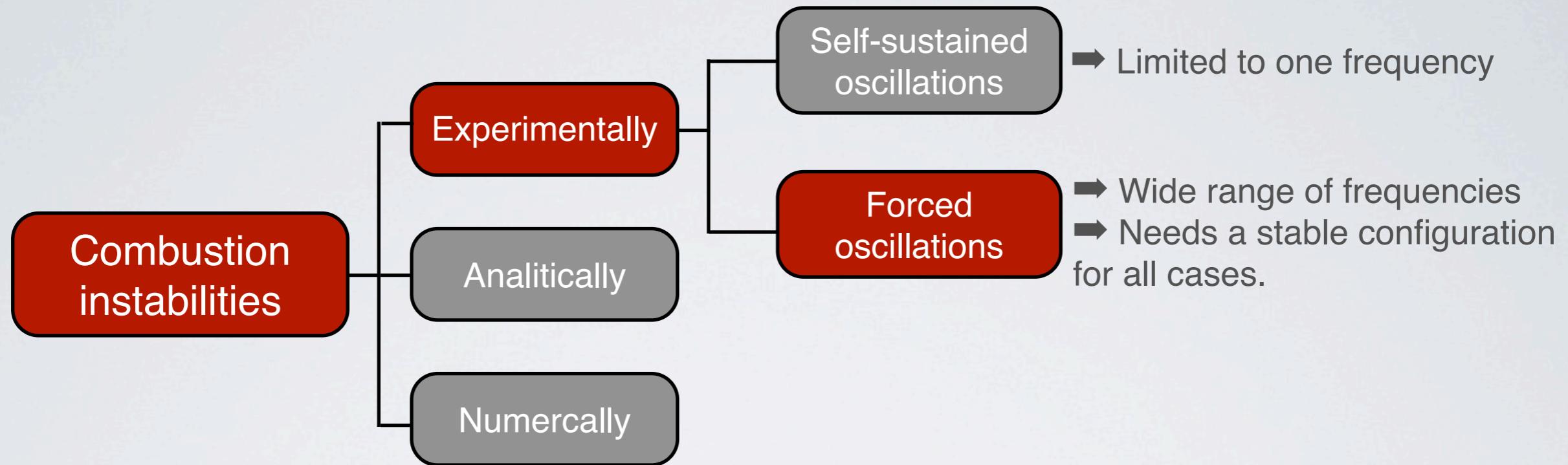


Stabilizing the flame

A simple method to stabilize the flame is to increase the length of the feeding duct: This increases the acoustic dissipation and decrease the Helmholtz frequency bringing back the configuration to an unconditionally stable region.



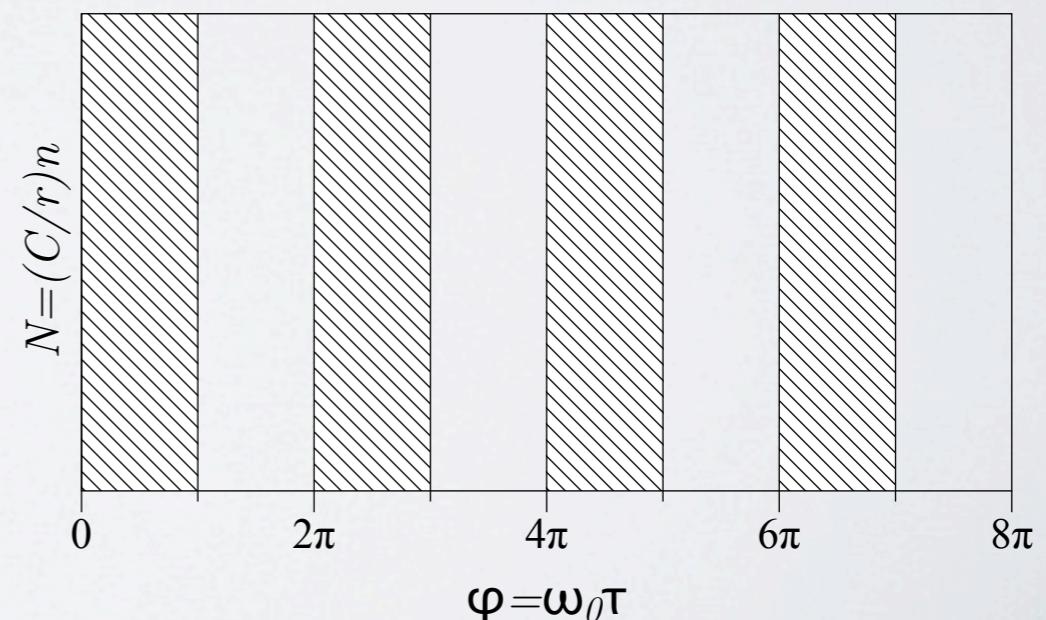
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$$\varphi = 2\pi f_0 \tau \neq [\pi, 2\pi]$$



EXPERIMENTAL MEASUREMENTS

	Need to determine	Configuration	Burner
Combustion noise	r	Reacting	B15
Acoustics	δ	Non-reacting	B07
Combustion dynamics	n	Reacting	B15

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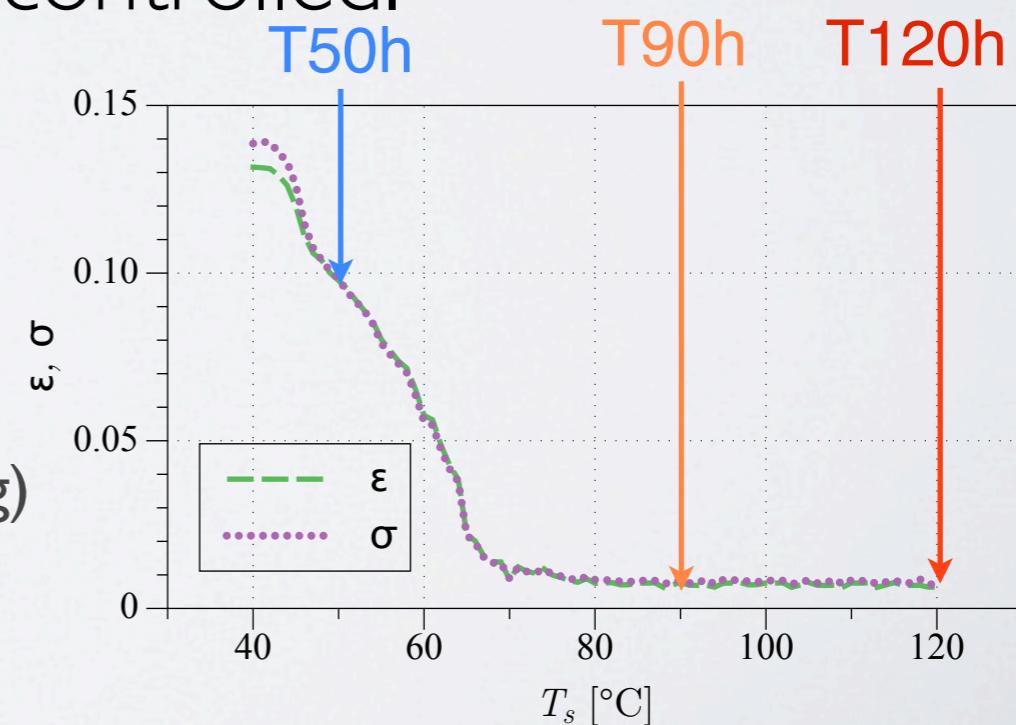
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Code for experiments:

T50c

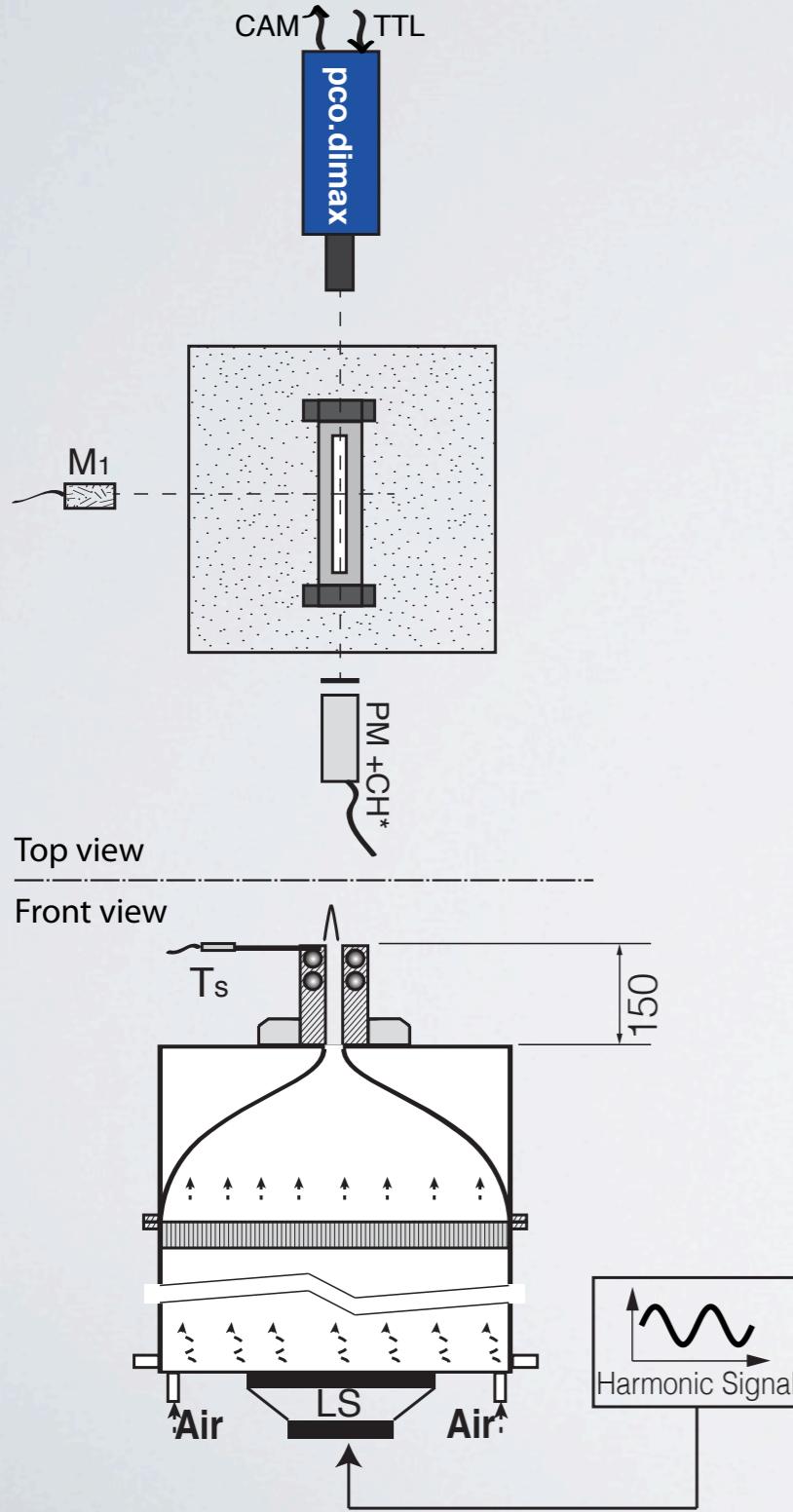
c: cold (non reacting)
h: hot (reacting)

Wall temperature [°C]



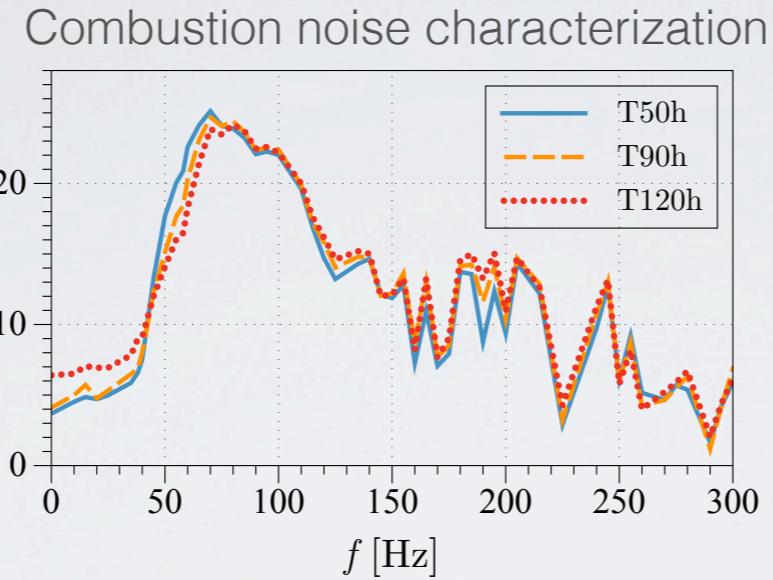
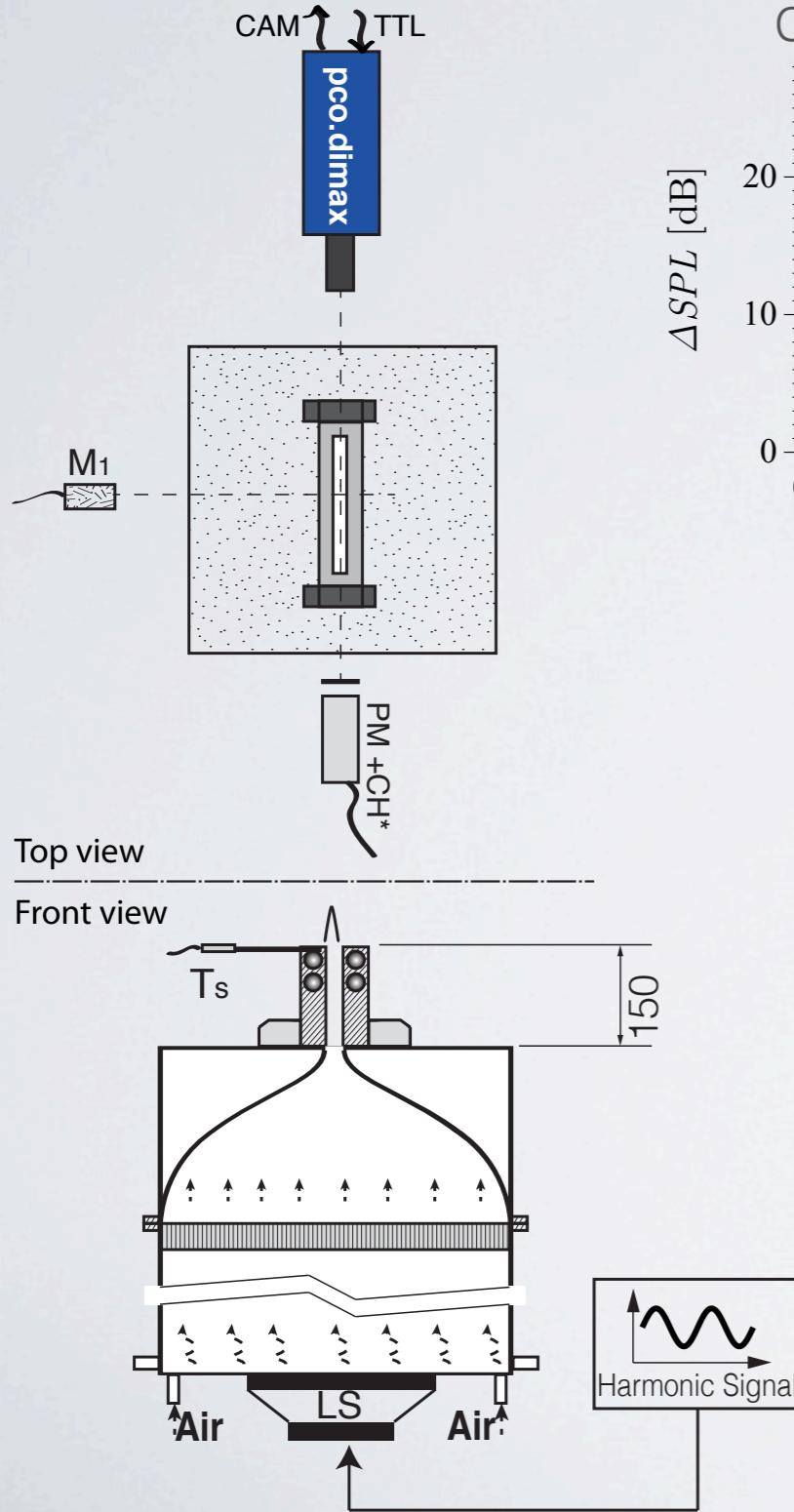
COMBUSTION NOISE

Validation of combustion noise theory



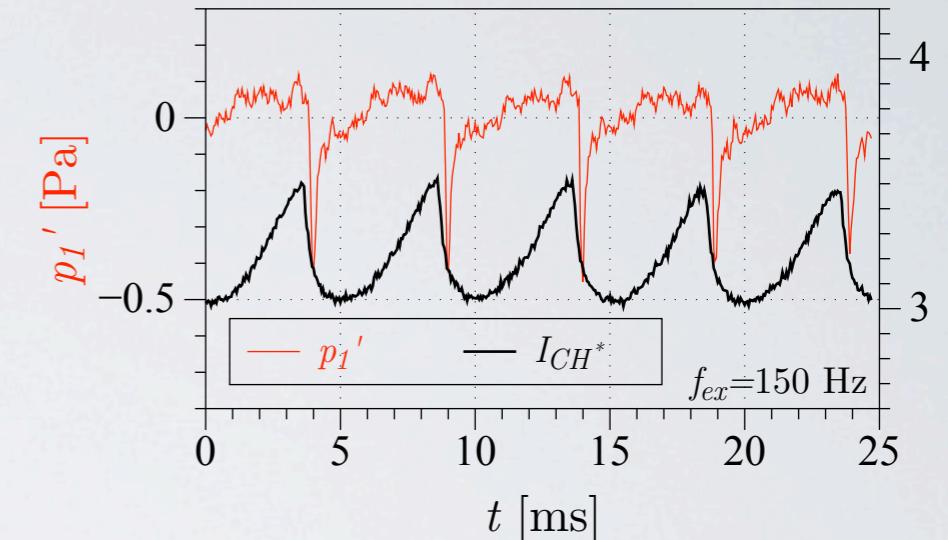
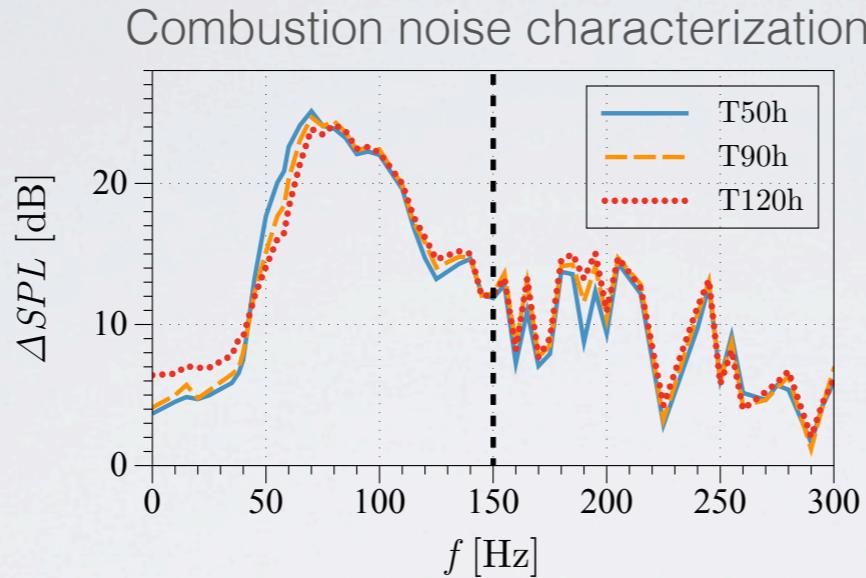
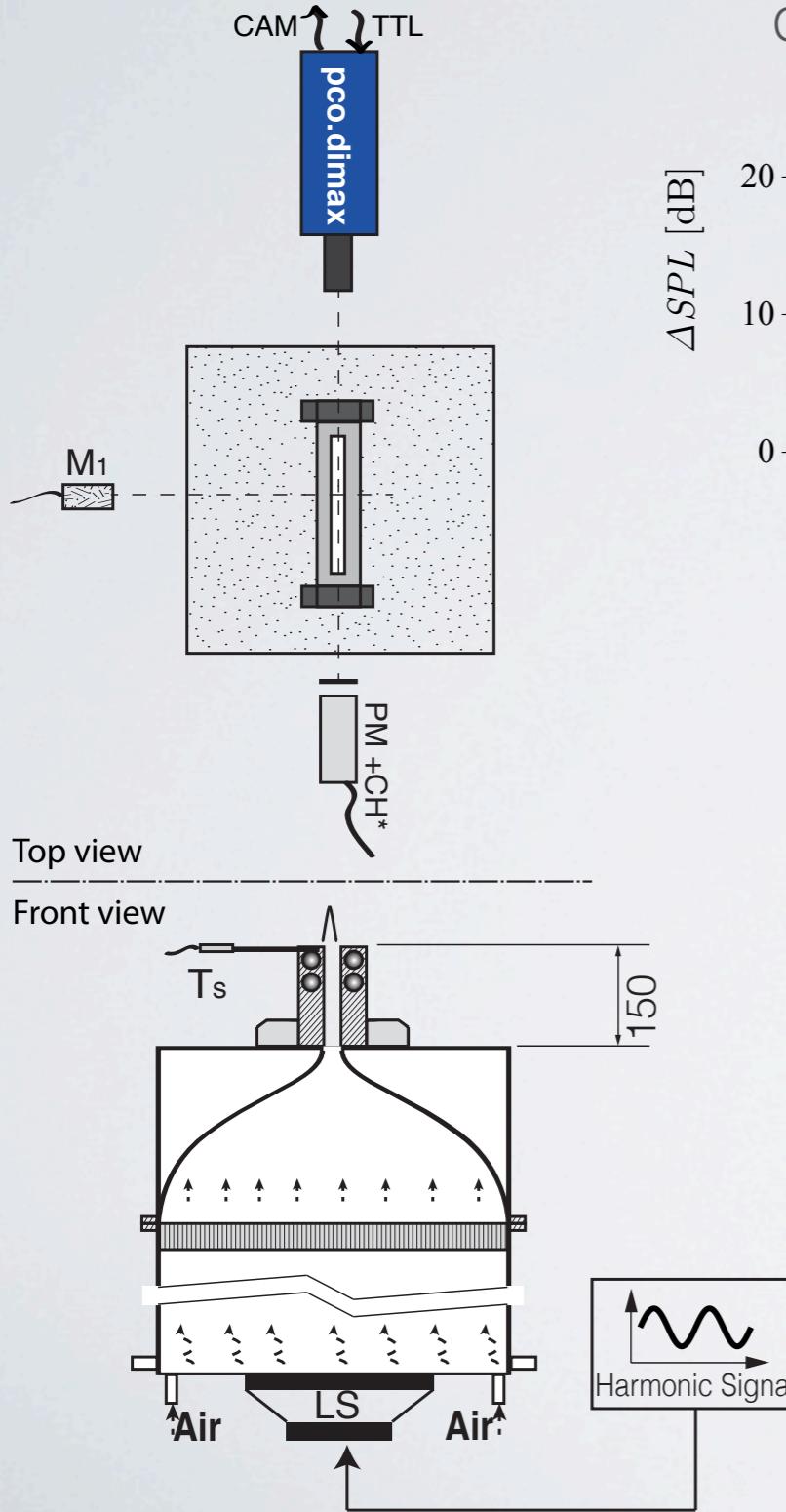
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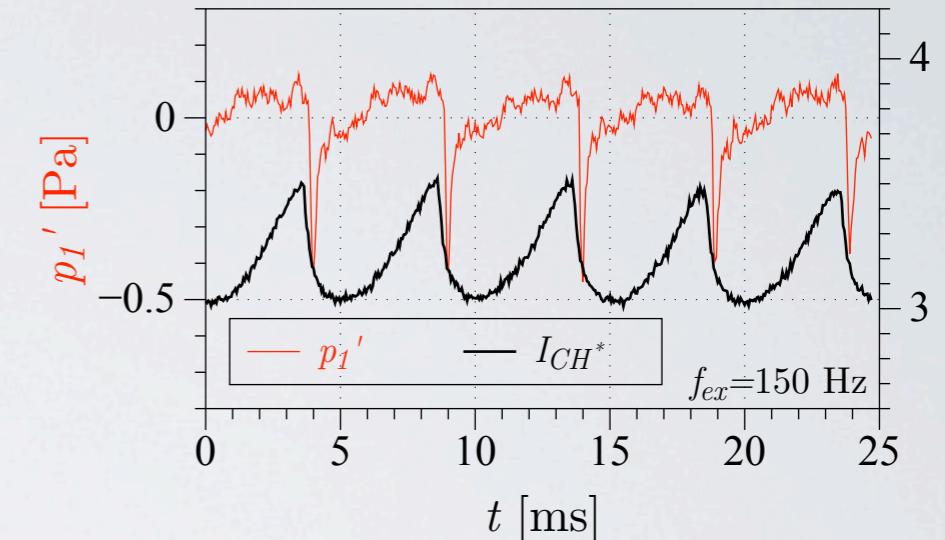
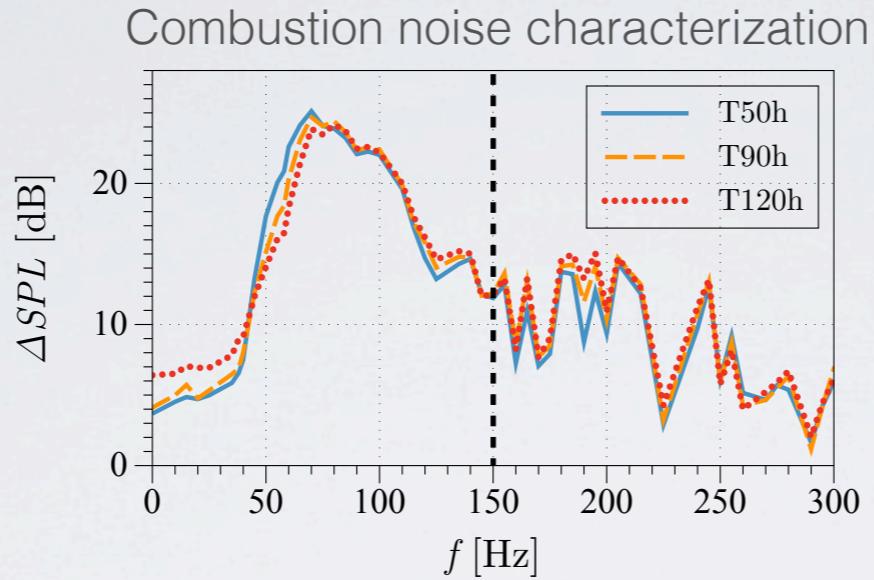
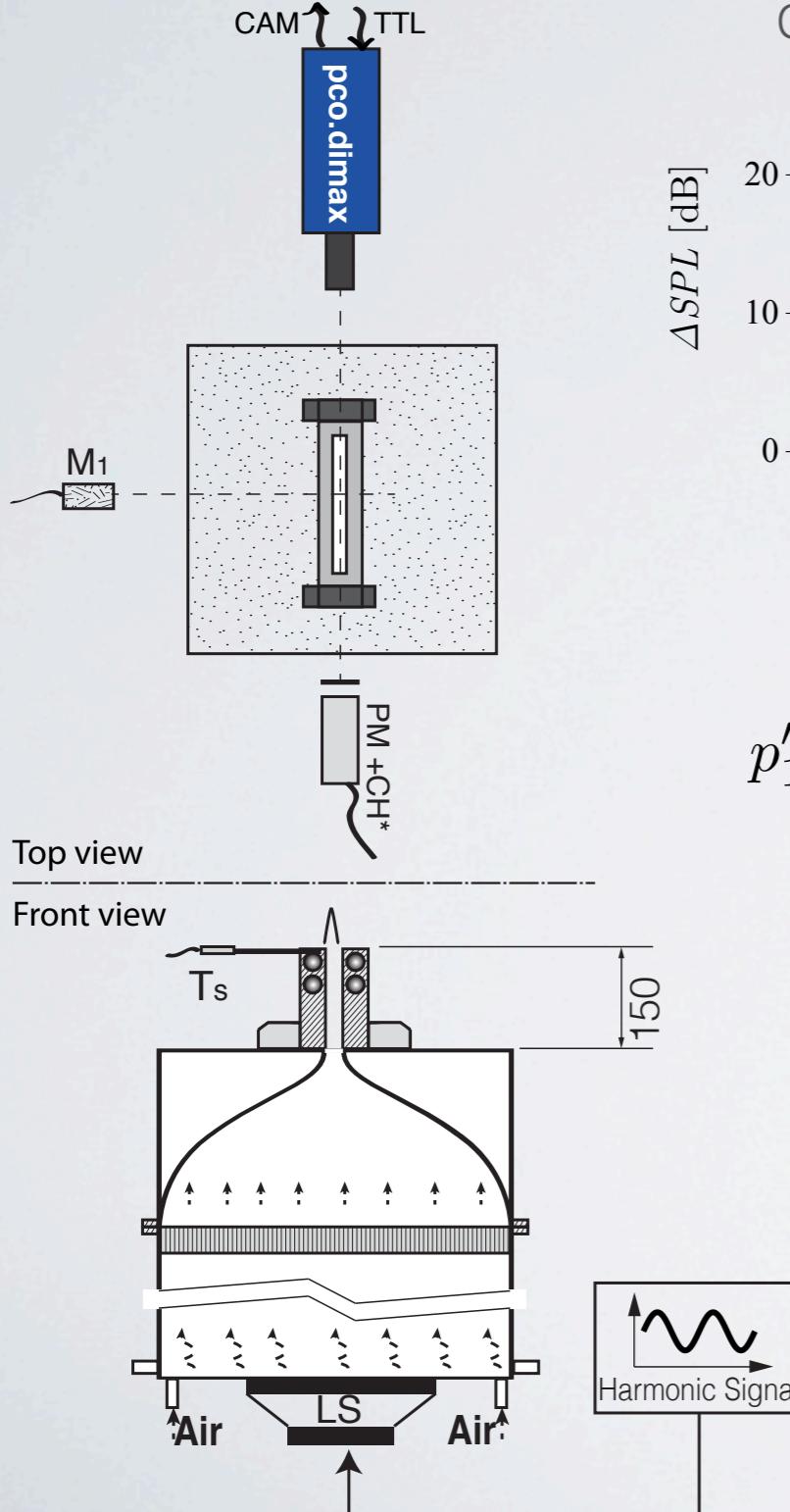
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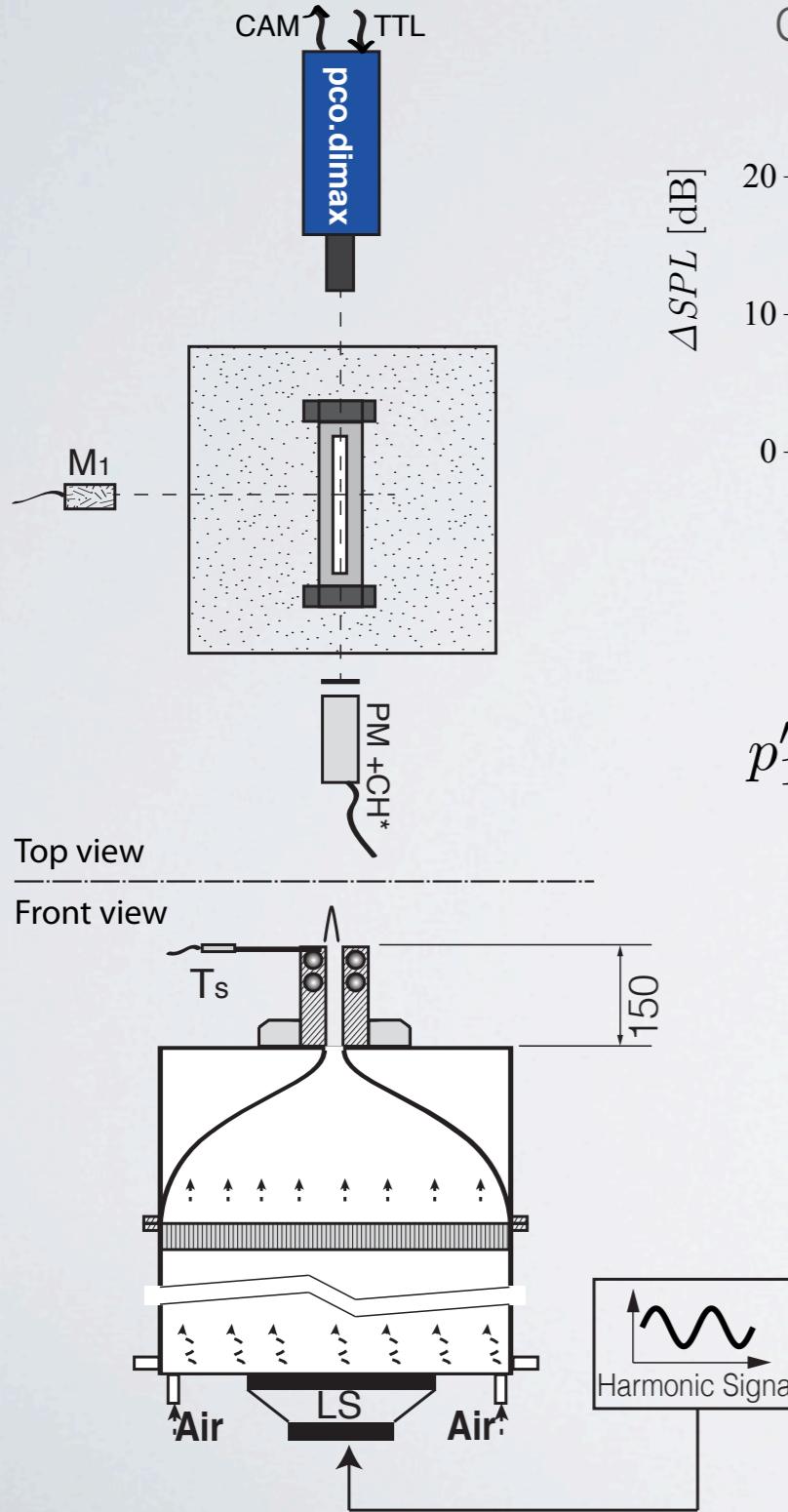


$$p'_1(\mathbf{x}, t) = \mathcal{K}(\mathbf{x}) \left[\frac{d I_{CH^*}}{d t} \right]_{t-\tau_{ac}}$$

$$\mathcal{K}(\mathbf{x}) = \frac{\rho(E-1)}{4\pi|\mathbf{x}|} \kappa$$

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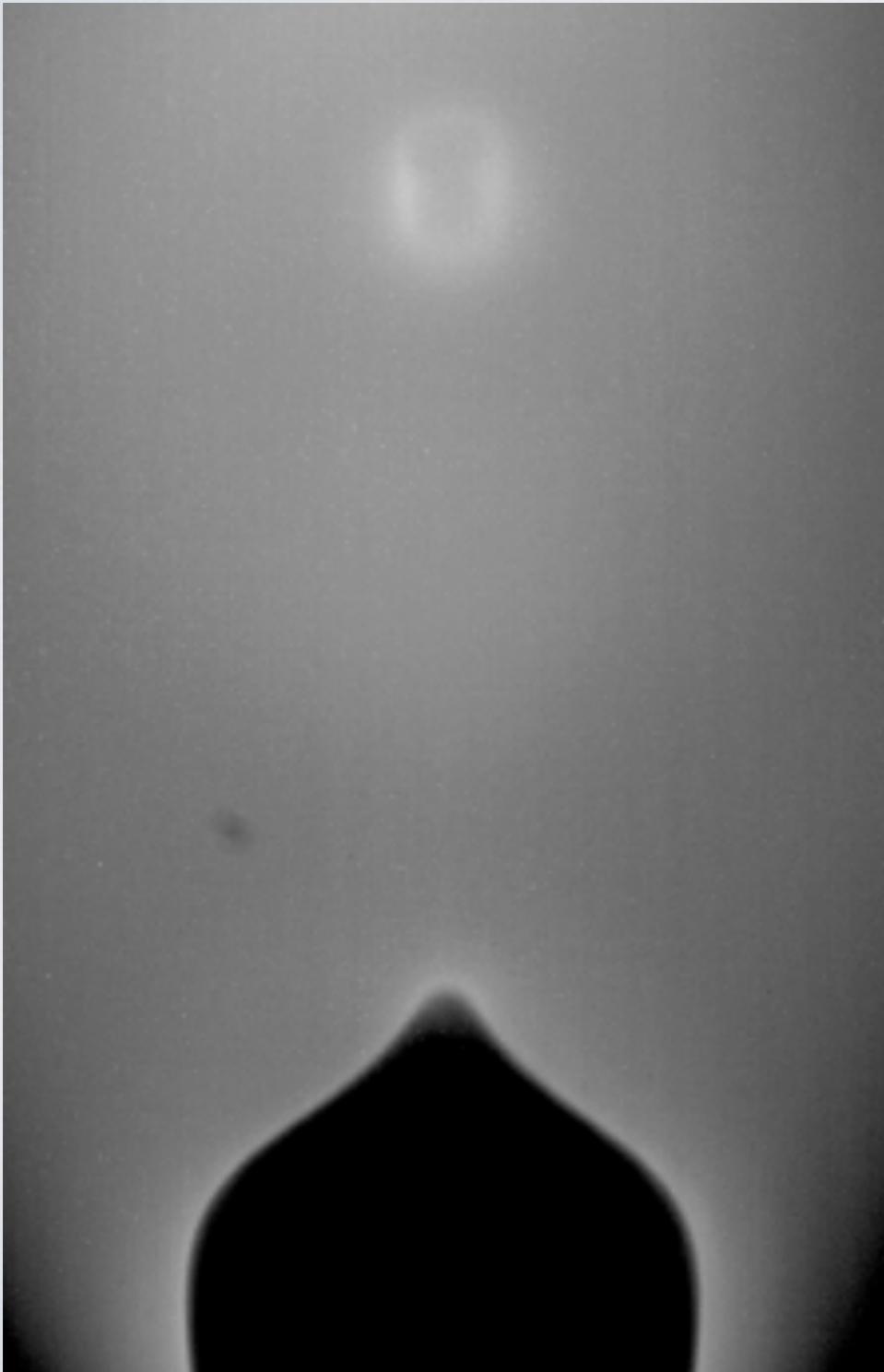
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COMBUSTION NOISE

Estimation of the pinching distance " r "

