Rupture nucleation and onset of dynamic propagation: new clues from the 2009 L'Aquila earthquake.

L. Chiaraluce

INGV - National Earthquake Centre

L. Valoroso, R. Di Stefano, D. Piccinini, L. Scognamiglio, E. Tinti and M. Cocco.

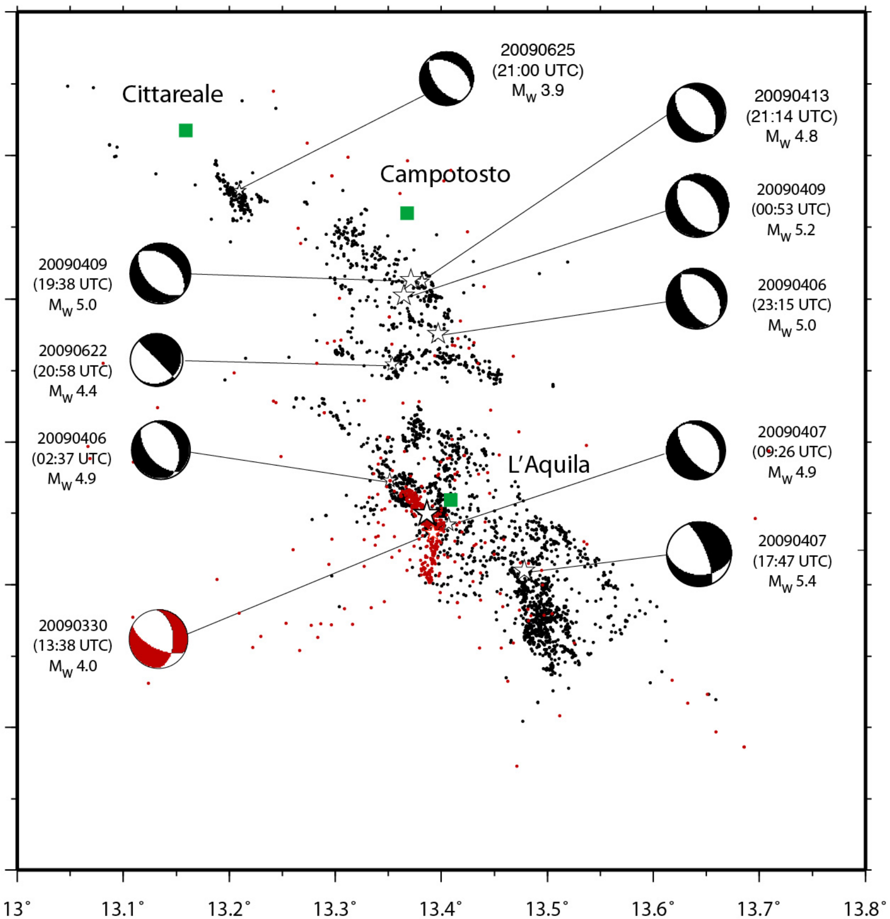
ECGS – Luxembourg, October 2012

Outline

- ✓ Geometry of the main L’Aquila fault
- ✓ Foreshocks evolution and geometry
- ✓ Mainshock rupture onset
- ✓ Rupture velocity and slip distribution
- ✓ Coseismic slip and seismicity pattern
- ✓ Foreshocks and aftershocks source parameters

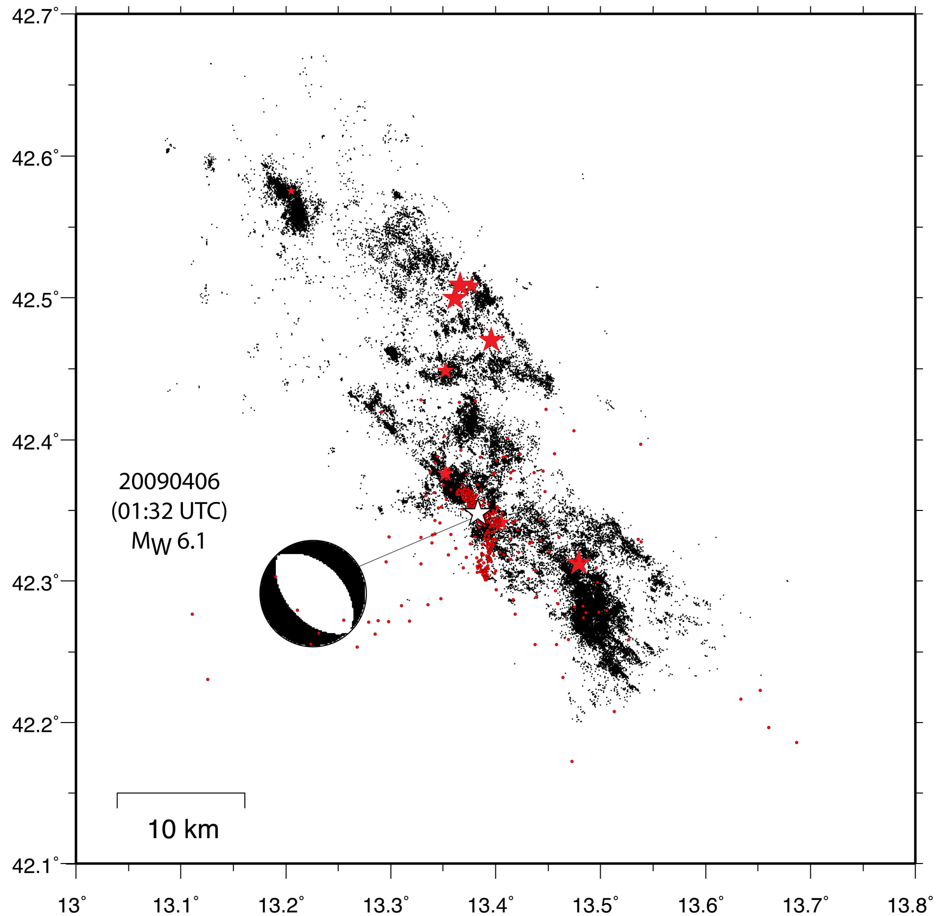
The seismic sequence

$M_C = 1.5\ M_L$



(Chiaraluce et al., 2011)

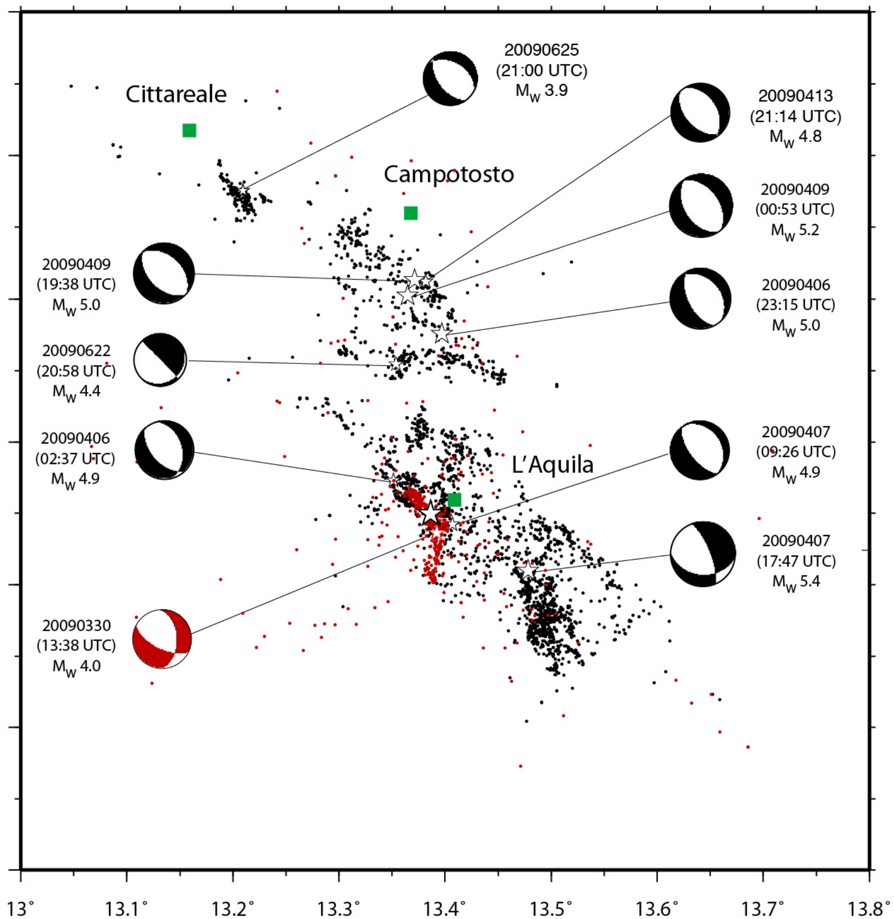
$M_C = 0.7\ M_L$



(Valoroso et al., submitted)

