MICRO-523: Optical Detectors

Week One: Introduction

Claudio Bruschini

Institute of Electrical and Micro Engineering (IEM), School of Engineering (STI)

Ecole polytechnique fédérale de Lausanne (EPFL), Neuchâtel, Switzerland

TAs: Samuele Bisi, Yazan Lampert

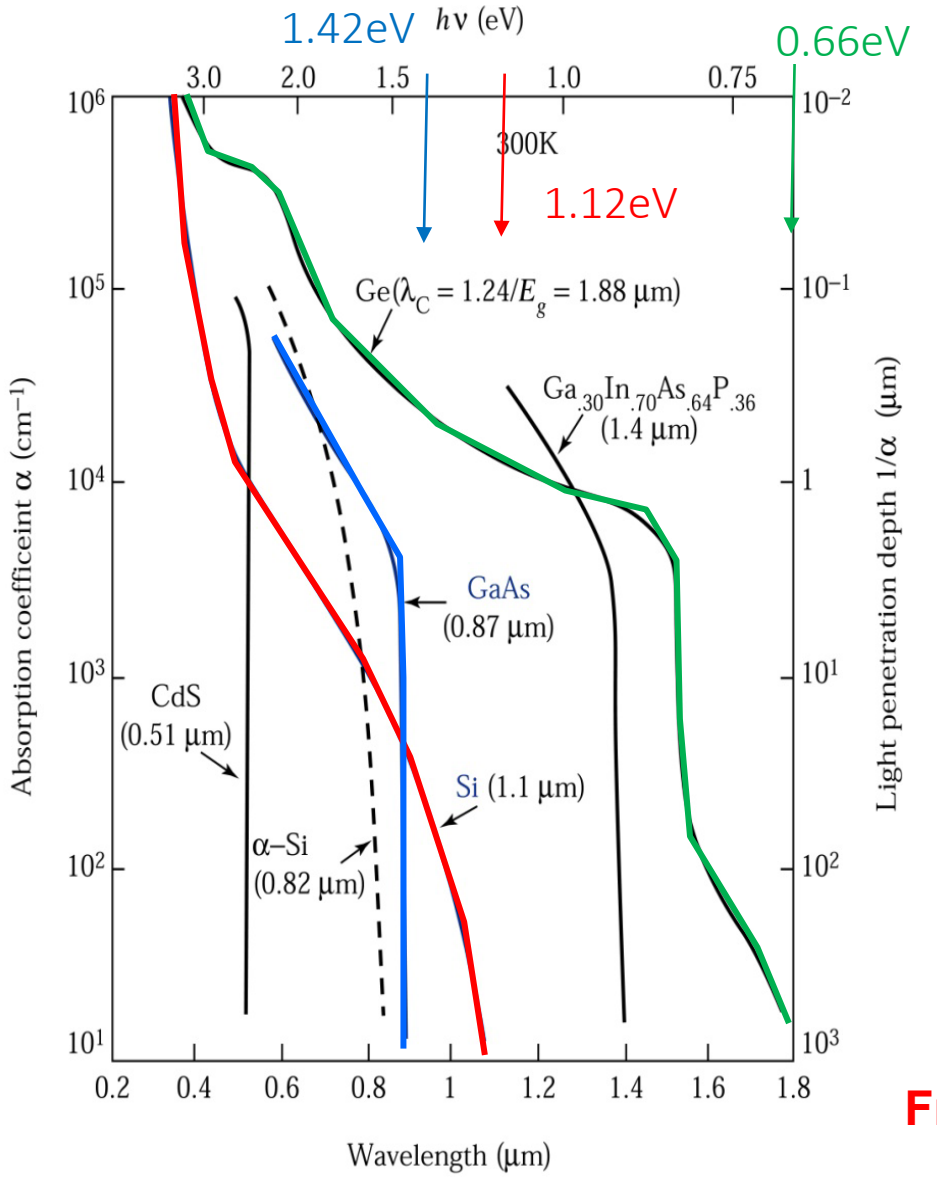
MICRO-523 Optical Detectors: course organisation

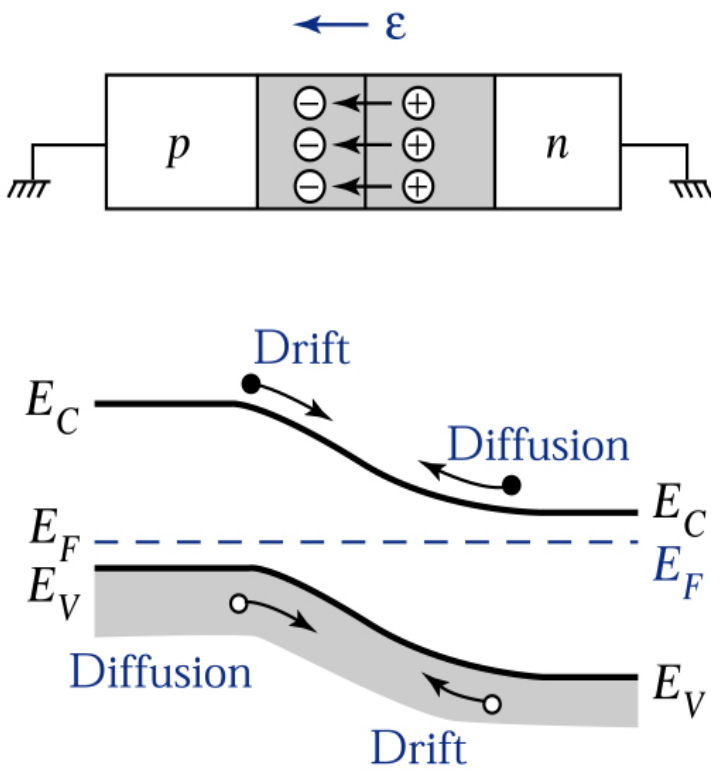
- 2+1 hours/week
- Slides and scripts as primary learning tools (Moodle)
- Exercises discussed in class during the following week
- Exam during exam session: 2 questions, 20-25’ and ~same preparation time. Cheat sheet (1-2 A4, recto-verso).
- Oral exam: before Jan 23 2025
- Office hours: discussion after class or on request. TAs (Samuele and Yazan) available, in particular for the exercises.
- Participation in class highly encouraged!

