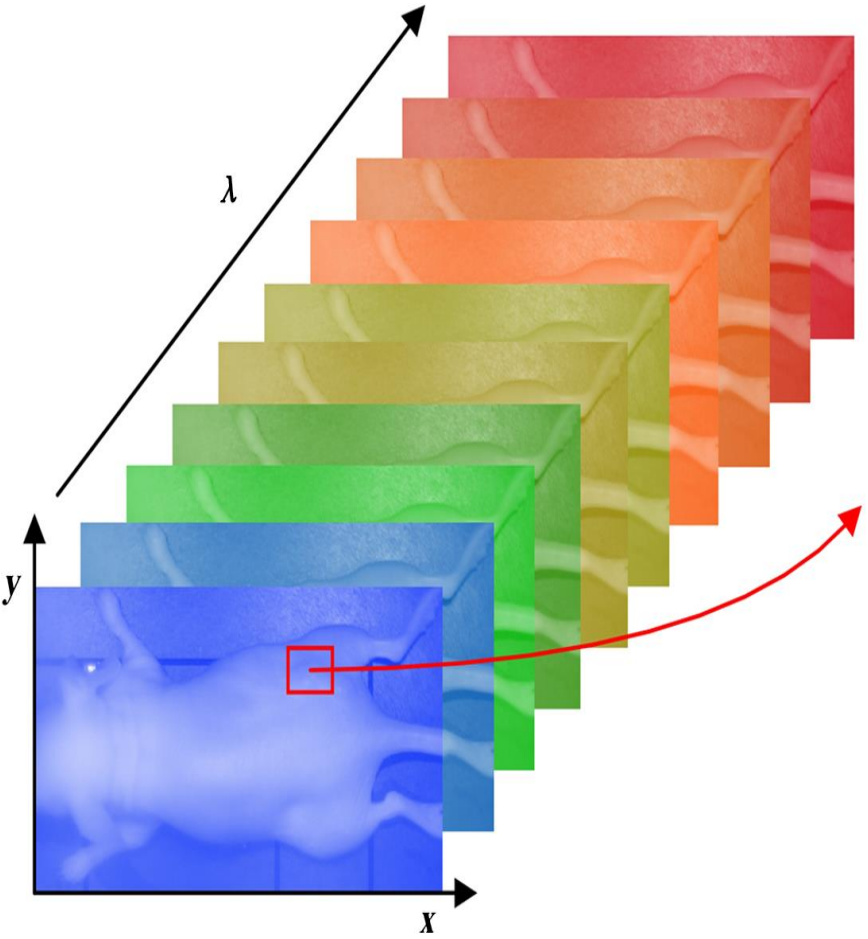
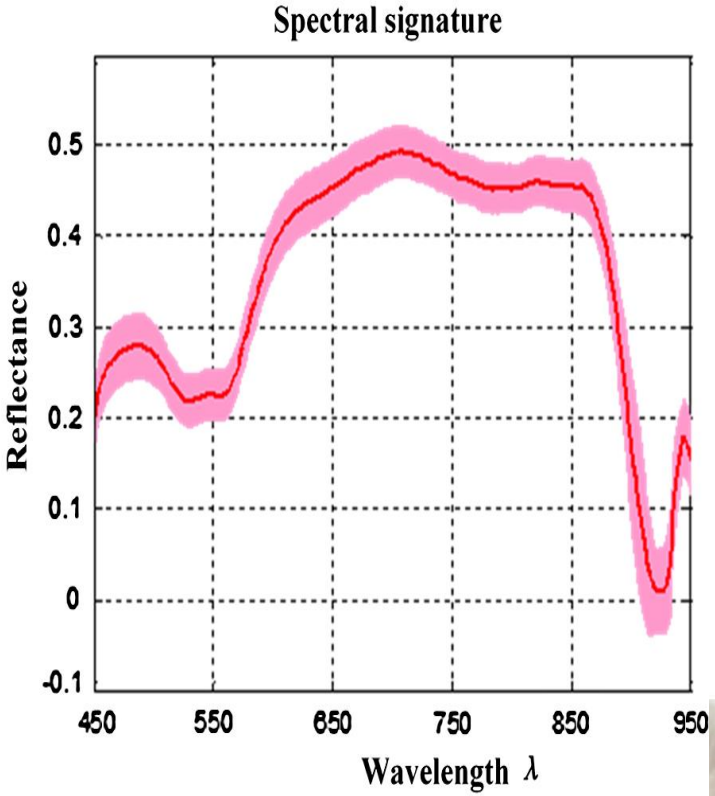
FAFF20:
Multispectral Imaging

From astronomy to microscopy

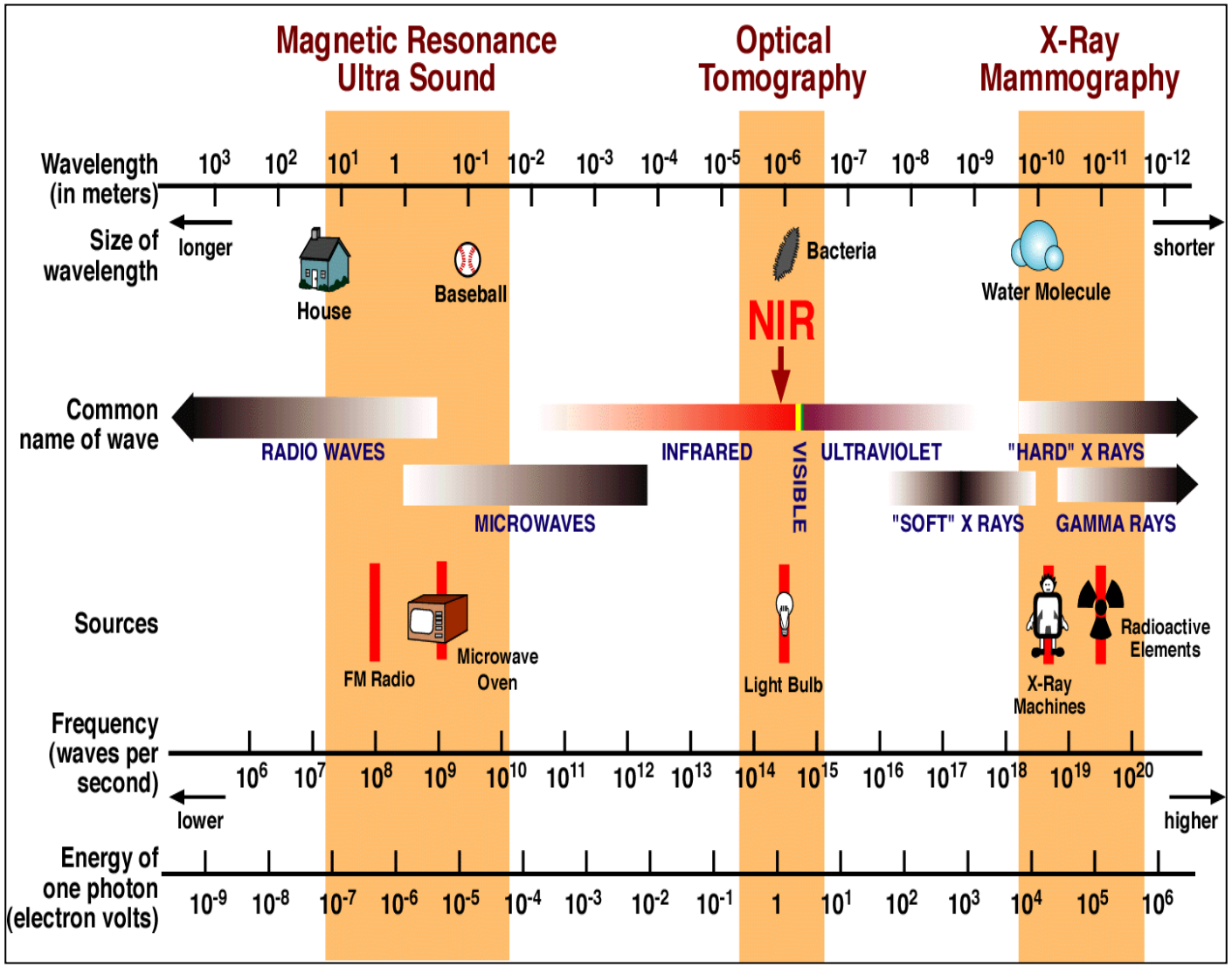
Multispectral = many spectral bands



”Each pixel contains a spectrum”



Spectral bands from the electromagnetic spectrum

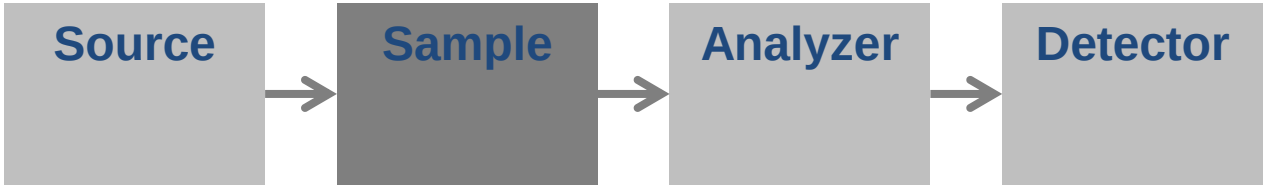


Aim

The aim of the course is to **provide theoretical and practical knowledge** on the **generation** of and **information extraction** from multi-spectral **images in different wavelength regions** and on **different spatial scales**.

Basic knowledge on **image processing** should be attained.

Basic arrangement for Multispectral imaging



Source	Sample	Analyzer	Detector
Sun	Plants	Filters	Photodiodes
Lamps	Forests	Spectrometers	Photomultiplier tubes
Lasers	Tissue	Monochromators	CCD cameras
LEDs	Cells		CMOS cameras
Synchrotron	Flames		Image intensifiers
X-ray tube	Chemical compounds		
	etc.		
	etc.		

Introductory lectures

Spectroscopic techniques, Stefan Kröll

Molecules, Joakim Bood

Spectroscopic equipment, Sune Svanberg

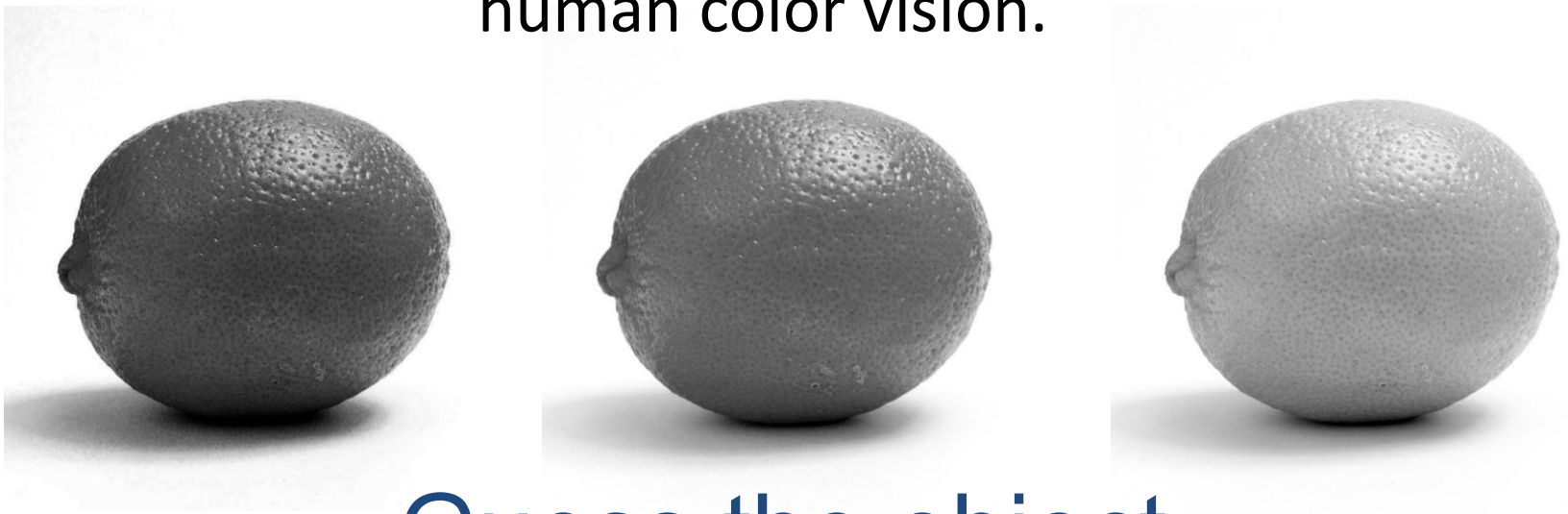
Data acquisition, Sune Svanberg

Multispectral Imaging

Multivariate analysis

Multispectral Imaging

What is optical spectroscopy? What is it good for? Let us start with our imbedded multispectral imager – the human color vision.



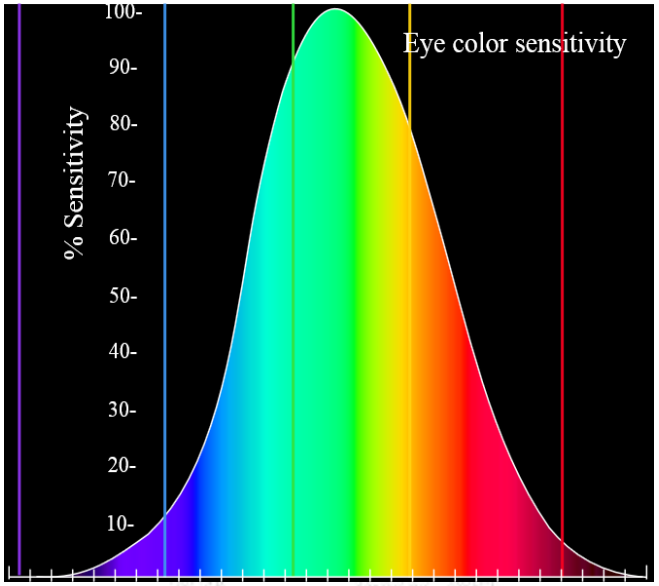
Guess the object…

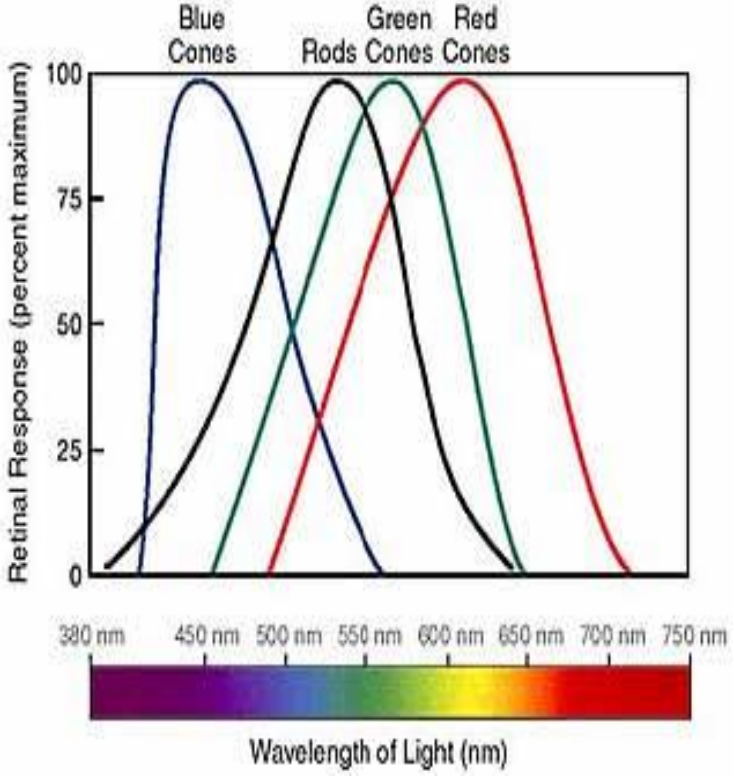
With colors we can retrieve information regarding chemical composition and classify our surroundings.

Detection of objects and contrast against natural background

Detection of objects and contrast against natural background

Detection of objects and contrast against natural background





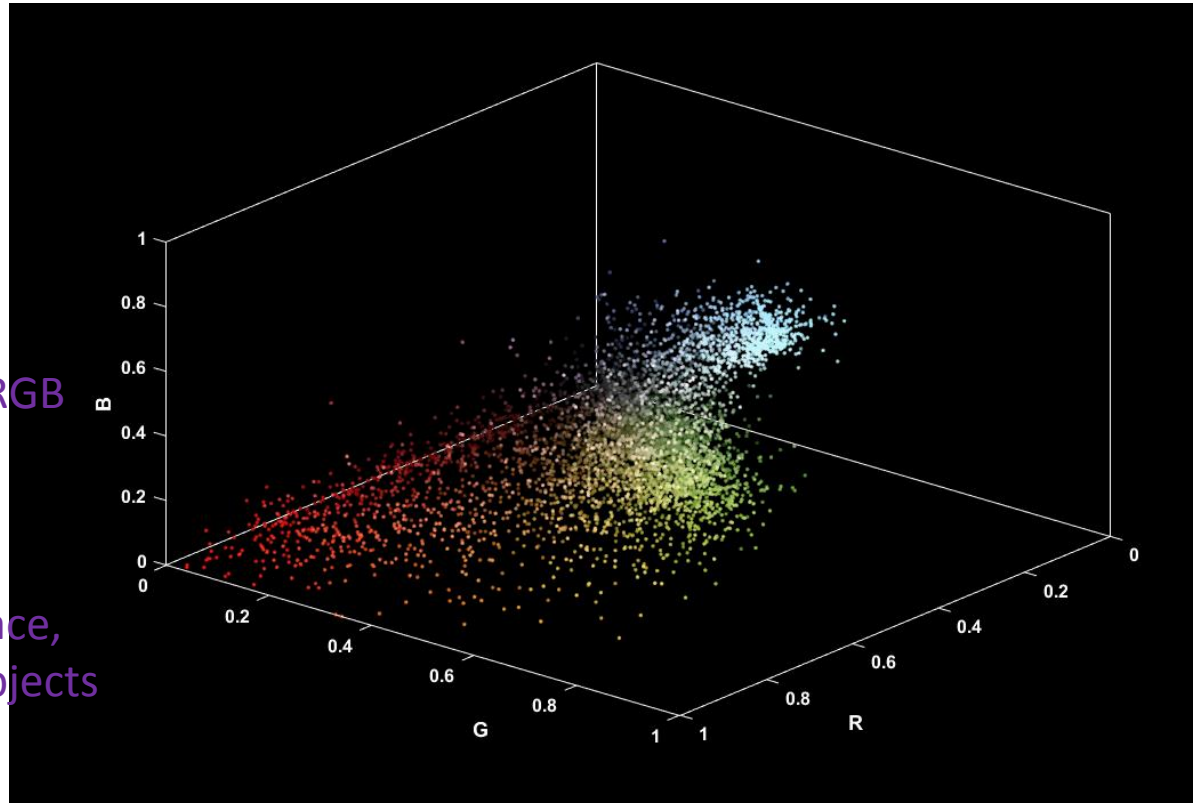
Lab

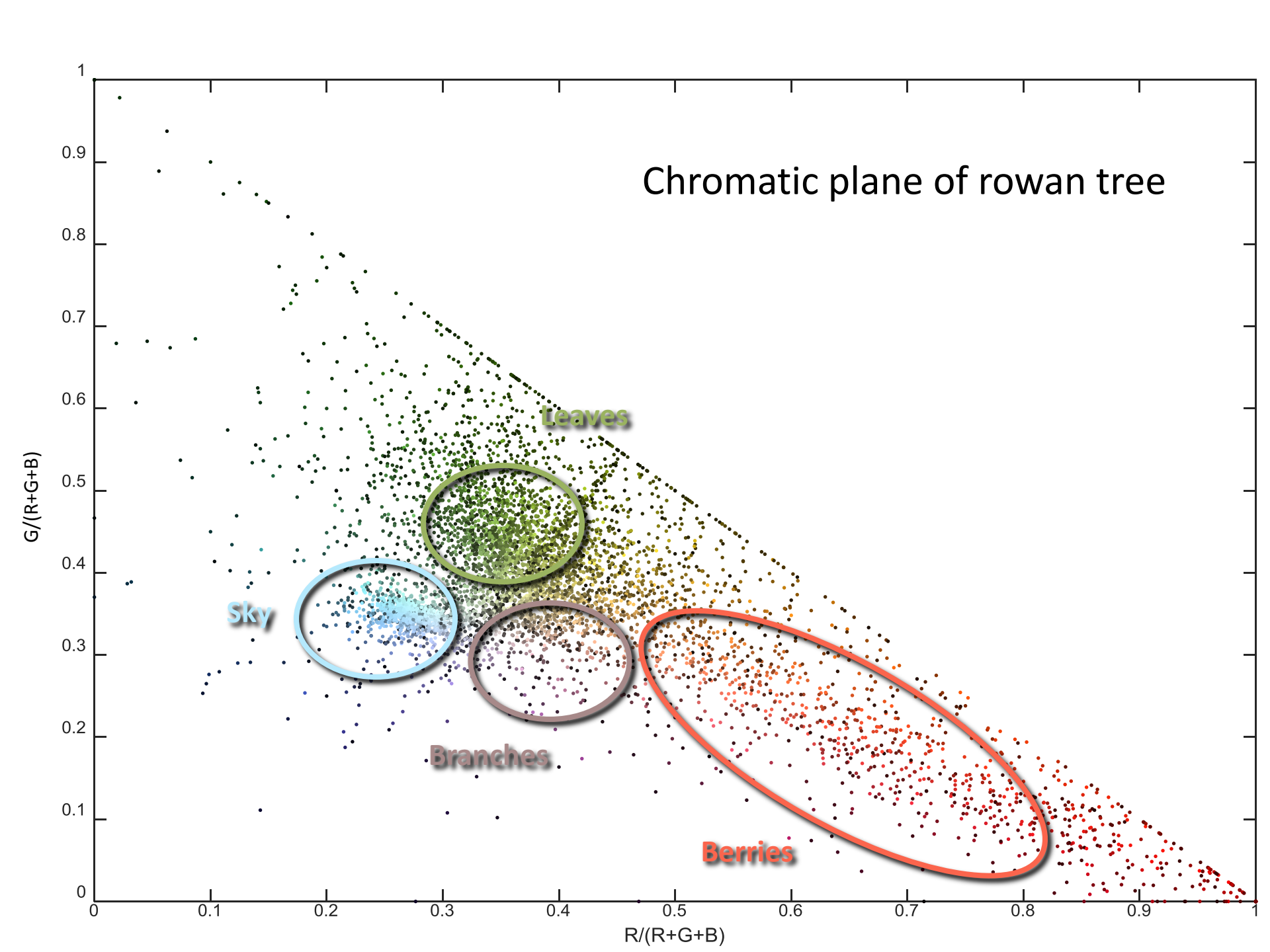
Digital Visible & infrared imaging

Detection of objects and contrast against natural background

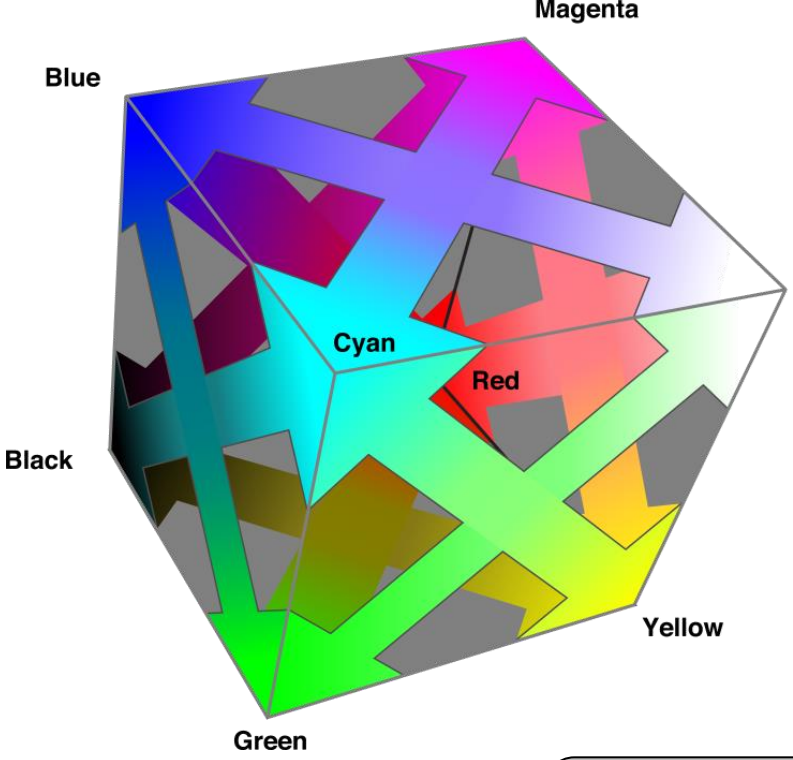
The RGB color space – a 3D case for trichromatic vision

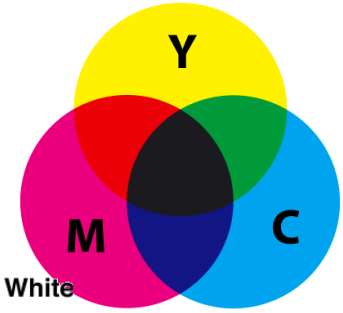
- Pixels of rowan tree mapped in RGB space
- Assign objects to the clusters
- Intensity is the distance to origo
- Color is the direction in color space, variance is minimal for similar objects

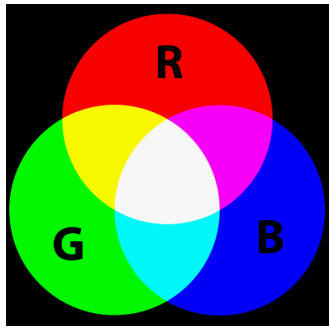



Chromatic plane of rowan tree
Leaves
Sky
Branches
Berries
G/(R+G+B)
R/(R+G+B)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Primary colors and color spaces



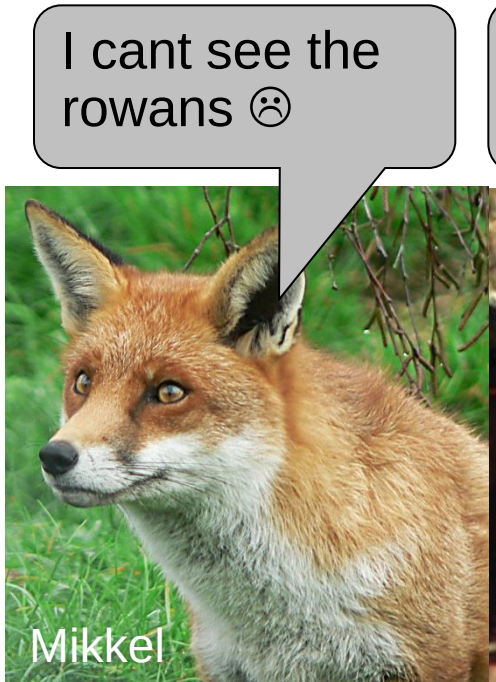




Fox 2D – 4 primary colors
Human 3D – 8 primary colors
Bird 4D – 16 primary colors
Insect 6D – 64 primary colors
Shrimp 16D – 65536 primary colors!

