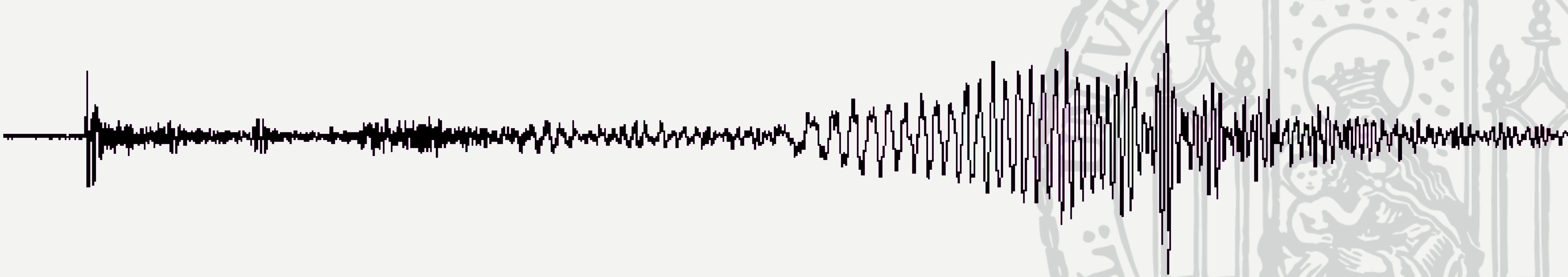
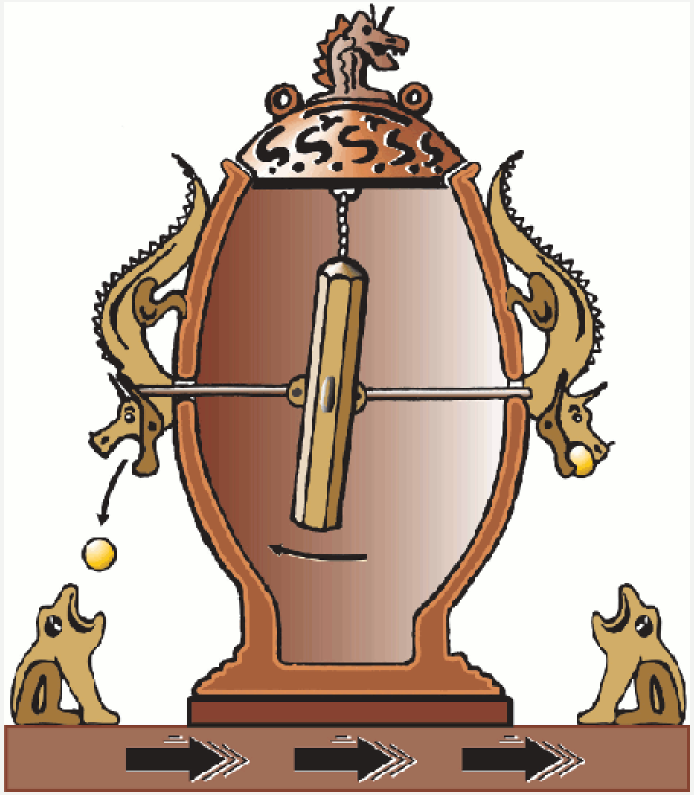
Seismometer

Stefanie Donner



Some history



Zhang Heng, China

132 AD

"instrument for measuring the seasonal winds and the movements of the Earth"

Some history

1755 – the Great Lisbon earthquake

- Subsequent fires and a tsunami destroyed the city
- Probably Mw 8.5 to 9.0
- Between 10.000 and 100.000 death
- First systematic analysis of earthquake damages with questionaires

Some history

First "modern" seismograph (1880-1885)

