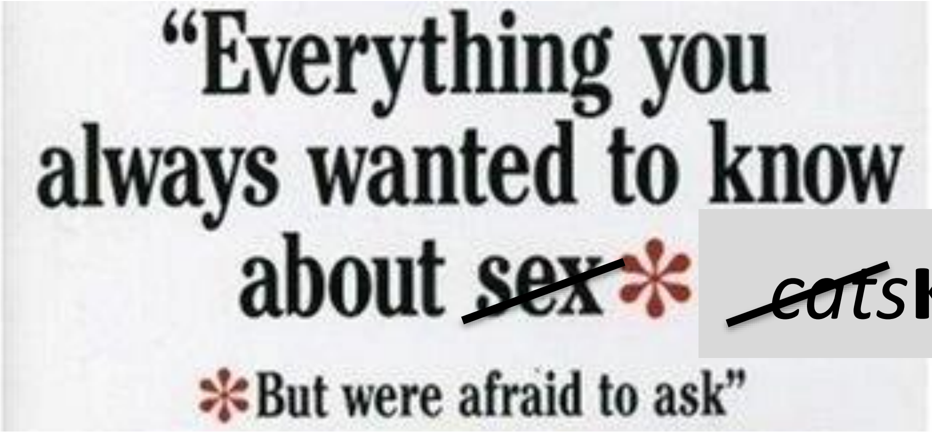
49th Risk, Hazard, Cats and Uncertainty Workshop



~~*cats*~~**K**

Olga-Joan Ktenidou

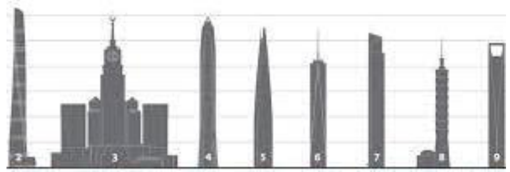
National Observatory of Athens
olga.κtenidou@noa.gr

15 June 2023
Hydra

Who’s afraid of HFs?

What are HFs?

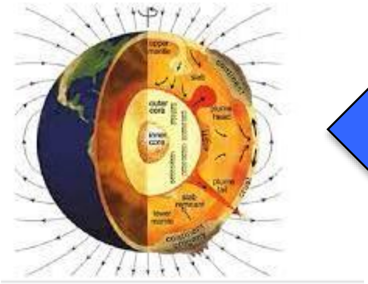
critical facilities!



typical structures

0.01 0.1 1 10 100

Frequency (hz)



hard-core
seismology!

Engineers

→ **Critical facilities:**

Engineers

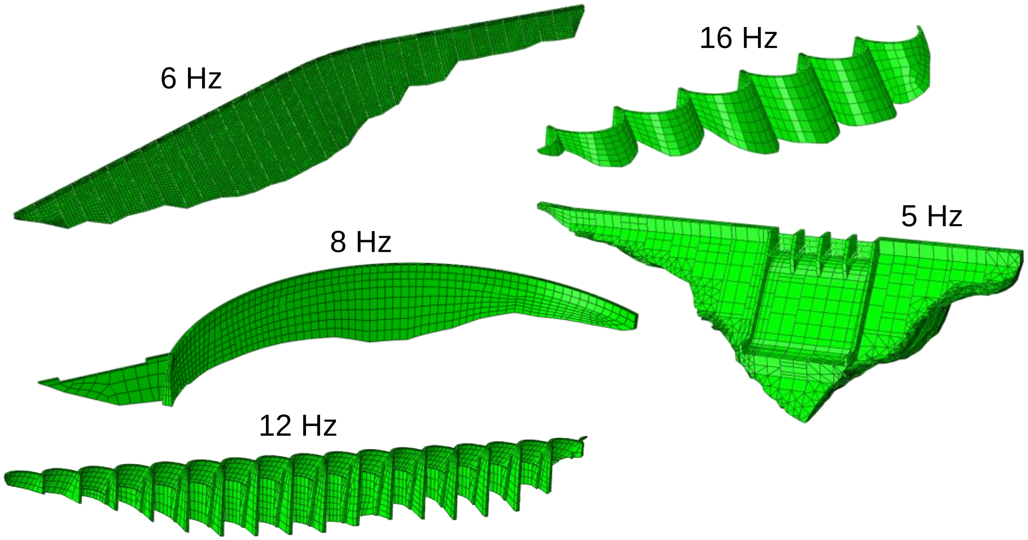
➔ Critical facilities:

Safety-related **equipment** is sensitive to ground shaking at frequencies above 10-20 Hz.

Engineers

➔ **Dams**:

- **Small, concrete dams** with eigenfrequencies up to 10-16 Hz

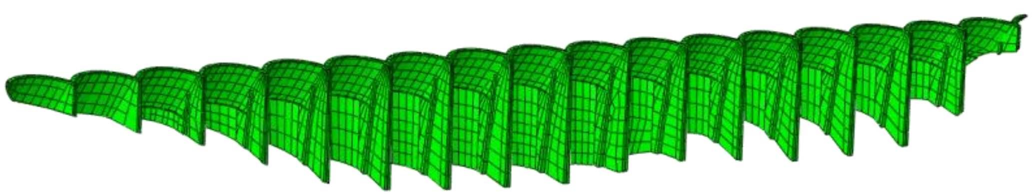


Courtesy of Matt Muto, Southern California Edison

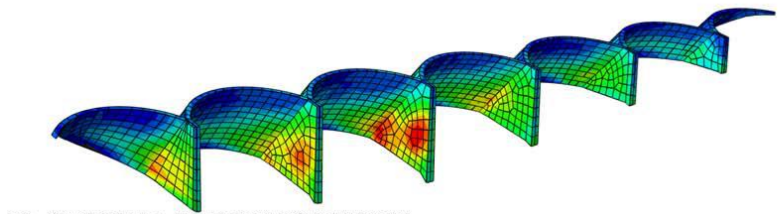
Engineers

➔ **Dams**:

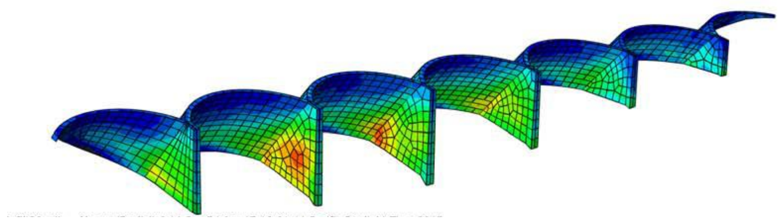
- Peak stresses are sometimes controlled by HFs



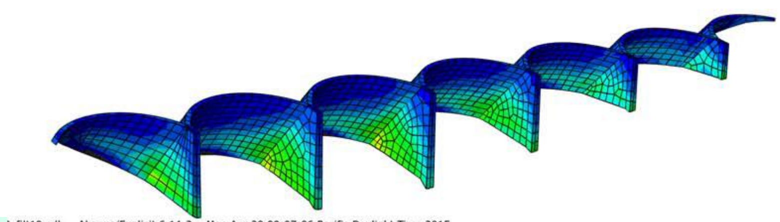
Shear Stress (unfiltered)



Shear Stress (20 Hz filter)



Shear Stress (10 Hz filter)



Courtesy of Matt Muto, Southern California Edison

Engineers

➔ **Dams**:

- Critical components **e.g. gates**

(not that small!)

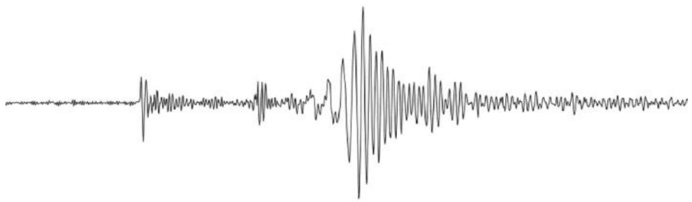
Engineers

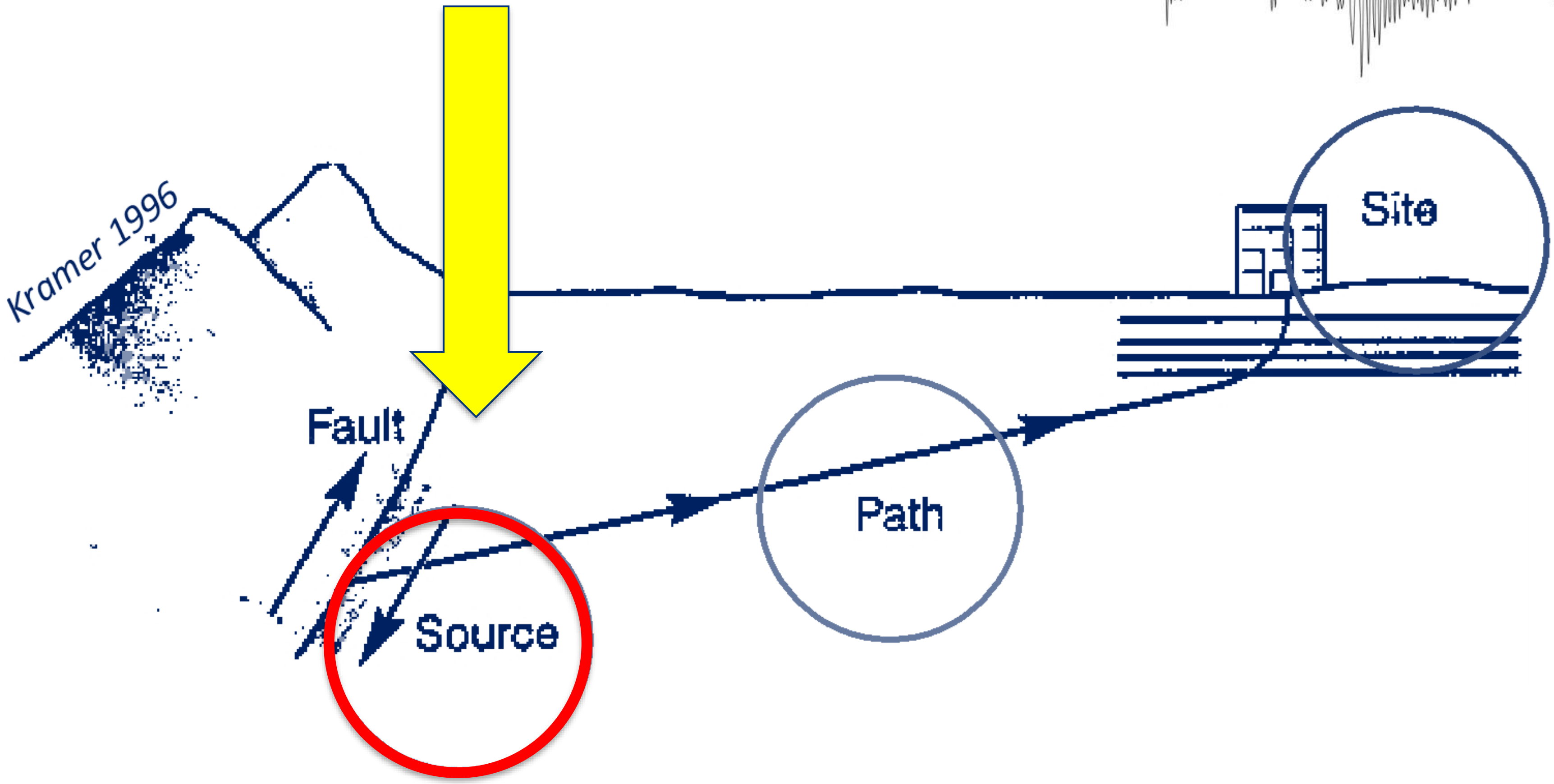
➔ **Tailings dams**:

need to maintain integrity for up to 10,000 years

Seismologists

blah blah blah the source..!

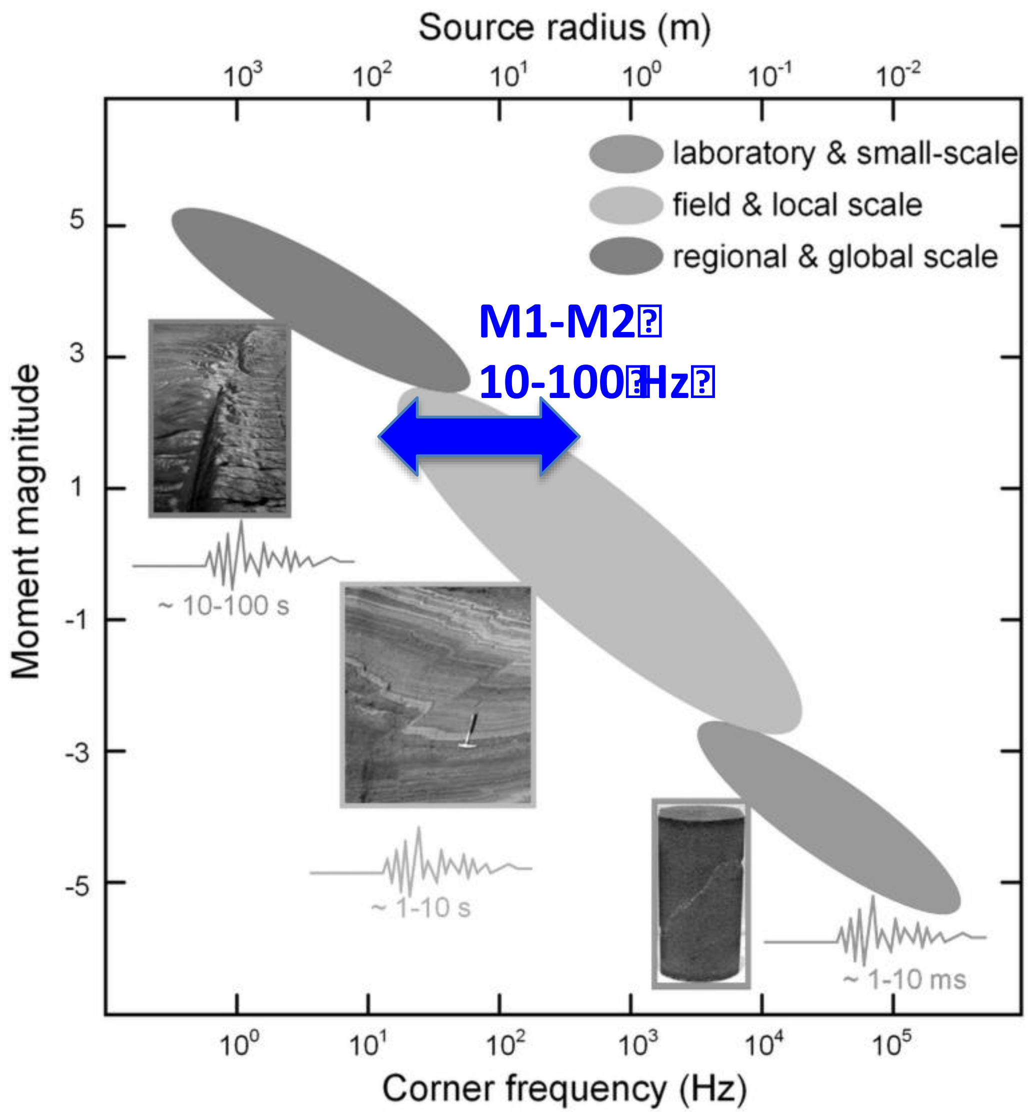




Seismologists

High frequencies are at the heart of some important ~~blah bl~~ debates:

- stress parameter
- corner frequency / scaling laws
- small-M events / microseismicity



Li et al. (2020)

κ: crossbreed or pedigree-in-disguise?