Much more nuances!

Colors needs names before they can be perceived by humans.



Animal vision/biological imaging

Eric Warrant

- Royal gala

- Red delicious

- Granny Schmith

- Orange

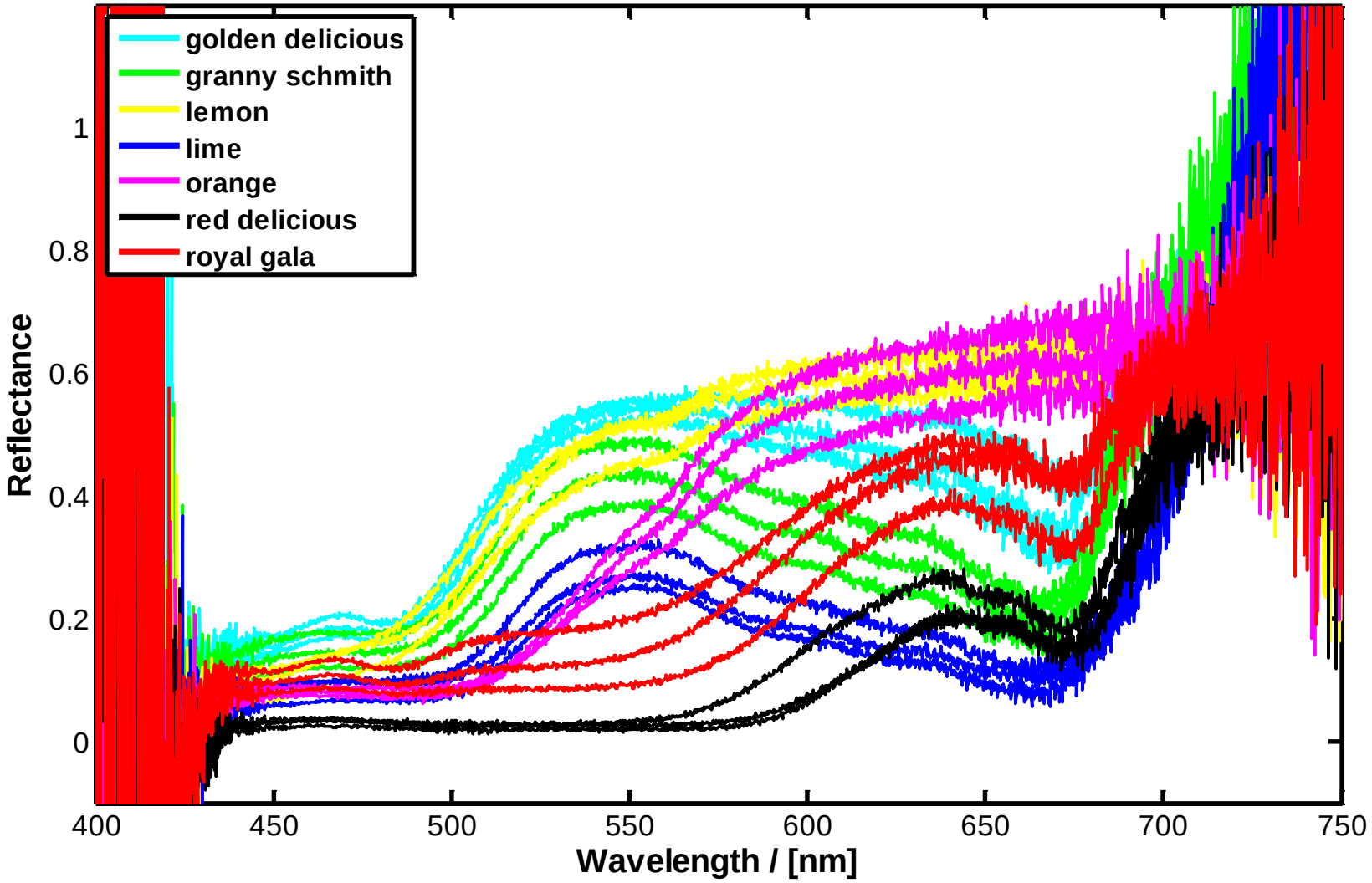
- Golden delicious

- Lemon

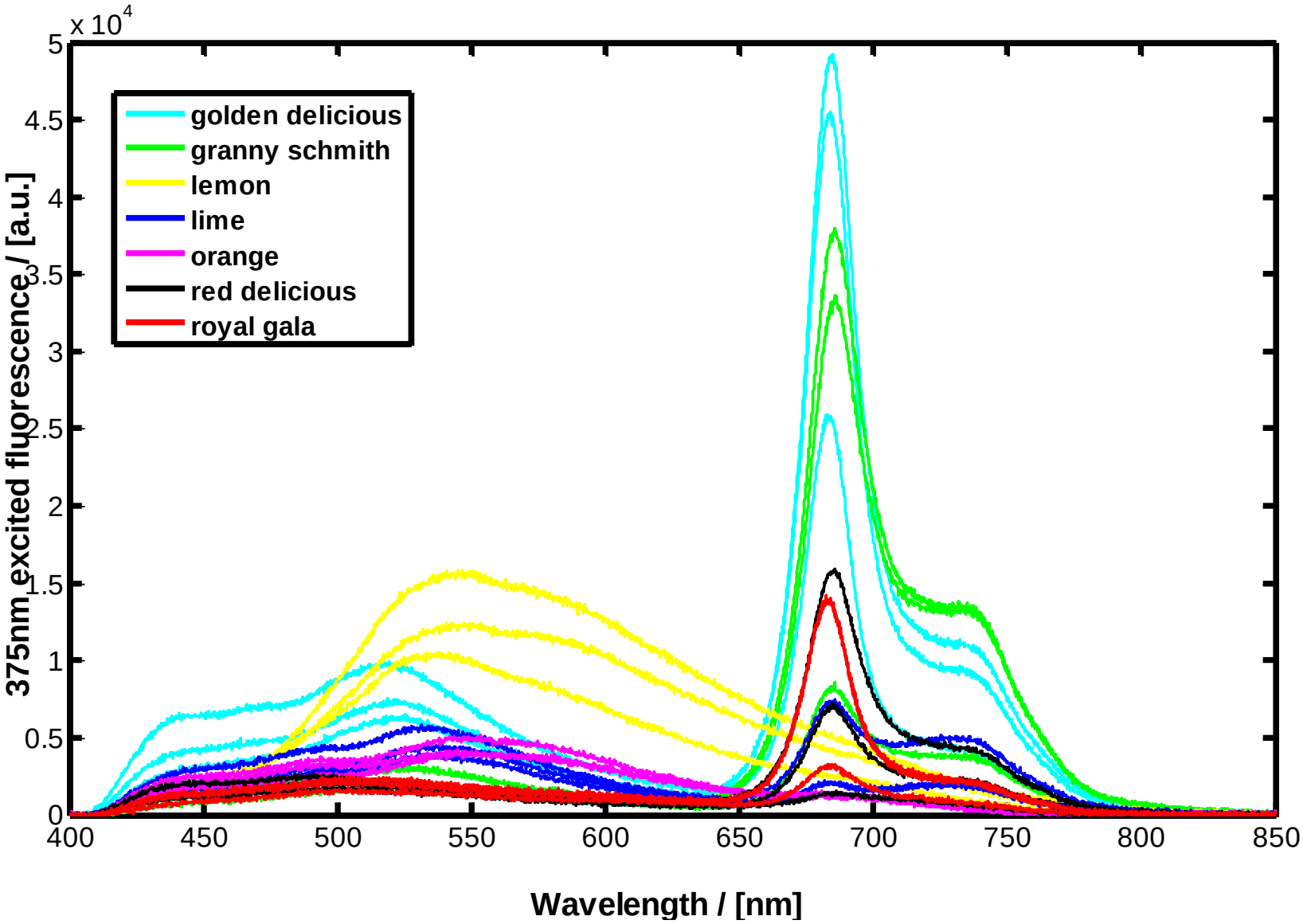
- Lime

Consider seven fruits

In reflectance



In fluorescence, Ex. 375 nm



Light intensity measurements in a matrix
7 fruits, 3 pseudo replications, 3648 spectral bands.

$I =$

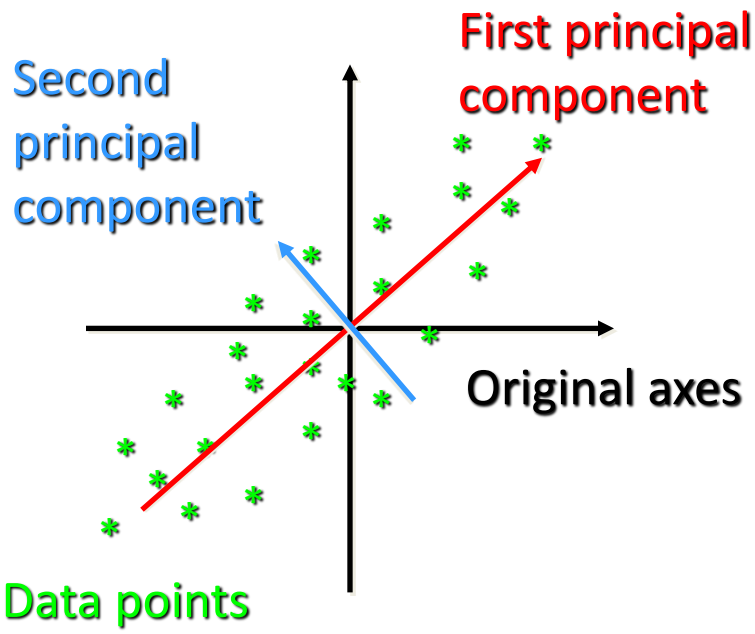
Spectral domain

Sample number

λ_{UV}		λ_{VIS}		λ_{NIR}
$I_{1,1}$	…	$I_{1,1000}$	…	$I_{1,M}$
$I_{2,1}$	…	$I_{2,1000}$	…	$I_{2,M}$
…	…	…	…	…
$I_{10,1}$	…	$I_{1,1000}$	…	$I_{1,M}$
$I_{11,1}$	…	$I_{2,1000}$	…	$I_{2,M}$
…	…	…	…	…
$I_{N-1,1}$	…	$I_{N-1,1000}$	…	$I_{N-1,M}$
$I_{N,1}$	…	$I_{N,1000}$	…	$I_{N,M}$

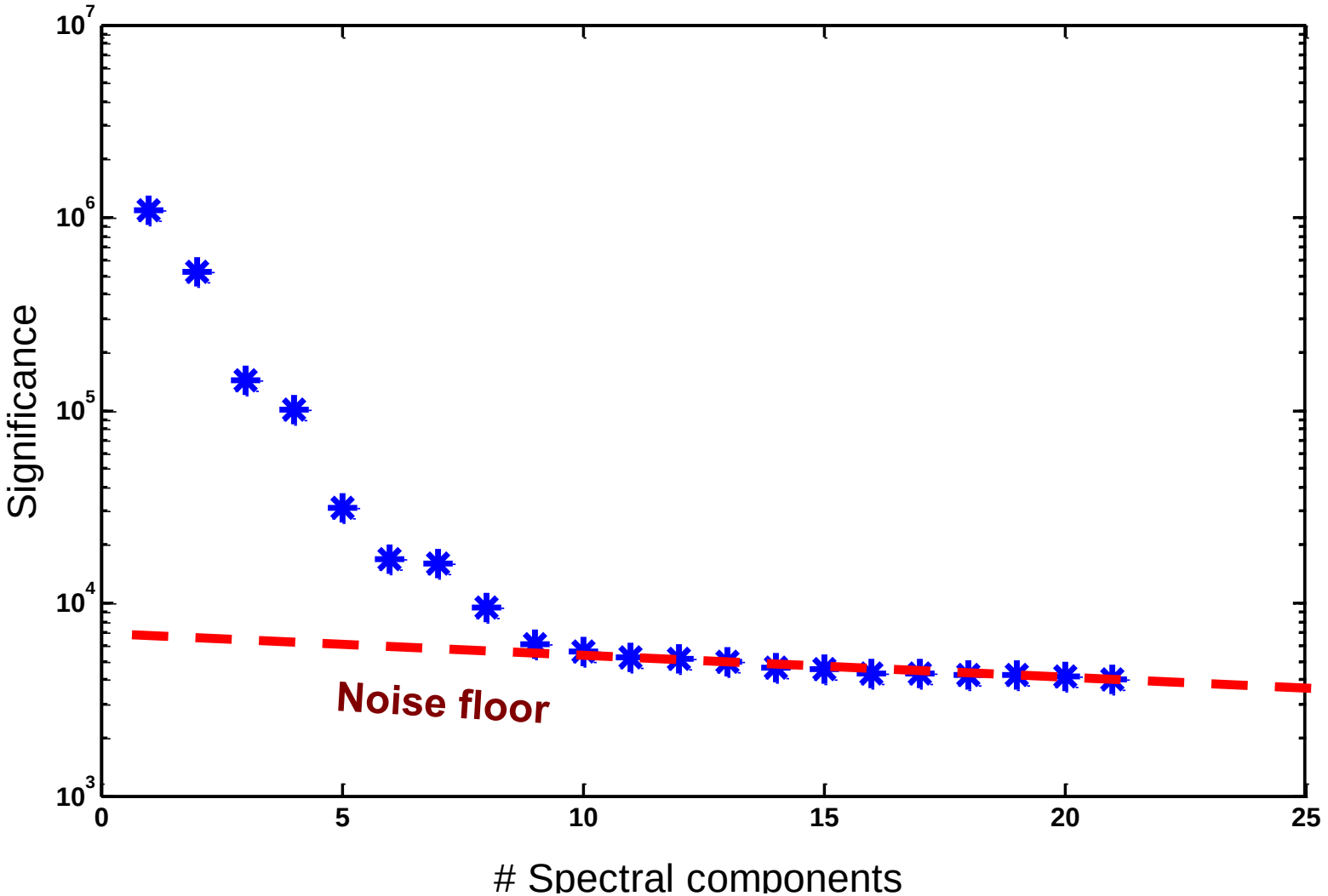
Singular Value Decomposition (principle component analysis)

- A matrix factorization method
- A coordinate transform
- Align the first dimension along the largest co-variance and so forth
- Projects data on optimal set of base functions
- Random noise are sorted in last components
- Base functions depends on data, e.g. may change if new data is included
- PCA is based on SVD but centers the data, data cannot be reconstructed after PCA.

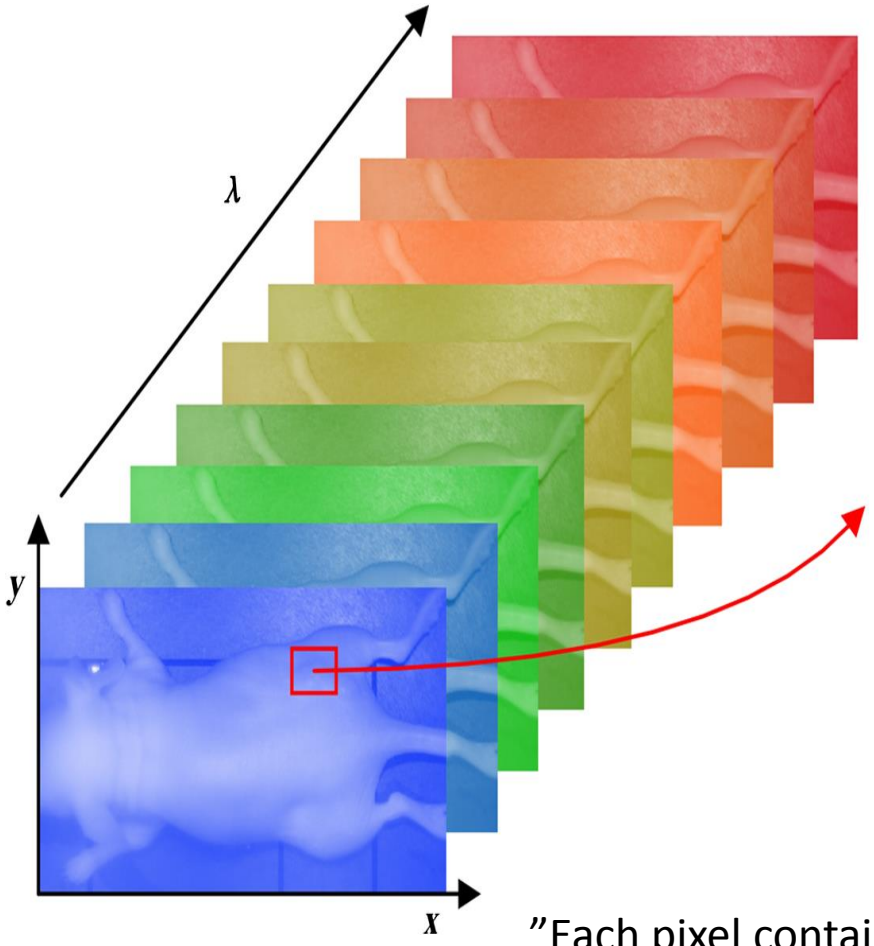


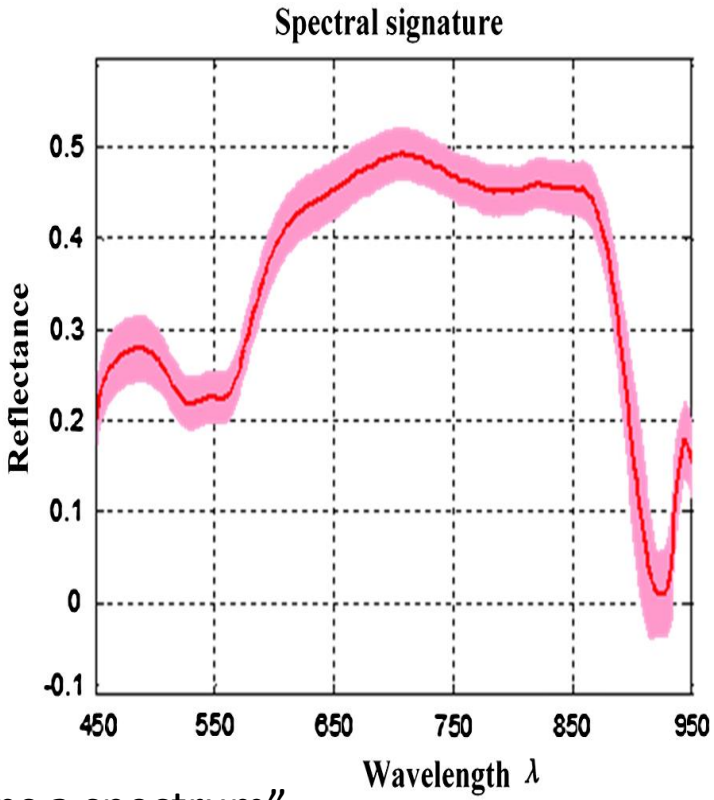
S, the Eigenvalues

- Eigenvalues from random noise decreases explonentially



Multispectral = many spectral bands





”Each pixel contains a spectrum”

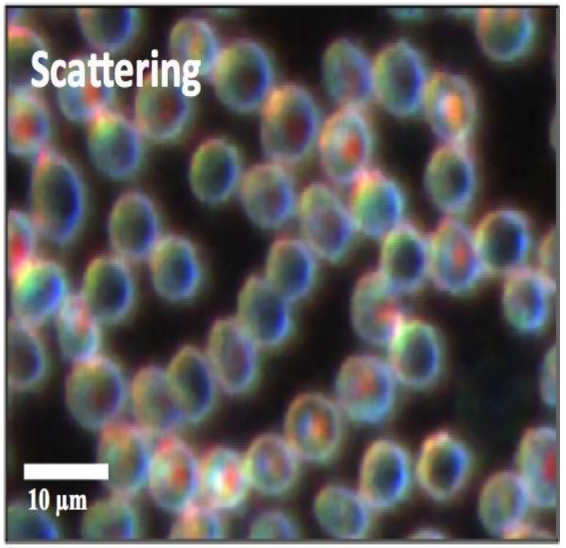
Image analysis
Kalle Åström

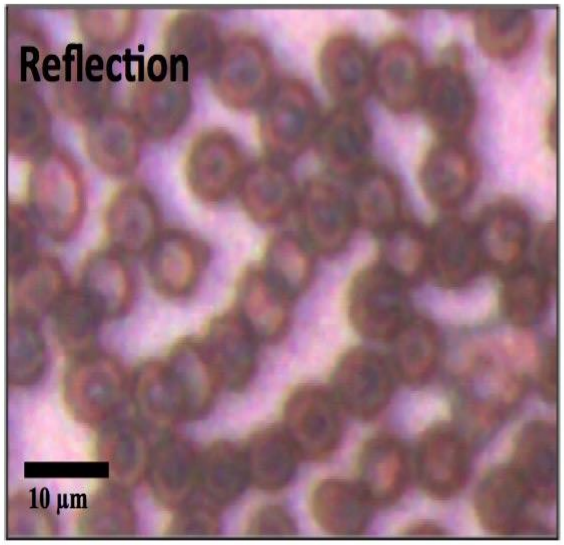
Multispectral Imaging

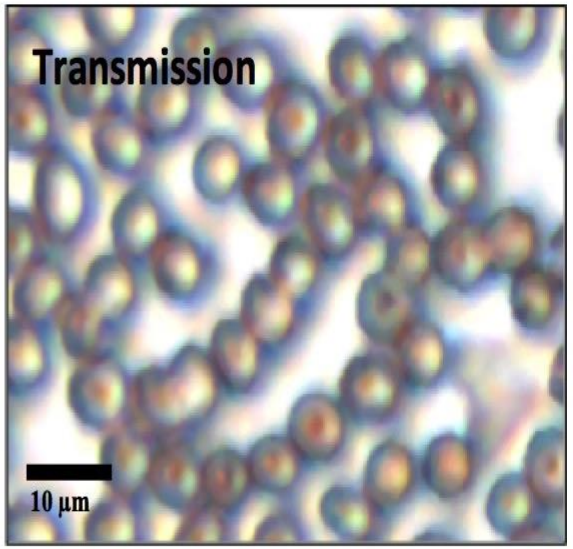
Multivariate analysis of microscopic imaging