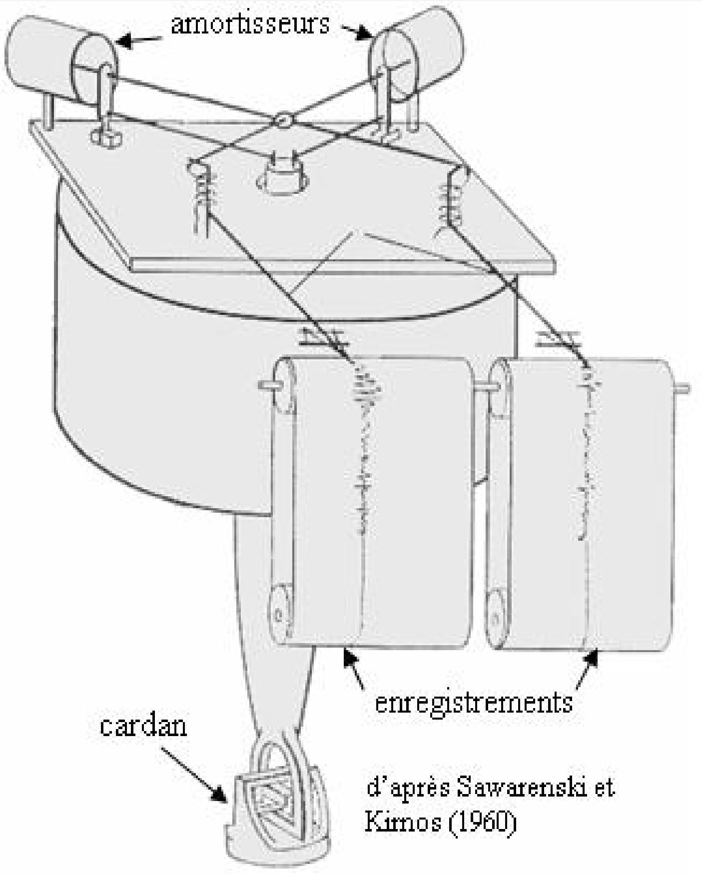
Horizontal pendulum

Pioniers: John Milne, Sir James Alfred Ewing and Thomas Gray

John Milne with Boris Galitzin and his wife, 1914

https://www.e-education.psu.edu/earth520/node/1784

Some history



Emil Wiechert (1861-1928)

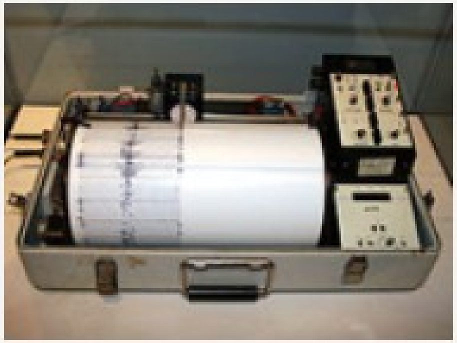
- Converted or astatic pendulum
- 1st seismograph with viscous damping → useful recordings for the entire duration of ground motion
- Founder of the 1st global seismic network
- One of the co-founder of the Association Internationale de Seismologie; today: International Association of Seismology and Physics of the Earth's Interior (IASPEI)

mass 1.000g

period 10s

Moxa

Quelle: http://musee-sismologie.unistra.fr/english/the-collection-seismology



Instruments

We want to measure ...

Ground motion!

Caused by ...

+ Earthquakes
  - Surface waves
  - Body waves
  - Free oscillations
  - Large & small
+ Cultural noise
+ Ocean noise
+ Tides
+ ...

We want to measure …

"… the Earth motion at a point with respect to this same point undisturbed."

Problems:

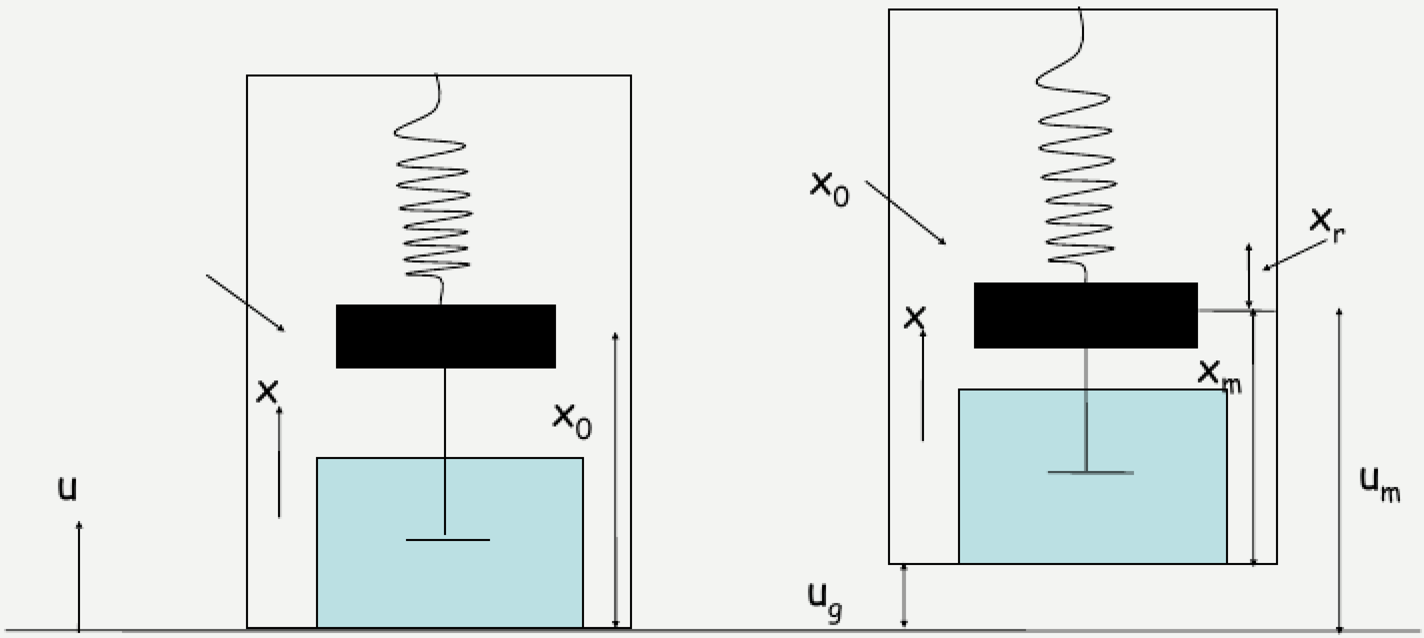
- measurement is done in a moving reference frame
  → displacement cannot be measured directly, can only observe the motion if it has an acceleration

- amplitude and frequency range of seismic signals is very large
  → need several instruments to cover the full range in amplitudes and frequencies

(Instrumentation in earthquake seismology, Havskov & Alguacil, 2002)

Seismometer
the basic principle

A seismometer is a mechanical pendulum.



u	ground displacement
x_r	displacement of seismometer mass
x_0	mass equilibrium position

Seismometer
the basic principle

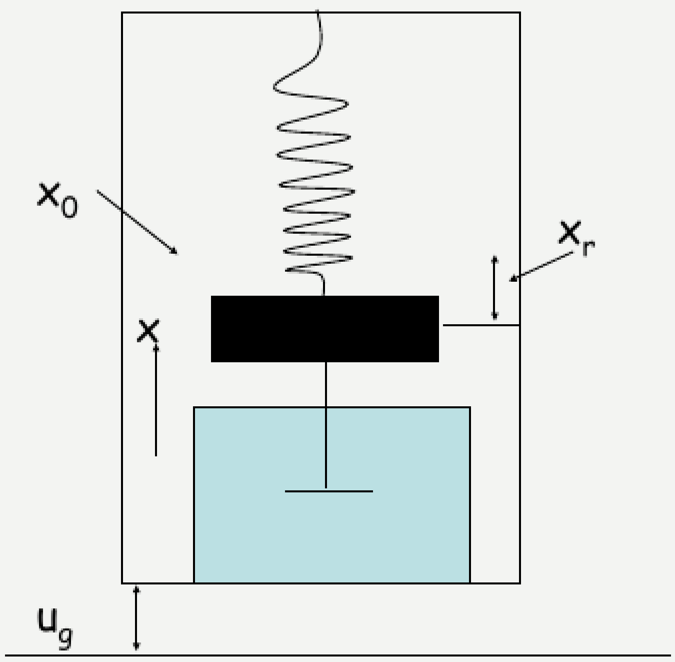
The motion of the seismometer mass as a function of the ground displacement is given through a differential equation resulting from the equilibrium of forces:

