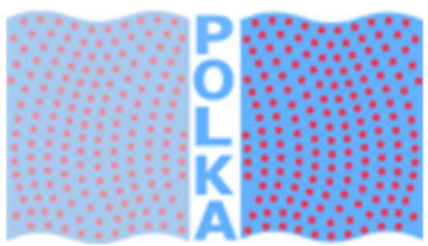
POLKA 6th Scientific Workshop: Imaging techniques and related post-processing

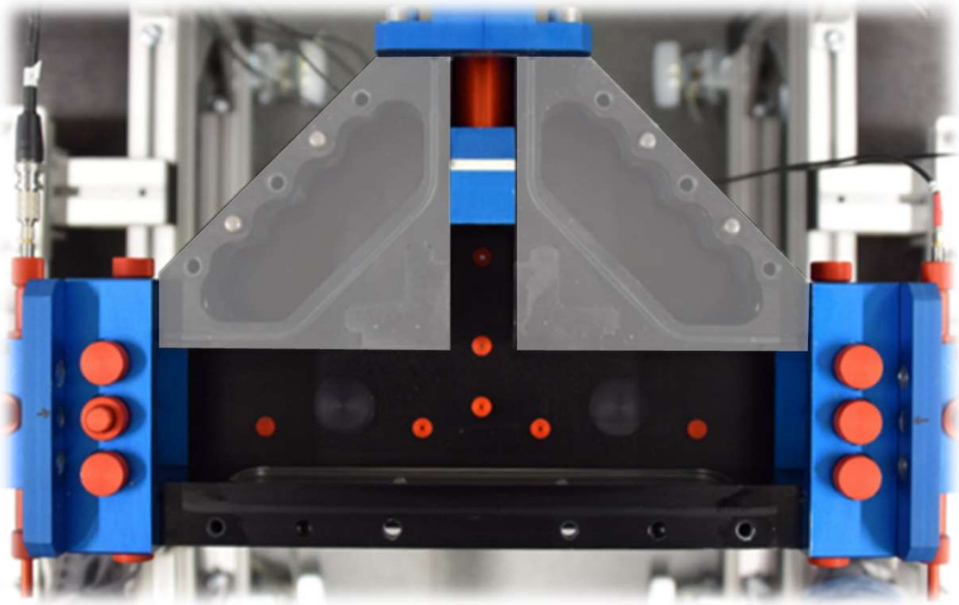


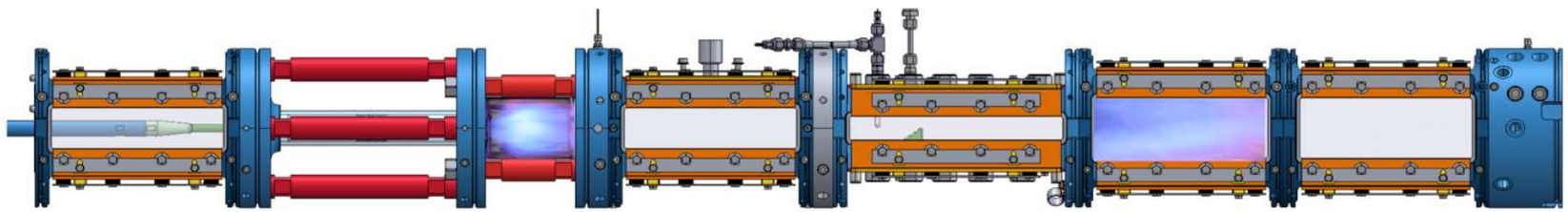
Claire Bourquard

March 16th, 2023

Montestigliano

Introduction: aero- and thermoacoustic setups with optical access





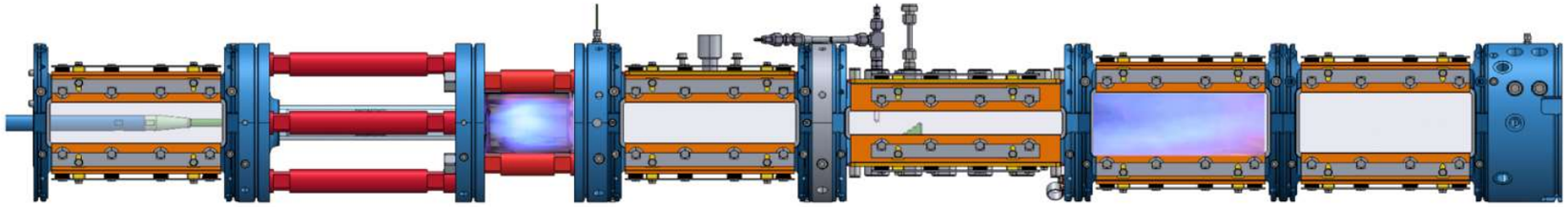
Courtesy of M. Weilenmann

Agenda

- Imaging techniques
  - OH radicals chemiluminescence
  - Planer Laser-Induced Fluorescence (PLIF)
  - Particle Image Velocimetry
  - Background-Oriented Schlieren

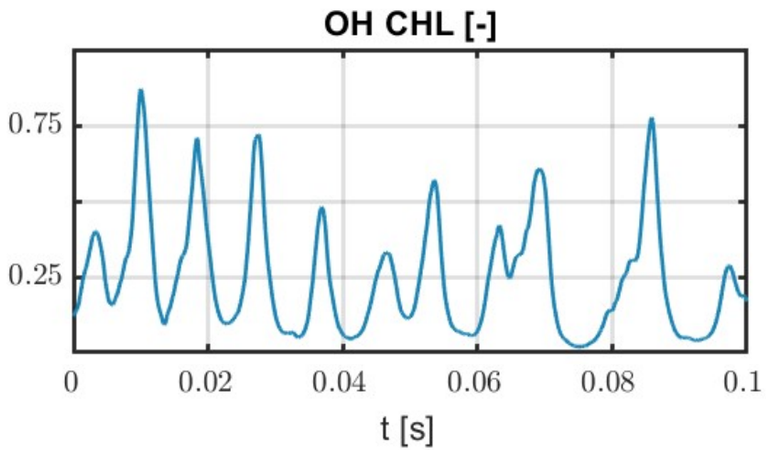
OH radicals chemiluminescence

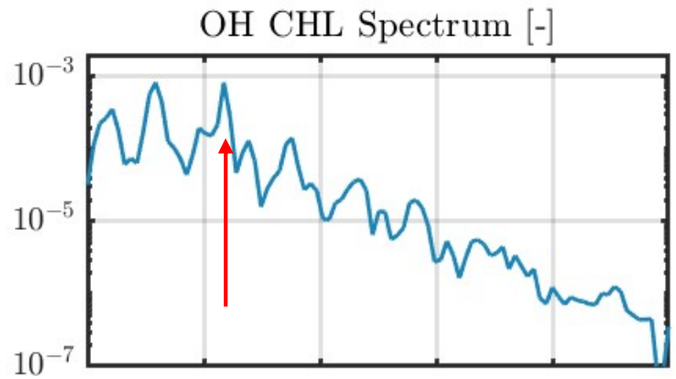
OH radicals chemuluminescence: requirements and setup