Attenuation

- loss of energy per cycle
- exponential amplitude decrease with t or R

- ‘frequency-independent’ intrinsic damping (anelastic attenuation)
- frequency-dependent scattering from smaller-scale heterogeneities

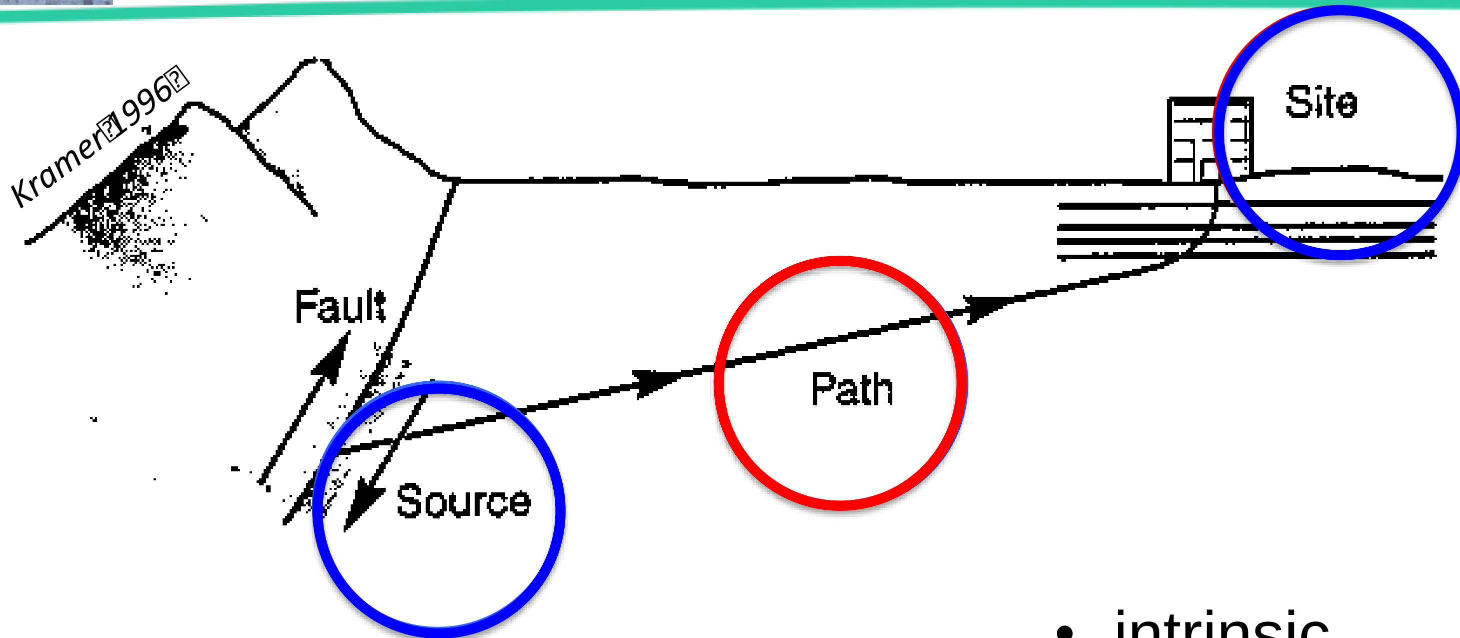
Attenuation

In ‘pure’ seismology the pedigree of attenuation terms is Q

κ is more empirical & controversial… thus handed over to ‘engineers’ as a crossbreed

⇨ Trying to understand its origins… treating it like a muddy mystery dog that needs washing

Attenuation



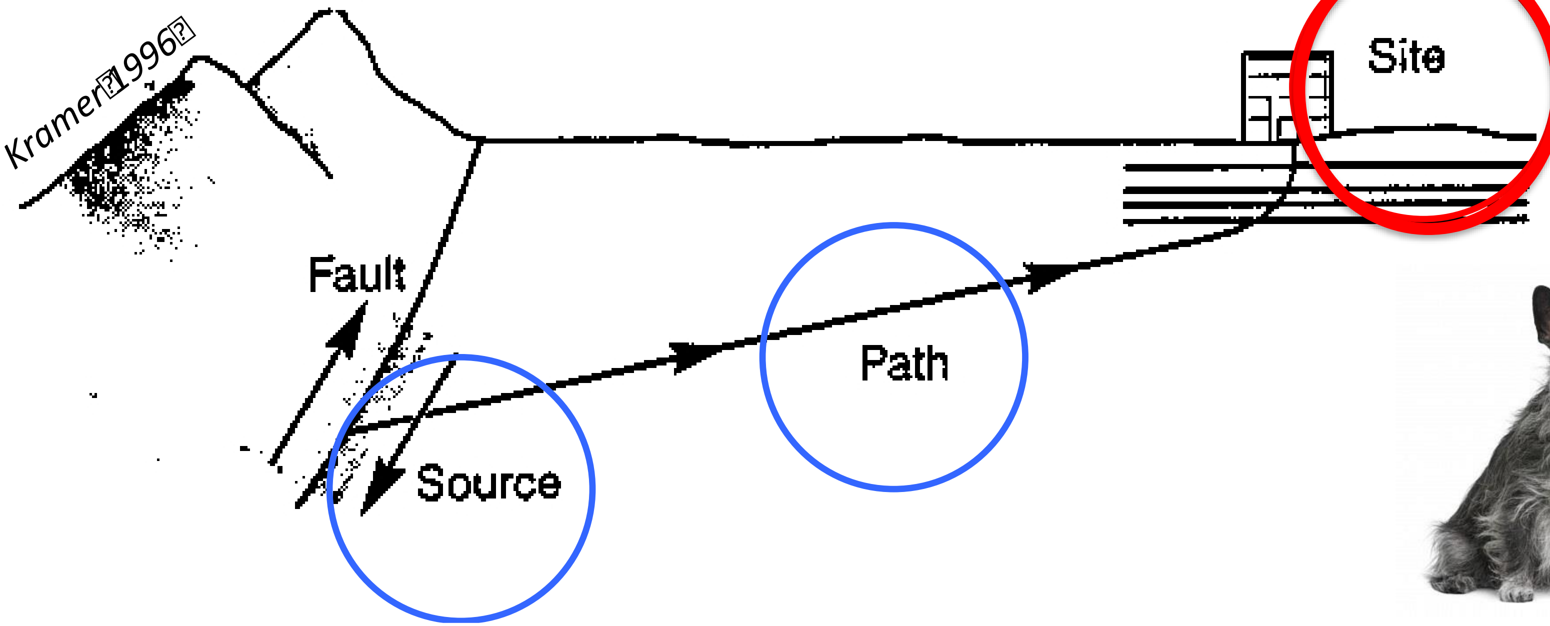
- intrinsic
- scattering

Quality factor = Q = 

Attenuation = $\frac{1}{Q}$ = $\frac{1}{\ }$ 

$\frac{1}{\ }$  $= \frac{1}{Q_{in}} + \frac{1}{Q_{sc}}$

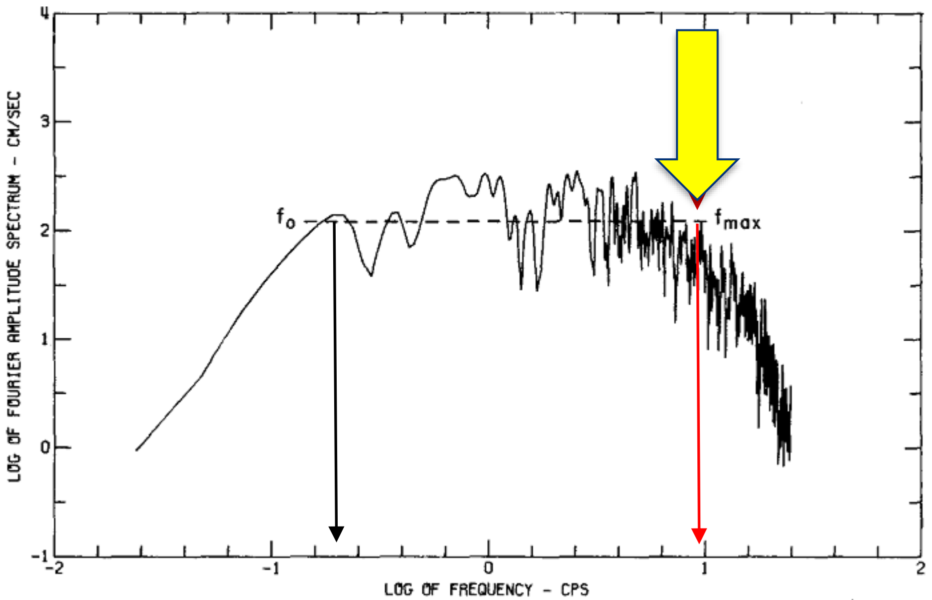
Attenuation



First came...

Hanks (1982) introduced f_{max}:

- the high-frequency band-limitation of radiated EQ energy
- attributed to local site conditions (after hot debate with Aki & Papageorgiou on path and source)



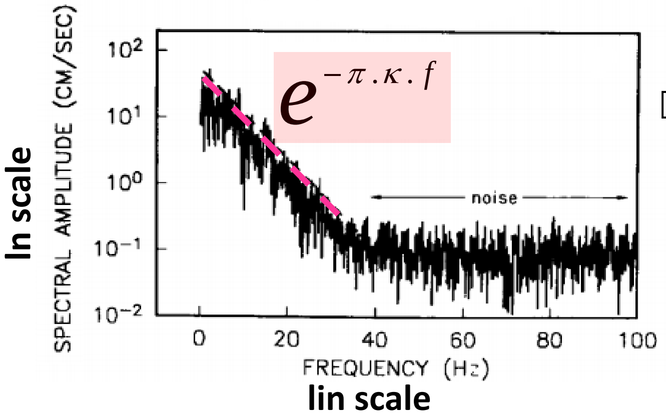
'crashing spectrum syndrome'

What is κ

Anderson & Hough (1984)

spectral decay parameter ‘κ’

$$A(f) = A_0 \cdot e^{-\pi\kappa f}, \quad f > f_E$$

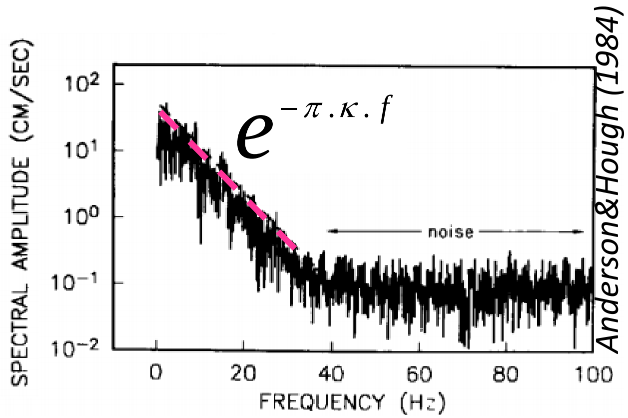


$$k = -\frac{slope}{p}$$

What is κ

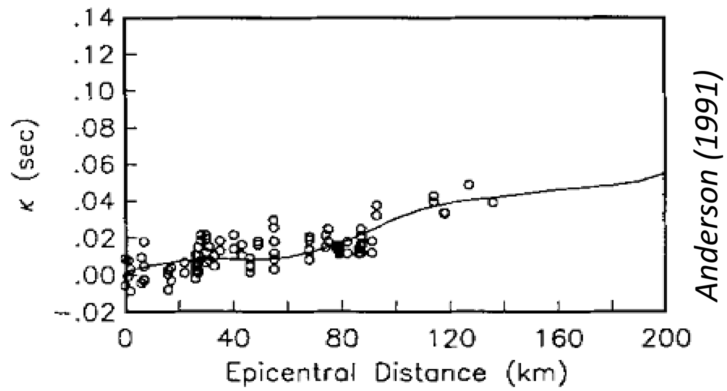
Anderson & Hough (1984)
spectral decay parameter ‘κ’

$$A(f) = A_0 \cdot e^{-\pi\kappa f}, \quad f > f_E$$



ln scale

lin scale

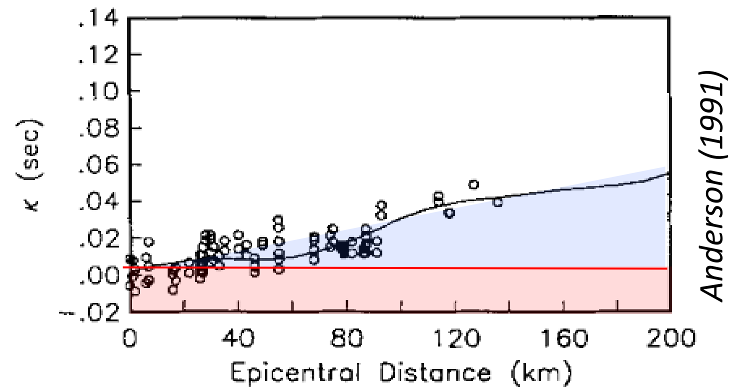


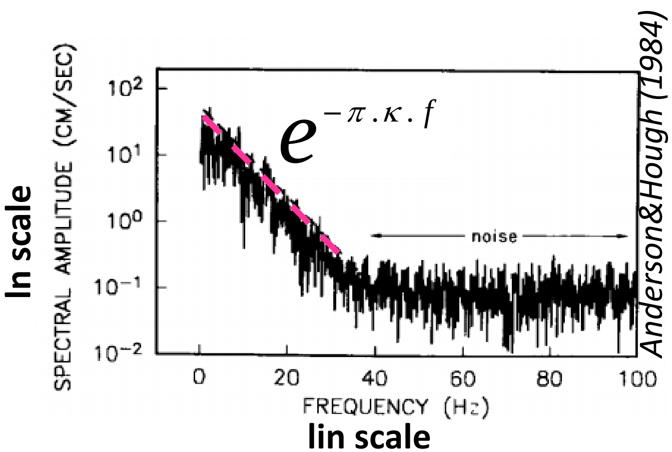
$$k = k_0 + \tilde{k}(R)$$

Distance

Anderson & Hough (1984)
spectral decay parameter ‘κ’

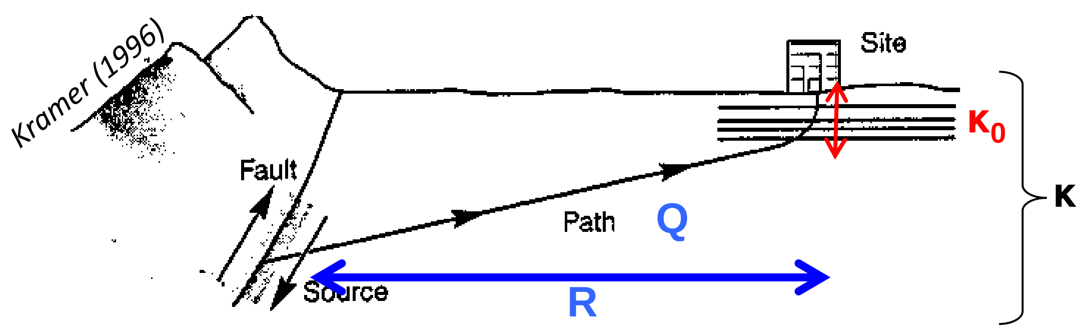
$$A(f) = A_0 \cdot e^{-\pi \kappa f}, \quad f > f_E$$





$$k = k_0 + \tilde{k}(R)$$

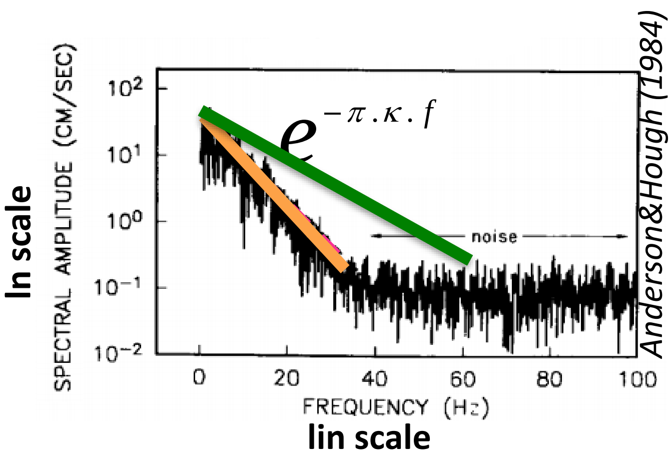
‘site’ ‘régional’

