Fragmentation: from theory to numerical applications using FEM approaches

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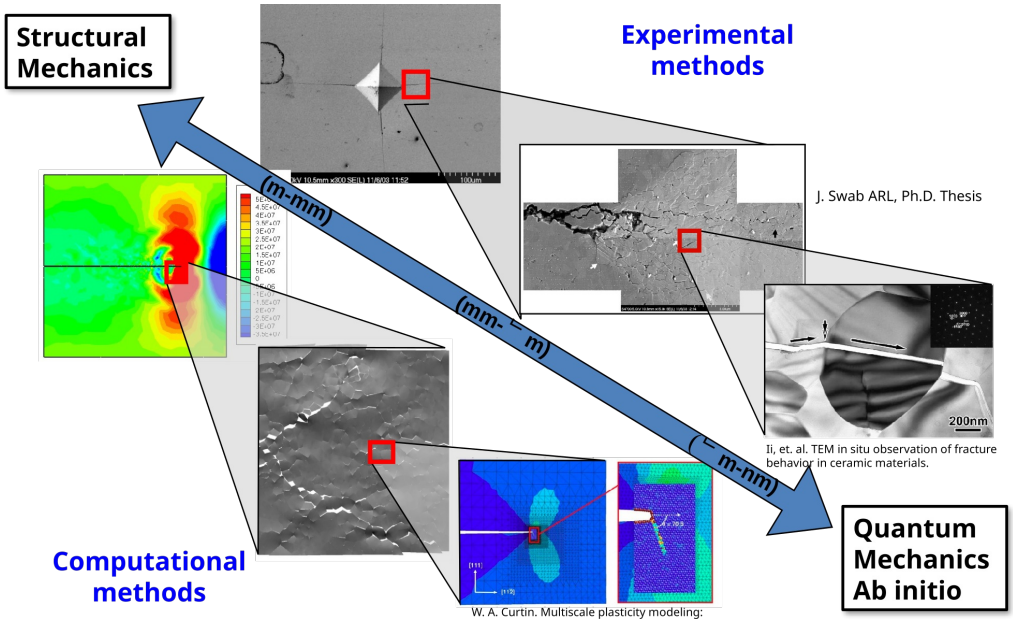
What is fragmentation ?

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

Fracture: Multi-scale and Multi-Physics models



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

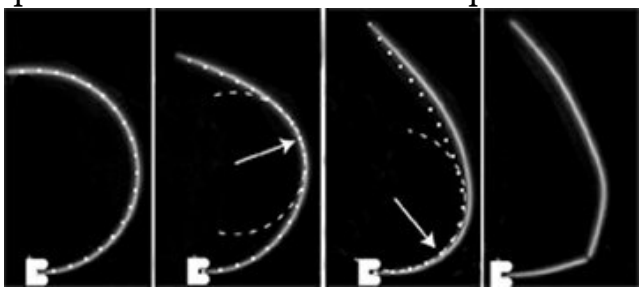
https://jacobsschool.ucsd.edu/news/release/377

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

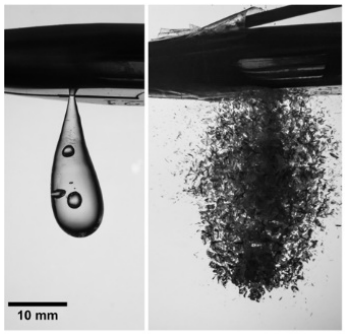
Why do pasta break in more than two pieces when bent?

