E-GRAAL project kick-off meeting

Matteo Barsuglia (APC-CNRS)

Outline

1) General information about the project and this meeting
2) The context and the E-GRAAL concept
3) Working program

Kick-off meeting

Summary, conclusions

Goals of the project

Study the benefits and feasibility of a new earthquake early-warning system (EEW) based on the gravity detection

2 questions:

1) Which are the benefits with respect to conventional systems
2) Is it feasible? On which timescale?

Goals of the kick-off meeting:

1) Review the status of the art

2) Discuss the goals of the project

3) Discuss the organization of the project

Participants

Project team

Matteo Barsuglia (coordinator)
Eric Chassande-Mottin
Christelle Buy
Eric Bréelle
Jean-Luc Robert
1 post-doc to be hired

Matteo Tacca
Eleonora Capocasa

Jean-Paul Montagner
Kévin Juhel
Eric Clévédé
Pascal Bernard
Ph.Lognonné

External experts/observers

Ayaka Shoda (Tokyo University)
Fiodor Sorrentino (INFN Genova)
Maren Boese (ETH)
Isabelle Panet (IGN)
Hubert Halloin (APC)
Jean-Paul Ampuero (Caltech)
Danièle Steer (APC)

Bernard Withing (Florida University – remote)
Masaki Ando (Tokyo University – remote)
Giovanni Losurdo (INFN Firenze – remote)

Meeting schedule

09:00 - 10:30 Introduction and status review talks

09:00 **Presentation of the E-GRAAL project** *30'*
Intervenant: M.Barsuglia (APC)

09:30 **Status review of earthquake early warning systems and future prospects** *30'*
Intervenant: Maren Boese (ETH)

10:00 **Measurements of time-varying gravity using satellites** *30'*
Intervenant: Isabelle Panet (IPGP)

10:30 - 11:00 Discussion + Coffee

11:00 - 13:00 Transient gravity signals from earthquakes: computation and data-analysis (I)

11:00 **Analytical computations of transient gravity signals from earthquakes** *30'*
Intervenant: J.-P.Ampuero (Caltech)

11:30 **Computation of transient gravity signals with earth normal modes - overview and open problems** *30'*
Intervenant: K.Juhel (IPGP)

12:00 **Earthquake signal detection with gravity detectors - preliminary analysis** *30'*
Intervenant: Jean-Paul Ampuero (Caltech)

12:30 **Discussion** *30'*

13:00 - 14:00 Lunch

Meeting schedule

14:00 - 16:00 Detector feasibility

14:00 **Overview of seismology instruments and their sensitivities** *30'*
Intervenant: P.Bernard (IPGP)

14:30 **TOBA experience and future plans** *30'*
Intervenant: Ayaka Shoda (Tokyo University)

15:00 **Experience with sub-Hz metrology at APC** *30'*
Intervenant: H.Halloin (APC)

15:30 **Atom interferometry gravity gradiometers** *30'*
Intervenant: F.sorrentino (INFN Genova)

16:00 - 16:30 Discussion + coffee

16:30 - 18:00 Transient gravity signals from earthquakes: computation and data analysis (II)

16:30 **Search for a transient gravity signal from the Tohoku 2011 earthquake** *1h0'*
Intervenant: J.-P.Montagner and K.JUhel (IPGP)

17:30 **Open problems and ideas on data analysis with gravity detectors** *30'*
Intervenant: Eric Chassande-Mottin (APC)

18:00 - 19:00 Summary and discussion *1h0'*
Intervenant: M.Barsuglia (APC)

19:30 - 22:30 Dinner

Funding

Plan d'action 2014

Agence Nationale de la Recherche

ANR

Scholarship
Double culture

SORBONNE PARIS CITÉ
RECHERCHE ENSEIGNEMENT SUPÉRIEUR

LabEx UnivEarthS

Working group
Geophysics
and gravitational wave detectors
(since 2011)

