Molecular Mechanisms of self-assembly and motion of the bacterial flagellum

Mexico-Japan Workshop on Pharmacobiology and Nanobiology
Universidad Nacional Autonoma de México (UNAM)
Mexico City, Mexico 2009.02.25-26

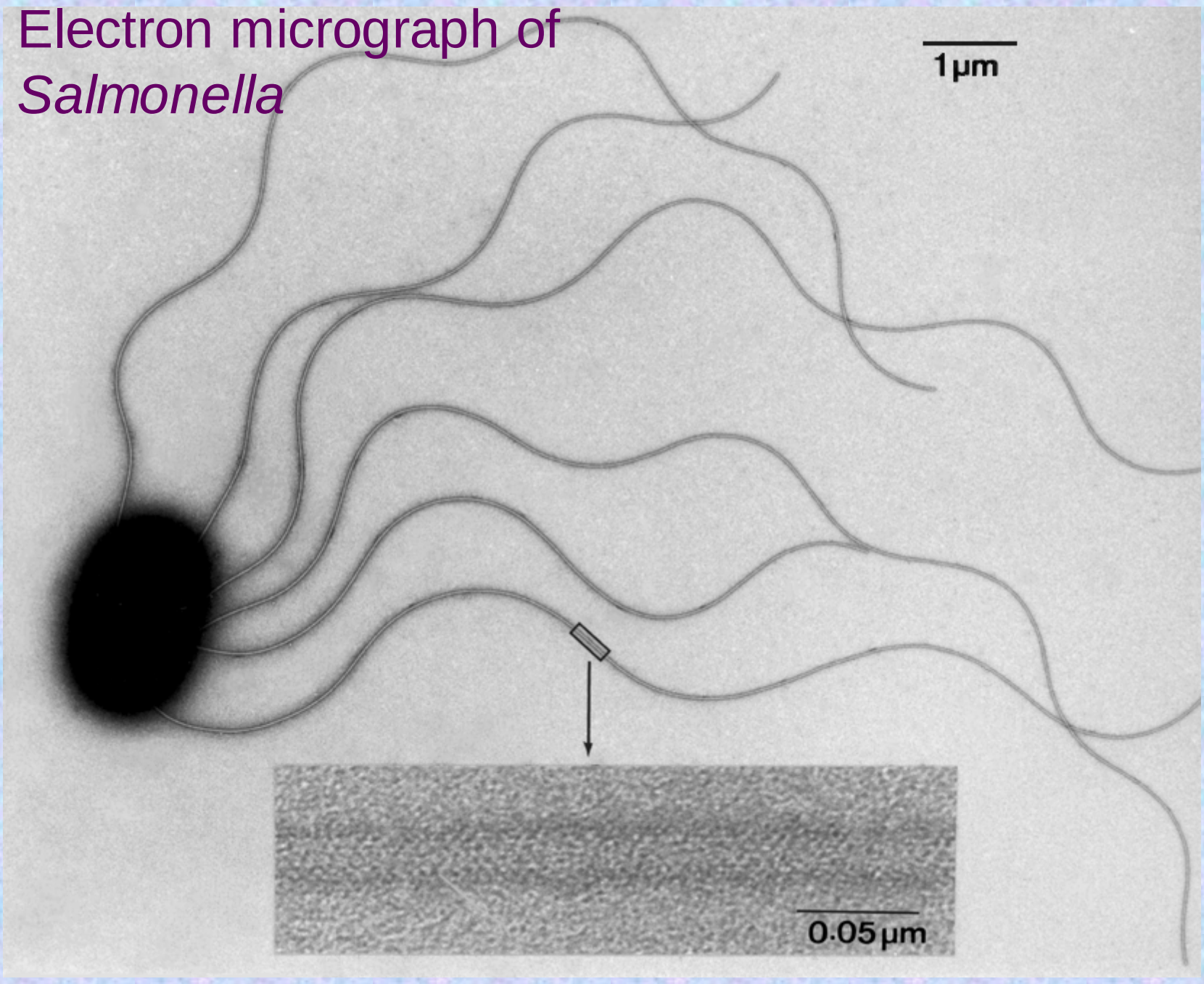
Keiichi Namba

Graduate School of Frontier Biosciences
Osaka University

Bacteria Swimming

Protonic NanoMachine

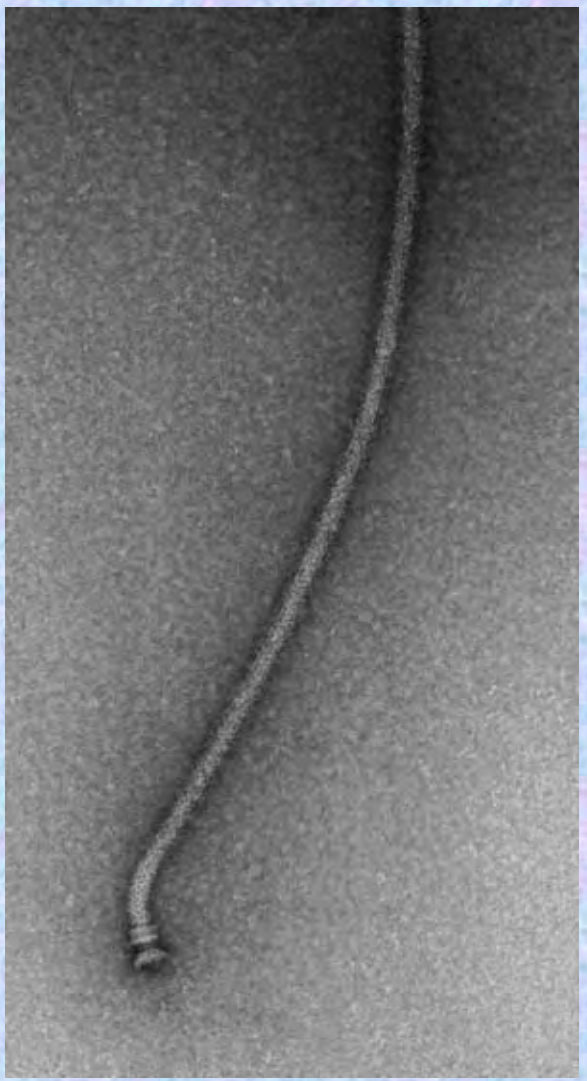
Electron micrograph of *Salmonella*

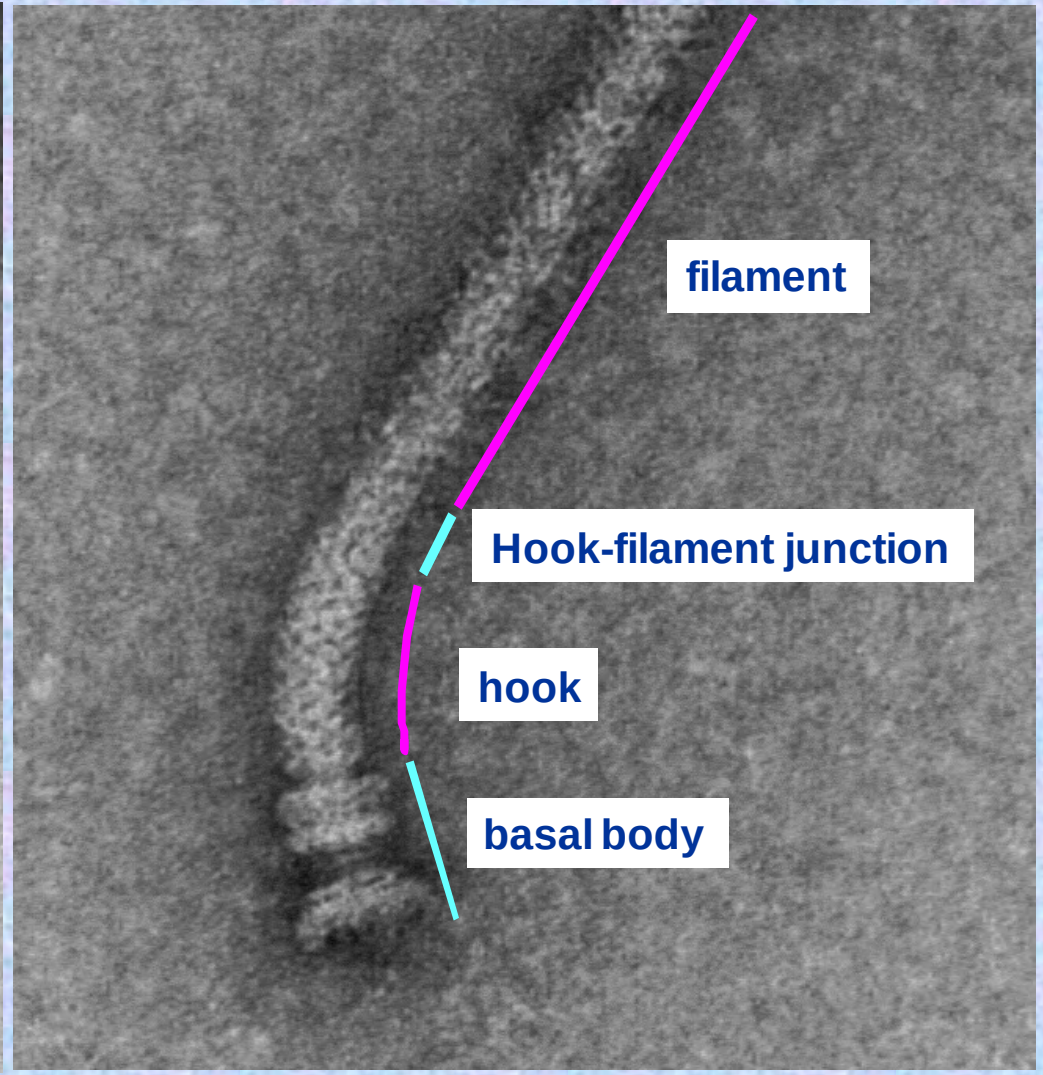


Flagellar bundle rotation

Protonic NanoMachine

Bacterial flagellum (Basal body-Hook-Filament)





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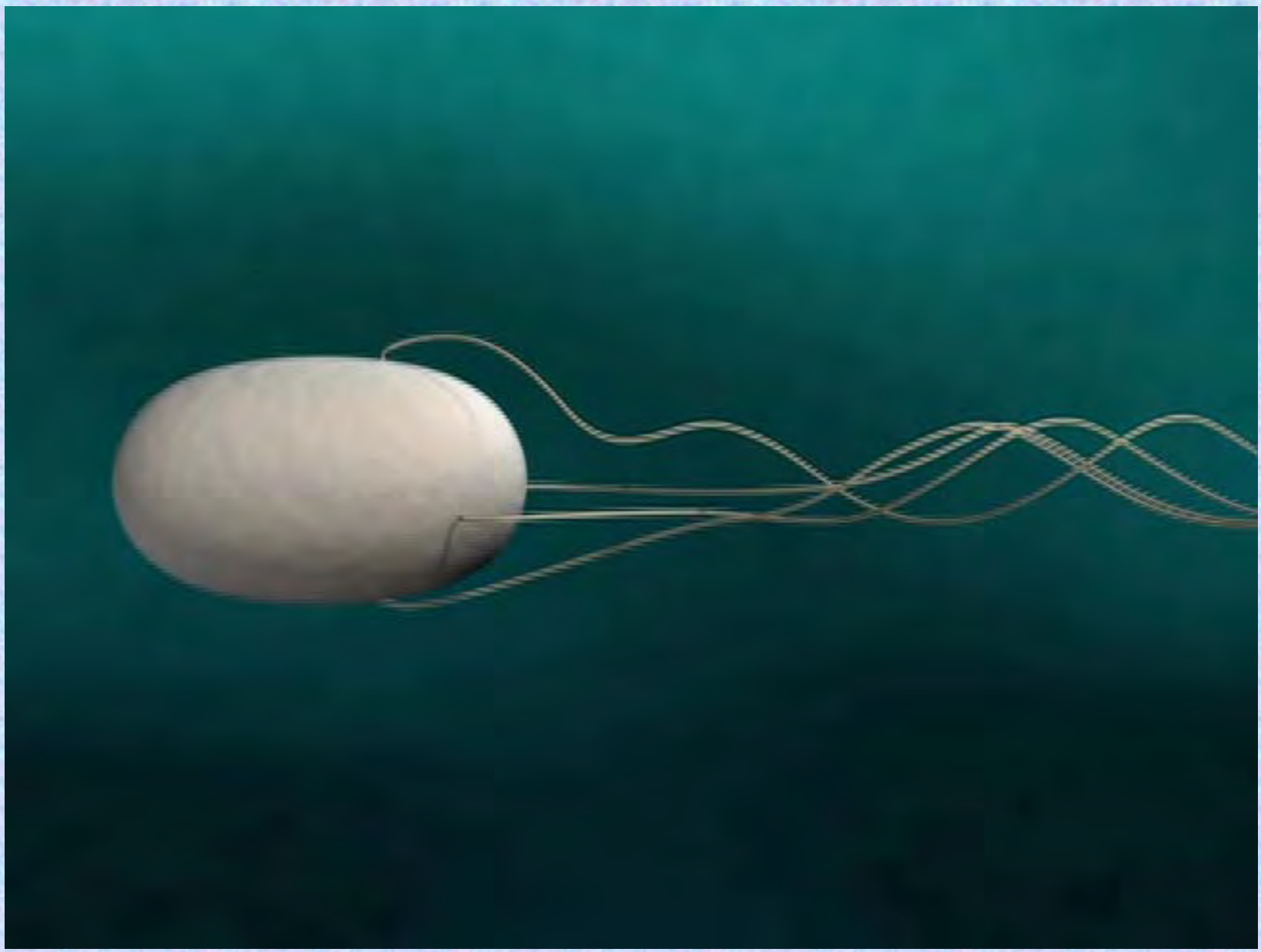
Flagellar motor driven by the proton motive force



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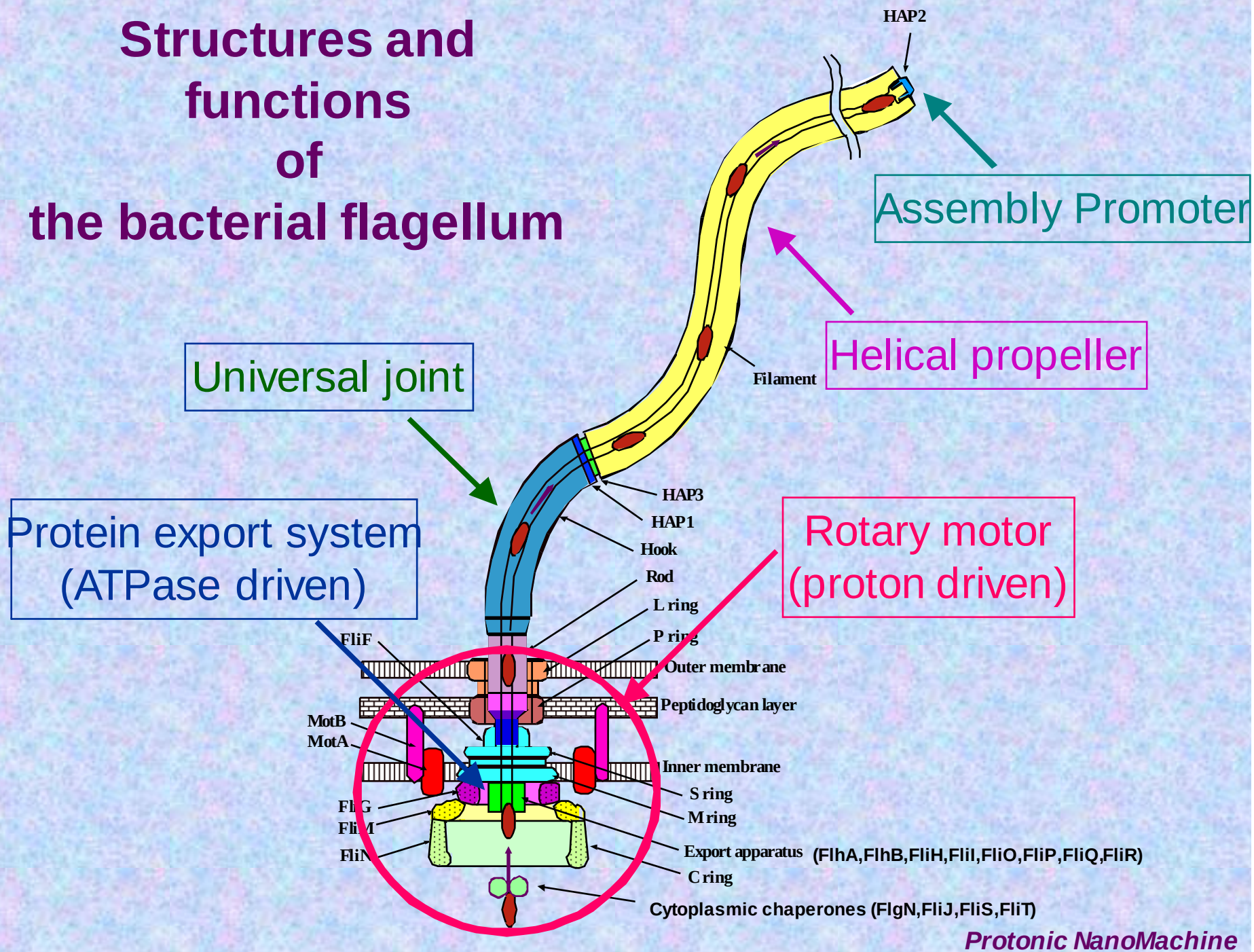
Structures and functions of the bacterial flagellum

