Laser Diagnostics Two Phase flows

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TSI INSTRUMENTS LTD

UNDERSTANDING, ACCELERATED

Outline

+ Particle Image Velocimetry (PIV)
+ Shadowgraph techniques
+ Volumetric PIV and Two Phase flows
+ MicroPIV

Particle Velocimetry

+ Numerous techniques
  - **Particle Image Velocimetry (PIV)**
  - Particle Tracking Velocimetry (PTV)
  - Volumetric 3-Component Velocimetry
  - Common elements
    - Optically clear Fluid
    - Small tracer particles follow fluid flow
    - Images of particle positions, illuminated by a pulsed laser, are captured at separate times
    - Particle displacements are calculated across dt, the time between laser pulses, to determine velocity

Definition

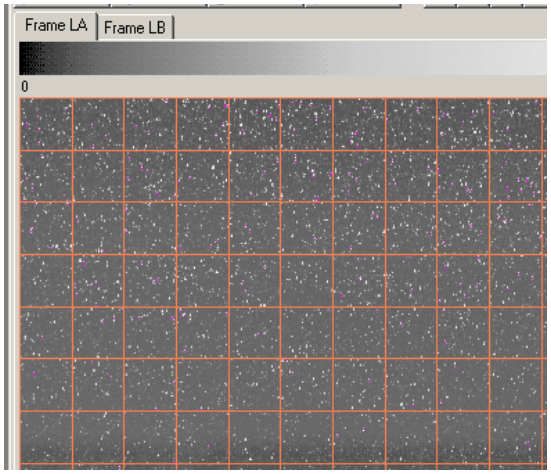
+ Particle Image Velocimetry (PIV)
  - an optical imaging technique to measure fluid or particulate velocity vectors at many (e. g. thousands) points in a flow field simultaneously.
  - Typically measurements (2 or 3 components of velocity) made in “Planar slices” of the flow field
    - Evolving into Volumetric
    - Time Resolved
+ Accuracy and spatial resolution
  - can be comparable to LDV and HWA.

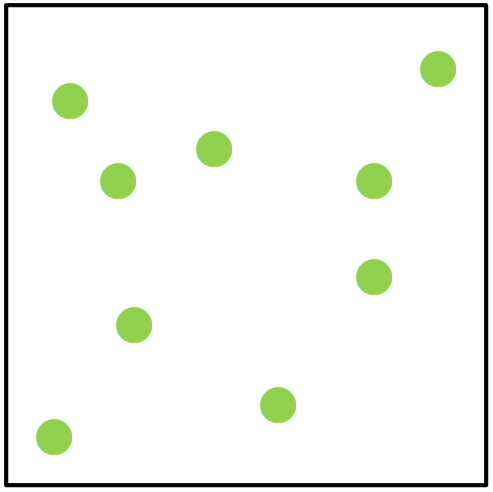
PIV Fundamentals

+ **PIV measures the displacement of tracer seed particles in a flowfield to determine the 2D velocity field**
  - At time t_1
    - Pulsed laser sheet illuminates a planar region of the flow
    - Particles are imaged on the camera (Frame A)
  - At time $t_1 + \Delta t$
    - A second image (Frame B) is taken of a second light sheet
  - Statistical (Cross-Correlation) methods are used to determine the particle displacement over the time Δt, and thus the local velocity
+ One **vector** represents flow "averaged" over a single cross-correlation **interrogation region**
  - Need enough particles to build up a good "average"
  - Velocity variation within a single interrogation region should be small

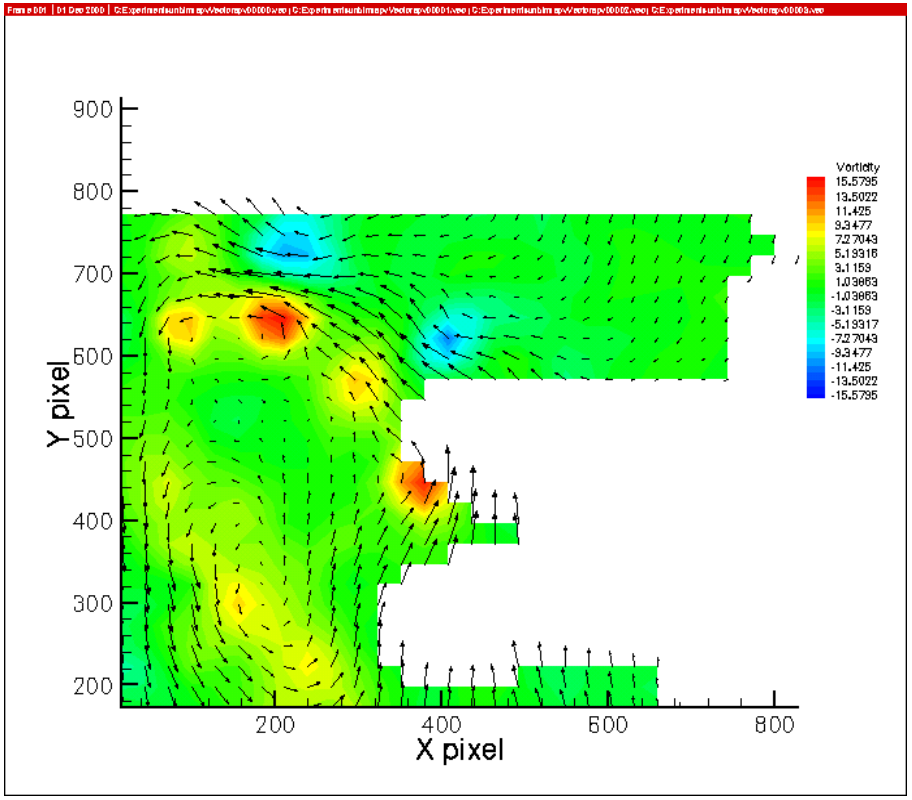
Cross Correlation

+ All particles look alike, so approach is not find the ‘same’ particle in both Frame A and B (as in PTV)
+ Instead, PIV uses a statistical approach to find the most likely displacement of a group of particles
+ Frame A is broken up into a grid of ‘interrogation regions’
+ The group of particles in the interrogation region creates a fairly unique ‘fingerprint’ that we can look for in both frames (PIV)





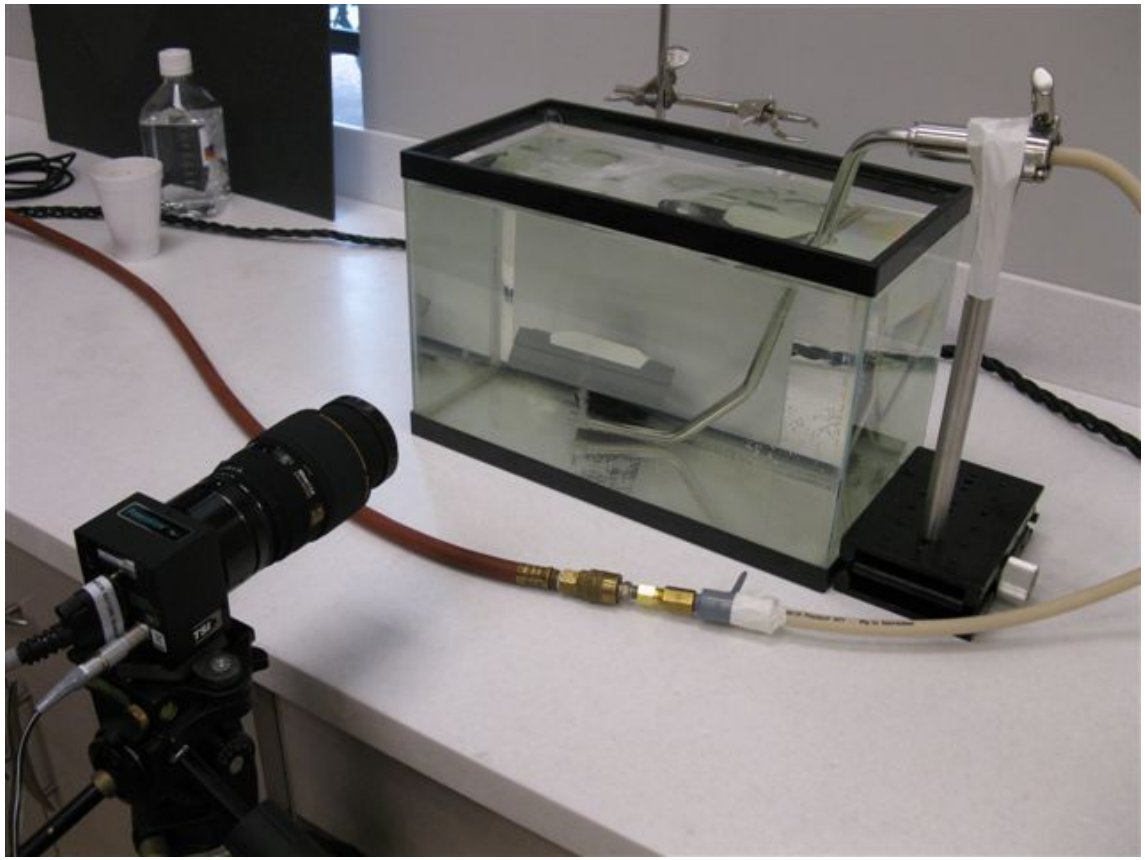
Impeller Mixing Study



Courtesy of University of Birmingham

Shadowgraphy to measure Particle size and velocity

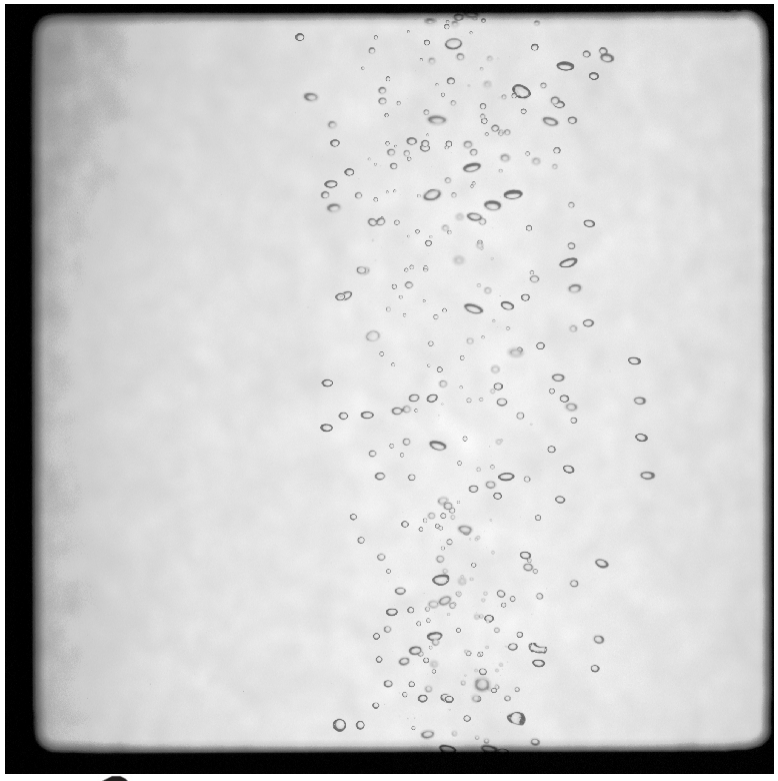
+ Sparger

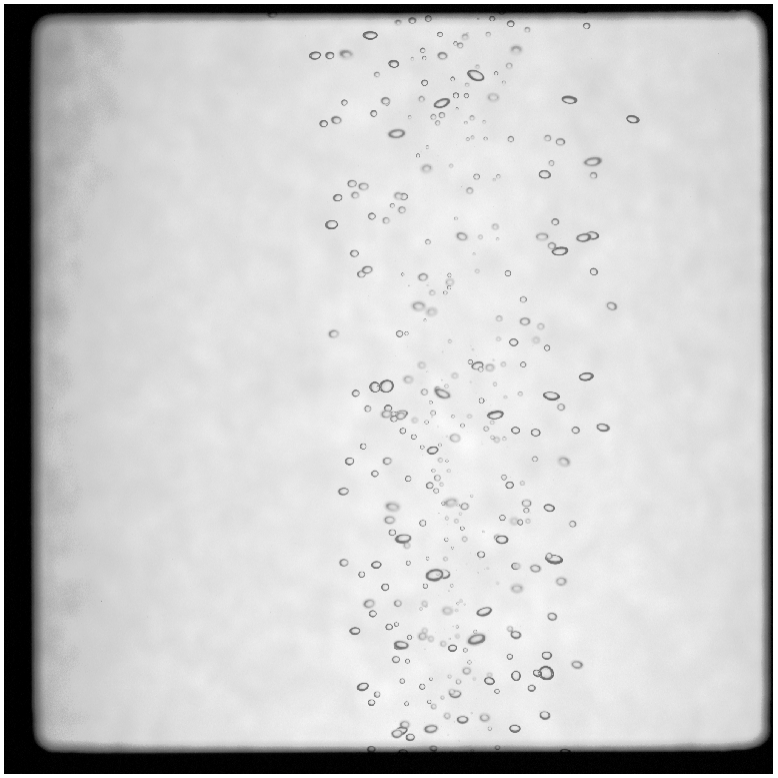


Sparge conditions

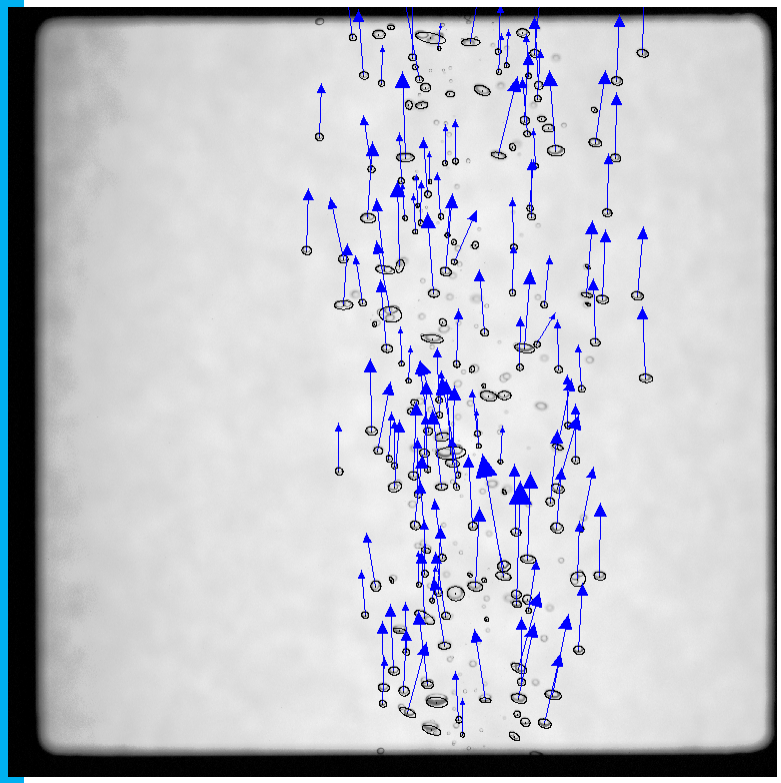
+ 50 mL / min
+ No applied flow
+ Fine sparger
+ No surfactant added
+ Approximate Field of View: 7 cm x 7 cm
+ 36 image pairs