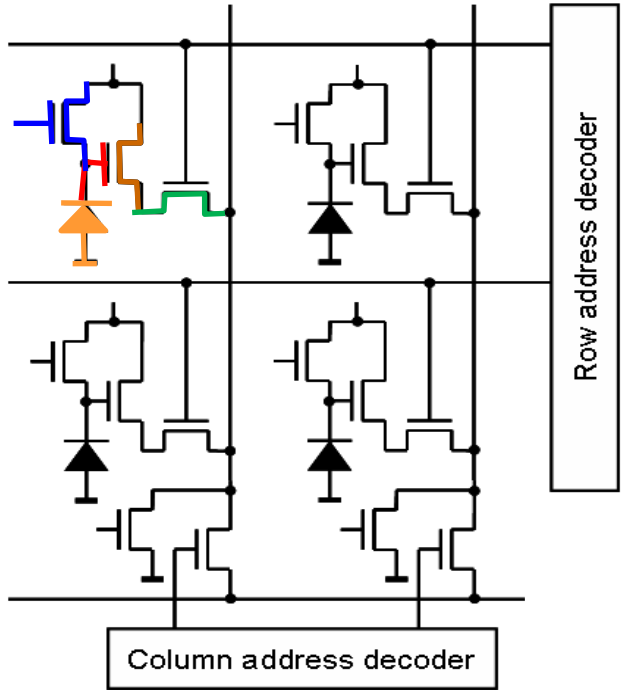
MICRO-523 Optical Detectors: contents

- *Students analyse the fundamental characteristics of optical detectors, their architectures, selected applications and case studies. Photoemissive devices, photodiodes, infrared sensors and single-photon detectors are studied. CCD, CMOS and SPAD cameras are analysed in detail*

