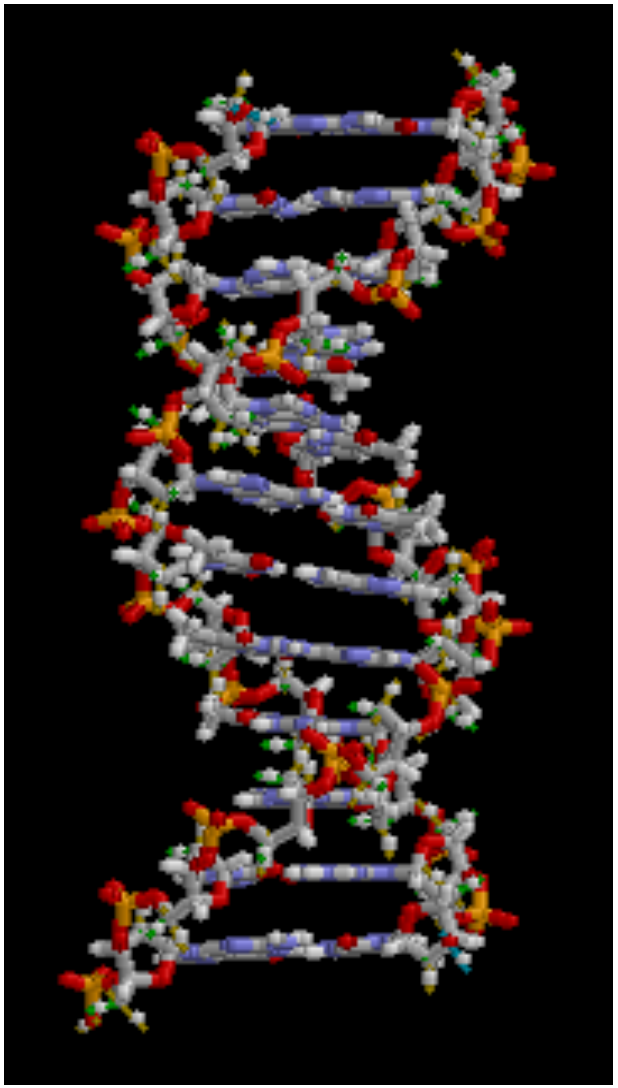
Roma, Ottobre 2016 --
La Scienza a scuola **Zanichelli**

Costruire con mattoni di DNA



Francesco Sciortino
Dipartimento di Fisica
Sapienza Universita' di Roma

francesco.sciortino@uniroma1.it

http://glass.phys.uniroma1.it/sciortino/talks.htm

Costruire …..

“Mattoni” (materiali)
Operai
Macchine

http://www.youtube.com/watch?v=Ps0DSihggio

Costruire (progetto)…..

“Mattoni” (materiali)
Messa in opera dei materiale: Operai/Macchine

http://www.youtube.com/watch?v=Ps0DSihggio

Anche la natura costruisce spontaneamente…..

“Mattoni” (atomi)
Condizioni chimico-fisiche adatte

Anche la natura “costruisce” spontaneamente…..

“Mattoni” (atomi)
Condizioni chimico-fisiche adatte

Anche la natura ha le sue macchine…..

(Costruzione di una proteina)

“Mattoni” (ammino acidi)
Materiali (Ammino acidi)
Operai (t-RNA)
Macchine (ribosoma)

Anche la natura ha le sue macchine…..

(Costruzione di una proteina)

“Mattoni” (ammino acidi)
Macchine (ribosoma)

Il nostro scopo: costruire materiali (e macchine)

sulla scala dei nanometri (10^{-9} m)

(ribosoma circa 20 nm)

Il self-assembly: progetto codificato nel materiale

… vogliamo fare questo …. Utilizzando come “mattone” il DNA

DNA NANOTECHNOLOGY

(Il mattone scelto per costruire e' una sequenza di DNA)

Citation Report: 3143

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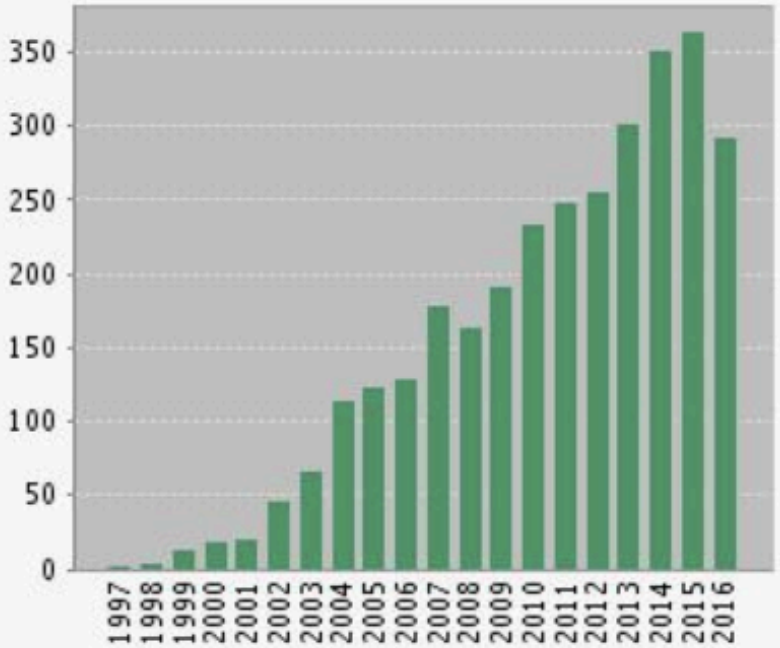
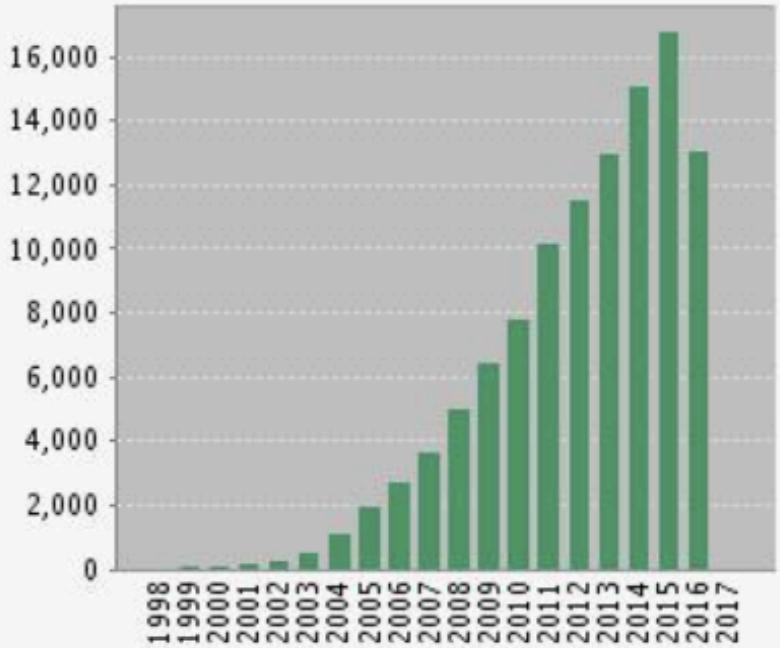
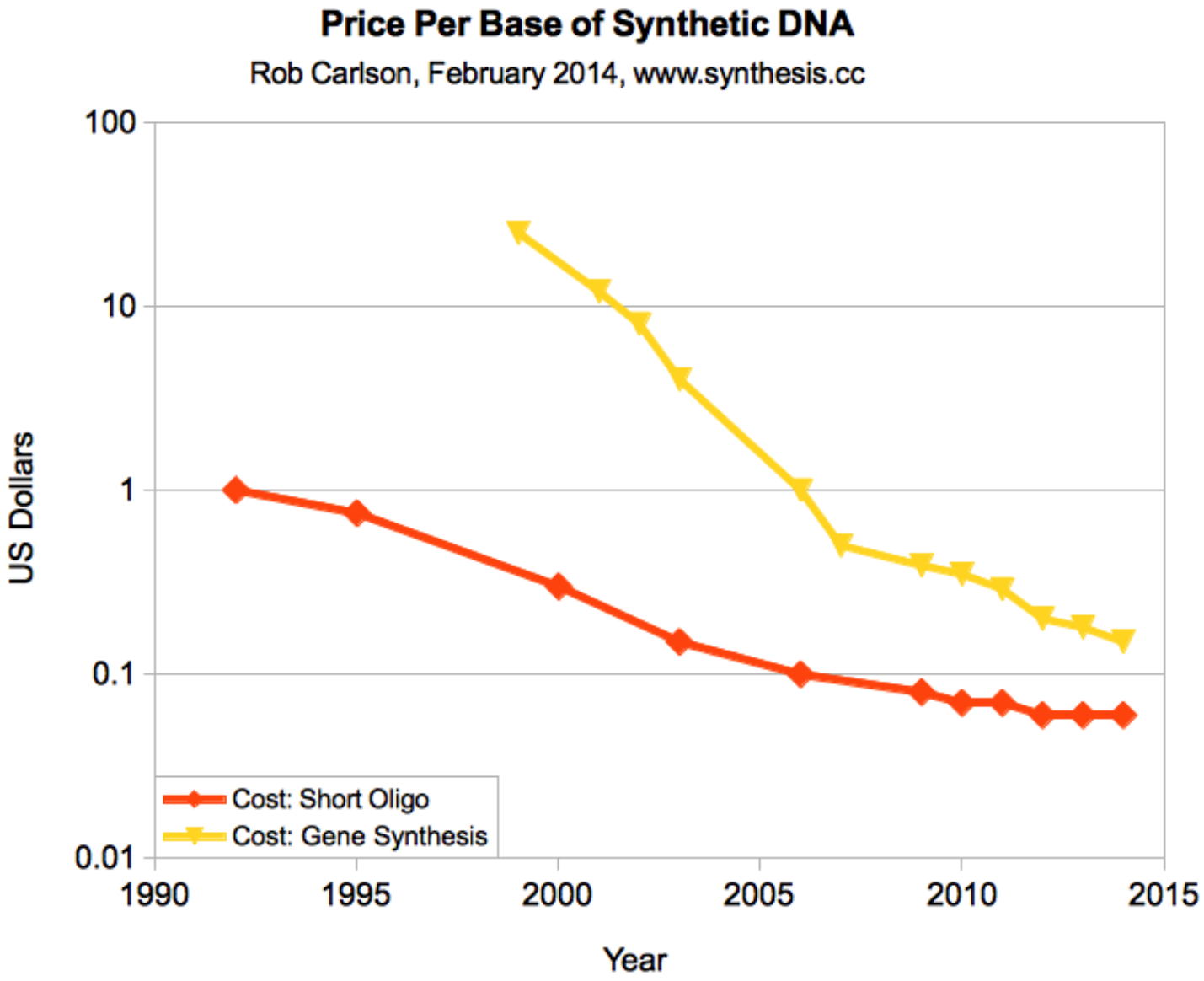


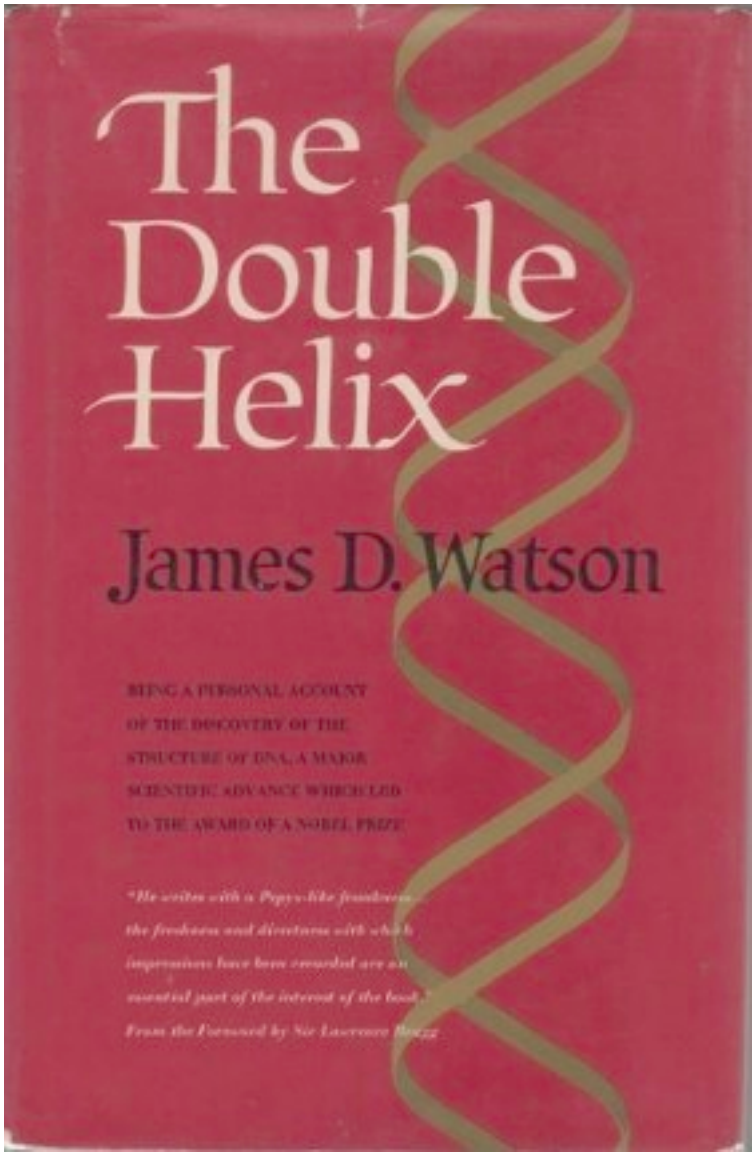
Citations in Each Year





http://www.synthesis.cc/

DNA come molecola biologica…….

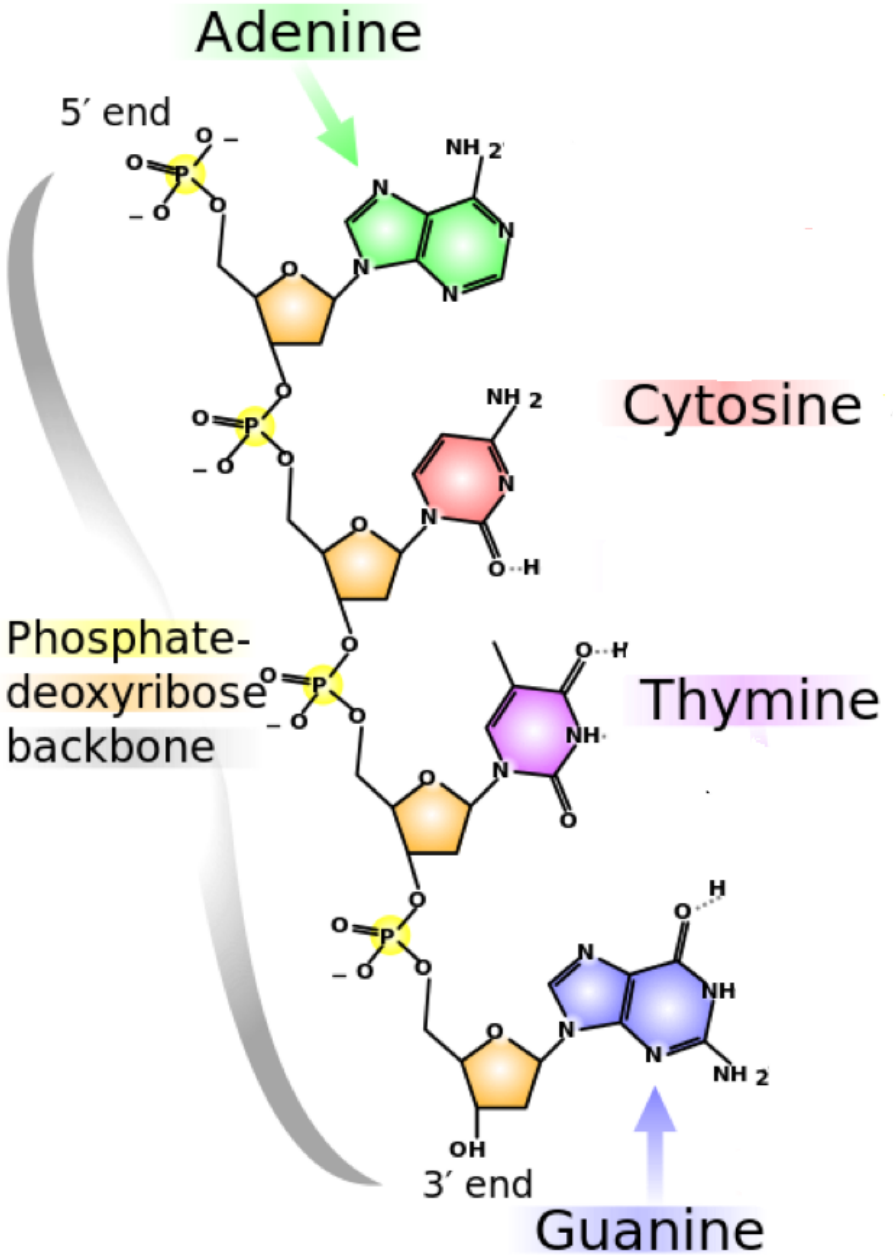


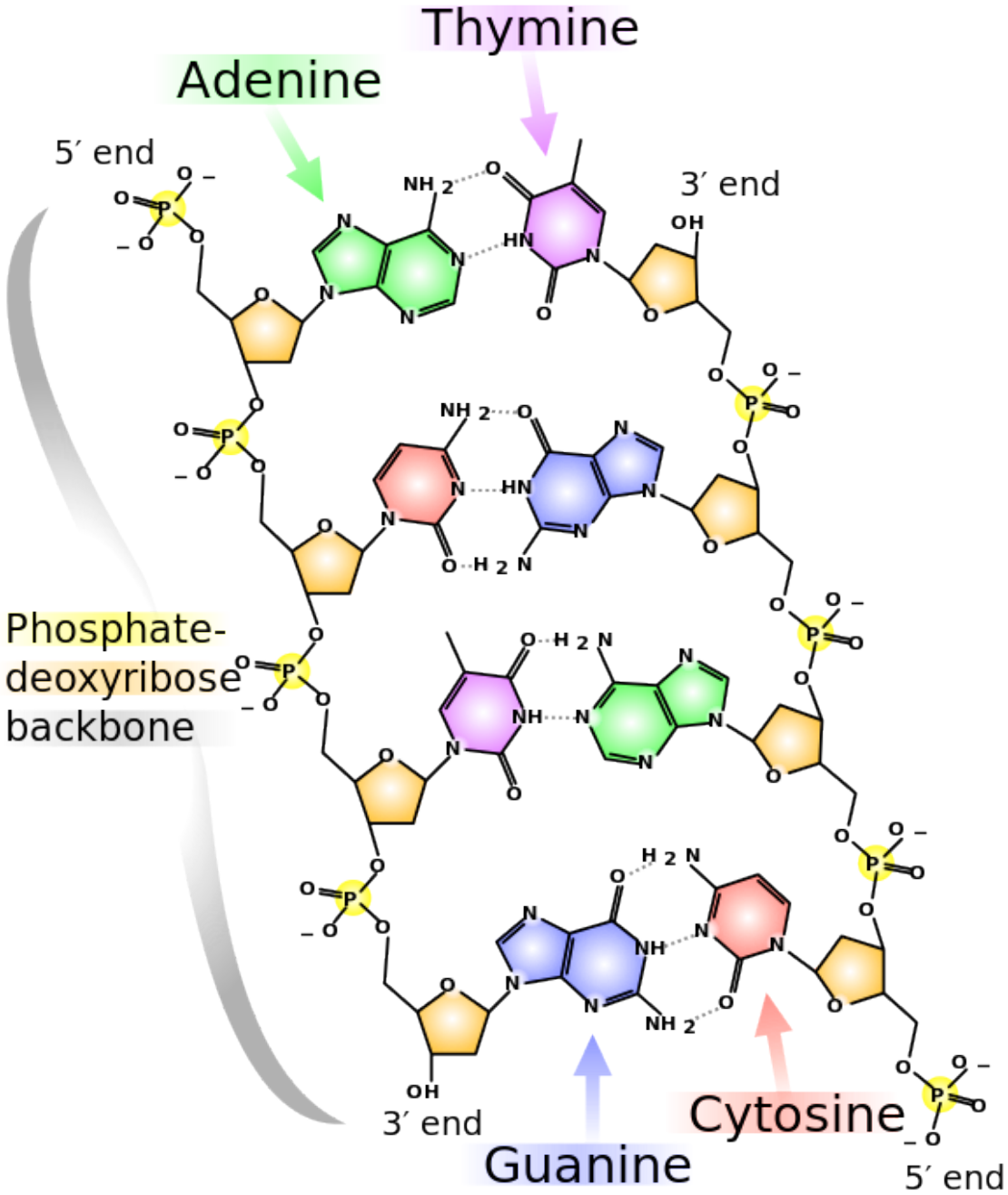
1953

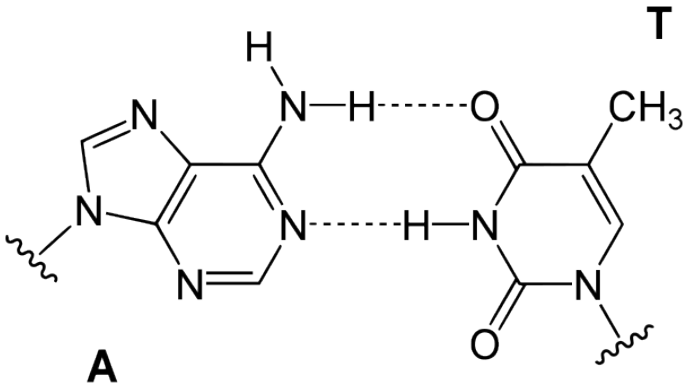
Un importante pub

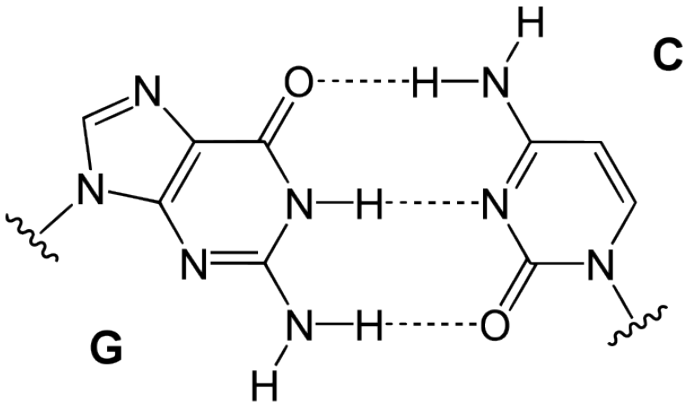
Singolo Filamento di DNA

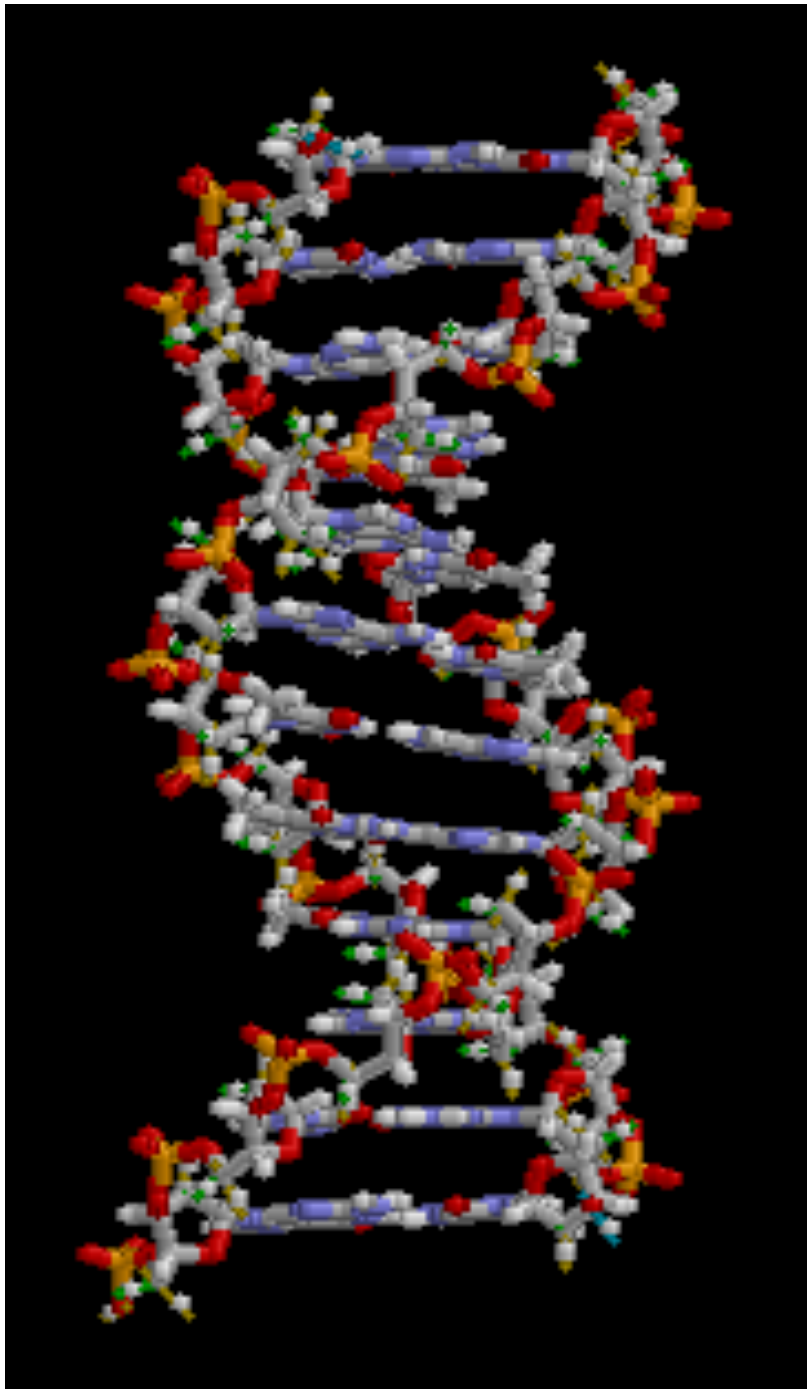
(250 milioni di basi in un cromosoma umano)



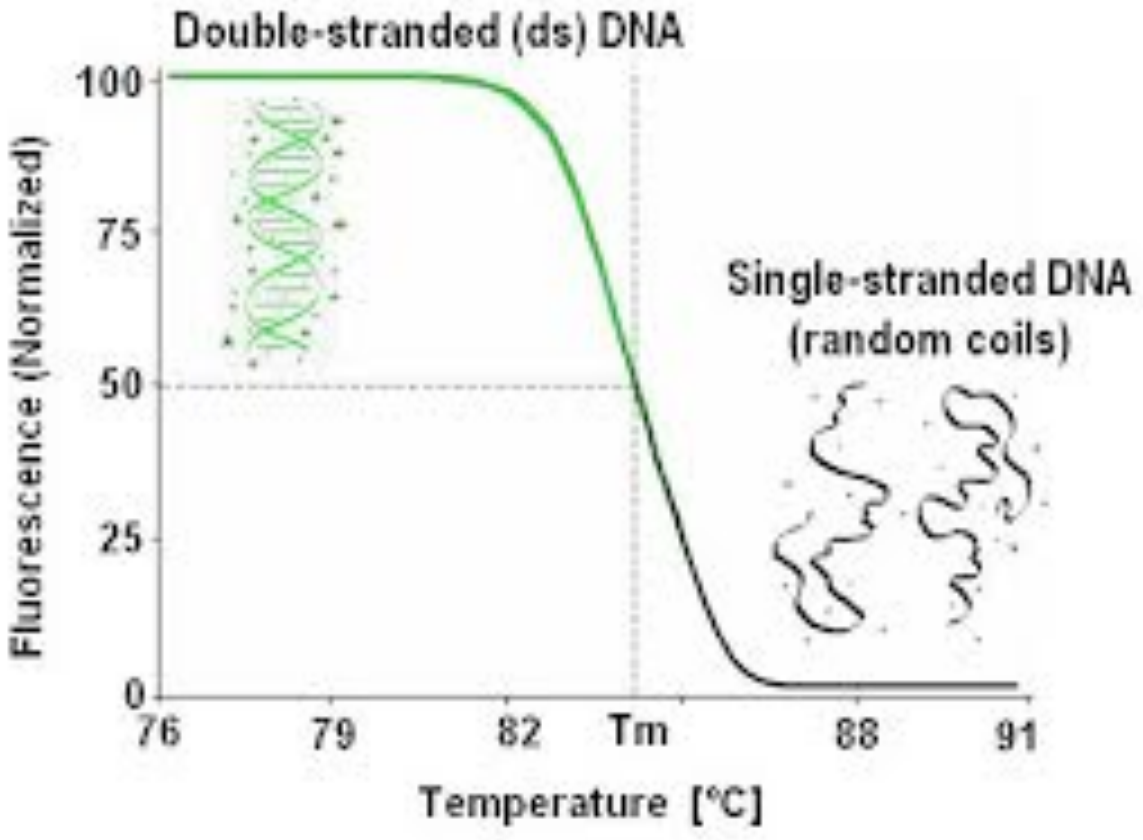

Thymine
Adenine
5′ end
3′ end
Phosphate-
deoxyribose
backbone
3′ end
Guanine
Cytosine
5′ end


T
A


C
G



Self Assembly con il DNA
curve di melting (per sequenze complementari).....

