Optical trap stability study for combining SR micro/nano-XRF methods with optical tweezers based sample manipulation

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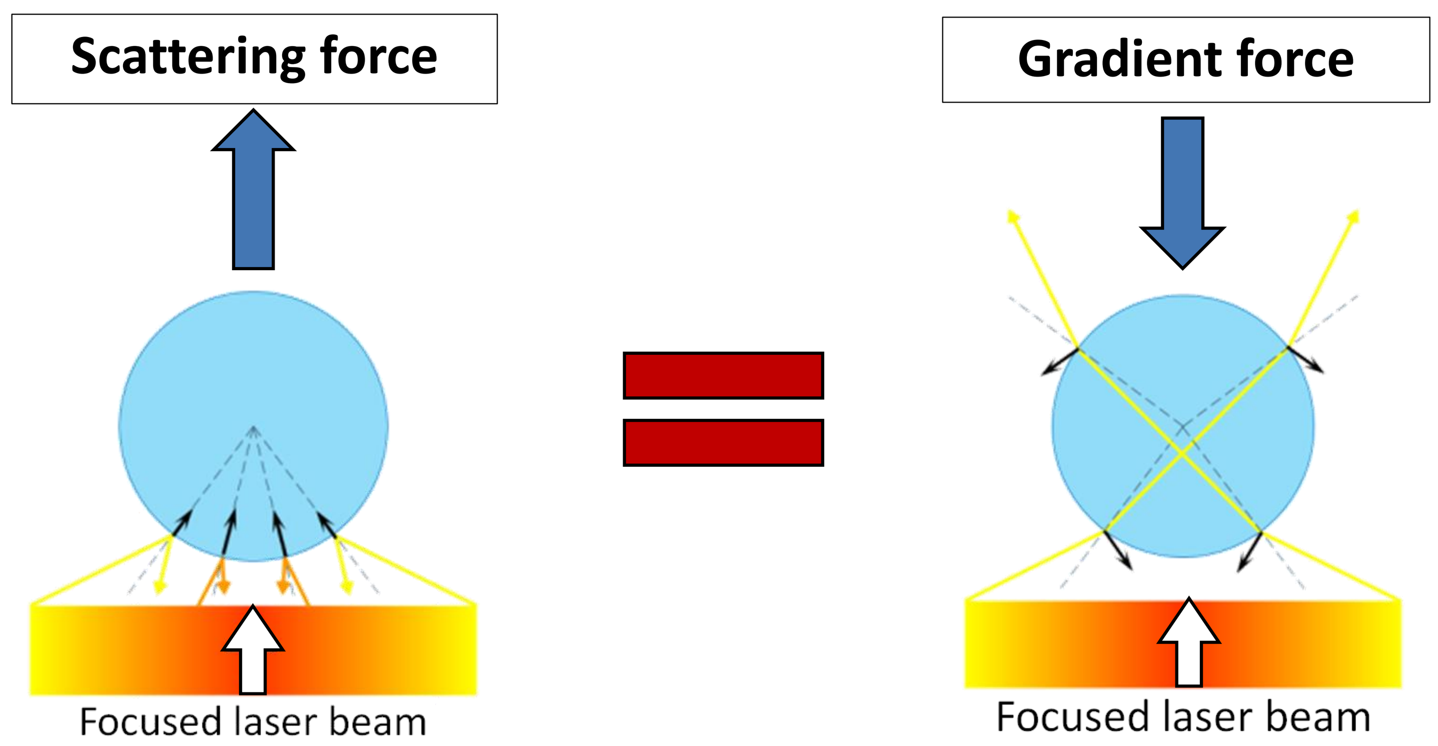
Abstract

The goal of this project involves the development of a new methodology that combines confocal SR micro/nano **X-ray fluorescence imaging** (XRF) with laser-based **optical tweezers** (OT) for **contactless sample manipulation**. This new methodology will enable the investigation of **biological model organisms** and single cells in a state that is much **closer to their natural state**. Since the combination with scanning XRF analysis on the micro- and nanoscale is planned, a stability study of a test object in the optical trap is crucial. Next to the description of our compact OT setup, the results of the initial characterization of the setup are presented in terms of **trapping performance** along the optical axis (Z-direction) and perpendicular to the laser beam (Y- direction).

Optical Trapping

- ⇨ An optical trap is a micro-manipulation tool that uses a highly-focused laser beam to trap, move and rotate microscopic dielectric objects in three dimensions [1].
- ⇨ Optical trapping results from the interaction between the (IR) laser and the **refractive index mismatch** of the object with its environment (e.g., water).
- ⇨ Scattering force: **reflection** of photons at the object-medium interface
  ⟶ Object is *pushed away* from the optical trap
- ⇨ Gradient force: **refraction** of photons at the object-medium interface
  ⟶ Object is *attracted* towards the optical trap
- ⇨ An object is stably optically trapped when both forces become equal in size.

