Rheophysical investigation in concentrated particle suspensions

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Geophysical flows

- Snow avalanches
- Mudflows
- Pyroclastic flows

Photo SLF

Geophysical flows

- Snow avalanches
- Mudflows
- Pyroclastic flows

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- Mudflows
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Geophysical flows

Geophysical flows

Complex fluids

- Particles
  - Material
  - Shape
  - Granulometry
  - Rugosity
- Interstitial fluids
  - Viscosity

$\Rightarrow$

How do we measure the rheological properties ?

- Yield stress
- Shear-thinning, Shear-thickening
- Thixotropy, rheopecty

Geophysical flows

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- Thixotropy, rheopecty

Consequences for the rheologist

1. $\begin{pmatrix} T \\ \Omega \end{pmatrix} \dashrightarrow \begin{pmatrix} \tau \\ \dot{\gamma} \end{pmatrix}$
2. **Wide gap** (because of the granulometry)

T : Total Torque
Ω : Angular velocity
τ : shear stress
$\dot{\gamma}$: shear rate

$\Rightarrow$

Solve the Couette inverse problem

$$\tau(r) = \frac{T}{2\pi r^2 h}$$

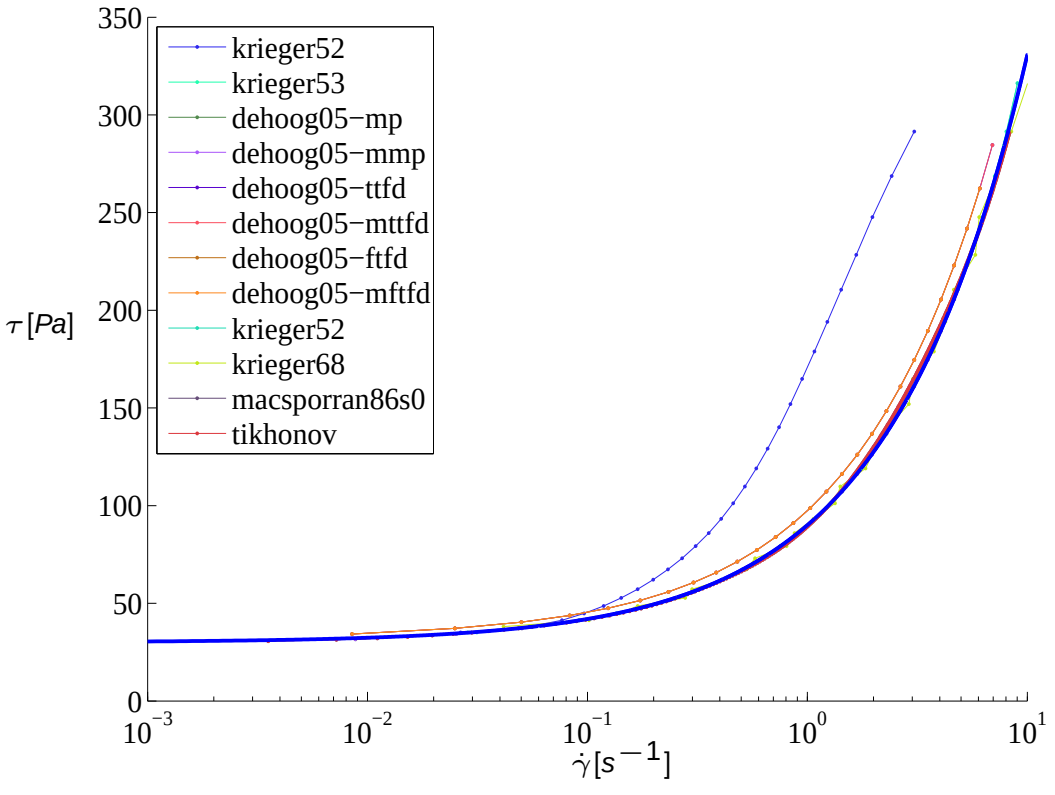
$$\Omega = \int_{R_{in}}^{R_{out}} \frac{\dot{\gamma}(r)}{r} dr$$

r : Radius
h : Height of fluid
$R_{in\,/\,out}$: Radius of the inner/outer cylinder

