The 4GLS Project

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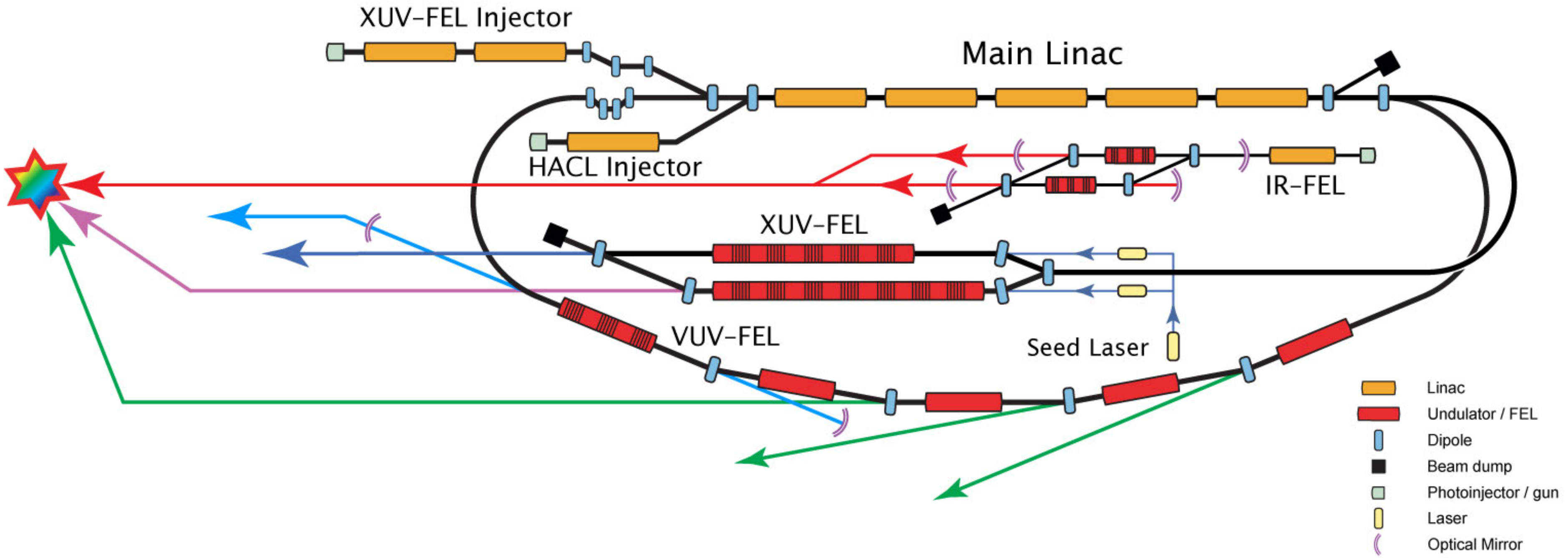
The 4GLS Design

4GLS combines superconducting ERL, SR and FEL technology in a multi-source facility

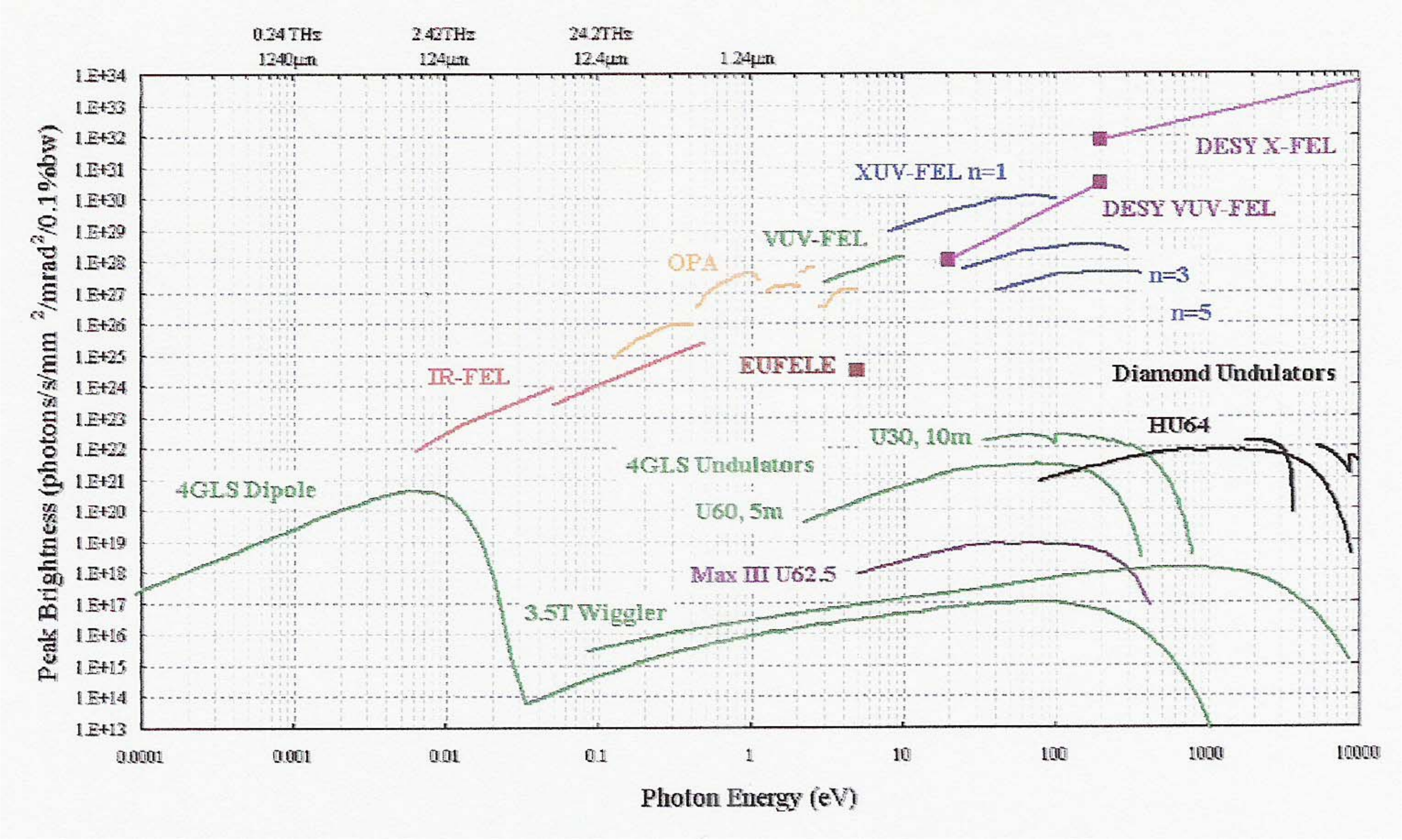
Stimulated emission sources: free electron lasers
Spontaneous emission sources: undulators and bending magnets
Combinations of sources: internal or with conventional lasers



750 MeV, 100 mA emittance < 1 nm rad, bunch length 50 fs - 50 ps

Conceptual design report available at http://www.4gls.ac.uk

4GLS Ouput: Peak Brightness



"Scientific advance is more often driven by the development of a new tool than a new concept"

Freeman Dyson

In a review of a biography of the mathematician George Green

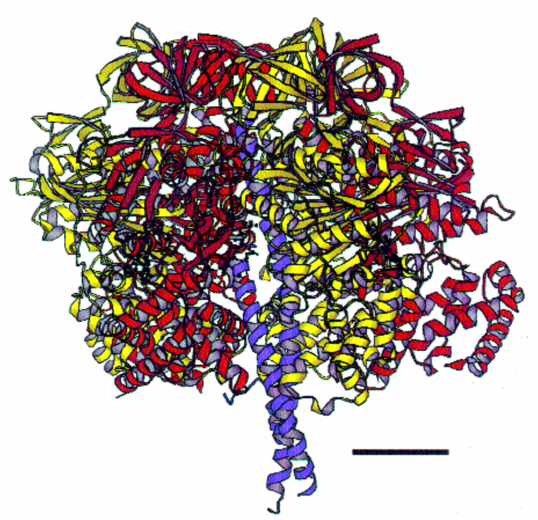
4GLS Complements the Diamond Synchrotron

Frances Crick "If you want to understand function study form"

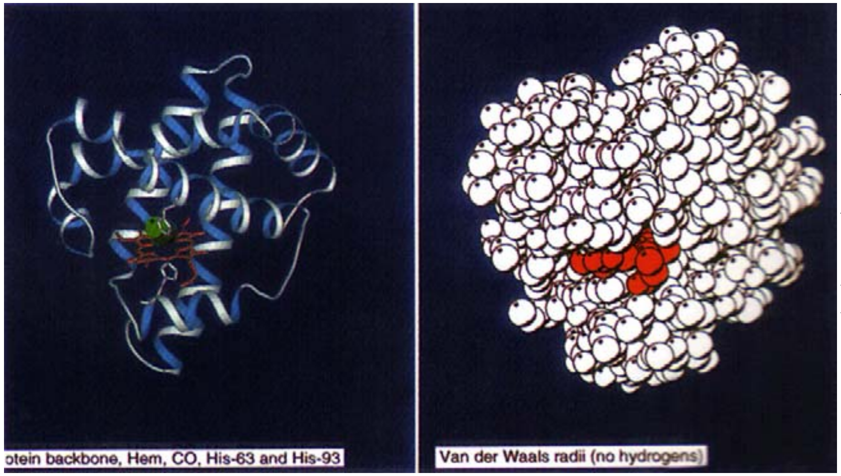
Sometimes structure gives insight into function DNA, ATP synthase

Often it doesn't:- Hemoglobin. How do the Fe groups interact?

Strucure of ATP synthase
from protein crystallography



Structure of Myoglobin
from protein crystallography



The structure must
be dynamic.

Where are the channels?

How do they open and close?

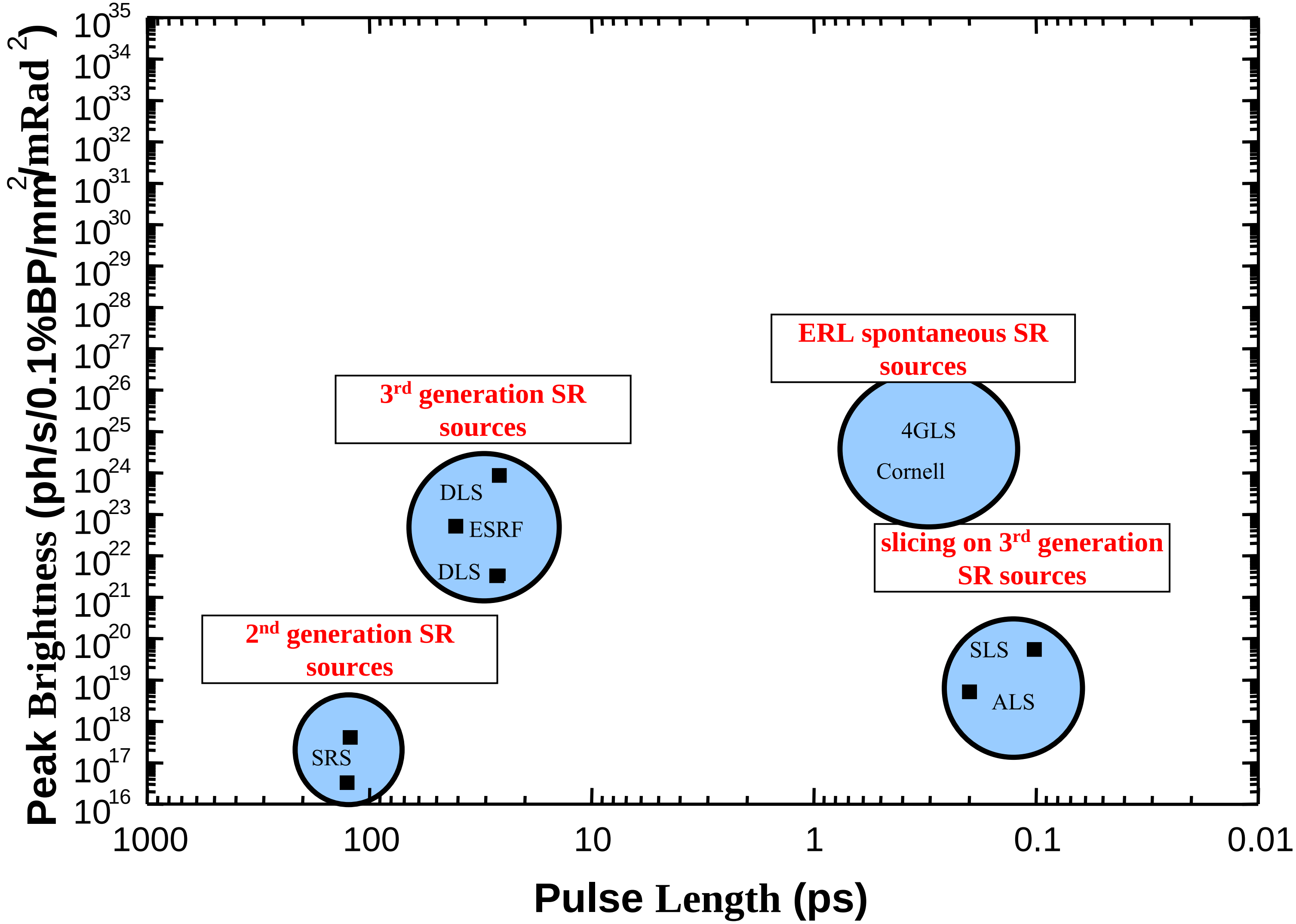
Over what timescales?

4GLS will provide insight into function directly

From fast spectroscopy and sub-cellular imaging.

Particularly useful for studies of membrane proteins: difficult to crystallise

Linac-based light sources:



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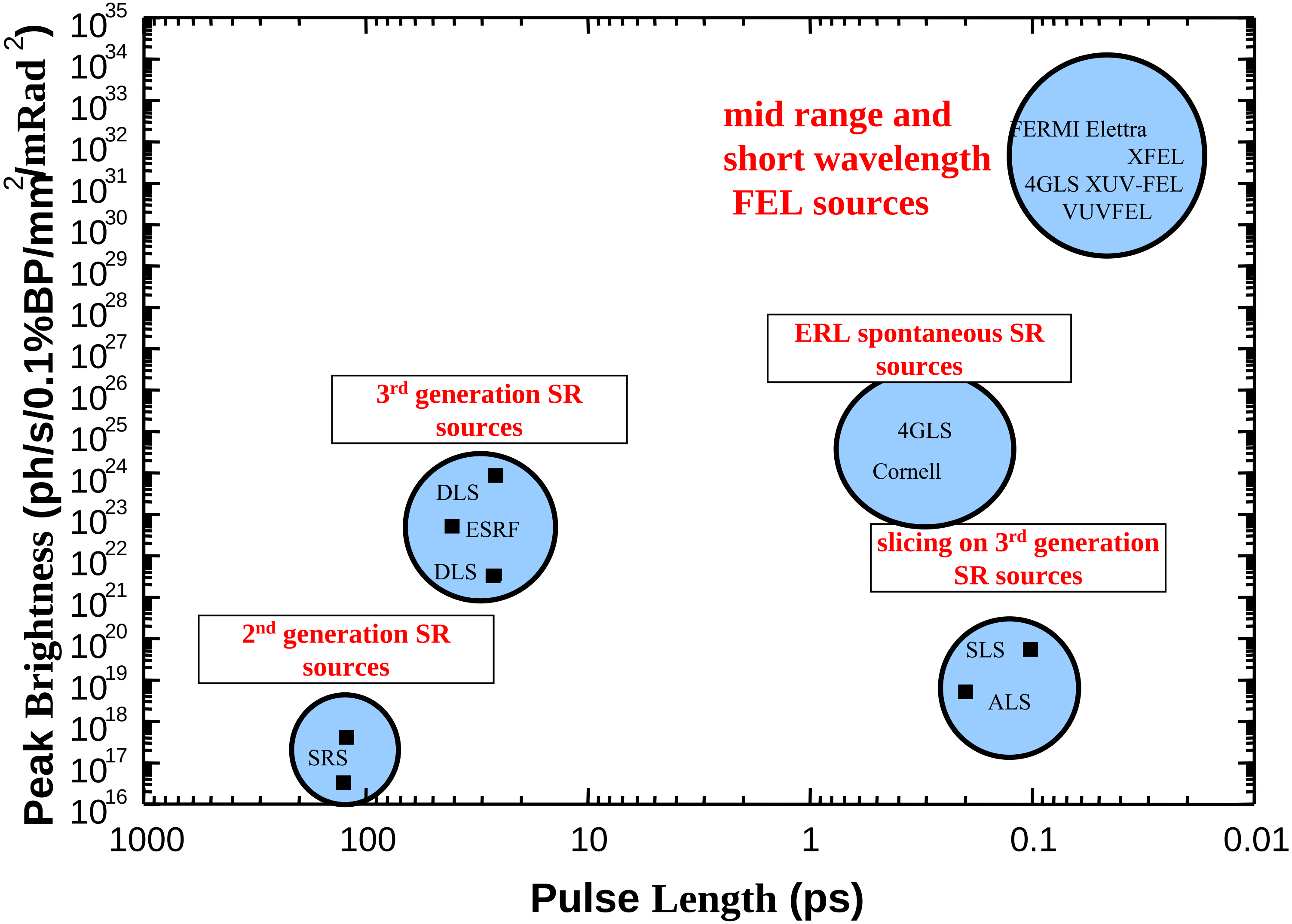
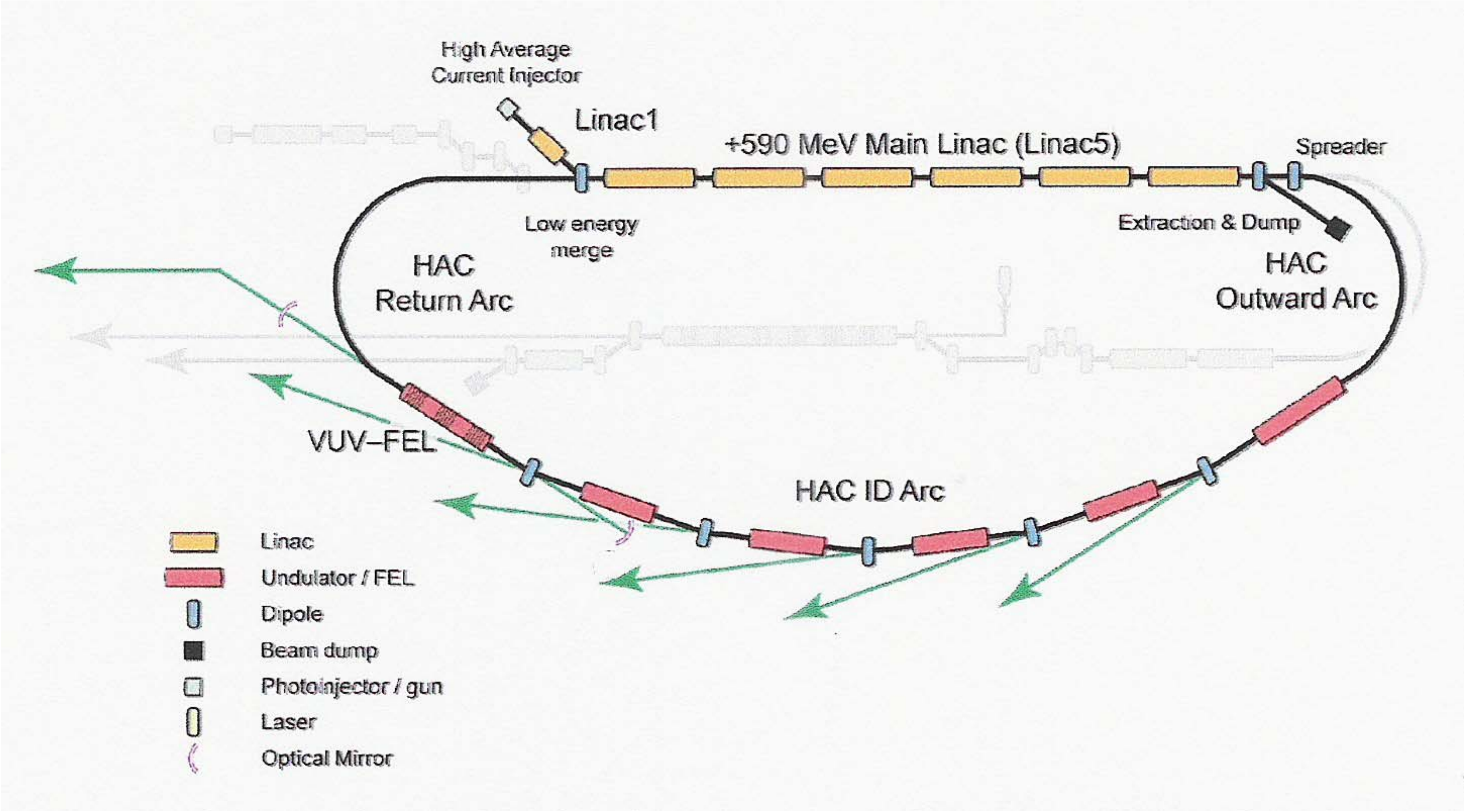


