The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

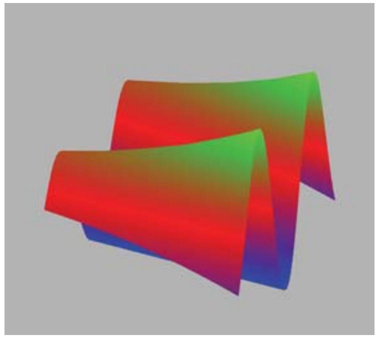
2139-1

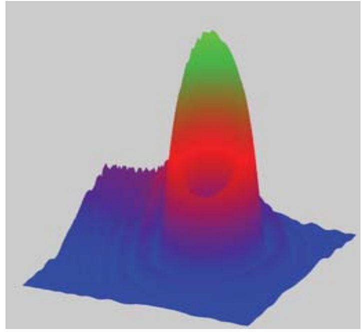
School on Synchrotron and Free-Electron-Laser Sources and their Multidisciplinary Applications

26 April - 7 May, 2010

Synchrotron Infrared Emission: From Basic Principles to Applications

Paul Dumas
SOLEIL Synchrotron-France
France





SYNCHROTRON INFRARED EMISSION: FROM BASIC PRINCIPLES TO APPLICATIONS

Paul Dumas

SOLEIL Synchrotron-France

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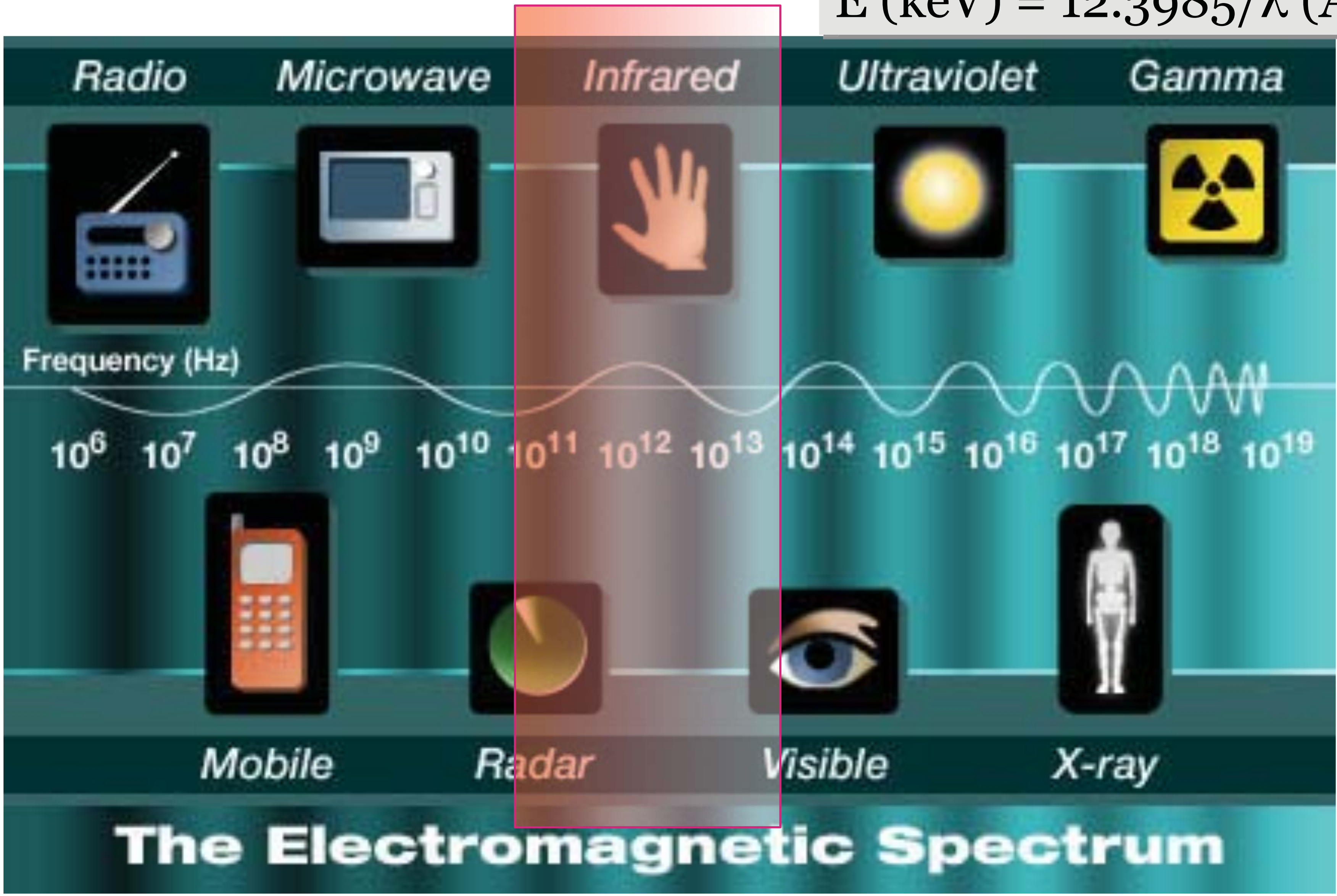
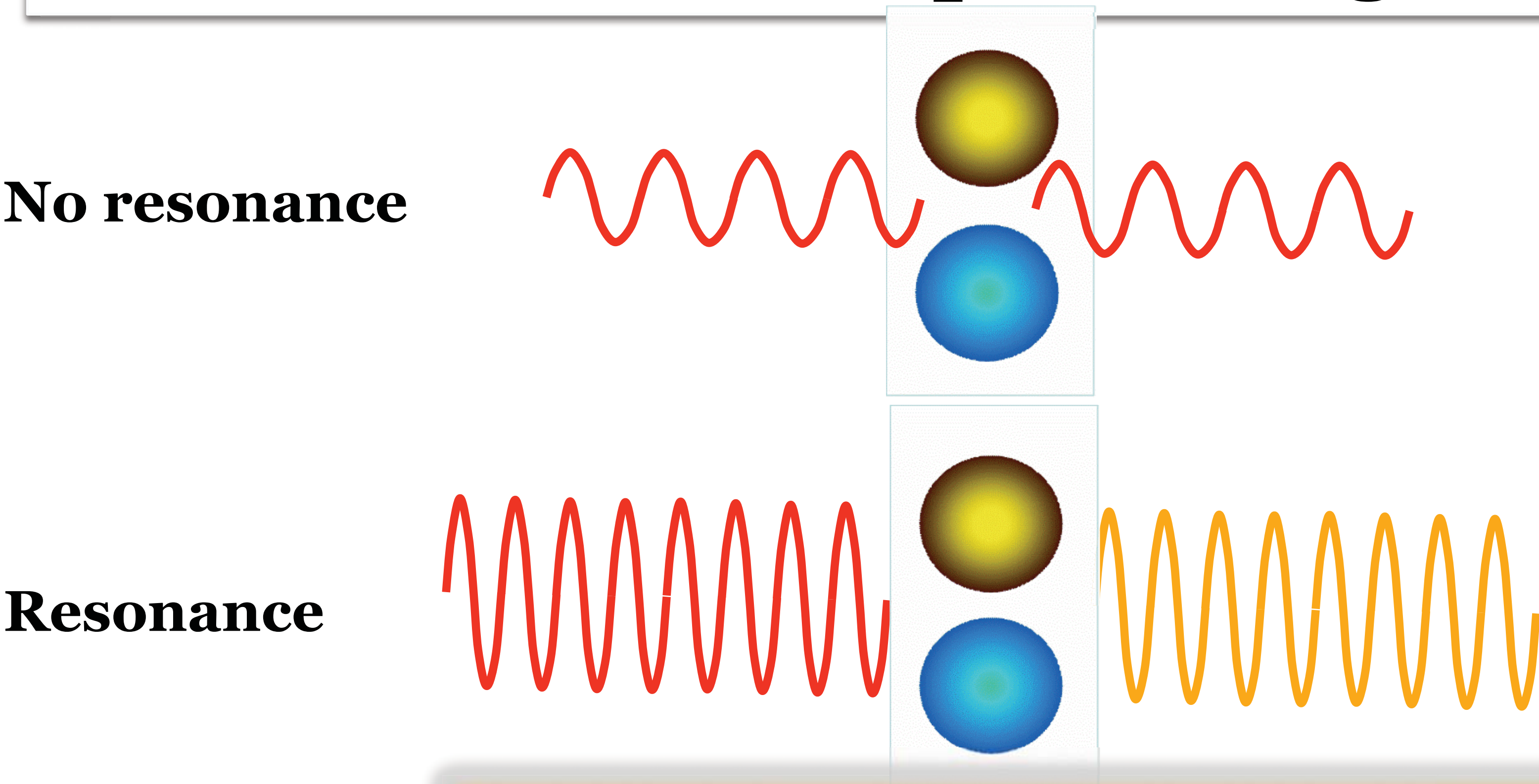
THE ELECTROMAGNETIC SPECTRUM

$E\,(keV) = 12.3985/\lambda\,(Å)$



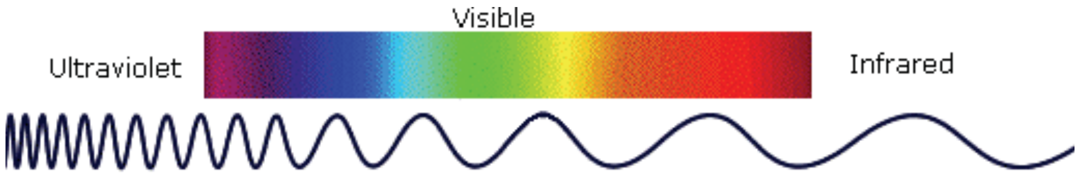
PHENOMENON AT THE HEART

All matters, atoms, molecules and all kind of substances vibrate . Only at absolute zero temperature (-273.15 °C or -459.67°F), that all stop vibrating.



IT IS AN ABSORPTION PROCESS

THE ENTIRE INFRARED DOMAIN



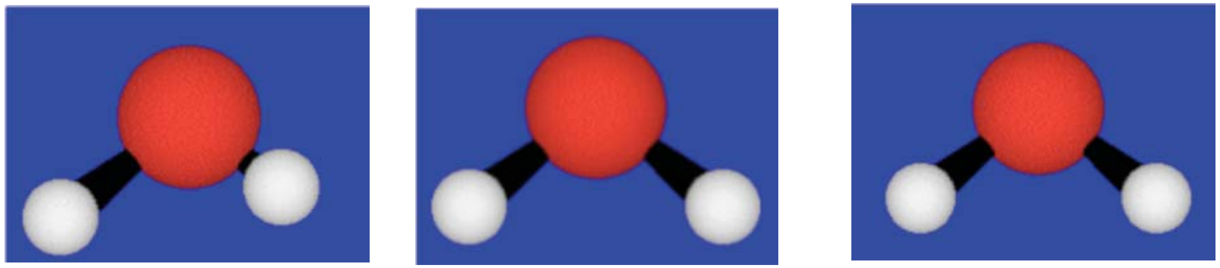
✓ **Energy range: 1 to ~500 µm**
(10000 to 20 cm-1 or 1.23 to 0.0025 eV)

✓ **~1 to ~2.5 µm (10000-4000 cm^{-1}) <u>Near IR</u>**
✓ **~2.5 à 20 µm (4000-500 cm^{-1}) <u>Mid- IR</u>**
✓ **~20 à ~2500 µm (500-50 cm^{-1}) <u>Far IR</u>**

✓ **They are long wavelengths, distributed in a wide range!**

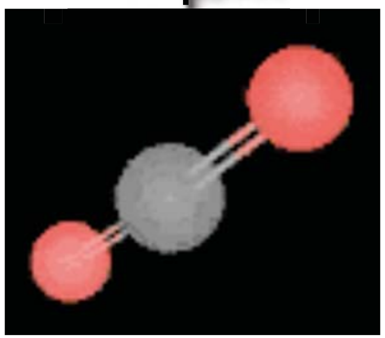
MOLECULAR MOTIONS

~3.3 µm

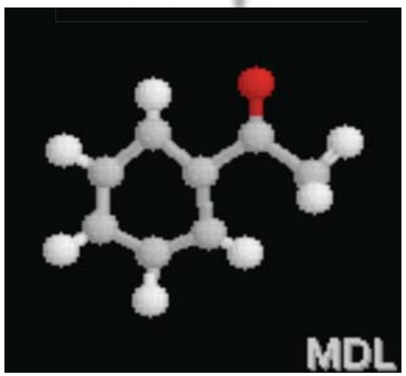


3756 cm-1 3652 cm-1 1595 cm-1

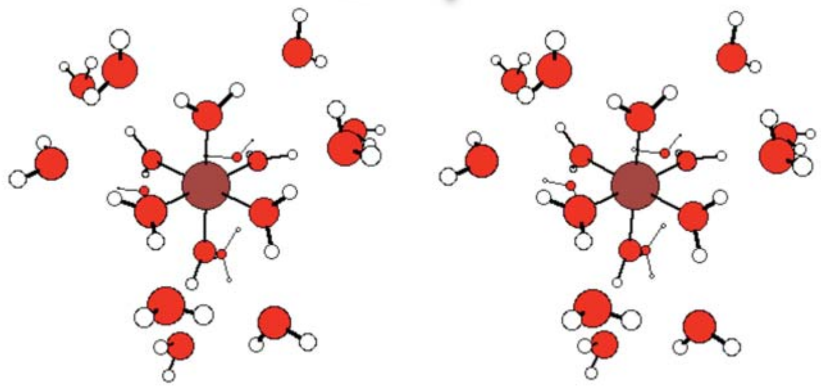
~6 µm



~10 µm



~30 µm



But also IR reflectivity and conductivity ….
(brodband change)

OUTLINE

I- Infrared Spectroscopy , Infrared micro-spectroscopy

II- Infrared Emission from synchrotron radiation:
- **Source of emission**
- **properties: flux, brightness, polarisation , time structure**

III- Infrared Beamline at synchrotron facilities:
Specificities, design and end stations

IV- Application in the Far-Infrared: Solid State Physics, High resolution gas phase, surface science

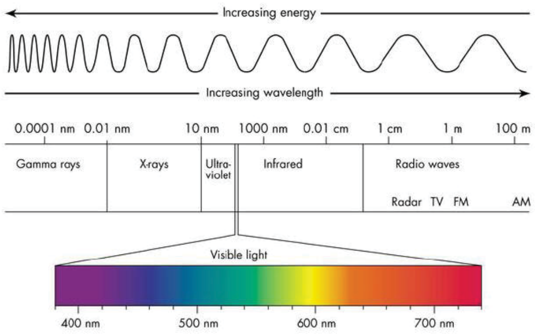
V- Application in Micro-spectroscopy:
V-1. Polymer
V-2. Astrophysique
V-3. Cultural Heritage
V-4. Earth Science
V-5. Very High Pressure
V-6. Biology

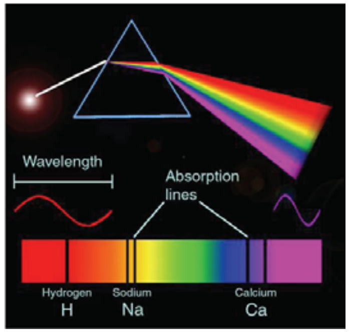
INFRARED SPECTROSCOPY

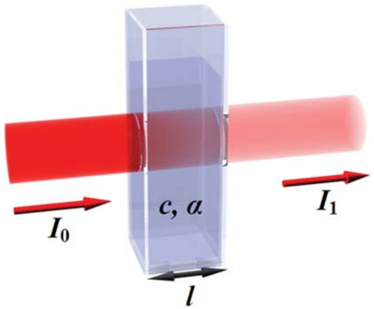
INFRARED MICRO-SPECTROSCOPY

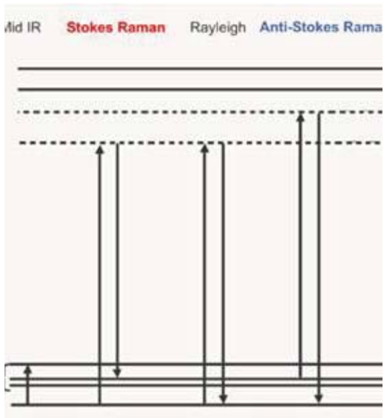
INFRARED SPECTROSCOPY: BASICS

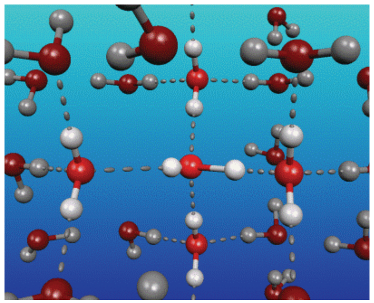






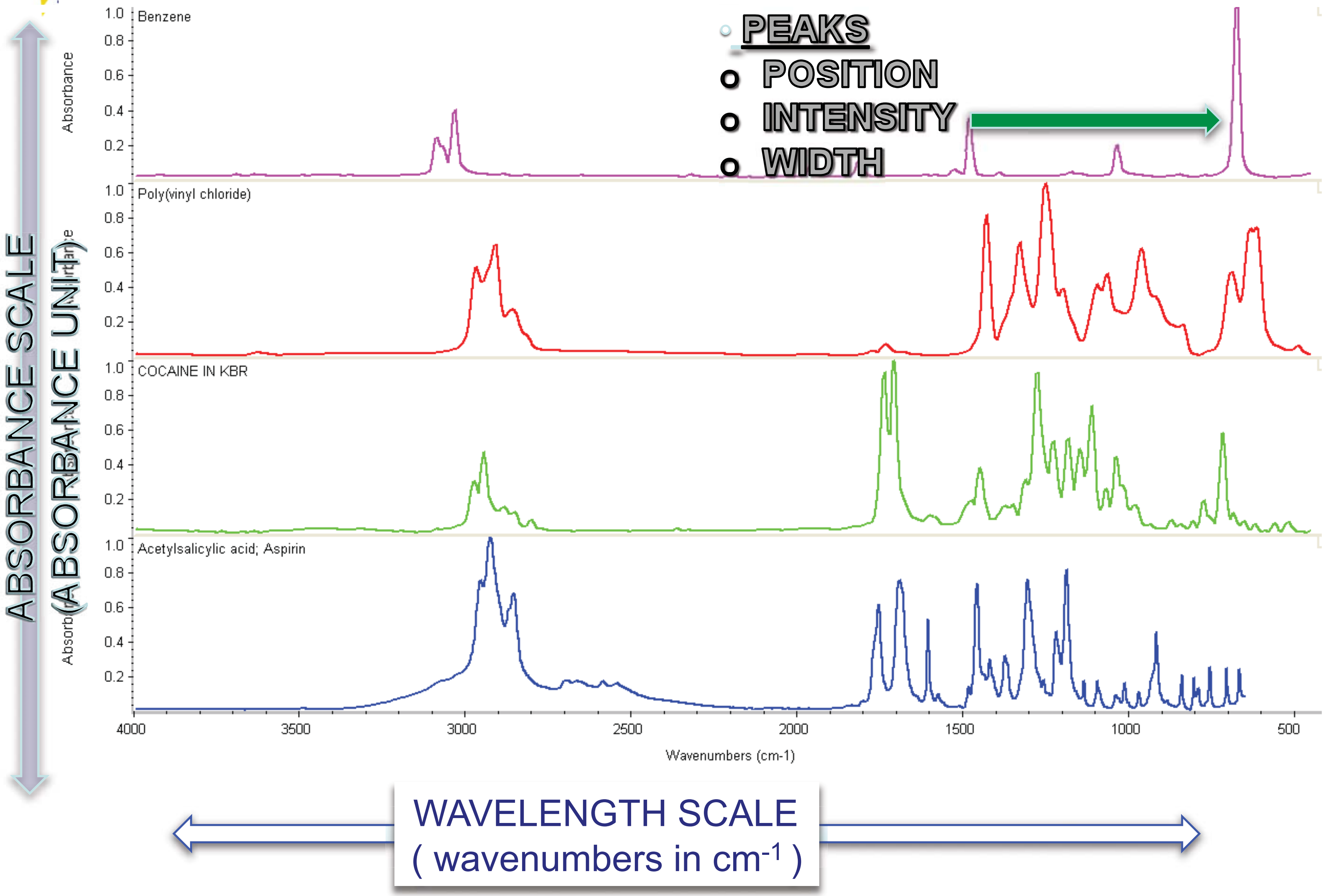




INFRARED (IR) SPECTROSCOPY

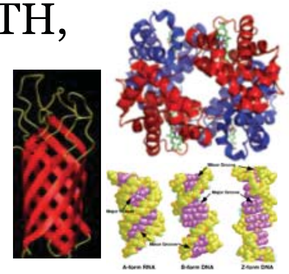
- **OPTICAL SPECTROSCOPY**
  - **MID-IR l: 2,5-25 µm**
  - **NEAR-IR l: 0,8-2,5 µm**
  - **FAR IR l: 25-200 µm**
- **ABSORPTION SPECTROSCOPY**
  - **$A = \alpha\ c\ l$**
  - **$A = -\log(I/I_0)$**
- **VIBRATIONAL SPECTROSCOPY**
  - **PROBES the VIBRATIONS of INTER-ATOMIC BONDS**

INFRARED SPECTRA: EXAMPLES

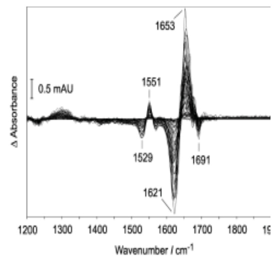


INFORMATIONS FROM SPECTRA?

- ***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
  - BOND CONFORMATION: C=C CIS/TRANS, PROTEINS α HELIX / β SHEET, A, B, Z DNA …



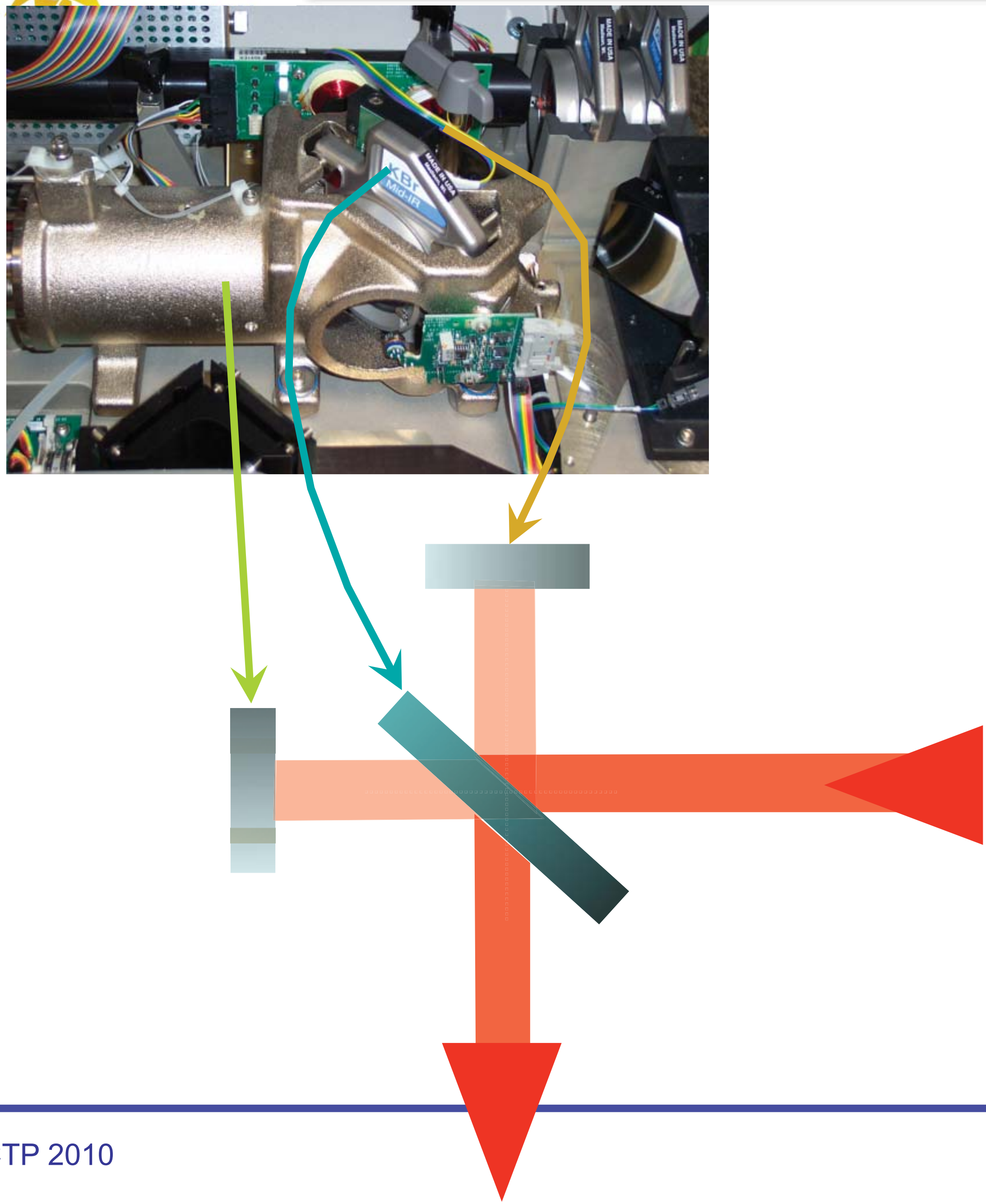
- ***FROM WHOLE SPECTRUM***
  - NATURE OF THE MOLECULE: SPECTRAL FINGERPRINT=> IDENTIFICATION IN SPECTRAL DATABASE
  - SAMPLE INTERACTIONS: FREE/BOUND WATER …
  - SAMPLE EVOLUTION: REACTION KINETIC, AGING, PHYSICO CHEMICAL TREATMENT, CONSTRAINTS (PRESSURE, STRETCHING, TEMPERATURE, pH) …
  - ATOMIC BOND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

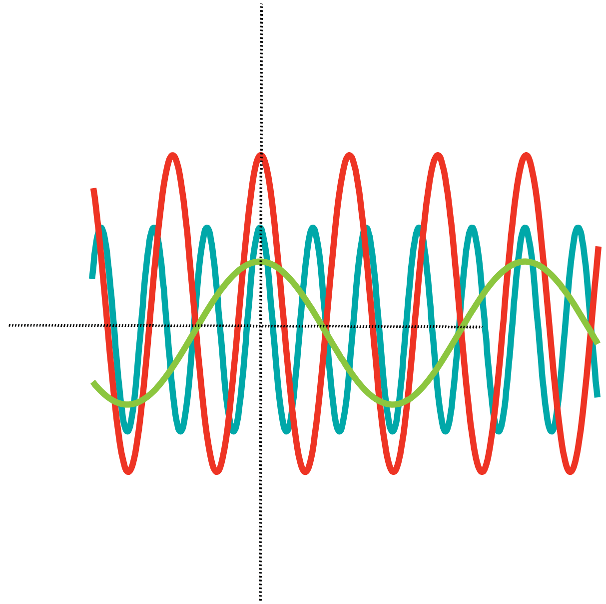


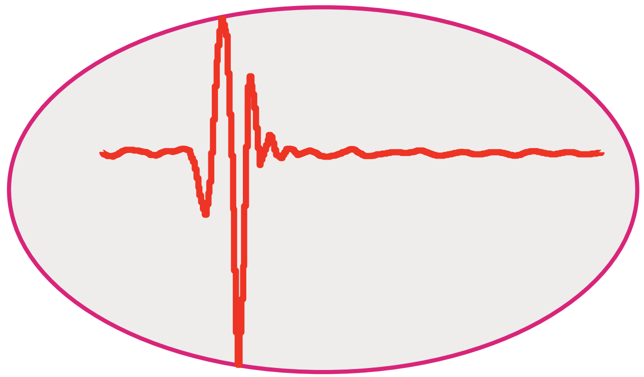
- ***QUANTITATIVE or SEMI-QUANTITATIVE ANALYSIS***
  - SIMPLE MIXTURES: BEER LAMBERT BOUGUER LAW
  - COMPLEX MIXTURE : PLS, CLS, ALS, MCR, PCR …

FOURIER TRANSFORM INFRARED SPECTROSCOPY

FOURIER TRANSFORM INFRARED SPECTROSCOPY

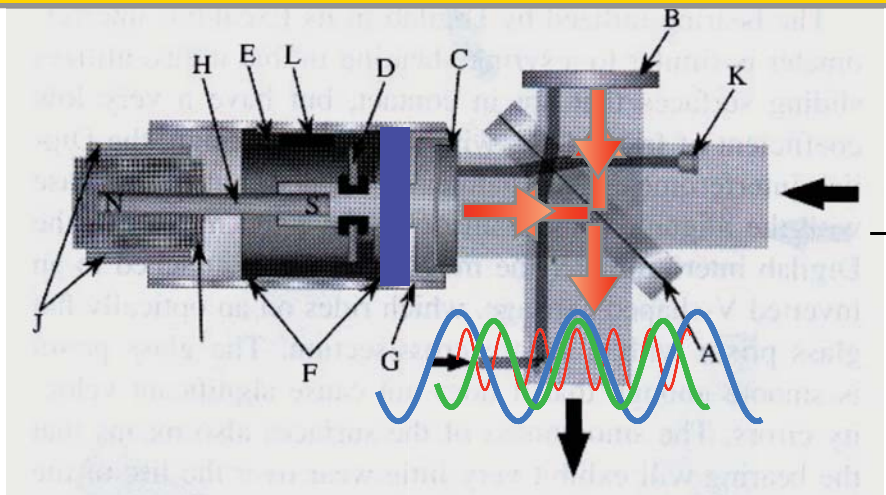


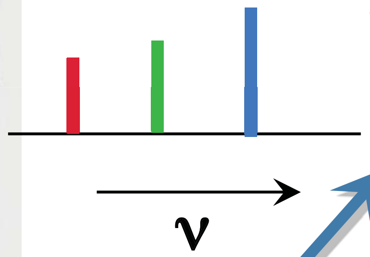


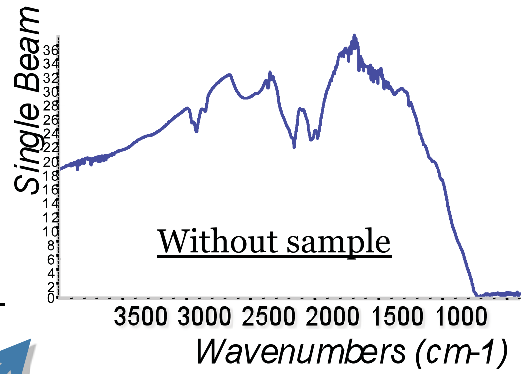


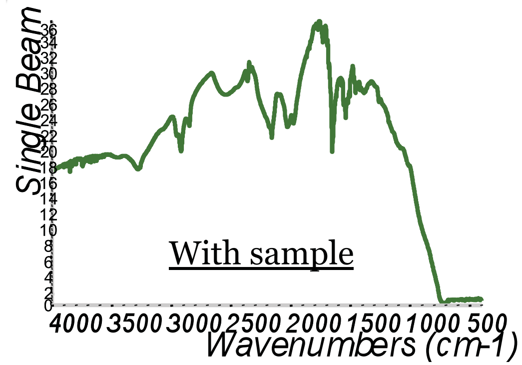
FOURIER TRANSFORM INFRARED SPECTROSCOPY

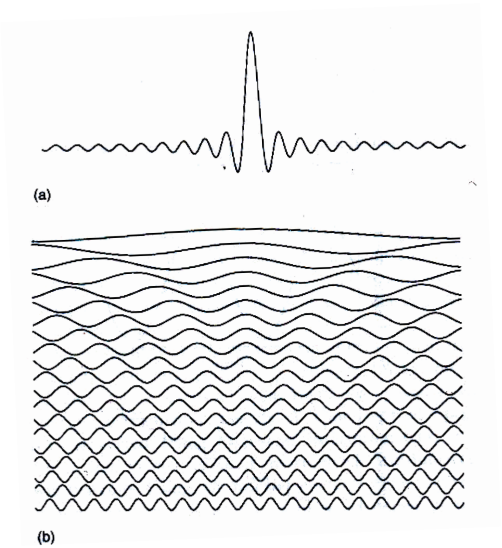
No monochromator, all wavelengths collected



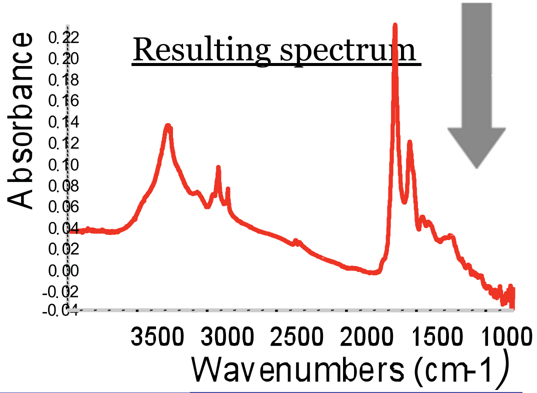








Fast Fourier Transform



INFORMATIONS FROM SPECTRA?

