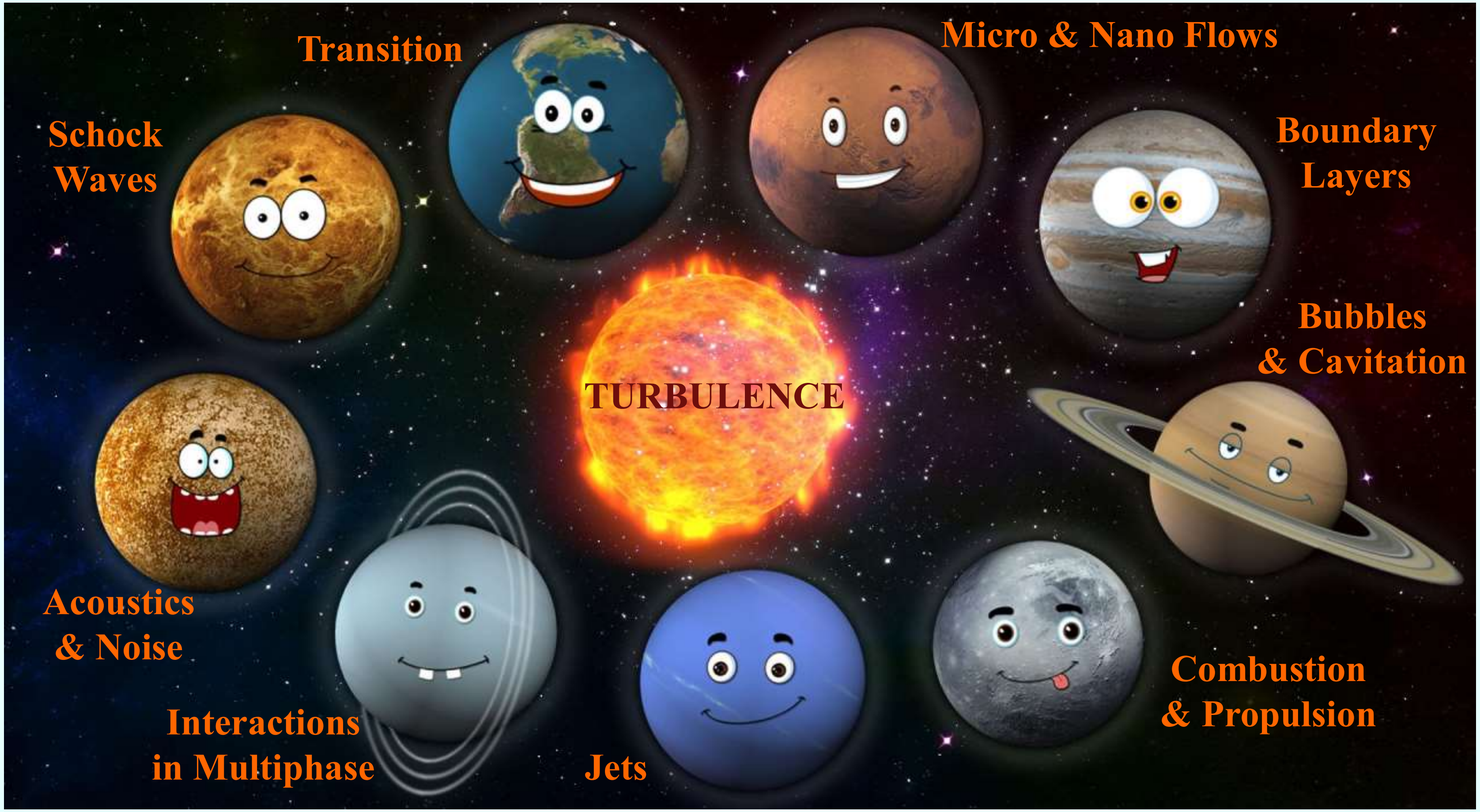
SSD

ING-IND/06

Fluidodinamica

PO – Casciola, Graziani, Romano
PA – Favini, Marino, Paciorri, Pirozzoli, Stella
RIC – Gualtieri
RTD – Battista, Bernardini, Giacomello, Meloni

Topics


Transition
Micro & Nano Flows
Schock
Waves
Boundary
Layers
Bubbles
& Cavitation
TURBULENCE
Acoustics
& Noise
Combustion
& Propulsion
Interactions
in Multiphase
Jets

Experimental techniques and phase-discrimination strategies for velocity and size measurements in two phase flows

Giampaolo Romano

References, Collaborations & Grants

INGV

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- Righetti & Romano, Journal Fluid Mechanics, 2004
- Cagnoli & Romano, Journal of Volcanology & Geot. Res., 2010a, 2010b, 2013, 2015; Journal of Geophysical Research 2012a, 2012b
- Lacagnina; Di Felice, Romano *et al.*, Experiments in Fluids, 2011
- Capone, Soldati & Romano, Experiments in Fluids, 2014; Physics of Fluids 2015
- Calabriso, Borello, Romano, Applied Energy, 2016
- Righetti, Romano, Nikora, Water Resour. Res., 2015, 2016
- Capone, Miozzi & Romano, Int. Journal of Multiphase Flows, 2017

ING-IND/09

ICAR/01
Uni Bolzano

Uni Udine
Cost Actions

CNR – INSEAN
Network of Excellence HTA

Why and what to measure in two-phase flows

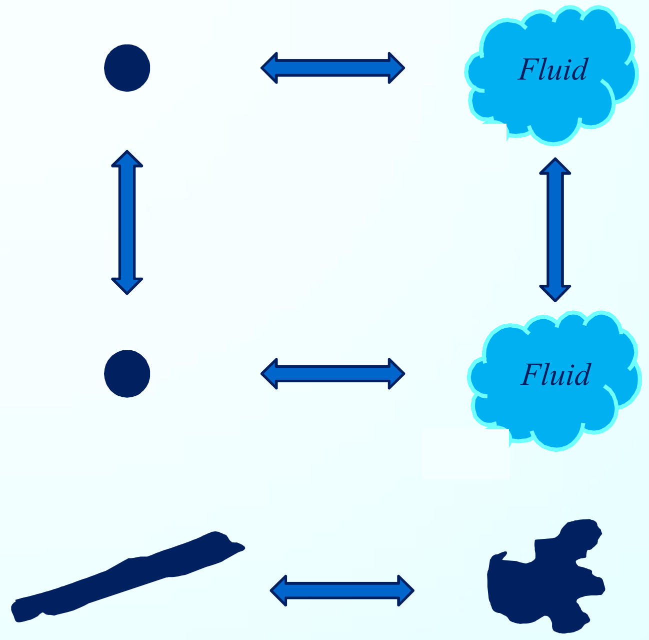
<u>Why</u>: drag reduction, noise control, sedimentation, pollution and environmental phenomena, fiber suspension, sprays and other industrial applications, ……

<u>What</u>: velocity components, concentration, size, cross-correlation among them SIMULTANEOUSLY FOR EACH PHASE !!!

<u>FLUID-PARTICLE COUPLING</u>

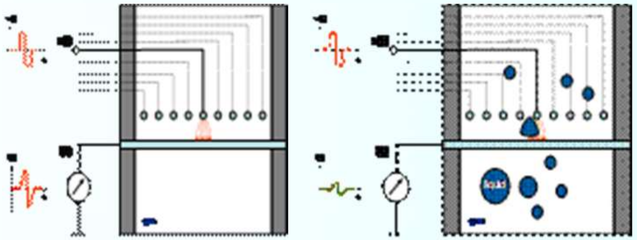
<u>PARTICLE-PARTICLE COUPLING</u>

<u>ADDITIONAL EFFECTS</u>
(rotation, stretching, shear)



Intrusive *vs* non-intrusive methods

INTRUSIVE: Grids, WMS (Wire Mesh Sensors), …. = good temporal resolution, very low spatial resolution, …… OK for industrial applications



Grunewald, 2012

NON-INTRUSIVE: capacitive and magnetic sensors, ultrasound sensors, … = sufficient temporal resolution, low spatial resolution $\Rightarrow$ OPTICAL TECHNIQUES

Spherical *vs* non spherical particles

spherical

Single-point methods: Phase Doppler Anemometry (PDA)

Multi-point methods: Global Phase Doppler (GPS) or Interferometric Laser Imaging Droplet Sizing (ILIDS), Image Analysis Methods