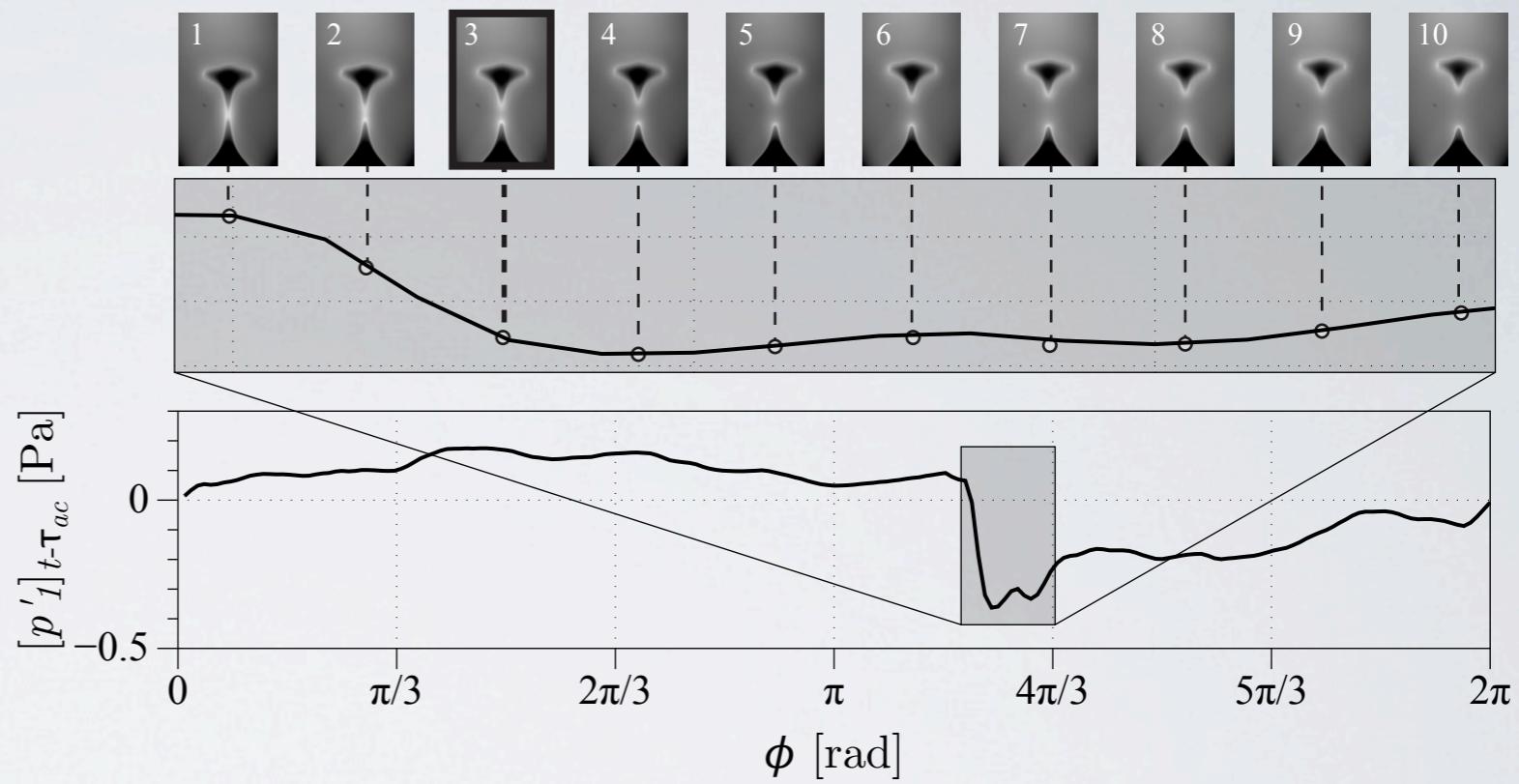
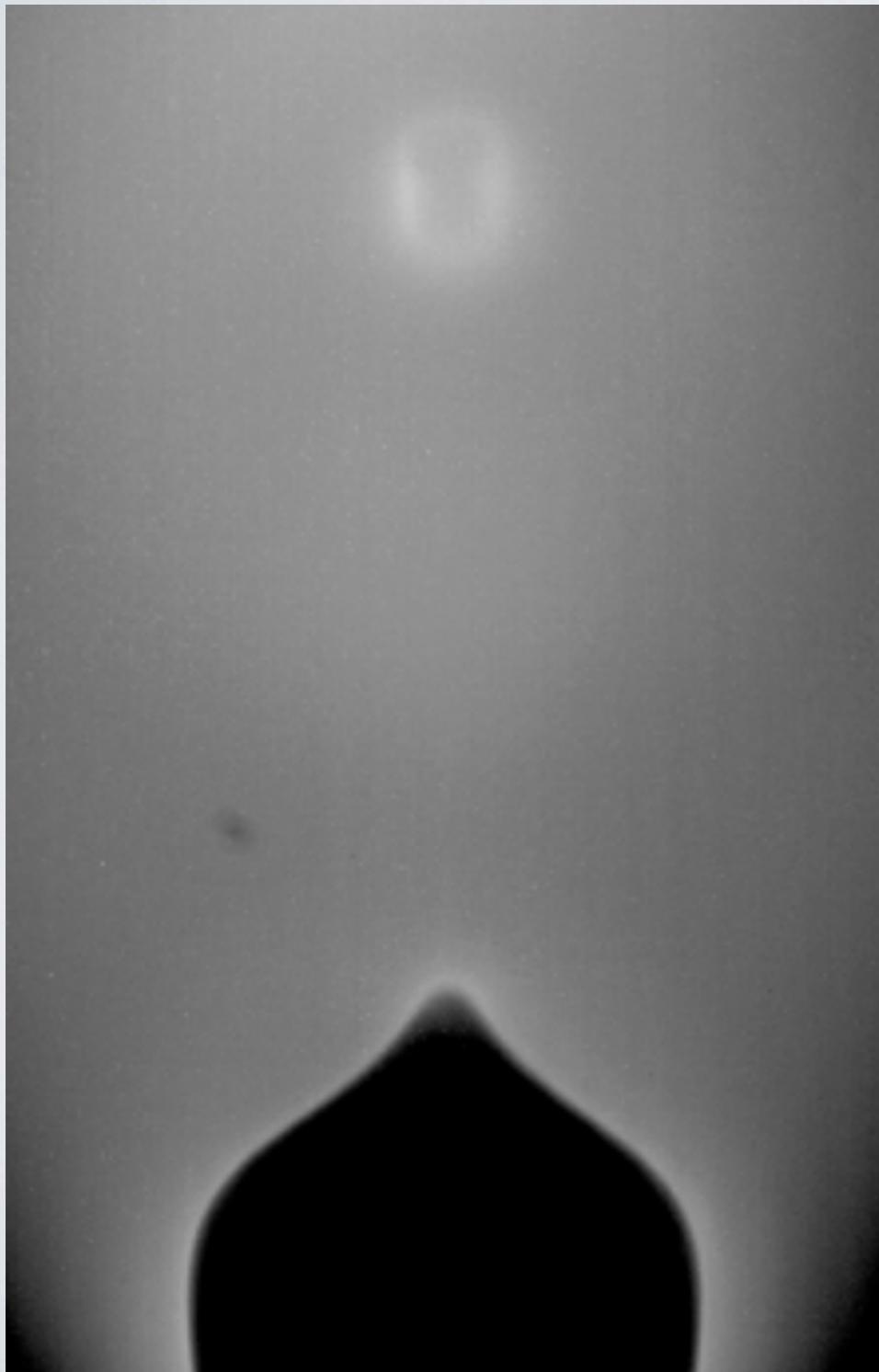
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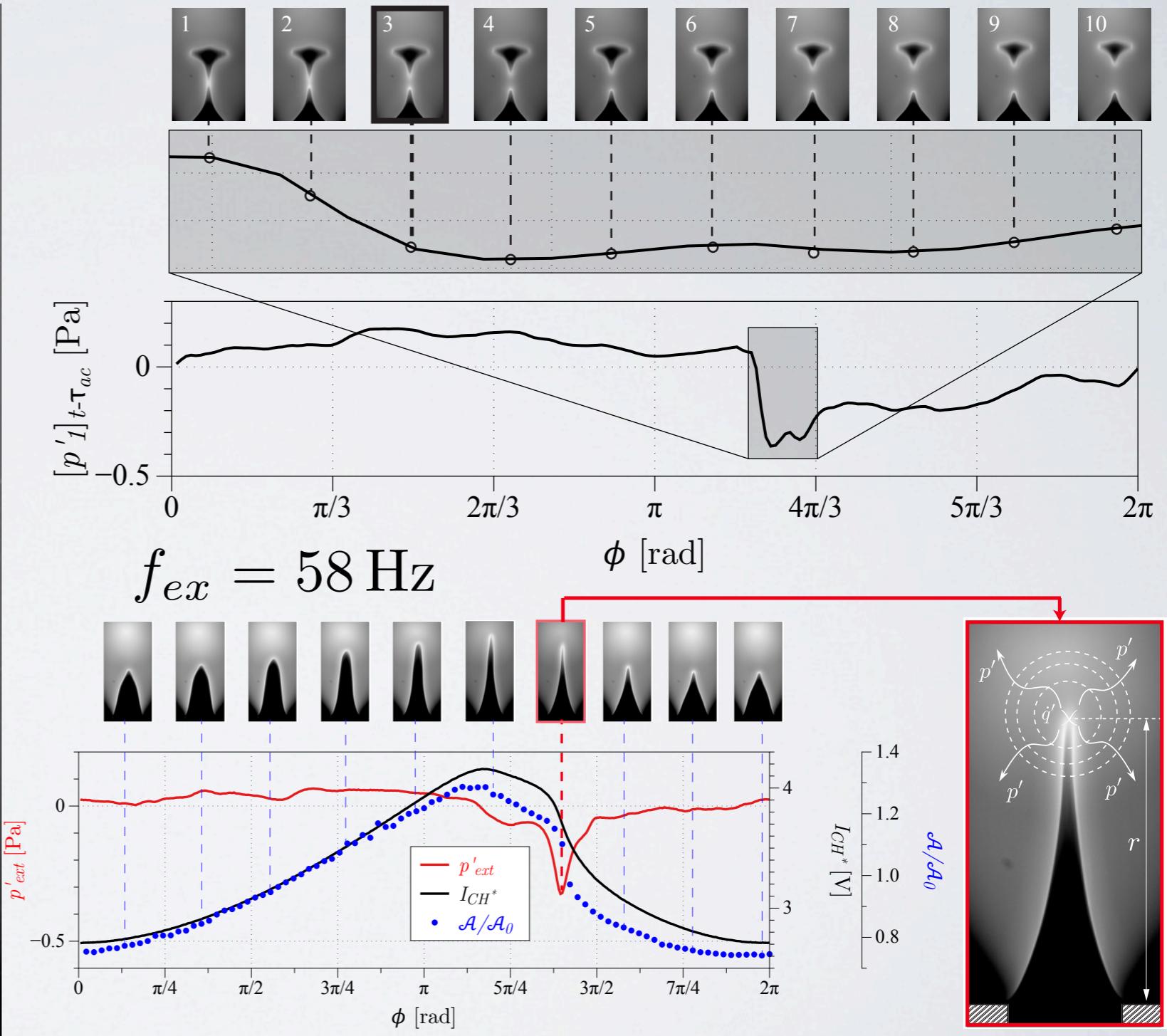
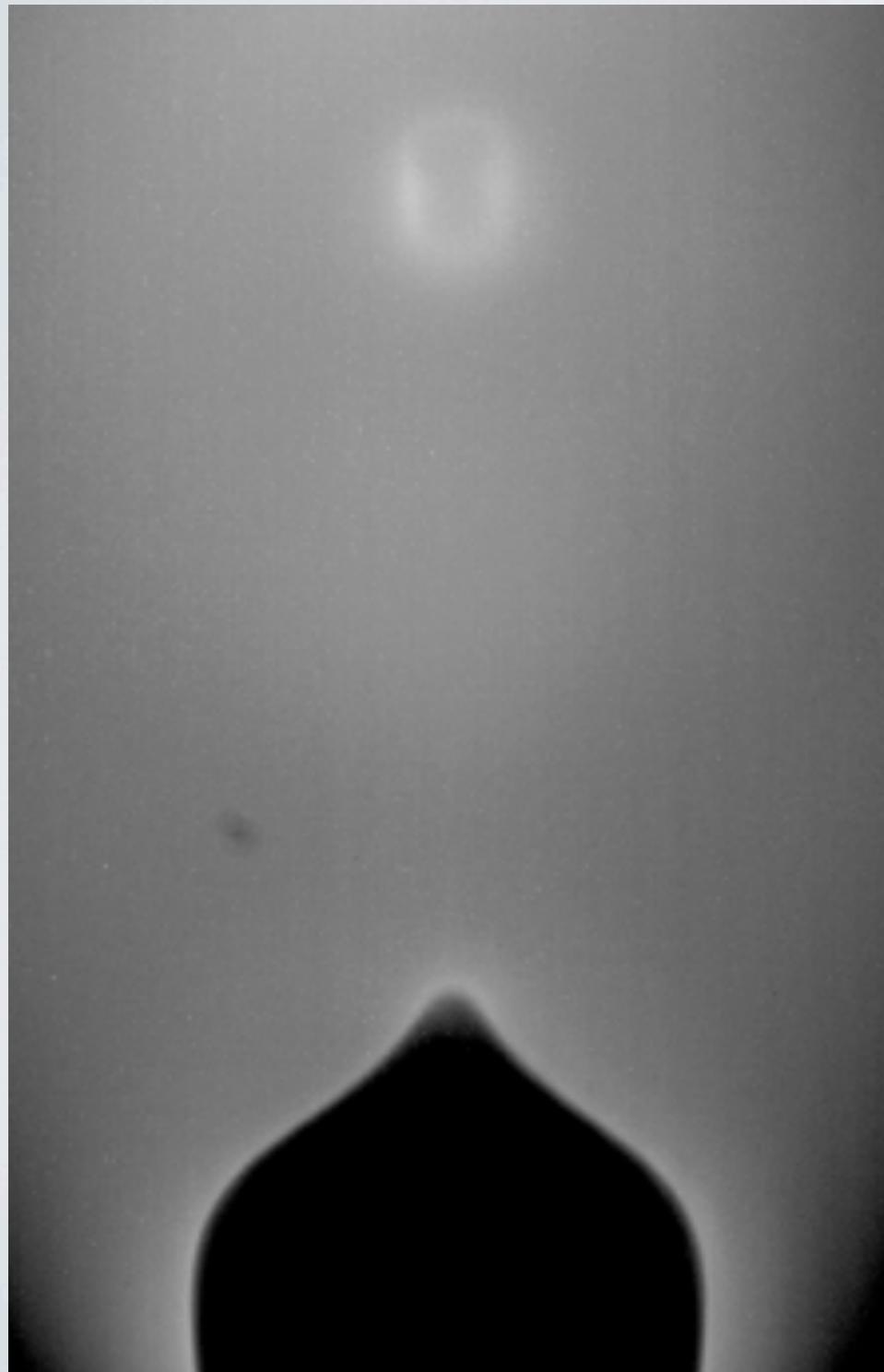
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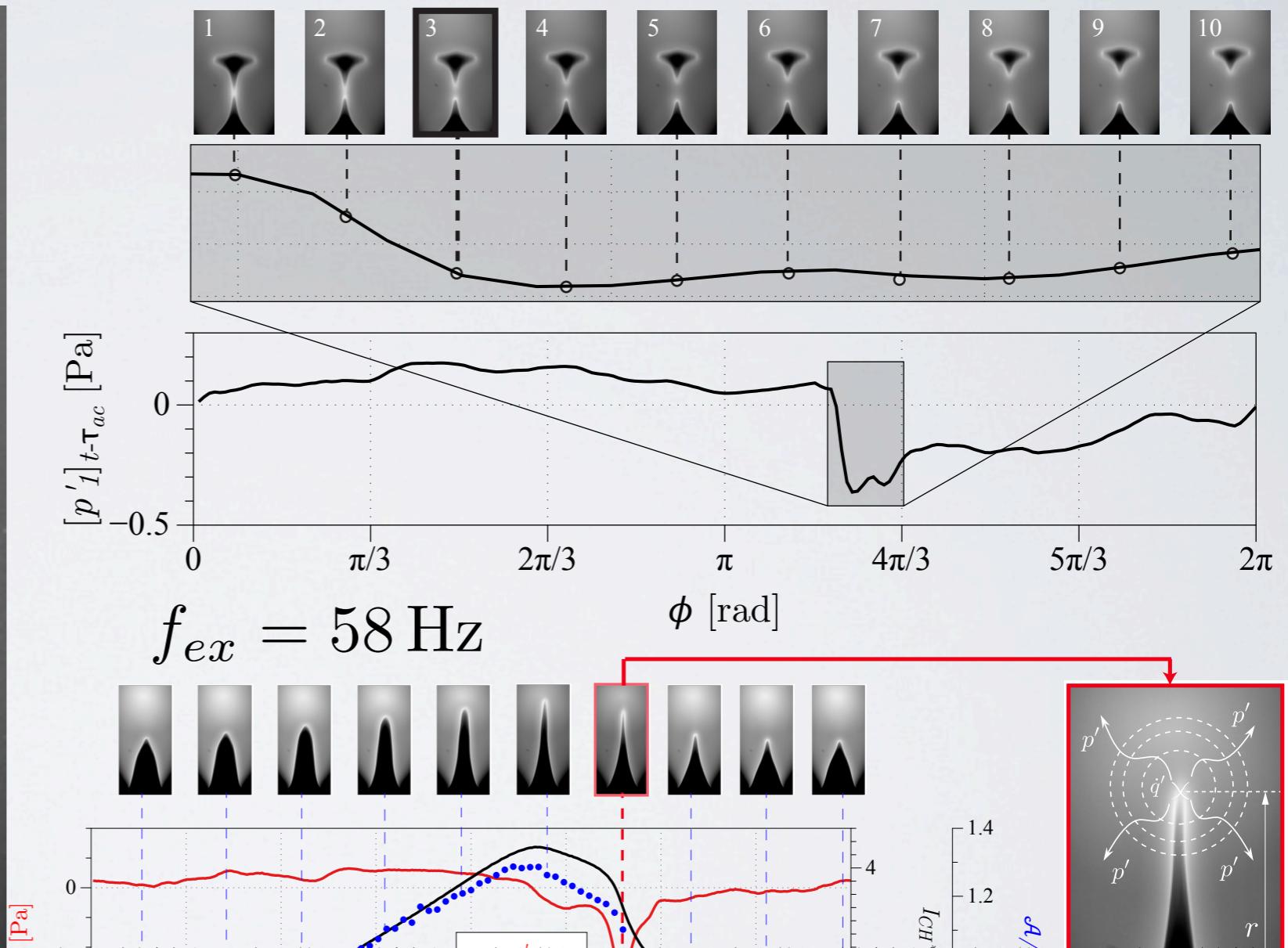
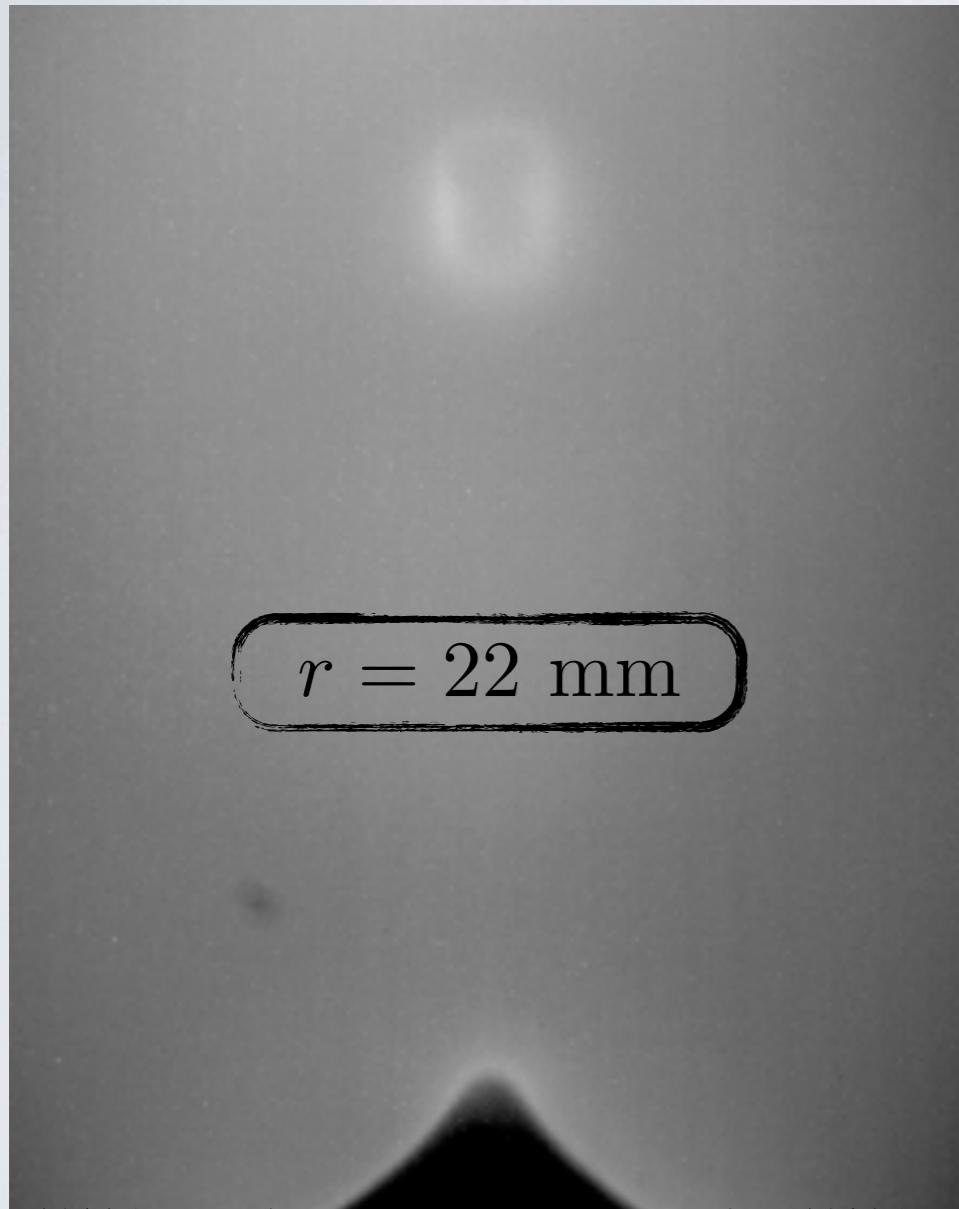
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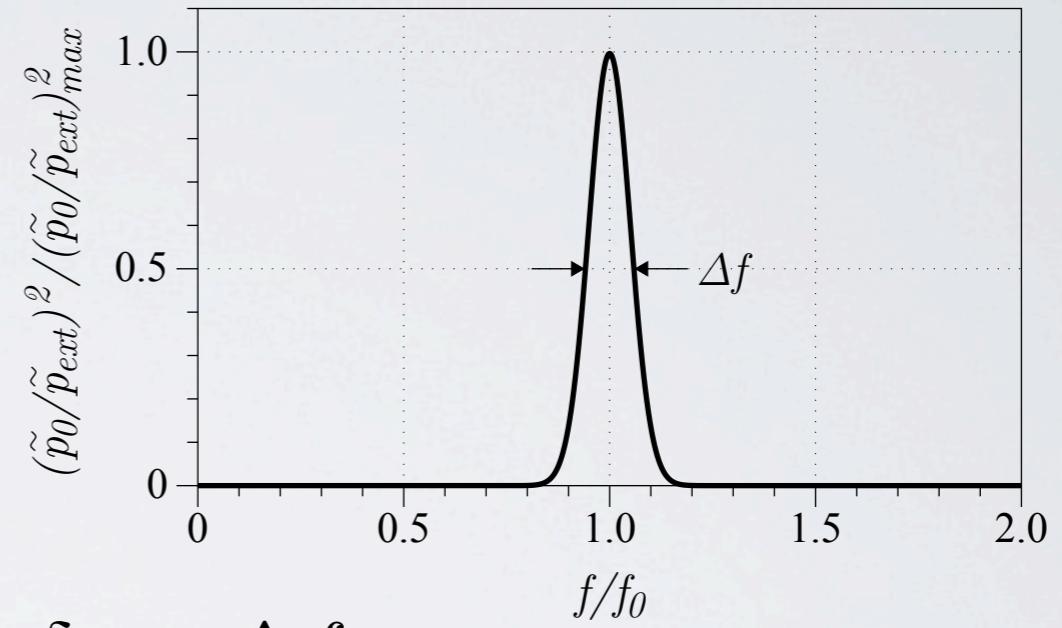
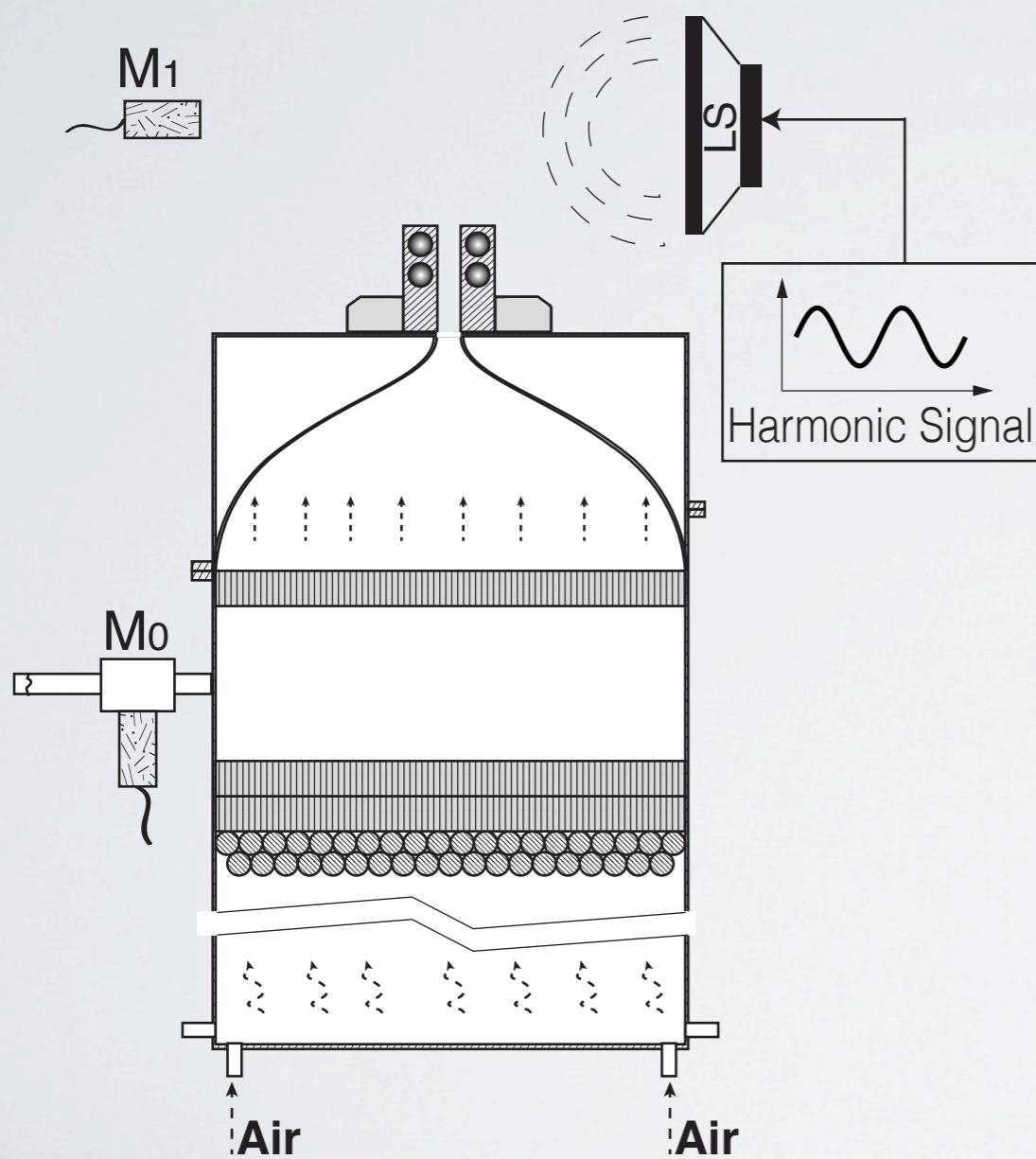
In the model r is assumed to be the stationary flame height h_f .

EXPERIMENTAL MEASUREMENTS

	Parameter	Depends on Ts ?
Combustion noise	$r = 22 \text{ mm}$	NO
Acoustics	δ	ω_0
Combustion dynamics	n	φ

BURNER ACOUSTICS

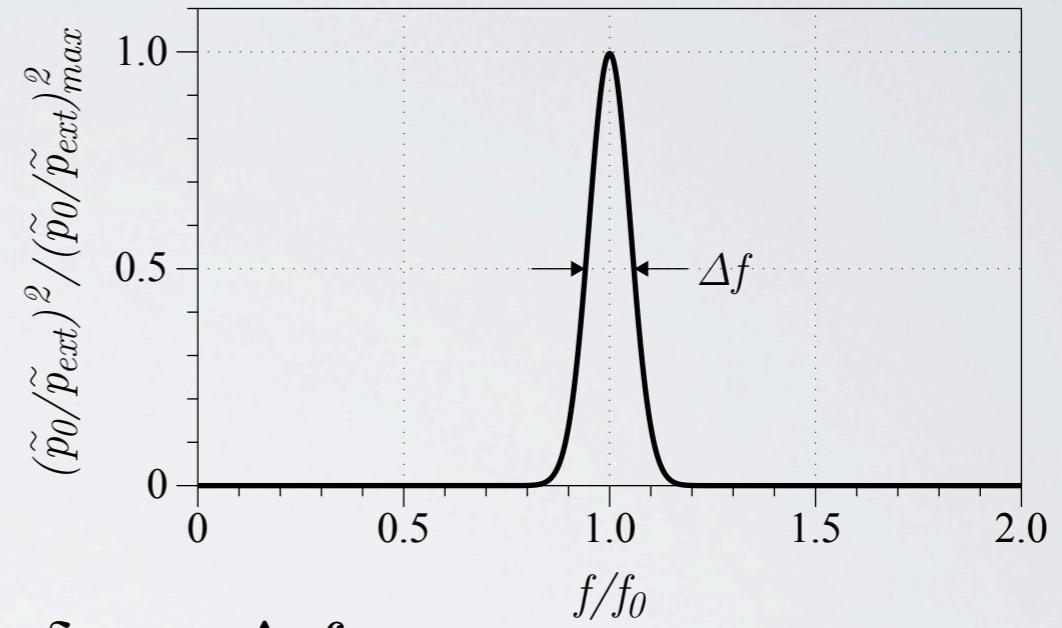
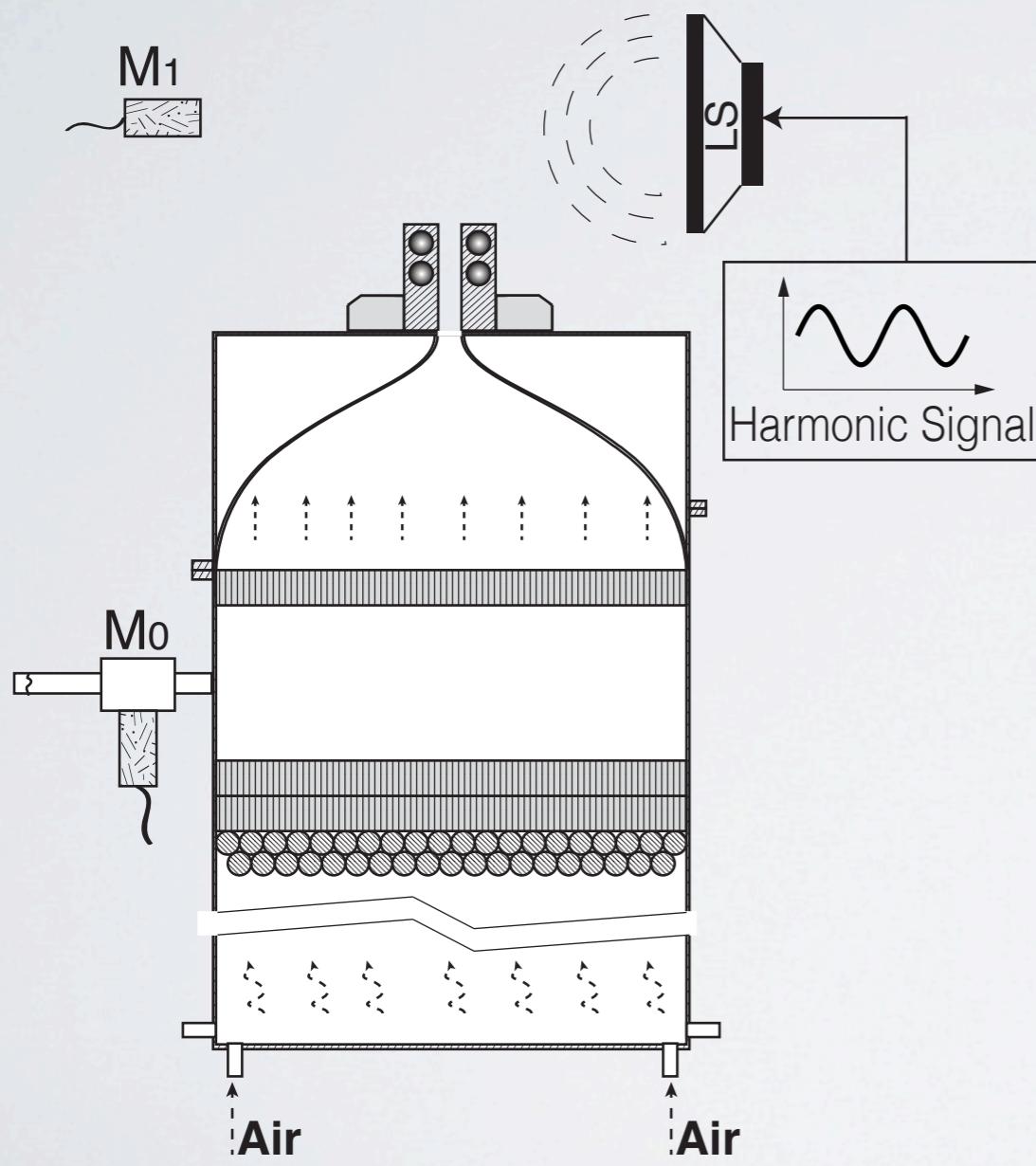
Harmonic Response



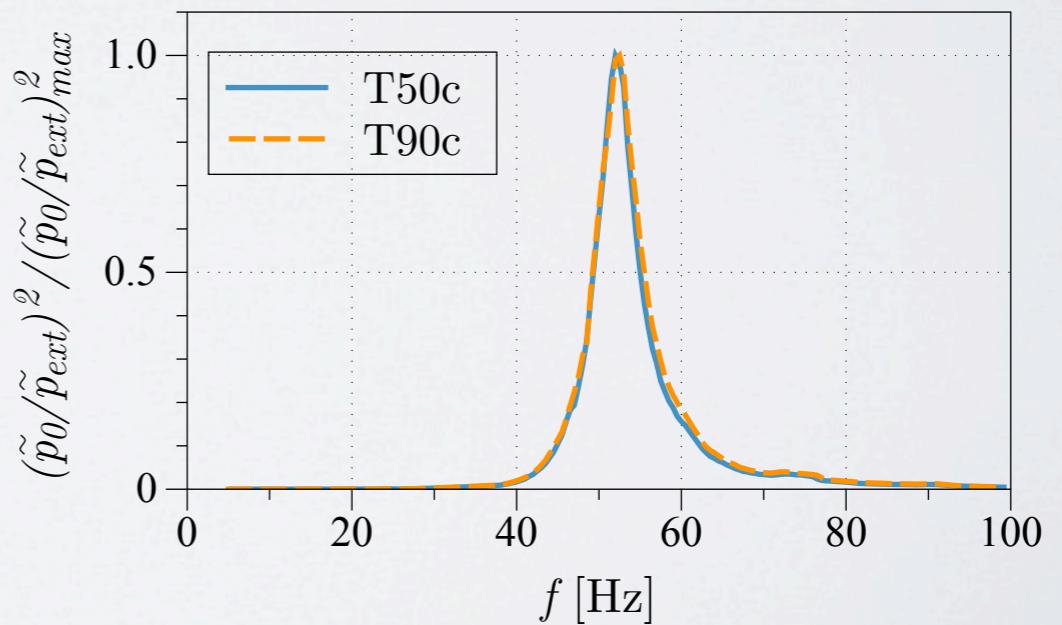
$$\delta = \pi \Delta f$$

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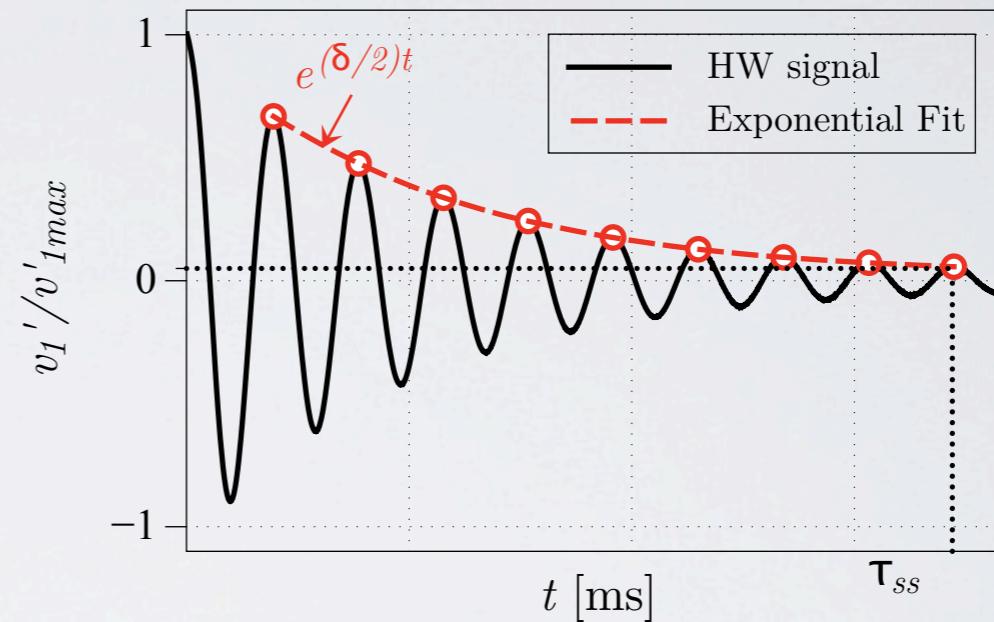
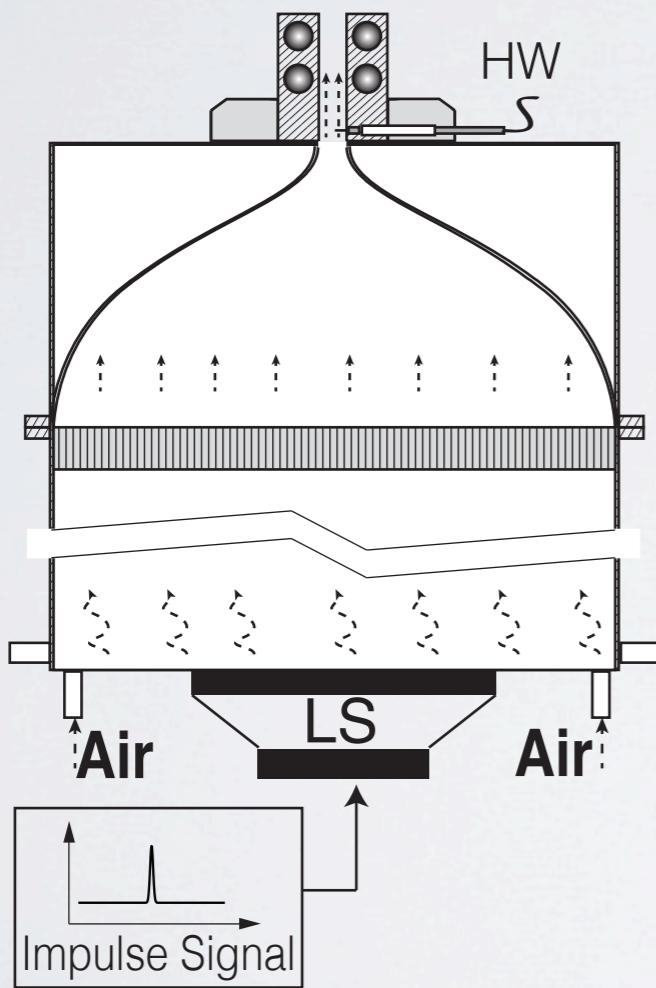


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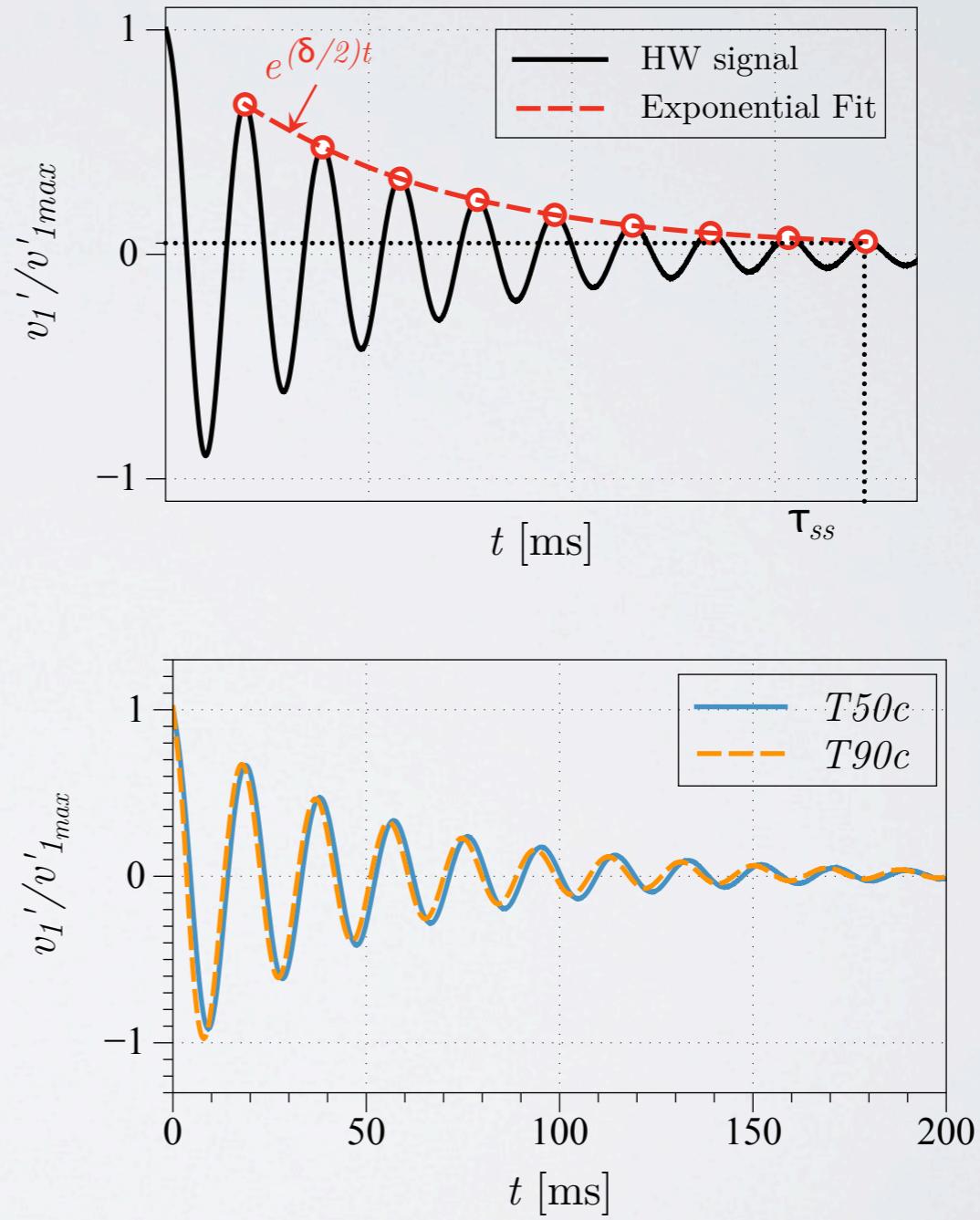
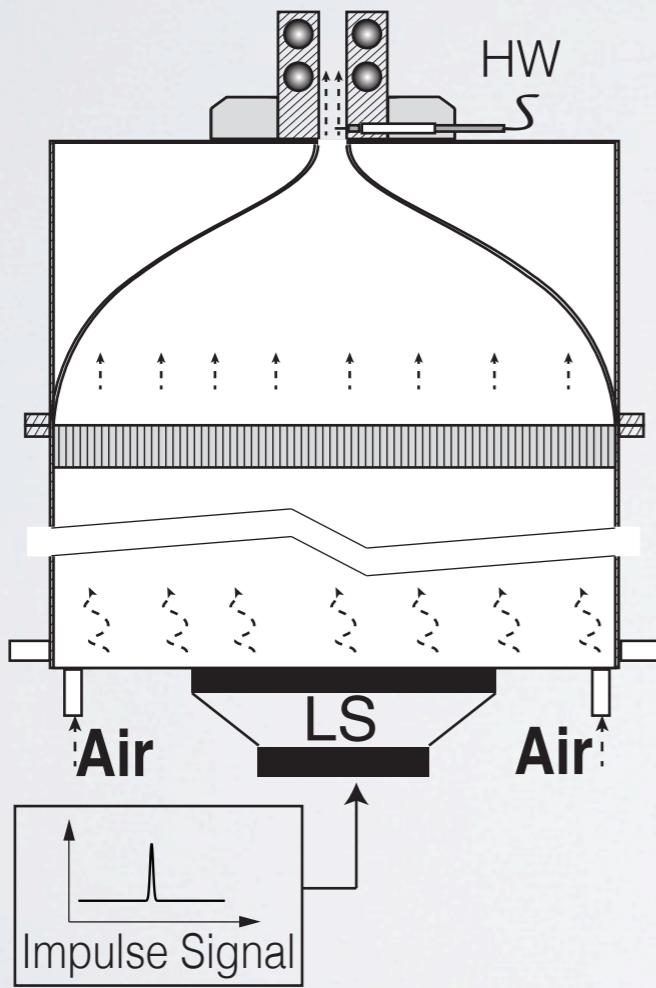
BURNER ACOUSTICS

Impulse Response



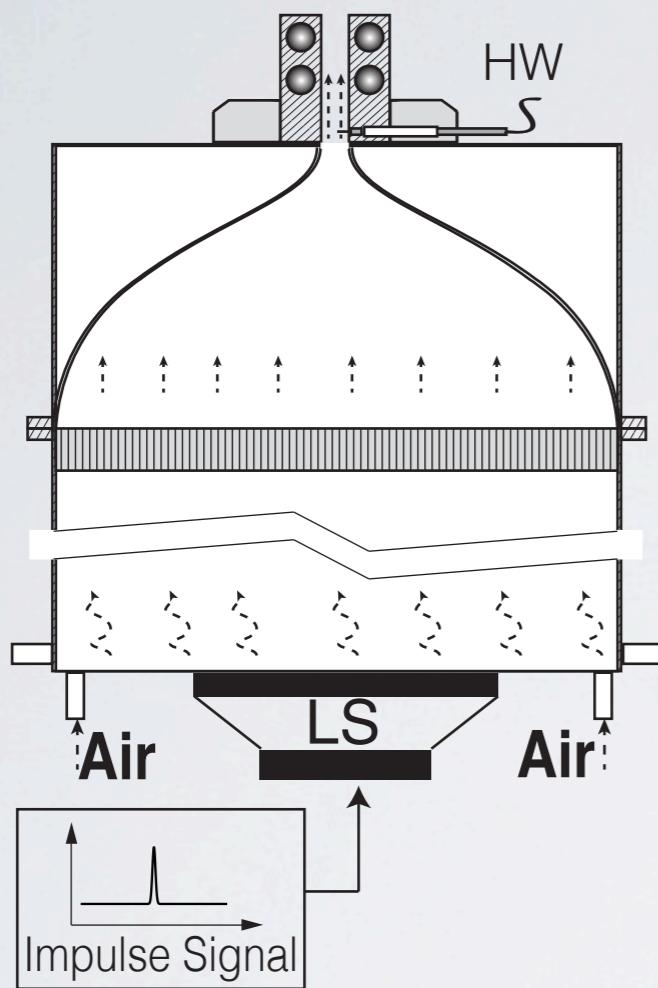
BURNER ACOUSTICS

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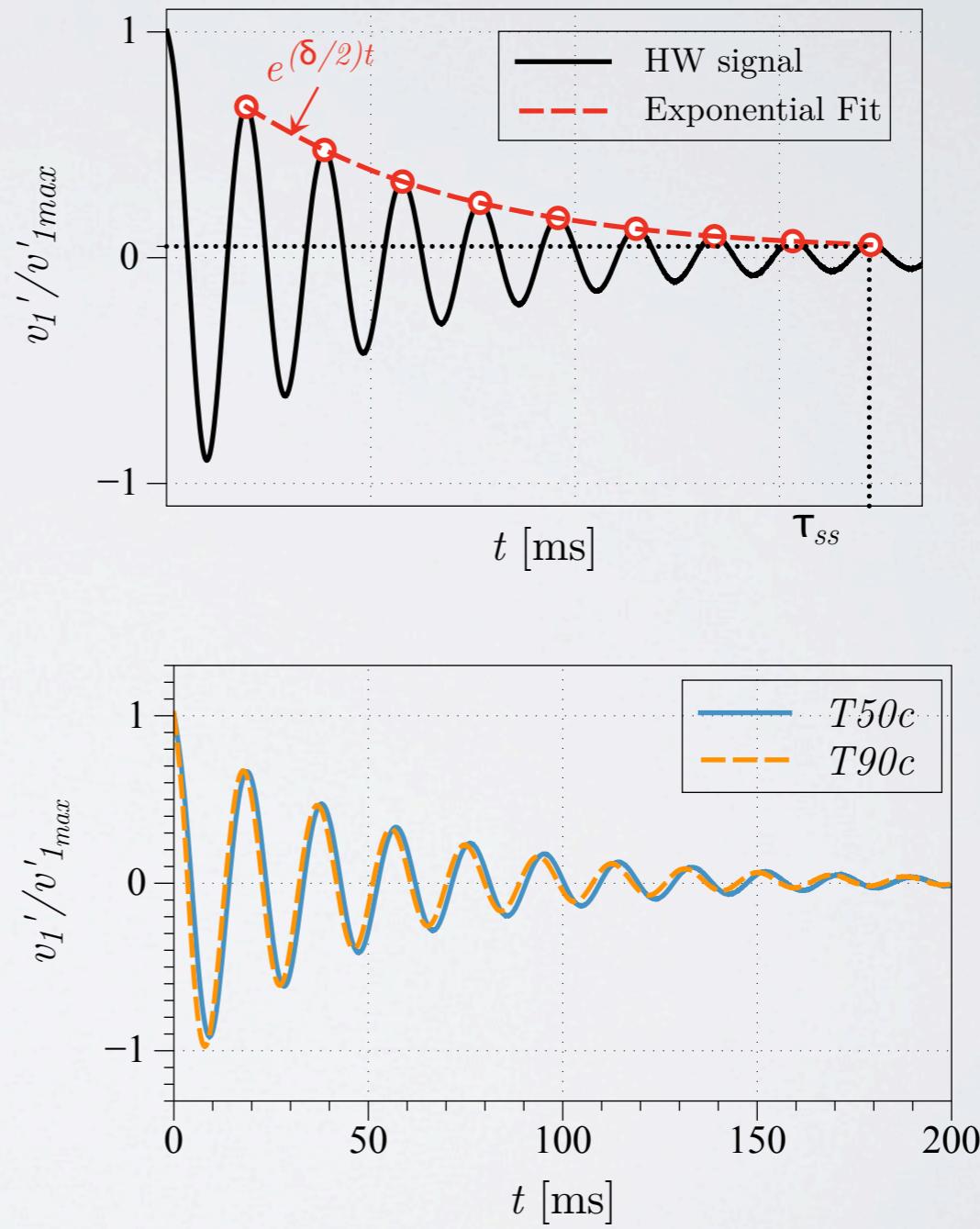


BURNER ACOUSTICS

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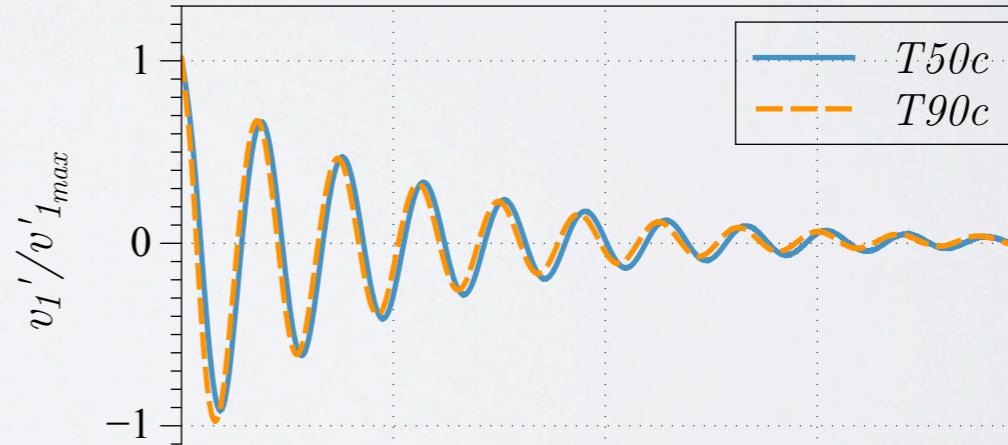
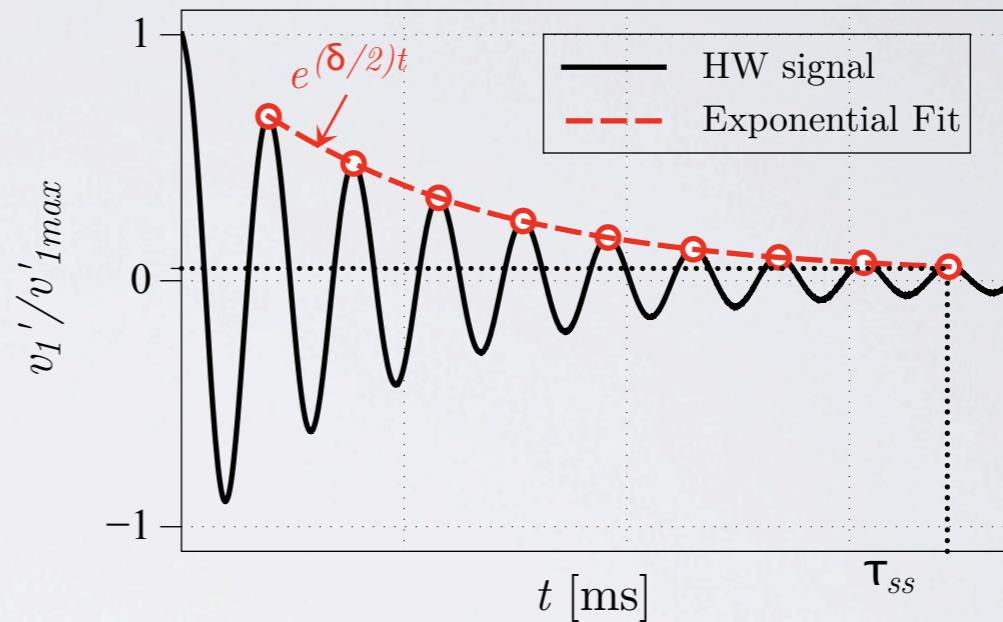
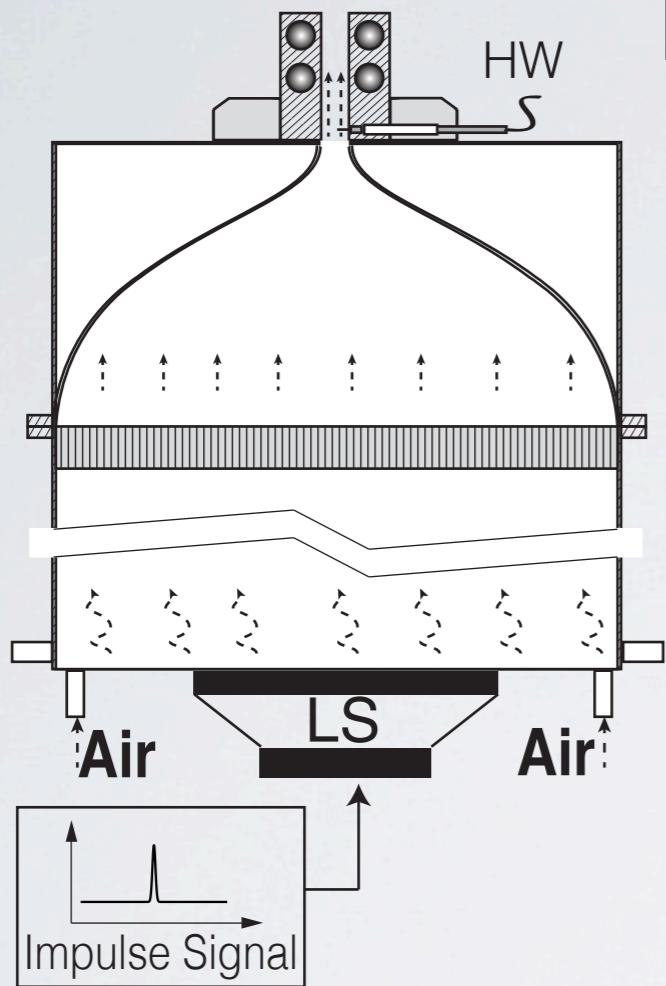


Method	HR		IR	
	δ [s ⁻¹]	f_0 [Hz]	δ [s ⁻¹]	f_0 [Hz]
T50c	15.7	52.0	16.9	52.4
T90c	16.0	52.0	17.1	53.1



BURNER ACOUSTICS

Impulse Response



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	δ [s^{-1}]	f_0 [Hz]	δ [s^{-1}]	f_0 [Hz]
T50c	15.7	52.0	16.9	52.4

For the model $\omega_0 = 2\pi f_0$ and δ is an intermediate value between the two methods.

