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1<sup>st</sup> International Conference on Applications  
of Radiation Science and Technology

# **Tomographic methods for multiphase flow measurement**

Prof. Geir Anton Johansen

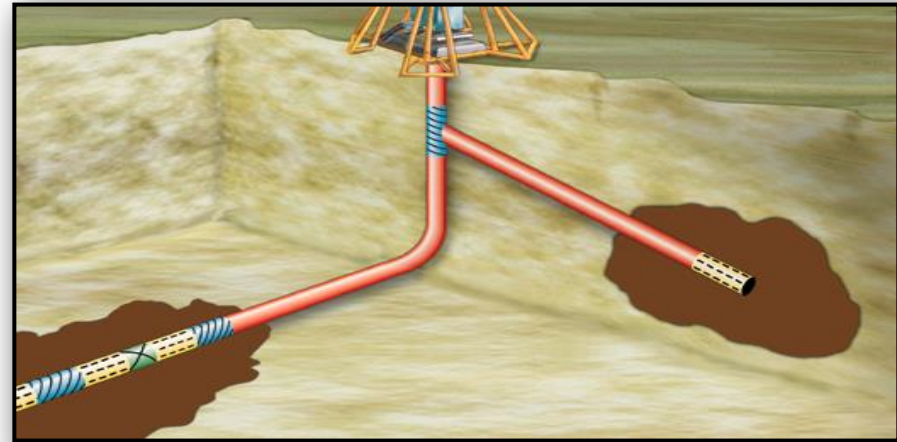
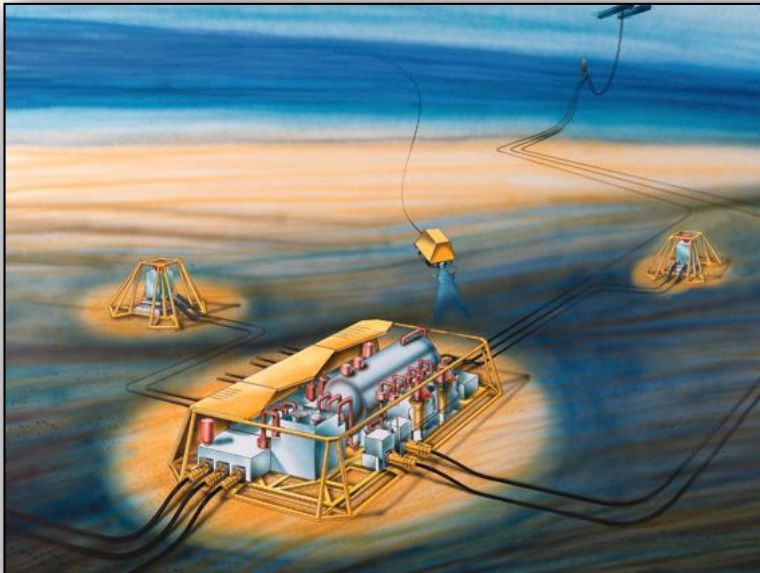
Department of Physics and Technology,  
University of Bergen, Norway

# Outline

- Multiphase flow measurement - challenges and measurement strategies
- Tomography as flow reference instrumentation
- The Bergen high-speed gamma-ray tomograph
- Tomographic measurement methods used as an integral part of MPFMs
- Conclusions

# Why multiphase flow measurement?

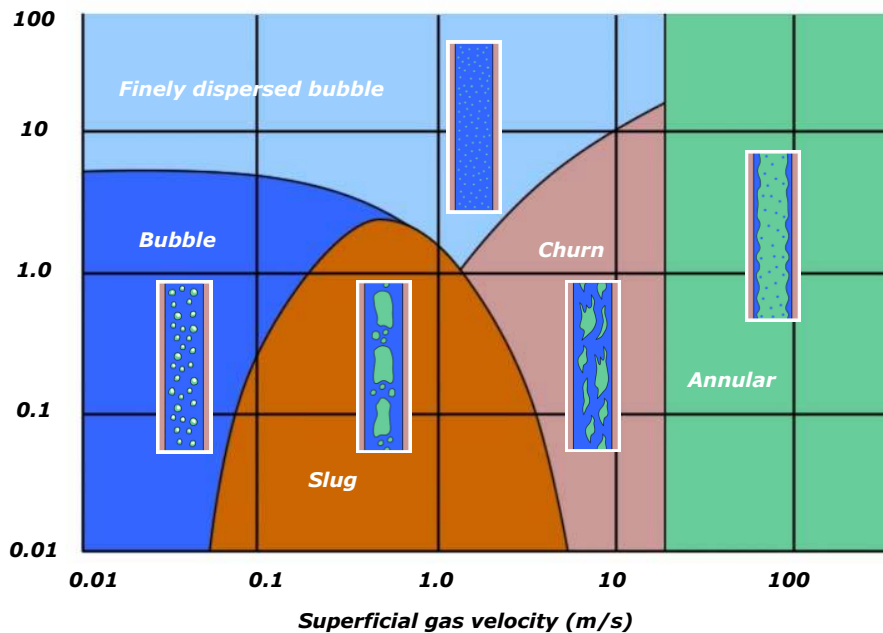
- Makes space consuming test separators redundant
- No moving parts
- Remote operation
- Smaller fields require unmanned platforms
- More and better reservoir information
- Improved reservoir management



