

MICRO-523: Optical Detectors

Week One: Introduction

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TAs: Samuele Bisi, Kodai Kaneyasu

The logo of the École Polytechnique Fédérale de Lausanne (EPFL), consisting of the letters 'EPFL' in a bold, red, sans-serif font.

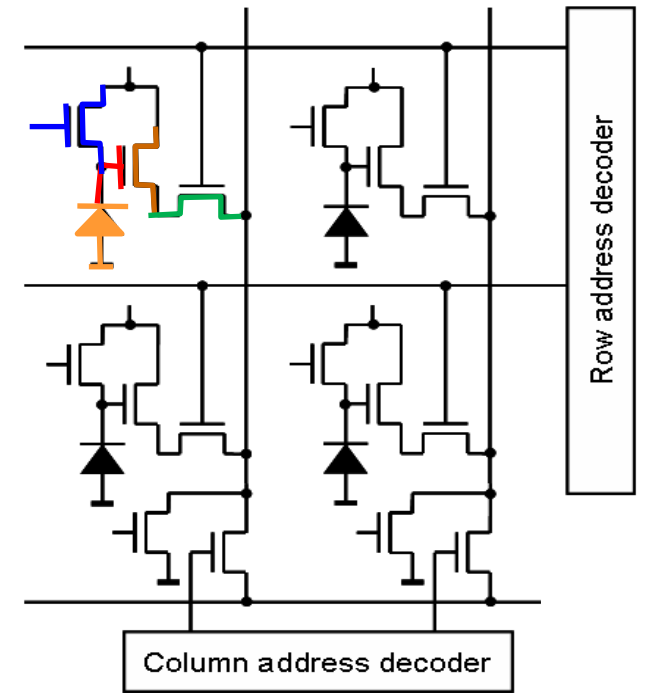
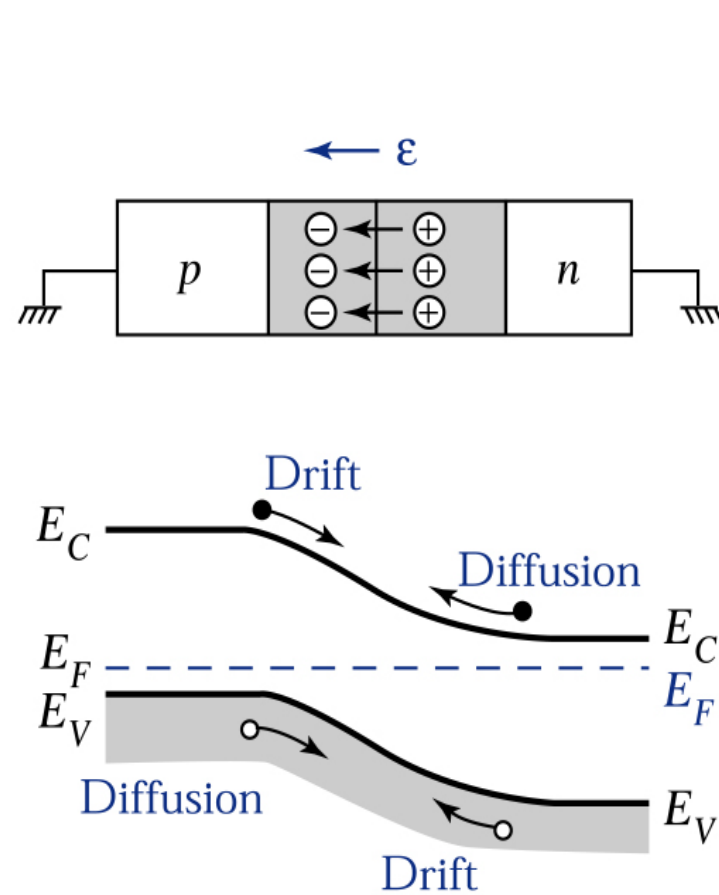
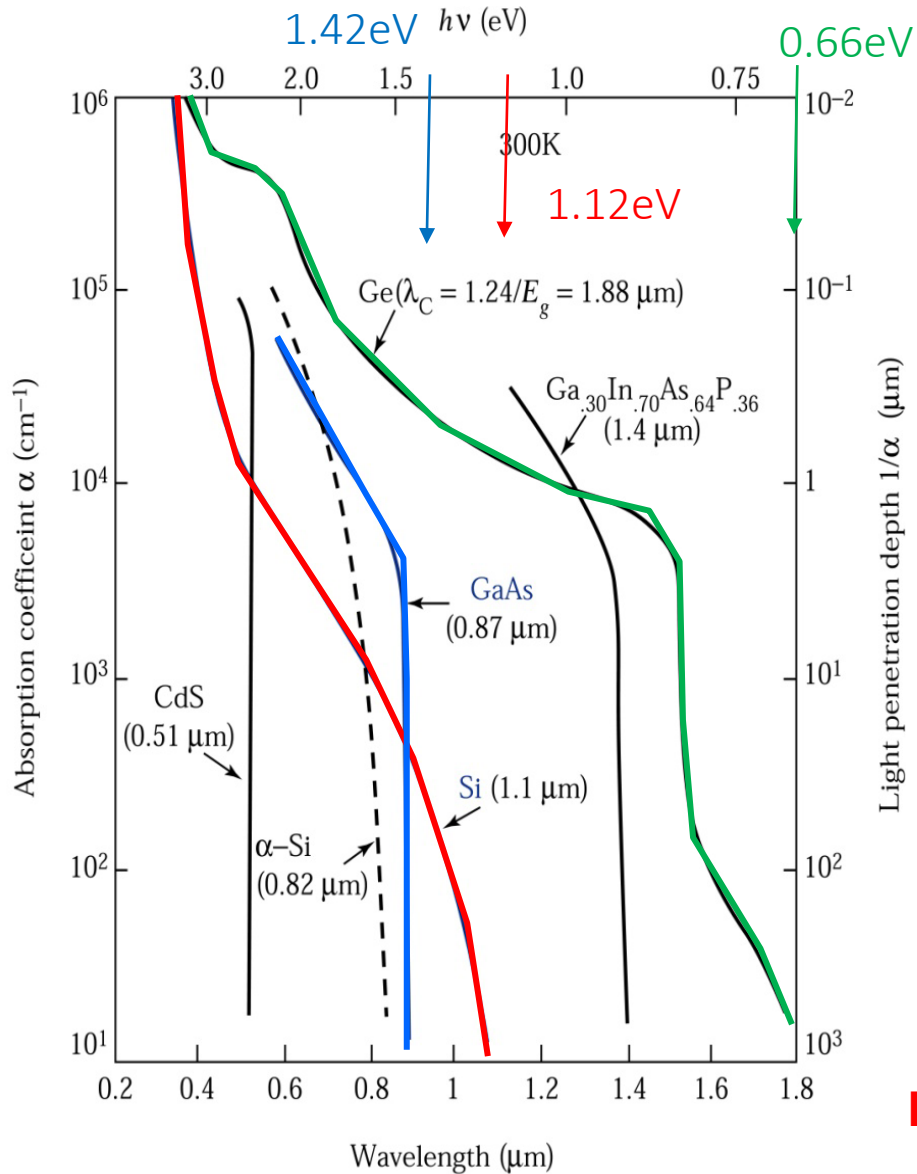
MICRO-523 Optical Detectors: course organisation

- 2+1 hours/week
- Slides and scripts as primary learning tools (Moodle)
- Exercises discussed in class during the same week
- Exam during exam session: 2 questions, 20-25' and ~same preparation time. Cheat sheet (1-2 A4 pages, recto-verso).
- Oral exam: Jan 2026
- Office hours: discussion after class or on request. TAs (Samuele and Kodai) 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

