



Shadowgraphy

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Pre-normative REsearch for Safe use of Liquid HYdrogen



A vertical sidebar of logos on the right side of the slide. From top to bottom: KIT (Karlsruher Institut für Technologie), Air Liquide, HEALTH & SAFETY LABORATORY, hySafe (INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY), INERIS, a logo with the Greek letters ΔΗΜΟΚΡΙΤΟΣ and a portrait of a man, Pro-Science, Ulster University, and WARWICK THE UNIVERSITY OF WARWICK.

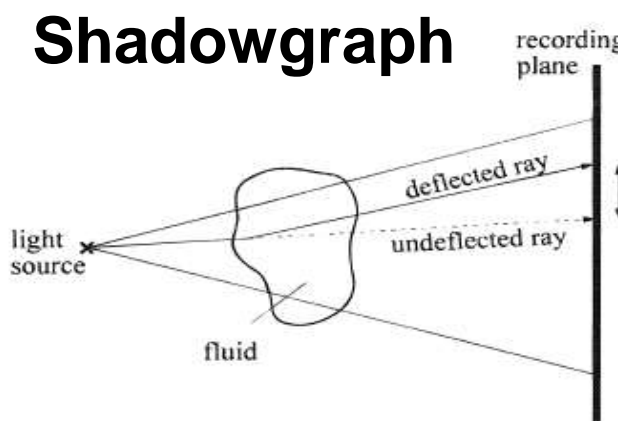
Content

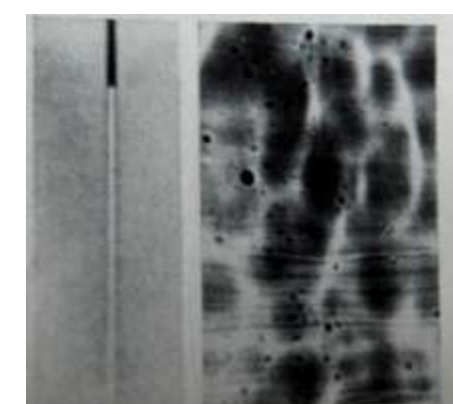
- Introduction
- Examples of different high speed Shadowgraphy applications
- Possible live performance (lab tour later)
- Conclusions

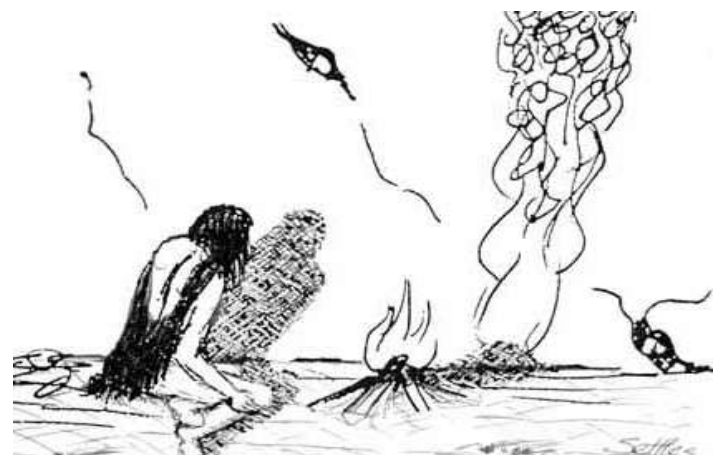
Introduction

Shadowgraph is an optical method that reveals non-uniformities in transparent media like air, water, or glass. It is related to, but simpler than, the schlieren and schlieren photography methods that perform a similar function. Shadowgraph is a type of flow visualization.