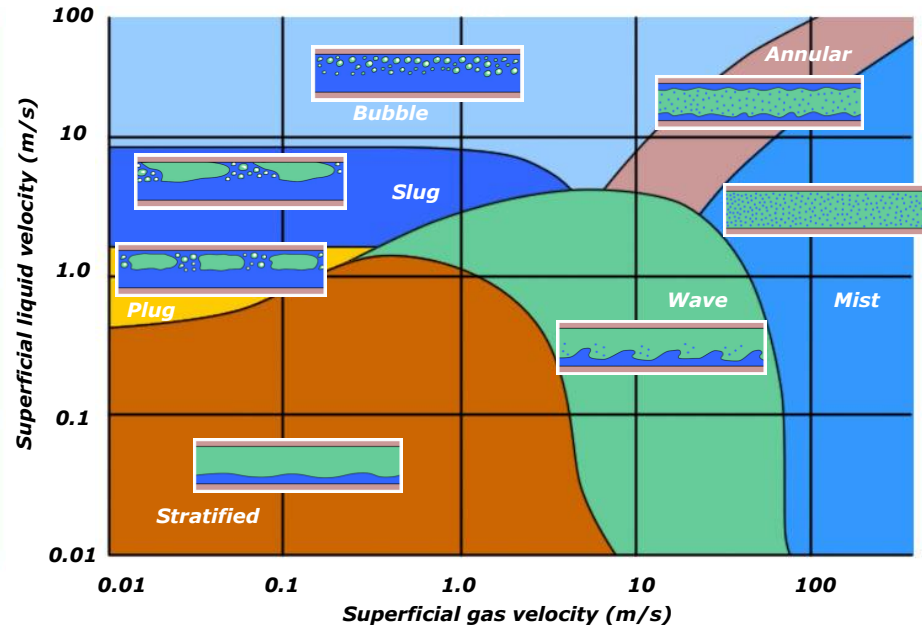
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# Generic gas/liquid flow maps

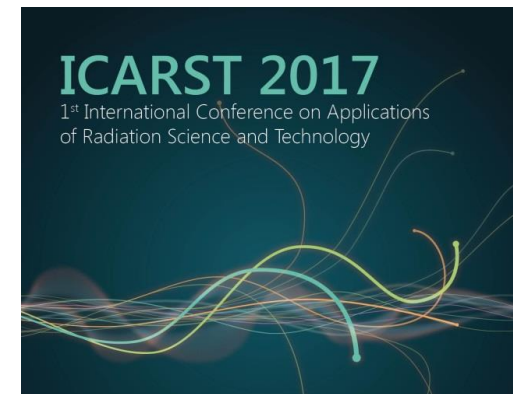
- Vertical flow



- Horizontal flow

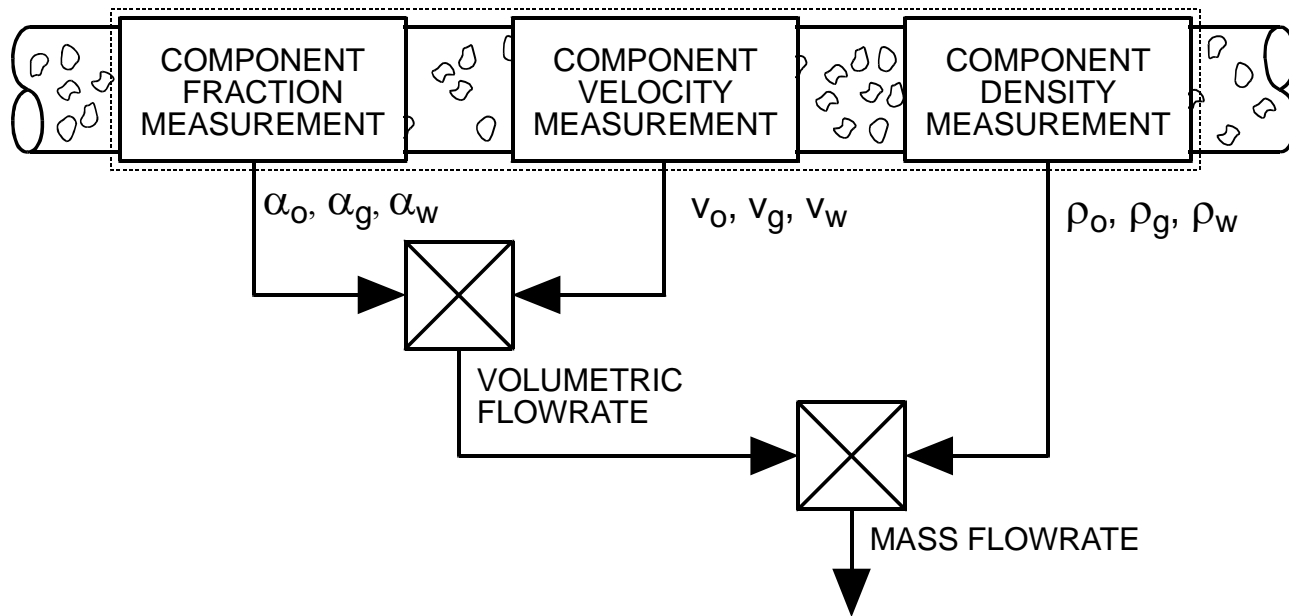


- Superficial velocities are used along the axes
- These maps will differ from one pipe diameter to another



# Multiphase flow metering and tomography

- Top side and subsea meters can be installed for vertical flow with semi-empirical models to determine  $\alpha_o$ ,  $\alpha_g$  and  $\alpha_w$ 
  - Tomography used for flow model development



- For downhole metering the flow inclination varies
  - Tomographic methods are required

# Multiphase flow measurement challenges

- Flow regime errors caused by temporal variations in the cross sectional flow pattern
- Variations in the salinity of the water component
- Reduce flow rate measurement uncertainty from typical  $\pm 10\text{-}15\%$  (AR) to  $\pm 5\%$  (AR).
- Take into account:
  - Minimal pressure drop across the meter
  - Possible slip between liquid and gas phases
  - Scaling and wax



MORE DATA  
IS REQUIRED!

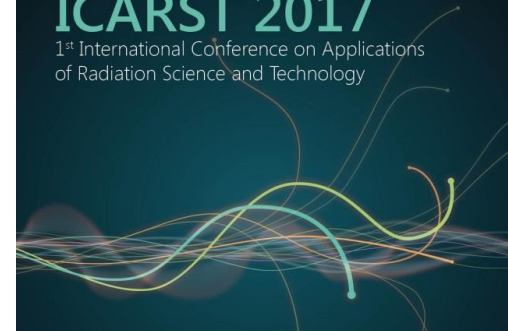


TOMOGRAPHY!



