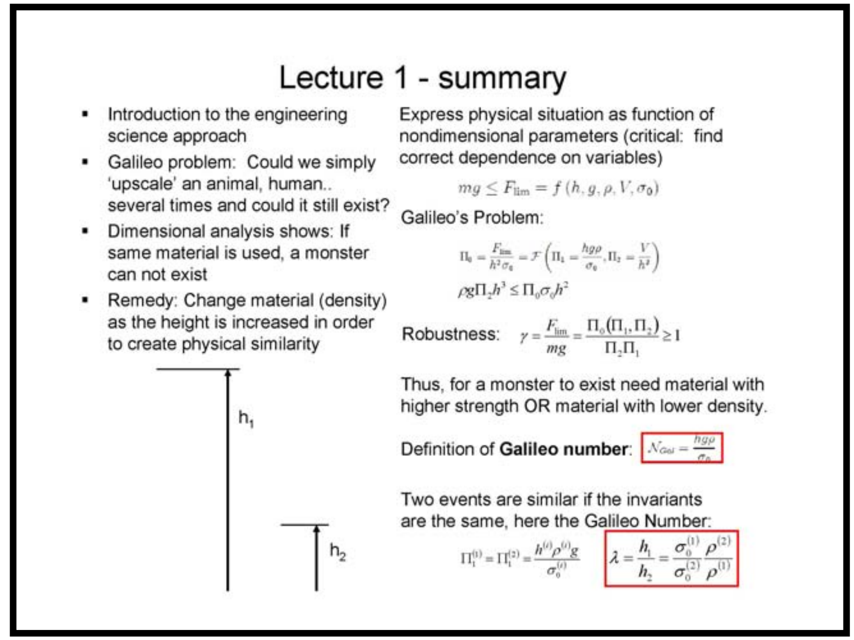
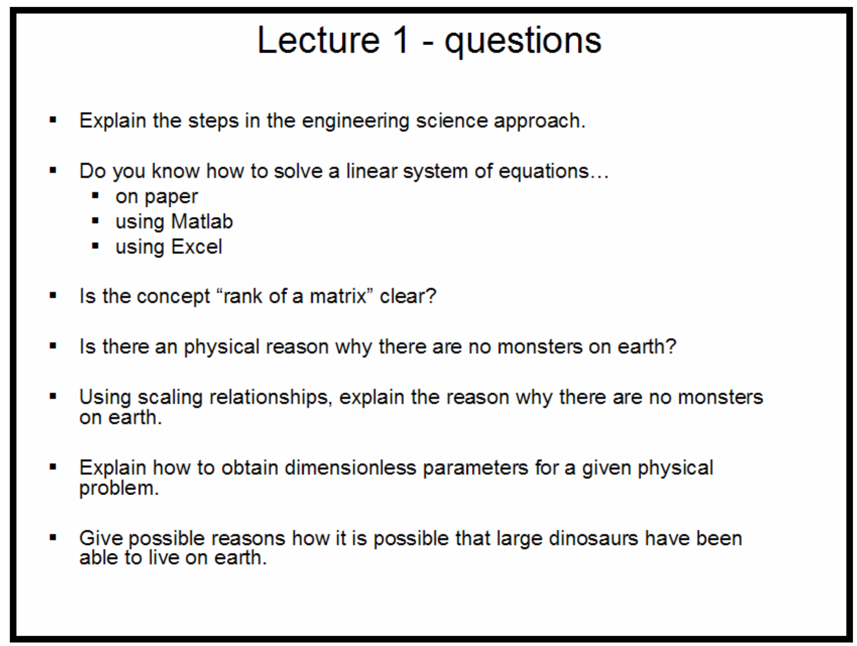
1.050 Engineering Mechanics I

Fall 2007

Notes and remarks

- Lecture Summary Slide
- Content Survey
- Lecture notes
- Homework assignments (weekly)
- Exams: 2 in-class quizzes, 1 final
  All exams are open-book
- Grading:
  Two quizzes (25%)
  Final (25%)
  Homework assignment (50%)





Assignments

- **Homework / Problem Sets (50%)**
  - Assigned weekly on Wednesday, evaluated and returned to you (ASAP)
  - Build *homework teams* of three students:
    - Engineering is team work. We expect a true team work, in which everybody contributes equally to the result. This is testified by the team members signing a declaration that "the signature confirms that all have equally contributed to the homework".
    - Typical teamwork:
      - ➢ Each student works individually through the homework set.
      - ➢ The team meets and discusses questions, difficulties and solutions.
      - ➢ Possibly, meet with TA or instructor.
  - You must reference your sources and collaborators, whether other students, sources on the web, archived solutions from previous years etc…

A few things we’d like you to remember…

- **We teach the class for you!** At any time please let us know if you have concerns or suggestions, or if you have difficulties. We’ll do the best to cater to your needs!

- The goal is that you will have an excellent basis for engineering science in many other applications – aside from the mechanics topic covered here…

- Our goal: **Discover Engineering Mechanics with you** – starting at fundamental concepts (Newton’s laws) to be able to apply the knowledge to complex engineering problems.