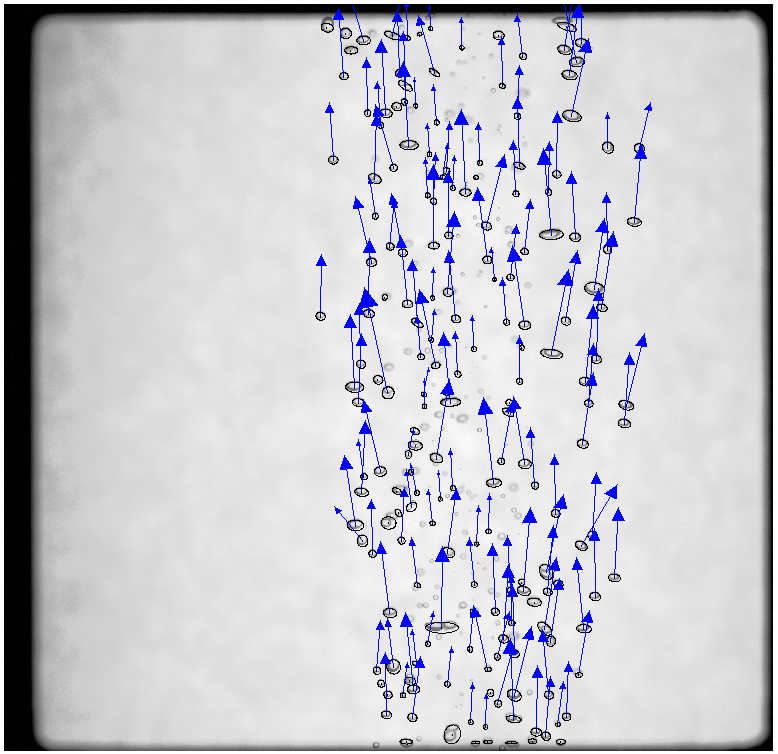
Sample Raw Images



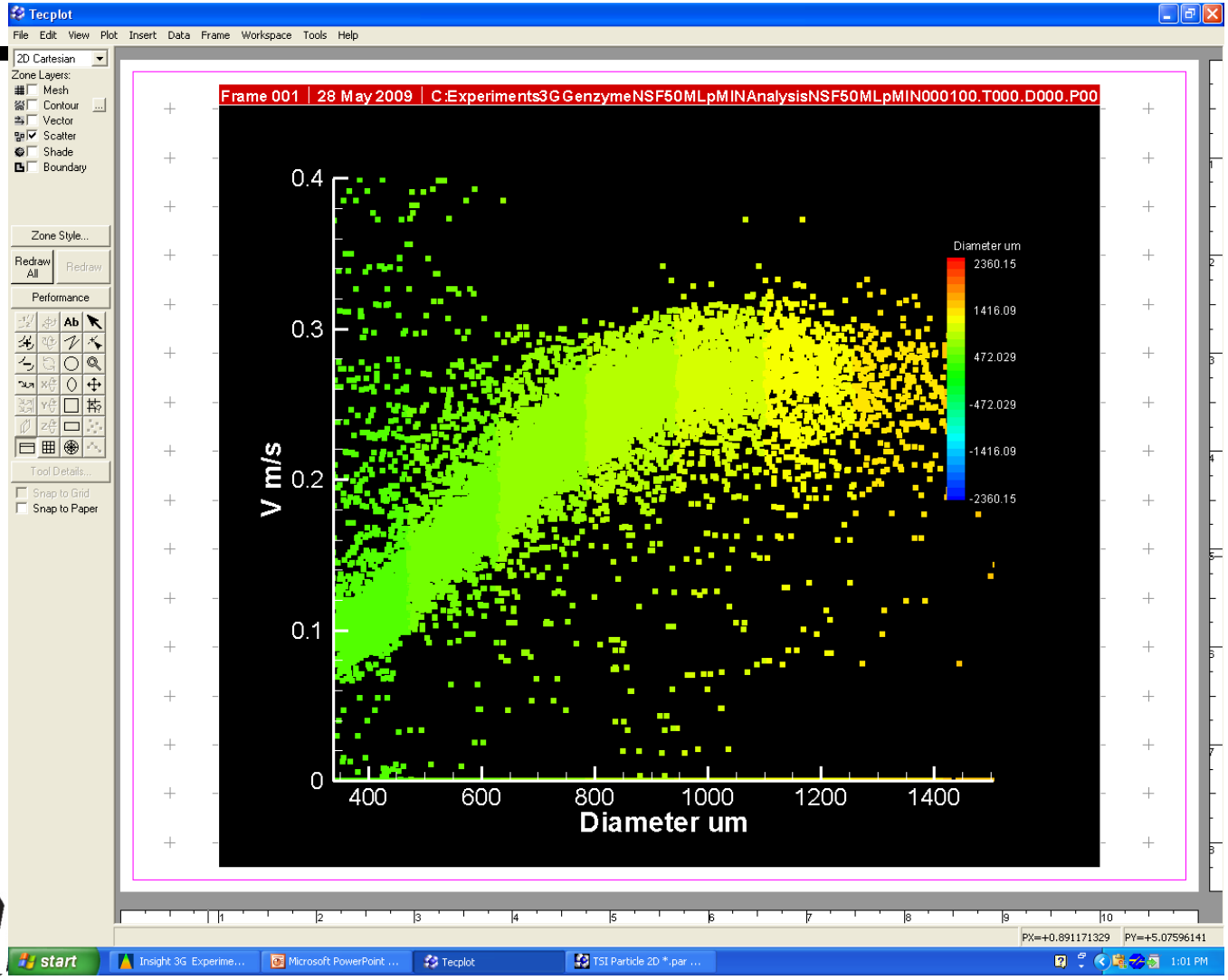


Processed Images

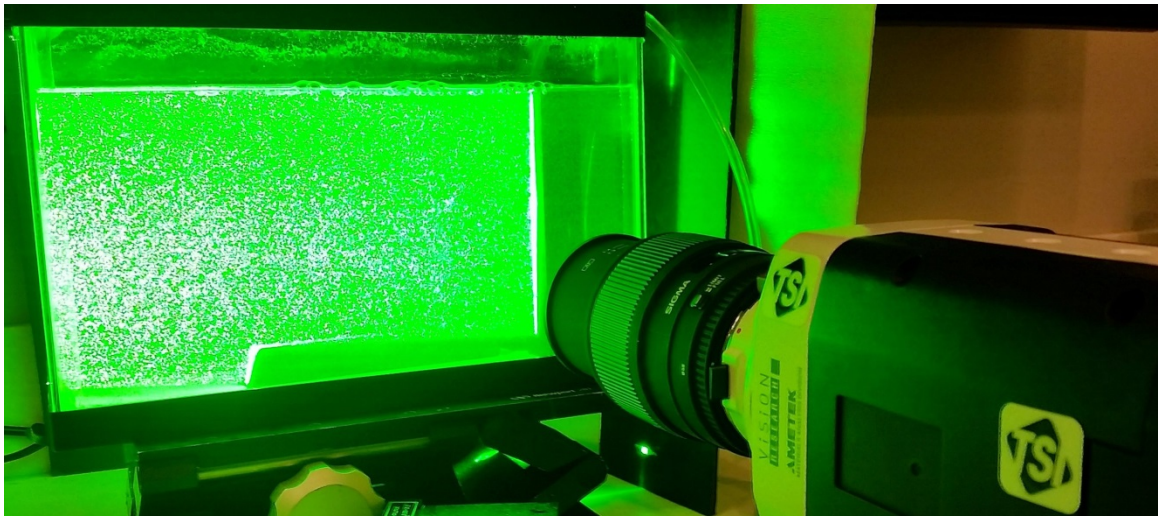




Size – Velocity Correlation



TIME-RESOLVED PIV MEASUREMENTS OF A 2-PHASE FLOW(BUBBLES AND MEDIA)

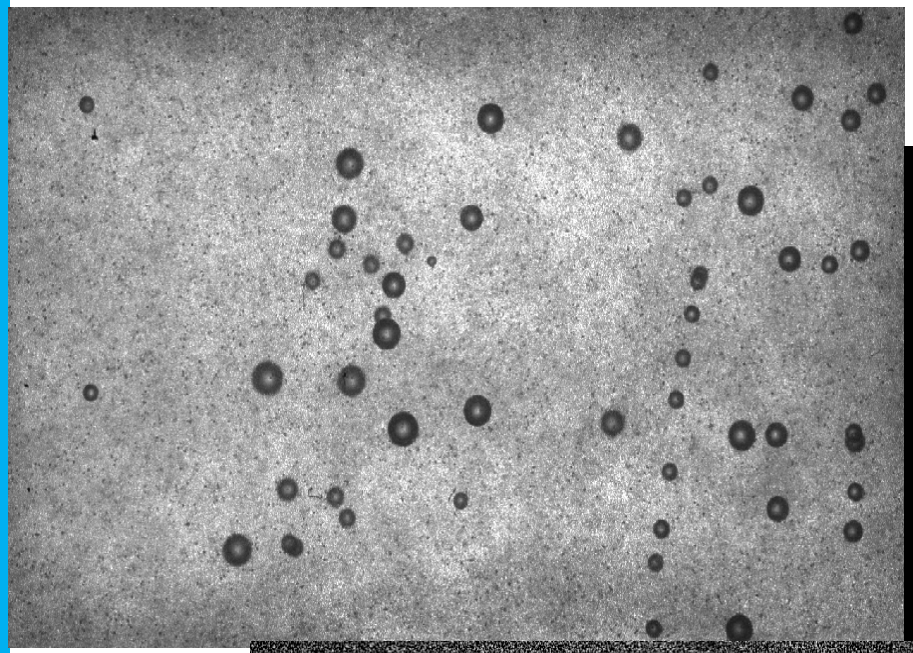


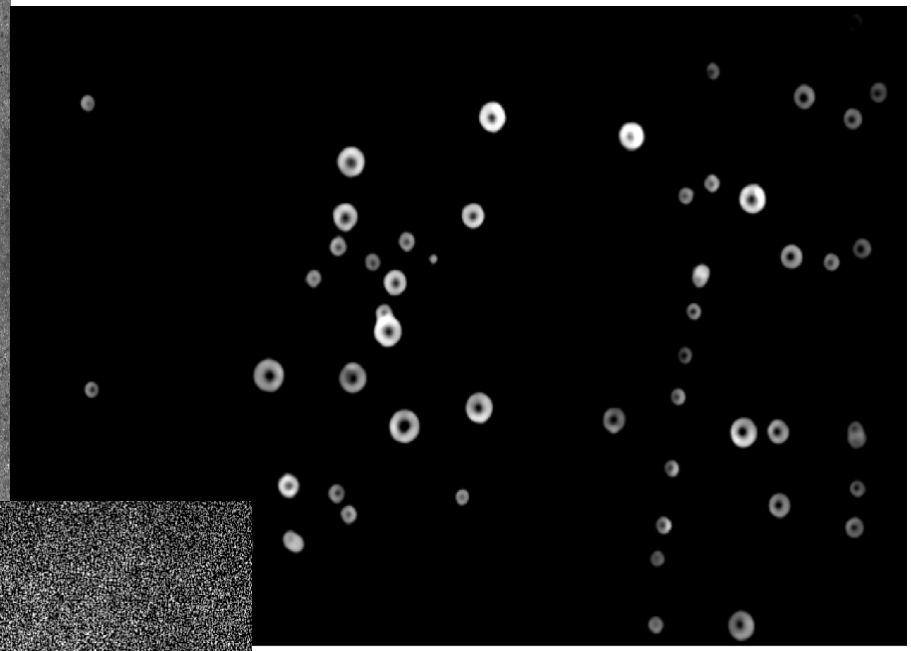
PIV system consisted of:

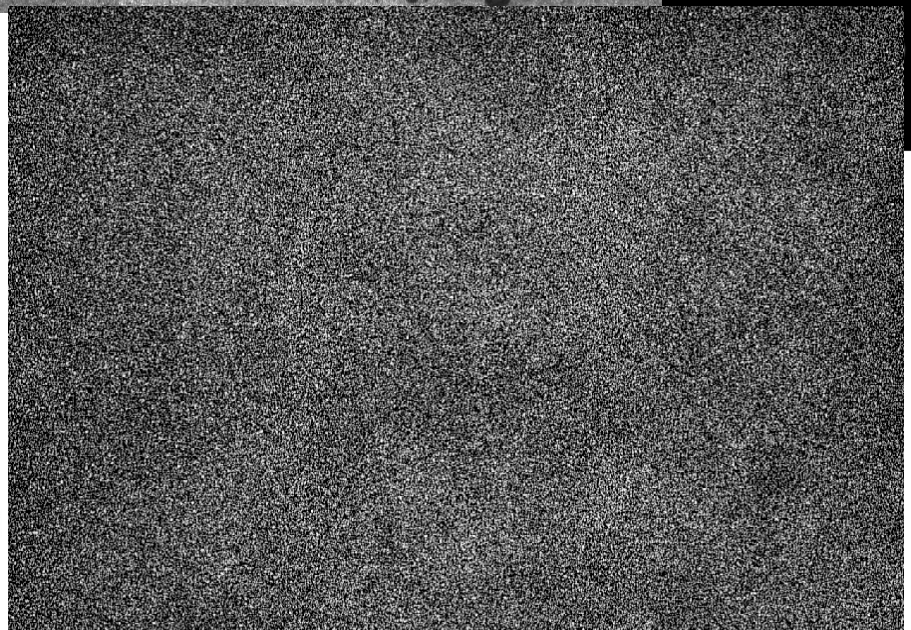
- Dual-head 1000 Hz Nd:YLF pulsed laser with 30 mJ/pulse and fitted with adjustable light sheet optics
- 1280 × 800 pixel CMOS camera operating at 1000 Hz (Model# 630083-3GB).