MICRO-523 Contents/1





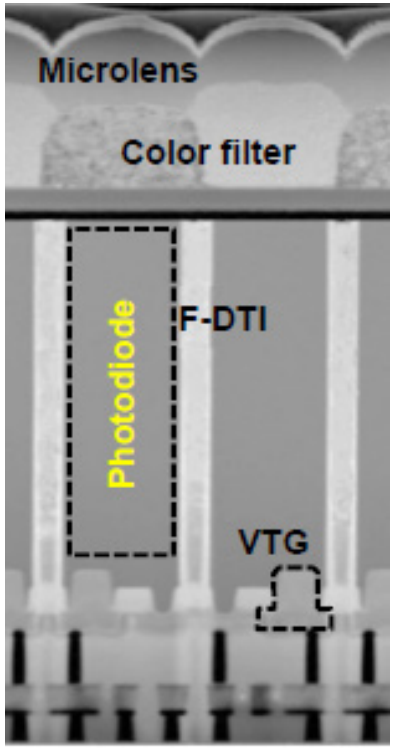


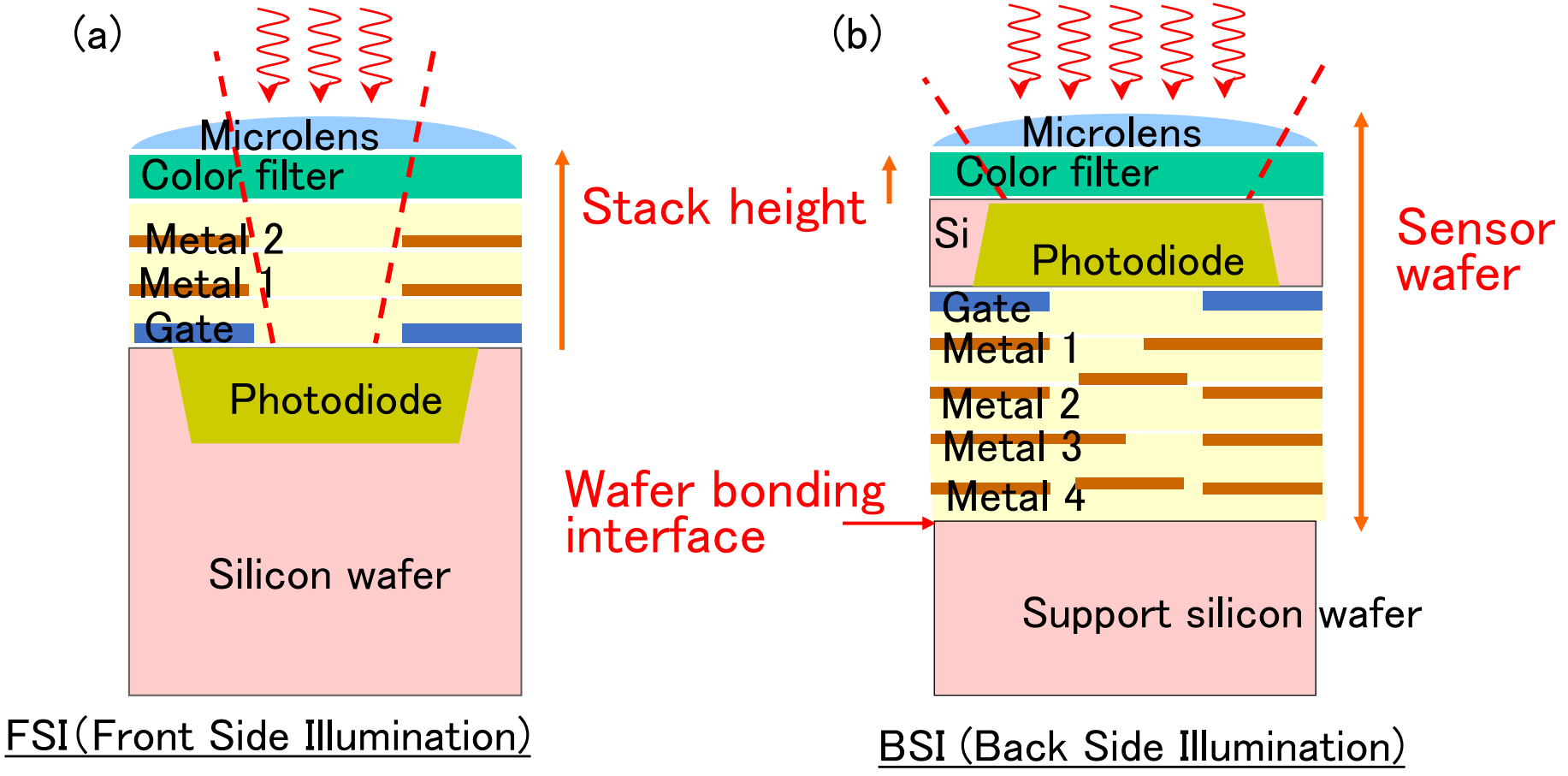
APS imager

3T pixel with
- Reset
- Follower
- Row selector

From materials to devices and circuits…

MICRO-523 Contents/2 - Technology



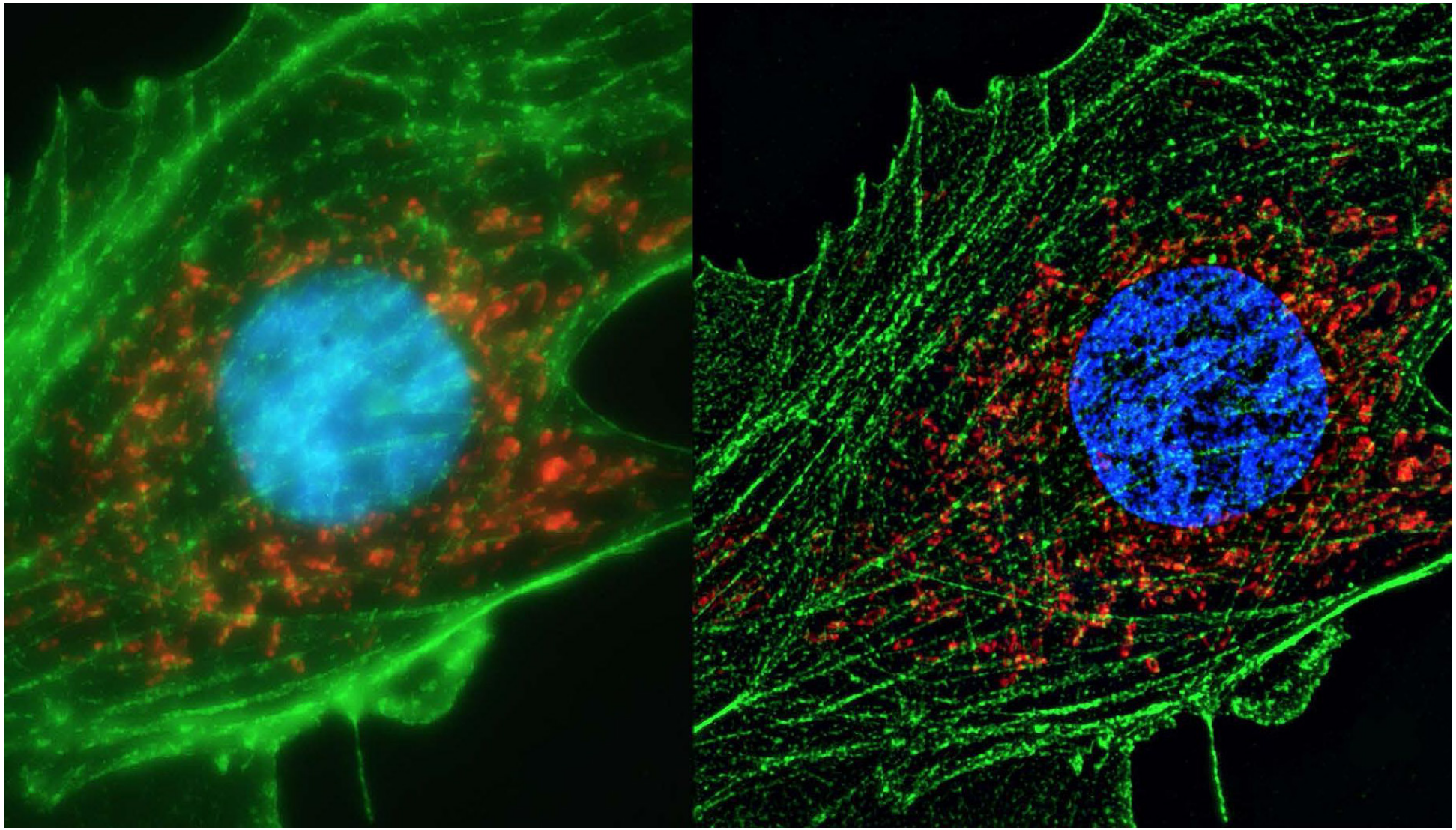


MICRO-523: Application example - Immersive Display

Requirements for CMOS Image Sensor

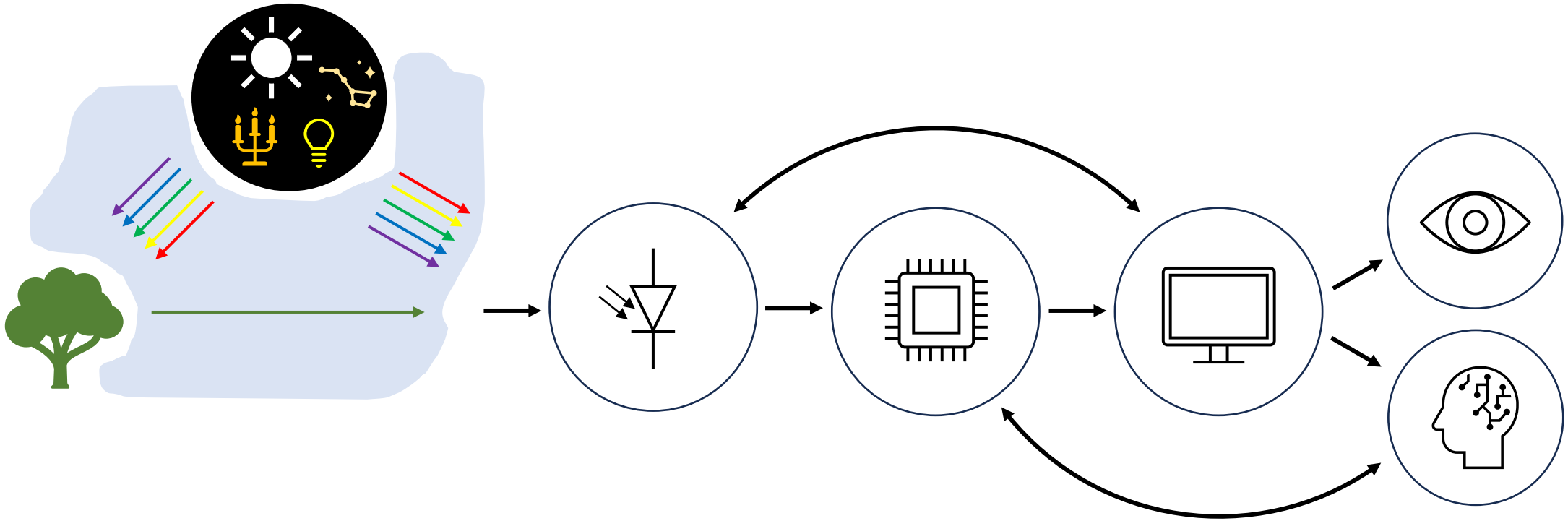
- Large size and high resolution
  - 16K resolution interior LED screen spanning 160,000 sq ft.
- Great image quality
- Low noise
- HDR
- Minimal motion artifacts

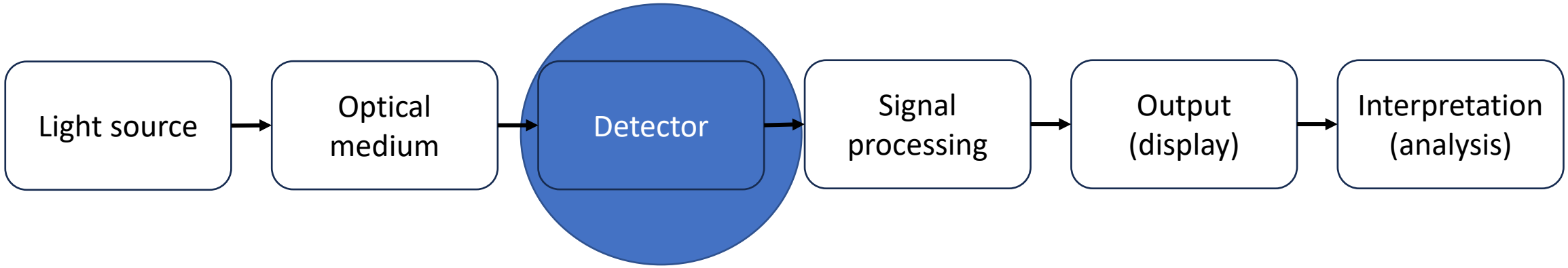
MICRO-523 Application Example - Optical superresolution techniques