Collaborations

Bernard Withing

UF UNIVERSITY of FLORIDA

NSF

SEISMOLOGICAL LABORATORY
California Institute of Technology

GORDON AND BETTY MOORE FOUNDATION

Earthquake Early Warning AT CALTECH

Jean-Paul Ampuero

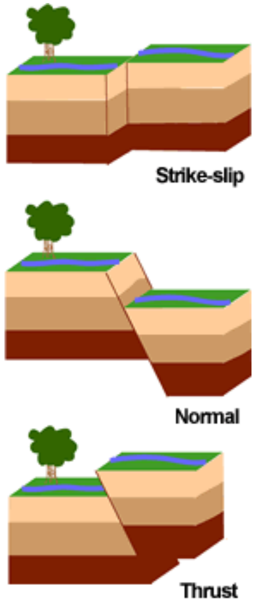
INFN Istituto Nazionale di Fisica Nucleare

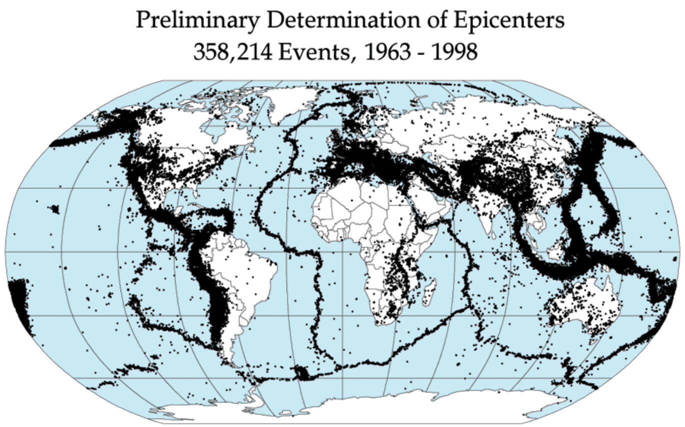
Jan Harms

東京大学 THE UNIVERSITY OF TOKYO

Masaki Ando
Ayaka Shoda

Context: Earthquakes





Huge mass displacement in tens of seconds

Can we detect the gravity change due to an earthquake?

Superconducting gravimeters and satellites

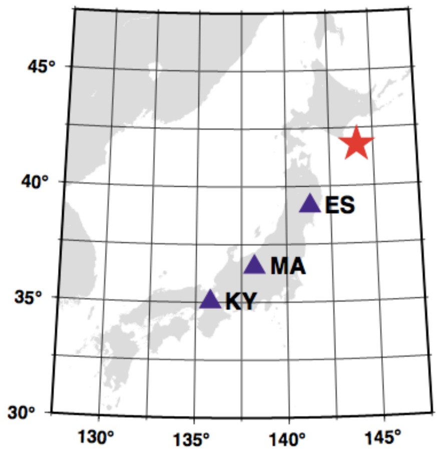


Fig. 1. Epicenter (asterisk) of the 2003 Tokachi-oki earthquake and SG station locations (triangles). ES, Esashi; MA, Matsushiro; KY, Kyoto.

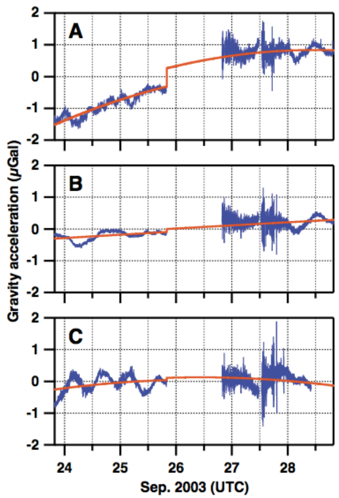


Fig. 2. Residual gravity data (blue) recorded by SGs for the 2003 Tokachi-oki earthquake. **(A)** Esashi, **(B)** Matsushiro, and **(C)** Kyoto. Red curves are best-fit functions given by Eq. 1.