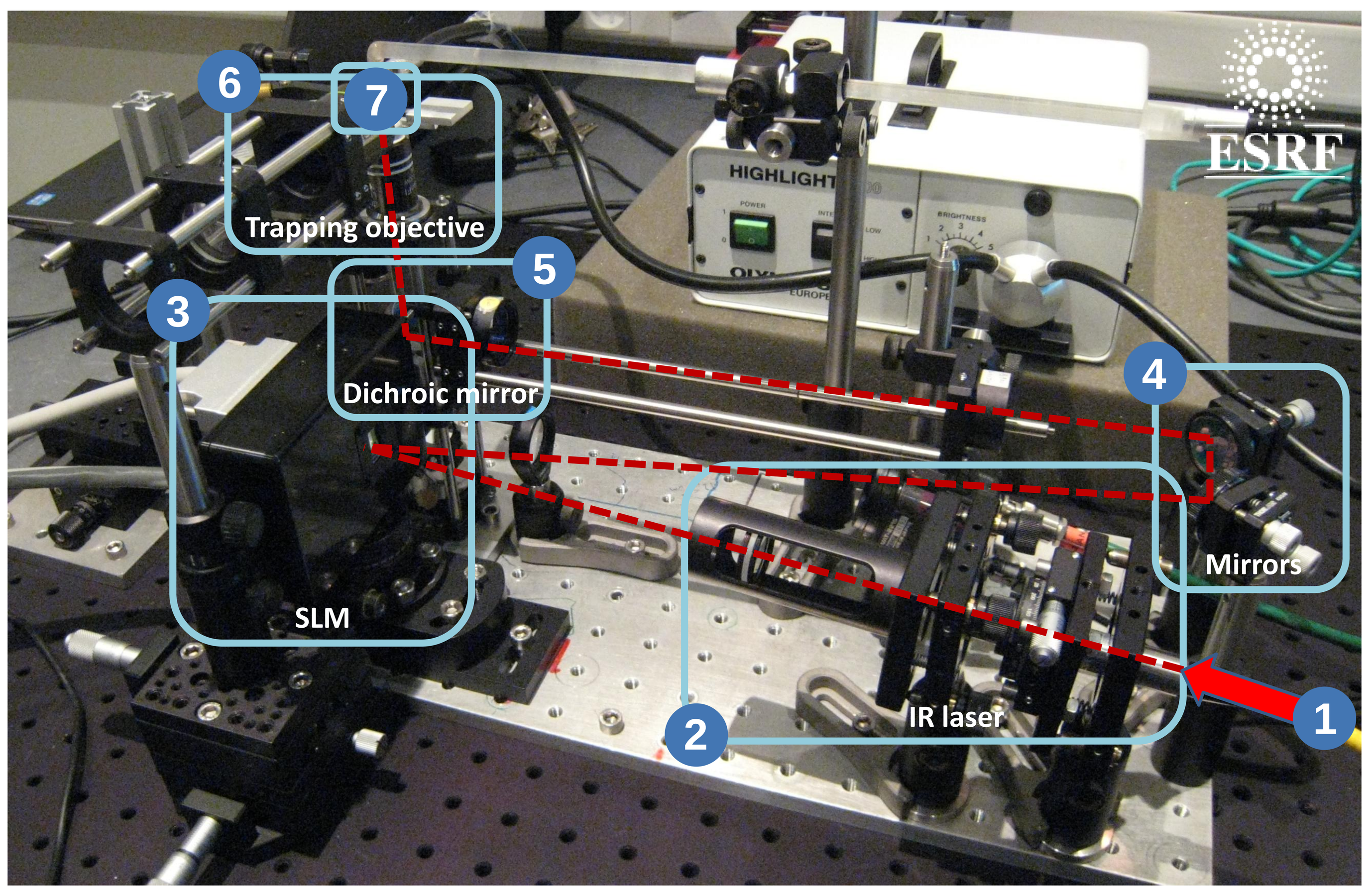


Compact Optical Tweezers Setup

Three major components: **Laser** + **Trapping Microscope Objective** + **Imaging system**

⇨ Compact optical tweezers setup available from beamline ID13, ESRF [2].