Photomultiplier sensor

Requires: combustion reaction
Output: scalar value





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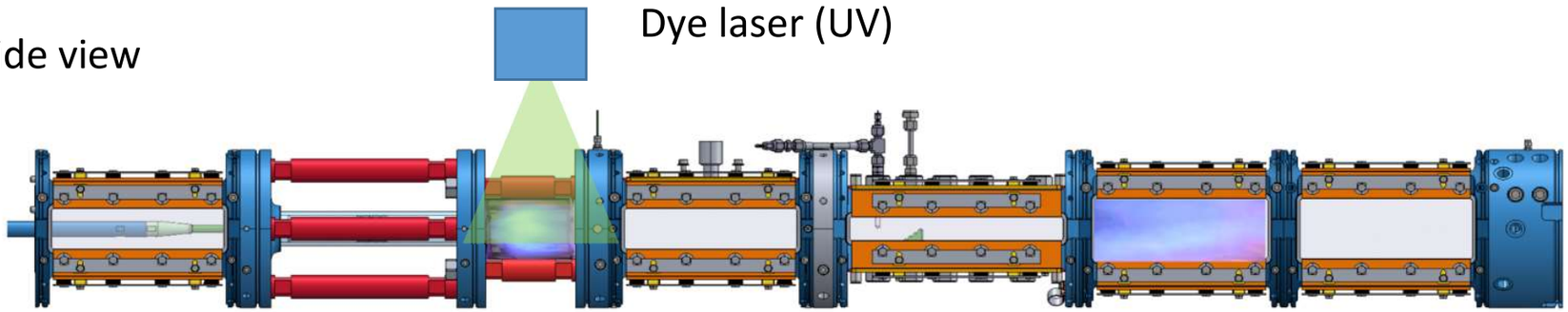
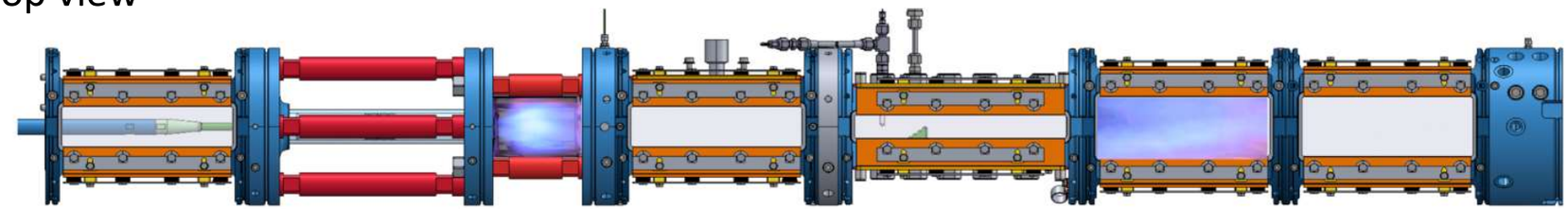
Planar Laser-induced fluorescence (PLIF)

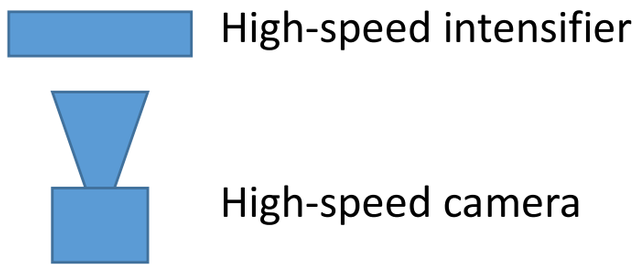
Planar Laser-induced fluorescence (PLIF): requirements and setup

Side view



Top view





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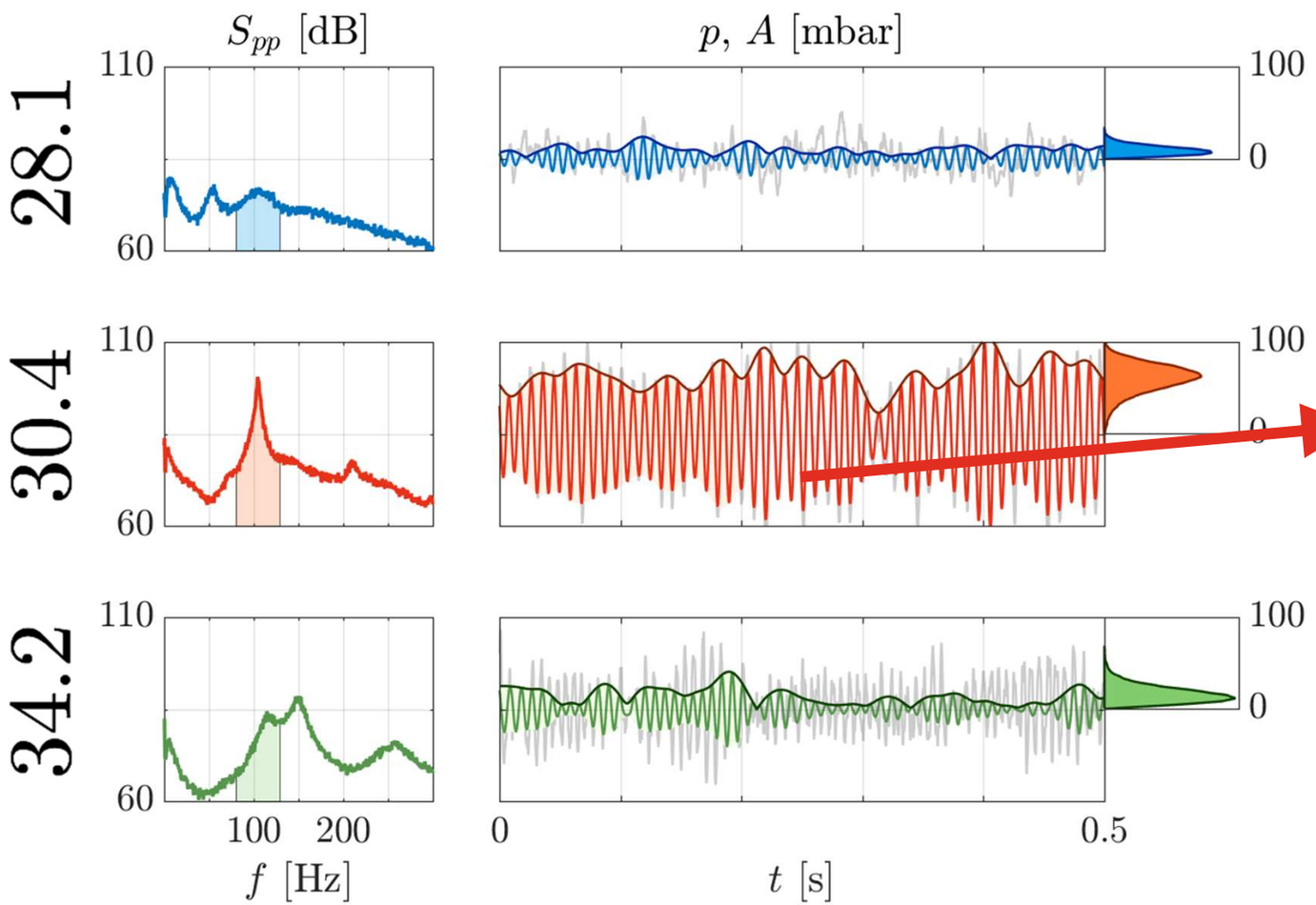
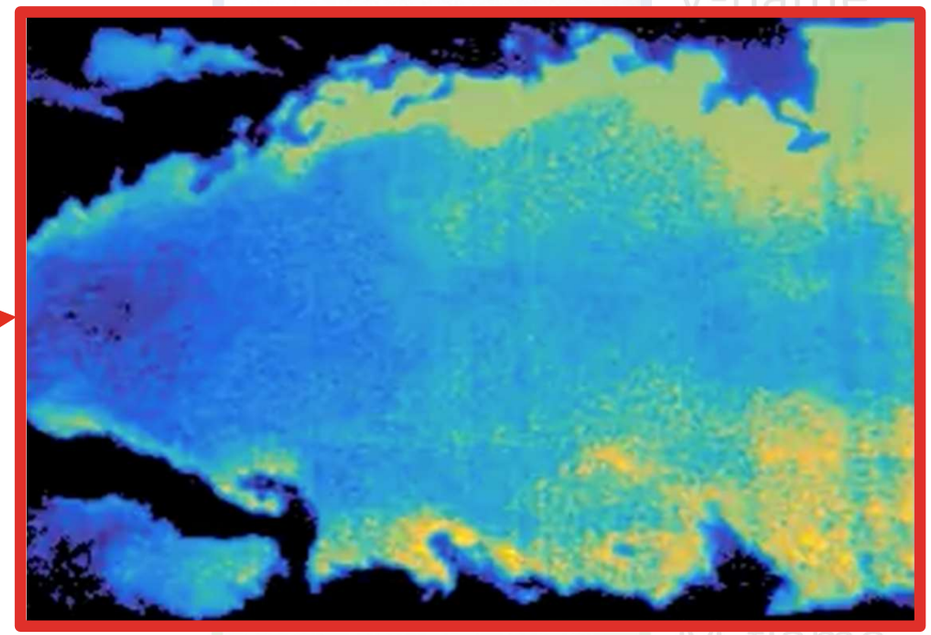
Requires: combustion reaction (fluorescence of OH radicals)
Output: intensity field