Shadowgraph

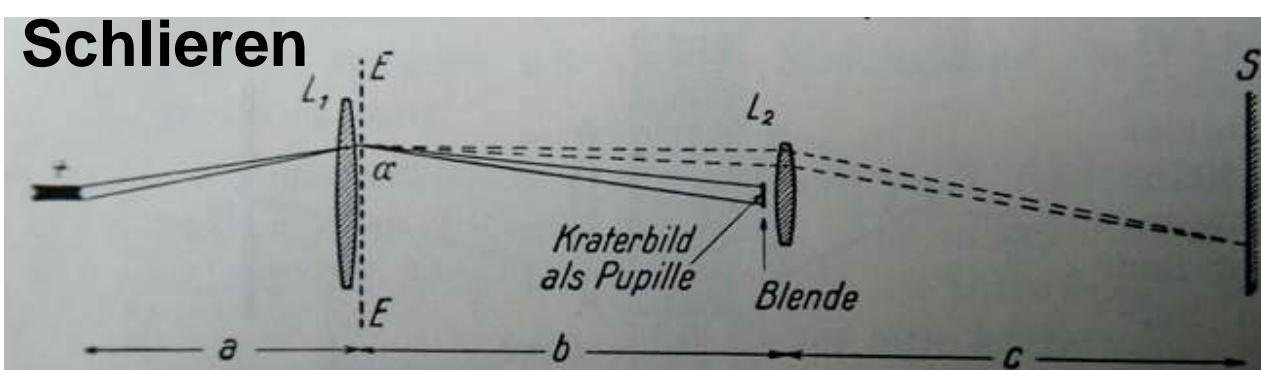


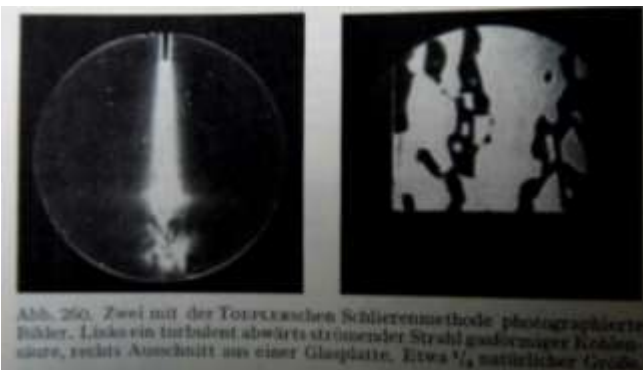




R.W. Pohl, Optik und Atomphysik, Springer 1954

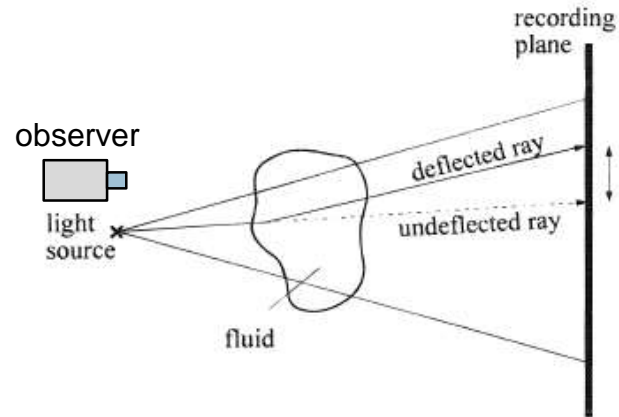
Schlieren





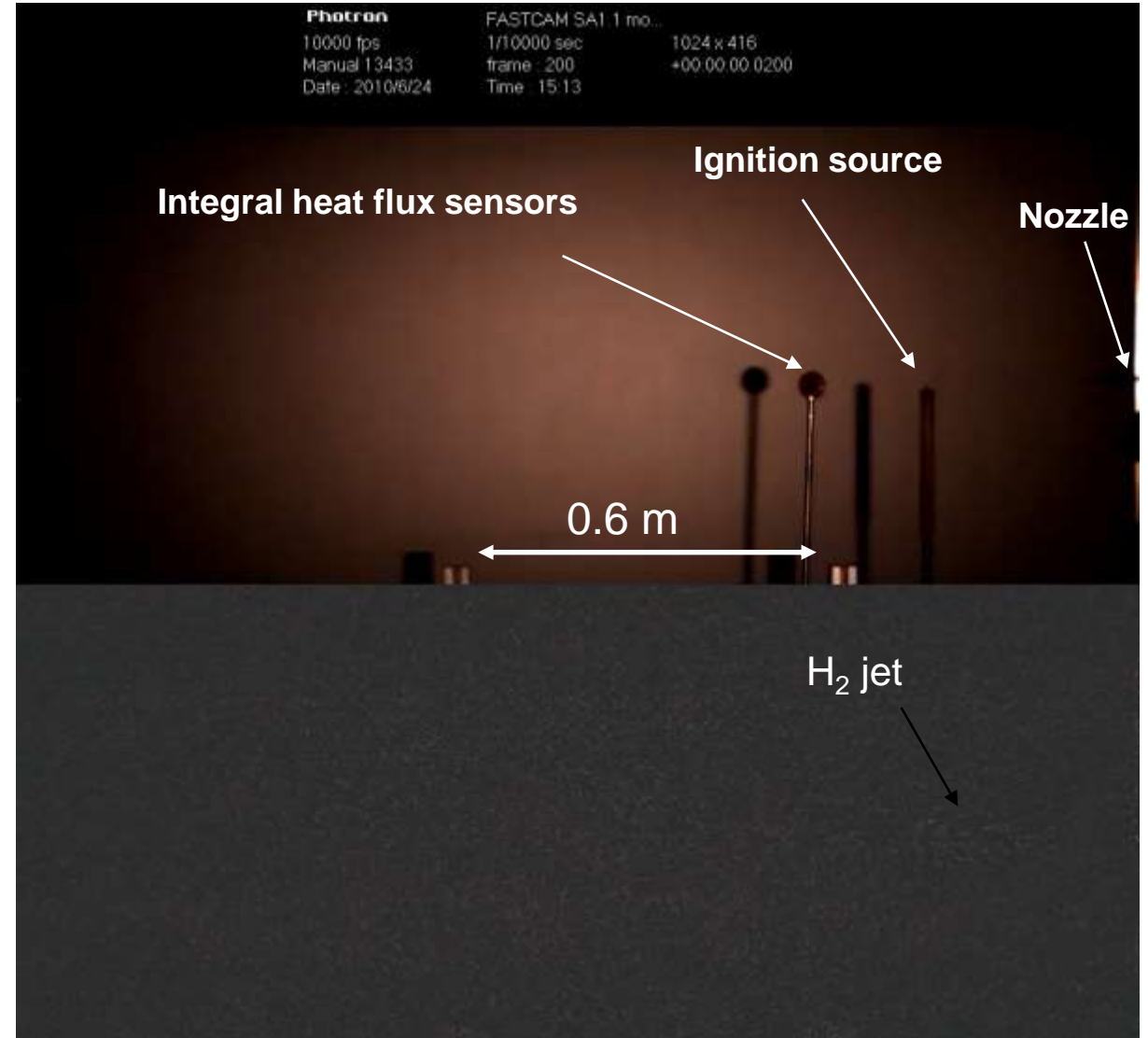
R.W. Pohl, Optik und Atomphysik, Springer 1954

Setup for shadowgraph without optical components



H₂ jet in air

Nozzle: 4 mm, $P_0 = 200$ bar, ignition time and distance optimized.



