

OpenSPM: A Modular Framework for Smart and Adaptive Microscopy

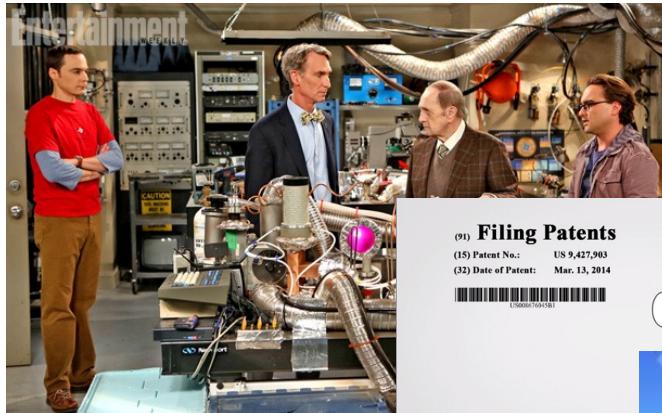
Marcos
Penedo

Definition by FOSTER Open Science Portal

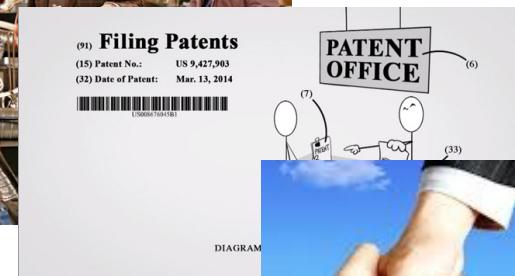
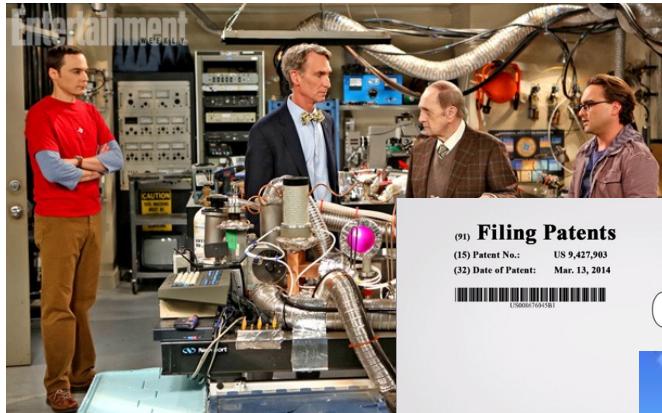
“Open Science is the practice of science in such a way that others can collaborate and contribute, where **research data**, **lab notes** and other **research processes** are freely available, under terms that enable reuse, redistribution and reproduction of the research and its underlying **data** and **methods**.“

- *Open access publications*
- *Open data repositories*
- *Open Source*

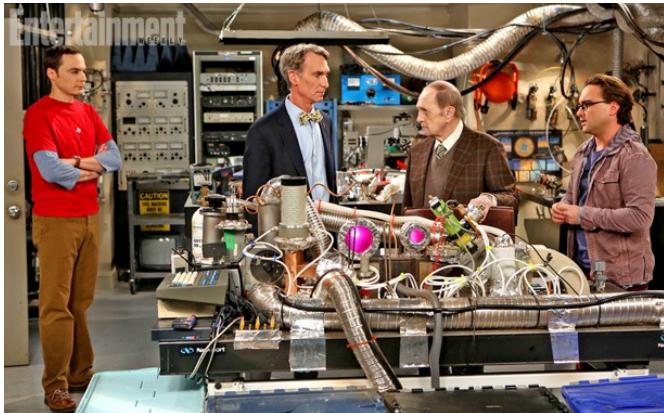
What if the research data is an instrument?



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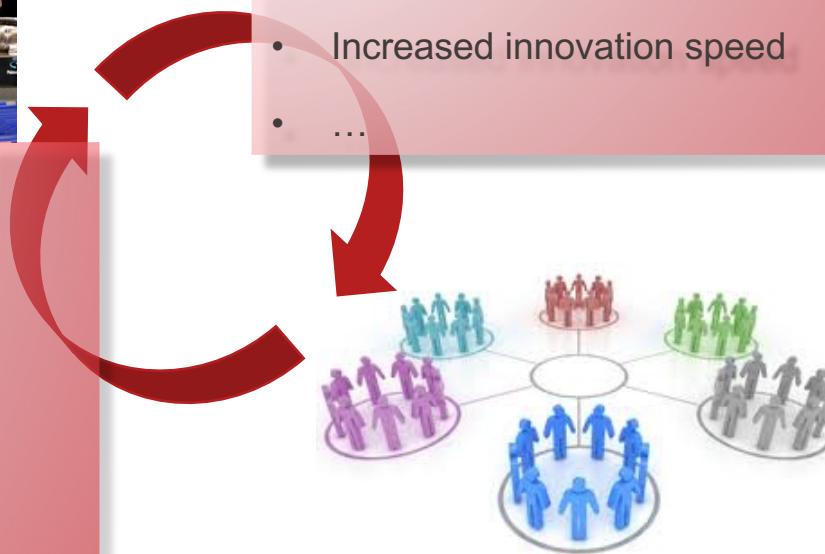


Benefits for developer

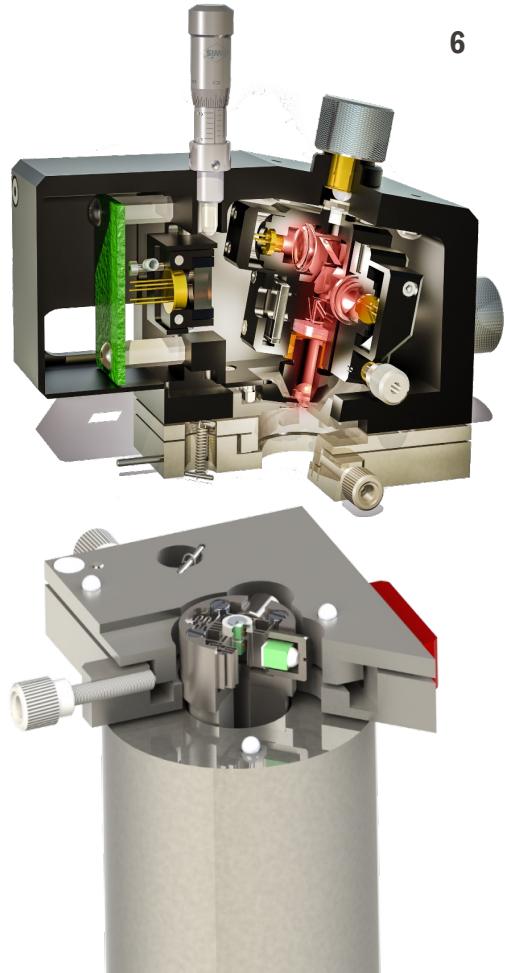
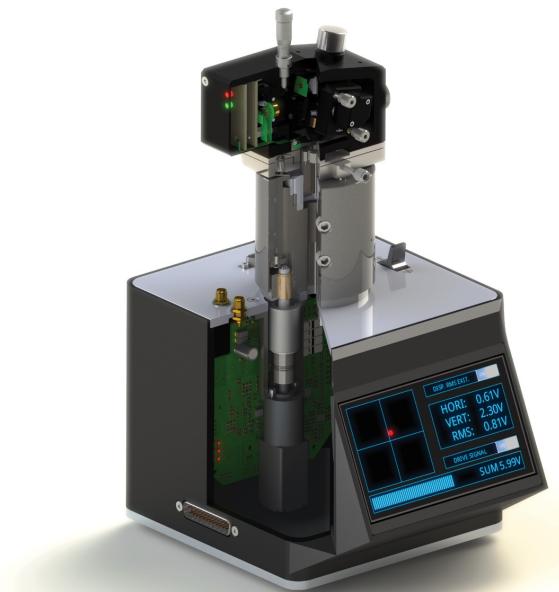
- Feedback
- Broader use
- Others contribute
- Citations and publications
- ...

Benefits for community

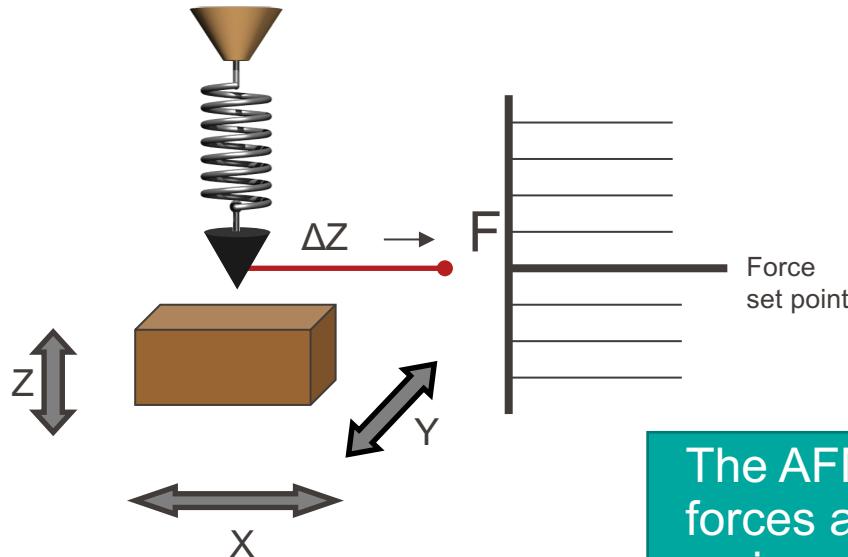
- Quicker and cheaper access to new technologies
- Full access
- Increased innovation speed
- ...