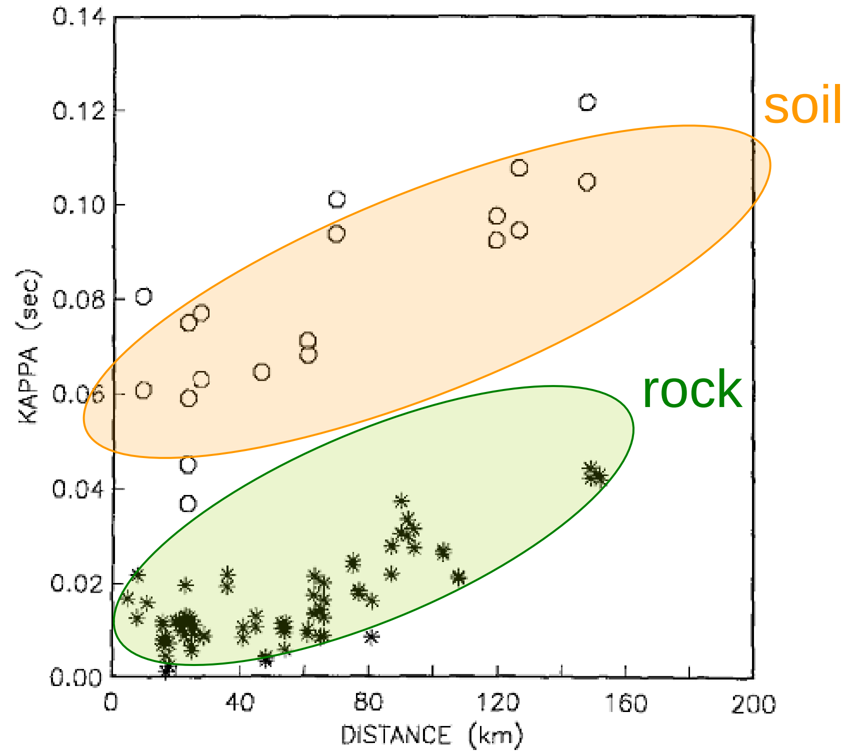


Geology

Anderson & Hough (1984)
spectral decay parameter ‘κ’

$$A(f) = A_0 \cdot e^{-\pi\kappa f}, \quad f > f_E$$

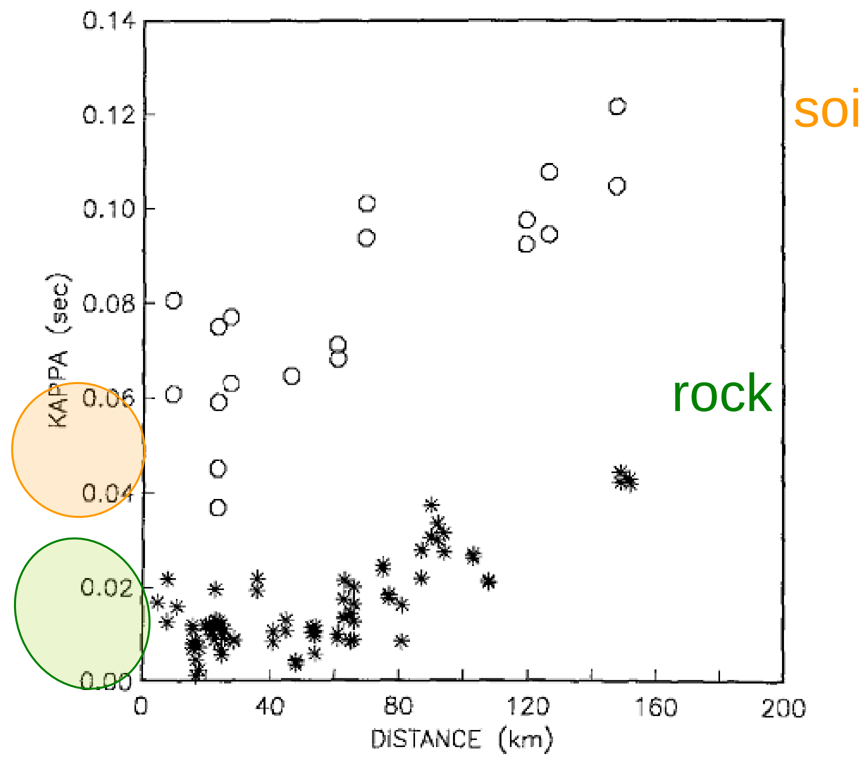




Time

$$A_o \times e^{\frac{-p f R}{Q b}} \times e^{-p f k o}$$

$$'t^*' = \frac{R}{bQ} + k_0$$



Units are seconds!

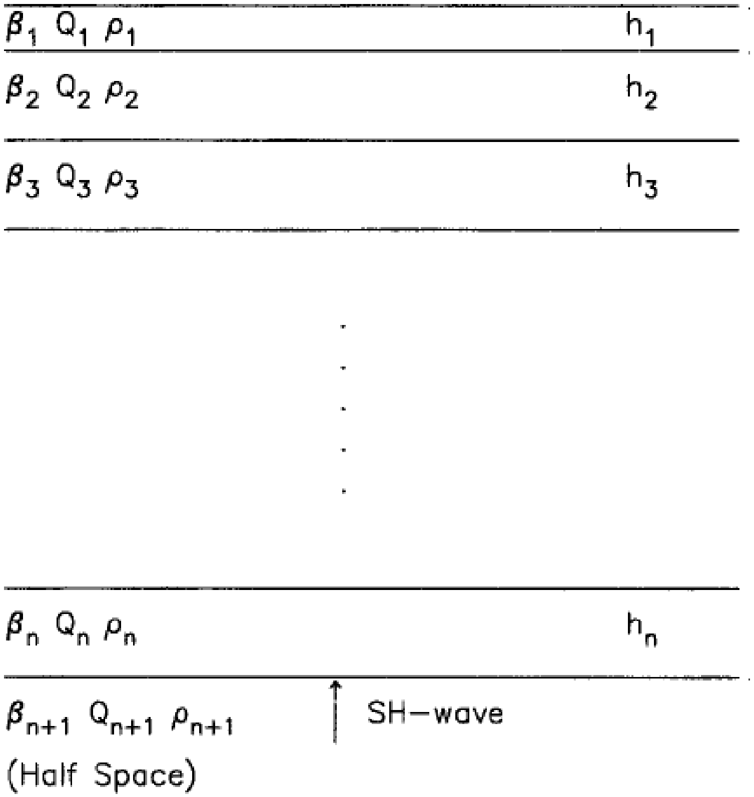
Damping

Small-strain intrinsic damping (from site or lab tests) can be related to κ_0 through Vs and layer thickness:

$$\sum_{i=1}^{N} \frac{H_i}{V_{si} Q_i} = \kappa_0.$$

Campbell (2009)

$$Q = \frac{1}{2\xi}$$

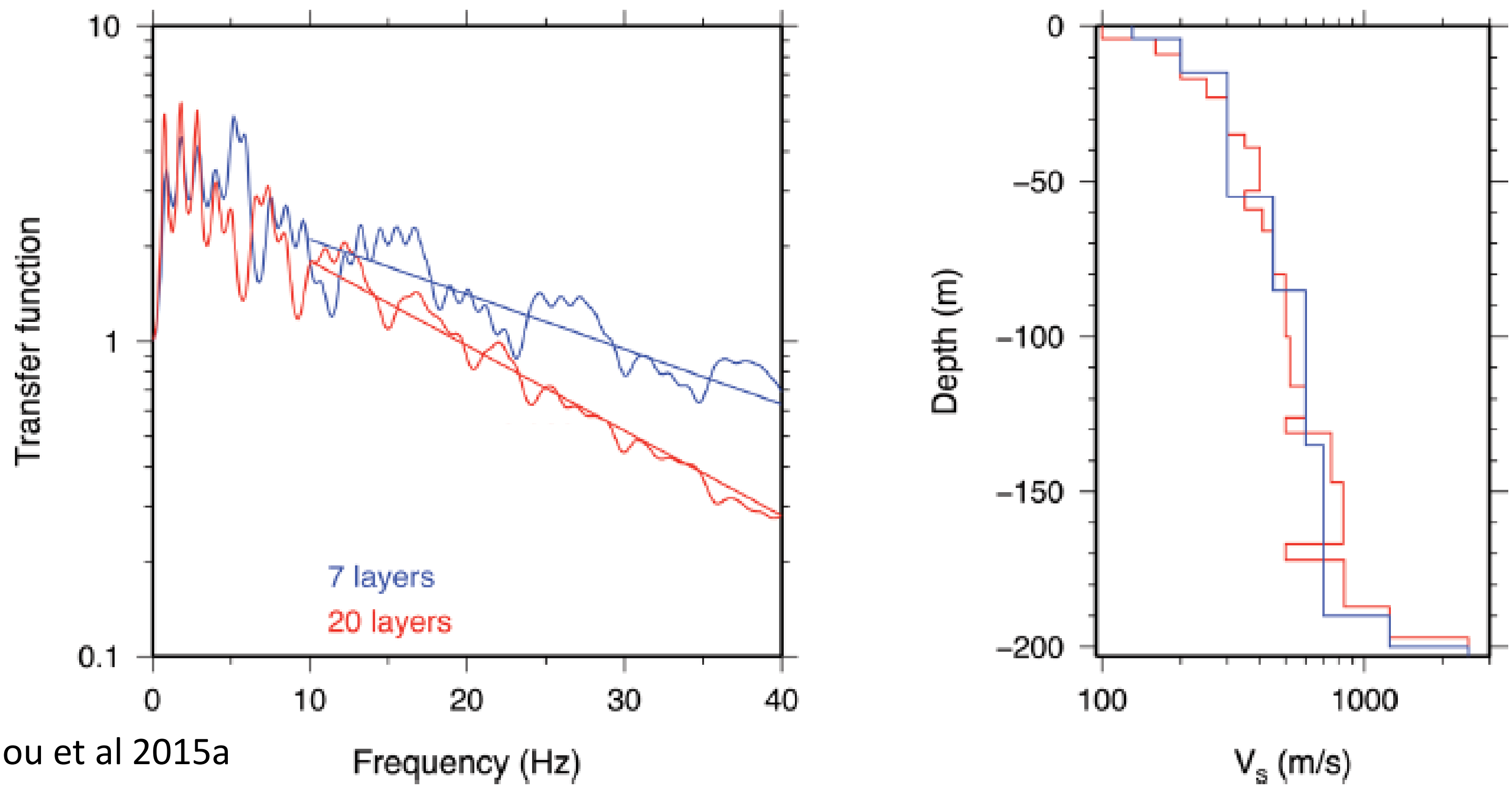


This is a lower-bound on total κ_0 not including….

Stratification

Scattering from small-scale fluctuations is an additional source of site attenuation

Adding layers/complexity/reversals to profile kills more HF energy



Ktenidou et al 2015a

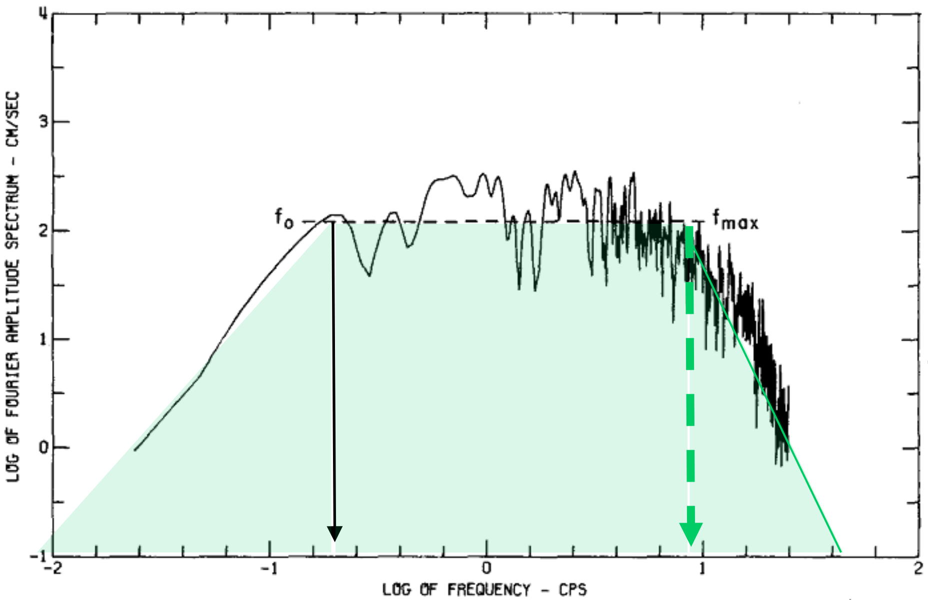
Damage

Filter on structural damage potential

κ puts the limit on a_{rms} computation (Singh et al., 1989)

$$a_{rms} = \sqrt{\frac{2}{T_d}\int_0^{\infty} a^2(f)\,df}$$

- where does the integration stop?
- for small κ it can go on for quite long



Hanks, 1982

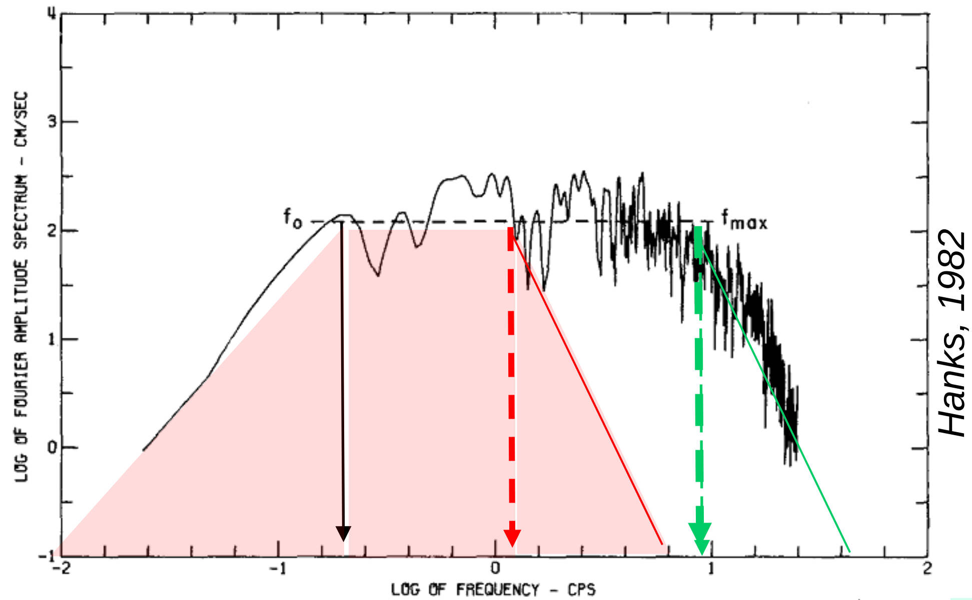
Damage

Filter on structural damage potential

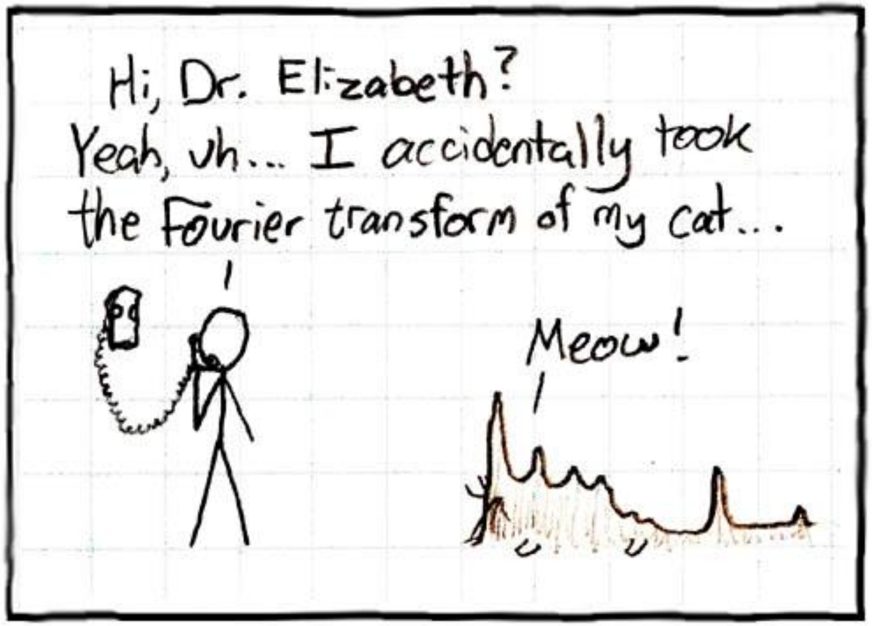
κ puts the limit on a_{rms} computation (Singh et al., 1989)

$$a_{rms} = \sqrt{\frac{2}{T_d}\int_0^{\infty} a^2(f)\,df}$$

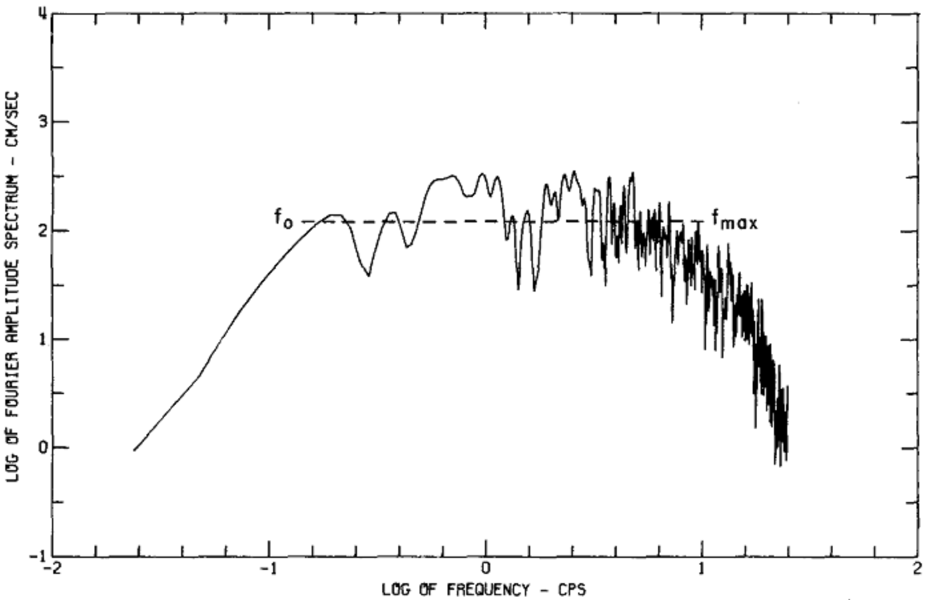
- where does the integration stop?
- for small κ it can go on for quite long