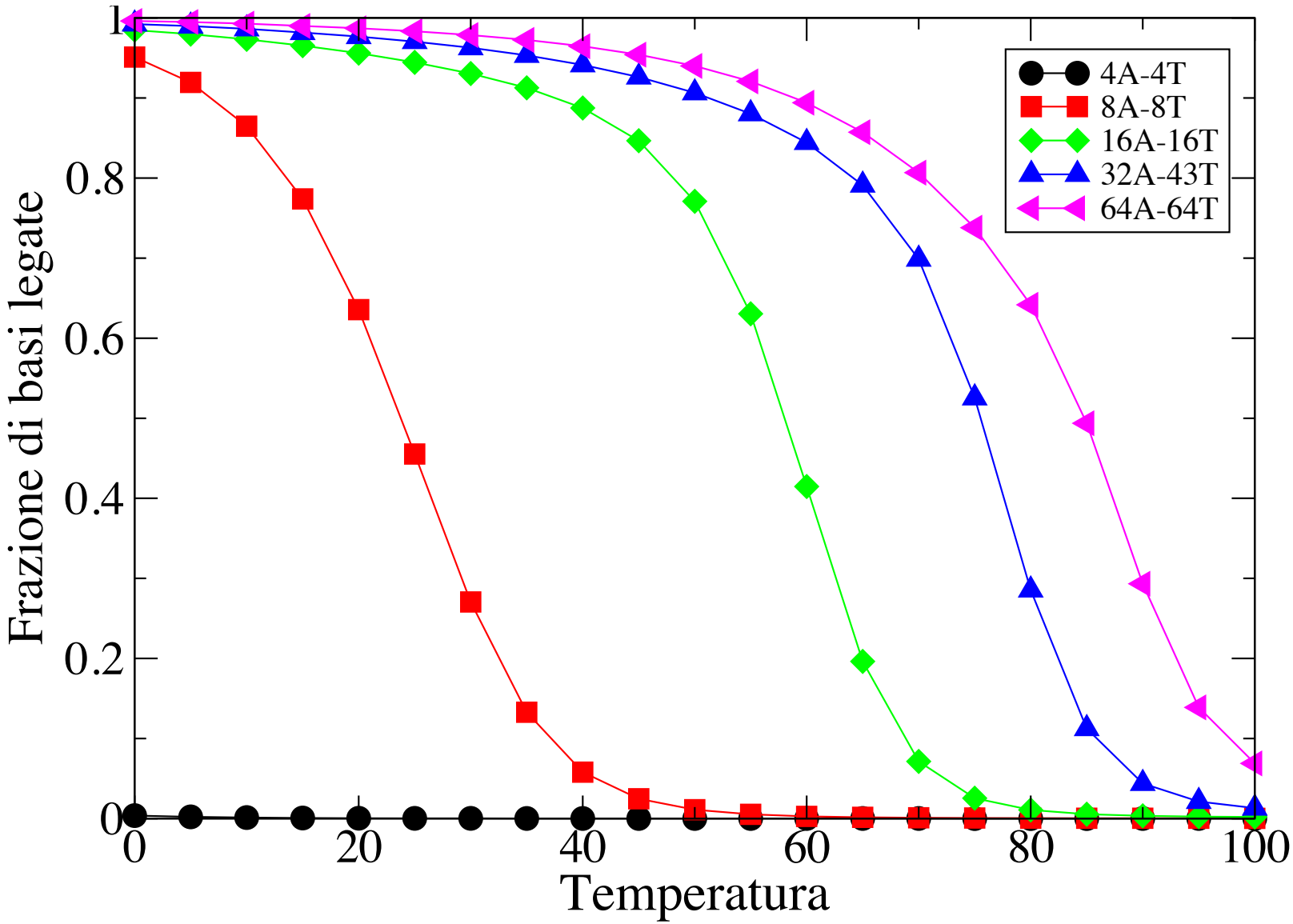


T melting

dipende da

Numero basi
Concentrazione DNA
Concentrazione sale
pH

Effetto della lunghezza del DNA



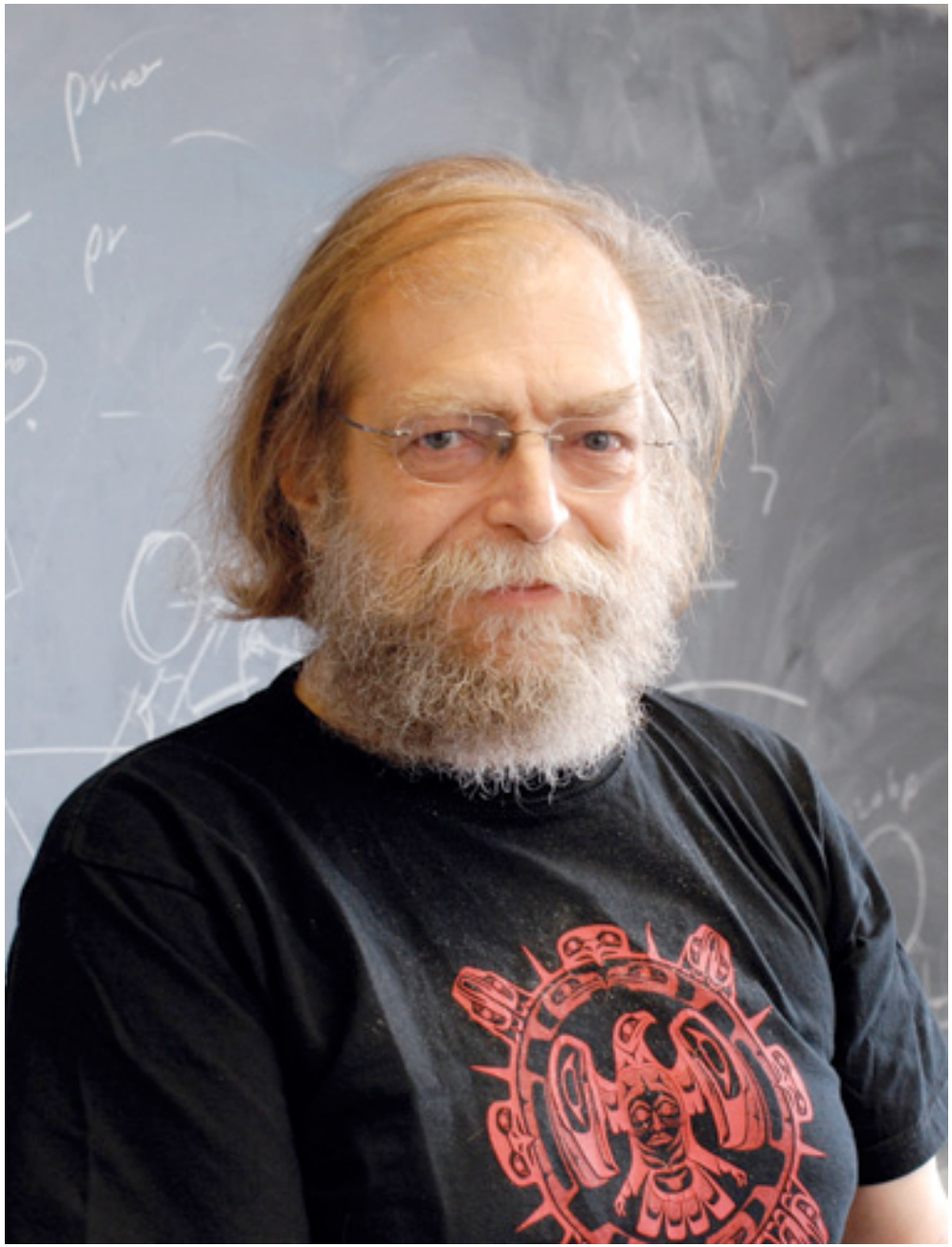
10 micromolare di ogni sequenza, 1 mol Na+

http://www.nupack.org

Il papa' del

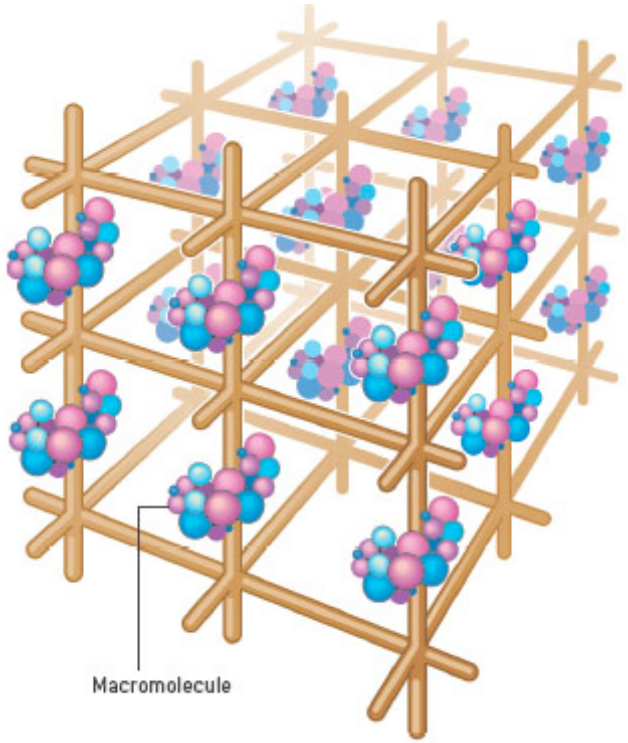
DNA Nanotechnogy

Nadrian C. "Ned" Seeman
(born December 16, 1945) is an American nanotechnologist and Crystallographer known for inventing the field of DNA nanotechnology.

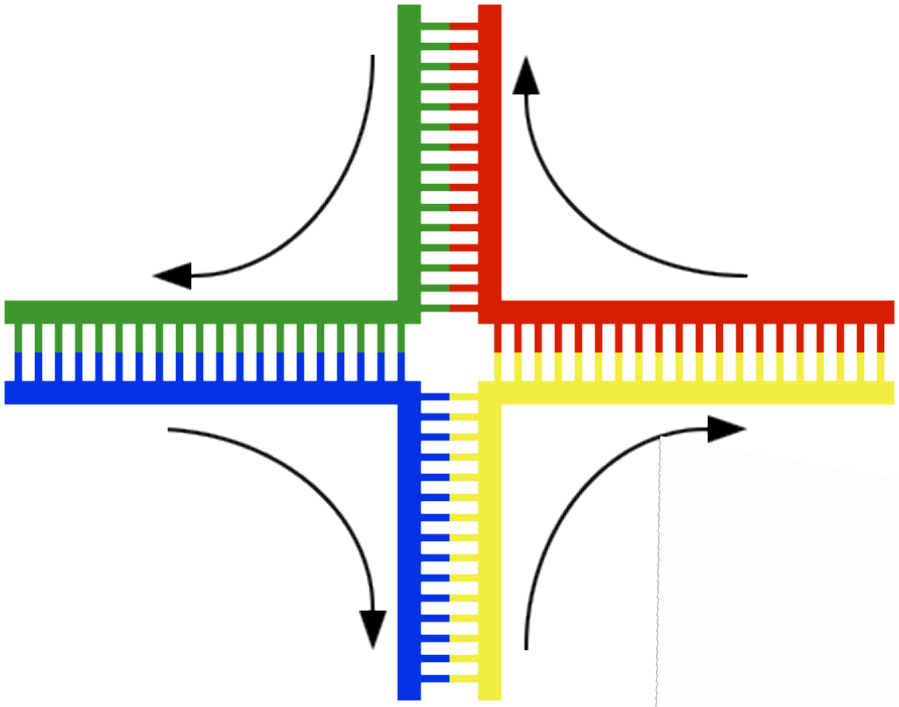


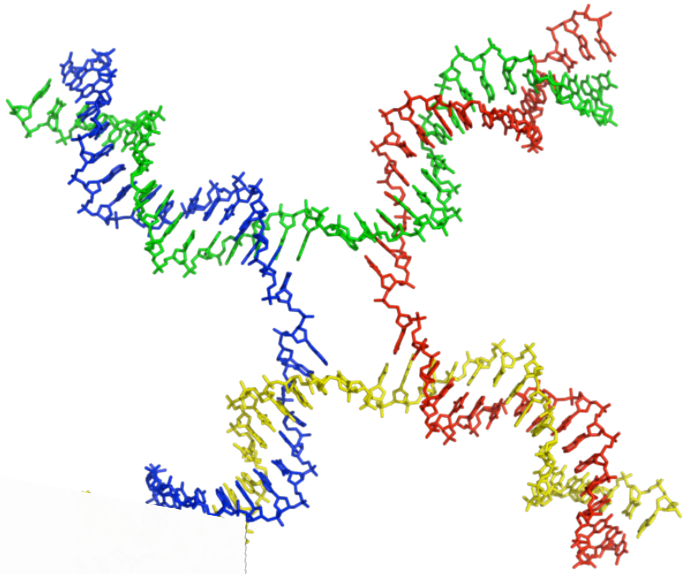
Un altro pub…. Escher e la storia di Seeman…….

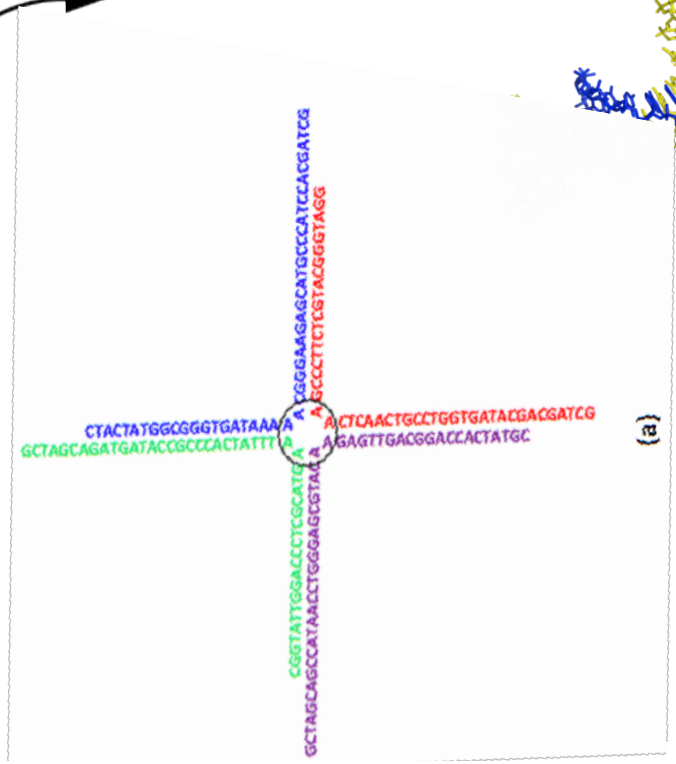
In fall 1980, while at a campus pub, Seeman was inspired by the M. C. Escher woodcut Depth to realize that a three-dimensional lattice could be constructed from DNA. He realized that this could be used to orient target molecules, simplifying their crystallographic study by eliminating the difficult process of obtaining pure crystals



Il “sogno” di Seeman:
Andare oltre il caso unidimensionale……







Il “mattone” tetramero

Self-Assembly di un tetramero: T < Tmelting

Come legare tra loro i mattoni (tetrameri) ?

ACCAVALLAVACCA

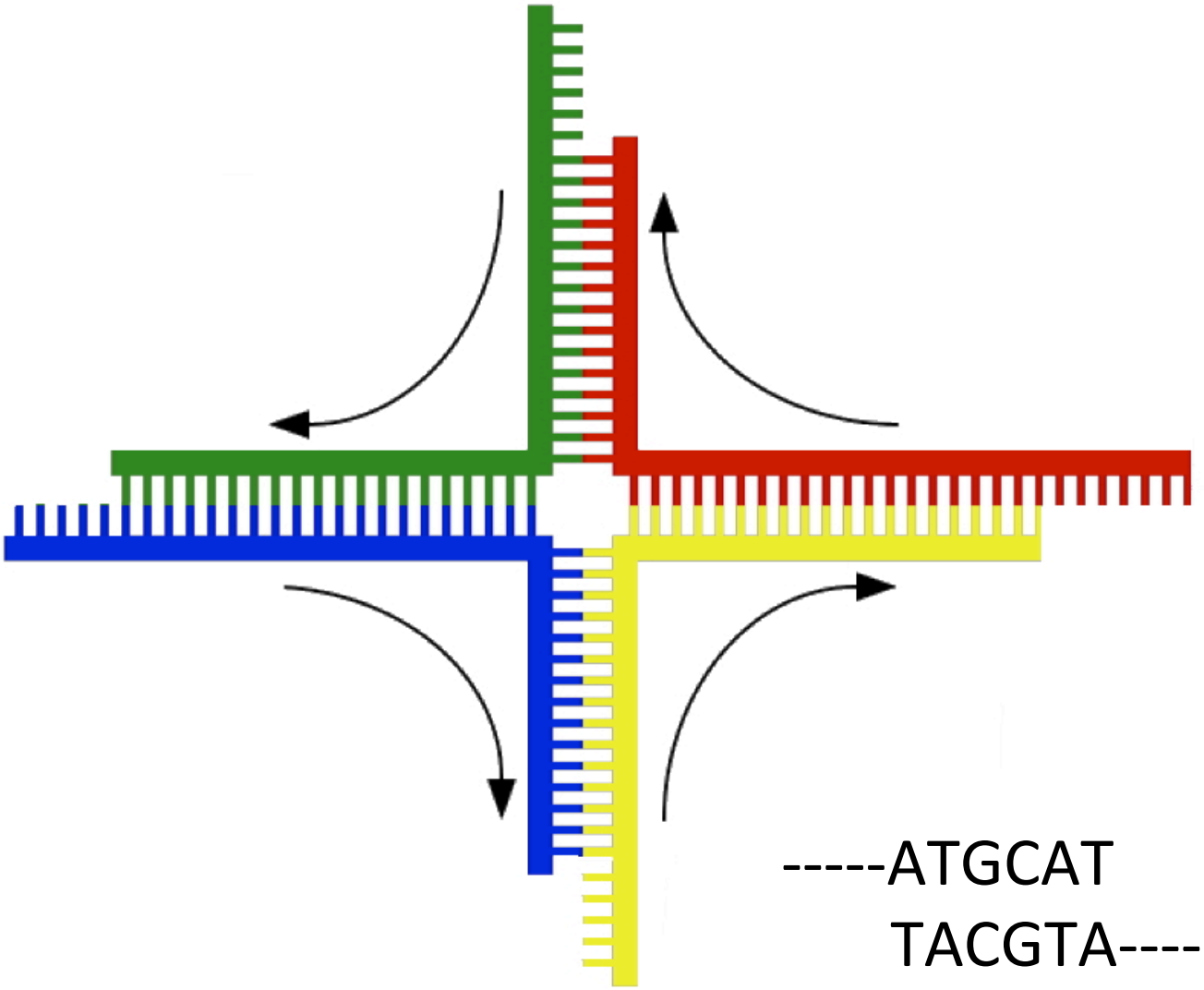
Legarsi con se stesso….

ACCAVALLAVACCA

A ma (romano)

Ed Irene se ne ride
I topi non avevano nipoti

Sticky ends…

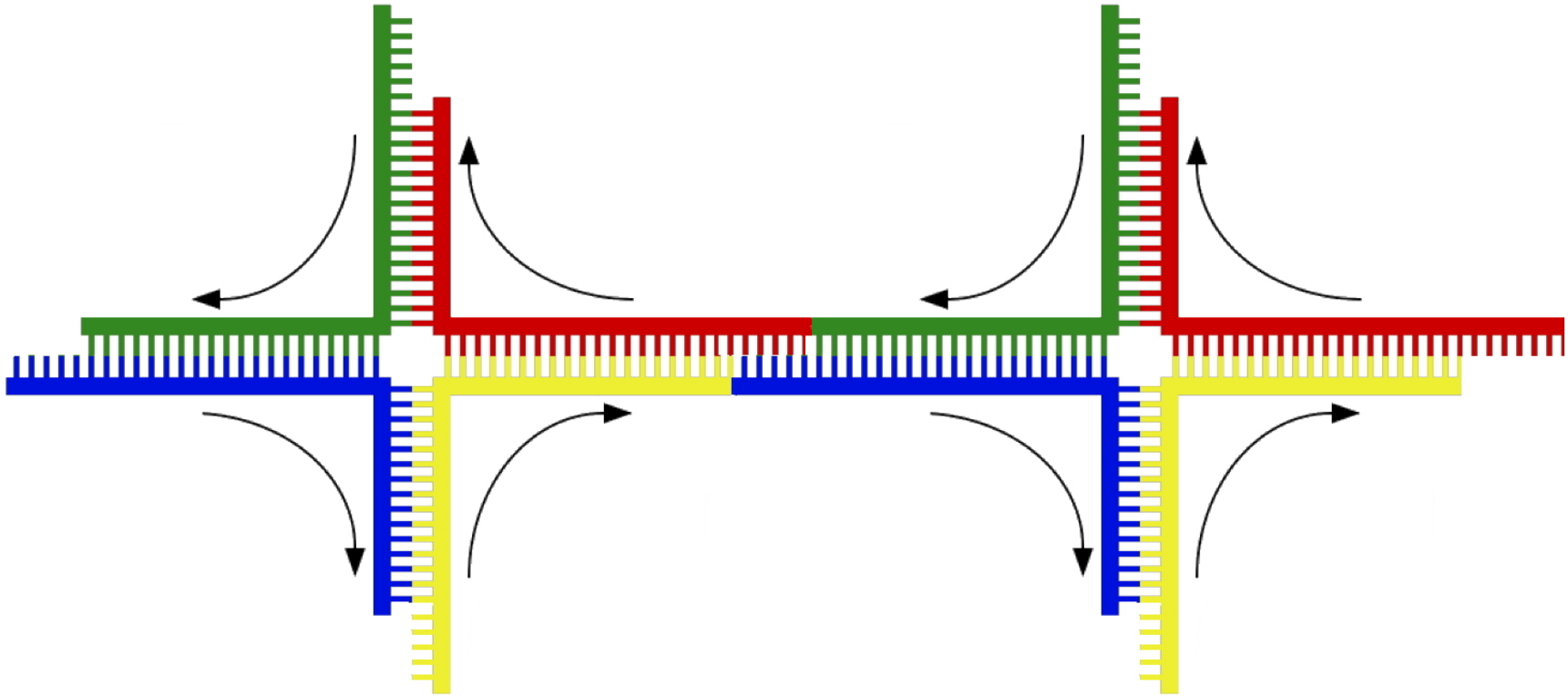


ATGCAT

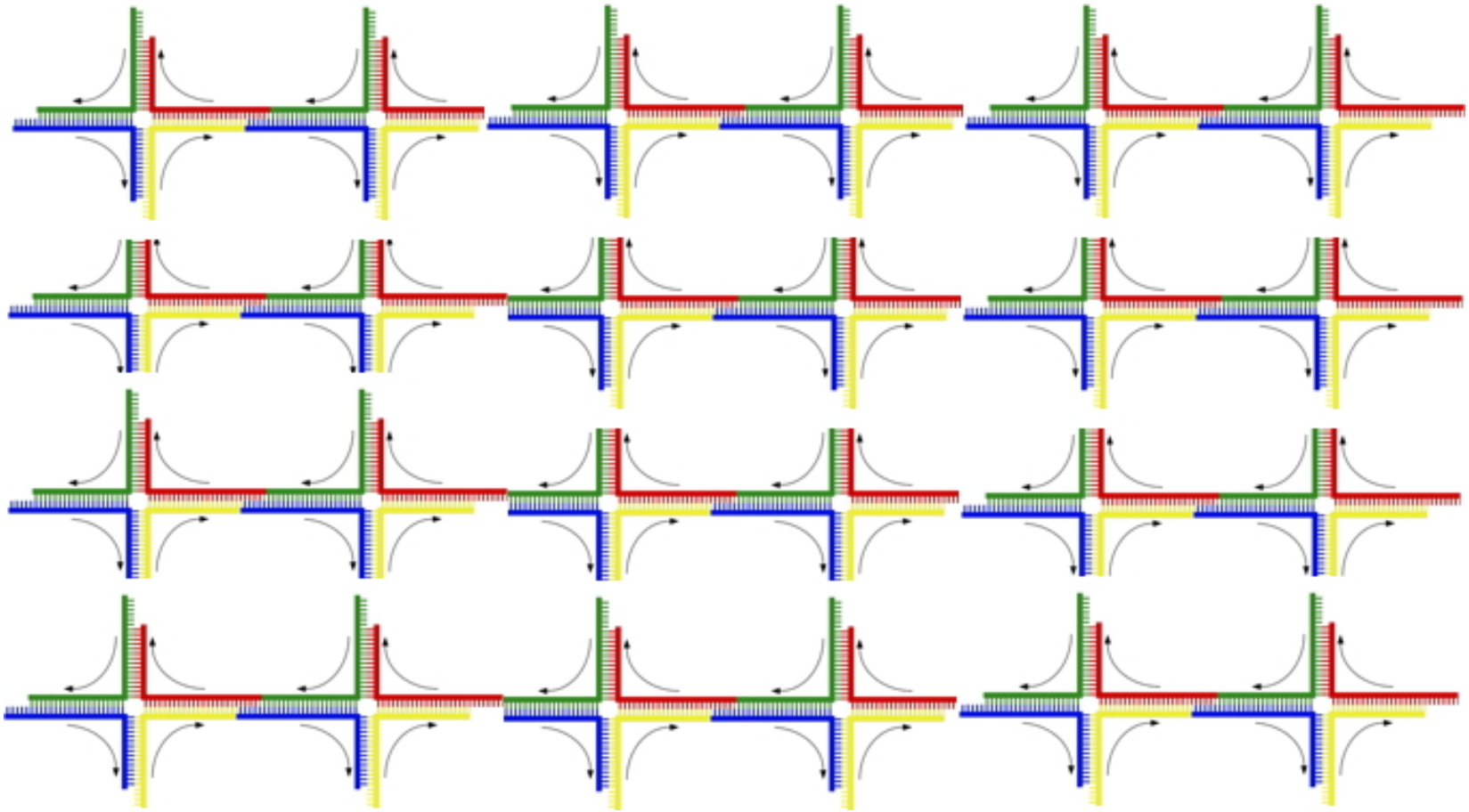
-----ATGCAT
TACGTA-------

Sequenze “palindromiche”