- The laser illuminated a diffuser placed at the background of the bubbly flow chamber.
- The camera was with its axis collinear with the laser illumination.
- A sparger was positioned at the bottom of the flow chamber, and bubbles of approximate size 1-2 mm were formed and were drawn upward through buoyancy forces

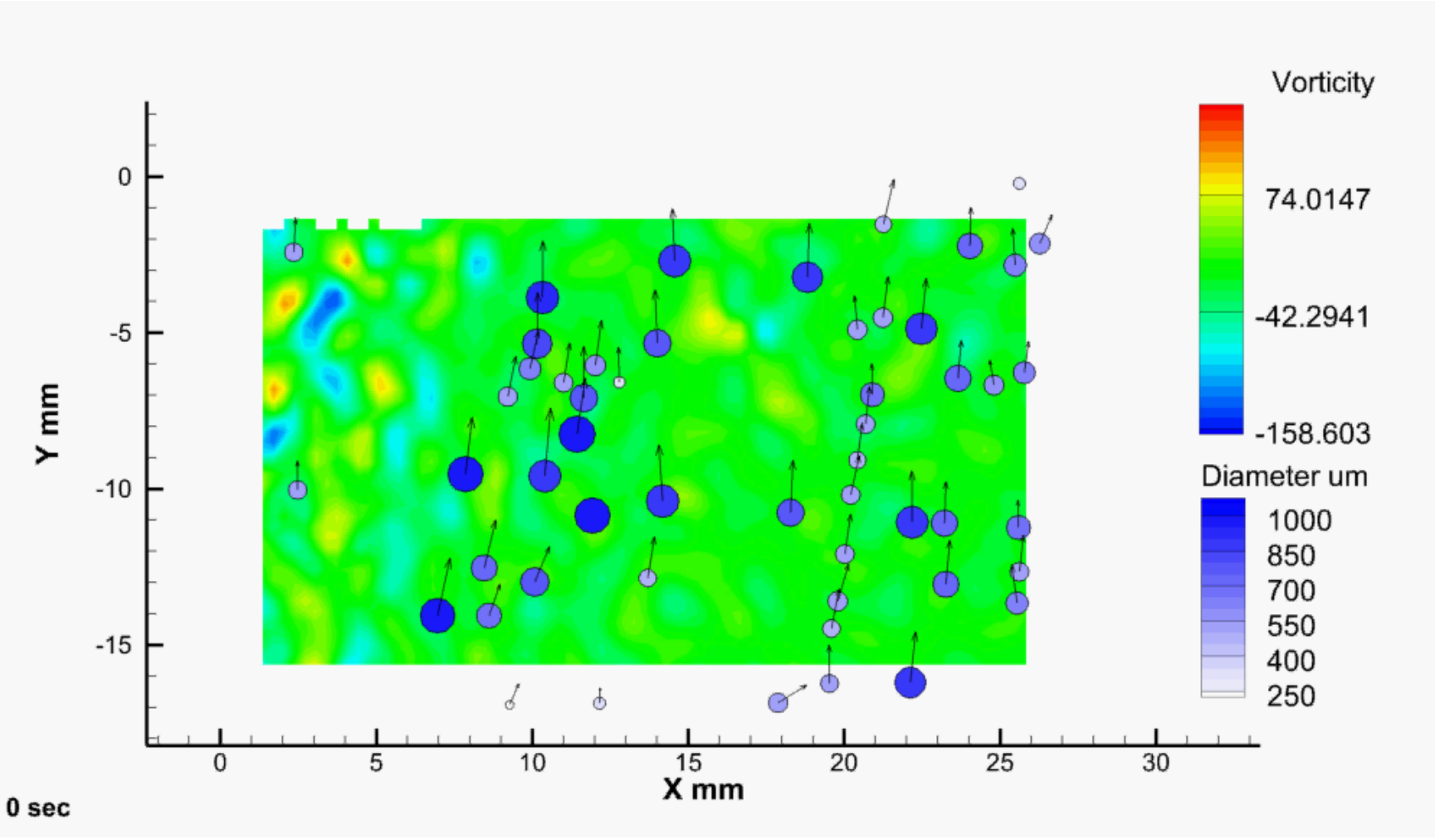
Phase Separation SSA PIV Bubbles



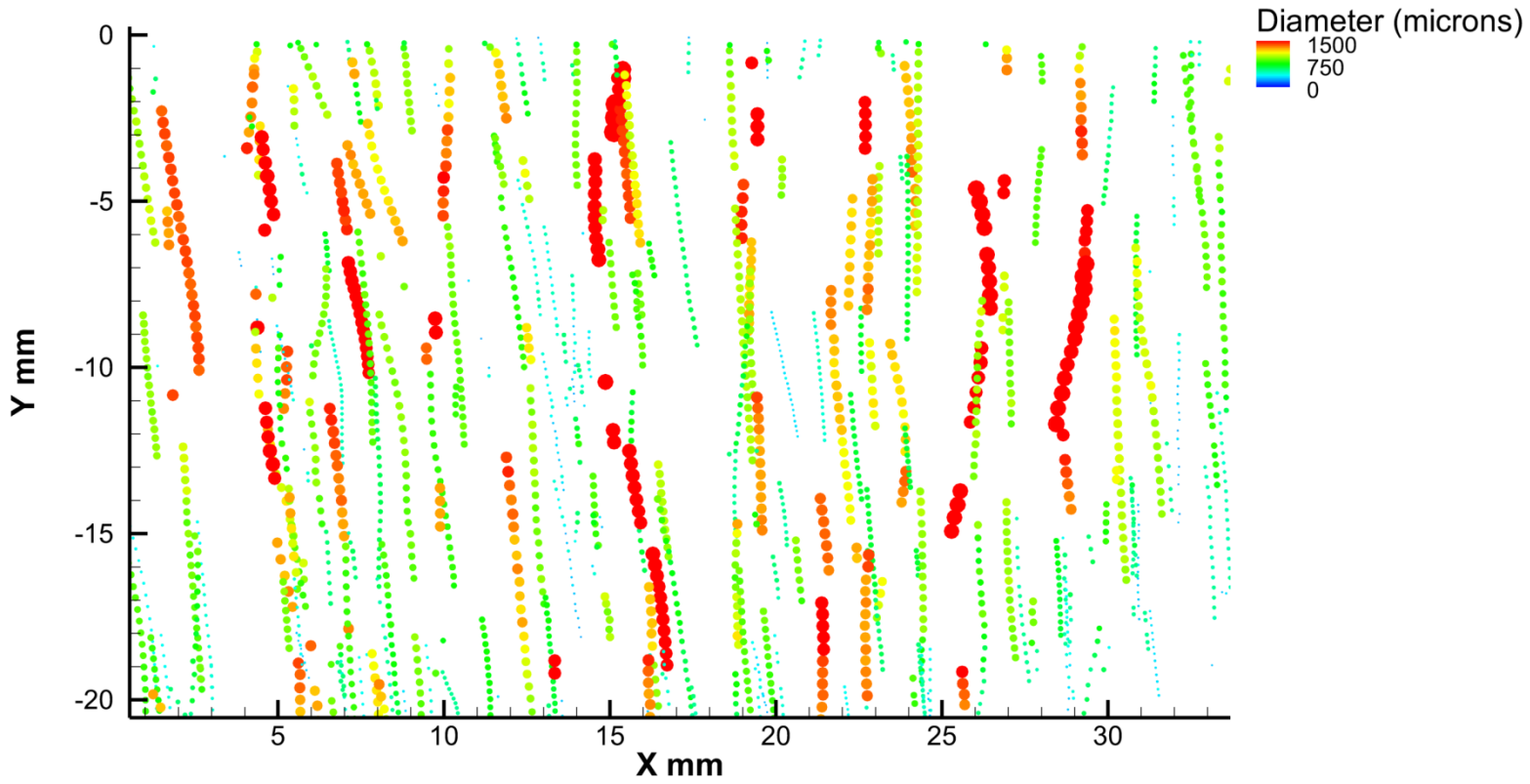




Bubbles and Flow Field



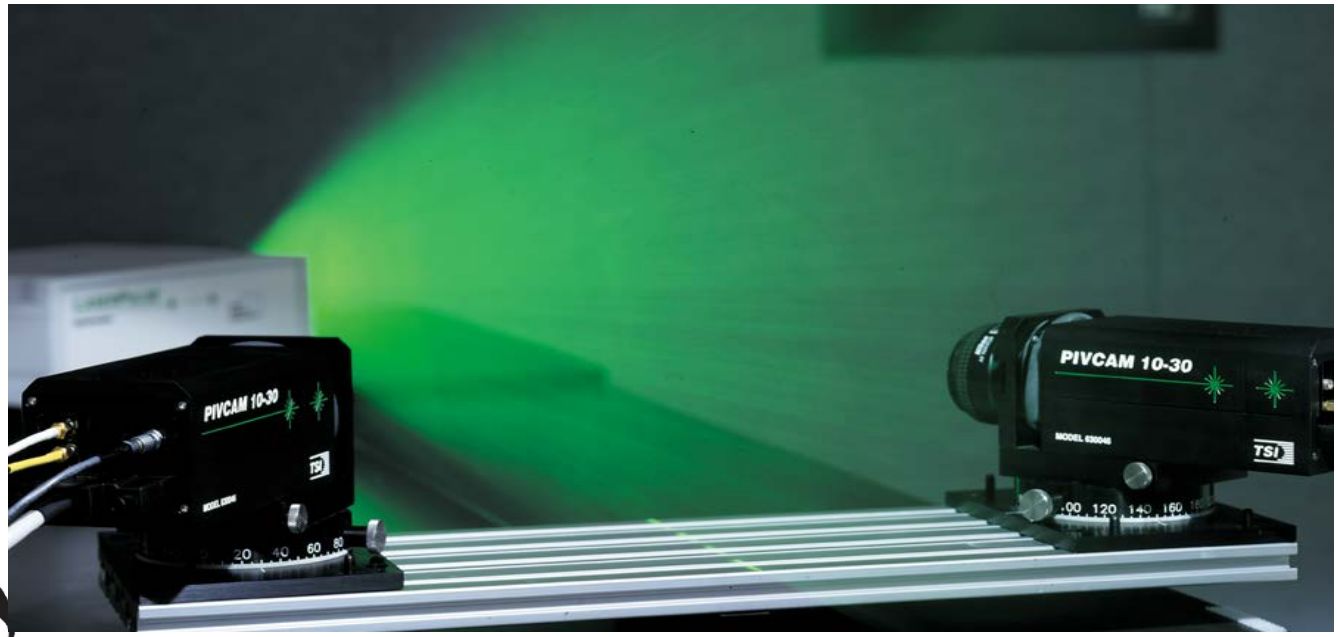
Bubble trajectories



Particle Image Velocimetry

3 Component measurements

+ Three Component PIV Measurements
  - Measurement of 3 components of velocity simultaneously
  - Illumination : using a light sheet
  - 3 components of measurements in a plane