$$F_{spring} + F_{friction} + F_{gravity} = 0$$

$$F_{spring} = -k\dot{x}$$ *k – spring constant*

$$F_{friction} = -D\ddot{x}$$ *D – friction coefficient*

$$F_{gravity} = -mu$$ *m – seismometer mass*



Seismometer the basic principle

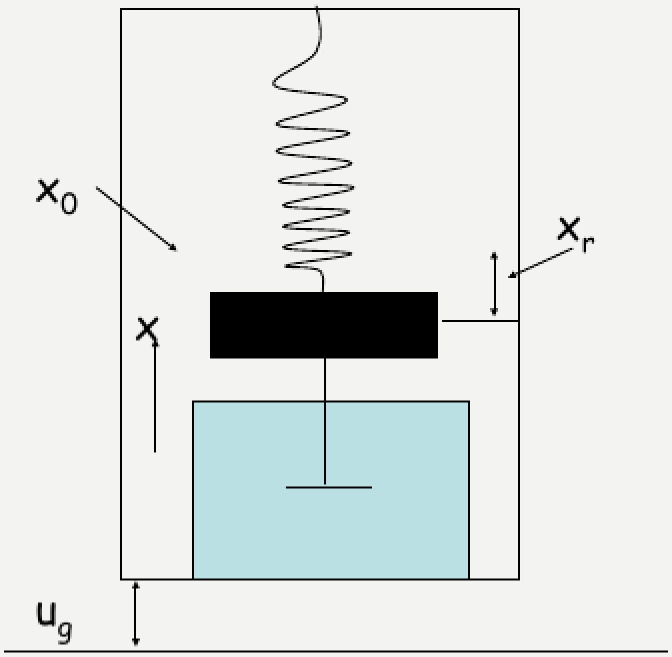
The equation of motion for the mass is then:

$$\ddot{x}_r(t) + 2\epsilon\dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)$$

$$\epsilon = \frac{D}{2m} = h\omega_0 \qquad \omega_0^2 = \frac{k}{m}$$

damping constant

eigenfrequency



What do we learn from the equation?

Mechanical pendulum

$$\ddot{x}_r(t) + 2\epsilon\dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)$$

- *For slow movements (low frequency)*

$x_r(t) \gg \dot{x}_r(t), \ddot{x}_r(t)$ ⇨ $\omega_0^2 x_r(t) \approx -\ddot{u}_g$

movement of mass ~ ground acceleration

→ measure ground acceleration

Mechanical pendulum

$$\ddot{x}_r(t) + 2\epsilon\dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)$$

- *For fast movements (high frequency)*

$$\ddot{x}_r(t) \gg \dot{x}_r(t), x_r(t) \quad \Rightarrow \quad \ddot{x}_r(t) \approx -\ddot{u}_g$$

