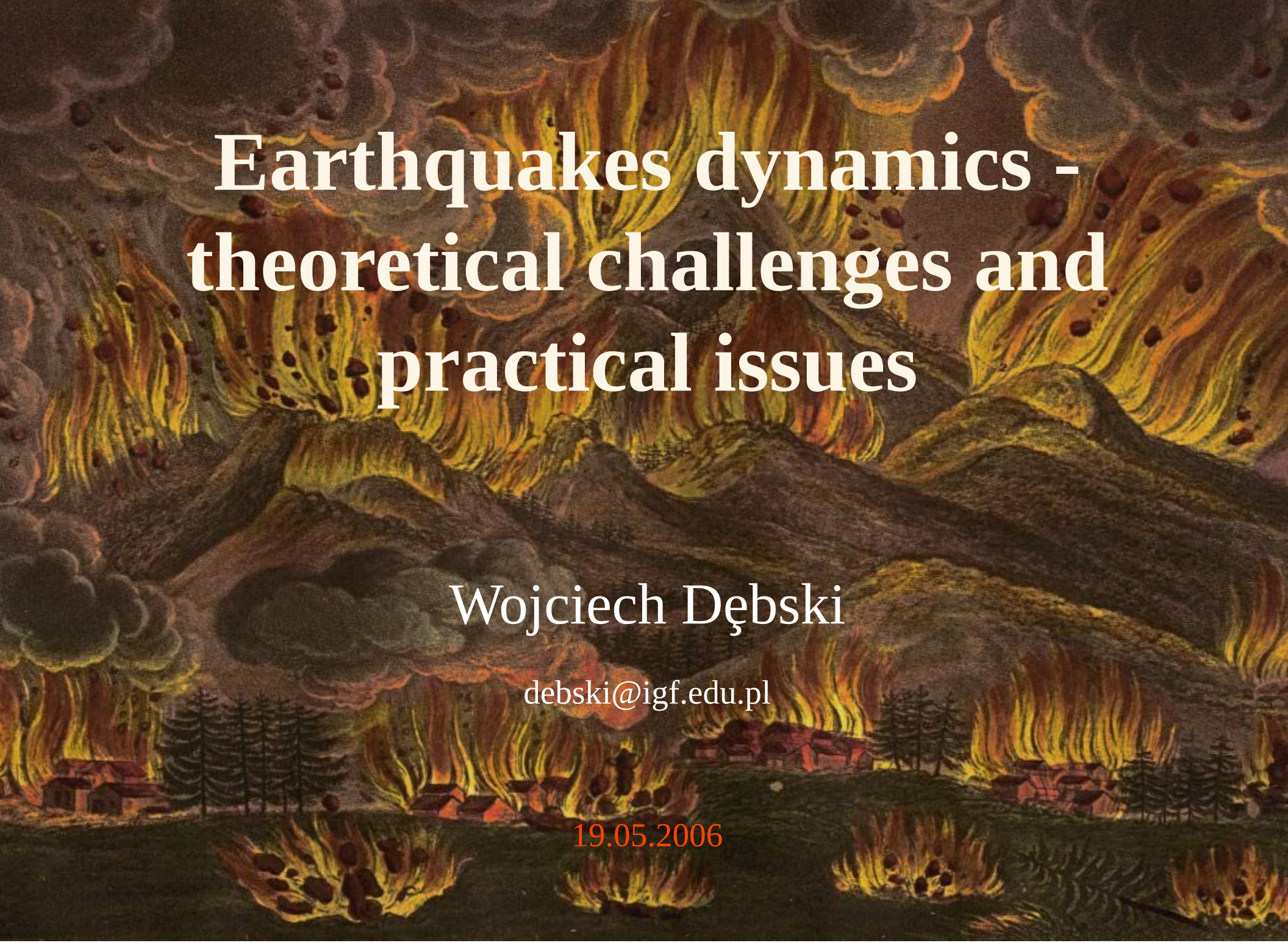

Earthquakes dynamics - theoretical challenges and practical issues

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19.05.2006

Plan of the talk

- Rupture dynamics and safety considerations
  - ★ earthquake prediction
    - ➡ statistical hazard estimation
    - ➡ early warning system
    - ➡ what the next earthquake will be?
  - ★ unknown damage mechanisms

- Inverse problems

- Rupture dynamics of induced seismic tremors

Earthquake prediction - I

General goal:

Quantify **when**, **where**, and **what size** (magnitude) an earthquake will occure.

Additionally

what damages can be expected.

Heuristic prediction - give the exact answer

Statistical prediction - give the probability

Earthquake prediction - II

Answer:

We cannot answer any of this question in a reliable way because of incomplete knowledge:

- crust (mantle) structure: fault structure,
- current state of faults, state of tectonic loadings, etc.
- physics of the rupture dynamics
- fault interactions and their evolution

Actually, each earthquake is different!

Earthquake prediction - III

Two ways :

- complete (almost) ignorance about source processes and treating earthqukes as stochastic process
- try to understand the rupture physics and use this knowledge to describe given earthquakes

give rise to two different practical approaches to earthquake safty issue

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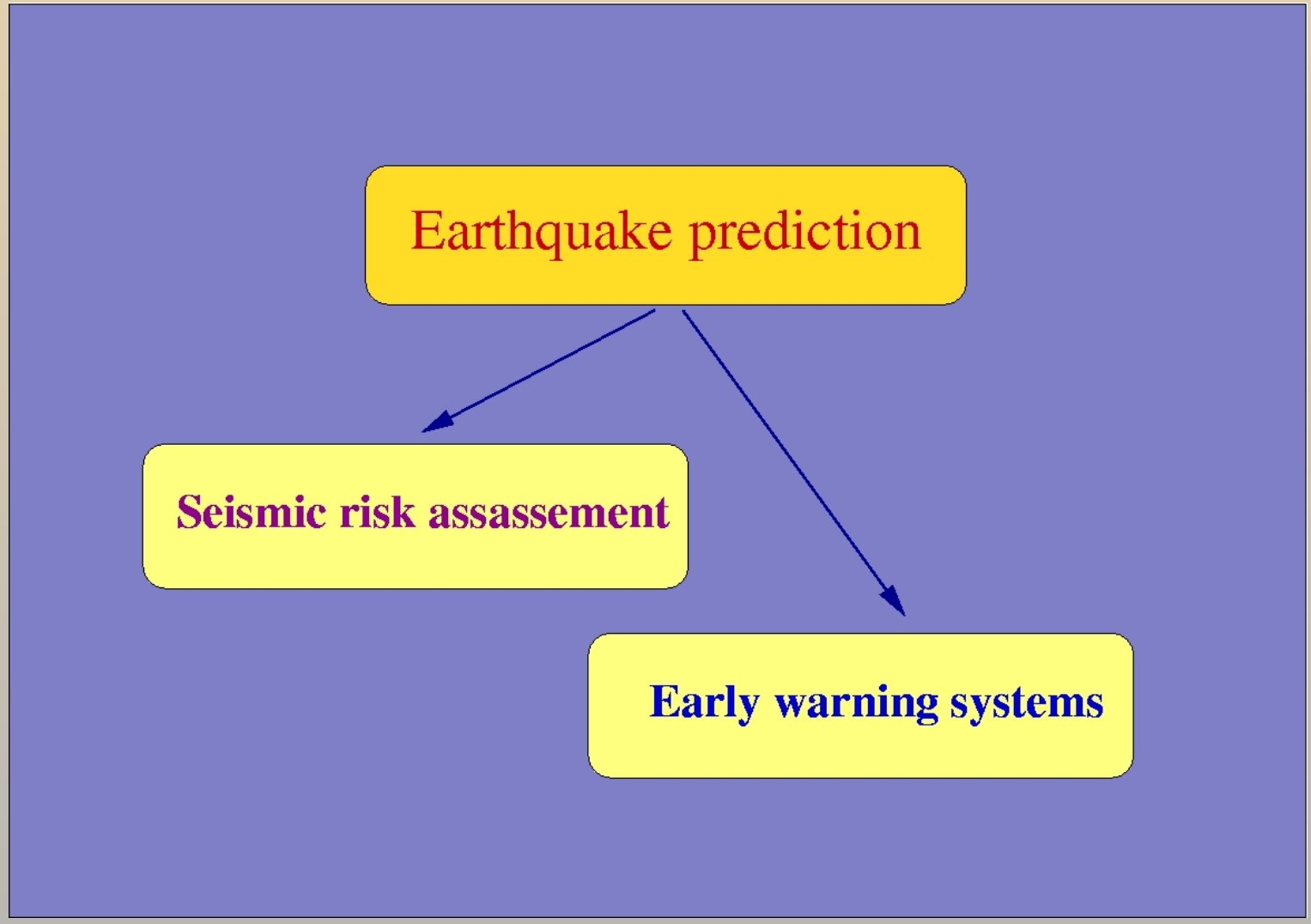
We still need to make some inference/measurements of the current state of the crust/mantle

Earthquake prediction - IV



Probabilistic Seismic Hazard Analysis

Seismic events as partially random phenomena

- recognizing source zones of statistically homogeneous seismic activity
- evaluating probabilistic characteristics of the source zones
- identifying local attenuation/amplification conditions
- converting probabilistic characteristics of seismicity (sources) into e.g., **maximum peak ground accelaration** at given point