ADVANTAGES

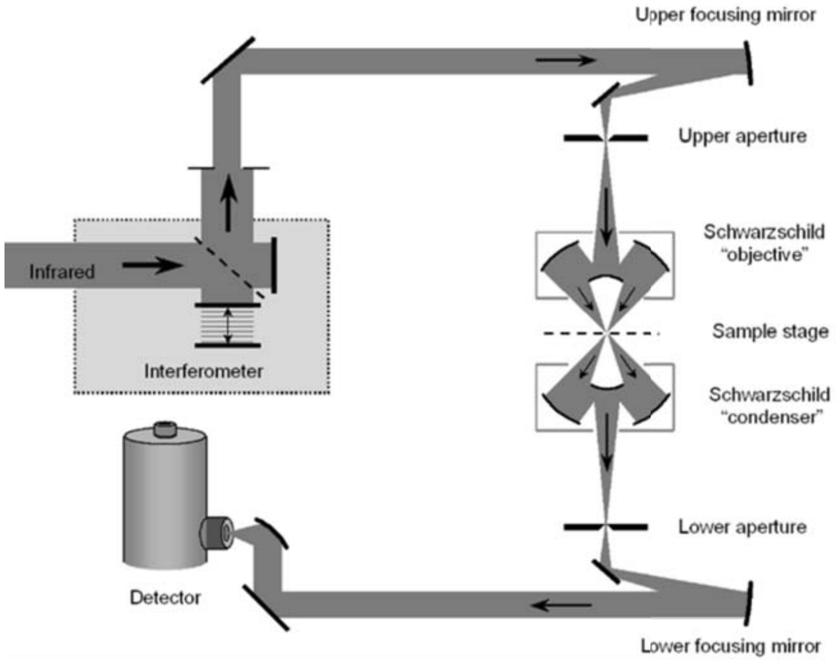
- SIMPLE
- CHEAP
- NON-DESTRUCTIVE
- COUPLING WITH OTHER TECHNIQUES
- QUICK
- SENSITIVE
- FLEXIBLE: SOLIDS, LIQUIDS, POWDERS, THIN FILMS, GAZ …

APPLICATIONS

- ASTROPHYSICS
- BIOLOGY
- PLANT BIOLOGY
- CHEMISTRY
- GEOLOGY
- HERITAGE SCIENCE
- PHARMACEUTICS
- PHYSICS
- POLYMERS
- SURFACE SCIENCES
- …

INFRARED MICRO-SPECTROSCOPY

- MICROSCOPE COUPLED TO IR SPECTROMETER

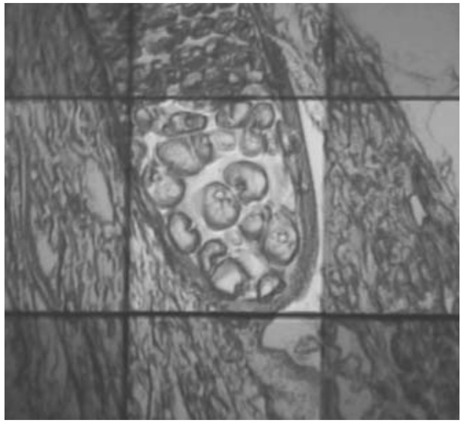


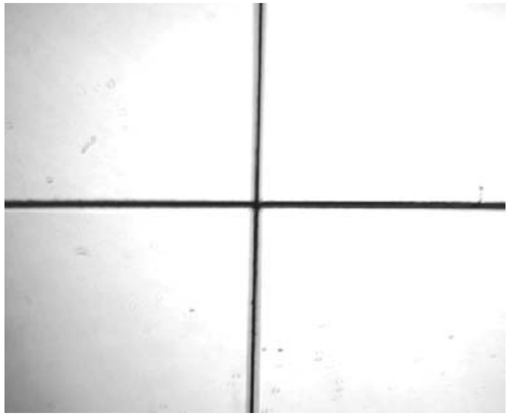
- SMALL SAMPLE ANALYSIS (<500 µm, even < 5 µm with synchrotron)
- ANALYSIS OF INCLUSION IN A MATRIX
- DISTRIBUTION OF COMPONENTS : CHEMICAL MAPS

INFRARED MICRO-SPECTROSCOPY AND SPATIAL RESOLUTION

- Set by aperture

KNIFE EDGE APERTURE





open **close**

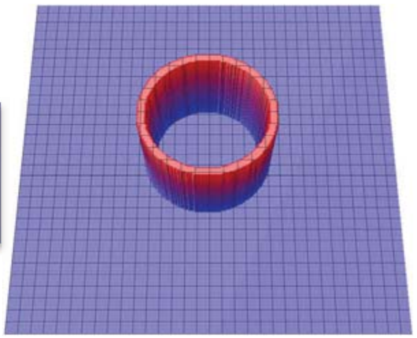
- Dual aperturing improves resolution...

INFRARED MICRO-SPECTROSCOPY AND SPATIAL RESOLUTION

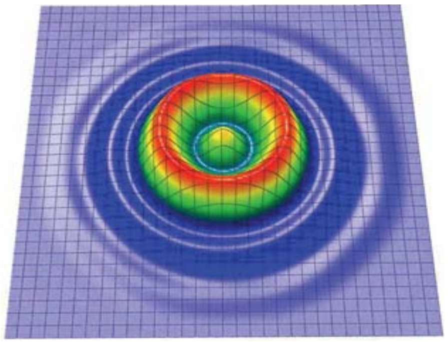
- MINIMUM DISTANCE BETWEEN TWO INDEPENDENTLY MEASURED OBJECTS THAT CAN BE DISTINGUISHED BY THE SPECTRA
- CLASSICAL SOURCE:
  - LIMITED BY SOURCE BRIGHTNESS: 20-500 µm
- SYNCHROTRON SOURCE:
  - DIFFRACTION LIMITED: 2-12 µm

SIMULATION FOR ANNULAR DISK

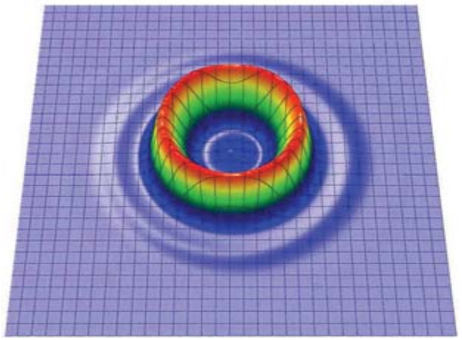
FOR $\lambda = 6$ µm



REAL OBJECT
ø int. 13 µm
Ø ext. 17 µm



SINGLE APERTURE

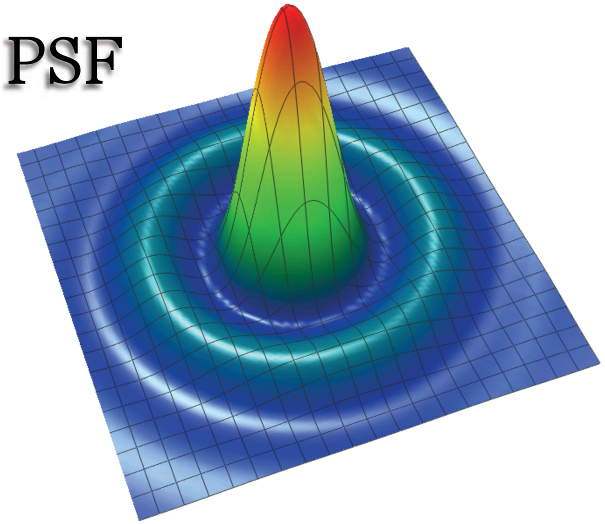


DOUBLE APERTURE

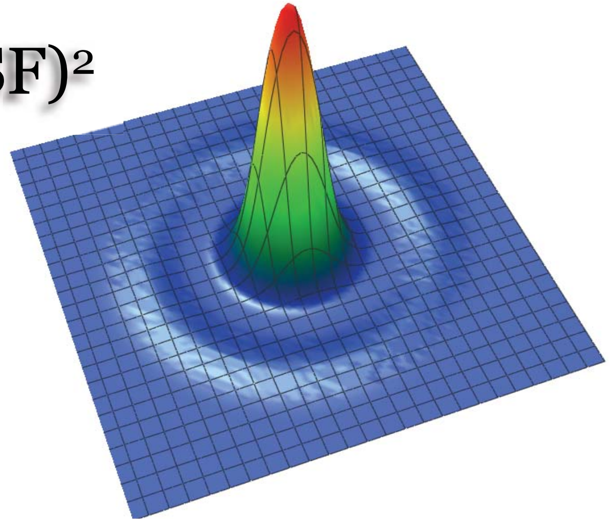
P. Dumas

SPATIAL RESOLUTION: CONFOCAL versus NON-CONFOCAL

PSF



$(PSF)^2$

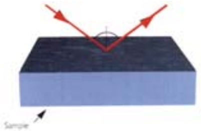


Confocal results in narrower central peaks, and also reduces effect of 1st order diffraction ring.

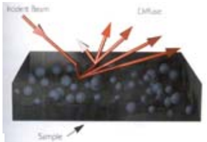
SAMPLING TECHNIQUES

- TRANSMISSION

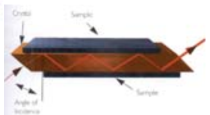
- REFLEXION
  - SPECULAR



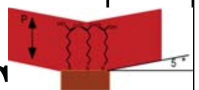
  - DIFFUSE



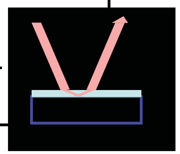
  - TOTAL



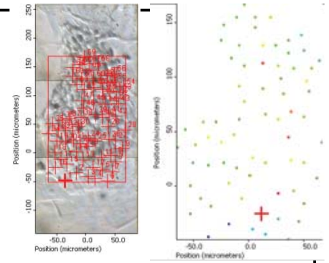
  - GRAZING INCIDENCE

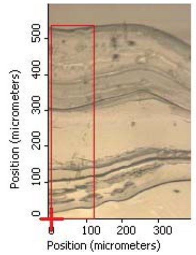


  - TRANSREFLECTION

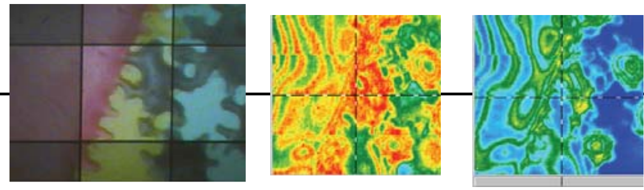


- MAPPING
  - CONFOCAL
  - POINT MAP
  - AREA MAP





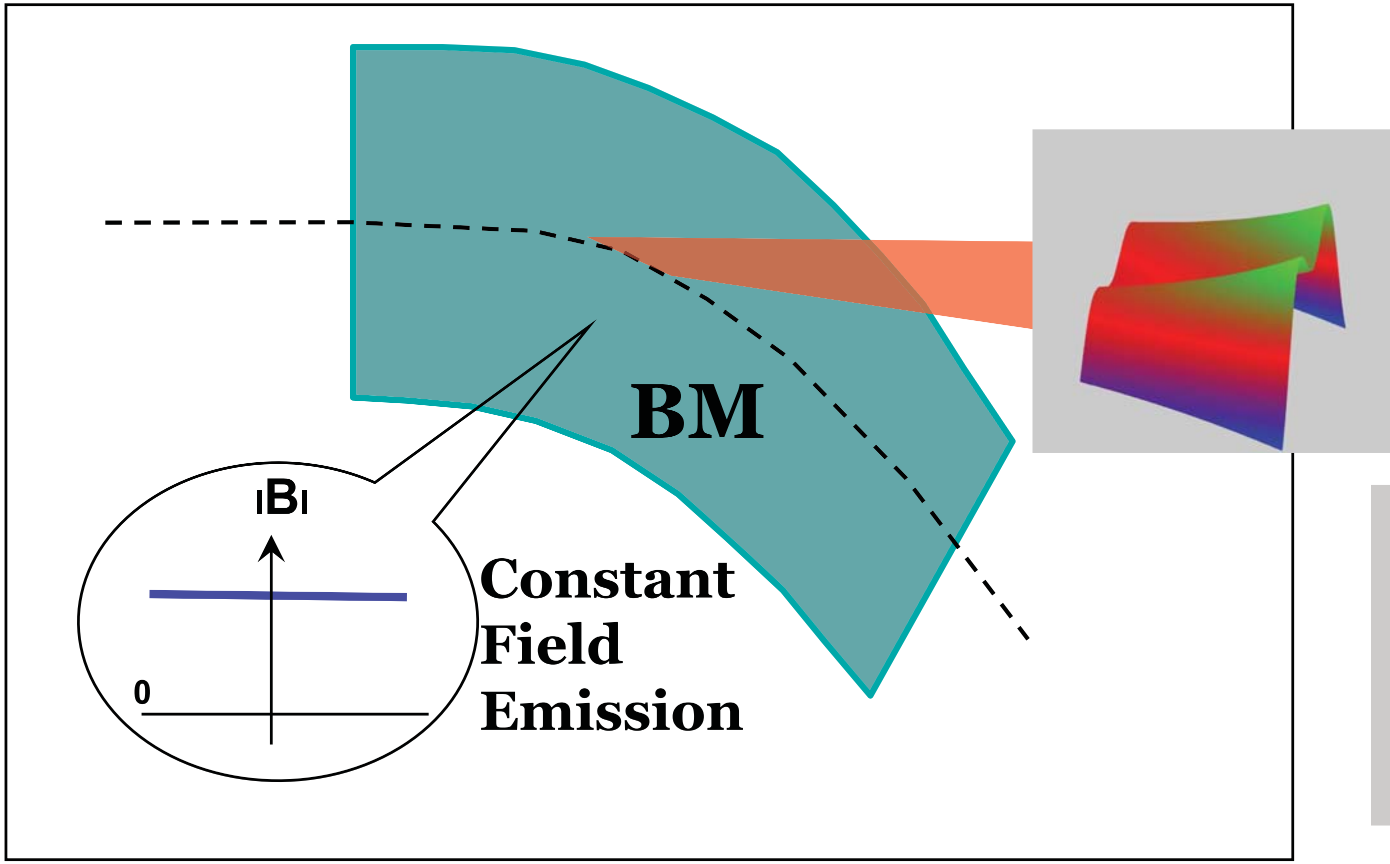
- IMAGING
  - SIMULTANEOUS ACQUISITION
  - NO CONFOCALITE



SYNCHROTRON INFRARED EMISSION

SOURCES OF INFRARED EMISSION

The most conventional is a Bending Magnet emission



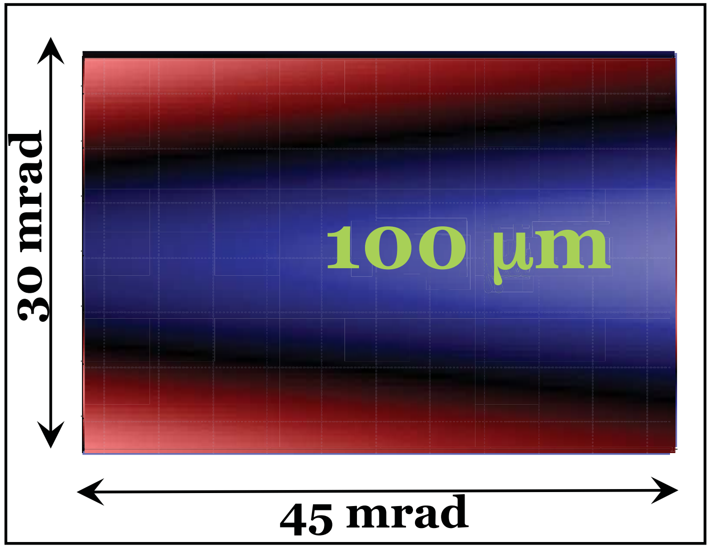
But Full Angle Emission (2* *θrms)* large!

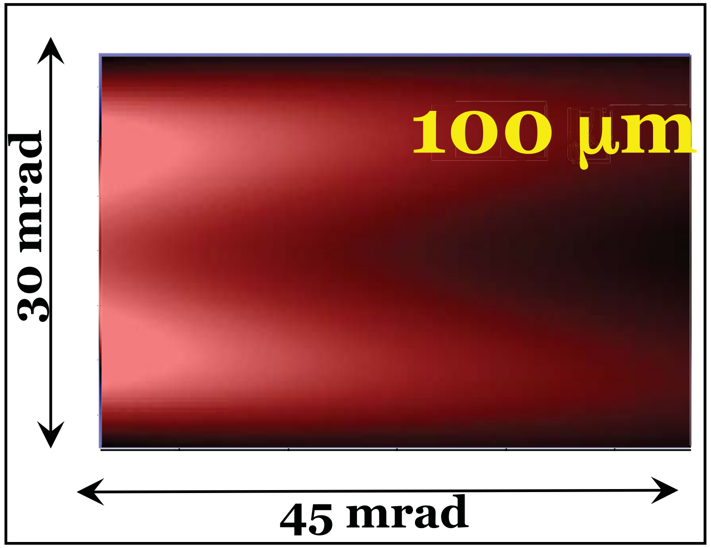
$\theta_{rms} = (3\lambda/4\pi\rho)^{1/3}$

SRW: **Chubar O, Elleaume P. Accurate And Efficient Computation Of Synchrotron Radiation In The Near Field Region. 1998; EPAC98 Conference p. 1177-9.**

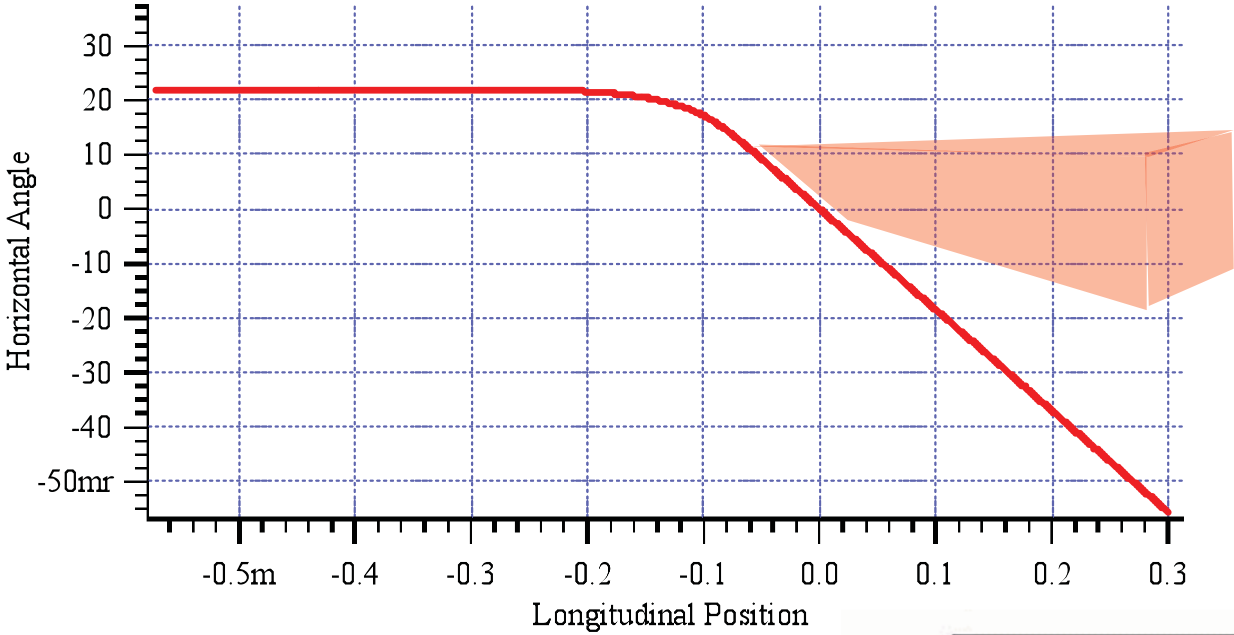
VERTICAL OPENING ANGLE DEPENDS ON ELECTRON ENERGY

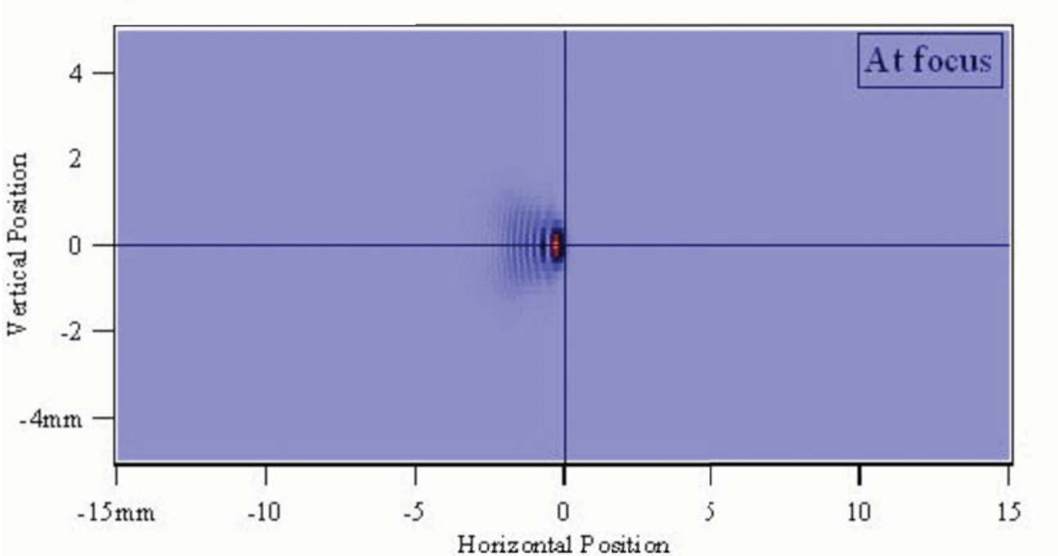
INDUS	*DIAMOND*
0.45 GeV	3.0 GeV
45 mrad H X 30 mrad V	45 mrad H X 30 mrad V
BM	BM





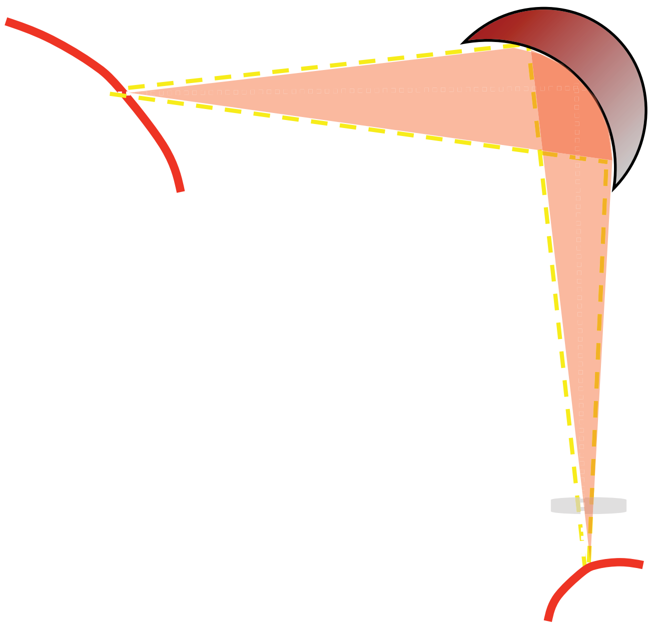
BM EMISSION AND SOURCE DEPTH





BM EMISSION AND SOURCE DEPTH

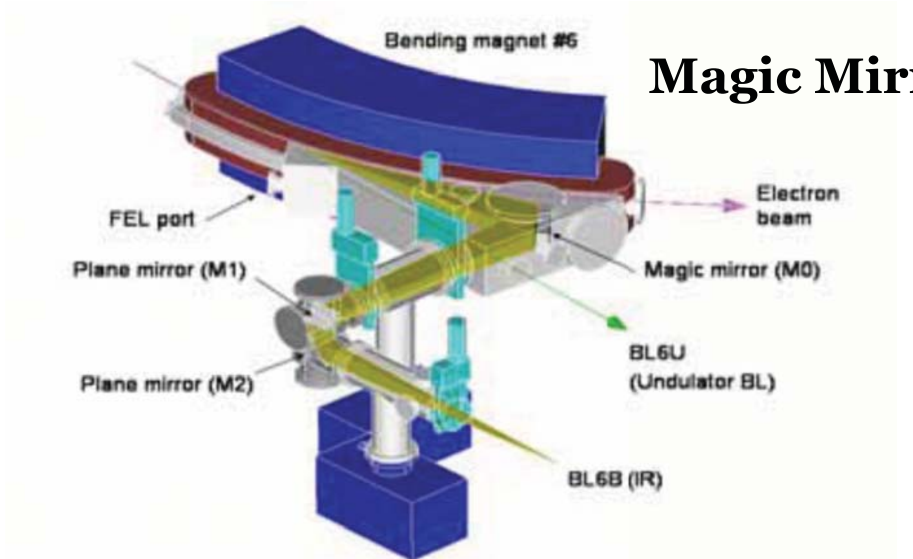
Most existing options use either an ellipsoid or toroid



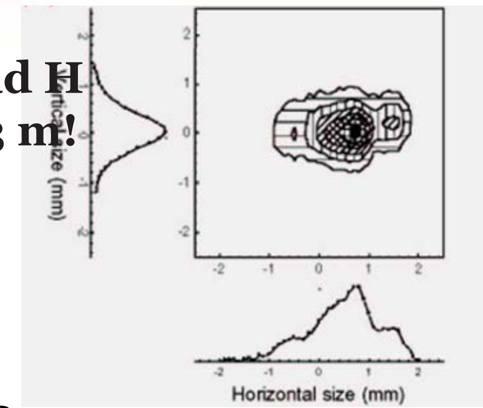
Most traditional optical set up

@ Spring-8 and UVSOR

Magic Mirror

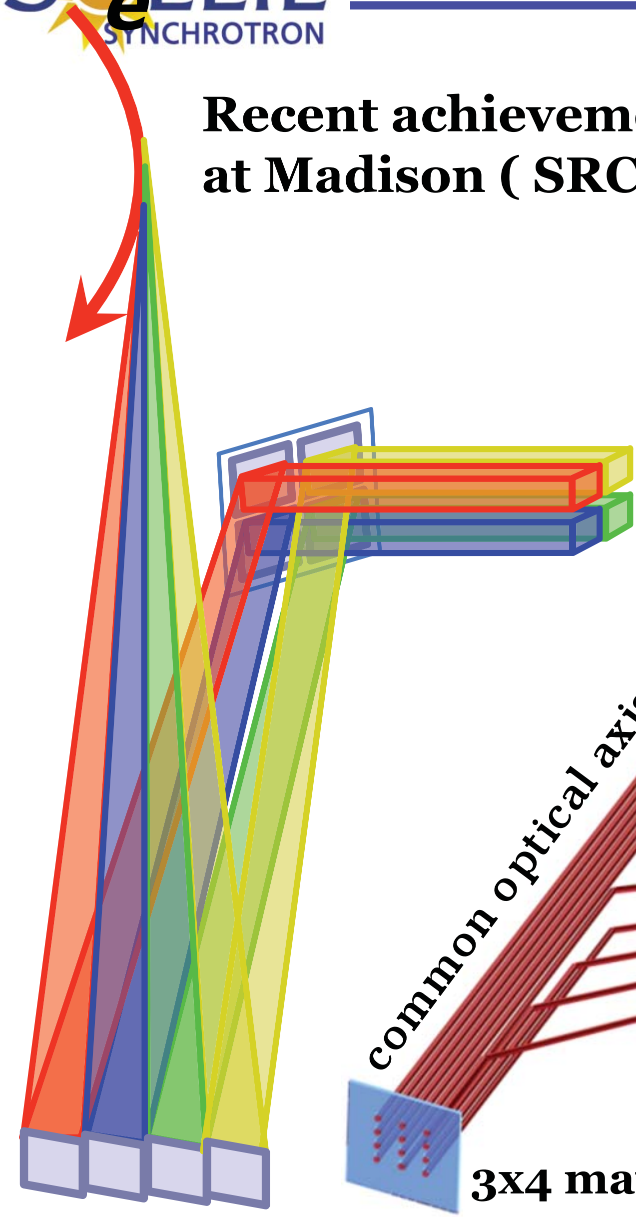


Spring-8=36.5 mrad H
Source depth= 1.43 m!