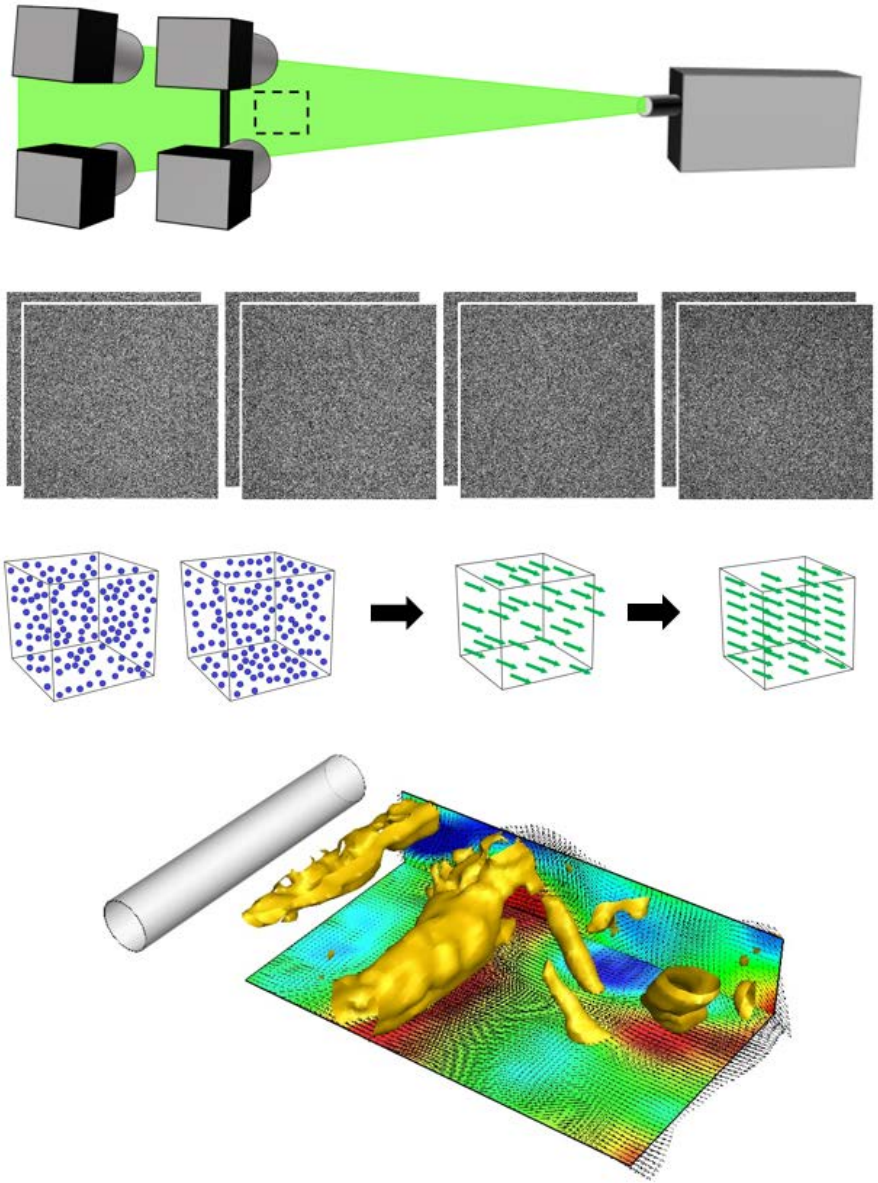


Volumetric PIV systems

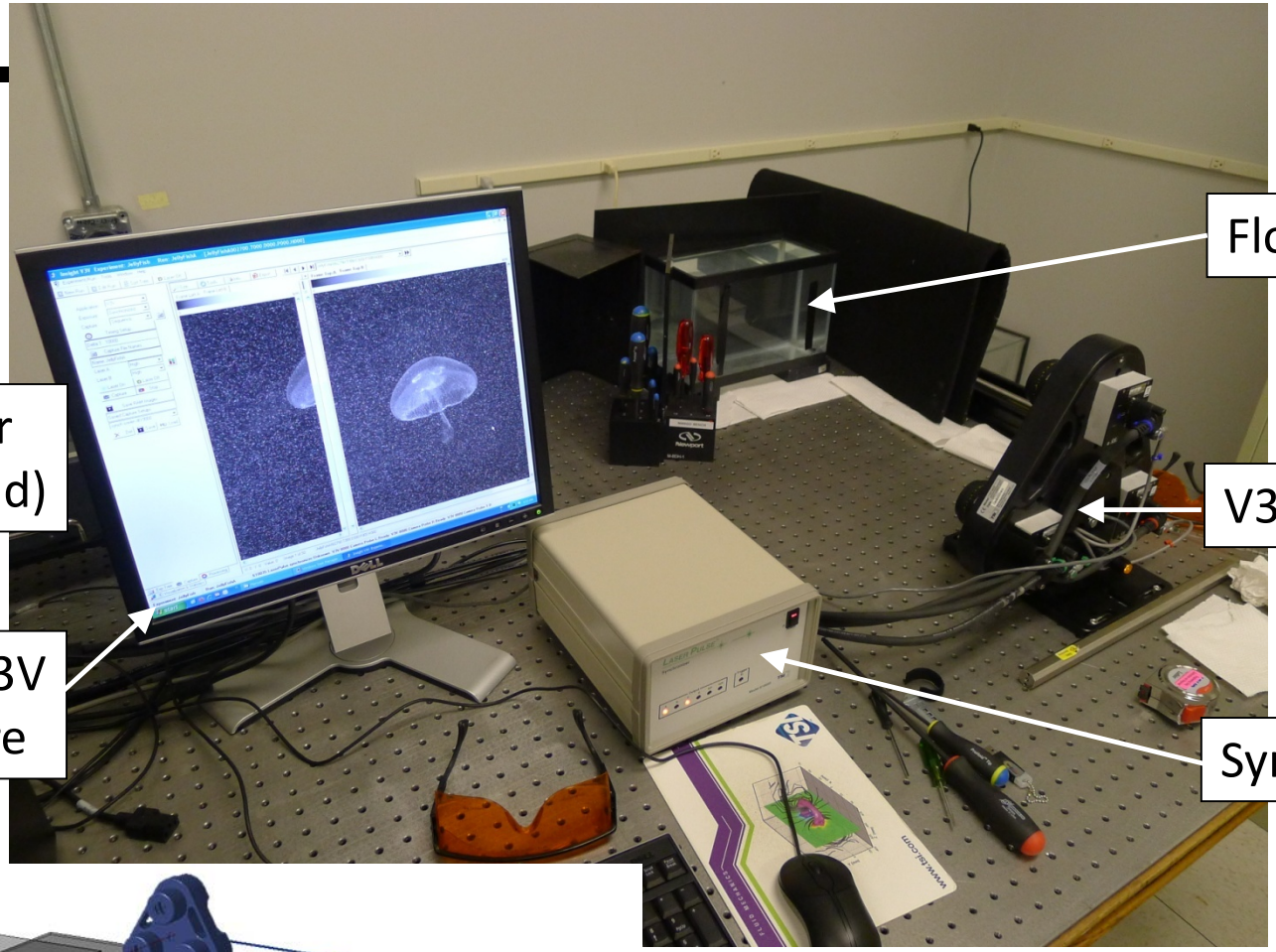
System Type	Characteristics and functions
	**V3V-TS volumetric PIV system** • Optimal system with fixed volume size -- 50 mm x 50 m x 30 mm max • Use of three camera configuration with detachable camera arrangement • High resolution cameras up to 29MPixels with frame rate up to 180 fps • High spatial resolution to resolve turbulent flow structure
	**V3V-CS volumetric PIV system** • Optimal system with fixed volume size -- 140 mm x 140 m x 100 mm max • Use of three camera configuration with detachable camera arrangement • High resolution cameras up to 29MPixels with frame rate up to 180 fps • Large volume size to capture complete coherent flow structure
	**4-Camera volumetric PIV system** • Flexible camera arrangement for optimized measurement volume and spatial resolution • Support of high speed cameras for Time-resolved volumetric measurements with capture rate up to 10kHz • Variety of hardware makes it possible to choose between high temporal or spatial resolution, or both • Upgradeable from single camera PIV, stereo PIV and V3V to the latest configuration

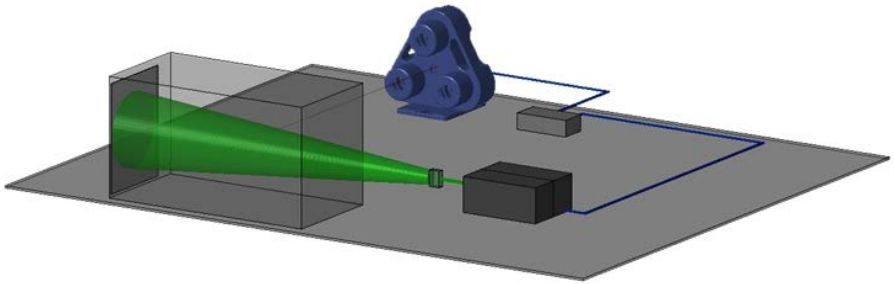
TAPTV Operation Overview

- **3D Imaging Technique**
  - Calibrate Camera with a target of known dot-spacing
- **Capture and Identify Particle Images**
  - Laser illuminates tracers in a volume
  - 2 laser pulses (like PIV)
  - Identify 2D particle locations in each image
- **3D Particle Mapping**
  - Map particle images into 3D space using the camera calibration
- **Particle Tracking**
  - Determine individual particle tracks within the volume
  - Velocity = displacement / time
- **Interpolation (Optional)**
  - Interpolate tracks onto a regular grid



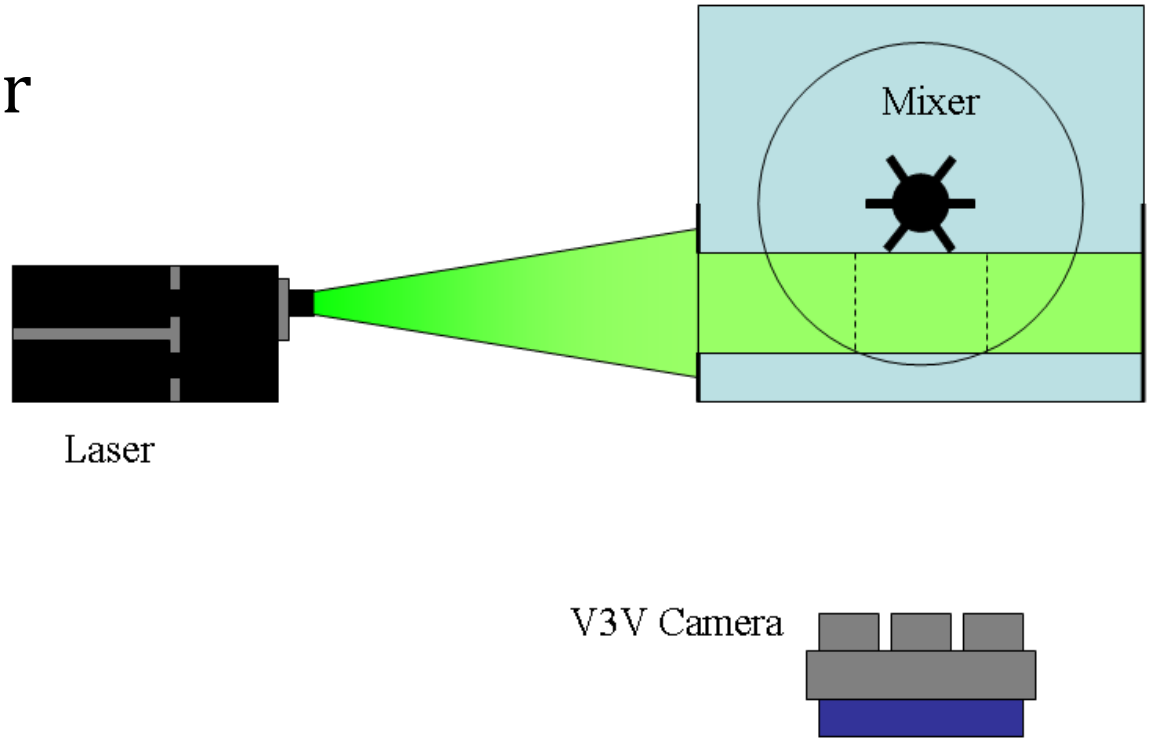
V3V System in Operation





Rushton Turbine

+ Rushton Mixer

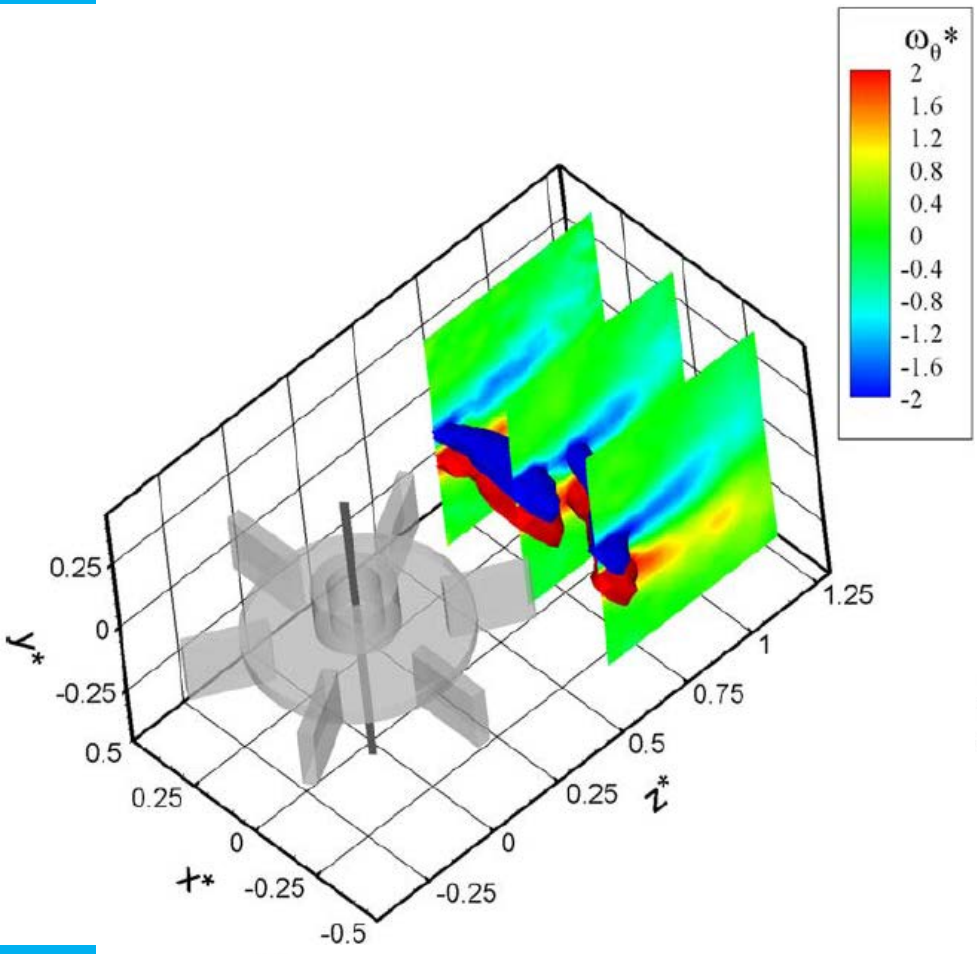


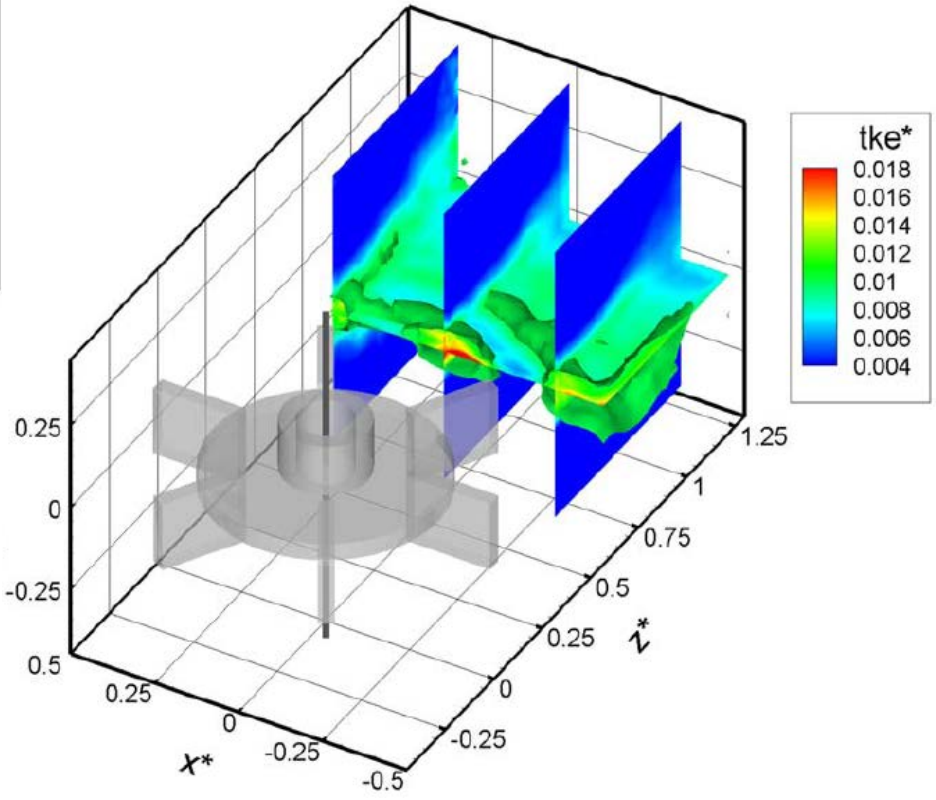
Sharp K, Hill D, Troolin D, Walters G, and Lai W (2009) "Volumetric 3-component velocimetry measurements of the turbulent flow around a Rushton turbine," *Experiments in Fluids*, 48(1), pp. 167-183, doi 10.1007/s00348-009-0711-9.