Consequences for the rheologist

Example : an artificial Herschel-Bulkley fluid $\tau = \tau_y + K\dot{\gamma}^n$

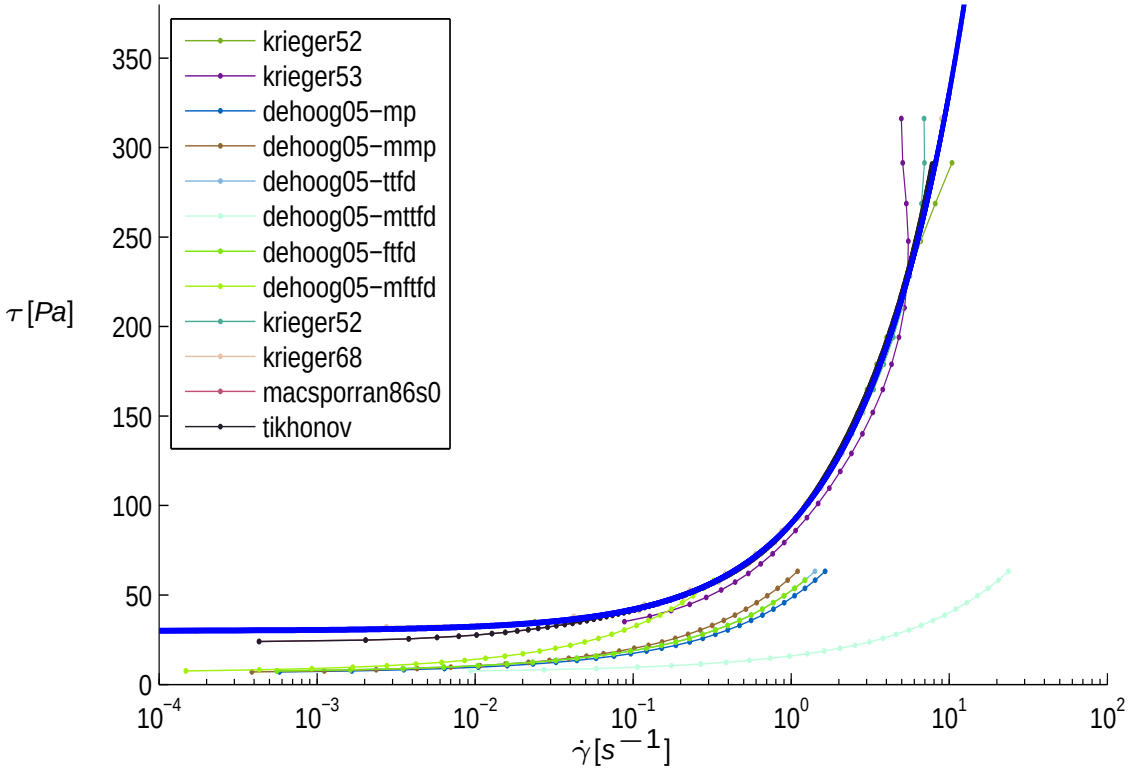
$$s = \frac{R_{in}}{R_{out}} = 0.9$$



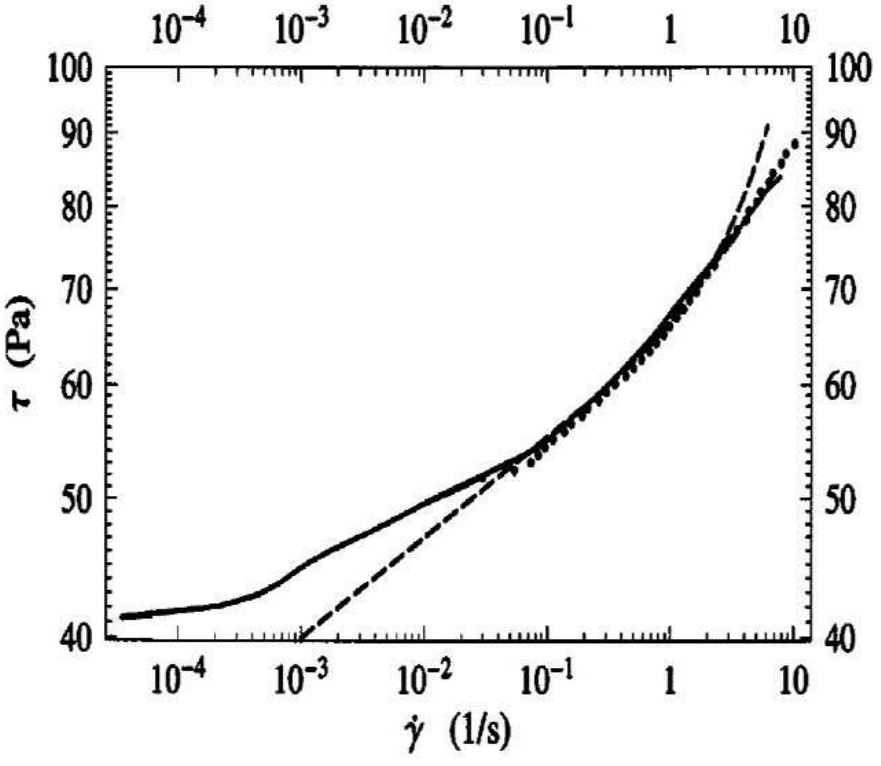
Consequences for the rheologist

The same fluid with a wide-gap geometry

$$s = \frac{R_{in}}{R_{out}} = 0.2$$

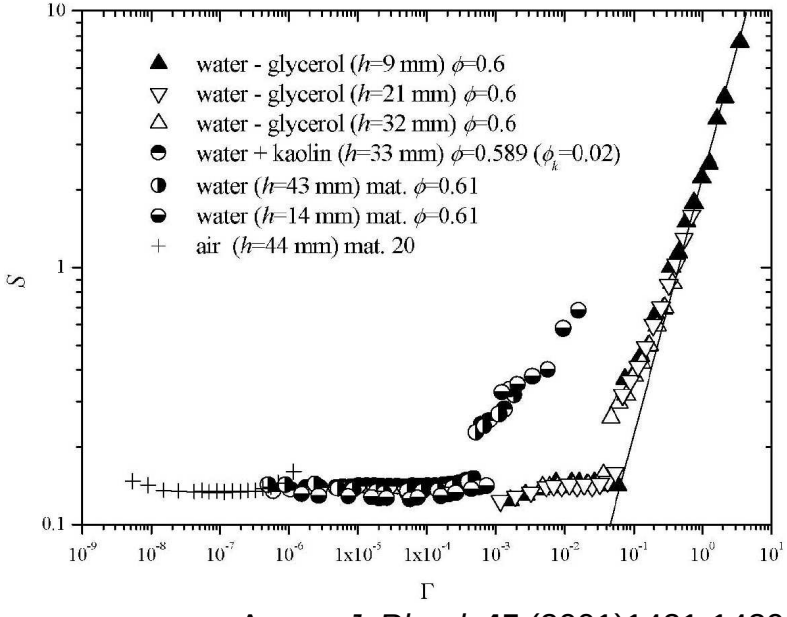


Example : a polymeric gel



Ancey, *J.Rheology* **49** (2005) 441-460

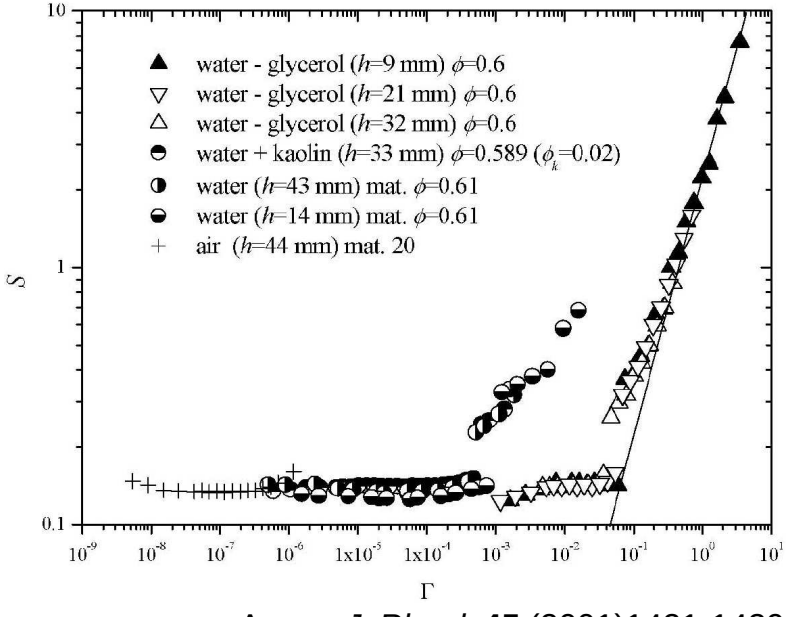
Example : a particle suspensions



Ancey, *J. Rheol.* **45** (2001)1421-1439

S : adimensionalized shear stress
Γ : adimensionalized angular velocity

Example : a particle suspensions



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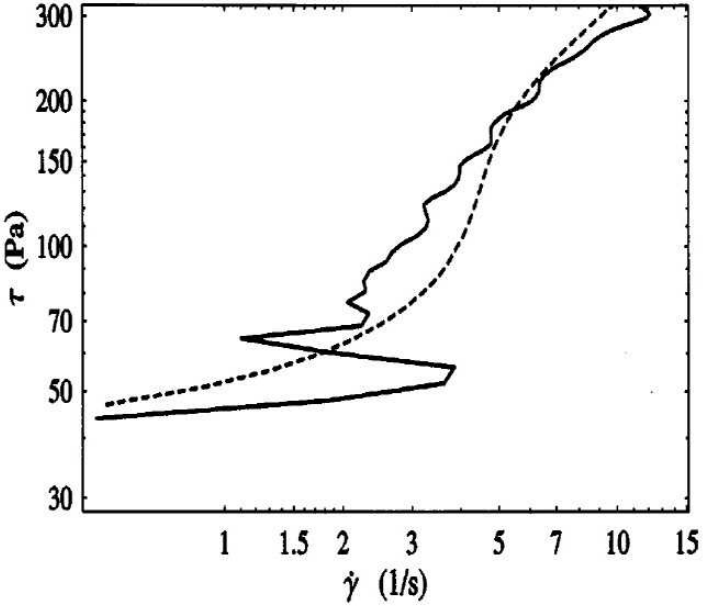

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S : adimensionalized shear stress
Γ : adimensionalized angular velocity

- Shear localization ?
- Particle segregation ?
- Particle migration ?
- Ordering ?

- Particle rugosity ?
- Particle Shape ?
- Slipping ?

Do we measure the material property...

...or some flow artifacts ?

Classical and optical rheometry

Continuum mechanics approach

$\Downarrow$

Classical rheometry

$\Downarrow$

T and Ω

$\Downarrow$

Solve the Couette inverse problem

$\Downarrow$

τ and $\dot{\gamma}$

Rheophysical approach

$\Downarrow$

Clear suspensions

$\Downarrow$

Particle motion (FPIV / FPTV)

$\Downarrow$

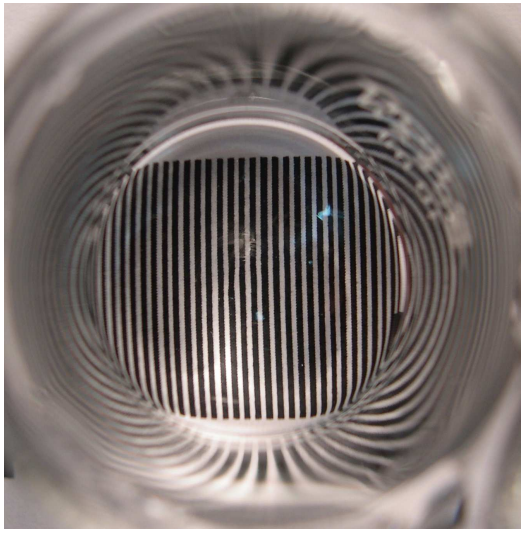
Differentiate the velocity profile

$\Downarrow$

τ and $\dot{\gamma}$

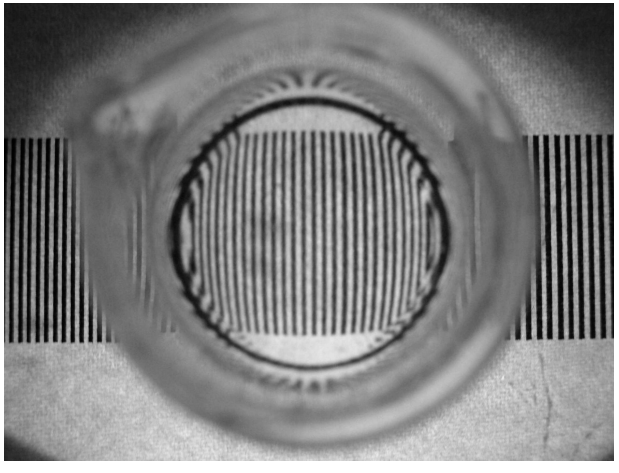
Where are the properties comming from ?

Interesting flows



Optical methods

$\Longrightarrow$



concentrated particle suspensions
(25mm thickness)

The simplest complex fluid

- Iso-index $\Rightarrow$ transparency
- Iso-density $\Rightarrow$ No gravitation effects
- Molecular tagging of the particles
  $\Rightarrow$ the laser excite the fluorescence