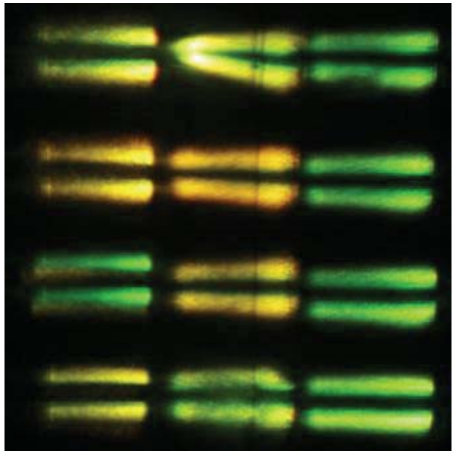


Front end and optics of infrared beamline at SPring-8
S. Kimura, et al.
NIM in Physics Reserach A: volume 467-468, part1, 21 July 2001, Pages 437-440

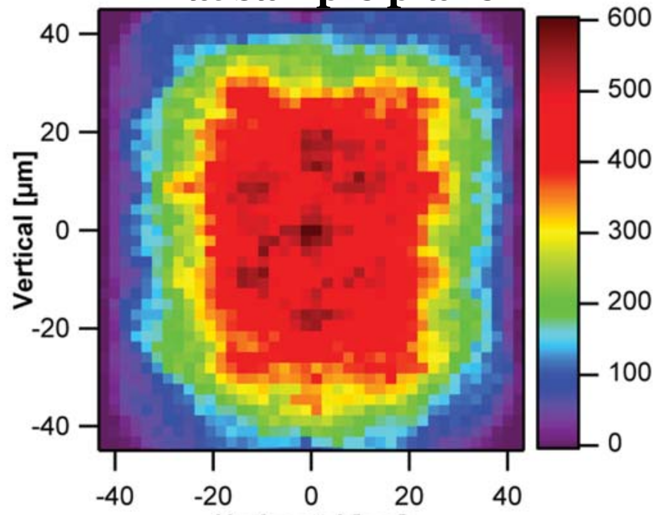
BM EMISSION AND SOURCE DEPTH

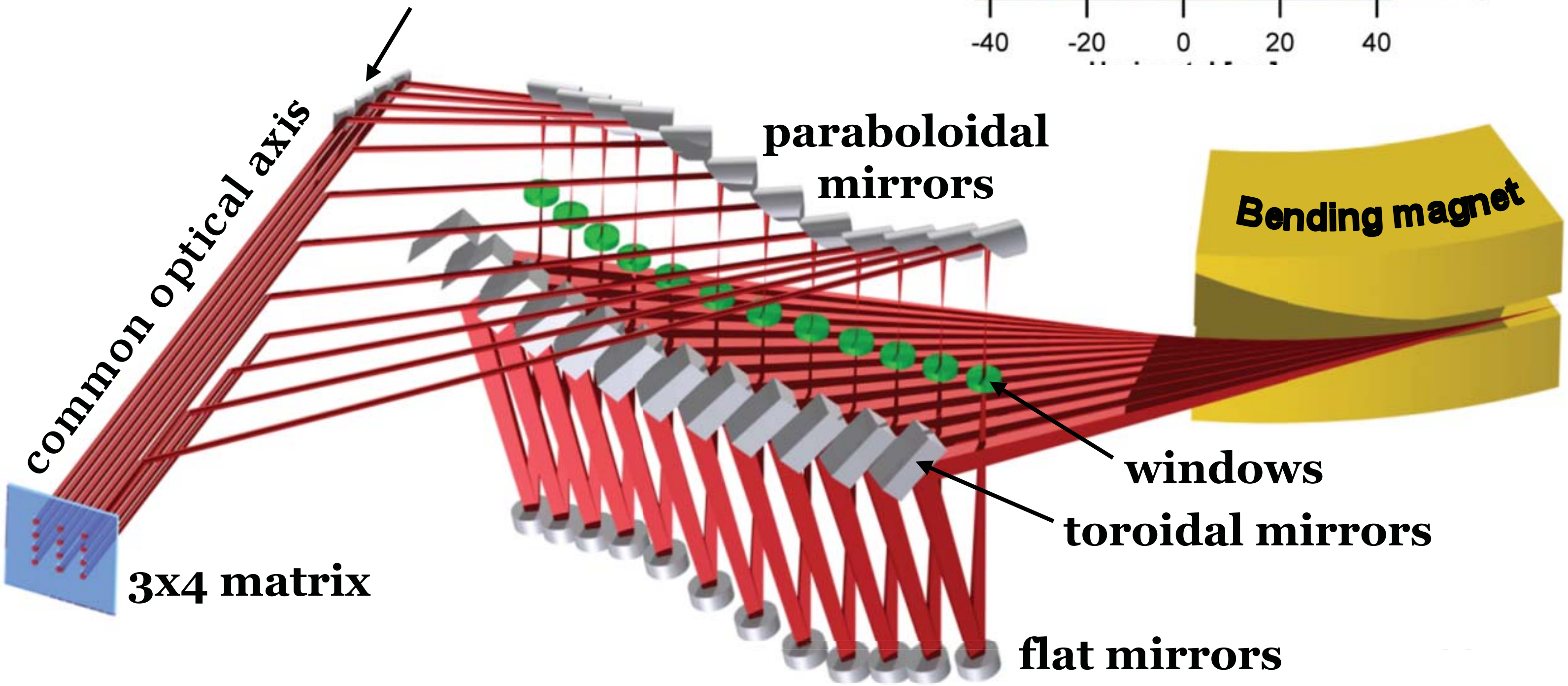


Recent achievement at Madison (SRC)



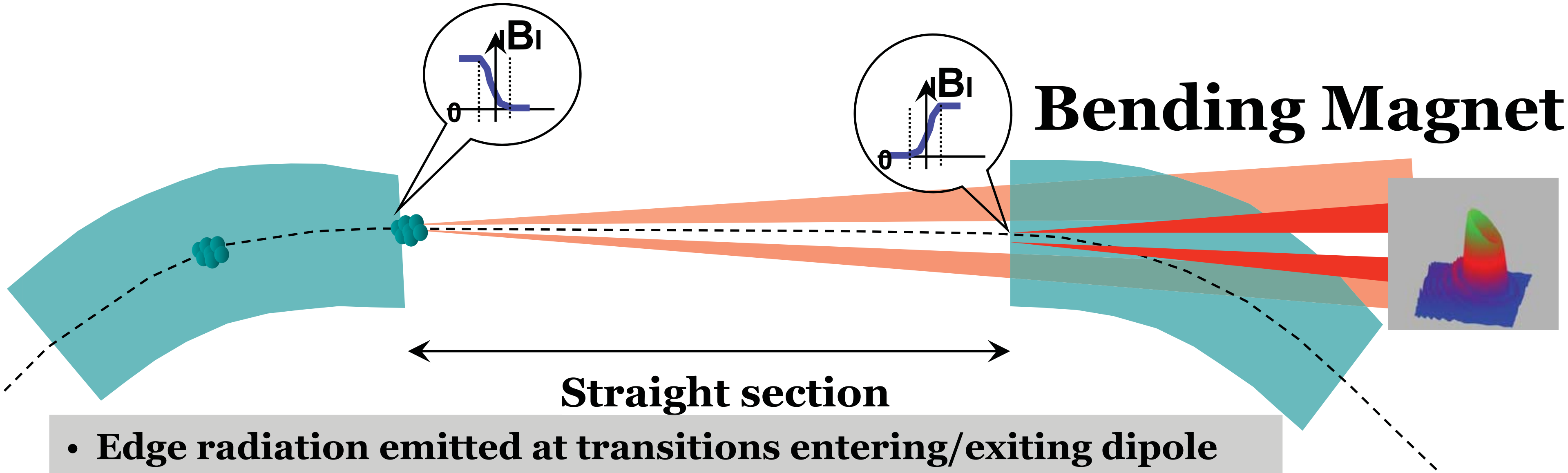
simulated overlap of defocused 3x4 matrix at sample plane





Nasse *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A 582 (2007) 107-110

Edge radiation was identified as a real potential IR source

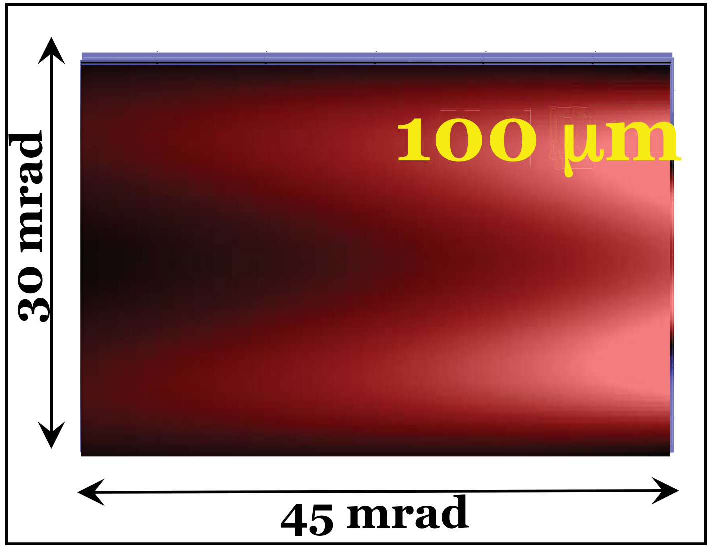


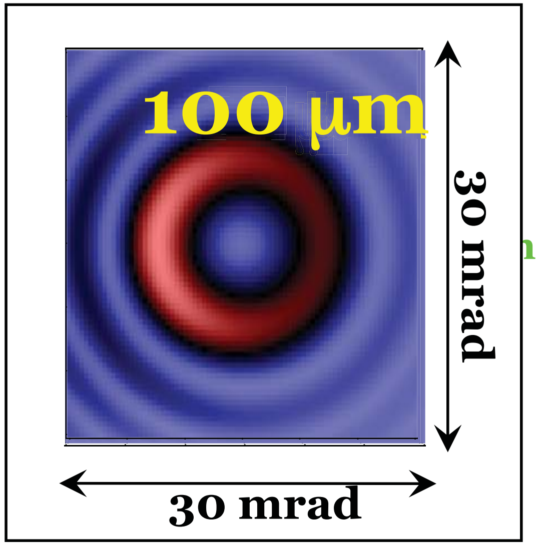
- Edge radiation emitted at transitions entering/exiting dipole magnets (two-edge interference, cancellation on-axis).
- Intrinsically bright.
- Radial polarization .

- It is not an extended source!!!

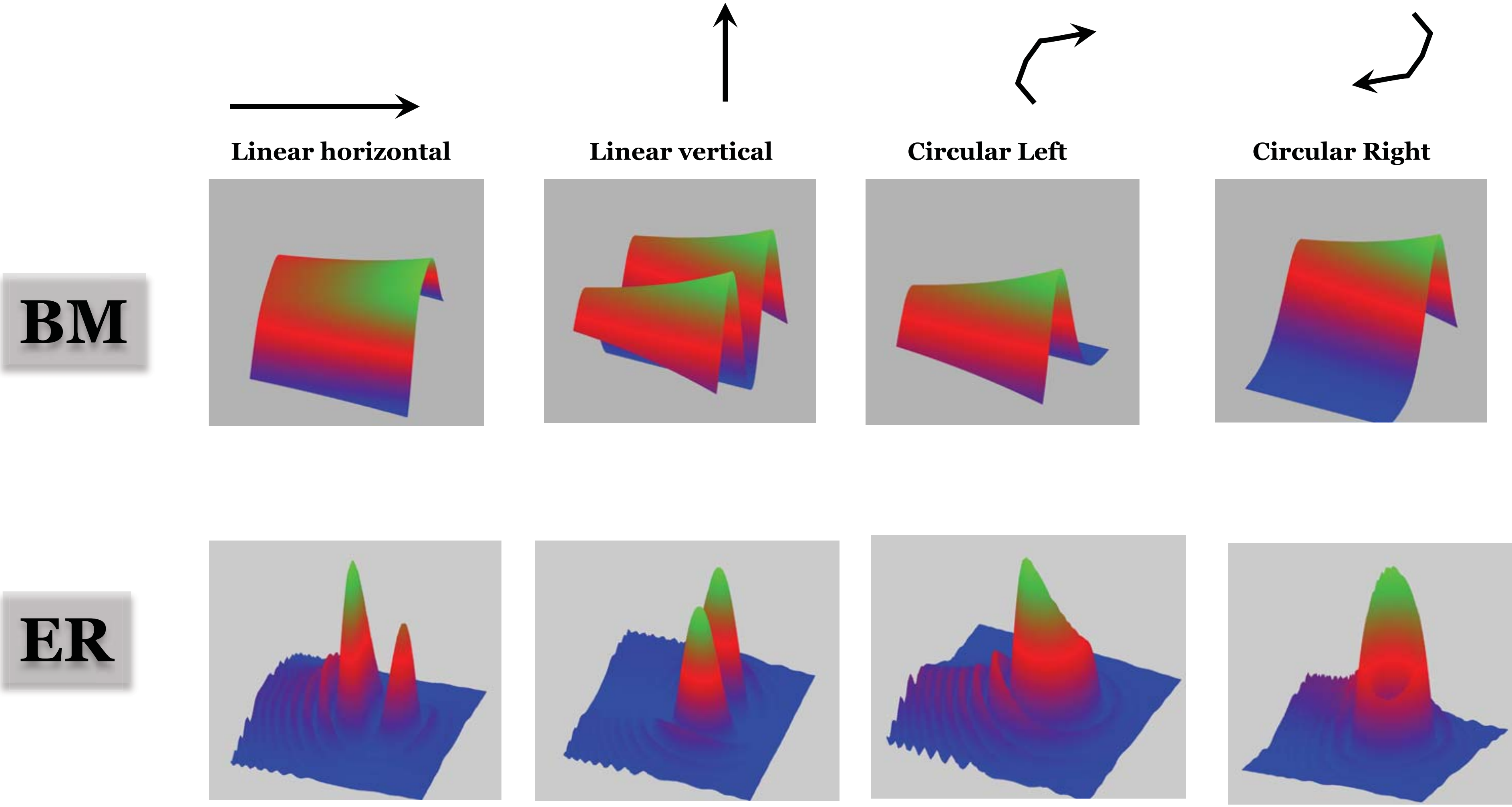
EDGE RADIATION EMISSION IN A NARROWER CONE

SOLEIL	***SOLEIL***
2.75 GeV	**2.75 GeV**
45 mrad H X 30 mrad V	**30 mrad H X 30 mrad V**
BM	**BM**





ER and BM EMISSION HAVE DIFFERENT POLARISATION PROPERTIES



MECHANICAL CHALLENGES: DIPOLE CHAMBERS HAVE TO BE LARGELY MODIFIED

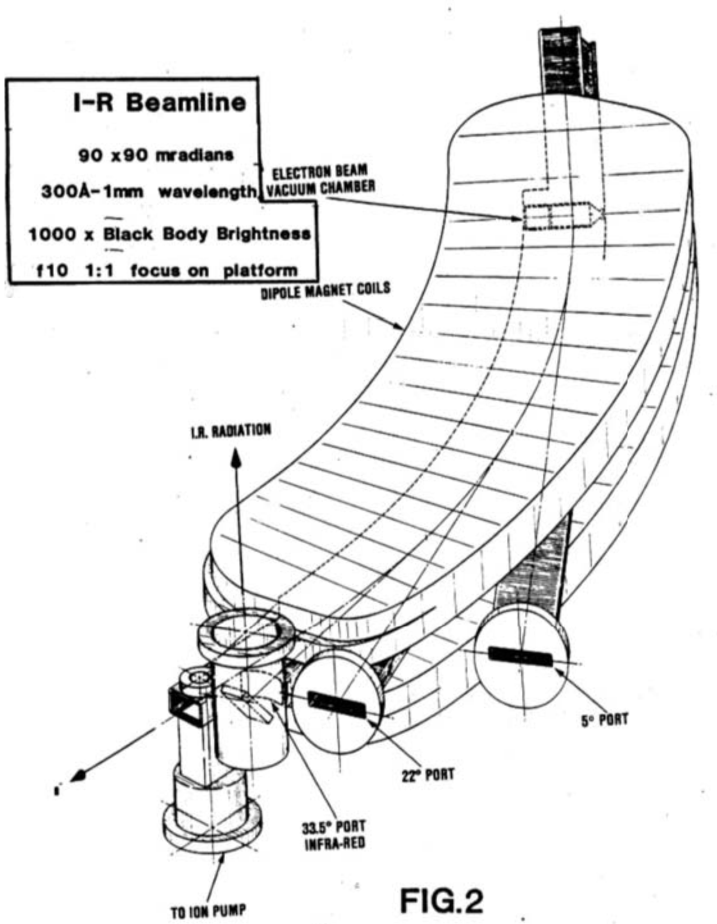
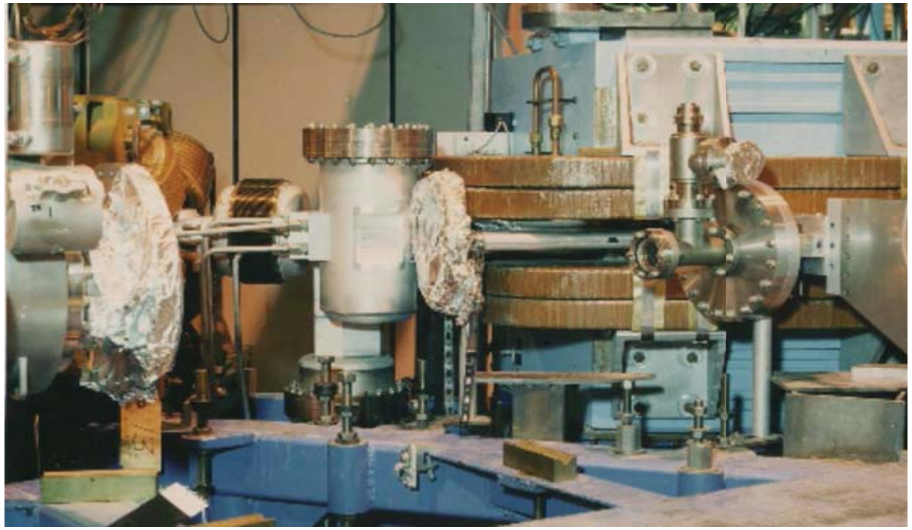


FIG.2

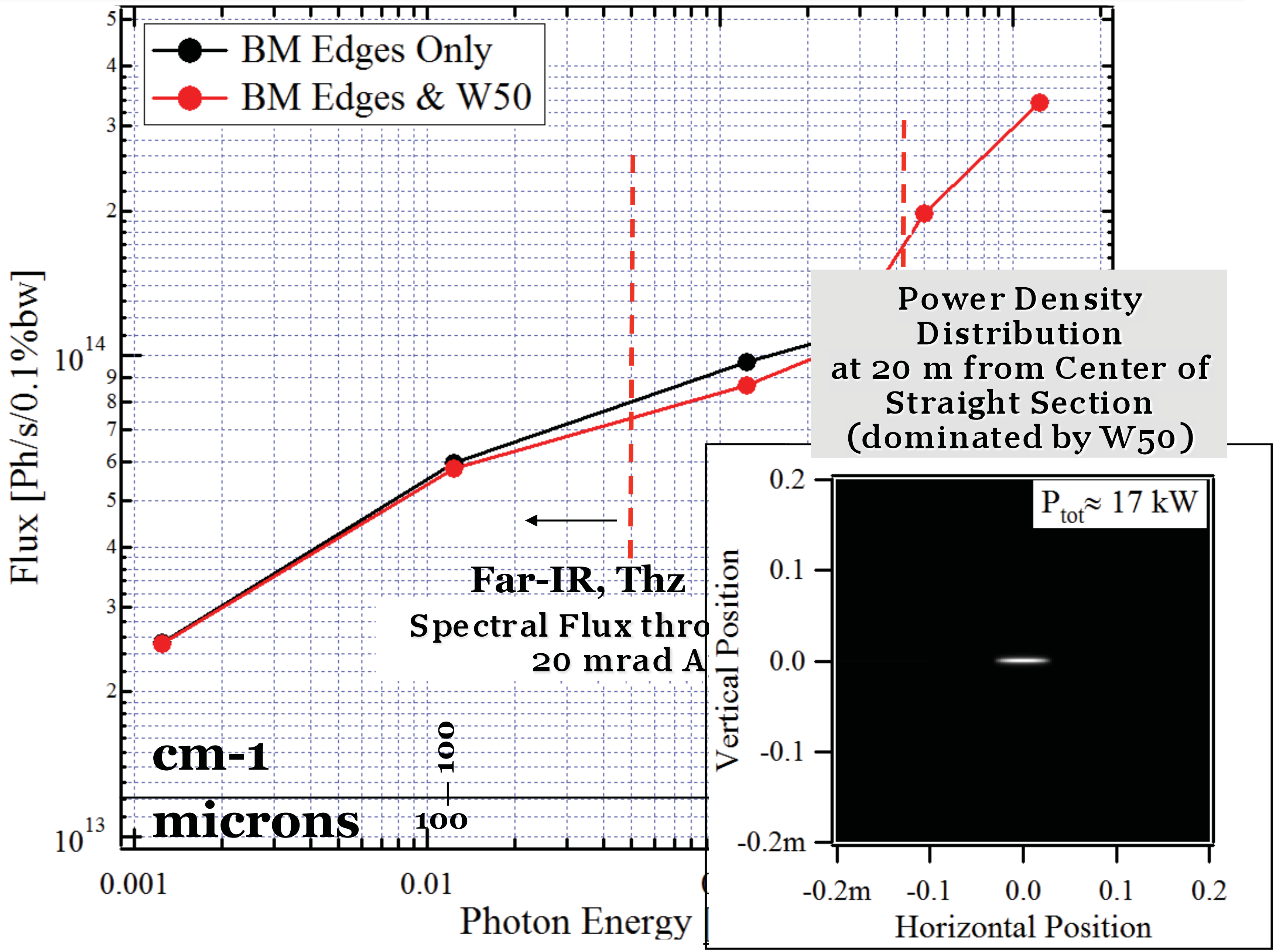
NSLS Phase2 Infra-Red Beam Extraction

NSLS 90x90 mrad, 1986

E= 0.808 GeV

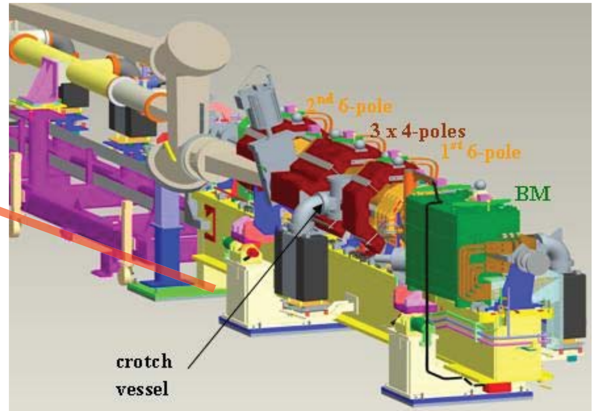


ARE INSERTION DEVICES CANDIDATES FOR HIGHER INFRARED PHOTON PRODUCTION?

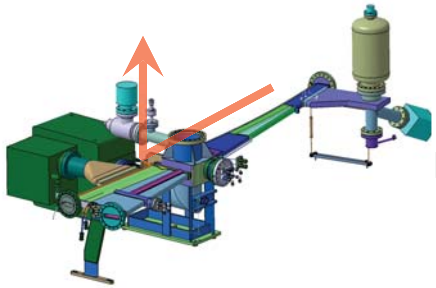


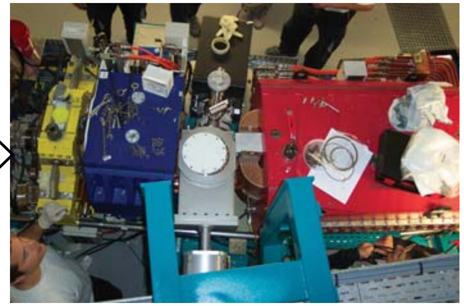
EXTRACTING INFRARED BEAM AT SYNCHROTRON STORAGE RINGS

Horizontal extraction
(e.g. DIAMOND)

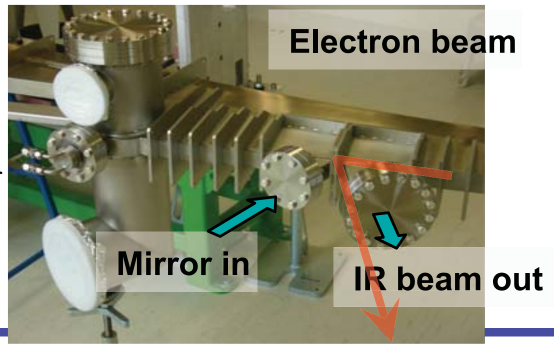


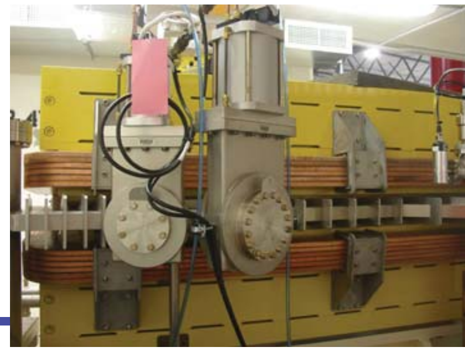
Vertical extraction
(e.g. SOLEIL)





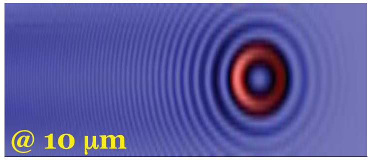
Horizontal extraction
(e.g. AS, ALBA)





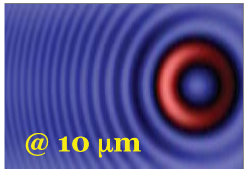
RECENT IR BEAMLINES EXPLOIT BOTH ER and BM

ANKA



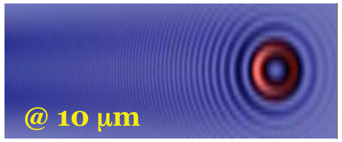
45 mrad H x 15 mrad V

ESRF



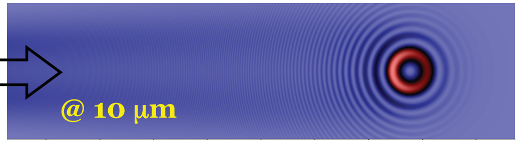
15 mrad H x 8.54 mrad V

AS



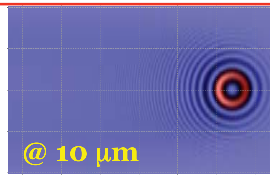
50 mrad H x 17 mrad V

SOLEIL



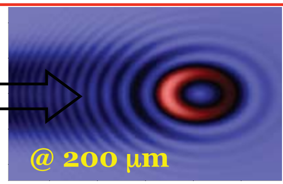
78 mrad H x 20 mrad V

DIAMOND



50 mrad H x 30 mrad V

Jefferson Labs

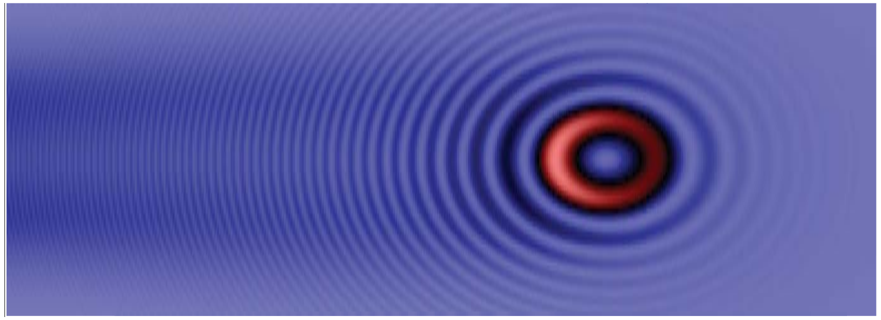


170 mrad H x 146 mrad V

AS WELL AS ONES IN DESIGN STAGE

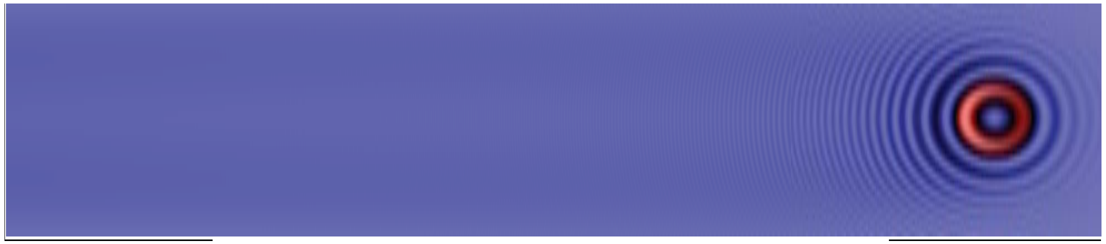
Facility (GeV)

ALBA(3)



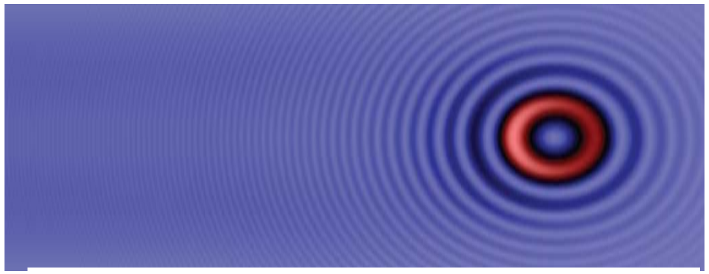
43 mrad (H) x 25.17 mrad (Vl)

SRLI(1.2)



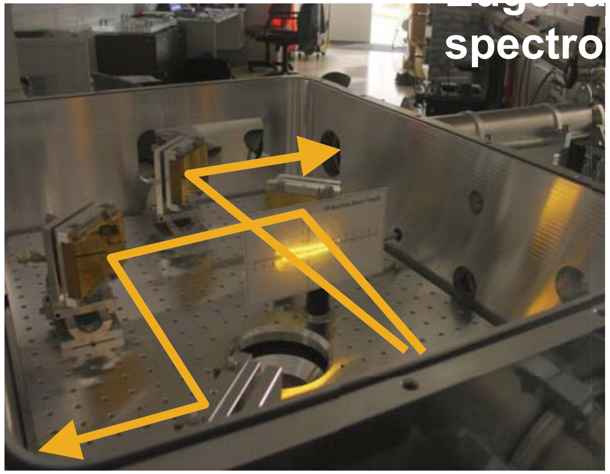
92 mrad (H) x 20 mrad (Vl)

SESAME (2.5)

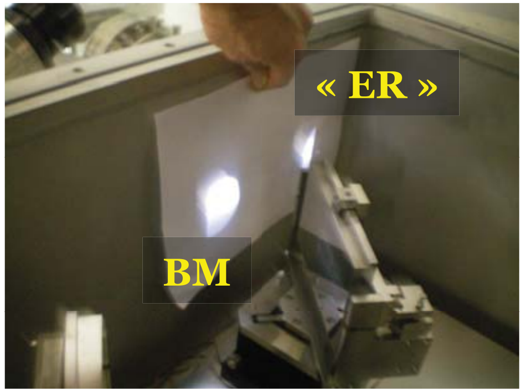


40 mrad (H) x 18 mrad (Vl)

DOUBLING THE CAPACITY....

