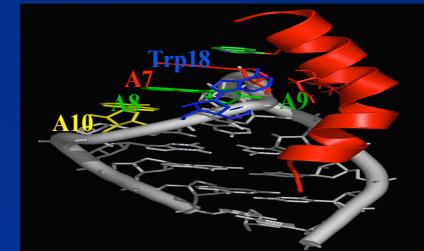
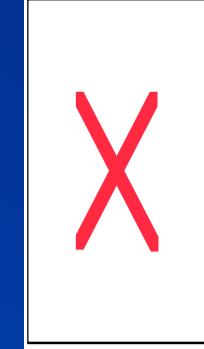
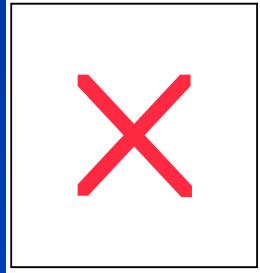




A century of progress

Dynamics of Matter in *Time*

with atomic-scale resolution



Seconds , Ensembles
Rates & Mechanisms

Milli to Picosecond
Kinetics

Femtosecond
Dynamics

Atomic-Scale
Function

Chemistry

Physics

Biology
Complexity

Van't Hoff (1901)
Arrhenius (1903)
Ostwald (1909)

Hinshelwood & Semenov (1956)
Eigen & Norrish , Porter (1967)

Townes & Basov , Prokhorov (1964)

Herschbach , Lee & Polanyi (1986)
Marcus (1992)

AZ (1999)

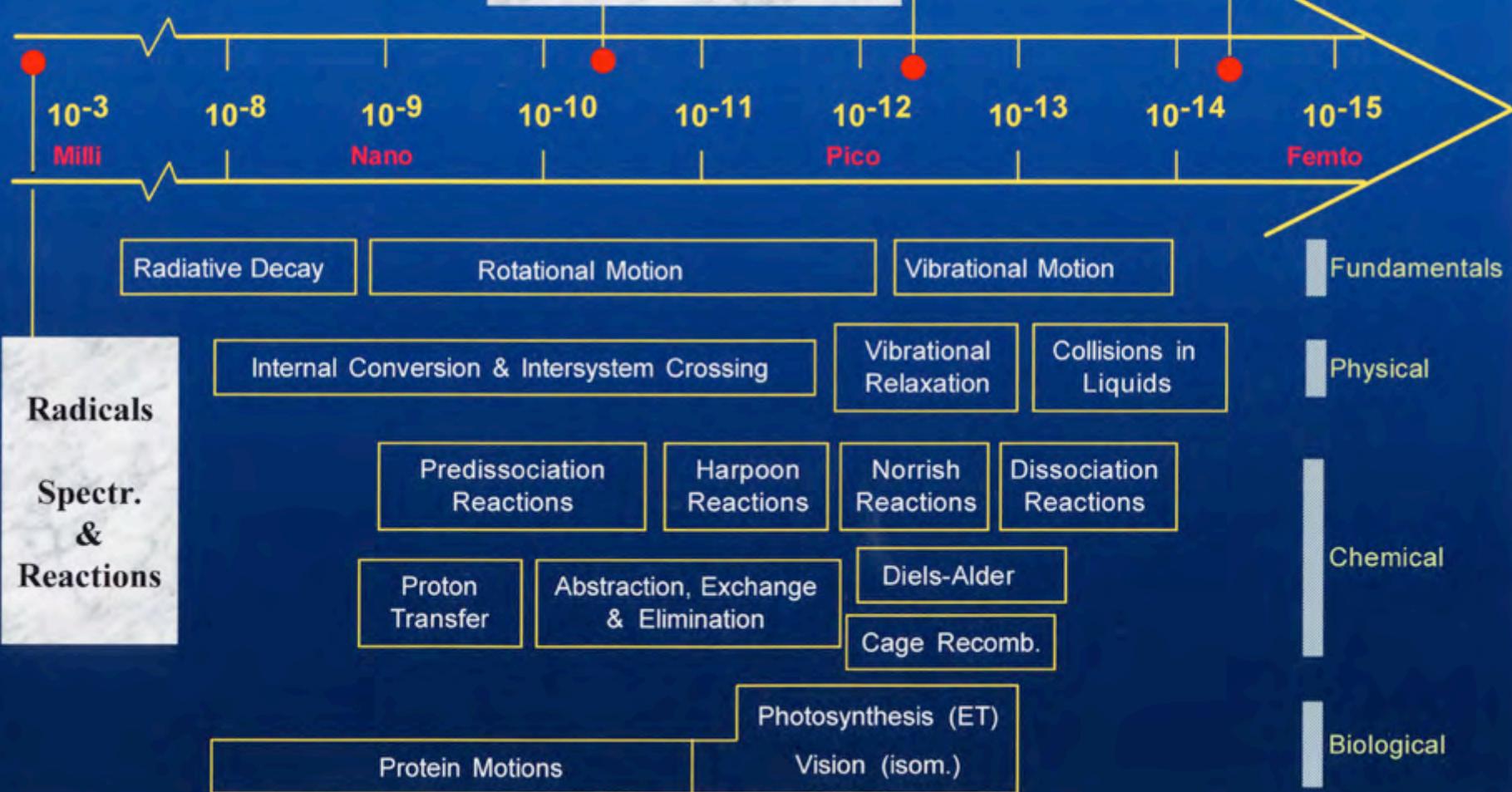
Dynamics : Over A Century

Time Scales: From Milli to Femtosecond Physical, Chemical, and Biological Changes

Atomic Resolution
Single Molecule Motion

Transition States &
Reaction Intermediates

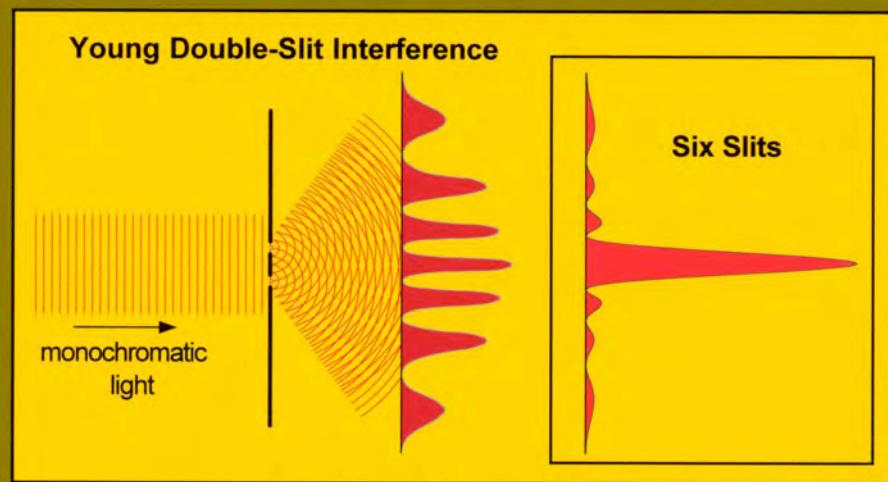
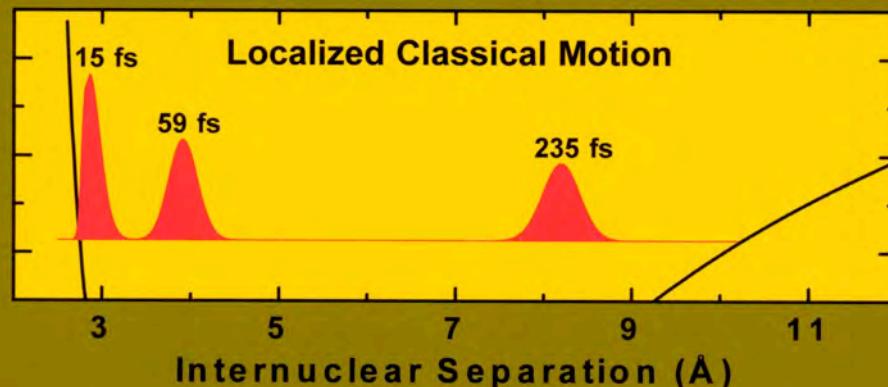
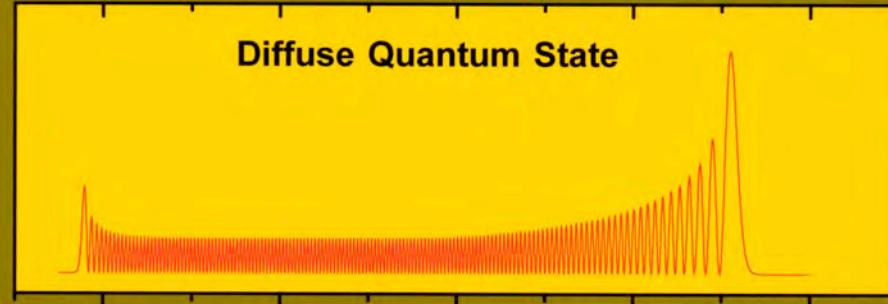
IVR & Reaction Products



Quantum Mechanics

Classical Mechanics

Coherence



The New Frontier

Structures & Dynamics
in *both Space and Time*

Can it be achieved ?

Why 4D ?