Alla temperatura di melting delle sticky-ends i tetrameri si attaccano tra loro……



Iterando…
un cristallo in 2 dimensioni in cui “intrappolare” le proteine

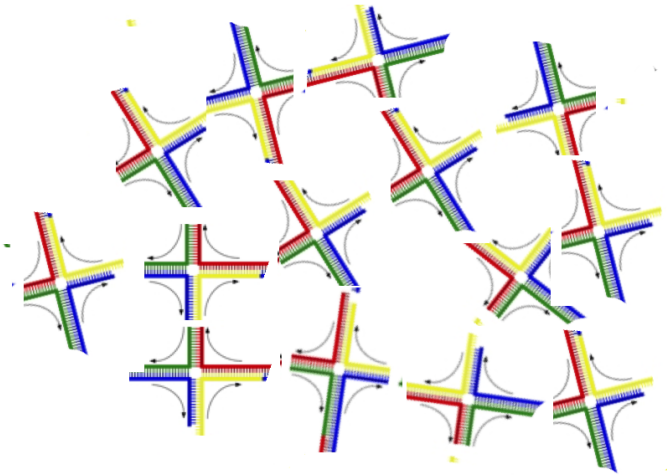


Ma……

I tetrameri si formano,

I tetrameri si legano…

Invece del cristallo si forma un “solido” disordinato (gel) !



Mattoni troppo flessibili !

Un fallimento (iniziale)
molto fecondo….

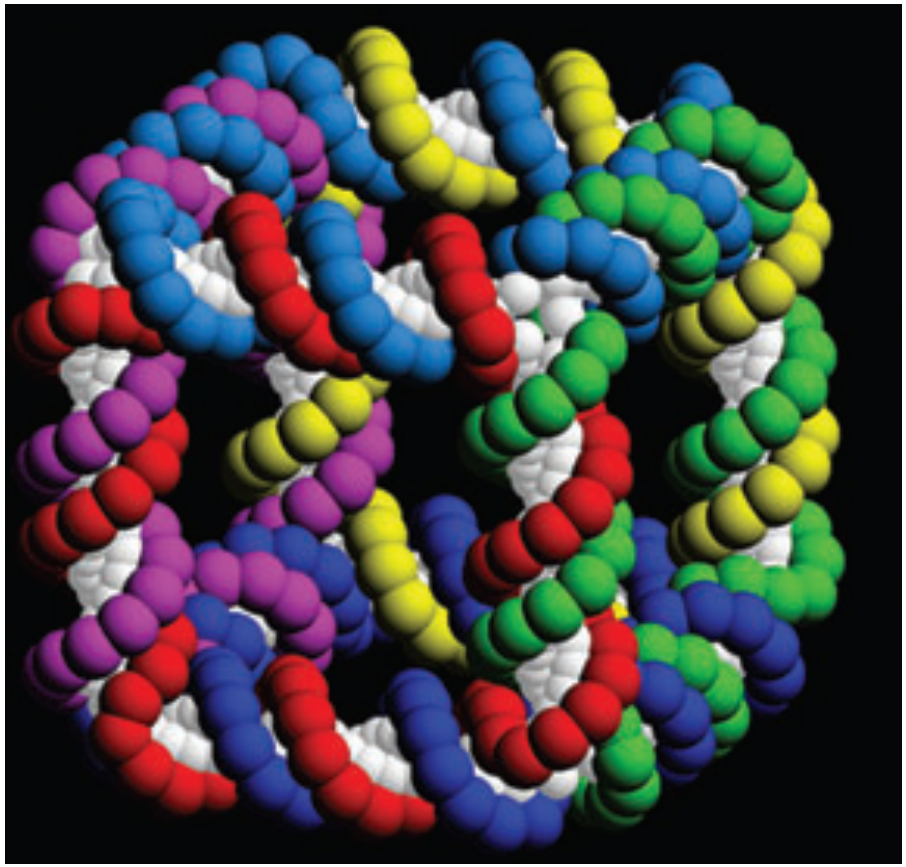
Come creare strutture tridimensionali?
Come creare strutture rigide ?

J. Am. Chem. Soc. **1994,** *116,* 1661–1669

Construction of a DNA-Truncated Octahedron

Yuwen Zhang and Nadrian C. Seeman*

Contribution from the Department of Chemistry, New York University, New York, New York 10003

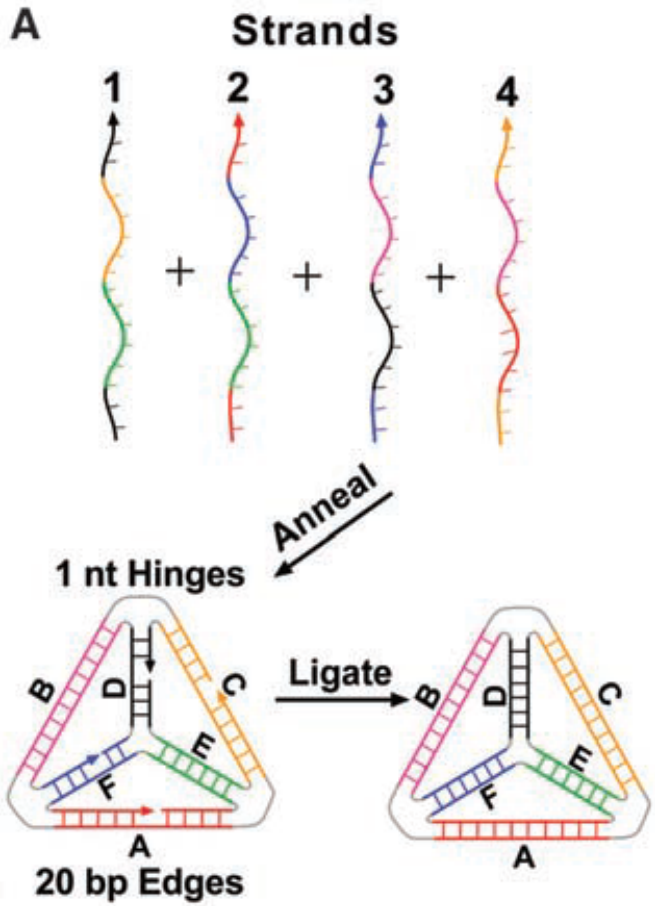


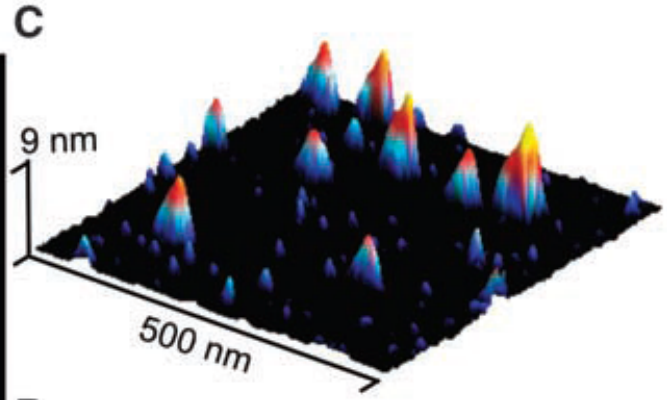
Tetraedri.....

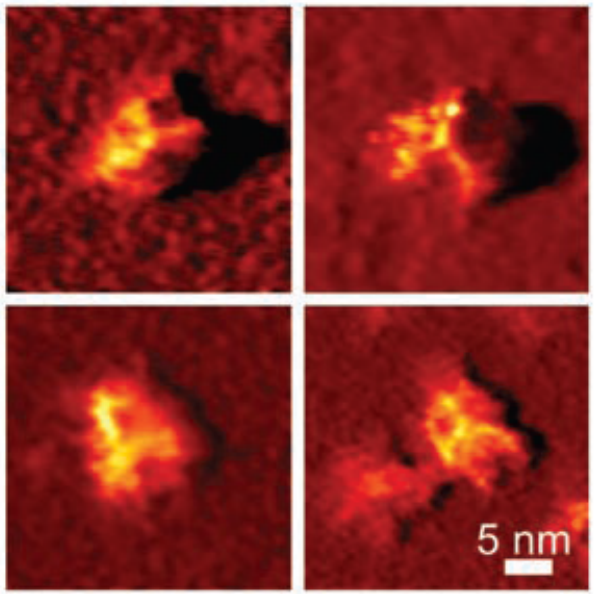
SCIENCE VOL 310 9 DECEMBER 2005

Rapid Chiral Assembly of Rigid DNA Building Blocks for Molecular Nanofabrication

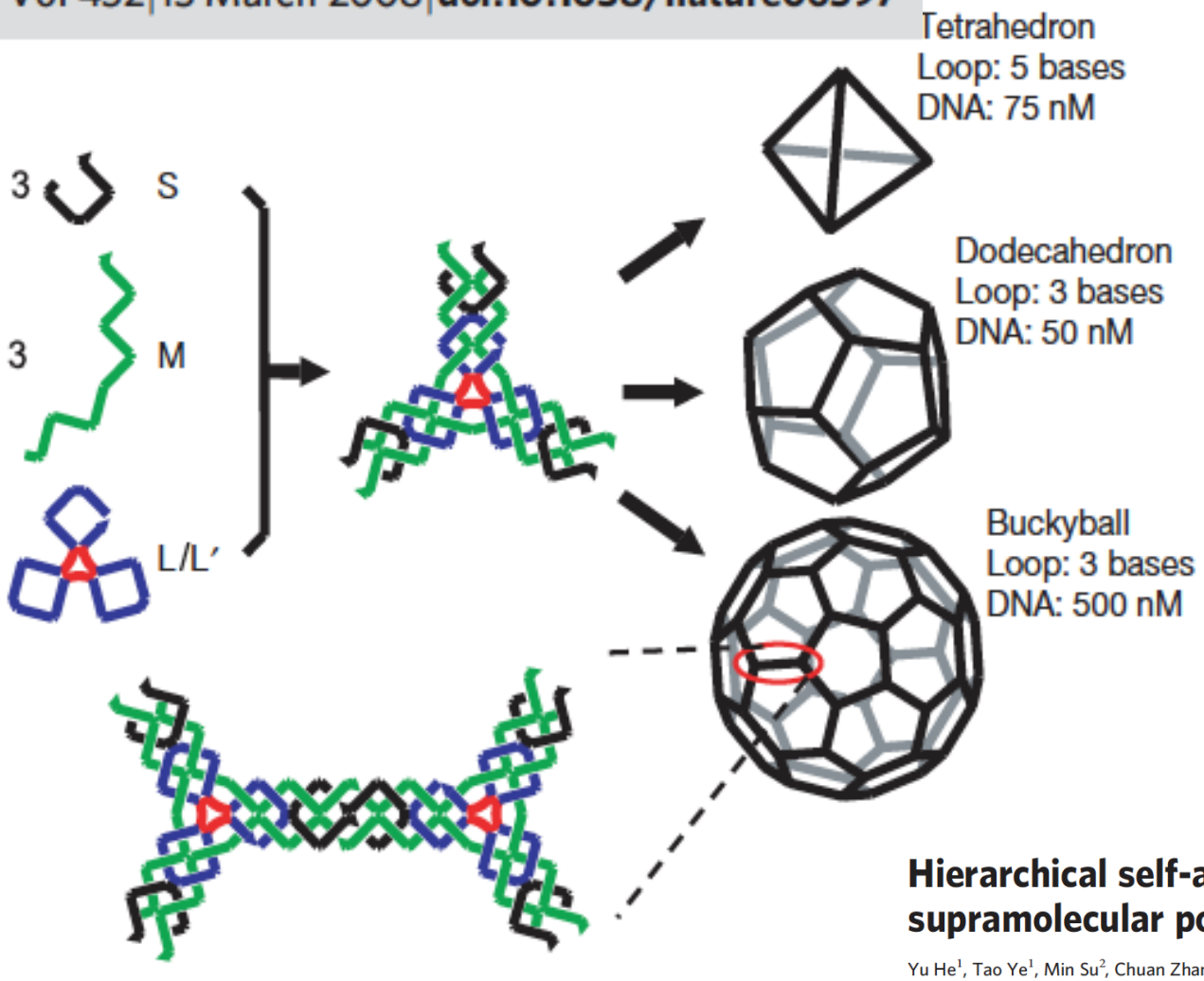
R. P. Goodman,[1] I. A. T. Schaap,[2] C. F. Tardin,[2] C. M. Erben,[1]
R. M. Berry,[1] C. F. Schmidt,[2] A. J. Turberfield[1]*

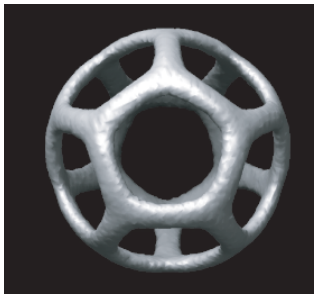


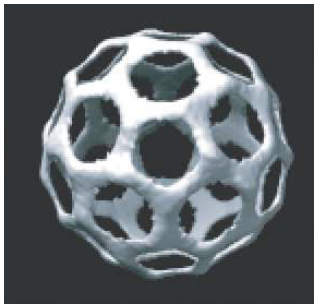




Vol 452|13 March 2008|doi:10.1038/nature06597







Hierarchical self-assembly of DNA into symmetric supramolecular polyhedra

Yu He[1], Tao Ye[1], Min Su[2], Chuan Zhang[1], Alexander E. Ribbe[1], Wen Jiang[2] & Chengde Mao[1]

Figure 1 | Self-assembly of DNA polyhedra. Three different types of DNA single strands stepwise assemble into symmetric three-point-star motifs (tiles) and then into polyhedra in a one-pot process. There are three single-stranded loops (coloured red) in the centre of the complex. The final structures (polyhedra) are determined by the loop length (3 or 5 bases long) and the DNA concentration.

Programming DNA Tube Circumferences

Peng Yin *et al.*

Science **321**, 824 (2008);
DOI: 10.1126/science.1157312

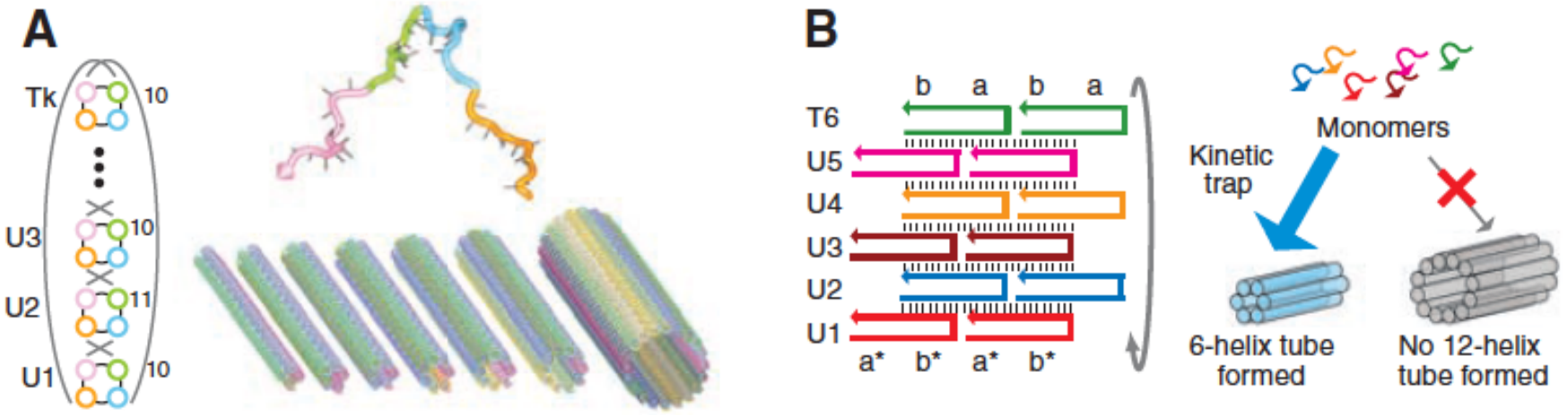
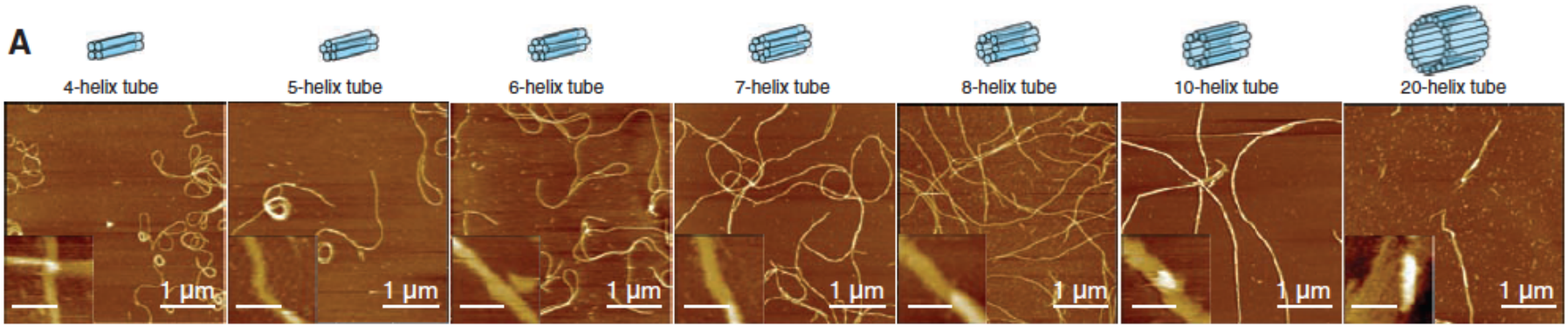
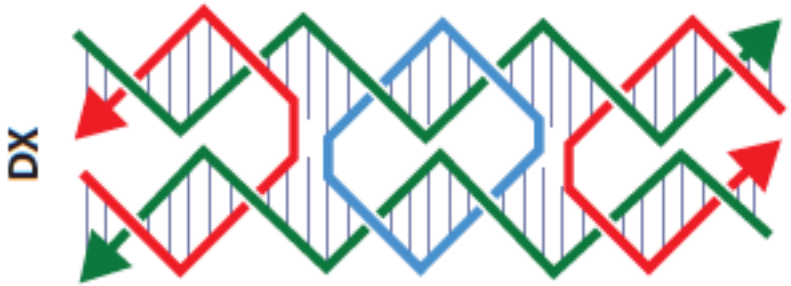
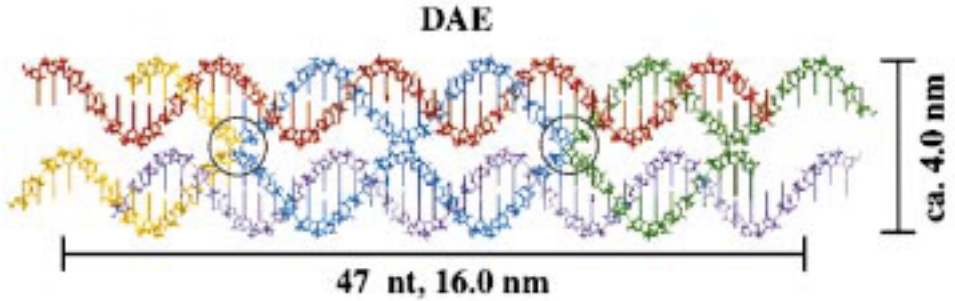


Fig. 3. Monodisperse DNA tubes with programmed circumferences. (**A**) Molecular program (left) and 3D illustrations (right) for assembling *k*-helix tubes. (**B**) Secondary structure (left) and putative kinetic trapping (right) for six-helix tubes. Asterisks denote complementarity.