movement of mass ~ ground displacement

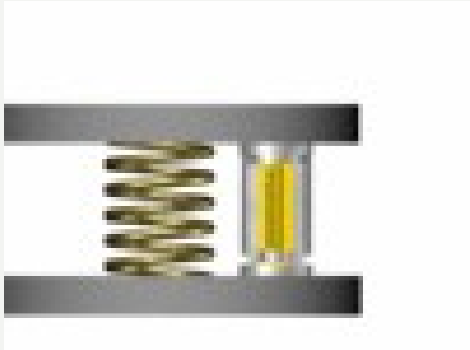
→ measure ground displacment

Mechanical pendulum

$$\ddot{x}_r(t) + 2\epsilon\dot{x}_r(t) + \omega_0^2 x_r(t) = -\ddot{u}_g(t)$$

- *Natural frequency*

  new push at exact the „right time“, i.e. when mass is at extreme position

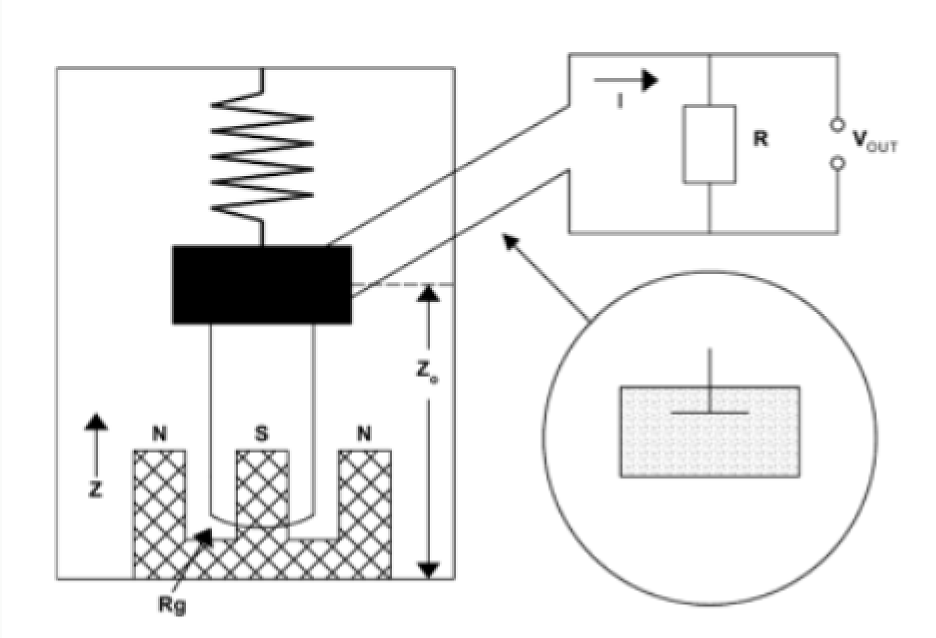


movement of mass >> ground displacement

→ amplitudes get larger and larger (gain > 1)

The electromagnetic seismometer

Modern, electromagnetic seismometers always measure **ground velocity.**



- Damping through a coil moving in a permanent magnetic field
- Movement induces voltage
- Voltage ~ velocity

seismometer by Boris B. Golizyn (1862-1916)
H: mass 7 kg, period 12 s
V: mass 10 kg, period 24 s