1.050: Engineering Mechanics
Why are there no monsters on Earth?

Images removed due to copyright restrictions.

Normandy Bridge 900m (1990ies)

Can we build bridges Between continents?

Jack and the giant

Hurricane Katrina

- What caused major flooding in the city?
  Why did the levees break?

Photograph of floodwaters removed due to copyright restrictions.

Geotechnical Design
- Load < strength capacity
- Failure (plasticity or fracture)
- Mechanism

Impact
- 2 million people
- Nationwide Life Line interruption

What caused this to happen?
- Global warming?
- Policy: Role of the federal government?

Minnesota bridge collapse

Aging infrastructure
-What caused the bridge to collapse?
-Are our bridges safe?
-Can we detect failure before tragedy happens?

Photographs of collapsed bridge removed due to copyright restrictions.

Fixing the problems
-Retrofitting?
-Rebuilding new bridges?
-Funding? -- Policy change to allocate more funding to fix unfit infrastructure

Earthquake disasters

<u>Earthquake in Peru</u>
(August 2007)

Map of Peru showing epicenter location removed due to copyright restrictions.

Photographs of collapsed roads removed due to copyright restrictions.

<u>Structural Design</u>

- Service State (Elasticity)
- Failure (Plasticity or Fracture)
- Mechanism

<u>Impact</u>

- Millions of people
- Nationwide Life Line interruption
- Economy

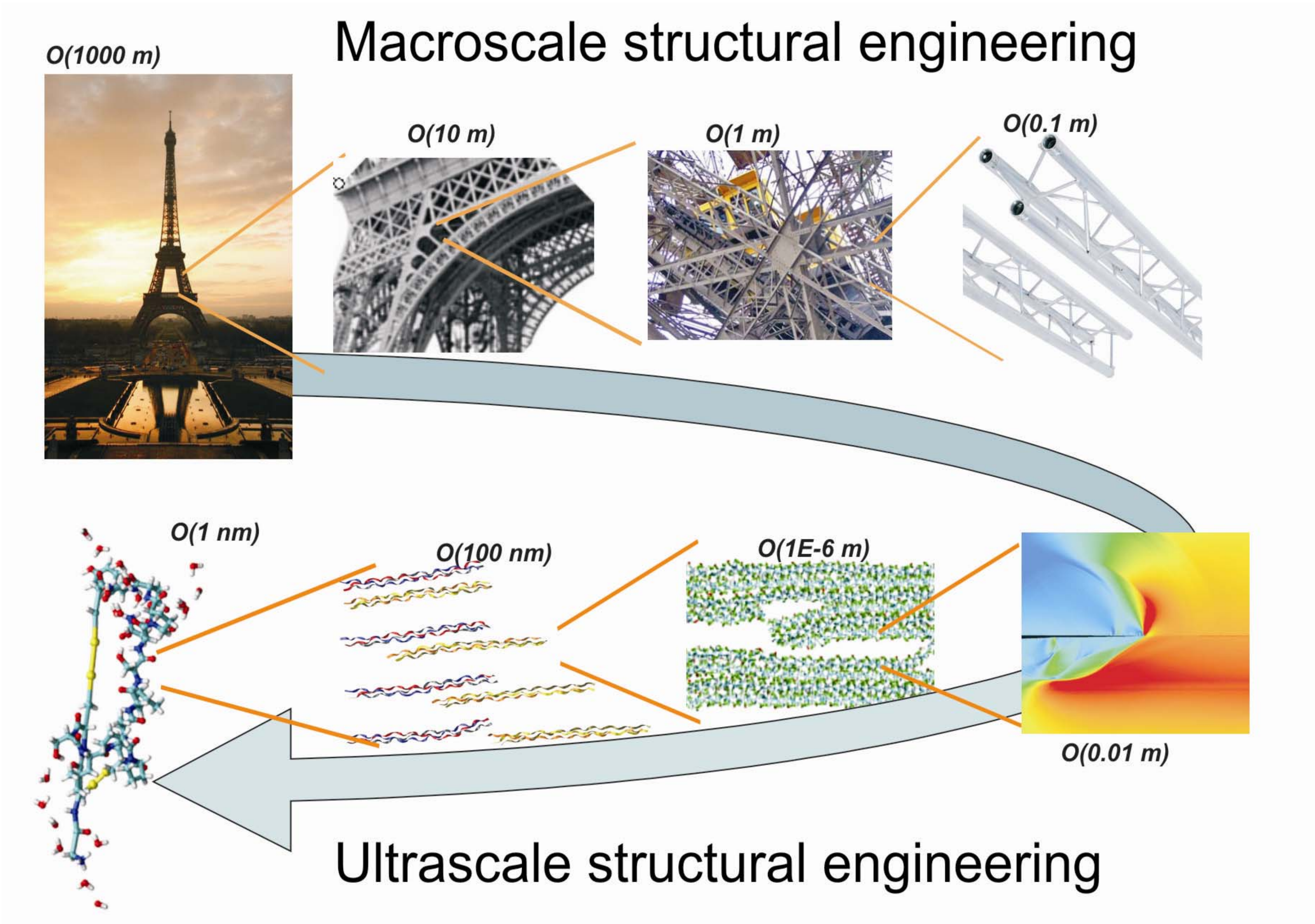
9-11: The Fall of the Towers

North Tower: 8:46 am above 96th floor, failed at 10:28 am
South Tower: 9:03 am above 80th floor, failed at 9:59 am