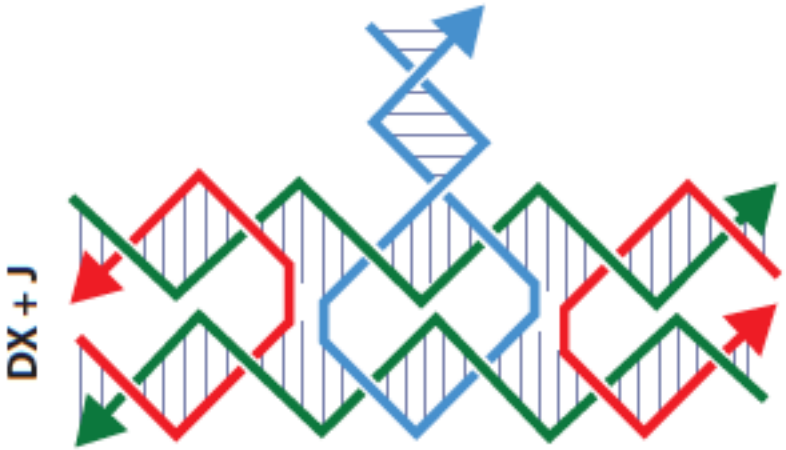


Come costruire dei mattoni piu' rigidi: DOPPIO CROSS-OVER (DX) + STICKY ENDS





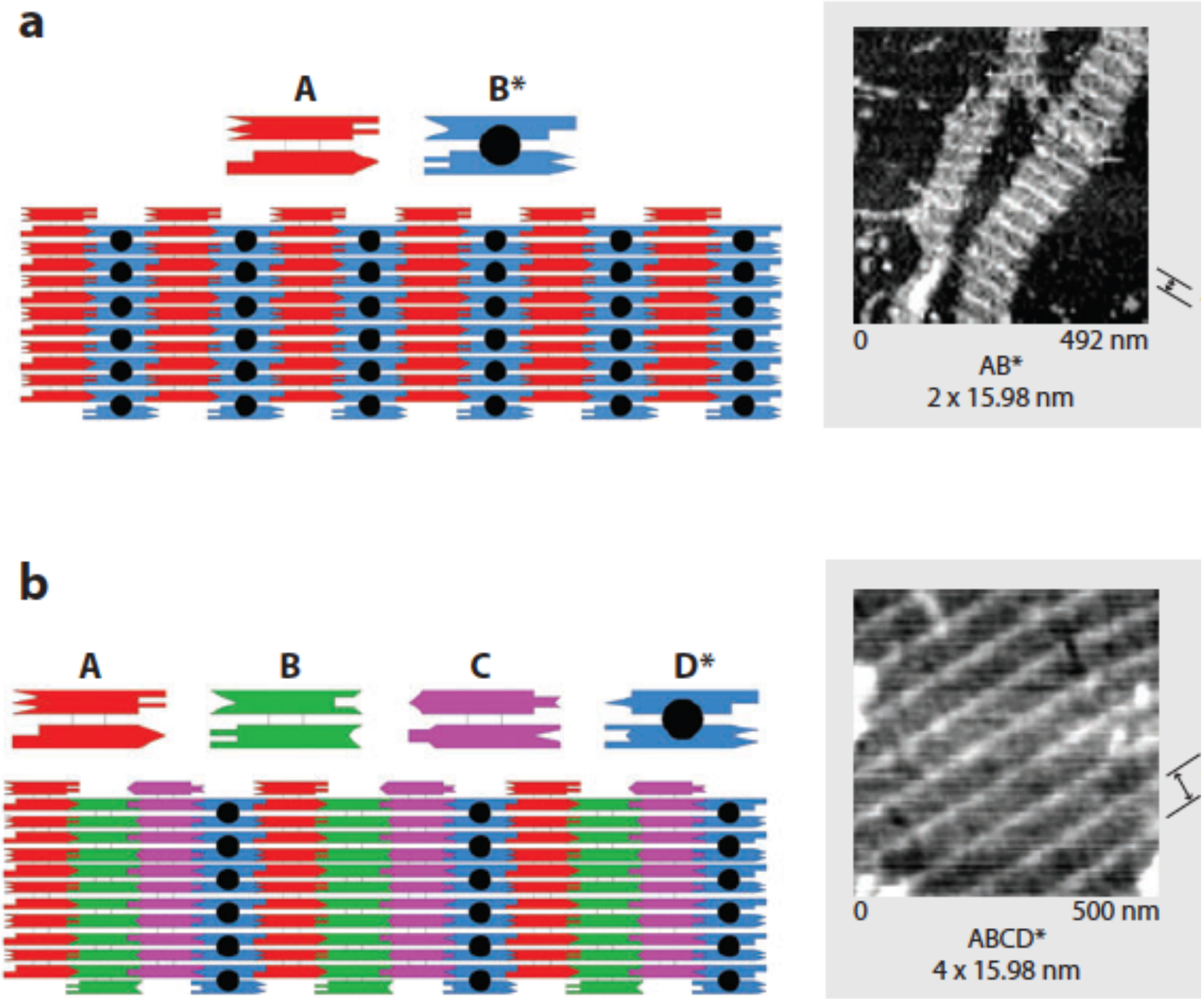
Double cross-over antiparallel odd number of half-turn



Design and self-assembly of two-dimensional DNA crystals

Erik Winfree*, Furong Liu†, Lisa A. Wenzler† & Nadrian C. Seeman†

* *Computation and Neural Systems, California Institute of Technology, Pasadena, California 91125, USA*
† *Department of Chemistry, New York University, New York, New York 10003, USA*

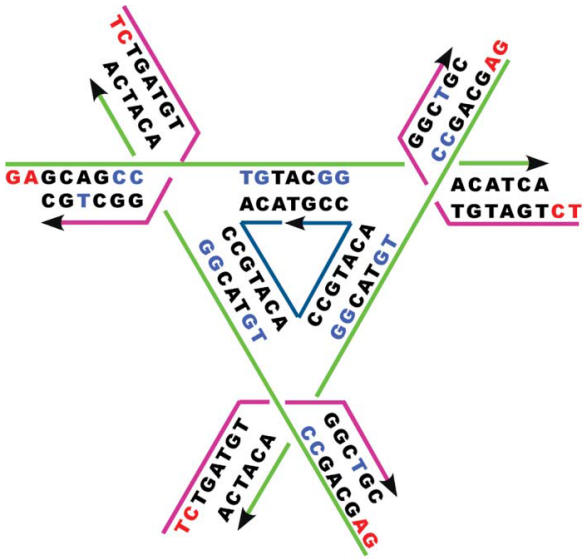

a
A
B*
0
492 nm
AB*
2 x 15.98 nm
b
A
B
C
D*
0
500 nm
ABCD*
4 x 15.98 nm

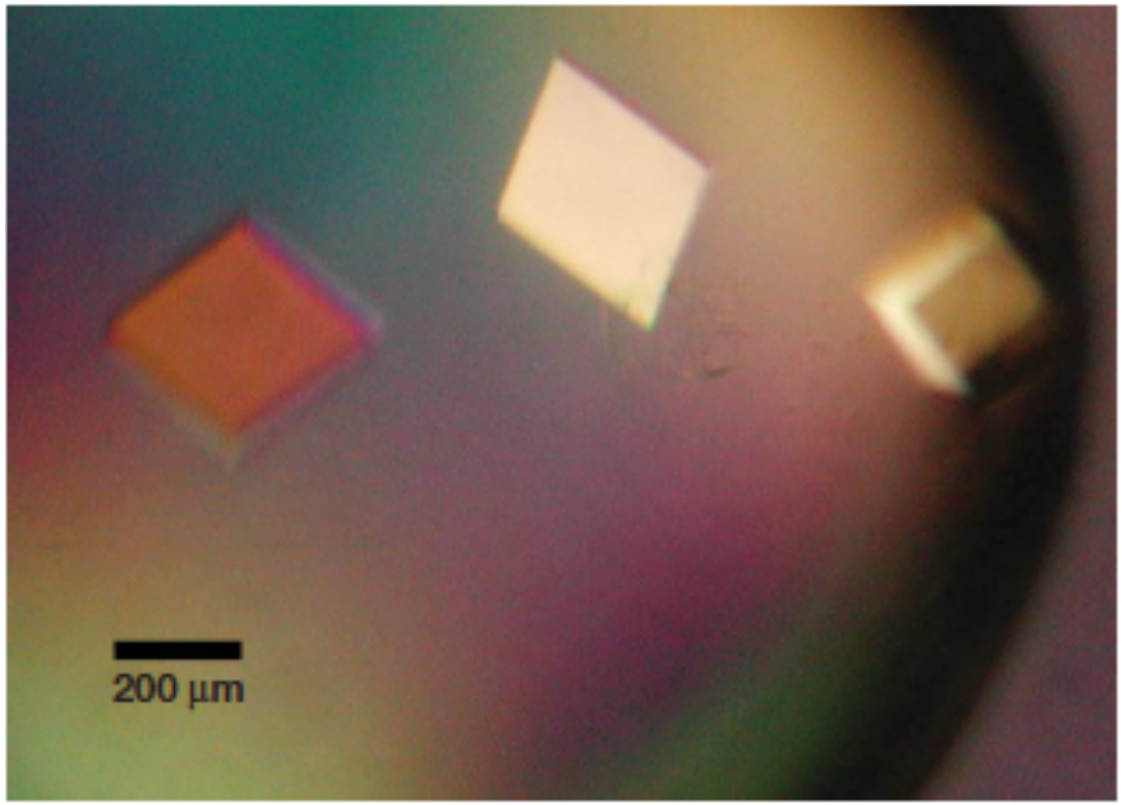
nature Vol 461|3 September 2009|doi:10.1038/nature08274

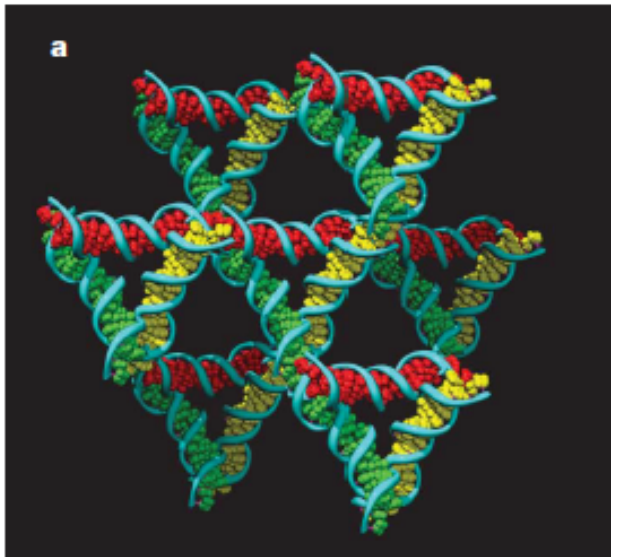
LETTERS

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]







2009

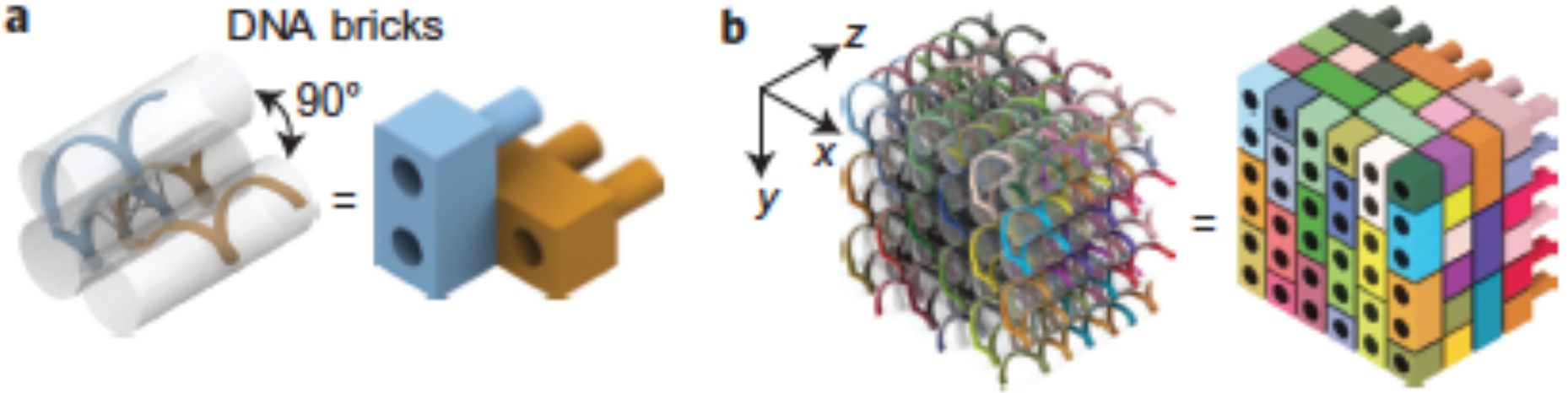
nature chemistry

ARTICLES

PUBLISHED ONLINE: 19 OCTOBER 2014 | DOI: 10.1038/NCHEM.2083

DNA brick crystals with prescribed depths

Yonggang Ke[1,2,3*†‡], Luvena L. Ong[1,4‡], Wei Sun[1,5‡], Jie Song[6], Mingdong Dong[6], William M. Shih[1,2,3] and Peng Yin[1,5*]



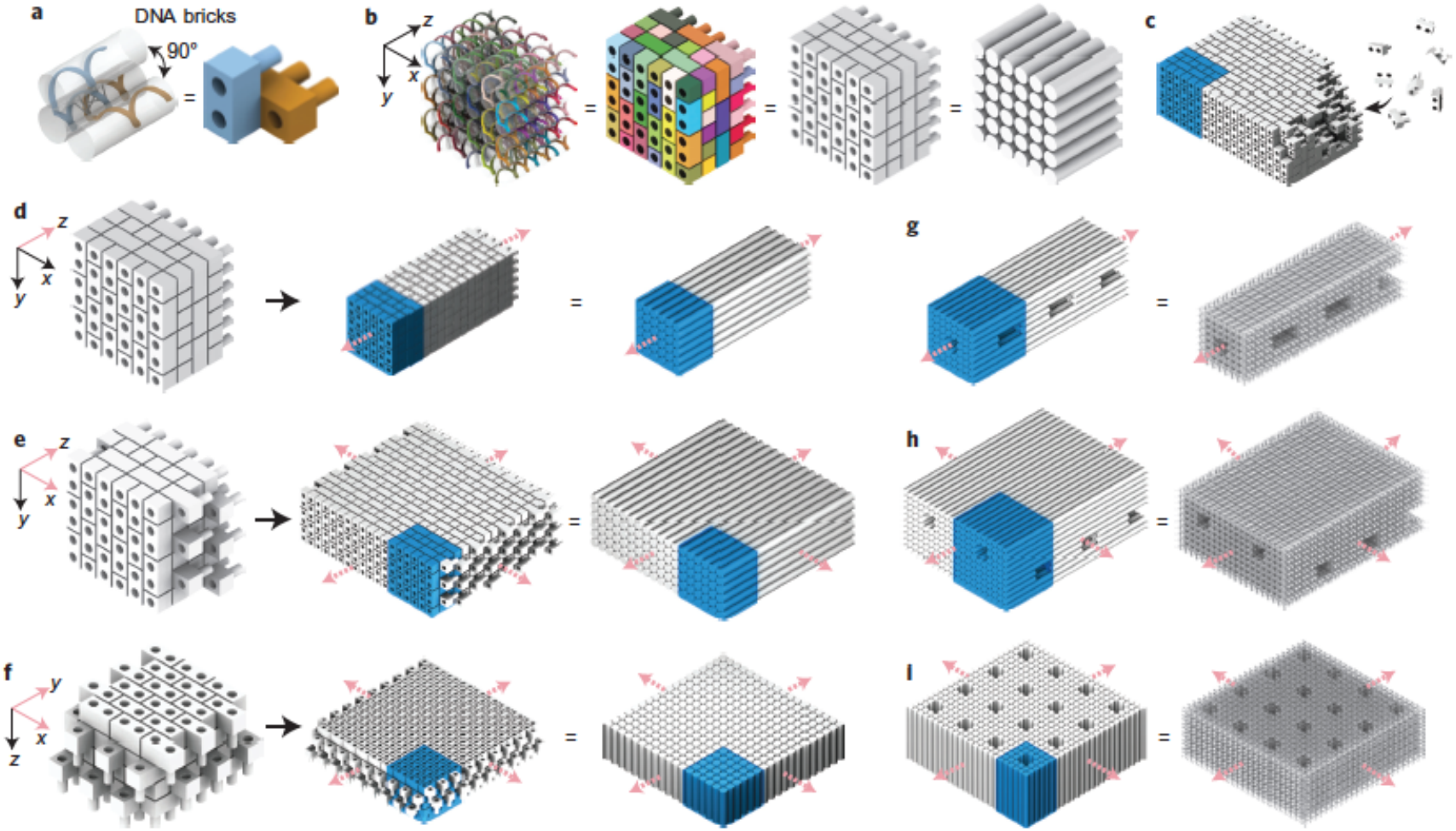
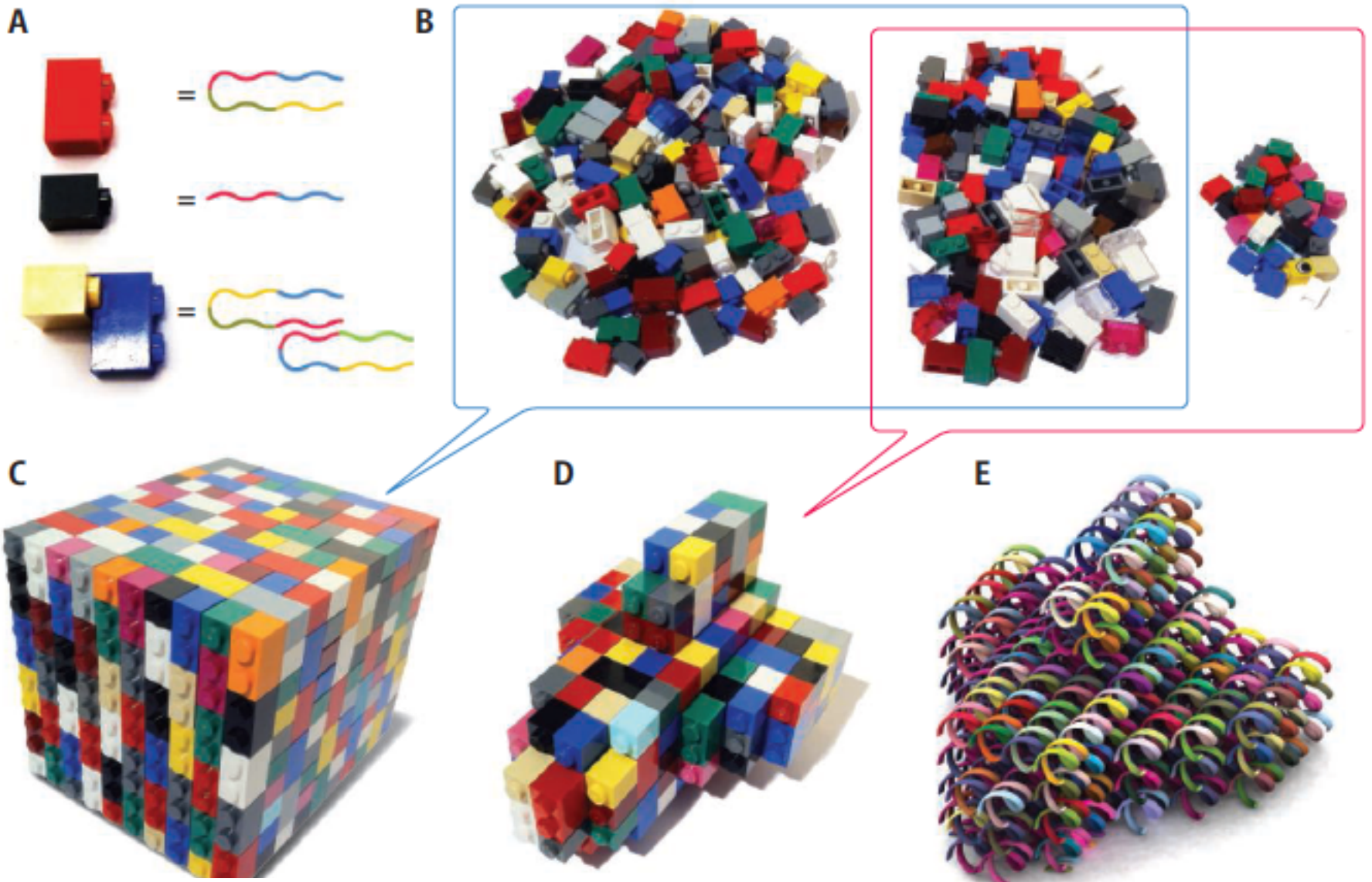


Figure 1 | Design of DNA brick crystals. a, Strand (left) and brick (right) models showing two 32-nt DNA bricks that form a 90° angle. **b**, Models of a 6H (helix) × 6H (helix) × 24B (base pair) cuboid with increasing levels of abstraction: (left to right) a strand model, a brick model (in which colours distinguish brick species), a brick model with all bricks coloured grey, and a model where cylinders represent DNA double helices. **c**, Individual DNA strands, rather than pre-assembled multi-brick blocks, are directly incorporated into the growing crystal. **d–f**, Brick and cylinder models of a one-dimensional Z-crystal (**d**), a two-dimensional ZX-crystal (**e**) and a two-dimensional XY-crystal (**f**) designed from the 6H × 6H × 24B cuboid. **g–i**, Cylinder and DNA-helix models of crystals with pores and tunnels: Z-crystal with a tunnel and periodic pores (**g**); ZX-crystal with two groups of parallel tunnels (**h**); XY-crystal with periodic pores (**i**). Repeating units of the crystals are denoted by blue boxes. Pink arrows indicate the directions of crystal growth.

DNA LEGO



Three-Dimensional Structures Self-Assembled from DNA Bricks
Yonggang Ke *et al.*
Science **338**, 1177 (2012);
DOI: 10.1126/science.1227268

DNA gels……

ACCOUNTS of chemical research

Article

pubs.acs.org/accounts

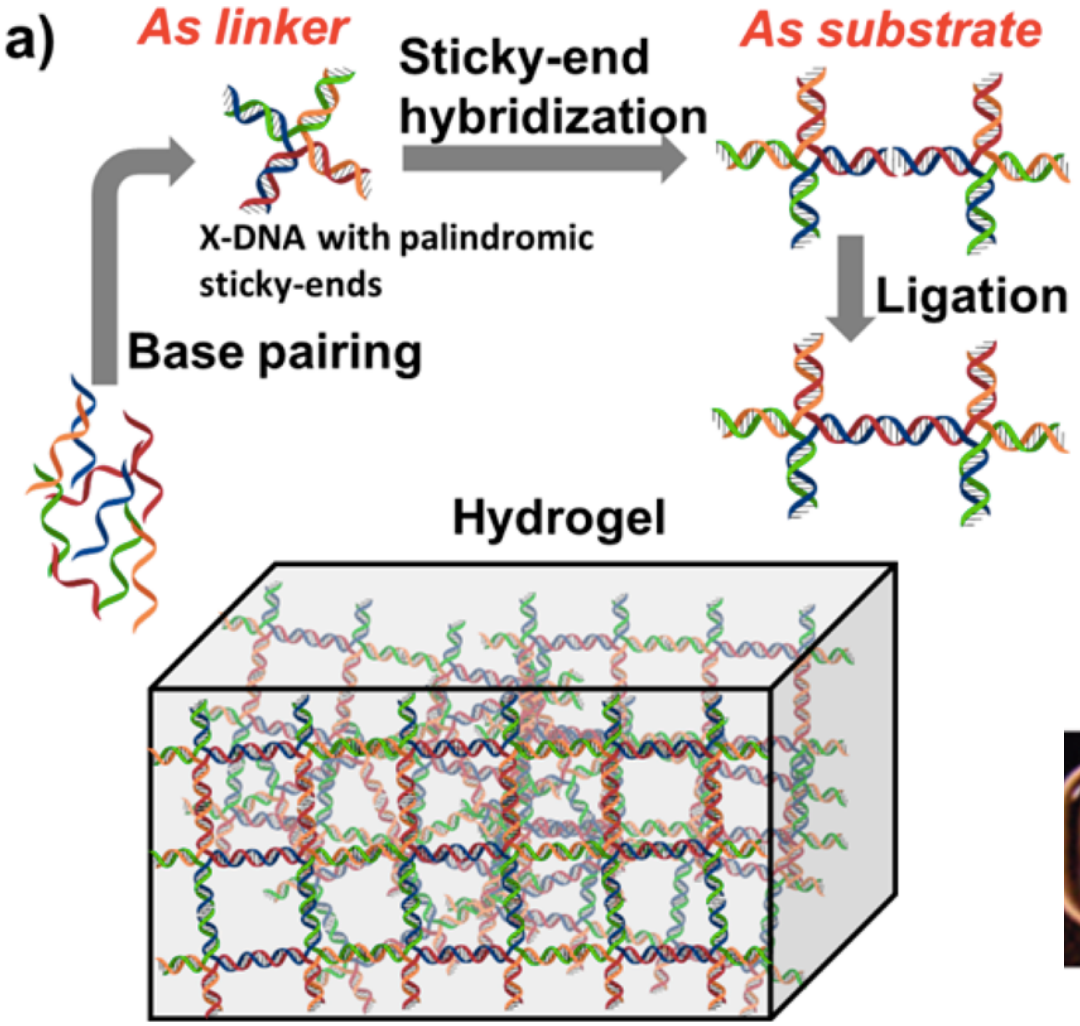
DNA Materials: Bridging Nanotechnology and Biotechnology

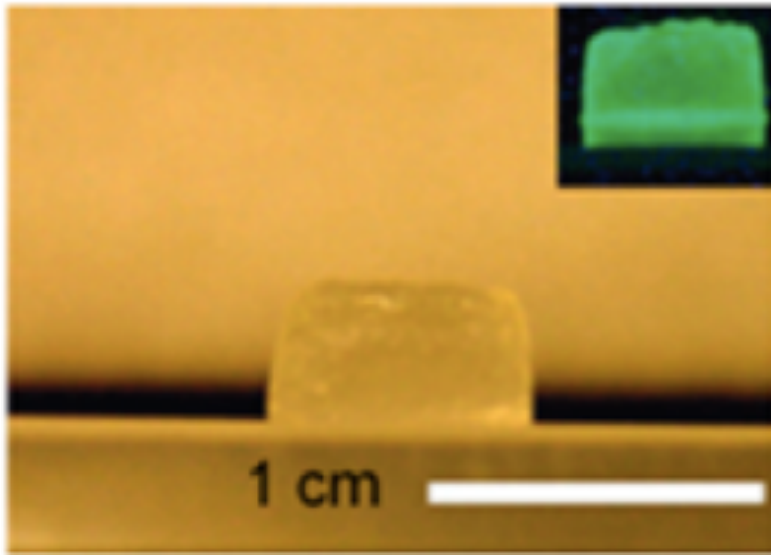
Dayong Yang,[†] Mark R. Hartman,[†] Thomas L. Derrien,[†] Shogo Hamada,[‡] Duo An,[†] Kenneth G. Yancey,[†] Ru Cheng,[†,§] Minglin Ma,[†] and Dan Luo*[,†,‡]

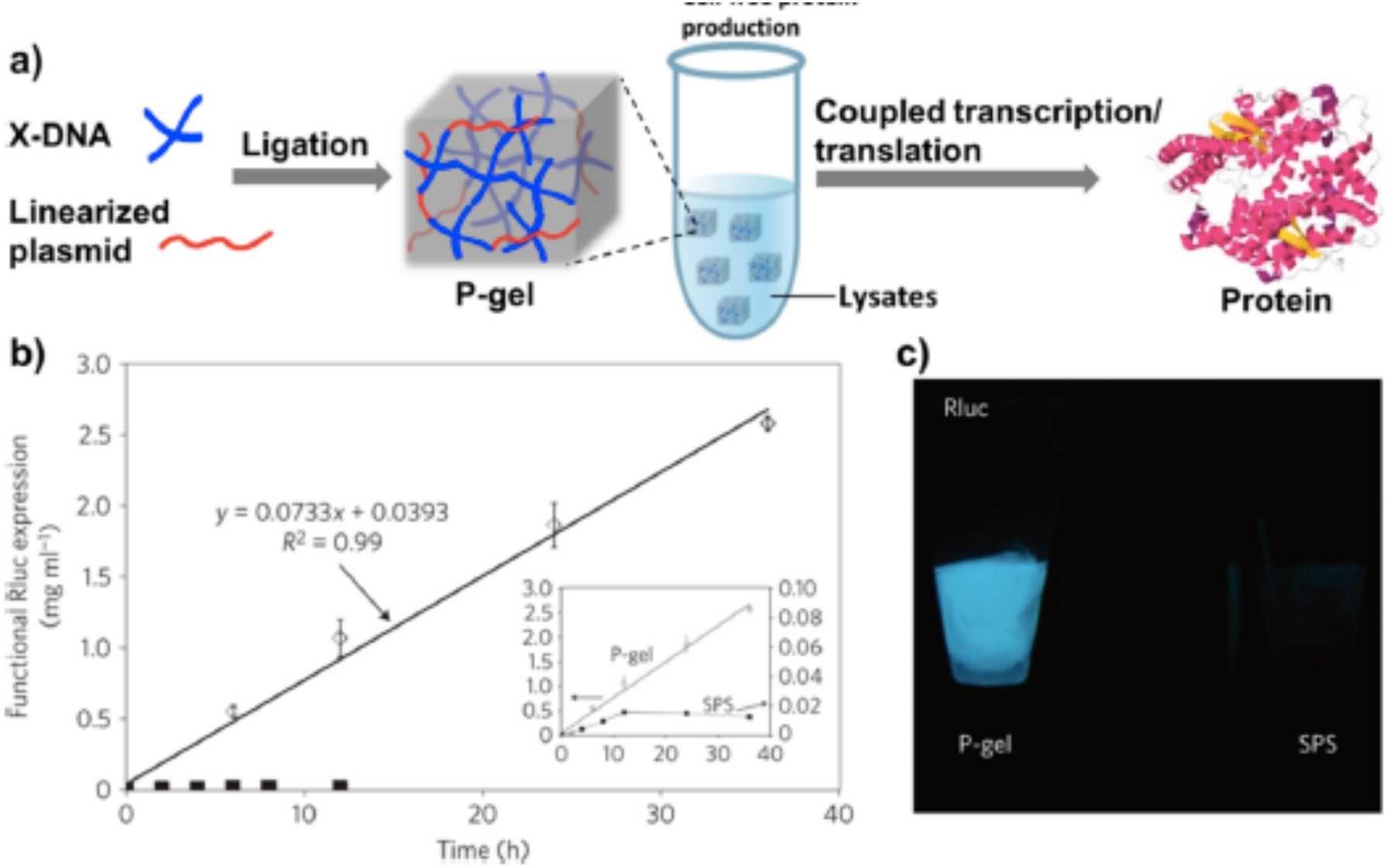
[†]Department of Biological & Environmental Engineering, Cornell University, Ithaca, New York 14853, United States

[‡]Kavli Institute at Cornell for Nanoscale Science, Cornell University, Ithaca, New York 14853, United States

[§]College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou 215123, China







protein-producing DNA hydrogel (P-gel). (a) Scheme of P-gel. (b) Protein production from P-gel (open dia
Bioluminescence image of Rluc protein expressed from P-gel over SPS.