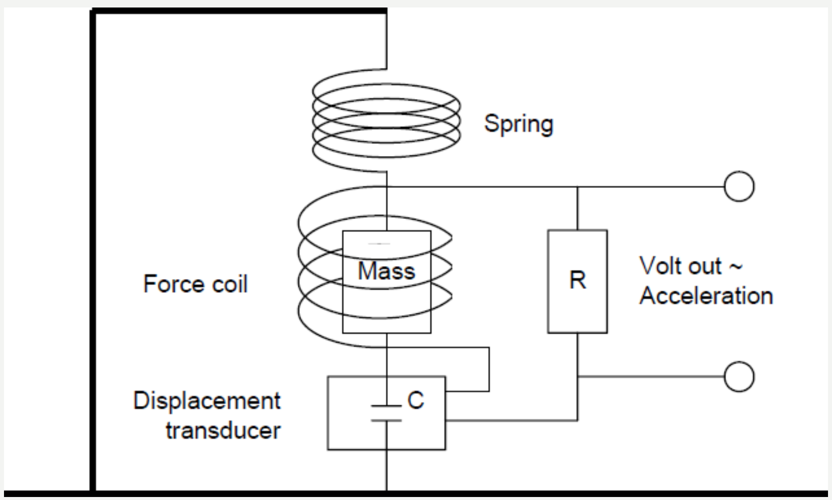
Problem: Nonlinearity

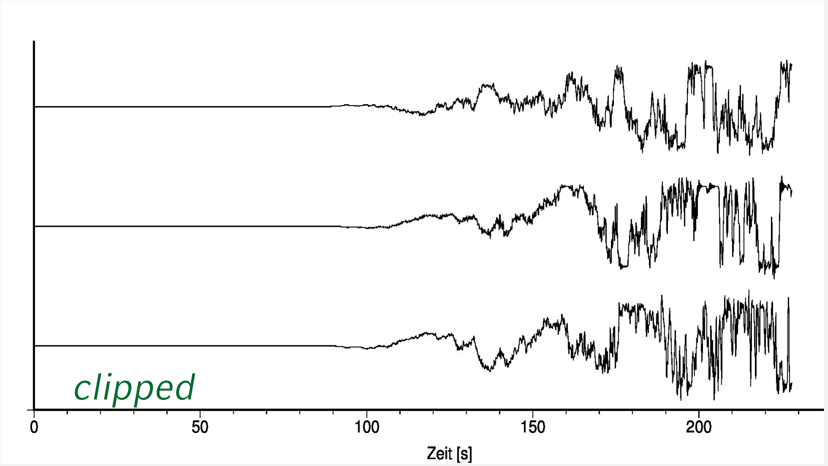
- Instruments are **non**linear when:

  + mass moves out of measurement range (or coil)
  + clipping
  + spring changes/ages
  + large spring extension

