Applications of synchrotron radiation sources

High School Teacher Programme

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Outline

- **Synchrotron radiation**
- **Synchrotron light source**
- **Applications of synchrotron radiation**
  - Daily life applications
  - Medical applications
  - Metallurgy
  - Understanding snow avalanche
  - Infra-red spectroscopy
  - Infra-red microscopy
- **Conclusion and outlook**

Introduction

- Synchrotron light is a powerful research tool with many applications.
- synchrotron light sources allow scientists to control the intensity and wavelength of light for research that's led to better batteries, greener energy, new high-performance materials, more effective drug treatments, etc…

Synchrotron radiation

- When accelerated, low-mass particles such as electrons lose far more energy to synchrotron radiation than heavy particles like protons do.
- synchrotron radiation in facilities called light sources
- electrons travel in circles radiate extremely intense light like mud flung from a spinning tire or sparks from spinning fireworks.

Synchrotron radiation

- Synchrotron light gets its name from the synchrotron particle accelerators where it was first observed
- Synchrotron radiation is the light emitted by:

  relativistic charged particle beam if it moves along curved trajectory

Accelerating charged particles

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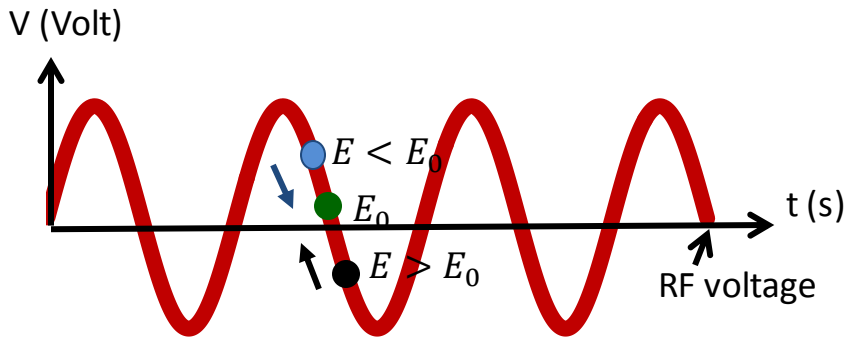
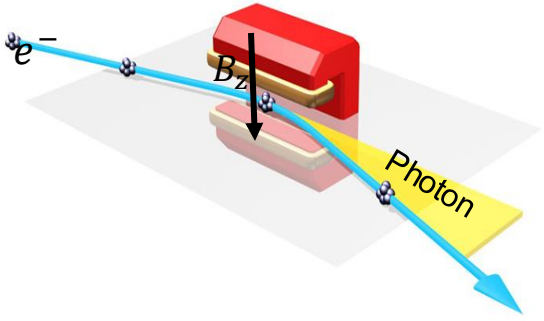
  relativistic charged particle beam if it moves along curved trajectory

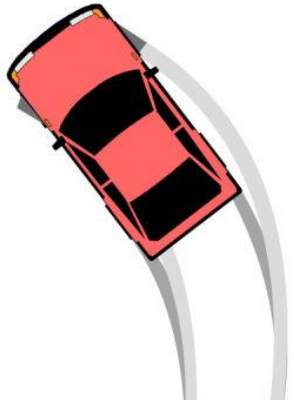
Acceleration of electrons is achieved by propelling them with parallel electric field. The energy of the waves is transferred to the particles as the particles travel through accelerating cavities (special cavities called Radio Frequency cavities made of copper or superconducting material)



Bending charged particle trajectory

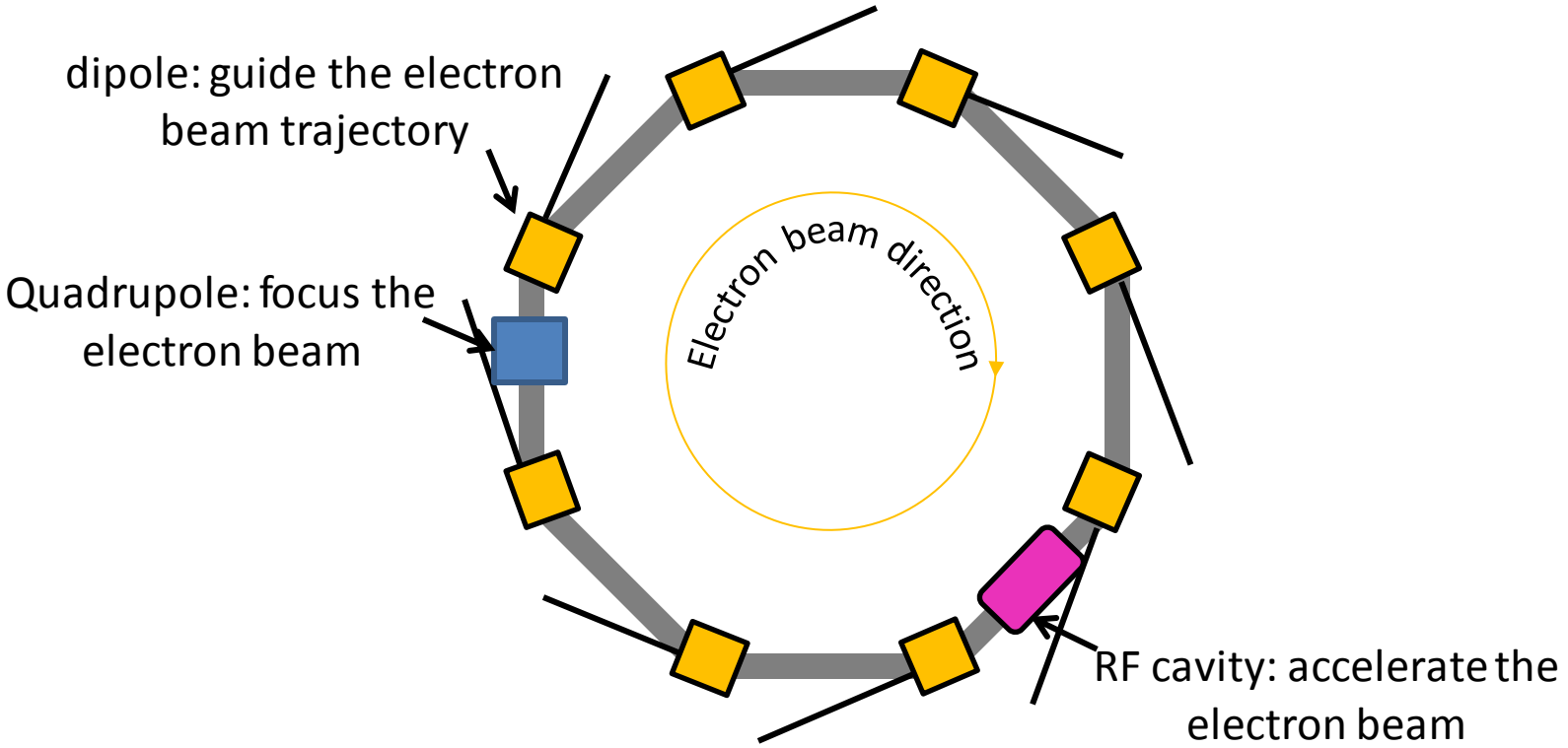
- Synchrotron light gets its name from the synchrotron particle accelerators where it was first observed
- Synchrotron radiation is the light emitted by:
  relativistic charged particle beam if it moves along curved trajectory
- Charged particle trajectory is bend by a magnetic field
- The simplest magnetic field used to bend the trajectory of charged particles is a dipole field (what you feel when you drive a car around a corner?)



