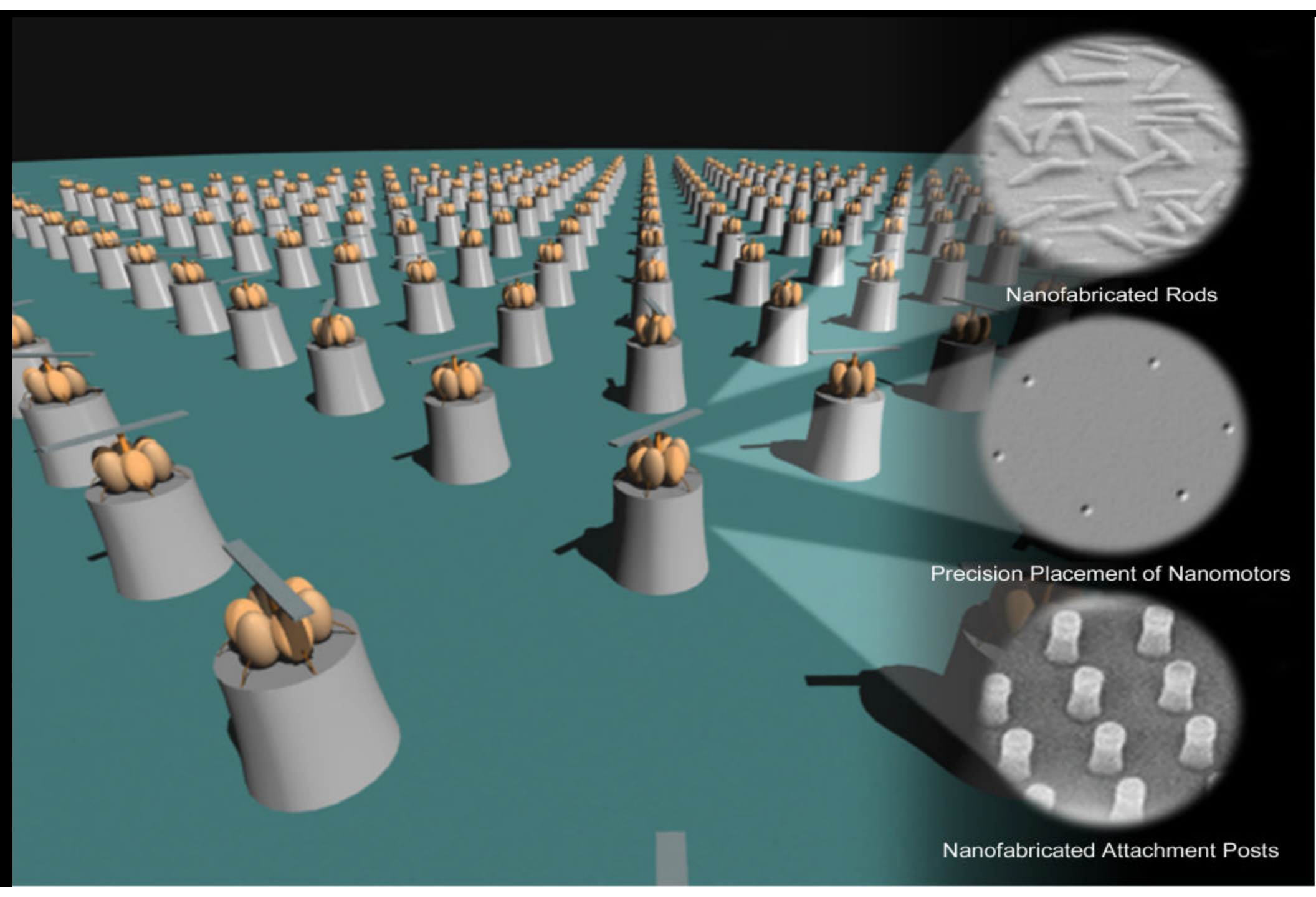
Engineering Life into Nanofabricated Systems

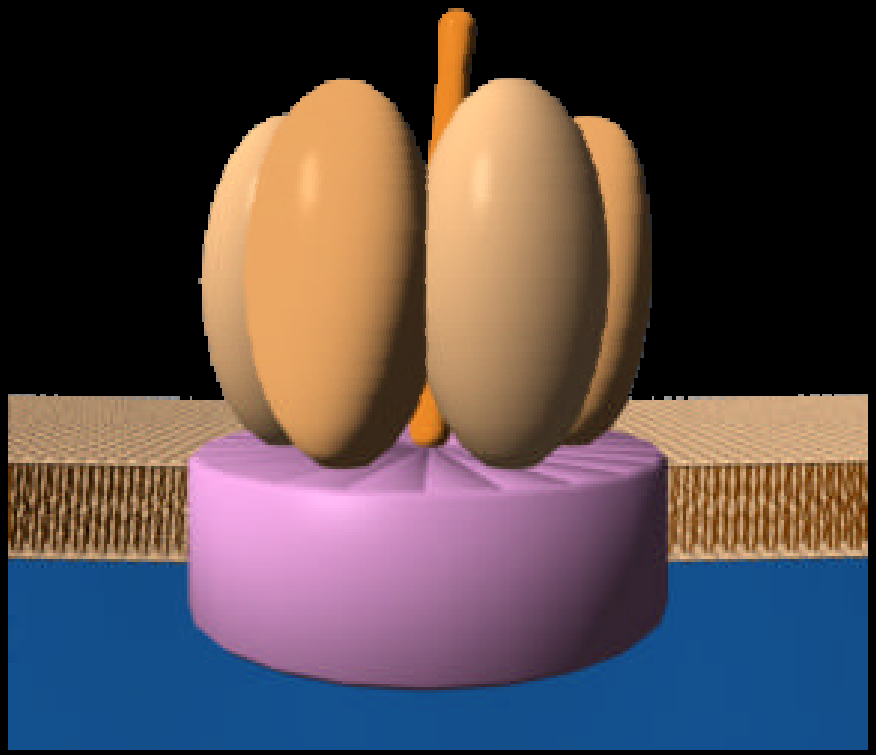
Carlo D. Montemagno

Department of Biological Engineering
Cornell University


Nanofabricated Rods
Precision Placement of Nanomotors
Nanofabricated Attachment Posts

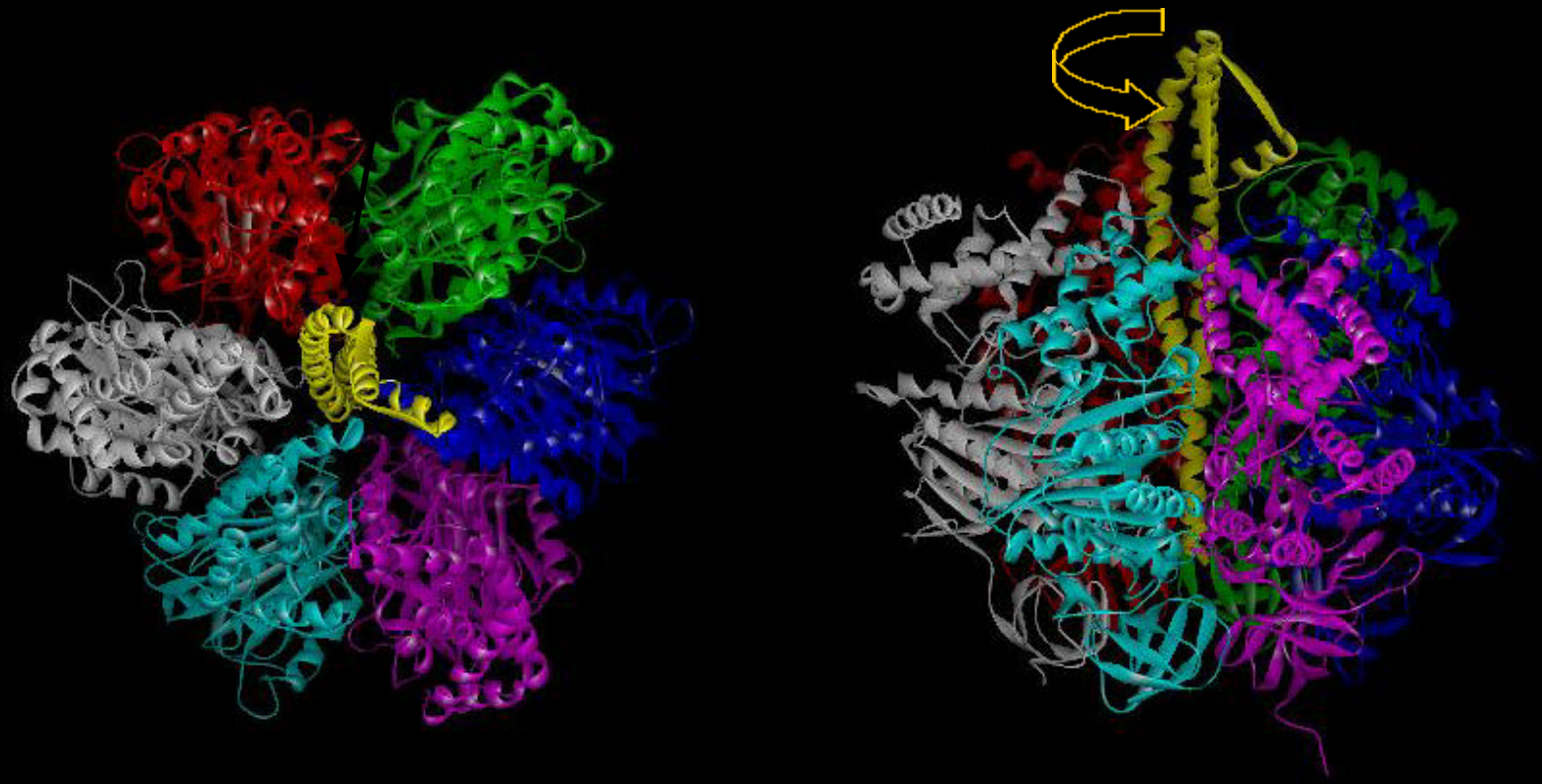
Introduction

F_oF_1-ATPase Biomolecular Motor

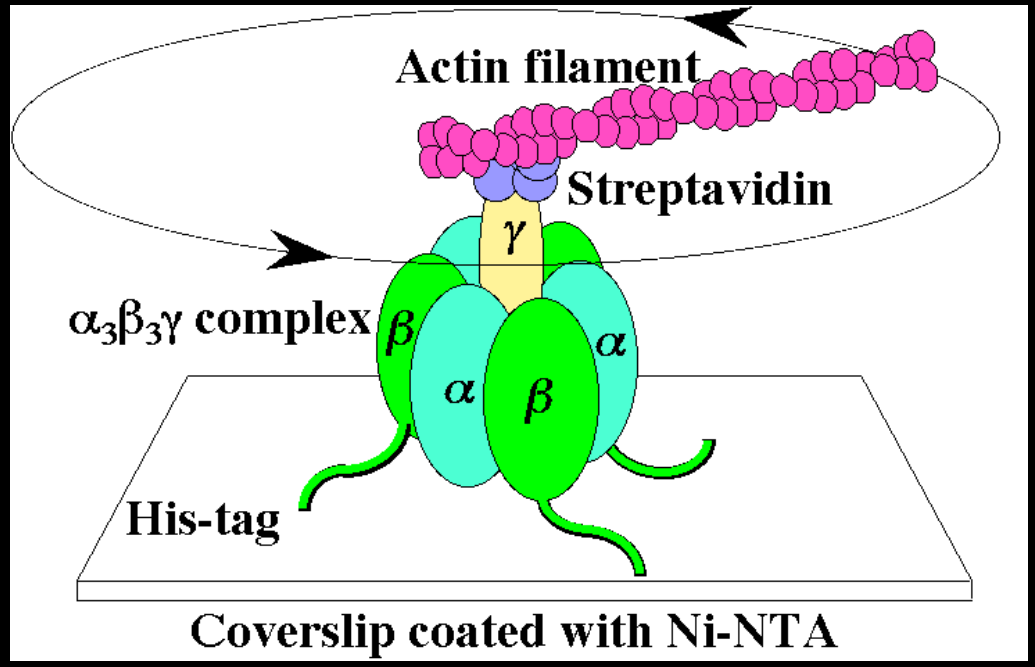


- **Ubiquitous enzyme**
- **Synthesize and hydrolyze ATP**
- **F_1 portion can act independently**
- **Gamma subunit of F_1 portion rotates (up to 17 r.p.s.)**
- **F_1 portion can generate up to 100 pN·nm torque**

