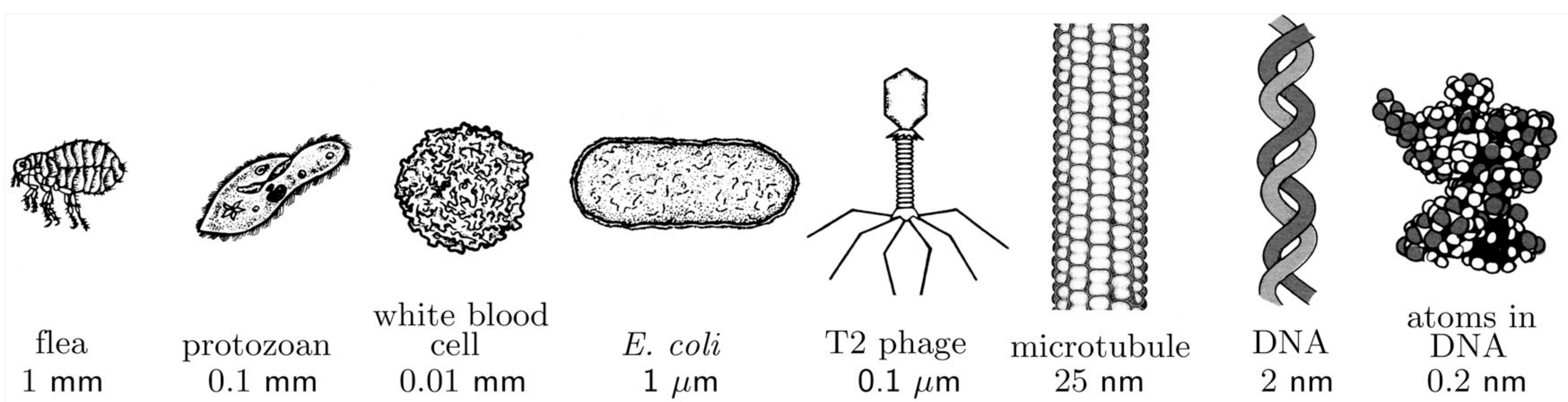
Programmable DNA-Based Nanosystems

William Shih

Thursday, 2011 March 3



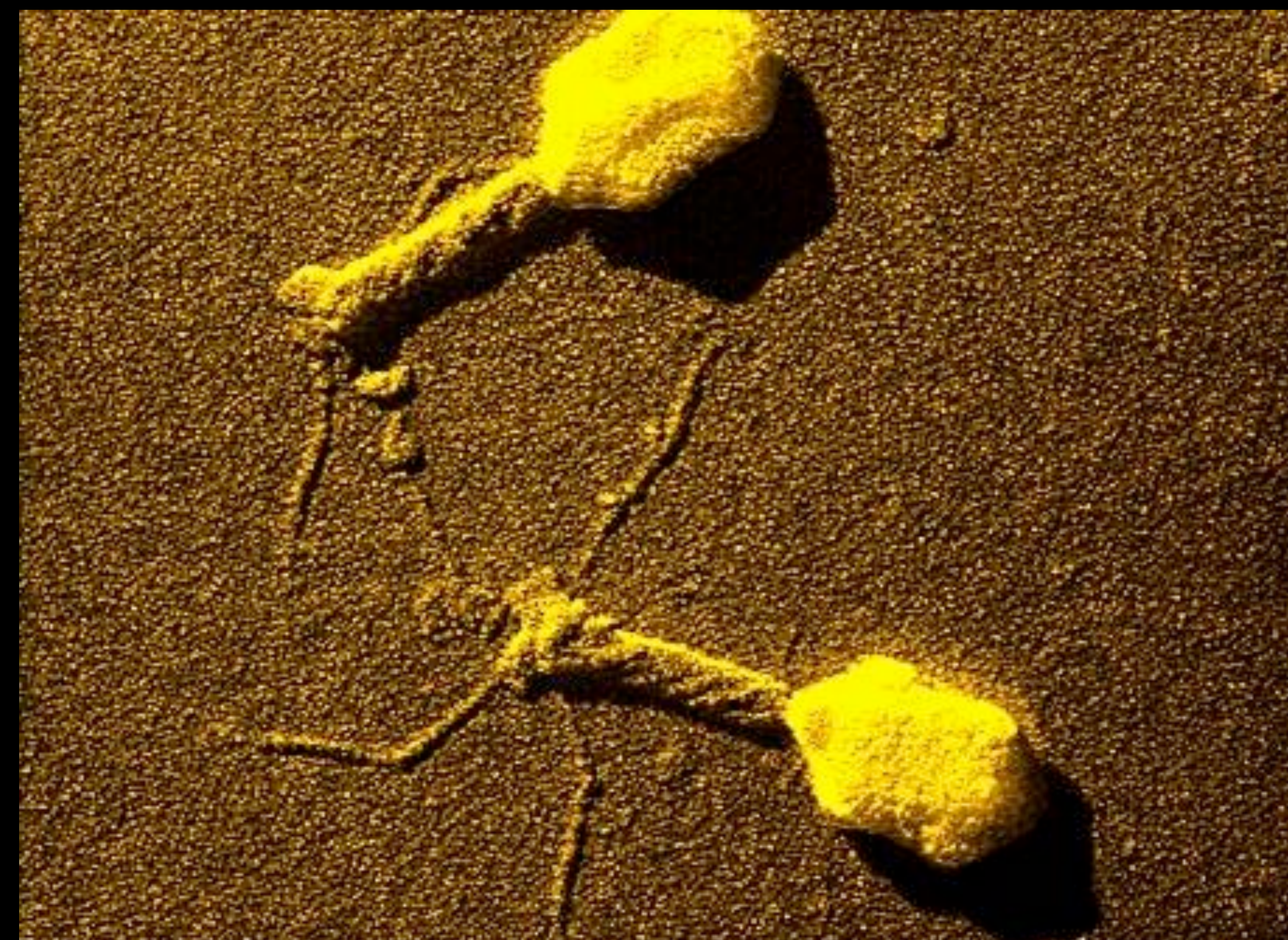
Living Systems exhibit extraordinary capabilities . . .

BUILD HEAL

ADAPT REPRODUCE

10 nanometers

100 nanometers



made possible by Molecular Manufacturing

Biopolymer Machines

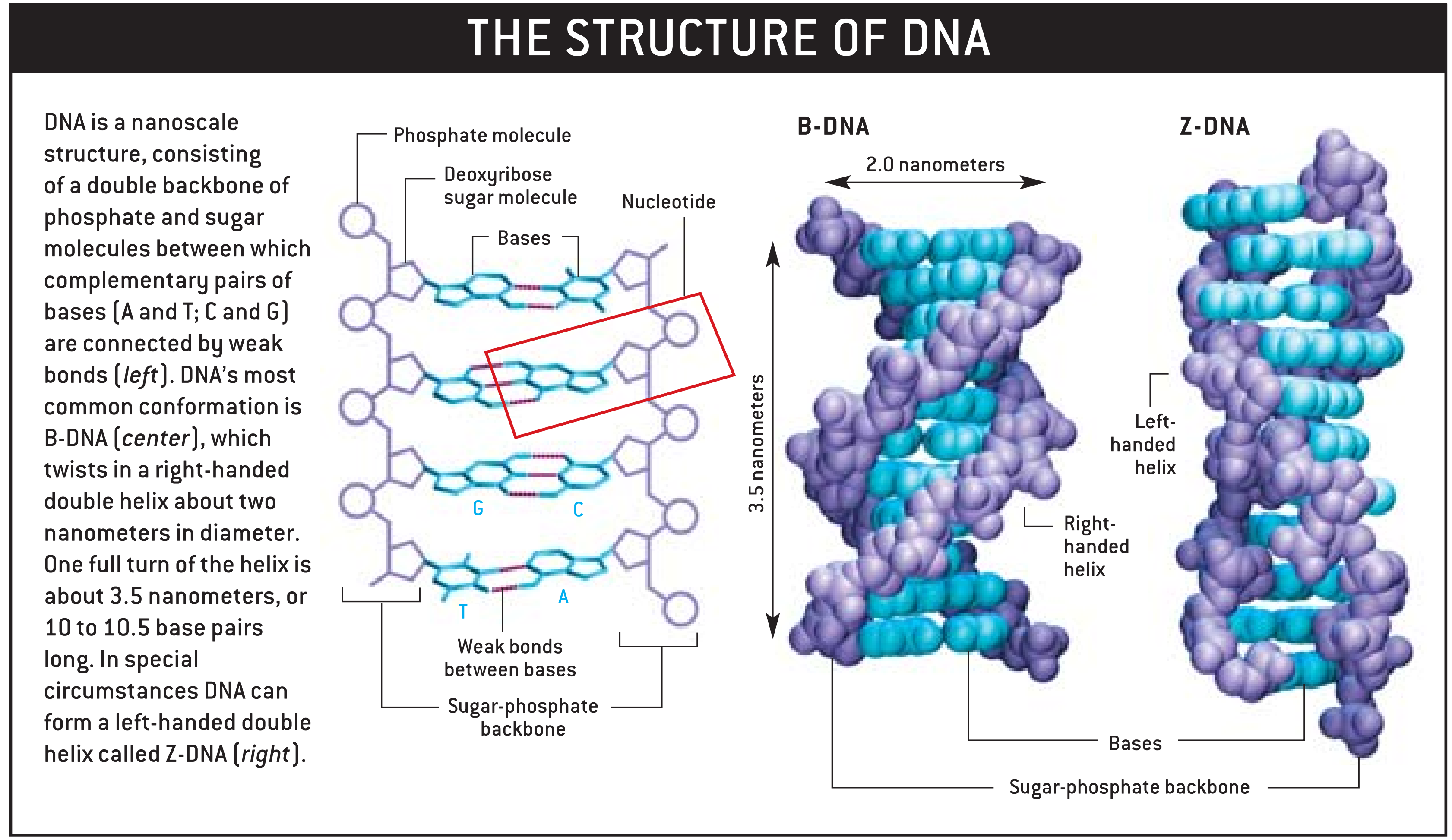
Synthetic Biology of Parts: Goals

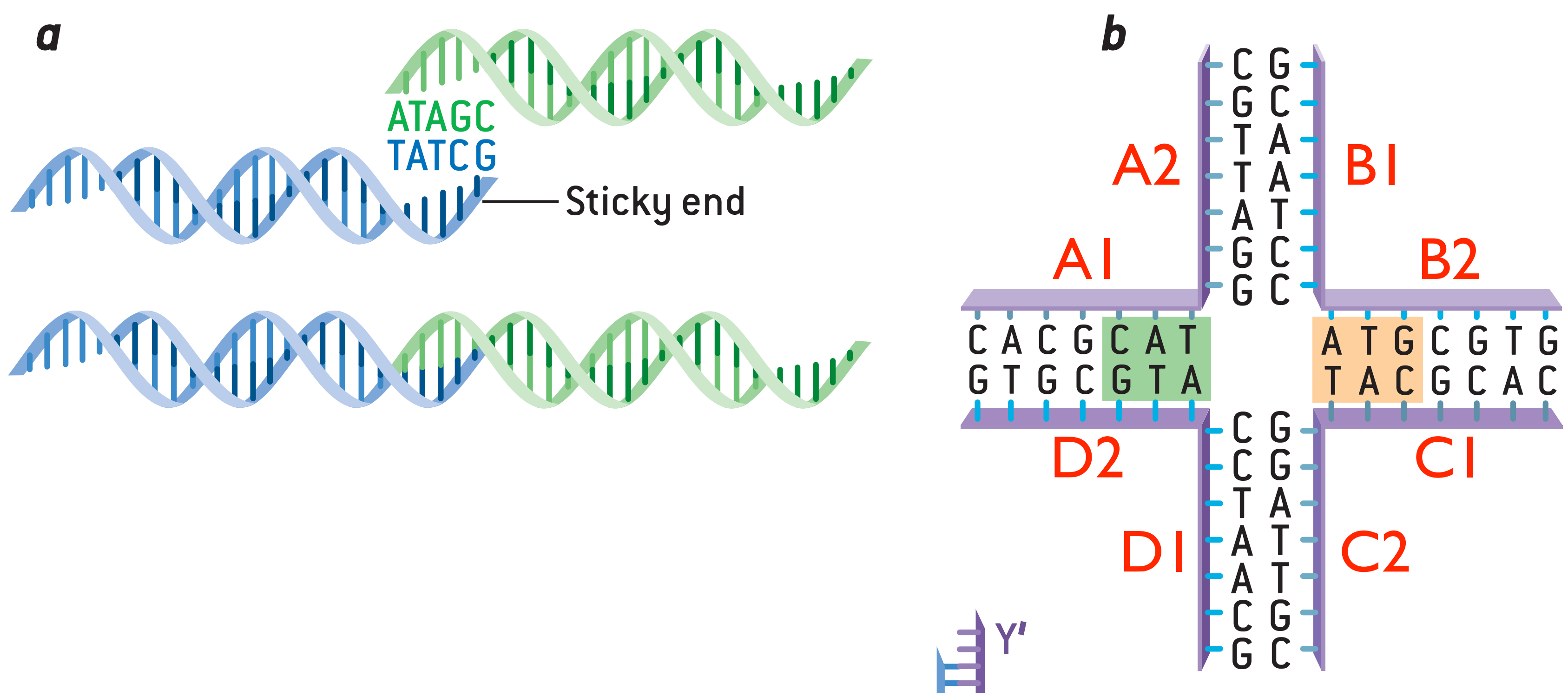
Understand how to build with atomic precision on increasing length scales (to 100 nm and beyond)

Understand how to build sophisticated molecular devices that rival those from Nature

Construct and deploy useful said devices
e.g. tools for biophysics, diagnostics, therapeutics
communication, computing, energy, etc.

Ned Seeman, NYU





Seeman NC, *Sci. Am.* 290, 64–75, 2004.