Durst et al. 1976, Konig et al. 1986, Kiger & Pan 2000

non-spherical

Single-point methods: PDA: not working

Multi-point methods: ILIDS: not working, Image Analysis Methods: OK

Parsa et al. 2011, Dearing et al. 2013

Multi-point for spherical

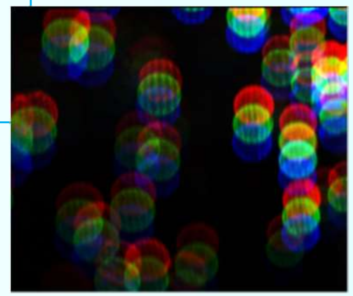
GPS & ILIDS: principle

$$d = \frac{2m\lambda M D_{ef}}{\delta}\left[\cos\left(\frac{\vartheta_r}{2}\right) - \frac{m\sin\left(\frac{\vartheta_r}{2}\right)}{\sqrt{1+m^2-2m\cos\left(\frac{\vartheta_r}{2}\right)}}\right]^{-1}$$

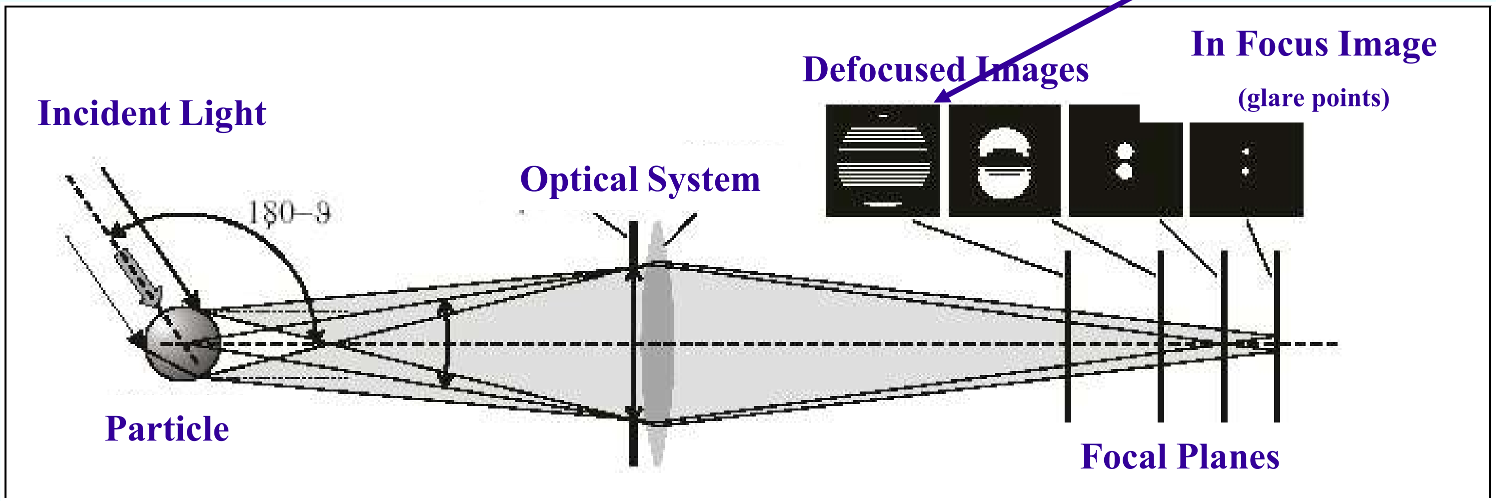
Konig et al. 1986
Glover et al. 1995
Maeda et al. 2000
Damaschke et al. 2001, 2002
Kobayashi et al. 2001

d = particle diameter
δ = fringe spacing
θ = scattering angle

$$d = \frac{K}{\delta}$$



fringe system

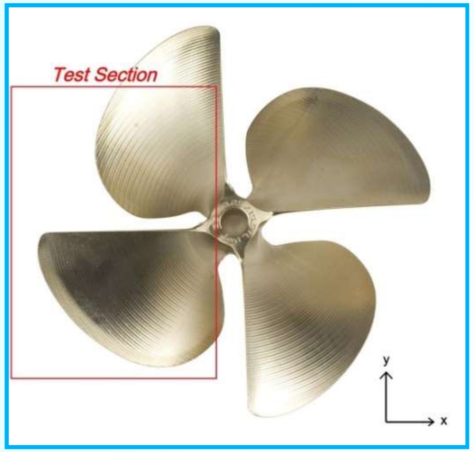


Damaschke et al. 2001

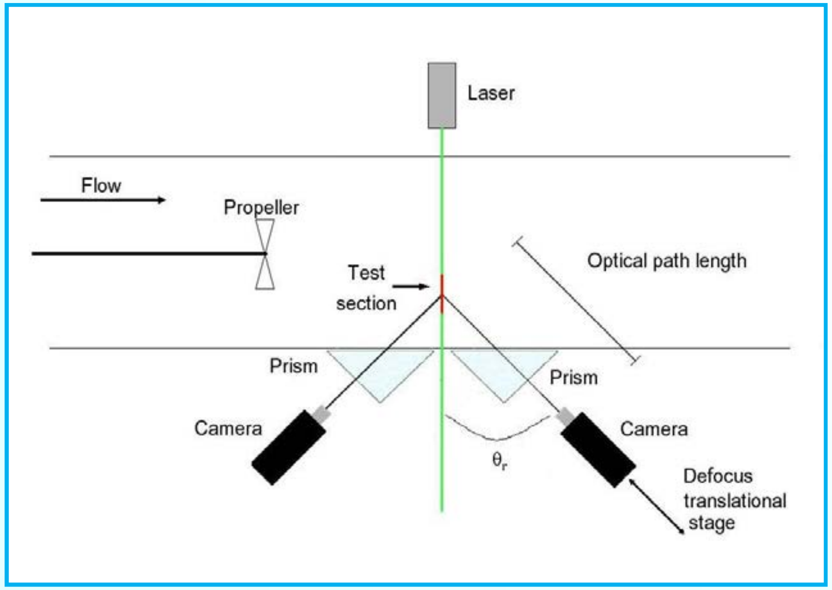
Example

GPS & ILIDS

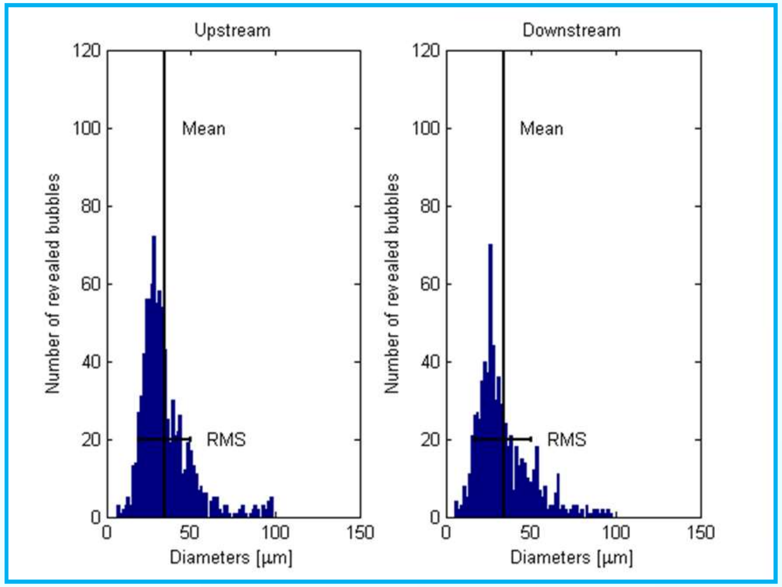
Cavitation bubbles



Lacagnina et al., 2011, in collaboration with CNR-INSEAN,
Network of Excellence "Hydro-Testing Alliance" FP6 (2006-2010)