Earthquake prediction $\Longrightarrow$ ground shaking prediction

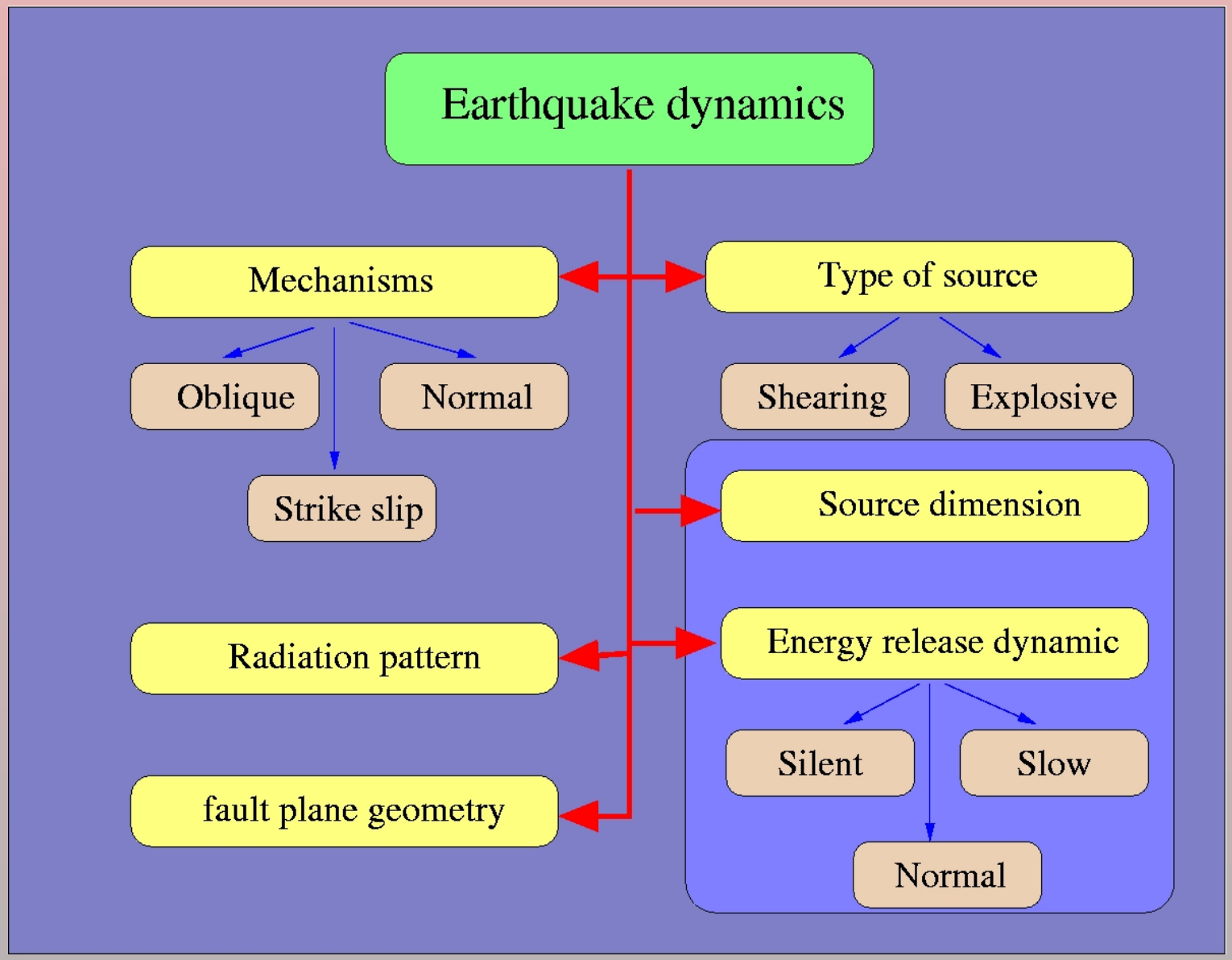
Early warning system

Seismic events as dynamical “reality”

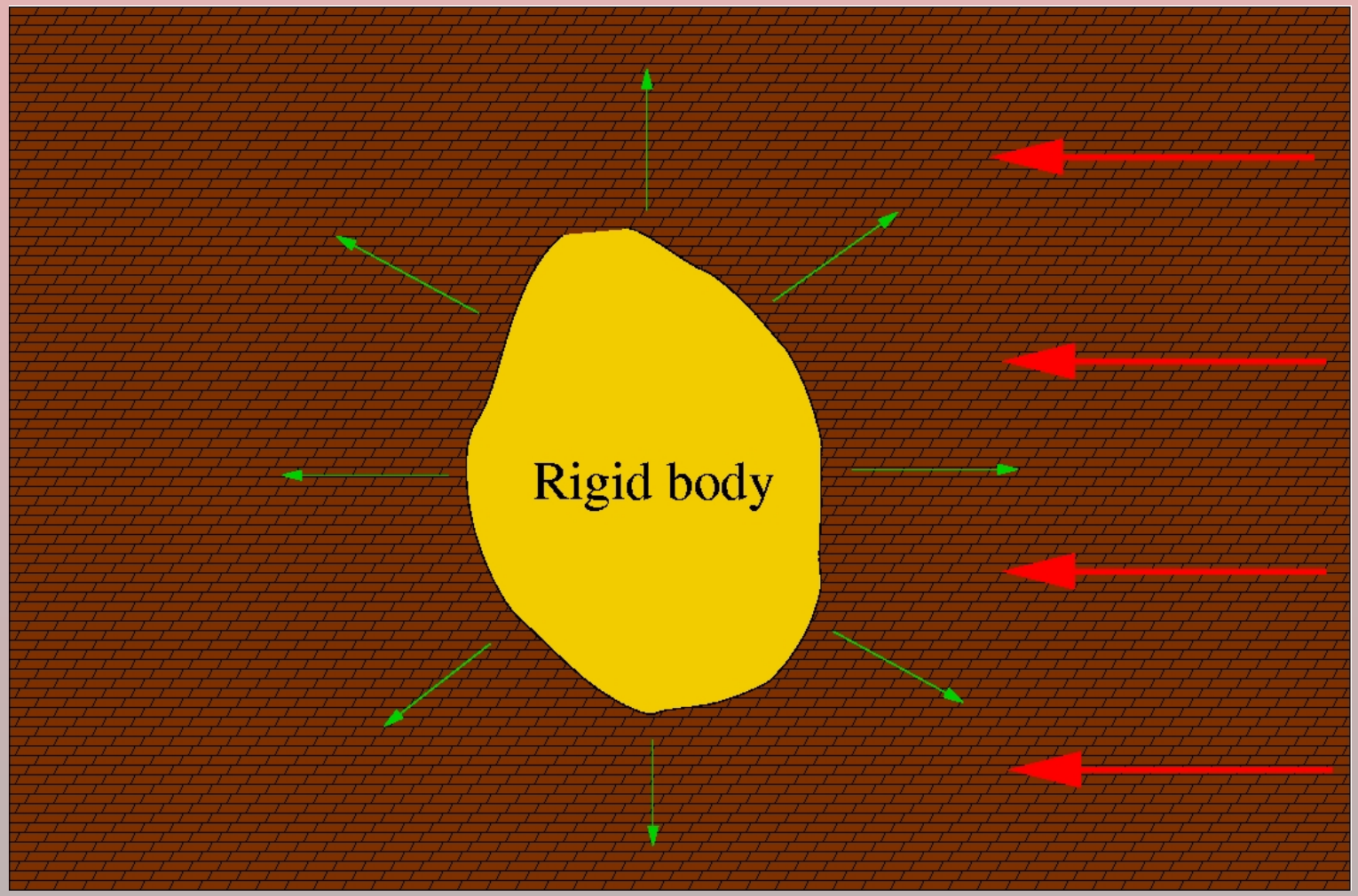
- Identifying the occurence of the earthquake
- Evaluating its significance at given point
- Lunching (no-) warning alert

Earthquake prediction $\Longrightarrow$ evaluation of the actually existing seismic risk and a possible impact