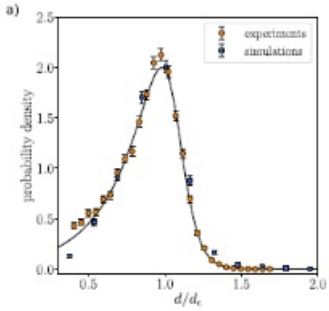


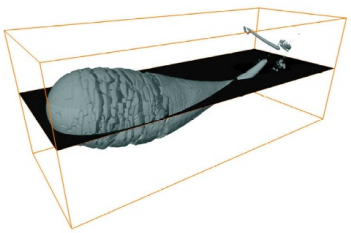
B. Audoly, S. Neukirch. *Fragmentation of Rods by Cascading Cracks: Why Spaghetti Does Not Break in Half*. Physical Review Letters. **95**(9),095505. (2005)

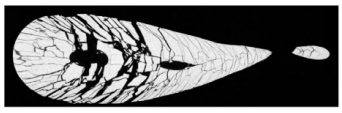
Challenging problems

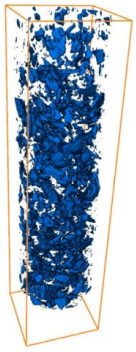
Prince Ruperts' drops





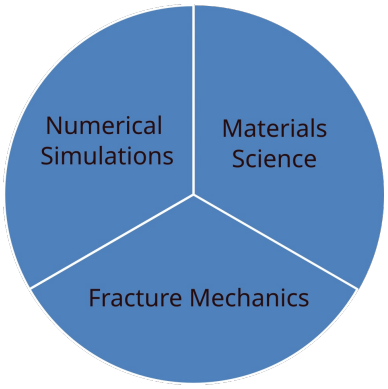






S. Kooij, G. van Dalen, J.-F. Molinari, D. Bonn. *Explosive Fragmentation of Prince Rupert's Drops Leads to Well-Defined Fragment Sizes*. Nature Communications. **12**(1),2521. (2021)

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

Akantu

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

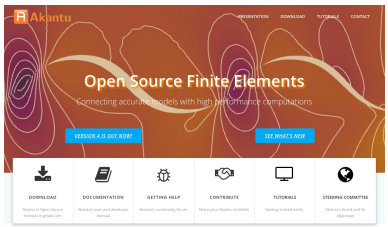
Some features of Akantu:

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

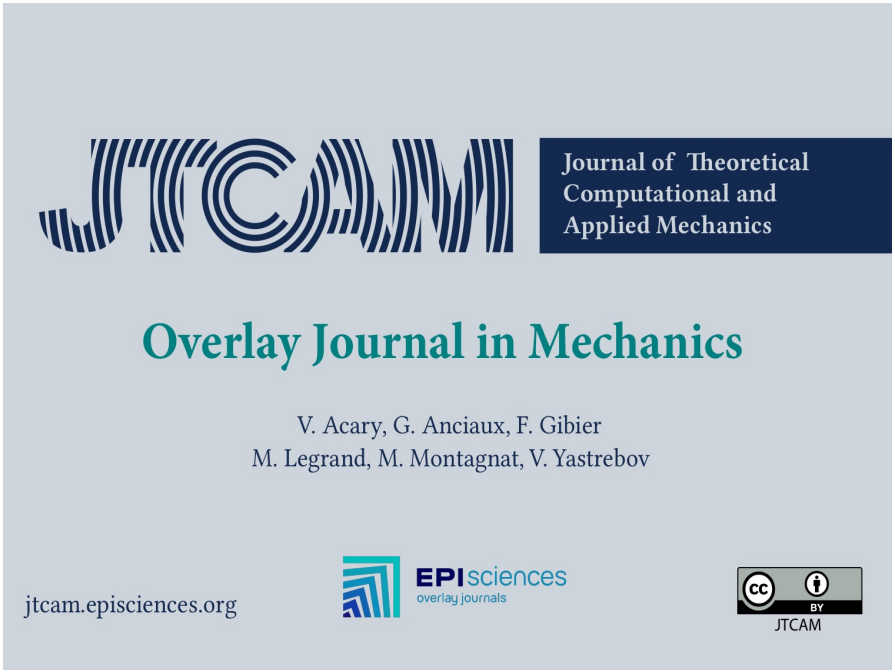
History

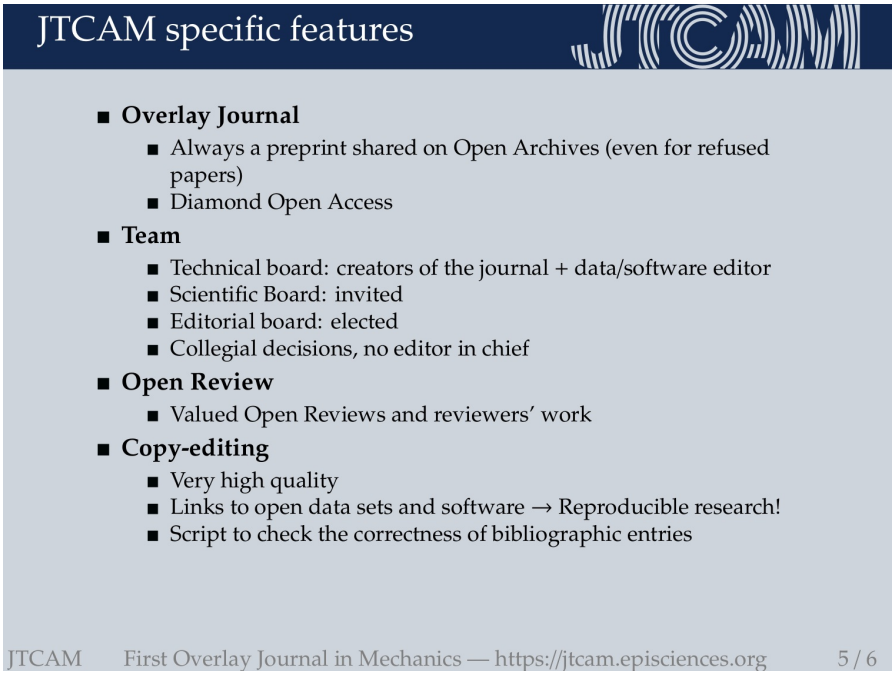
- 12 years of development
- C++ code with a python interface
- High performance parallel computing
- Hosted on GitLab (continuous integration and delivery with GitLab tools)
- Full documentation online

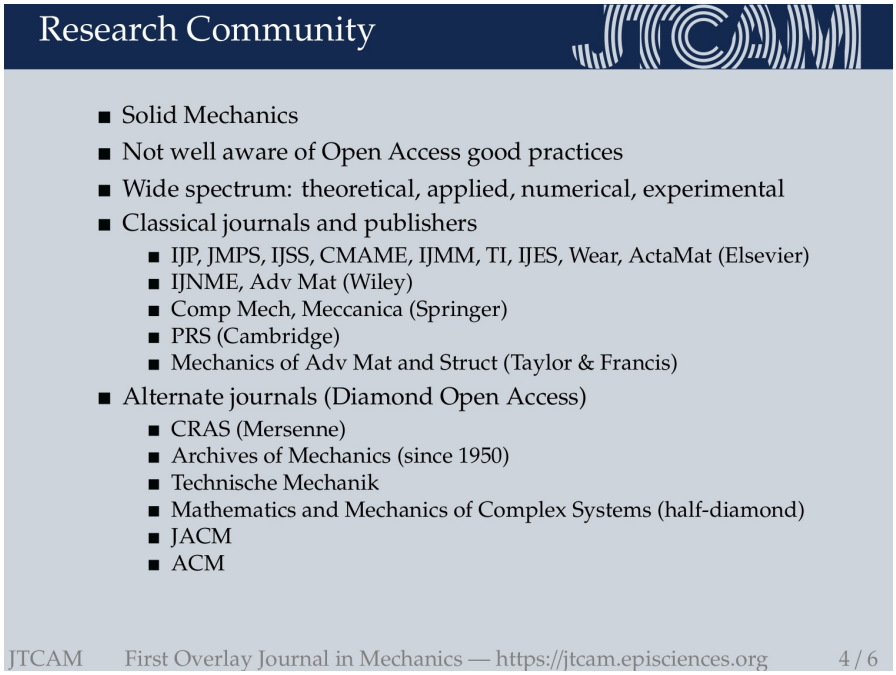
- Issues Review and Merge Requests
- Online tutorials on notebooks



https://akantu.ch







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