Computer exercise/Lab

- Microscopy of red blood cells
- Find which red blood cells that are infected with the malaria parasite



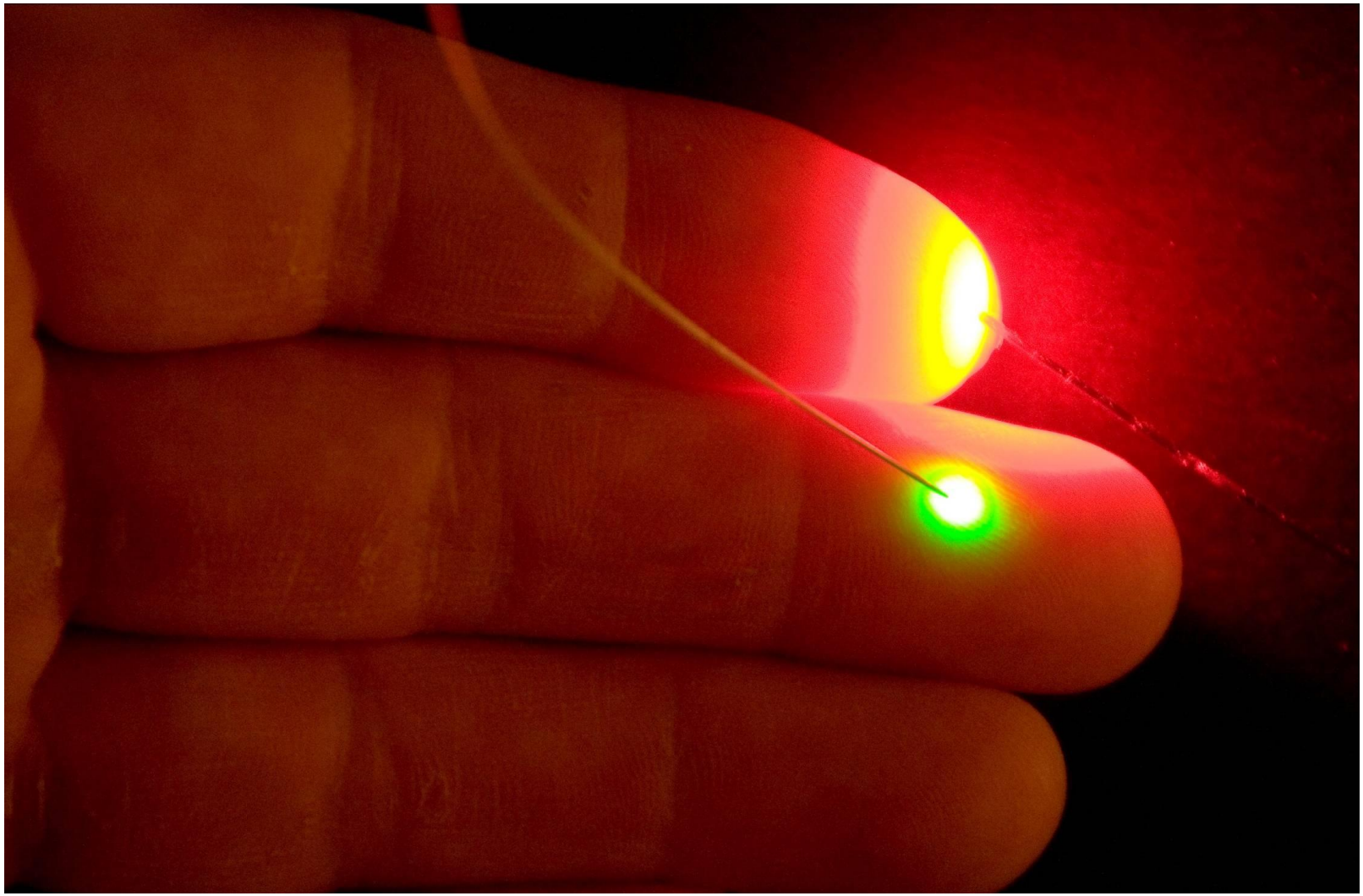




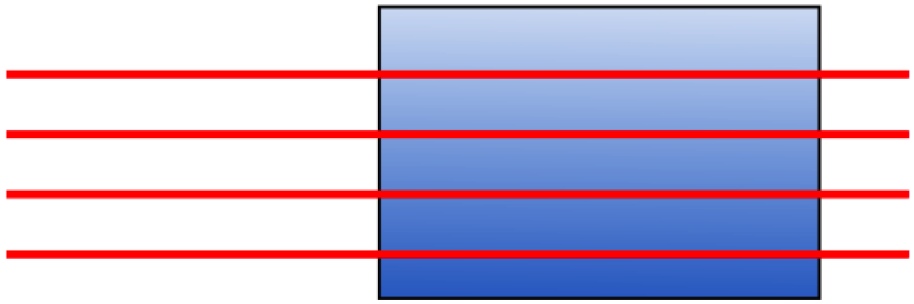
Medical Imaging

Multispectral Imaging

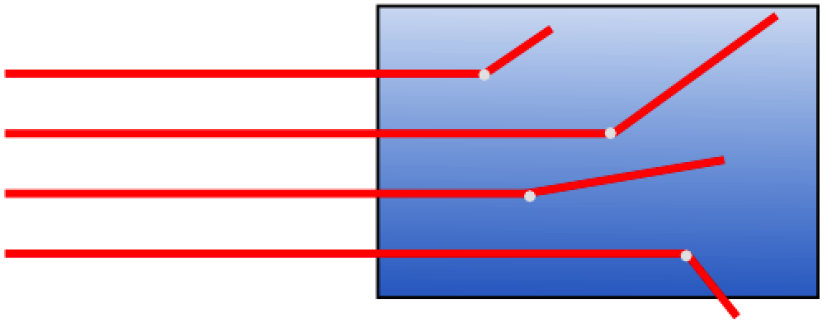
Light in tissue



Scattering of light



No scattering



Scattering due to ”small particles”

Scattering ”particles” in tissue:
cell nuclei, cell membrane, mitochondria

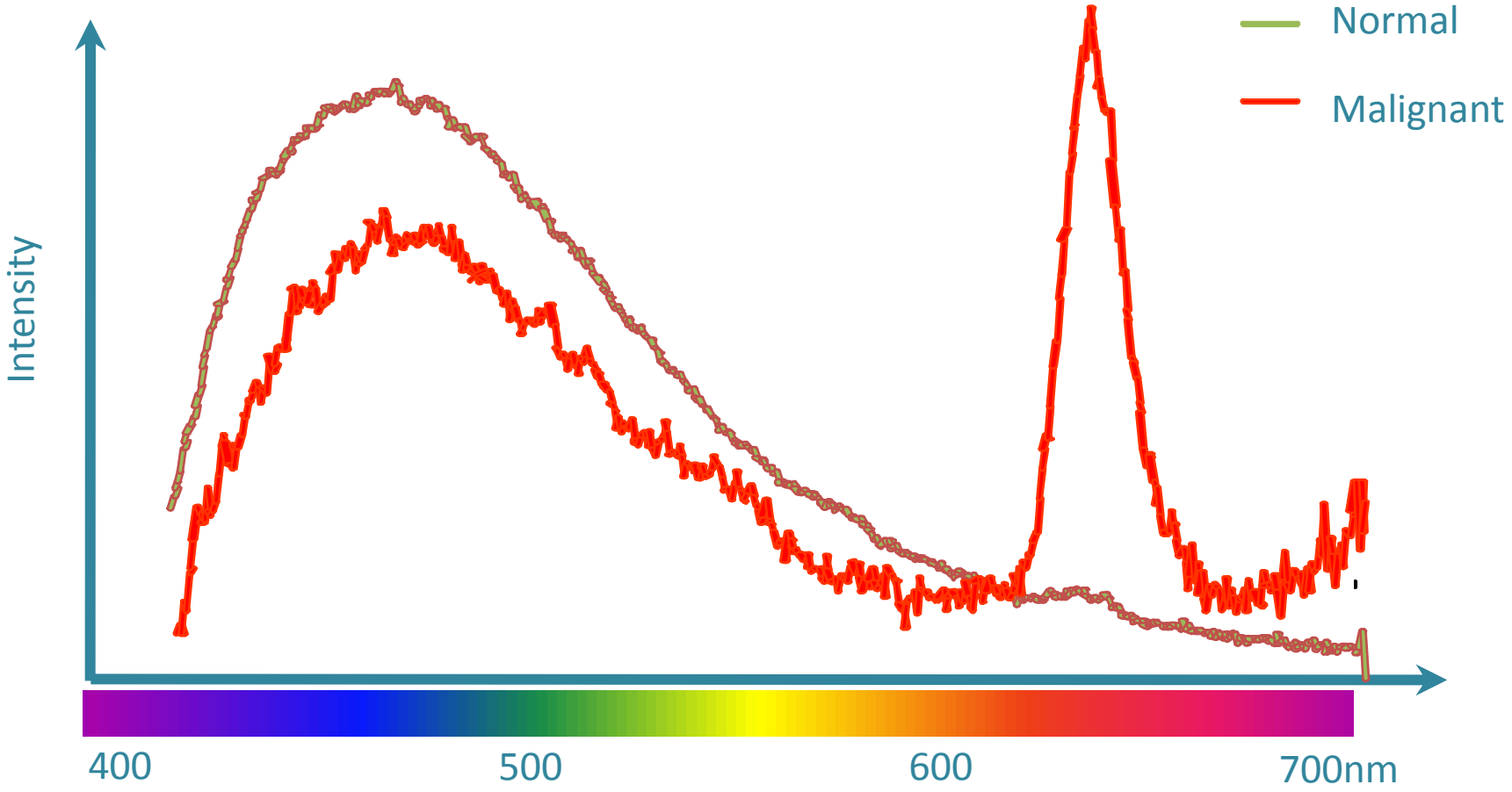
Light photons change direction!

From clear liquid to diffusive media

Cuvette filled with water. HeNe laser beam coming in from left.

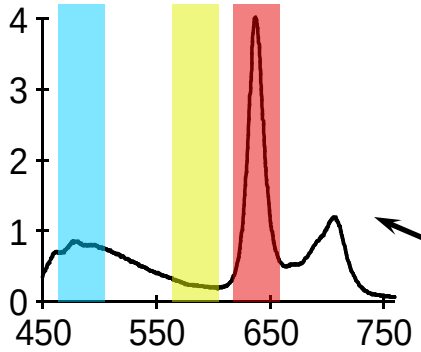
Increase scattering by adding droplets of milk-like material.

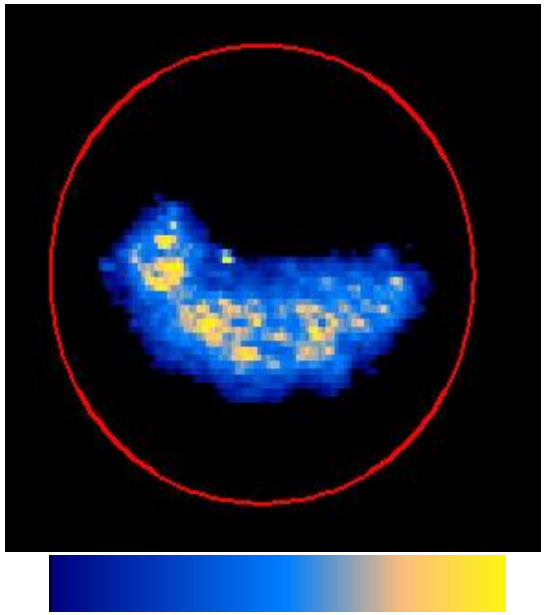
Spectra from Protoporfyrin IX



Ratiometric imaging

fluorescent contrast agents

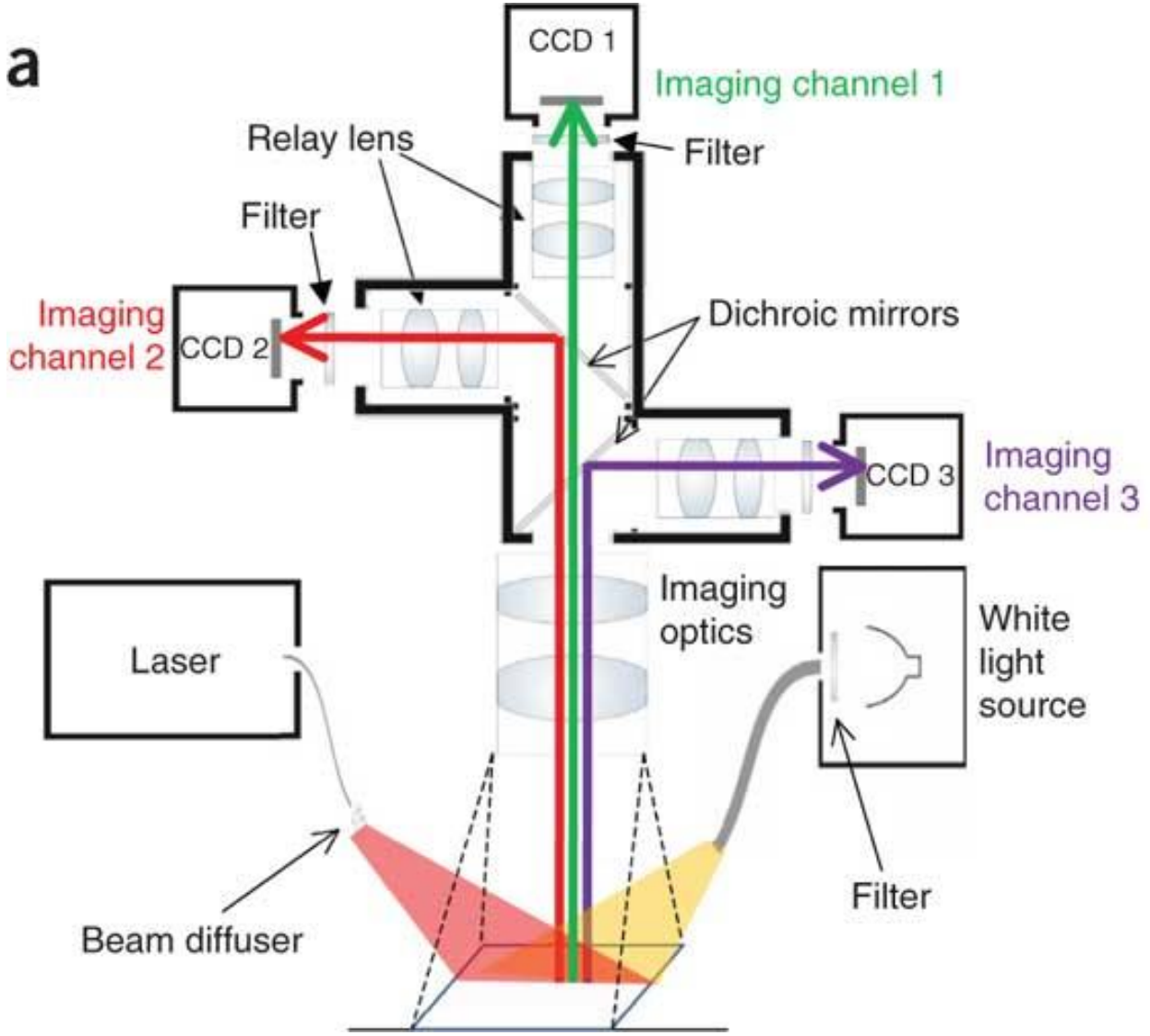




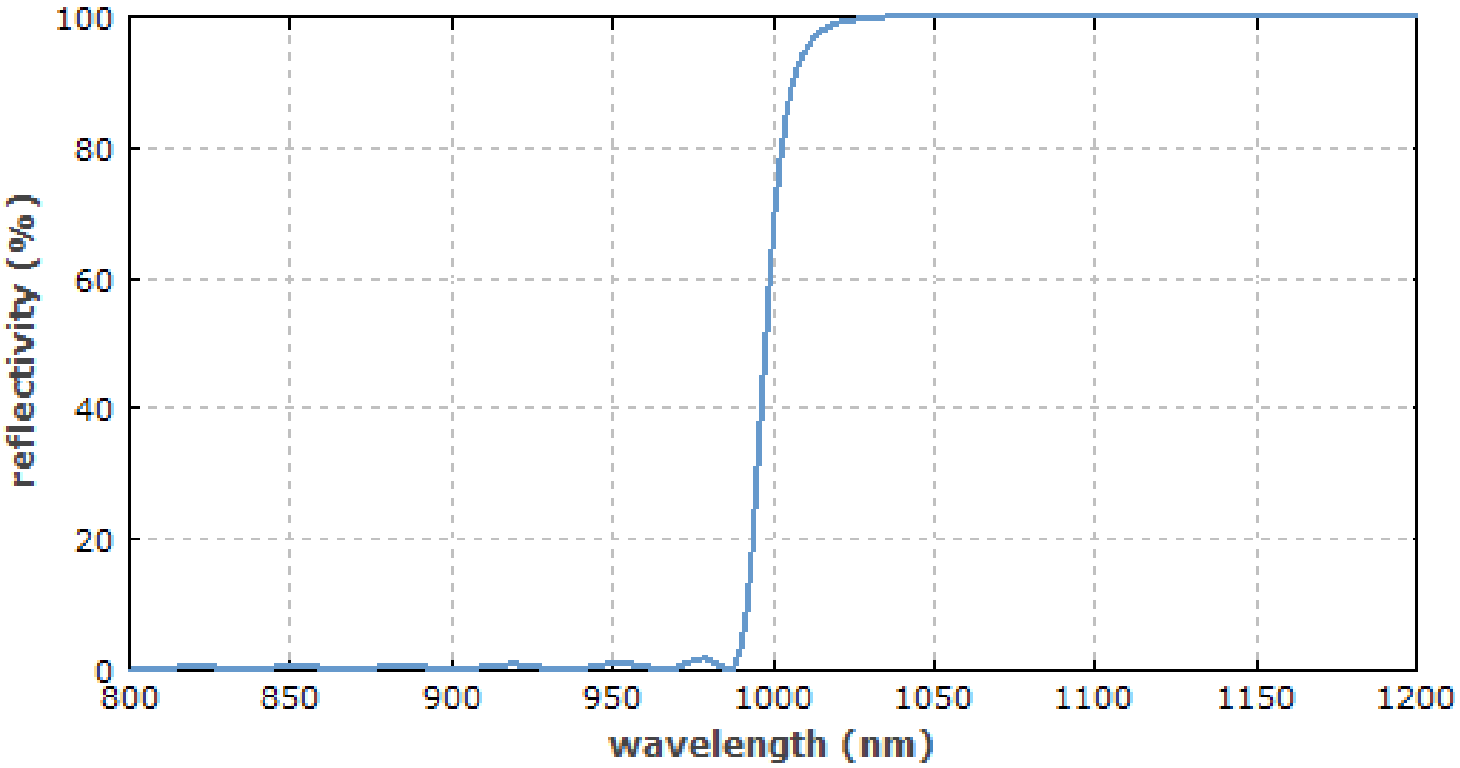
$$F_c = \frac{A - k_1 D}{k_2 B}$$

$$\frac{\text{Red} - \text{Yellow}}{\text{Blue}}$$

Real-time multispectral imaging

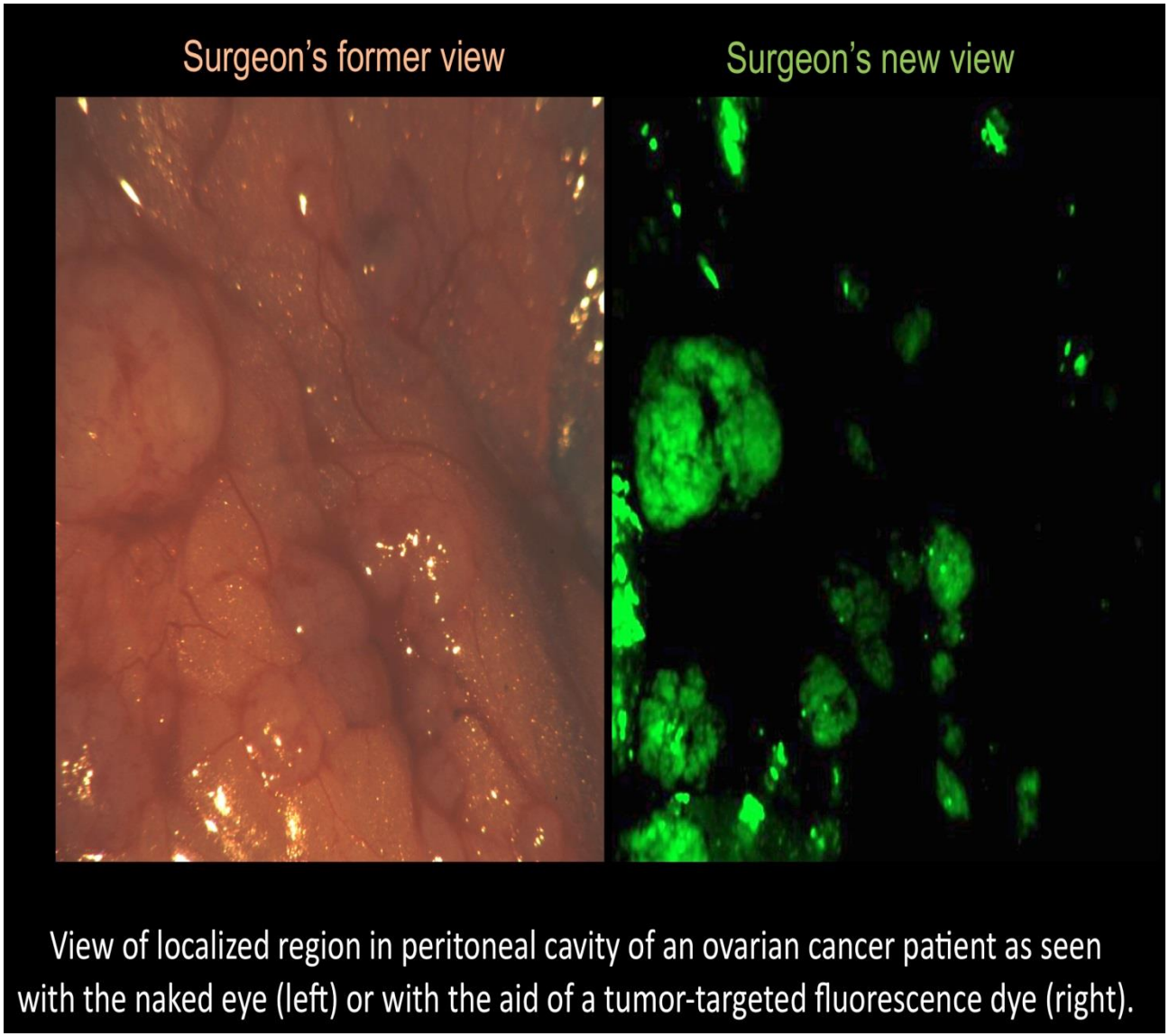


Dichroic mirrors



https://www.rp-photonics.com/dichroic_mirrors.html

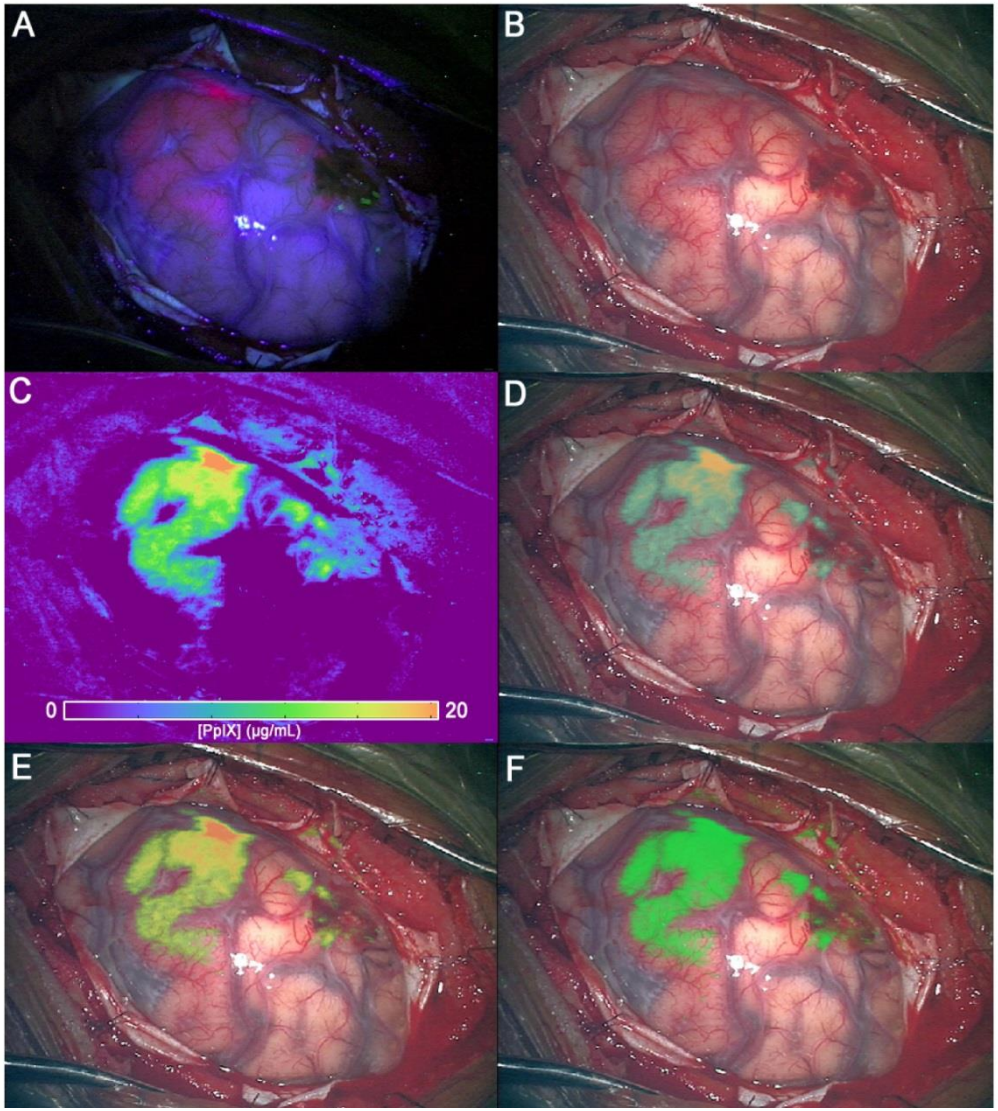
Fluorescence guided cervical tumor resection