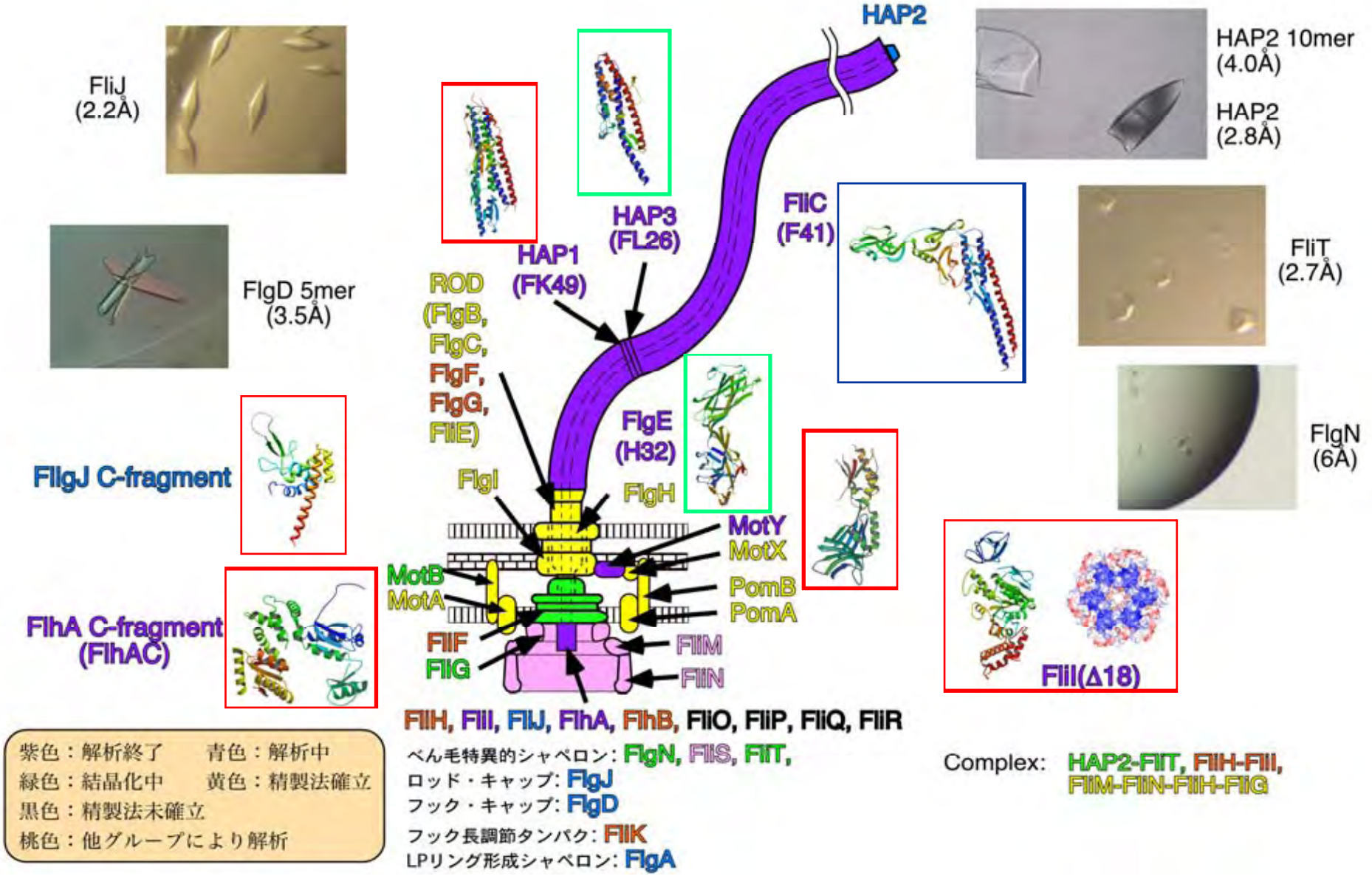


Protonic NanoMachine

SPring-8 at Harima, Hyogo, Japan

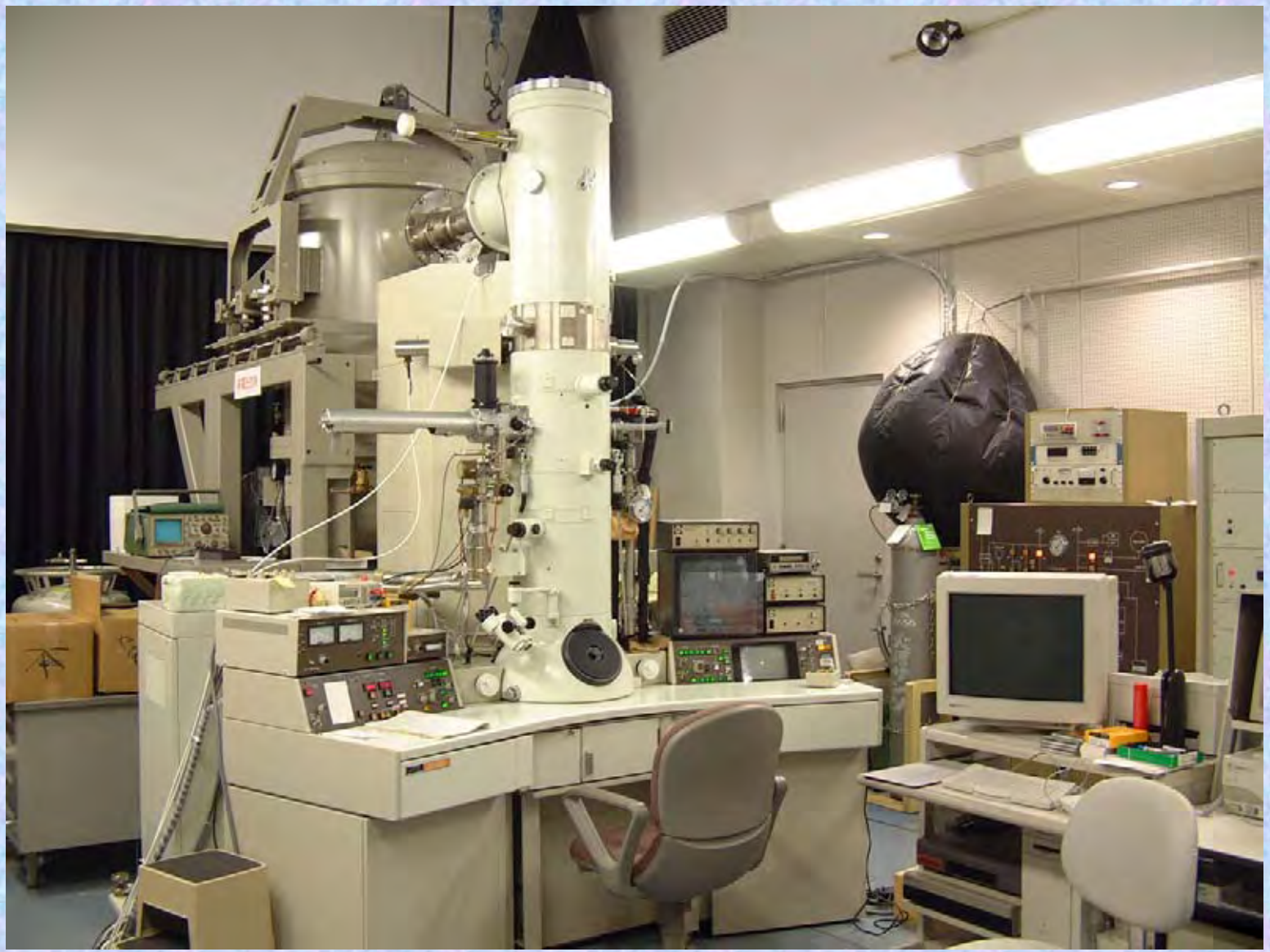
Super Photon ring 8 GeV (giga electron volt)
Highly brilliant X-ray with variable wavelength
by synchrotron radiation

Crystallography of flagllar proteins (update December 2007)



Electron CryoMicroscope JEM3000SFF

(300 kV FEG & specimen holder cooled at 4 K)



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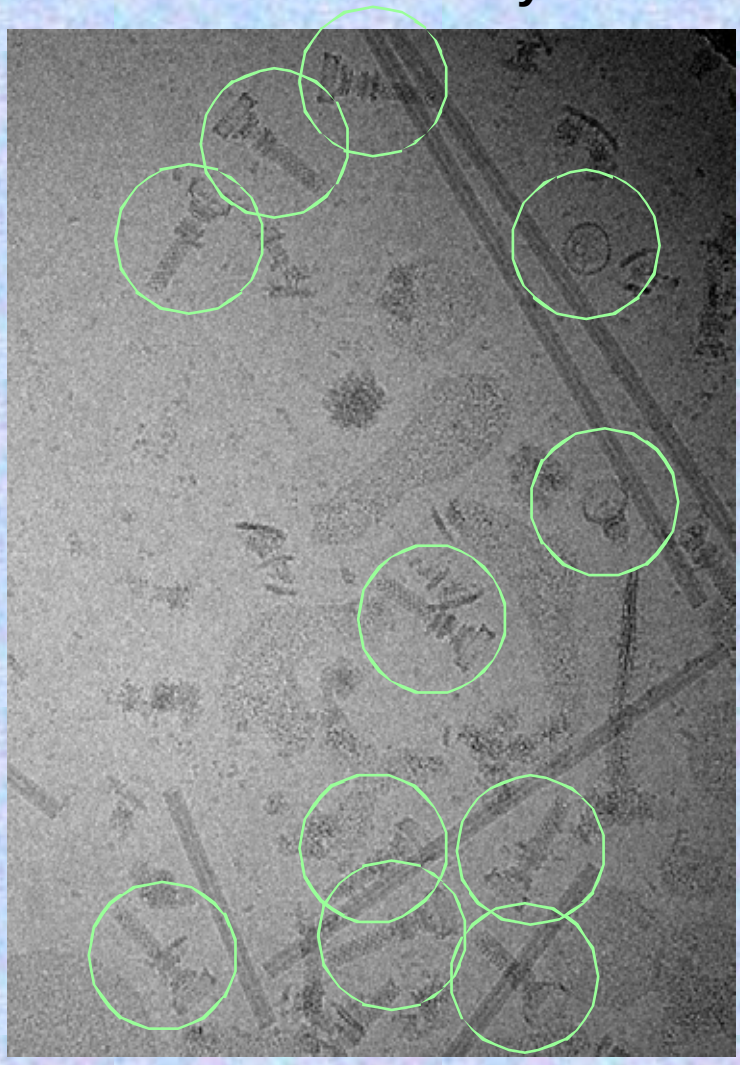
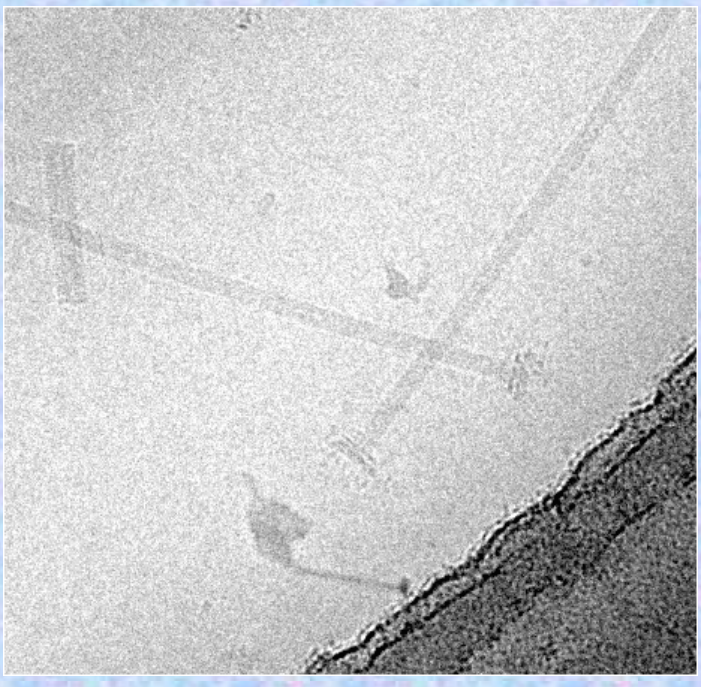
Electron cryomicroscopy of flagellar subcomplexes

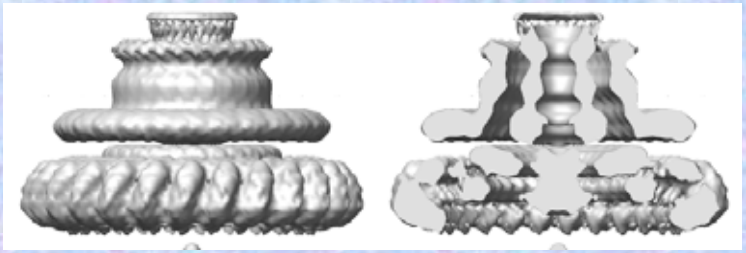
Hook basal body



Polyrod basal body



Fujii & Kato, *unpublished*



Miyata & Kato, *unpublished*

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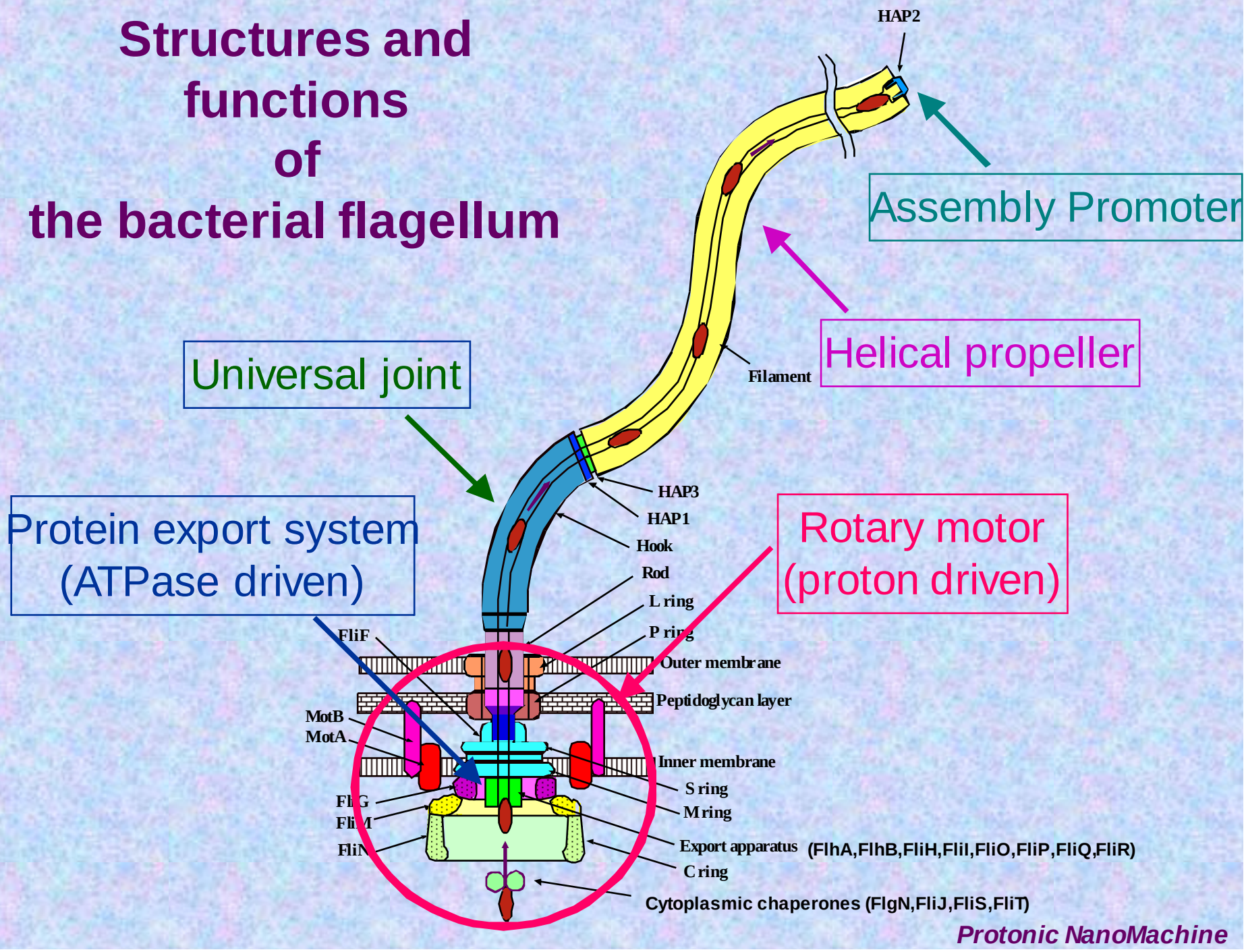
Structures and functions of the bacterial flagellum



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Structure of the filament as a helical propeller with switchable helical hand

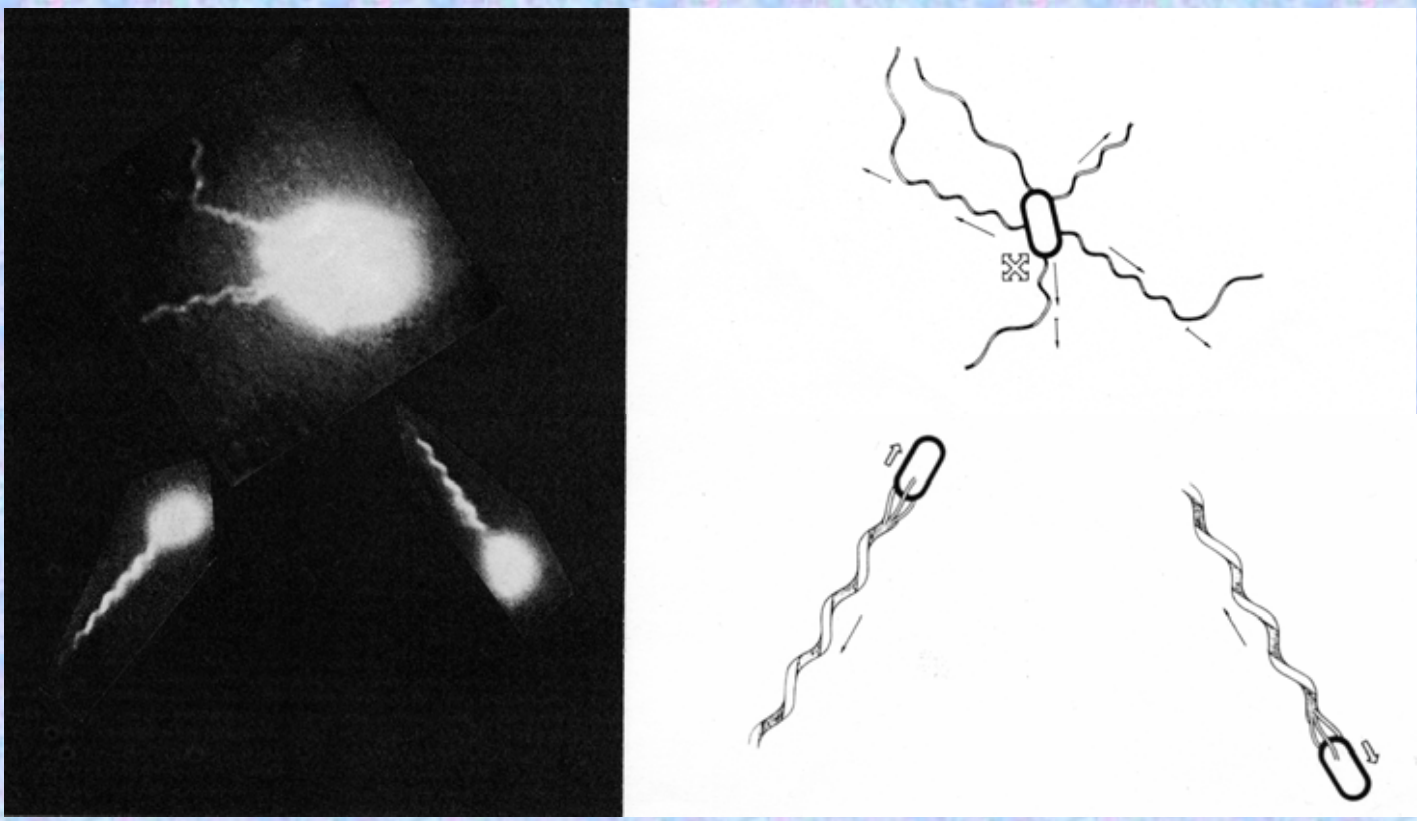
Flagellar bundle rotation

Protonic NanoMachine

Run and Tumble

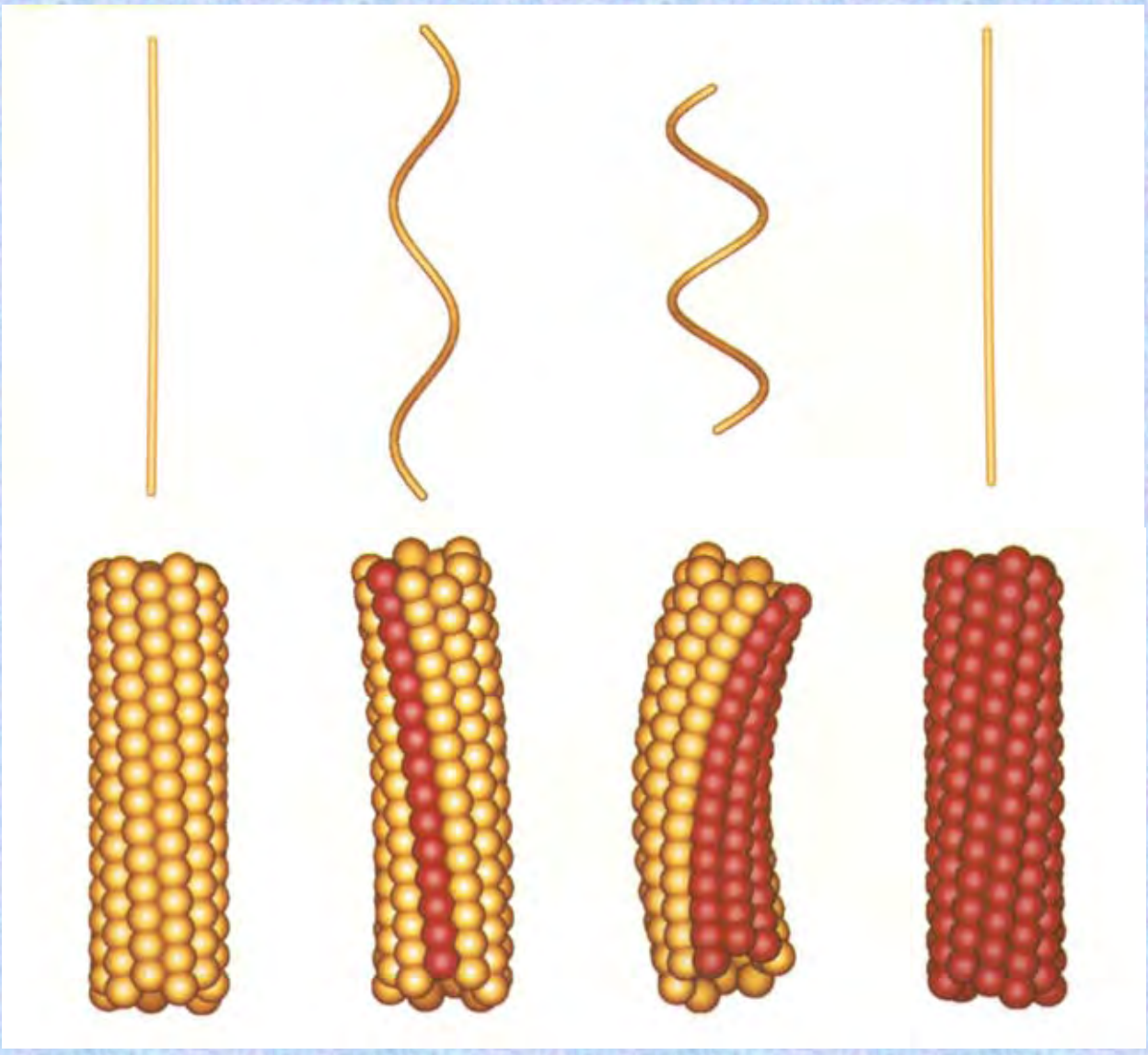
Protonic NanoMachine

Switching from left-handed to right-handed supercoil by quick reversal of the motor rotation



