Nano-Physical Characterization (in the Physics Department)

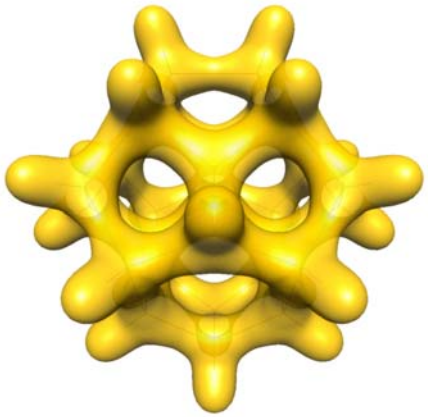
Keith Weninger
North Carolina State University
Physics Department

Nanoscale Characterization in the Physics Department

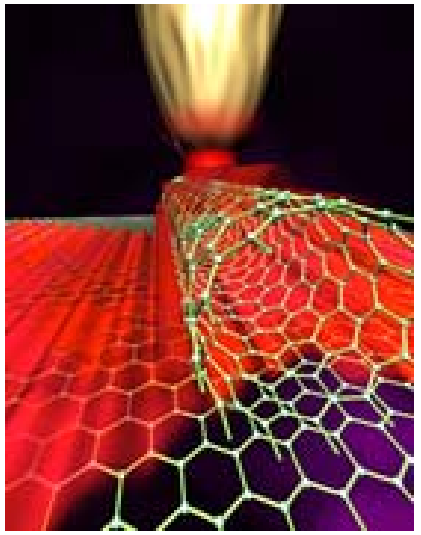
- Computational studies
  - Mitas, Bernholc, Buongiorno Nardelli, Sagui, Roland
- Spatially resolved studies
  - Pearl, Scanning probe microscopy
  - Rowe, PEEM
  - Hallen, NSOM Nanoraman
  - Ade, 2-D spatially resolved STXM (& XAFS)
- Dynamic motional studies
  - Clarke, Molecular rotors through electrical studies
  - Bochinski, Molecular rotors through optical studies
  - Krim, Molecular origin of friction and lubrication
  - Riehn, Biomolecules in nanochannels
  - Weninger, Bio molecular motion studied by FRET

Computational Physics:

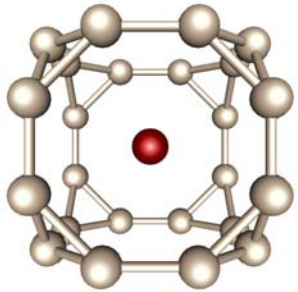
Mitas, Bernholc, Buongiorno Nardelli, Sagui, Roland



-Carbon nanotubes
-silicon nanoparticles
-biomolecules



-electronic/transport properties of nanostructures
-nanoconfinement effects
-protein dynamics



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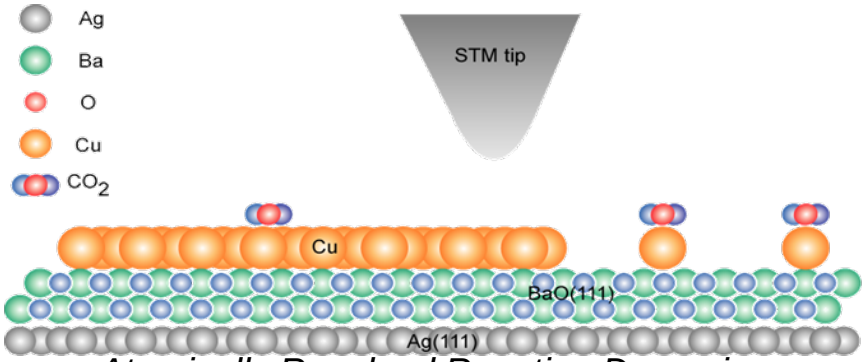
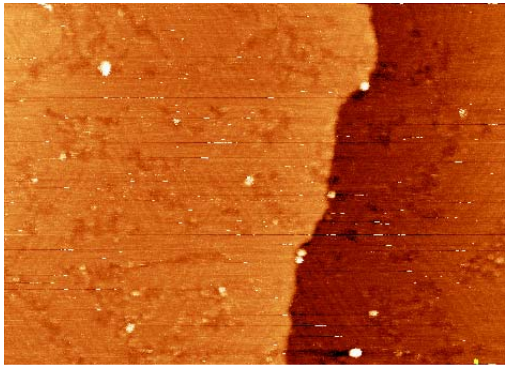
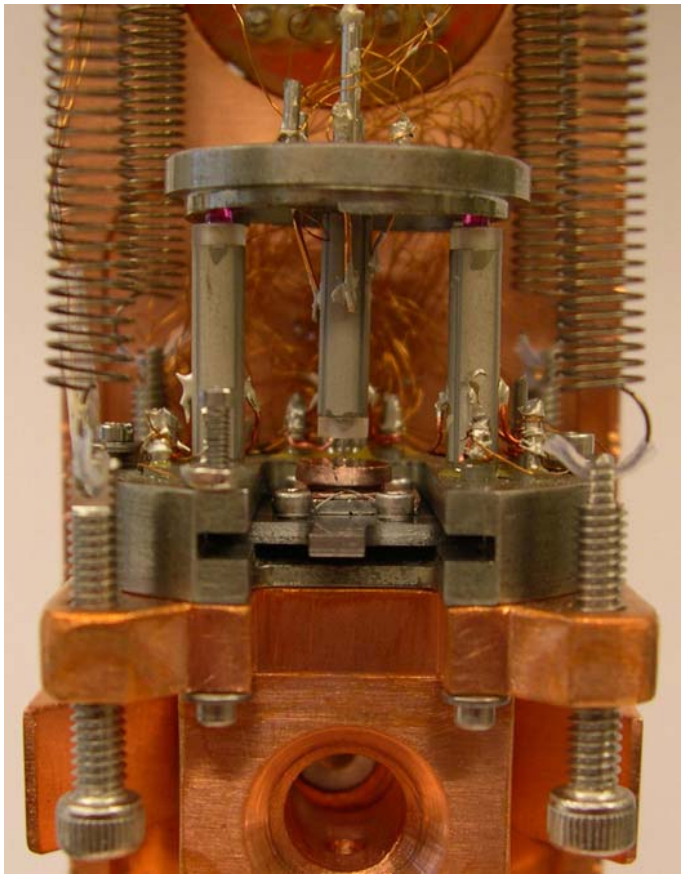
Pearl group: Probing surface chemical reactions, interactions, and behavior of single molecules with atomic scale tools



Atomically Resolved Reaction Dynamics Involving Catalytically Active, Surface Supported Clusters



