



# **MICRO 372 - Advanced Mechanisms for Extreme Environments**

## **Chapter 2b Application fields and examples**

**Florent Cosandier**

# Application fields

■ Space

■ Astrophysics

■ Optomechanics

■ Metrology

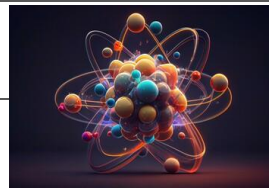
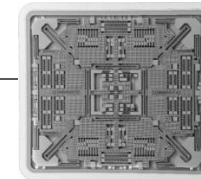
■ Medical instrumentation

■ Watchmaking

■ Robotics

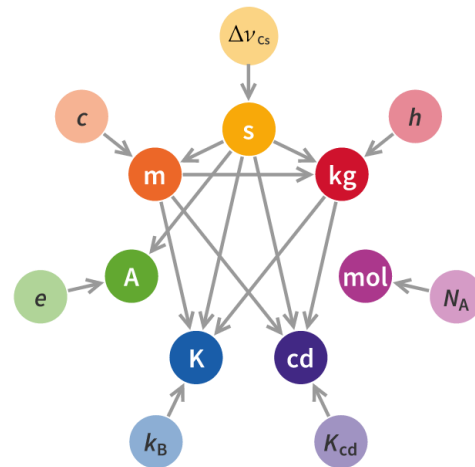
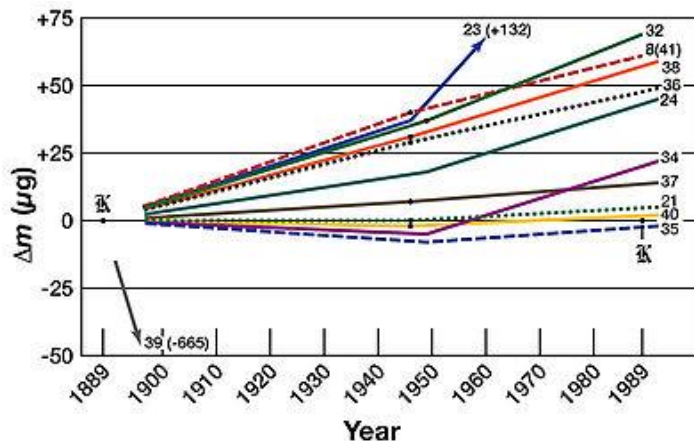
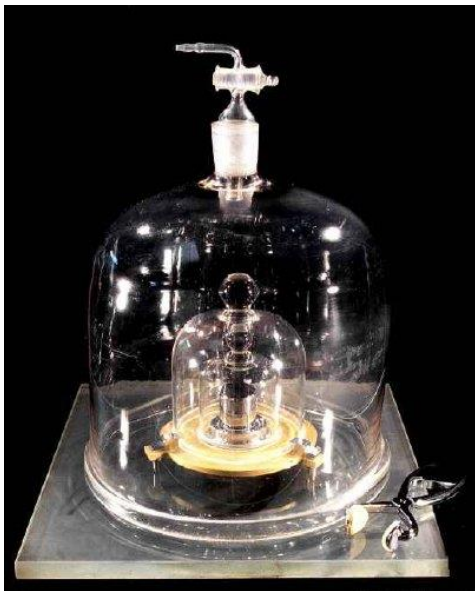
■ MEMS

■ Nuclear and particles physics



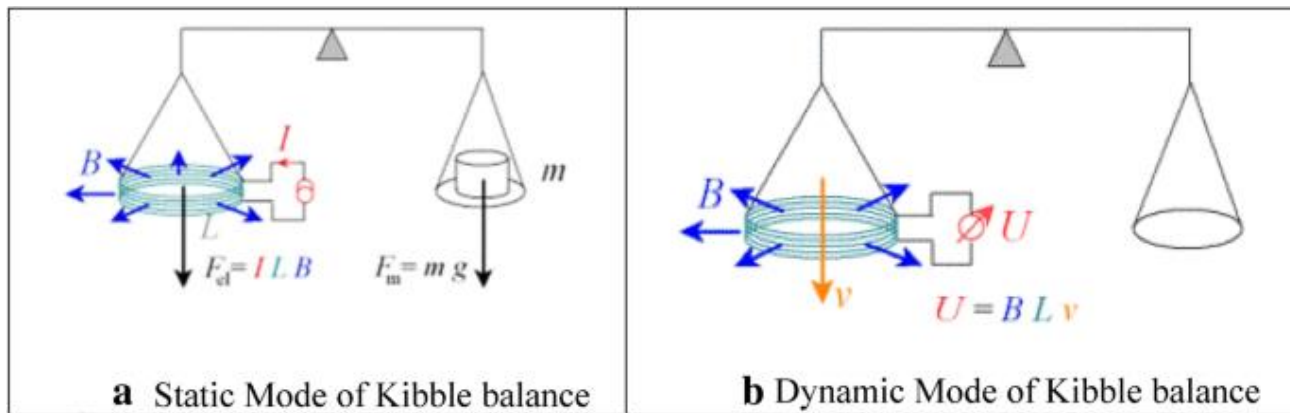
# Metrology app 1: Swiss Kibble balance

- International Prototype of the Kilogram (IPK) drifted by 50  $\mu\text{g}$  over 130 years
- IPK is kept in a vault in Paris
- New SI relates units to fundamental constant
- Since the 20<sup>th</sup> of May 2019, the kg is linked to the Planck constant



# Metrology app 1: Swiss Kibble balance

- The device used for **linking the mass unit to the Planck constant** is a **Kibble balance**
- The weight of a mass is compensated by the electromagnetic force of a coil in a magnetic field