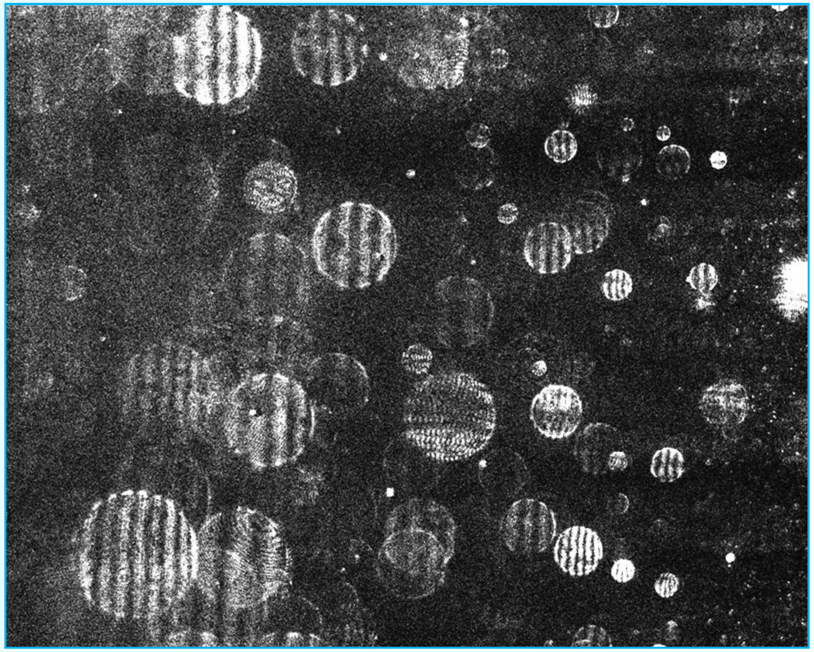


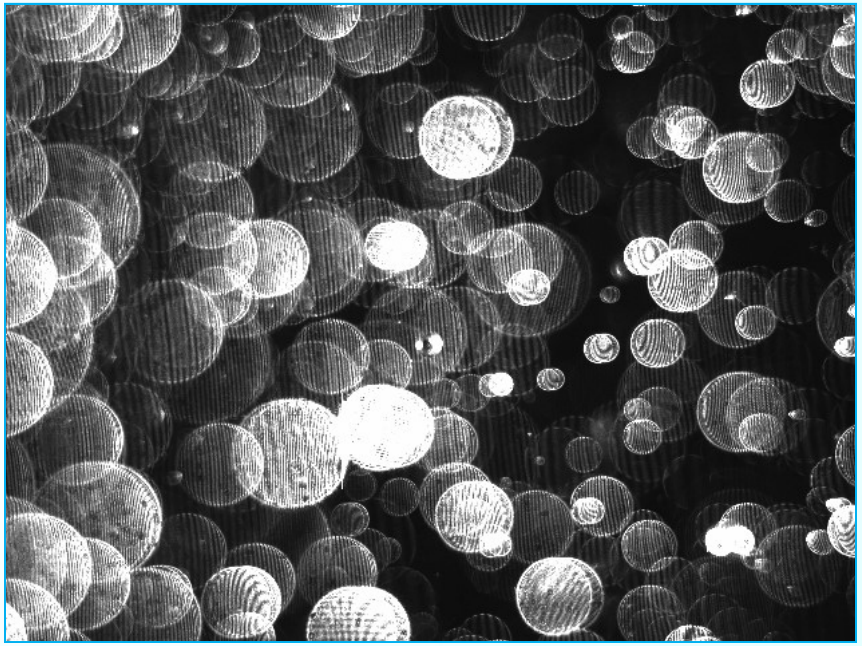
comparison of the two cameras



Limitations

GPS & ILIDS: drawbacks

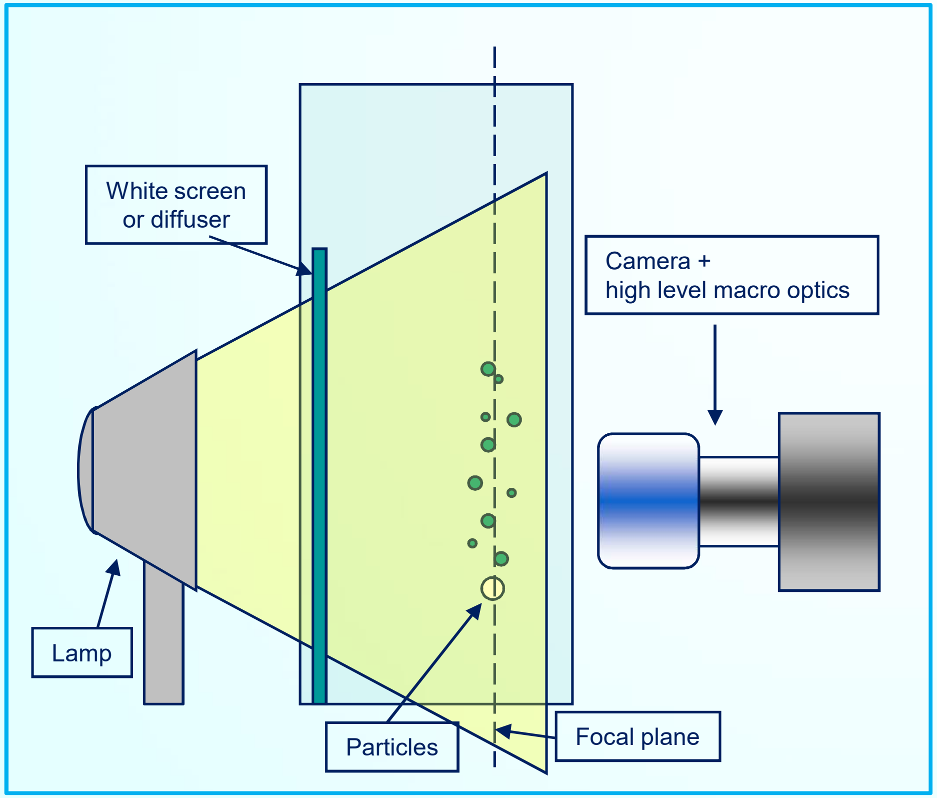




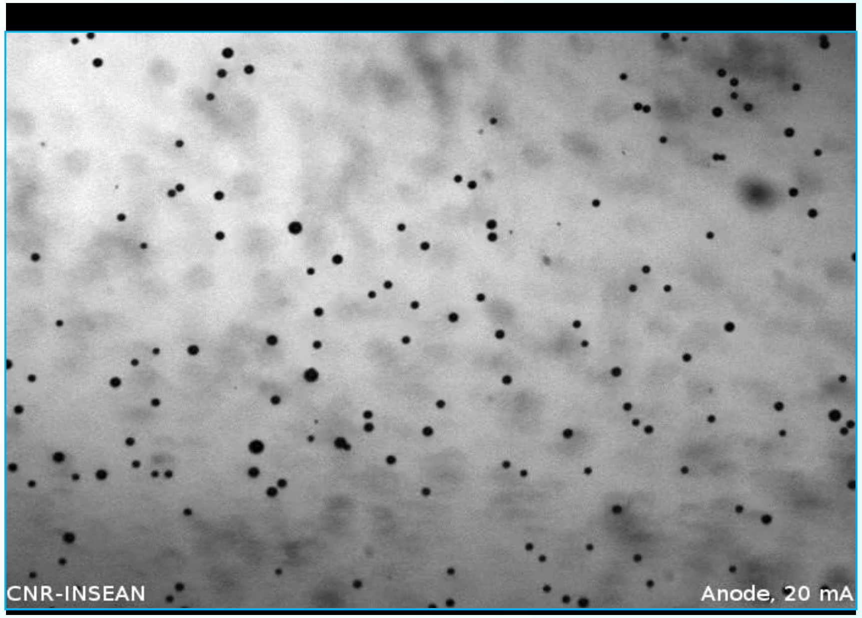
Spherical particles
Low particle density