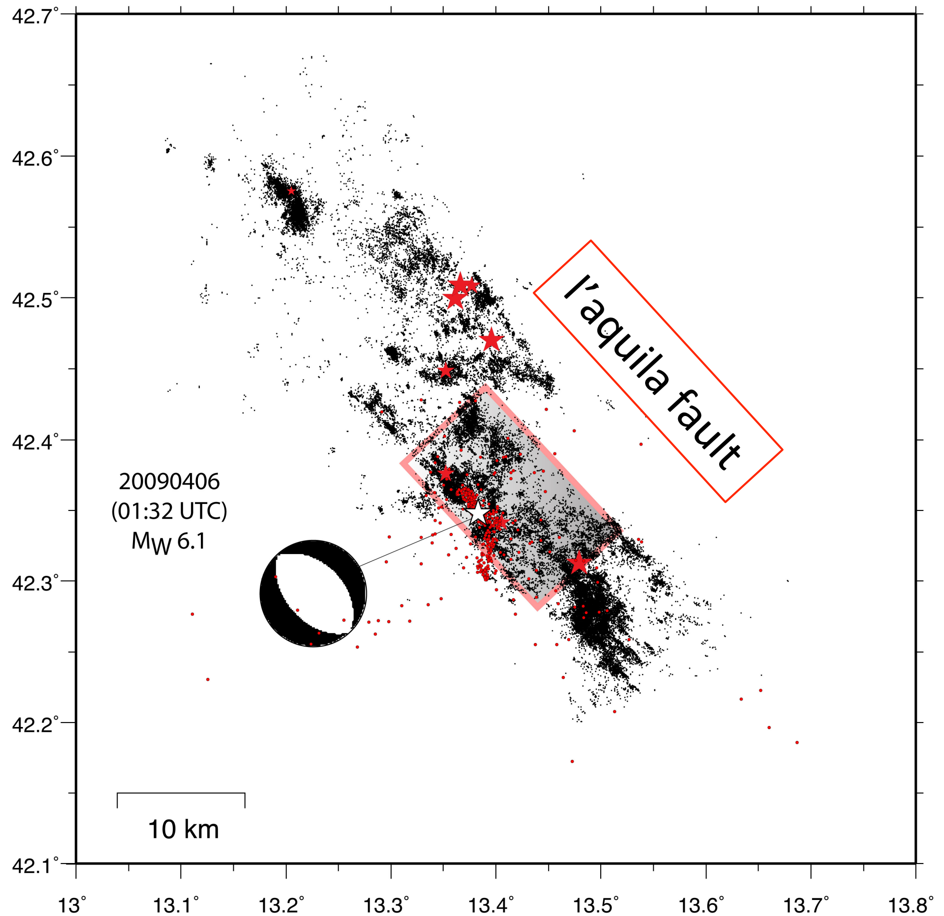
The seismic sequence

$M_C = 1.5\ M_L$

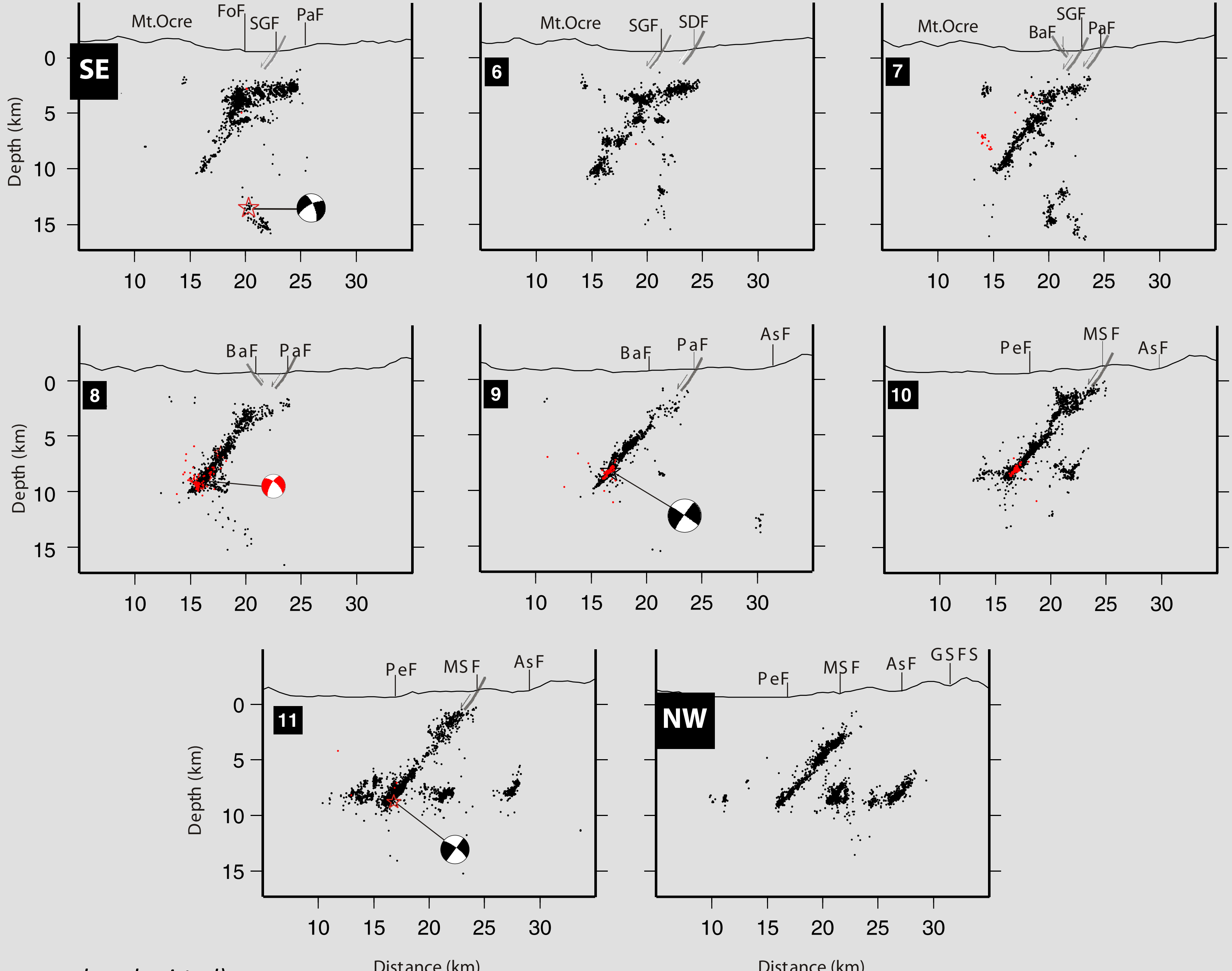


(Chiaraluce et al., 2011)

$M_C = 0.7\ M_L$

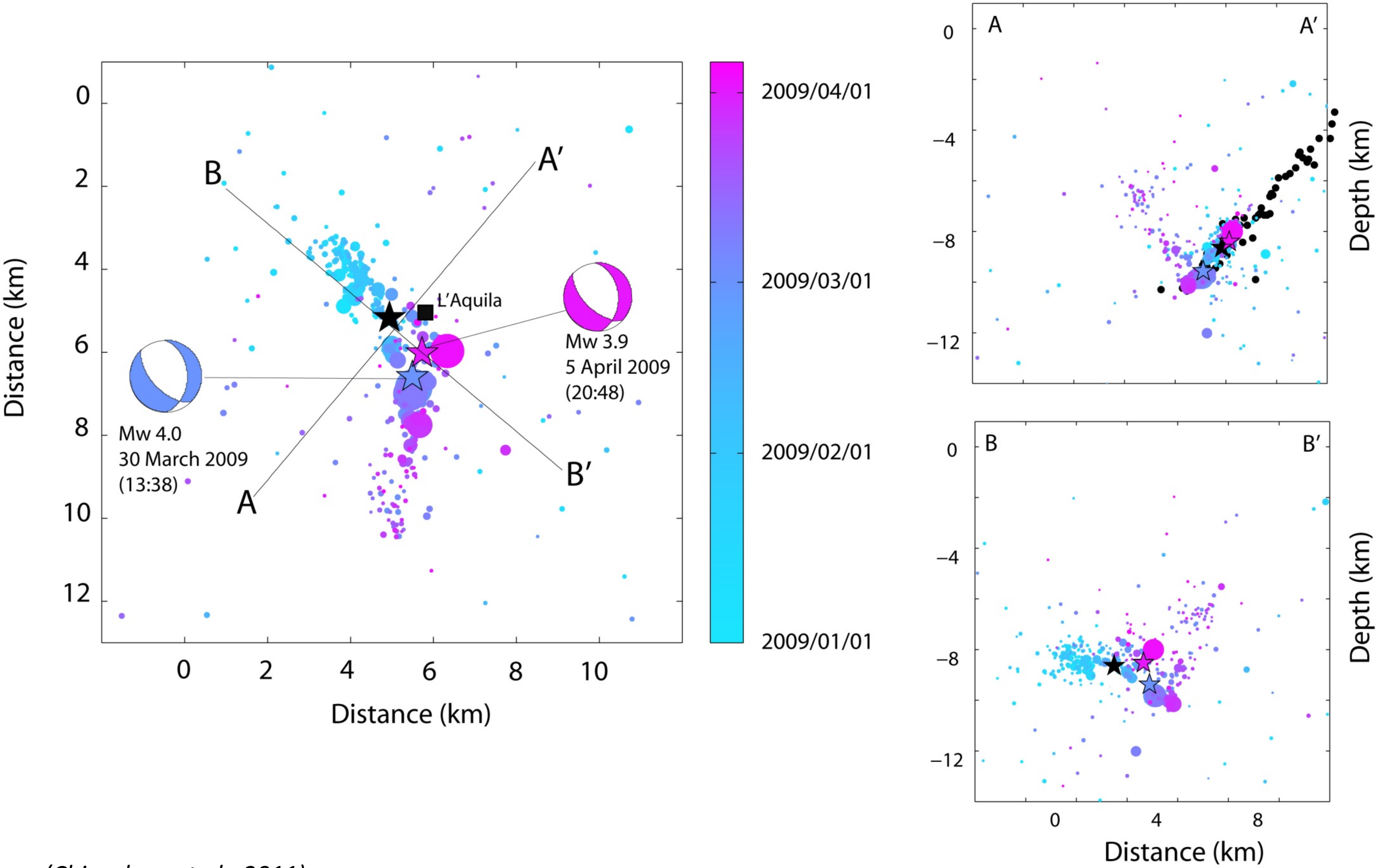


(Valoroso et al., submitted)