$$m g = B L I$$

$$U = B L v$$

Mechanical power

$$m g v = U I$$

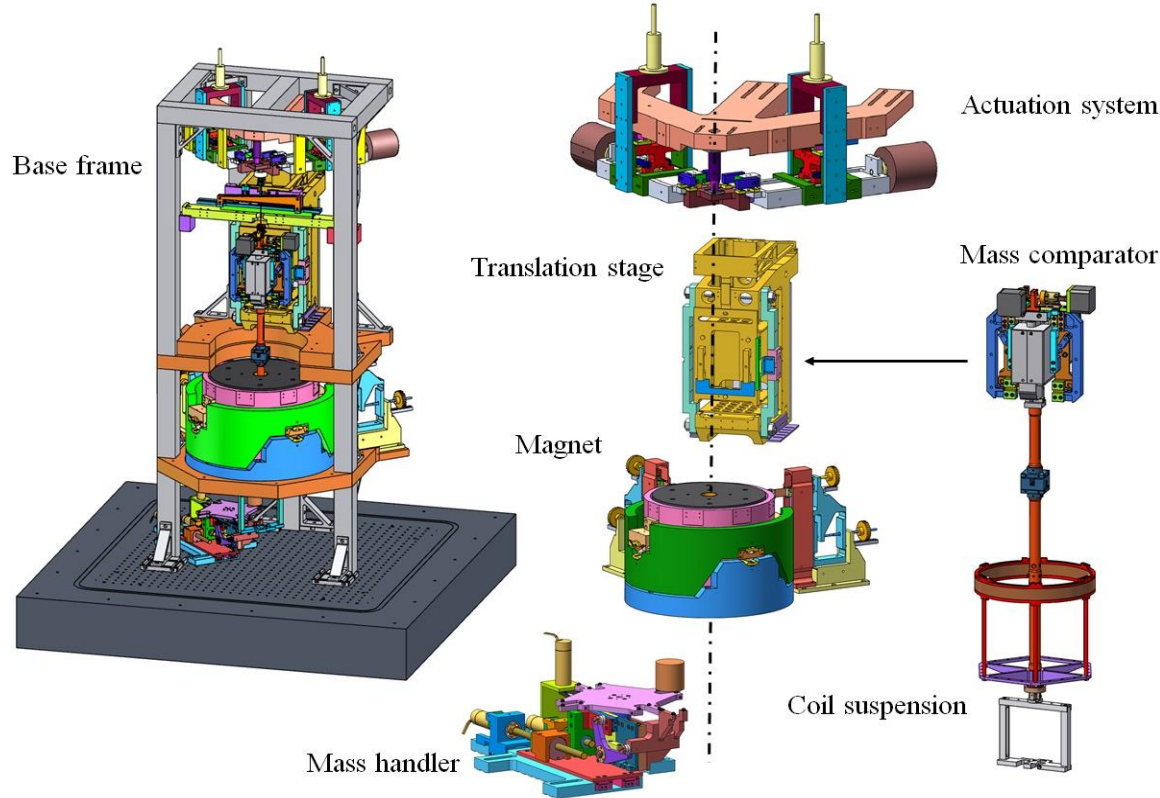
Electrical power

$$h = \frac{4 m g v}{(K_J^2 R_K) U I}$$

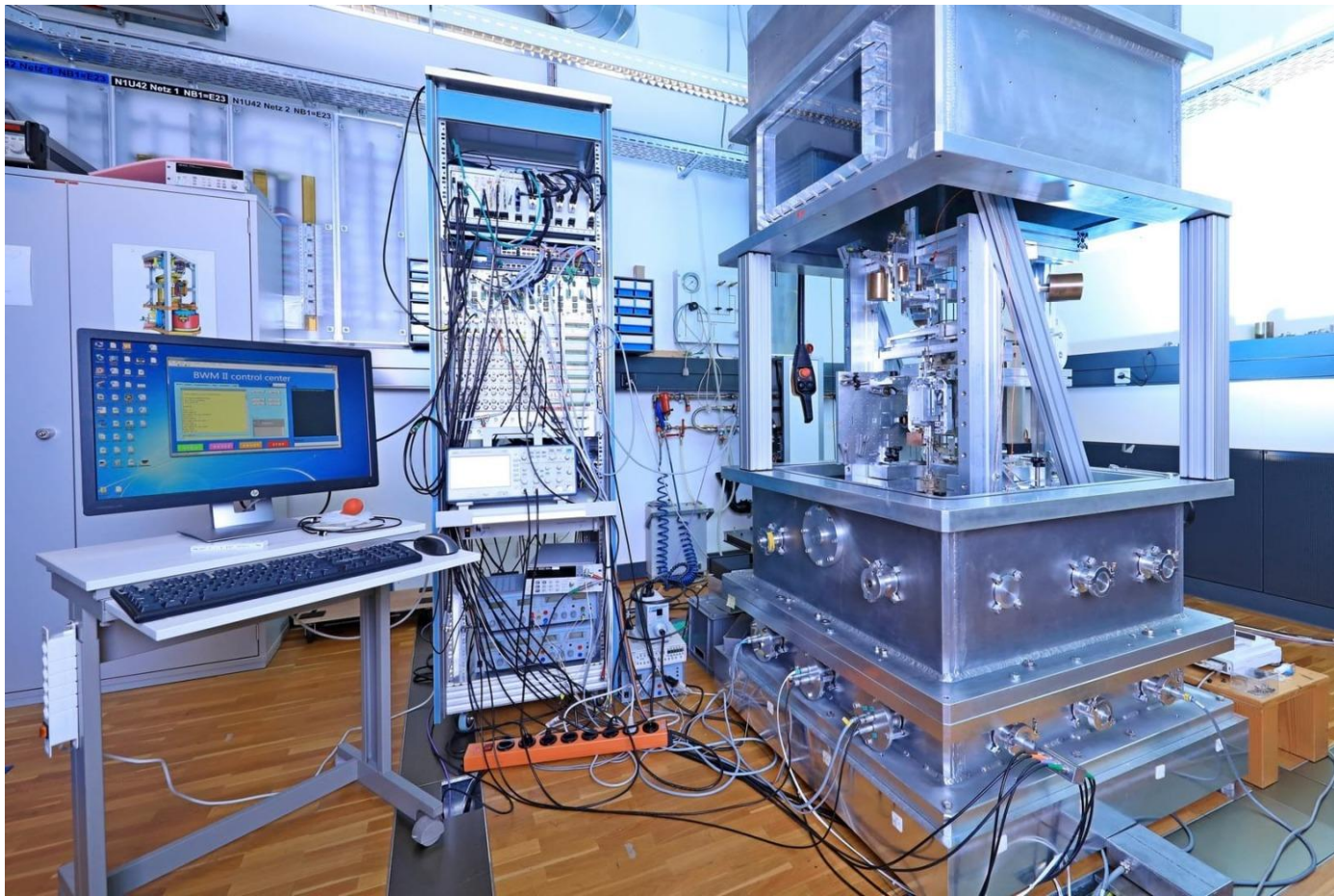
Planck constant  $h$   
 Josephson constant  $K_J$   
 von-Klitzing constant  $R_K$

# Metrology app 1: Swiss Kibble balance

- A metrological apparatus aiming at redefining the kilogram



# Metrology app 1: Swiss Kibble balance, in the lab..



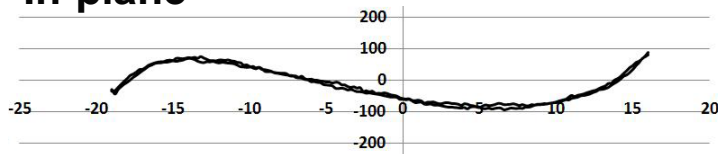
# Metrology app 1: Swiss Kibble balance, linear guiding system

Performances:

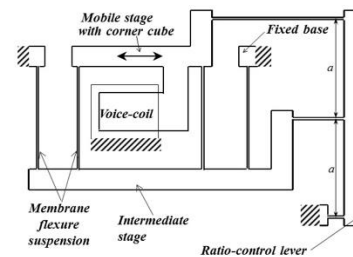
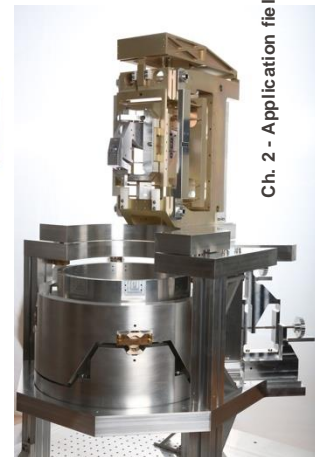
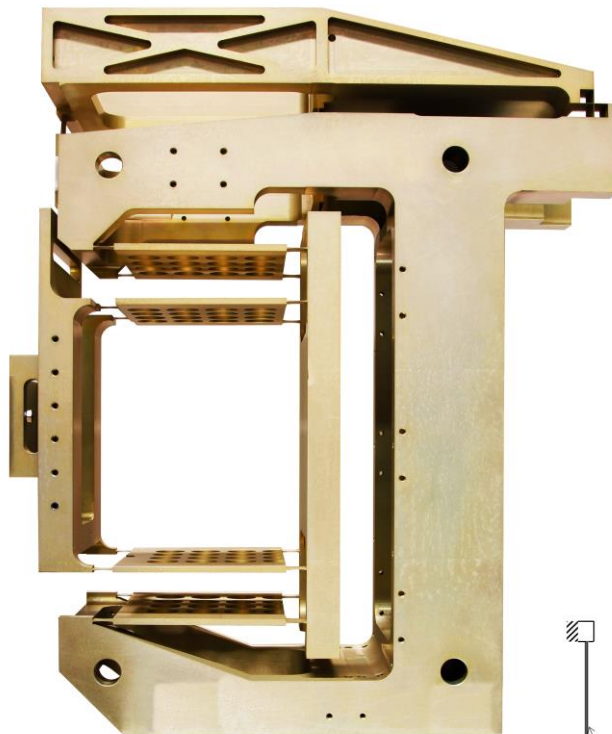
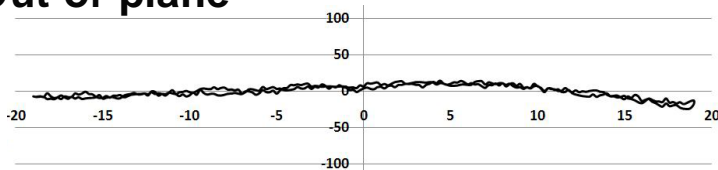
- Stroke: 36 mm
- In-plane lateral shift:  $\pm 90$  nm
- Out-of-plane lateral shift:  $\pm 20$  nm
- Material: Perunal 7022 ( $\text{AlZn5Mg3Cu}$ )
- Mass: 15 kg
- Dimensions: 140 x 350 x 450 mm<sup>3</sup>

Lateral displacement [nm]