Real and shadow image →

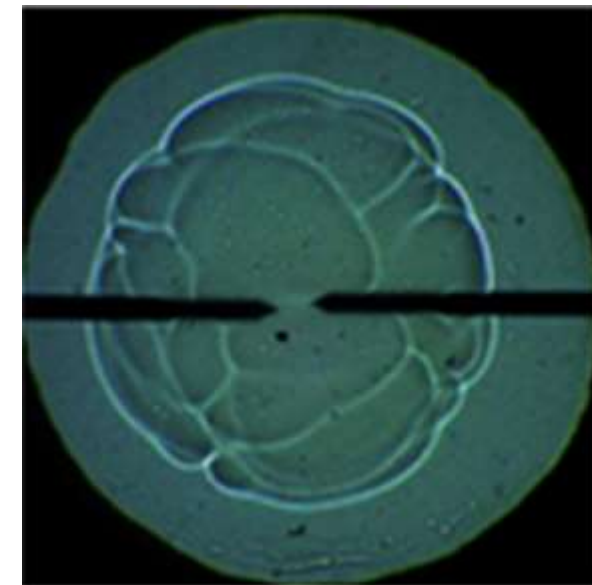
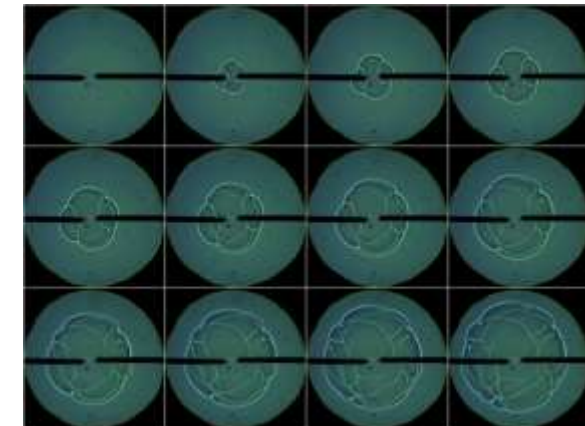
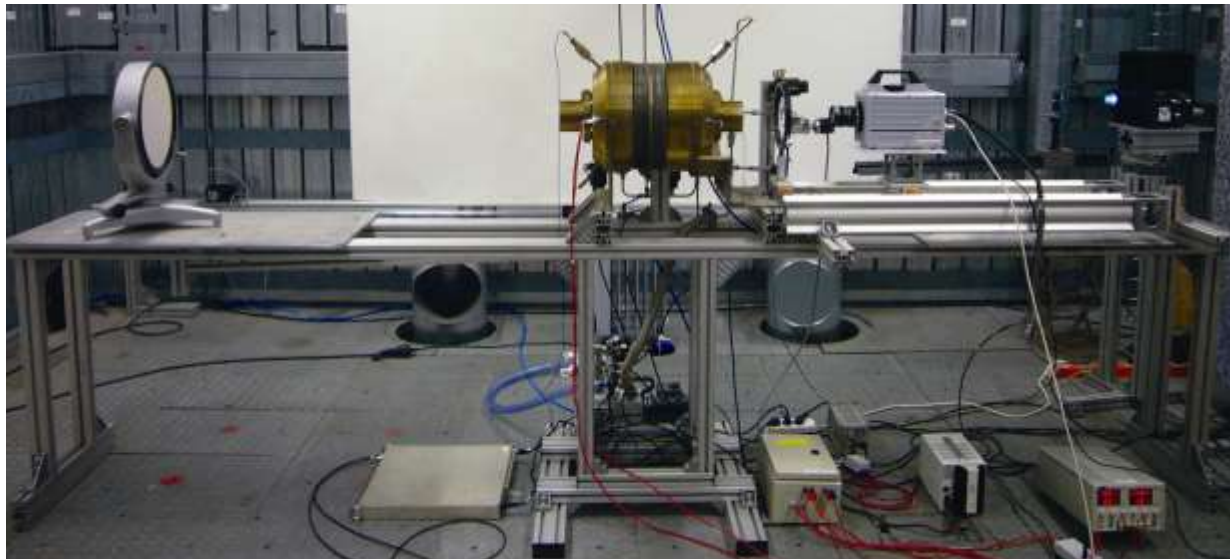
- 5 KW flood light
- Recording plane
- (wood, painted in white)
- Fast Cam SA 1

Digitally processed →
Subtraction of background images

Software: ImageJ

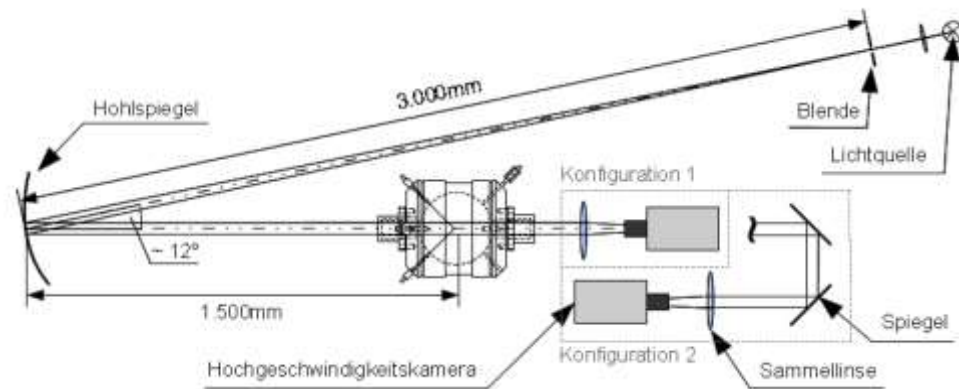
(pressure wave visualization)

Setup for shadowgraph with optical components (parallel light)



