Infrared Spectroscopy with Synchrotron Sources

Ferenc Borondics
Mid-IR beamline
Canadian Light Source

Canadian Light Source
Centre canadien de rayonnement synchrotron

Cheiron 2011

SPring-8

Available online

http://midir.lightsource.ca/talks

Acknowledgements

Tim May

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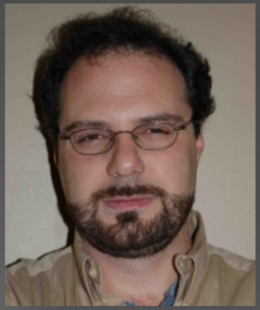
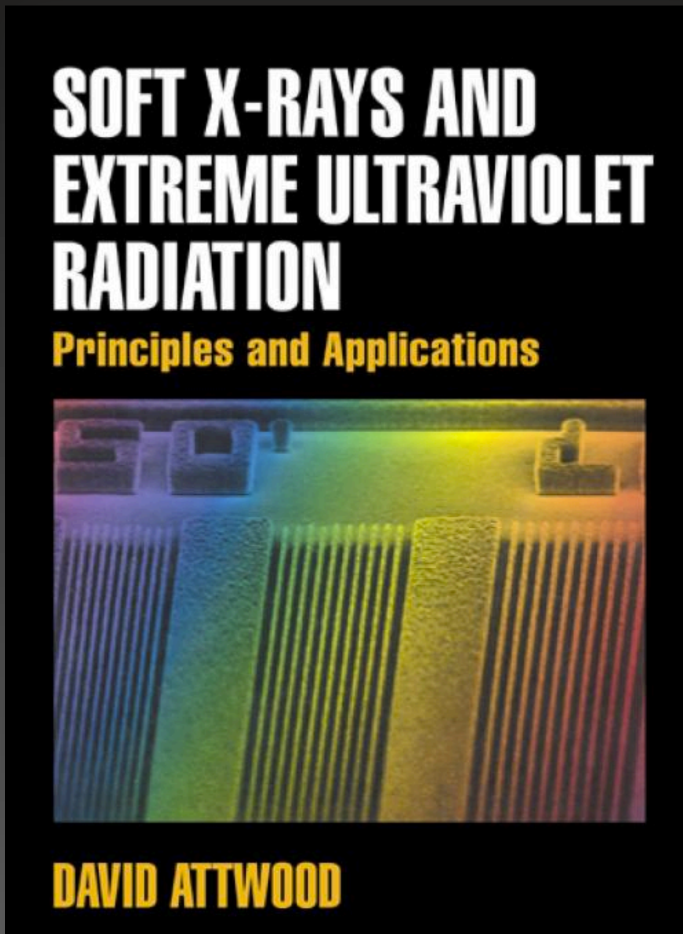
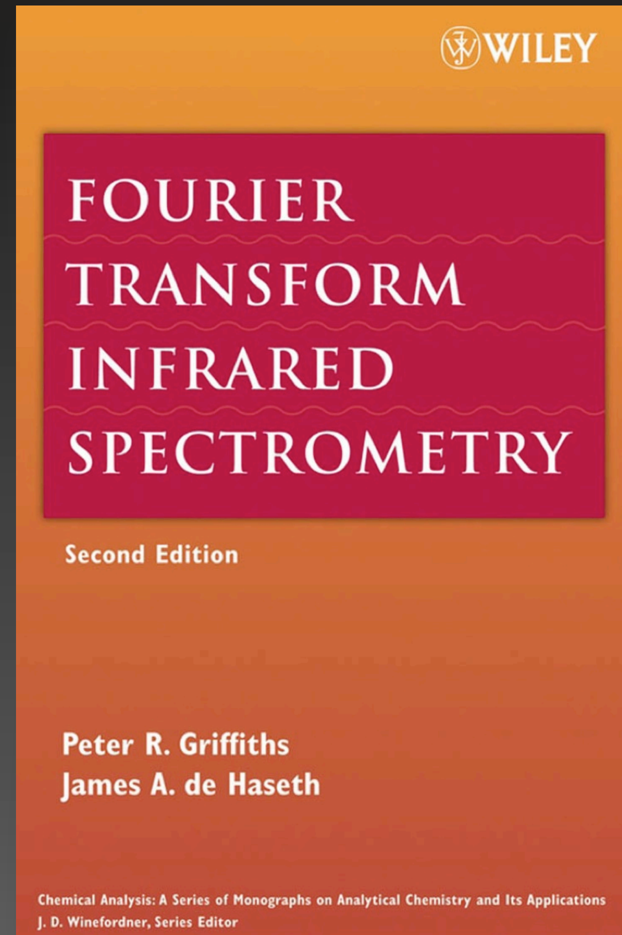


Outline

- IR spectroscopy – basic theory
- IR instrumentation
- Some IR beamlines (CLS, ALS, NSLS, SRC…)
- Practical things
- Examples

Something to read...

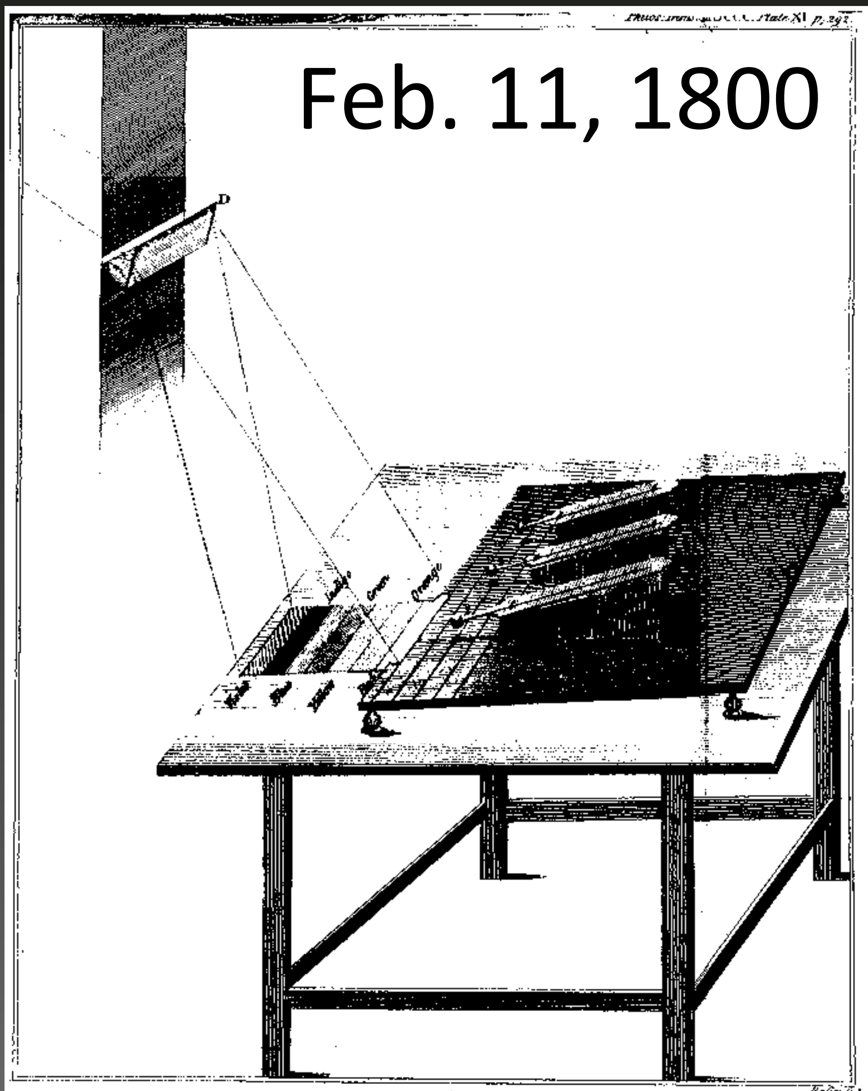




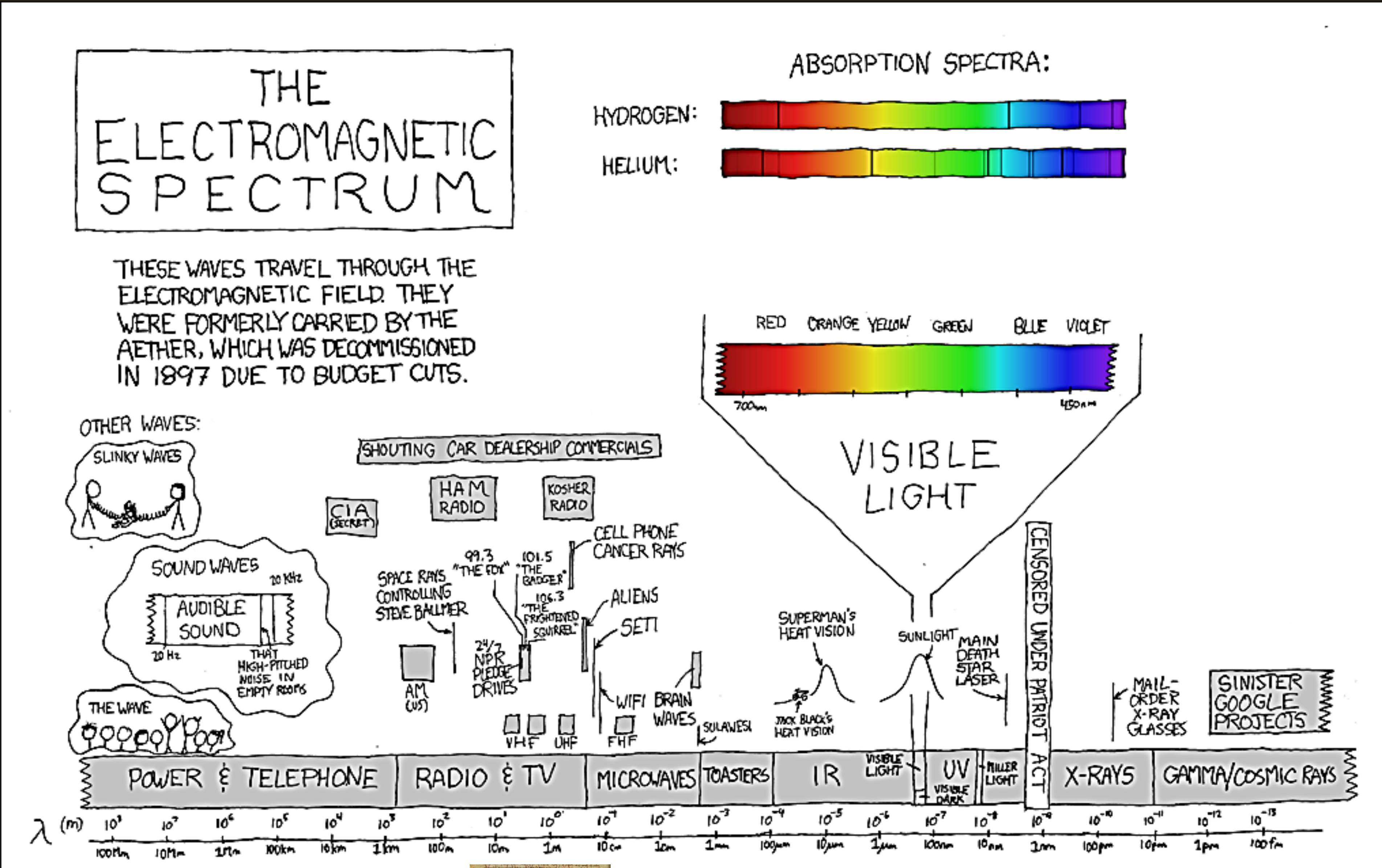
IR beamlines in the world

Source: http://infrared.als.lbl.gov

Sir William Herschel (1738-1822)



W. Herschel, Phil. Trans. R. Soc. London, Vol 90, 284-292, (1800)


THE ELECTROMAGNETIC SPECTRUM
ABSORPTION SPECTRA:
HYDROGEN:
HELIUM:
THESE WAVES TRAVEL THROUGH THE ELECTROMAGNETIC FIELD. THEY WERE FORMERLY CARRIED BY THE AETHER, WHICH WAS DECOMMISSIONED IN 1897 DUE TO BUDGET CUTS.
RED
ORANGE
YELLOW
GREEN
BLUE
VIOLET
700nm
450nm
VISIBLE LIGHT
OTHER WAVES:
SLINKY WAVES
SOUND WAVES
AUDIBLE SOUND
20 Hz
20 KHz
THAT HIGH-PITCHED NOISE IN EMPTY ROOMS
THE WAVE
SHOUTING CAR DEALERSHIP COMMERCIALS
CIA (SECRET)
HAM RADIO
KOSHER RADIO
CELL PHONE CANCER RAYS
SPACE RAYS CONTROLLING STEVE BALLMER
99.3 "THE FOX"
101.5 "THE BADGER"
106.3 "THE FRIGHTENED SQUIRREL"
ALIENS
SETI
24/7 NPR PLEDGE DRIVES
AM (US)
WIFI
BRAIN WAVES
SULAWESI
VHF
UHF
FHF
SUPERMAN'S HEAT VISION
JACK BLACK'S HEAT VISION
SUNLIGHT
MAIN DEATH STAR LASER
CENSORED UNDER PATRIOT ACT
MAIL-ORDER X-RAY GLASSES
SINISTER GOOGLE PROJECTS
POWER & TELEPHONE
RADIO & TV
MICROWAVES
TOASTERS
IR
VISIBLE LIGHT
UV
VISIBLE DARK
MILLER LIGHT
X-RAYS
GAMMA/COSMIC RAYS
λ (m)
10⁸ 10⁷ 10⁶ 10⁵ 10⁴ 10³ 10² 10¹ 10⁰ 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹² 10⁻¹³
100Mm 10Mm 1Mm 100km 10km 1km 100m 10m 1m 10cm 1cm 1mm 100μm 10μm 1μm 100nm 10nm 1nm 100pm 10pm 1pm 100fm

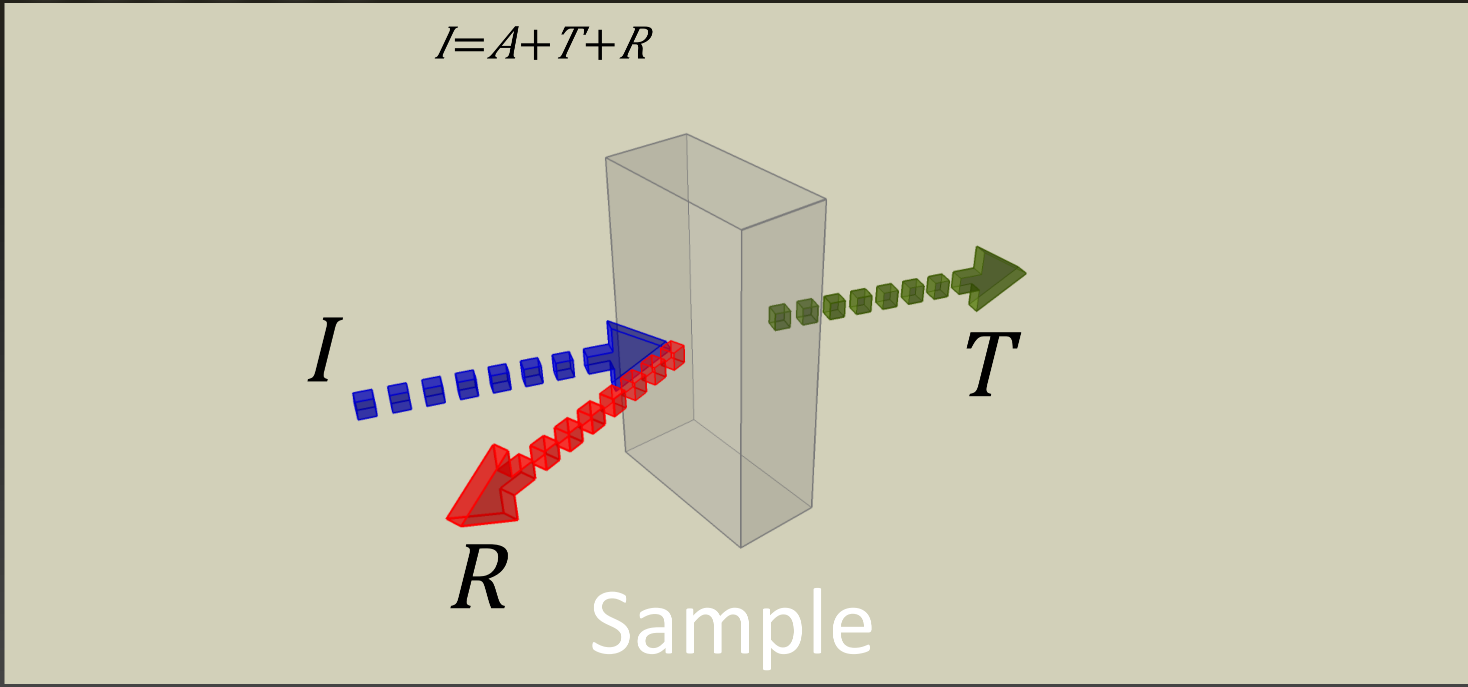
With numbers…

Near-IR	12500 - 4000 cm^{-1}	0.8 - 2.5 μm	1.55 - 0.5 eV
Mid-IR	4000 - 500 cm^{-1}	2.5 - 20 μm	0.5 - 0.06 eV
Far-IR	500 - 5 cm^{-1}	20 - 2000 μm	60 - 0.6 meV

What can we look at?

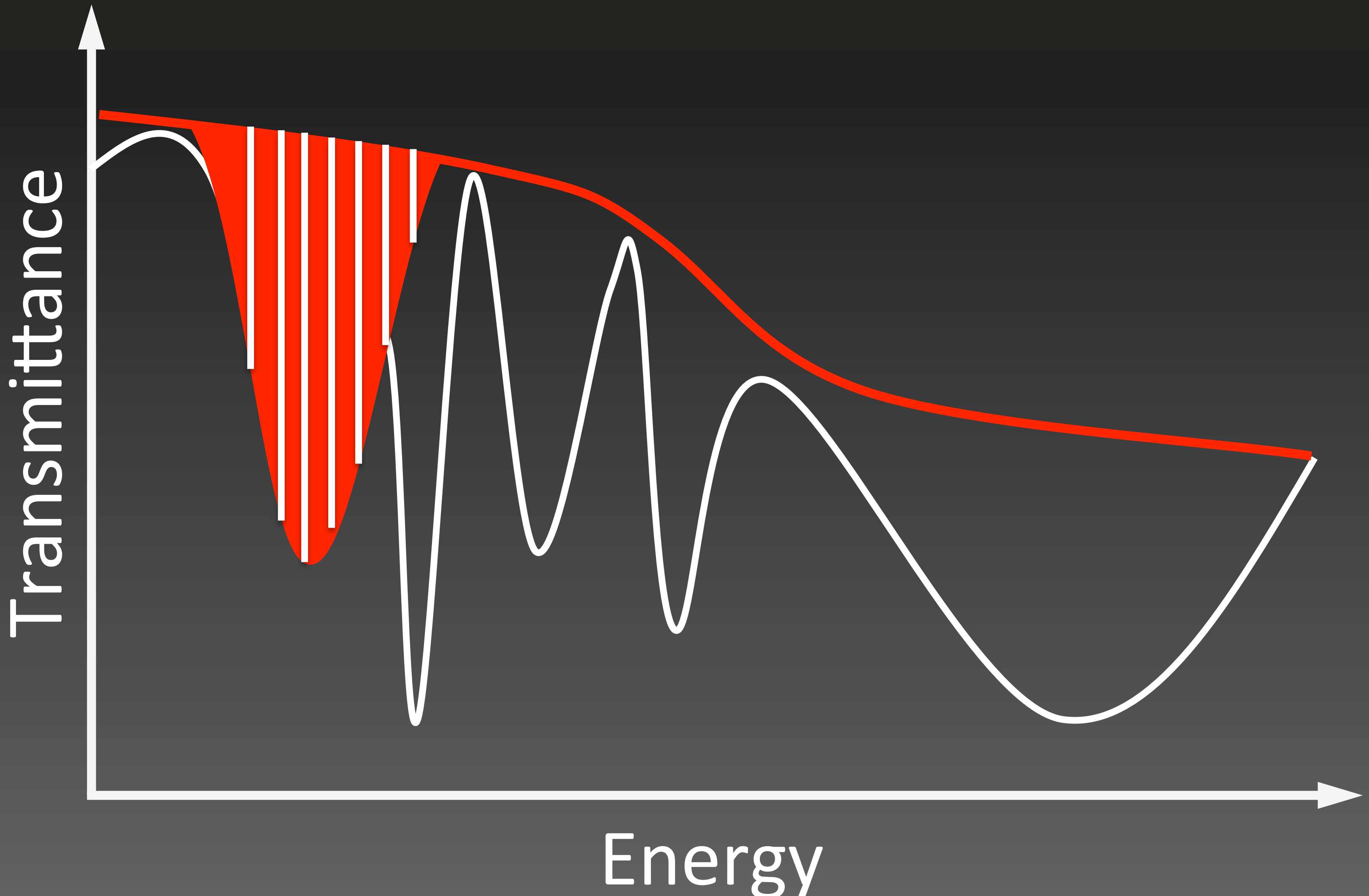
- Broad band electronic excitations
- Rotations
- Vibrations

Processes



- Transmission $$T = \frac{I}{I_0} = e^{-\varepsilon cl}$$
- Absorption $$A = -logT = \varepsilon cl$$
- Reflection $$R$$

An infrared spectrum



Basic optical functions

Goal: determine ε(ω), the dielectric function

Information about the electronic structure

Measure: reflectivity, r(ω); transmittance, T(ω)

☺ All of them are related

$$n = n' + in'' = \frac{1+r}{1-r} = \frac{1+\sqrt{R}e^{i\Theta}}{1-\sqrt{R}e^{i\Theta}}$$

$$R = \frac{(n'-1)^2 + n''^2}{(n'+1)^2 + n''^2}$$

$$\epsilon_{rel} = \epsilon'_{rel} + i\epsilon''_{rel} = n^2$$

Basic optical functions

Goal: determine ε(ω), the dielectric function

Information about the electronic structure

Measure: reflectivity, r(ω); transmittance, T(ω)

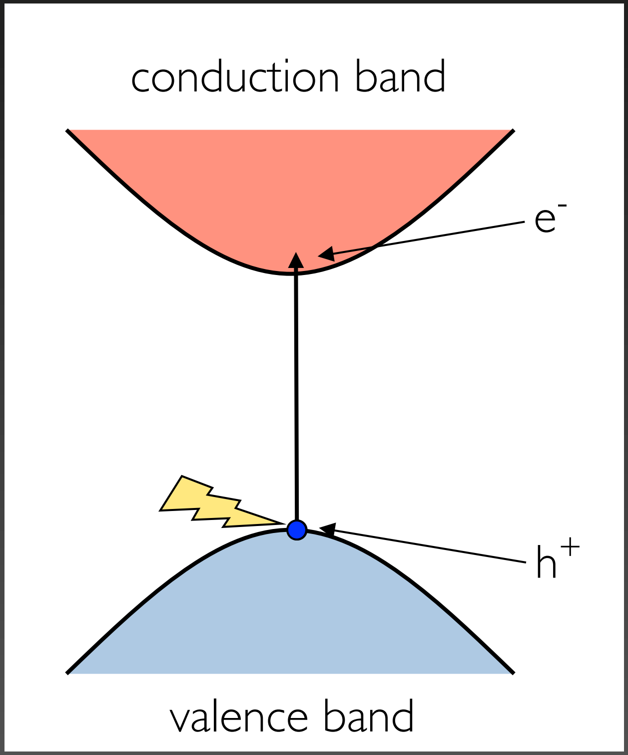
☹ All complex functions

☺ Kramers Kronig transformation

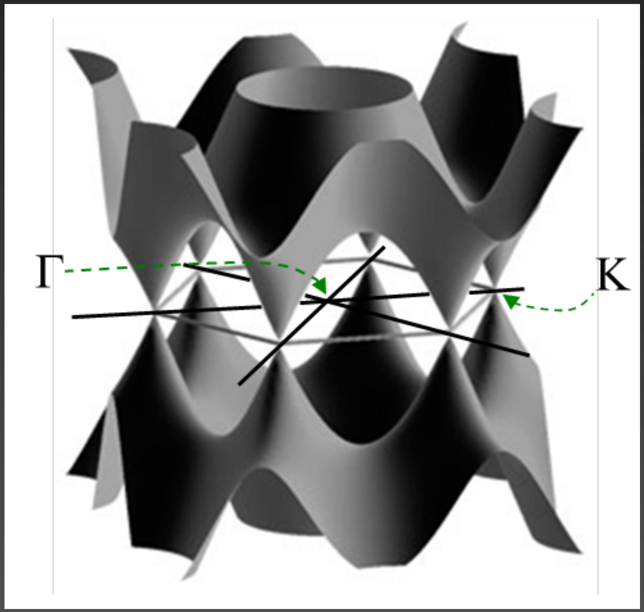
$$\Theta(\omega) = \frac{\omega}{\pi}\int_0^{\infty}\frac{lnR(\xi)-lnR(\omega)}{\xi^2-\omega^2}d\xi$$

$$\Theta(\omega) = -\frac{2\omega}{\pi}\int_0^{\infty}\frac{lnT(\omega')}{\omega'^2-\omega^2}d\omega + 2\pi\omega d$$

Studies on low energy gaps

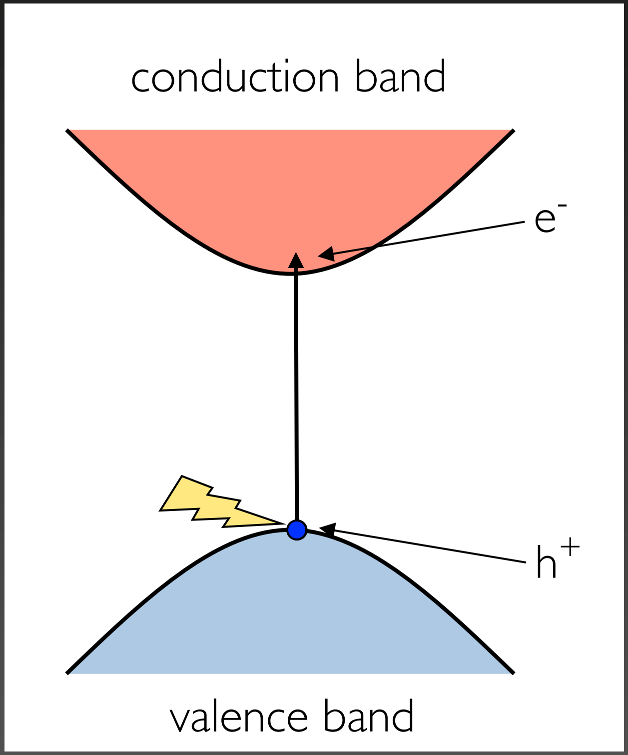


General semiconductor

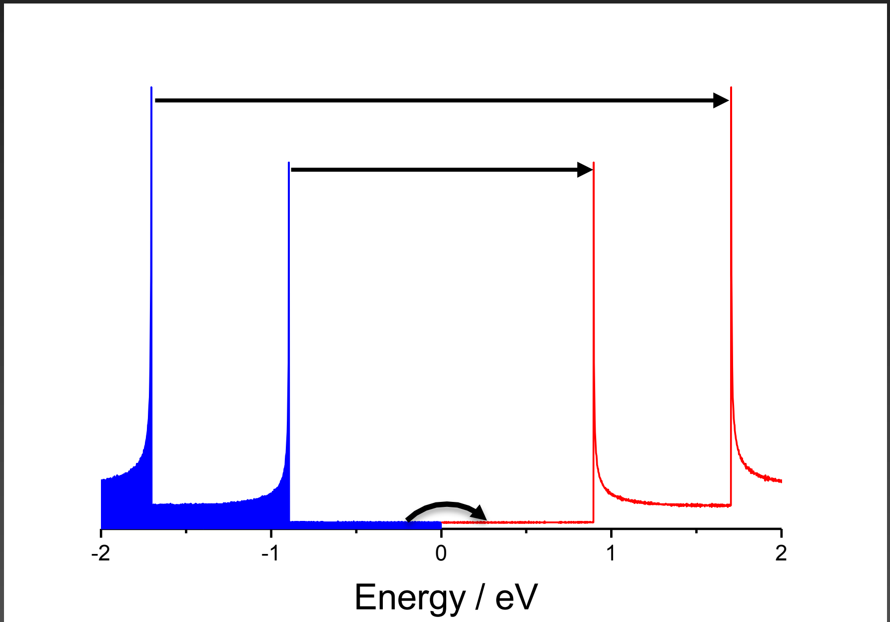


Graphene

Energy gaps of semiconductors



General semiconductor

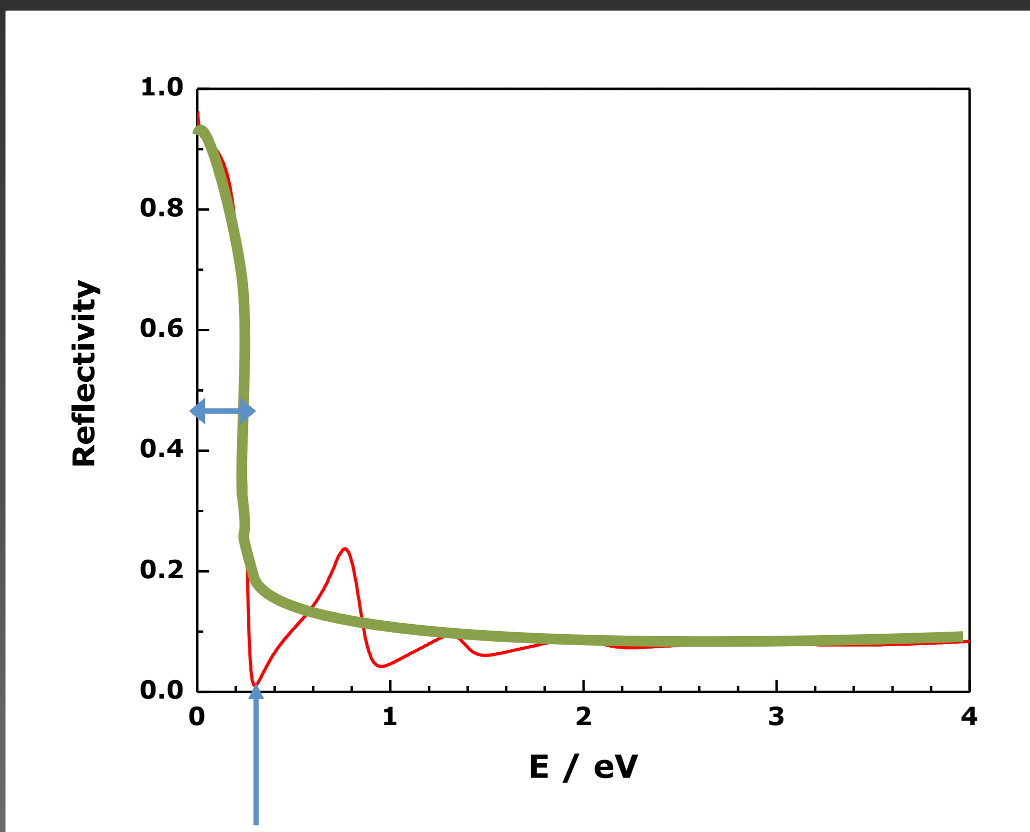


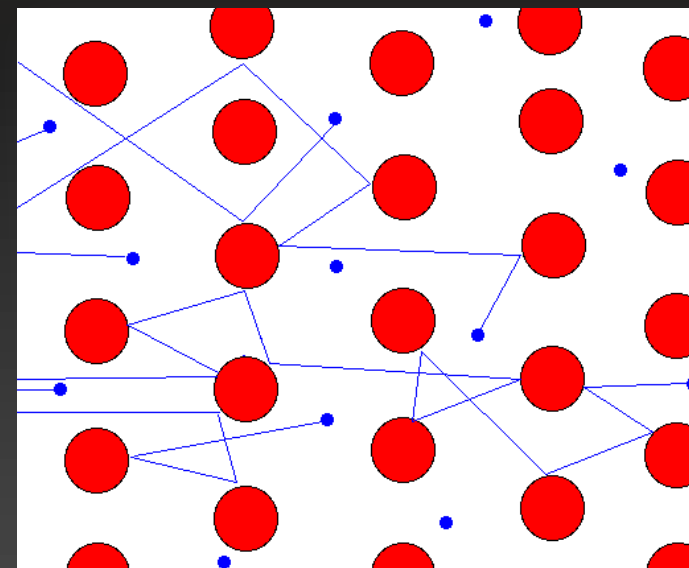
Nanotubes

Models to understand ε

Drude model

$$\epsilon_{rel} = \epsilon_{\infty} - \frac{\omega_{pD}^2}{\omega^2 + i\gamma_D\omega}$$



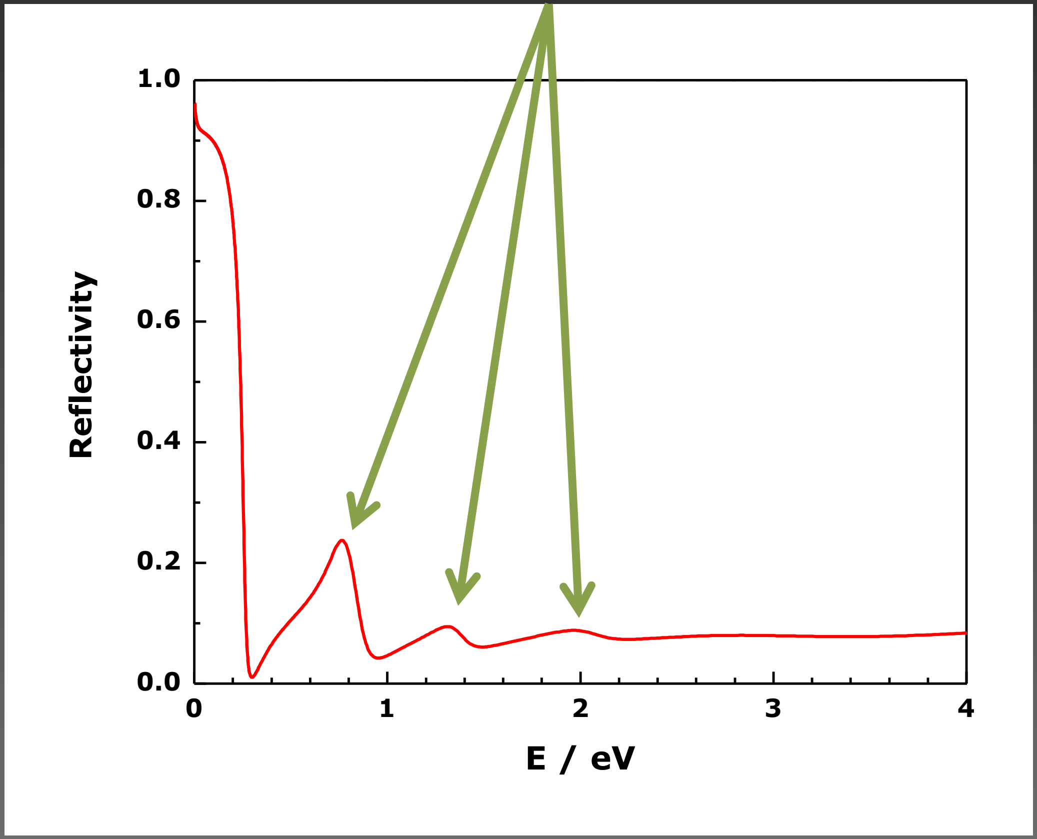


$$\omega_{pD} = \sqrt{\frac{n_e e^2}{m^* \varepsilon_0}}$$

Models to understand ε

Drude – Lorentz model

$$\varepsilon_{rel} = \varepsilon_{\infty} - \frac{\omega_{pD}^2}{\omega^2 + i\gamma_D\omega} + \sum_{i=1}^{n} \frac{\omega_{pi}^2}{\omega_i^2 - \omega^2 + i\gamma_D\omega}$$



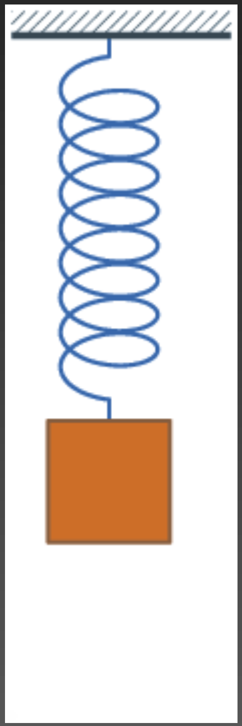
Vibrations

Harmonic oscillator

Hooke's law

$$F = ma$$

$$m\frac{d^2x}{dt} = -kx$$



Potential energy

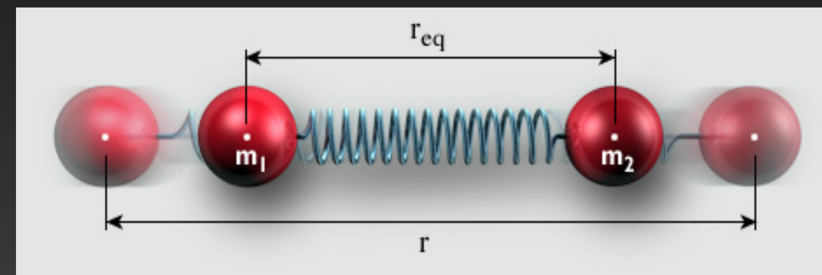
$$V = \frac{1}{2}kx^2$$

Molecular vibrations

Diatomic molecule, harmonic oscillator

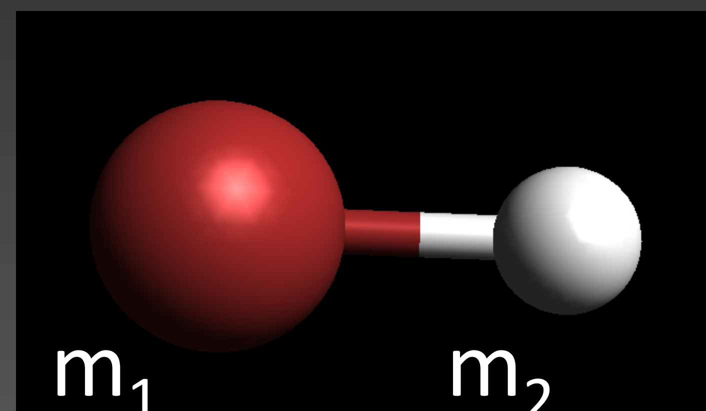
$$x = r - r_{eq}$$

$$\mu = \frac{m_1 + m_2}{m_1 m_2}$$



$$-kx = F = \mu \ddot{x}$$

$$x(t) = X_0 sin(\omega t + \phi)$$



$$-kx = -4\pi^2 \nu^2 x \mu$$

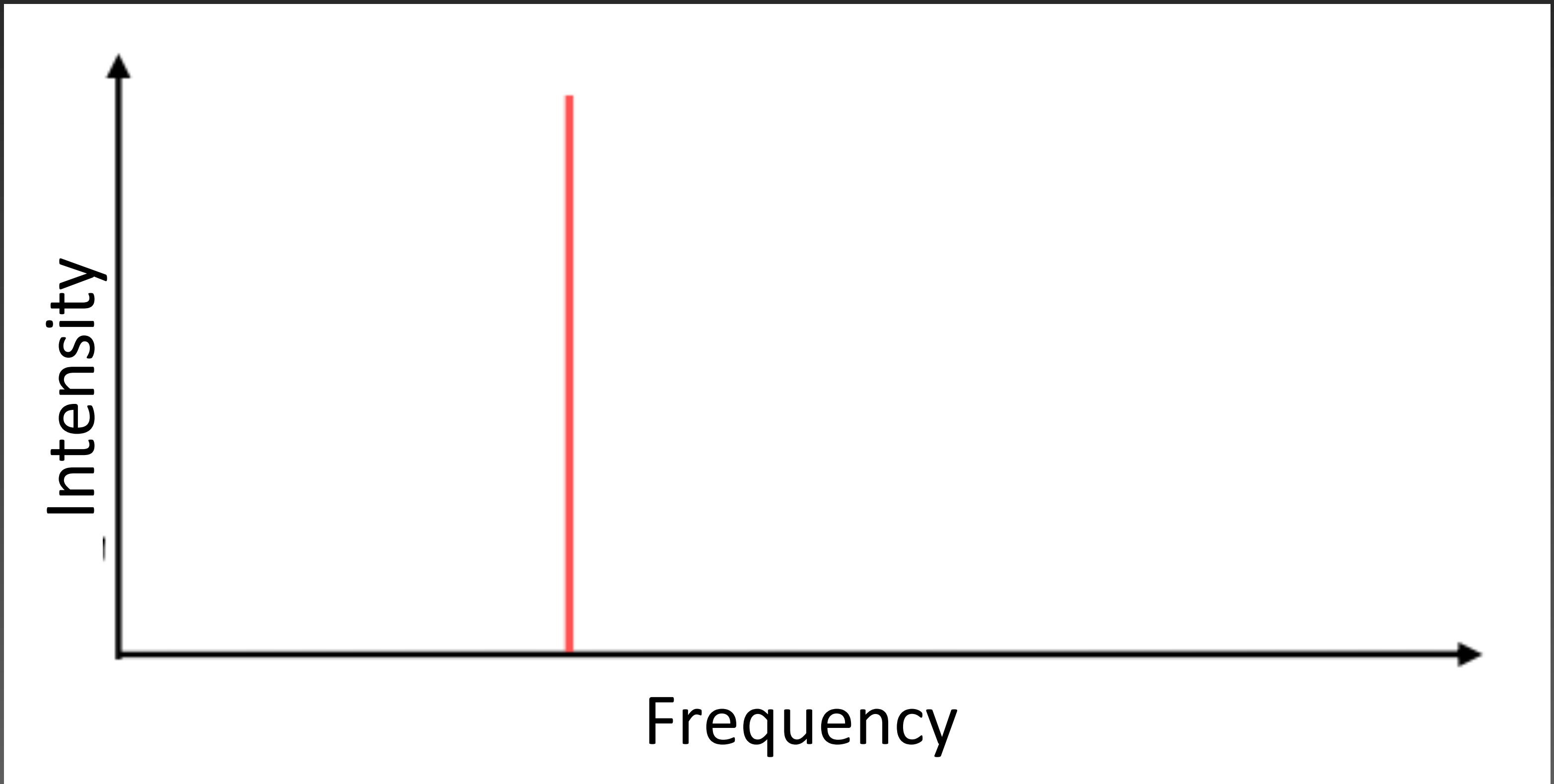
$$\tilde{\nu} = \frac{1}{2\pi c}\sqrt{\frac{k}{\mu}}$$

