VISUALISATION OF JET FIRES FROM HYDROGEN RELEASE

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INTRODUCTION

Dominating risks of hydrogen jet fires beneath pressure effects are emerging from:

- Direct contact of the flame and its reacting species
- Dispersion of hot gases
- Radiation (for remote distances)

Therefore the presented work fokuses on time resolved investigation of

- Explosive Volume
- Ignition behaviour
- Pressure wave propagation & speed
- Flame lengths & velocities

INTRODUCTION

- Evaluation of joint experiments at HSL (Buxton, UK) in 2008 under the work programme of **HySafe**
- HSL provided within HYPER Project:
  - Test facilitiy for Hydrogen Jetfires and Ignition
  - Pressure measurements
  - Video analysis
- Fraunhofer ICT applied:
  - Spectroscopic & Imaging Techniques

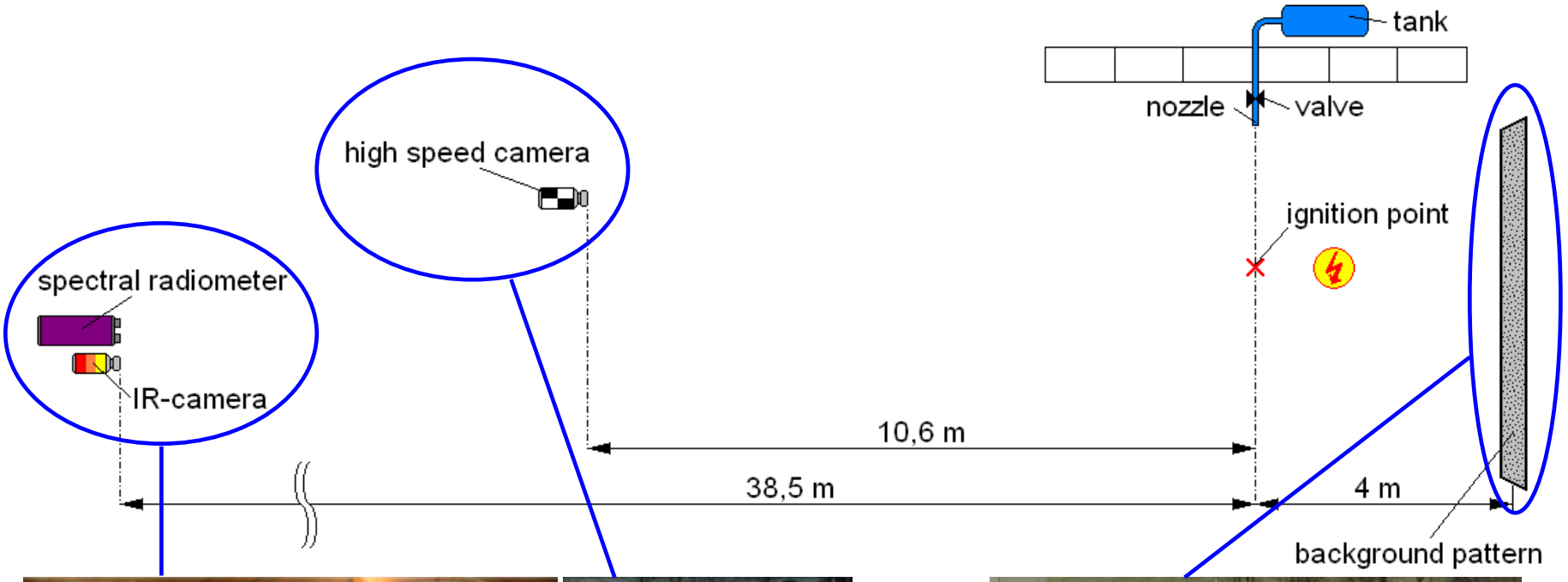
Measurement equipment applied by ICT

HIGH SPEED VIDEO CAMERA (VISION RESEARCH, PHANTOM V9)
Framerate: 1000 fps (full frame)
Resolution: 1200 x 1630 Px

SPECTRAL RADIOMETER (ICT, based on circular variable filters)
Spectral range: 1.6µm to 14.5µm
Scanrate: 100 scans/s

HIGH SPEED IR CAMERA (CEDIP, ORION with ICT wheel module)
Spectral range: 1.5µm to 5.3µm
Framerate: 384 fps (at full frame size 320 x 256 Px)
Wheel mode: 400 frames in four selected ranges (each 100 Hz)