Structure of F_1-ATP Synthase



F_1-ATPase Motor-Actin Filament System

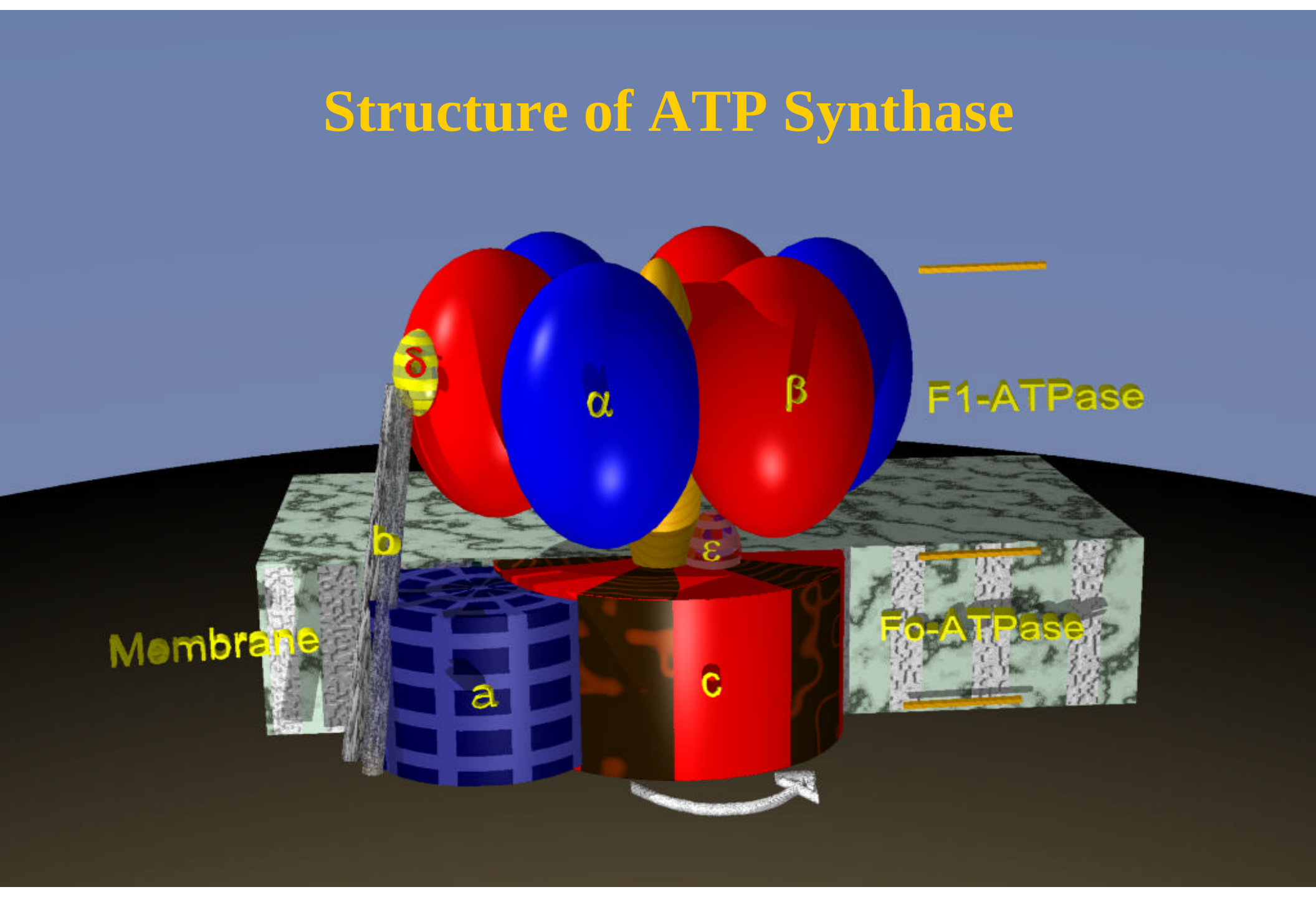


(from Noji *et. al.* 1997)

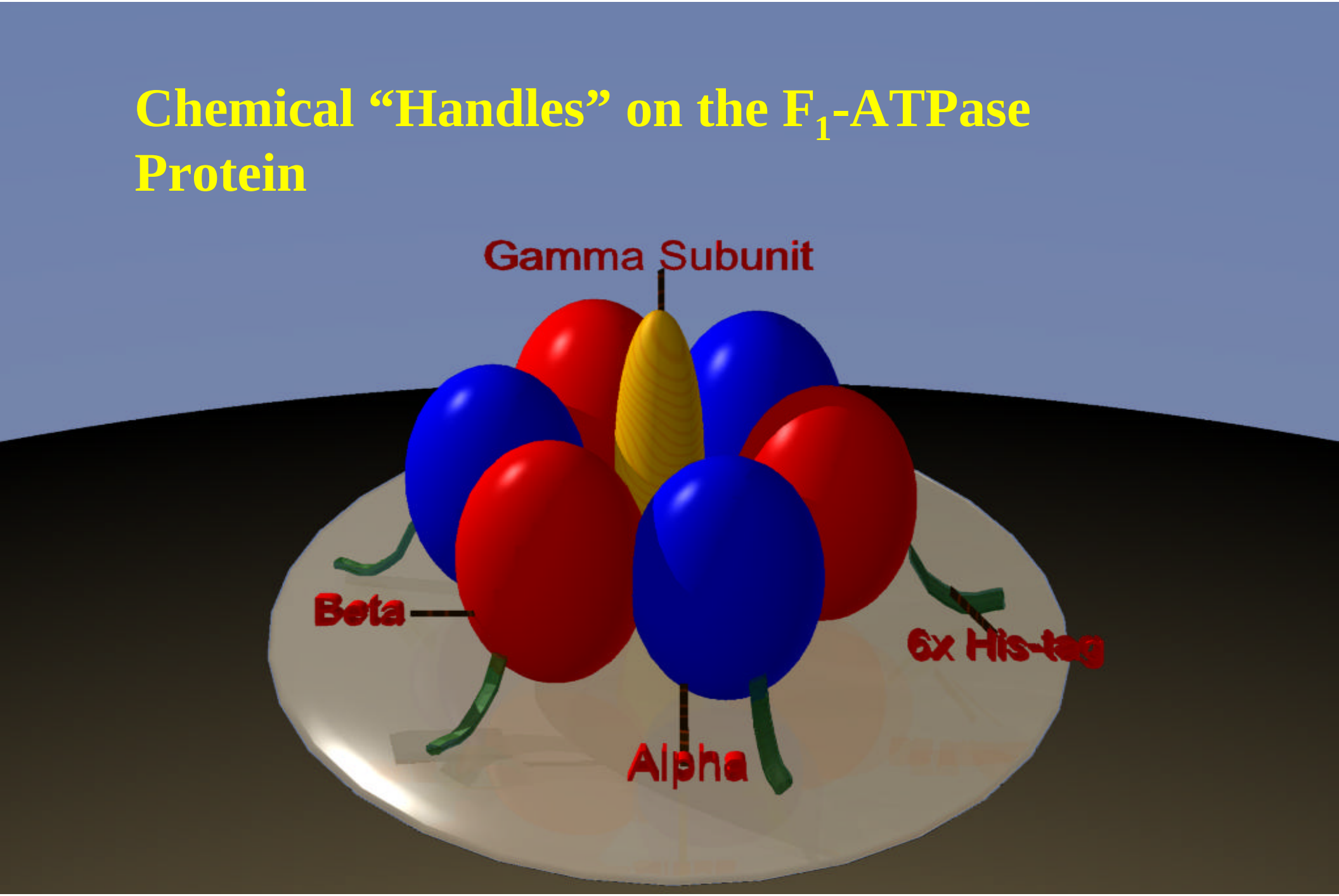
Prerequisite Foundation Technologies

- ✓ Produce an engineered, stable motor protein in large quantities
- ✓ Fabricate chemically active features at the size scale of the protein
- ✓ Construct mechanical assemblies with spring constants consistent with the forces produced by the motor protein
- ✓ Observe and quantify the forces and motion of single molecules

