Seismic Energy: Scaling, Variability, and Implications for High Frequency Ground motion

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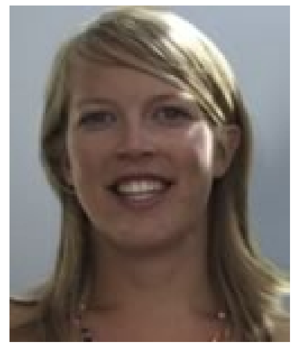


STANFORD
SCHOOL OF EARTH SCIENCES
Universidad de los Andes
東京大学
THE UNIVERSITY OF TOKYO

3rd SCEC-ERI Joint Workshop
Tuesday March 16th 2010, Tokyo, Japan

Radiated seismic energy

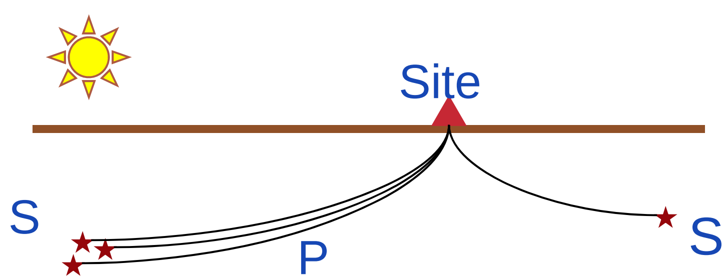
$$E_S = \frac{1}{4\pi^2 \rho \beta^5} \int_0^{\infty} \left| \omega \cdot \dot{M}(\omega) \right|^2 d\omega$$

Integrated source spectra over all frequencies

Most is radiated above corner frequency

Scaled energy: E_s / M_0

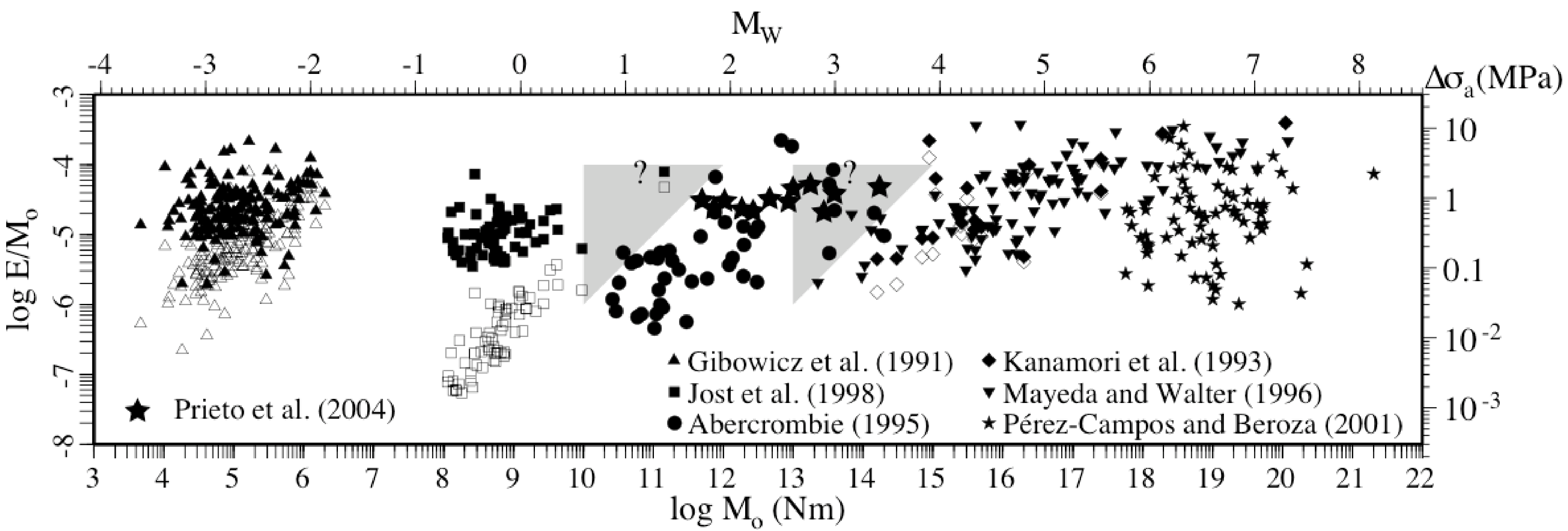
Apparent stress: $T_a = \mu (E_s / M_0)$




$= f($Source,Path,Site$)$

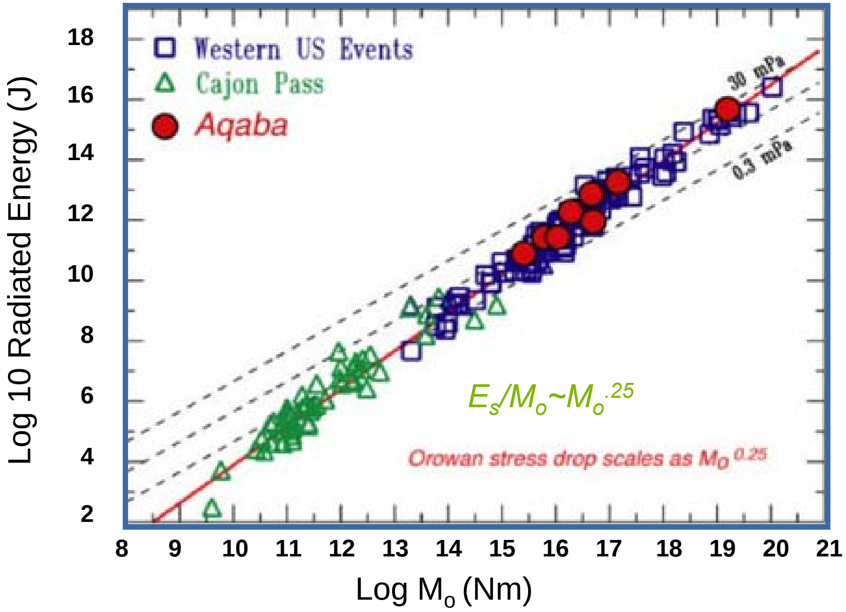
Use co-located events → Empirical Green's Functions

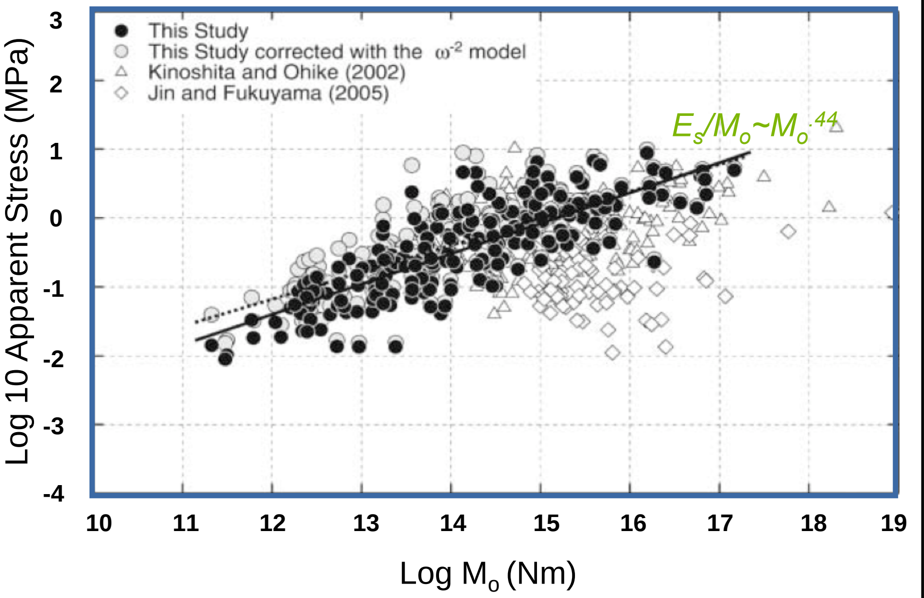
Previous Studies: No scaling?



Ide and Beroza (2001)

Scaling?



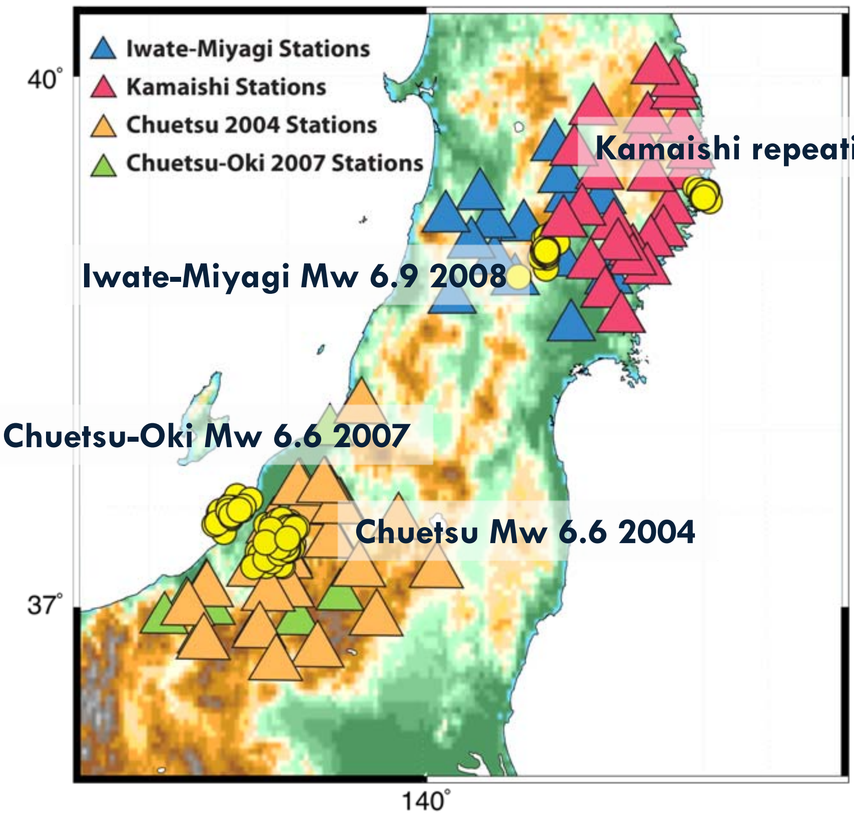


Strongest evidence comes from coda studies.