In seismological terms



xkcd (2005)



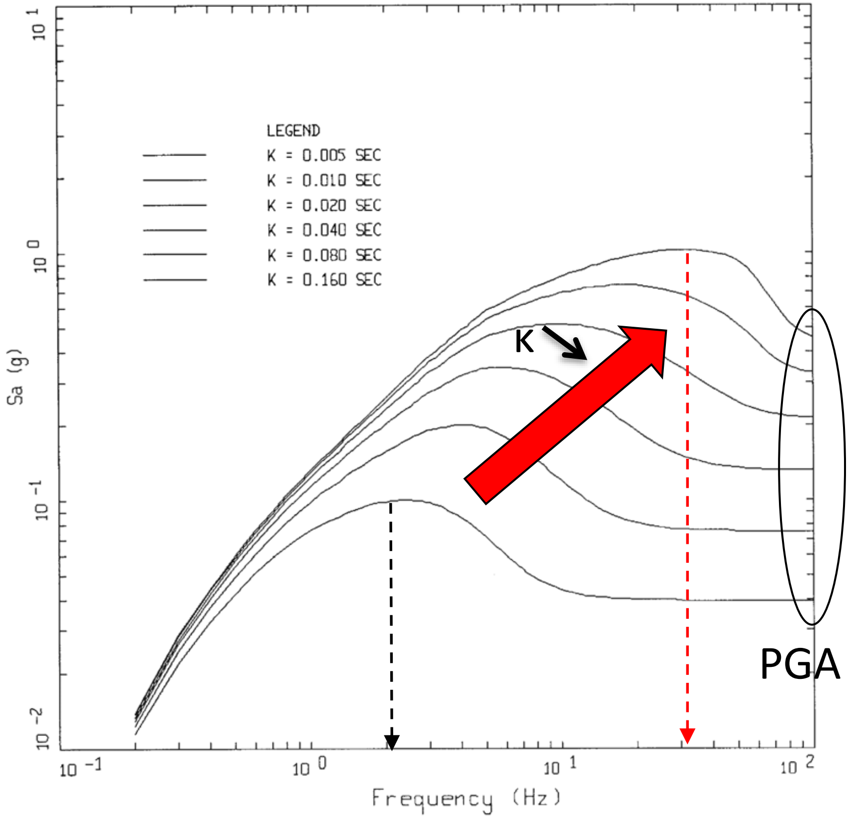
Hanks, 1982

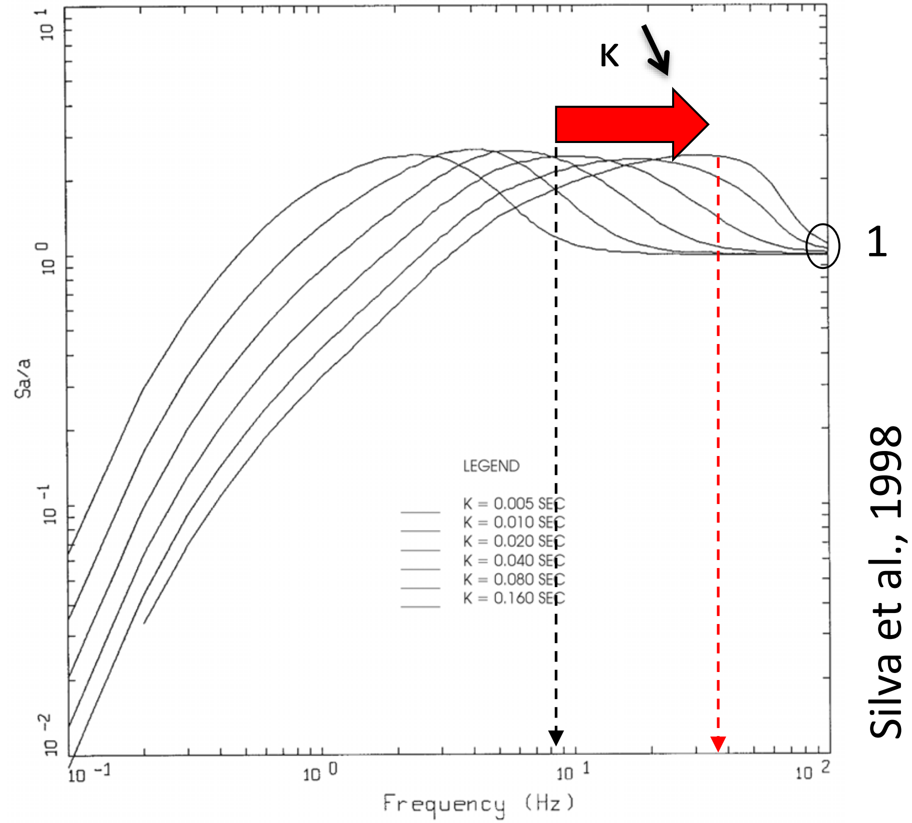
In engineering terms

For response spectra: κ is where it peaks

f_{peak}=40 Hz, κ=0.005 s

f_{peak}=10 Hz, κ=0.020 s



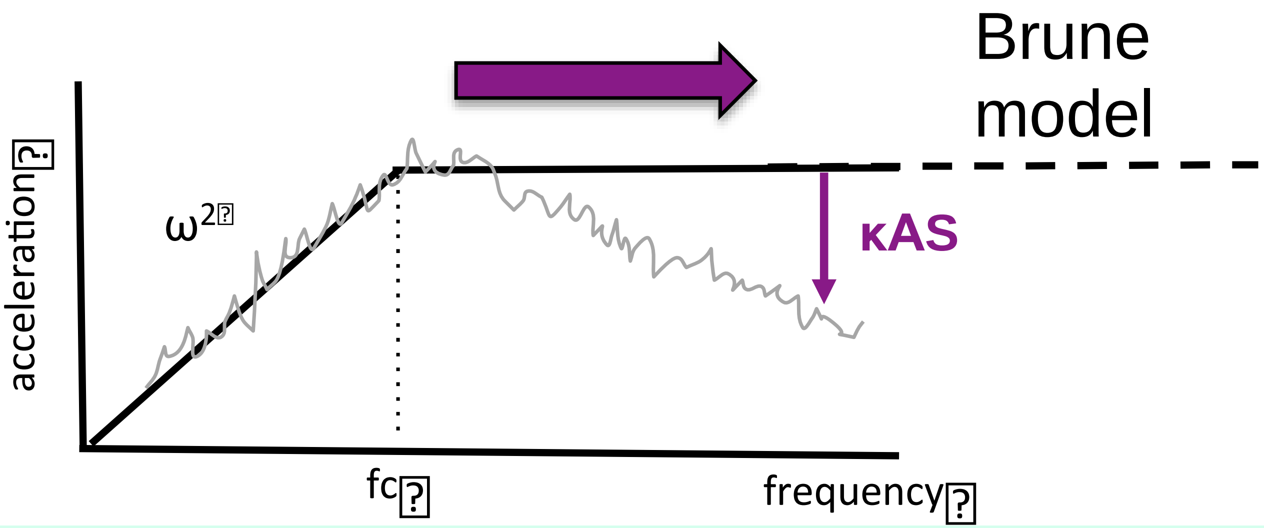


Silva et al., 1998

Inherent issue…..

κ: characterises a profile but is <u>not a property per se!</u>
…defined and measured as the deviation from an assumed theoretical model
…measured as absence!

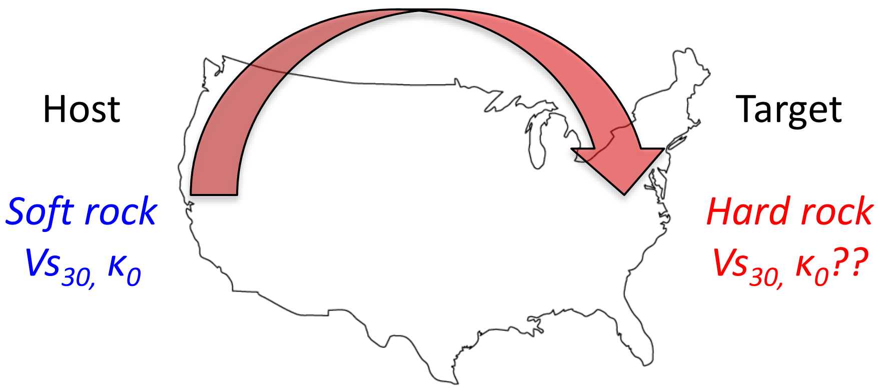
as opposed to…
Vs: a material property - usually directly measured

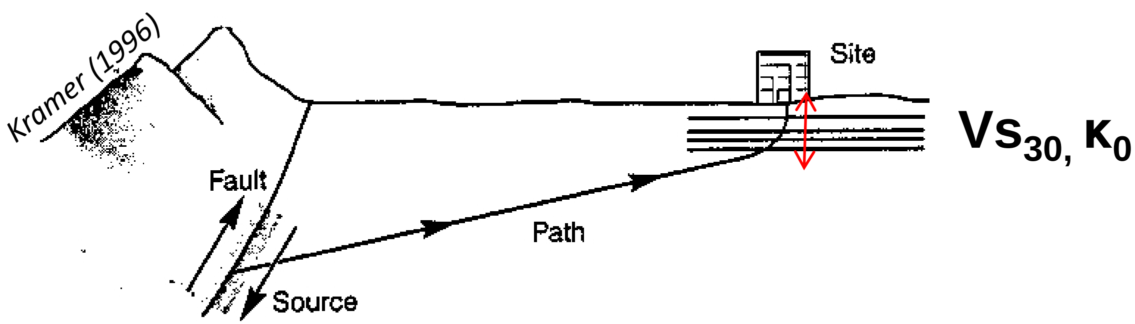


Some issues
with hard-rock κ
for PSHA

Adjustments

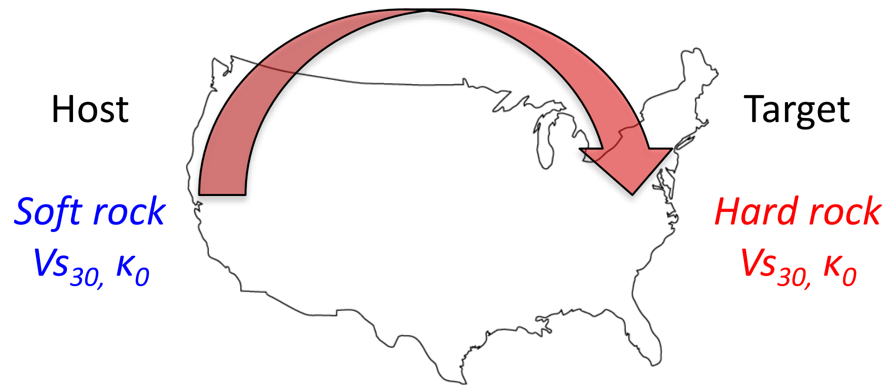
adjusting **soft to hard rock**

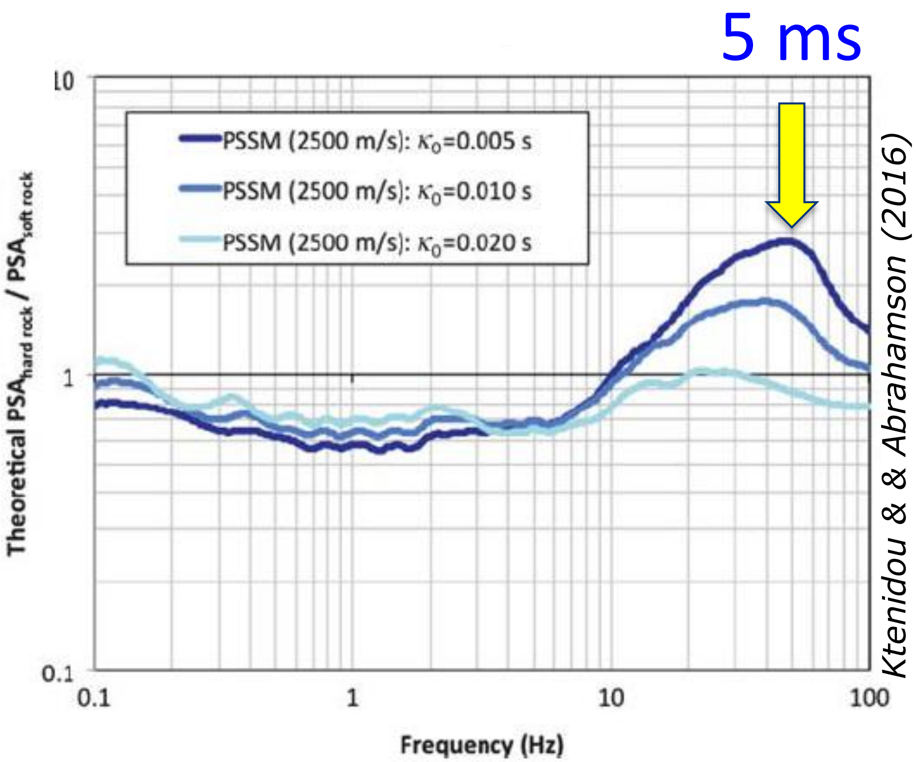




Problem with current methods

things that go bump
in HFs





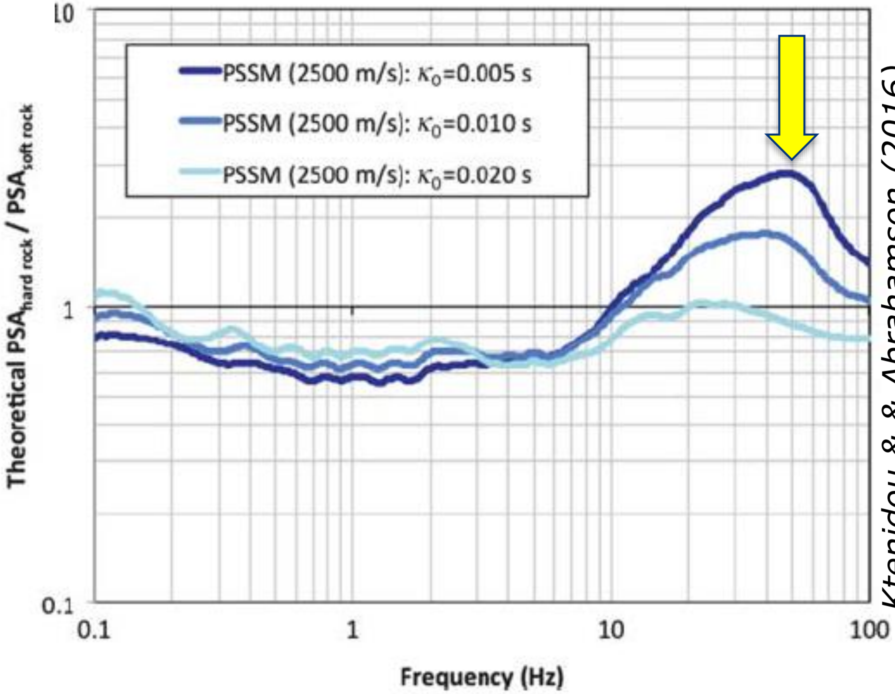
typically, tiny κ_0
values for hard rock

lead to increased ground
motion at high frequencies

Problem with current methods

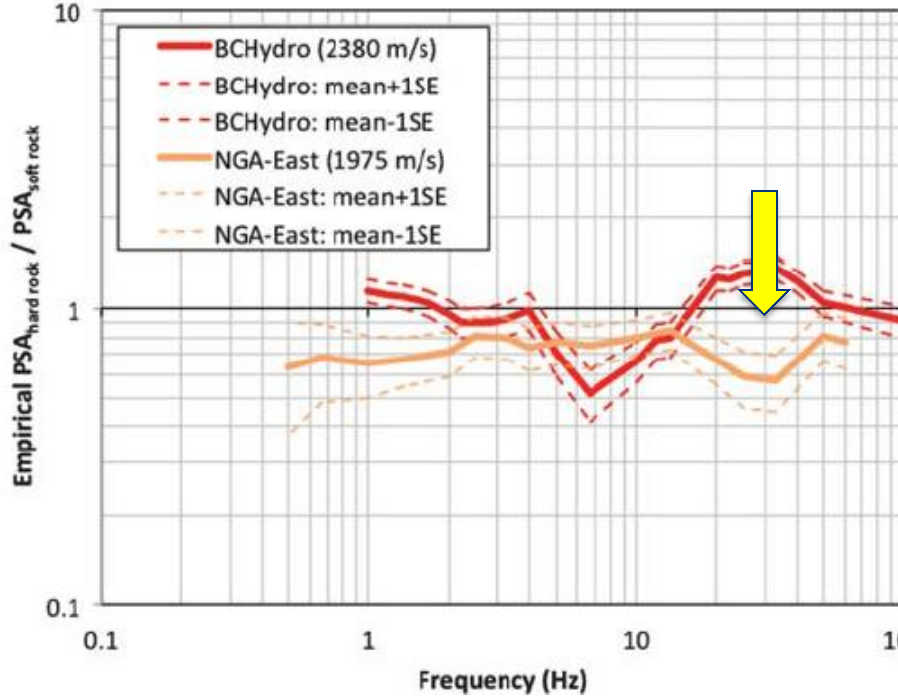
such amplification from theoretical estimates not confirmed by data