Immediate Question: How did the towers fail? - Mechanism – Lecture 4

Three sequential photographs of tower collapse removed due to copyright restrictions.

Engineering science paradigm: Multi-scale view of materials

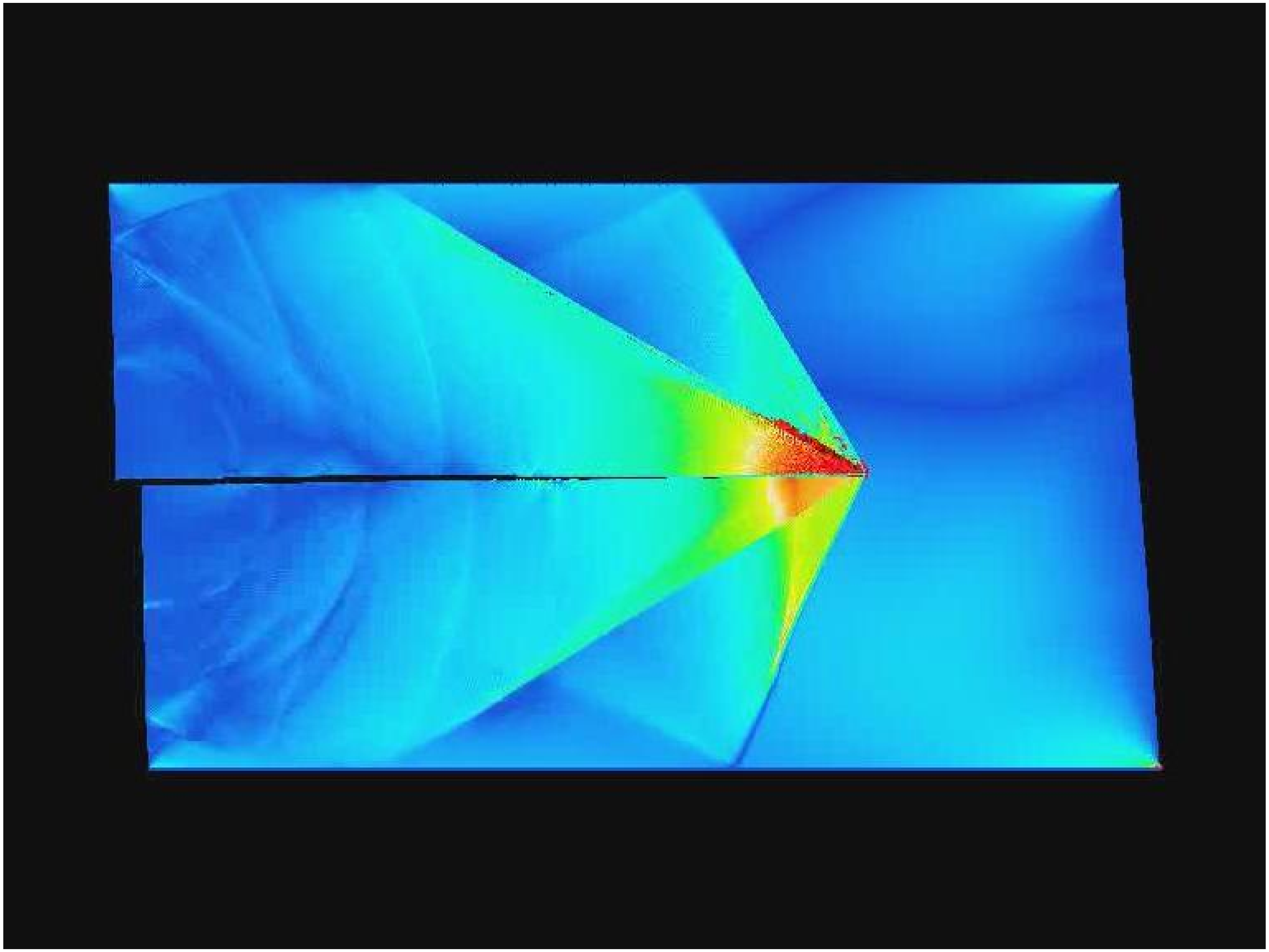


Buehler and Ackbarow, *Materials Today*, 2007