In-plane

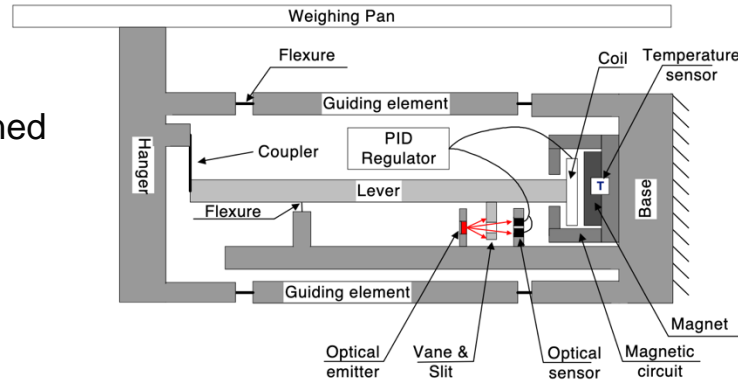


Out-of-plane



# Metrology app 1: Swiss Kibble balance, mass comparator

- Mettler Toledo Load Cell
- Used as a mass comparator
- Weight measurement at a defined working point (1.2 kg  $\pm$  4g)
- Repeatability 0.3  $\mu$ g



imeko.org

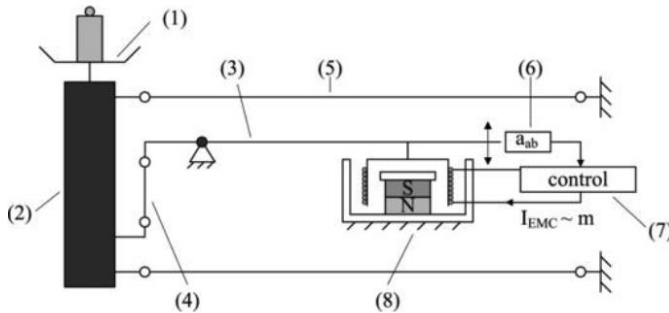
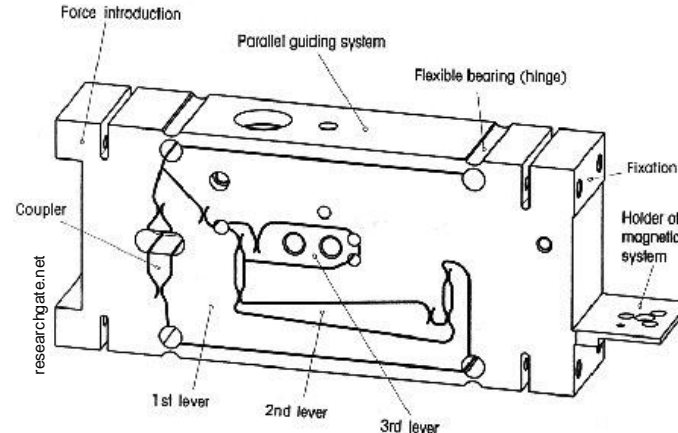


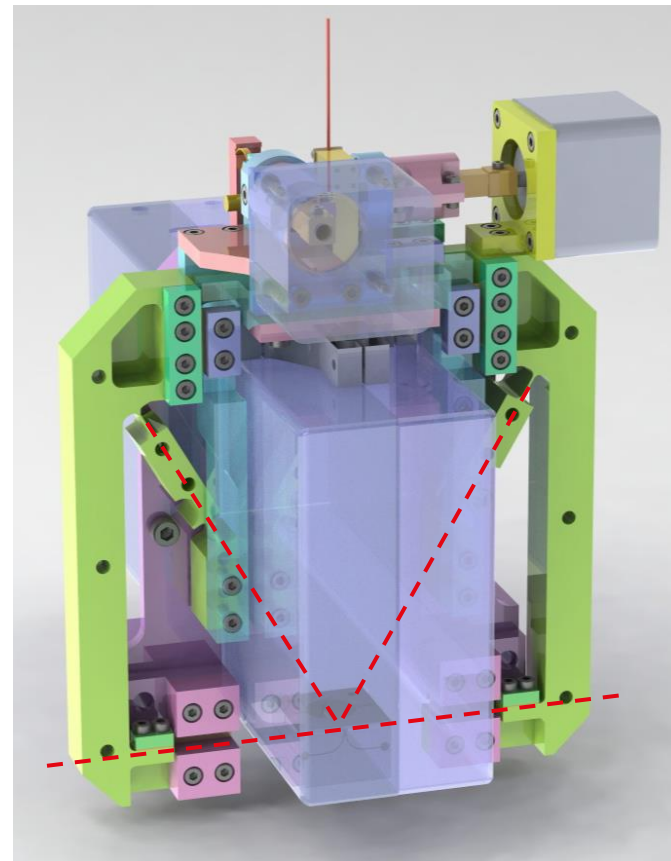
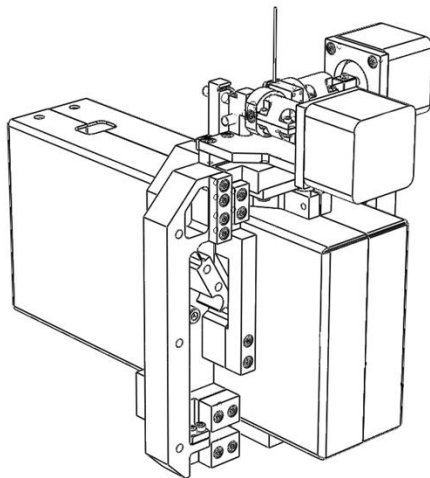
Figure 1.5: Basic operation of an EMFR weighing system. (1) weighing pan, (2) pan carrier, (3) conversion lever, (4) coupling element, (5) parallel beams, (6) optical position sensor, (7) control loop, (8) voice coil with permanent magnet [21, Figure 1]. © 2012 IOP Publishing Ltd.



Photography of 30 $\mu$ m coupler and a hair

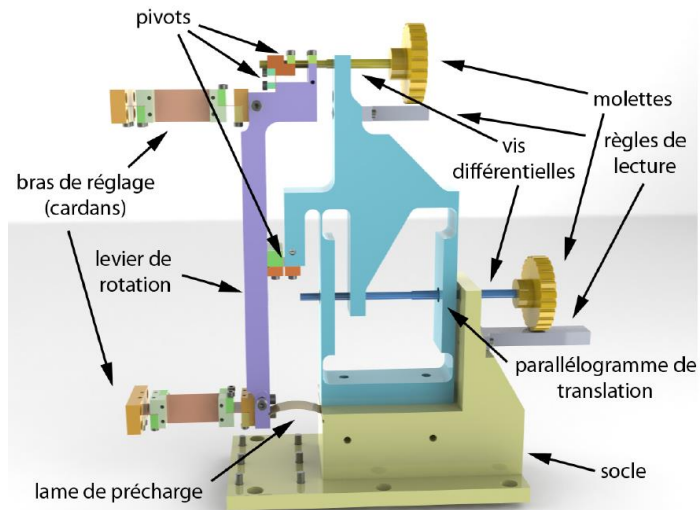
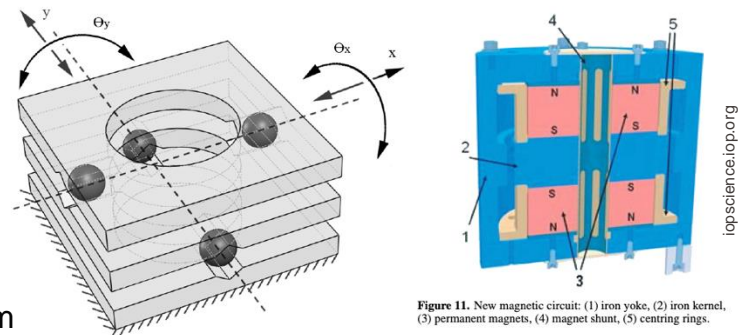
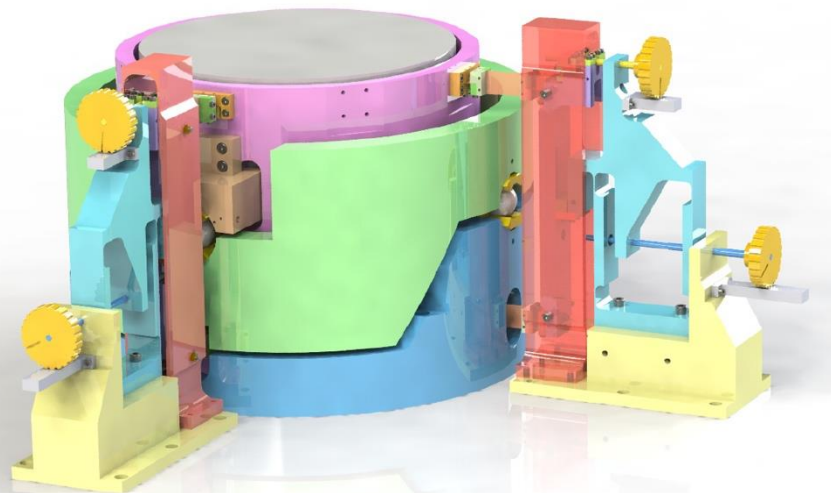
# Metrology app 1: Swiss Kibble balance, mass comparator alignment system