Complex Energy Landscapes

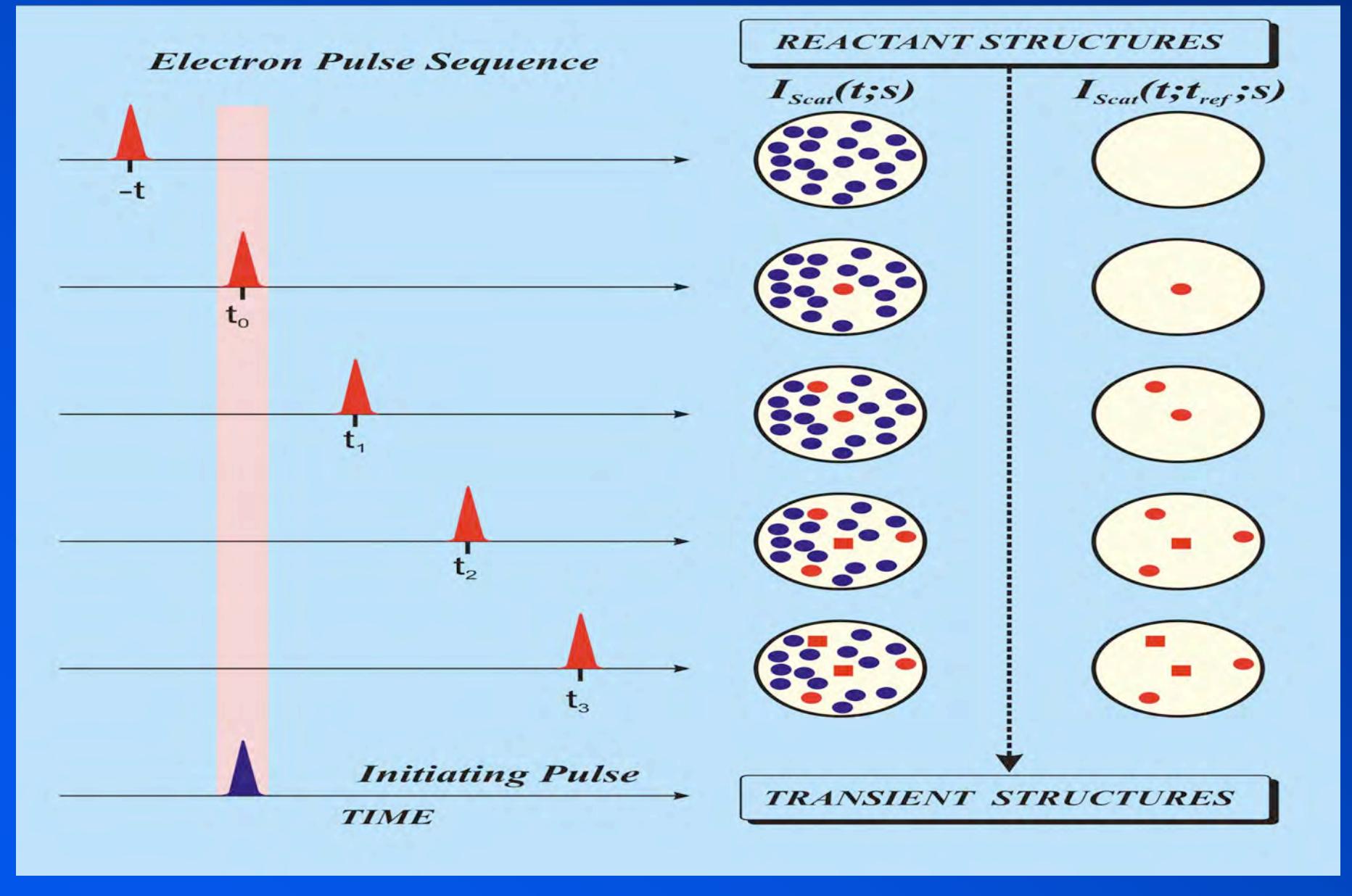
FES vs PES

Non-equilibrium Structures

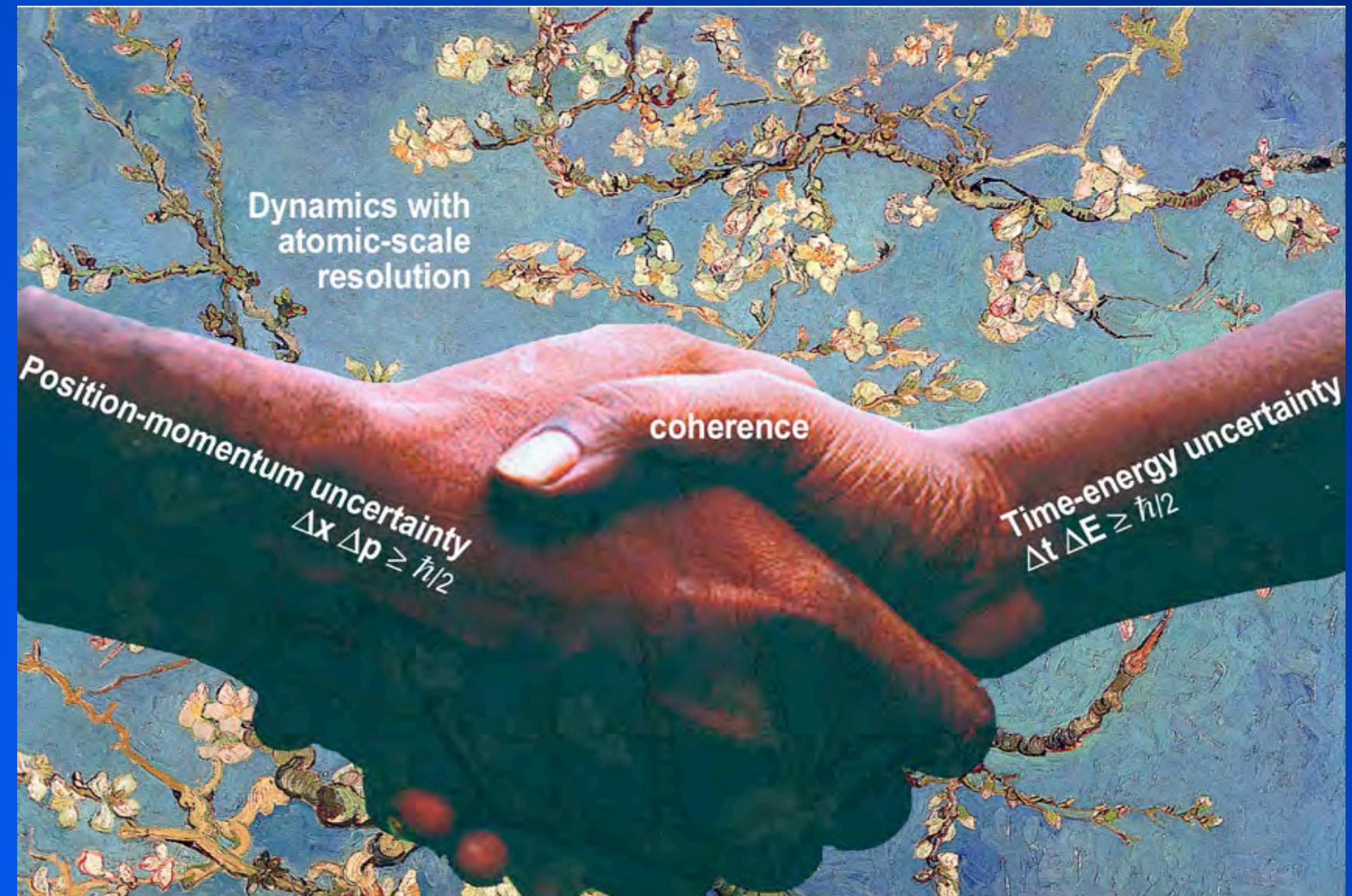
Weak Forces :HI, EI, DI & HB

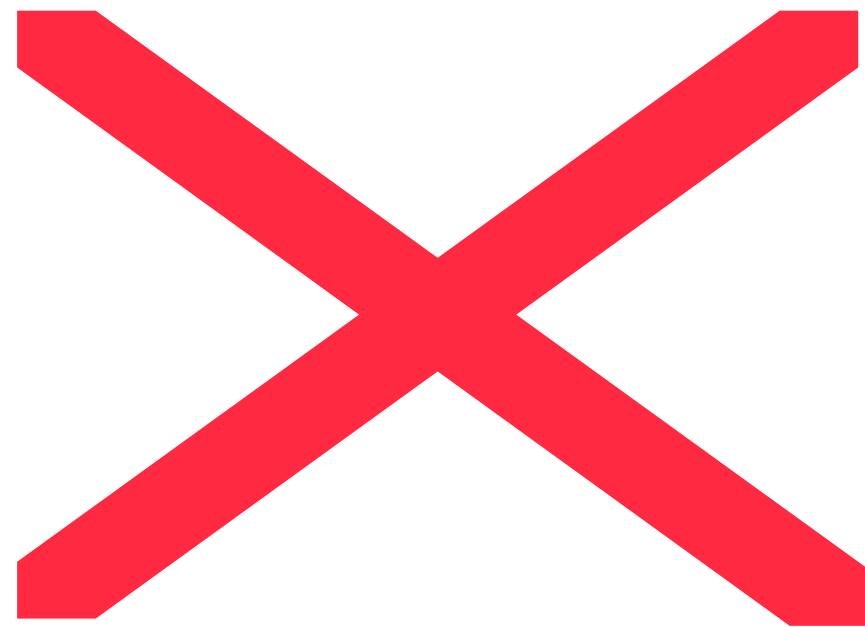
Structure , Dynamics , Function

Concept of UED



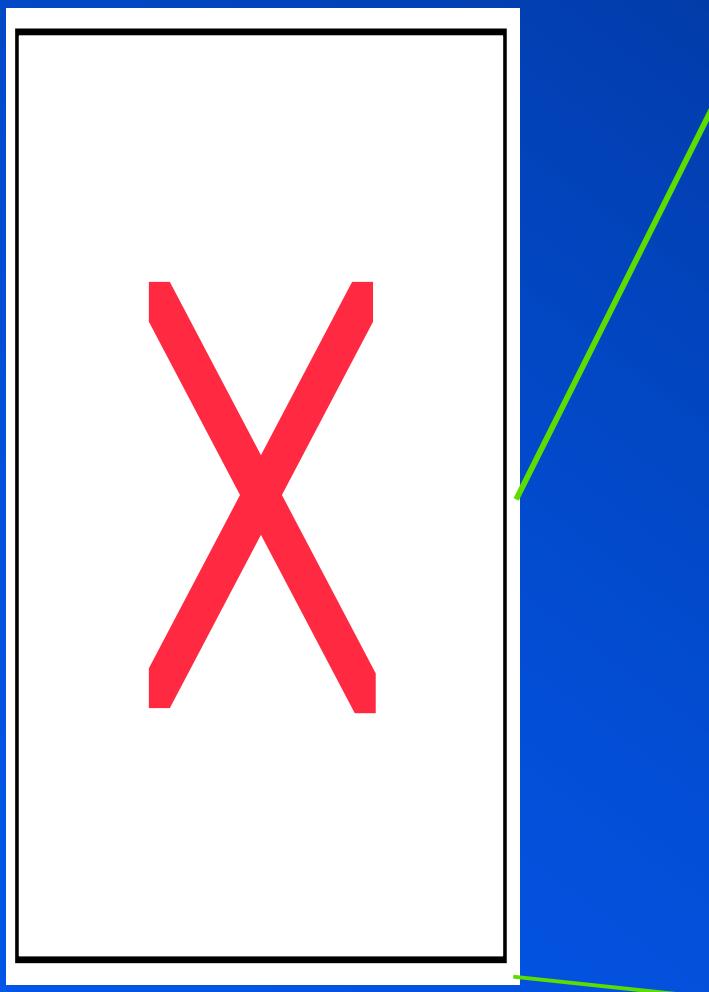
Nature(London) 412, 279 (2001)



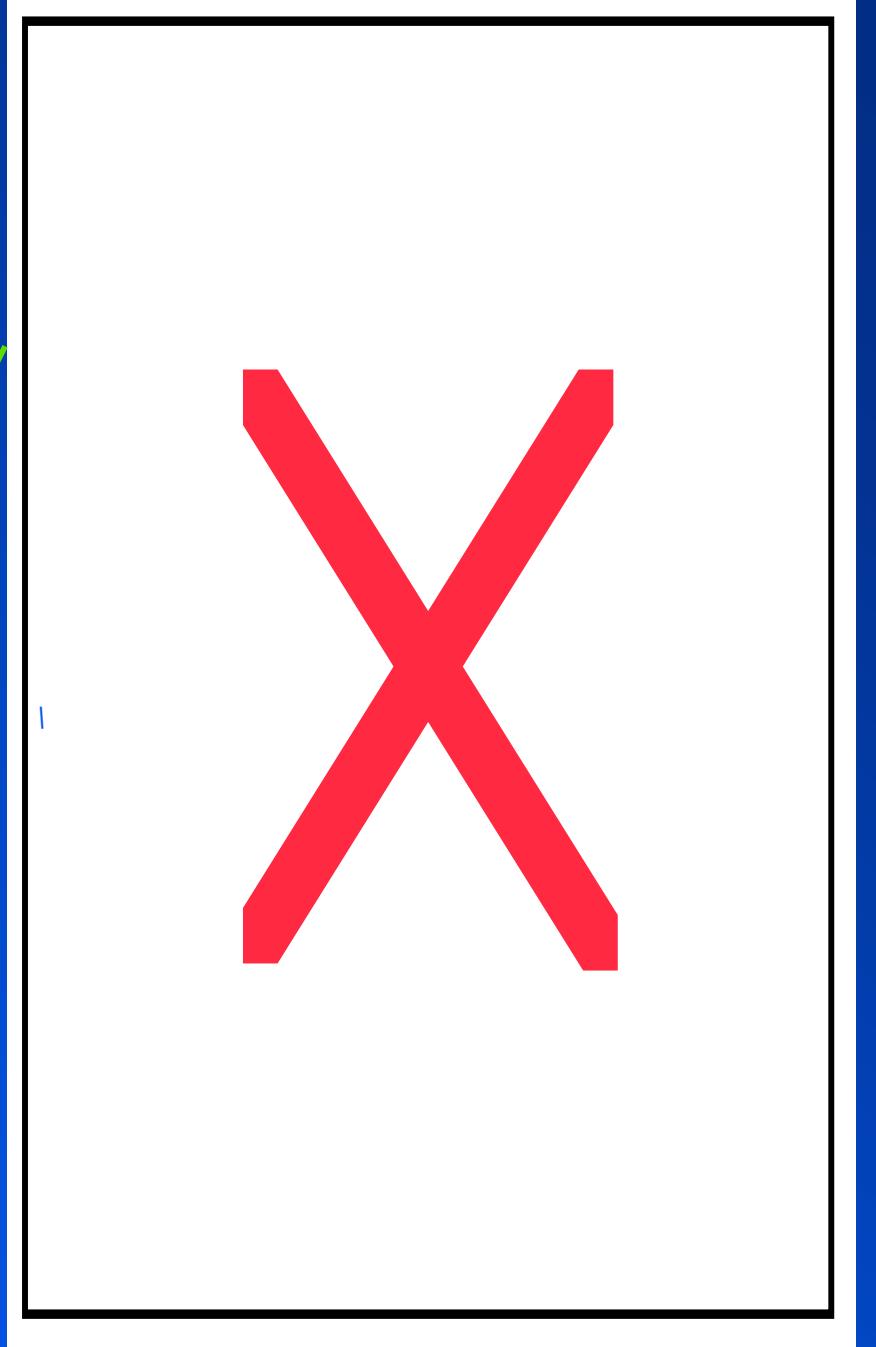


Science, 291, 458 (2001)

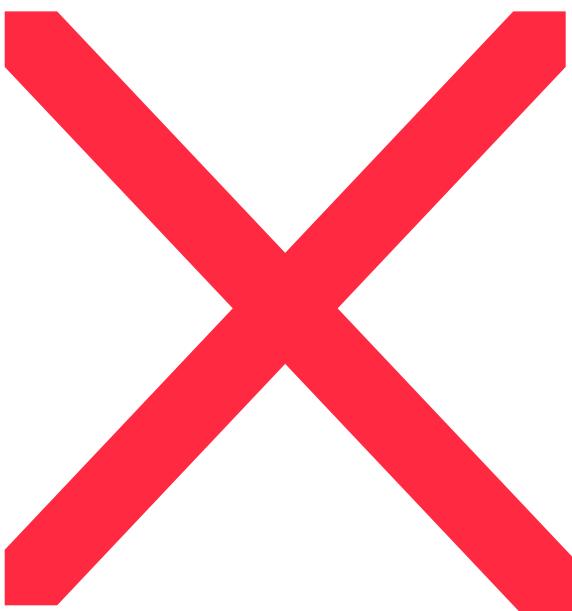
Diffraction Frame- Reference Method



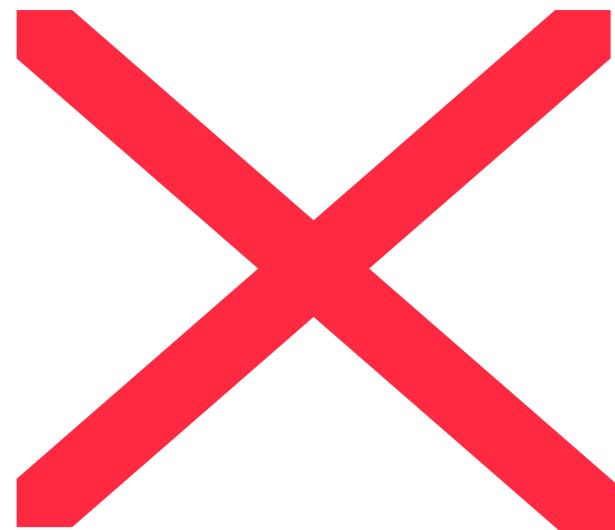
1% change !!