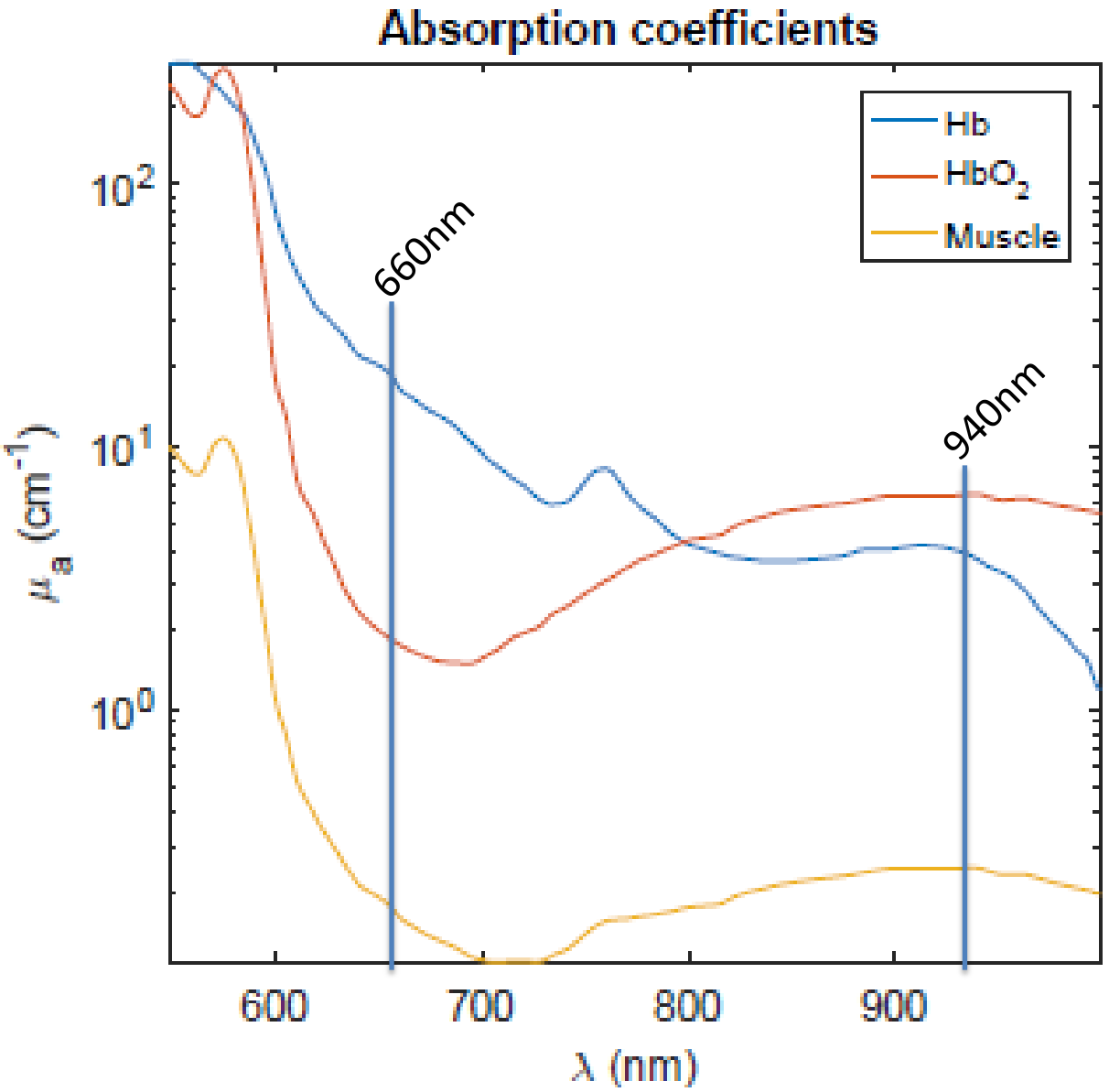
View of localized region in peritoneal cavity of an ovarian cancer patient as seen with the naked eye (left) or with the aid of a tumor-targeted fluorescence dye (right).

Fluorescence guided resection

Brain tumor



Reflectance/Transmittance imaging



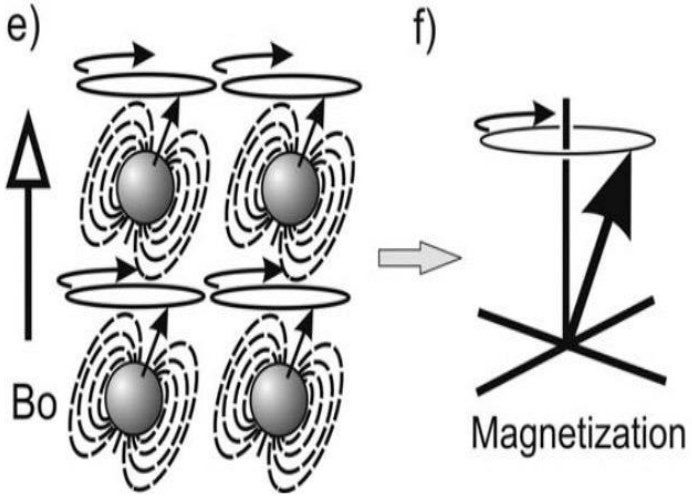
Magnetic Resonance Imaging

Freddy Ståhlberg

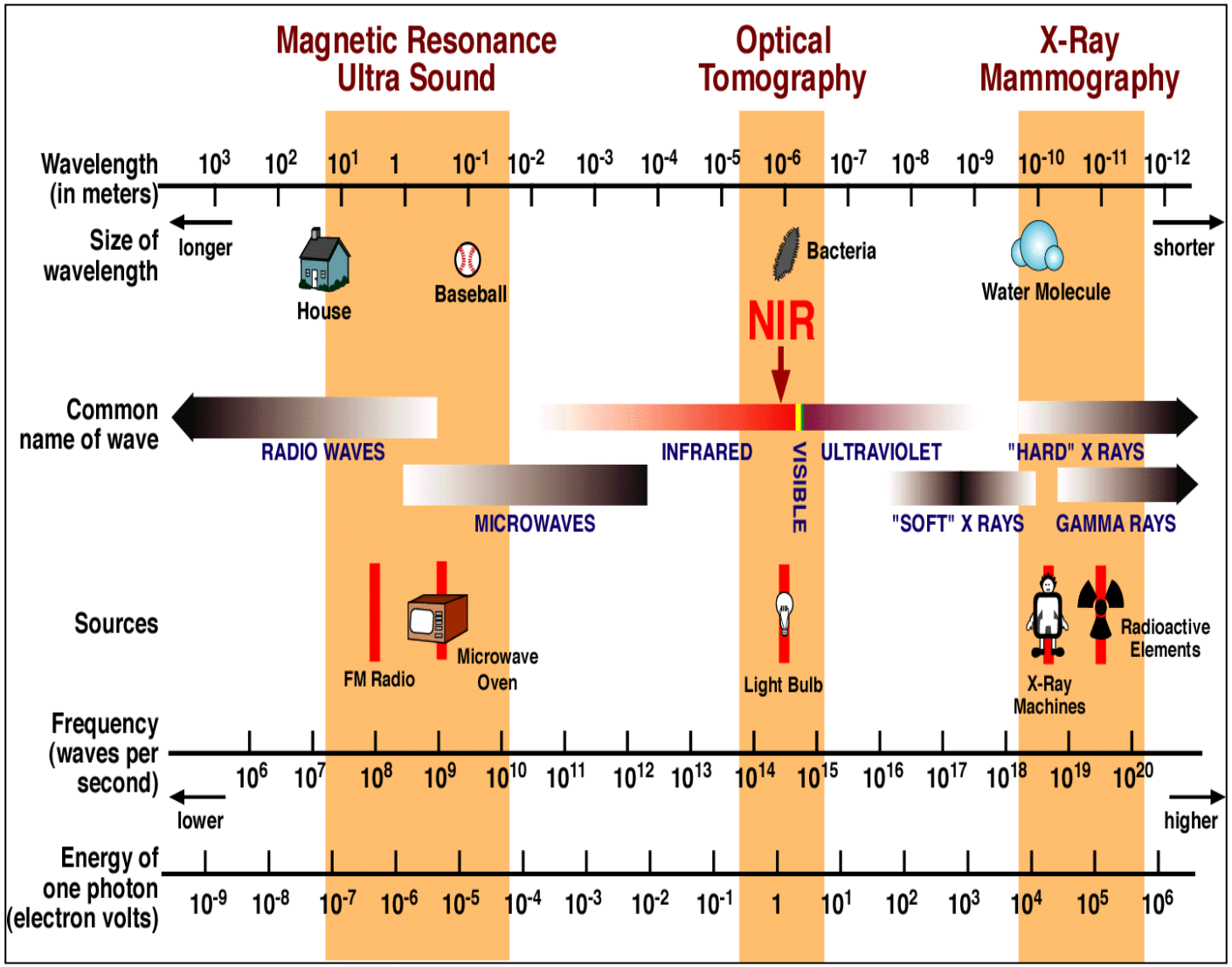
Multispectral Imaging

Magnetic Resonance Imaging (MRI)

National 7-Tesla facility



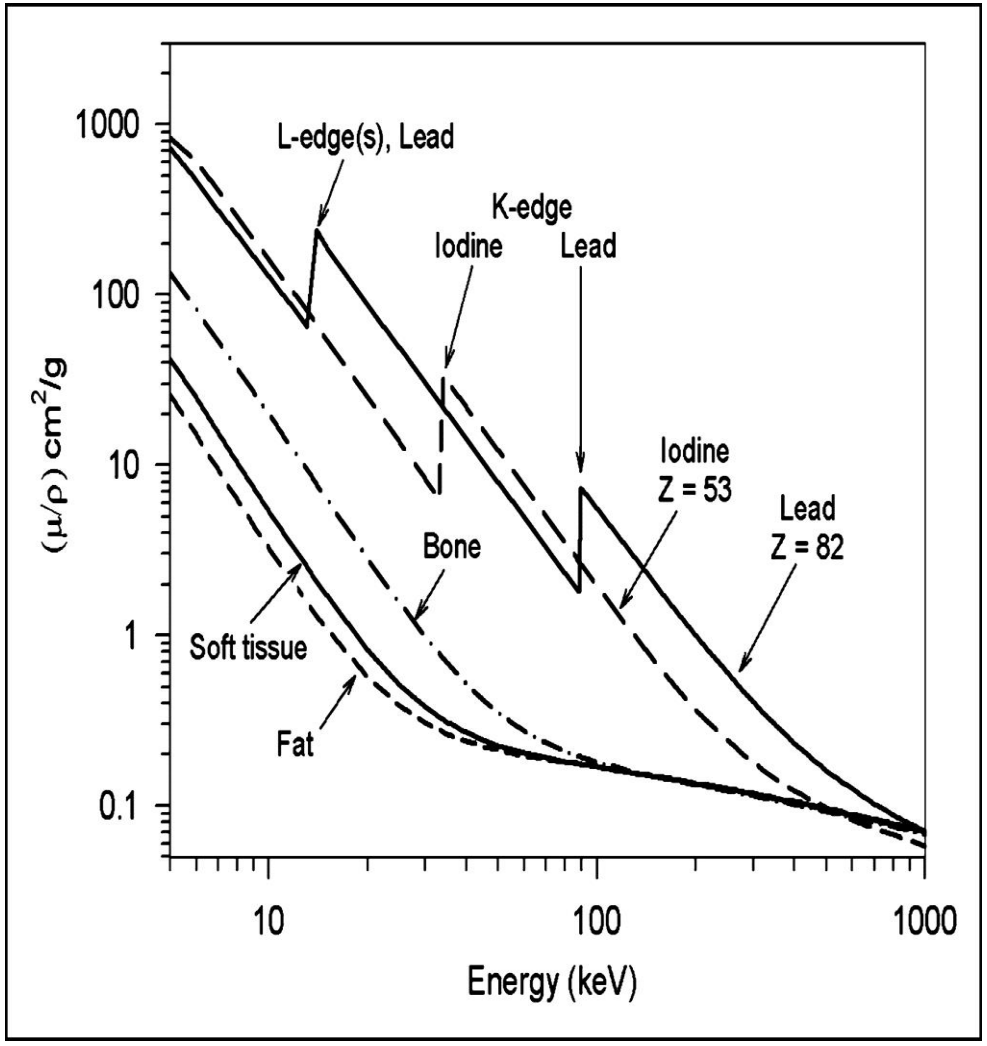
Spectral bands from the electromagnetic spectrum



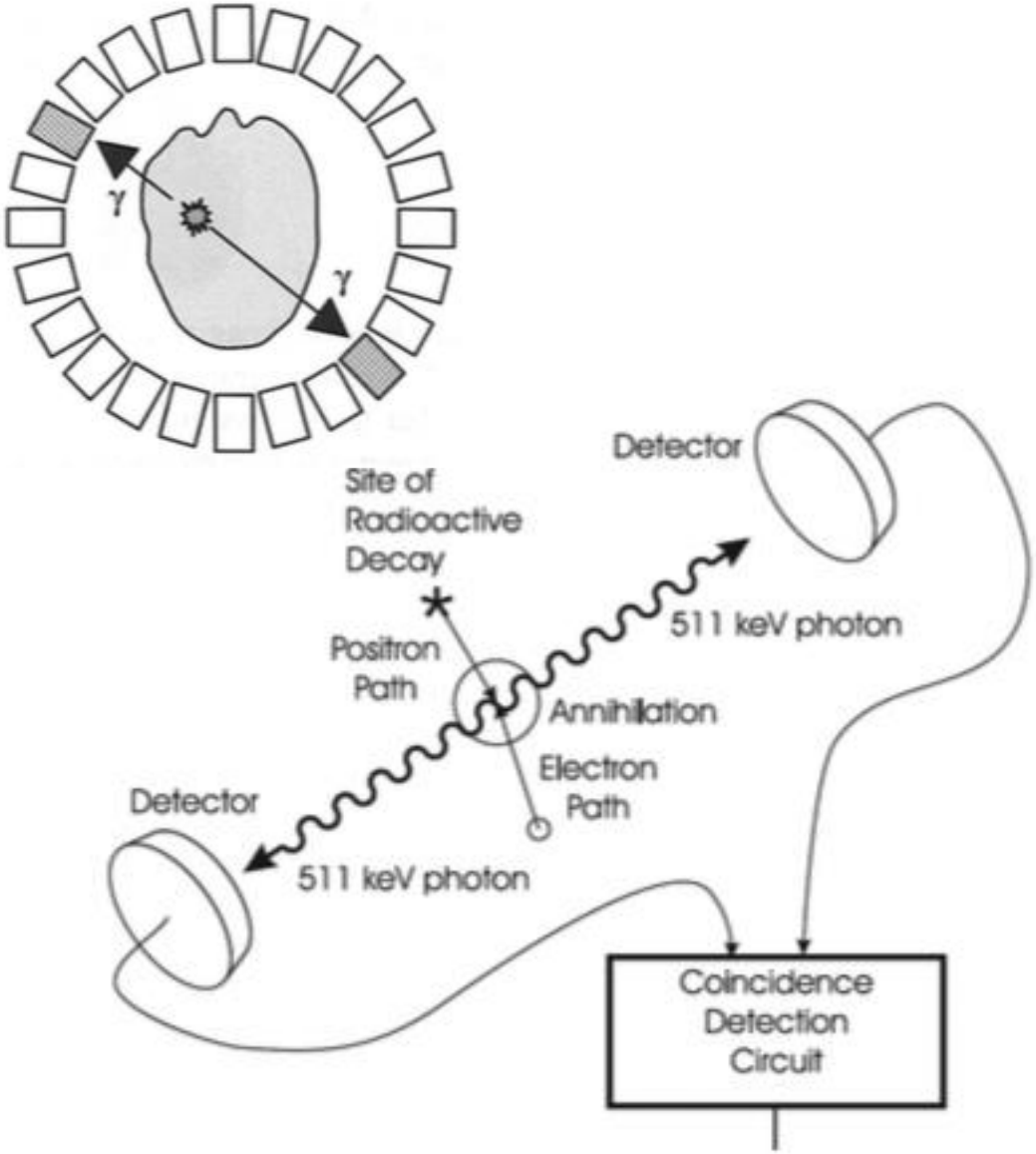
High Energy Imaging

Multispectral Imaging

Multispectral X-ray

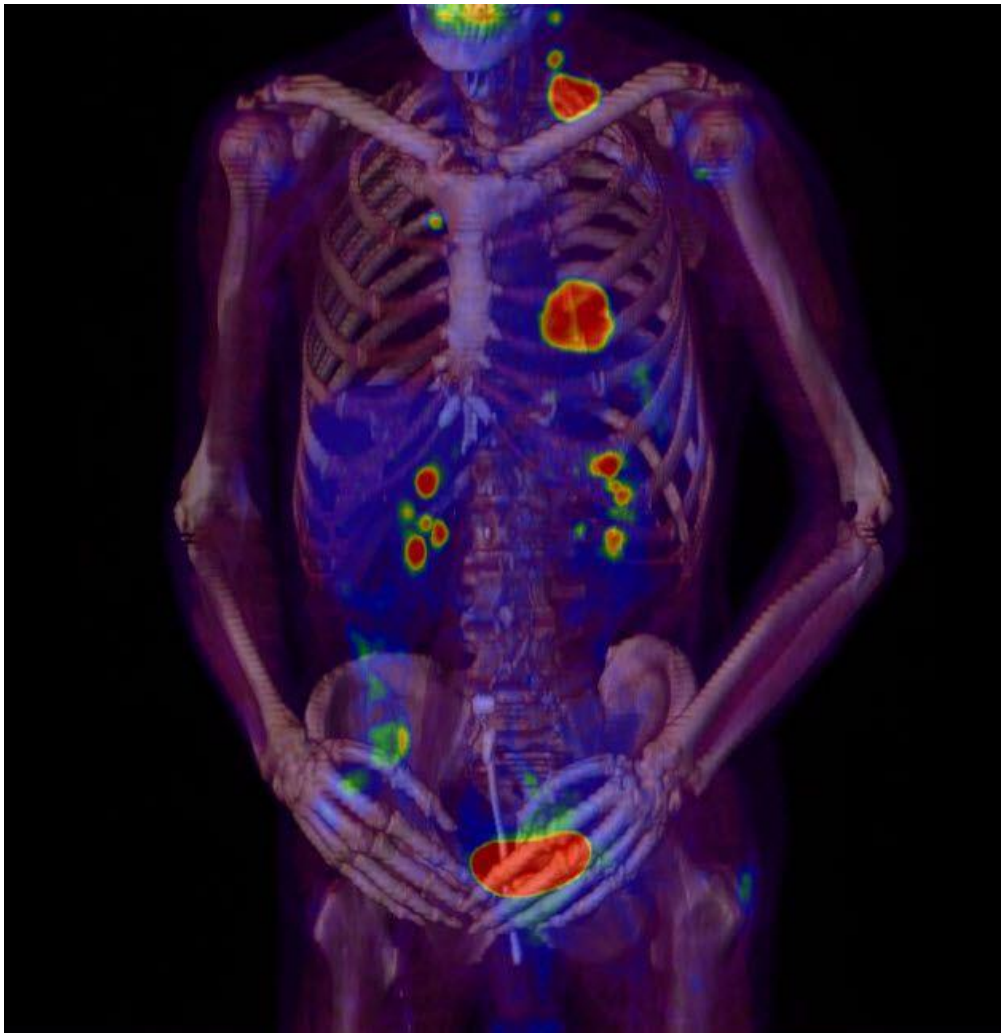


Positron emission (PET)