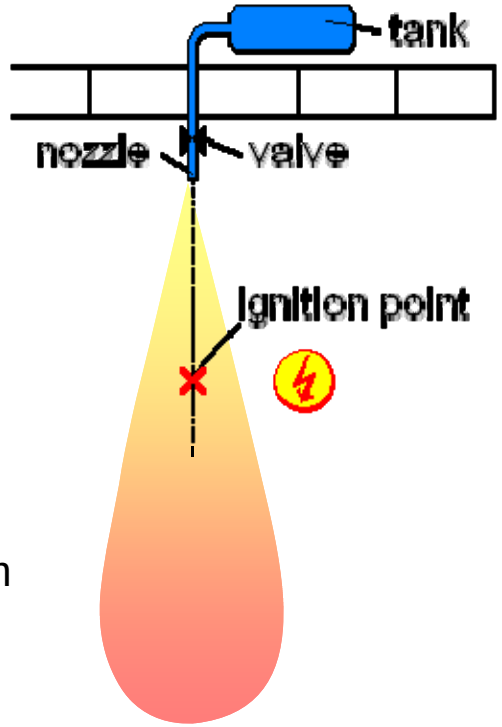
SKETCH OF THE EXPERIMENTAL SETUP



TEST PARAMETERS

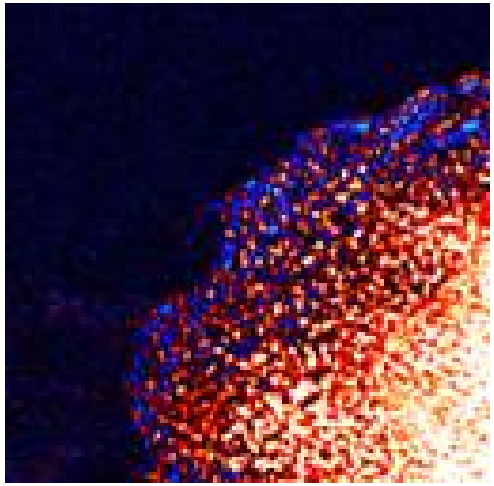
The campaign consists of 23 jet experiments

- Tank Volume 100l (2x50l)
- Initial tank pressure 20 MPa
- Nozzle diameters 1.5 / 3.2 / 6.35 / 10 mm
- Initial mass flow 40 / 160 / 450 / 670 g/s
- Ignition Point 160 / 220 / 250 / 300 / 400 cm behind orifice
- Ignition delay various



Methods of Image Analysis (1) Grey value subtraction

A fast method to visualize changes is the digital subtraction of grey values for each pixel from the previously taken or another reference frame

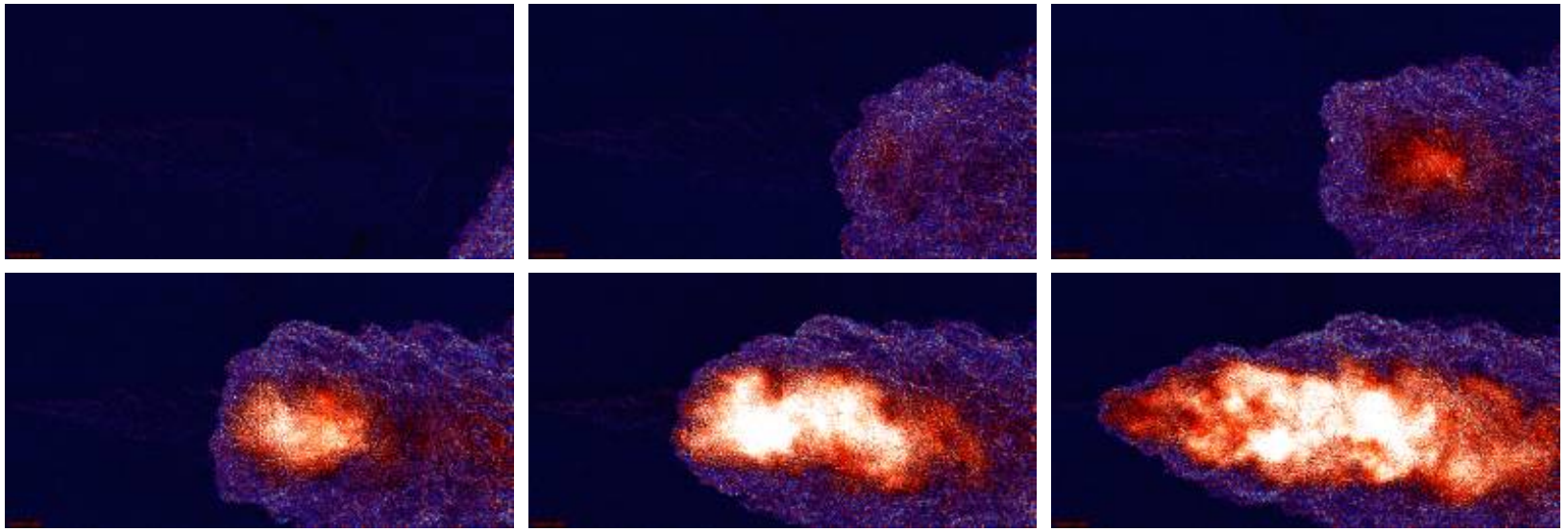


- Brightness difference magnitude scaled from
  low: dark
  high: bright
- brightness differences indicated by colours
  darker: blue color
  brighter: red color