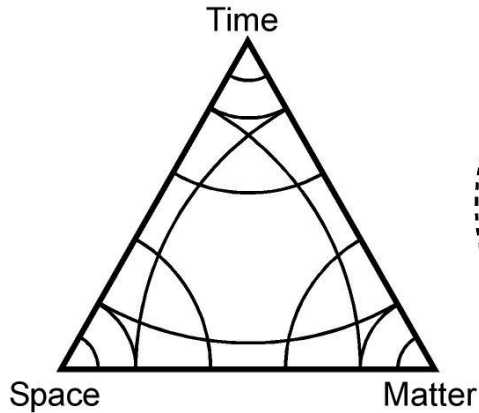
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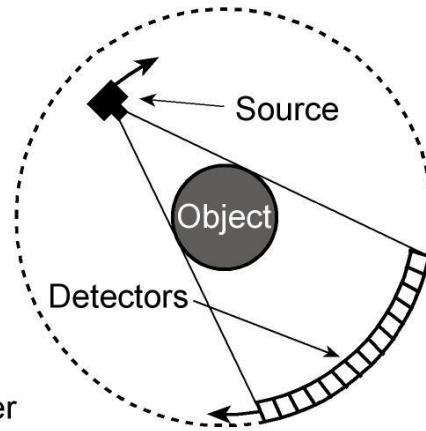


# Measurement geometries

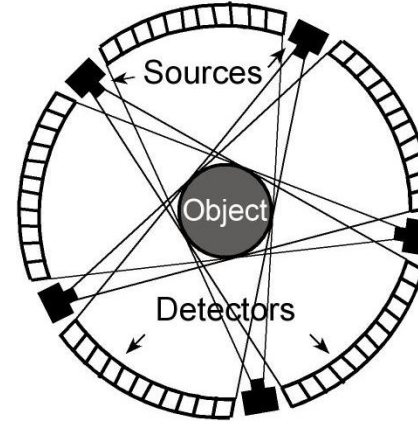
**A:** Conflicting requirements:



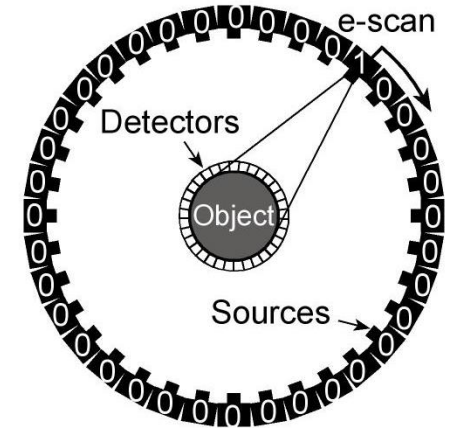
**B:** 3<sup>rd</sup> gen. CT scanning:



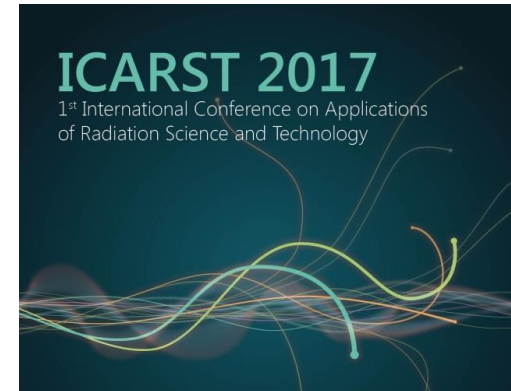
**C:** Instant, non-scanning:



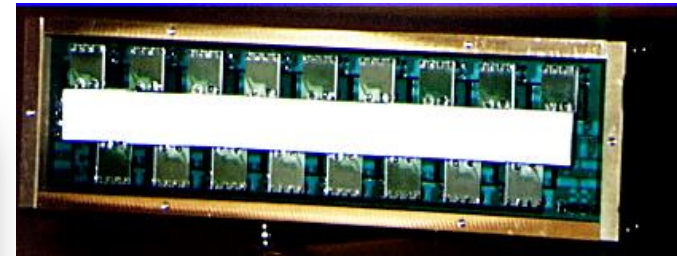
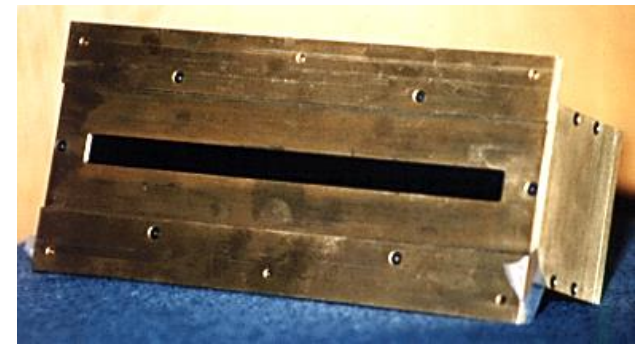
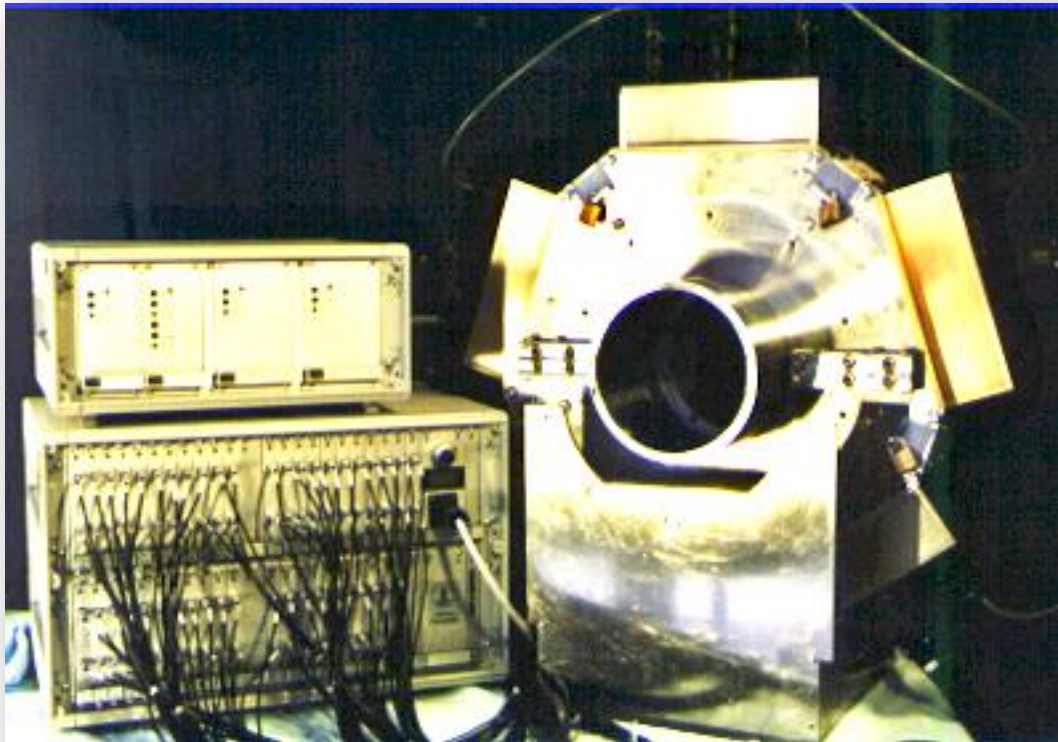
**D:** Electronic scanning:



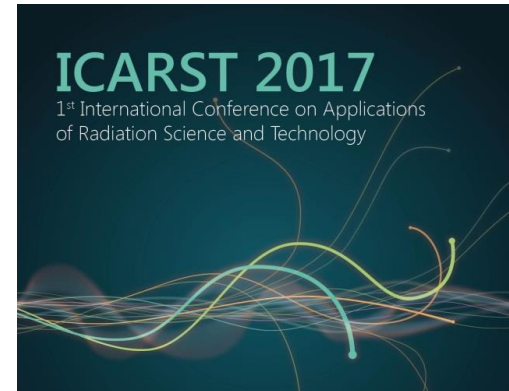
- High speed instant imaging requires non-scanning systems
- Drawbacks of instant systems are high cost and less flexibility with respect to object geometry, e.g. diameter



# The high-speed $\gamma$ -ray tomograph at University of Bergen



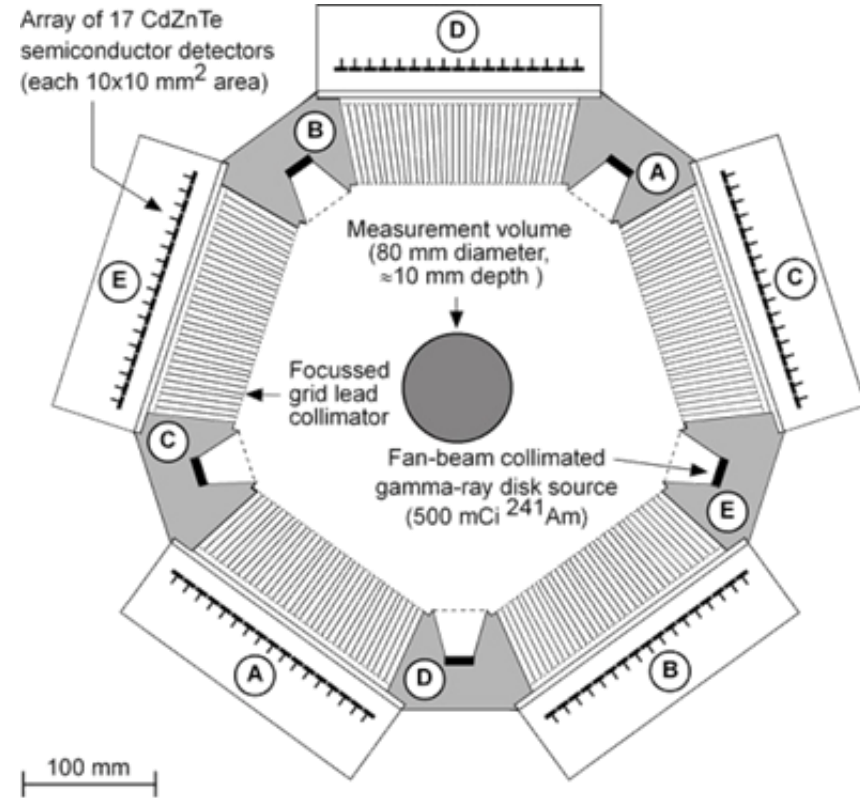
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# The high-speed $\gamma$ -ray tomograph at University of Bergen