Riassunto (fin qui)….

- E’ possibile, con ingegno, costruire oggetti di varie forme a partire da oligomeri di DNA
- E’ possibile anche costruire veri e propri mattoni con cui far crescere spontaneamente strutture ordinate (cristalli)
- E’ possibile “indirizzare” in modo selettivo regioni del materiale….

Paul Rothemund

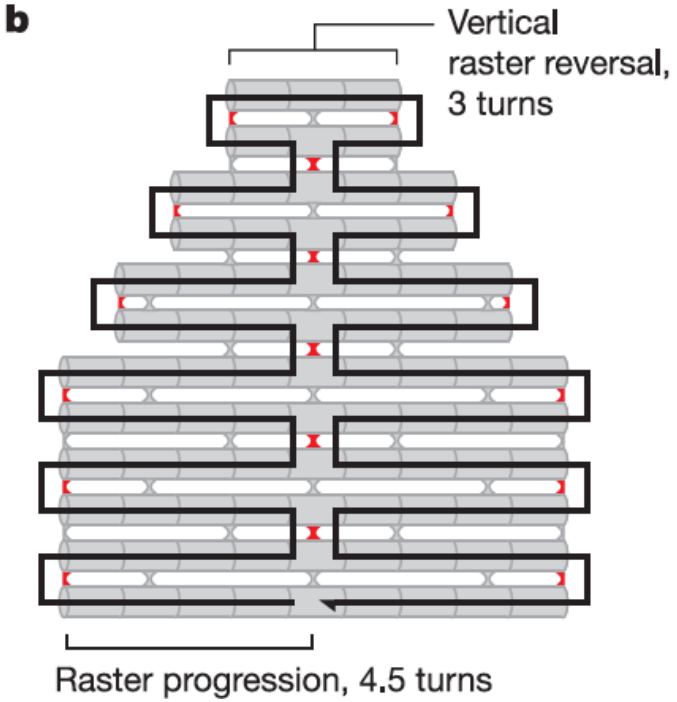
2006

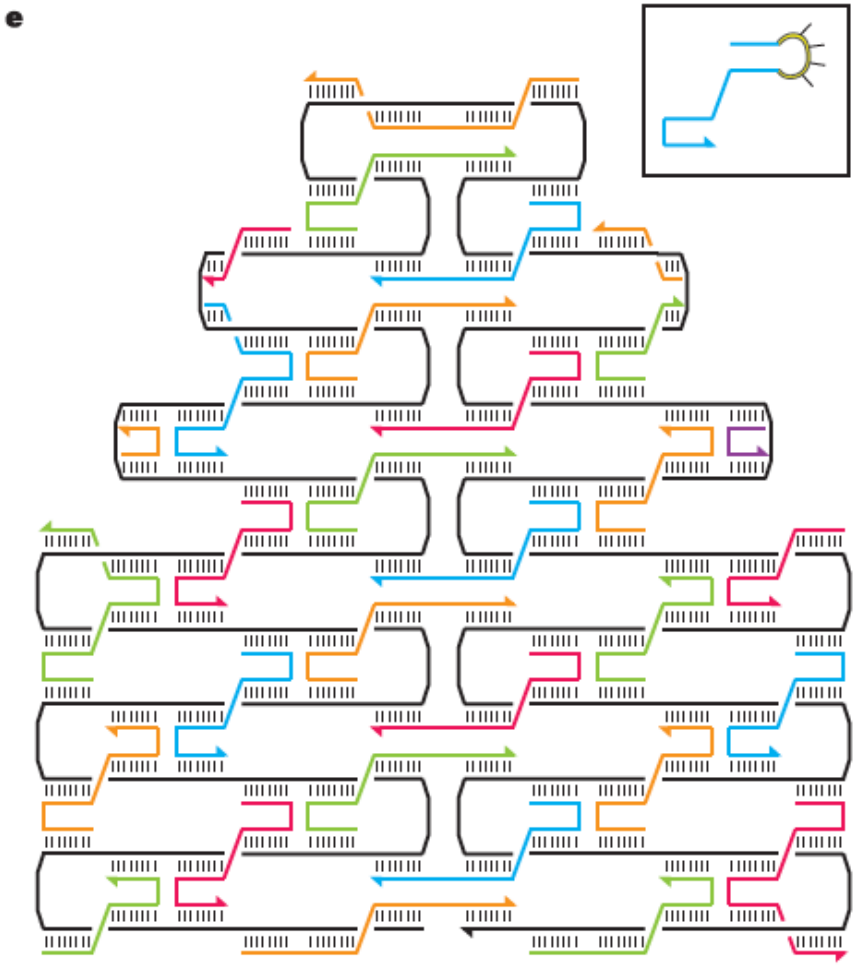
2006 Origami di DNA.....

Vol 440|16 March 2006|doi:10.1038/nature04586

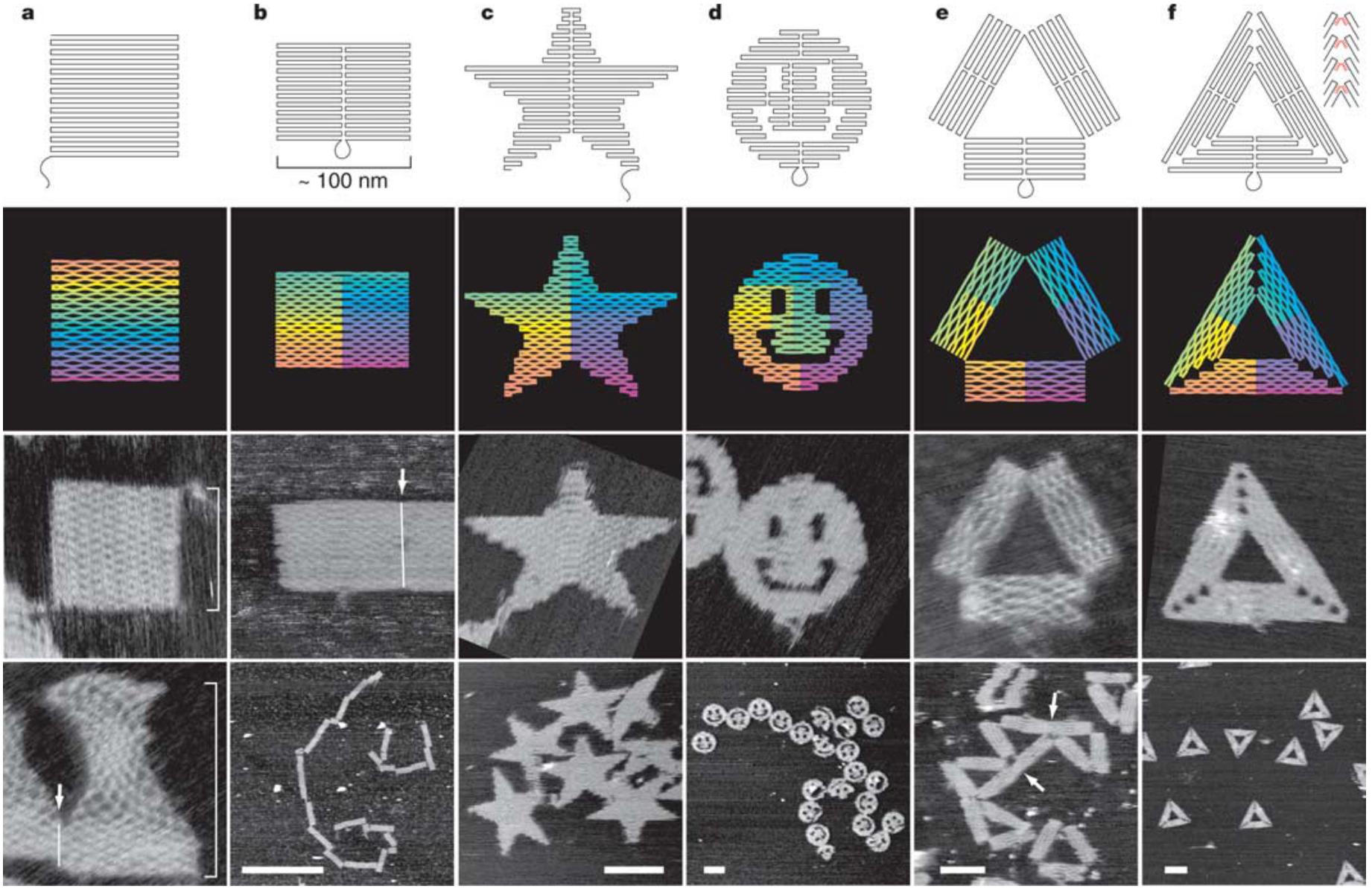
Folding DNA to create nanoscale shapes and patterns

Paul W. K. Rothemund[1]



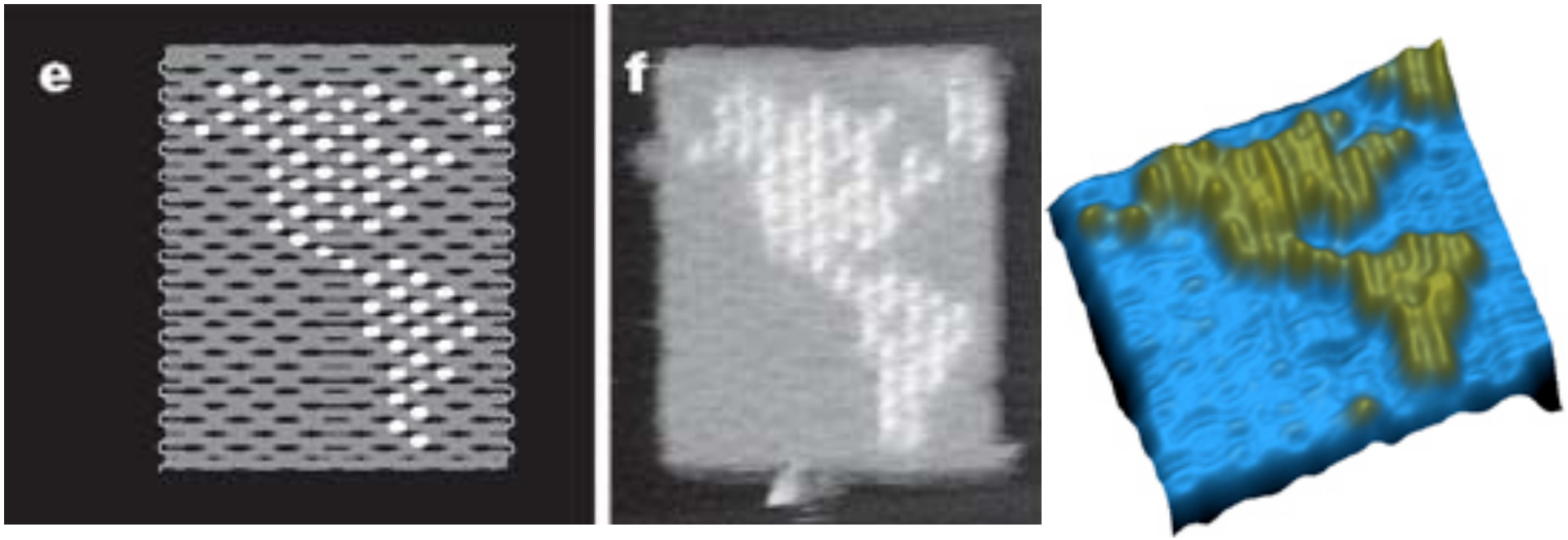


Single strand 8000 basi


a
b
c
d
e
f
~ 100 nm

DNA scritto con DNA

Geografia: Le americhe

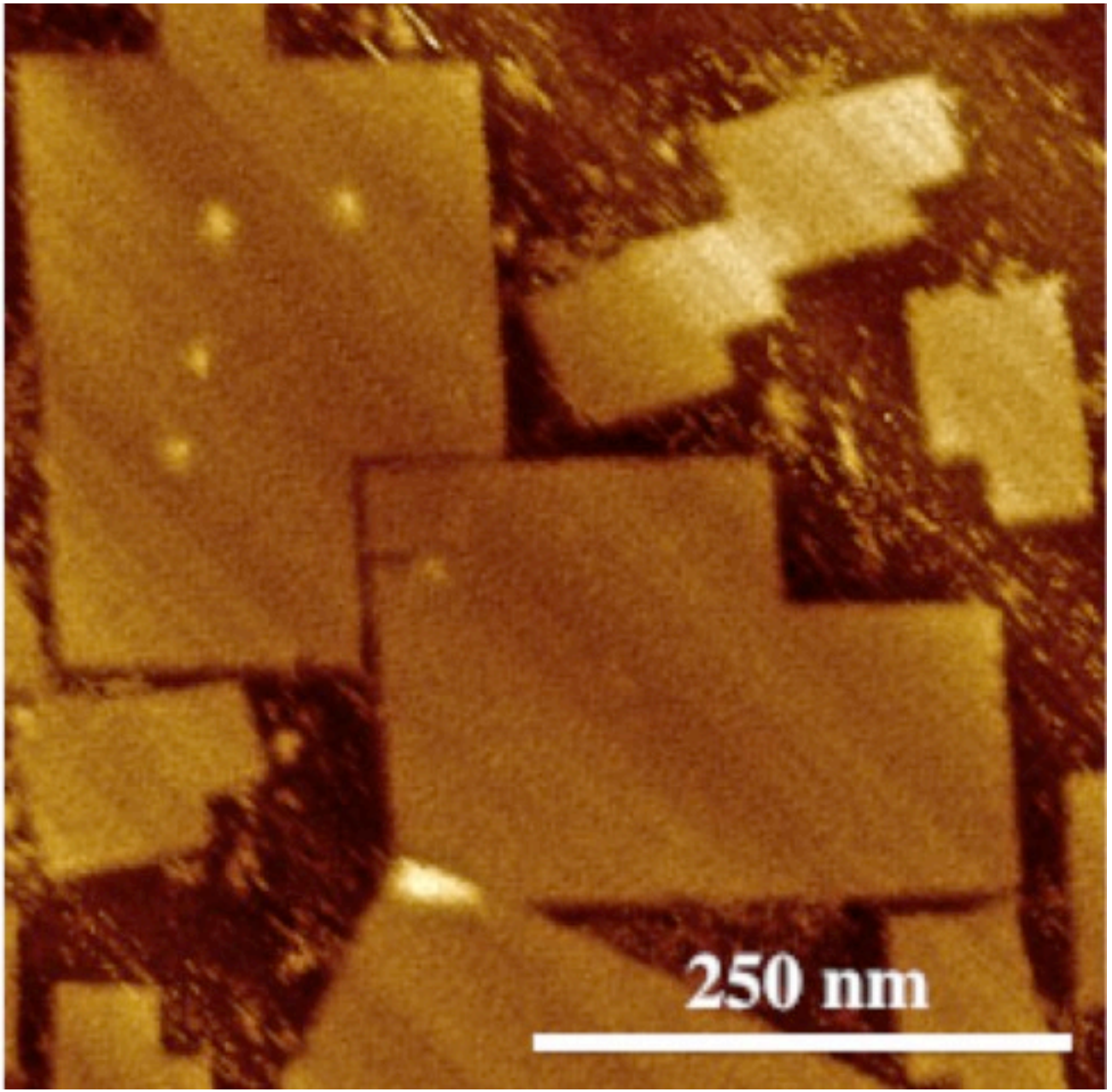


atomic force microscope (AFM) data of DNA molecules

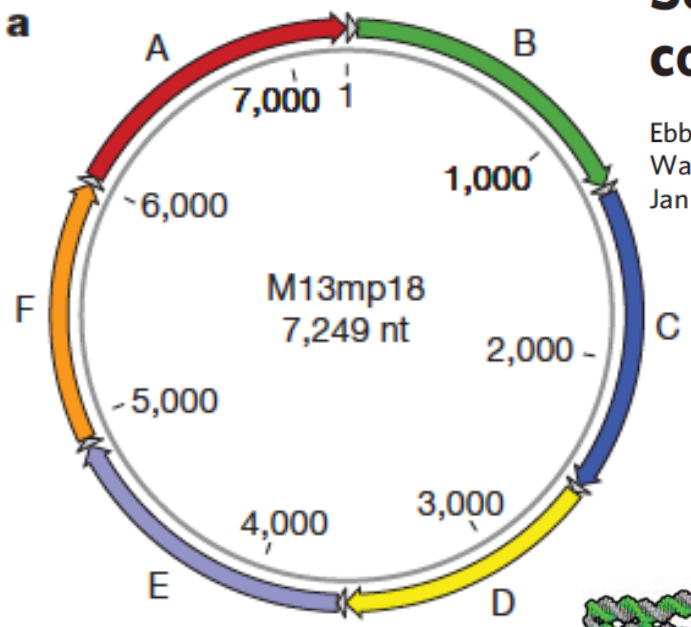
51000 single-strand

200 diverse sequenze
di 13 basi ciascuna

Maggio 2014 !



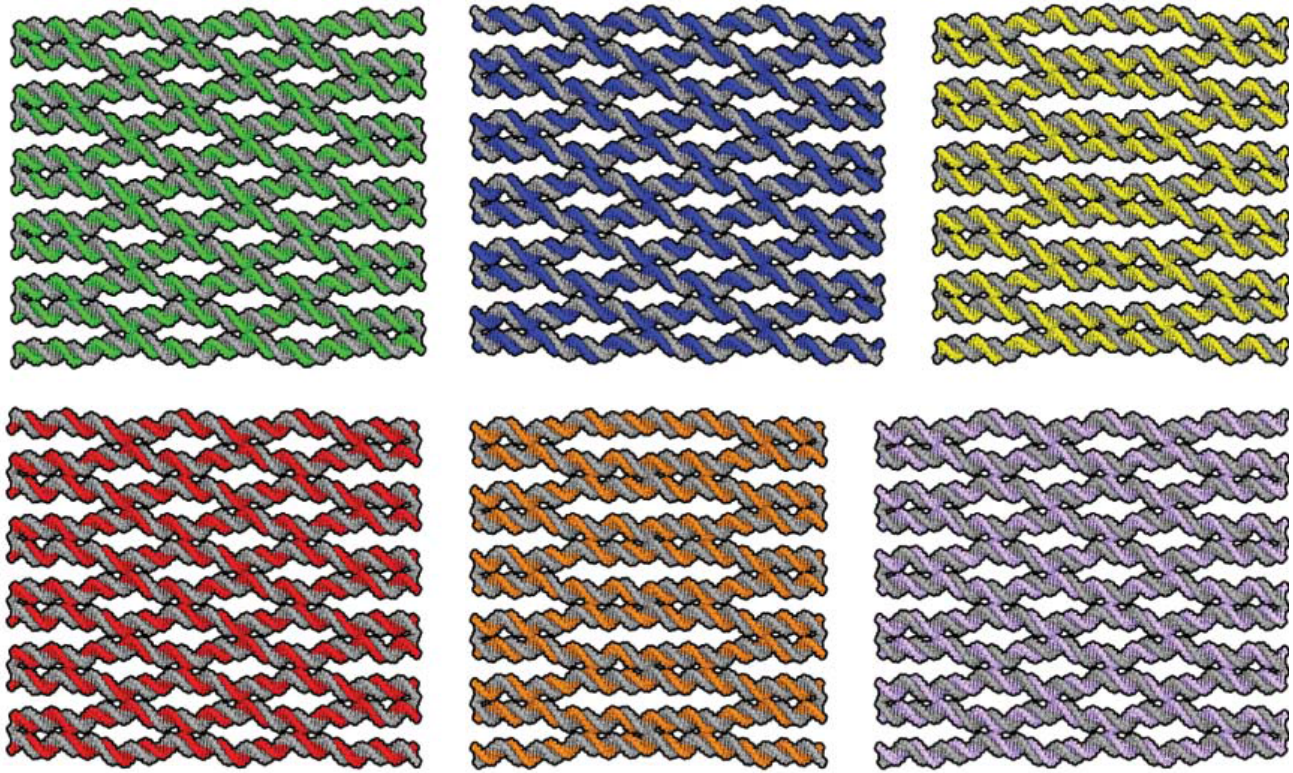
Toward Larger DNA Origami
A. N. Marchi et al.
Nano Lett., 2014, 14, 5740

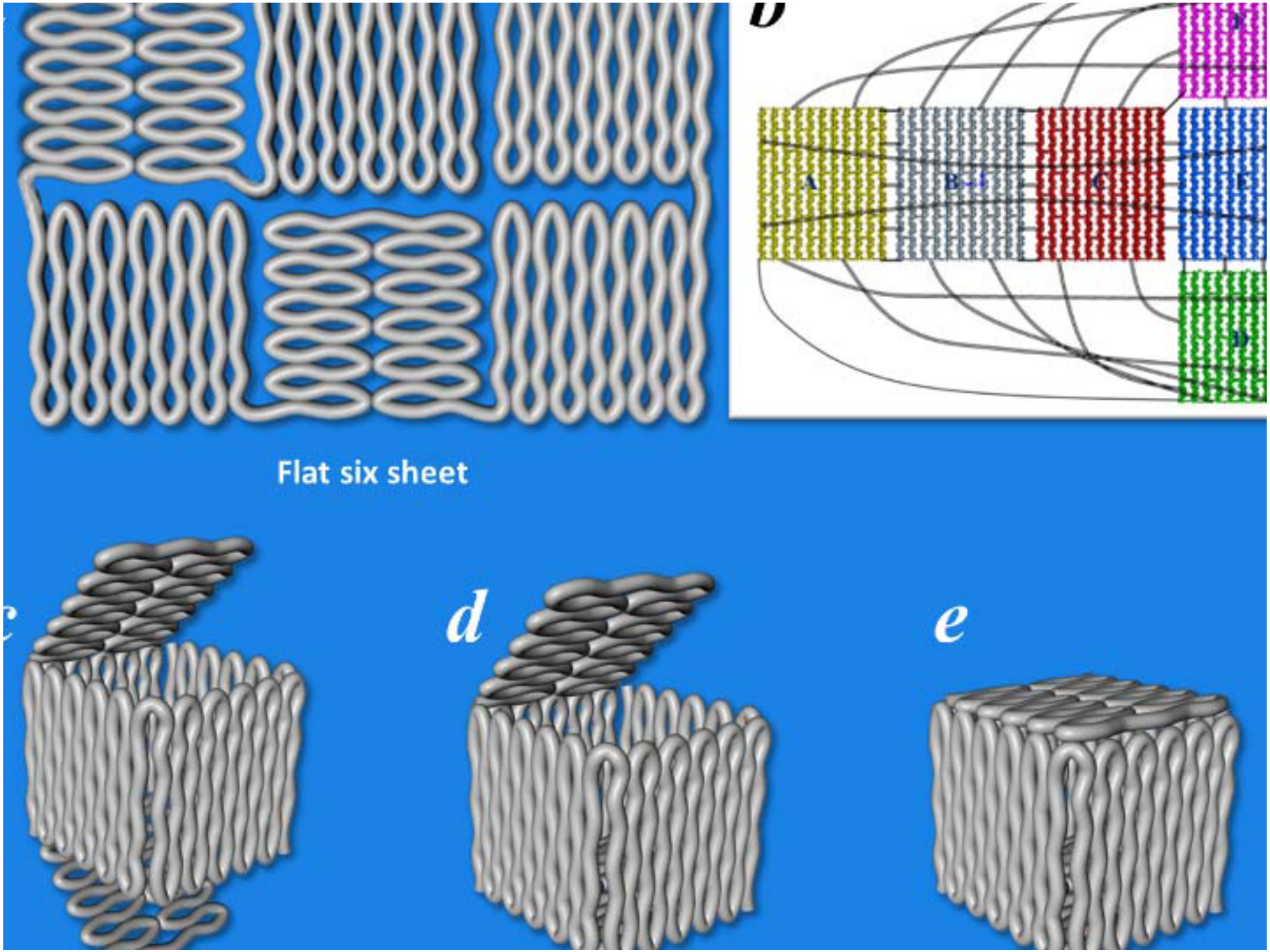


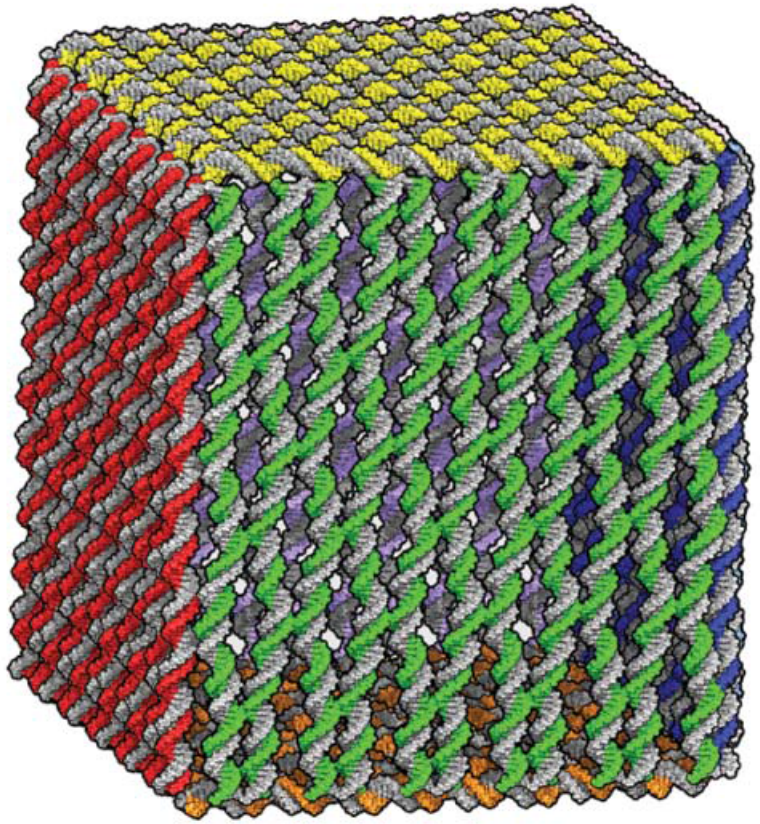
Self-assembly of a nanoscale DNA box with a controllable lid