5 ms



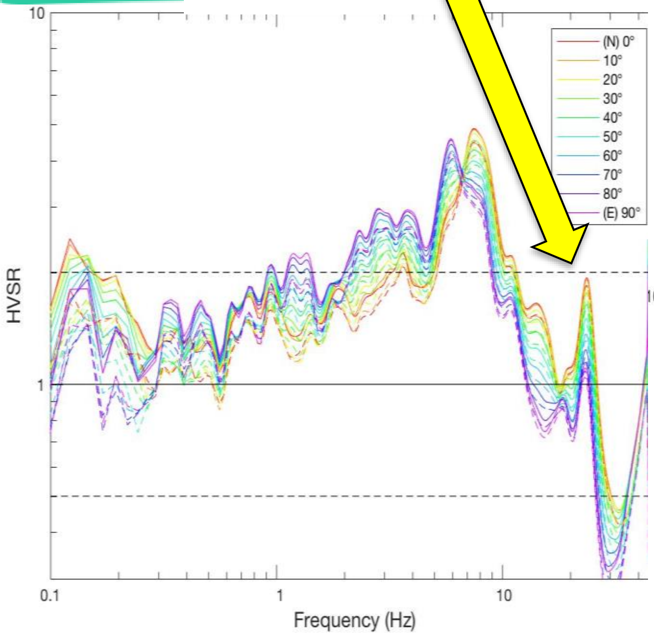
Ktenidou & & Abrahamson (2016)

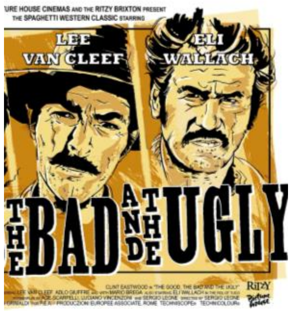
>15 ms

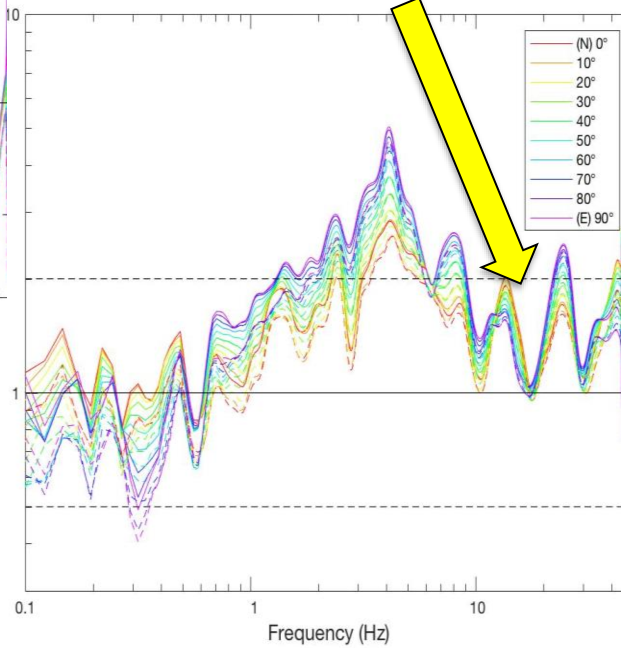


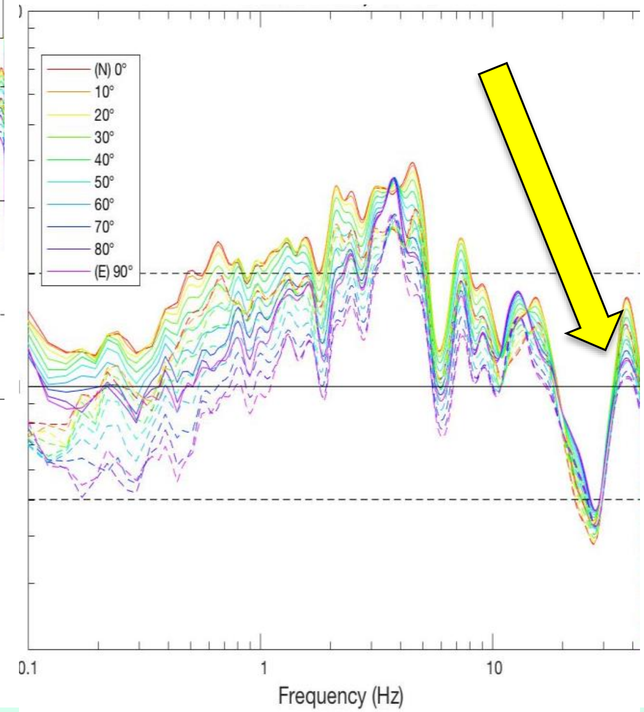
When we have data

Bad & ugly rock sites

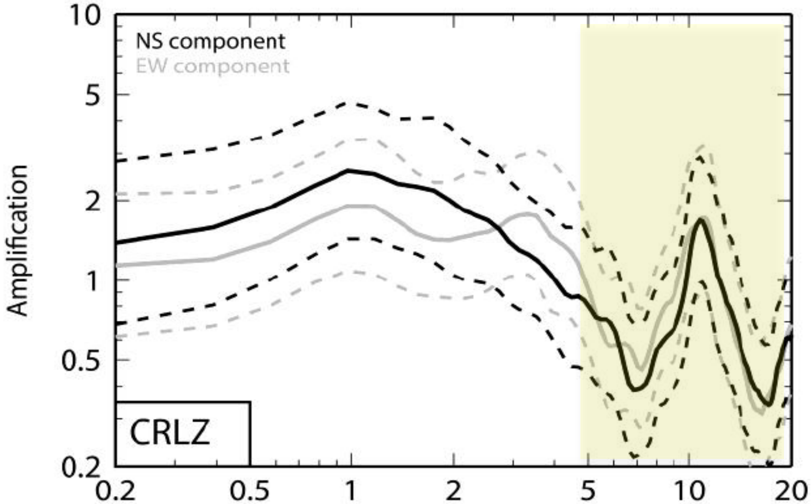


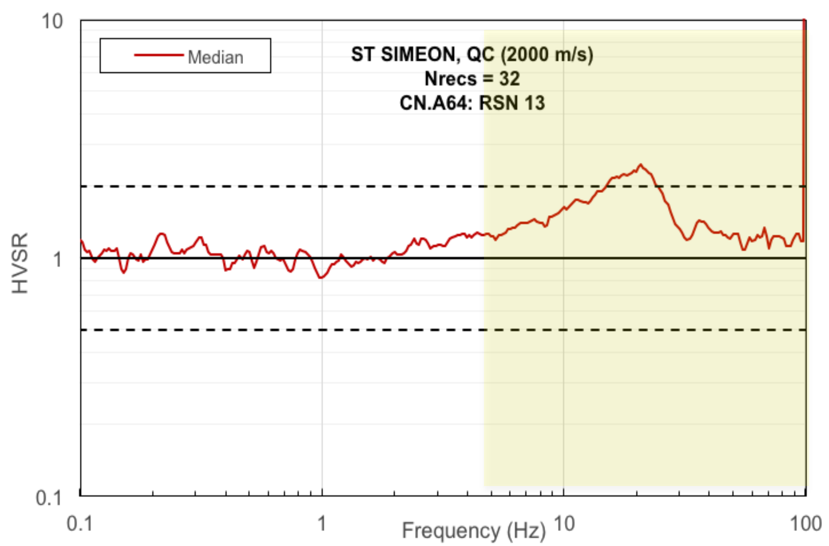


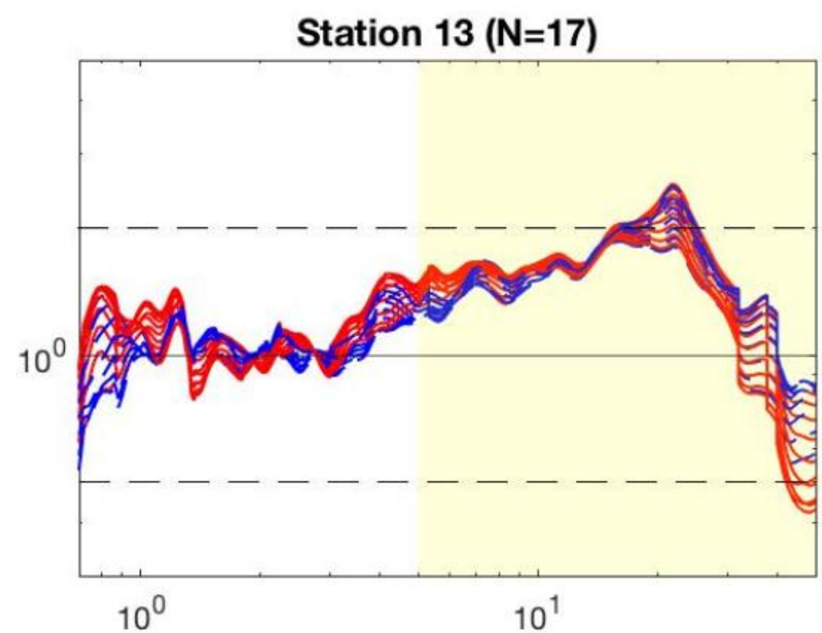




Bad & ugly rock sites







Ktenidou & friends -- various

Rock definition schemes

Ground type	Description of stratigraphic profile	Parameters
		$v_{s,30}$ (m/s)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800

EC8
CEN (2004)

Soil class	Description	$V_{s,30}$ (m/s)
A	Hard rock	>1500
B	Rock	760-1500

NEHRP
BSSC (2004)

	Ground class	Stiff	Medium stiff
Depth class	$V_{s,H}$ range / H_{800} range	400 m/s ≤ $V_{s,H}$ < 800 m/s	250 m/s ≤ $V_{s,H}$ < 400 m/s
Very shallow	$H_{800} \leq 5$ m	A	A

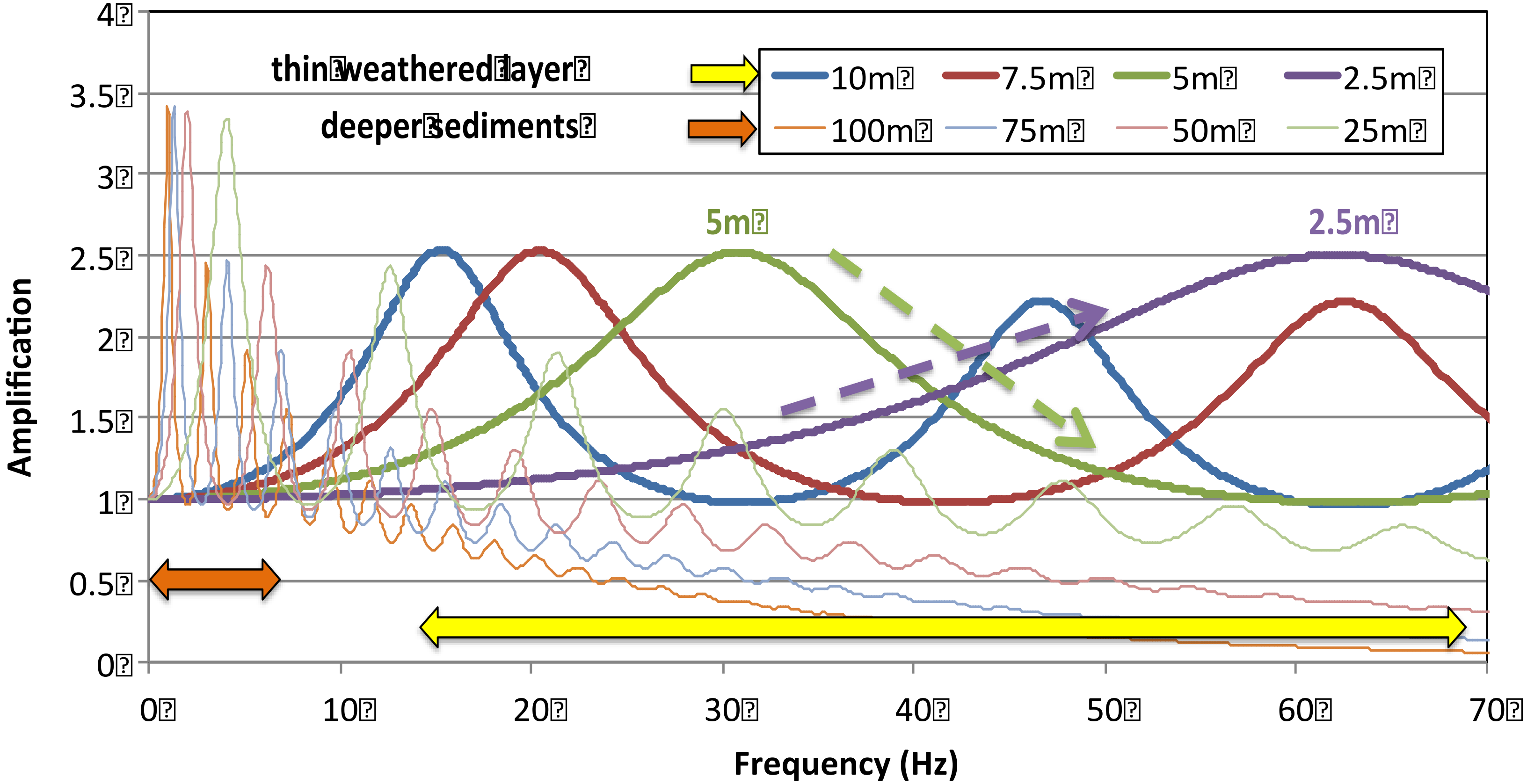
Combination of f_0 (Hz) and $V_{s,H}$ (m/s)	Site category
$f_0 > 10$ and $V_{S,H} \geq 250$	A

EC8 new draft
CEN/TC 250/SC 8 (2021)

➔ thanks to R. Paolucci !!

