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Introduction

The realism of Discrete Fracture Network (DFN) models, beyond the bulk statistical properties, relies on the spatial organization of fractures, which is not issued by stochastic Poisson's (spatially random) DFN models. This can be improved by injecting prior information in DFN from a better knowledge of the geological fracturing processes. We first develop a model using simple kinematic rules for mimicking the growth of fractures from "nucleation" to "arrest", The model generates fracture networks with power-law scaling distributions and a percentage of T-intersections that are consistent with field observations. Nevertheless, a larger complexity relying on the spatial variability of natural fractures positions cannot be explained by the random nucleation process. We propose to introduce a stress-driven nucleation in the timewise process of this kinematic model to study the correlations between nucleation, growth and existing fracture patterns.

1. The kinematic UFM model

Kinematic DFN model divided in three main stages in a time-wise approach [1,2]

Inputs:

$\dot{n}$: nucleation rate

a: growth speed exponent

t_{end}: ending time of simulation

- **Nucleation**: randomly positioned
- **Propagation**: subcritical, following Charles' law:

$$v(l) = Cl^a \quad \text{with } l \text{ the fracture diameter}$$

- **Arrest** : fractures cannot cross larger ones

Outputs:

Two power-law scaling of the fracture length distribution

⇒ "dilute" regime: $n_{dilute}(l) \sim l^{-a}$

⇒ "dense" regime: $n_{dense}(l) \sim l^{-D+1}$

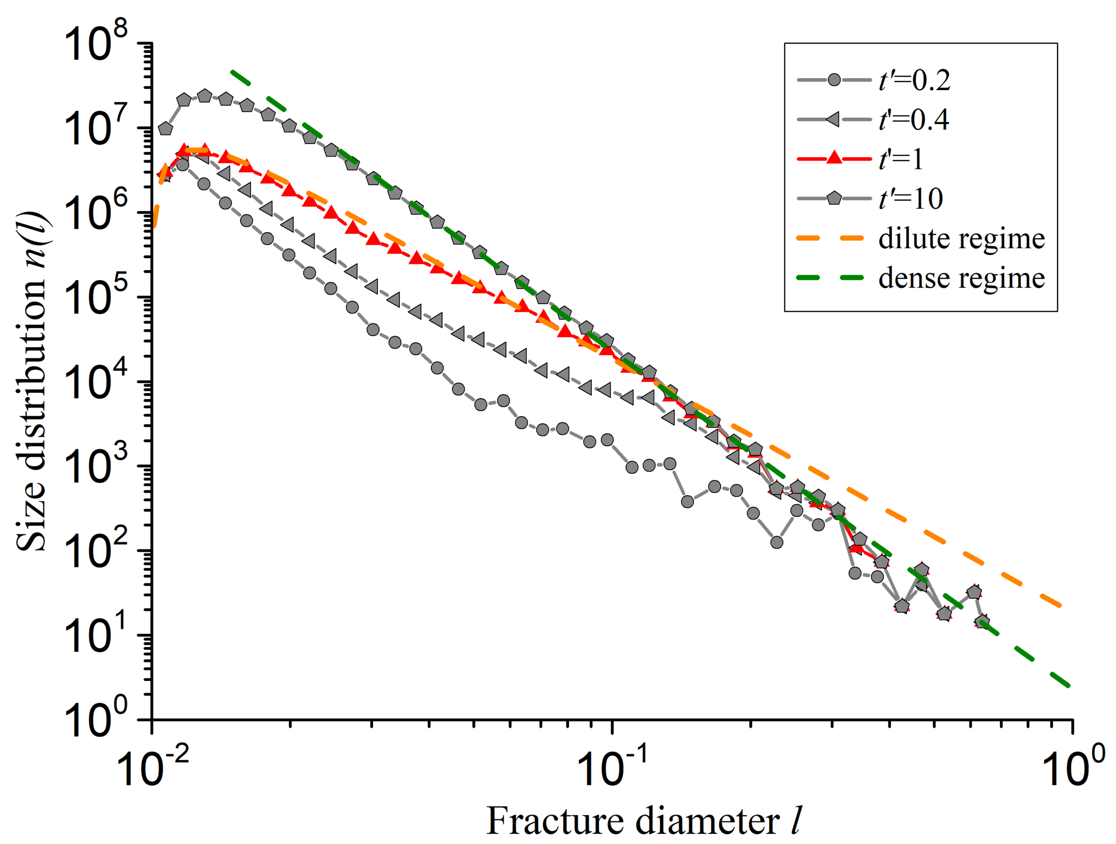

Figure 1: Size distribution evolution of a kinematic UFM model with normalized simulation time (modified from [2])