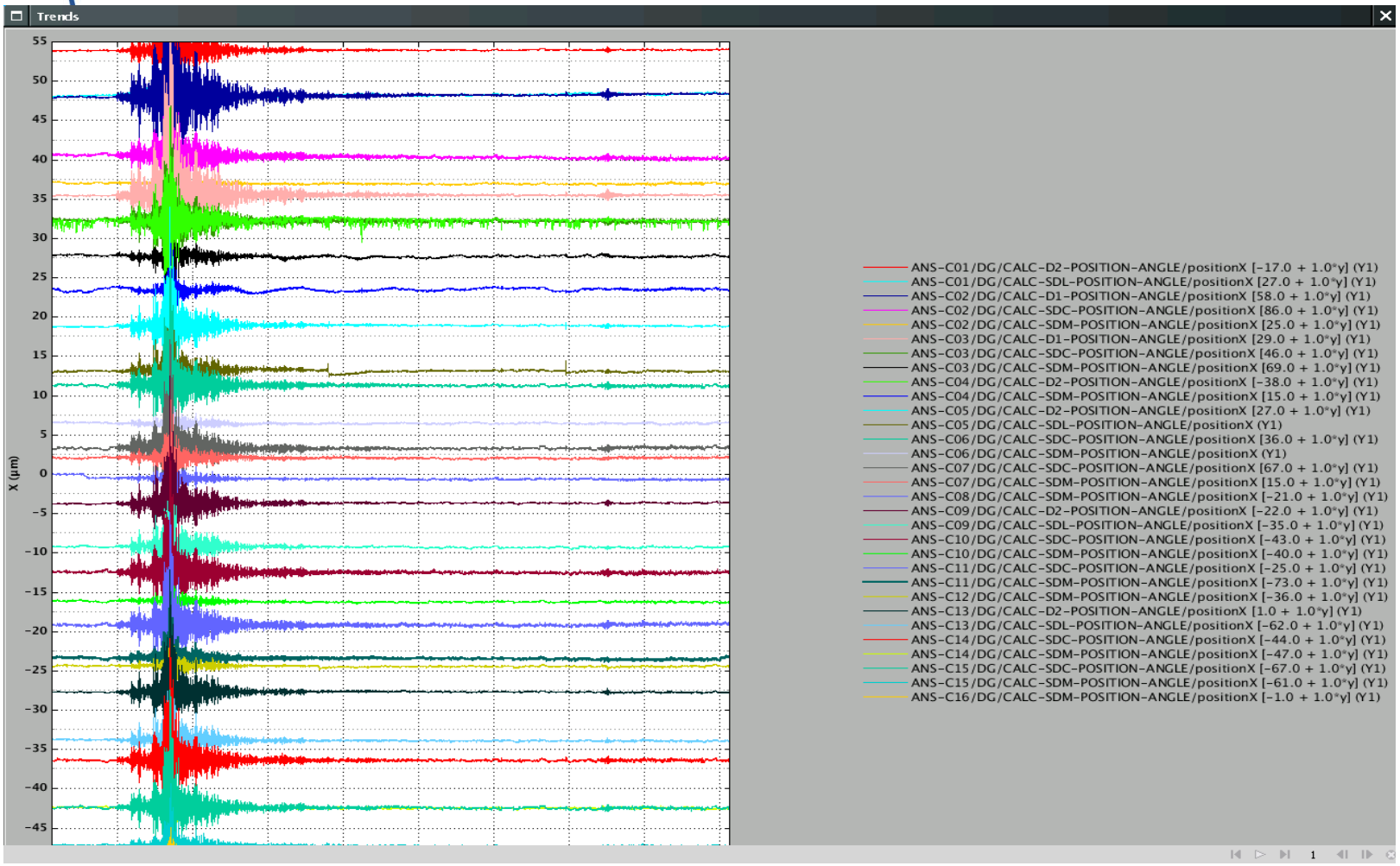


Synchrotron radiation

Storage ring

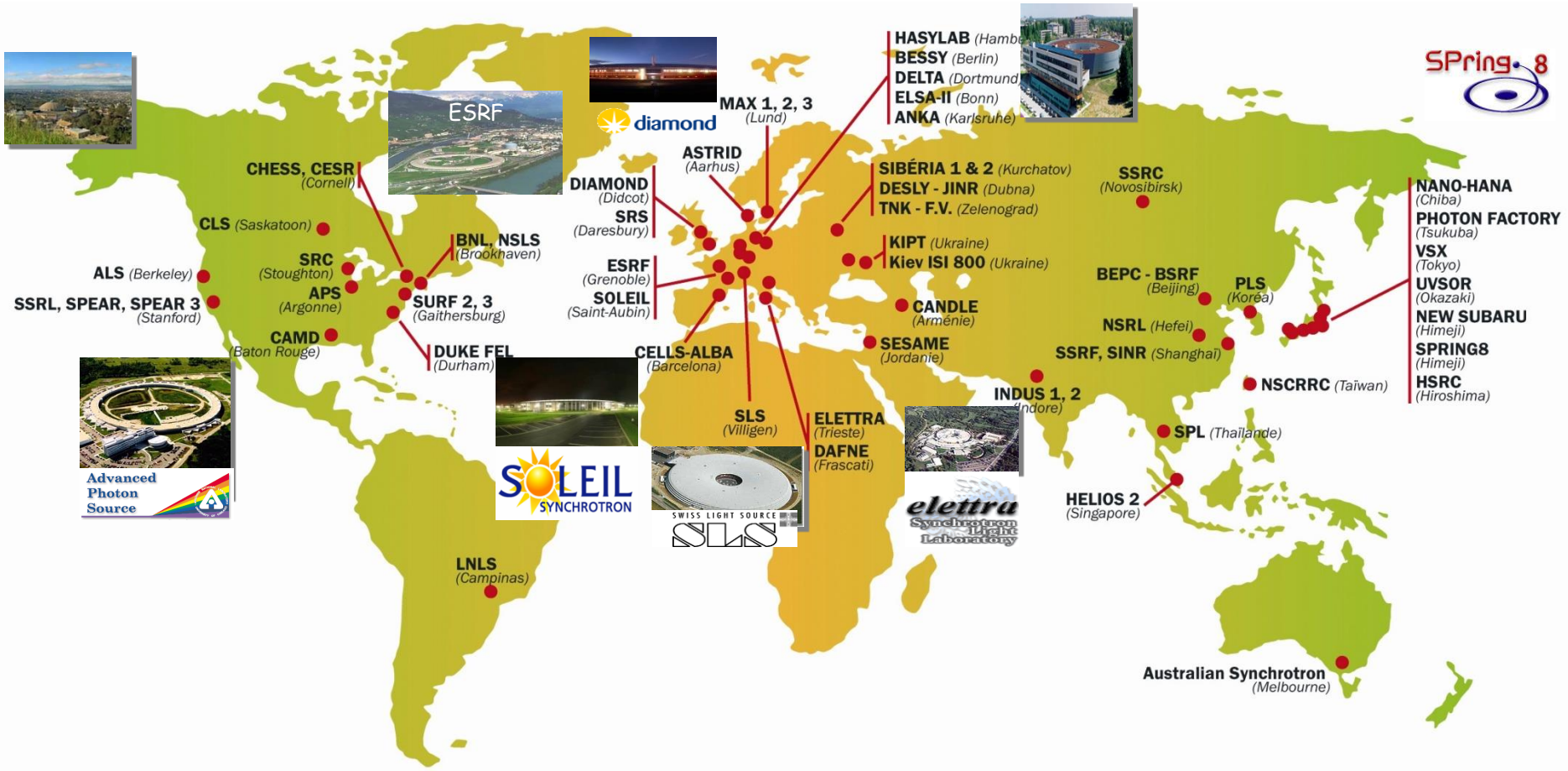


Very stable electron beam



Seism earth quick in Japan in 2011 observed @ SOLEIL in France

Synchrotron light sources in the world

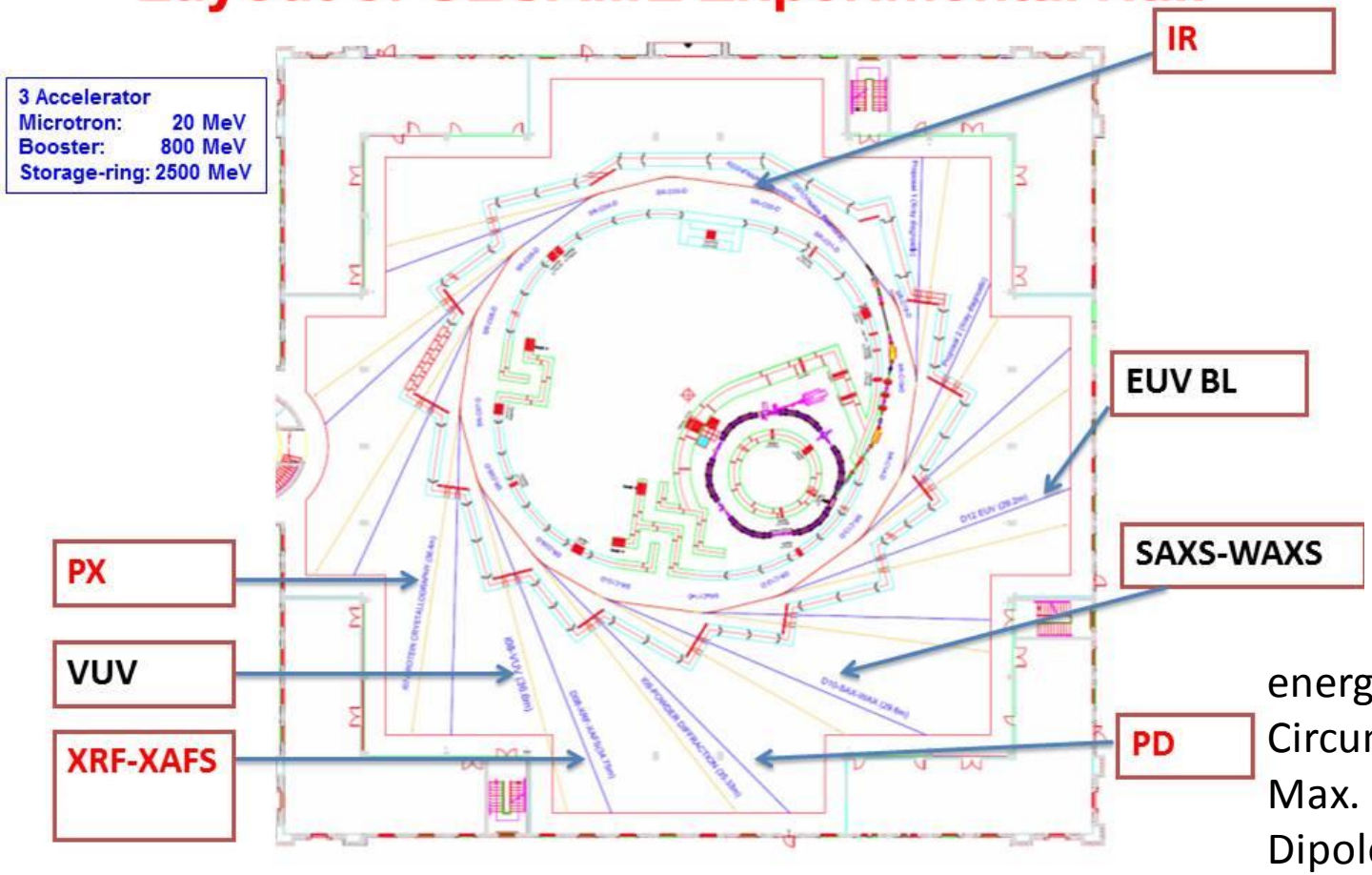


SESAME Synchrotron

- The first synchrotron light source for the Middle-East
- Under construction in Amman in Jordan
- It is a cooperative venture by scientists and governments of the region set up on the model of CERN
- Members: Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Turkey and Palestine
- Observers: Brazil, China, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, Russian Federation, Sweden, Switzerland, the UK, and the USA

SESAME Synchrotron

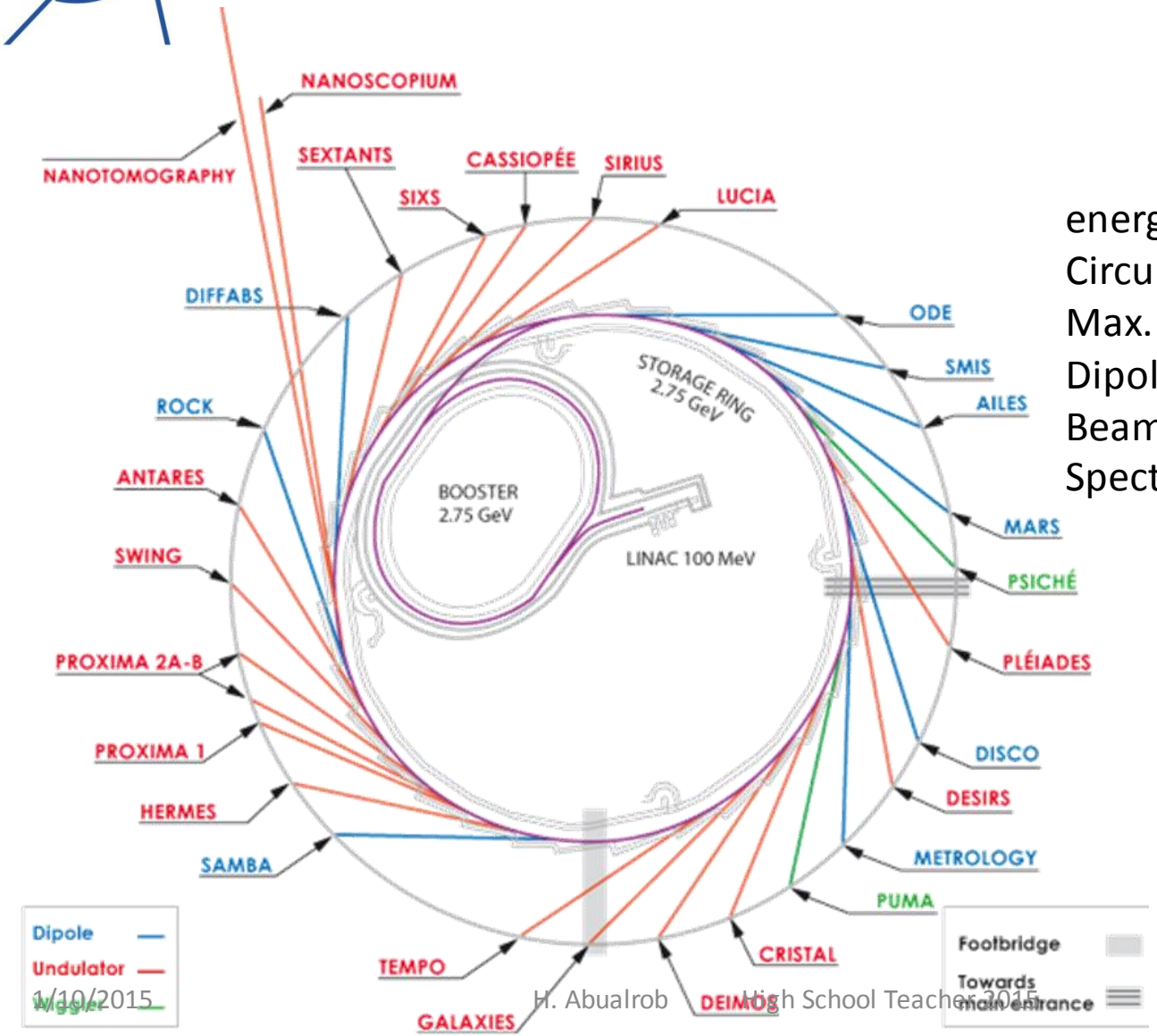
Layout of SESAME Experimental Hall



energy: 2.5 GeV
Circumference: 133.2 m
Max. injected current: 400 mA
Dipoles field: 1.45 T

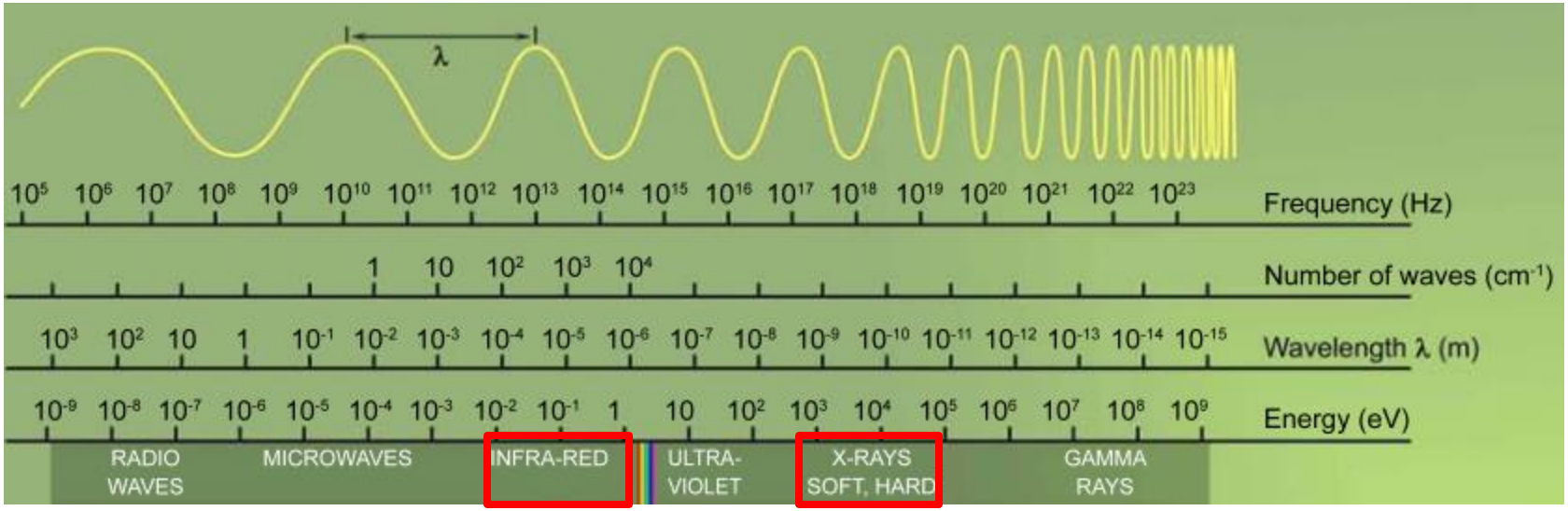
SOLEIL Synchrotron

Synchrotron SOLEIL



energy: 2.75 GeV
Circumference: 354 m
Max. injected current: 500 mA
Dipoles field: 1.72 T
Beamlines: 26
Spectral range: far IR-hard X-ray

Synchrotron radiation: wide spectral range



Wide spectral range from far Infra-Red to hard X-ray
Spectral range selection enable different scientific applications

Synchrotron radiation applications

Biologie

Medecine

Pharmacology

Cosmetics

Chemistry

Archeology

Energy & environment

Material science

Food quality

Astrophysics

Geophysics

Applications in our daily life

Have you ever thought how the quality of your baby diapers was improved?

First observation of the detailed wet structure of the superabsorbent polymer material used in diapers. That enabled them to adjust and improve the formula for the superabsorbent polymers until they had the material used in all modern-day diapers

Applications in our daily life

Many ports are now turning to high-energy X-rays generated by particle accelerators to identify contraband and keep ports safe. These X-rays penetrate deeper and give screeners more detail about the nature of the cargo.