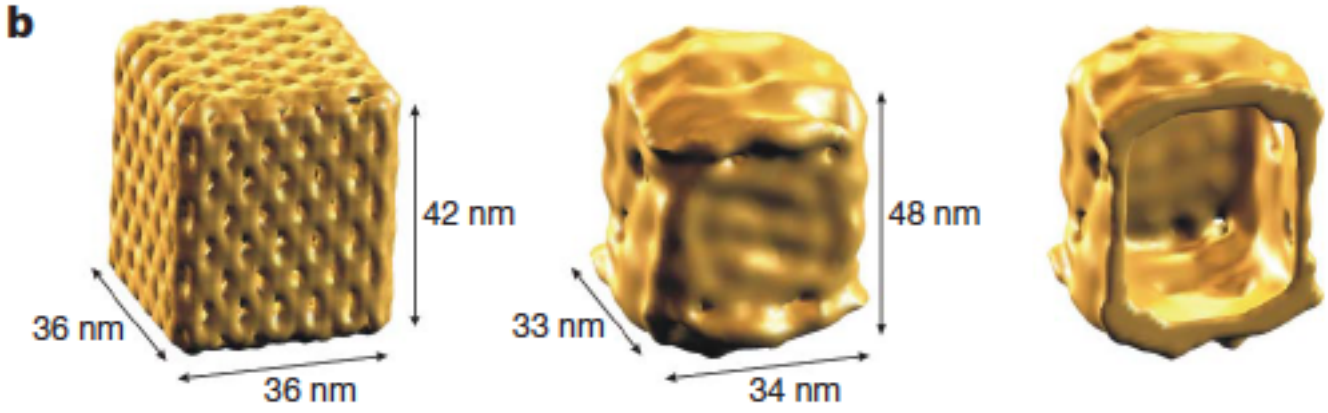
Ebbe S. Andersen[1,2,3], Mingdong Dong[1,2,4]†, Morten M. Nielsen[1,2,3], Kasper Jahn[1,2,3], Ramesh Subramani[1,2,4], Wael Mamdouh[1,2,4], Monika M. Golas[5,8], Bjoern Sander[6,8], Holger Stark[8,9], Cristiano L. P. Oliveira[2,7], Jan Skov Pedersen[2,7], Victoria Birkedal[2], Flemming Besenbacher[1,2,4], Kurt V. Gothelf[1,2,7] & Jørgen Kjems[1,2,3]

Vol 459|7 May 2009|doi:10.1038/nature07971

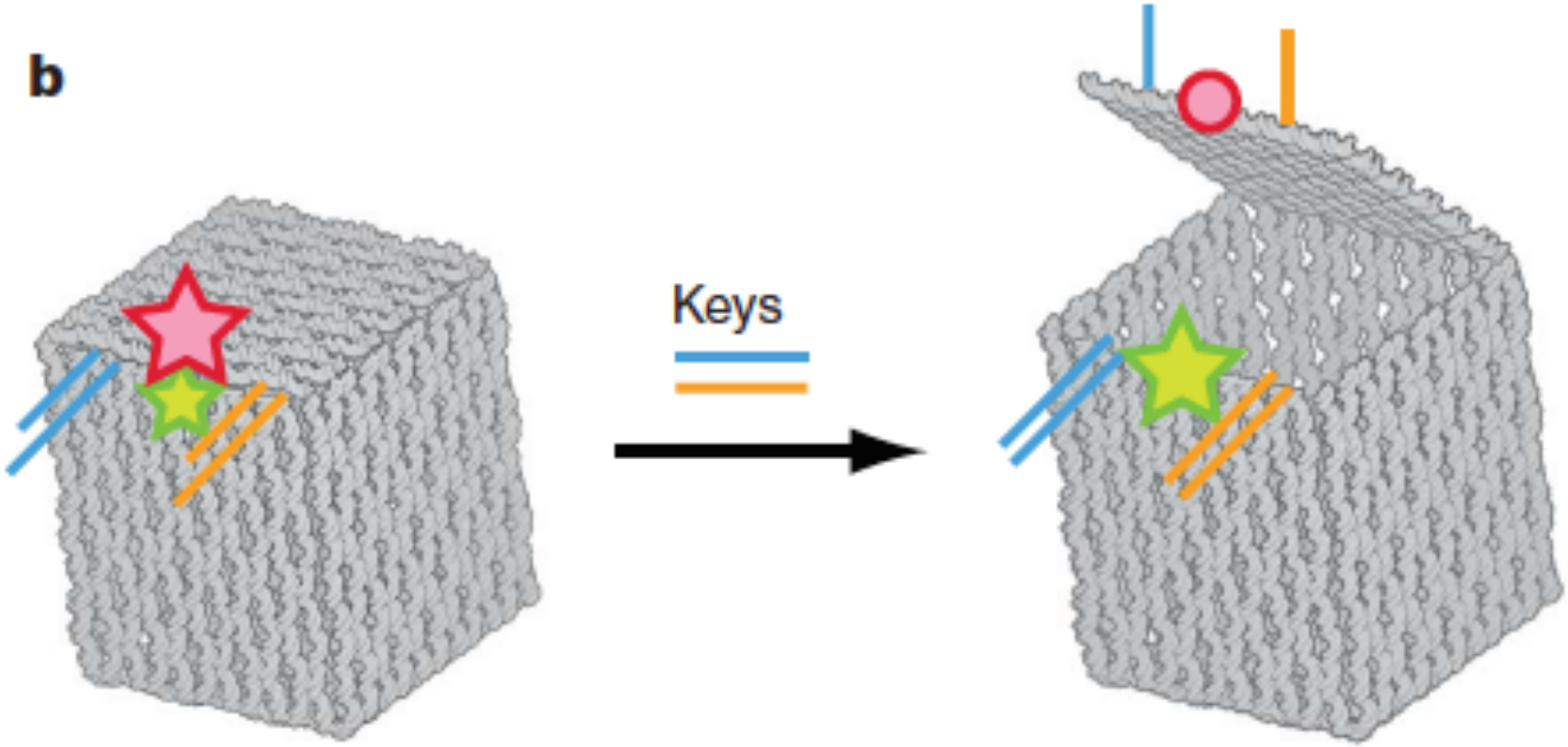



Flat six sheet
d
e




b
42 nm
36 nm
36 nm
48 nm
33 nm
34 nm

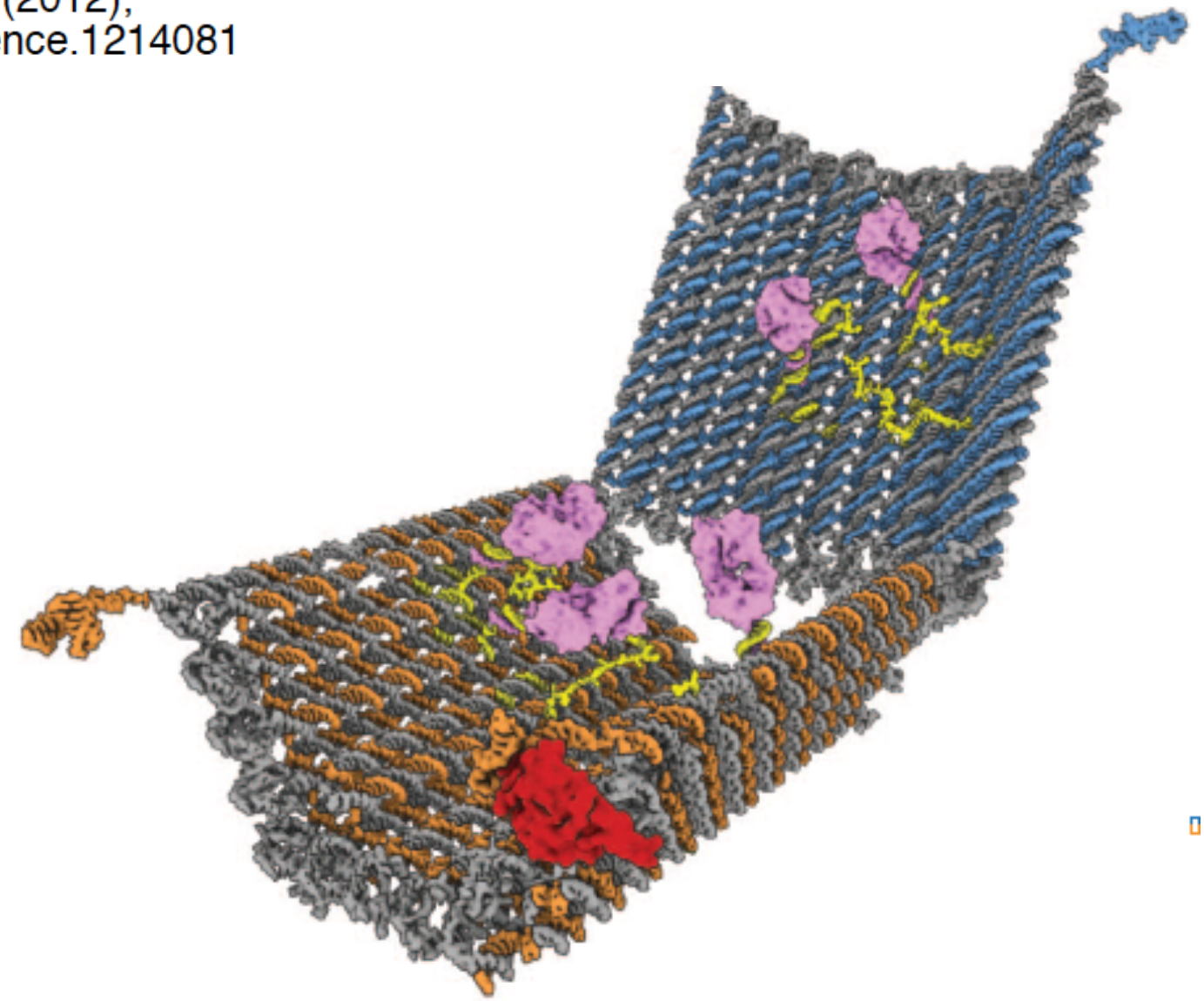
Apertura programmata del coperchio



A Logic-Gated Nanorobot for Targeted Transport of Molecular Payloads

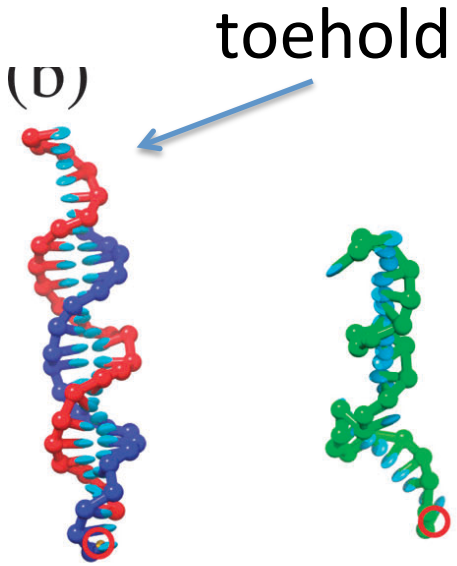
Shawn M. Douglas *et al.*

Science **335**, 831 (2012);
DOI: 10.1126/science.1214081

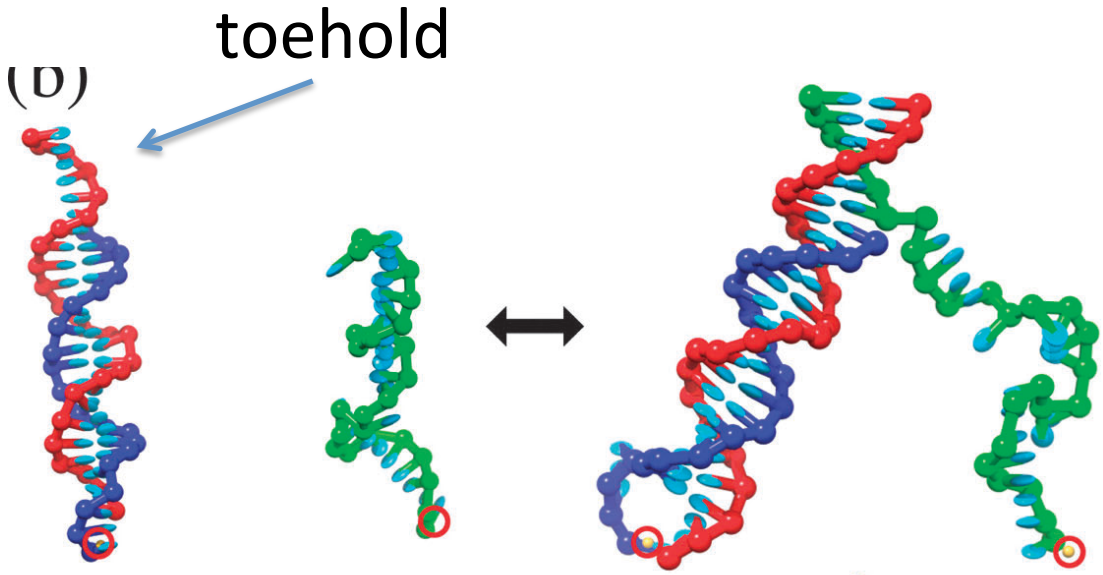


Primi passi verso le macchine

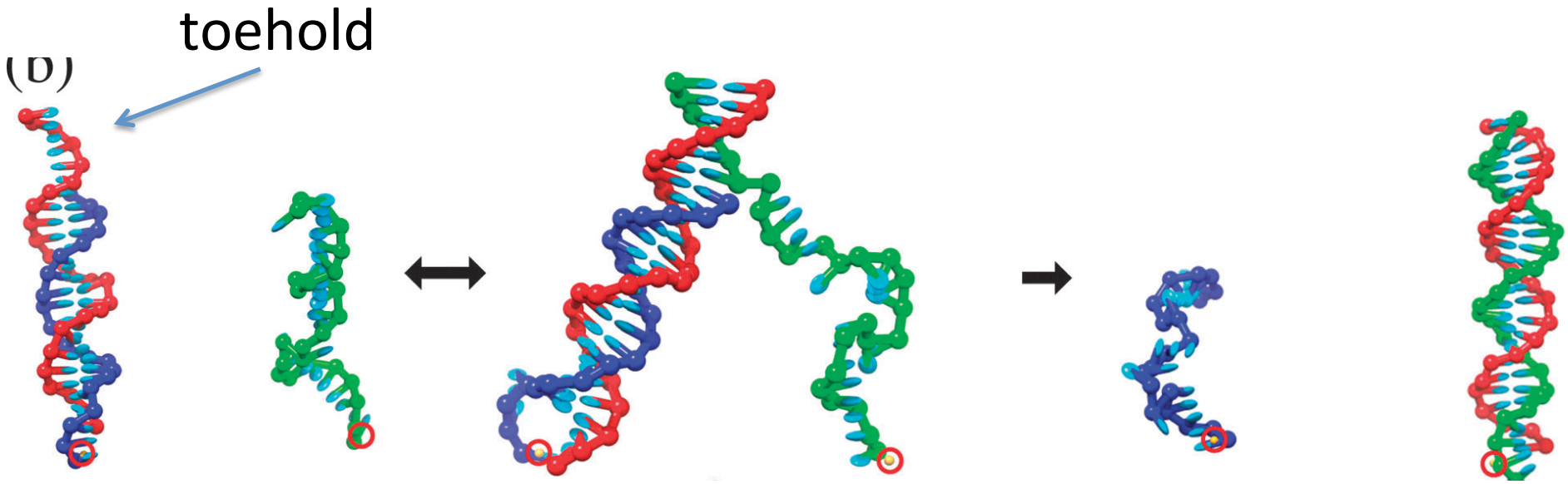
Il meccanismo di aggancio (toehold)



Il meccanismo di aggancio (toehold)



Il meccanismo di aggancio (toehold)

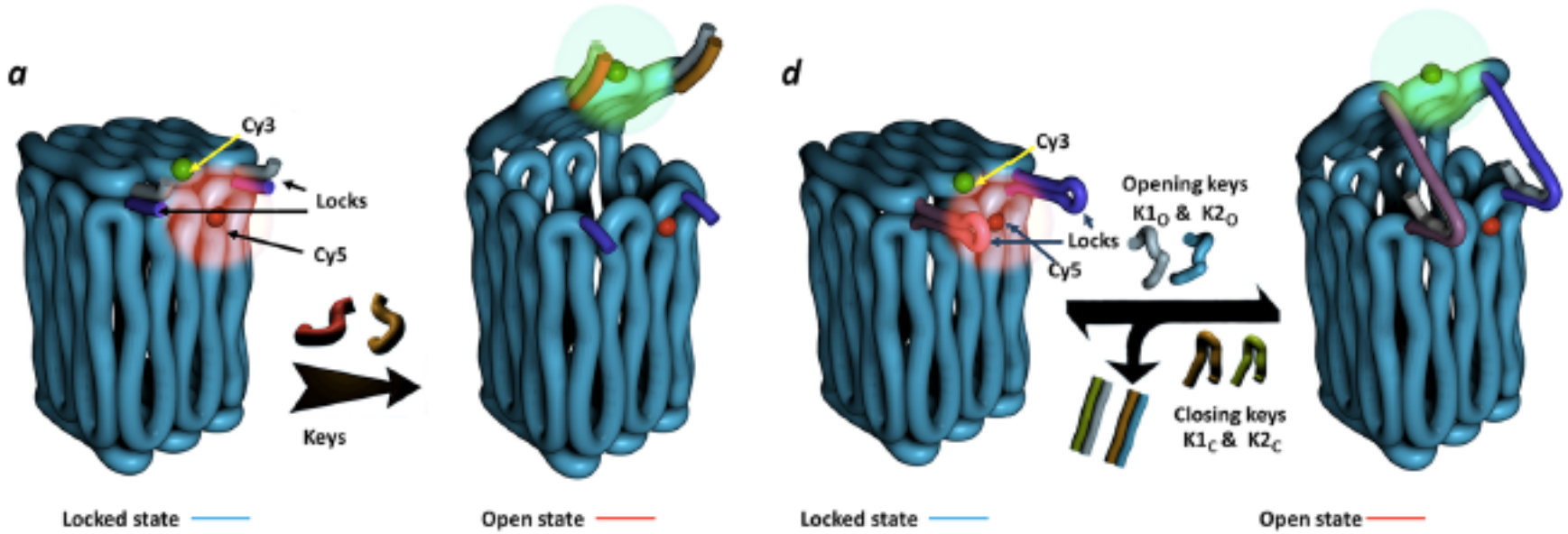


10^{-21}

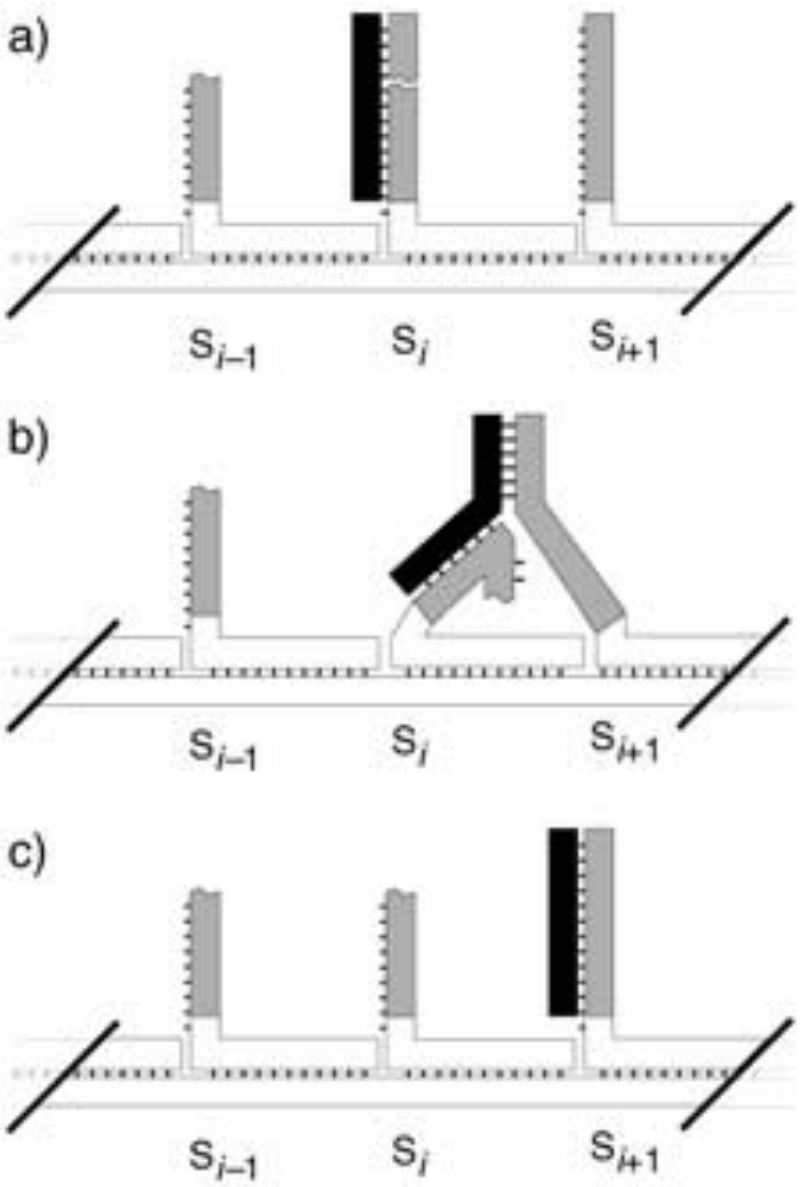
Construction of a 4 Zeptoliters Switchable 3D DNA Box Origami

Reza M. Zadegan,[†,‡,§] Mette D. E. Jepsen,[†,‡,§] Karen E. Thomsen,[§] Anders H. Okholm,[†,‡,§] David H. Schaffert,[†,‡,§] Ebbe S. Andersen,[†,‡,§] Victoria Birkedal,[‡,§] and Jørgen Kjems[†,‡,§,*]

[†]Department of Molecular Biology and Genetics, [‡] Danish National Research Foundation: Centre for DNA Nanotechnology (CDNA) and [§] Interdisciplinary Nanoscience Center (iNANO), Aarhus University, DK-8000 Aarhus, Denmark



DNA walkers…….