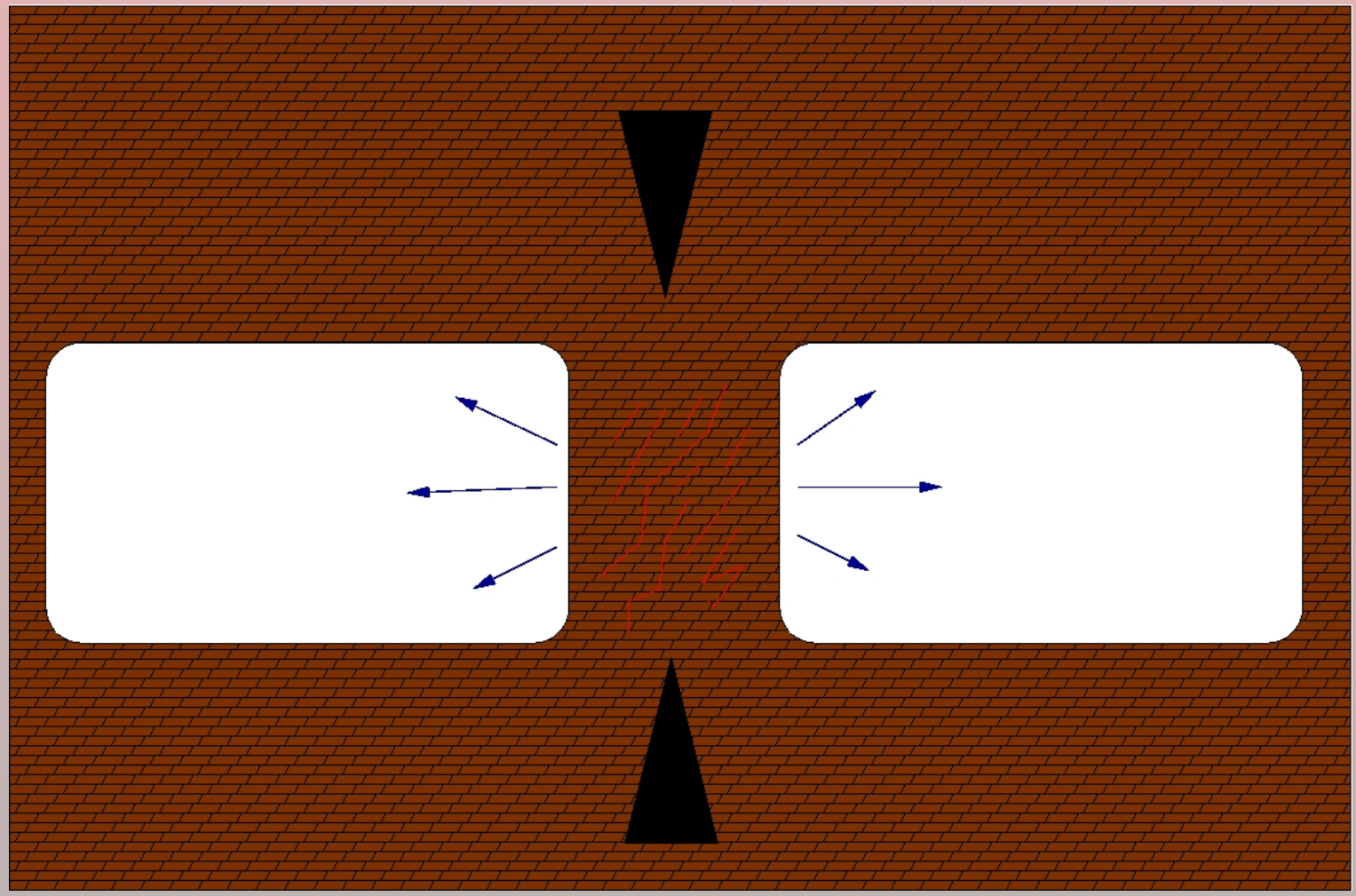
Earthquake dynamics factors



Explosive source - I

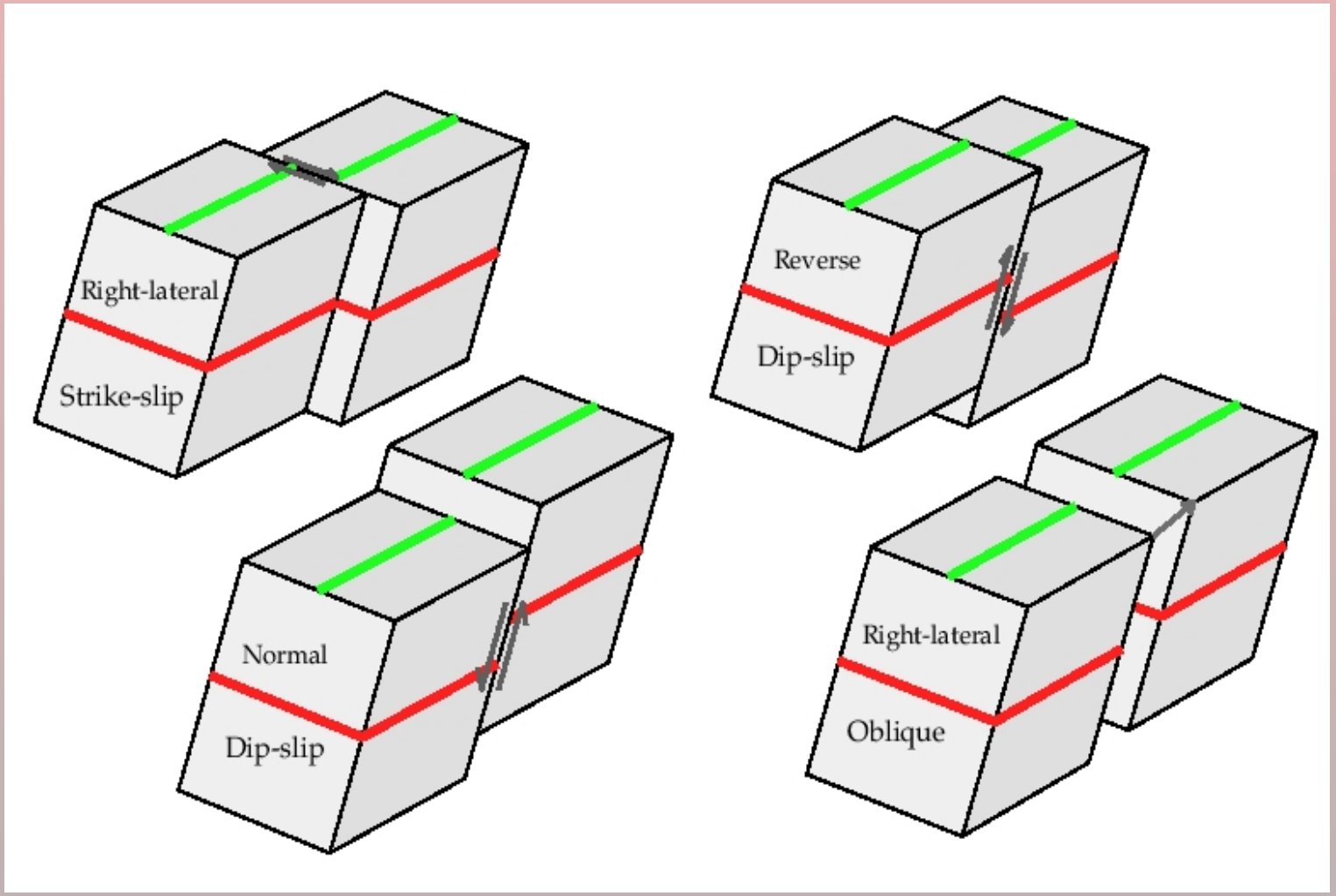


Explosive source - II

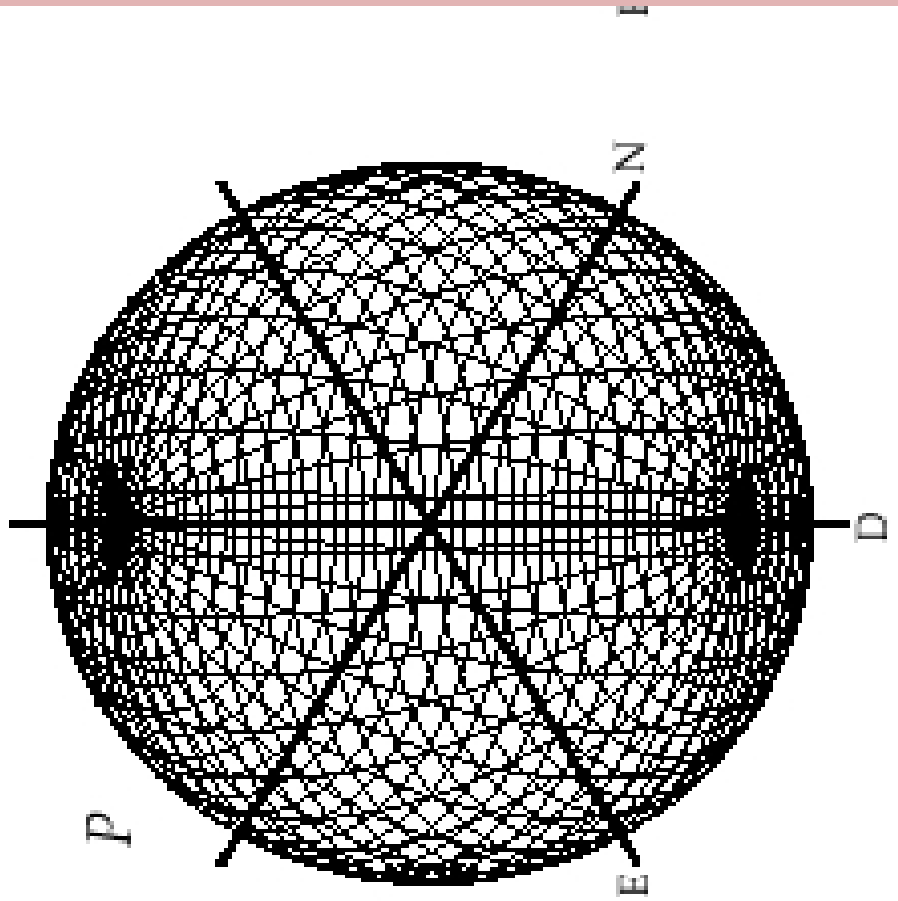


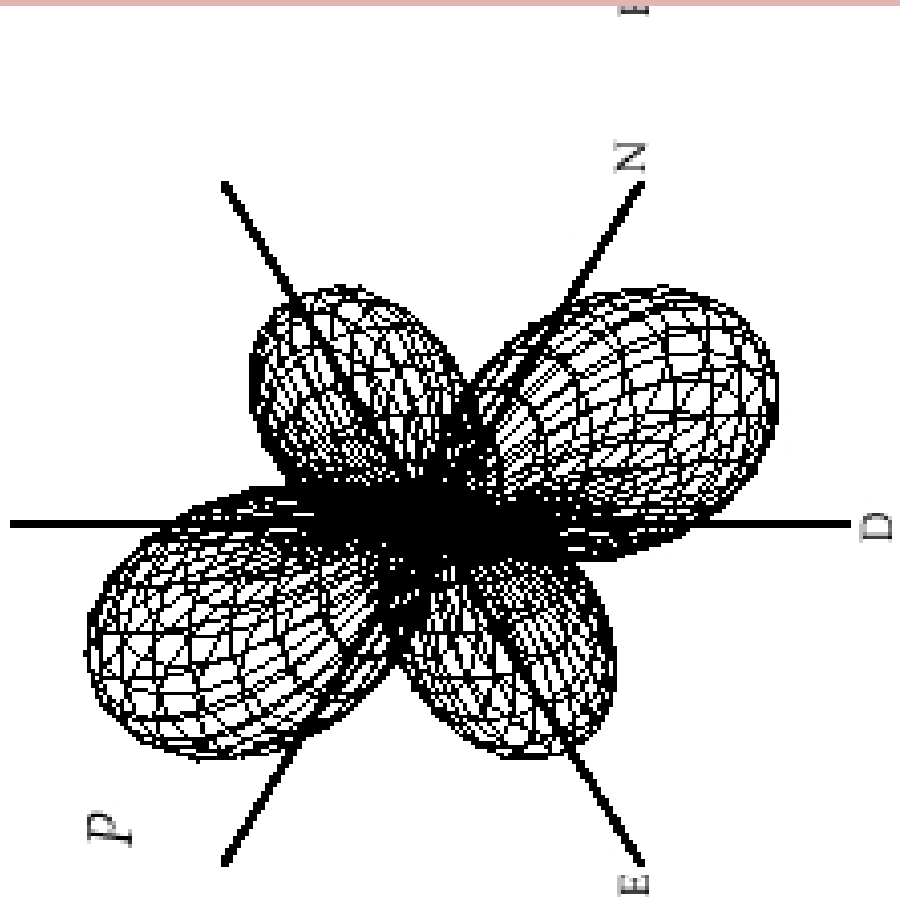
Slipping source

Mechanisms

