



**Earthquake nucleation**

# Nucleation Models

## 1. *SELF – SIMILAR MODEL*

- Always fully dynamic process
- Slip velocity linearly increases with time
- Waves emission since initial stages of nucleation



## 2. *CASCADE MODEL*

- Small events with mutual triggering accumulate up to a big event
- Only the final stage is fully dynamic with waves emission



## 3. *PRE – SLIP MODEL*

- Initially an aseismic process increases the total cracked area
- When a critical dimension is reached the process is spontaneous
- Dieterich and Andrews models

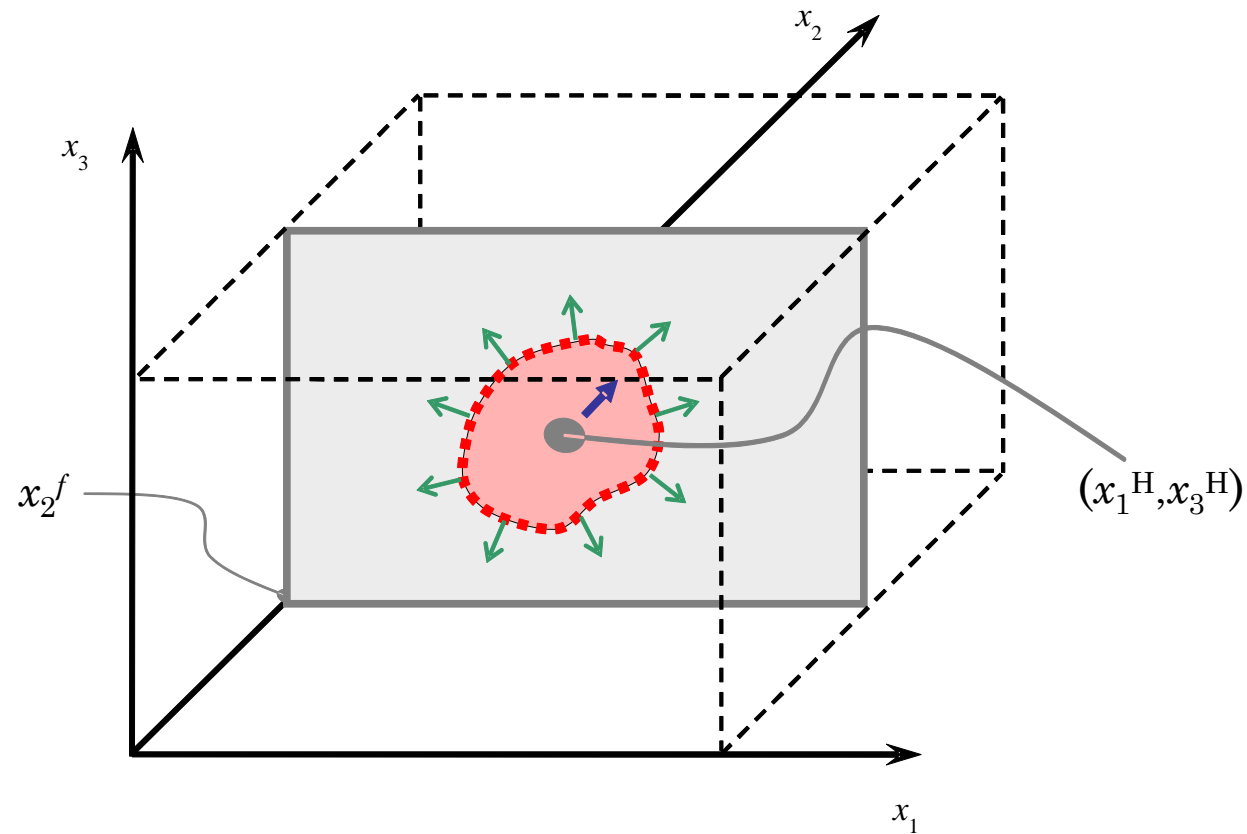


**How to simulate the  
earthquake nucleation?**

## **1. SLIP – WEAKENING CONSTITUTIVE EQUATION**

- Linear SW is **un**able to model the nucleation stage and therefore rupture initiation has to be prescribed ( i. e. imposed )
- Different nucleation strategy have to be compared in order to see what are the effects of the initialization parameters on the following rupture propagation
- In order to correctly represent a physical process nucleation strategies have to be equivalent results
- The Ohnaka' s SW contain the slip – hardening phase and is able to account for nucleation

# Notations and symbols



→ *Local crack enlargement*

→  $T(x_1, x_3, 0)$

# Time - weakening

inuclstrat = 1

$$\tau = \begin{cases} \left[ \mu_u - (\mu_u - \mu_f) \frac{(t - t_{force})}{t_0} \right] \sigma_n^{eff} & , t - t_{force} < t_0 \\ \mu_f \sigma_n^{eff} & , t - t_{force} \geq t_0 \end{cases}$$