Atomistic mechanisms of fracture

Simulations of atomistic fracture mechanisms

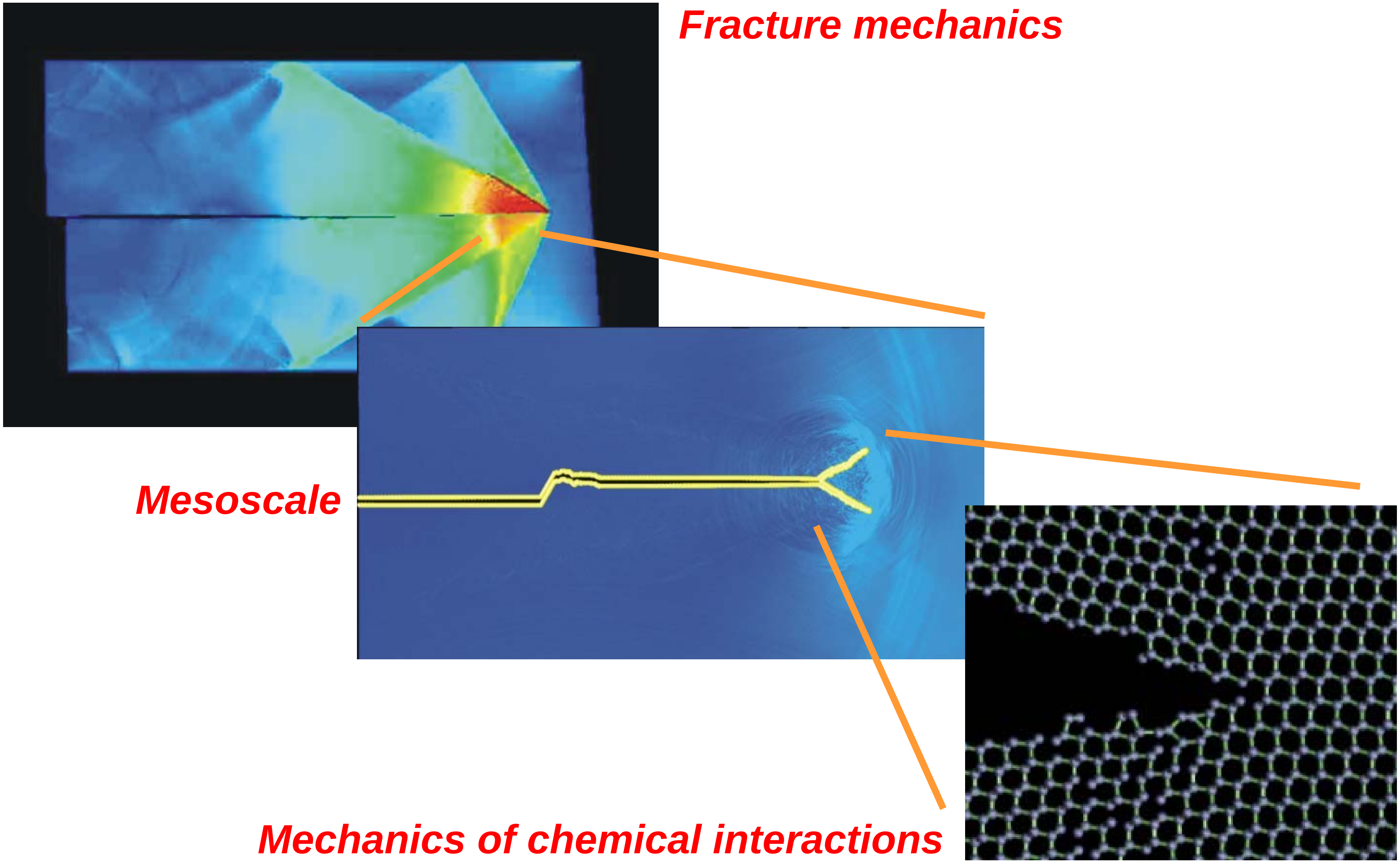
Reveals new fracture mechanism: Supersonic fracture



View the complete movie at:
http://web.mit.edu/mbuehler/www/research/supersonic_fracture.mpeg.