Mayeda et al. (2000)

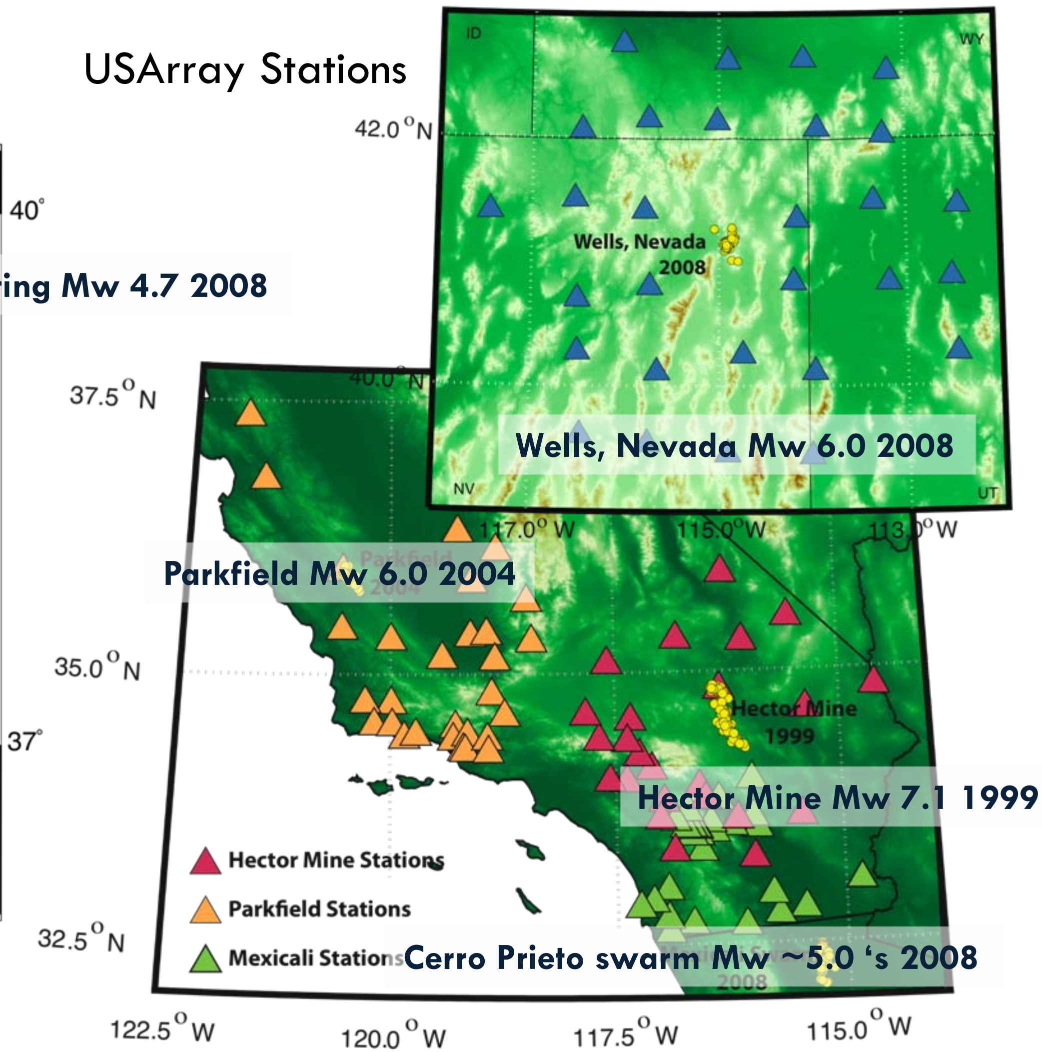
Takahashi et al. (2005)

Sequence Locations



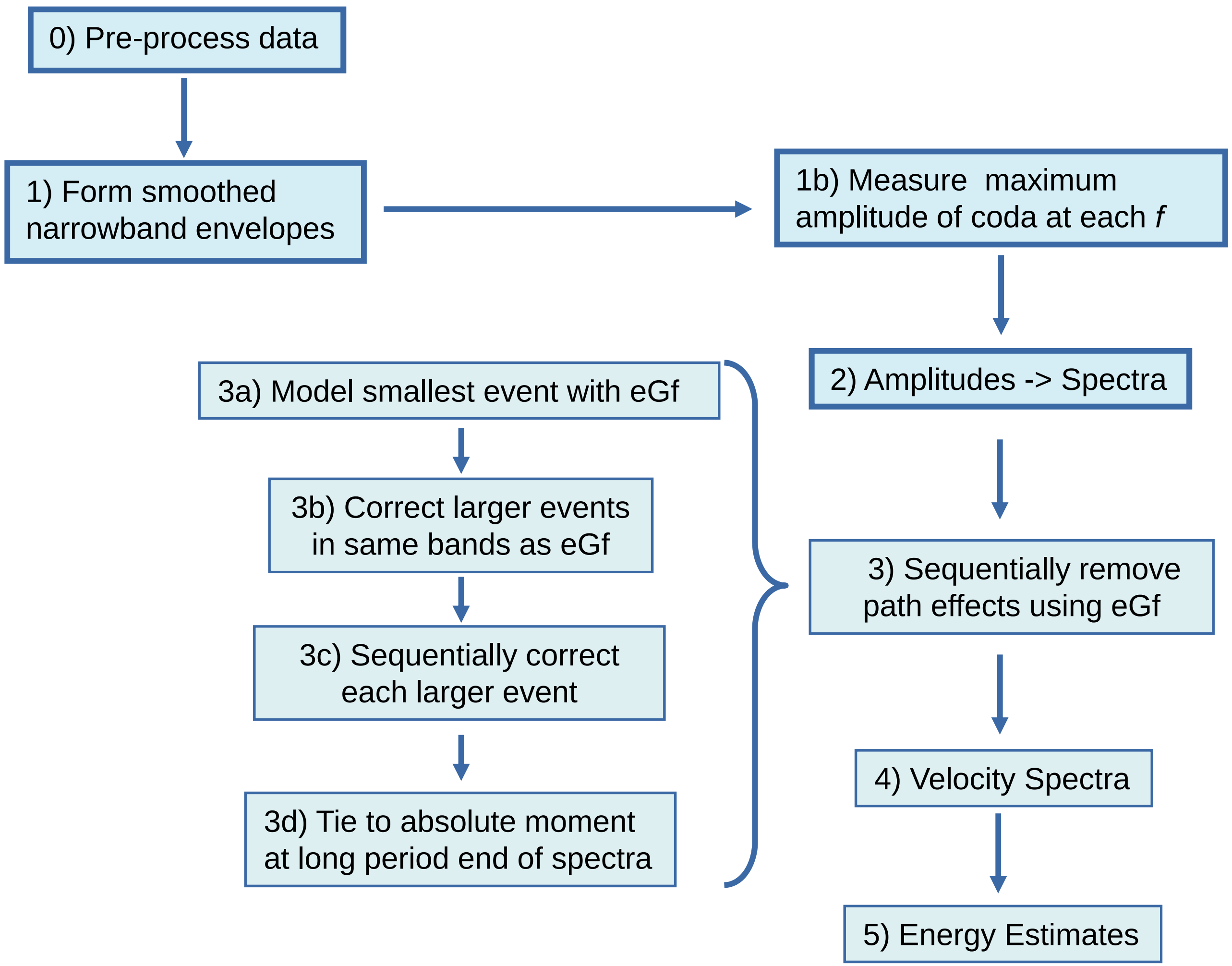
HiNet and KNet stations

USArray Stations

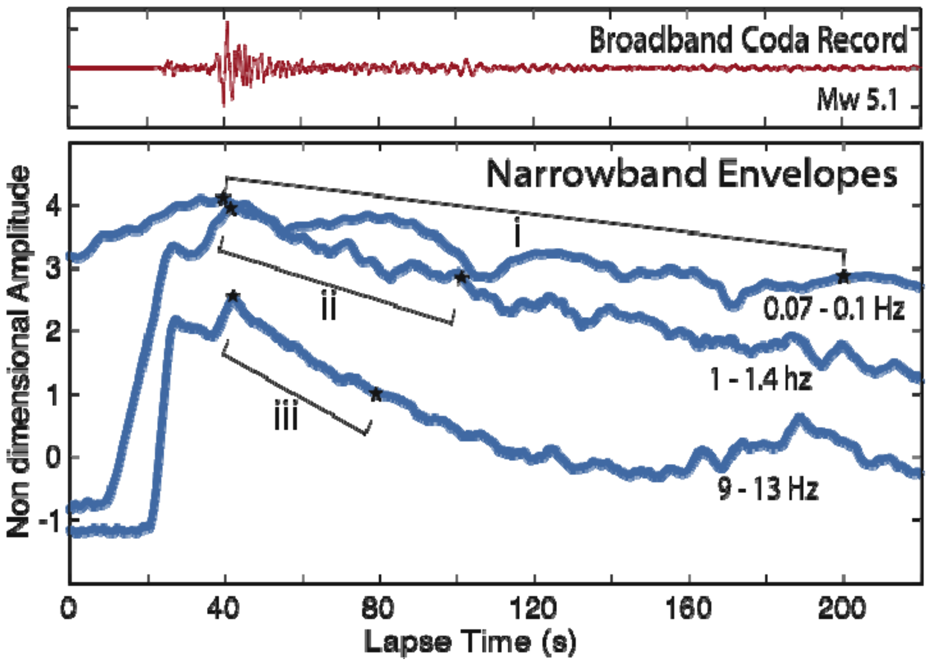


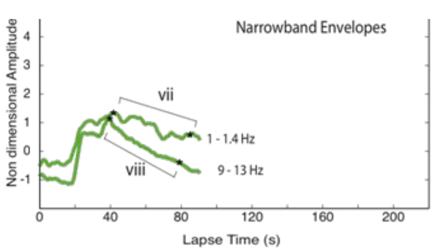
CalTech, Berkeley, Anza networks

Empirical Green's Function Approach



1) Narrowband Envelopes



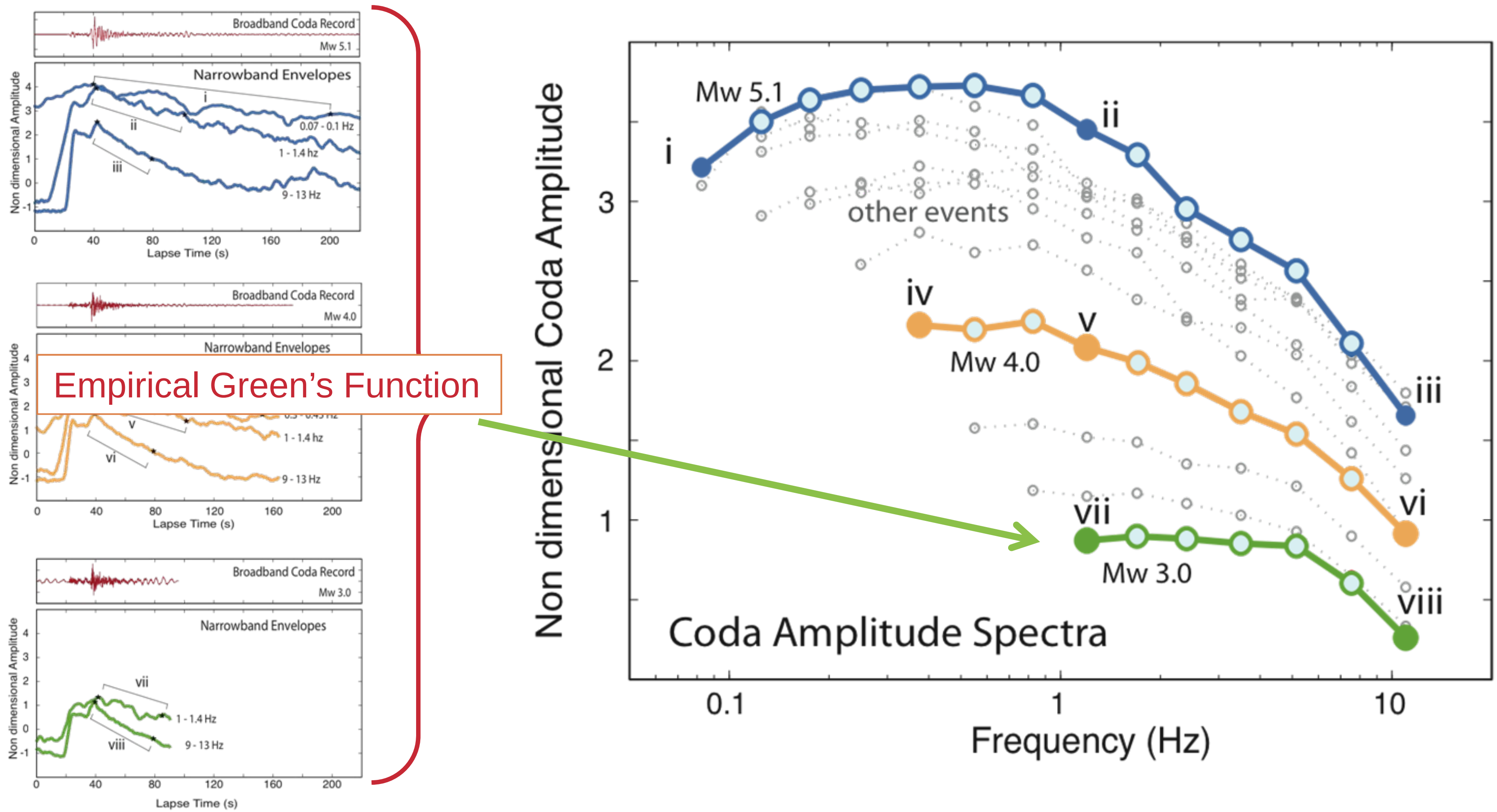


- Band pass filter in 20 narrowbands
  - → Continuous in time
  - → Discrete in frequency
- Take envelope