Particles

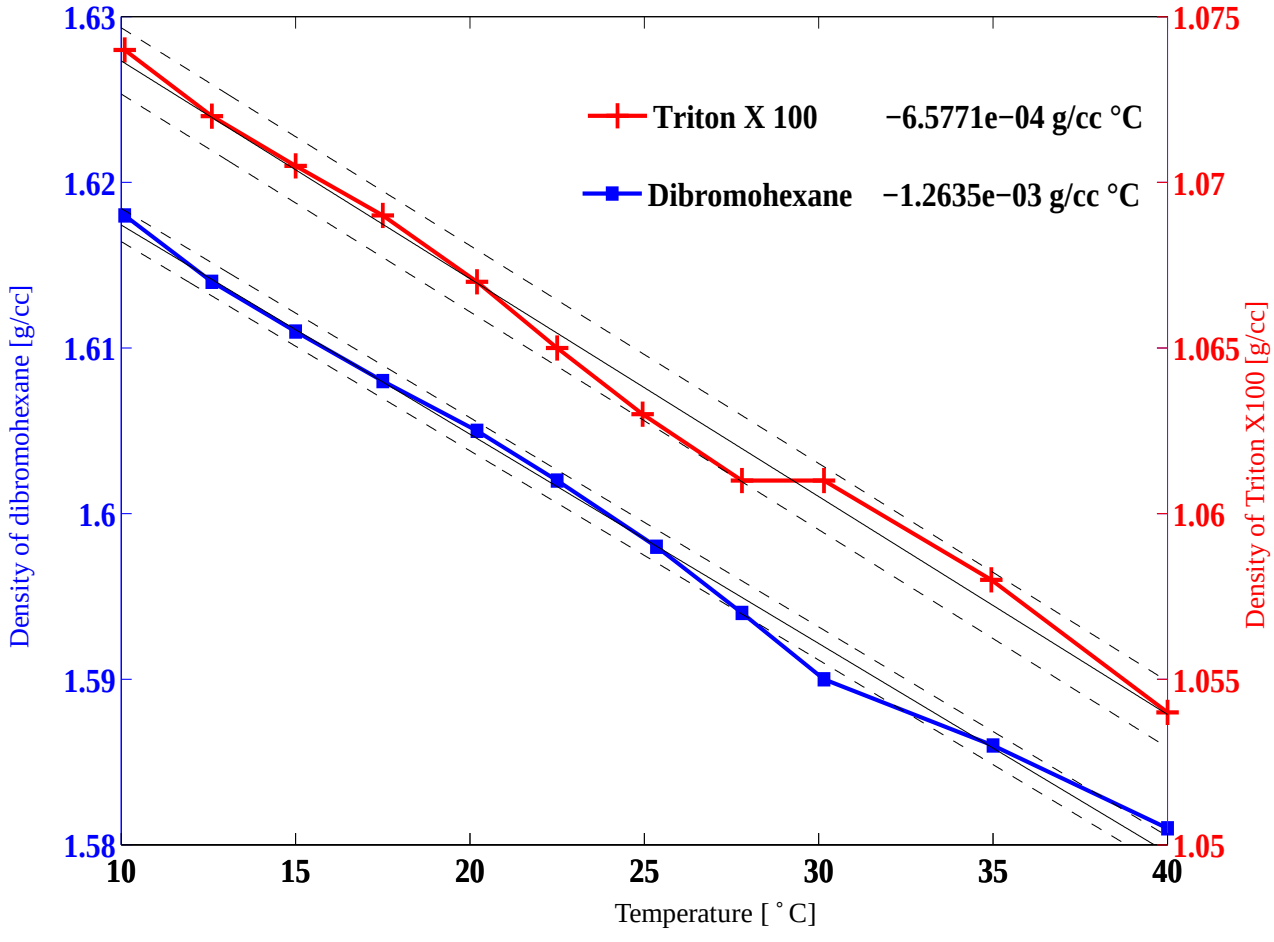
- Shape : spherical
- Granulometry

Fluid

- Three fluids mixture
- Newtonian
- Viscosity : variable

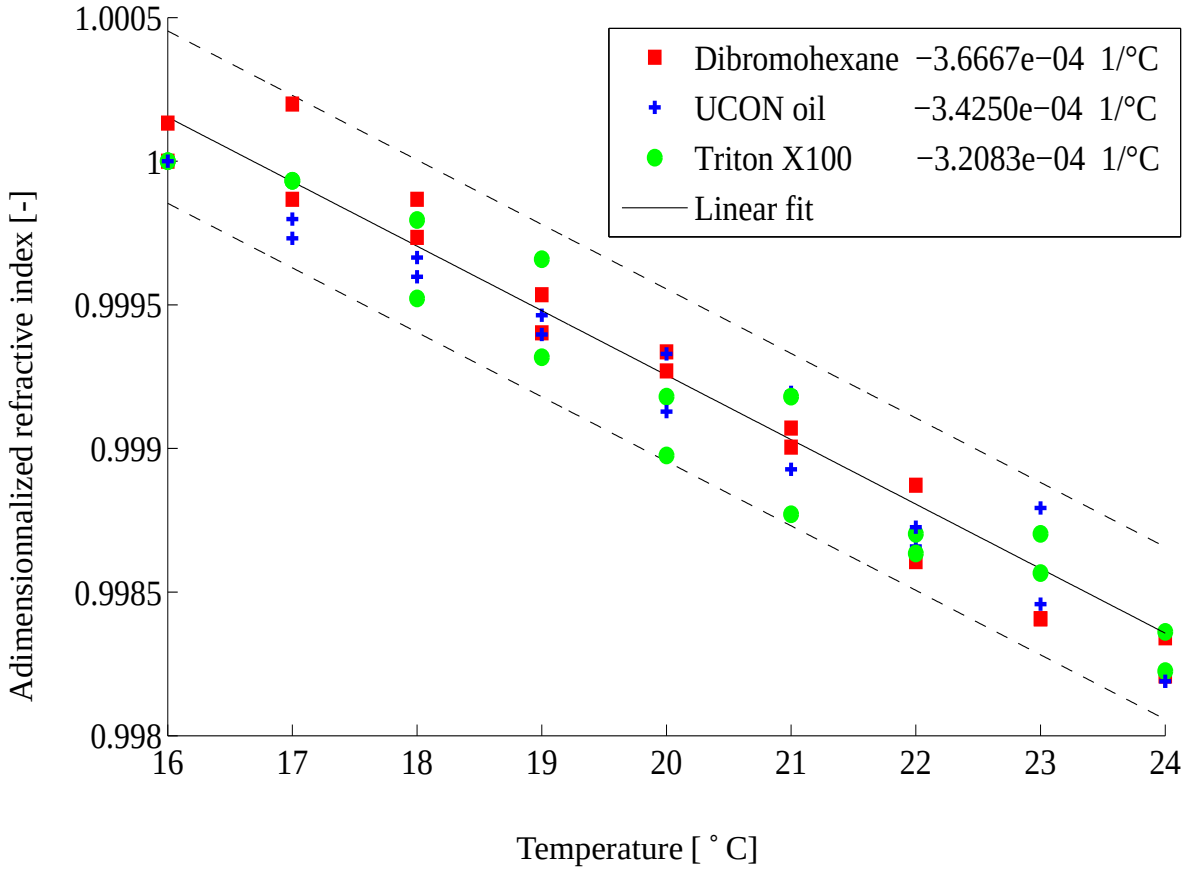
Temperature effects

- Density
- Refractive index

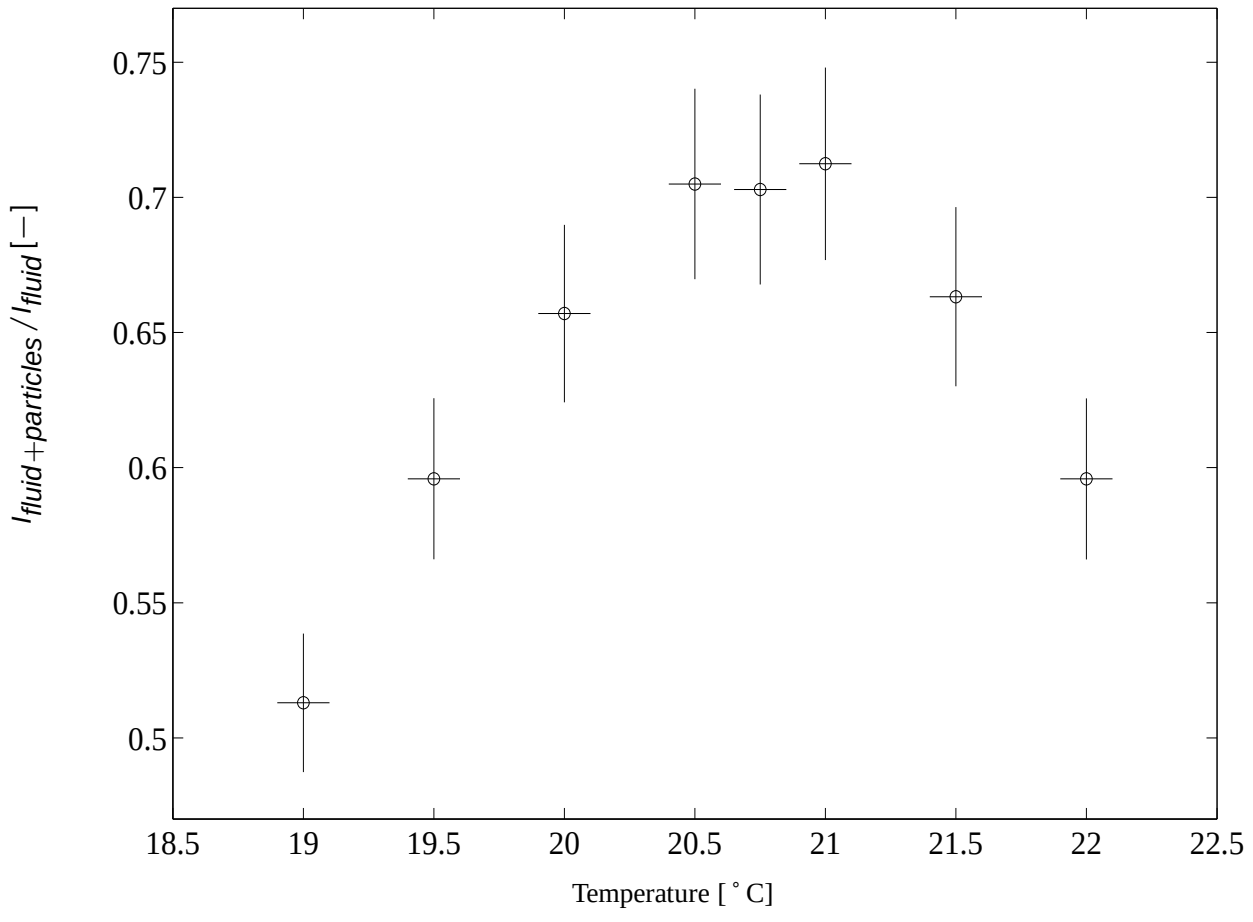


Temperature effects

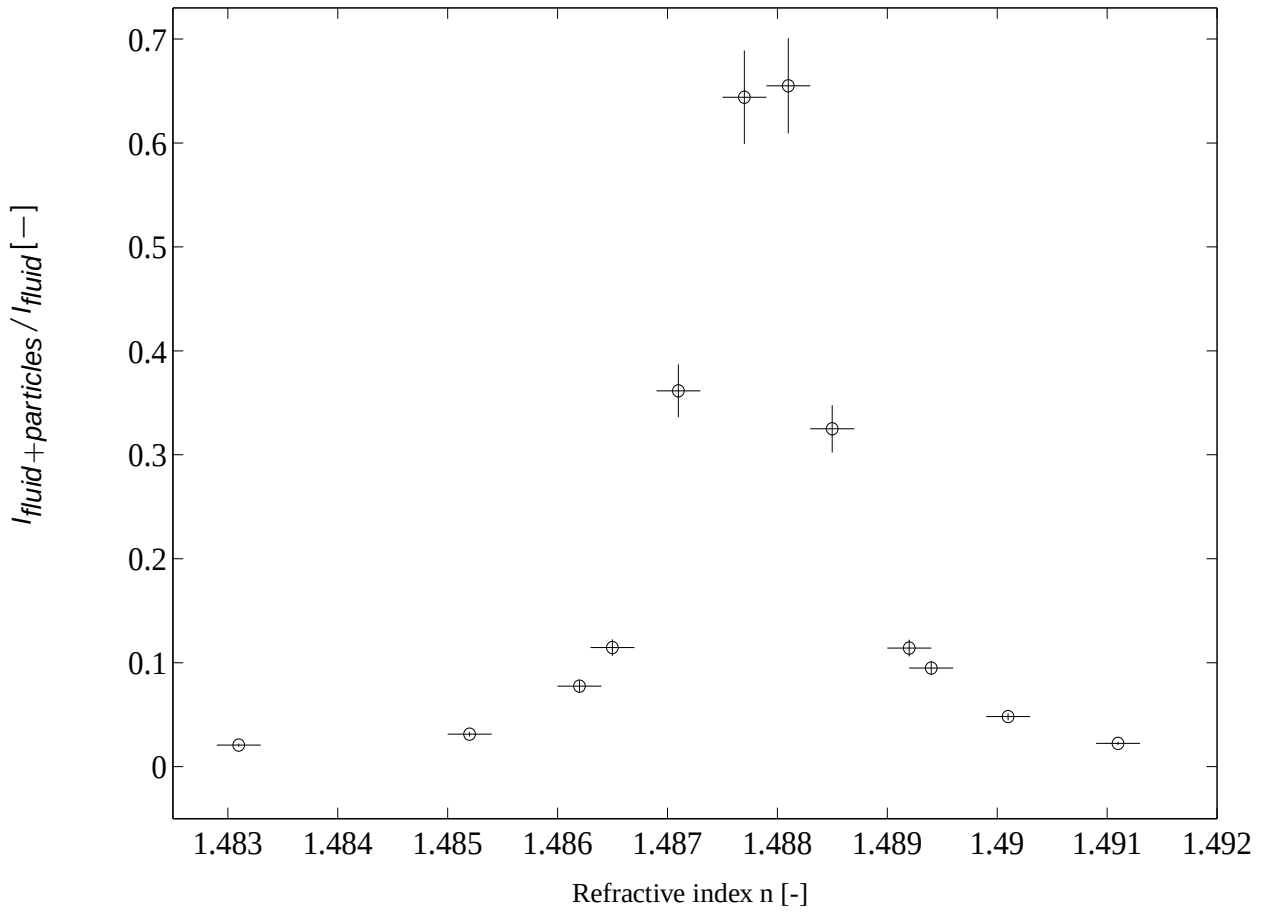
- Density