- Tip-tilt angles :  $\pm 2.5$  mrad
- Motorized adjustment through differential screws
- Linear resolution on screws : 50  $\mu\text{m}/\text{turn}$
- Angular resolution : 300  $\mu\text{rad}/\text{turn}$



# Metrology app 1: Swiss Kibble balance, magnetic circuit alignment system

- Positioning system of the 100 kg magnetic circuit
- Tip-tilt angles and lateral displacements manual adjustment through differential screws ( $\pm 2$  mm and  $\pm 1^\circ$ )
- Uncoupling through flexible arms
- Guiding and support load on four balls, zirconium oxide 30 mm diam. Rolling for translations and sliding for rotations.

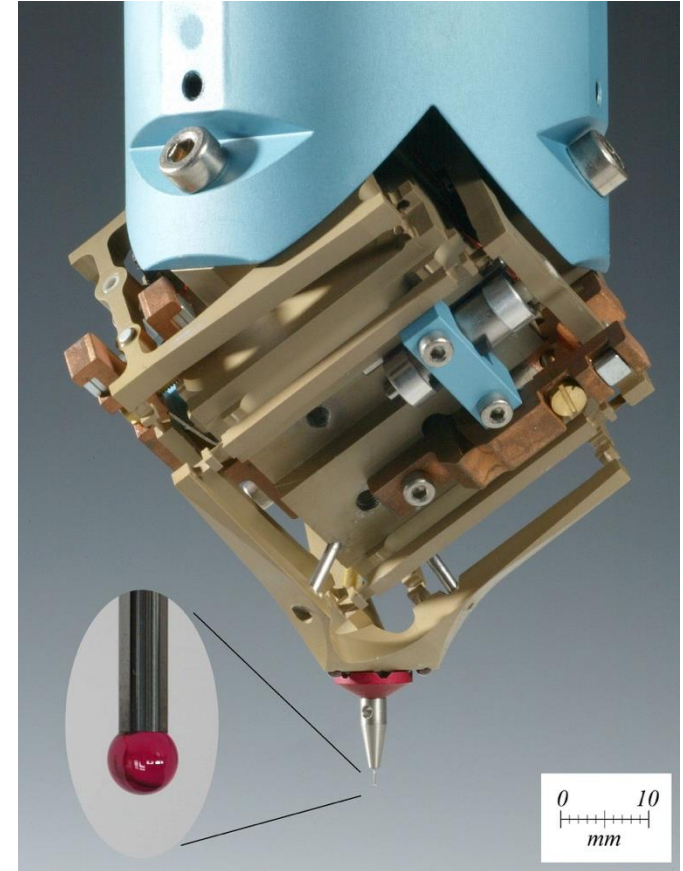
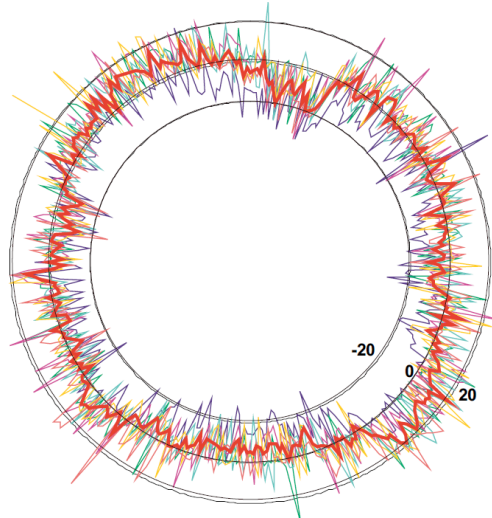


# Metrology app 1: Swiss Kibble balance, mass exchanger

**maxon**

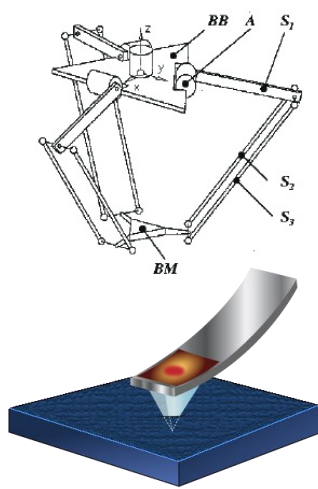
# Metrology app 2: Coordinate Measurement Machine (CMM)

- State-of-the-Art coordinate measurement machine
- 3 axes XYZ coordinates measurement
- Delta kinematics with 3 « space parallelograms »
- Measurement of a 3 mm diameter sphere within  $\pm 20$  nm

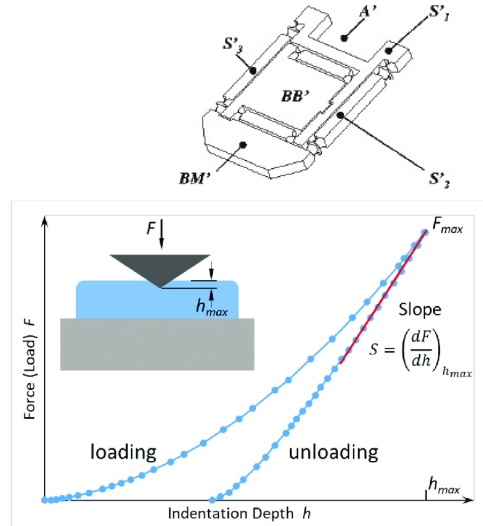


# Robotics applications: Delta Cube and Sigma 6 Robots

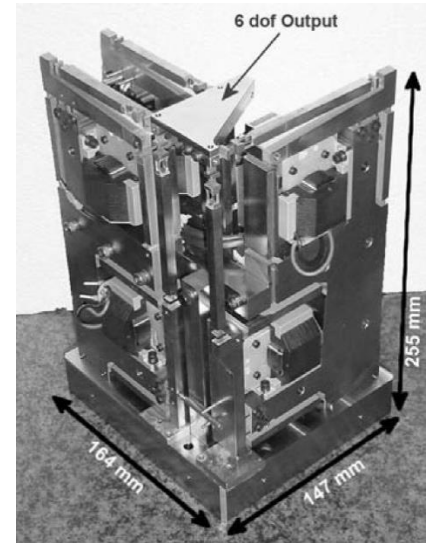
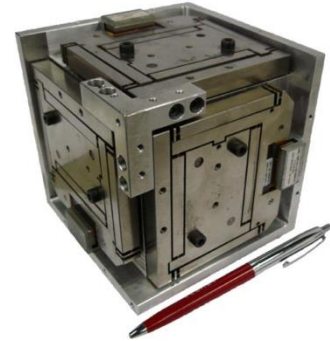
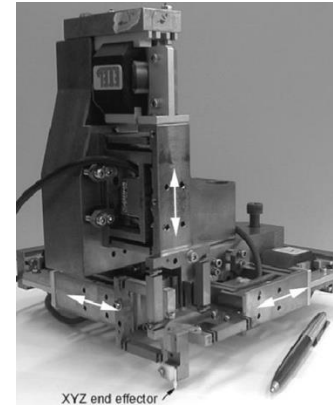
- Ultra-high precision 3 DOFs and 6 DOFs robots
- Delta cube is used for nano-indentation
- It is calibrated in function of the temperature and force
- The calibrated delta robot has an absolute accuracy of  $\pm 9$  nm over its working volume 20 mm squared