EXPERIMENTAL MEASUREMENTS

	Parameter	Depends on Ts ?
Combustion noise	$r = 22 \text{ mm}$	NO
Acoustics	$\delta = 16 \text{ s}^{-1}$	$\omega_0 = 327 \text{ rad}$
Combustion dynamics	n	φ

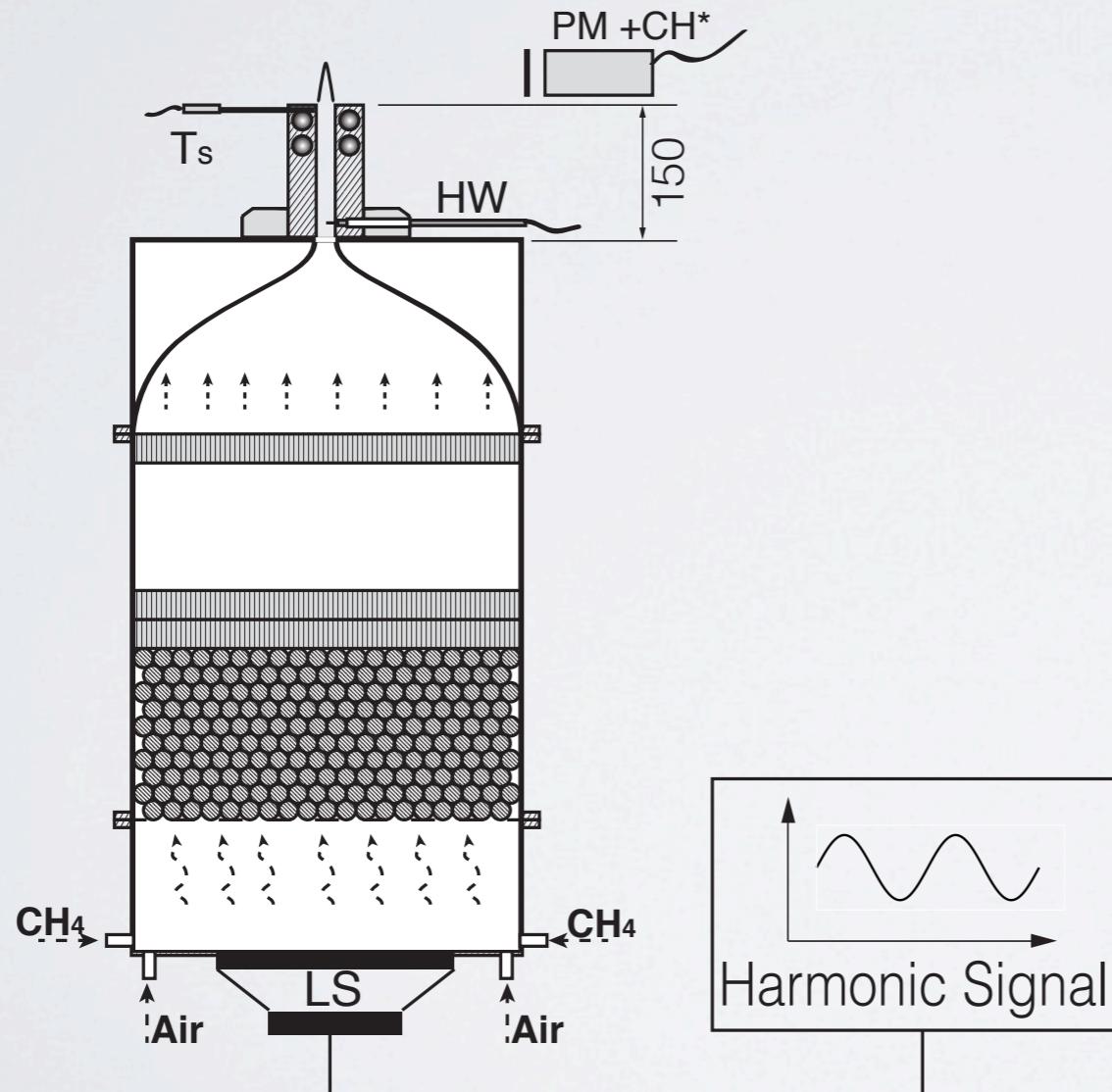
COMBUSTION DYNAMICS

Flame Transfer Function

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$$G = |\mathcal{F}(\omega, T_s)|$$

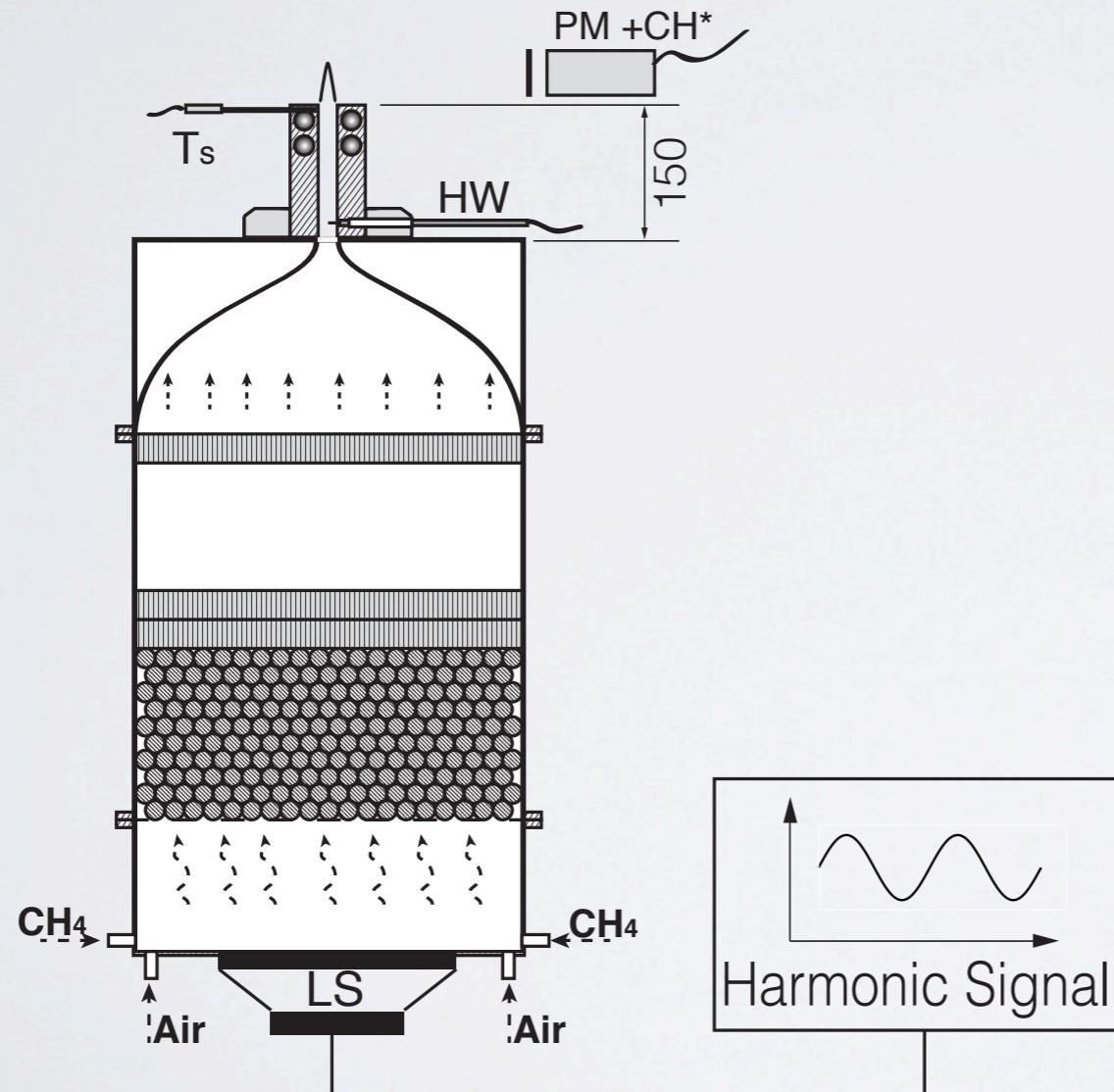
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COMBUSTION DYNAMICS

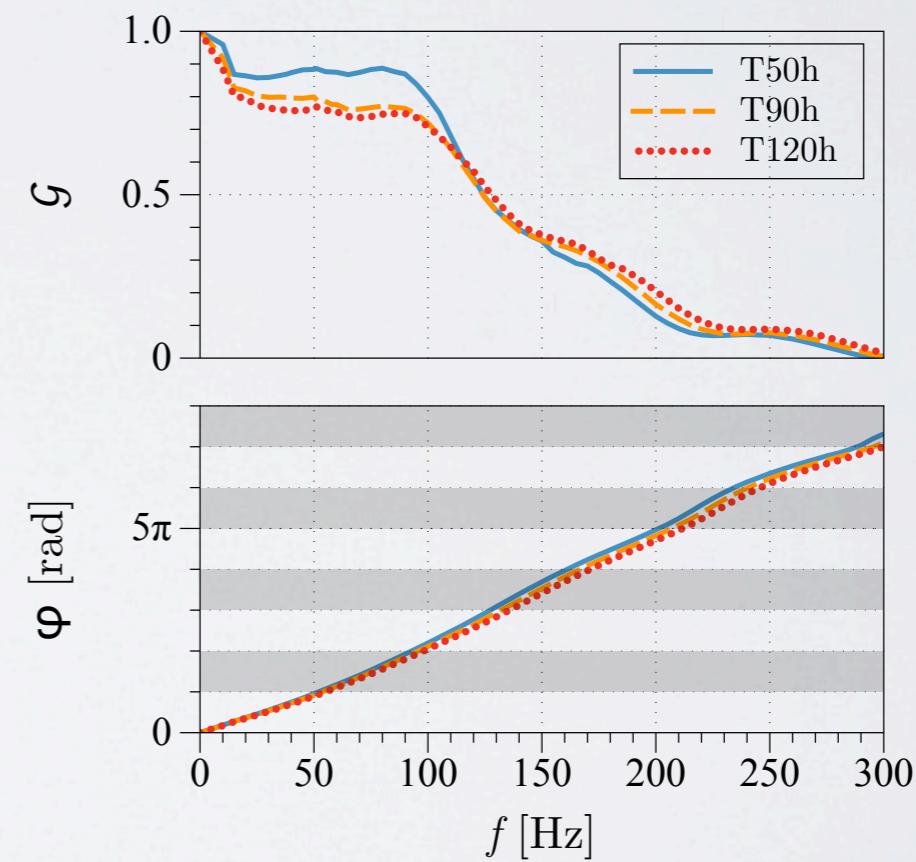
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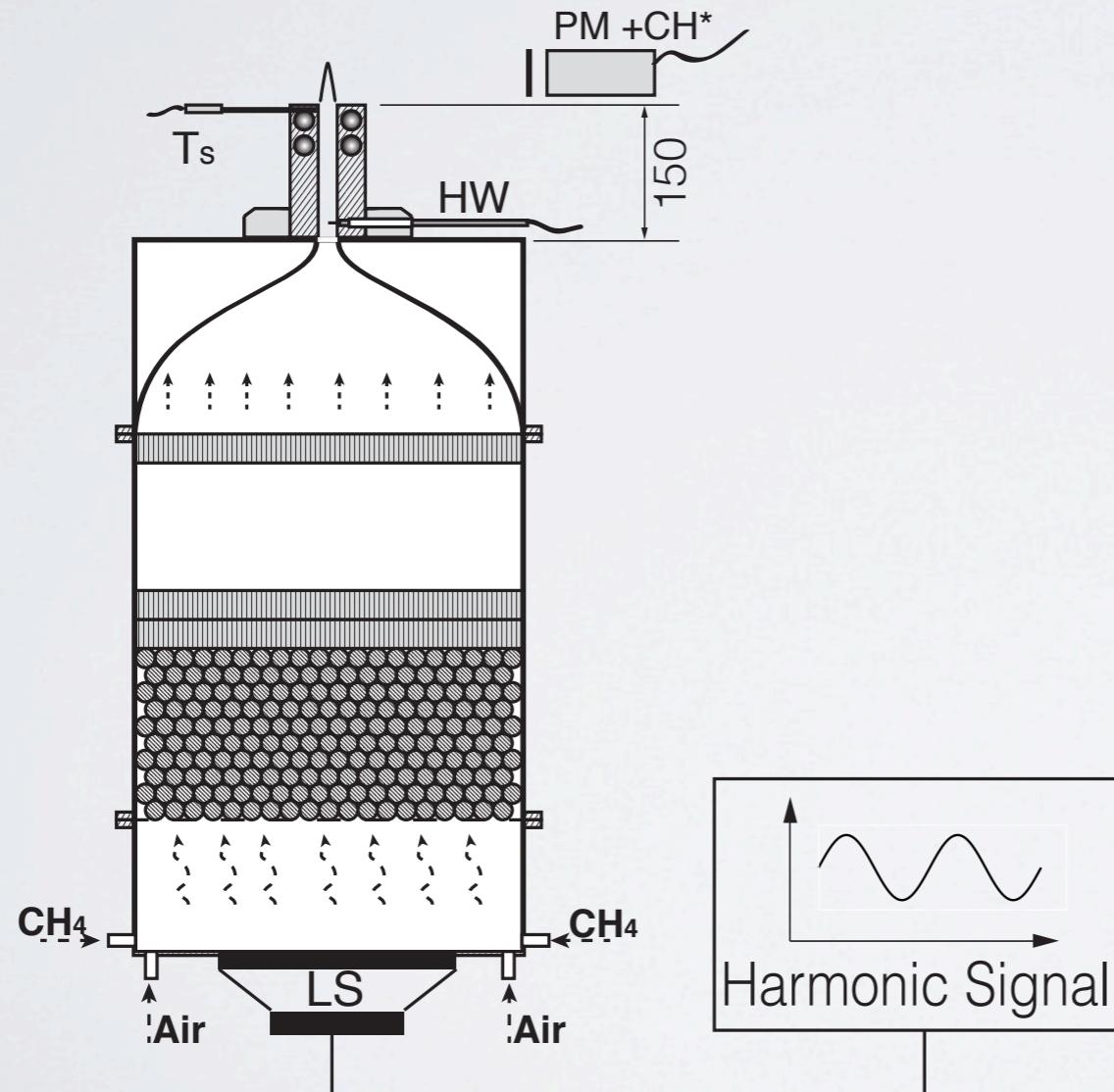
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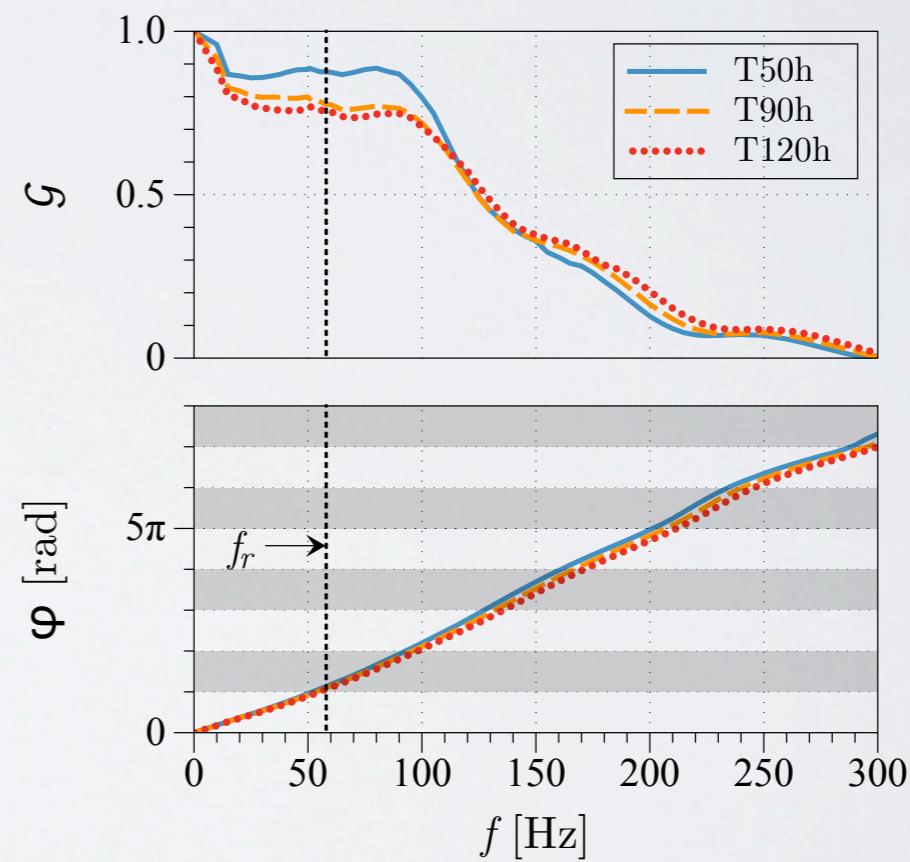
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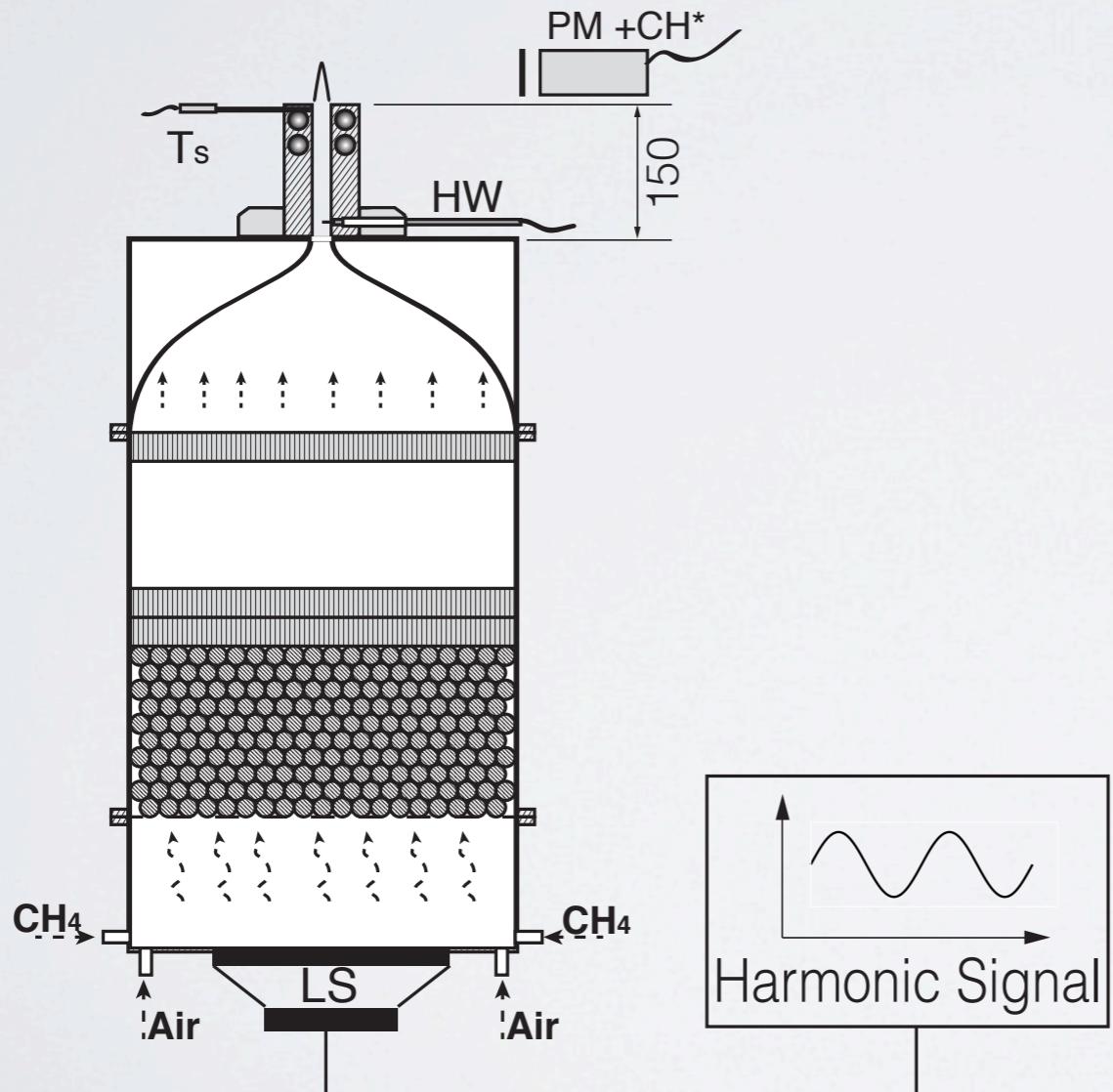
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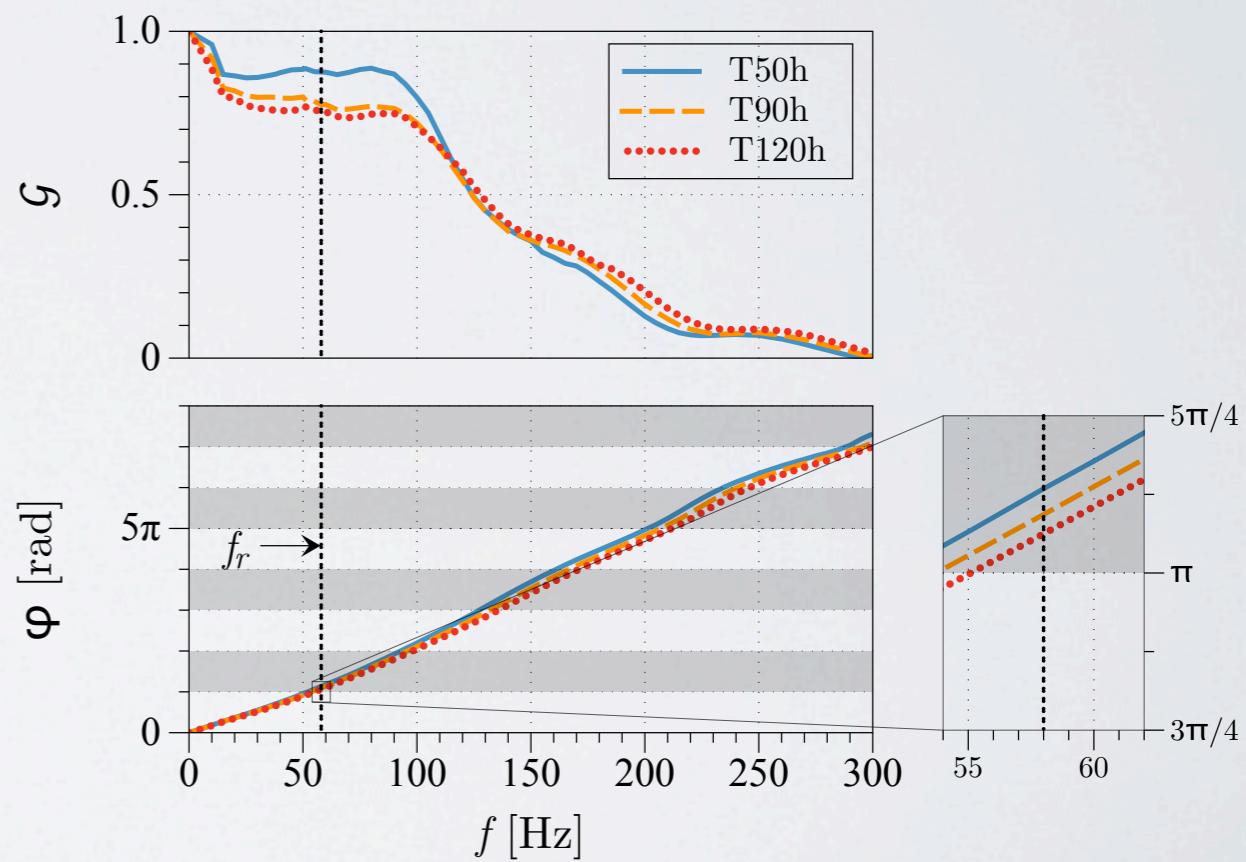
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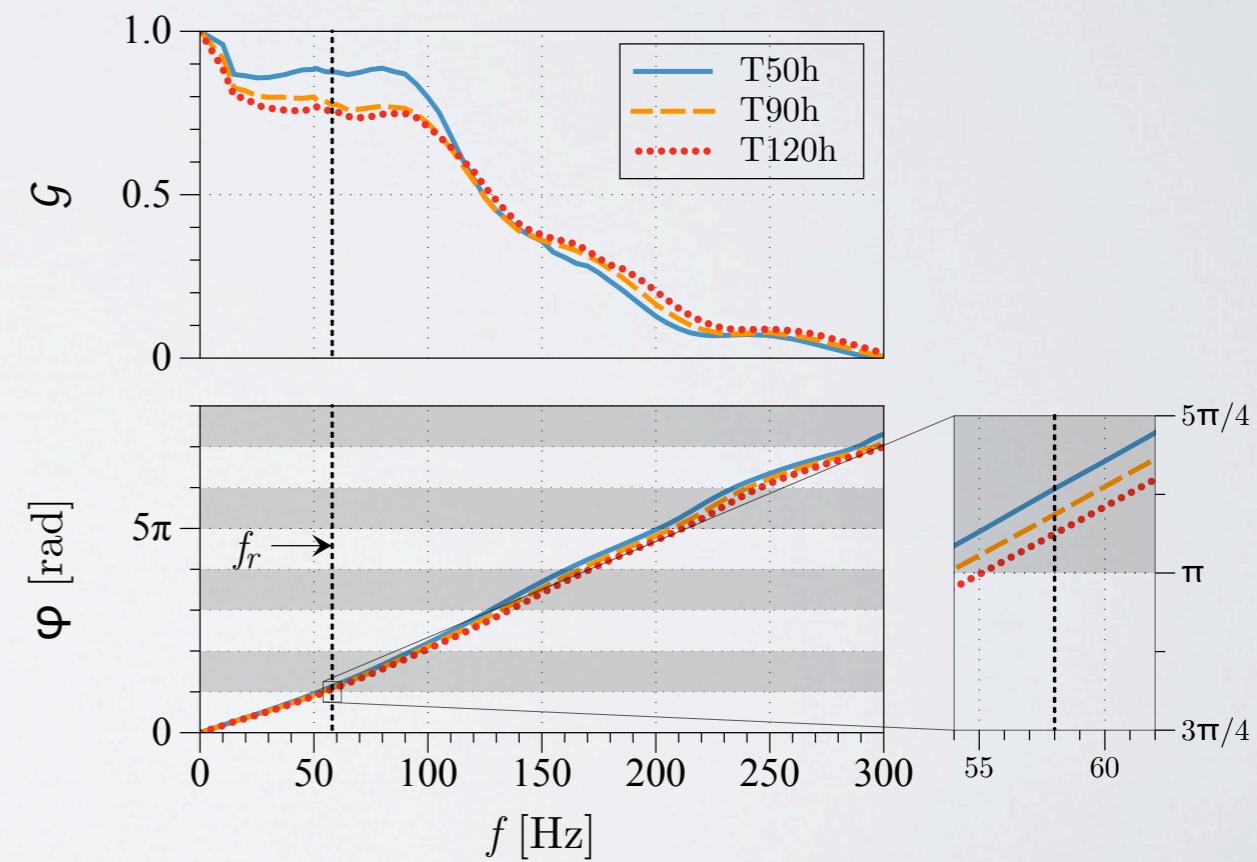
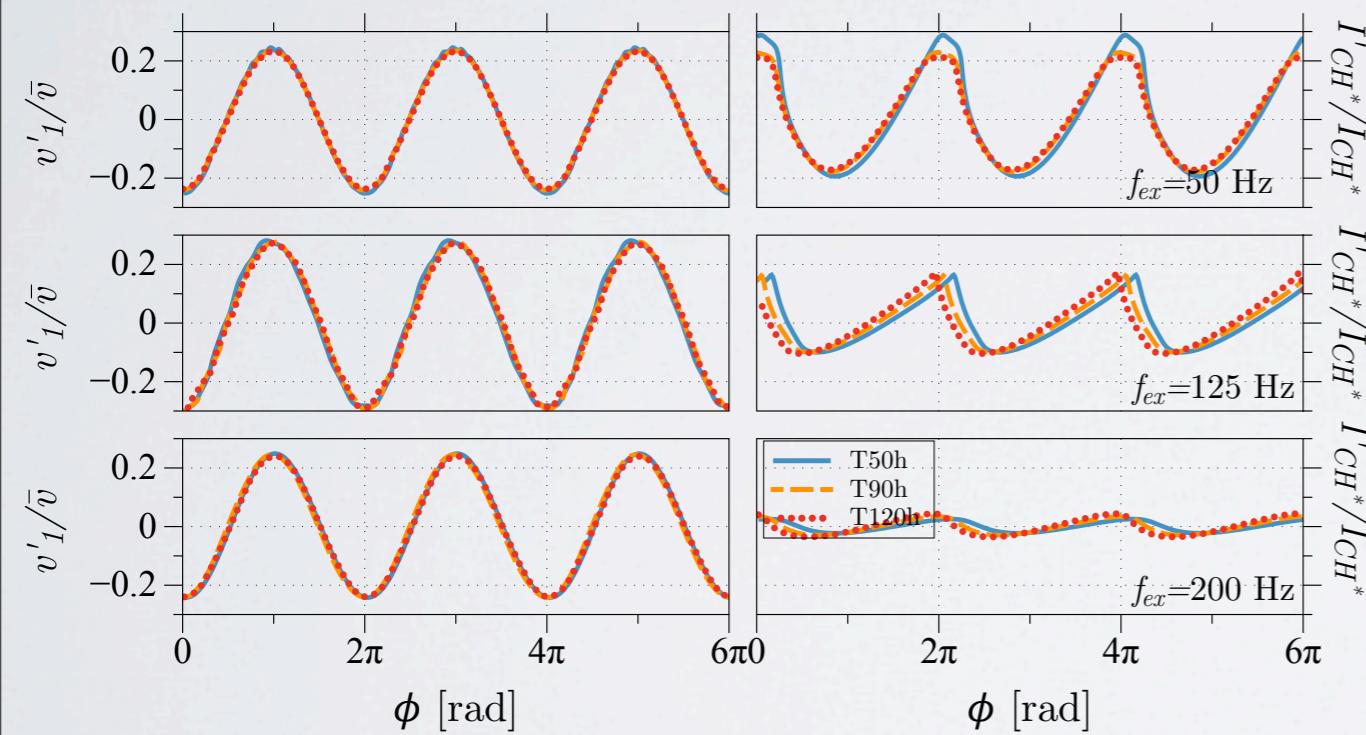


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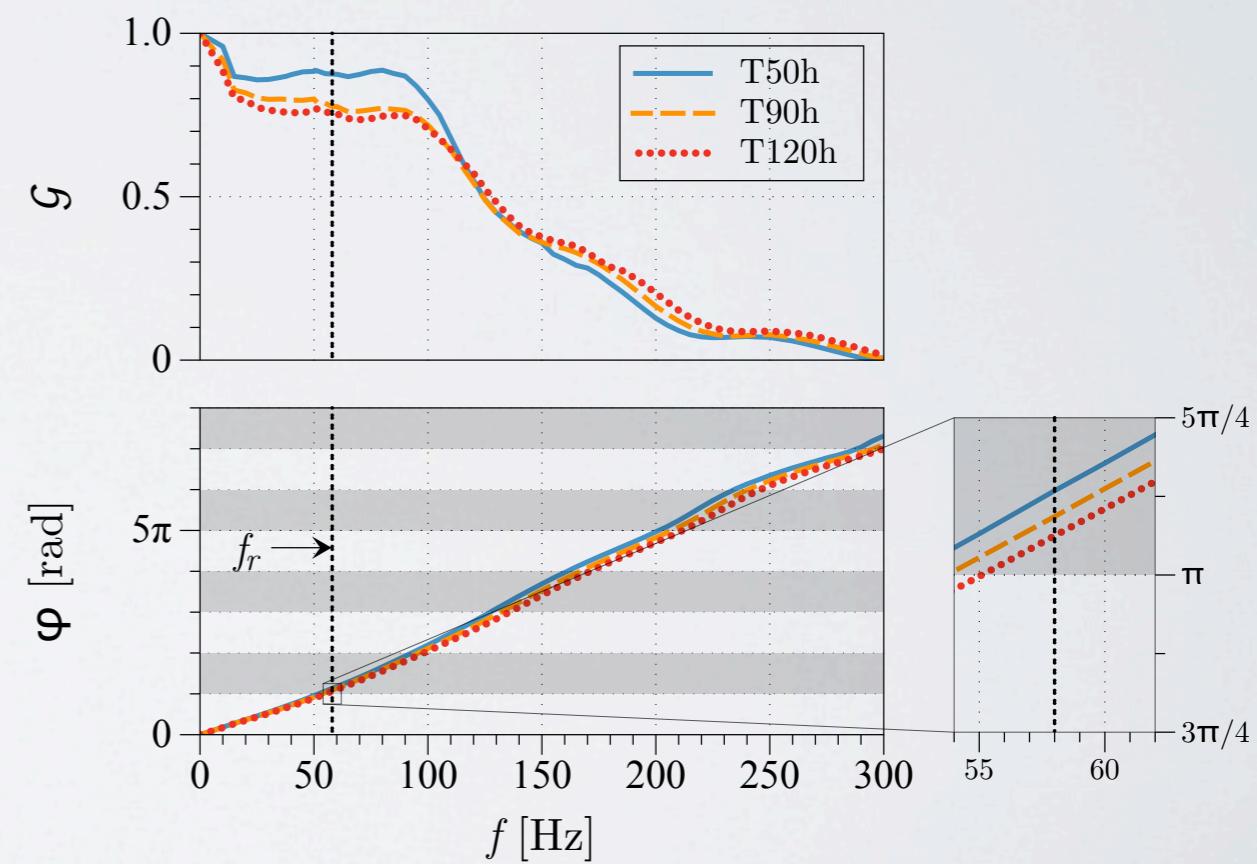
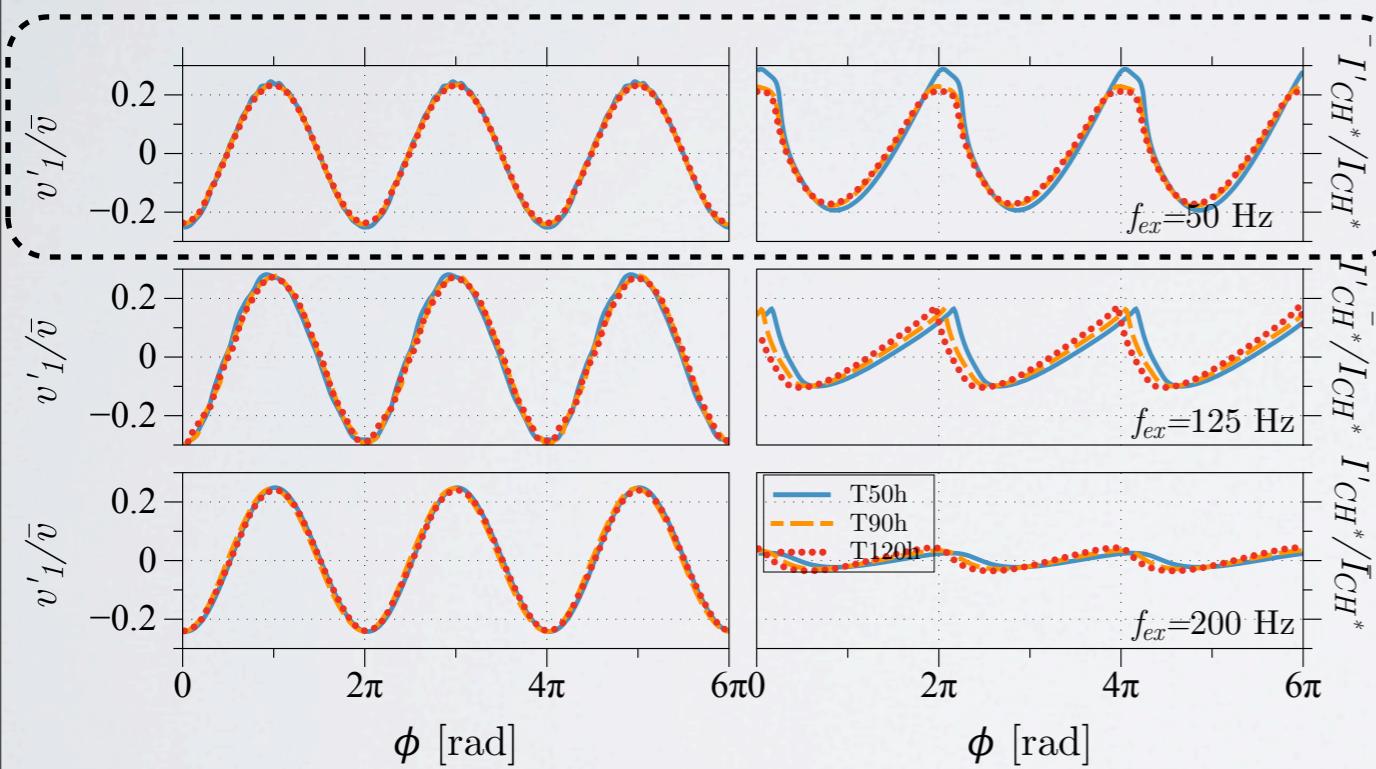


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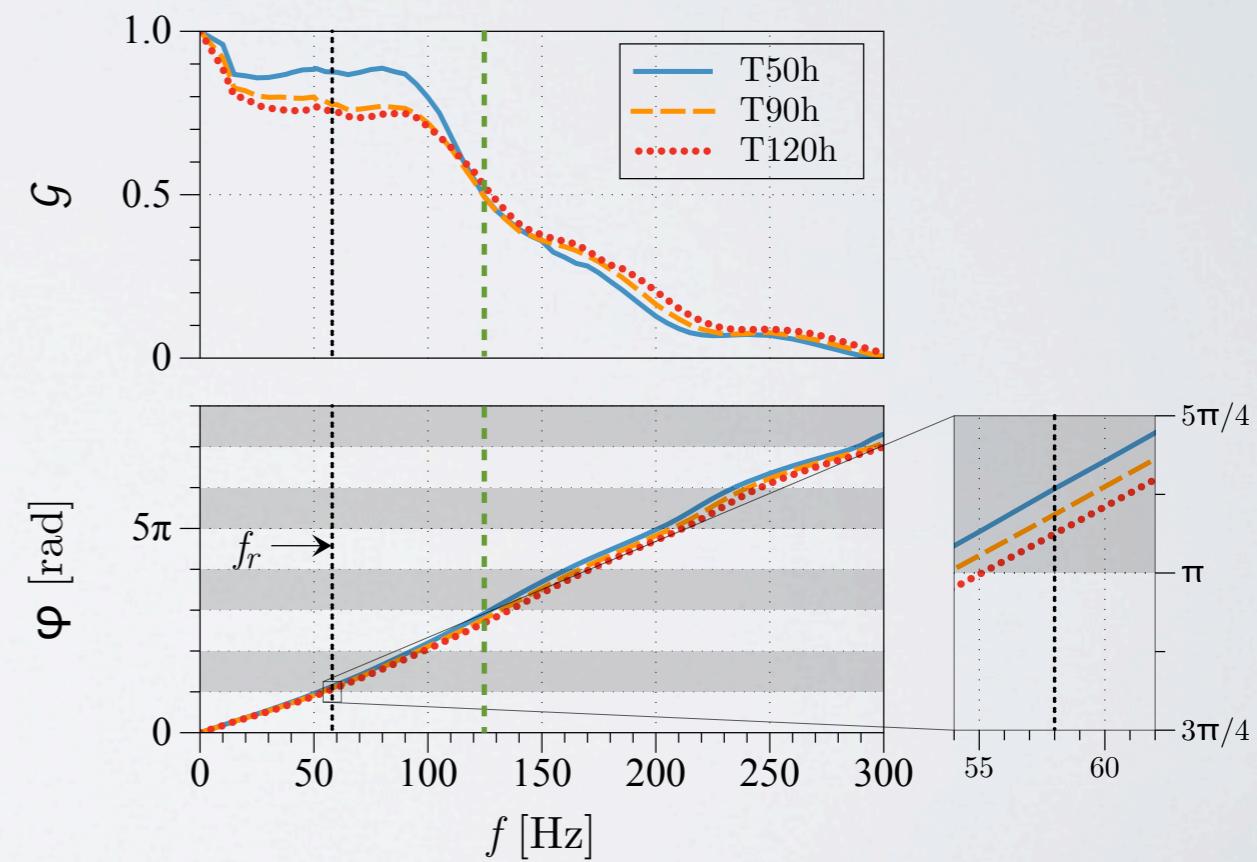
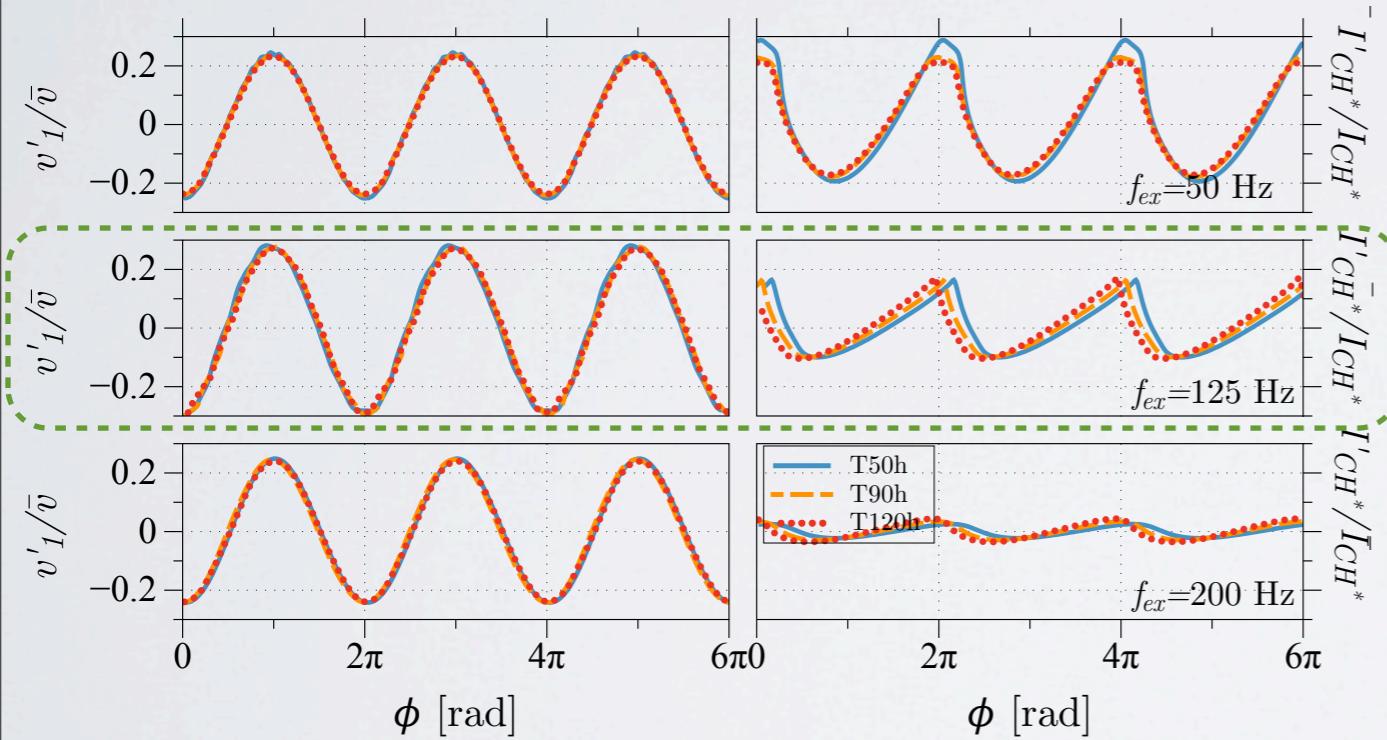


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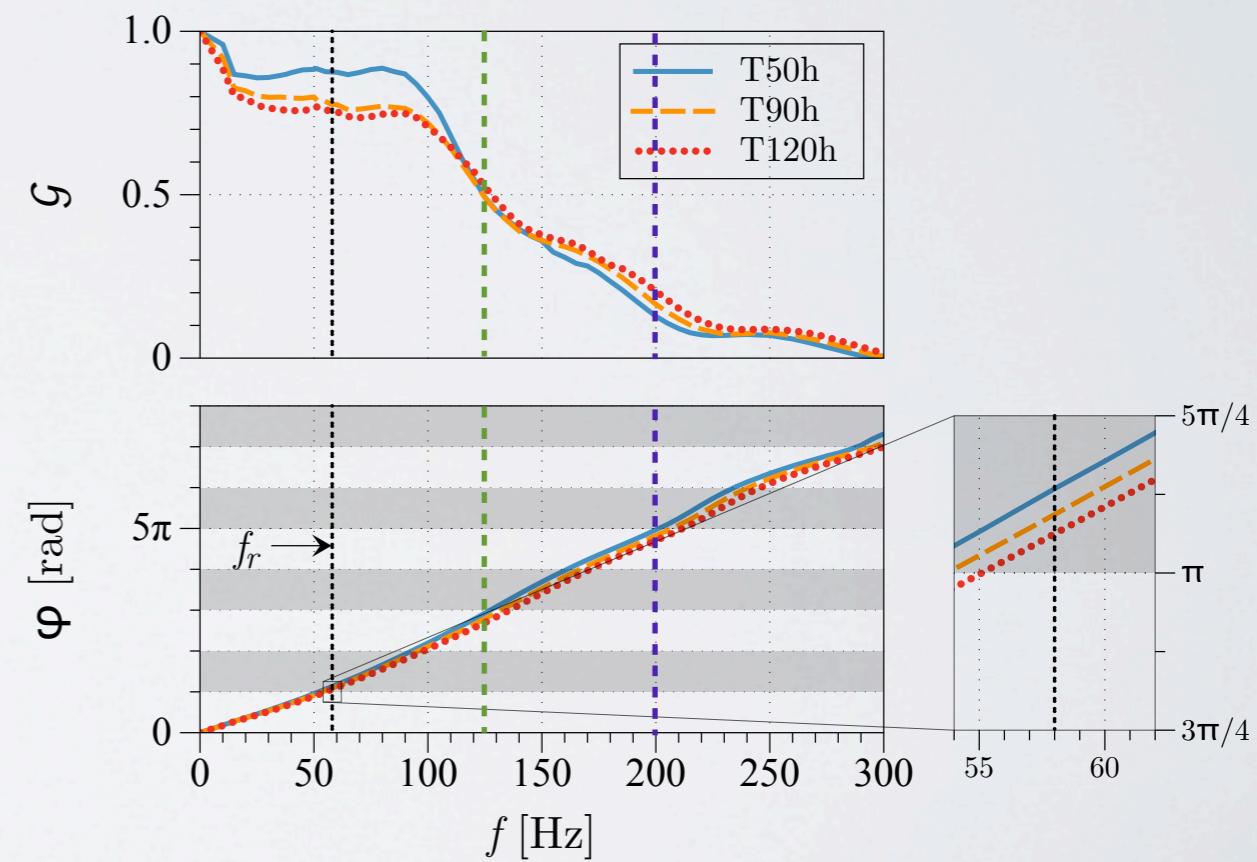
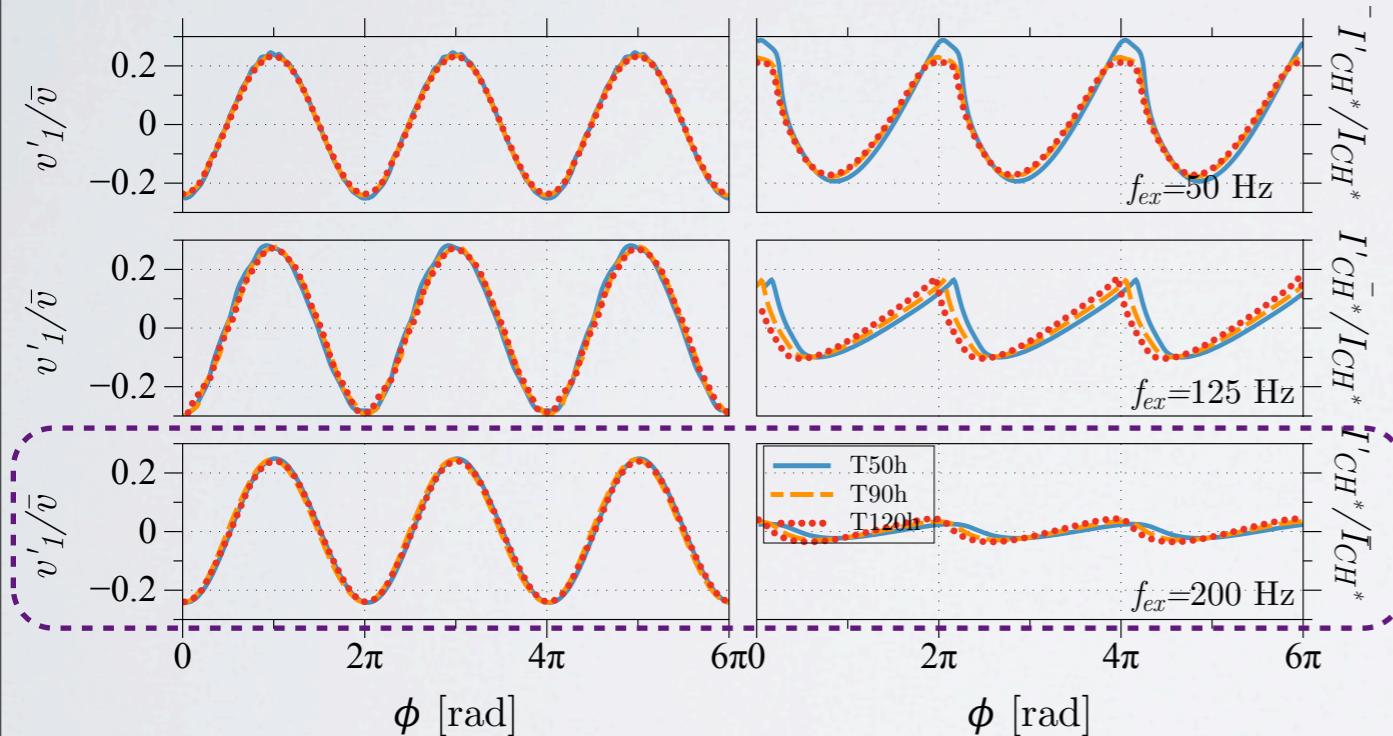