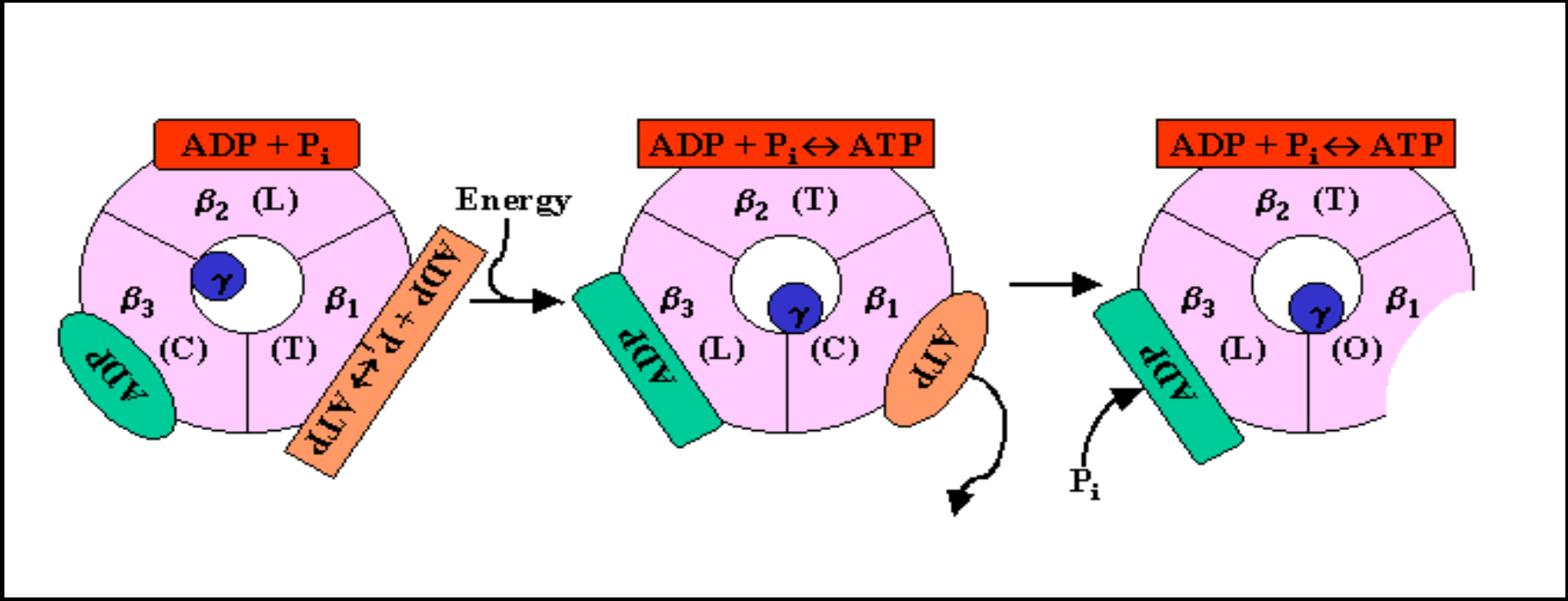
Structure of ATP Synthase



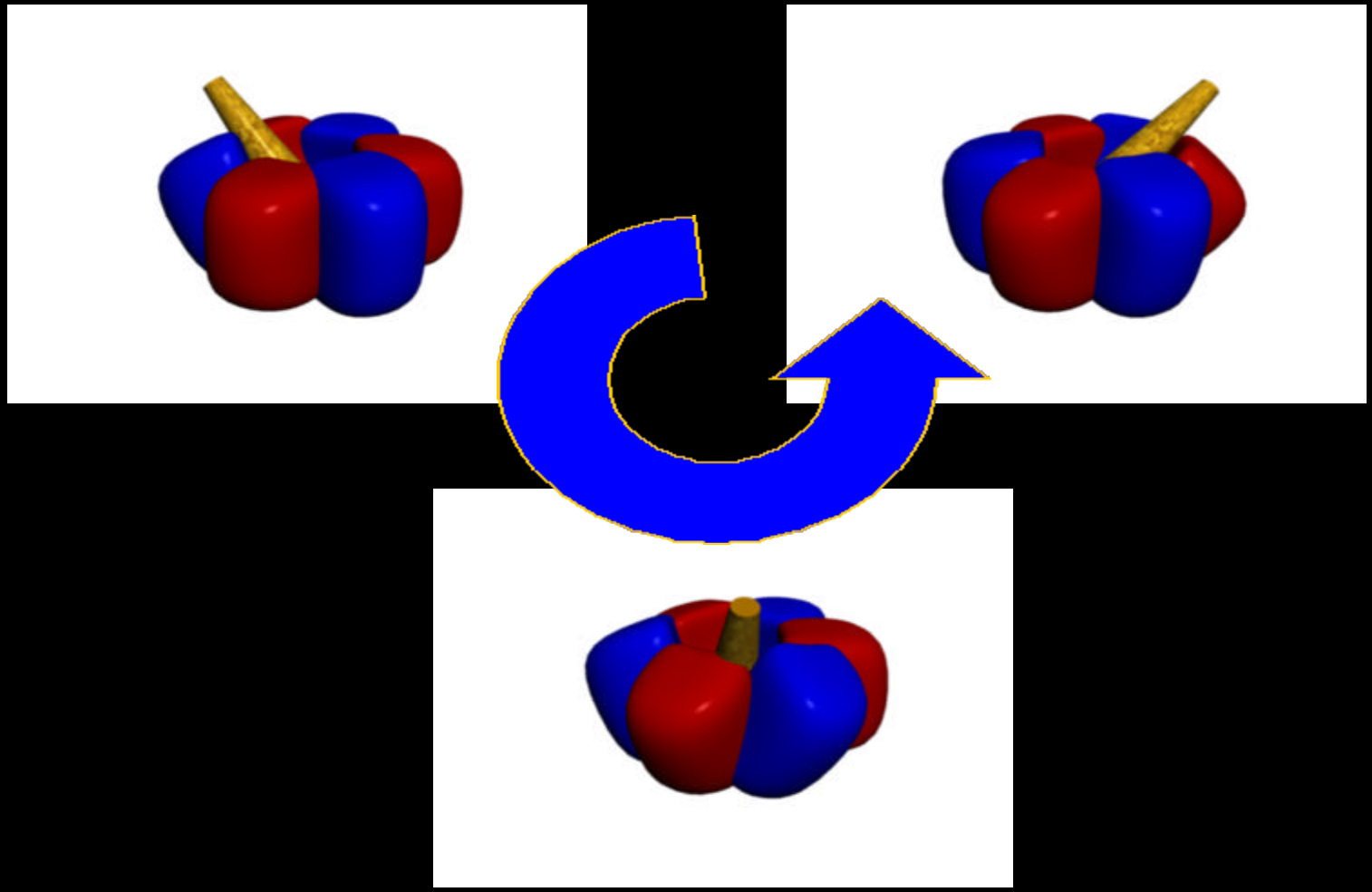
Chemical “Handles” on the F_1-ATPase Protein