The 4GLS Design

4GLS: High Average Current Loop



Conceptual design report available at http://www.4gls.ac.uk

4GLS Terahertz beamlines: Output

High Average Current Loop

Maximum Average Flux	$2\text{x}10^{21}$ photons/0.1%BW at 3 meV
Energy per pulse	$1\text{x}10^{-4}$ μJ
RMS bunch length	100 fsec
Repetition rate	1.3 GHz
Average power	2600 W
Peak power	6 MW

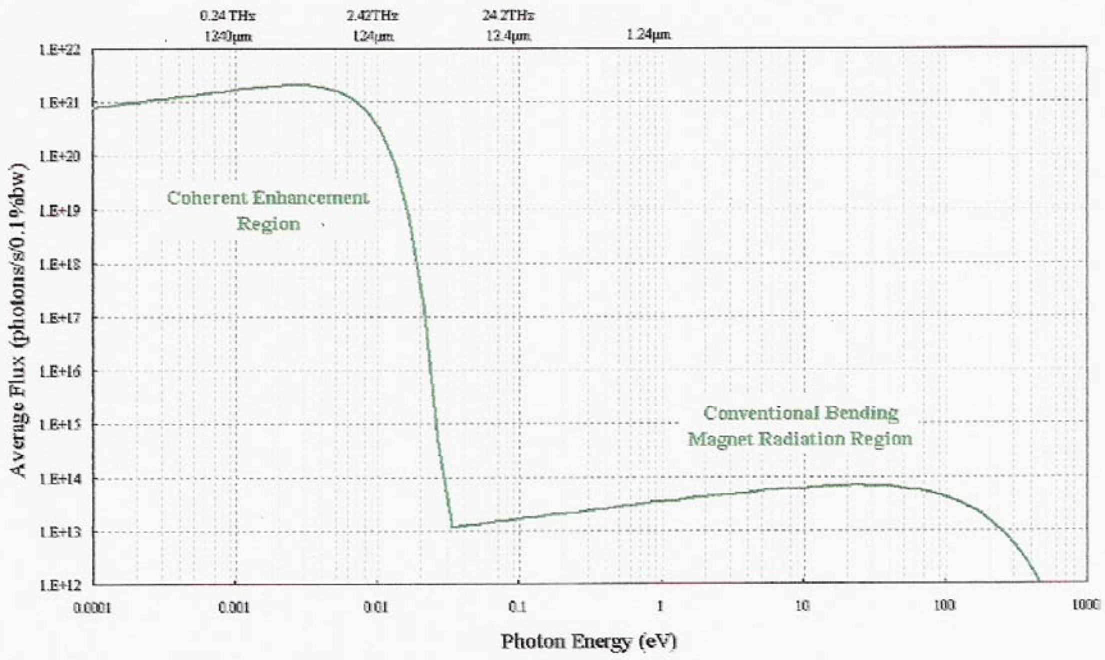
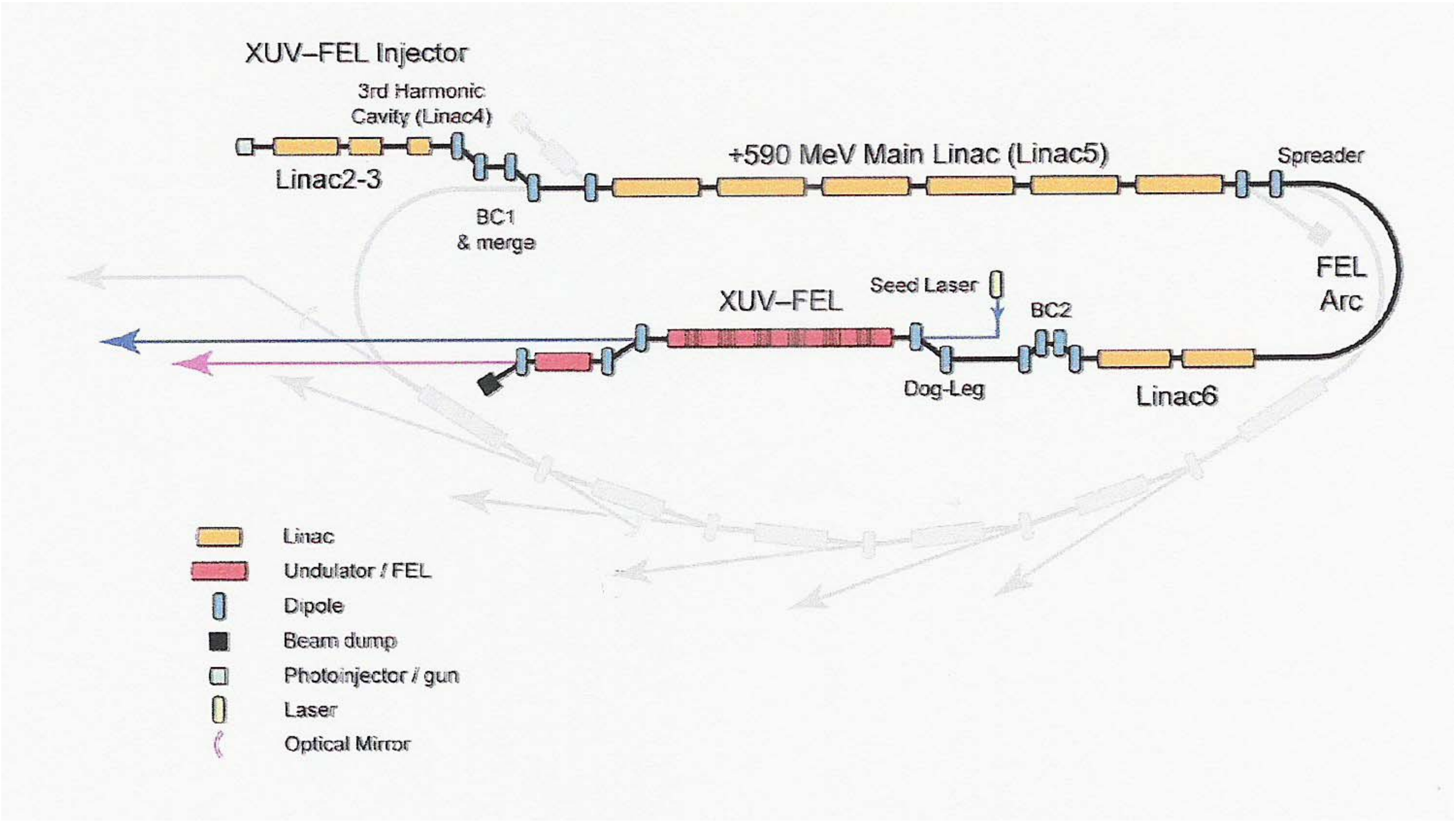


Figure 9.6 Average flux from a 0.35 T bending magnet into a 50 mrad aperture with 100 mA beam current and RMS bunch length of 100 fs.

The 4GLS Design

4GLS: XUV FEL



Conceptual design report available at http://www.4gls.ac.uk

4GLS Terahertz beamlines: Output

XUV-FEL branch

Maximum Flux per pulse	**$2x10^{14}$ photons/0.1%BW at 1 meV**
Energy per pulse	**90 μJ**
RMS bunch length	**266 fsec**
Repetition rate	**1 kHz**
Average power	**0.09 W**
Peak power	**100 MW**

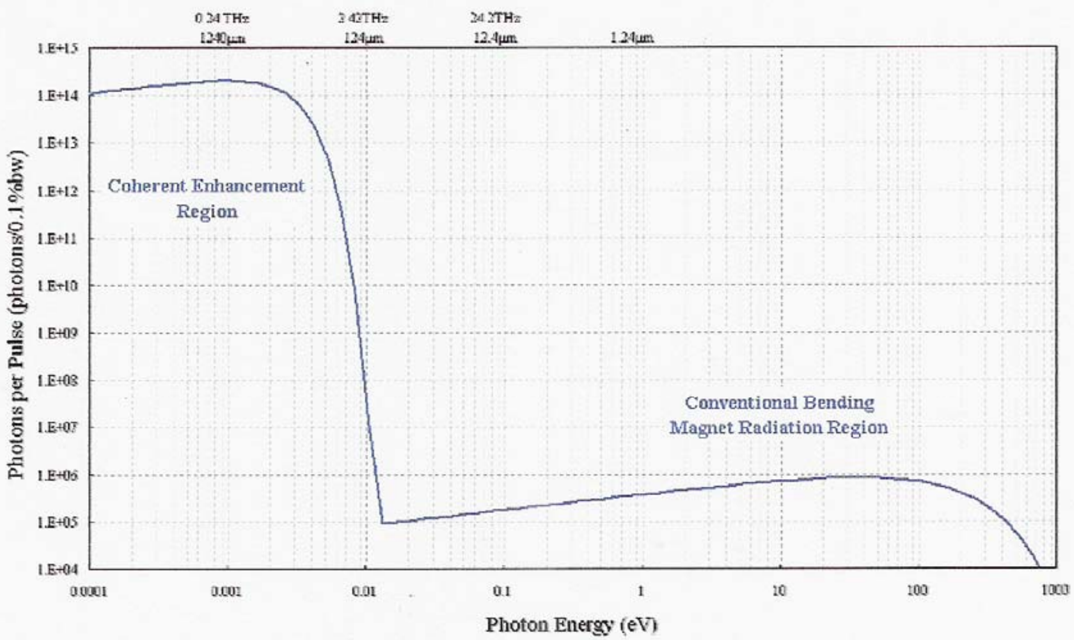
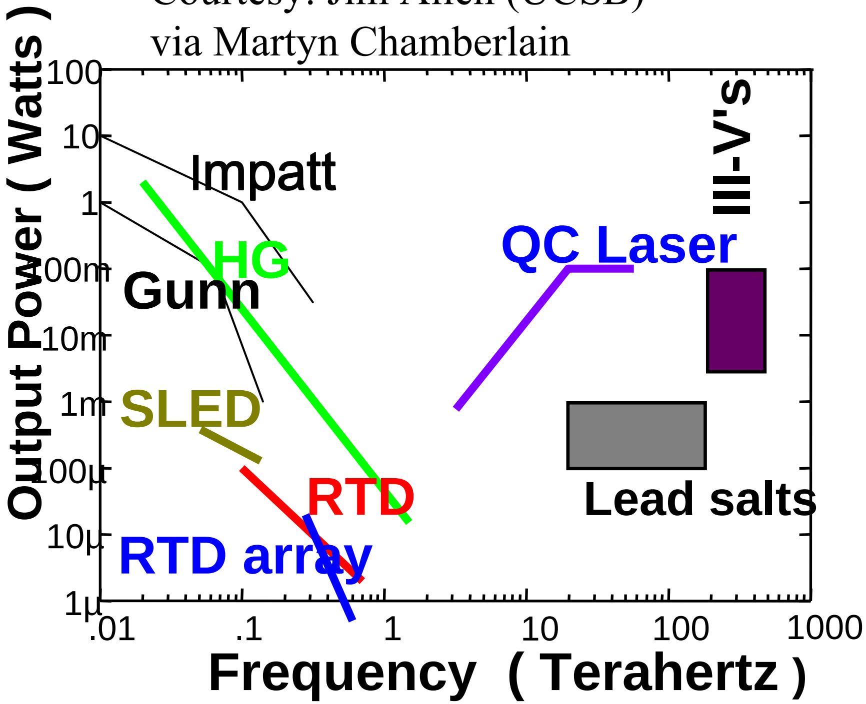
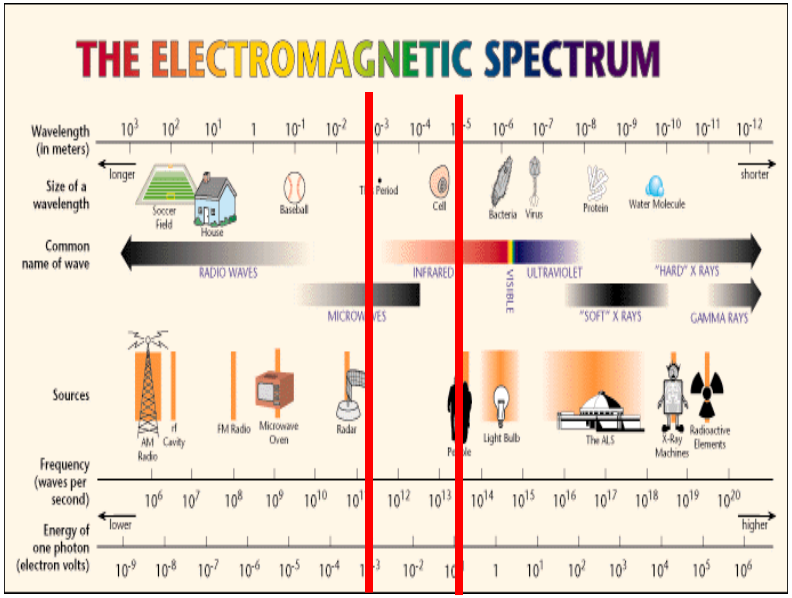


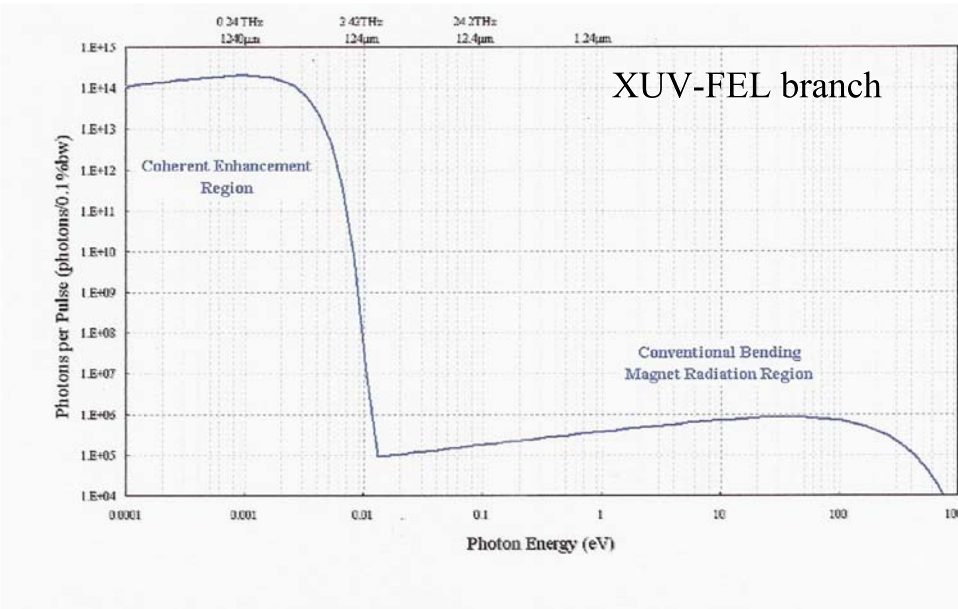
Figure 9.8 Flux per pulse from a 0.35 T bending magnet into a 50 mrad aperture with 1 nC bunch charge and RMS bunch length of 266 fs in the XUV-FEL branch at 750MeV.

Extending Spectral Range: Terahertz

Courtesy: Jim Allen (UCSB)
via Martyn Chamberlain







4GLS: Fills the Terahertz Gap

Maximum Flux per pulse	**2×10^{14} photons**
RMS bunch length	**266 fsec**
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Average power	**0.09 W**
Peak power	**100 MW**

4GLS Flagship Proposals

1 Origins (M. McCoustra, University of Heriot Watt)

2 Spintronics (S. Thompson, University of York))

3 Nanocomposites (B. Hamilton, University of Manchester)

4 Quantum chemical control (I. Powis, University of Nottingham)

5 High field physics (L. Frasinski, University of Reading)

6 Molecular assemblies in extra-cellular matrix and cell signaling

(D. Fernig, University of Liverpool)

7 Biocatalysis, photosynthesis and membrane proteins

(N. Scrutton, University of Manchester)

8 Protein structure and dynamics (D. Klug, Imperial College)

9 Cell and tissue imaging (P. O'Shea, University of Nottingham)

10 Catalysis (R. Catlow, UCL)

11 Nuclear astrophysics (R. Herzberg, University of Liverpool)

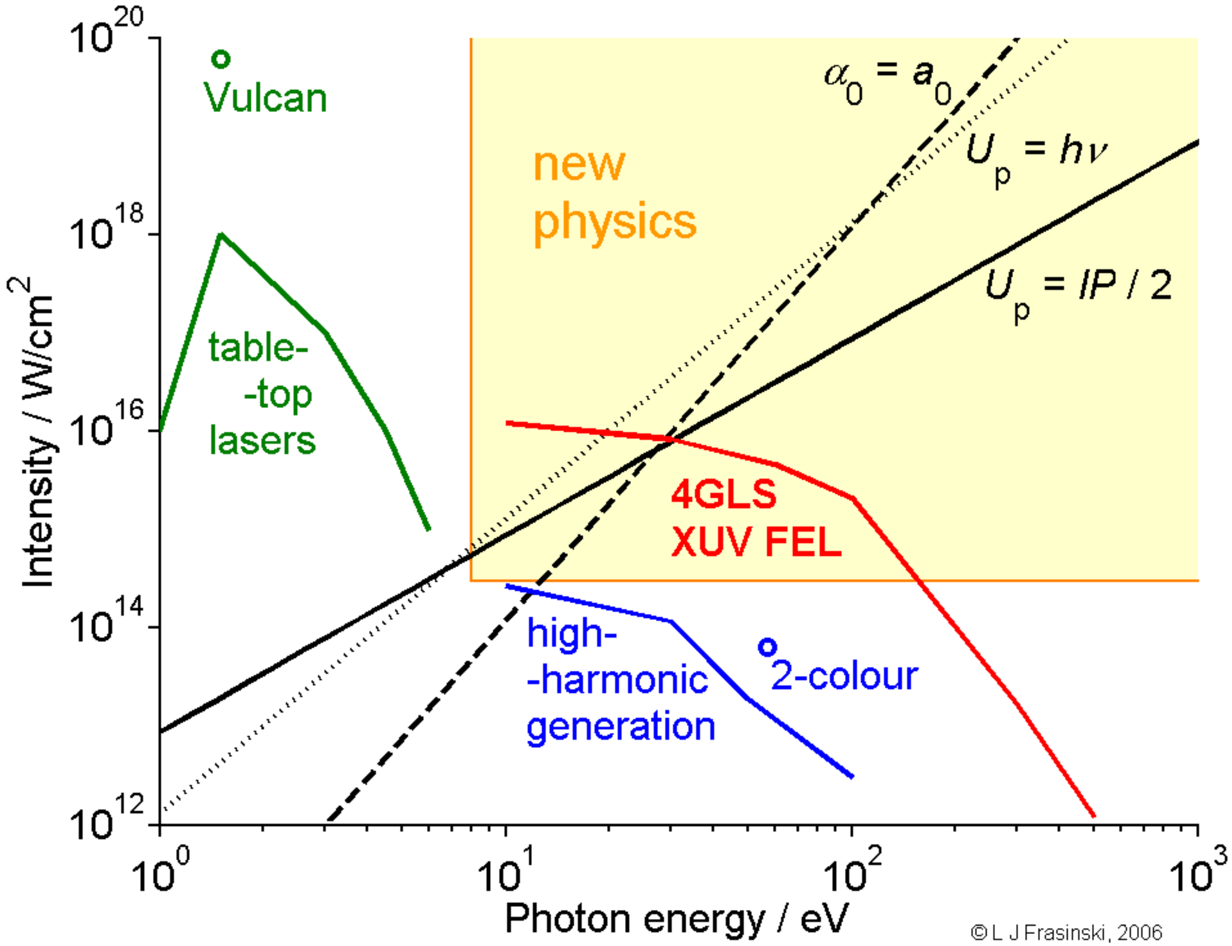
Summary: "4GLS Science Landscapes" available at http://www.4gls.ac.uk

High Field Physics

Leszek Frasinski

4GLS: Potential for Major Advances: New Physics

Uncharted Territory of Strong Field Science at High Frequencies



α_0 amplitude of electron quiver motion

U_p ponderomotive potential

Aims:

- **Molecular structure and dynamics can be probed with an unprecedented resolution on ångström spatial and attosecond temporal scales.**
- **Quantum-state tomography can reveal the fundamentals of chemical reactions.**
- **Unique parameter regime enables intense-field interactions with atoms and molecules.**

Ångström structural resolution with *attosecond* temporal resolution

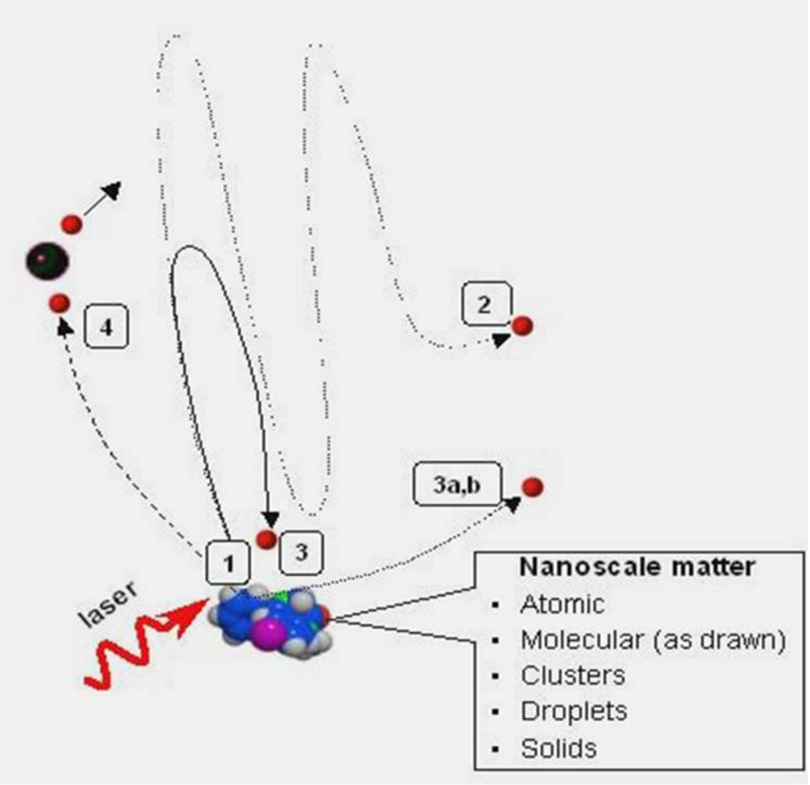
Reaction dynamics is probed through tomographic imaging of molecular orbitals.