Buehler *et al.,* Nature, 2003; Nature, 2006

Fracture is linked to the mechanics of chemical bond breaking



Fracture mechanics

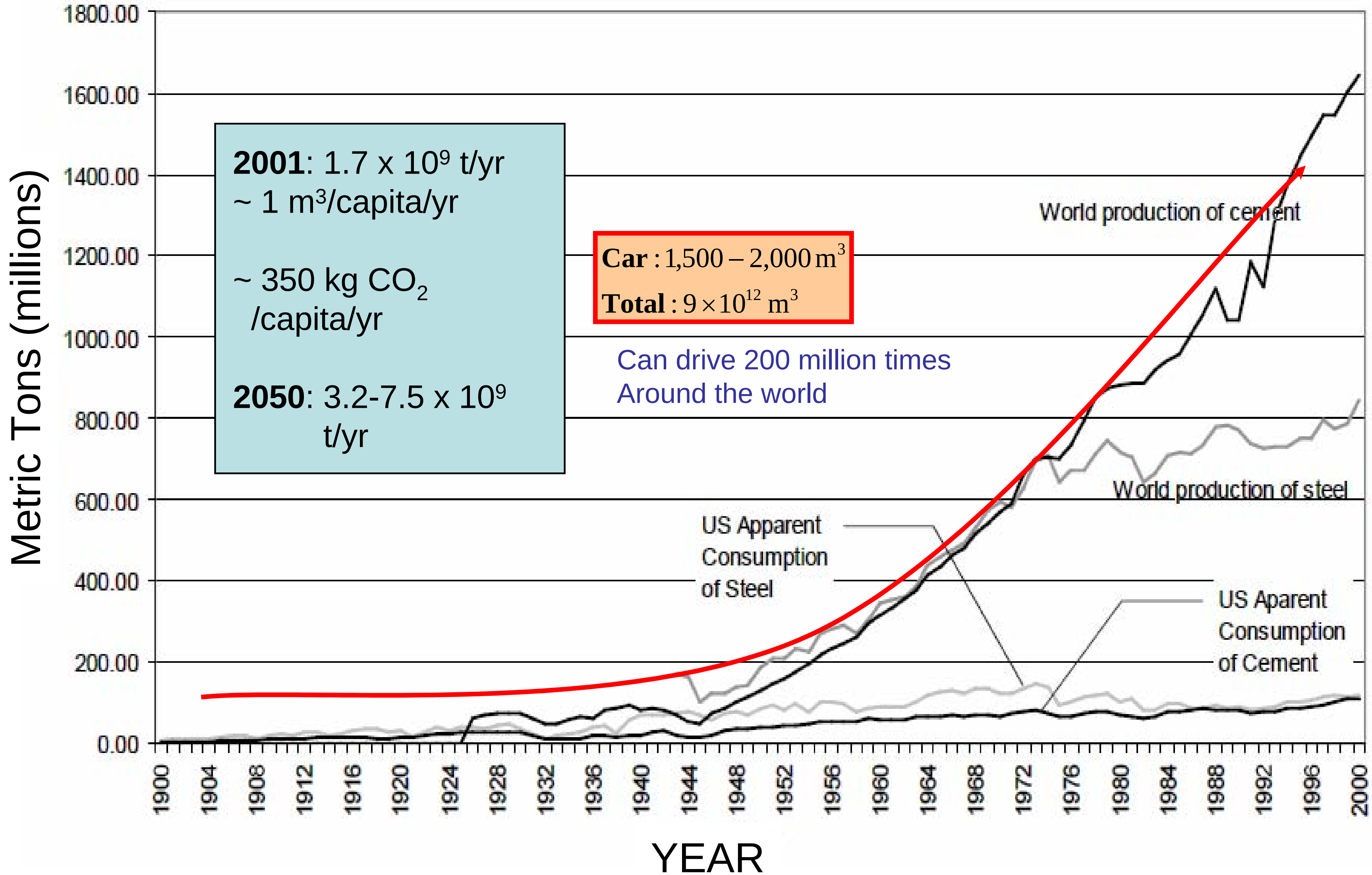
Mesoscale

Mechanics of chemical interactions

Buehler *et al.,* Nature, 2003; Nature, 2006

Impact of cement on worldwide CO2 production

Worldwide Cement Consumption $CaCO_3 + \text{heat} \rightarrow CaO + CO_2$



Worldwide Cement Consumption equates to 10% of worldwide CO2 Emission

Chaturvedi, S. and Ochsendorf, J., “Global Environmental Impacts Due to Concrete and Steel,” *Structural Engineering International*, 14/3, Zurich, Intl. Assoc. of Bridge and Structural Engineers, August 2004, 198-200.

Concrete: A complex multi-scale material

New materials for construction industry?

Ti, Mg… based cement?

New production pathways?

Mortar
few mm

Concrete
1 cm

Cement paste
< 0.1 mm

Images of concrete from the nanometer to centimeter scale removed due to copyright restrictions.