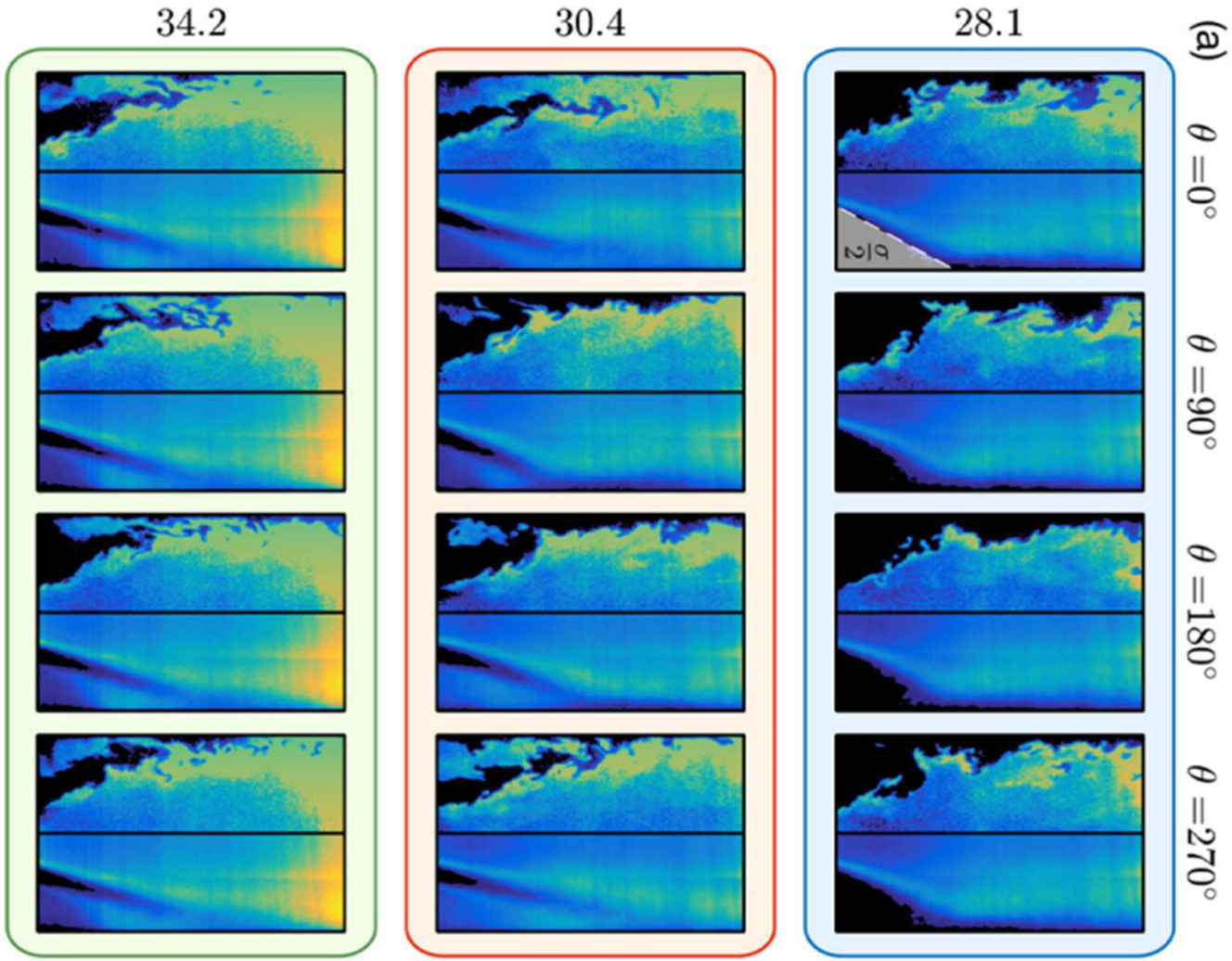
Planar Laser-induced fluorescence (PLIF): example





Courtesy of G. Bonciolini

Planar Laser-induced fluorescence (PLIF): postprocessing



Courtesy of G. Bonciolini

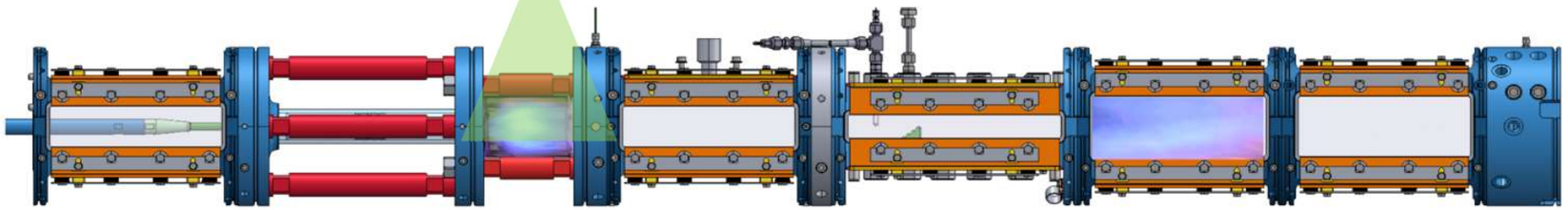
Phase averaging

Particle Image Velocimetry (PIV)

