# ME 517: Micro- and Nanoscale Processes

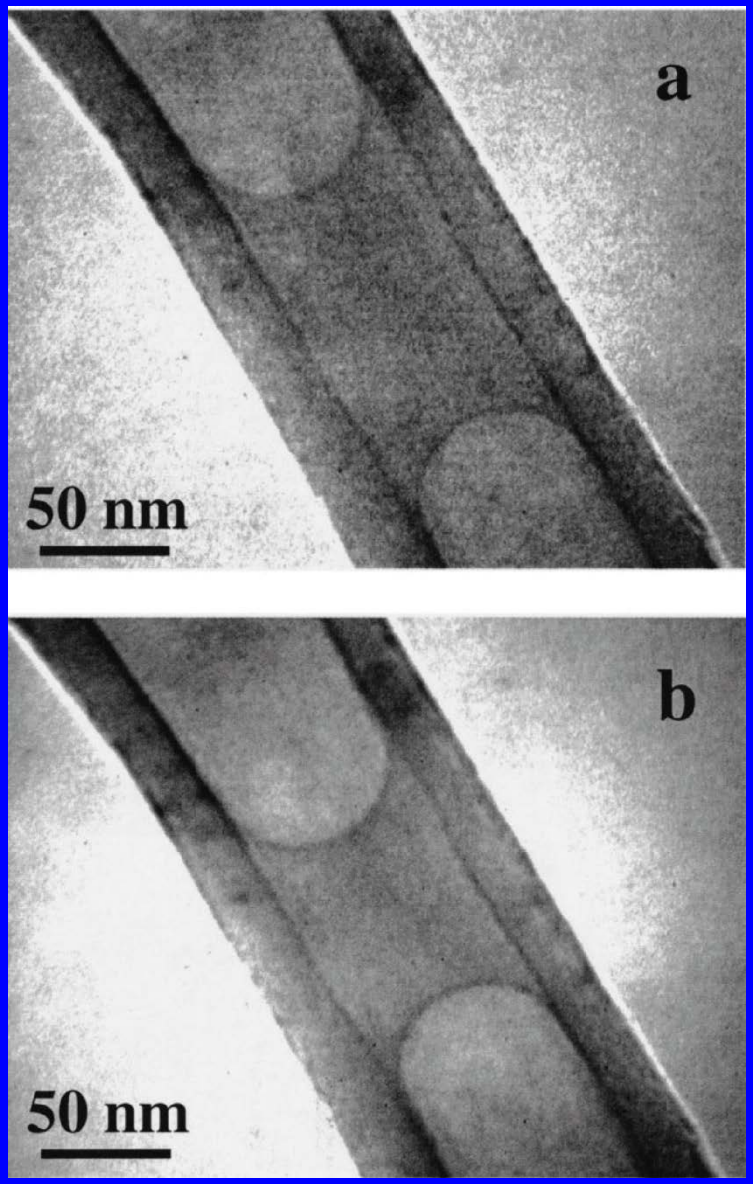
## Lecture 36: Microfluidic Diagnostics

**Steven T. Wereley**
Mechanical Engineering
Purdue University
West Lafayette, IN USA

Spring 2014

PURDUE UNIVERSITY

# Water in Carbon Nanotubes




- Hydrothermally produced multi-wall carbon nanotube
- Water inside nanotube
- TEM micrographs of meniscus
- Water volume decreases from a to b upon heating
- Explanations:
  - Bubble expansion
  - Liquid evaporation
  - Thermocapillarity
- Results inconclusive

Megaridis, Phys. Fluids, Vol. 14, pp L5-L9, 2002

# Full-field Experimental Microfluidic Velocimetry

- X-ray microimaging
  Lanzillotto, et al., *Proc. ASME*, 1996, **AD52**, 789-795.

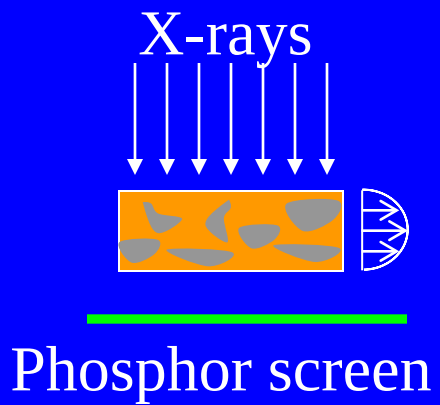
- Molecular-Tagging Velocimetry
  Paul, et al., *Anal. Chem.*, 1998, **70**, 2459-2467.
  Lempert, et al., *AIAA Journal, 2002*.

- Micro-PIV
  Santiago, et al., *Exp. Fluids*, 1998, **25**(4), 316-319.
  Wereley and Gui, *AIAA Journal*, 2002.

- Papers available on class web site under 'Paper Download'

# X-ray Microimaging

- Positives
  - Can image inside normally opaque devices
- Negatives
  - low resolution ~20-40μm
  - depth averaged (2-D)
  - requires slurry to scatter x-rays
  - long exposure times limit measurable flow speeds



# Outline of X-Ray Microimaging Procedure

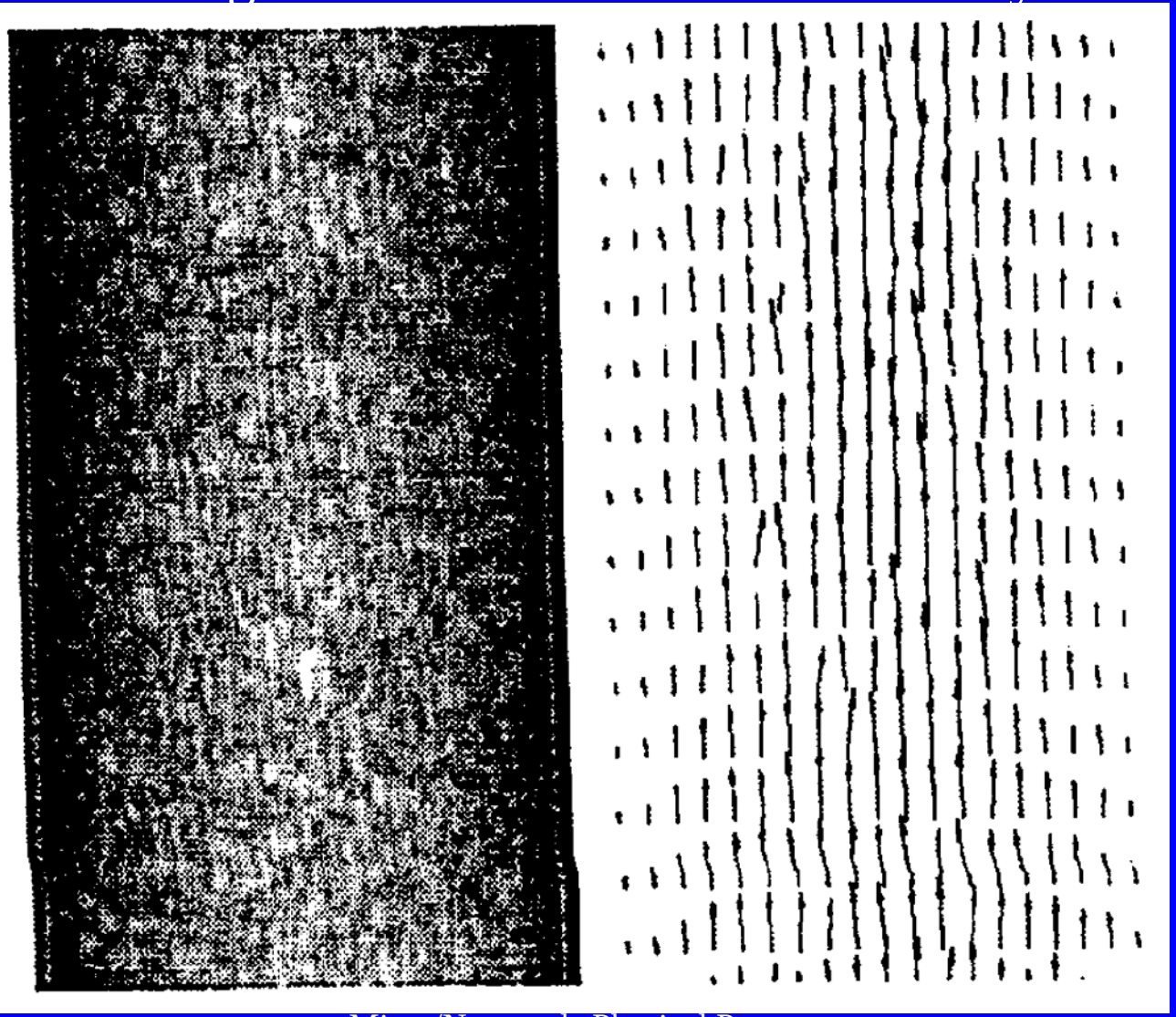
- Assume translation and rotation of infinitesimal material particles (assumes incompressibility)
- Enforce smoothness of velocity field
- Two constraints combined as