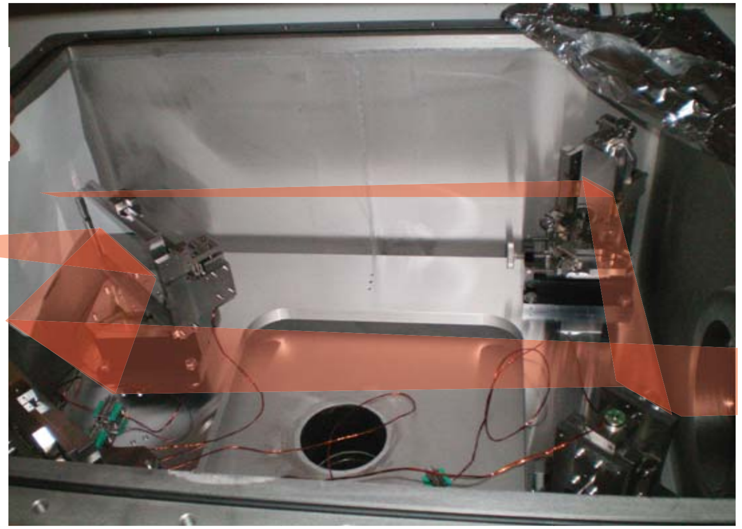


@ AS



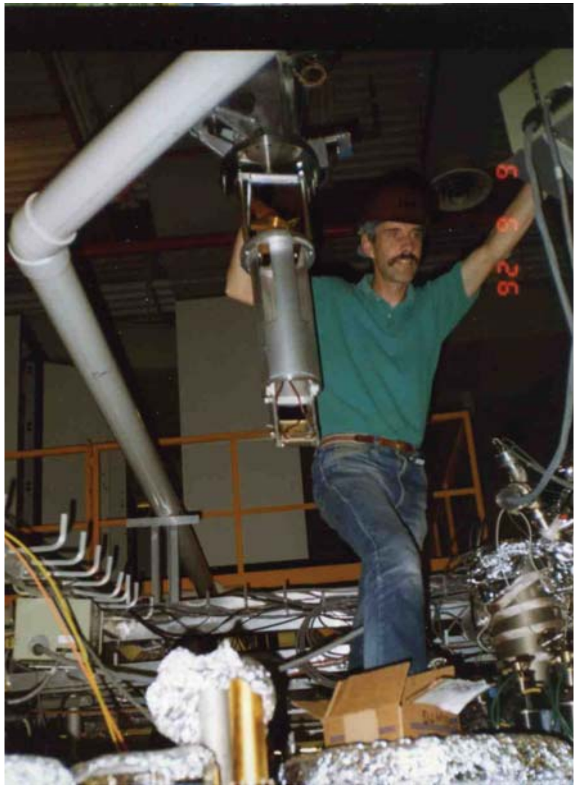
Microscope 2
Branche ER

Microscope 1
Branche BM



@ SOLEIL

CRUCIAL: THE FIRST EXTRACTION MIRROR

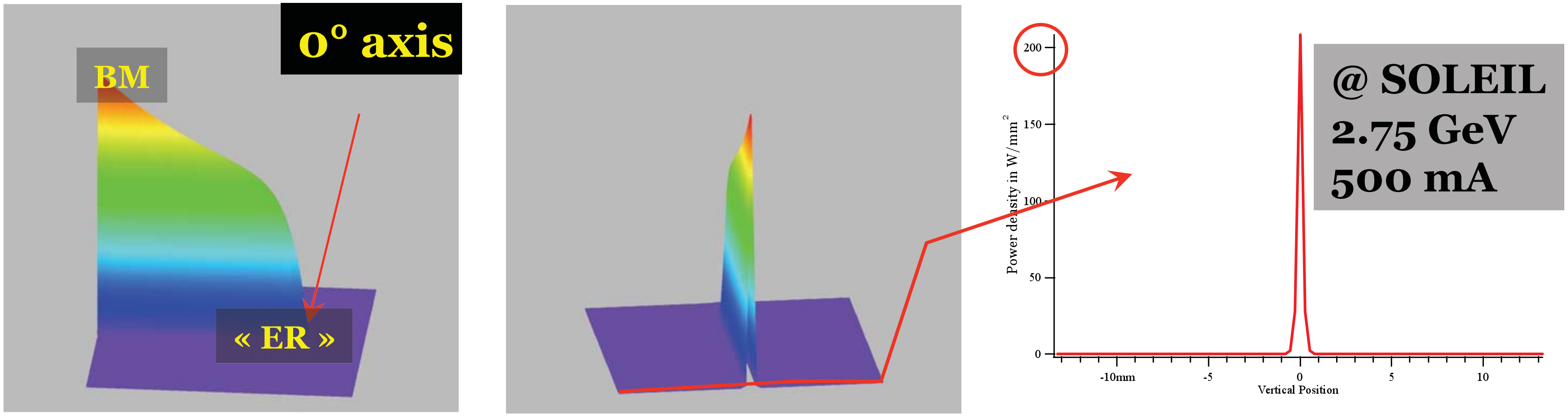


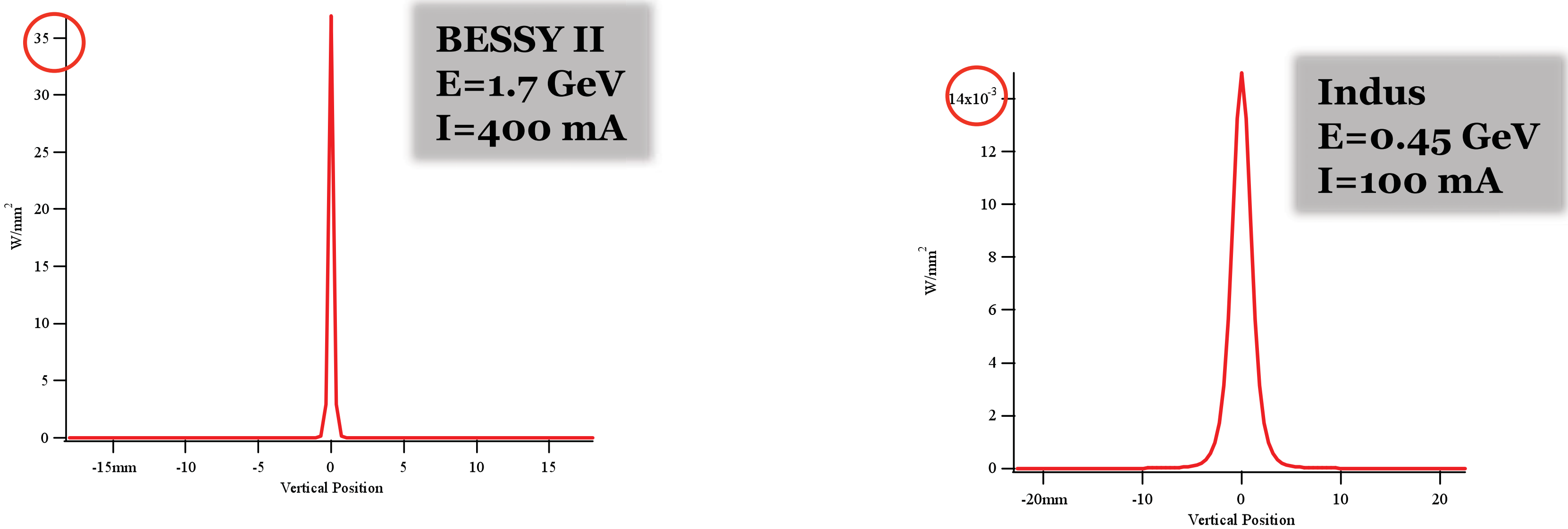
Heat load and cooling issues

Precise positioning issues (and often retraction)

Blackening issues

HEAT LOAD AT FIRST EXTRACTION MIRROR

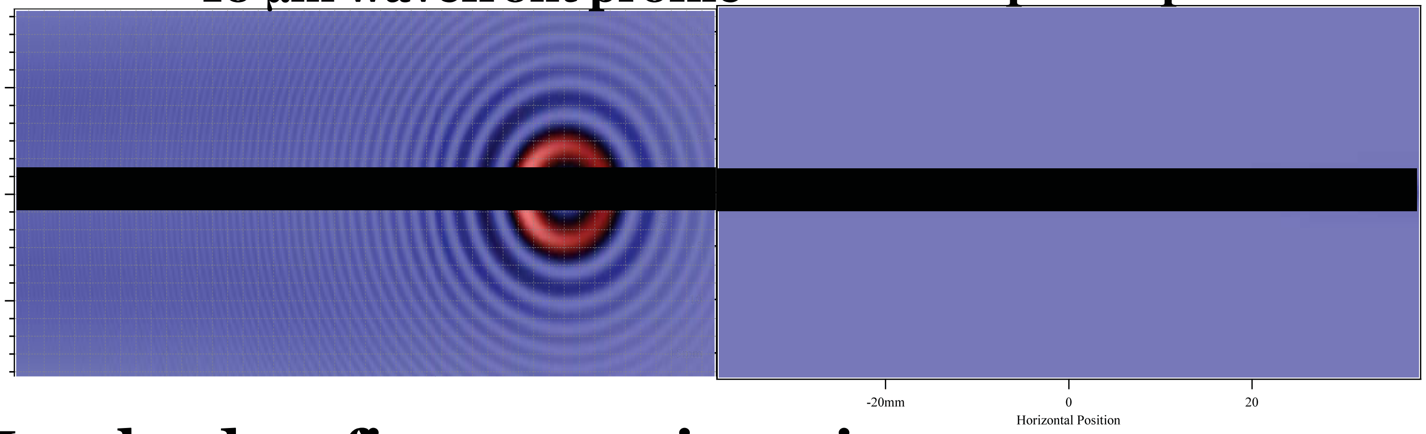


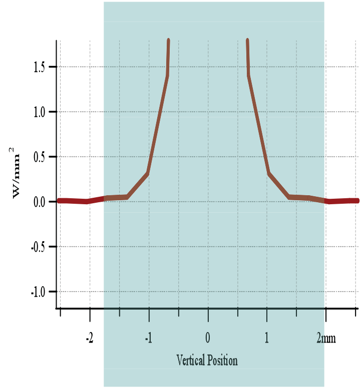


SLOTTED MIRROR

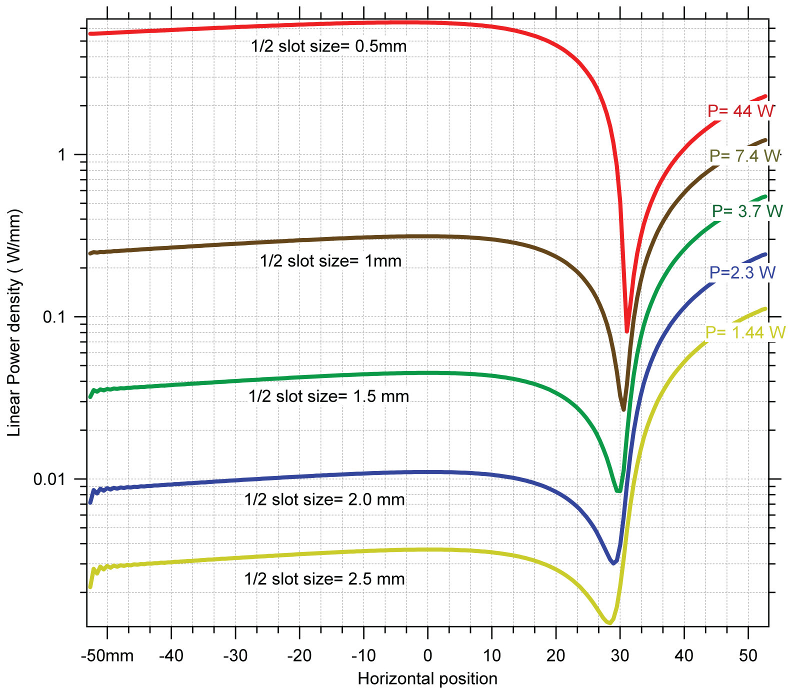
10 µm wavefront profile

Heat power profile

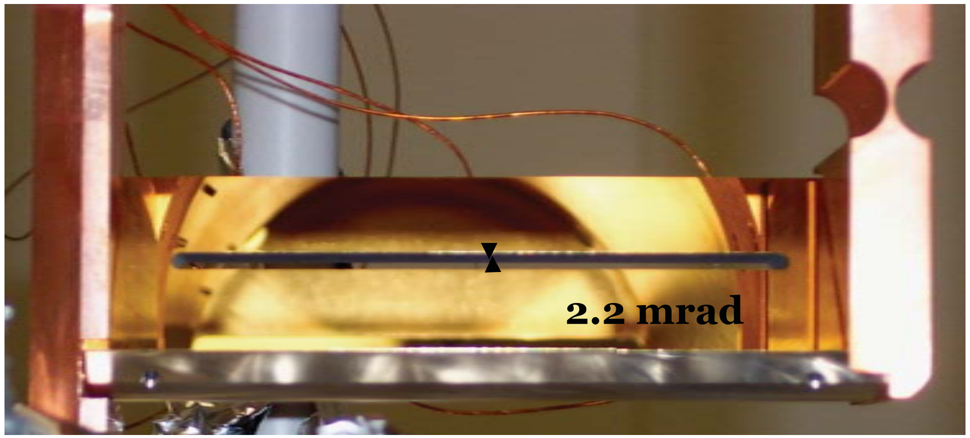




Heat load on first extracting mirror:

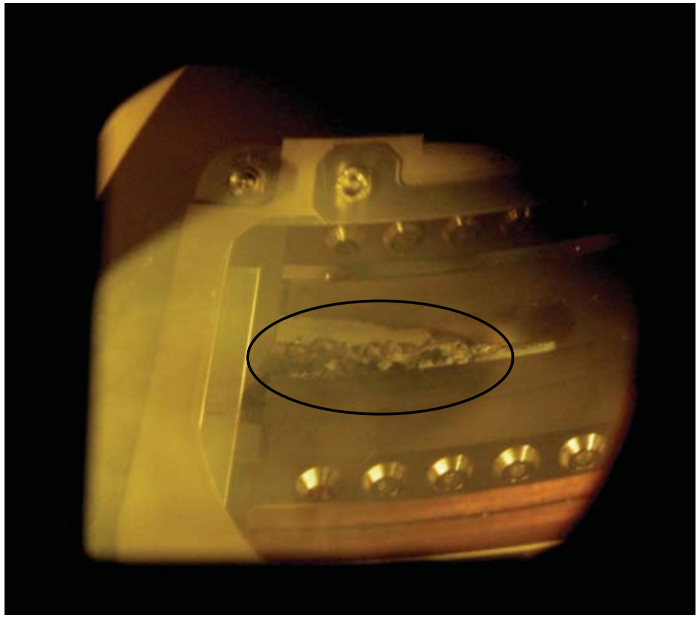


Case at SOLEIL



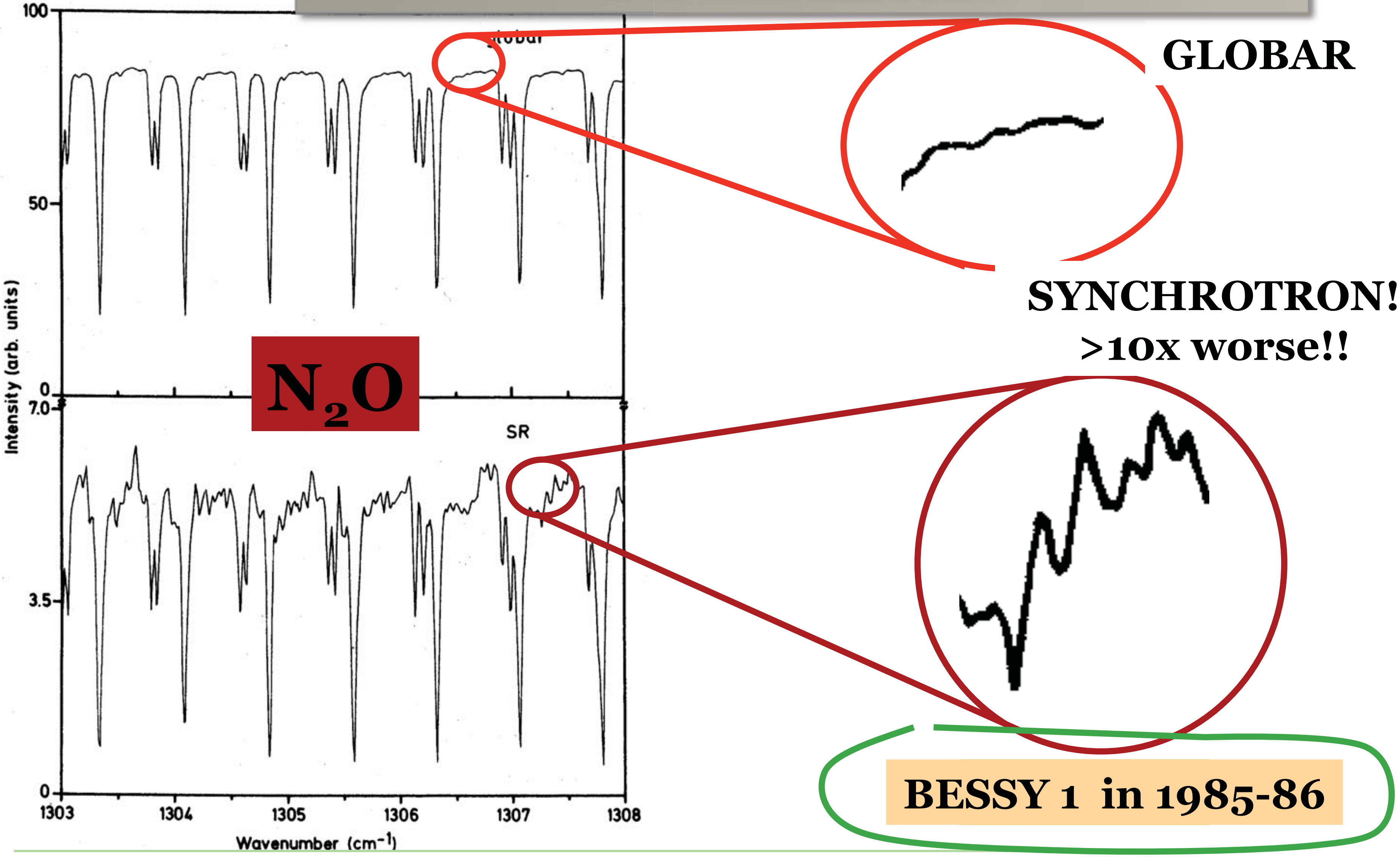
MIRROR POSITIONNING MUST BE PRECISE AND REPRODUCIBLE

@ SLS



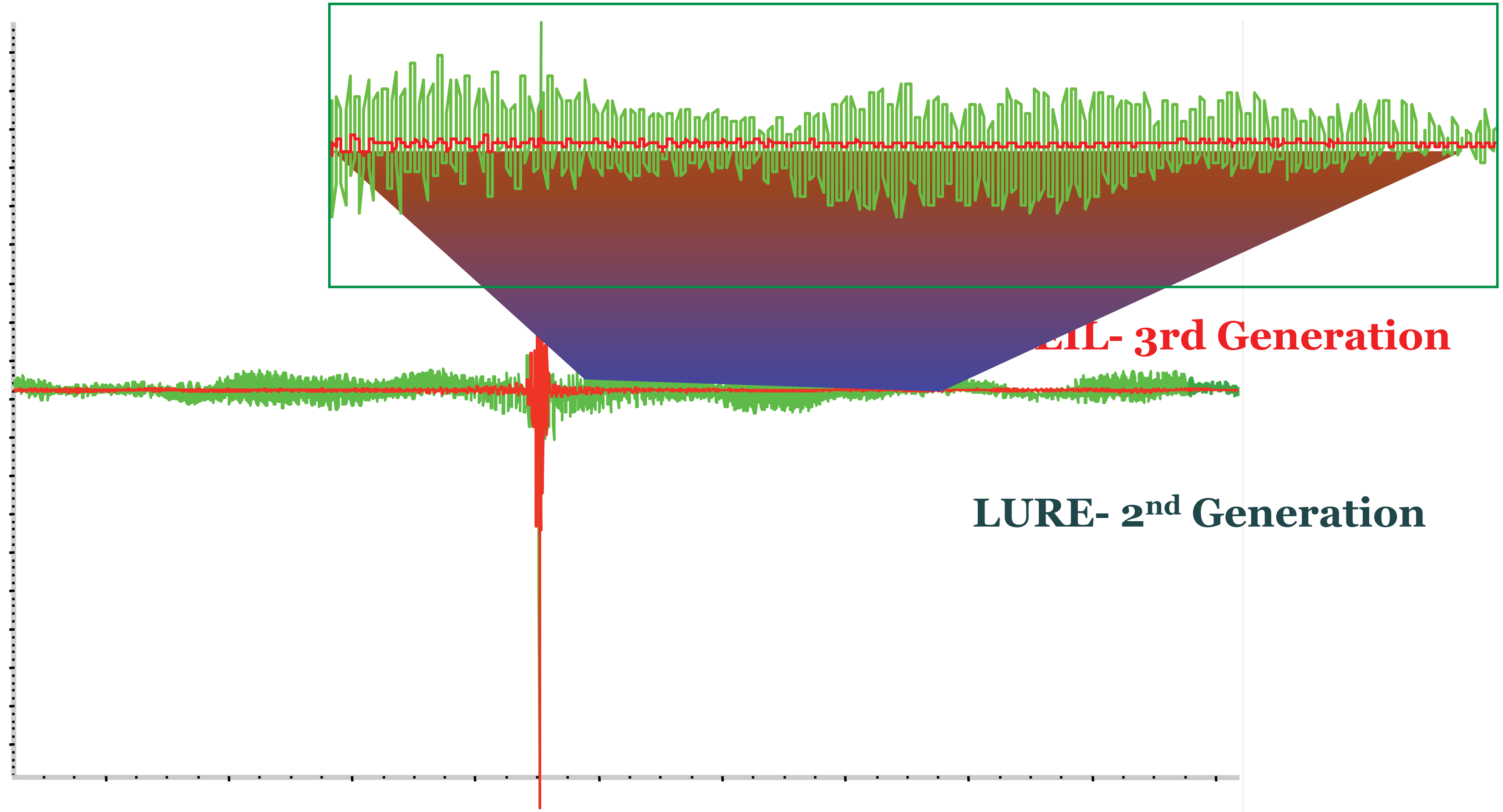
@ SPRING-8

INFRARED EMISSION AND BEAM INSTABILITIES



Schweitzer, Nagel, Brain, Lippert and Bradshaw Nucl. Instr. & Methods A246 163 (1986)

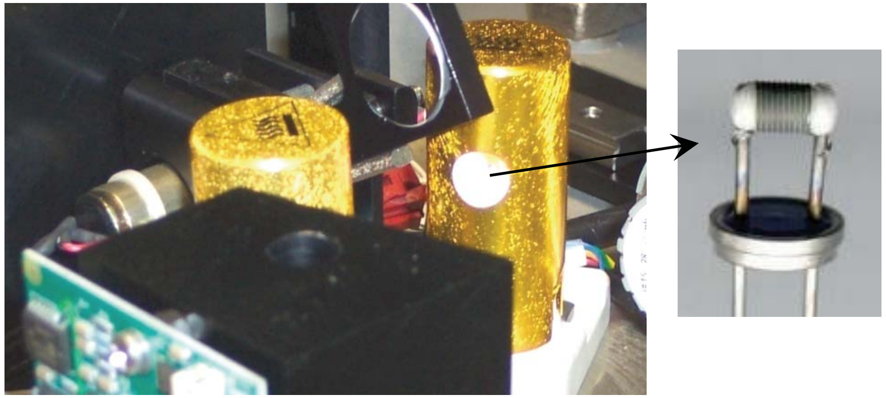
IMPORTANT IMPROVEMENTS WITH THIRD GENERATION SYNCHROTRON FACILITIES



S_{src}

FLUX AND BRIGHTNESS

Blackbody radiation



S_{src} The spectral flux emitted by isotropic black-body source into a solid angle $\Omega = 2\pi \sin\theta_r$ (where is the angular radius of the first optical element of the spectrometer), is:

$$\left(\frac{dW}{d(1/\lambda)}\right)_{BB} \approx \frac{2\pi hc^2 S_{src} \sin\theta_r}{\lambda^3}\left[\exp\left(\frac{hc}{\lambda k_B T}\right) - 1\right]^{-1}$$

h =Planck constant

c =Speed of light

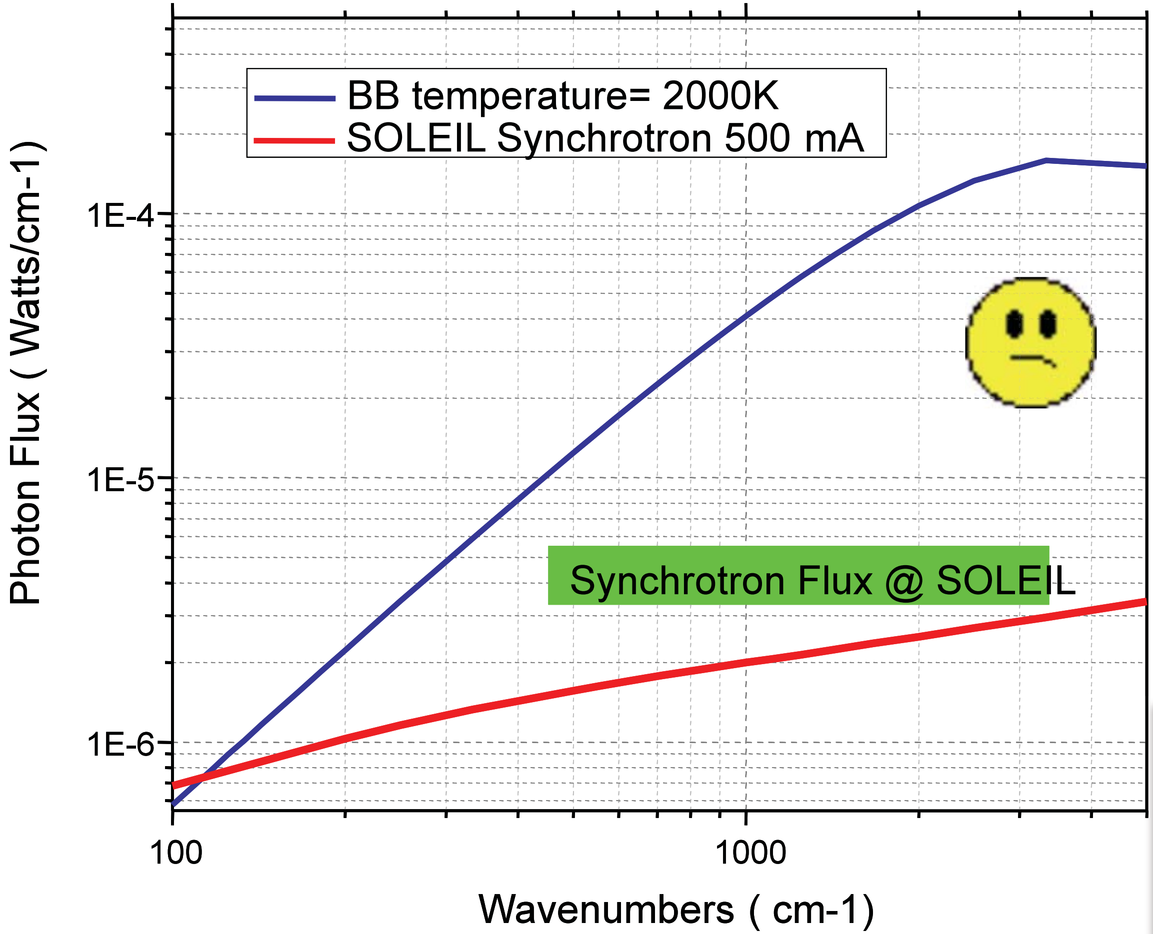
λ =Radiation wavelength

k_B =Boltzmann constant

S_{src} =Source area

FLUX AND BRIGHTNESS

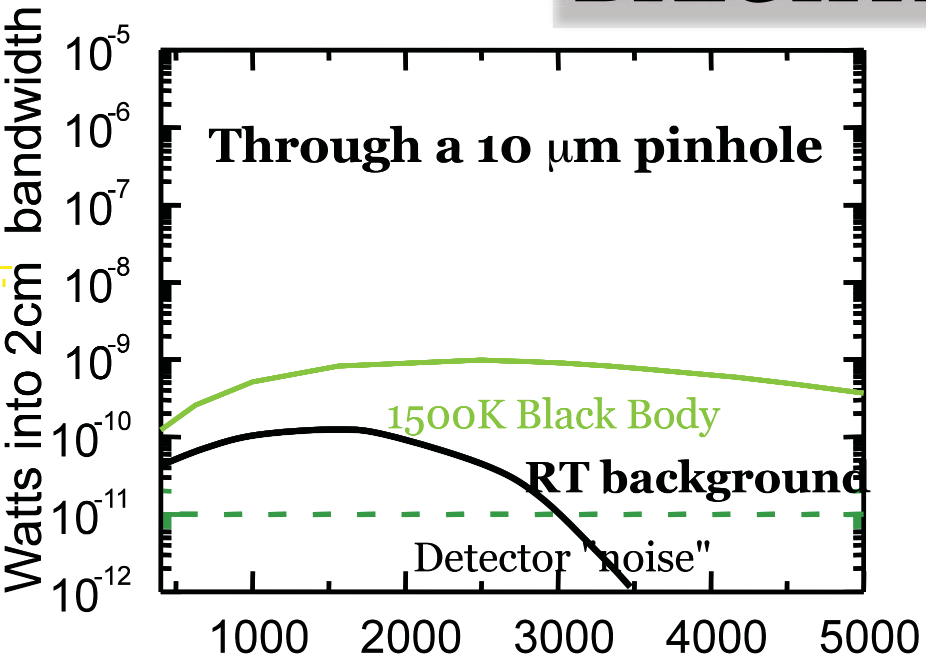
FLUX:

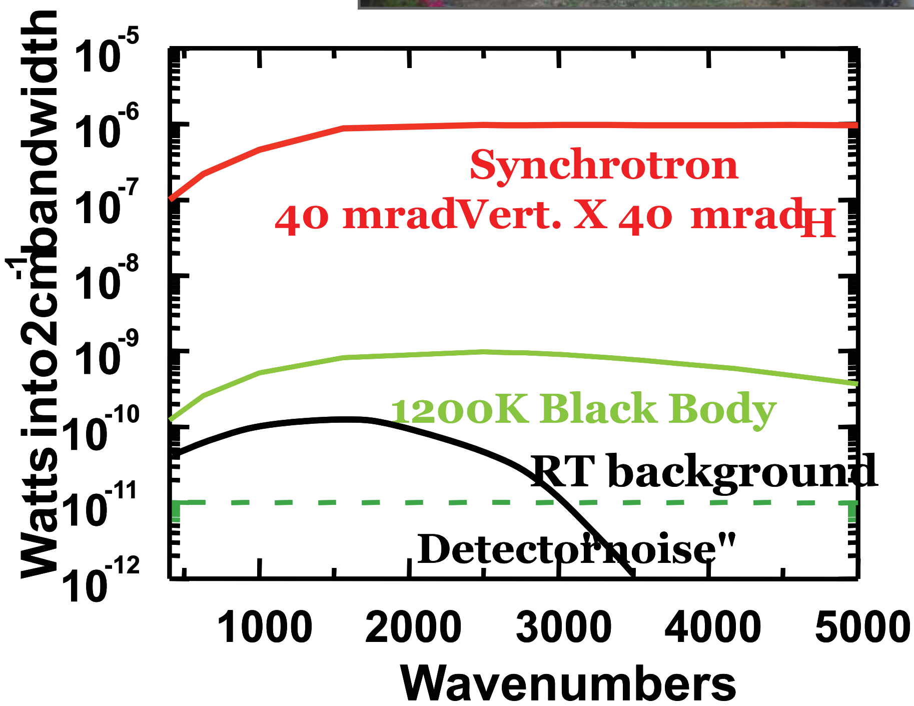


Synchrotron IR is much brighter !