Rushton Turbine

- Re = 107,000
- 295rpm
- Inner Diameter D=44.3cm
- Turbine placed at D/2
- Water depth =D
- Turbine Blade Diameter D/3 (tip to tip)
- Volume 120 by 120 by 100mm
- Seeding polycrystalline particles 100 micron
- Average of 250 Phase locked measurements shown
- Spacing 4mm between vectors

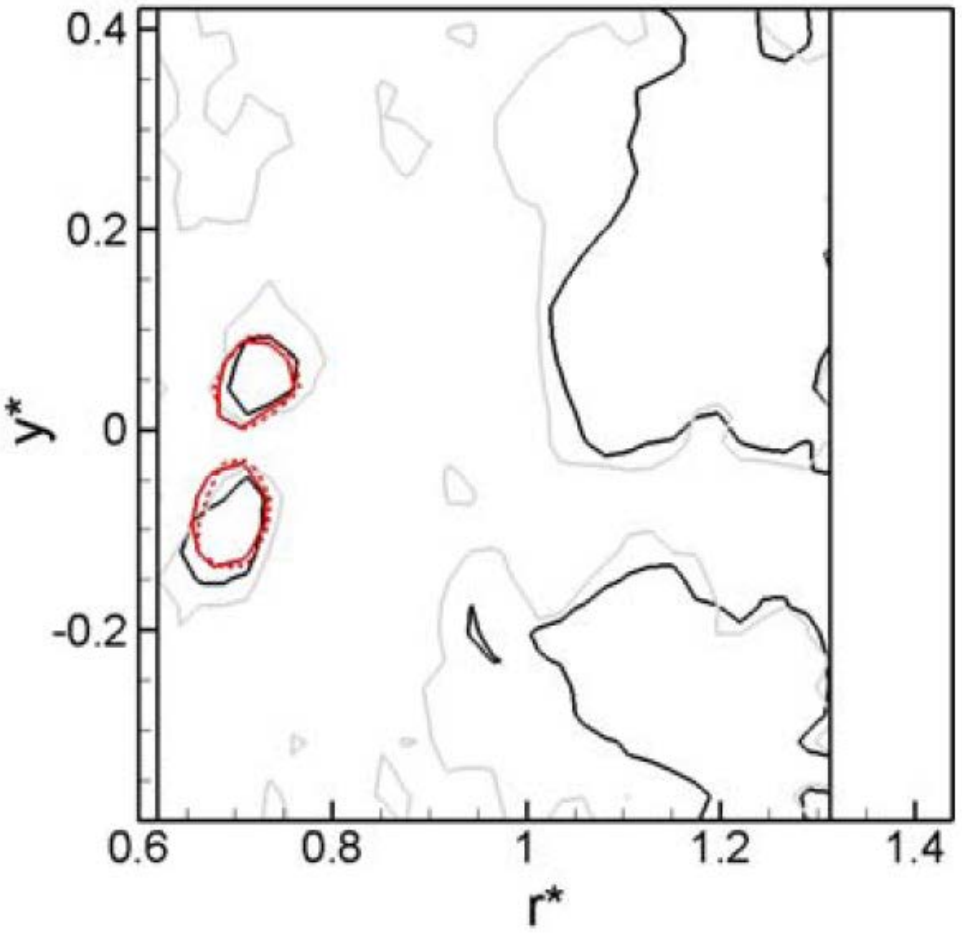
Rushton Turbine



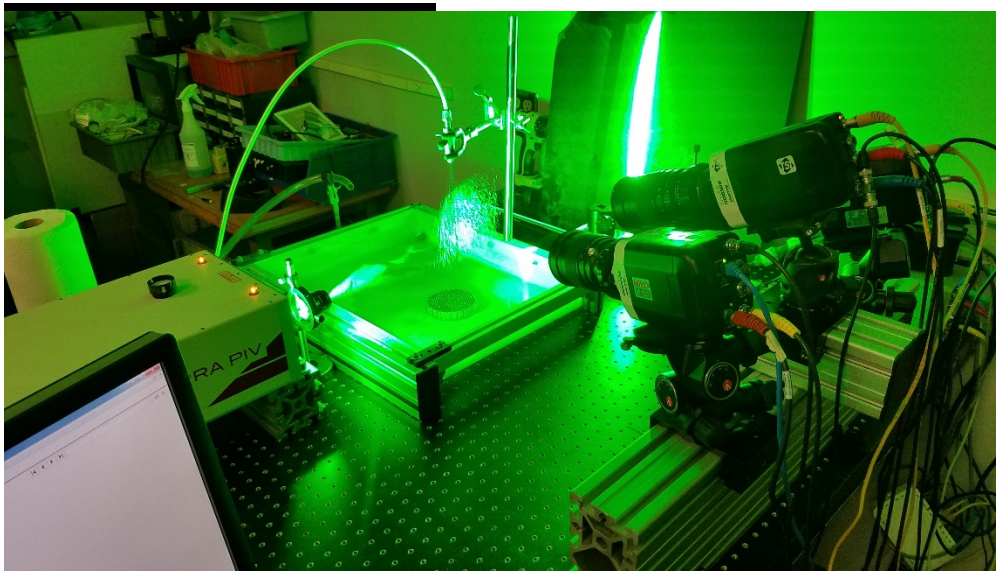


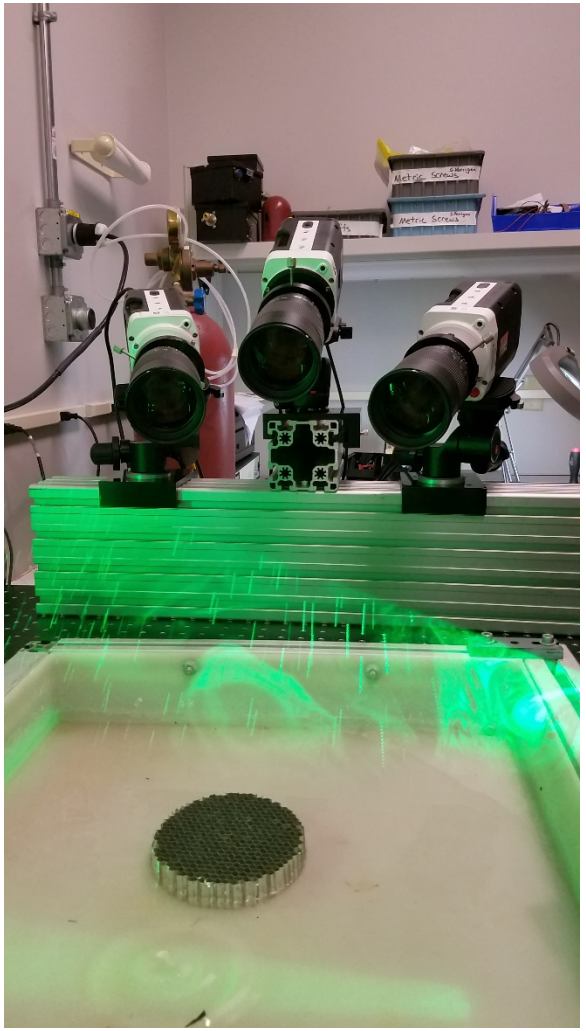
Rushton Turbine

- Comparison to PIV
- λ_{ci}
  - Red Solid – V3V
  - Red Dashed – PIV
- λ_2
  - Black – V3V
  - Gray – PIV

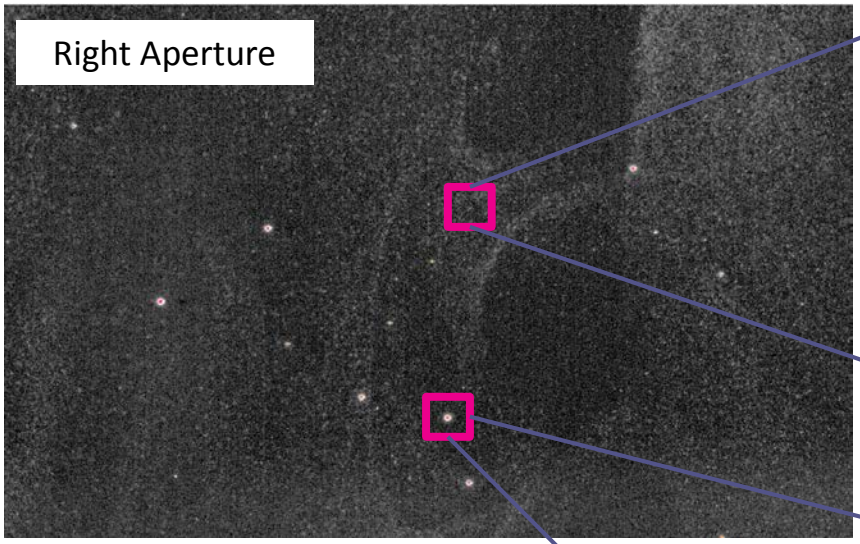


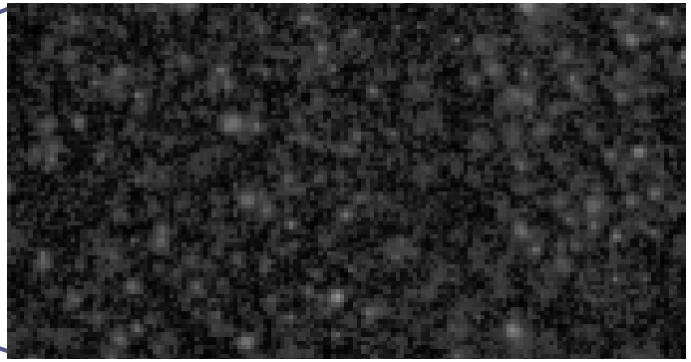
Volumetric PIV:
Experimental Setup



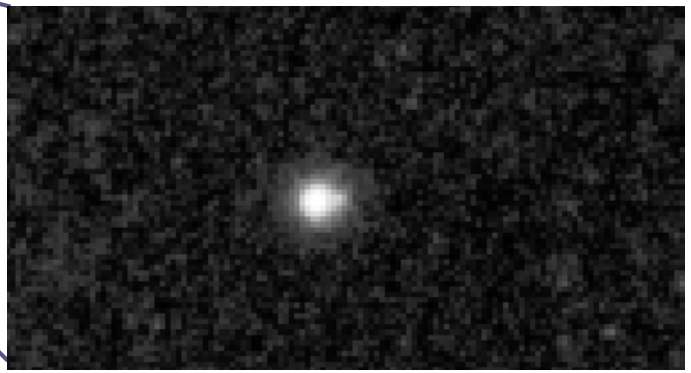


Volumetric PIV:
Two-Phase Particle Identification





Seed Particle Images



Rain Drop Particle Image

Rain drops with flow tracers

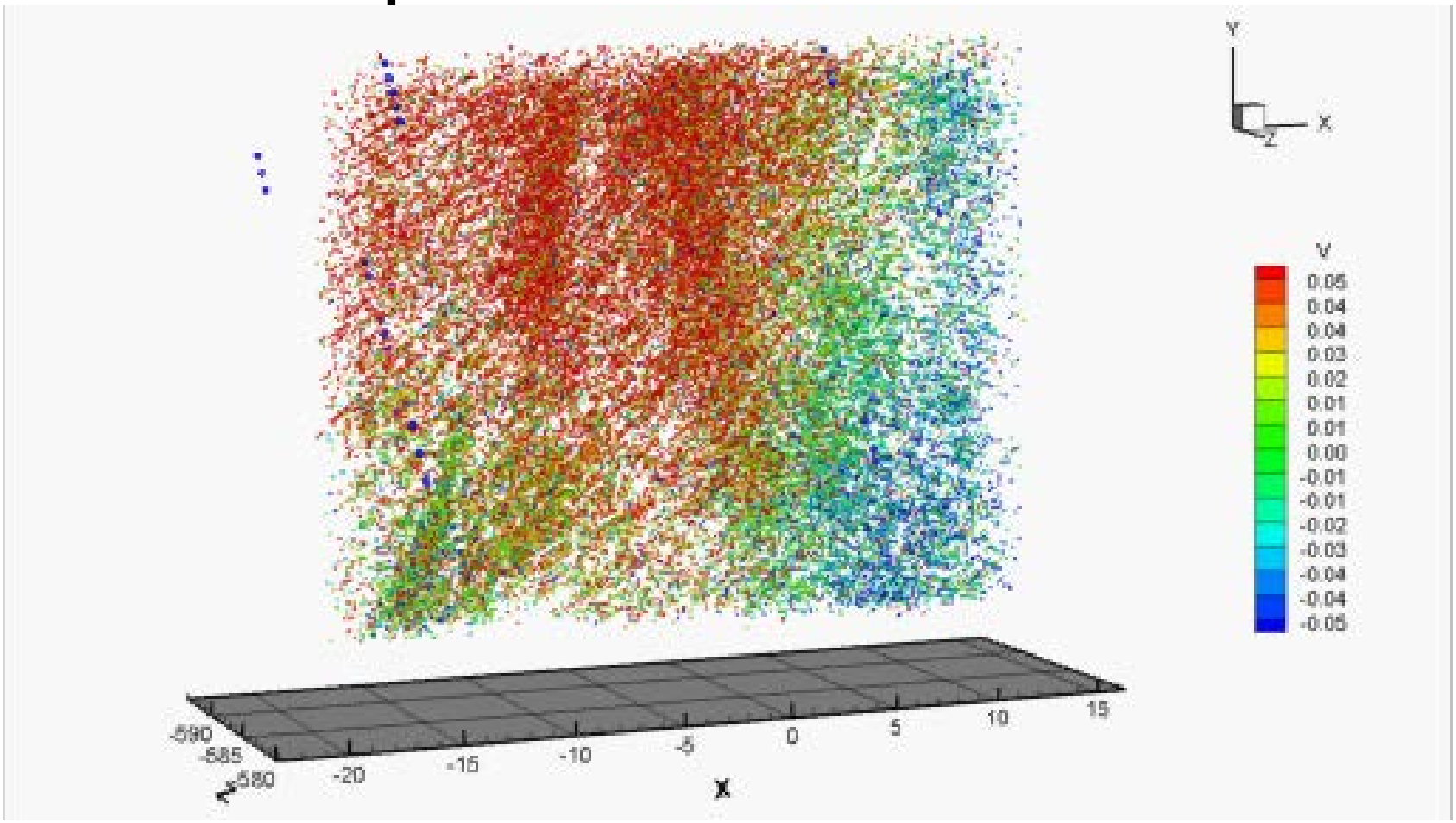
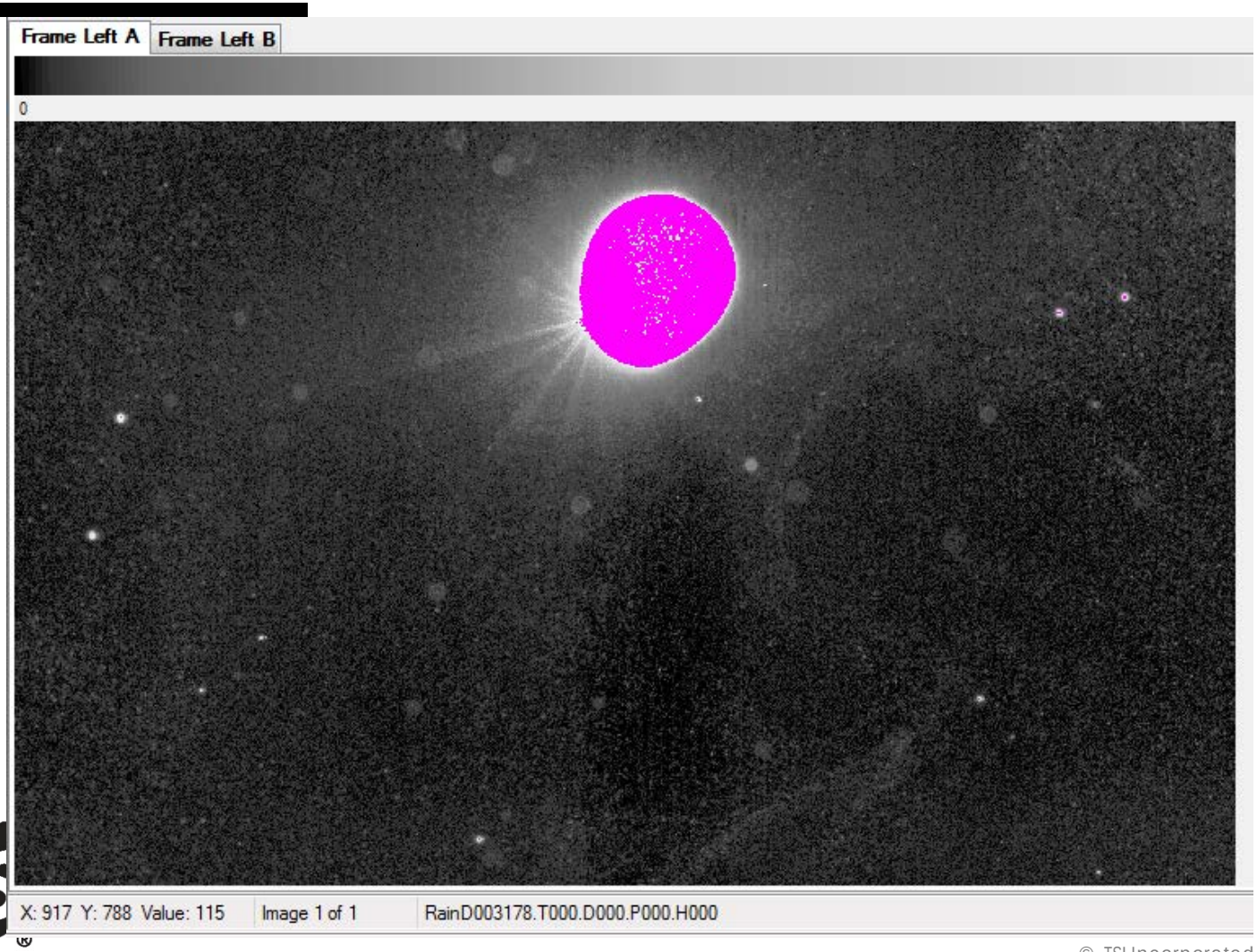
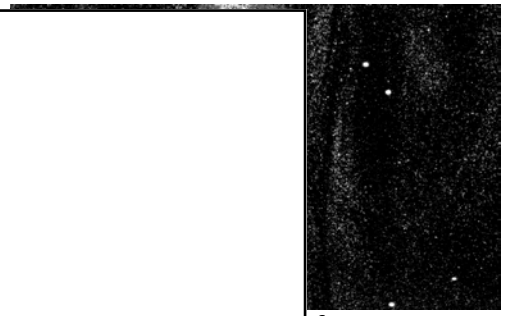