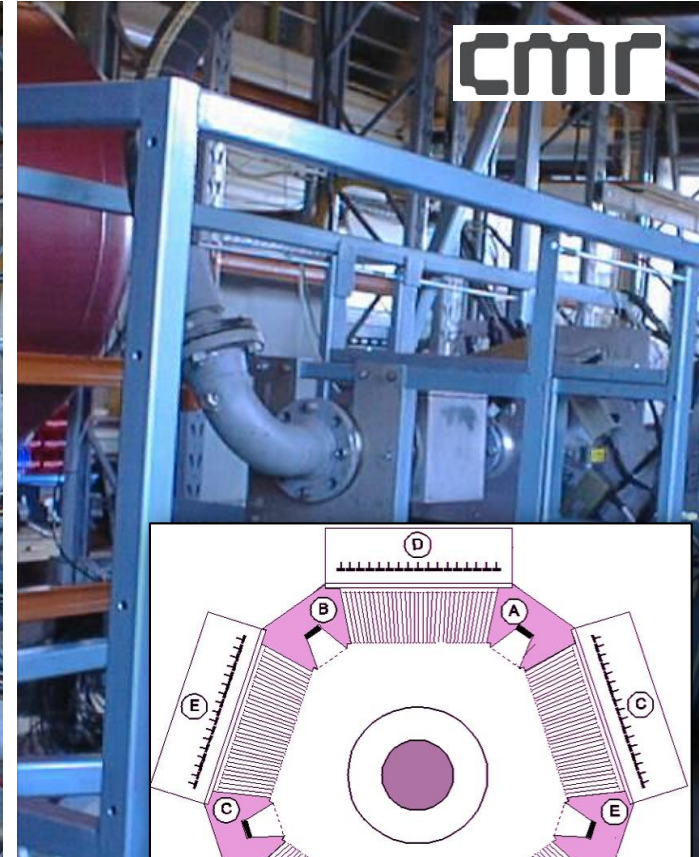
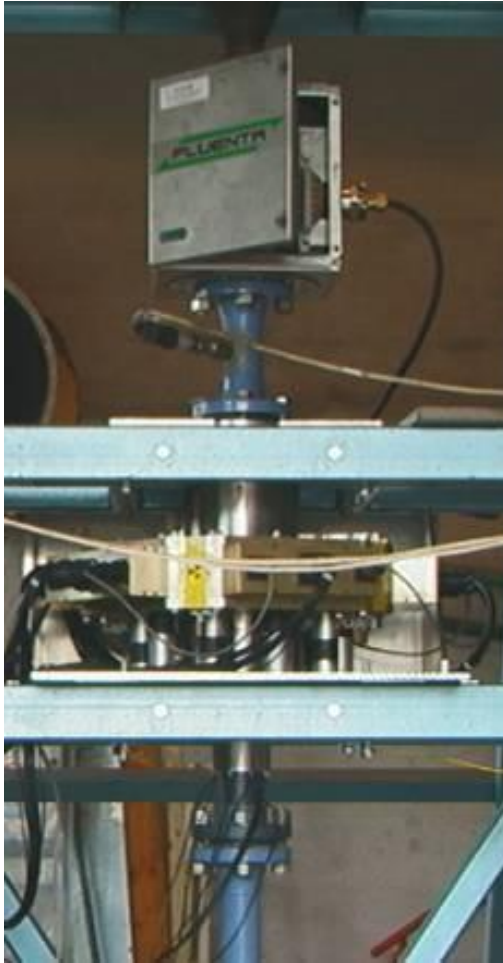
- 5  $^{241}\text{Am}$  low energy (60 keV - 500 mCi) sources each facing 17 CdZnTe detectors, i.e. 85 views in total
- Low dose rate to the surroundings, ( $0.1 \mu\text{Sv/hr}$  @ 1 m, i.e.  $<$  background)
- Sensor image rate capability:  $\approx 300$  frames/s (data streaming to disk)



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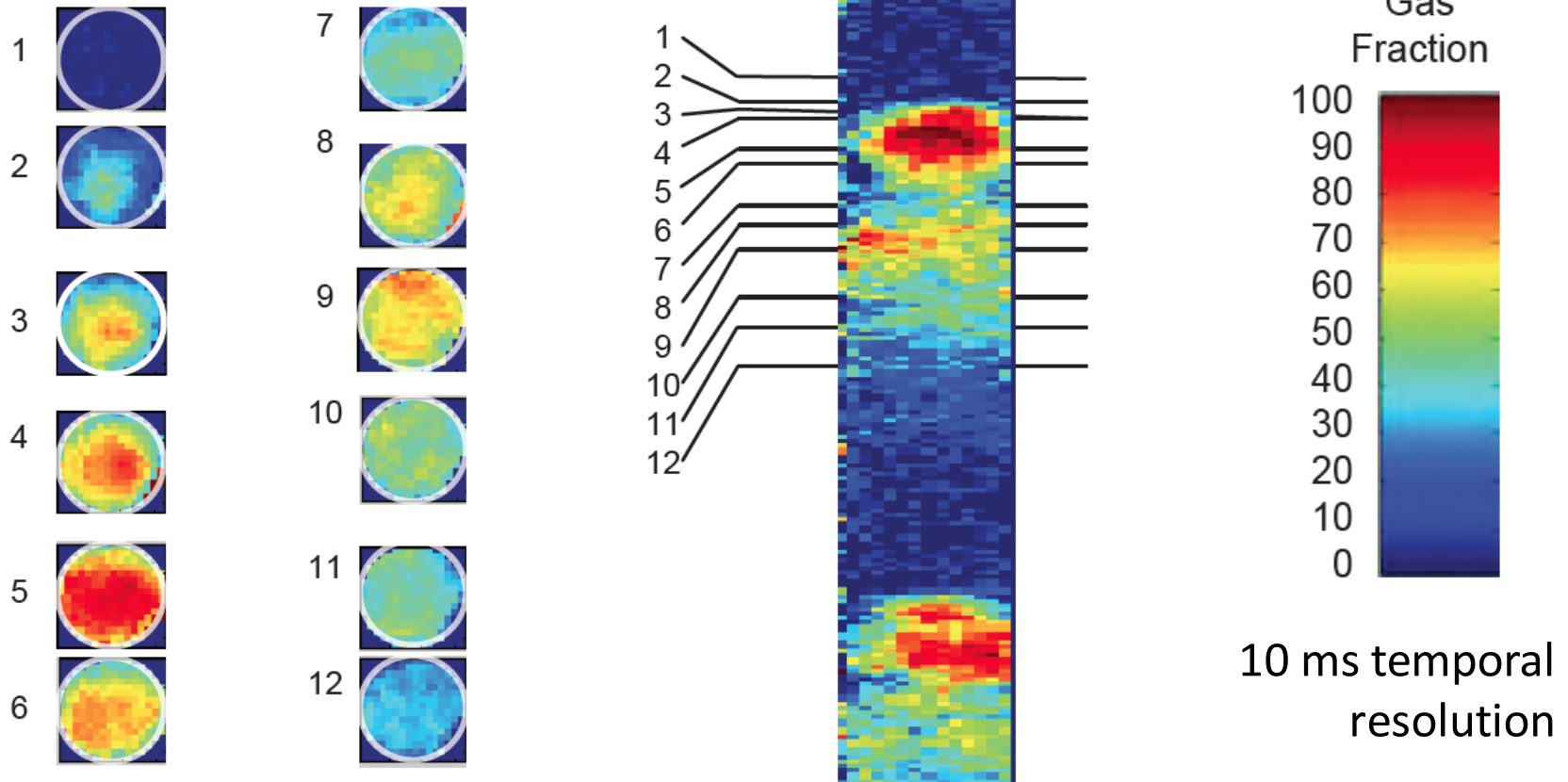
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# High speed $\gamma$ -tomography reference imaging of MPFMs in CMR\*'s flow loop