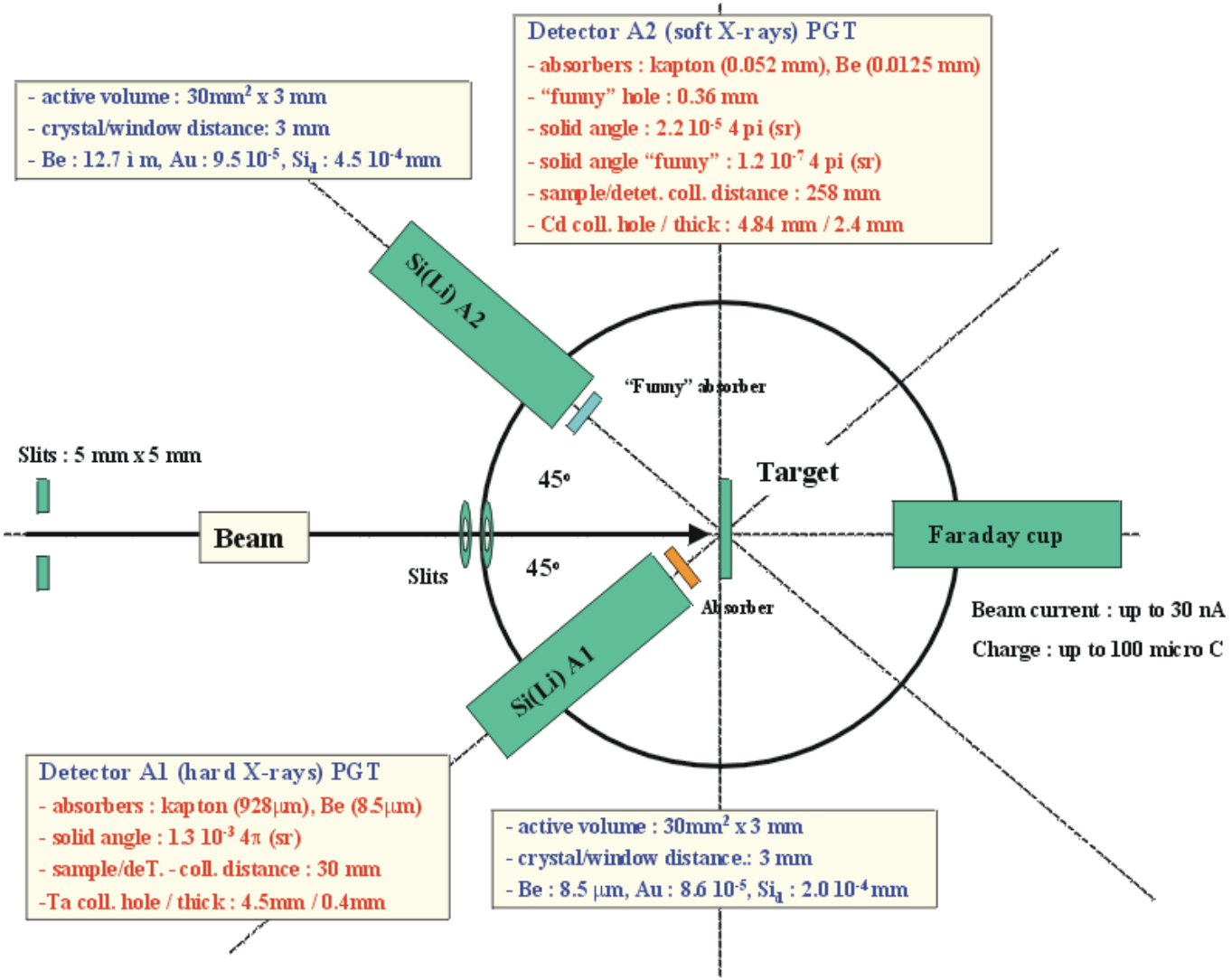
- Use radionuclides that emit positron (e.g. ^{18}F)
- Positron annihilation
  - produces two 511 keV gamma rays
  - gamma rays emitted in 180^{o} opposite directions
- Principle: detect ***coincident*** gamma rays
- Time window ~2-20 ns (typical 12 ns)
- No detector collimation required – higher sensitivity

PET



PIXE

Particle Induced X-ray Emission or **Proton Induced X-ray EmissionC**

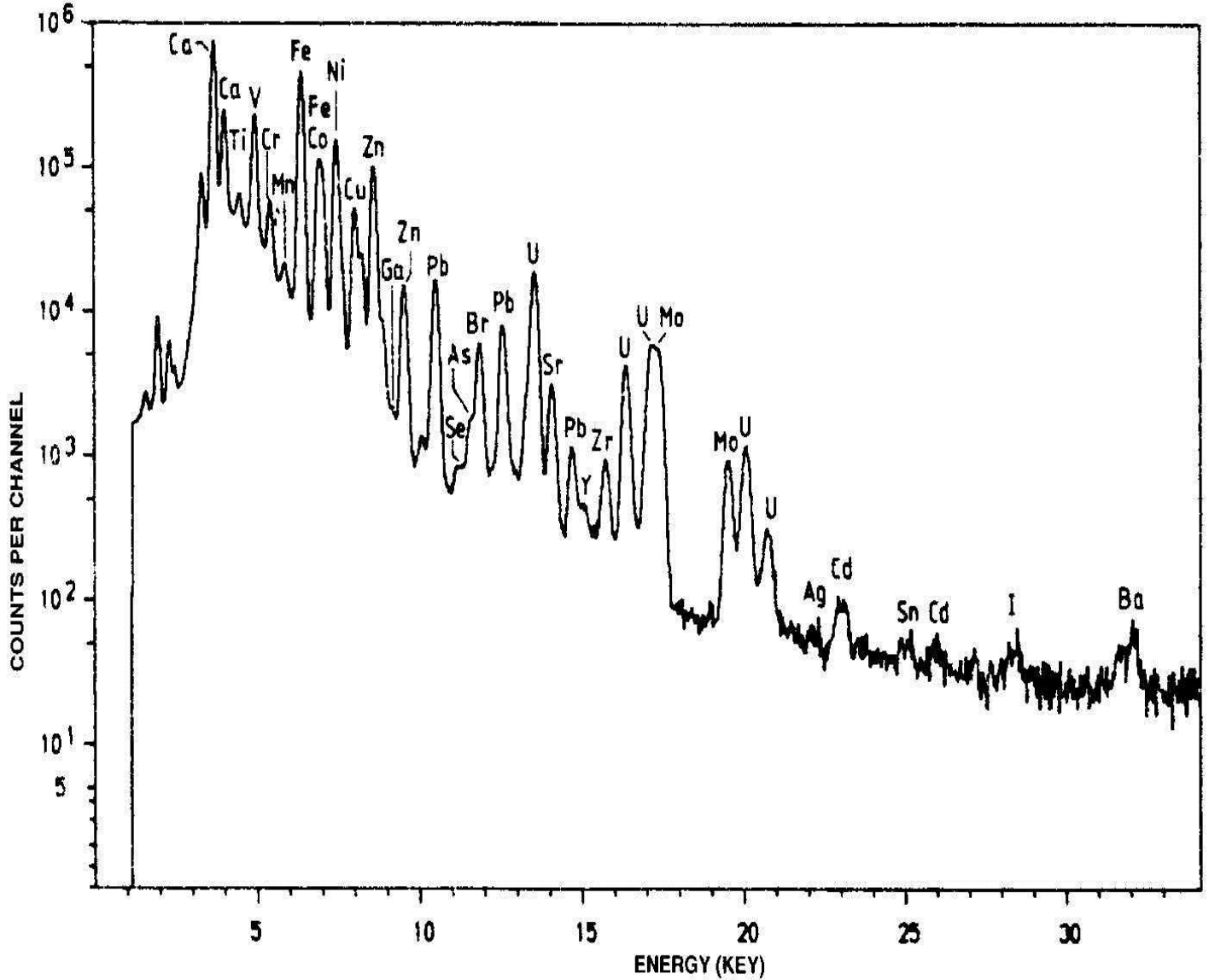


X-ray production cross-section is high for protons with a few MeV (~3 MeV).

By directing a proton beam towards a sample very sensitive elemental analysis can be performed.

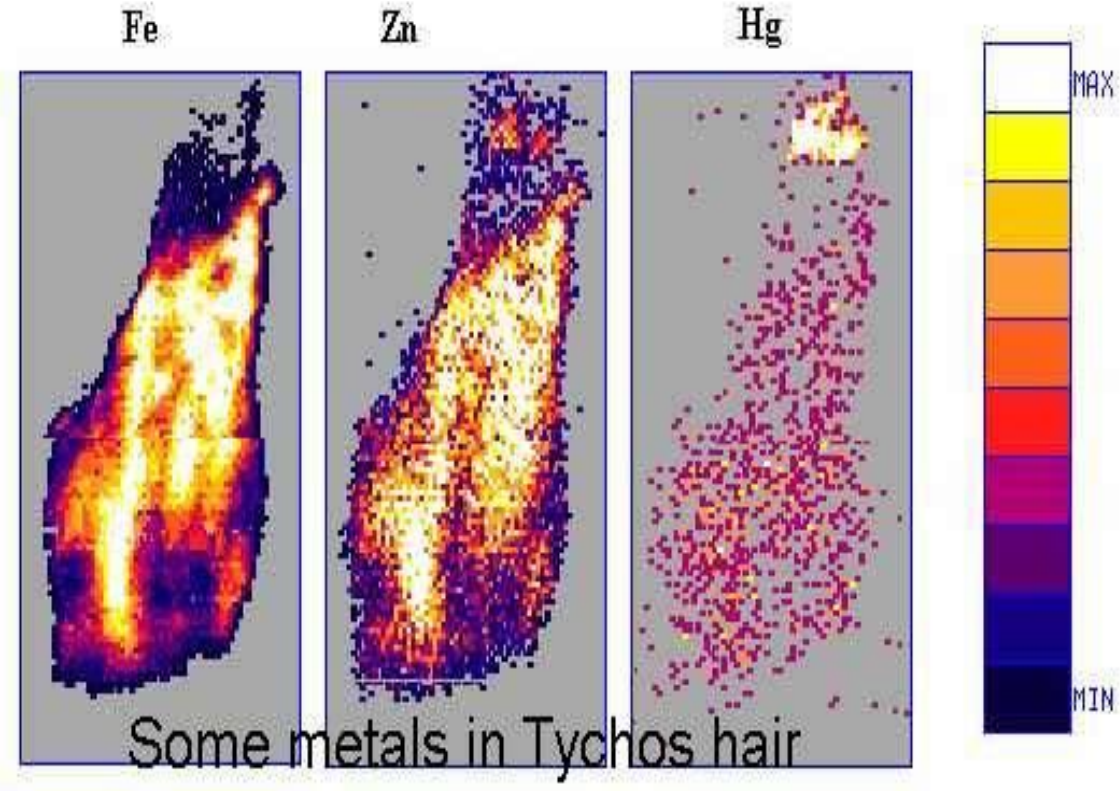
PIXE

Jan Pallon



PIXE

Hair follicle from Tycho Brahe



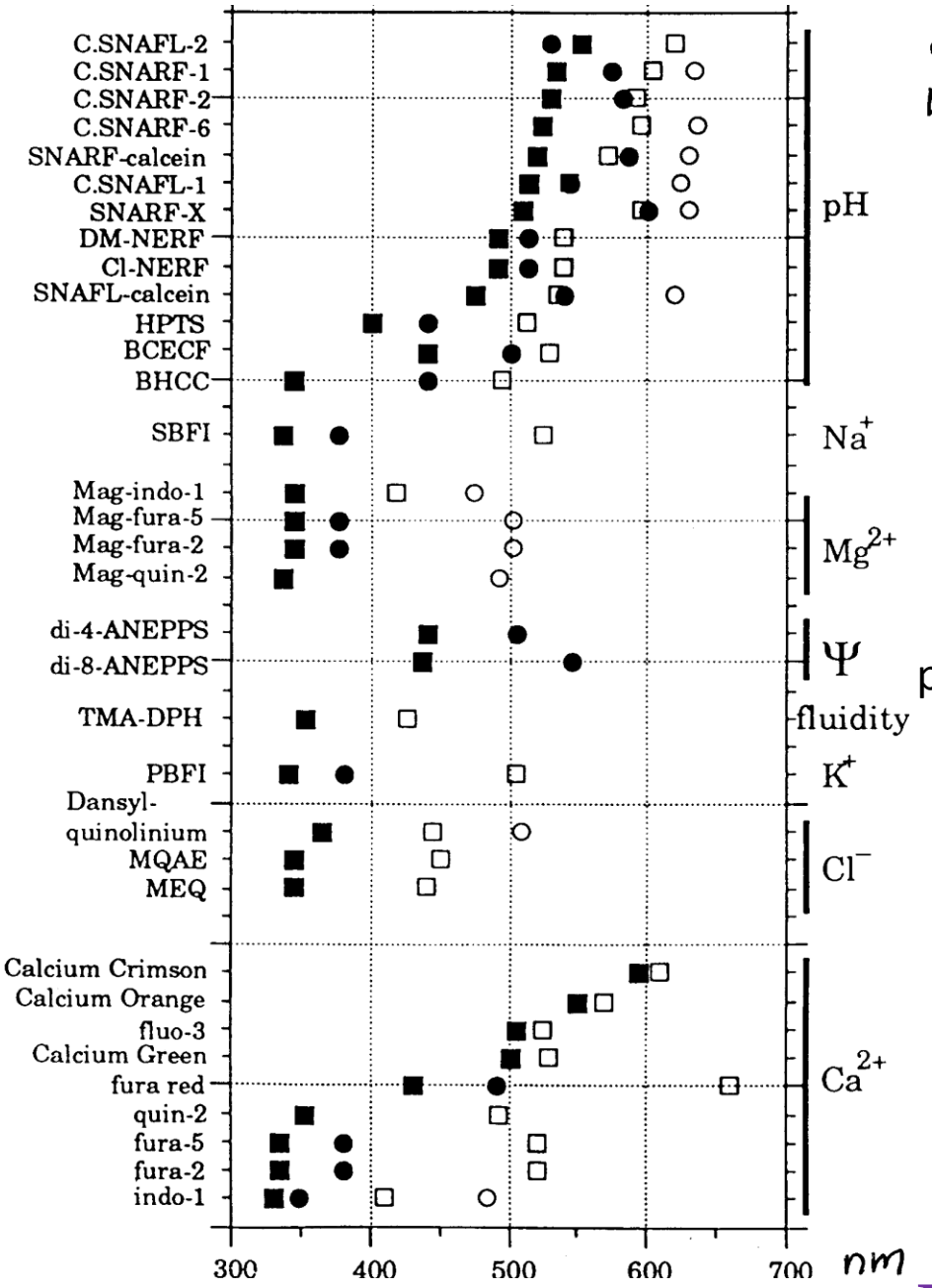
Microscopy

Multispectral Imaging


Microscopy

Functional fluorescent substances

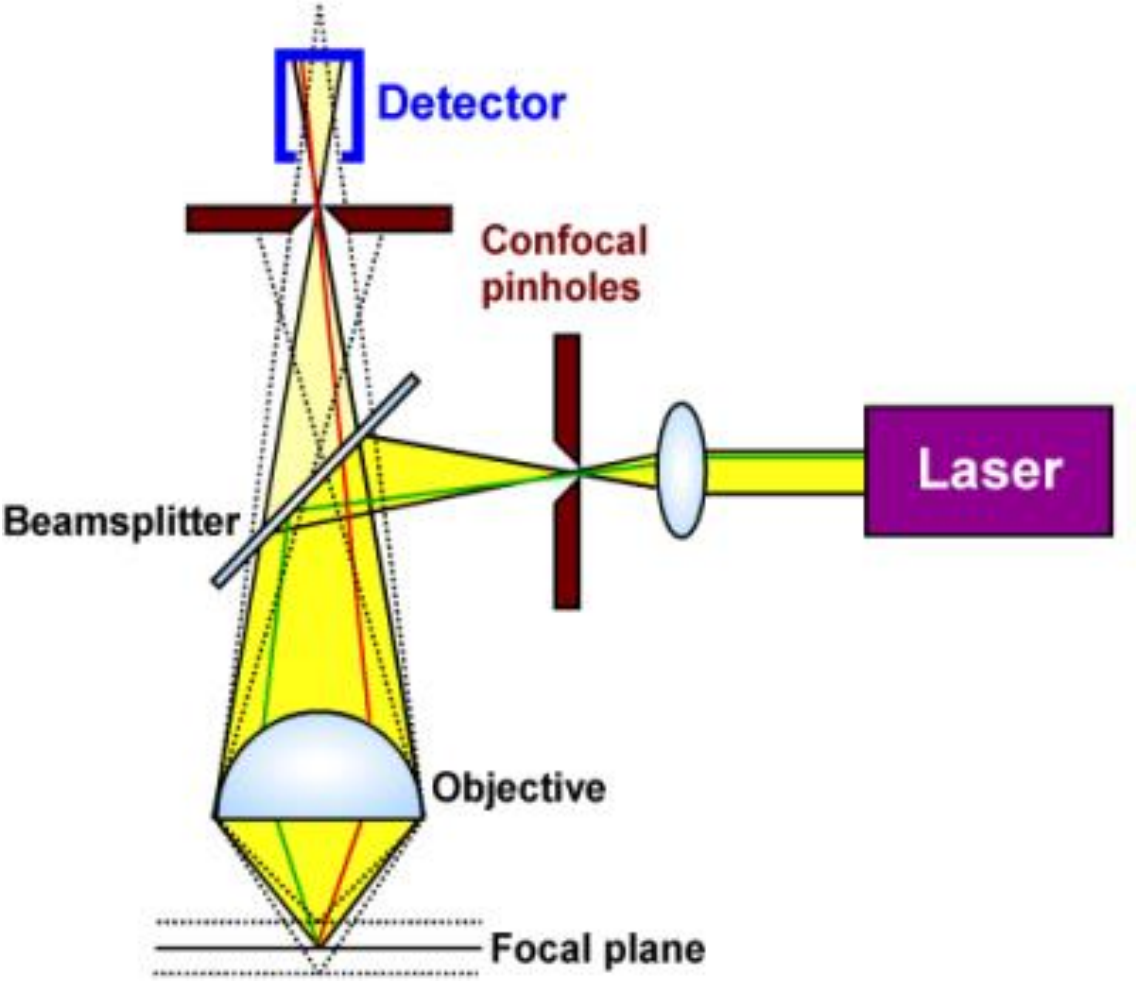
Filled & unfilled symbols correspond to the substance frequency shift



Electric potential

Fig 10.7

Scanning confocal fluorescence microscope

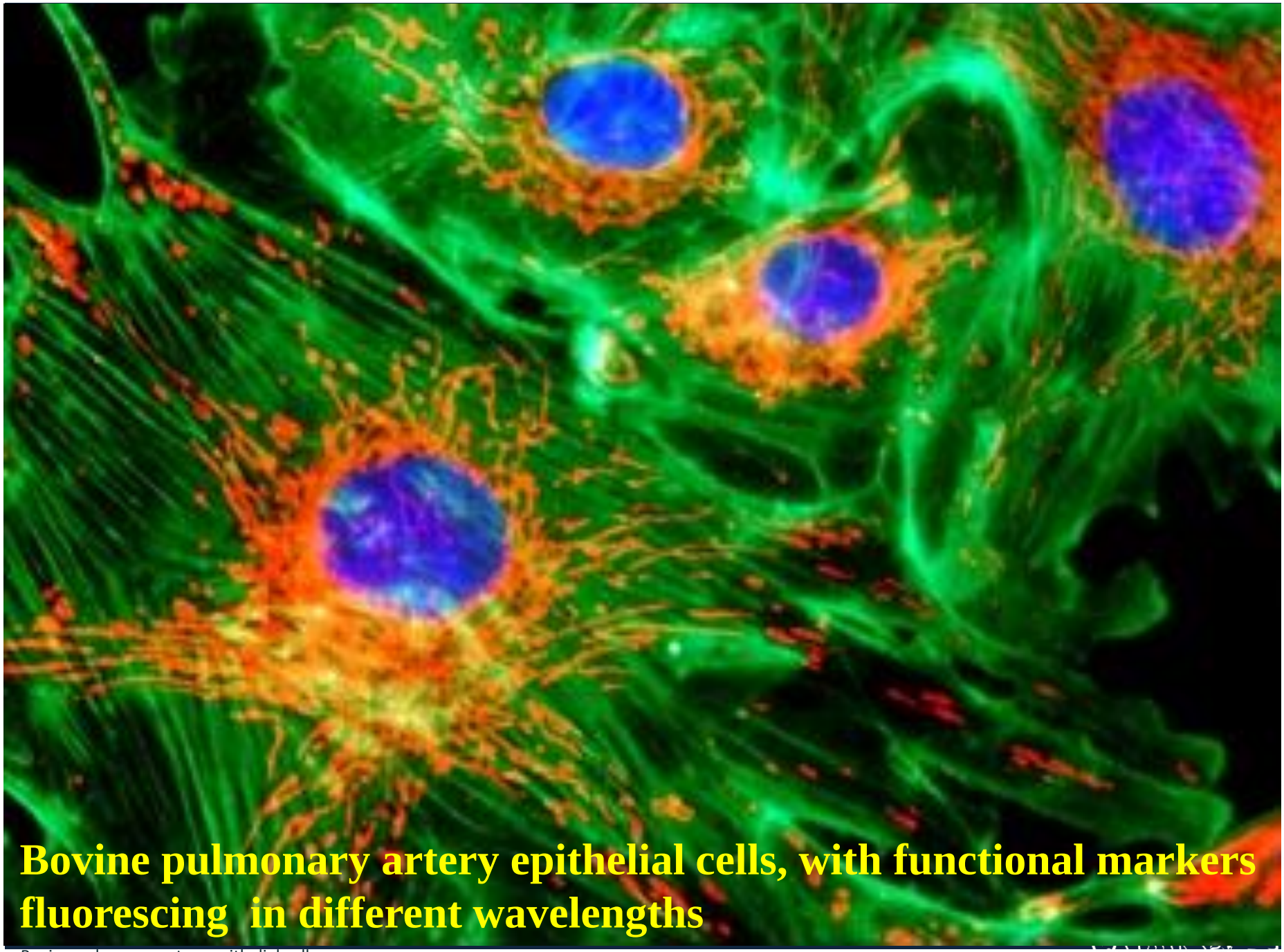


A confocal configuration improves resolution and in particular longitudinal resolution

It also decreases interference or background from scattered light

A disadvantage is that the object needs to be scanned

http://blogs.brandeis.edu/marderlab/a-practical-guide-for-fluorescent-confocal-microscopy/