Surface anchoring of biomolecules for molecular sensing and optoelectronics

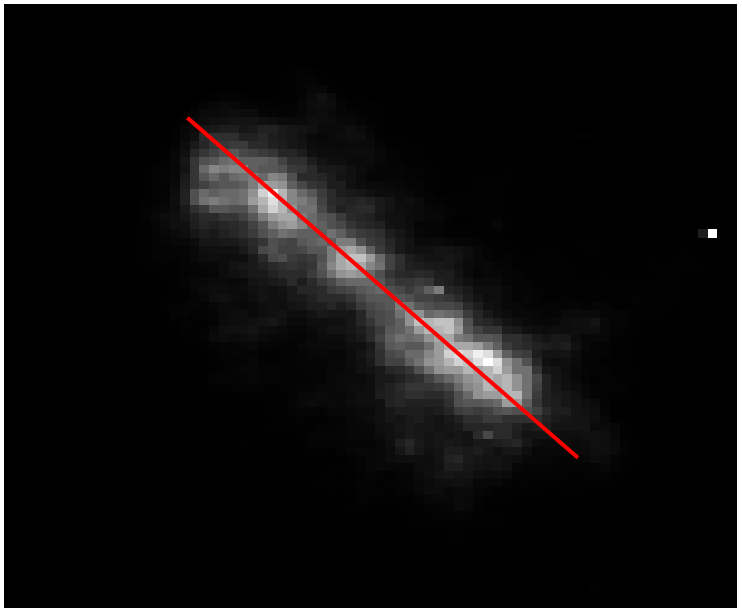


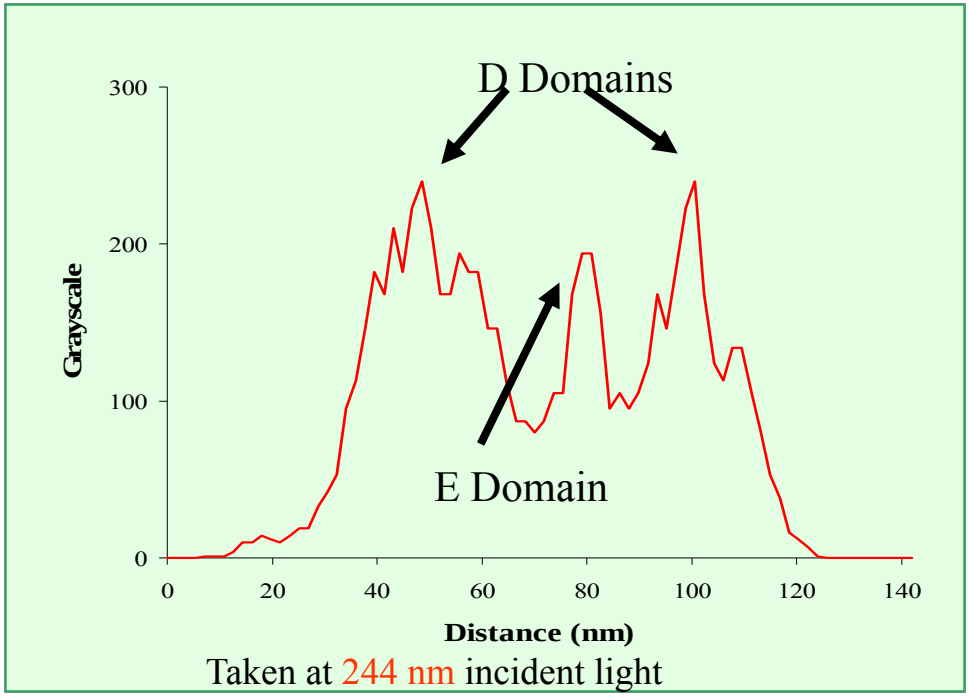
Custom built, ultra-stable electron tunneling and chemical force sensitive microscopes

Rowe group (former Nemanich group students):

Photoelectron emission microscopy of molecules on surfaces

PEEM at Duke FEL Lab with sample prep & transfer chambers. Fix wavelength & record image; then change wavelength. Also use AFM in solution on same surfaces.



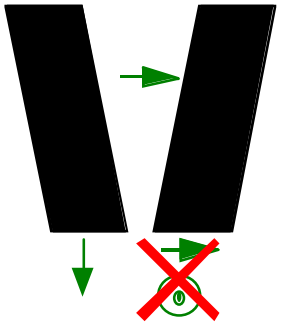


PEEM Image of Fibrinogen on Oxidized Silicon, resolution ~10 nm (maybe better)

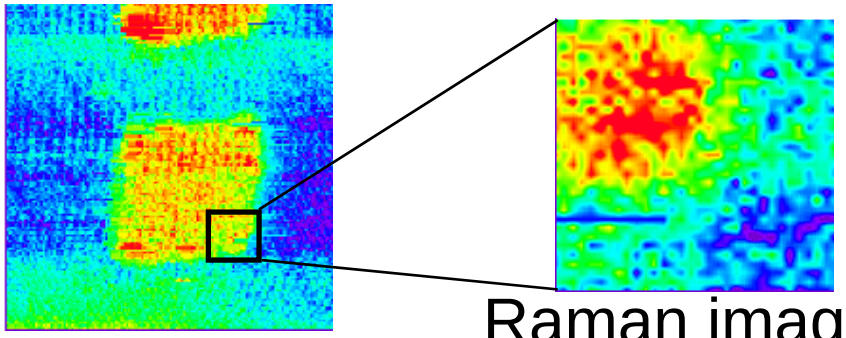
Electron emission microscope: spatial determination of a material's photothreshold with a resolution of less than 100 nm

Hallen group: Nano-raman spectroscopy

Near field scanning optical microscope

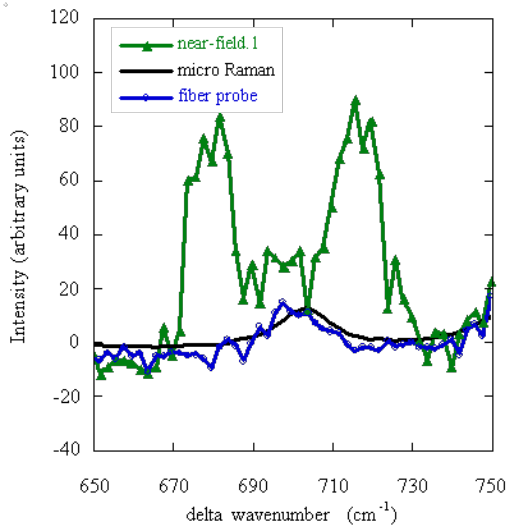


Rb-doped KTP
(5 μm square)