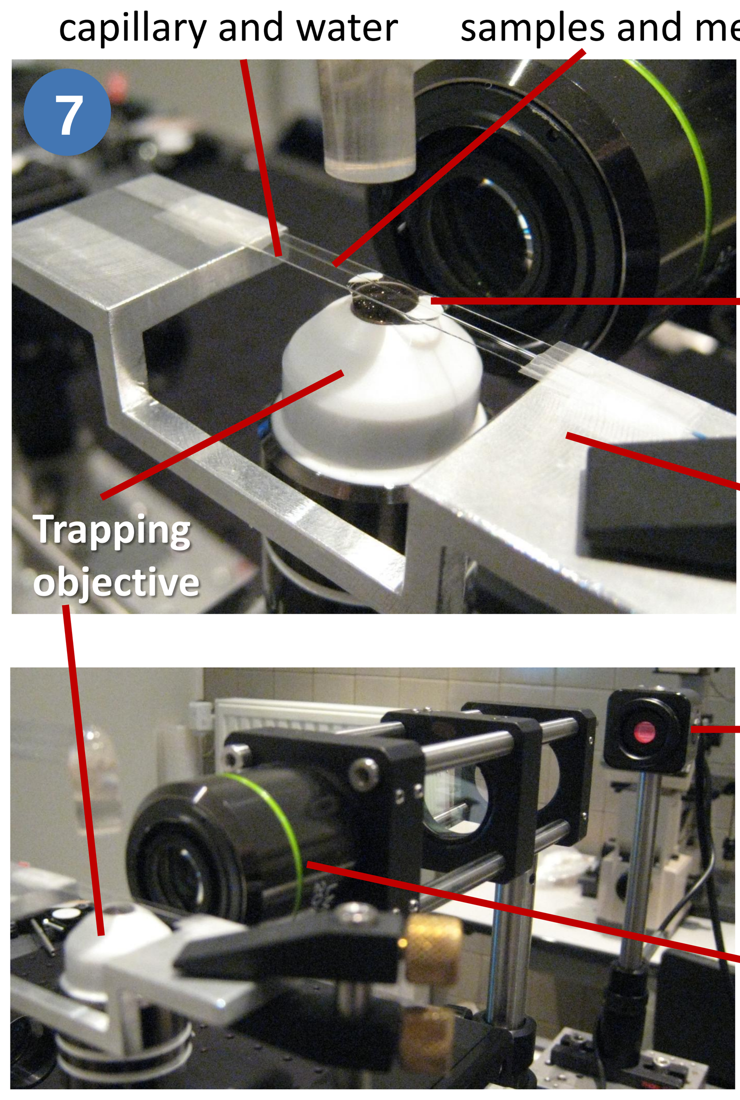
1. **Start optical path (- - -)**
2. **IR laser coupled with fiber optics:**
   - λ = 1070 nm, transparent wavelength for biological samples
   - Beam expander in front of laser collimator
   - IPG Photonics
3. **Spatial Light Modulator (SLM):**
   - Bi-functional: beam splitter or mirror
   - Control via holograms (pc)
   - Hamamatsu Photonics



4. **Mirrors:**
   - Manipulated for alignment
5. **Dichroic mirror:**
   - ⇧ reflection IR light
   - Transparent for visual light
6. **Microscope trapping objective (MO):**
   - Focusses IR beam
   - 100x, Olympus
   - NA = 1
   - Water immersion
   - 1 mm working distance
7. **Sample area**