G. Fantner, MICRO-428 Week 6

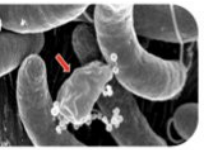
MICRO-523 Optical Detectors – the full picture

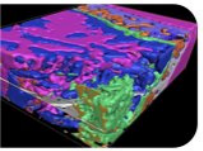




The Minor in Imaging

Broaden your career horizon





Open to all EPFL students

- **Transversal & interdisciplinary** program
- Covers **theoretical and practical aspects** in imaging
- Useful in **industry and academic world**

Requirements

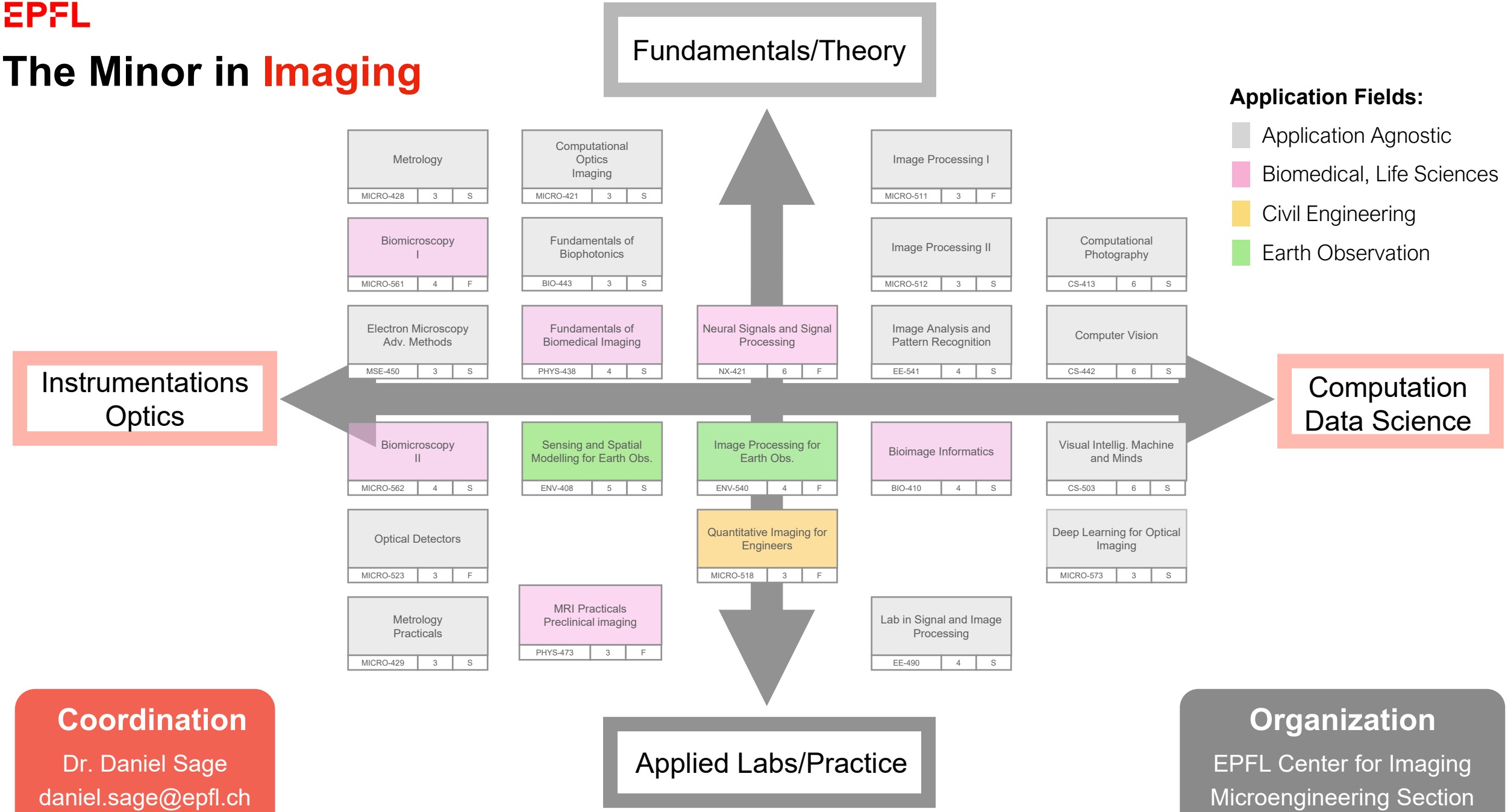
- **Mathematics**
  Linear algebra & analysis
- **Basis of programmation**
  One language
- **Basis of physics**
  Optics

Minor (30 ECTS):