$$E(t) = \sqrt{u(t)^2 + H(t)^2}$$

- Window from S arrival to window length, set by smallest event

2) Create Coda Spectra



Empirical Green's Function

$$u(f) = \frac{M_o}{1 + (f/f_c)^2}$$

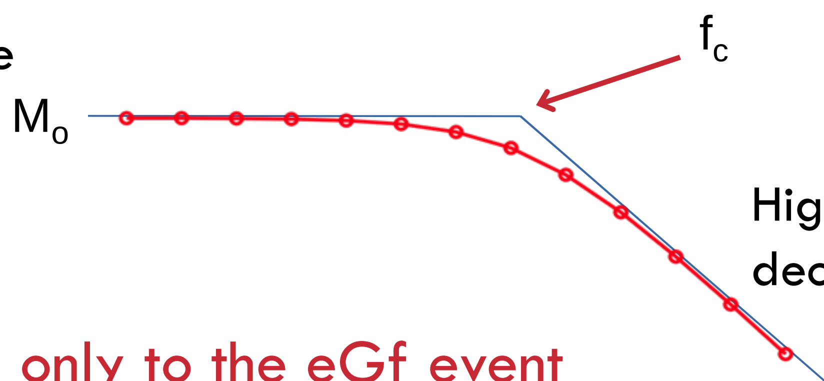
Brune (1970) model

Assume point source

- Short duration
- High corner frequency

Low frequency asymptote

→ Moment



High frequency asymptote decays as f^{-2}

Assumptions applied only to the eGf event

$$f_c = \beta \left(\frac{\Delta\sigma}{8.5 M_o} \right)^{1/3}$$

Hanks and McGuire (1980)

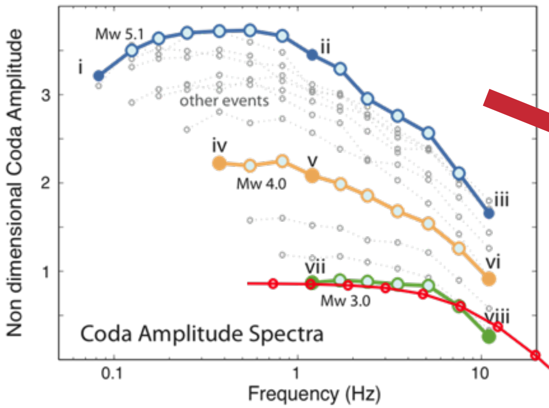
Assume $\Delta\sigma$ of 3 MPa

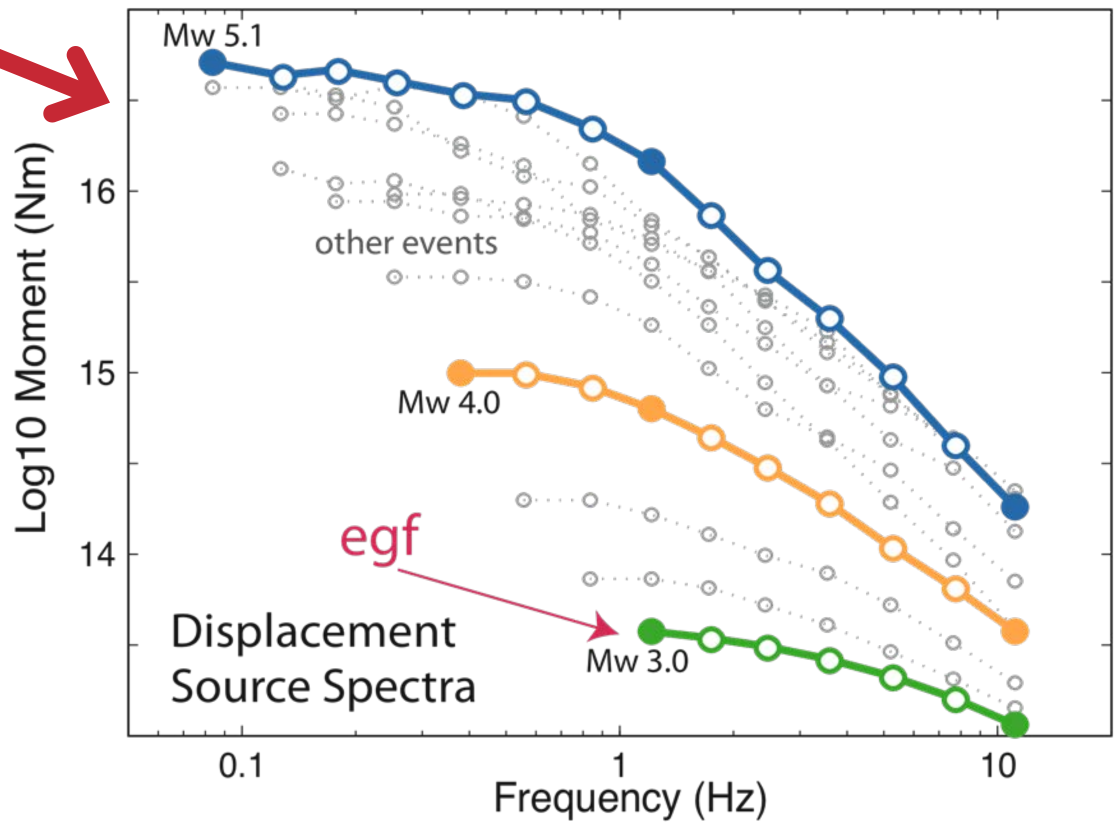
β of 3.5 km/s

Use catalog moment of eGf

Mw 3.0 → f_c = 7.5 Hz

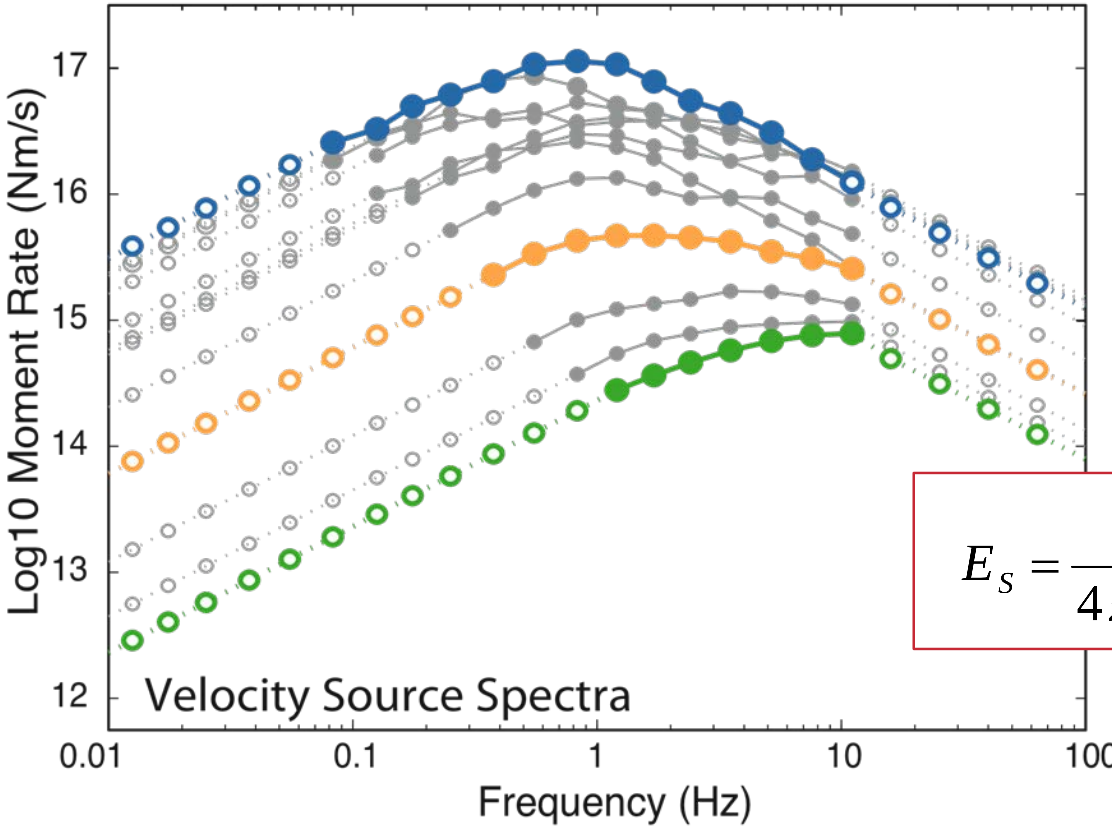
3) Sequentially remove path effects





- Model smallest event with eGf
- Correct larger events in same bands as eGf
- For each event:
  - flatten lowest represented frequency point
  - correct larger events in the same band
- Tie amplitudes to moment