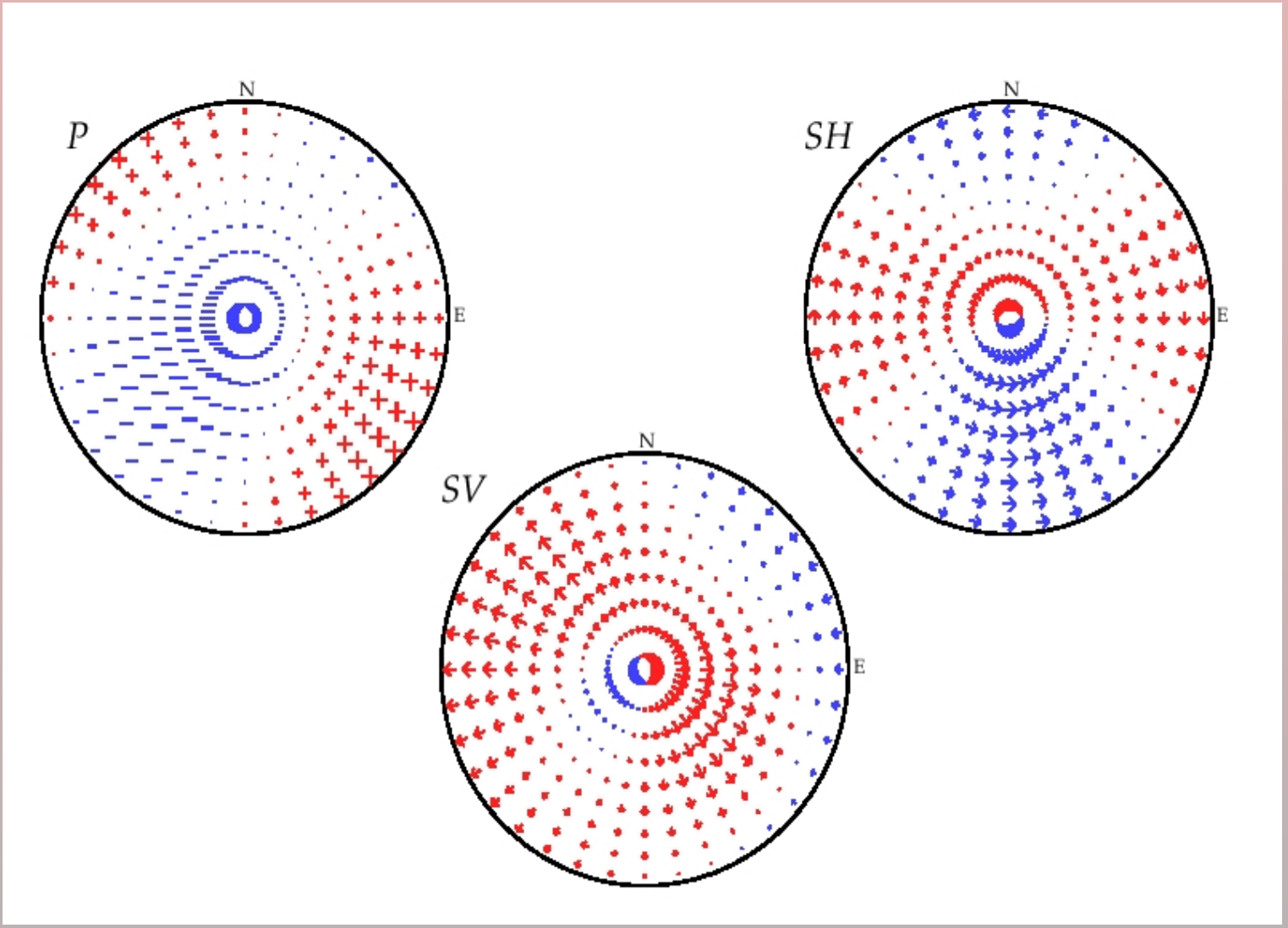

Right-lateral
Strike-slip
Reverse
Dip-slip
Normal
Dip-slip
Right-lateral
Oblique

Radiation pattern

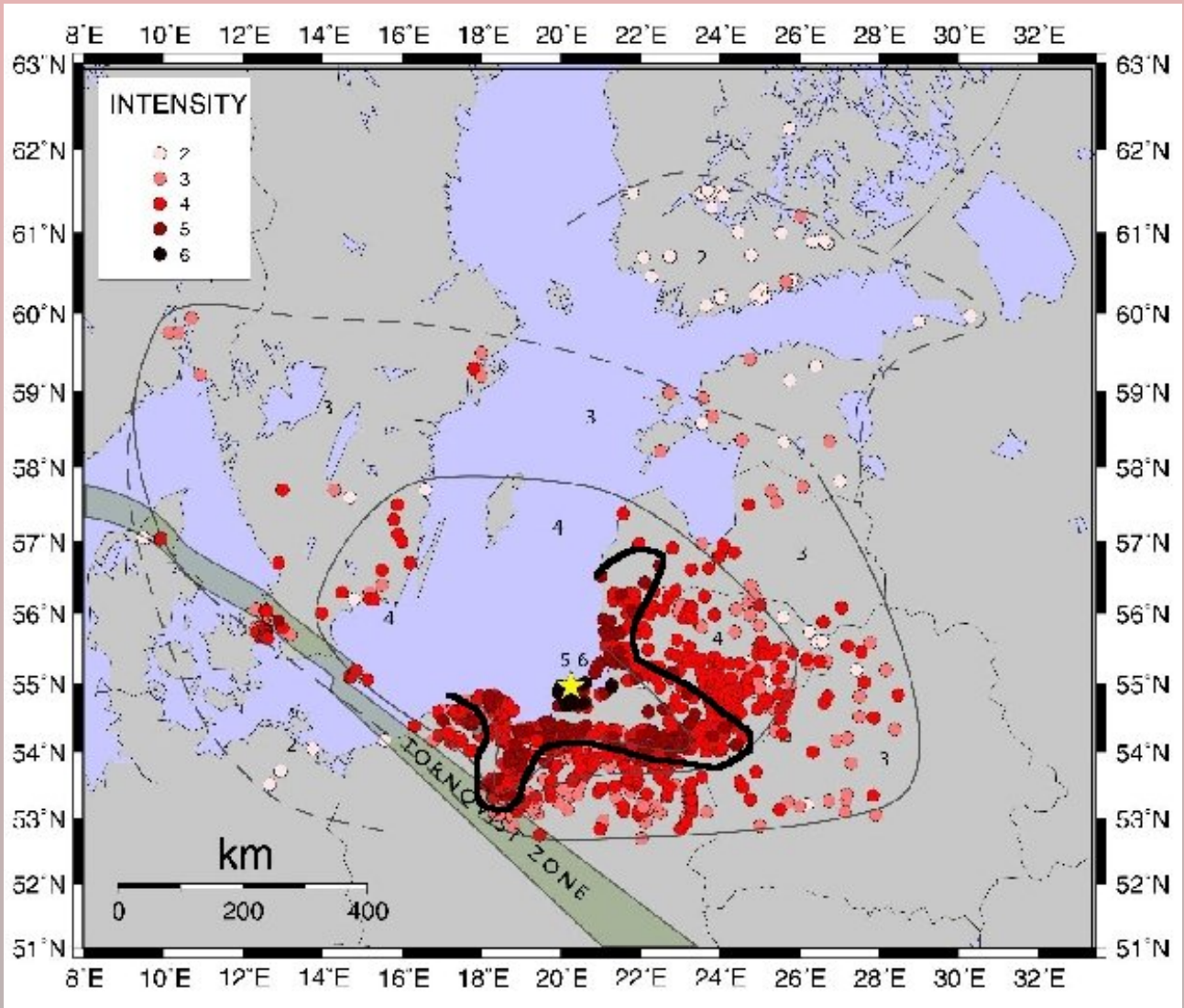




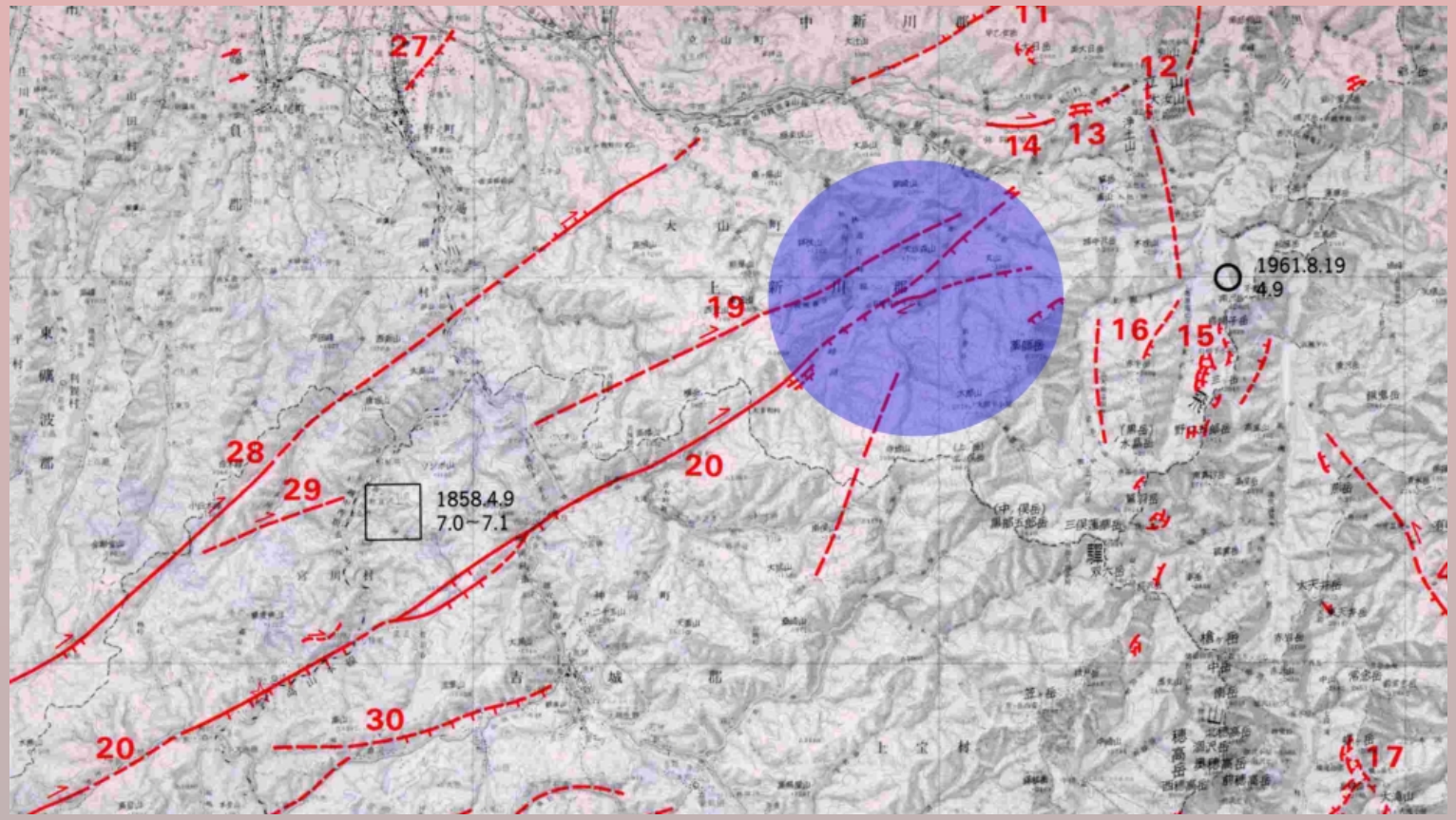
Radiation pattern