Recollision-induced processes in a molecular sample.

Following ionisation (1) the electron may be driven away (2) or recollide (3) with the molecule depending on the field phase at the instant of ionisation.

If recollision occurs the electron can
(a) recombine – with the emission of a higher energy photon,
(b) scatter elastically or inelastically from the molecule.

In a dense sample the outgoing electron may collide with neighbouring atoms or molecules (4).



The interpretation is testing the limits of quantum mechanics

Ångström structural resolution with *attosecond* temporal resolution

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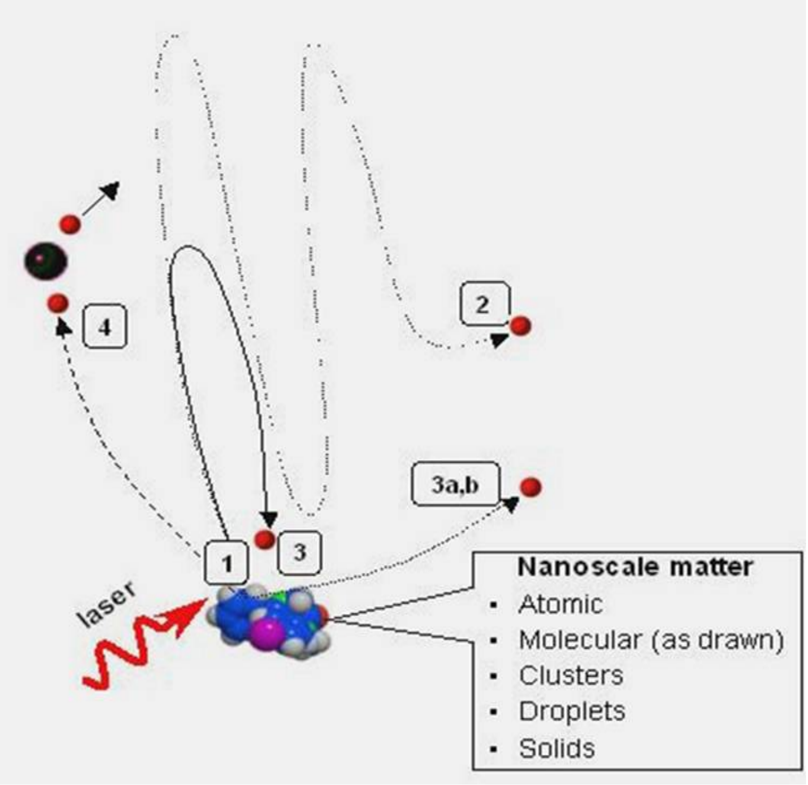


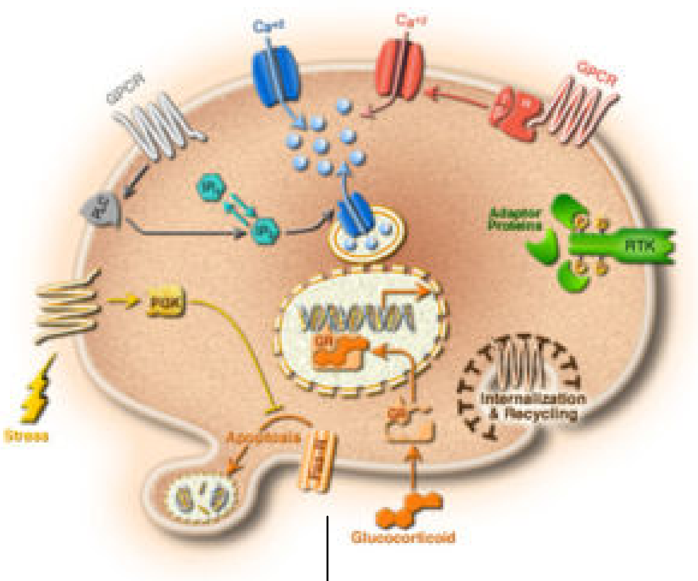
The interpretation is testing the limits of quantum mechanics

"In this meaninglessness one finds usefulness"

Leszek Frasiński

Biological and Medical Fields

The Cell is the Atom of Biology



Theory

Non-equilibrium thermodynamics
complexity, information theory
statistical mechanics

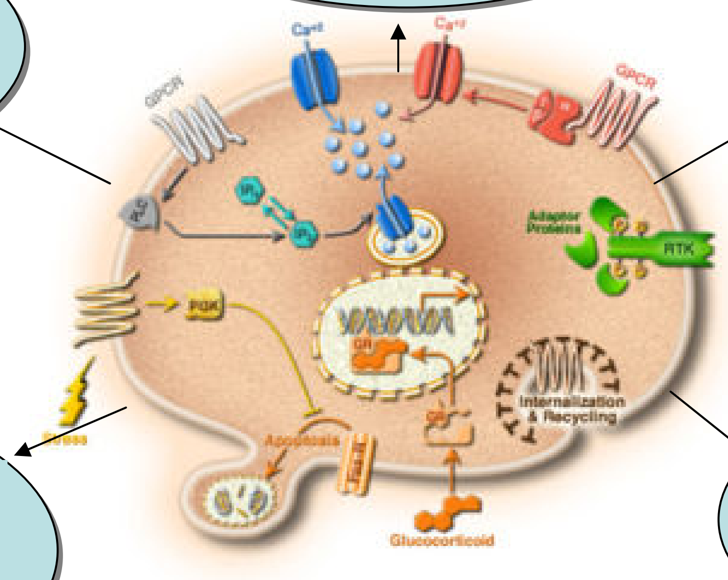
Biological and Medical Fields

The Cell is the Atom of Biology

The extra-cellular matrix
cell signaling
wound healing, disease

Enzymes and enzyme catalysis
biocatalysis, photosynthesis

Membranes and membrane proteins
cell signaling
pharmaceutical targets



Cell and tissue imaging
sub cellar structures and dynamics

Protein structure and dynamics
pharmaceutical screening
proteomics

Protein Structure and Dynamics

David Klug

Principle of 2D IR

2D IR: A pump probe experiment: H bond between amino acids

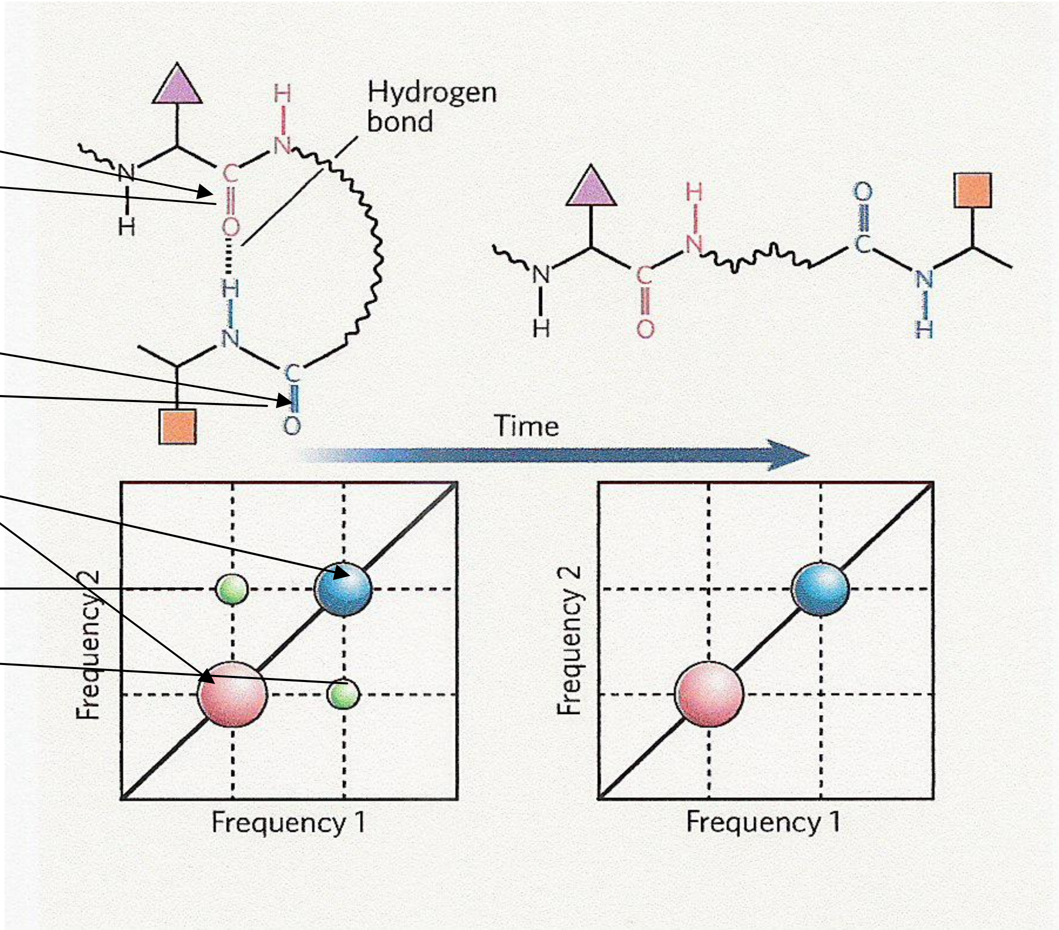
Pump

Probe

Pump

Probe

Long range coupling



M. Cho Nature **444** 431 2006

As the Hydrogen bond breaks and the protein changes conformation the long range coupling between the local modes weakens

Example of 2D IR

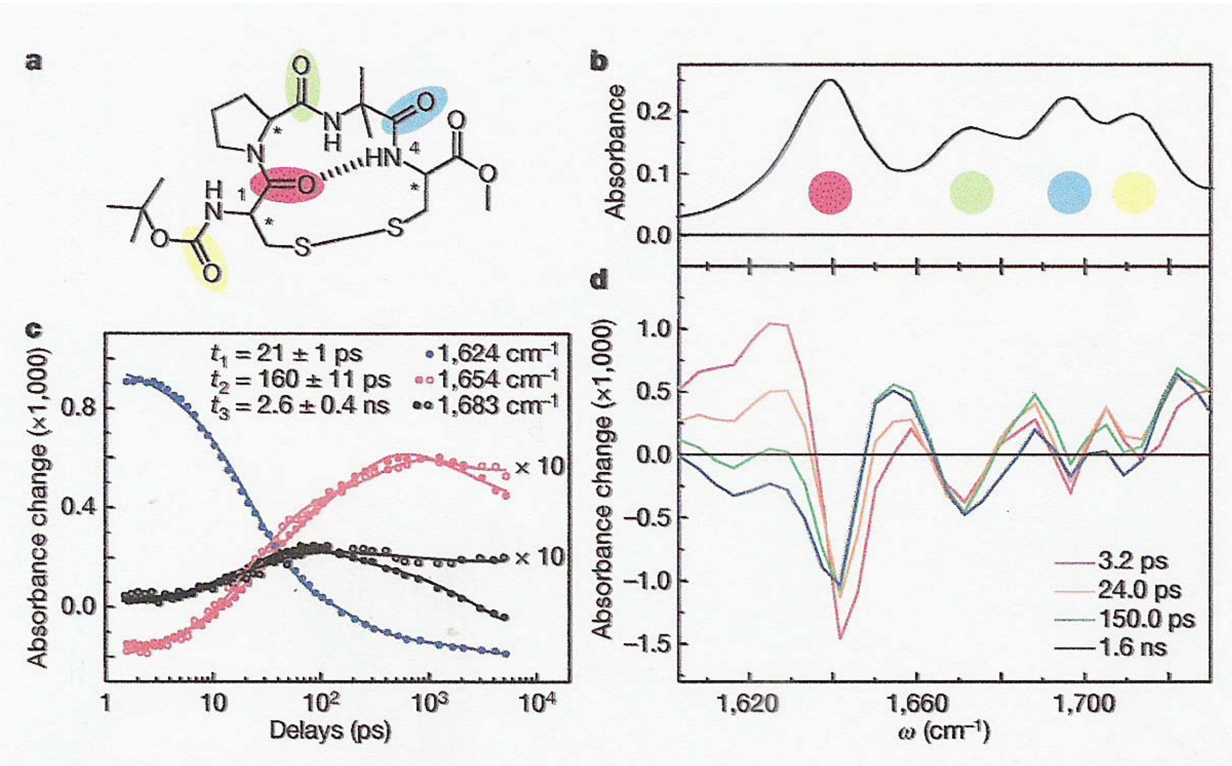
2D IR: Watching H bond dynamics in a β turn

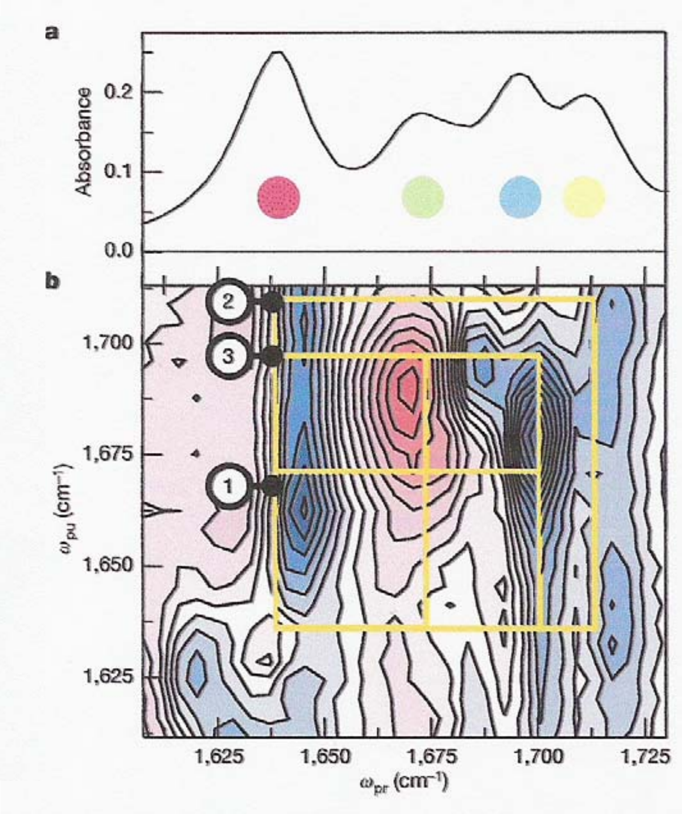
Small amino acid sequence forming a β turn linked by a S-S bond

Boc-Cys-Pr-Aib-Cys-Ome

Time dependence of IR spectrum following breaking of S - S bond by UV pulse

2D IR spectrum following breaking of S-S bond

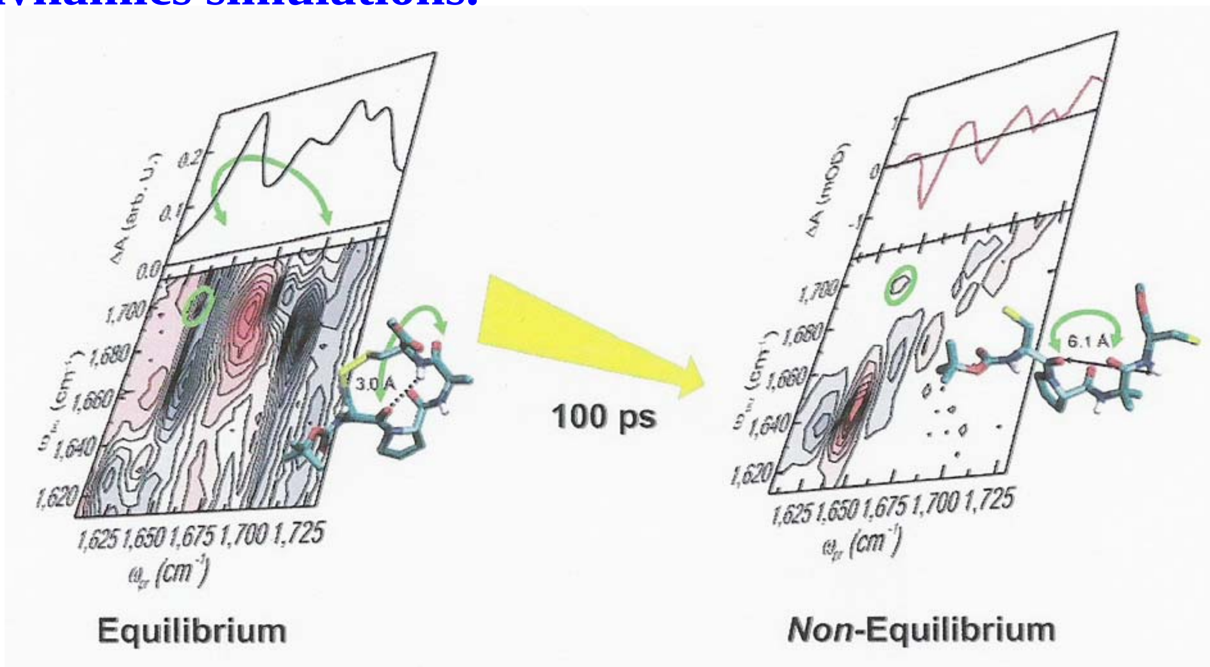




C. Kolano, J. Belbing, M. Kozinski, W. Sander and P. Hamm Nature **444** 469 2006

Example of 2D IR: Conclusion

The hydrogen bond separates at a rate that is two orders of magnitude faster than the "folding speed limit" between protein side chains given by molecular dynamics simulations.