Macnab & Ornston (1977) *J. Mol. Biol.*

A model of polymorphic supercoiling



Based on the proposal by Asakura (1970) and Calladine (1975)

Polymorphic transition - *Normal to Curly 1 & 2*

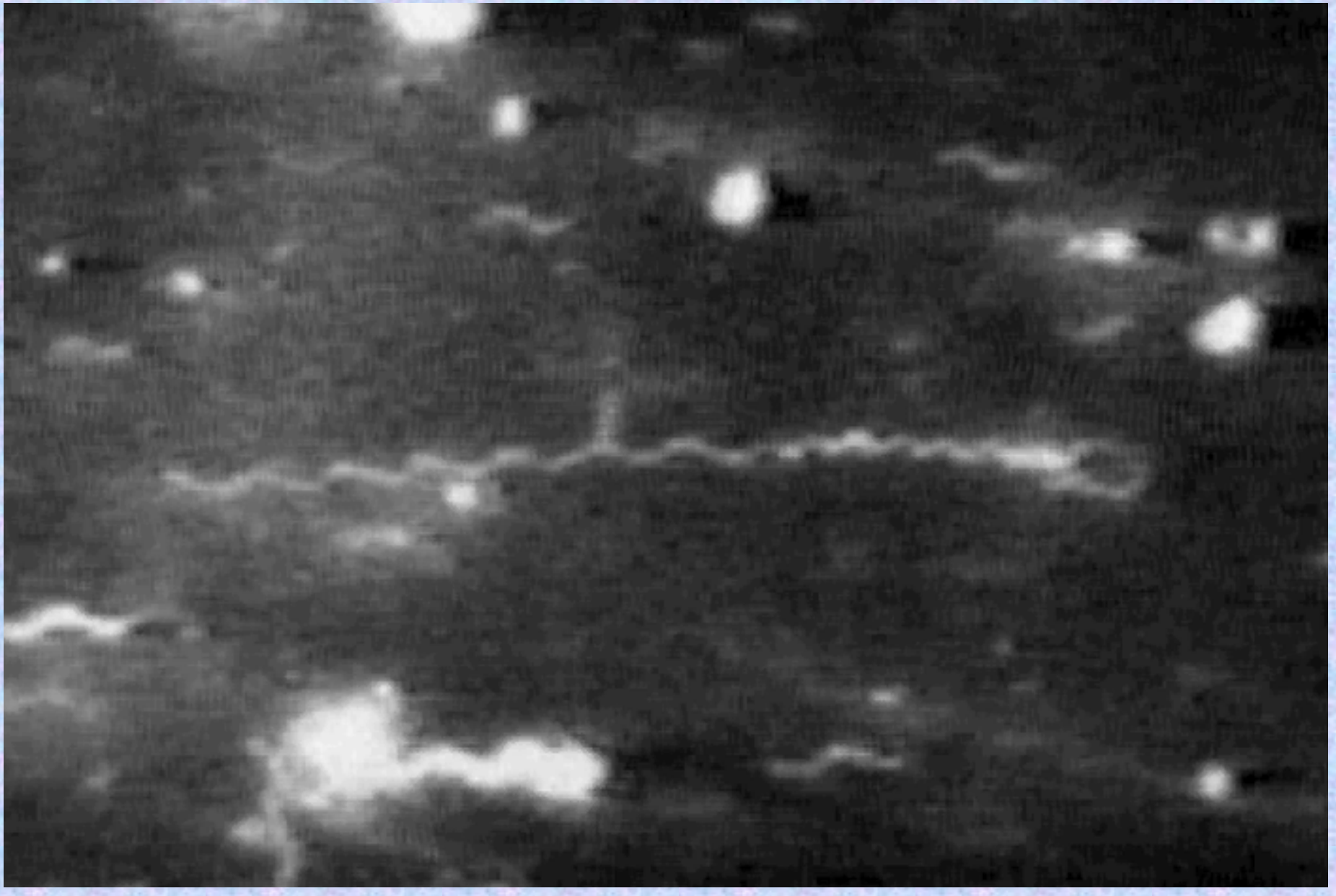


Image recorded by H. Hotani

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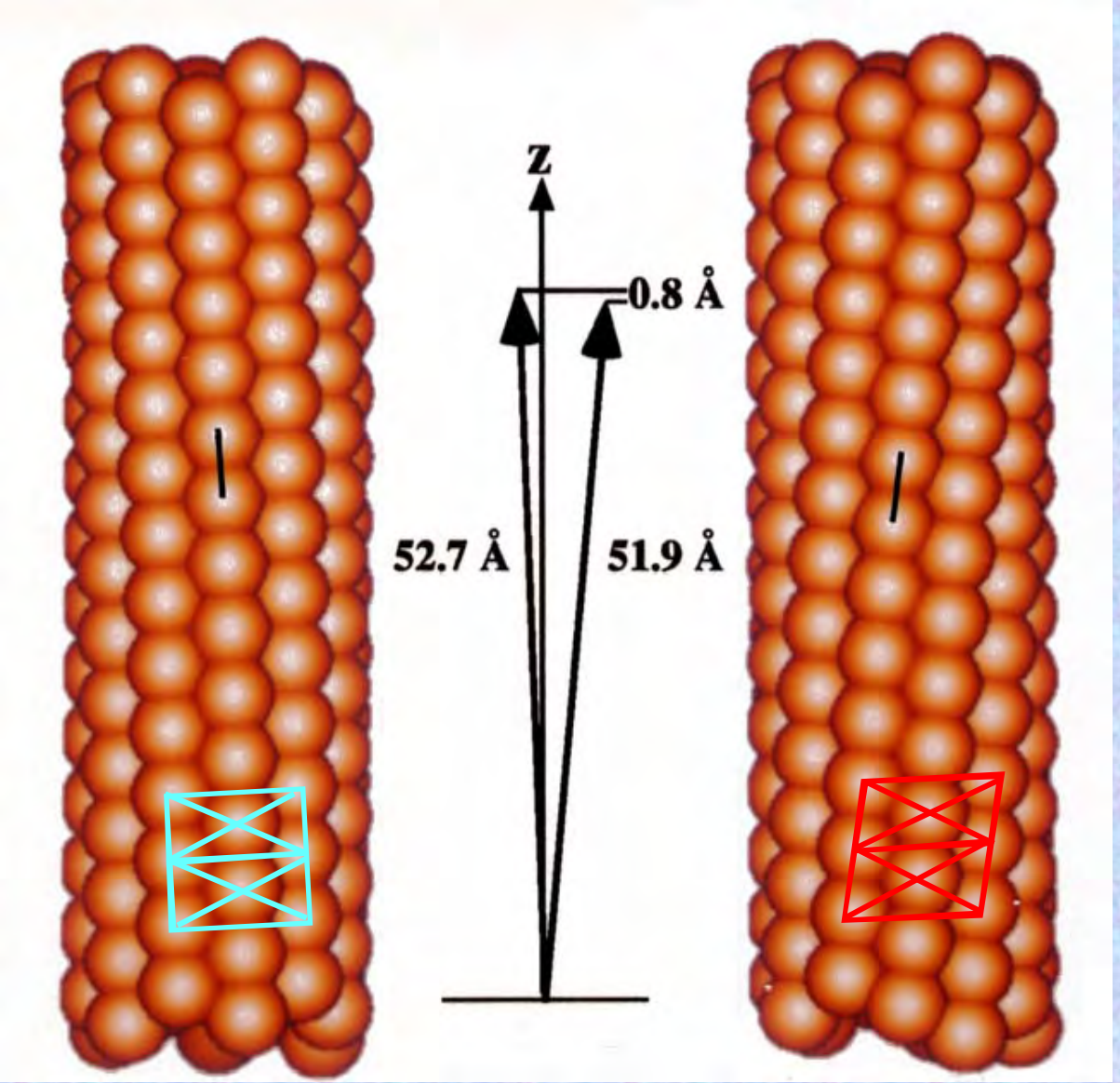
Repeat distance along the protofilament

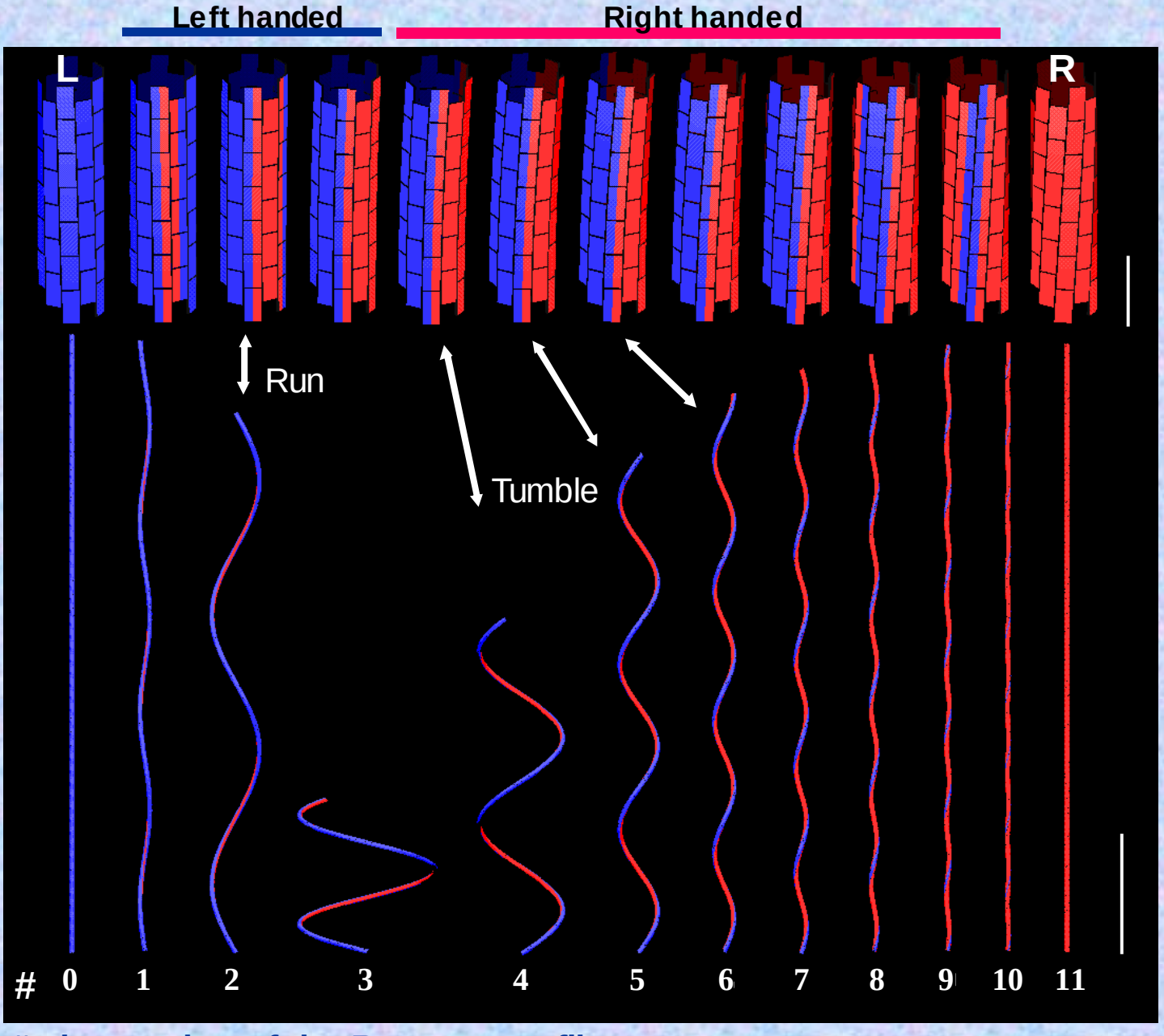
L-type



R-type

Yamashita *et al*. (1998) *Nature Struct. Biol.*

Models of 10 supercoils with 2 straight filaments



#: the number of the R-type protofilaments

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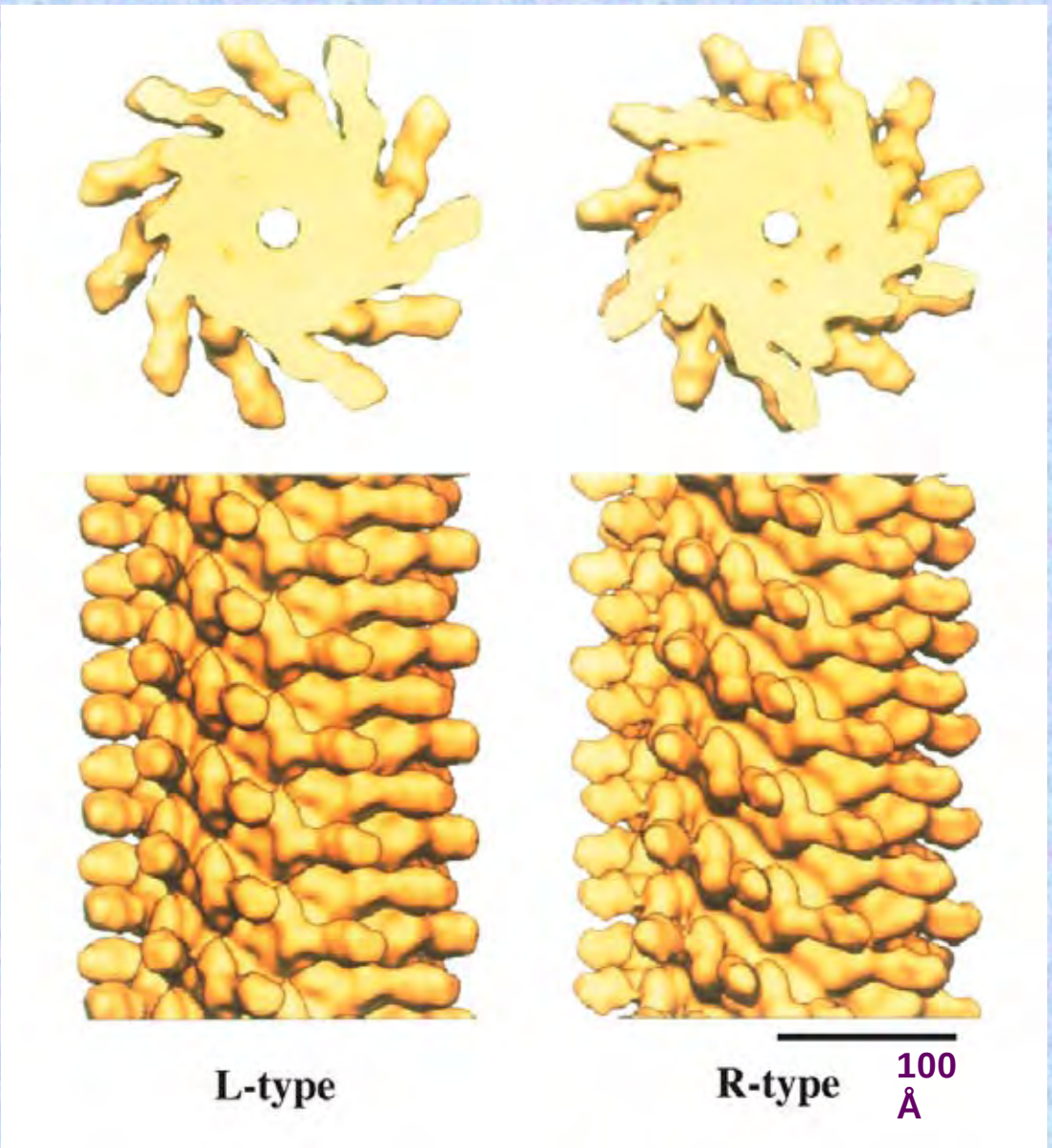
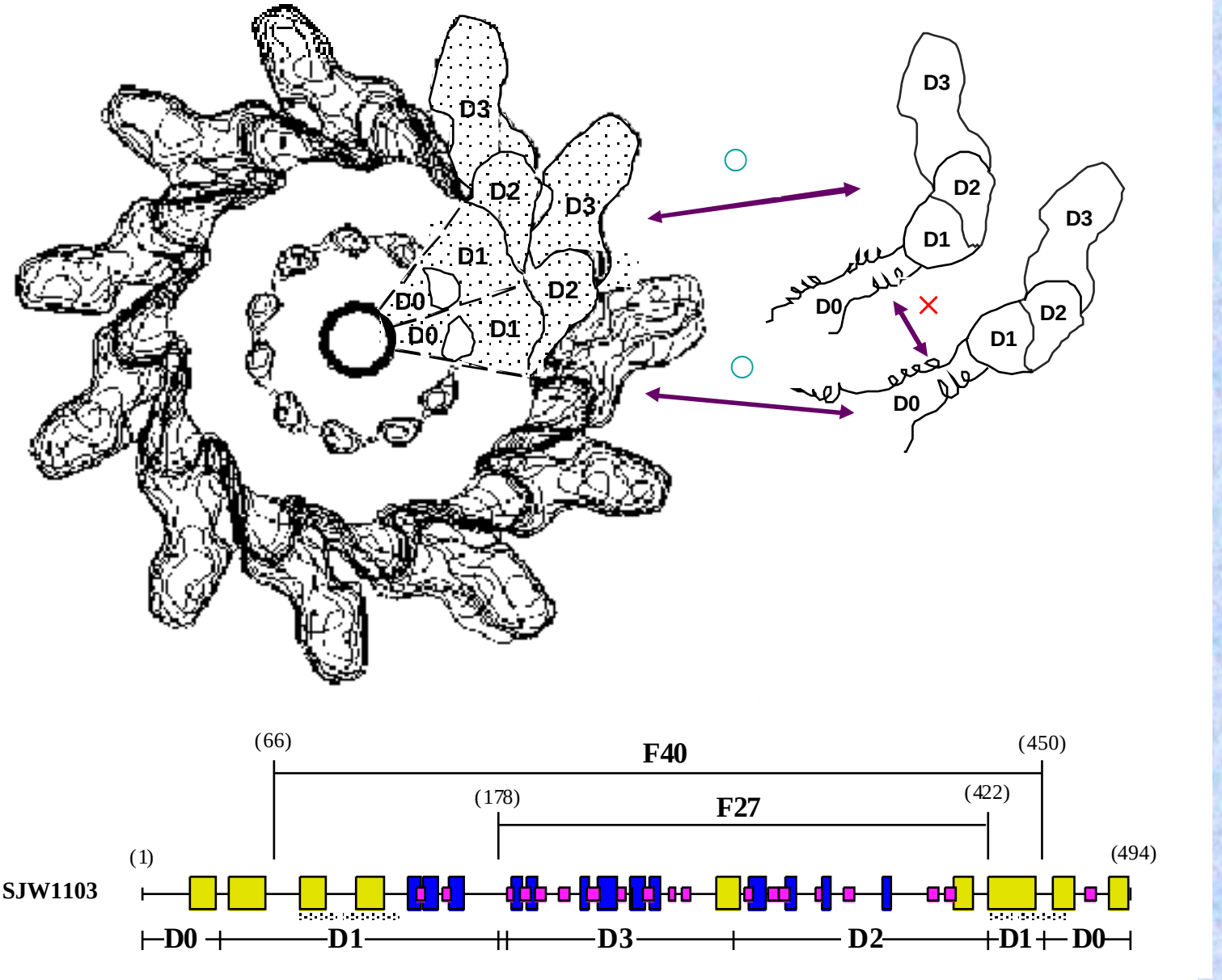
Comparison of the two structures at 10 Å resolution