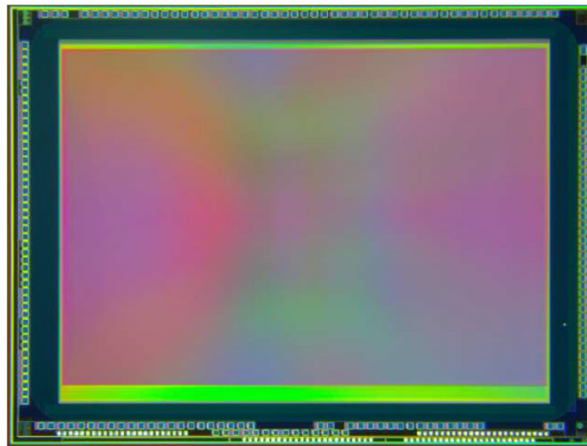
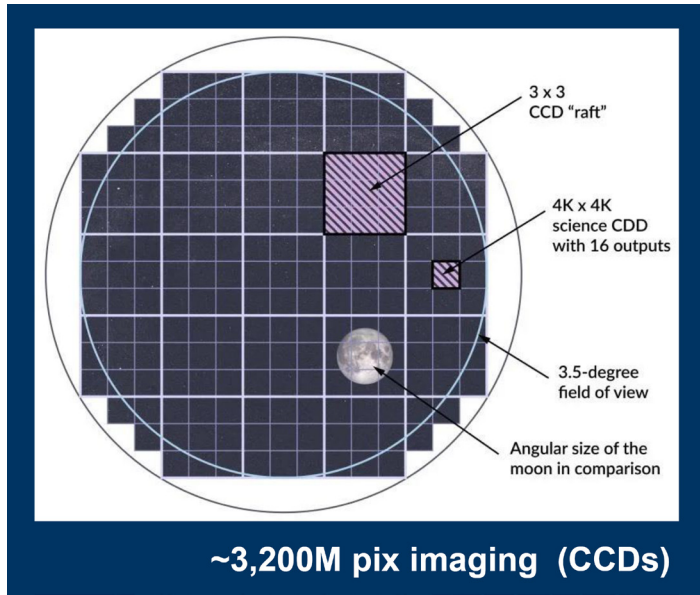


From materials to devices and circuits...

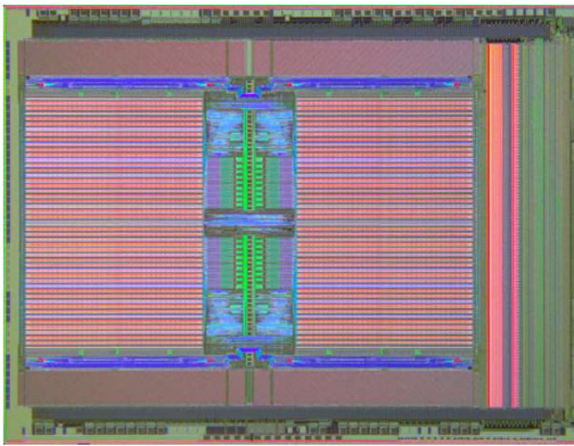
3T pixel with

- Reset
- Follower
- Row selector

MICRO-523 Contents/2 – CCD and CMOS Cameras



Pixel array



DRAM + row drivers

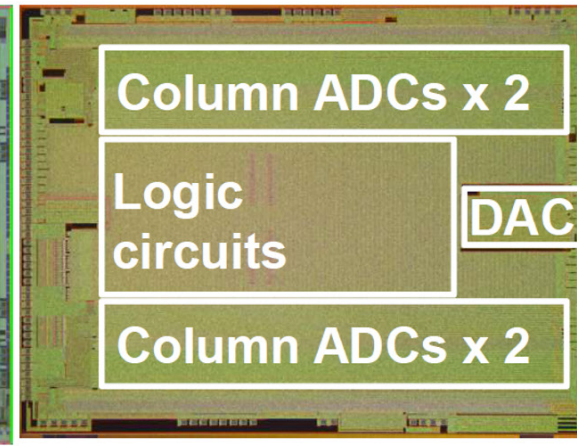
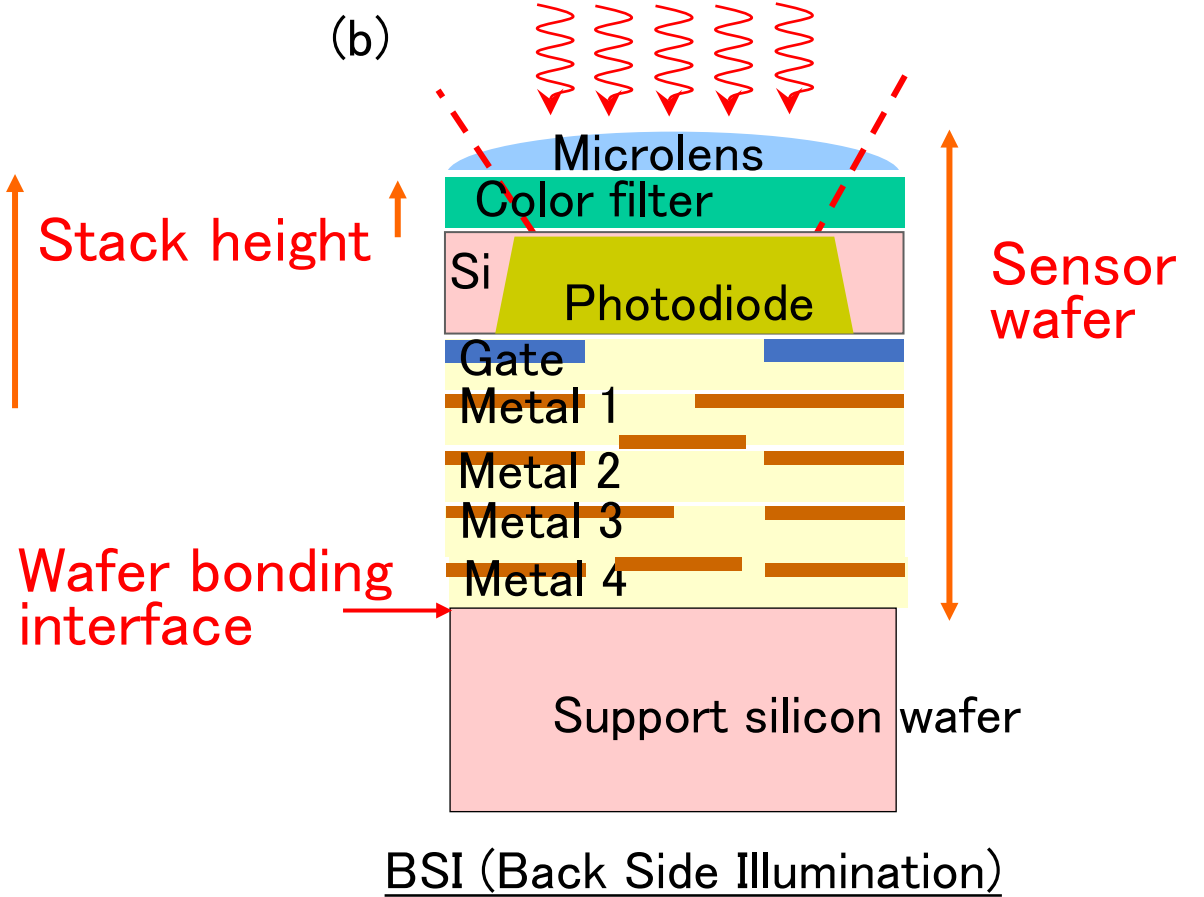
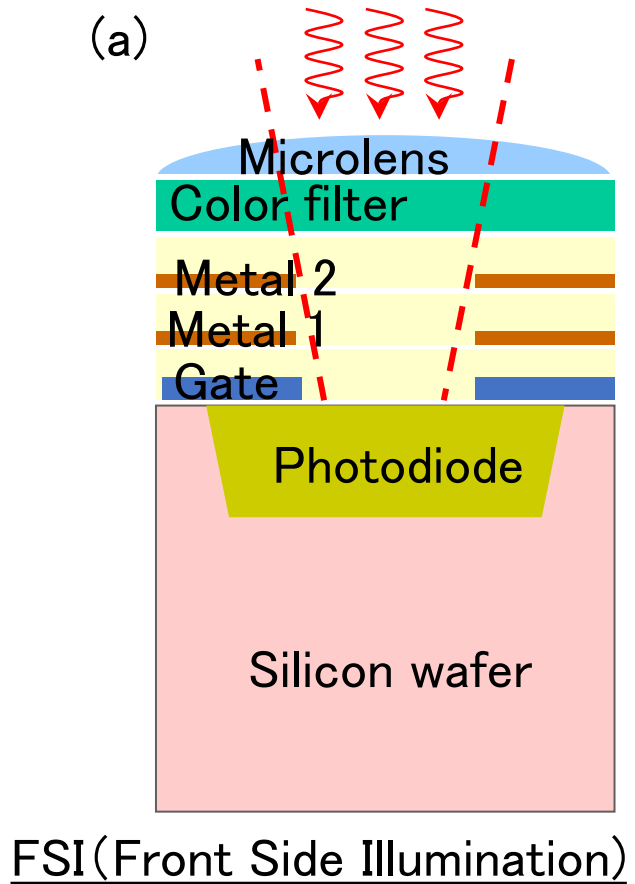
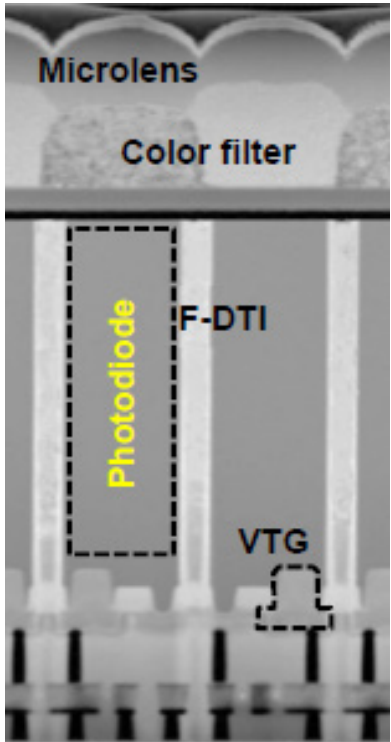