Topography-
12 nm uplift in doped region

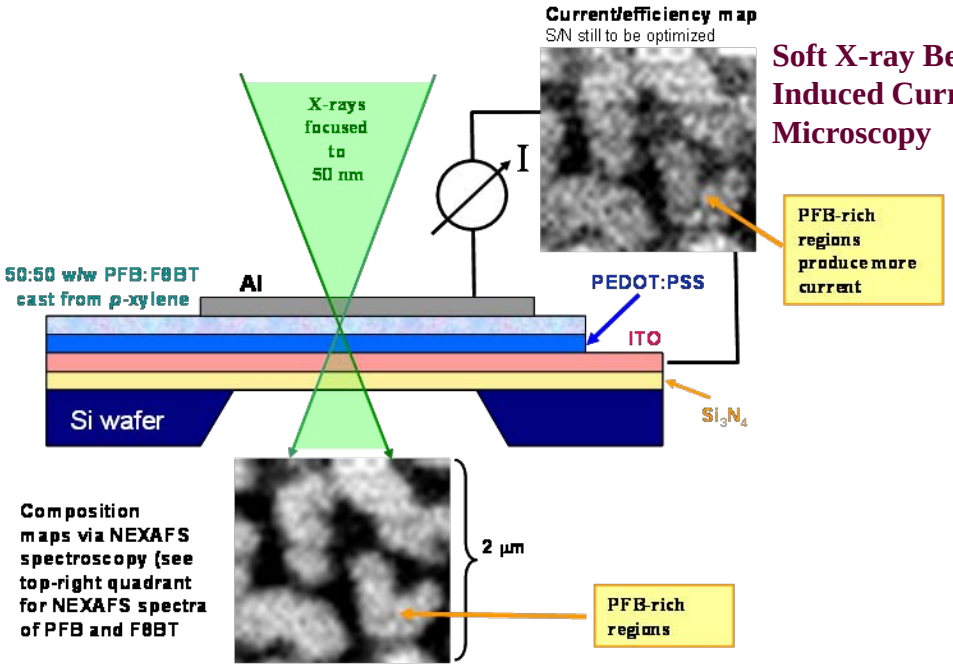
Raman image
Zoomed region

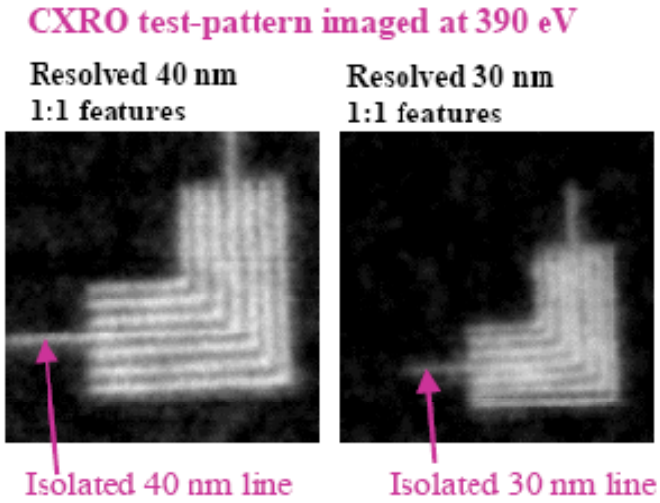


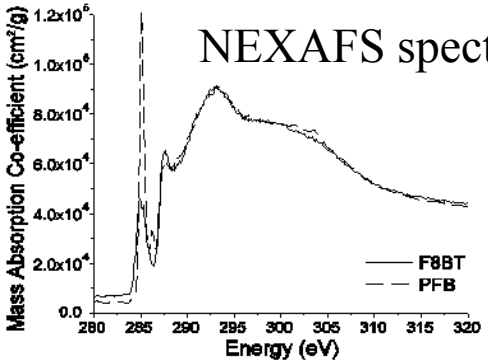
- 2-D imaging and topography simultaneous with Raman Spectroscopy
  - 50-100 nm resolution

Ade group: Scanning transmission X-ray microscopy

Advanced Light Source







- **Organic photovoltaic devices (PFB and F8BT based)**
- **Quantitative, simultaneous *composition and efficiency* maps**
  - **No imaging artifacts such as coupling to topography**
- **Potential of *10 nm* spatial resolution in near future (now 50 nm)**

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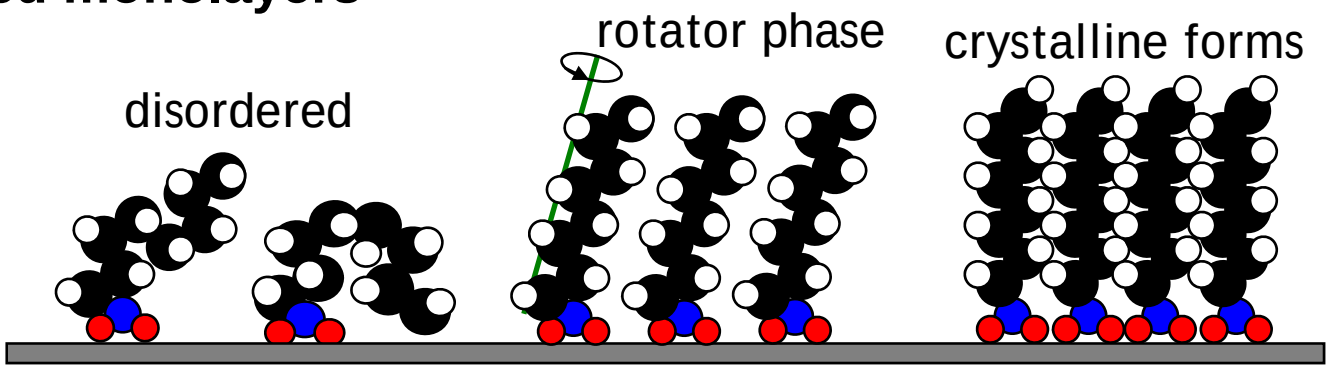
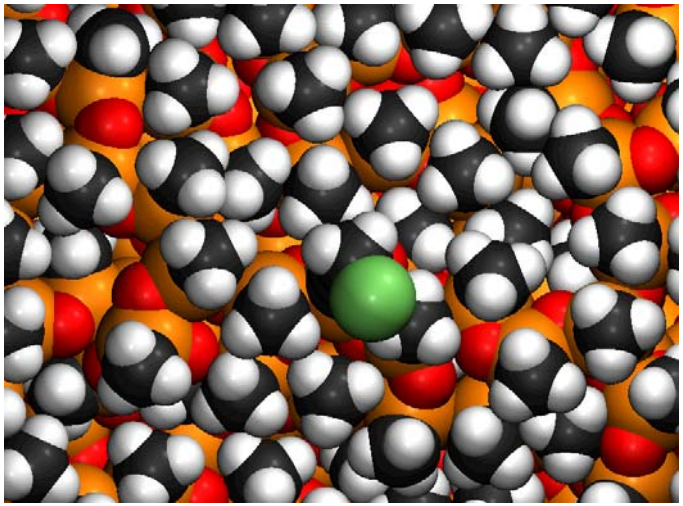
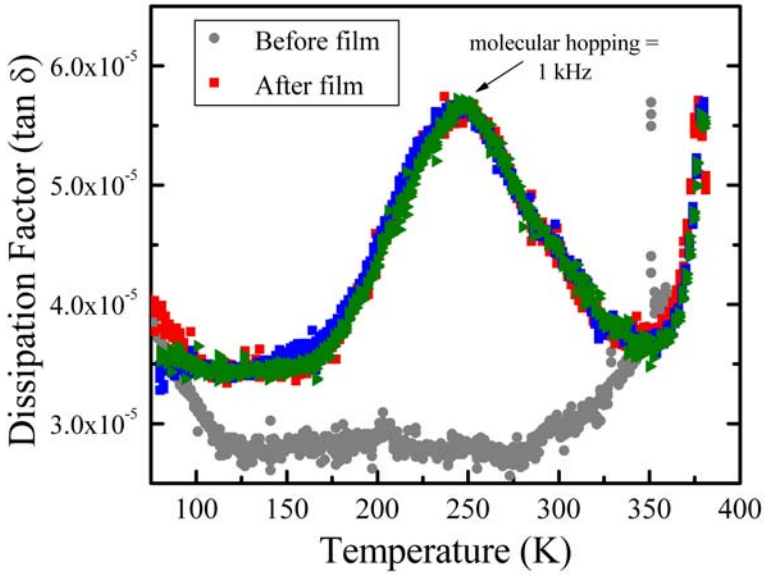
Clarke group: Electrical measurements of molecular rotation – with particular interest in observing phase transitions in self-assembled monolayers