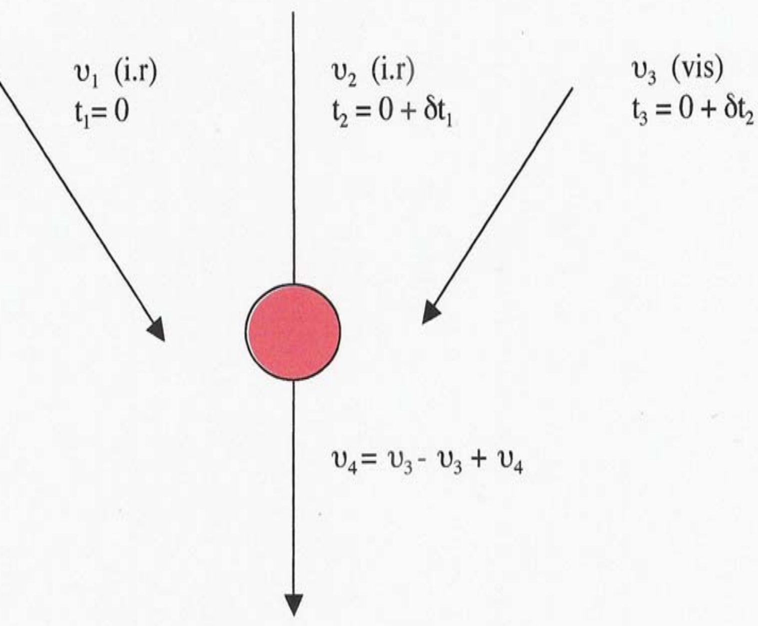


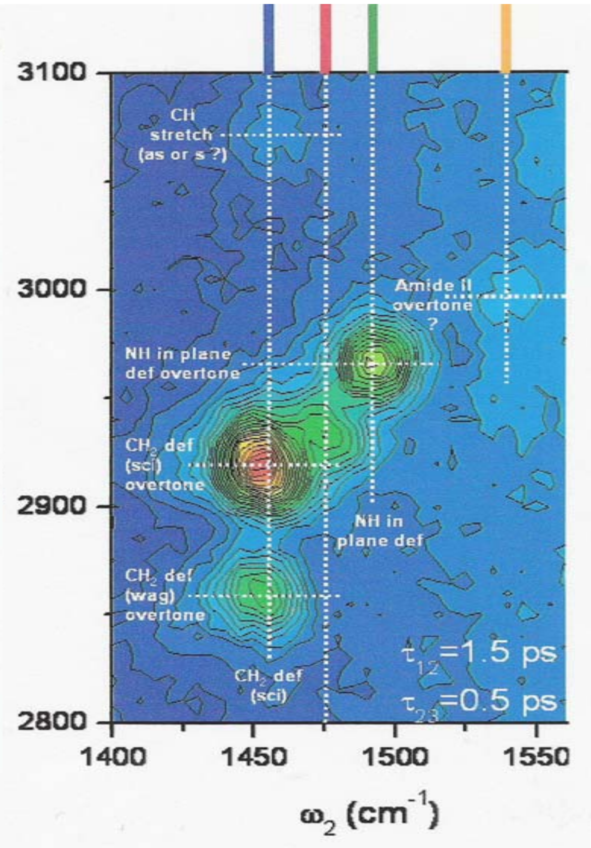
Following rupture of S-S bond system evolves on time scales of 20 ps, 160 ps and 2.6 ns

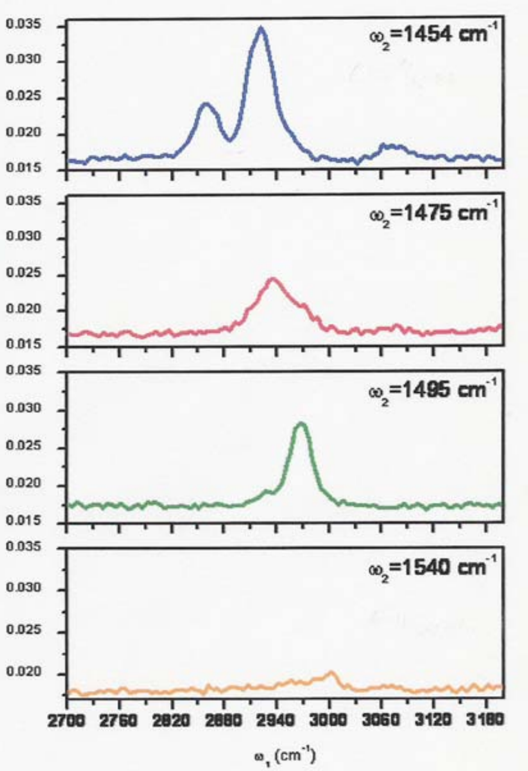
UV pulse to cleave S-S bond: 2 experiments with UV on and with UV off
Variable delay after UV pulse before starting 2D IR experiment
Vary delay between pump and probe IR pulses: 3 ps, 25 ps, 100 ps: 2D maps
Parallel and perpendicular polarisations of pump and probe pulse to enhance cross peaks
2D map is limited by signal to noise

DOVE-FWM: Double Vibrationally Enhanced Four Wave Mixing

: vibration-vibration coupling in polyhistidine (Courtesy David Klug)







δt_1 and δt_2 vary from 0 to 20 psec.

beam overlaps to > 2% on 0.1 mm

υ_1 and υ_2 are varied independently

υ_1, υ_2 and υ_3 impinge collinearly onto specimen

υ_1 and υ_2 line widths of 10 to 40 cm^{-1}

Scanning υ_4 gives a 2D map of 100 x100 pixels

4GLS: Potential for Major Advances: Protein Function: 2D IR

Mid IR FEL 0.5 eV to 0.05 eV Far IR FEL 0.05 eV to 0.005 eV THz 0.005 eV to 0.0001 eV

4GLS will open a spectral "area" 10 x greater than currently explored with 2D IR

Nine tenths of the structural-dynamics elements of a protein will remain hidden without 2D IR on 4GLS

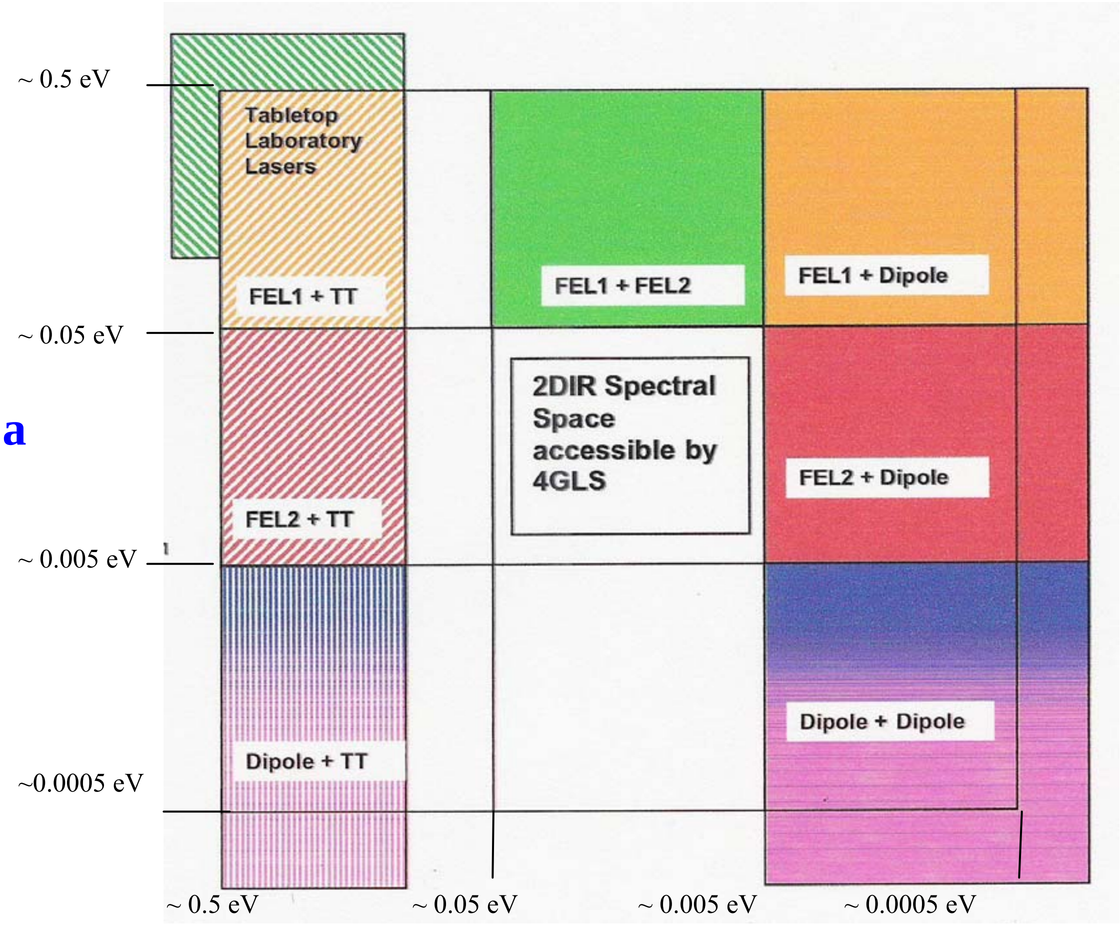
Potential for fast through put

Protein analysis ~ 10^4 faster than with laboratory 2D IR instruments

Complete proteome of a cell line in a few minutes

Screen 10^6 potential drug molecules against 10^3 proteins in 6 weeks

Equivalent cost with laboratory instruments £ 5 billion



Enzyme Catalysis

Nigel Scrutton

Enzyme Catalysis and 4GLS

Enzyme mechanisms – current the state of the art

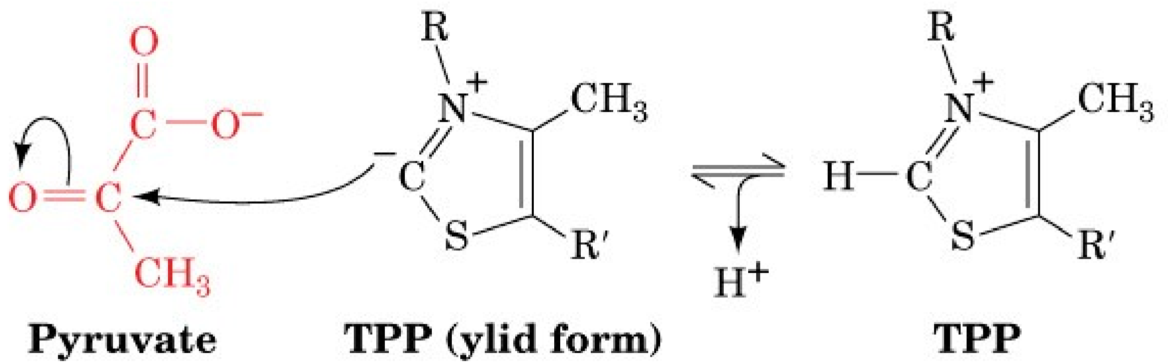
Good appreciation of reaction mechanism *i.e.* 'electron flow'

Good appreciation of enzyme structure and 'static' view of mechanism inferred from protein crystallography

Something is missing in our physical understanding of enzyme catalysis

Observe a 10^{21} fold increase in reaction rate over reference reaction in absence of an enzyme

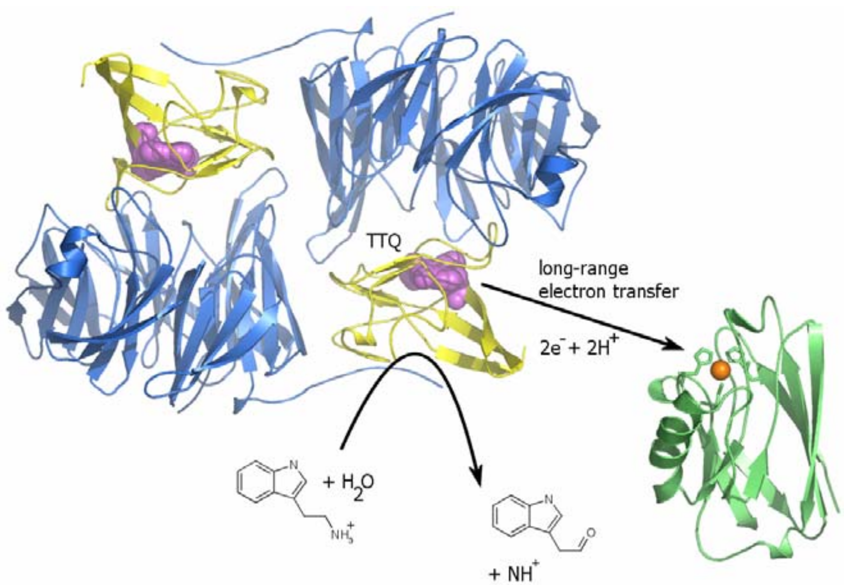
Current <u>physical models</u> (eg transition state theory) only account for ~10^6

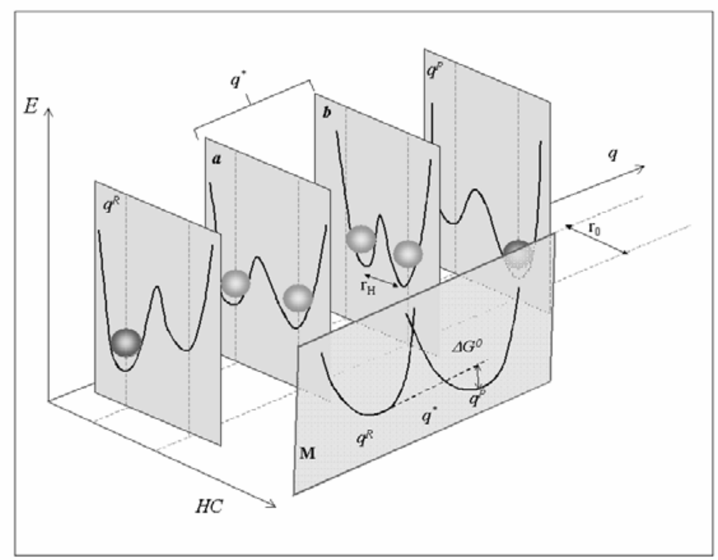


Courtesy Nigel Scrutton

Fast tunnelling models for enzyme catalysis: H and electron-transfer

- New theory emerging that fundamentally challenges TST for enzymes
- Protein motion (millisecond to sub picosecond) modulates barrier properties (*i.e.* 'squeezing') to facilitate tunnelling
- Fast (sub-picosecond) small-scale promoting vibrations/motions promote H-transfer and electron transfer by quantum tunnelling mechanisms.
- Large-scale motion also narrows the barrier in electron transfer





Masgrau *et al.*, *Science* in press

Leys, Sutcliffe & Scrutton *Nature Struct. Biol.* (2003)

Courtesy Nigel Scrutton

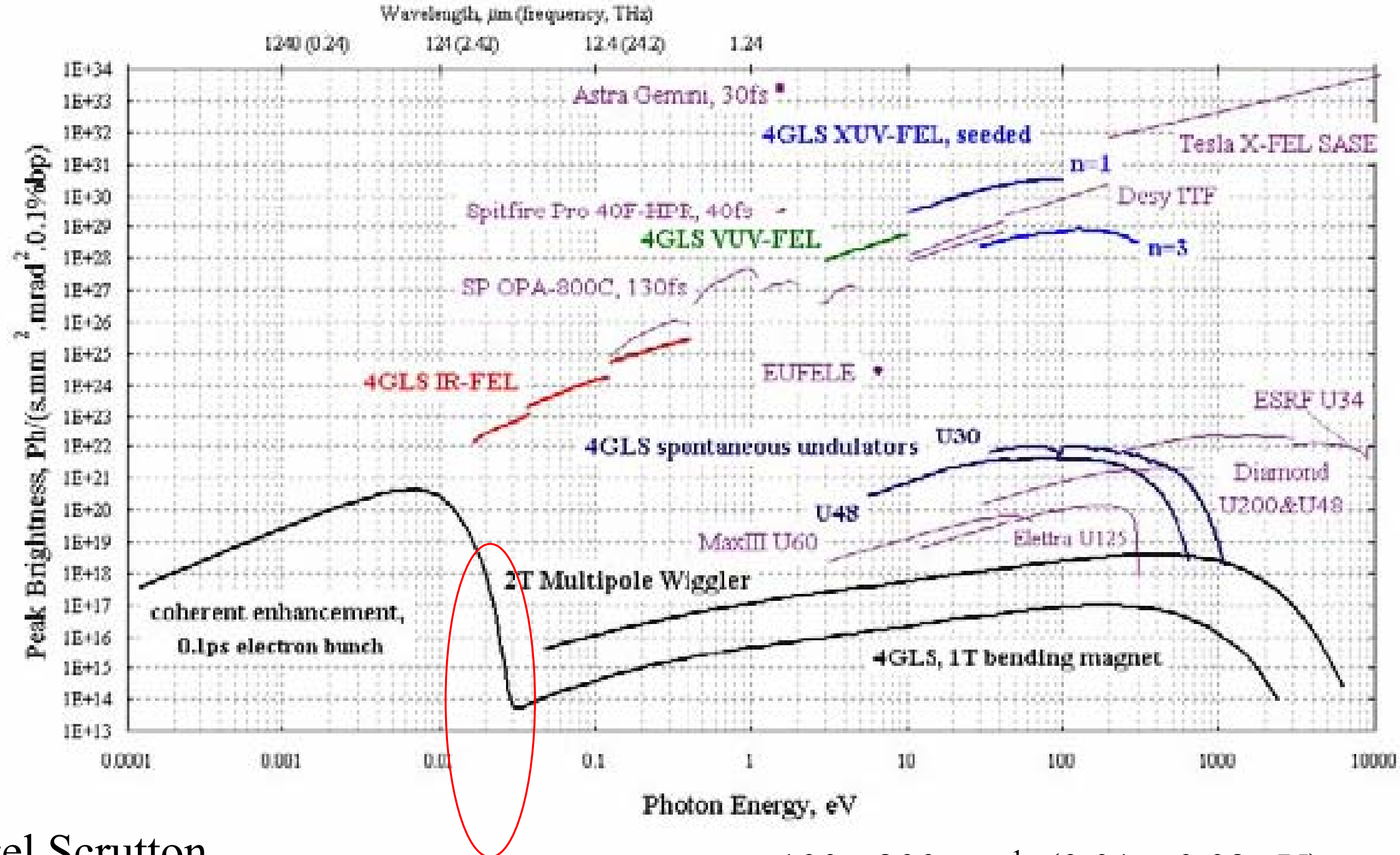
Timescale limitations for studies of biological mechanism

ms and longer (stopped-flow methods)
ms to ms (equilibrium perturbations methods)
ns to ms (photolysis methods/fluorescence)

Computationally <10 ns, but no experimental methods that get us faster than ns time domain

4GLS gets us into this experimental time domain

THz excitation of low frequency protein modes



Courtesy Nigel Scrutton

100 - 200 cm^{-1} (0.01 – 0.03 eV) range

Summary: Enzyme Catalysis Flagship

- **Our knowledge of mechanism is mainly descriptive (curly arrow and structural 'snapshots')**
- **Quantitative analysis is restricted by incomplete physical models and limitations on experimental timescales**
- **4GLS is required to test experimentally new physical frameworks for enzyme catalysis**
- **Fast time domains open up studies of coupled motions and highly reactive intermediates (e.g. radicals)**
- **4GLS will catalyse a 'step change' in our experimental capability and understanding of enzyme catalysis and mechanism**

Courtesy Nigel Scrutton

Extra-Cellular Matrix

David Fernig

4GLS and the Extra-Cellular Matrix

Consists of molecular assemblies of proteins and polysaccharides (glycosaminoglycans)

A key regulator of cell function, and hence organ and organism function

The Central Problem

How does the structure of glycosaminoglycans drive their functional interactions with other molecules of the extracellular matrix and the cell surface to regulate cell activity?

Medical Relevance

Cancer eg. FGF, VEGF and angiogenesis in carcinomas.
Neurodegeneration eg. BACE in Alzheimer's and PrP in CJD.

Inflammation eg. cytokines in RA, asthma, skin.

Congenital disorders eg. craniosynotoses, dwarfism, EXTs, SGB.

Pathogens eg. HIV, herpes, malaria, chlamydia.