$$\min\left\{\iint_R \left[\lambda\left(\frac{DI}{Dt}\right)^2 + \|\nabla \mathbf{u}\|^2\right] d^2\mathbf{x}\right\}$$

- where I(**x**) is image intensity function, λ is a control parameter,
- Apply boundary conditions
  - No-penetration B.C.at surfaces

# X-Ray Microimaging Images

– Raw Image Calculated Velocity



# X-Ray Microimaging Results

- Flow of X-Ray emulsion in quartz capillary
- Tube diameters from 640 to 1000 μm
- Flow rates 4-8 nanoliters/sec
- exposure time: 500 m

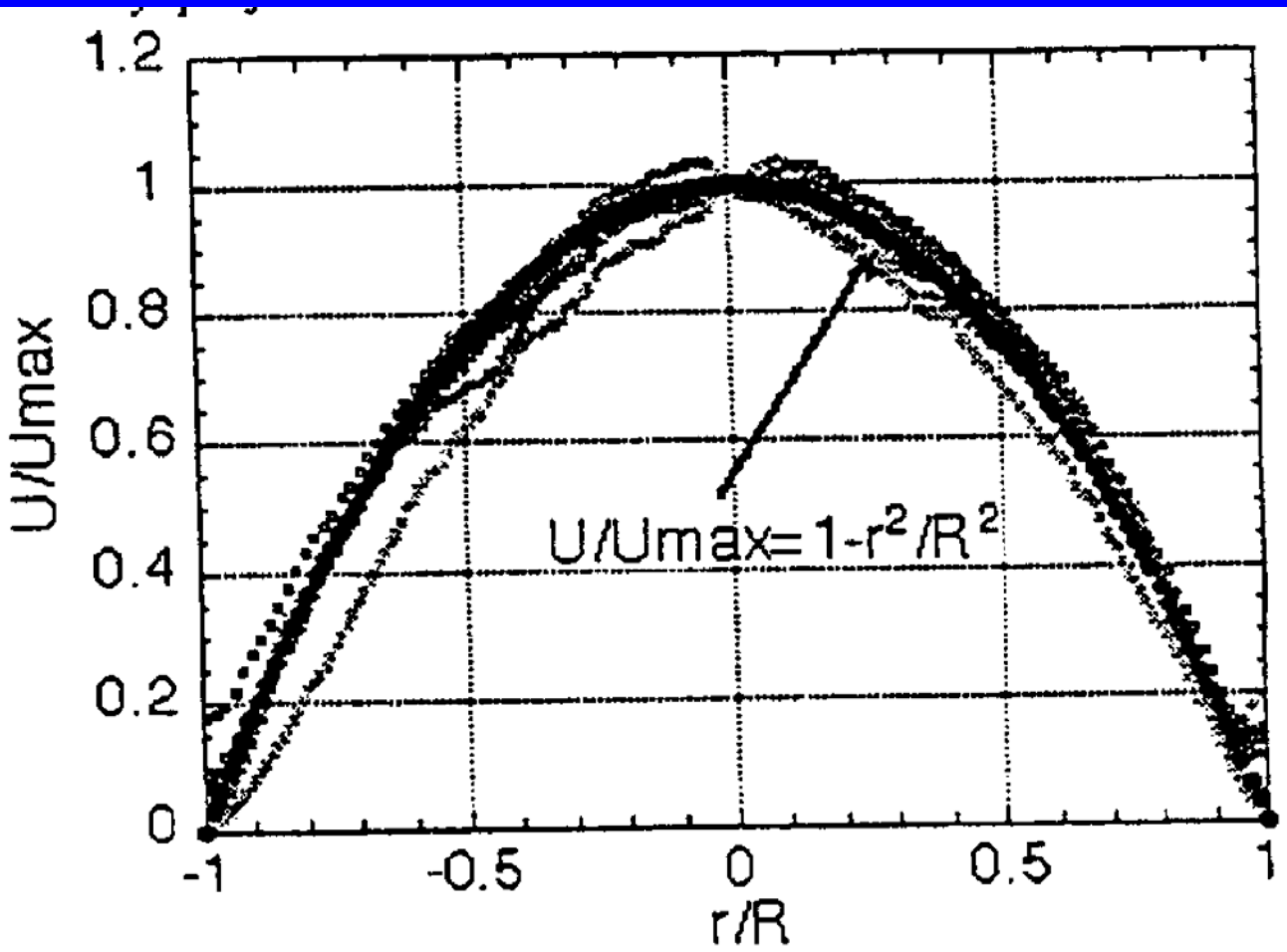
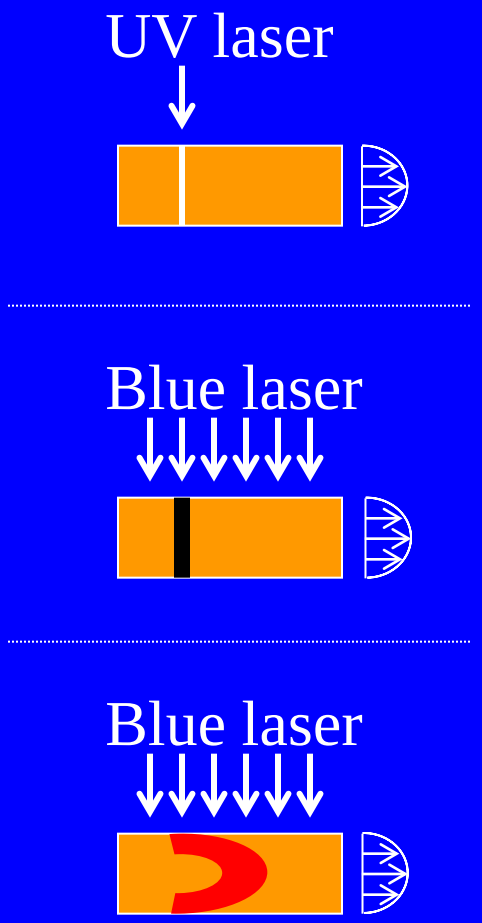