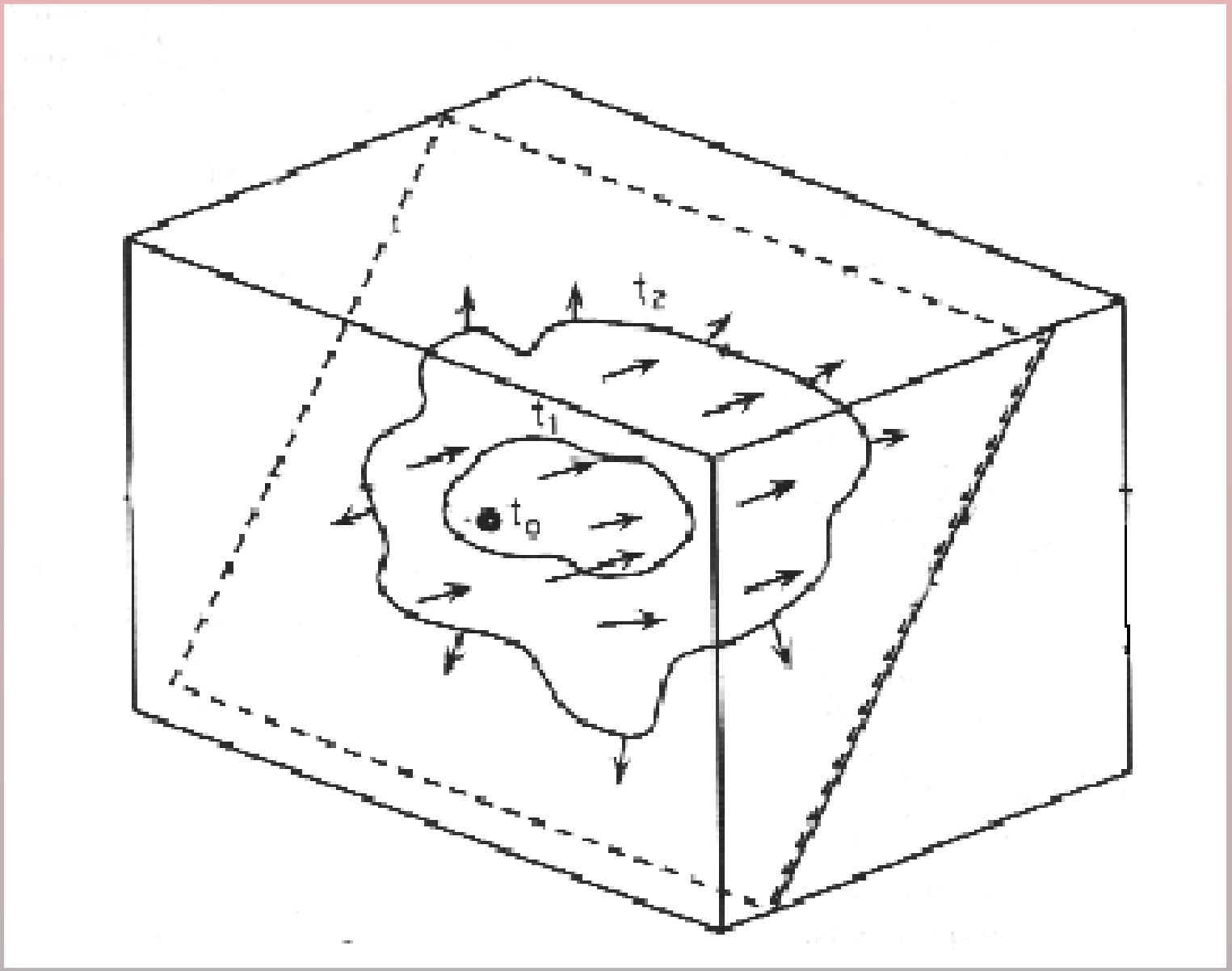
Radiation pattern



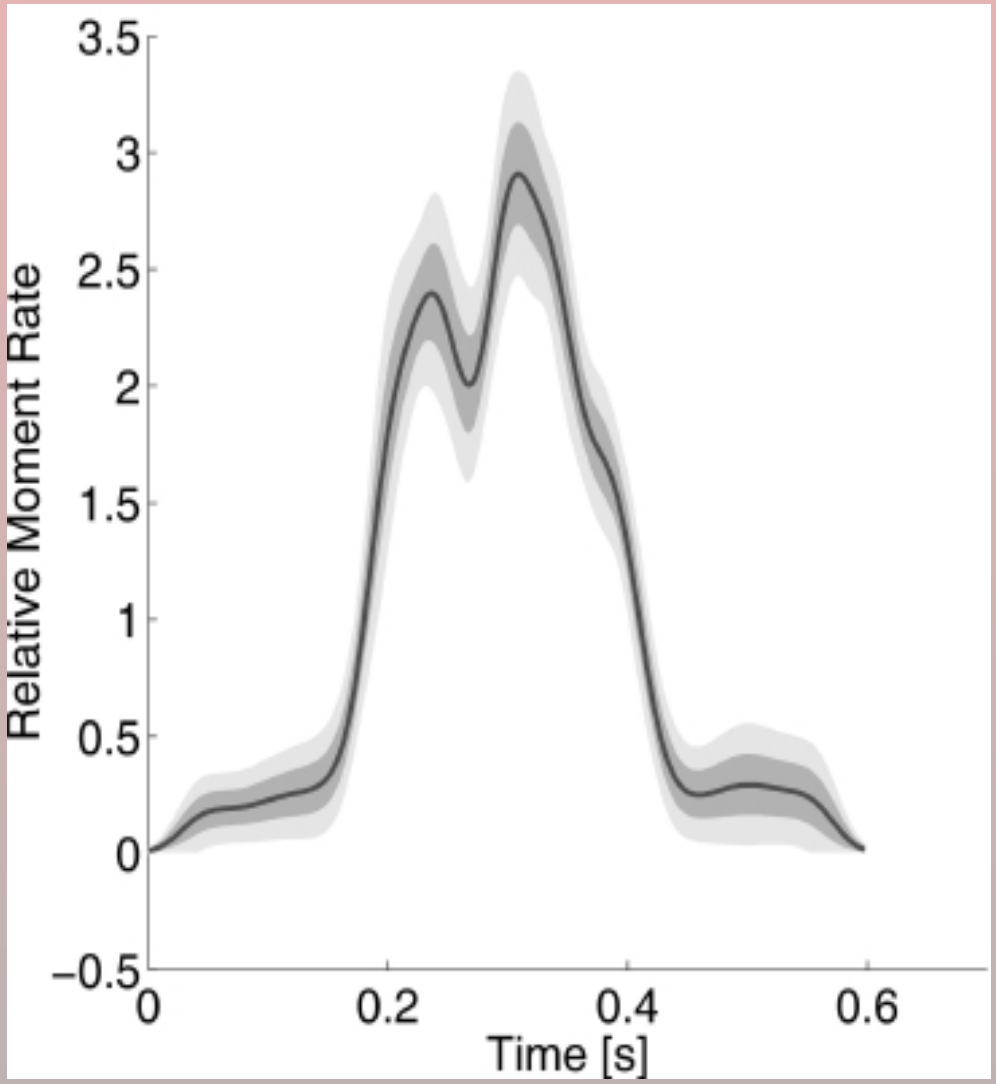
Fault geometry



Source size

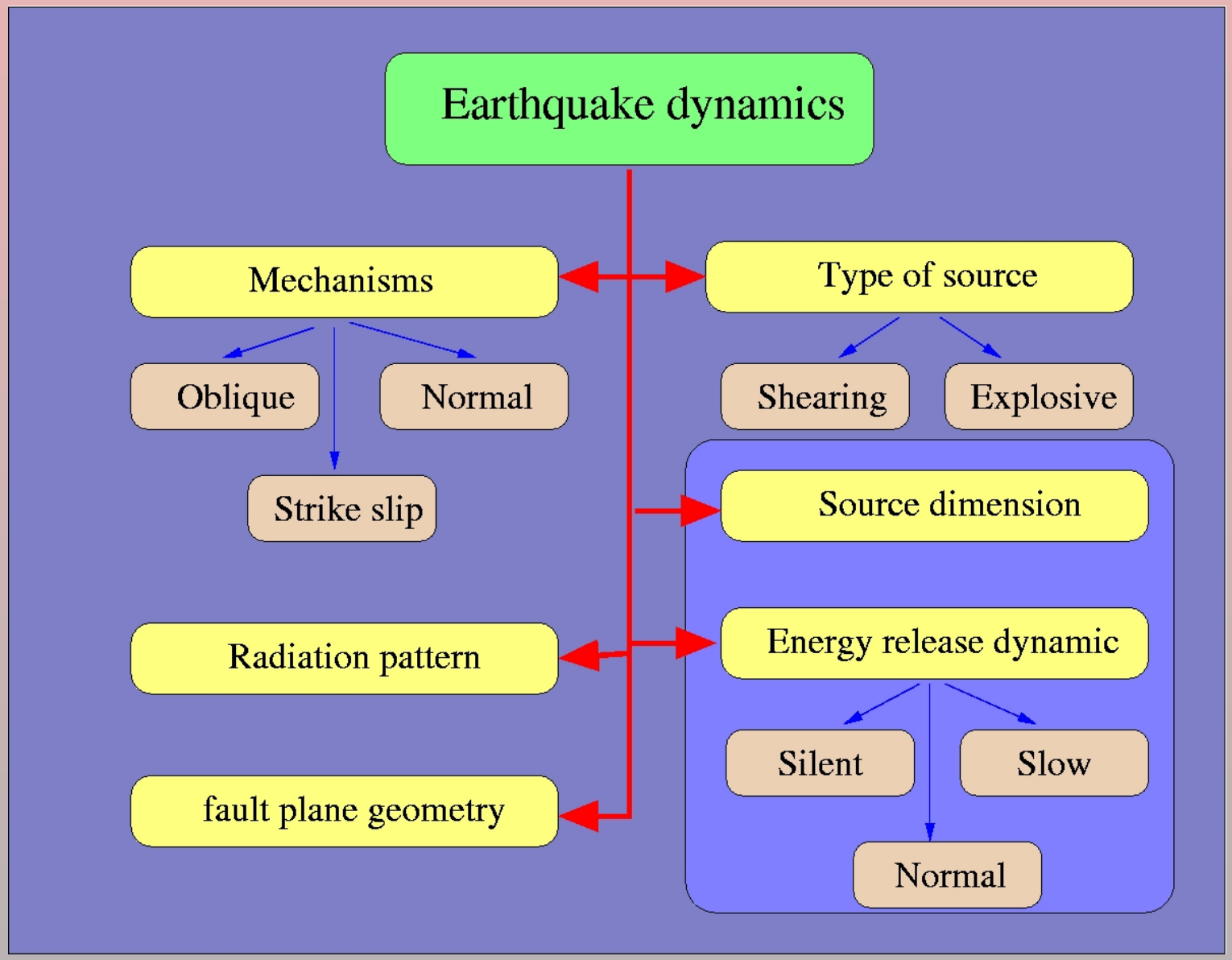


Rupture duration time



Rupture “slowness”

Earthquake dynamics factors



Unknown damage mechanisms ???