- Refractive index



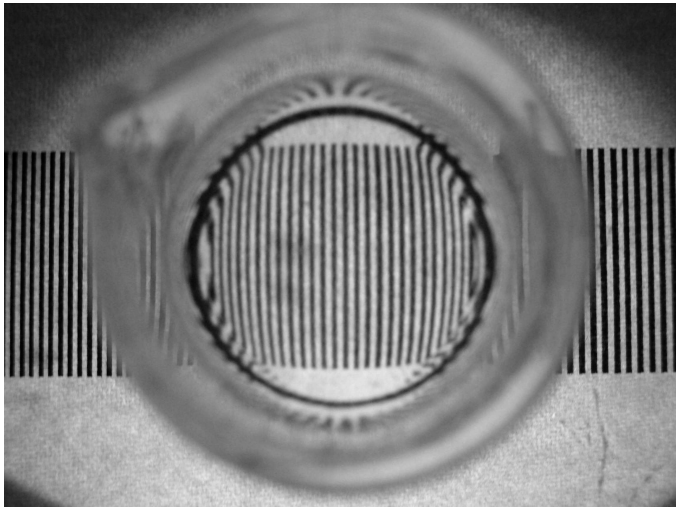
Temperature effects on the light transmission

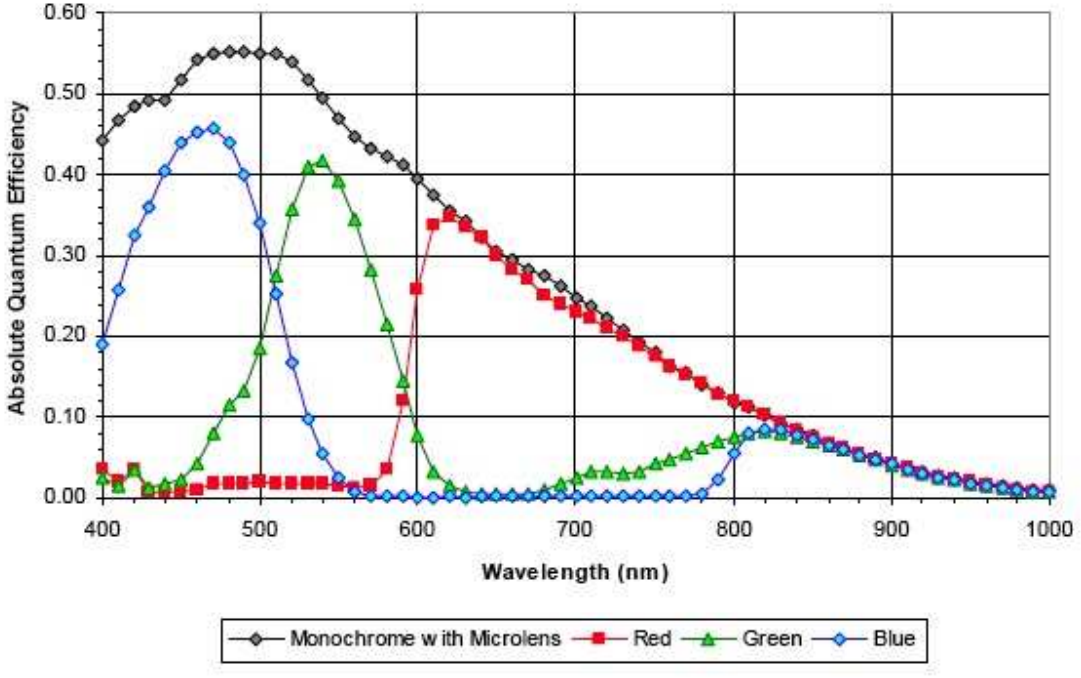


Refractive index mismatch effects on the transmission



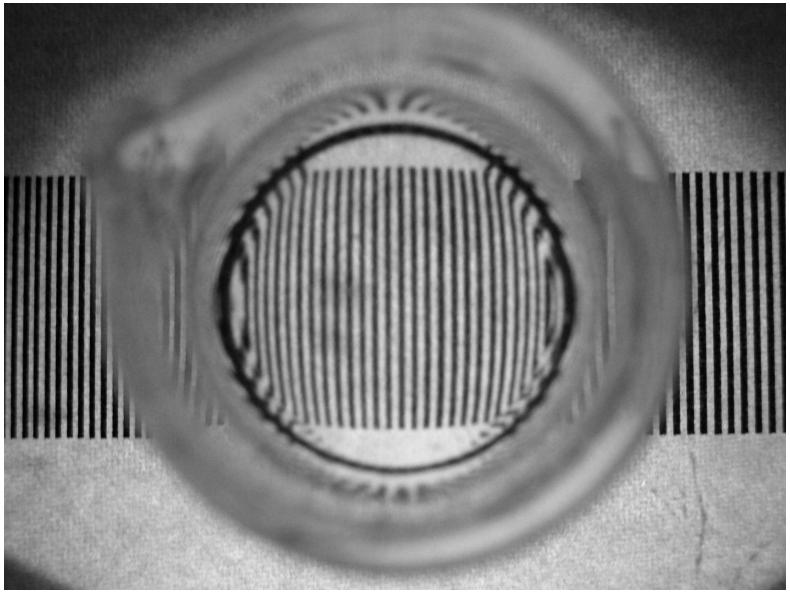
Wavelength effects



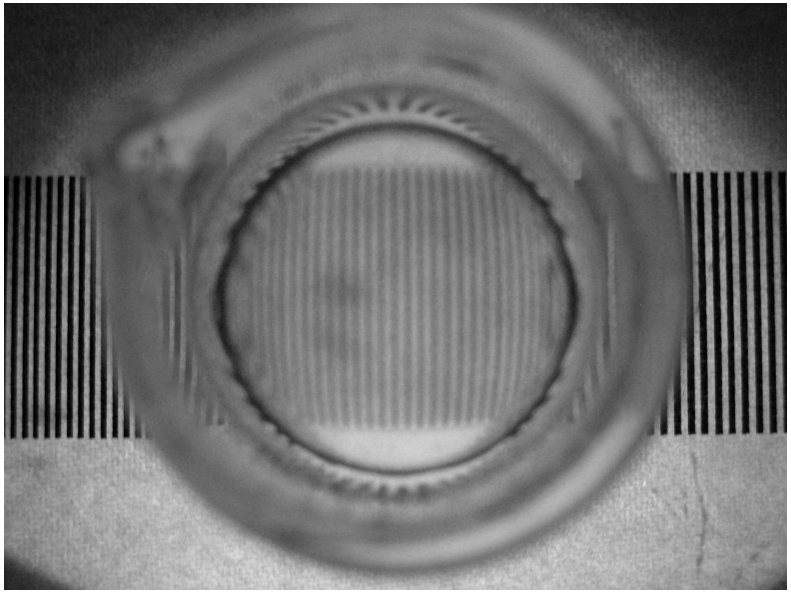


Wavelength effects

RGB picture with a color CCD camera :