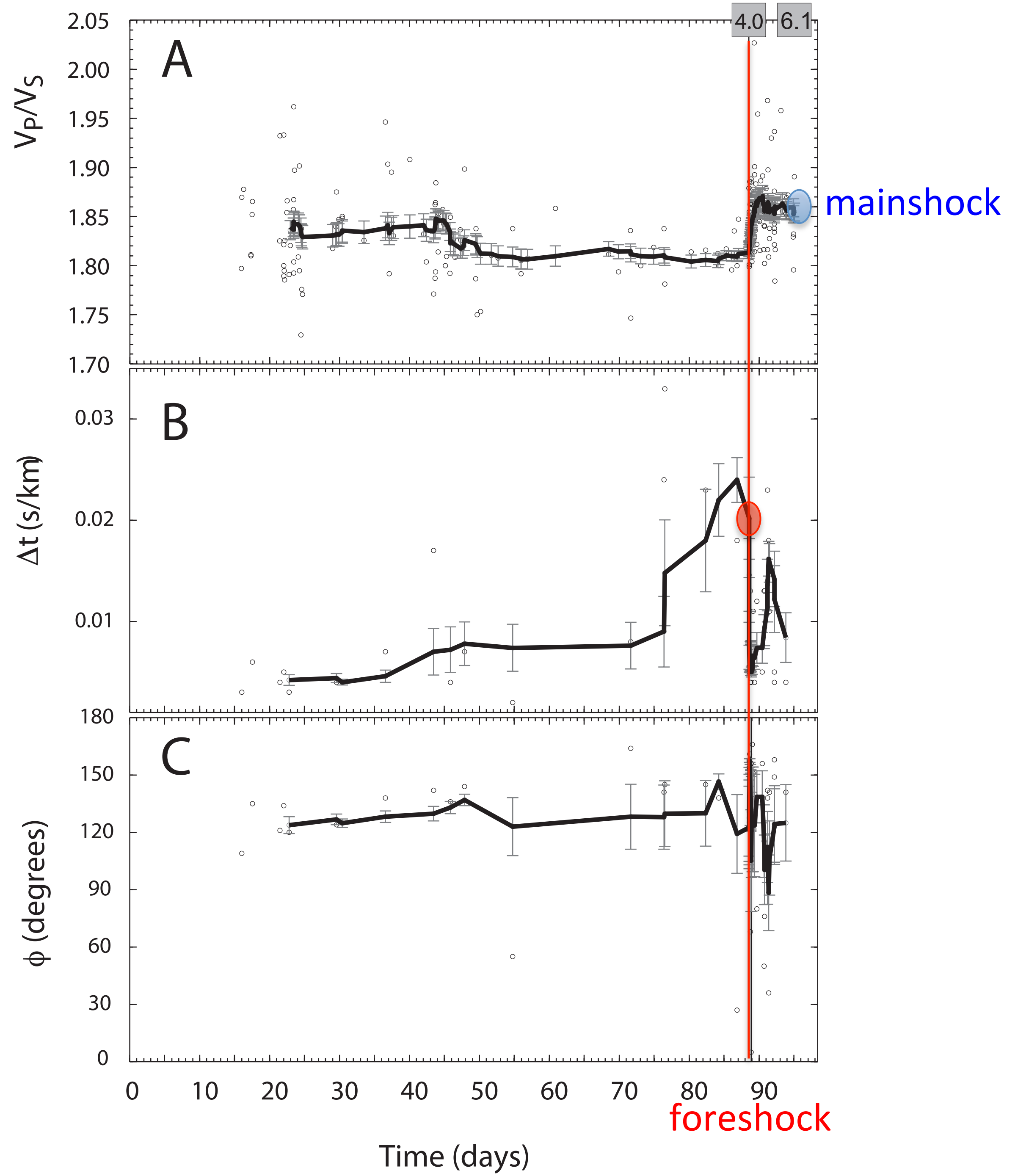
(Valoroso et al., submitted)

The foreshocks sequence



(Chiaraluce et al., 2011)

Temporal variation of seismic velocity and anisotropy occurring the days before the mainshock

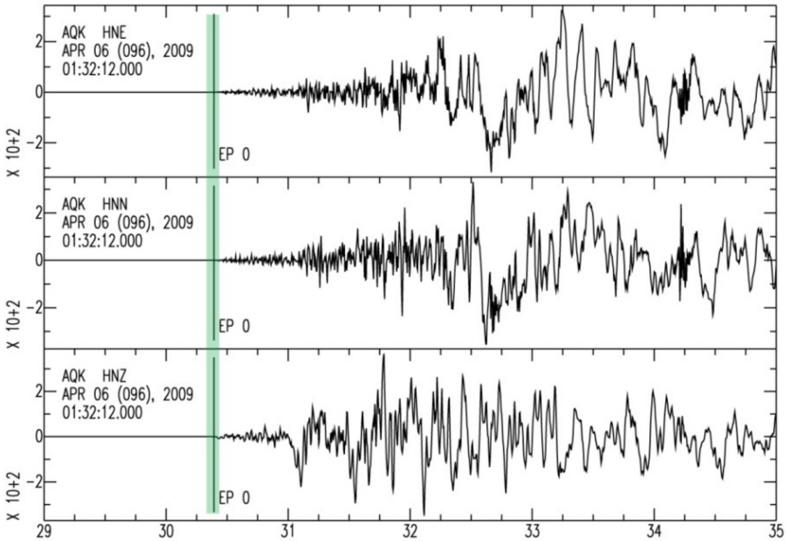


(Lucente et al., 2010)

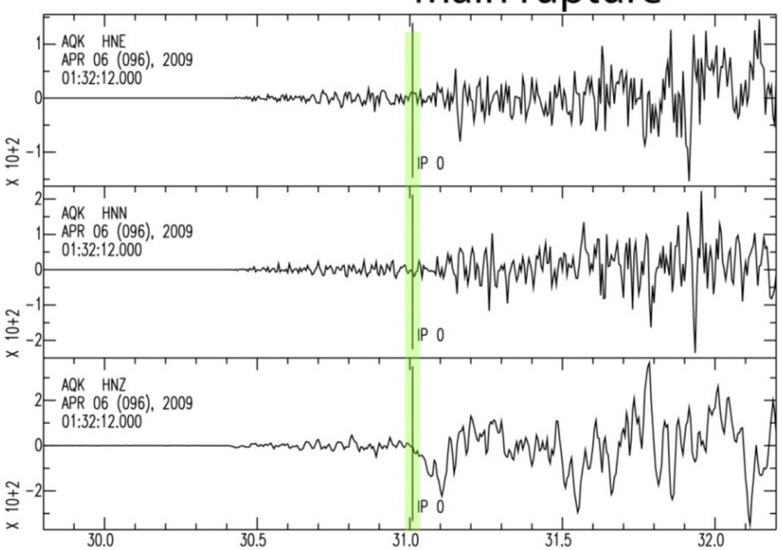
Mainshock (20120406 01:32 UTC M_W 6.1) source complexity

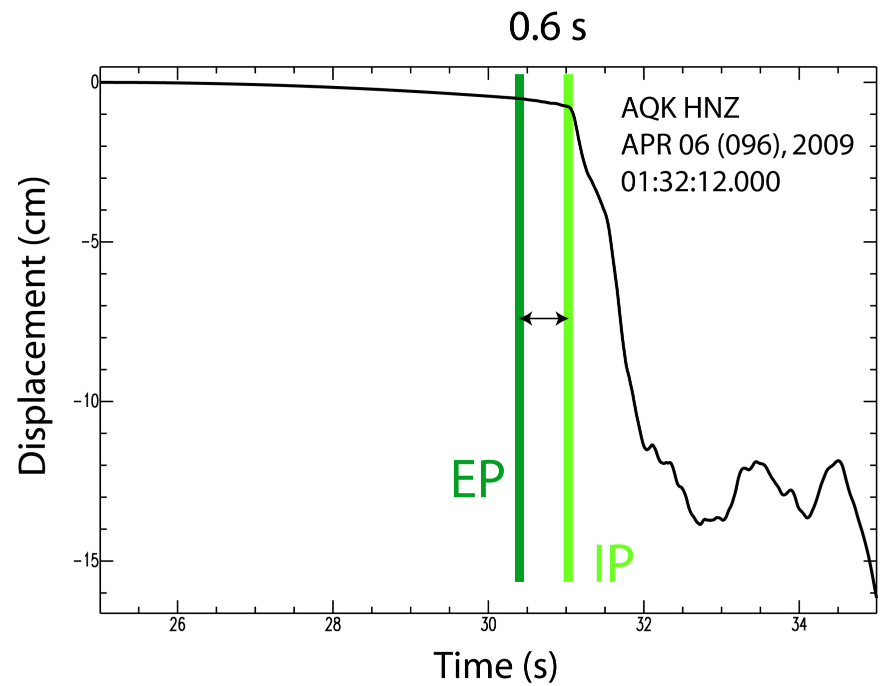
The mainshock waveform shows evidence for source complexity: an *emergent (EP)* onset 0.6s before an *impulsive (IP)* arrival (observed at 33 stations!!!). Below an example of a near field station.