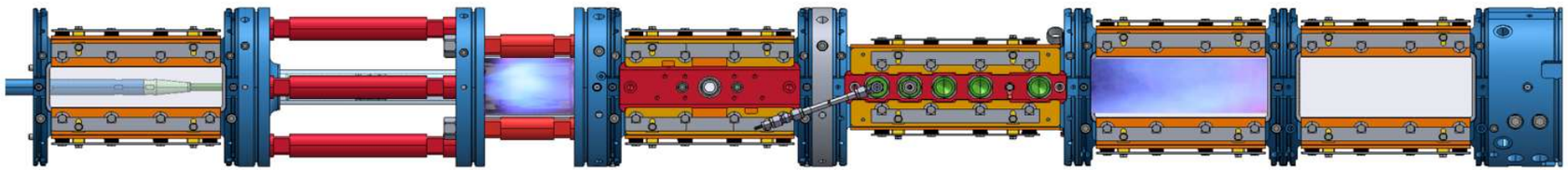
Particle Image Velocimetry (PIV): requirements and setup

Side view

Laser



Top view

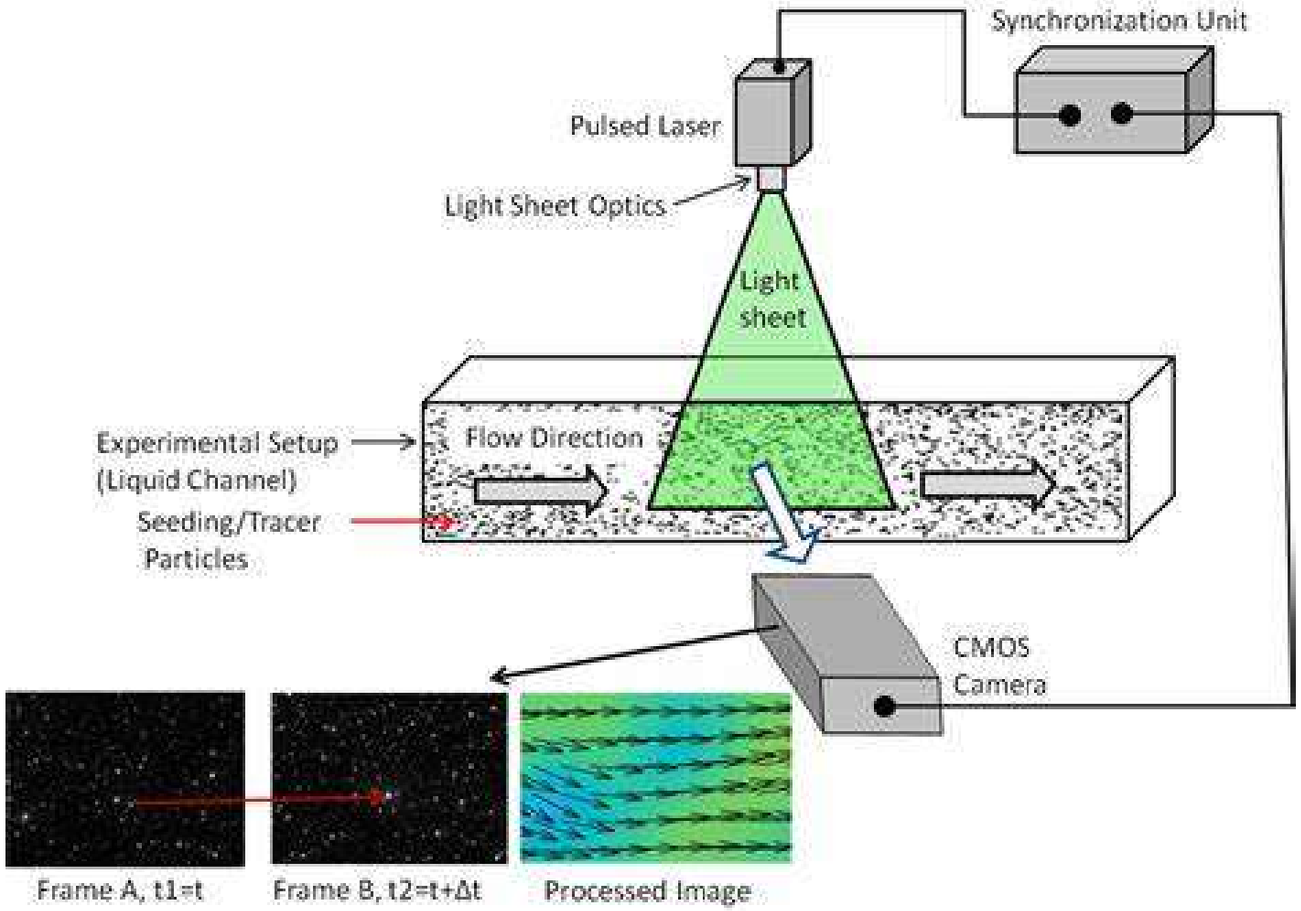


High-speed camera

Requires: particles (atomized liquid for non-combustion purposes, powder otherwise)
Output: intensity field of particles