Science,
291, 458 (2001)



Dark Structures



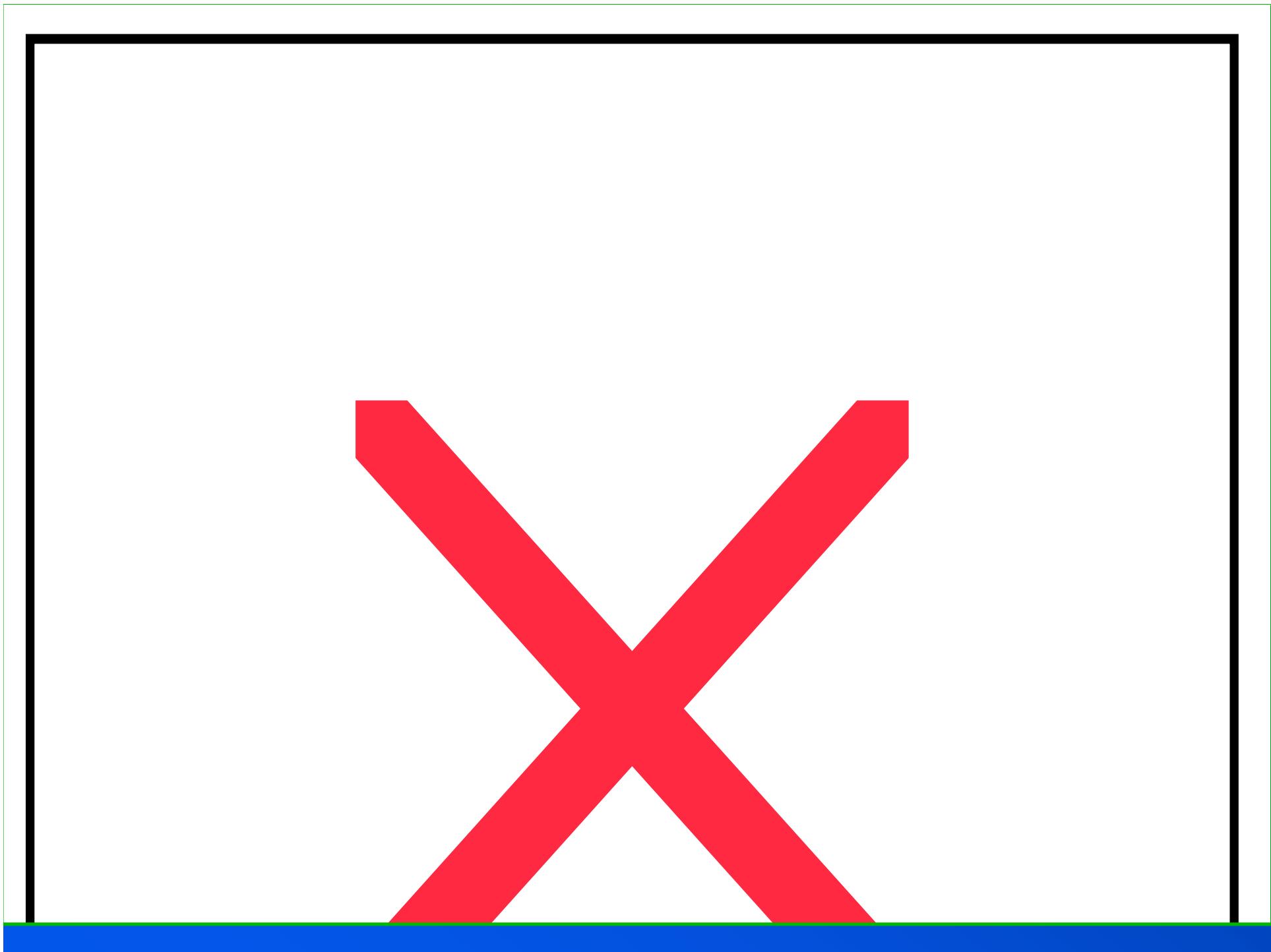
Science
(2005)

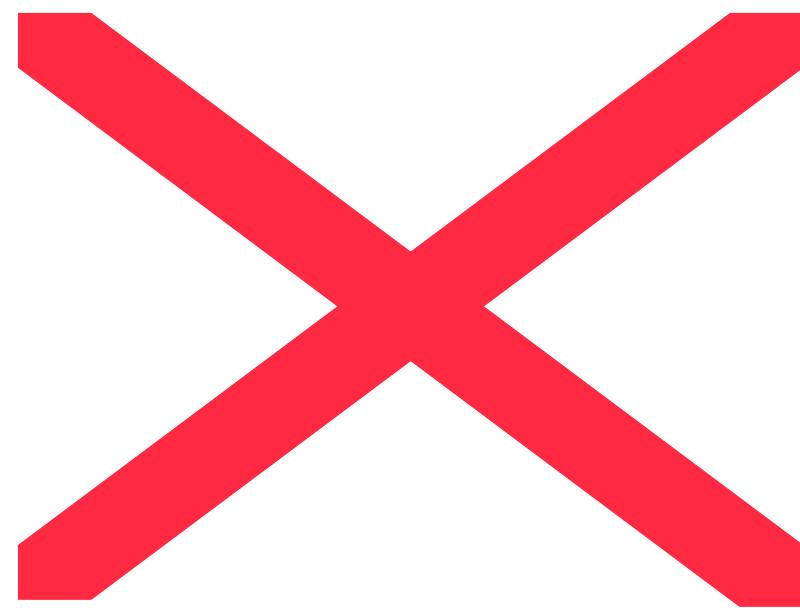
Condensed Phase & Biological Opportunities in the New Field

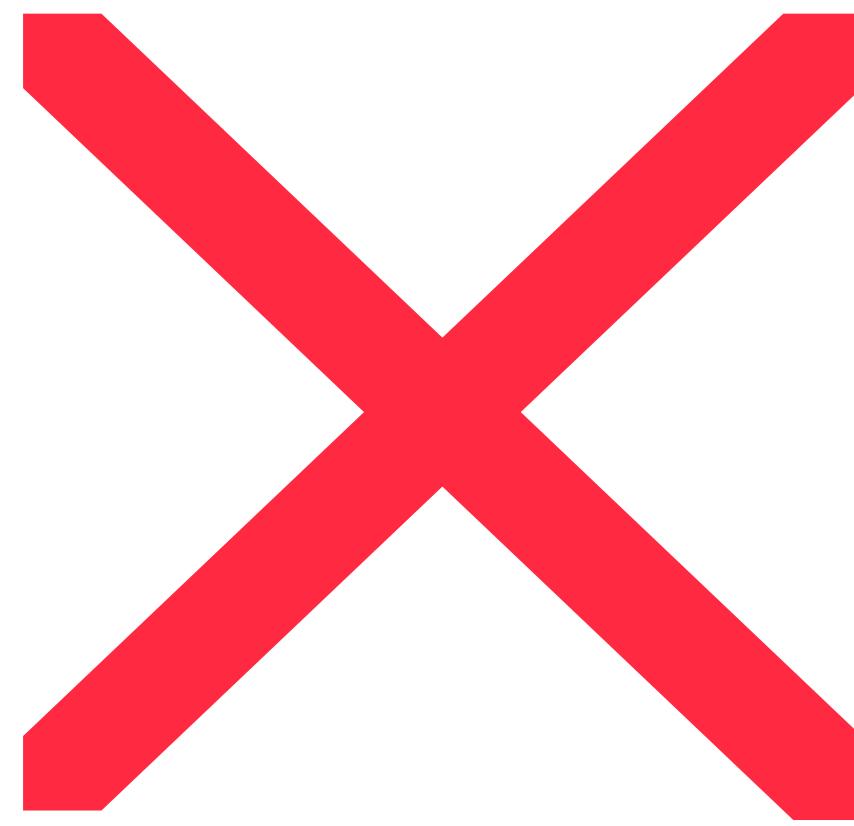
(Experimental & Theoretical)

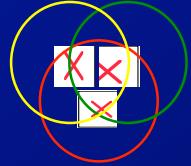
- UEC & Structures of Condensed Phases**
- UEM & Molecular and Cell Imaging**

- SURFACE REACTION DYNAMICS**
- CRYSTALS**
- PHASE TRANSITIONS**
- SELF-ASSEMBLY**
- BIOLOGICAL STRUCTURES**

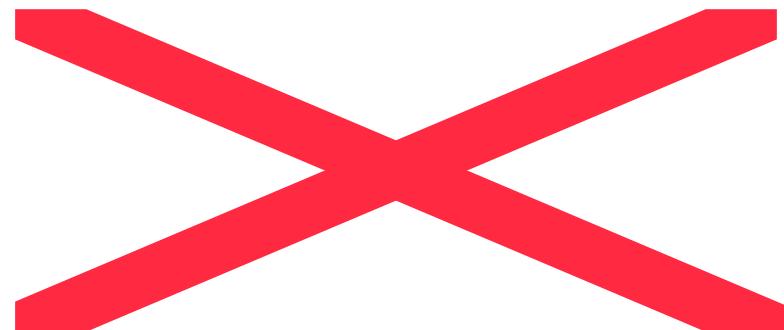


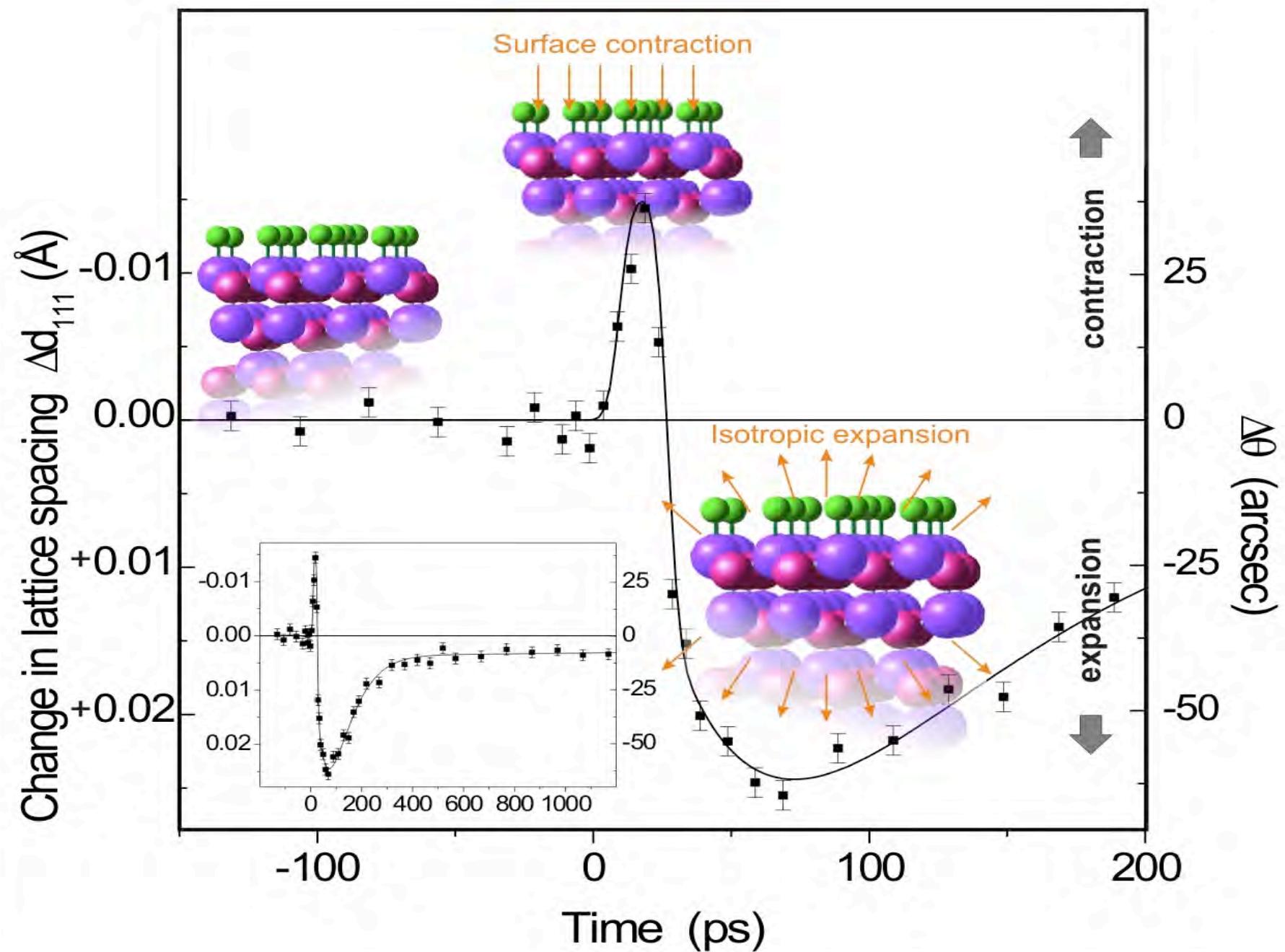






Paradigm case study : structural dynamics of GaAs (111)-Cl





Time & length Scales with Atomic Resolution

- *Potential driven contraction*

fs to 1ps - 0.015Å surface atoms

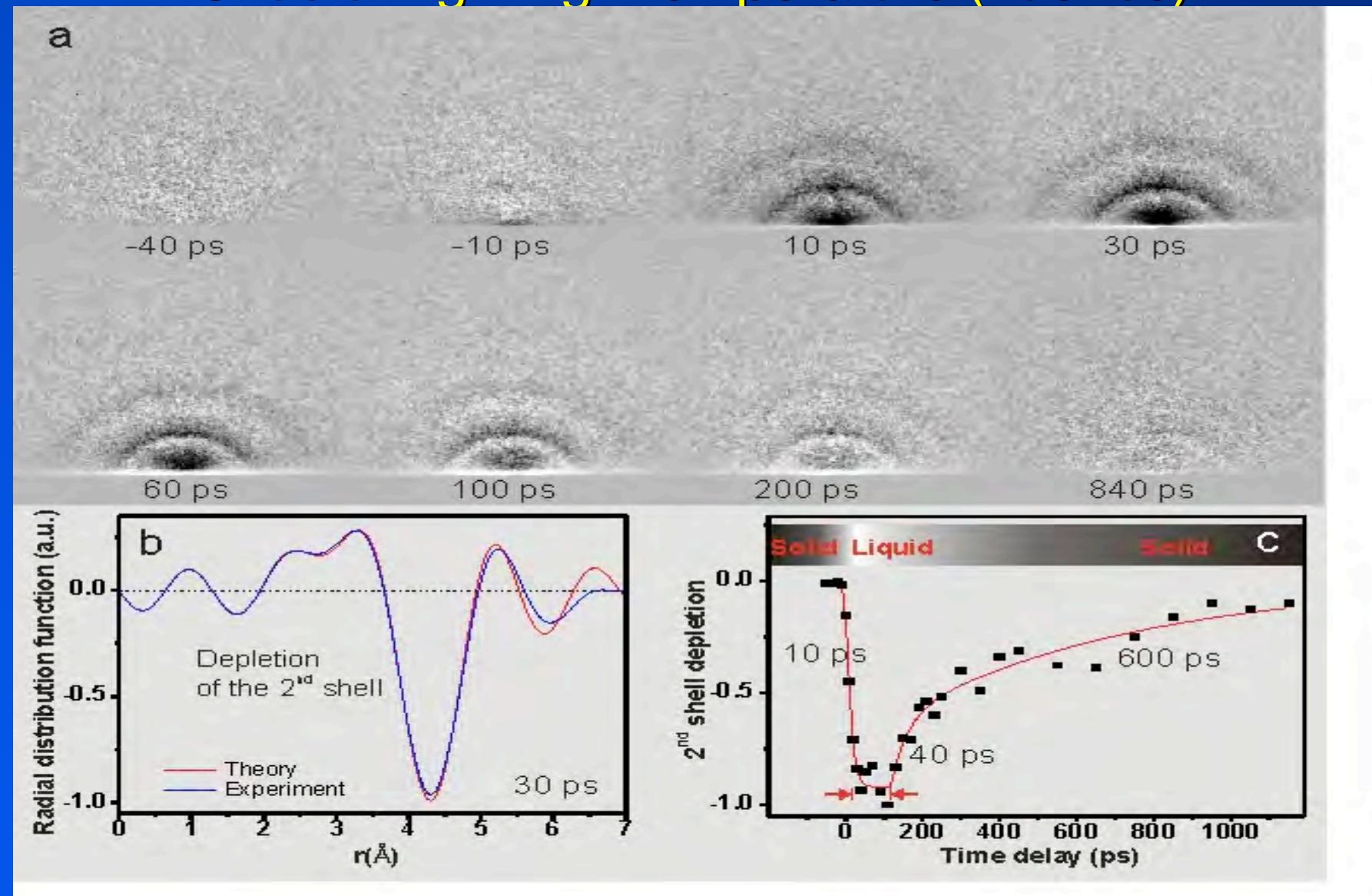
- *Coherent to isotropic lattice expansion*