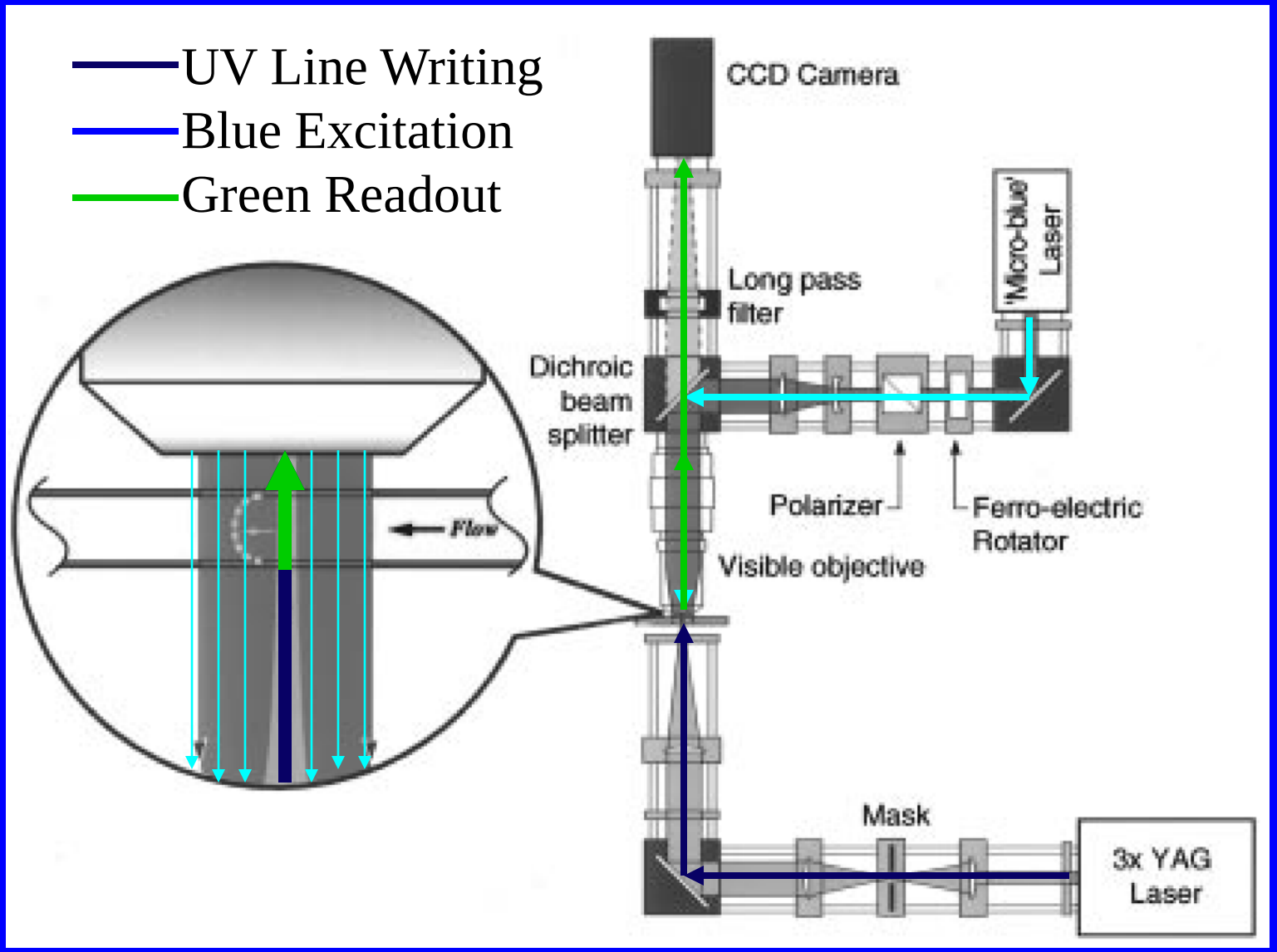

*Figure 7. Nondimensional average velocity profiles experimental versus theoretical (solid line)*

# Molecular-Tagging Velocimetry

- Positives
  - minimally intrusive
  - better with electrically-driven flows
  - works with gas or liquid flows
- Negatives
  - low resolution ~20-40μm
  - depth averaged (2-D)
  - greatly affected by diffusion
  - must invert convection eq.