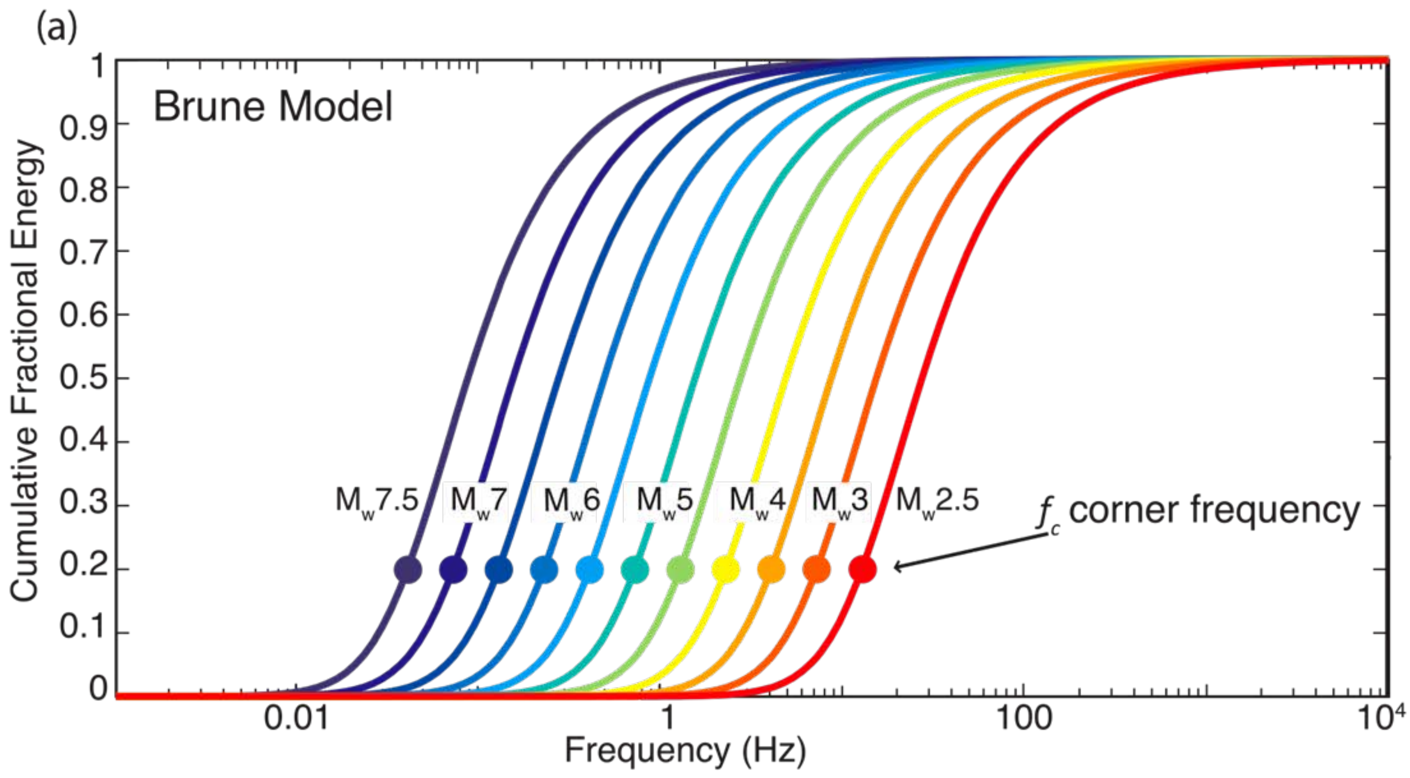
4) Velocity Spectra



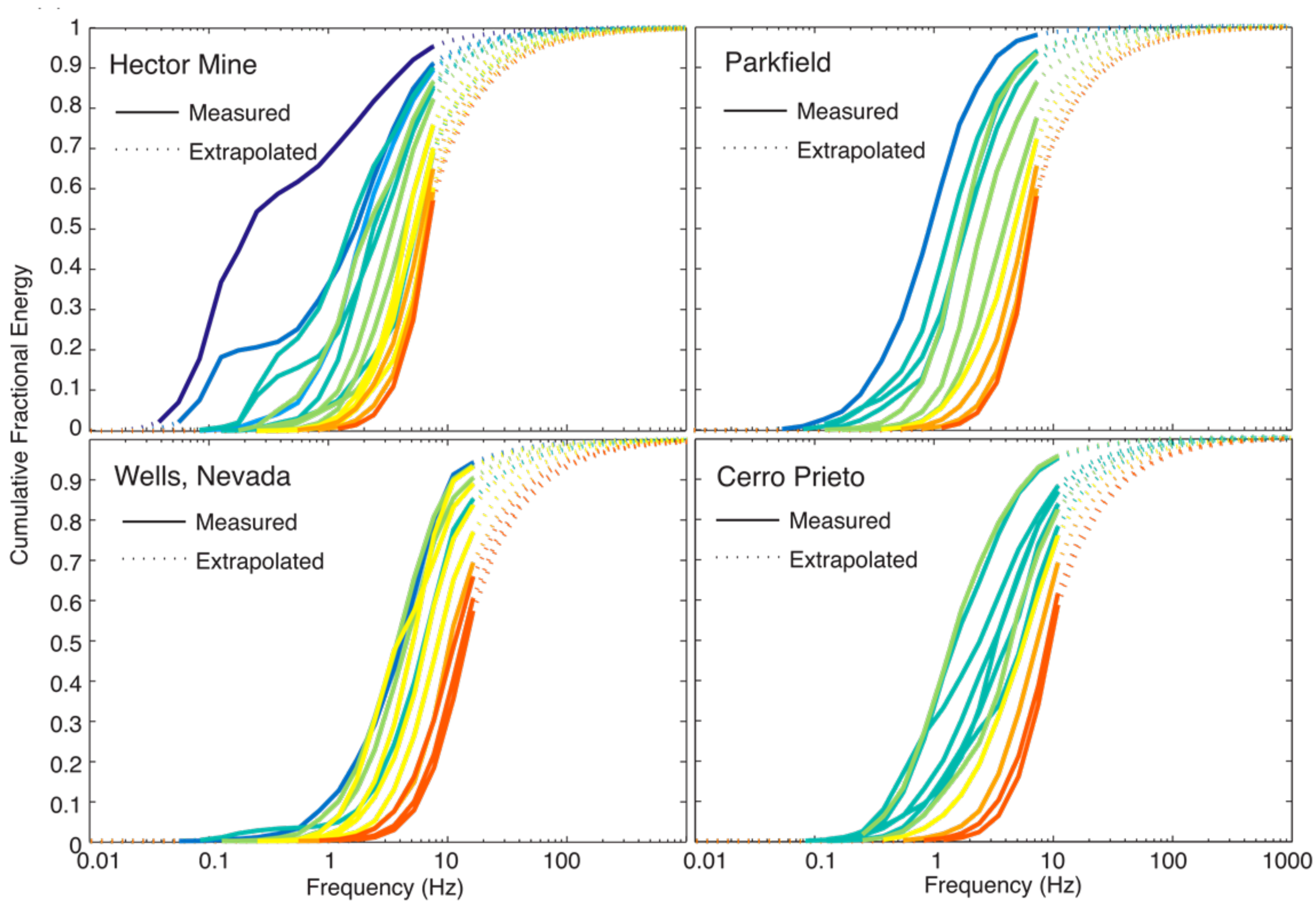
displacement spectra

$$E_S = \frac{1}{4\pi^2 \rho \beta^5} \int_0^{\infty} \left| \underbrace{\omega \cdot \dot{M}(\omega)}_{\text{velocity spectra}} \right|^2 d\omega$$