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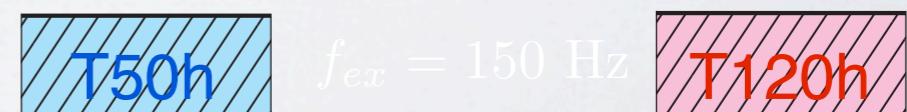
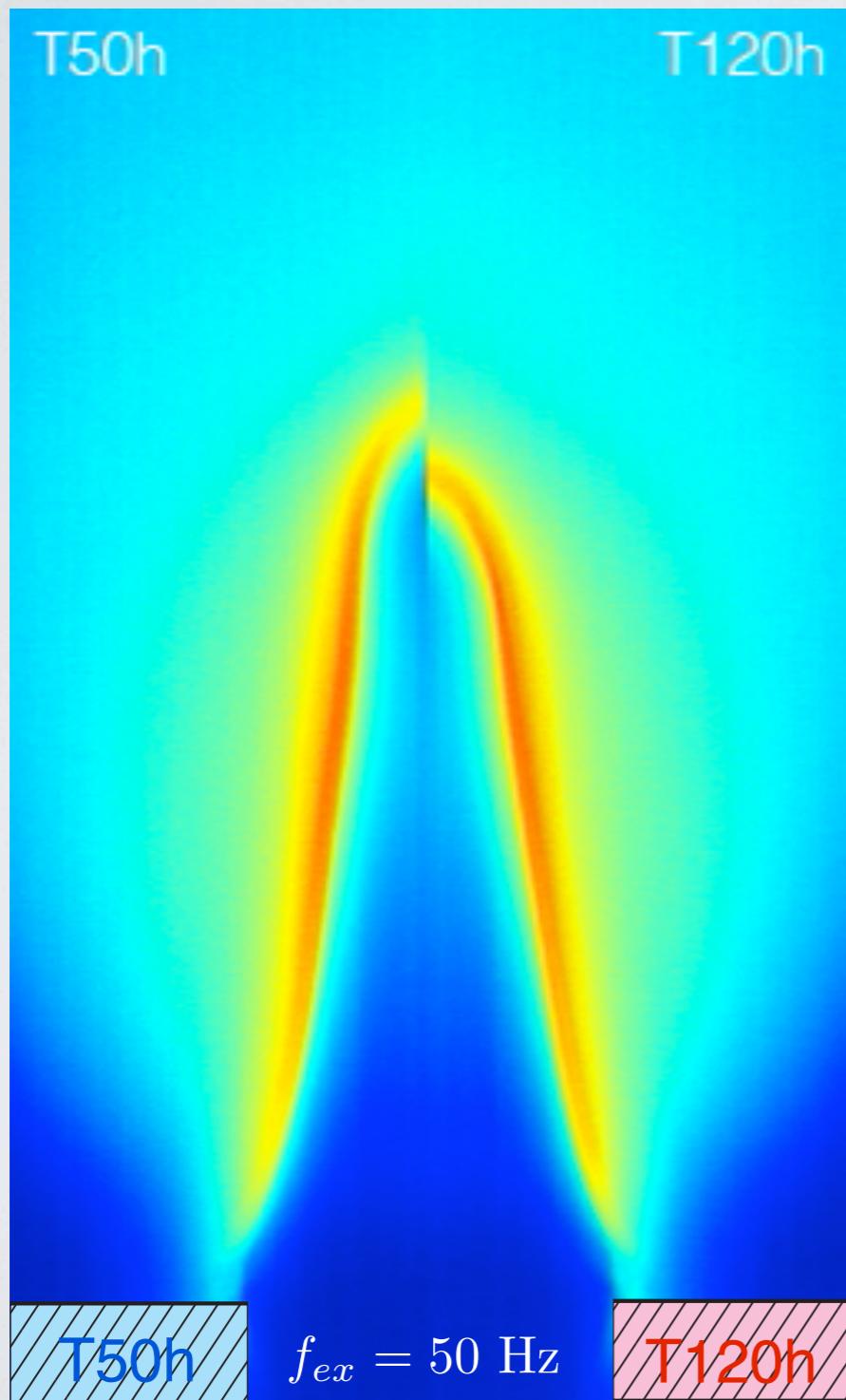
$$\mathcal{F}(\omega, T_s) = \frac{\dot{q}'/\bar{q}}{v'_1/\bar{v}} = \frac{\mathcal{A}'/\bar{\mathcal{A}}}{v'_1/\bar{v}} = \frac{I'_{CH^*}/\bar{I}_{CH^*}}{v'_1/\bar{v}}$$

$$\boxed{\begin{aligned}\mathcal{G} &= |\mathcal{F}(\omega, T_s)| \\ \varphi &= \arg[\mathcal{F}(\omega, T_s)]\end{aligned}}$$



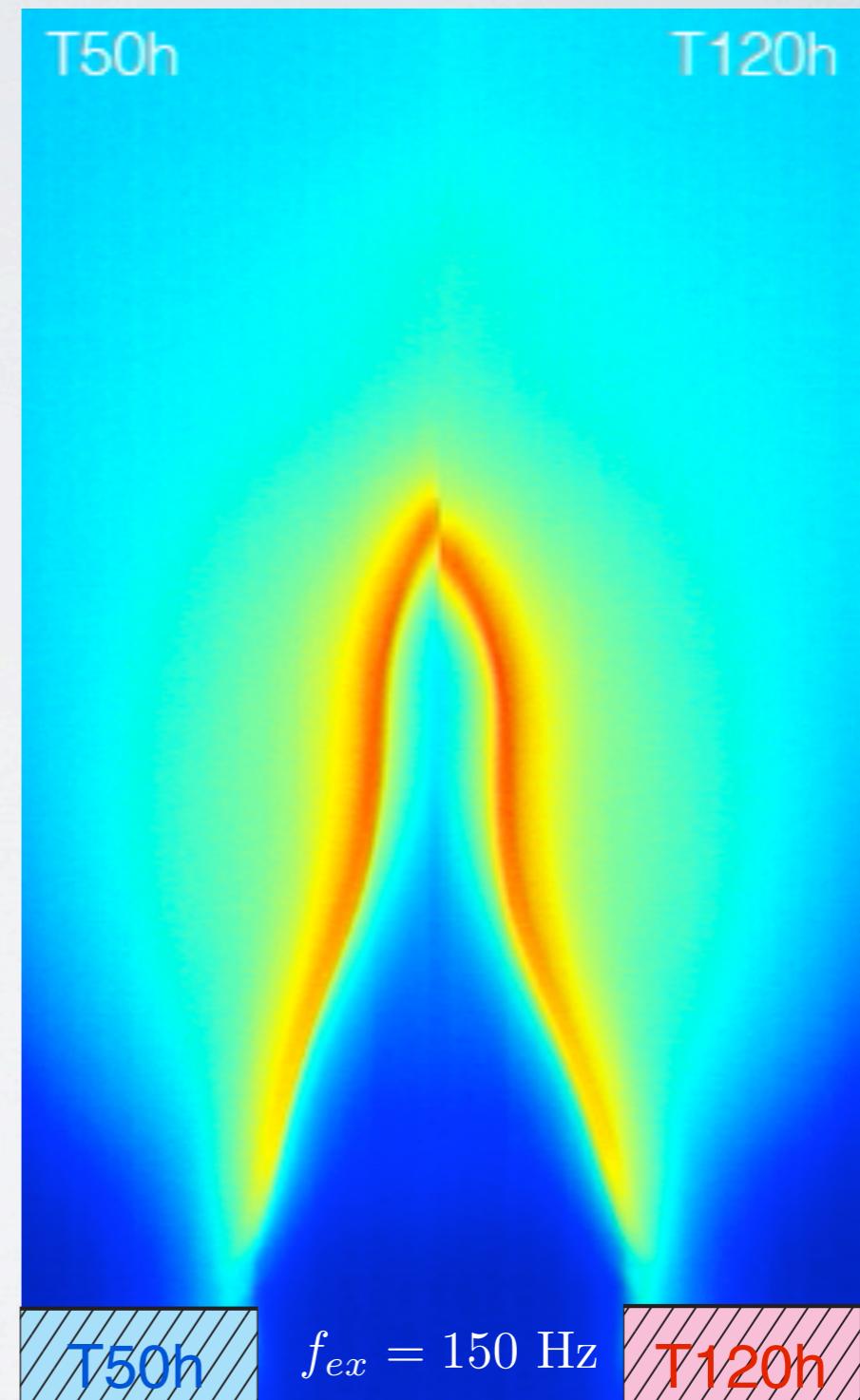
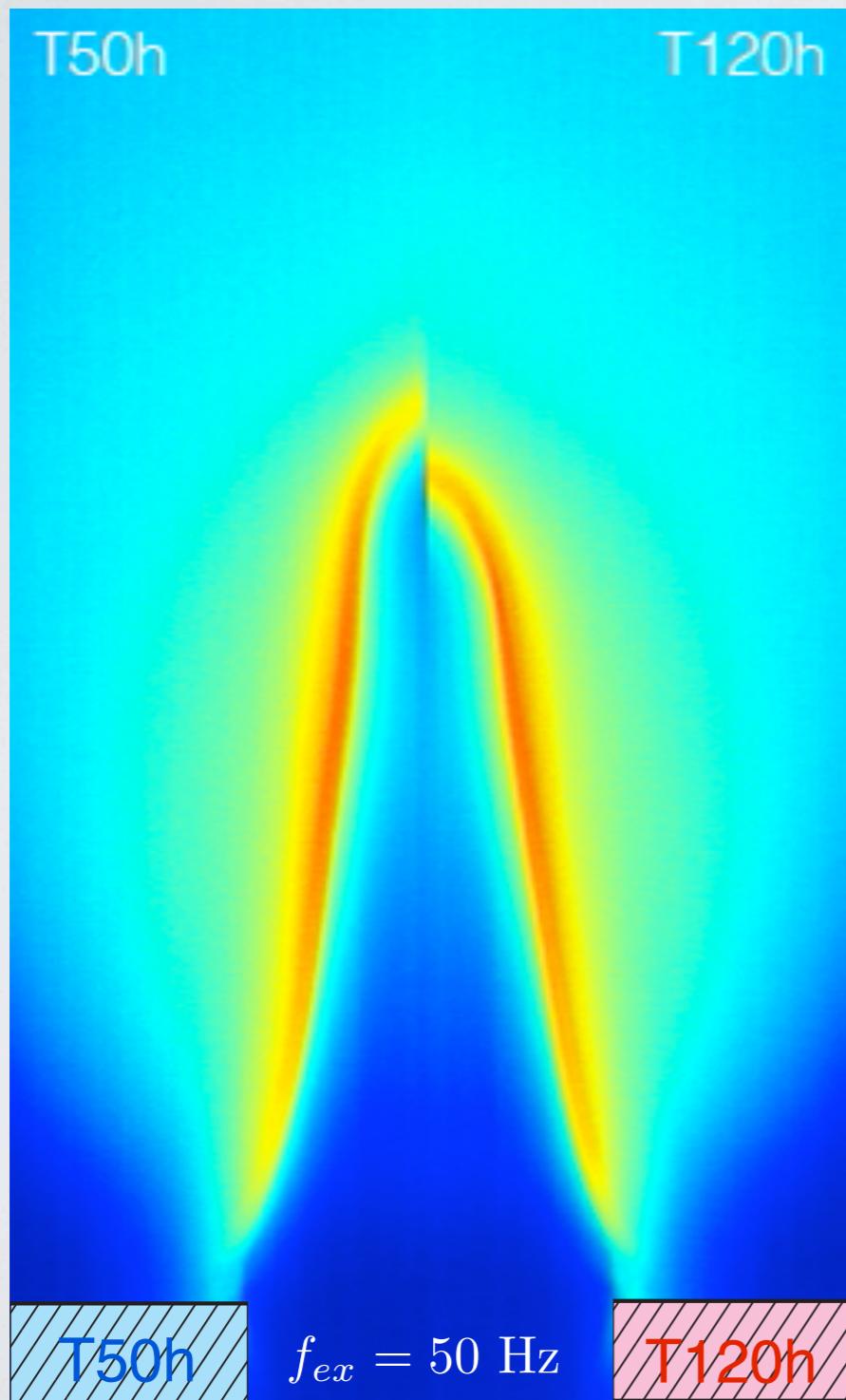
COMBUSTION DYNAMICS

Flame Transfer Function



COMBUSTION DYNAMICS

Flame Transfer Function



EXPERIMENTAL MEASUREMENTS

	Parameter	Depends on Ts ?
Combustion noise	$r = 22 \text{ mm}$	NO
Acoustics	$\delta = 16 \text{ s}^{-1}$	NO
Combustion dynamics	$n \begin{pmatrix} 50 \\ 90 \\ 120 \end{pmatrix} = \begin{pmatrix} 0.87 \\ 0.77 \\ 0.75 \end{pmatrix}$	$\varphi \begin{pmatrix} 50 \\ 90 \\ 120 \end{pmatrix} = \begin{pmatrix} 1.13\pi \\ 1.09\pi \\ 1.05\pi \end{pmatrix}$

SOLUTION OF THE DISPERSION EQUATION

		T50	T90	T120
Combustion Noise	r [mm]		22	
Burner Acoustics	ω_0 [rad/s]		327	
	δ [s ⁻¹]		16	
Combustion Dynamics	n [1]	0.87	0.77	0.75
	φ [rad]	1.13π	1.09π	1.05π

$$\left[1 + C \frac{1}{r} n e^{i\varphi}\right] \omega^2 + 2i\delta\omega - \omega_0^2 = 0$$

$\omega_r \rightarrow$ Frequency of resonance

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Case	ω_r	ω_i	Observation
T50h	369	2.45	Instable
T90h	366	-6.27	Stable
T120h	365	-11.22	Stable

SOLUTION OF THE DISPERSION EQUATION

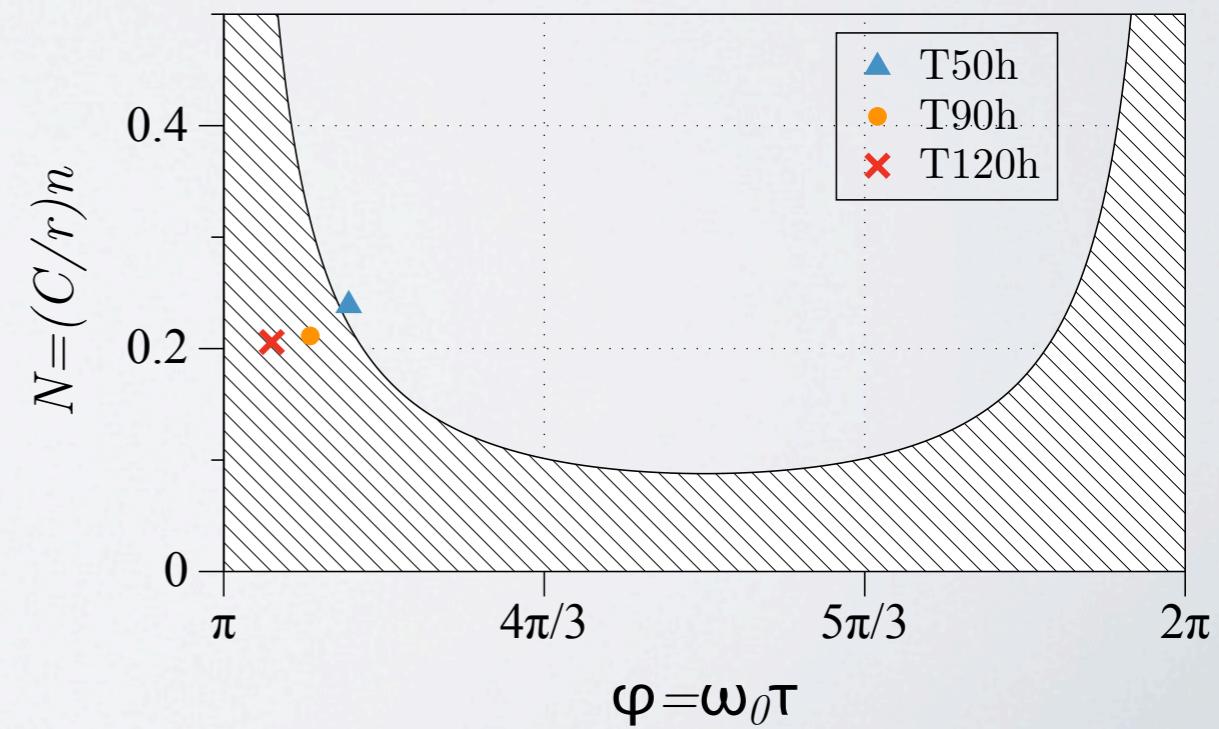
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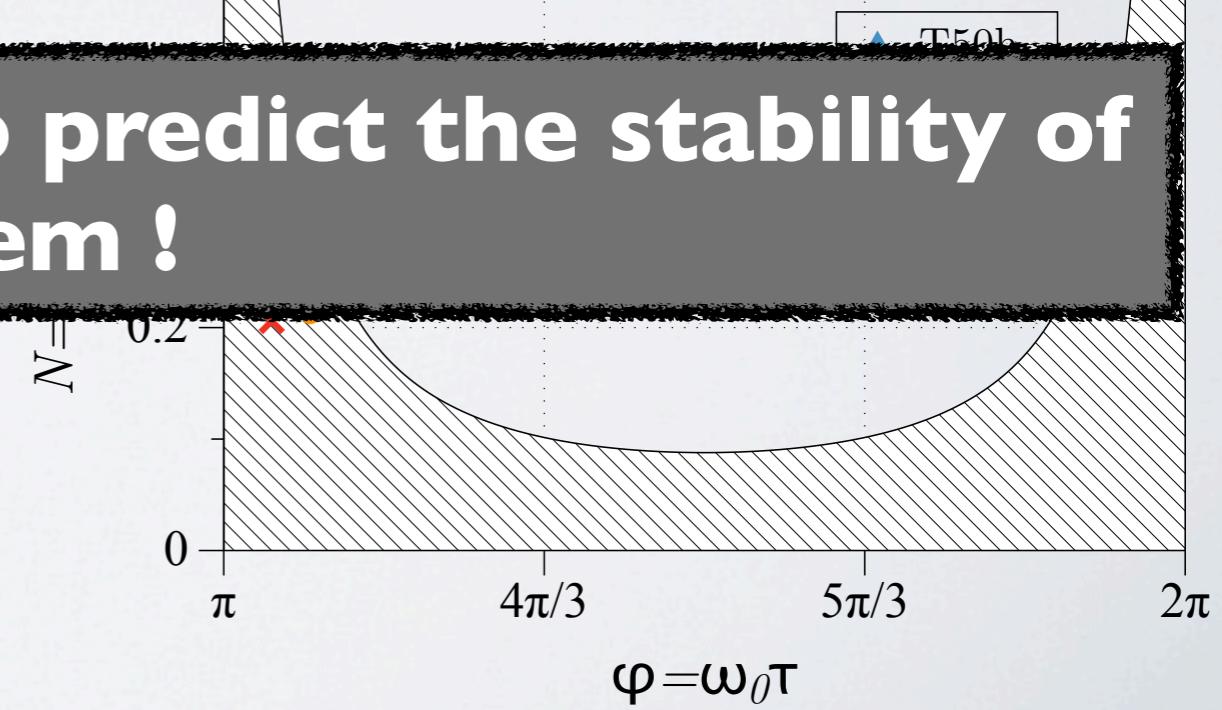
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A low order model is able to predict the stability of the system !

T90h	366	-6.27	Stable
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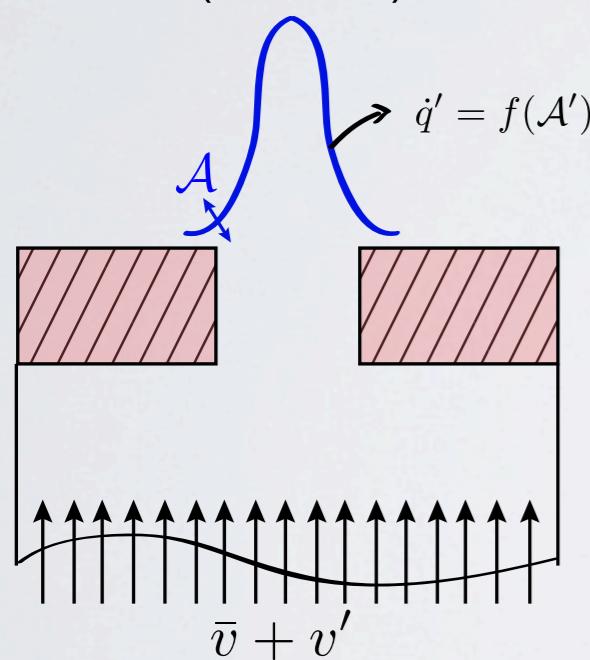
WHY COMBUSTION DYNAMICS IS AFFECTED BY THE WALL TEMPERATURE ?

The combustion instabilities are suppressed by the combined effect of the wall temperature on both, the gain and the phase of the flame response !

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Elongated flames
(EM2C)

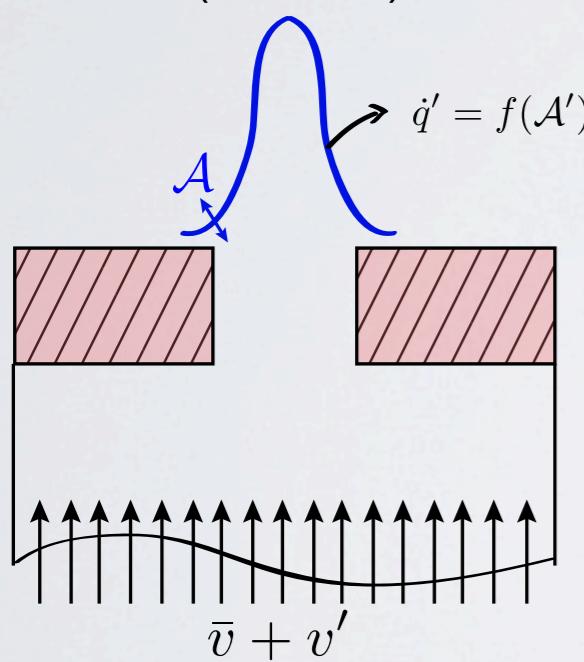


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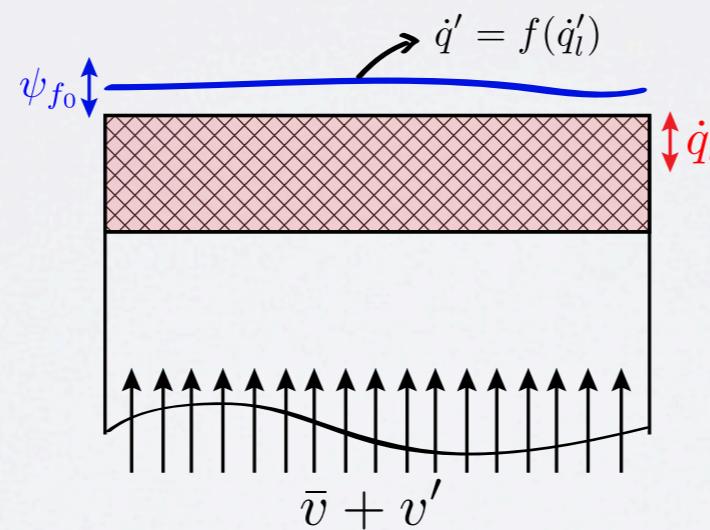
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Flat flames stabilized
over porous media
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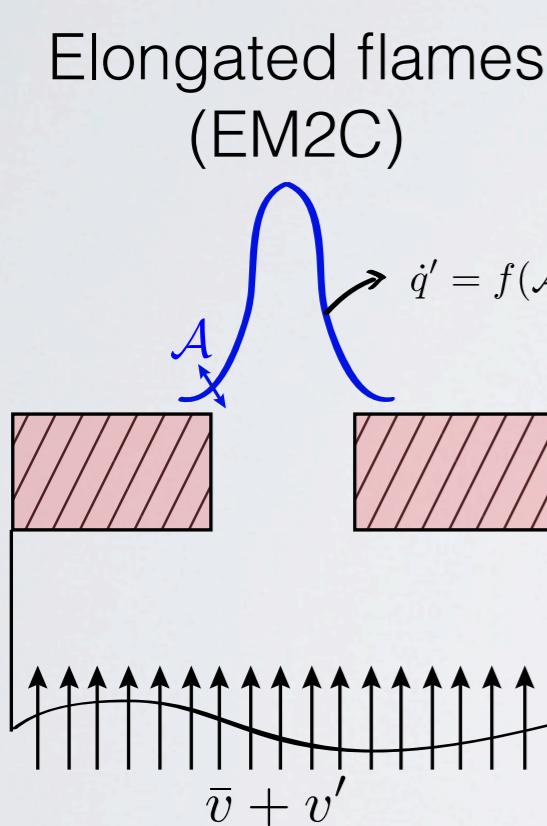


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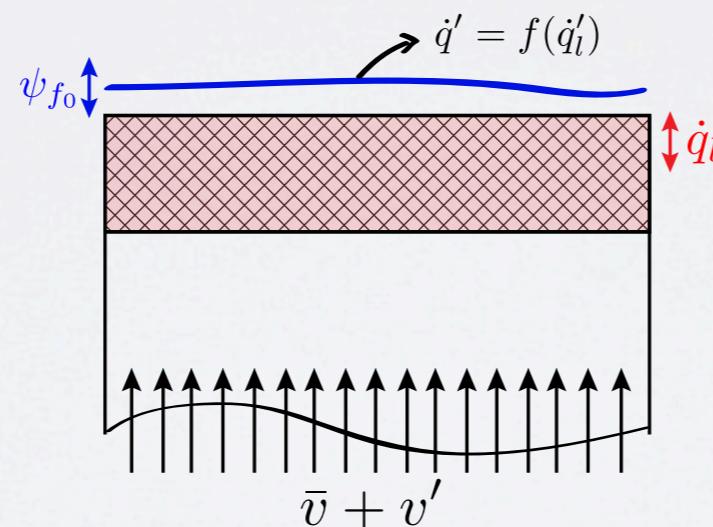
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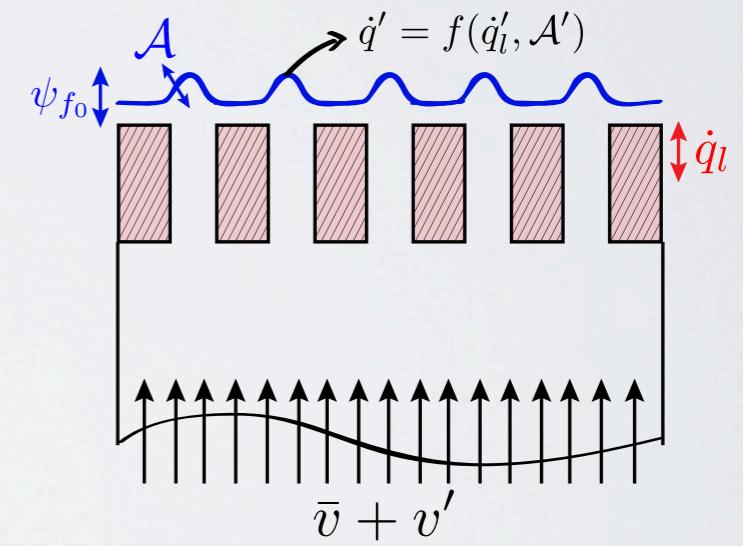
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Perforated-plate
stabilized flames
(MIT)

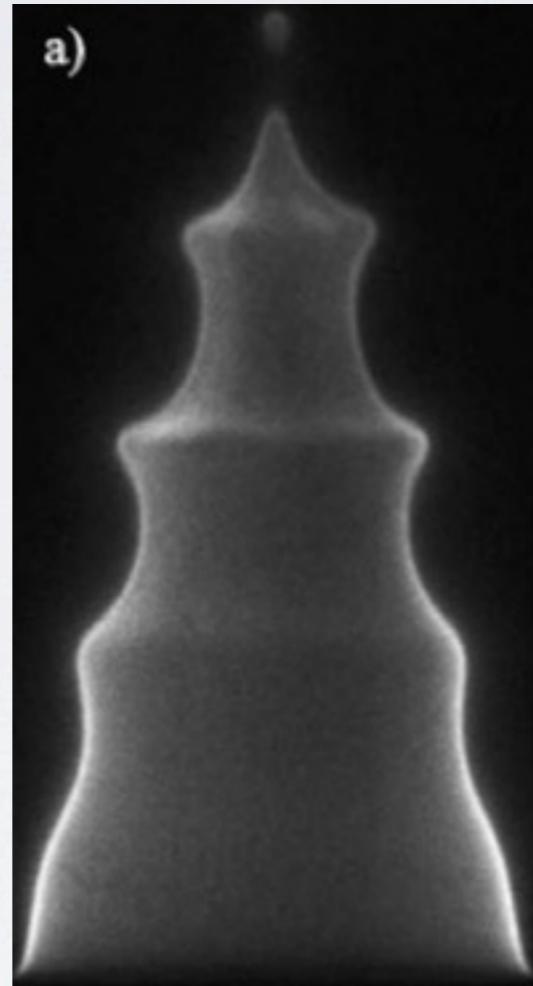
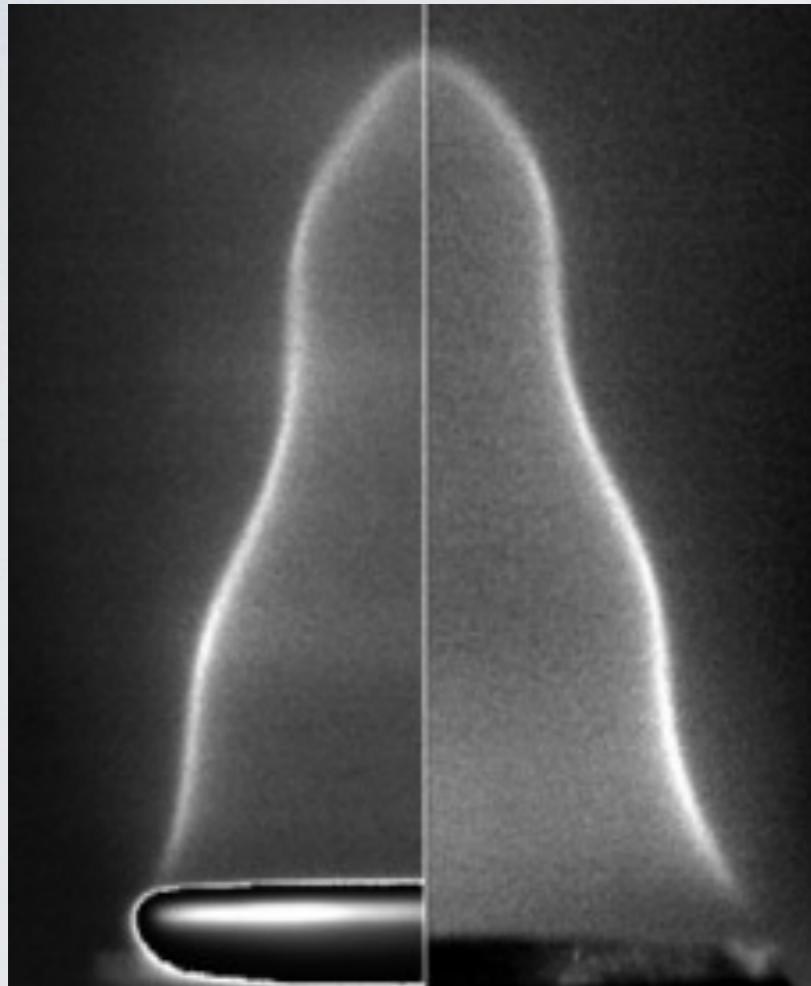


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- ❖ Altay et al. (2009)
- ❖ Murat et al. (2010)
- ❖ Kedia et al. (2011)

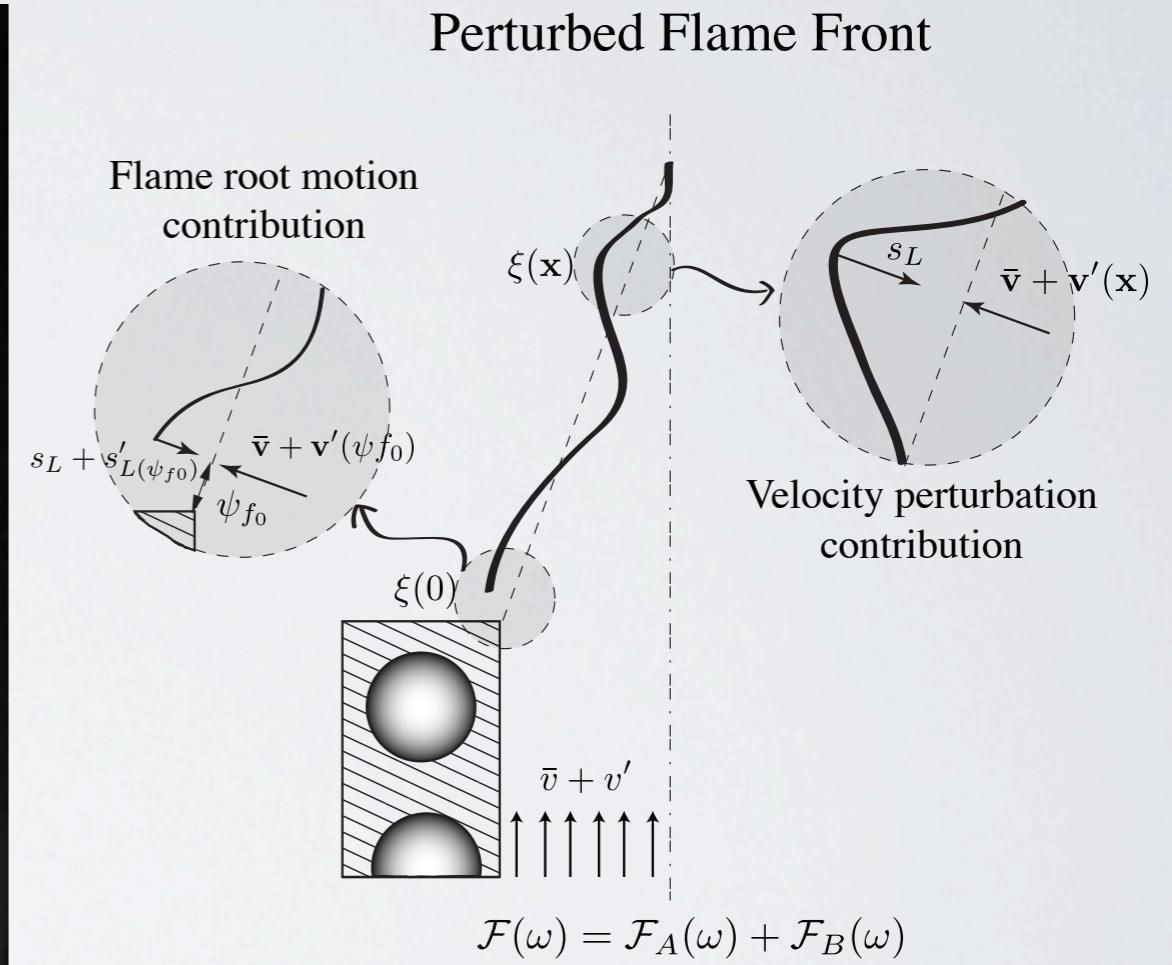
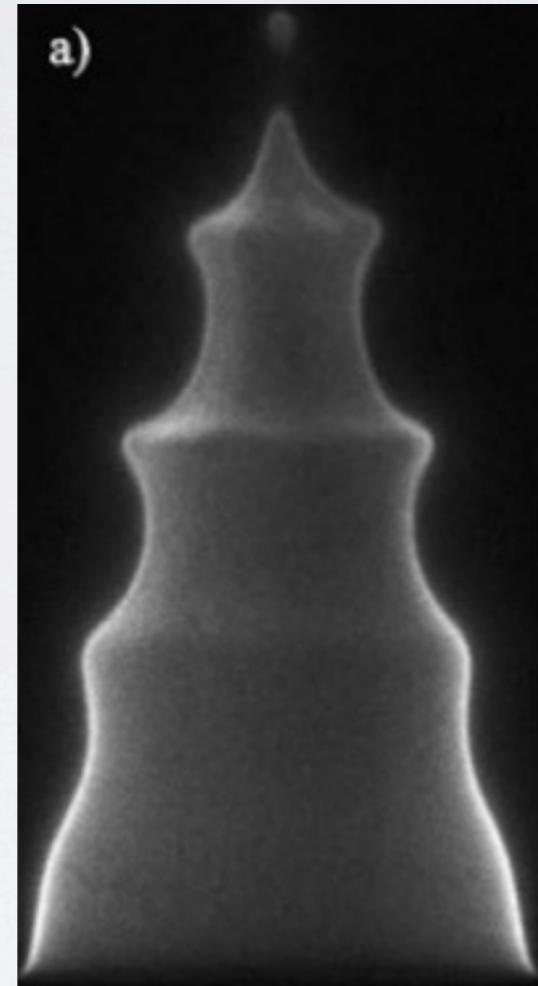
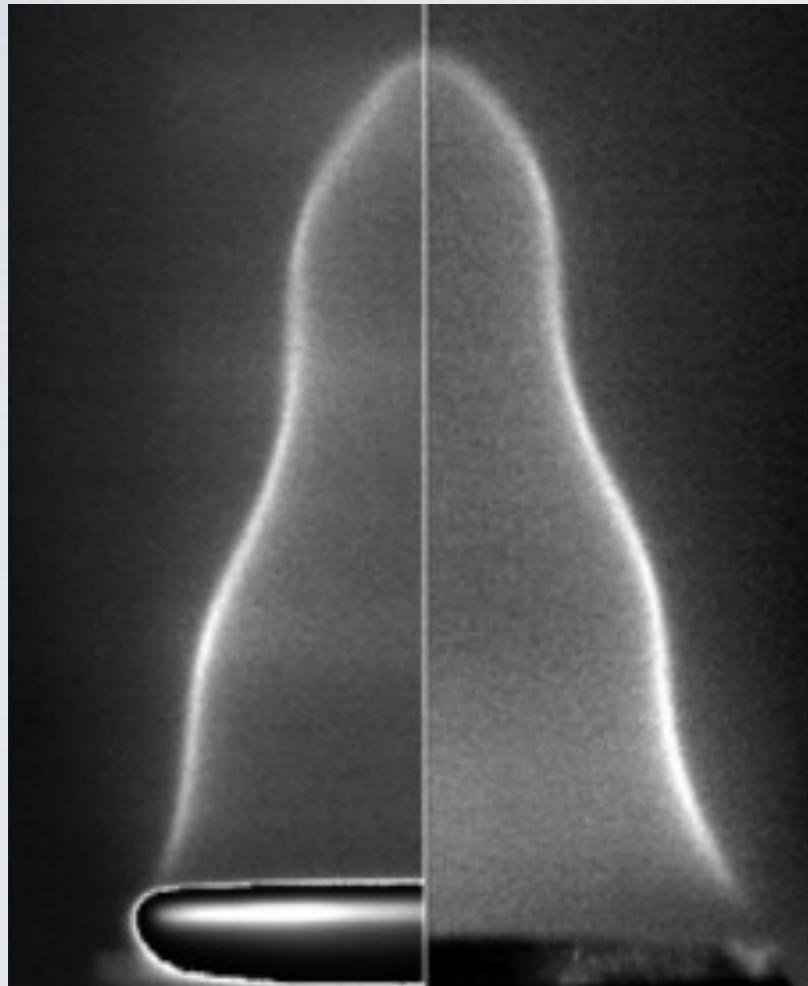
IMPORTANCE OF THE ANCHORING POINT DYNAMICS



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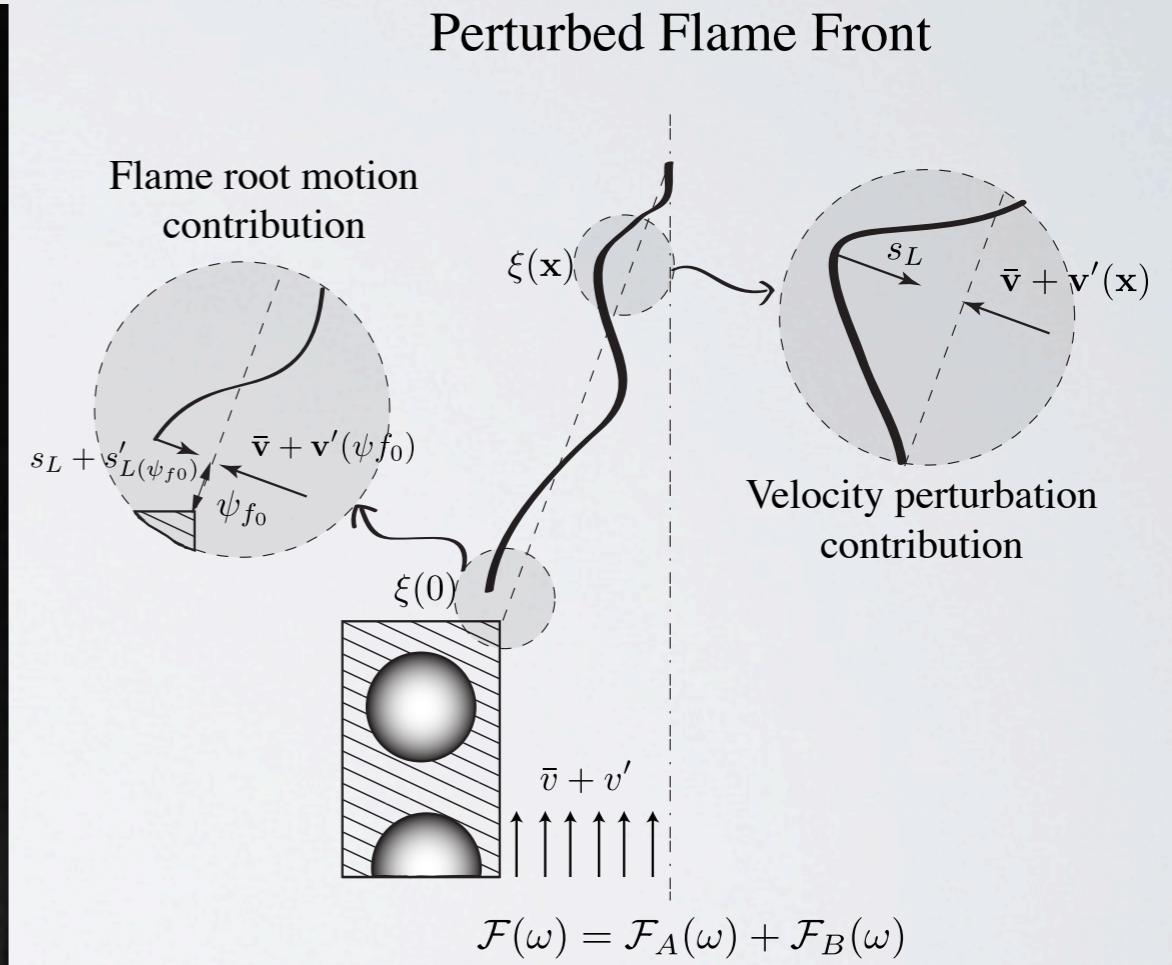
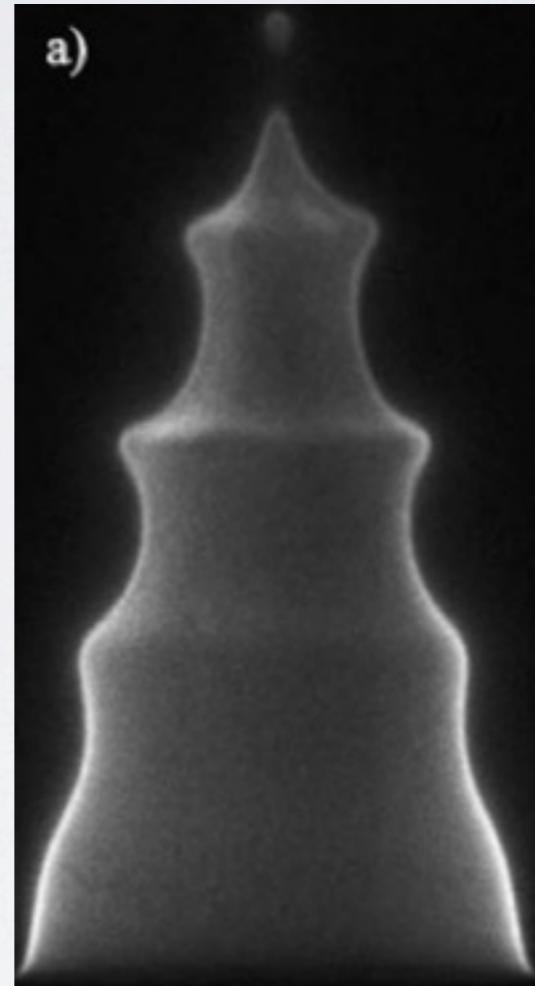
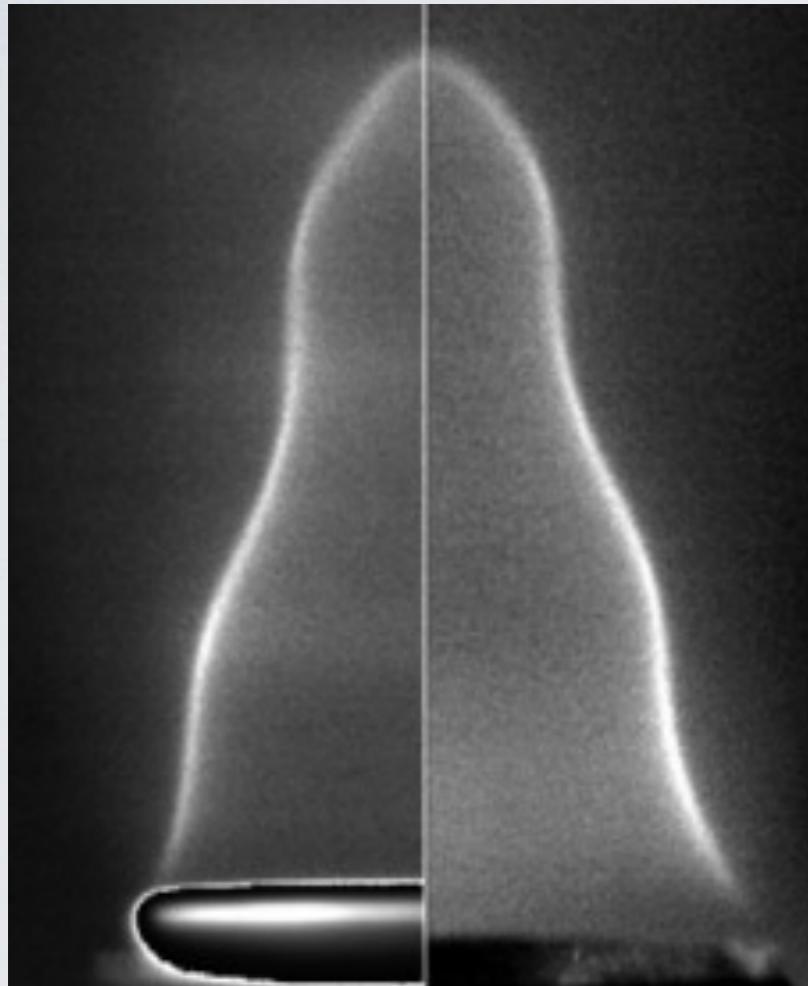


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IMPORTANCE OF THE ANCHORING POINT DYNAMICS



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$\mathcal{F}_A(\omega) \rightarrow$ Flame surface contribution

$\mathcal{F}_B(\omega) \rightarrow$ Flame base contribution

I. FLAME SURFACE CONTRIBUTION

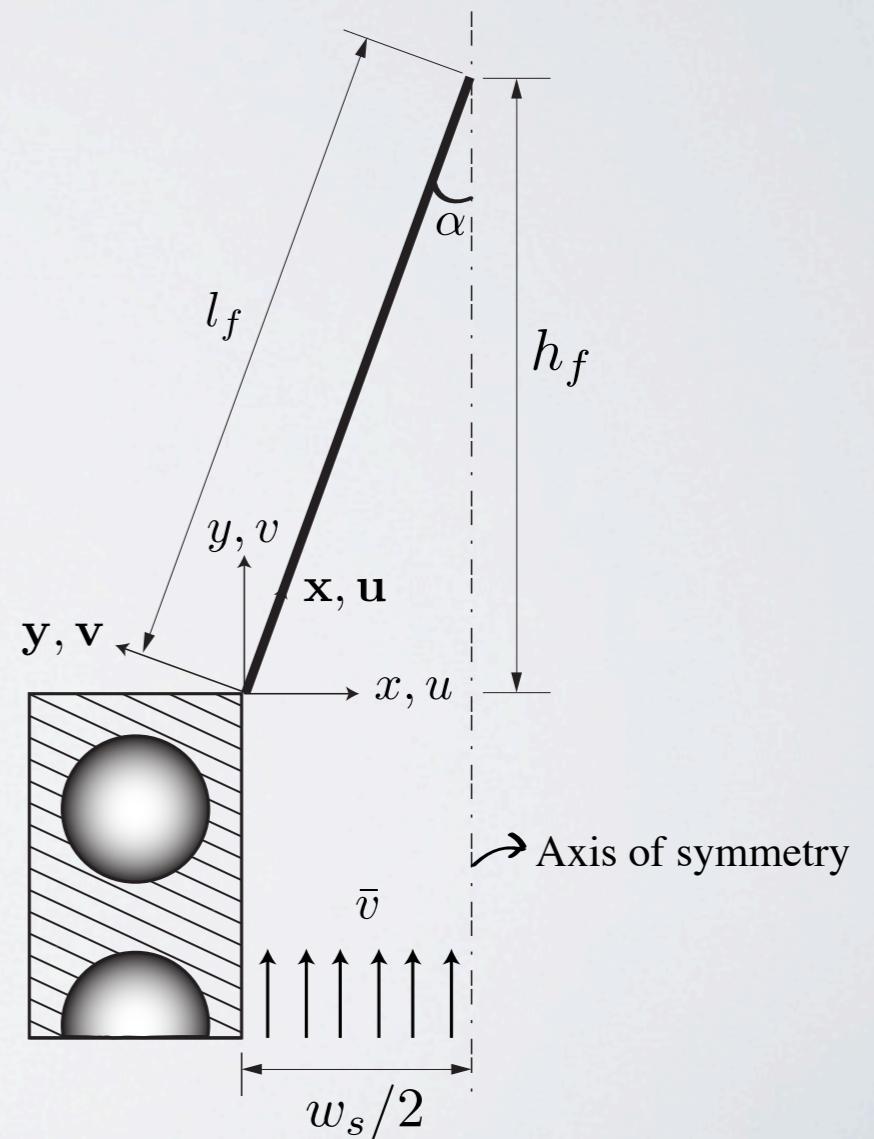
Flame front dynamics is controlled by two adimensional frequencyes that only depend on the stationay flame geometry:

$$\omega_* = \frac{\omega}{s_L \cos \alpha} \frac{w_s}{2} = \frac{\omega}{\bar{v} \cos \alpha} l_f, \quad \diamond$$

$$\kappa_* = \omega_* \cos^2 \alpha = \frac{\omega}{\bar{v}} h_f, \quad \star$$

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Stationary Flame Front



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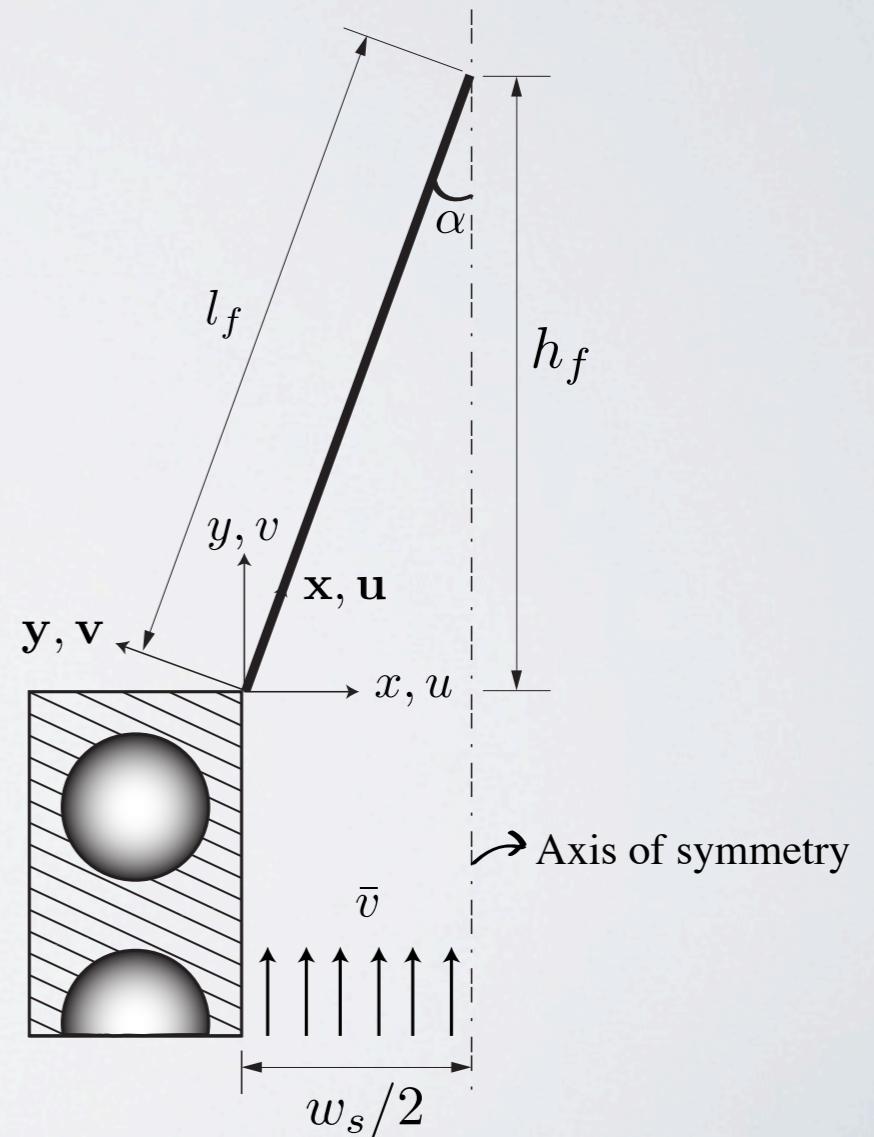
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If the flame surface contribution that is affected by the wall temperature is because on of this parameters has changed:

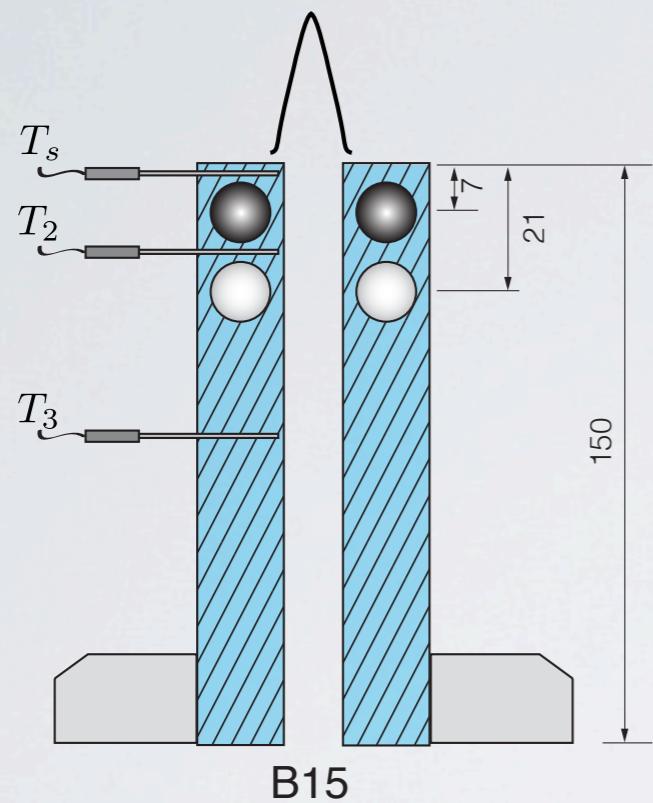
- ★ Flame geometry,
- ★ bulk velocity.