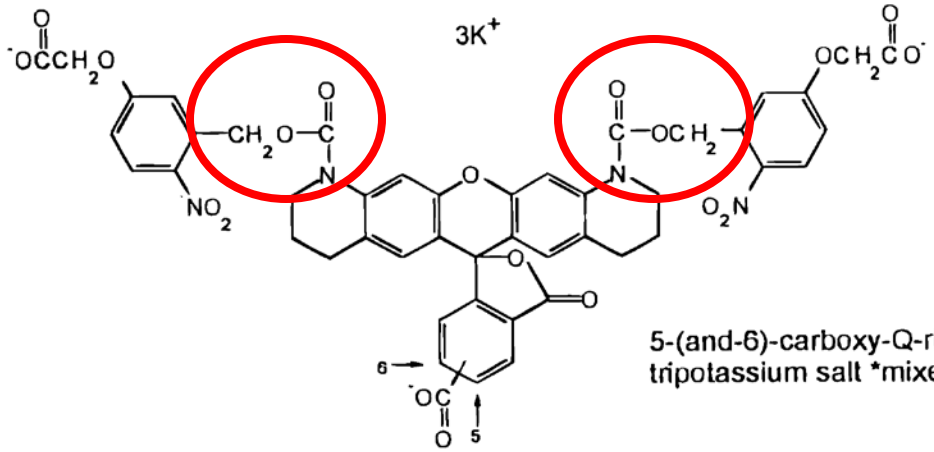


# Liquid MTV

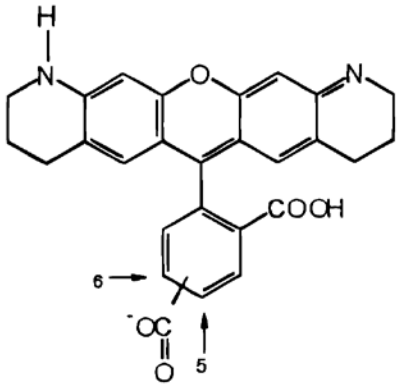



Paul, 1998

# Liquid MTV (Paul, et al.)



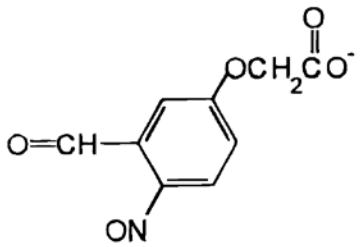

pulsed UV light (<365 nm)
two step process



5-(and-6)-carboxy-Q-rhodamine

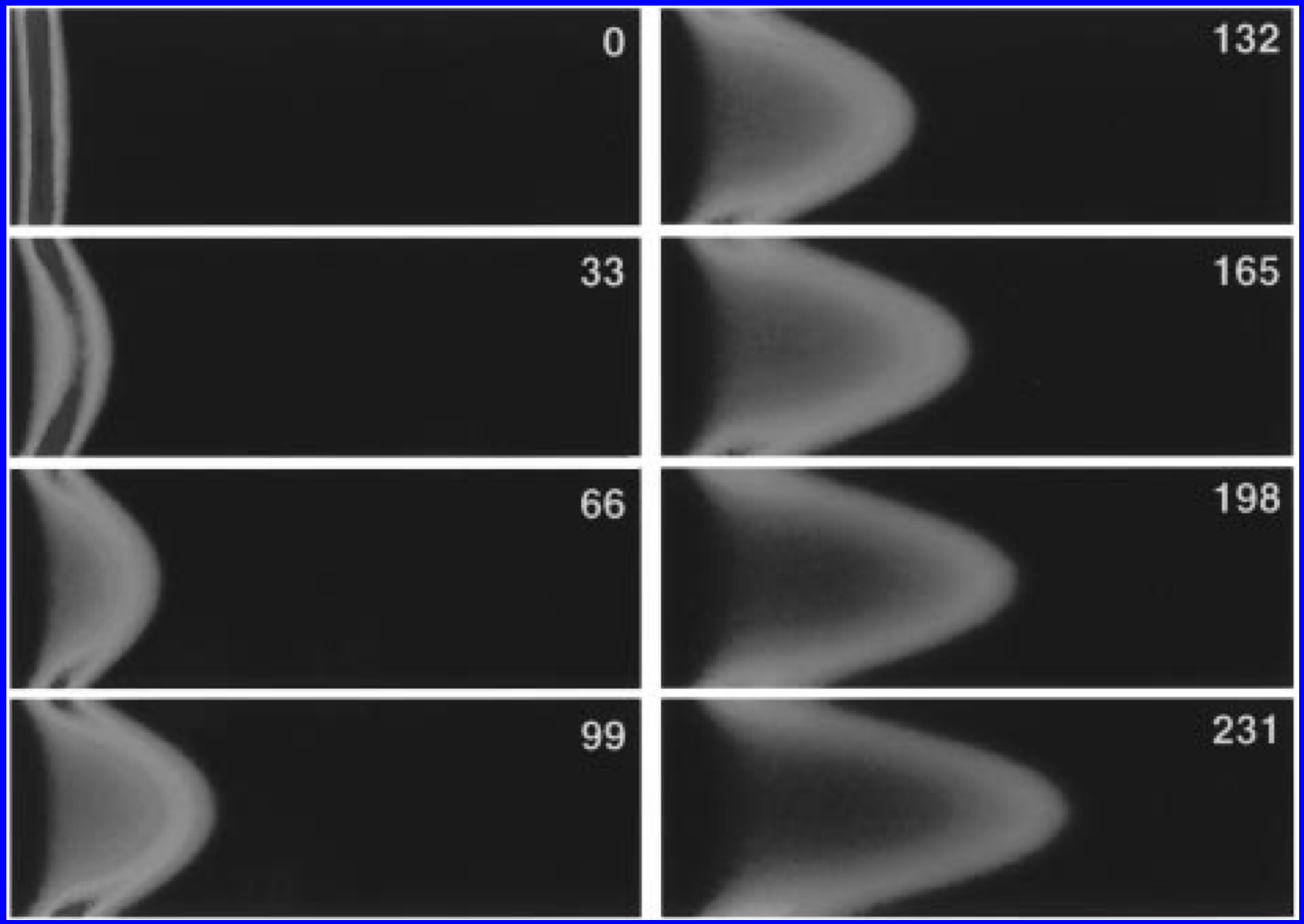
$\varepsilon_{537\ nm}$= 94,000 $cm^{-1}M^{-1}$(pH 9)