50 mm

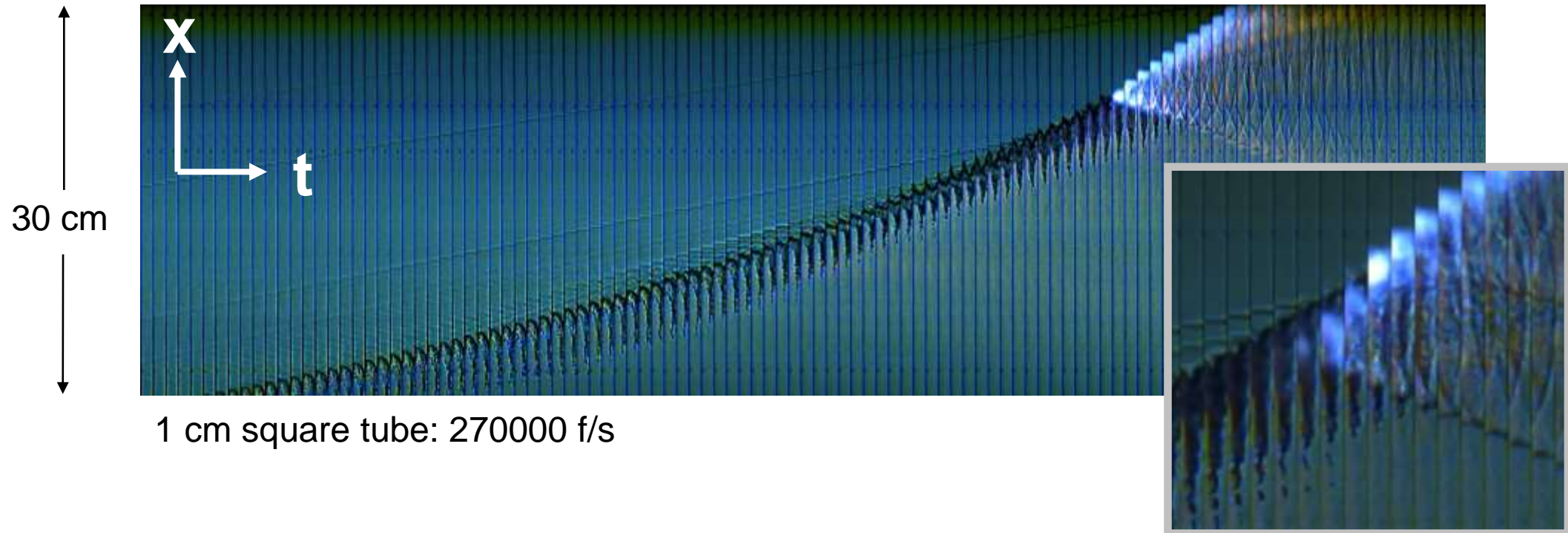
Combustion 12 % H₂ in air



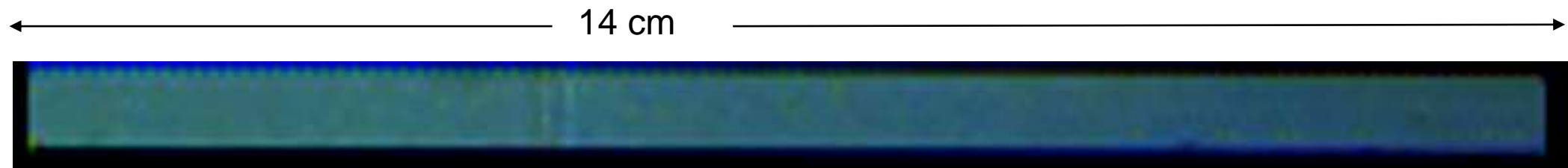
- 100 W point light source
- Concave mirror (30 cm) and optical lens
- Fast Cam SA 1

Setup for shadowgraph with optical components (parallel light)

Example: DDT initiation by shock wave (H_2/O_2).



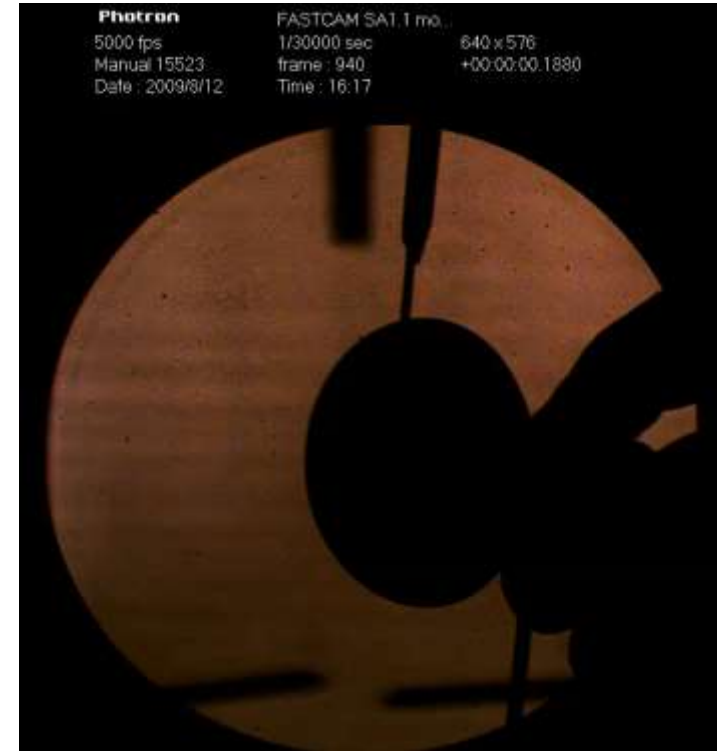
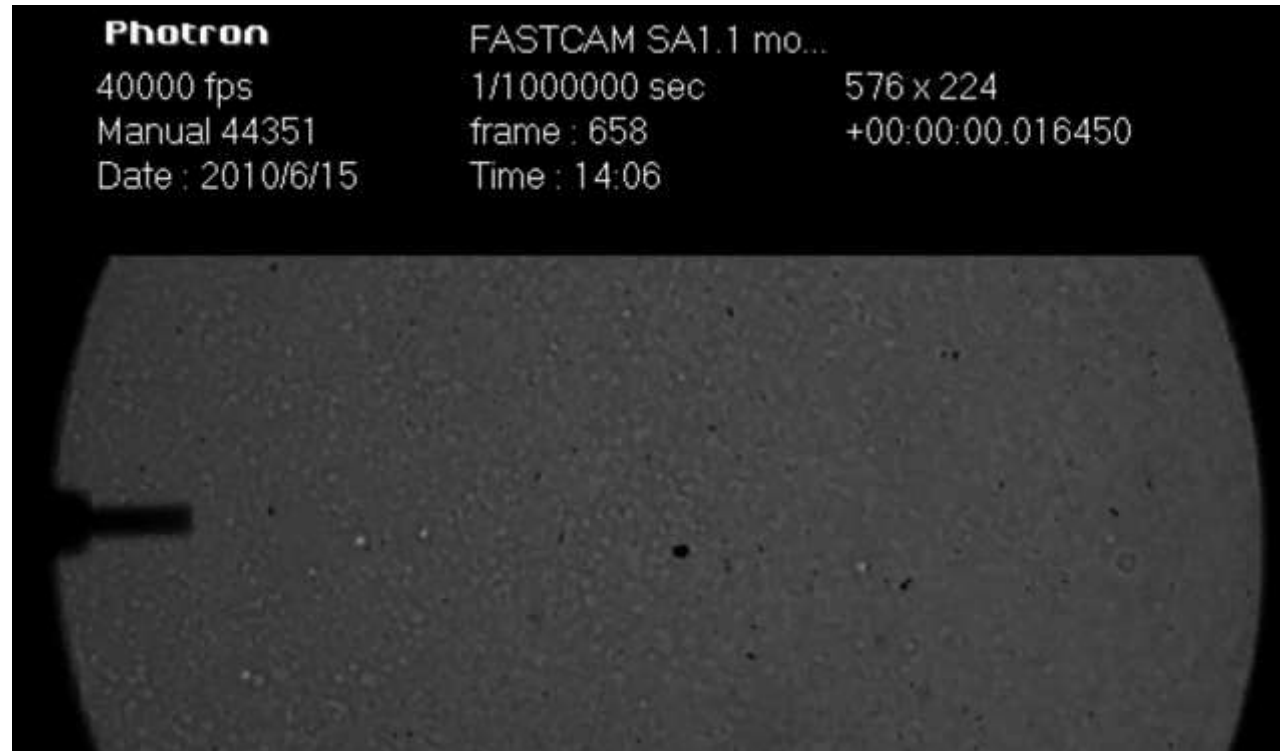
Example: DDT in 1 cm square tube: 540000 f/s