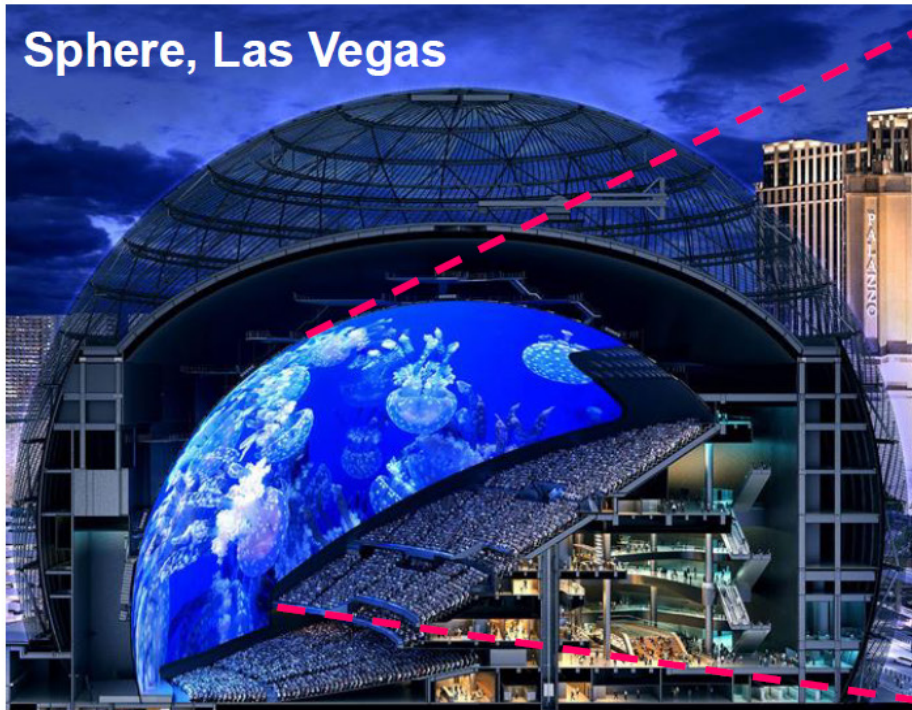
Image processor

Source: Sony/ISSCC

MICRO-523 Contents/3 - Technology



MICRO-523: Application example - Immersive Display



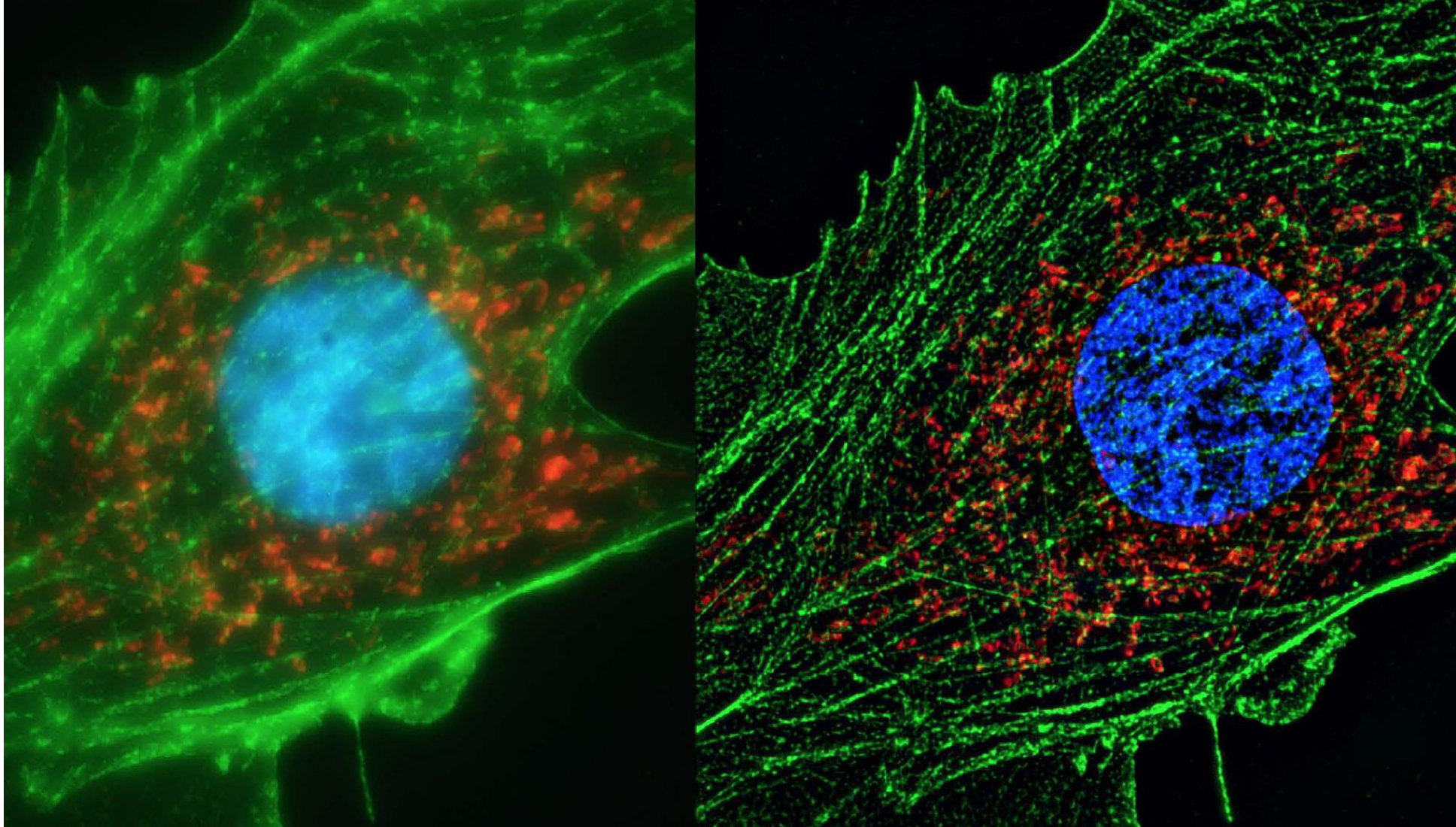
16K immersive display



Requirements for CMOS Image Sensor

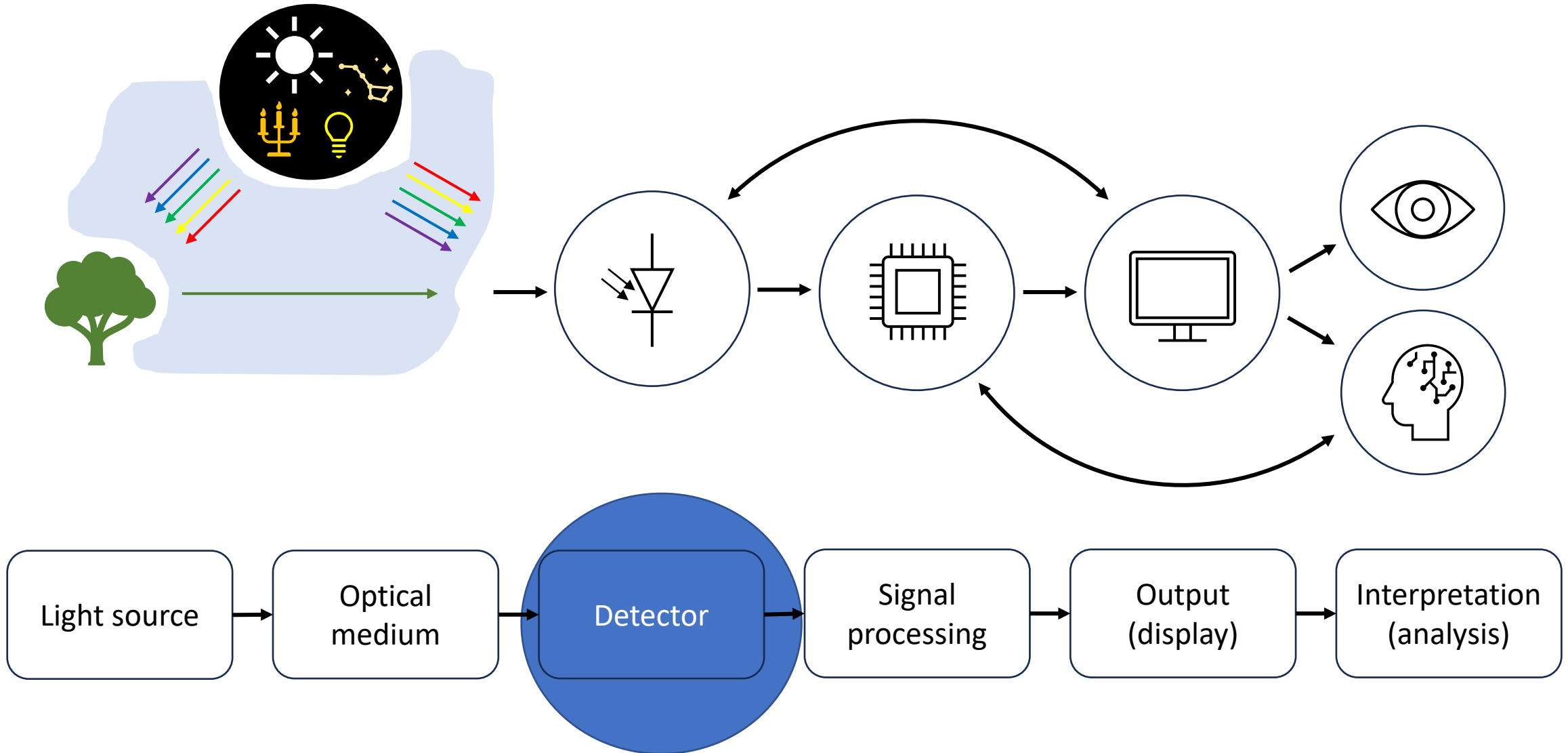
- Large size and high resolution
 - 16K resolution interior LED screen spanning 160,000 sq ft.
- Great image quality
- Low noise
- HDR
- Minimal motion artifacts