Multi-point for non-spherical

Shadow Imaging



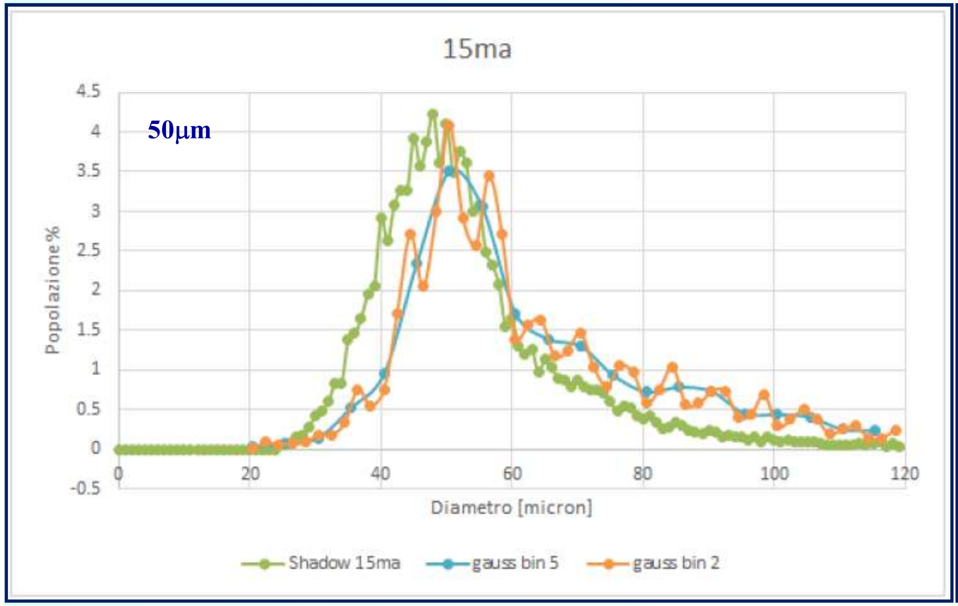
5 mm

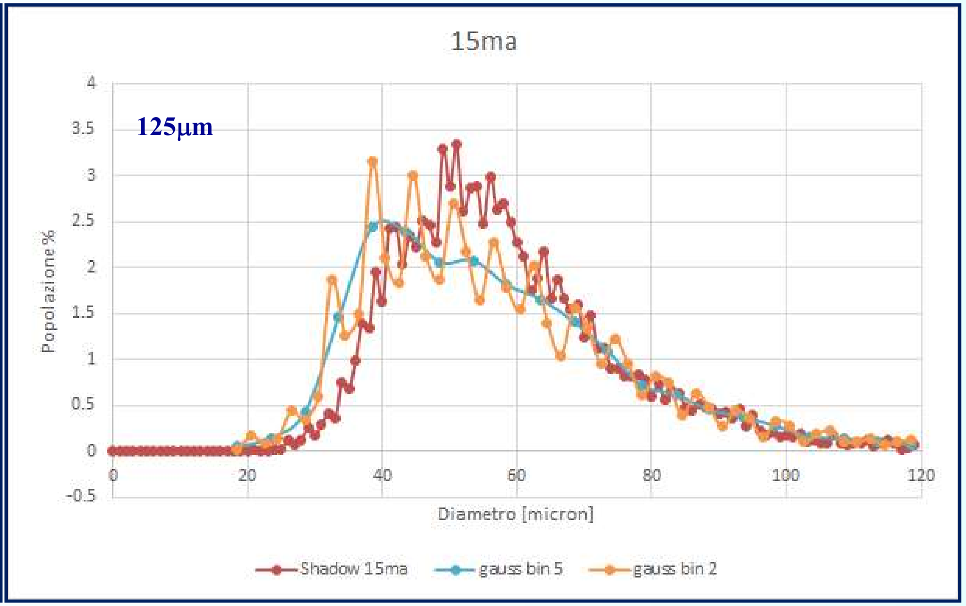


Contour → Area → Size

ILIDS AND SHADOW IMAGING

COMPARISON





- slight overestimation of mean values
- overestimation of the standard deviation
- pixel locking due to fringe evaluation

BUT SMALL IMAGED REGIONS

Non-spherical particles – image analysis methods

- Non-spherical particles are imaged as spherical → LOW RESOLUTION
- Non-spherical particles are imaged as non-spherical → HIGH RESOLUTION

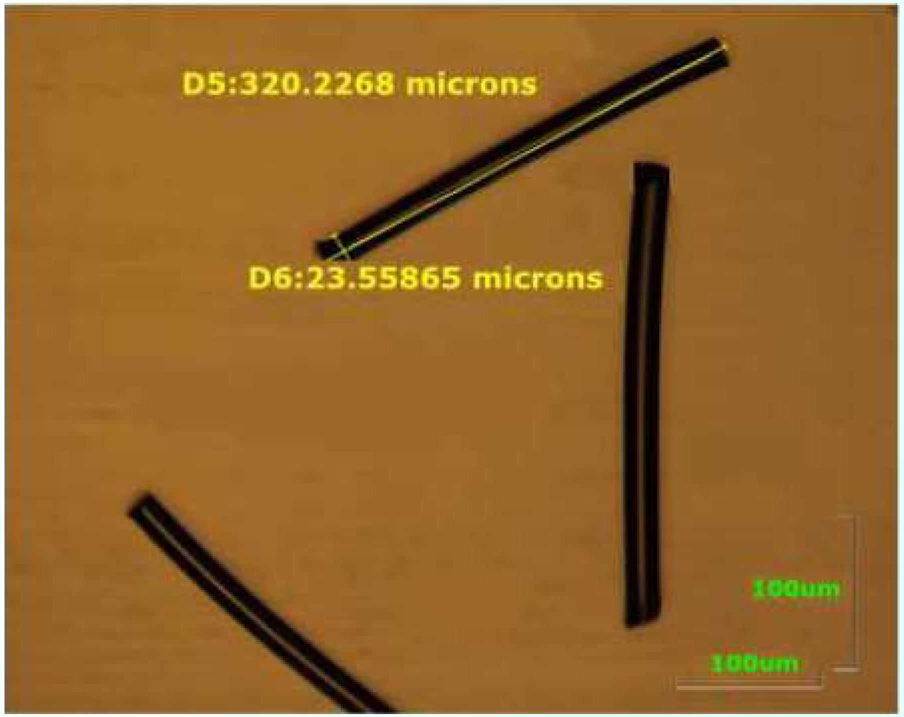
SPATIAL RESOLUTION =

CAMERA + DIMENSIONS

Example

Synthetic plastic rod fibers (nylon) in turbulent flows

- Density 1.13-1.15 g/cm3
- Mean length L=320 μm
- Mean diameter d=24 μm
- Aspect ratio L/d=13.3

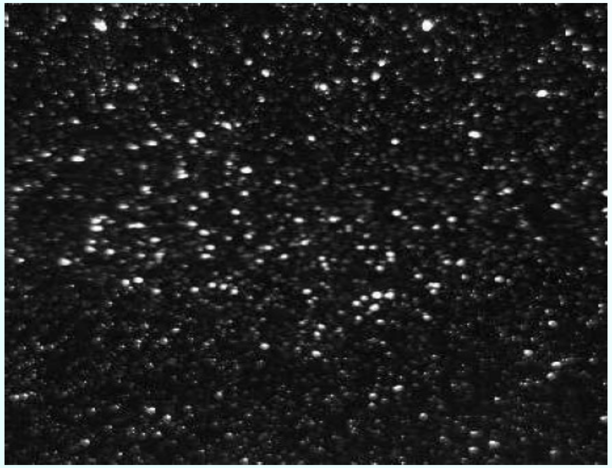


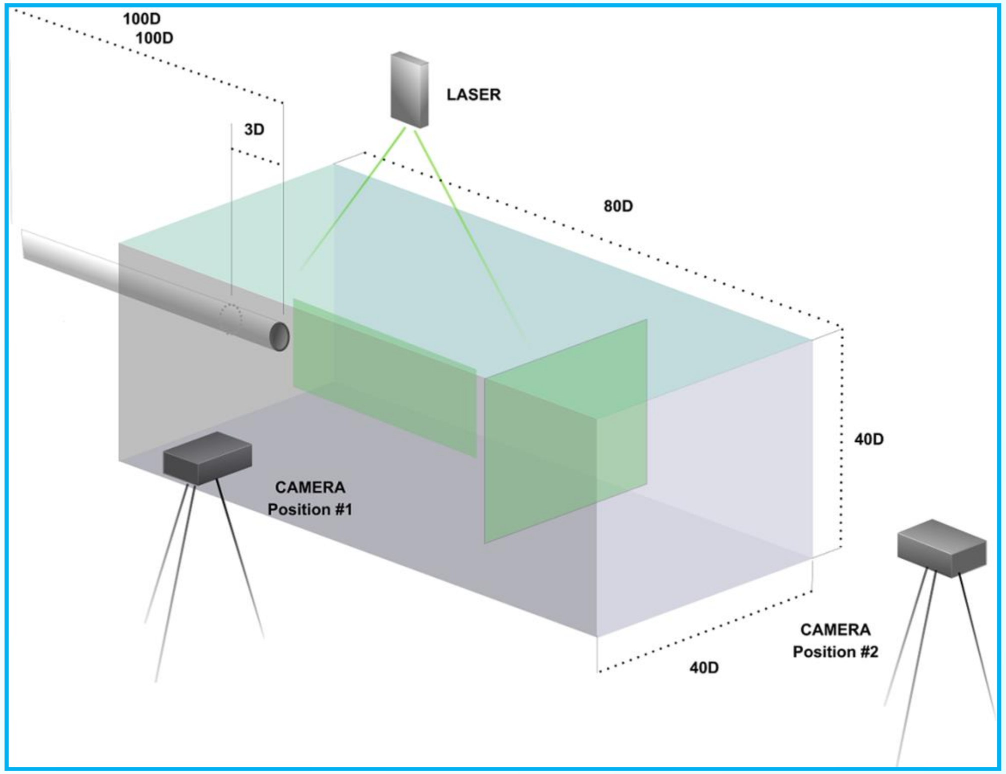
Flow tracers: hollow glass spheres
Mean diameter 12 μm, neutrally buoyant