nanophys.kth.se



The robot Delta Cube 2

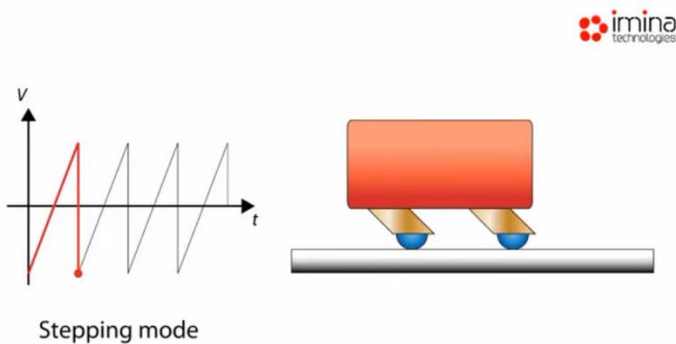


The robot Sigma6

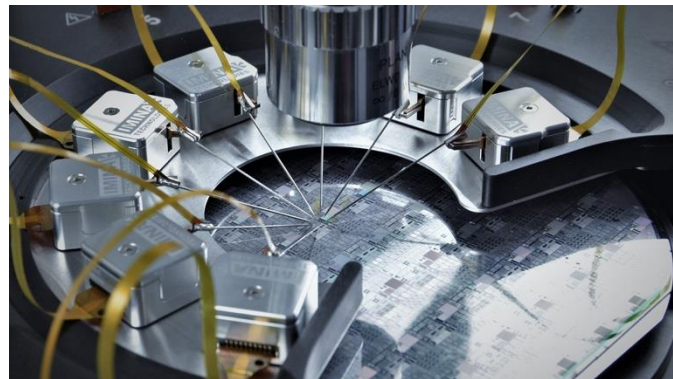
[1] Utke I et al. Mechanical Properties of 3D Nanostructures Obtained by Focused Electron/Ion Beam-Induced, April 2020, Micromachines 11(4):397, DOI: 10.3390/mi11040397

# Robotics applications: High precision robots for microscopes

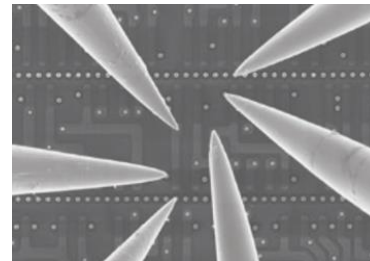
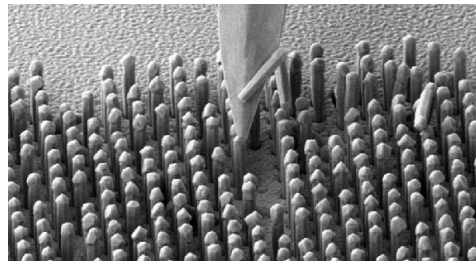
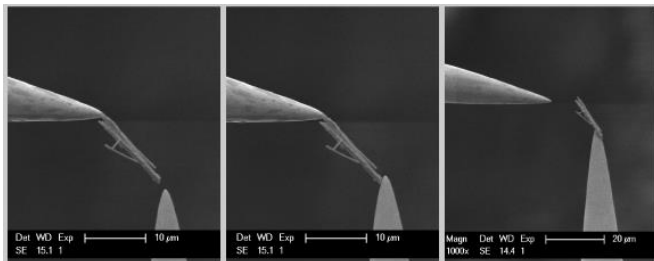
- Imina Technologies miBot used for electrical probing, material science and photonics
- 2 modes : stepping and scanning
- Nanometric resolution in scanning mode



[video link](#)

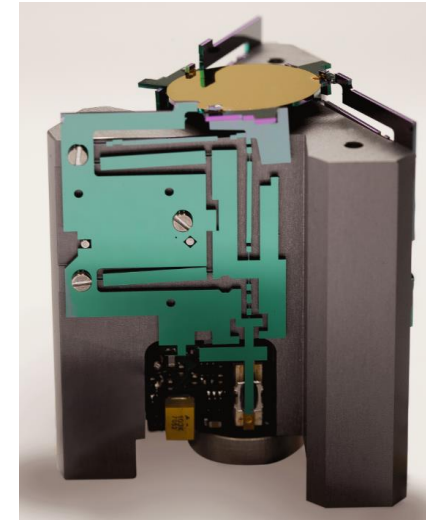
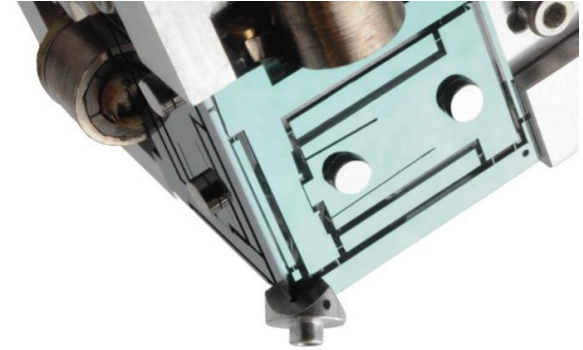


[rapportannuel2021.vaud-economie.ch/entreprises/aides-directes-du-spei/investissement](http://rapportannuel2021.vaud-economie.ch/entreprises/aides-directes-du-spei/investissement)

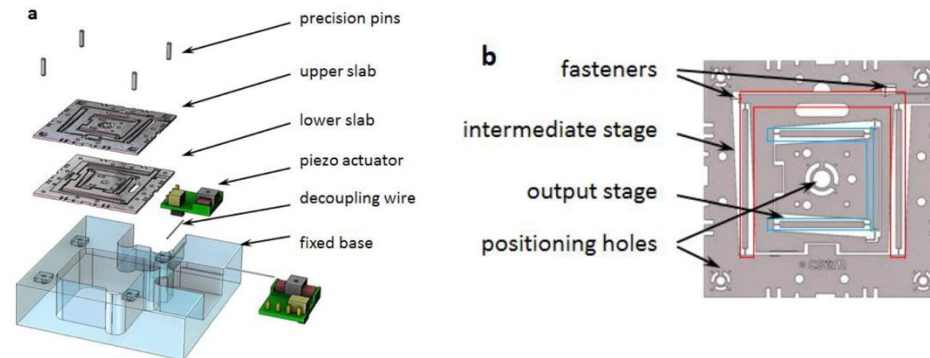
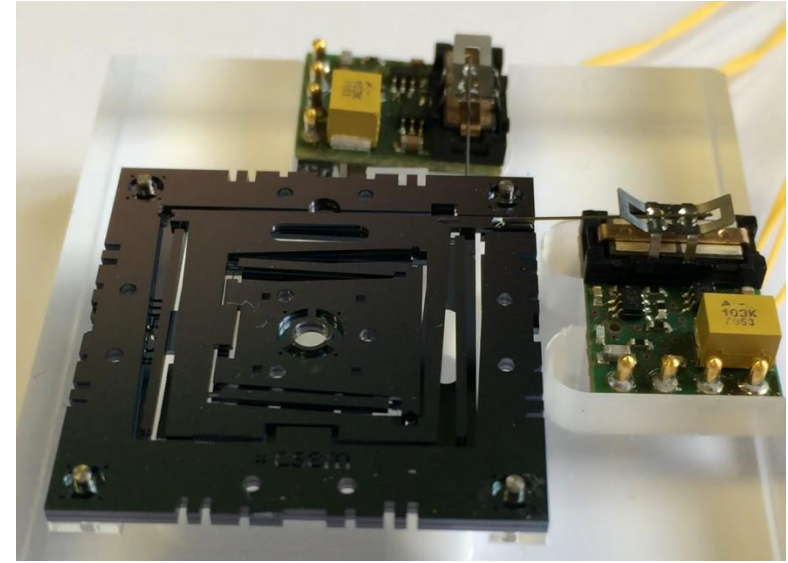


# MEMS applications

- **Delta sugar cube:**
  - X,Y,Z translation micro-manipulator
  - Silicon slabs with hinges and universal joints
  - Each plate is articulated by 12 hinges with a thickness of 45 microns
  - Stroke is 1.2 mm in all three directions (x-y-z)
  - Size of a large sugar-cube (20 x 20 x 20 mm)
- **Tip-tilt piston mechanism:**
  - $\pm 4^\circ$  ( $\pm 70$  mrad) tip/tilt rotations,
  - $\pm 0.6$  mm translation in piston mode (z)
  - Ultrasonic piezo-actuators