A Free-Running DNA Motor Powered by Nicking Enzyme**

Jonathan Bath, Simon J. Green, and Andrew J. Turberfield*

Angew. Chem. Int. Ed. **2005**, *44*, 4358–4361

2005

Velocita' media= 0.1 nm/s

restriction endonuclease N.BbvC IB

nature Vol 465|13 May 2010|doi:10.1038/nature09012

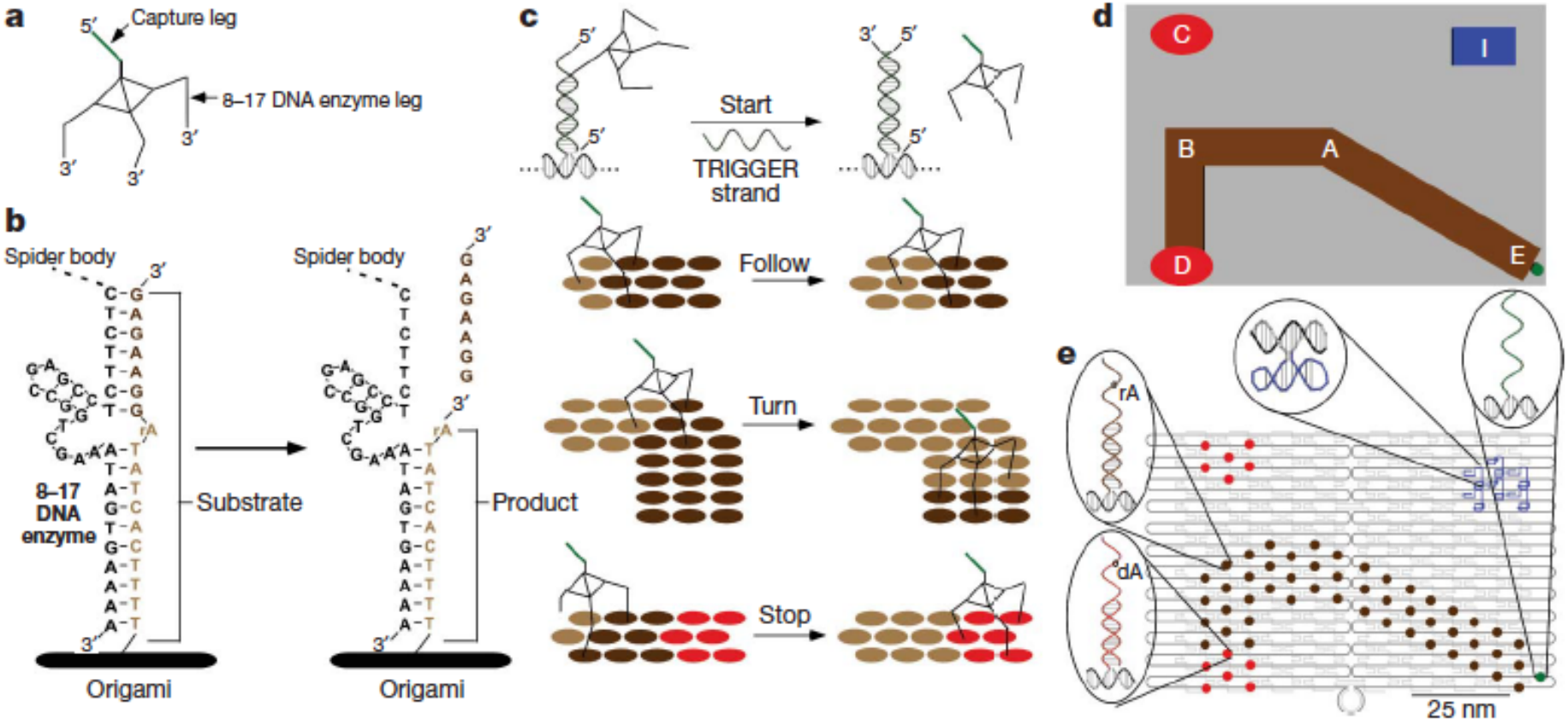
(I ragni di minority report)

2010

LETTERS

Molecular robots guided by prescriptive landscapes

Kyle Lund[1,2], Anthony J. Manzo[3], Nadine Dabby[4], Nicole Michelotti[3,5], Alexander Johnson-Buck[3], Jeanette Nangreave[1,2], Steven Taylor[6], Renjun Pei[6], Milan N. Stojanovic[6,7], Nils G. Walter[3], Erik Winfree[4,8,9] & Hao Yan[1,2]

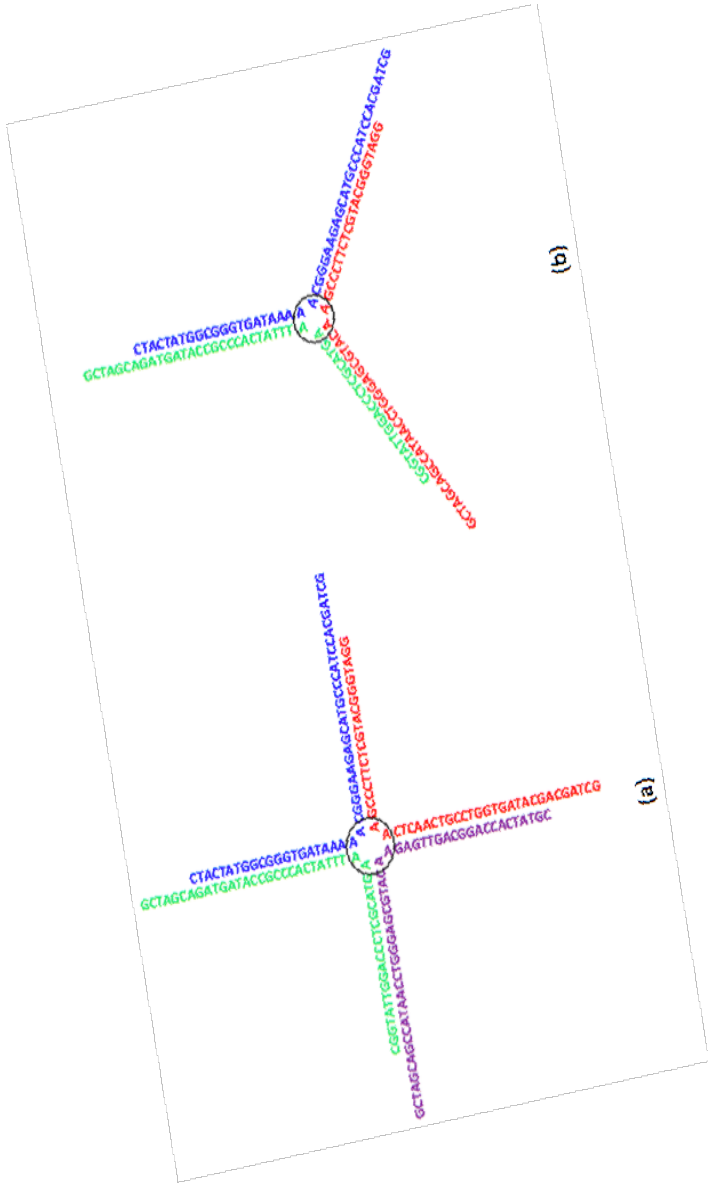


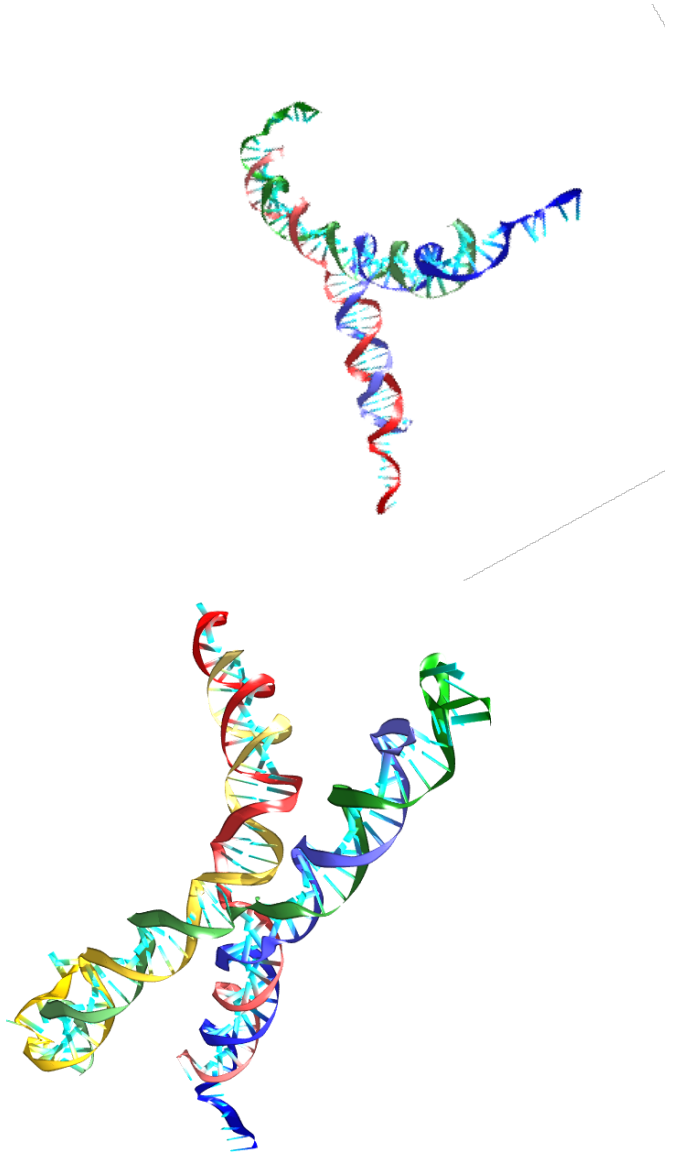
E a Roma … ?

E a Roma che facciamo ?

Usare costrutti di DNA per affrontare problemi di meccanica statistica (comportamenti collettivi di atomi e molecole).

Usare i costrutti di DNA per costruire particelle che consentono di verificare i modelli teorici


(b)
CTACTATGGCGGGTGATAAA
GCTAGCAGATGATACCGCCCACTATTT
(a)
CTACTATGGCGGGTGATAAA
GCTAGCAGATGATACCGCCCACTATTT
GCTAGCAGCCATAACCTGGGAGCGTAC
CGGTATTGGACCCTCGCATC
GCTAGCAGCCATAACCTGGGAGCGTAC
CGGTATTGGACCCTCGCATC

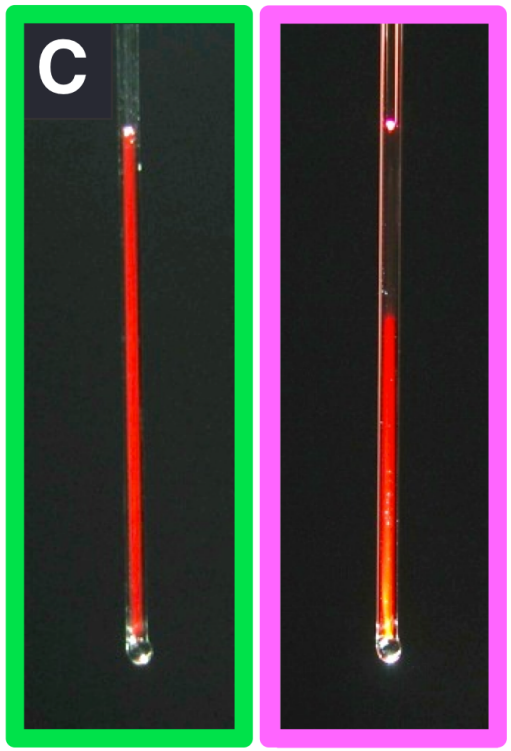


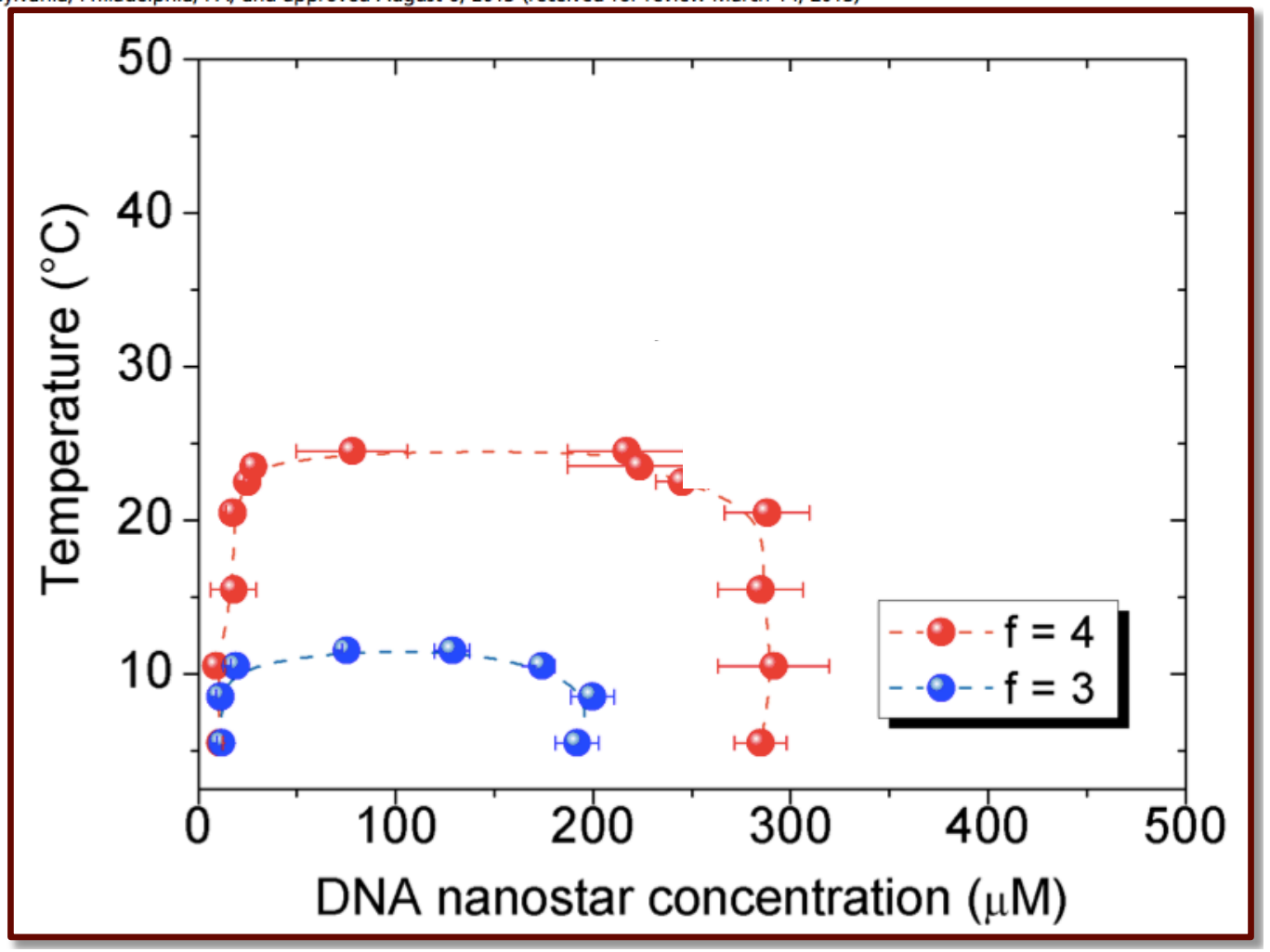
Phase behavior and critical activated dynamics of limited-valence DNA nanostars

Silvia Biffi[a], Roberto Cerbino[a], Francesca Bomboi[b,c], Elvezia Maria Paraboschi[a], Rosanna Asselta[a], Francesco Sciortino[b,1], and Tommaso Bellini[a,1]

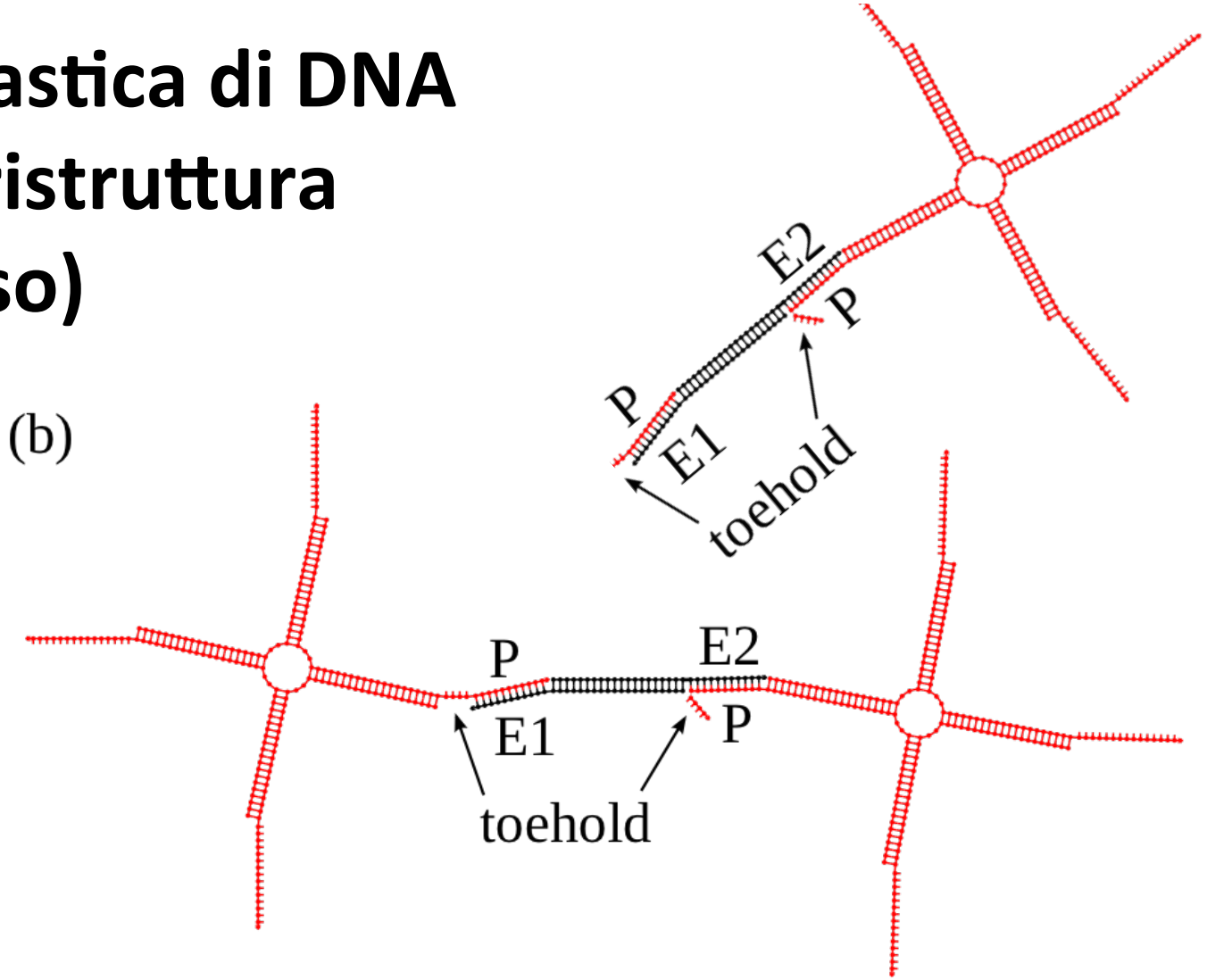
[a]Department of Medical Biotechnology and Translational Medicine, Universitá degli Studi di Milano, I-20133 Milan, Italy; [b]Department of Physics, Sapienza, Universitá di Roma, I-00185 Rome, Italy; and [c]Department of Physics, Università degli Studi Roma Tre-Consorzio Nazionale Interuniversitario per le Scienze Fisiche della Materia, I-00146 Rome, Italy

Edited by T. C. Lubensky, University of Pennsylvania, Philadelphia, PA, and approved August 6, 2013 (received for review March 14, 2013)





Una plastica di DNA che si ristruttura (in corso)



Toehold mediated strand displacement

Un gel che si forma riscaldando

nature COMMUNICATIONS

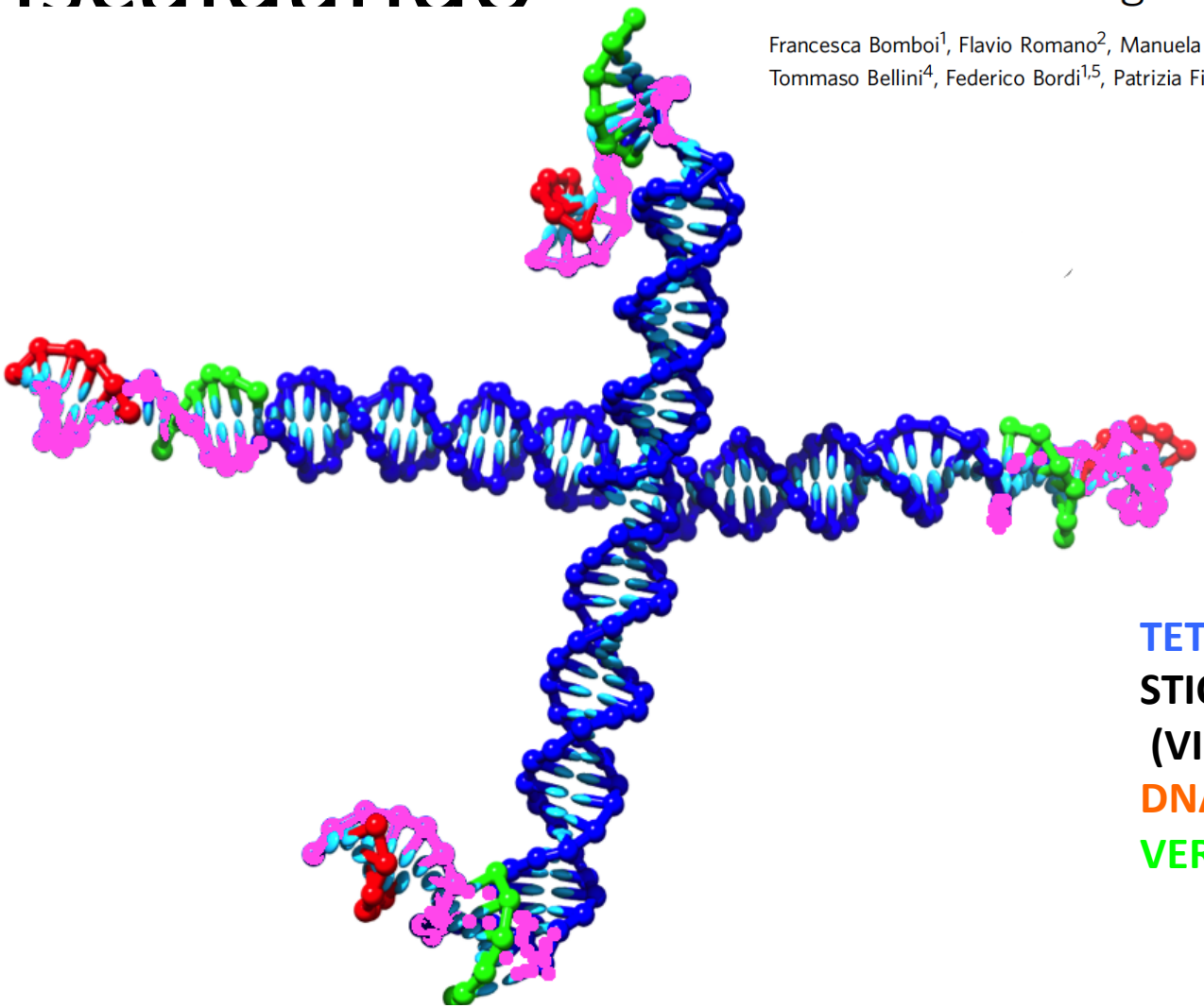
ARTICLE

Received 24 Mar 2016 | Accepted 12 Sep 2016 | Published 21 Oct 2016

DOI: 10.1038/ncomms13191 OPEN

Re-entrant DNA gels

Francesca Bomboi[1], Flavio Romano[2], Manuela Leo[1,3], Javier Fernandez-Castanon[1], Roberto Cerbino[4], Tommaso Bellini[4], Federico Bordi[1,5], Patrizia Filetici[6] & Francesco Sciortino[1,5]

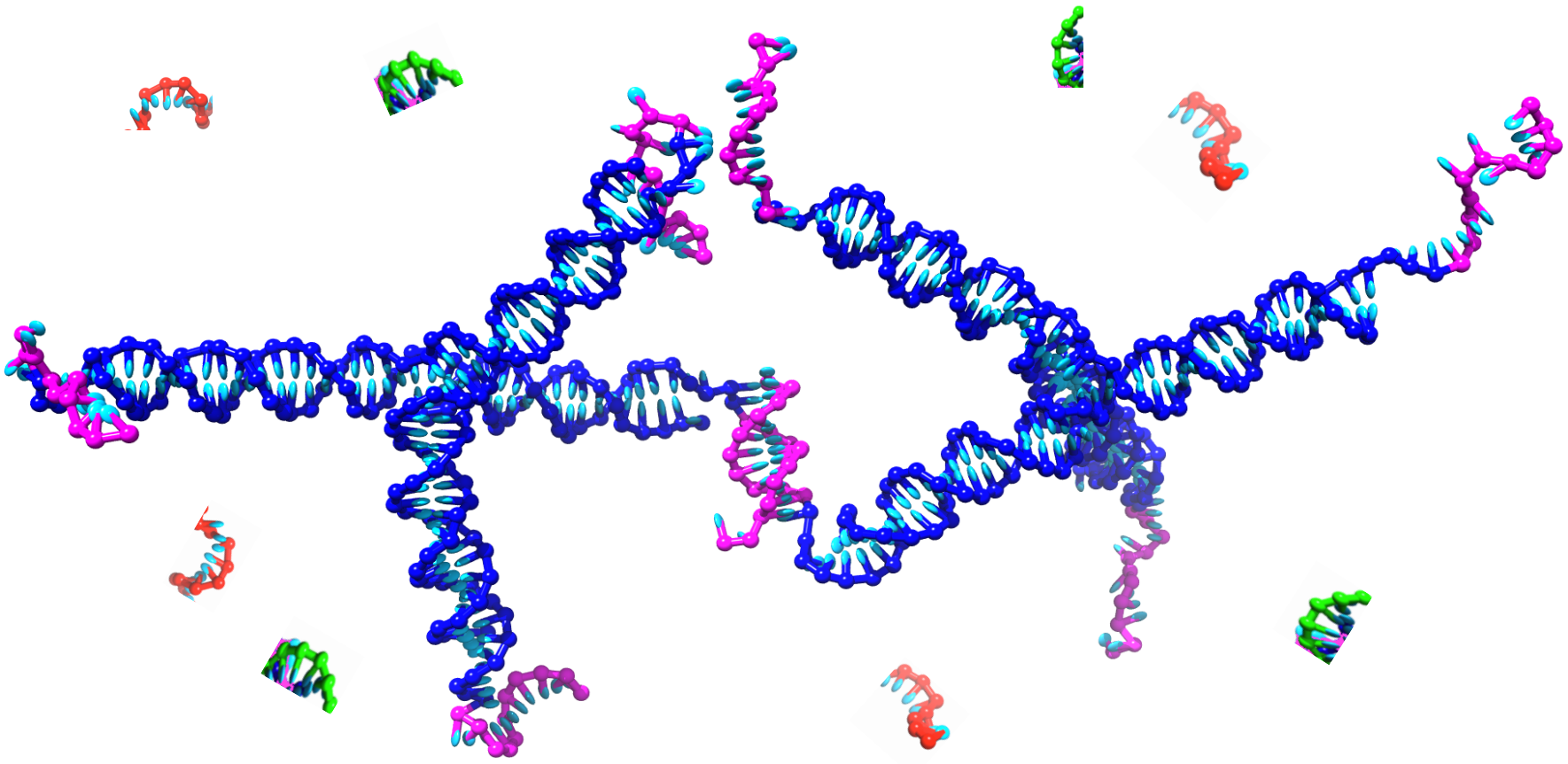


TETRAMERO (BLUE)

STICKY ENDS TETRAMERO (VIOLA)

DNA BLOCCANTE (ROSSO E VERDE)