- 100 W point light source
- 2 x Concave mirror (30 cm)
- Fast Cam SA 1

Setup for shadowgraph with optical components (parallel light)

Example: H₂ release in air

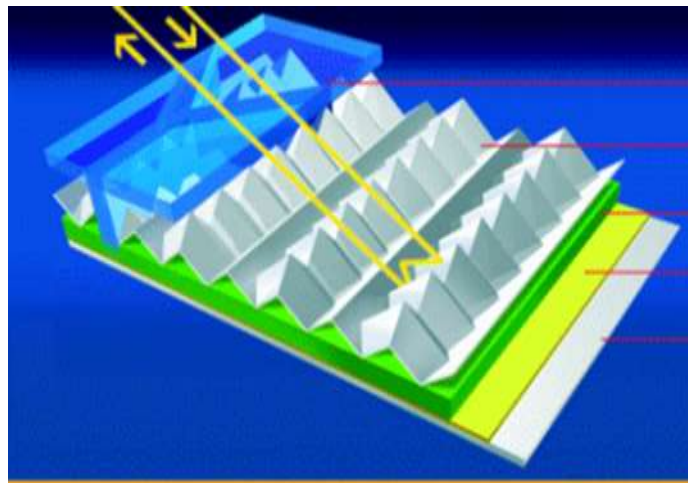
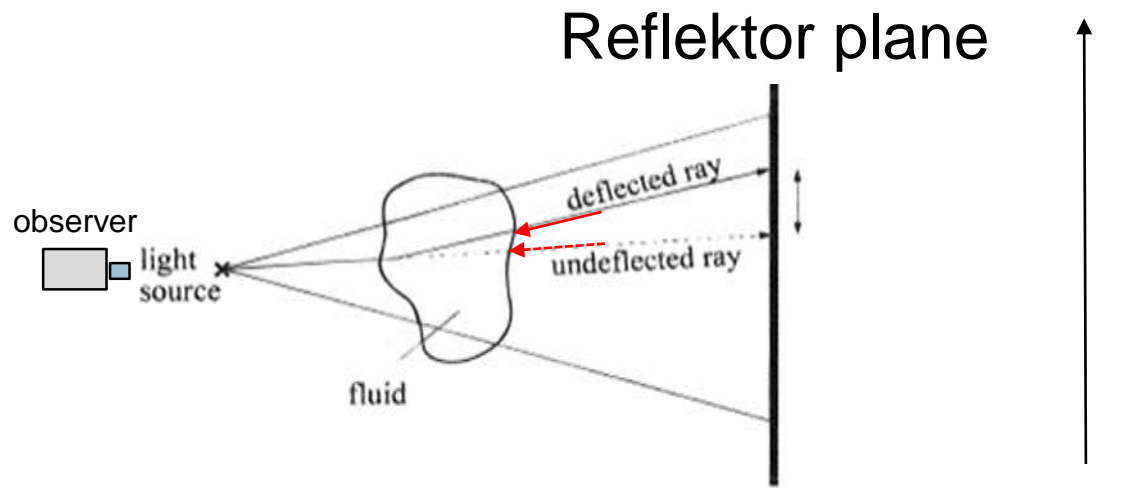


← 30 cm →

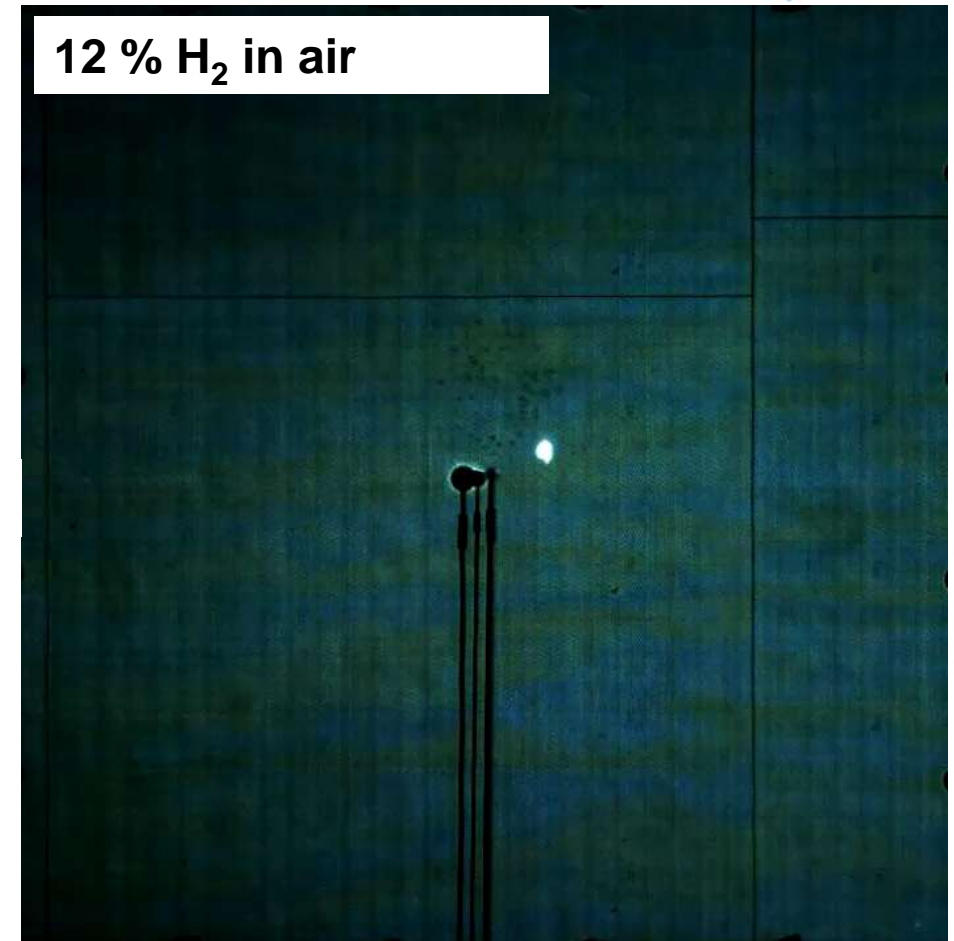
Limitation scale size: devices for parallel light.