David Fernig

Macromolecular assemblies in the matrix

Macromolecular concentration:
~400 mg/mL

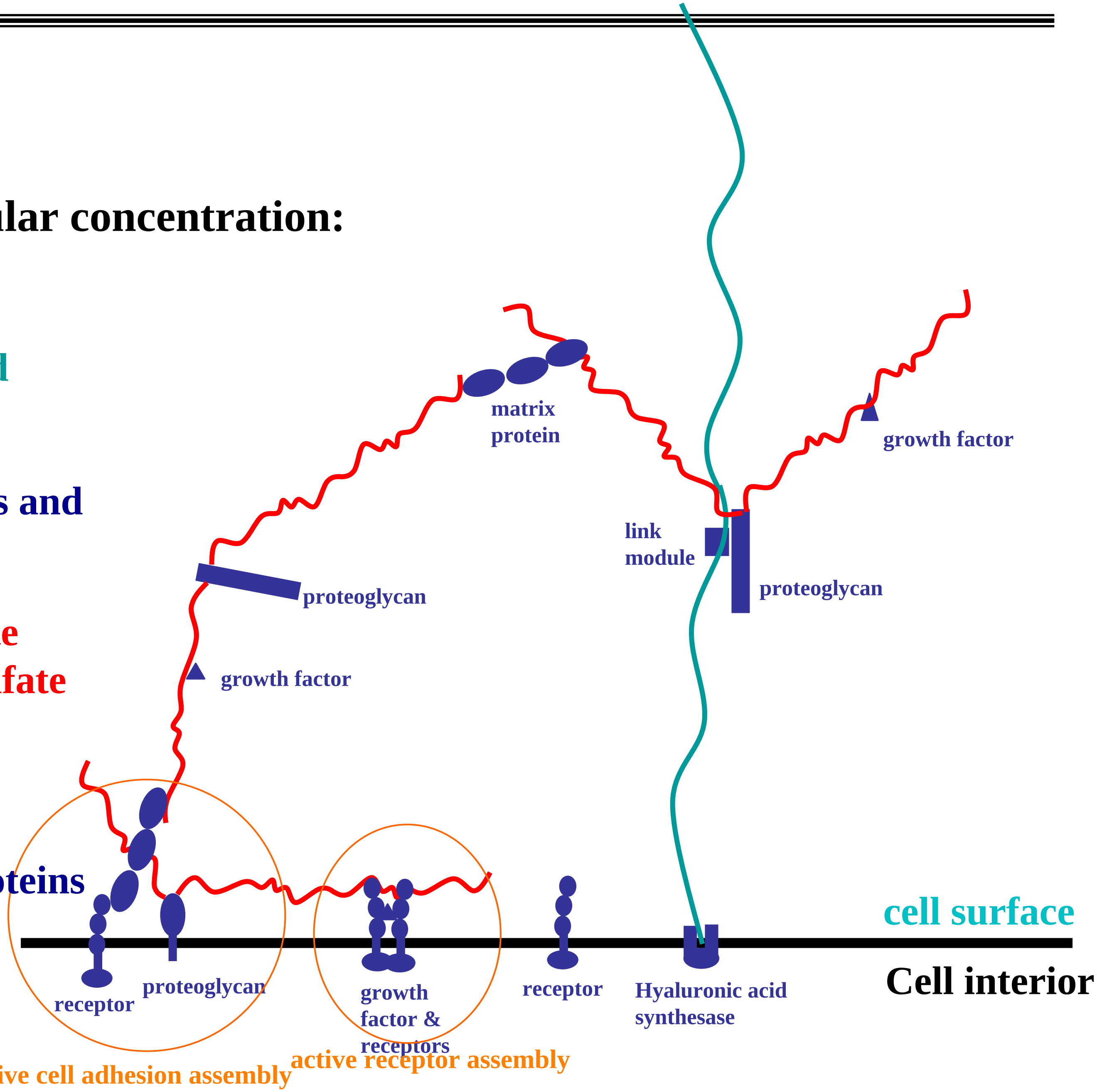
hyaluronic acid

matrix proteins and growth factors

heparan sulfate
chondroitin sulfate

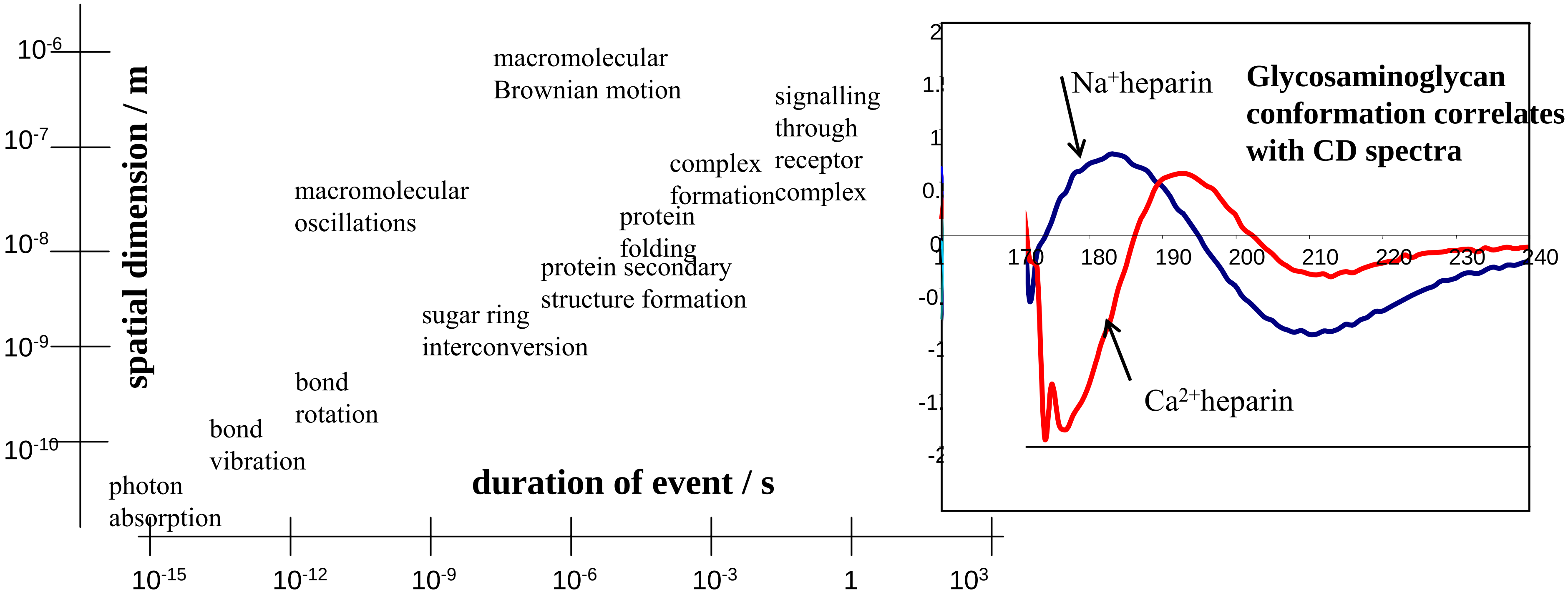
cell surface proteins

membrane



David Fernig

Spatial and temporal dimensions of events at the molecular level



Examples of Science Need

CD studies in THz, IR, Visible at low concentration:

VCD - bench top instrument needs 100 mg/ml,

4GLS = μg/ml --> selectively study protein in presence of GAGs (GAG invisible)

2D IR on fast timescales

Pump probe THz UV on fast timescales

Strategy for resolving glycosaminoglycan function with 4GLS

Localised structural perturbations by electromagnetic pumping and spectroscopic monitoring:

- **TeraHertz: domains and solvent structure.**
- **Infrared: selective chemical bonds and protein secondary structure.**
- **UV and visible: electronic states.**
- **Far IR and THz: bound water.**

Chemical perturbations of biological function:

- **amino acid mutations of proteins**
- **chemical modification of GAG chains**
- **selective labelling of complex components with fluorophores**
- **mass labels, eg. D_2O to bandshift**

Biology is chiral: CD in the IR and THz domains

Combine spectroscopies: including UV/THz absorption in the fast time domain

Non-linear techniques:

- **2D-spectroscopy, for coherently coupled interactions providing 3D/dynamic information.**

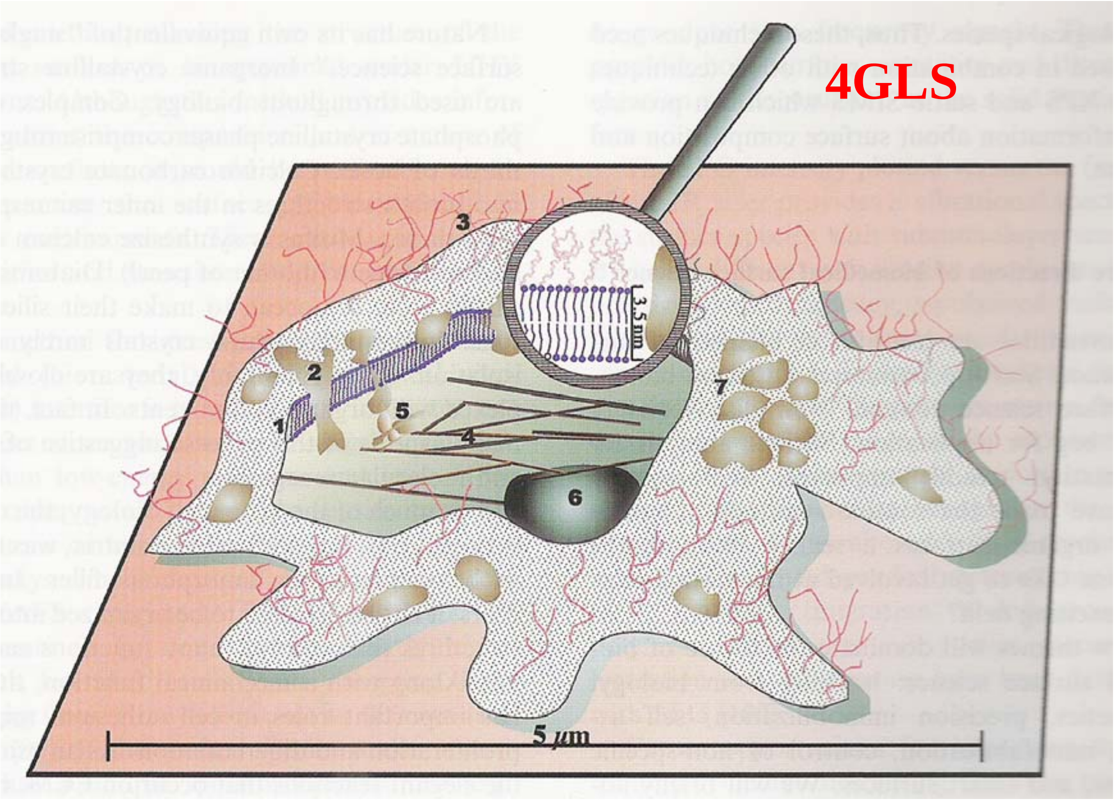
David Fernig

Cell and Tissue Imaging

(membranes)

Paul O'Shea and Mike Somekh

4GLS: Membrane Analysis and Dynamics



Cell Surface

1 lipid bilayer
2 embedded proteins
3 saccharide chain
4 cell cytoskeleton
5 small proteins
6 cell nucleus
7 exposed proteins

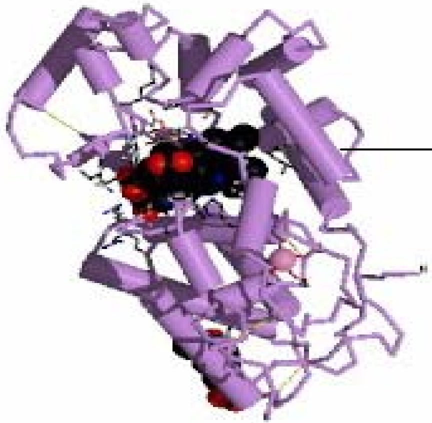
Human Genome == > 30% of proteins are membrane proteins
60% of drug targets are membrane proteins

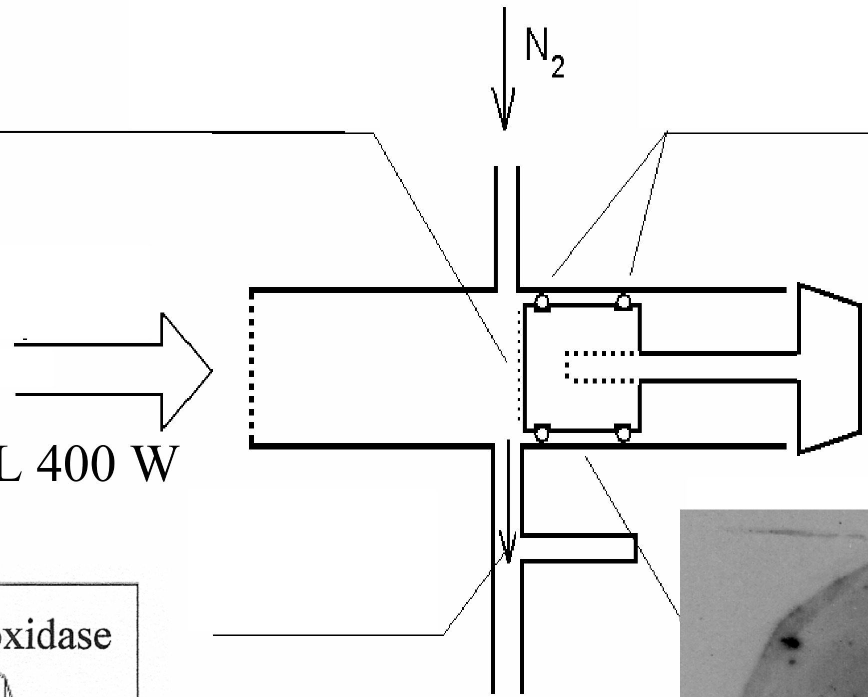
3D Structures of ~ 1500 soluble proteins have been determined
Only ~ 50 are membrane proteins

4GLS: Membrane Analysis and Dynamics

THz Desorption of proteins from surfaces (Budker)

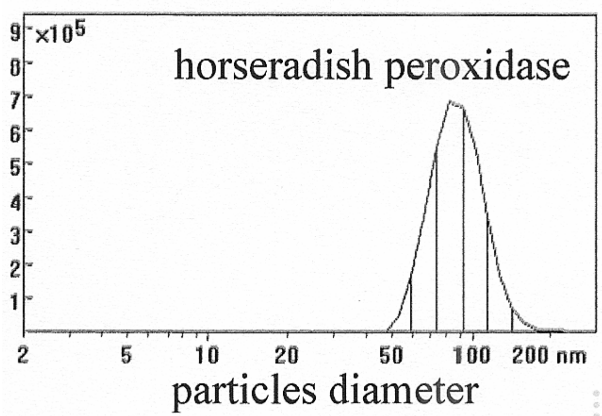
THz ablation of horseradish peroxidase desorbes the molecule intact into a gas flow.

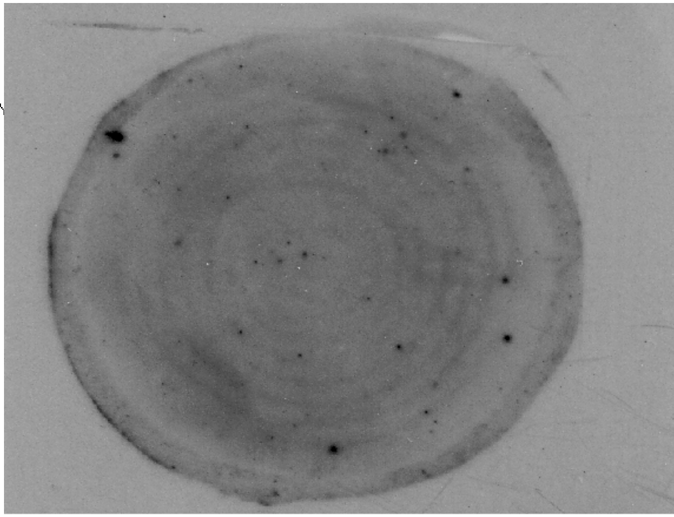




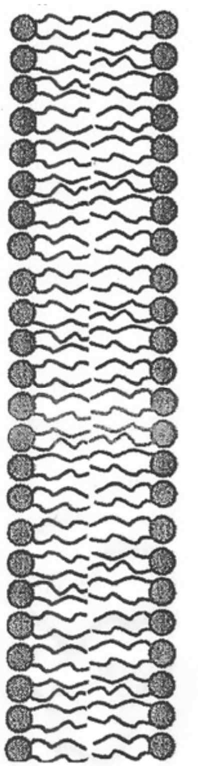
THz FEL 400 W

The enzeme retains its functional activity after “landing”





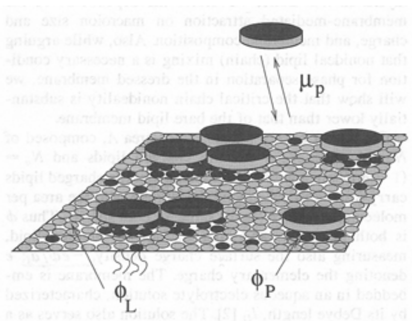
The Problem of Membrane Fusion



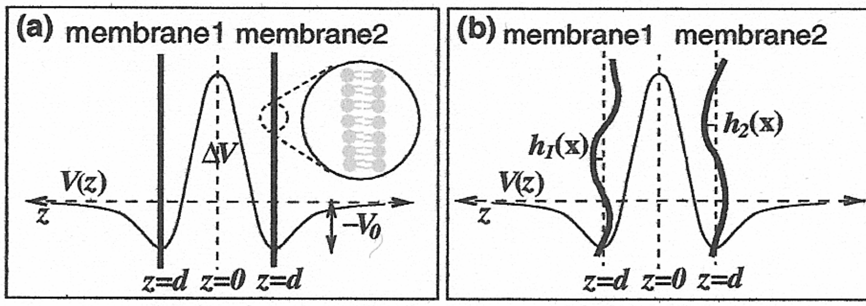
Virus and cell are surrounded by a phospholipid bilayer

While the structures of the virus, its coating and its cellular membrane target are important the dynamic interaction between them is the key to understanding how the virus and cellular membranes can fuse together and allow the virus DNA/RNA to enter the cell.

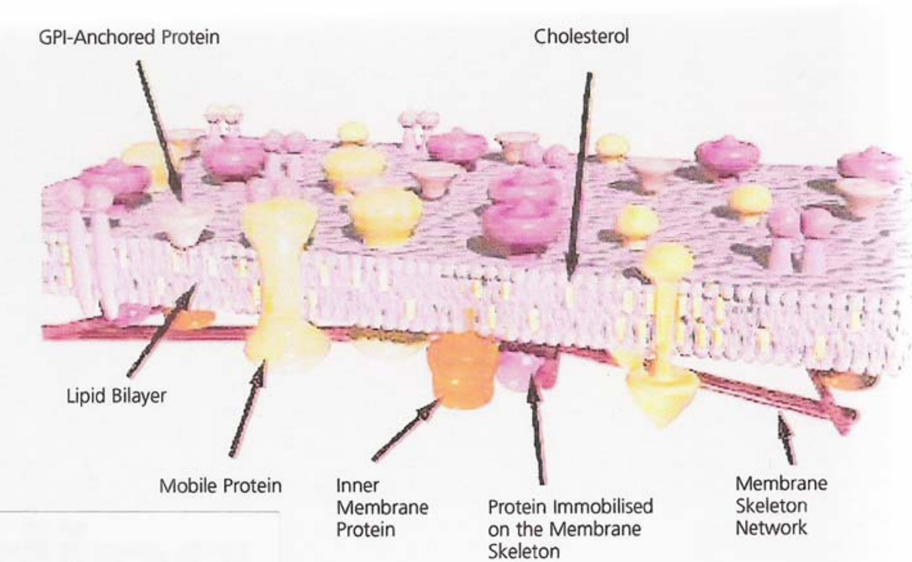
Theory:
Low frequency vibrations mediated by the environment are crucial to membrane fusion and repair.
Natural membrane frequency ~ 10^{11} Hz



Membrane Interactions: Due to presence of counter ions in solution oppositely charged membranes do not always attract, similarly charged membranes do not always repel
Membrane Fusion is important in:-
viral infection, gene therapy and intracellular trafficking
Membrane Rafts are important in cell signaling and cell interactions. May be mediated by variations in membrane dipole across cell surfaces. Interaction with H_2O a key factor.