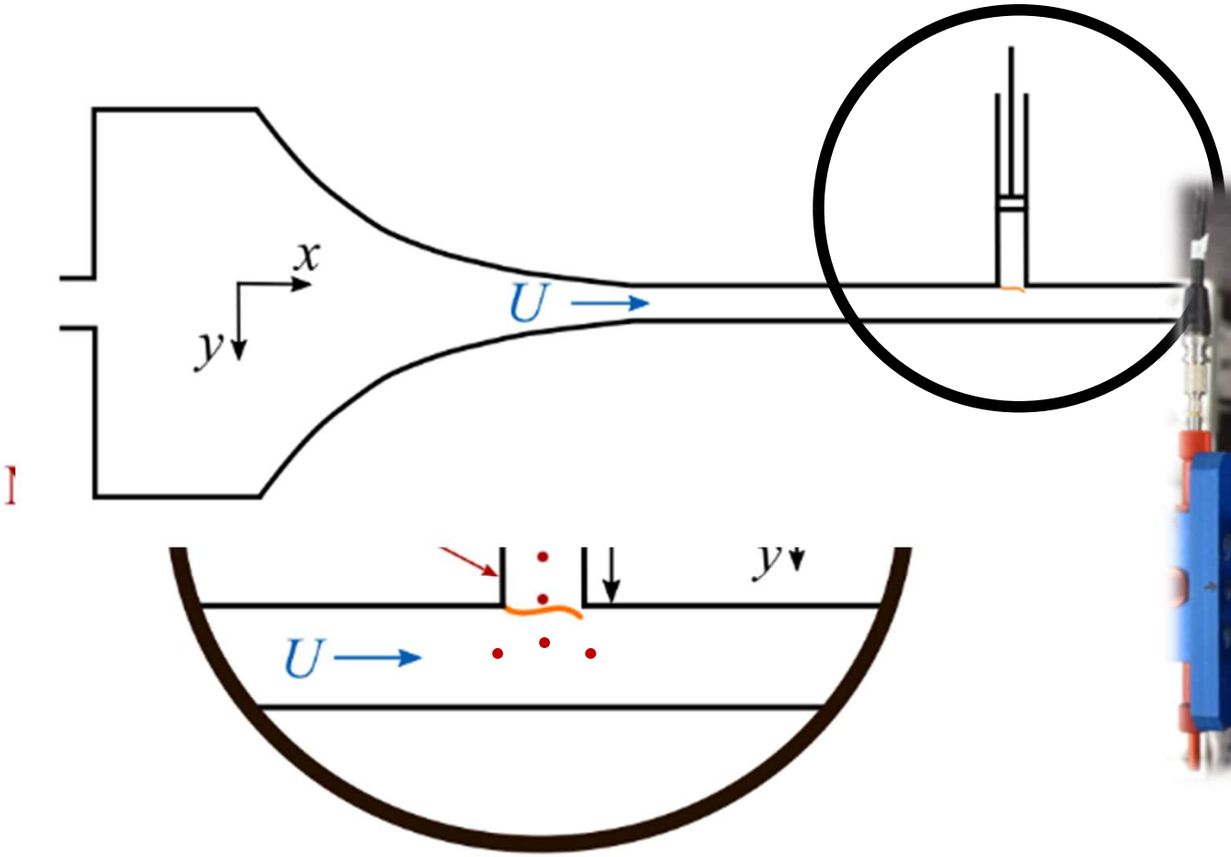
Courtesy of M. Weilenmann

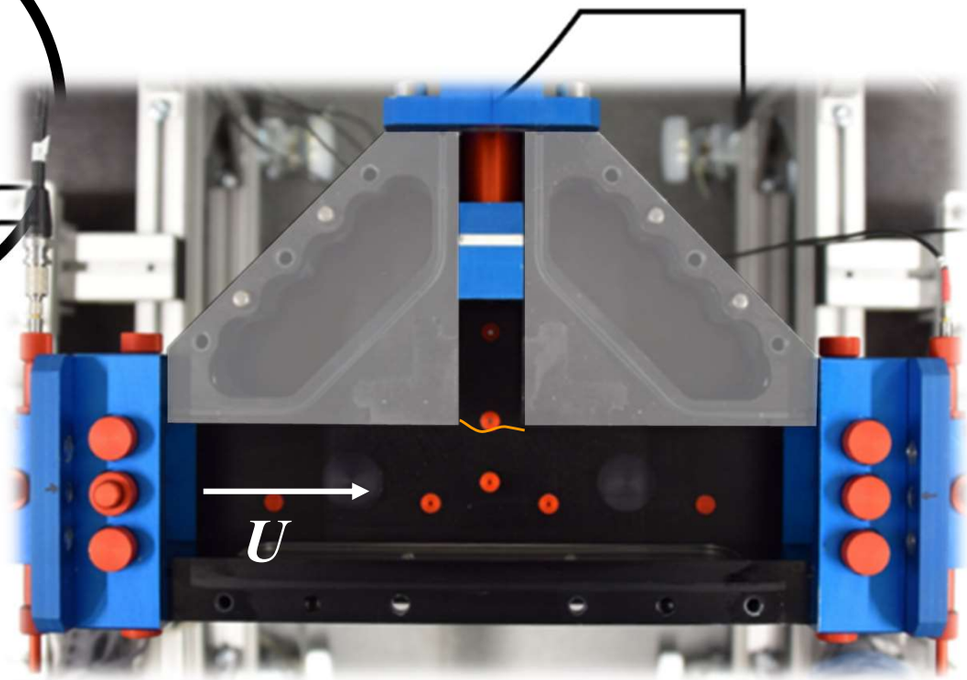
Particle Image Velocimetry (PIV): postprocessing