MICRO-523 Application Example - Optical superresolution techniques



G. Fantner, MICRO-428 Week 6

MICRO-523 Optical Detectors – the full picture



The Minor in **Imaging**

Open to all EPFL students

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

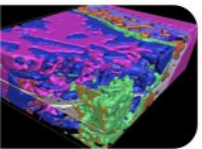
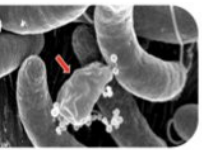
Requirements

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

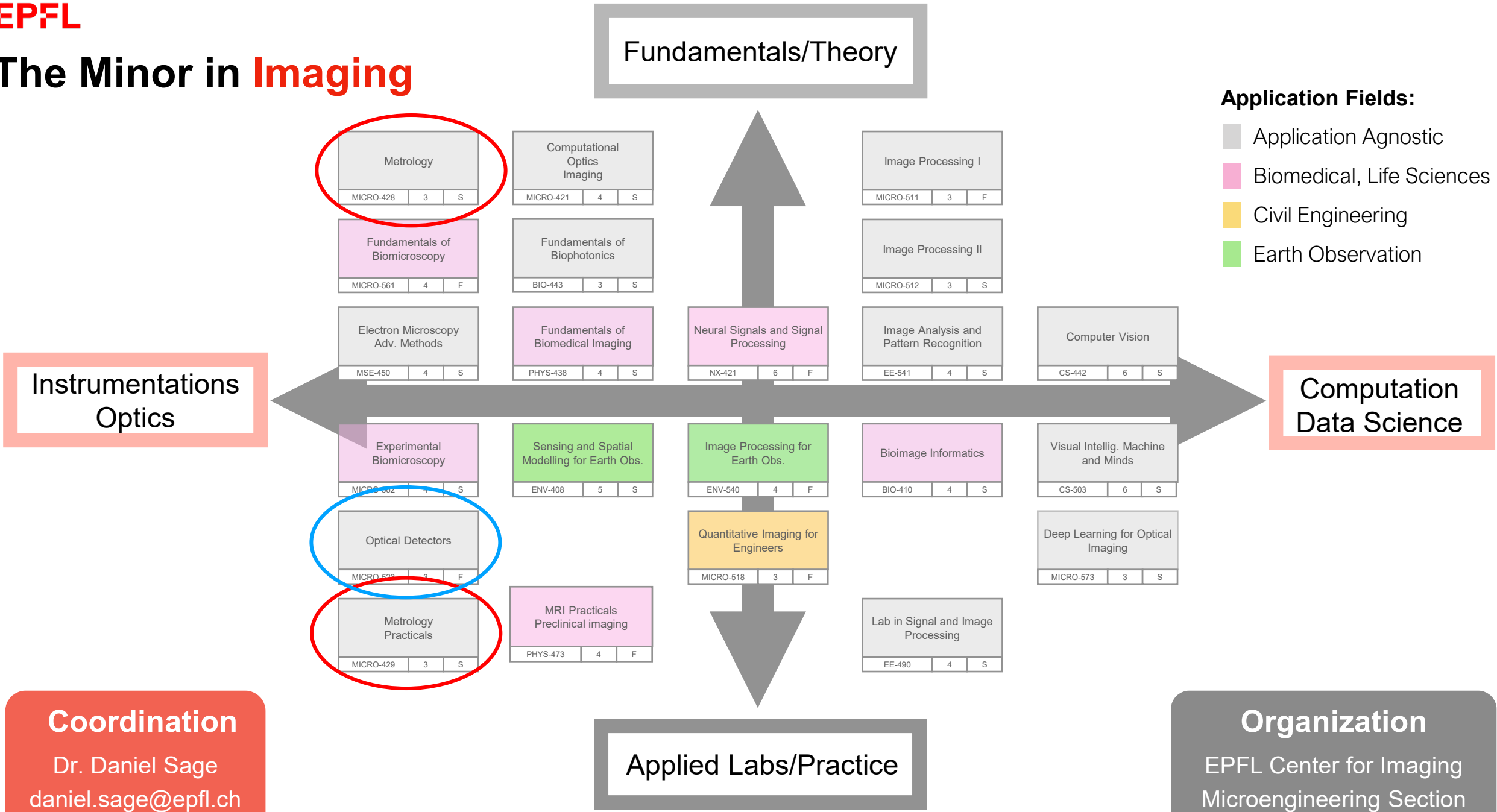
Minor (30 ECTS):