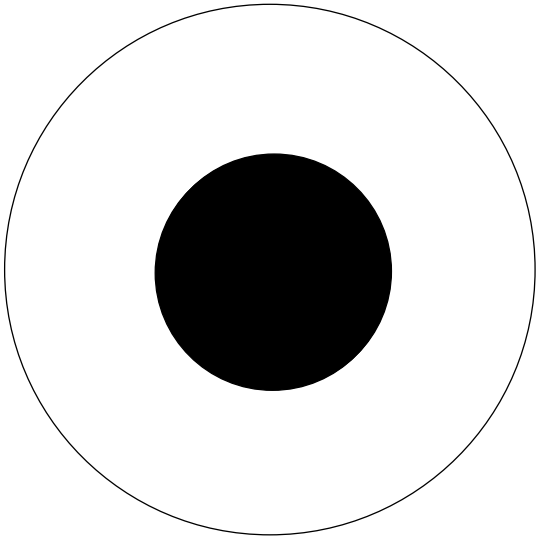


Blue component

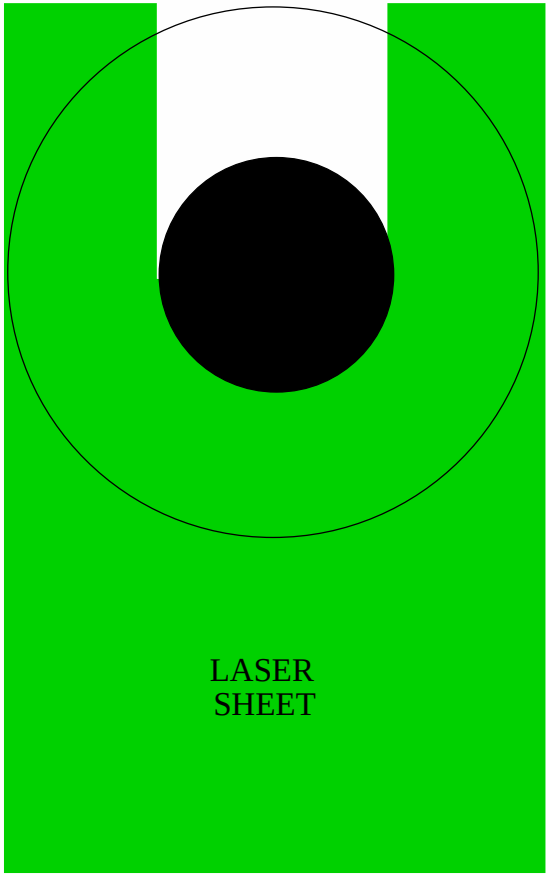


Red component

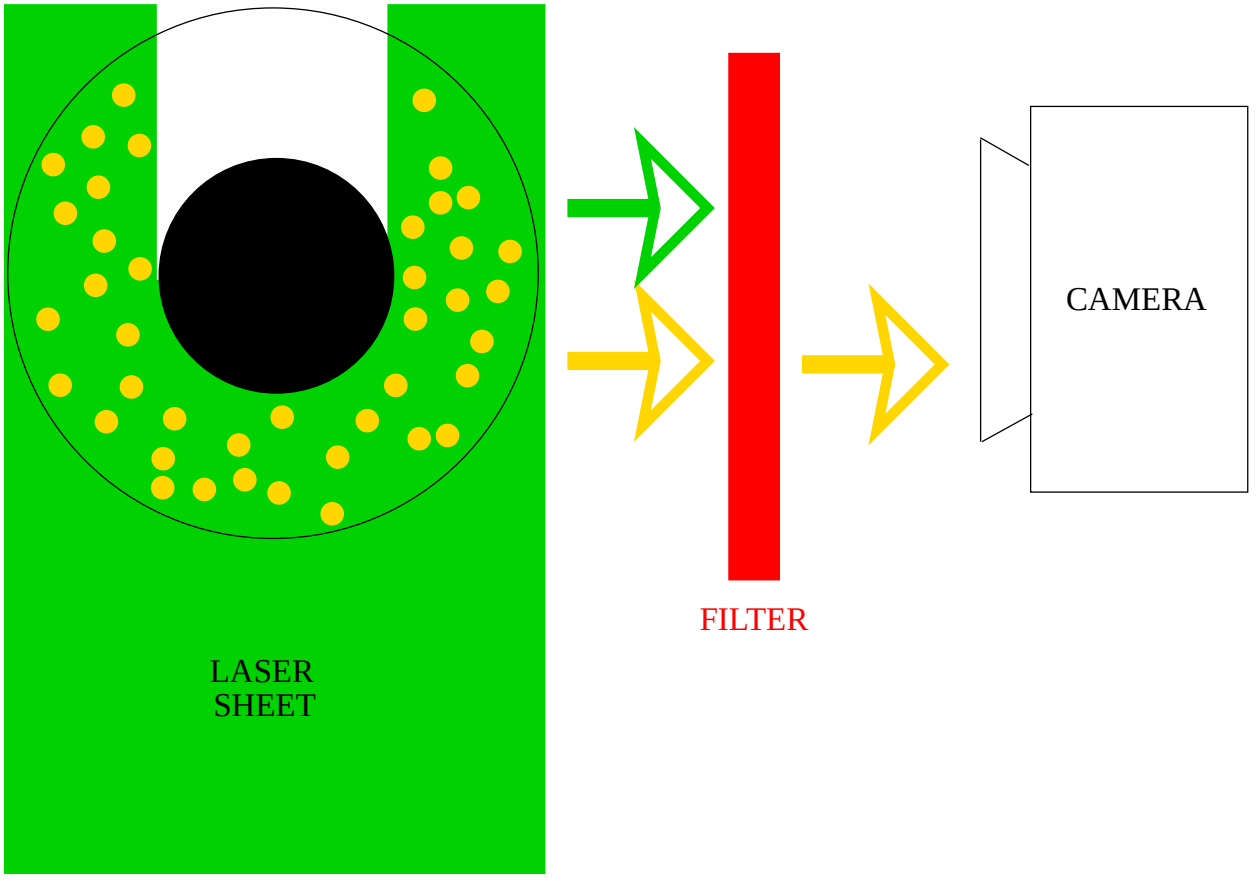
Measurement methods



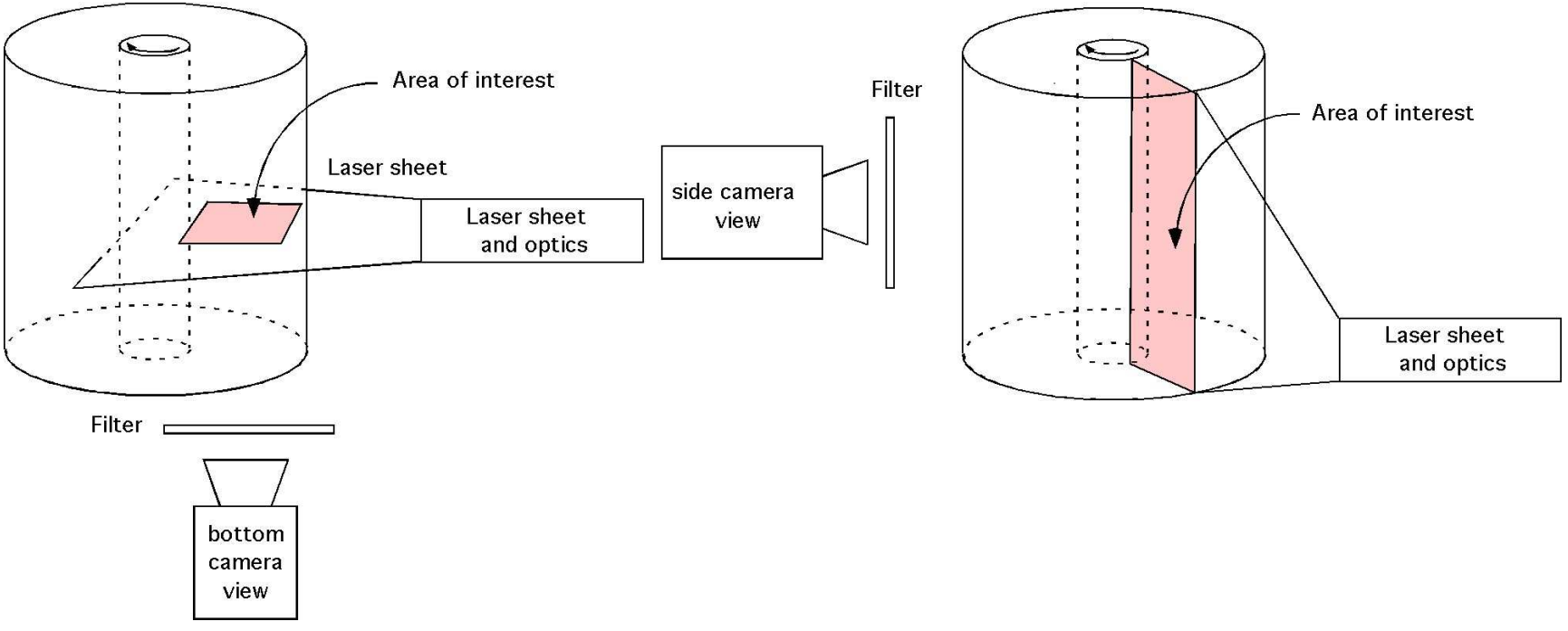
Measurement methods



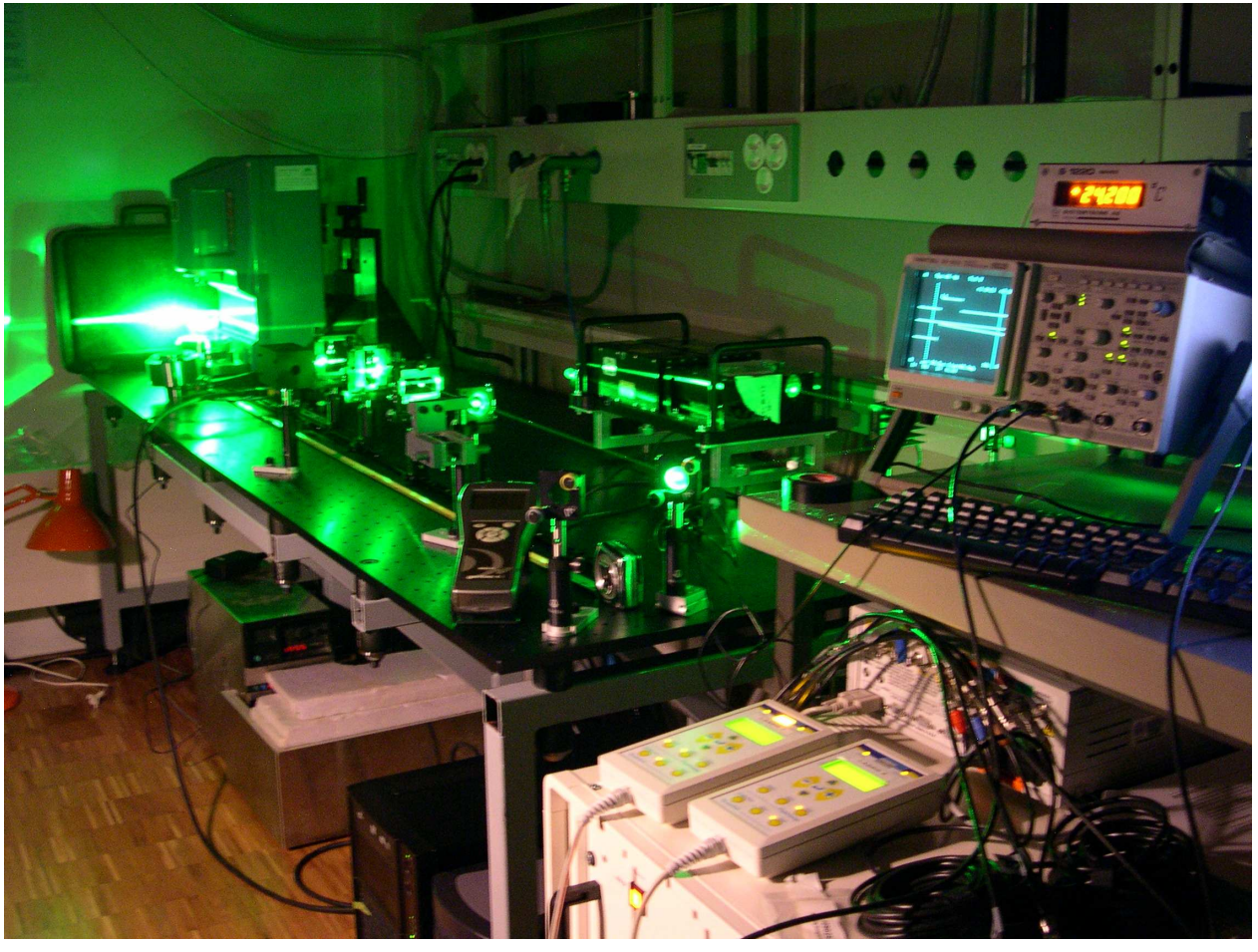
Measurement methods



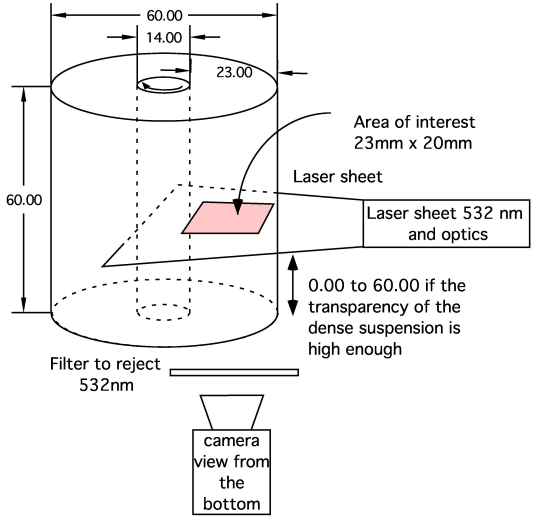
Measurement methods



The setup

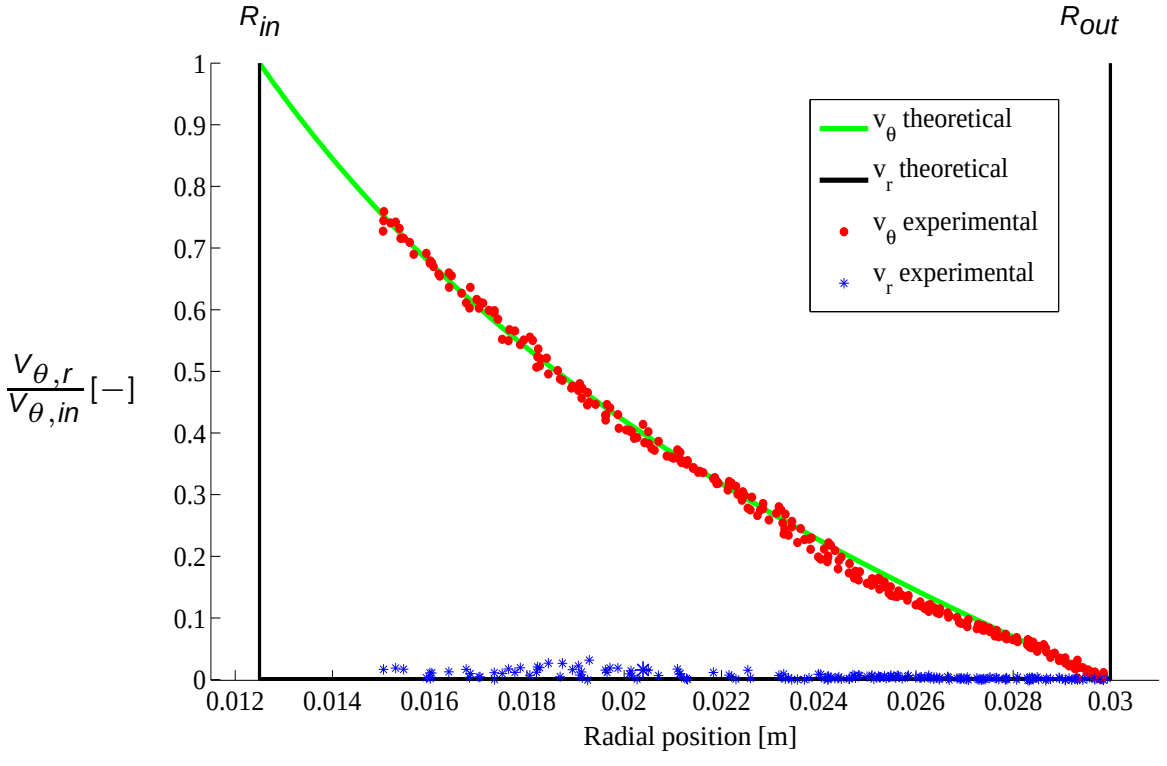


FPIV Images

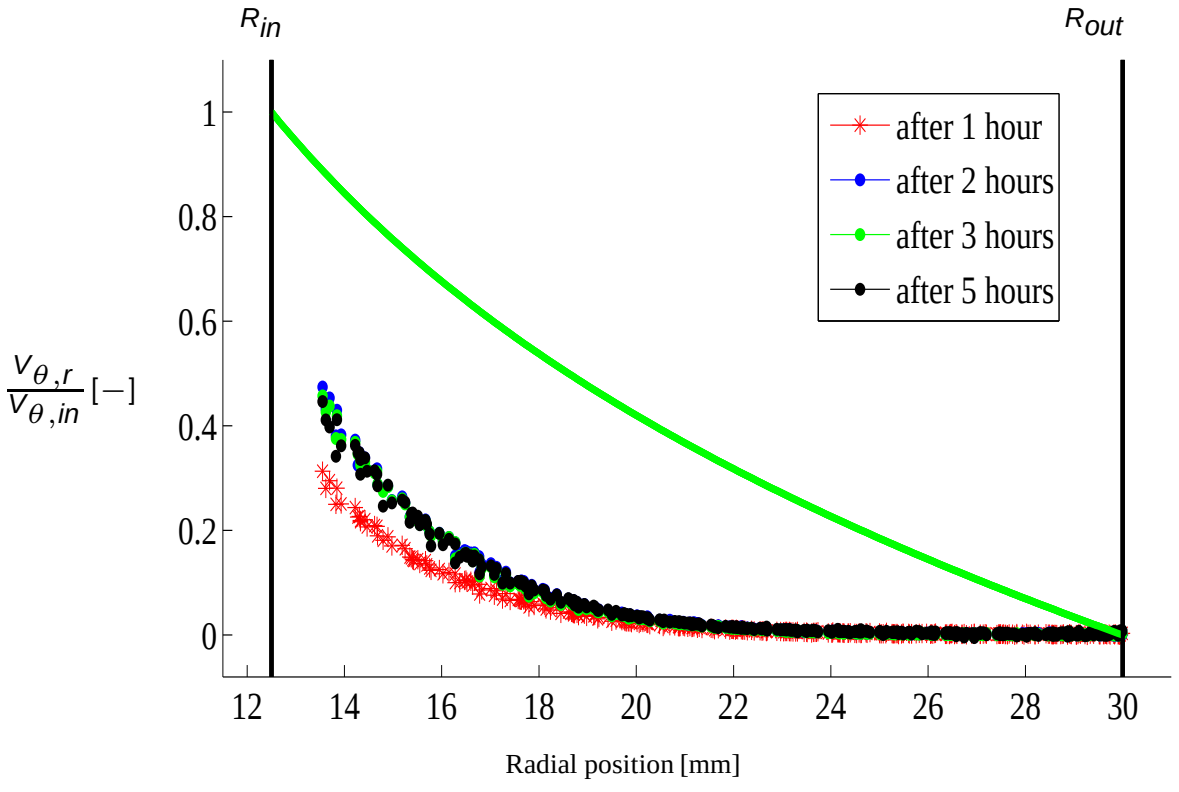