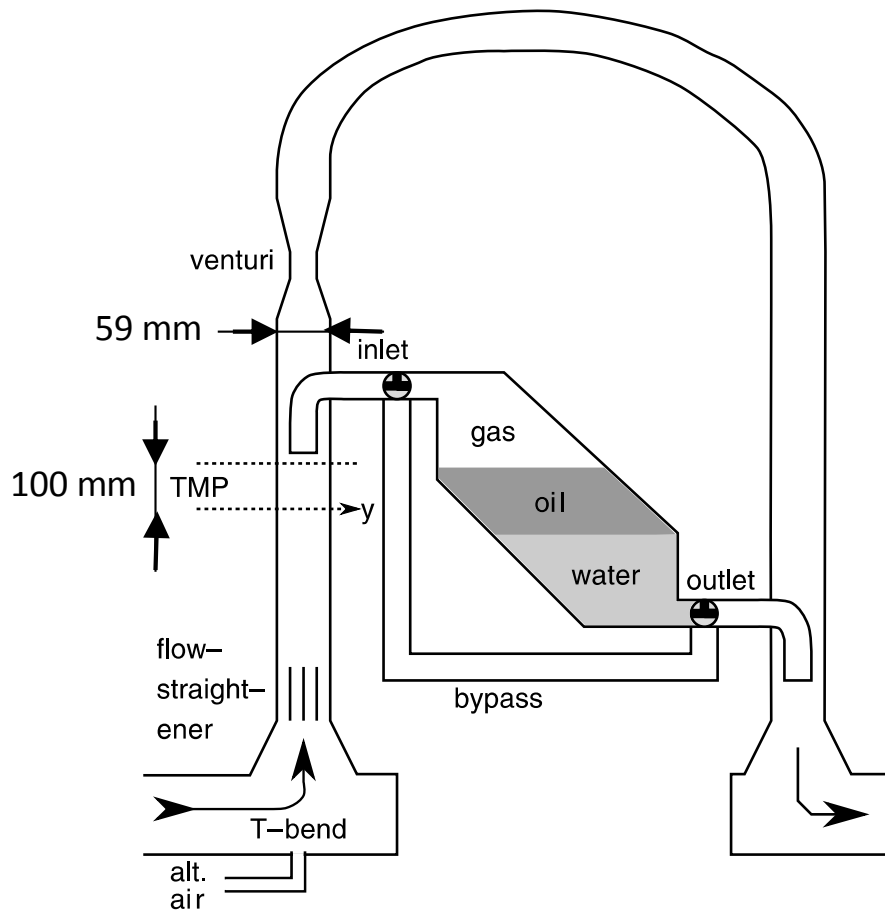
\* Christian Michelsen Research, Bergen

# Correction of models in MPFM computer



2.5 s slug flow sequence, more complex than the model used to compensate for non-homogeneously mixed flow

# Tomographic imaging of sampling system



Subsea online fluid sampler and analyzer,  
patented by Christian Michelsen Research

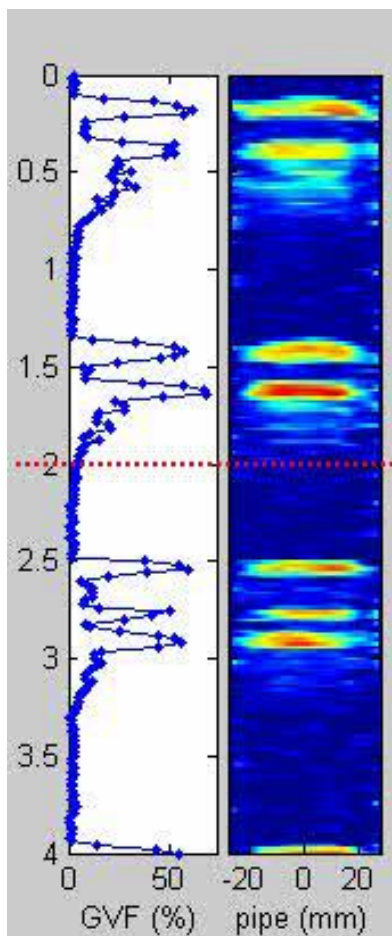
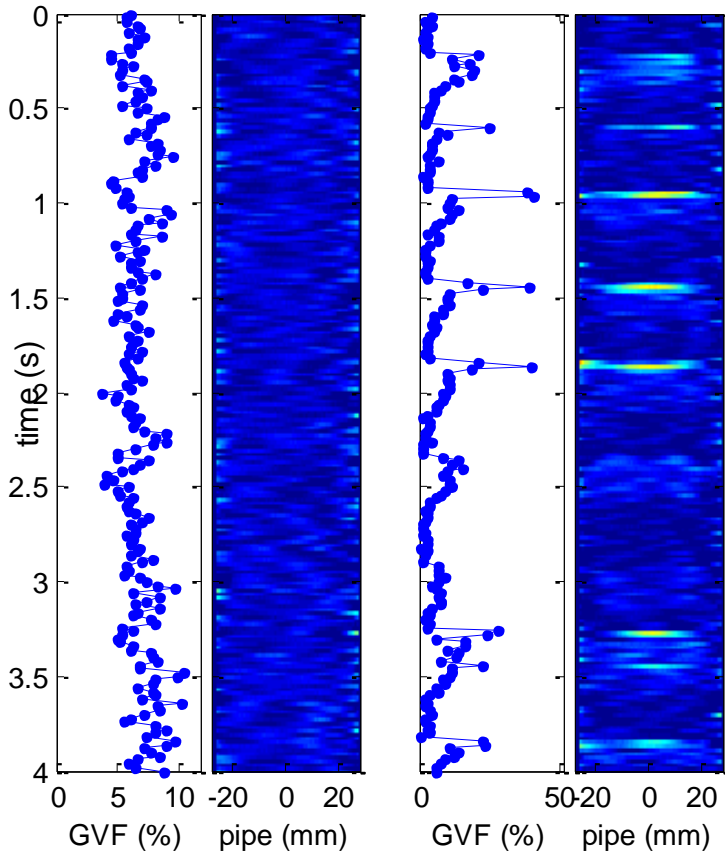