4GLS: Membrane Analysis and Dynamics

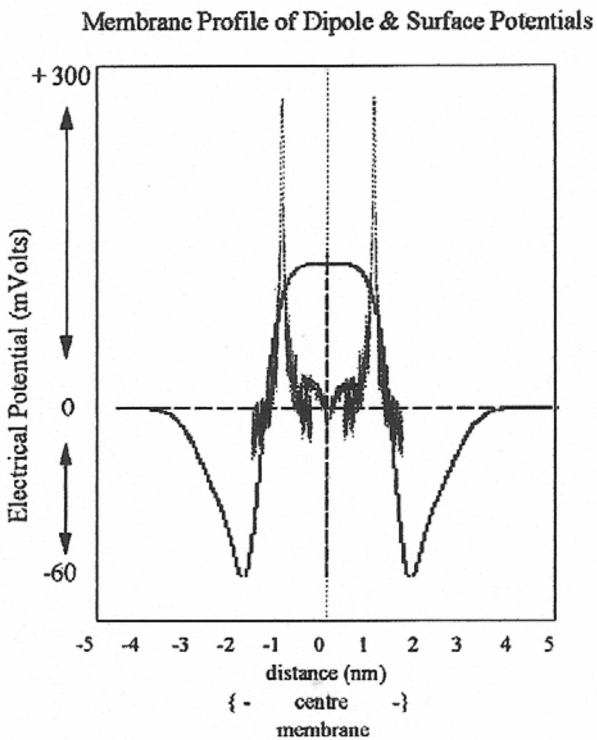


Membrane Rafts: Area ~ 50 nm

Paul O'Shea and Mike Somekh (Nottingham) have shown the importance of membrane "rafts" for cell signaling and cell interactions. Possible that the membrane dipole varies spatially across cell surfaces and that variations in dipole field and interaction with H_2O are key factors.

Membrane electrical potentials

1 Gradient of charge across phospholipid bilayer
2 Surface potential due to surface charge ~ -30 mV.
3 Dipole potential, dipoles associated with carbonyl. and oxygen bonded phosphate groups ~ 100 mV.
Different sensitivities and responses to environment.



Approach

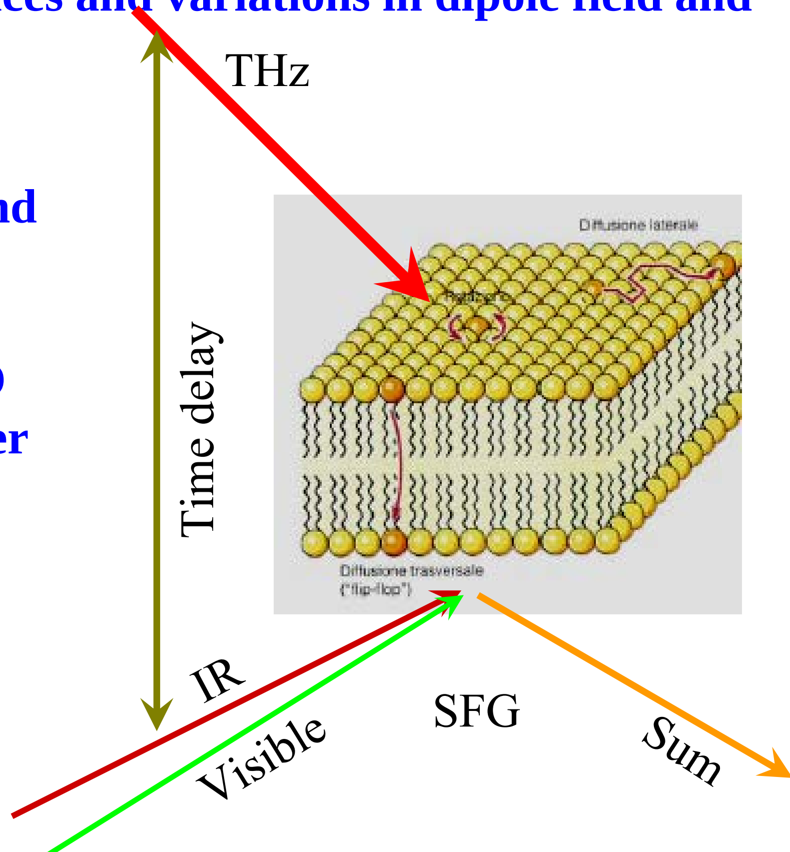
Near field imaging and spectroscopy: RAS, IR, THz, SFG
Pump probe: monitor fluorescence markers while scanning the H_2O THz spectrum

4GLS: Potential for Major Advances: Virus cell interactions

How does the Aids virus enter a cell? Virus and cell surrounded by a phospholipid bilayer

The structures of the virus and cell membranes are important but the dynamic interaction between them is the key to understanding how the membranes fuse together for the virus DNA/RNA to enter the cell.

Membrane Rafts: Area ~ 50 nm are important in cell signaling and cell interactions.
The membrane dipole varies spatially across cell surfaces and variations in dipole field and interaction with H_2O are key factors.



4GLS Key Contributions
High intensity THz: Near field sub-cellular imaging and Spectroscopy of live cells.
Pump probe: IR, Visible, THz, SFG
Monitor fluorescence markers while scanning the H_2O THz spectrum. Modulation of raft dipole - bound water Interactions changes activity of membrane proteins involved in signaling

Explore Novel Therapies
Based on use of THz to modify cell behaviour
Eliminating drug treatments for some neurological conditions

THz Near Field Imaging of Live Neuronal Cells

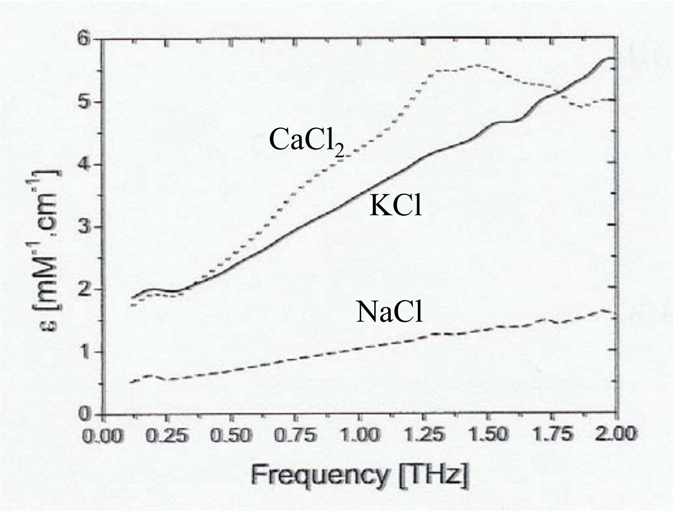
Neuronal activity results from the precise control of transient variations in ionic conductance and water exchange between the extracellular matrix and the intra-axonal compartment.

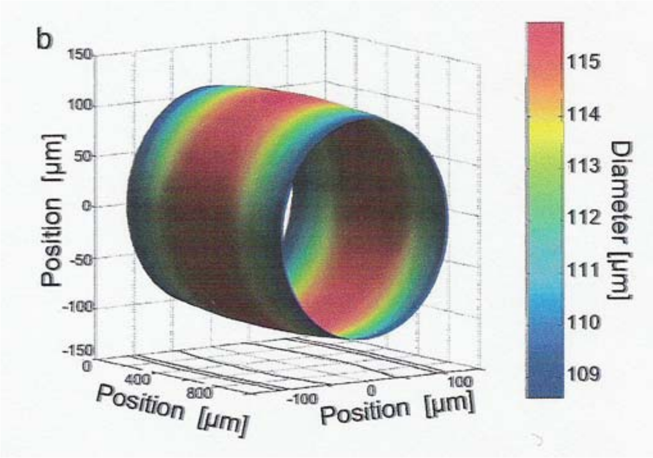
Experiment

The absorption of THz by Na and K solutions is very different and can be used as a contrast mechanism in transmission near field THz measurements of neurons.

Near field THz imaging of live functioning neuronal cells in Na and K ionic solutions. Provides quantative measurements of the ionic concentration in both the intercellular and extra cellular compartments of the neuron.

A series of of 2D scans can be used to build up a 3D image of the axon





J.B. Masson, M.P. Sauviat, J.L. Martin and G. Gallot PNAS **103** 4808 (2006)

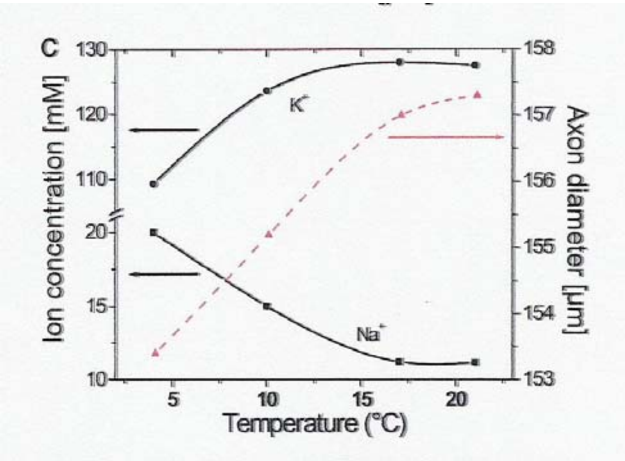
THz Near Field Imaging of Live Neuronal Cells

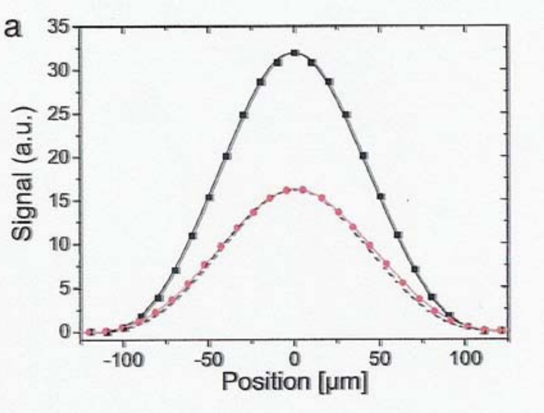
The shape of the axon is shown to vary with

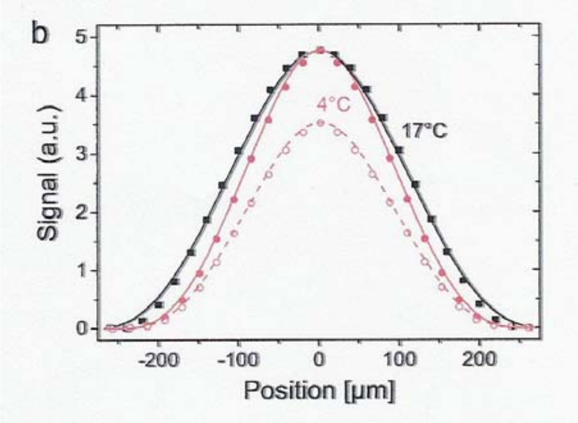
a) **Introduction of veratridine, a toxin that activates Na channels in the membrane**

b) **Temperature**

c) **Concentration of K in the physiological solution surrounding the neurons**







Can be used for direct non-invasive imaging of neurons during electrical, toxin or thermal stress

Results

Direct observation of neuron swelling induced by Temperature change or neurotoxin poisoning

J.B. Masson, M.P. Sauviat, J.L. Martin and G. Gallot PNAS **103** 4808 (2006)

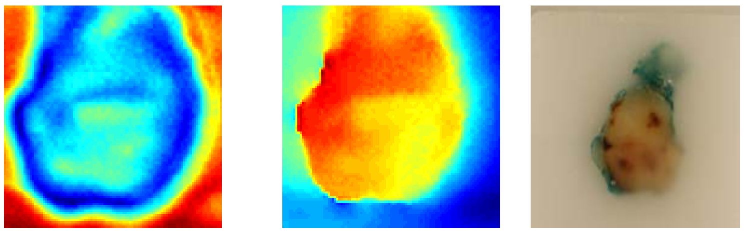
Medium and Large Scale

THz Imaging

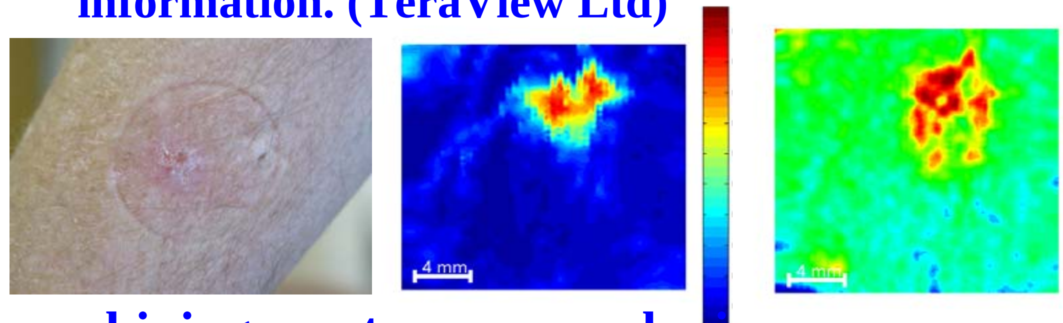
THz Imaging: Medium scale

Basal Cell Carcinoma (Martyn Chamberlain)

In vitro images, using pulse amplitude and time delay



In vivo images, with and without depth information. (TeraView Ltd)



Research into contrast mechanism: combining spectroscopy and microscopy

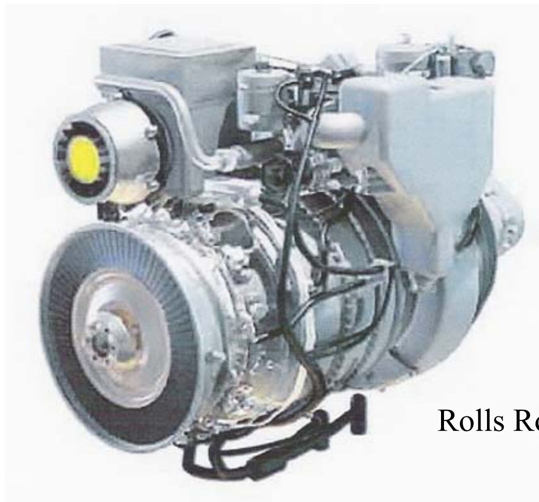
Does malignancy have a THz signature?

Combustion: imaging and spectroscopy-environmental impact and improved efficiency

The detailed chemistry of combustion in aero engines is not understood.

Combustion process is opaque in IR due to soot

However it is transparent in THz.



Rolls Royce T800/CTS800

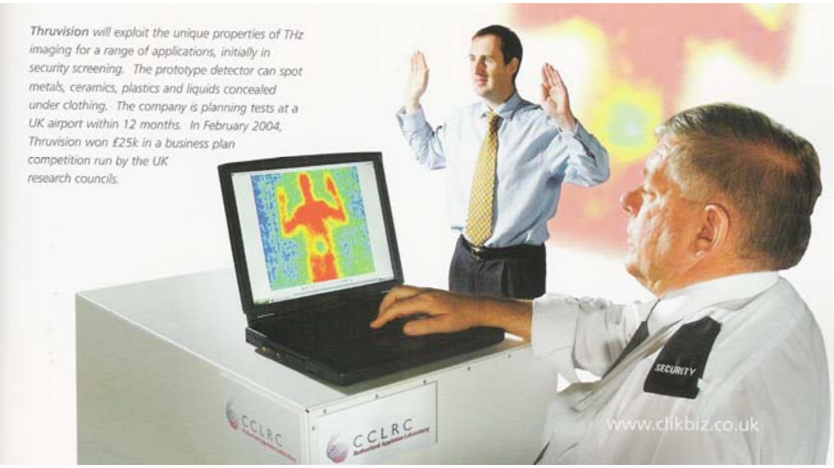
Need to develop fast large area detectors for imaging and spectroscopy

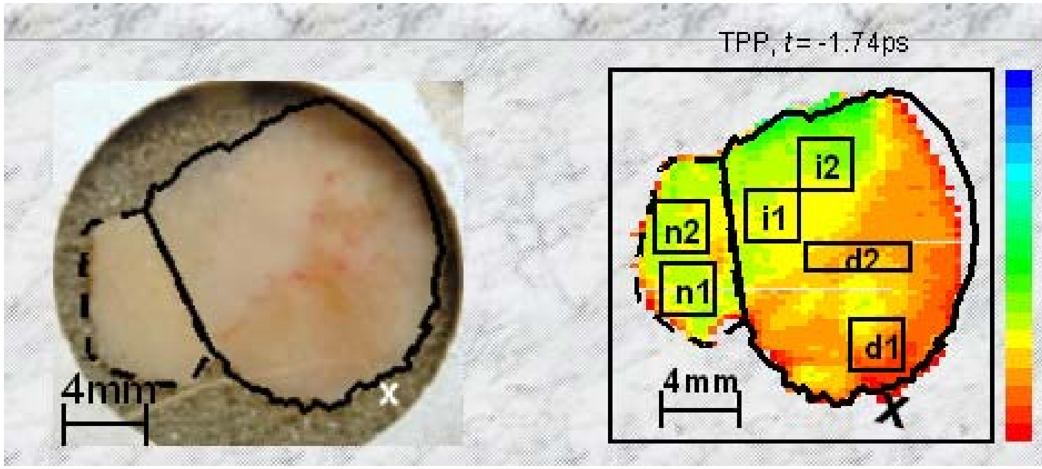
K. Ozanyan and Y. Zhang (Manchester) and colleagues THz Basic Technology Programme

THz Imaging: Large Scale

Remote Scanning: Results currently with laboratory sources of power ~ µwatts

Security | **Bio-medical cancer screening**





Basal cell carcinoma: malignancy in red. (Teraview)
1 mW source images 1 cm^2 in 1 minute
100 W source images whole body (50 x 200cm) in secs
Does malignancy have a THz signature?

Requires high intensity wide band THz and remote area detection
Proof of principle. Development of portable systems

RAS on 4GLS

Peter Weightman

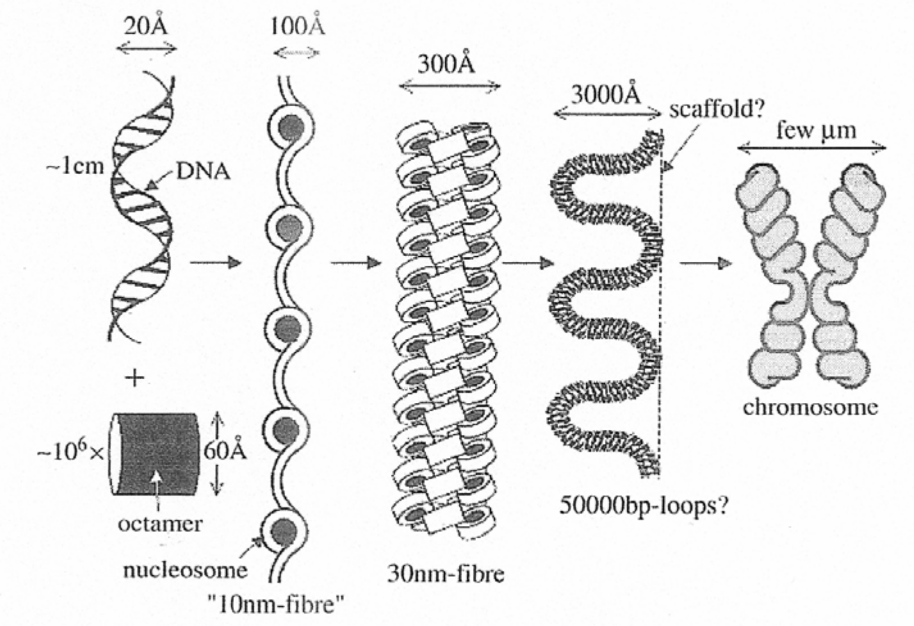
Science Drive: The Mechanisms of Molecular Organisation

Biological molecules operate at kT: show remarkable organisation and activity

Room Temperature kT ~ 6 THz

Example: DNA
Human genome 3 billion base pairs
Double helix 2m long folded into ~ 2 μm

Unwound, read and rewound on a daily basis



Molecular organisation must involve vibrational and rotational modes
There should be many modes and the long range ones will be important
How quickly do they dissipate energy into "adjacent" modes? (~ psec)
Are there long lived coherent modes that mediate biological processes?
Spectroscopy is not much use

IR: spectra will be dominated by strong local modes
long range coupling between local modes ~ 10^3 times weaker
THz: many modes will be excited simultaneously

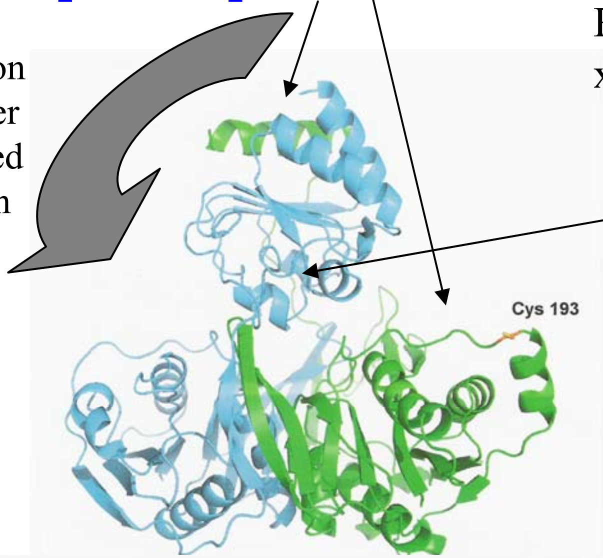
Reflection Anisotropy Spectroscopy: A monitor of protein dynamics