Molecular mechanics

C-S-H
< µm

Enables structures

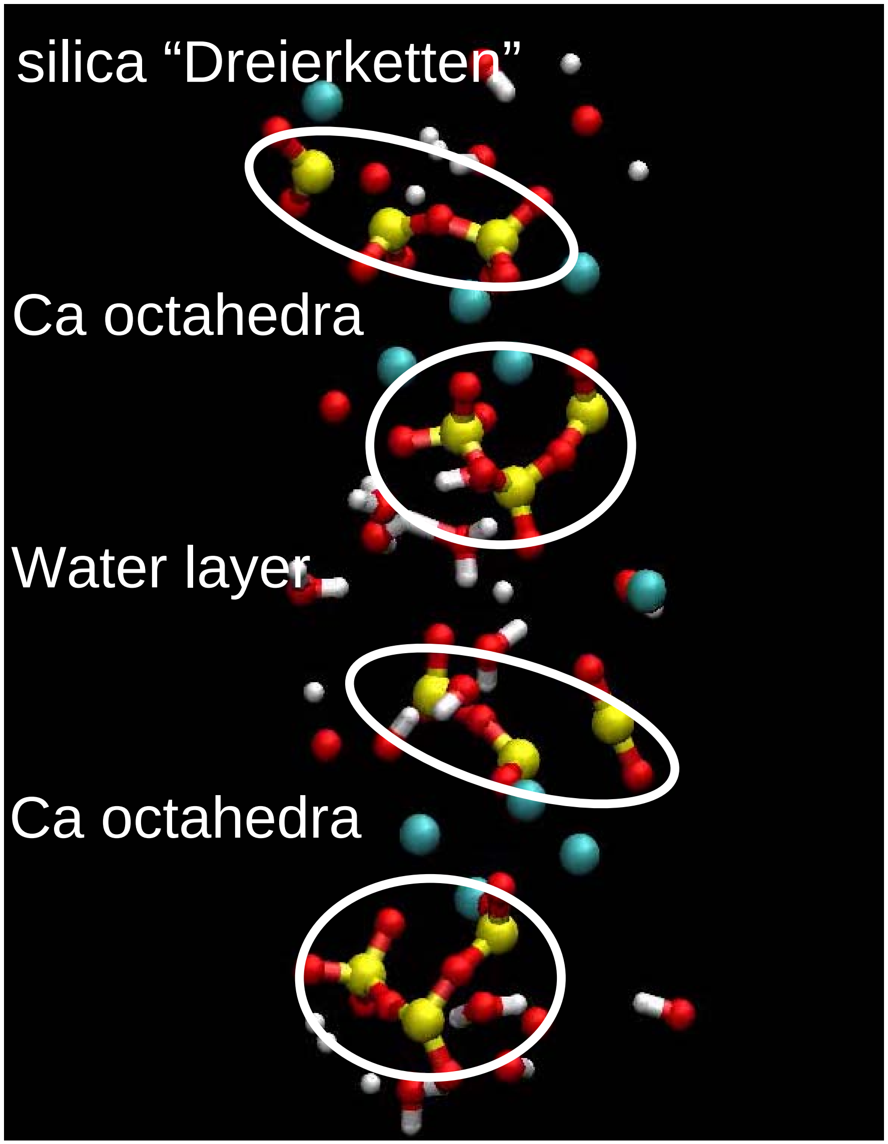
Platelets
few 10 nm

Chemistry
Angstrom-nm

Kilometers

Image of suspension bridge removed due to copyright restrictions.

Opening molecular-nanoscale for engineering design



Production of ‘green concrete’

Reduce CO_2 emission during production

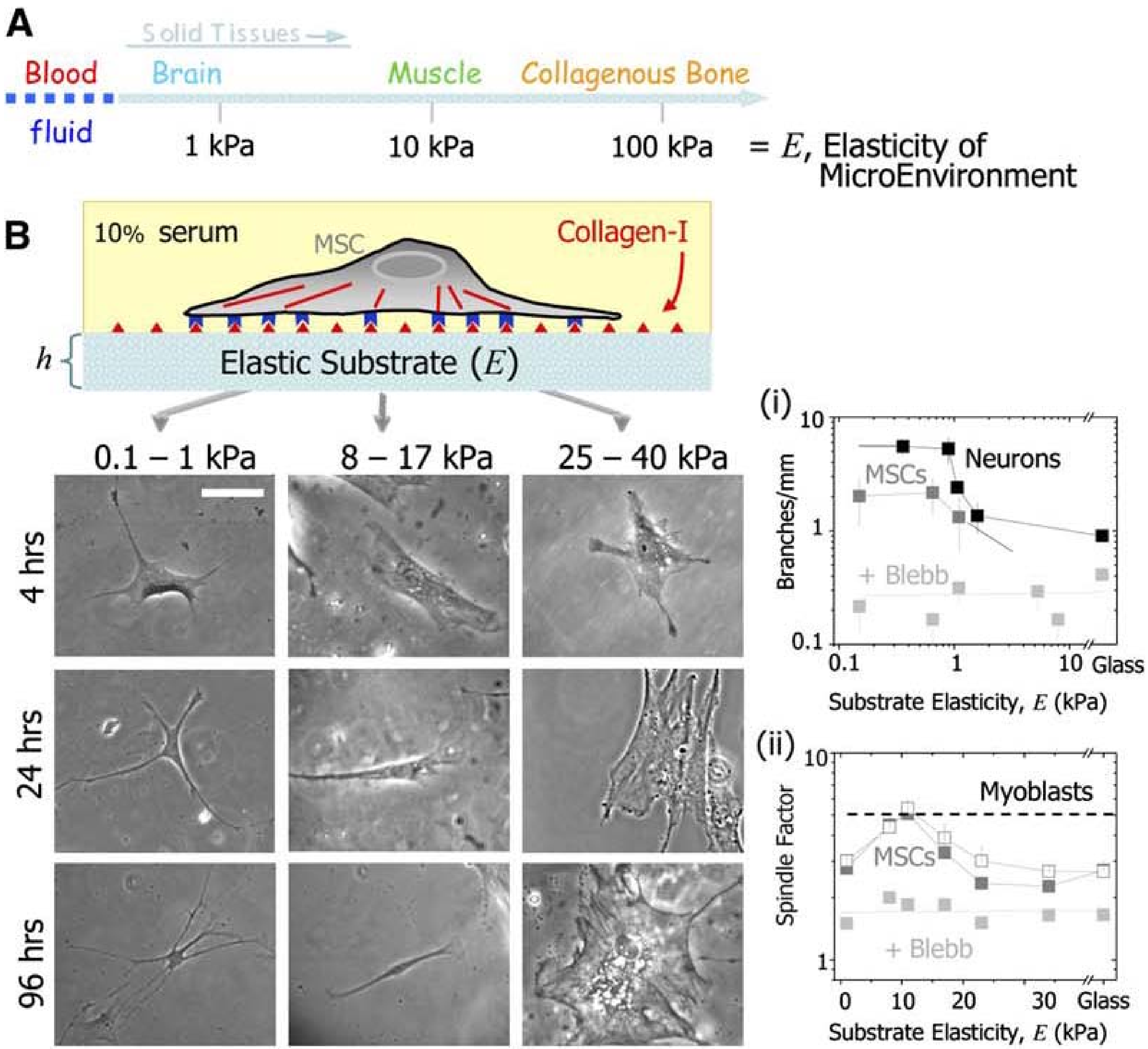
Understand diffusion of radioactive waste through concrete