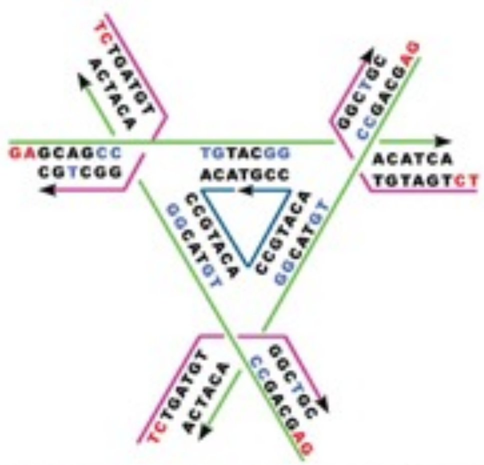
nature Vol 461|3 September 2009|doi:10.1038/nature08274

LETTERS

From molecular to macroscopic via the rational design of a self-assembled 3D DNA crystal

Jianping Zheng[1]*, Jens J. Birktoft[1]*, Yi Chen[2]*, Tong Wang[1], Ruojie Sha[1], Pamela E. Constantinou[1]†, Stephan L. Ginell[3], Chengde Mao[2] & Nadrian C. Seeman[1]

a



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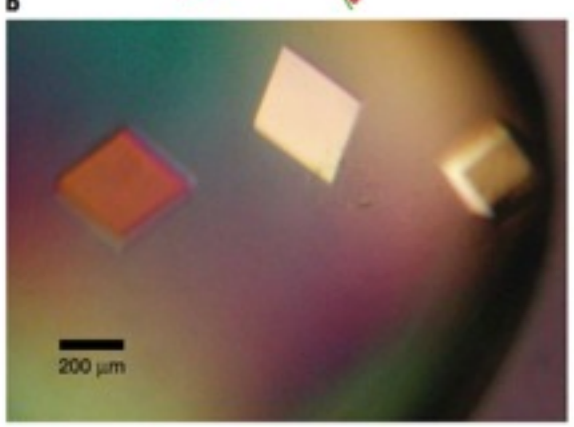
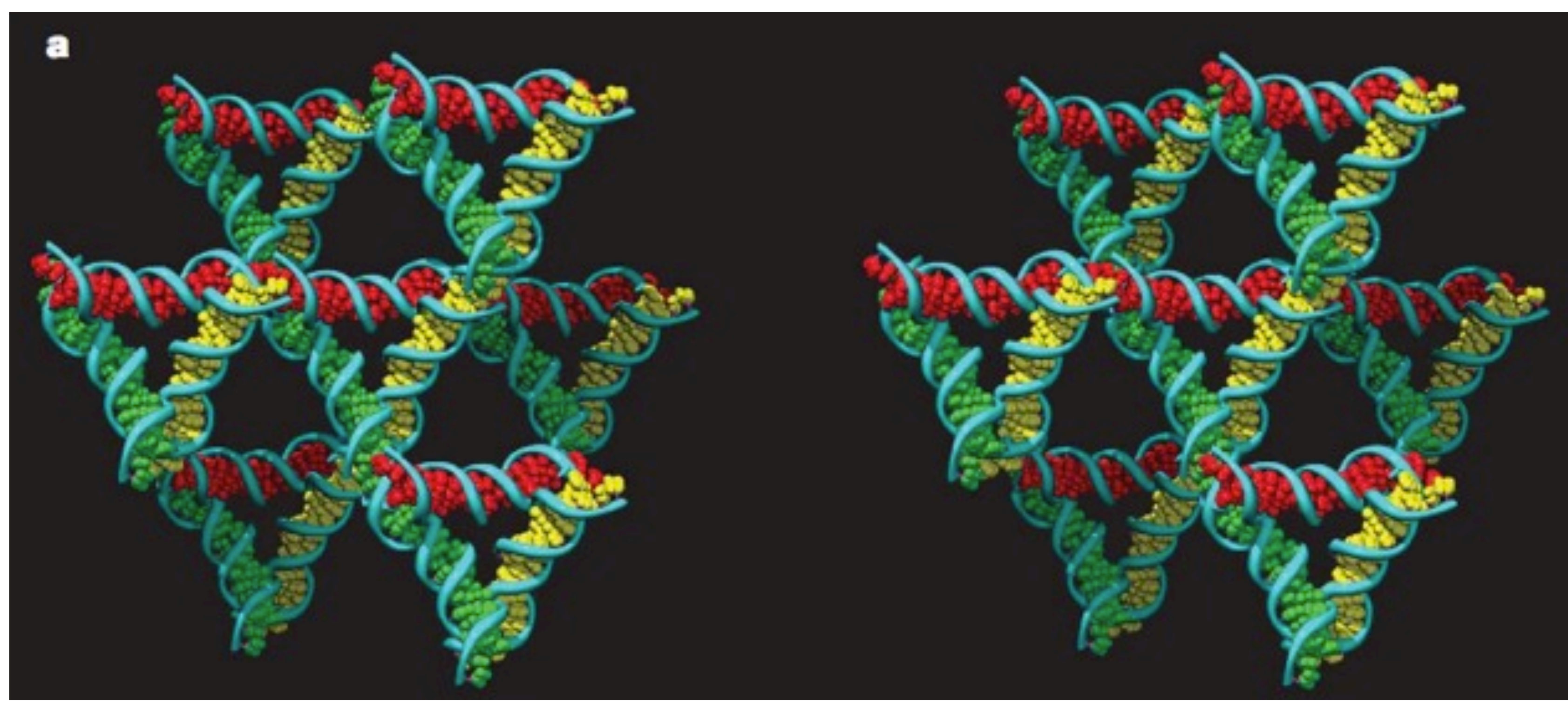
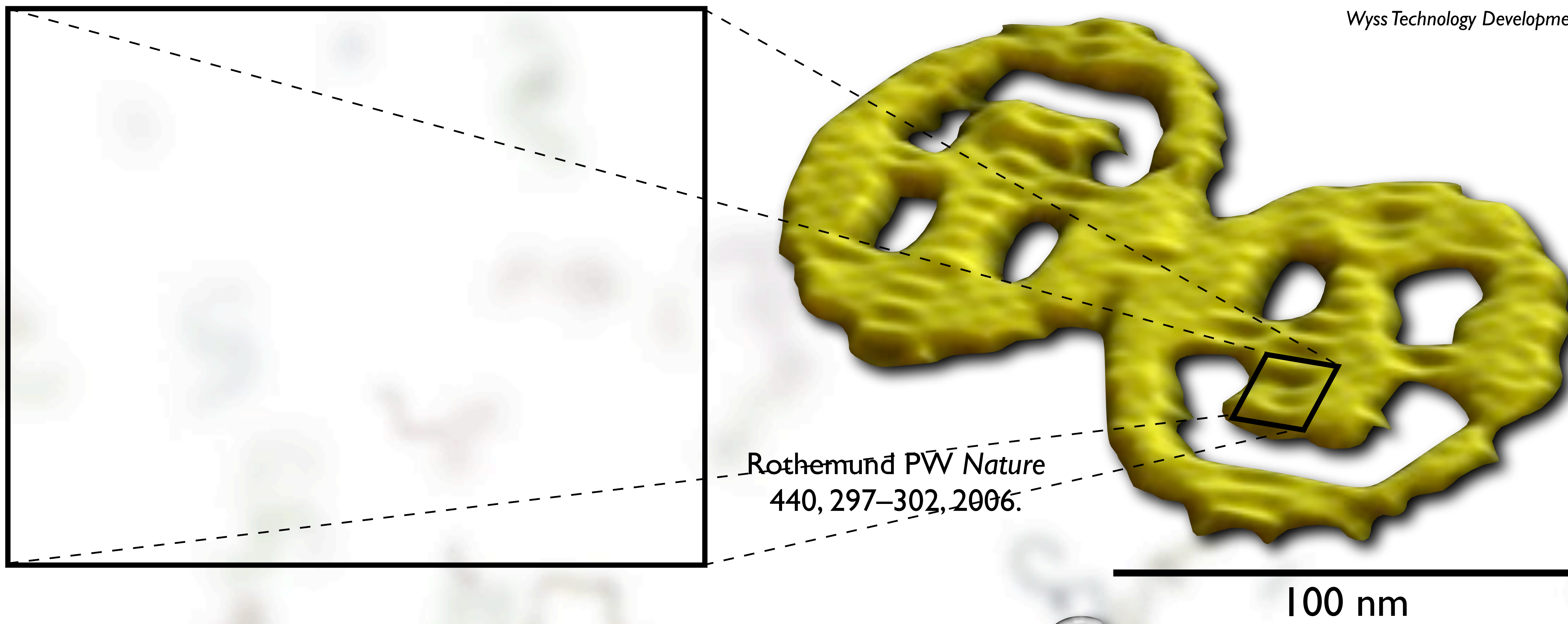
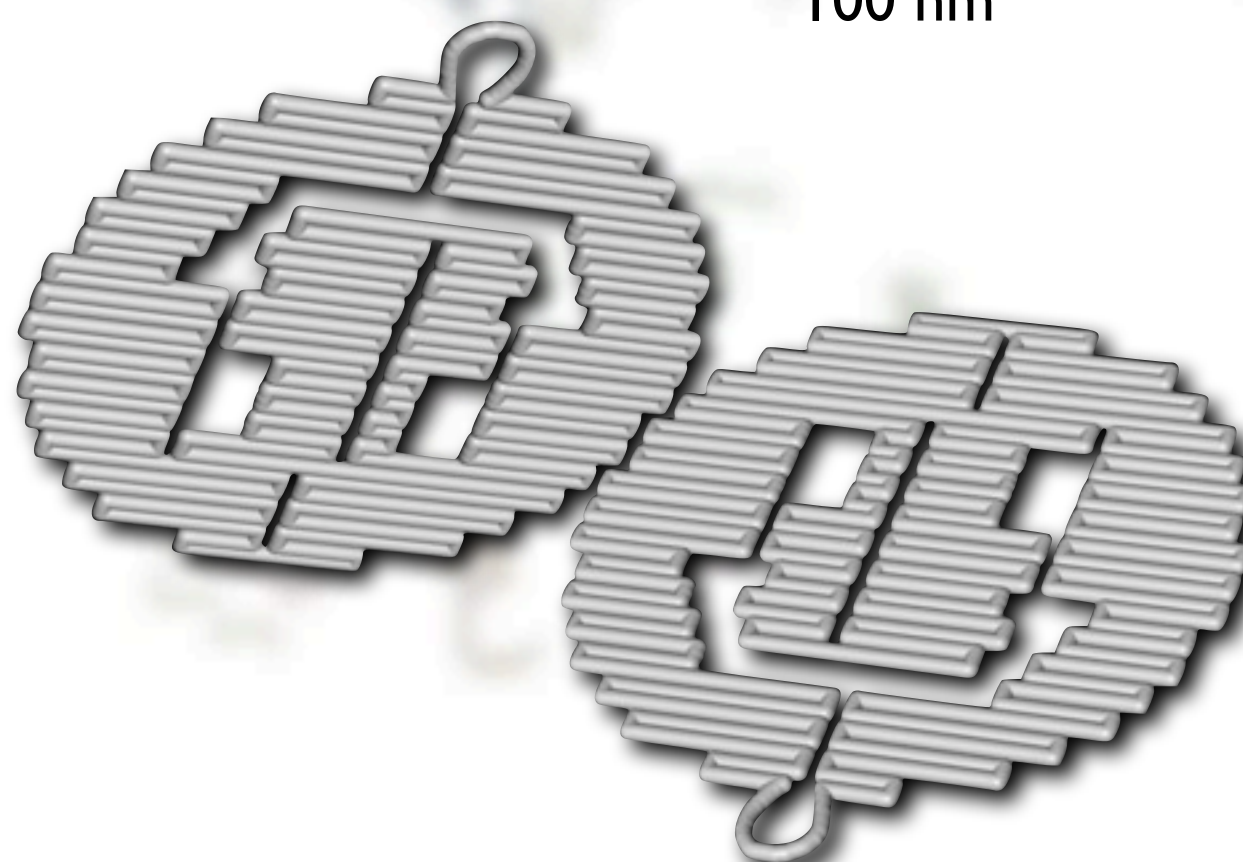




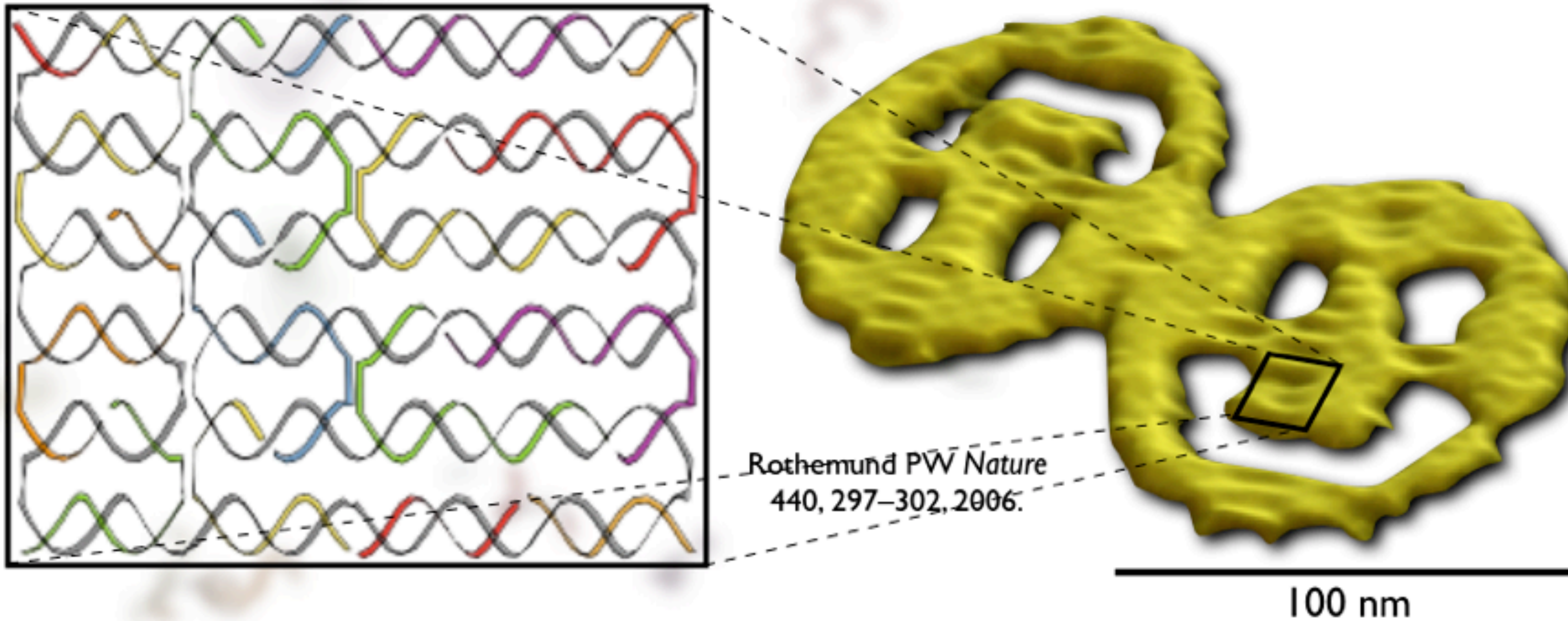
Shawn Douglas
Wyss Technology Development Fellow

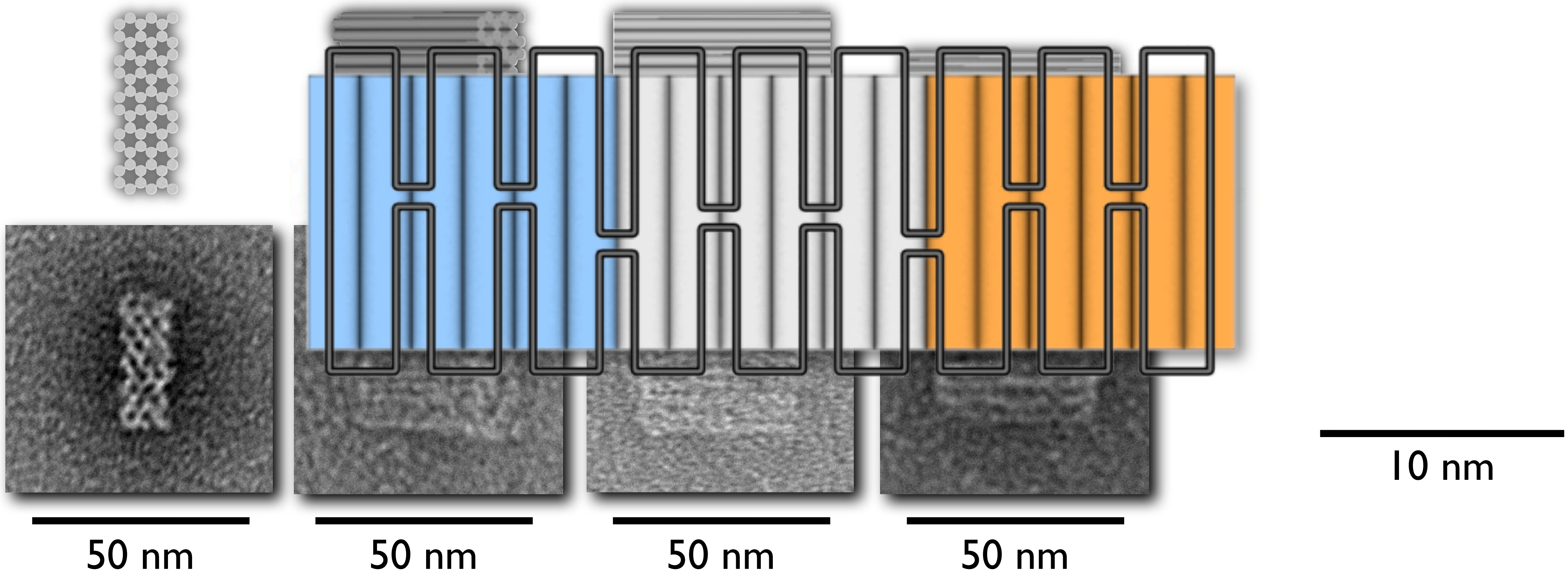


Rothemund PW *Nature*
440, 297–302, 2006.