Flavoprotein

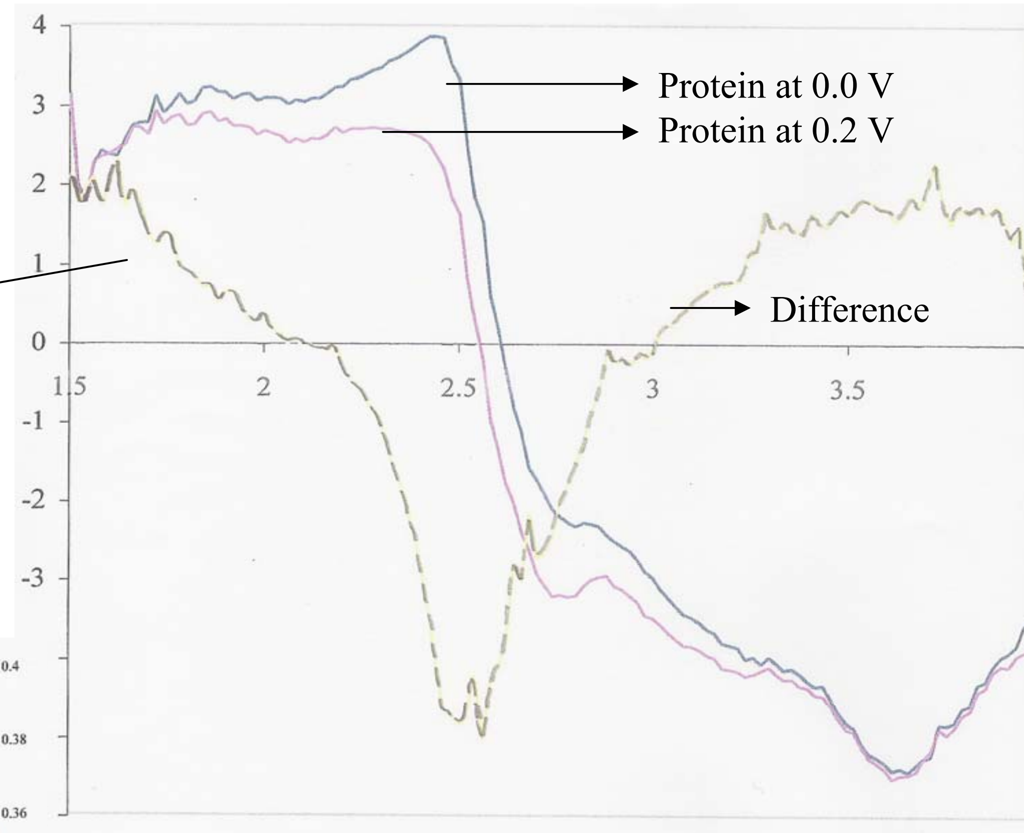
Good structural data from protein crystallography of component parts

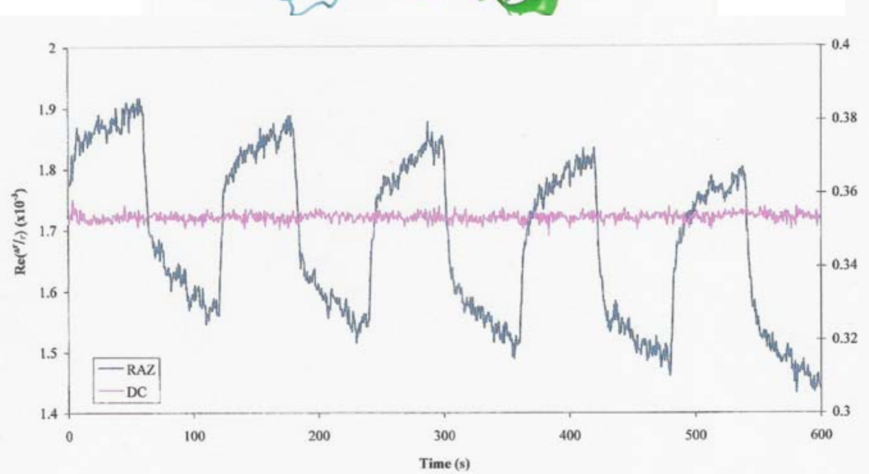
Anchor protein to Au(110)/liquid interface through S on Cys 193: forms ordered structure

electron
transfer
induced
motion



RAS
x 10^{-3}





C.I. Smith, H. Messiha, N. Scrutton, P. Weightman 2007

4GLS: THz pump -- RAS probe experiments

Recent work on the potential of reflection anisotropy spectroscopy (RAS)

Can determine the 3D orientation of a molecule at a metal/liquid interface

Weightman et al Phys. Rev. Lett. **96** 86103 (2006)

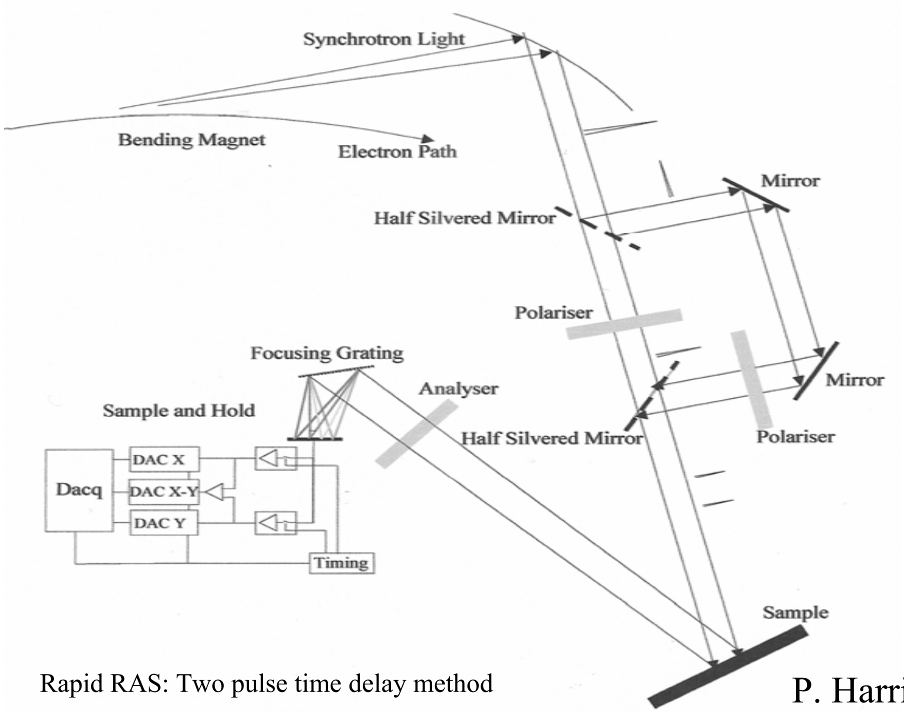
Can distinguish between single and double stranded DNA at metal/liquid interfaces

C. Cuquerella et al Langmuir:Langmuir **23** 2078 (2007)

Can monitor molecular interactions in real time LeParc et al Langmuir **22** 341 (2006)

Can monitor for the study of peptide-membrane dynamics

4GLS --> Rapid RAS in the UV at < 1 nsec, 250,000 faster than laboratory work.

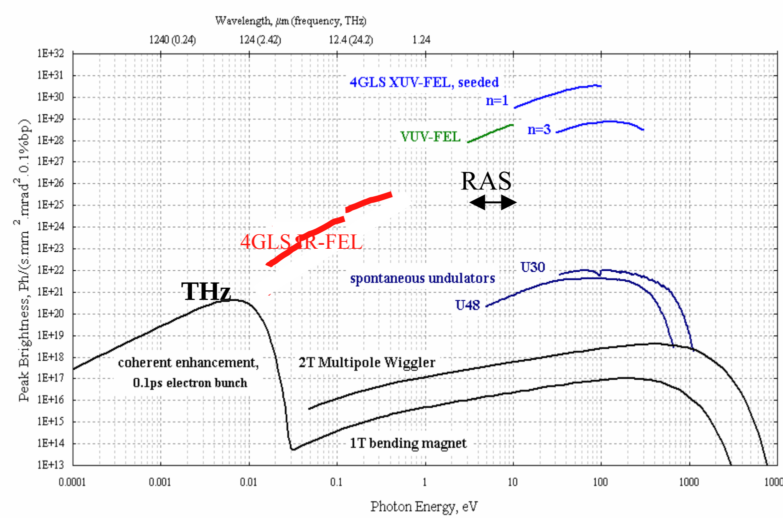


Rapid RAS: Two pulse time delay method

P. Harrison 2006

THz Pump, RAS probe

Does peptide enter membrane?



4GLS: Potential of RAS on VUV FEL

1 Extended Range: VUV FEL Range 3 eV to 10 eV

2 Increased intensity: Rapid RAS in the UV at ~ p sec to f sec

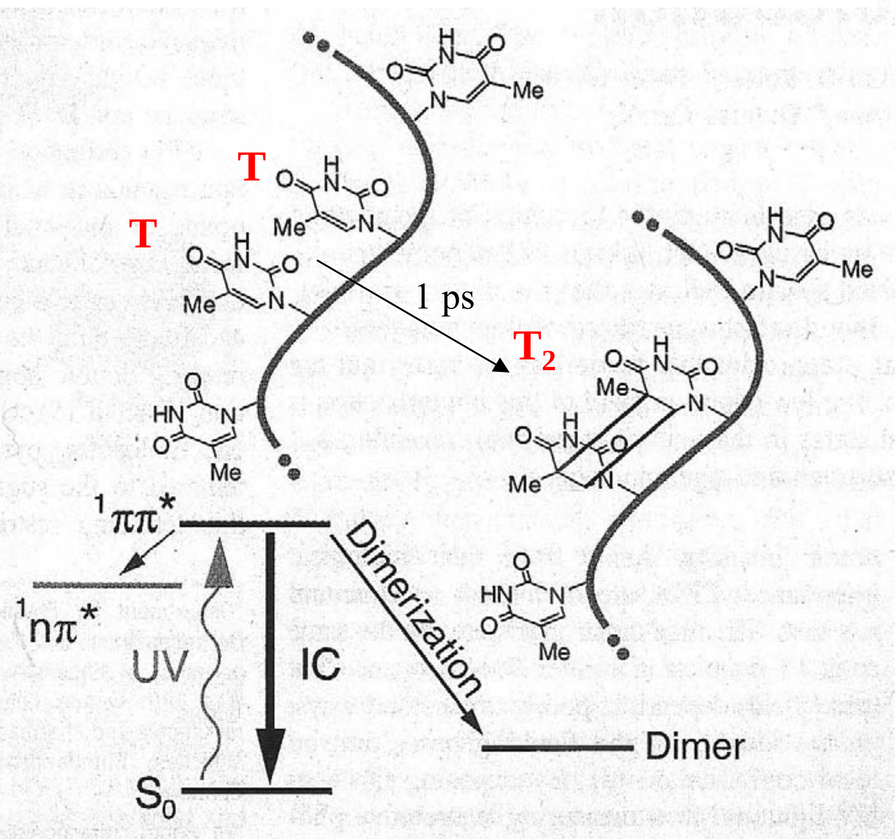
THz pump -- RAS probe on VUV FEL

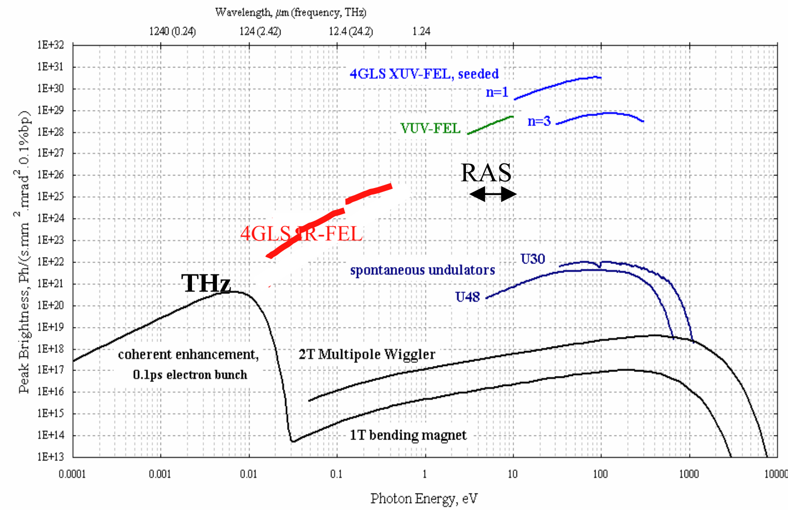
Thymine Dimerization in DNA Is an Ultrafast Photoreaction

Wolfgang J. Schreier,[1] Tobias E. Schrader,[1] Florian O. Koller,[1] Peter Gilch,[1] Carlos E. Crespo-Hernández,[2] Vijay N. Swaminathan,[3] Thomas Carell,[3] Wolfgang Zinth,[1*] Bern Kohler[2*]

SCIENCE **315** 625 (2007)

Femtosecond time-resolved infrared spectroscopy was used to study the formation of cyclobutane dimers in the all-thymine oligodeoxynucleotide $(dT)_{18}$ by ultraviolet light at 272 nanometers. The appearance of marker bands in the time-resolved spectra indicates that the dimers are fully formed ~1 picosecond after ultraviolet excitation. The ultrafast appearance of this mutagenic photolesion points to an excited-state reaction that is approximately barrierless for bases that are properly oriented at the instant of light absorption. The low quantum yield of this photoreaction is proposed to result from infrequent conformational states in the unexcited polymer, revealing a strong link between conformation before light absorption and photodamage.

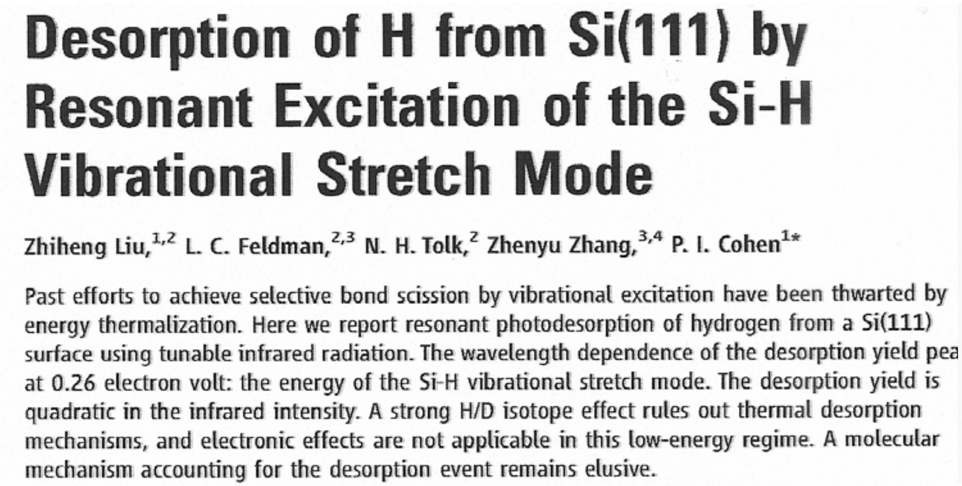




Speculation

FEL's as promoters of complex organisational processes

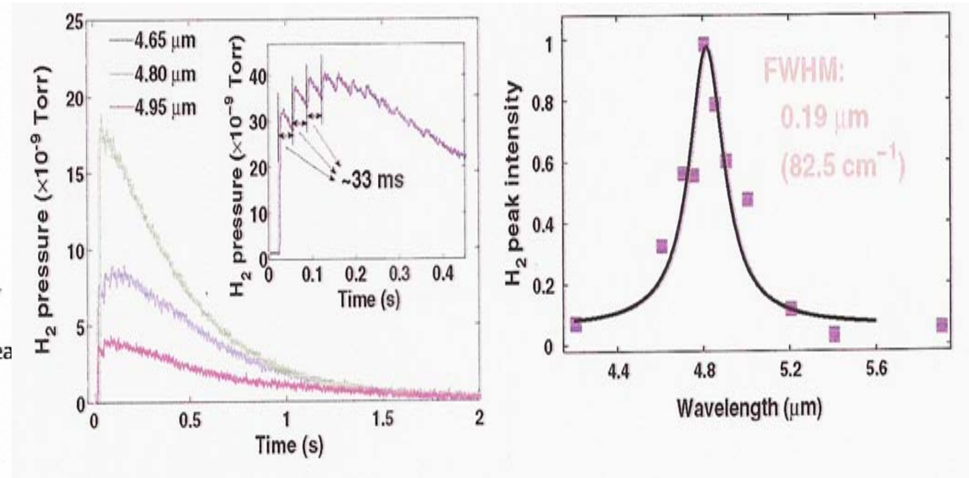
Desorption by Resonant Excitation of Vibrational Modes



Desorption of H from Si(111) by Resonant Excitation of the Si-H Vibrational Stretch Mode

Zhiheng Liu,[1,2] L. C. Feldman,[2,3] N. H. Tolk,[2] Zhenyu Zhang,[3,4] P. I. Cohen[1*]

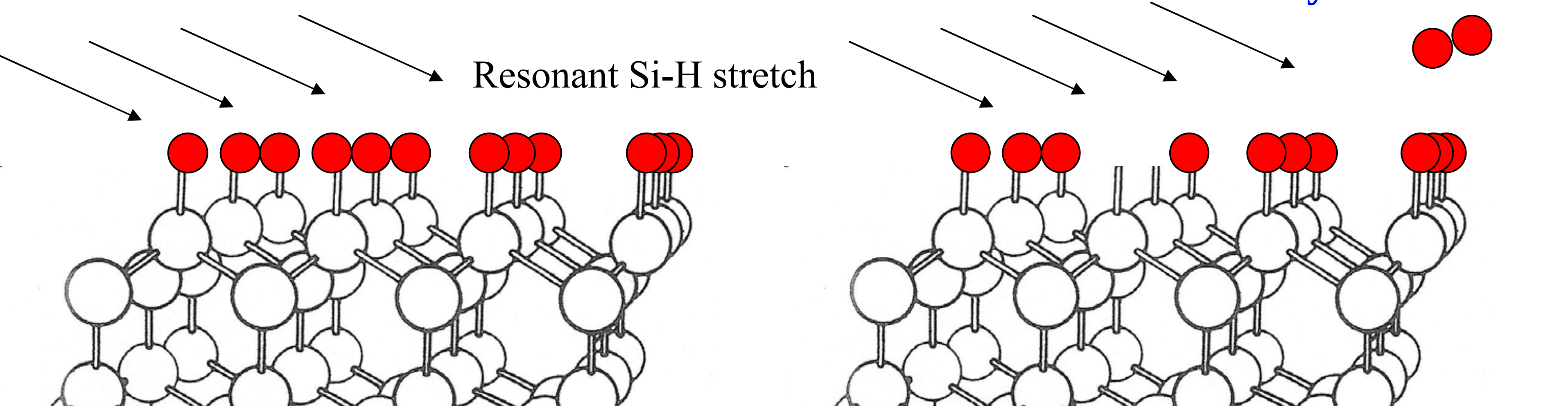
Past efforts to achieve selective bond scission by vibrational excitation have been thwarted by energy thermalization. Here we report resonant photodesorption of hydrogen from a Si(111) surface using tunable infrared radiation. The wavelength dependence of the desorption yield pea at 0.26 electron volt: the energy of the Si-H vibrational stretch mode. The desorption yield is quadratic in the infrared intensity. A strong H/D isotope effect rules out thermal desorption mechanisms, and electronic effects are not applicable in this low-energy regime. A molecular mechanism accounting for the desorption event remains elusive.