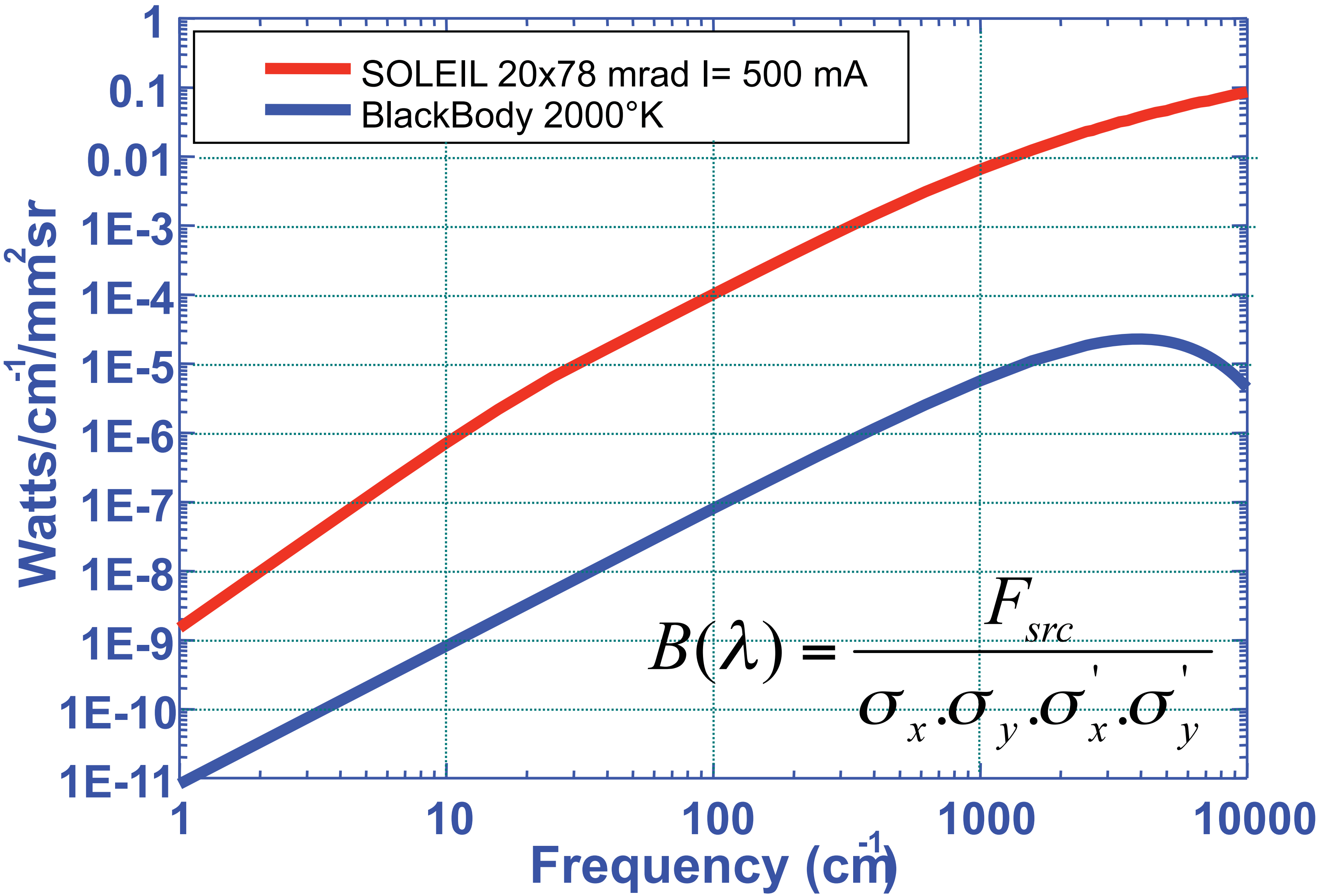
FLUX AND BRIGHTNESS

BRIGHTNESS:



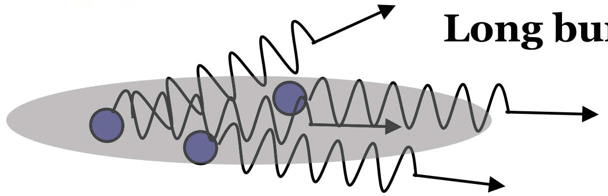


BRIGHTNESS CURVE

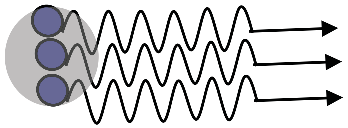


$$B(\lambda) = \frac{F_{src}}{\sigma_x . \sigma_y . \sigma'_x . \sigma'_y}$$

MULTIPLE PARTICLE COHERENCE

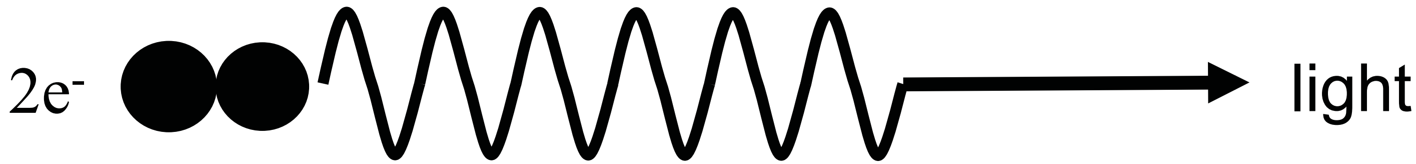


Long bunch emits incoherently



Short
bunch emits coherently

A source optimized for Coherent THz
10^6 - 10^{10} more flux than other broadband sources

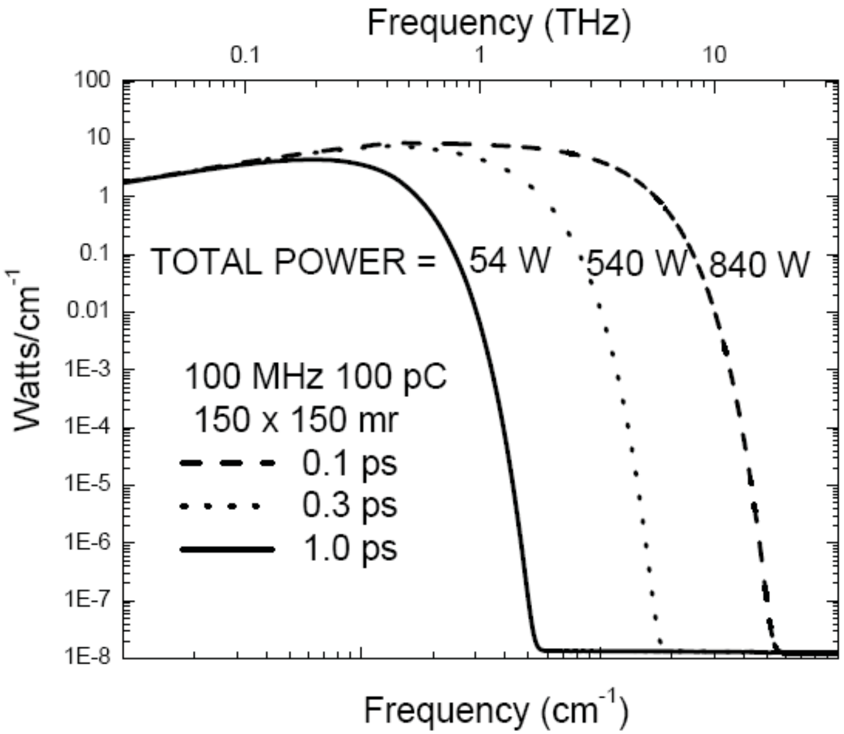


Larmor's formula:

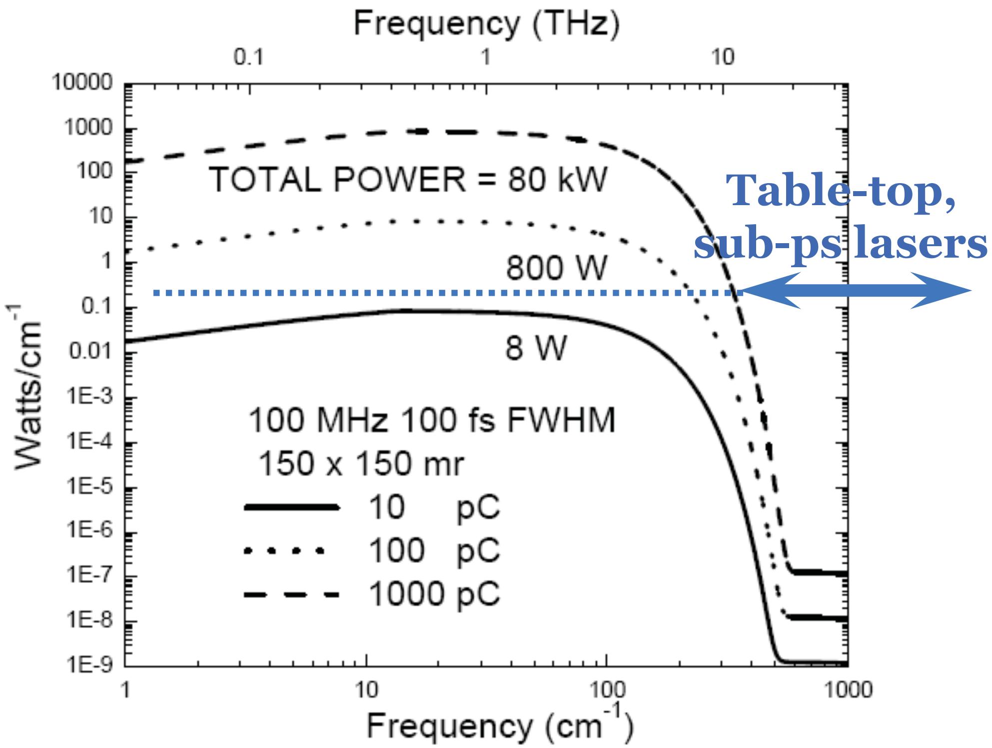
$$\text{Power} = \frac{2(Ne)^2 a^2}{3c^3}\gamma^4 \quad \text{(in cgs units)}$$

$P \propto N^2$
Can be huge!

CALCULATED THz EMISSION FROM A COHERENT SYNCHROTRON RADIATION SOURCE



For 100 pC bunch, 100 MHz, versus bunch lengths



For 100 fs FWHM pulses, 100 MHz, versus bunch charge

From G.P. Williams *« Filling the THZ gap-High Power sources and applications »* Report on Progress in Physics and Applications (2005) in print

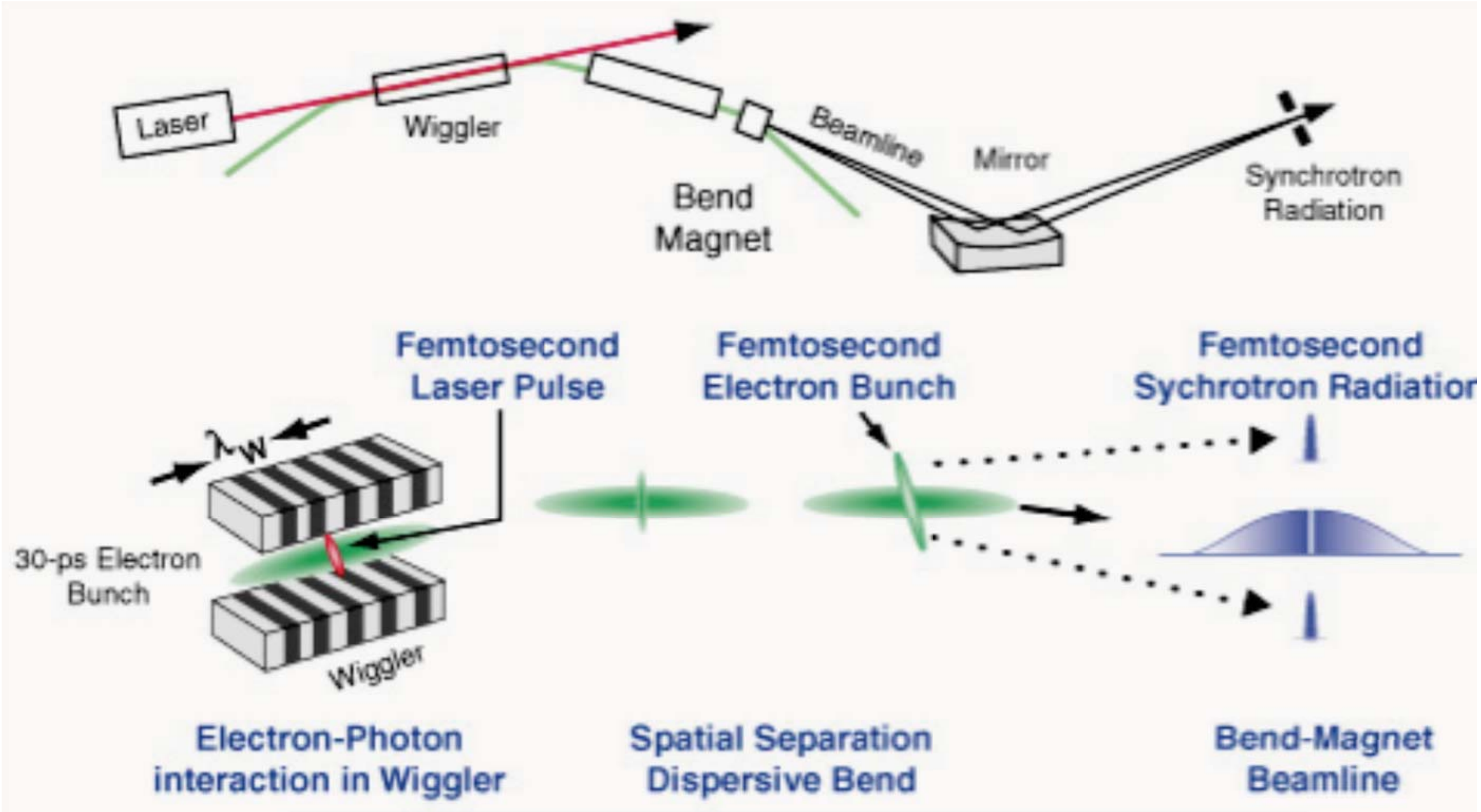
GENERATING SHORT PULSES IN STORAGE RINGS

1) **Generating short pulses < 10ps *(with significant photon flux))* in storage ring is not that easy .**

2) **In general, the natural pulse length is ~ 20ps rms (6mm) :(energy dispersion , RF voltage,Touschek, …).**

3) **Increasing the current per bunch increases the bunch length(impedance)**

SHORT PULSES BY LASER SLICING

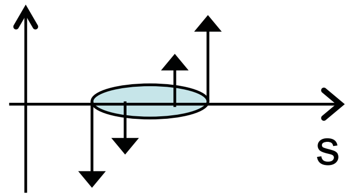


Weak photon flux, but doable

SHORT PULSES IN CRAB CAVITIES

A. Zholents [NIM A425 385 (1999)]

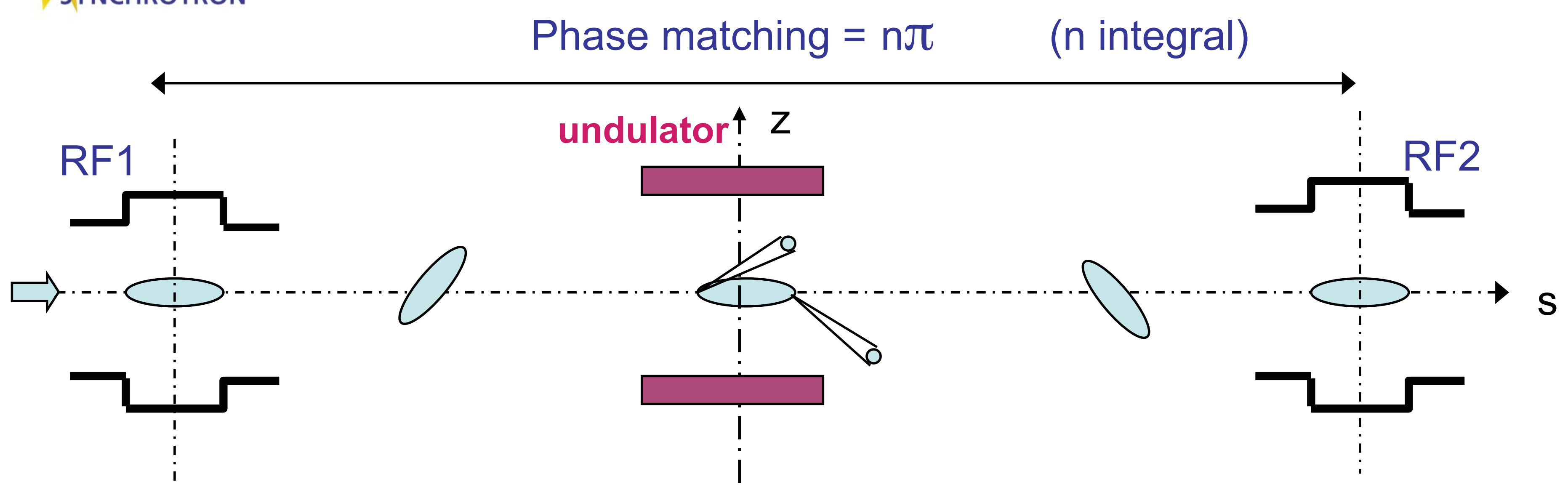
- RF cavities, named « Crab cavities » , can provide transverse « kick » to an electron bunch where the force is proportional to the longitudinal distance for the bunch center



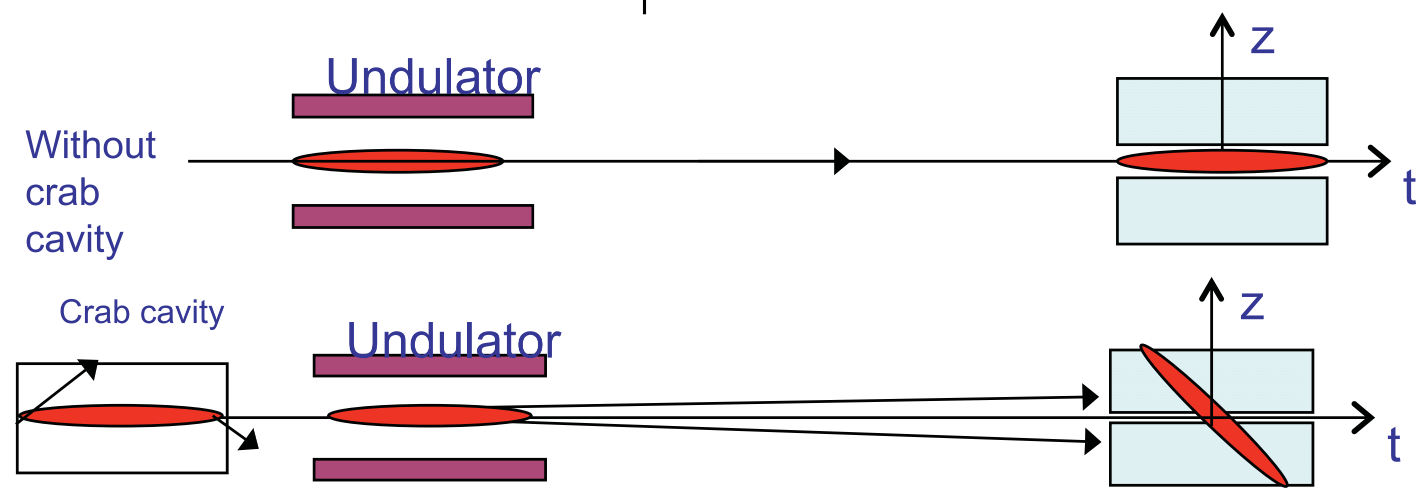
- One, then, creates a correlation between the longitudinal position of an electron in the bunch and its transverse angle (momentum)

- By passing through an undulator,photons are emitted with dispersion (correlation effect).. So the « head »photon are oriented upright , and tail photons downright

CRAB CAVITY SET UP



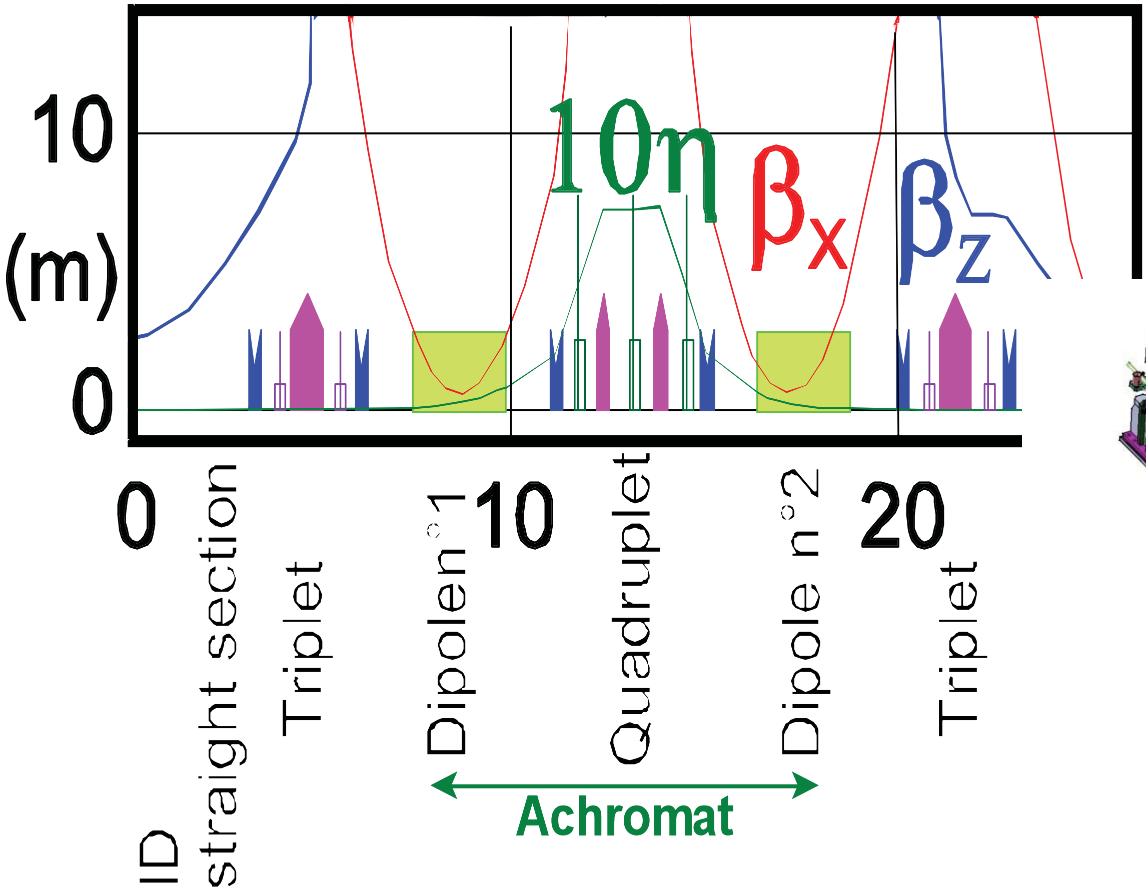
Requires two cavities: one for inducing the « kick », the other to cancel the « kick »



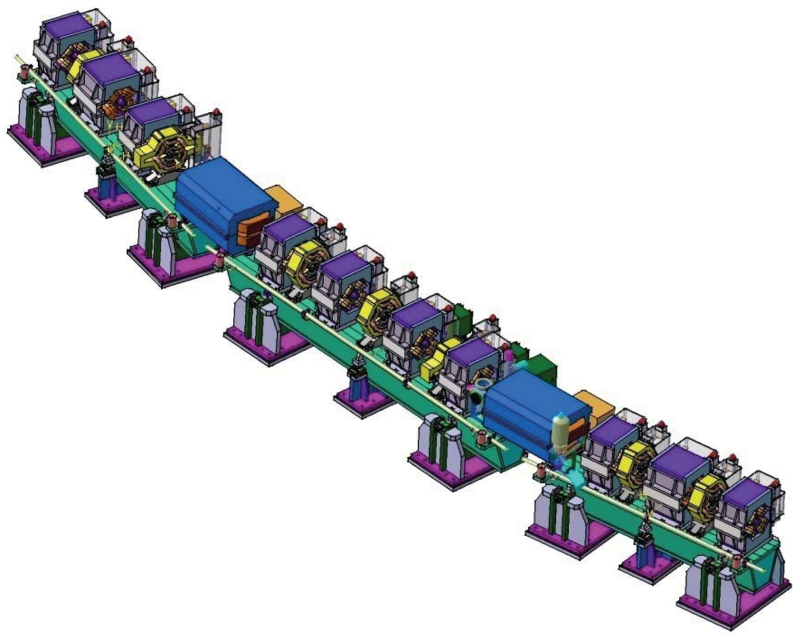
SHORT PULSES BY MOMENTUM COMPACTION

Typical storage ring lattice

Dispersion η generated in the first dipole brought back to zero by the quadruplet
Dipole n°1 + Quadruplet + Dipole n°2 = Achromat
Triplets at both ends of the straight sections allow for a good match of the envelop in the ID

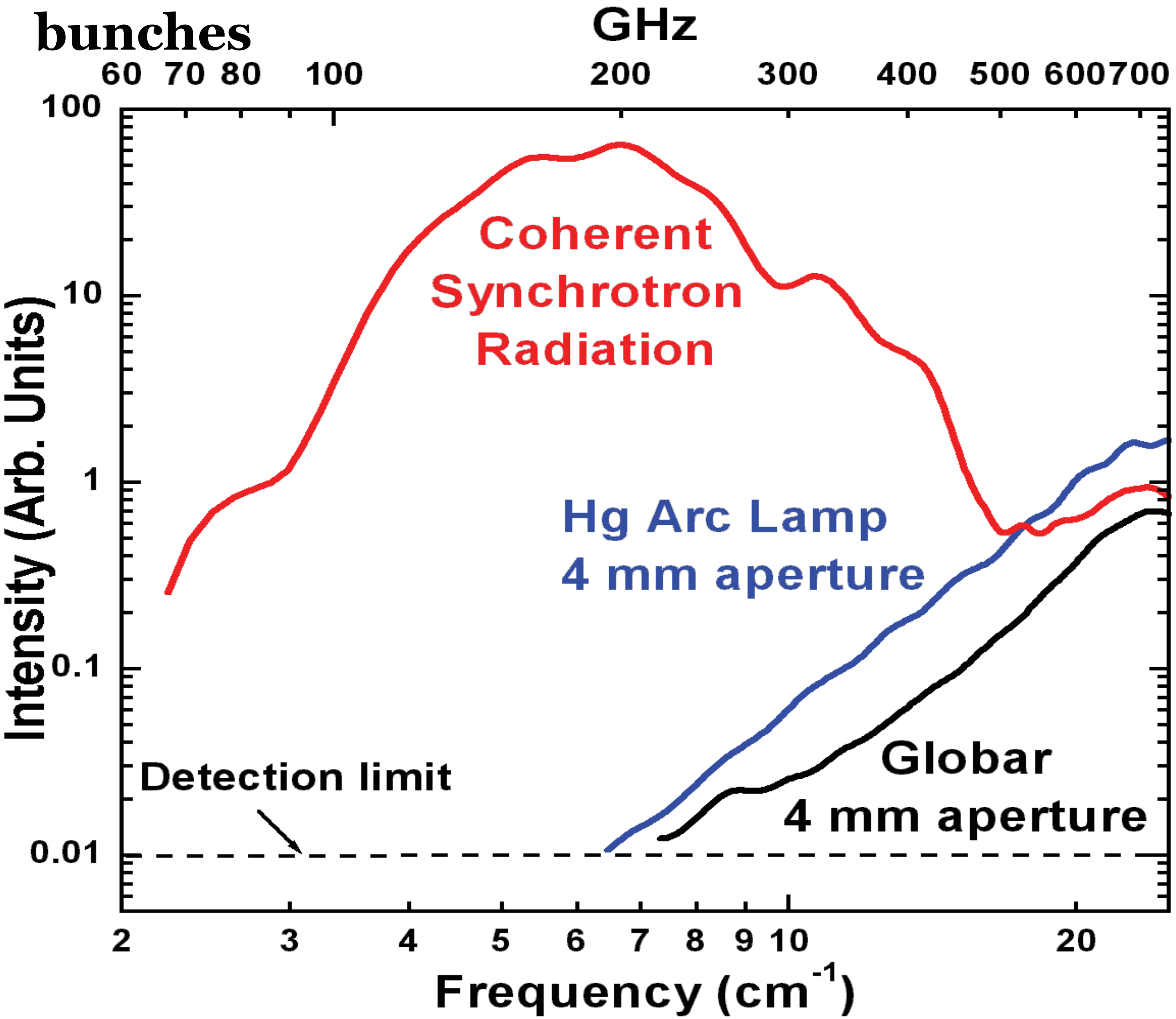


Dipole (Bending Magnet)



MOMENTUM COMPACTION: PROOF OF PRINCIPLE

Used BESSY-II synchrotron to get low-α tune: short & shaped bunches



BESSY-II

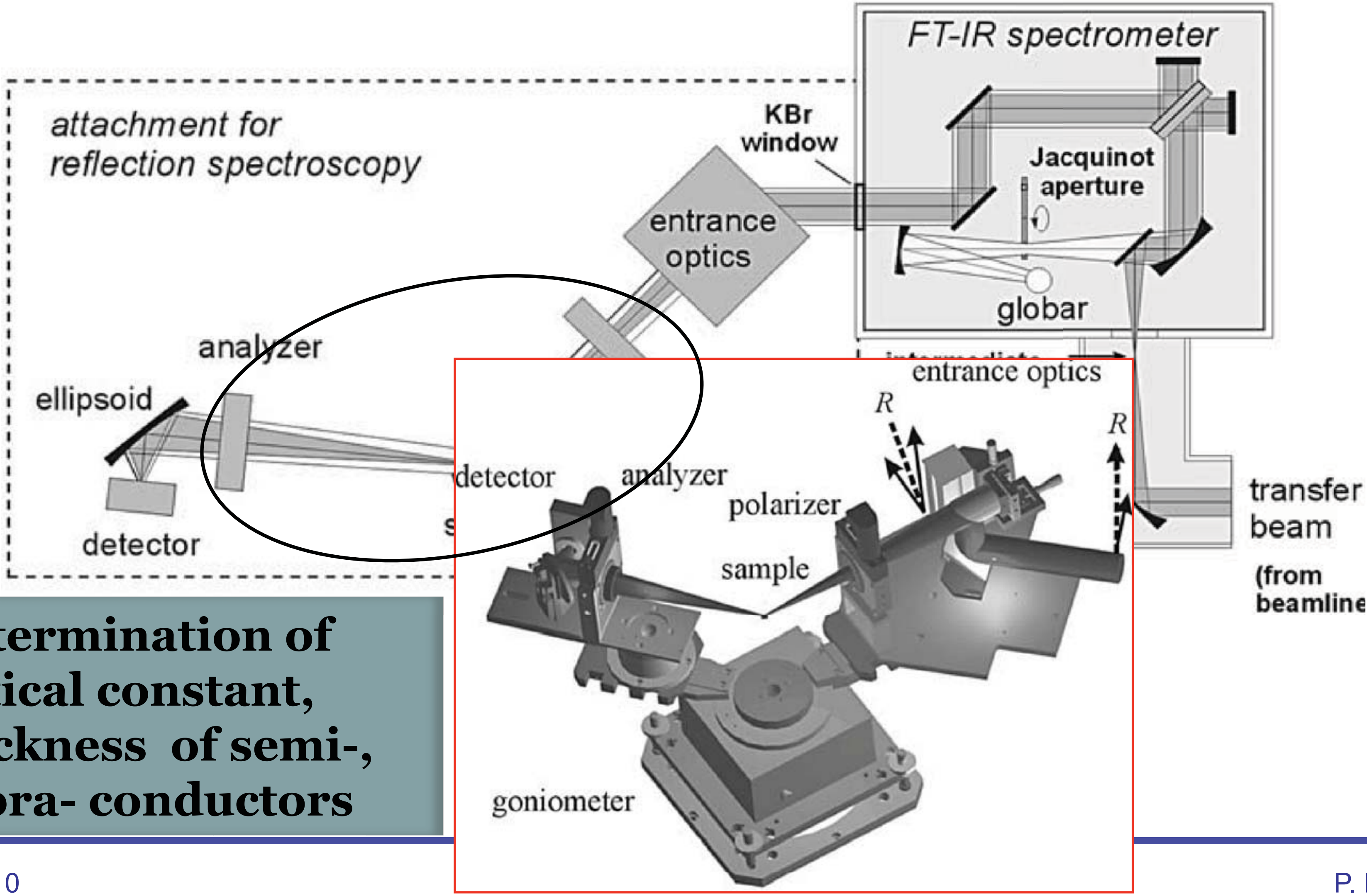
Abo-Bakr *et al.*, PRL (2002) & (2003).
Singley *et al.*, PRB 69, 092512 (2004).