- 22 ECTS of courses
- 8 ECTS for a project

Info: imaging.epfl.ch/education

The Minor in Imaging



Coordination

Dr. Daniel Sage

daniel.sage@epfl.ch

Organization

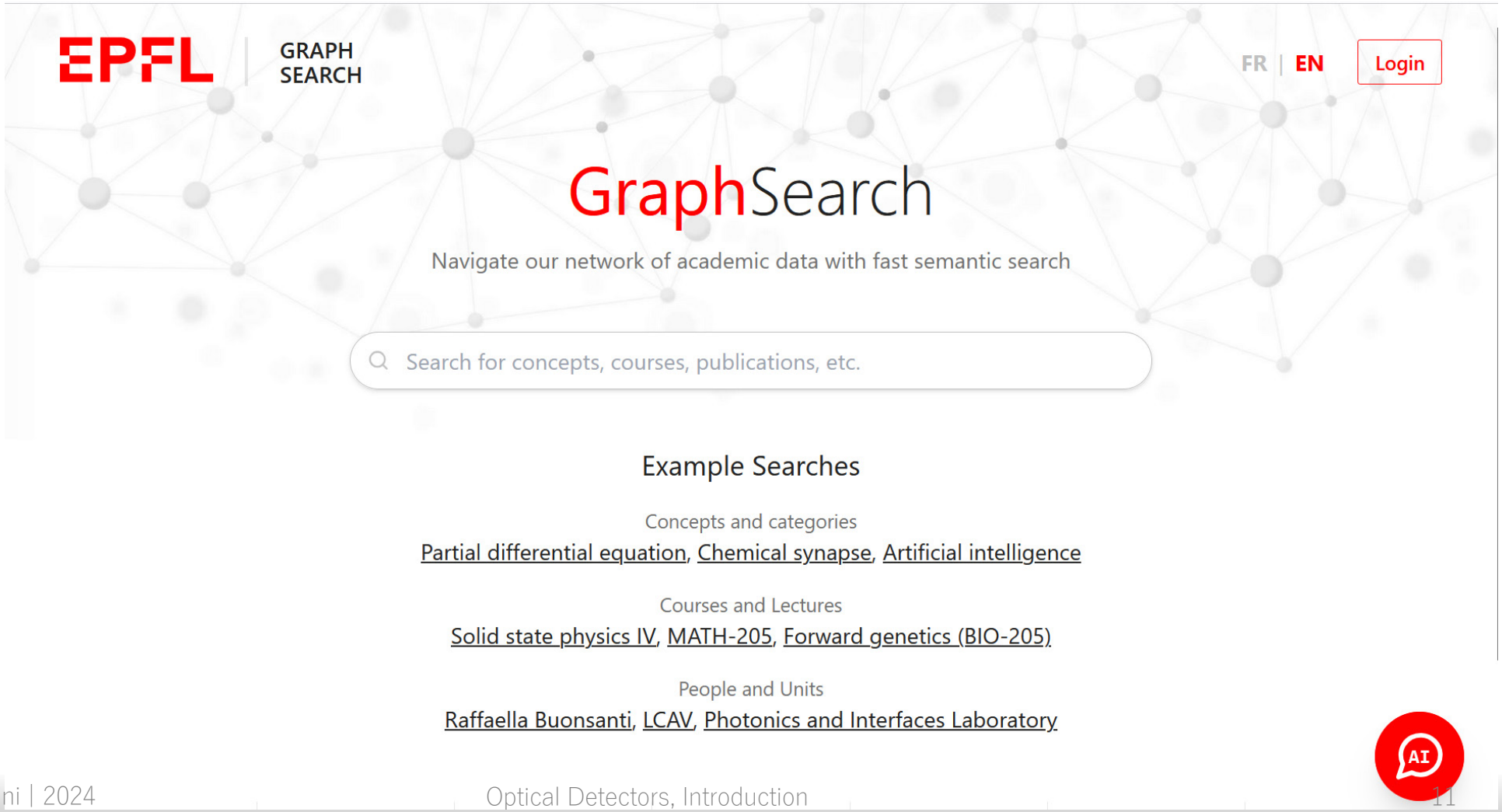
EPFL Center for Imaging

Microengineering Section

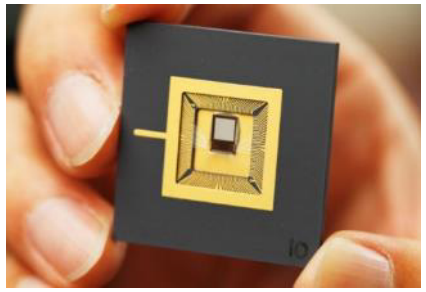
Info: imaging.epfl.ch/education

EPFL Tool: GraphSearch - https://graphsearch.epfl.ch

Cet outil permet d'explorer l'ensemble des contenus en ligne de l'EPFL (40'000 heures de vidéo, livrets de cours, publications, laboratoires, personnes, startups, news, etc...) ainsi que d'interagir avec un chatbot "maison".

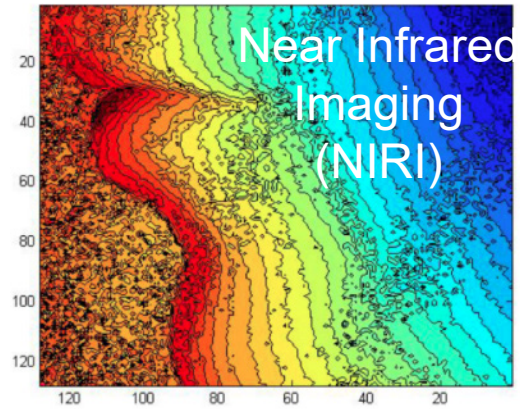


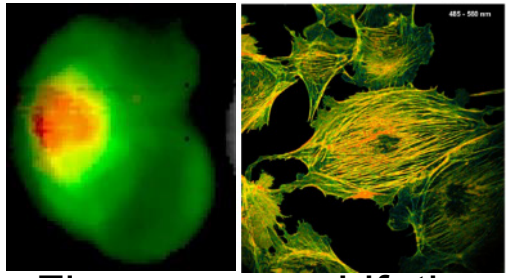
Background – AQUAlab Single-Photon Imaging Applications



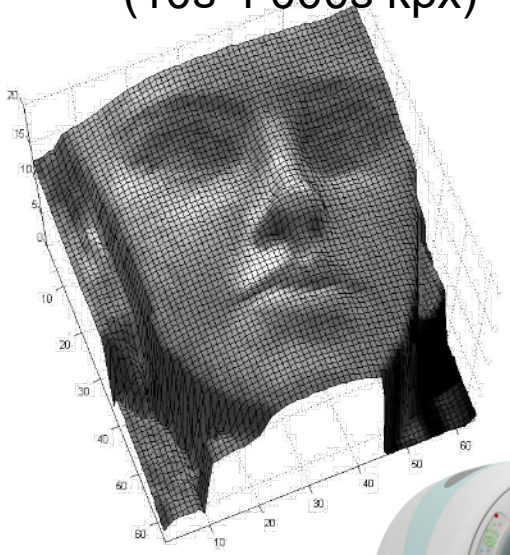
Quantum Security

Detect/time-stamp single optical photons with (CMOS) SPADs
Excellent timing resolution (10-100 ps)
Increasing spatial resolution (10s-1'000s kpx)

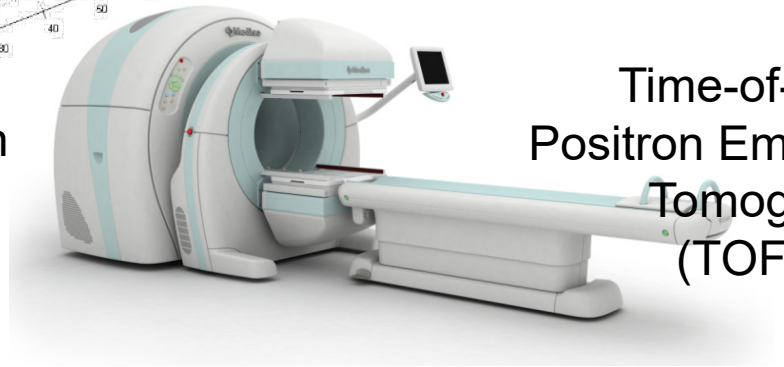




Fluorescence Lifetime Imaging Microscopy (FLIM) and super-resolution microscopy (STED, STORM, SSIM, PALM, ...)