Limitation recording velocity: performance of the high speed camera.

Setup for shadowgraph with optical components (reflector plane)



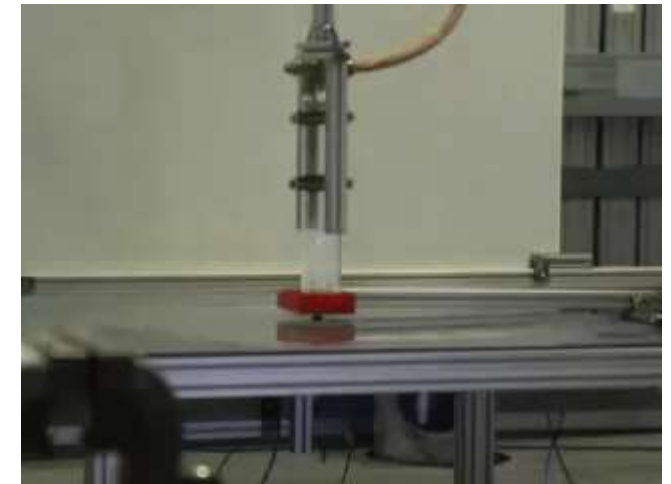
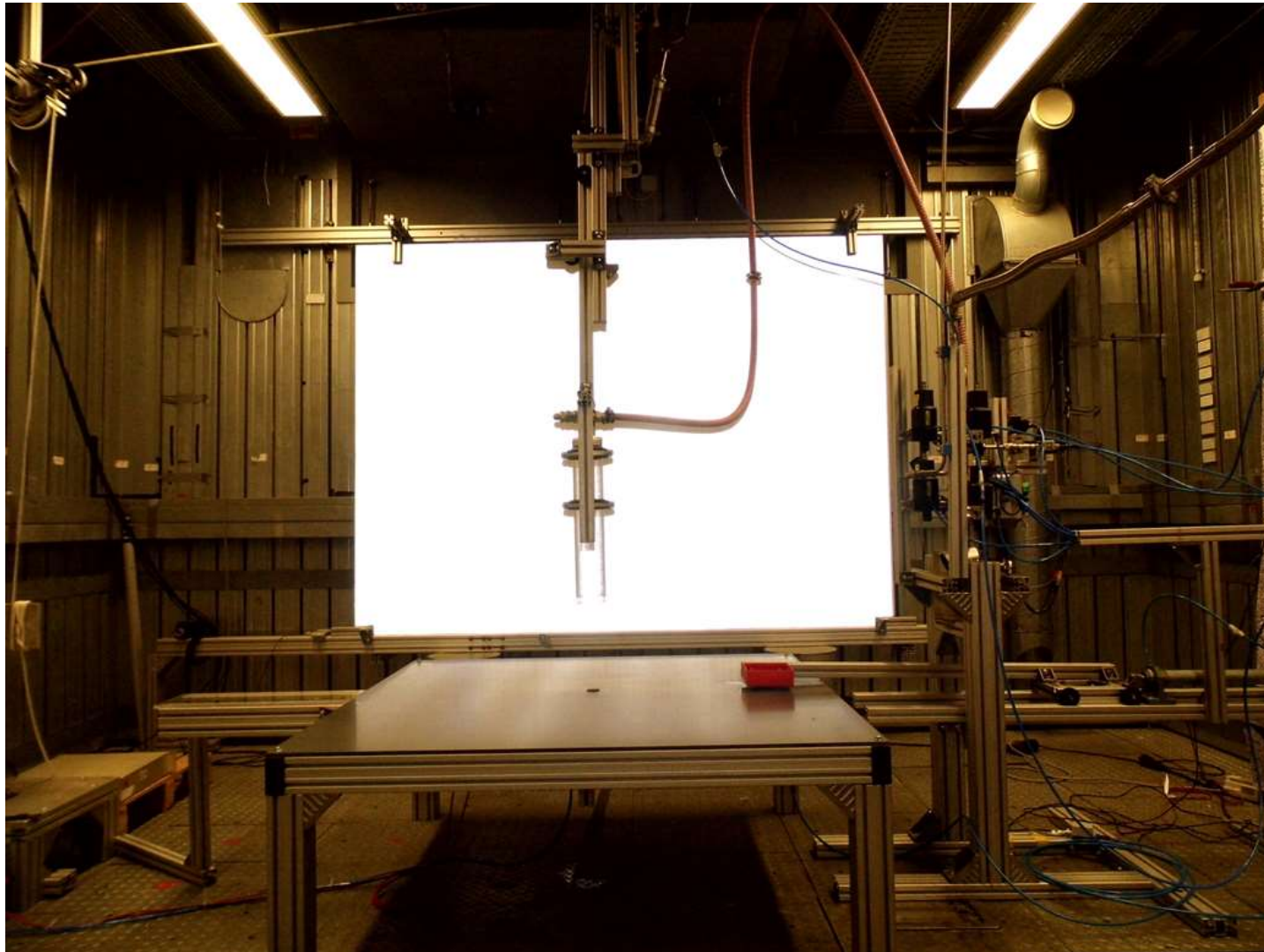
Reflektor plane