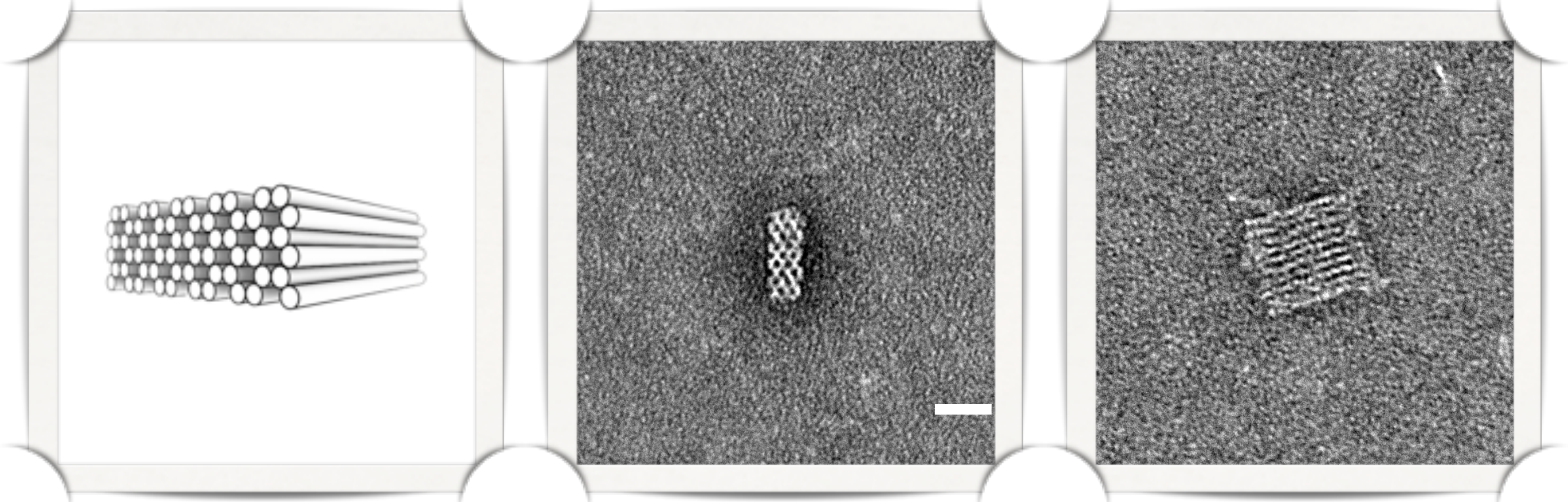


Shawn Douglas





“Monolith”

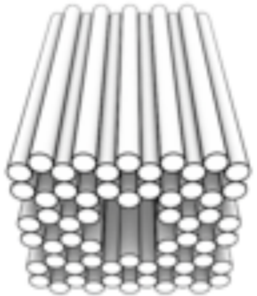


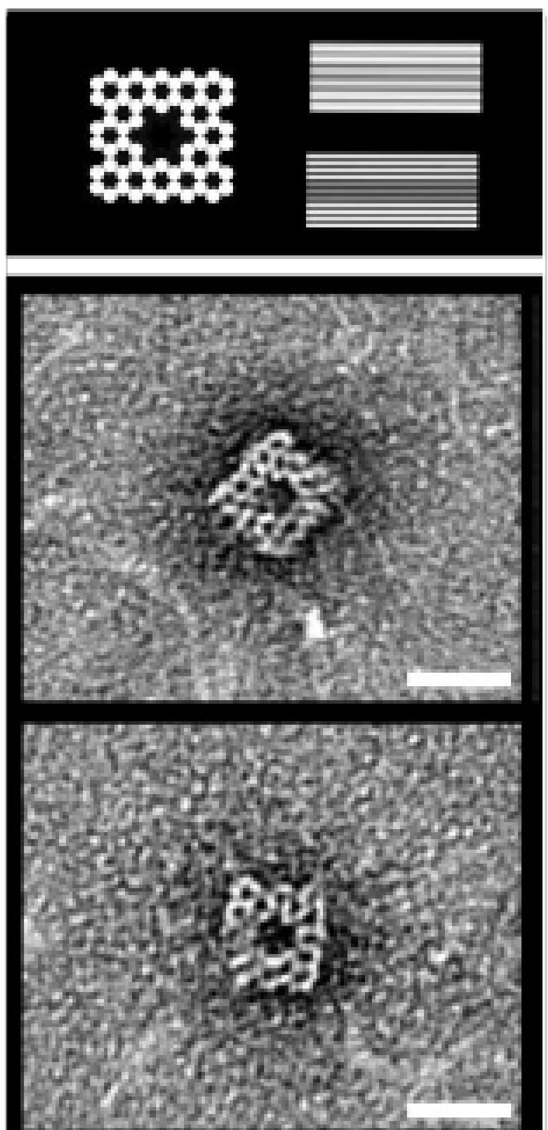
Shawn Douglas

“Genie Bottle”

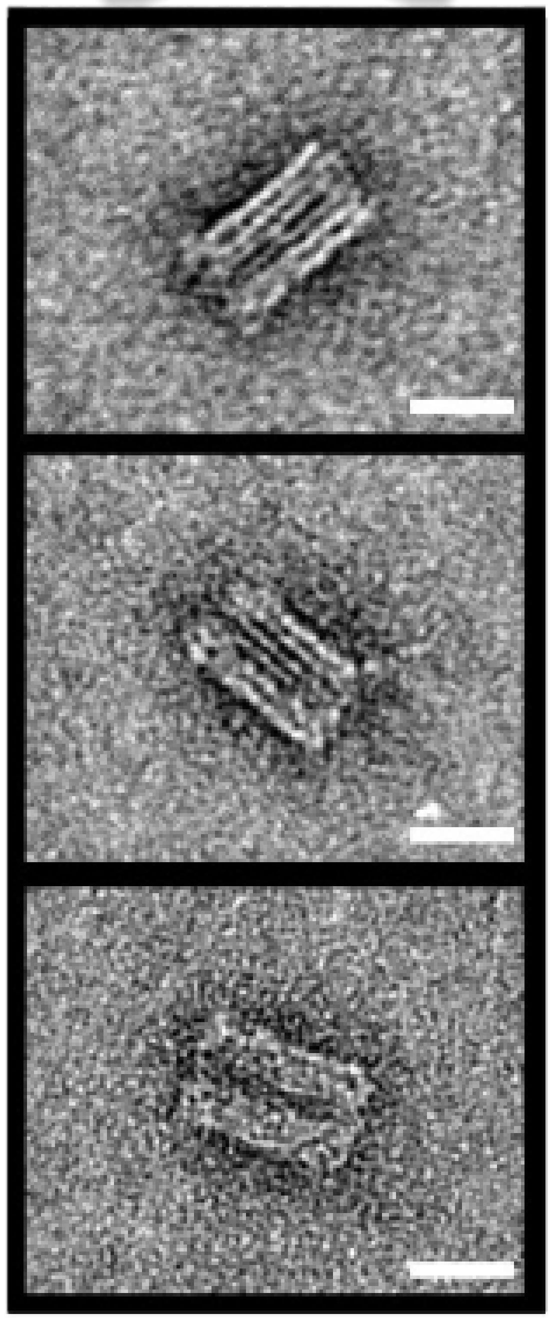
Franziska Graf

“Square Nut”

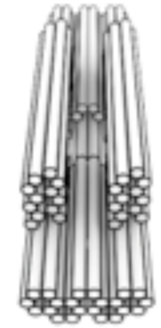


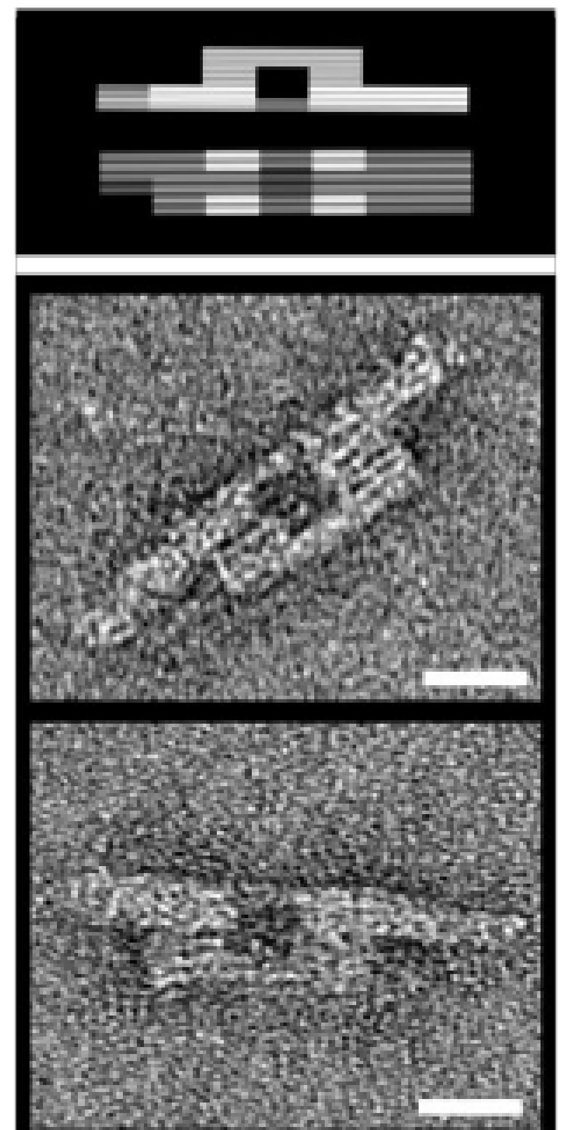


Shawn Douglas

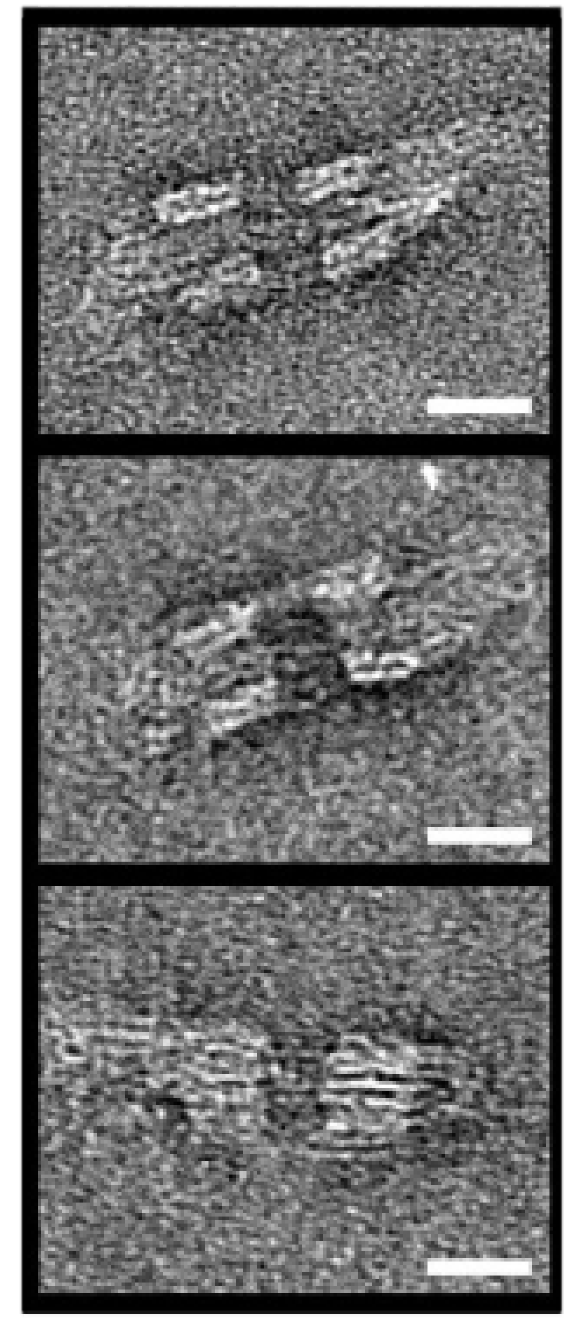


“Railed Bridge”