3D Vision



Time-of-Flight Positron Emission Tomography (TOF-PET)

Background – The early days…

Figure 1.1: HALO Trust deminer in Cambodia, checking the ground with an Ebinger 420SI metal detector

[Images' Source: EPFL/DeTeC]

Figure 1.2: (Top) Example of metallic debris (ruler: 25 cm long):

Figure 1.3: (Bottom) Chinese Type 72 minimum-metal AP mine (78 mm large, 38 mm high)

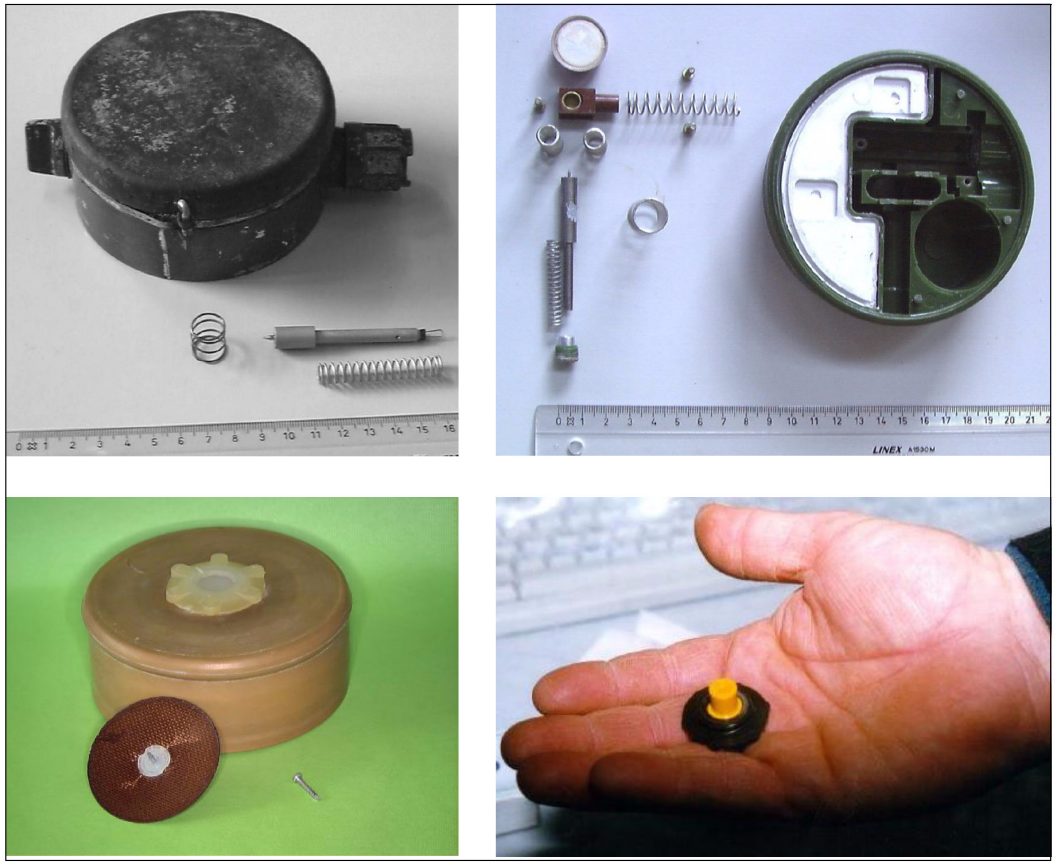
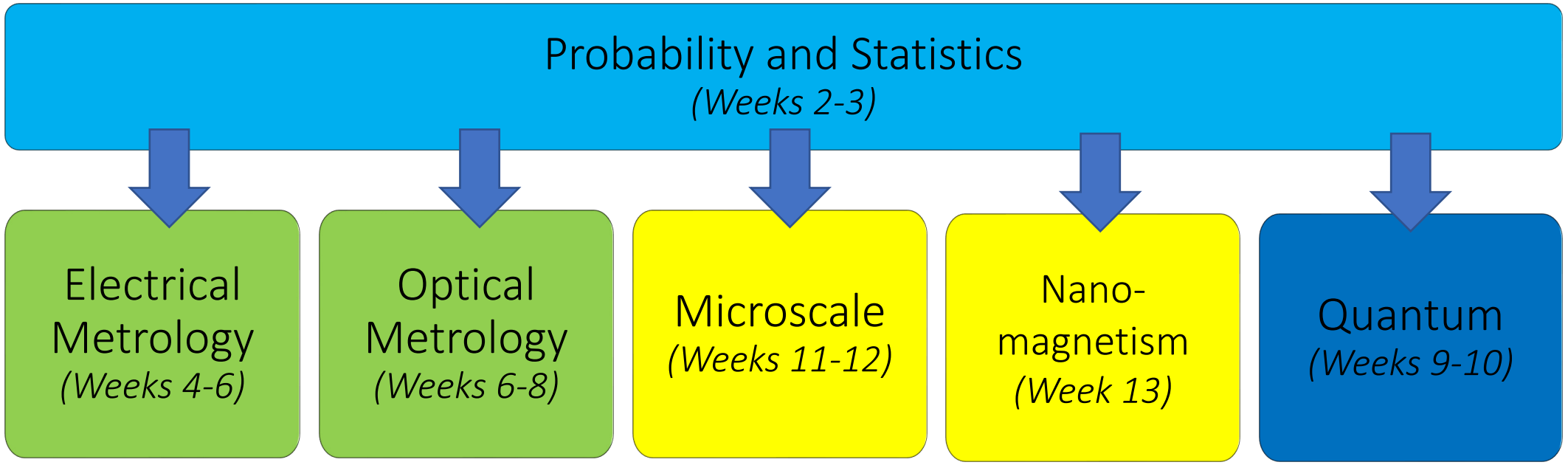


Figure 5.4: Metallic content of a Russian PMN (**`pmnCambodia`**; top left), a Russian PMN2 (top right), and an LI11 min.-metal mine (**`mich`**; bottom left), with detail of striker pin (**`mist`**) and original detonator (**`midereal`**, bottom right). (Source: EPFL/DeTeC)

Synergies: A) Metrology (MICRO-428, Spring semester)

- 2+1 h/week, 3 credits
- *The course deals with the concept of measuring in different domains, particularly in the electrical, optical, and microscale domains. The course will end with a perspective on quantum measurements, which could trigger the ultimate revolution in metrology.*
- There is an optional experimental addition: MICRO-429 (Metrology Practicals).
- Written exam at the end of the semester.