ps to 7ps + 0.025Å nm bulk

- *Heat diffusion & re-structuring*

50ps to 1ns + 0.0032Å bulk

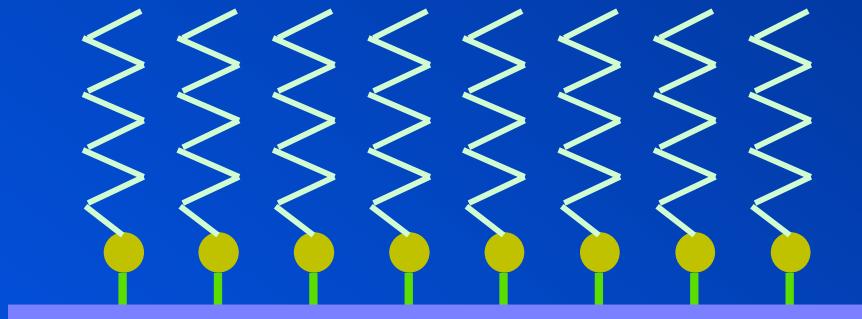
Surface melting , phase transition & re-structuring : high temperature (fluence)



PNAS 101, 1123 (2004)

Diffraction Frame Reference (Si : -150 ps)

Interfaces

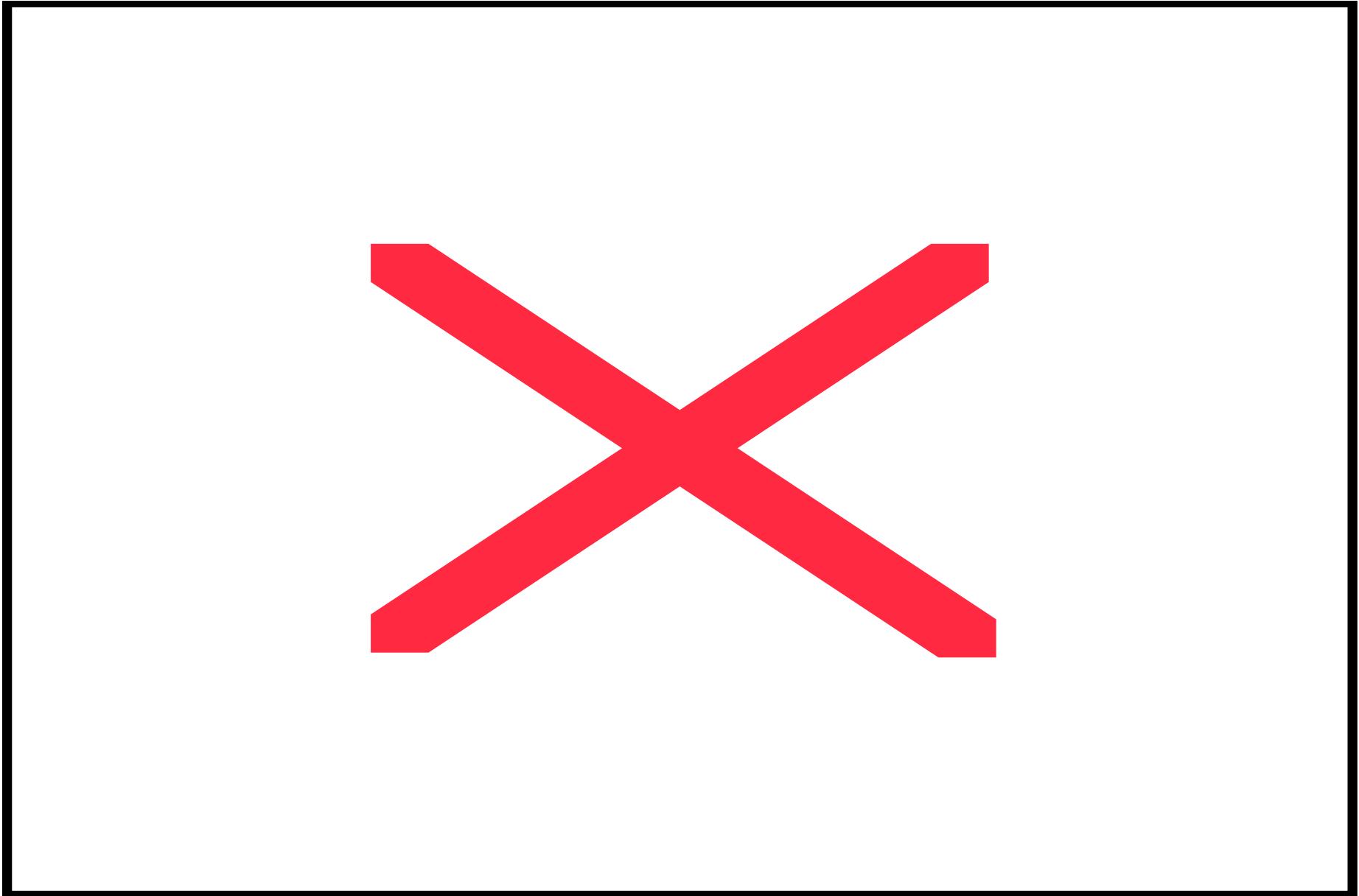


Molecular Self-
Assembly

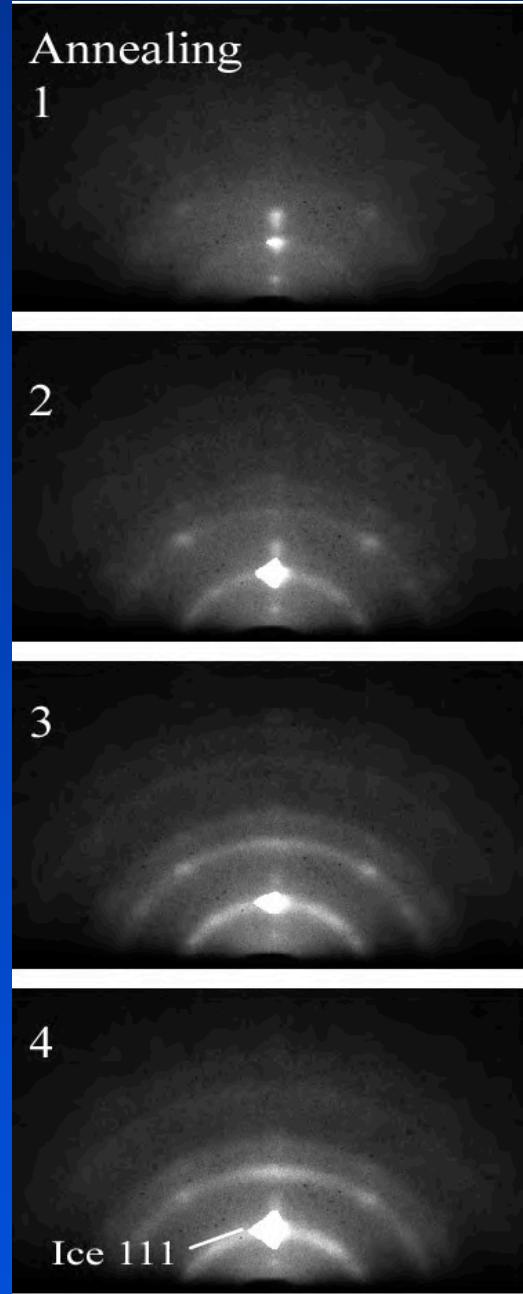
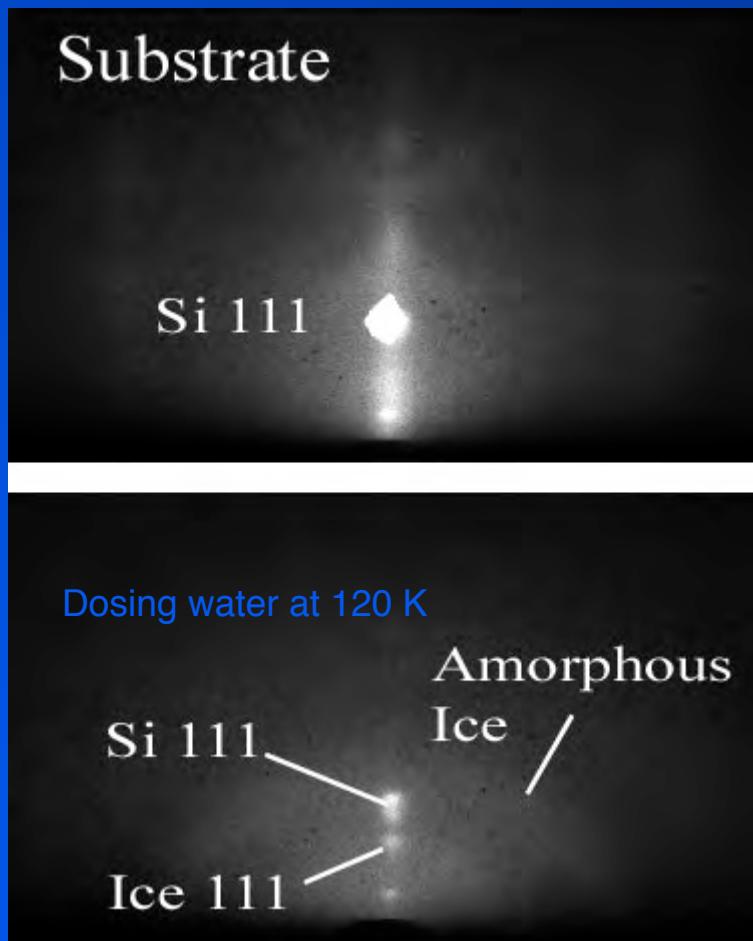
Surface as a Template