Mechanism of ATP Synthesis/Hydrolysis

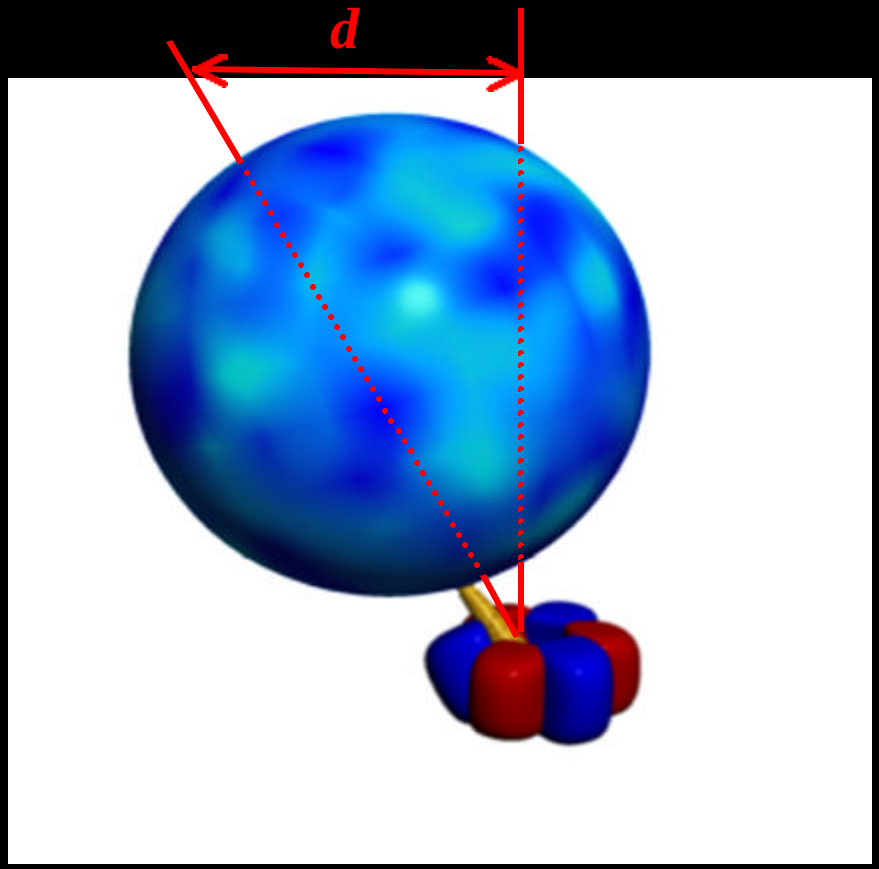


F_1-ATPase Deformation During Rotation

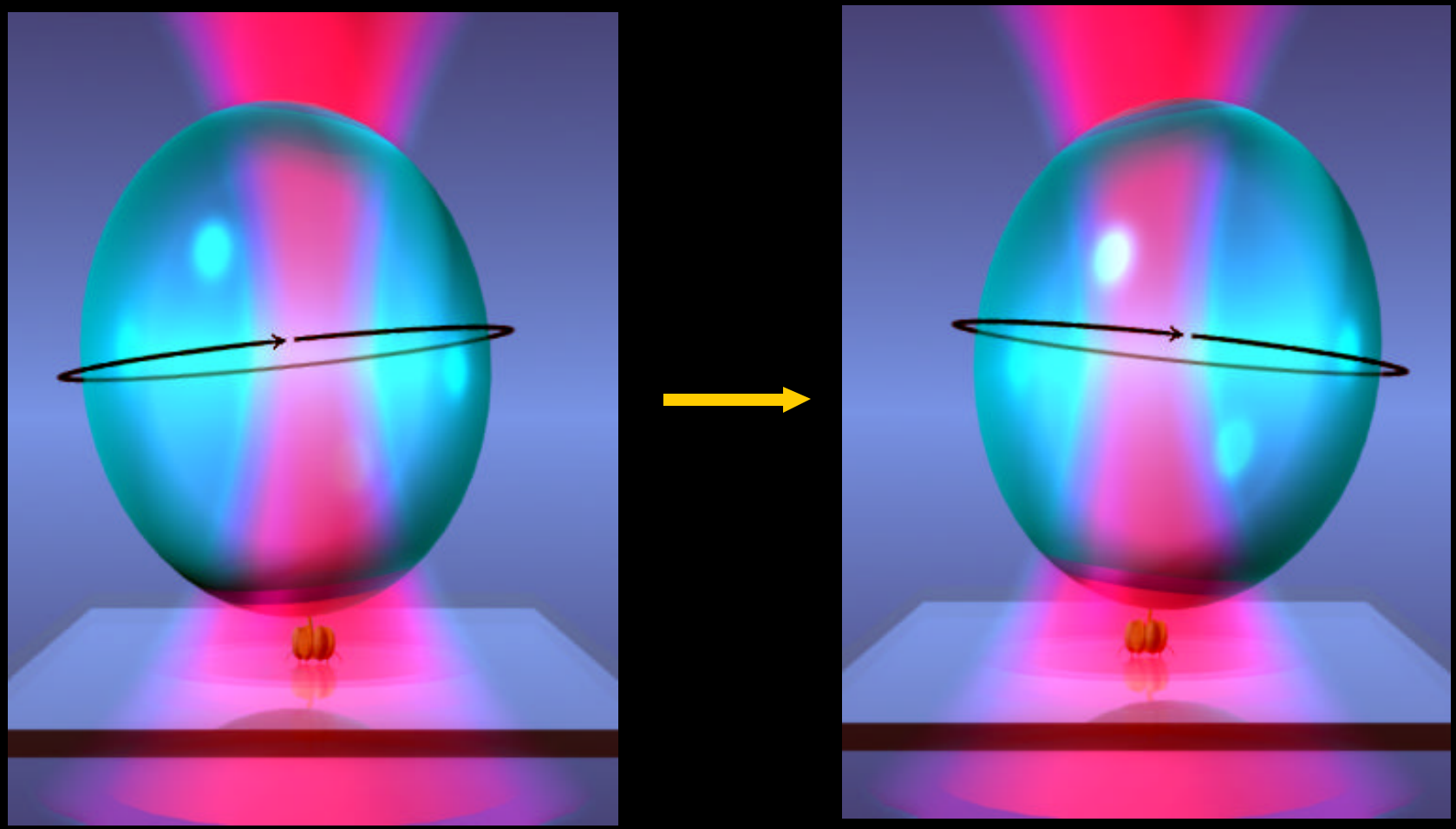


Single Molecule Measurements of Catalytic Transitions of the F_1-ATPase Rotor

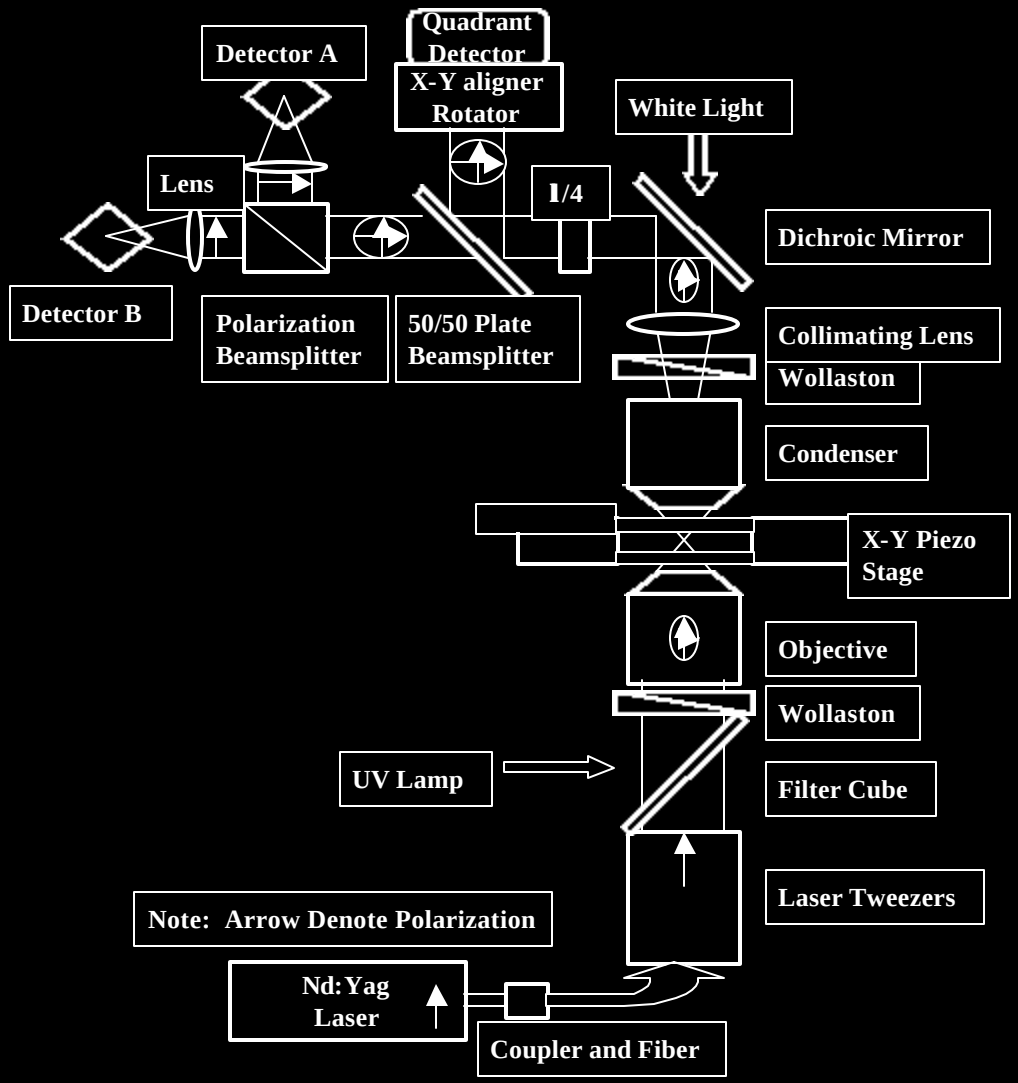
Deformation Detection and Measurement