~ 0.6 10^{-8} m/s^2 = 0.6 μgal

Imanishi et al., *A Network of Superconducting Gravimeters Detects Submicrogal Coseismic Gravity Changes*
Science 306, 476 (2004)

S. Okubo (1991), *Potential and gravity changes raised by point dislocations*, Geophysical Journal International, 105(3), 573– 586.

S. Okubo (1992), *Gravity and potential changes due to shear and tensile faults in a half-space*, Journal of Geophysical Research, 97(B5), 7137–7144.

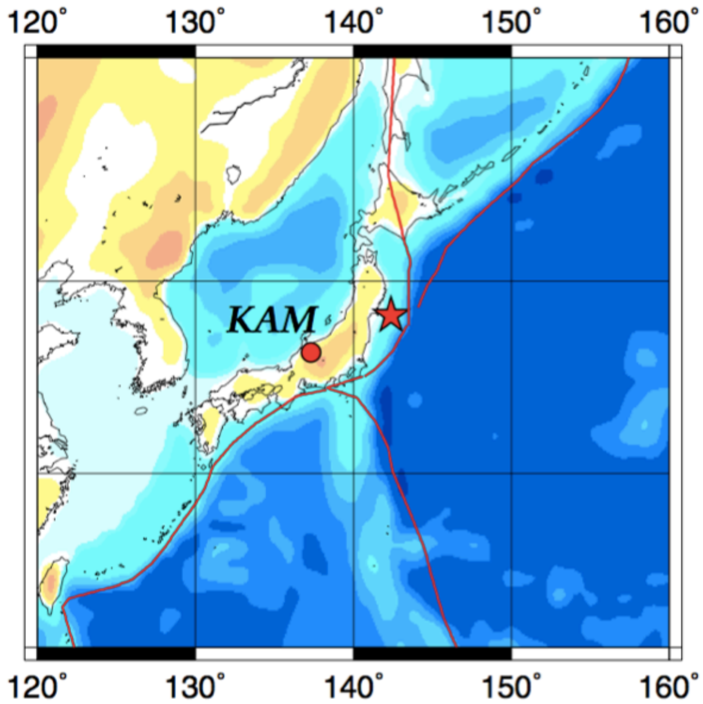
Isabelle Panet presentation

Those experiments detect static changes
(from before to after the event)

Can we detect the gravity change due to an earthquake
promptly (few seconds after the fault rupture)?

Not published results
(to our knowledge)