Open Source High-Speed Atomic Force Microscope

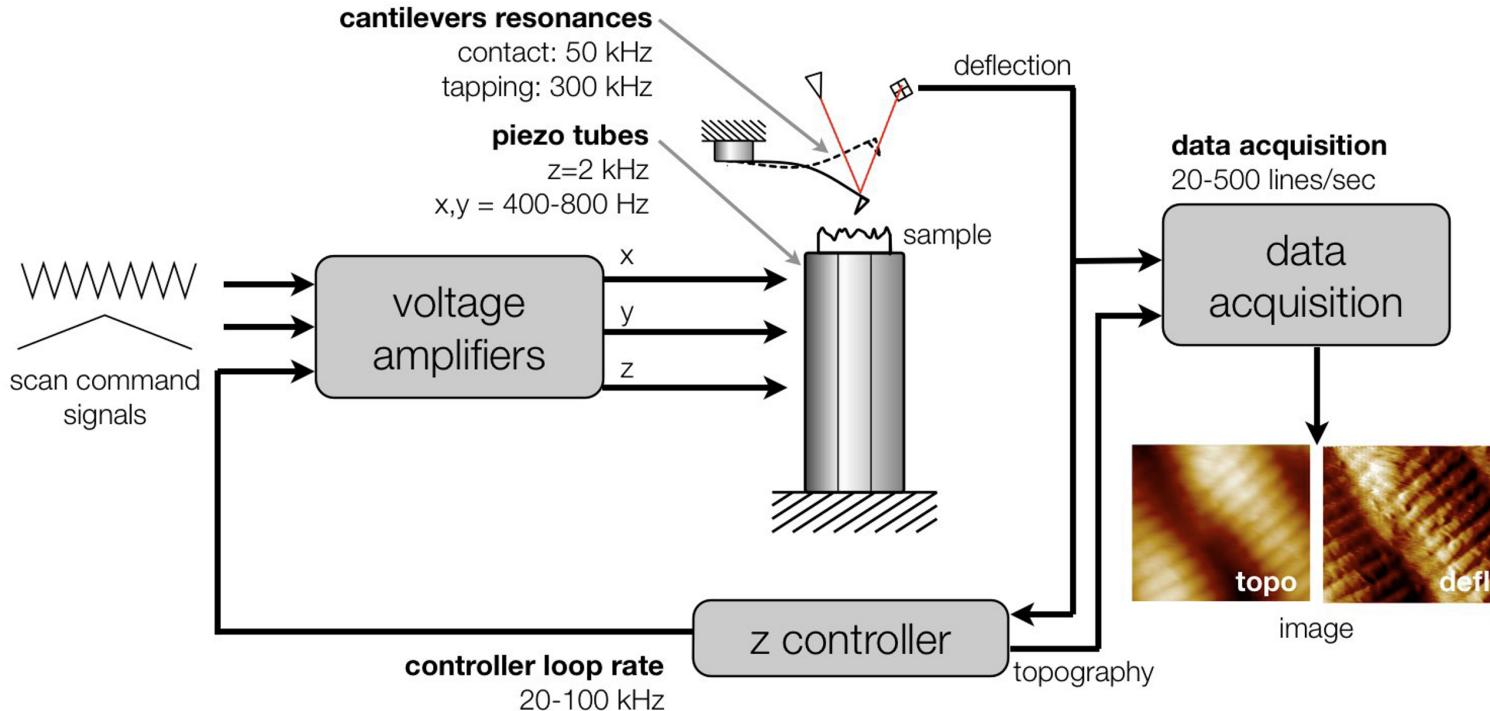


What is an AFM? “Scanning Force Microscopy“ SFM

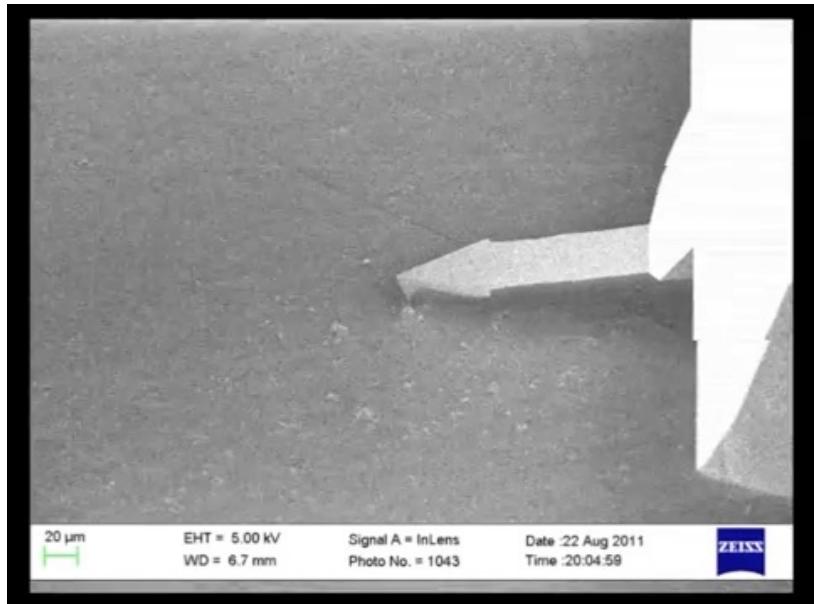


The AFM measures the effect of forces acting on the sharp tip on a spring as a function of the position on the surface. – sometimes these forces are due to topography

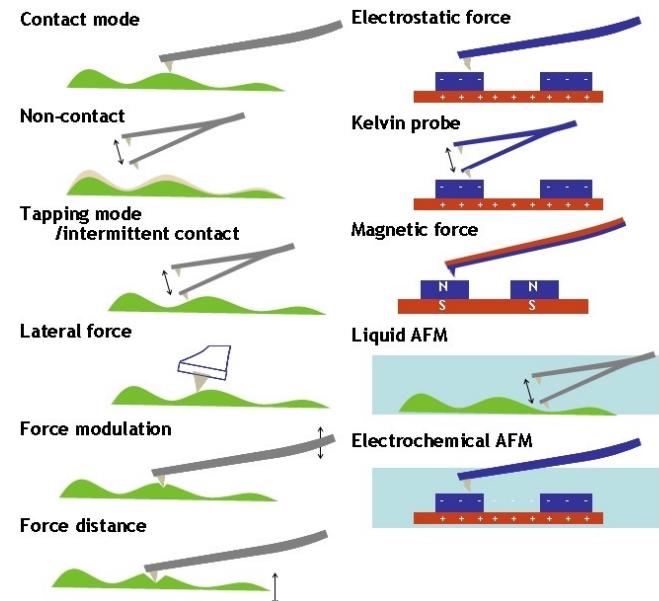
What's in an AFM?



Atomic force microscopy (AFM)

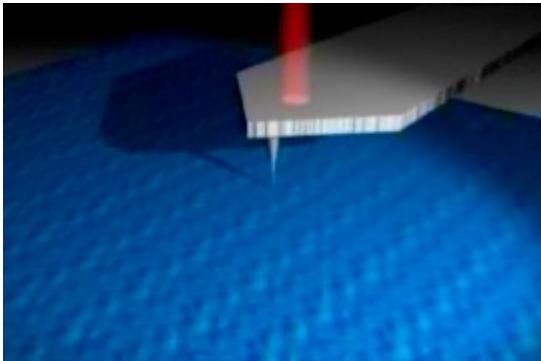


From www.zeiss.com

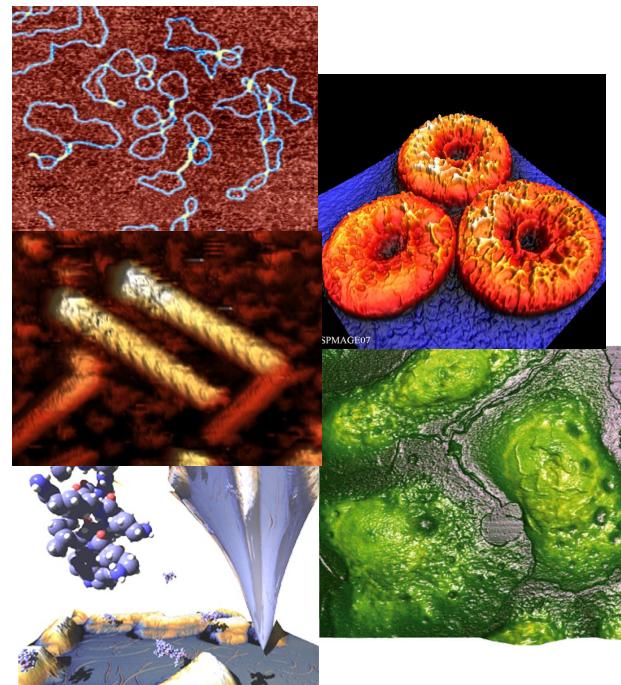


Atomic Force Microscopy

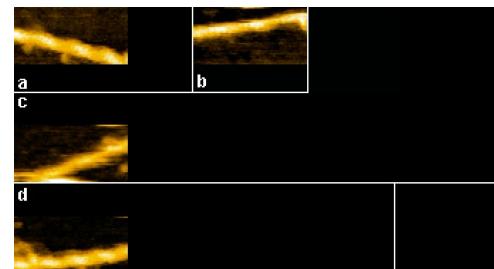
- a versatile tool for nanoscale Biology



- Single molecule resolution
- High resolution imaging in aqueous solution
- Nanomanipulation
- Single molecule mechanics
- Imaging of living cells