+



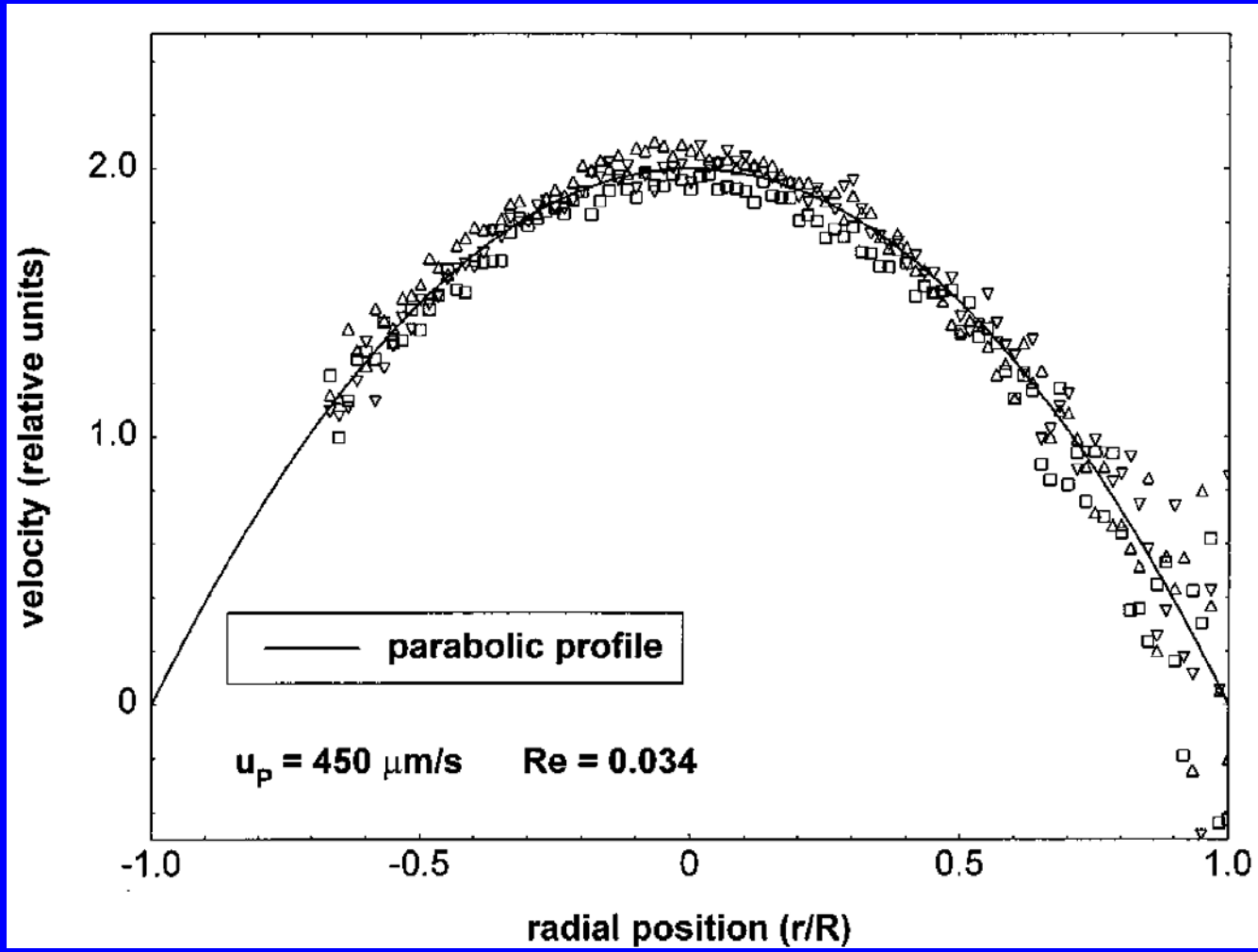
+ $CO_2$

# Liquid MTV (Pressure-driven flow)



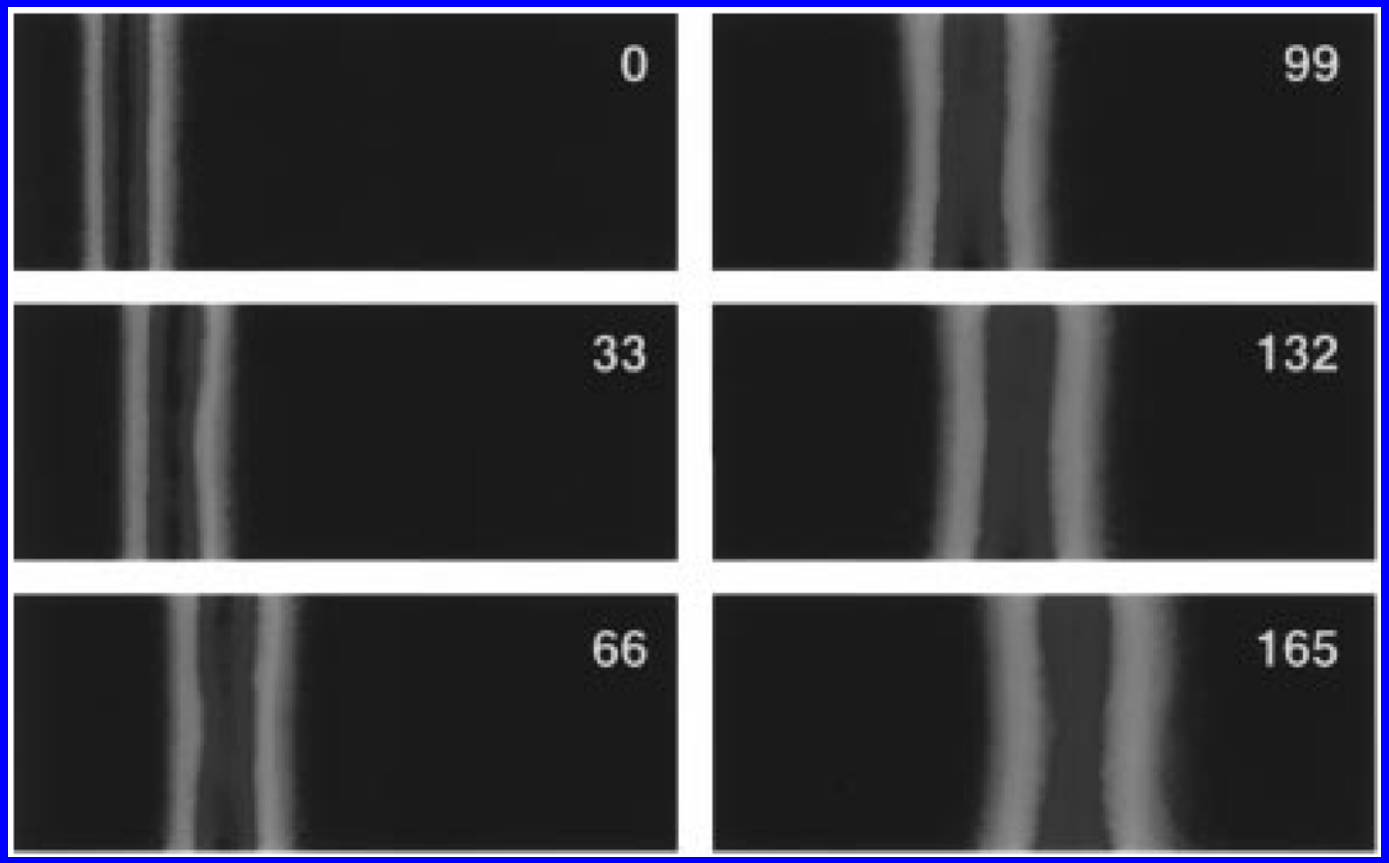
# Liquid MTV Results

- DI water flow in 75 μm cap.
- Pretty good results in center of channel

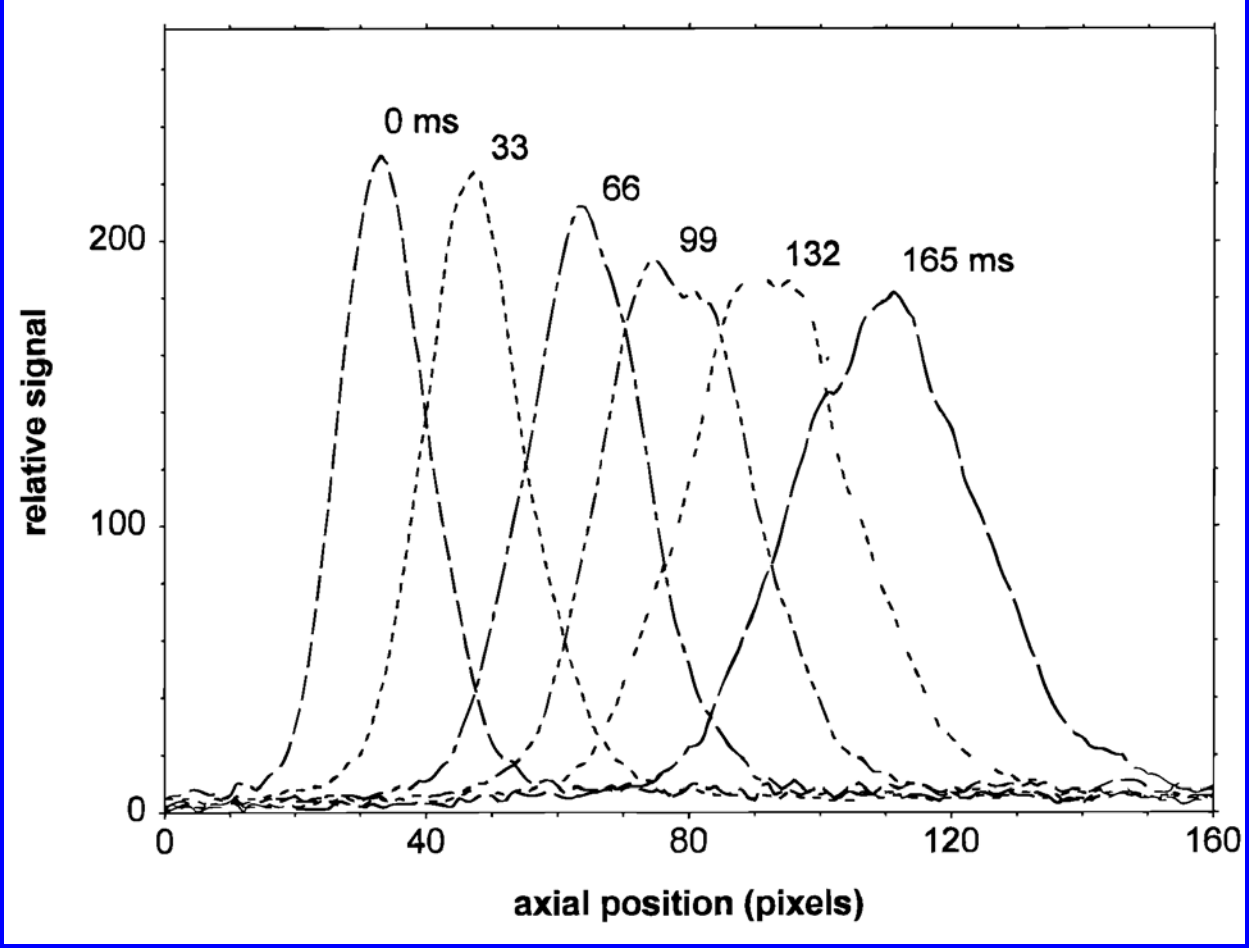


# Liquid MTV in electrically driven flows

- Electroosmotically driven flow
- Shows potential for resolving slip B.C.s



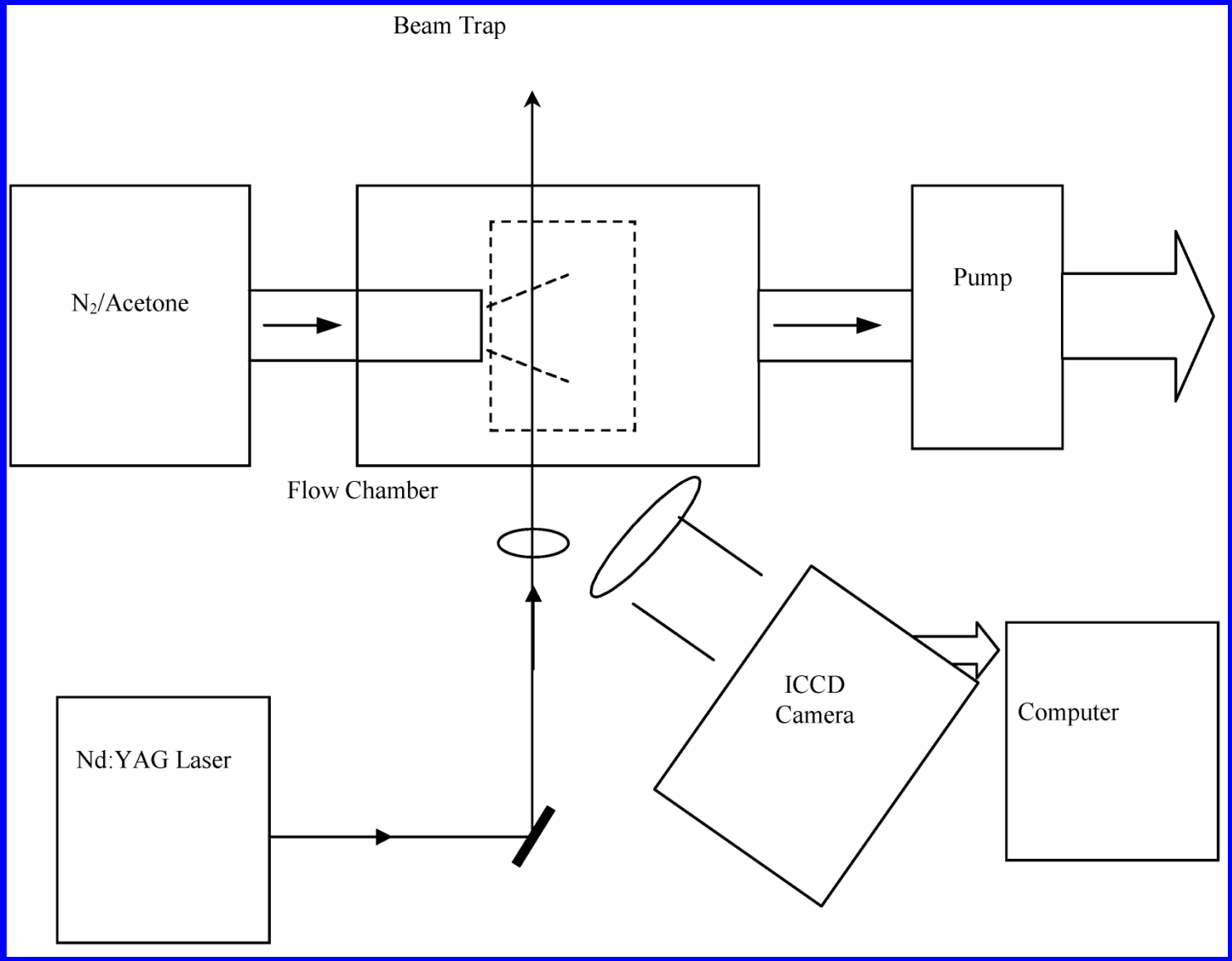