BH 2400	CH 3000	NH 3400	OH 3600	FH 4000
2.04	2.55	3.04	3.44	3.98

OH 3600 OD 2600

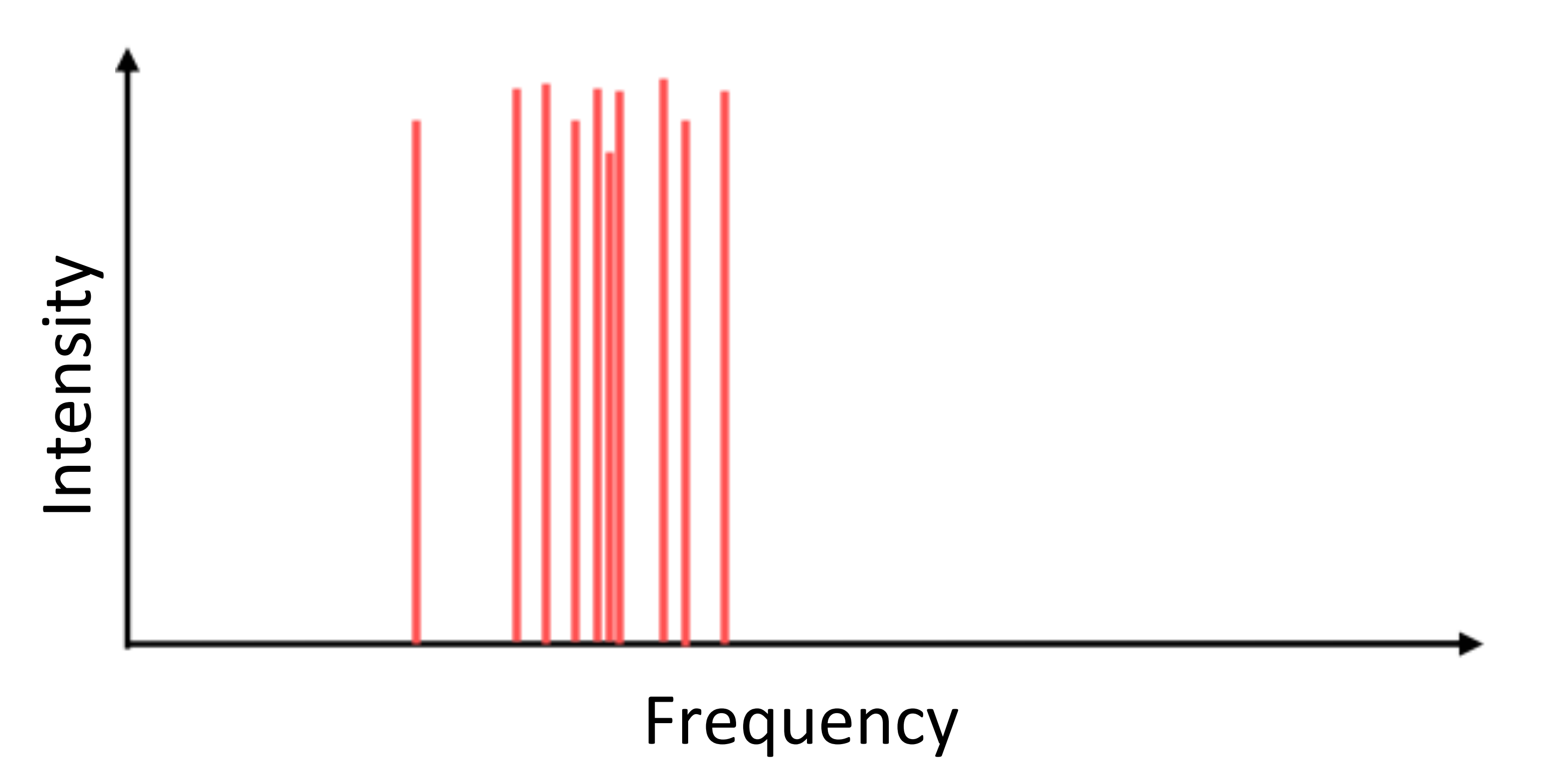
Molecular vibrations

Diatomic molecule, ideal case (alone)



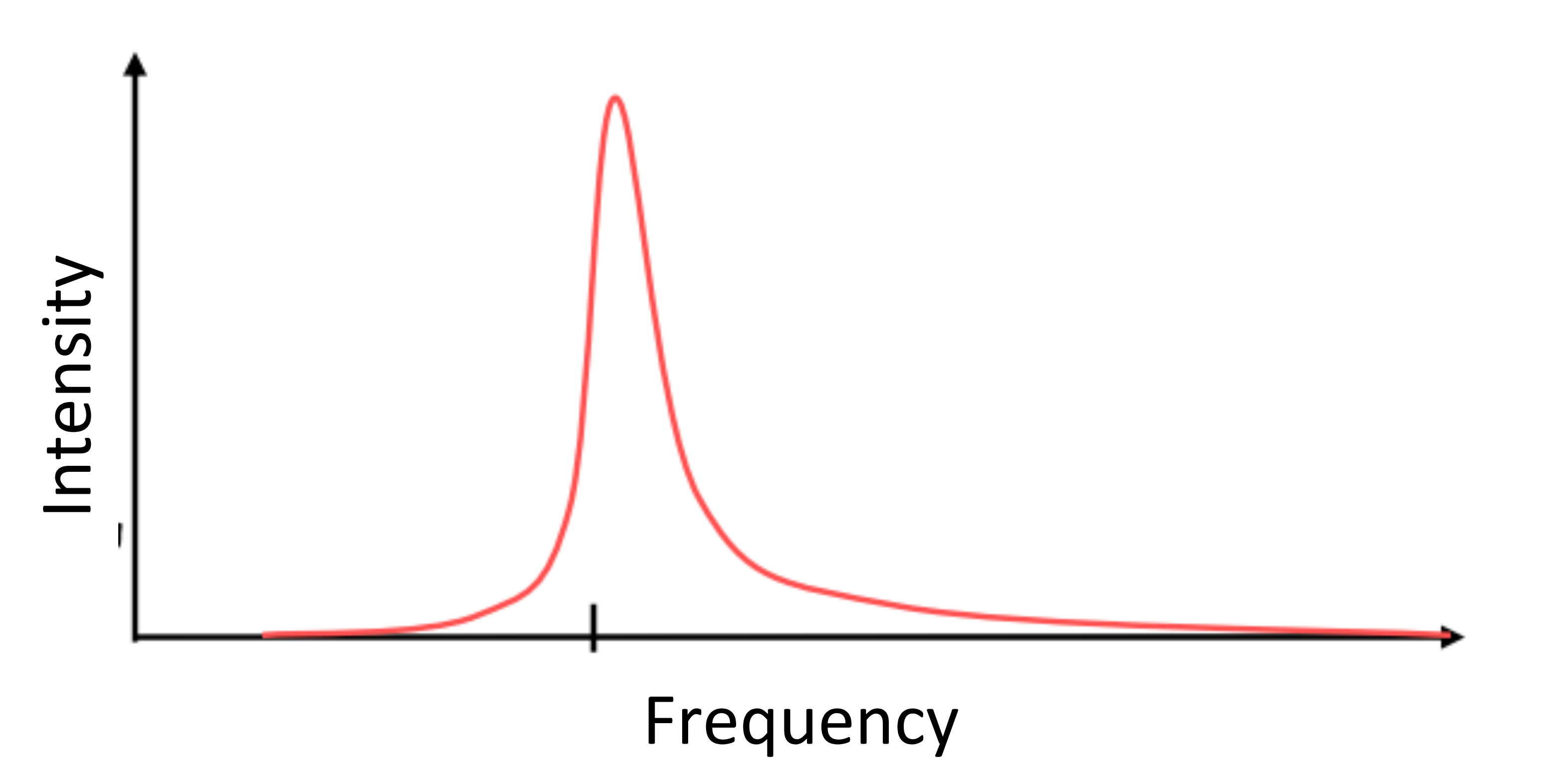
Molecular vibrations

Diatomic molecule, realistic case (solution)



Molecular vibrations

Diatomic molecule, realistic case (solution)

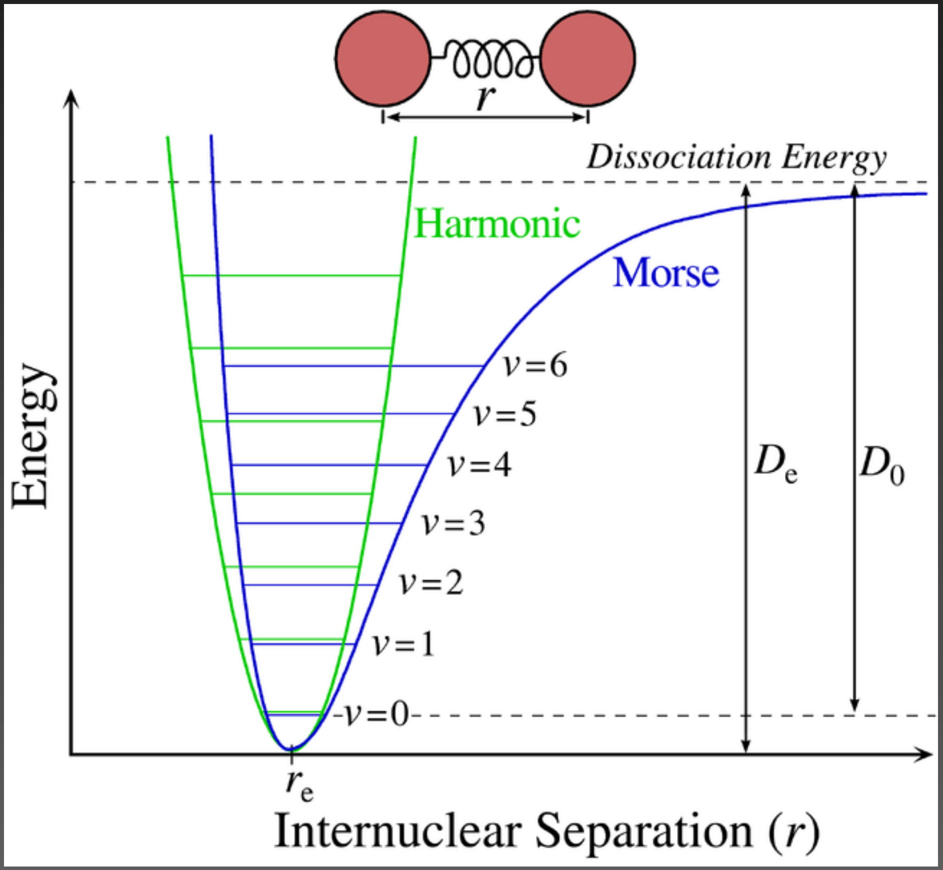


Molecular vibrations

Quantized oscillator

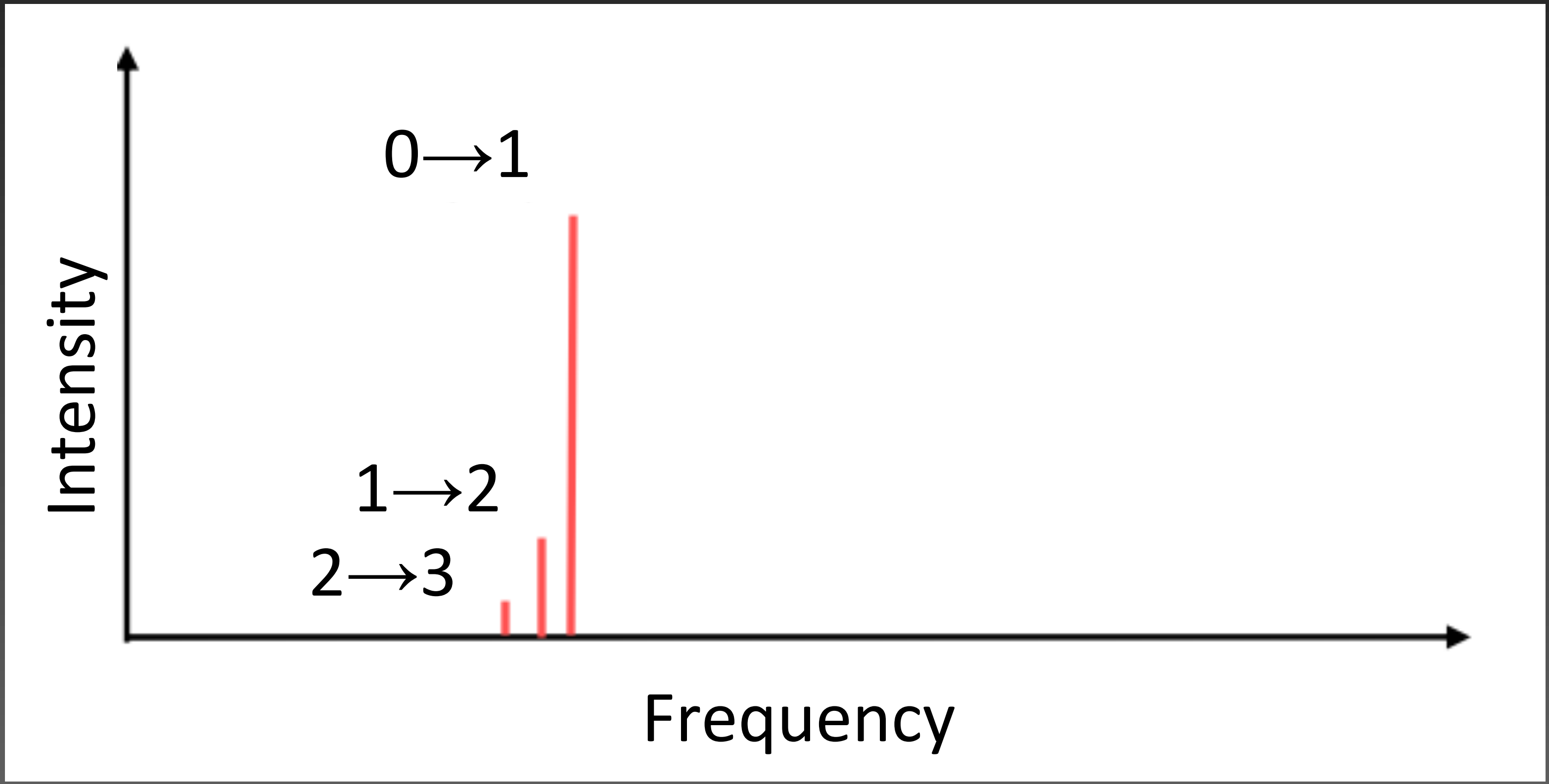
Energy levels

$$E_\nu = \hbar\omega(\nu + \frac{1}{2})$$



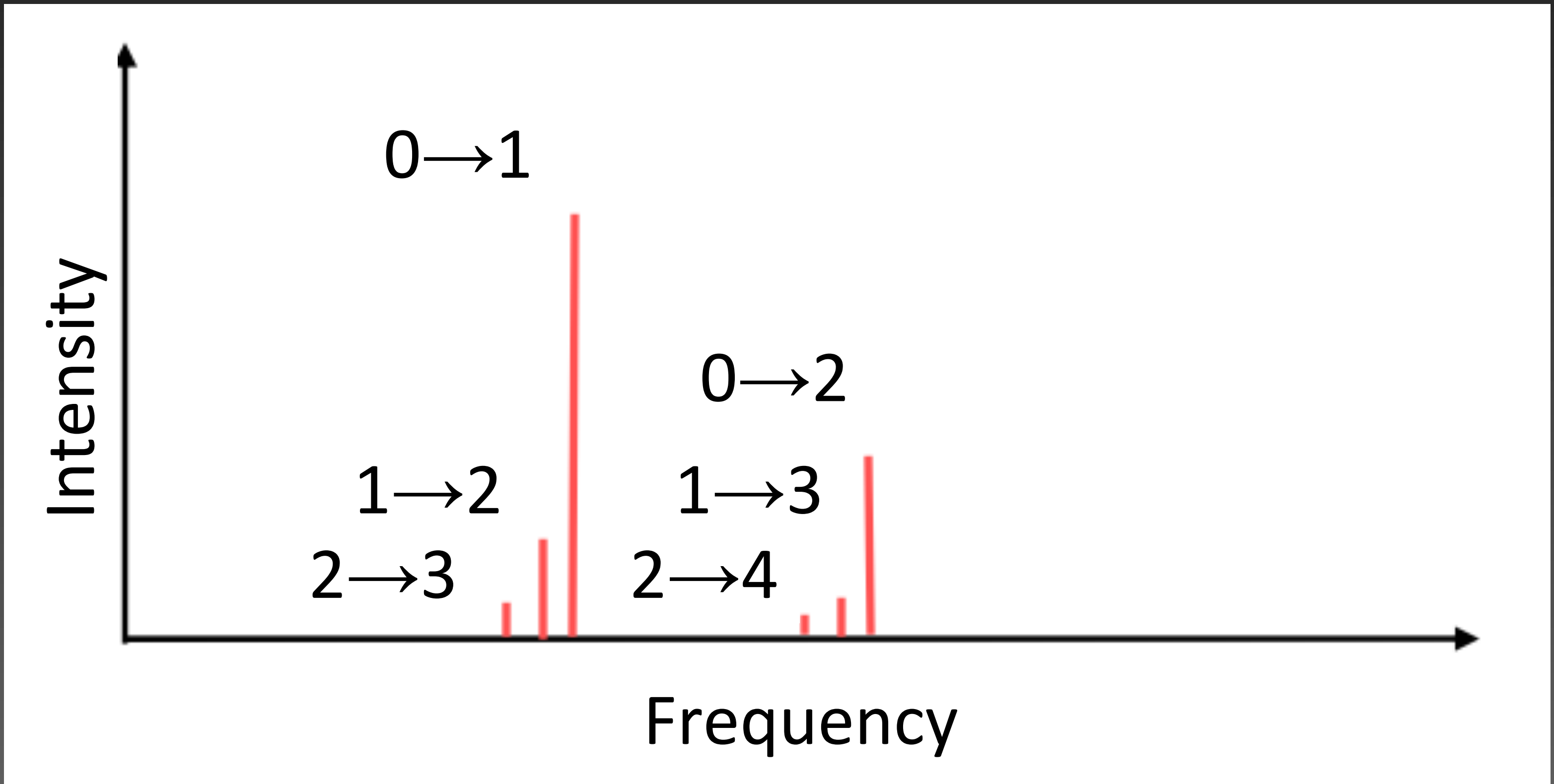
Anharmonicity

Diatomic molecule, anharmonic



Anharmonicity

Diatomic molecule, anharmonic

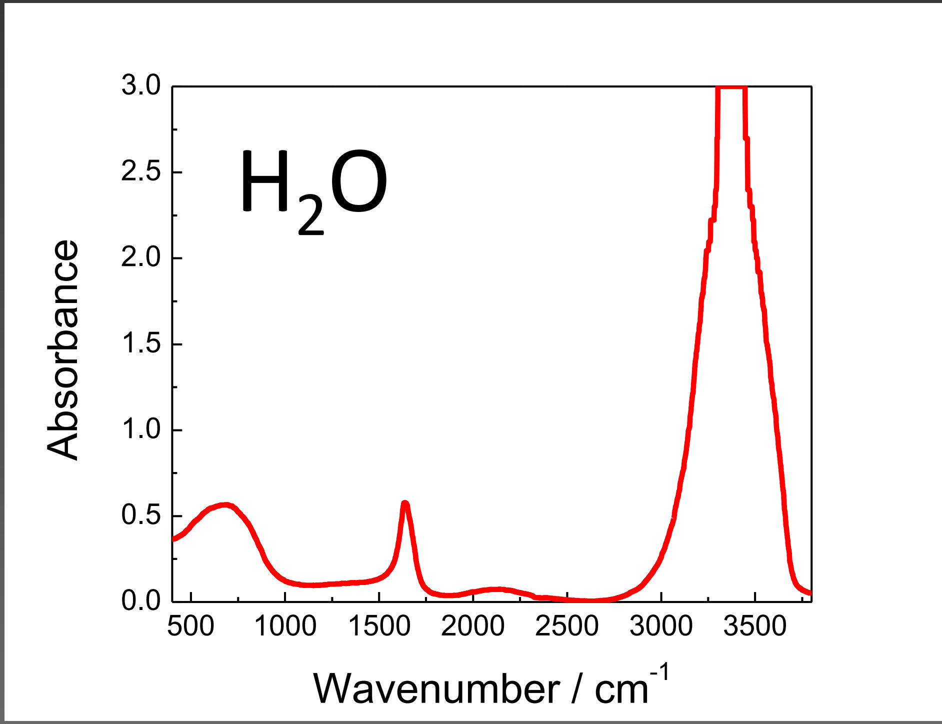


of molecular vibrations

3N-6 degrees of freedom $H_2O \rightarrow 3x3-6=3$

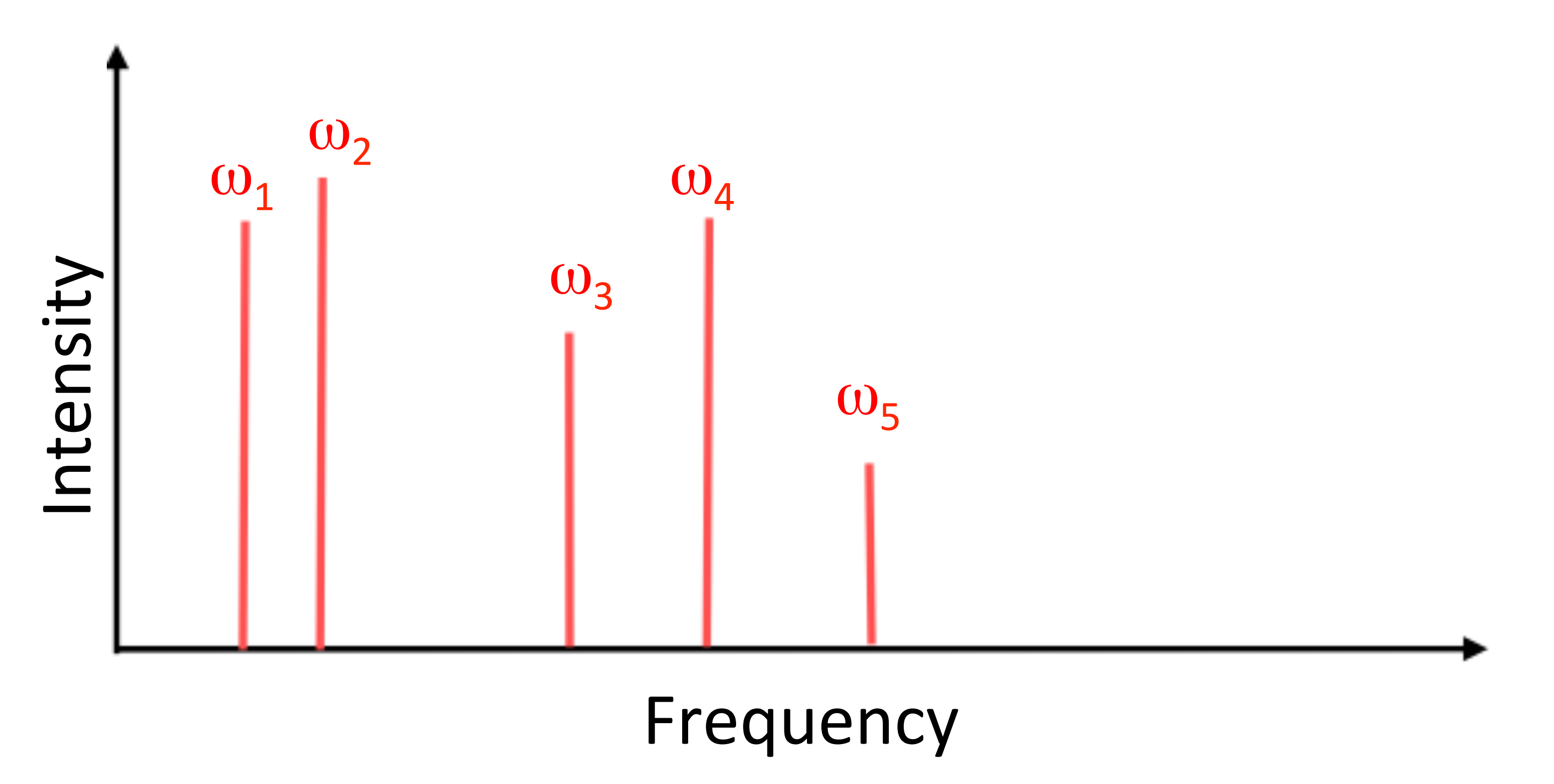
or

3N-5 for linear molecules $CO_2 \rightarrow 3x3-5=4$



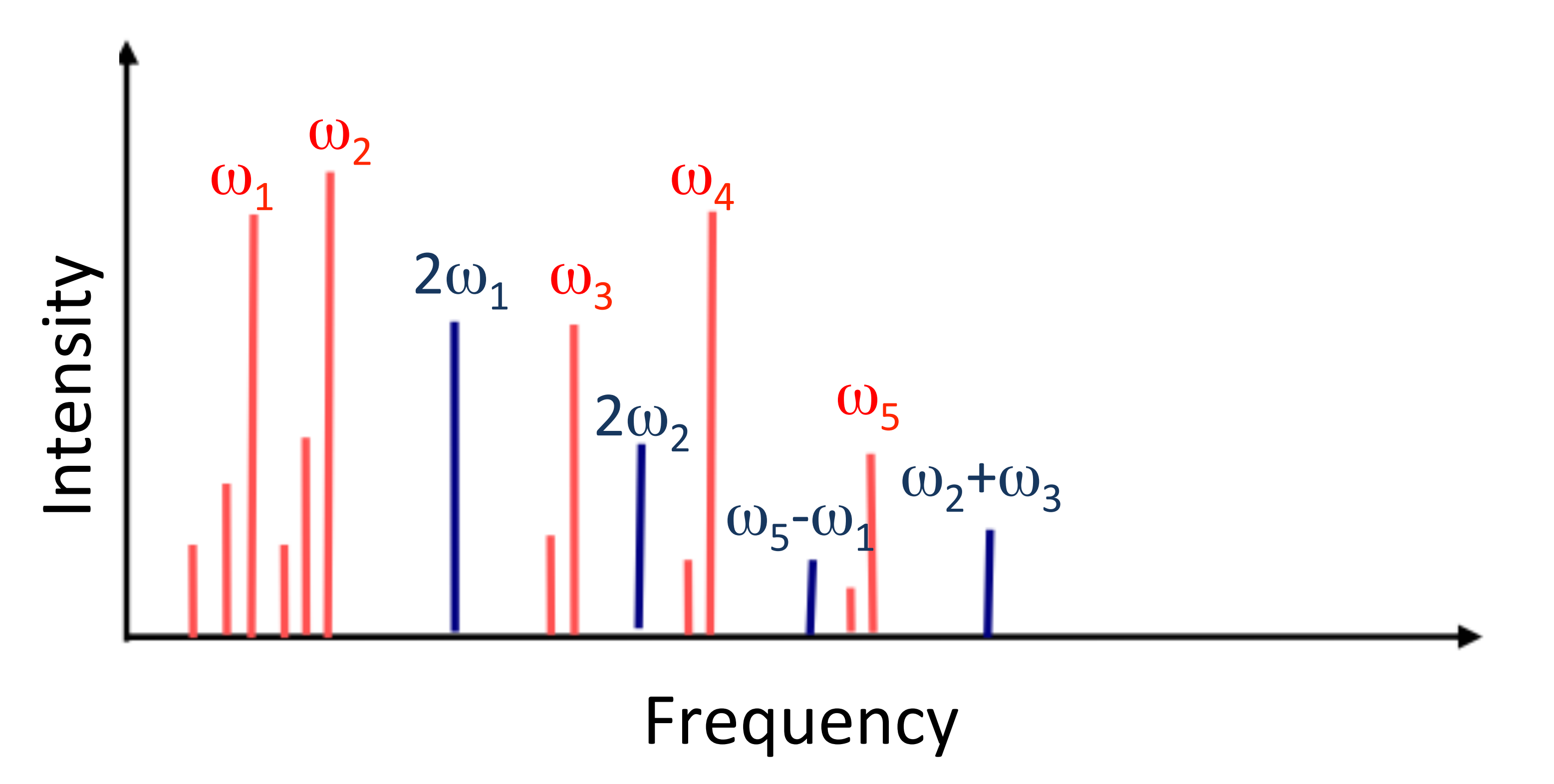
More atoms

Polyatomic molecule, ideal case, harmonic

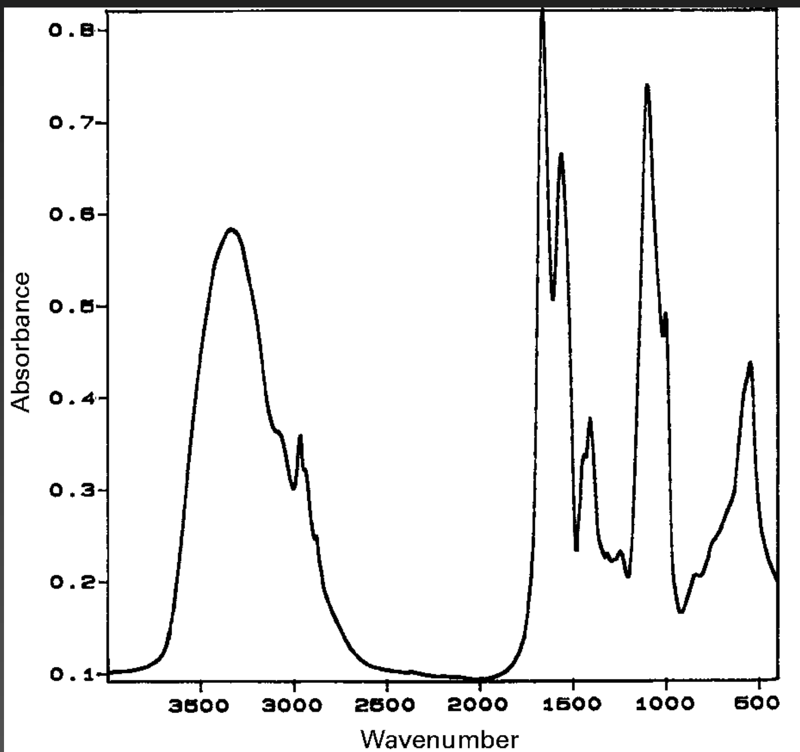


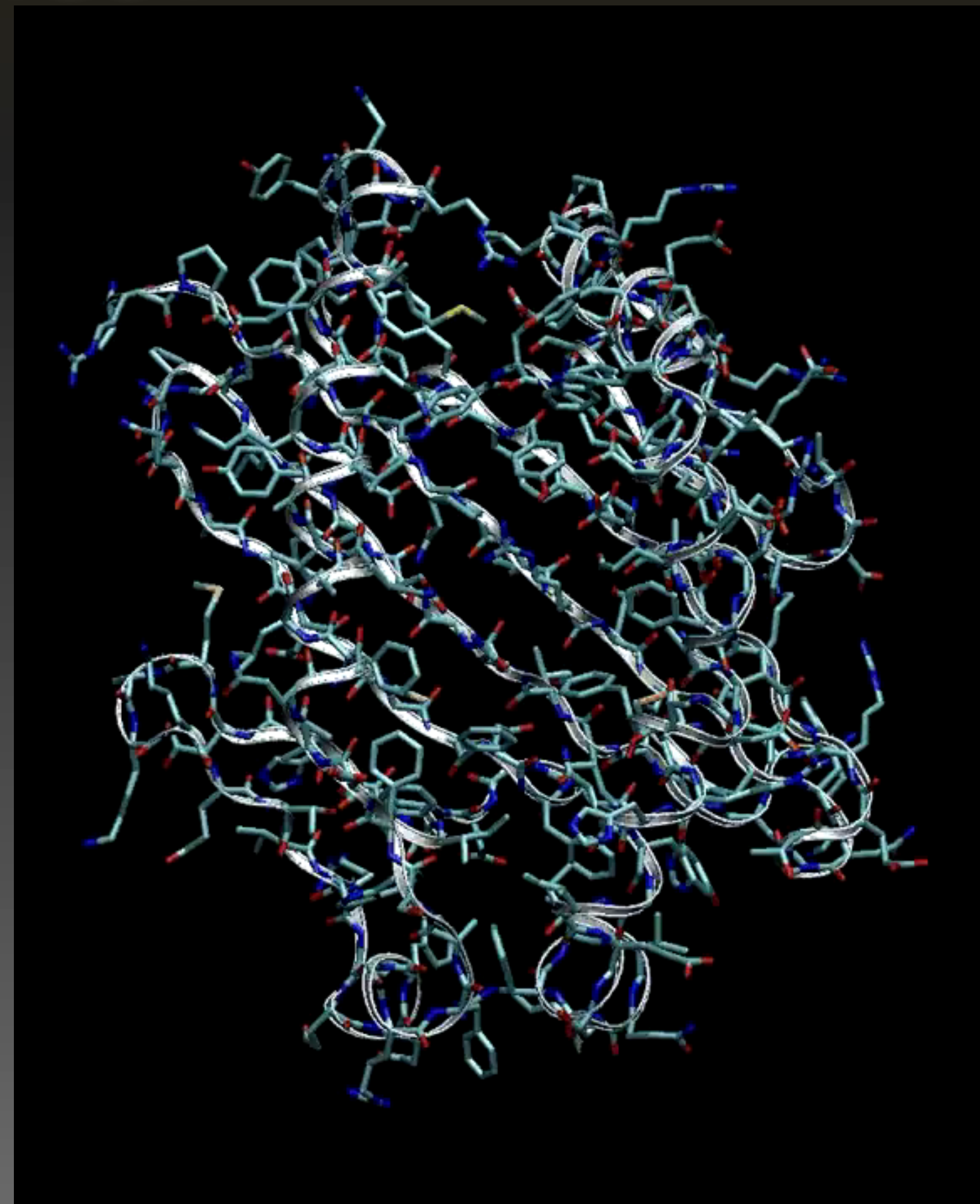
More atoms

Polyatomic molecule, real case, **an**harmonic



Larger molecules?





Chromophores

Holt et al. Biochem J. 314, 1035-1039 (1996)

IR active vibrations

Selection Rules IR: $\frac{\partial \mu}{\partial q} \neq 0$ Raman: $\frac{\partial \alpha}{\partial q} \neq 0$

Group theory

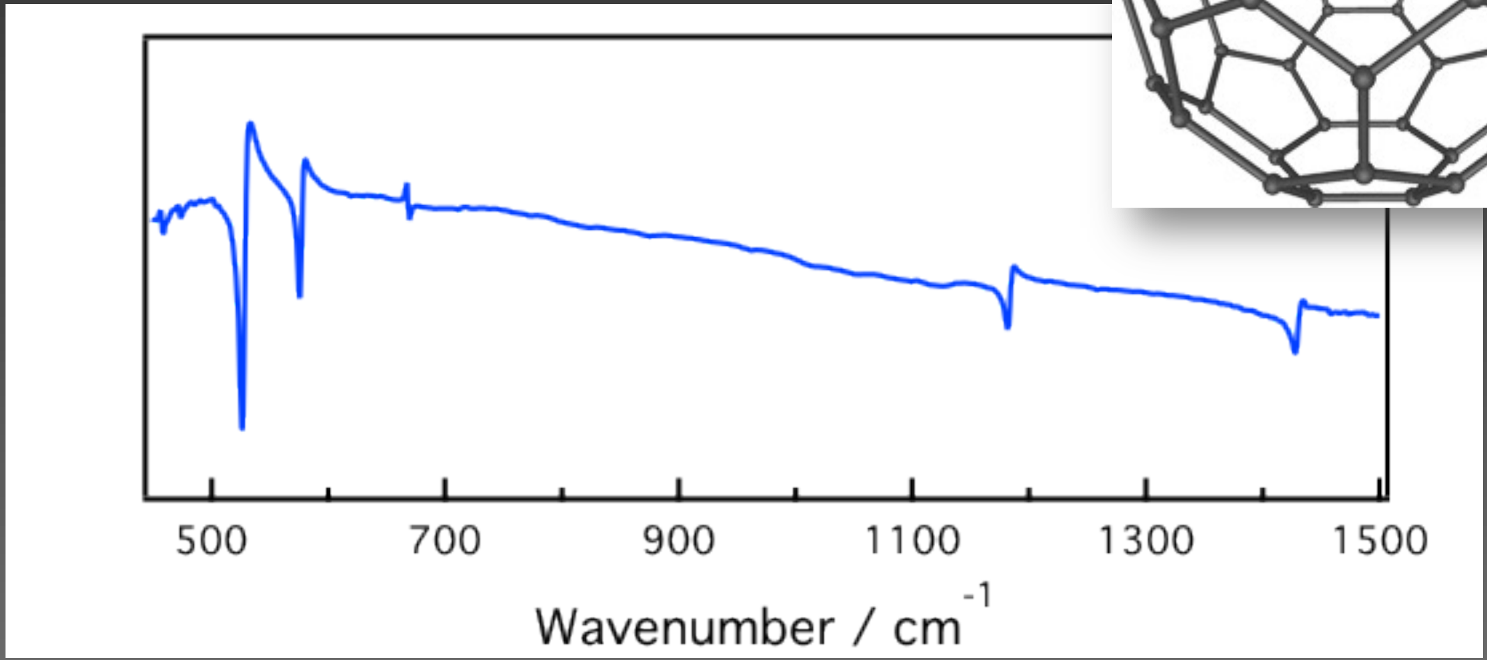
C_{2v}	E	C_2	$\sigma_v(xz)$	$\sigma_v(yz)$	
A_1	1	1	1	1	z, x^2, y^2, z^2
A_2	1	1	-1	-1	R_z, xy
B_1	1	-1	1	-1	x, R_y, xz
B_2	1	-1	-1	1	y, R_x, yz