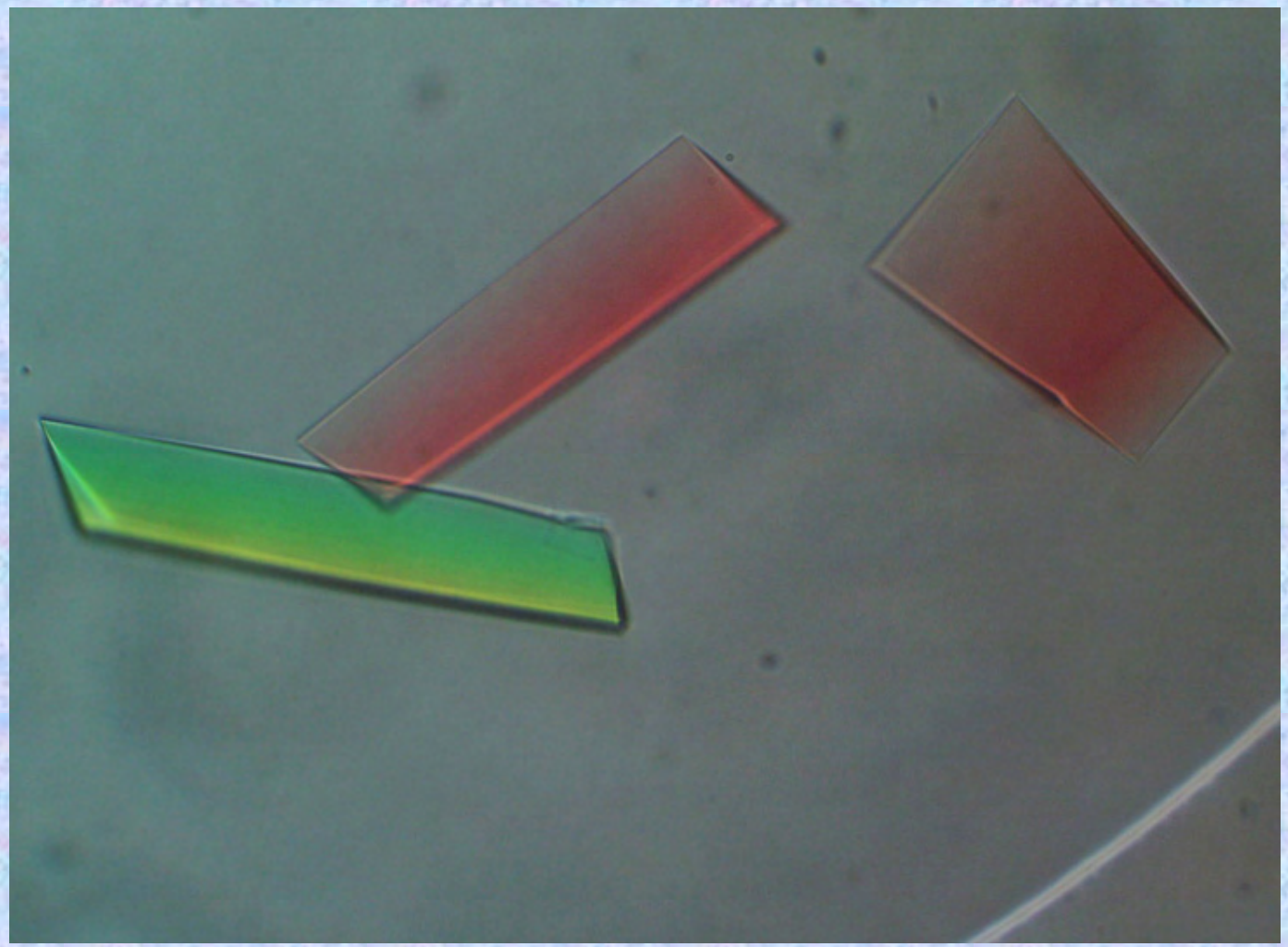
Subtle changes in the conformation still not visible at this resolution

Mimori-Kiyosue *et al*. (1996) *P.N.A.S.*

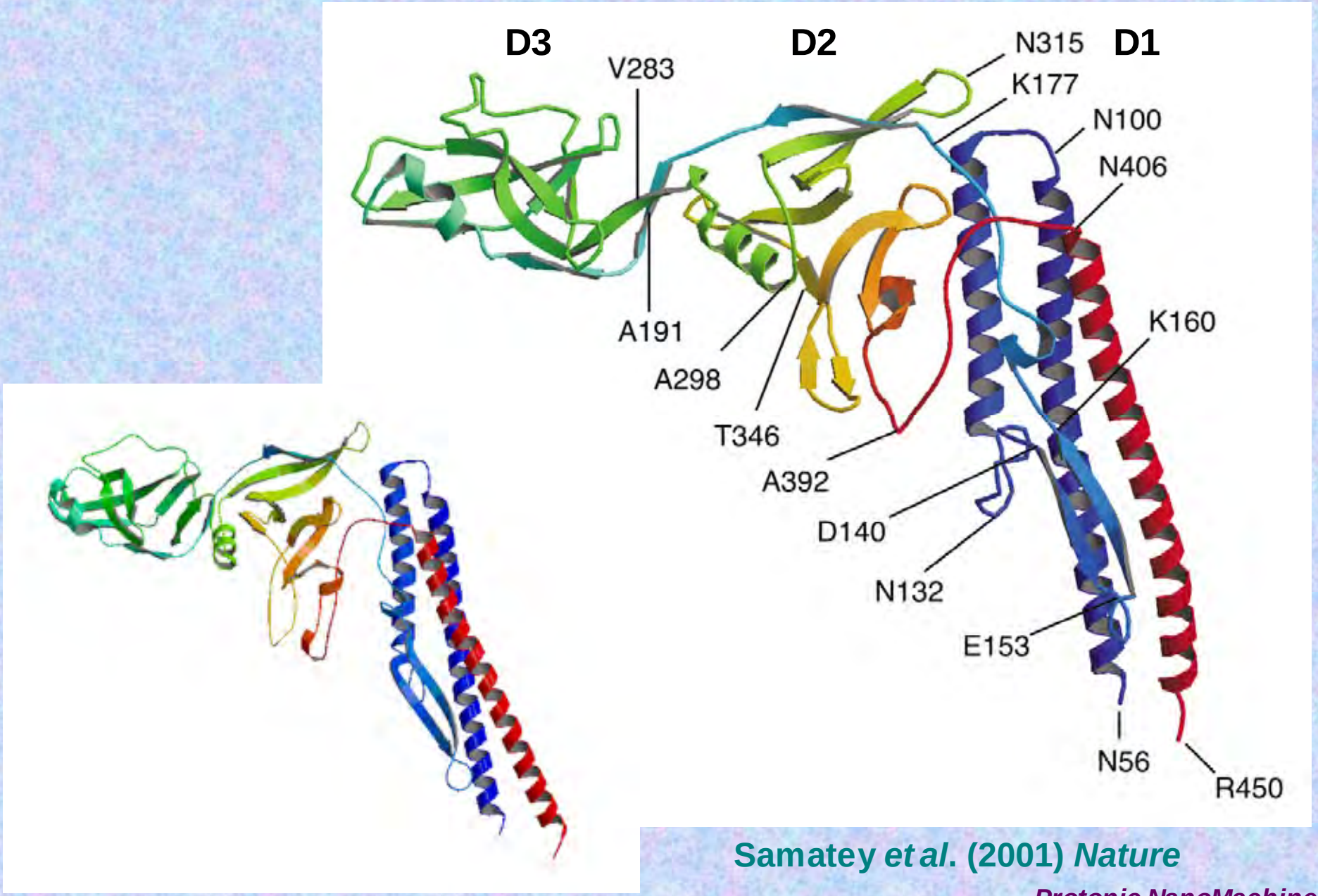
Disassembly into subunits for crystallization



Crystal of the F41 fragment of flagellin



Cα backbone trace of F41



Samatey *et al*. (2001) *Nature*

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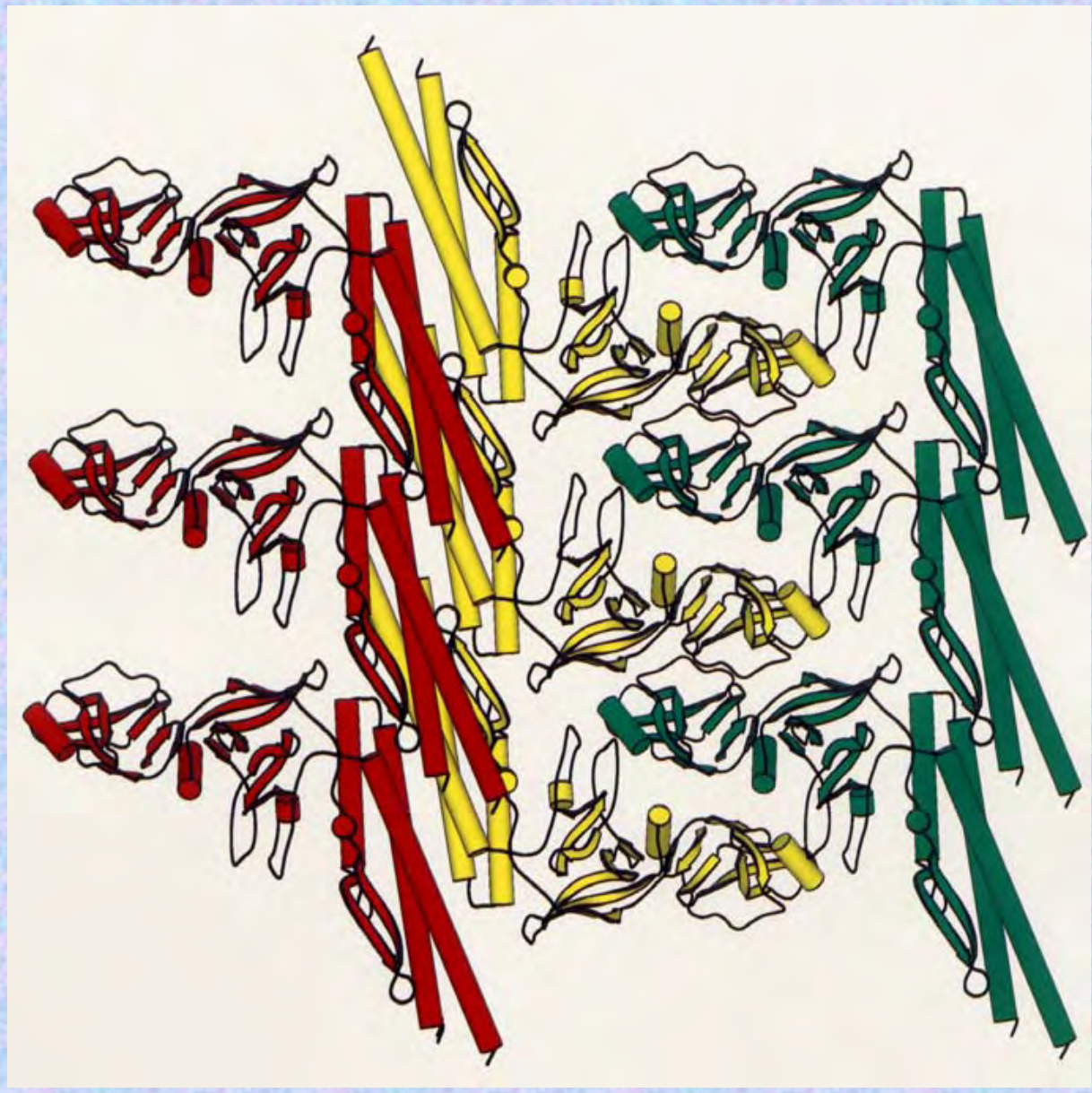
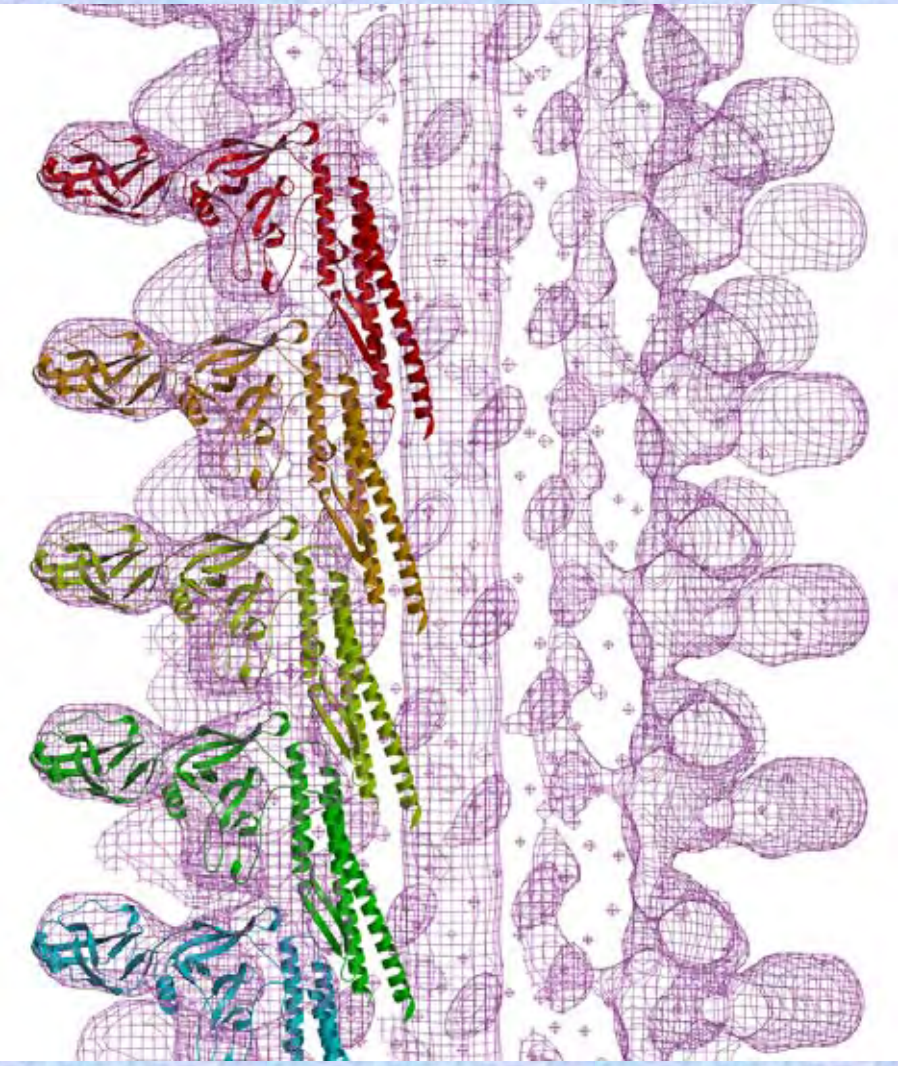
Crystal packing of F41 (a-c plane)

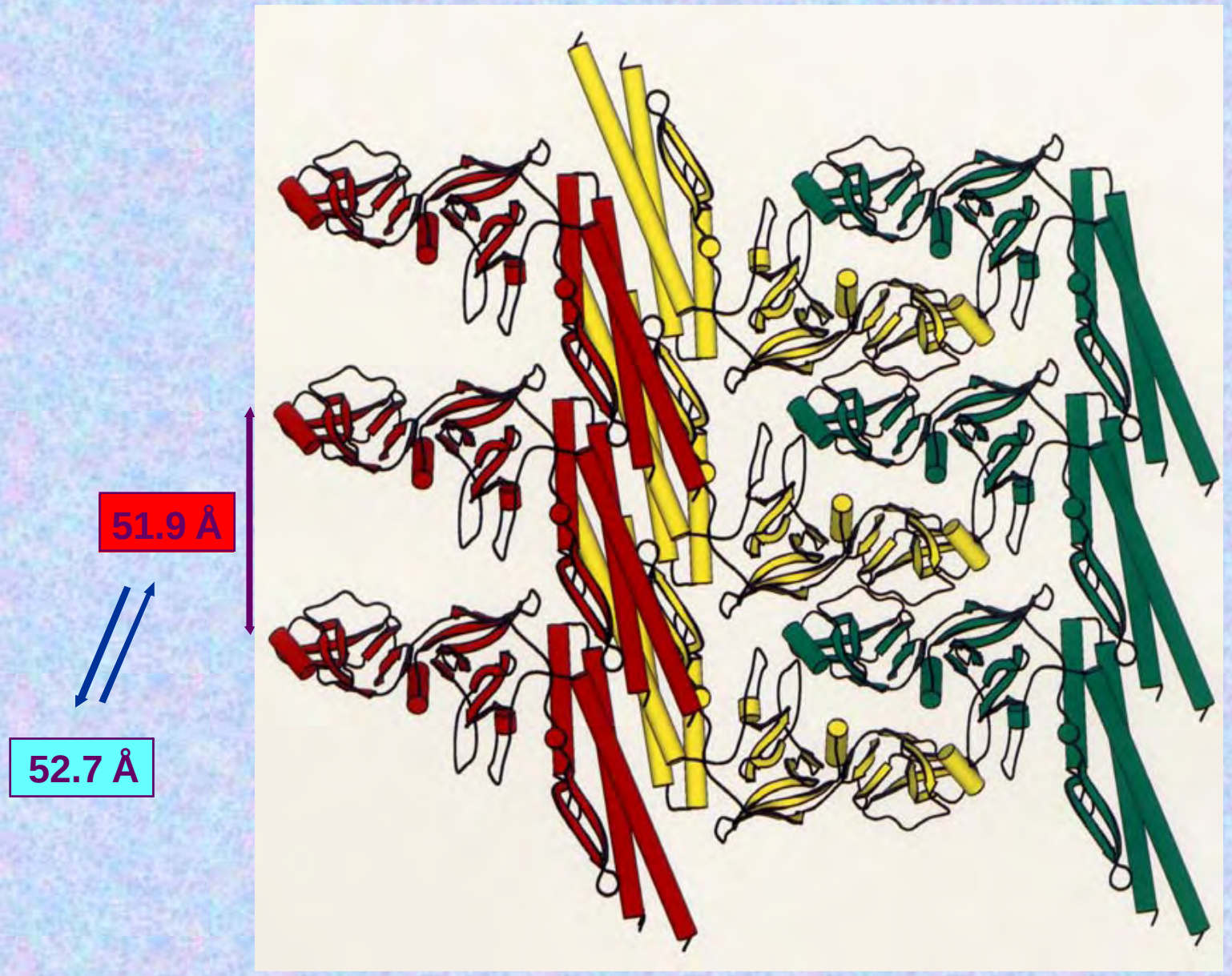


A protofilament on EM map and the filament model

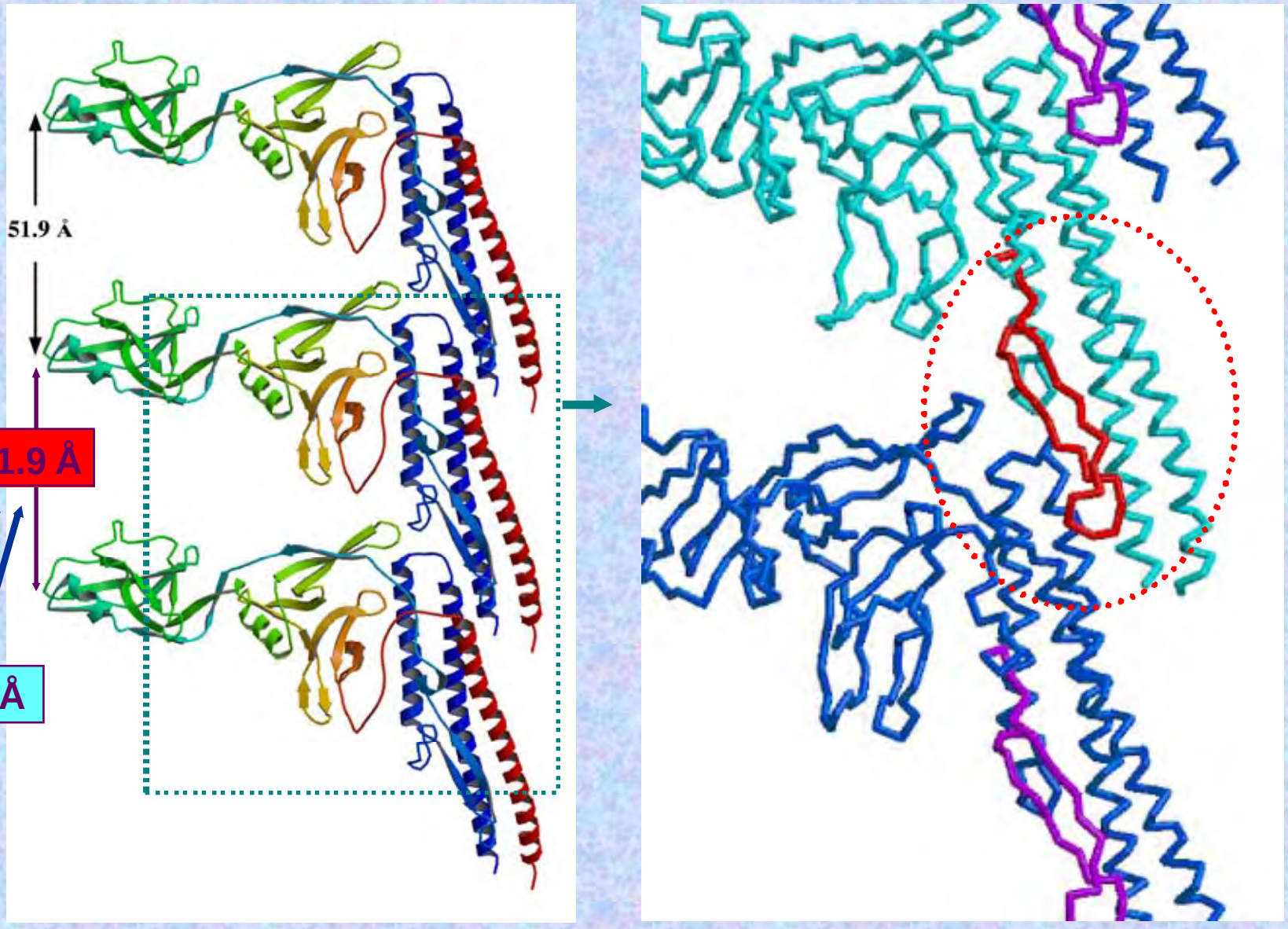


Samatey, Imada *et al*. (2001) *Nature*

Crystal packing of F41 (a-c plane)