- ▶ 22 ECTS of courses
- ▶ 8 ECTS for a project

Broaden your career horizon



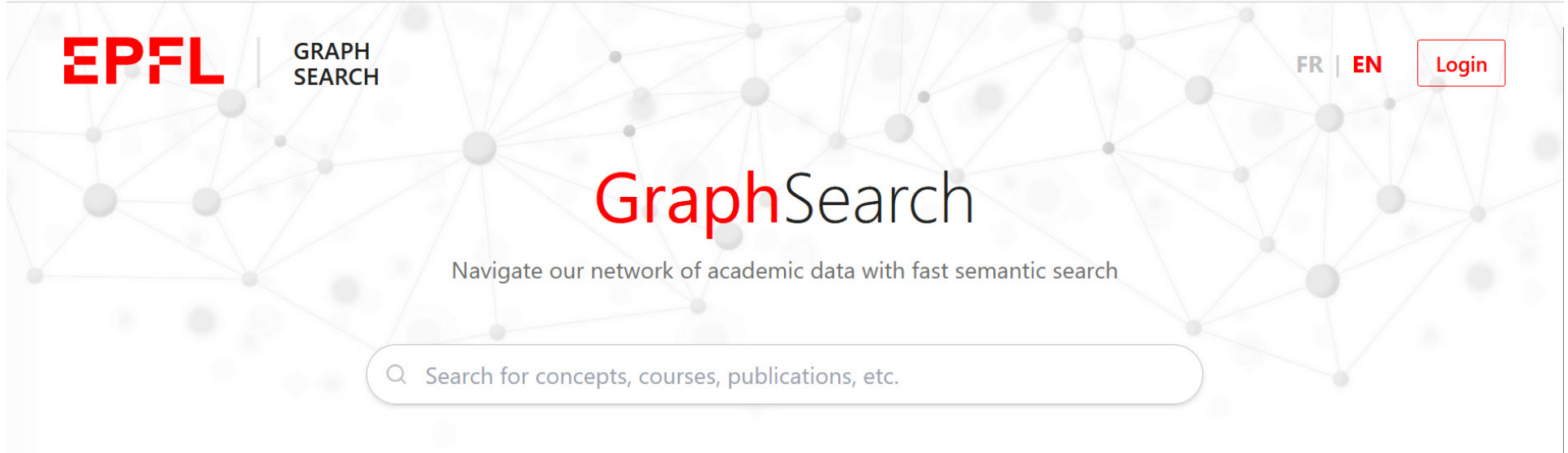
The Minor in Imaging



Coordination
Dr. Daniel Sage
daniel.sage@epfl.ch

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".



Example Searches

Concepts and categories

[Partial differential equation](#), [Chemical synapse](#), [Artificial intelligence](#)

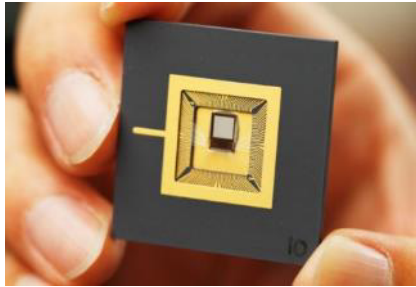
Courses and Lectures

[Solid state physics IV](#), [MATH-205](#), [Forward genetics \(BIO-205\)](#)

People and Units

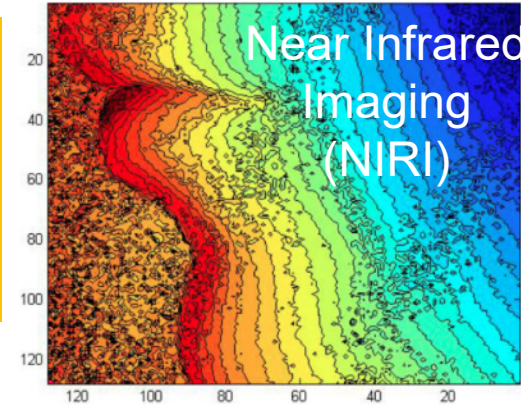
[Raffaella Buonsanti](#), [LCAV](#), [Photonics and Interfaces Laboratory](#)

Background – AQUALab Single-Photon Imaging Applications

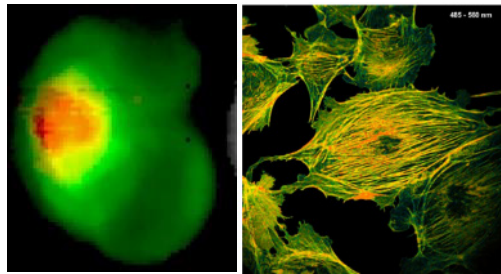


Quantum Security

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



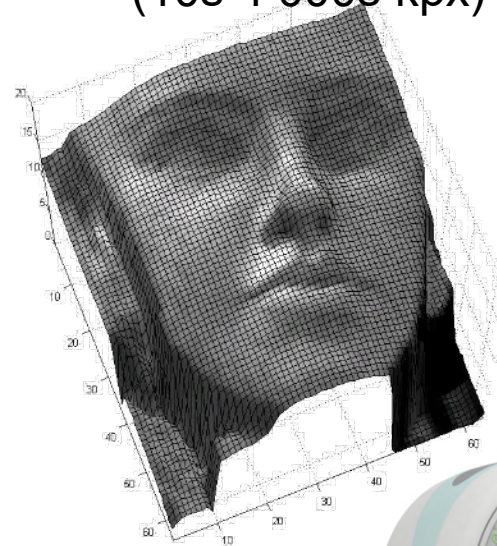
Near Infrared Imaging (NIRI)



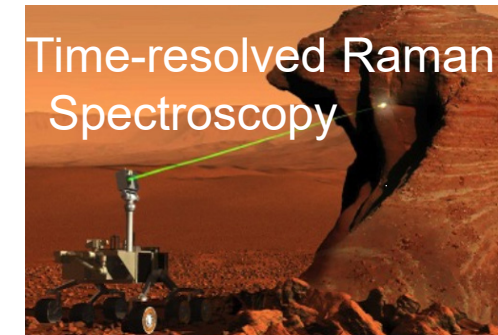
Fluorescence Lifetime Imaging Microscopy (FLIM) and super-resolution microscopy (STED, STORM, GDPIM, PALM, ...)