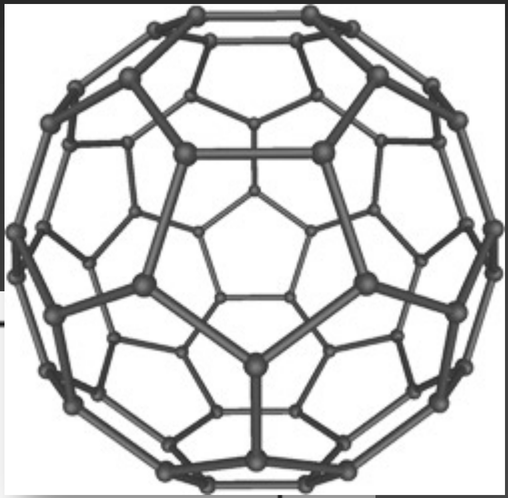
Example: H_2O

If there is an inversion symmetry IR≠Raman

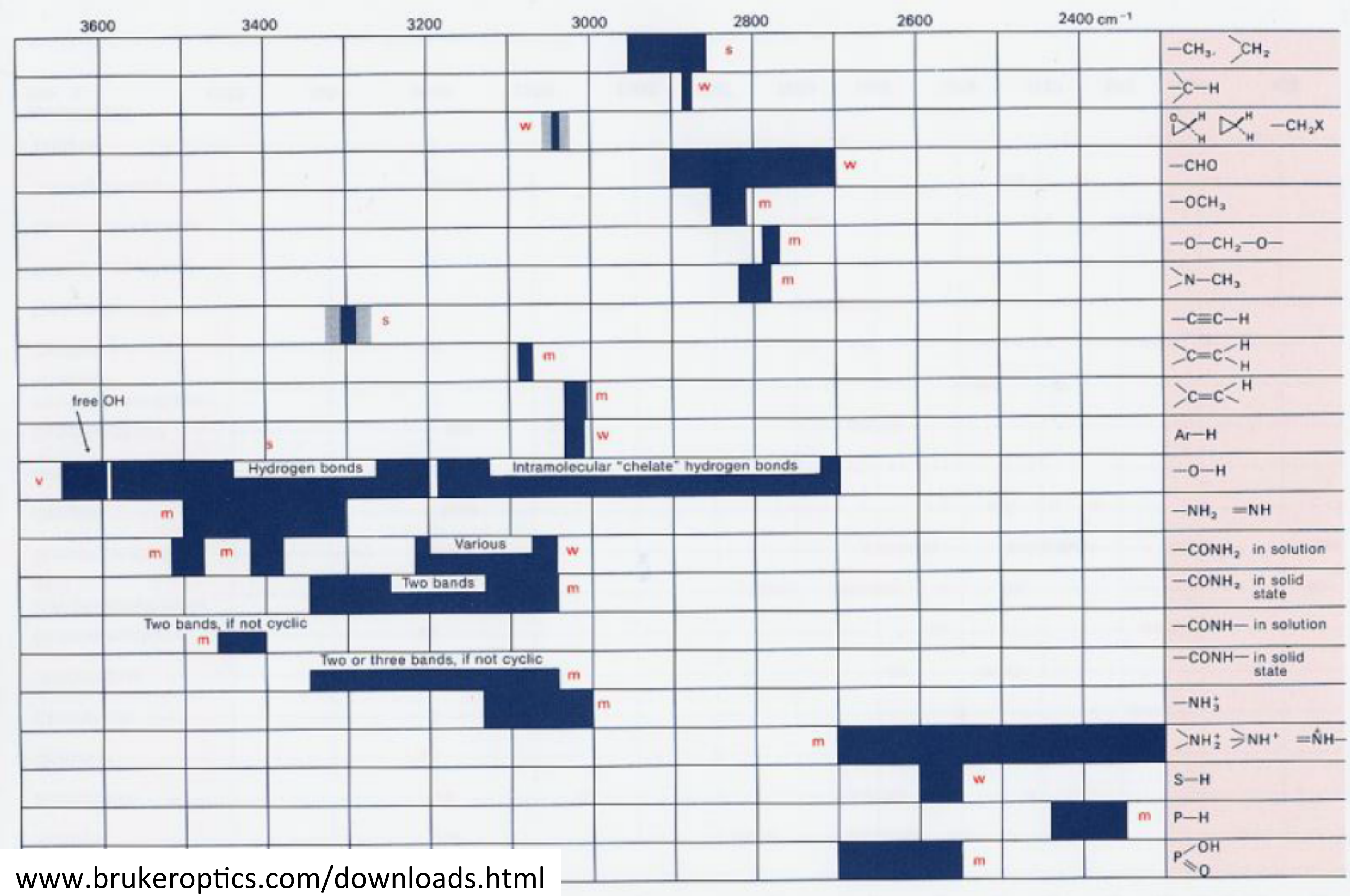
Simplifying factors

- Chromophore groups
- Selection rules
- Symmetry





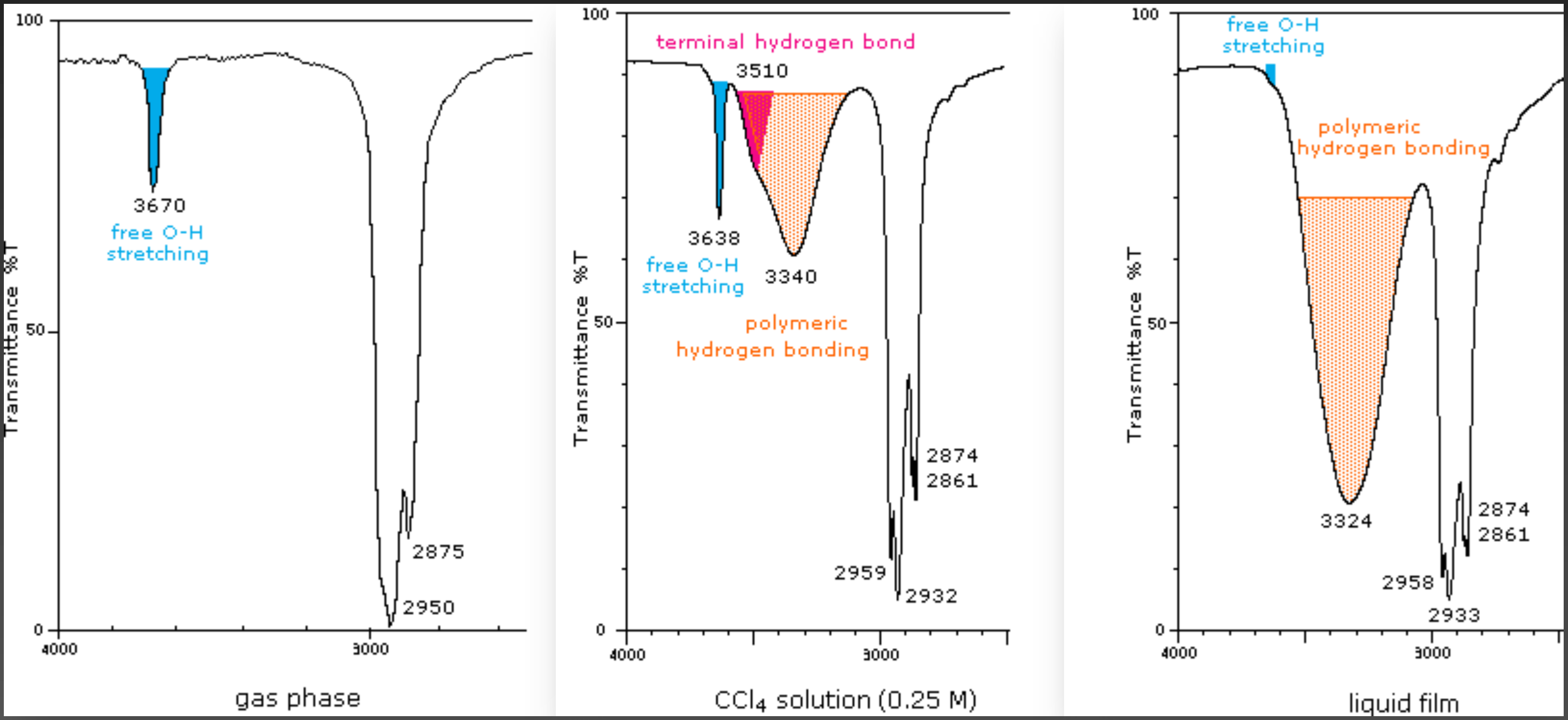
Characteristic frequencies



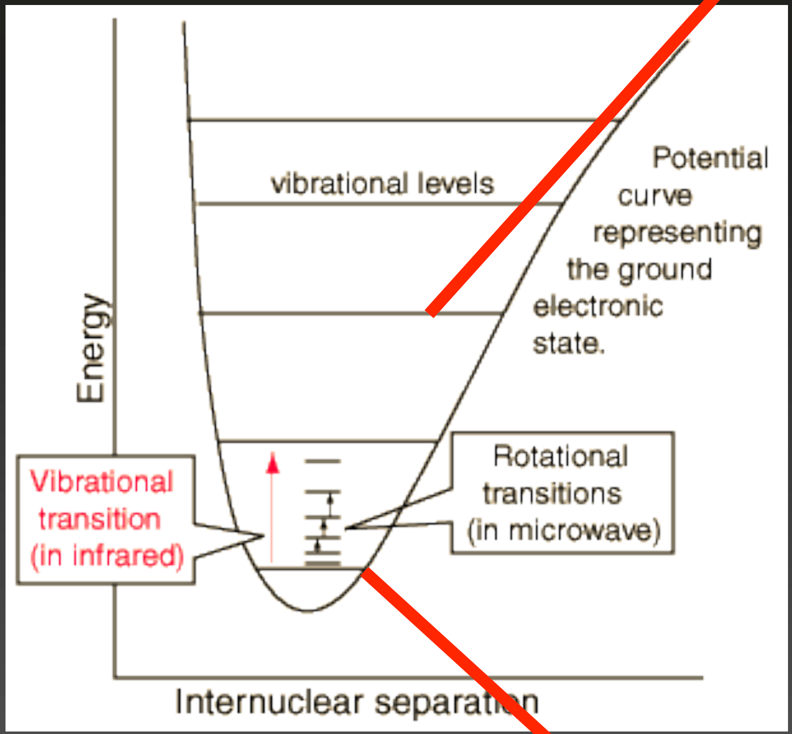
www.brukeroptics.com/downloads.html

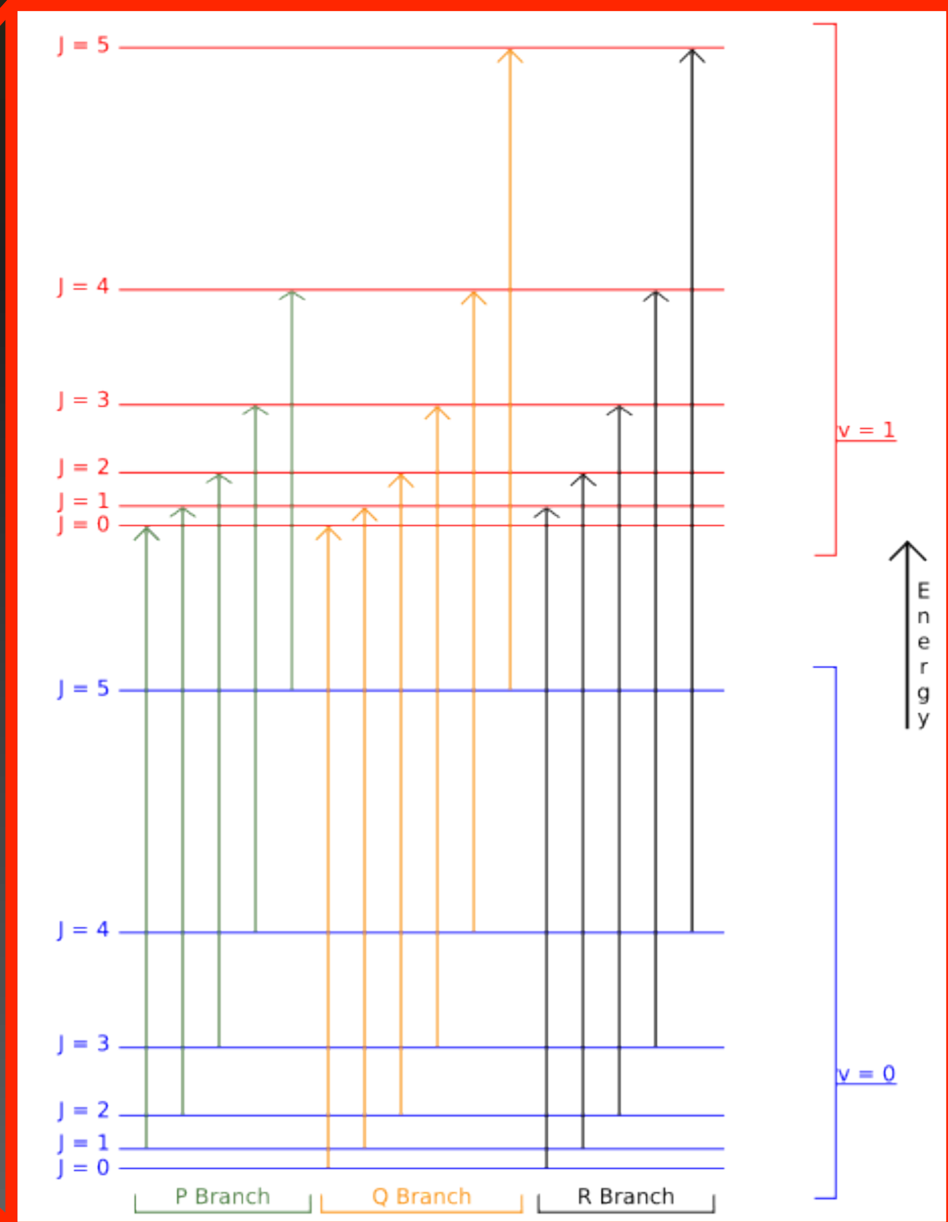
Influencing factors

Shifts



Rotations

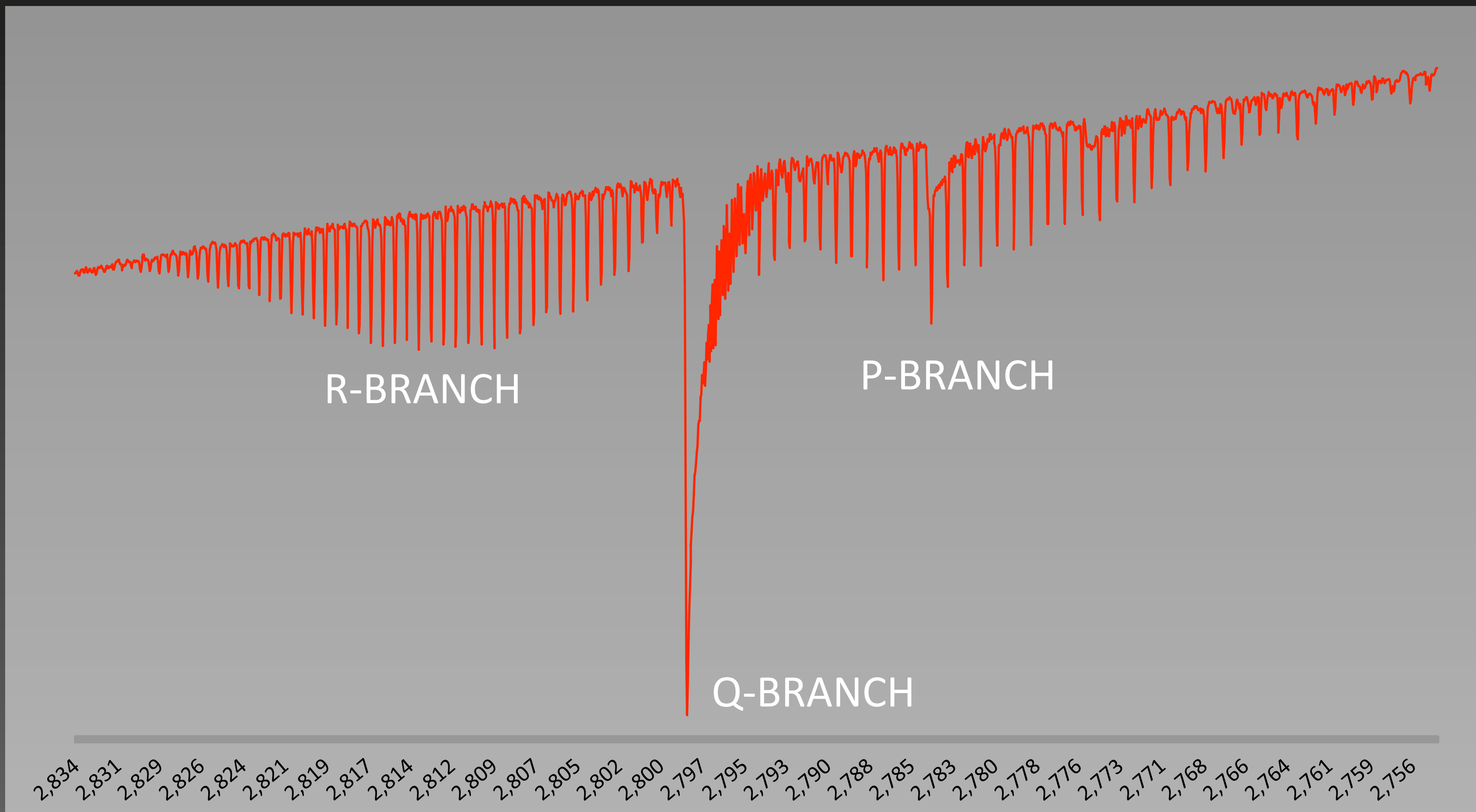




Δj=-1 Δj=0 Δj=+1

Rotational spectrum example

Nitrous Oxide

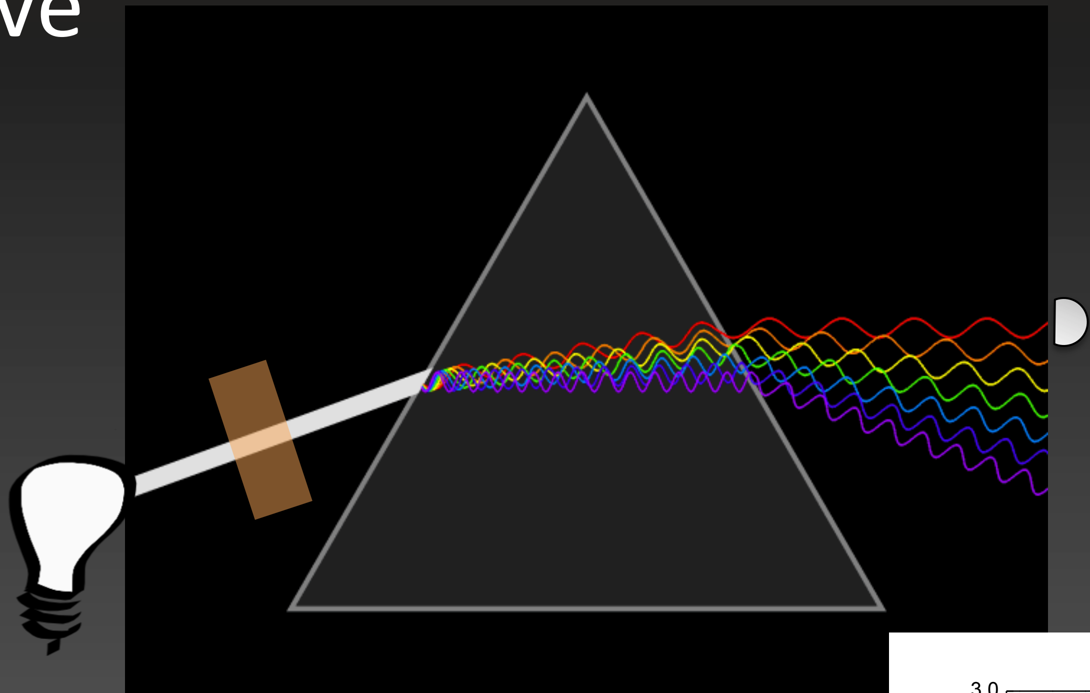


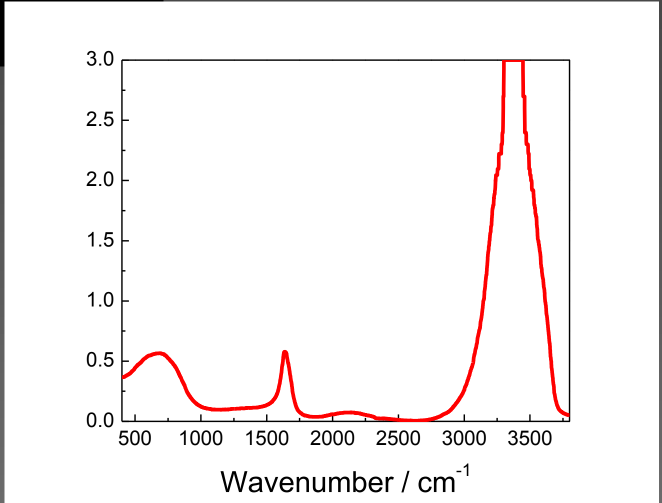
Frequency / cm^{-1}

Note: spectral range ➔ high resolution

Spectrometer designs

Dispersive





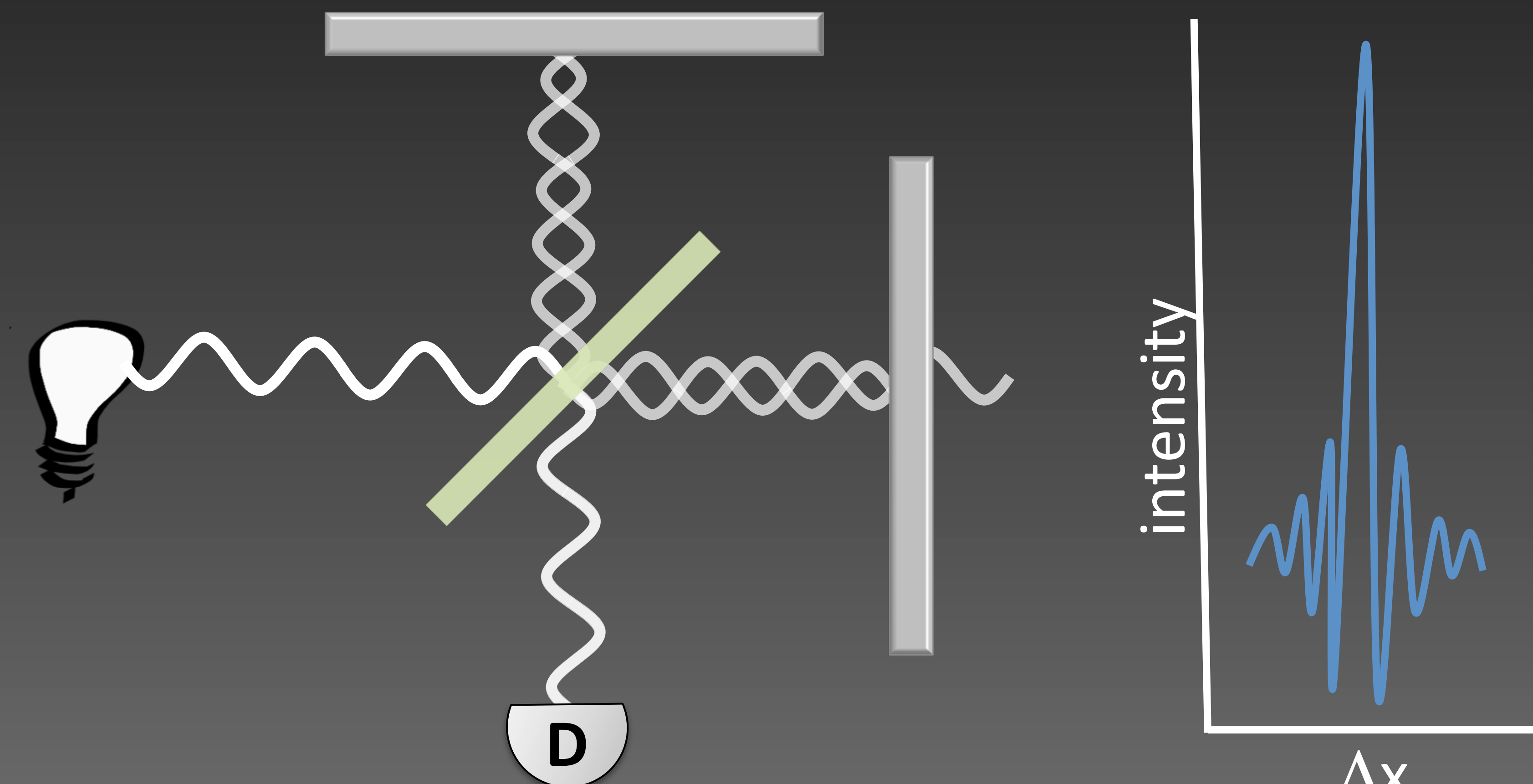
Slow, but simple

Resolution, throughput, etc…

Spectrometer designs

Fourier Transform

Michaelson interferometer

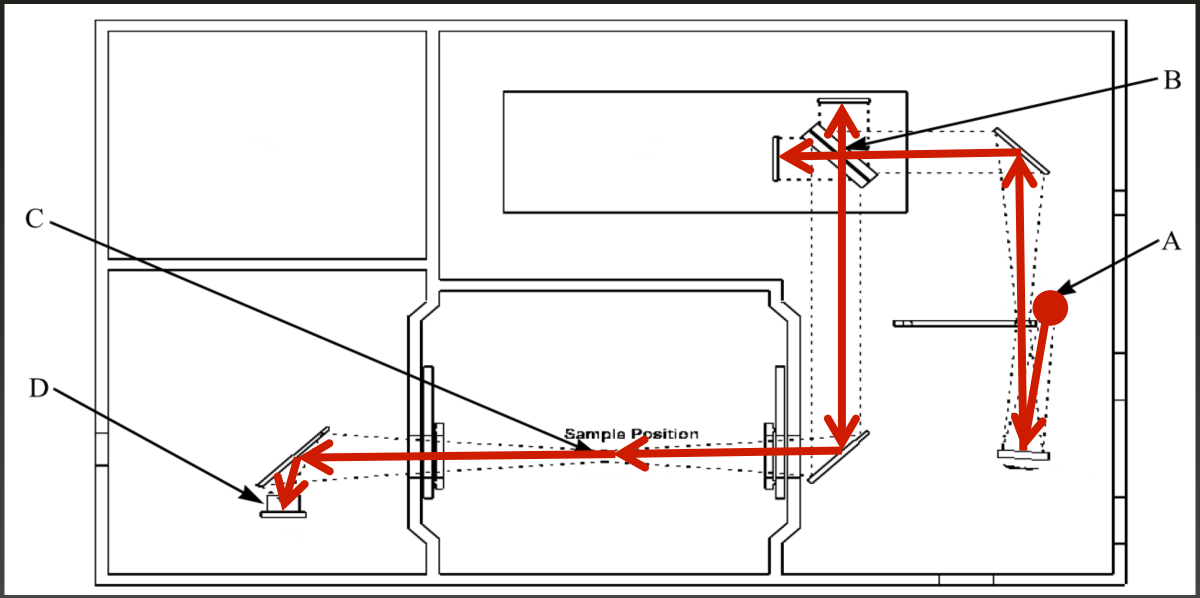


FT spectroscopy advantages

- Connes advantage: internal calibration He/Ne
- Jacquinot advantage: interferometer is bright
- Fellgett advantage: all ν in the same time
- No stray light

∑: FT is 2000x more sensitive than dispersive

A spectrometer layout



A – source

B – beamsplitter

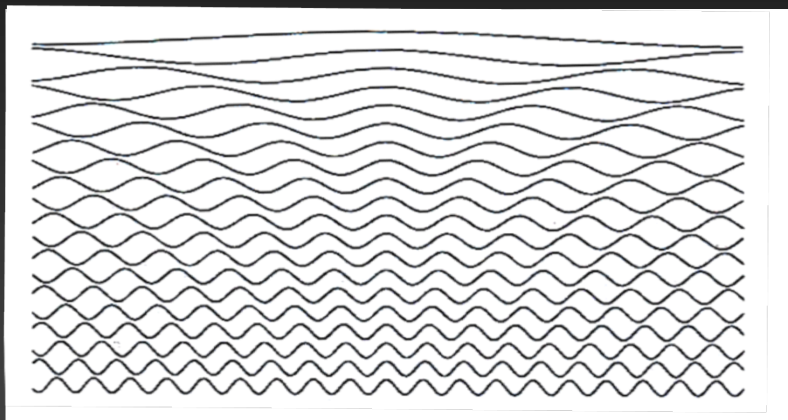
C – sample

D - detector

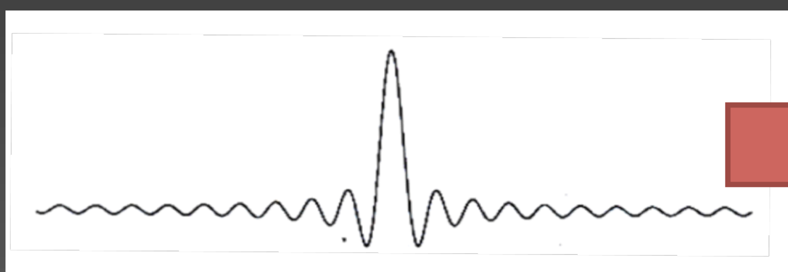
FT-IR

Michaelson interferometer

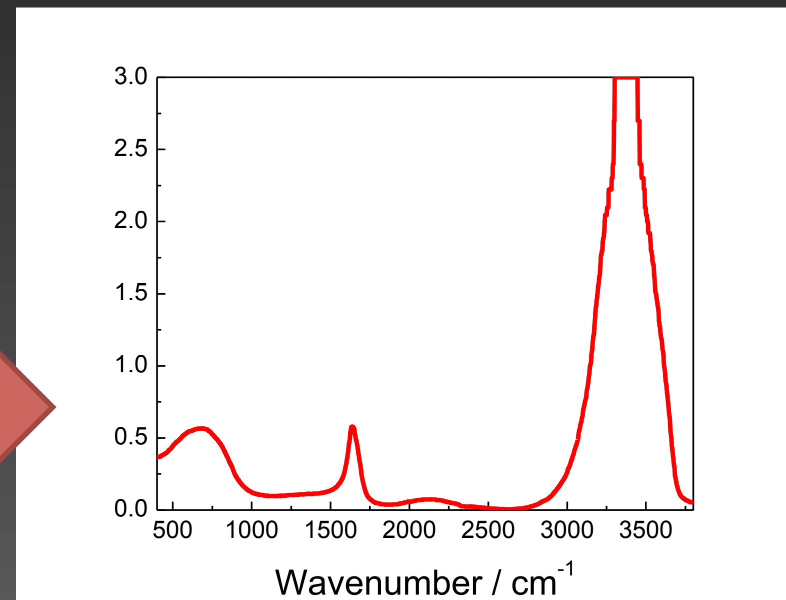
Wavelenth



$$I(x,\tilde{\nu}) = I_0(\tilde{\nu})cos(2\pi\tilde{\nu}x)$$



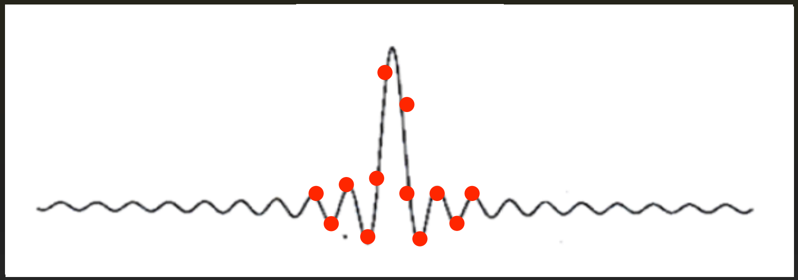
FT



$$I(x) = \int_0^{\infty} I(x,\tilde{\nu})d\tilde{\nu}$$

$$I(\tilde{\nu}) = \int_{-\infty}^{+\infty} I(x)cos(2\pi\tilde{\nu})dx$$

Resolution

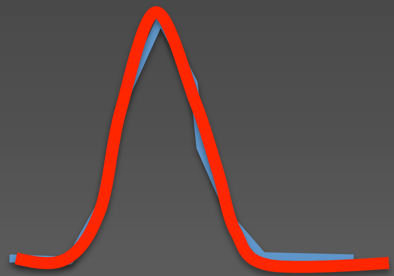


FT: $f(\omega) = \int_0^\infty F(x)$

$$f(\omega_i) = \sum_{i=0}^{\infty} F(x_i)$$ discrete

Nyquist: $\omega_{max} = \frac{1}{2\Delta x}$

$$f(\omega_i) = \sum_{i=0}^{N} F(x_i)$$ Resolution!



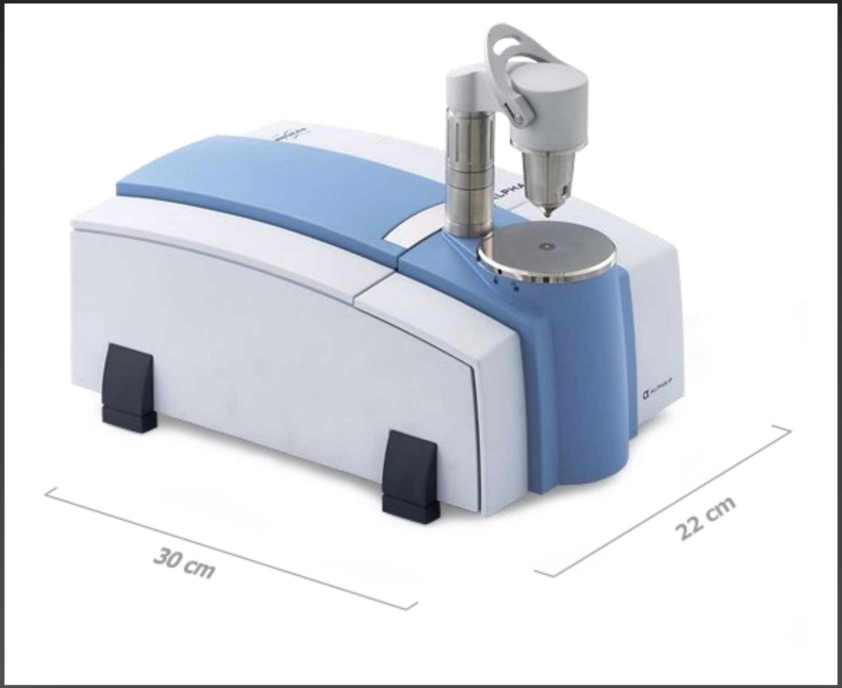
Solutions:

Zero filling – looks nicer, but useless

Pathlength – real information

Size matters

Bruker Alpha



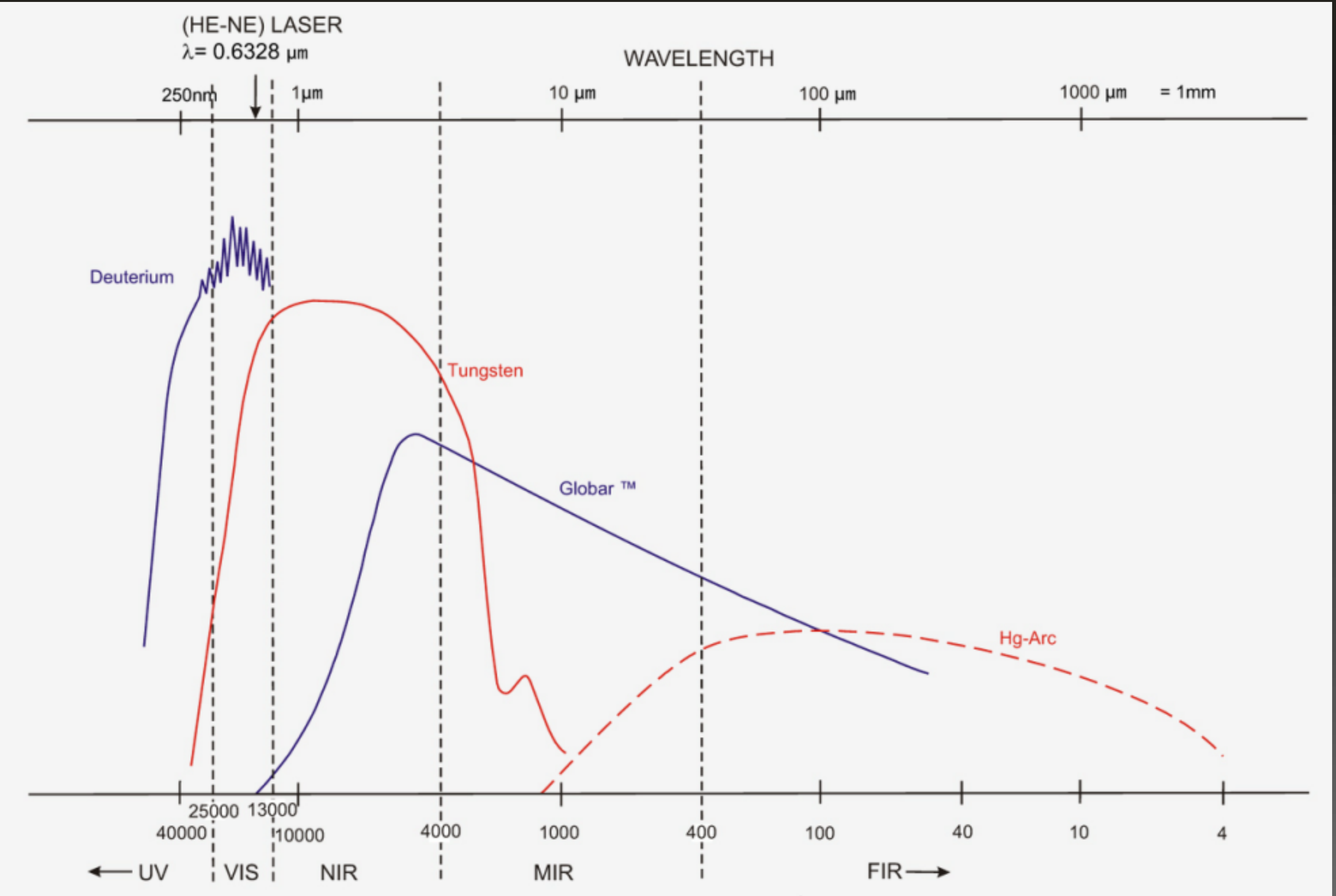
Bruker 125hr

A4 paper size

Moving mirror - meters

http://infrared.als.lbl.gov

Conventional Light Sources



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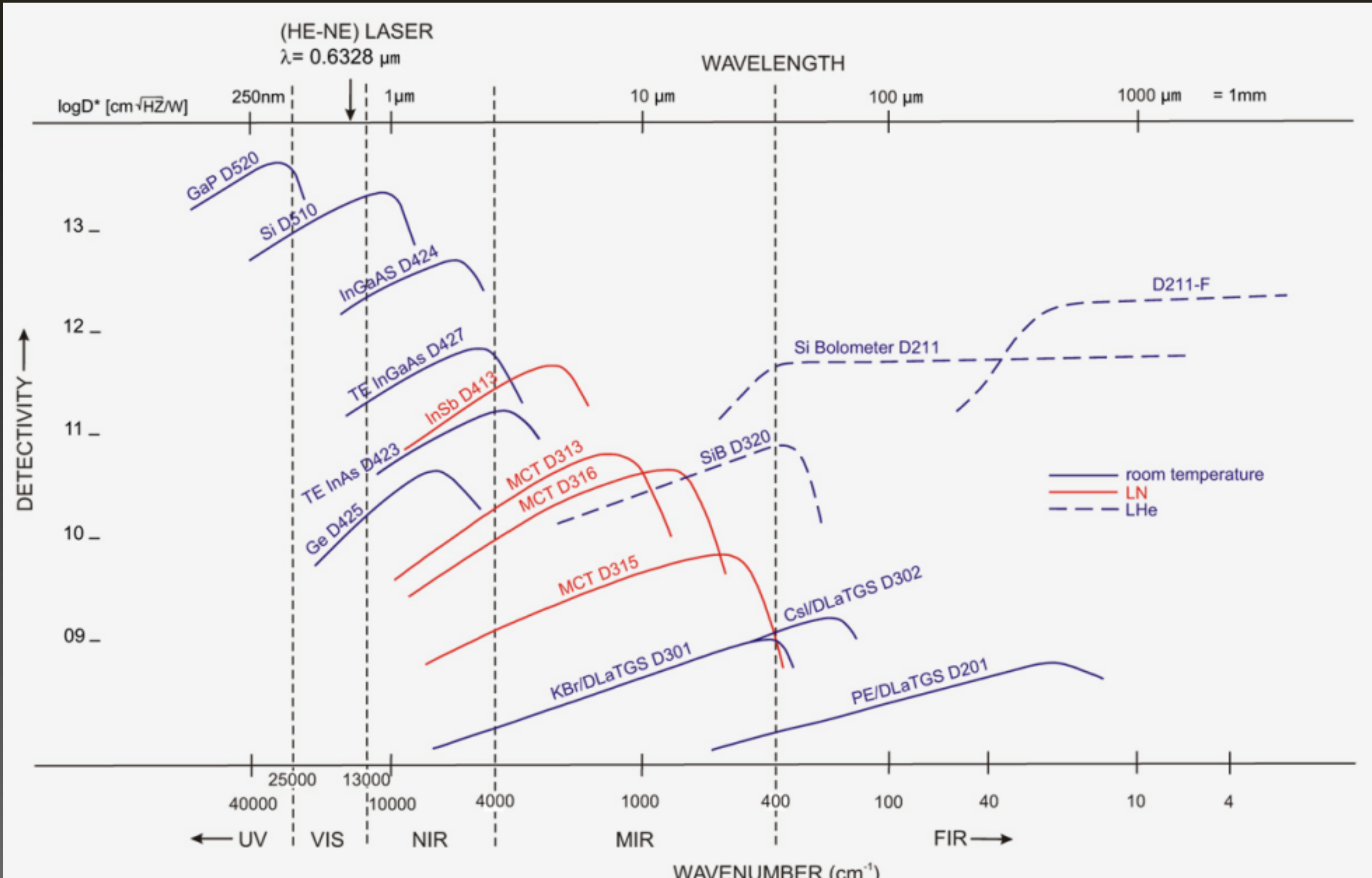
Detectors



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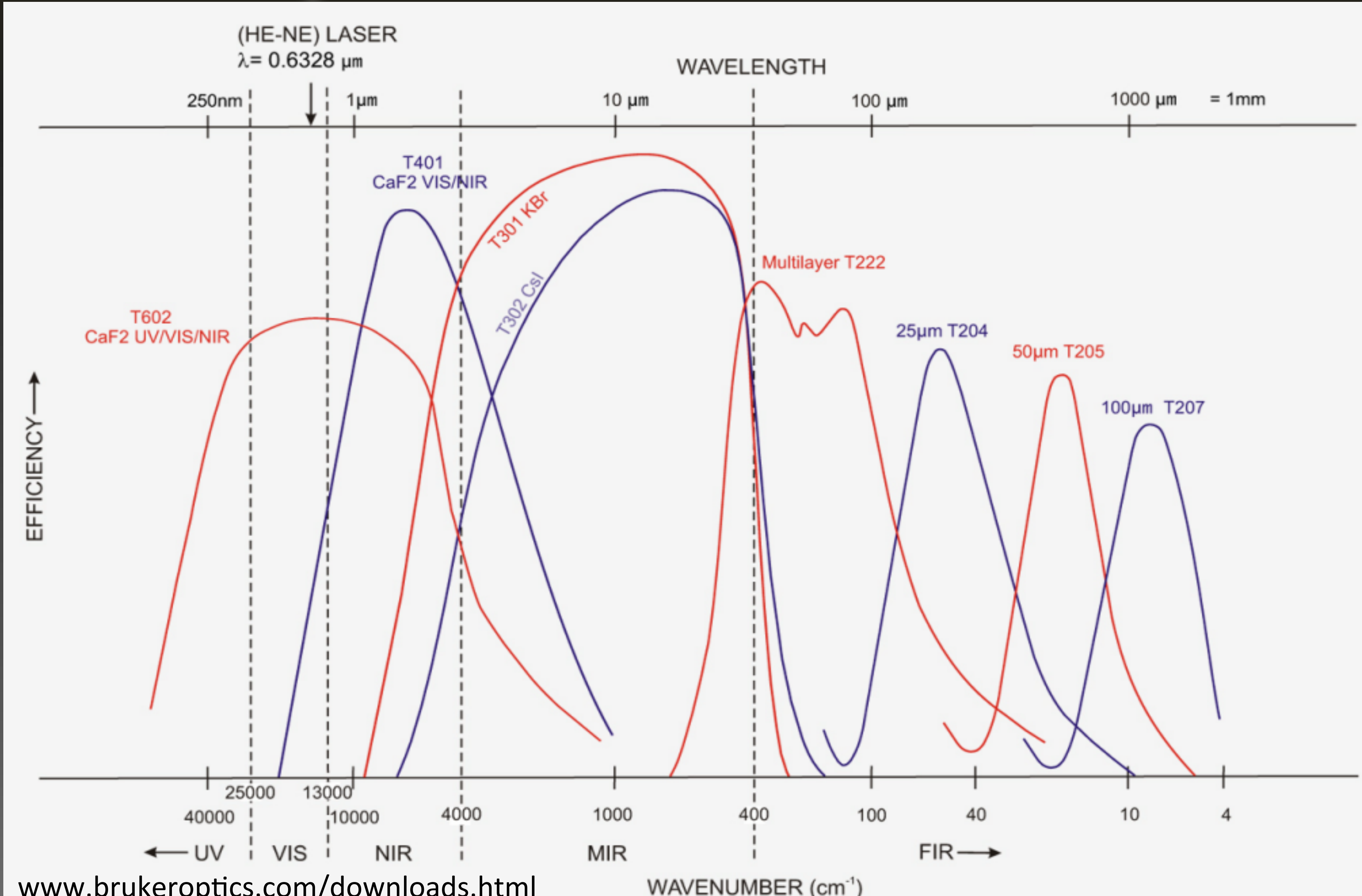
Beamsplitters