Simulated extension of the protofilament



Distribution and packing of hydrophobic side chains

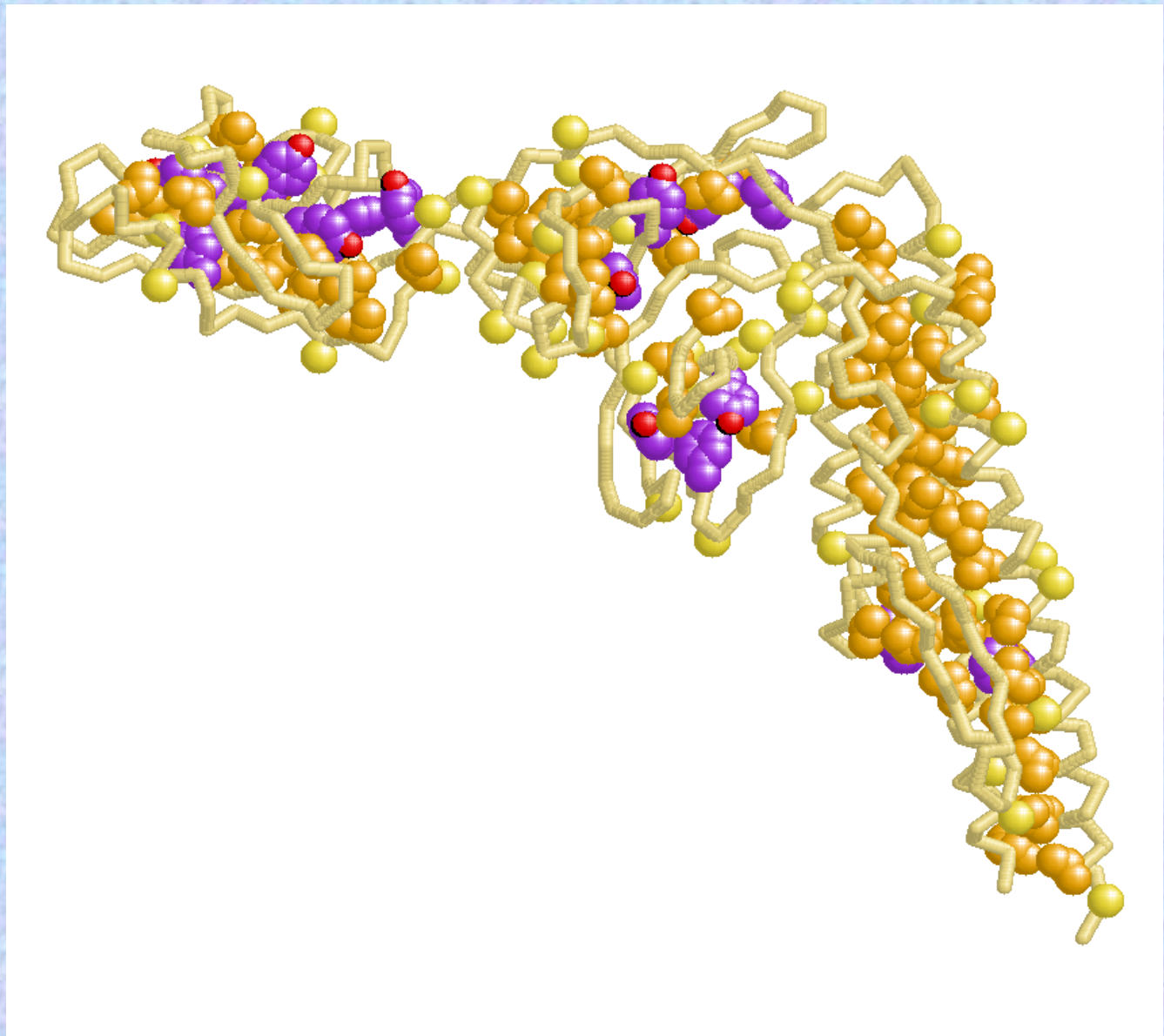
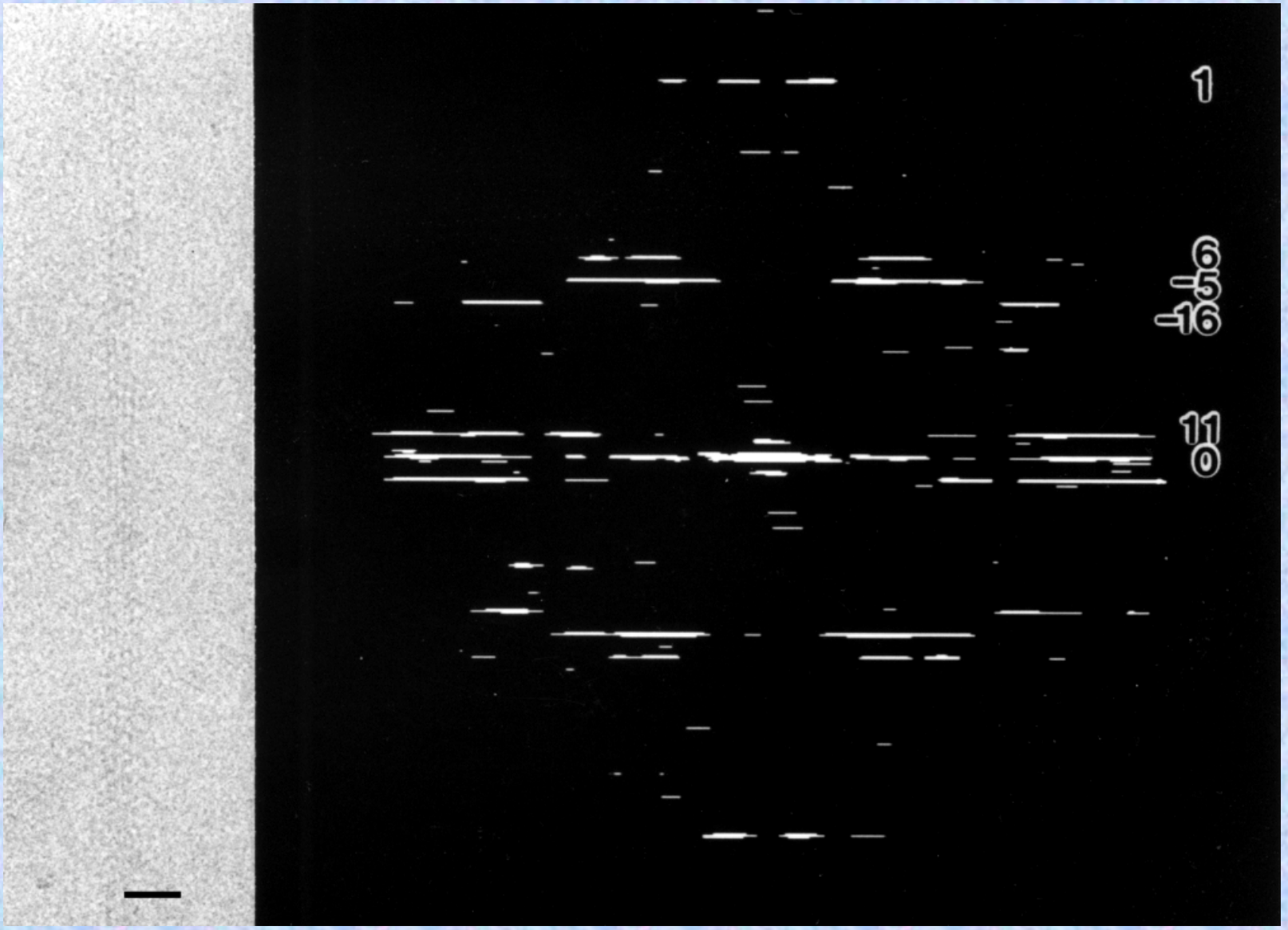


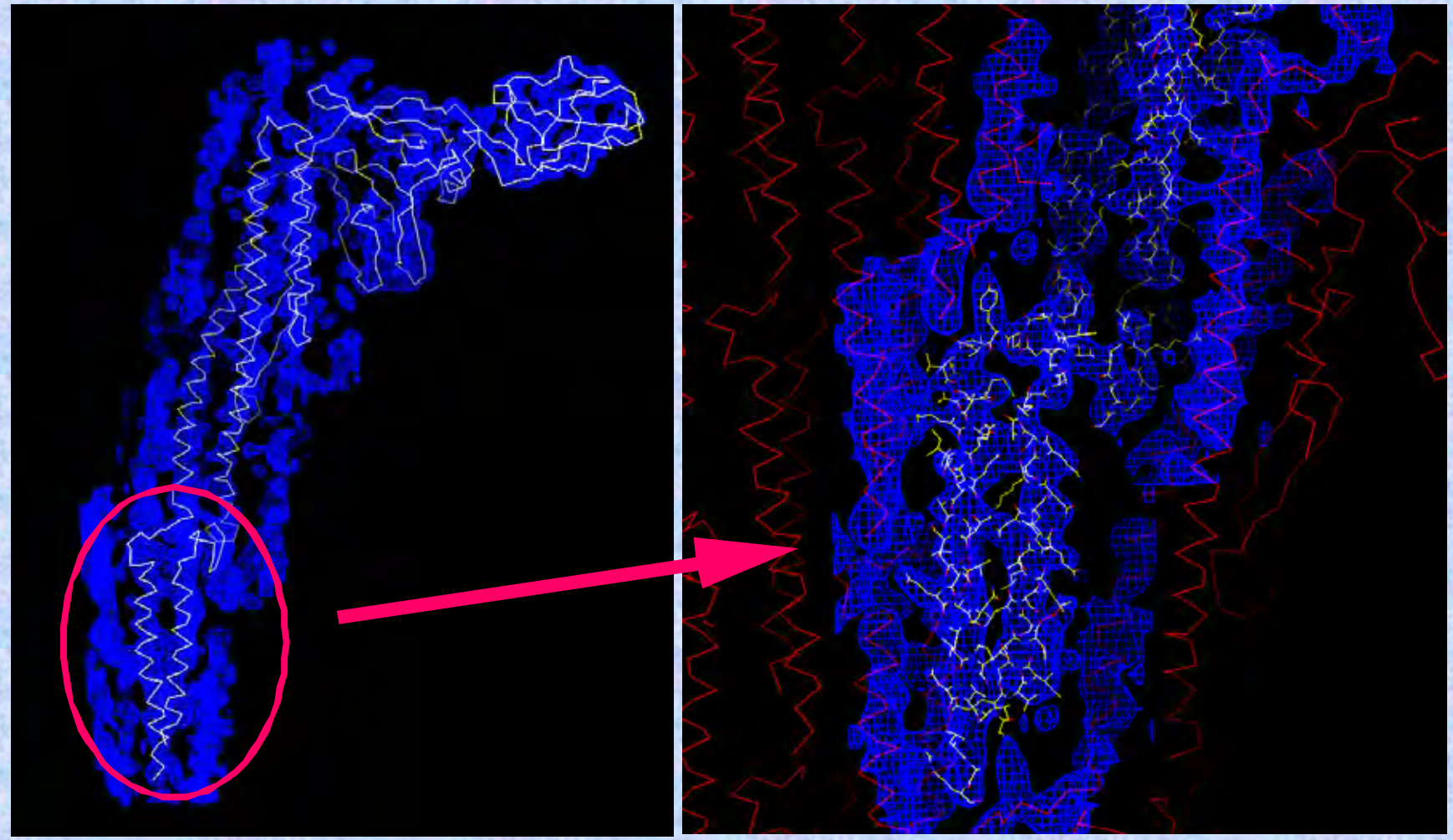
Image of a single filament and its Fourier transform



Mimori *et al*. (1995) *J. Mol. Biol.*

High-resolution cryoEM map of the filament

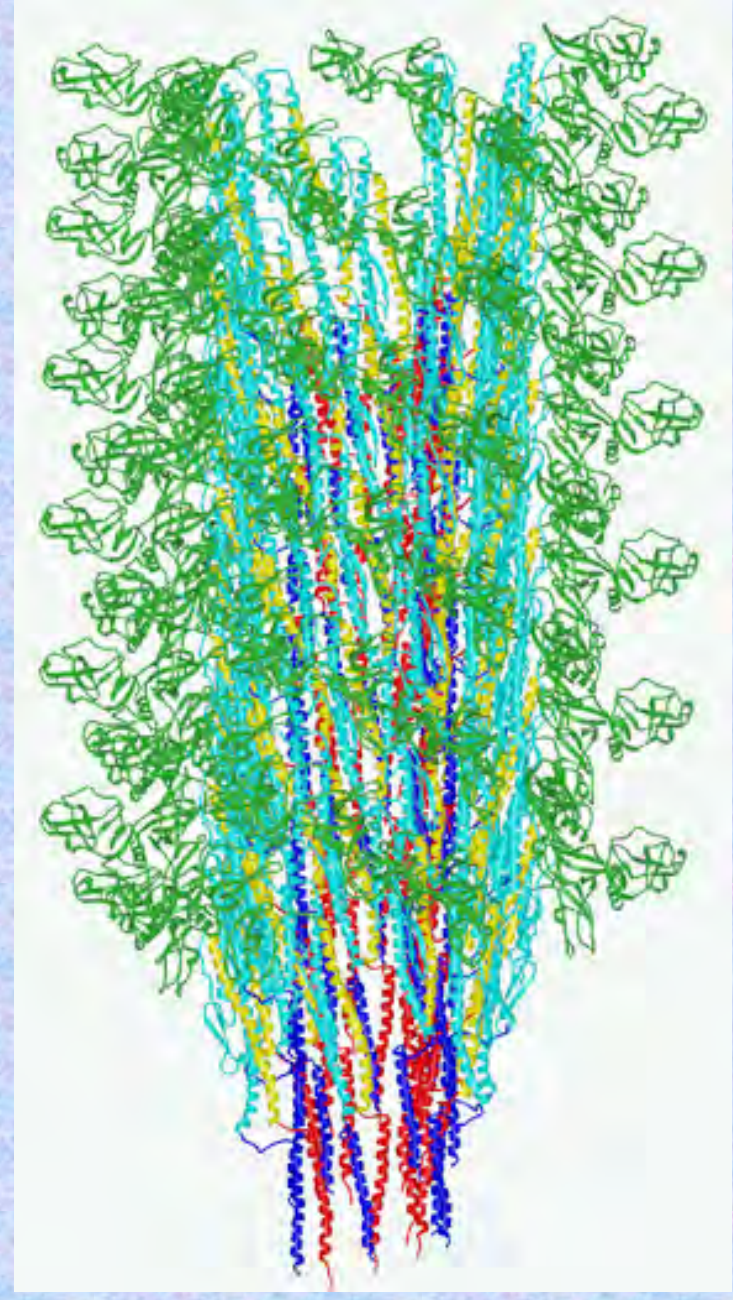
(Resolution: meridional, 4 Å; equatorial, 5 Å)



Average of 100 filament images (~ 41,000 molecules)
with unbending and solvent flattening refinement

Yonekura & Maki-Yonekura *et al.* (2003) *Nature*

Complete atomic model of the flagellar filament



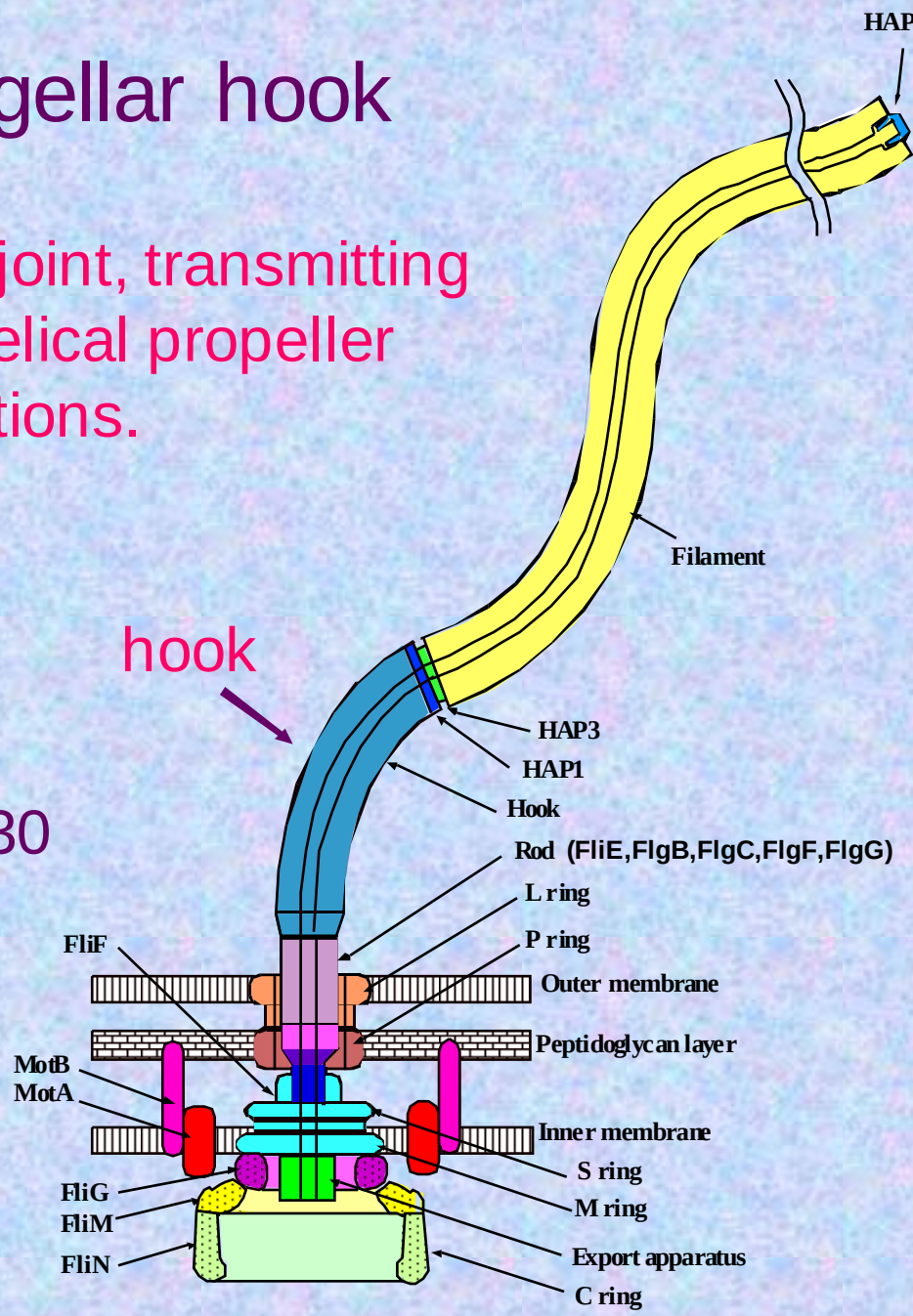
Yonekura & Maki-Yonekura *et al.* (2003) *Nature*