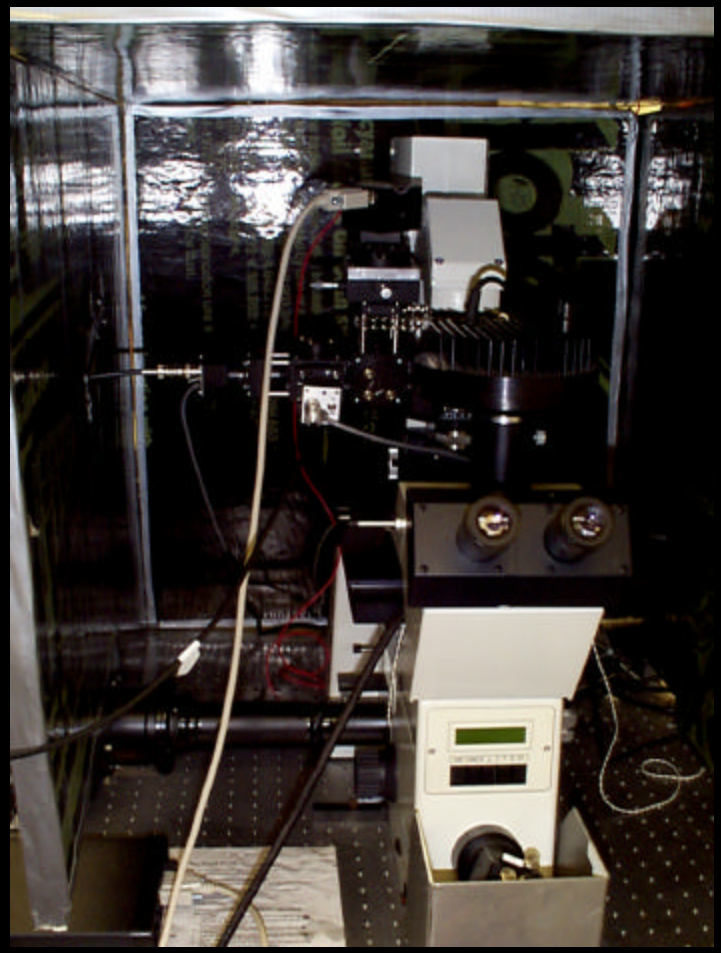


Catalytic Transition Assay

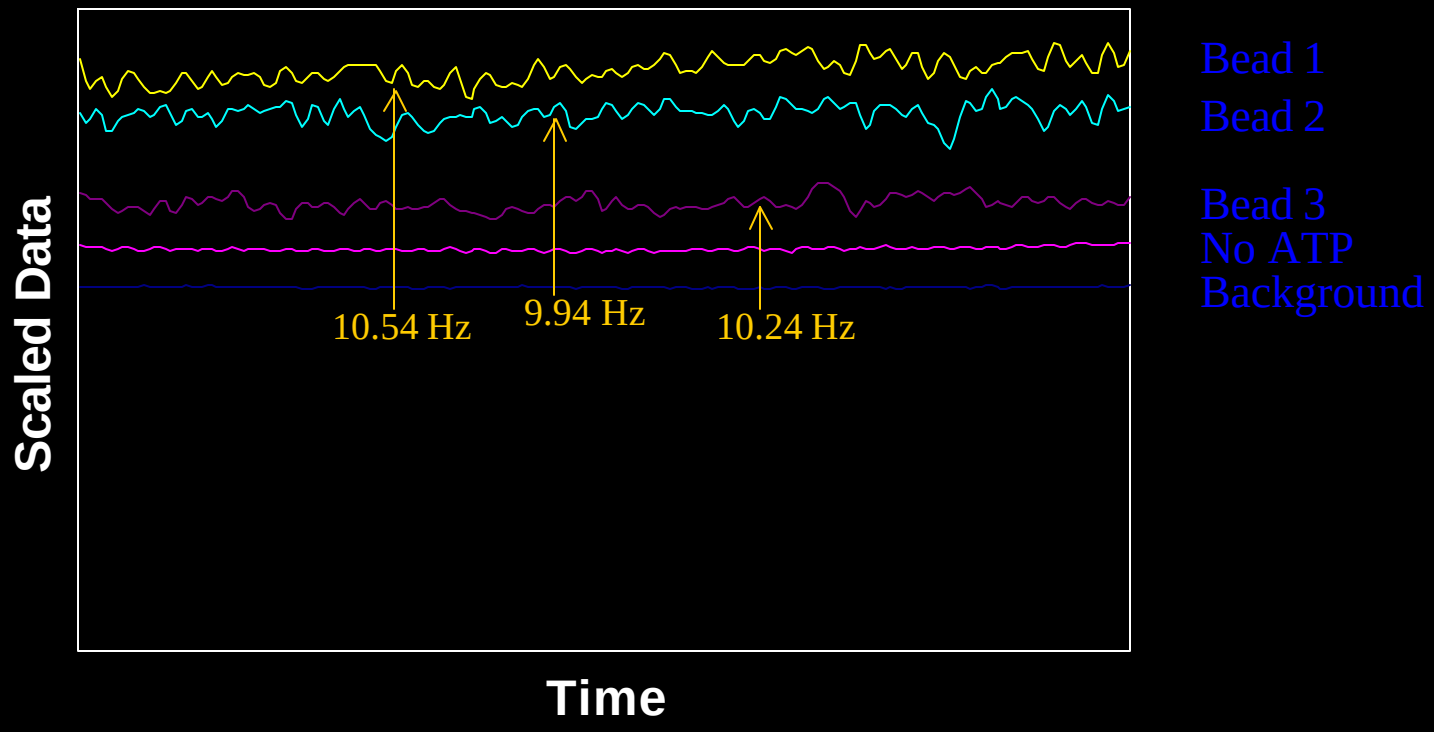


Quadrant Detector/Interferometer Measurement System

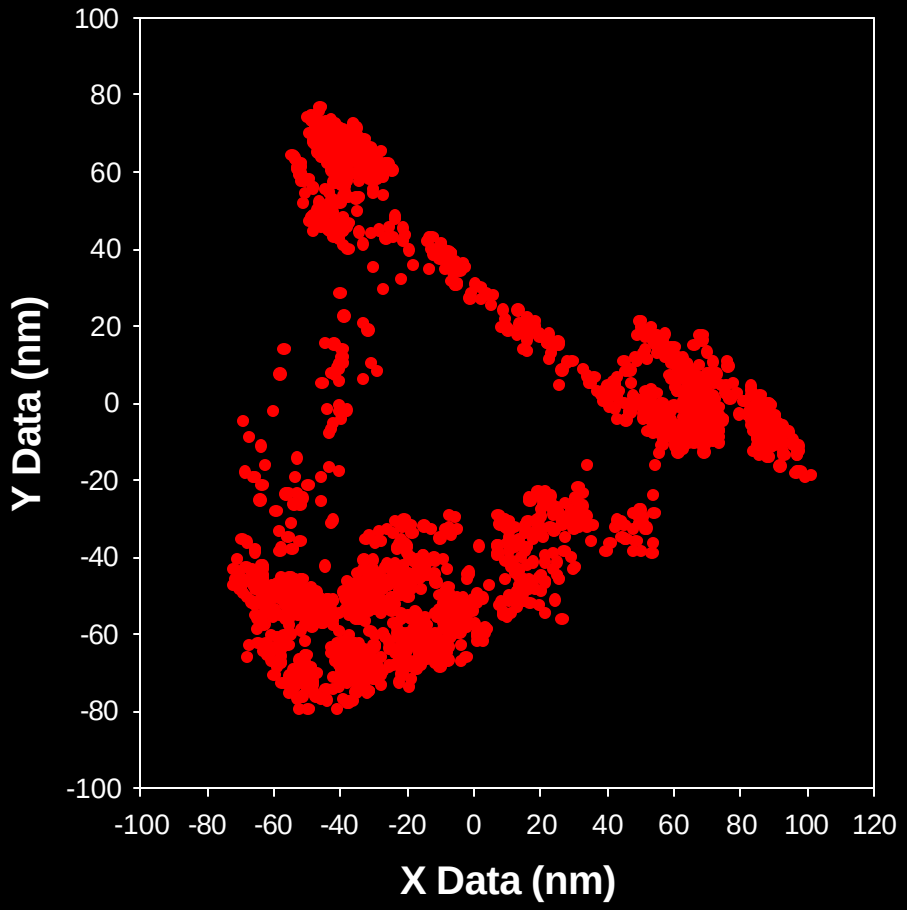


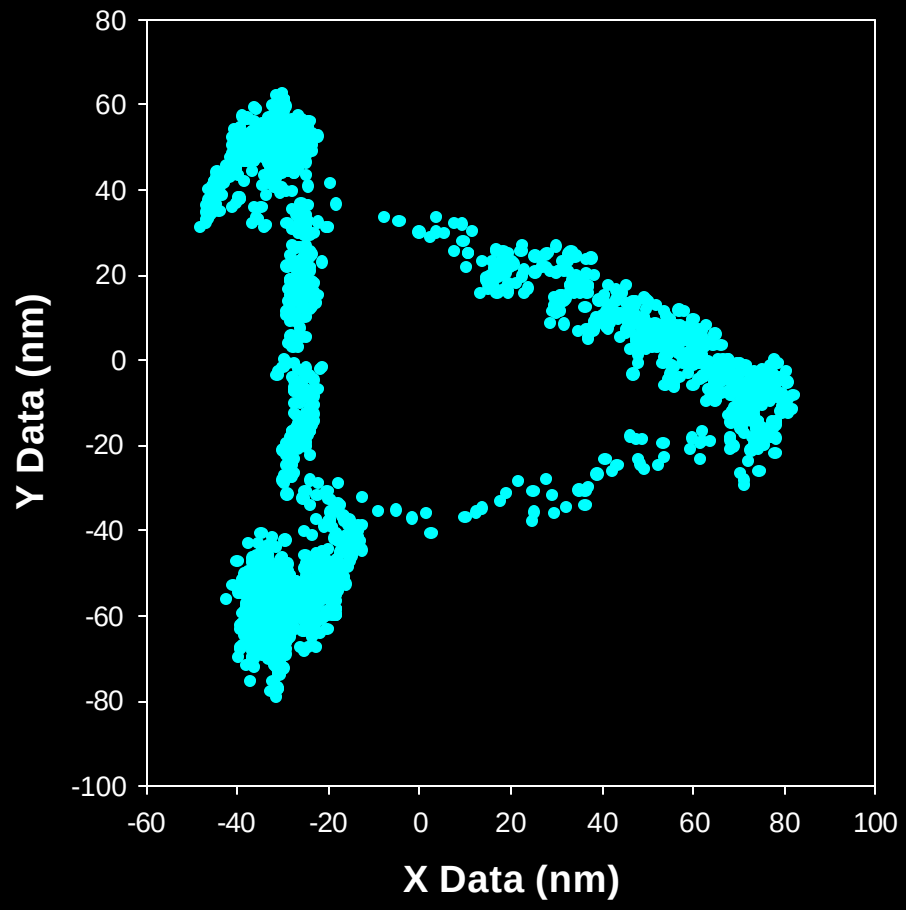


Interferometer Measurement of Motor Rotation

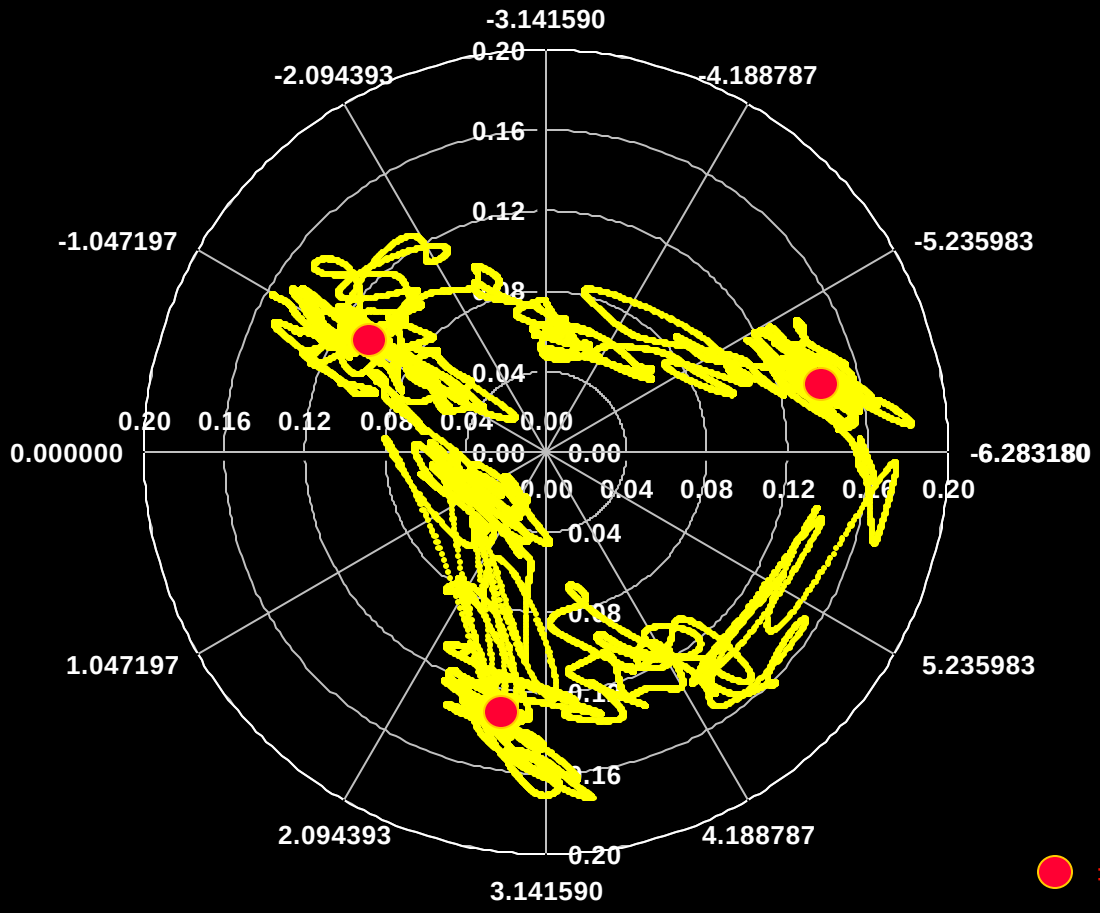