Image showing large rain drop



Volumetric PIV:
InsightV3V Two-Phase Measurements



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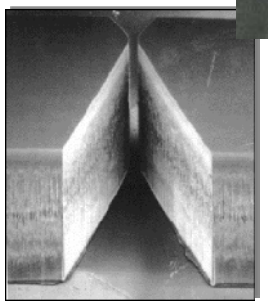
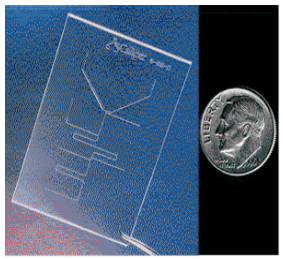
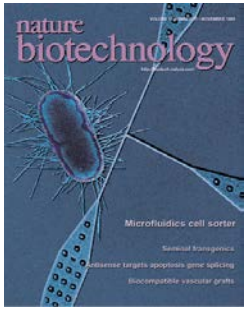
Simultaneous seed particle velocity vectors & droplet particles size & velocity vectors. Colored by normalized velocity magnitude.

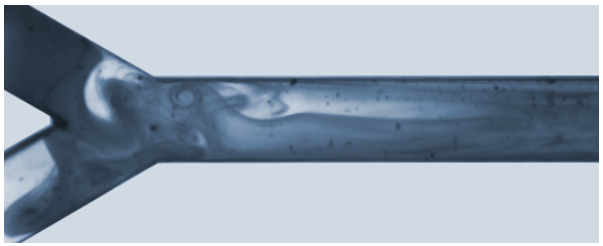
MicroPIV Motivation



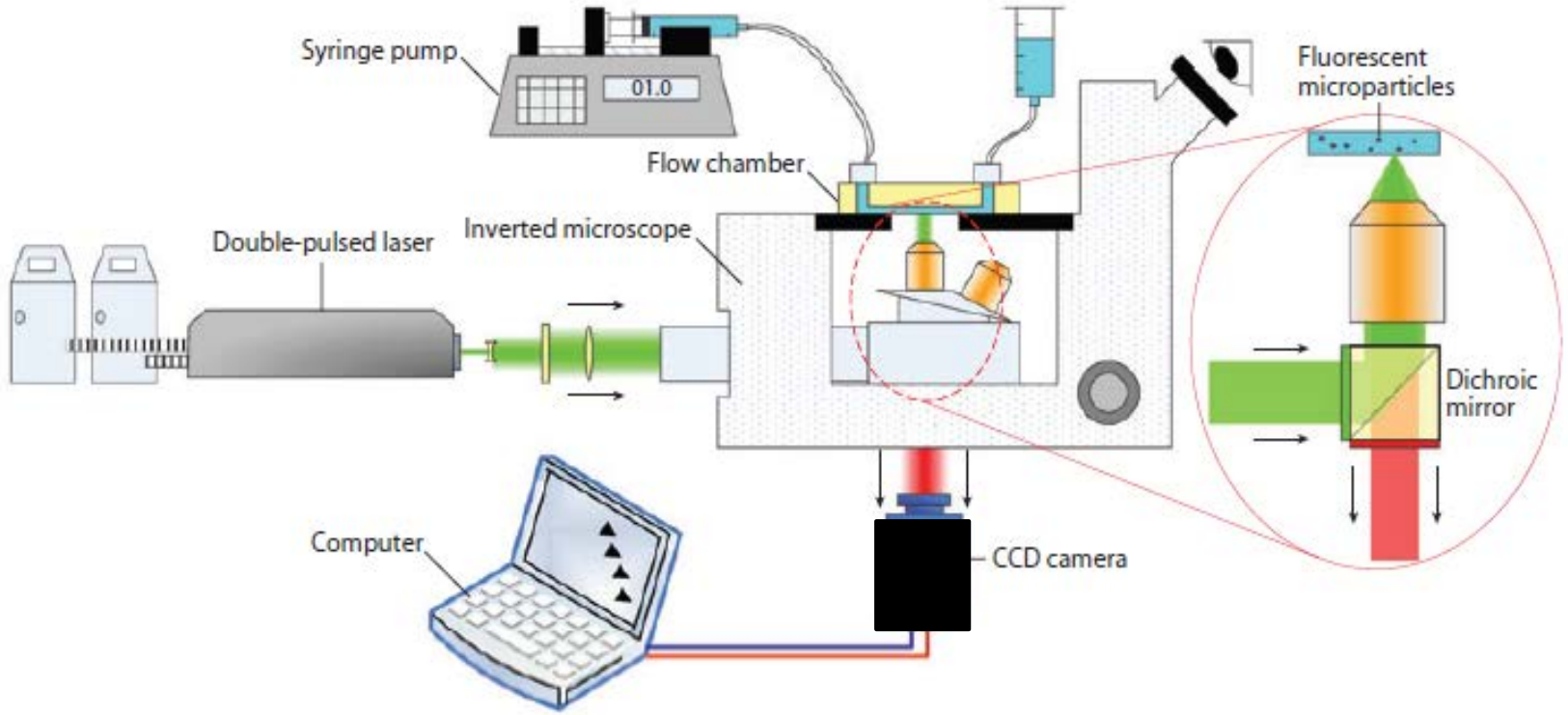
+ **Aero-MEMS applications**
  - Micron scale supersonic nozzles (MIT)
  - Remote surveillance aircraft (UCLA, Caltech)
  - Micro Air Vehicle (MAV): flapping-wing vehicle < 15 cm in all directions (UCLA)
  - Micro-jet engine (Epstein *et al.*, MIT)
+ **Bio-MEMS Applications:**
  - Chemical and biological analysis: "lab-on-a-chip" for medical and defense applications
  - Microfabricated needles for drug delivery
  - Flow sorter (Caltech)
+ **Complex microfluidic devices:**
  - Micro mixers
  - Micro bio-reactors
  - Micro heat-exchangers



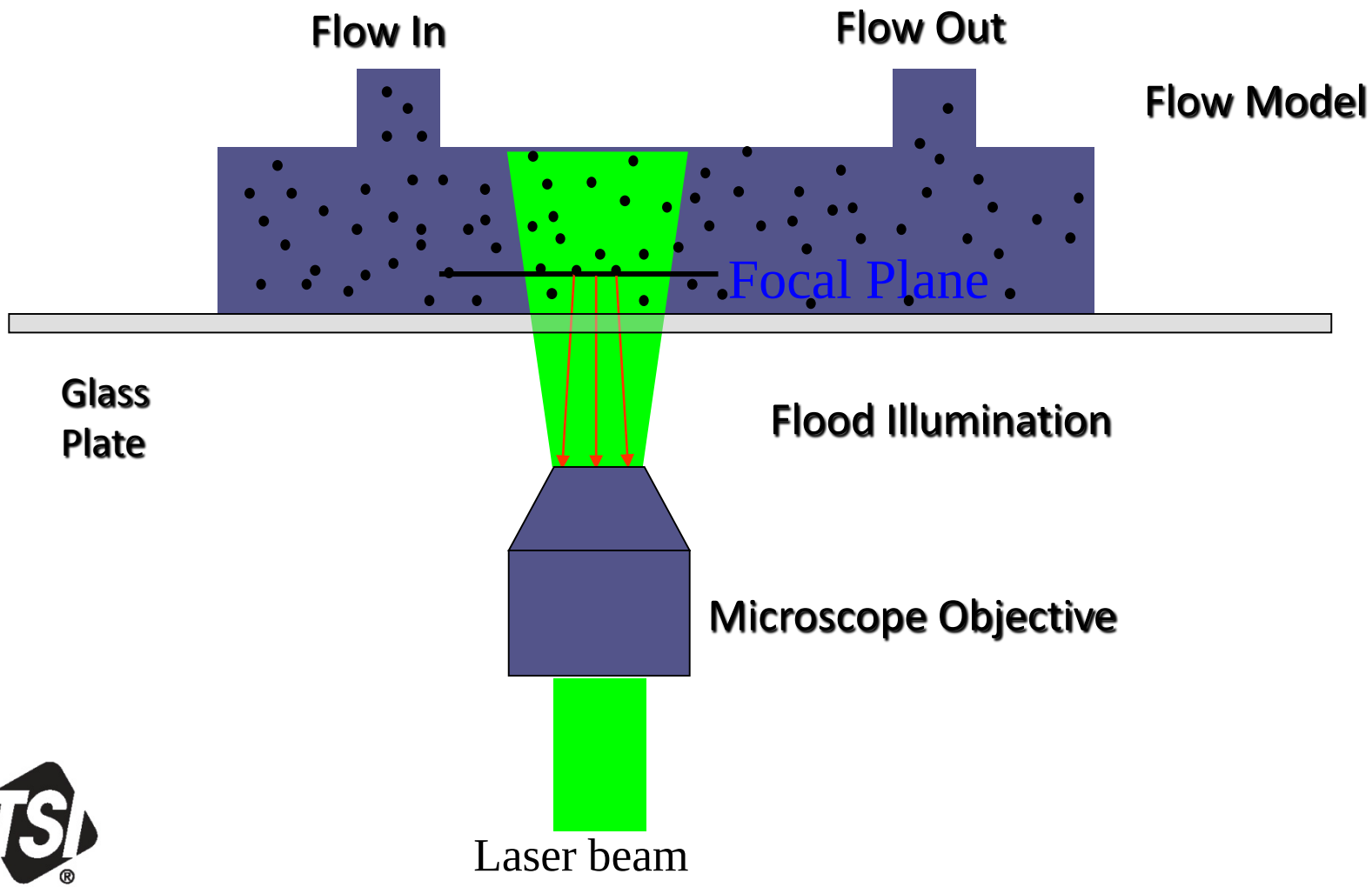




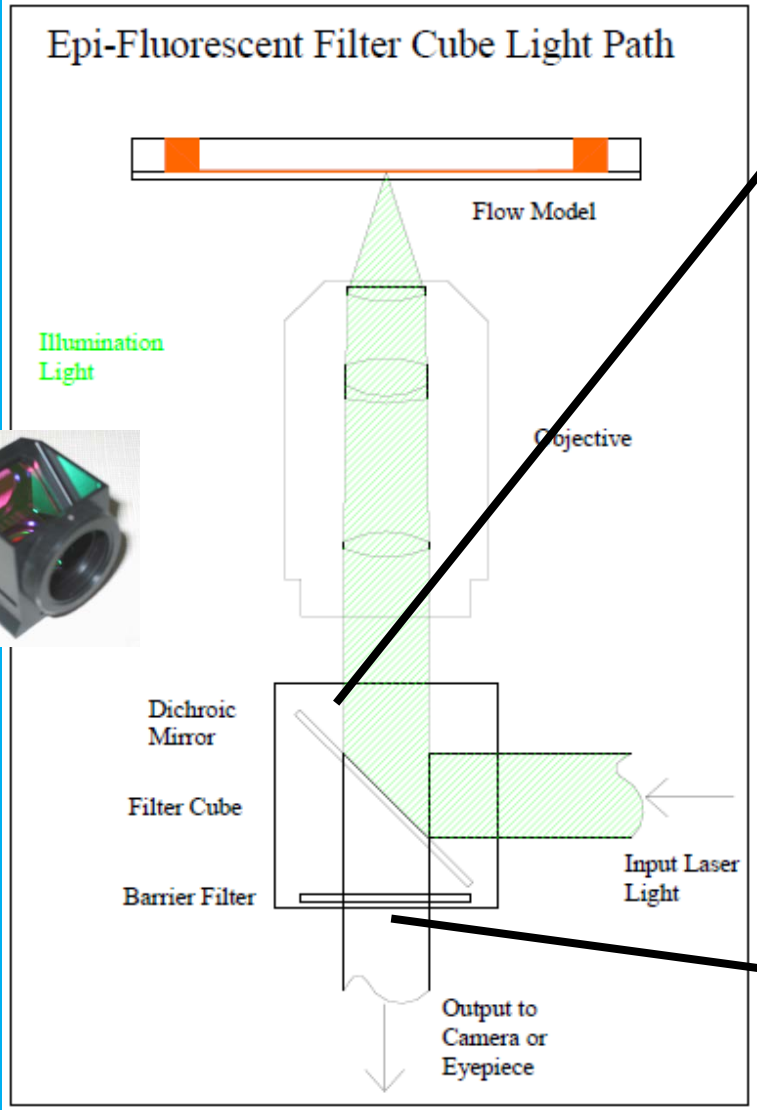
Theory of Operation (Schematic)