Cover glass: Interface between capillary and water

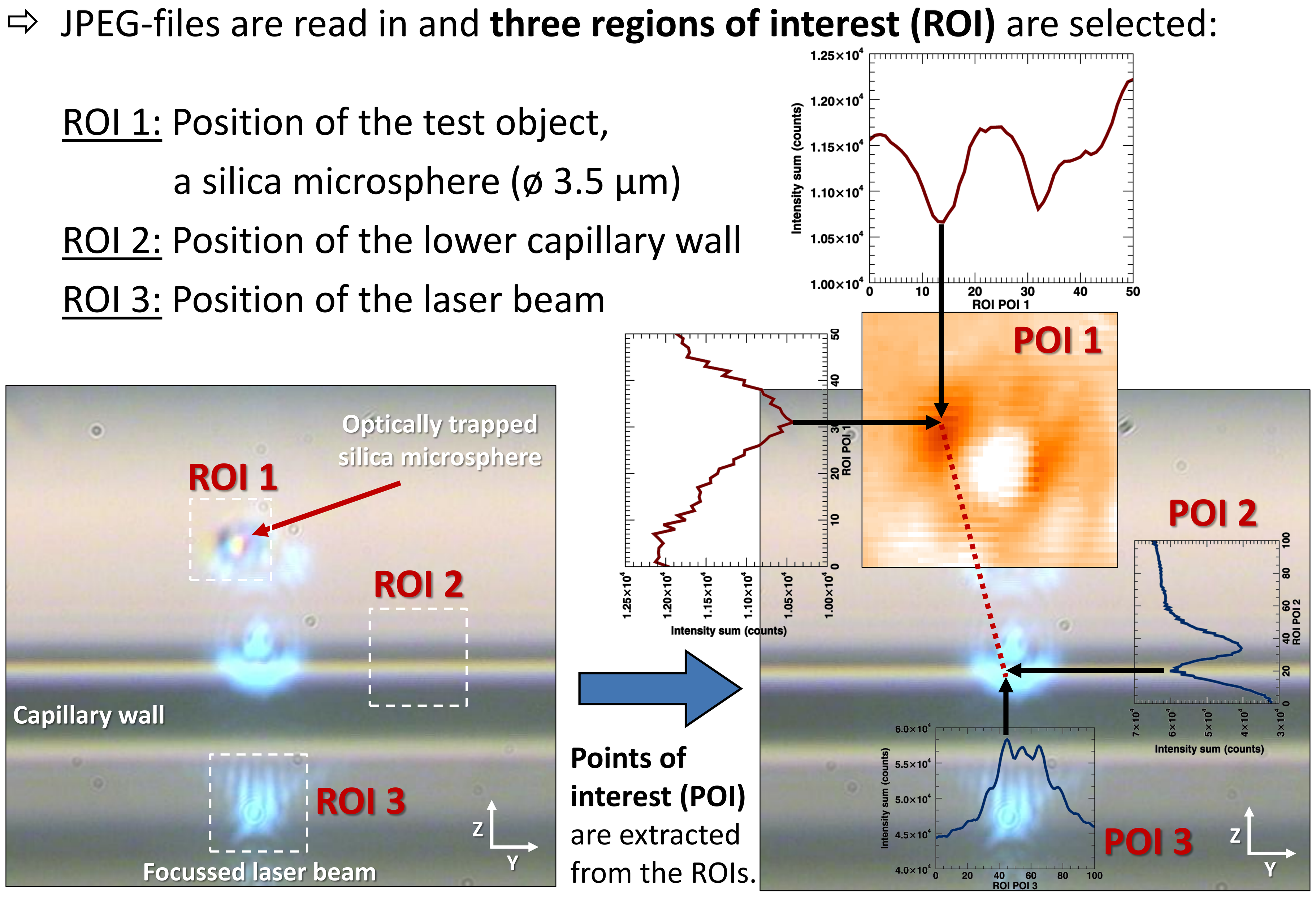
Glass capillary (CTS, UK): Filled with (biological) samples and medium



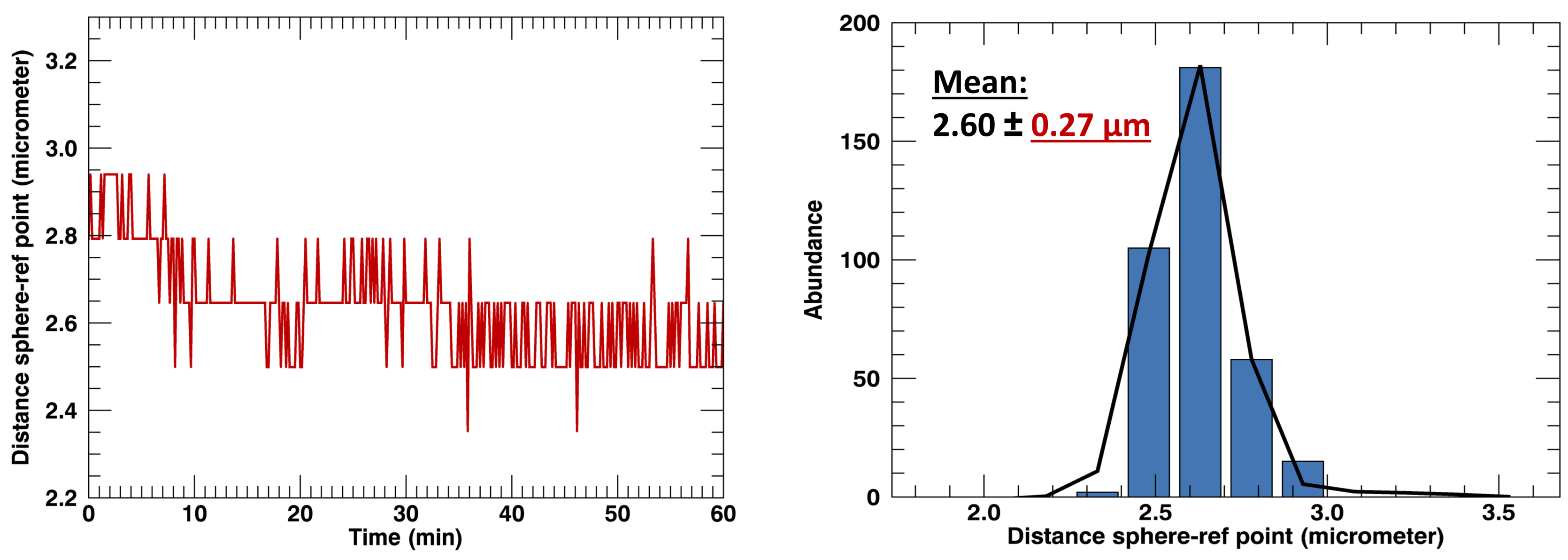
Data Processing and Optical Trap Stability