Search for a prompt gravity signal from the Tohoku-oki earthquake

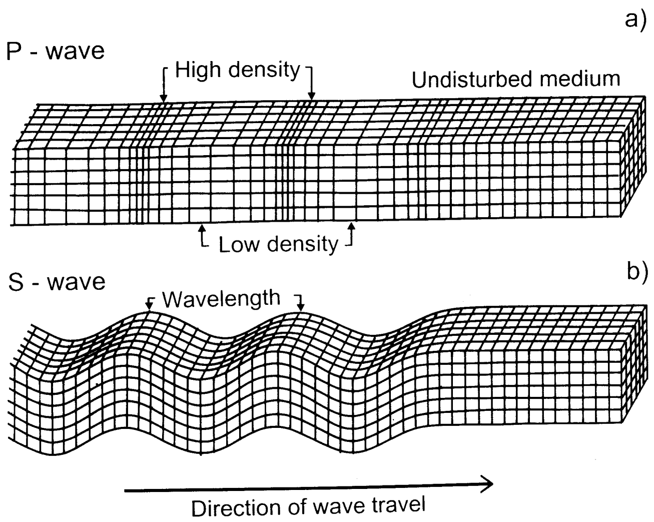


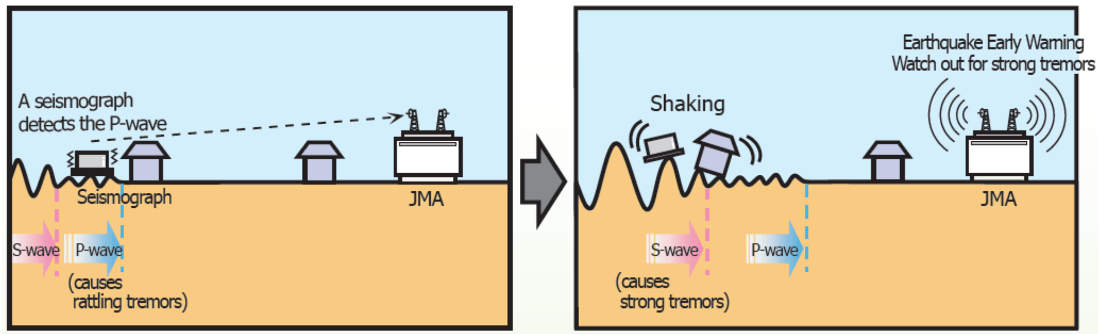
Jean-Paul Montagner presentation

First search for a quasi-instantaneous gravity signal due to an earthquake

Paper under finalization

Main motivations:
Earthquake early-warning systems





Source: Japan meterological agency

For example (for some densities) : P-waves ~ 5 km/s S-waves~ 2.5 km/s

What an early warning system can do ?

Public Alert

- warn people to take protective measures
- move people to safe positions
- prepare physically and psychologically for the impending shaking

Trigger Automatic Responses

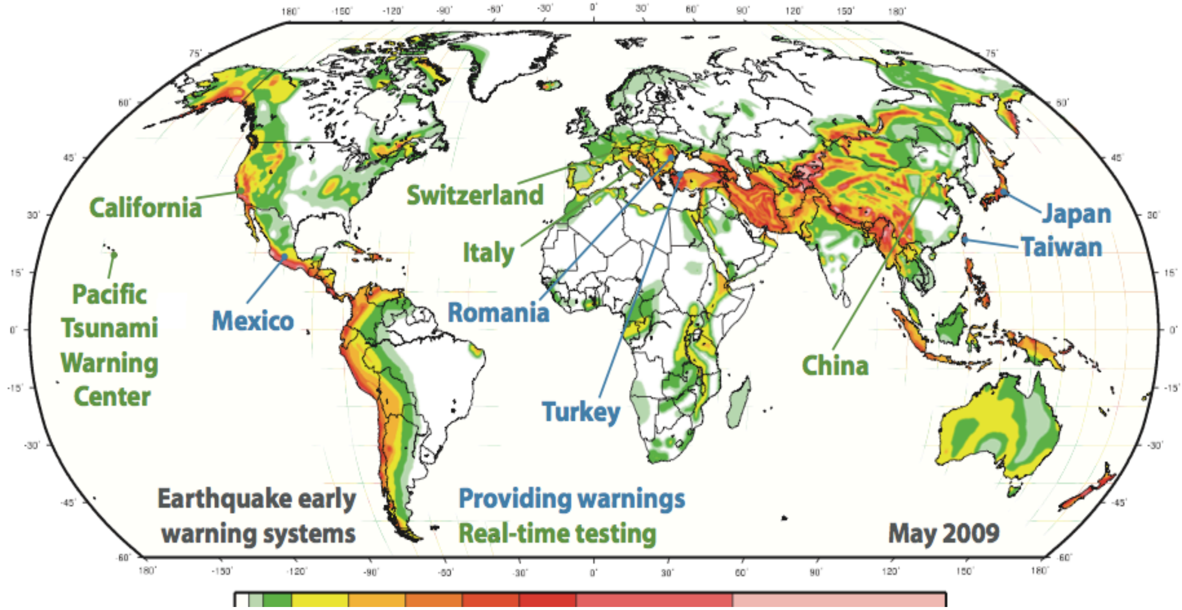
- slow down/stop trains
- control traffic by turning signals red on bridges, freeway entrances
- close valves and pipelines
- stop elevators
- save vital computer information

Maren Boese presentation

Limitations:

- chance of false alarms
- no warning in blind zone

Earthquake early warning systems around the world

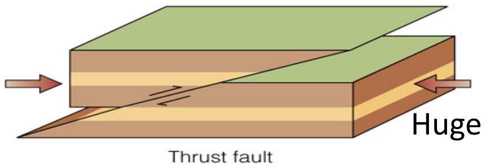


▲ **Figure 1.** Map of global seismic hazard showing locations where active EEW systems are providing warnings to one or more users (blue) and where EEW systems are currently being tested as part of a real-time seismic system (green).