Structure of the hook for universal joint mechanism

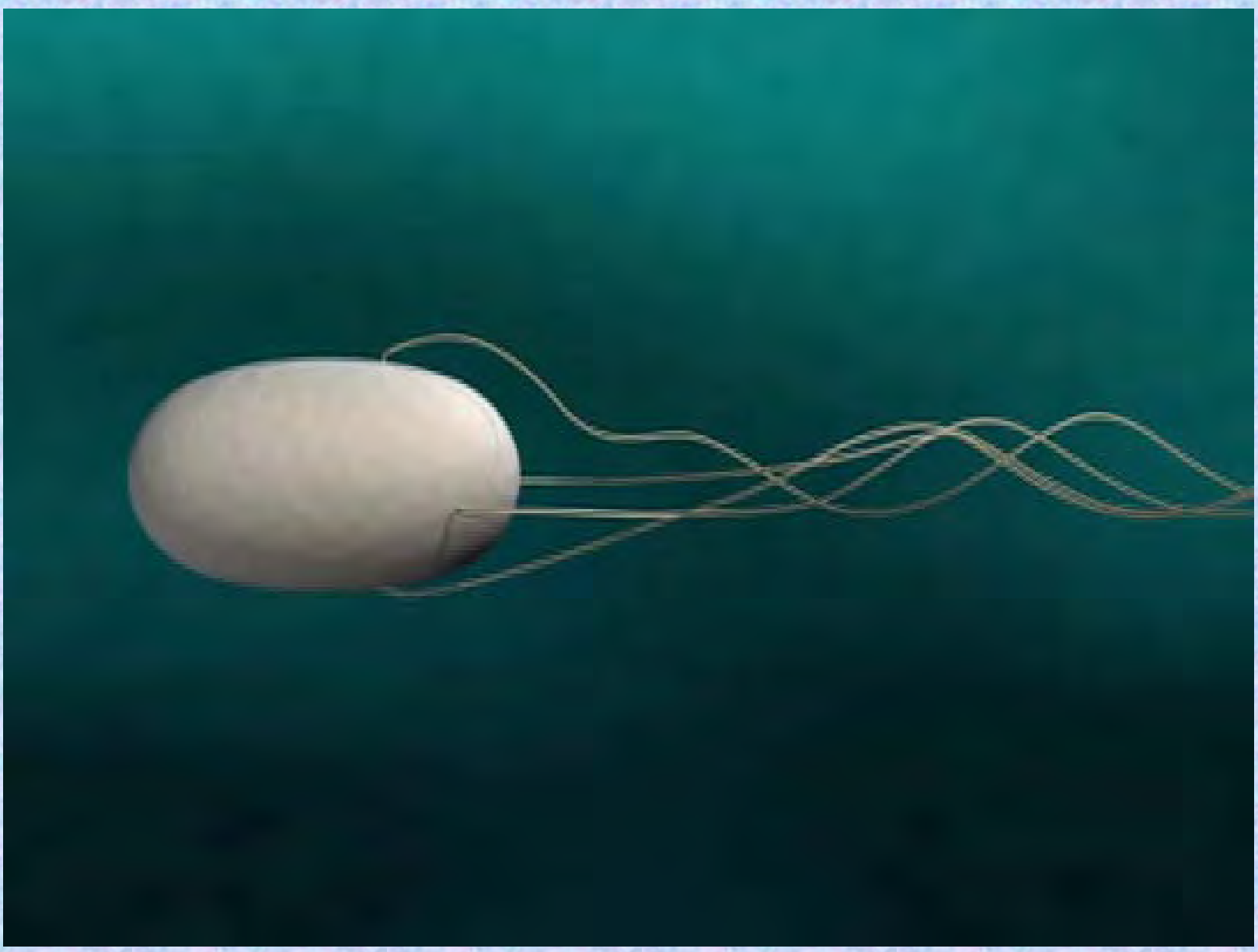
The flagellar hook

Functions as a universal joint, transmitting the motor torque to the helical propeller oriented in different directions.

Length: 55 nm (±6 nm)
Number of subunits: ~130



Flagellar hook working as a universal joint



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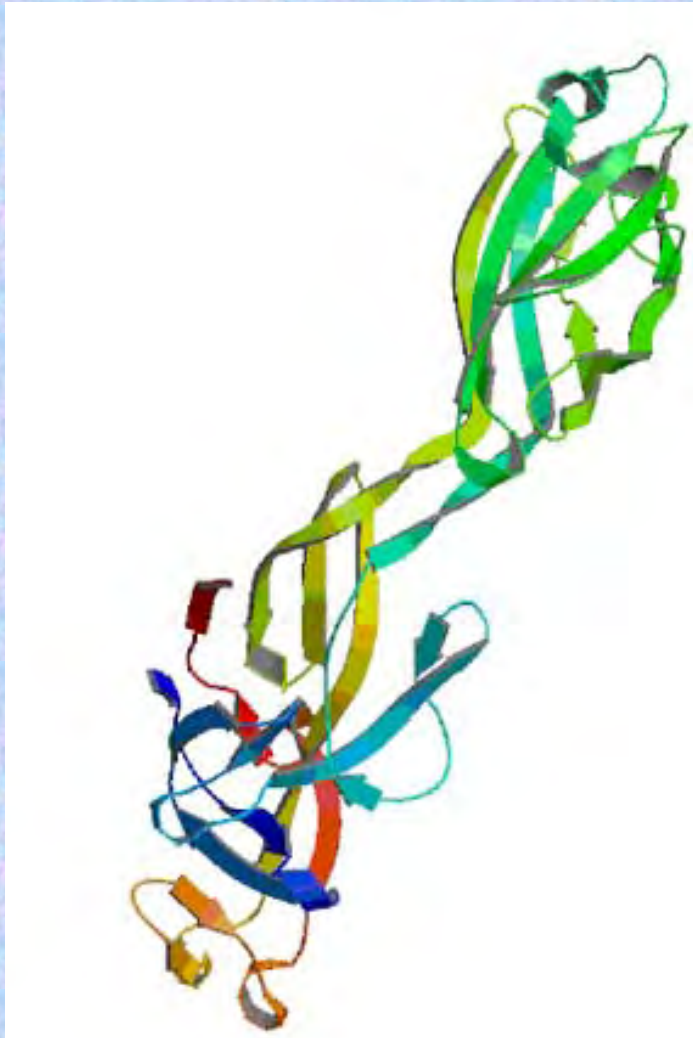
Run and Tumble

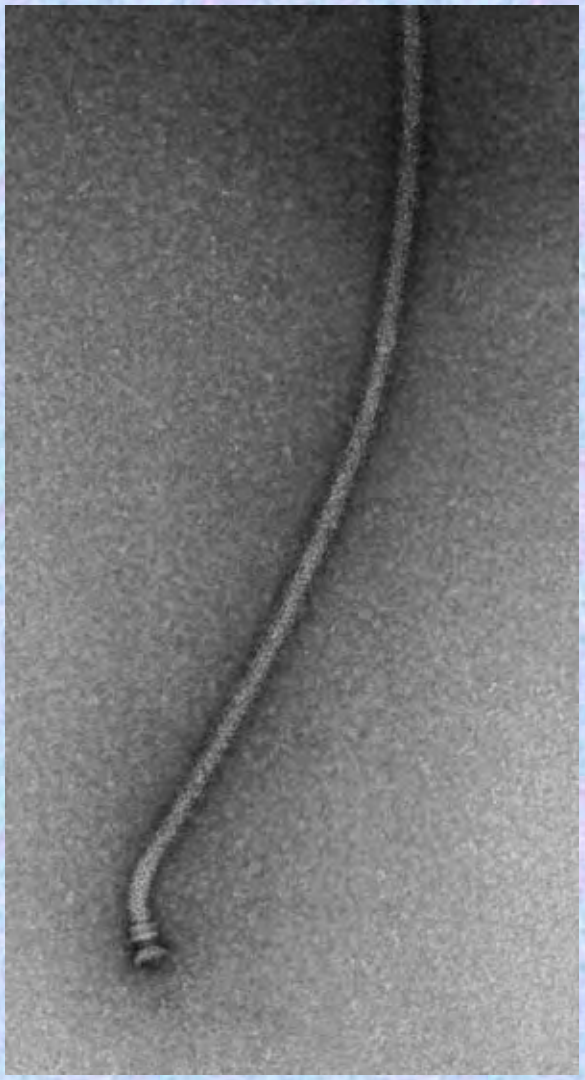
Protonic NanoMachine

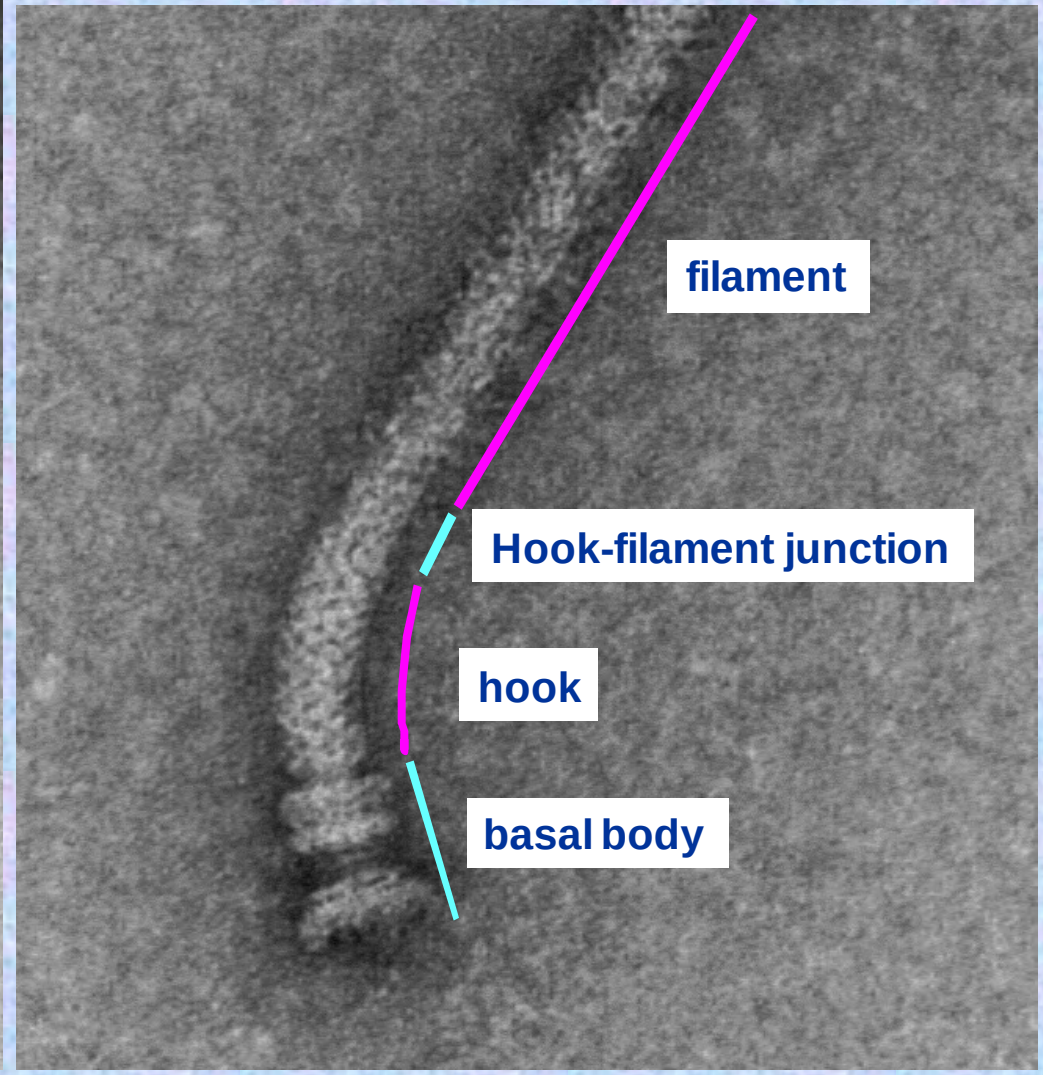
Cα Backbone of FlgE-32



Samatey, Matsunami, Imada *et al*. (2004)
Nature

Bacterial flagellum (Basal body-Hook-Filament)