Low resolution

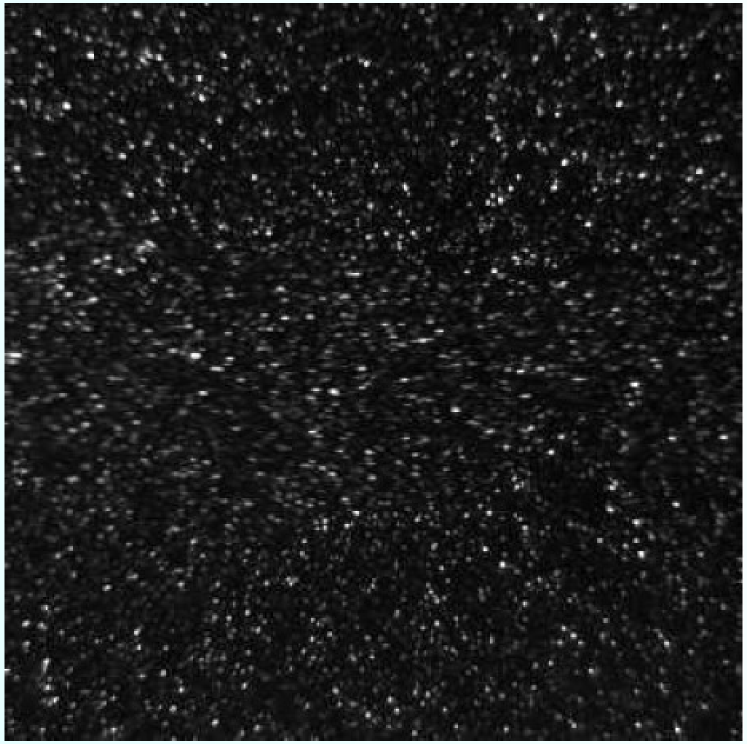
Low spatial resolution: fibers *eqv* to spheres

- Turbulent pipe jet
- Reynolds numbers 3000-30000
- Stokes number ≈ 0.7
- Imaged region ≈ 11 cm
- Camera sensor 1024 pixel
- Spatial resolution ≈ 8 px/mm
- 1 fiber length = 3 pixel

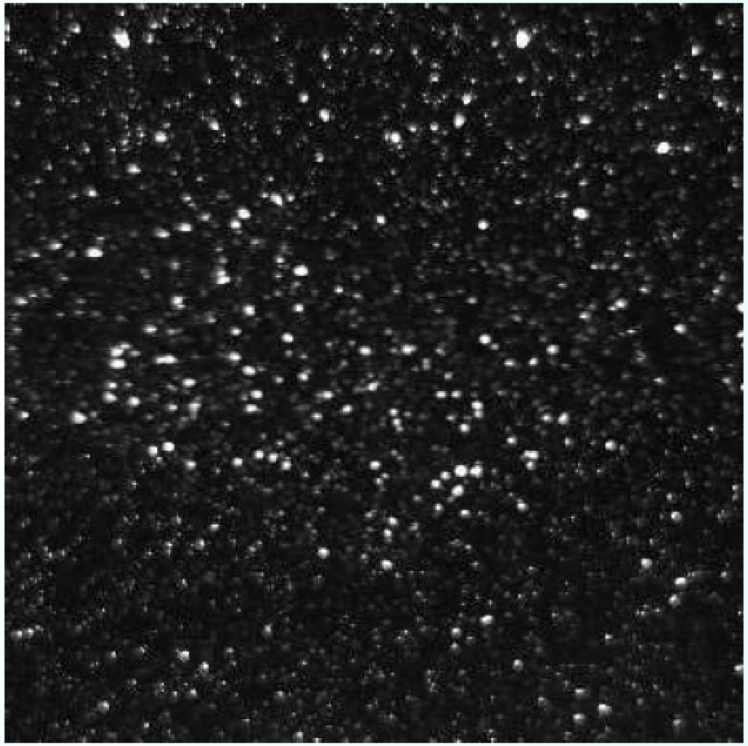




Phase discrimination



NO FIBERS



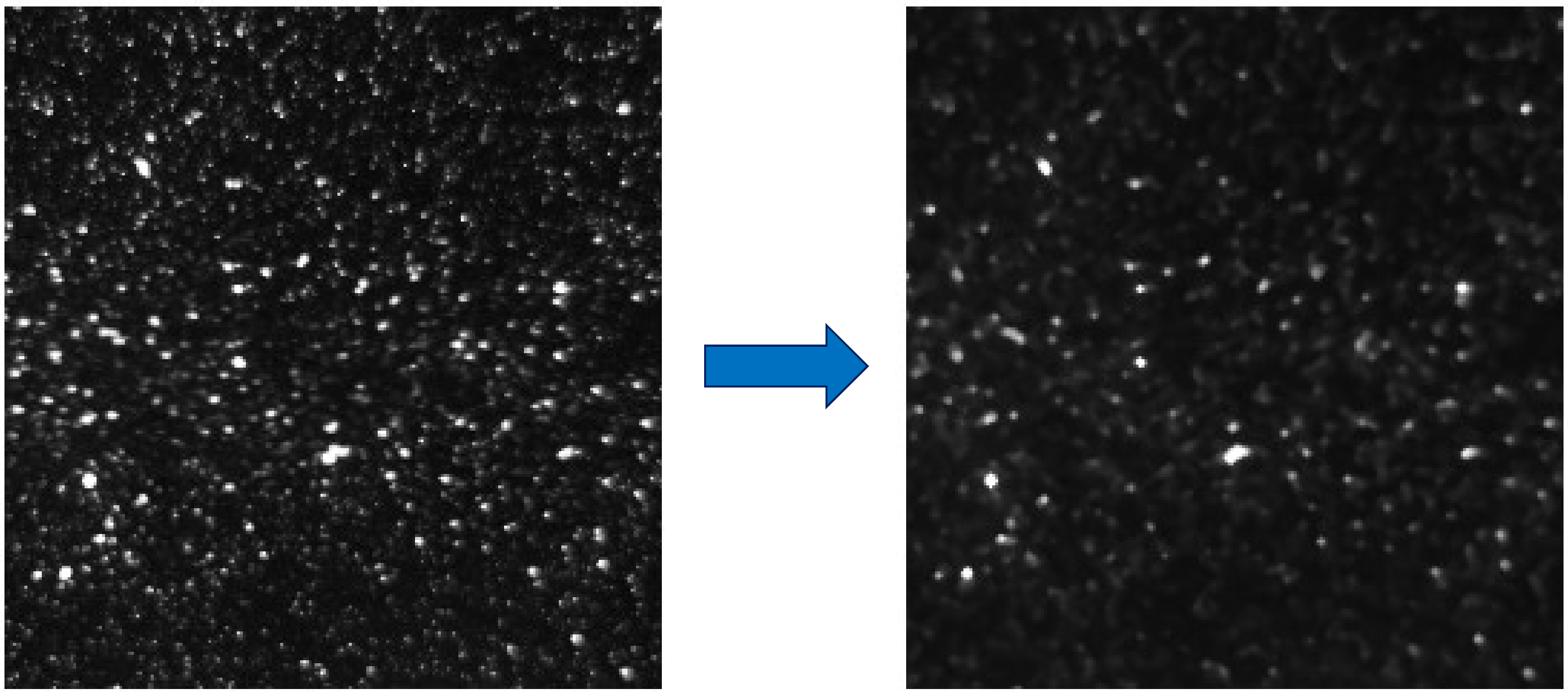
WITH FIBERS

<u>Single</u> or multiple cameras

Phase discrimination

Flow-particle separation: spatial median filter

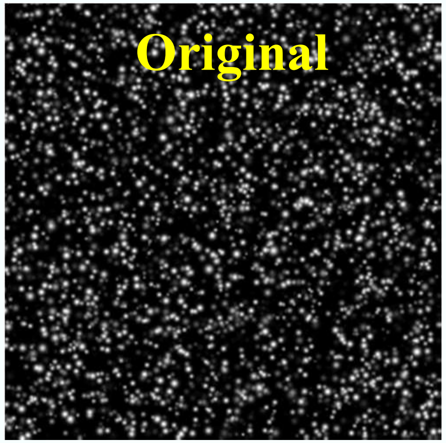
Kiger & Pan, 2001



Median filter 5x5 attenuates seeding particles

Median Filter

Particle ≡ Intensity level (0-255)