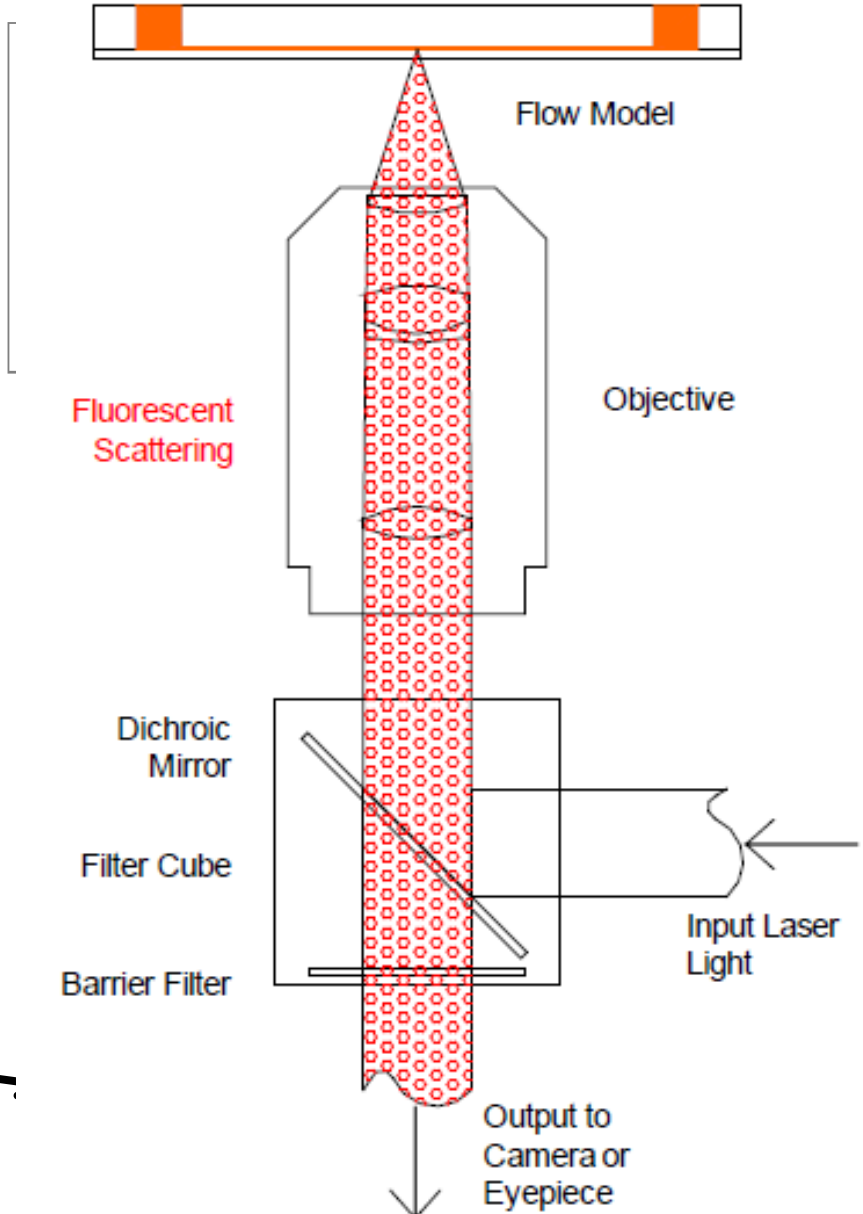


Details on Micro-flows Measurement



Theory of Operation (Filter cube light path)

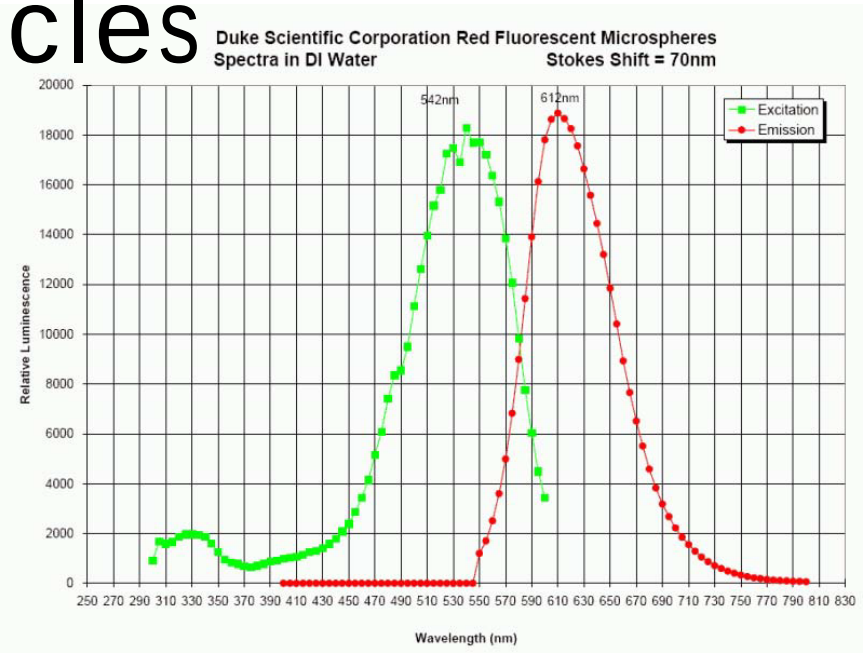




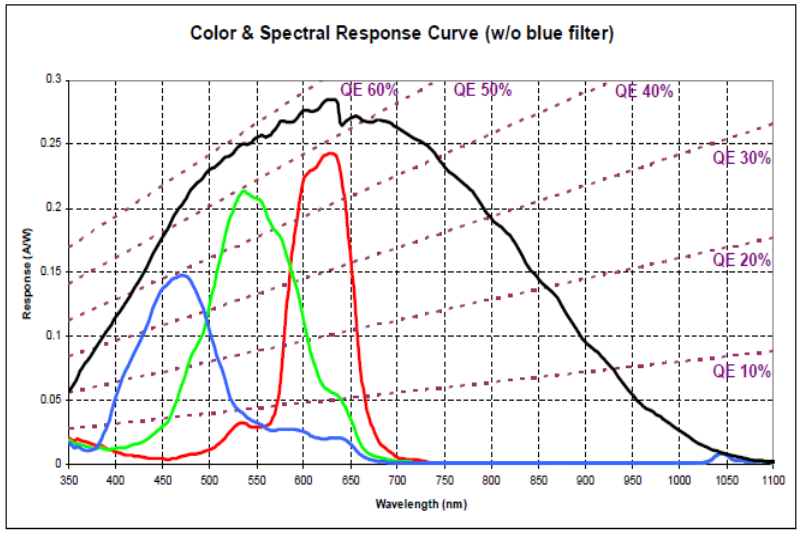
Theory of Operation (Similarities and Differentiators with PIV)

+ **Illumination sources:**
  - Dual pulsed – Dual Head Lasers (527 or 532Hz, 15Hz to kHz)
  - CW lasers
  - LED
+ **Volume illumination**
  - Via microscope objectives
  - Measurement plane defined by Depth of Correlation (DOF)
+ **Fluorescent particles**
  - In general working with smaller size particles (0.1 to 3 um)
  - Important to mention:
    - Brownian motion → random thermal vibration of seed particles
    - Saffman force → can become large near boundary
    - External arbitrary forces → hard to account for…

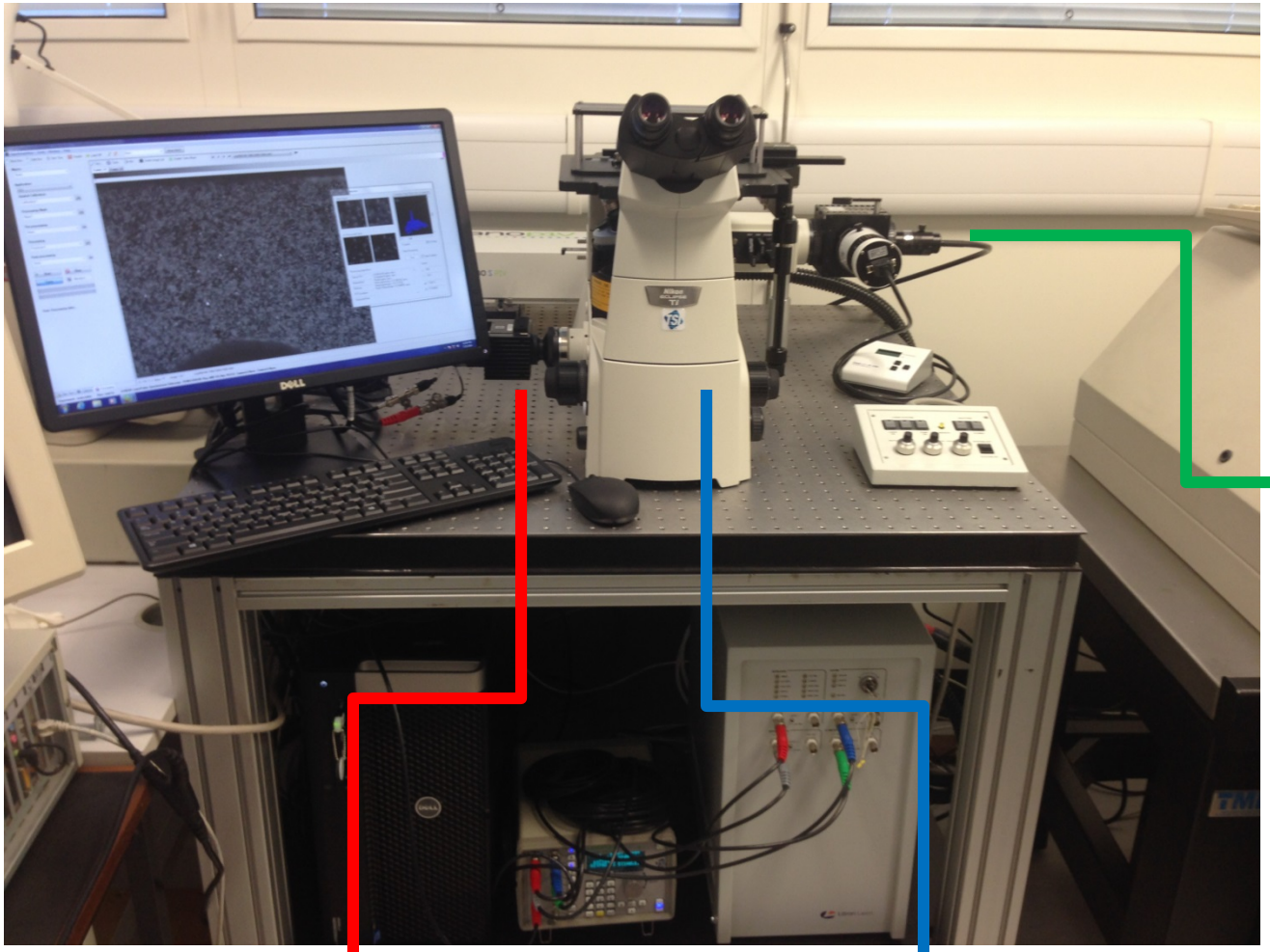
Fluorescent Particles



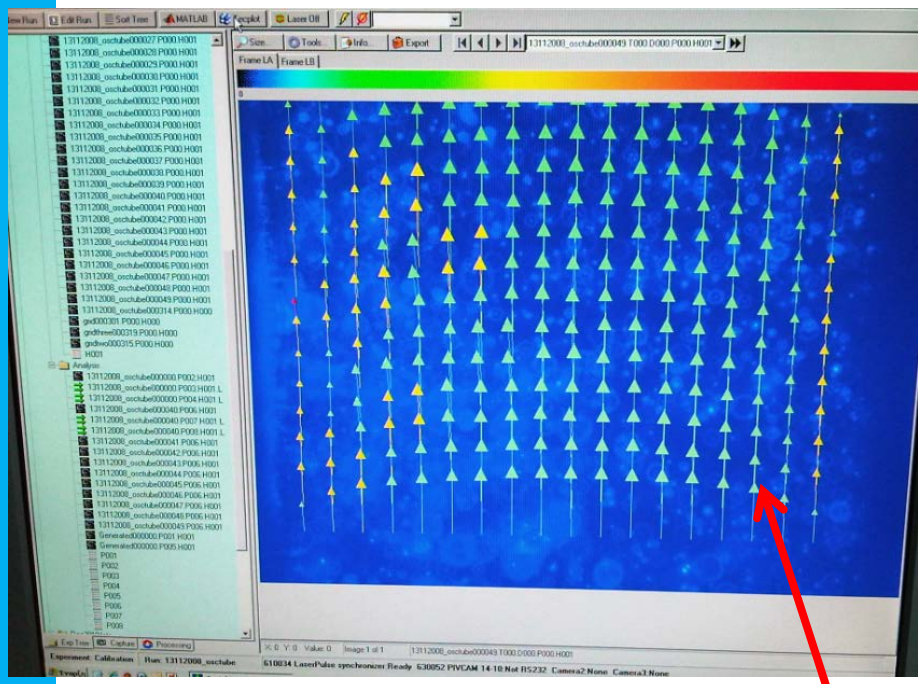
+ Sizes (0.1 to 3um)
+ Orange
  - (540nm, 565nm)
+ Red
  - (542nm, 612nm)
+ Vendors
  - Molecular probes
  - Thermo
+ Quantum Efficiency (QE):
  - CCD sensors
  - CMOS sensors
  - Intensified cameras