- ⇨ **Data processing** is performed in Linux using **IDL** (Interactive Data Language)
- ⇨ Integrated **CCD camera** collects **JPEG-files** (every 10 seconds for 1 hour).
- ⇨ JPEG-files are read in and **three regions of interest (ROI)** are selected:

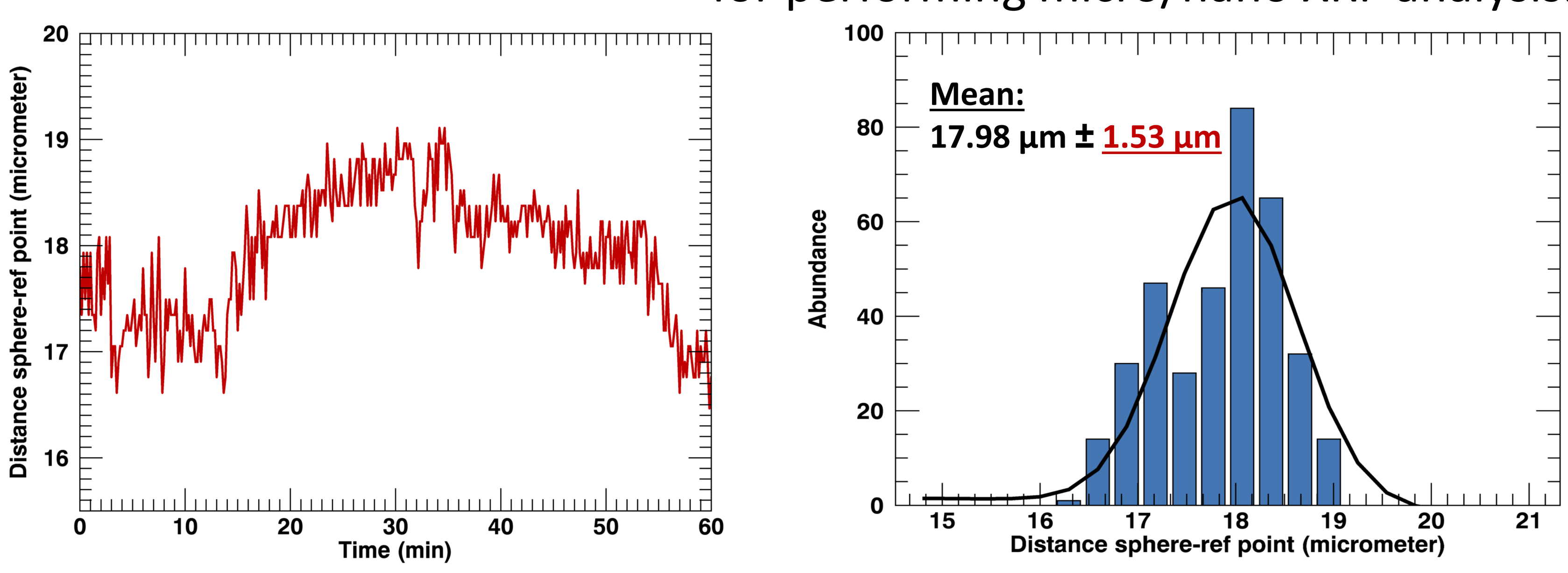
ROI 1: Position of the test object, a silica microsphere (ø 3.5 µm)
ROI 2: Position of the lower capillary wall
ROI 3: Position of the laser beam



Stability in Y-direction: Sufficient sub-micron stability.



Stability in Z-direction: Stability in Z-direction should be improved for performing micro/nano XRF analysis.



References

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[2] Santucci, S.C., et al., Analytical Chemistry, 2011. 83(12): p. 4863-4870.

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