- **X-Y stage:**
  - Each 26 x 26 mm<sup>2</sup> slab has two moving parallelograms orthogonally and serially arranged. They are linked by base and output.
  - Actuated DOF at the intermediate stage (active) and free DOF at the output stage (passive)
  - Piezo actuators actuates the stage through decoupling wires



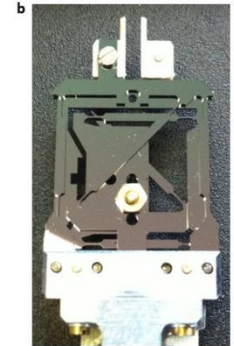
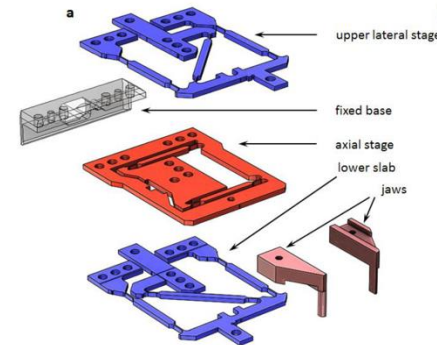
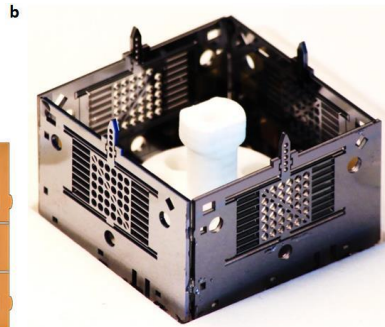
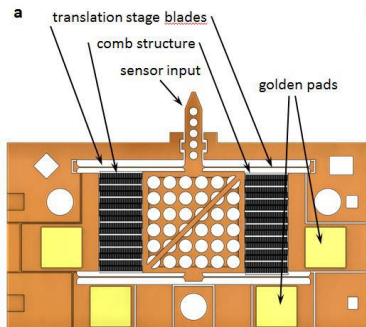
# MEMS applications:

## ■ Force sensor:

- Characterize the weight and center of gravity of parts in the 20 g range
- Differential capacitive sensor is made up using overlapping comb structures
- Space between the moving and the fixed fingers is 10  $\mu\text{m}$
- Maximal stroke of 200  $\mu\text{m}$  for a force of 200 mN

## ■ Micro-gripper:

- Central slab has a parallel stage that guides the input of the mechanism
- Outer slabs transform the input motion into a lateral motion of the jaws via tilted rods
- Two versions of jaws are available (straight and corner)



# Watch applications: flexure-based watch oscillators



a) Genequand System,  
VMF & CSEM (2014) [1]



b) Defy Lab, Zenith (2017) [2]



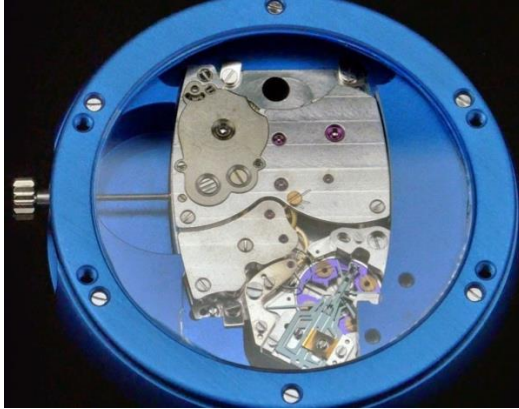
c) Freak NeXt, Ulysse Nardin  
(2019) [3]

- [1] Barrot, F., Dubochet, O., Henein, S., Genequand, P., Girsens, L., Kjelberg, I., Renevey, P., Schwab, P., & Ganny, F. (2014). *Un nouveau régulateur mécanique pour une réserve de marche exceptionnelle*. Journée d'Etude de la Société Suisse de Chronométrie 2014, 43–48.

- [2] Semon, G., Ypma, W. J. B., Weeke, S. L., & Tolou, N. (2017). Device for a Timepiece, Timepiece Movement and Timepiece Comprising a Device of Said Type (Patent No. WO2017157870A1).

- [3] von Gunten, S., Gyax, P., & Humair, L. (2015). *Oscillateur mécanique* (European Union Patent No. EP2273323B1).

# Watch applications: flexure-based watch oscillators



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- [3] von Gunten, S., Gyga, P., & Humair, L. (2015). *Oscillateur mécanique* (European Union Patent No. EP2273323B1).

# Watch applications: balance wheel resonance coupling spring

- Armin Strom Mirrored Force Resonance includes:
  - Two balance wheels
  - One coupling spring with optimized shape
- Coupling time between the two BW divided by a factor 2



[video link](#)

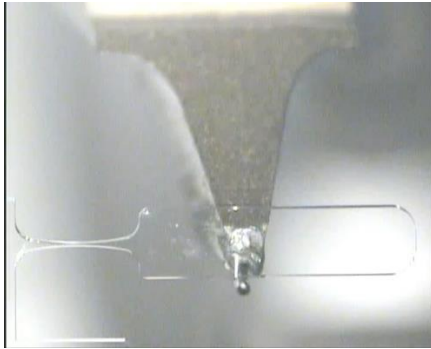
A COLLABORATIVE JOURNEY  
WITH **ARMIN STROM**



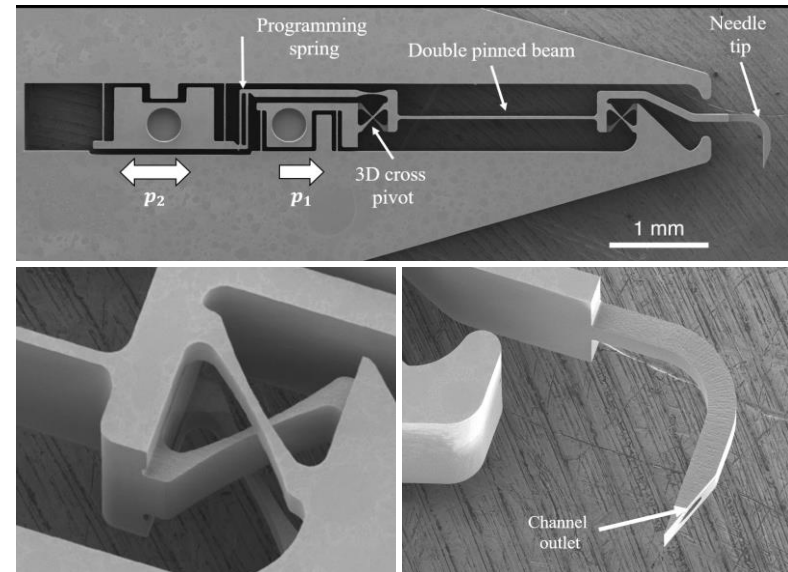
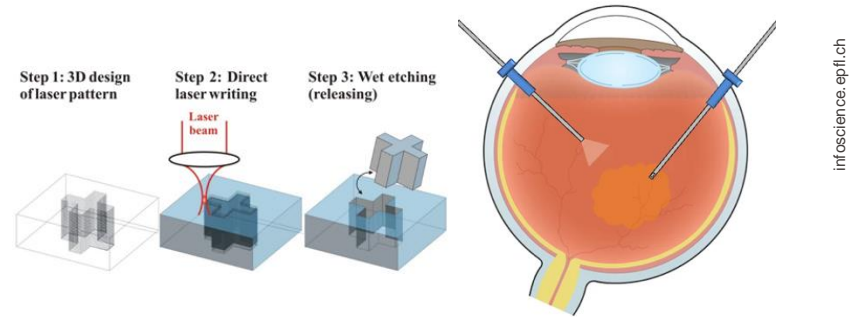
csem  
FACING THE CHALLENGES OF OUR TIME

# Biomedical applications: SPOT (Safe Puncture Optimized Tool)

- Material: fused silica (glass)
- Produced by femto laser printing technology
- $\sigma_{adm} = 1 \text{ GPa}$  for  $E = 74 \text{ GPa}$
- Tool developed for retinal surgery
- With programable bistable effect



Bellouard, Y. (2011). On the bending strength of fused silica flexures fabricated by ultrafast lasers. *Optical Materials Express*, 1(5)