Main obstacles (incomplete knowledge)

- Uknown geological, tectonic stress, etc. condition influencing rupture dynamics

  requires some measurements and accumulation of evidences (direct measurements)

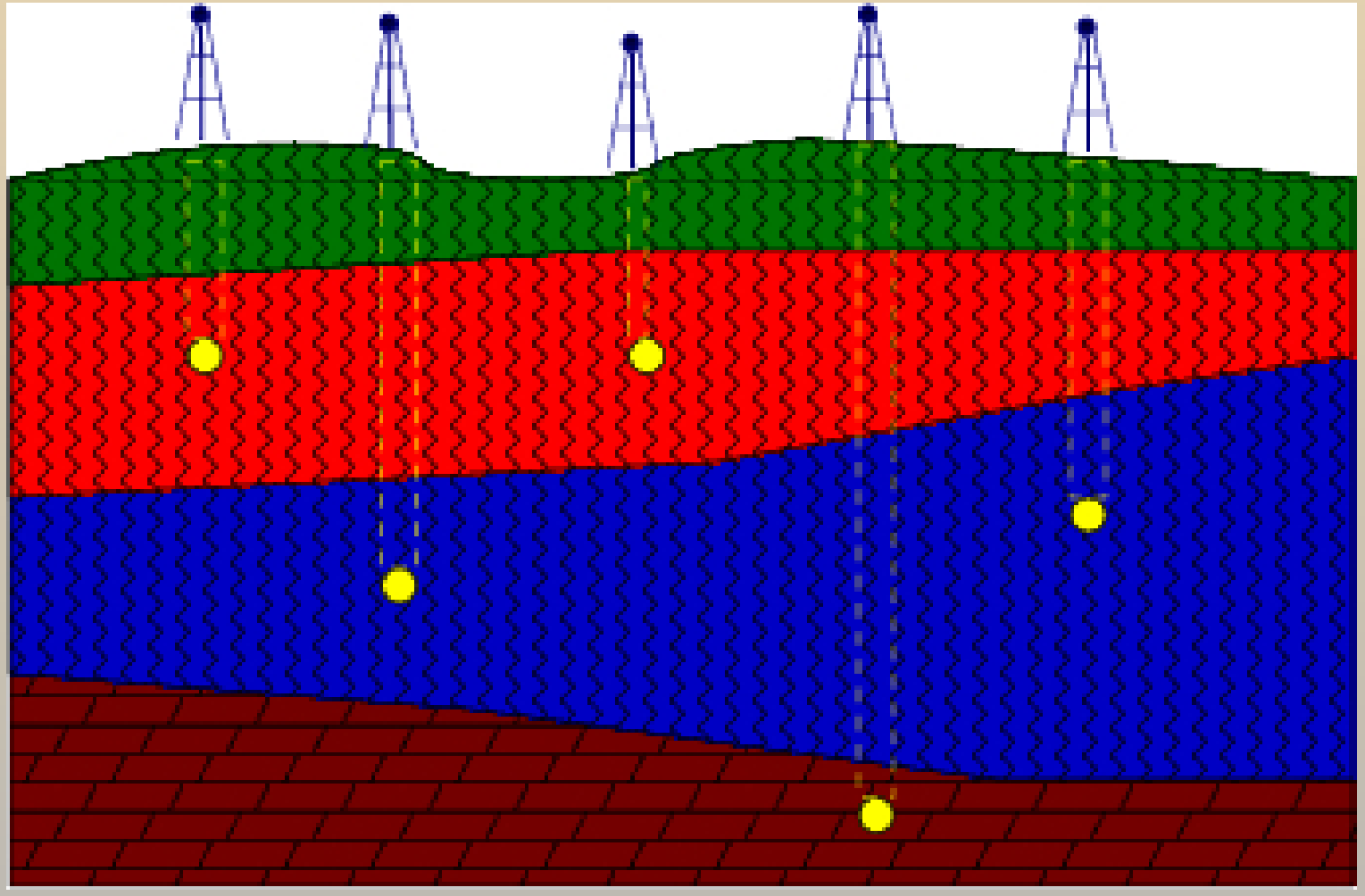
- Rupture process cannot be directly observed

  need for indirect-measurements (inversion methods)

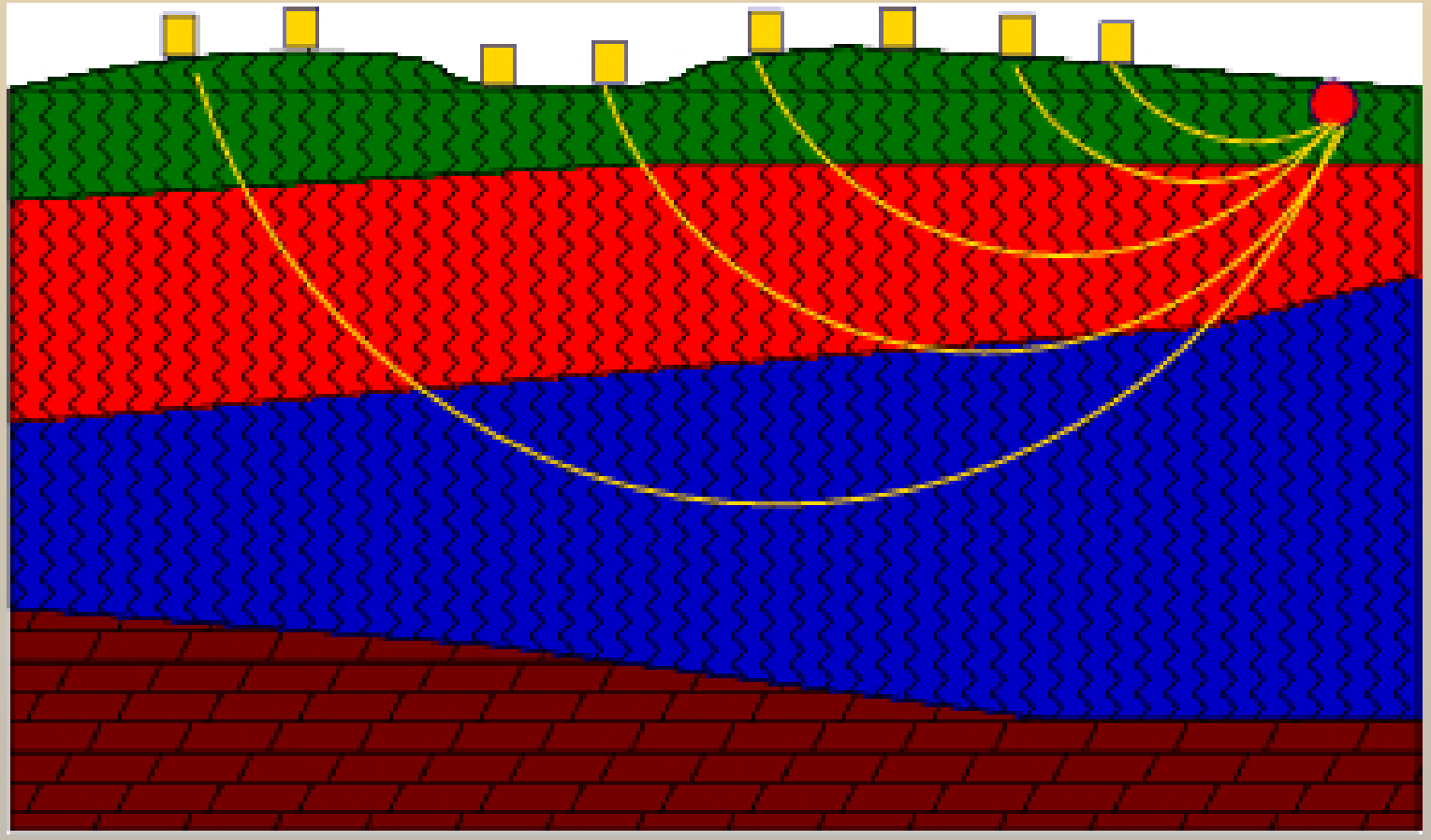
- Complexity of the rupture physics

  more theoretical investigations, numerical simulations, etc. needed

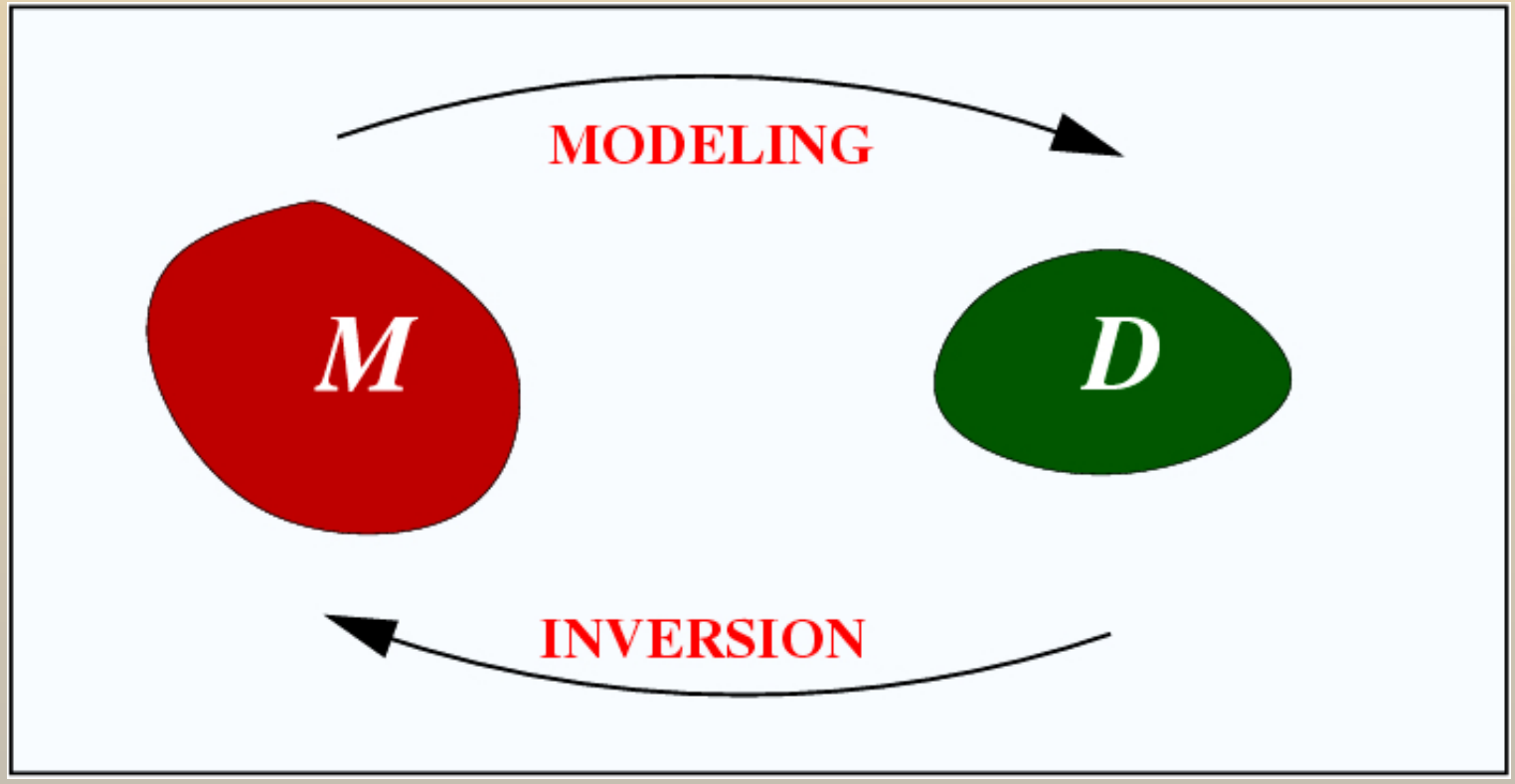
Direct measurement



Indirect measurement



Modeling vs. Inversion



Inverse problem - Indirect Measurements

$$\mathbf{d}^{obs} \implies \mathbf{m}$$

Solution

$$||\mathbf{d}^{obs} - \mathbf{d}^{th}(\mathbf{m})|| + \lambda||\mathbf{m} - \mathbf{m}^{apr}|| = \min$$