Metrology Course Structure



Metrology Course Structure

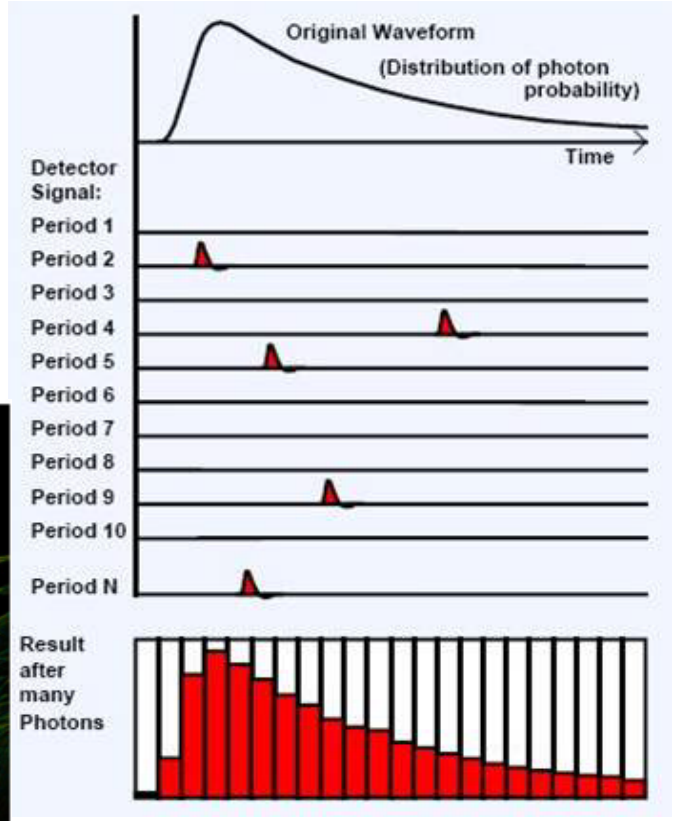
Application Examples

High Speed Binary Imaging

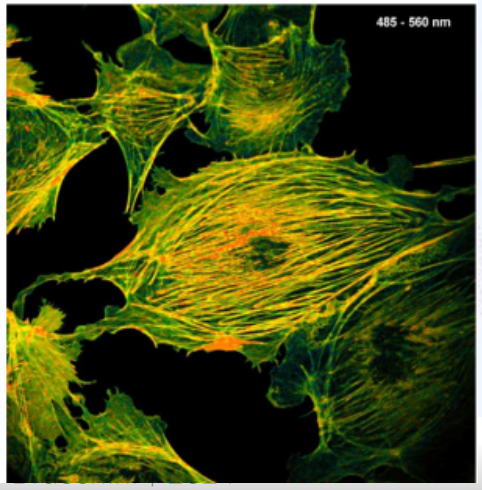
(a)

Shot noise limited!

Time-Correlated Single Photon Counting



Nanosecond Lifetimes!

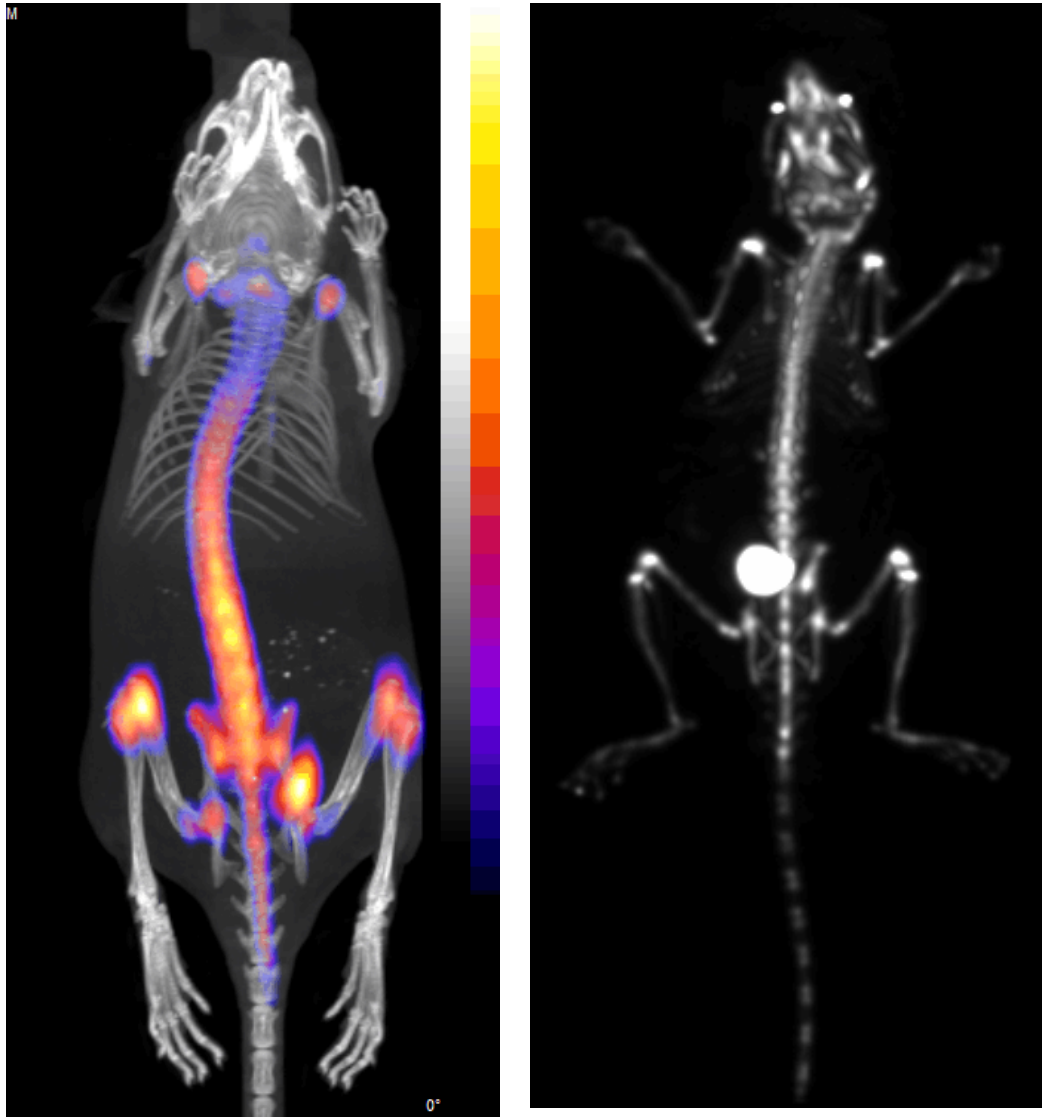


Light Detection and Ranging

cm/mm level precision!

Application Example: Positron Emission Tomography (PET)

Positron
Emission
Tomography
Reconstruction
Example



G. Nemeth, Mediso, Delft WS 2010

Synergies: B) Metrology Practicals (MICRO-429, Spring semester)

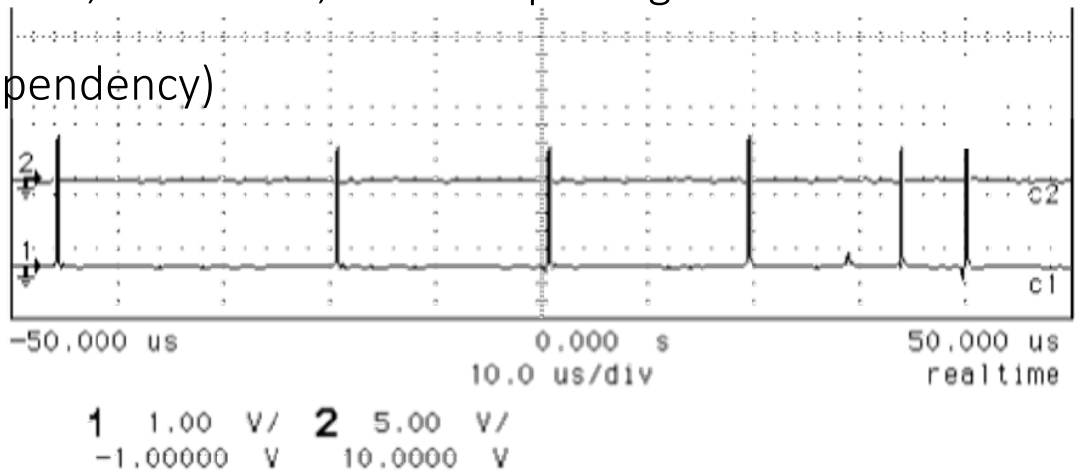
- 7 weeks @4(+)h/week, 3 credits
- This course is intended as the experimental addition to MICRO-428 (Metrology).
- The students will have a chance to practice the theoretical concepts they learnt there.
- They will also learn good practices during measurements, while designing the experiments required for specific measurements.
- The course will propose 6 experiments in time slots of 4(+) hours in the second part of the semester.
- The experiments will be graded. No additional exam is foreseen.
- “Sans retrait” (two weeks to decide)