Applications in our daily life [1]

- ✓ A basic chocolate recipe consists of roughly one-third cocoa butter, a fat that crystalizes easily. How the butter crystalizes determines the quality of the chocolate.
- ✓ Until recently, food scientists didn't know what the cocoa crystals looked like and thus didn't know how to avoid the bloom. But with the help of synchrotron light beam, scientists were able to use a focused beam of light to see the crystal structure of cocoa butter for the first time.

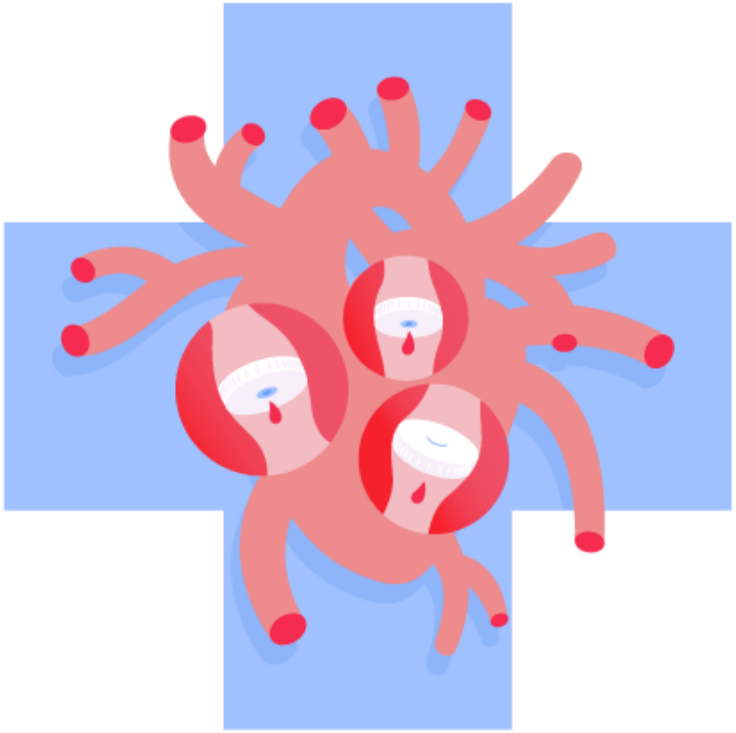
- ✓ Using the European Synchrotron Radiation Facility, scientists from the got a close-up view of the molecular structure of chocolate [1].
- ✓ This allowed candy manufacturers to develop new techniques that could avoid the dreaded "fat bloom" - the white powder that can form on the outside of chocolate.
- ✓ In order to obtain the ideal crystal form, chocolate manufacturers repeatedly heat the butter to a specific temperature and then cool it down. If the chocolate doesn't reach its ideal crystal state, it will develop the "fat bloom."

[1] http://www.esrf.eu/UsersAndScience/Publications/Highlights/2004/SCM/SCM8

Applications in our daily life

Study the properties of beauty creams, hair products, lipsticks or nail varnishes and their tolerance by skin or hair.
By examining their nanostructure, the cosmetics engineers are able to develop more stable products with longer-lasting effects. Trace of these products trapped in the skin or in the hair can be detected by using synchrotron X-ray microscopy.

Medical applications

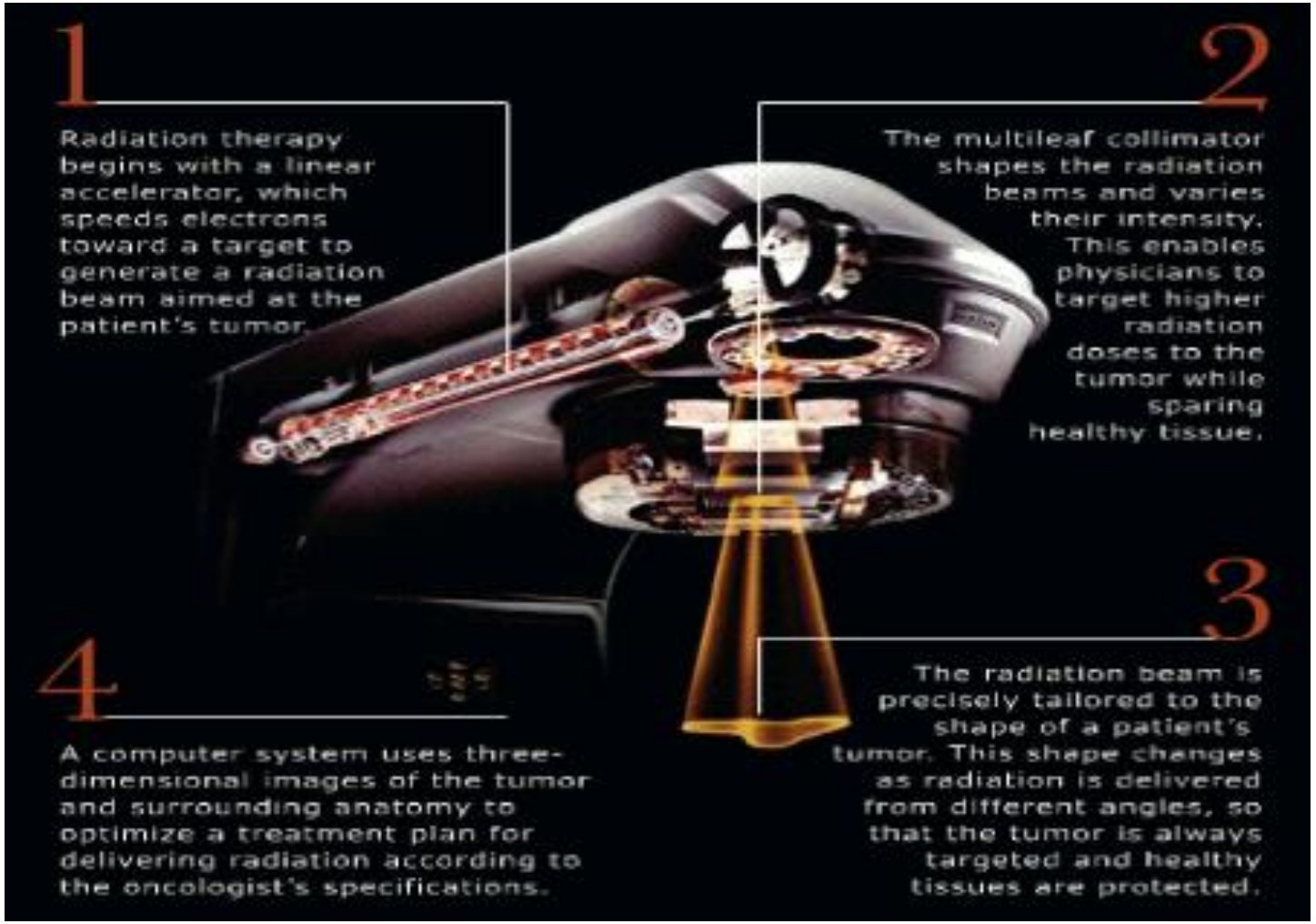


Physicists are improving the safety of artificial heart valves by designing a new material bombarded with silver ions from a particle accelerator. The treated surface of the material keeps the body from identifying the valve as an invader and surrounding it with potentially dangerous extra tissue

Medical applications

Magnetic Resonance Imaging makes detailed images of soft tissue in the body. Unlike X-rays, MRIs can distinguish gray matter from white matter in the brain, cancerous tissue from noncancerous tissue, and muscles from organs, as well as reveal blood flow and signs of stroke. Key aspects of this important technology emerged from particle physics research.

Medical applications



Radiation therapy to treat cancer cells

Metallurgy

Metallic components are subject to considerable mechanical stress leading to deformation, which affect its performance and can lead to failure.

X-ray is used to measure the structural deformation of the metallic lattice at the atomic level in the bulk of the sample.

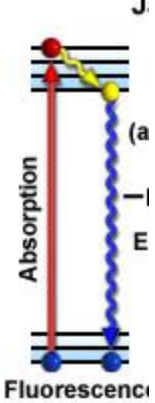
Metal testing @ SESAME?