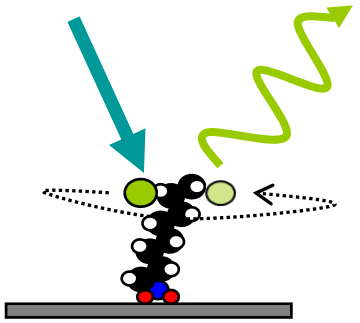


increasing molecular density (decreasing temperature)

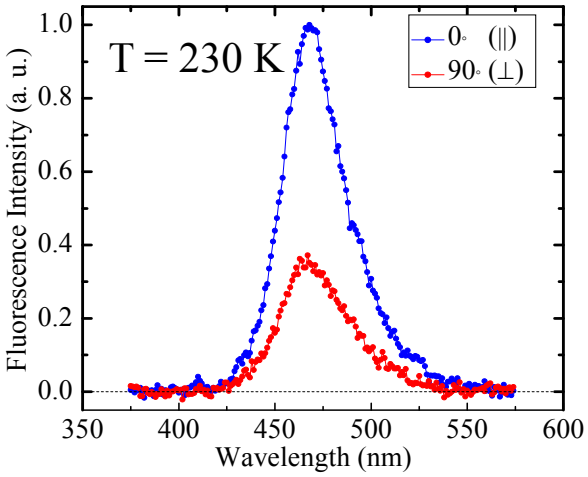


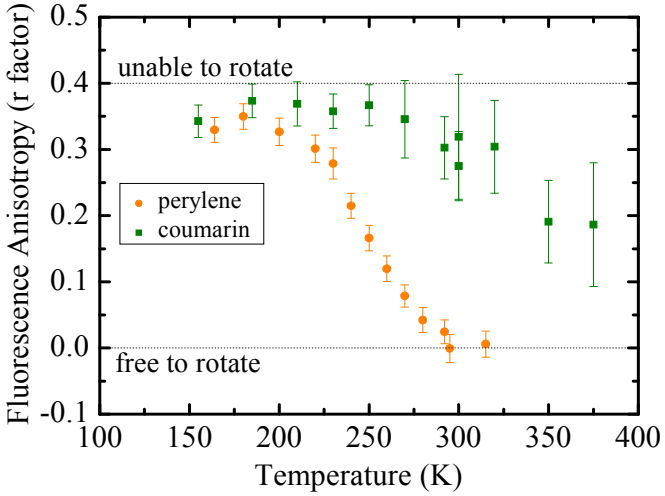


Bochinski group: Motional dynamics of molecules on surfaces through optical measurements



• Development of novel optical techniques to detect/control motion in self-assembled monolayers.





Spectrally-resolved, polarized fluorescence intensity

Temperature-dependent, rotational anisotropy

Example: dilute fluorophores in a frozen medium (3-D case)

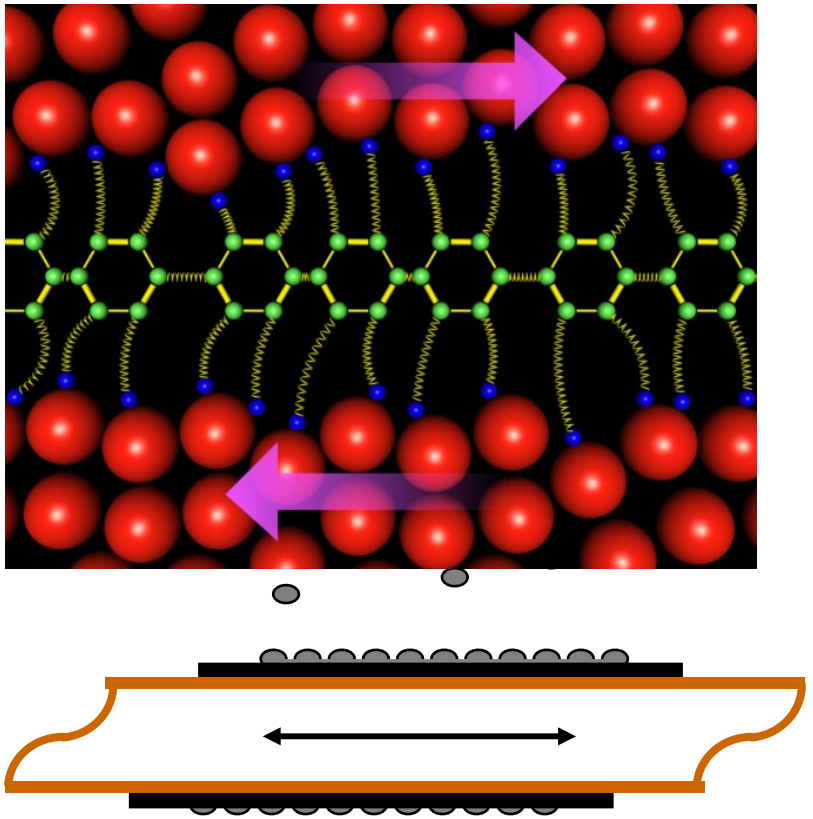
Krim group: Quartz crystal microbalance studies of atomic-scale friction

Nanotribology

Our research program is unique world-wide, exploring the nano-scale origins of friction with a quartz crystal microbalance technique that the PI developed in the late 1980's with the support of NSF.

This year we published the first systematic study of how molecular rotation impacts sliding friction . [1] Our results were featured in both Nature Nano-technology and Nanozone news.