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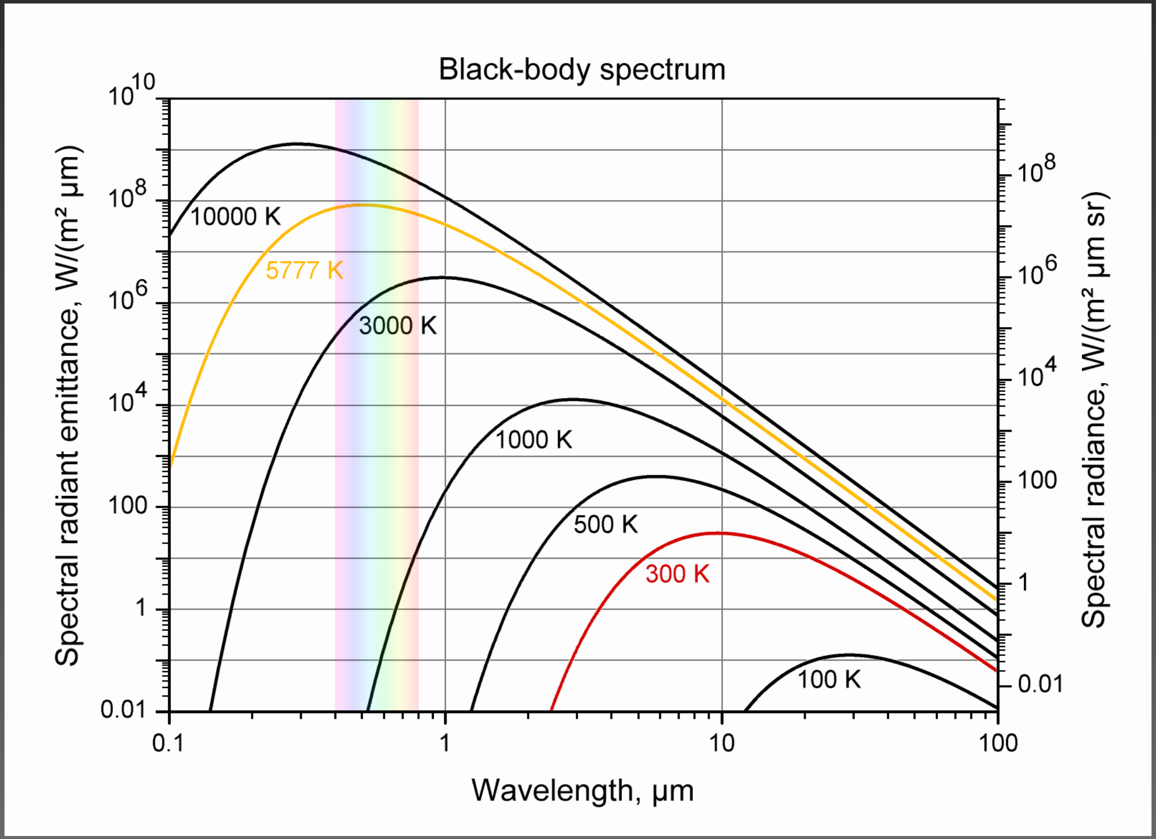
IR Sources
- a comparison -

Producing IR light

Black body radiation

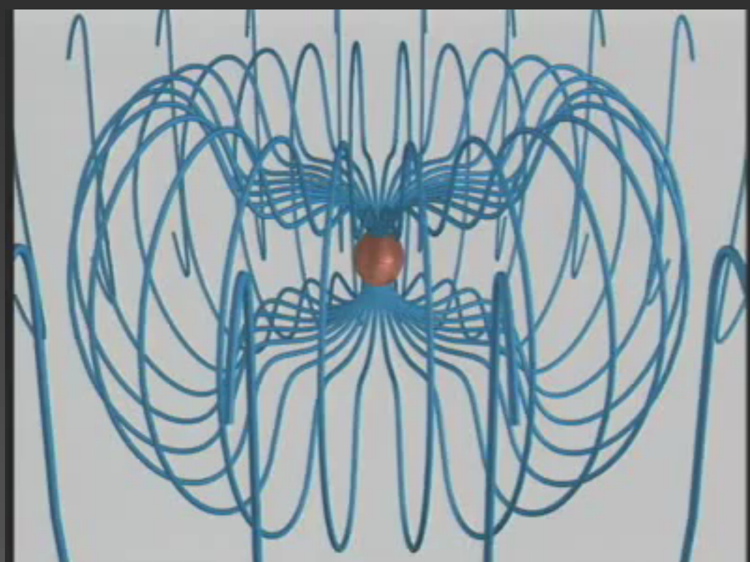
GLOBAR – SiC rod, resistive heating



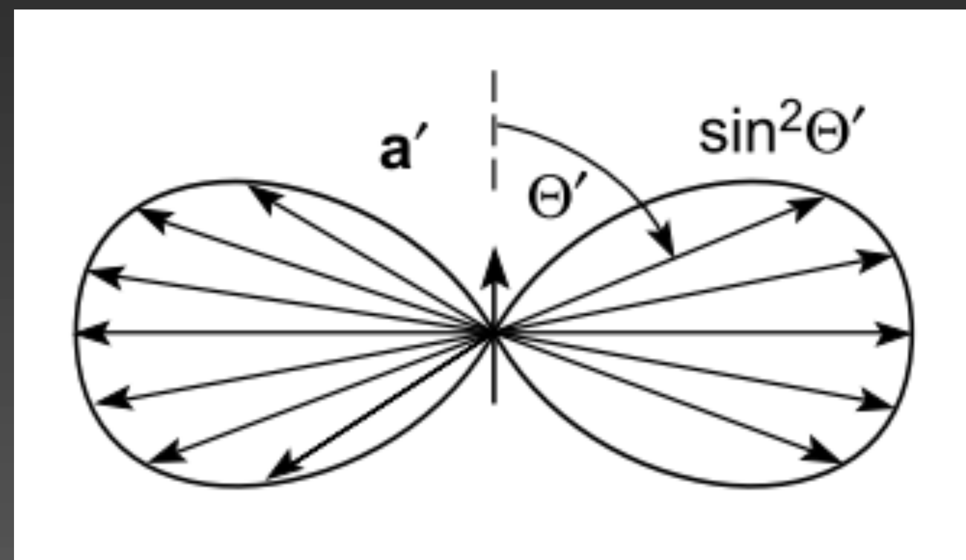
Producing IR light

Using moving charges

Dipole radiation



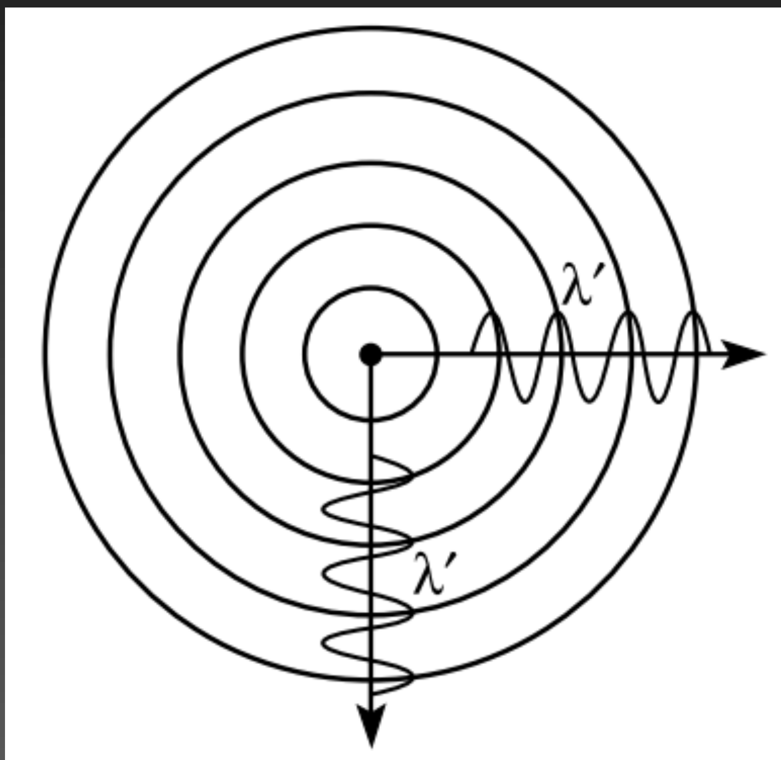
http://ocw.mit.edu



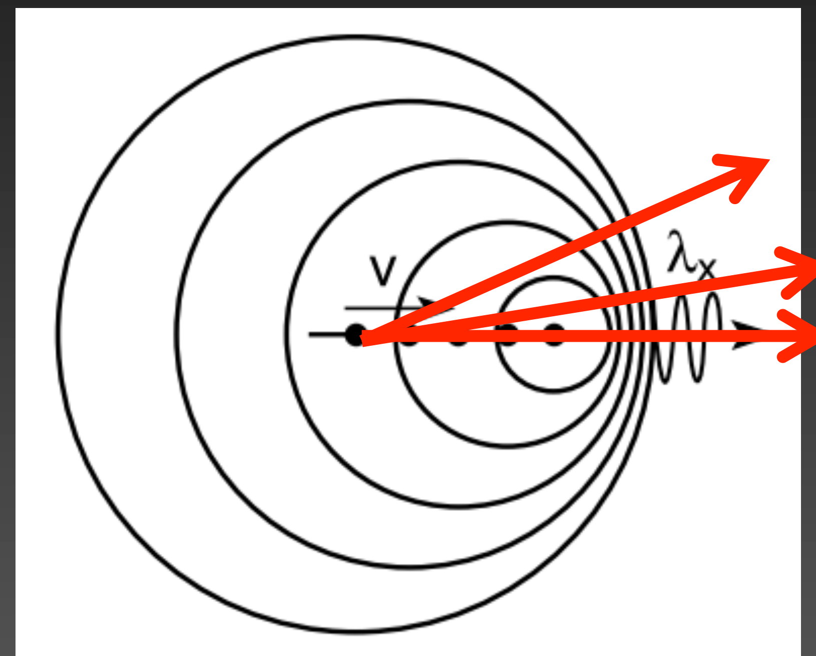
D. Attwood, UC Berkeley, http://ast.coe.berkeley.edu/srms/2007/Intro2007.pdf

Producing IR light

$\nu \ll c$



$\nu \sim c$



$$\lambda' = \lambda'\gamma(1 - \frac{\nu}{c}cos\theta)$$

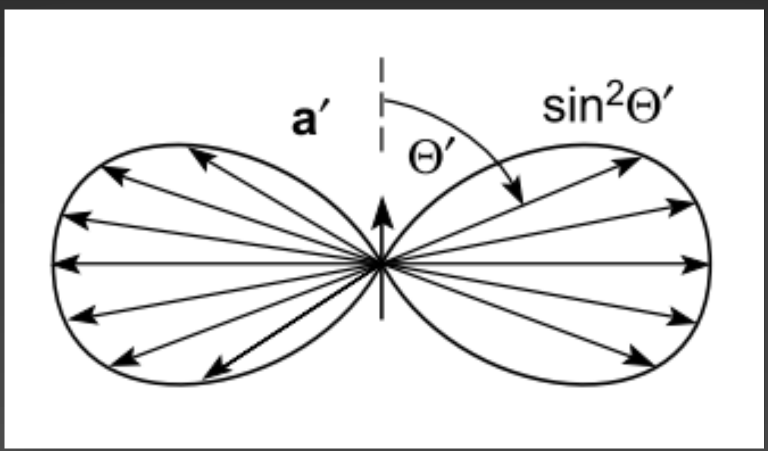
$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

D. Attwood, UC Berkeley, http://ast.coe.berkeley.edu/srms/2007/Intro2007.pdf

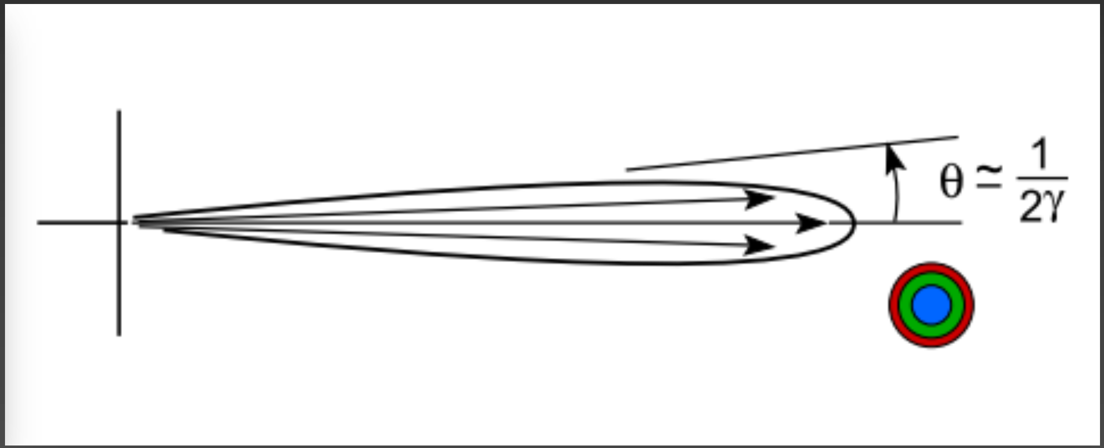
Producing IR light

$\nu \sim c$

Moving frame of reference



Laboratory frame of reference

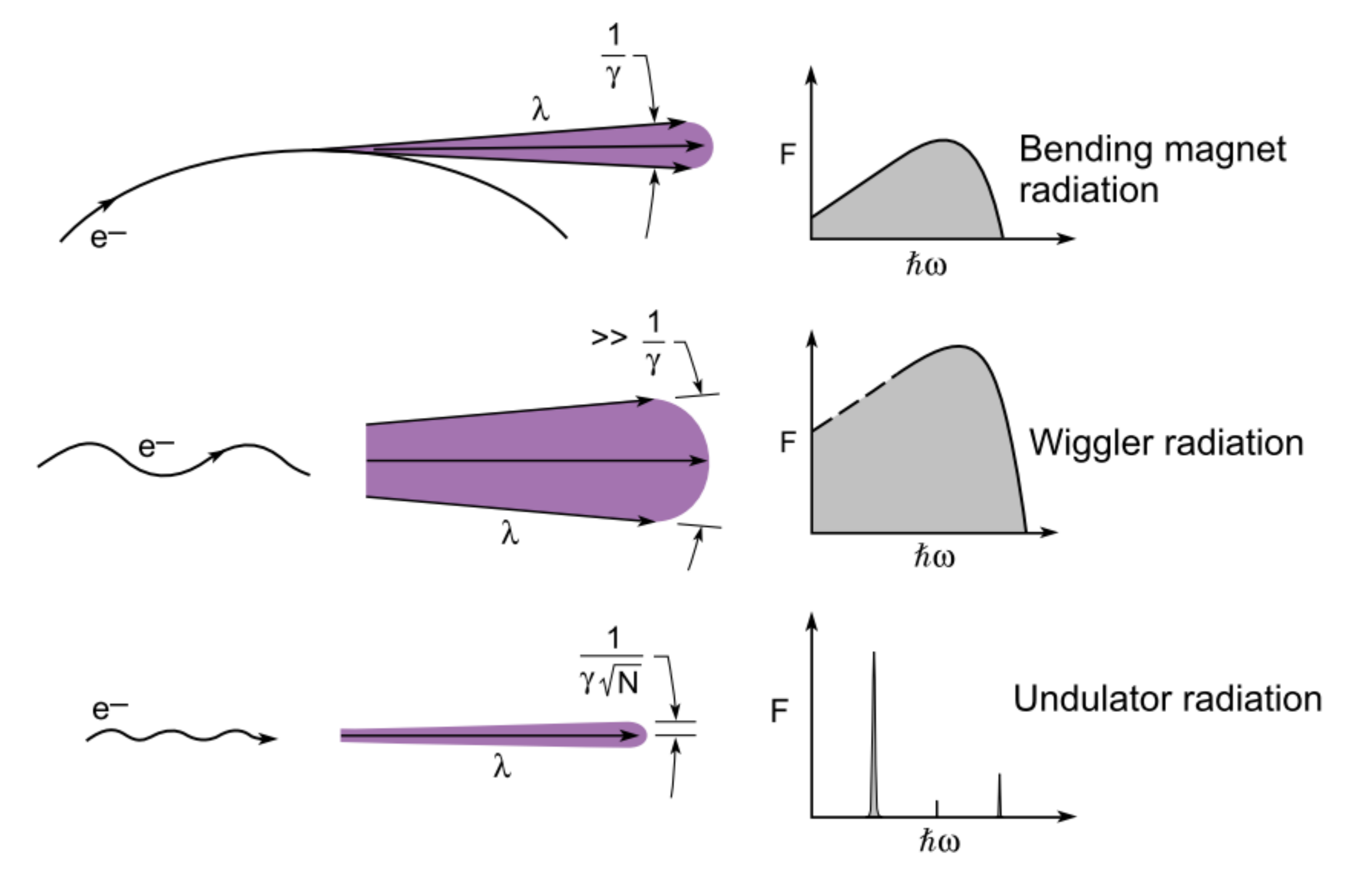


Synchrotron radiation

D. Attwood, UC Berkeley, http://ast.coe.berkeley.edu/srms/2007/Intro2007.pdf

Insertion devices

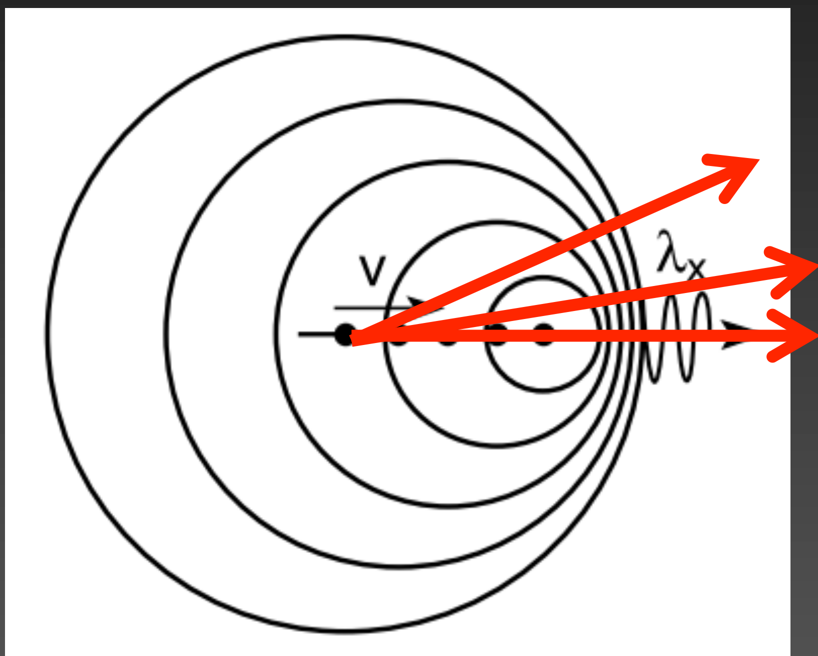
Radiation2D

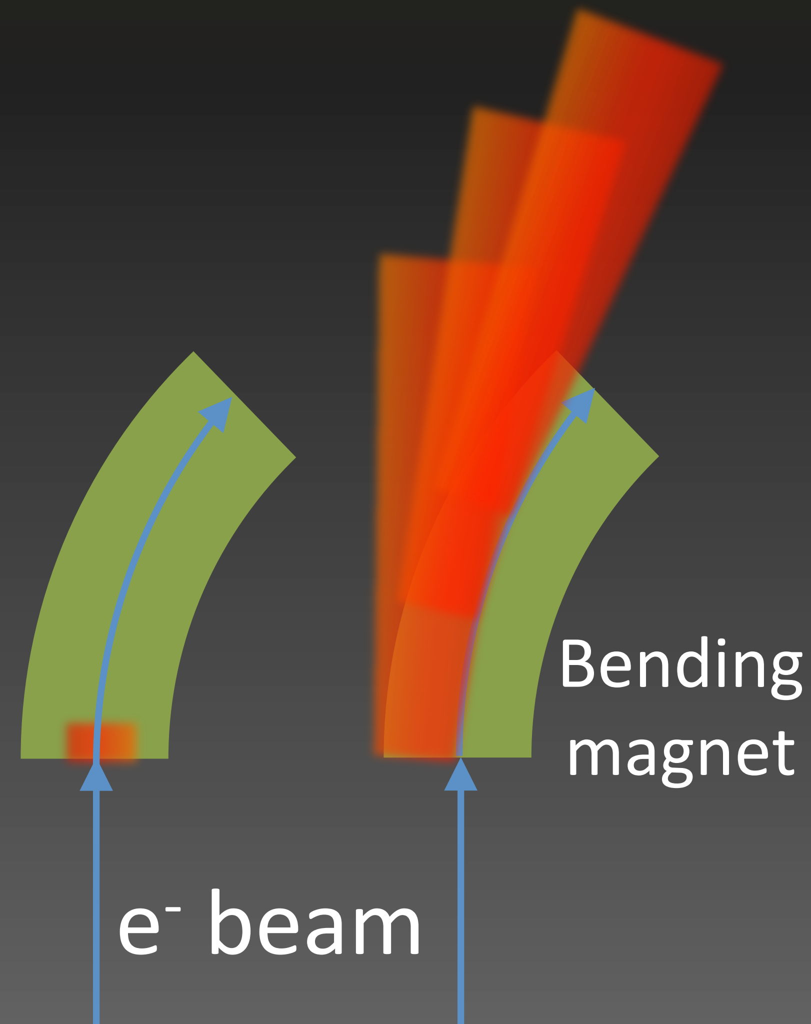


D. Attwood, UC Berkeley, http://ast.coe.berkeley.edu/srms/2007/Intro2007.pdf

Producing IR light

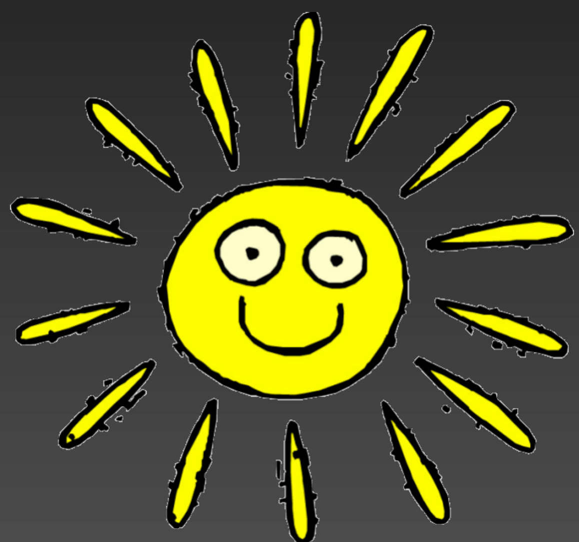
Bending magnet radiation



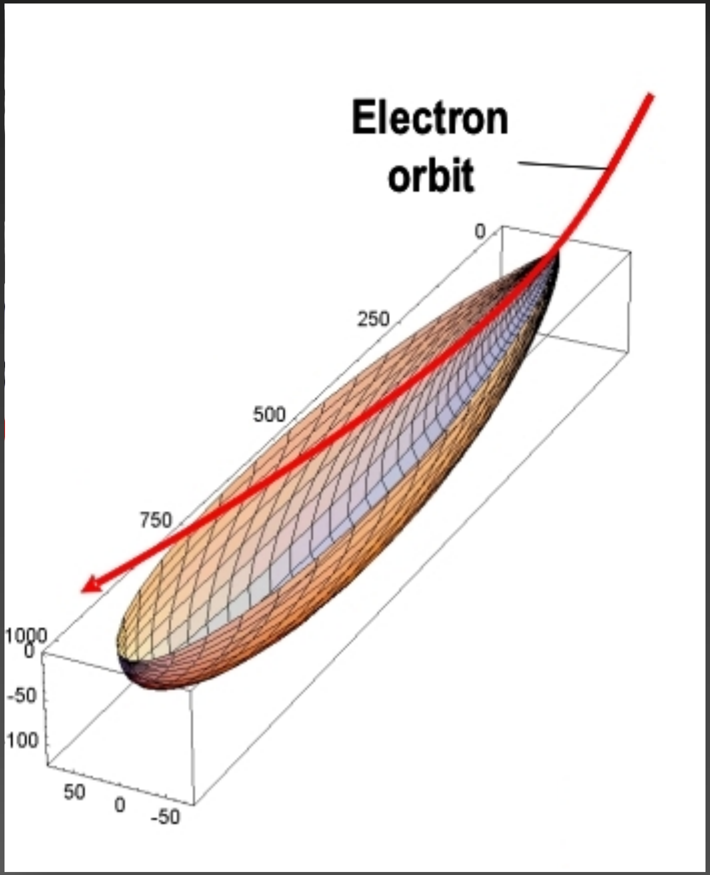


Problem: source size, focusing

Which one is better?

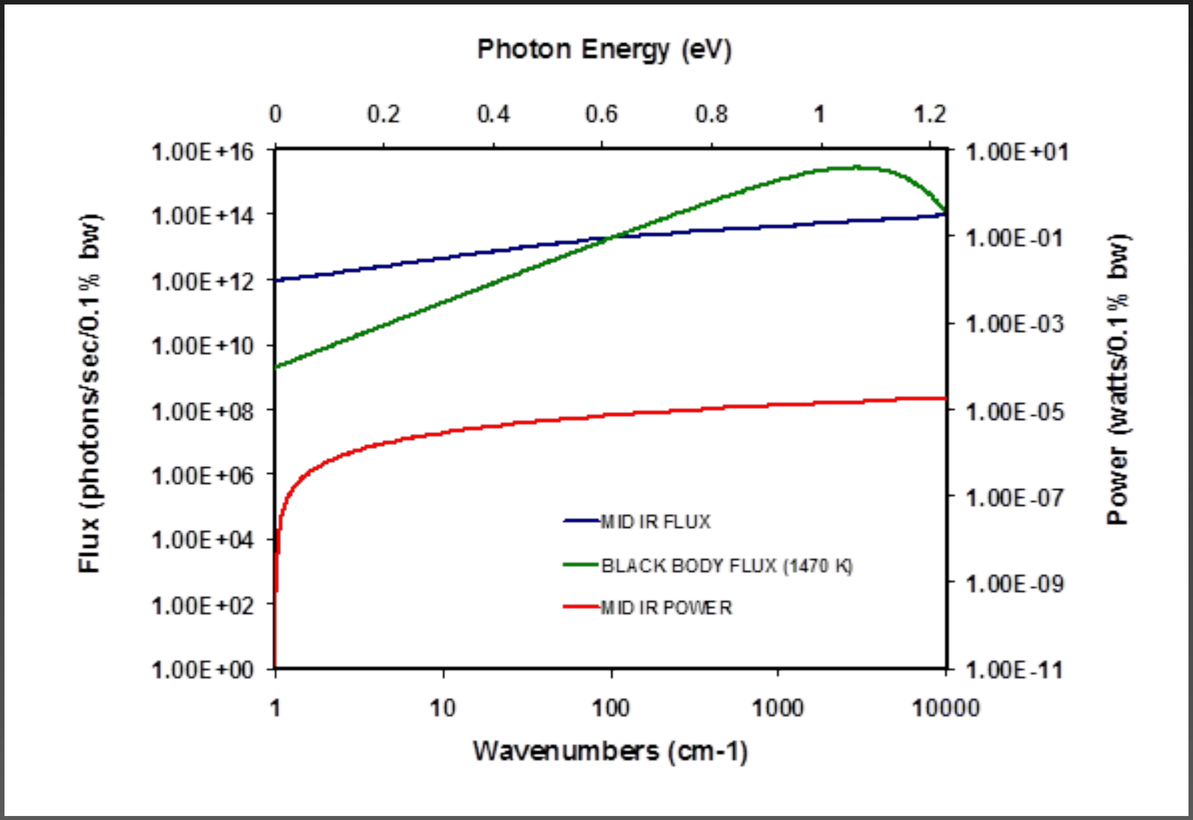


Globar



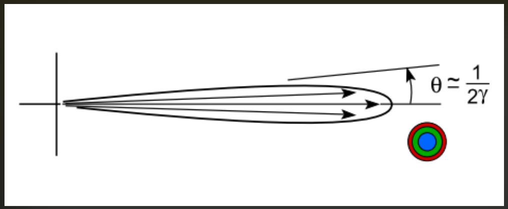
SR

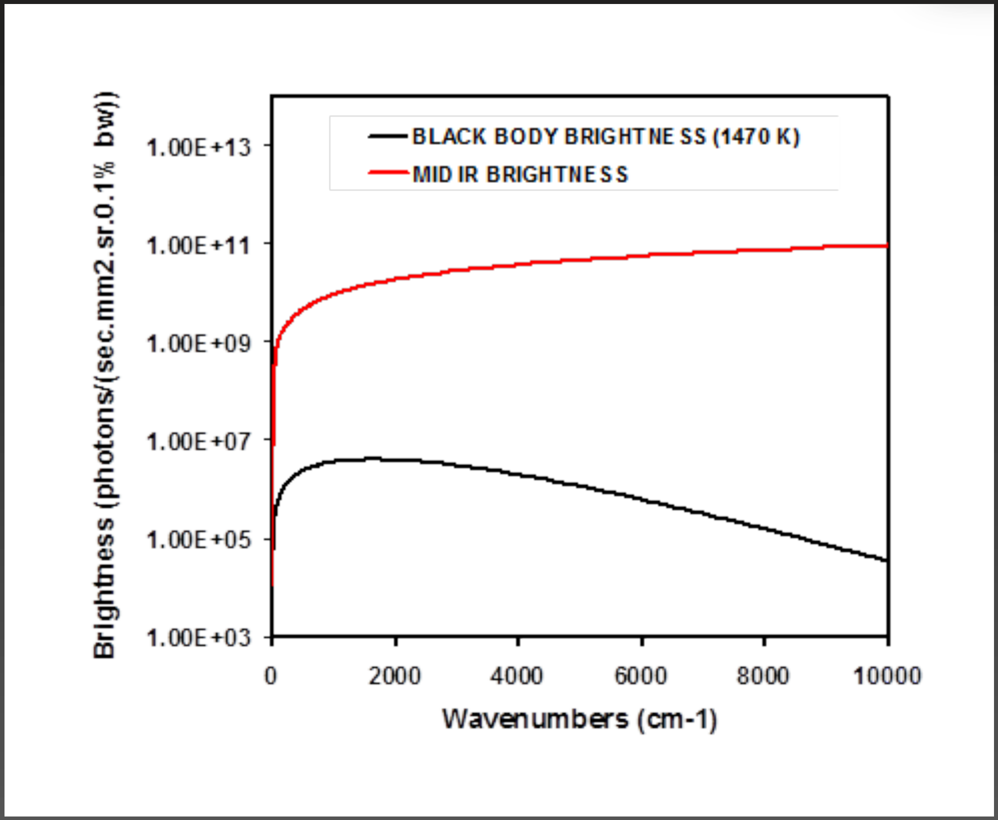
Globar wins



Total flux
(CLS)

Synchrotron wins

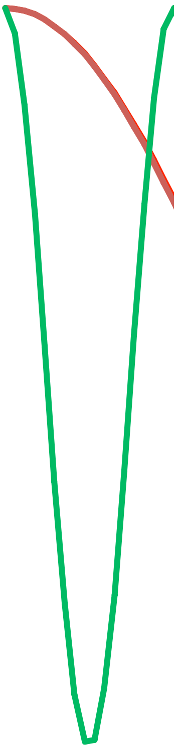




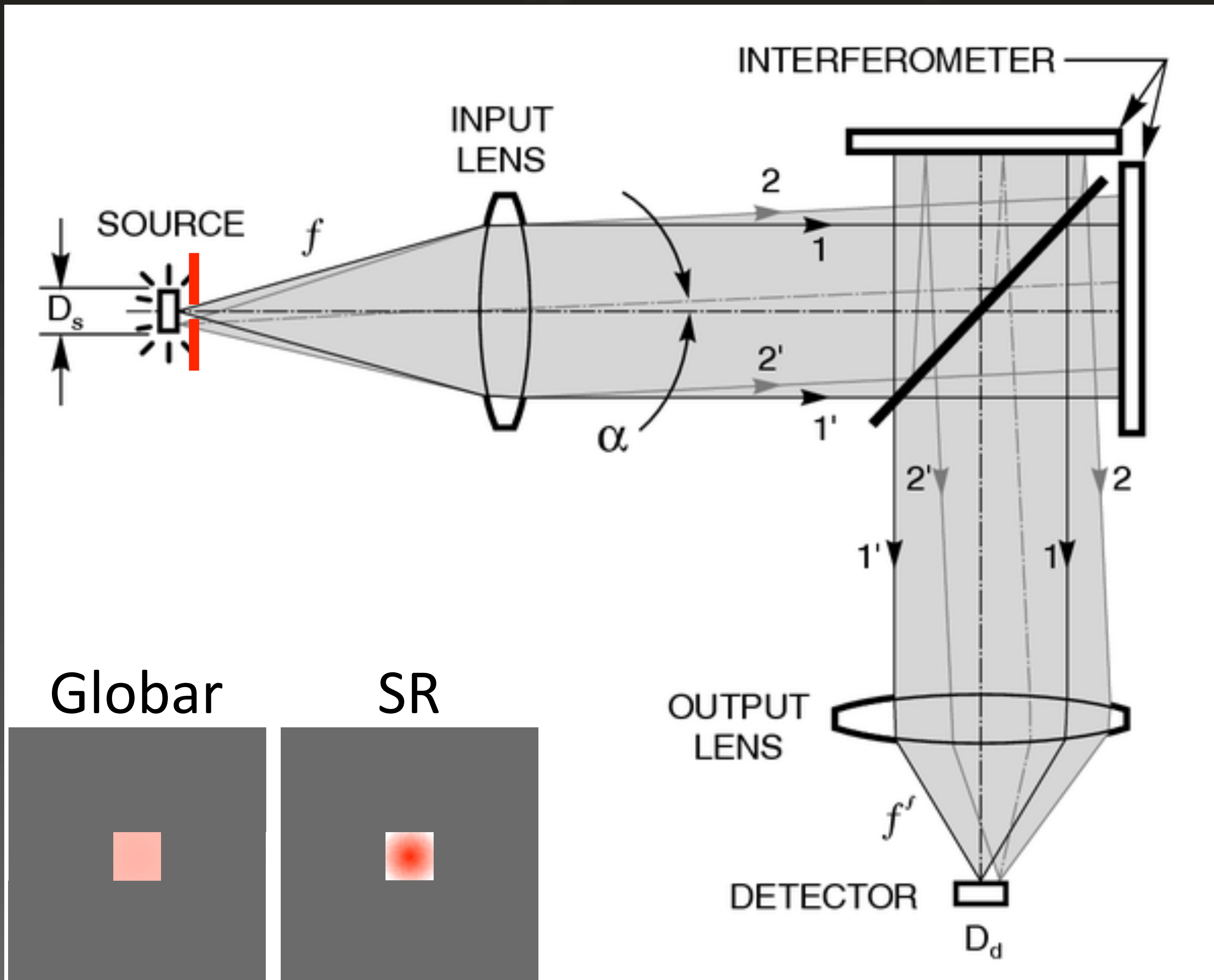
Brightness
(CLS)

High-resolution spectroscopy

Pathlength and resolution

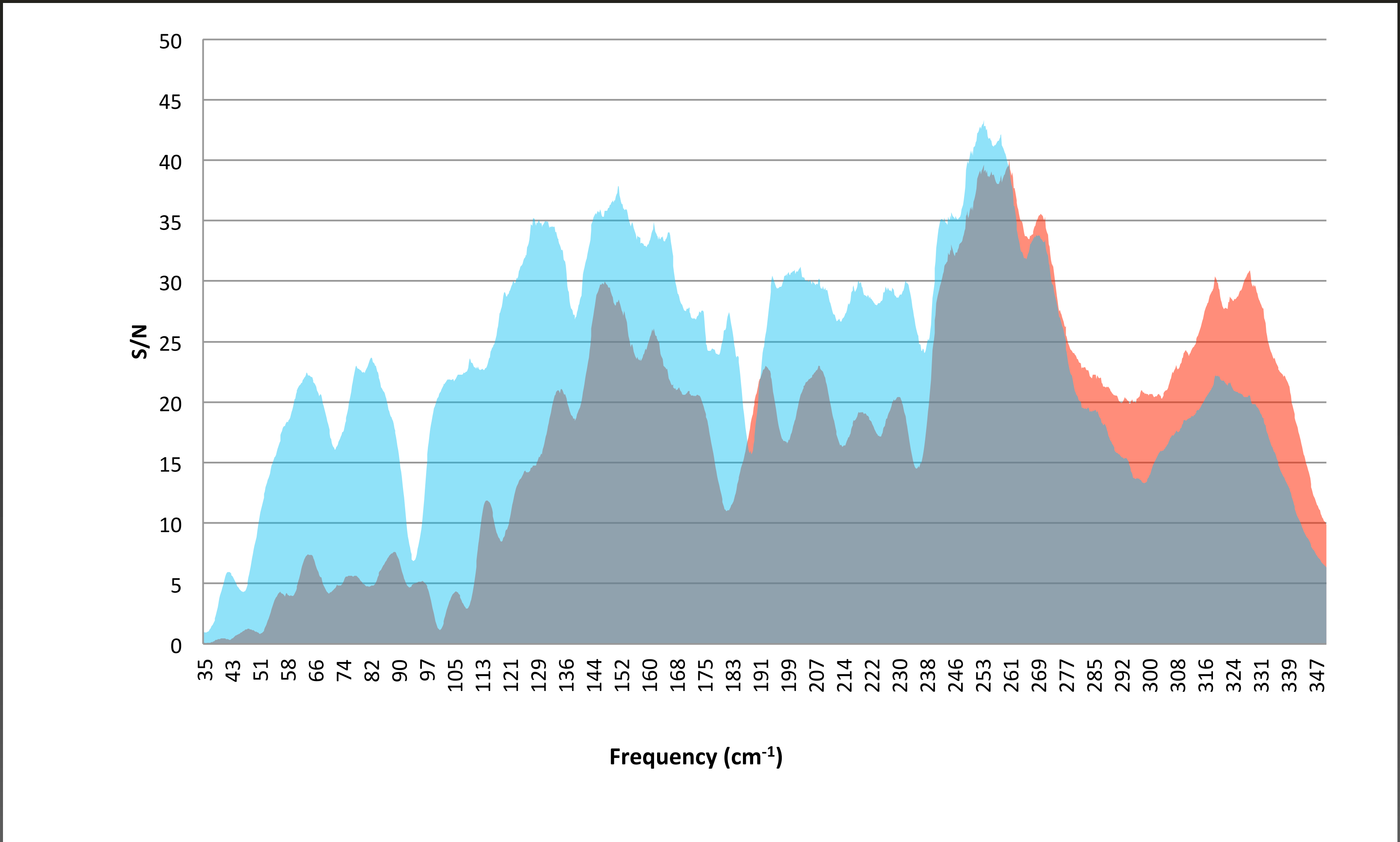


Source size (pinhole)



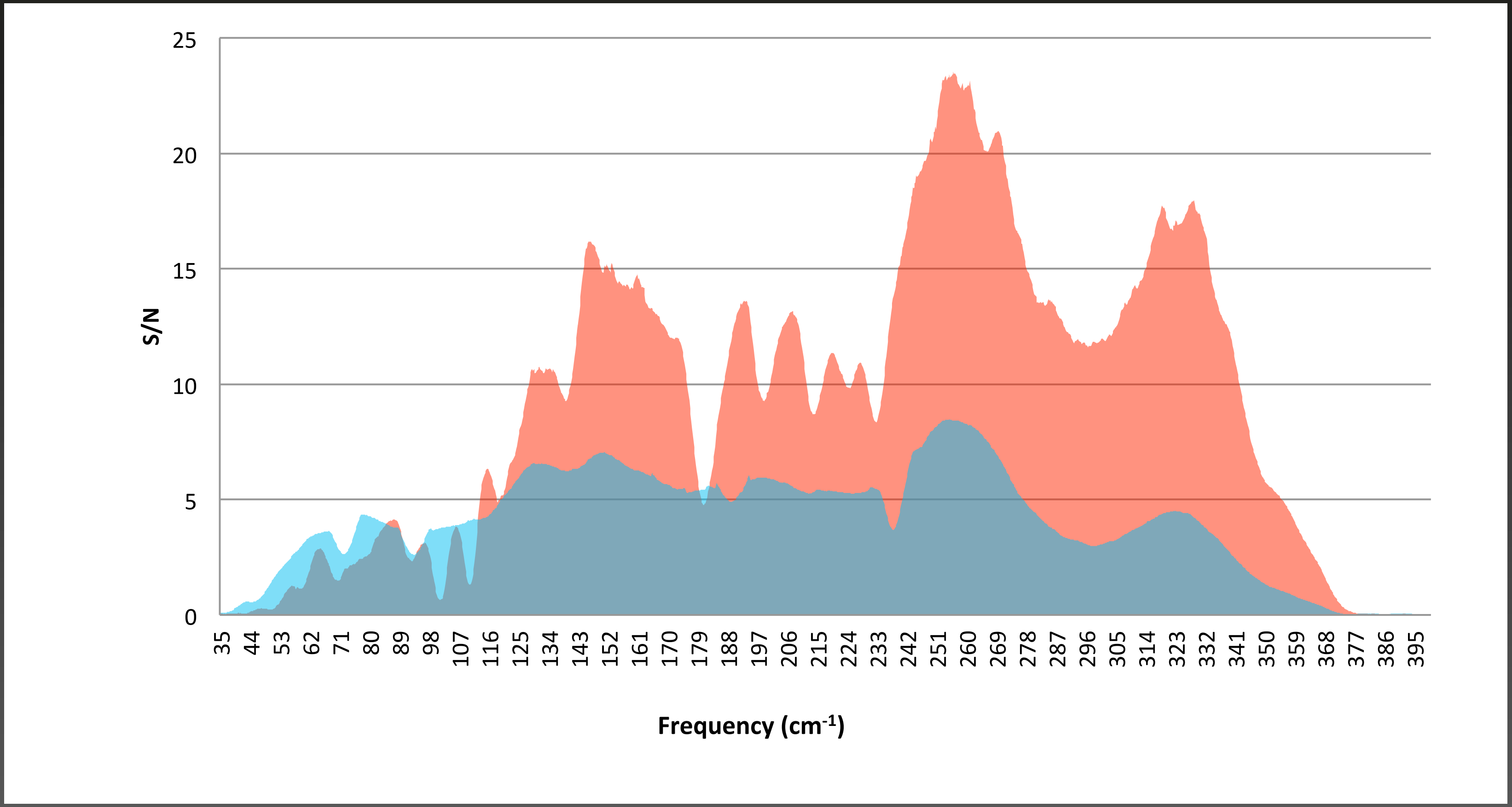
http://www.newport.com/images/web600w-EN/images/2407.gif

SR advantage – low res?