Spatial & Temporal Resolutions

Surface Temperature Jump

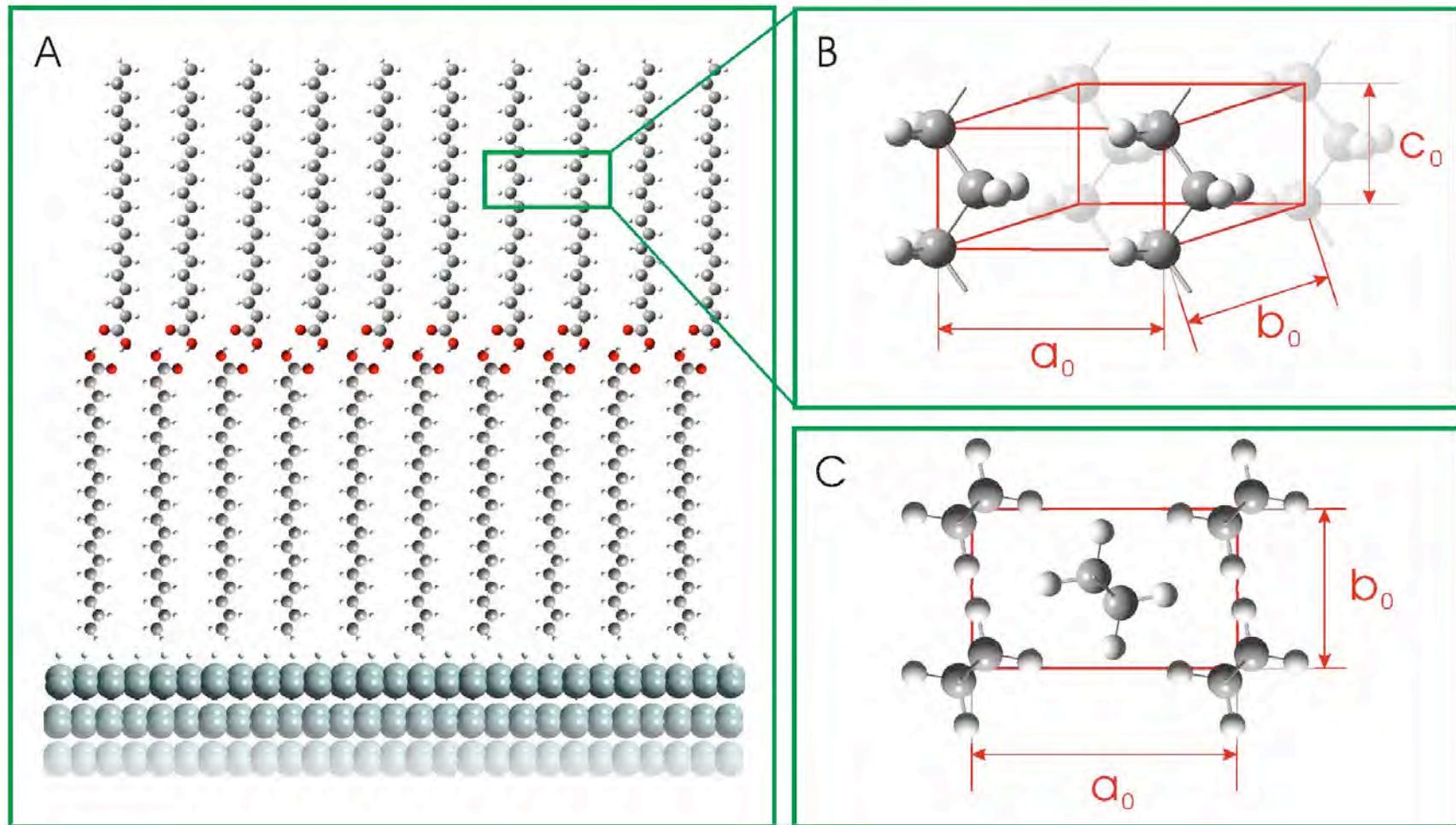


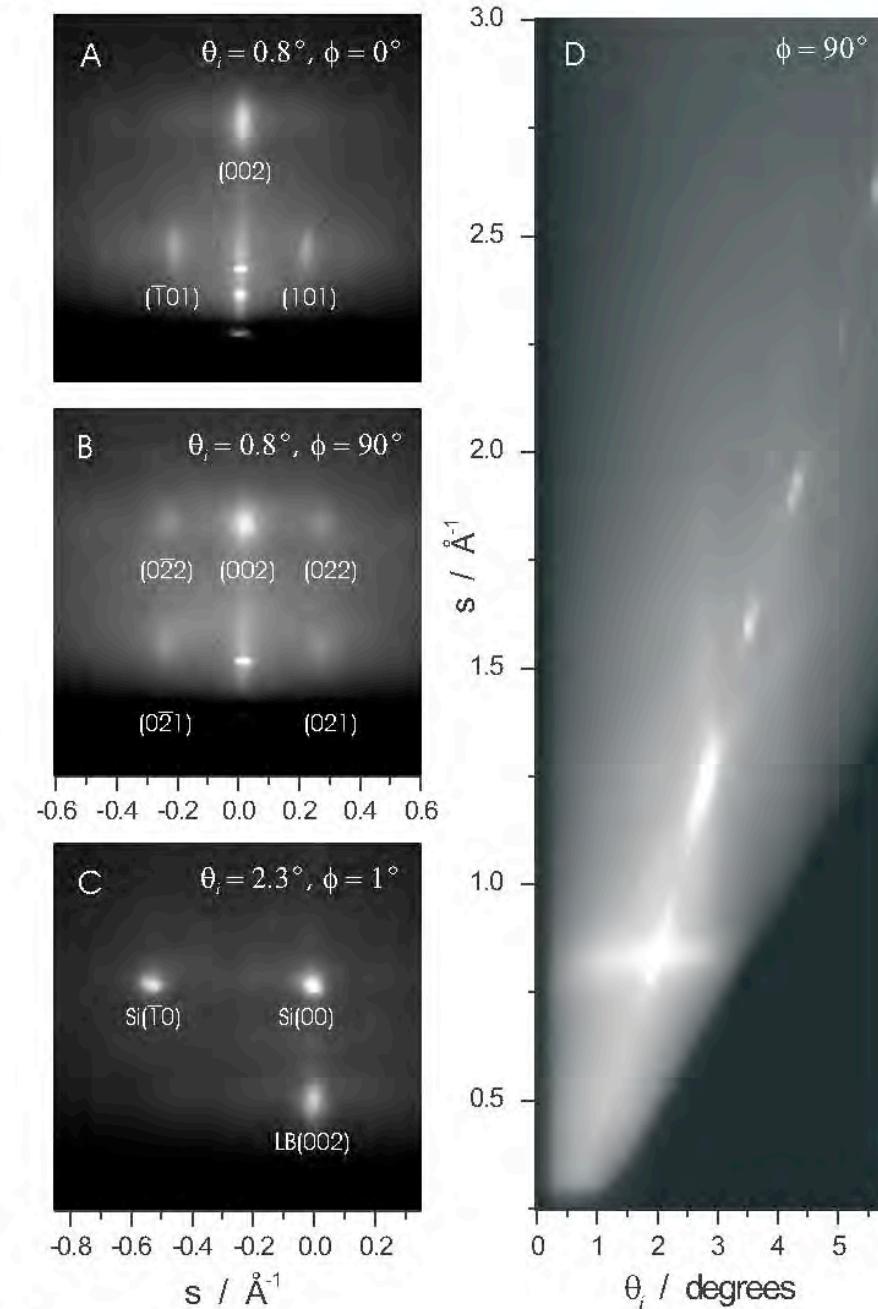
Structure: interface ordered bulk disordered



Science (2004)

Bilayers – Structure & Dynamics





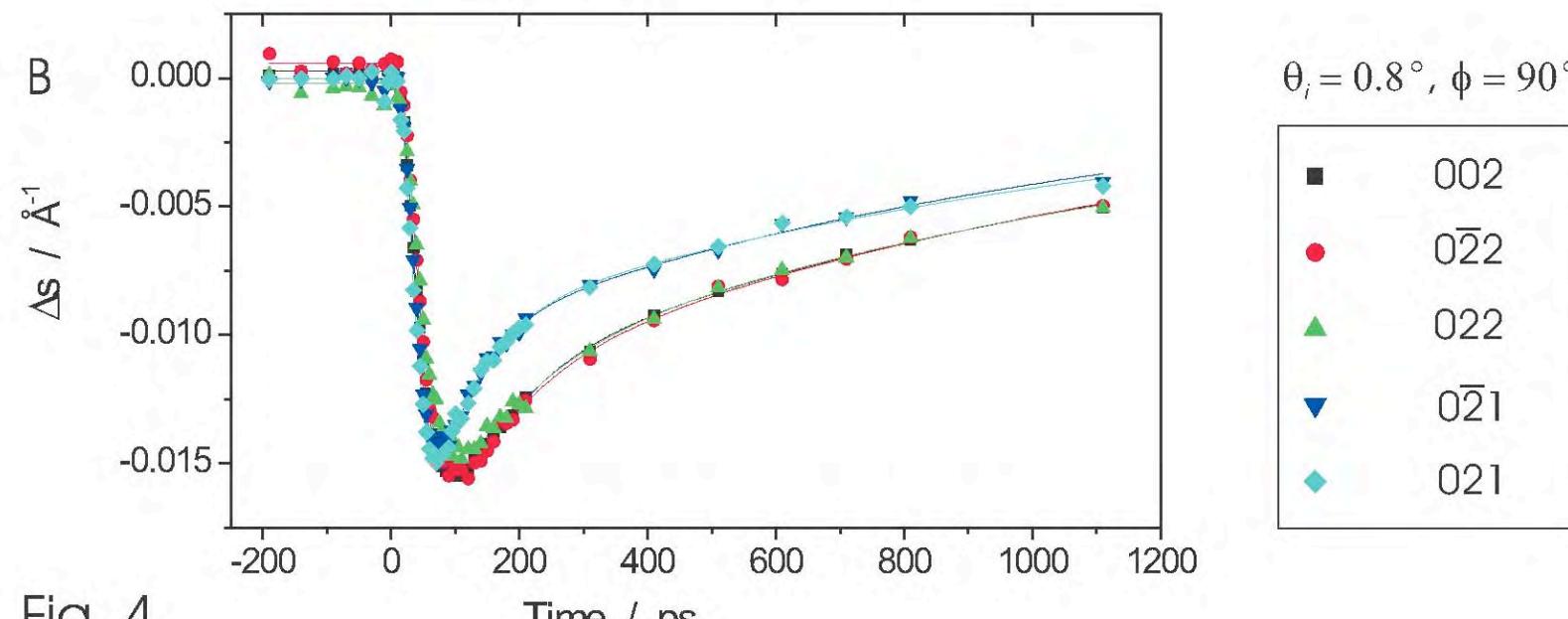
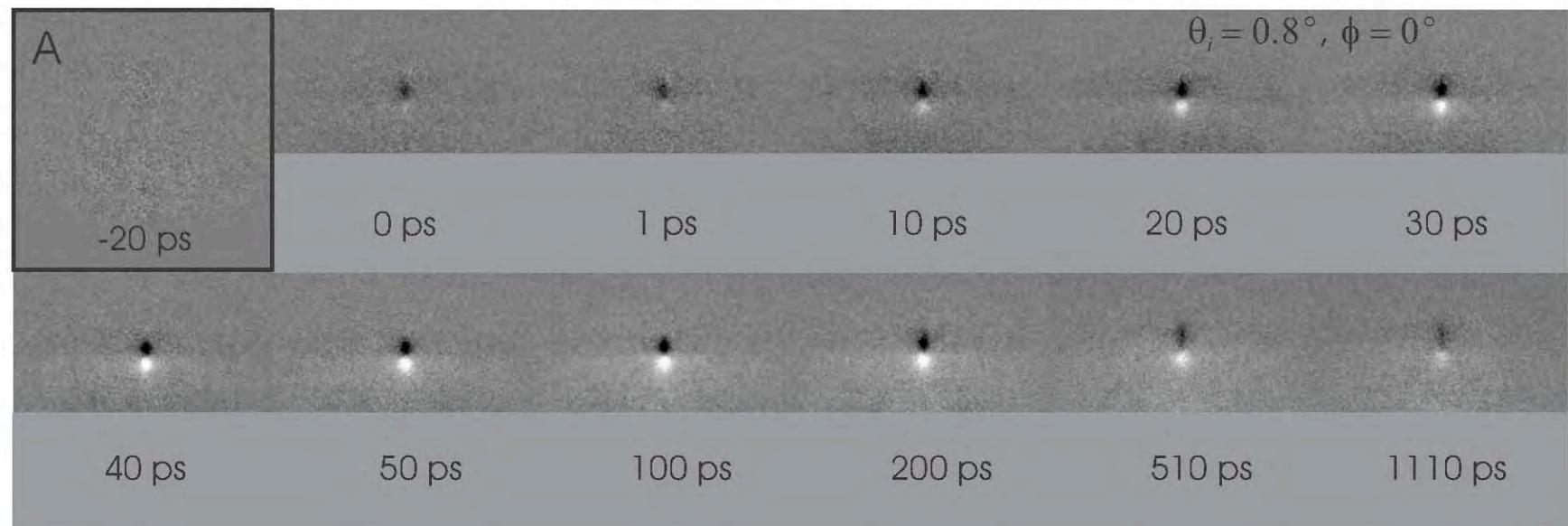
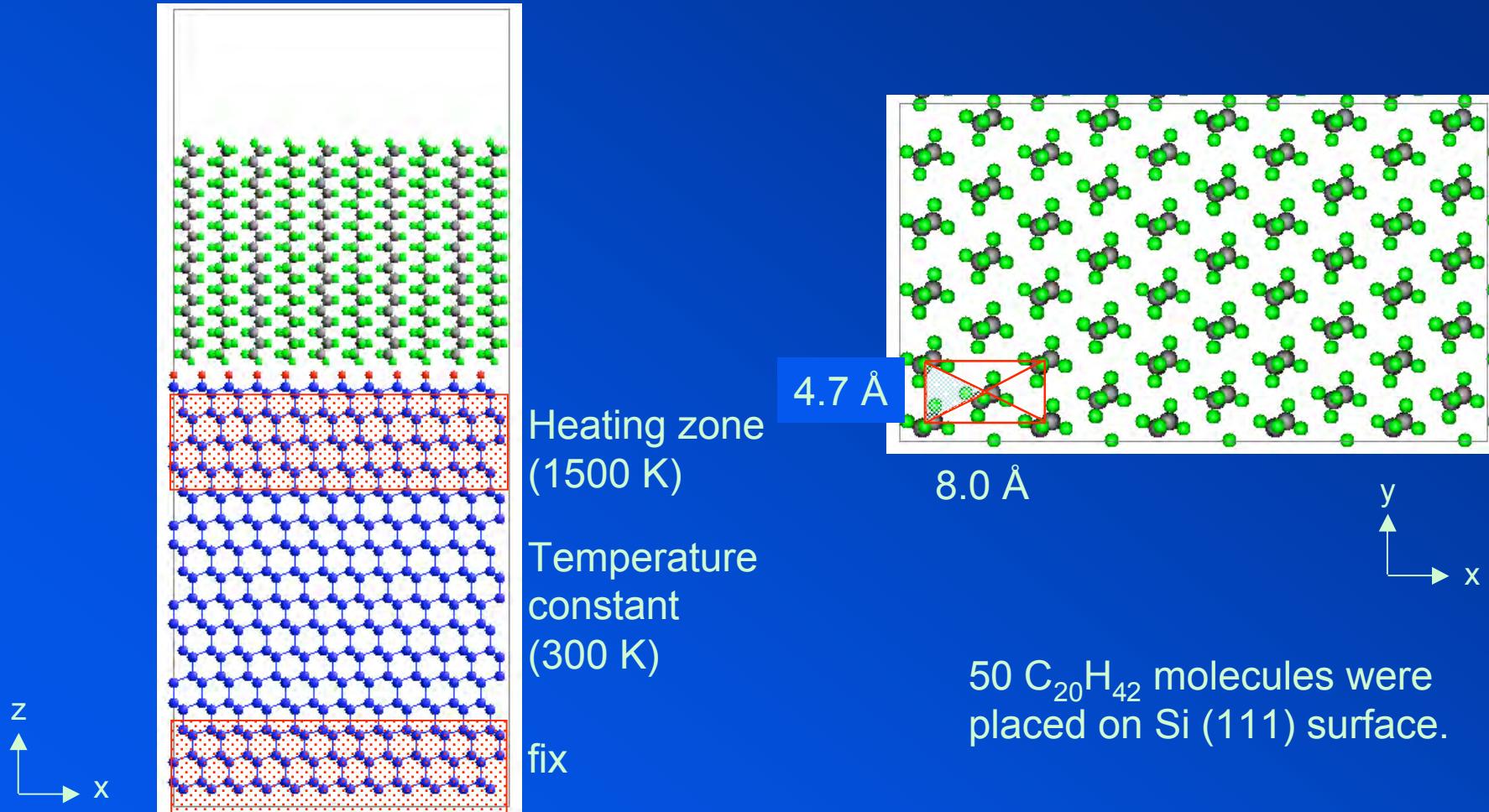