# Liquid MTV data interrogation



# Gas MTV (Lempert, et al.)

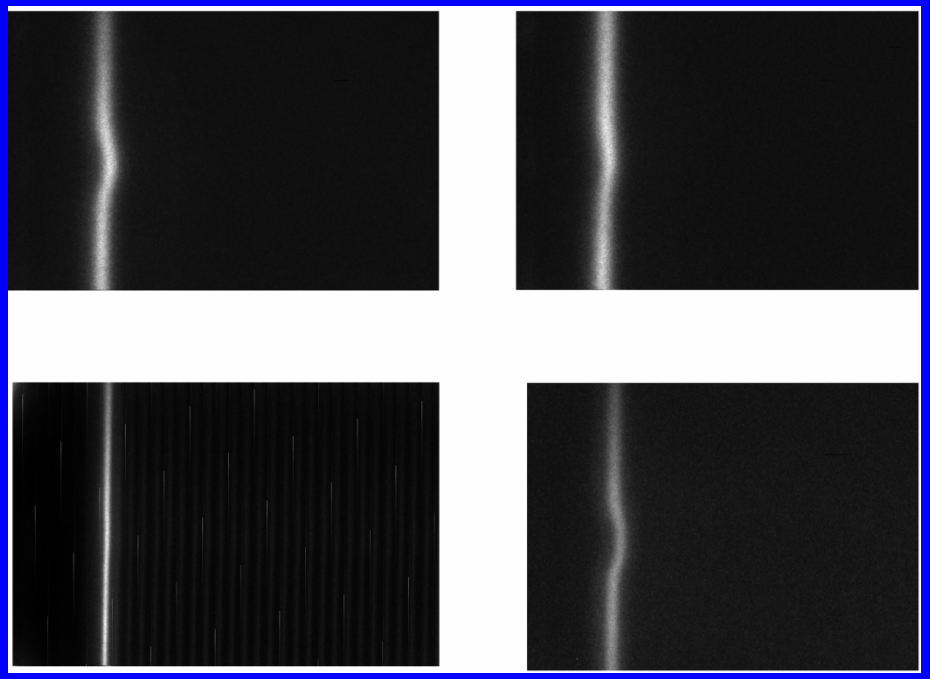
- Measured velocity outside of supersonic ‘milli nozzle’ with exit diameter of 1 mm
- Very similar procedure to liquid MTV
  - Data analysis routines are similar/identical
  - Necessary changes in speed of process and tracer molecules
- Biacetyl molecule
  - Absorbs at 405 nm
  - Fluorescence lifetime up to 1 ms
- Acetone molecules used as tracers
  - Absorbs at 230-340 nm
  - Lifetime on the order of 200 ns