  → enhanced contrast

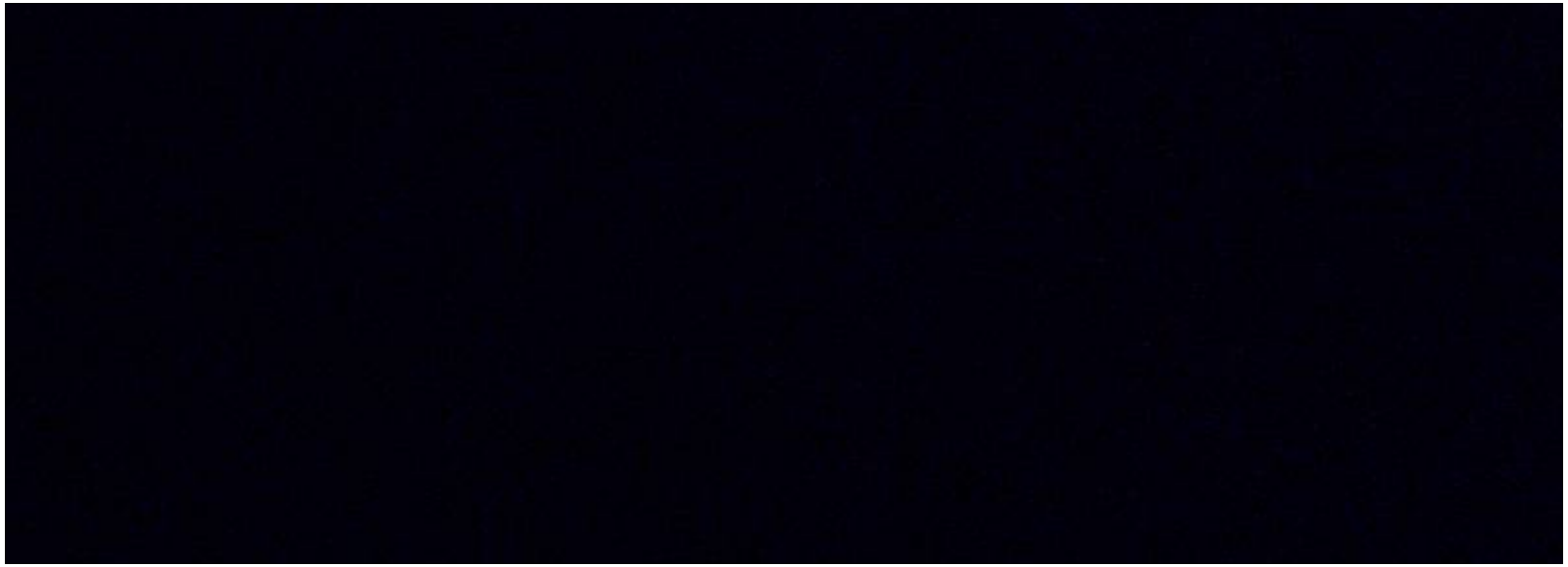
→ Only visualisation possible due to floating scale

Grey value subtraction Example 1



- Experiment HYPER 12, 1.5mm Orifice, 40g/s Initial flow
  brightness difference to frame 1 computated

Grey value subtraction Example 1



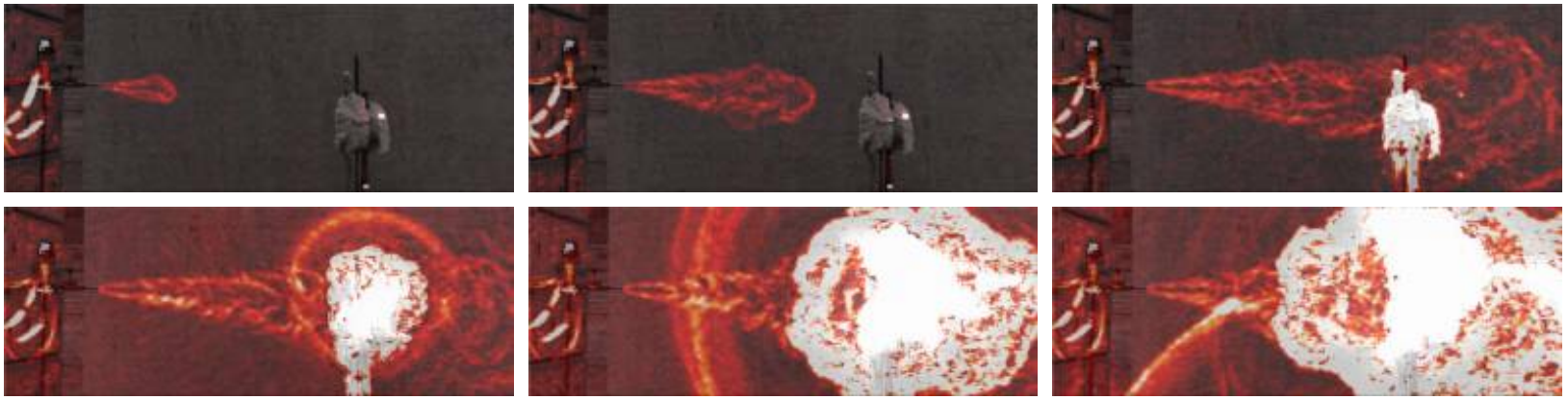
- Brightness difference to frame 1
- Experiment HYPER 13, 3.2mm Orifice, 160g/s Initial flow