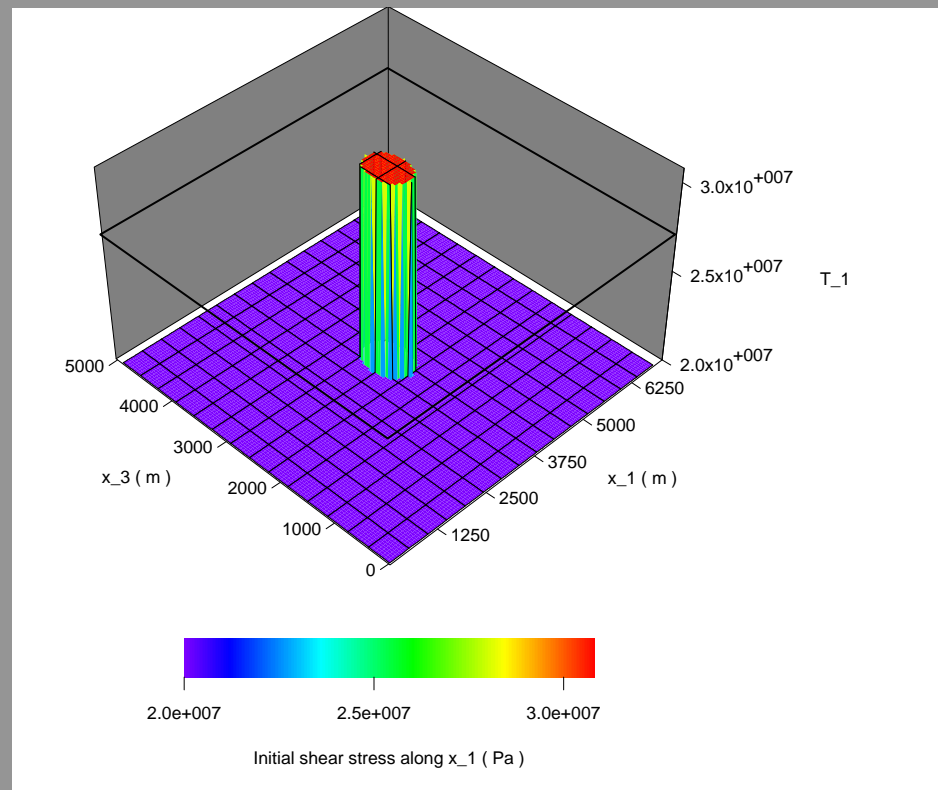
$t_{force} = t_{force}(\xi)$  is the forced rupture onset time in every fault point  $\xi = (x_1, x_3)$ :

$$t_{force}(x_1, x_3) = \frac{\sqrt{(x - x_1^H)^2 - (x - x_3^H)^2}}{v_{force}}$$

Andrews ( 1985 ), Bizzarri et al. ( 2001 ) and other following Bizzarri' s papers

$t_0$  is the characteristic time – weakening duration.

# Pre - stress asperity



inuclstrat = 2

$i\_nucl$  is the asperity radius. In general, arbitrary distribution of  $T(x_1, x_3, 0)$  is read from input files.

*Bizzarri and Cocco (2005c, 2005d)* and other following Bizzarri's papers

# Slip velocity perturbation

inuclstrat = 3

$$V \begin{Bmatrix} 1 \\ 2 \\ 3 \end{Bmatrix} (x_1, x_2, x_3, 0) = \frac{1}{2} \text{sign}(x_2 - x_2^f) v_{init} \begin{Bmatrix} \cos \varphi \\ 0 \\ \sin \varphi \end{Bmatrix} e^{\frac{(x_1 - x_1^H)^2}{(x_1 - x_1^H)^2 - (i_{nucl} \Delta x_1)^2}} e^{\frac{(x_3 - x_3^H)^2}{(x_3 - x_3^H)^2 - (j_{nucl} \Delta x_3)^2}} e^{-\frac{(x_2 - x_2^f)^2}{(r_{nucl})^2}}$$

$$H\left((i_{nucl} \Delta x_1)^2 - (x_1 - x_1^H)^2\right) H\left((j_{nucl} \Delta x_3)^2 - (x_3 - x_3^H)^2\right)$$

$\varphi$  is the rake angle, measured from  $x_1$  in anti – hourly sense;  $\varphi = 0$  represents a left – lateral strike slip fault