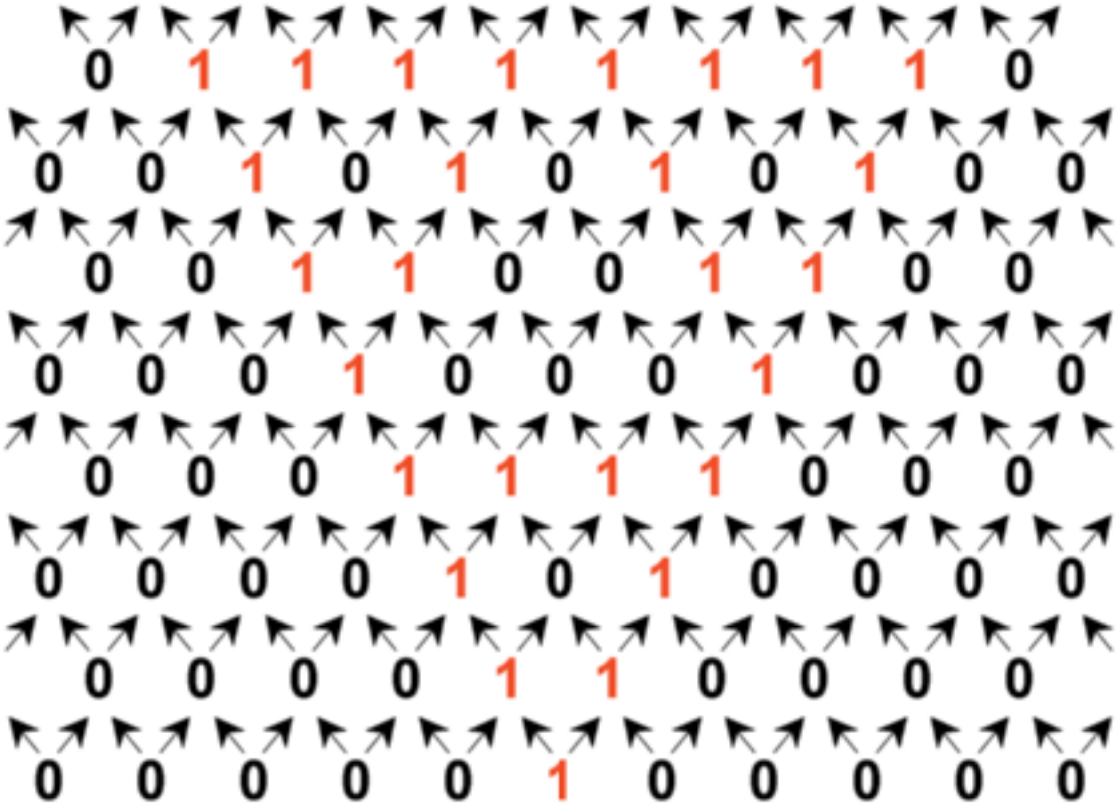
Alzando T, il DNA bloccante va via e le sticky ends si legano formando il gel



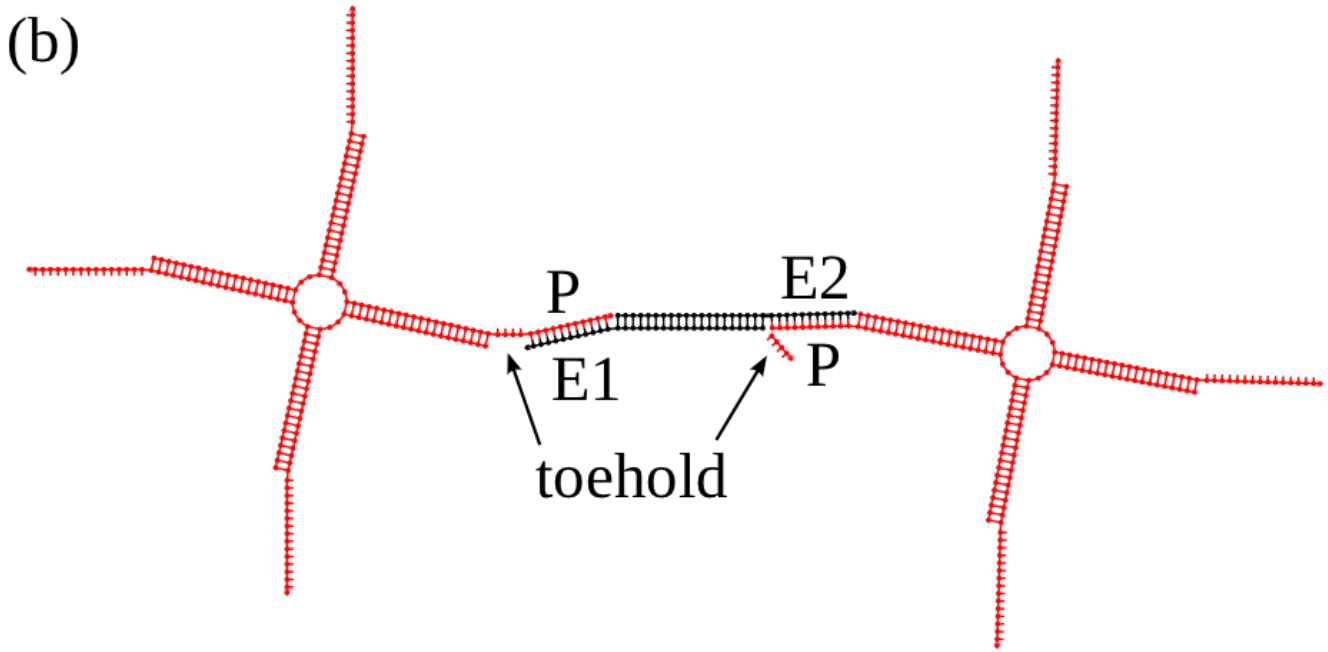
dell’ attenzione…

Animazioni: Lorenzo Rovigatti (cad nano, OxDNA)

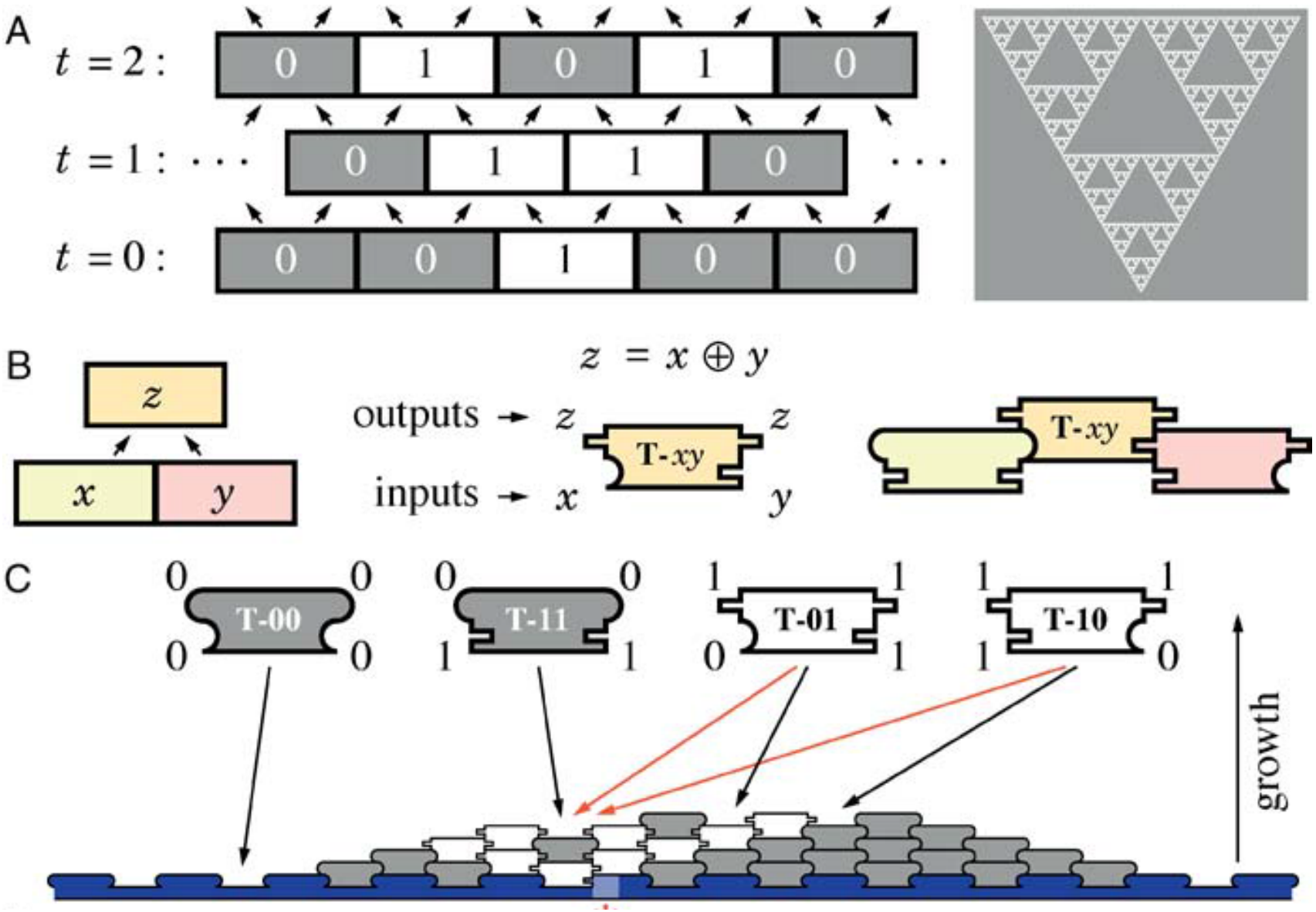
Costruire e calcolare…



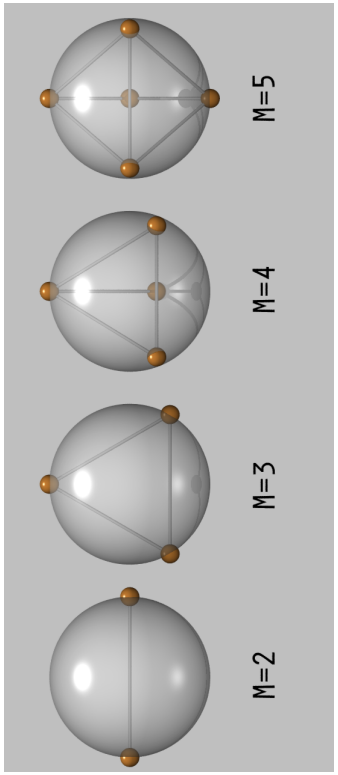
Una plastica di DNA che si ristruttura (in corso)

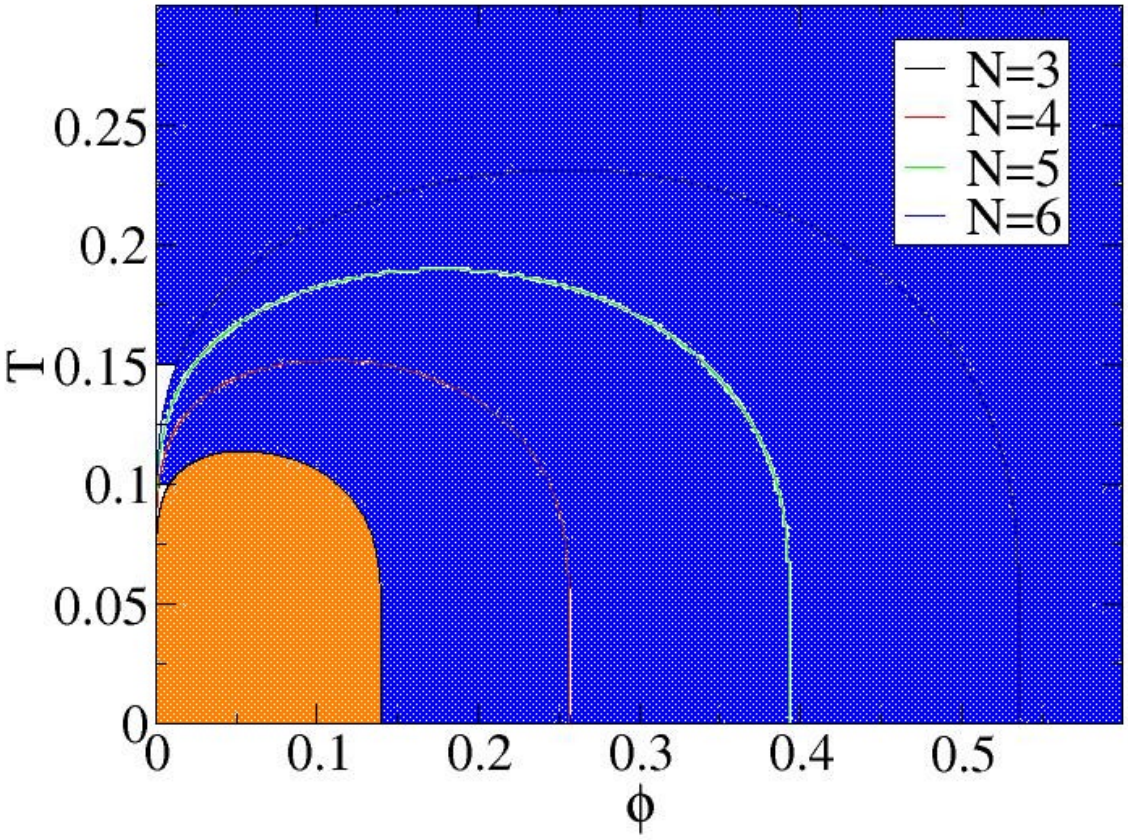


Toehold mediated strand displacement


A
t = 2 :
0 1 0 1 0
t = 1 : · · ·
0 1 1 0
· · ·
t = 0 :
0 0 1 0 0
B
z
x y
z = x ⊕ y
outputs → z
T-xy
z
inputs → x
y
T-xy
C
0 0
T-00
0 0
0 0
T-11
1 1
1 1
T-01
0 1
1 1
T-10
1 0
growth

Il ruolo del # di legami nella transizione gas-liquido





nature COMMUNICATIONS

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Re-entrant DNA gels

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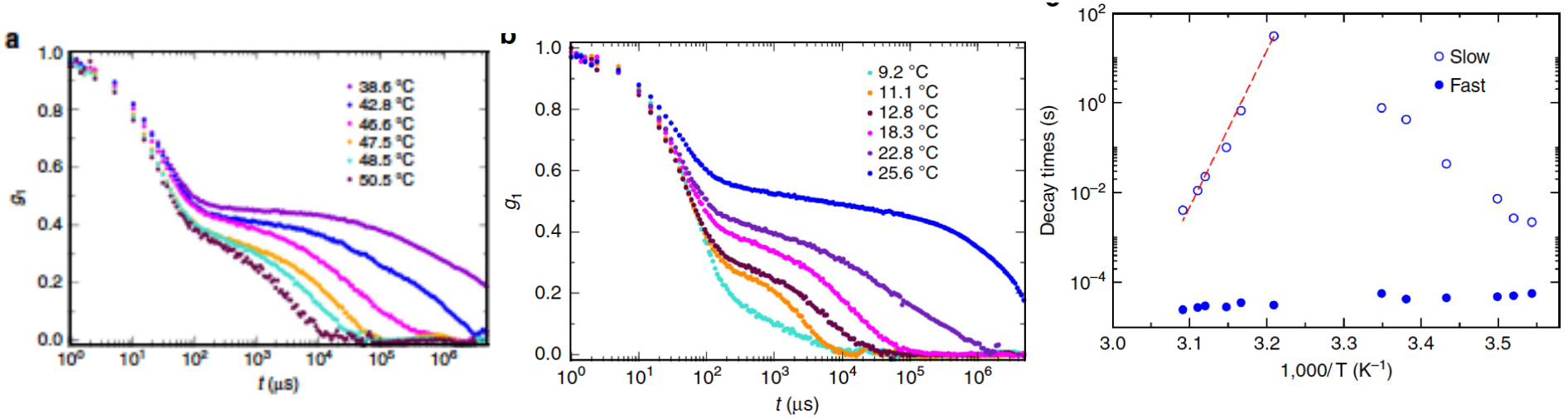
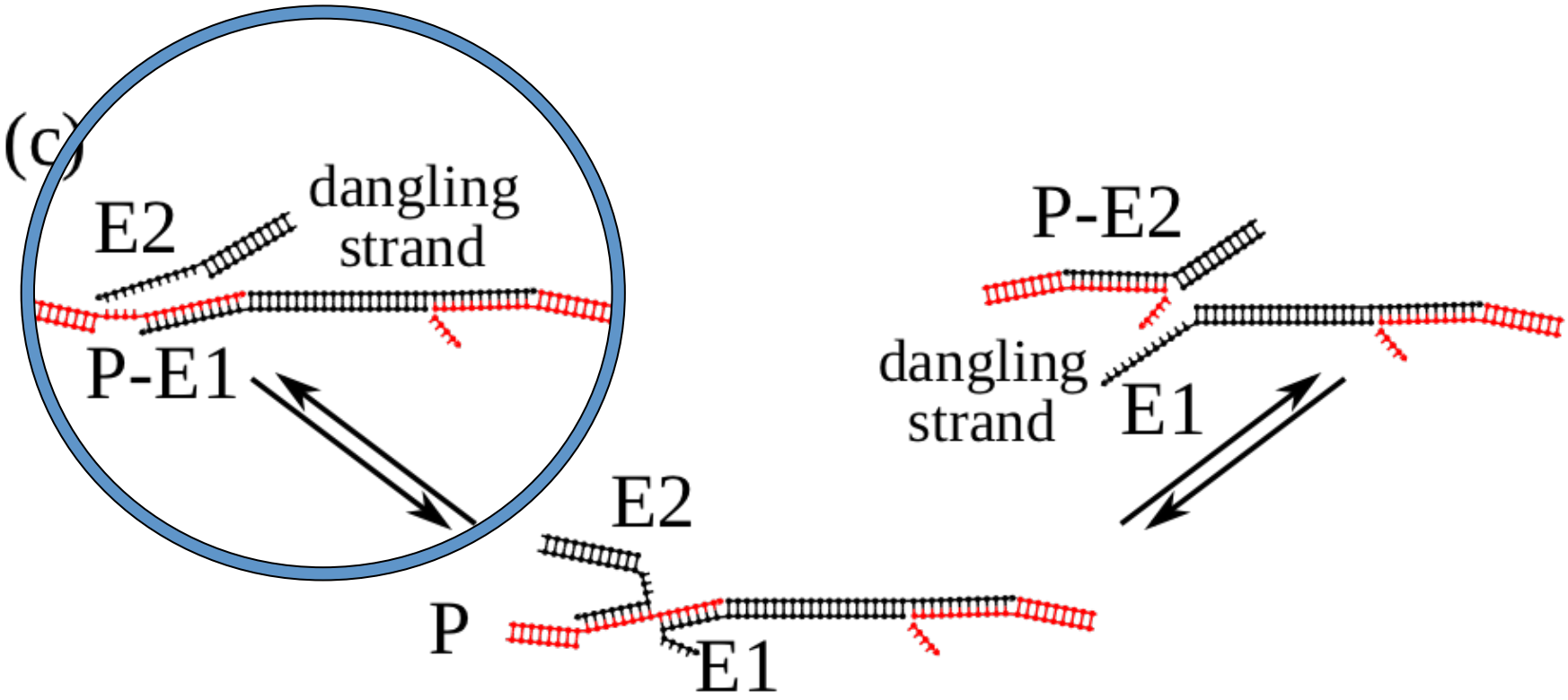
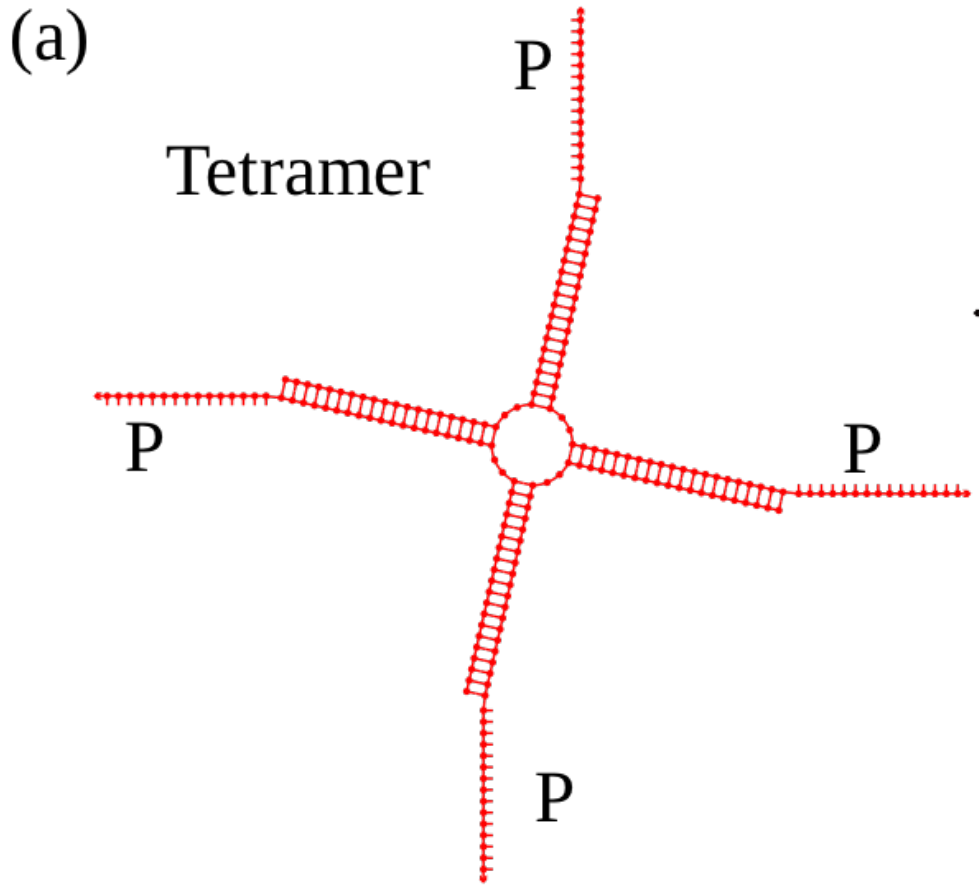


Una plastica che si ristruttura!

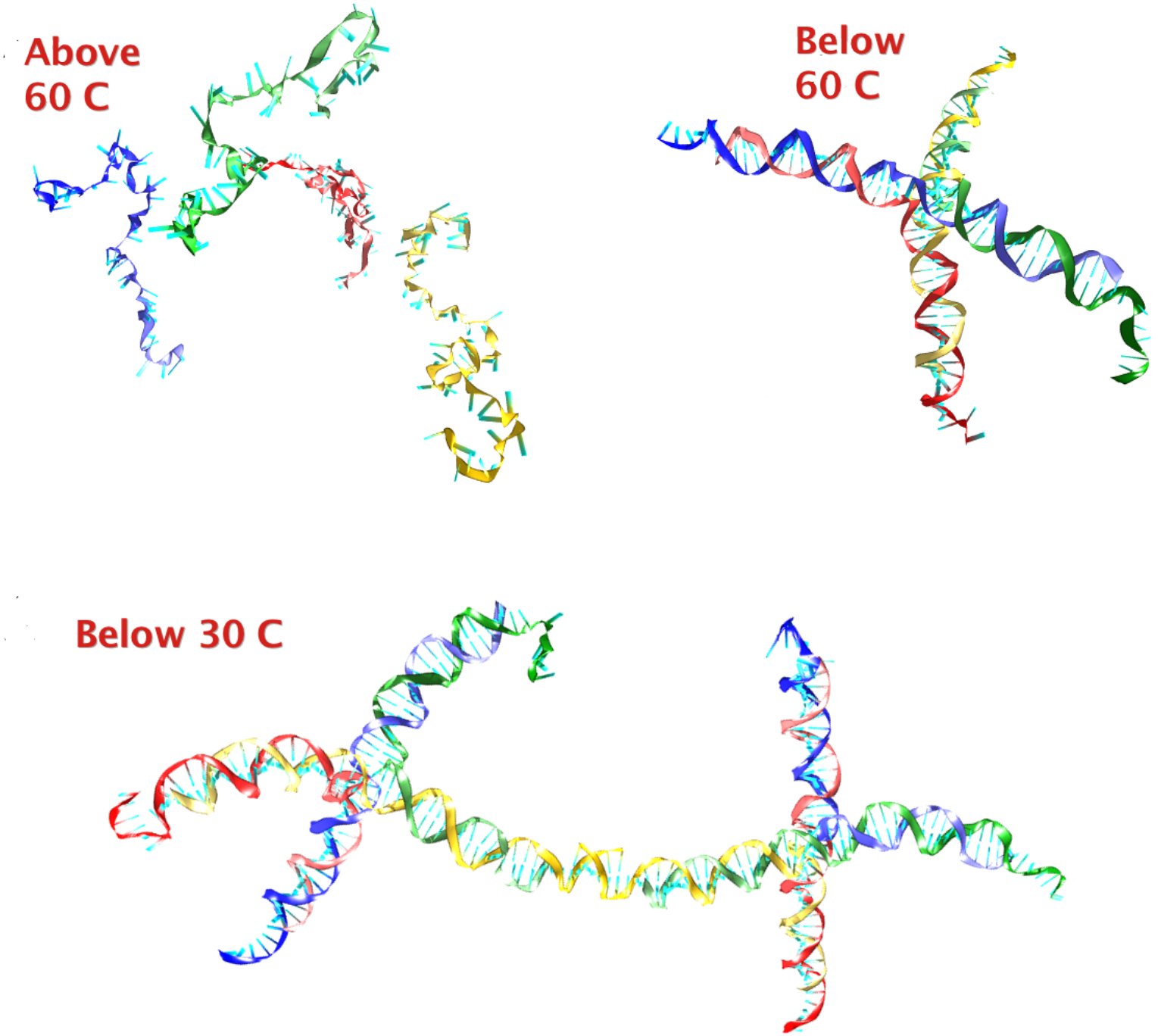


$E1$	$5'$-GGTTCGACACG-$3'$
P	$3'$-CCAAGCTGTGCTCAC-$5'$
$E2$	$5'$-CGACACGAGTG-$3'$

Una plastica di DNA che si ristruttura (in corso)



$E1$	$5'$-GGTTCGACACG-$3'$
P	$3'$-CCAAGCTGTGCTCAC-$5'$
$E2$	$5'$-CGACACGAGTG-$3'$



OxDNA