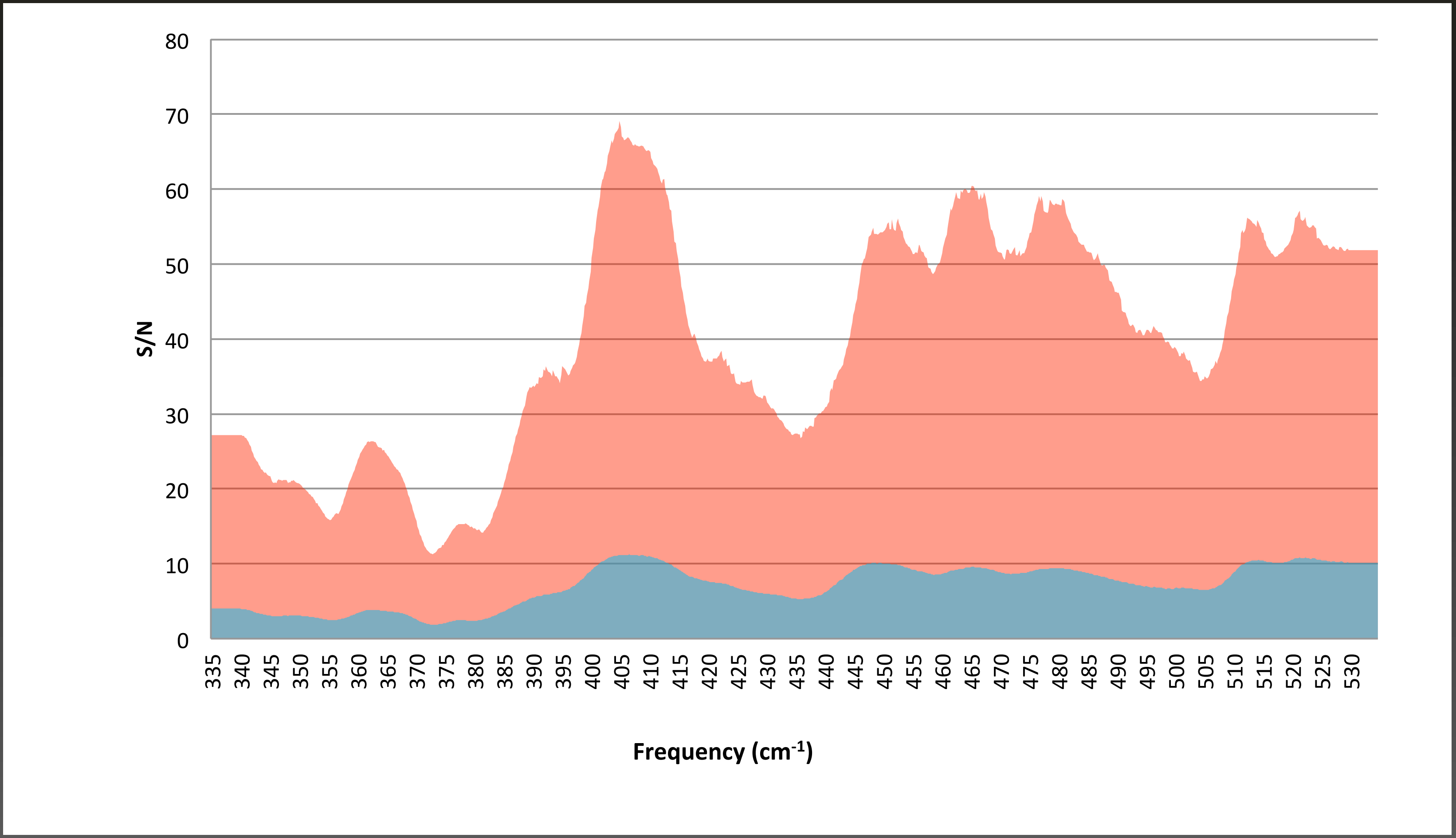
35-350 cm^{-1} | Resolution: 0.002 cm^{-1} | <u>Aperture: 3.15 mm</u> | Velocity: 30 KHz / 5KHz

SR advantage



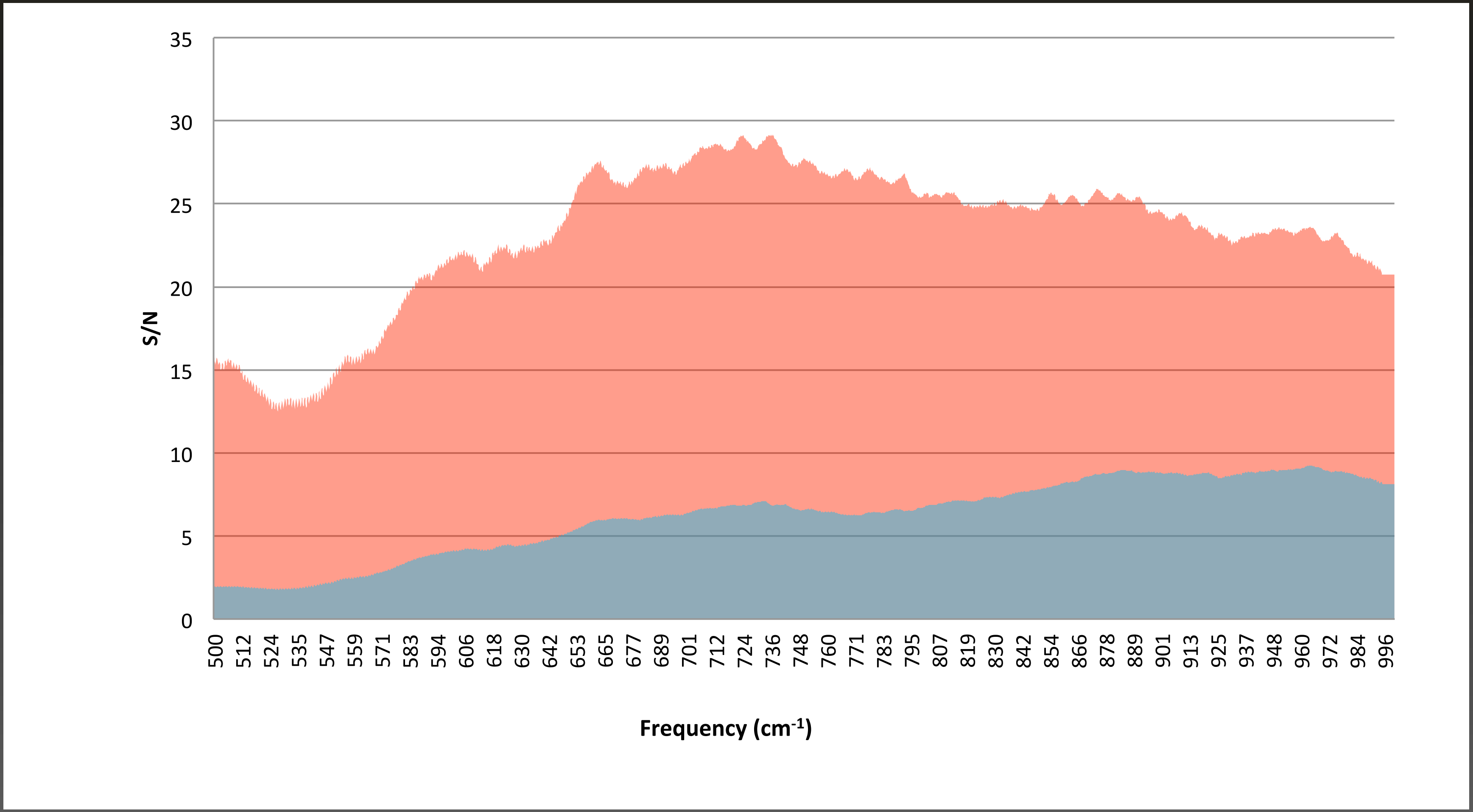
35-350 cm^{-1} | Resolution: 0.00096 cm^{-1} | Aperture: 2 mm | Velocity: 30 KHz / 5KHz

SR advantage



335-535 cm^{-1} | Resolution: 0.001 cm^{-1} | Aperture: 1.5 mm | Velocity: 40 KHz

SR advantage



500-1000 cm^{-1} | Resolution: 0.001 cm^{-1} | Aperture: 1.15 mm | Velocity: 40 KHz

Applications

High resolution FTIR on gases

- Important for Astronomy

  (interstellar gases, small molecules)

- Atmospheric sciences

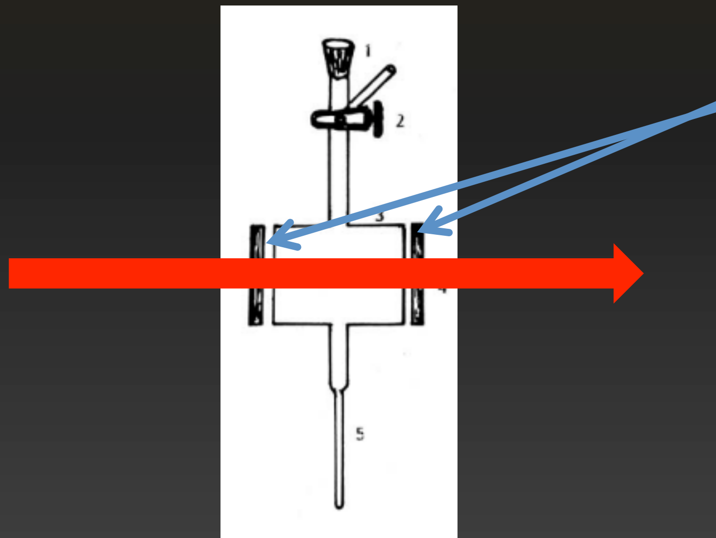
  (ozone, pollution, radicals)

- Basic physical chemistry

  (molecular dynamics, radicals, etc…)

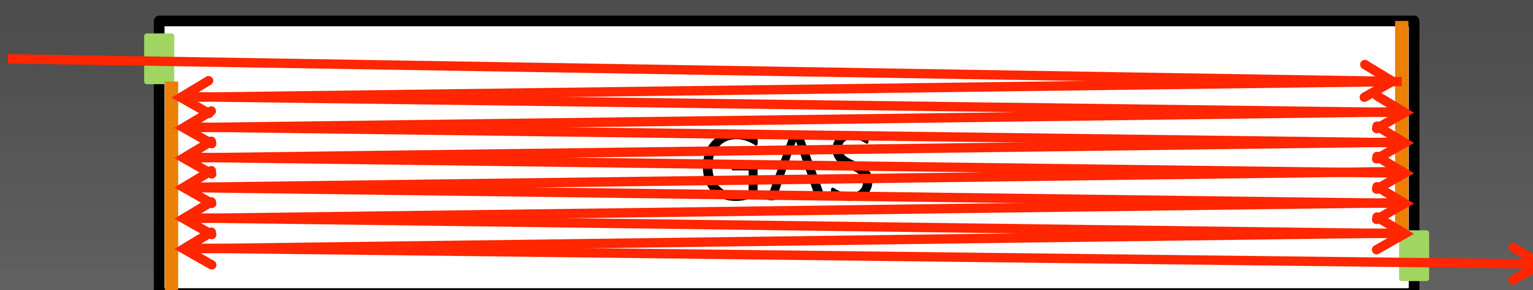
Sample preparation

Gases



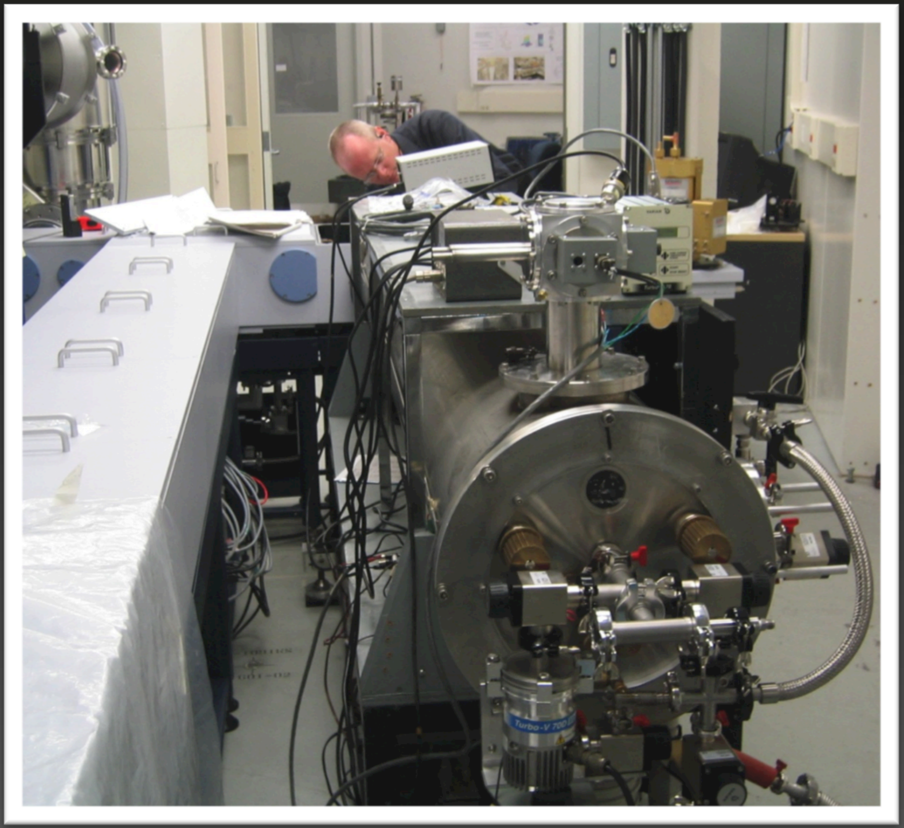
IR transparent windows

Multi-pass cells



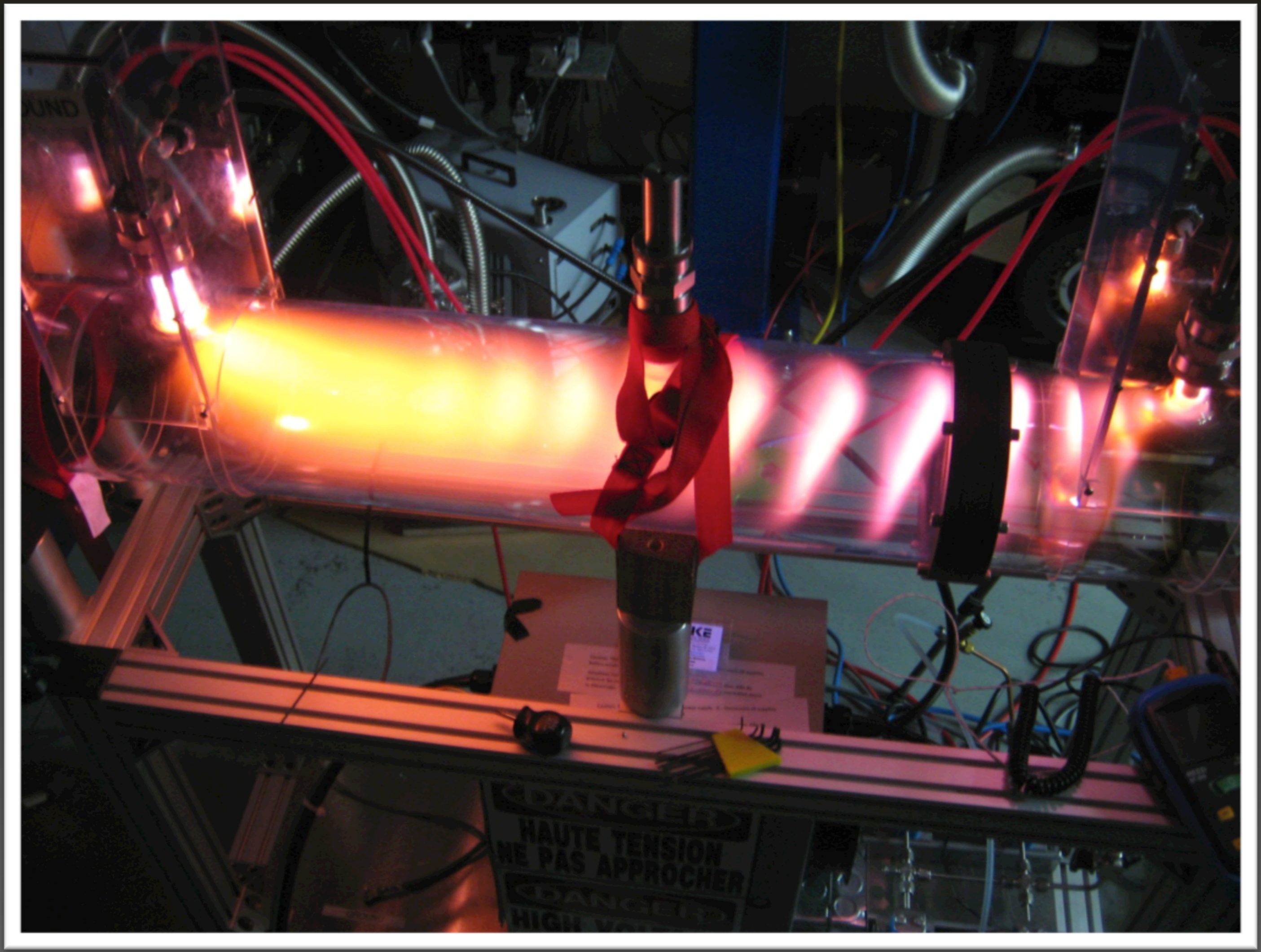
Gas cells

- 30 cm White Cell
- Ambient Temperature
- Paths up to 12 m



- 2 m White Cell
- Coolable (down to -80 °C)
- Paths up to 80 m

Gas cells (discharge)



- 1 m White Cell
- Adjustable Power
- 4 m Path

The CLS high resolution IR BL

Bruker IFS 125 HR
Maximum Resolution: 0.00096 cm^{-1} ~0.1 μeV

Beamsplitter	Spectral Range
Mylar 6 μm	30-630 cm^{-1}
Mylar 75 μm	12-35 cm^{-1}
Ge/KBr	400-4800 cm^{-1}
CaF_2	1850-20000 cm^{-1}
Detectors	
MCT N	600-10000 cm^{-1}
MCT B	450-10000 cm^{-1}
DTGS	100-3000 cm^{-1}
DTGS PE	15-700 cm^{-1}
Si Bolometer	10-370 cm^{-1}
Ge:Cu	300-1850 cm^{-1}
Internal Sources	
Globar	10 – 13000 cm^{-1}
Hg – Lamp	10 – 1000 cm^{-1}
Tungsten Lamp	1000-25000 cm^{-1}

More information

The CLS Far IR website: http://goo.gl/idUP

Brant Billinghurst

Tim May

Microscopy

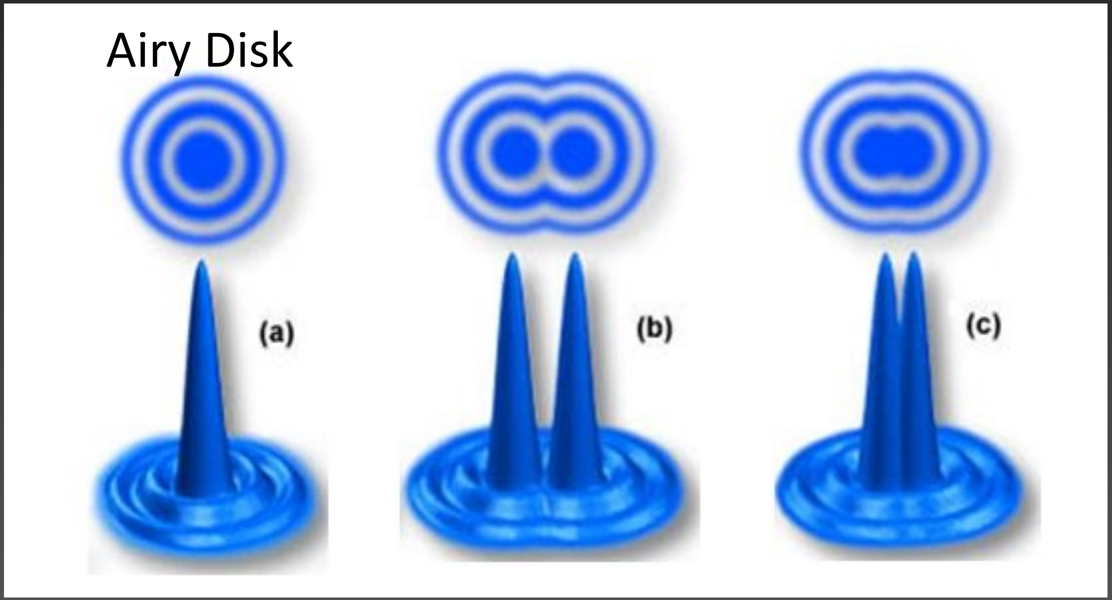
- microspectroscopy or spectromicroscopy -

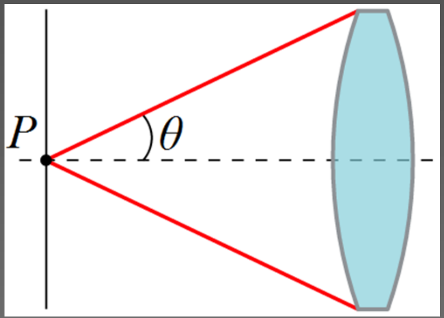
Theoretical optical resolution

Rayleigh's Resolution Limit
(Diffraction Limit)

$d = \lambda / 2NA$

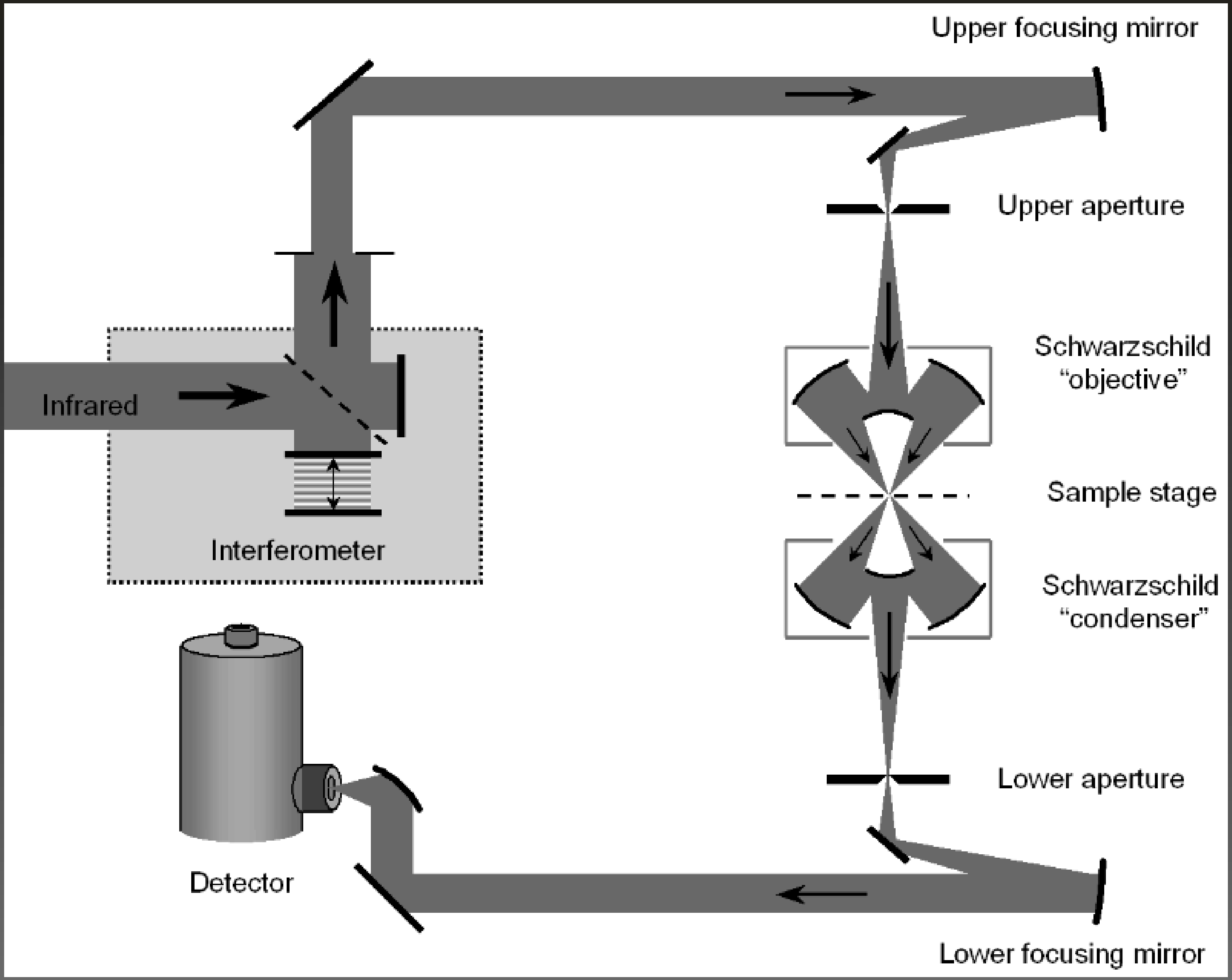
Intensity Distribution at the Focal Point



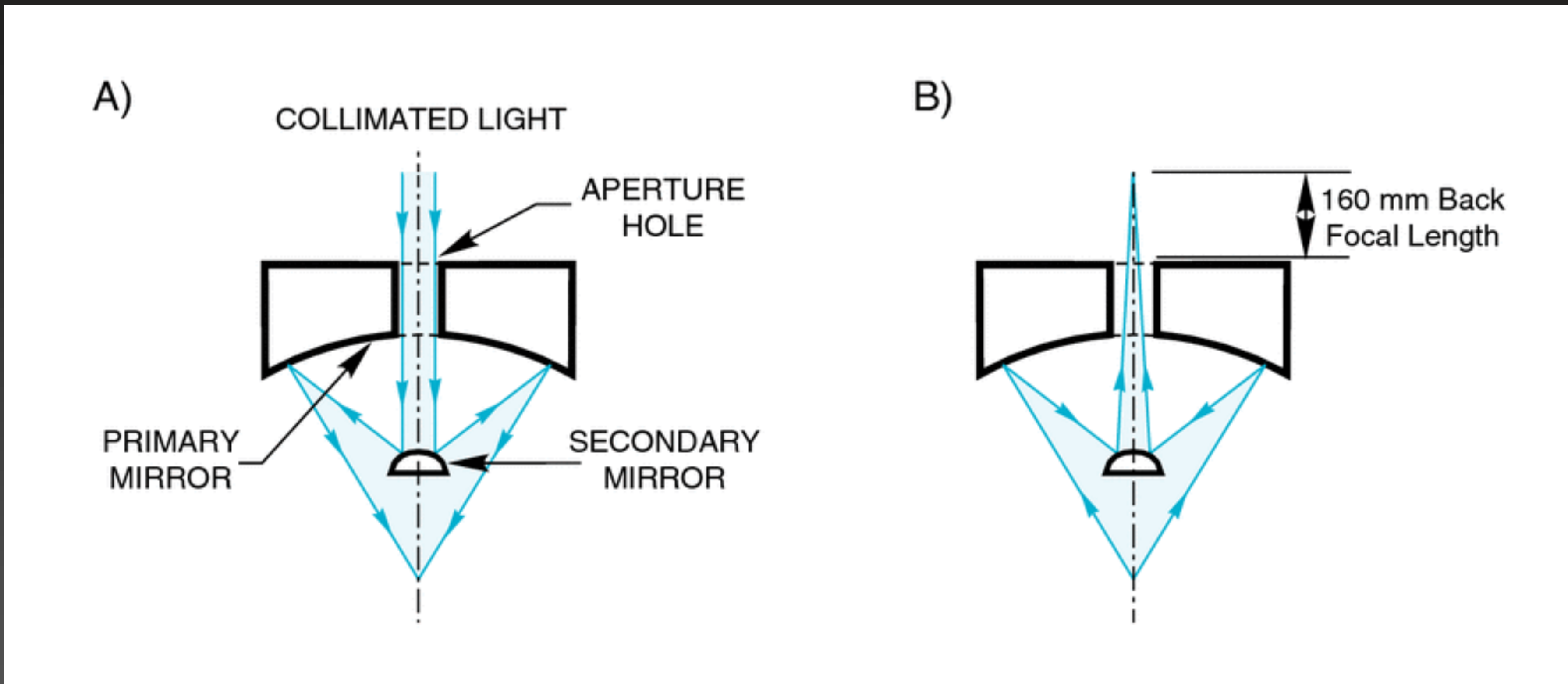


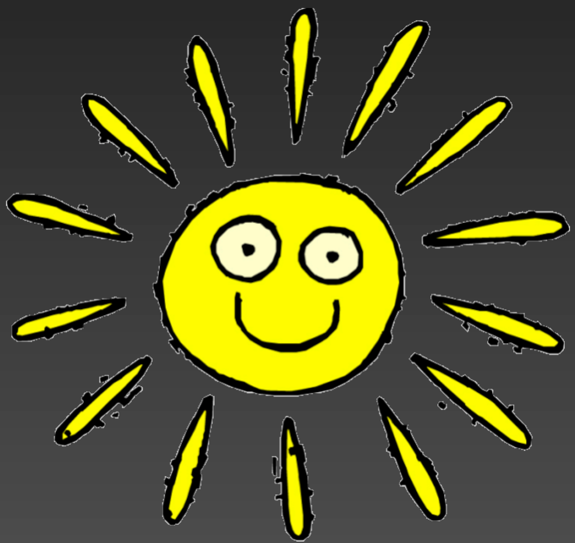
$$NA = n sin(\theta)$$

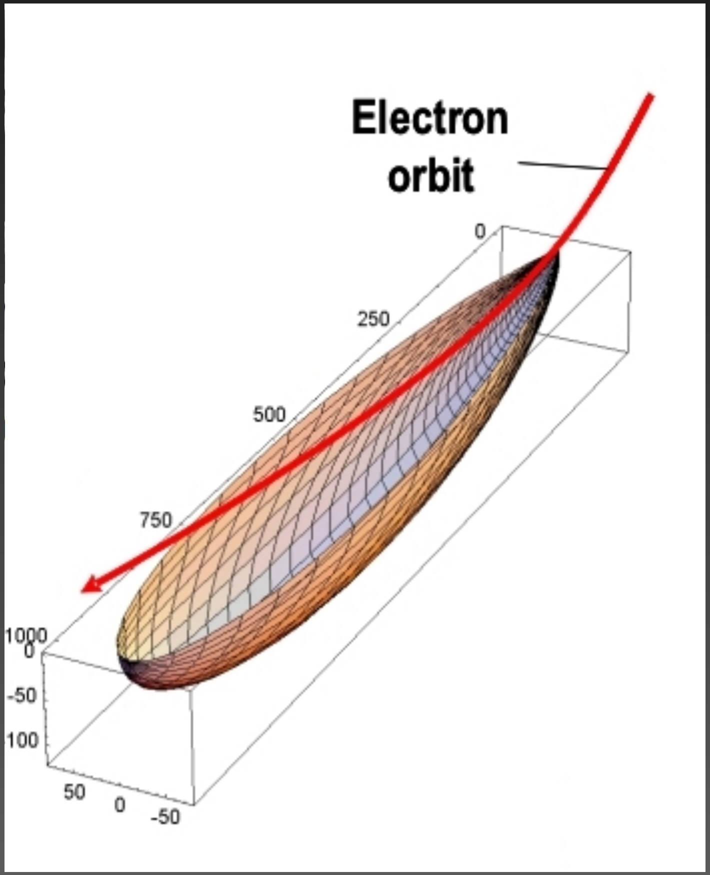
General Layout



The Schwarzschild objective



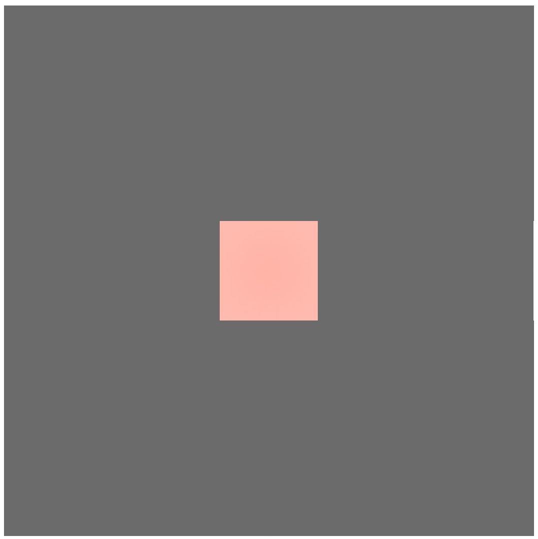




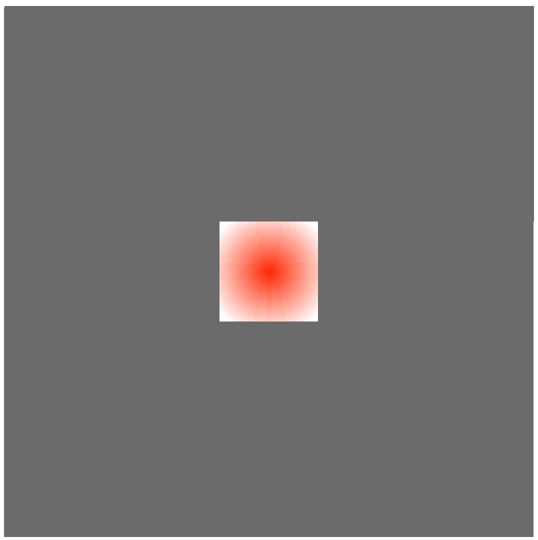
Globar

SR

Why use a synchrotron?

