Flow Capture®

See the unseen with fast response X-ray system

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Barry Azzopardi Experimental Summer School
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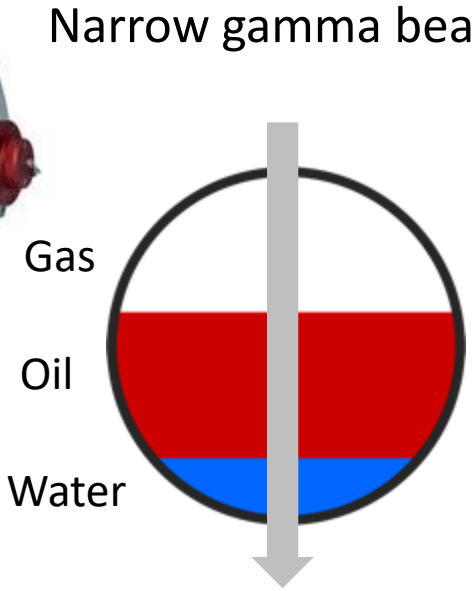
Outline

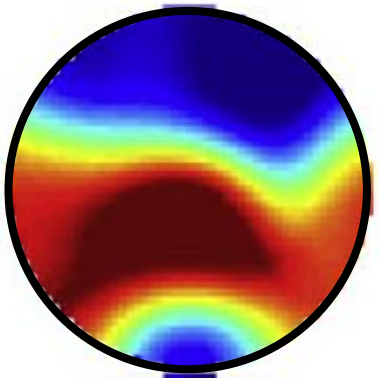
- Introduction to X-rays
- Selected applications and results
  - Large scale pipe flow
  - Channels and other geometry
- Summary

Complex multiphase flow

- Can current instruments capture accurately
  - Complexity of multiphase flows
  - Transient behaviour
  - Detailed hydrodynamics

Challenges of commonly used systems



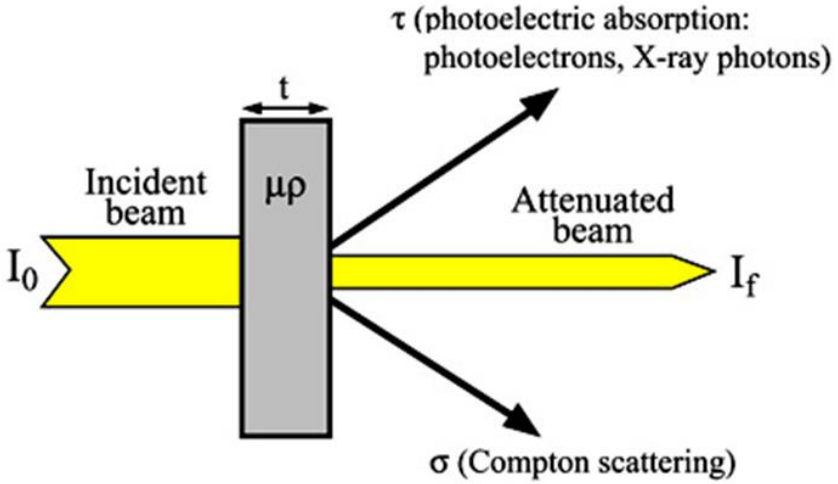


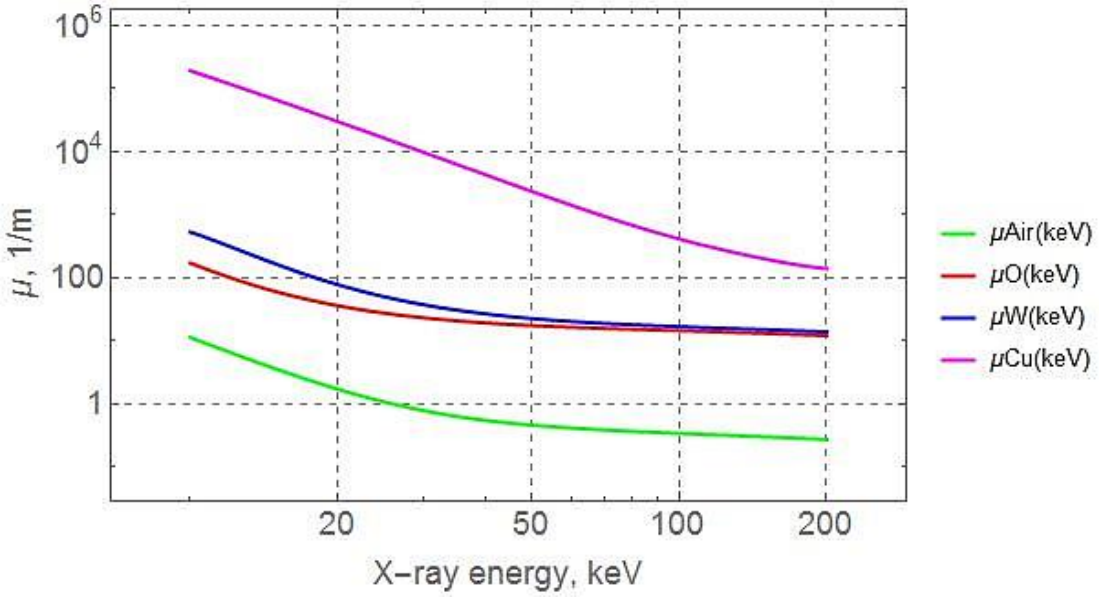
Measurement 66 (2015) 150–160

Gamma meter	ECT/ERT
HSE concern	Minimum HSE work
Cross-section ≠ Centre line	Artefacts in reconstruction
Limited application to 3-phase	Unsuitable for 3-phase flows

Quantitative analysis: principle

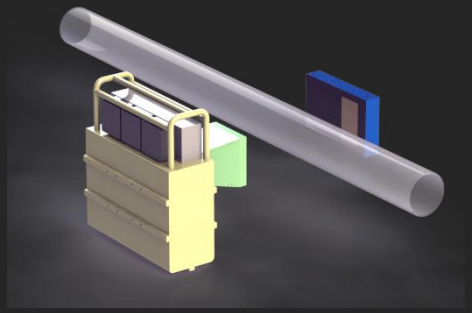
- X-ray attenuates differently for different materials