Methods of Image Analysis (2)

A more sophisticated method is the Background Oriented Schlieren-method to visualize density gradients in flow fields.

- Original Frame
- Experiment HYPER 6, 6.35mm Orifice, 450g/s Initial flow

Background Oriented Schlieren



Results are:

- Explosive Volume (before ignition)
- Flame speed / Flame dimensions
- Pressure wave speed & shape

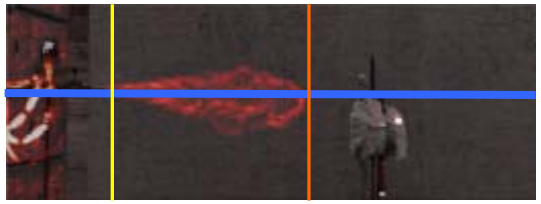
Background Oriented Schlieren

Results are:

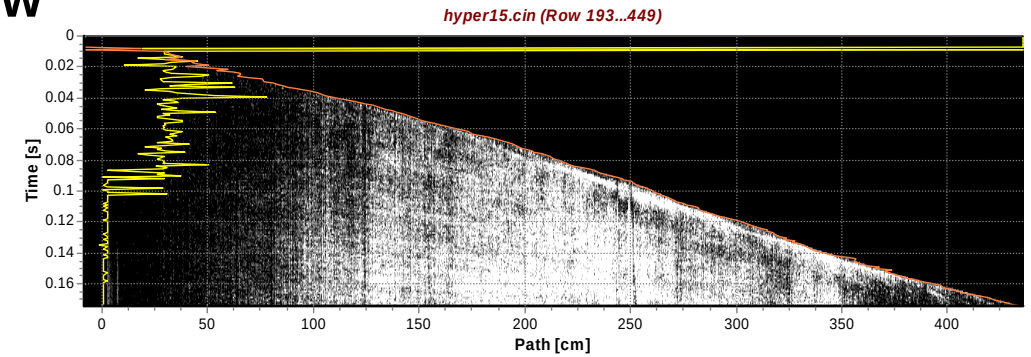
- Explosive Volume (before ignition)
- Flame speed / Flame dimensions
- Pressure wave speed & shape