<u>Solution:</u>

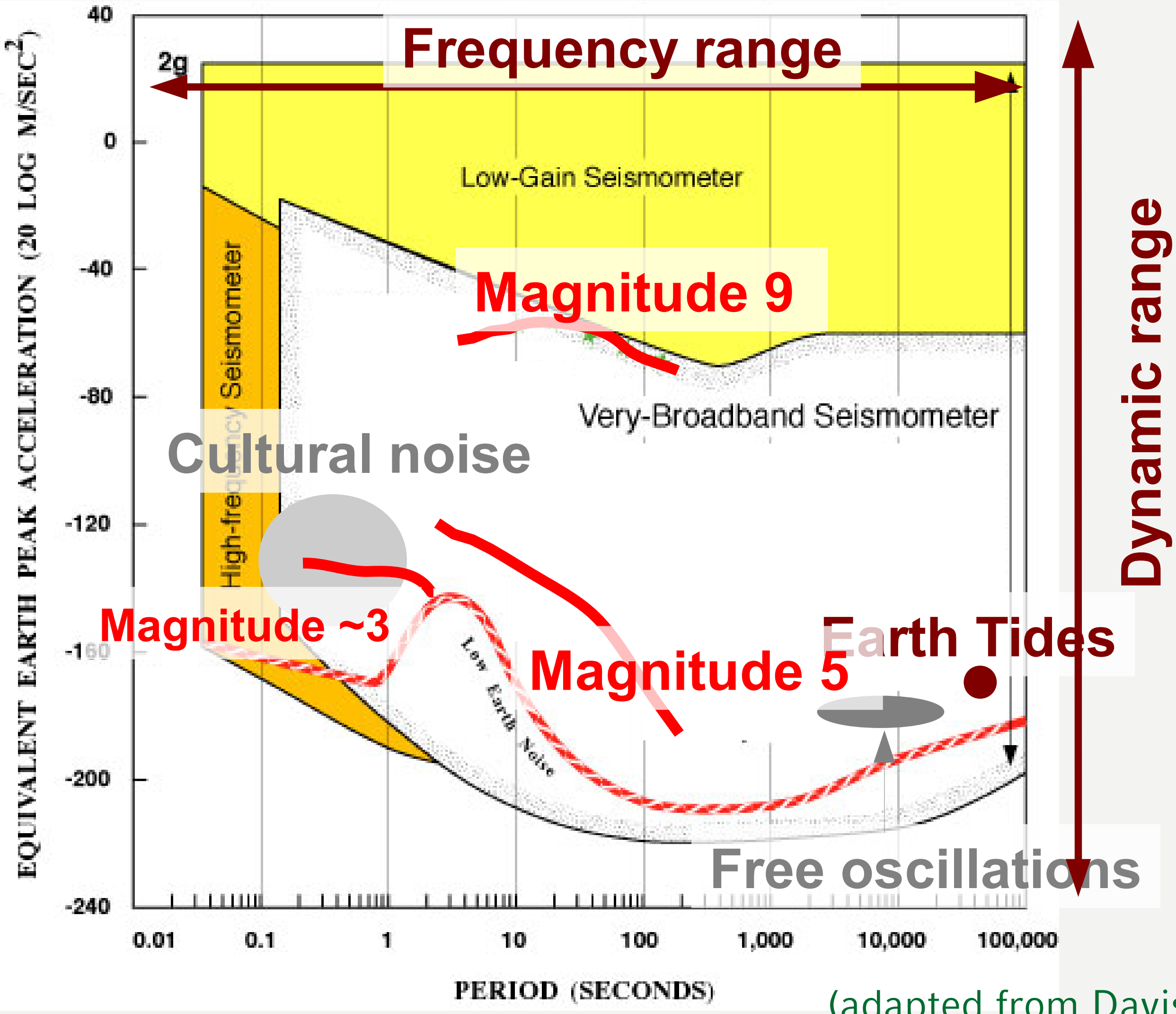
force feedback seismometer





Don't let the mass move!

We want to measure ...



Frequency range:

10 – 10e-4 Hz

Amplitude or dynamic range:

10e-1 – 10e-10 m

~ 180 dB

(adapted from Davis, IGPP)

Seismometer bandwidth

The type of construction defines which frequency range can be discovered

→ scientific question defines the choice of instrument

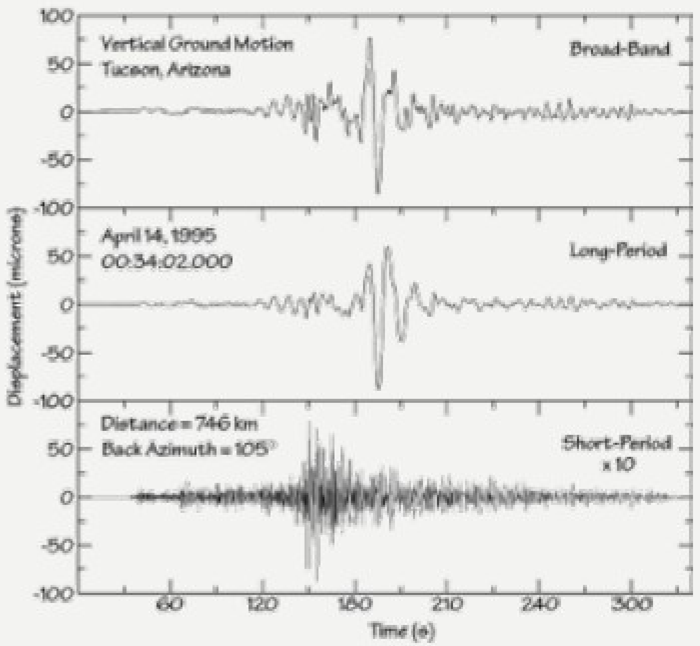
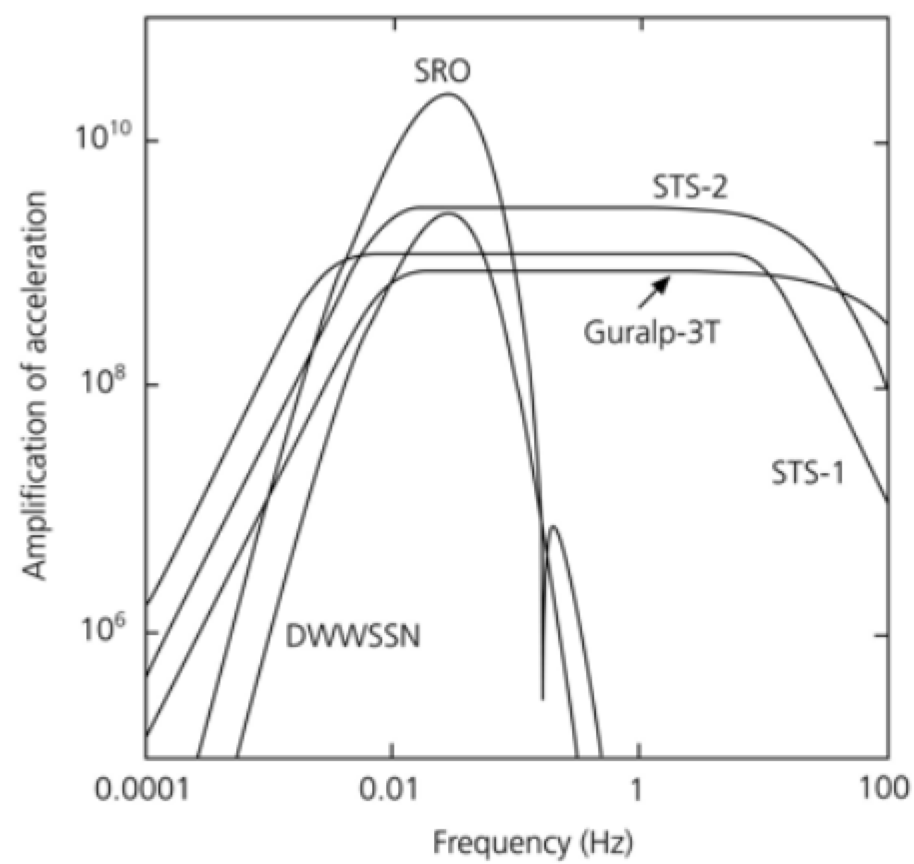
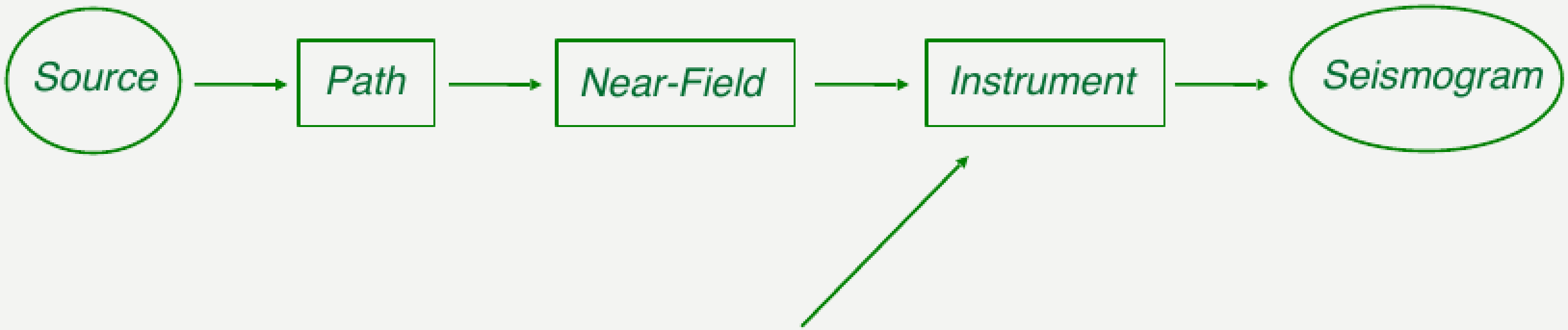