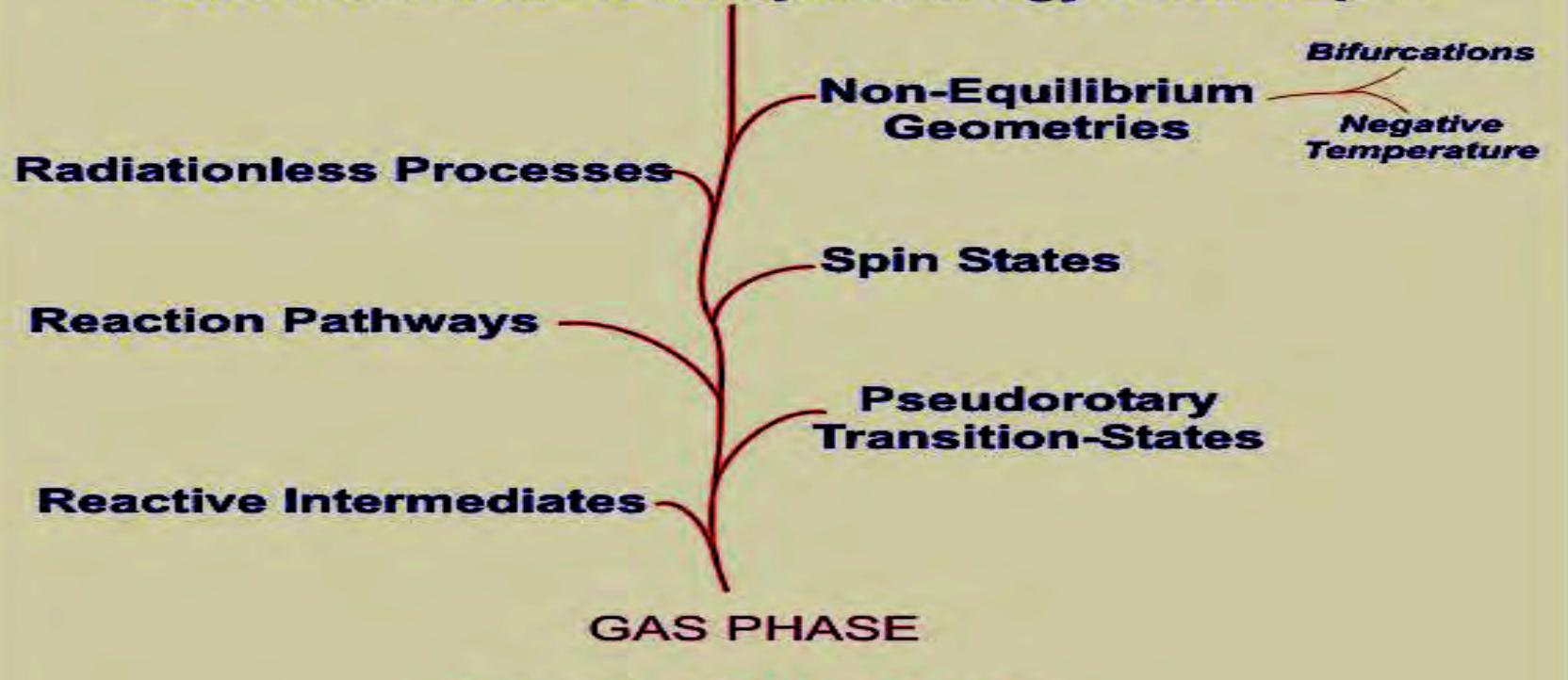
Fig. 4

Theory : Heating Pulse Dynamics



Suzuki , Kubo , Shoji & Zewail

Conformations on Complex Energy Landscapes



Transient Structures



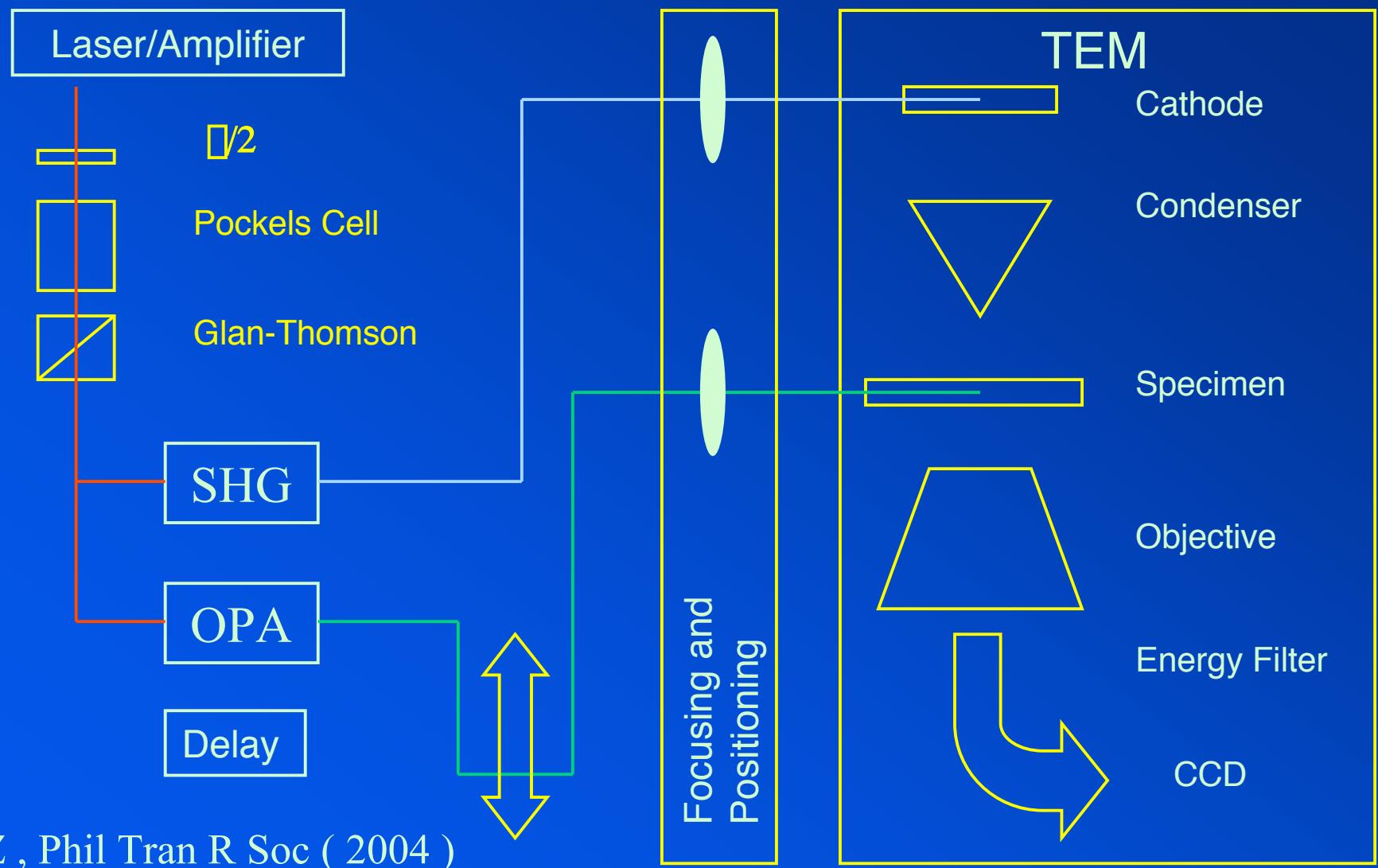
Ultrafast Electron
Crystallography

Ultrafast Electron
Diffraction

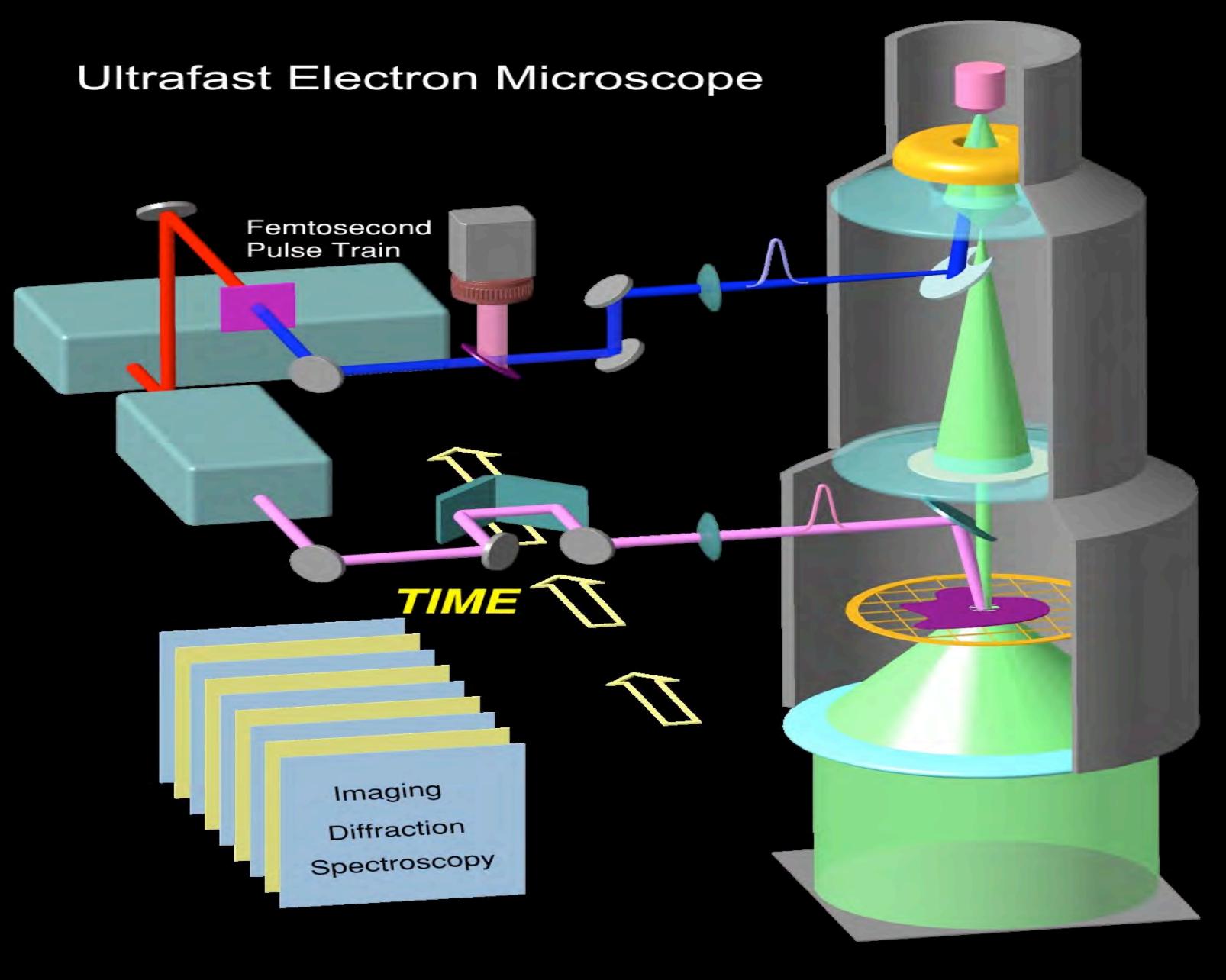
Ultrafast Electron
Microscopy

Ground State Structures

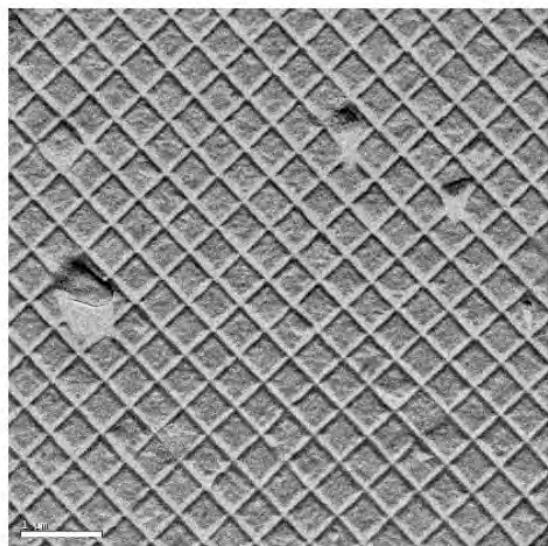
UEM



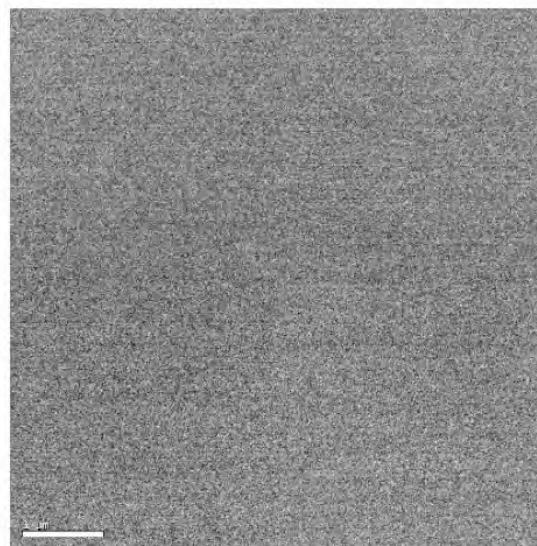
Ultrafast Electron Microscope



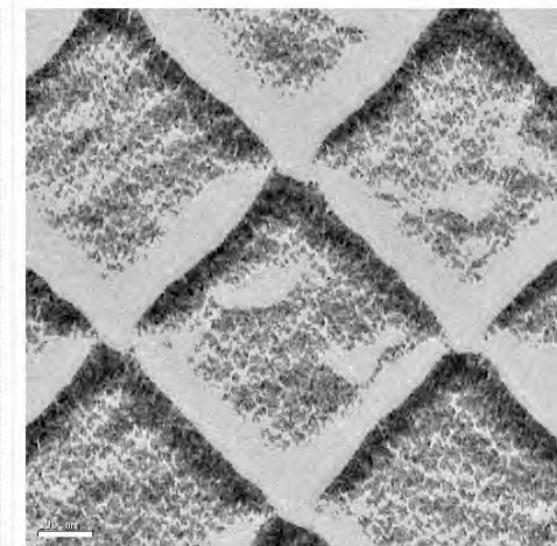
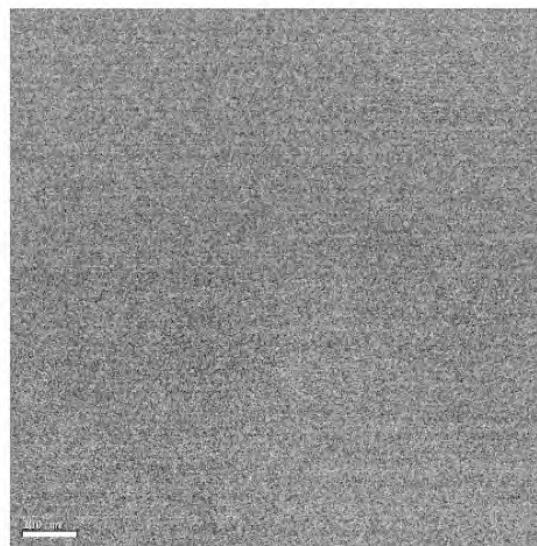