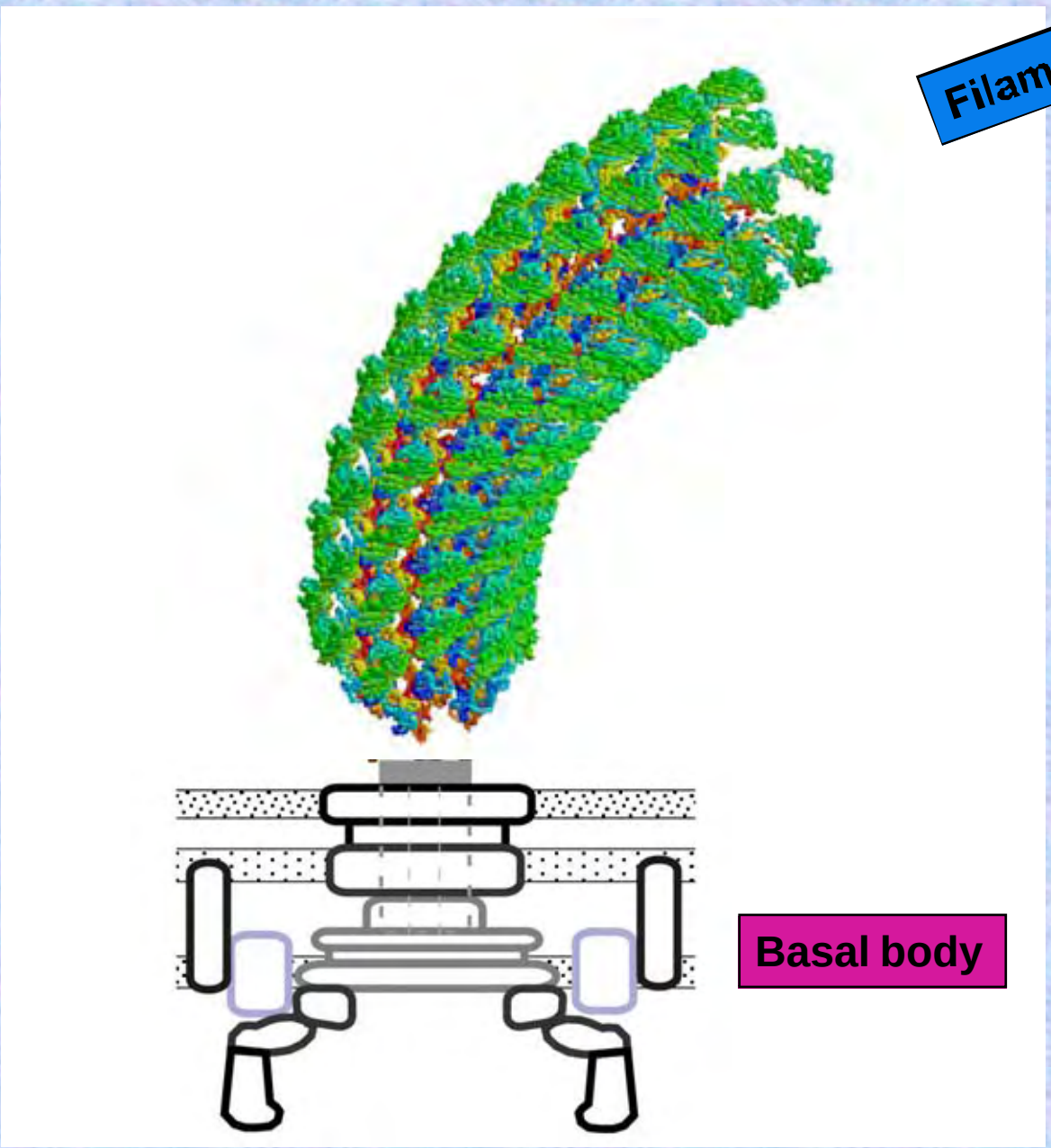




By Nao Moriya

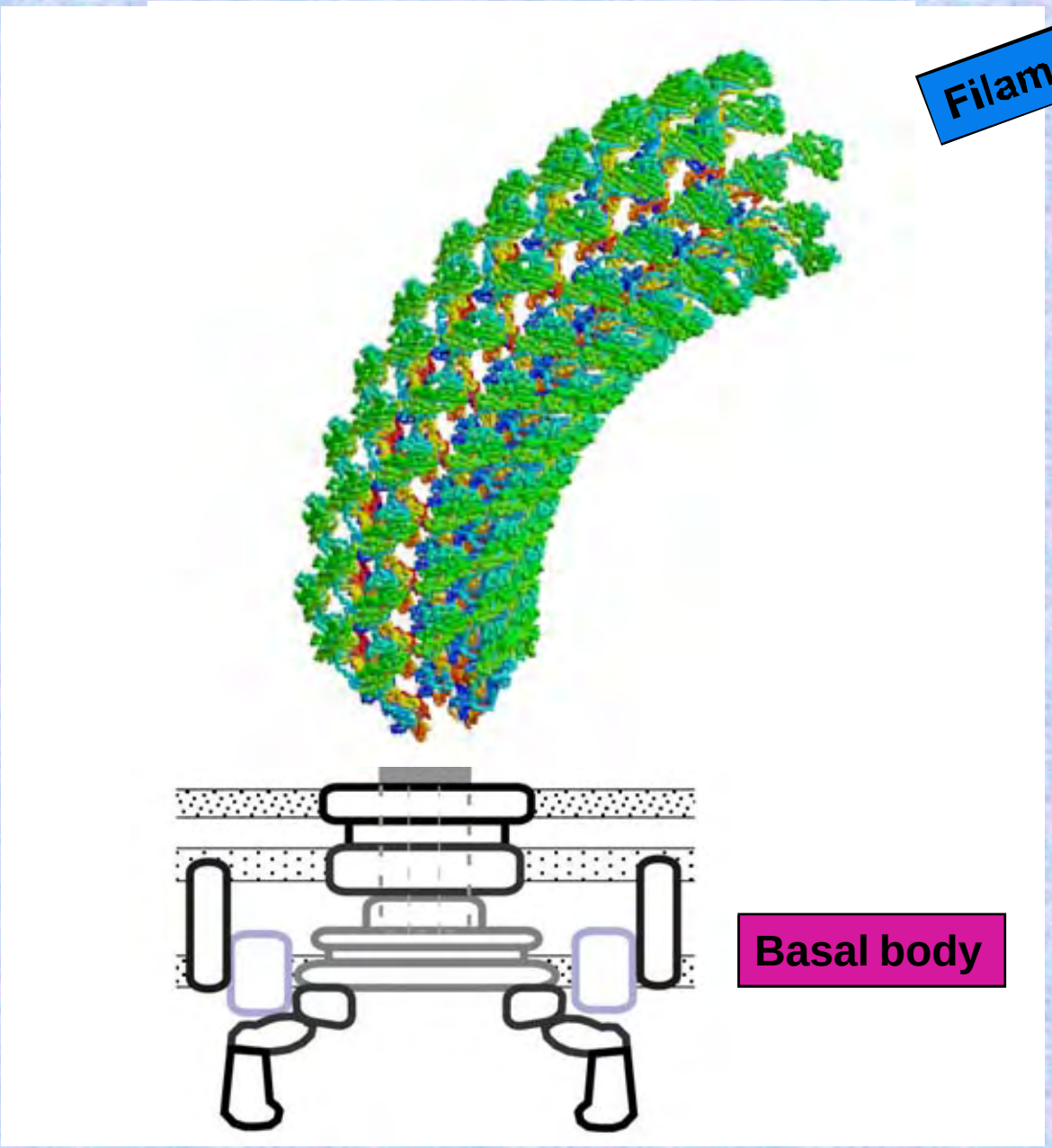
Protonic NanoMachine

Universal joint motion of the flagellar hook



Protonic NanoMachine

Universal joint motion of the flagellar hook



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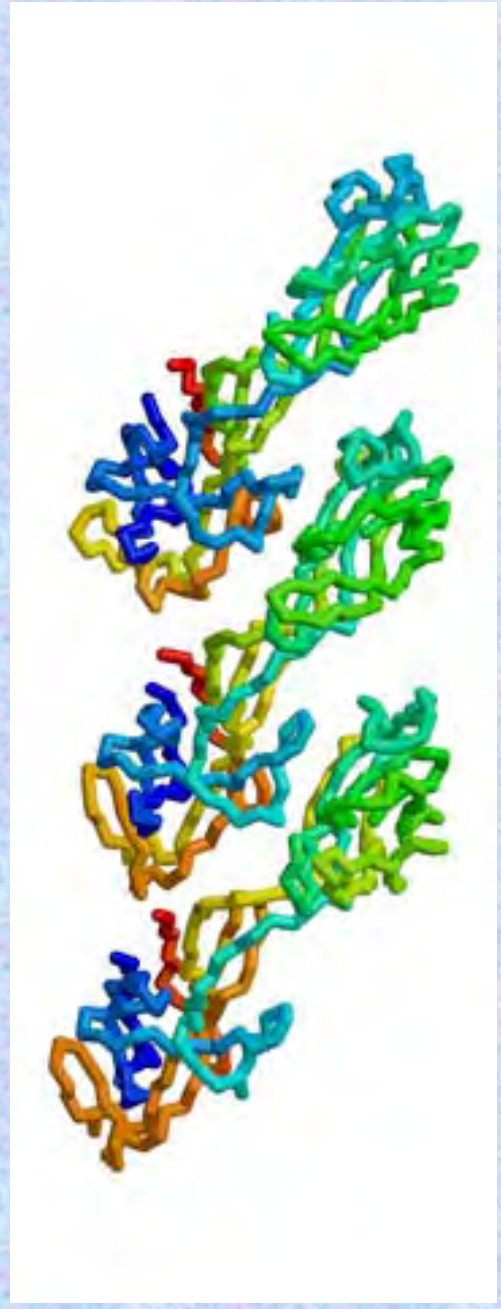
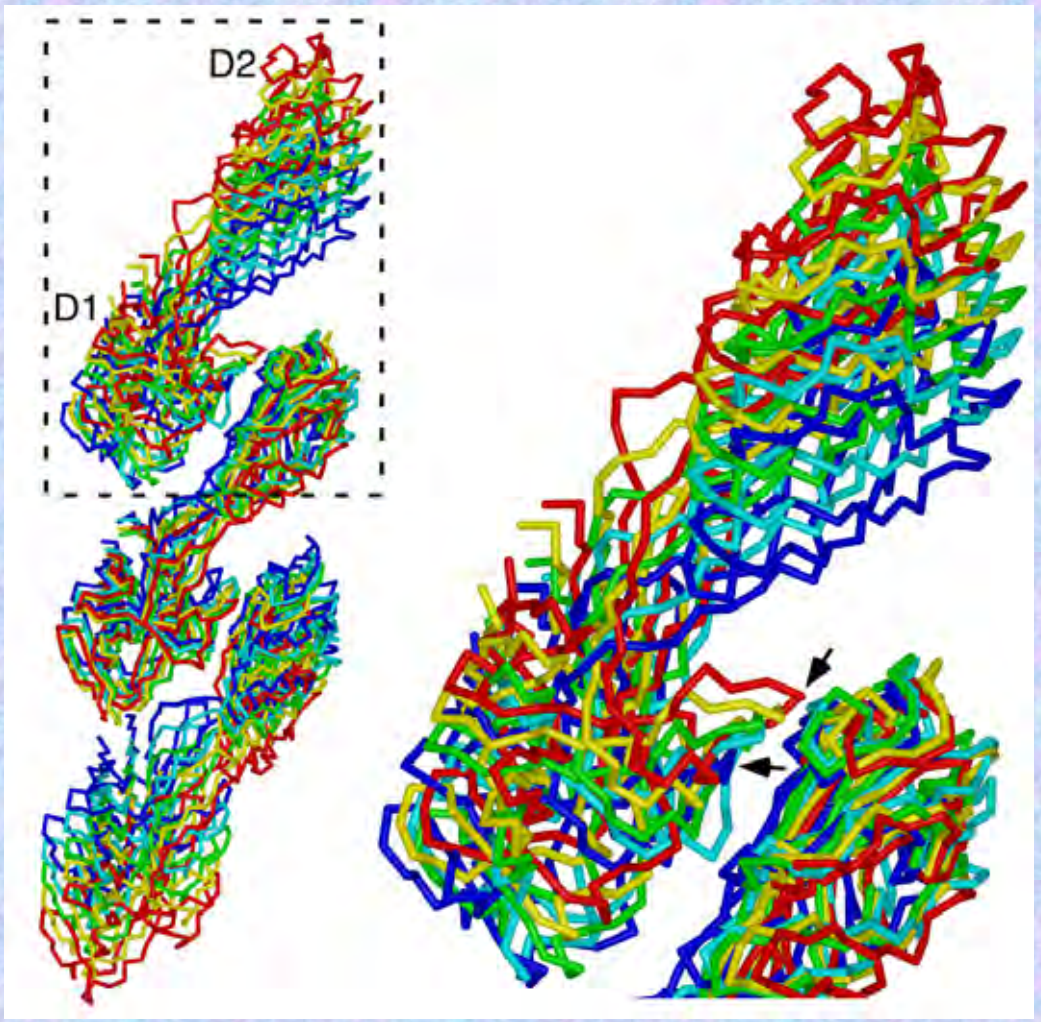
Simulated extension of a hook protofilament model

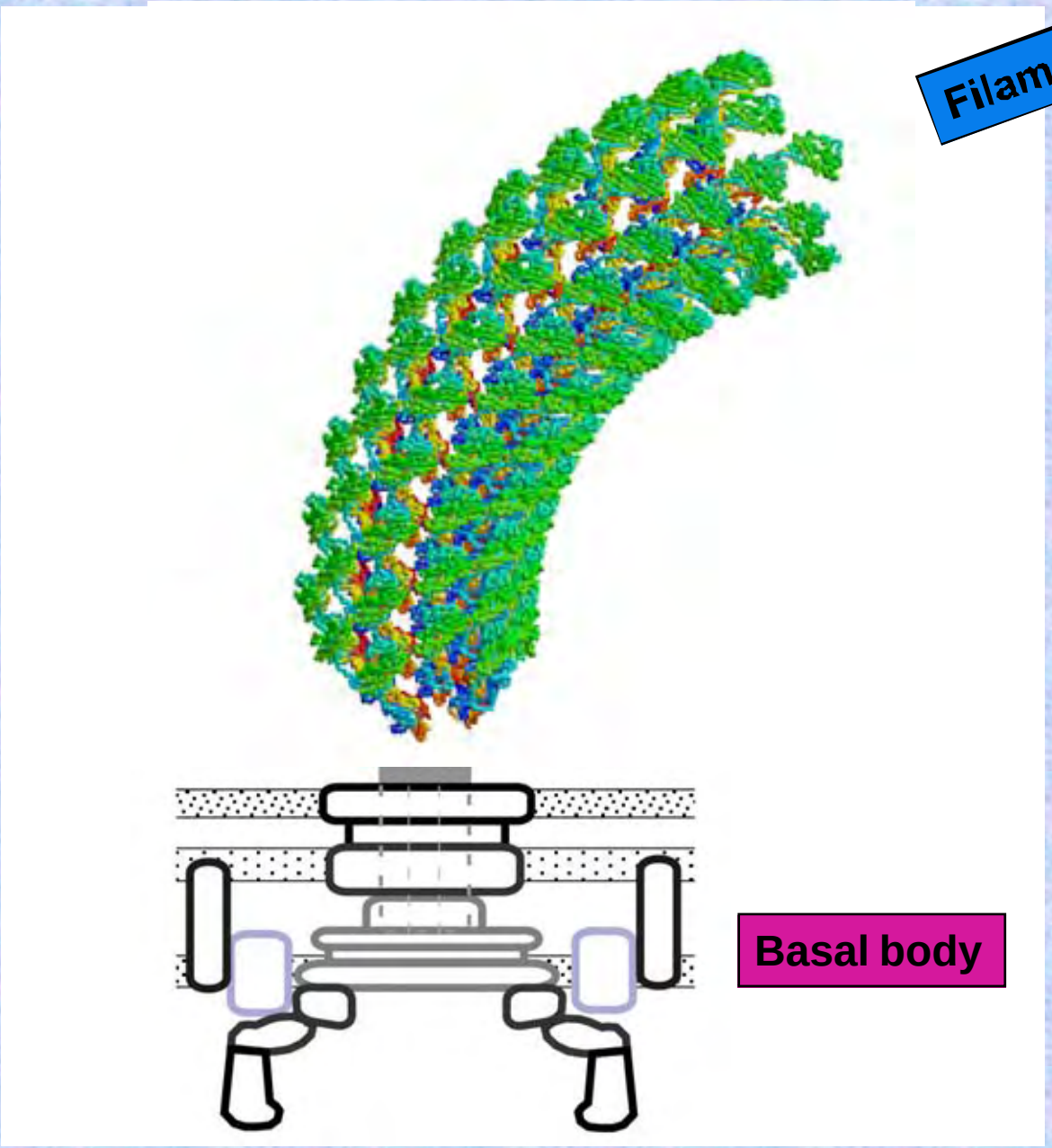




Molecular dynamic simulation of hook protofilament extension by Akio Kitao

Samatey, Matsunami, Imada *et al*. (2004) *Nature*

Universal joint motion of the flagellar hook



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Self-assembly of the flagellum

The assembly process of the bacterial flagellum

(update 2002)

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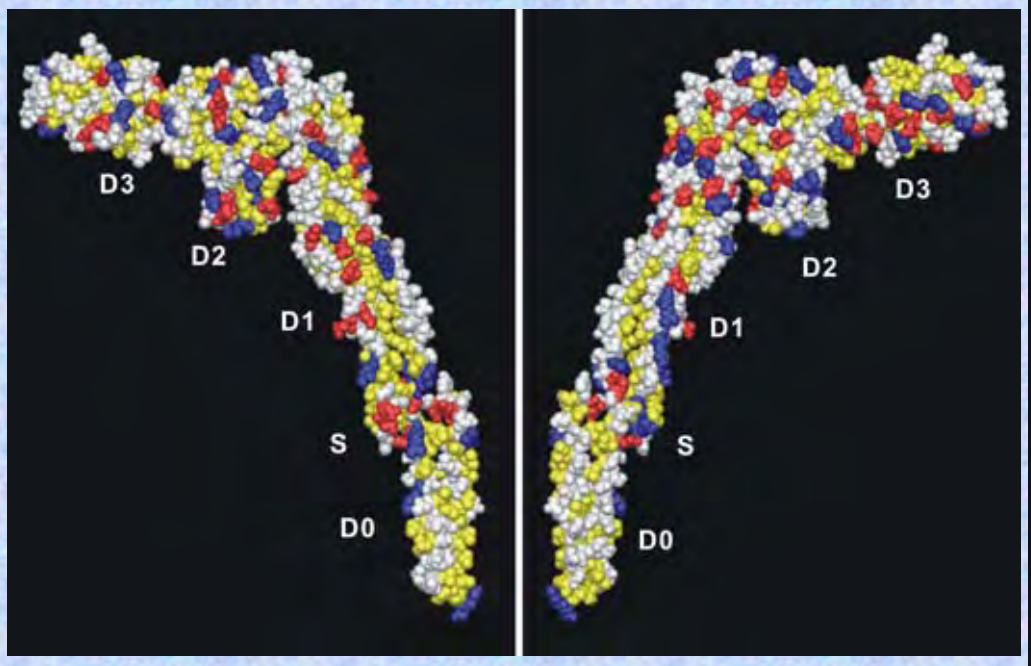
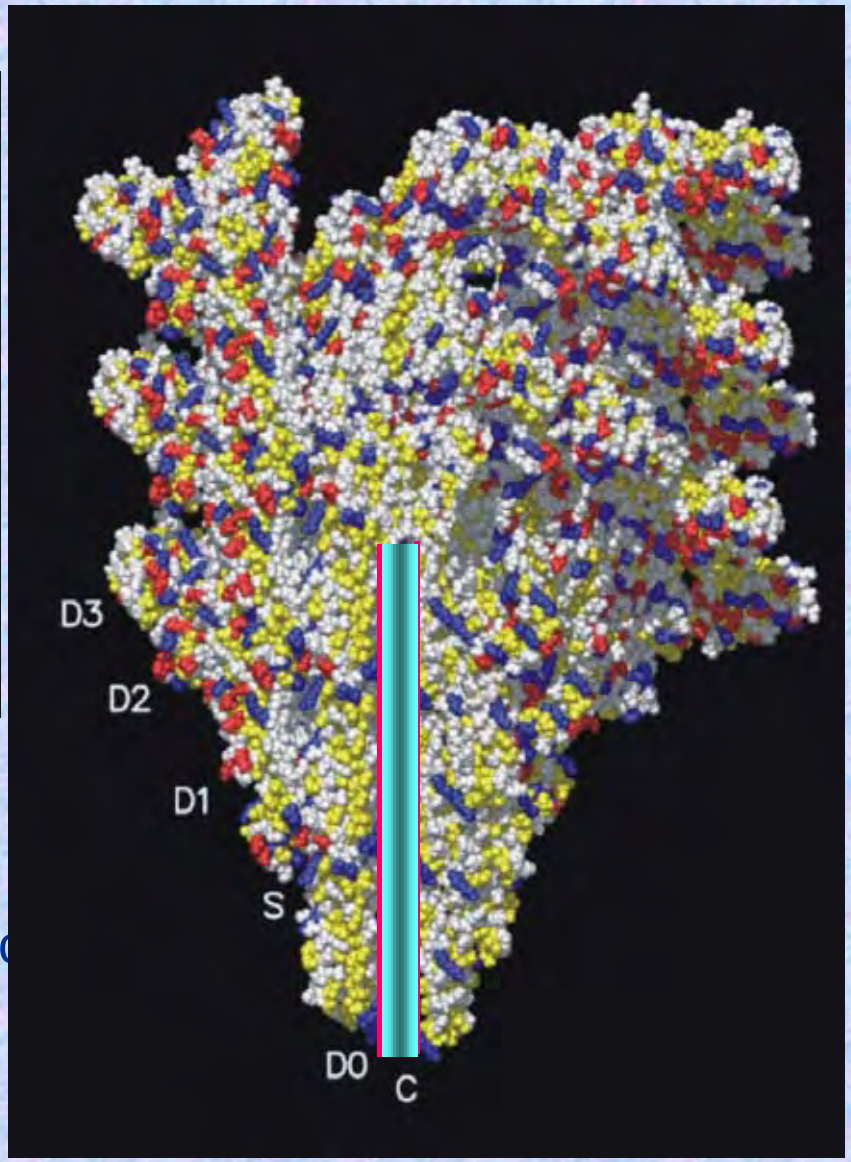
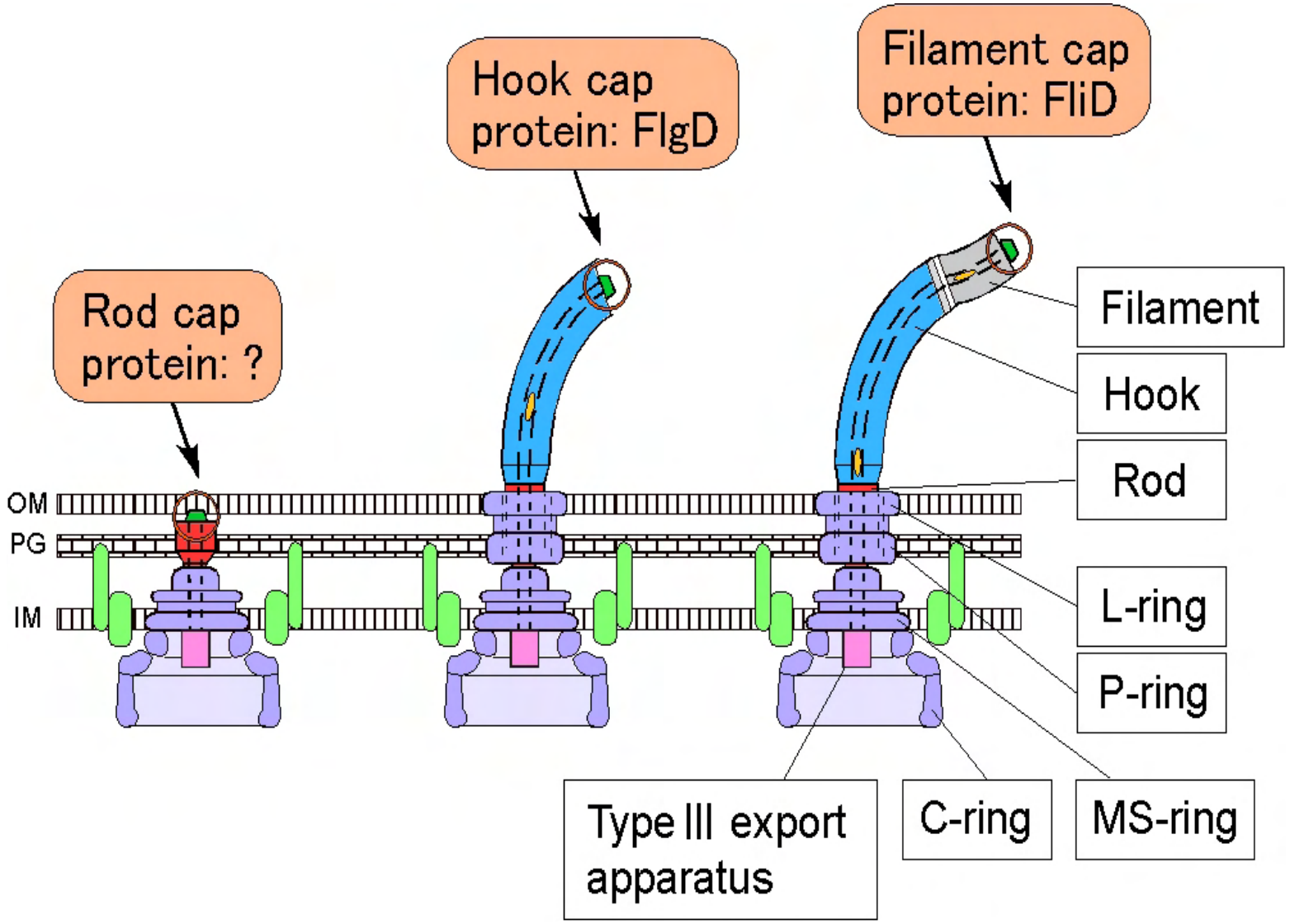
Nature of lateral intersubnit interactions in the filament and inner surface of the central channel



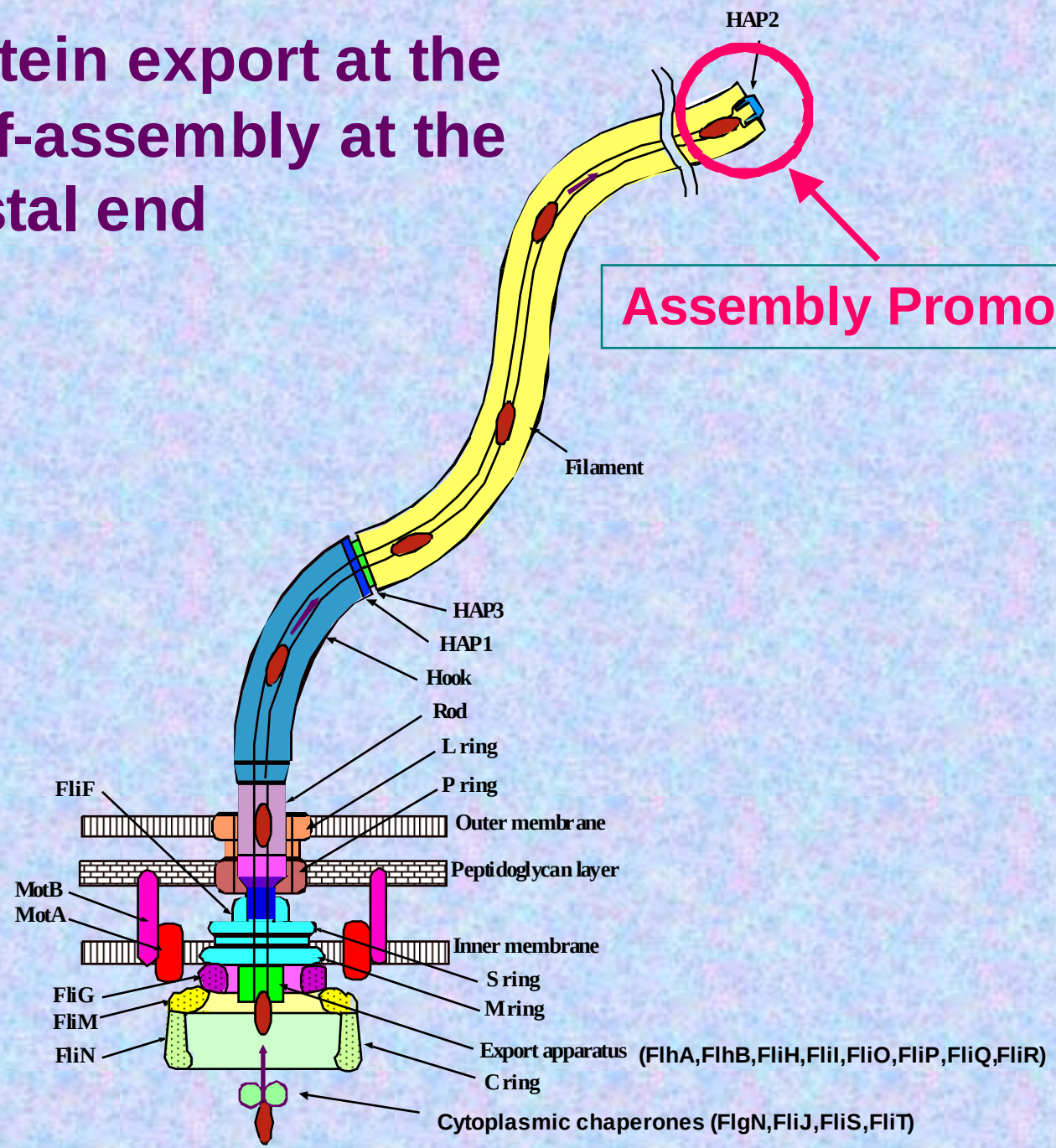


* D1-D1: hydrophilic
* D0-D0: hydrophobic
* Surface of the central channel: hydrophilic
  (Inner diameter of the channel: 20 Å)