Errors

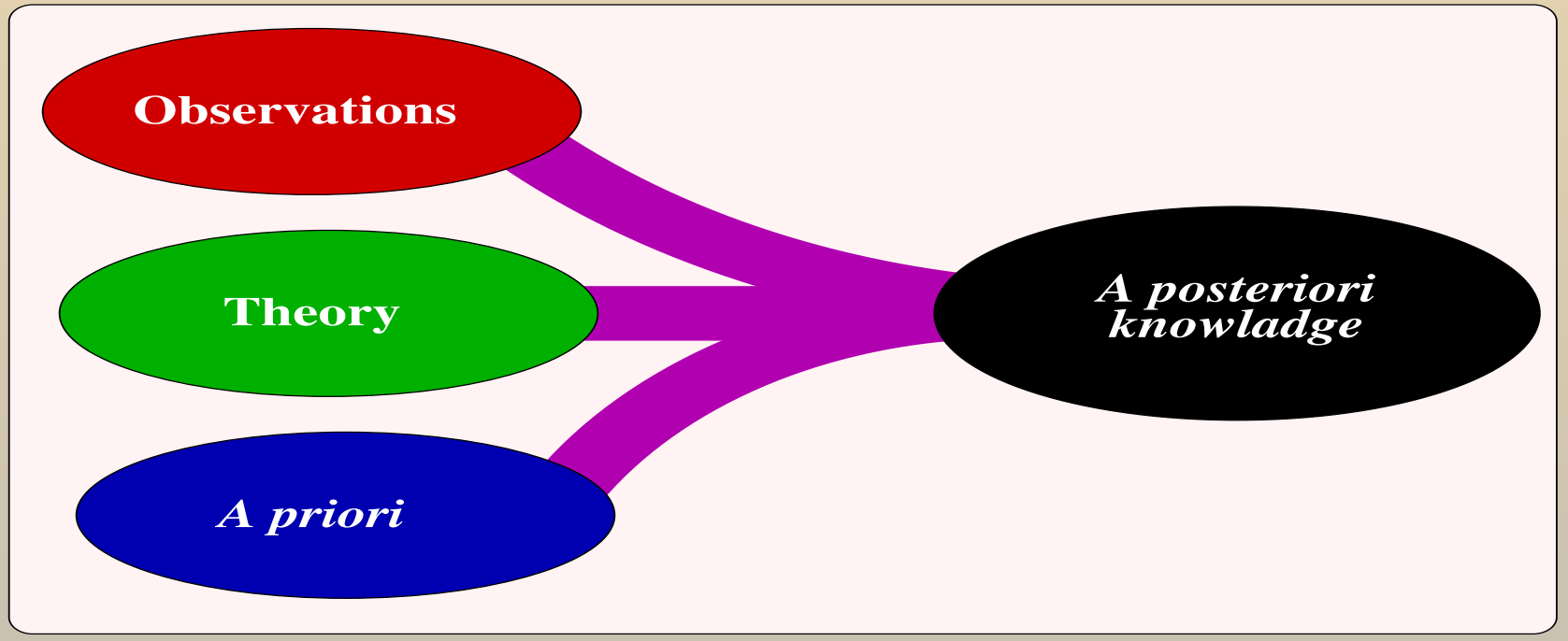
$$\mathbf{m}^{true} = \mathbf{m}^{ml} + \epsilon_{\mathbf{m}}$$

$$\epsilon_{\mathbf{m}} = ???$$

Inversion by optimization - ANIMATIONS

OPTIMIZATION

Bayesian Inversion - Basic Ideas



$$\sigma_{post}(\mathbf{m}|\mathbf{d}^{obs}) \sim \sigma_{apr}(\mathbf{m}) \int_{\mathbf{D}} \sigma_{th}(\mathbf{d}|\mathbf{m}) \star \sigma_{obs}(\mathbf{d}|\mathbf{d}^{obs}|)$$

Bayesian Inversion

(parameter estimation)

A posteriori pdf

$$\sigma(\mathbf{m}) = f(\mathbf{m}) L(\mathbf{m}, \mathbf{d})$$

- f - A priori pdf (prob. dens. funct.)
- L - Likelihood function

Errors independent of $\mathbf{m}$ and $\mathbf{d}$

$$\mathbf{d}^{th} = \mathbf{G}(\mathbf{m})$$

$$\sigma(\mathbf{m}) = f(\mathbf{m}) \exp\left(-||\mathbf{d}^{obs} - \mathbf{G}(\mathbf{m})||\right)$$

Examination of $\sigma(\mathbf{m})$

- Searching *Maximum Likelihood* solution
  - ★ Gradient methods
  - ★ Deterministic methods (e.g. simplex)
  - ★ Monte Carlo - Global Optimization
    - ➡ Simulated Annealing
    - ➡ Genetic Algorithm
- Sampling over regular grid
- **Random (Monte Carlo) Sampling**