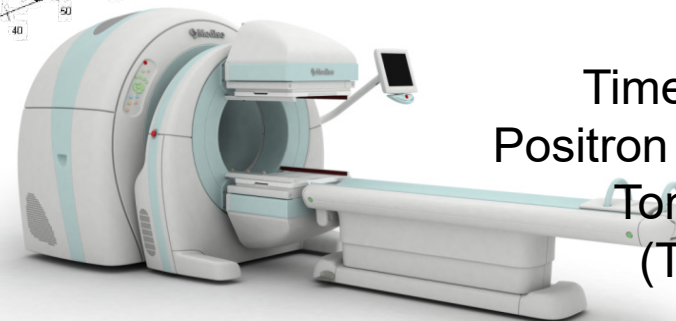
Super-resolution Microscopy



3D Vision



Time-resolved Raman Spectroscopy



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)

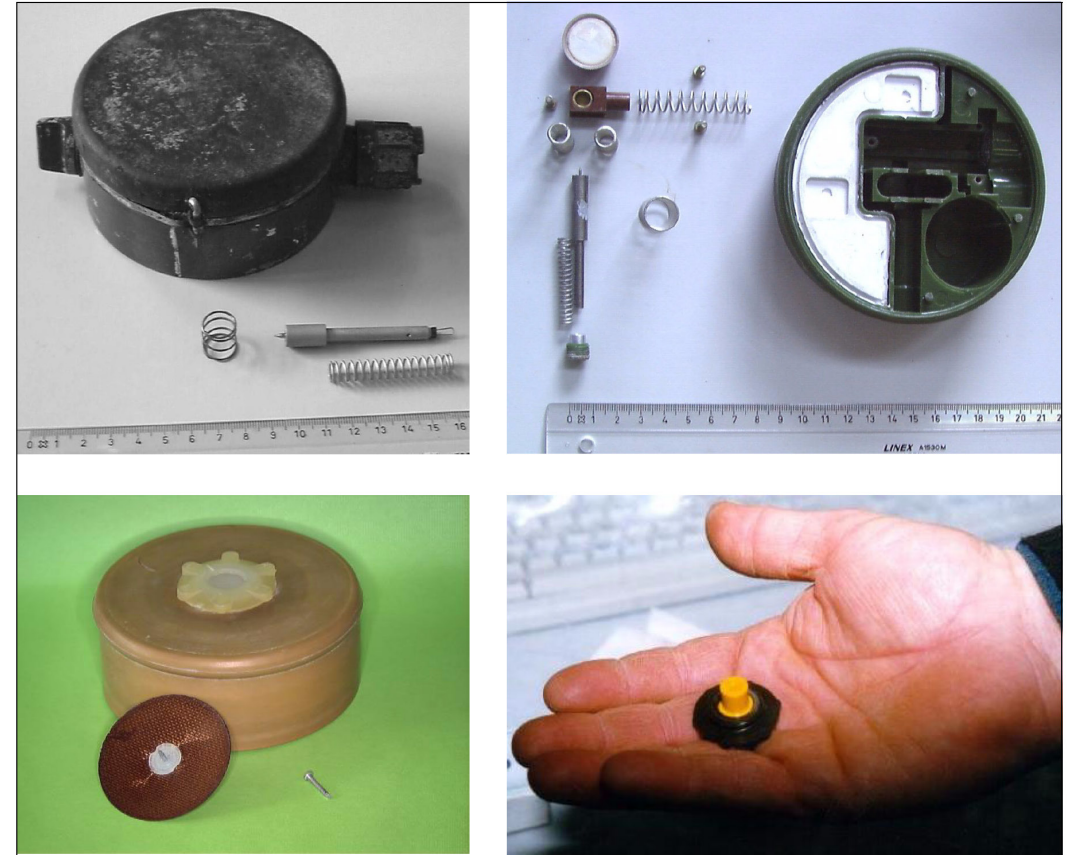
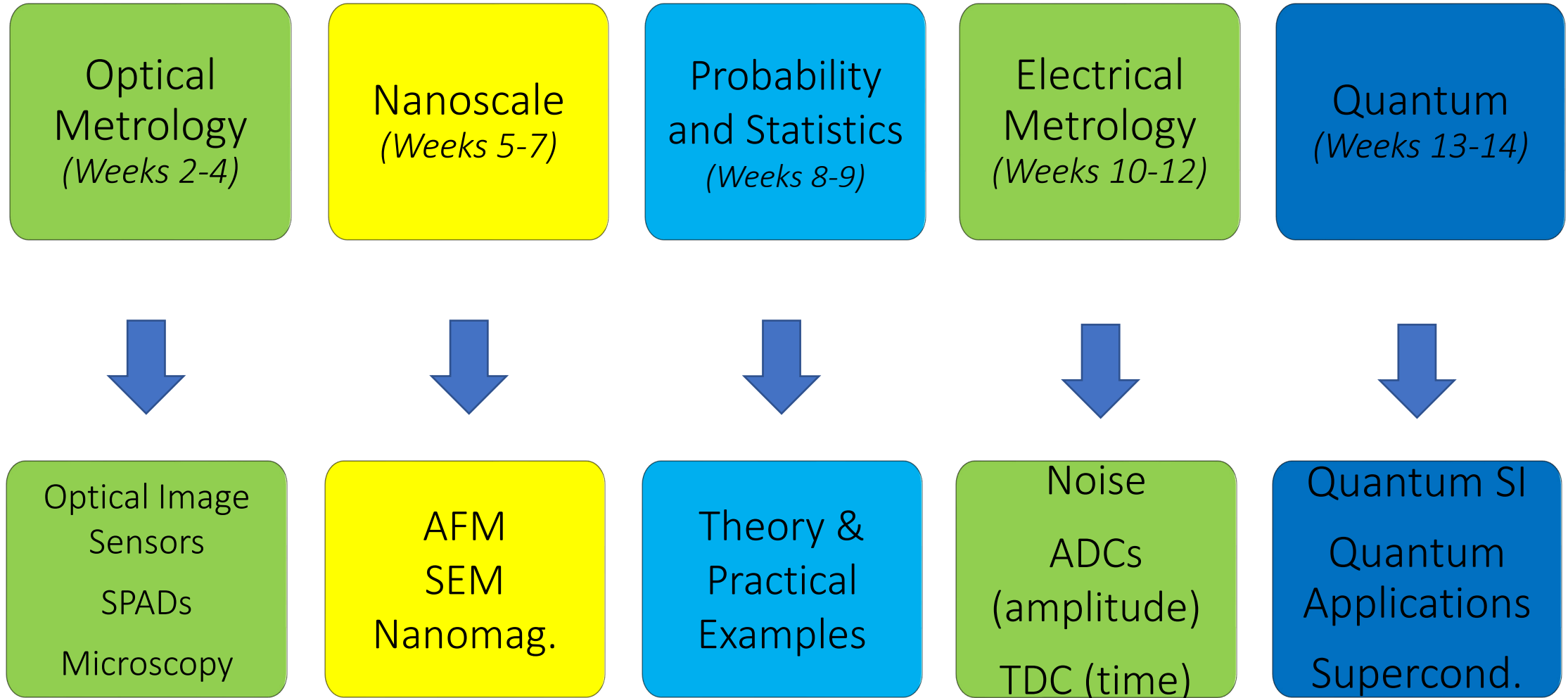


Figure 5.4: Metallic content of a Russian PMN (**pmmCambodia**; top left), a Russian PMN2 (top right), and an L111 min.-metal mine (**mich**; bottom left), with detail of striker pin (**mist**) and original detonator (**midereal**, bottom right). (Source: EPFL/DeTeC)