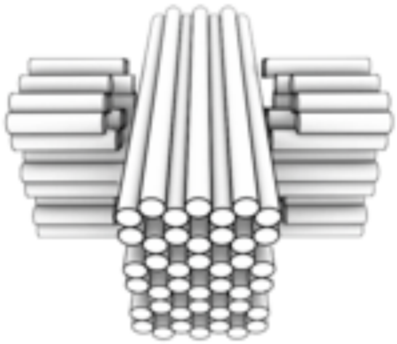


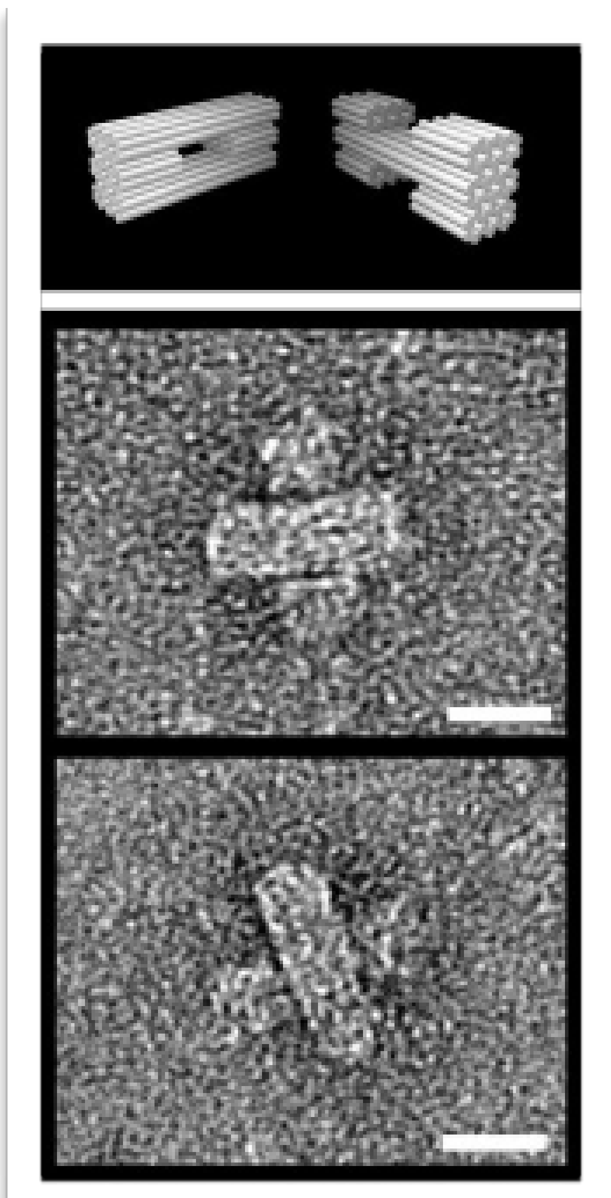
Tim Liedl

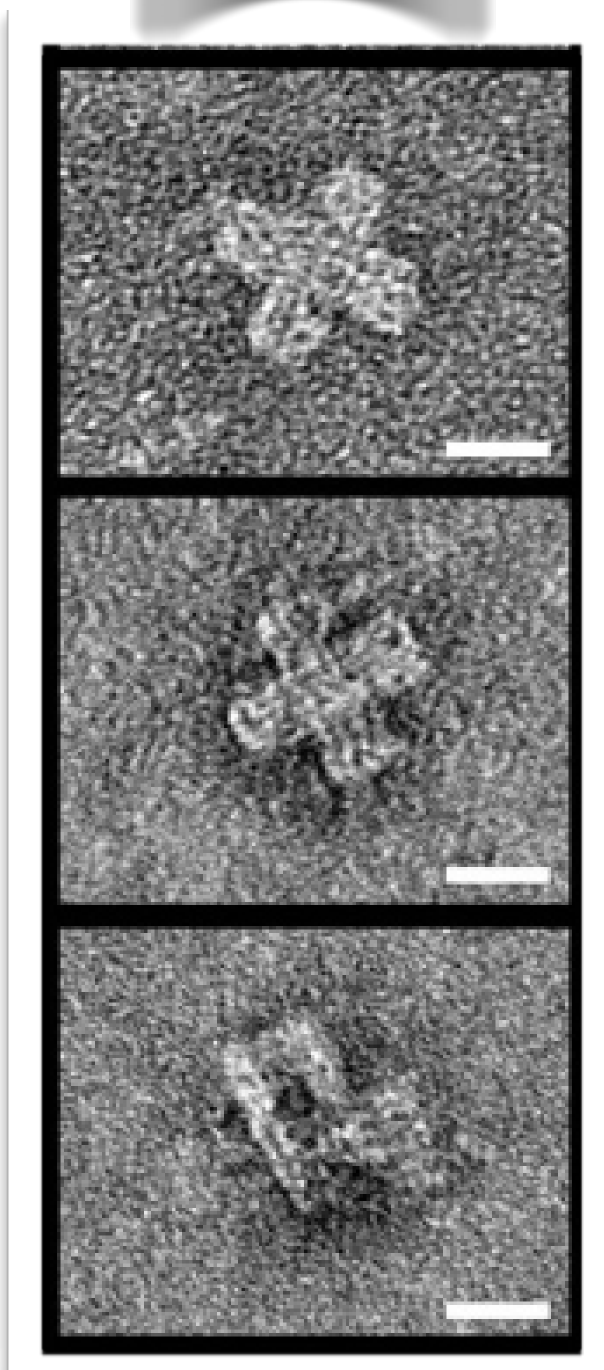


“Slotted Cross”

Björn Högberg

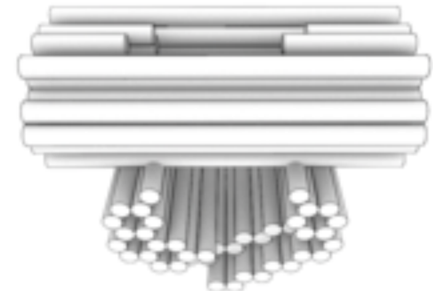


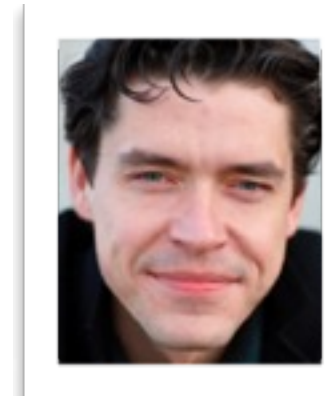


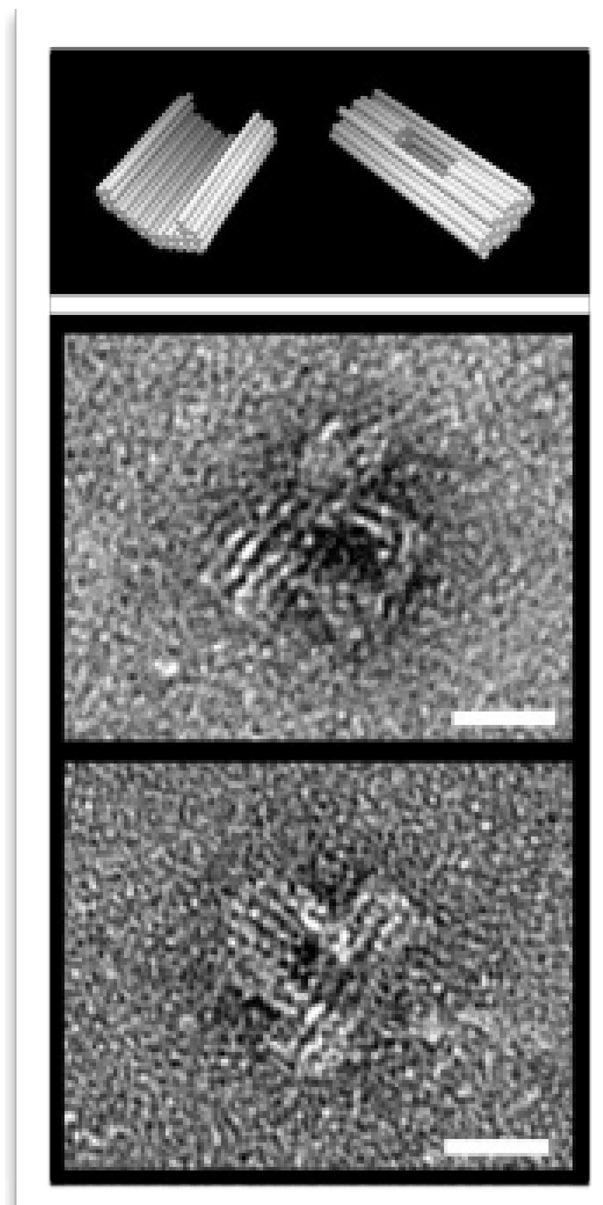


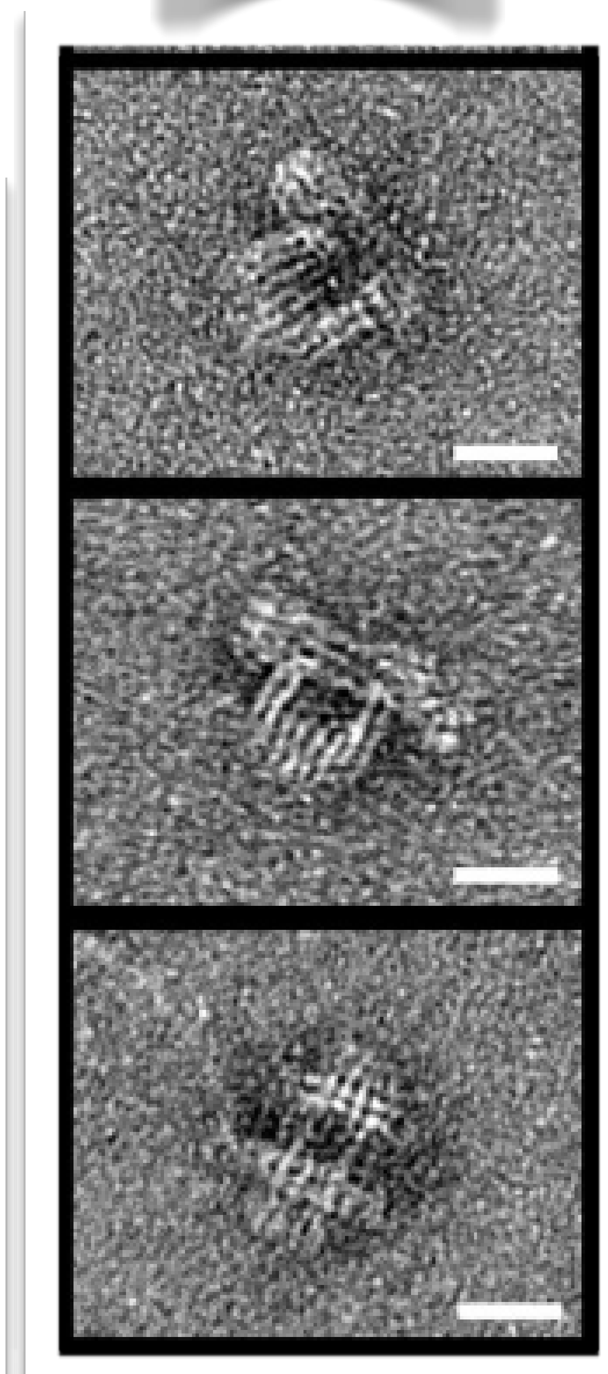
“Stacked Cross”