# Biomedical applications: SPOT (Safe Puncture Optimized Tool)



# SPOT

**Safe Puncture Optimised Tool  
for Retinal Vein Cannulation**

**EPFL**



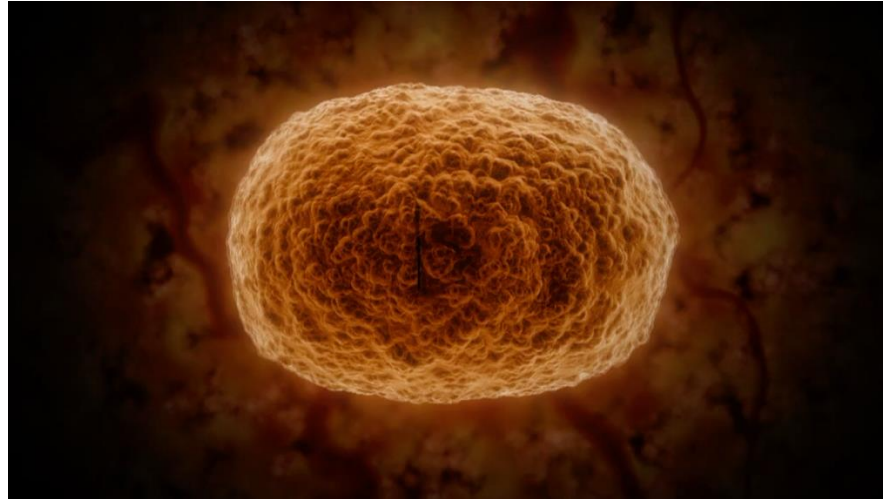
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# Biomedical applications: robotic surgery

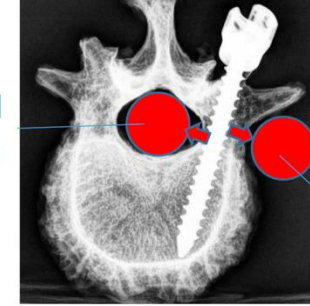
- Mobile robotic system linked with an optical tracking system guides the surgeon through the various stages of the surgery
- KB Medical was founded as a spin-off company of EPFL



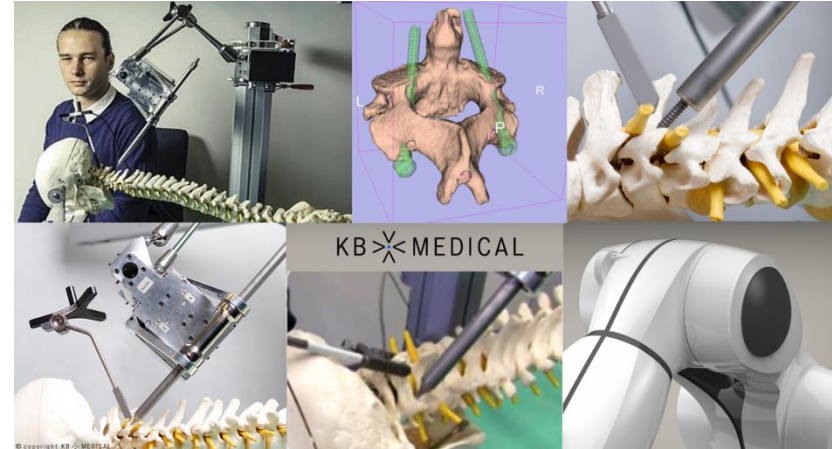
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**Spinal Cord**  
risk of paralysis