Normalized Quadrant Detector Data

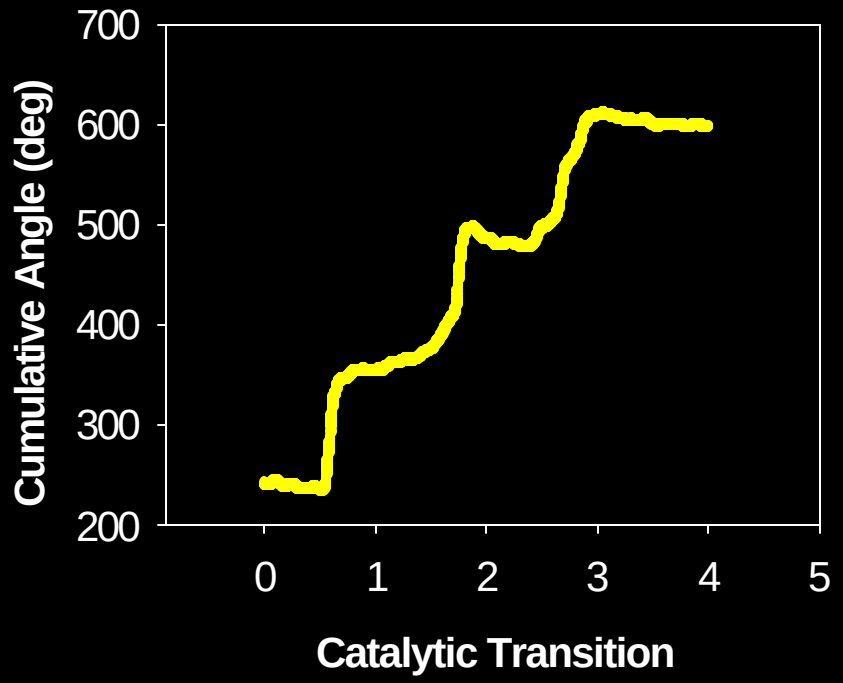


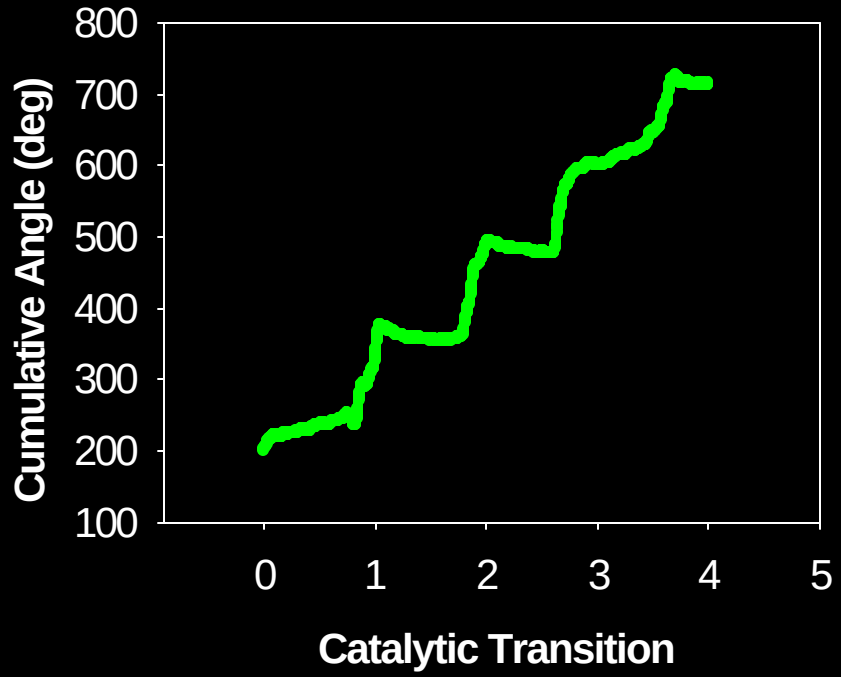


Polar Plot of Quadrant Detector Data

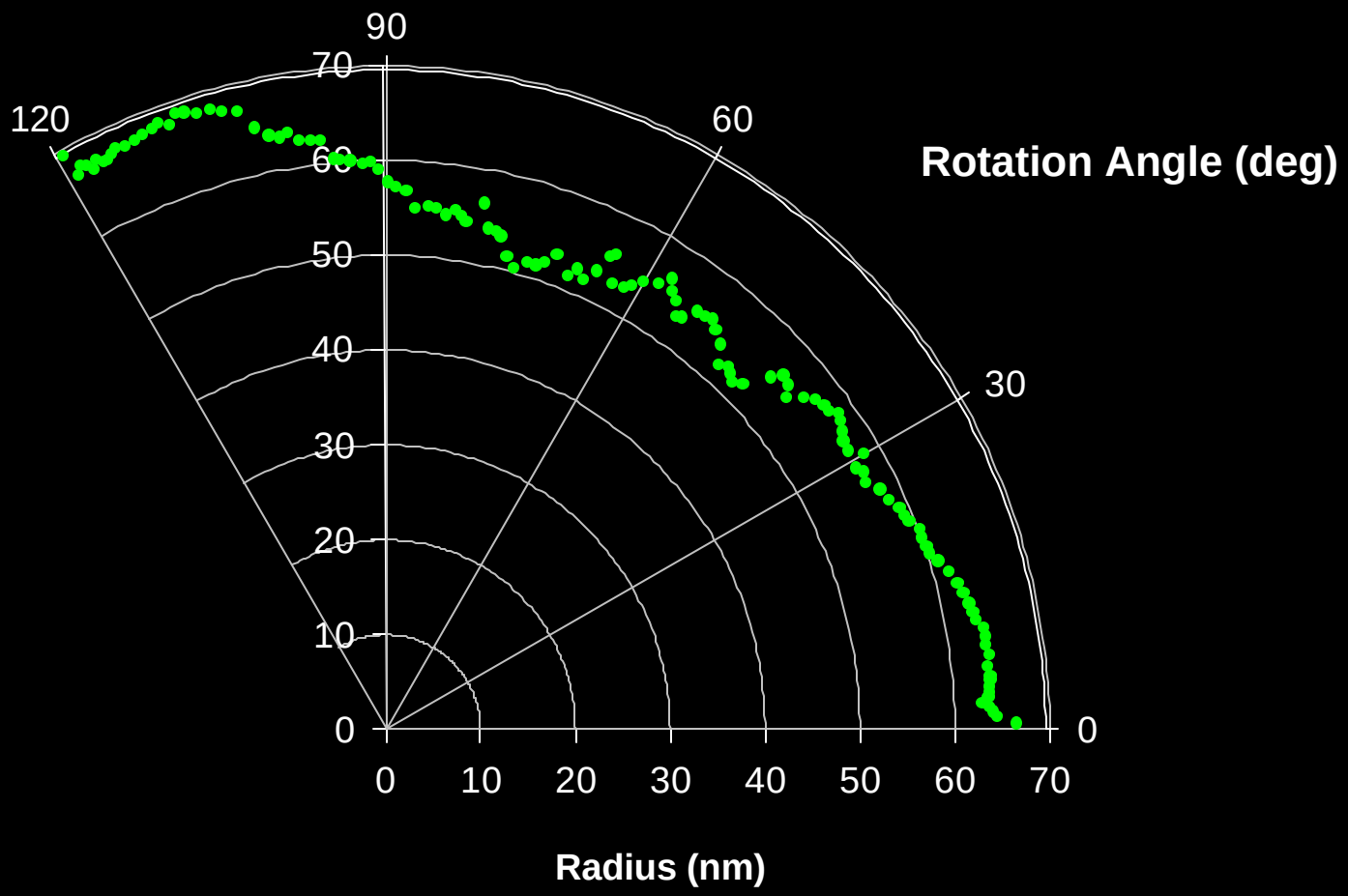


Cumulative Angle During ATP Hydrolysis

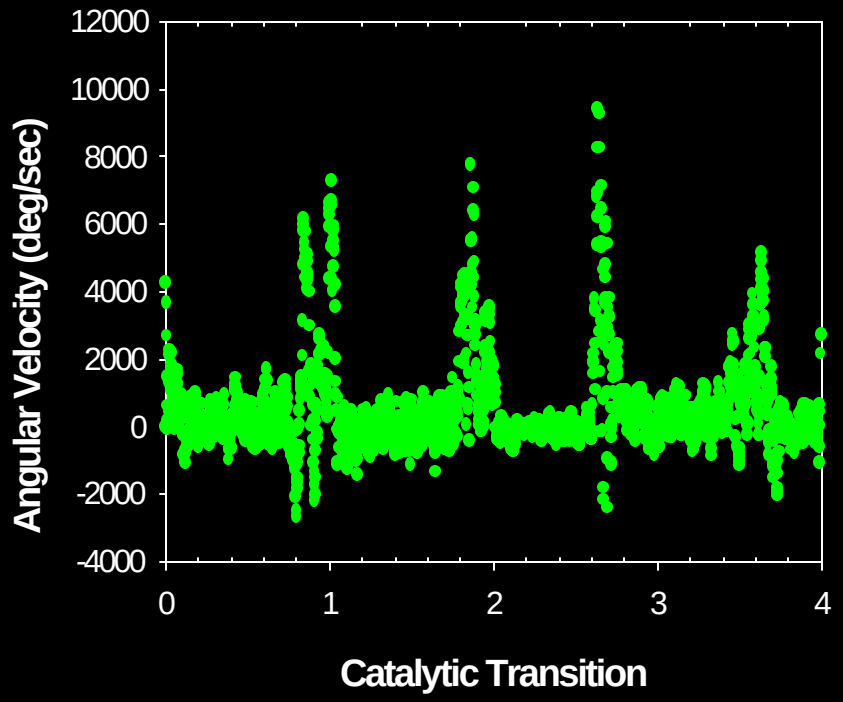