2. Stress driven nucleation

Nucleation: function of the stress redistribution of growing fractures,

⇒ Stress field $\bar{\bar{\sigma}}$ at a position $\bar{x}$: superposition of the remote stress field $\overline{\overline{\sigma^{\infty}}}$ and the contribution of every fracture $\overline{\overline{\sigma_f}}$ ignoring interactions

$$\bar{\bar{\sigma}}(\bar{x}) = \overline{\overline{\sigma^{\infty}}} + \sum_f \overline{\overline{\sigma_f}}$$

⇒ Using 3D tensorial analytical solutions of uniformly loaded penny-shaped cracks [3]

⇒ Monte Carlo sampling at each timestep over a range of potential nuclei candidates whose probability is given by the Von Mises stress at their location, power m (selectivity parameter)

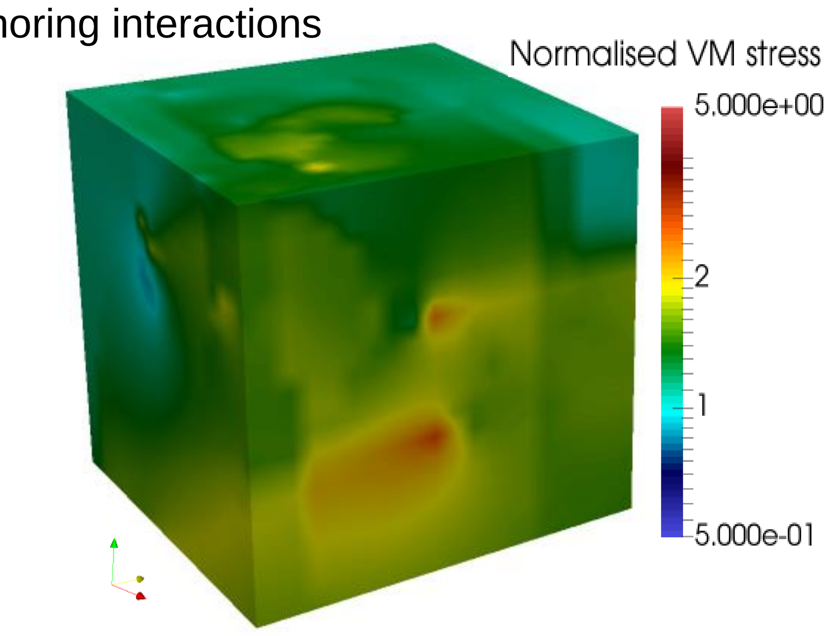

Figure 2: Normalised Von Mises stress in a growing network

We perform 50 realizations using the same parameters for:

- **Poisson**'s (stochastic) model
- **Kinematic UFM** model (UFM m=0)
- **Stress-driven UFM** model (UFM m=4)