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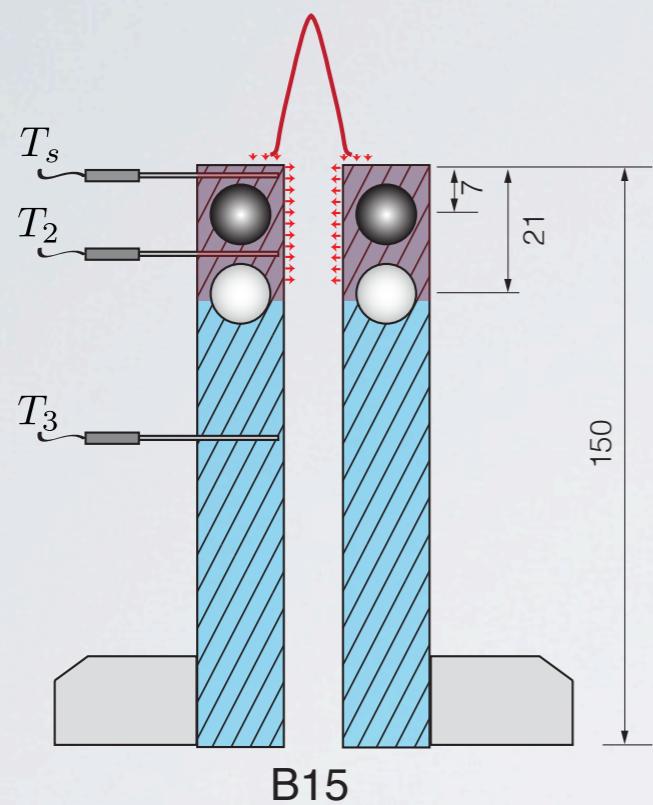
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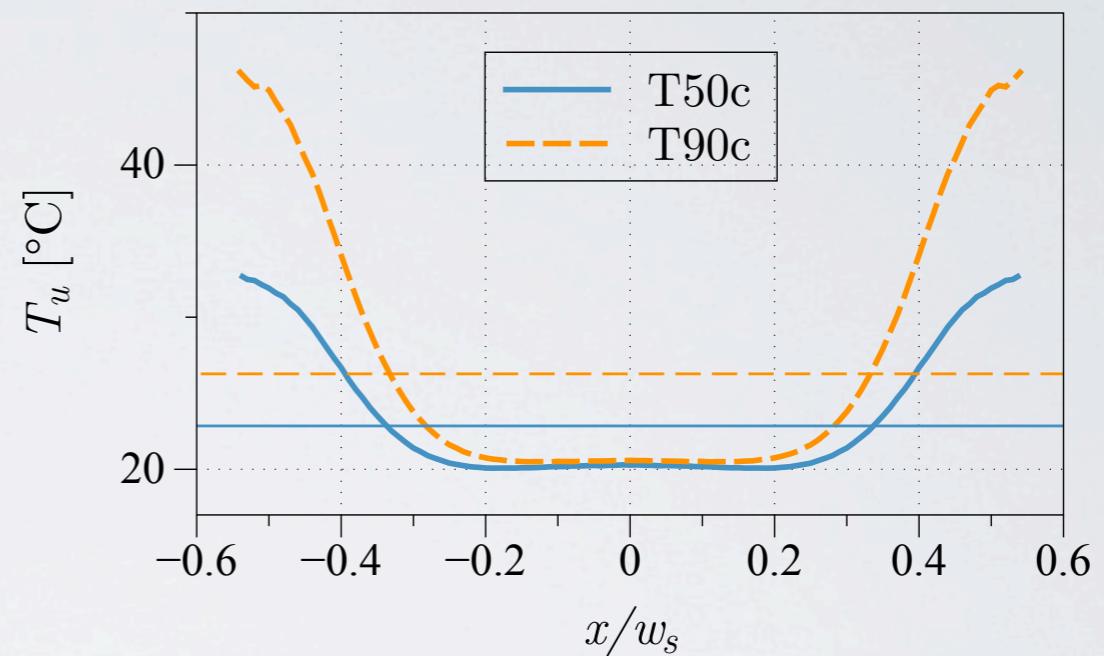
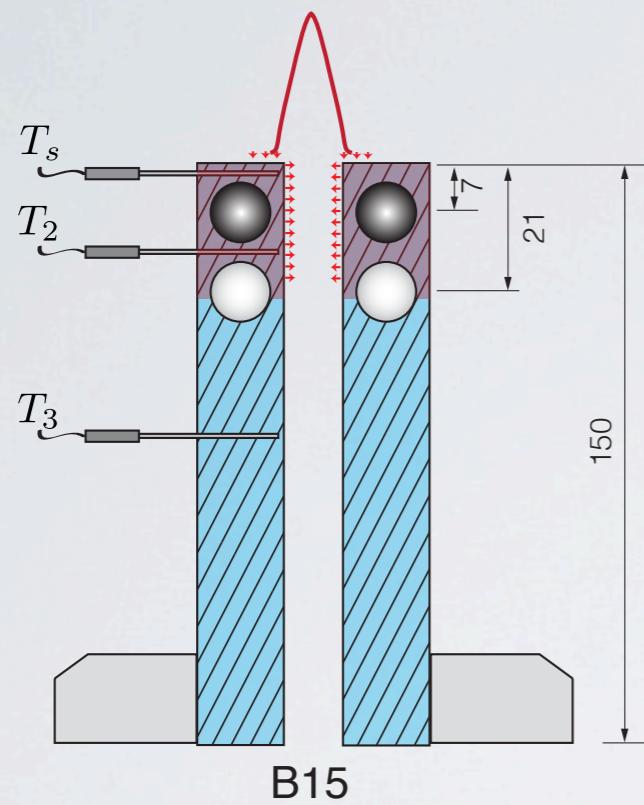
PRE-HEATING OF FRESH GASES ?



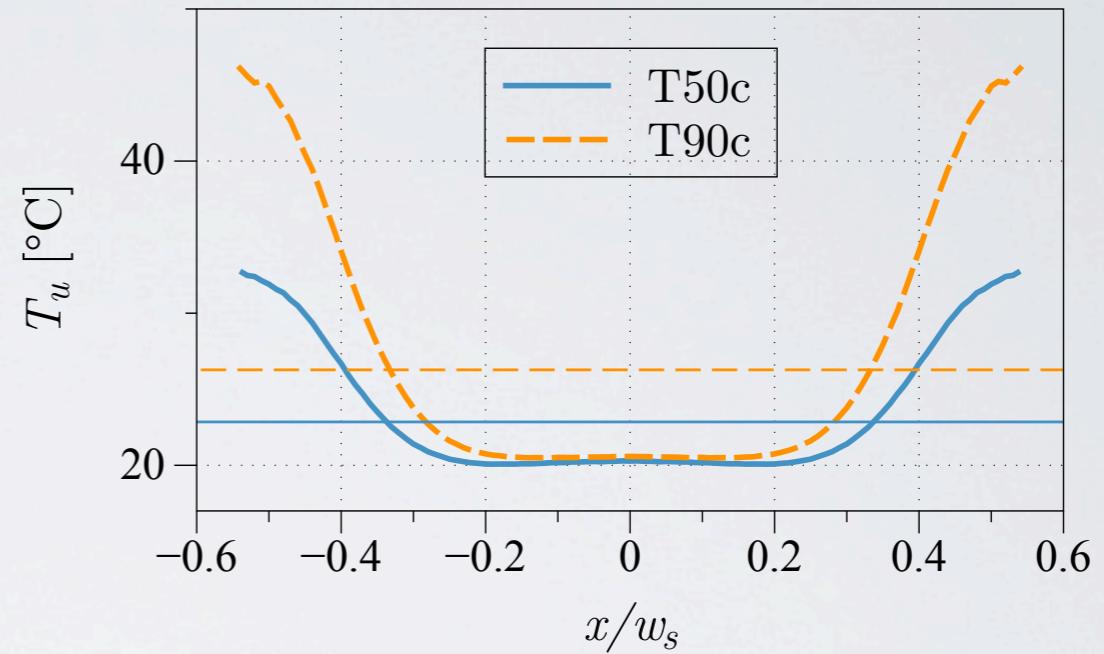
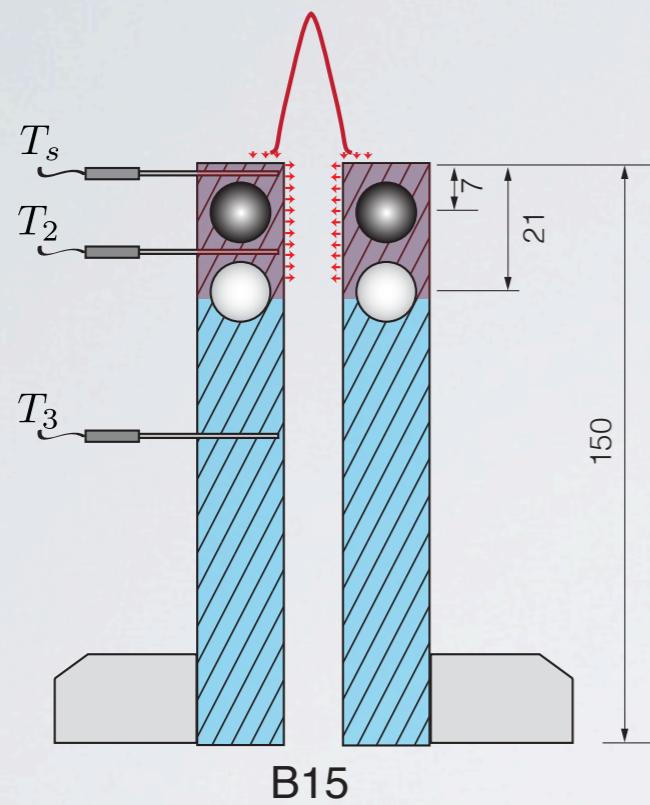
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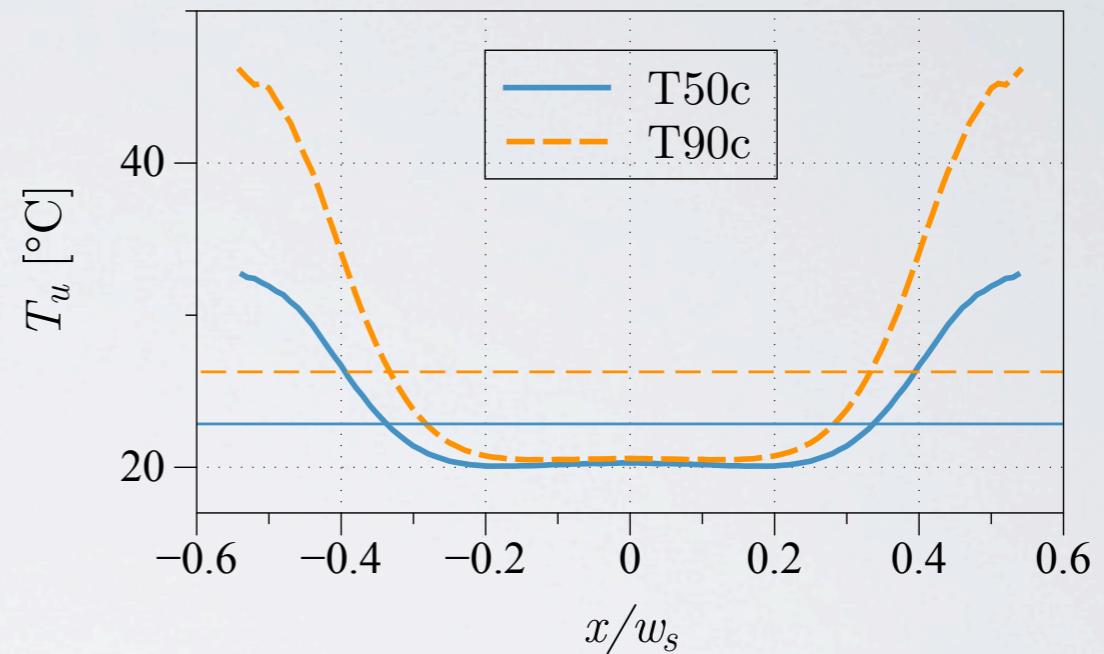
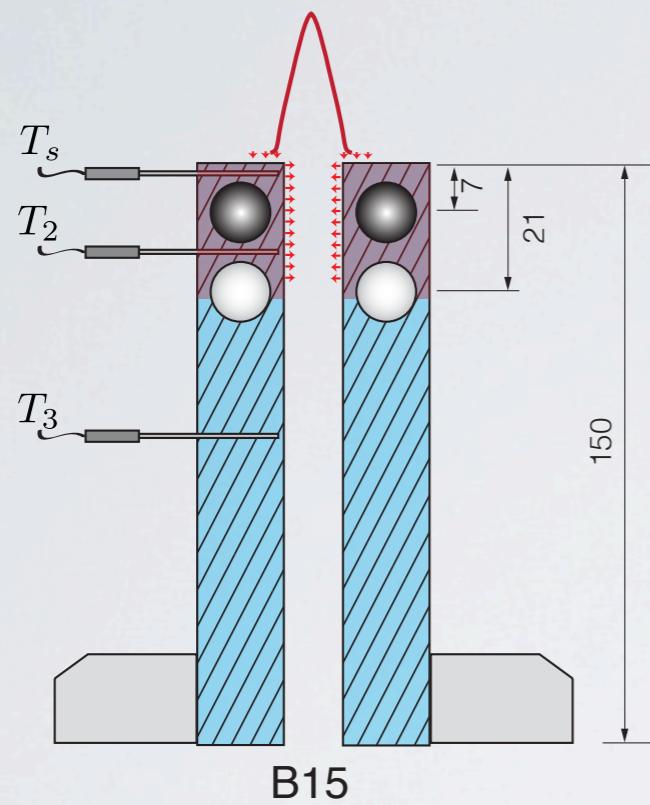


PRE-HEATING OF FRESH GASES ?



1. Does it affects the bulk velocity ?

PRE-HEATING OF FRESH GASES ?

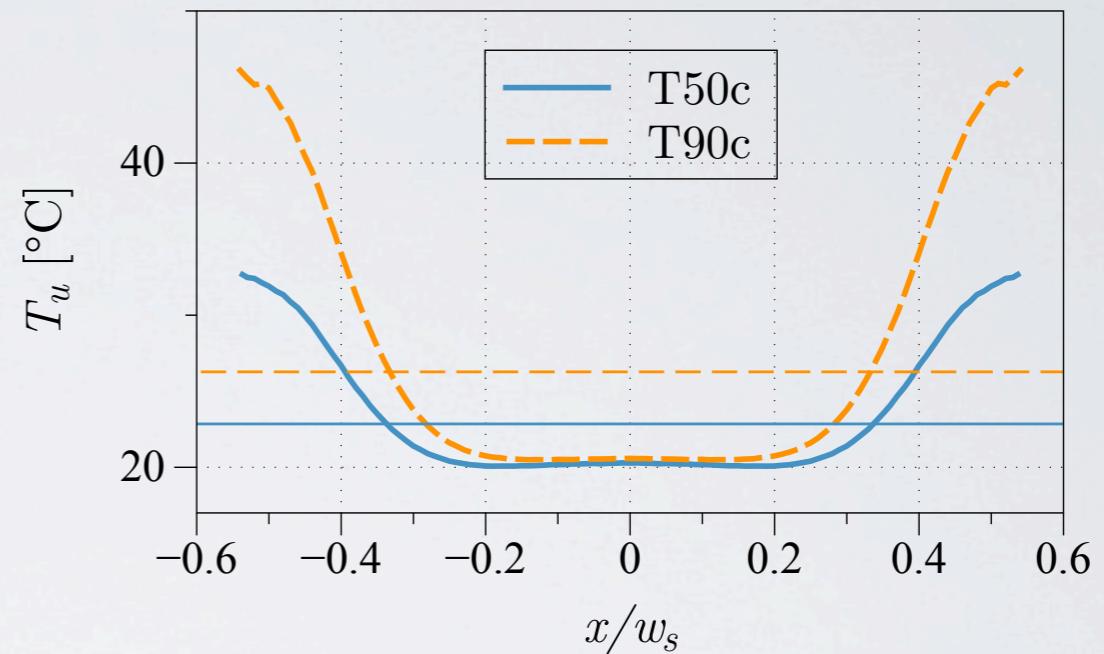
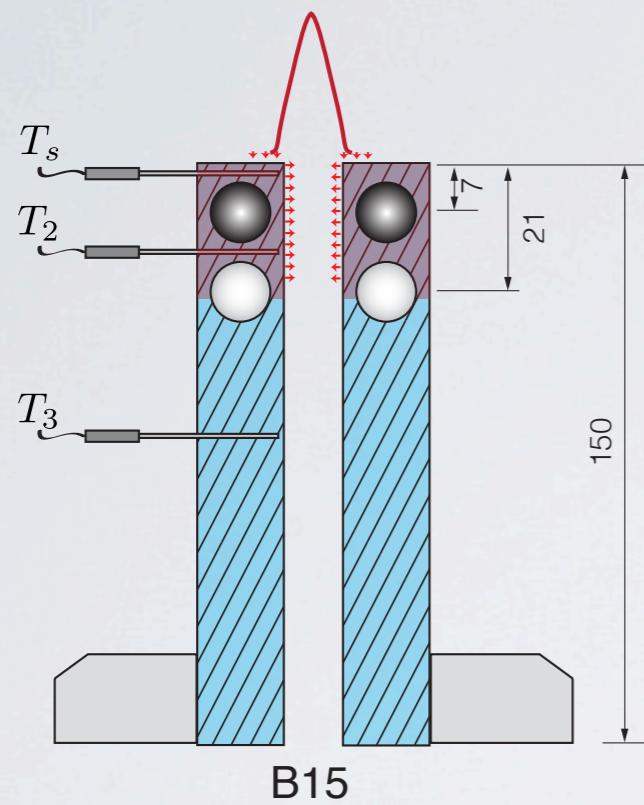


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$$\bar{v}^{\text{T90c}} = \bar{v}^{\text{T50c}} \frac{T_u^{\text{T90c}}}{T_u^{\text{T50c}}}$$

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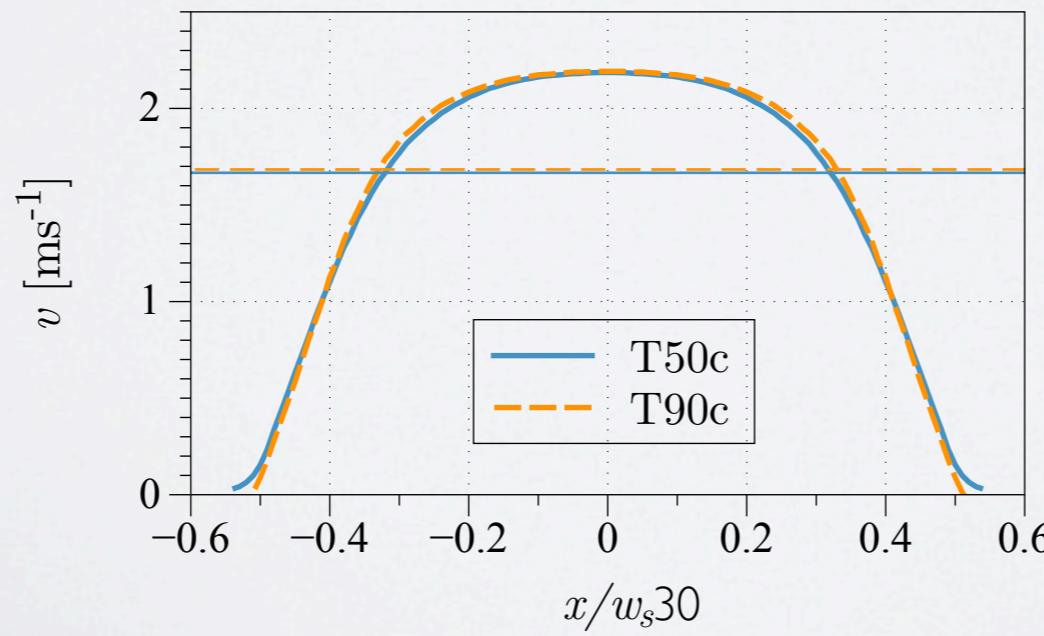
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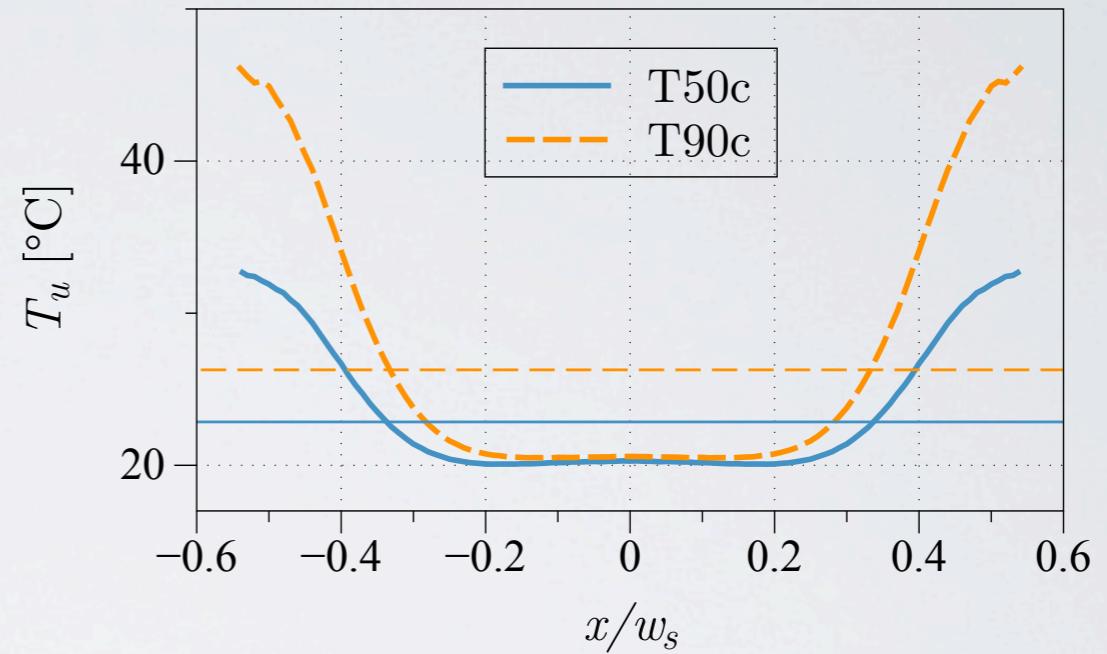
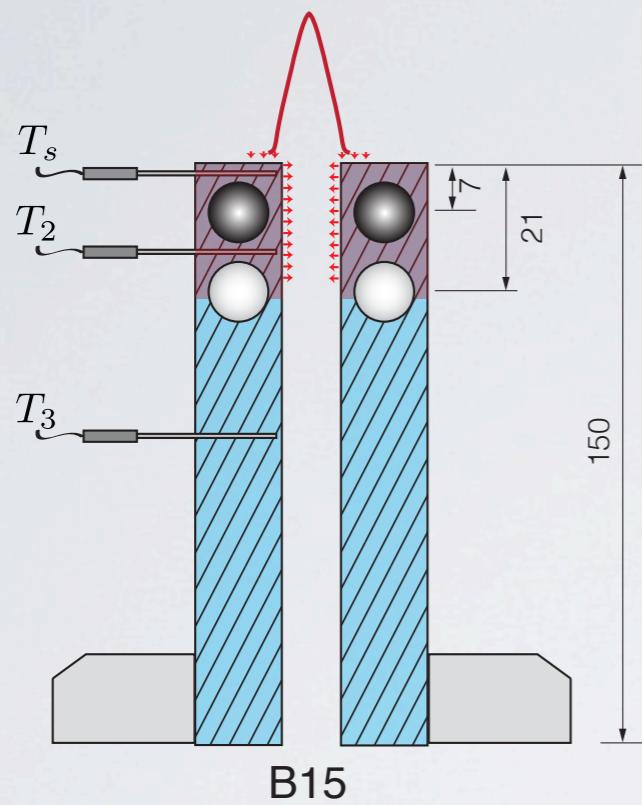
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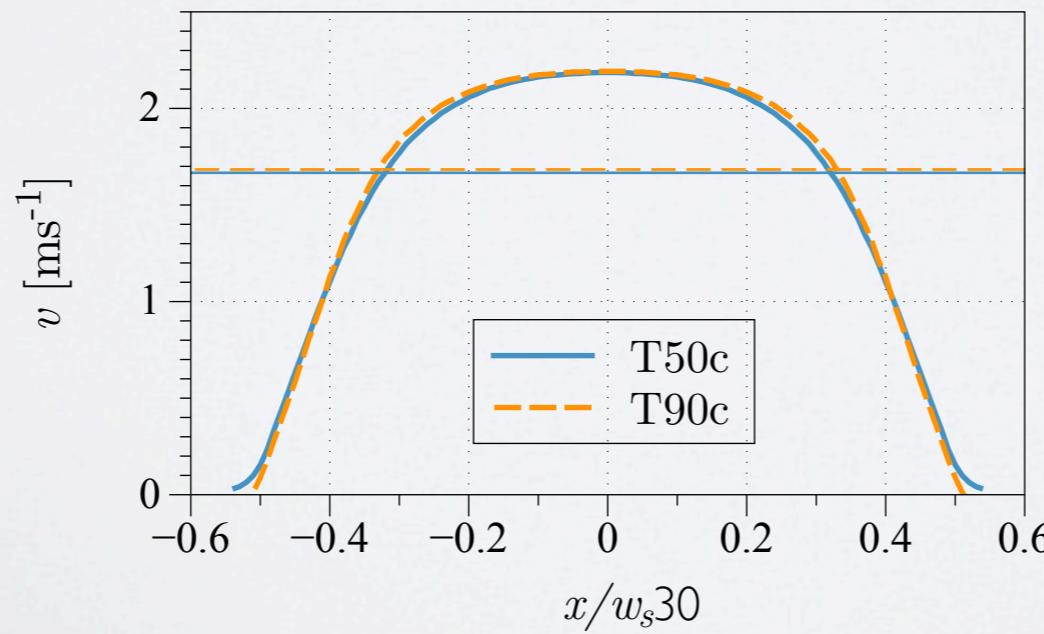
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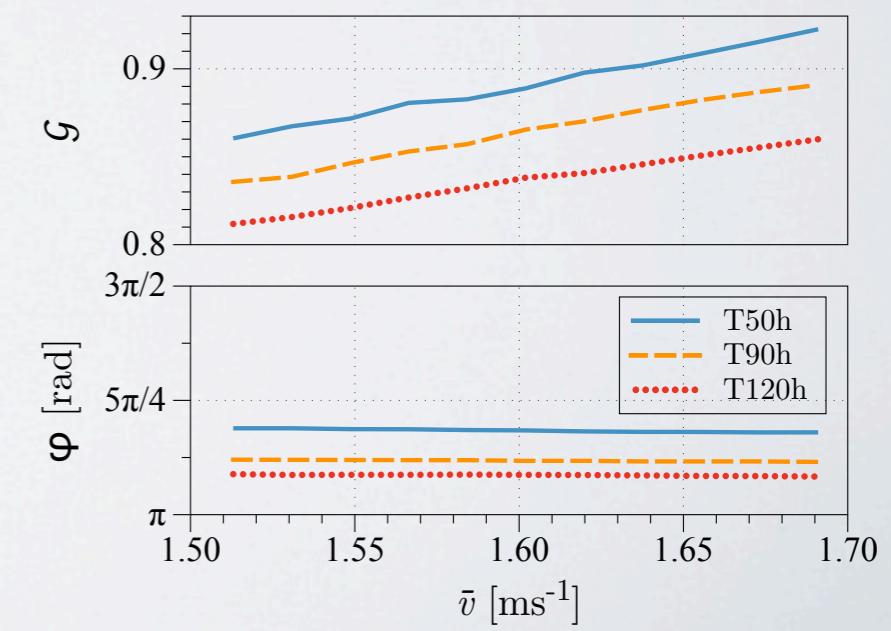
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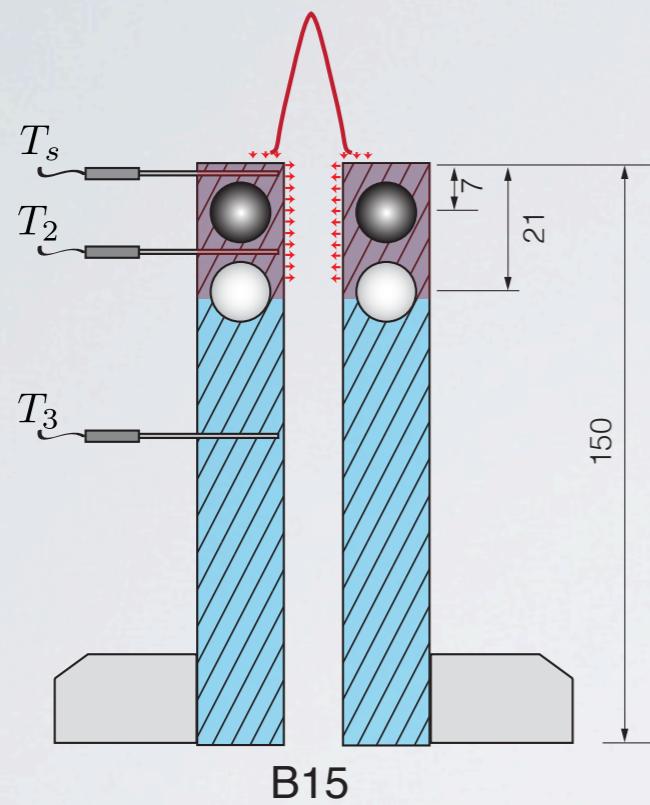
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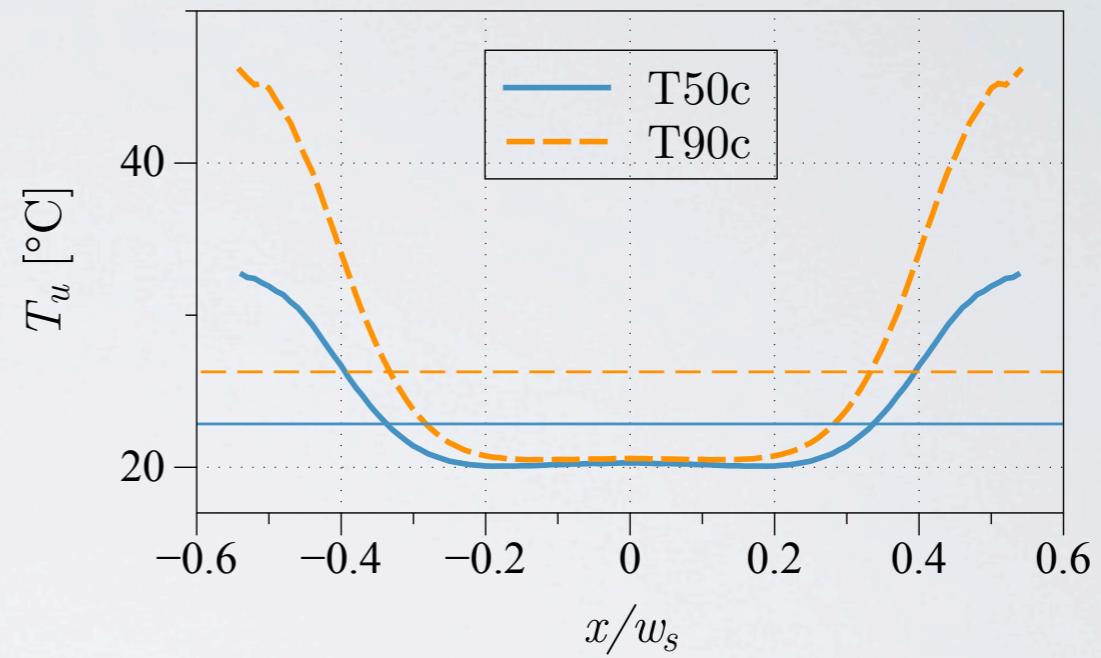
FTF at $f_{ex} = 58$ Hz



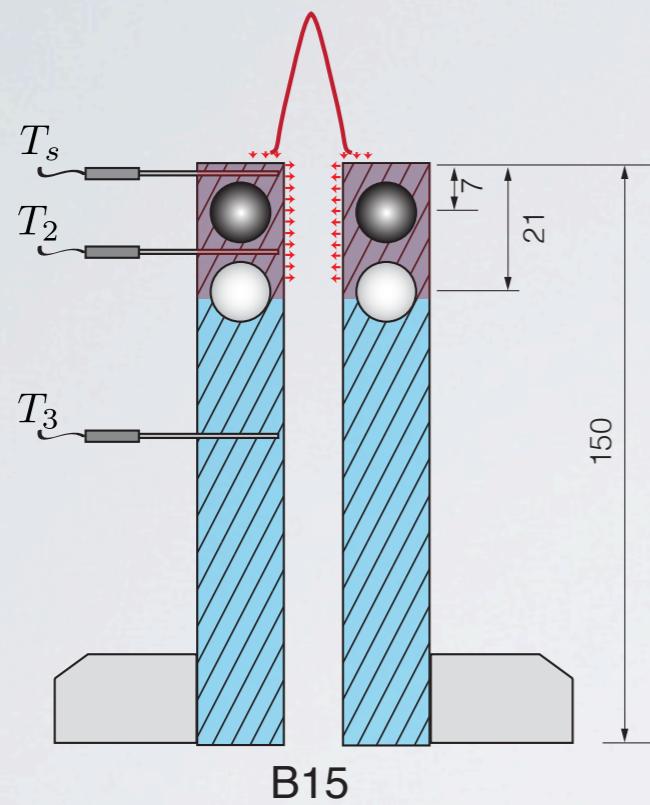
PRE-HEATING OF FRESH GASES ?



2. Does it affects the flame speed ?



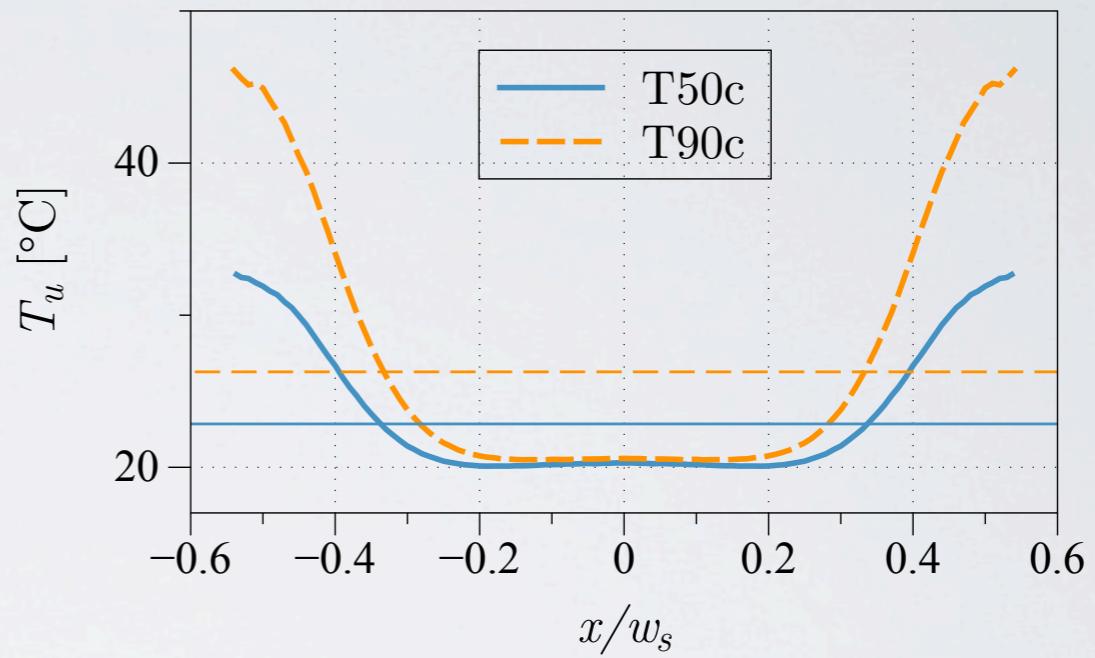
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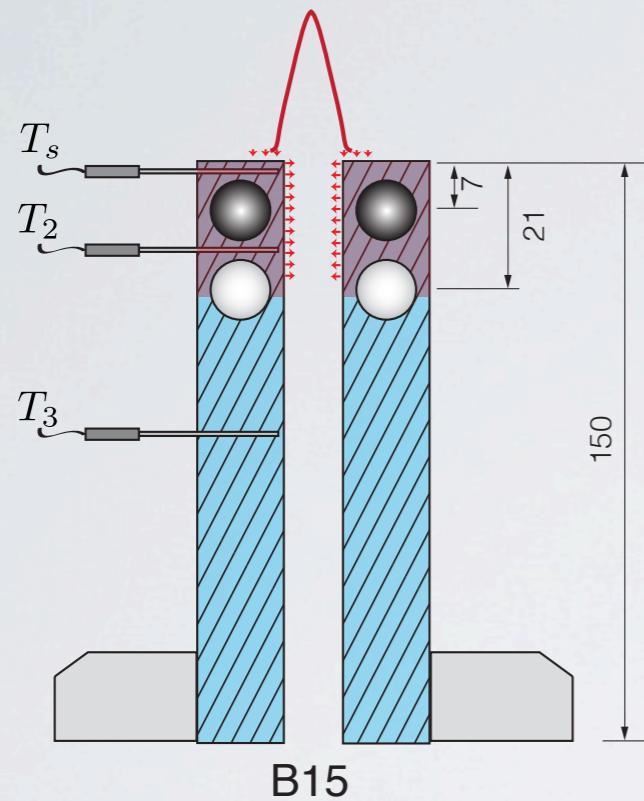
2. Does it affects the flame speed ?

$$s_L \propto \left(\frac{T_u}{T_u^0} \right)^{\alpha_T}, \quad \alpha_T = 1.9$$

$$\frac{s_L^{T90h}}{s_L^{T50h}} = 1.03$$



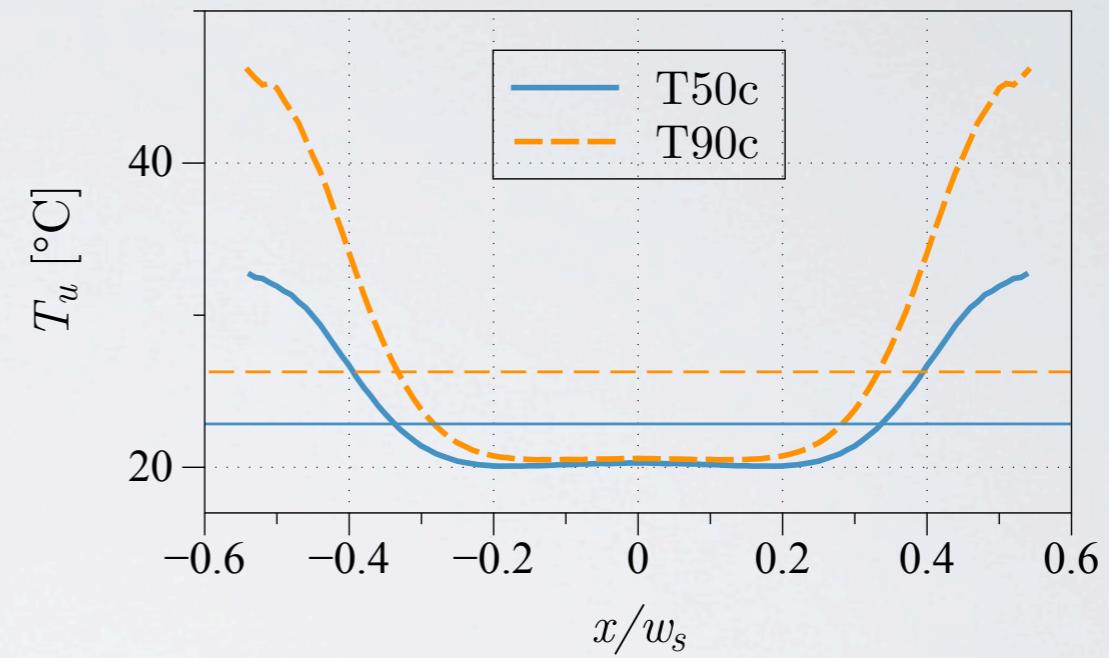
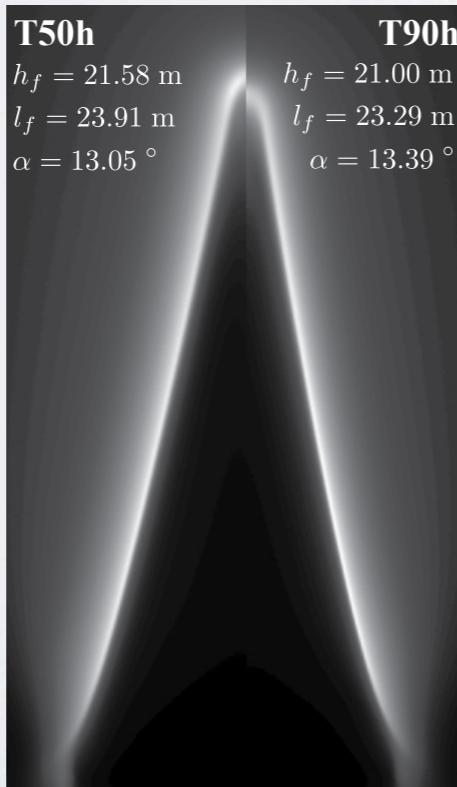
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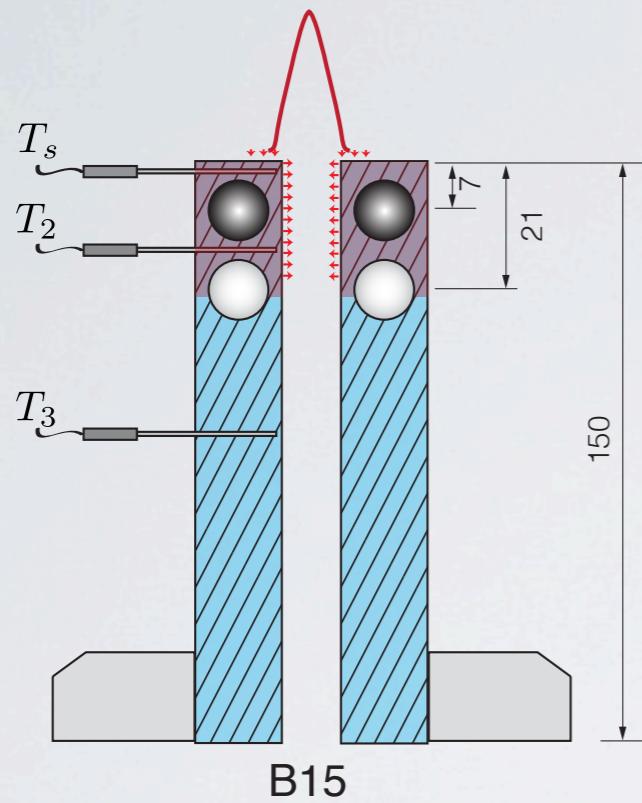
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$$s_L \propto 1/l_f$$