Walking myosin V on actin fibers

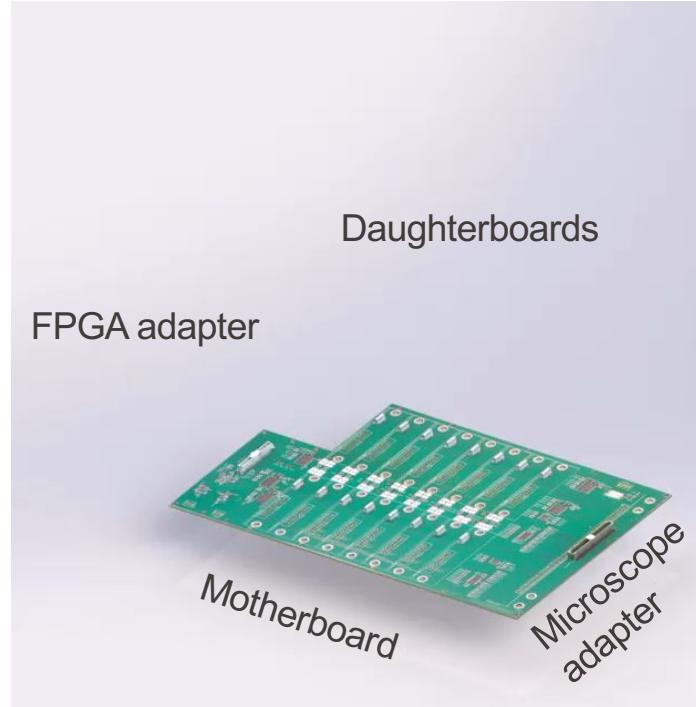


OpenSPM platform

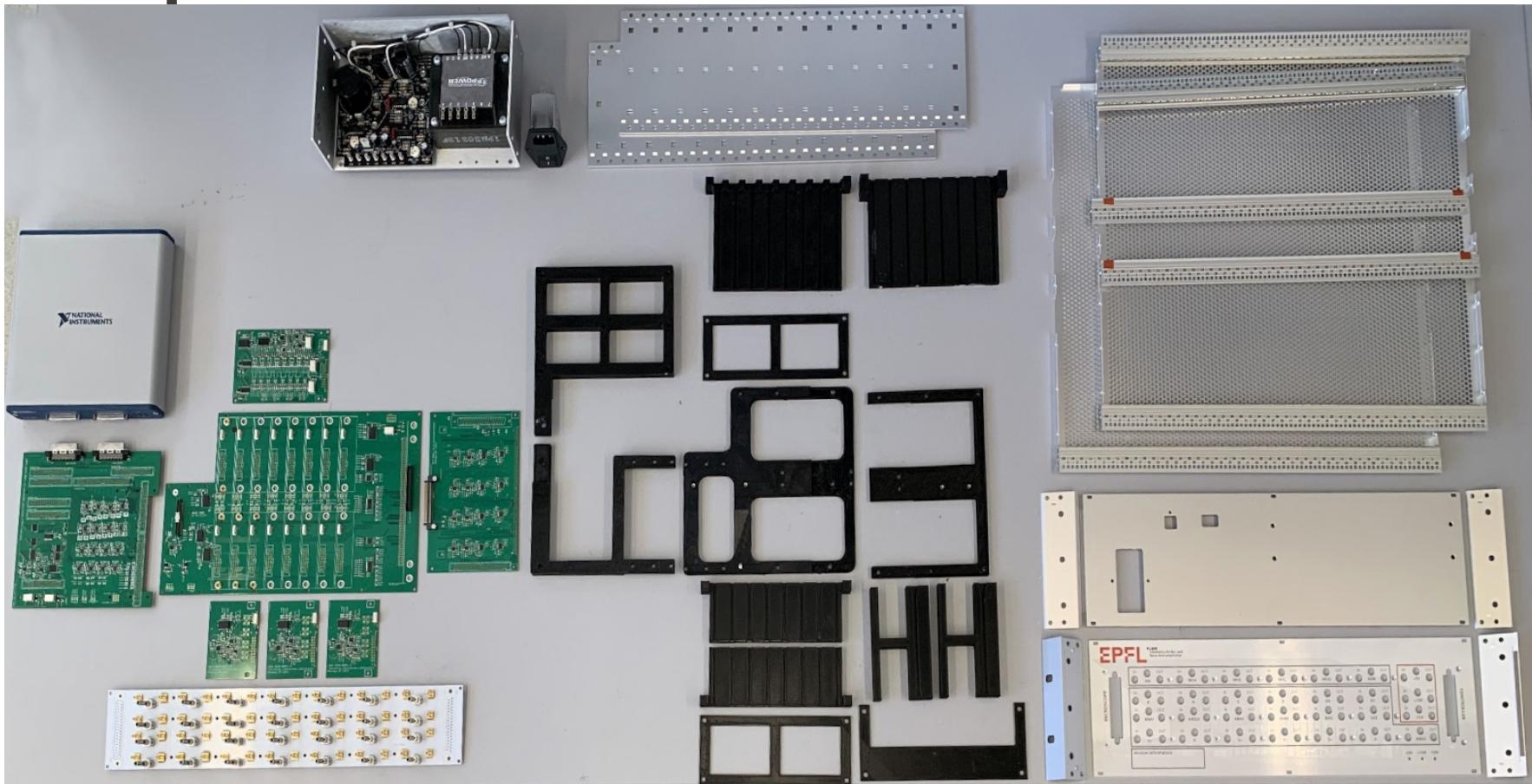
- Small lever head
 - $4 \mu\text{m} \times 0.7 \mu\text{m}$ spot size
 - Readout and excitation laser
- High-speed scanner
- Base unit
 - Approach mechanism
 - User interface
- Low voltage controller
 - NI 7856R FPGA
 - Up to 40 MHz sampling rate (AI/AO)
 - 8 x 1 million pixel per second
- High-voltage amplifier
 - 500 kHz bandwidth for Z
 - 7 kHz bandwidth for X&Y



- FPGA adapter
 - Additional functionalities: ADC/DAC pair
- Motherboard
 - Hosts the other boards
 - Slow analog digital channels
- Daughterboards
 - Dynamic range: gain and offset stages
 - High-pass and low-pass filters
- Microscope adapter
 - Signal leveling
 - Pin assignment

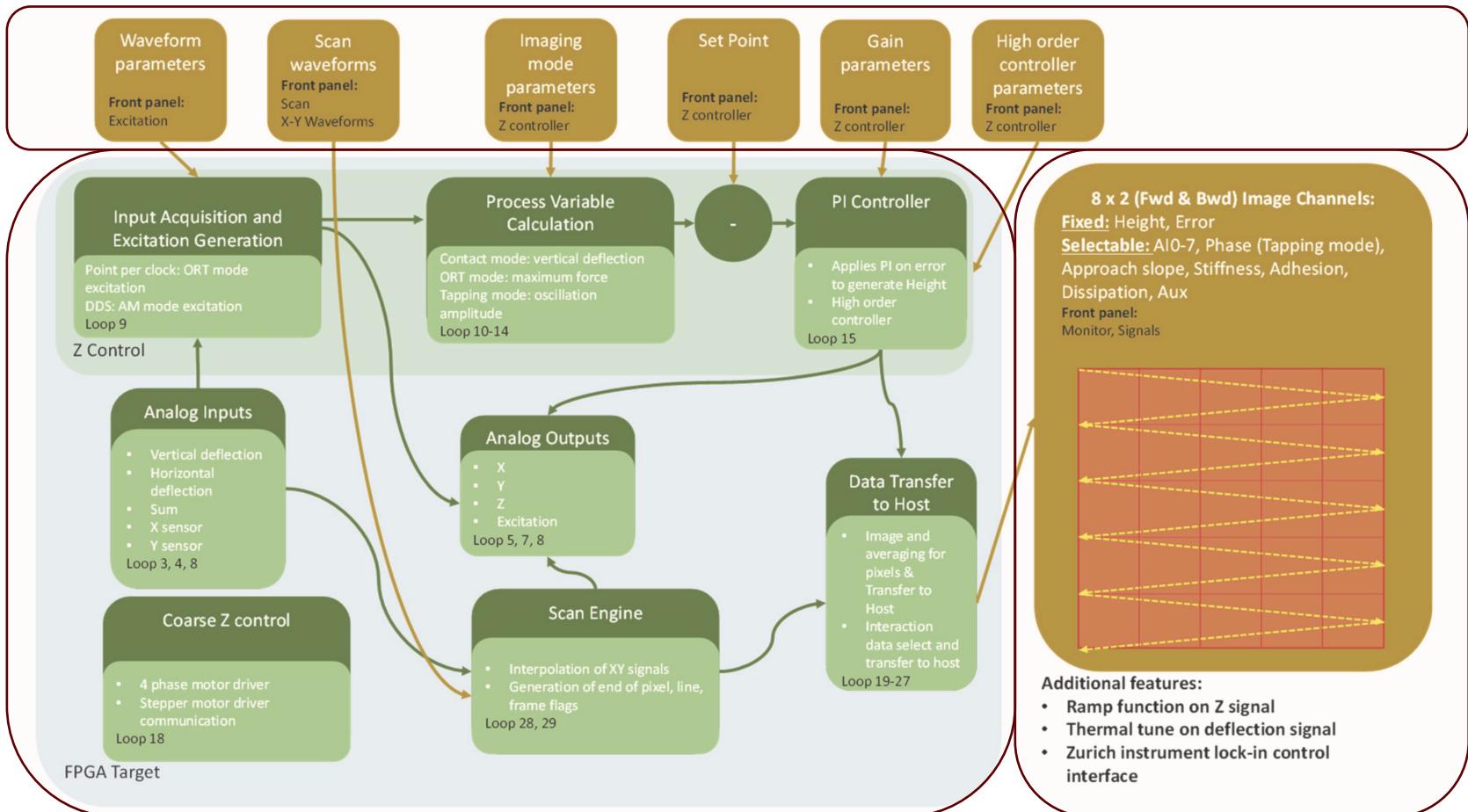


OpenSPM controller

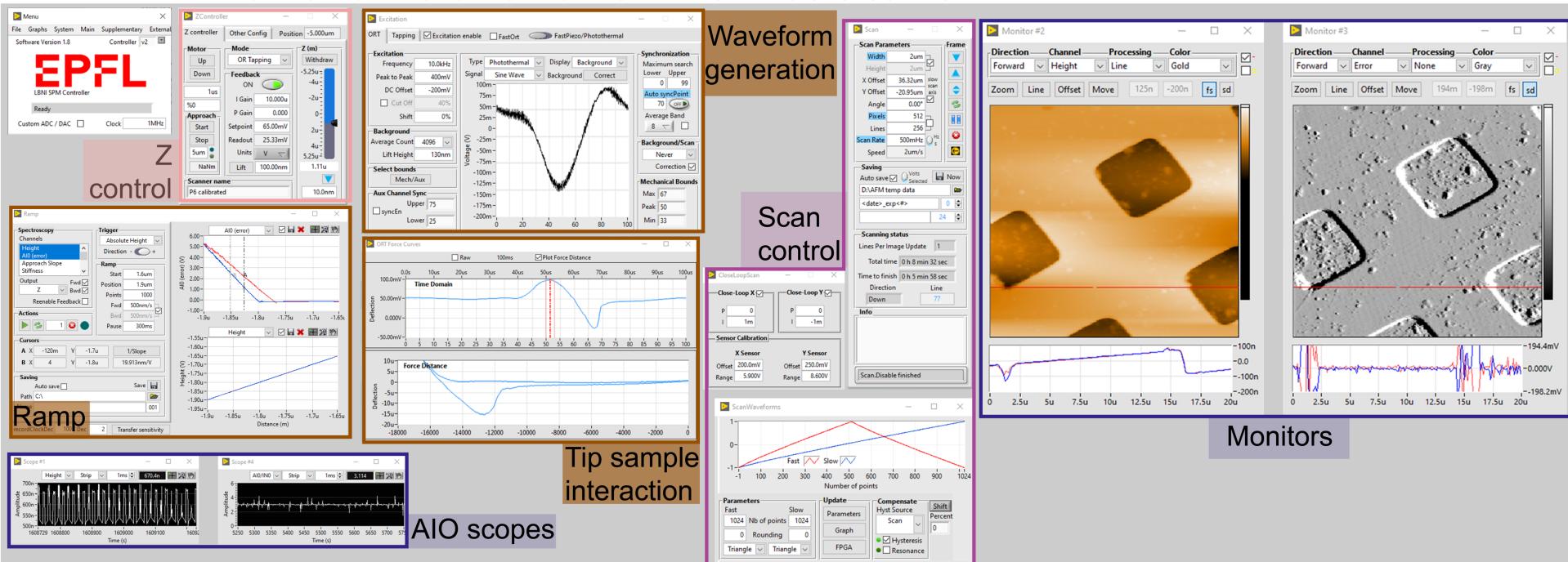


OpenSPM Software (LabView): Modularity

LabView
Front Panel

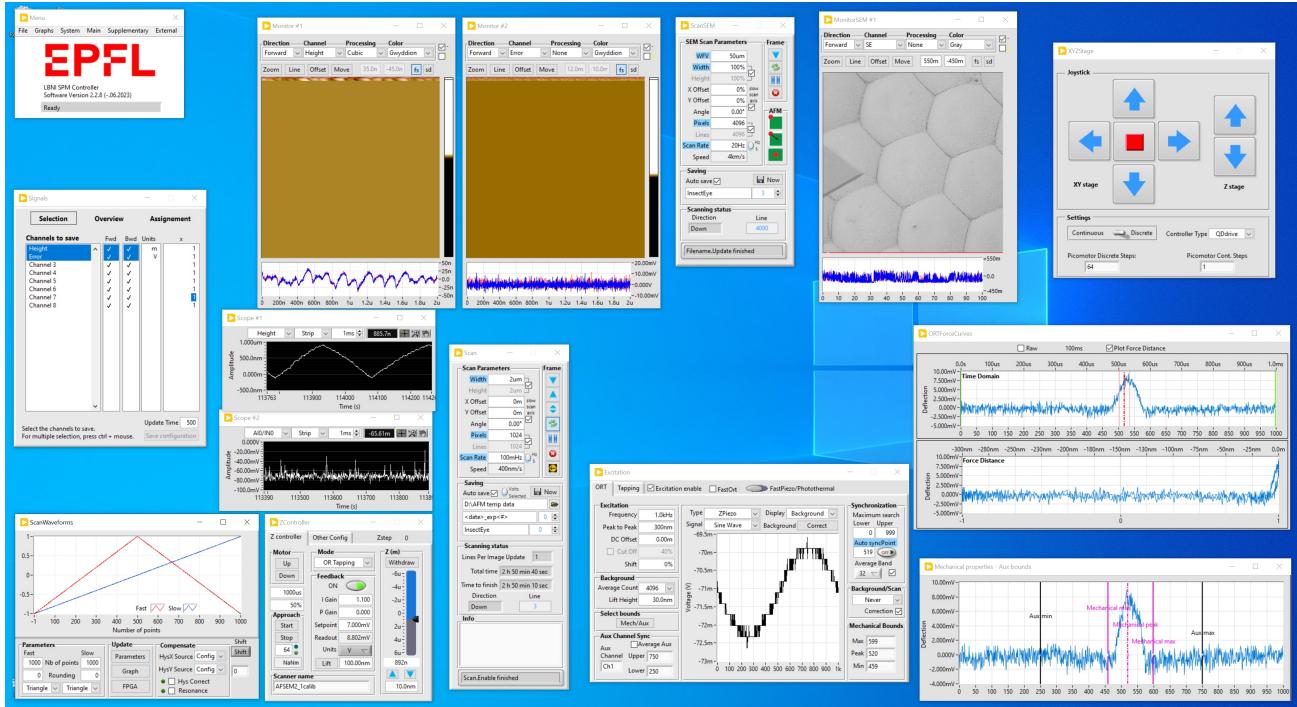


Modular Software Architecture



- Feedback control
- Scan generation
- Mapping data into multi-dimensional images
- Data display and user interface