-1	-1	-1
-1	8	-1
-1	-1	-1

Median Filter = ordering + medium value

"peaked" particle

1	1	1	1	1
1	40	80	40	1
1	80	100	80	1
1	40	80	40	1
1	1	1	1	1

Median Filter = 1

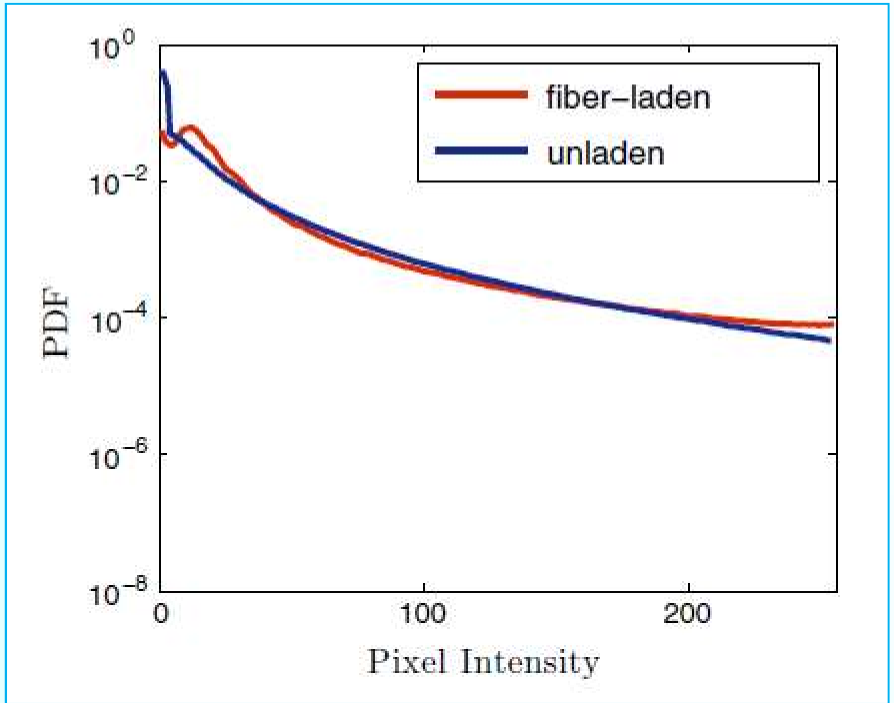
"distributed" particle

10	20	20	20	10
20	30	30	30	20
20	30	30	30	20
20	30	30	30	20
10	20	20	20	10

Median Filter = 20

Phase discrimination

Flow-particle separation: spatial median filter + thresholding



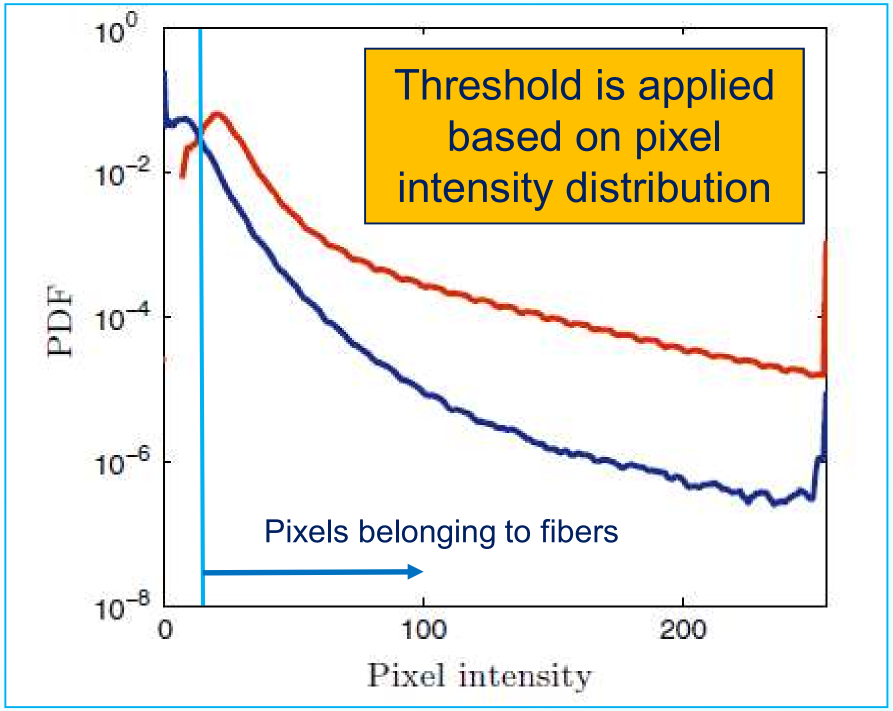


Fig. 4 PDF of light intensity at each pixel for single-phase data, compared to fiber-laden case before (at the *top*) and after (at the *bottom*) median filter

where ?

Phase discrimination

Validation

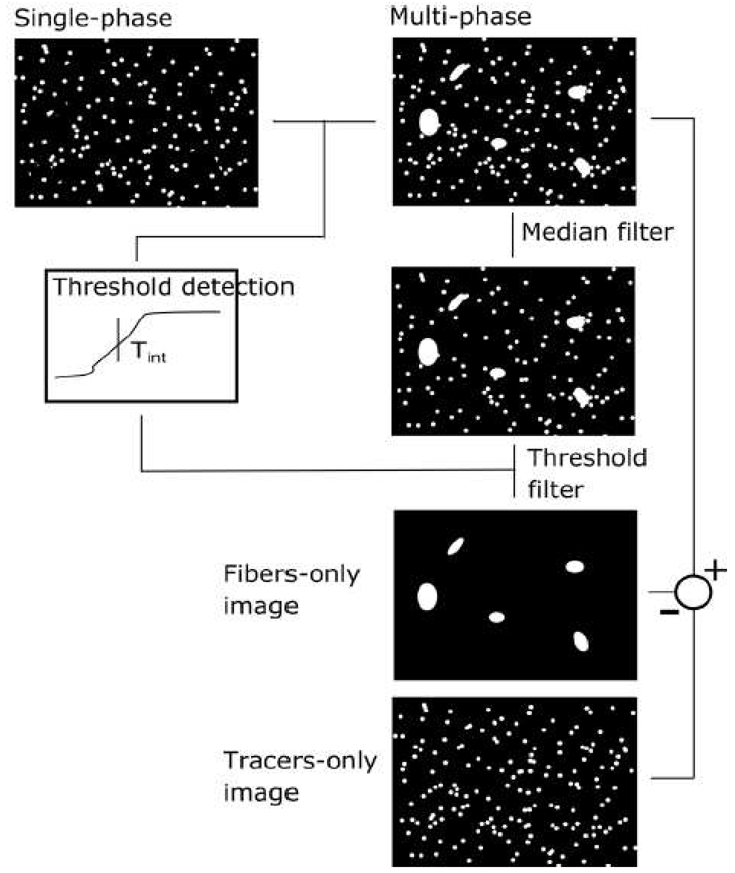


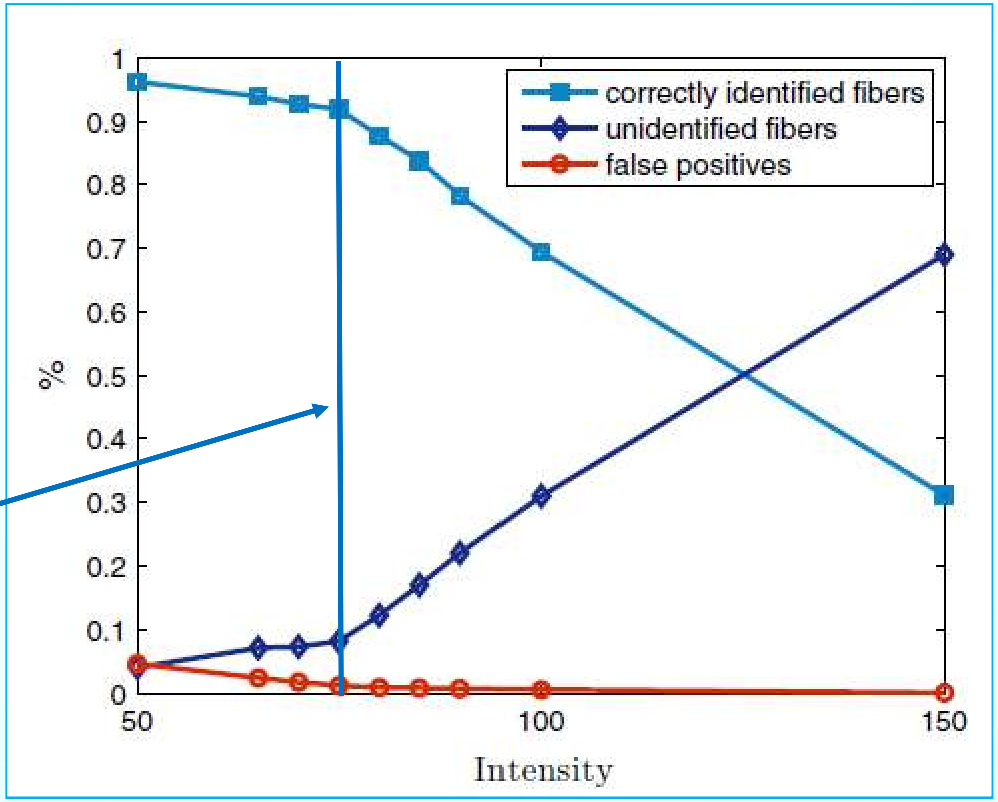
Fig. 6 Schematic of the phase discrimination algorithm