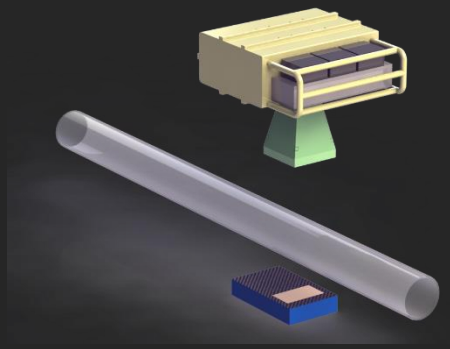


Configurations

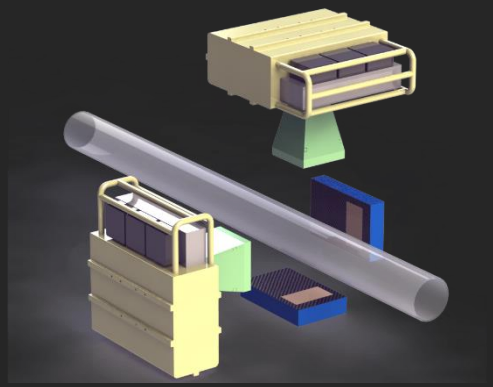
REX-CELL™ 1X



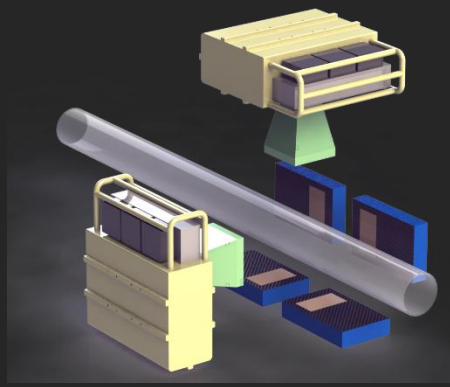
REX-CELL™ 1XV



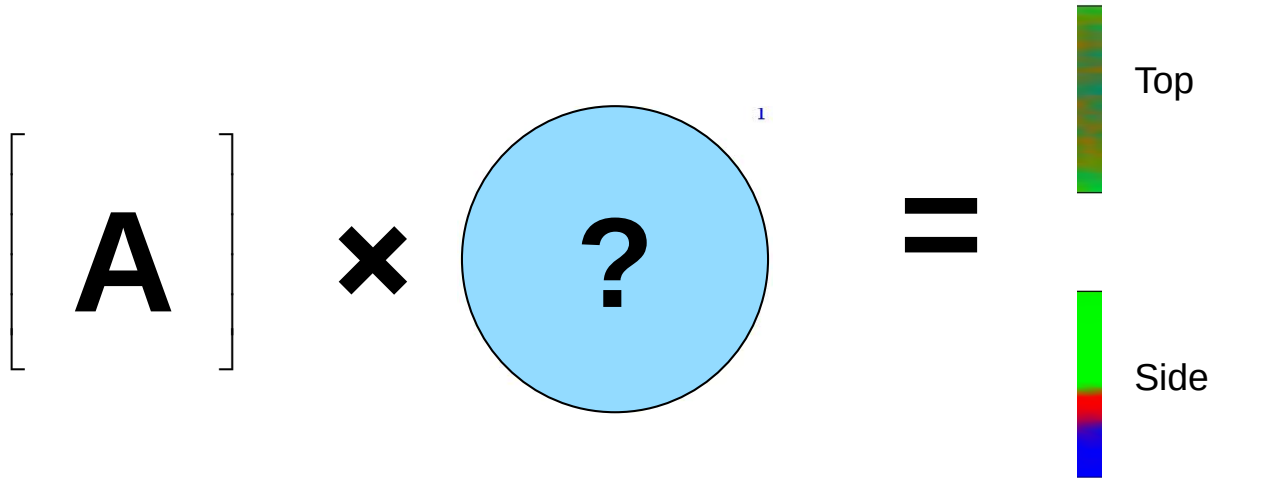
REX-CELL™ 2X



REX-CELL™ 4X



Advanced reconstruction algorithm



System configuration

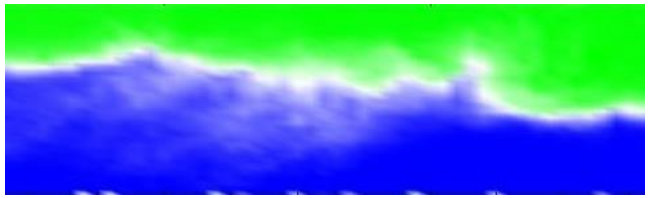
Measurements

Visualise, analyse and quantify flows

- State-of-the-art X-ray system (REX-CELL™)

Fast	Up to **191 fps**
Real-time	Built-in data analysis
High resolution	**75 um/pixel**
Large sensor	**23 cm X 6.4 cm**

High speed video



REX-CELL™

Results and highlights

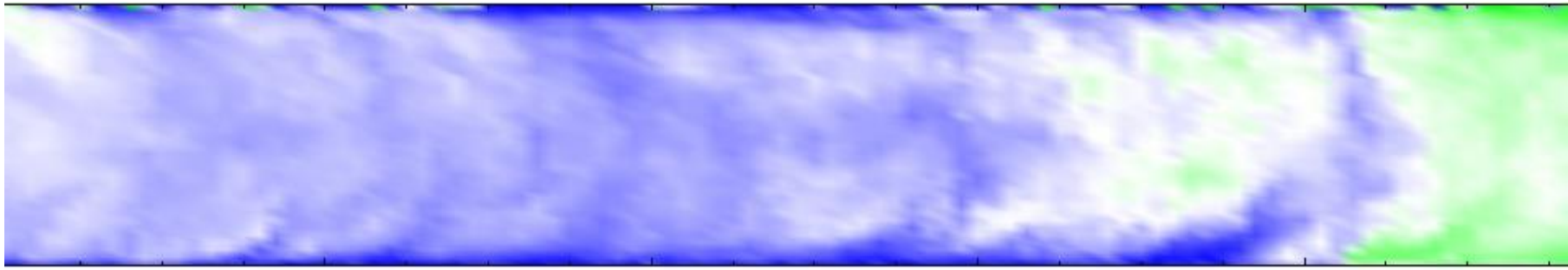
- 2-phase stratified flows
- 2-phase slug flows
- 3-phase flows
- Flows in other geometries

1. Two-phase stratified flows

Surface waves in gas-liquid flows

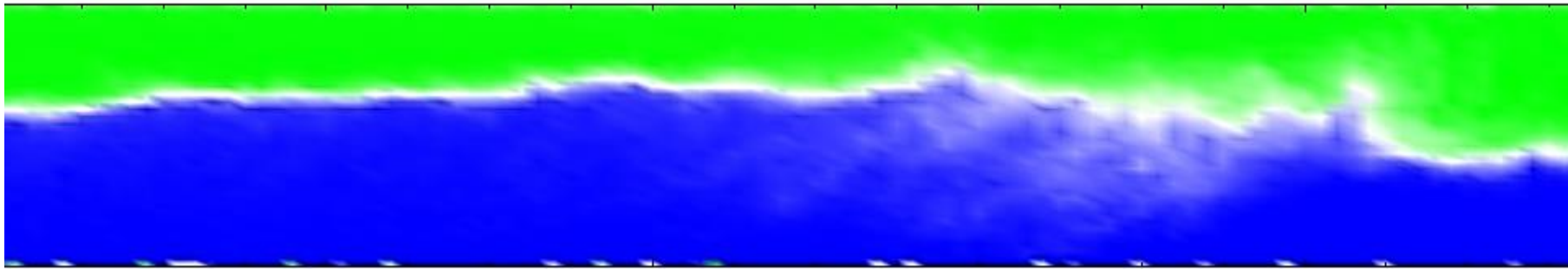
Gas-liquid wavy flows
4-inch ID

Top and side view of waves (140 fps)