- Additional functionalities
 - Coarse stage motor drivers
 - Scope to plot different signals
 - Ramp function
 - Function generators
 - Digital lock-in amplifier



SEM/AFSEM add-on

The collage illustrates the complex software ecosystem for scanning probe microscopy. It includes:

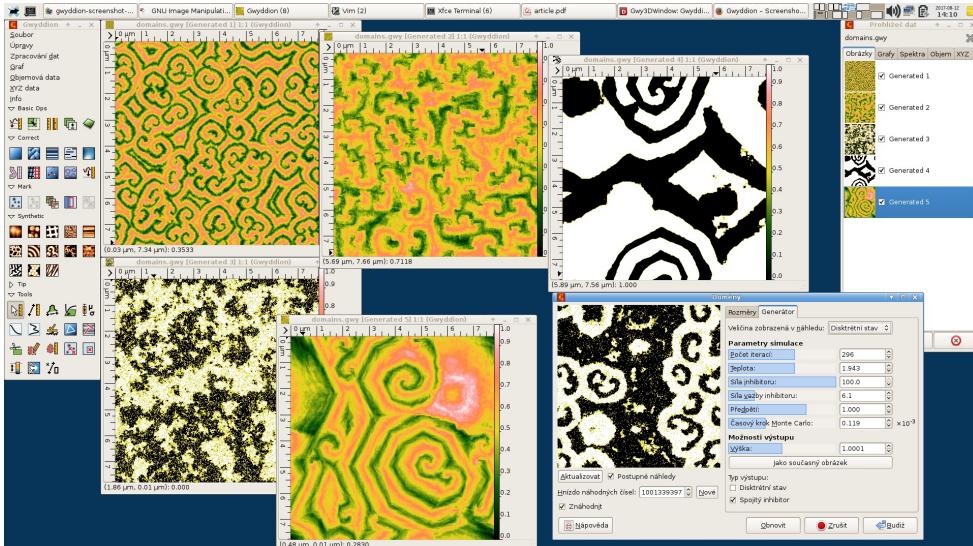
- LBM SPM Controller:** Shows a main window with a grayscale image and multiple signal plots (Scope 1, Scope 2, Scope 3) for monitoring and controlling the measurement.
- SEM Scan Parameters:** A configuration window for setting scan width, height, offset, angle, and speed.
- XY stage:** A control interface for the XY stage with a joystick and a grid overlay.
- GMR Force Curves:** A plot showing Force Distance curves over time domains, with specific regions highlighted.
- Mechanical properties - Aux bounds:** A plot showing mechanical properties like Amplitude and Phase shift across a grid.
- Scan Waveforms:** A graph showing the relationship between the number of points and scan parameters like Fast, Slow, and Roundings.
- Controller:** A detailed configuration window for the Z controller, including parameters for Motor, Feedrate, and Apparatus.
- SEM device control:** A window for controlling the SEM device, showing current position and scaling.



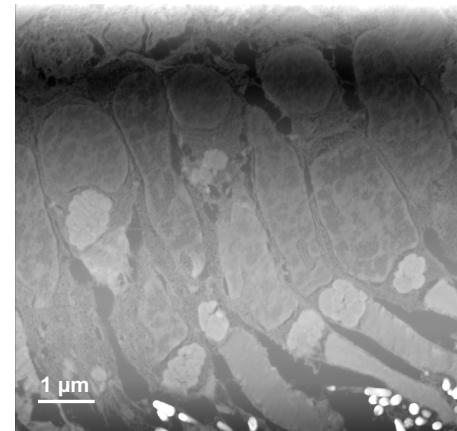
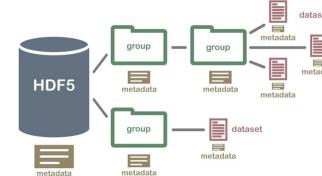
SEM/AFSEM add-on

OpenSPM file formats

Gwyddion

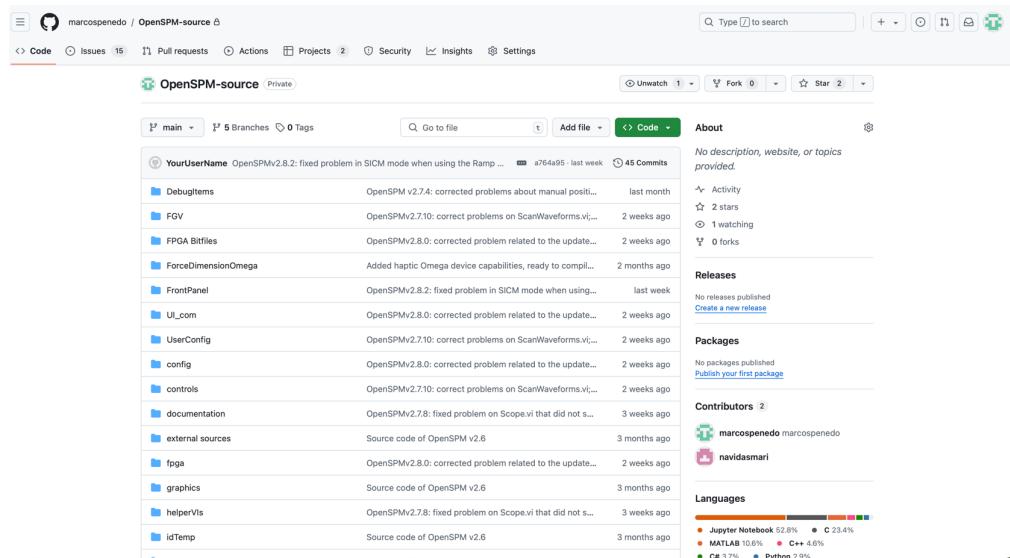


HDF5



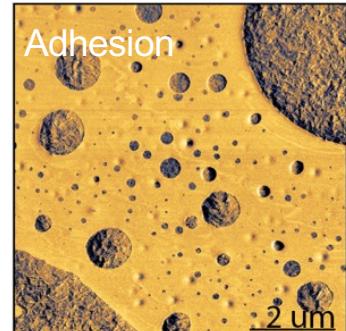
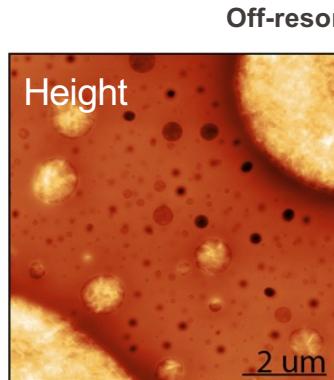
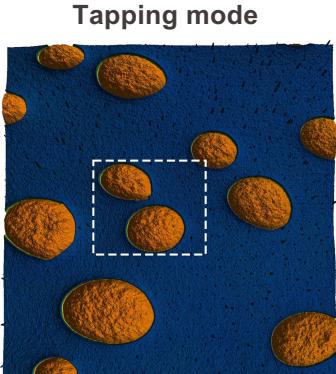
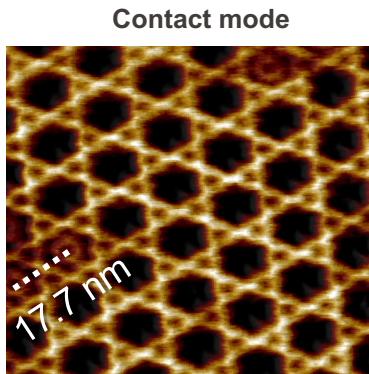
400 megapixels

- Hardware
 - Top level diagram
 - Design files & manufacturing
 - Assembly guides & videos
- Software
 - User manuals
 - Developer's guidelines
 - Unit tests
 - Repositories with version control
 - Ticket system to report problems



<https://github.com/Open-SPM/OpenSPM-source>
<https://github.com/Open-SPM/OpenSPM-executable>

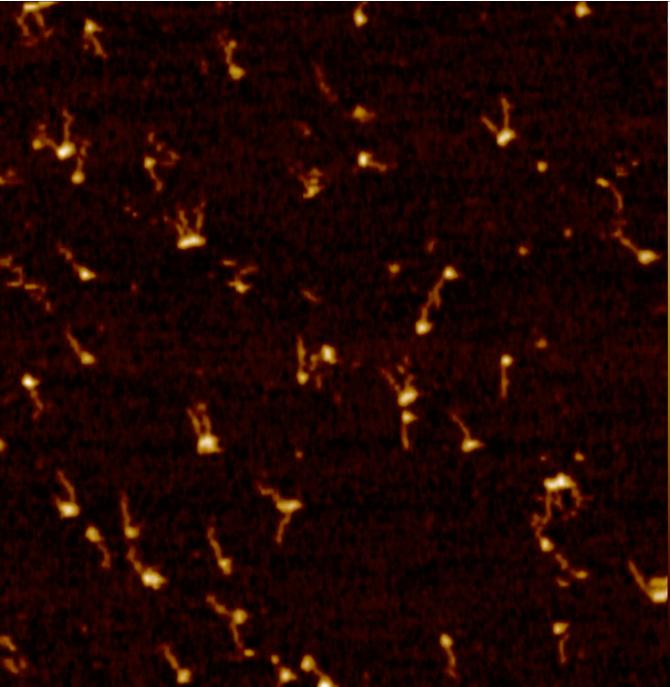
<https://www.notion.so/openspm/>



Adapted instruments:

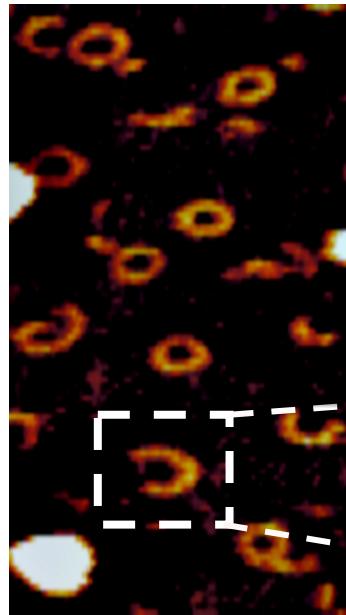
- **Bruker:** Multimode, Dimension 3100, Bioscope
- **Nanosurf:** FlexAFM, Drive AFM
- **QD-Microscopy:** AFSEM 1.0, AFSEM Nano
- **Nenovision:** Litescope
- **Omicron:** STM
- **Zurich Instruments:** HF2, UHF
- **Witec:** Alpha-SNOM
- **Zeiss:** SEM Crossbeam 550L
- **Park systems:** XE-100
- **JPK:** Nanowizard 3

Self-assembly of SAS-6 proteins (PORT)

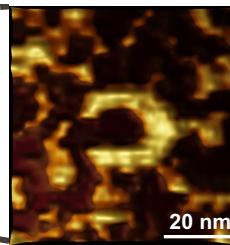


N. Banterle et al. *Nature Communications* 2021
G. N. Hatzopoulos et al. *Nature Communications* 2021

Self-assembly of SAS-6 proteins (PORT)

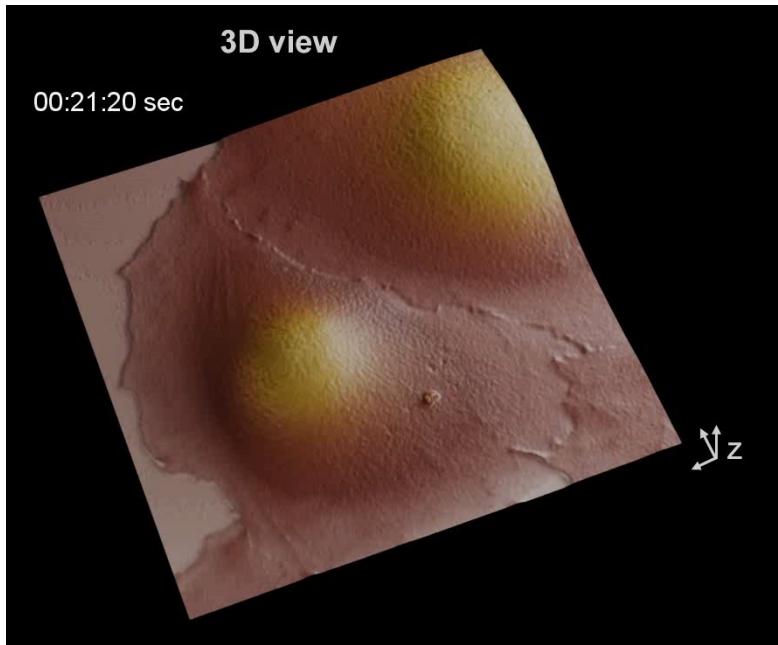
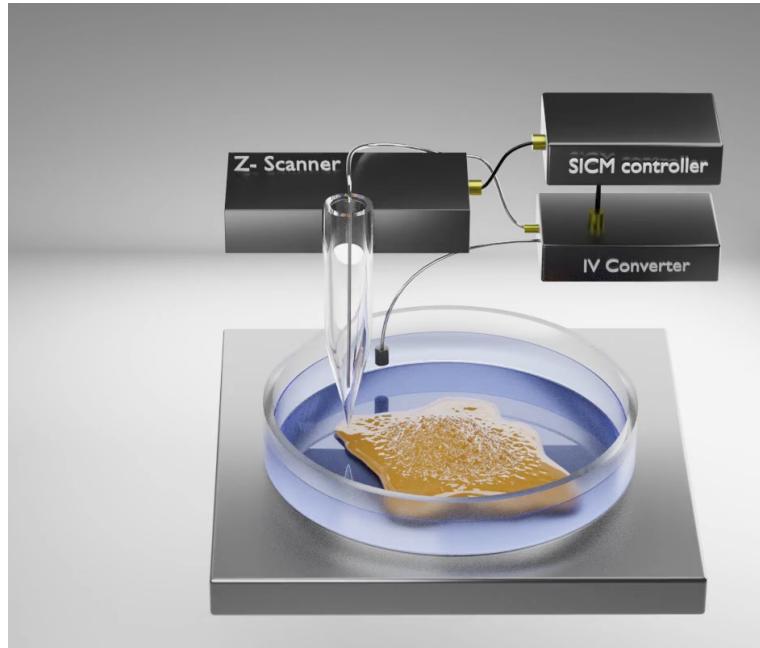


- Photothermal off-resonance tapping
- 10 FPS at 50 pixels x 50 pixels



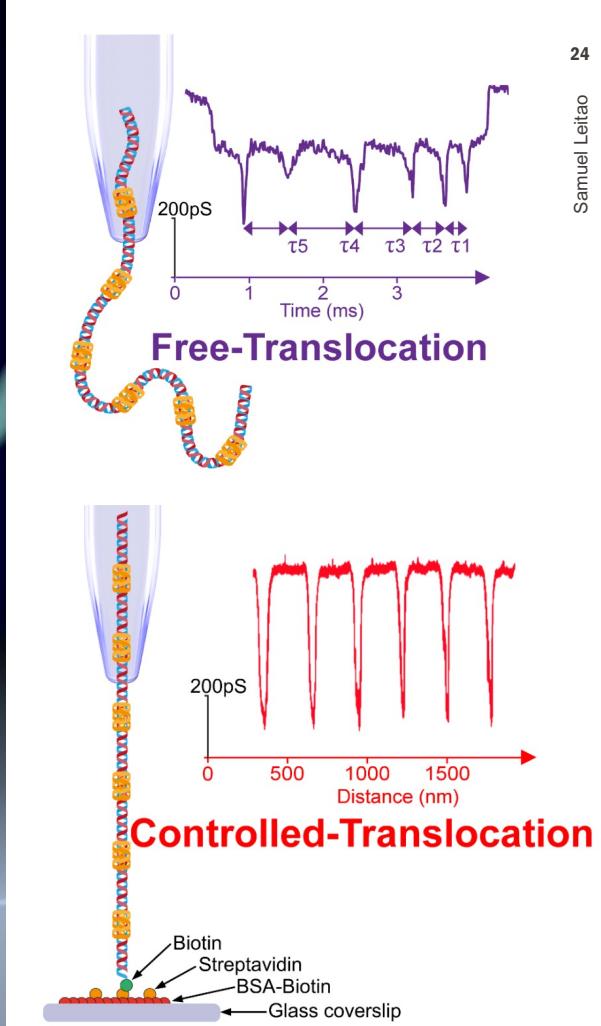
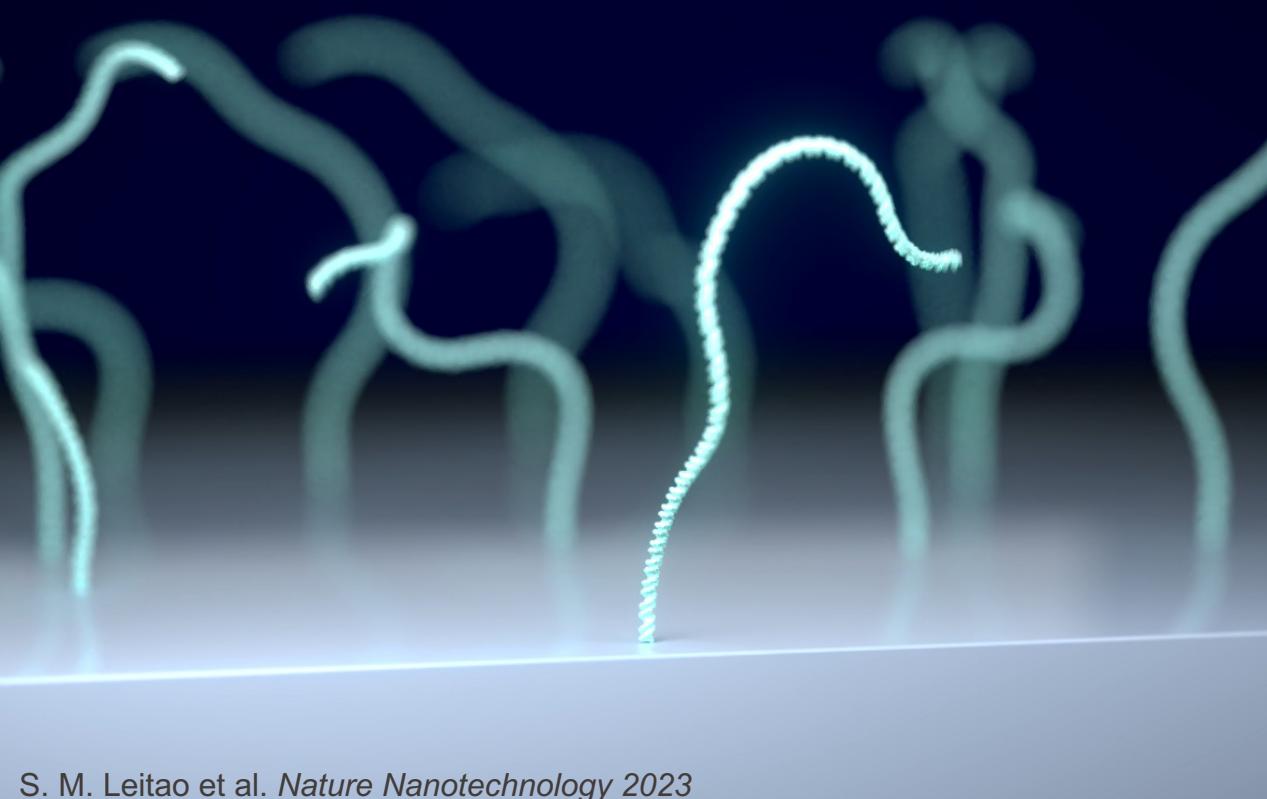
EPFL Scanning Ion Conductance Microscopy (SICM)