Long-term stability/durability → avoid disasters

Environmental effects (chemicals, moisture,..)

Mechanical stability

Mechanics in life sciences

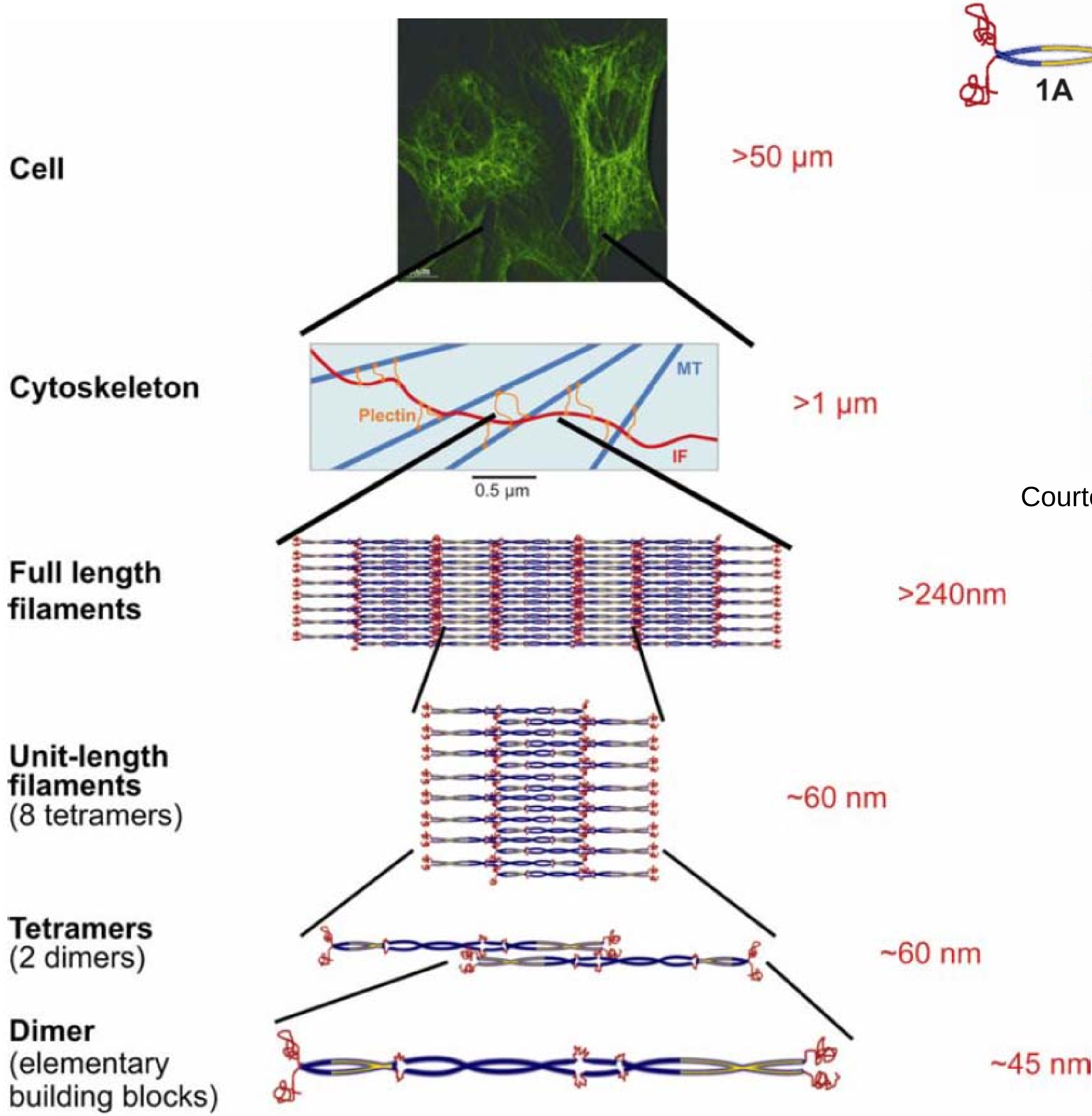


Elasticity of environment directs stem cell differentiation

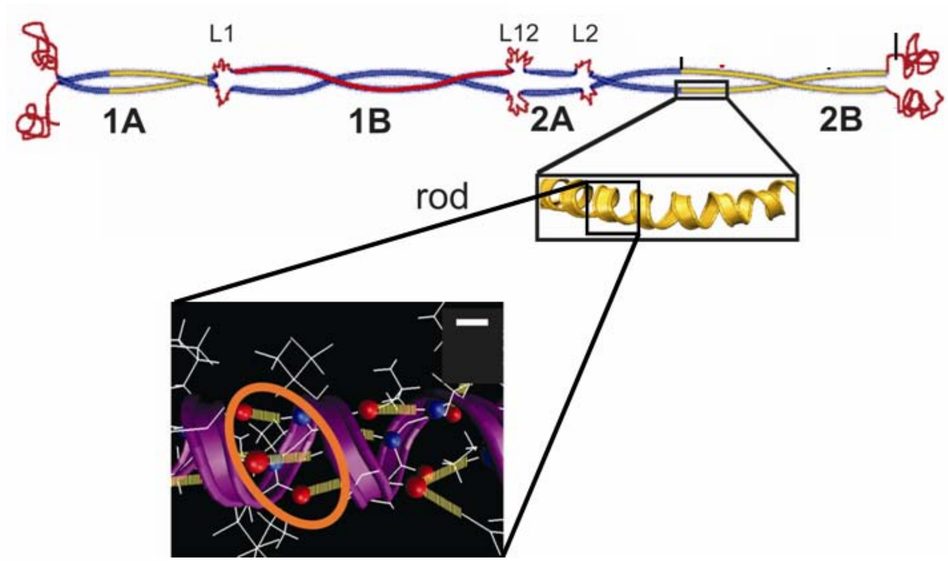
- Brain tissue
- Muscle
- Bone

D. Discher, *Cell*, 2006

Mechanics in life sciences



Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.



Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

- Change of mechanics in diseases?
- How can we use self-assembly to synthesize new materials?

Buehler and Ackbarow, *Materials Today*, 2007

Mechanics in life sciences

- Single point mutations in IF structure causes severe diseases such as **rapid aging disease *progeria* – HGPS** (*Nature*, 2003; *Nature*, 2006, *PNAS*, 2006)
- Cell nucleus loses stability under cyclic loading
- Failure occurs at heart (fatigue)

Substitution of a single DNA base: Amino acid guanine is switched to adenine

Experiment suggests that mechanical properties of nucleus change (Dahl *et al*., *PNAS*, 2006)

Images from the organismal to cell to molecular scales removed due to copyright restrictions.

1.050 – Content overview

I. Dimensional analysis

1. On monsters, mice and mushrooms
2. Similarity relations: Important engineering tools

Lectures 1-3
Sept.

II. Stresses and strength