Bovine pulmonary artery epithelial cells

Fluorescence microscopy

Dyes sensitive to
Ca ion concentration and to pH value

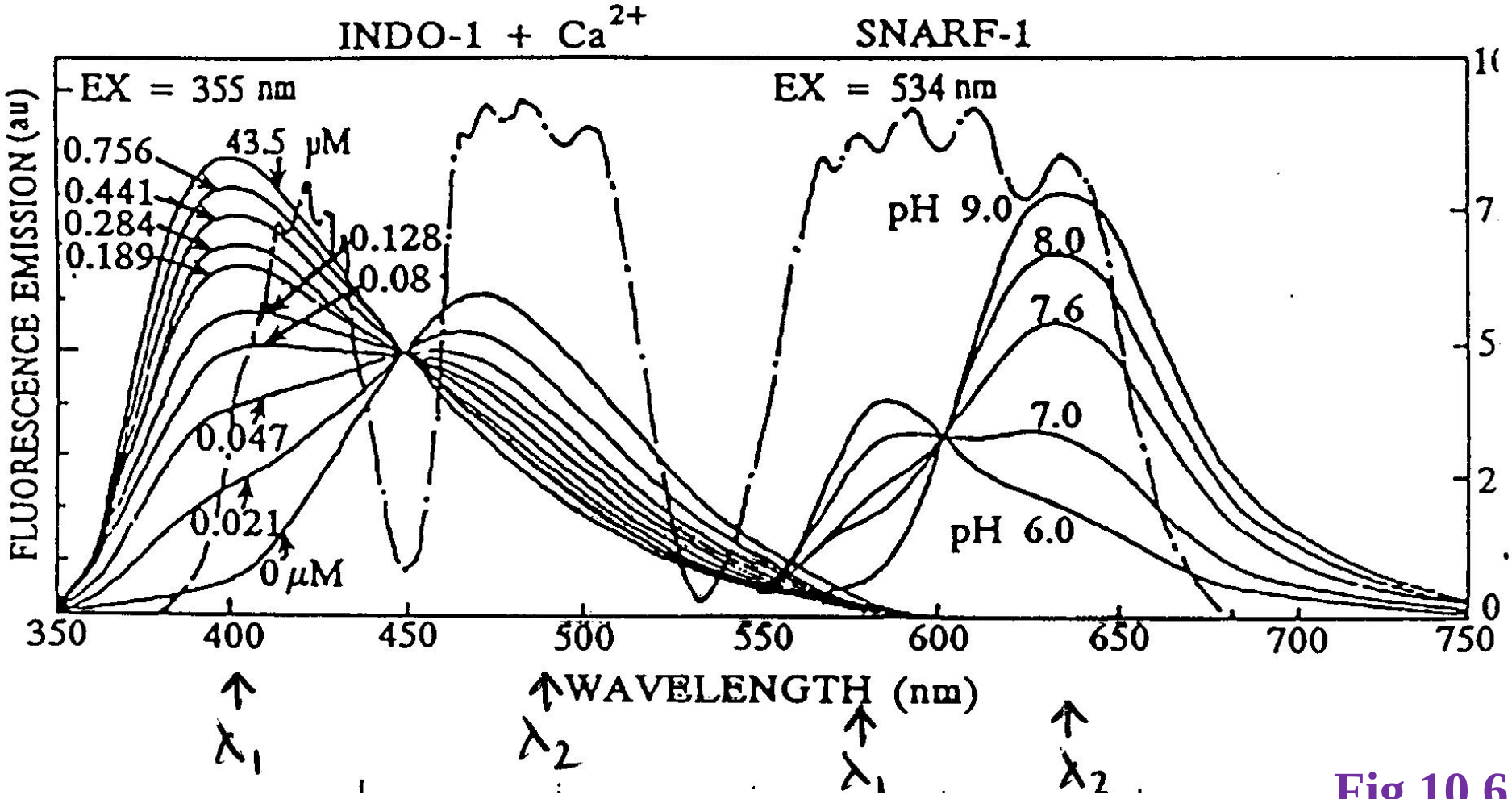


Fig 10.6

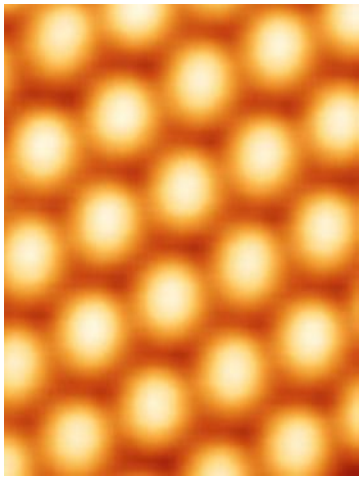
Scanning probe microscopy

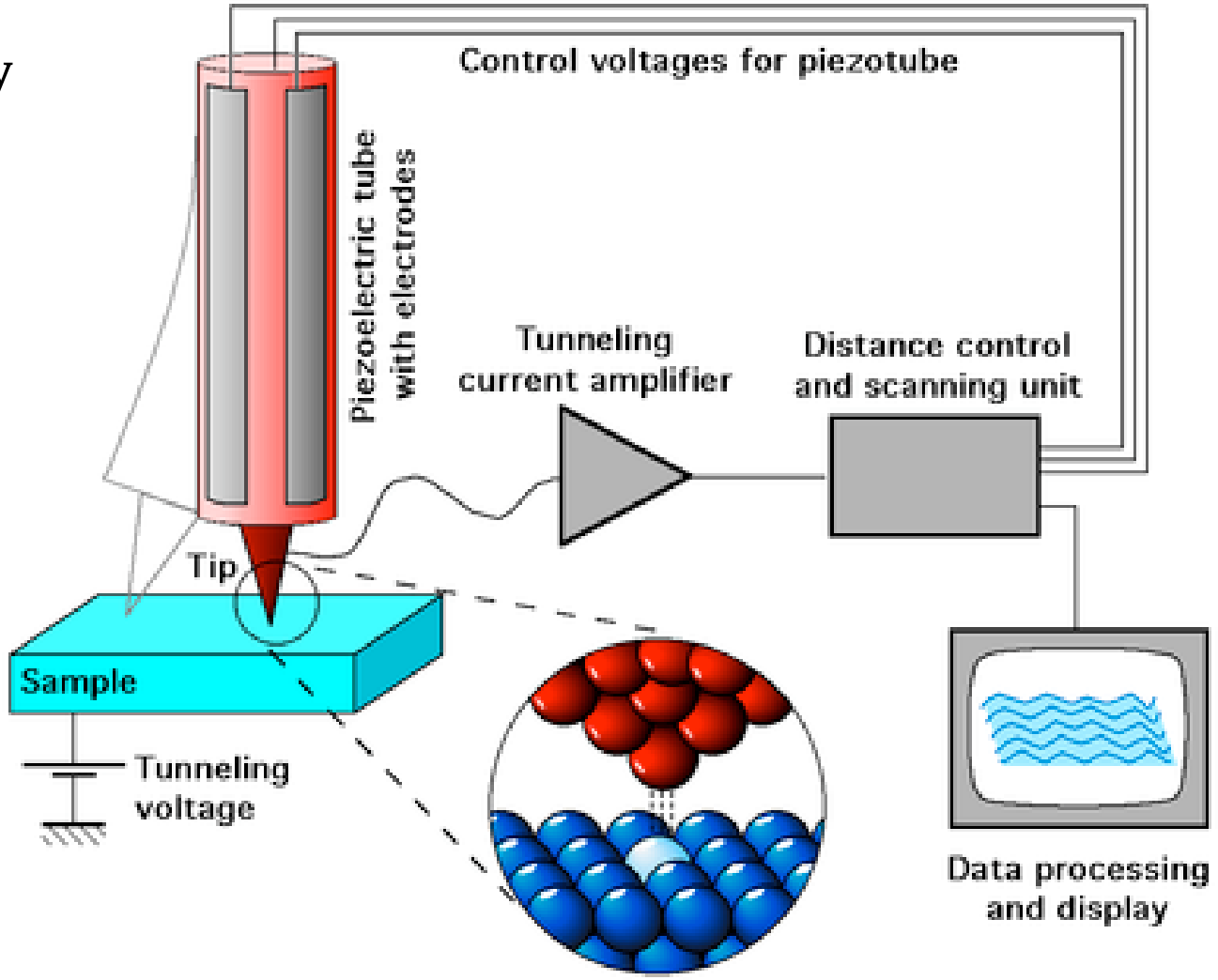
Anders Mikkelsen

Multispectral Imaging

Scanning tunneling microscope (STM)

Invented in 1982 by Binnig and Rohrer, for which they shared the 1986 Nobel Prize in Physics





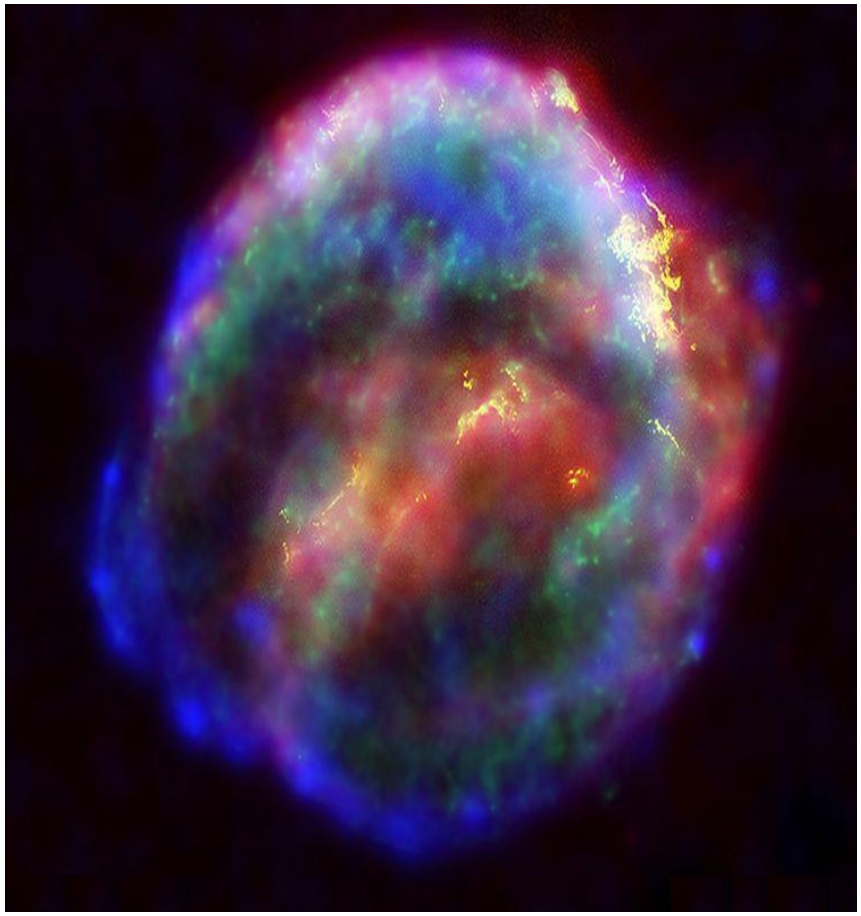
https://en.wikipedia.org/wiki/Scanning_tunneling_microscope

Astronomical imaging

Dainis Dravins

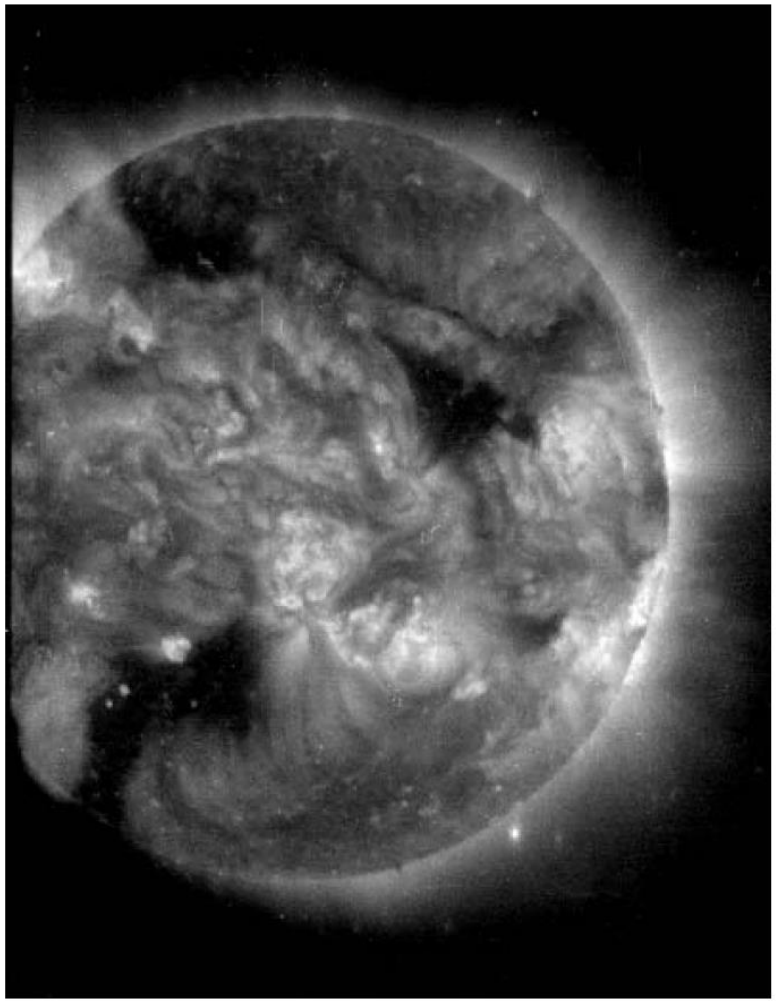
Multispectral Imaging

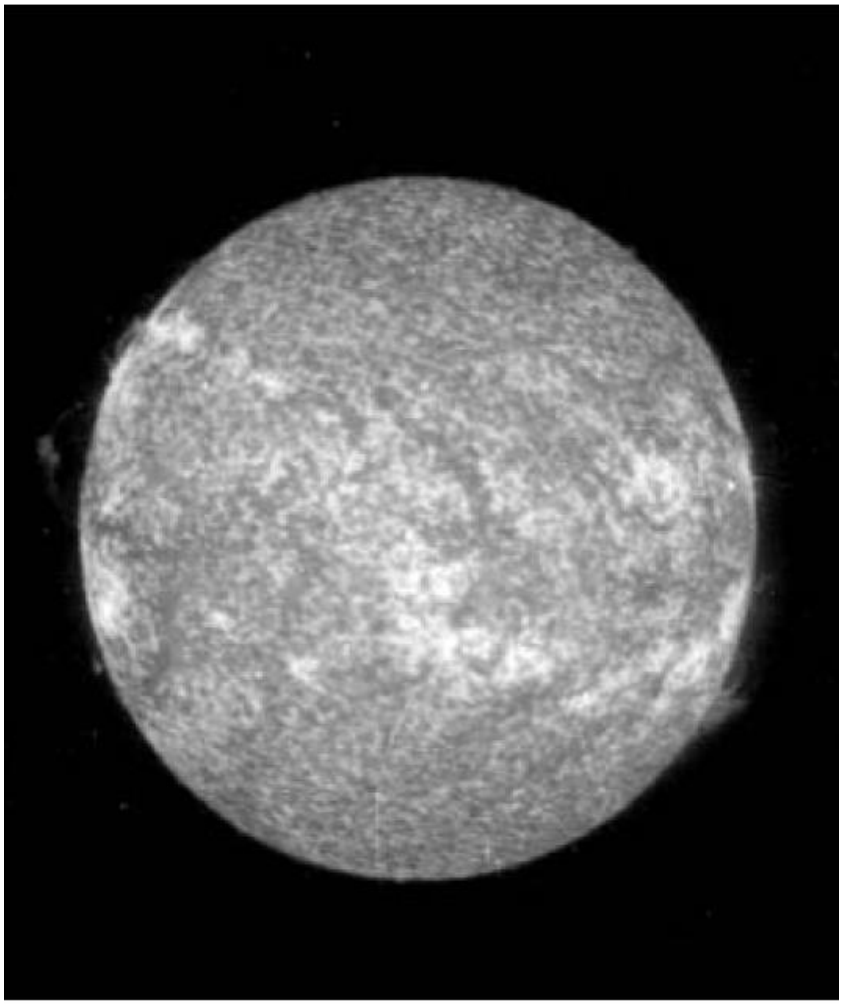
Supernova 1604



Multispectral (X-ray, optical and infrared) representation of the last supernova and the Milky Way in 1604

Coronal temperature diagnostics derived from multilayer observations with the multi-spectral solar telescope array





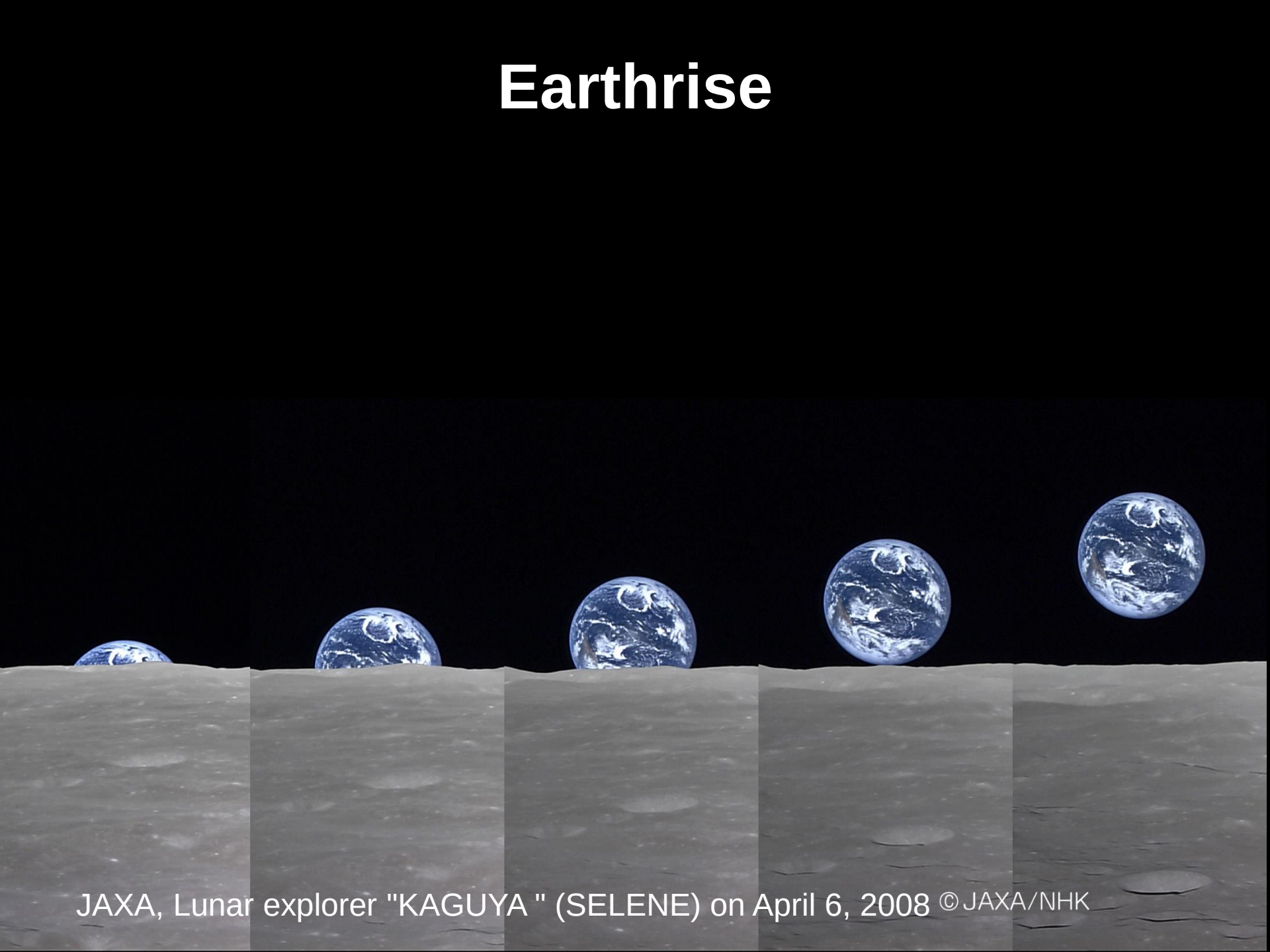
Images from the 1216 Å Ritchey-Chrétien telescope

