Fragmentation: from theory to numerical applications using FEM approaches

G. Anciaux
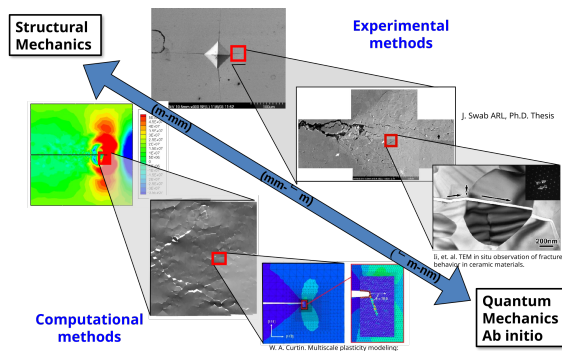
Civil Enginering, Materials Science, EPFL

EPFL

What is fragmentation ?

Essentially, this is fracture ...
... with dynamical effects

Fracture: Multi-scale and Multi-Physics models

Structural Mechanics

Experimental methods

(m-mm)

(mm - m)

(~ m-mm)

J. Swab ARL, Ph.D. Thesis

li, et. al. TEM in situ observation of fracture behavior in ceramic materials.

Computational methods

W. A. Curtin. Multiscale plasticity modeling:

Quantum Mechanics Ab initio

Dynamic fragmentation

- Many cracks
- They propagate (at high speeds!)
- They coalesce
- Lots of mechanical waves

Complexity

analytical work intractable

Not well understood...

Costly...

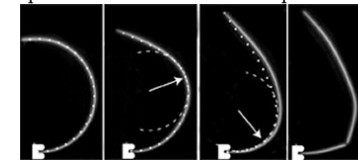UCSD simulates car bomb blast of 1,100 pounds of TNT at curbside

Many applications

- Mining industry, road excavation, fuel fragmentation (1930's)
- 1940's: seminal contribution of Mott (bomb shells)
- Applications in
  - engineering (crash performance, impact)
  - medecine (kidney stone fragmentation)
  - Astrophysics (asteroid impact, big bang)
  - low-orbit launch debris

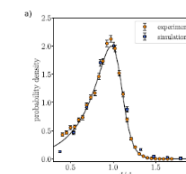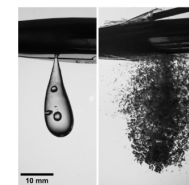## Fundamental physics problems

Why do pasta break in more than two pieces when bent?
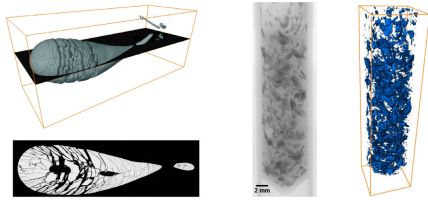

B. Audoly, S. Neukirch. *Fragmentation of Rods by Cascading Cracks: Why Spaghetti Does Not Break in Half*. Physical Review Letters. **95**(9),095505. (2005)
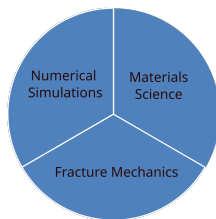
Challenging problems

Prince Ruperts' drops

S. Kooij, G. van Dalen, J.-F. Molinari, D. Bonn. *Explosive Fragmentation of Prince Rupert's Drops Leads to Well-Defined Fragment Sizes*. Nature Communications. **12**(1),2521. (2021)

Multi-disciplinary efforts

Open science ?

LSMS ?

Open-source software @ lsms.epfl.ch

- Head: J.F. Molinari
- Team: https://www.epfl.ch/labs/lsms/members/

Numerical methods and open-source software (production of LSMS)

- Akantu

- Cracklet

- Tamaas

- LibMultiscale

Akantu – Swiss-Made Open-Source Finite-Element Library

General considerations on FE software

- Huge business: ex. Dassault Systèmes (3,5 billions €)
- Commercial software : Abaqus, Ansys, Comsol, …
  - ○ (+) Stable, robust, certified : great for industry
  - ○ (-) Cost, "black box", slow evolution
- Academic software : agile but confidential, tailored for specific pbs

Our philosophy:

- Knowledge creation and transmission for the greater good (tax payer money)
- Open-Source Software development

Akantu today

Some features of Akantu:

- statics
- dynamics
- contact detection
- extrinsic cohesive elements
- non-local continuum damage
- phase-field fracture
- *High Performance Computing* (HPC)

History

- 12 years of development
- C++ code with a python interface
- High performance parallel computing
- Hosted on GitLab (continuous integration and delivery with GitLab tools)
- Full documentation online
- Issues Review and Merge Requests
- Online tutorials on notebooks

https://akantu.ch

JTCAM specific features

- **Overlay Journal**
  - Always a preprint shared on Open Archives (even for refused papers)
  - Diamond Open Access
- **Team**
  - Technical board: creators of the journal + data/software editor
  - Scientific Board: invited
  - Editorial board: elected
  - Collegial decisions, no editor in chief
- **Open Review**
  - Valued Open Reviews and reviewers' work
- **Copy-editing**
  - Very high quality
  - Links to open data sets and software → Reproducible research!
  - Script to check the correctness of bibliographic entries

Research Community

- Solid Mechanics
- Not well aware of Open Access good practices
- Wide spectrum: theoretical, applied, numerical, experimental
- Classical journals and publishers
  - IJP, JMPS, IJSS, CMAME, IJMM, TI, IJES, Wear, ActaMat (Elsevier)
  - IJNME, Adv Mat (Wiley)
  - Comp Mech, Meccanica (Springer)
  - PRS (Cambridge)
  - Mechanics of Adv Mat and Struct (Taylor & Francis)
- Alternate journals (Diamond Open Access)
  - CRAS (Mersenne)
  - Archives of Mechanics (since 1950)
  - Technische Mechanik
  - Mathematics and Mechanics of Complex Systems (half-diamond)
  - JACM
  - ACM

Open-science

Benefits:

- Reproducibility in science
- Transparency
- Efficiency
- Transfer of knowledge
- Sustainability
- Visibility
- Less cost (for society)
- Better Quality

Class Objectives

Open science

- Akantu
- Overlay journals (JTCAM)

Fundamentals

- Wave dynamics
- Fracture mechanics (mostly LEFM)
- Fragmentation theories

Numerical modeling with Finite Elements

- Dynamics
- Fracture
  - cohesive-element method
  - phase field models
- Dynamic fragmentation

Class content

https://go.epfl.ch/anciaux-gdr-mecawave