Emergent onset



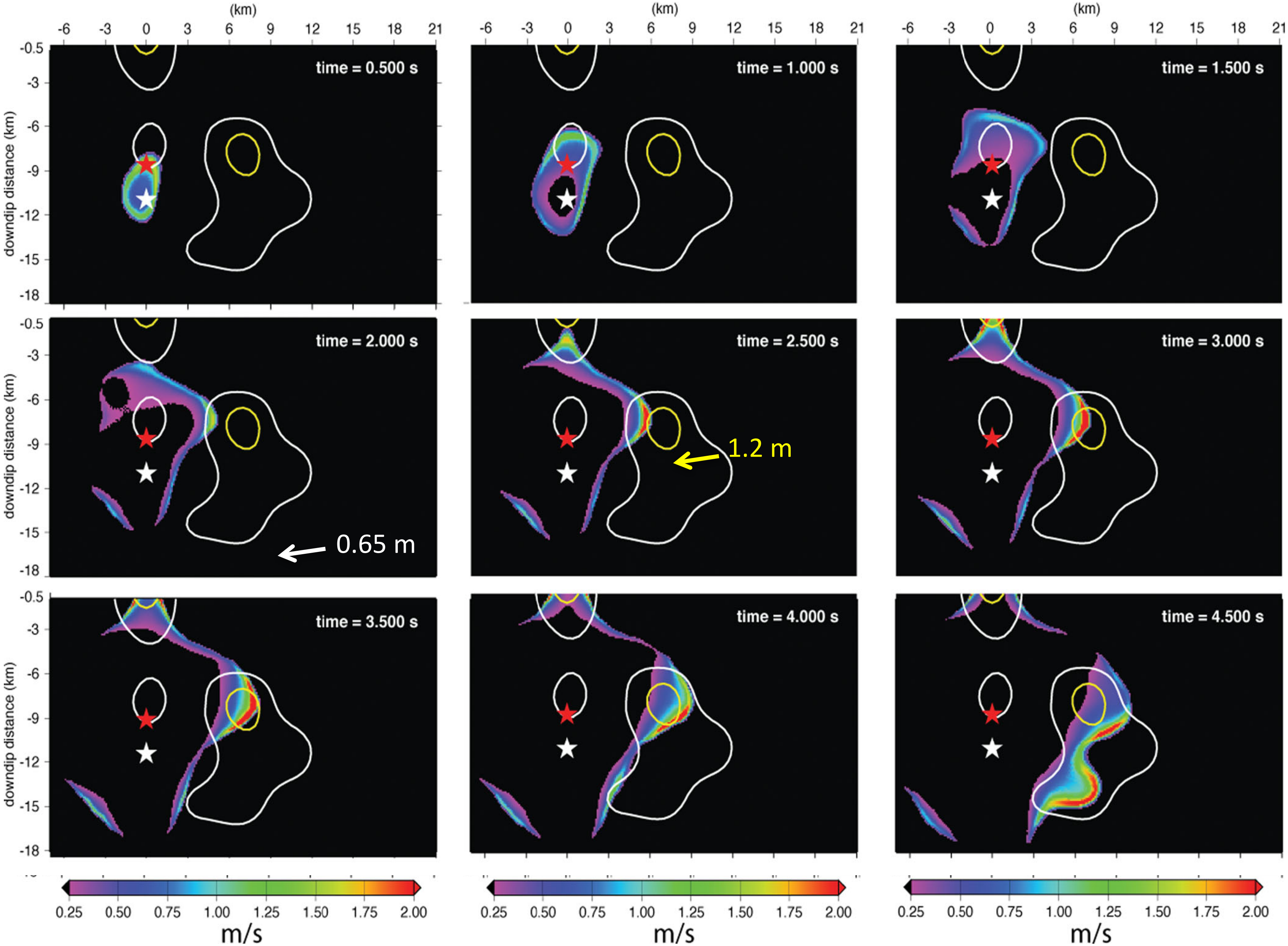
Main rupture





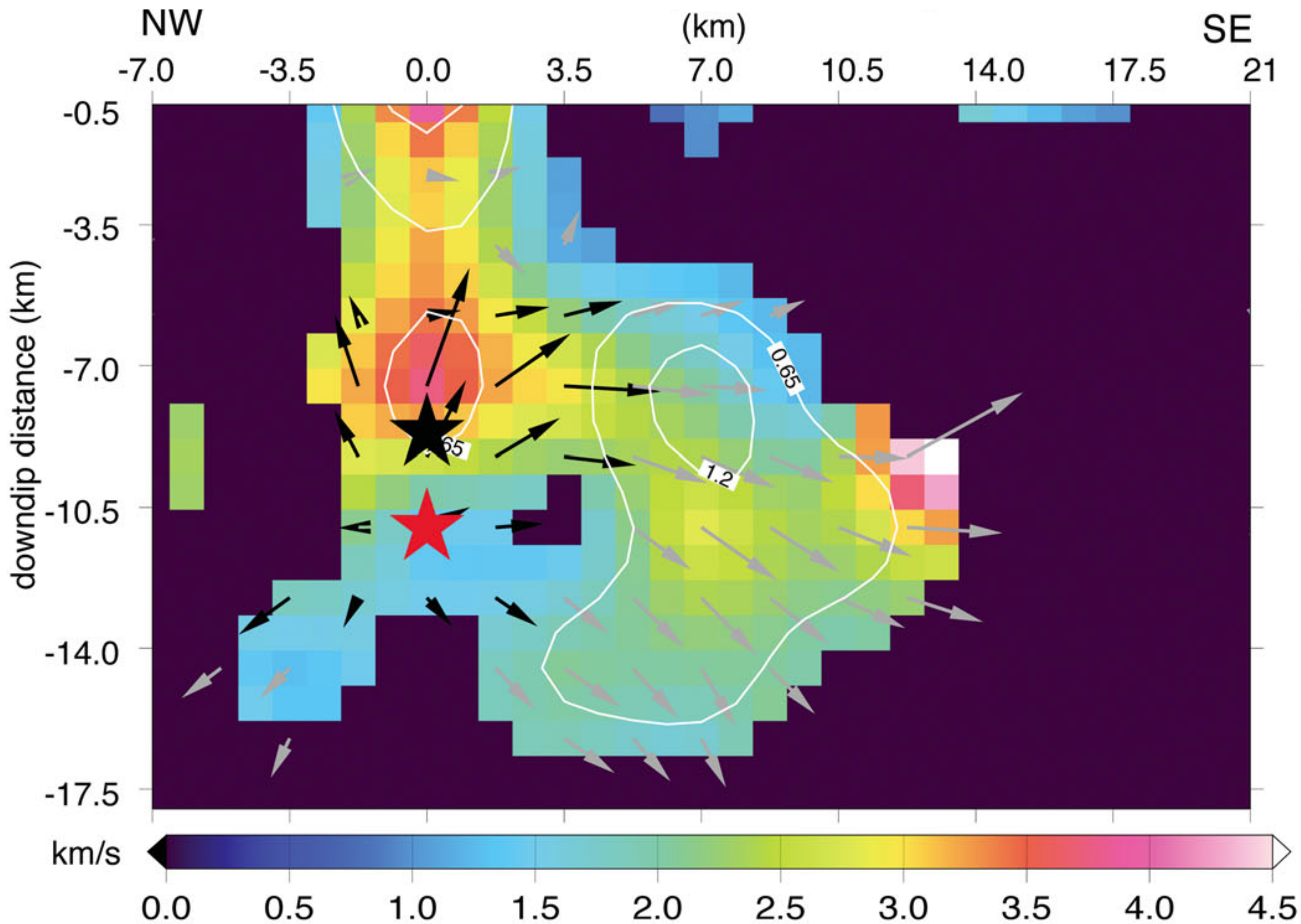
(Di Stefano et al., 2011)

Slip velocity on the fault plane (every 0.5s)



(Cirella et al., 2012)