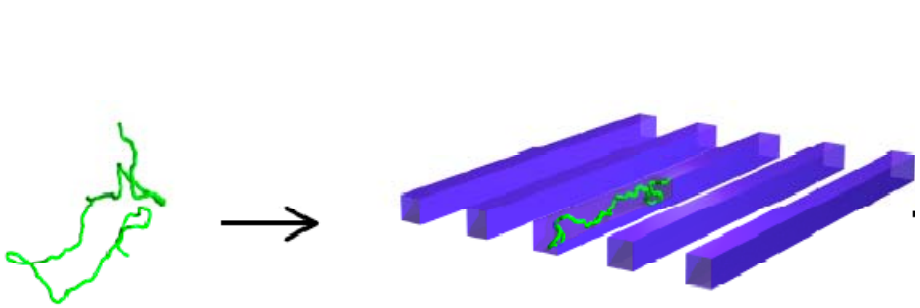
[1]T. Coffey and J. Krim, *"C60 molecular bearings and the phenomenon of nanomapping"*, Phys. Rev. Lett. 96, 186104 (2006)

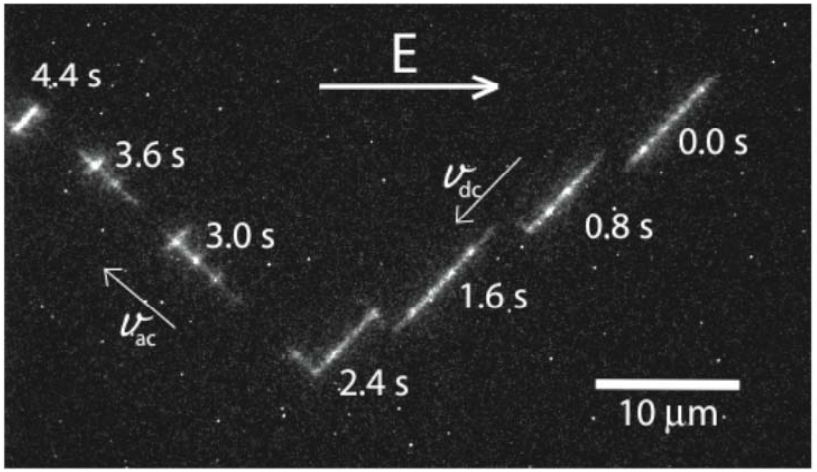


Upper: Artist's rendition of the atomic vibrations that give rise to phononic friction, recently confirmed by our experiments.

Lower: schematic of the quartz crystal oscillator technique employed by our research group.

Riehn group: Biological molecules confined in nano scale containers





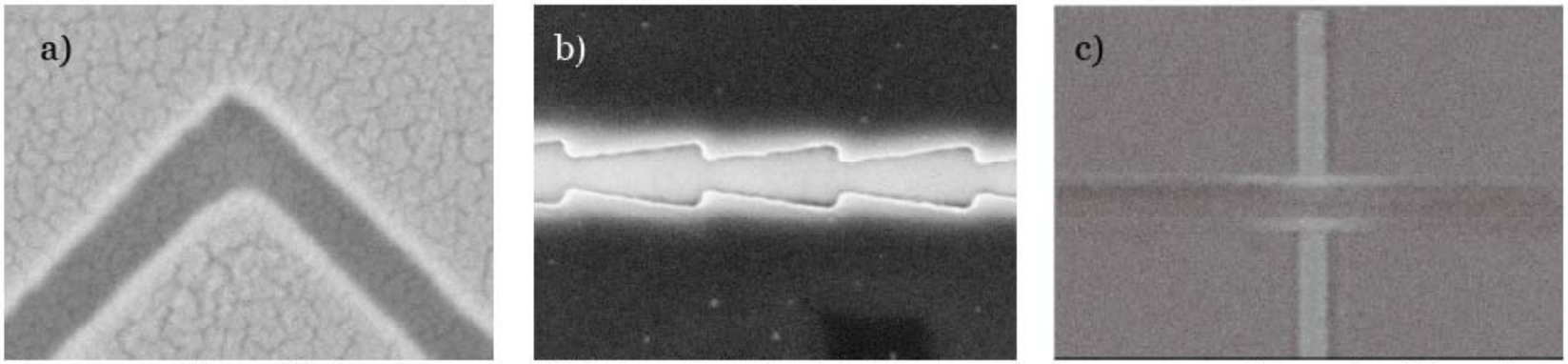
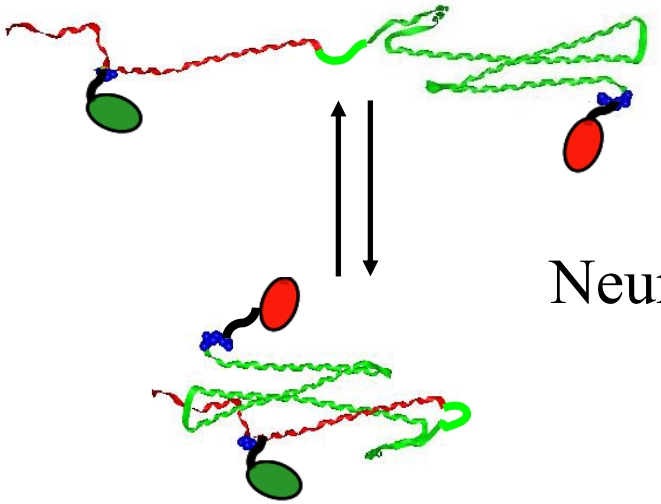


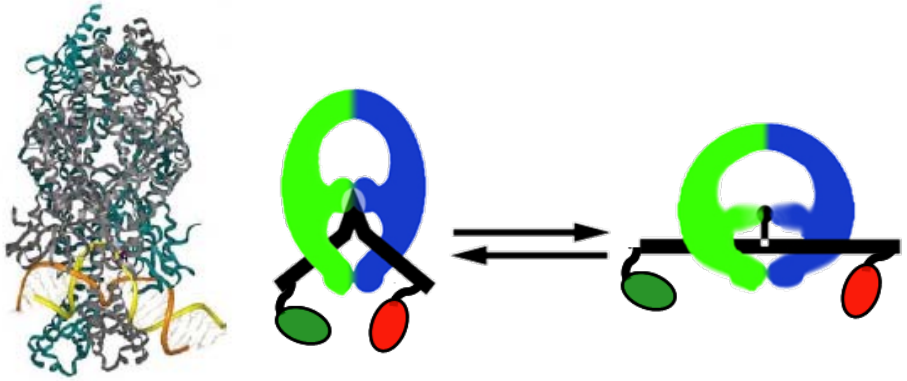
Figure 9: Nanofabrication capabilities (SEM). (a) Kink in 50-nm nanochannel, (b) tailored nanoenvironment (100-200 nm wide), (c) horizontal nanofluidic channel (100 nm) with perpendicular nanofluidic electrode (80 nm).