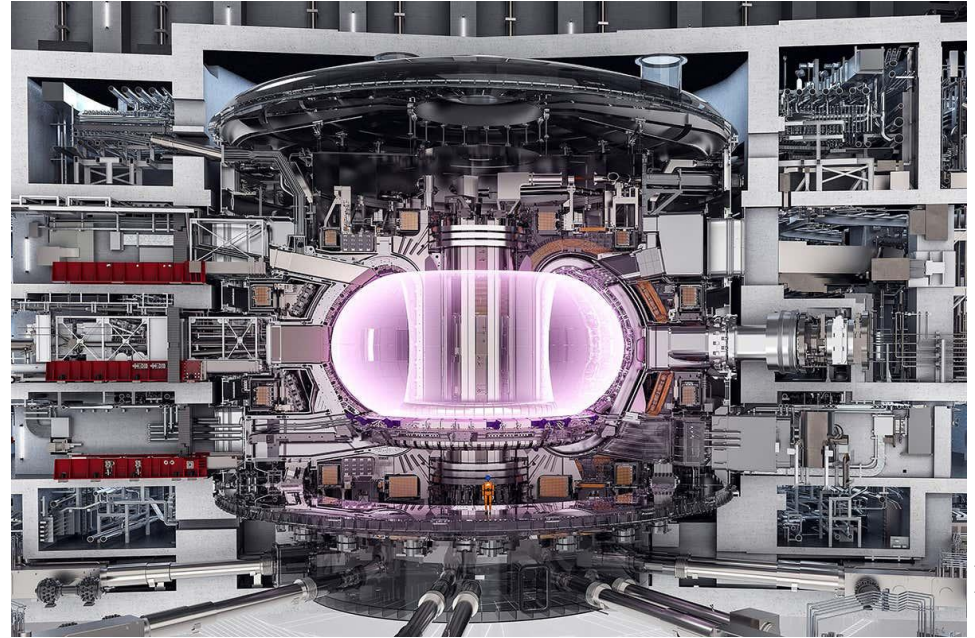


**Vessels**  
risk of death

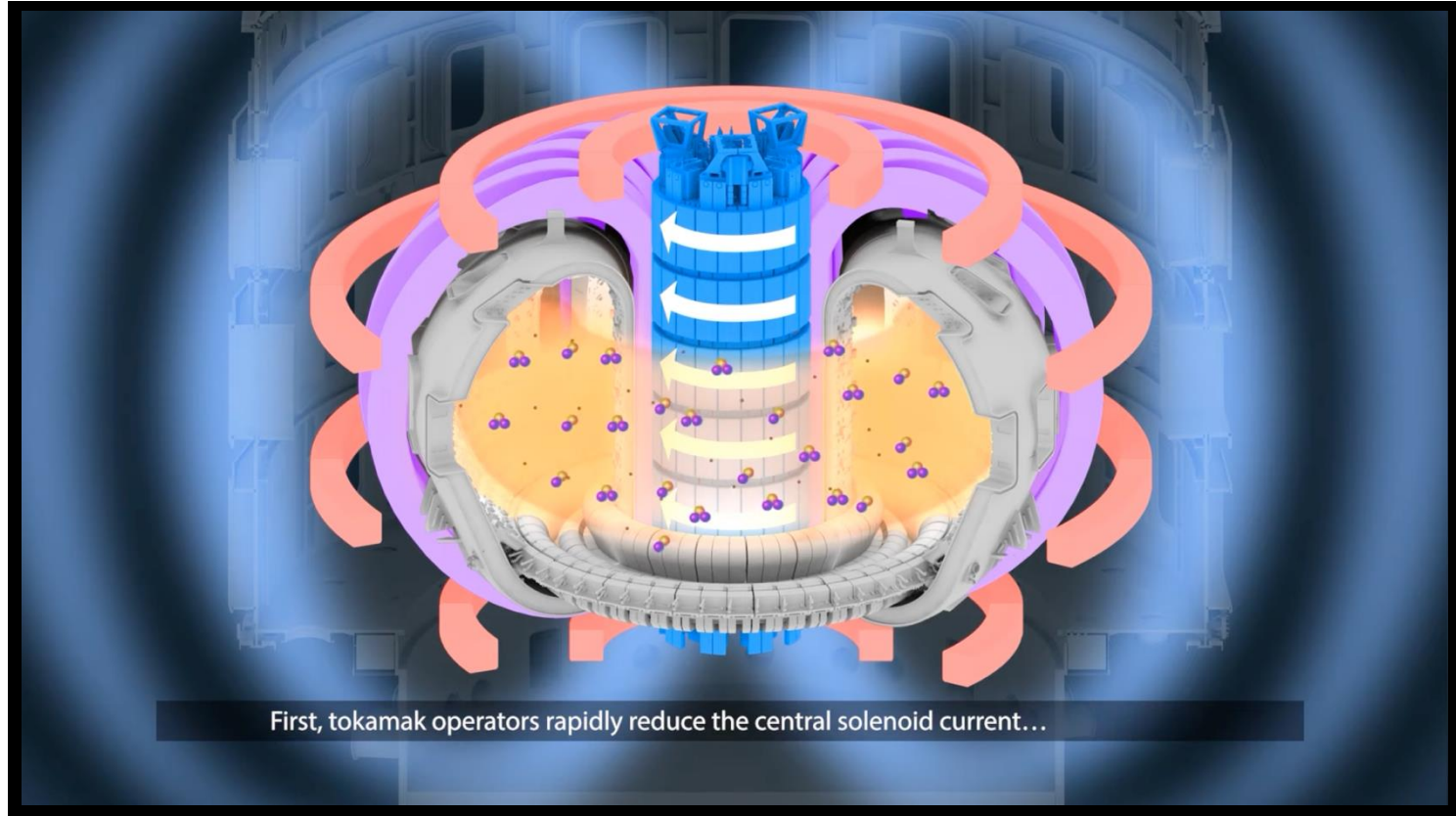


# Nuclear and particles physics app 1: International Thermonuclear Experimental Reactor (ITER)

- Biggest tokamak in the world (30 m in height)
- International nuclear fusion research and engineering megaproject
- Creating energy through a fusion process like that of the Sun.
- Magnetic energy: 41 GJ
- Magnetic field: 11,8 T
- Plasma temperature : 150 MK
- Cost: about €22 billion
- First plasma in 2025

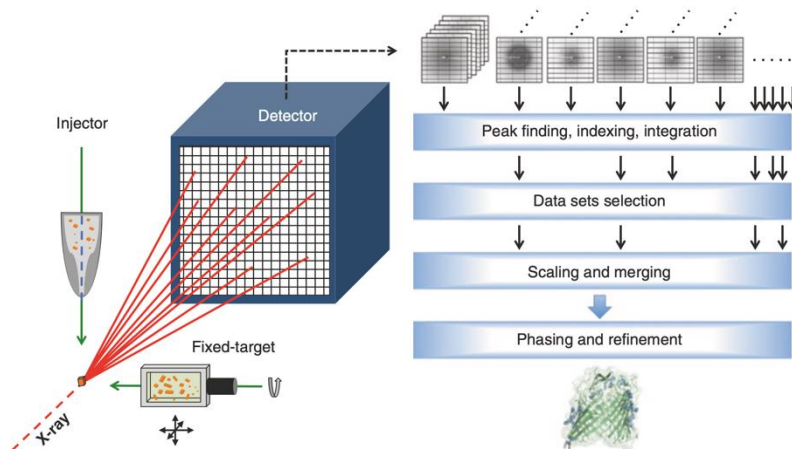
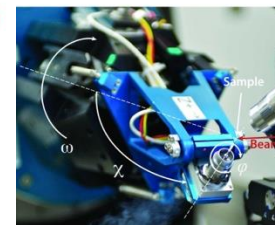
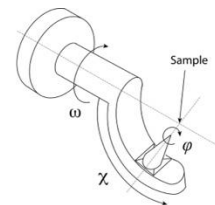
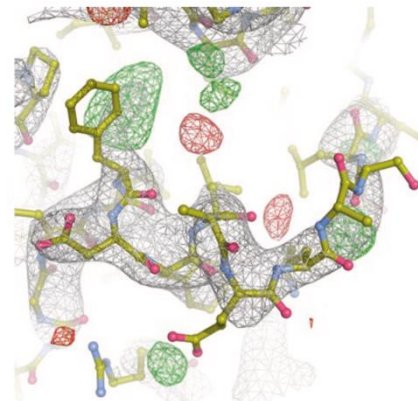


# Nuclear and particles physics app 1: International Thermonuclear Experimental Reactor (ITER)



# Nuclear and particles physics app 2: Synchrotron

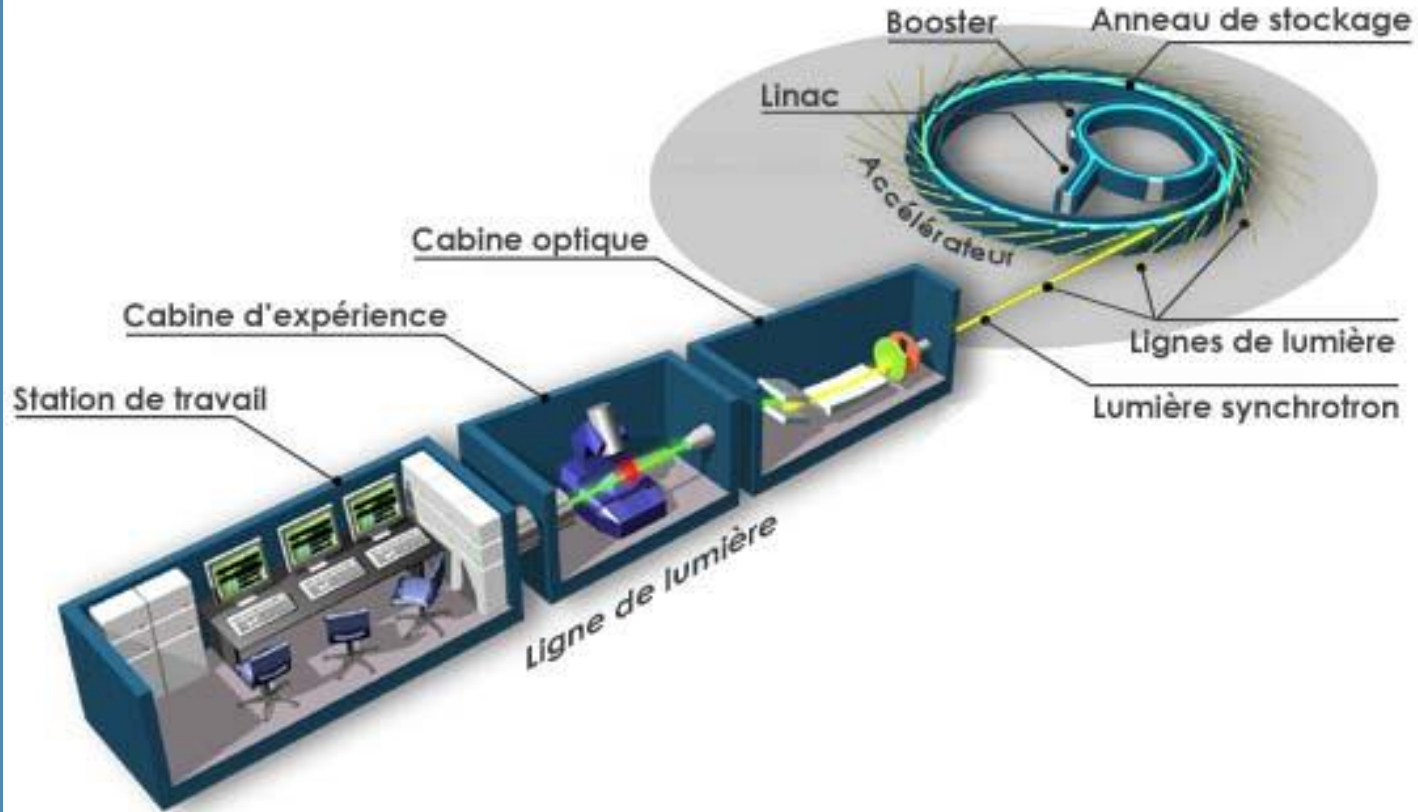
- A synchrotron is a particular type of cyclic particle accelerator in which the accelerating particle beam travels around a fixed closed-loop path
- LHC at CERN is the biggest synchrotron (energy ~ TeV)
- Used for x-ray crystallography, material science, physics, chemistry, ..
- Precision robots are needed to hold and rotate the samples



**Fig. 1** Serial synchrotron crystallography (SSX): from crystals to structures

Protein Crystallography, Alexander Wlodawer et al., Methods and Protocols, Springer Protocols, 2017

# Nuclear and particles physics app 2: Synchrotron SOLEIL (Source optimisée de lumière d'énergie intermédiaire du LURE)



# Week 2 exercises and homework

## Exercise

- COMSOL basics tutorial on MOODLE : EXO\_2\_tuto\_COMSOL.pdf
  - Connect to : [VDI.EPFL.CH](http://VDI.EPFL.CH)

## Homework

- Watch all (or part) of this video on the solar system  
<https://www.youtube.com/watch?v=cY25s0sCdMI>