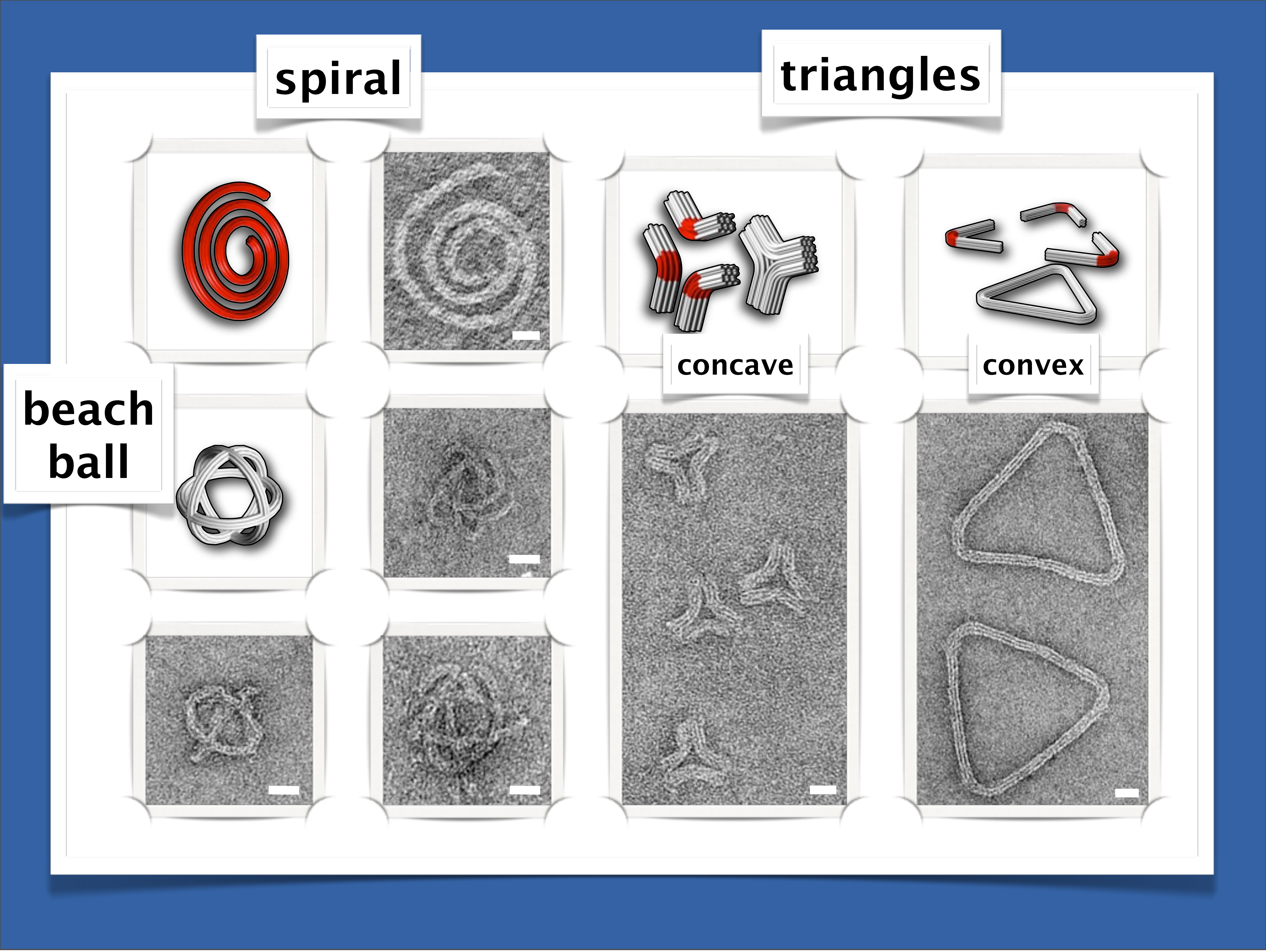
Hendrik Dietz

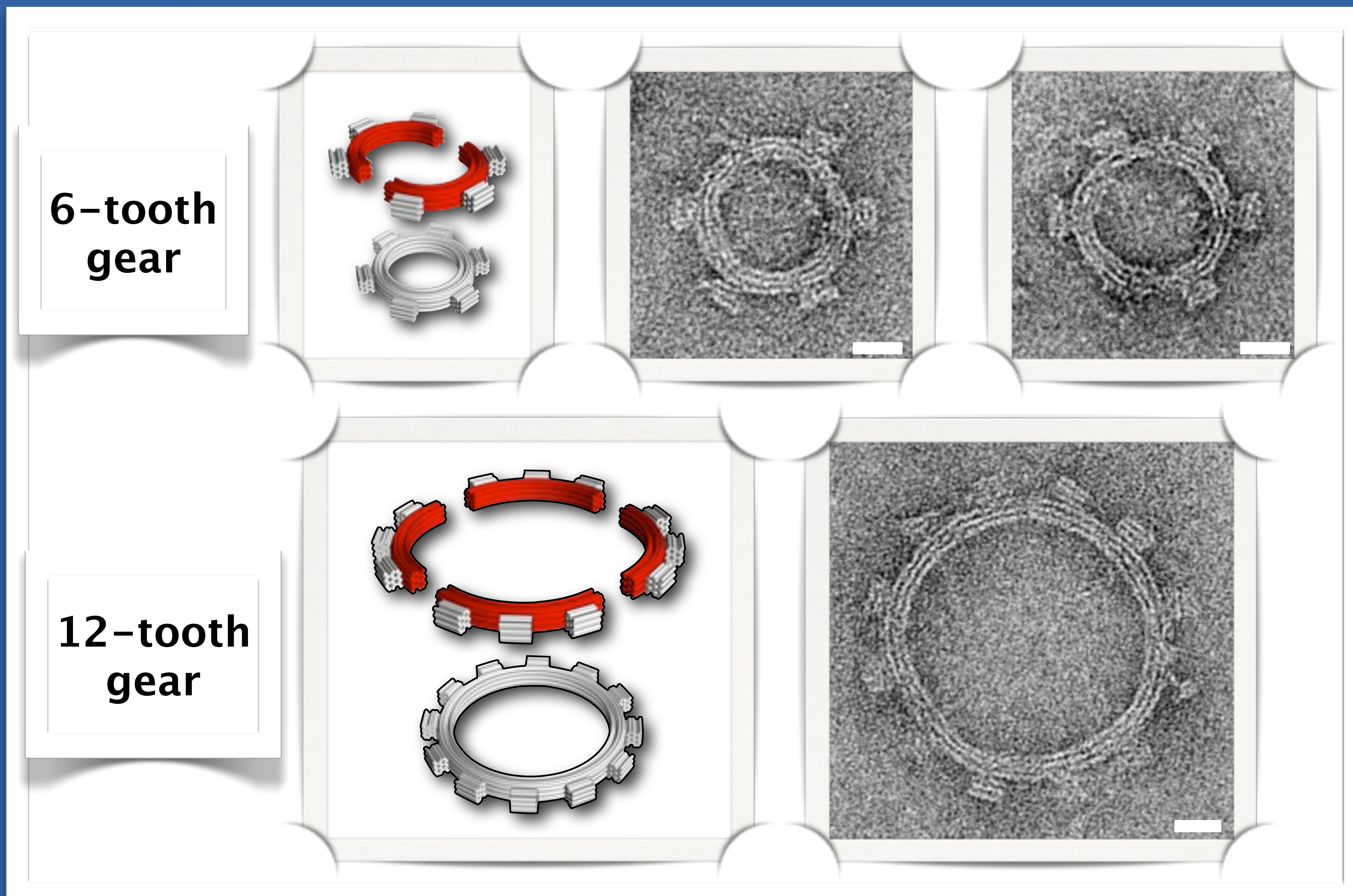


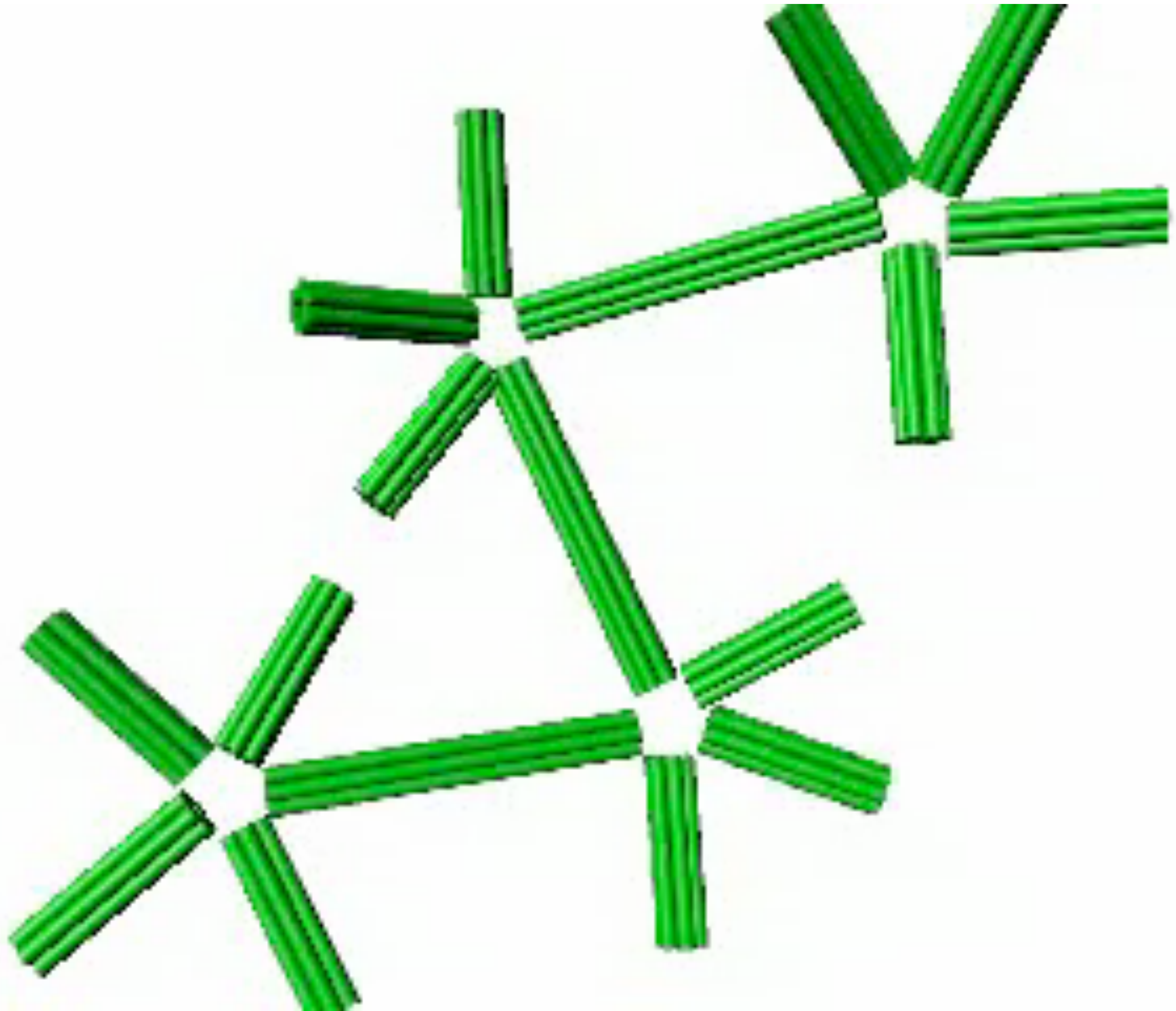
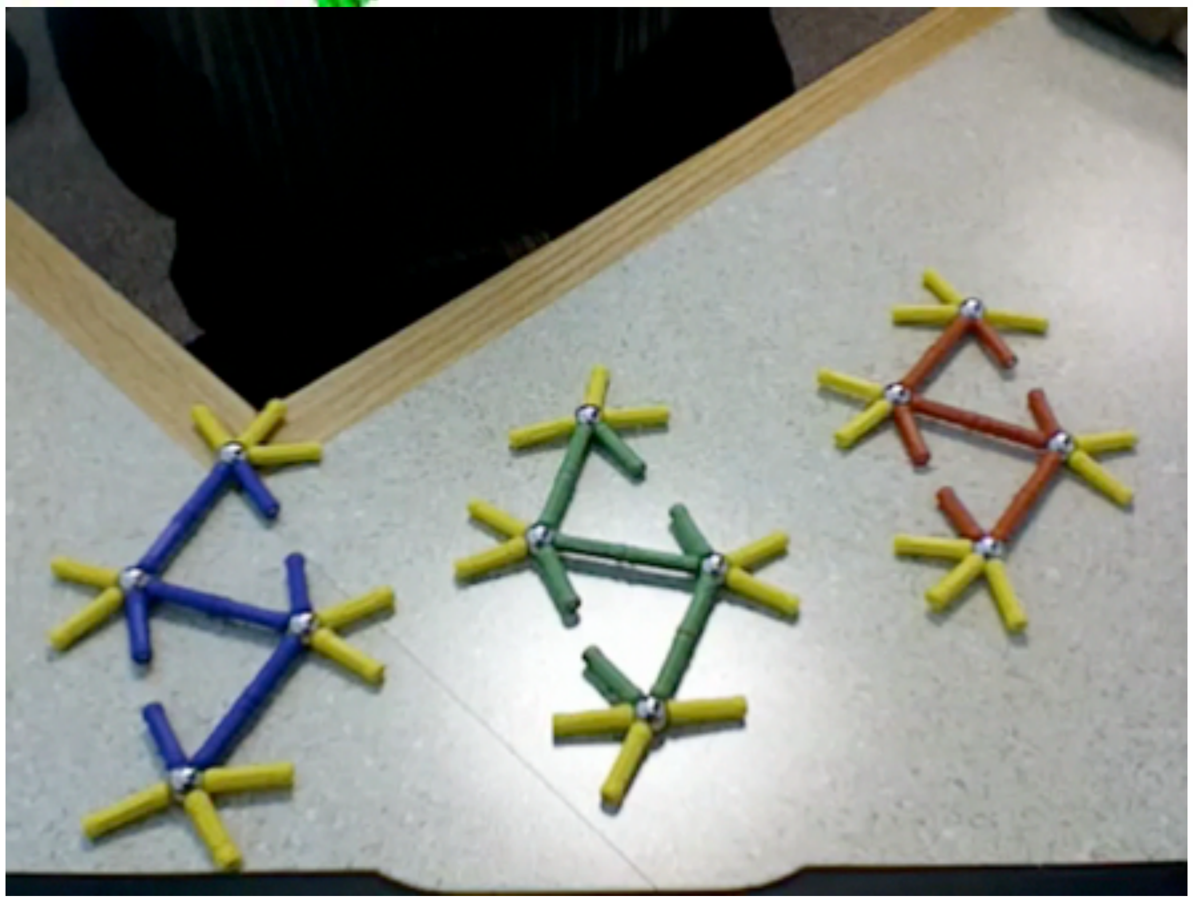
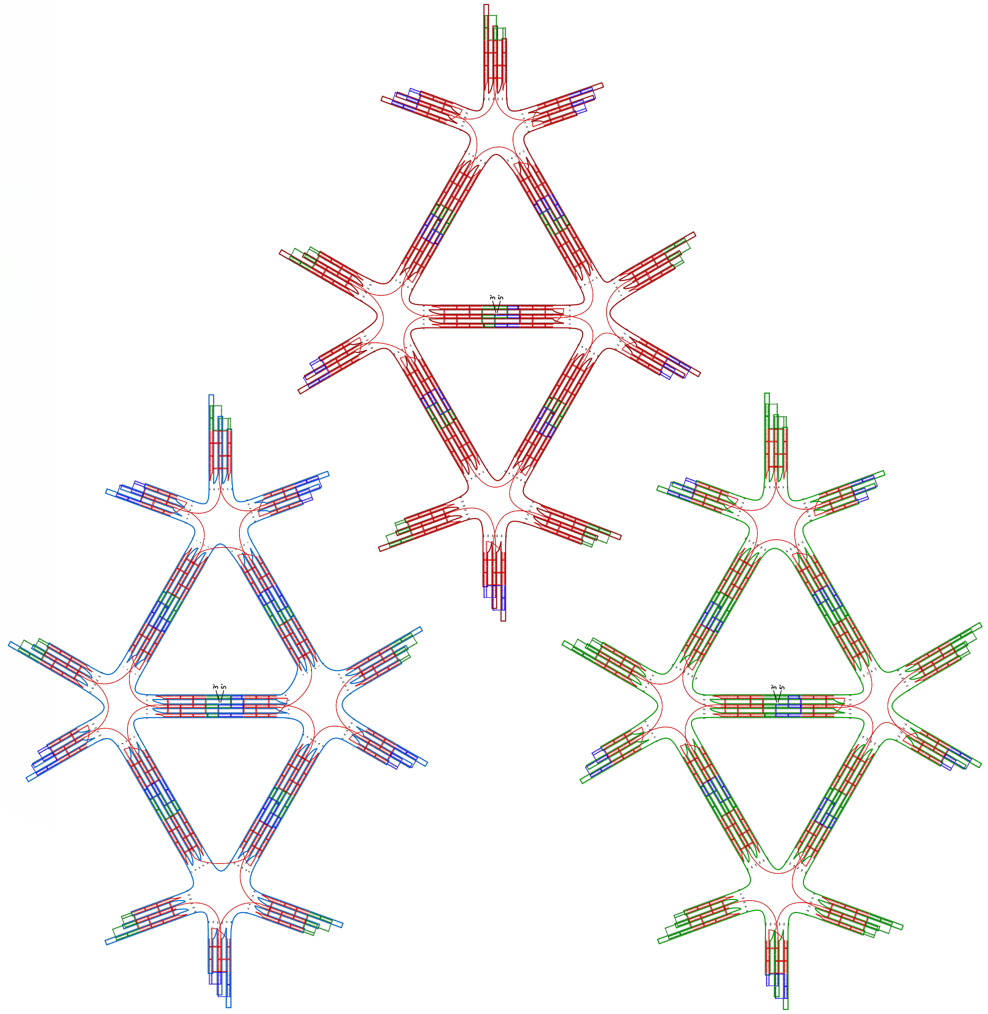
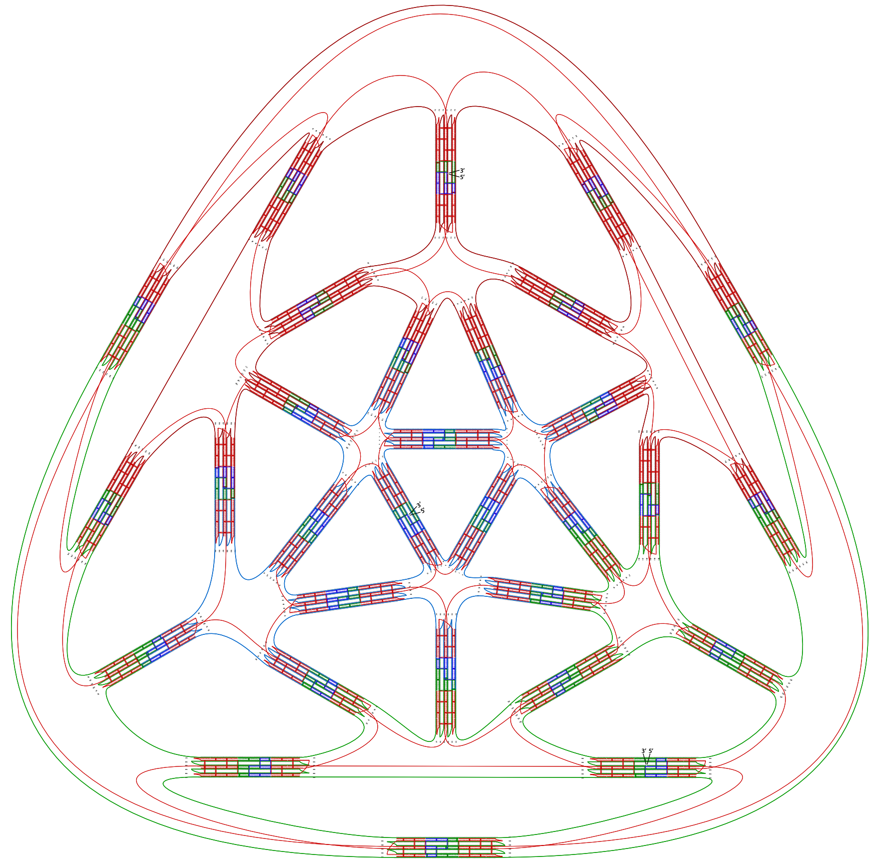