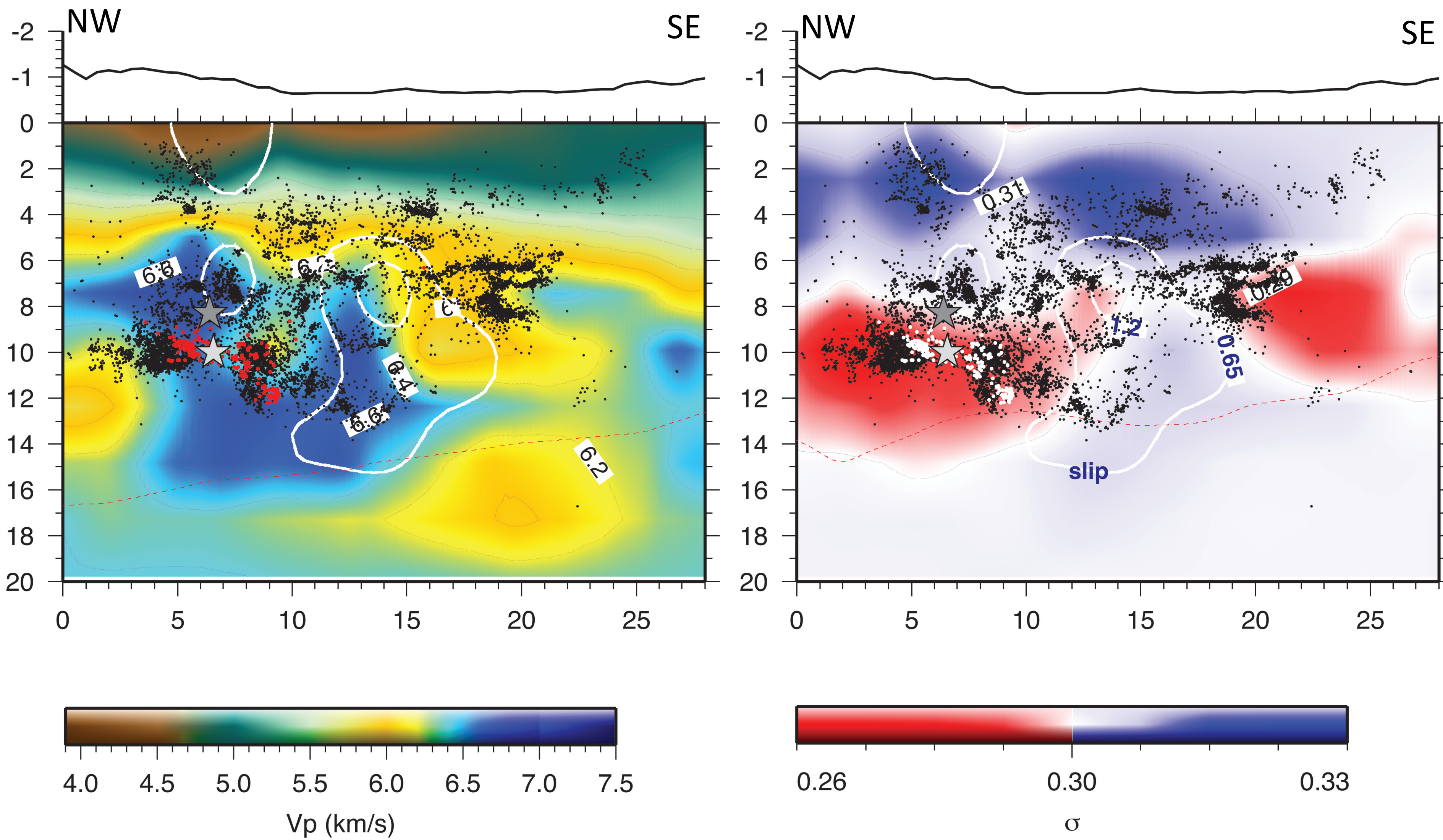
Local rupture velocity and slip



Black and grey arrows are the rupture velocity vectors for rupture times between 0-2s and over 2.0 s, respectively.

(Cirella et al., 2012)

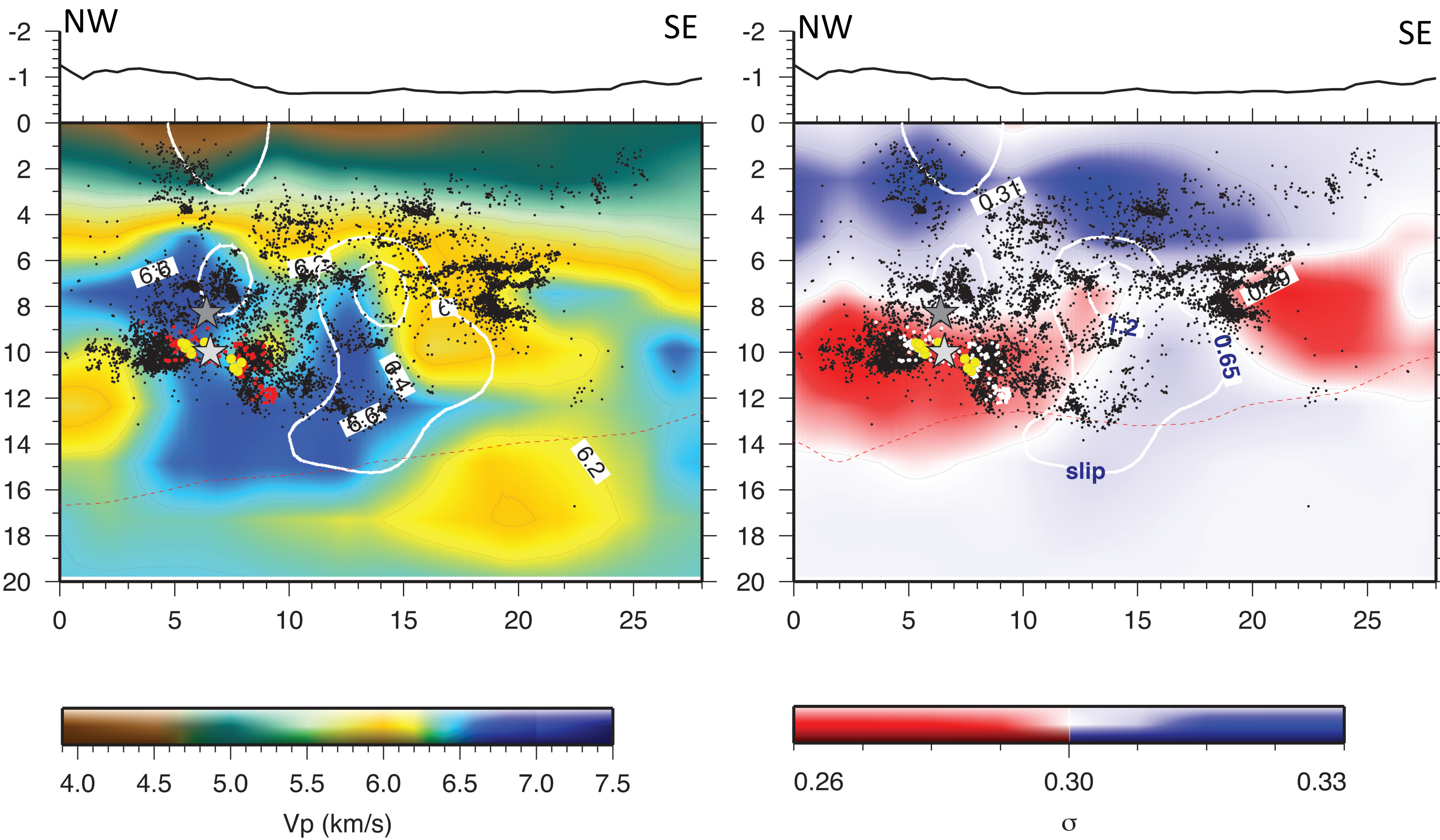
Hypocenter (EP) and impulsive phase (IP) versus V_P, Poisson and coseismic slip



(Di Stefano et al., 2011)

Coseismic slip from *Cirella et al., 2012*

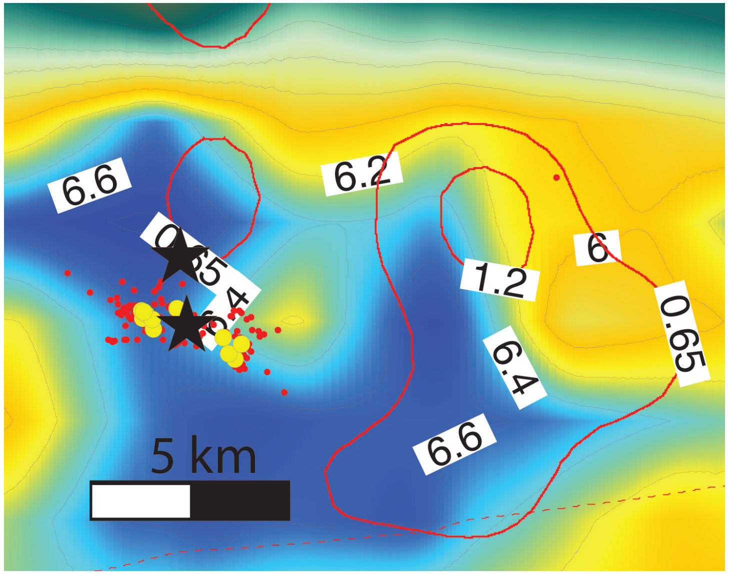
Hypocenter (EP) and impulsive phase (IP) versus V_P, Poisson and coseismic slip