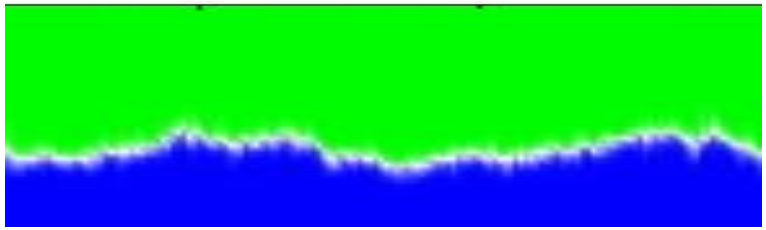
Top view

Flow



Side view

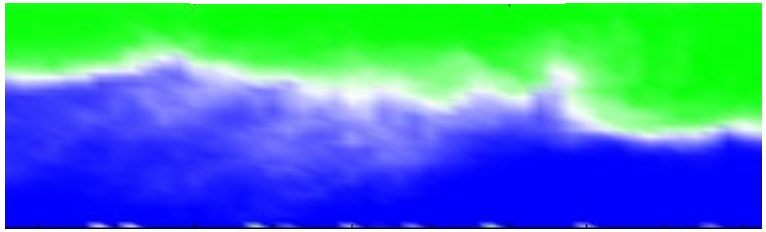
Gas entrainment in the liquid layer



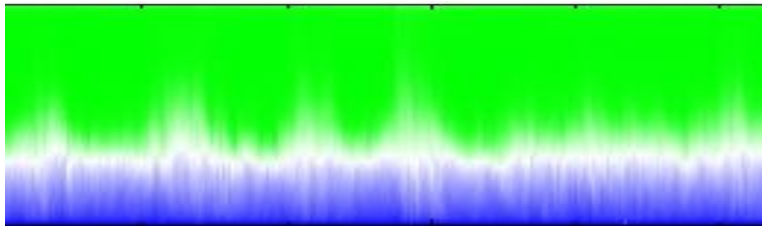
Umix

High speed images

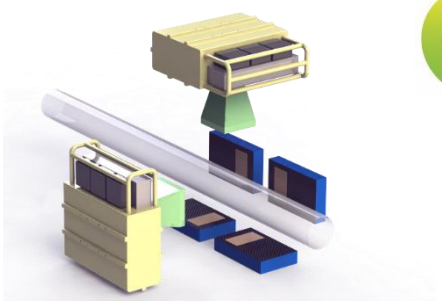
X-ray side view

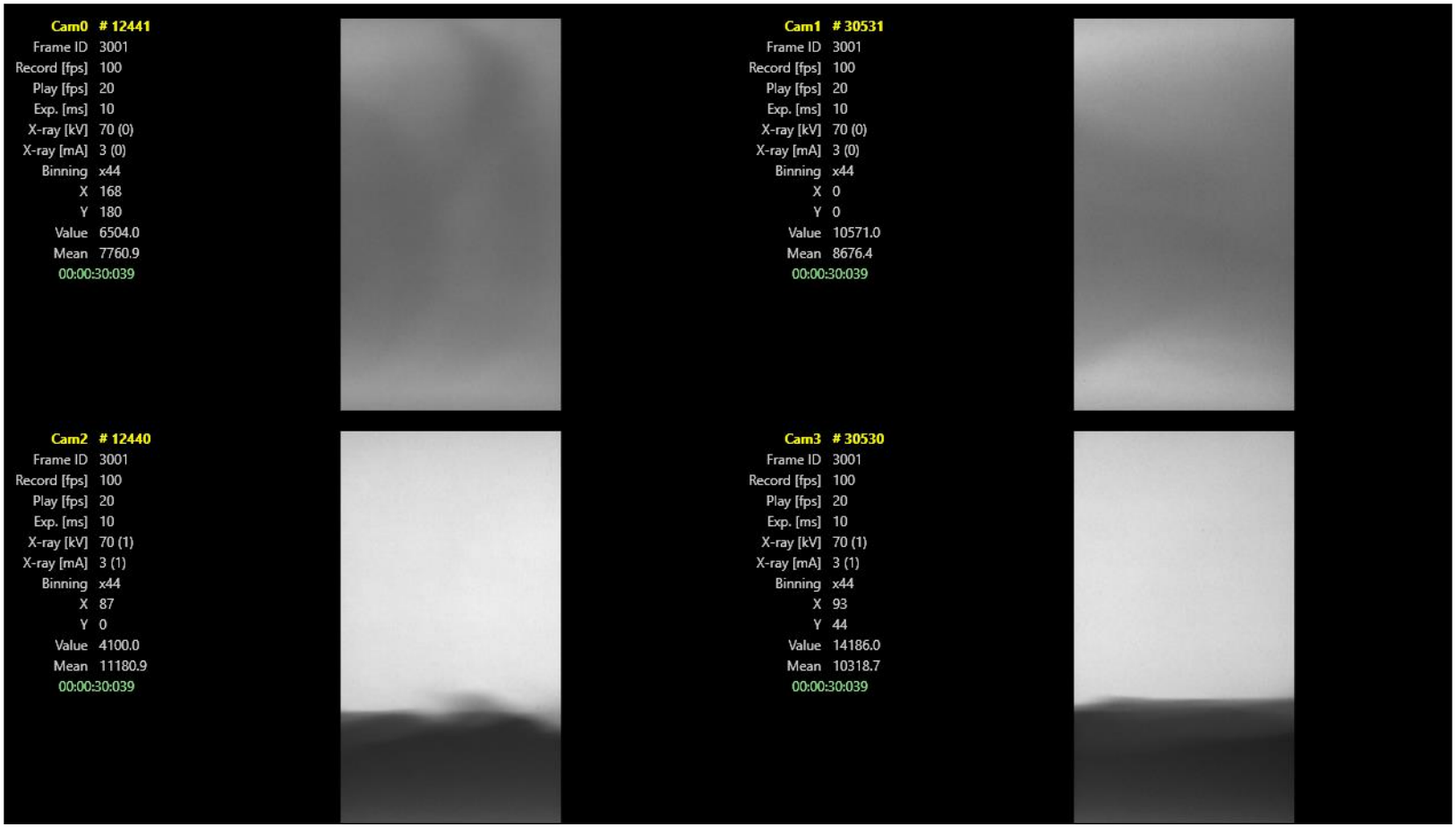


Flow



RE-CELL™ 4X

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Exp. [ms] 10
X-ray [kV] 70 (0)
X-ray [mA] 3 (0)
Binning x44
X 168
Y 180
Value 6504.0
Mean 7760.9
00:00:30:039
Cam1 # 30531
Frame ID 3001
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Exp. [ms] 10
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X-ray [mA] 3 (0)
Binning x44
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Y 0
Value 10571.0
Mean 8676.4
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Cam2 # 12440
Frame ID 3001
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Play [fps] 20
Exp. [ms] 10
X-ray [kV] 70 (1)
X-ray [mA] 3 (1)
Binning x44
X 87
Y 0
Value 4100.0
Mean 11180.9
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Cam3 # 30530
Frame ID 3001
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Exp. [ms] 10
X-ray [kV] 70 (1)
X-ray [mA] 3 (1)
Binning x44
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Y 44
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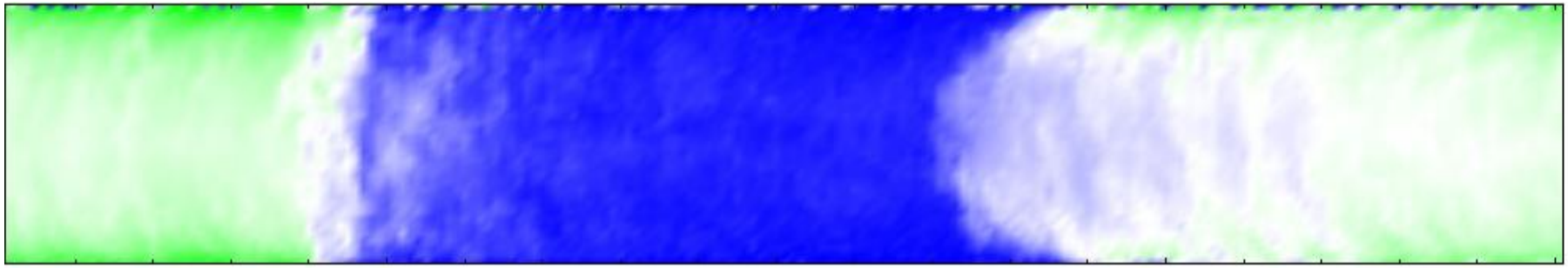
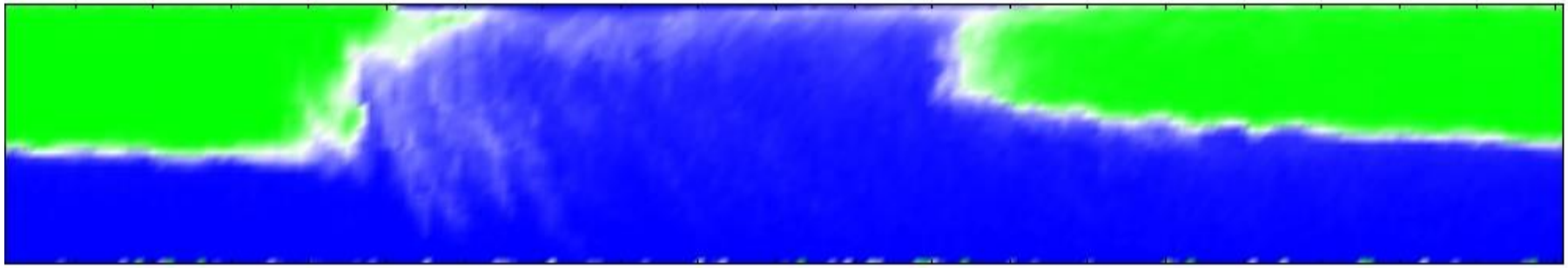
2. Two-phase slug flows