60.00
14.00
23.00
60.00
Area of interest
23mm x 20mm
Laser sheet
Laser sheet 532 nm
and optics
0.00 to 60.00 if the
transparency of the
dense suspension is
high enough
Filter to reject
532nm
camera
view from
the
bottom

Validation measurements

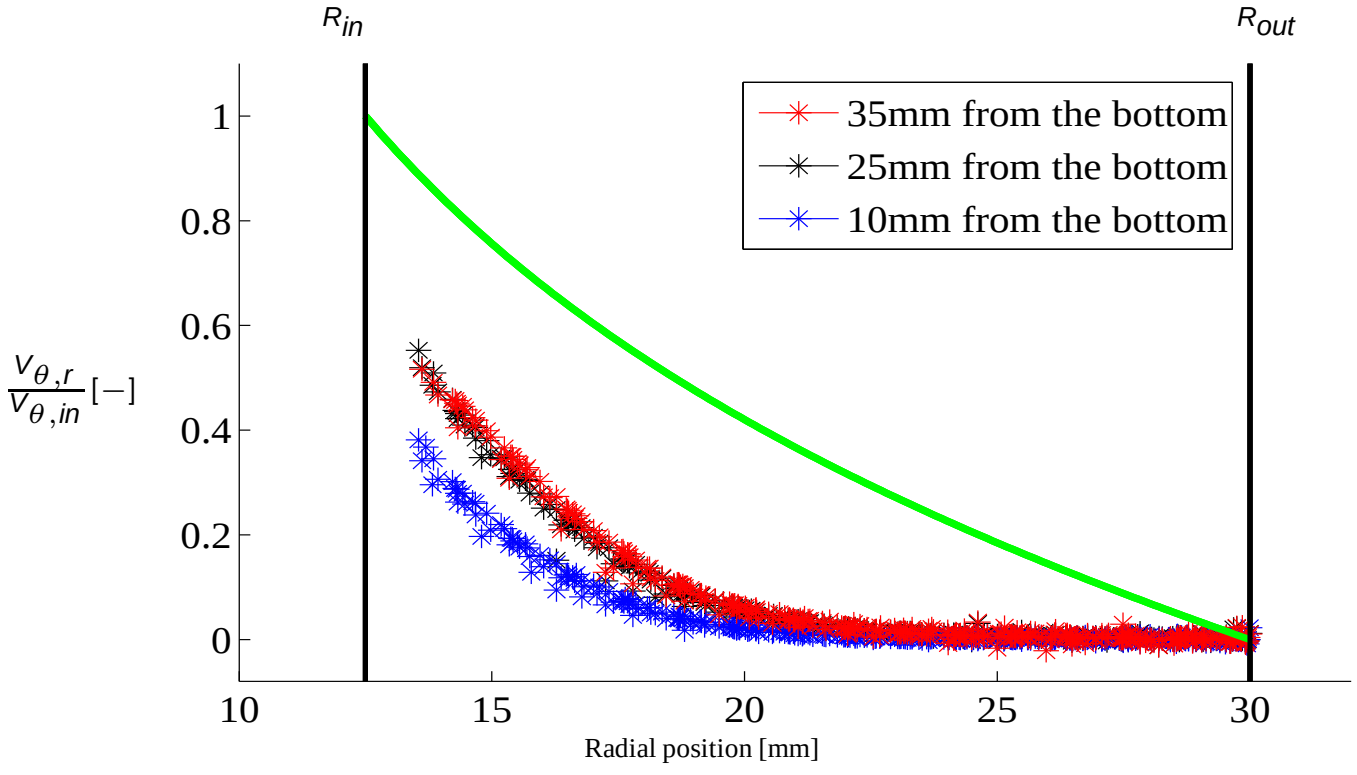
$$V_\theta(r) = \frac{A}{r} + Br \text{ with } A = \frac{R_{in}^2 R_{out}^2 \Omega}{R_{out}^2 - R_{in}^2}, \; B = \frac{R_{in}^2 \Omega}{R_{in}^2 - R_{out}^2}$$