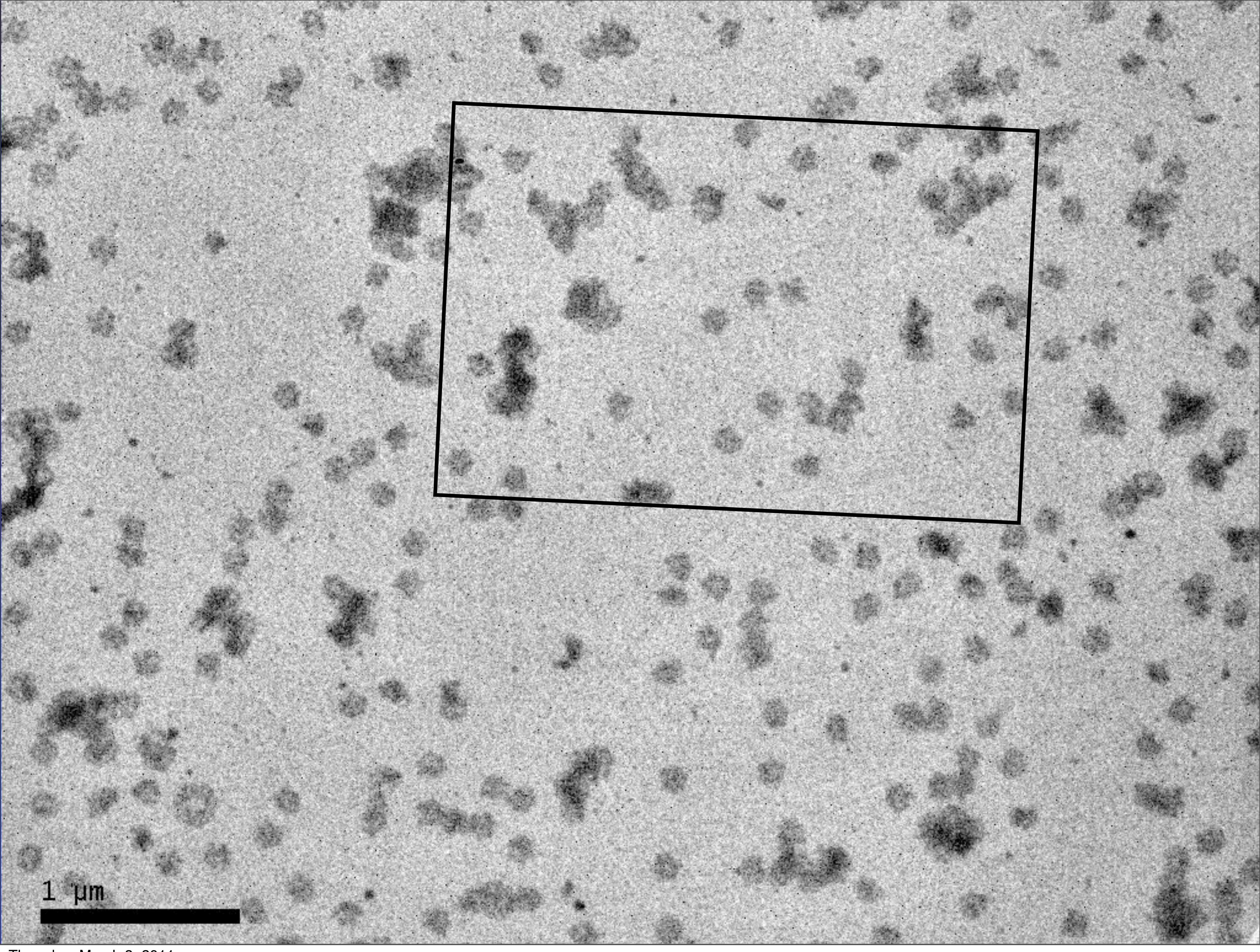


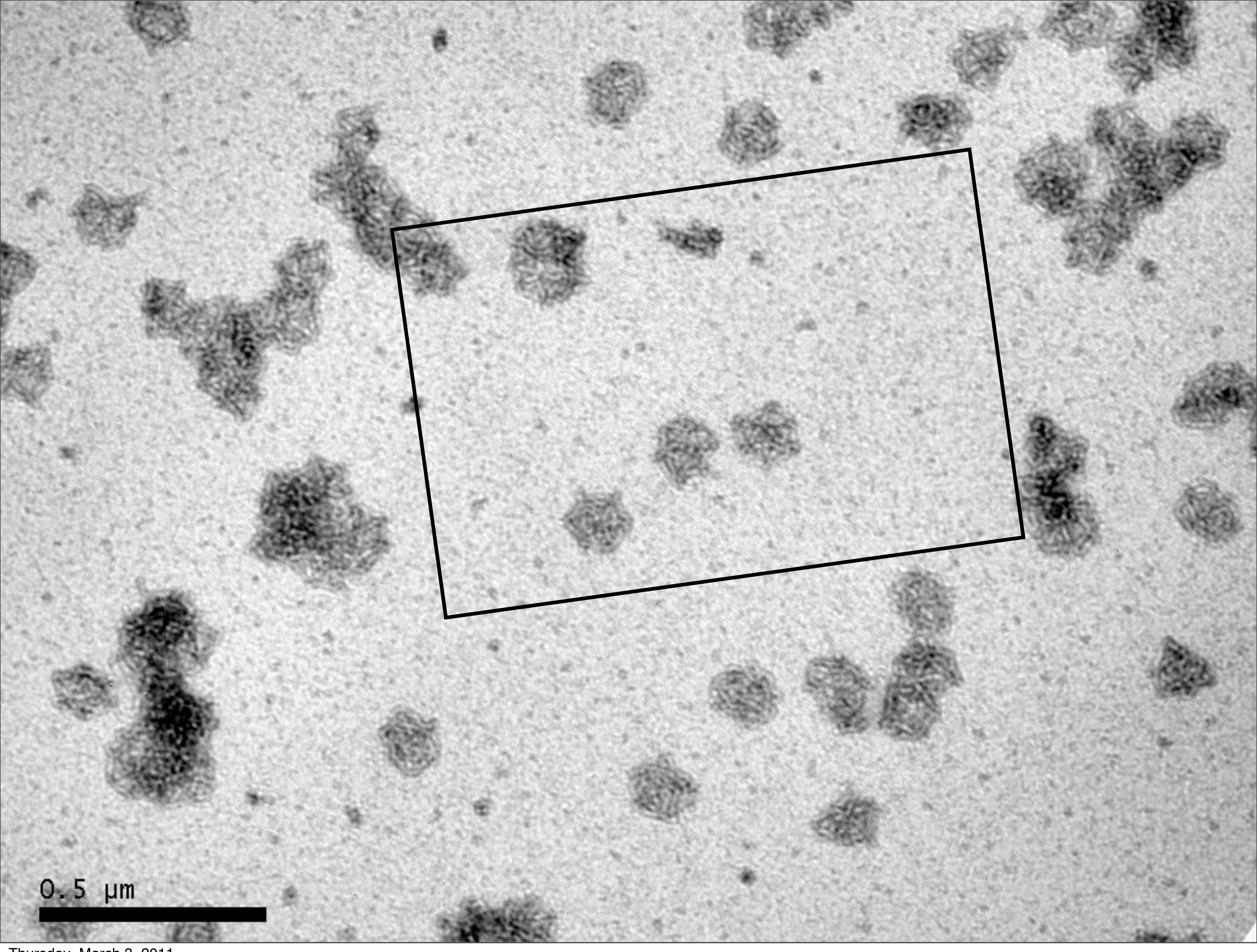


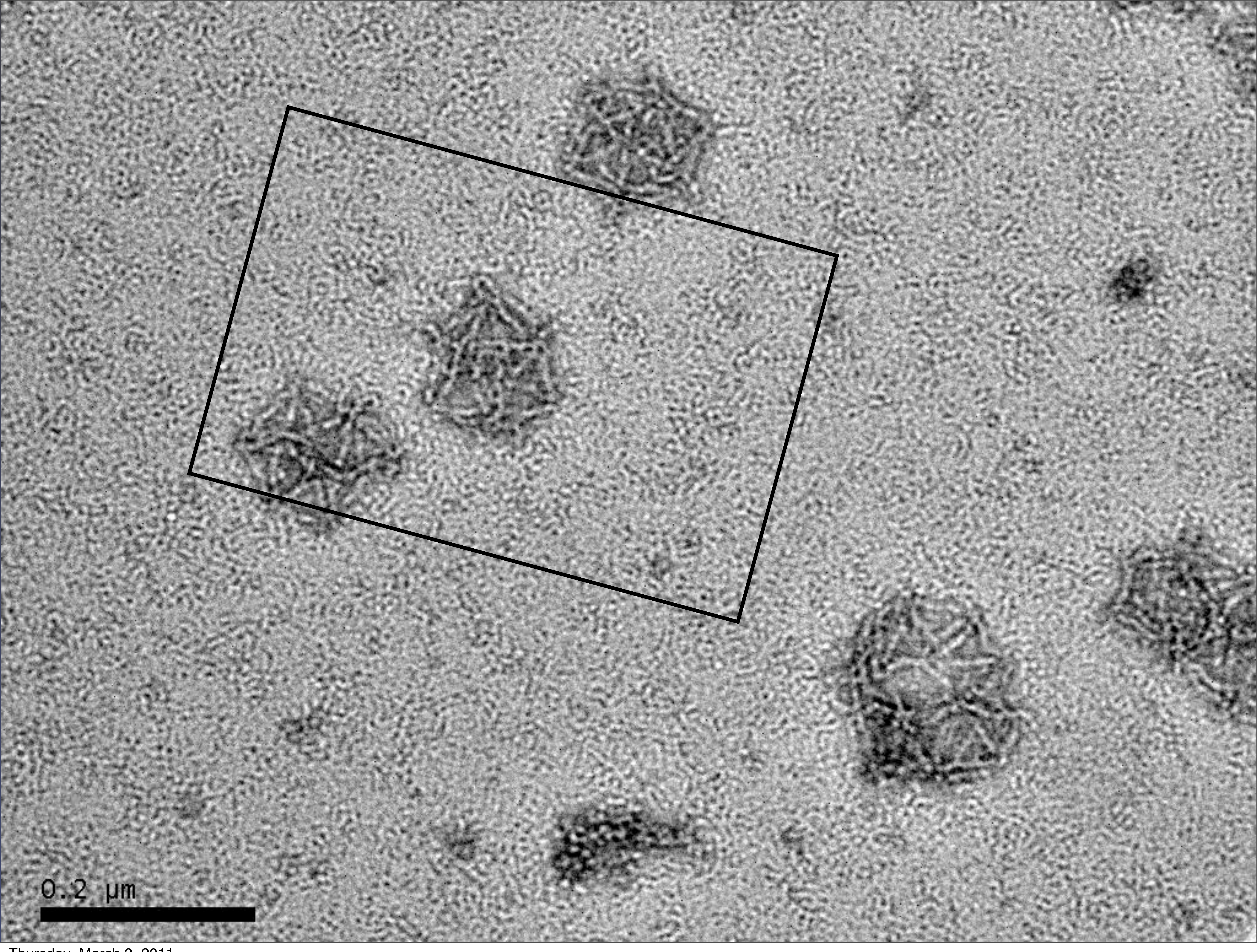

spiral
triangles
beach ball
concave
convex

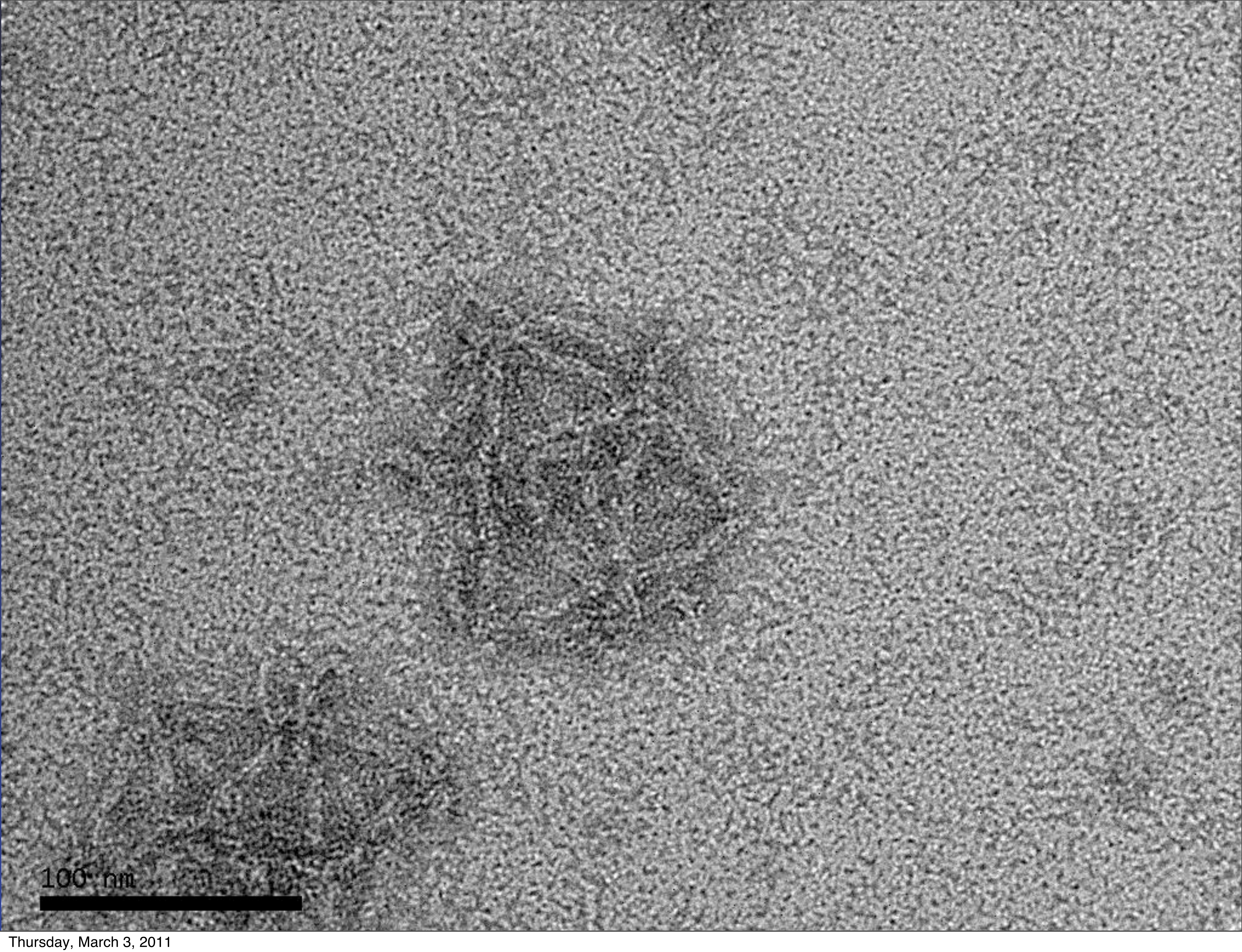

6-tooth gear
12-tooth gear

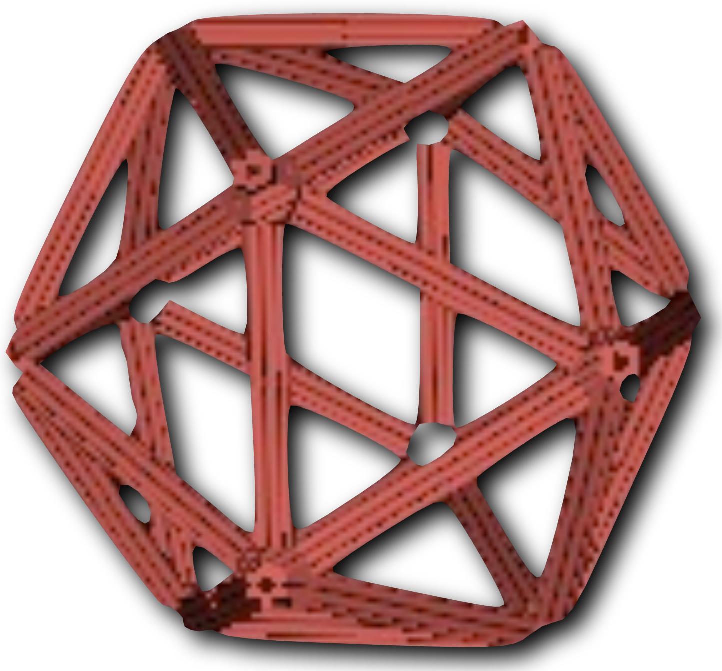

1 µm

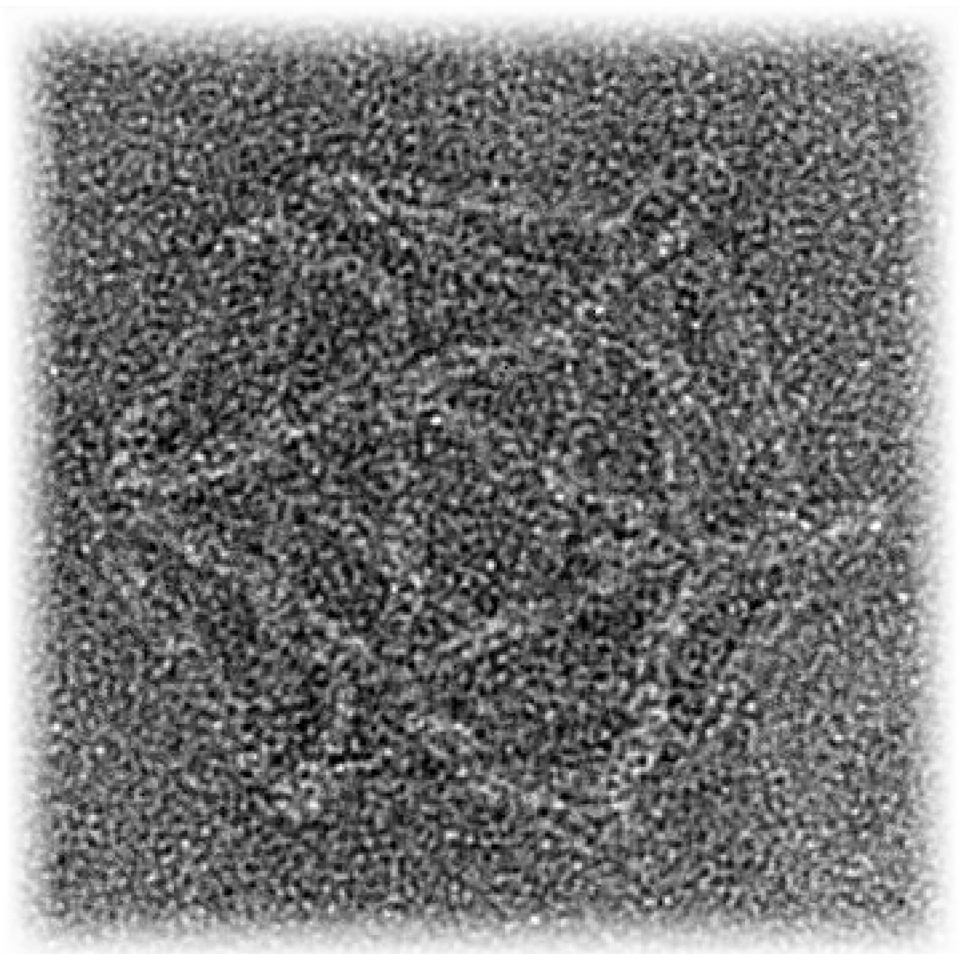