Paul Boerner Dissertation thesis Stanford University July 2004

Satellite imaging

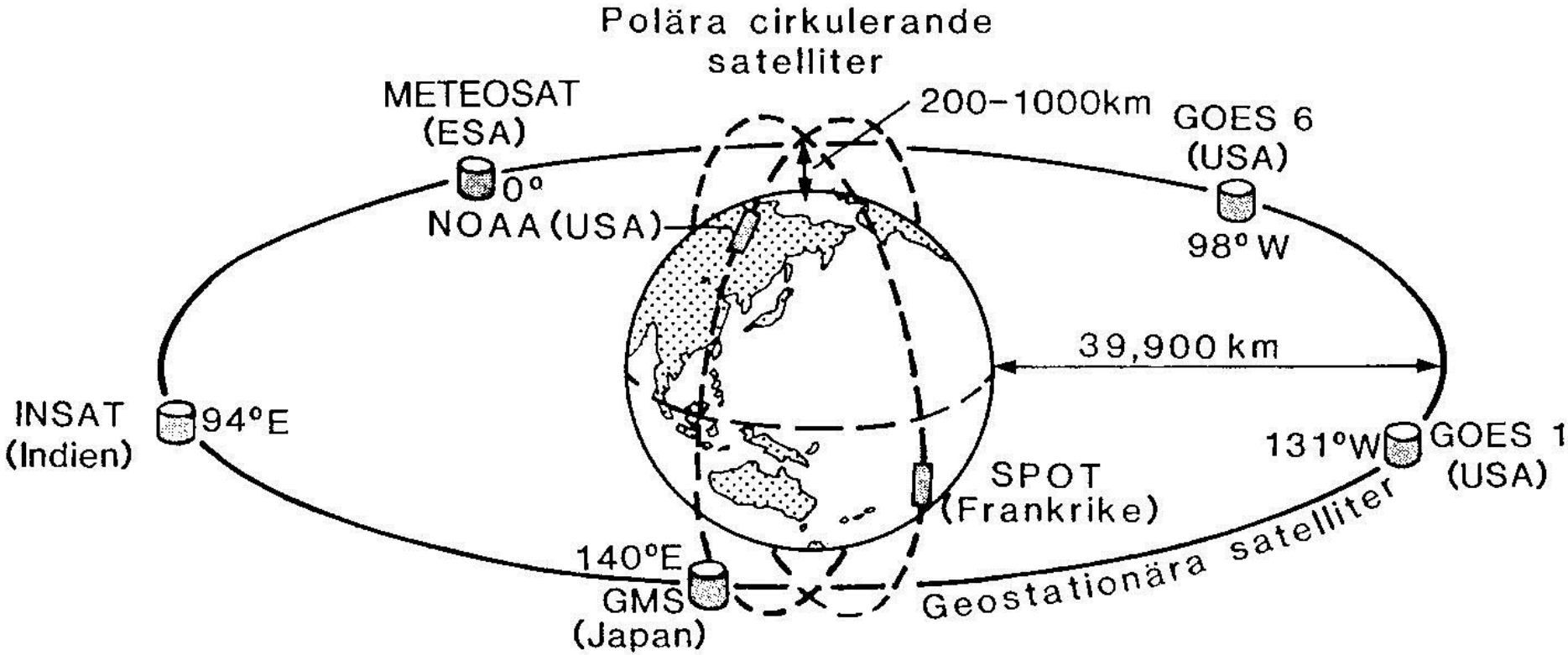
Multispectral Imaging

Earthrise

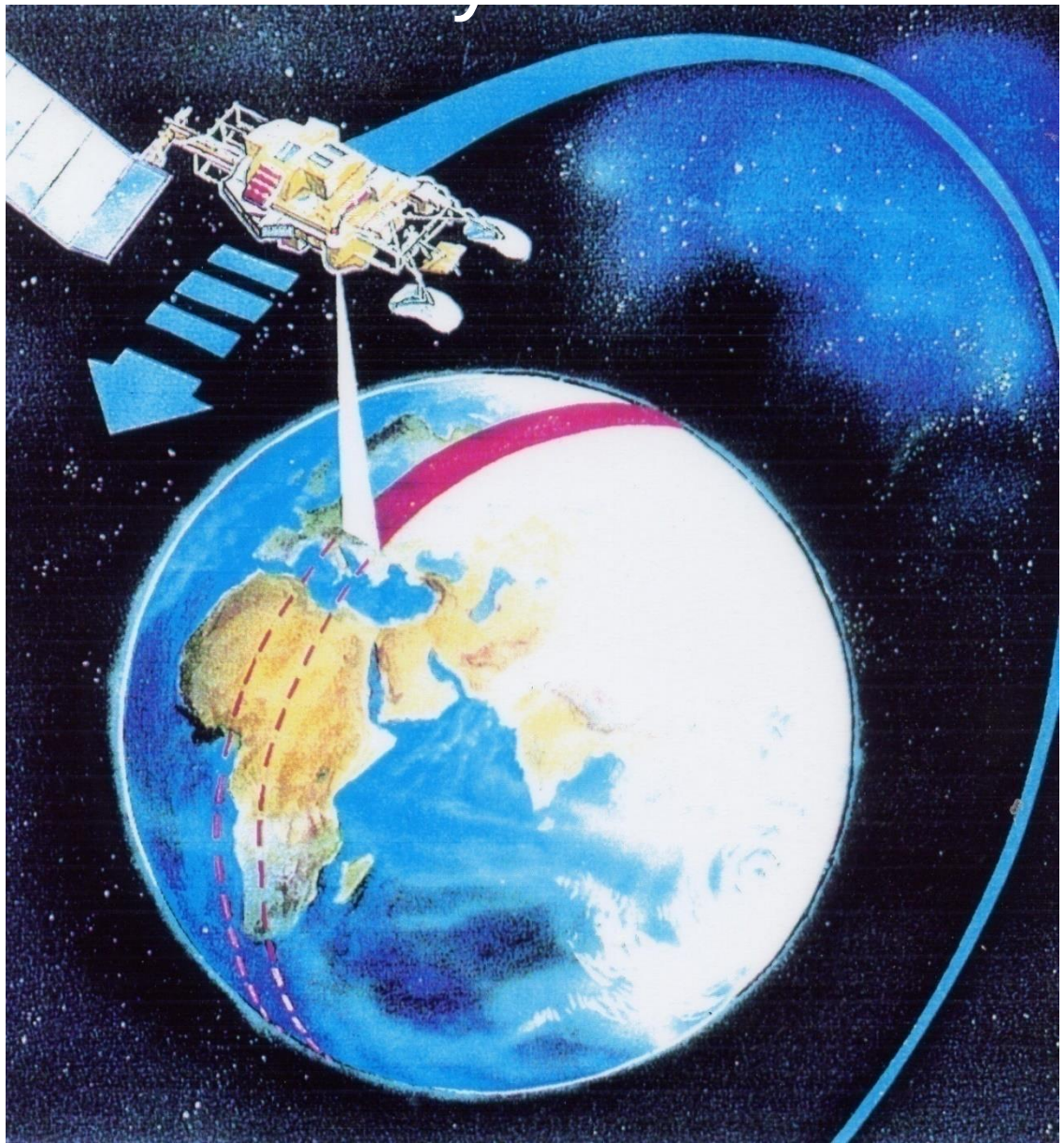


JAXA, Lunar explorer "KAGUYA " (SELENE) on April 6, 2008

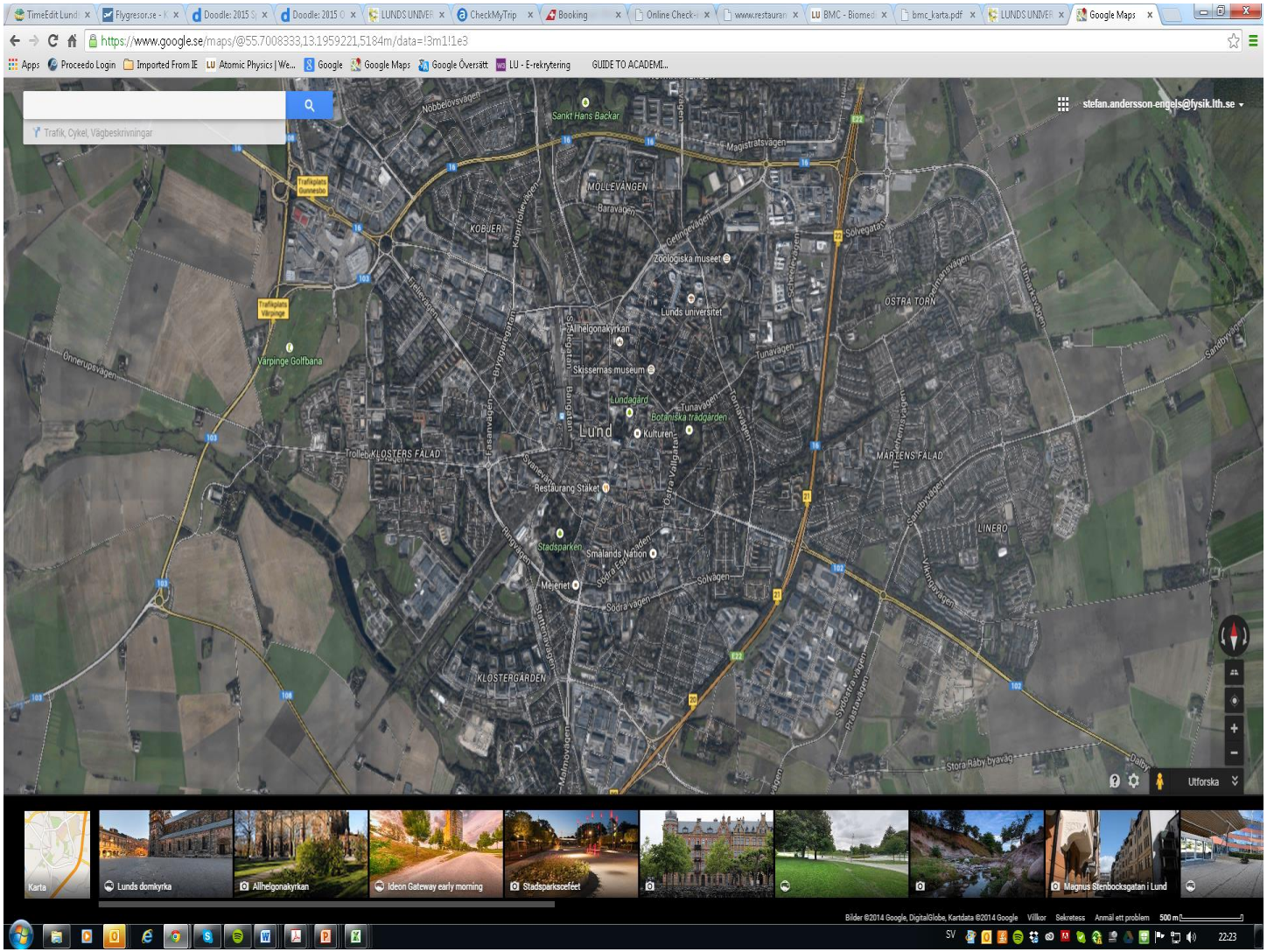
Polar and Geostationary Orbits



ISS: 350-410 km
Sun-synchroneous: 600-800 km
GPS: 20.200 km
Geostationary: 39.900 km
Moon: 384.000 km



Google Earth



Hyperion imaging spectrometer

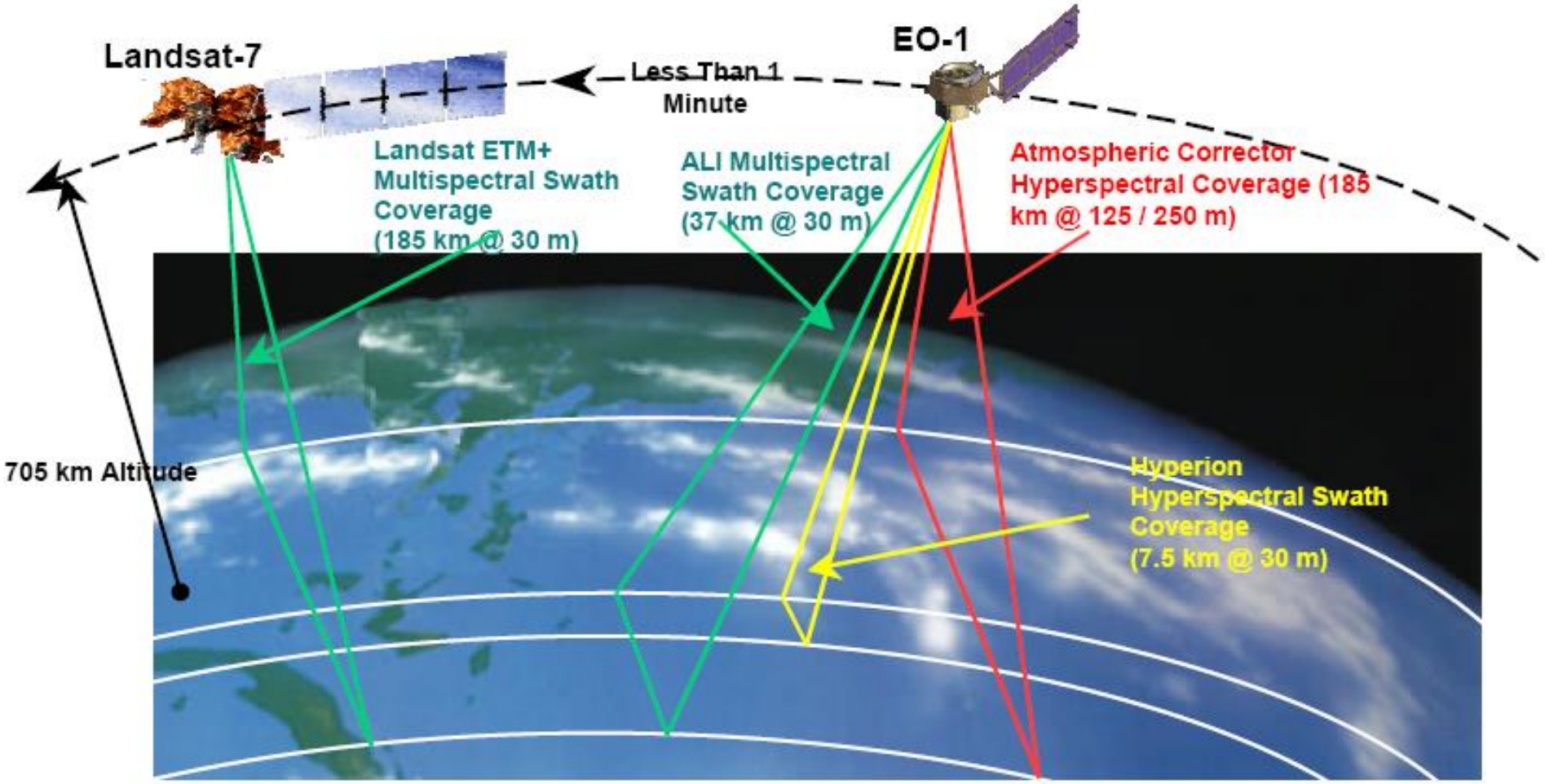
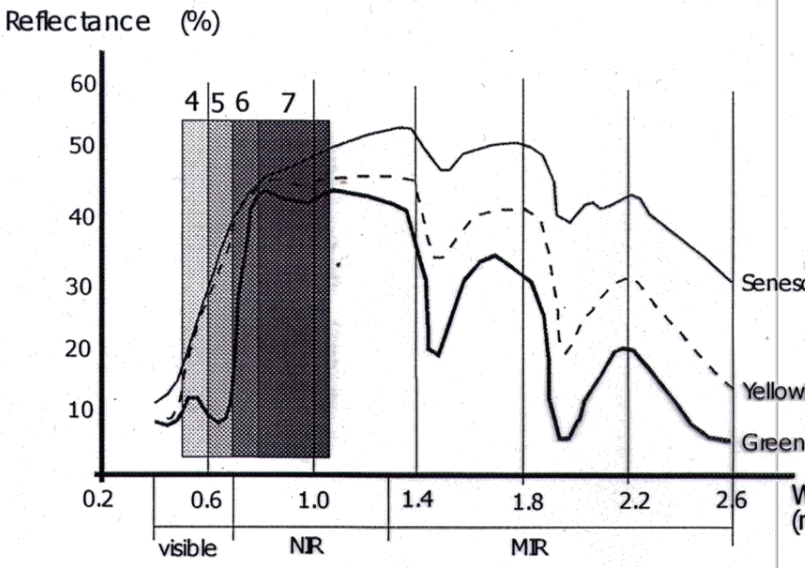
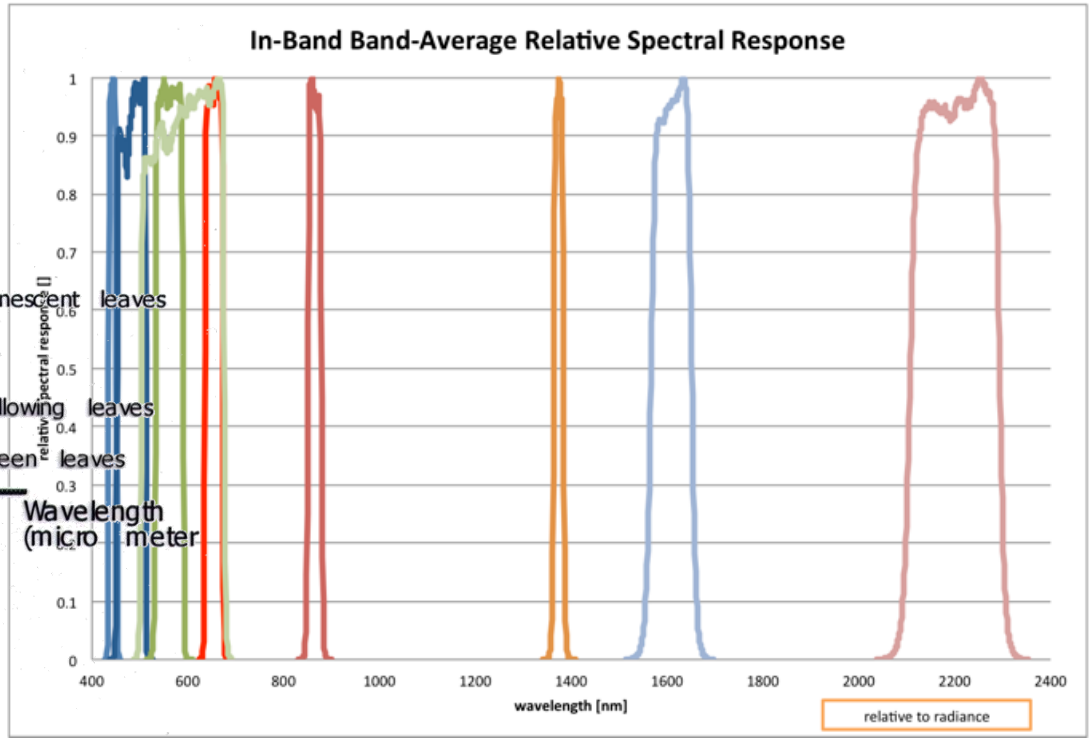


Figure 1-1– A view of the Earth with EO-1 above showing instrument swath widths

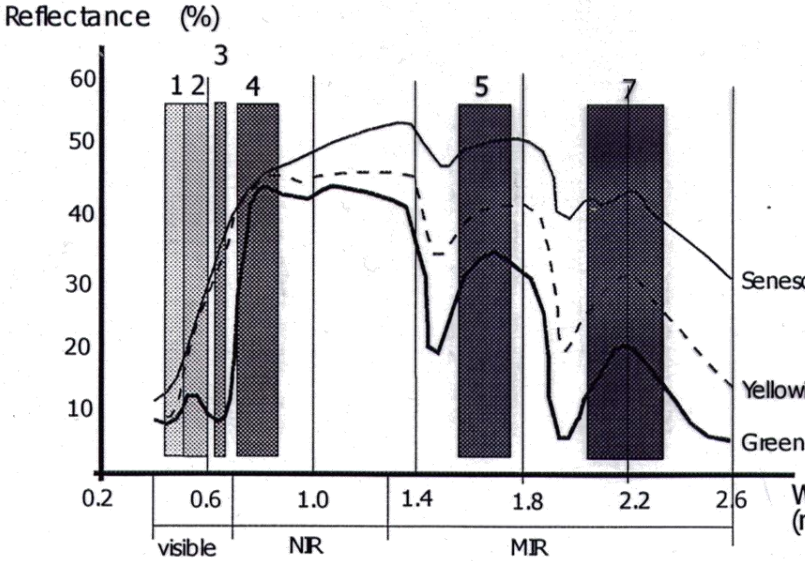
Landsat MSS

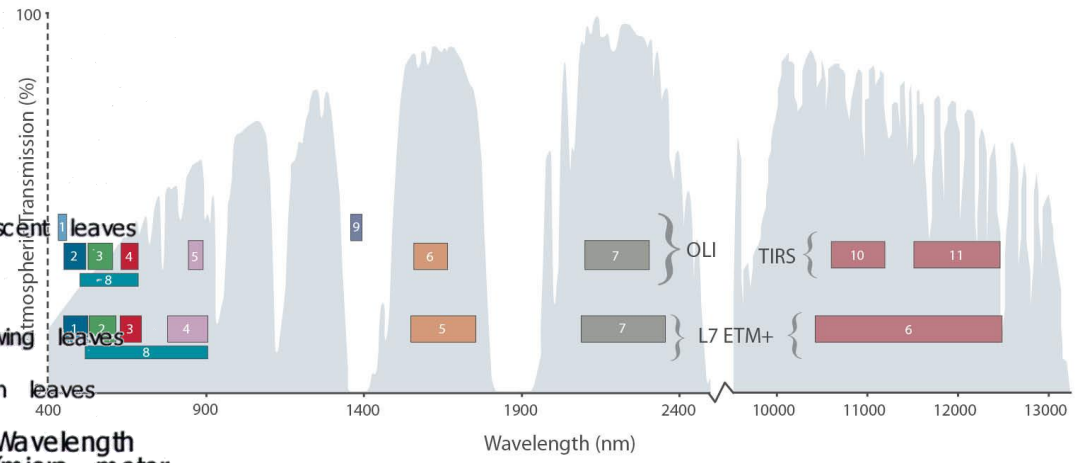


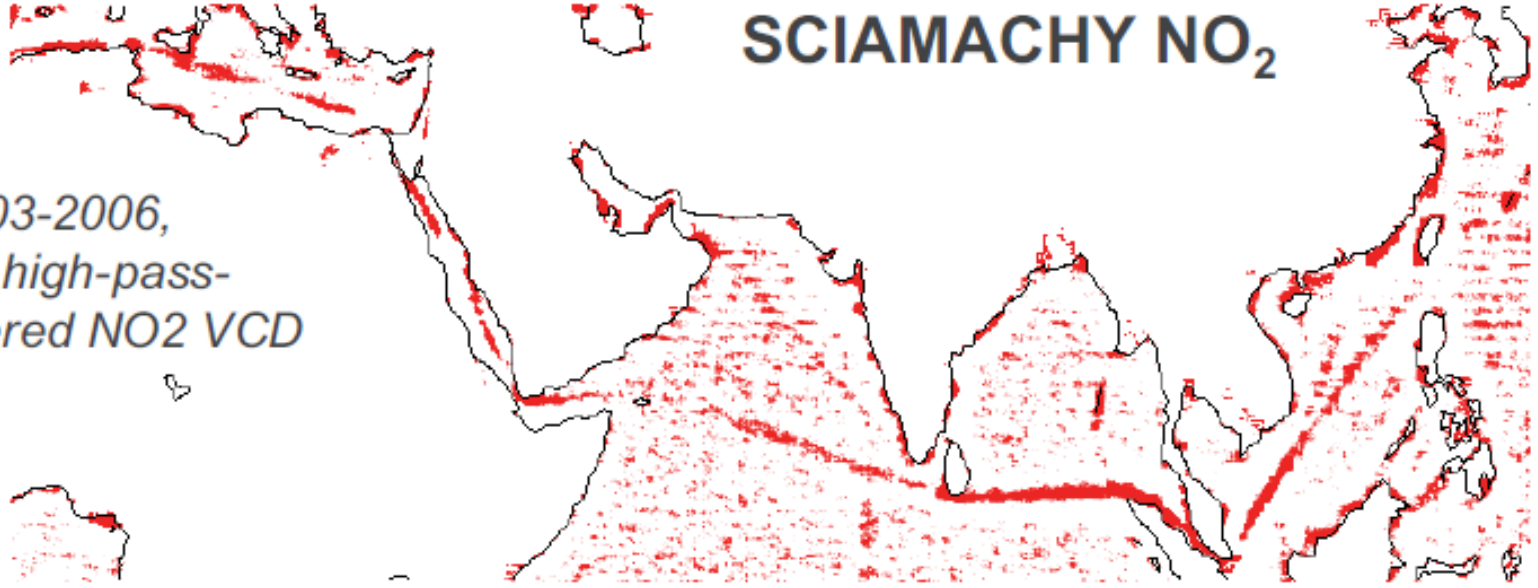
OLI Landsat 8



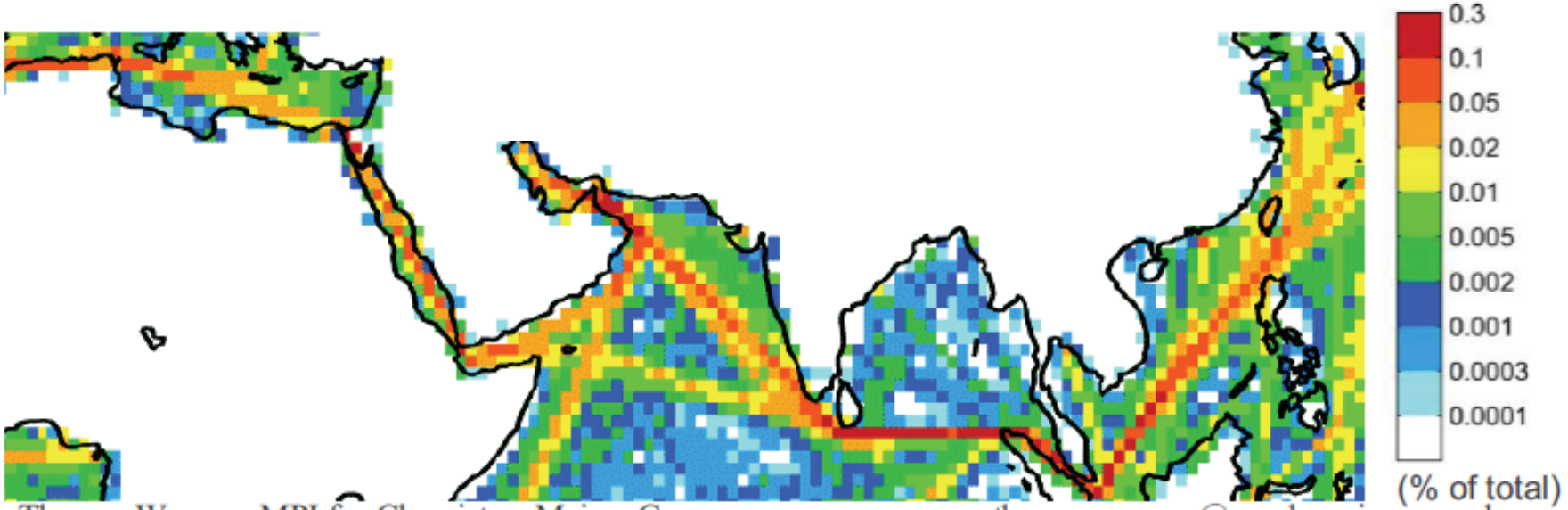
Landsat TM





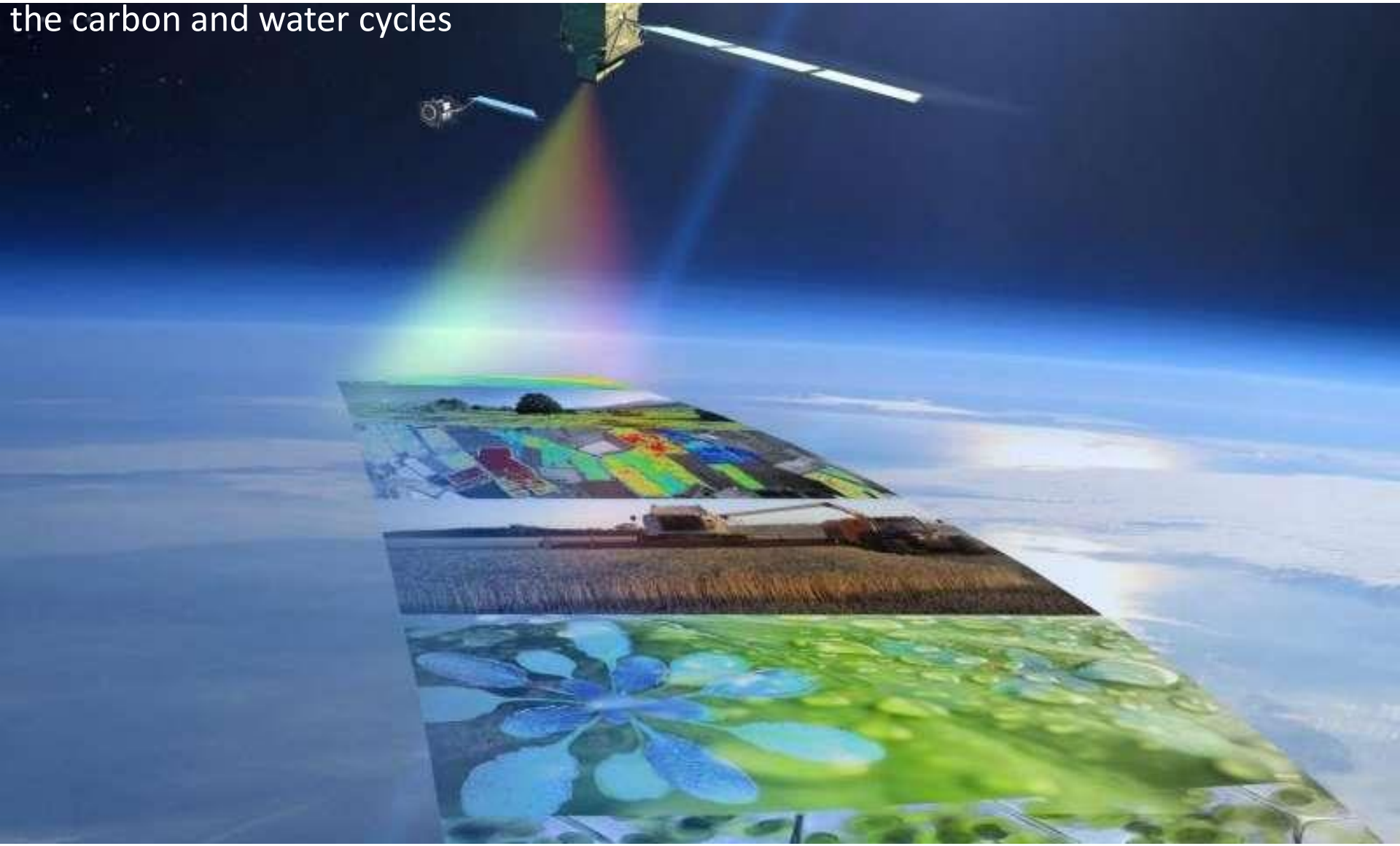


Automated Mutual-Assistance Vessel Rescue System



Thomas Wagner, MPI for Chemistry, Mainz, Germany thomas.wagner@mpch-mainz.mpg.de

The Fluorescence Explorer mission will provide global maps of vegetation fluorescence, which can be converted into an indicator of photosynthetic activity to improve our understanding of how much carbon is stored in plants and their role in the carbon and water cycles