23

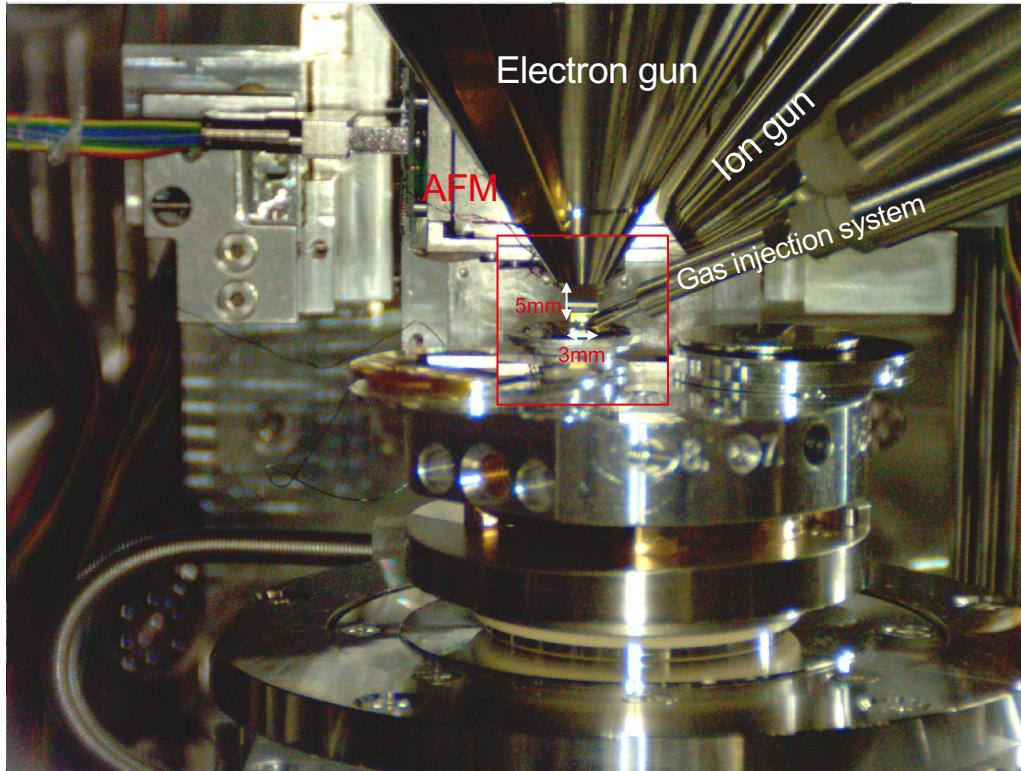


- V. Navikas et al. *Nature communication* 2022
- S. M. Leitao et al. *ACS Nano* 2021

Scanning Ion Conductance Spectroscopy (SICS)



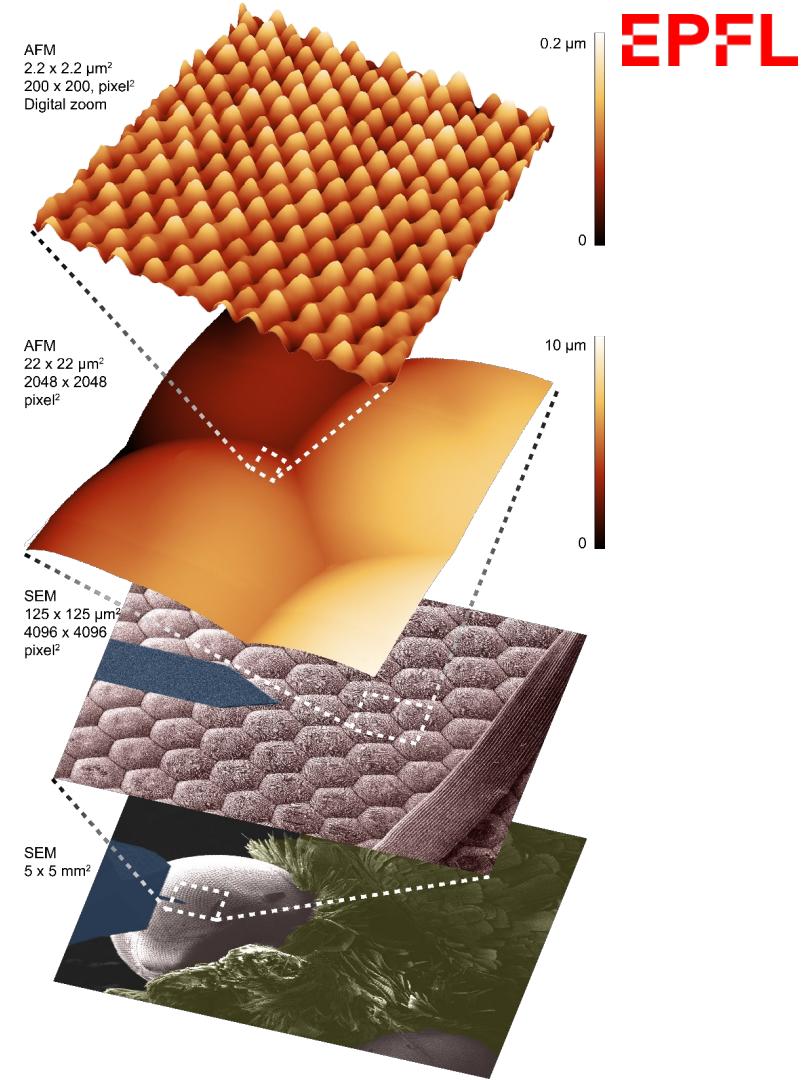
A compact AFM inside SEM/FIB

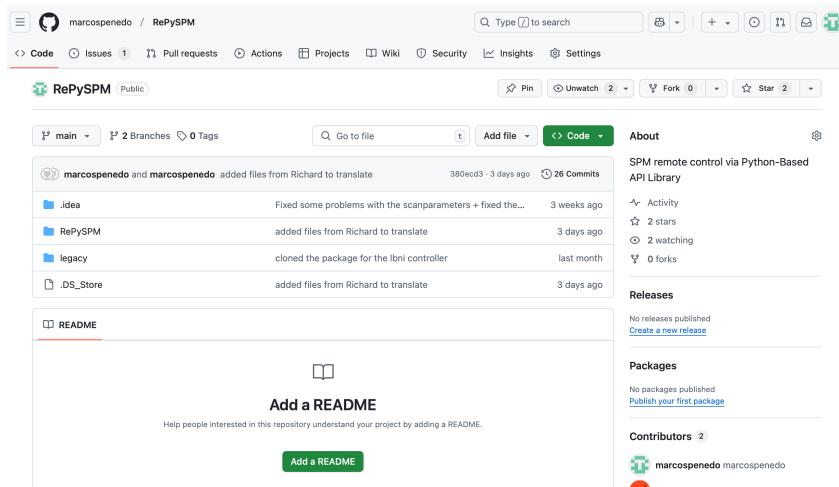
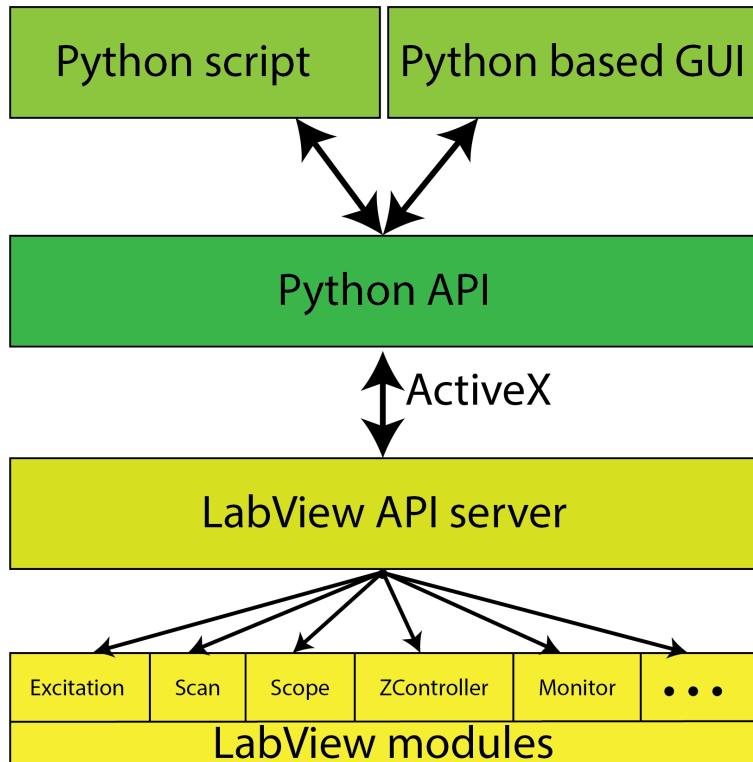


Combined a **Zeiss Crossbeam 550L SEM/FIB** with a modified **Quantum Design AFSEM™ -nano**

- Tip scanning AFM
- Coarse positioner
- Scanner : 25um x 25um x 12um
- Compatible across various SEMs with FIB, EDX and GIS capabilities
- Piezo-resistive cantilevers for AFM deflection

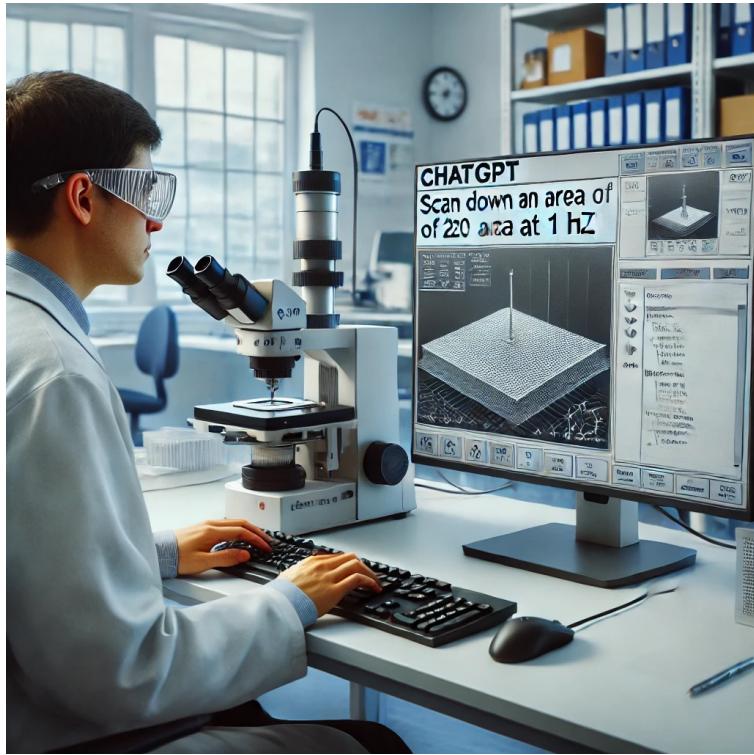
Correlative Imaging with Open Hardware Controller





- Nanosurf (Switzerland)
- Asylum Research (USA)
- QD Microscopy (USA)
- NenoVision (Czech Republic)

Python API – RePySPM - OpenAI

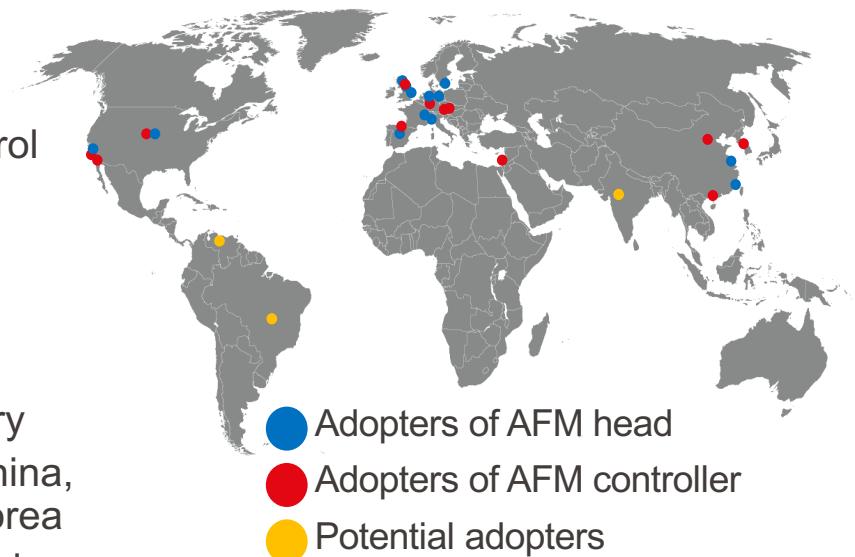


- Open-source research grade instrumentation

- High-speed AFM applications
 - Enhanced control methods
 - Provides new imaging modalities, advanced control schemes
 - Base platform for innovations
 - Rapid customization