The status of earthquake early warning around the world: an introductory Overview , Allen et al, Seismological Research Letters Volume 80, Number 5, 2009

Gravity-based early warning system

Rupture



Huge mass displacement

p-waves
(qq km/s)

Gravity field change
(not a gravitational-wave)

Seismic signal
delayed by the p-waves
propagation

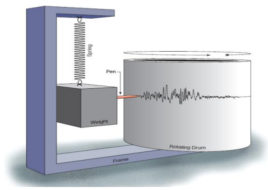
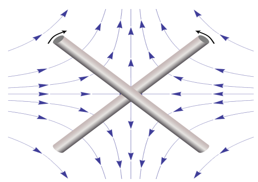


Image: IRIS



Gravity-based early warning system

Potential gains

- Increase of available time for warning
  - Conventional system at 100 km: 40s (s-waves)- 20s (p-waves) - 5s (comp) ~ 15s
  - Gravity based system at 100 km: 40s (s-waves)- 5s (comp) ~ 35s
- Reduction of the blind zone
- Quick estimation of the magnitude?

Which are the benefits?

Jean-Paul Ampuero presentation

Is it feasible?

To do:

(1) Computation/simulation gravity signals due to the fault rupture (Signal)

(2) Feasibility of a detector (noise)

(3) Detection pipeline (signal to noise ratio – warning time – false alarm rate)

(1)

Analytical computation of gravity signals

$$\delta\psi(\boldsymbol{r}_0\,,t) = -G\int \mathrm{d}V\,\frac{\delta\rho(\boldsymbol{r}\,,t)}{|\boldsymbol{r}-\boldsymbol{r}_0|}$$

$$\delta\rho(\boldsymbol{r}\,,t) = -\rho_0\boldsymbol{\nabla}\cdot\boldsymbol{\xi}(\boldsymbol{r}\,,t)$$

Assumption: point-source earthquake in an infinite elastic medium

→ known solution for the displacement fields as function of the seismic moment

$$\delta\psi(\boldsymbol{r}_0\,,t) = -\frac{6G}{r_0^3}R_{\mathrm{P}}(\theta_0,\phi_0)\;I_2[M_0](t)$$

Transient gravity perturbations induced by earthquake rupture

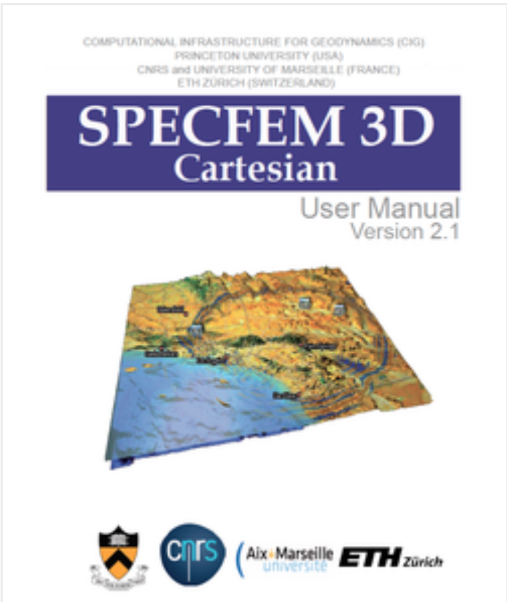
J. Harms, J.-P. Ampuero, M. Barsuglia, E. Chassande-Mottin, J.-P. Montagner, S. N. Somala and B. F. Whiting accepted for publication in GJI