0.5 µm

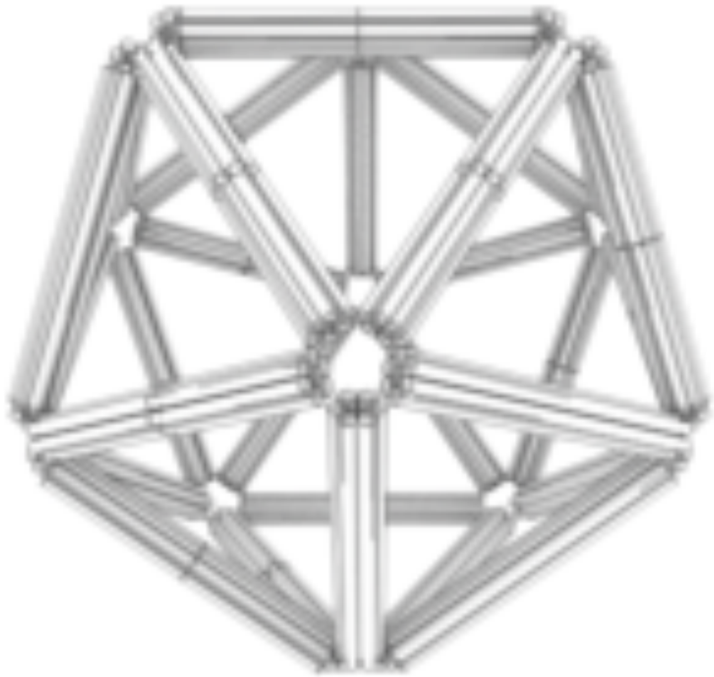

0.2 µm

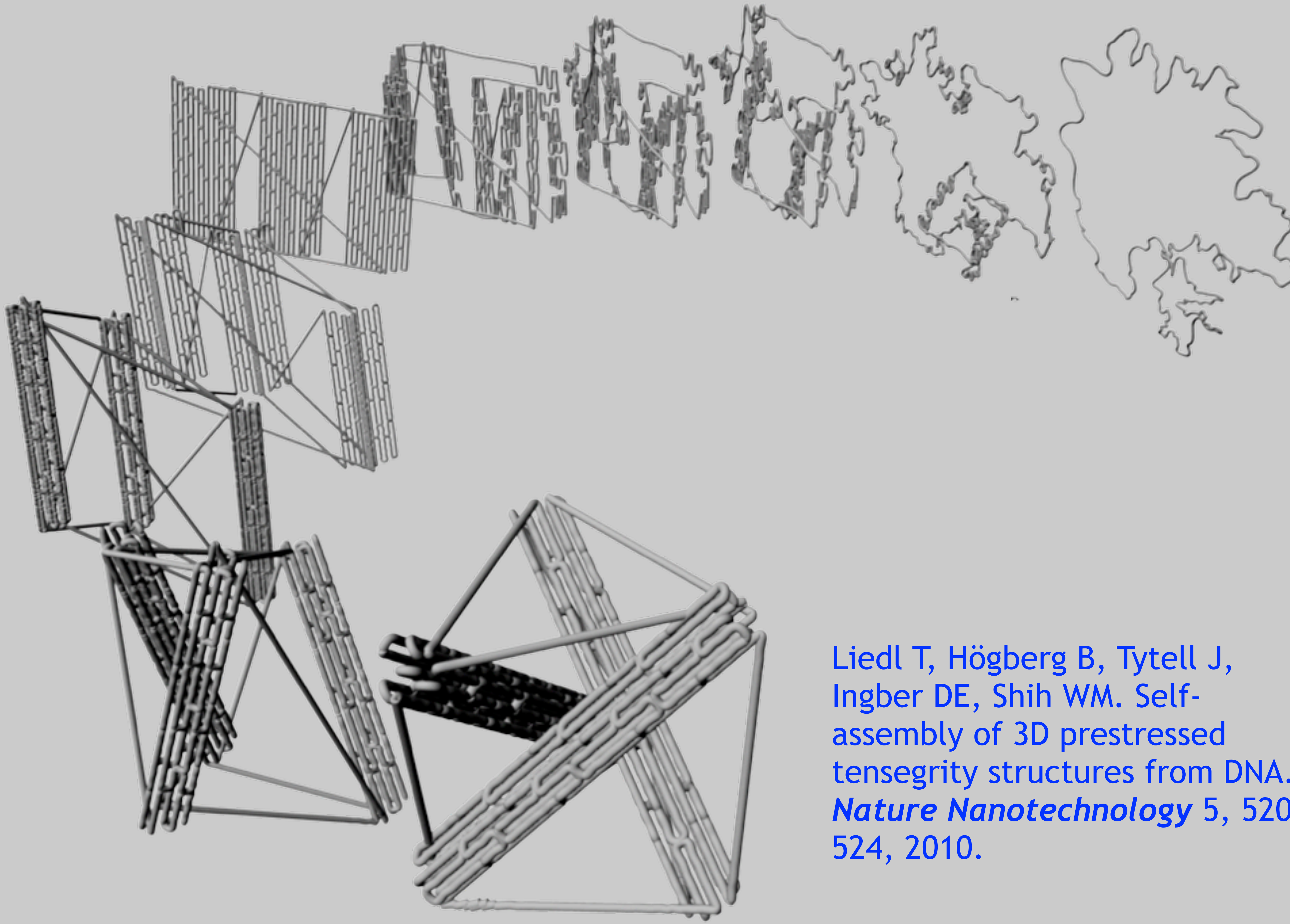

100 nm

3D Wireframe Icosahedron

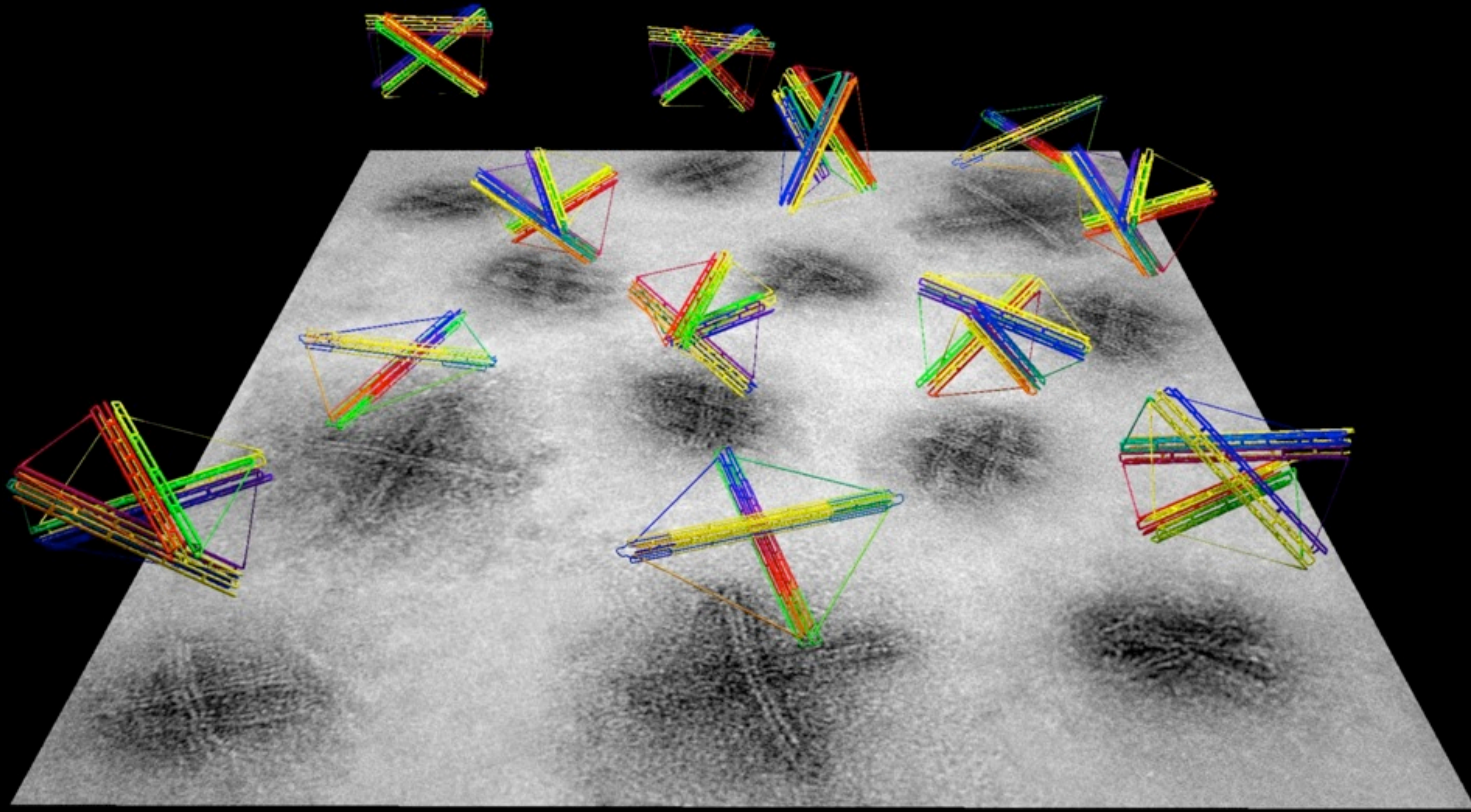








Liedl T, Högberg B, Tytell J, Ingber DE, Shih WM. Self-assembly of 3D prestressed tensegrity structures from DNA. *Nature Nanotechnology* 5, 520–524, 2010.