Weninger group: Conformational dynamics of individual biological molecules through optical measurements



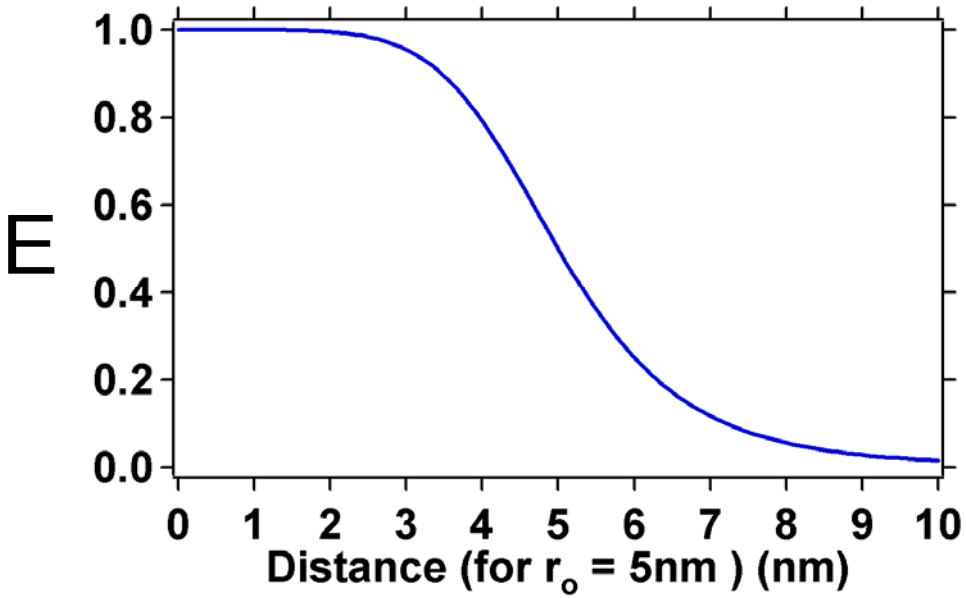
Neurotransmitter release proteins

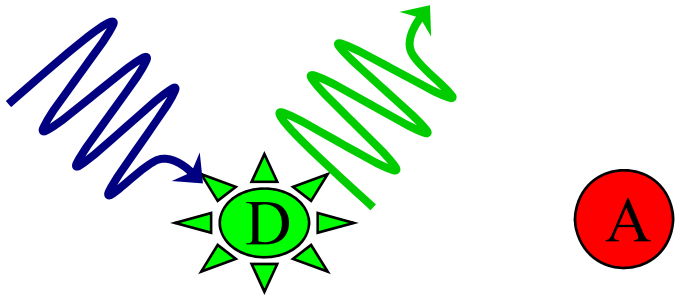
DNA repair proteins - locate DNA mismatches



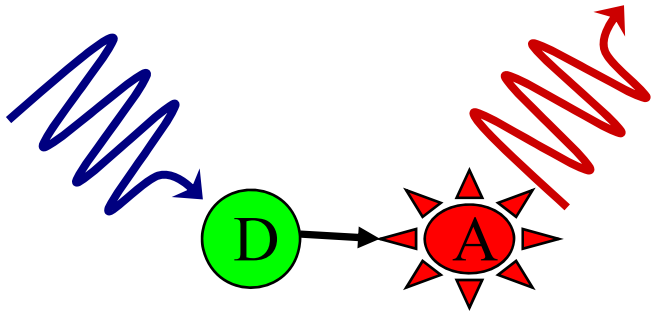
Fluorescence Resonance Energy Transfer

$$E = \frac{1}{1 + \left(\frac{r}{R_o}\right)^6} = \frac{I_{acceptor}}{I_{donor} + I_{acceptor}}$$