Topics

- Quantum metrology - Claudio Bruschini & Edoardo Charbon, STI AQUA
  - ➢Single-photon experiments
  - ➢Correlated / uncorrelated noise
  - ➢Time-resolved experiments
- AFM (Atomic Force Microscopy) – Georg Fantner, STI LBNI
- SEM (Scanning Electron Microscopy) – Georg Fantner, STI LBNI

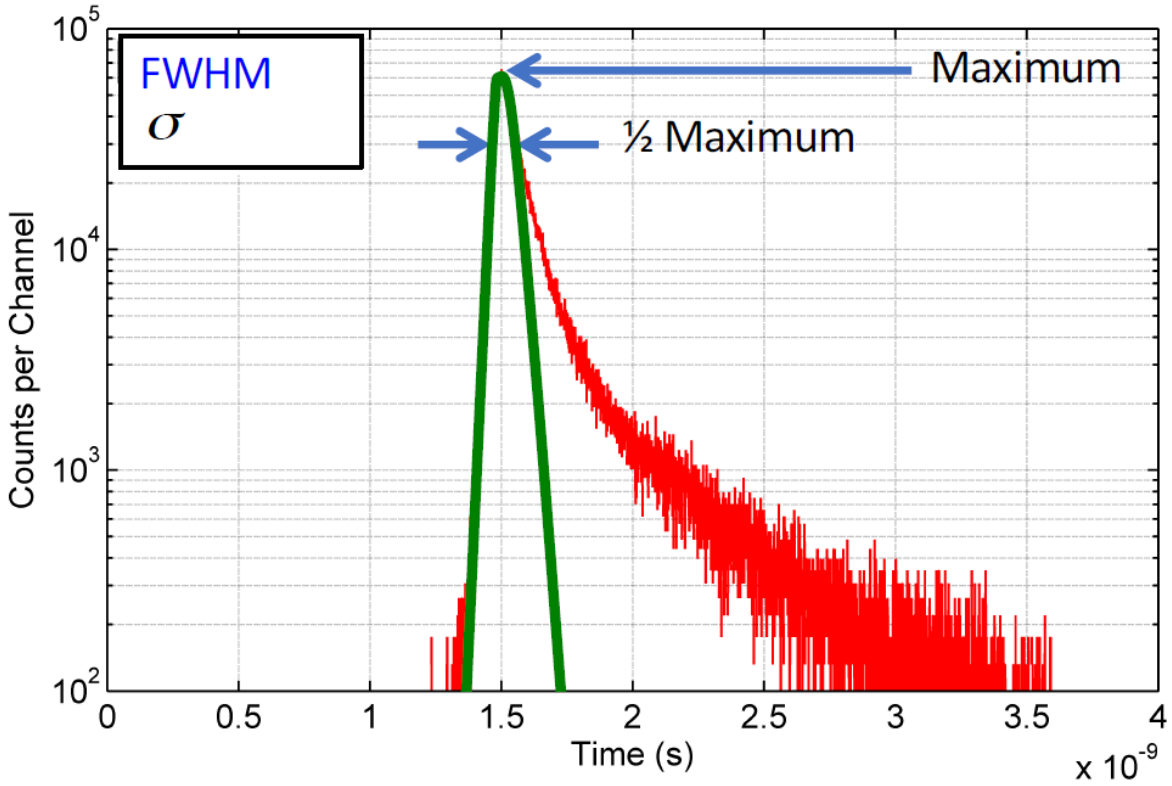
Content/1

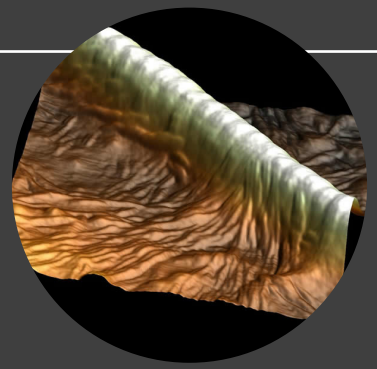
- [T1] Dark count rate (DCR) and afterpulsing statistics in photon-counting devices
  - Understanding single-photon avalanche diodes (SPADs) & photon counting
  - DCR vs. excess bias voltage
  - Inter-arrival statistics, dead time, and afterpulsing
  - (Temperature dependency)

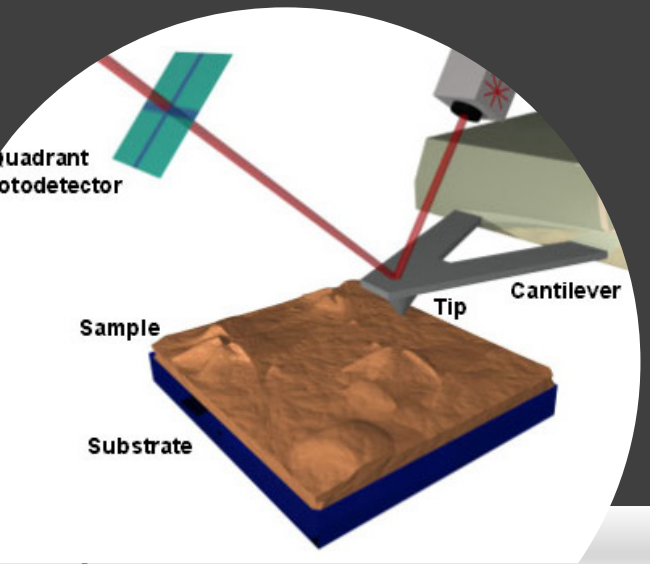


Content/3

- [T3] Timing jitter measurements in single-photon detectors
  - Time-correlated single-photon counting (TCSPC)
  - Single-photon timing resolution (SPTR)
  - Pile-up effect







AFM a Versatile Tool for Nanoscale Measurements

- Things you will learn:
  - Make surface topography images with sub nanometer resolution
  - Nanoscale imaging of E.coli.
  - Extract tendons from rat tails, image microfibrils of collagen and measure the characteristic D-banding structure of collagen fibrils
  - How to process and analyze AFM data

Electron Microscopy

- Learn how to prepare samples for SEM use (drying, conductive coating)
- Learn to operate the top-of-the-line SEM from Zeiss:
  - Focus
  - Astigmatism
  - Saturation and contrast
  - Elemental analysis (EDX spectroscopy)
- Data processing:
  - Image interpretation
  - Effect of acceleration voltage
  - resolution

Acknowledgements

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Slide preparation and first revision:

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- Victoria Chalain, EPFL MA

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- Nobukazu Teranishi, Shizuoka University