Resonances

Low (soil) vs. high (rock) resonant frequencies
Effect of a varying thickness of the weathered layer
Also, damping dictates HF TF slope

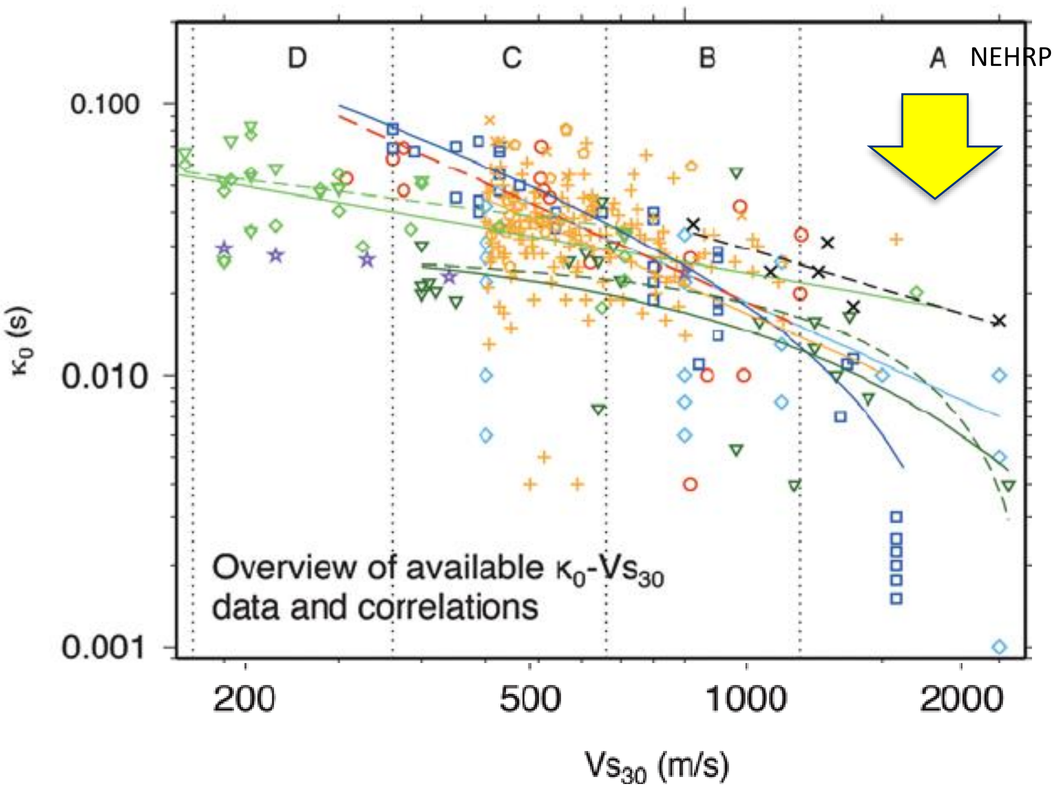


…and other kinds of resonance (Cranswick in 1980s)

When we dont

"If you don't give me numbers (from data), I'll make them up"
- Norm Abrahamson, on engineers

"If you don't give me numbers (from data), I'll make them up"
- Norm Abrahamson, on engineers

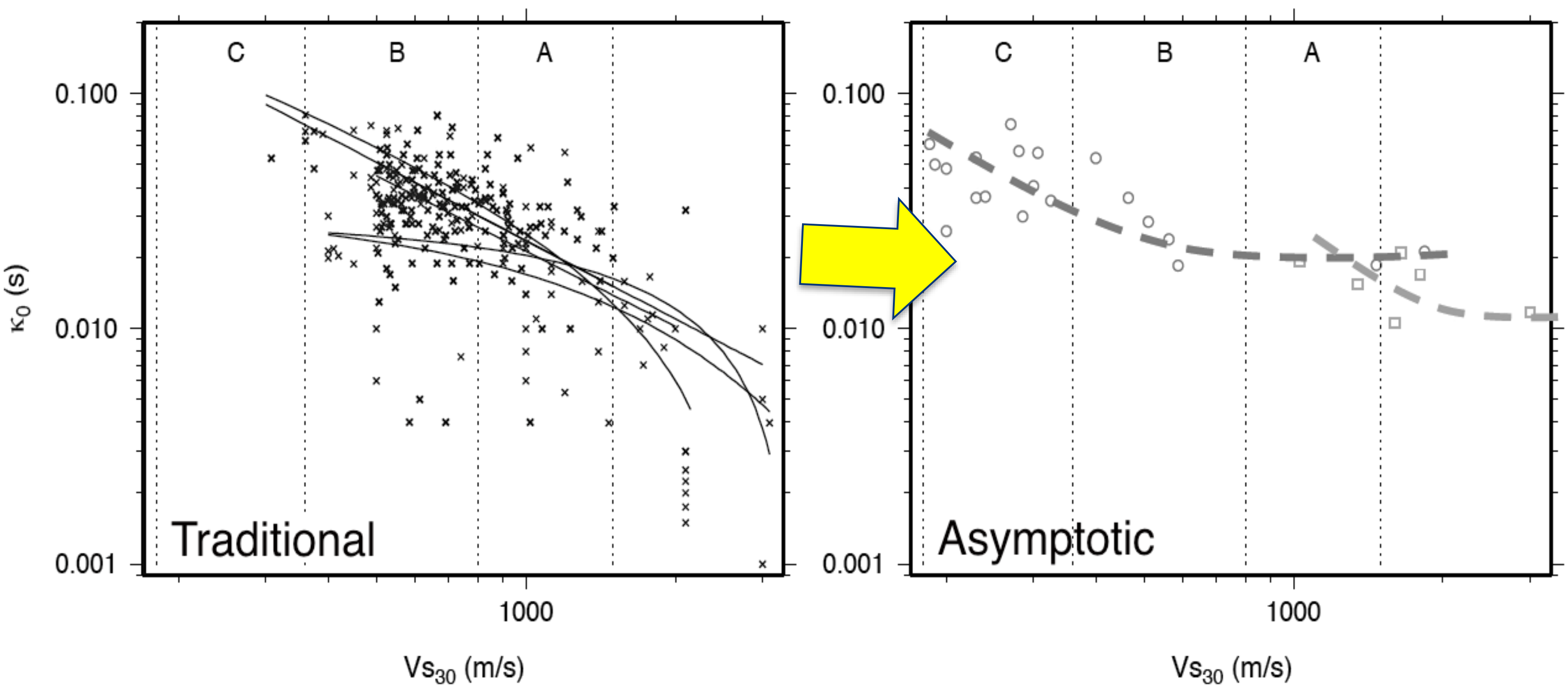


Ktenidou et al 2014

Empirical correlations all assume infinitely decreasing damping with Vs / G

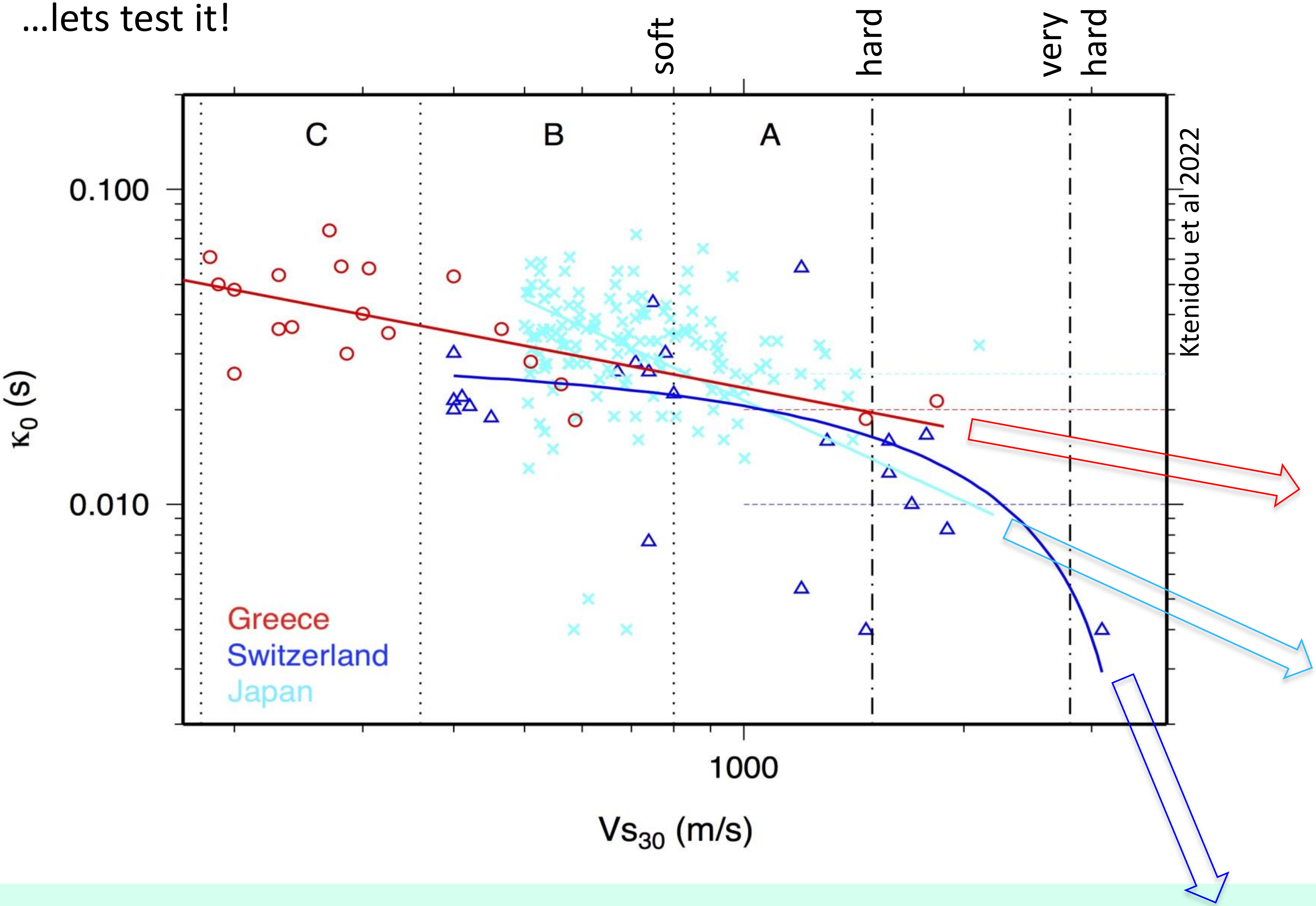
scatter & lack of data
lack of physical meaning

2015 asymptotic model:
minimum values for different kinds of hard rock, constant within it

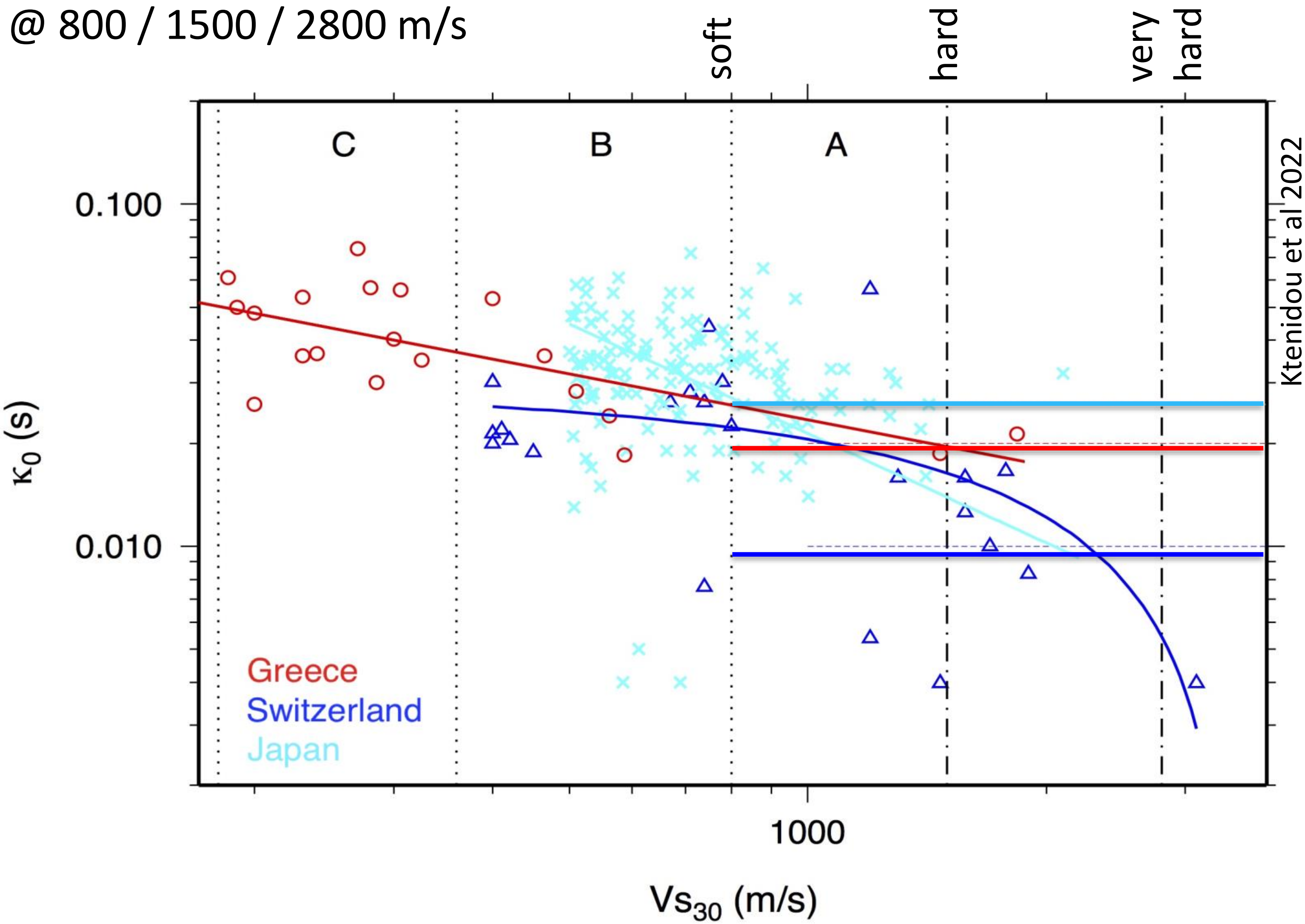


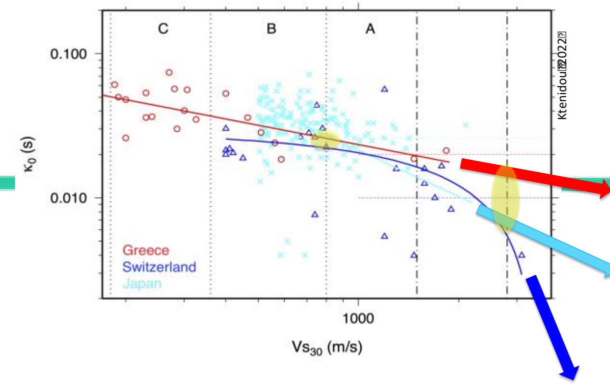
Ktenidou et al 2015

…lets test it!


soft
hard
very hard
C
B
A
0.100
0.010
κ0 (s)
Greece
Switzerland
Japan
1000
Vs30 (m/s)
Ktenidou et al 2022

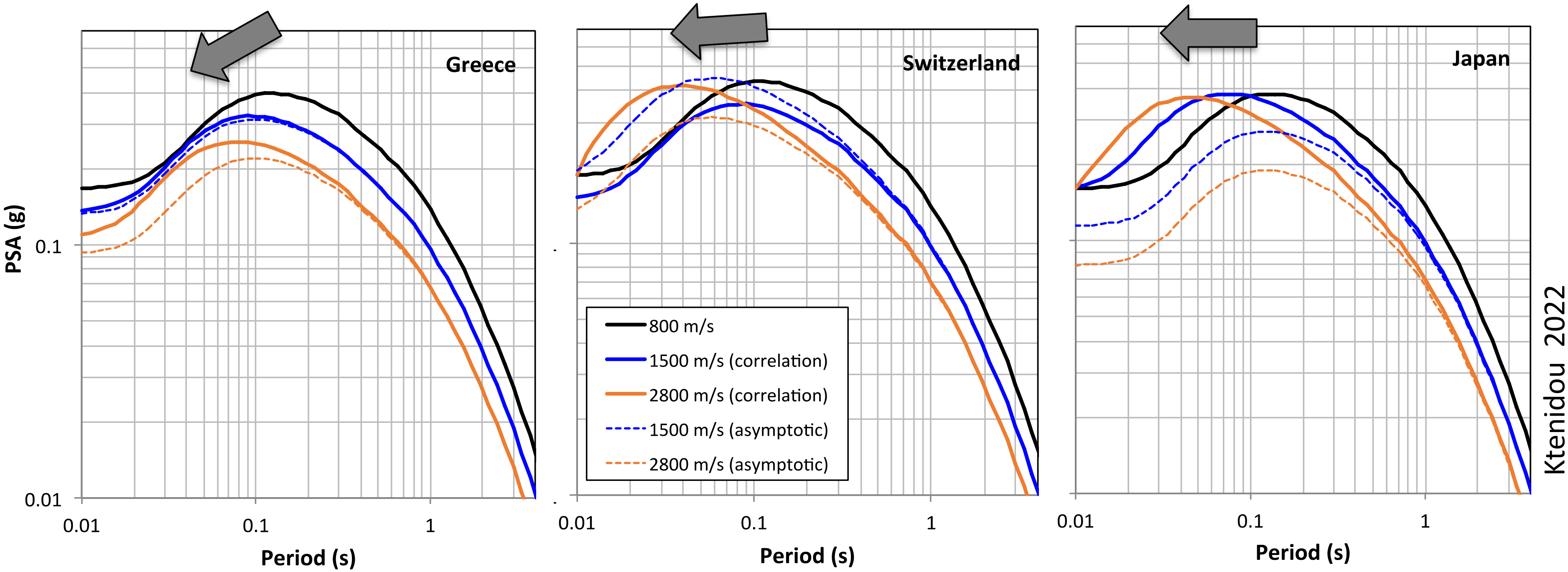
@ 800 / 1500 / 2800 m/s

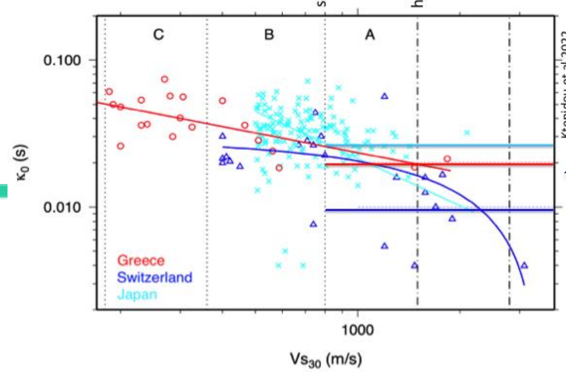




M6 @ 20 km (stochastic simulations)