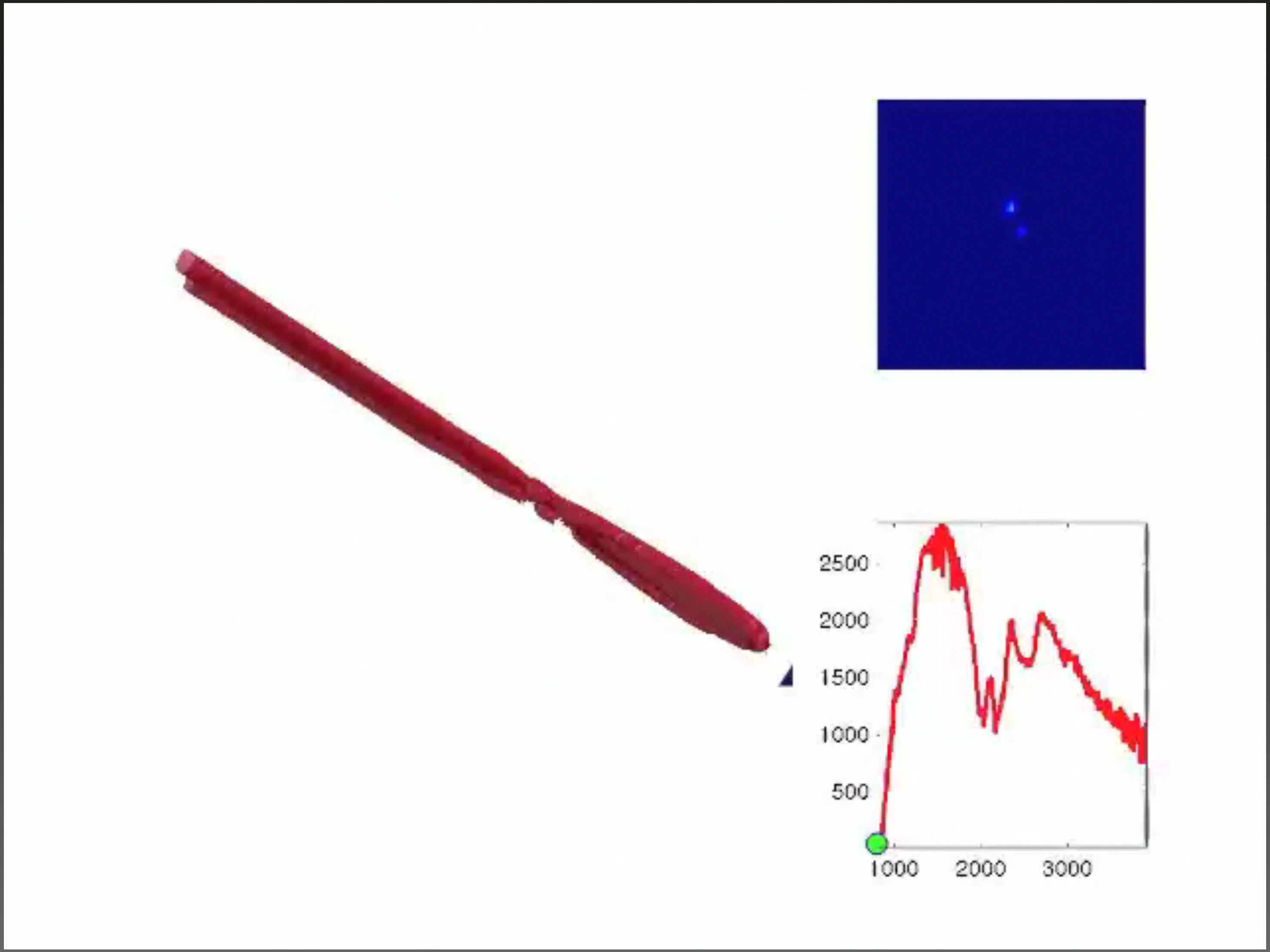


Globar Light Spot in Plane of Confocal Aperture

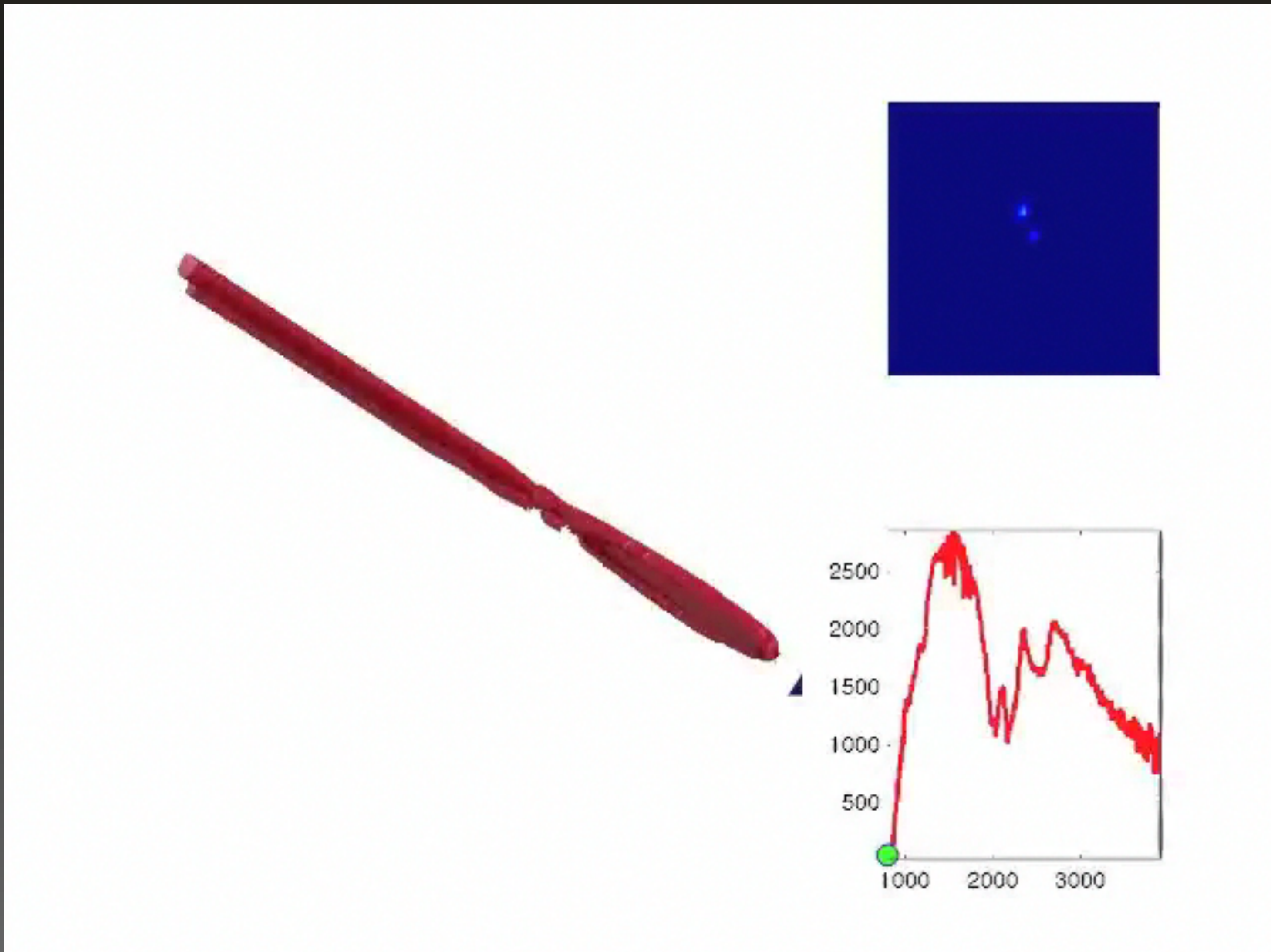


Synchrotron Light Spot in Plane of Confocal Aperture

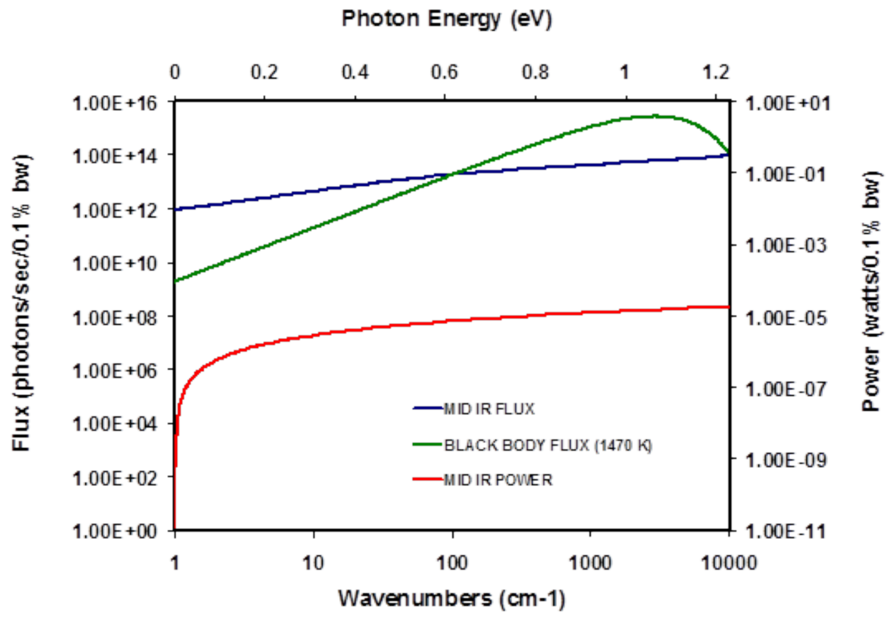
Beam spot in the CLS

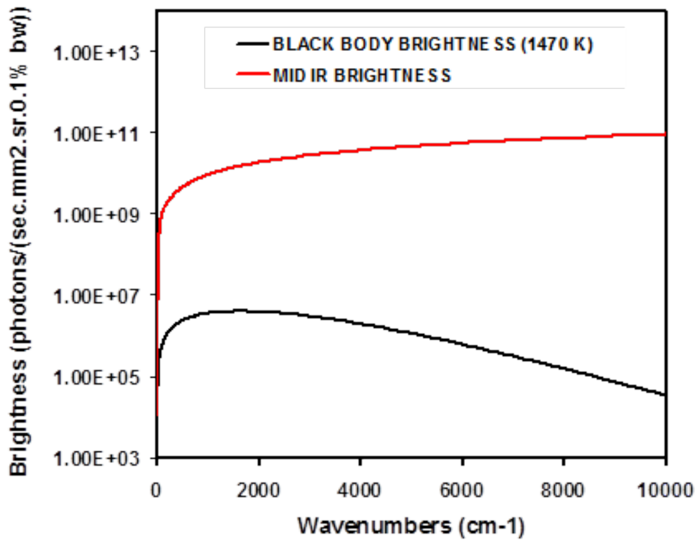


Beam spot in the CLS



Globar vs. Synchrotron





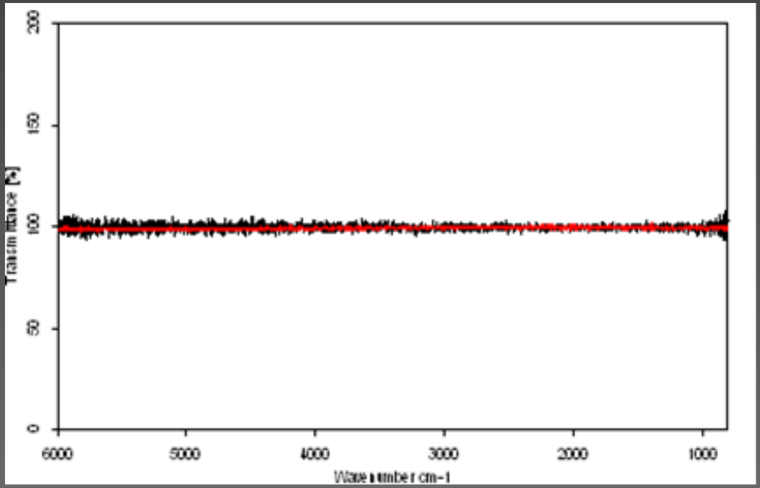
Globar vs. synchrotron

2x2 μm pinhole

5x5 μm pinhole

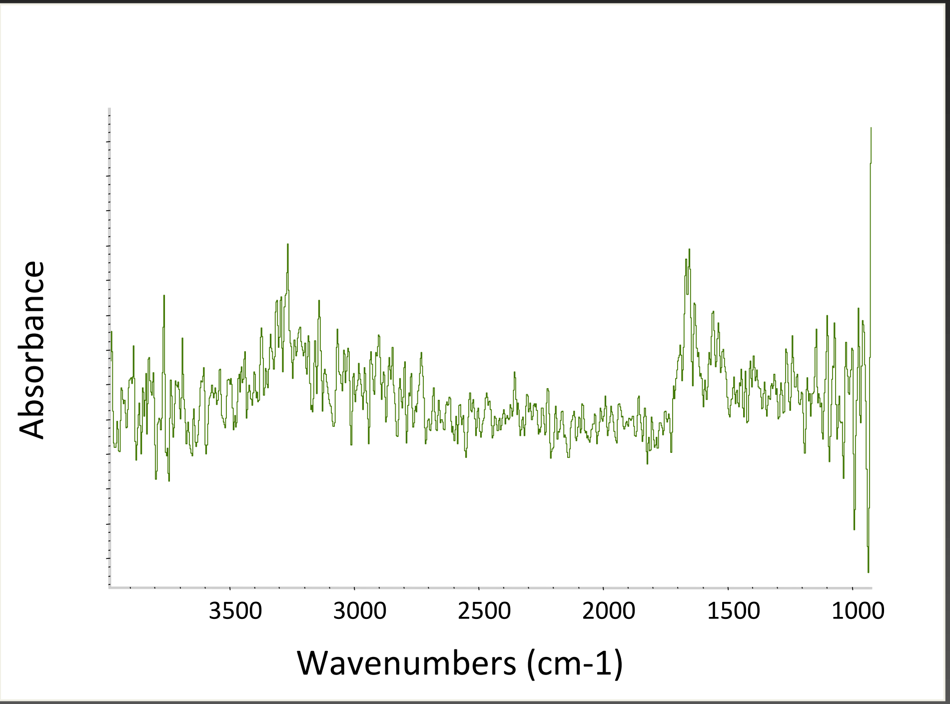
3x3 μm pinhole

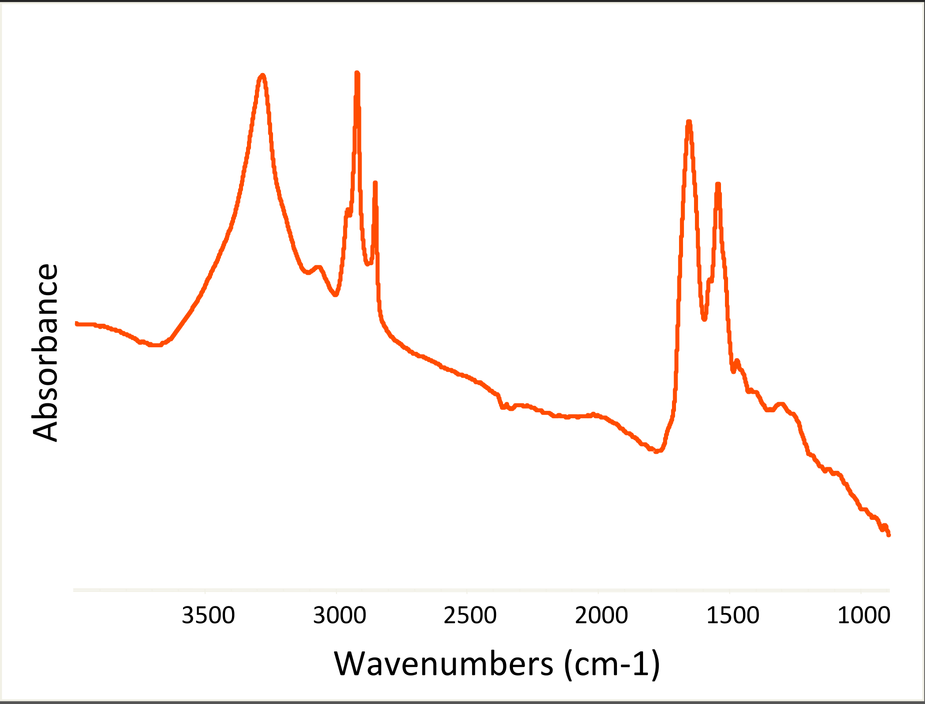
10x10 μm pinhole



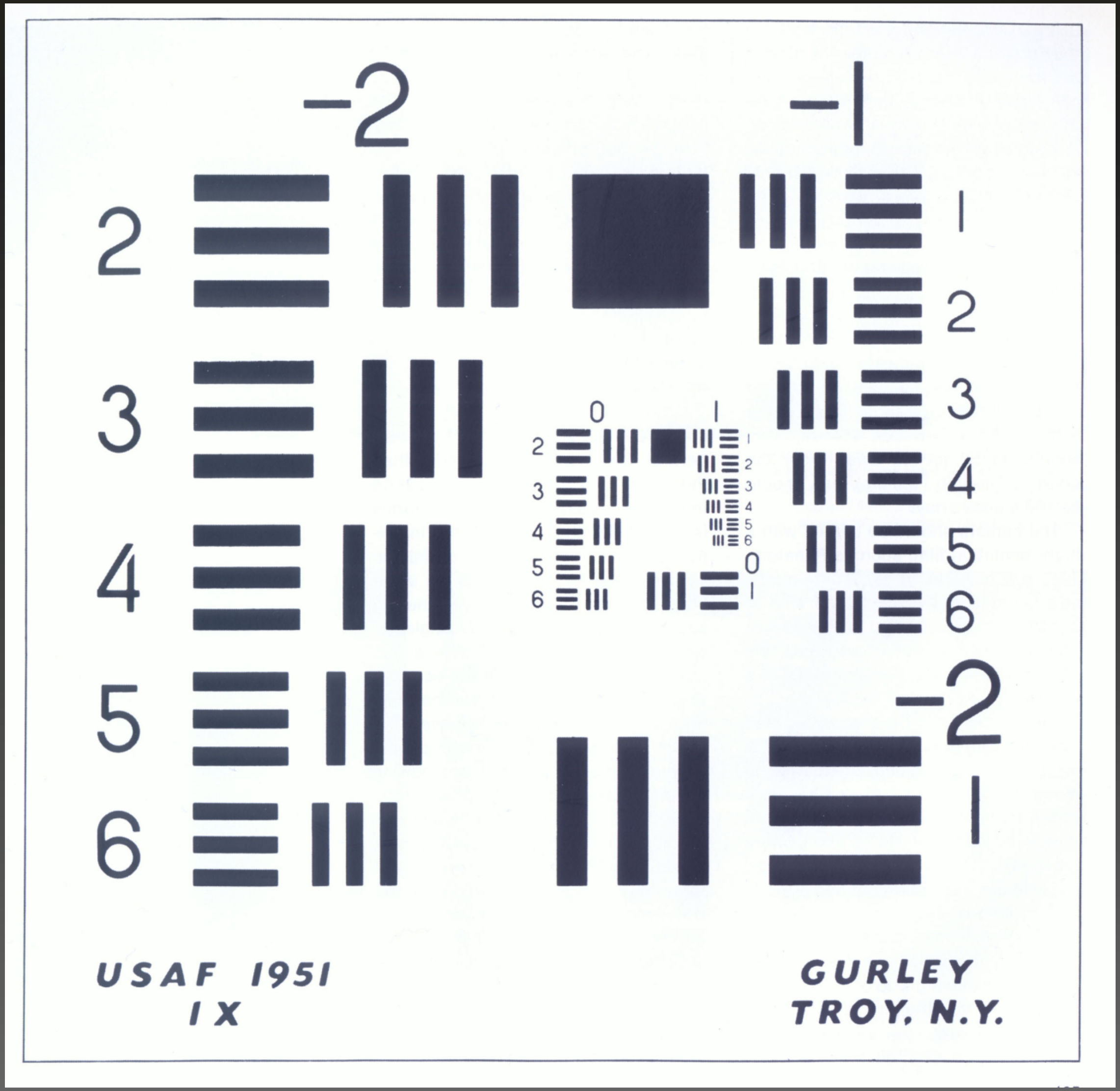
Globar vs. synchrotron

6x6 μm aperture (single cell)

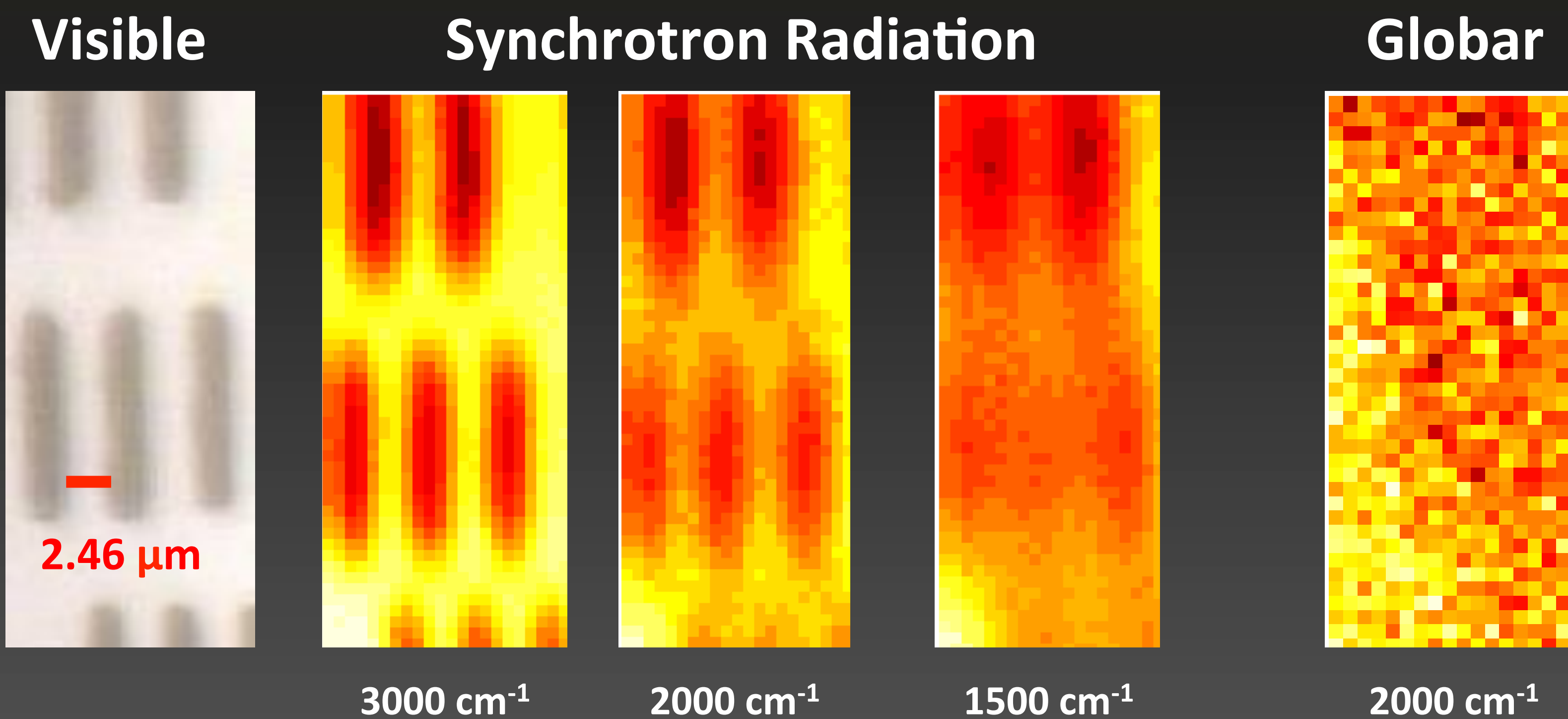




Spatial resolution

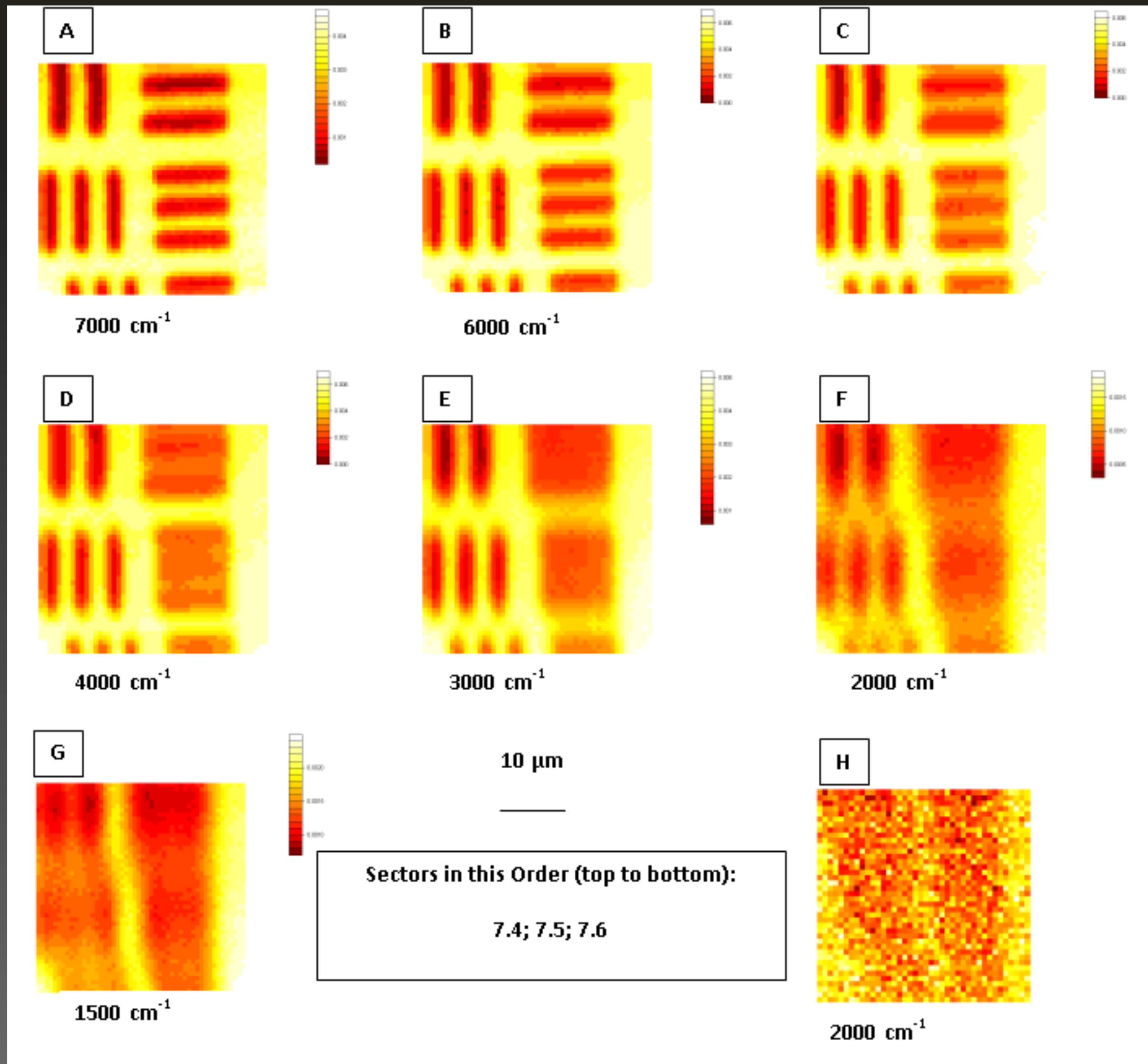


Spatial resolution…



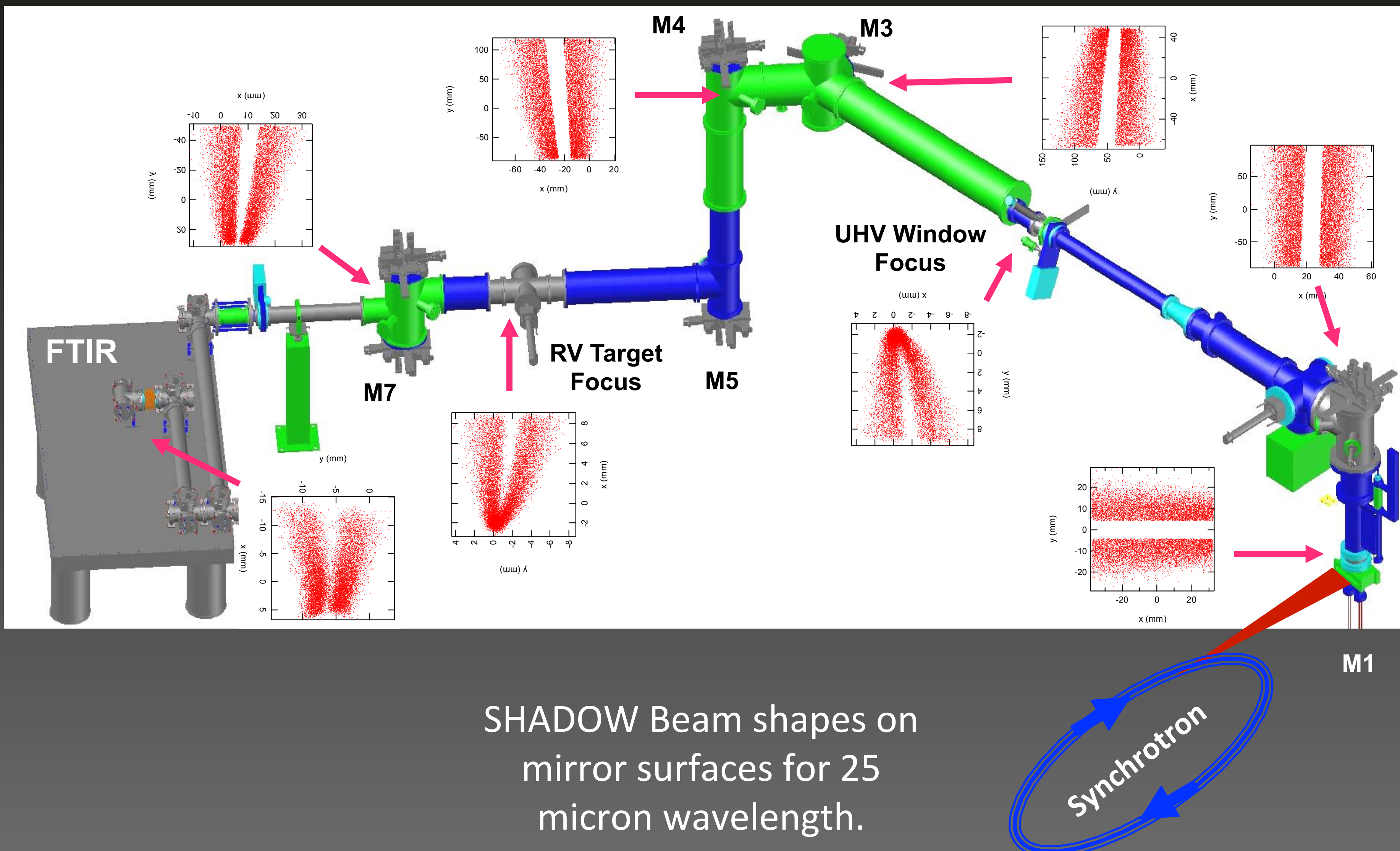
Diffraction limited resolution
can be achieved only by SR

...diffraction limited



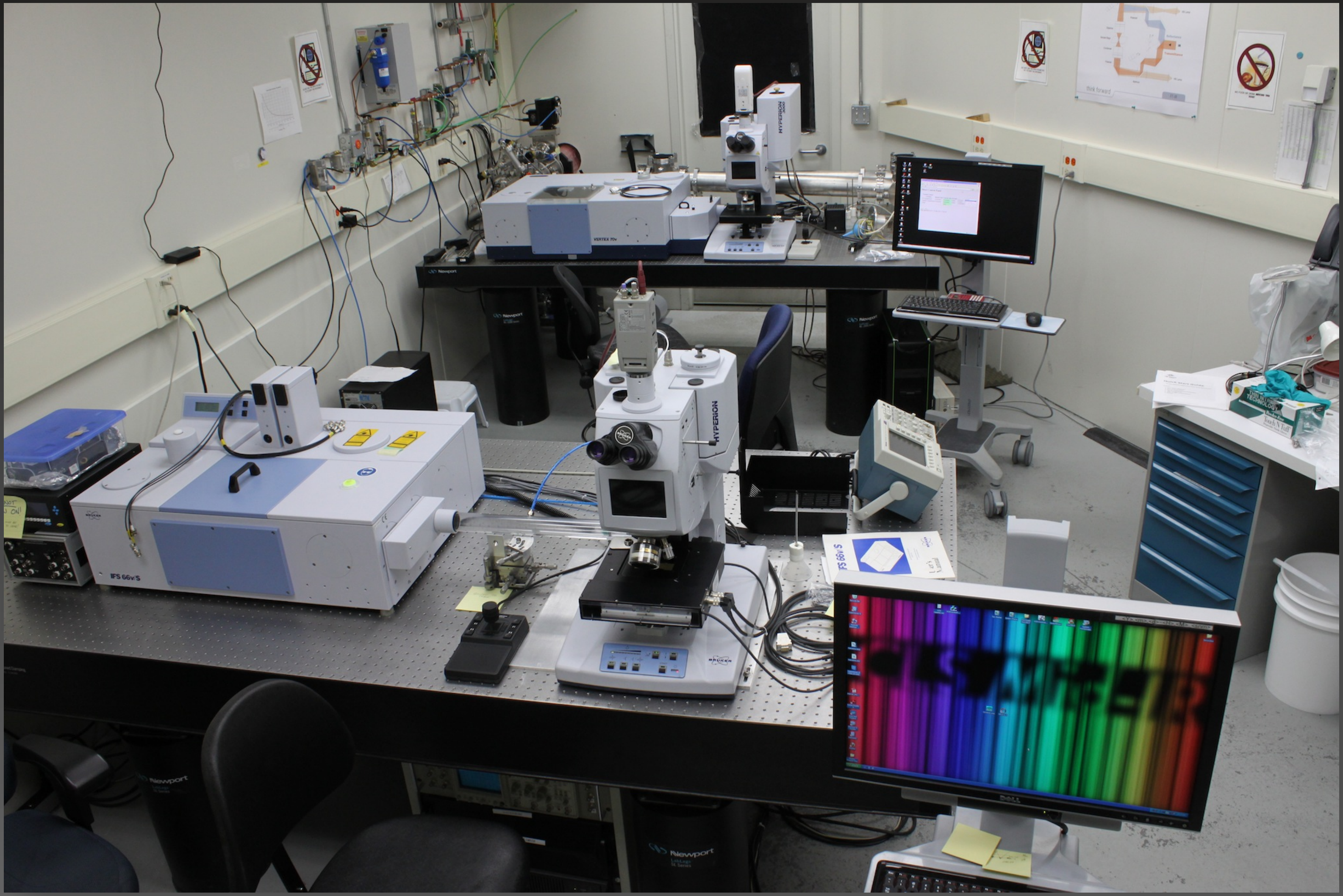
Infrared beamlines
- some examples -

Canadian Light Source Mid-IR

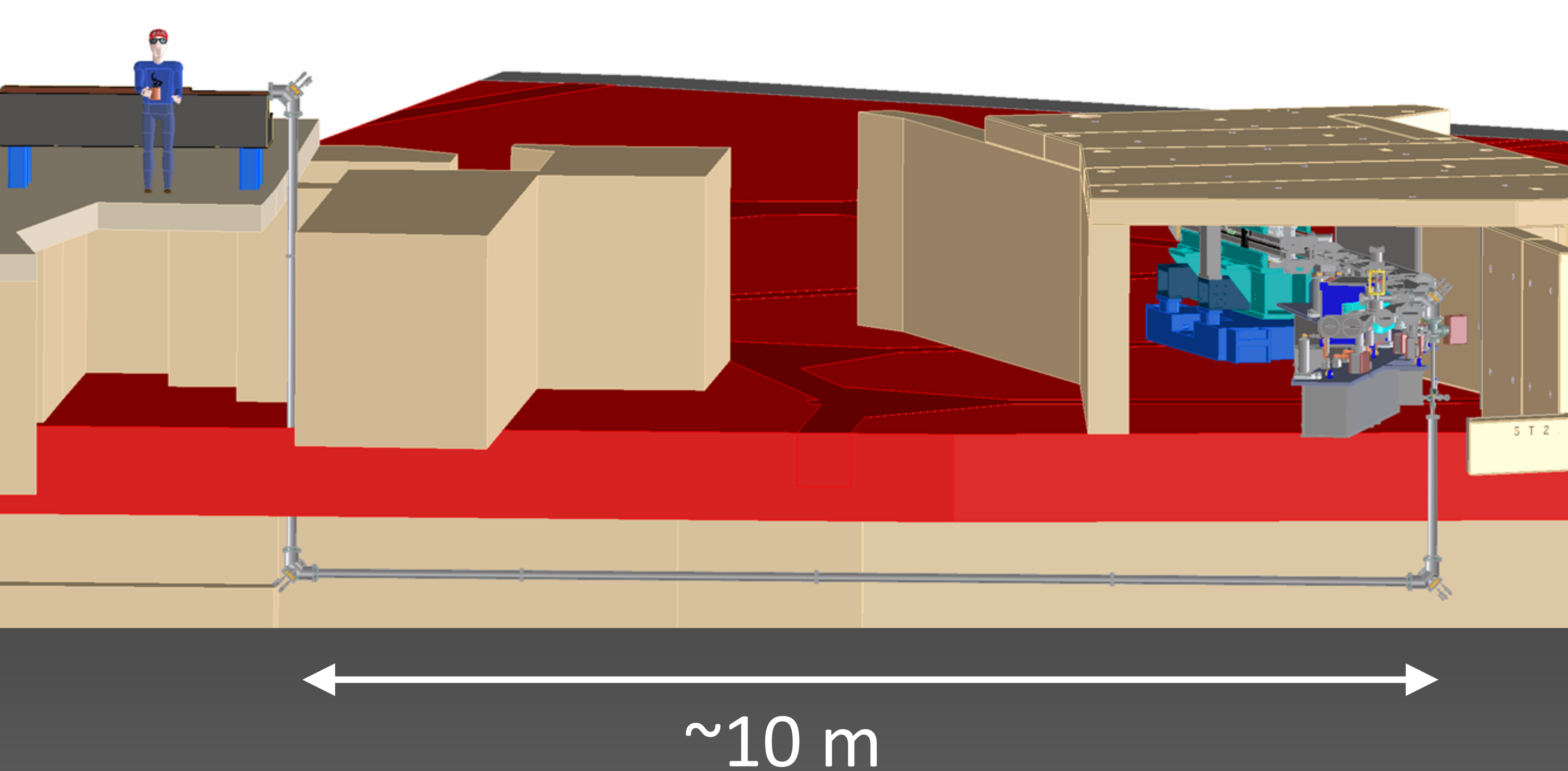


SHADOW Beam shapes on mirror surfaces for 25 micron wavelength.

Canadian Light Source Mid-IR



Advanced Light Source, Bl 5.4



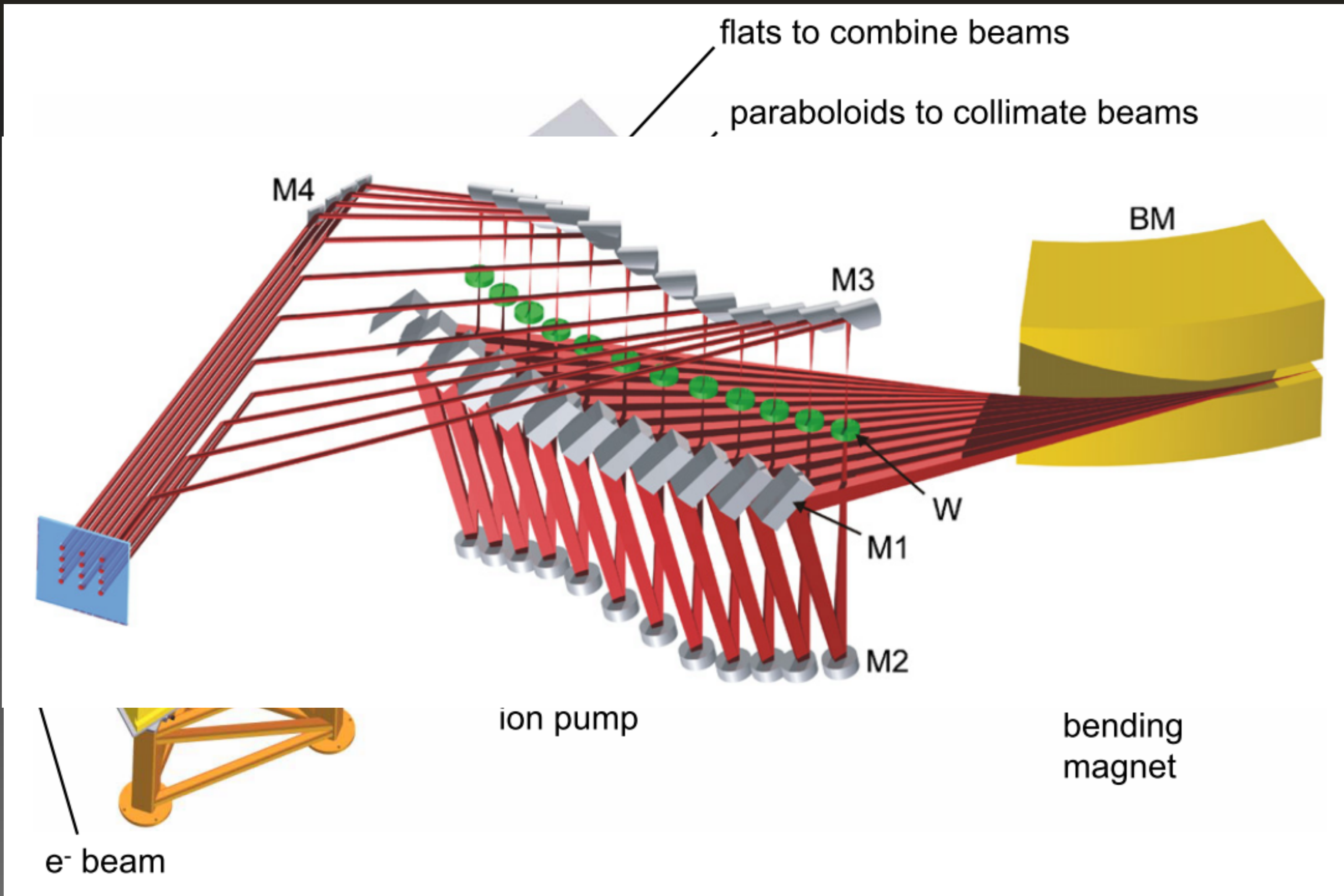
+ Beamline 1.4

NSLS VUV-IR ring

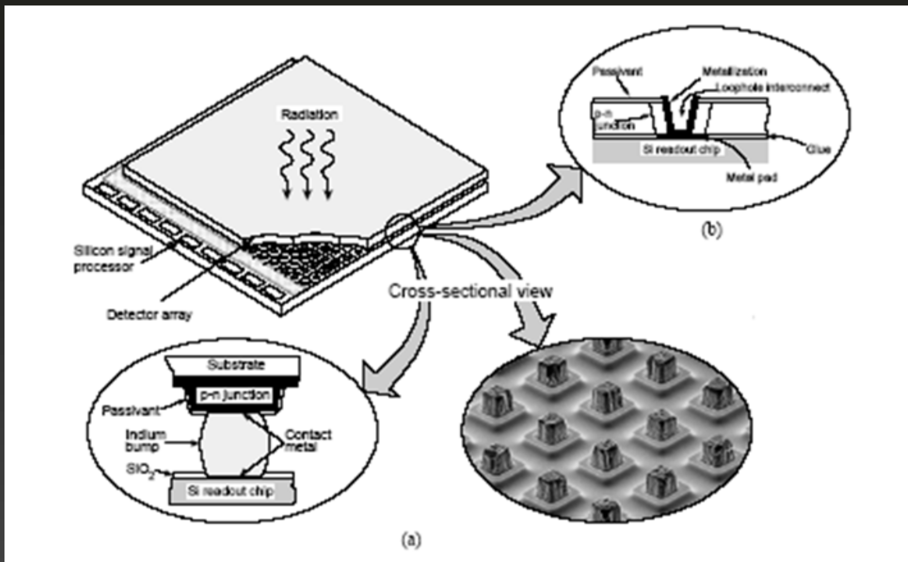
U2A	Geophysics, materials at extreme pressures and microspectroscopy
U2B	Mid-IR microspectroscopy
U4IR	Instrumentation development
U10A	Far-IR microspectroscopy
U10B	Mid-IR microspectroscopy
U12IR	Far-IR, THz and millimeter wave spectroscopy. Materials physics

Shutting down soon because of NSLS II

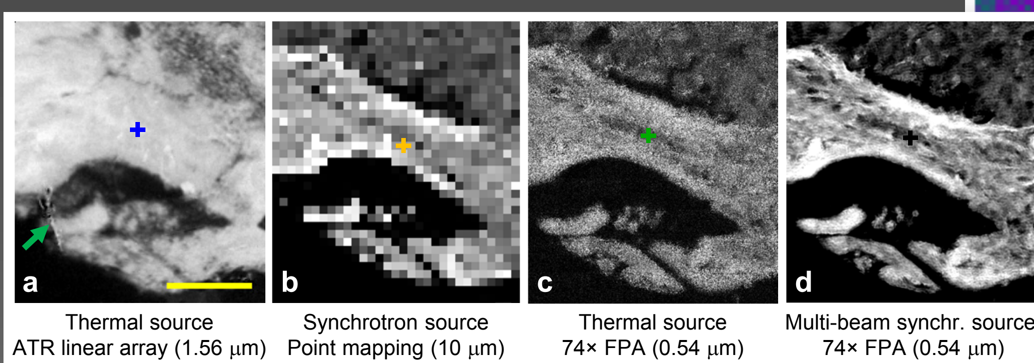
IRENI beamline, SRC



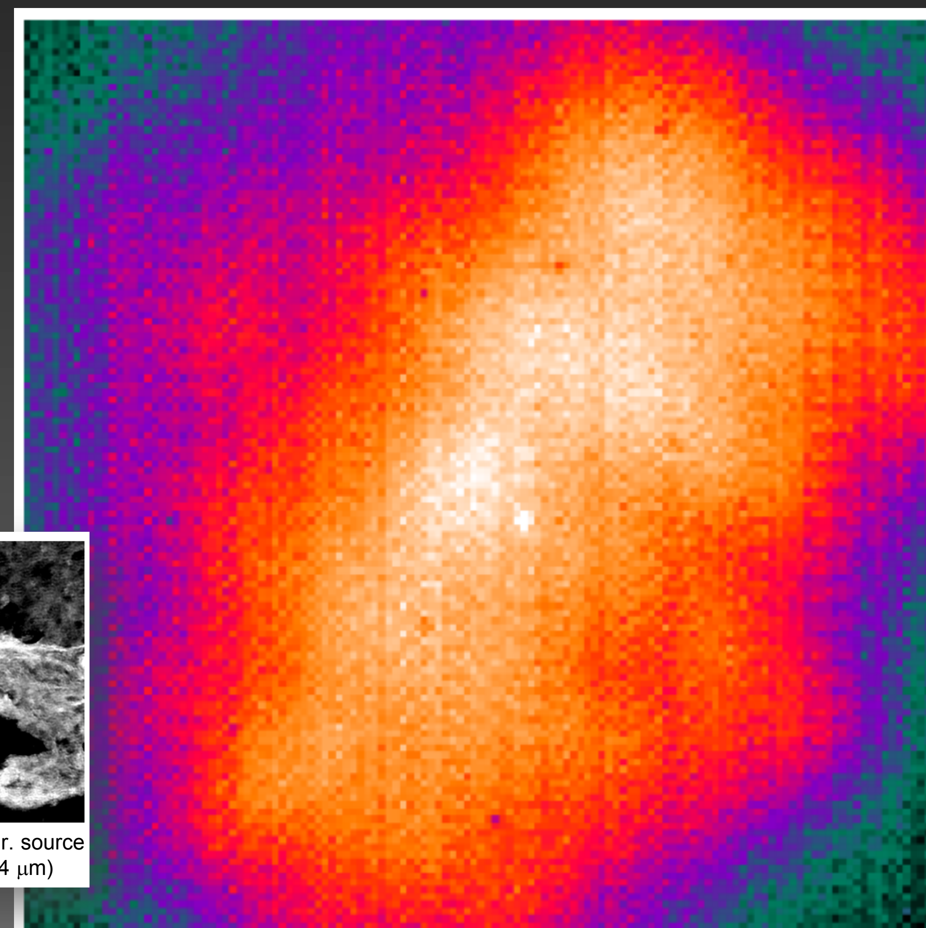
IRENI beamline, SRC



Focal Plane Array

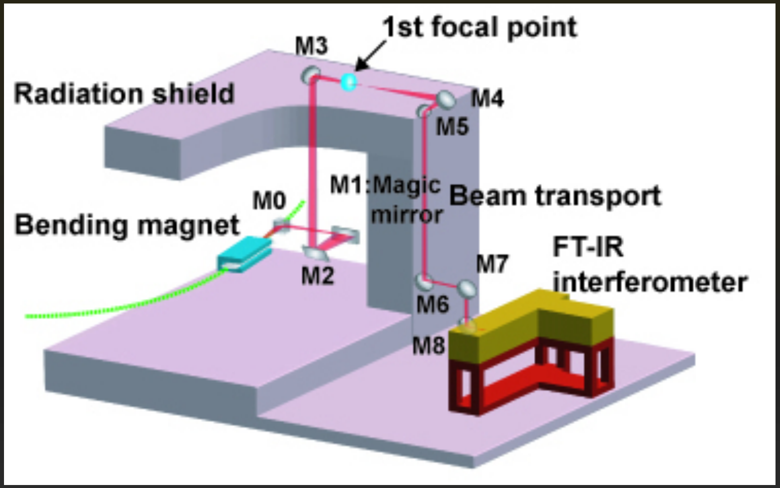


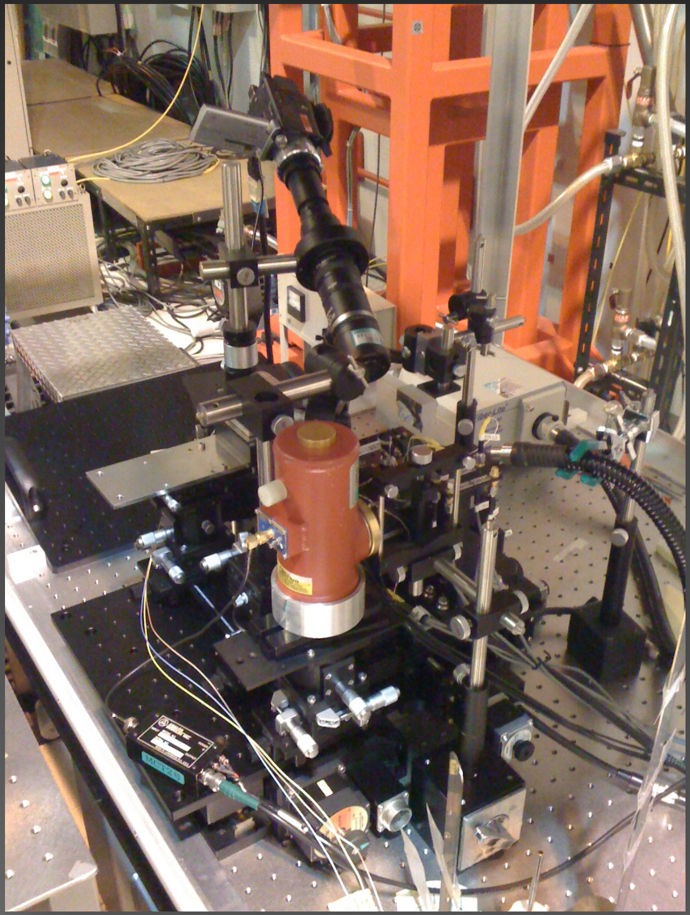
Nasse et al., Nature Methods 2011, DOI:10.1038/nmeth.1585