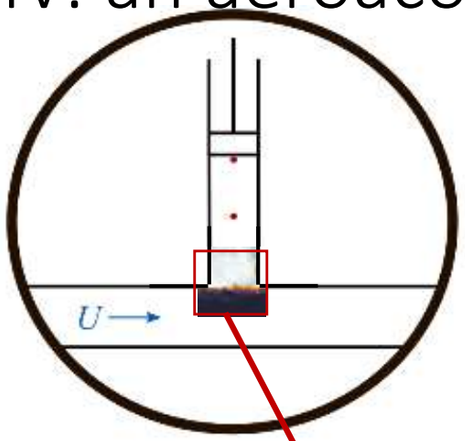
Courtesy of IIT Bombay

PIV: an aeroacoustic example

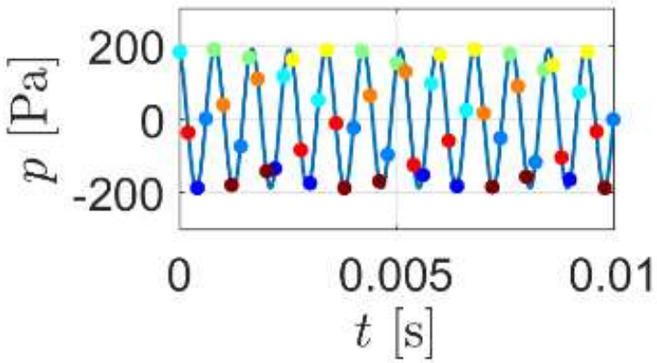


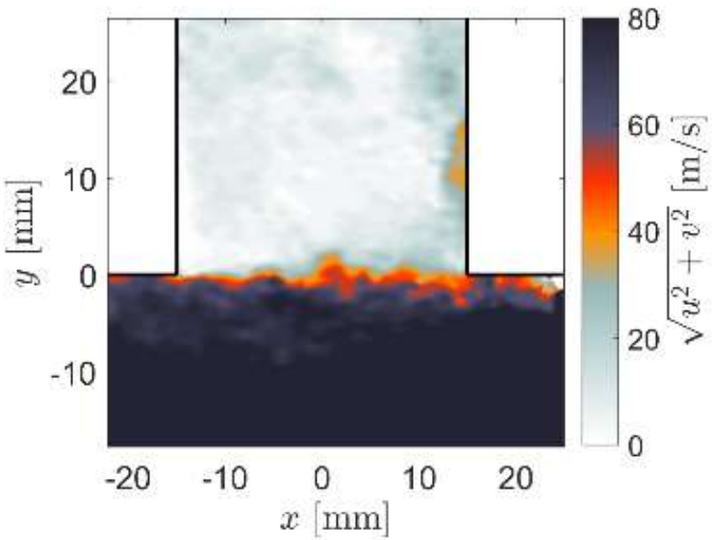


PIV: an aeroacoustic example

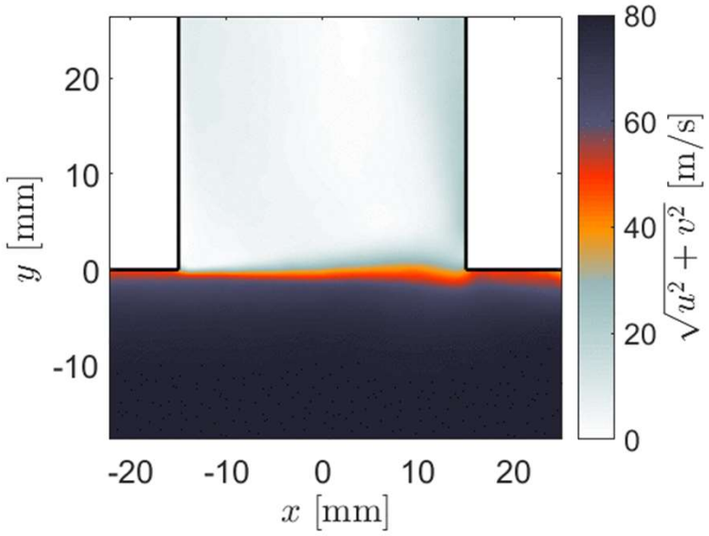


Self-sustained oscillation for
U = 74 m/s,
L = 250 mm



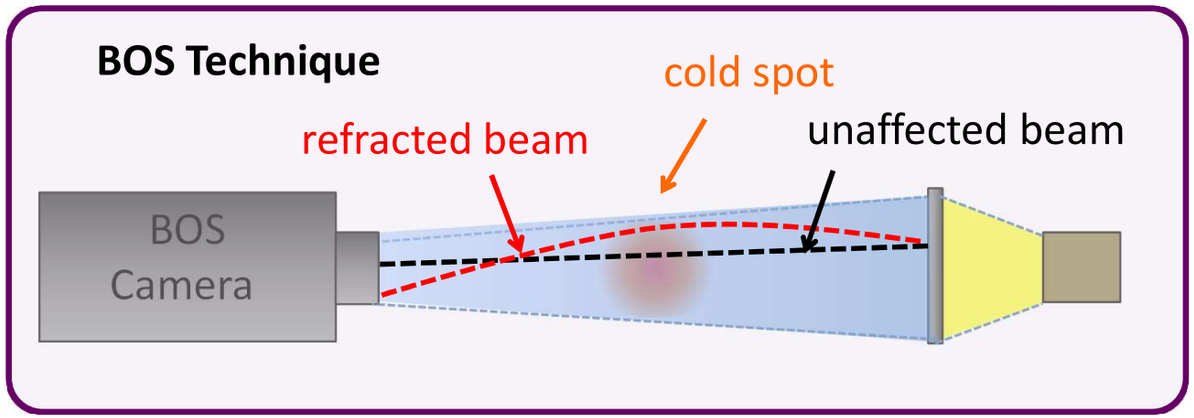


Subtract phase averaging



Background-Oriented Schlieren (BOS)

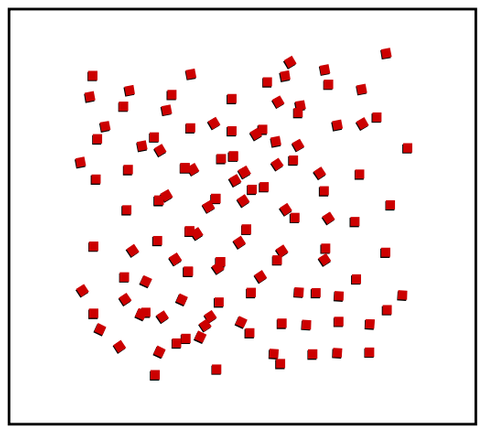
Background-Oriented Schlieren technique



Requires: Density variations (typically: temperature)
Output: deformed background image