APPLICATIONS IN THE FAR-INFRARED (THz)DOMAIN

ELLIPSOMETRY IN THE FAR INFRARED

M. Gensch · K. Hinrichs · A. Roseler · E. H. Korte · U. Schade

Anal Bioanal Chem (2003) 376 : 626–630

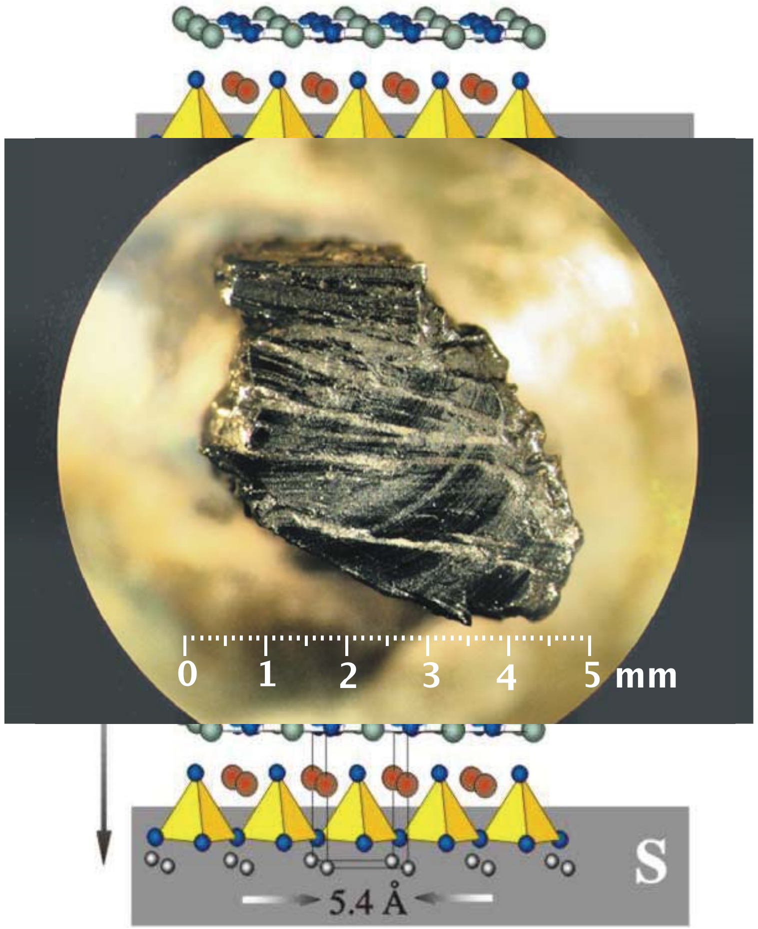


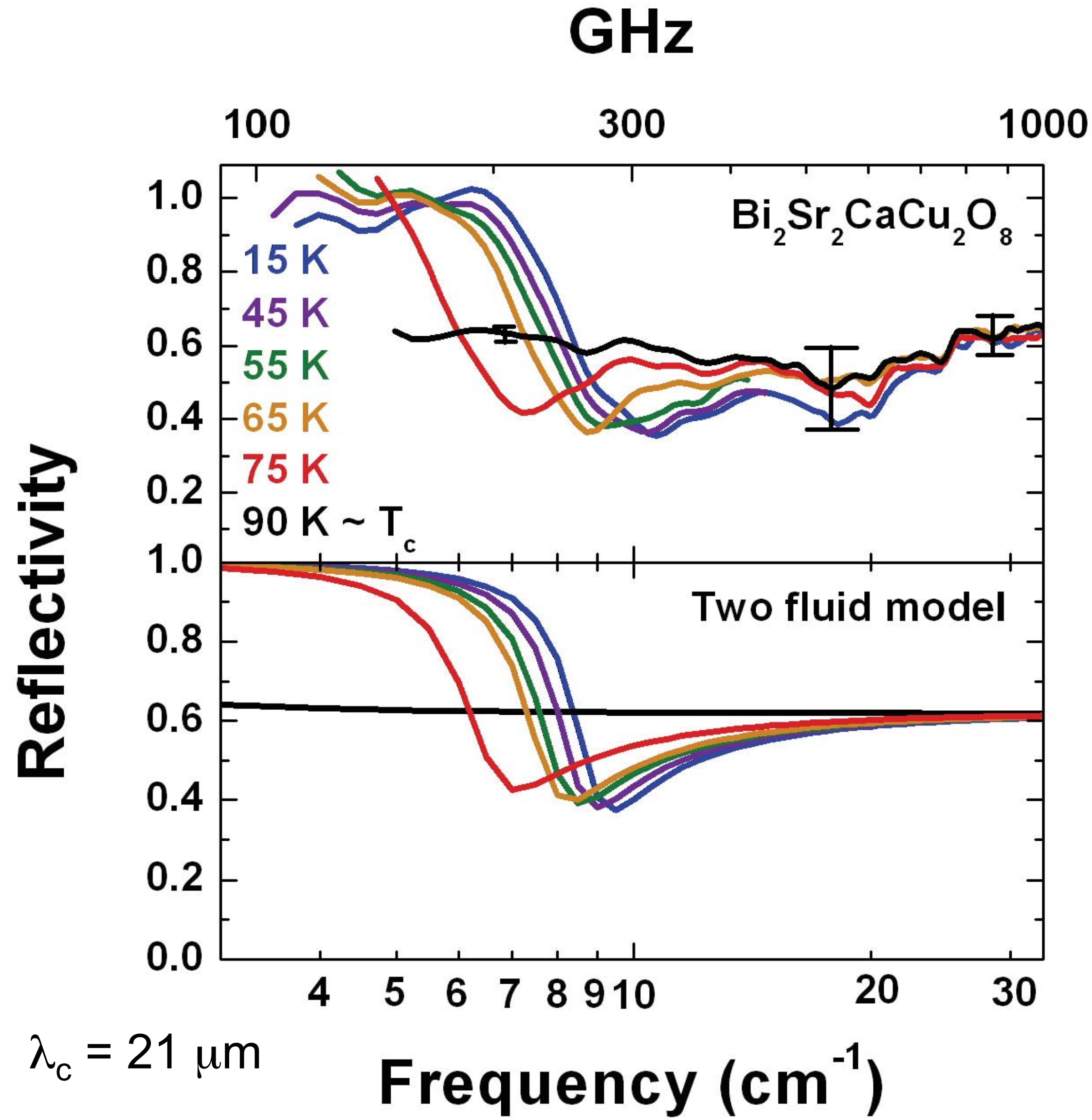
Determination of optical constant, thickness of semi-, supra- conductors

Ernest Orlando Lawre
Berkeley National Laboratory

First CSR Science: JPR in $Bi_2Sr_2CaCu_2O_8$

BESSY

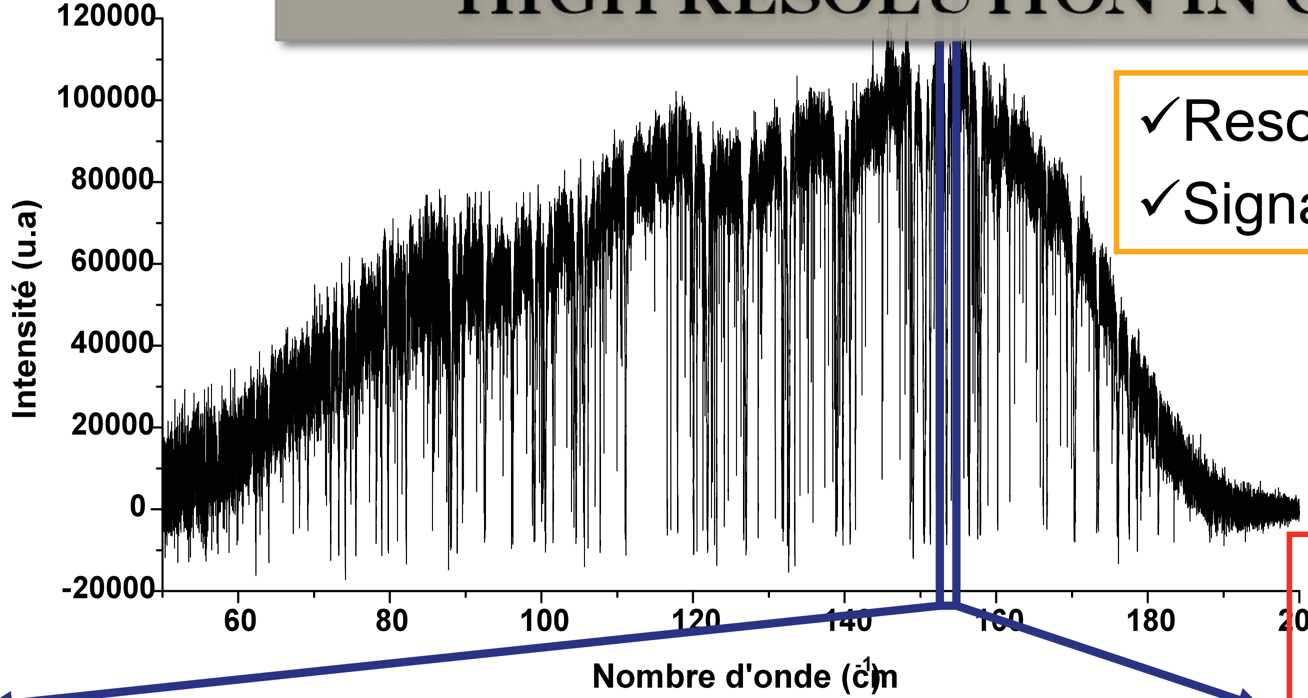




+ Indications for inhomogeneous superfluid

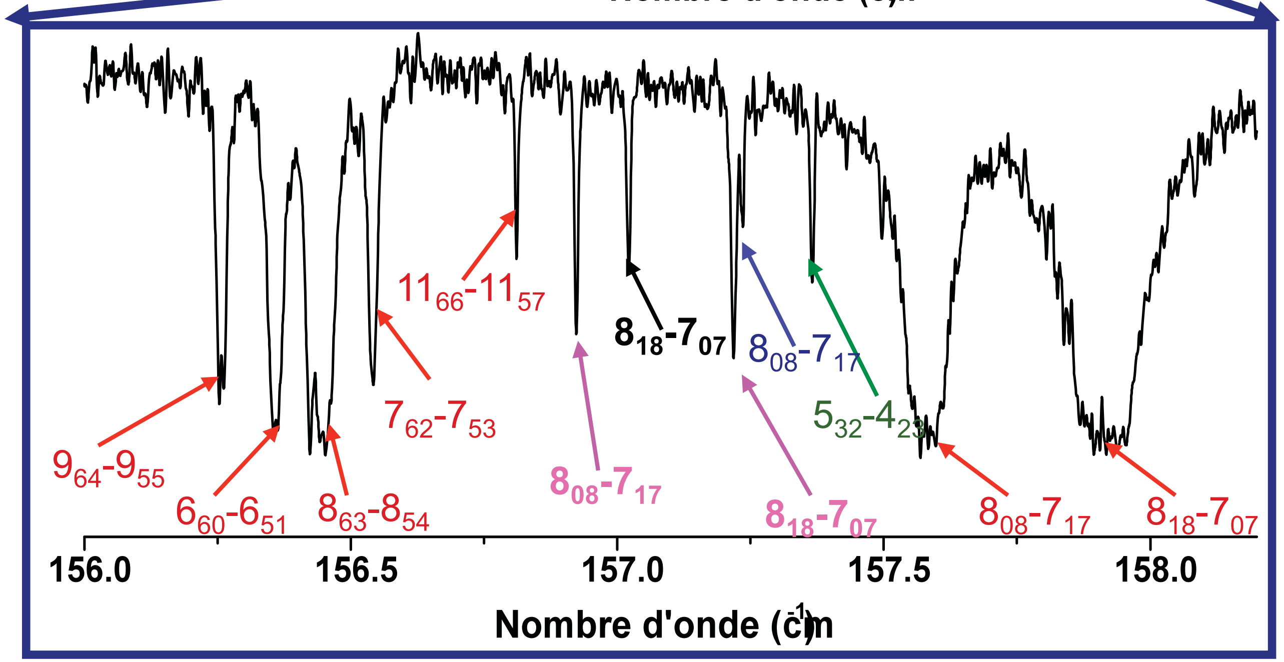
Singley, Martin, Schade, et al., *PRB **69**, 092512 (2004)*

HIGH RESOLUTION IN GAS PHASE



- ✓Resolution = 0.004 cm^{-1}
- ✓Signal /Noise bruit ≈ 30

- ✓ Isotopes identification



- $H_2{}^{16}O$
- HDO (≈ 0.03 %)
- $H_2{}^{18}O$ (≈ 0.2 %)
- $H_2{}^{17}O$ (≈ 0.04 %)
- $H_2{}^{16}O$ ν_2=1

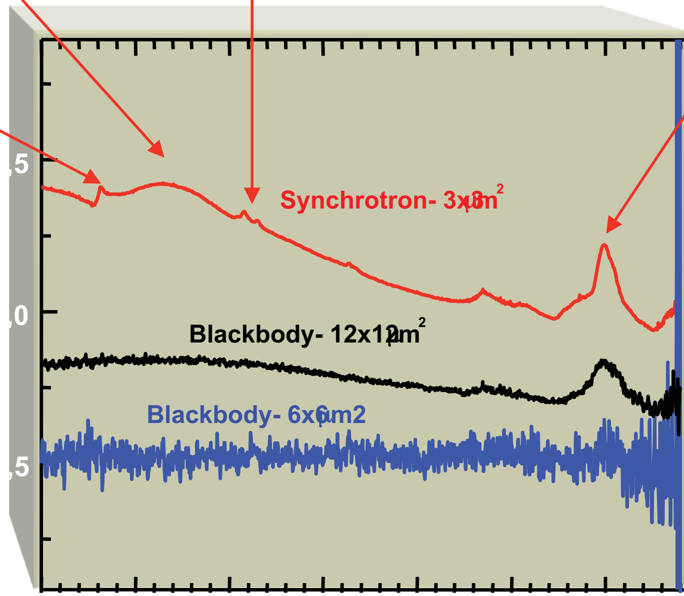
P. Dumas

APPLICATIONS IN THE MID-INFRARED DOMAIN

1- Space Science

IDENTIFYING SMALL INTERSTELLAR PARTICLE

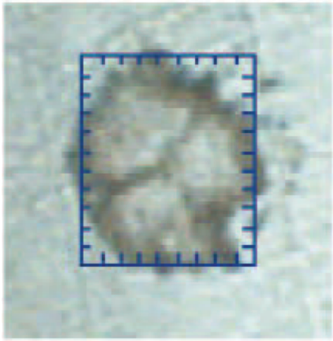
“Orgueil” particules



Ph. Raynal, L. D’Hendecourt, J. Borg, J.P. Bibring , G.P. Williams and P. Dumas

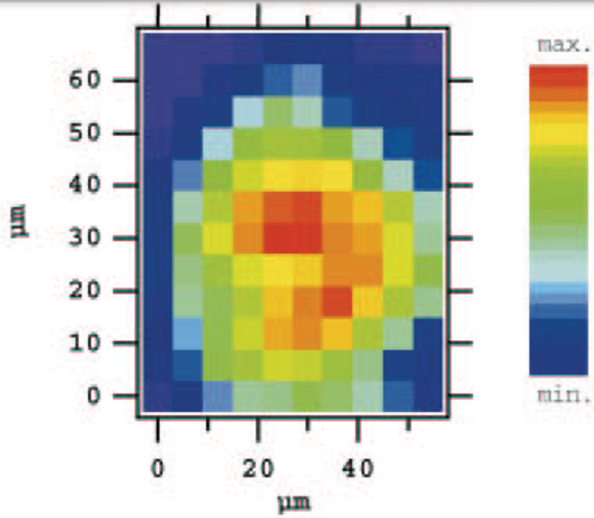
IDENTIFYING SMALL INTERSTELLAR PARTICLE

Aperture= 3x3 µm

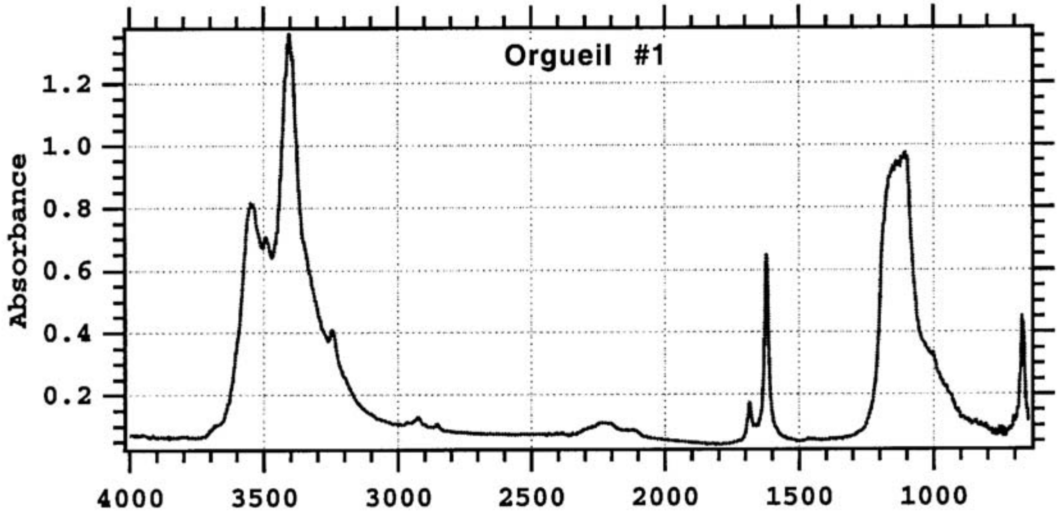


40 µm

- optical snapshot



- mapping of the stronger H_2O bands; integrated Absorbance, [3800; 3000] cm^{-1} range

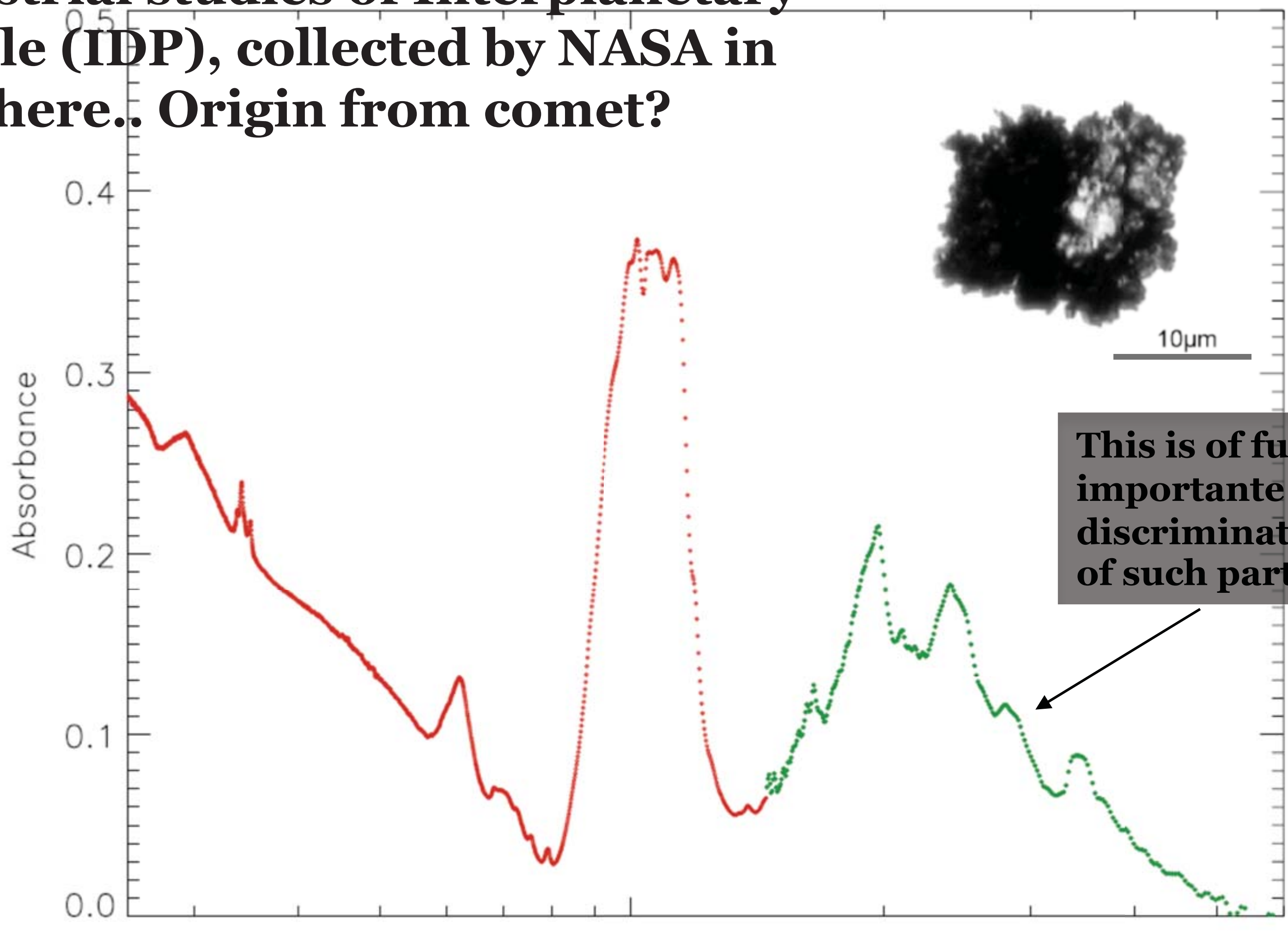


Chemical image of water distribution inside a 40 µm particle

P. Dumas

IDENTIFYING SMALL INTERSTELLAR PARTICLE

Extra terrestrial studies of Interplanetary Dust Particle (IDP), collected by NASA in the statosphere.. Origin from comet?



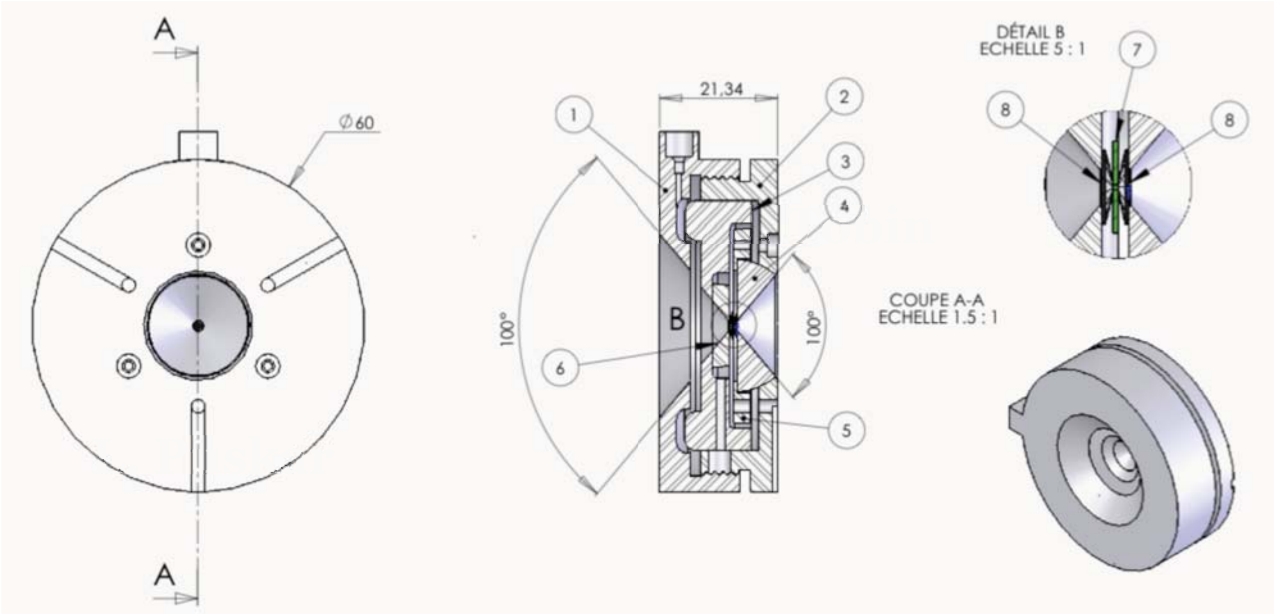
This is of fundamental importante to discriminate the origin of such particles