Top and side views of a slug flow



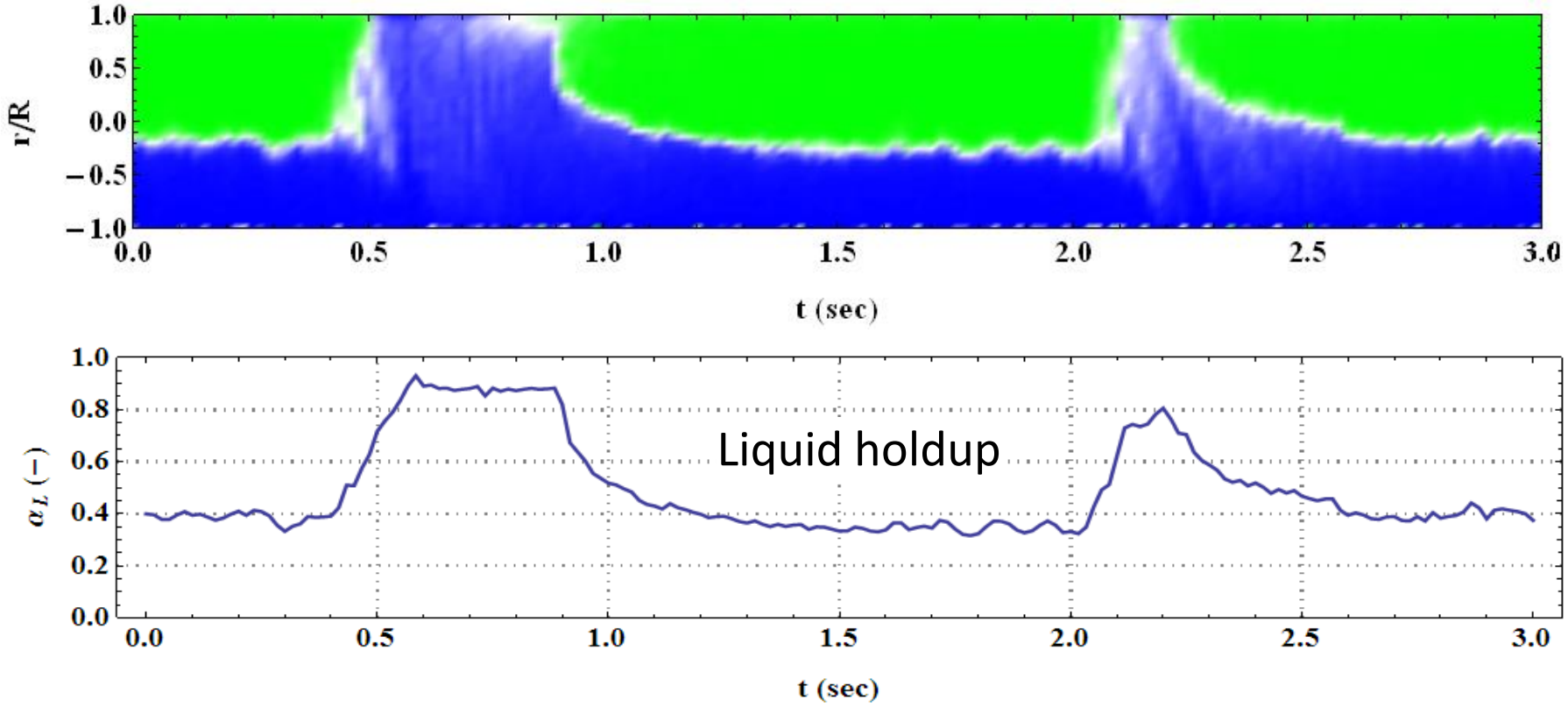
Top view

Flow

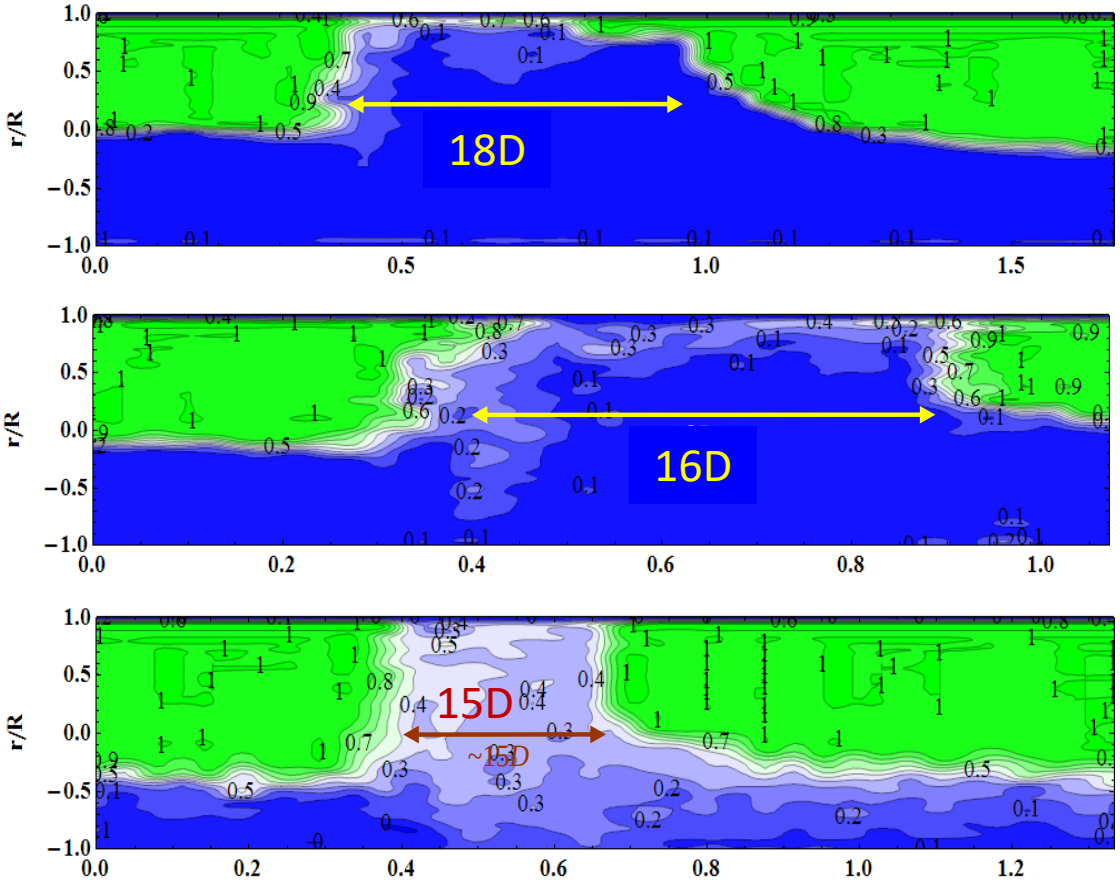


Side view

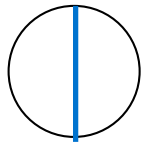
Cross-sectional average holdup traces



Gas distribution in slug flow



contour plot
on t-y slice view

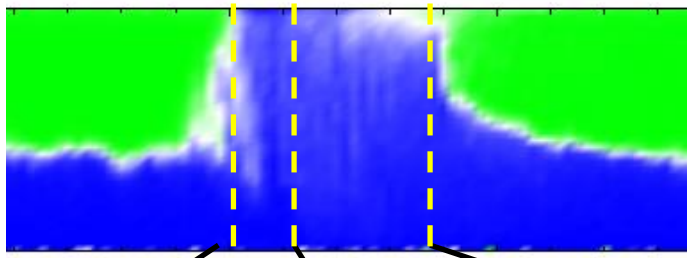


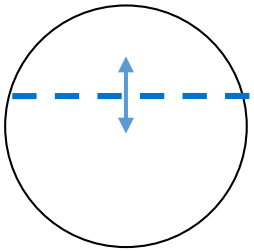
little or no
gas entrainment

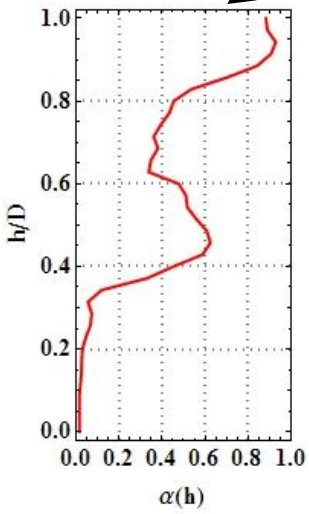
mixing zone
and developed zone