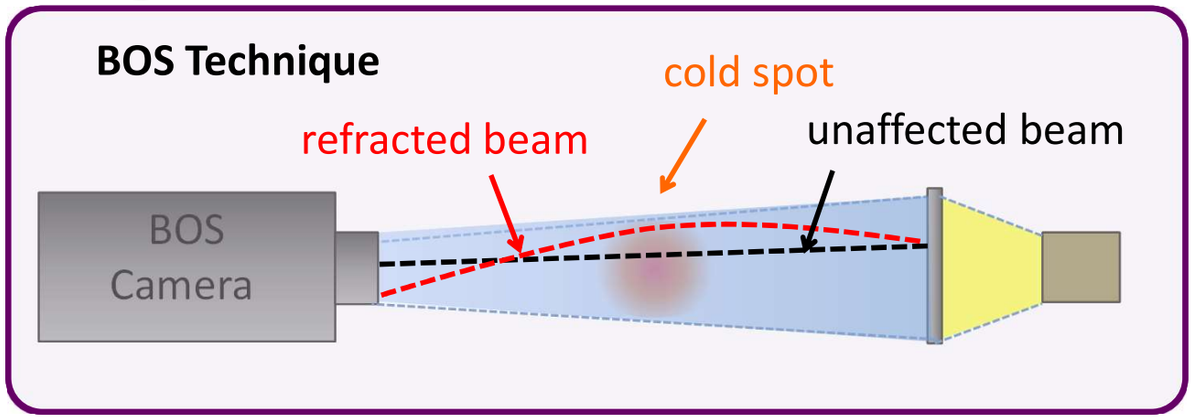
Foto: NASA

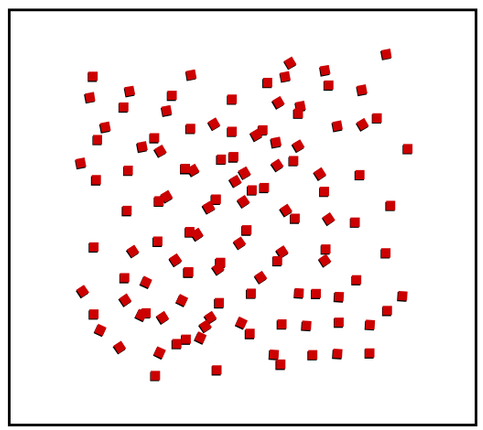
Courtesy of M. Weilenmann



Output: 2D field of line of sight integrated local refractive index gradient

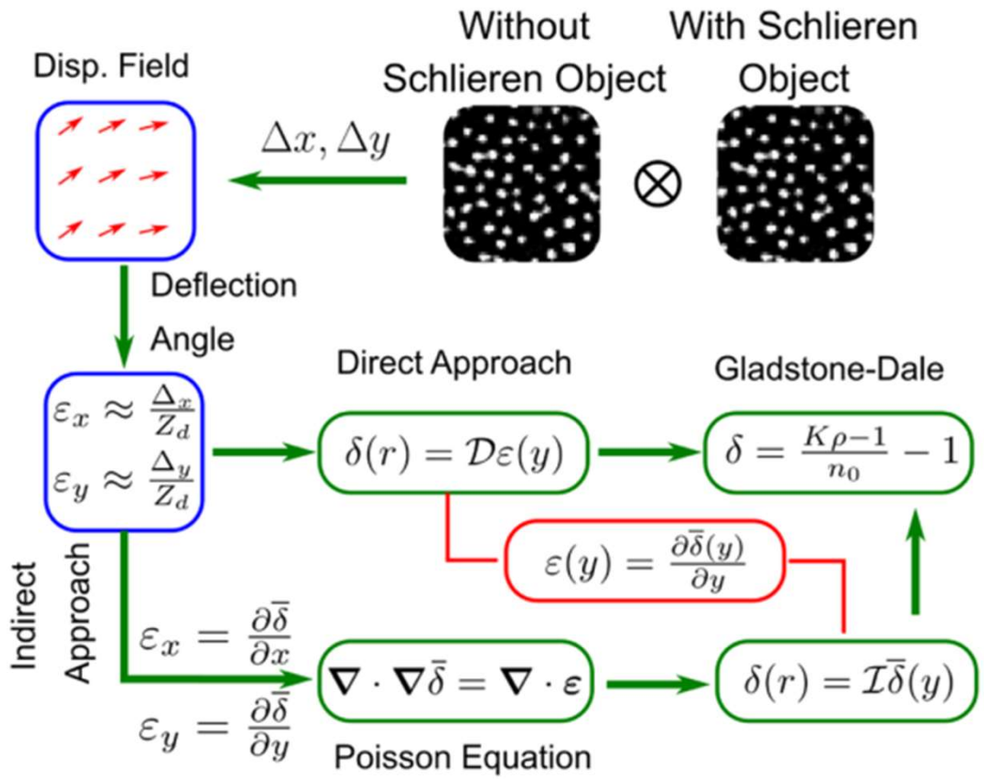
Background-Oriented Schlieren technique





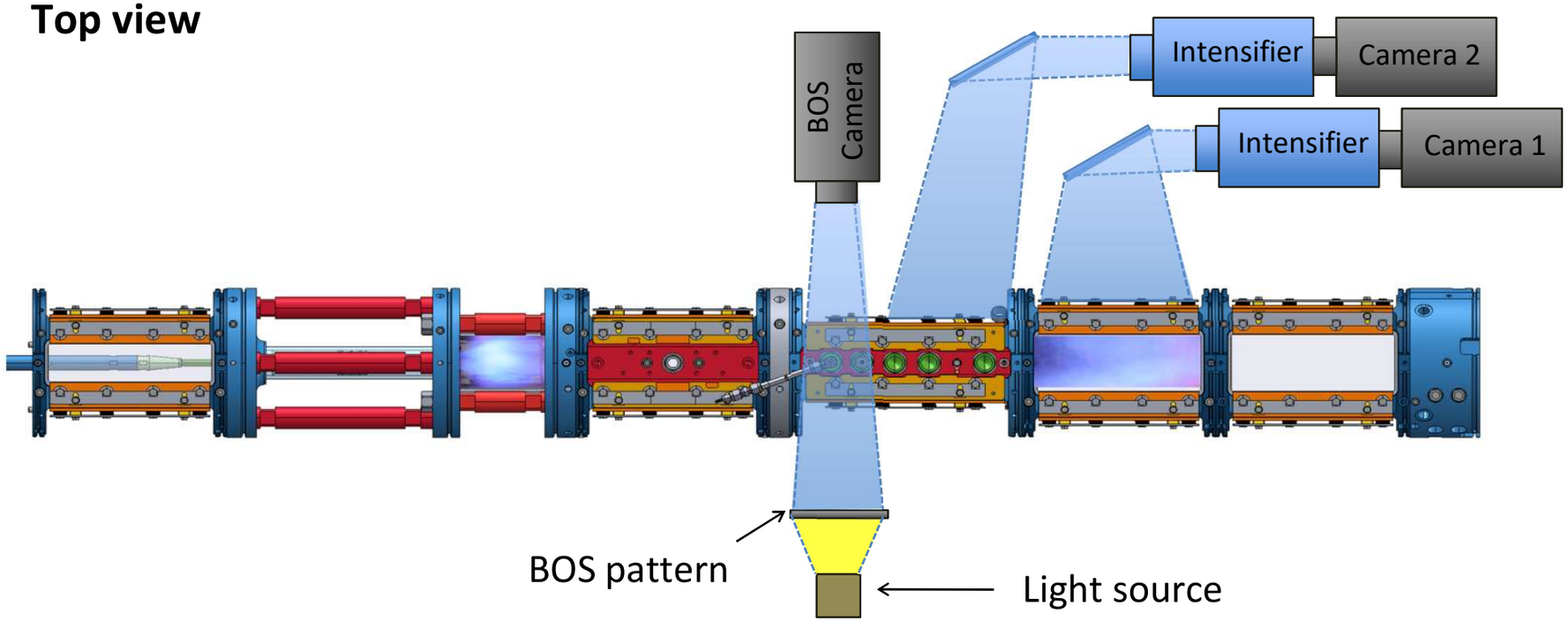
Output: 2D field of line of sight integrated local refractive index gradient

Courtesy of M. Weilenmann



Background-Oriented Schlieren setup

Top view

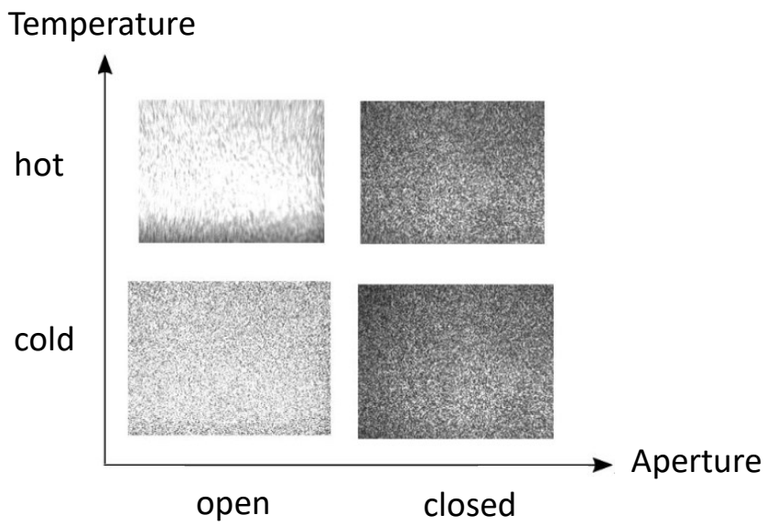


Courtesy of M. Weilenmann

Background-Oriented Schlieren technique

Problem:

Larger depth of field is required



Solution:

Stop down aperture

Courtesy of M. Weilenmann

Problem:

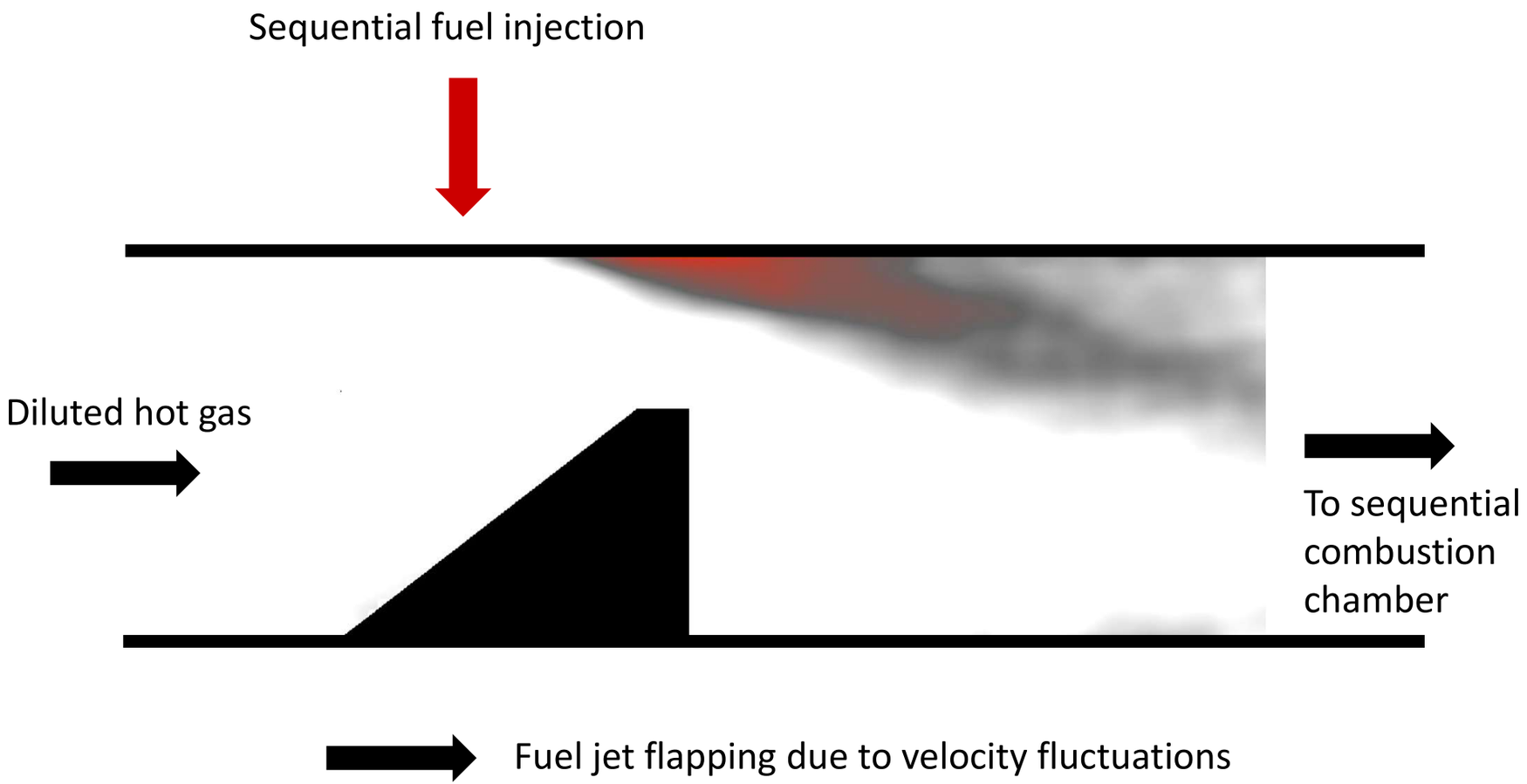
Large bias error if reference image taken before test rig operation