(Di Stefano et al., 2011)

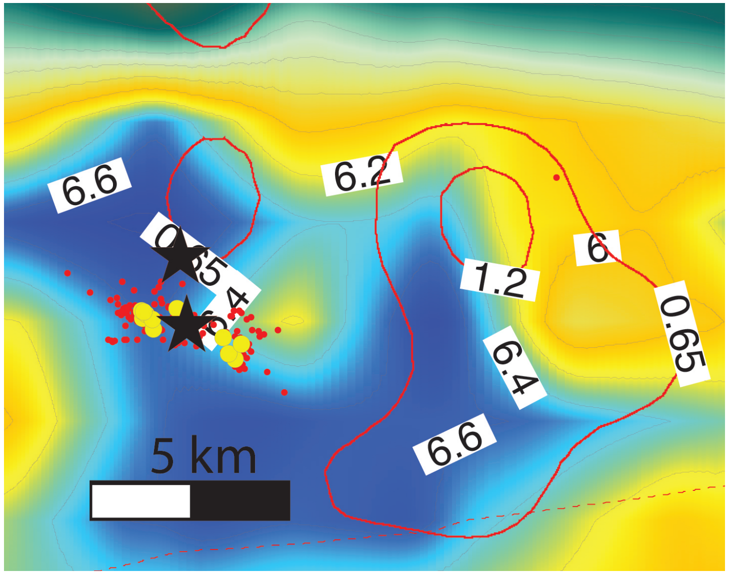
Coseismic slip from *Cirella et al., 2012*

The nucleation volume with time (Mainshock April 6th 01:32)

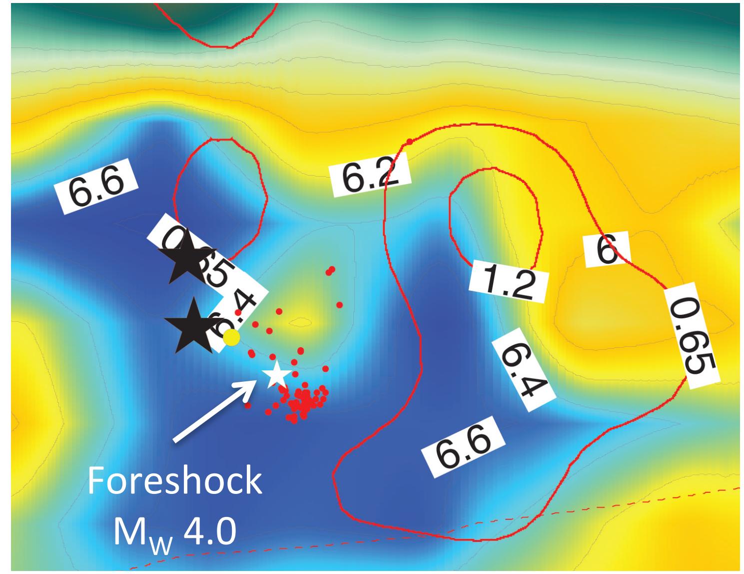


1° January – 30° March

The nucleation volume with time (Mainshock April 6th 01:32)

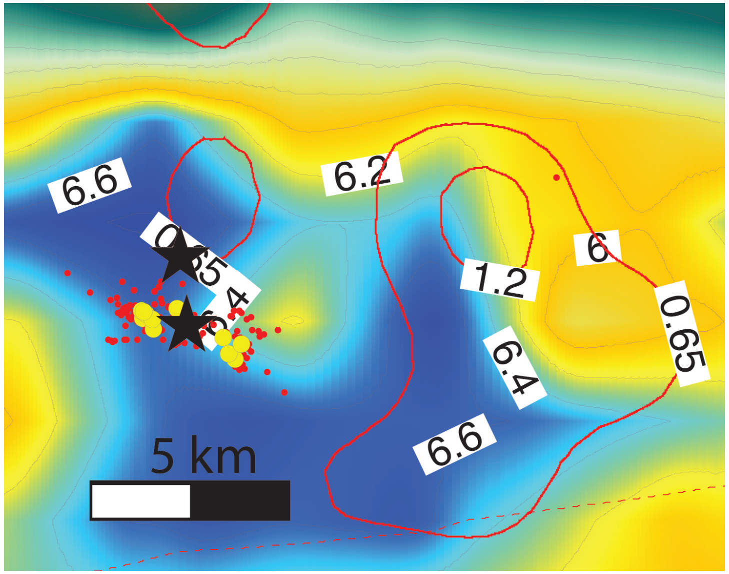


1° January – 30° March

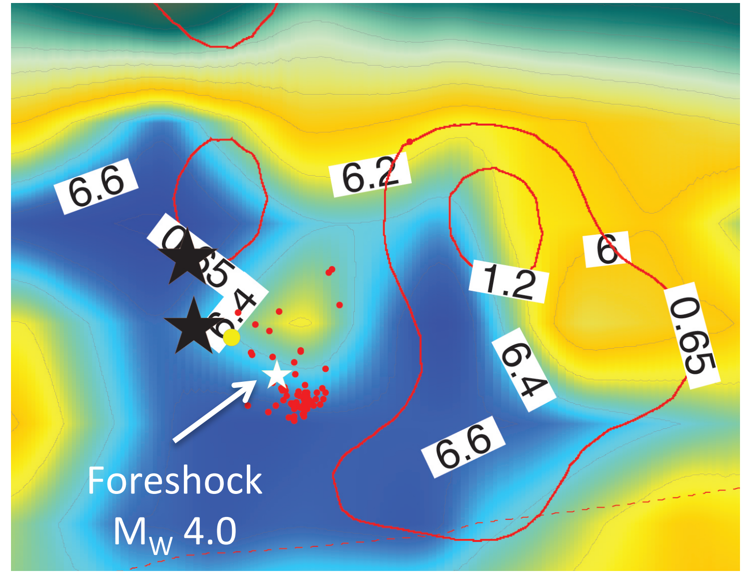


30° March – 5° April

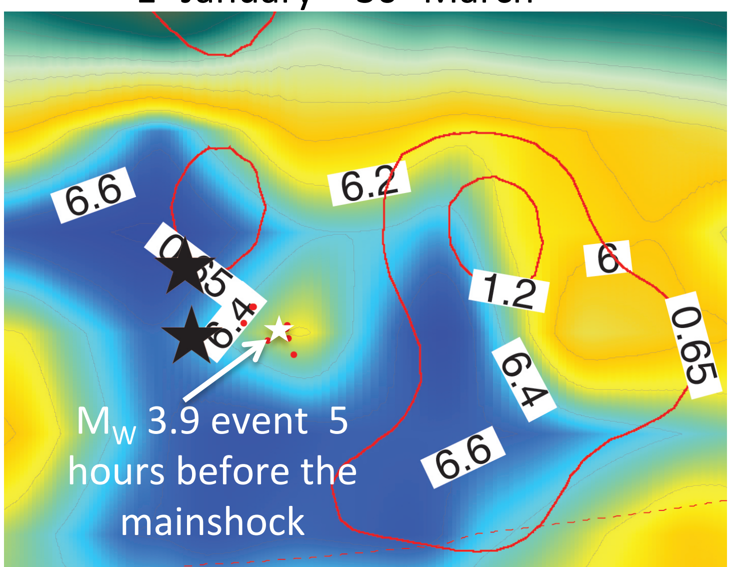
The nucleation volume with time (Mainshock April 6th 01:32)