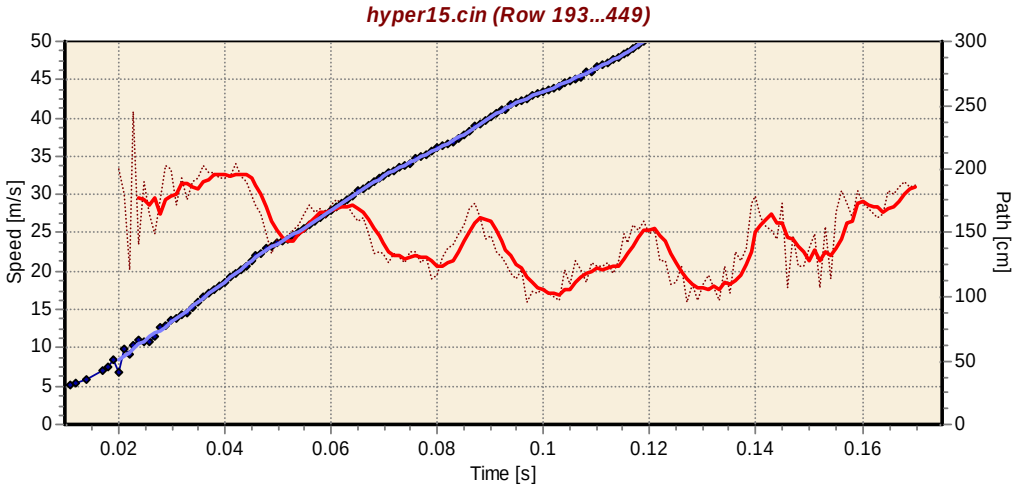
1000ms RT, Replay 4% / 1% RT

Velocitiy of cold gas flow



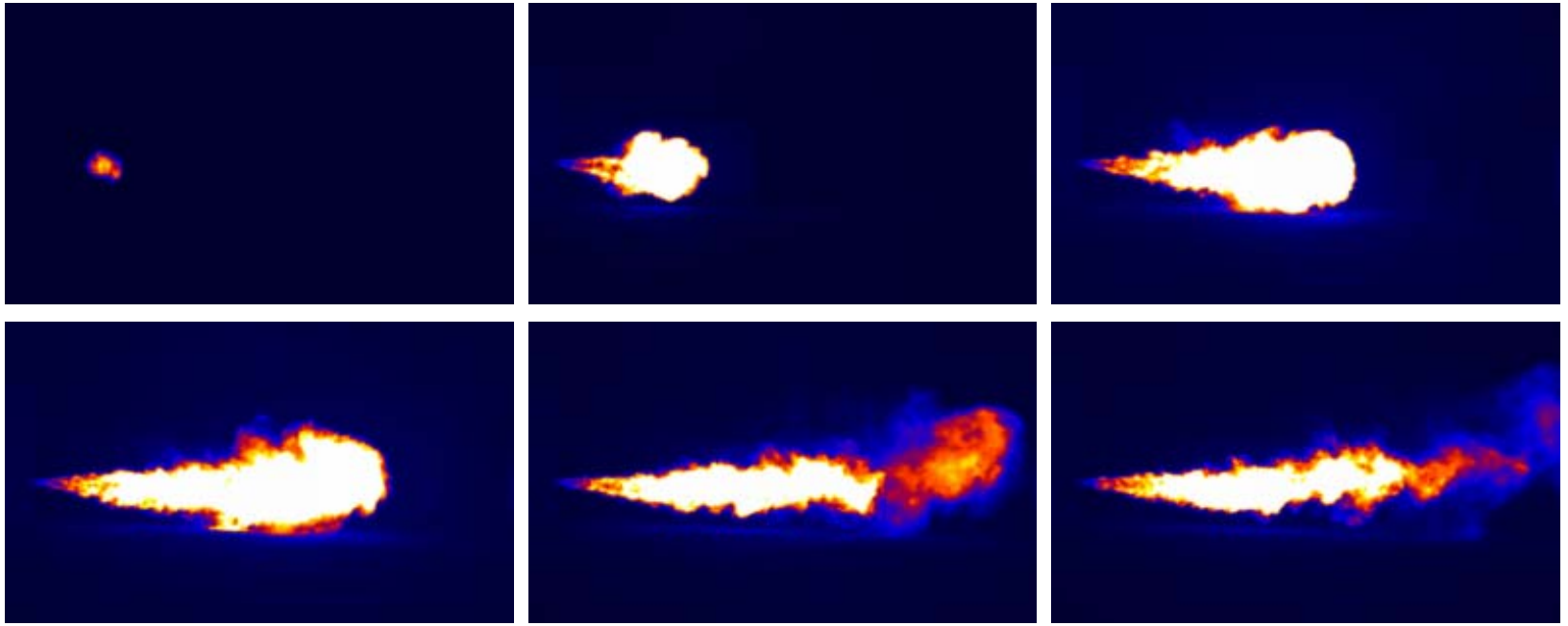
Centerline of each frame





- gas flow propagation
- Speed of flow
- Speed of pressure / shock waves can be evaluated using the same method