Extension to the far-IR microscopy important for a thorough identification

APPLICATIONS IN THE MID-INFRARED DOMAIN

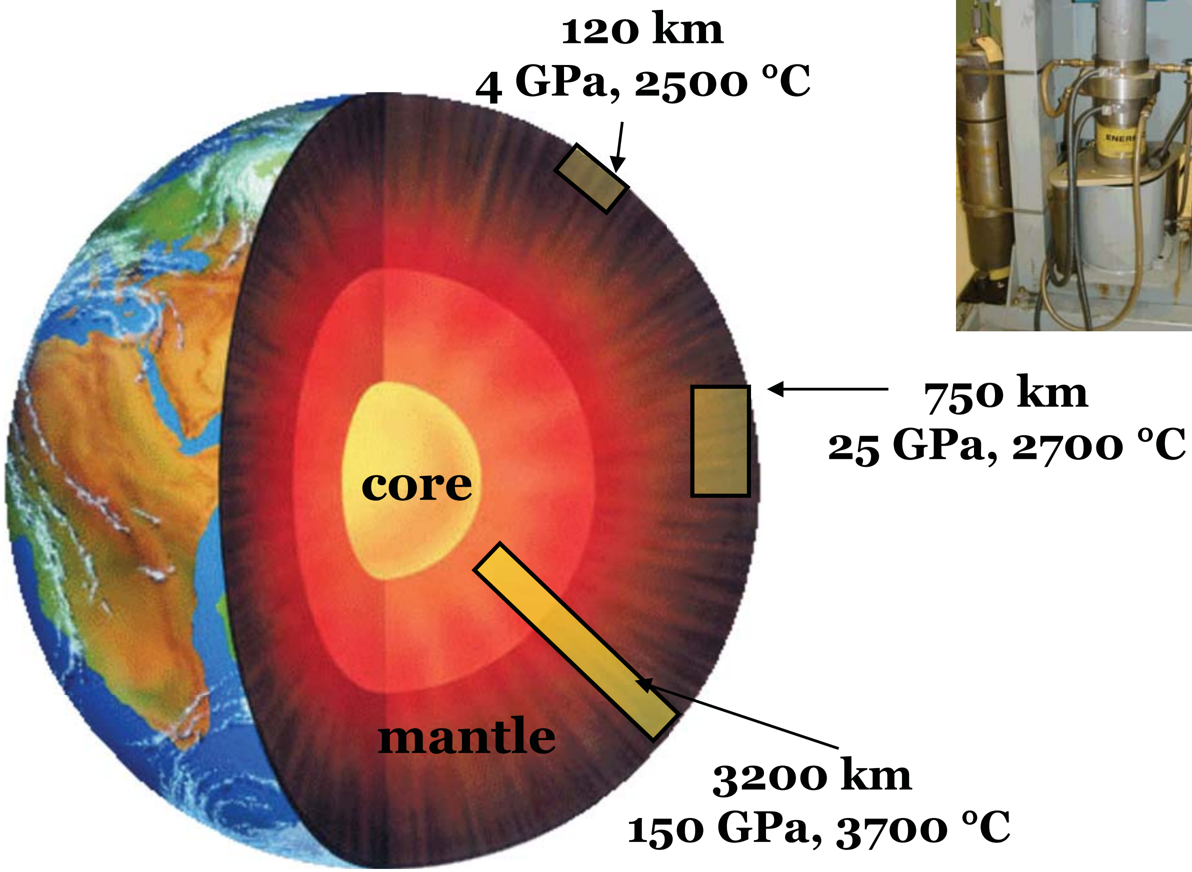
2- High Pressure studies

Requires a Diamond (Moissonite) anvil cell



SOLEIL SYNCHROTRON

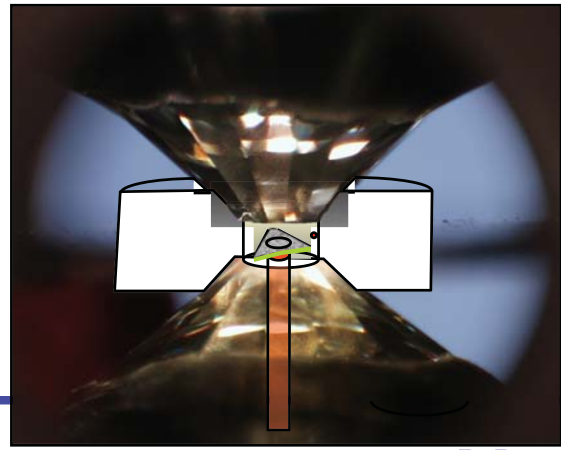
EARTH SCIENCES STUDIES AT FOREFRONT OF SUCH STUDIES



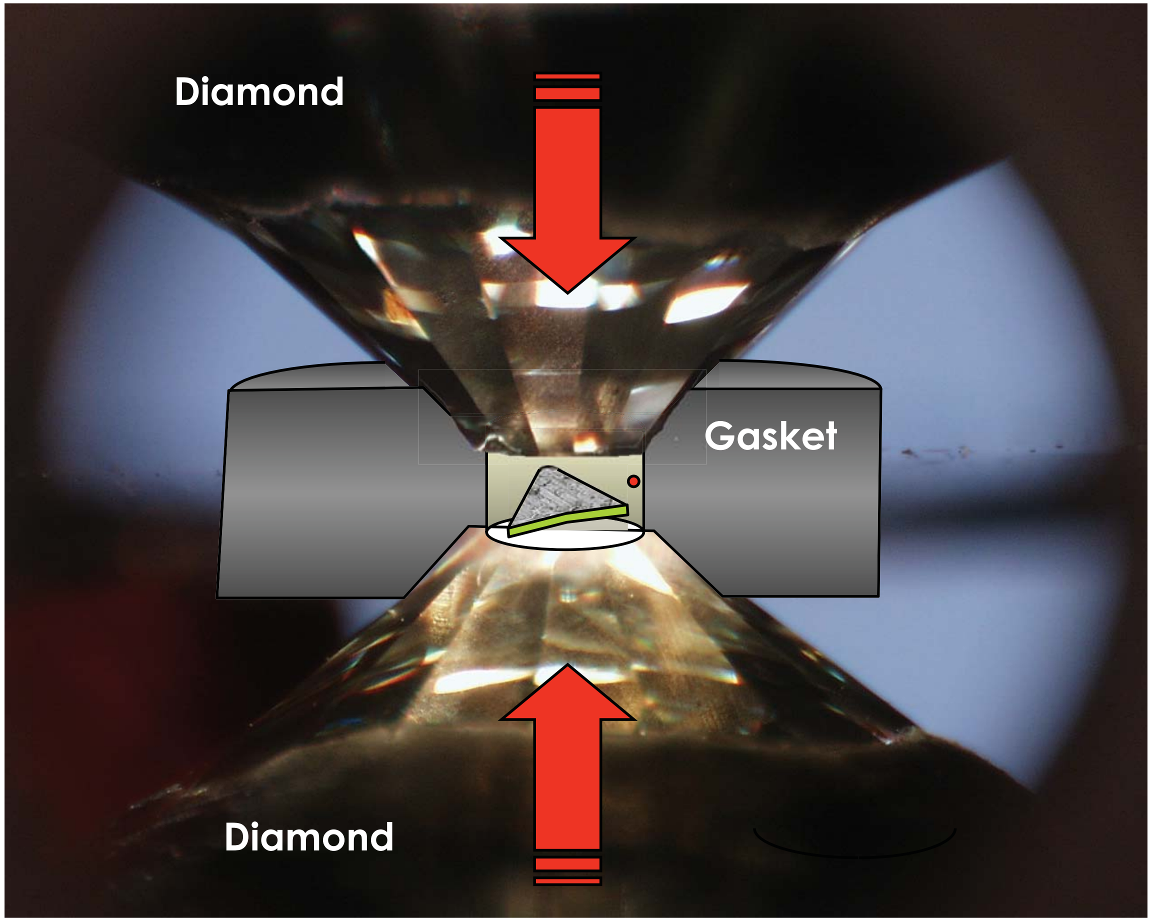
0.1 cm

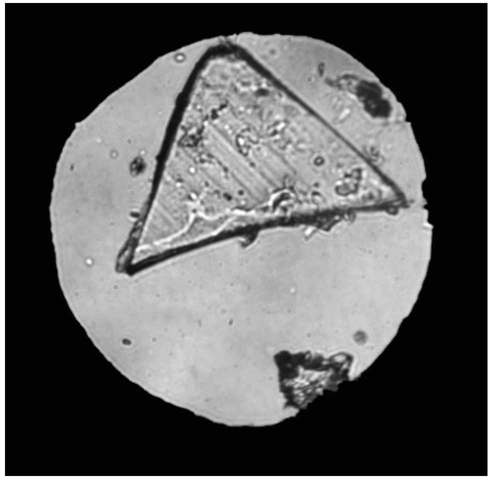
100 µm

10 µm



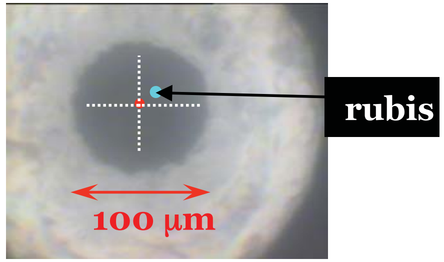
DAC (Diamond Anvil Cell) IN DETAILS



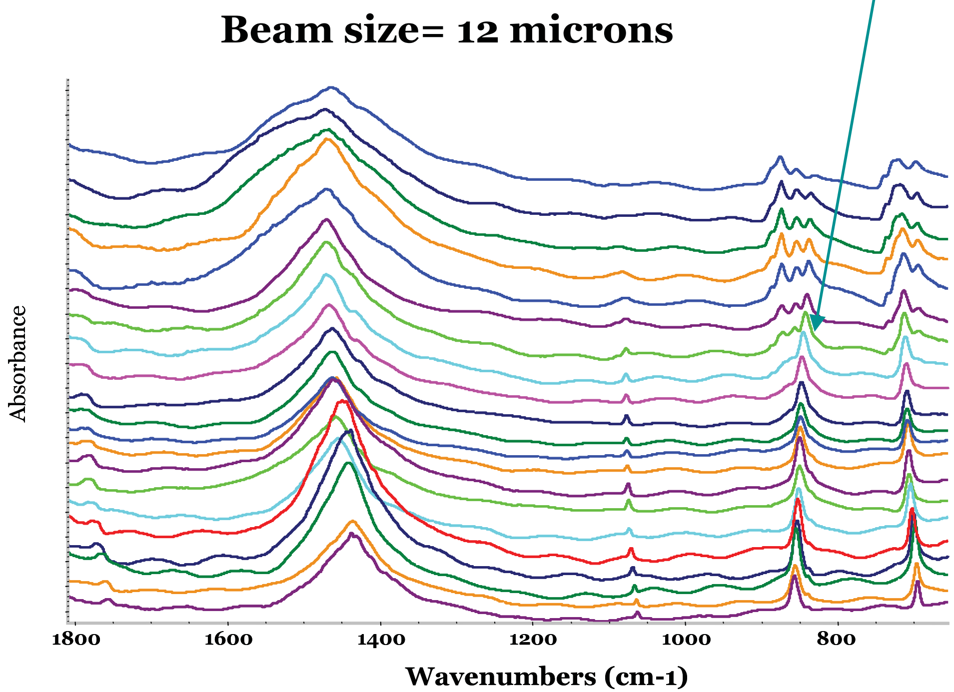


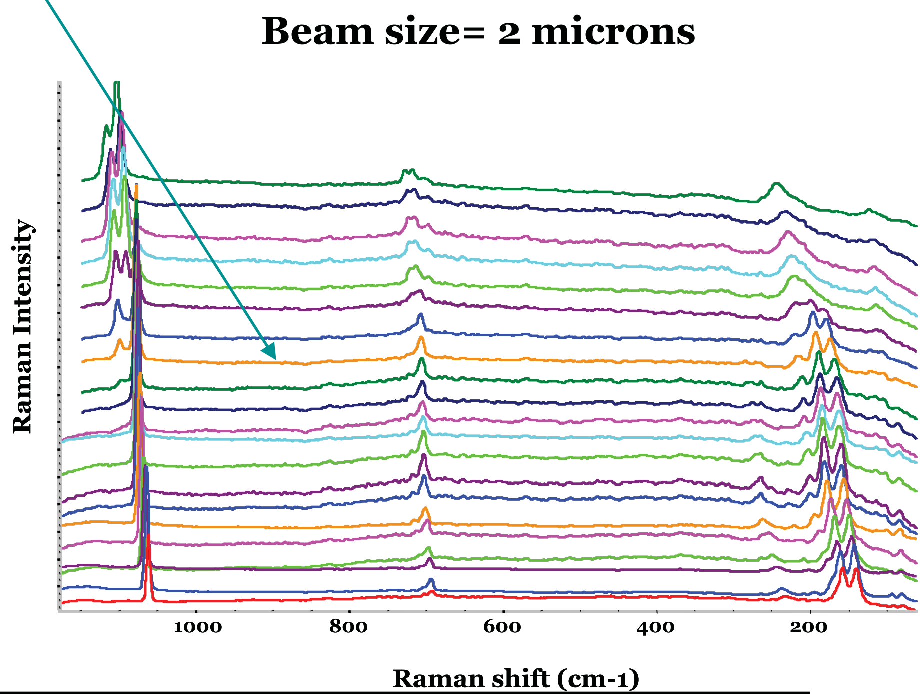
EXAMPLE OF WHITERITE ($BaCO_3$)

L. Puskar, M.J. Tobin, I. Yousef et al.



Phase transition over 8.1 GPa



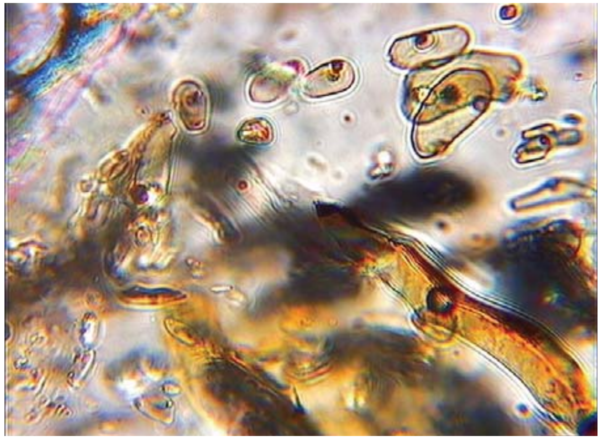


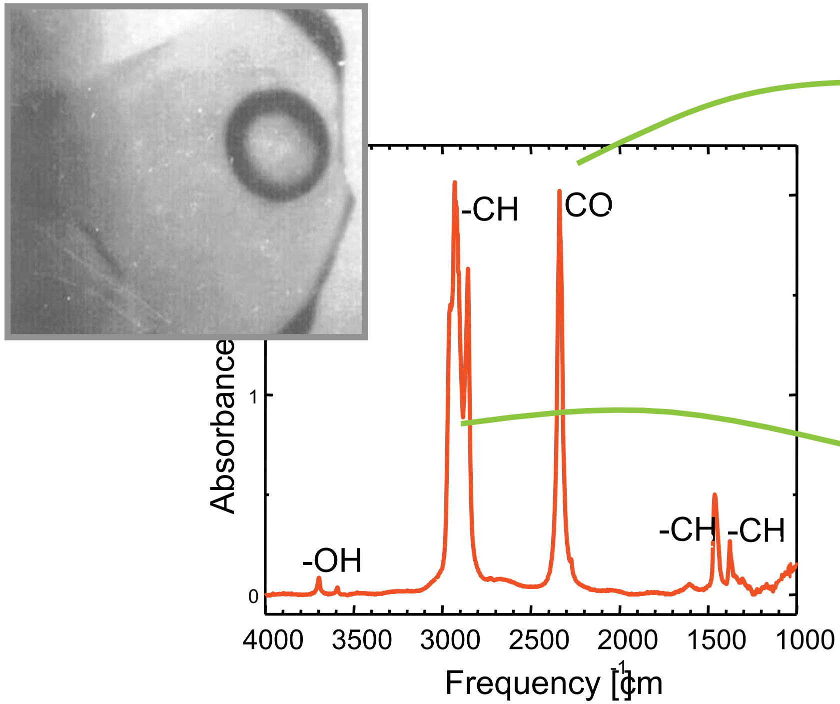
When possible, combination Raman and Synchrotron-IR very potential

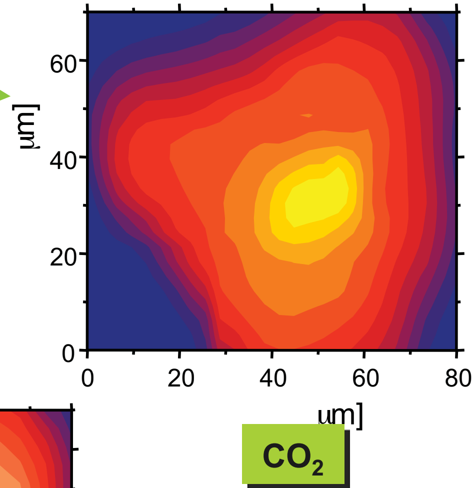
APPLICATIONS IN THE MID-INFRARED DOMAIN

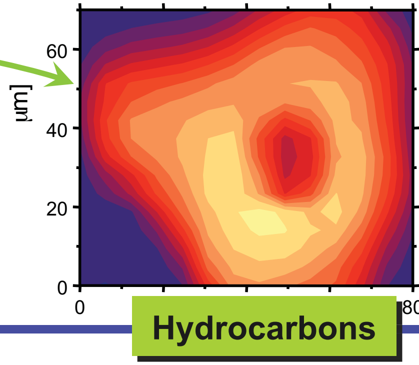
3- Earth Science

INCLUSIONS IN ROCKS





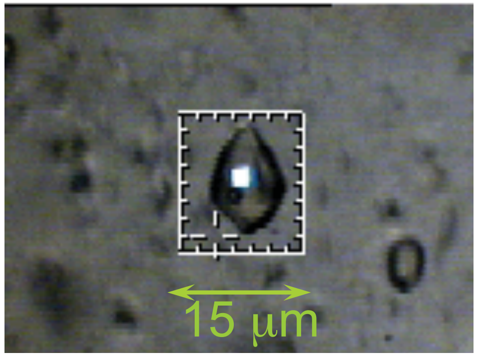


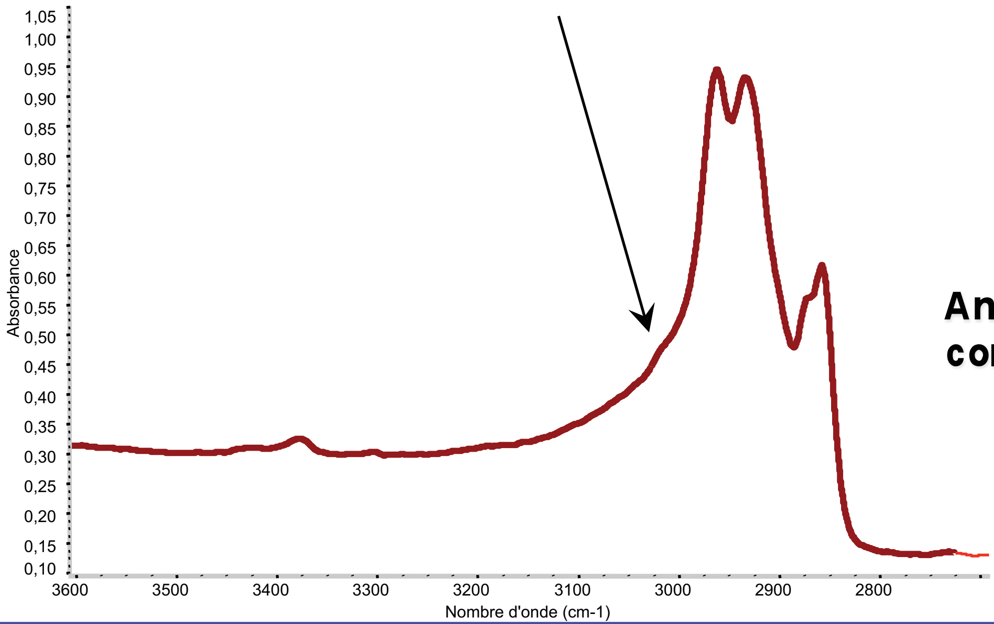


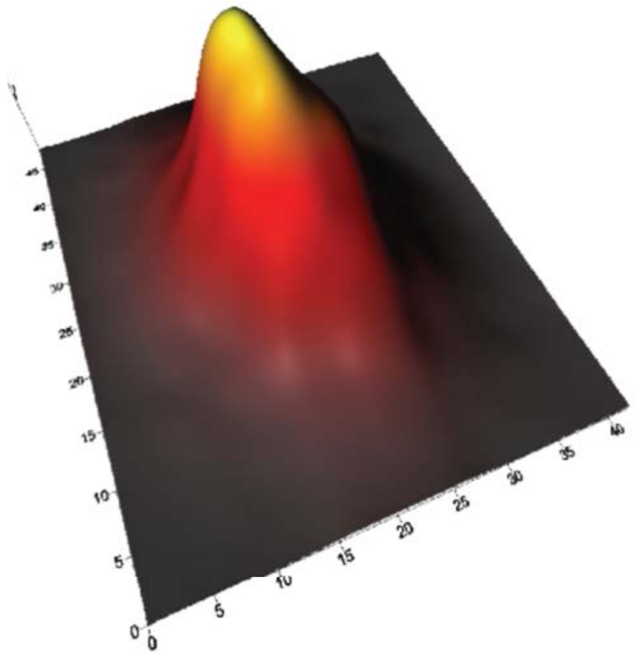
N. Guilhaumou et al. Appl.Spectrosc.

INCLUSIONS IN ROCKS

Inclusion in calcite
Benzenic C=H





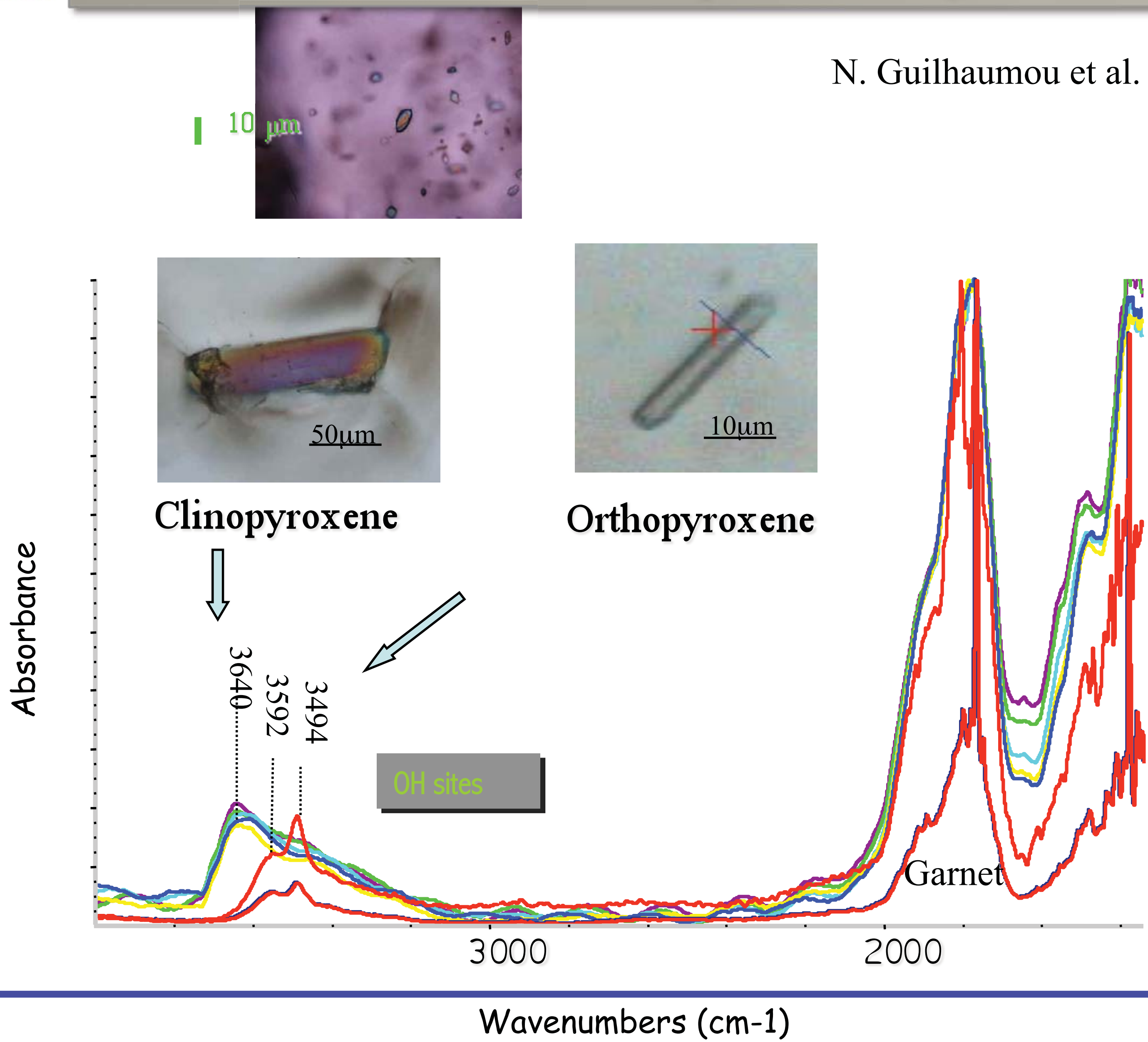


Analysis realized with aperture, confocal, of 3x3 μm^2

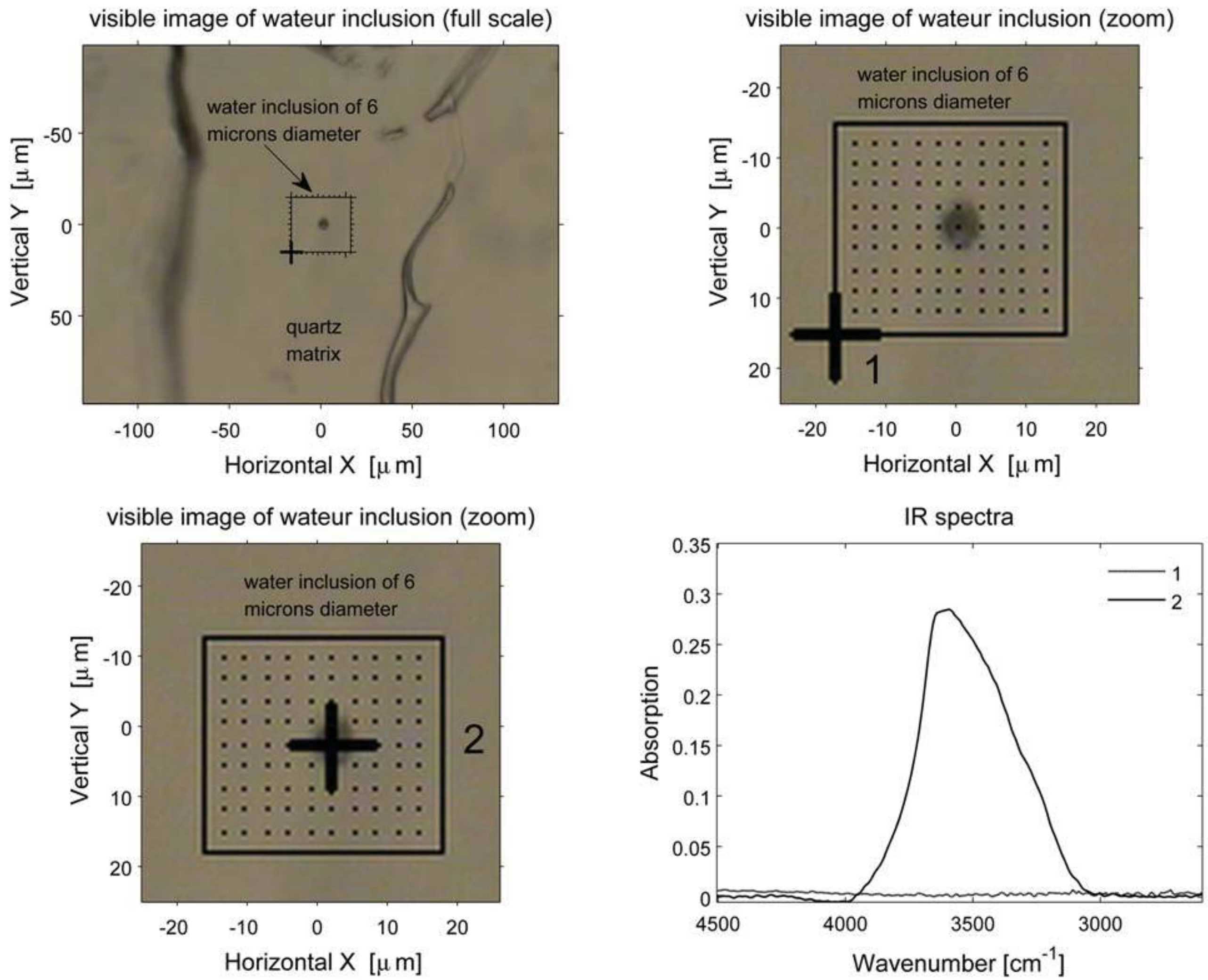
N. Guilhaumou ,P. Dumas et al.

WATER IN DEEP SEATED MINERALS
(200-400 KMS)

N. Guilhaumou et al.

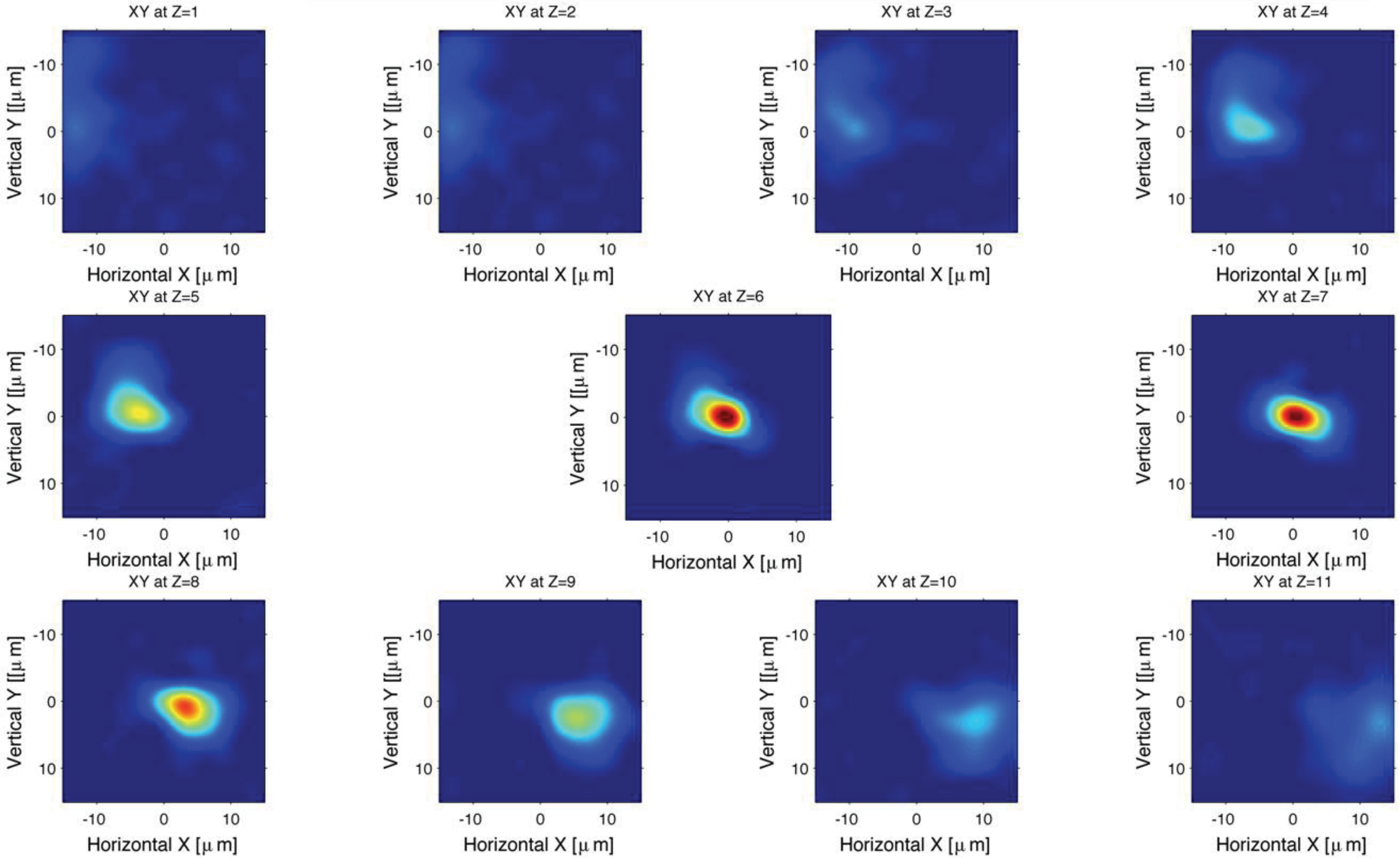


EXPLOITING THE CONFOCAL PROPERTIES FOR INCLUSIONS



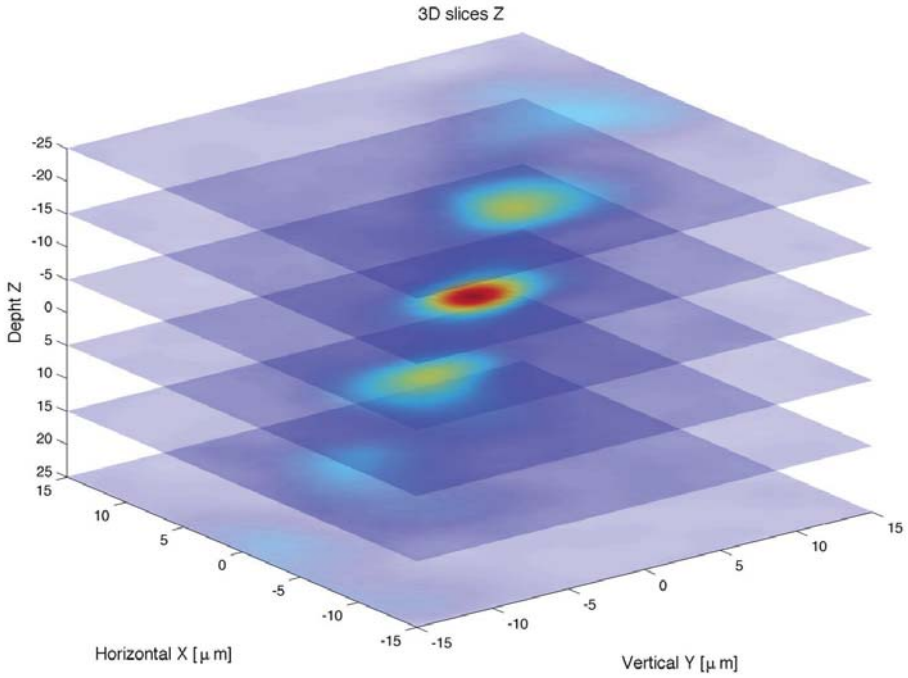
L. Mercury, F. Jamme and P. Dumas
In preparation

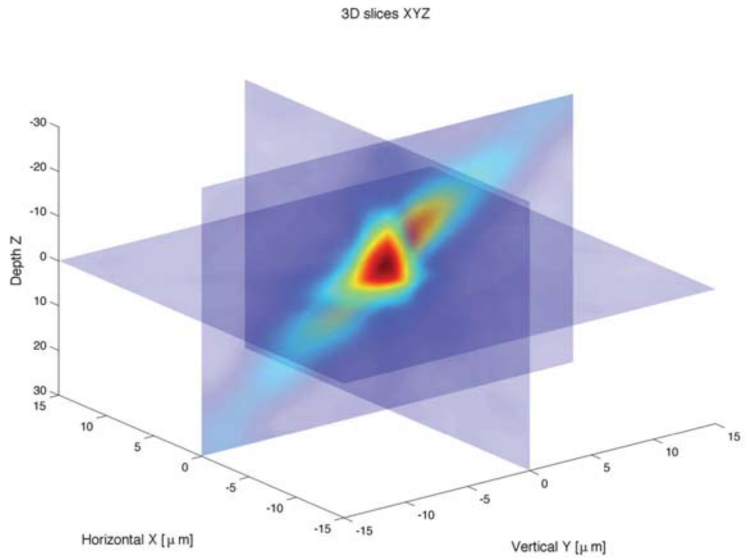
2D CHEMICAL IMAGES AT VARIOUS Z POSITION (1 Micron Step)