1° January – 30° March

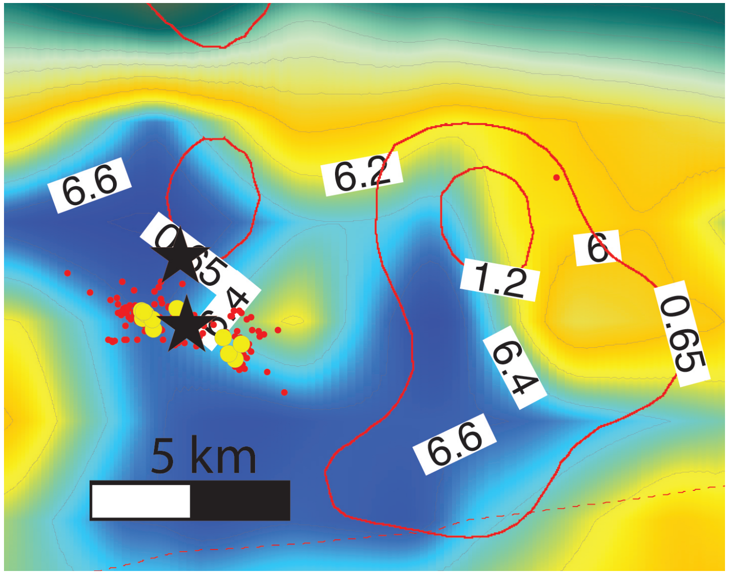


30° March – 5° April

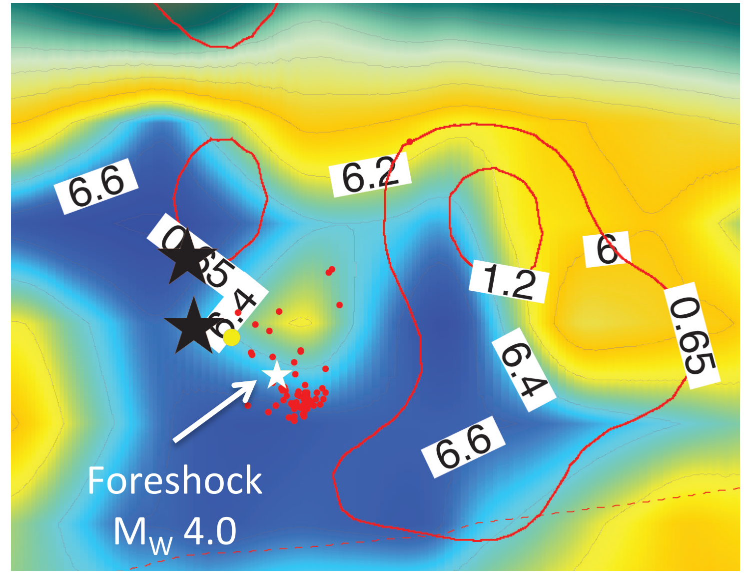


5° April – 6° April

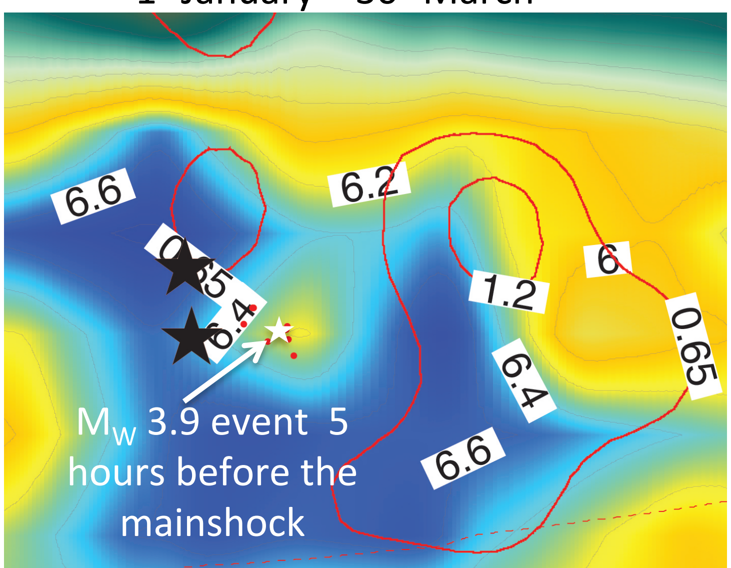
The nucleation volume with time (Mainshock April 6th 01:32)



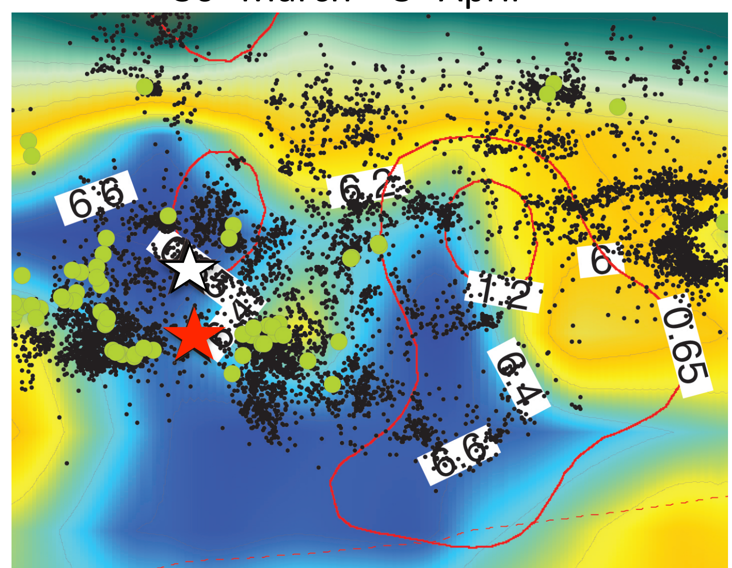
1° January – 30° March



30° March – 5° April

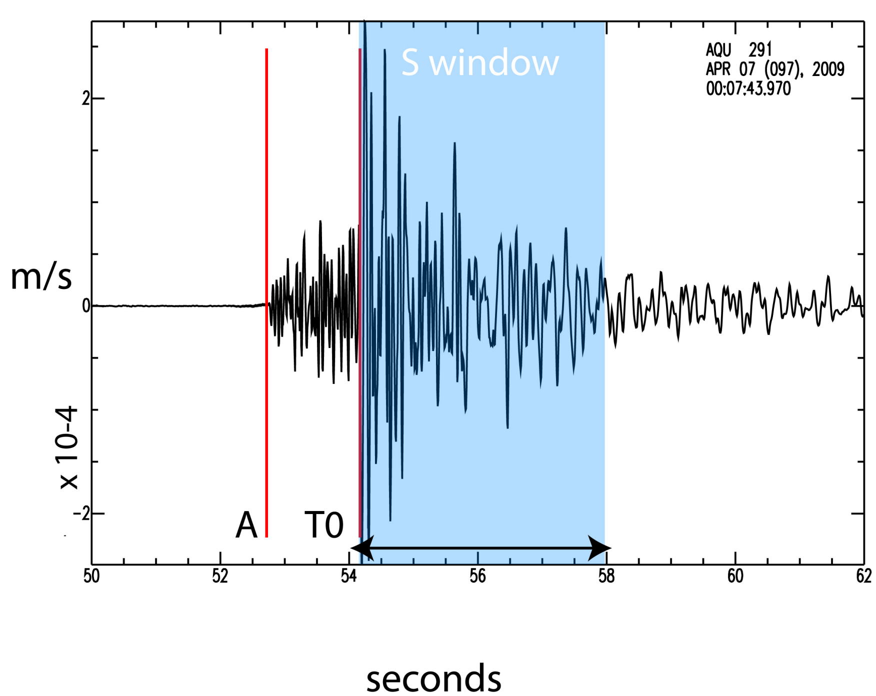


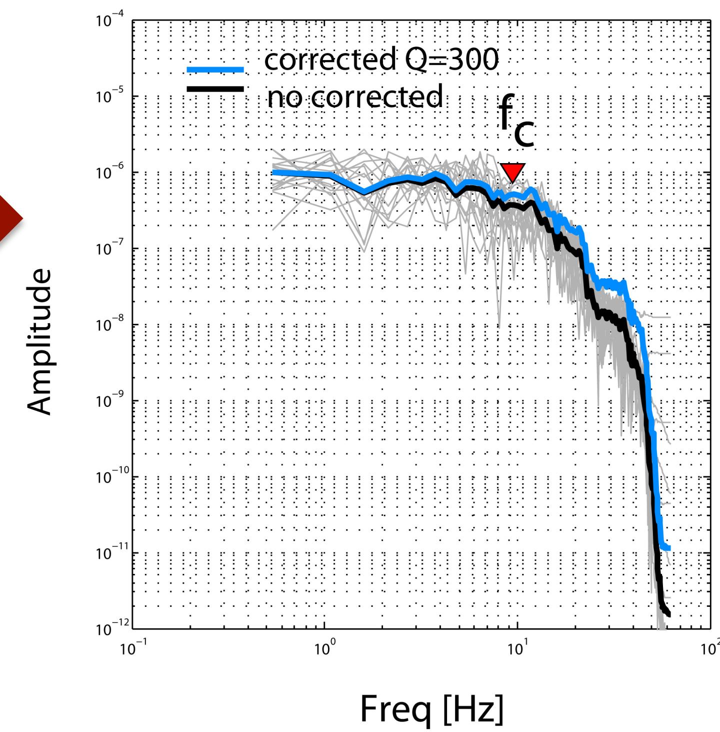
5° April – 6° April



Mainshock – December 2009

Inferring source parameters





$$E_R = \frac{4\pi\rho\beta D^2 \int \left(V(f)_z^2 + V(f)_n^2 + V(f)_e^2\right) e^{\frac{2\pi f D}{\beta Q}} df}{F^2}$$