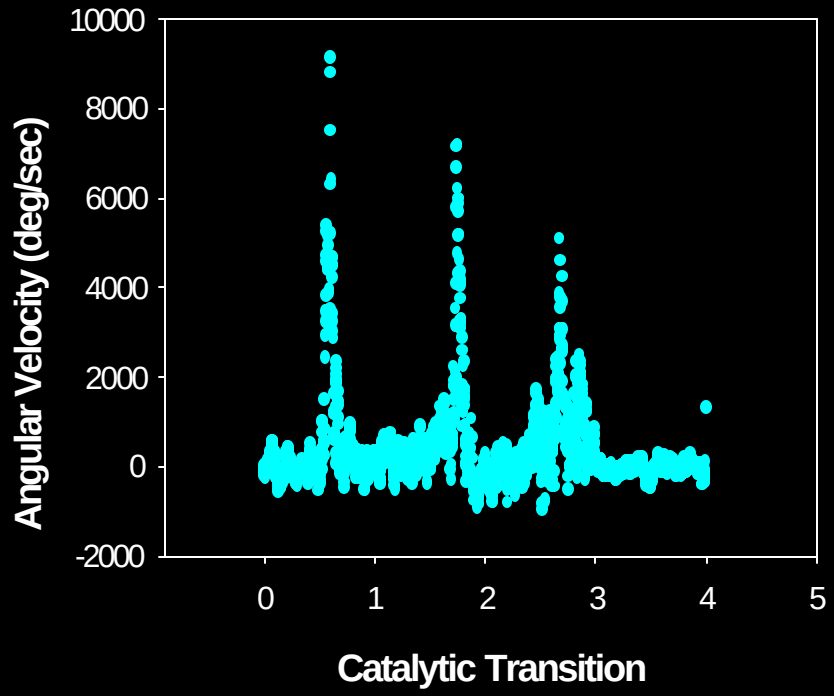


Transition Path Between Two Catalytic Sites

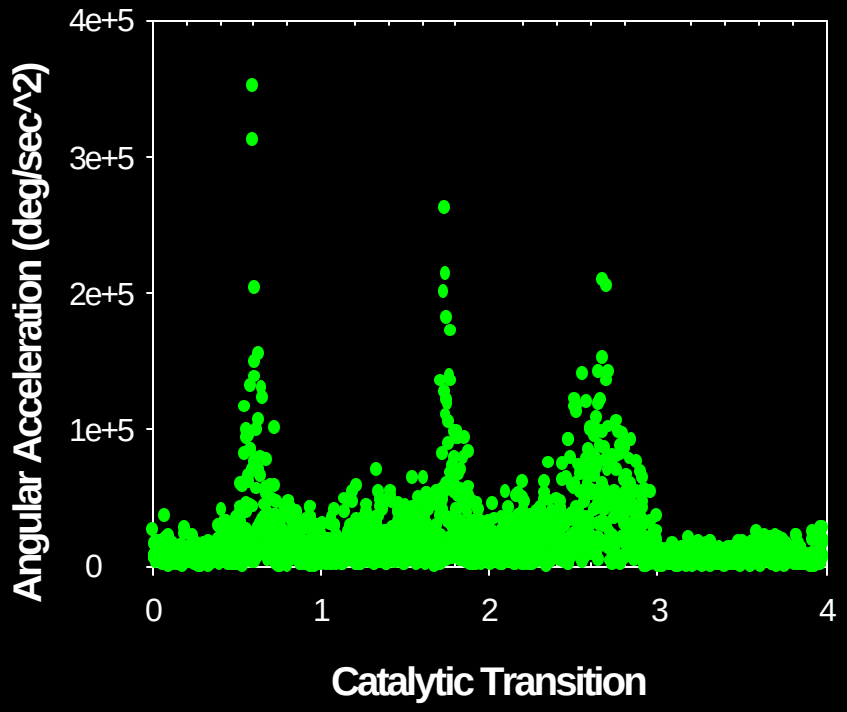


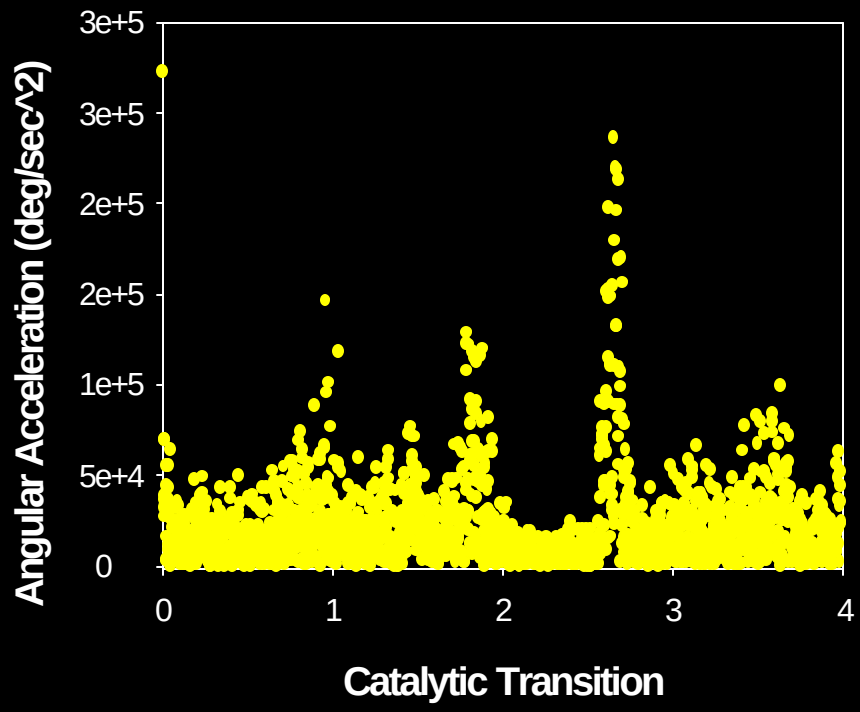
Angular Velocities For One Revolution



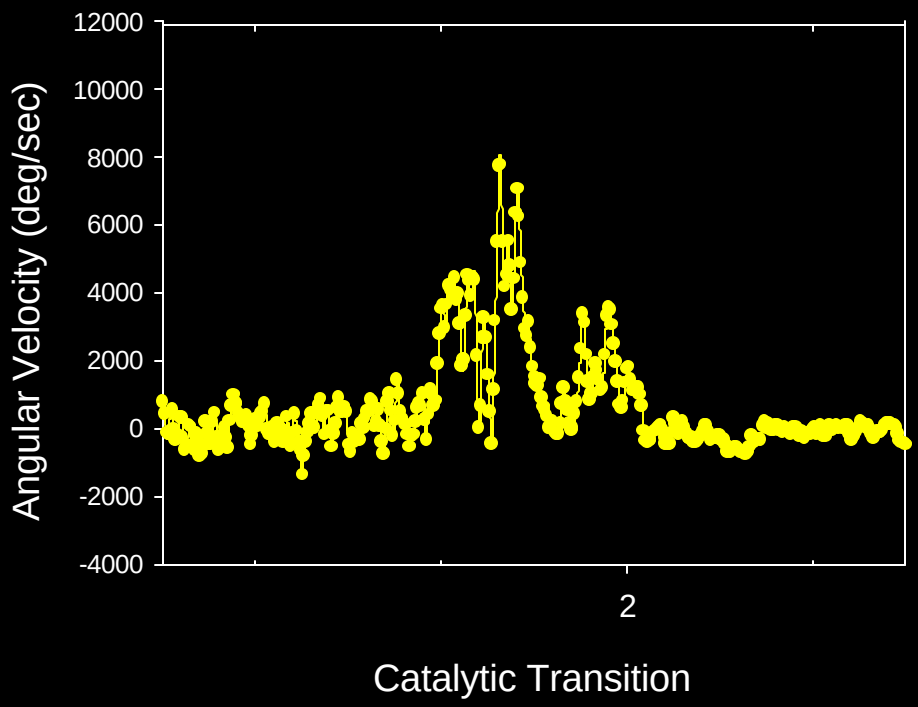


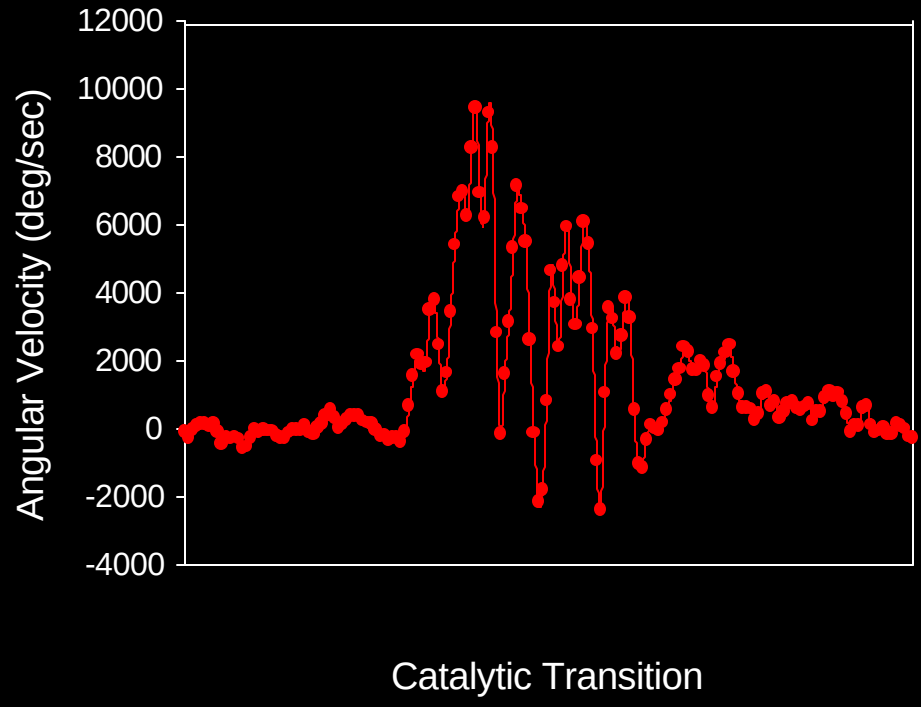
Angular Acceleration Over One Revolution