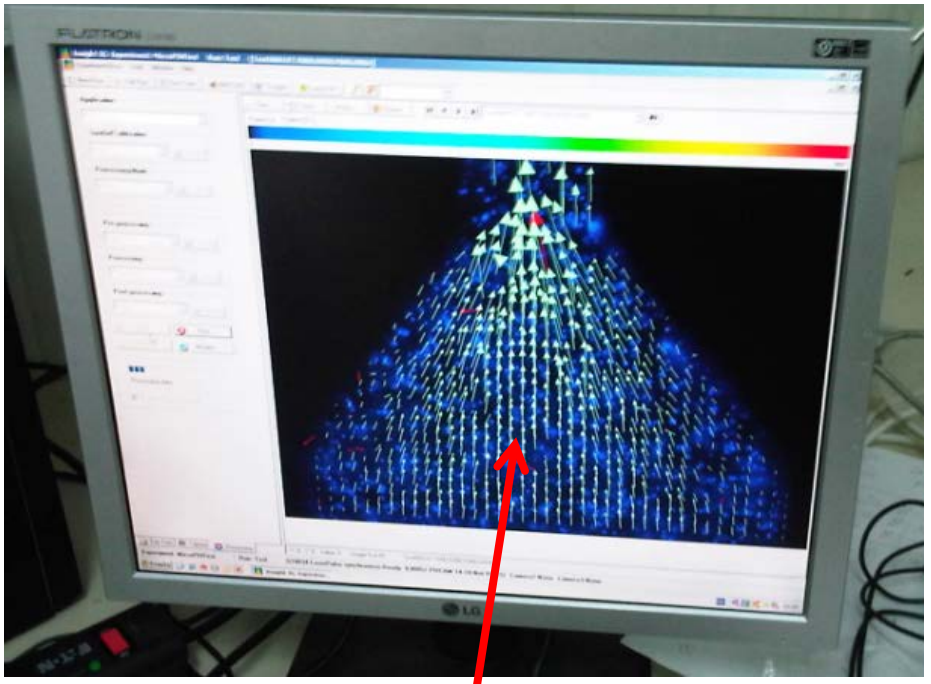


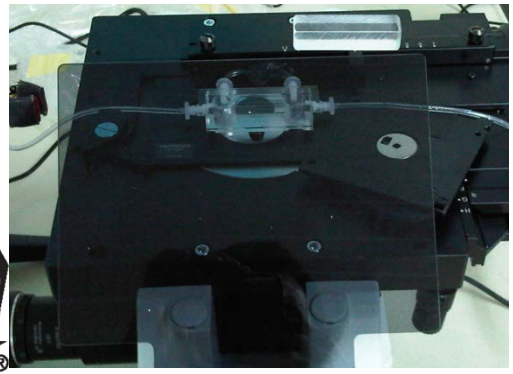
Typical micro PIV system

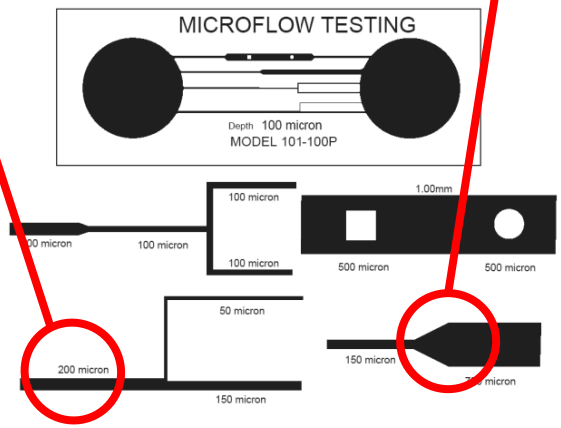


Typical micro PIV system

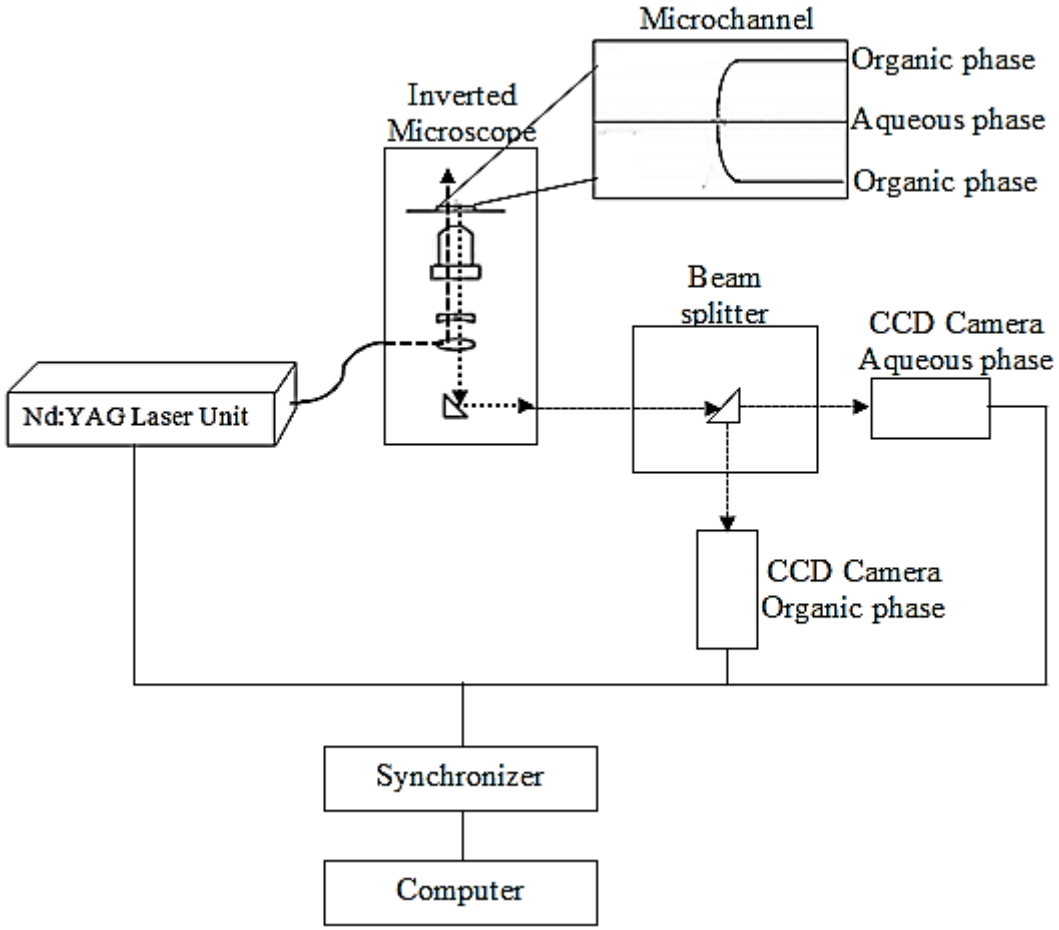




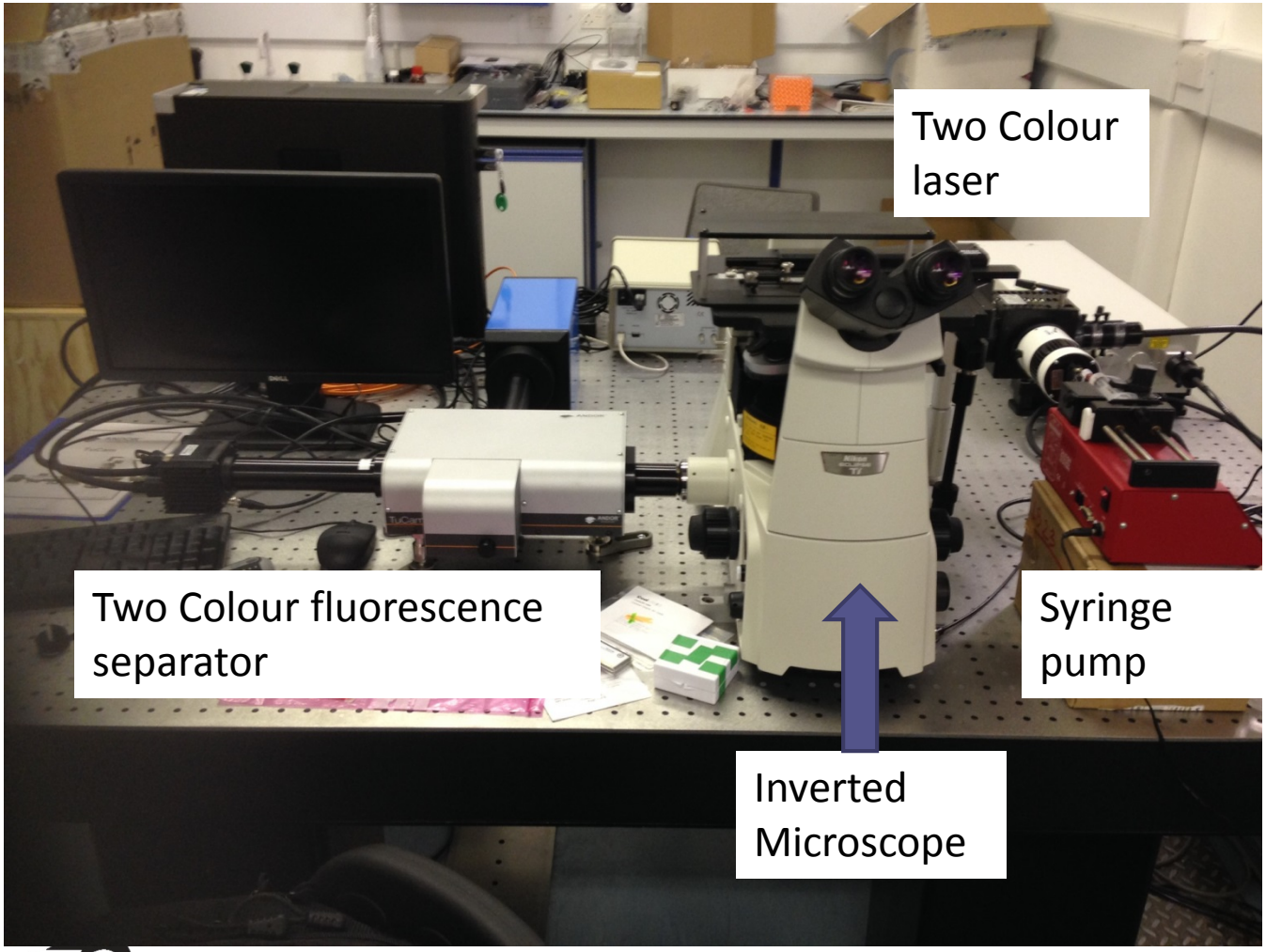




Two Colour Micro PIV



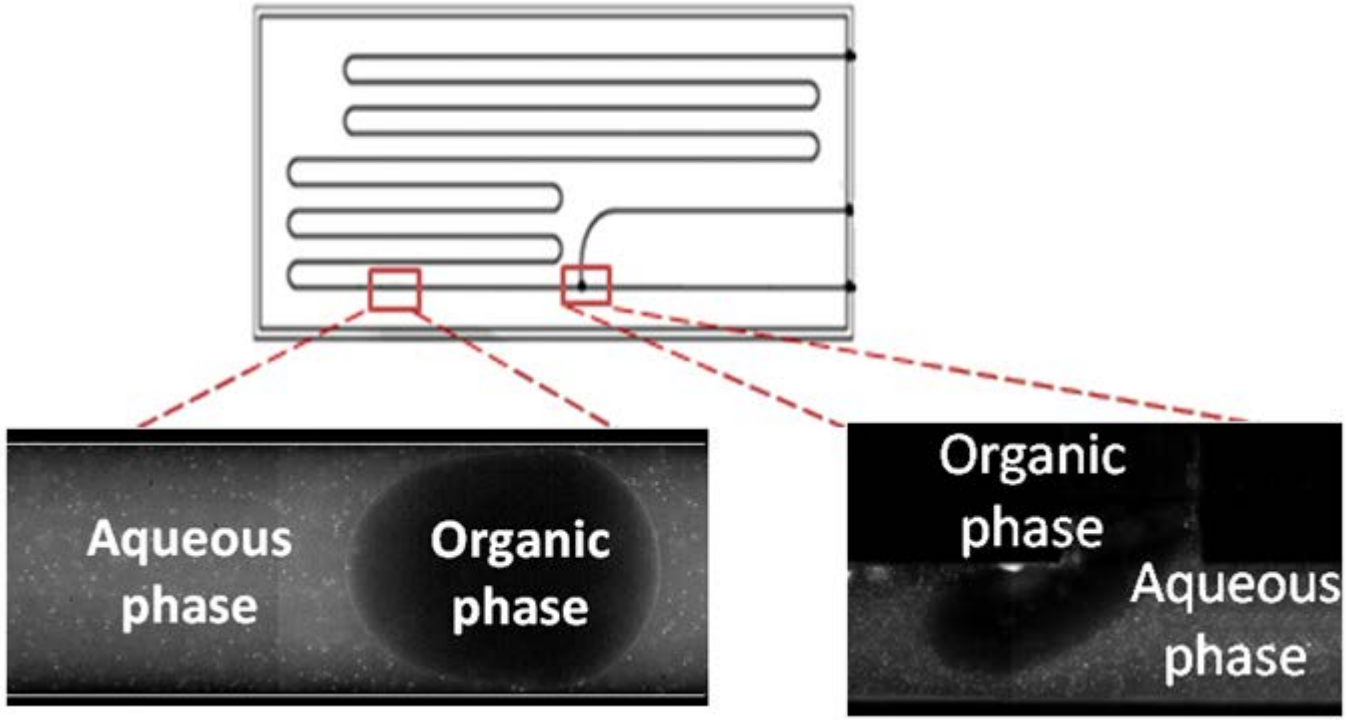
Two Colour Micro PIV



Details of set up

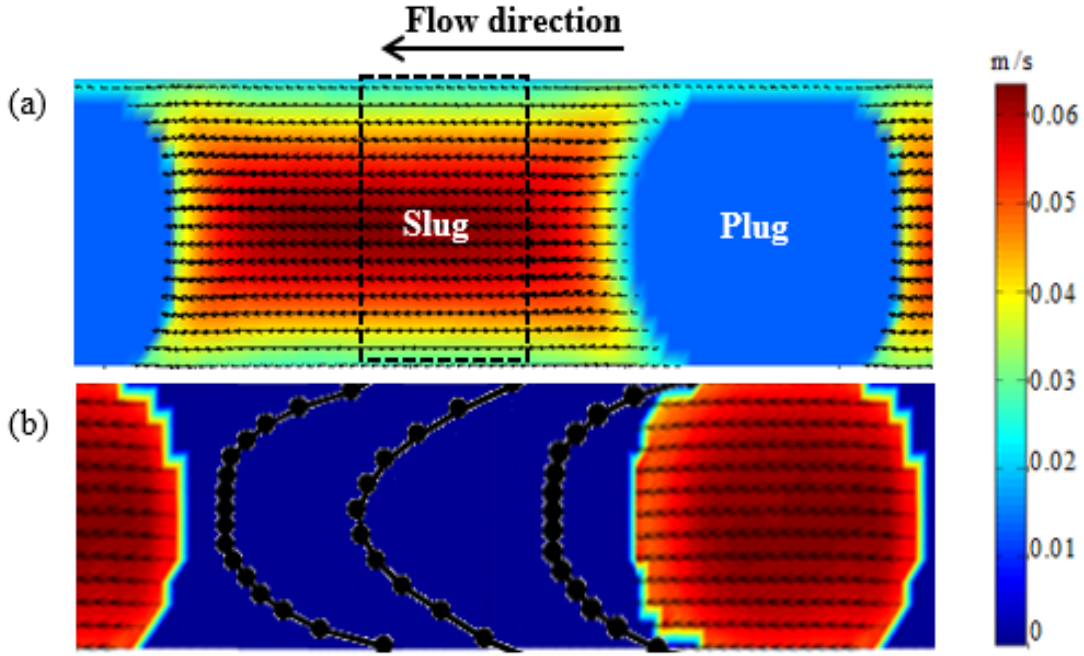
+ Aqueous phase seeded with 1 µm carboxylate-modified microspheres FluoSpheres® (540/560 nm)
+ Organic phase with 1 µm blue silica microspheres particles Sicastar® (350/440 nm).
+ Rhodamine 6G fluorescent dye (1 ppm) was also added in the aqueous phase to improve the detection of the liquid-liquid interface

Two Colour Micro PIV



Use the velocity fields of both the continuous and dispersed phase in order to understand the two-phase flow droplet formation and to evaluate the effect of interfacial tension and viscosity on the flow

Averaged velocity profiles using the two-colour PIV (Newtonian fluid)



(a) slug 48% w/w water and 52% w/w glycerol
(b) plug for silicone oil
(c) Dotted rectangle indicates the fully developed laminar flow area (Q_C = 0.07 cm^3/min; Q_D = 0.03 cm^3/min).

Questions

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