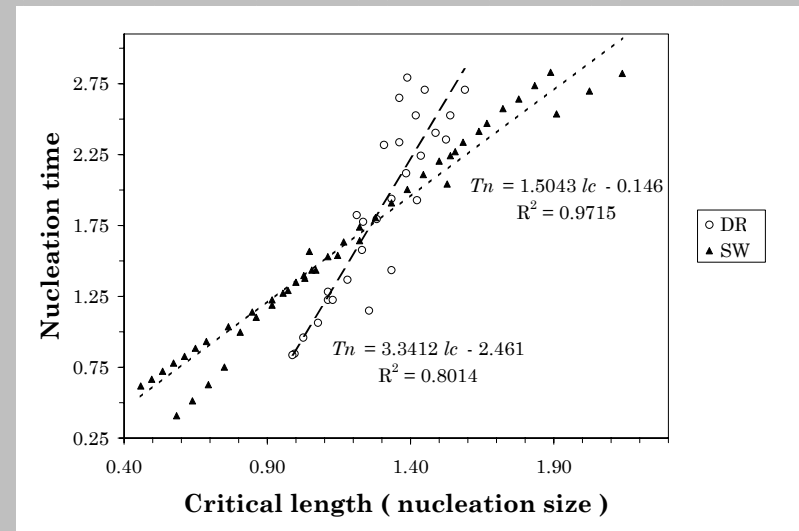
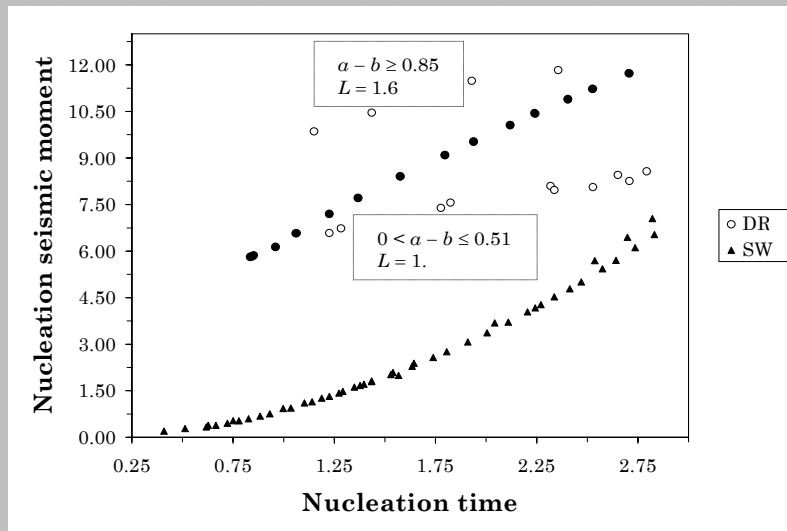
With opportune corrections and modifications of Ionescu and Campillo (1999) and Badea et al. (2004)

$v_{init}$  is the maximum imposed fault slip velocity;  $i_{nucl}$  and  $j_{nucl}$  determine the extension of the nucleation patch and  $r_{nucl}$  is a sensitivity factor

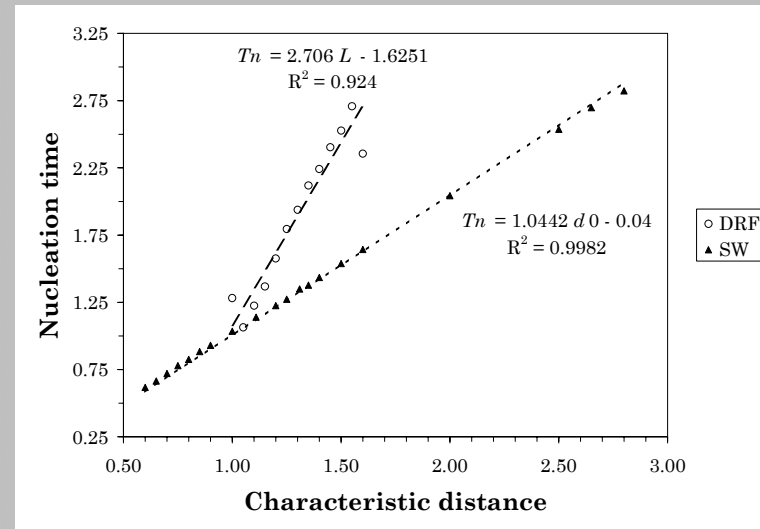




# Some correlations during nucleation



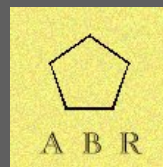
$T_n$  is the time necessary for the rupture tip to reach a distance along  $x_1$  equal to the critical half-length  $L_c^{(II)}$



## ***2. RATE AND STATE CONSTITUTIVE EQUATIONS***

- Rate – and state – dependent friction laws are able to describe the nucleation stage
- The **spontaneous** rupture nucleation is modeled through the evolution of the state variable
- The earthquake initiation is promoted in a nucleation path assuming a different distribution of the contact time of the micro – asperities

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# **Support Slides: Parameters, Notes, etc.**

*To not be displayed directly. Referenced above.*