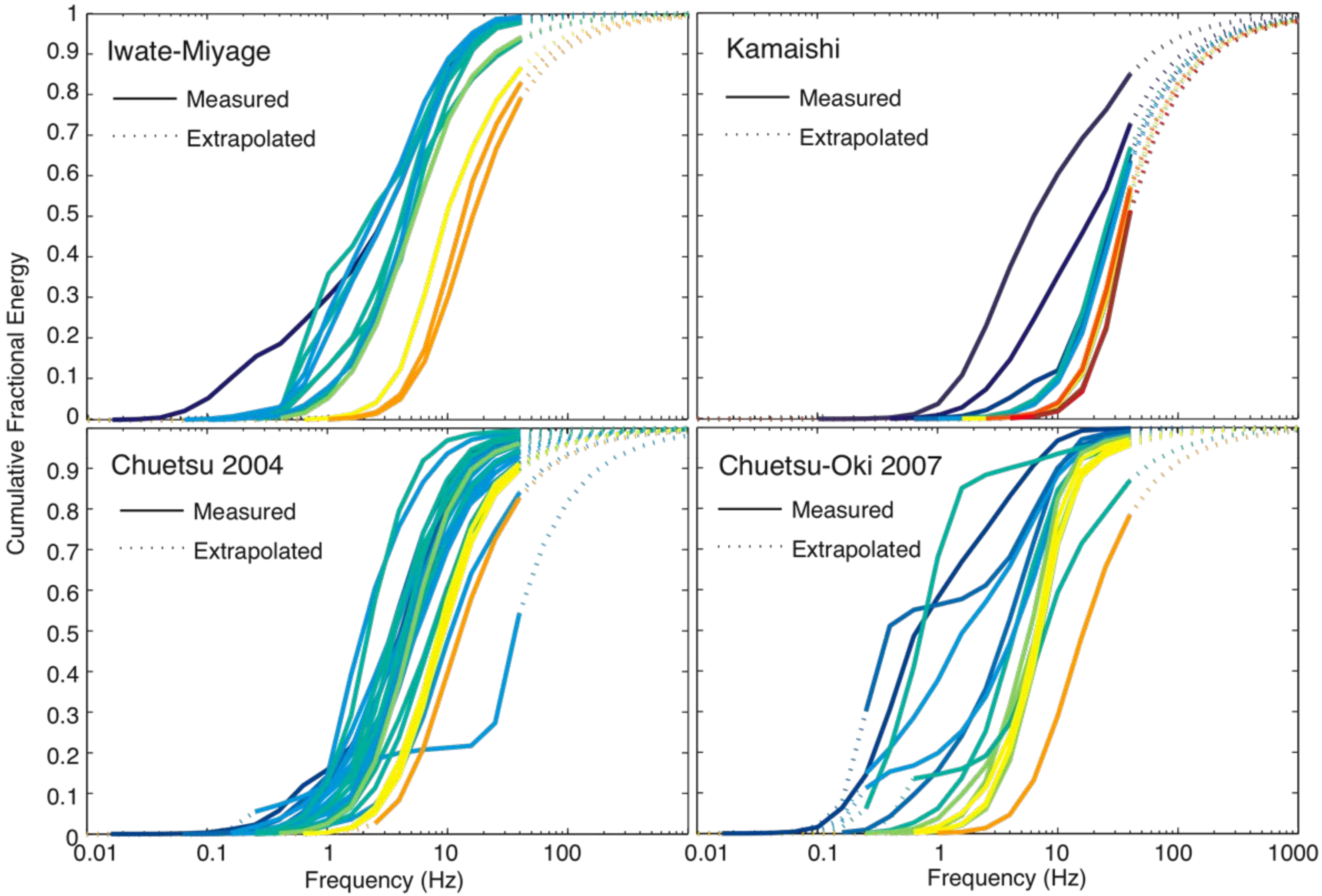
Ideal Cumulative Energy



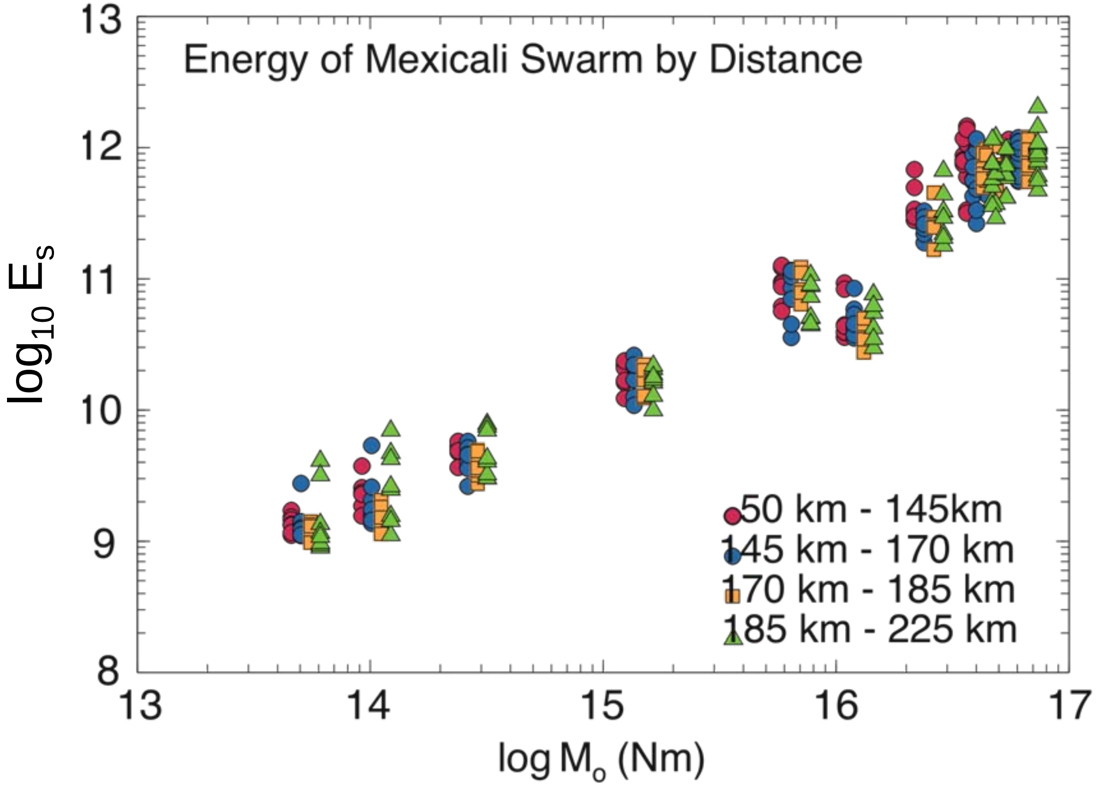
Cumulative Energy – US Events



Cumulative Energy – Japan Events

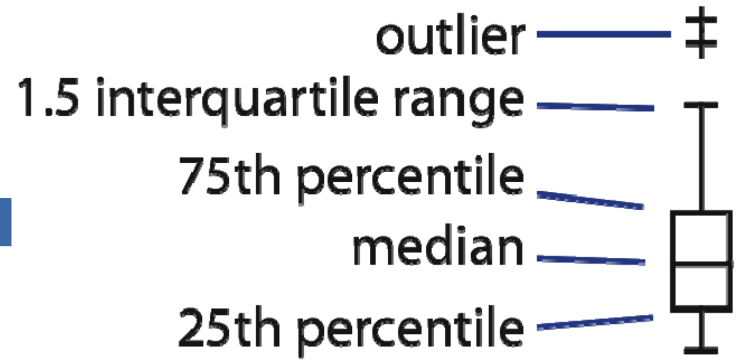


No Distance Bias

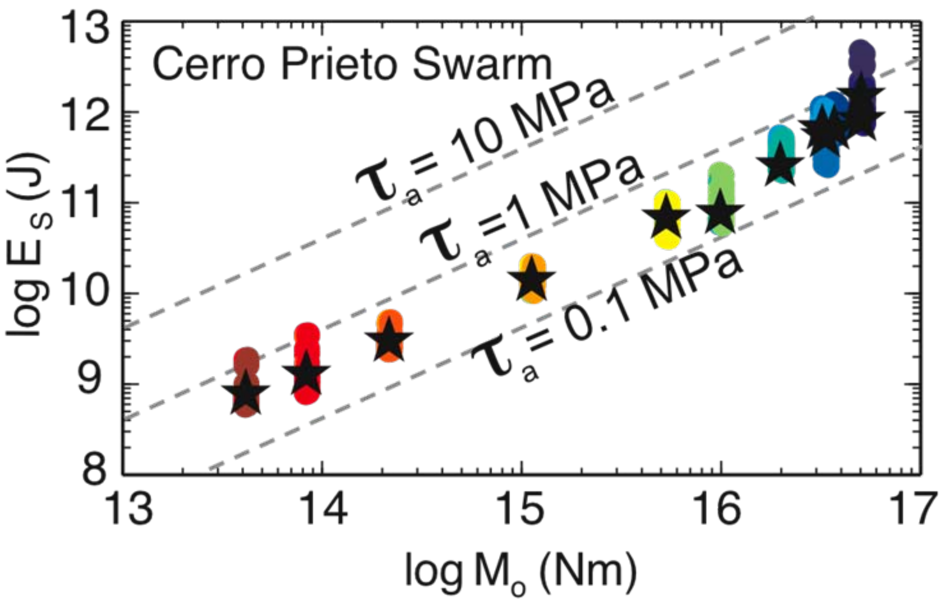


→ Validates empirical Green's function approach

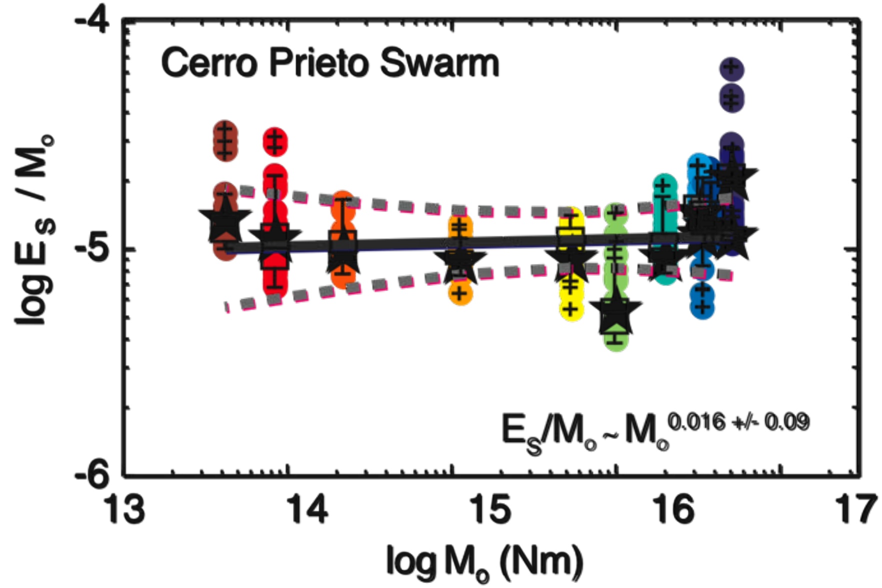
5) Radiated Energy



Radiated Energy

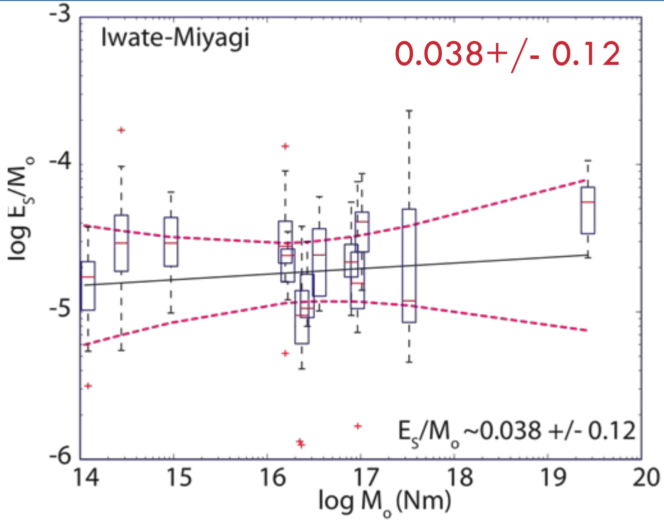


Scaled Energy

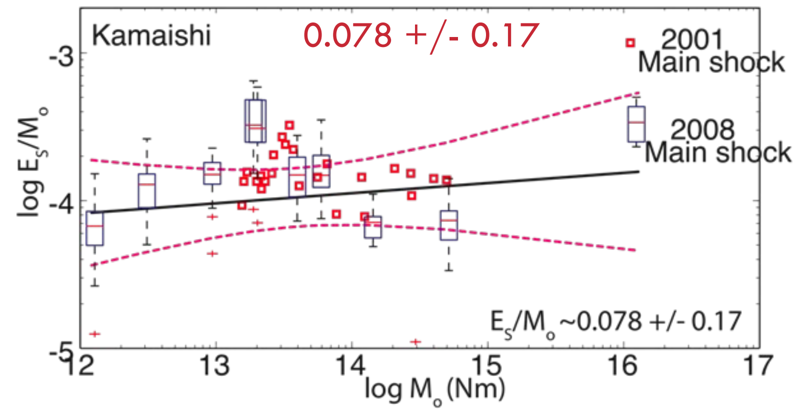


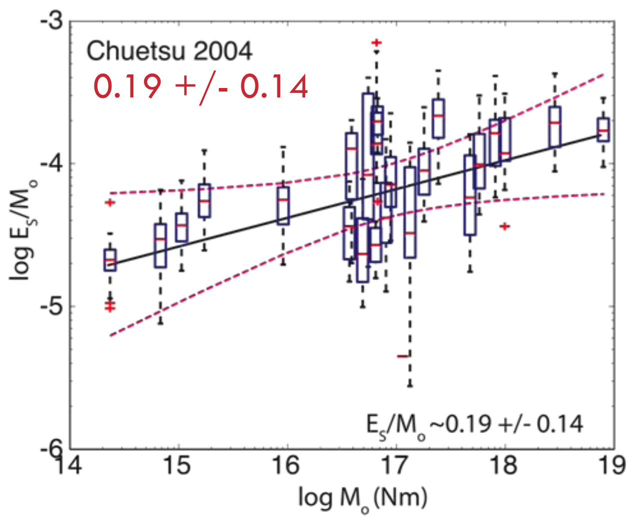
Cerro Prieto Sequence

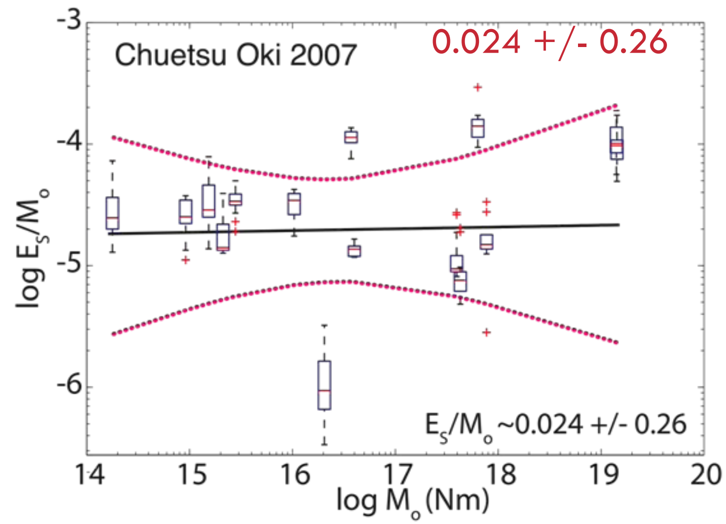
Scaled Energy:
Japan Earthquake Sequences