Solution:

use **average image** as reference

Limitations:
→Only moving gradients are observable

Background-Oriented Schlieren: flapping jet example



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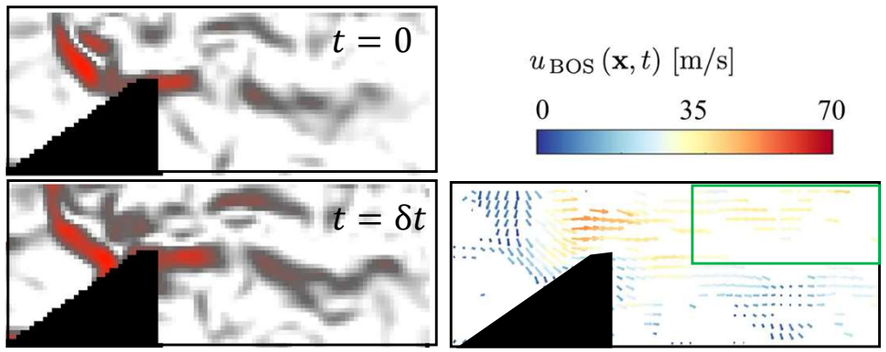
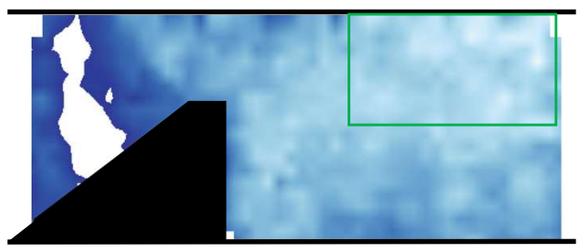
Background-Oriented Schlieren: velocimetry



refractive index gradient structures → tracking → $\boldsymbol{u}_{\mathrm{BOS}}\,(\boldsymbol{x}, t)$ →



Courtesy of M. Weilenmann

Bulk velocity:

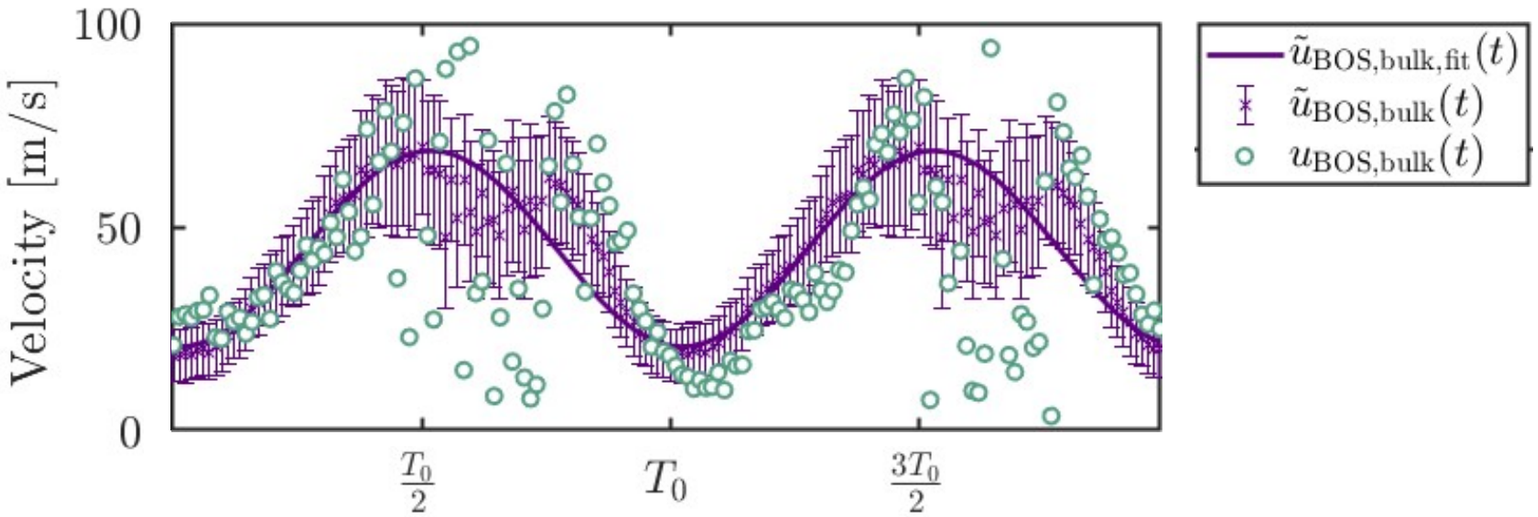
- Eliminate values below threshhold
- Histogram

$$u_{\mathrm{BOS,bulk}}\,(t) = \sum_{i=1}^{3} W_i(t) \cdot C_i(t)$$

$$\text{with} \quad W_i = \frac{H_i}{\sum_{k=1}^{3} H_k}$$

Background-Oriented Schlieren: velocimetry example

Phase averaged bulk velocity



Courtesy of M. Weilenmann

Conclusion / Takeaway

- You know which various optical techniques are there for aero- and thermoacoustic instabilities characterization
- You know their various requirements
- You have an idea of the postprocessing required

References:

Bourquard, C., Faure-Beaulieu, A., & Noiray, N. (2021). Whistling of deep cavities subject to turbulent grazing flow: intermittently unstable aeroacoustic feedback. *Journal of Fluid Mechanics*, *909*, A19.

Bonciolini, G., Ebi, D., Doll, U., Weilenmann, M., & Noiray, N. (2019). Effect of wall thermal inertia upon transient thermoacoustic dynamics of a swirl-stabilized flame. *Proceedings of the Combustion Institute*, *37*(4), 5351-5358.

Xiong, Y., Weilenmann, M., & Noiray, N. (2020). Analysis and reduction of spurious displacements in high-framing-rate background-oriented Schlieren. *Experiments in Fluids*, *61*, 1-12.

Weilenmann, M., Xiong, Y., Bothien, M., & Noiray, N. (2019). Background-oriented schlieren of fuel jet flapping under thermoacoustic oscillations in a sequential combustor. *Journal of Engineering for Gas Turbines and Power*, *141*(1), 011030.

And references therein…

Acknowledgements

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- Dr. Luigi Miniero

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Thanks for your attention!

Questions?