Road sign

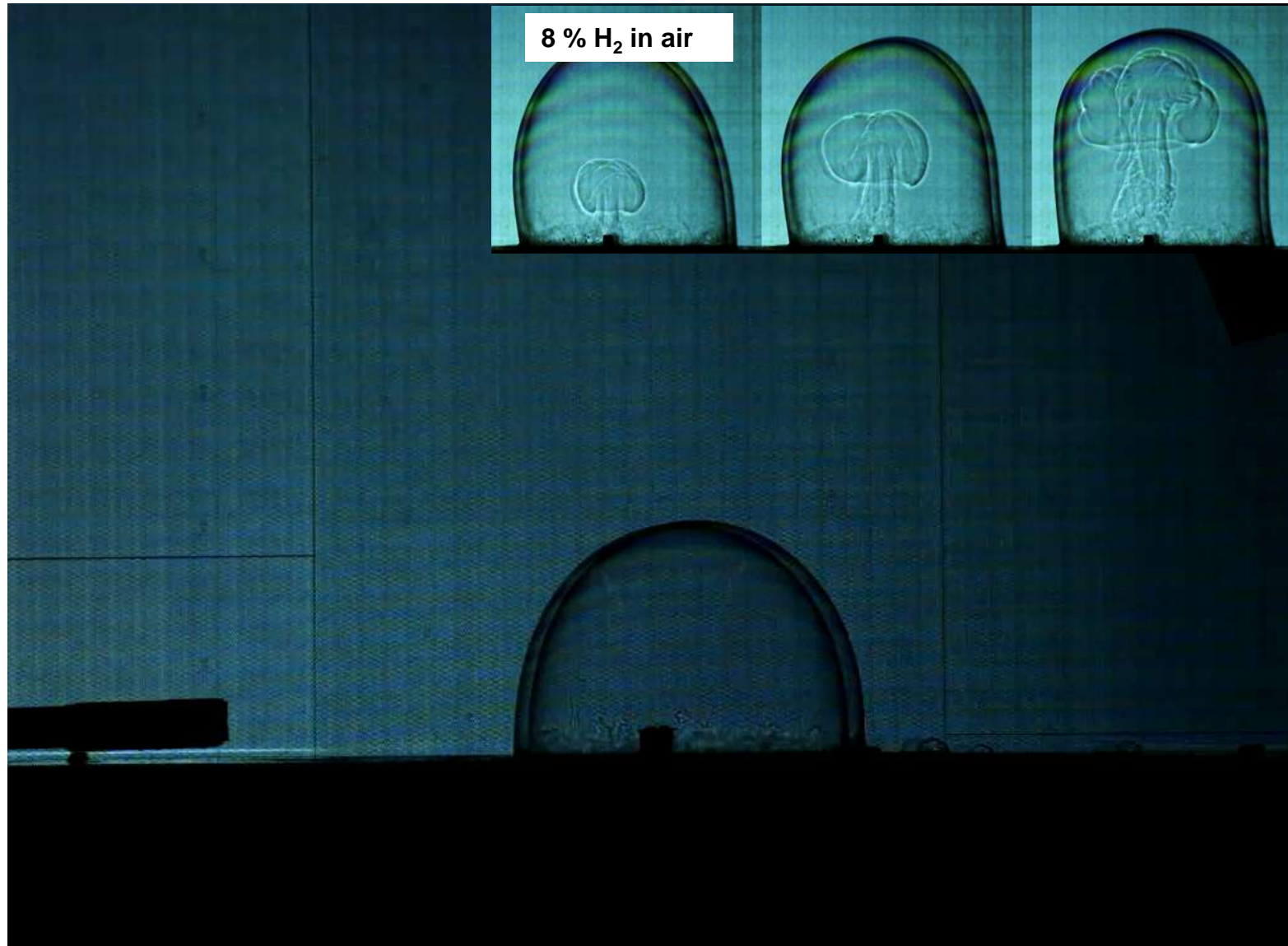
- 100 W point light source
- Recording plane: reflecting foil-coated
- Fast Cam SA 1

Setup for shadowgraph with optical components (reflector plane)



Automatic “soap bubble” machine:

Setup for shadowgraph with optical components (reflector plane)



12 % H₂ in air

Setup for shadowgraph with optical components (reflector plane)



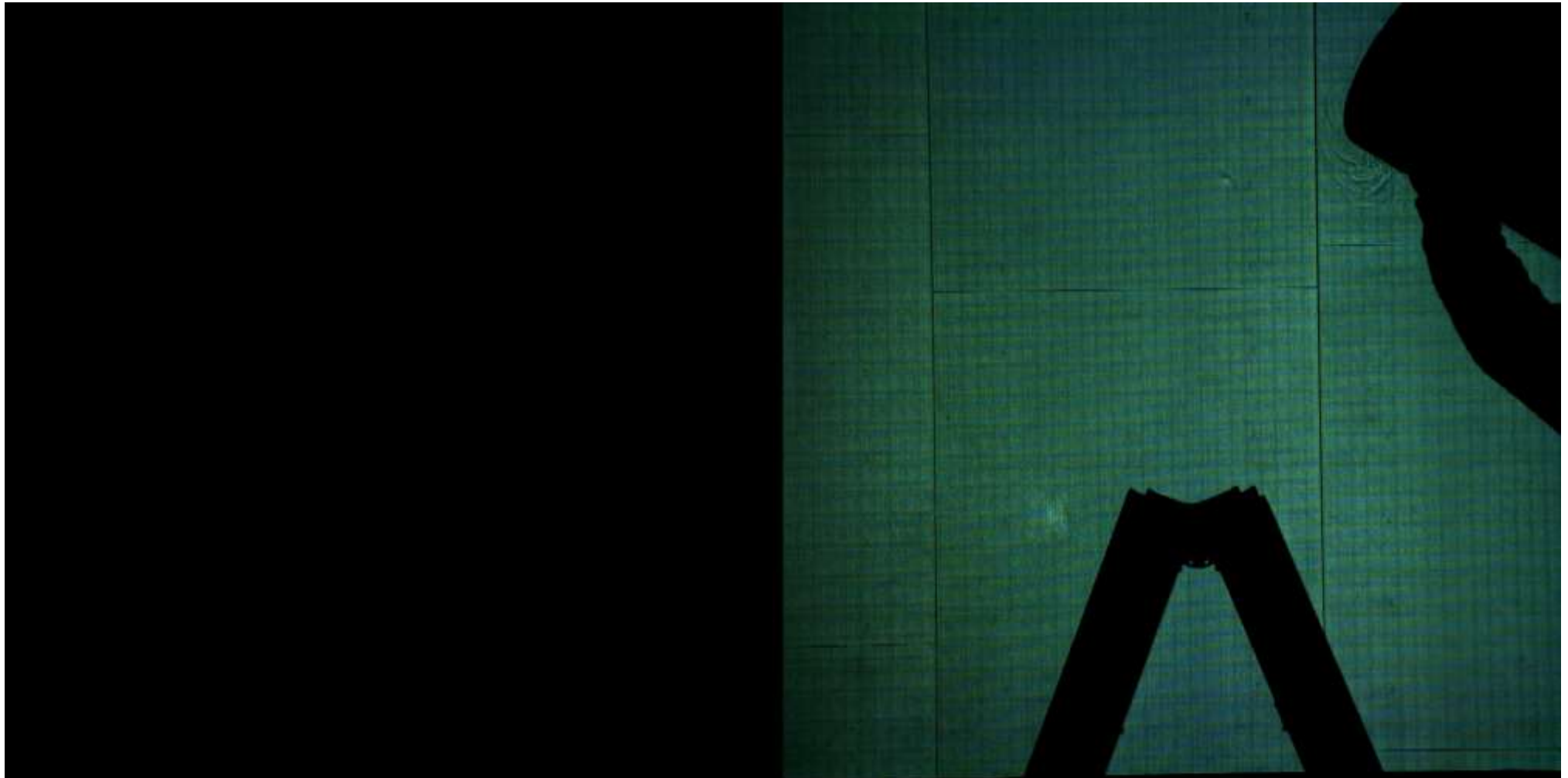
Stoichiometric CH_4/O_2 (device for rapid flame acceleration)