frothy slug
gas in stratified layer

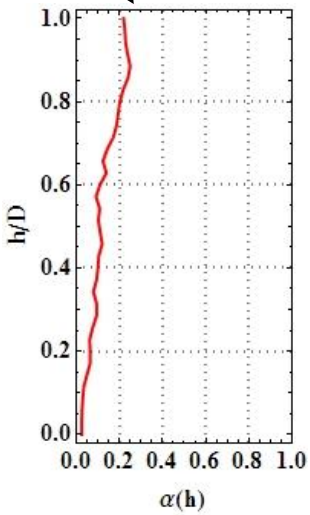
Y-axis void distribution (chordal averaged)



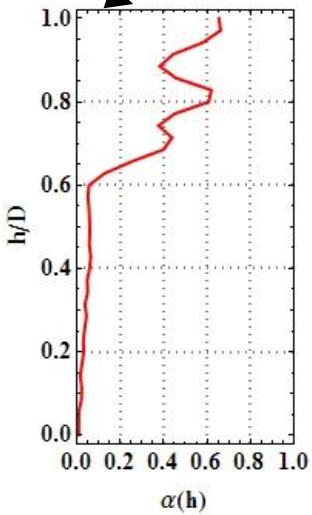




(a) t= 0.48 s, front



(b) t = 0.60 s, middle

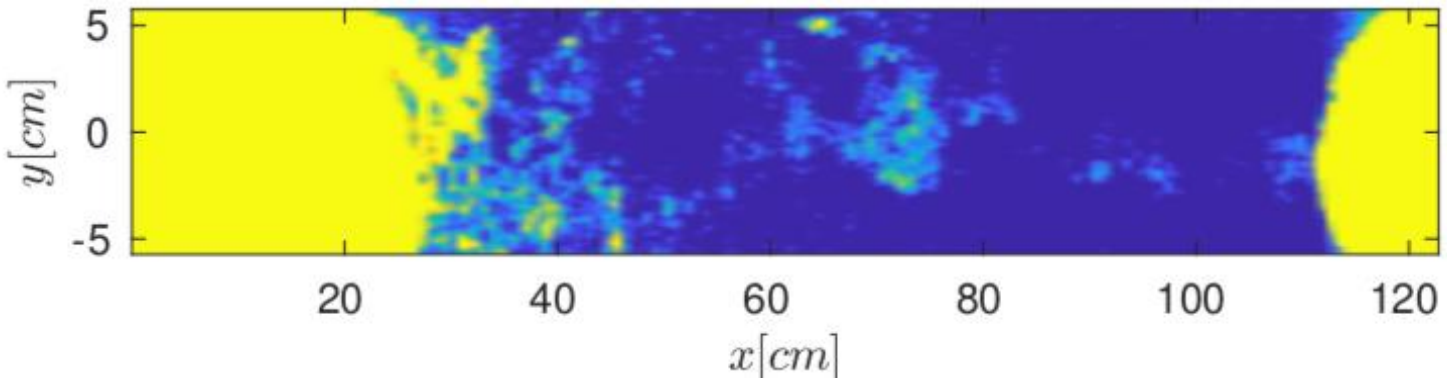


(c) t = 0.92 s, rear

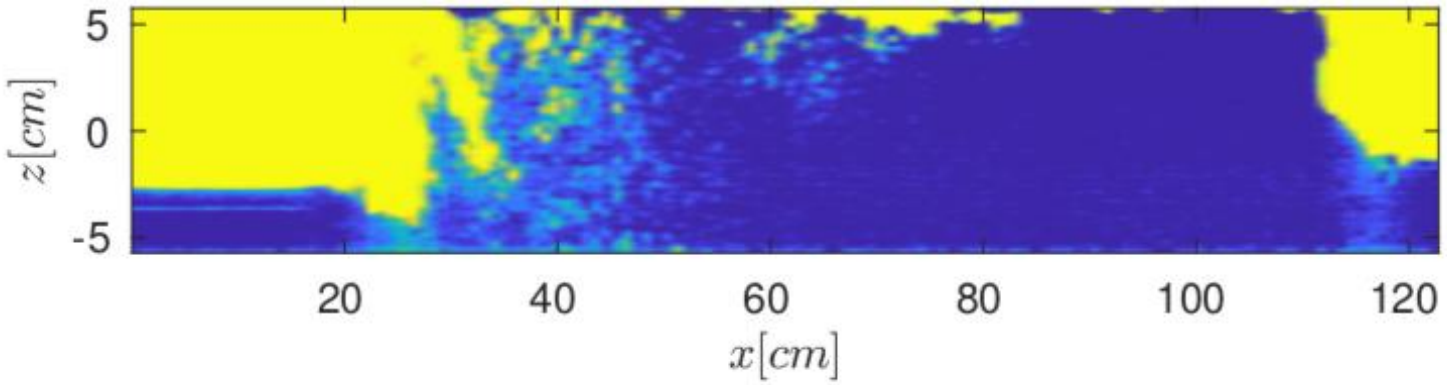
Evolution of void profile (Y-axis) along a slug

Internal structure of a slug

Flow



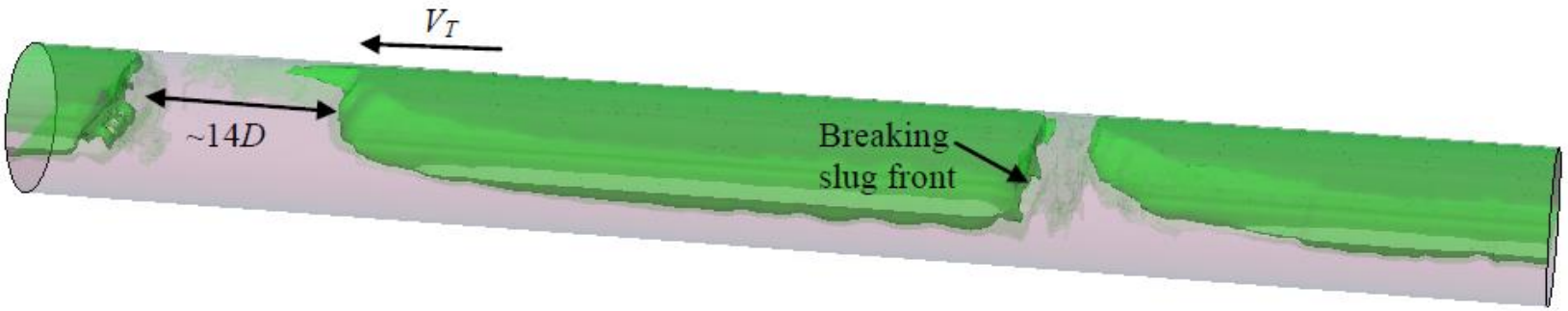
Top view



Side view

Smith (2018)