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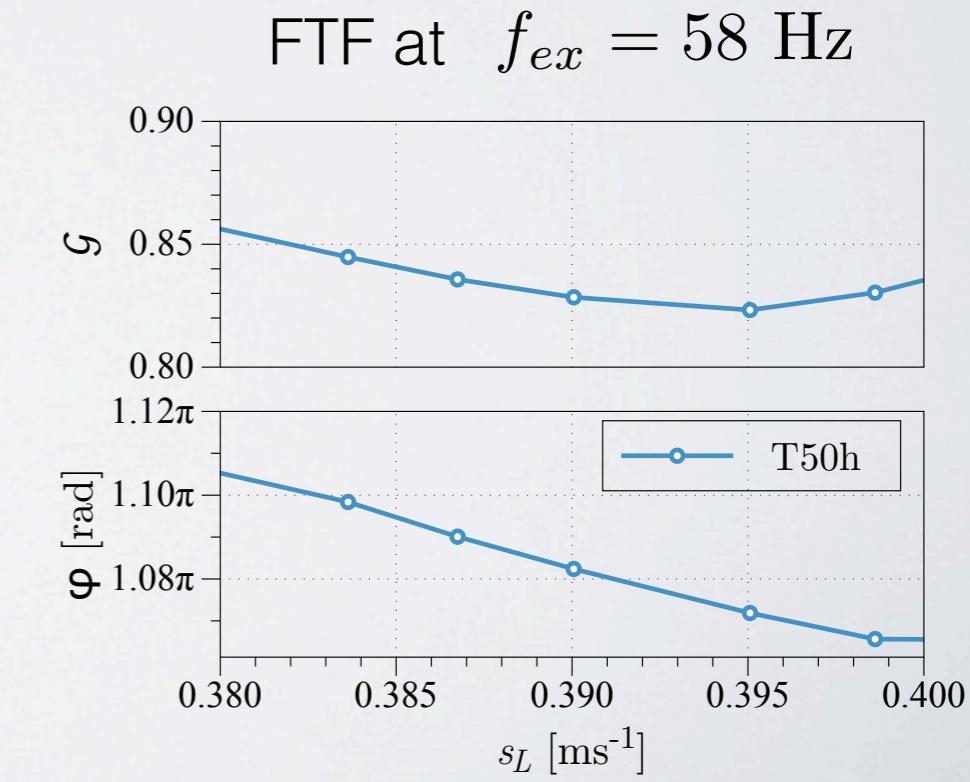
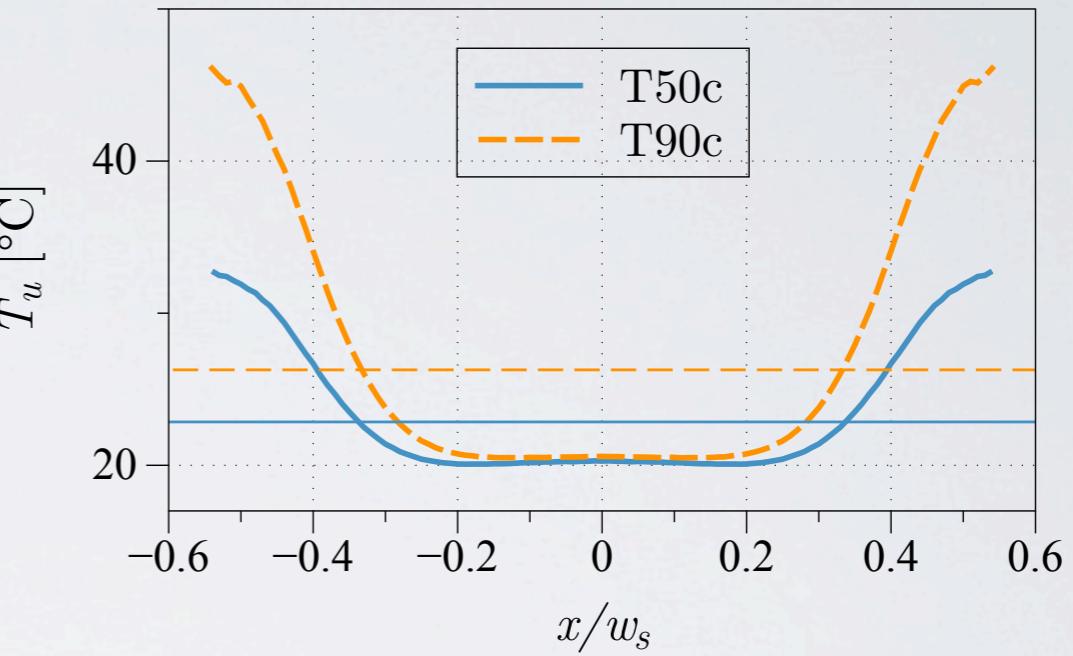
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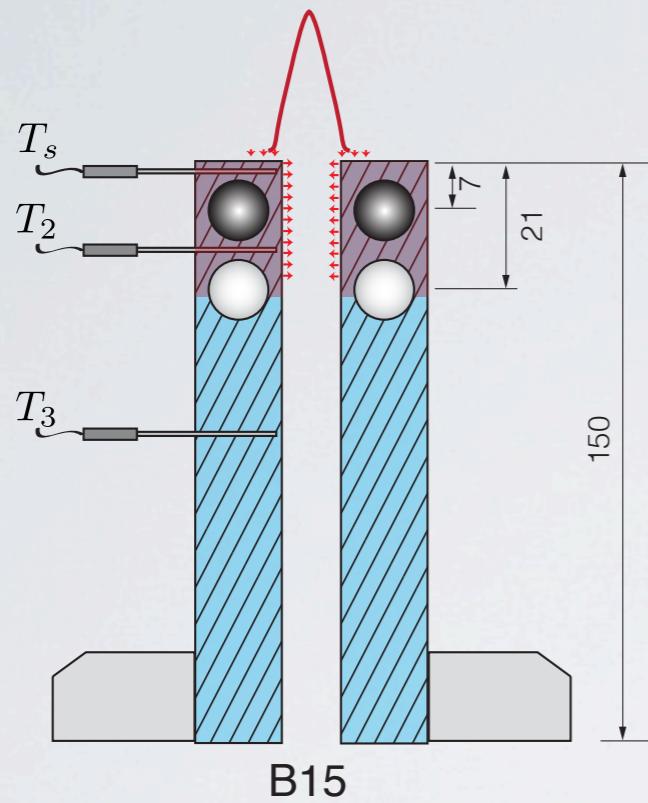
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31



PRE-HEATING OF FRESH GASES ?



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T50h
 $h_f = 21.58 \text{ m}$
 $l_f = 23.91 \text{ m}$
 $\alpha = 13.05^\circ$

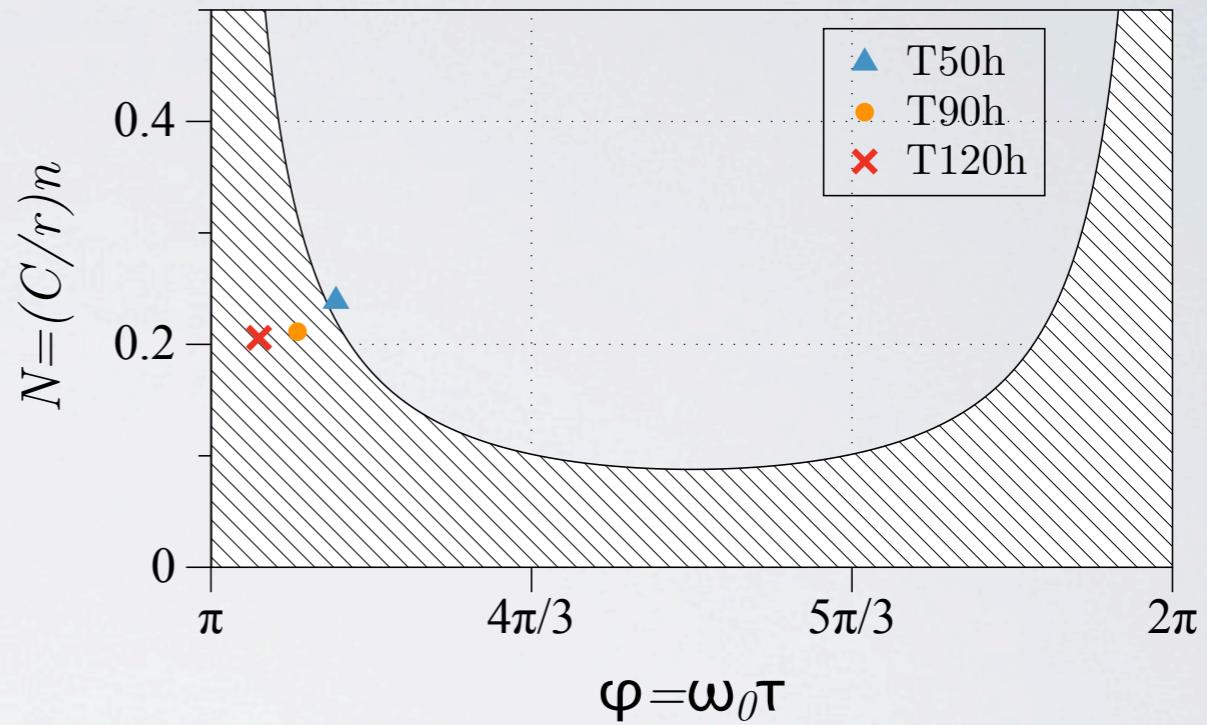
T90h
 $h_f = 21.00 \text{ m}$
 $l_f = 23.29 \text{ m}$
 $\alpha = 13.39^\circ$



$$s_L \propto 1/l_f$$

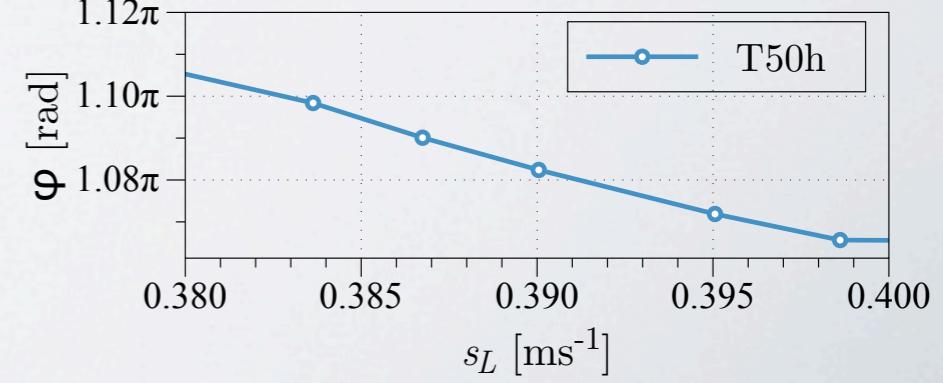
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31

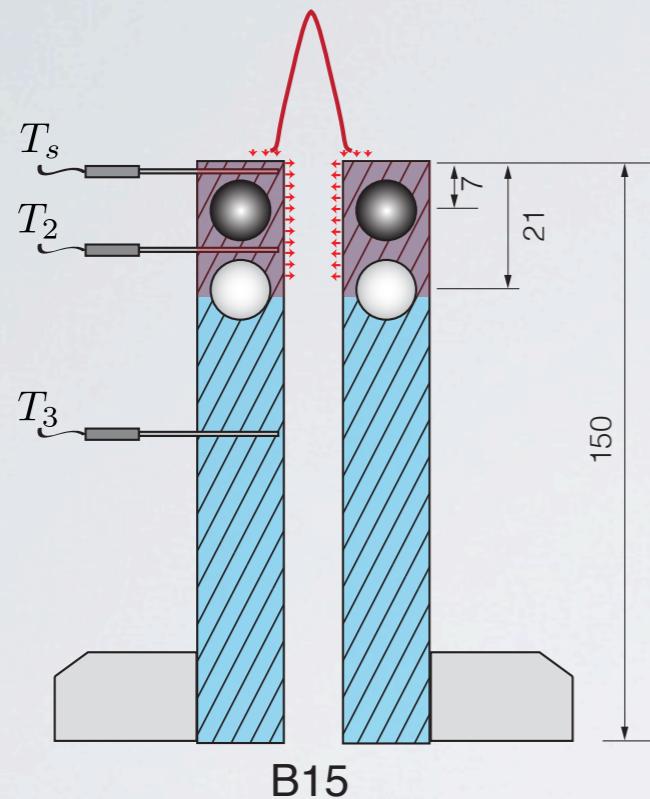


$\varphi = \omega_0 \tau$

FTF at $f_{ex} = 58 \text{ Hz}$



PRE-HEATING OF FRESH GASES ?

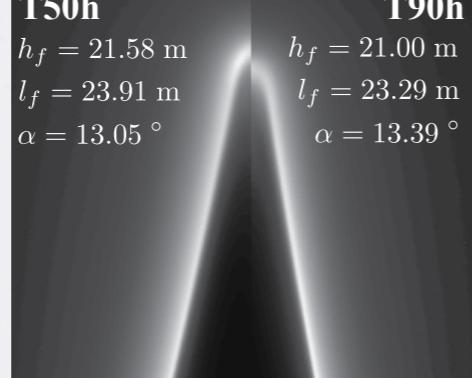


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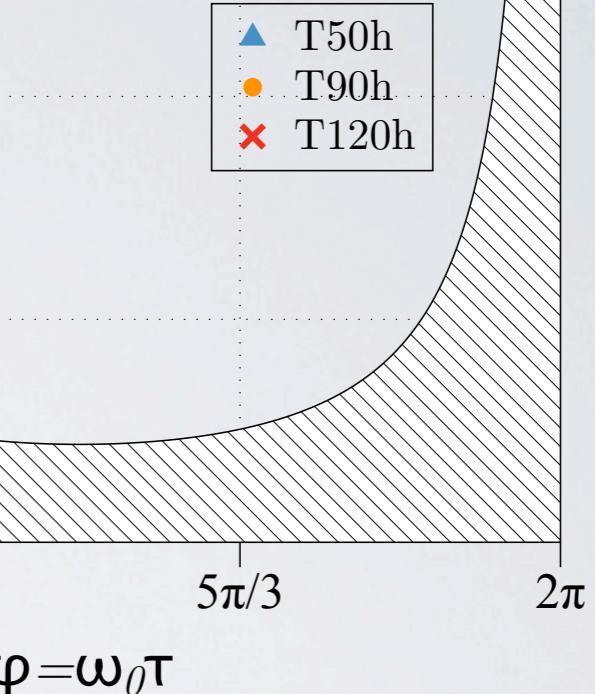
T50h
 $h_f = 21.58 \text{ m}$
 $l_f = 23.91 \text{ m}$
 $\alpha = 13.05^\circ$



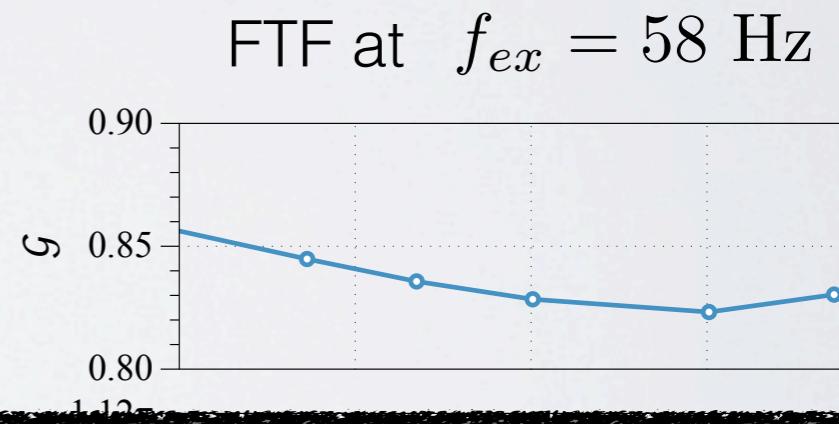
T90h
 $h_f = 21.00 \text{ m}$
 $l_f = 23.29 \text{ m}$
 $\alpha = 13.39^\circ$

$$s_L \propto 1/l_f$$

$$\frac{l_f^{T50h}}{l_f^{T90h}} = 1.03$$



$$\varphi = \omega_0 \tau$$

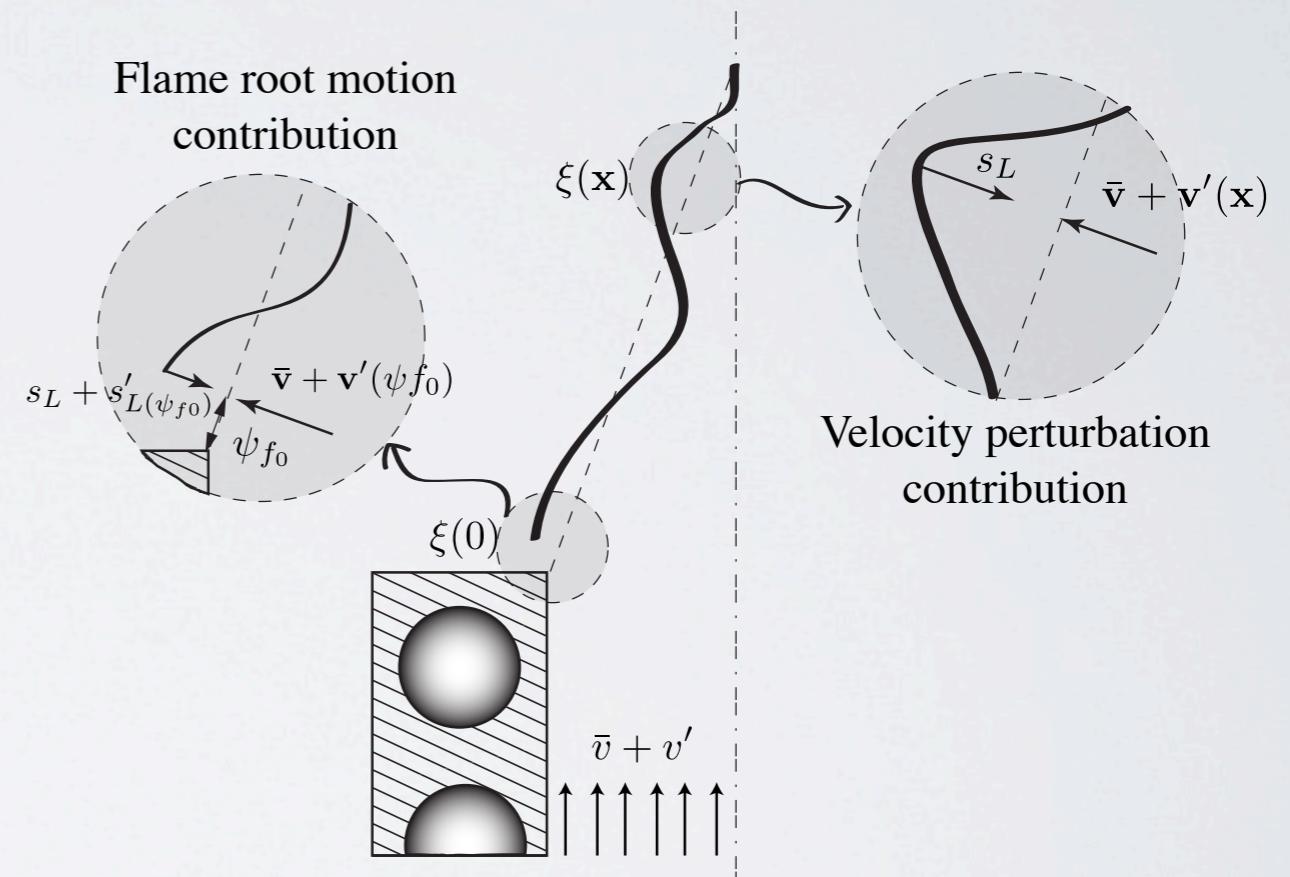


Phase decrease with T_s is due to the increase on the flame speed by the effect of the pre-heating of fresh gases.

2. FLAME ANCHORING POINT CONTRIBUTION

Analytical Model

Perturbed Flame Front



✿ Cuquel *et al.* (2013)

2. FLAME ANCHORING POINT CONTRIBUTION

Analytical Model

Flame speed fluctuation at the flame base model:

$$\mathcal{S}(\hat{\omega}) = \frac{\tilde{s}_L(\psi_{f0})}{\tilde{\mathbf{v}}(\psi_{f0})} = \left[1 - \frac{i\hat{\omega}}{Ze} \sinh(\Psi_f) e^{-\Psi_f(1+(1-4\hat{\omega})^{1/2})} \right]^{-1},$$

$$\hat{\omega} = \omega \frac{\delta_f}{s_L} \quad Ze = \frac{T_a}{T_b} \frac{T_b - T_u}{T_b}$$

$$\Psi_f = \frac{\psi_{f0}}{2\delta_f} = \frac{1}{2} \log \left(\frac{T_{ad} - T_u}{T_{ad} - T_b + T_s - T_u} \right),$$

G-Equation at: $\mathbf{x} = \psi_{f0}$

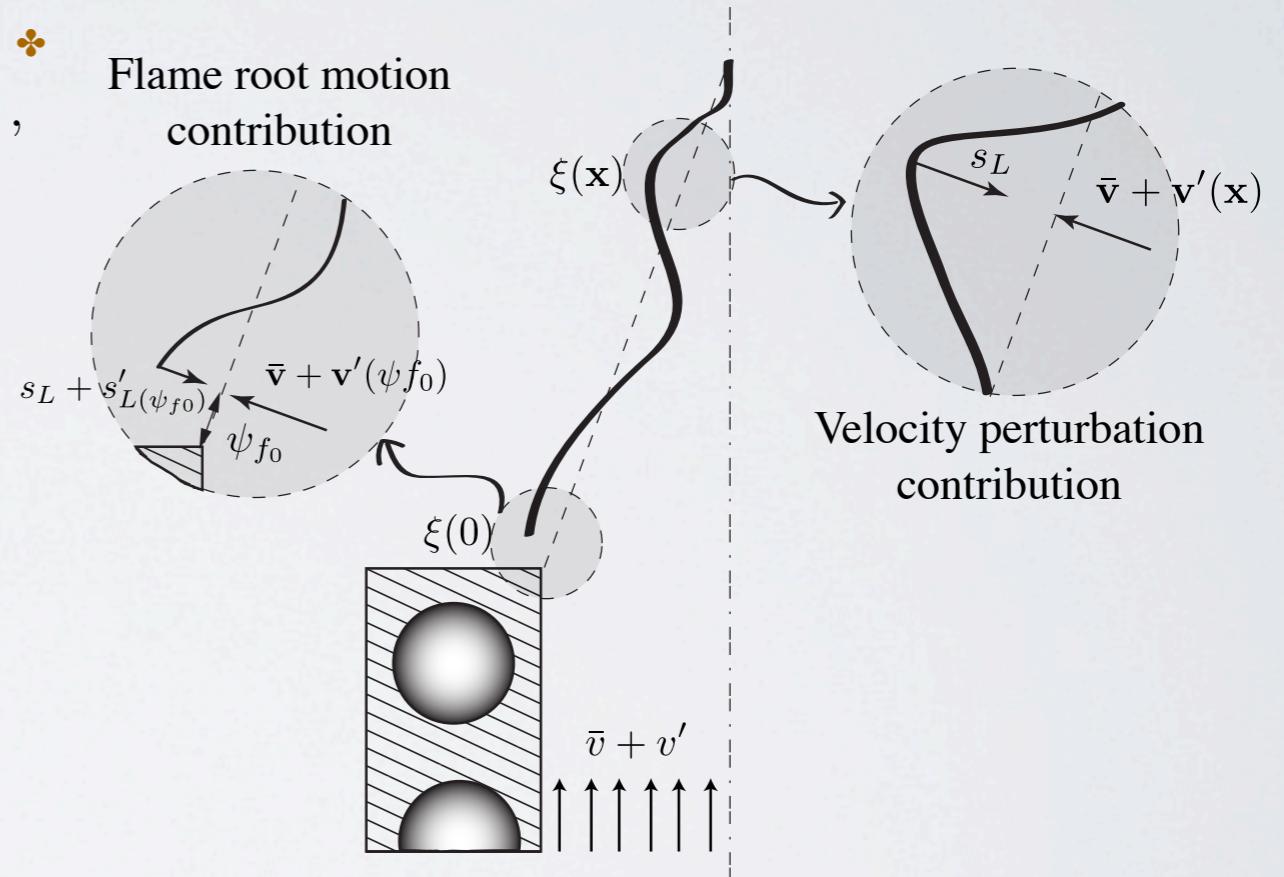
$$\frac{\partial \xi(0)}{\partial t} = \mathbf{v}'(\psi_{f0}, t) - s'_L(\psi_{f0})(t),$$

Flame base transfer function

$$\Xi(\hat{\omega}) = \frac{\tilde{\xi}(0)/(w_s/2)}{\hat{v}/\bar{v}} = -4\delta_* \frac{1 - \mathcal{S}(\hat{\omega})}{i\hat{\omega} \cos \alpha} \left(1 - i \frac{1}{4} \frac{\hat{\omega}}{\delta_*} \cos^2 \alpha (1 - 2\delta_* \Psi_f \tan \alpha) \right) e^{i \frac{1}{2} \hat{\omega} \Psi_f \cos \alpha \sin \alpha}$$

* Cuquel et al. (2013)

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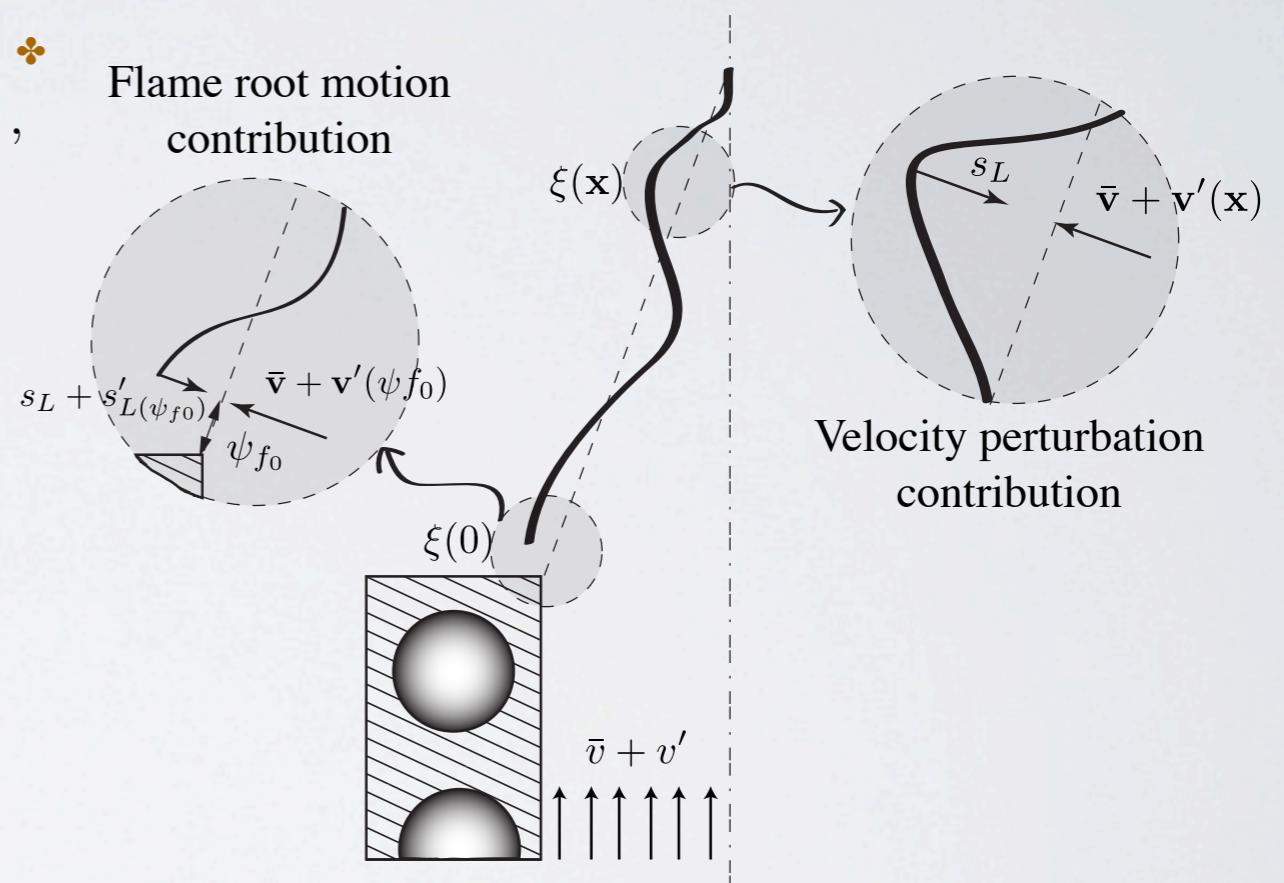
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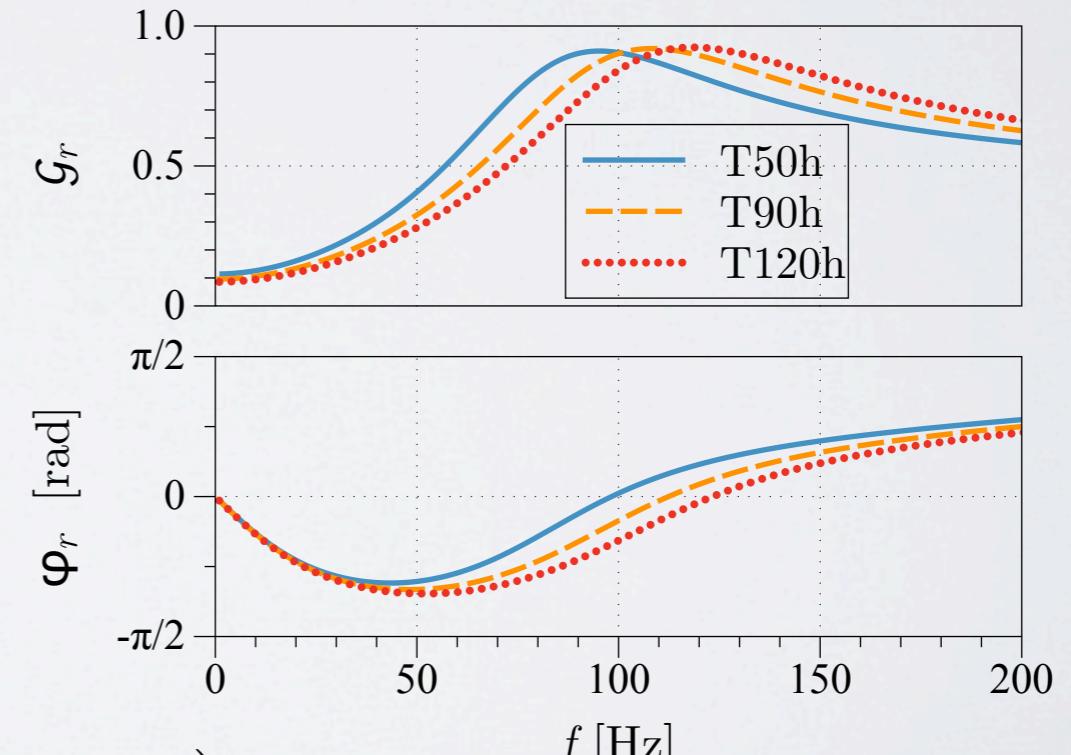
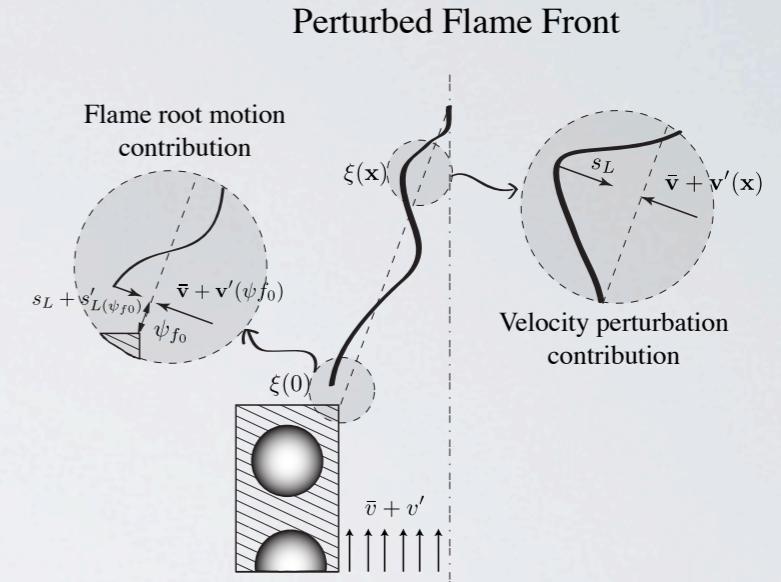
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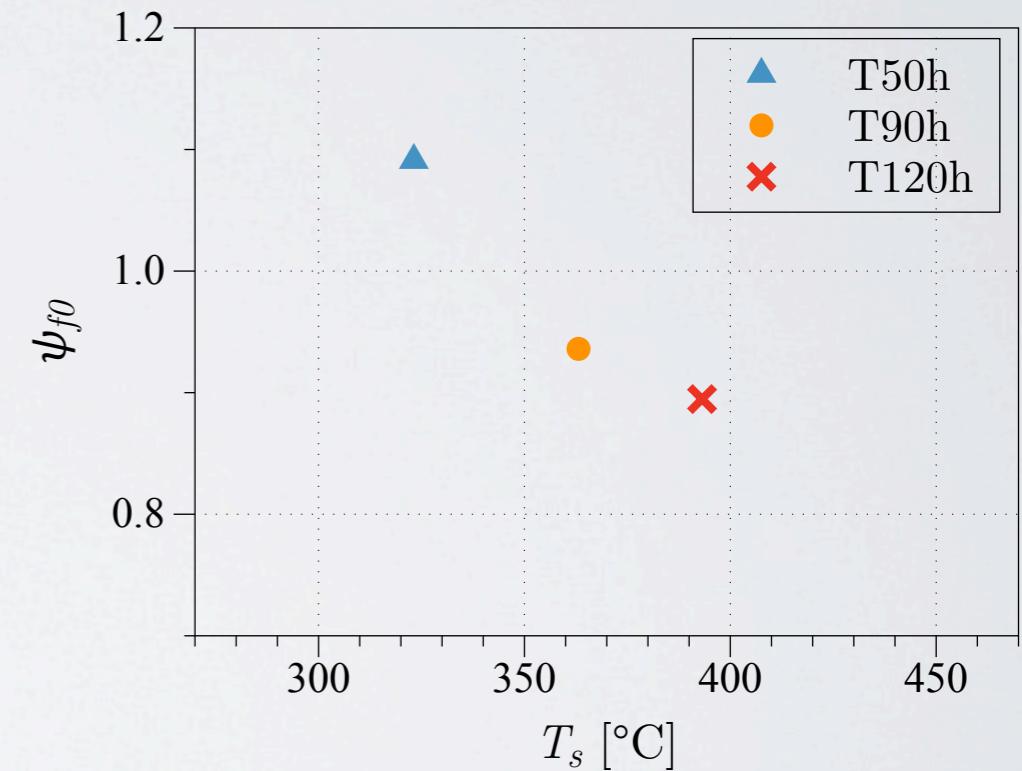
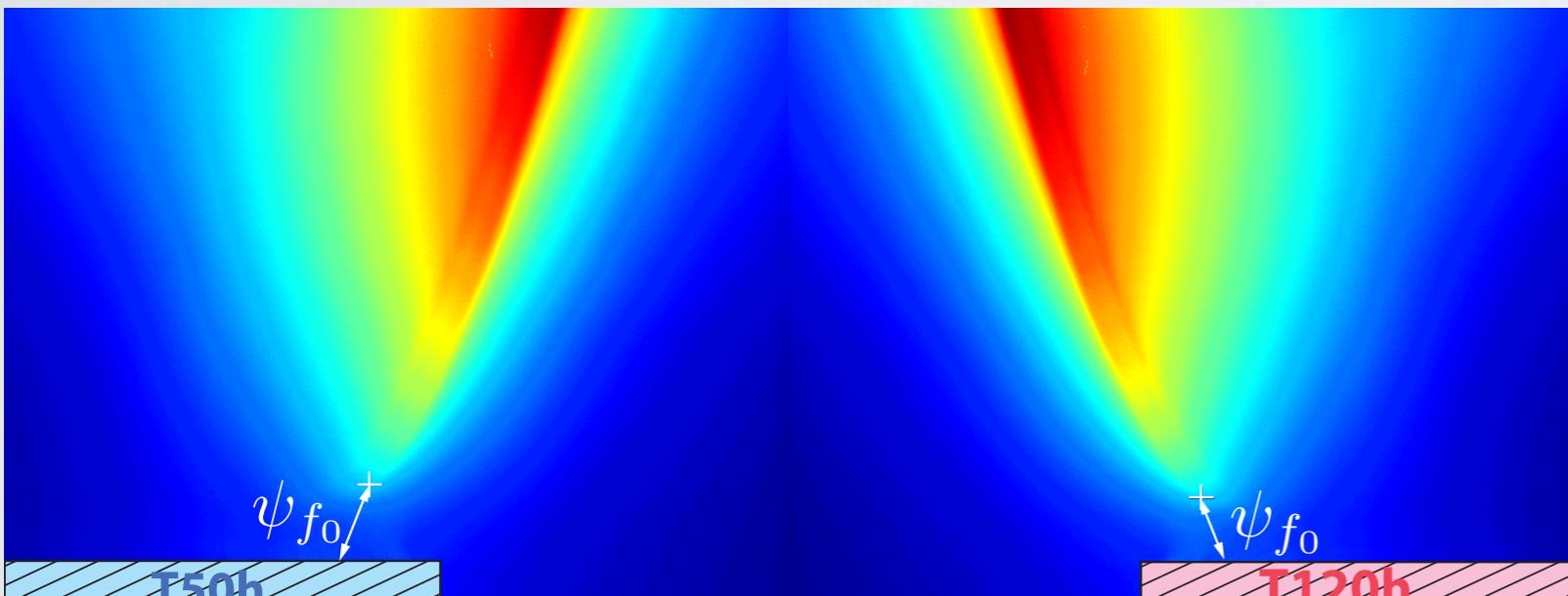
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2. FLAME ANCHORING POINT CONTRIBUTION

Experimental

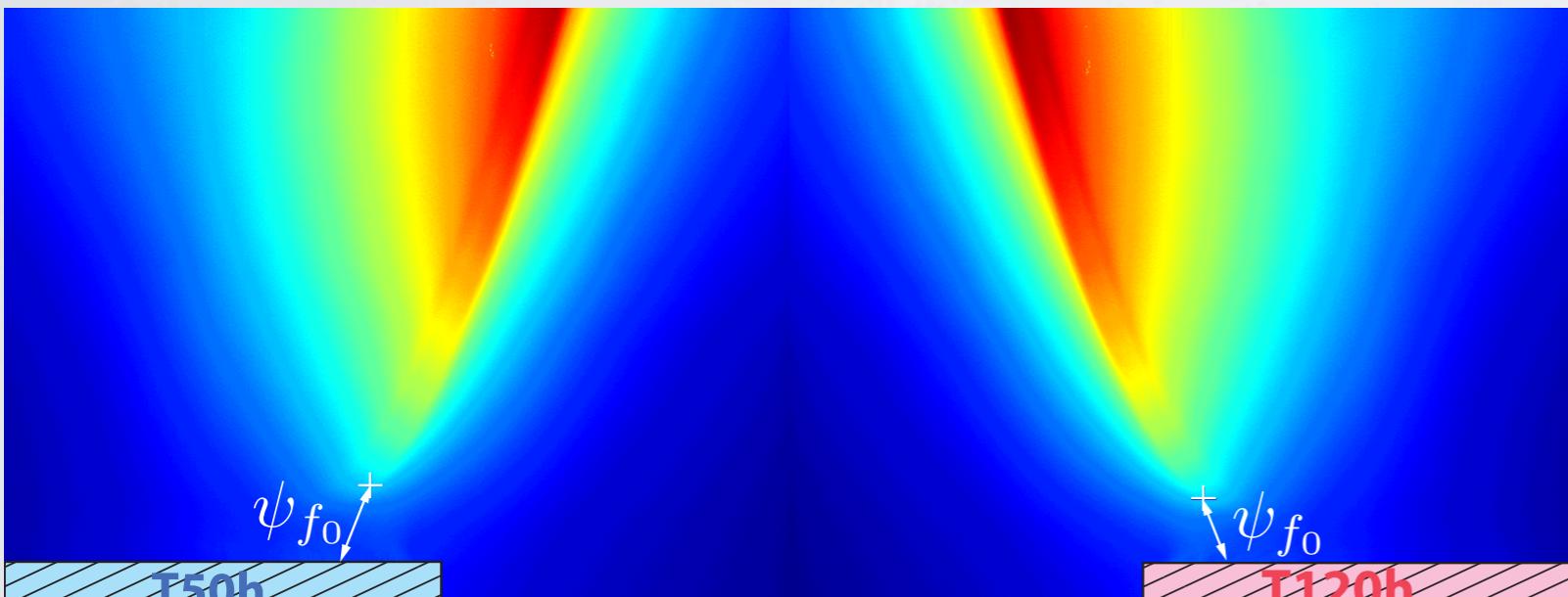
Stationary Stand-off distance



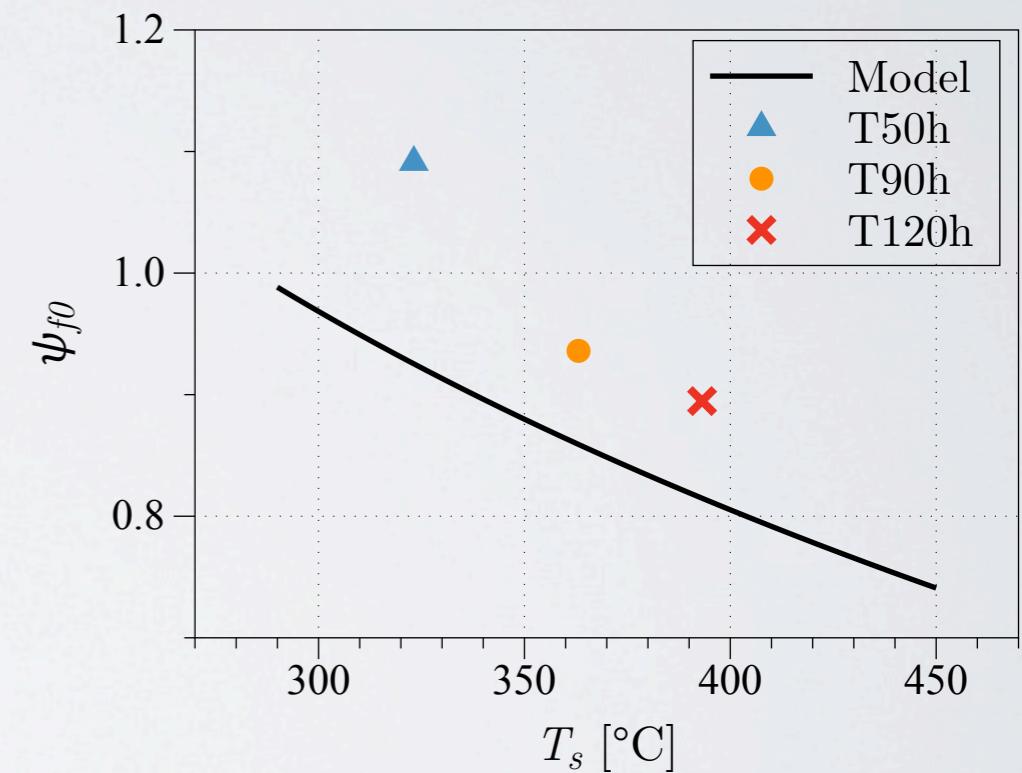
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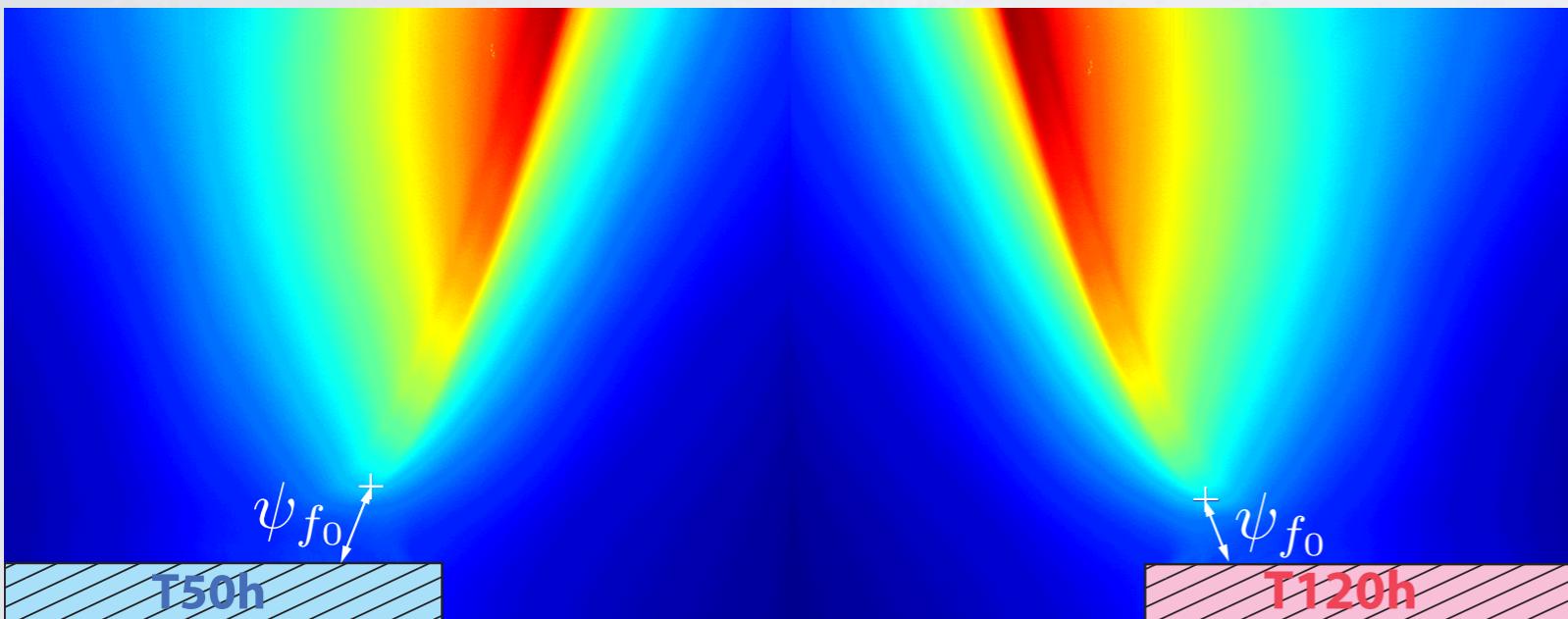
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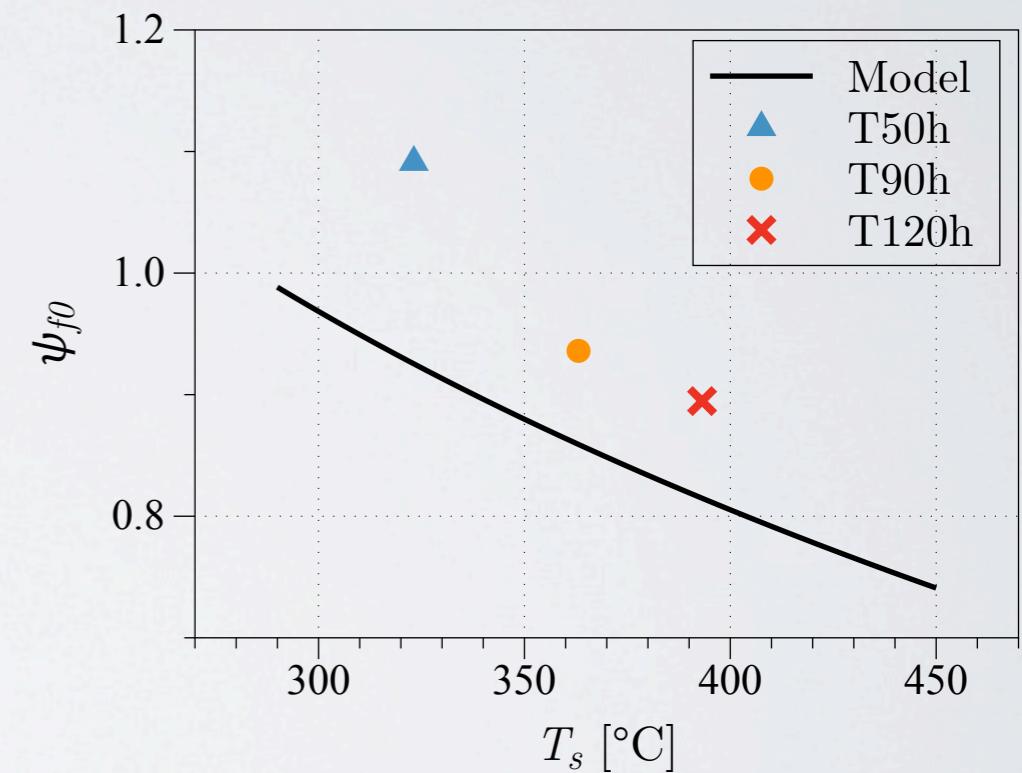
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$$\psi_{f_0} = \frac{1}{2} \delta_f \log \left(\frac{T_{ad} - T_u}{T_{ad} - T_b + T_s - T_u} \right),$$



The flame root location is chosen as the intersection of the crest of light intensity with the iso-contour at 65 % of the maximum pixel value over the whole image.