3D CHEMICAL IMAGE OF WATER

✓ *5- Relevant studies in Earth Science*





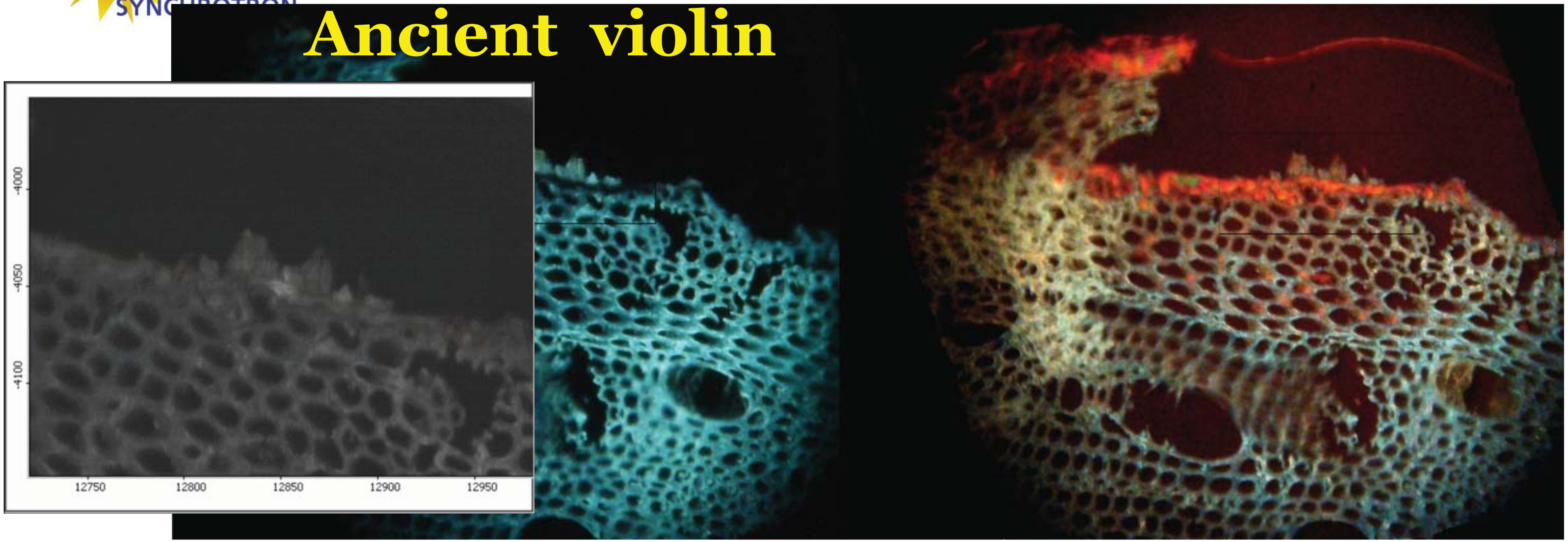
APPLICATIONS IN THE MID-INFRARED DOMAIN

4- Archeaology, Cultural Heritage

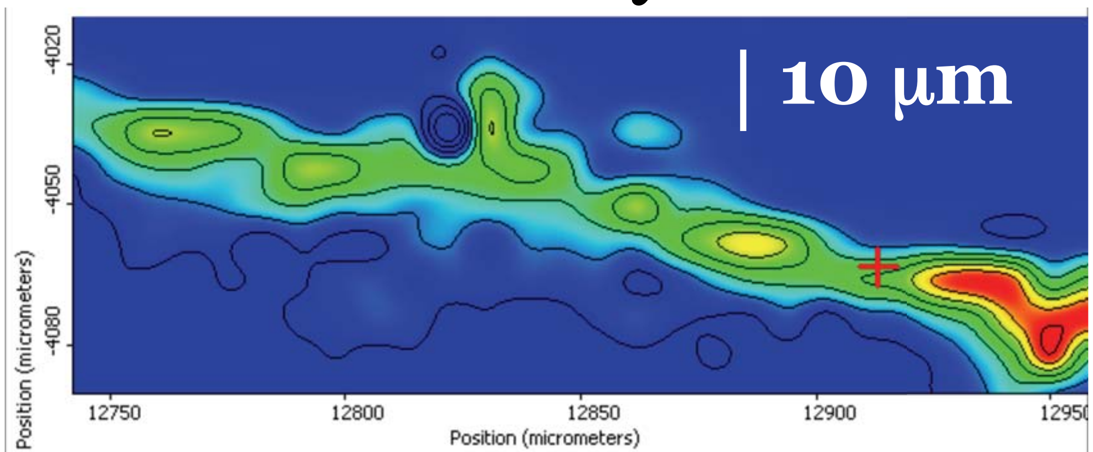
ANCIENT VIOLIN MAKINGS

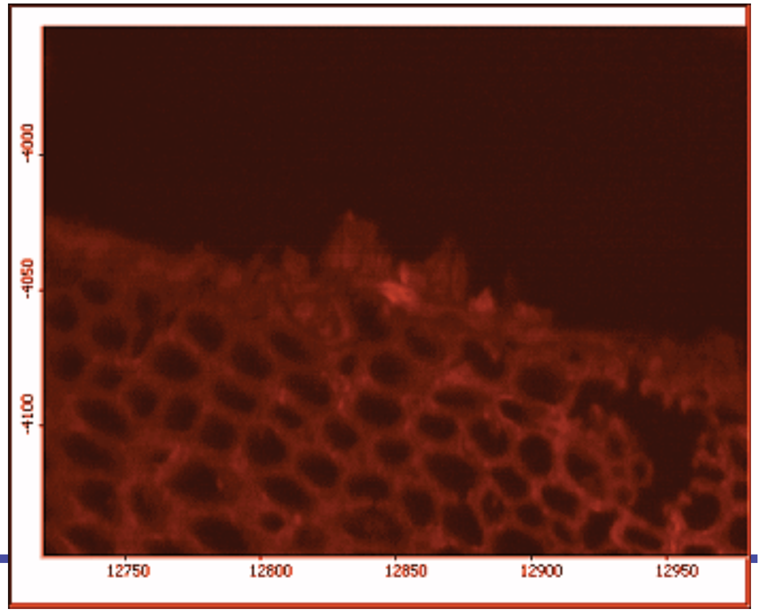
SOLEIL SYNCHROTRON

Ancient violin



Protein layer



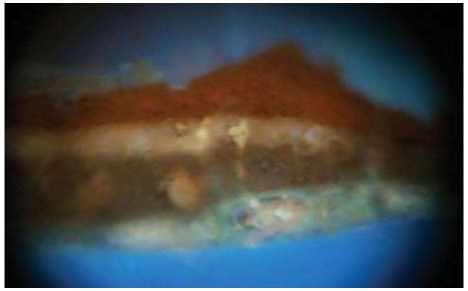


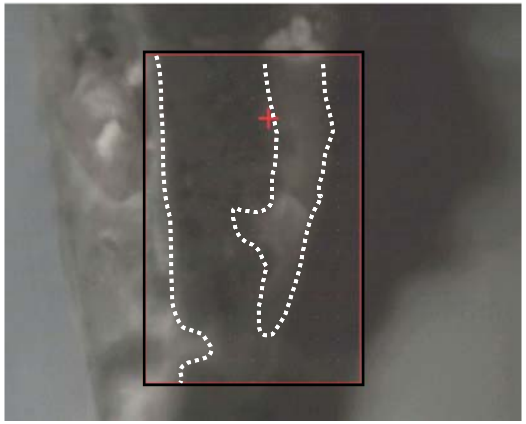
J.F Echard et al. (submitted)

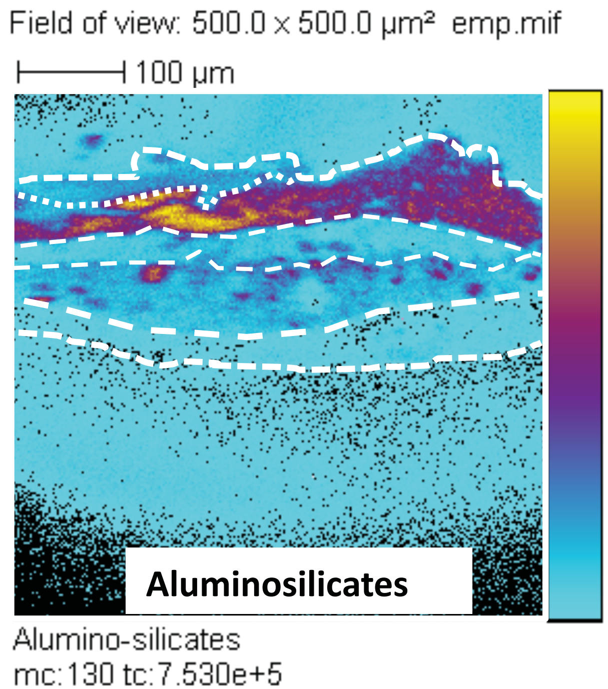
REMBRANDT FRAGMENT PAINTING

✓ 6- On going developments

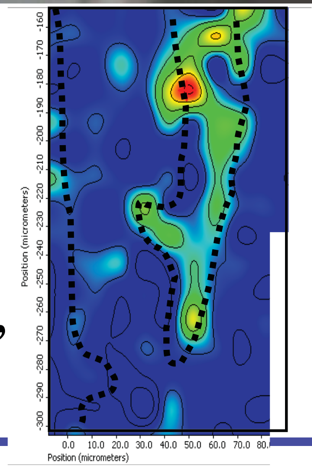
Fluorescence illumination

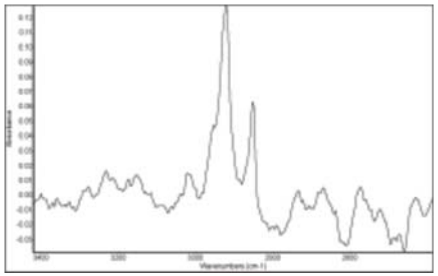






Portrait of Nicolaes van Bambeeck
Rembrandt (Leiden, 1606 - Amsterdam, 1669)





ToF SIMS

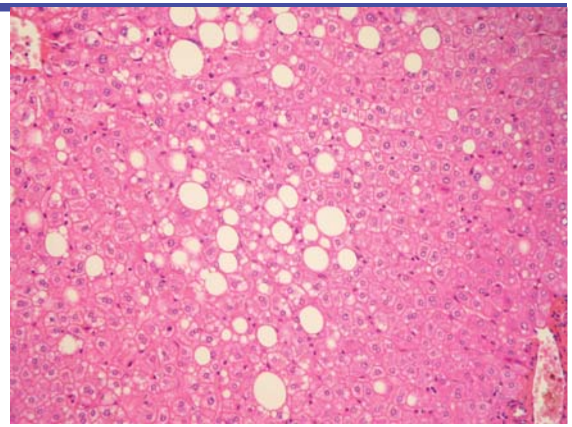
Synchrotron IR with 12x12 µm2, reflection mode

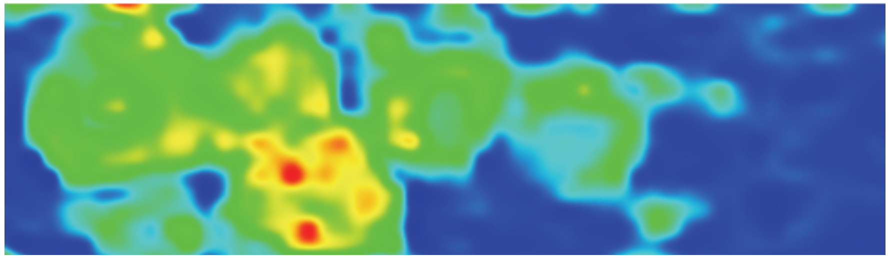
APPLICATIONS IN THE MID-INFRARED DOMAIN

5- Biology, Biomedical

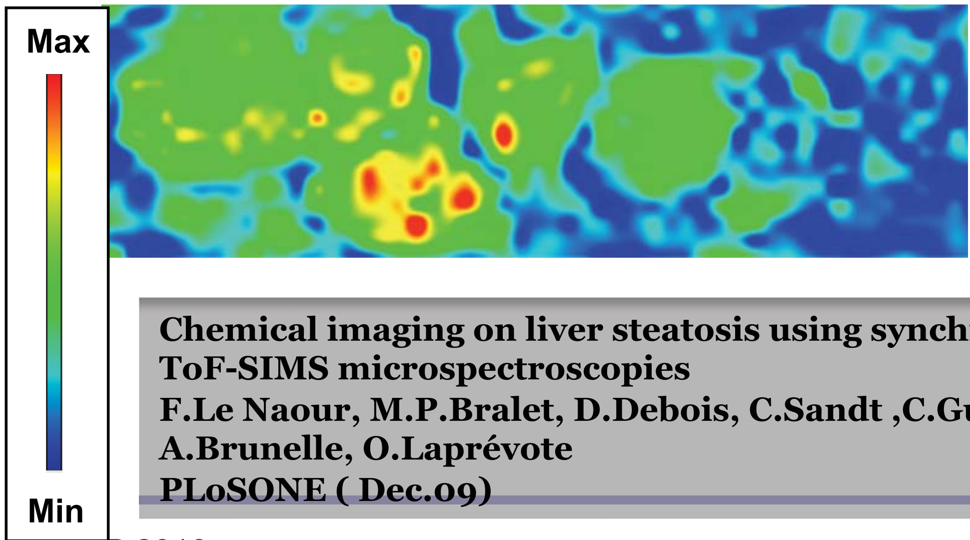
STEATOSIS ON LIVER

25 µm

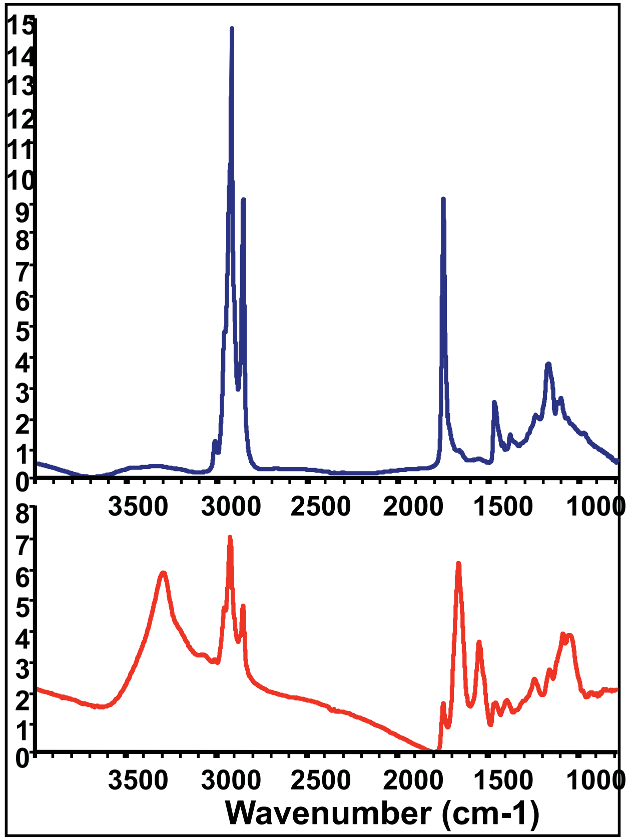




Unsaturated lipids



Saturated lipids

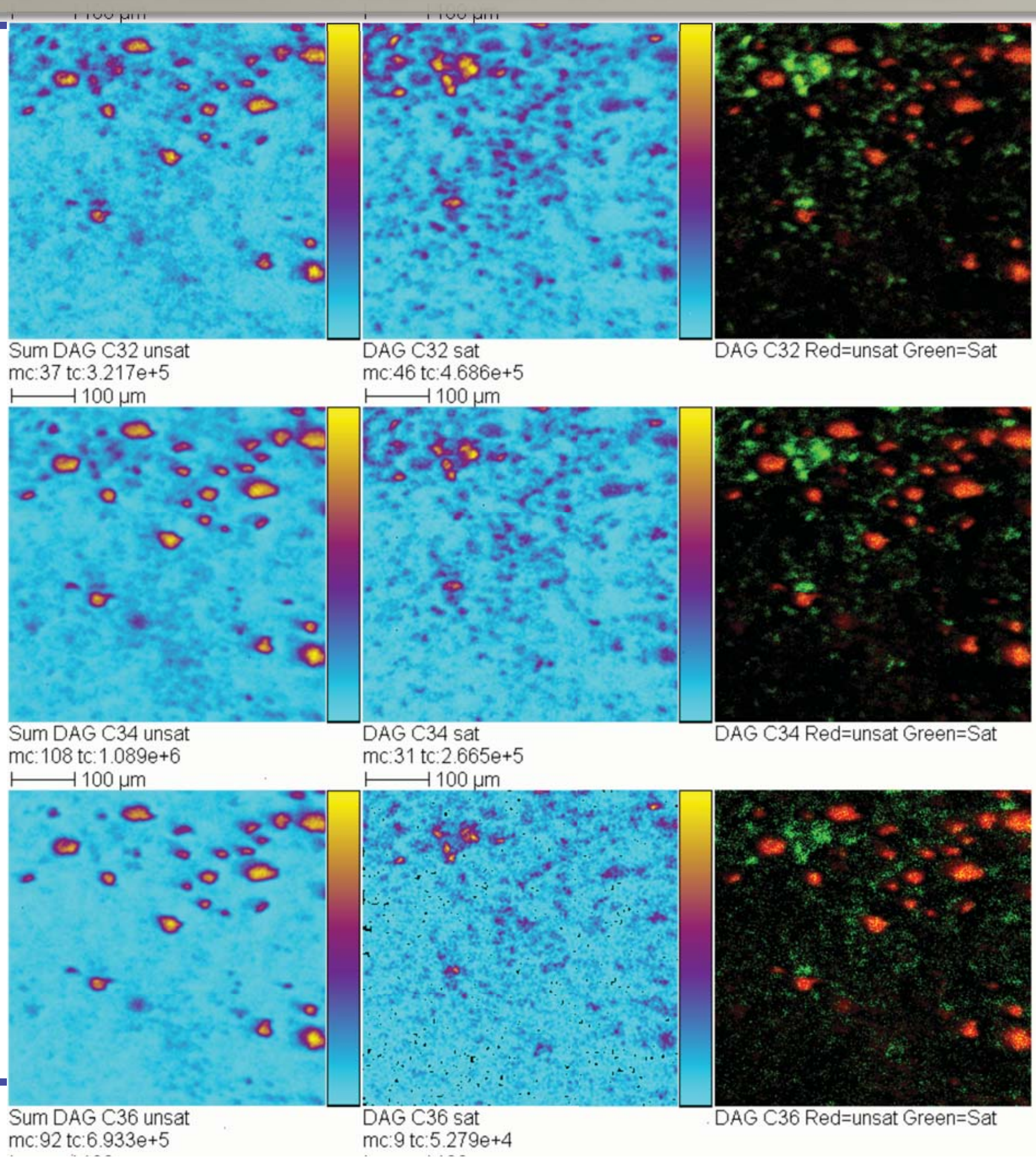


Chemical imaging on liver steatosis using synchrotron infrared and ToF-SIMS microspectroscopies
F.Le Naour, M.P.Bralet, D.Debois, C.Sandt ,C.Guettier, P.Dumas, A.Brunelle, O.Laprévote
PLoSONE (Dec.09)

STEATOSIS ON LIVER: COMBINING ToF SIMS

ToF-SIMS IV (Ion-Tof GmbH, Münster, Germany) reflectron-type TOF mass spectrometer Primary ion source: bismuth liquid metal ion gun.

DAG= diacylglycerol

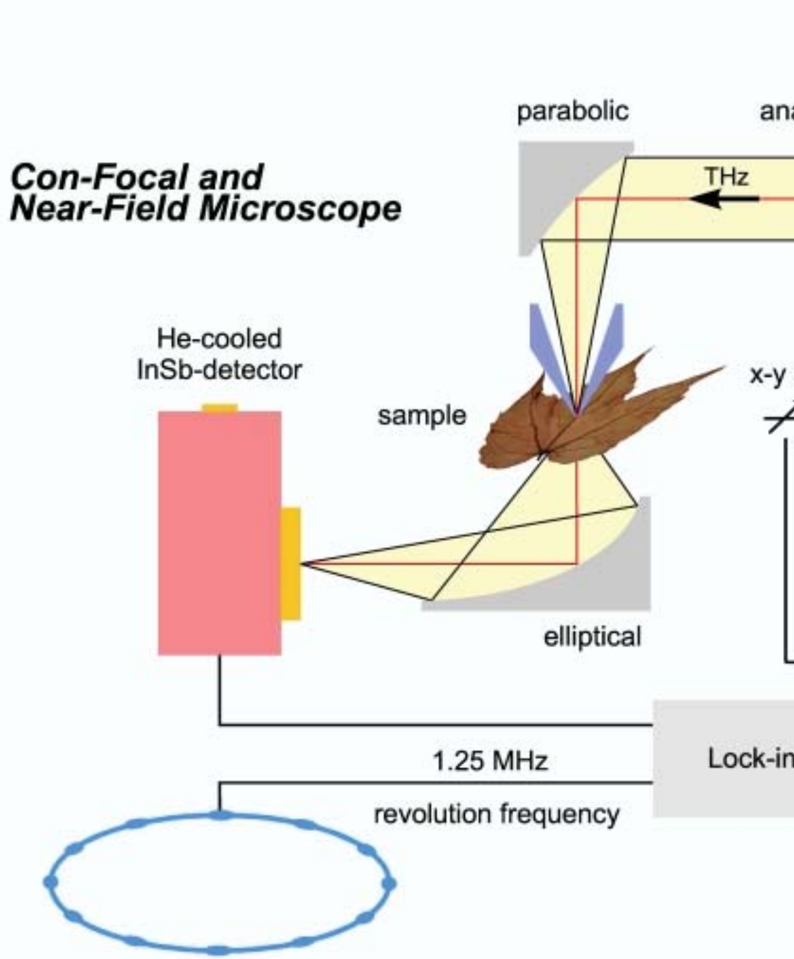


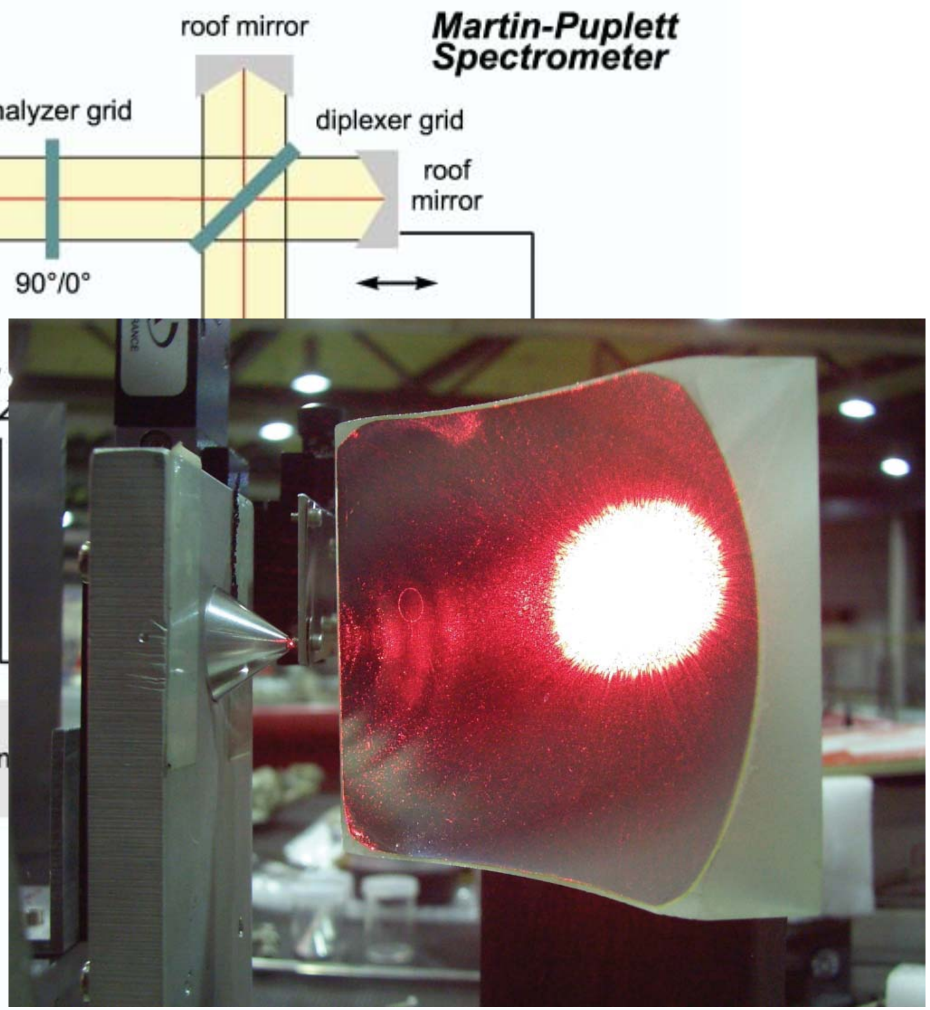
APPLICATIONS IN THE FAR-INFRARED DOMAIN

5- Near Field Microscopy

IMAGING PLANT LEAVE

Courtoisy of Ulrich Schade (Bessy-Germany)



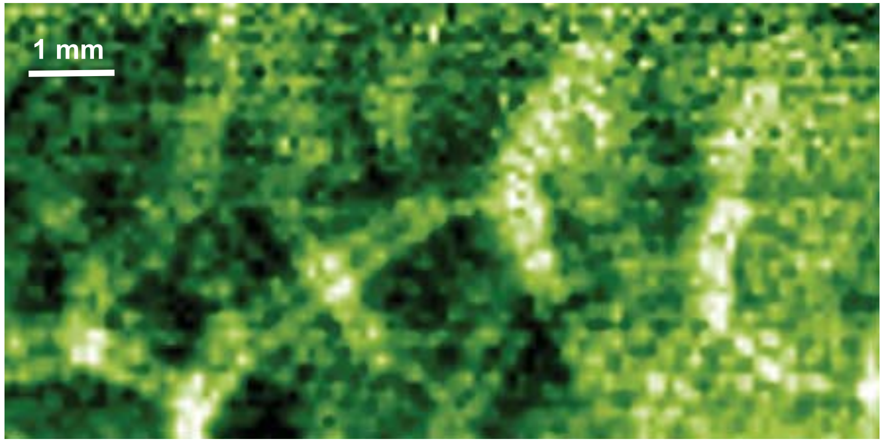


λ/8 at 130 µm wavelength

IMAGING PLANT LEAVE

VIS- image

Near-field image



- **VIS and THz near-field image of a laurel leaf**
- **spatial resolution: ~20 µm**
- **spectral weight @ 1 mm wavelength (0.3 THz)**
- **veins and granular structure resolved**

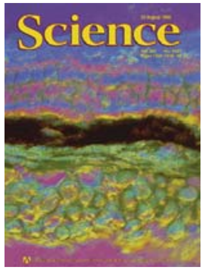
U. Schade et al., *APL* **84** 1422 (2004).

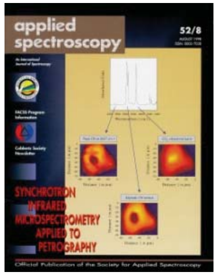
SYNCHROTRON INFRARED ACTIVITY WORDWIDE

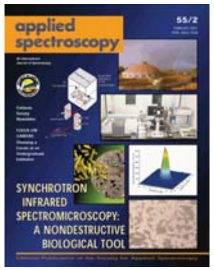
SOLEIL SYNCHROTRON

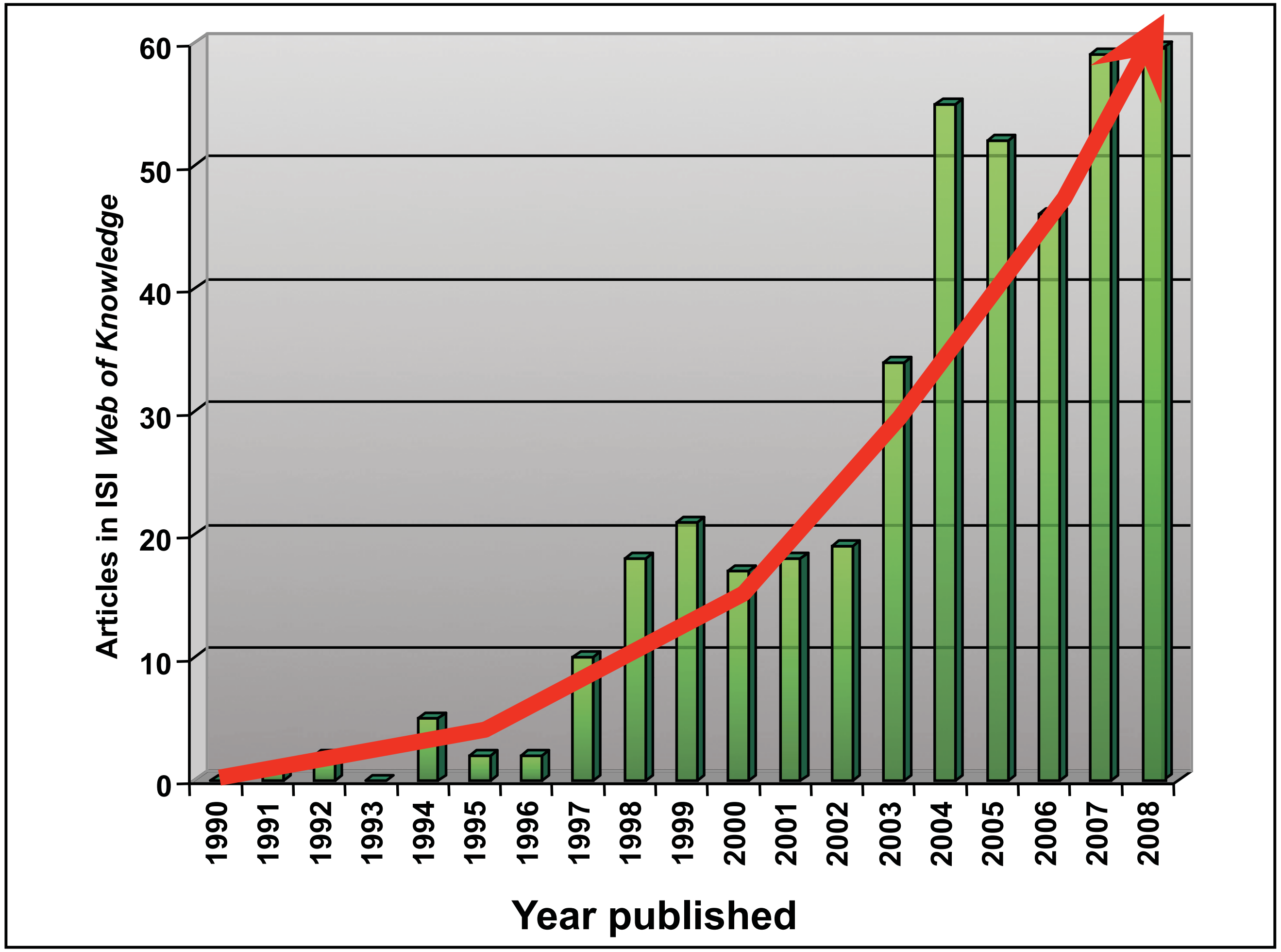
INCREASING PRODUCTION

Foreseen: 2 articles/week in 2010



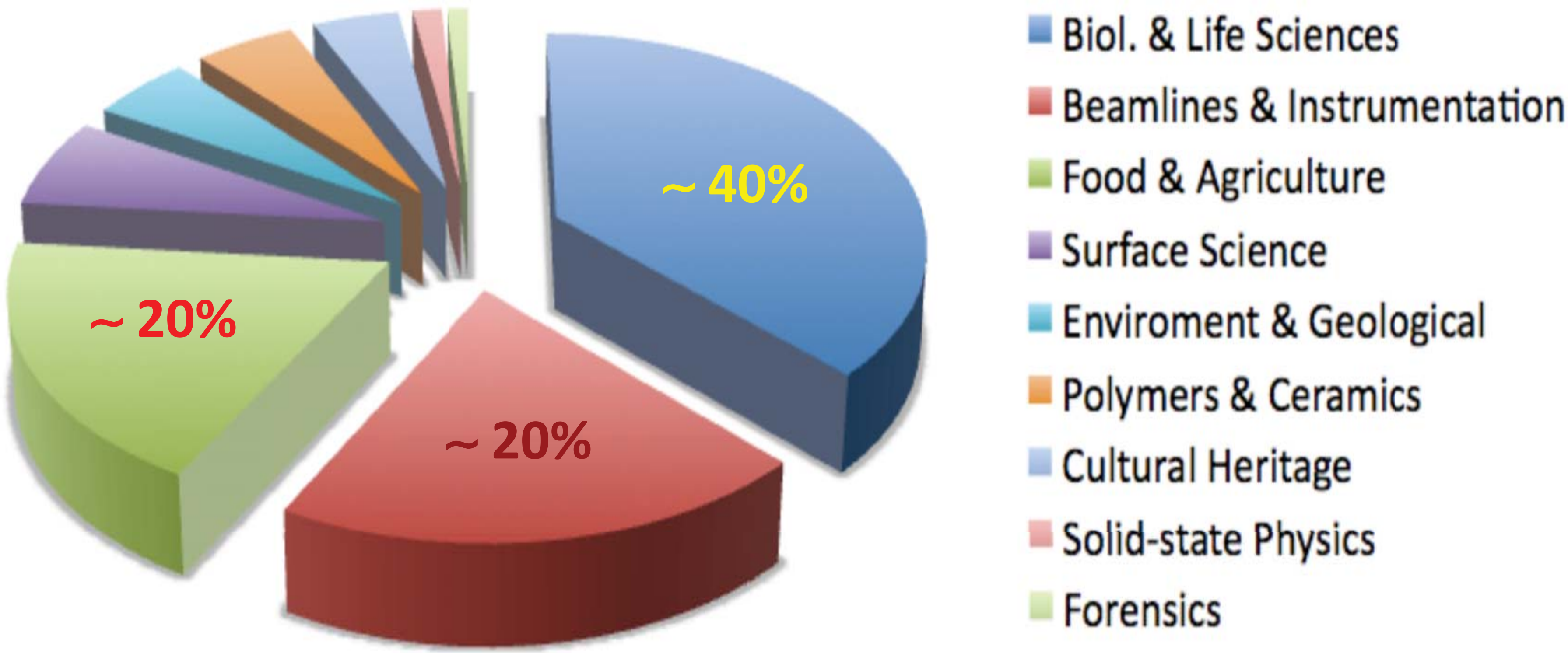






From G. Santoro, G. Ellis (Madrid)

ENLARGING SCIENTIFIC DISCIPLINES



Last 270 ISI publications

From G. Santoro, G. Ellis (Madrid)

WORDWIDE STATUS

Operational | In construction | In design

SUMMARY

✓ **Synchrotron radiation is a bright source of infrared photons**

✓ **Synchrotron infrared spectroscopy opened up new scientific challenges:**

- **Solid state physics**
- **Surface science**
- **Biology**

✓ **Synchrotron infrared microscopy and imaging is increasingly popular not only in academic but also in application domains , as imaging will play major role with new methodologies**

✓ **Future is bright, including the filled gap of THz radiation**

✓ **Dynamics will be a future key issue (time domain investigation) and synchrotron source, will be among the « key players »**