Pseudo-3D reconstruction of a slug



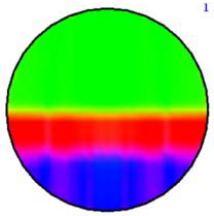
Side view

Top view

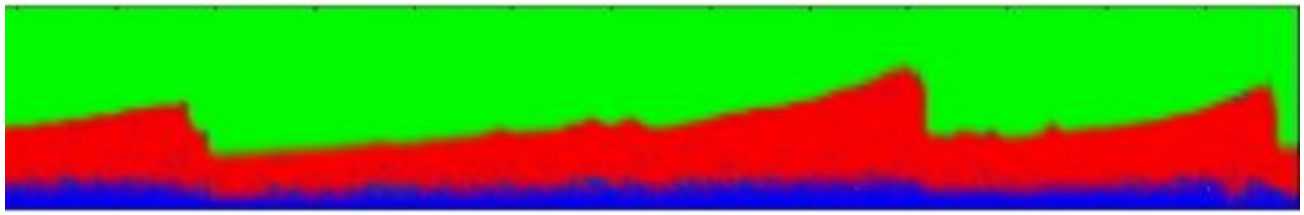
Time

3. Three-phase flows

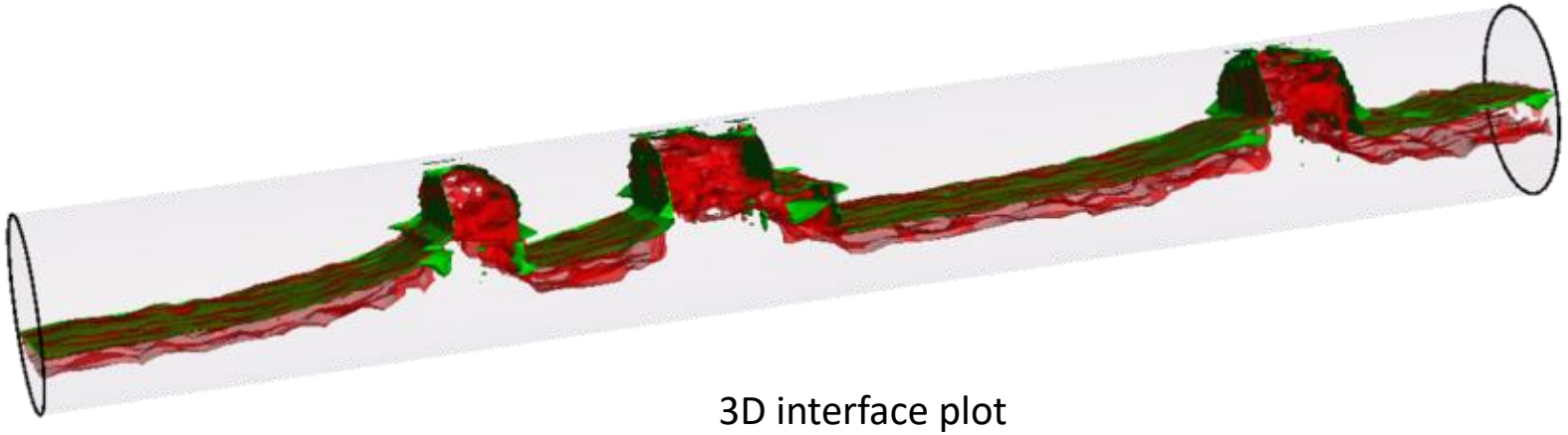
Unique chance to look into local details