- Separation error by artificial two-phase images:
  1) Acquisition of tracer only and fiber only images
  2) Separate processing and location+velocity results
  3) Artificial multiphase image = tracer only+fiber only
  4) Phase discrimination (median + thresholding)
  5) Combined processing and location+velocity results
  6) Comparison as a function of threshold

- PIV average error on whole field below 3%
- Fibers detection error below 0.1%
- Detected particles 99.8%

Phase discrimination

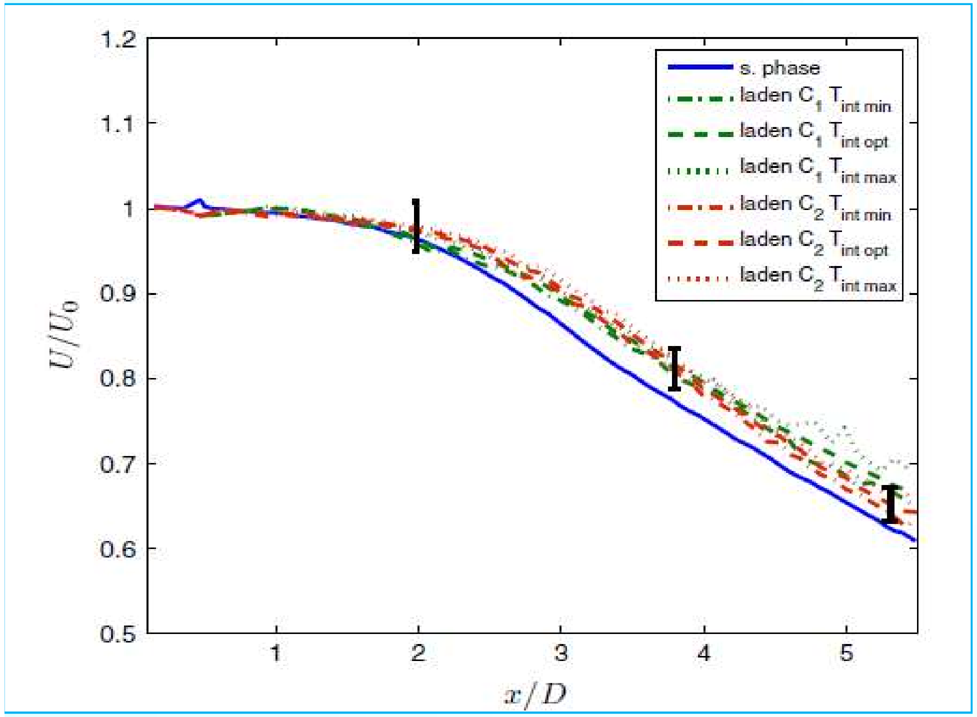
Validation

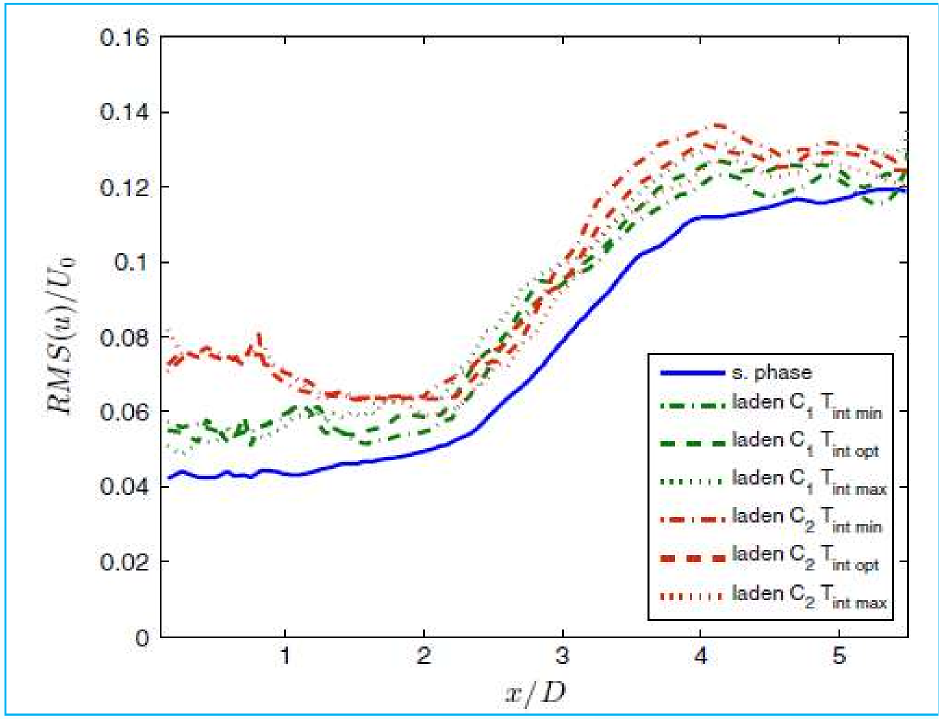


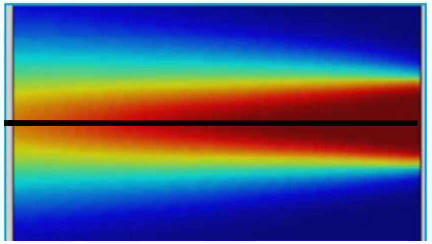
optimal around 75

Low resolution

Example: turbulent jet with fibers – effect on results



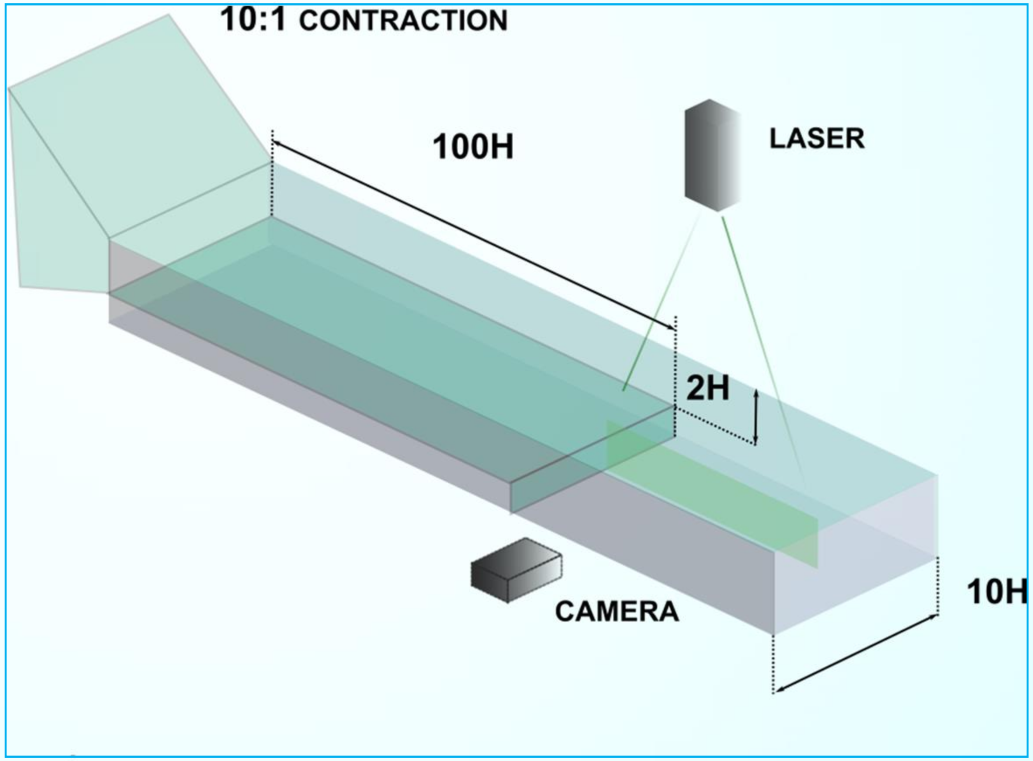




High resolution

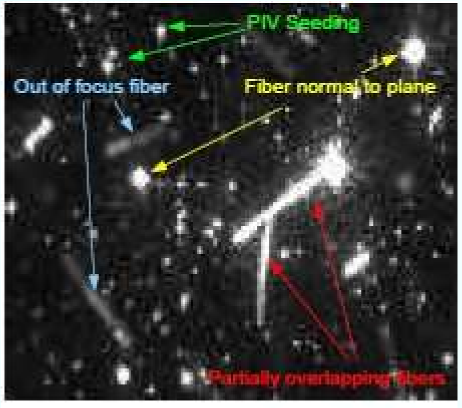
High spatial resolution: fibers NOT *eqv* to spheres

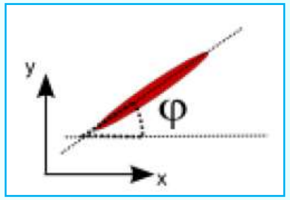
- Backward facing step
- Reynolds numbers 15000
- Stokes number ≈ 0.5
- Imaged region ≈ 1 cm
- Camera sensor 1024 pixel
- Spatial resolution ≈ 100 px/mm
- 1 fiber length ≈ 30 pixel



High resolution