Understanding snow avalanche

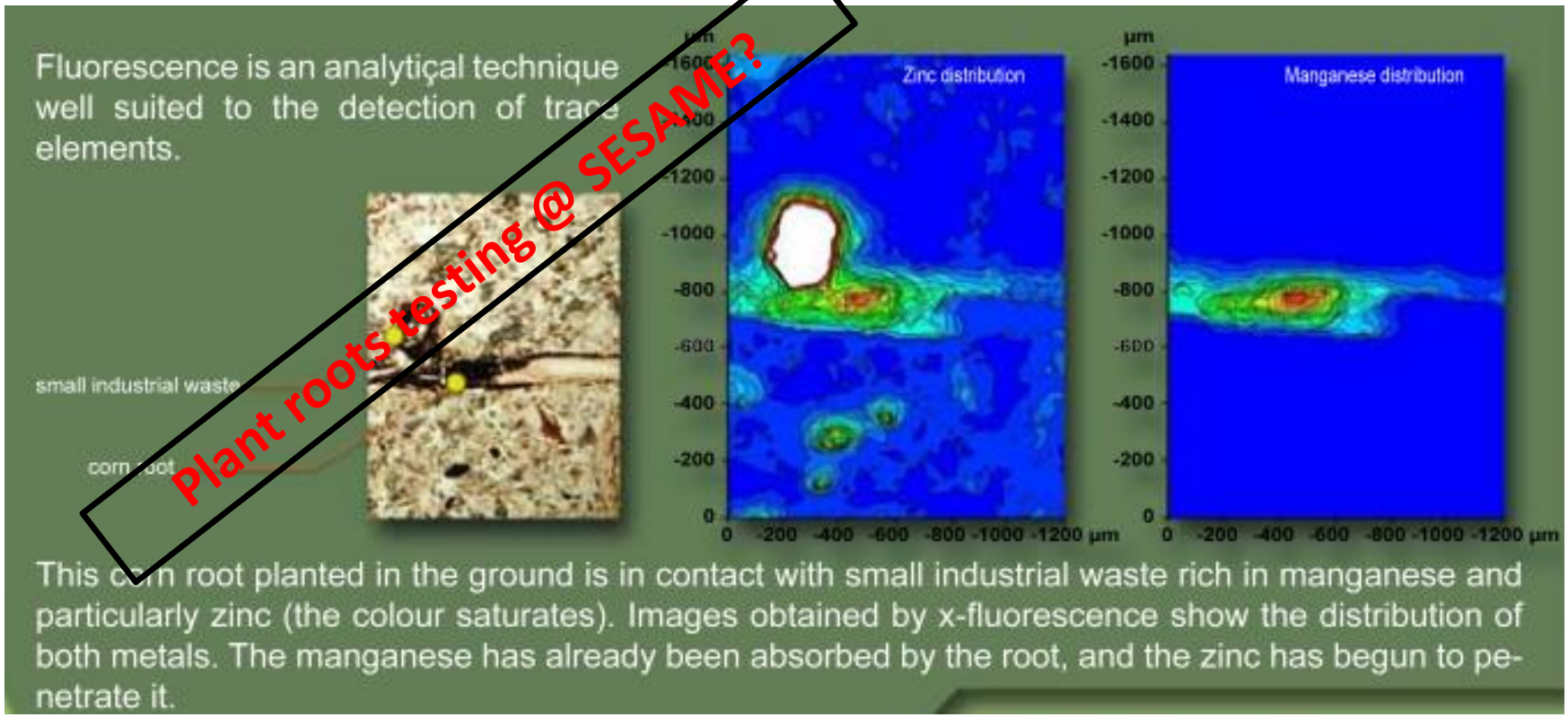
Micro-tomography: study of the microscopic structure of the snow grains to obtain detailed three-dimensional information about the internal structure of the snow to evaluate the avalanche risks.

Perhaps not enough snow in the middle east region?!

X-ray fluorescence to study industrial waste on plants



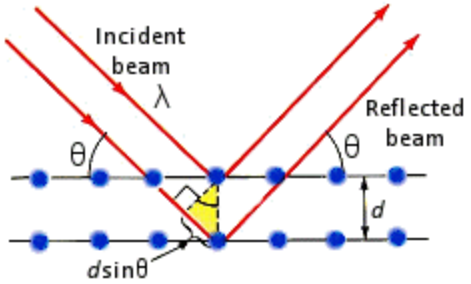
Fluorescence is the emission of light by a substance that has absorbed light or other electromagnetic radiation . It is a form of luminescence. In most cases, the emitted light has a longer wavelength, and therefore lower energy, than the absorbed radiation



X-ray diffraction to investigate the function of a protein

crystalline atoms cause a beam of incident X-ray to diffract into many specific directions.

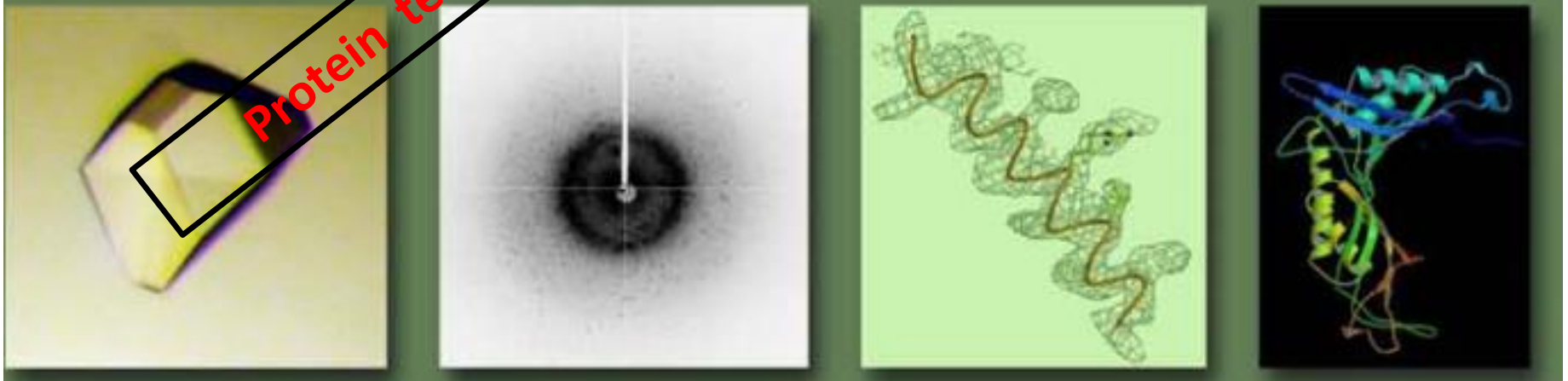
$n\,\lambda = d\,sin\theta$



$n\,\lambda = d\,sin\theta$

Protein testing @ SESAME?

One of the aims of modern biology is to understand how proteins function. Their activity depends on their atomic structure, which is highly complex. This can be determined using the diffraction of very intense x-rays produced by synchrotrons.



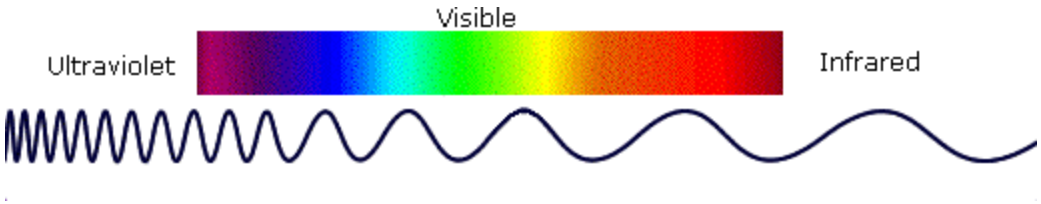
After mathematical processing, the diffraction image reveals the three-dimensional geometry of the protein.

Infrared spectroscopy and micro-spectroscopy

The results presented in this part are private communication from Paul Dumas, Infra-red beamline scientist, Synchrotron SOLEIL

Infrared spectroscopy

Three known IR regions :

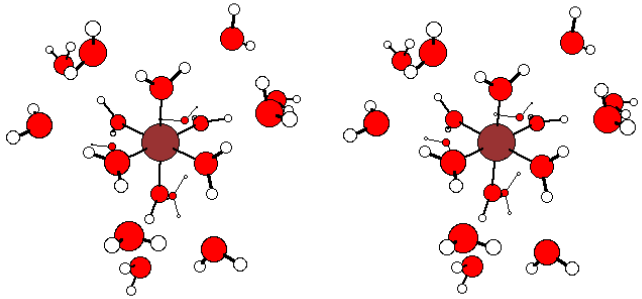


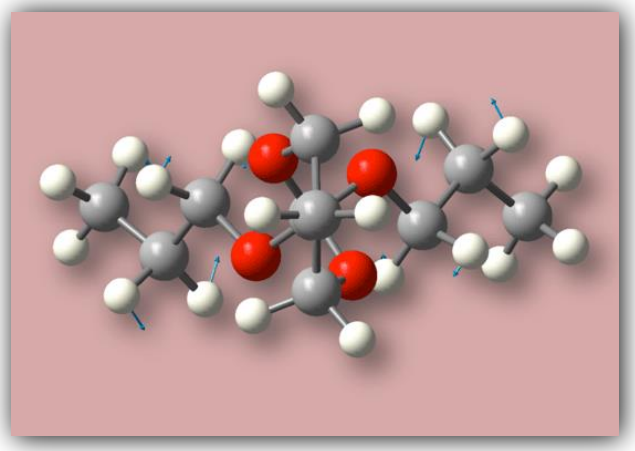
Wavelengths are in the micron range

- Energy range: 1 to ~500 µm
  (10000 to 20 cm-1 or 1.23 to 0.0025 eV)
  - ~1 to ~2.5 µm (10000-4000 cm^{-1}) Near IR
  - ~2.5 à 20 µm (4000-500 cm^{-1}) Mid- IR
  - ~20 à ~2500 µm (500-50 cm^{-1}) Far IR

Infrared spectroscopy

In the Mid- and Far- Infrared, molecular motions are mainly investigated





Building your own molecule and visualizing the correspondent IR spectrum (simple organic molecules)

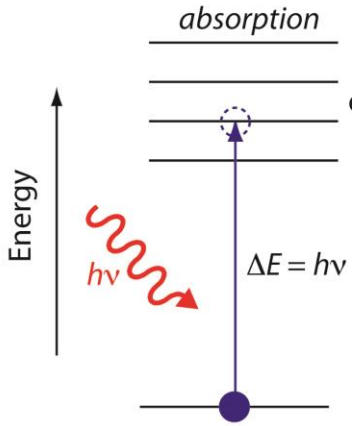
@ http://www.ccp14.ac.uk/ccp/web-mirrors/ortex/cryst/oscail_tutorial/moilin/gamess/gamess2.htm

Infrared spectroscopy

molecules absorb specific wavelengths that are characteristic of their structure.