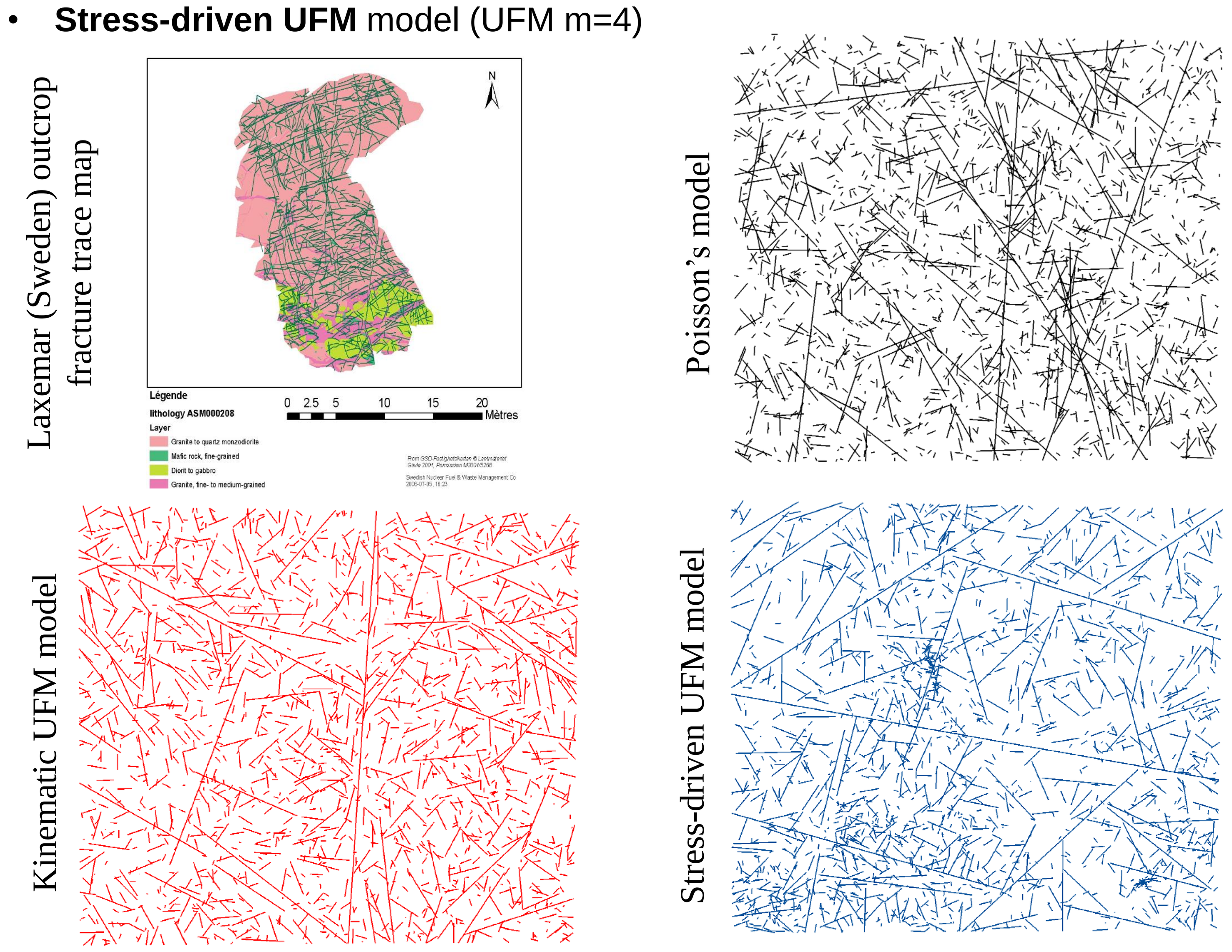

Figure 3: 2D trace maps comparison of a natural pattern with Poisson's, Kinematic UFM and Stress-driven UFM models

3. Spatial analysis

3.1 Fractal analysis

⇒ Fractal dimension of a fracture network: measure of the spatial organization of fractures

⇒ Correlation dimension of fracture centers defined as:

$$D = \lim_{r \to 0} \frac{\log C_2(r)}{\log r}$$

$C_2(r)$: pair correlation function [5]