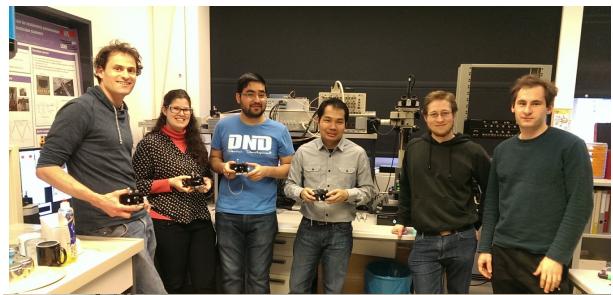
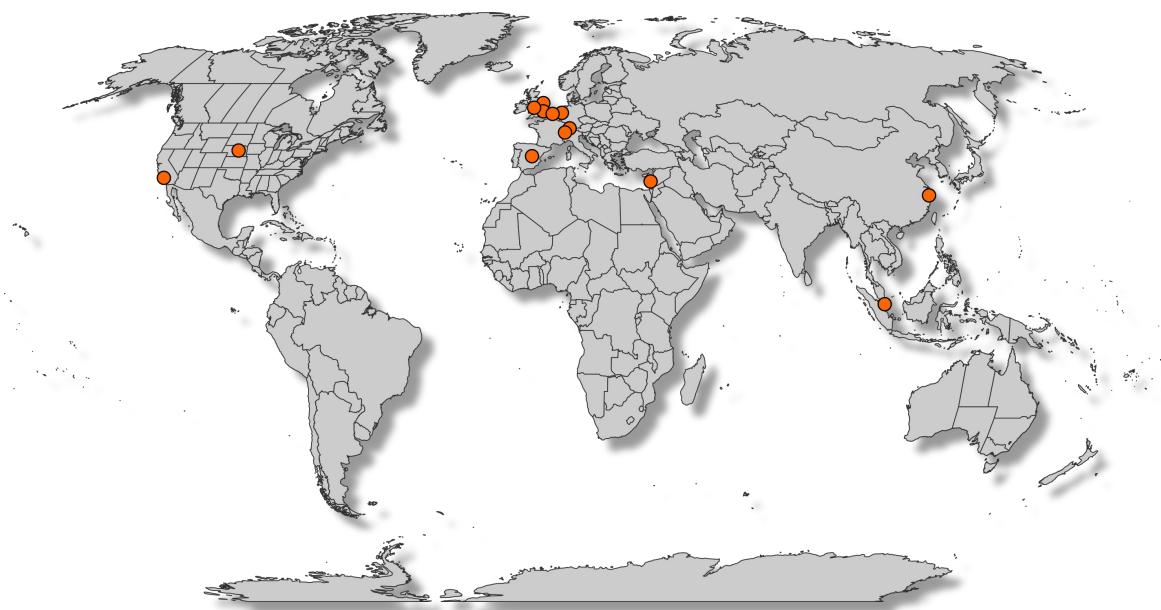
- Open SPM community

- Running more than 10 setups within our laboratory
 - Adopted by collaborators in Switzerland, USA, China, Austria, India, Israel, Germany, UK, Spain and Korea
 - Part of a commercial microscope of Quantum Design
 - We provide workshops
 - Collaborative philosophy



Open Hardware Workshops

- Ca. once per year (except for COVID)
- One week of intense work by participants
- One month of intense preparation by our team
- Small groups (up to 4 instruments at a time)



OpenSPM 2024 conference



- Common data storage file formats
- Define standards for SPM specifications: bandwidth, speed, calibrations, etc.
- Create a platform to exchange SPM designs
- Defining cabling and connector standards to facilitate the implementation of a different SPM module



A playground for SPM development

- New imaging modes
- New feedback mechanisms
- New scanning trajectories
- New automation/autonomous operation
- New combined methods (SPM with other signals)
- ...

People involved

Contributors:

Prof. Georg Fantner

Mustafa Kangul

Navid Asmari

Charlène Brillard

Adrian

Nievergelt

Santiago Andany

Jialin Shi

Prabhu Swain

Barney Drake

Ekin Ozek

Zahra Ayar Dulabi

Nahid Hosseini

Veronika Cencen

Esther Raith

Samuel Leitao

Yiwei Zheng

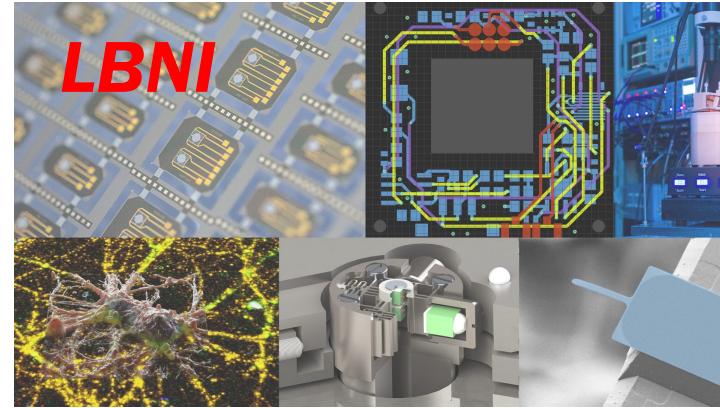
Mahdi Mehdikhani

Vikash Chandra

Matthias

Neuenschwander

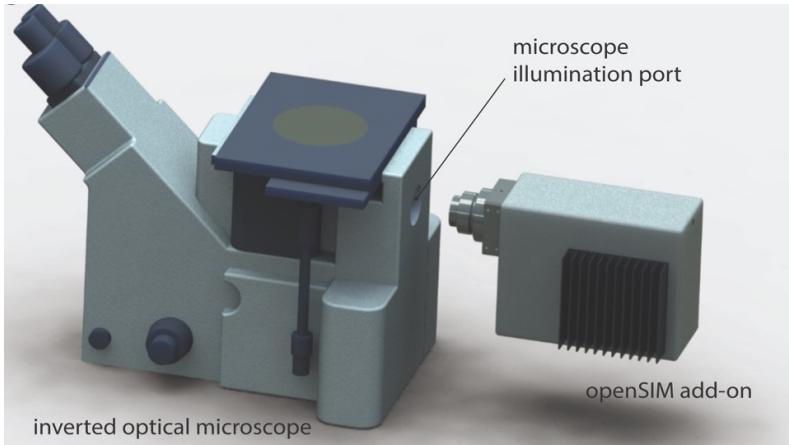
Mélanie Hannebelle





open source
microscope add-on for
structured illumination
microscopy

Add-on approach

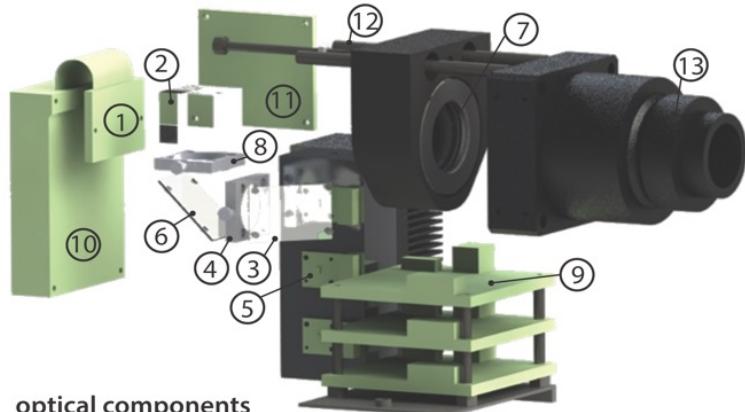
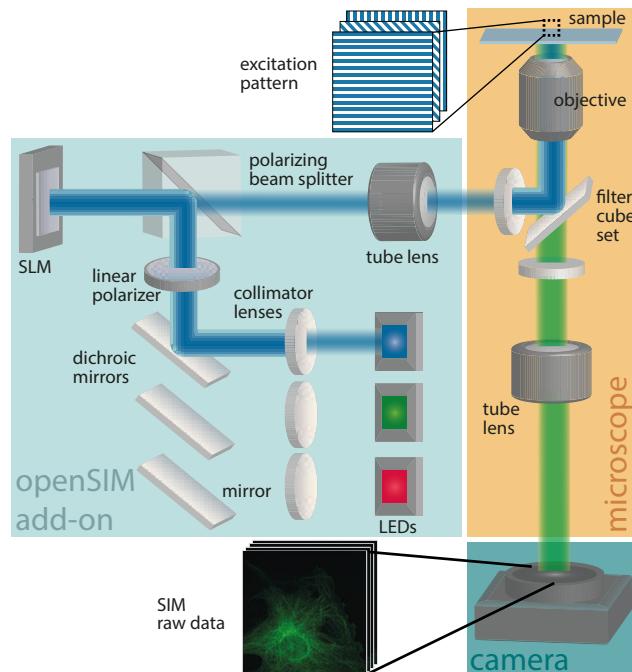


Extends the imaging capabilities of existing lab equipment

- Without the need to build completely new system
- Without too many modifications and at a moderate cost