Setup for shadowgraph with optical components (reflector plane)



50 % CH₄/ 50 % O₂

Possible live performance: Flow air (- 15°C) in air (20°C)



Digitally processed
Subtraction of background images
Software: ImageJ

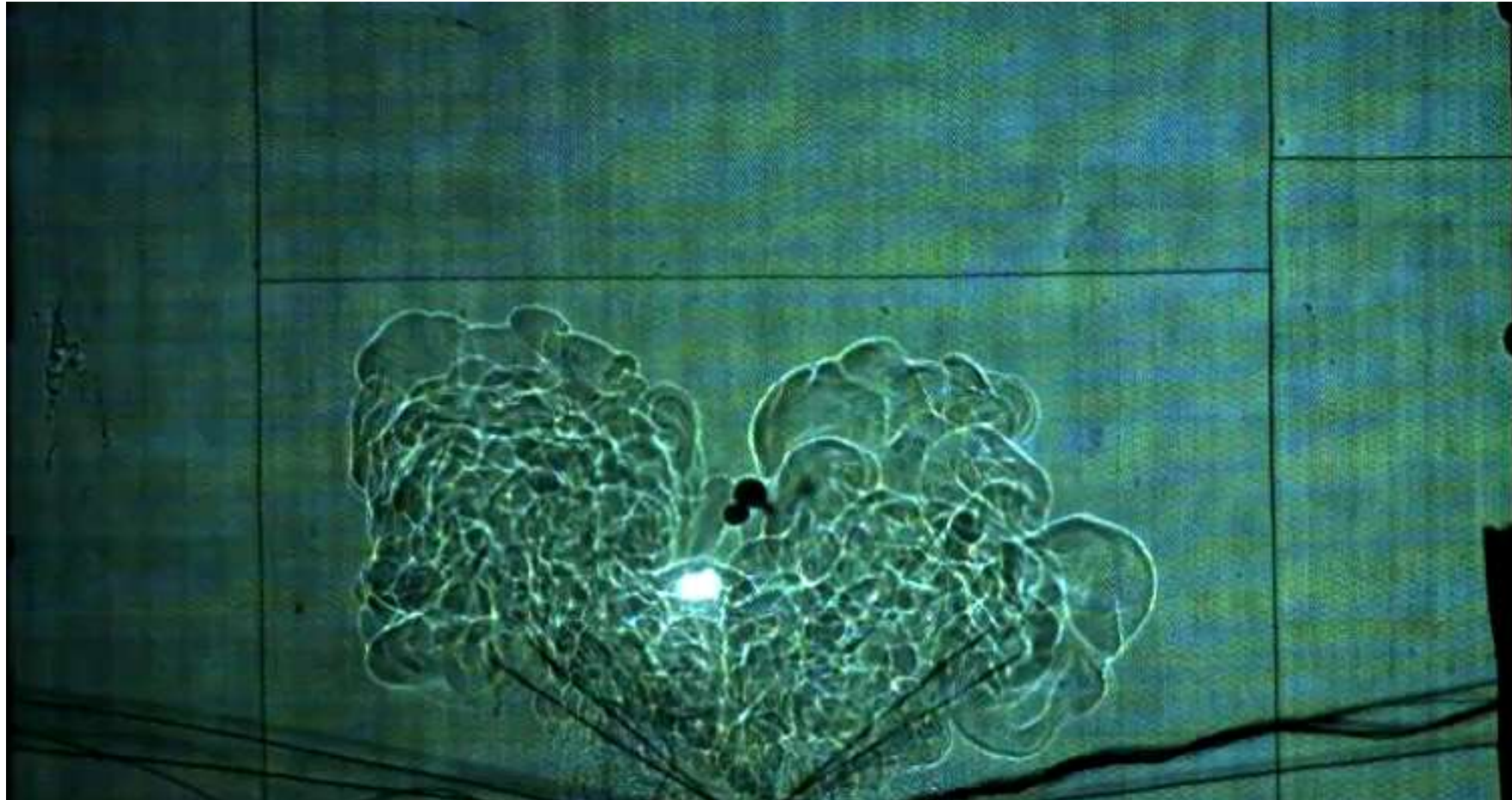
Original shadow

Conclusions

Shadowgraph is a usable and simple type of flow visualization.

Examples of different high speed applications were presented and discussed.

It is expected that the main limitation of flow visualization of cold gases in ambient air will be gained by humidity. Frozen water or condensed water particles will destroy the transparencies of the media.



Butterfly or night bird?