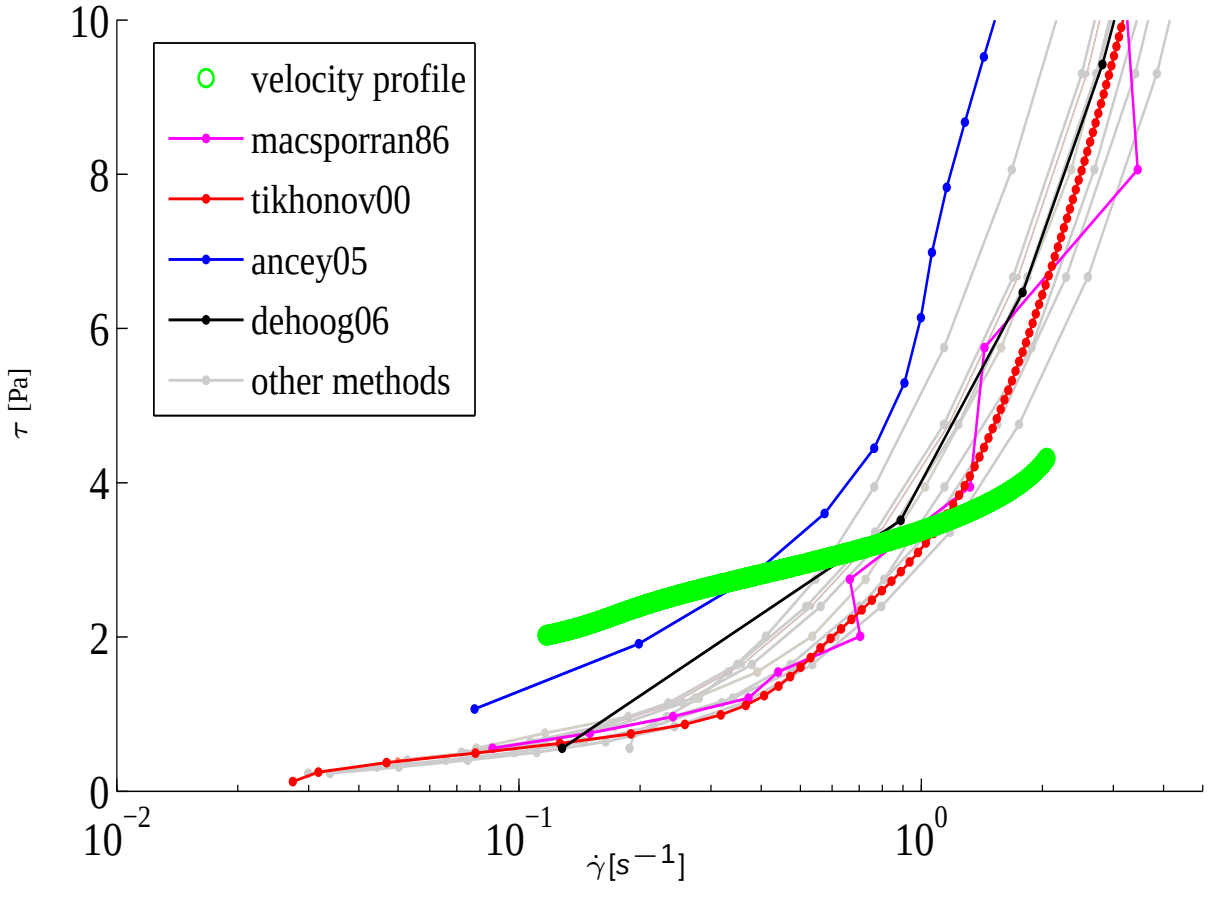
Time evolution of the suspension



Bottom end effects



Flow curve comparison



Futur work

We want to use the same techniques
to make dam-break experiments
and measure the inner velocity profile at the front

See Poster 165 at the poster session

Acknowledgment

- Christophe Ancey
- Nicolas Andreini, Martin Rentschler
- Michel Teuscher and his team
- The Swiss National Science Foundation

- Iso-index $\Rightarrow$ transparency
- Iso-density $\Rightarrow$ No gravitation effects
- not toxic

Particules

- Sphericity
- Good optical properties
- Granulometry
- Fluorecent molecular tagging

Fluide

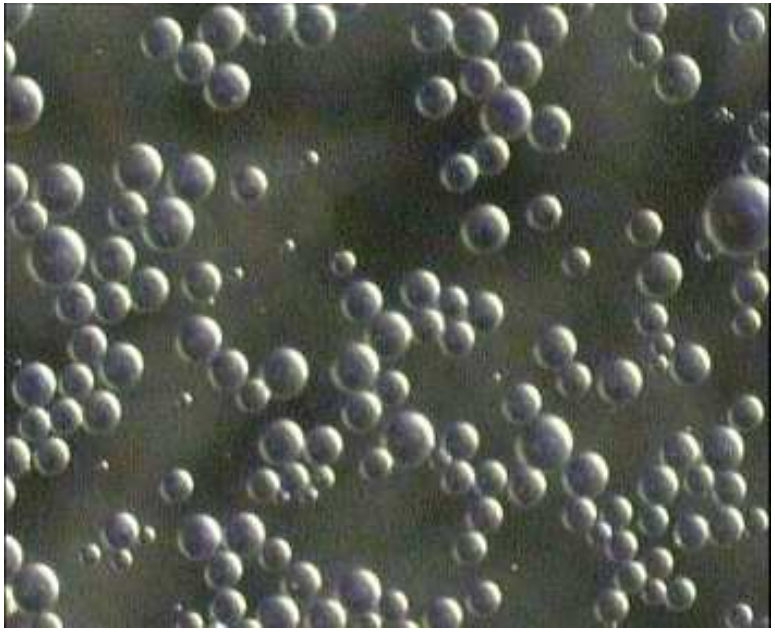
- No evaporation
- Wet the PMMA
- Should not disolve PMMA
- Low absorption
- No excitation
- Variable viscosity

Fluides

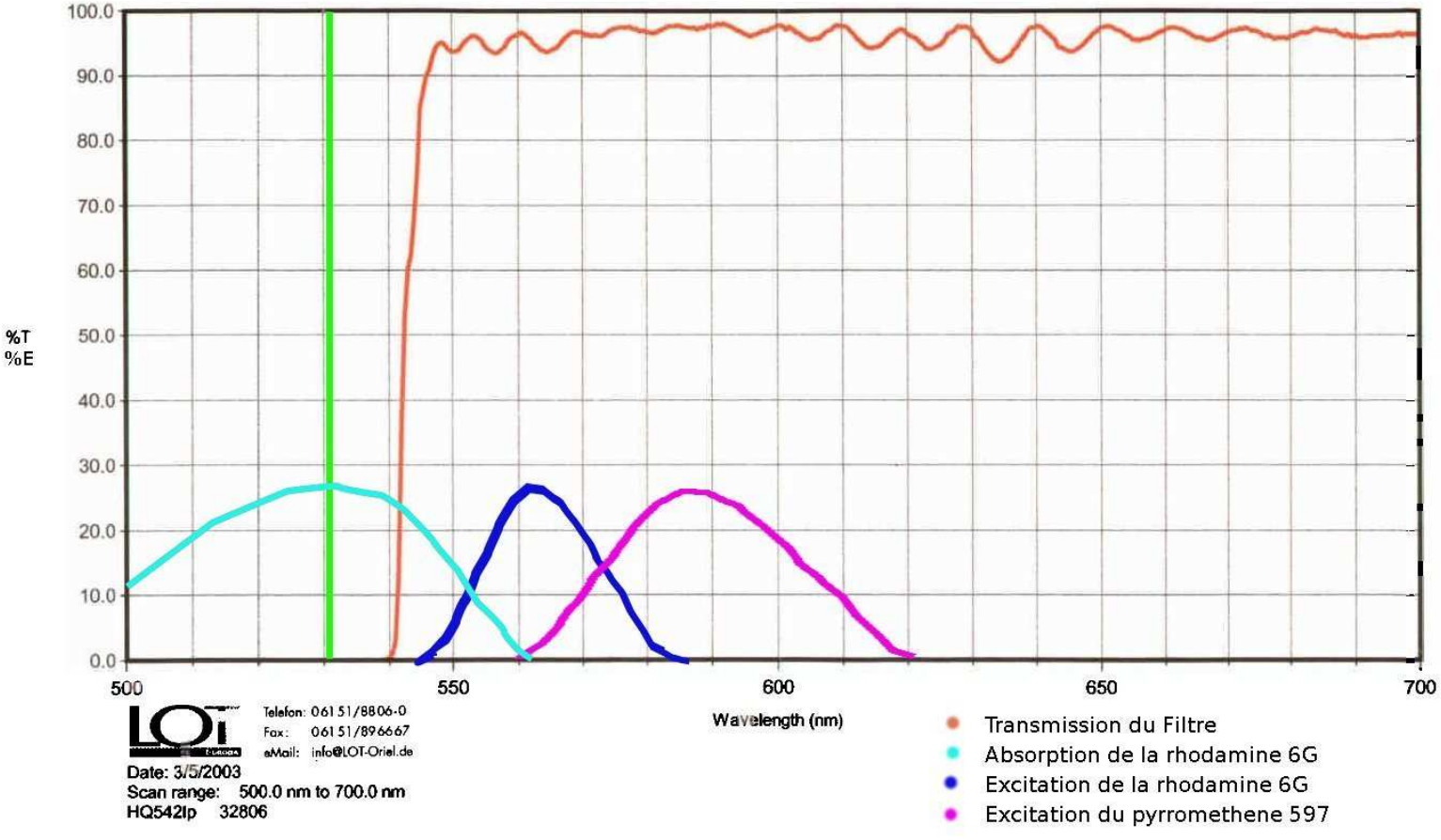
- **Lyon (1997)**
- Dibromohexane
- Triton X 100
- Huile UCON 75H

Transparent concentrated noncolloidal suspensions

- Spherical particles : 200 to 600 μm
- Iso-index and iso-density fluid mixture



Why Rhodamine 6G ?