DYNAMICS OF THE FLAME ANCHORING POINT

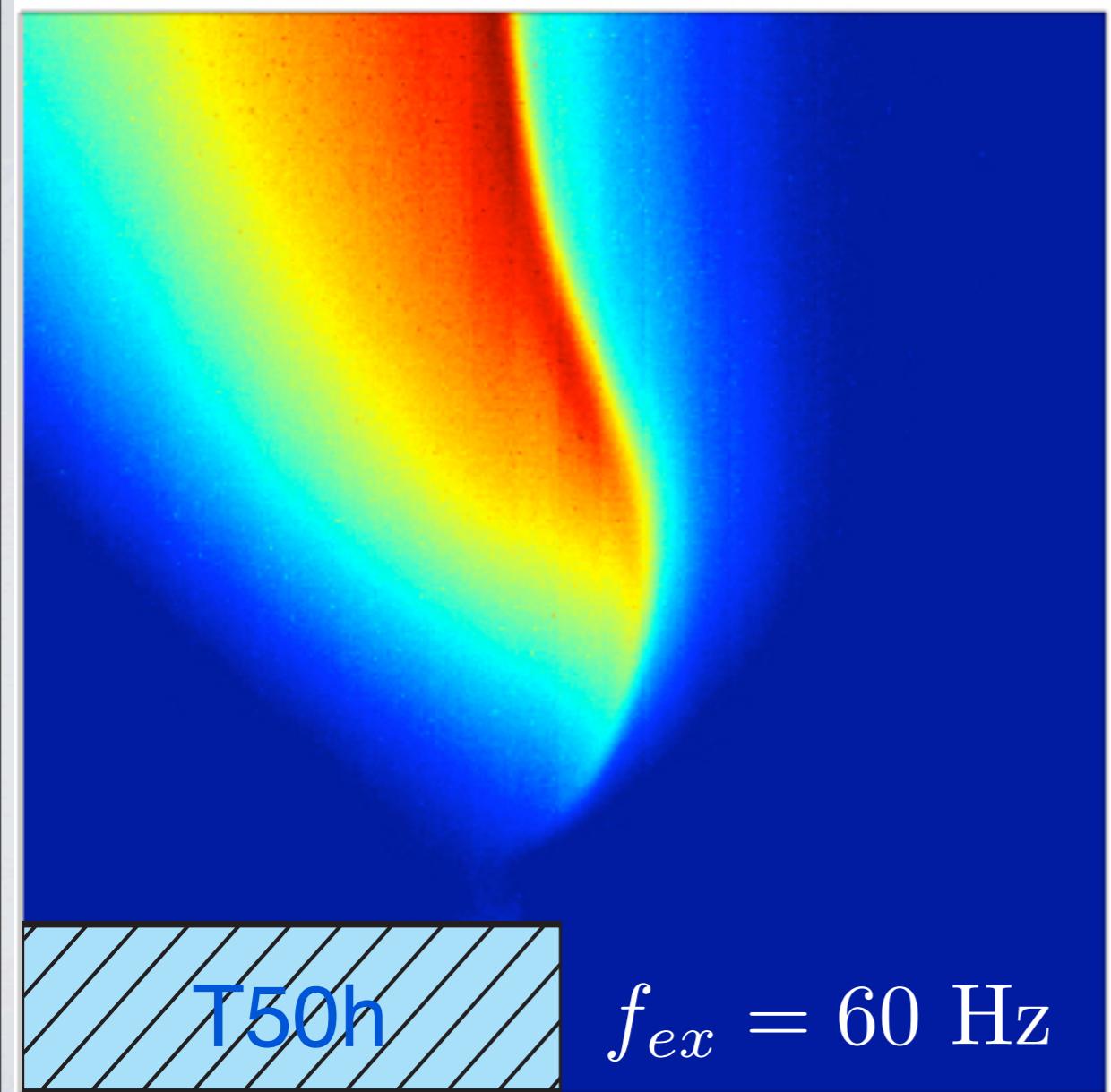
Experimental



T50h

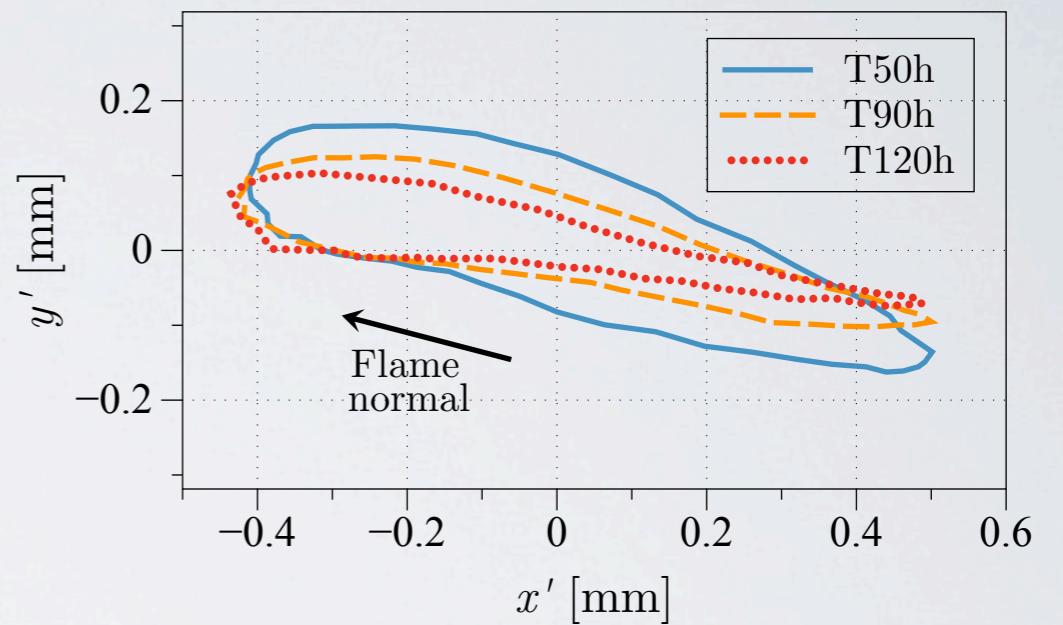
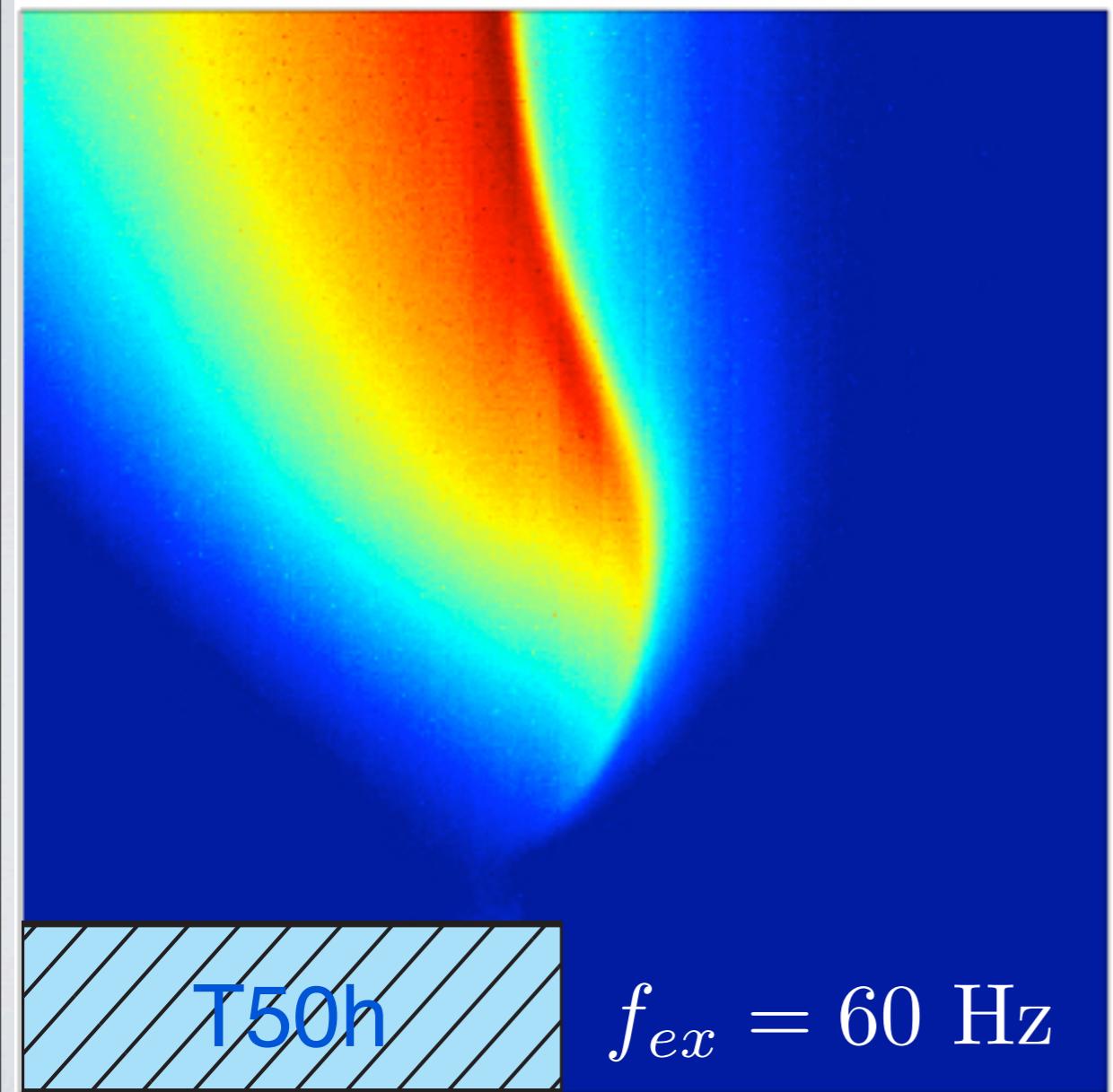
DYNAMICS OF THE FLAME ANCHORING POINT

Experimental



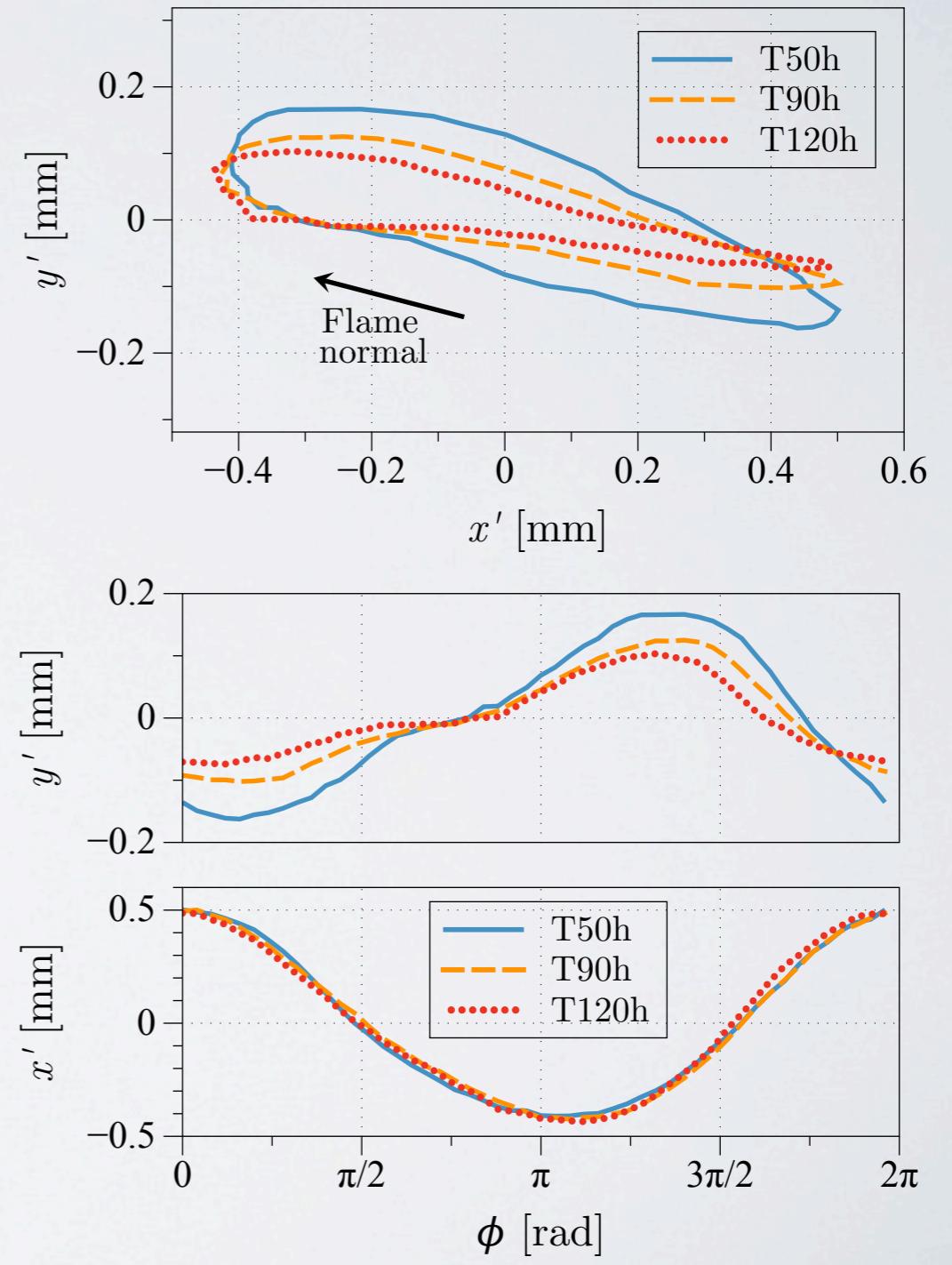
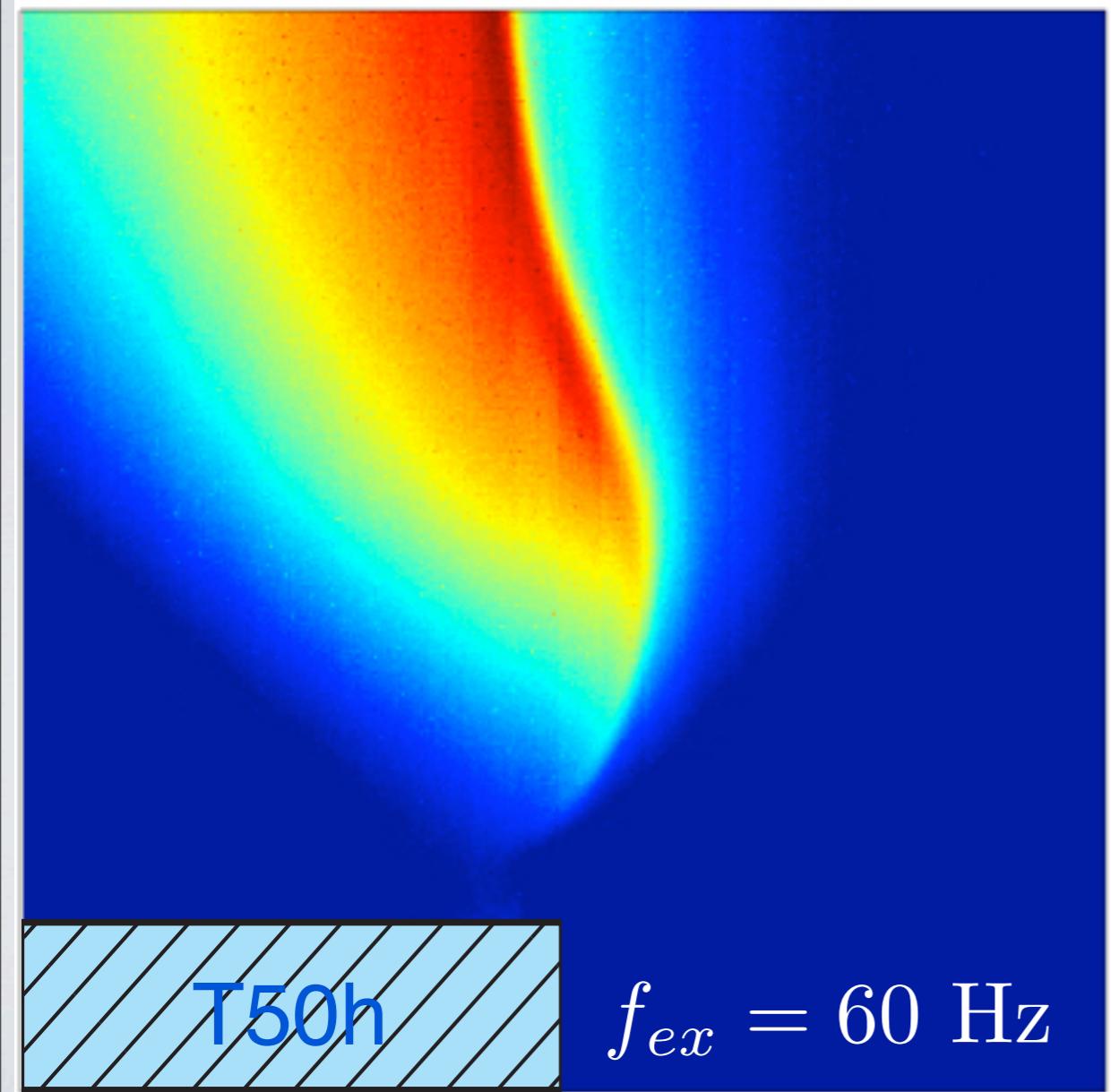
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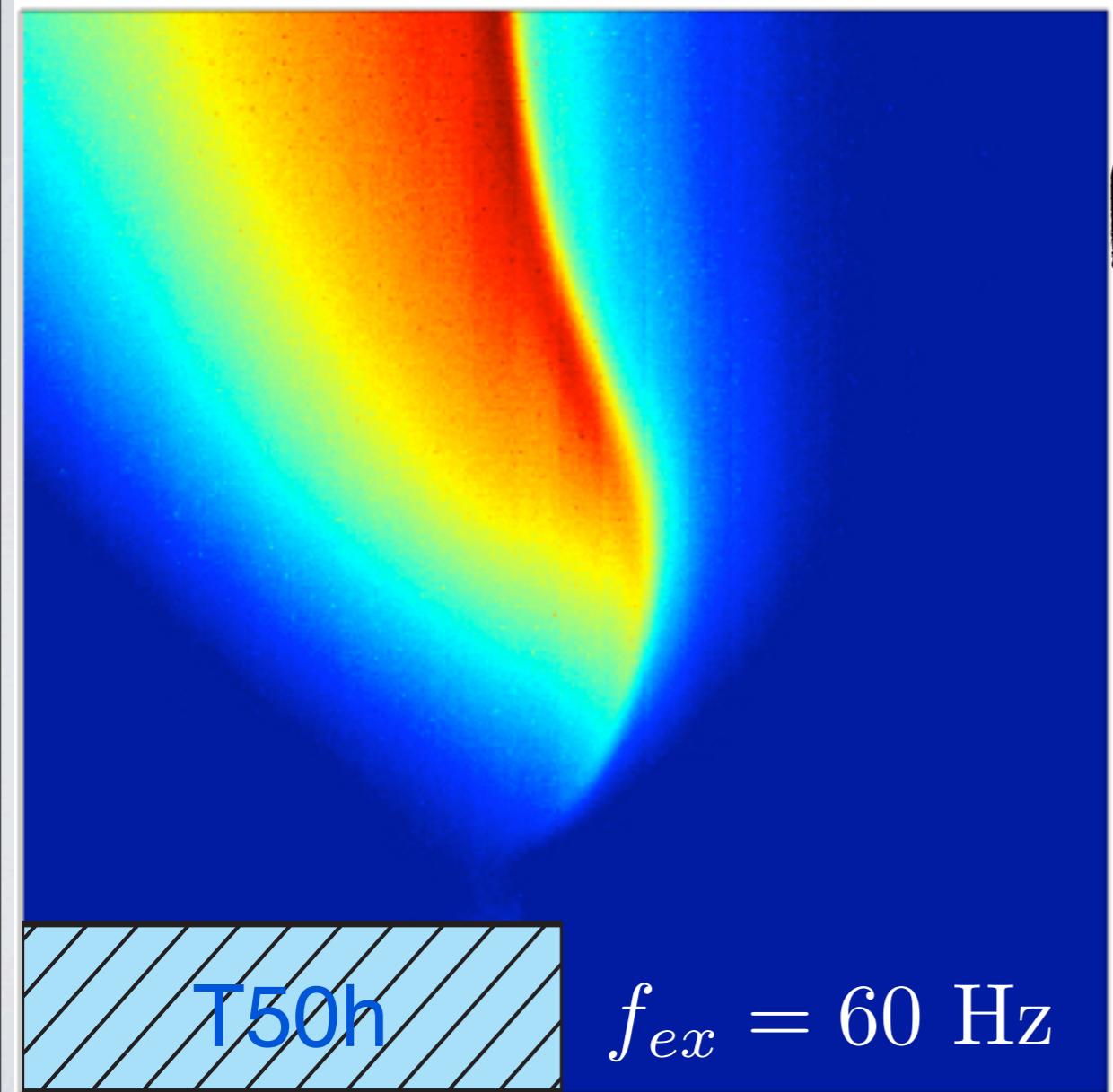
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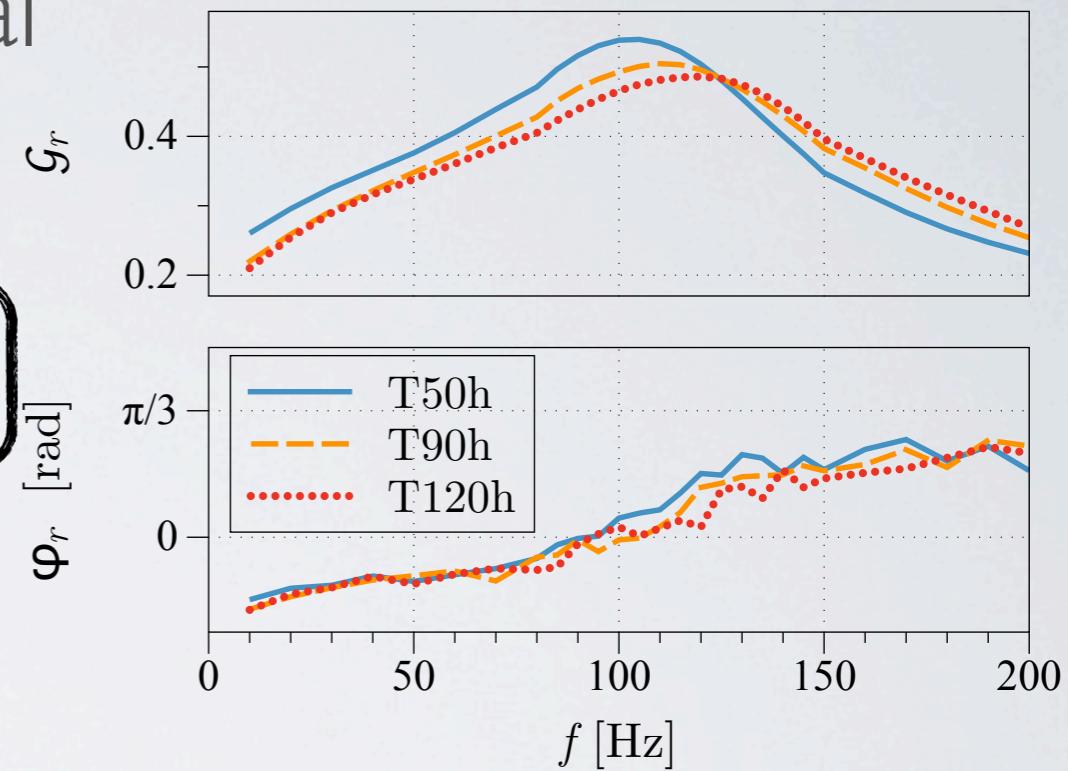
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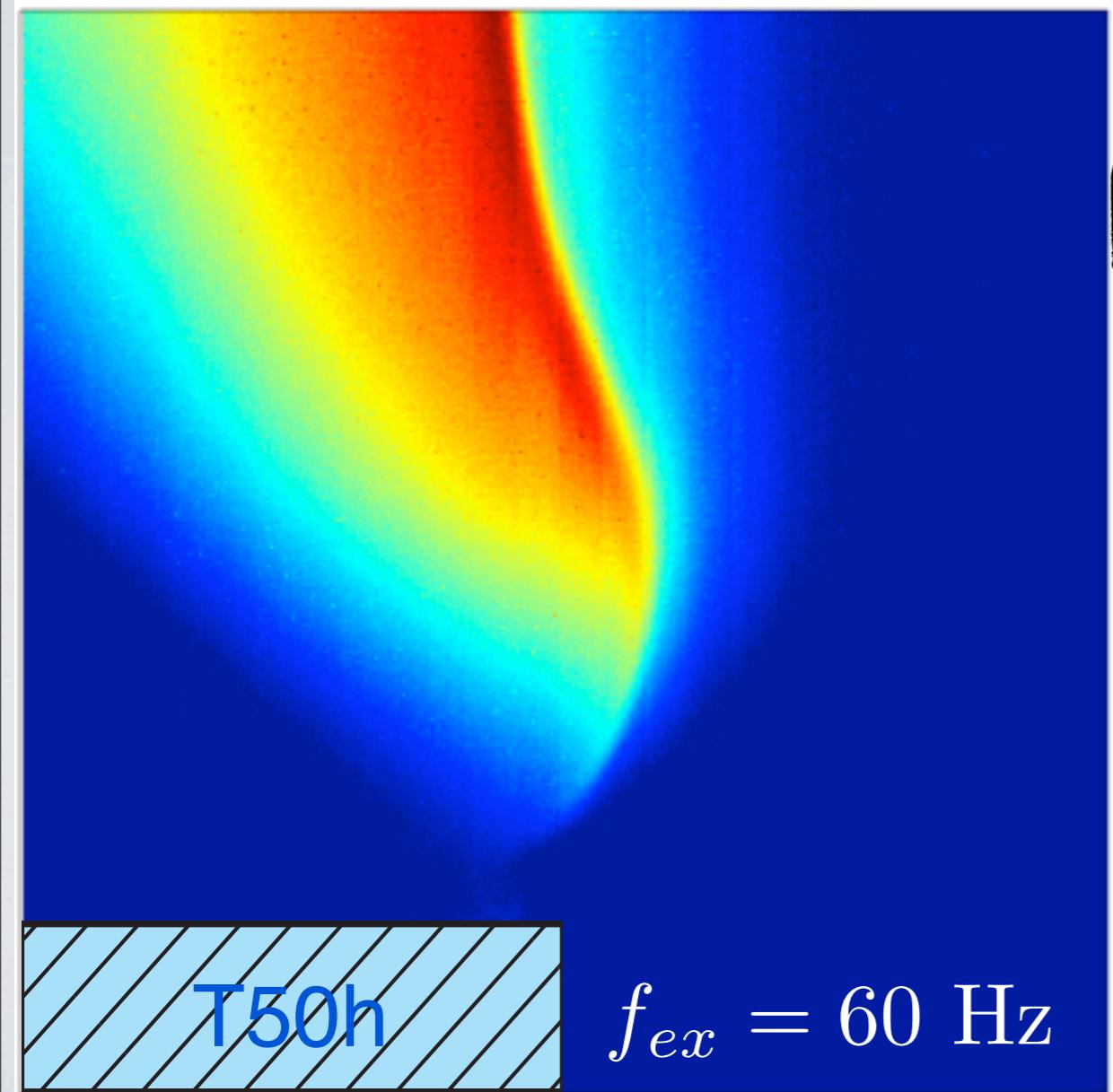
$$\Xi(\omega) = \frac{\xi(0)/(w_s/2)}{v'/\bar{v}}$$

$$\begin{aligned}\mathcal{G}_f &= |\Xi(\omega, T_s)| \\ \varphi_f &= \arg |\Xi(\omega, T_s)|\end{aligned}$$



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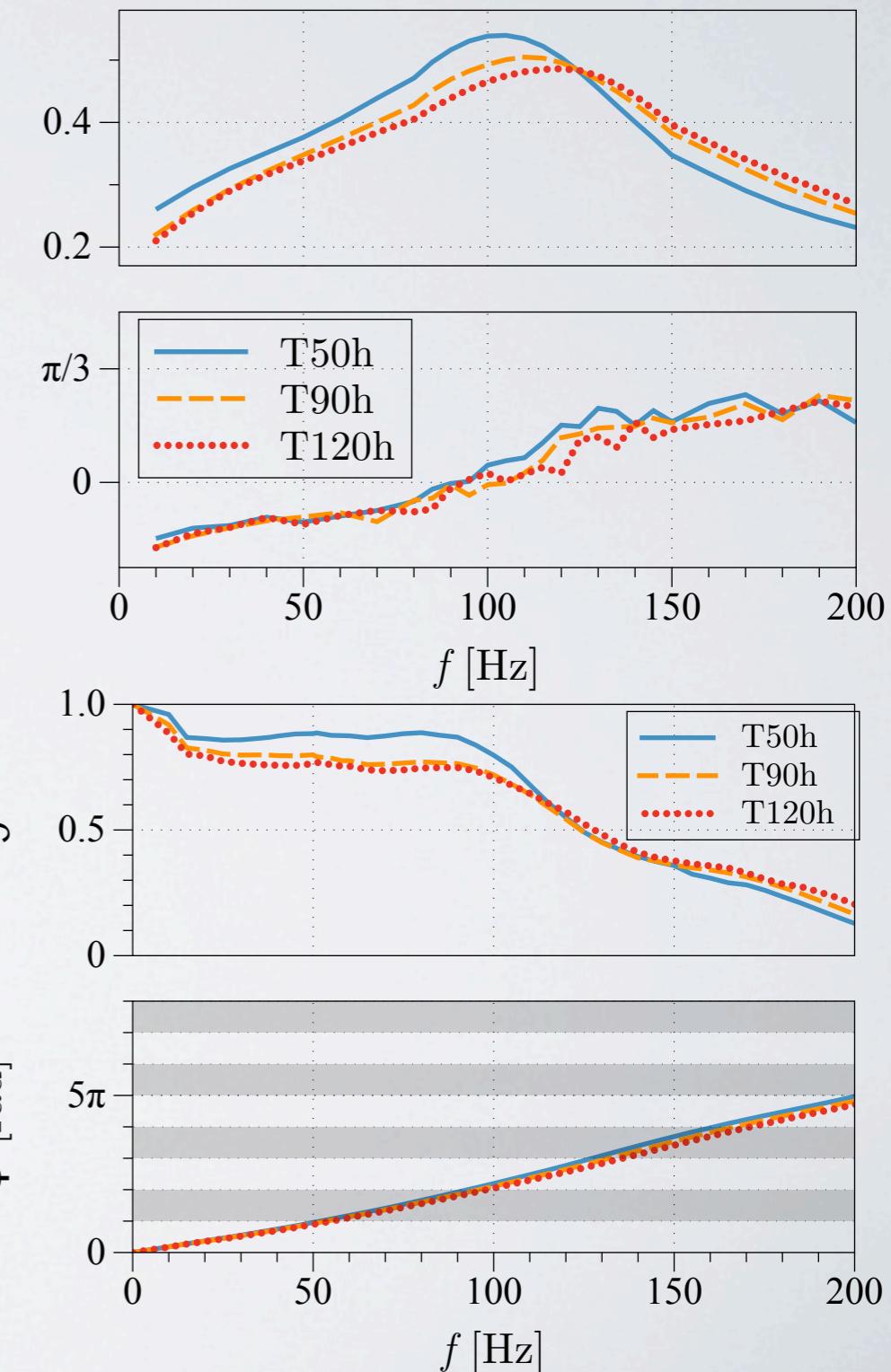
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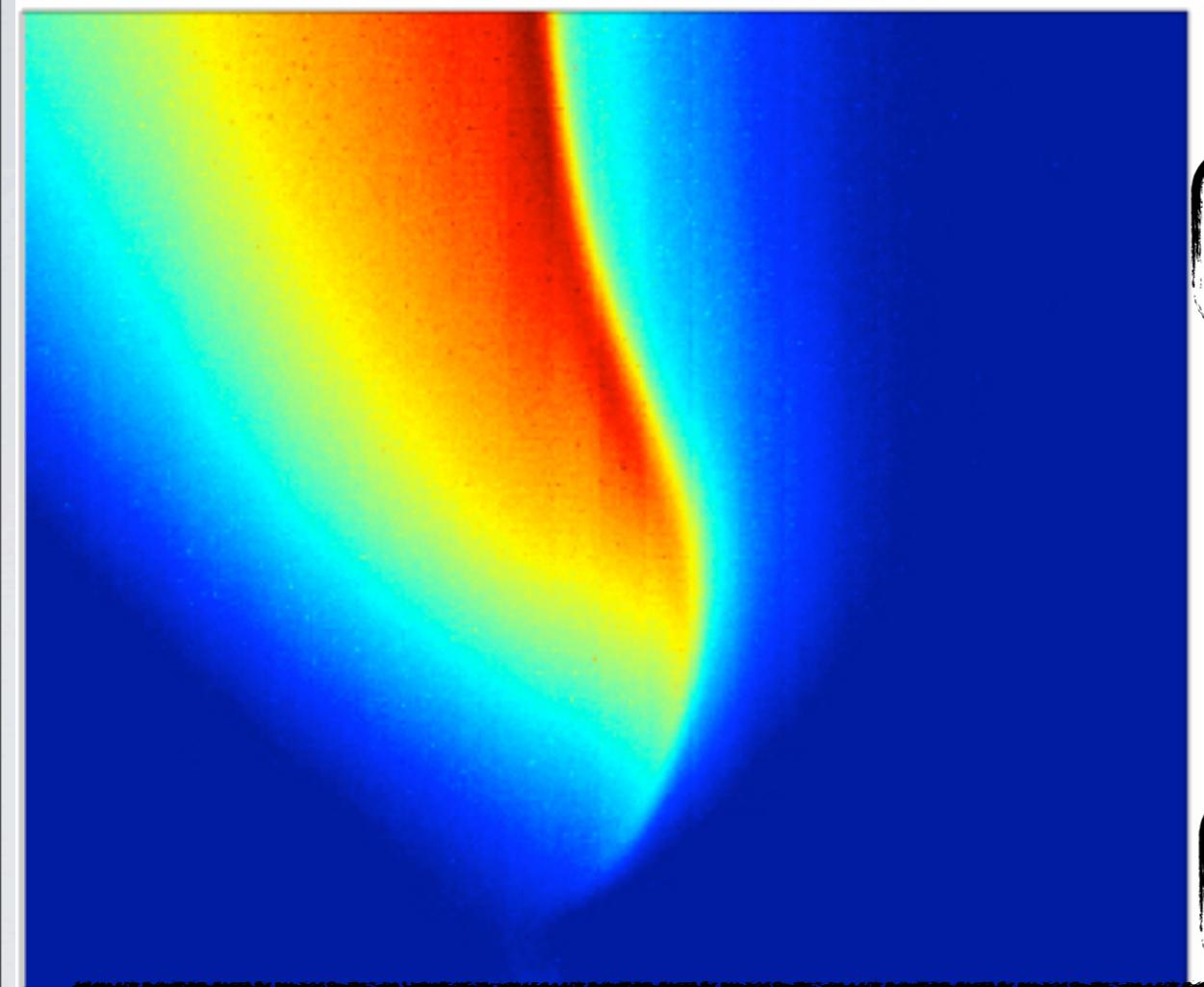
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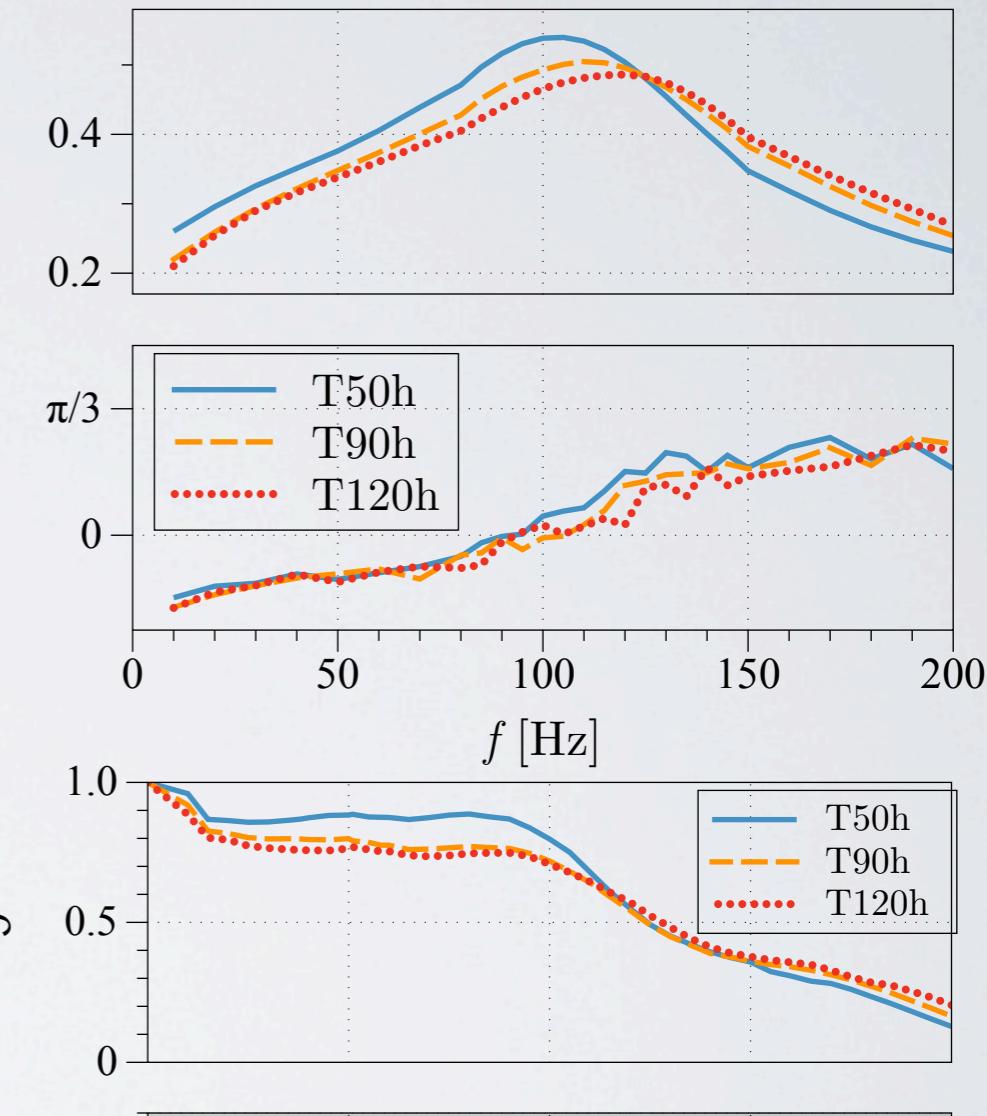


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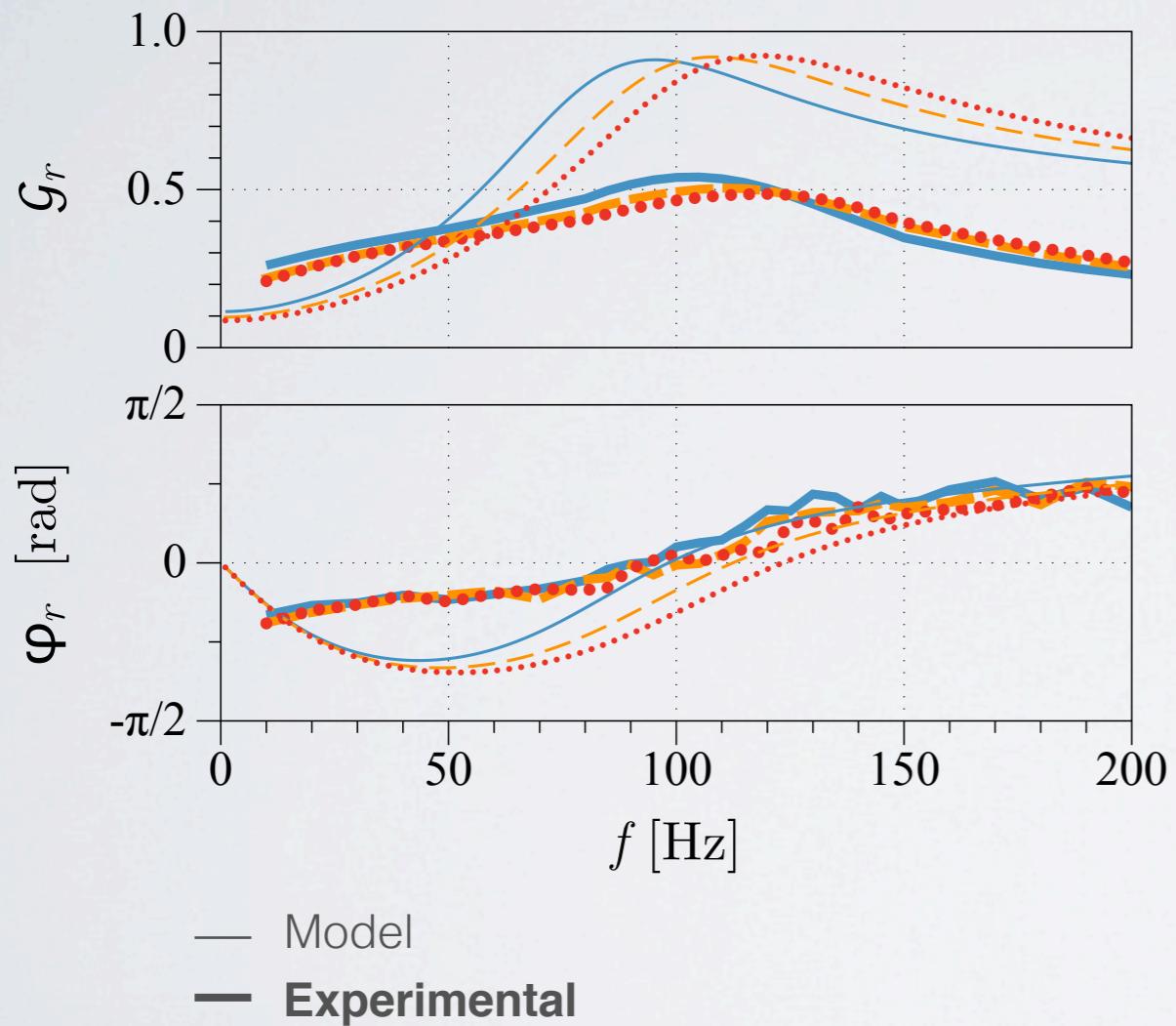
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Gain decrease with T_s is due to the switch toward the higher frequencies on the flame root response to velocity perturbations.

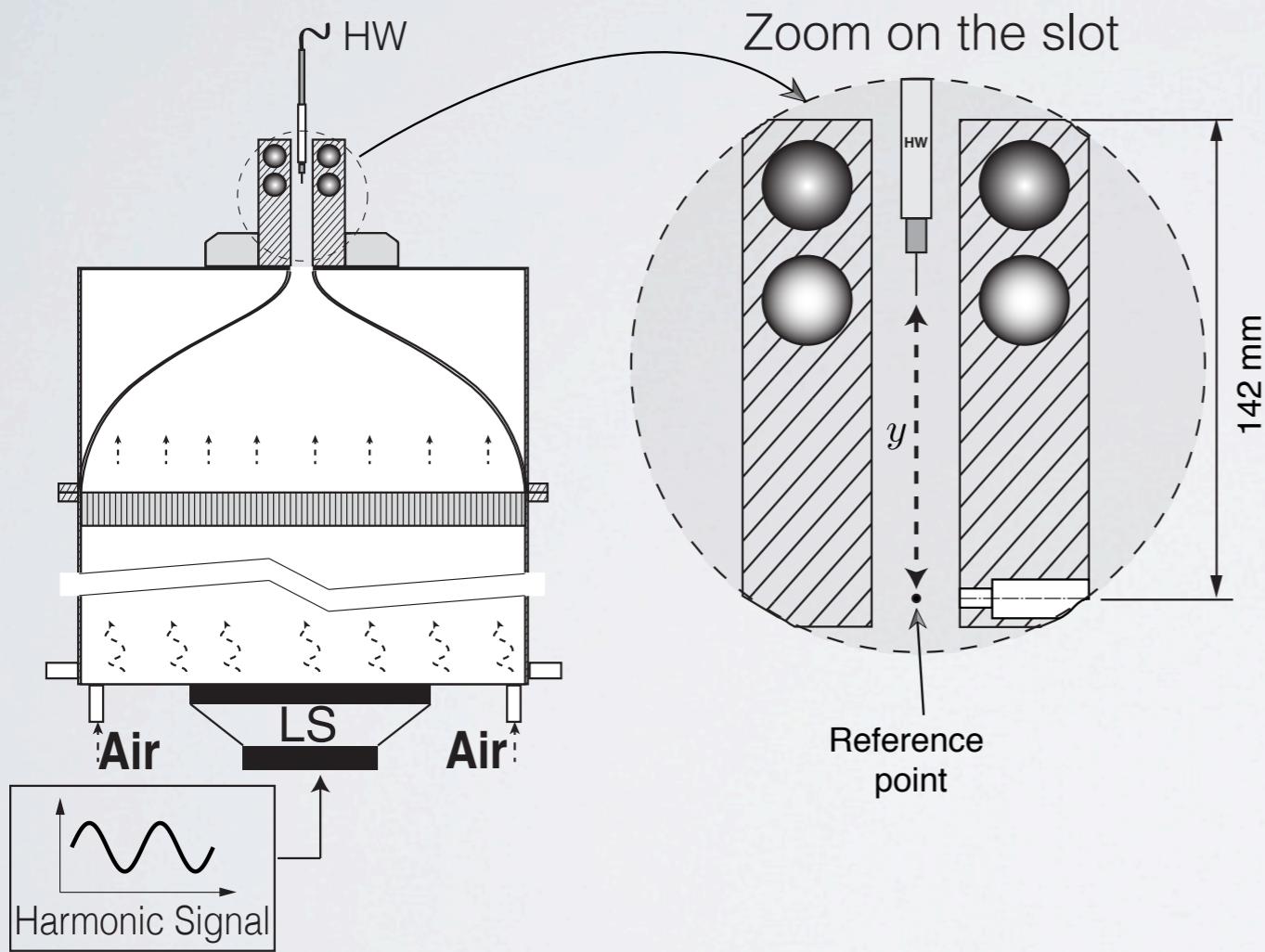
COMPARATION



Test	f_p [Hz]	Model	f_p [Hz]	Expe
T50h	96		105	
T90h	108		110	
T120h	118		120	

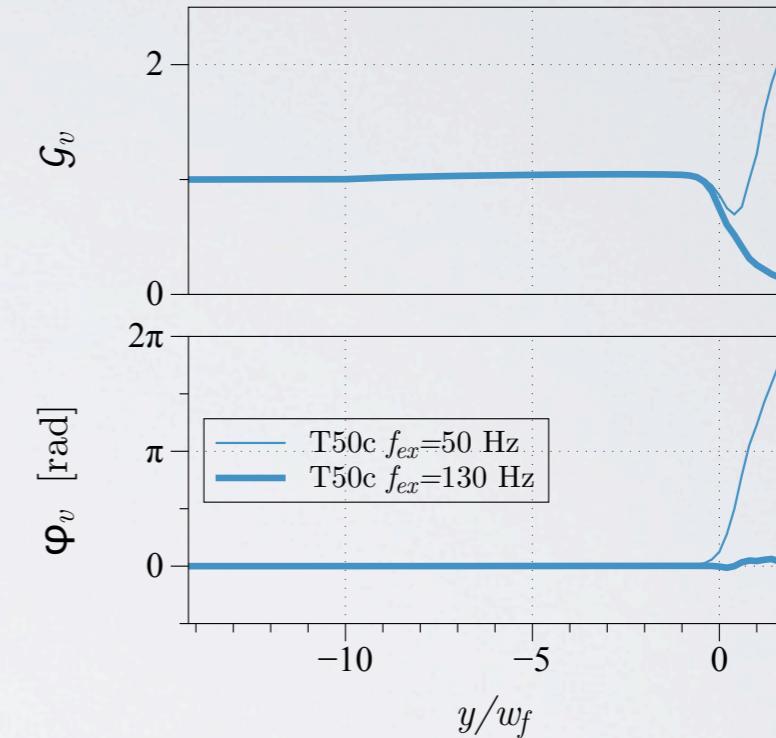
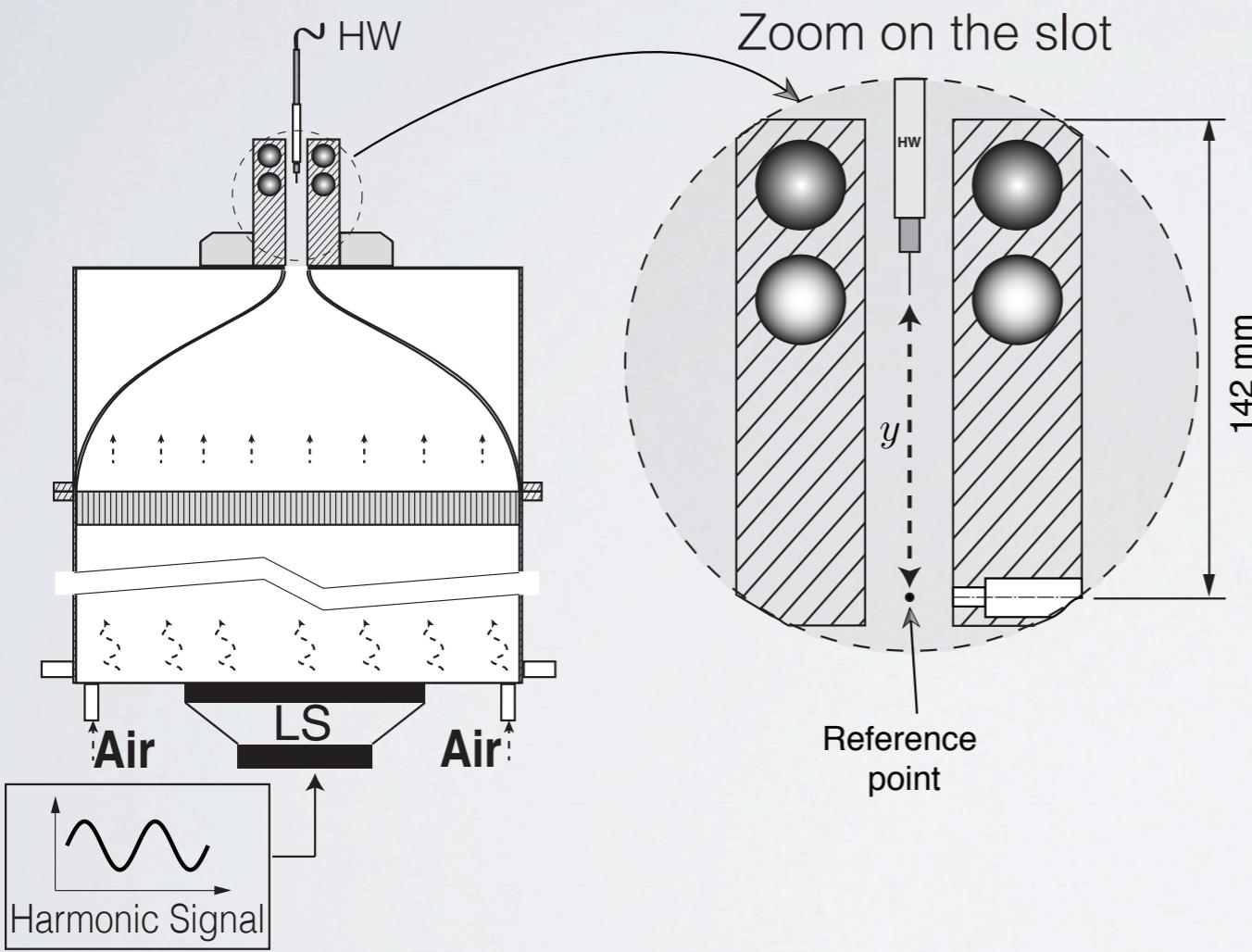
FTF

Where to measure the velocity fluctuation ?