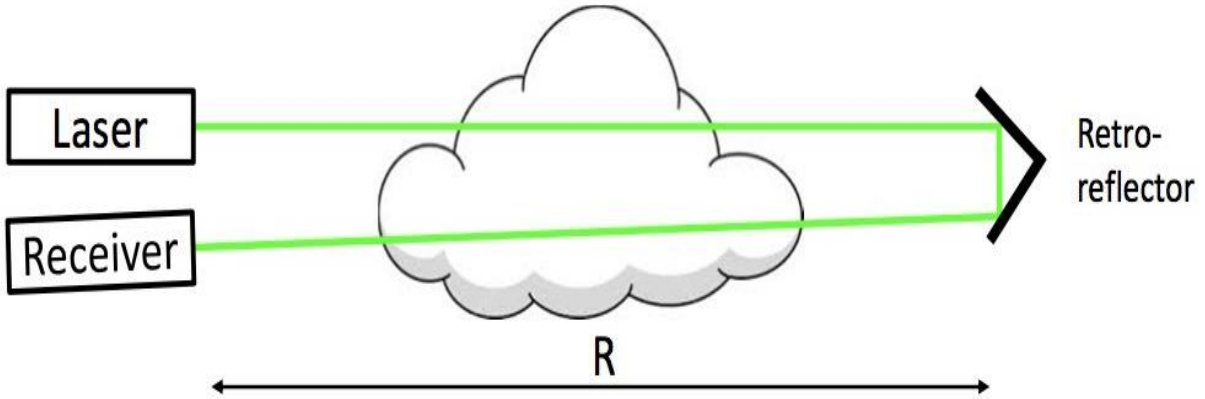
https://phys.org/news/2015-11-satellite-health.html#jCp

Active remote sensing

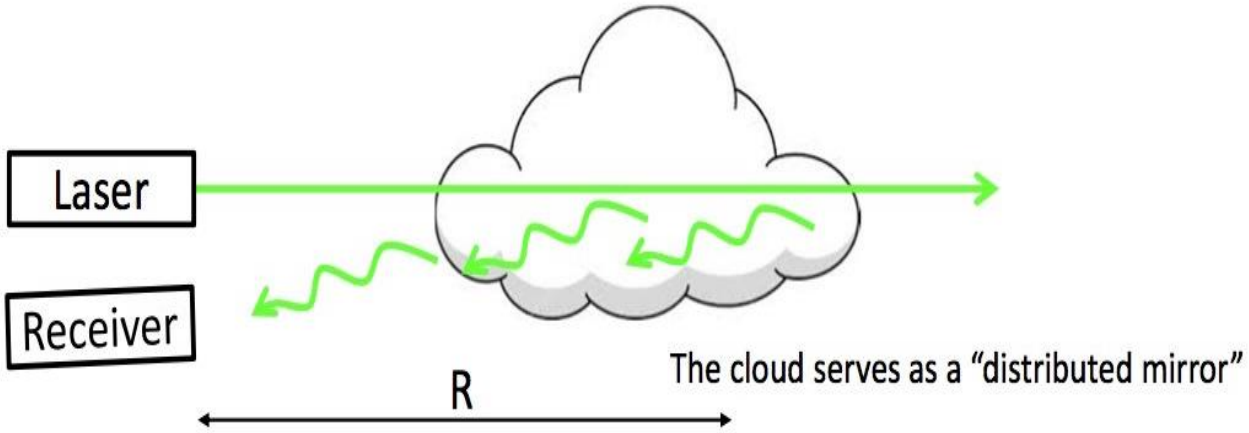
Multispectral Imaging

Active remote sensing

Long-path absorption measurements

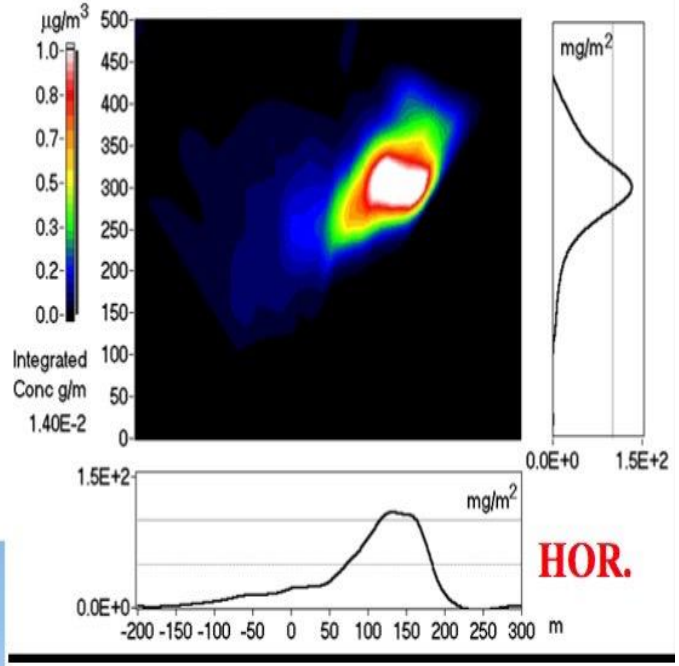


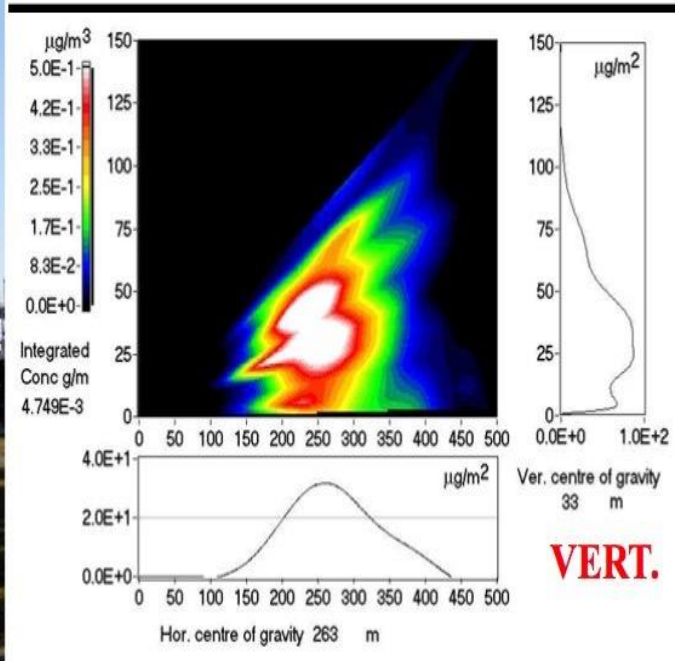
Light detection and ranging (LIDAR) a.k.a. laser radar



Active remote sensing

Atomic Mercury
LIDAR Mapping and Flux Measurement
Rosignano Solvay, Italy





Combustion imaging

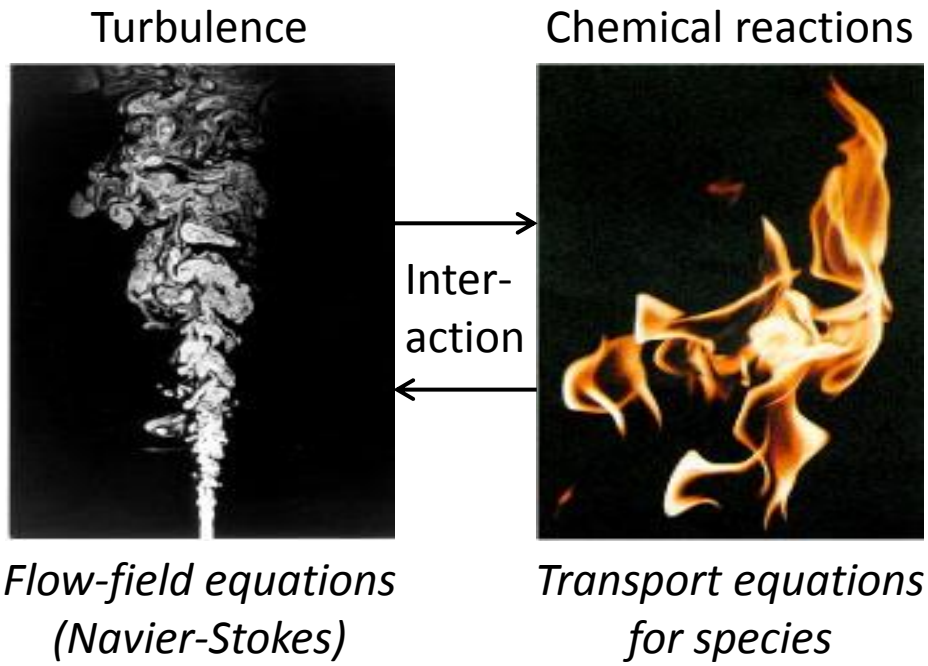
Joakim Bood

Multispectral Imaging

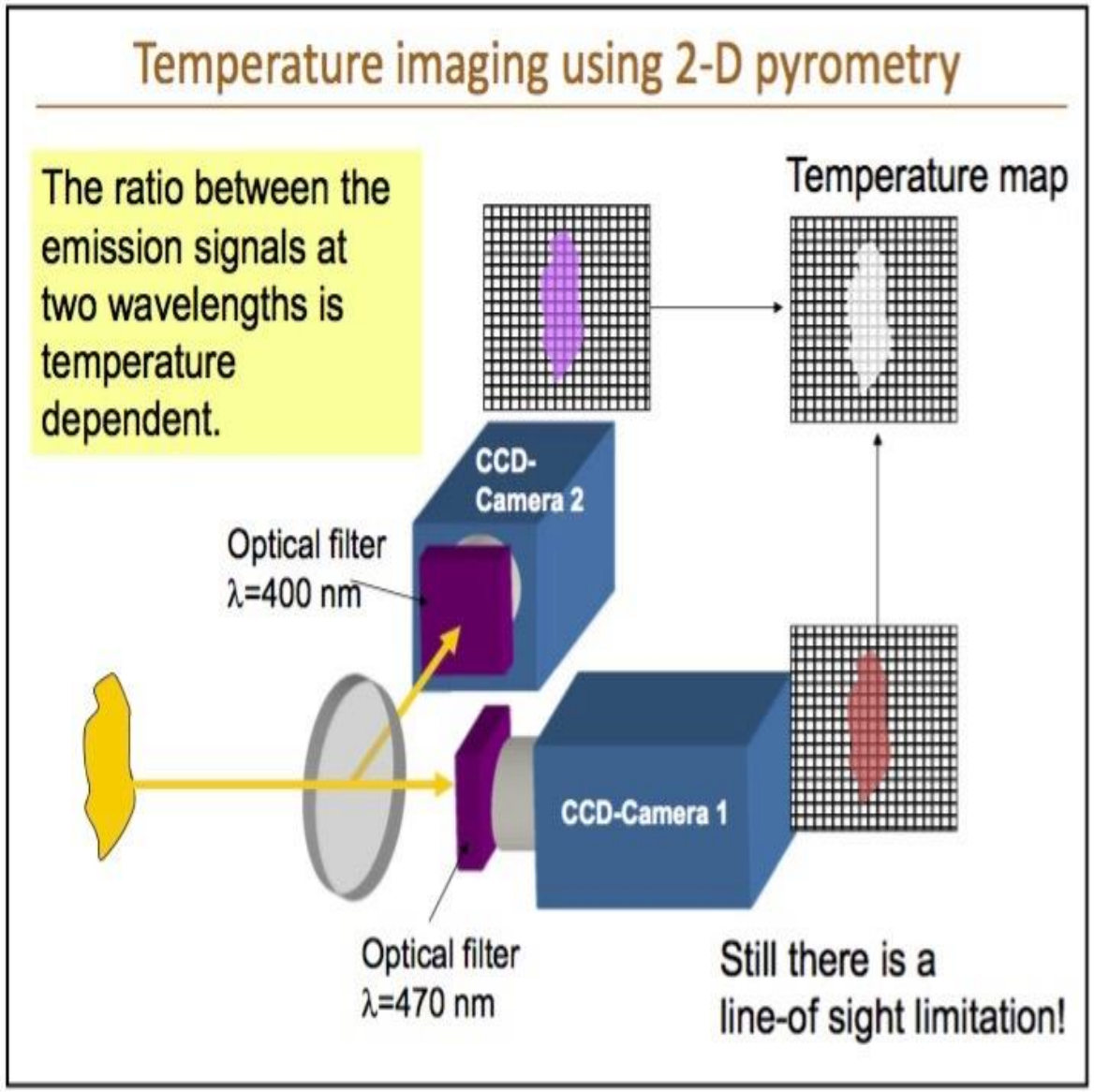
Combustion processes are very complex

The chemistry is extremely complicated…

then there is also interaction between the chemistry and the turbulent flow

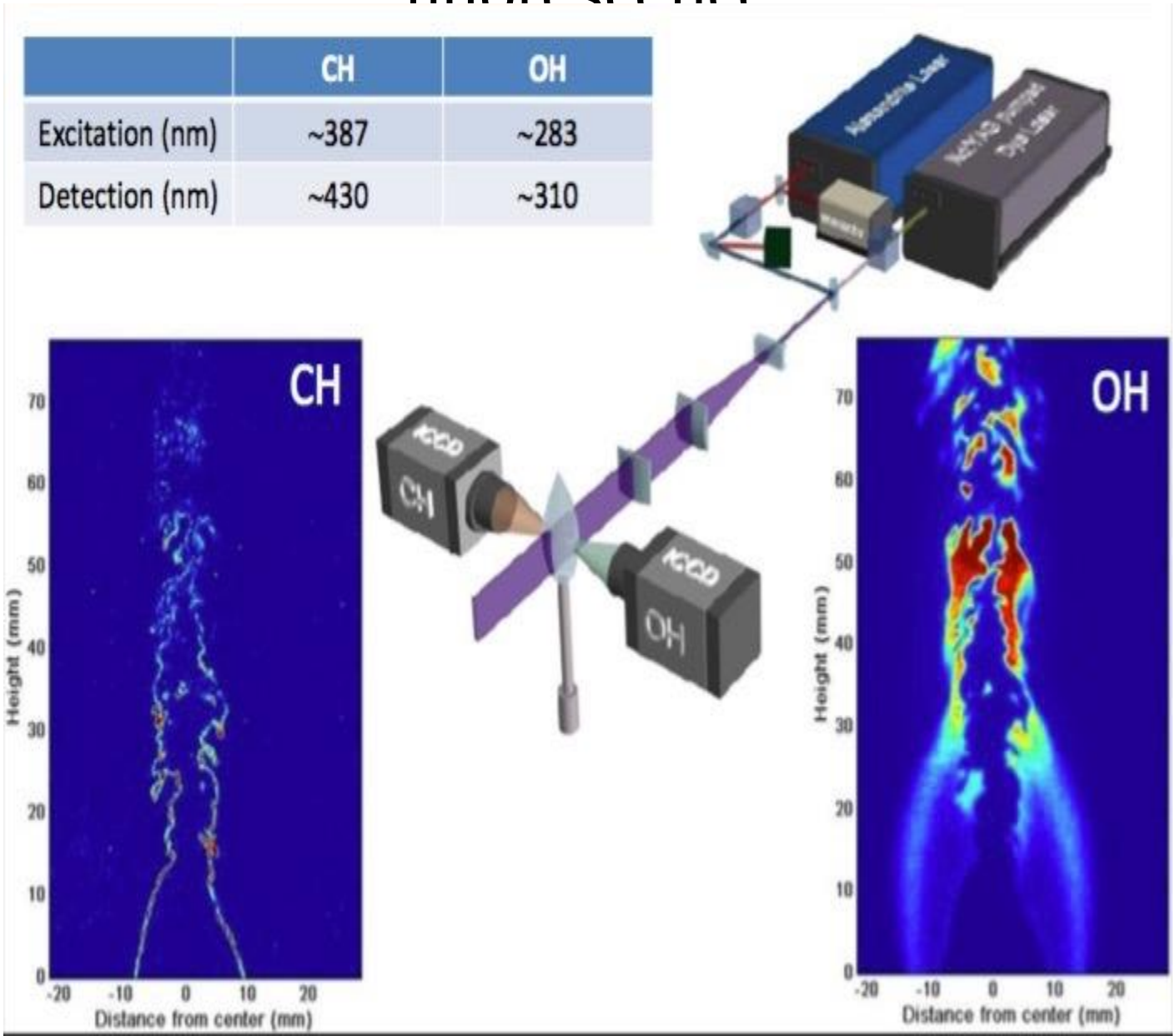


Combustion diagnostics: Non-contact temperature measurements



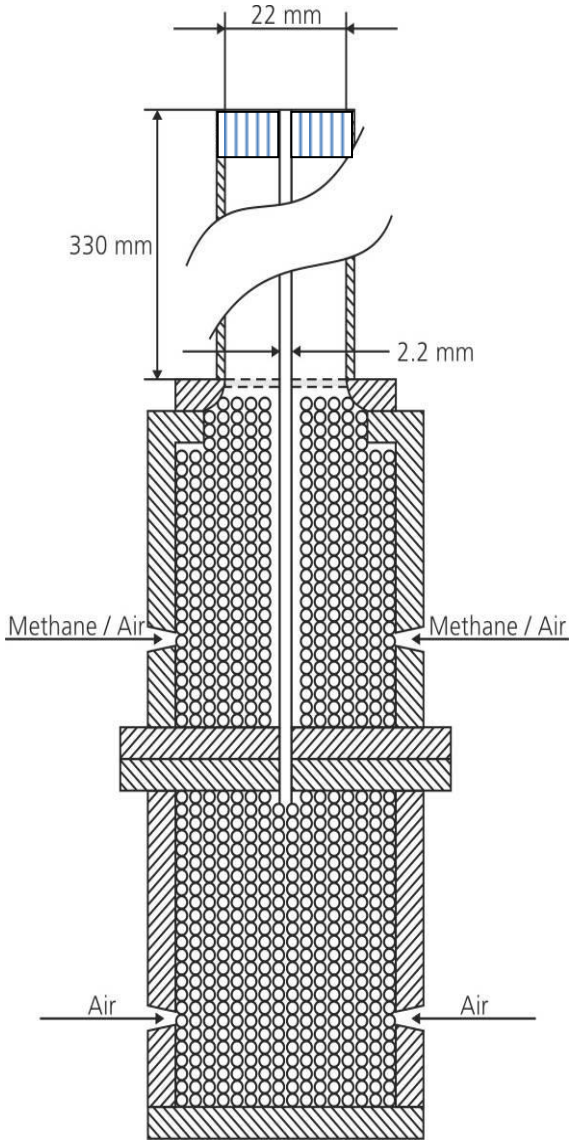
Combustion diagnostics: Laser-induced fluorescence

	CH	OH
Excitation (nm)	~387	~283
Detection (nm)	~430	~310

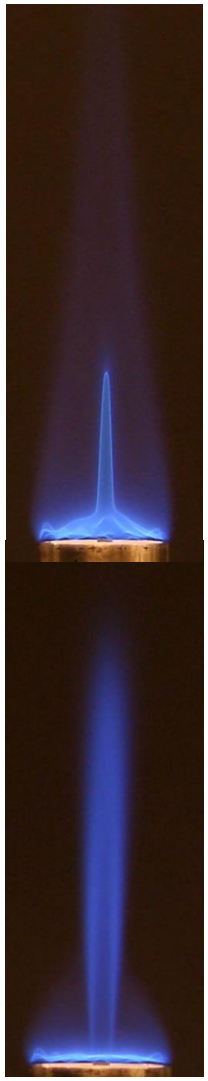


Simultaneous PLIF imaging of CH and CH_2O

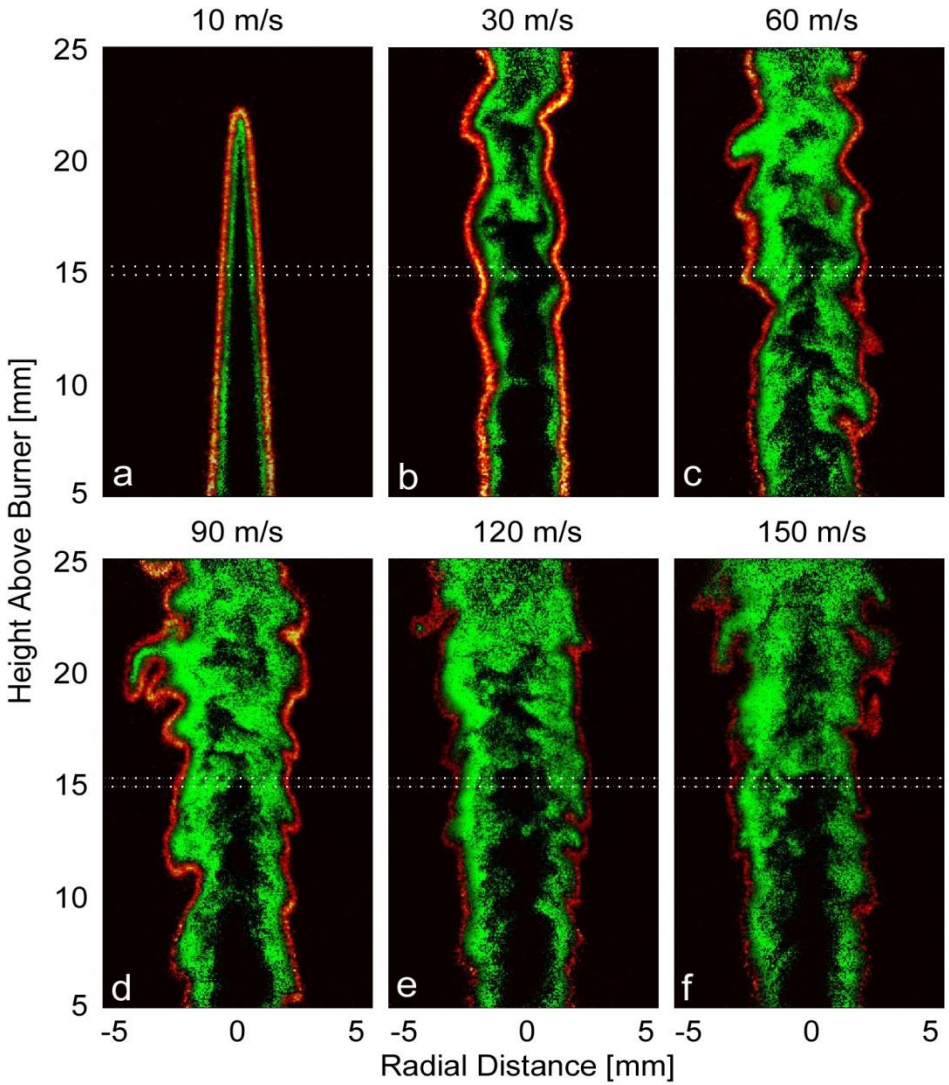
Burner



Flames



PLIF images (CH anf CH_2O)



Li et al. Comb. and Flame, 2010

Multispectral imaging – from astronomy to microscopy