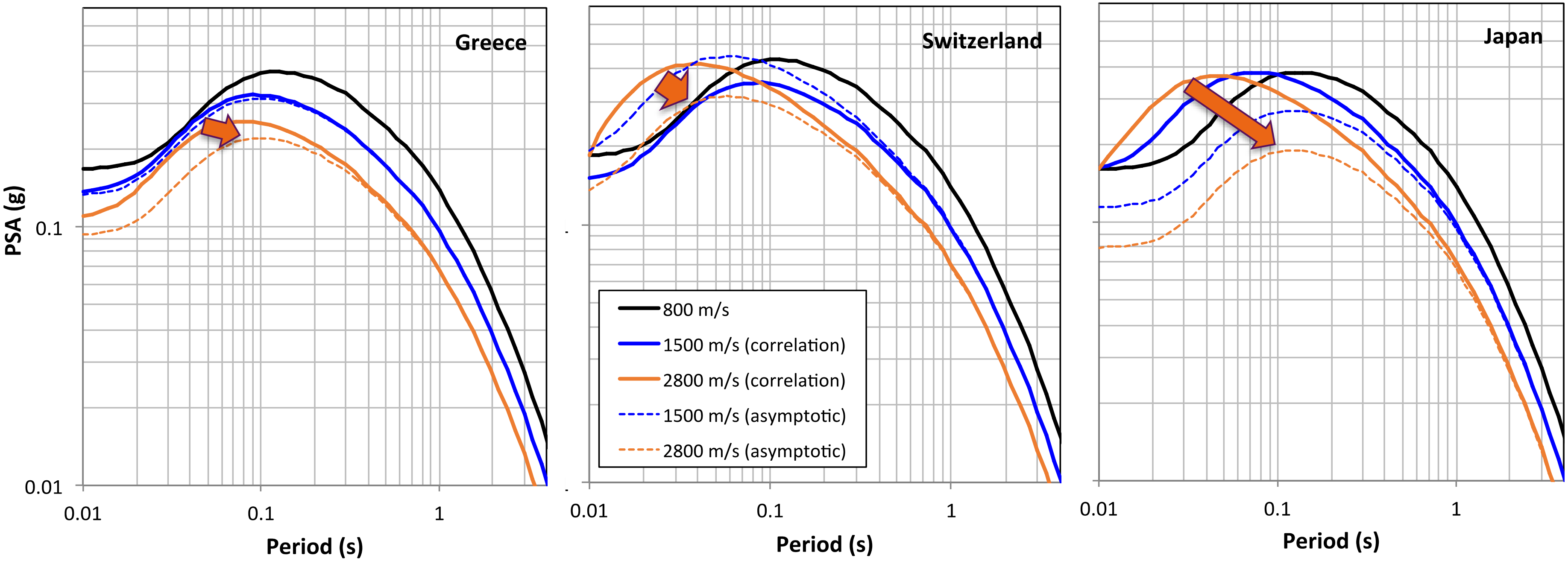
Traditional ever-decreasing model: soft ➔ hard ➔ very hard





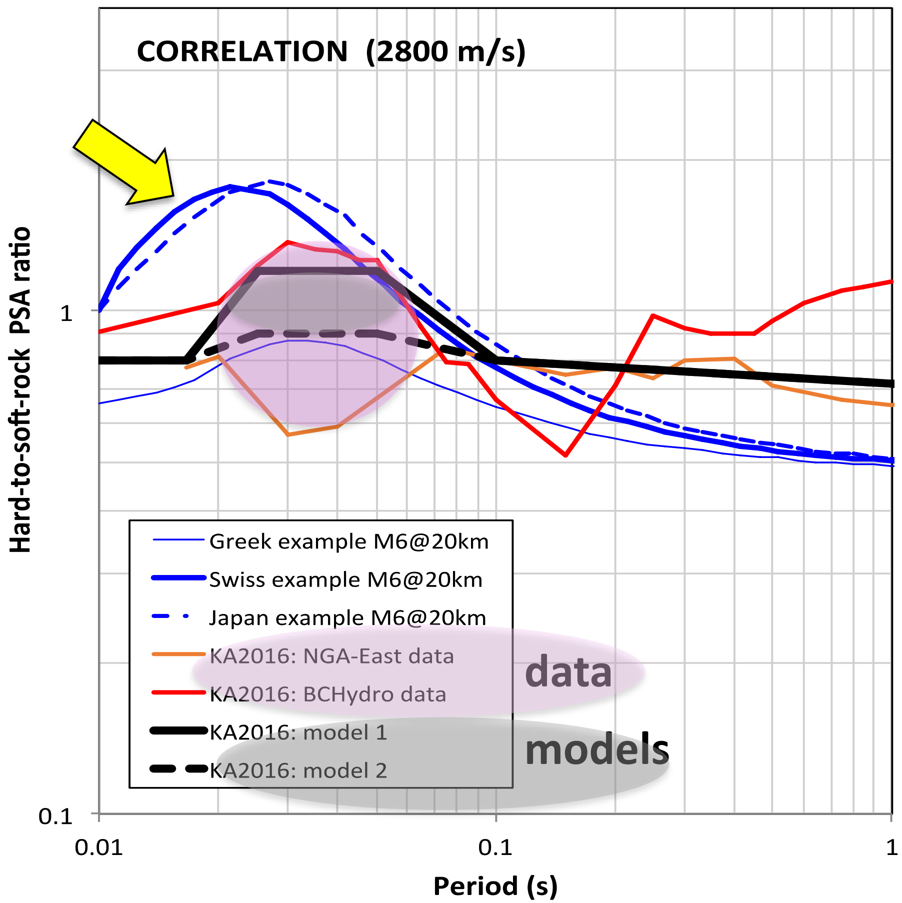
M6 @ 20 km

Asymptotic model: much lower GM on VHR: soft ➔ hard ➔ very hard

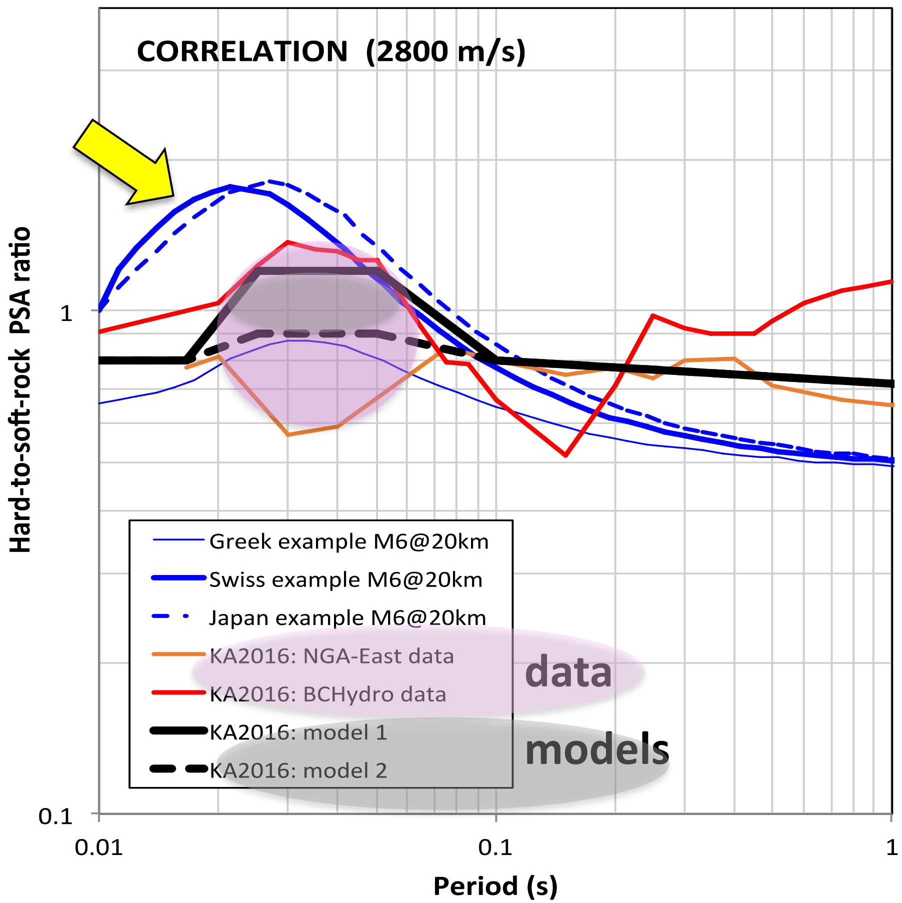


Ktenidou 2022

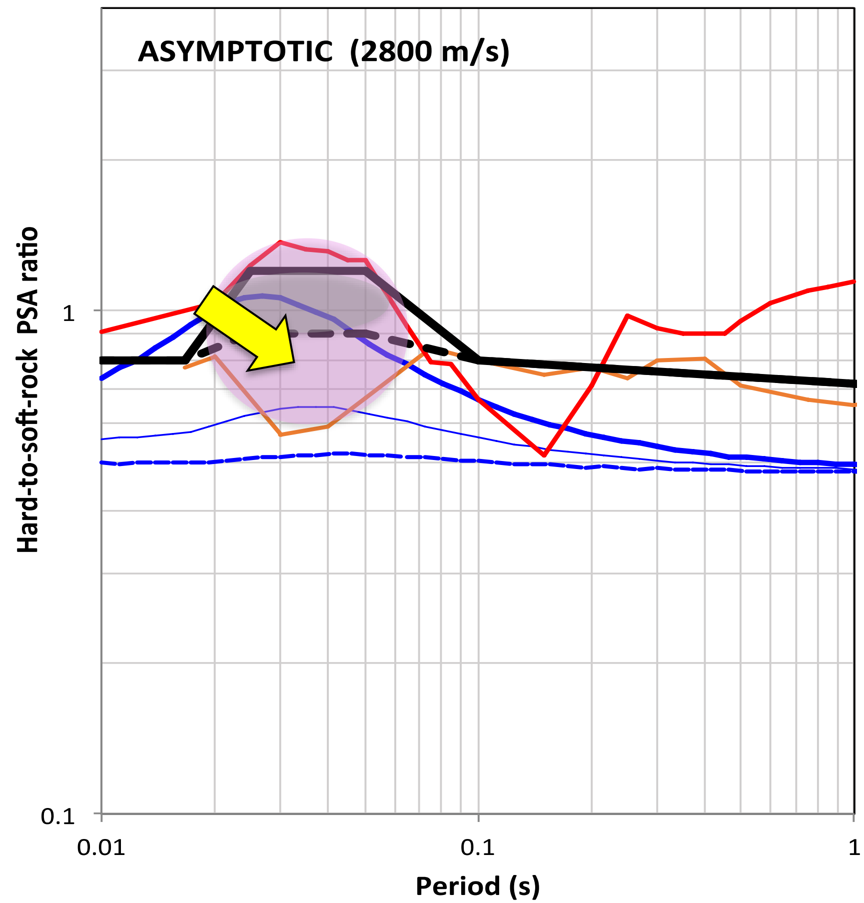
Traditional ever-decreasing model



Traditional ever-decreasing model



Asymptotic model



Ktenidou 2022

Final thoughts looking forward

So…

Practice right now is overpredicting HF GM:

- Measured HR attenuation is not necessarily ‘clean’ damping
- Stiffness is not necessarily a proxy for HR damping

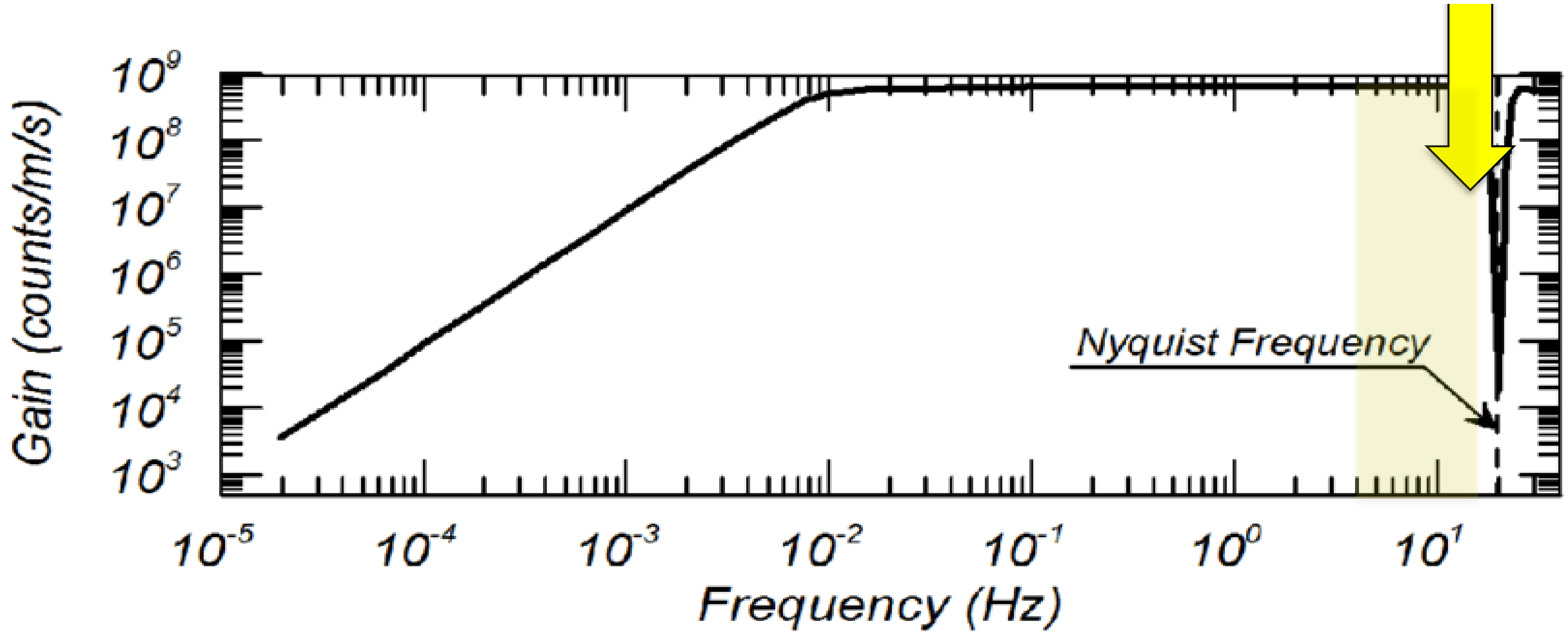
Data confrontations do not confirm these working hypotheses.

Need:

- More (good, high-sampled) observations on hard rock sites
- New tools & methods to get to higher frequencies robustly

As long as you don't….