Science **312** 1024 May 2006

Irradiation of $H_{15}D_{85}$/Si(111): 4.8 µm (0.26 eV) radiation (H-Si stretch). IR FEL

95 % of desorption is H_2 ----> rules out local heating mechanisms
have achieved mode selective chemistry



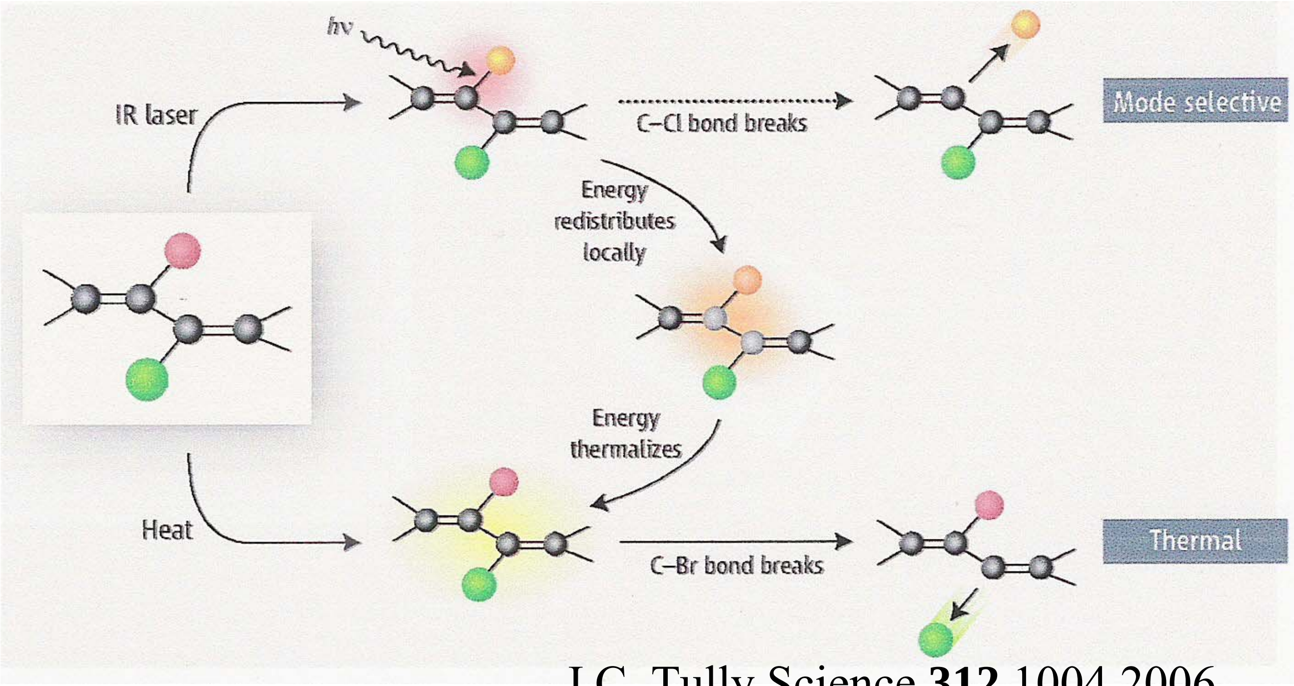
Chemical reactions usually proceed thermally

Previous work

IR tuning into selective modes ---> chemistry is due to non-selective heating

Hypothetical example: Rapid redistribution of vibrational energy to "thermal bath"

For large molecules and molecules on surfaces expect many well coupled low frequency modes giving rapid energy randomisation (~ psec).



J.C. Tully Science **312** 1004 2006

Mode selective chemistry does not happen!

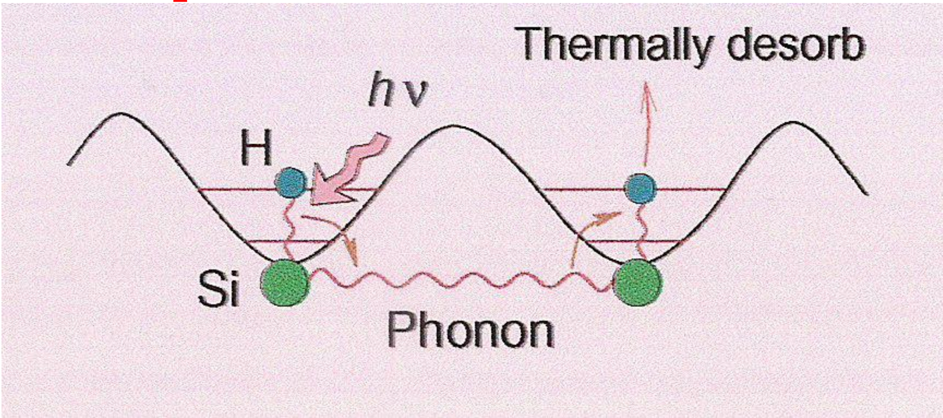
See also Rabtz Science **314** 264 2006 Sussman et al Science **314** 278 2006

IR FEL desorption of H_2 from H/Si(111): Mechanism?

Energy needed to break 2 Si-H bonds ~ 7.0 eV

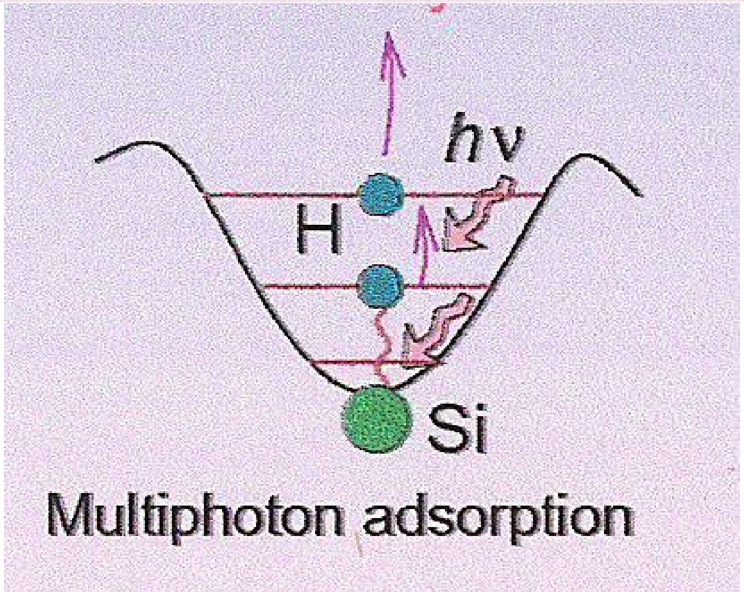
Energy released by forming H-H bond ~ 4.5 eV

Energy of IR photons ~ 0.26 eV Need 10 photons!



Direct Laser heating or coupling of Si-H stretch to substrate phonons?

No selectivity ie 95 % of desorption is H_2 from $H_{15}D_{85}$/Si(111)



Multiphoton absorption?

The Si-H potential well is anharmonic (90 cm^{-1})

There is no change in the desorption when the linewidth of the excitation is changed from 80 cm^{-1} to 8.7 cm^{-1}

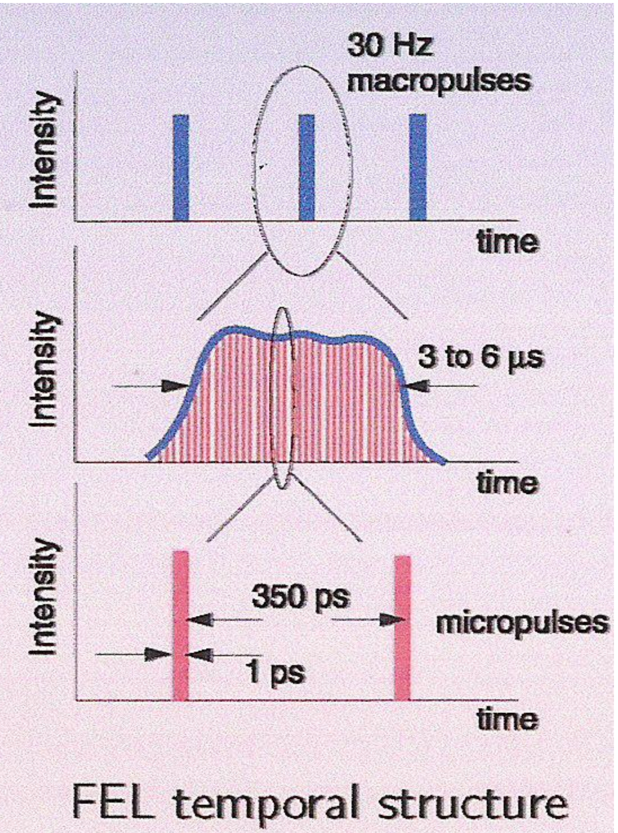
IR FEL desorption of H_2 from H/Si(111): Mechanism?

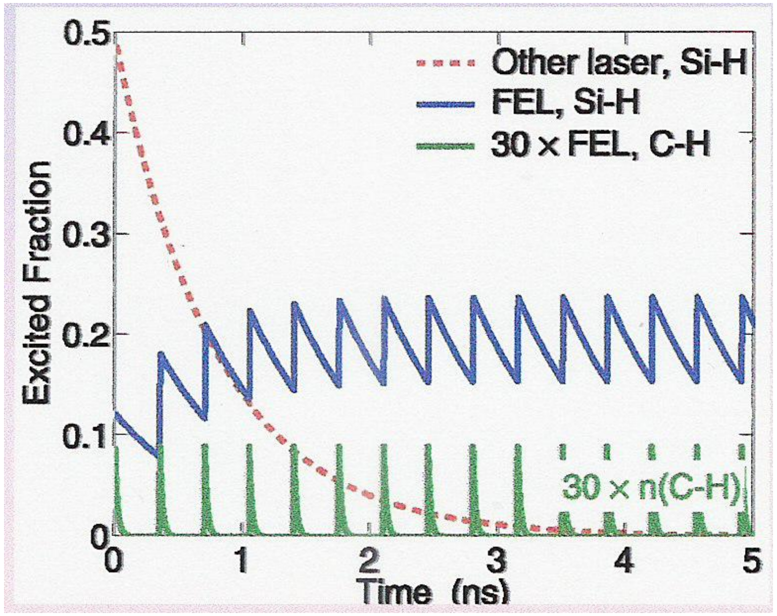
Intensity is not the key factor: H desorption was not observed in a previous IR experiment on H/Si(111) with an IR laser source of comparable intensity

P Guyot-Sionnest, P. Dumas, Y.J. Chabal and G.S. Higashi Phys. Rev. Lett. **64** 2156 (1990)

Key difference is pulse structure of IR FEL

IR FEL pulse separation 350 ps (IR Laser > 100 μs) Vibrational lifetime 800 ps





Liu et al OSI -VII July 2007

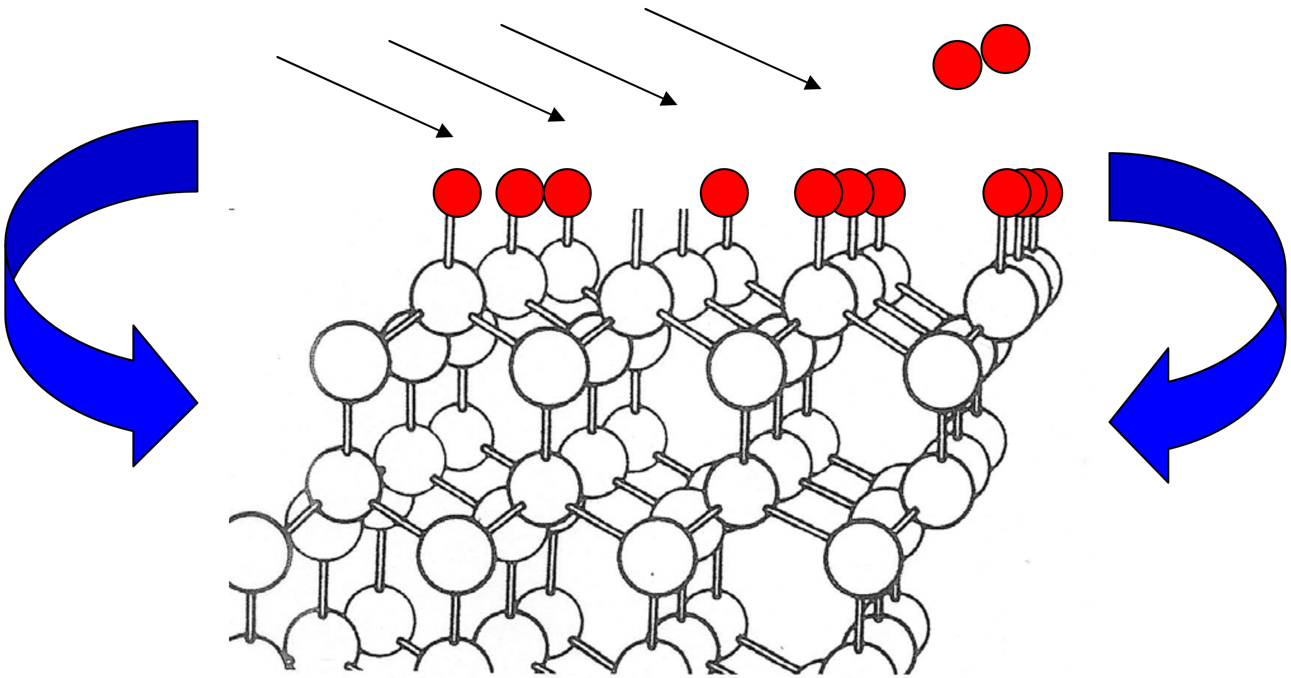
It takes a long time for two excited H atoms to desorb associatively

Non-Equilibrium: Self-organisation in dissipative systems

Continuous Flux of High Quality Free Energy

IR FEL

Low Entropy



Low Quality Free Energy

High Entropy

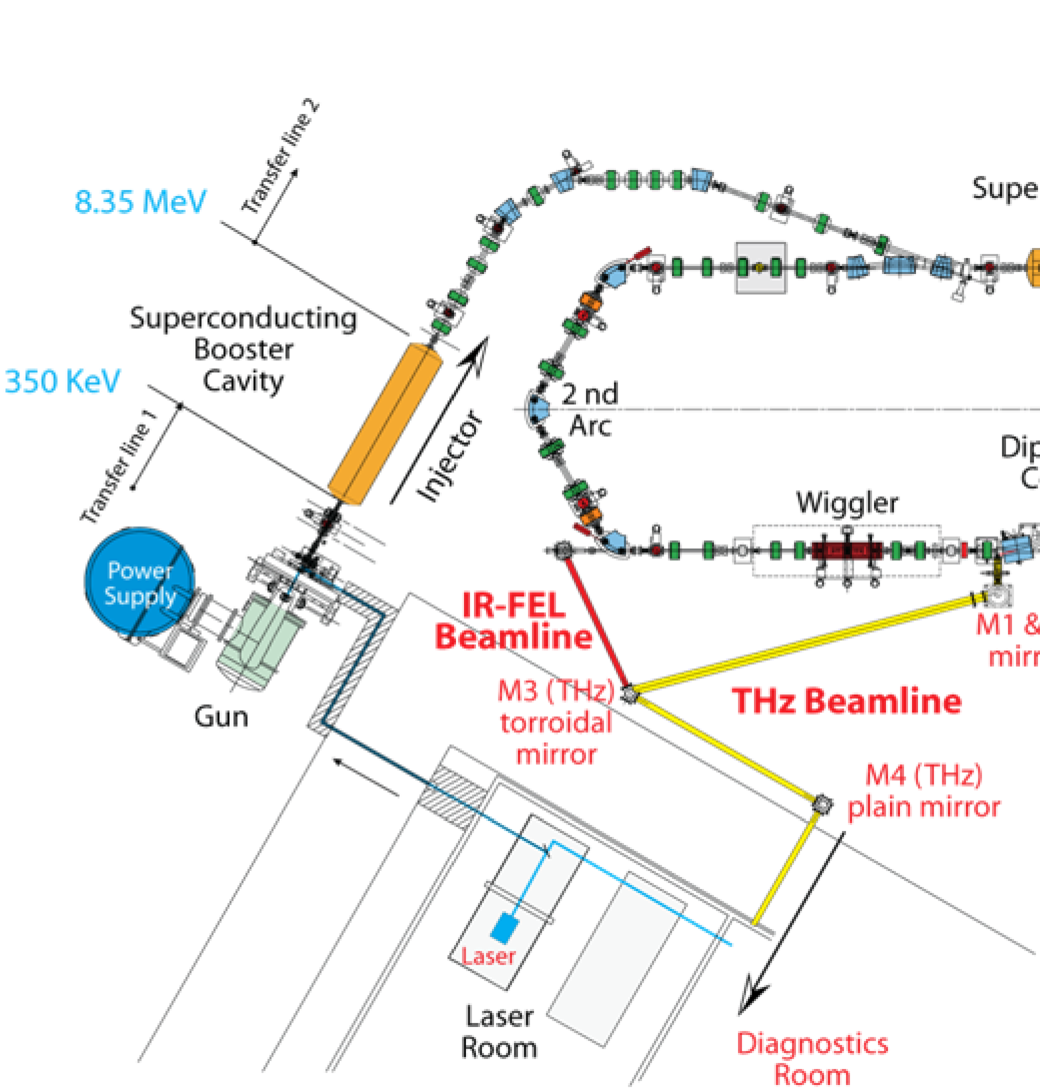
Implications

The vibrationally excited H/Si(111) surface should adopt a complex ordered dynamic state.

The dissipation of free energy into entropy is facilitated by the creation of free H_2

4GLS Energy Recovery Linac Prototype (ERLP)

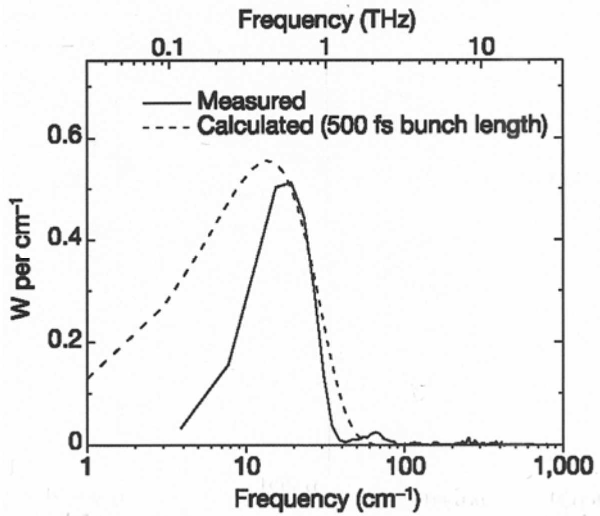
ERL Prototype Layout



NW Science Fund: Exploiting ERLP THz Radiation

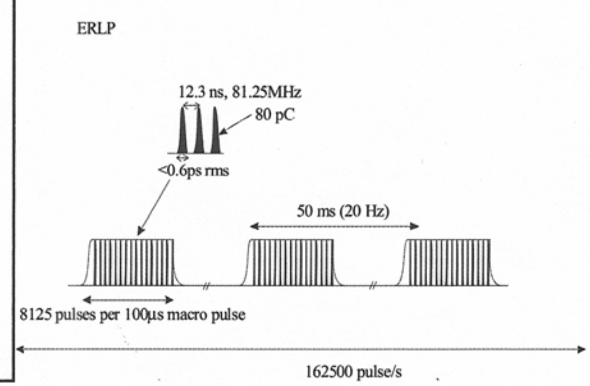
1 Construct a THz beamline on ERLP

Based on Carr et al Nature **420** 153 (2002)



Electron Beam Parameters	
Operating Mode	
long pulse	
Electron Energy	35 MeV
Gamma Factor	68.49
Charge per Bunch	80 pC
Bunch Repetition Rate	81.25 MHz
Train Length	100 us
Train Repetition Rate	20 Hz
Number of Electrons per Bunch	5.0E+08
Bunch Spacing	12.31 ns
Train Spacing	49.90 ms
Duty Factor	0.002
Bunches per Train	8125
Bunches per second	162500
Average Current	13.0000 uA

Average power ~ 20 mW



2 Establish a Tissue Culture Facility to GLP Standard

grow and maintain live tissue

3 THz beamline into Tissue Culture Facility

4 Exposure experiments on:-

live tissue

model membrane systems

model DNA sequences

NW Science Fund Programme: Key Questions

The mechanisms of cell death

Cells die by two main mechanisms,
necrosis: overt damage that causes cells to swell and rupture
apoptosis: programmed cell death, cells are carefully dismantled.
necrosis involves rapid changes in water content apoptosis does not
i.e. these mechanisms involve differences in cellular water retention.

Potential therapy for skin cancer

Idea is based on the fact that cancer cells are often less differentiated and thus larger and more active.
Thus their water content should be higher and this could be exploited to preferential kill cancerous cells by strong absorption of THz radiation by water.

Determination of the safe limits of human exposure to THz radiation

Due to the limited power available at present this is particularly relevant to the future development of mobile phone technology and also screen the general public at airports and possible railway stations instead of X rays.

Preliminary study R.H. Clothier and N. Bourne, J. Biological Physics **29** 179 (2003)

Acknowledgements

- **The 4GLS Team**
- **The 4GLS International Advisory Committee**
- **The 4GLS Steering Committee**
- **National and international scientific community**
- **Funding: OST/DTI, CCLRC, NWDA and EU**

information http://www.4gls.ac.uk