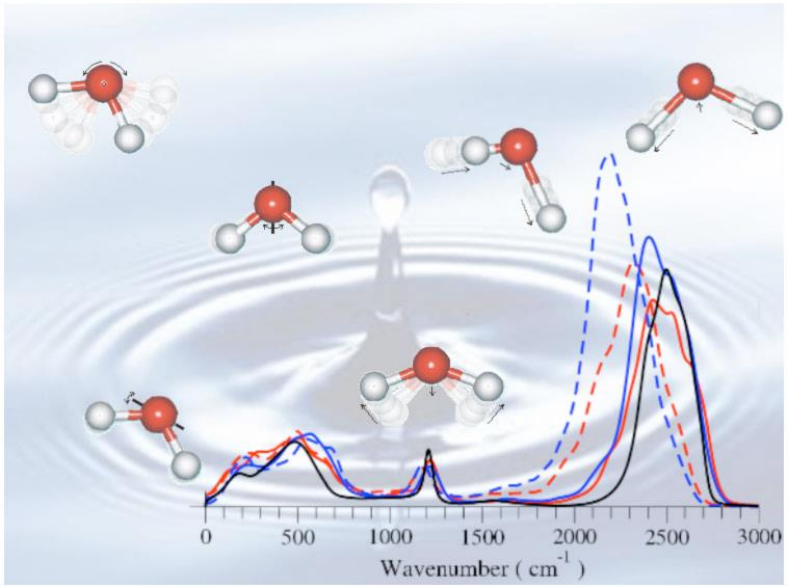
Absorptions occur at the resonance wavelength, i.e. the wavelength of the absorbed radiation matches the transition energy of the bond.

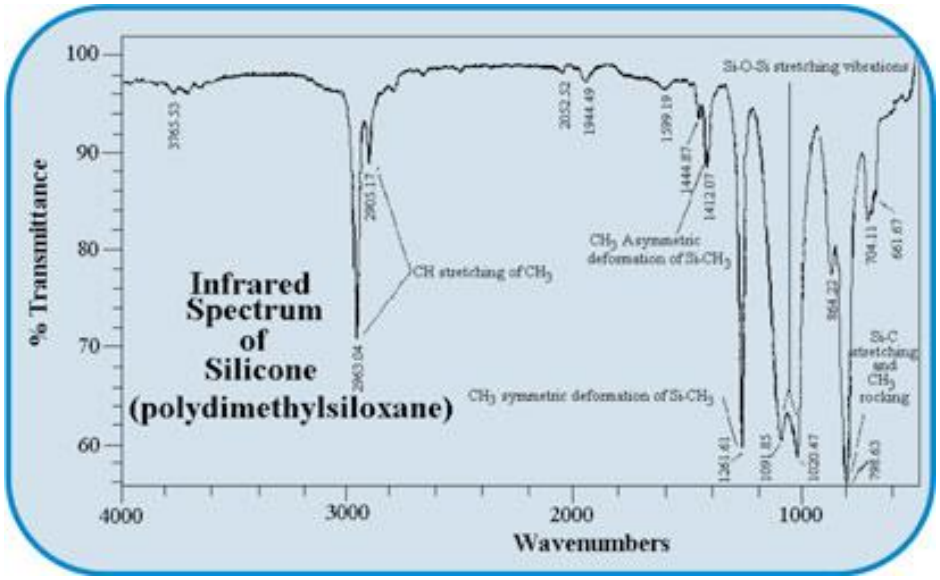
Examination of the transmitted light reveals how much energy was absorbed at each frequency (or wavelength).



Infrared spectroscopy

Infrared spectra are fingerprint of molecules and compounds



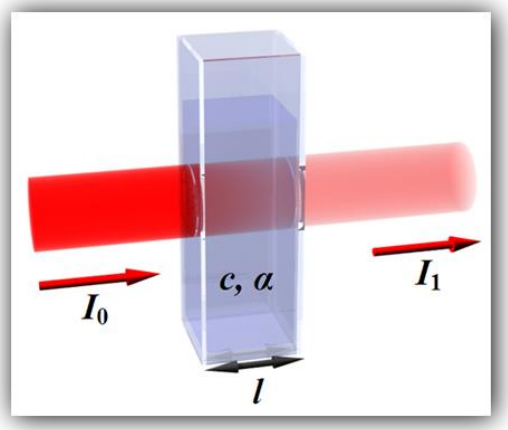


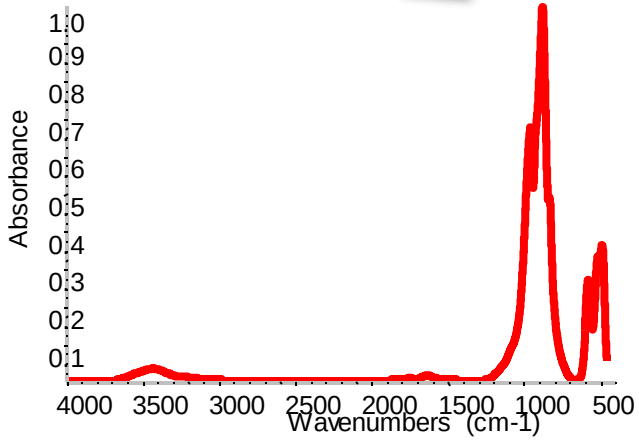
Some vibrational band assignments @
http://orgchem.colorado.edu/Spectroscopy/irtutor/tutorial.html

An interesting tutorial about IR spectroscopy @
http://www.columbia.edu/itc/chemistry/chem-c1403/ir_tutor/IRTUTOR.htm