Jean-Paul Ampuero presentation

(1)

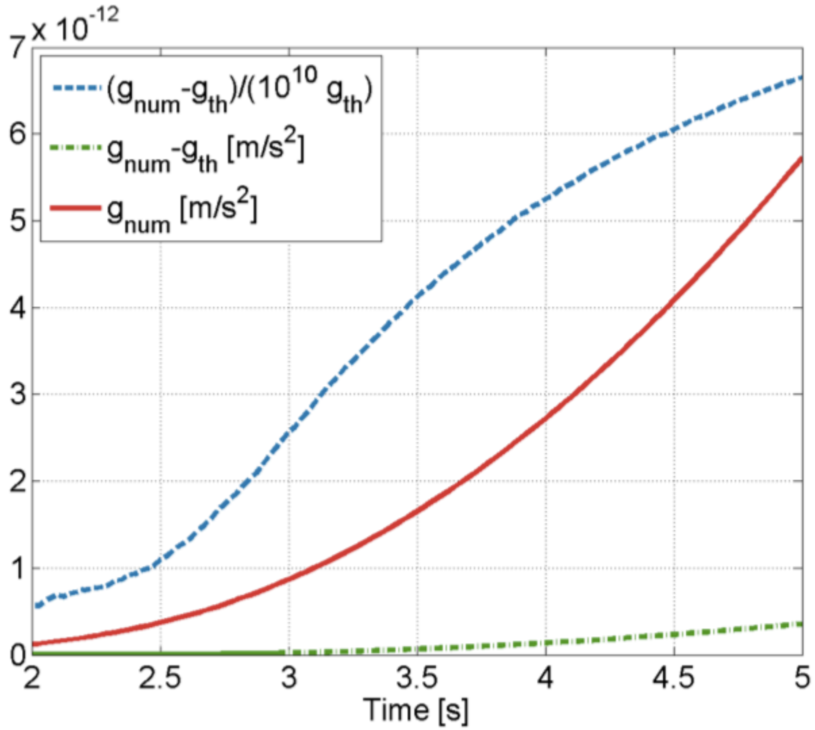
Gravity signals: simulation vs calculation

computation of gravity field implemented in the program SPECFEM3D



http://geodynamics.org/cig/software/specfem3d/

m/s²



0.5 ngal

distance=50 km
M=6.1

(2)

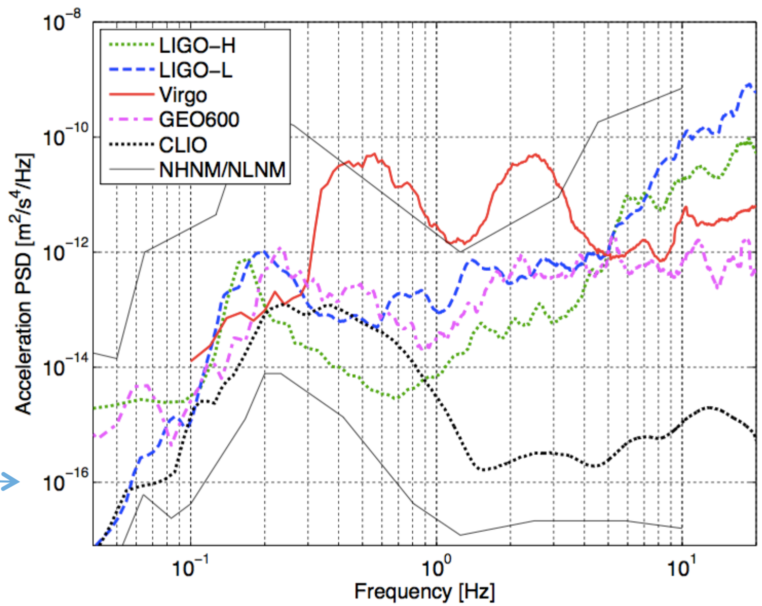
Why gravitational-wave detectors are interesting for this problem