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

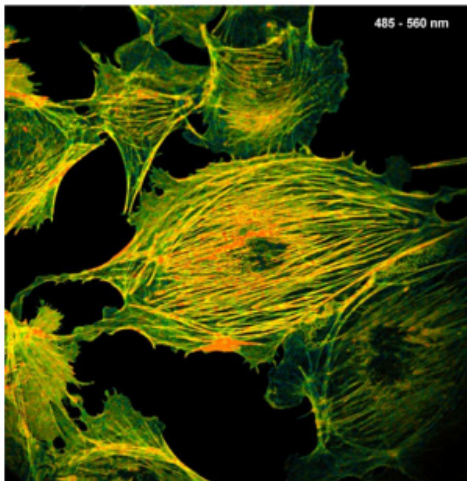
Application Examples

High Speed Binary Imaging

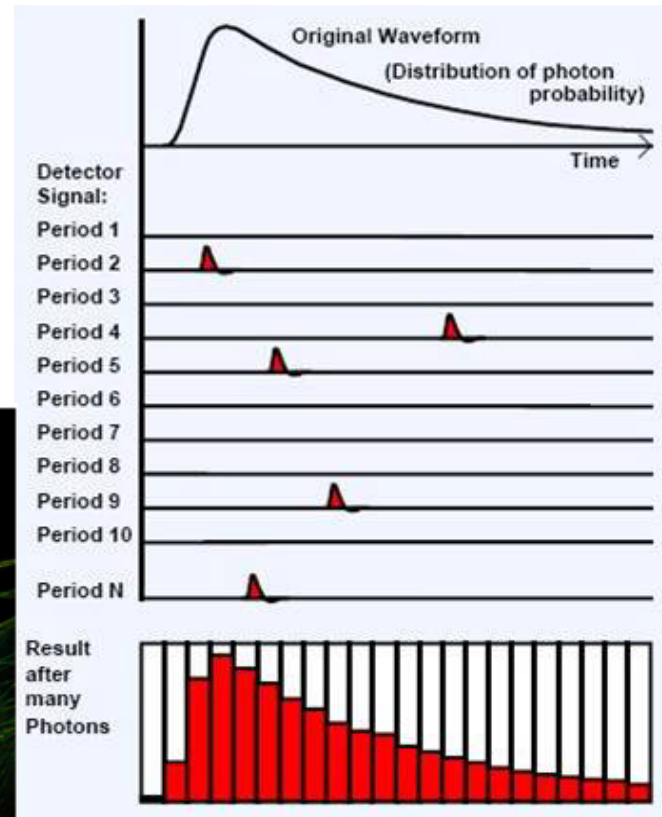


(a)
Shot noise limited!

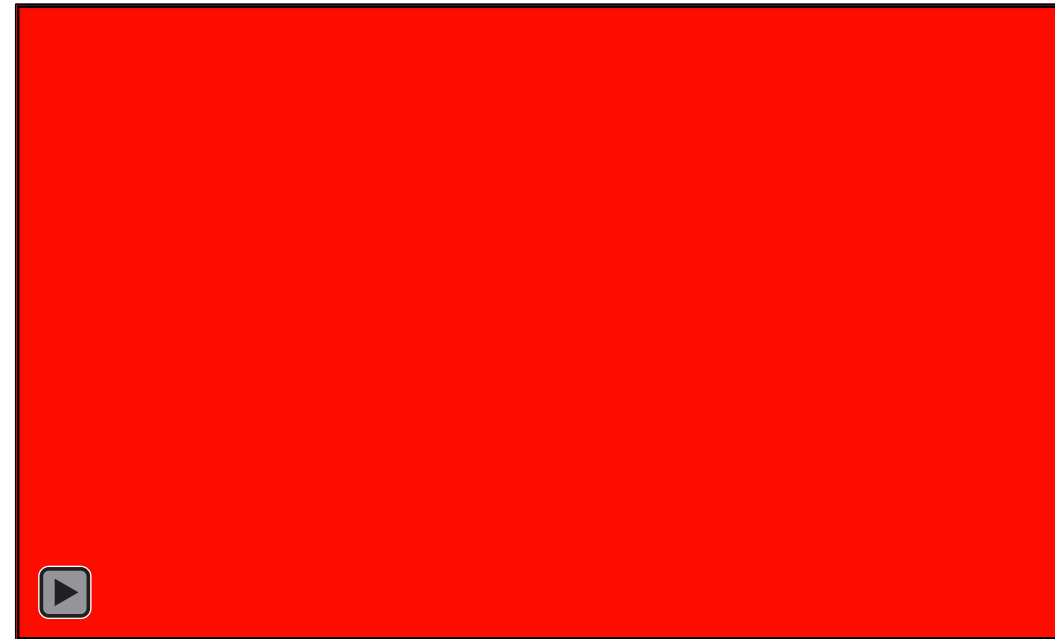
Nanosecond Lifetimes!



Time-Correlated Single Photon Counting



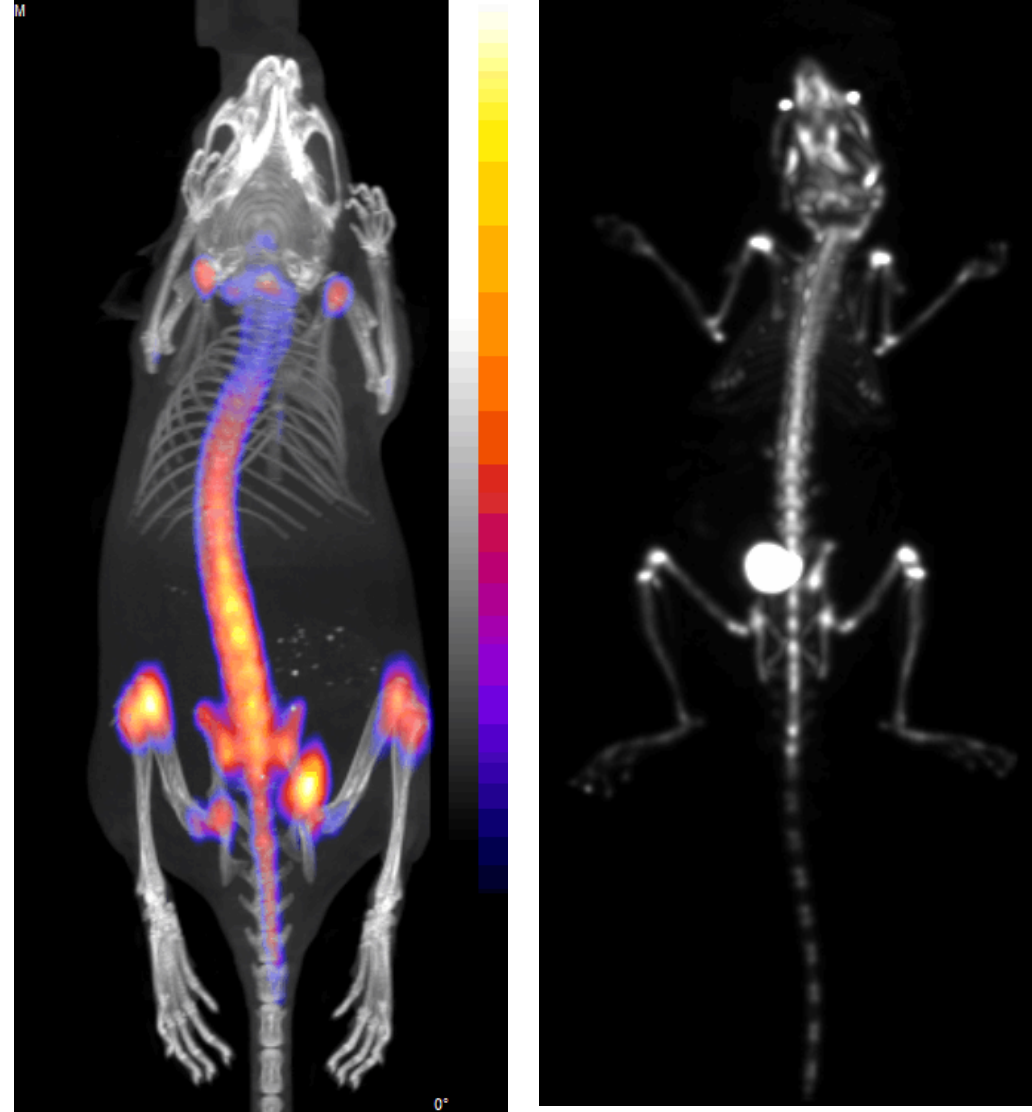
Light Detection and Ranging



cm/mm level precision!