How much rhodamine 6G ?

High concentration

⇓

More fluorescence

⇓

COMPROMIS

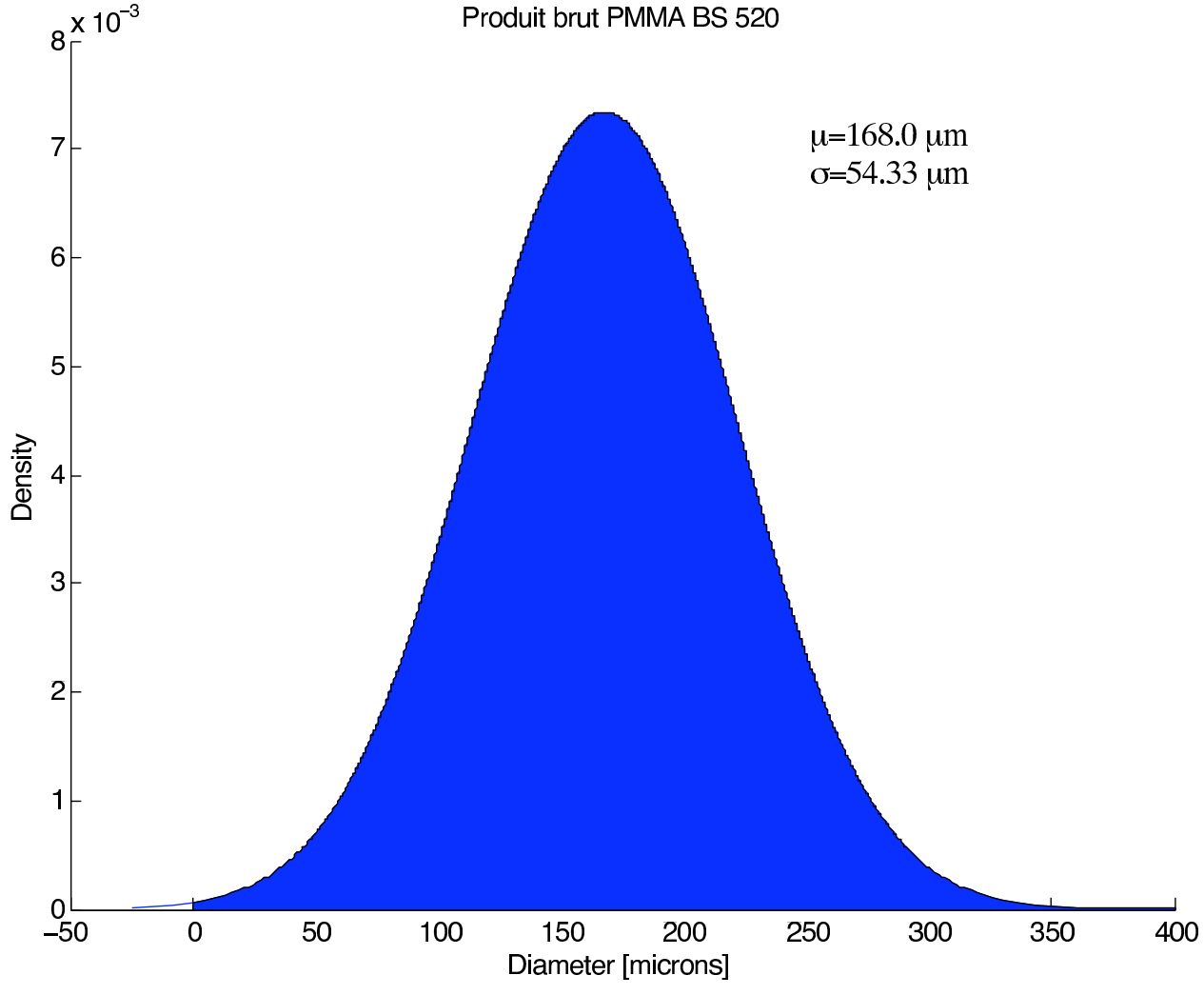
⇑

Lower effect on the refractive index

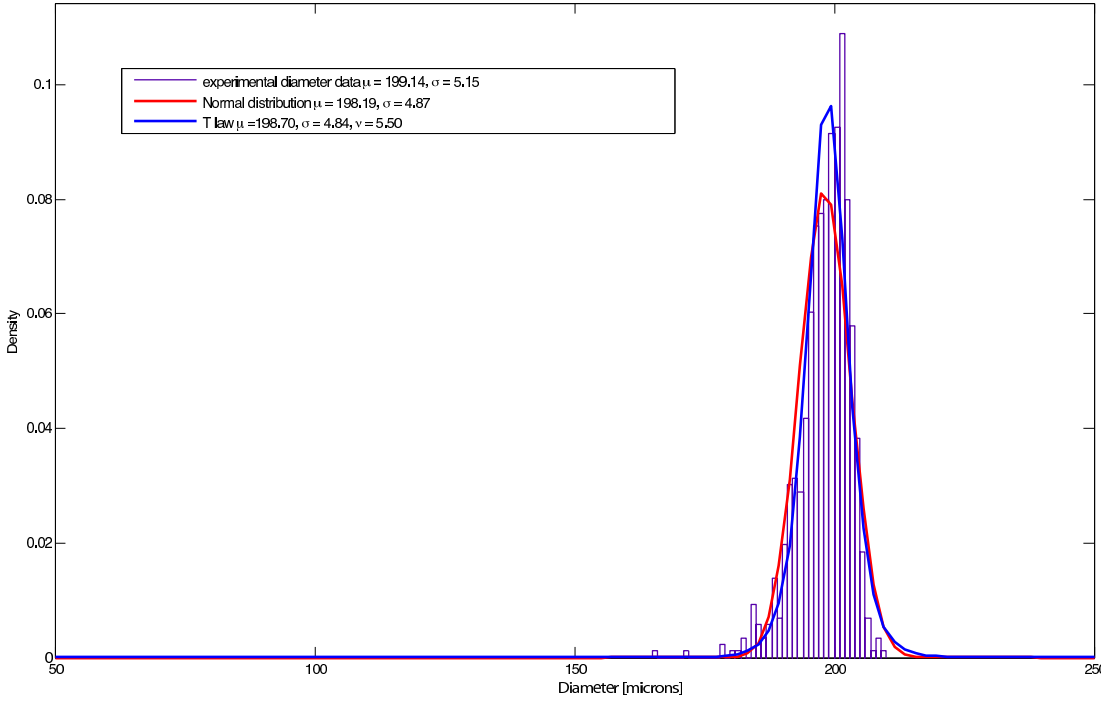
⇑

Low concentration

Produit brut



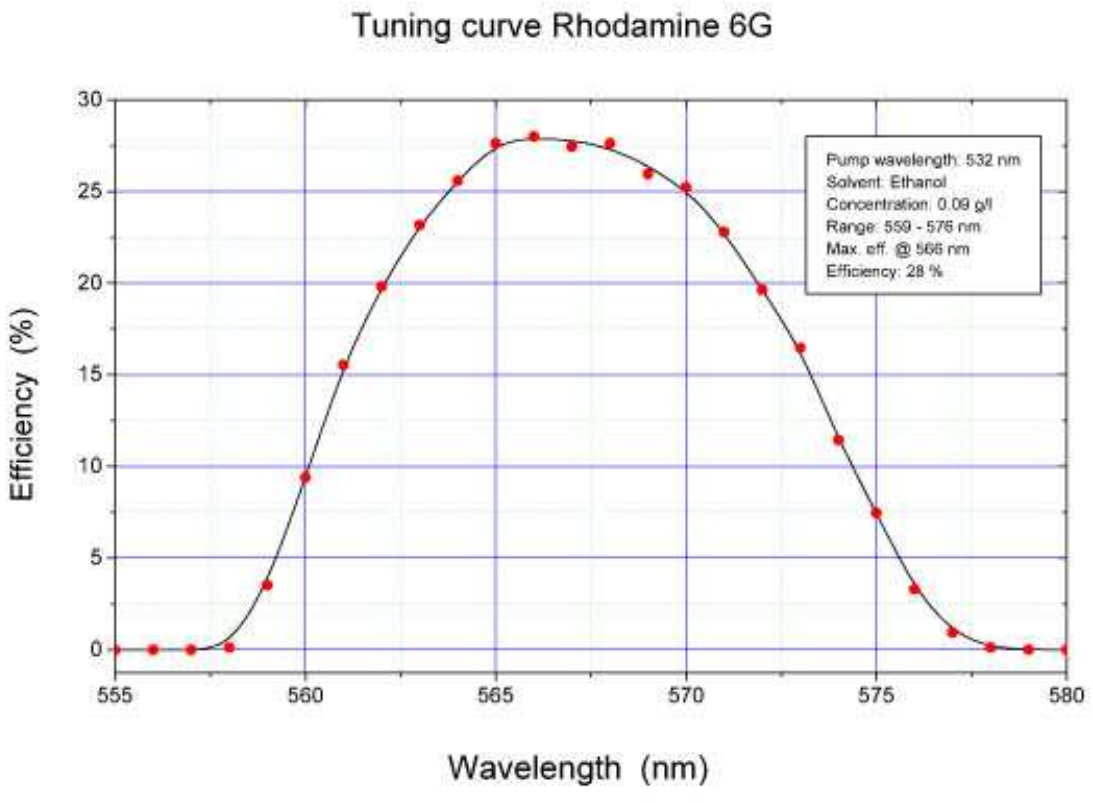
Produit tamisage par voie humide dans de l’ ?thanol



REPRODUCTIBILITE

Choix de la Rhodamine 6G

- Excellent efficacit ?
- suffisamment faible ”Stokes shift”



Suspension properties

- **Iso-index $\Rightarrow$ transparency**
- **Iso-density $\Rightarrow$ No gravitation effects**
- **Non toxic**

Particules

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