(Singh and Ordaz, 1994)

$$f_c = \sqrt[3]{\frac{\int \left(2\pi f V(f) df\right)^2}{2\pi^3 \Omega_0^2}}$$

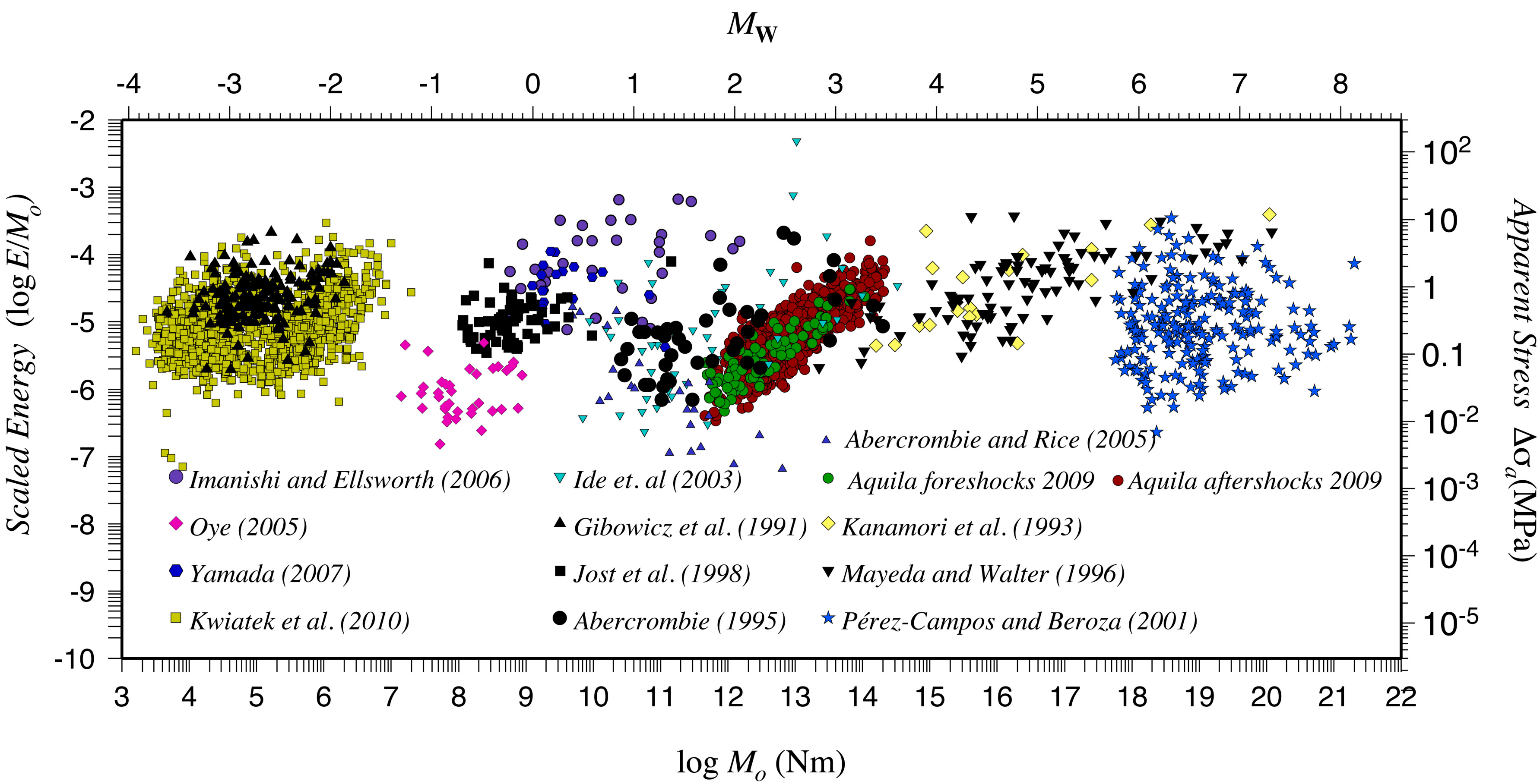
Snoke (1987)

$$Mo = \frac{M_0 = 4\pi\rho\beta^3 D\Omega_0}{RadPat}$$

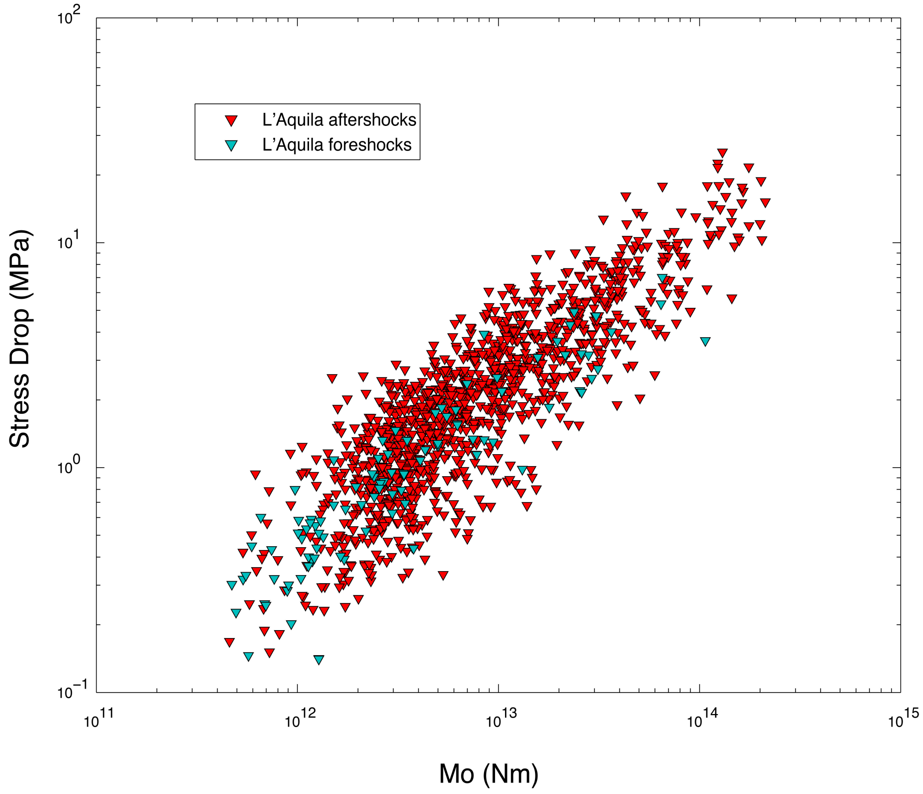
$$\Delta\sigma = \frac{7M_0}{16r^3}$$

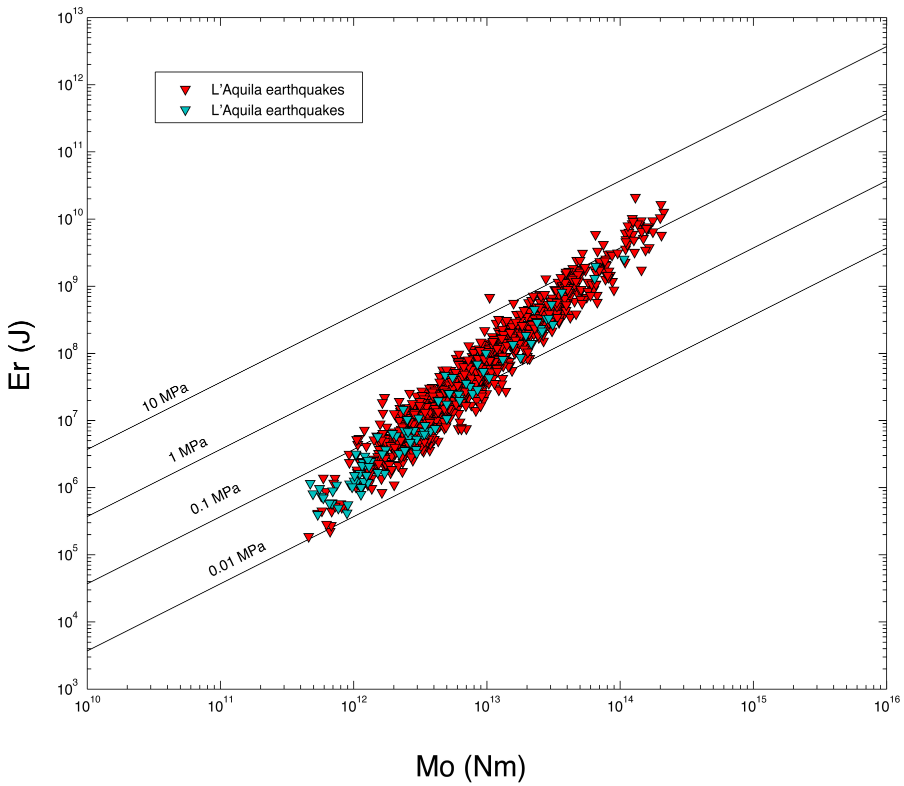
Eshelby (1957)

The 2009 L'Aquila sequence and literature



Stress drop – Radiated Energy and Seismic Moment





We observed

- a foreshock sequence lasting for months at the base of the main fault plane and showing a sharp change in the seismic wave propagation properties about a week before the mainshock

- no evidence for accelerating moment release before the mainshock

- a complex rupture onset and evolution (EP and IP phases) characterized by two distinct (up-dip and along strike) stages of rupture history likely due to structural complexities

- heterogeneous slip distribution anti-correlated with seismicity pattern

- similar values of source parameters for fore- and aftershocks.

Discussion

Our results show that the L'Aquila earthquake, despite its moderate size, featured:

✧ clear directivity effects coherently with previous normal faulting earthquakes in the Apennines;

✧ a complex directivity characterized by an up-dip and along-strike rupture propagation;

✧ a peculiar spatio-temporal evolution of seismicity near the nucleation volume with co-located foreshocks, repeaters and aftershocks;

✧ evident implications for structural and frictional control of faulting.

thank you for the attention