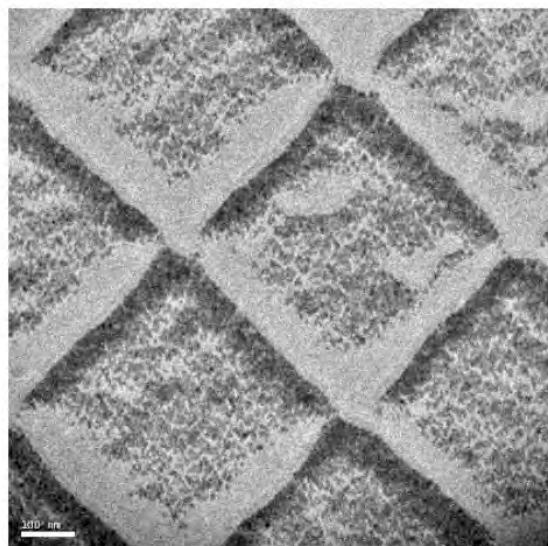
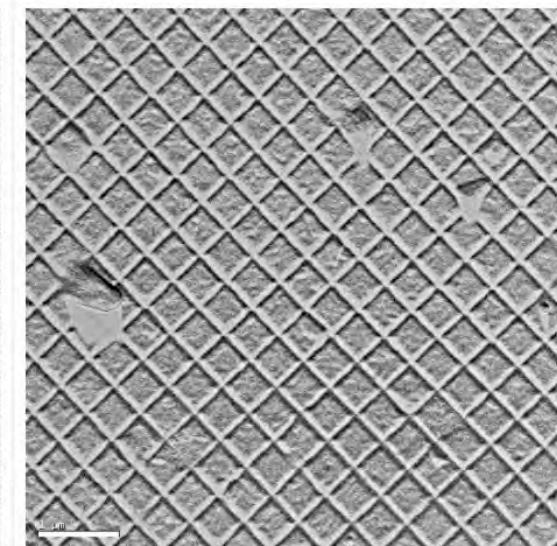
UEM



UEM (Background)

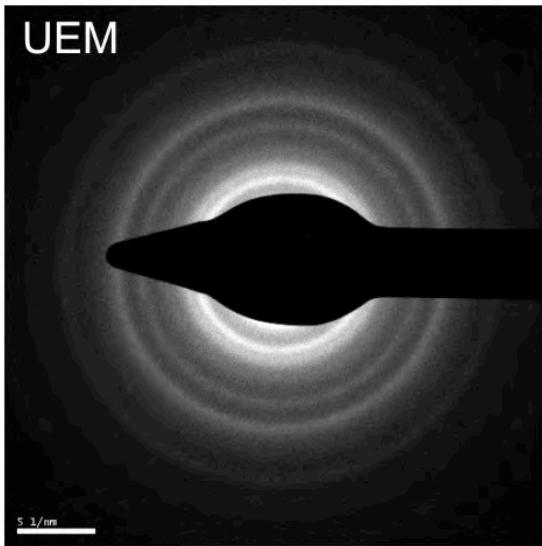


TEM

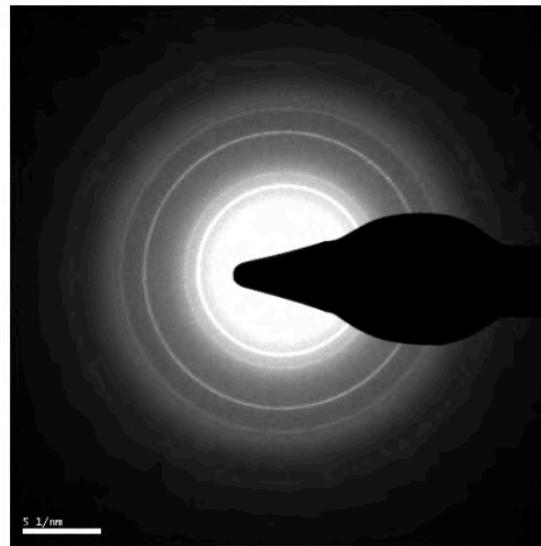


Amorphous Carbon

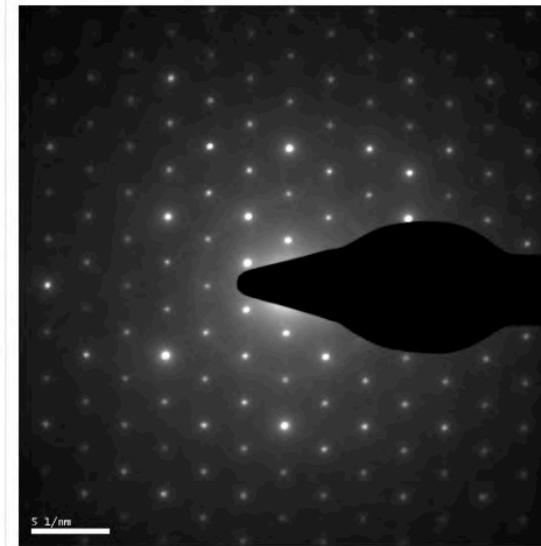
UEM



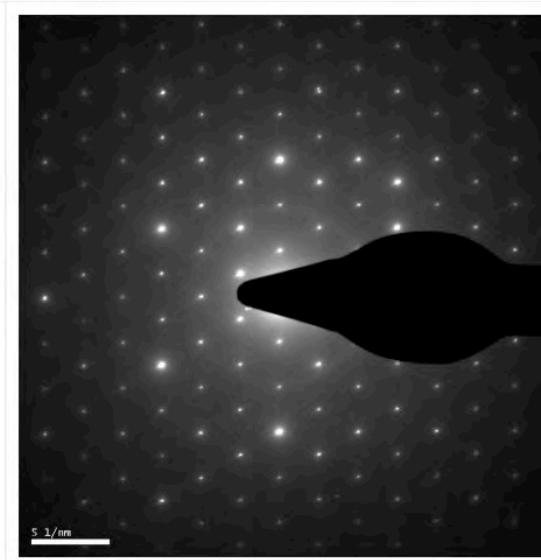
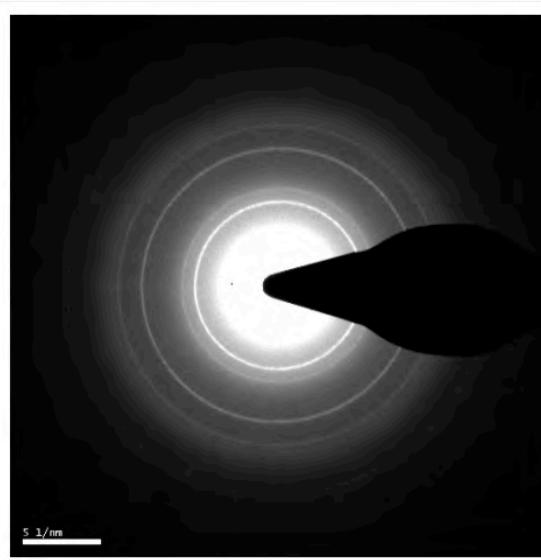
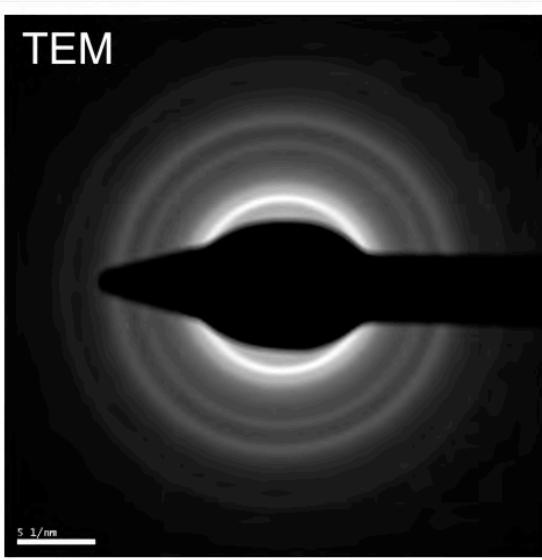
Polycrystalline Aluminum



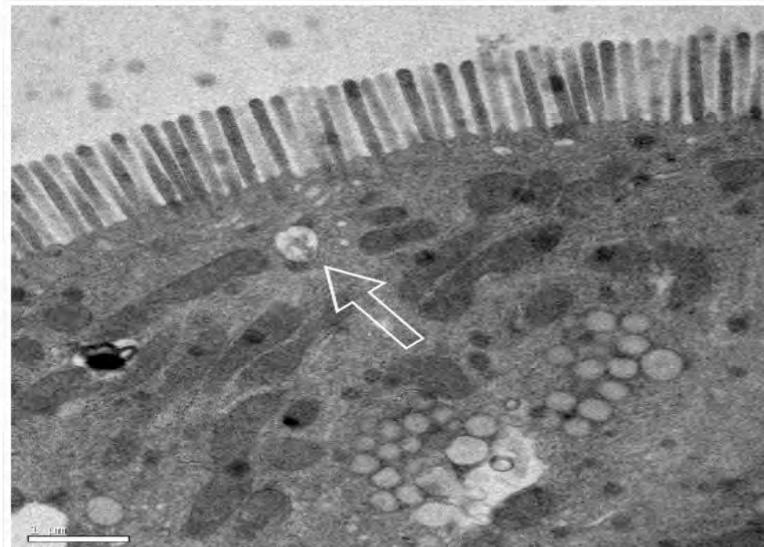
Single Crystal Gold



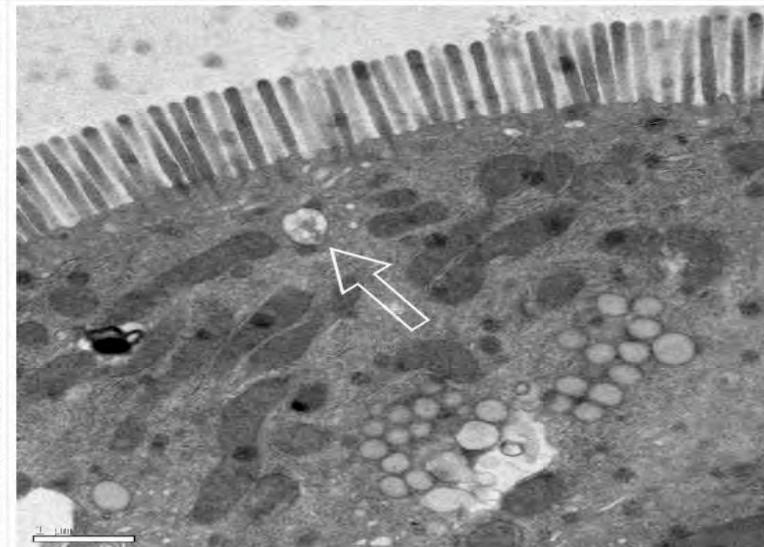
TEM



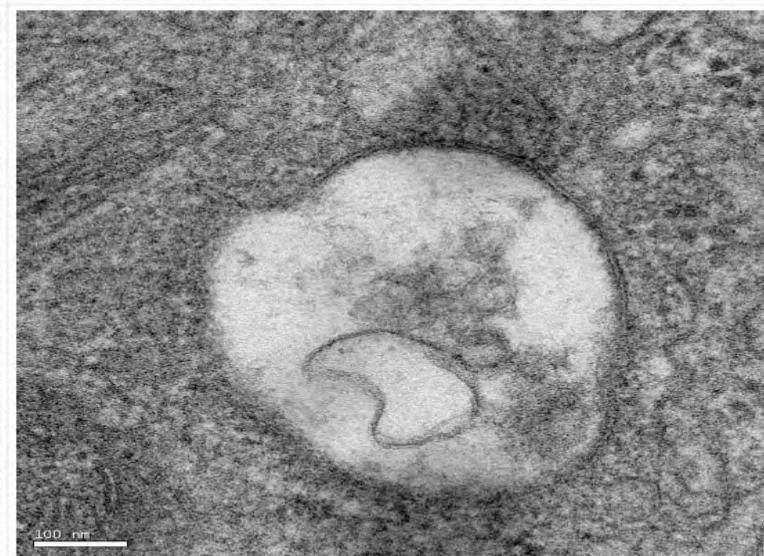
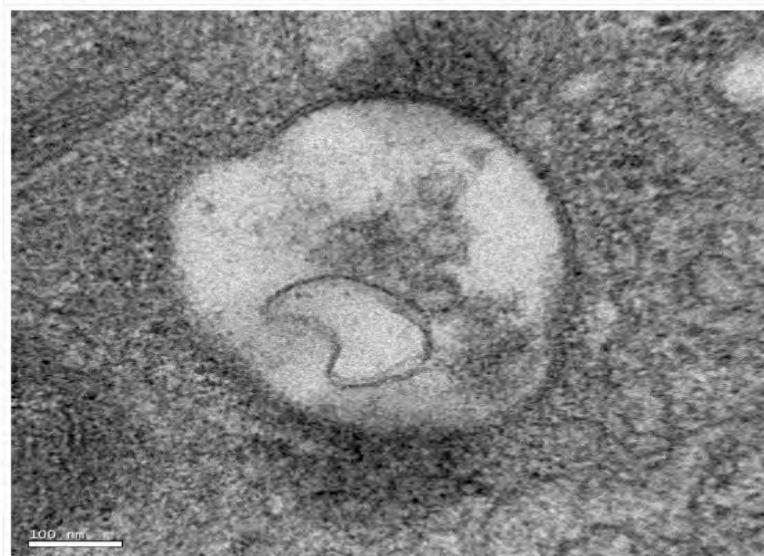
UEM