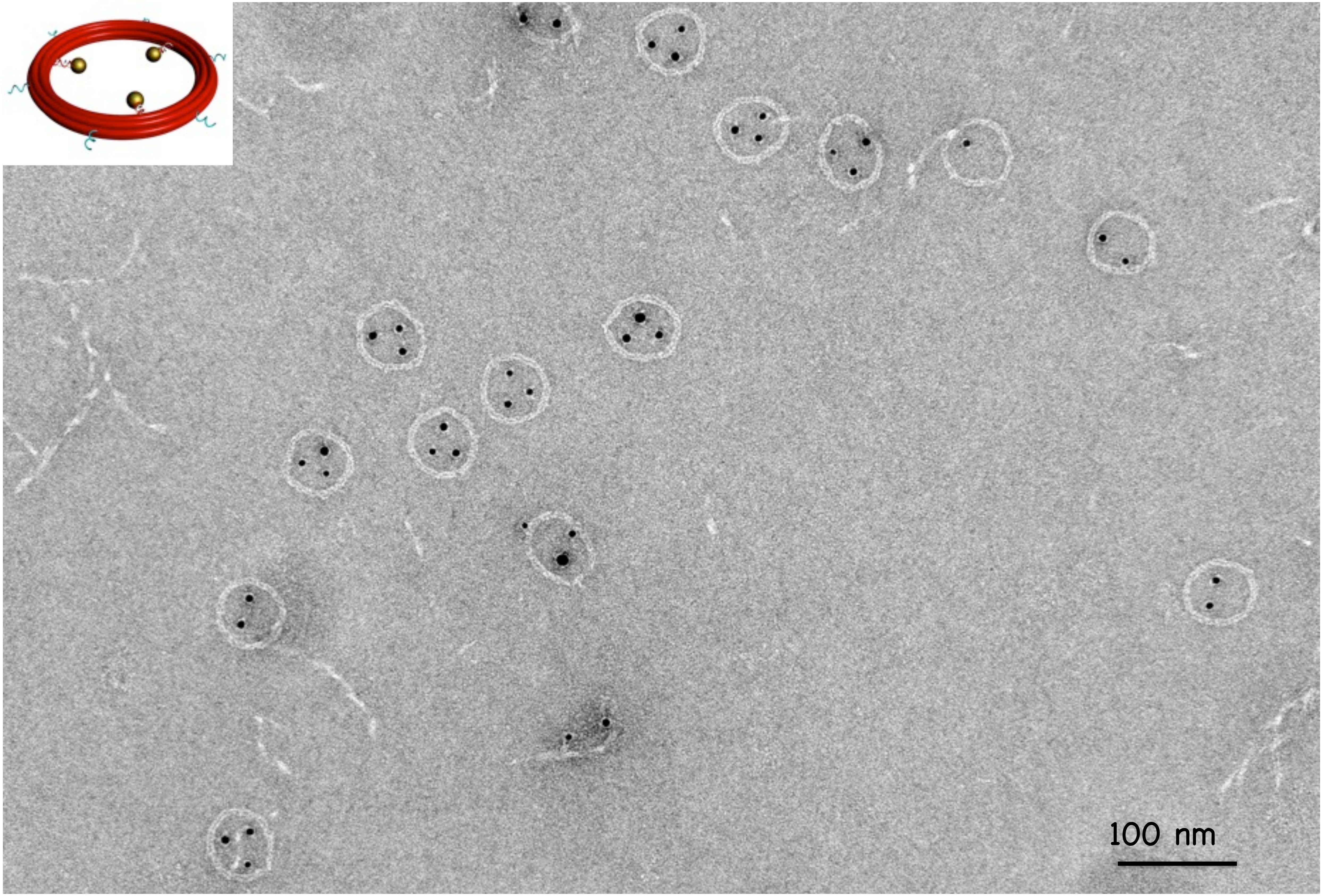


High porosity and surface area
for delivery of morphogens

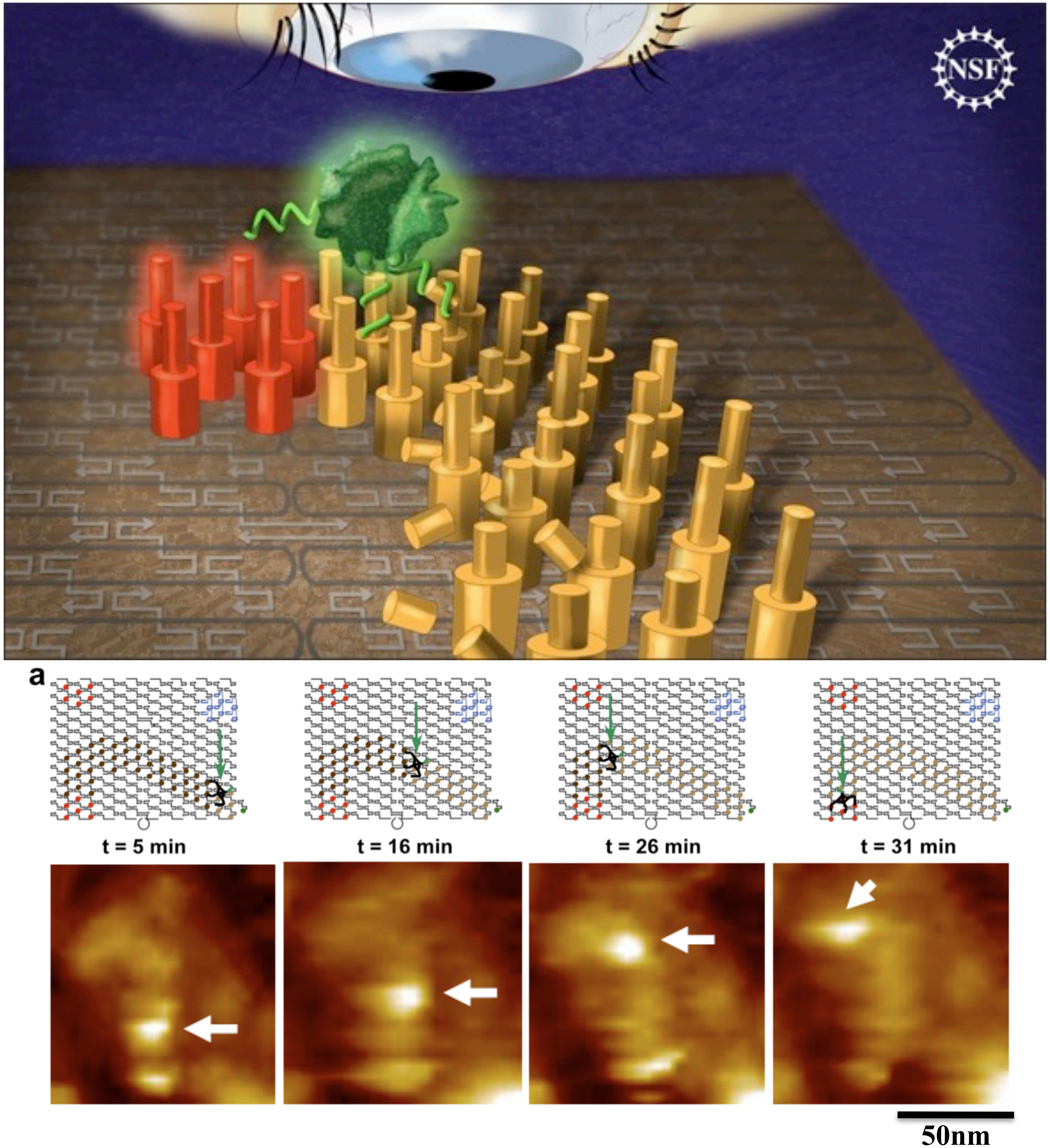
Potential for
mechanical actuation

Guest molecules on a DNA ring

Chenxiang Lin

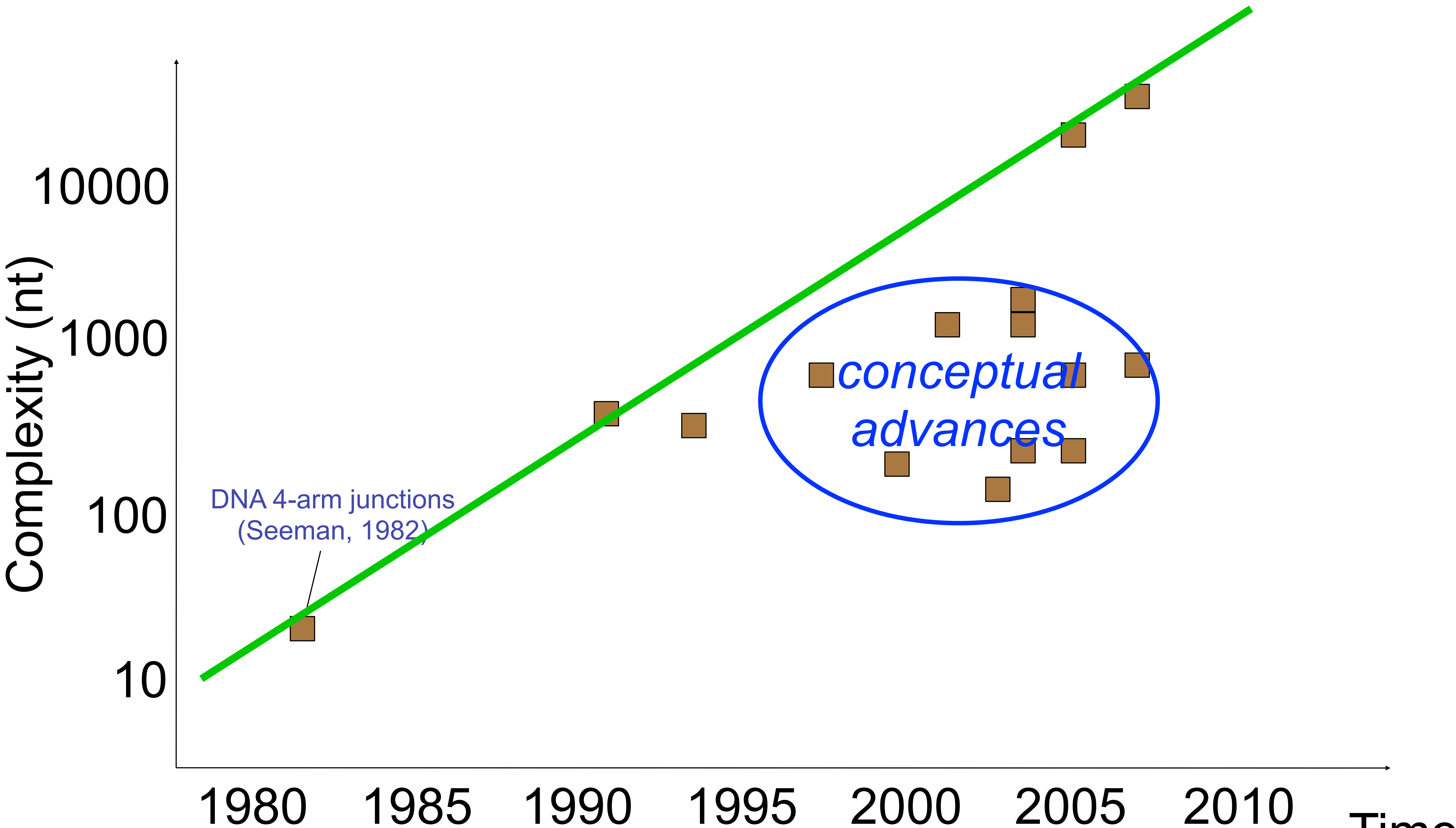


Molecular robots guided by prescriptive landscapes



K.Lund, A. J. Manzo, N. Dabby, N. Michelotti, A. Johnson-Buck, J. Nangreave, Steven Taylor, R. Pei, M. N. Stojanovic*, N. G. Walter*, E. Winfree*, H. Yan*, Molecular Robots Guided by Prescriptive Landscapes, ***Nature*** 465, 206-210 (2010).

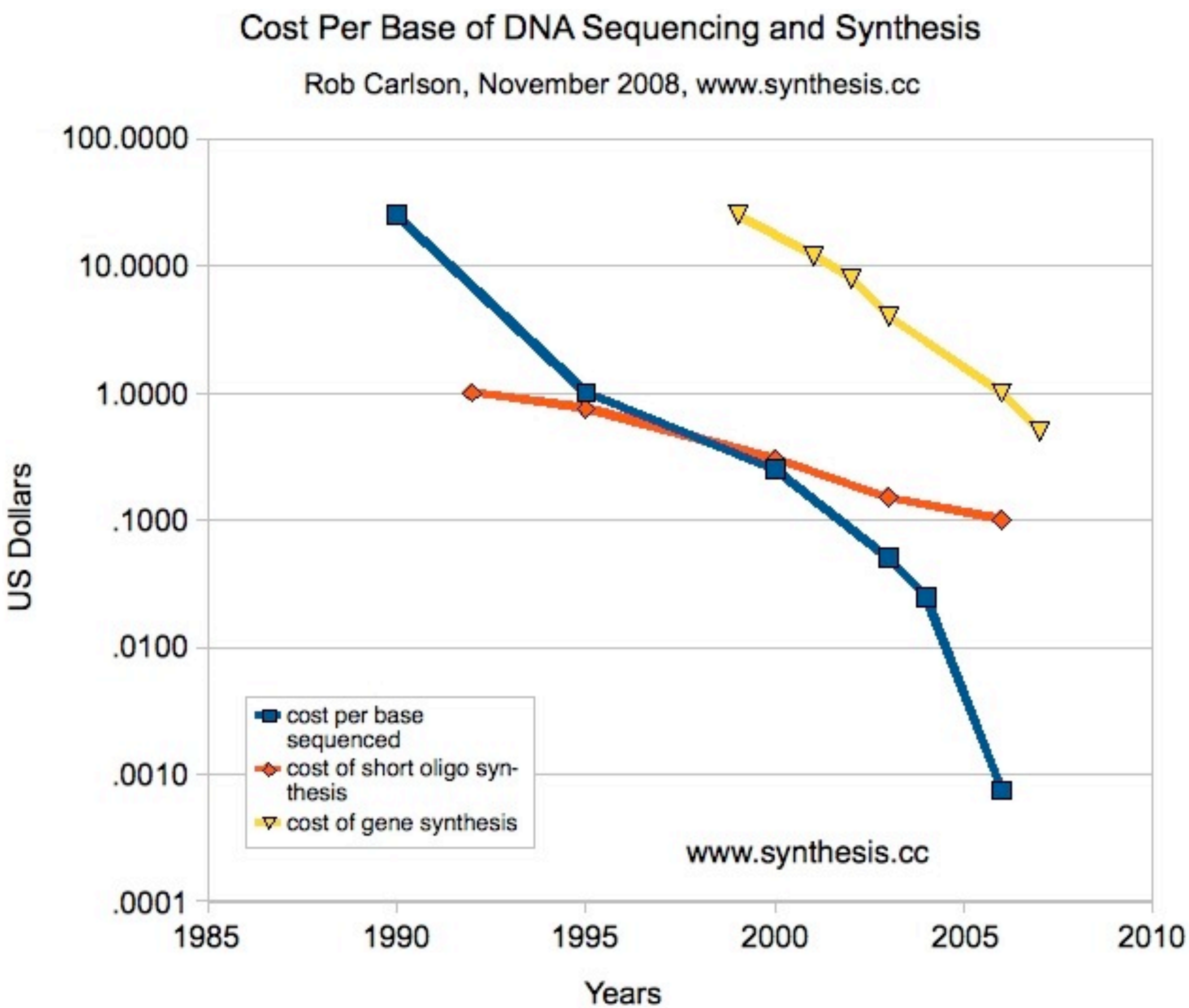
Growth of design complexity in DNA nanotechnology



doubles every 3 years

Erik Winfree

DNA synthesis as a rate-limiting factor



How do we sustain exponential growth in DNA-nanostructure design complexity?

Decrease cost of gene-length DNA synthesis

Decrease cost of mass DNA synthesis

Employ templated, hierarchical, active self-assembly

Abstraction and software support

HEALTHCARE

Diagnostics (imaging, sensing)
Enhanced-delivery, smart therapeutics
Regenerative medicine
Implants and prosthetics

ENERGY/ENVIRONMENT

Low-cost photovoltaics and fuel cells
Low-cost, efficient lighting
Efficient carbon sequestration
Environmental remediation

A mature Synthetic Biology and DNA Nanotechnology

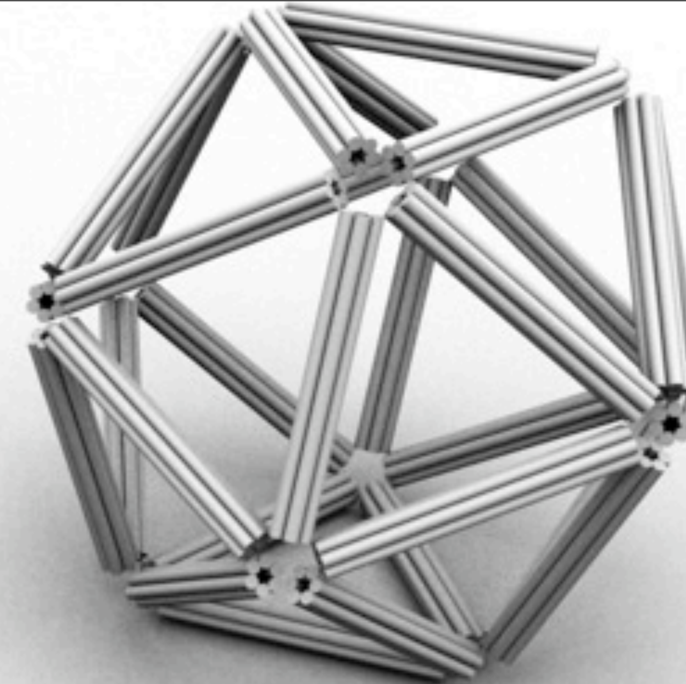
COMPUTATION

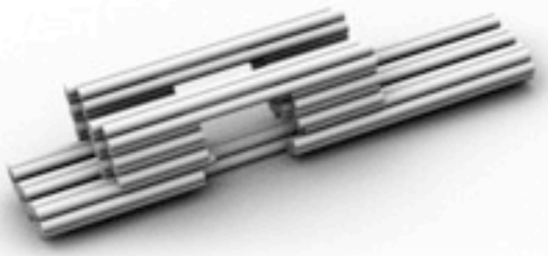
High-density memory
Plasmonic circuits and switches
Low-loss optical waveguides
Quantum computers

MATERIALS

Insulation, packaging, coatings
Membranes, filters, catalysts
Superlenses and cloaking devices
Embedded sensors

Conclusions





We can self-assemble
arbitrary 3D-origami
DNA nanostructures.

Support
NIH New Innovator Award
DFCI Barr Award in Innovative
Basic Cancer Research
Wyss Institute for Biologically
Inspired Engineering at Harvard

Precise control over
self-assembly of
3D DNA nanostructures
will be useful.