Tomography



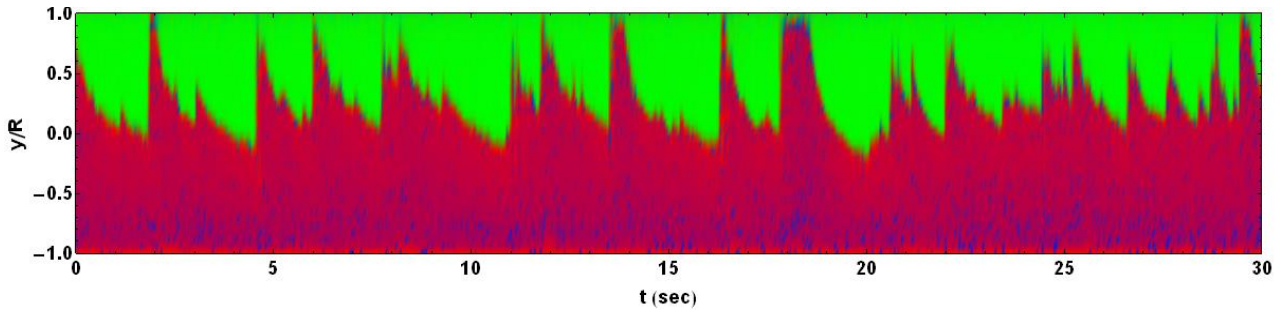
Side projection



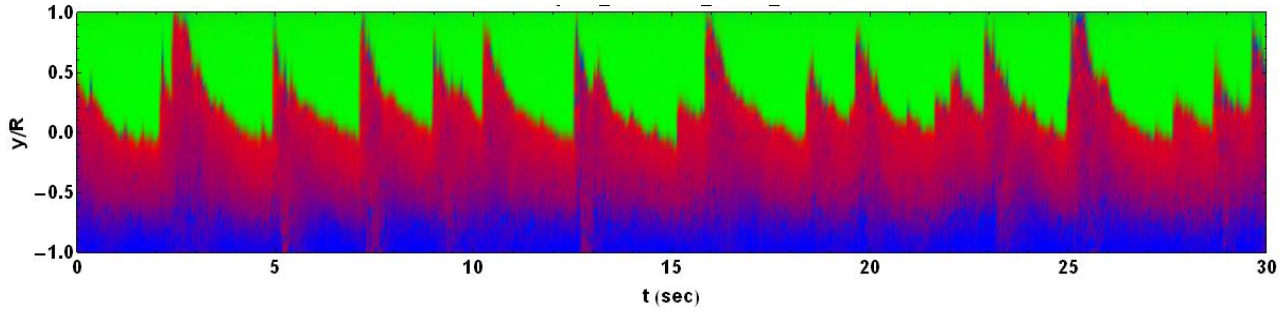
3D interface plot

Effect of water cut

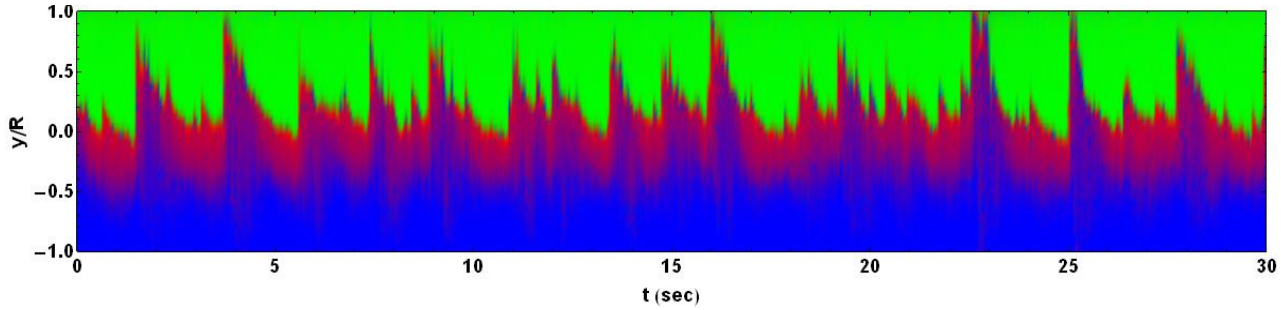
Oil viscosity 69 cP



Water cut
10%

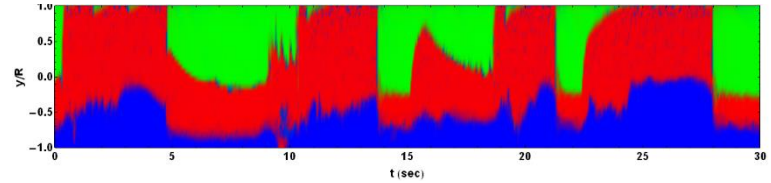


25%

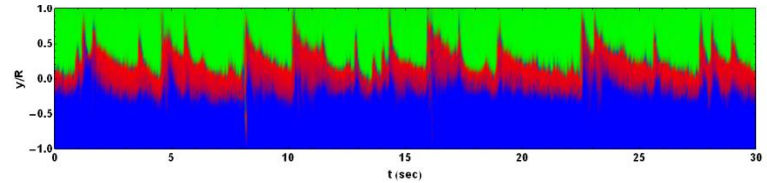


50%

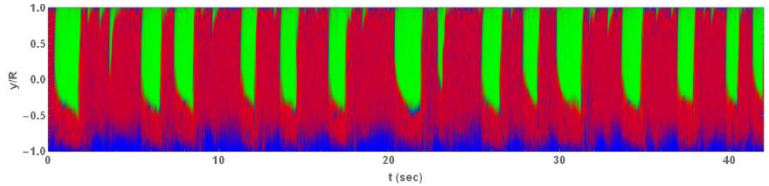
Three-phase viscous oil slug flows



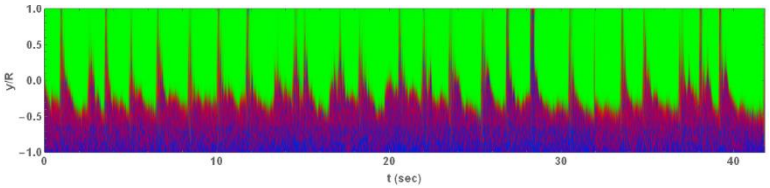
Plug flow with less gas entrainment and oil-water being separated



Slug flow with water dominated slugs and a passive oil layer



Slug flow with oil dominated slugs and a layer of water at the bottom

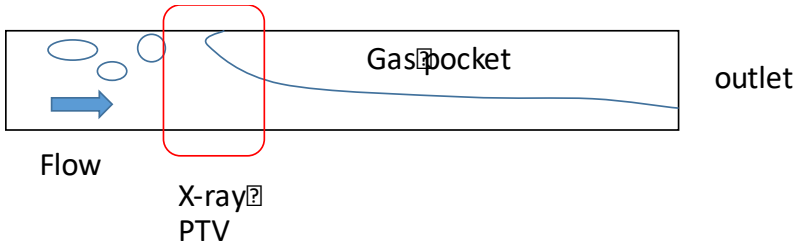


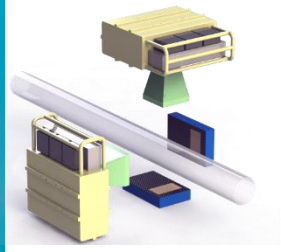
Slug flow with severe gas entrainment and oil-water mixing

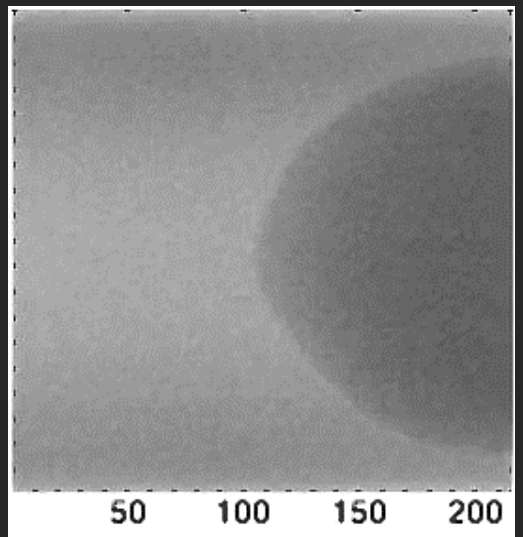
4. Other applications

Flow around Benjamin bubble

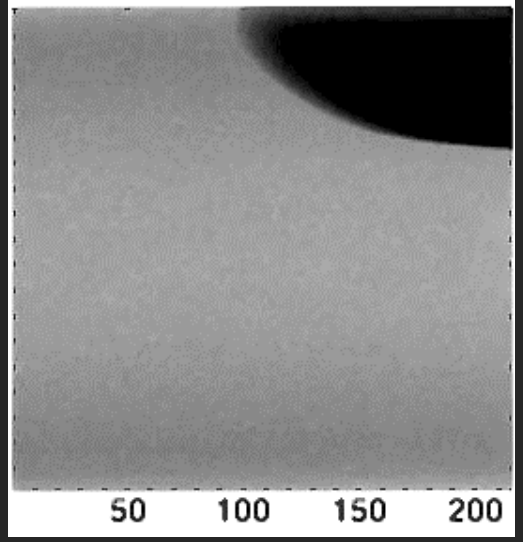
- Pixel size 300 um
- Tracer particles 1-1.5 mm
- 100 fps