Cell of Rat Intestine

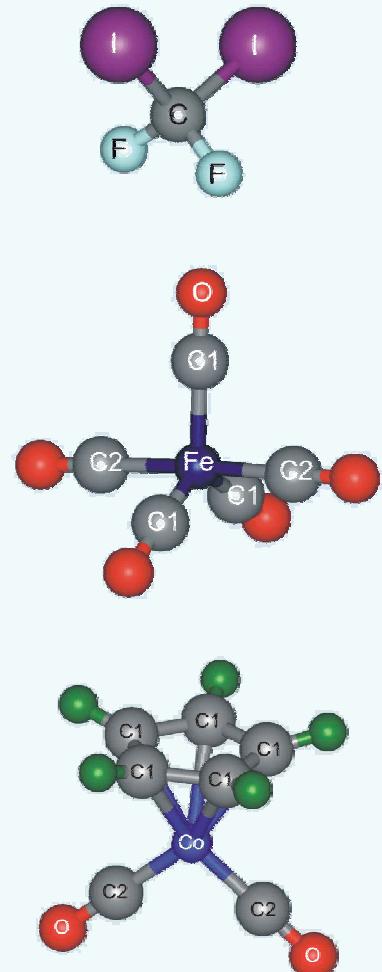


TEM

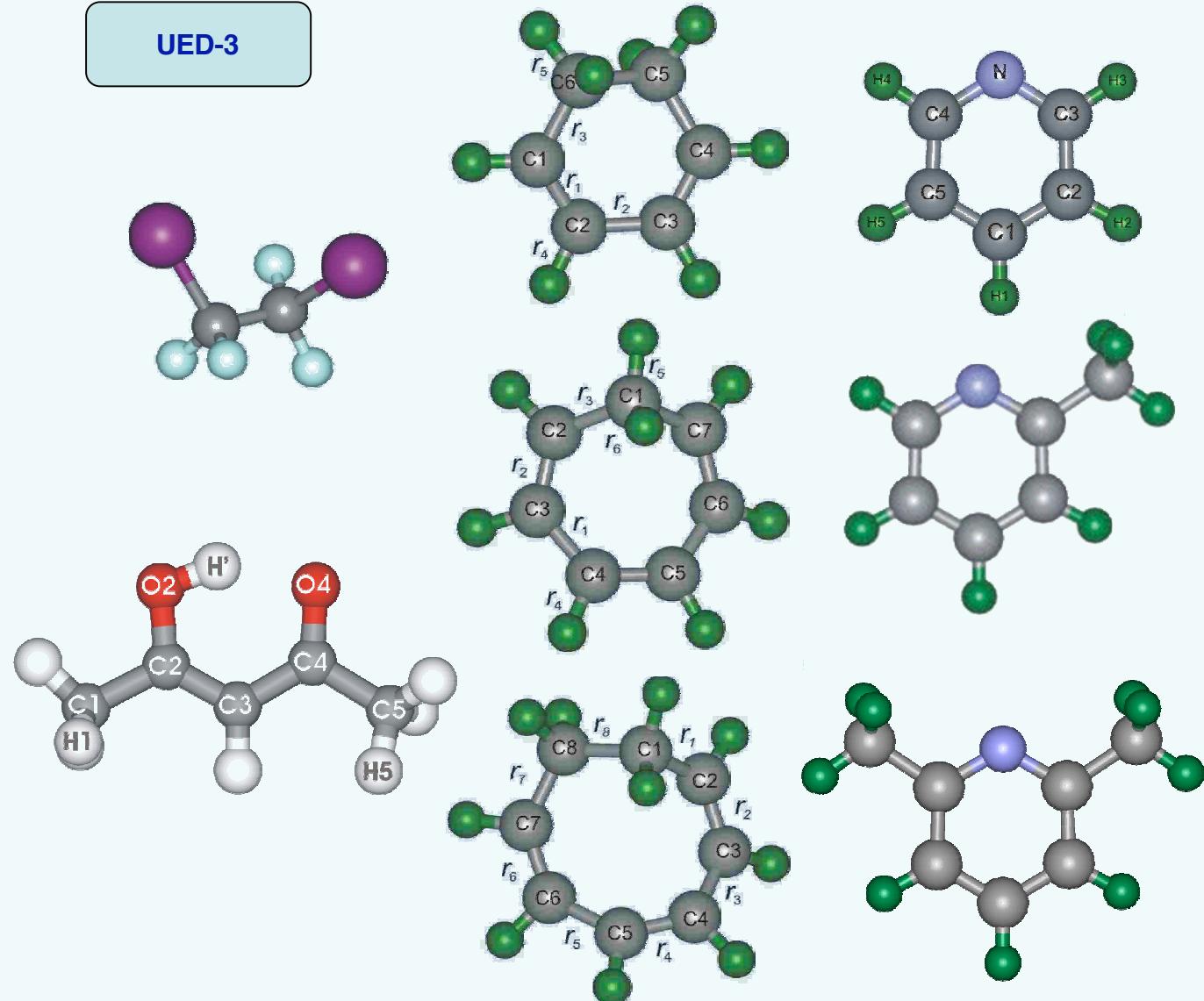


Molecular Complexity

UED-1 / UED-2

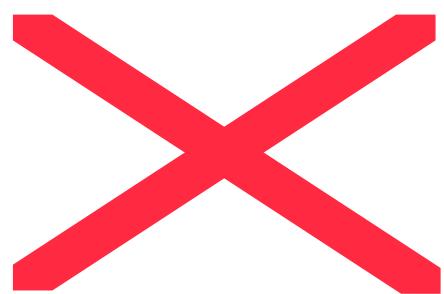


UED-3

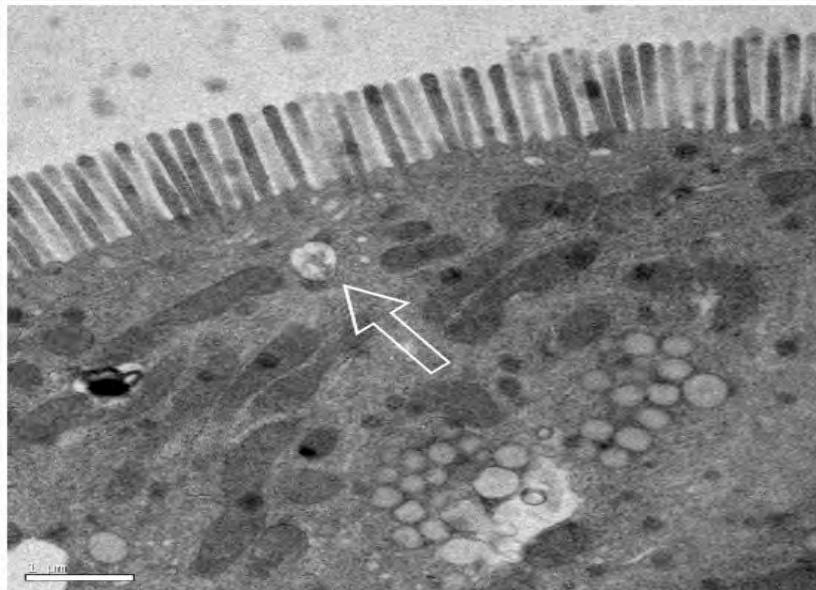


Macromolecular Assemblies

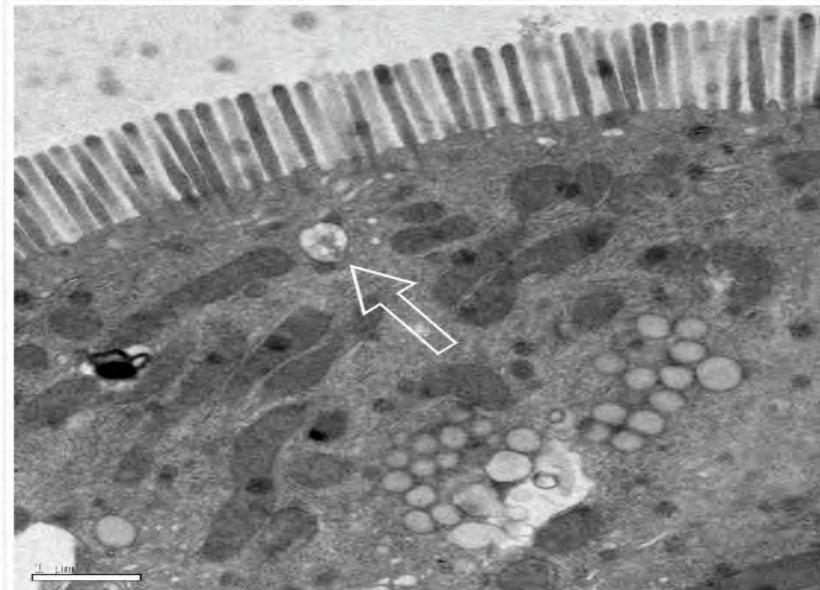
UED-4



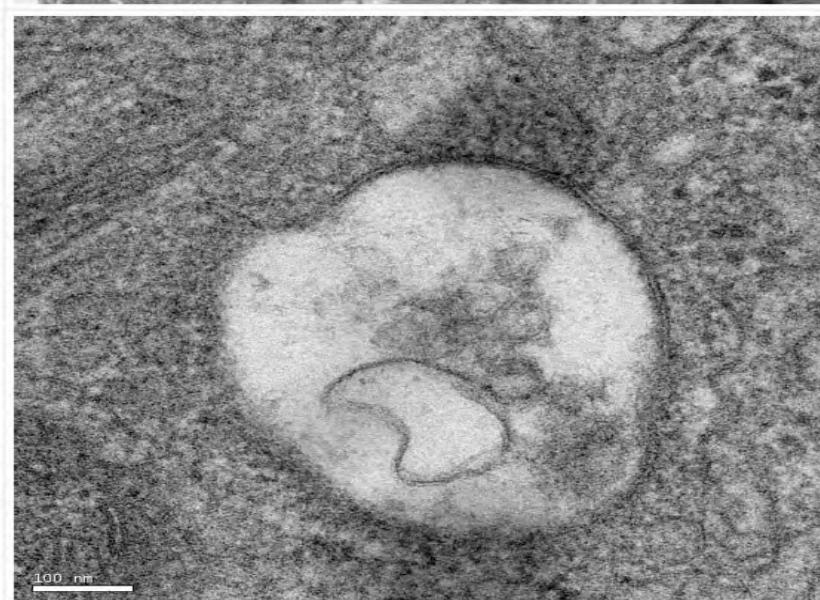
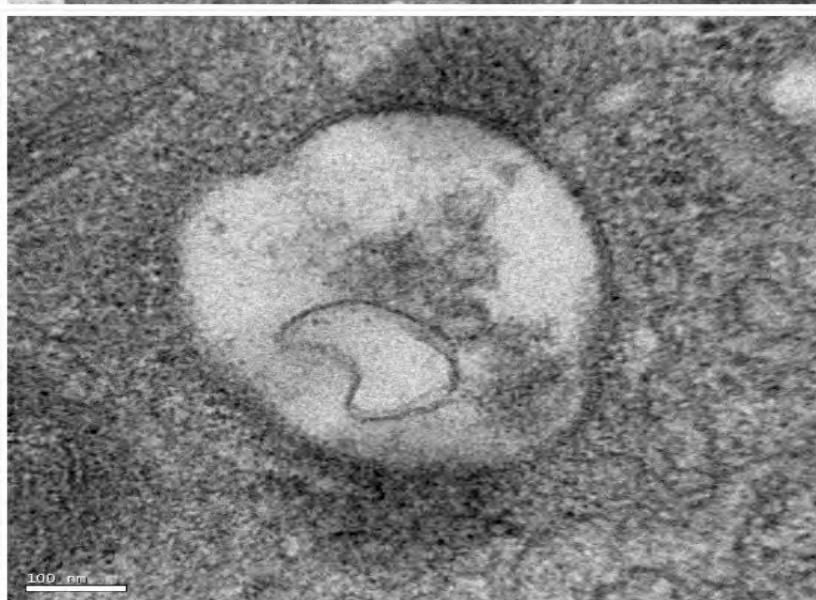
UEM



Cell of Rat Intestine



4D-EM



Structures & Dynamics
in **both** *Space* and *Time* !!!

UED UEC UEM

UED , UEC , UEM

Chuck Williamson

Marcos Dantus

Scott Kim

Hyotcherl Ihee

Jiaming Cao

Hans Frey

Udo Gomez

Chong-Yu Ruan

Boyd Goodson

Franco Vigliotti

Shoujun Xu

\$ National Science Foundation
Air Force

Spencer Baskin

Jonathan Feenstra

Dmitry Shorokhov

Milo Lin

Sangtae Kim

Jerry Yang

Nuh Gedik

Scott Habershon

Marco Seidel

Songye Chen

Vladimir Lobastov

Ramesh Srinivasan

Bill Anderson