SPring-8, BL43B

Three IR endstations





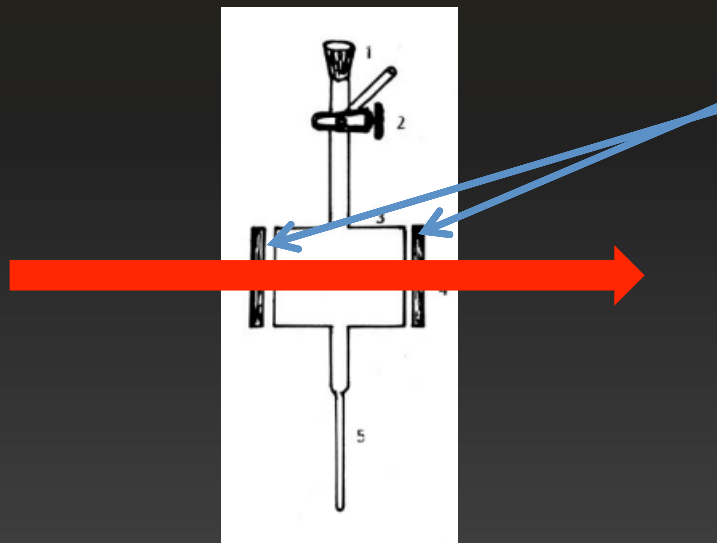
- spectromicroscopy
- magneto-optical spectroscopy
- high-pressure studies
- near field microscopy

IR spectroscopy

- samples and measurement techniques -

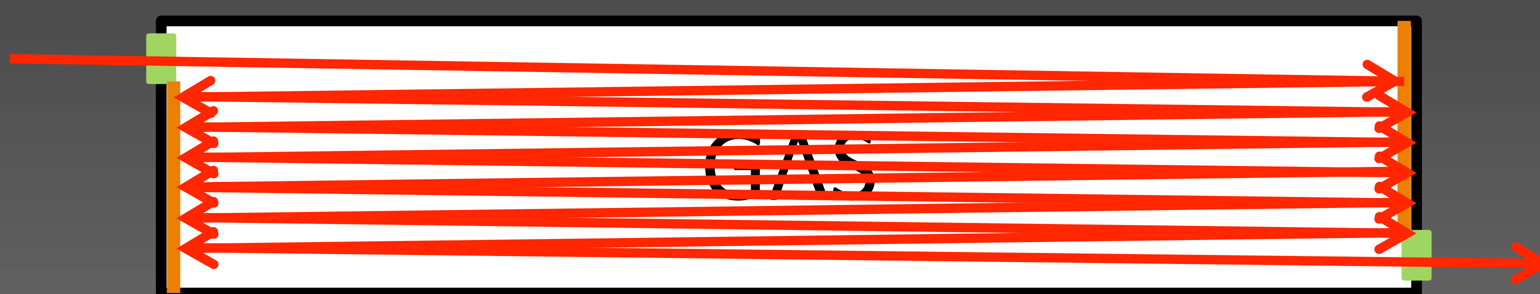
Sample forms

Gases



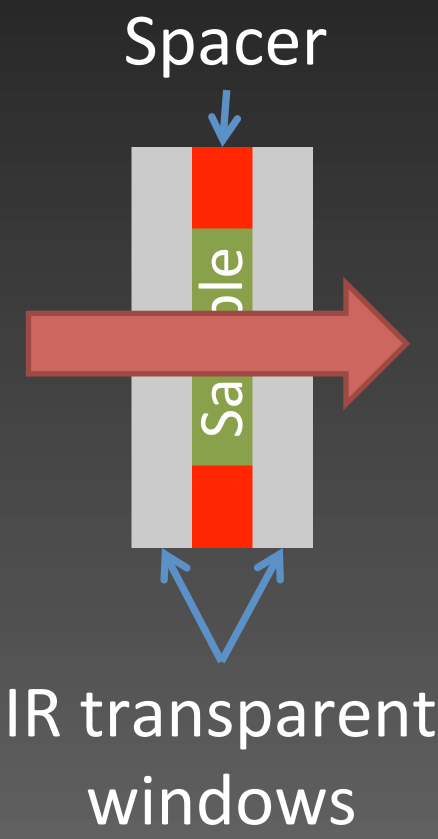
IR transparent windows

Multi-pass cells



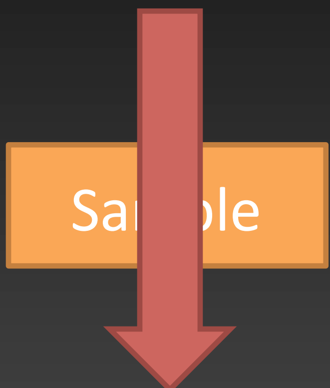
Sample forms

Liquids



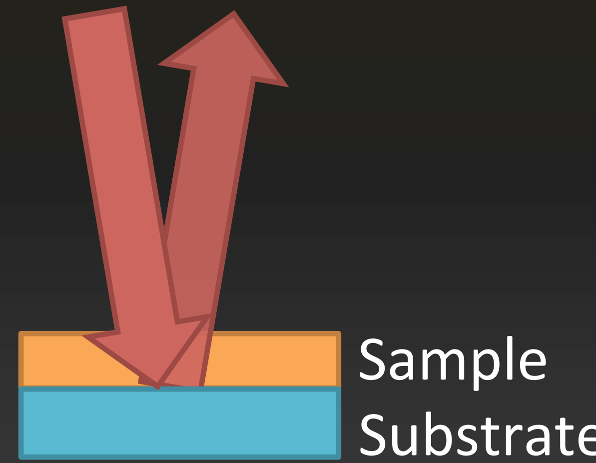
Sample forms

Solids



Transmission

Reflection



Reflection-absorption
Transflecion

Self supporting
Lying on substrate
Suspended in carrier
    KBr
    Nujol

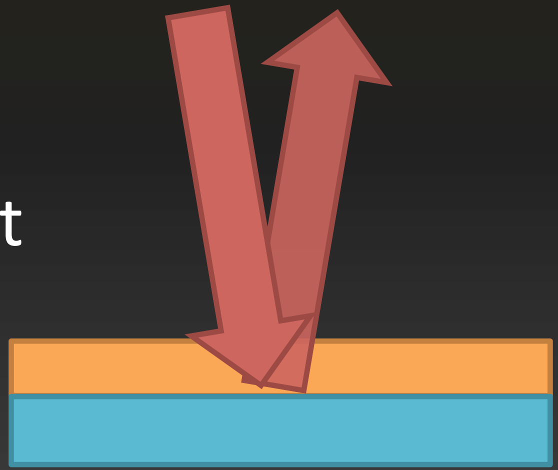
Reflection setups

Regular

Convenient

Sample

Substrate



Very thin samples

Grazing angle incidence

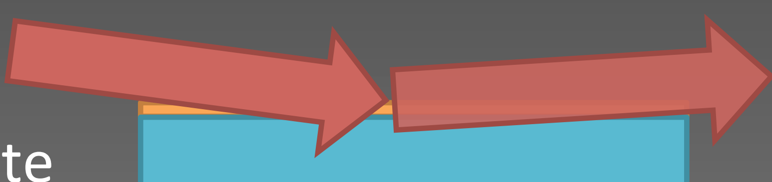
Special microscope objectives

Increases optical pathlength

- Monolayers
- Sub-monolayers

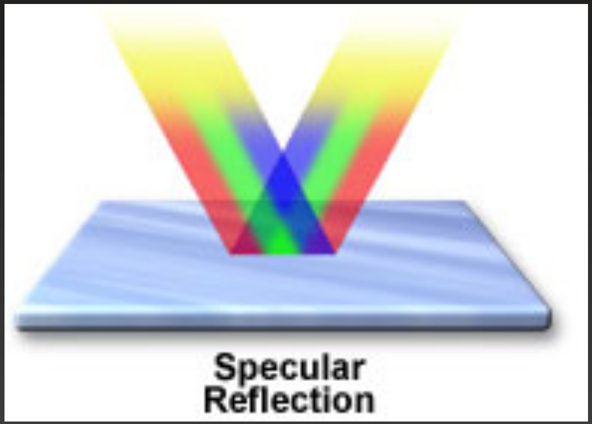
Sample

Substrate

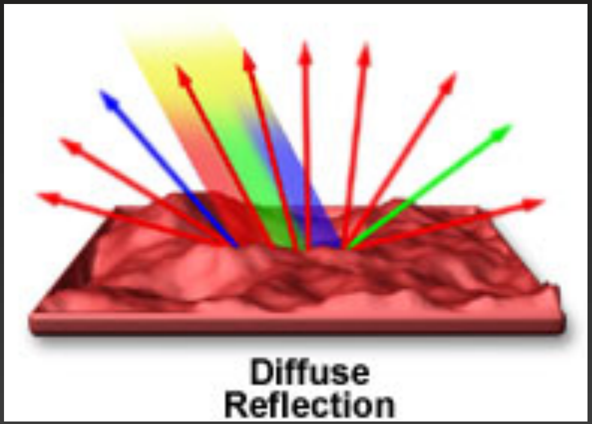


Reflection setups

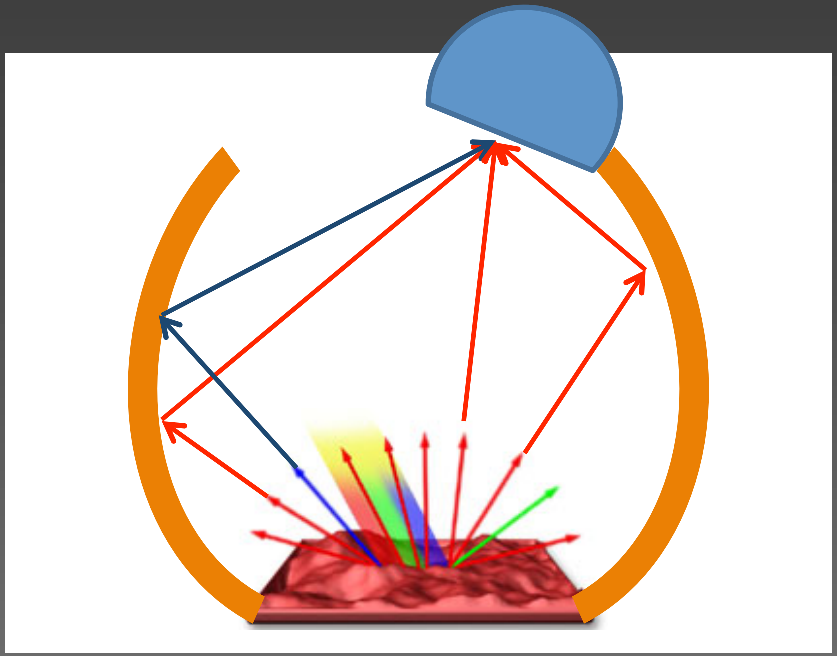
We are happy



Not so lucky



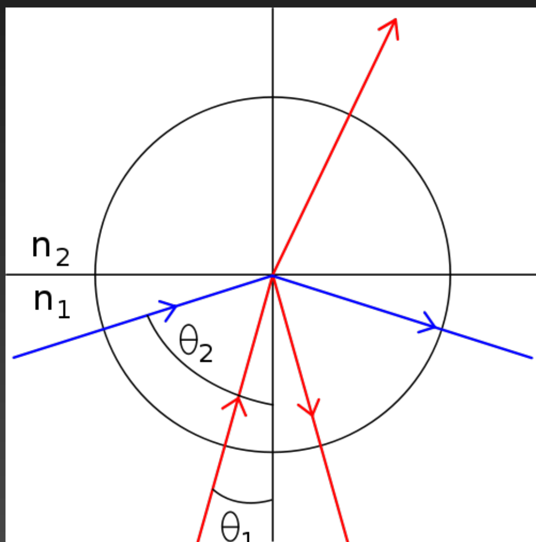
DRIFTS
Diffuse reflection
Integrating sphere

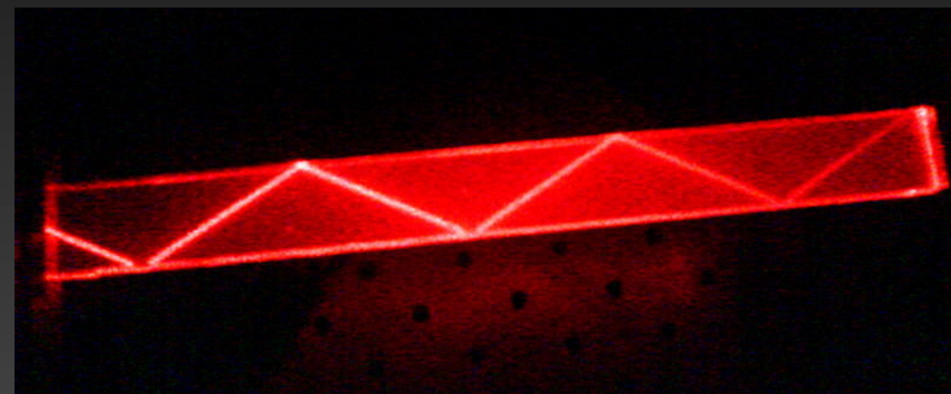


Application:
- Powders
- Catalysis!!!

Reflection setups

Total internal reflection

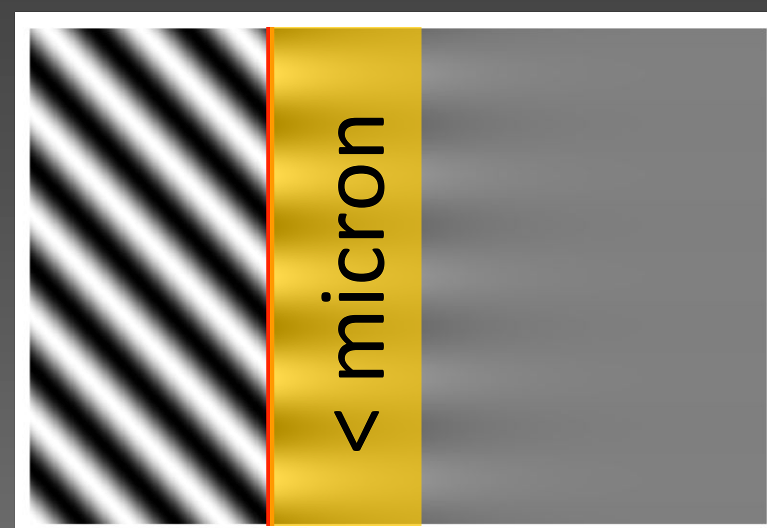




$$\Theta_c = sin^{-1}(\frac{n_1}{n_2})$$

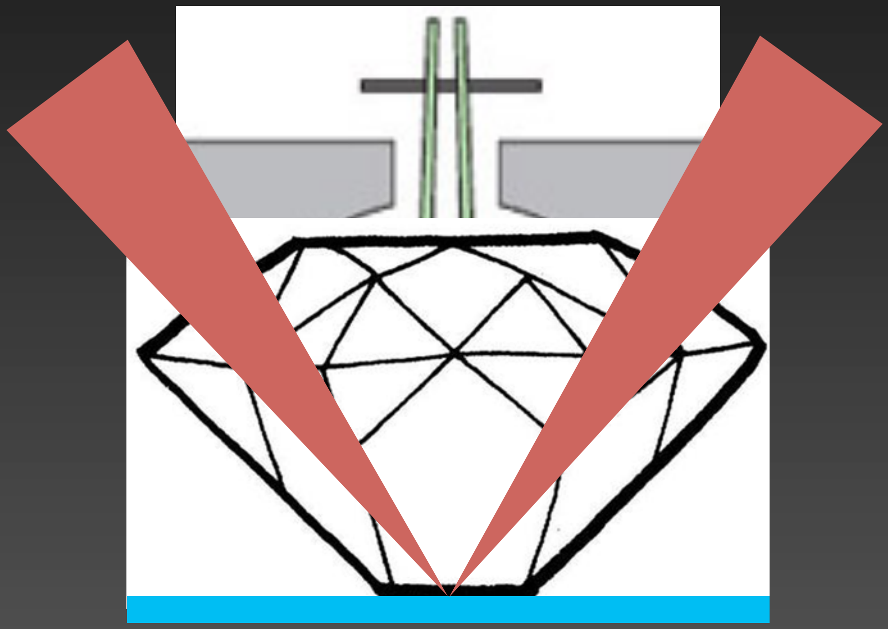
$$E_T = E_0 e^{-z/d_p}$$

$$d_p = \frac{\lambda}{2\pi n_1 \sqrt{sin^2\theta - n_{21}^2}}$$



Reflection setups

Attenuated total internal reflection



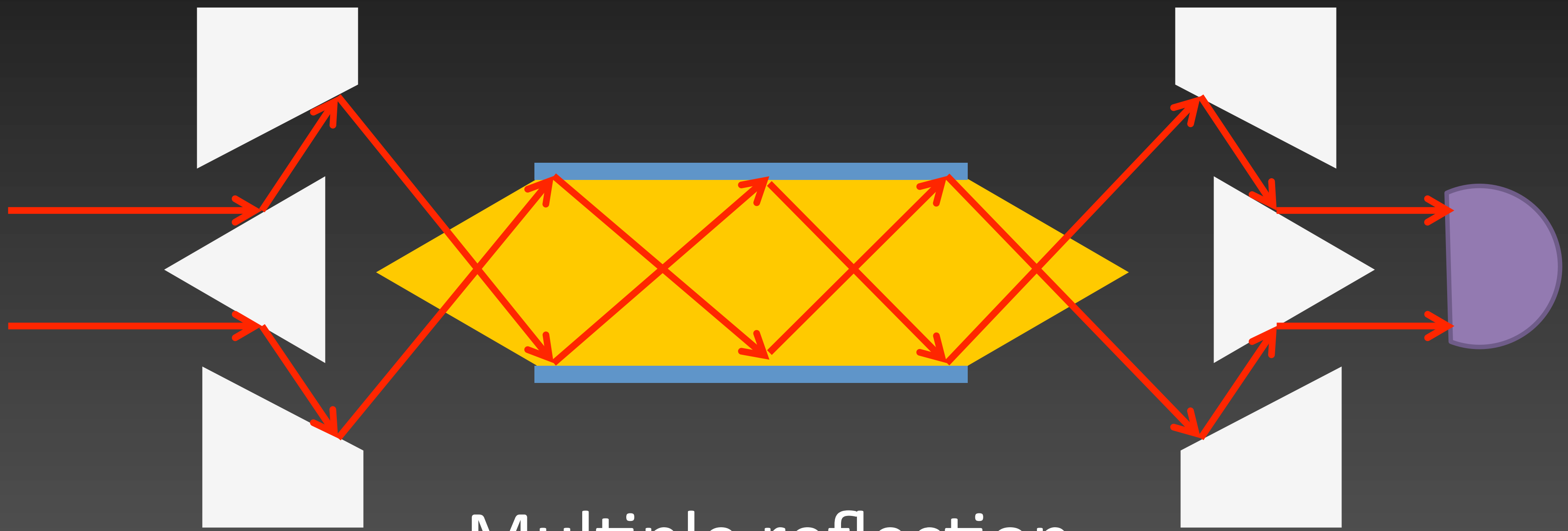
Single reflection
Surface sensitive
Microscopy

$$d = \frac{\lambda}{2NA}$$

$$NA = nsin(\theta)$$

Reflection setups

Attenuated total internal reflection



Multiple reflection

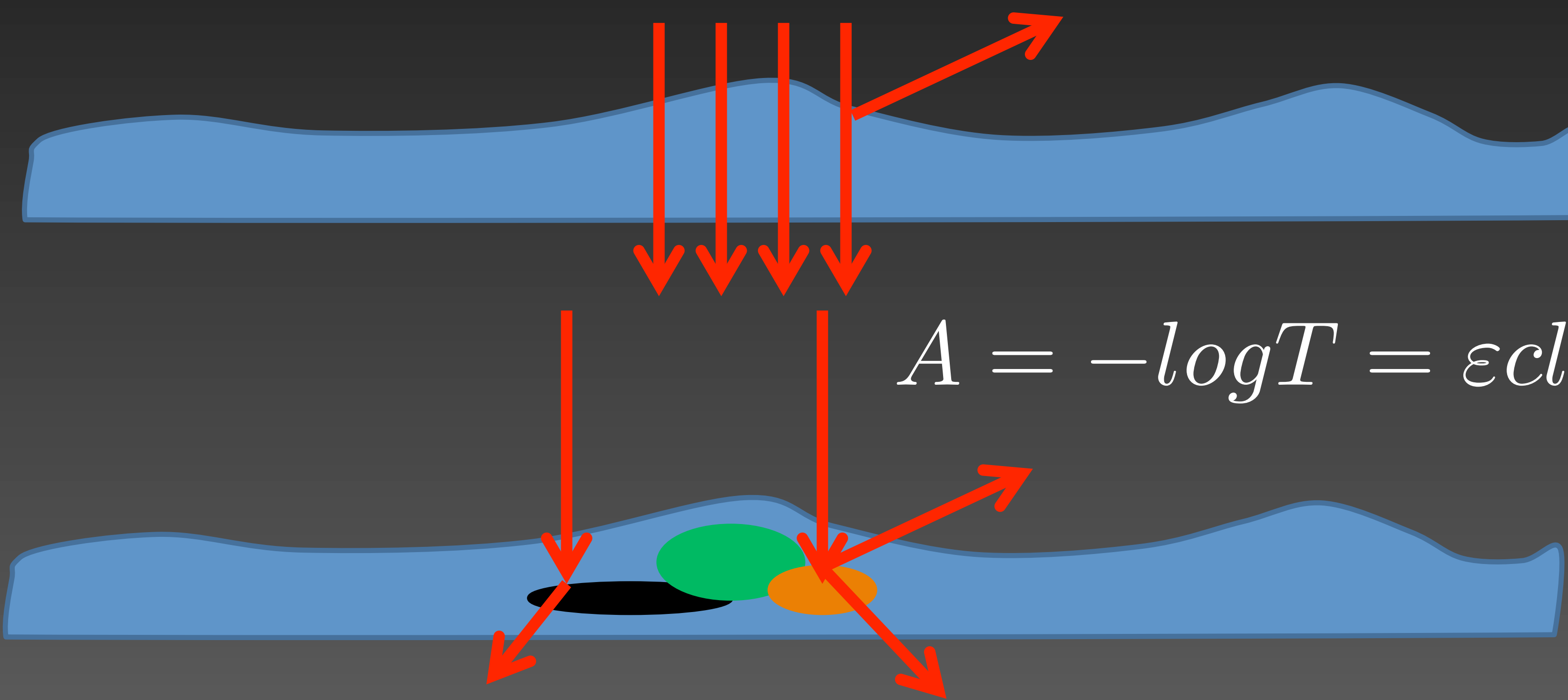
Very sensitive

Number of reflections: $N_{bounces} = \frac{length_{crystal}}{thickness_{crystal}} ctg\theta$

Possible problems

Artifacts?

Samples are not ideal…thickness/roughness

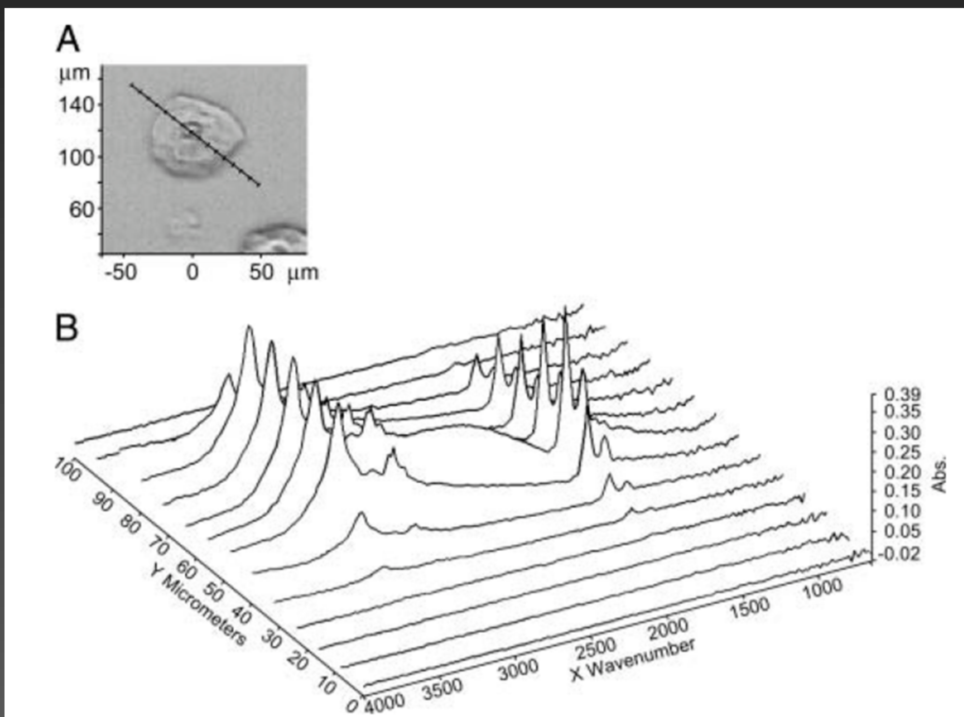


$$A = -logT = \varepsilon cl$$

Life gets very complicated

Artifacts?

Samples are not ideal…



Mie Scattering

$$Q = 2 - \frac{4}{p}\sin p + \frac{4}{p^2}(1 - \cos p)$$

$$p = 4\pi a \frac{n-1}{\lambda}$$

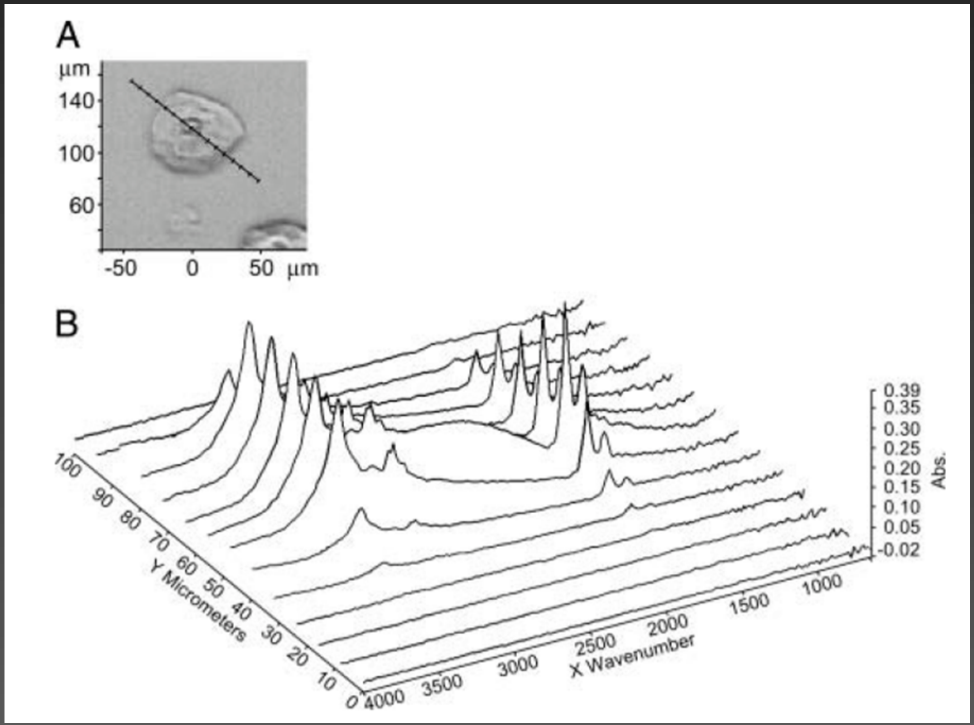
$$a : r_{sphere}$$

$$n = \frac{n_{inside}}{n_{outside}}$$

Mohlenhoff et al., Biophysical Journal 88, 3635-3640, (2005)

Artifacts?

Samples are not ideal…scattering.



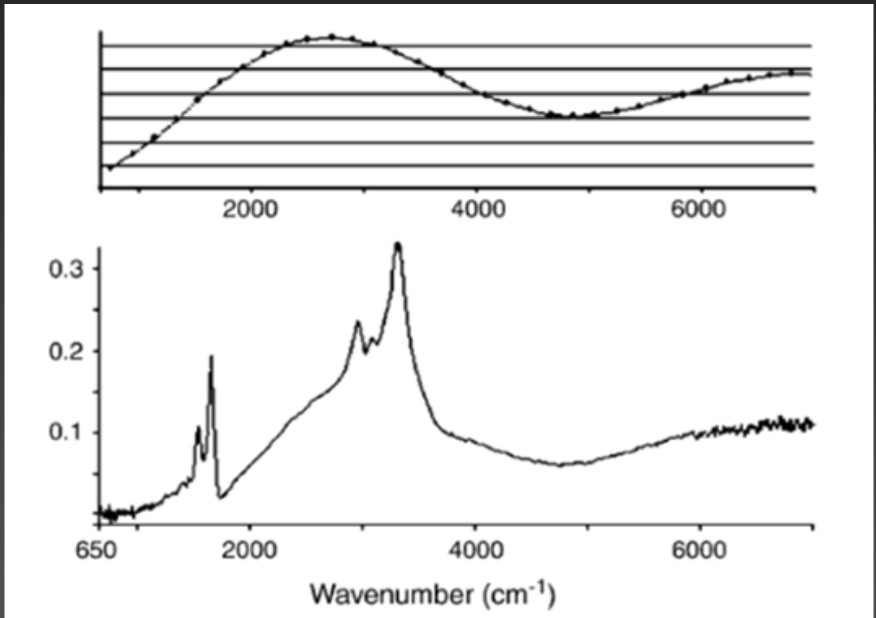


FIGURE 5 IR spectrum of oral mucosa cell (*bottom*), and scattering spectrum for a dielectric sphere with $a = 4.2$ μm (*top*).

Mohlenhoff et al., Biophysical Journal 88, 3635-3640, (2005)

Artifacts? – solutions…

- Second derivatives
- EMSC (extended multiplicative scattering correction)
- Mie Scattering corr., Resonant Mie Scattering corr.

How to differentiate spectra?

- Statistical analysis
  - Cluster analysis
  - Principal Component Analysis
  - Partial Least Squares regression

Cytospec
R, Matlab,
Eigenvetcor
The Unscrambler

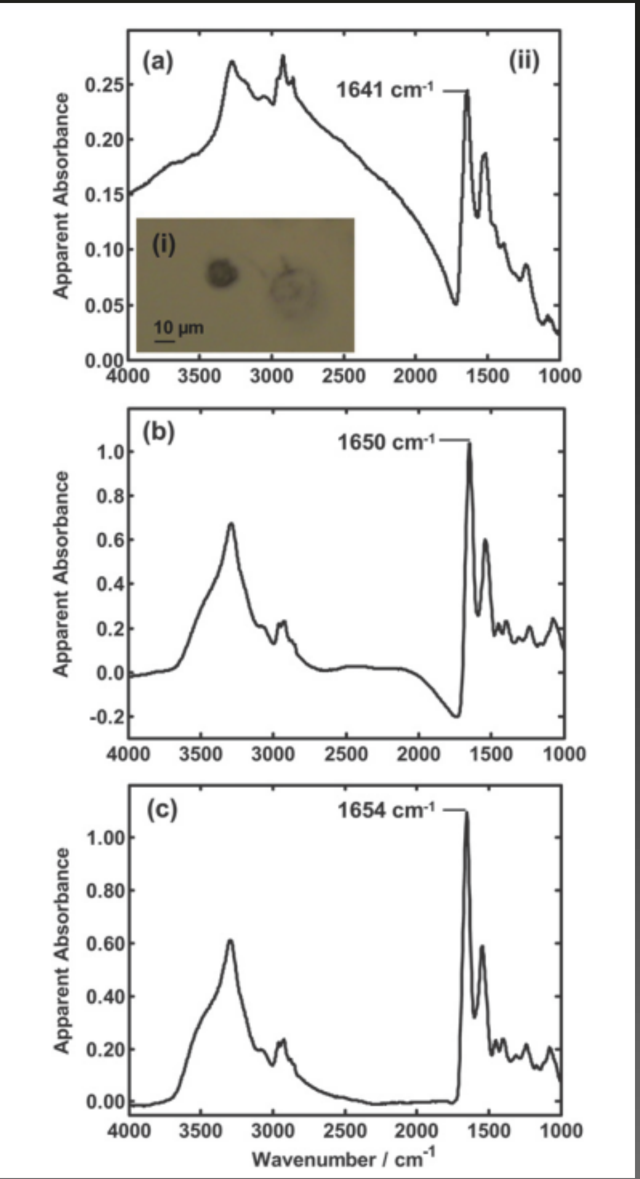
Artifacts? – RMieSc

Samples are not ideal…
resonant scattering.

Amide I – 1641 cm^{-1}
β-sheet, random

Amide I – 1650 cm^{-1}
random, turns

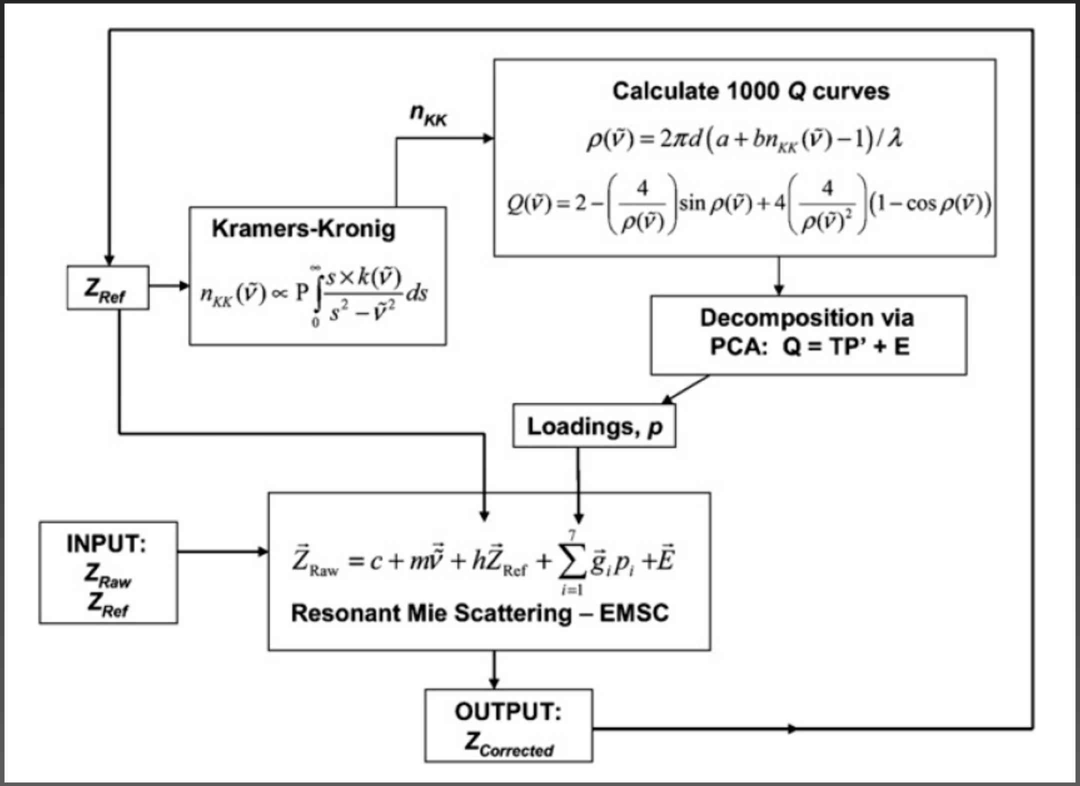
Amide I – 1654 cm^{-1}
α-helix



Bassan et al., The Analyst 135, 268-277, (2010)

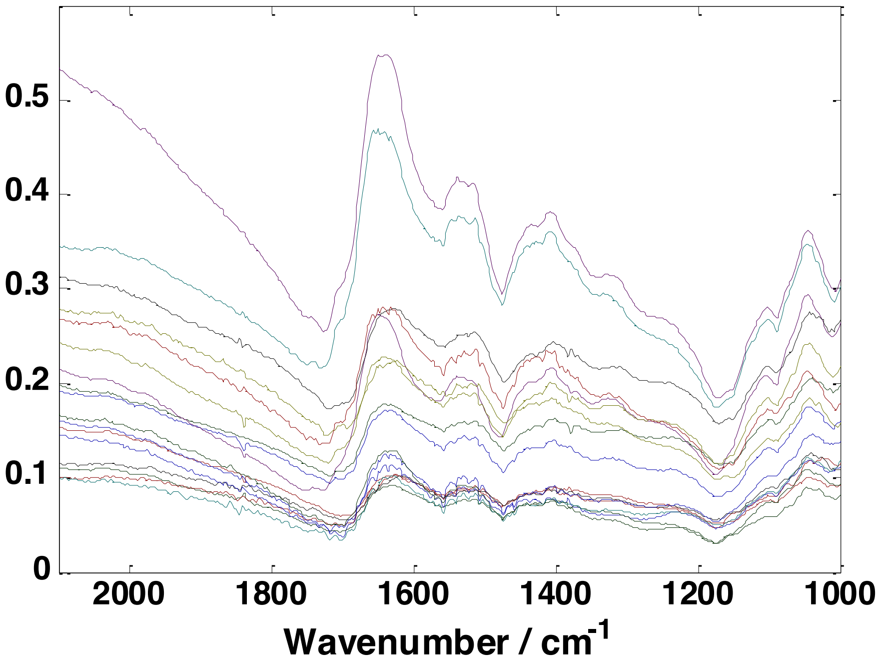
Artifacts? – RMieSc…

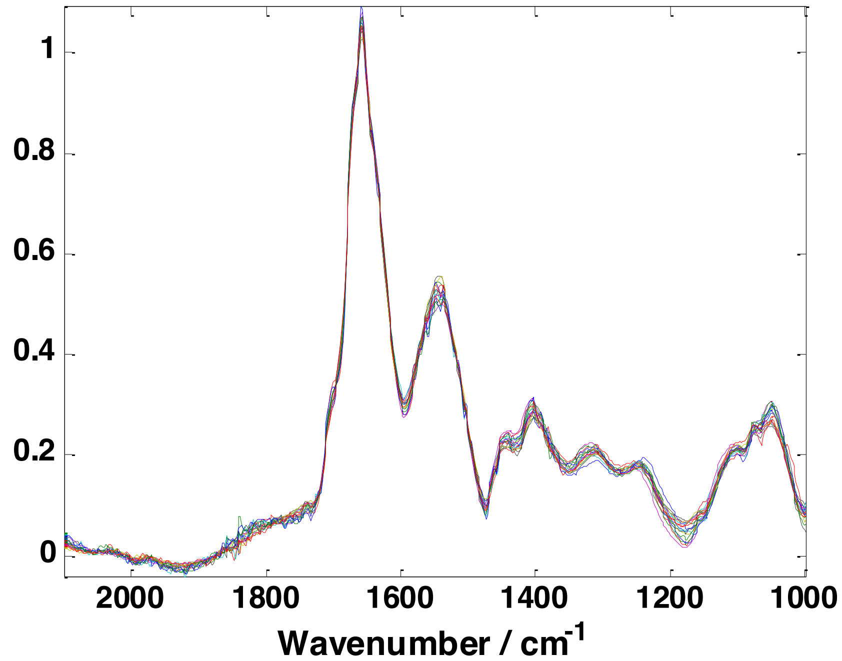
Samples are not ideal…resonant scattering.



Artifacts? – RMieSc…

Samples are not ideal…resonant scattering.