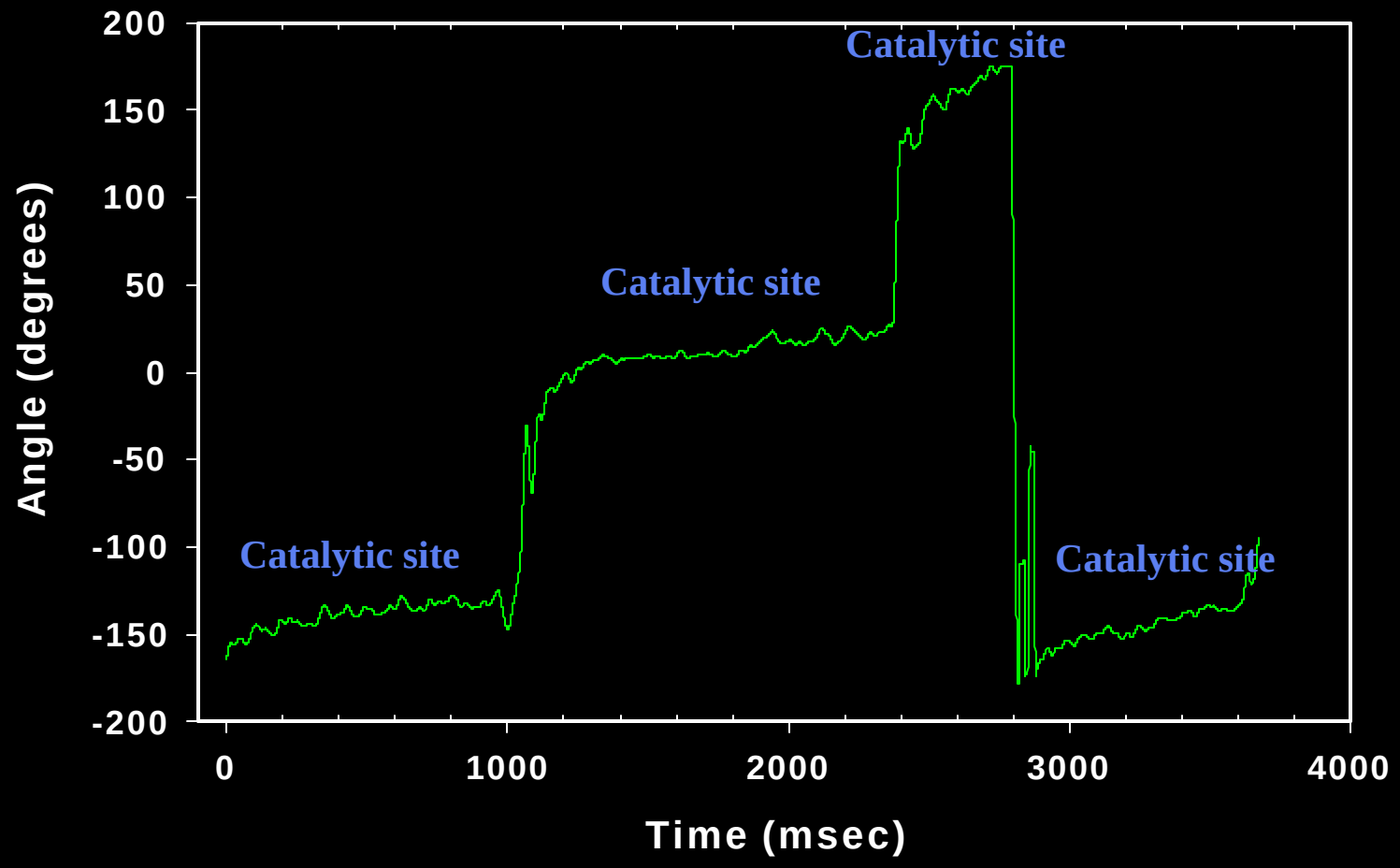


Angular Velocity of Individual Transitions

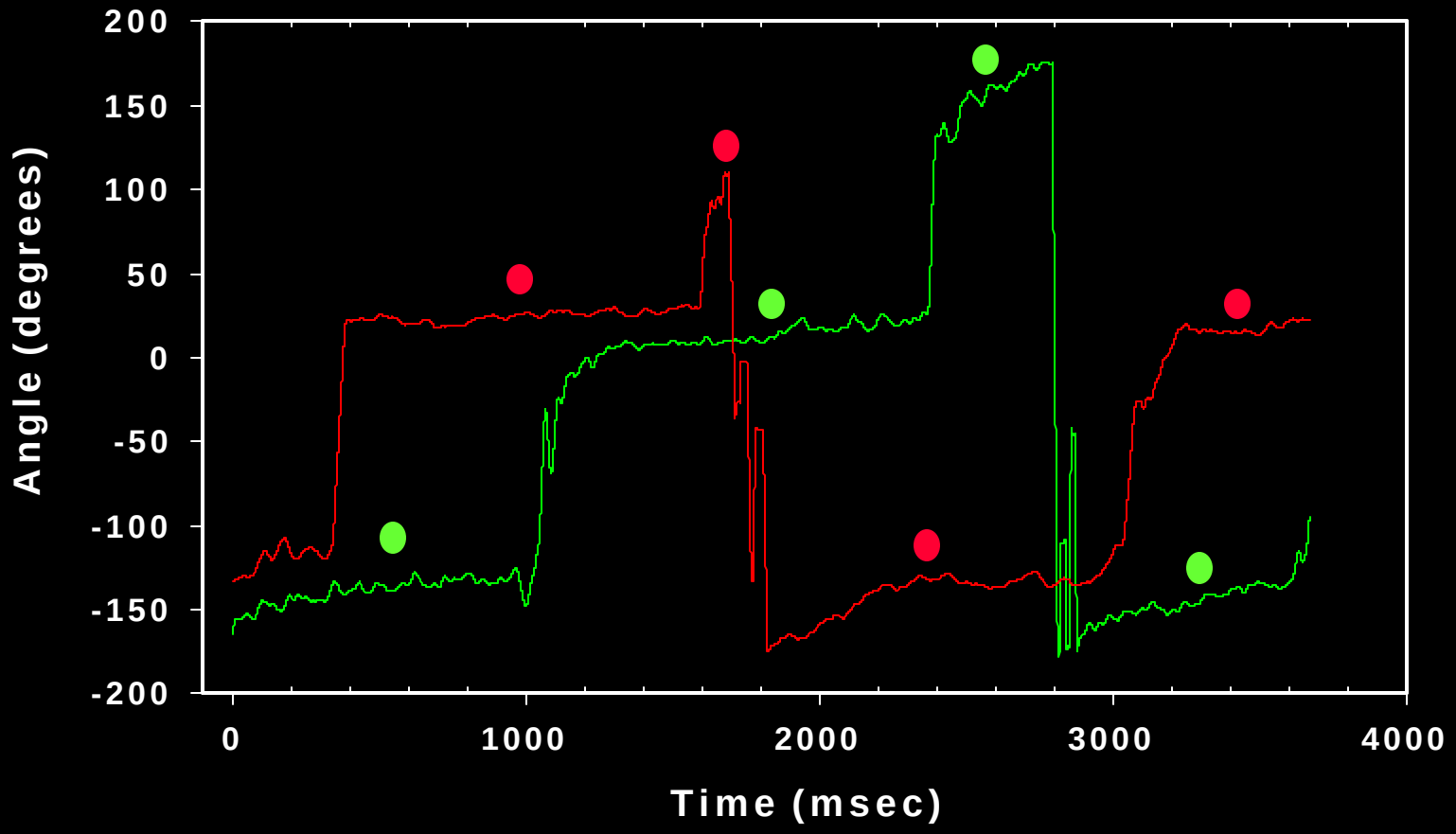




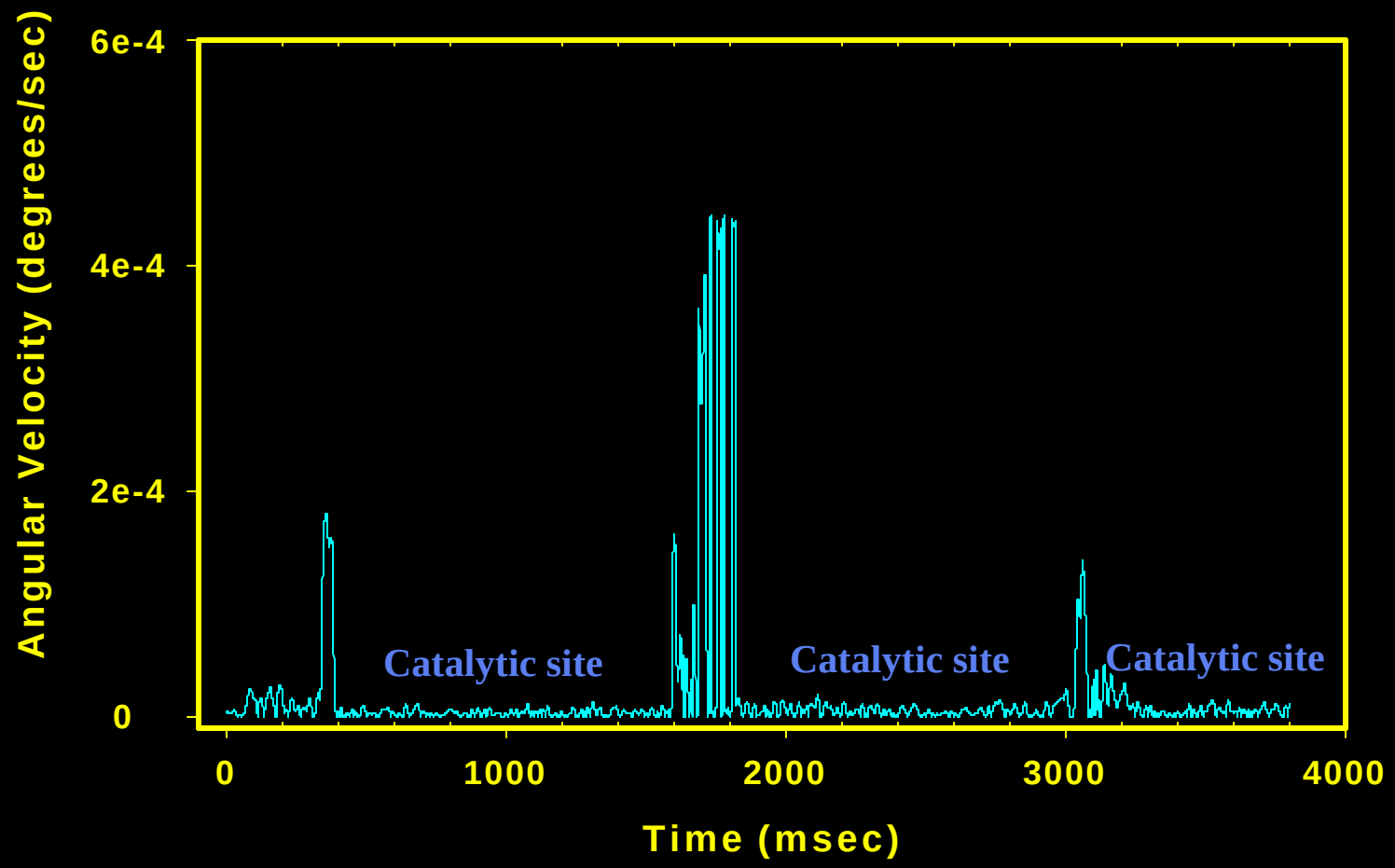
Change in Angle as a Function of Time



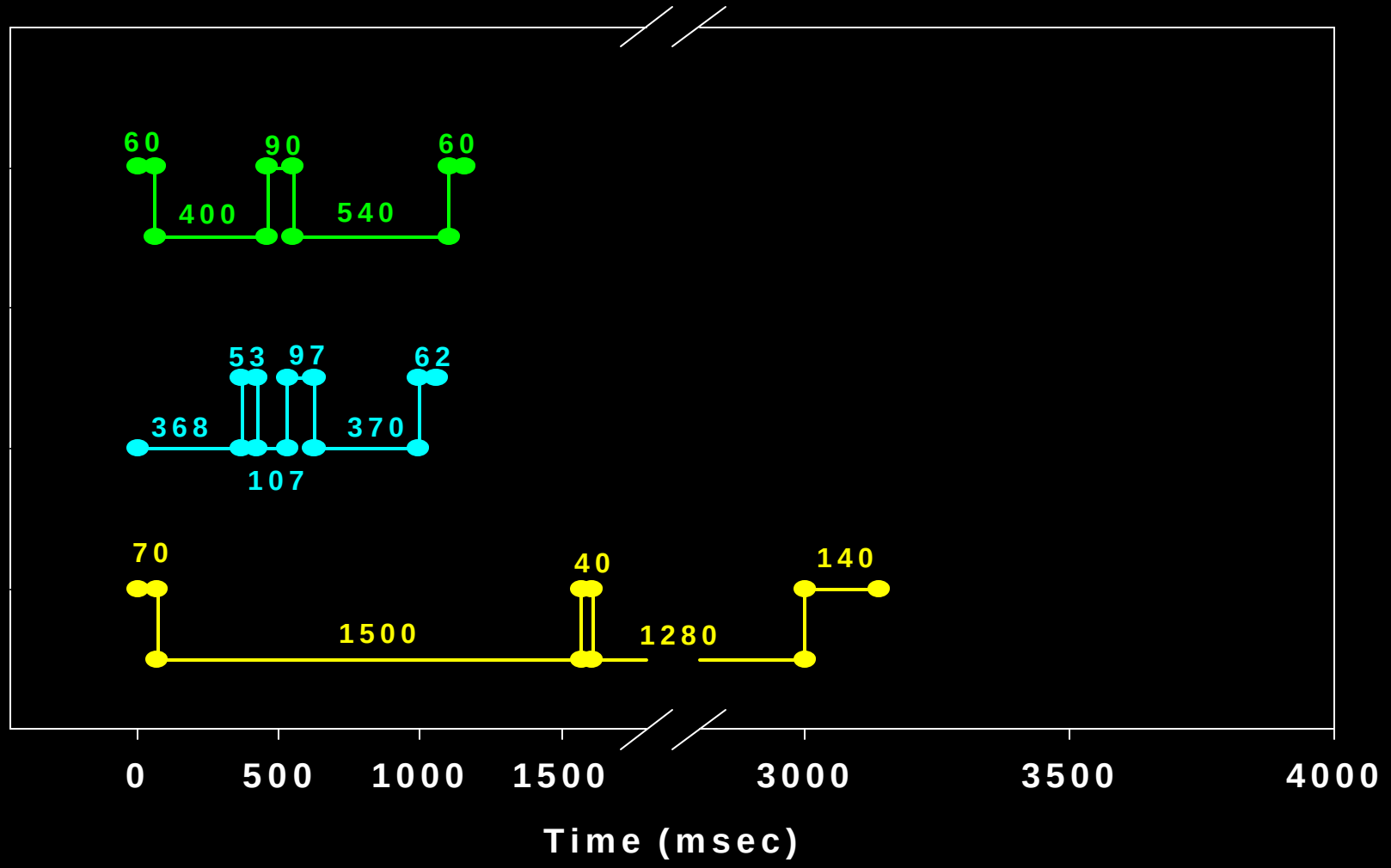
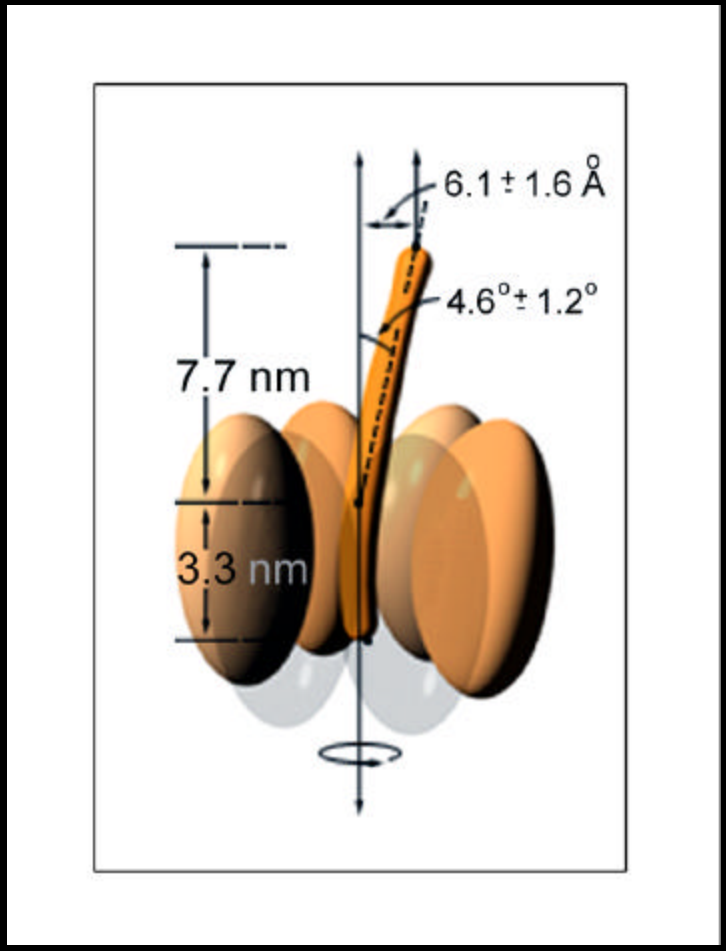
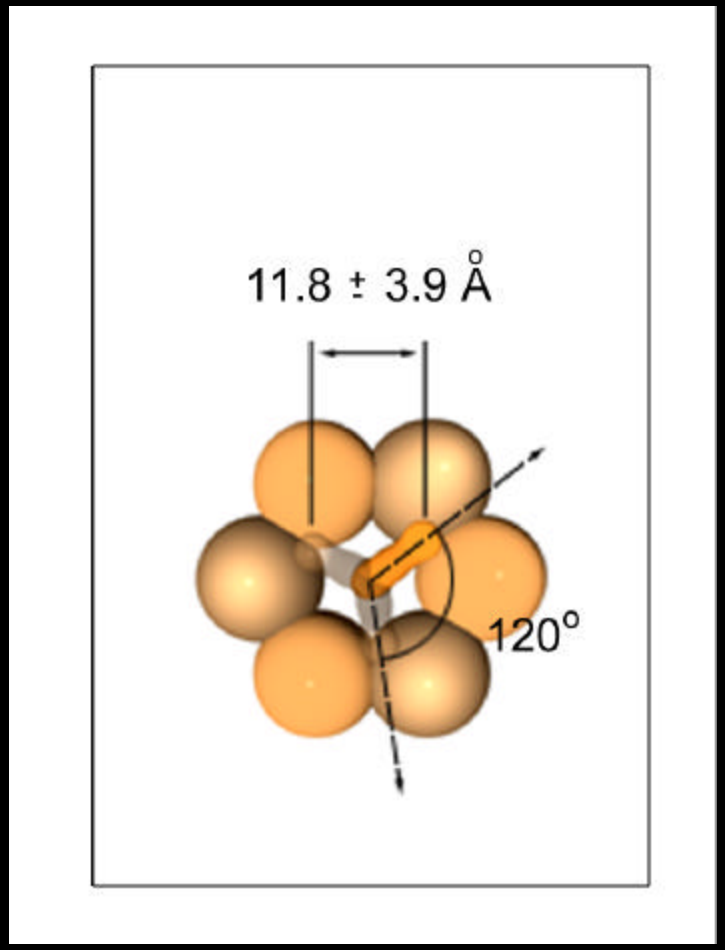
Change in Angle as a Function of Time



Angular Velocity



Estimated Transition and Dwell Times



Gamma Subunit Deformation During Catalysis