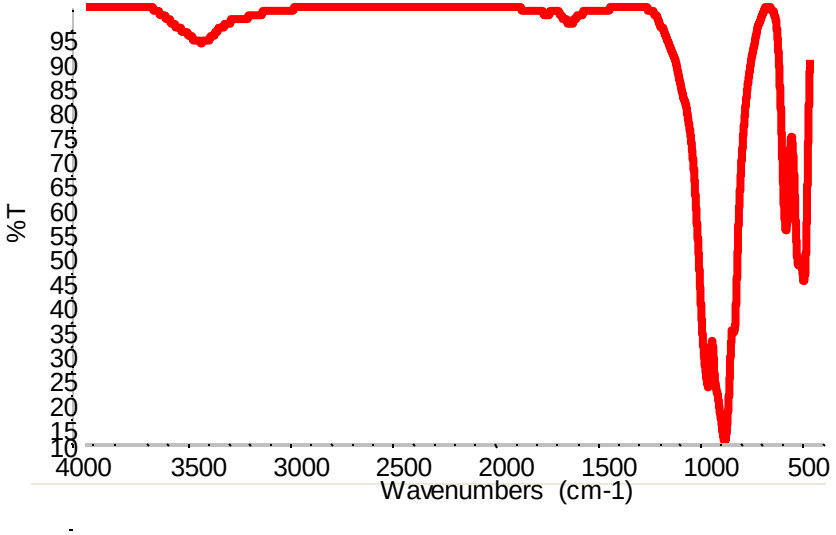
Infrared spectroscopy

It's, basically, an absorption process



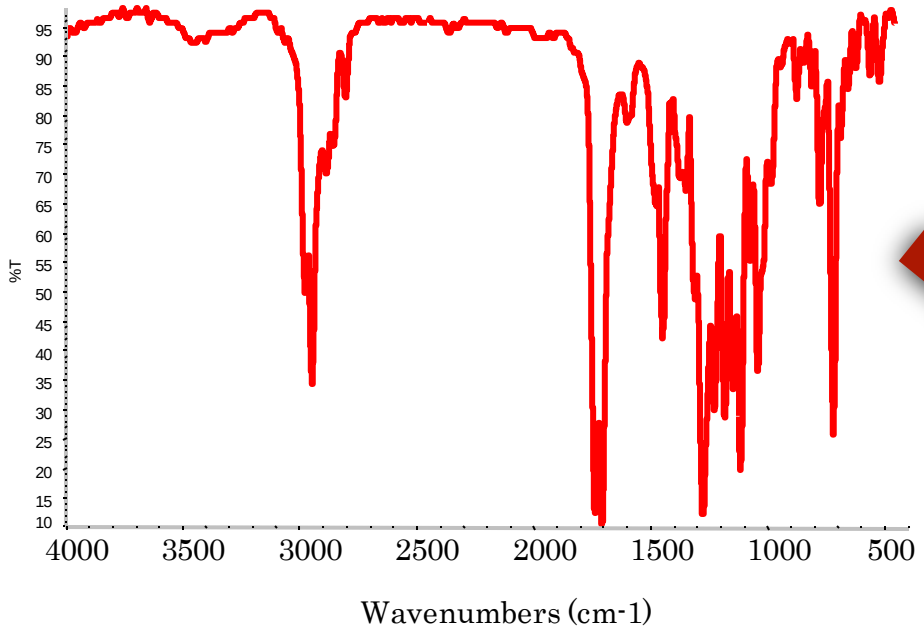


Olivine



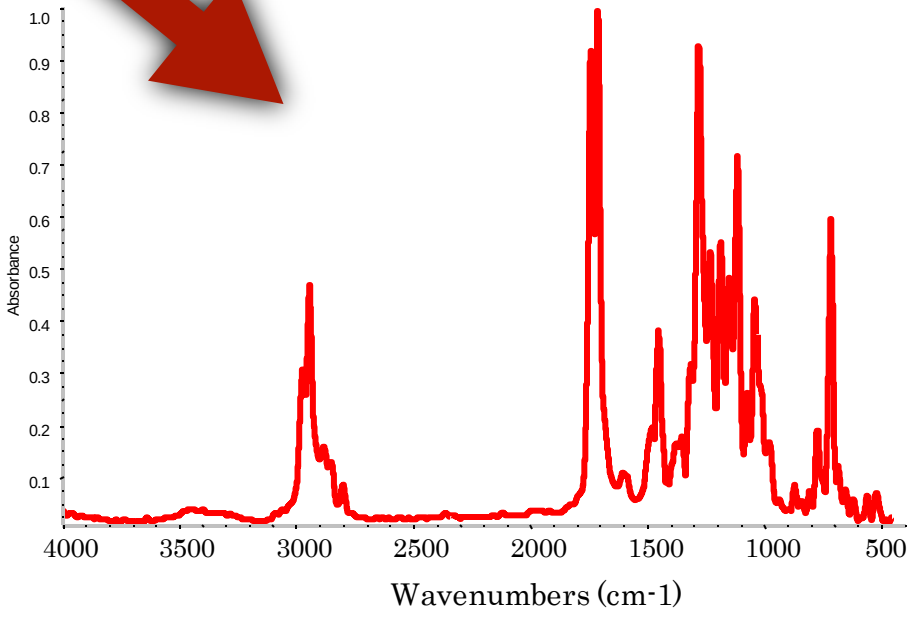
Infrared spectroscopy

COCAINE-Transmittance



An another example

COCAINE-Absorbance



Infrared spectroscopy

What do we learn from an IR spectrum?

- FROM PEAK POSITION, INTENSITY AND WIDTH
  - NATURE OF THE ATOMIC BOND
  - PARAMETERS OF THE ATOMIC BOND : BOND STRENGTH, LENGTH, VIBRATION FREQUENCY
  - CHEMICAL ENVIRONMENT, CHEMICAL MOIETY

- FROM WHOLE SPECTRUM
  - NATURE OF THE MOLECULE: SPECTRAL FINGERPRINT=> IDENTIFICATION IN SPECTRAL DATABASE
  - SAMPLE INTERACTIONS: FREE/BOUND WATER …
  - SAMPLE EVOLUTION: REACTION KINETIC, AGING, PHYSICO CHEMICAL TREATMENT, CONSTRAINTS (PRESSURE, STRETCHING, TEMPERATURE, pH) …
  - ATOMIC BOND ORIENTATION: POLARIZATION MEASURMENT

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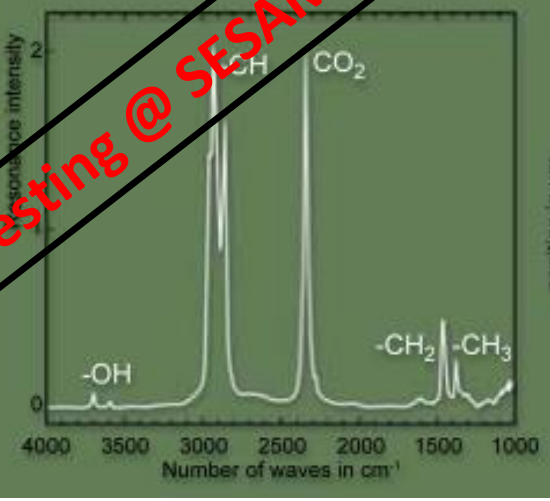
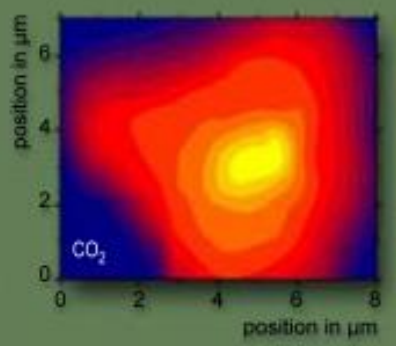
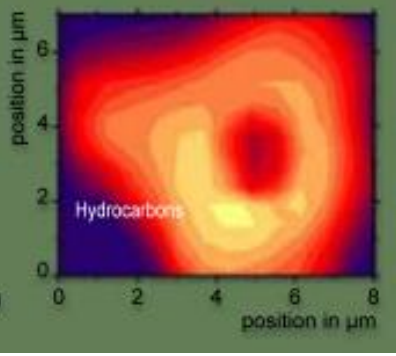
Infrared spectroscopy

Using IR spectroscopy, synchrotron light can probe rock inclusions a few microns in size. By revealing the presence of certain chemical compounds (water, carbon dioxide, hydrocarbons, etc.), it supplies geologists, vulcanologists, and petrochemical research specialists with valuable data about the nature of the subsoil.

Spectral analysis of the bubble included in this quartz indicates the presence of carbon dioxide and hydrocarbons. The images of the inclusion in IR microscopy, to the right of the spectrum, specify their concentration and their location.







Rock samples testing @ SESAME?

Far Infrared microscopy

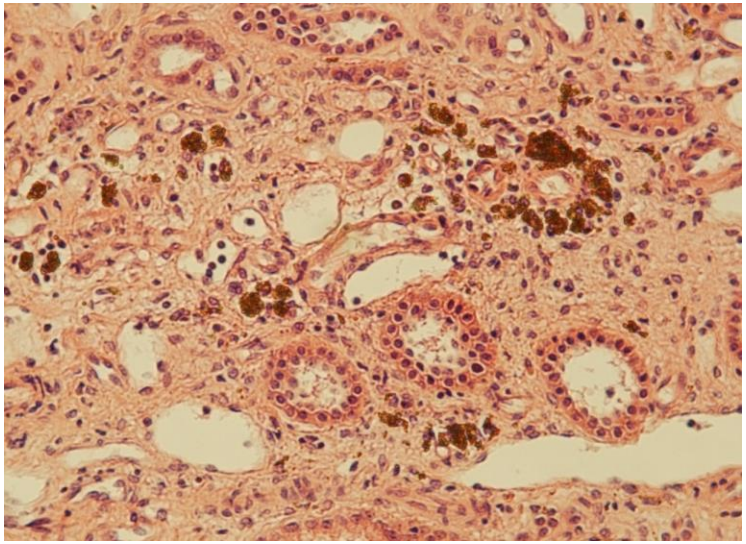
- Scientific method for the chemical identification of particles or contaminants and for visualizing the distribution of certain substances in complex compounds.
- It allows for the measurement of even large sample areas with a very high lateral resolution.

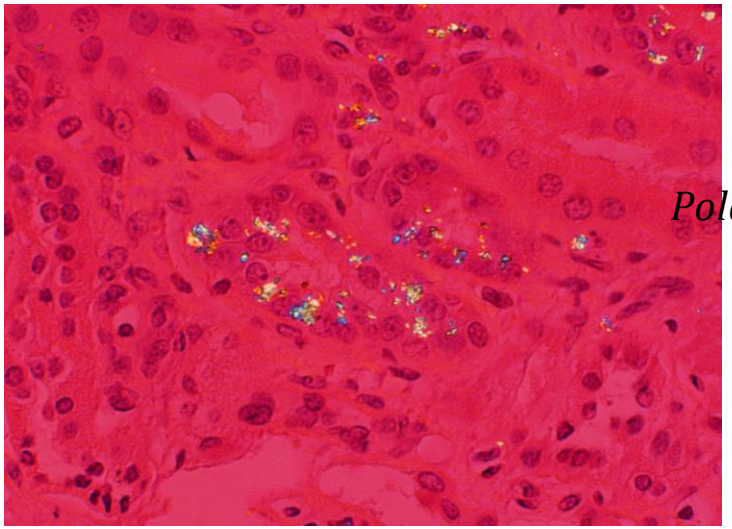
Selected examples

- biology and biomedicine
- cultural heritage
- Catalysis
- extreme conditions
- solid state

Kidney clasification

Biopsy shows extensive tubulo-interstitial fibrosis scattered with multiples small crystals





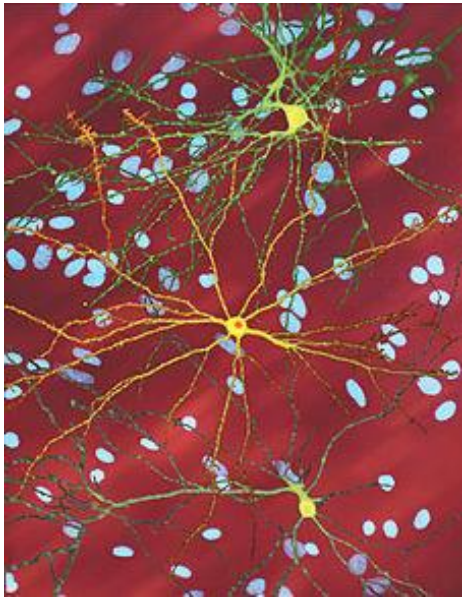
Polarized light

They are too small in size to allow morphologic identification at simple microscopic examination

A. Dessombz, D. Bazin, P. Dumas, C. Sandt, J. Sule-Suso, and Michel Daudon
PLoS ONE 6(11), e28007 (2011)

AP-HP, Hôpital Necker, Service de Biochimie , Paris , France.
Laboratoire de Physique des Solides, Orsay, France.
Synchrotron SOLEIL, Gif-sur-Yvette, Cedex, France.