Top view

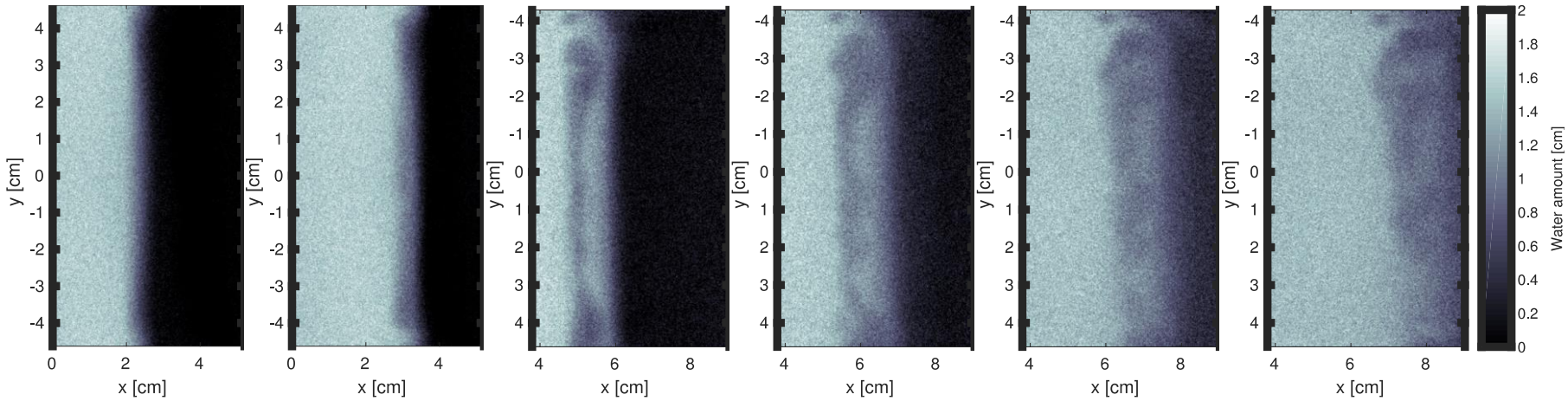


Side view

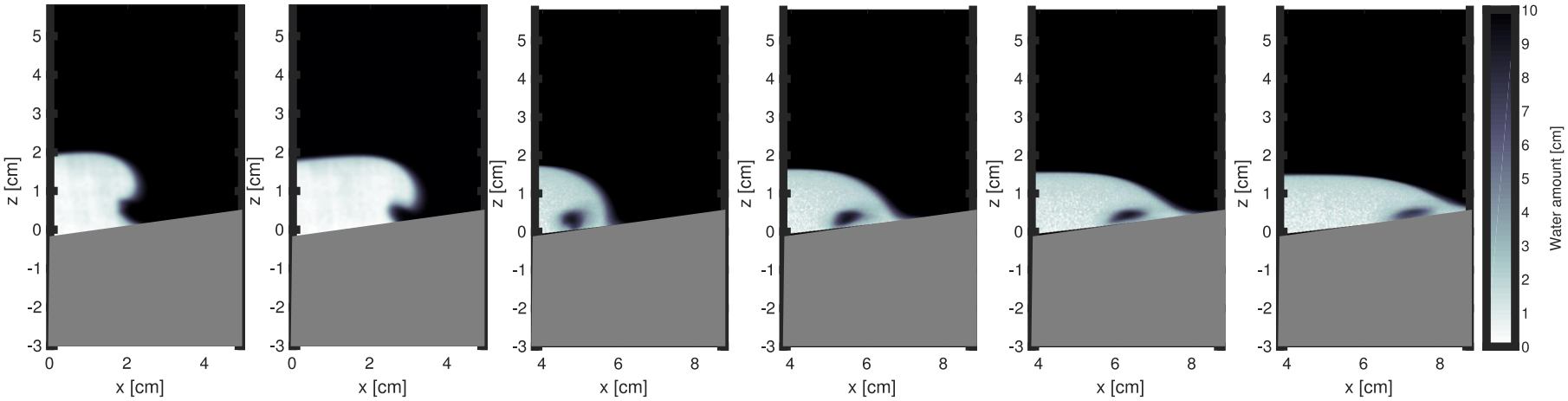
Breaking solitary wave at ramp-up

Top view

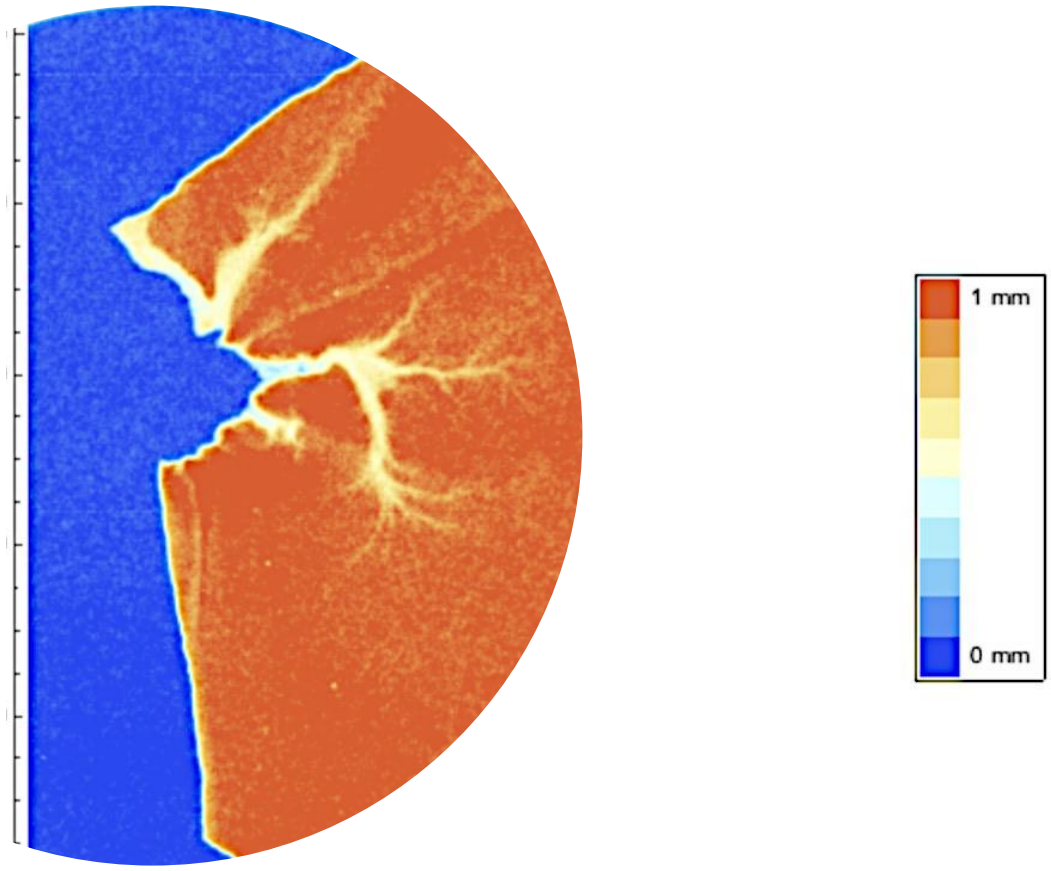
Smith (2017)



Side view



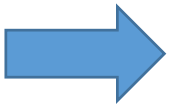
Liquid flow through porous media (1mm thick plaster)

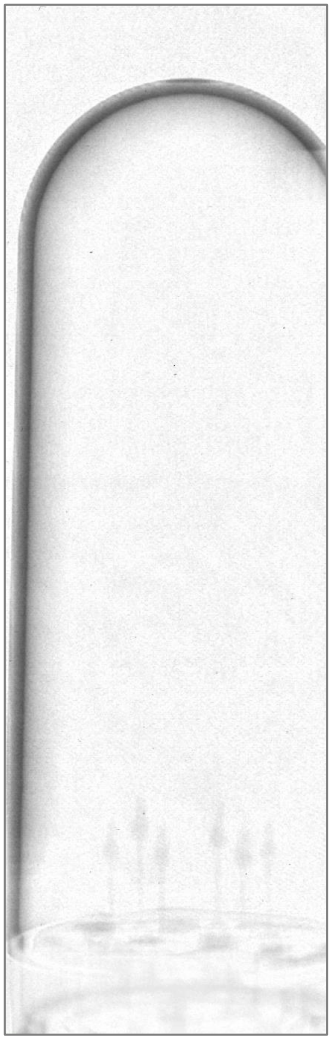


Reveal the details of liquid path and fingering effect

Interesting jets and droplets

- Sampling rate: 155 fps
- Pixel size: 150 µm

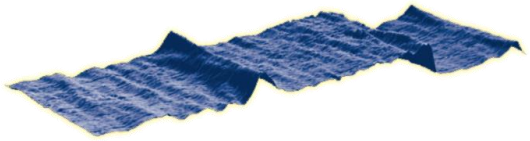




REX-CELL™: A great tool to have

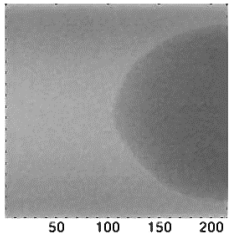
Interface

Wavelets

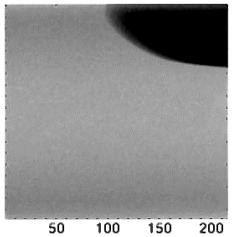


Velocity & flow field

3D particle tracking



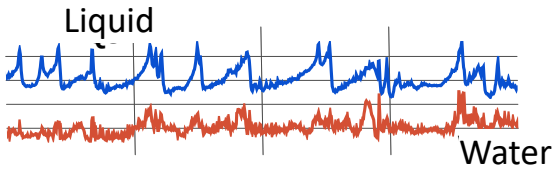
Top view



Side view

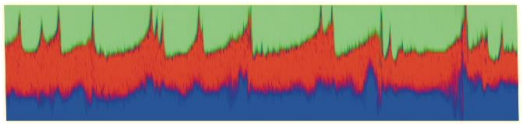
Volume fraction

Mean & time-series



Dynamics

Flow pattern
Flow charateristics
Flow evolution

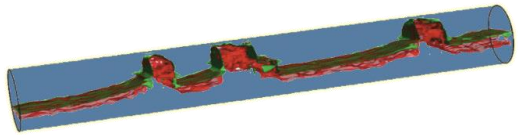


Tomography

In-situ fraction
Entrainment
Mixing/separation

3D flow

Space-time feature



Summary

- Excellent tool to characterize transient multiphase flows
  - high spatial and temporal resolution

- Detailed and accurate qualitative and quantitative information are captured

- A powerful key to help us answer questions
  - WHAT?
  - WHY?
  - HOW?