# Gas MTV

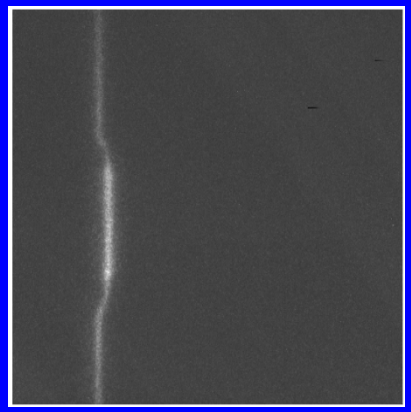

Beam Trap
$N_2$/Acetone
Flow Chamber
Pump
Nd:YAG Laser
ICCD
Camera
Computer

# Gas MTV

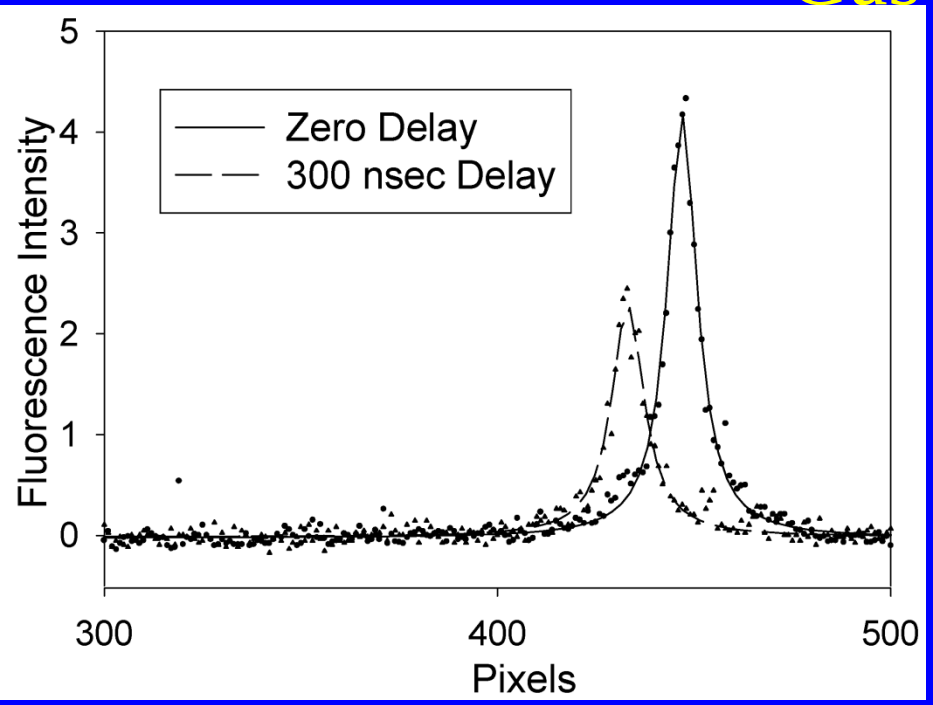
- Operating at design conditions (pressures matched)