Infrared Imaging



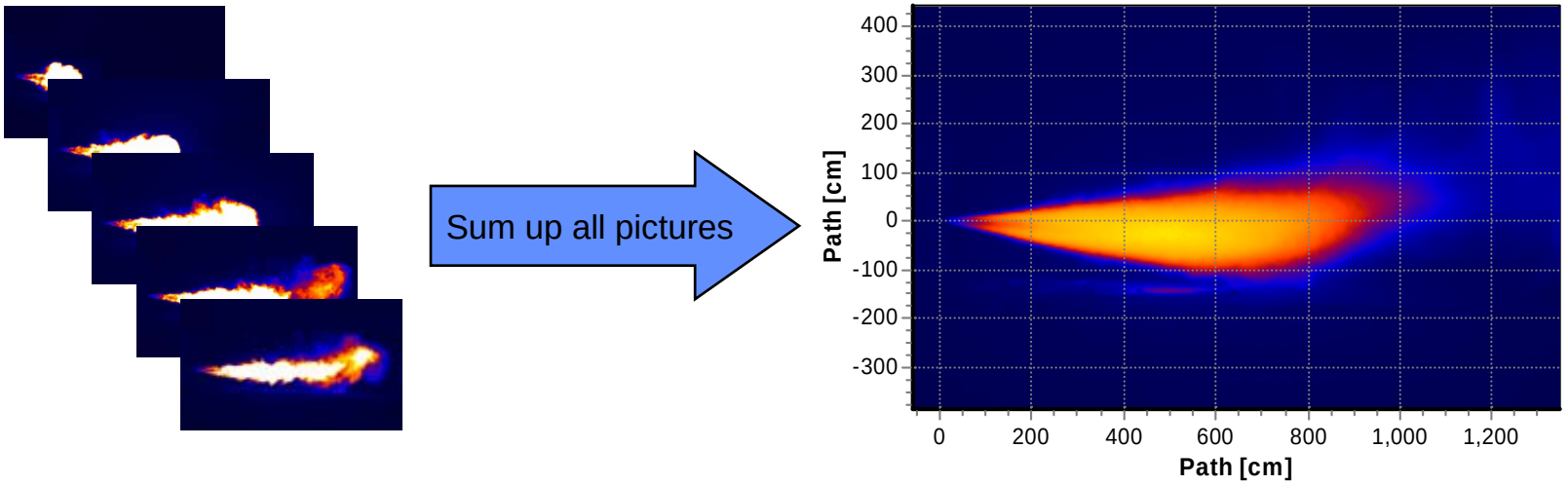
- Experiment HYPER 12, Filter 4, calibrated
  10mm Orifice, 670g/s Initial flow

Infrared Imaging

1000ms RT, Replay 4% / 1% RT

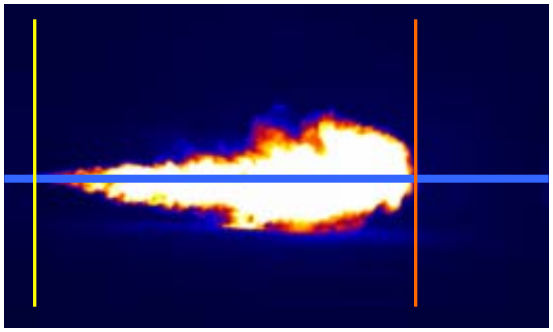
- Example for Filter Range 4
- Experiment HYPER12
  10mm Orifice
  670g/s Initial gas flow
- All others similar

Data Analysis / Results

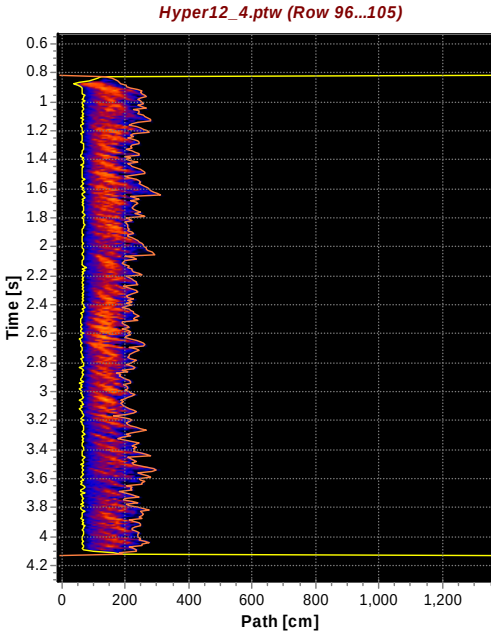


- Overall Radiation of the flame
- Seperately in four Spektral Ranges: 1.5-2.5 / 3.0-3.9 / 3.0-5.0 / 4.1-5.3µm