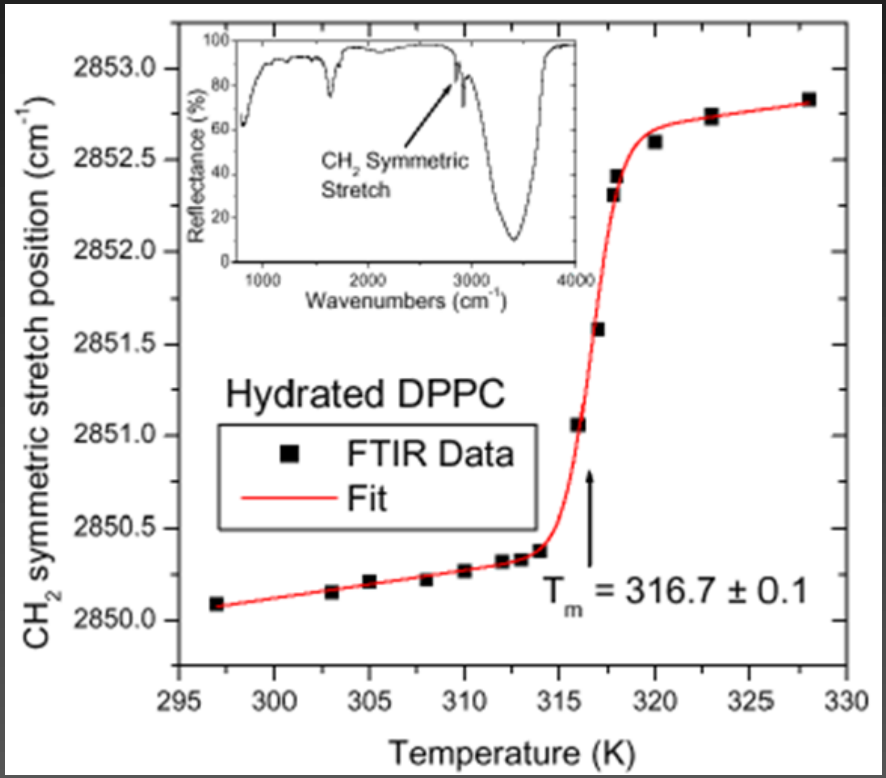




Bassan et al., Analyst 135, 268-277 (2010)

Artifacts?

Does the synchrotron light heat the sample?

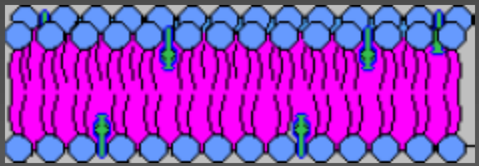


Observed < 0.5˚ C temp rise on sample

Synchrotron source:
Measured 1 mW focused onto ~10 X 10 μm^2

DPPC = dipalmitoylphosphatidylcholine,
a phospholipid bilayer

Undergoes a gel to liquid-crystalline phase transition at T= 316 K



Important: No Evidence for Cytotoxic Effects on Living Cells

M.C. Martin et al., Applied Spectroscopy 55, 111 (2001)

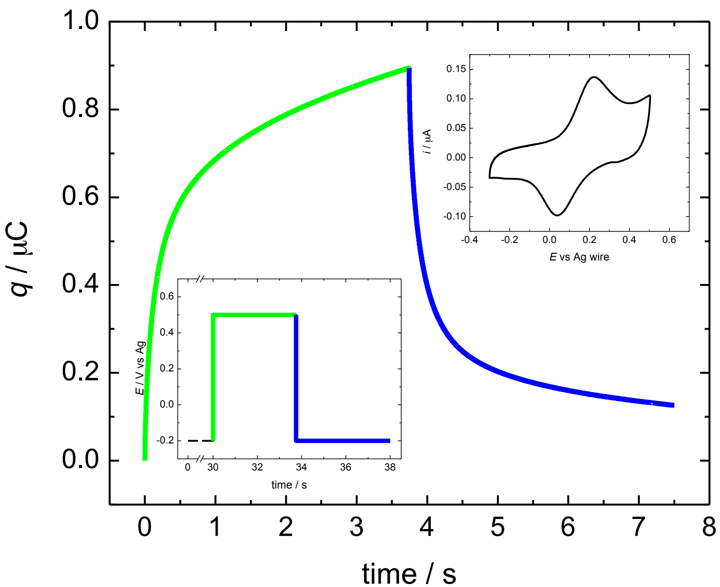
SR IR spectroscopy
- applications -

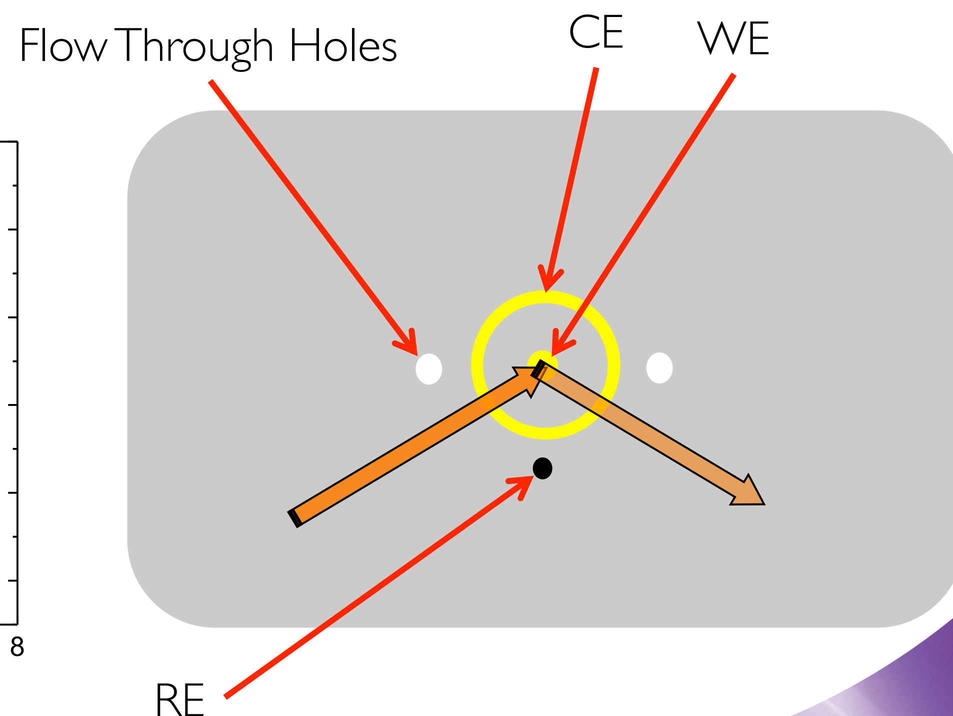
The Burgess Research Group

Kinetics: problem RC time constant of the electrode
solution: decrease size

Small electrode size ~ 10 μm

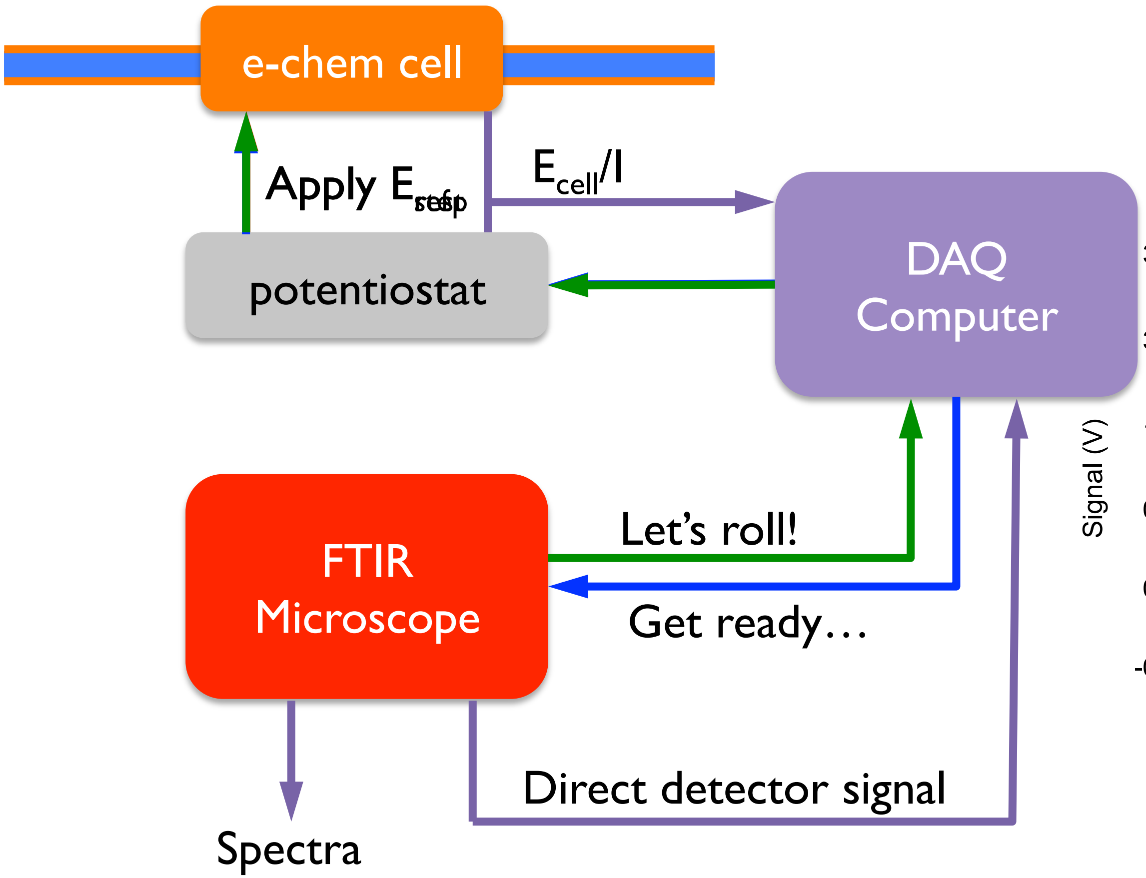
Need for SR

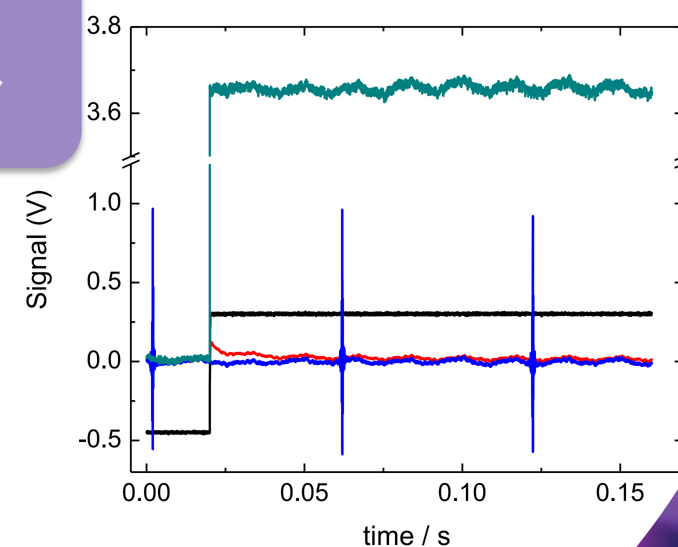




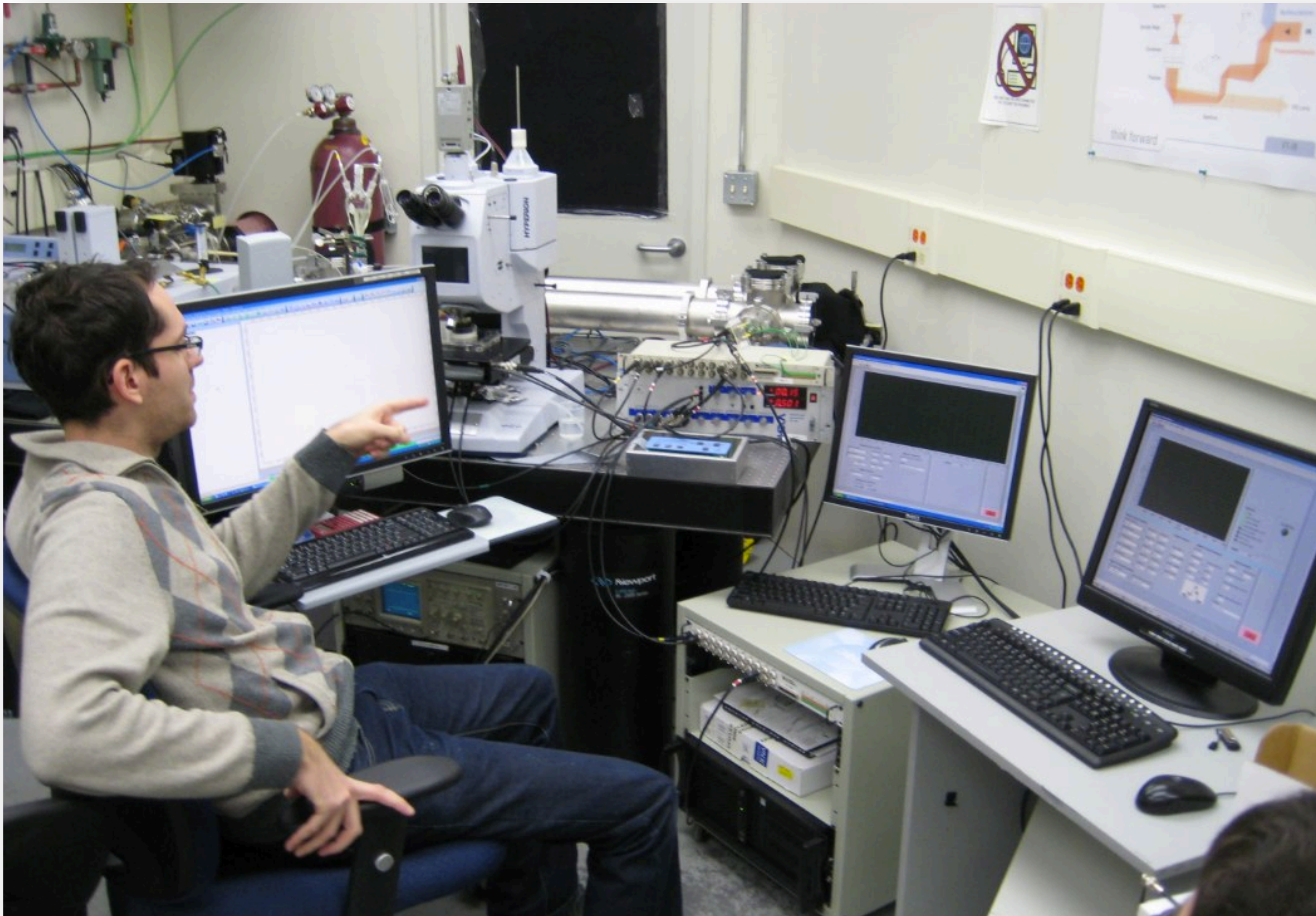
Rosendahl SM; Borondics F; May T; Pedersen T; Burgess I, Anal. Chem. 83 (10), 3632-3639, 2011.

The Burgess Research Group





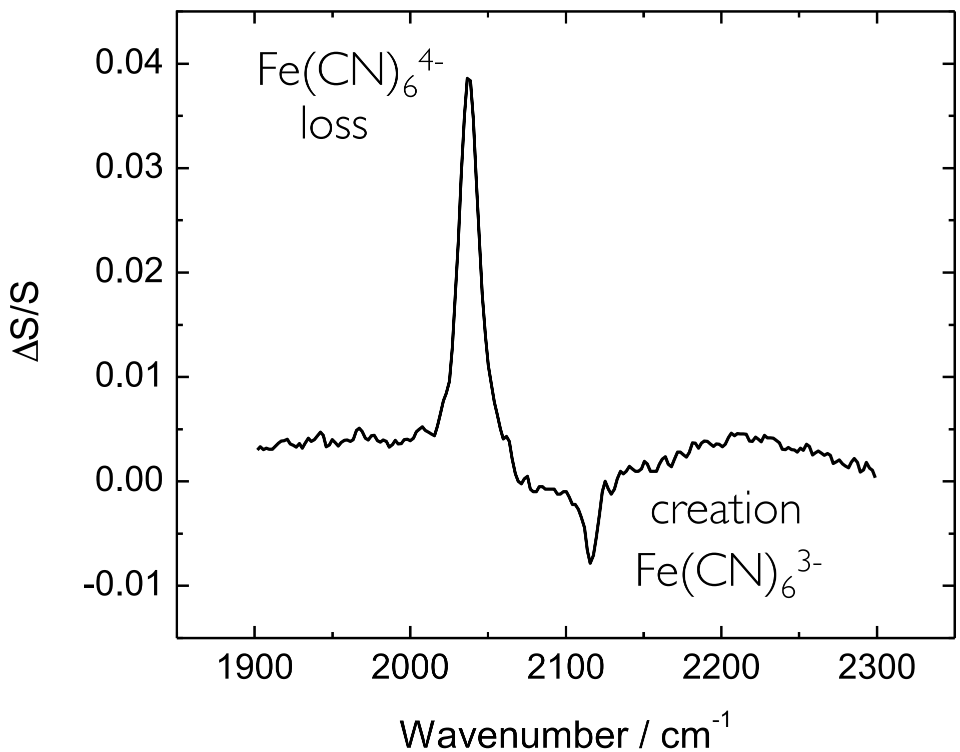
Rosendahl SM; Borondics F; May T; Pedersen T; Burgess I, Anal. Chem. 83 (10), 3632-3639, 2011.

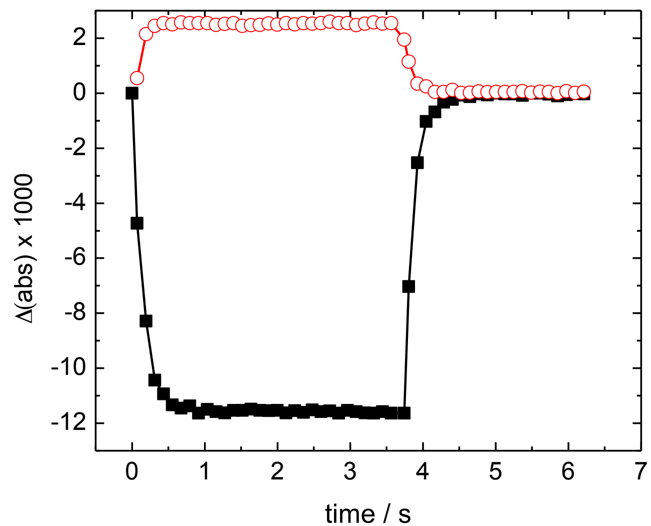


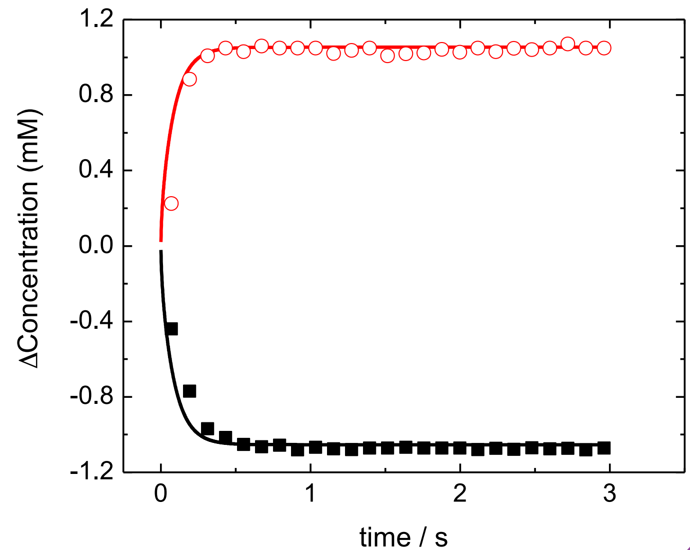
Rosendahl SM; Borondics F; May T; Pedersen T; Burgess I, Anal. Chem. 83 (10), 3632-3639, 2011.

Results

$Fe(CN)_6^{4-} = Fe(CN)_6^{3-} + e-$





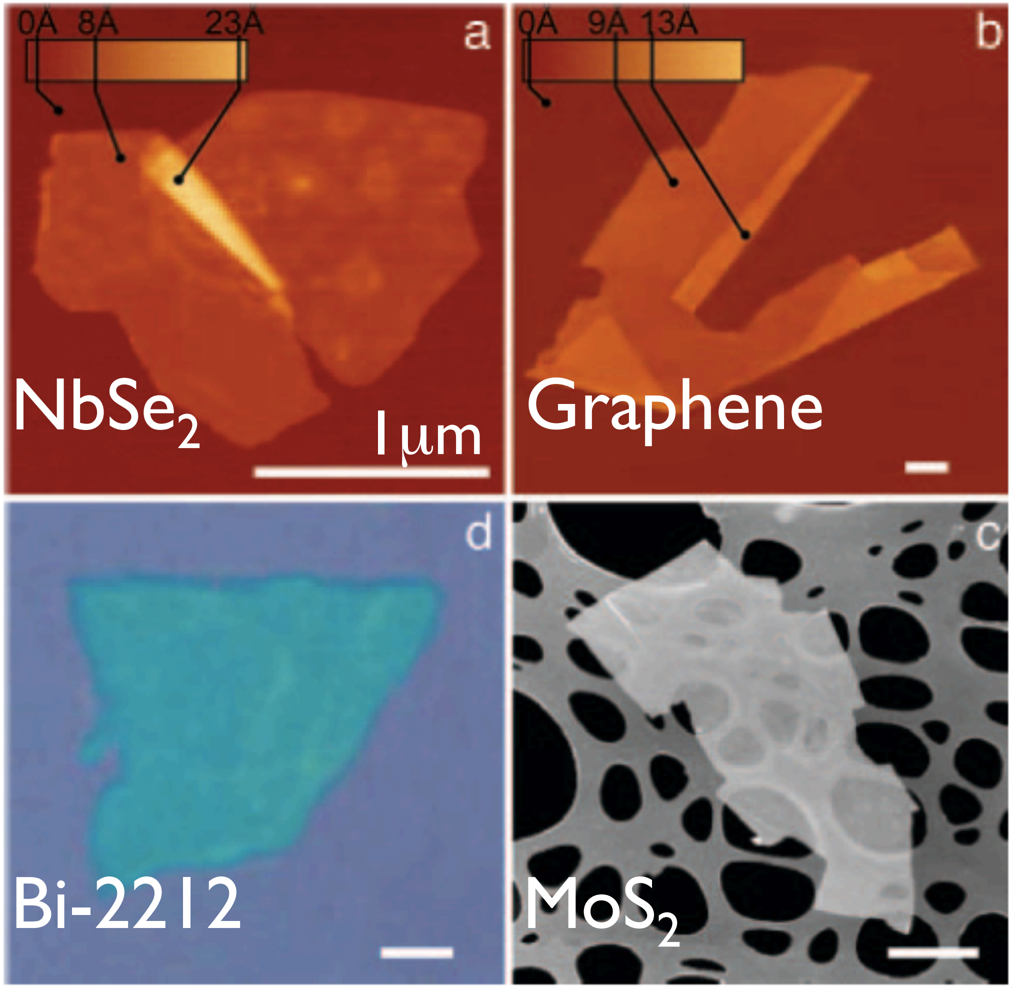


Rosendahl SM; Borondics F; May T; Pedersen T; Burgess I, Anal. Chem. 83 (10), 3632-3639, 2011.

Two-dimensional atomic crystals

K. S. Novoselov*, D. Jiang*, F. Schedin*, T. J. Booth*, V. V. Khotkevich*, S. V. Morozov†, and A. K. Geim*‡

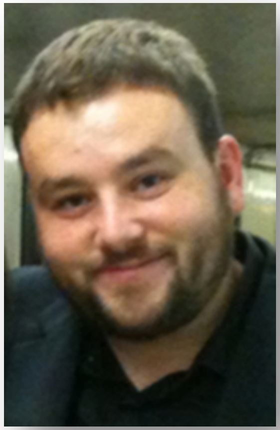
*Centre for Mesoscience and Nanotechnology and School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom; and †Institute for Microelectronics Technology, Chernogolovka 142432, Russia



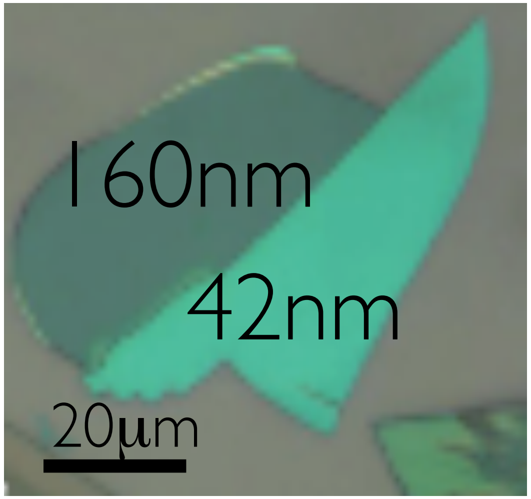
Exfoliation

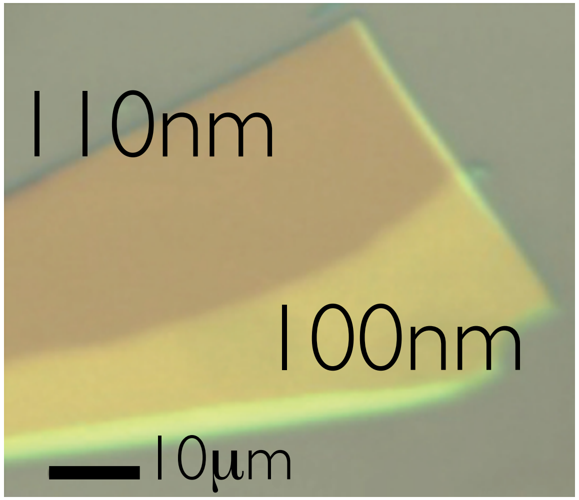
(Scotch tape-ing)

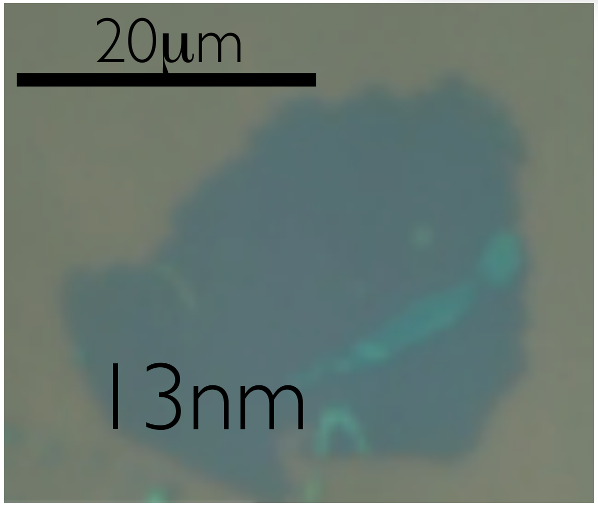
Exfoliated superconductors



L.J. Sandilands et al., PRB 82, 064503 (2010)







$Bi_2Sr_2Ca_{1-x}Dy_xCu_2O_{8+\delta}$

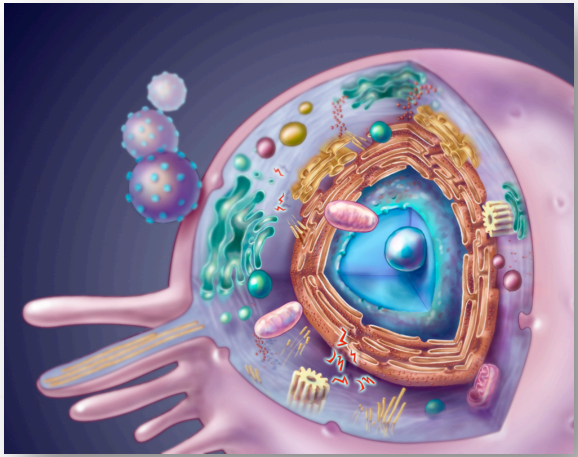
$x=0.3, 0.4$

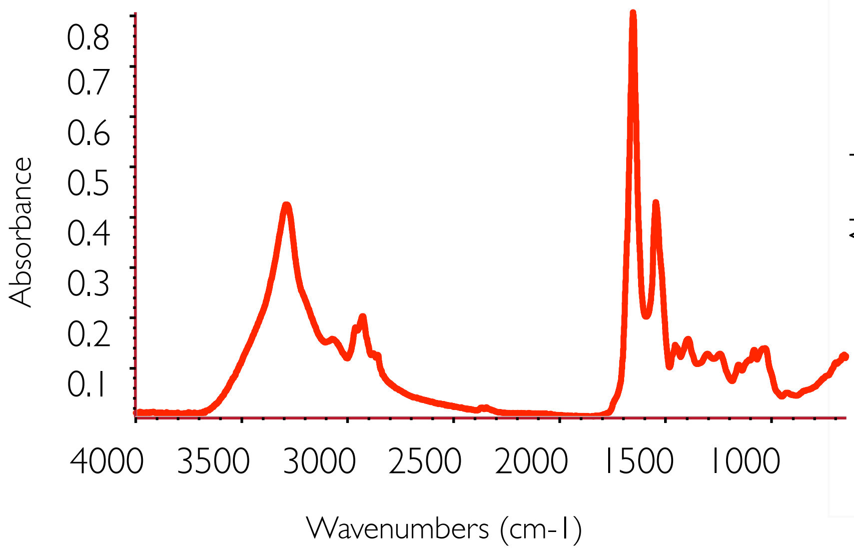
Topological insulators

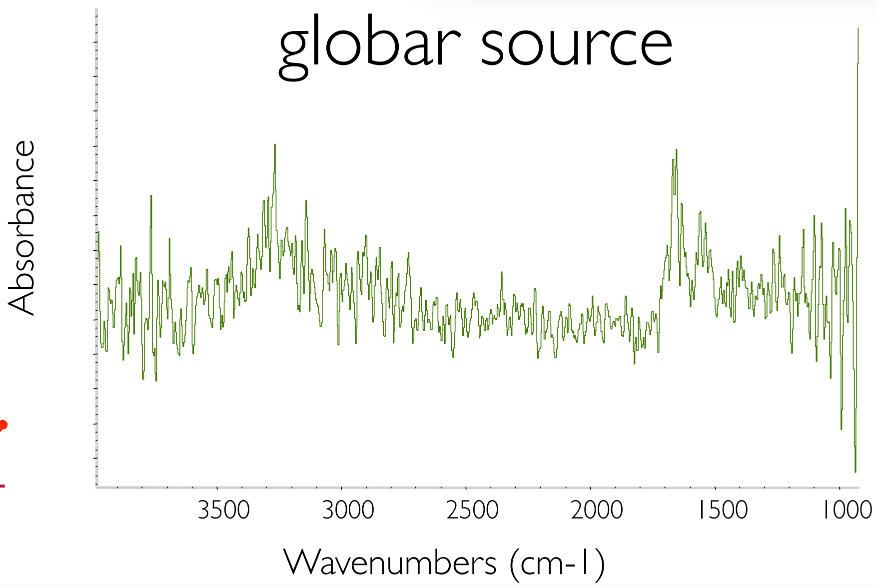
http://www.physics.utoronto.ca/~kburch/

Biology

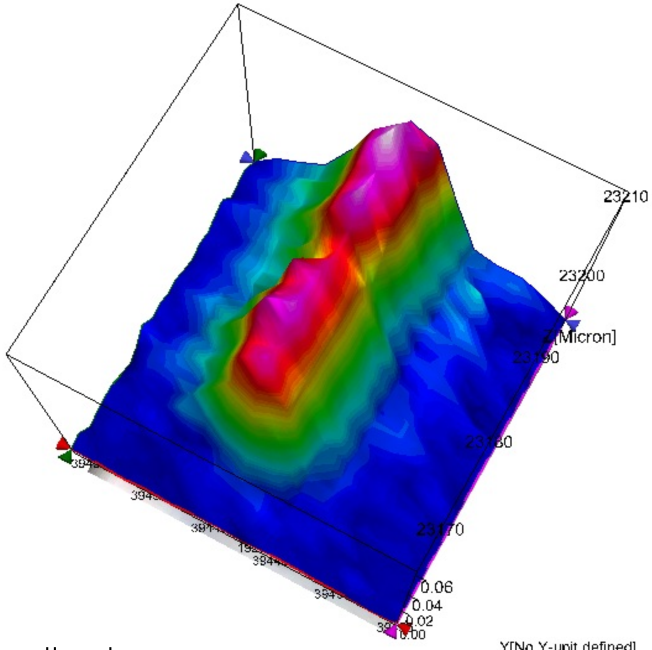
Ideal size range for resolution
Cells, tissues, bacteria, fungi



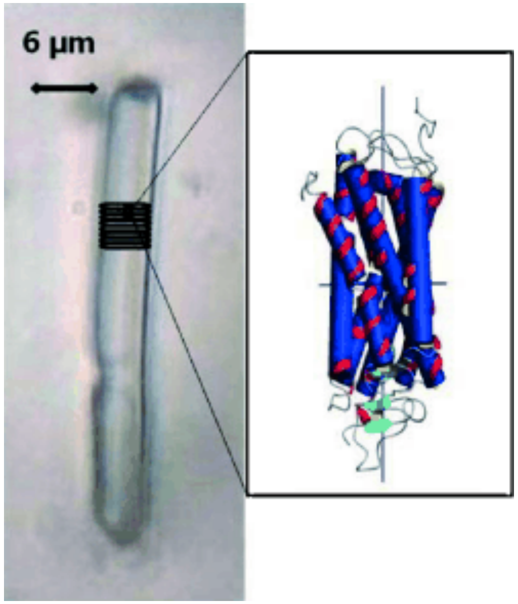




Spectromicroscopy in Rod Cells



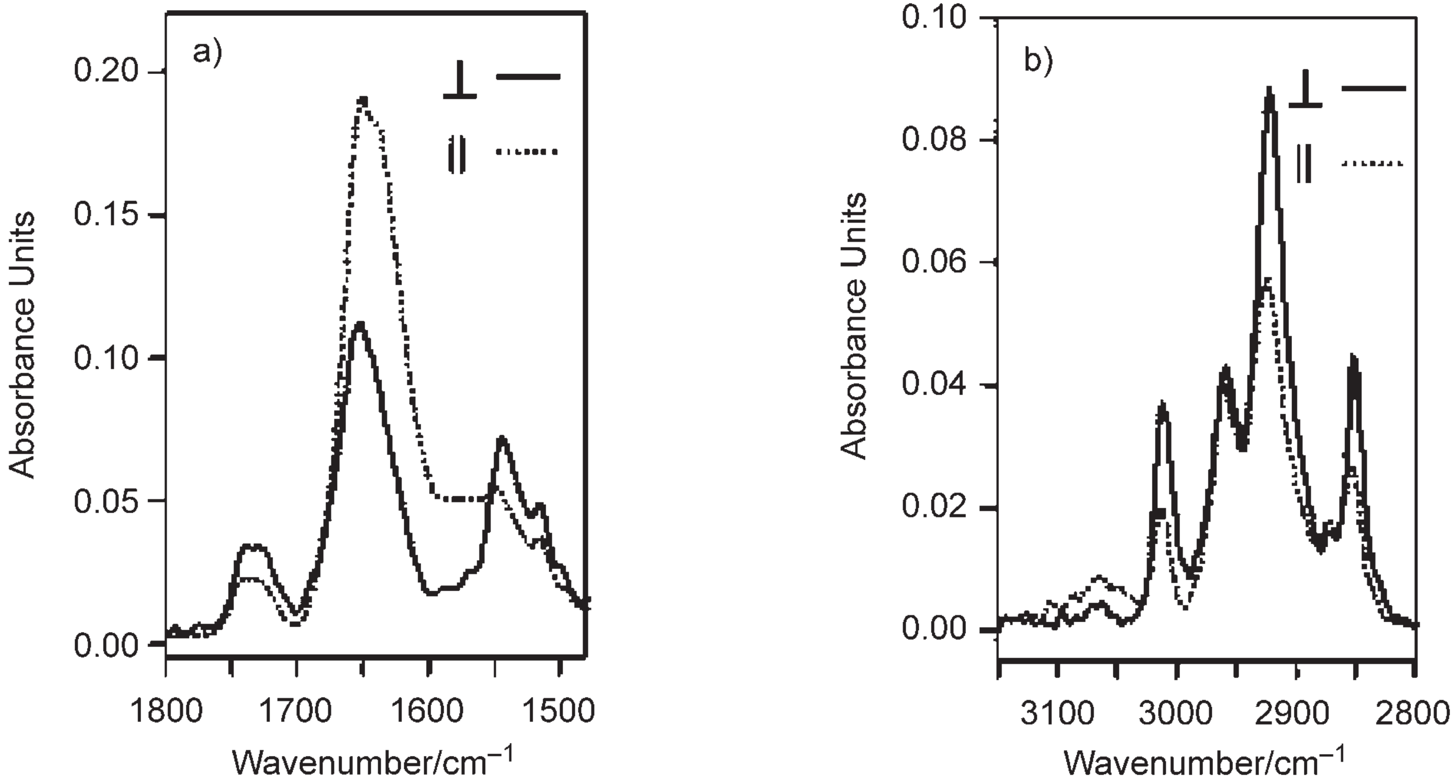
Lipid distribution:
absorbance at 2925 cm^{-1}



Measurement of molecular orientation in a subcellular compartment by synchrotron infrared spectromicroscopy

Quaroni et al., ChemPhysChem 9 (10) 1380-1382, 2008

Results – polarization studies



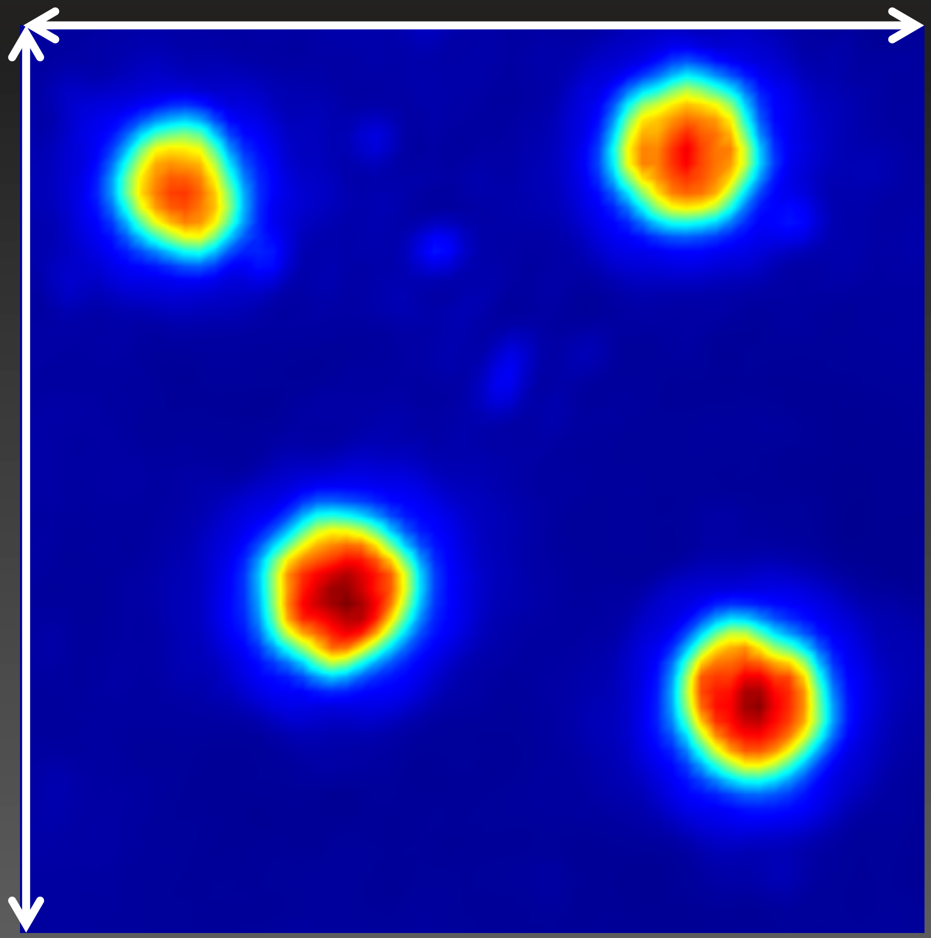
The measurement confirmed previous results obtained by crystallography on model systems.

Others

Chemical Imaging

Biology, medicine, etc.

…Materials Science



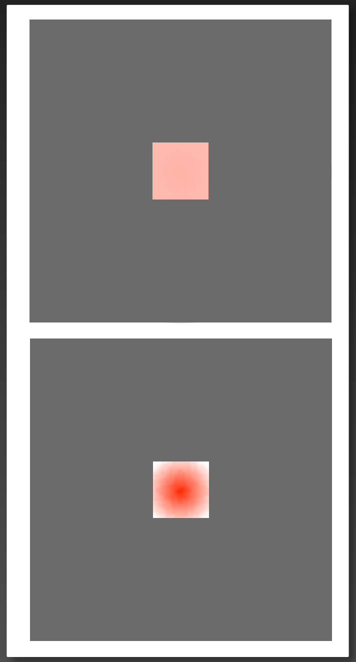
# of pixels: 128*128 = **16384**

Something to remember

Synchrotron = high brightness

Diffraction limited resolution

Small samples!



High spectral resolution

Data processing…another story

Resources

- CLS Mid-IR webpage http://midir.lightsource.ca
- ALS Infrared beamlines http://infrared.als.lbl.gov
- William Reusch: Virtual Textbook of Organic Chemistry http://goo.gl/NEUW
- David Attwood SR course (EE290f) at UC Berkeley (http://www.youtube.com/watch?v=1WWnxA6odso)
- Wolfram Demonstrations Project (http://demonstrations.wolfram.com)
- Synchrotron Simulator
  T. Shintake, Nuclear Instruments and Methods in Physics, 507 (1-2), 89-92 (2003)
  (http://www-xfel.spring8.or.jp/dlmonitor.html)

Contact

Ferenc Borondics

Mid-IR beamline

Canadian Light Source

Ferenc.Borondics@lightsource.ca

http://midir.lightsource.ca