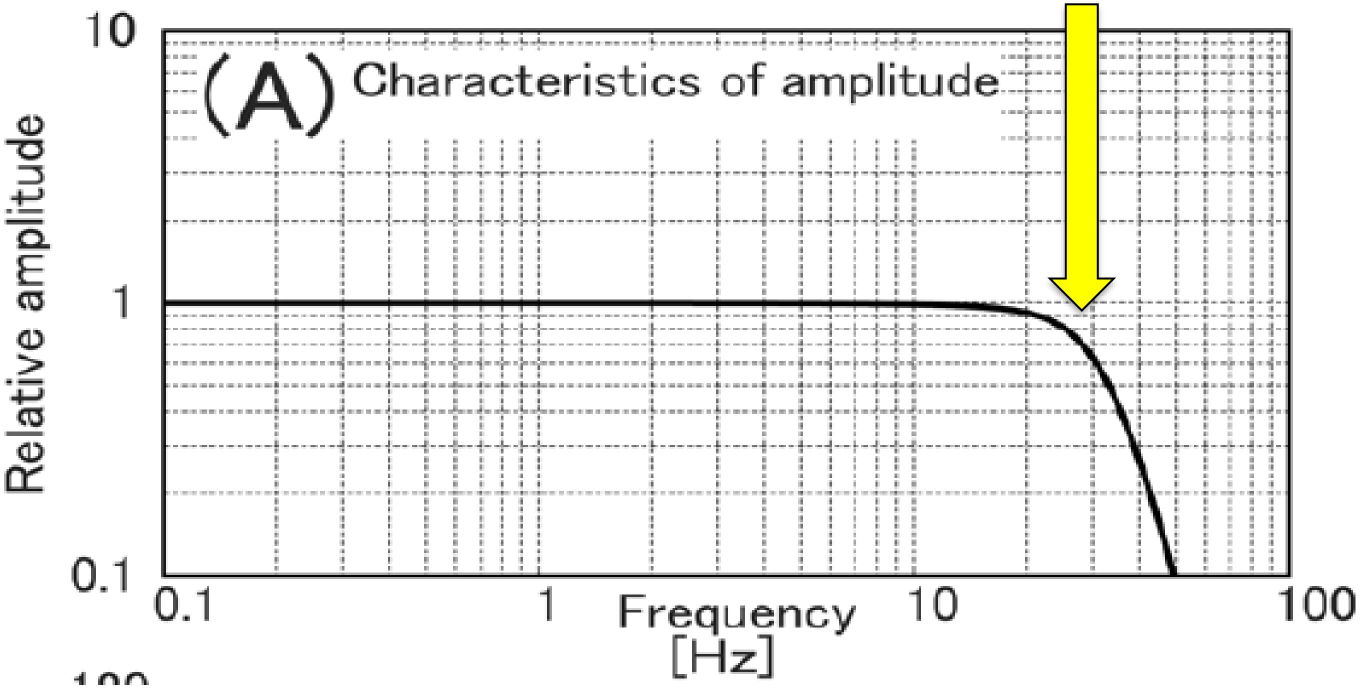
- **sampling rate / Nyquist**
  (e.g. TA, <20 Hz !!)



Kishida et al. 2014

As long as you don't….

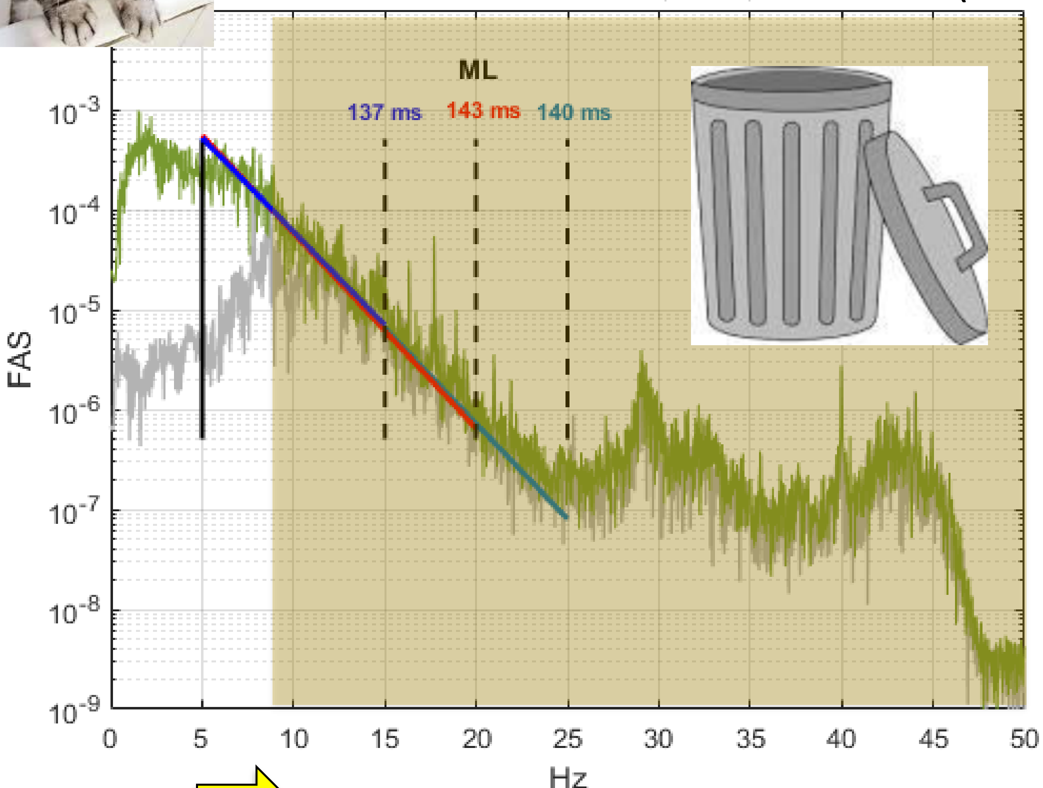
- **sensor filters** (e.g. Kik-net, Knet, <30 Hz)



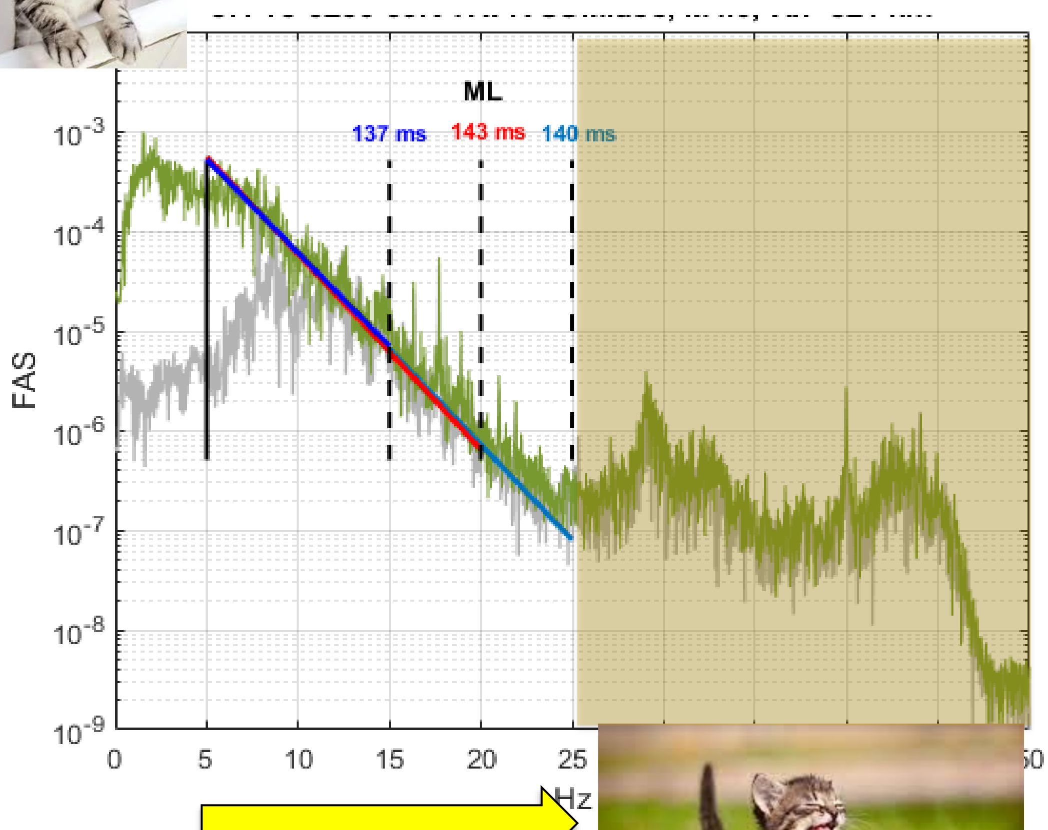
Aoi et al., 2004

…this can help

Ktenidou & Pikoulis (2022)



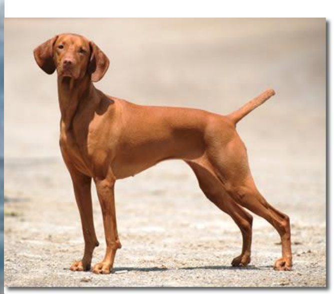
...this can help



Pikoulis et al. (2020):

- noise modelling, not avoidance
- extend usability to HFs + render unusable records exploitable
- for κ as well as amp
- more robust estimate – likely systematic underestimation in global values

Keep in touch or help wash the dog!



Visit, call or write to discuss more!

olga.κtenidou@noa.gr

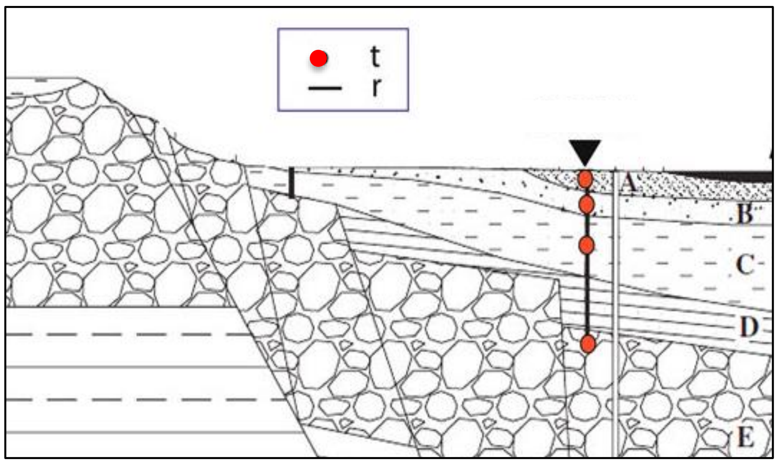
The end

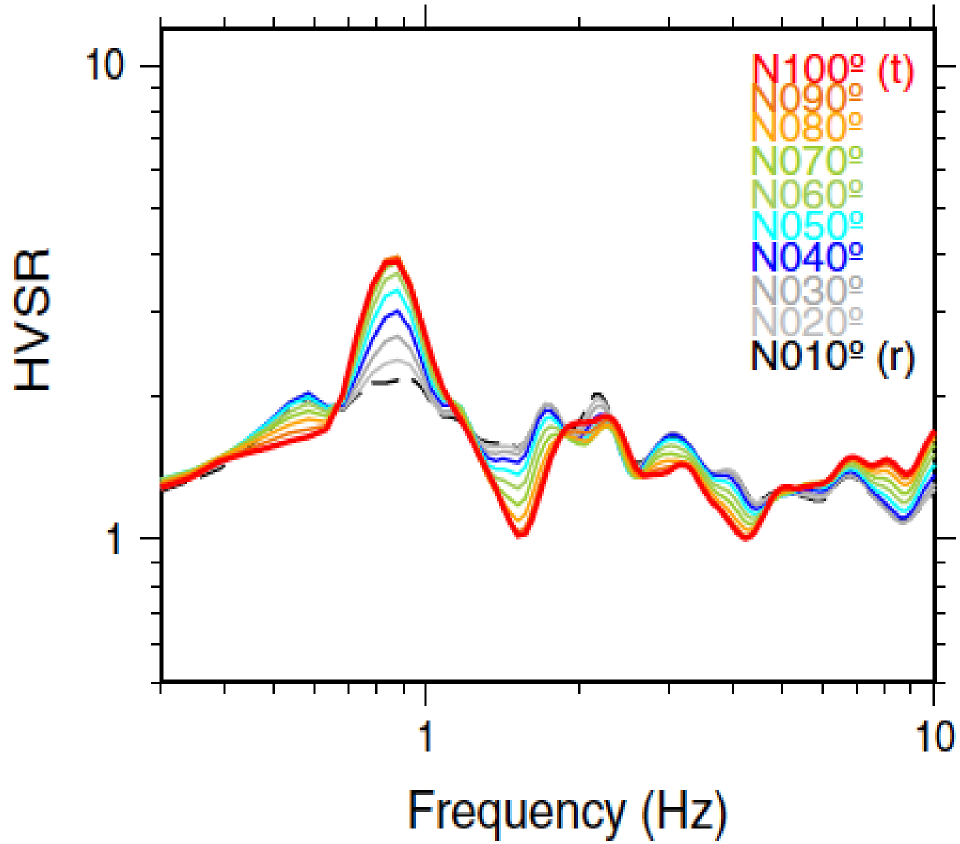
Cross-disciplinary brainstorming

towards a quantitative assessment of the fluffiness of cats?

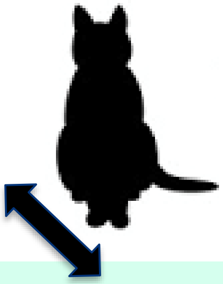
Amplification

Directionality

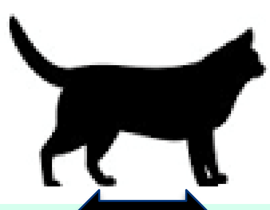




trasvrse (N100)



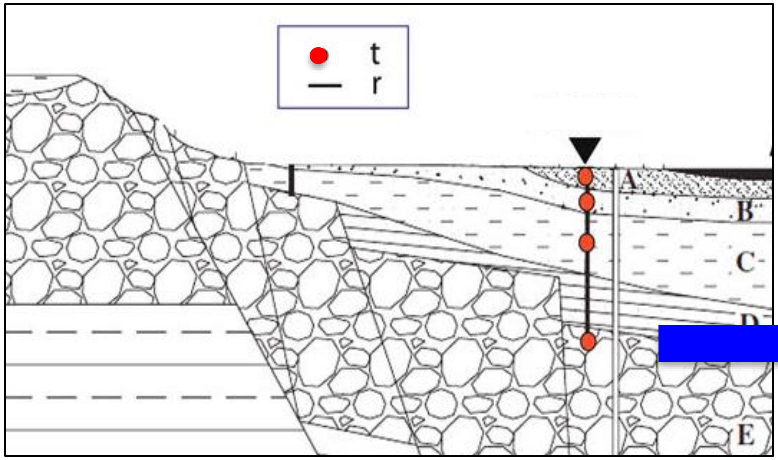
radial (N010)

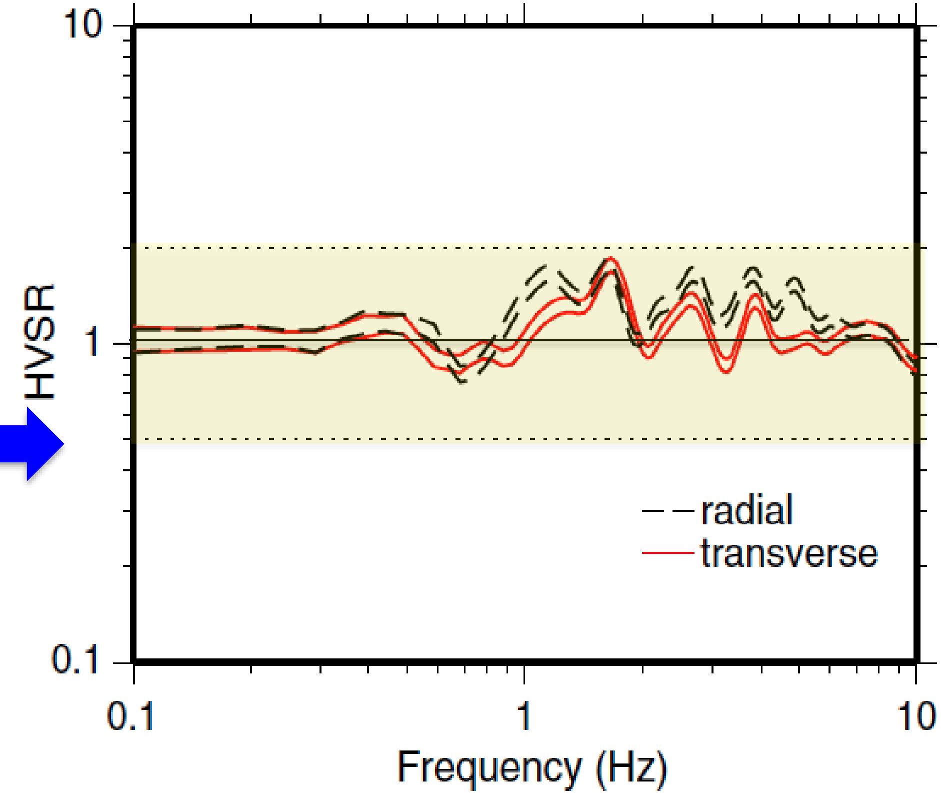


Ktenidou et al 2016

Amplification

Reference conditions





… always so??

Ktenidou et al 2011