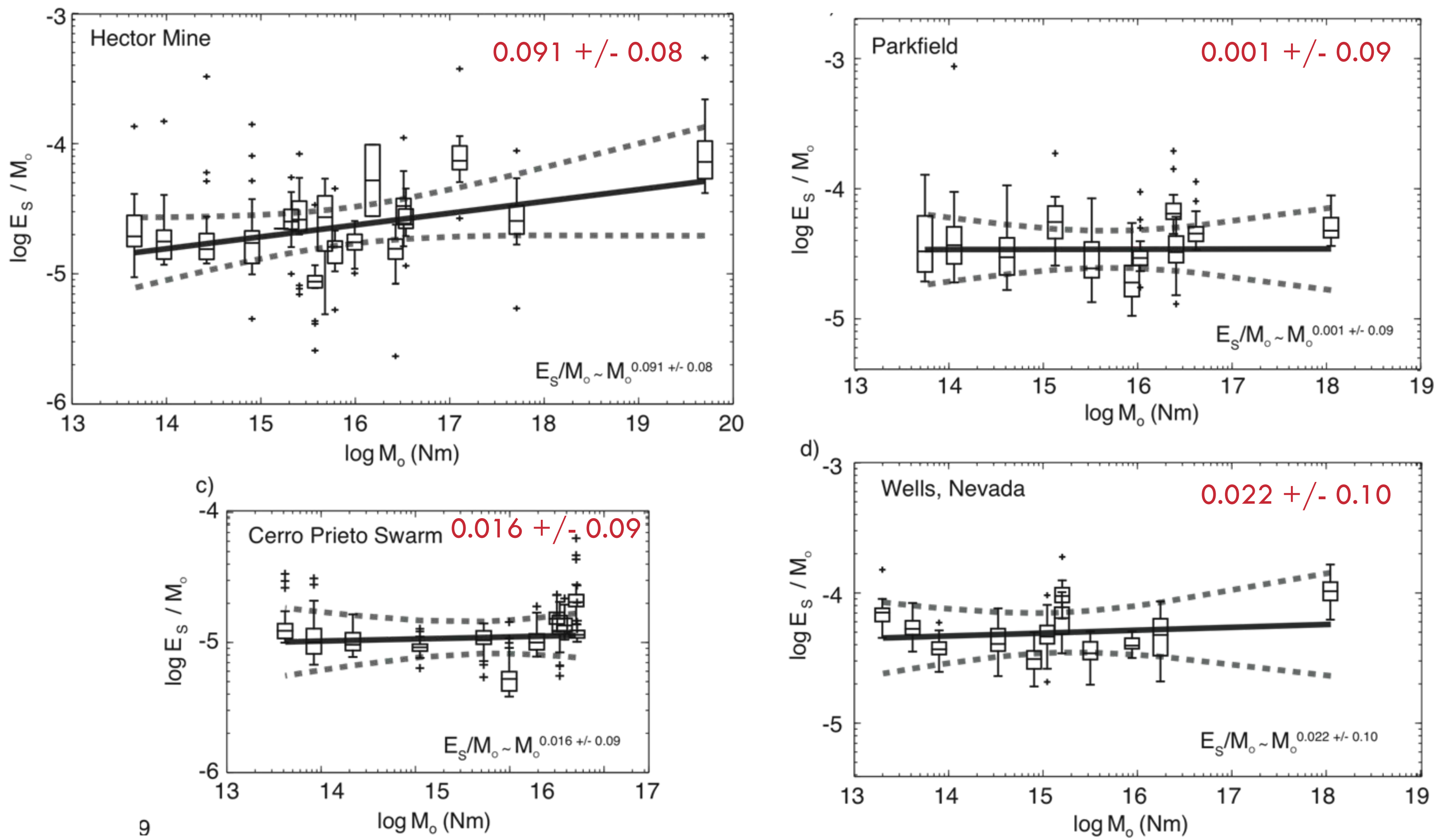
Red squares from Uchida et al, 2008.