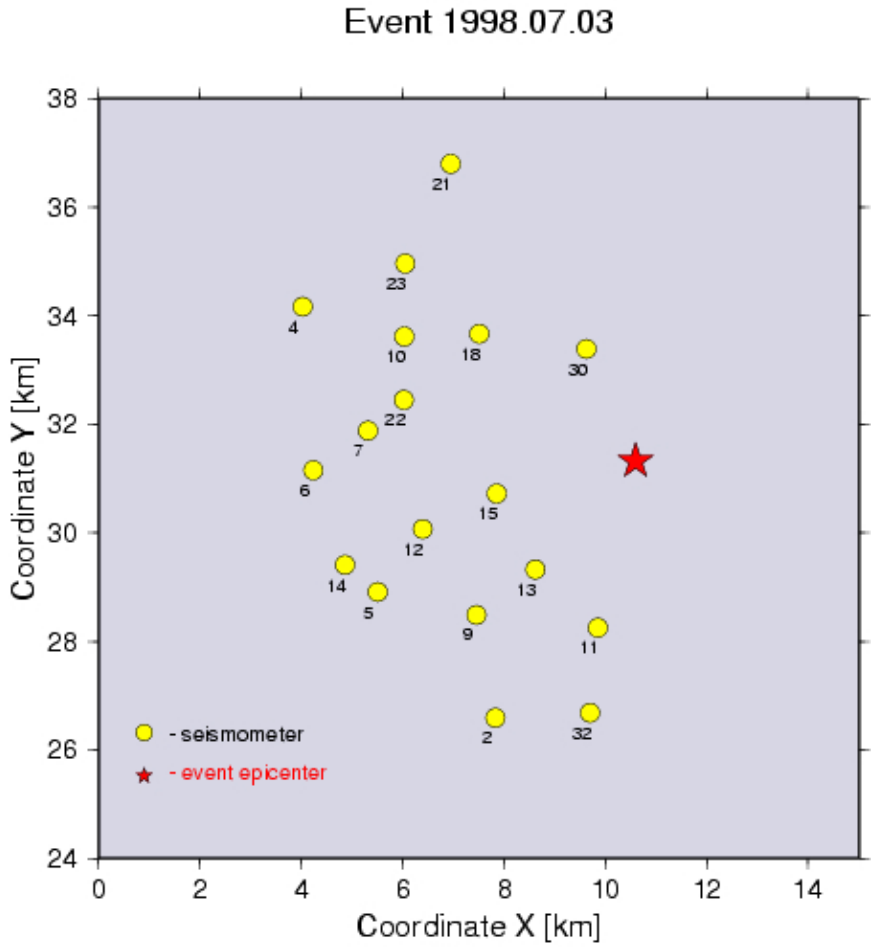
Inversion - ANIMATIONS

BAYES-1 BAYES-2

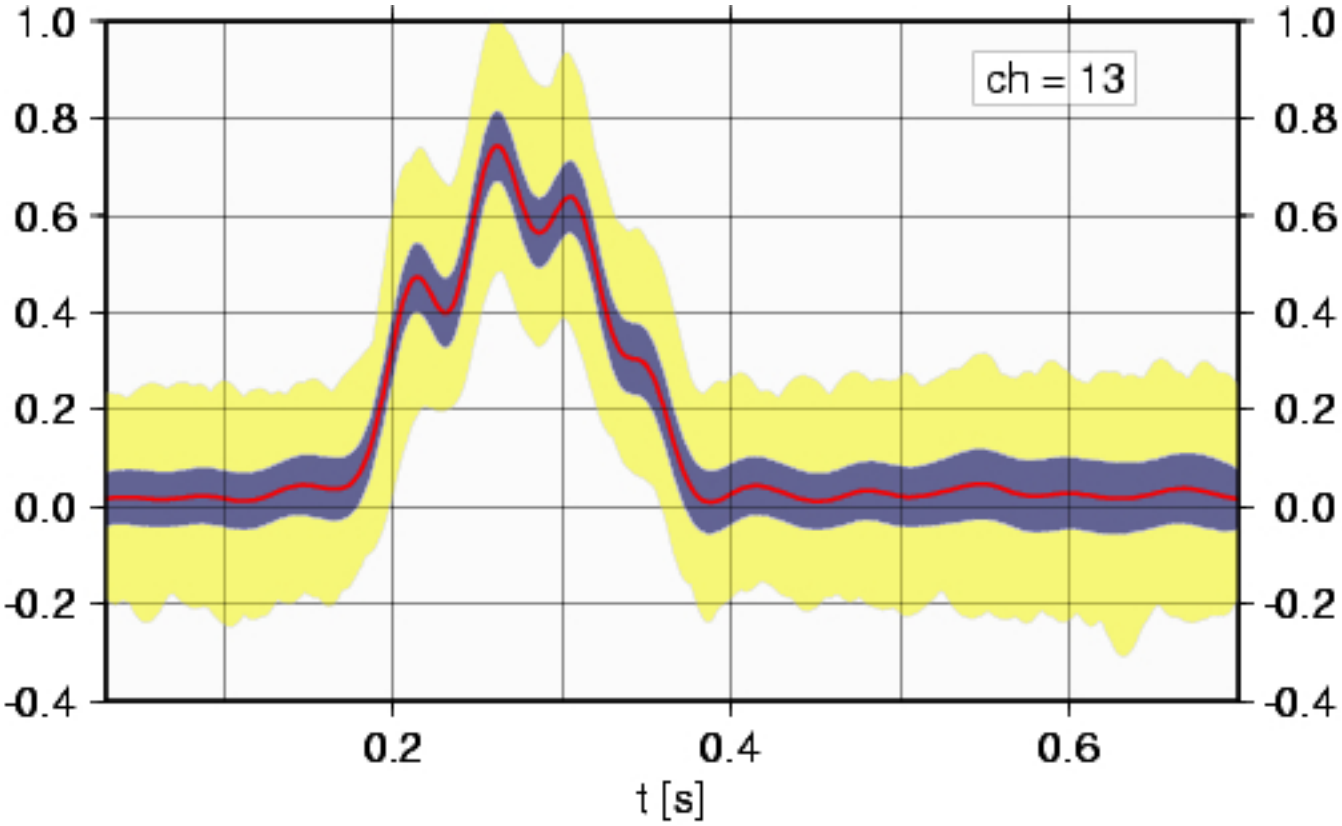
Imaging rupture process

$$u(x,t) = \int_{t,x'} \dot{M}(t) G(t-t', x-x')$$

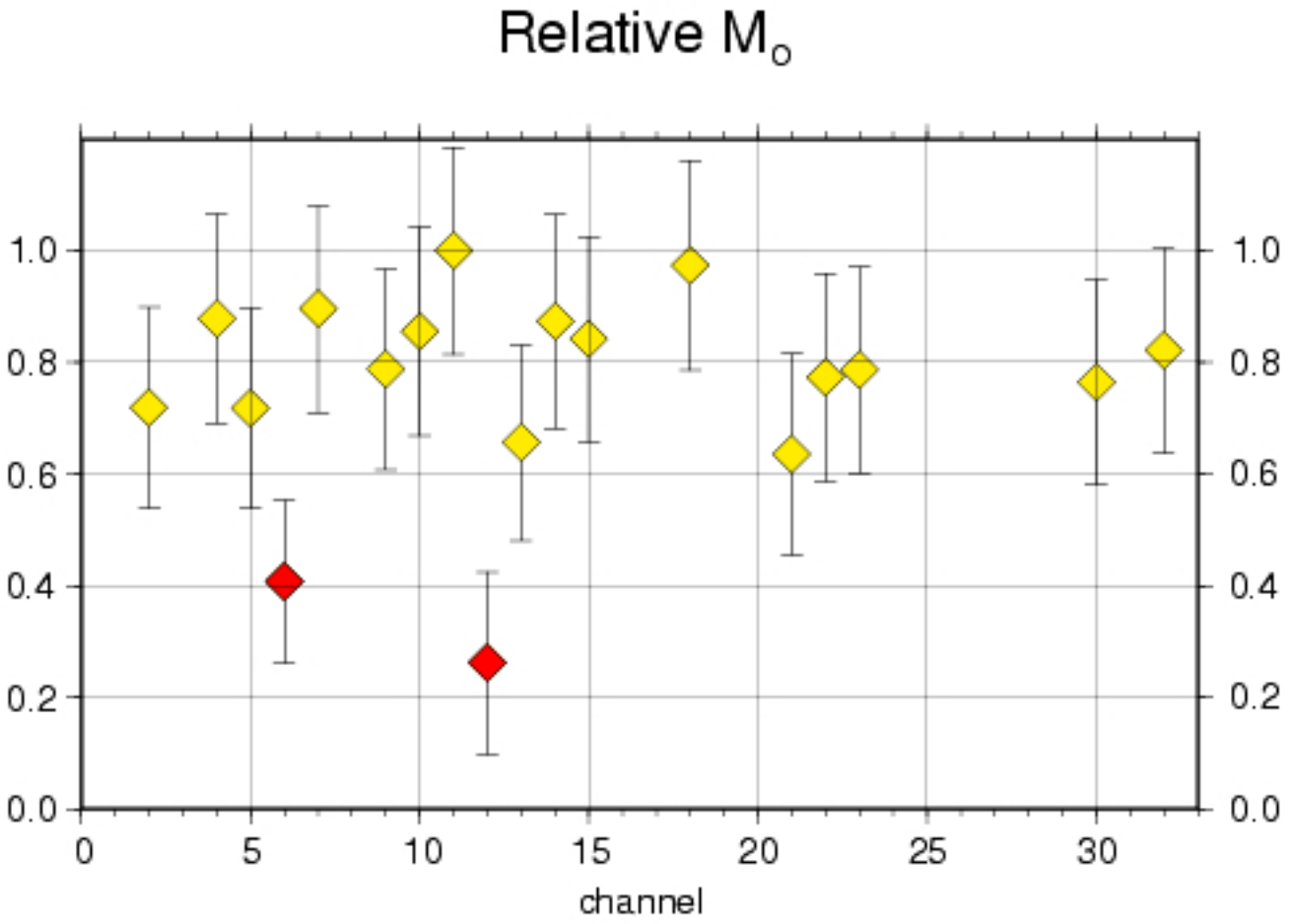
Copper mines seismic network



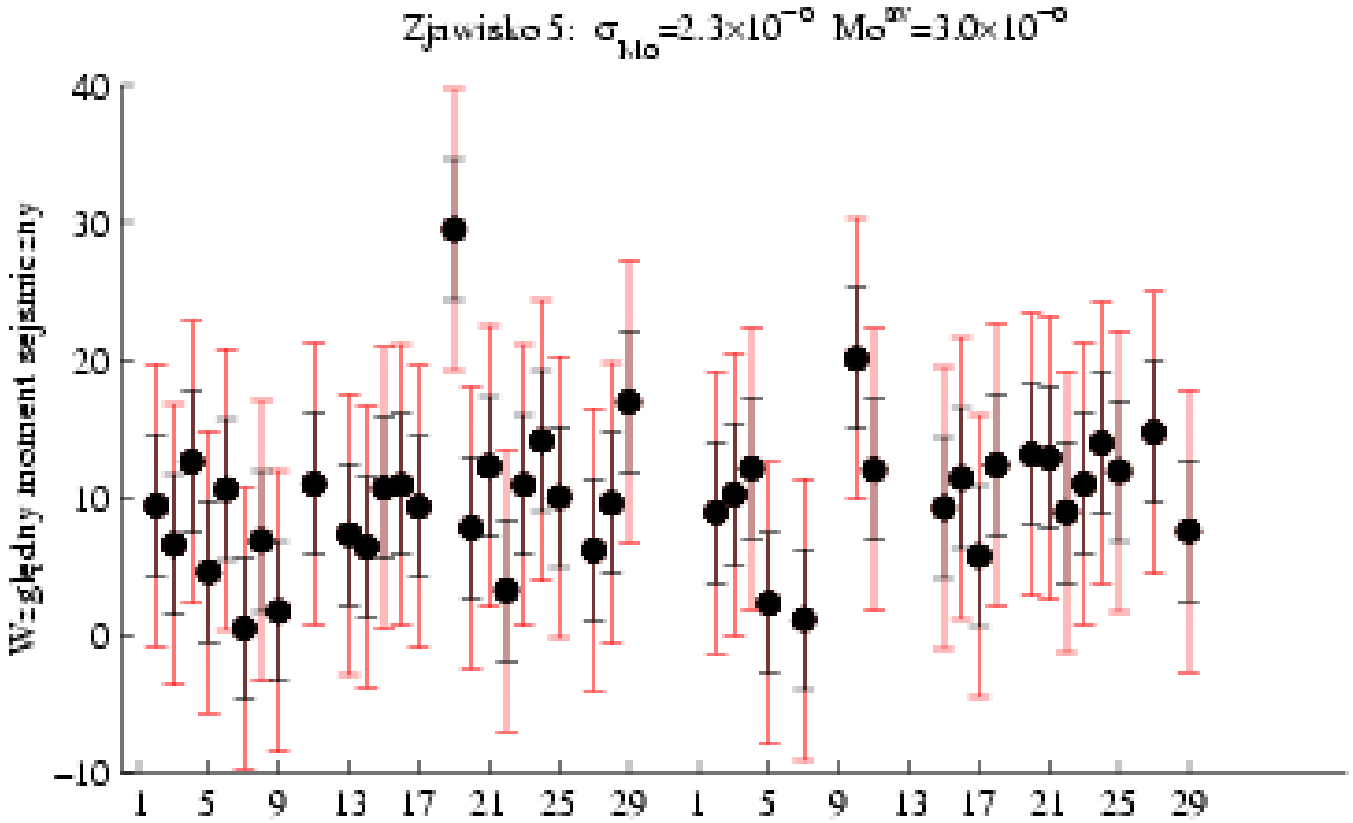
STF - channel 13



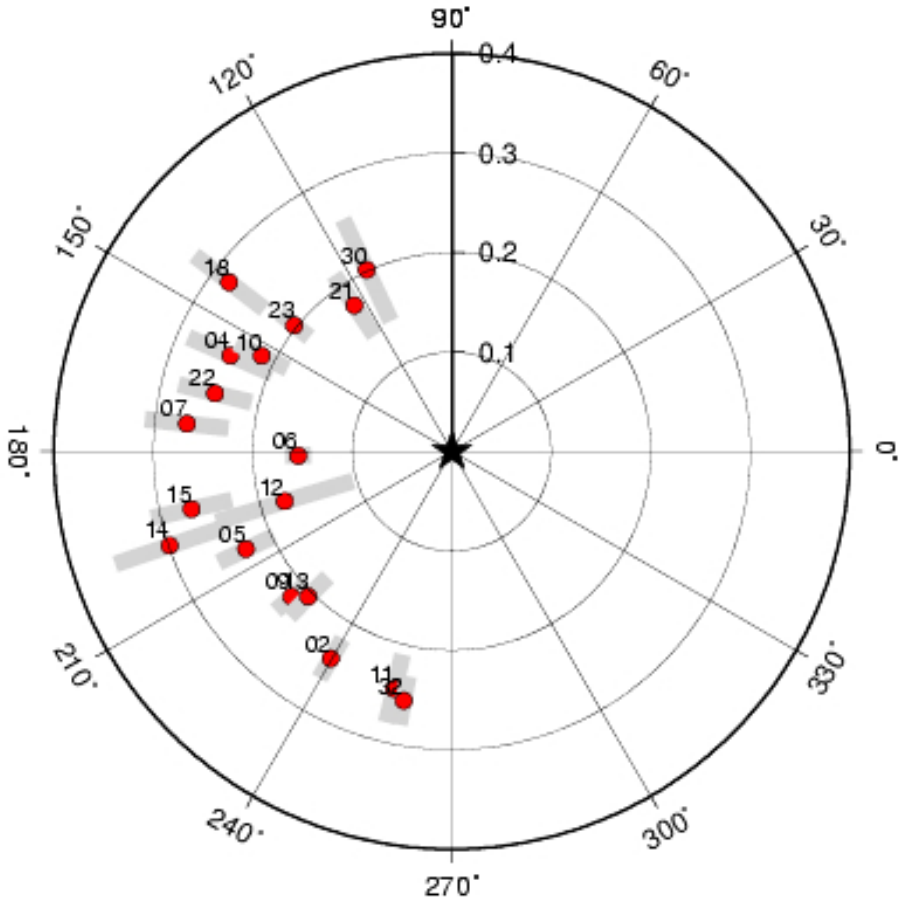
Seismic moment M_o



Another example



Radiation pattern



Source dynamics

SOURCE