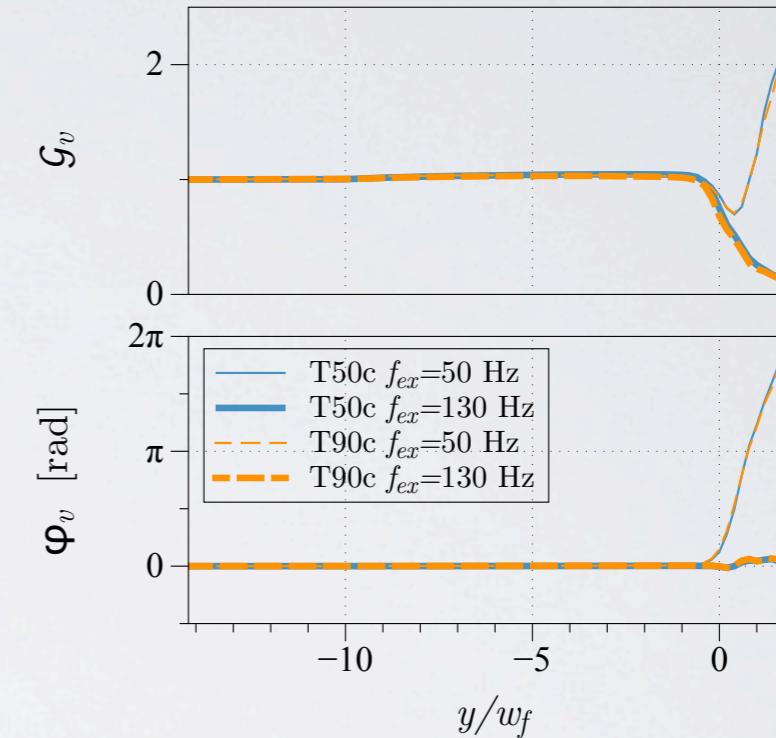
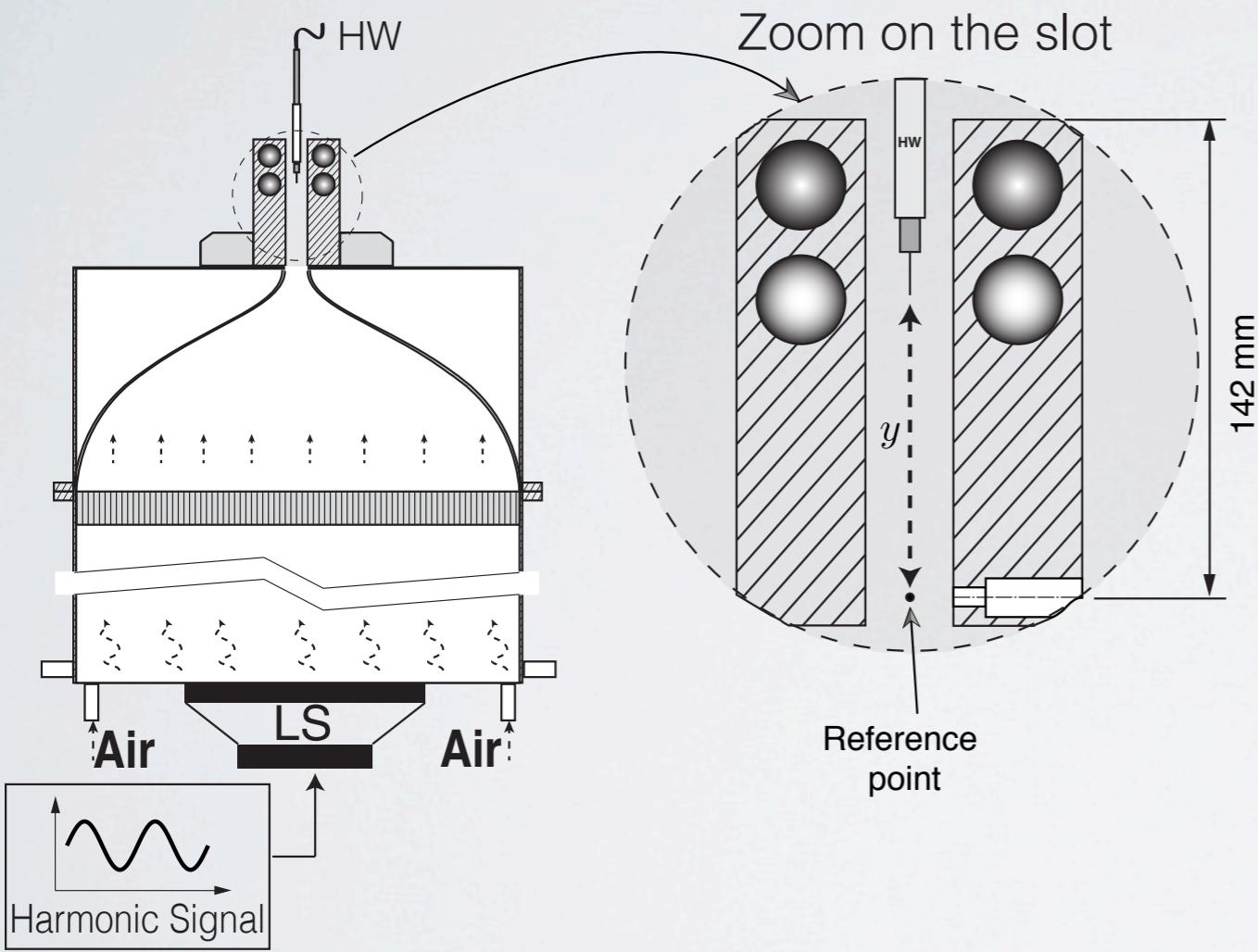
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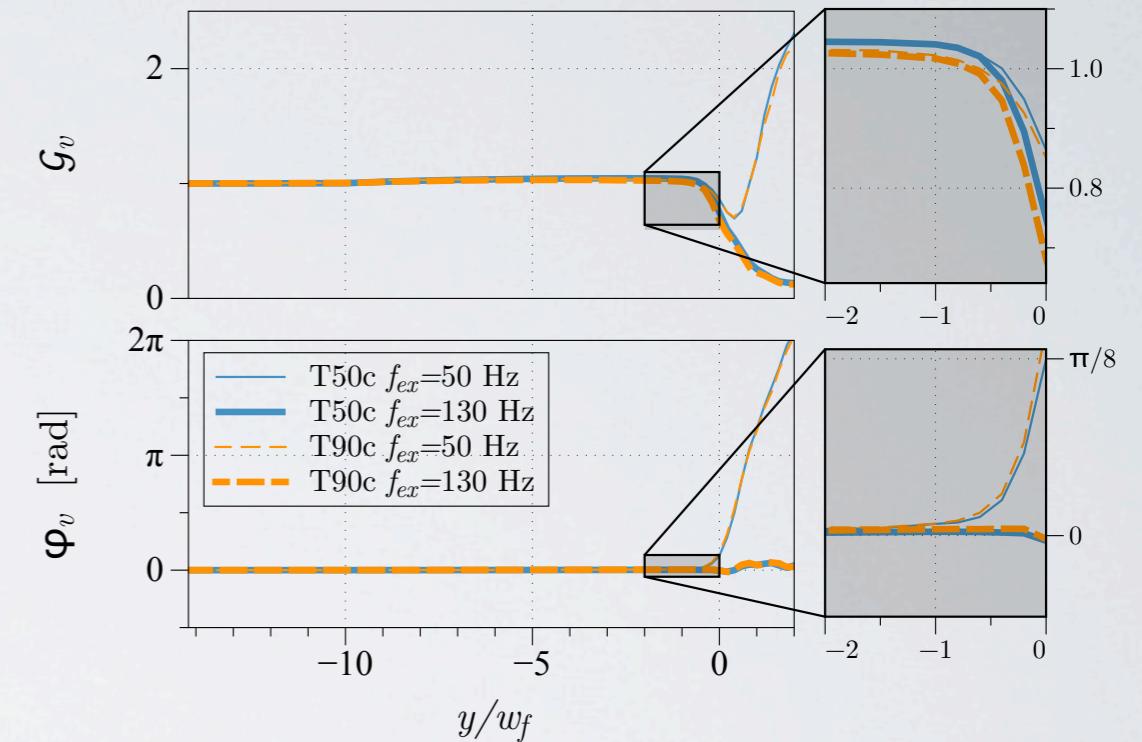
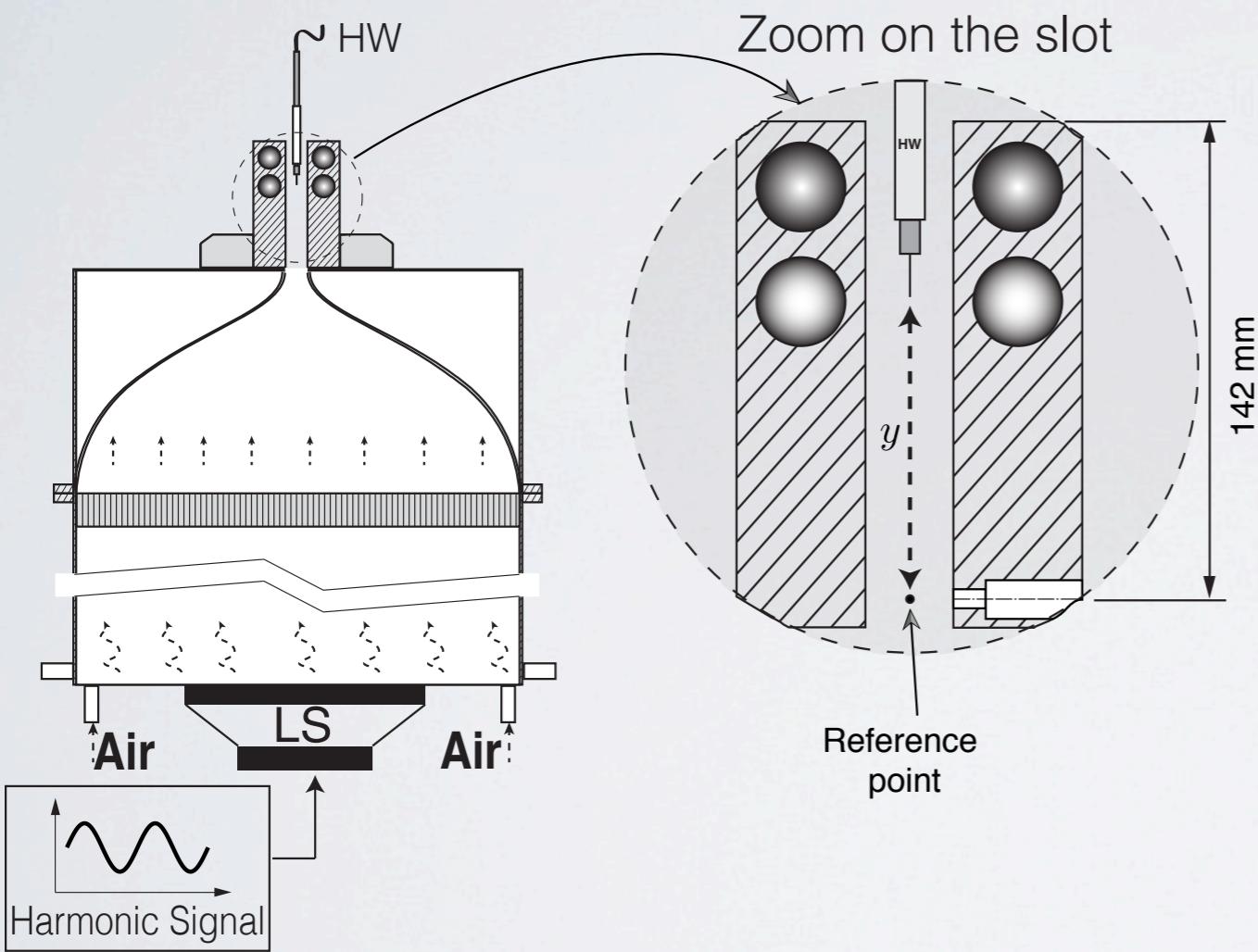
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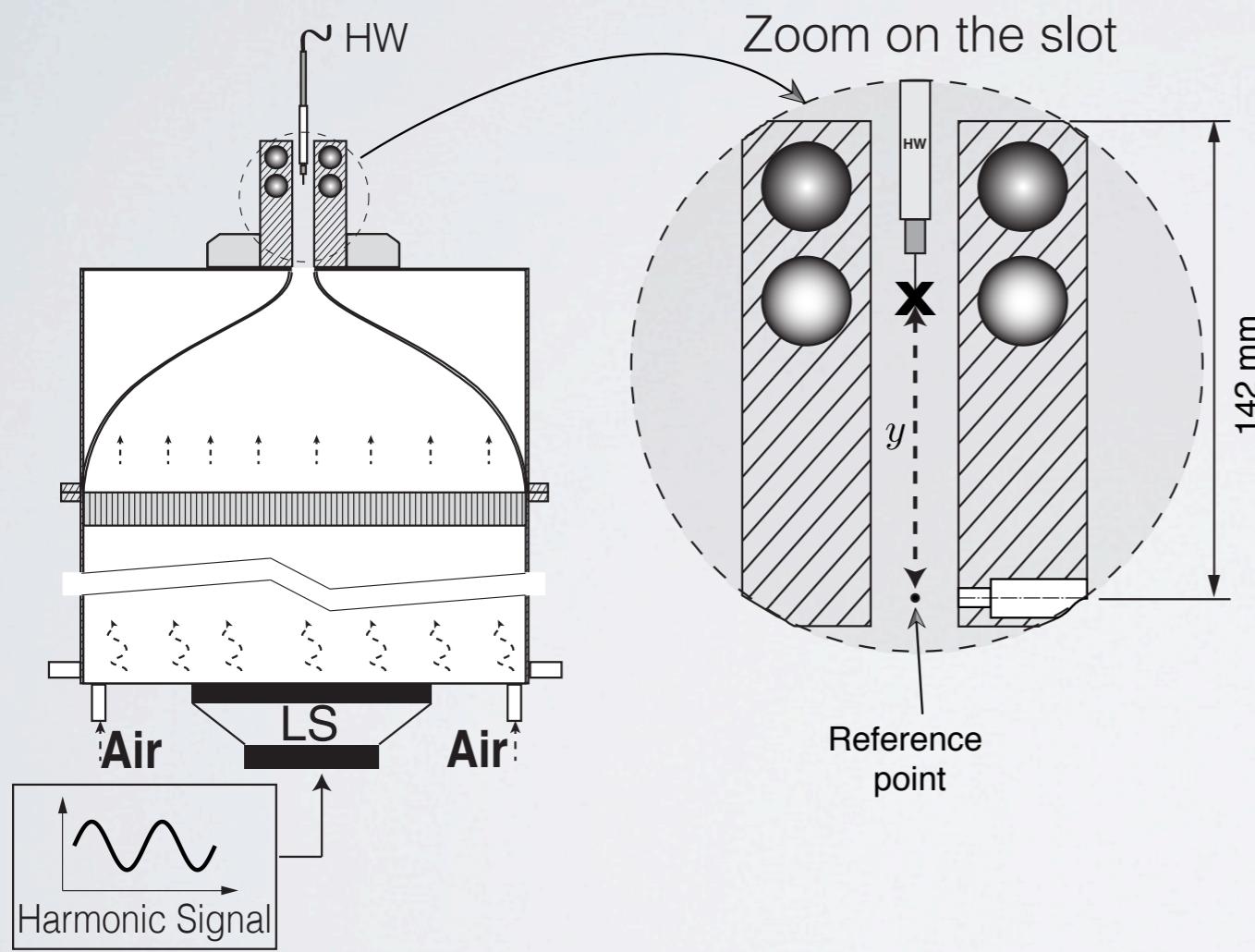
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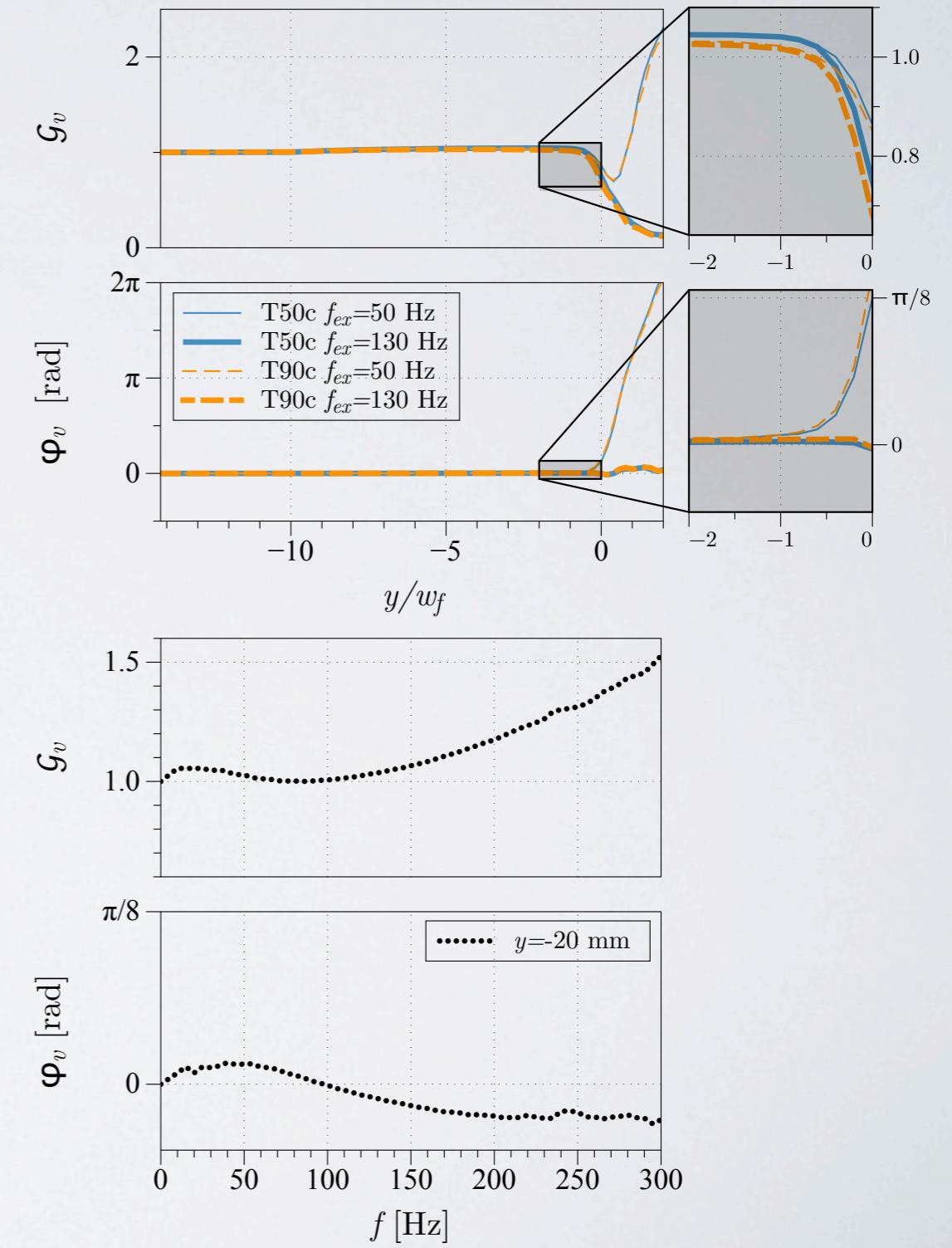


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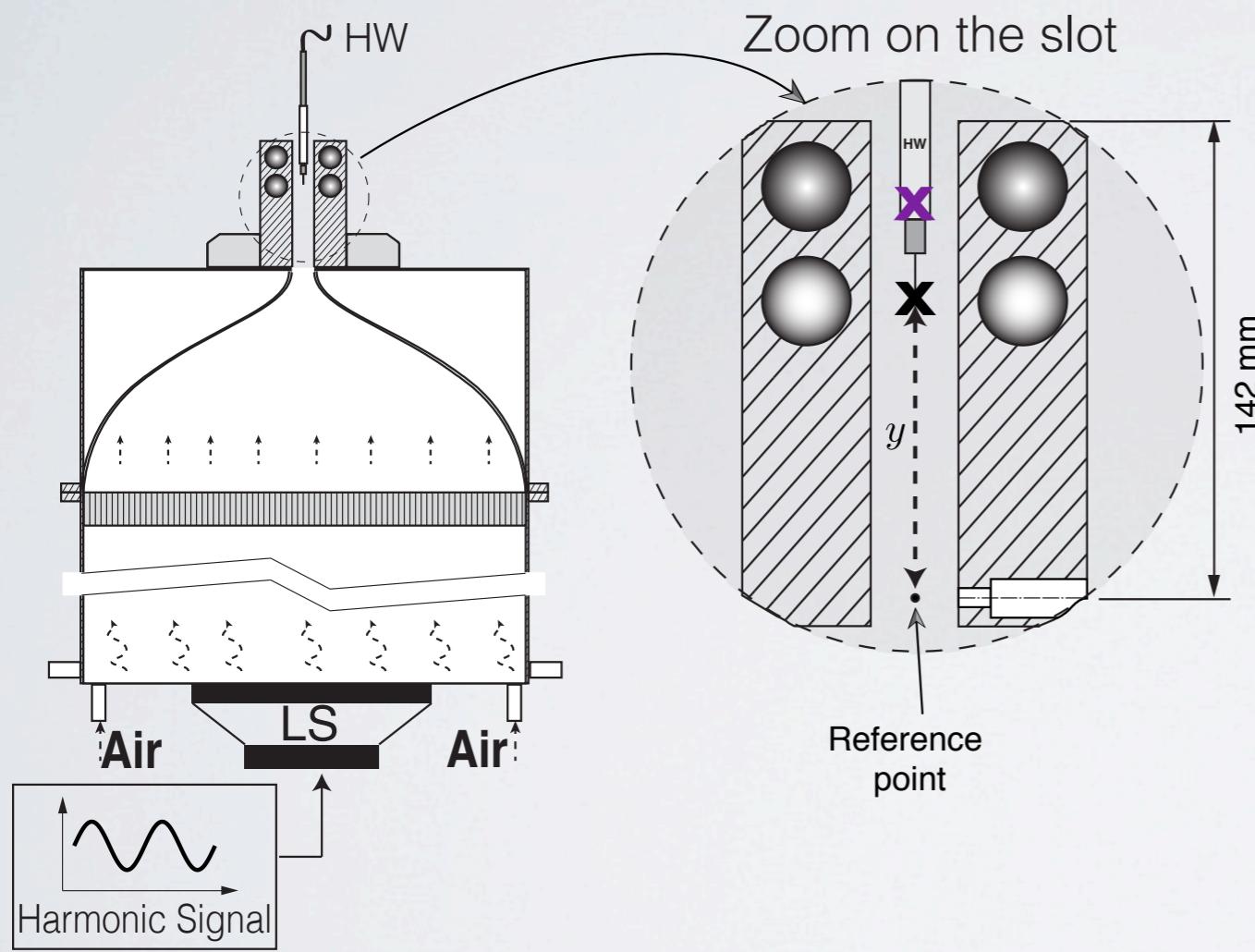


36

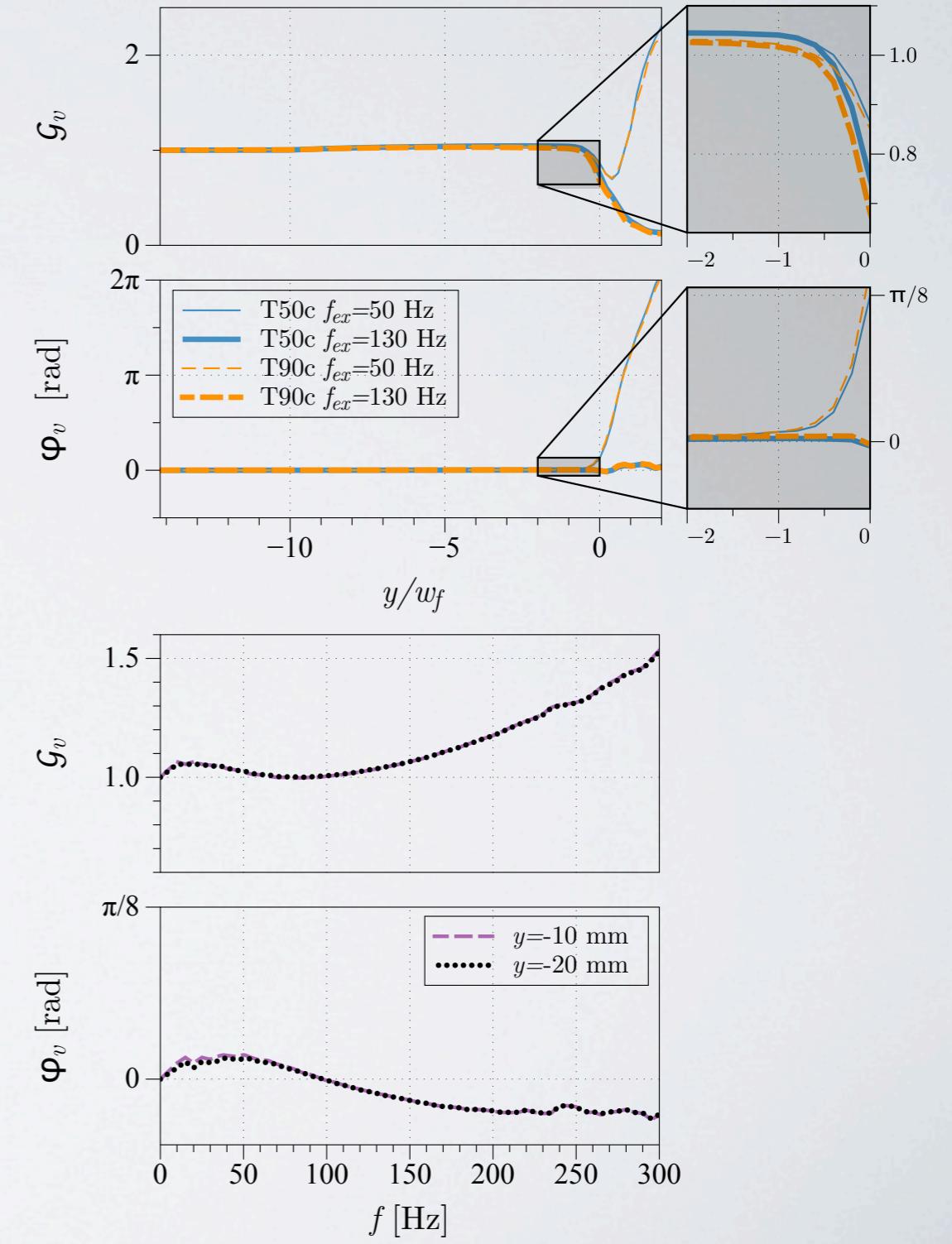


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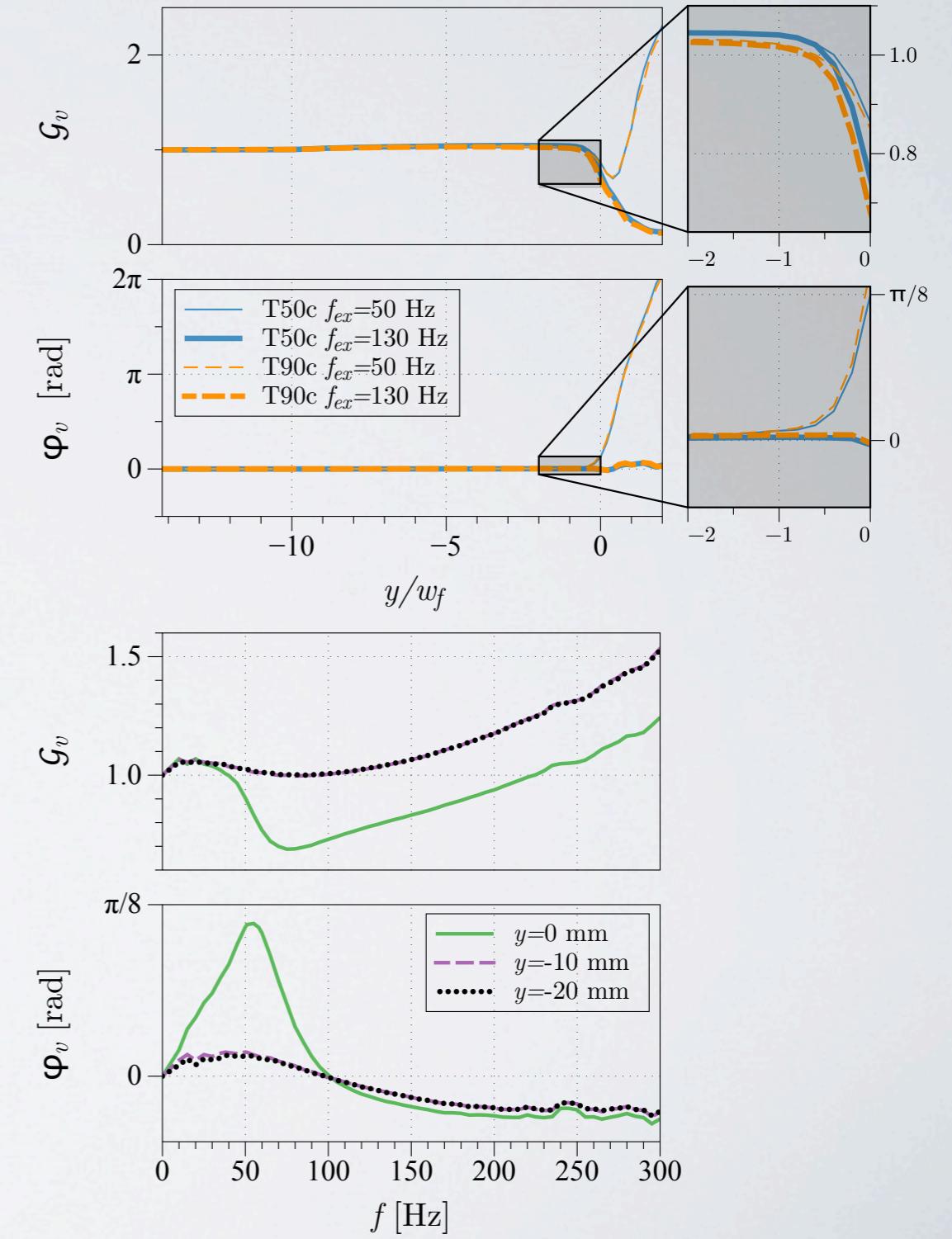
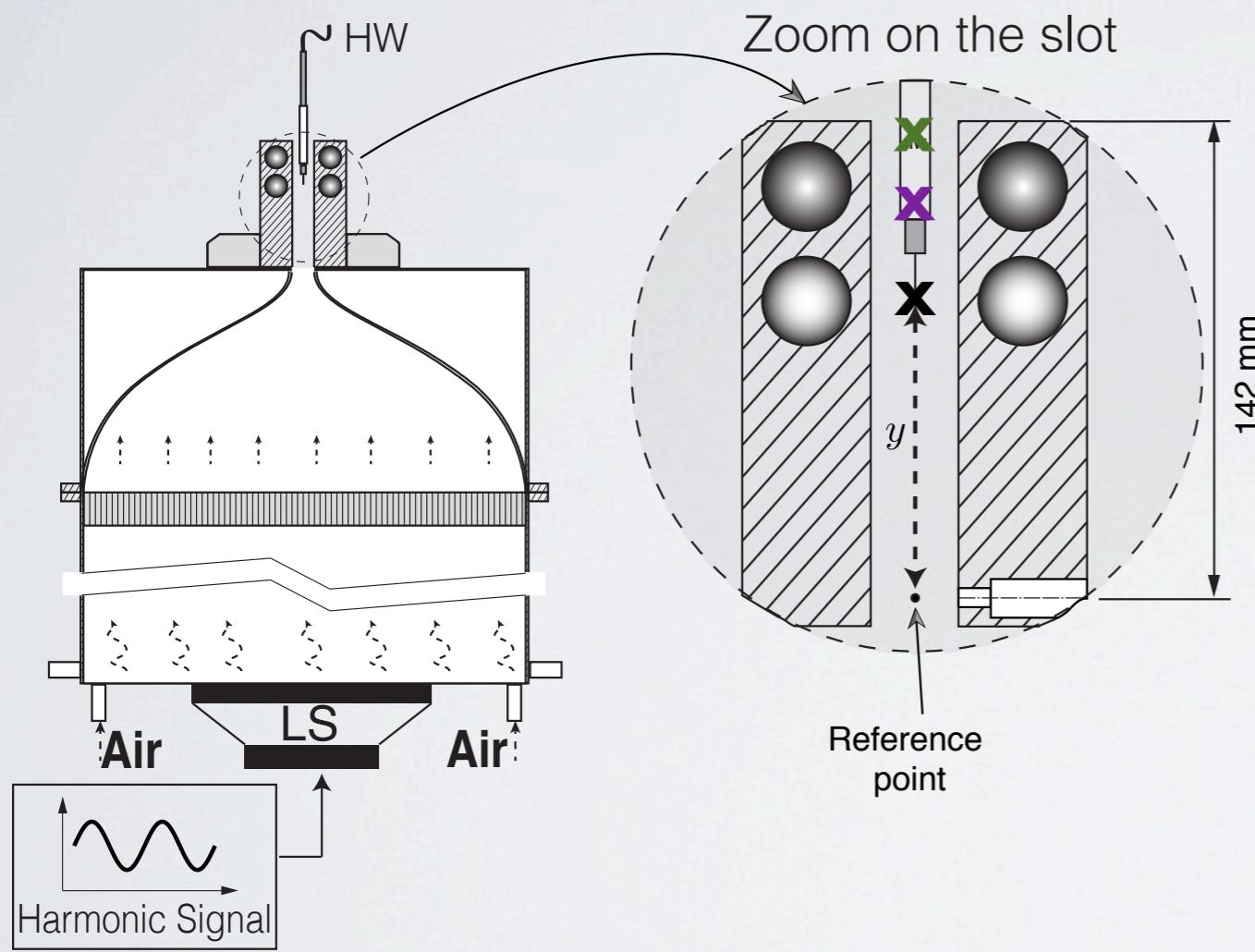


36



FTF

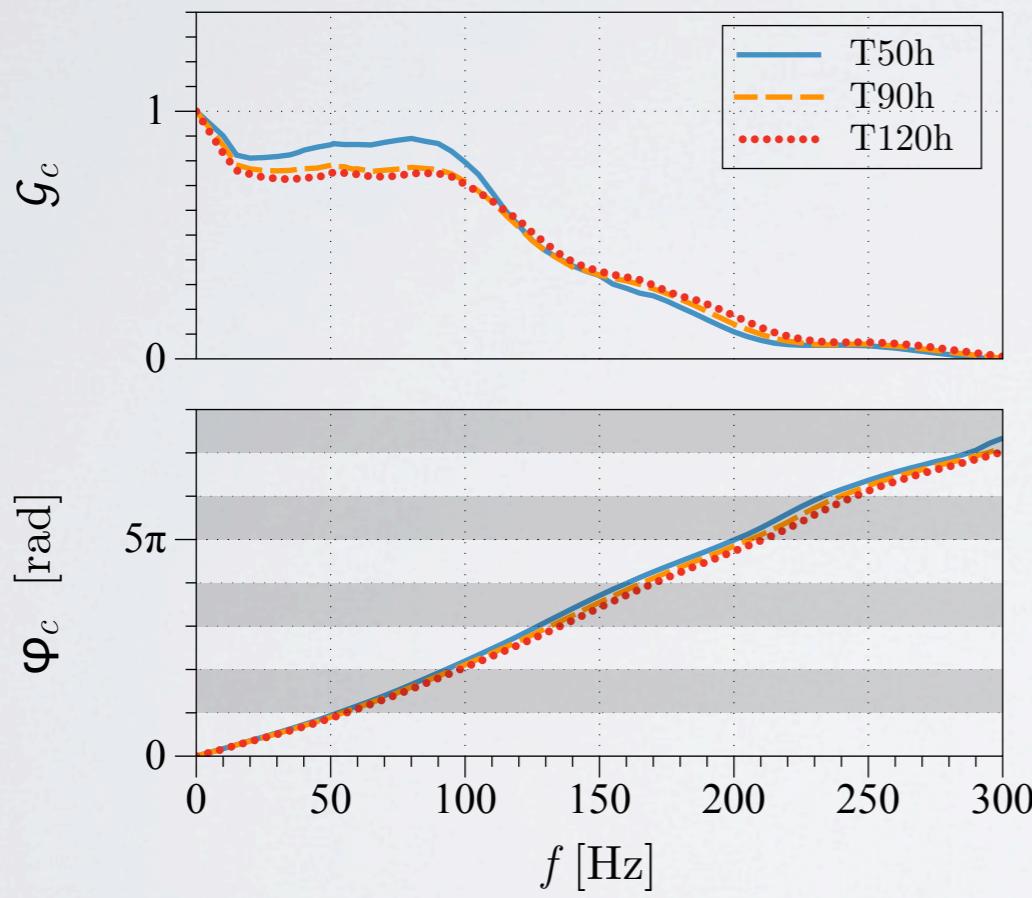
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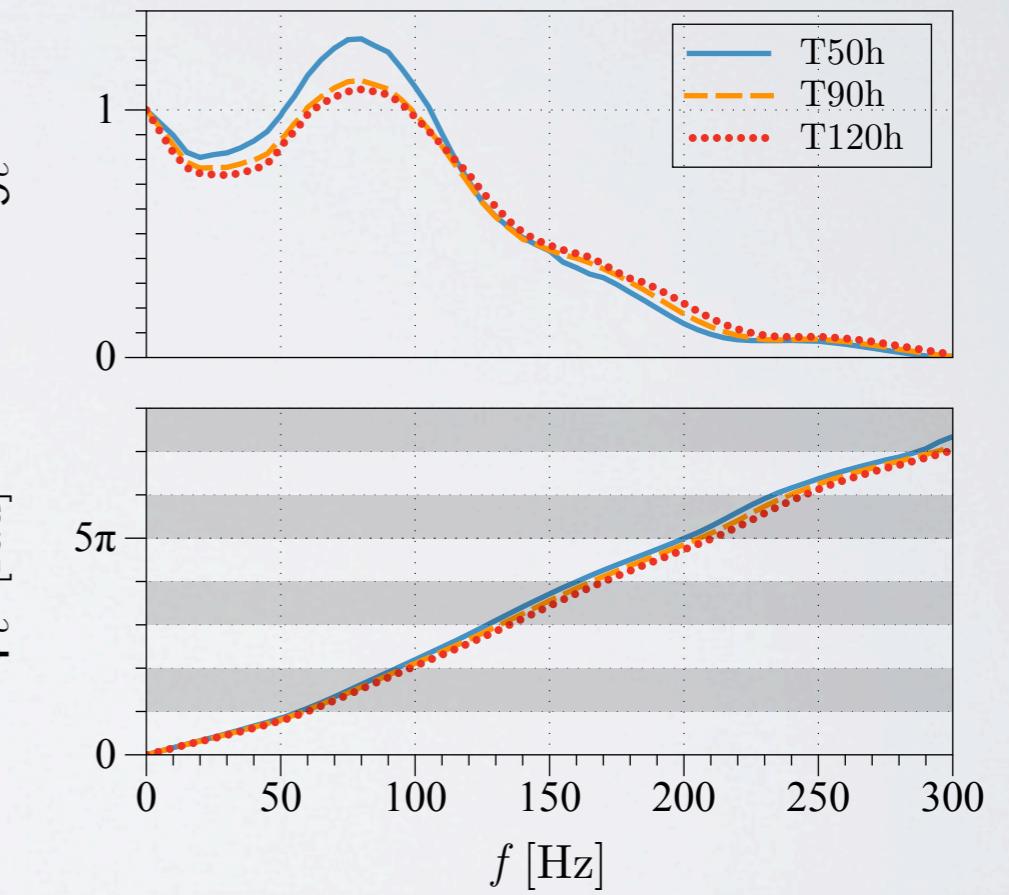
FTF

Different Flame Transfer Functions

$y = -10 \text{ mm}$



$y = 0 \text{ mm}$



CONCLUSIONS

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Do wall temperatures modify the...

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Do wall temperatures modify the...

I. Combustion Noise: NO,

CONCLUSIONS

Do wall temperatures modify the...

1. Combustion Noise: NO,
2. acoustics: NO,

CONCLUSIONS

Do wall temperatures modify the...

1. Combustion Noise: NO,

2. acoustics: NO,

3. flame dynamics: YES.

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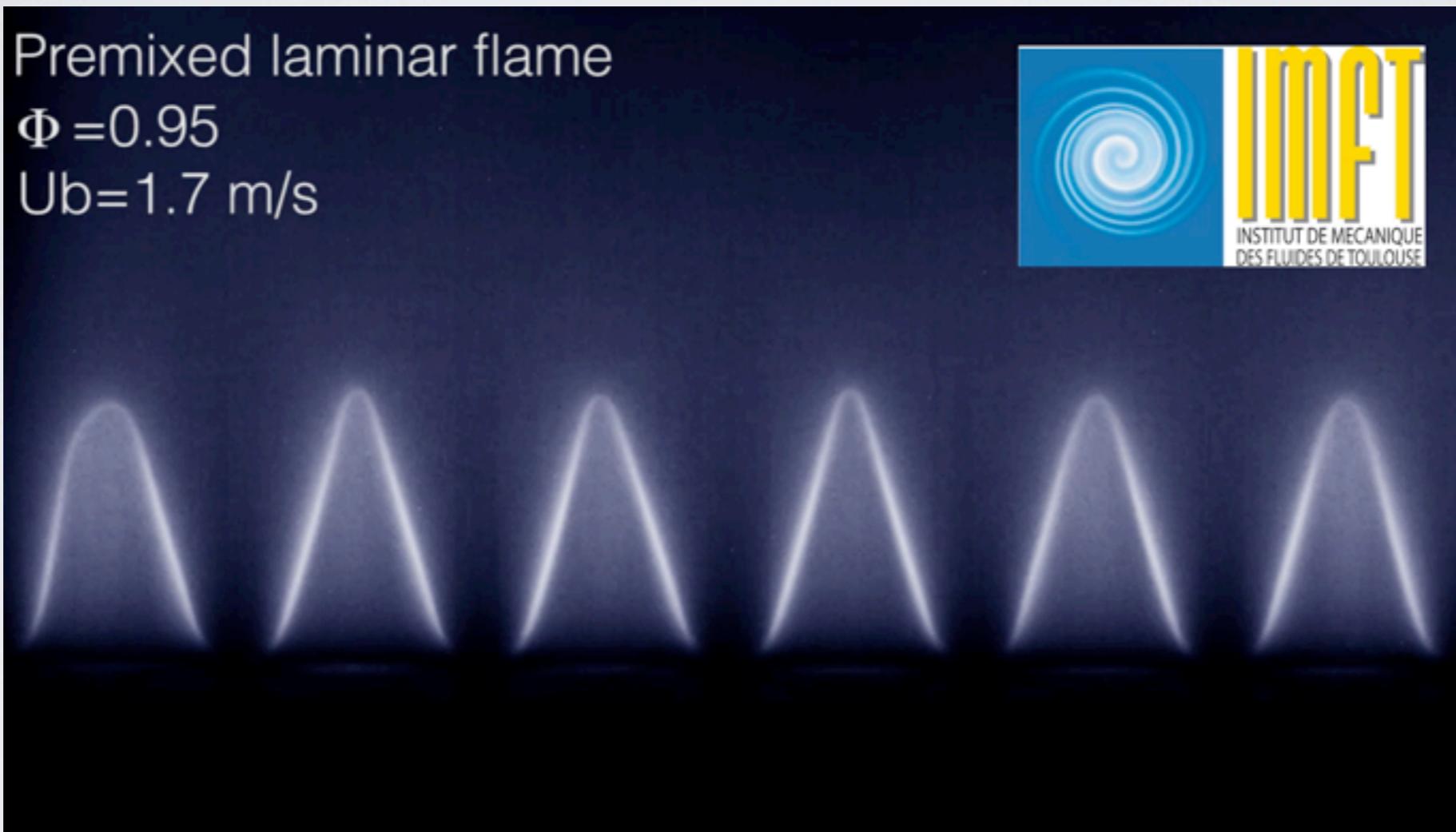
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 - ♦ local modifications of flame speed in boundary layers,
 - ♦ modification of the flame base dynamics.
- the place where the velocity fluctuation is measured is a key parameter in for an accurate measure of the FTF.

Merci de votre attention

Questions ??



Daniel MEJIA
dmejia@imft.fr