→ Reduces the entry barrier to adopt open source super-resolution technology

Optical design



optical components

1. spatial light modulator
2. polarizing beam splitter
3. mirror
4. collimation lens
5. LED
6. dichroic mirror
7. tube lens
8. polarizer

electronic components

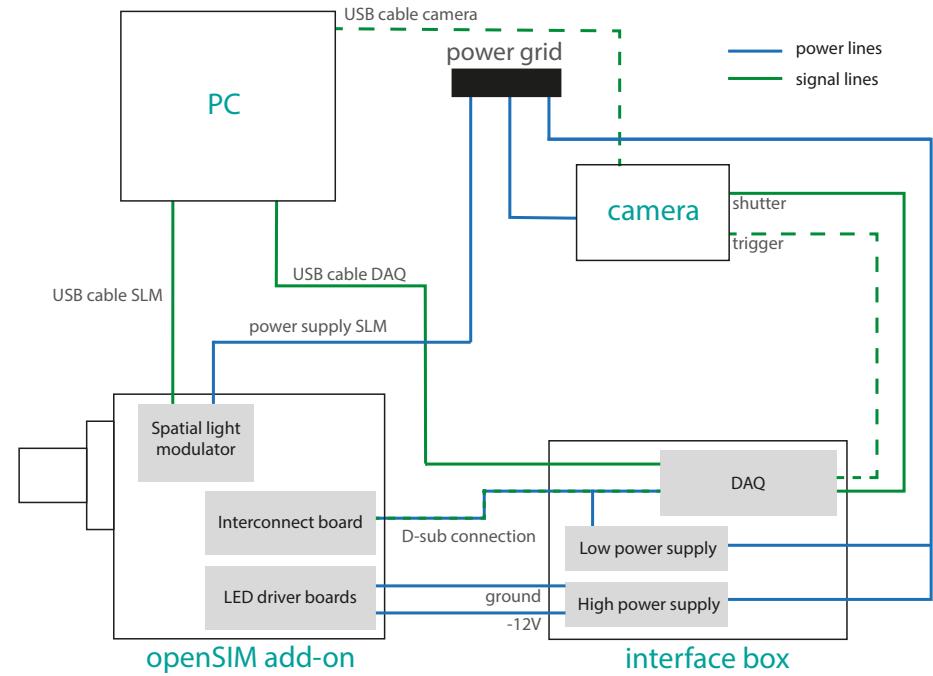
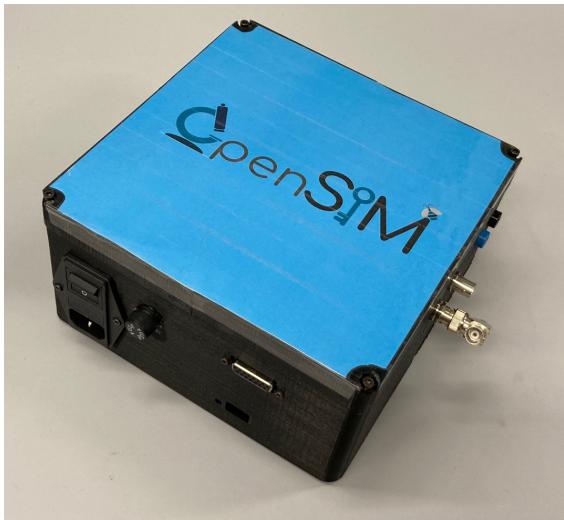
9. LED driver board
10. SLM driver board
11. interconnect board

mechanical components

12. linear translation stage
13. connection to microscope

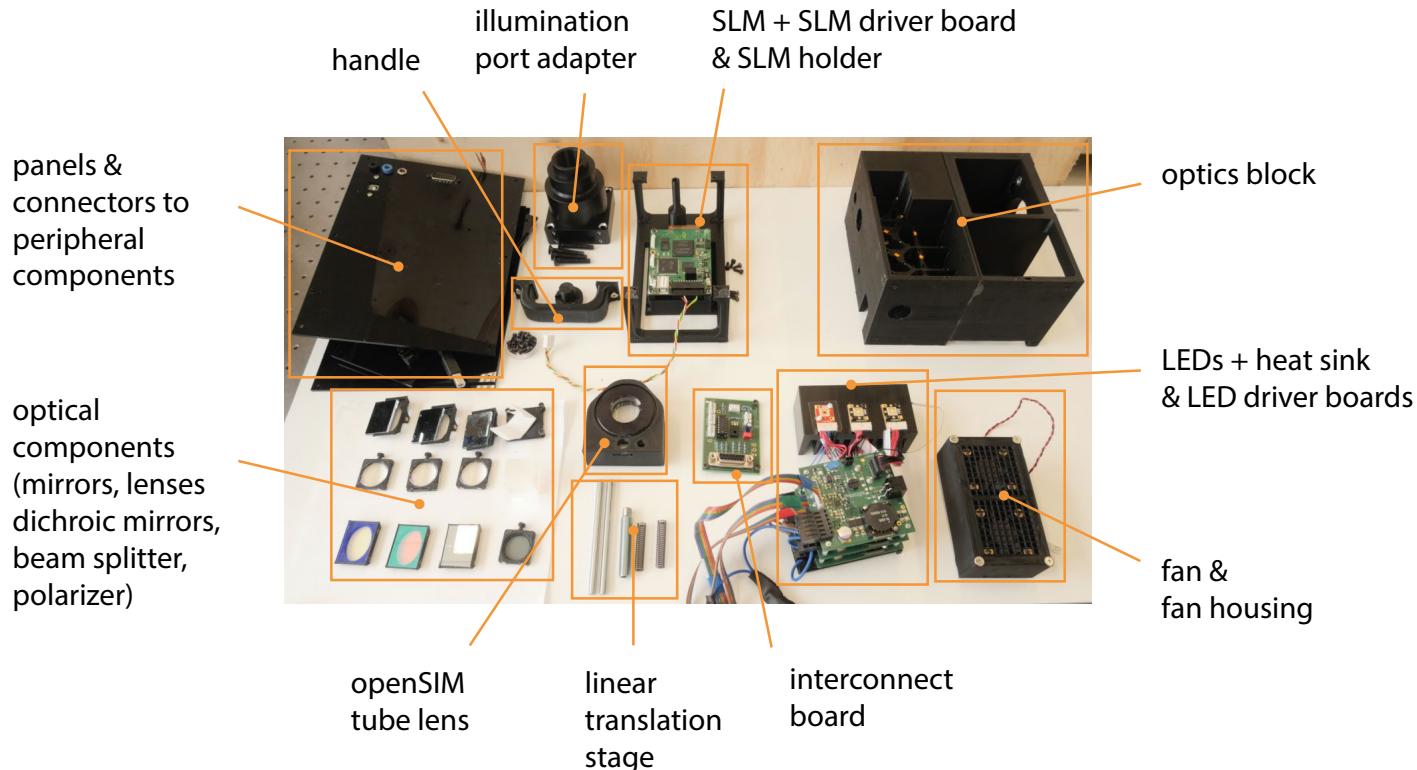
- ✚ Simple optical design
- ✚ Use of readily available components of moderate cost
- ✚ Minimal alignment and maintenance

Interface box

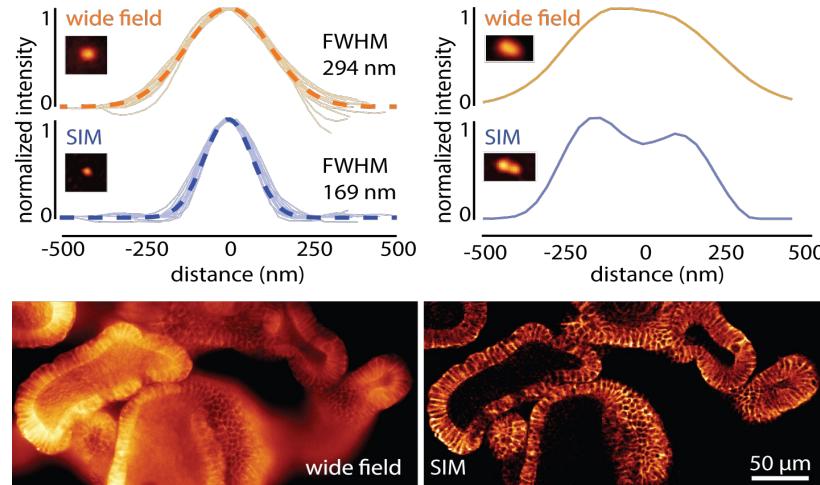


- Allows simple cabling between the different elements of the system (openSIM add-on, camera, PC, DAQ, power supplies)

Optical, electronical and mechanical components of openSIM

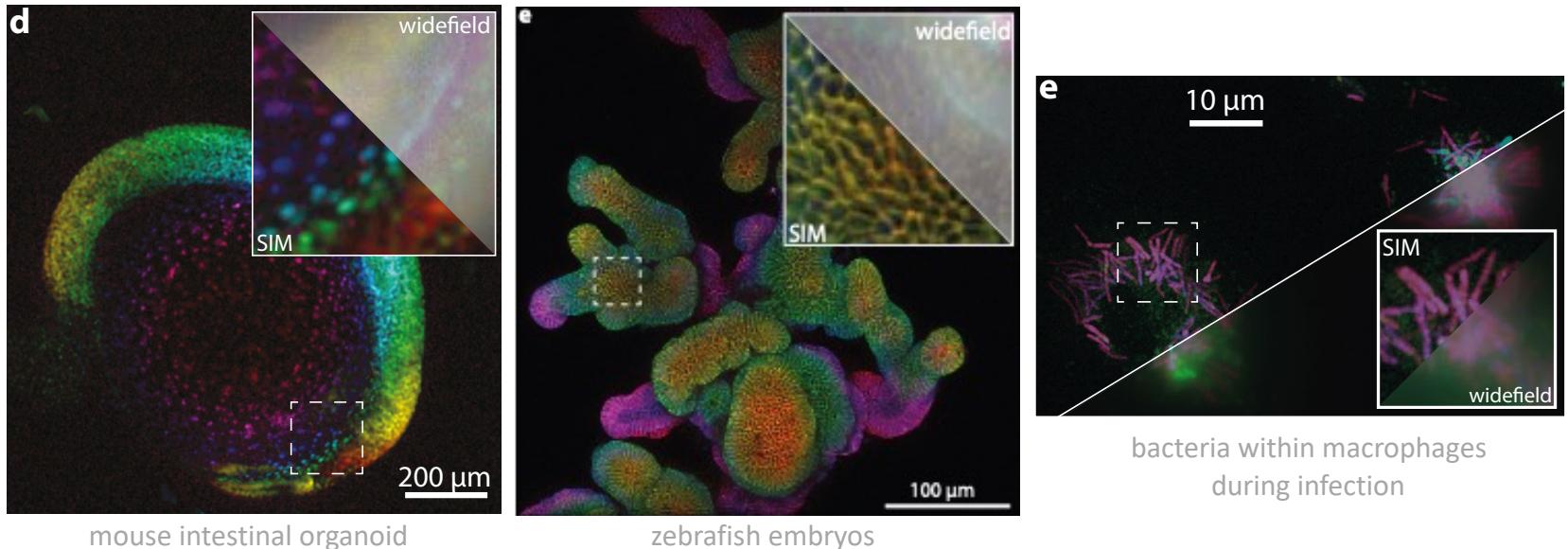


Performance of openSIM

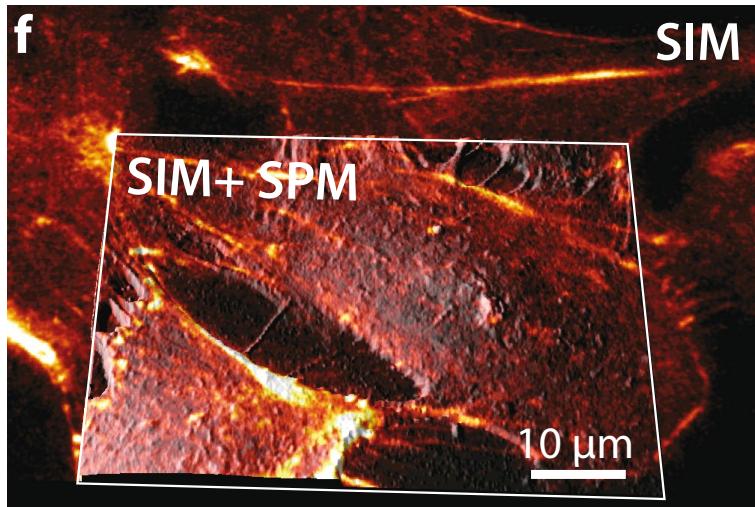


→ Increase in resolution and optical sectioning

Performance of openSIM



→ openSIM can be used for a broad range of biological samples



- openSIM can be coupled to complex instruments without deteriorating their performance