Three caps for flagellar assembly

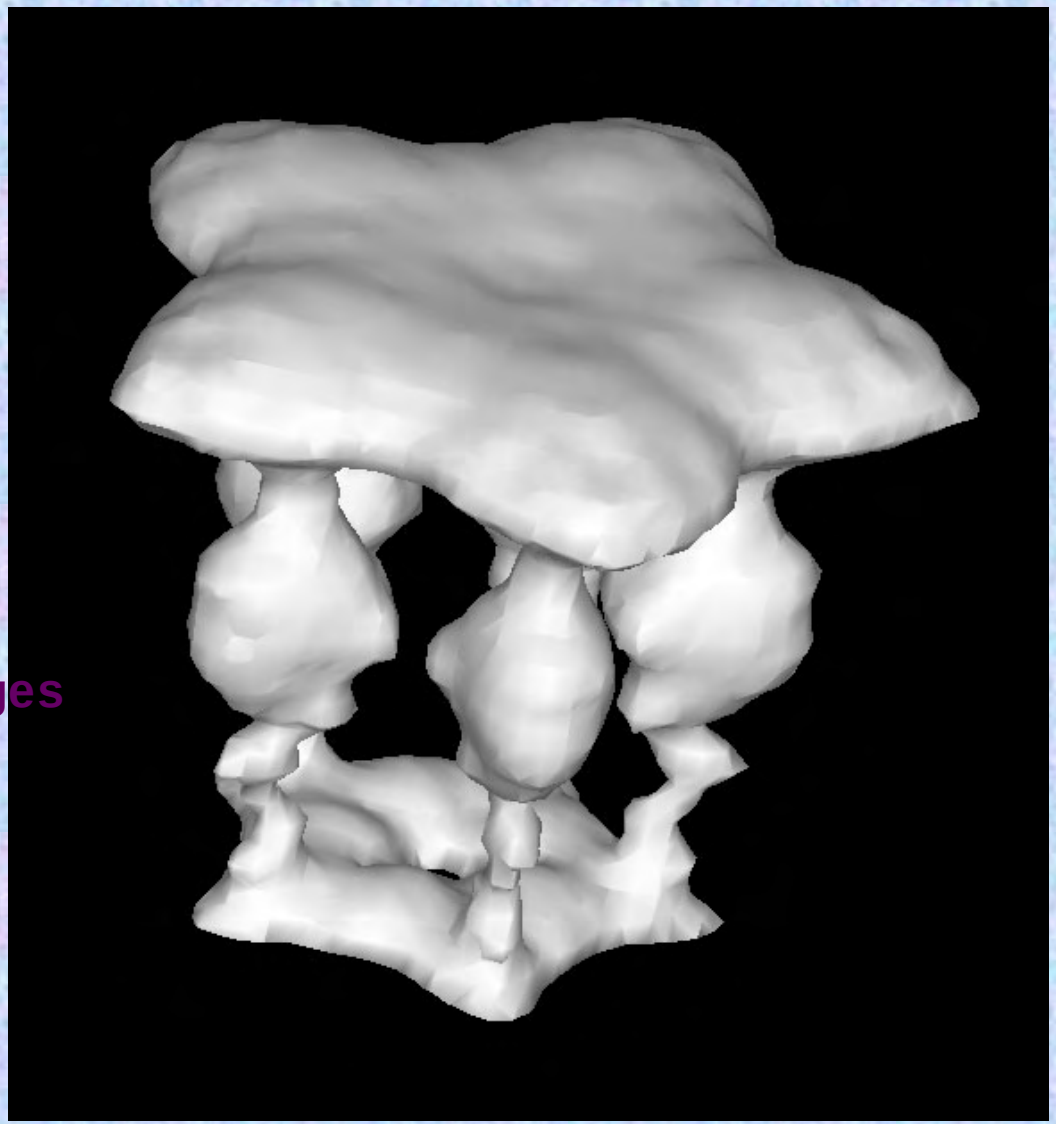


Flagellar protein export at the base and self-assembly at the distal end



3D structure of the HAP2 pentamer cap

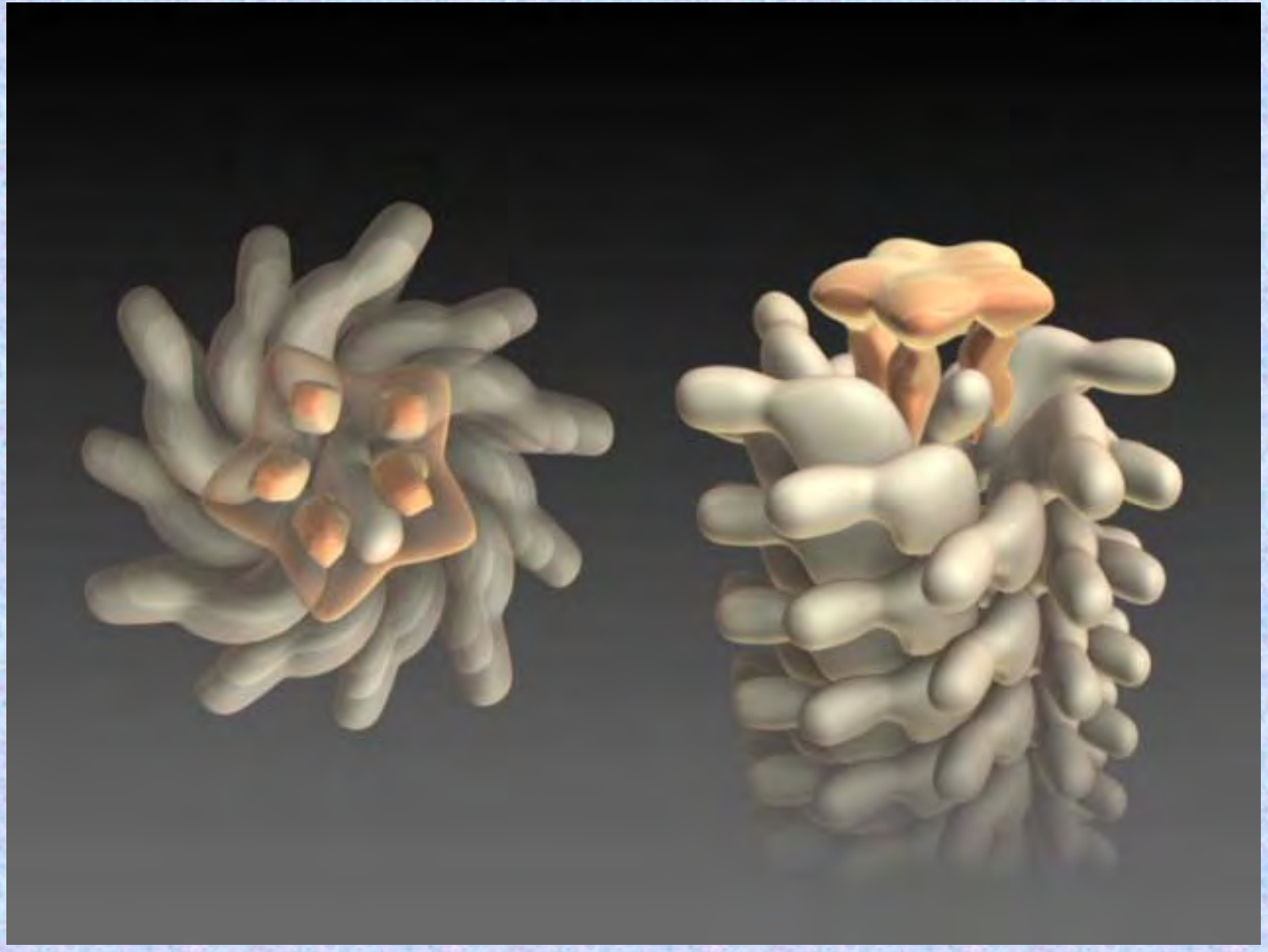
2D average of side-view images



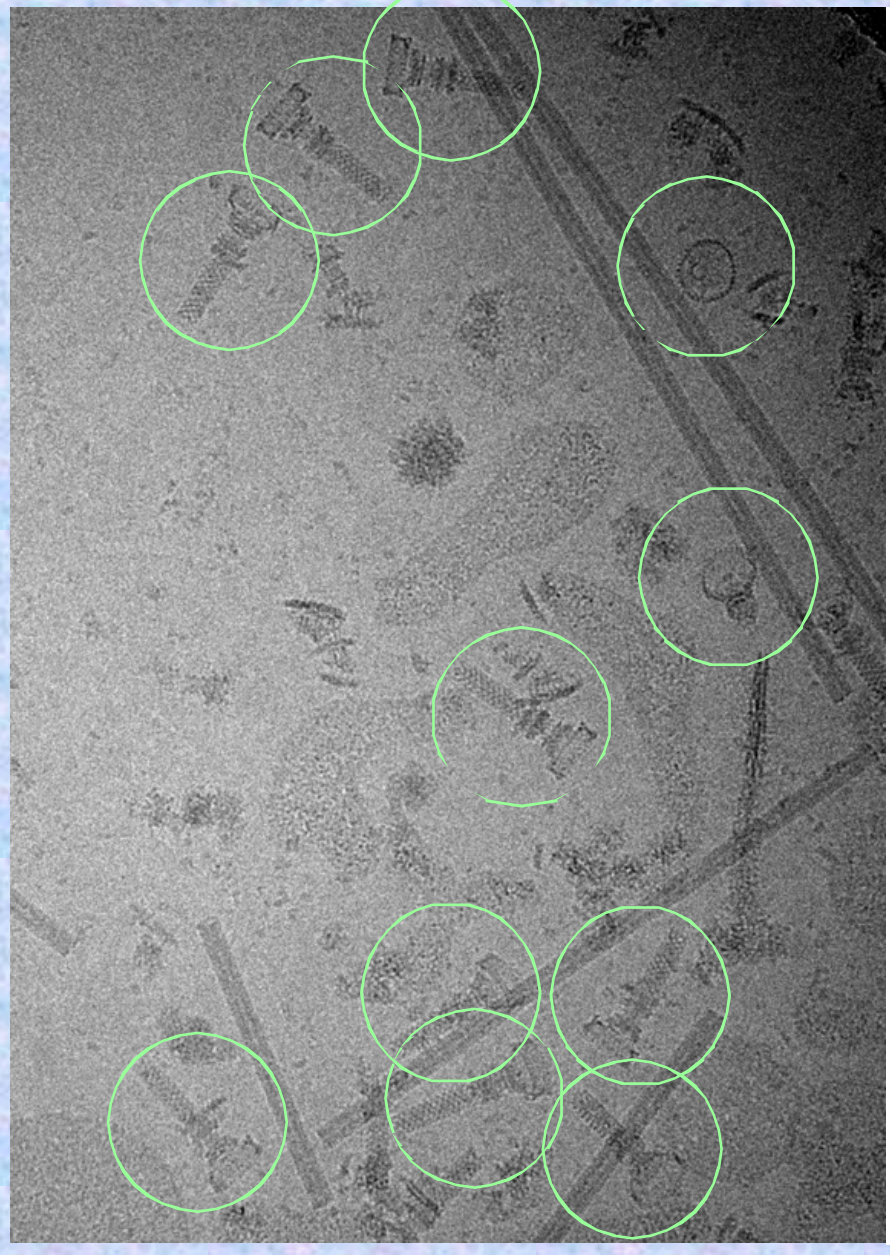
Pentamer cap as one half of the HAP2 decamer

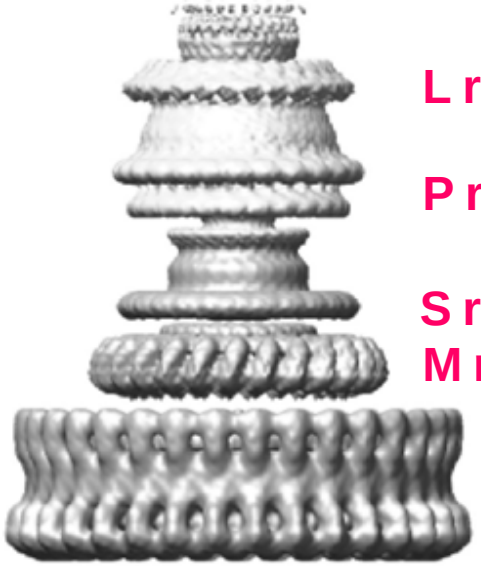
Maki-Yonekura & Yonekura *et al.* (2003) *P.N.A.S.*

Rotary mechanism of the flagellar cap promoting the self-assembly of flagellin



Single particle cryoEM image analysis of the basal body





L ring

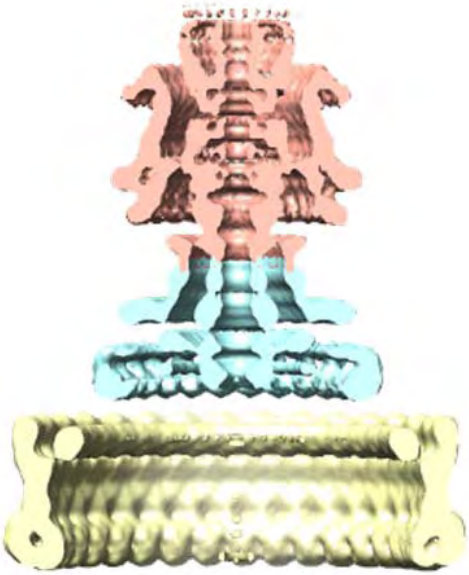
P ring

S ring

M ring

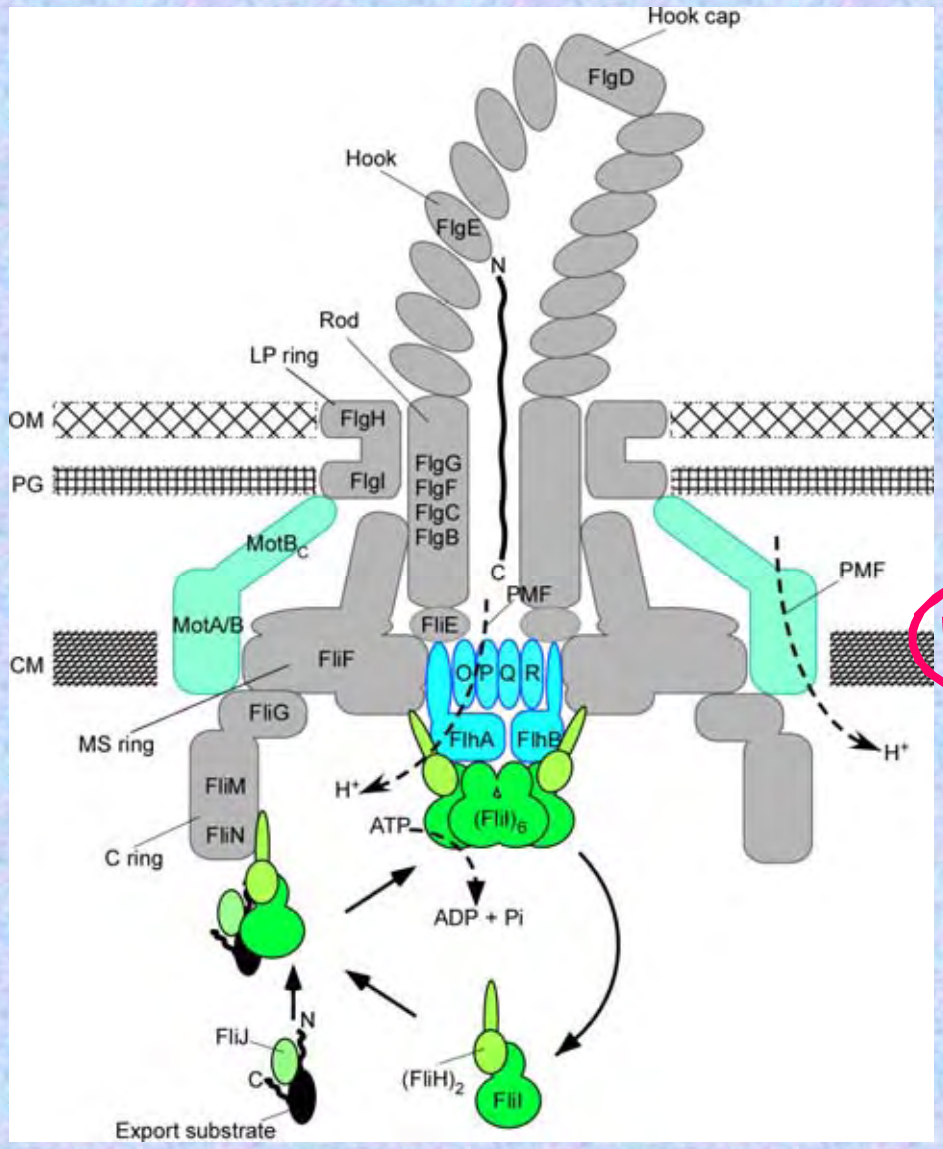
C ring

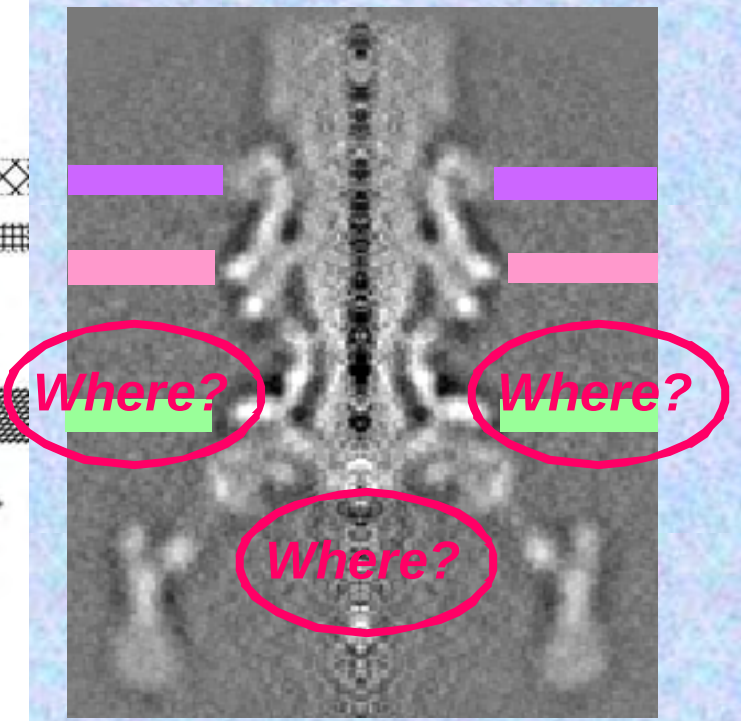
100 Å



Miyata & Kato *unpublished*

Structural information of important part still largely missing





Protonic NanoMachine

Lab members

April 5, 2007 at EXPO Park

Protonic NanoMachine Project, ERATO, JST (1997-2002)
Dynamic NanoMachine Project, ICORP, JST (2002-2007)