Huntington disease



Huntington ***Disease: the context***

- **ROLE OF NORMAL HUNTINGTIN IS UNCLEAR, DISEASE IS CAUSED BY A GAIN OF A TOXIC FUNCTION.**

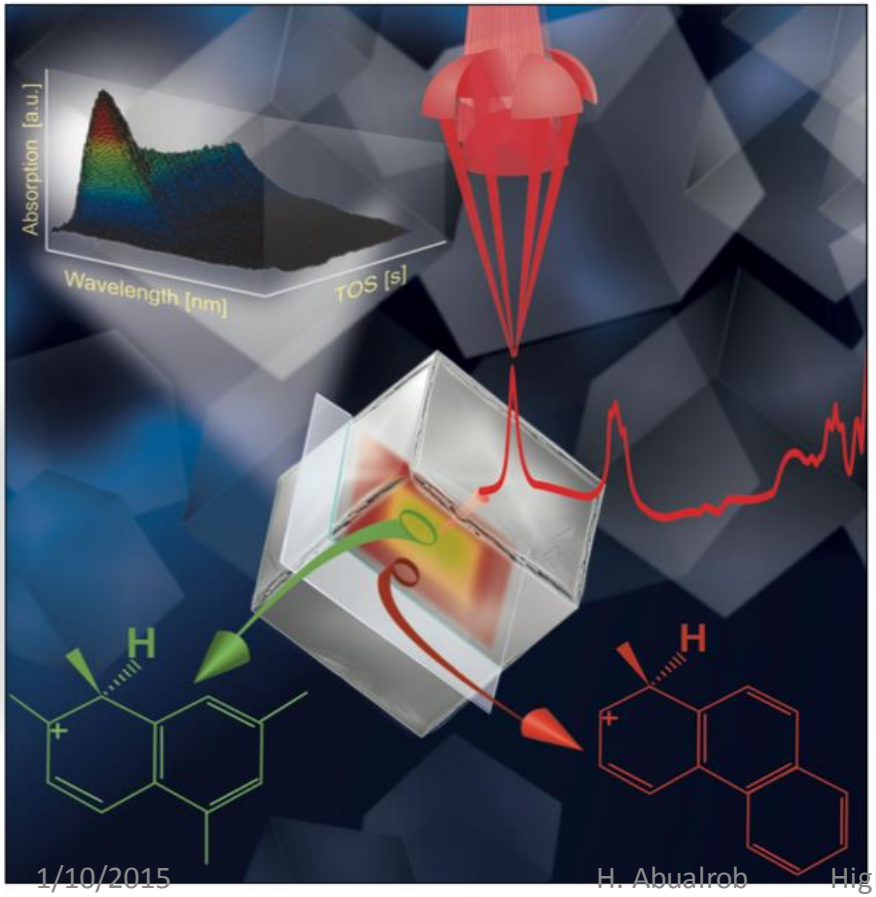
André, W., Sandt, C., Dumas, P., Djian, P., & Hoffner, G.
Structure of Inclusions of Huntington's Disease Brain Revealed by Synchrotron Infrared Microspectroscopy: Polymorphism and Relevance to Cytotoxicity.
Analytical Chemistry, 2013, 85(7): 3765–3773

Catalysis

CHEMISTRY
A EUROPEAN JOURNAL
ChemPubSoc Europe
DOI: 10.1002/chem.201300540

Single-Particle Spectroscopy on Large SAPO-34 Crystals at Work: Methanol-to-Olefin versus Ethanol-to-Olefin Processes

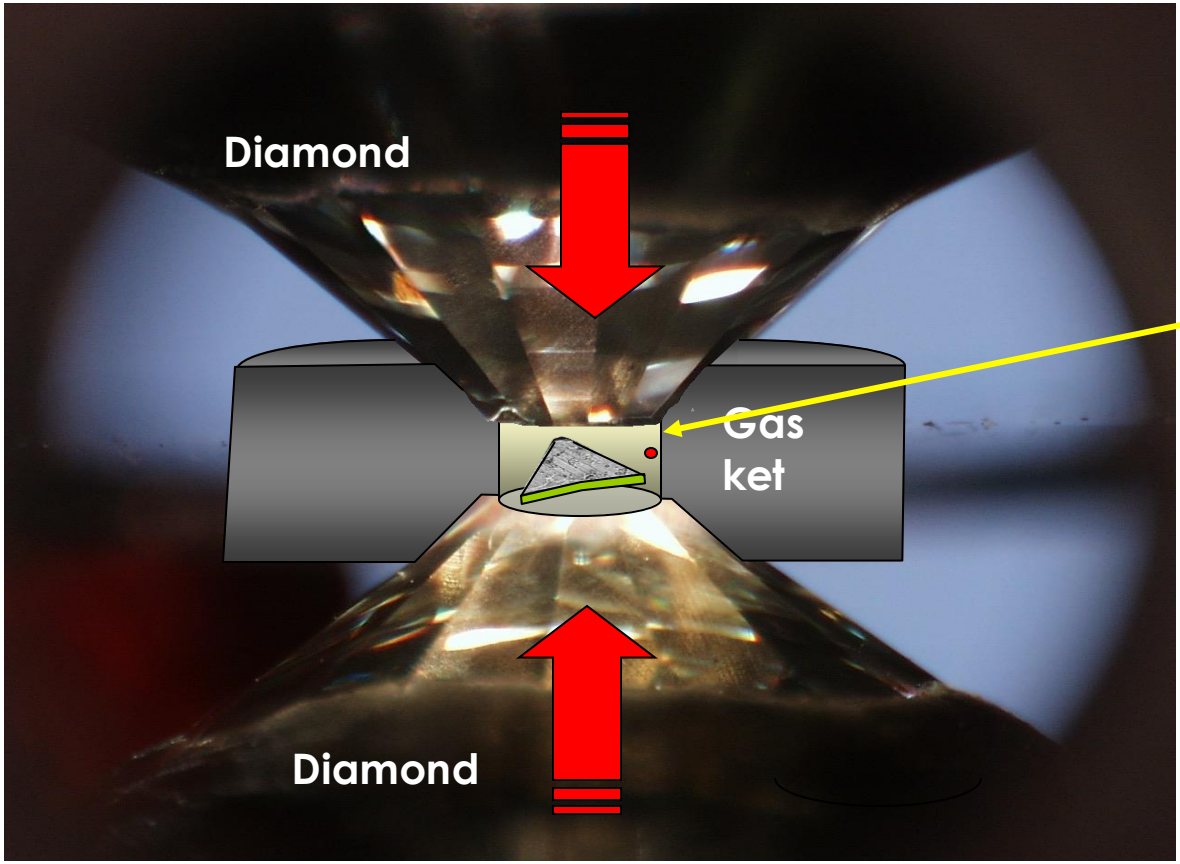
Qingyun Qian,[a] Javier Ruiz-Martínez,[a] Mohamed Mokhtar,[b] Abdullah M. Asiri,[b, c] Shaeel A. Al-Thabaiti,[b] Suliman N. Basahel,[b] Hendrik E. van der Bij,[a] Jan Kornatowski,[d] and Bert M. Weckhuysen*[a]



The conversion of methanol-to-hydrocarbons is an attractive catalytic technology to obtain gasoline or olefins from alternative feedstocks, such as natural gas and biomass. This process is catalyzed by acidic materials, better known as zeotypes, which are going to define the selectivity to the desired product.

Extreme conditions

Sample between the two diamonds ends, inside a gasket hole of 5 to 200 microns



A small rubis is most often introduced to measure the pressure using its fluorescence (needs a laser irradiation)

Conclusion

- Synchrotron radiation provides a powerful tool to perform different scientific experiments
- SESAME provides a unique research center using synchrotron radiation in the middle east
- It is your turn now to start thinking about possible proposals for few applications @ SESAME…….

Thank you