r > Ro = No FRET

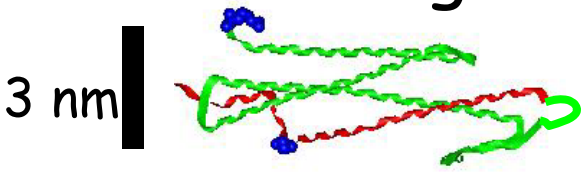


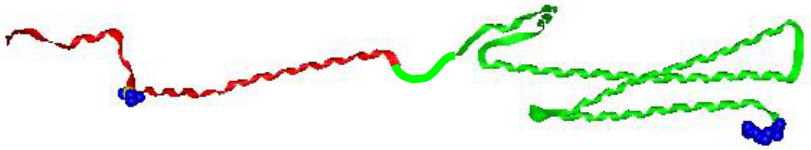
r < Ro = High FRET

Neuronal SNARE protein Open/Close Transition

Closed = High FRET

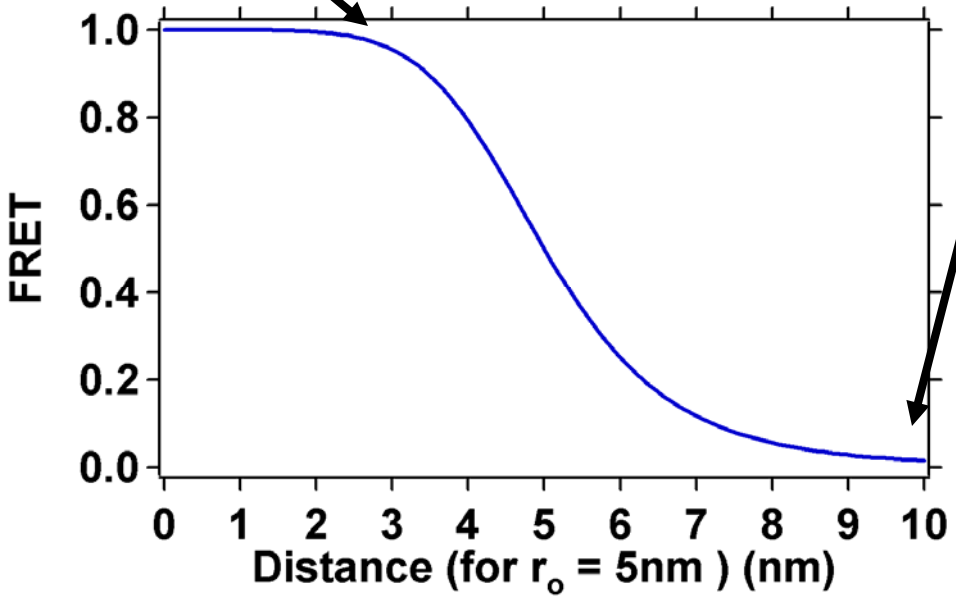
Open = Low FRET



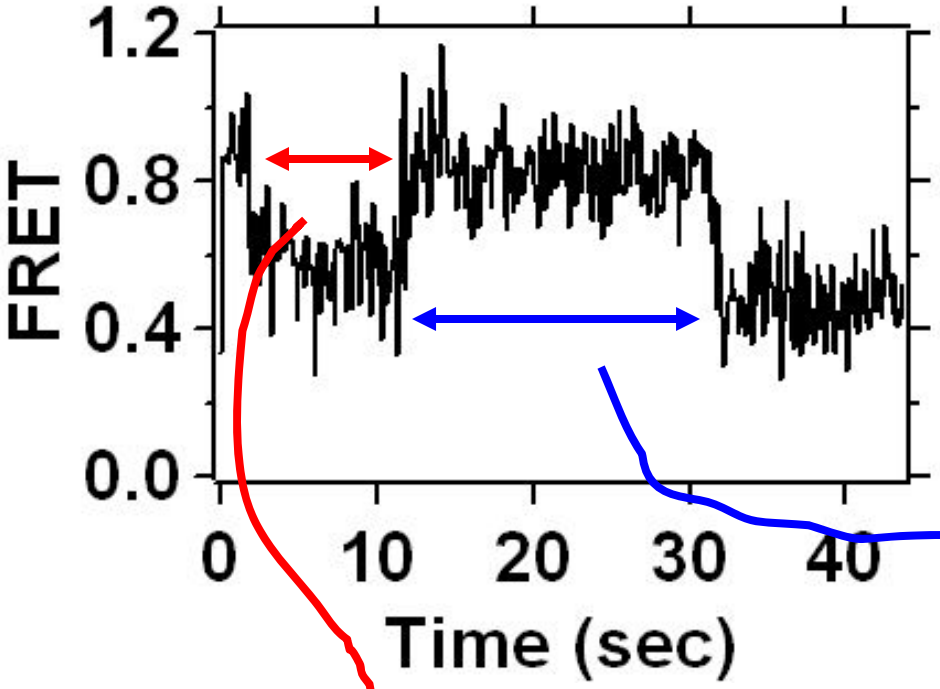


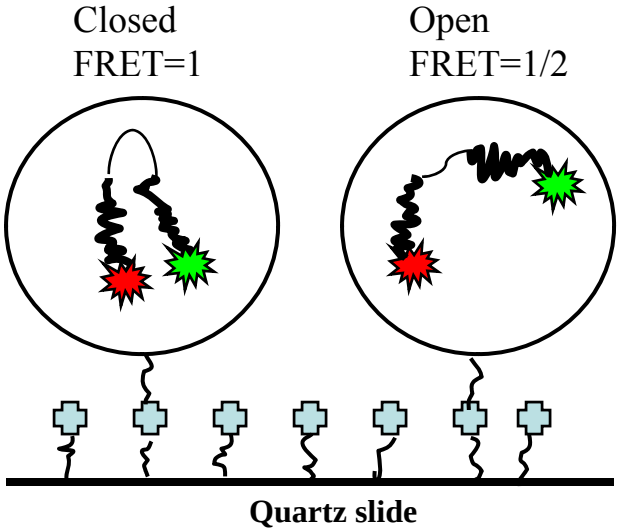
3 nm apart

>10 nm apart

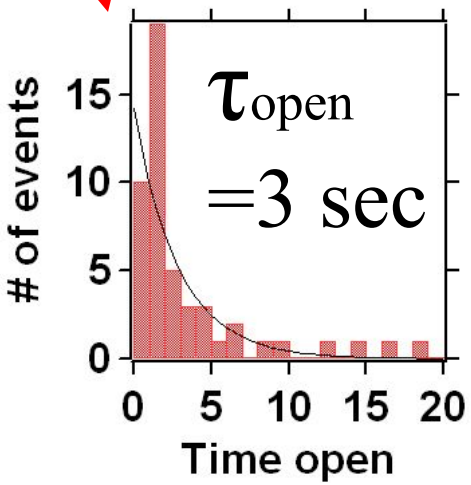


Engineer specific dye label sites

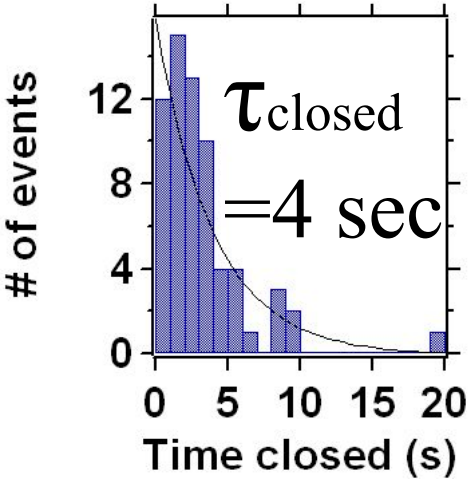




Time open

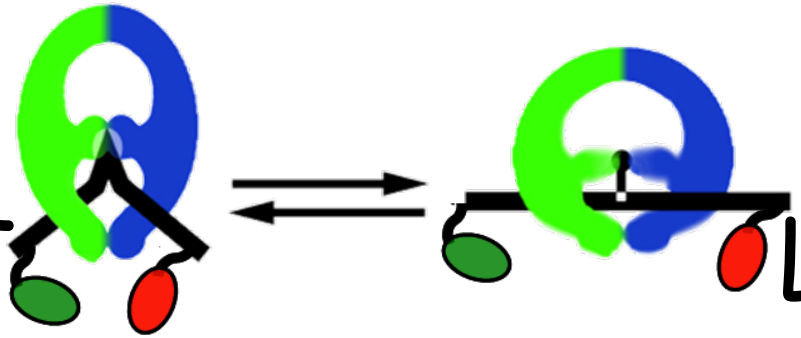


Time closed

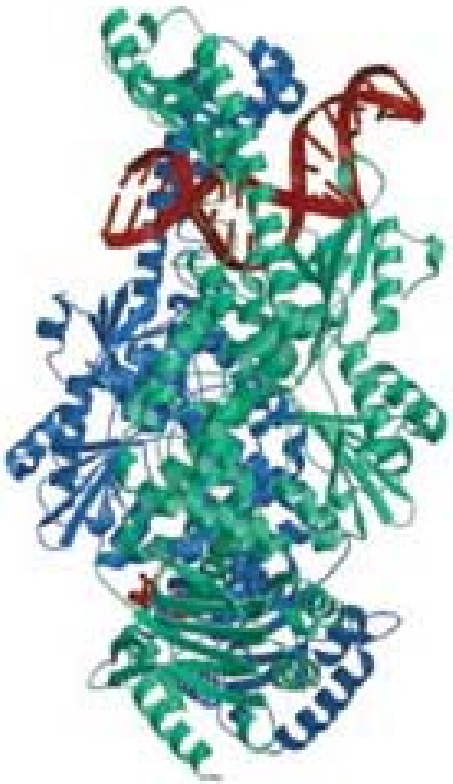


DNA mismatch repair proteins

Bent
High FRET



Unbent
Low FRET



DNA mismatch repair proteins

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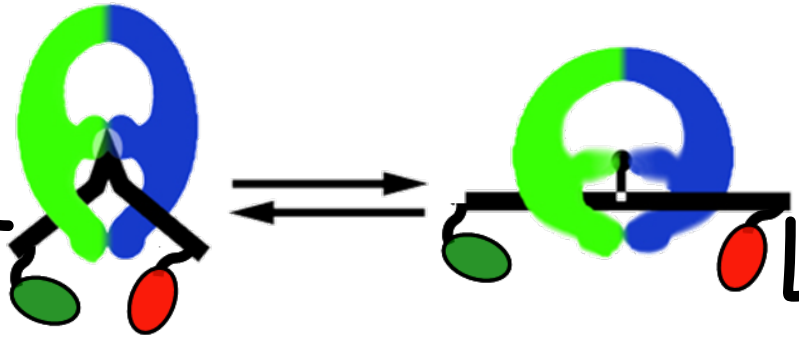