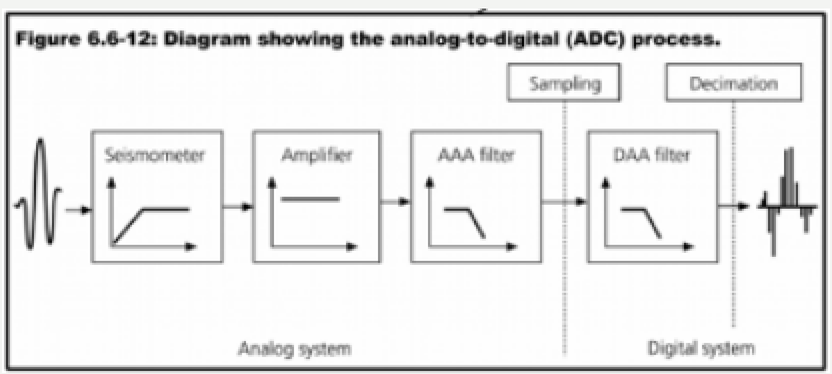
Figure 6.6-8: Instrument responses for several types of seismometers.



Recording seismic data

… several influencing factors alter the seismogram …





Seismometer = Filter

Seismometers act as a filter on the recorded data.

Filter-effect needs to be corrected by restitution (removing instrument response)