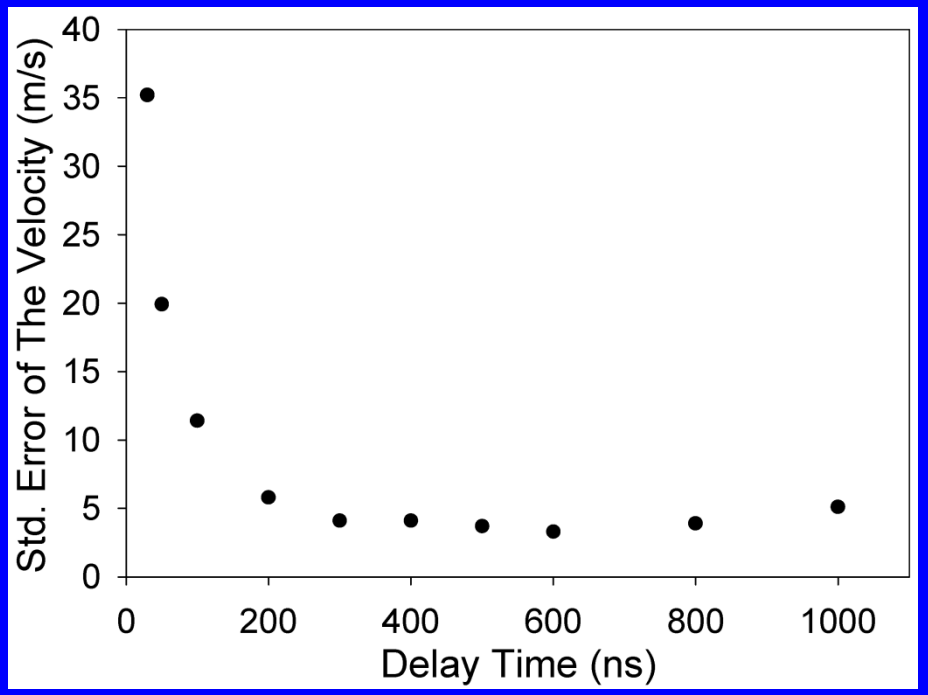


- Severely under-expanded condition



# Gas MTV

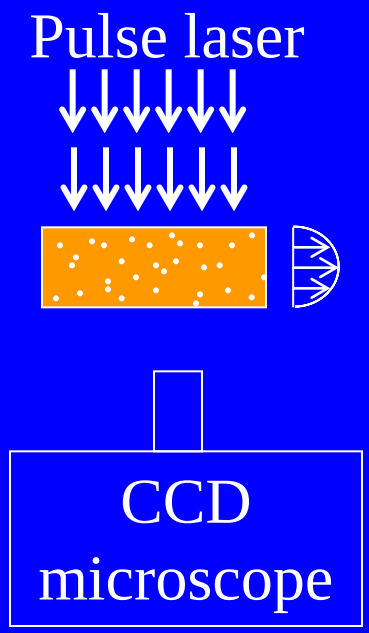


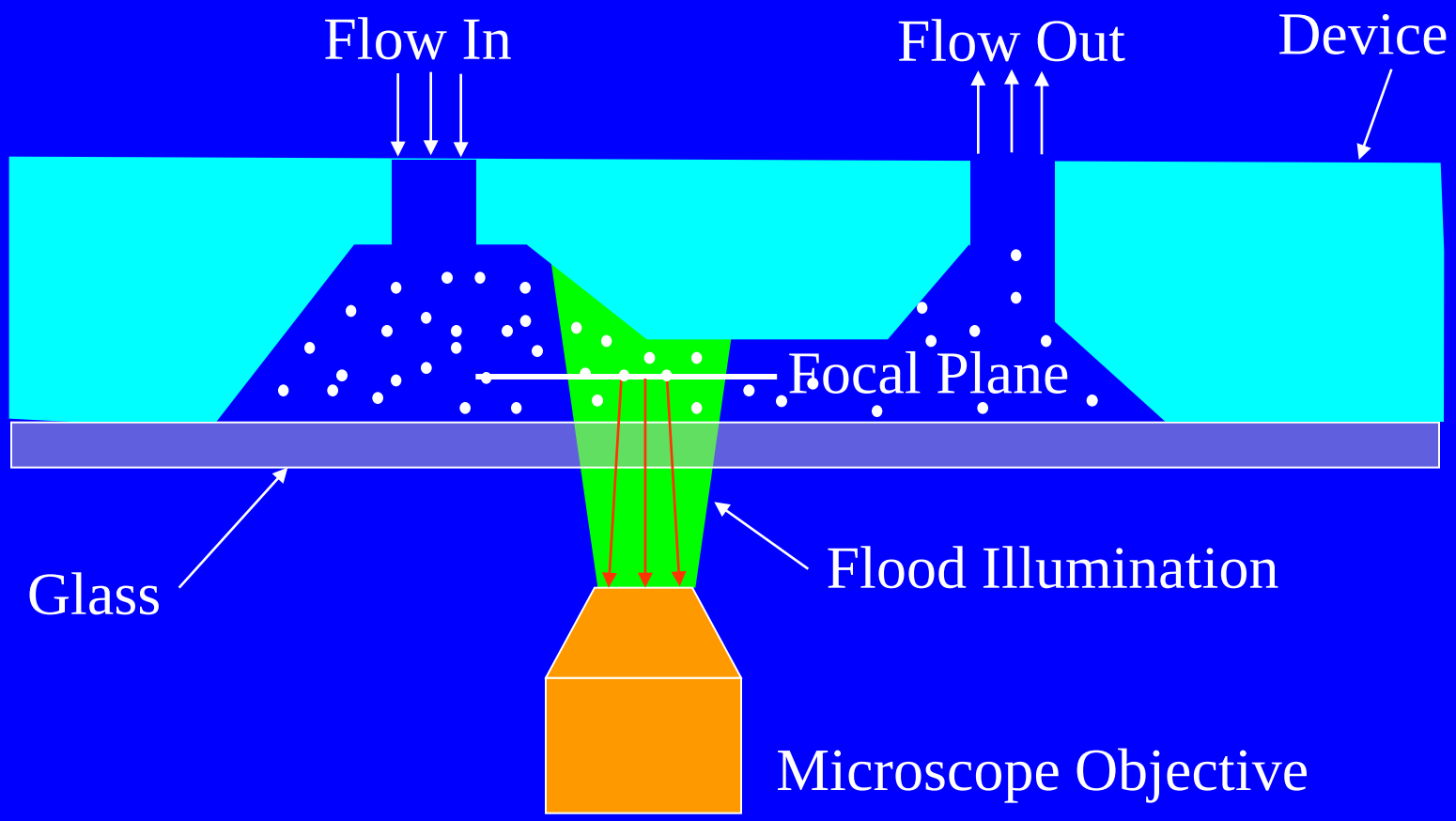

- Left figure cross section of preceding profiles
- Right figure variation of error with time delay

# Micro-Particle Image Velocimetry
(μPIV)

- Positives
  - high resolution ~1 μm
  - small depth average ~2-10 μm
  - minimally intrusive
- Negatives
  - requires seeding flow
  - particles can become charged



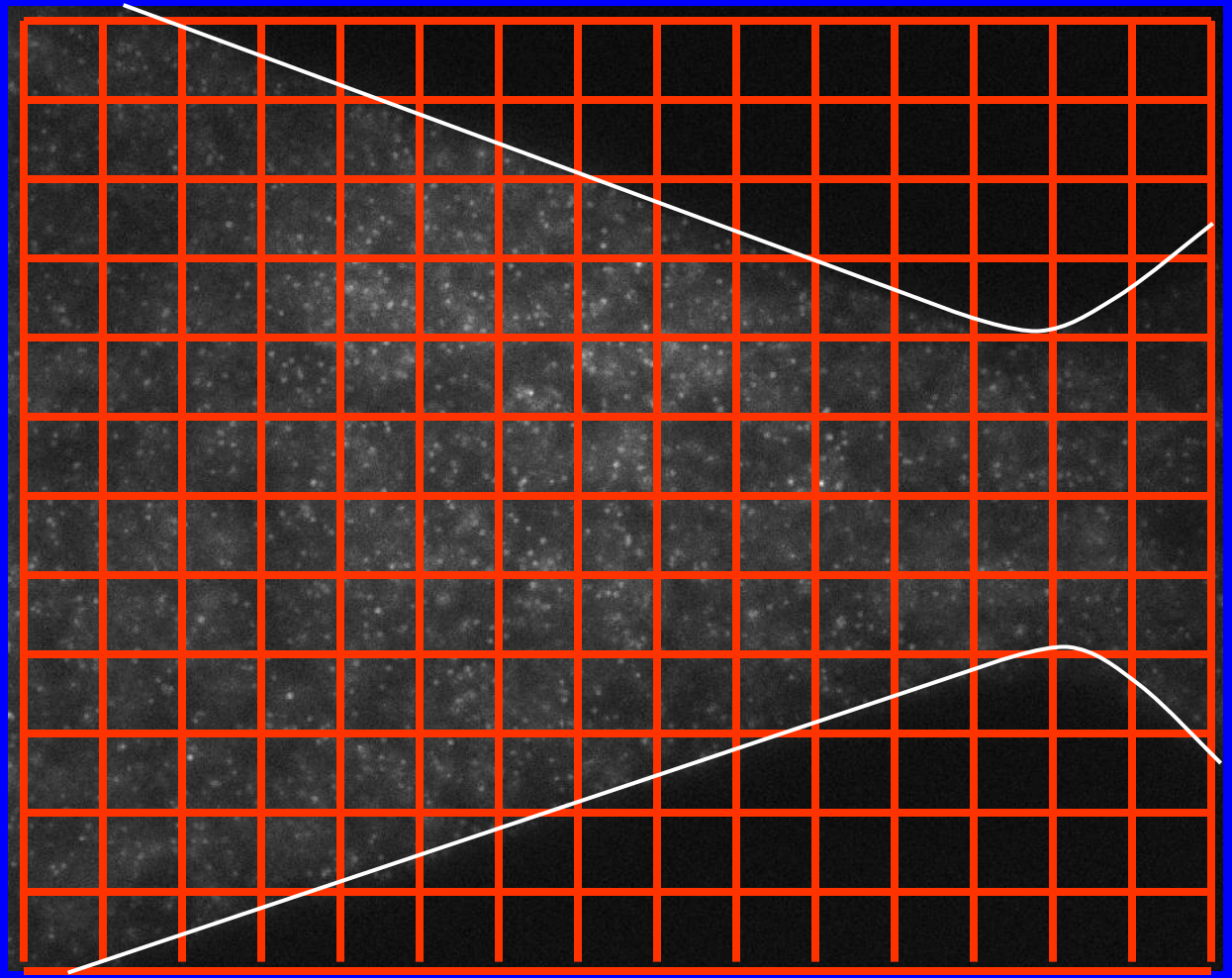
# Micro-PIV Schematic



# Typical Micro-PIV Image

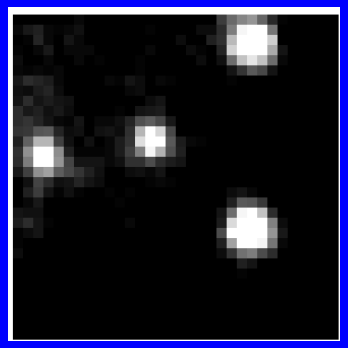
Microthruster:  Magnification 40x, particle size 700 nm

courtesy of K. Breuer, Brown University



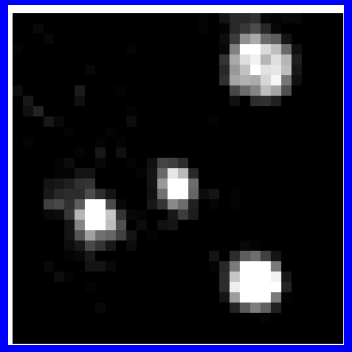
# Cross-Correlation PIV

Interrogation Region #1



$f_k(i,j)$

Interrogation Region #2




$g_k(i,j)$