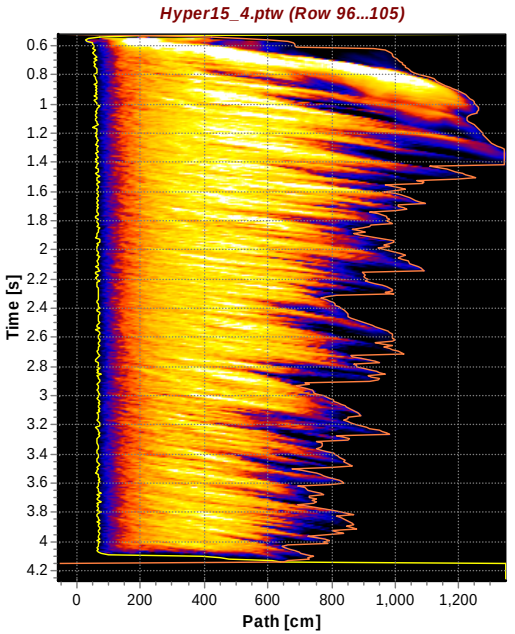
Data Analysis / Results



Centerline of each frame
Averaging 10 rows



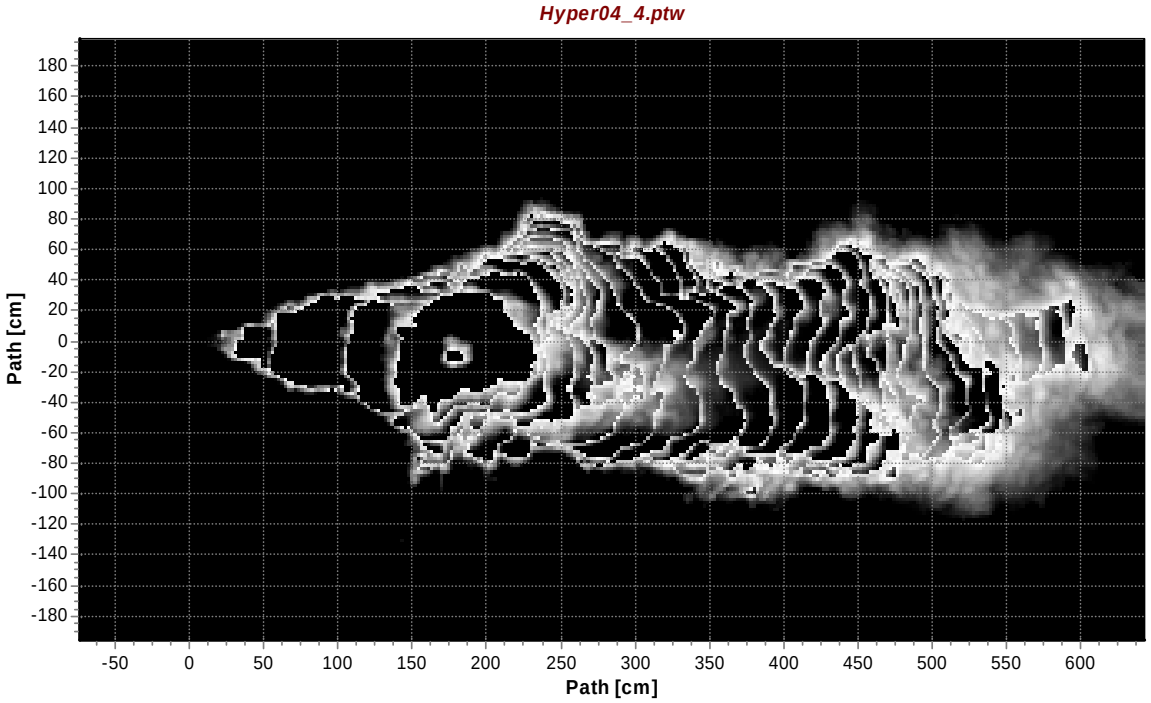
HYPER12 1,5mm / 40g/s



HYPER15 10mm / 670g/s

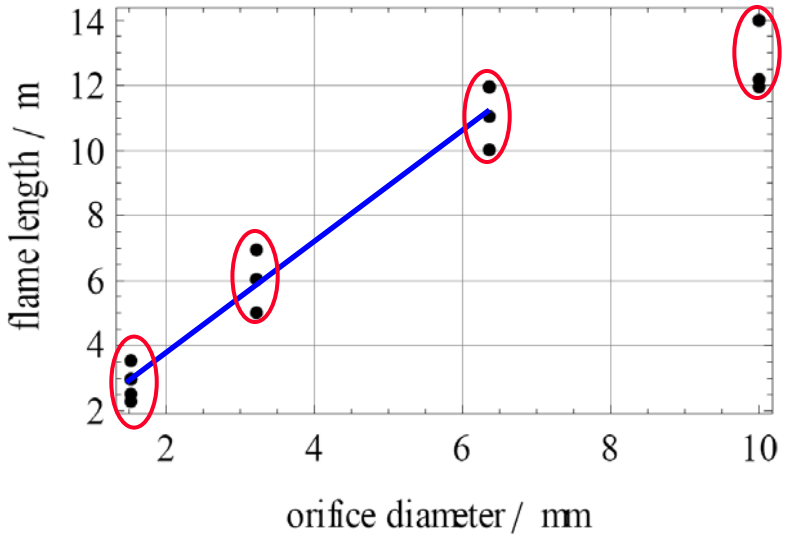
- Flame length development

Data Analysis / Results

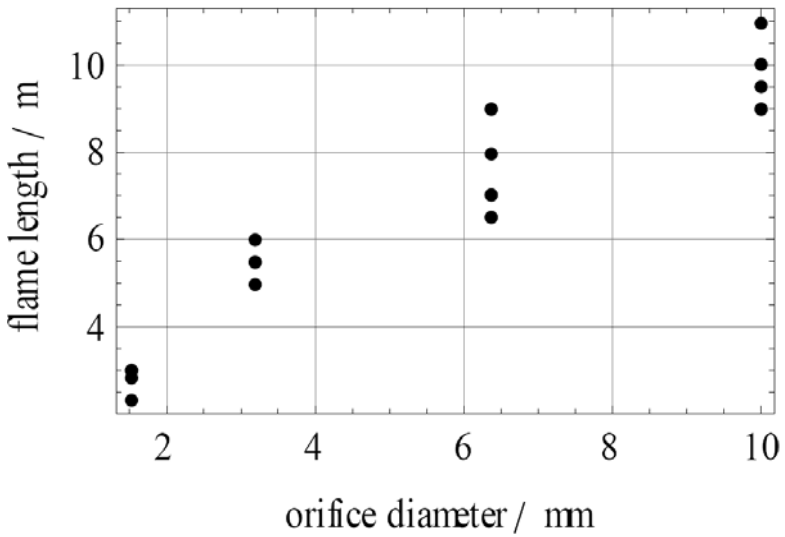


- Example for Flame Propagation Map
- Experiment HYPER4
  3.2mm Orifice
  160g/s Initial gas flow
- All regions of highest radiation gradient stacked, Ignition on top

Averaged flame lengths vs. orifice diameter



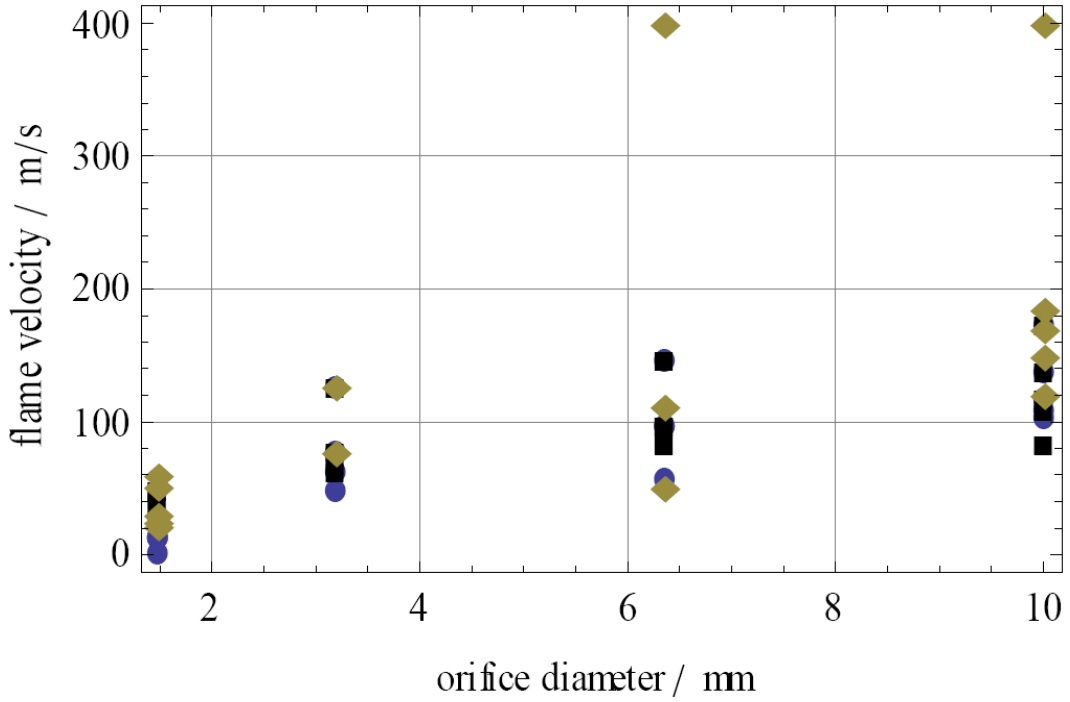
Shortly after Ignition



after 4-6 Seconds

- Proportional increase of flame length with orifice diameter for smaller diameters
- Large scatter of ±1m in flame length

Averaged apparent flame velocities



- upstream (Start)
- downstream
- Downstream Averaged

CONCLUSION

- Image analysis techniques enable a detailed visualisation of hydrogen jets and jet flames
- The unreacted hydrogen release jet cone shows a half angle of 8-10°, while in burning condition the half angle increases to 16-20°
- Flame length depends on the flow rate and reached a maximum length of 12 m in the tested configuration
- Flame velocities after ignition exceed more than 100m/s,
  2 of 23 reached 400m/s

OUTLOOK

- Zone of explosive Mixture
- Flame Dimensions
- Pressure & Shock Wave propagation

BOS, Thermography

- Temperature Field
- Heat flux, spectral resolved

Spectroscopy
Filterwheel Thermography

→ Volker WEISER
Paper 228, Session 13 (Jet2)

Acknowledgements

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THANK YOU FOR YOUR ATTENTION!