⇒ Stress-driven UFM model: $D < 3$

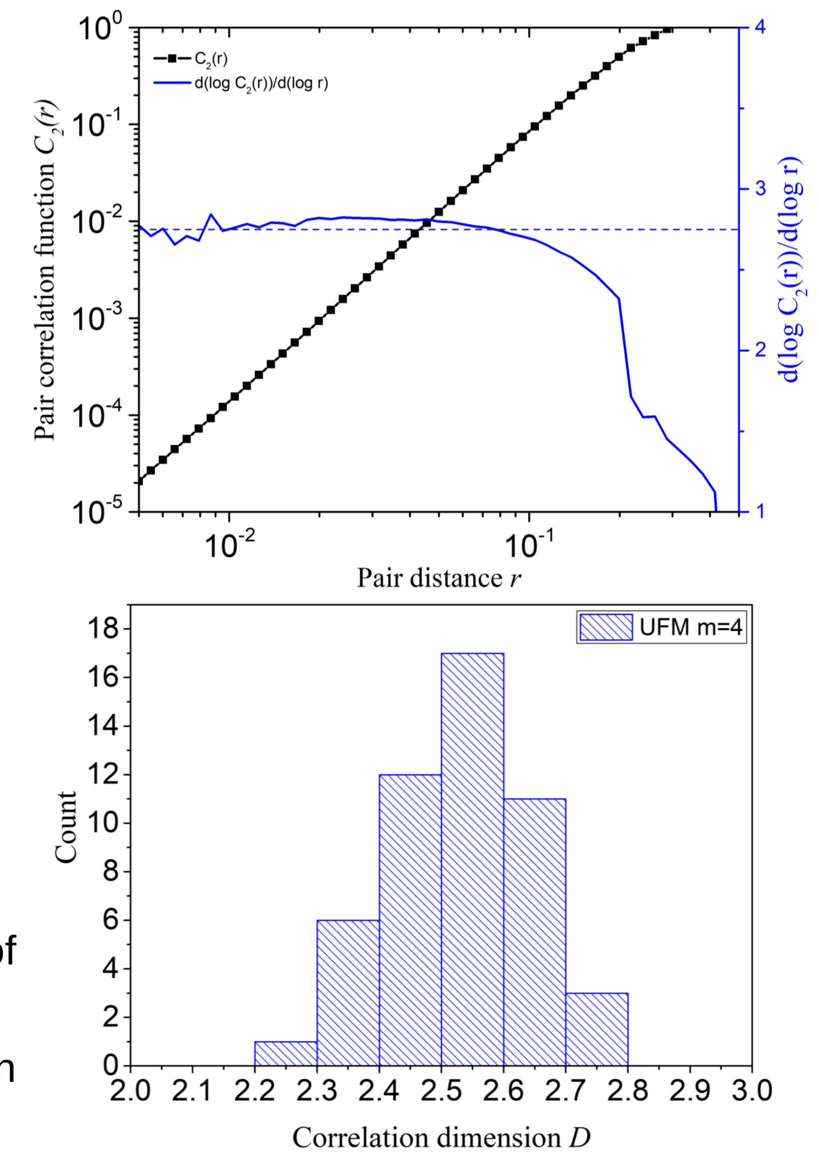

Figure 4: Correlation dimension analysis of the stress-driven UFM model (50 realizations))

3.2. Lacunarity

⇒ Fracture densities lacunarity [4]: measure of the textural heterogeneity of fracture patterns and its evolution with scale

⇒ The lacunarity of a measure M of an object O following a probability distribution Q at scale s is given by:

$$\lambda(M,Q,s) = \frac{Z_Q^{(2)}(s)}{\left[Z_Q^{(1)}(s)\right]^2} \quad \text{with } Z_Q^{(n)} \text{ the } n^{th} \text{ moment of the distribution}$$

⇒ Classical 3D fracture densities are:

- The fracture center density p_{30} : number of fracture centers per unit volume of rock mass
- The fracture intensity p_{32} : area of fractures per unit volume of rock mass
- The percolation parameter p: total excluded volume per unit volume of rock mass

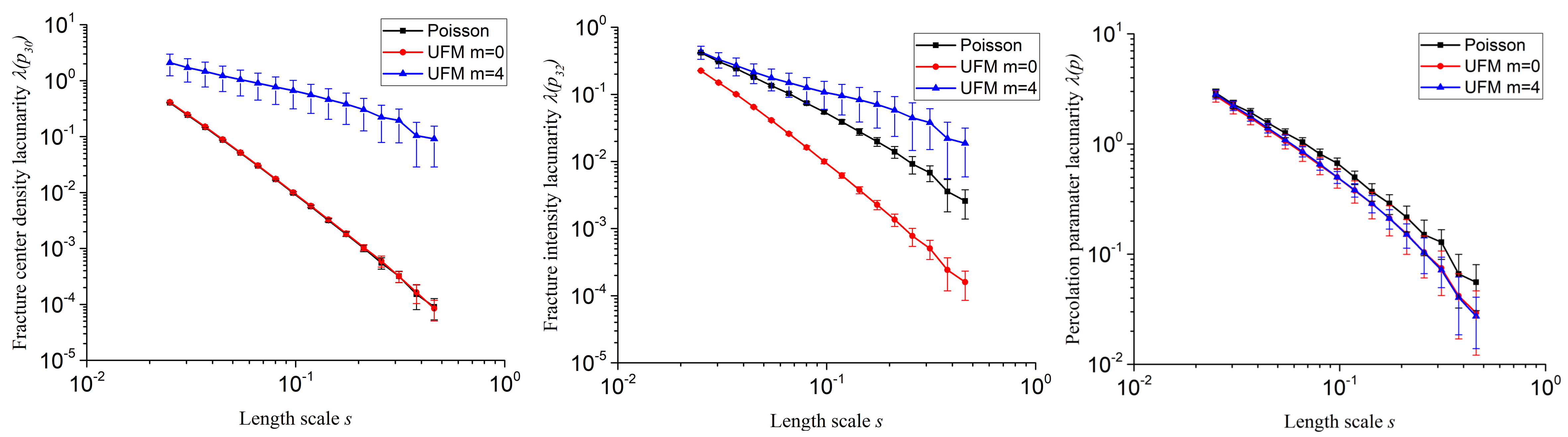

Figure 5: Lacunarity density analysis (p_{30}, p_{32}, p) for the Poisson, UFM, and stress-driven UFM models (50 realizations)

⇒ The percolation parameter is not affected by the nucleation process (concerning textural heterogeneity)

⇒ p_{30} and p_{32} variability evolves differently with scale and is higher for stress-driven than for random nucleation

Conclusion

We introduce a stress-driven nucleation step in the timewise process of the kinematic UFM model of [2]. This nucleation step is function of the local stress field. Networks so generated have fractal correlations, with a correlation dimension that varies with the function that relates the nucleation probability to stress. Moreover, this fractal center positioning process, coupled with the UFM rule, emphasize the correlation between size and position of fractures, leading to high textural heterogeneity.
Further work is on going to constrain also the orientation and growth velocity of fractures by the remote stress. A comparative analysis of the density lacunarity of our models with real data is also envisioned.

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