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# Temporal flow variations

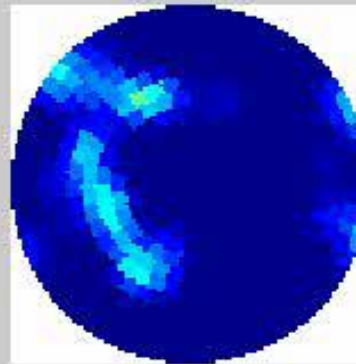
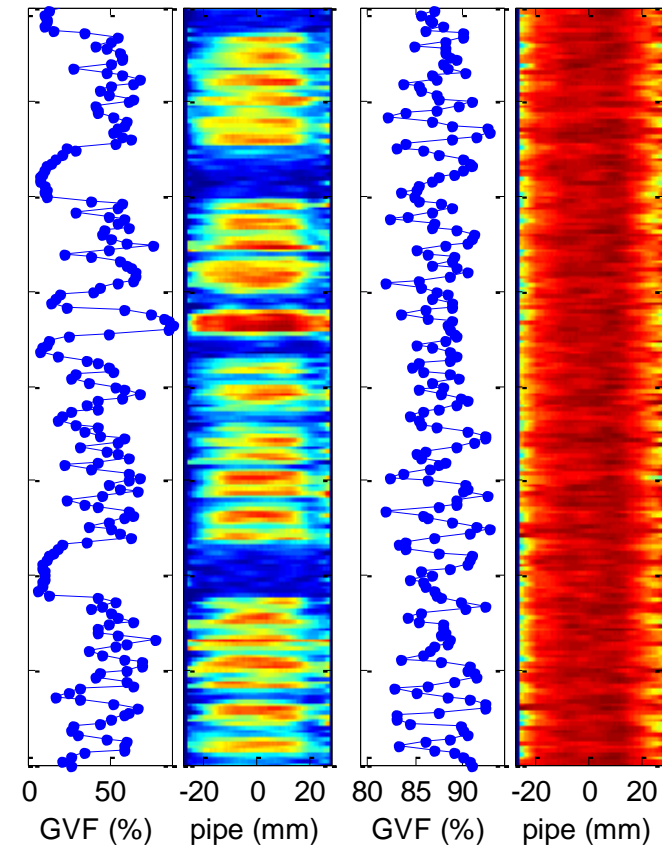
dispersed