High spatial resolution → orientation

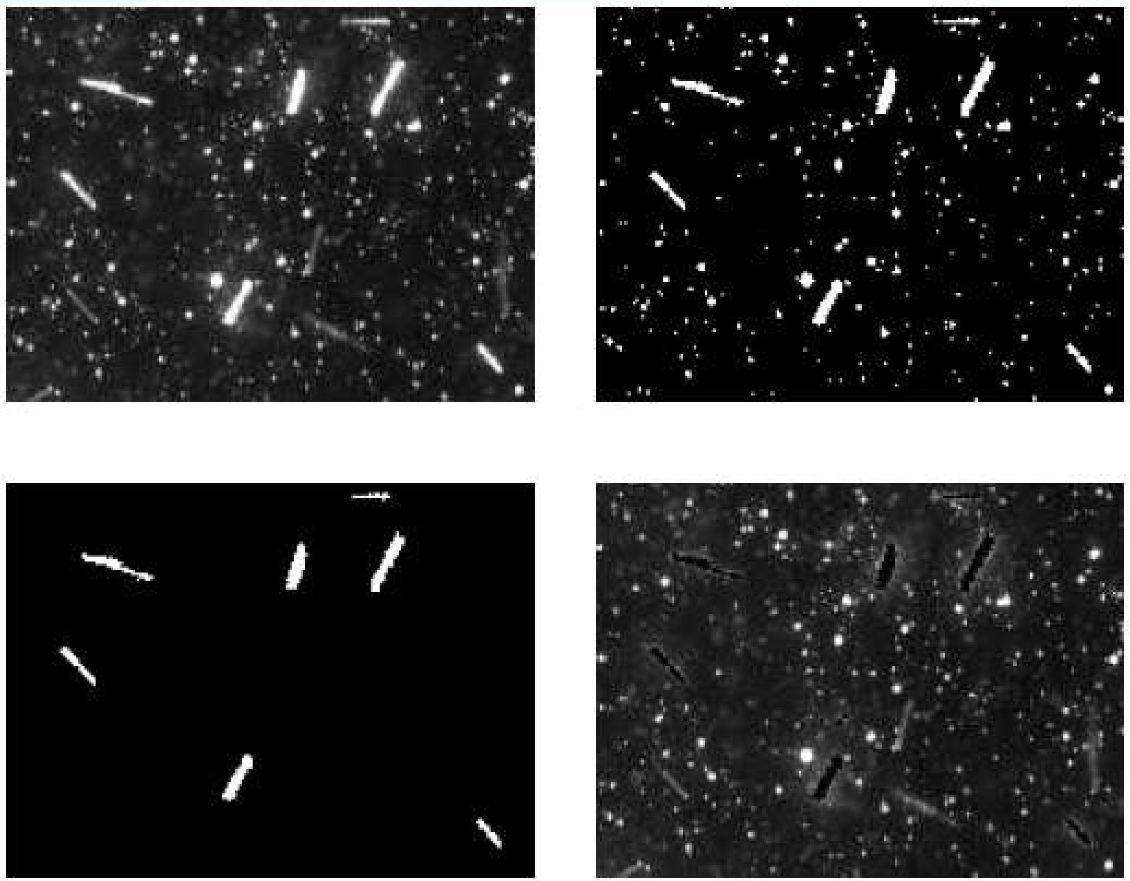




L=fiber length
D=fiber diameter

High resolution

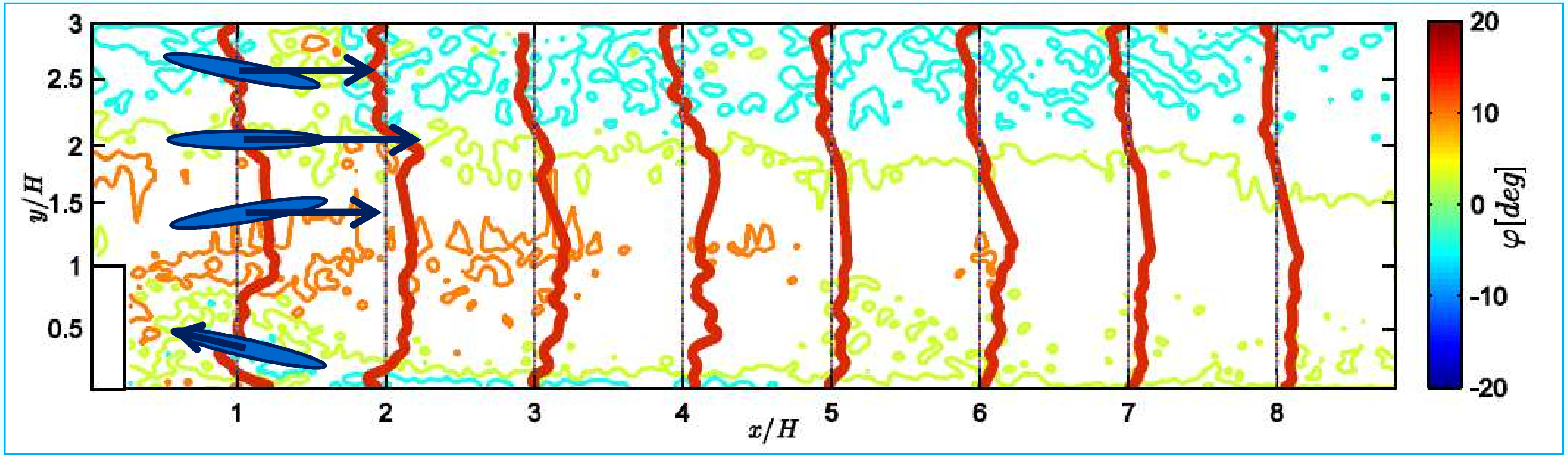
High spatial resolution → orientation



1) Image threshold + median filter 3×3
2) Ellipses labelled as "fibers" if
   $L/d>1.5$ and $L>9d_{tracer}$
3) Fibers subtracted from images
   → <u>HOLES</u>
4) Tracer processed with PIV
5) Fibers processed with
   Particle Tracking

Non-spherical particles – multi-point measurements

Example: BFS with fibers – fiber orientation



agreement with upstream flow data
correlation with with local velocity ?

Remarks

- Tracers & particles

Use of optical techniques: the problem of tracers
Light scattering by particles: position and distance
Low concentration and size: follow the fluid without disturbing

-Single-point measurements

Spherical particles: Phase Doppler
Non-spherical particles: Shadow Imaging

- Multi-point measurements

Spherical particles: Global Phase Doppler & Interferometry
Non-spherical particles: Shadow Imaging & Image Analysis
Low spatial resolution: phase discrimination complex
High spatial resolution: orientation