2. Stresses and equilibrium
3. Strength models (how to design structures, foundations.. against mechanical failure)

Lectures 4-15
Sept./Oct.

III. Deformation and strain

4. How strain gages work?
5. How to measure deformation in a 3D structure/material?

Lectures 16-19
Oct.

IV. Elasticity

5. Elasticity model – link stresses and deformation
6. Variational methods in elasticity

Lectures 20-31
Nov.

V. How things fail – and how to avoid it

7. Elastic instabilities
8. Plasticity (permanent deformation)
9. Fracture mechanics

Lectures 32-37
Dec.

1.050 – Content

- The contents of 1.050 will be important in several subjects

- Spring: 1.060 Engineering Mechanics II –
  - Fluid Mechanics
    - Hydrostatics
    - Hydrodynamics
    - Open Channel Flow

- Application in many engineering applications and in engineering science
  - Biomechanics
  - Molecular mechanics & molecular dynamics
  - Microfluidics
  - Environmental science and application
  - Earthquake engineering
  - Structural engineering
  - Materials science
  - …

1.050 – Content overview

I. Dimensional analysis

Lecture 1: Introduction & Galileo's problem

Lecture 2: Dimensional Analysis and Atomic Explosion

Lecture 3: Dimension analysis and application to engineering structures

II. Stresses and strength

III. Deformation and strain

IV. Elasticity

V. How things fail – and how to avoid it