bubble



churn

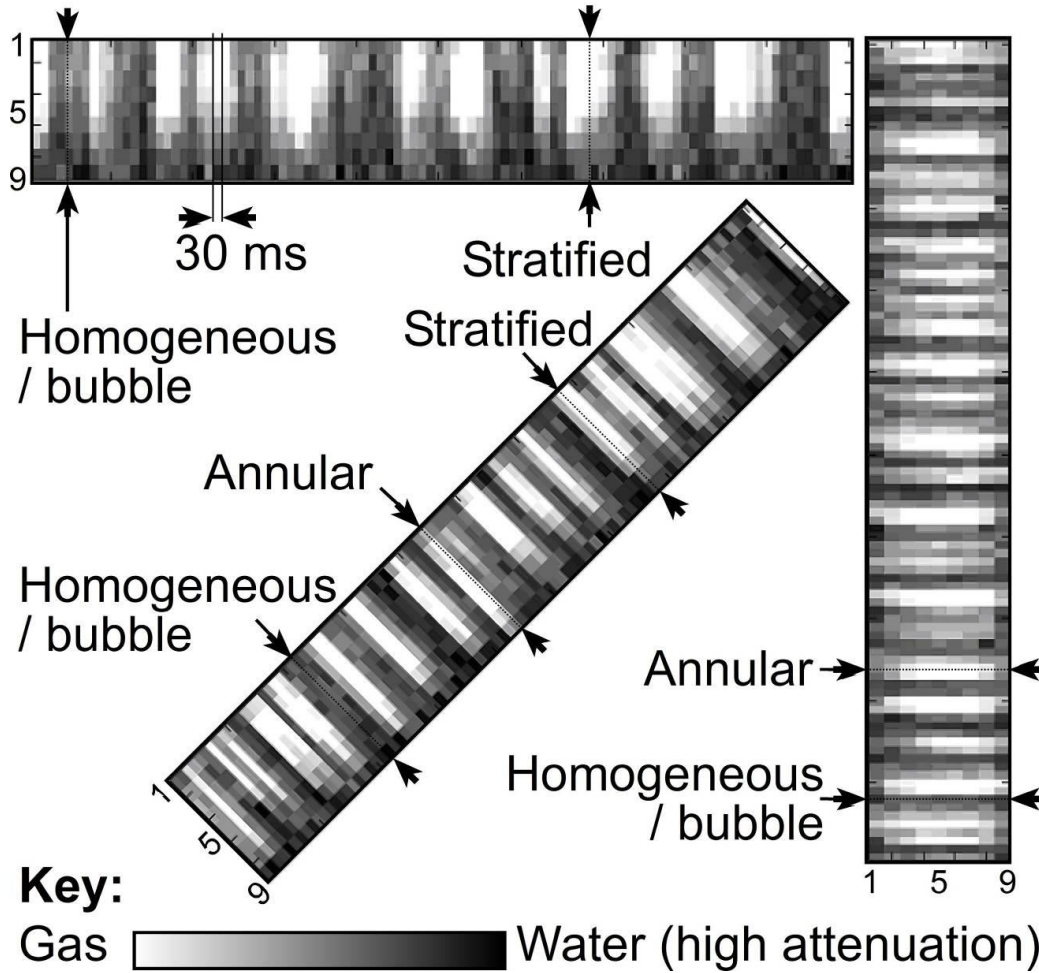
annular



- 3.2 sec sequence
- 20 ms resolution

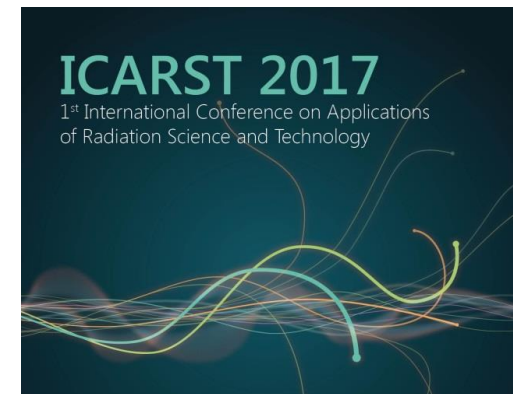
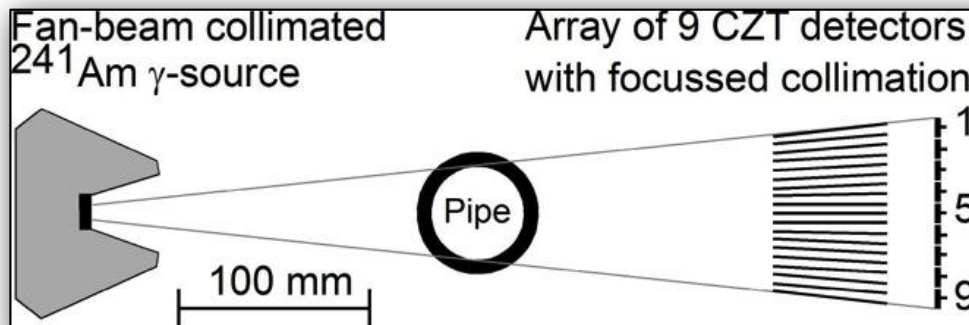
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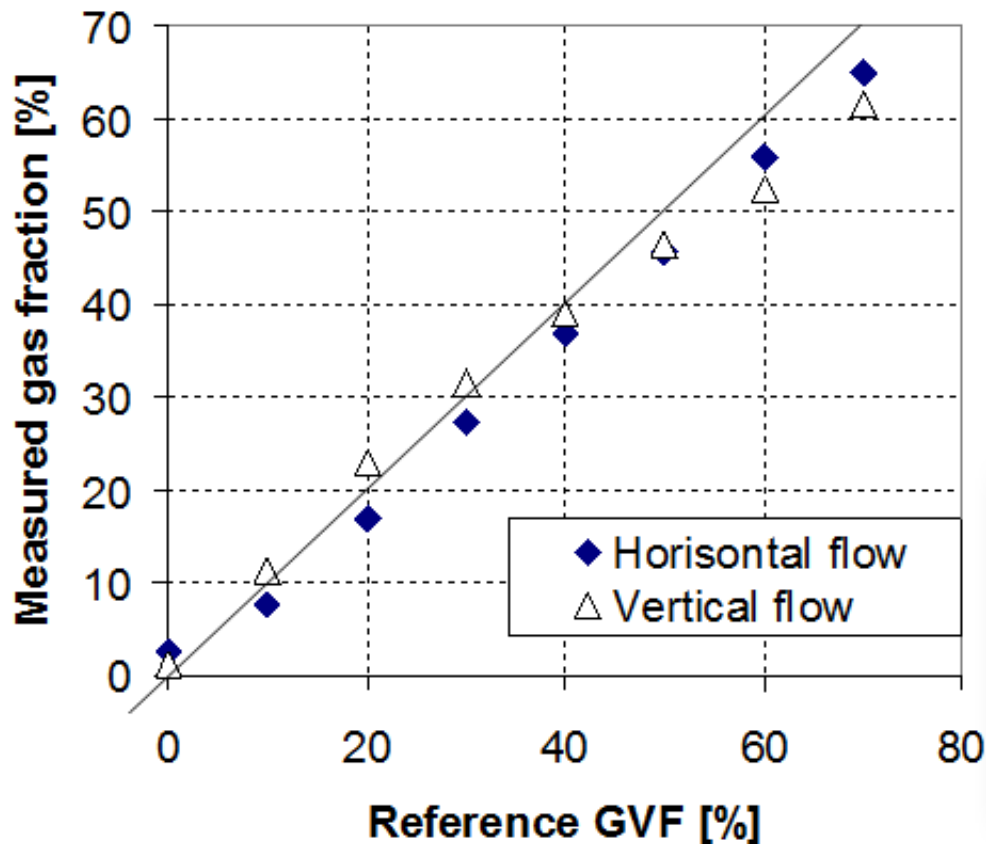


# Tomographic MPFM strategy:

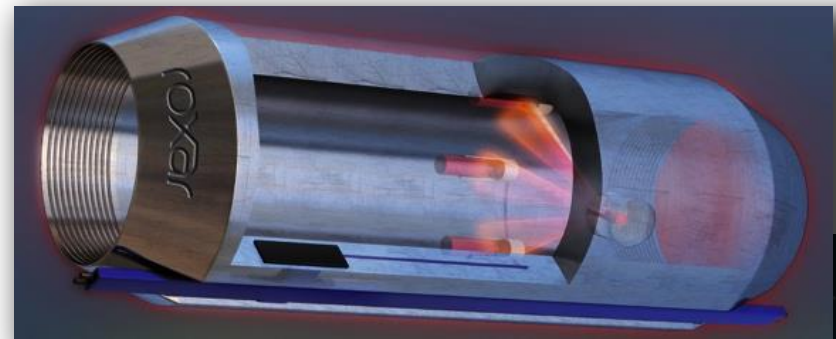
1. Split **flow** into **short temporal segments** where the **flow pattern** is identified
2. Make **corrections** in MPFM computer.



# Tomometry for multiphase flow measurement



- The Roxar downhole three-beam gamma sensor launched in 2011



# Conclusions

- High speed tomography is now frequently used to provide experimental reference data
  - Gamma-ray methods
  - X-ray methods
  - Electrical and electromagnetic methods
- Tomographic methods are applied to down-hole meters
  - One source and a few detectors
  - Simple and rugged
  - Improved measurement accuracy



# Acknowledgements

My research colleagues and co-authors:

- C Sætre, Christian Michelsen Research, Bergen
- S-A Tjugum, Roxar Flow Measurement, Bergen
- BT Hjertaker, University of Bergen

THANK YOU FOR  
YOUR ATTENTION!

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