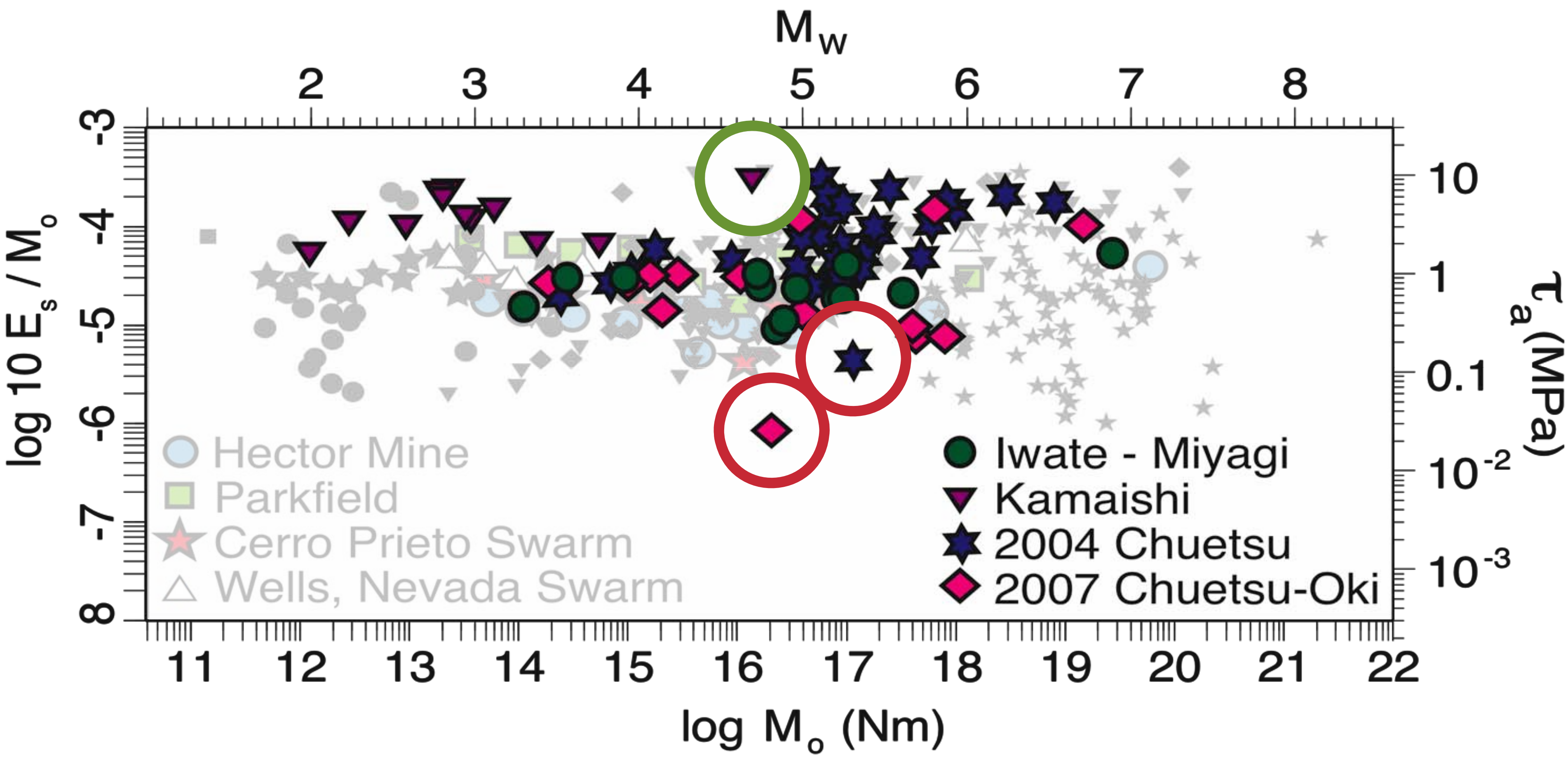




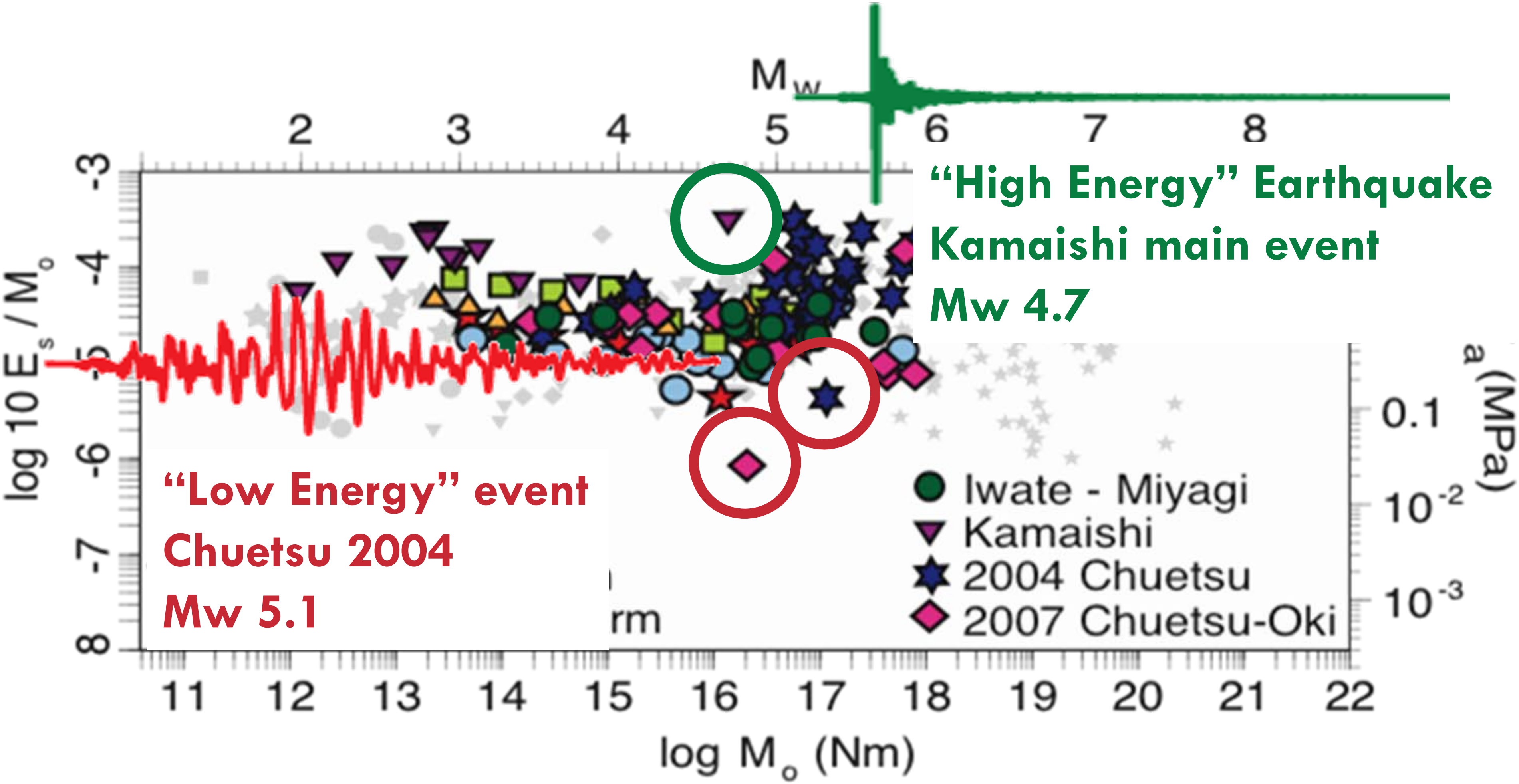
Scaled Energy:
US Earthquake Sequences



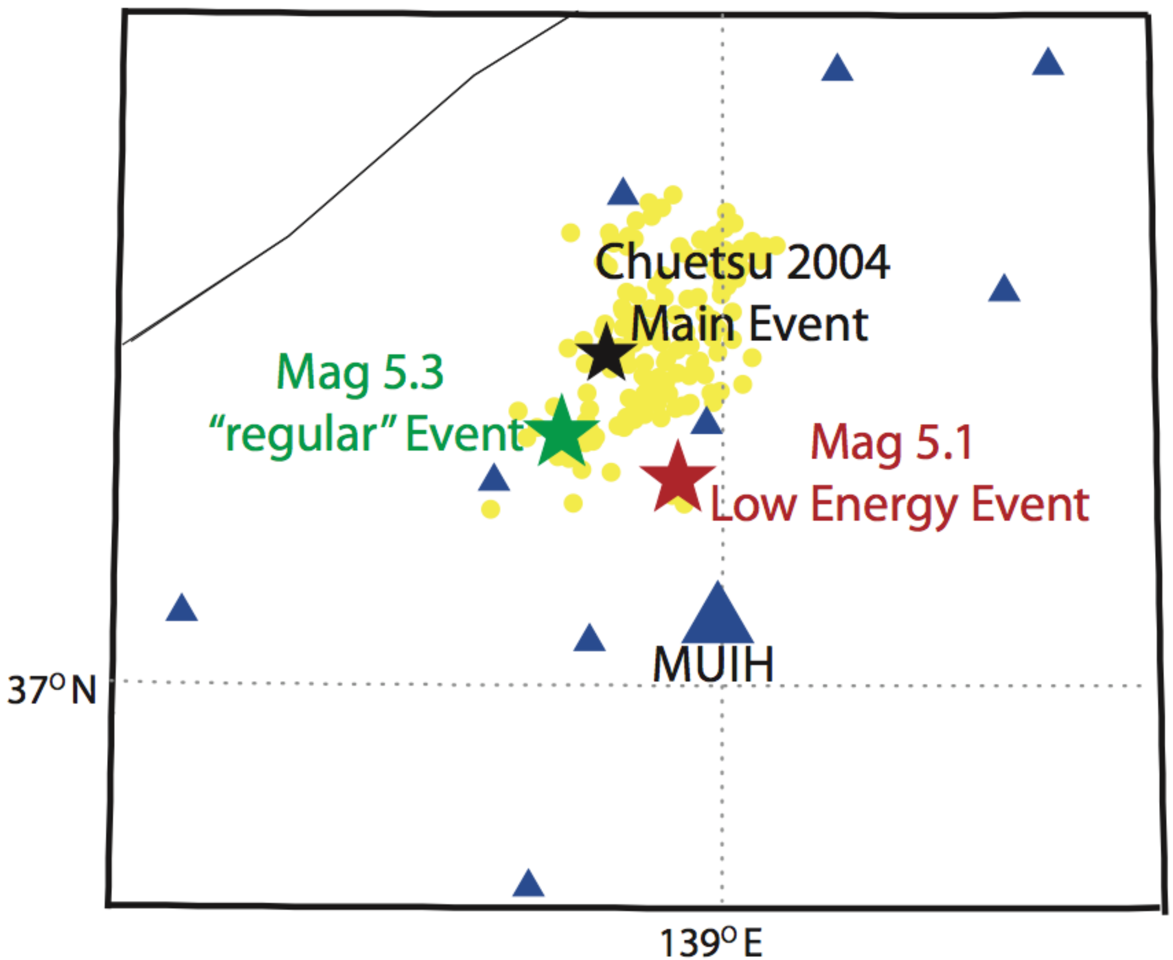
No scaling of radiated energy



Anomalous events



Anomalous vs. Normal Event

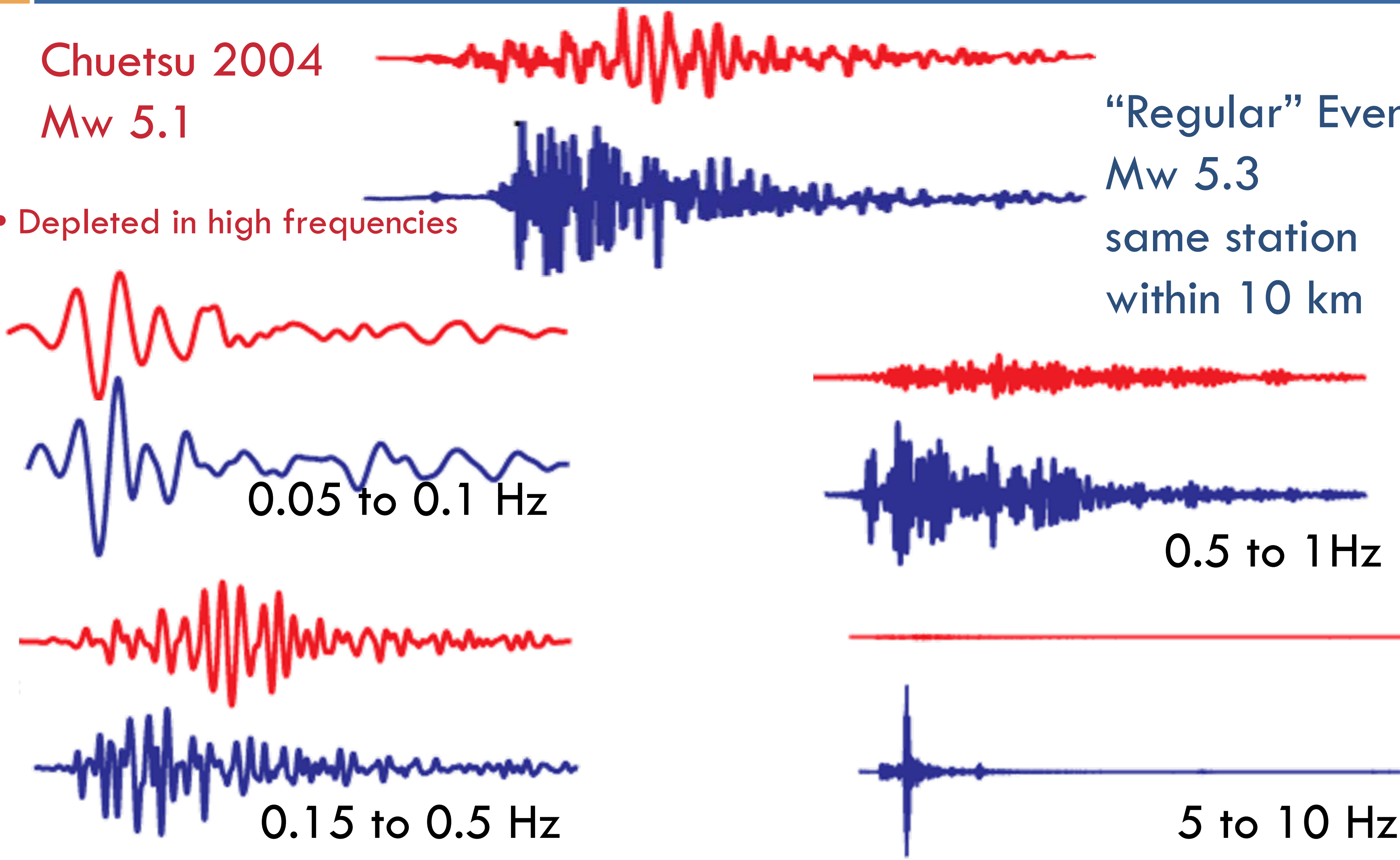


Low Energy Earthquake

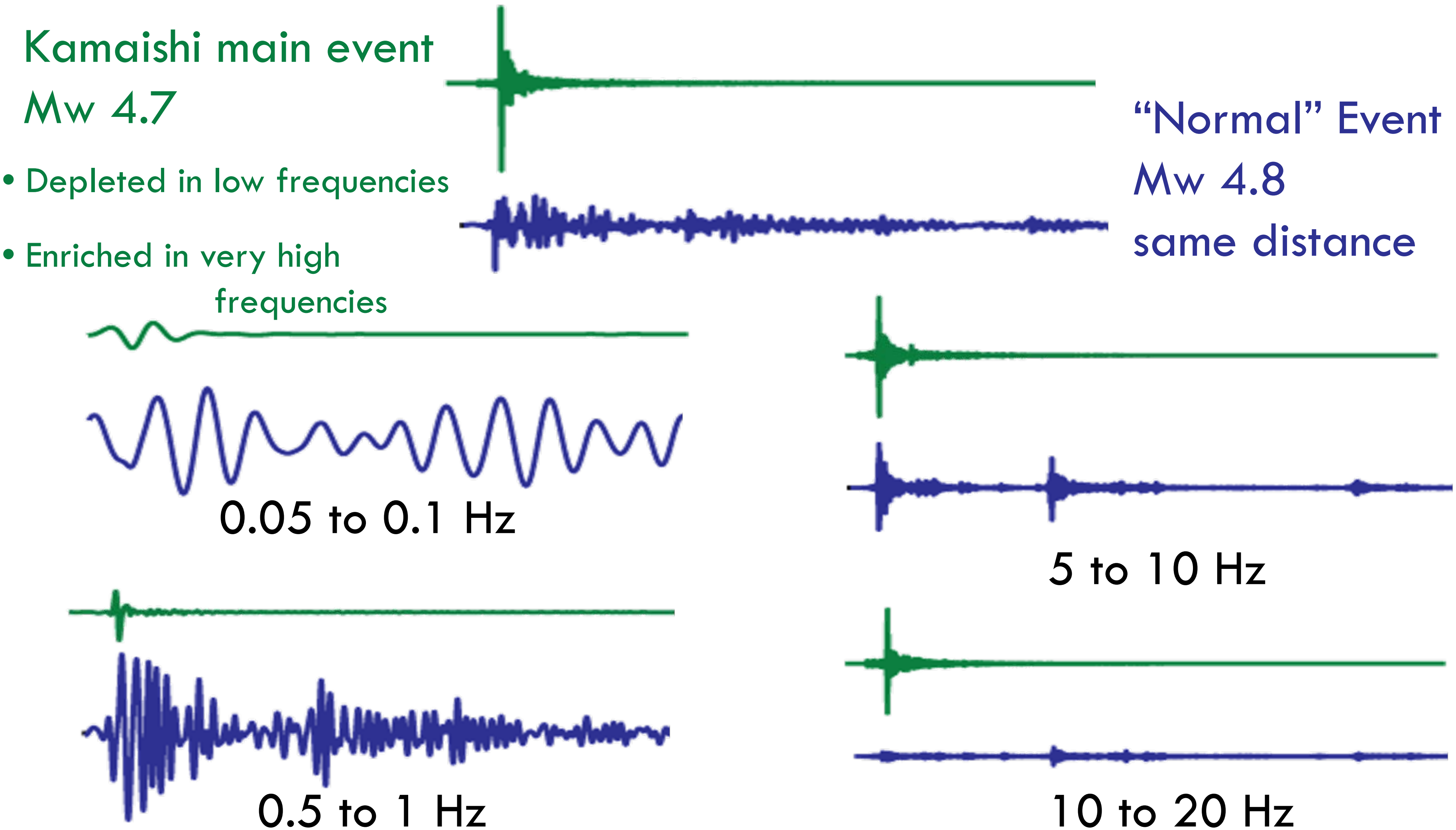
Chuetsu 2004
Mw 5.1

- Depleted in high frequencies

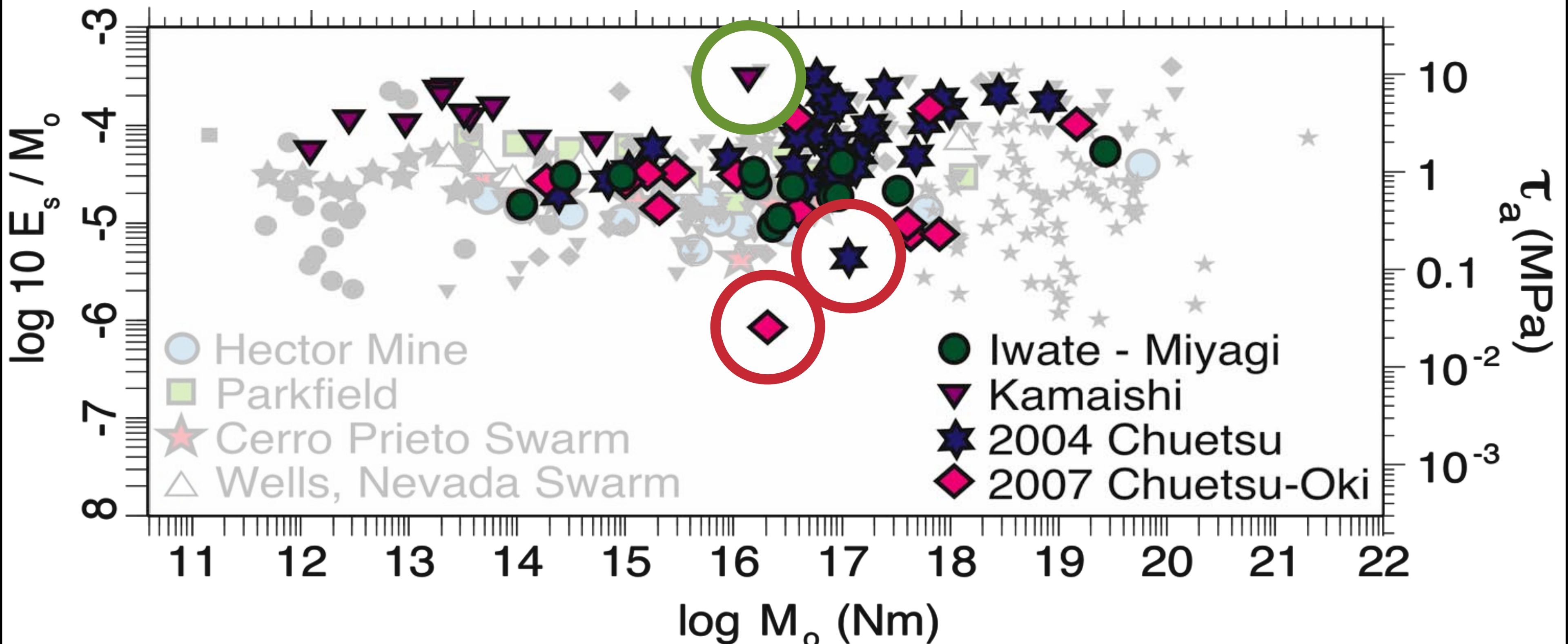
“Regular” Event
Mw 5.3
same station
within 10 km



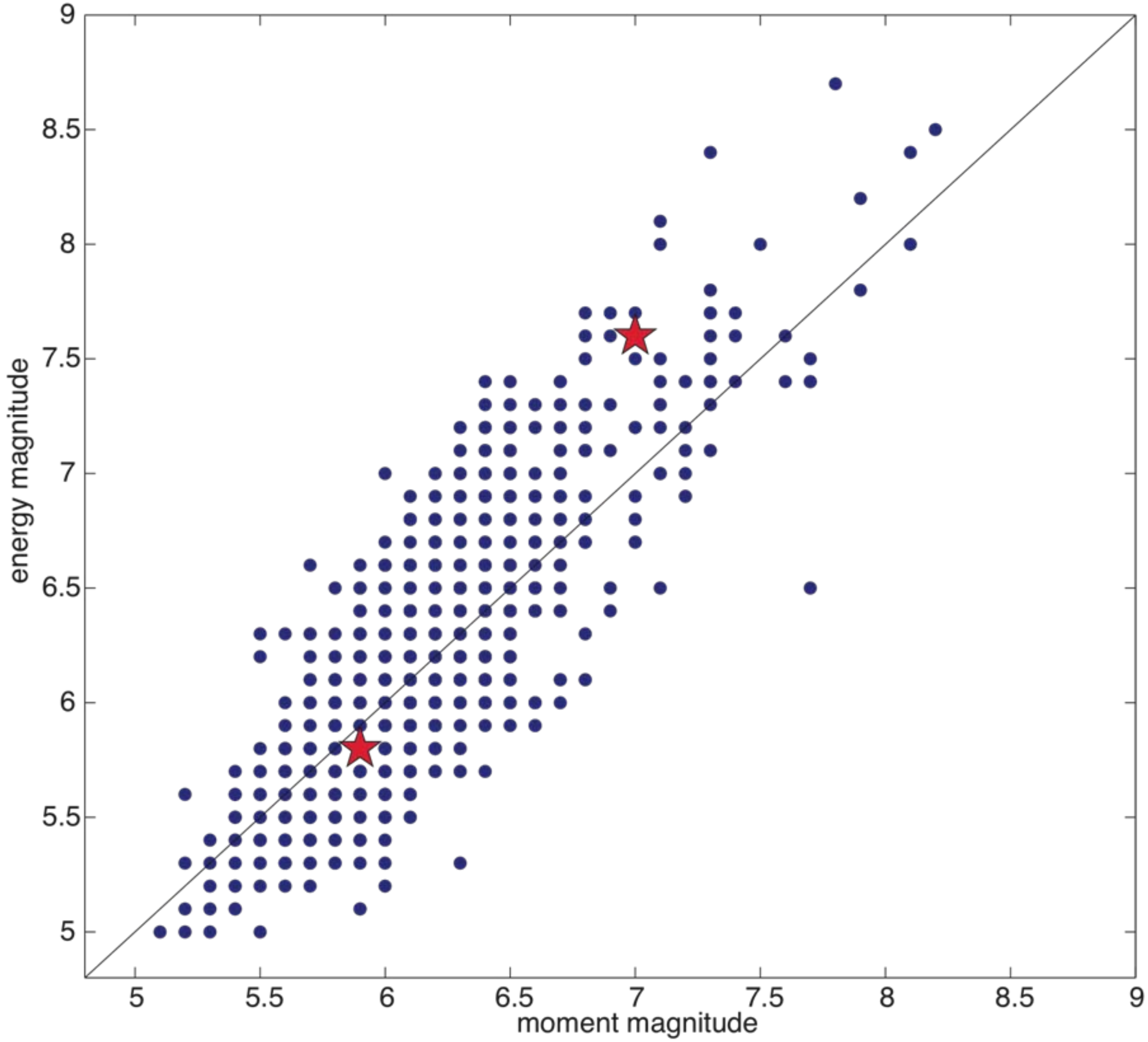
High Energy Earthquake



Scatter in apparent stress is real

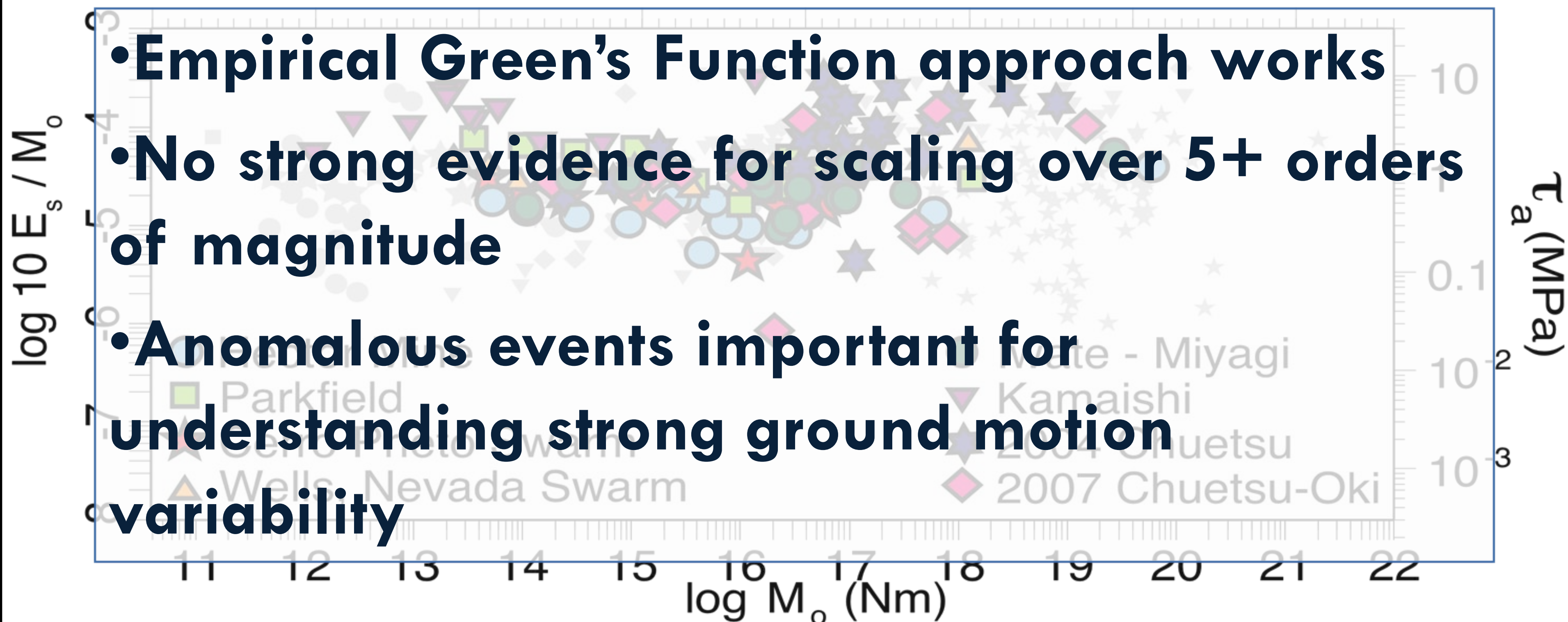


USGS-NEIC: M_W vs. M_E



Conclusions

Iwate-Miyagi	$E_S/M_o \sim M_o$ ^ 0.038 +/- 0.12	Hector Mine	$E_S/M_o \sim M_o$ ^ 0.091 +/- 0.08
Kamaishi	$E_S/M_o \sim M_o$ ^ 0.078 +/- 0.17	Parkfield	$E_S/M_o \sim M_o$ ^ 0.001 +/- 0.09
Chuetsu 2004	$E_S/M_o \sim M_o$ ^ 0.190 +/- 0.14	Cerro Prieto	$E_S/M_o \sim M_o$ ^ 0.016 +/- 0.09
Chuetsu Oki 2007	$E_S/M_o \sim M_o$ ^ 0.024 +/- 0.26	Wells	$E_S/M_o \sim M_o$ ^ 0.022 +/- 0.10



- **Empirical Green's Function approach works**
- **No strong evidence for scaling over 5+ orders of magnitude**
- **Anomalous events important for understanding strong ground motion variability**

Thank you