Unbent
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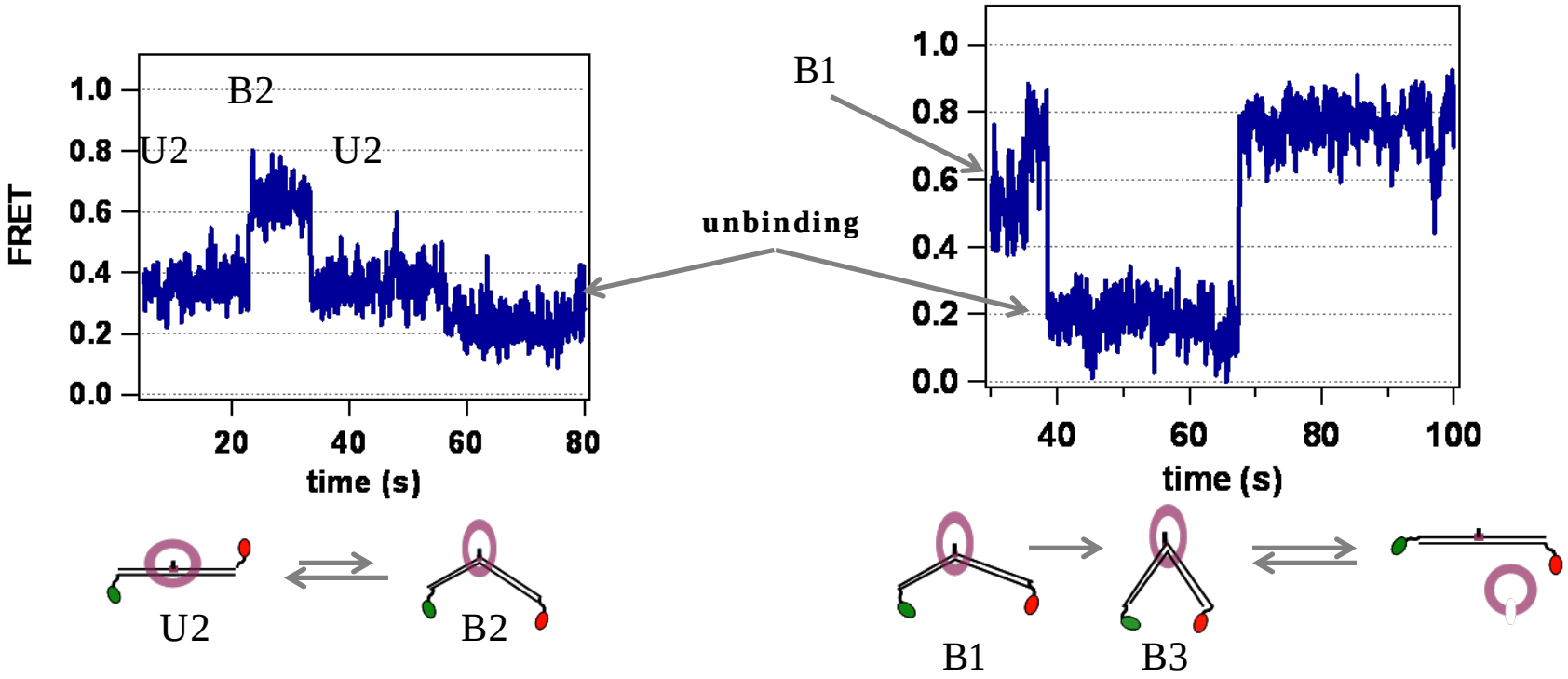
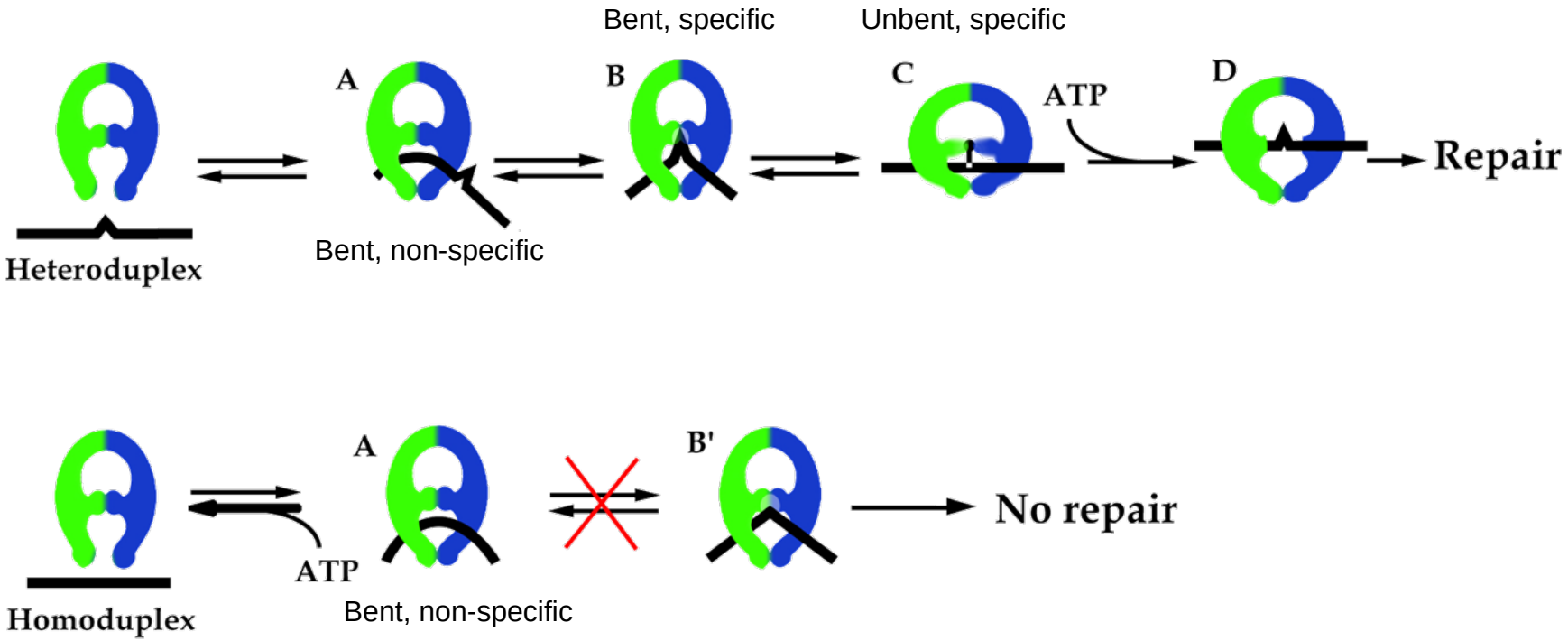


DNA mismatch repair:
DNA Bending Model



Nanometer scale motion is critical to bio-molecule function, and FRET can measure it

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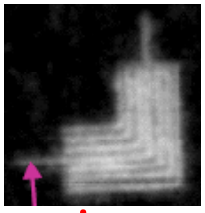

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  - Mitas, Bernholc, Buongiorno Nardelli, Sagui, Roland
- **Spatially resolved studies** -topography along with spatial elemental, chemical, electronic information
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  - Hallen, NSOM Nanoraman
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  - Riehn, Biomolecules in nanochannels
  - Weninger, FRET

-surface attached monolayers
-biological molecules