Application Example: Positron Emission Tomography (PET)

Positron Emission Tomography Reconstruction Example



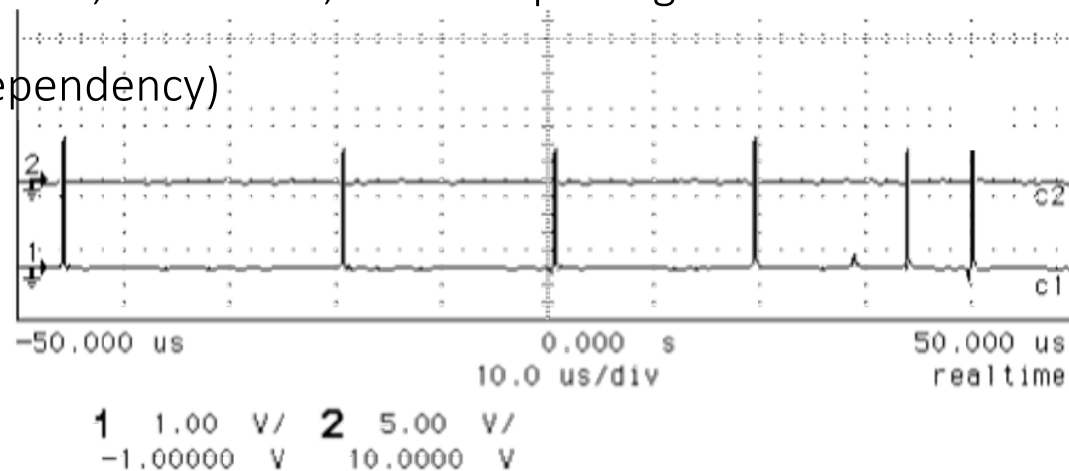
Synergies: B) Metrology Practicals (MICRO-429, Spring semester)

- 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)

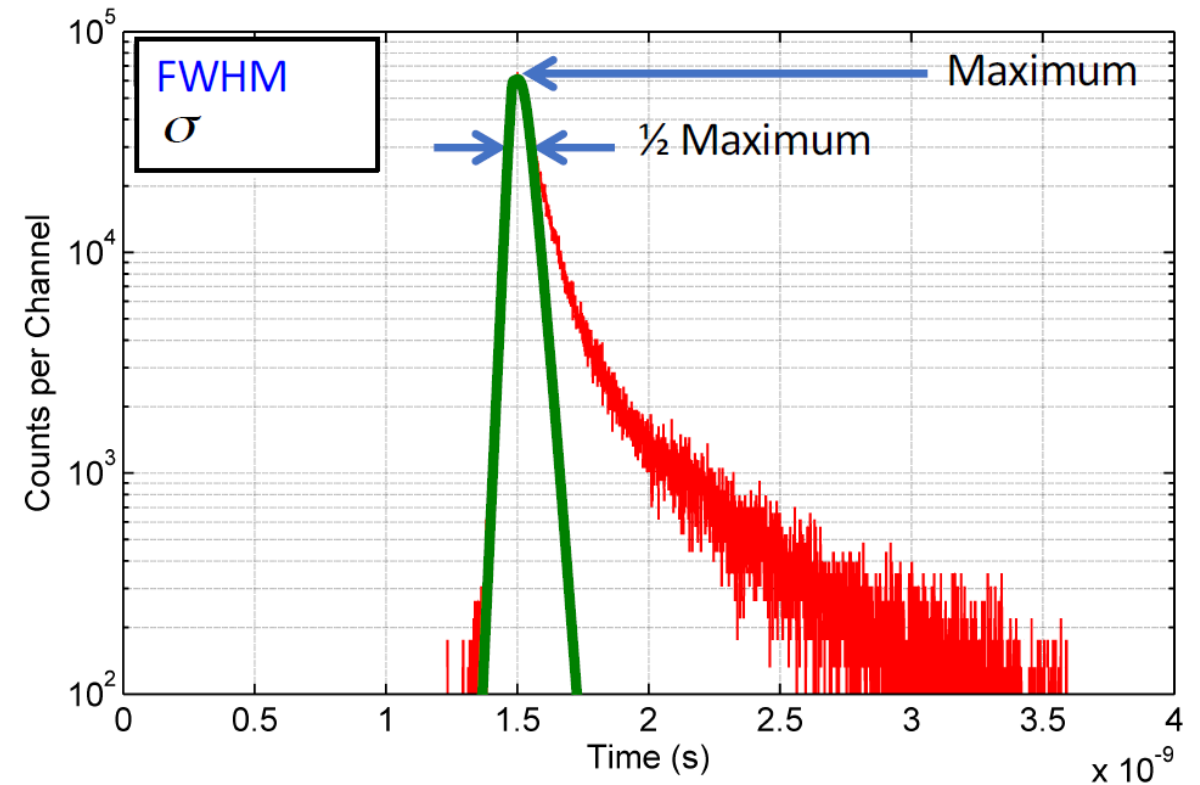
- Quantum metrology - Claudio Bruschini & Edoardo Charbon, STI AQUA
 - Single-photon experiments
 - Correlated / uncorrelated noise
 - Time-resolved experiments
- AFM (Atomic Force Microscopy) – Georg Fantner, STI LBNI
- SEM (Scanning Electron Microscopy) – Georg Fantner, STI LBNI

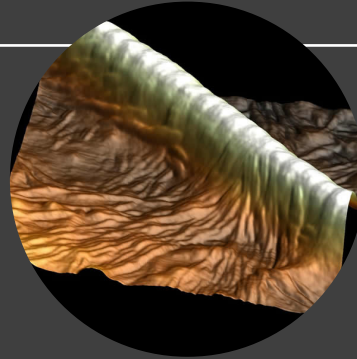
- [T1] Dark count rate (DCR) and afterpulsing statistics in photon-counting devices

- Understanding single-photon avalanche diodes (SPADs) & photon counting
- DCR vs. excess bias voltage
- Inter-arrival statistics, dead time, and afterpulsing
- (Temperature dependency)



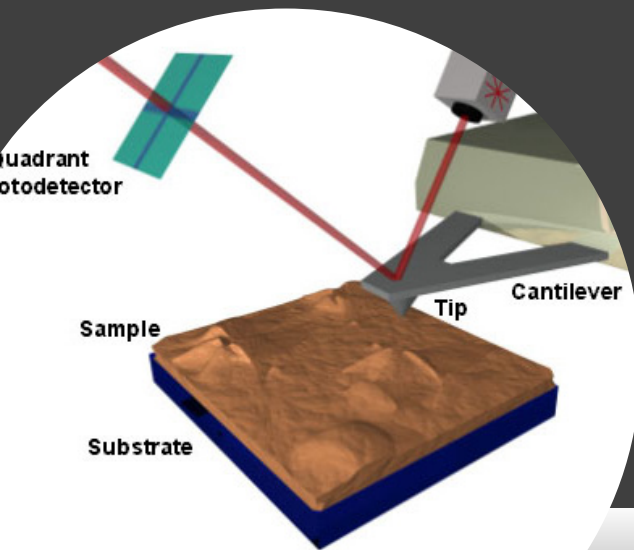
- [T3] Timing jitter measurements in single-photon detectors
 - Time-correlated single-photon counting (TCSPC)
 - Single-photon timing resolution (SPTR)
 - Pile-up effect





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

Previous course version: P.-A. Besse, 2023

Slide preparation and first revision:

- Edwin Bertschy, EPFL MA
- Victoria Chalain, EPFL MA

Additional slide material:

- Abhinav Agarwal, Forza Silicon (AMETEK Inc)
- Nobukazu Teranishi, Shizuoka University