Pascal Bernard presentation

→ Seismometers/gravimeters at 0.1-1 Hz limited by the seismic noise (inertial effects)

→ We need a strainmeter with seismic isolated test masses

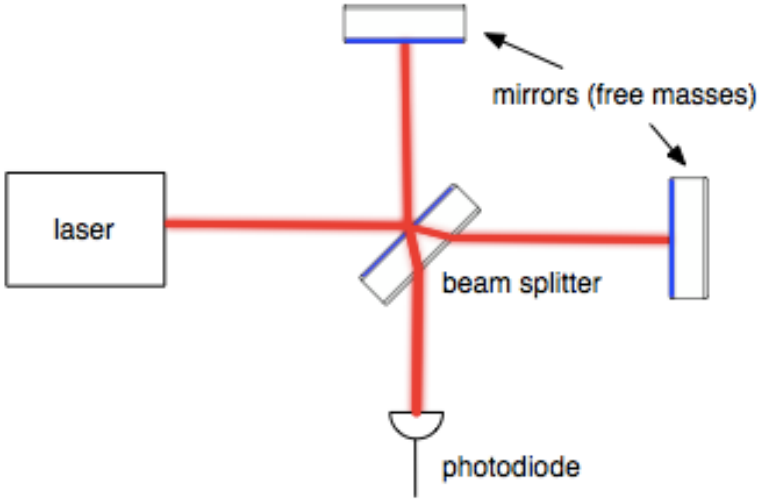
1 microgal →



(2)

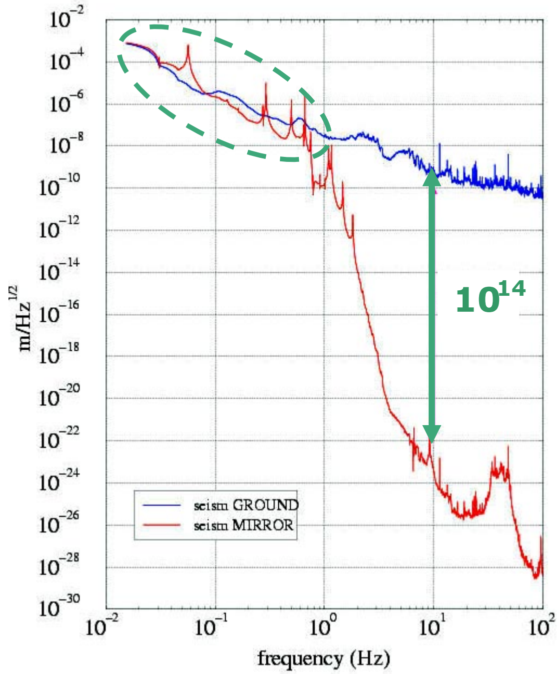
Strainmeters

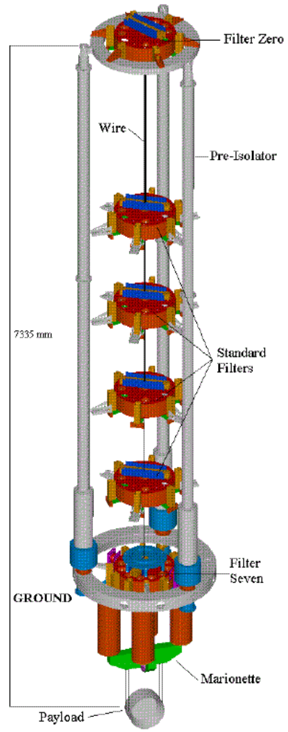
Interferometer with suspended masses



(2)

GW detectors: seismic wall at f>1 Hz





(2)

Sub-Hz gravitational-wave detectors

Hubert Halloin presentation

1) Torsion bar antennas

Ayaka Shoda presentation

2) Atom interferometers

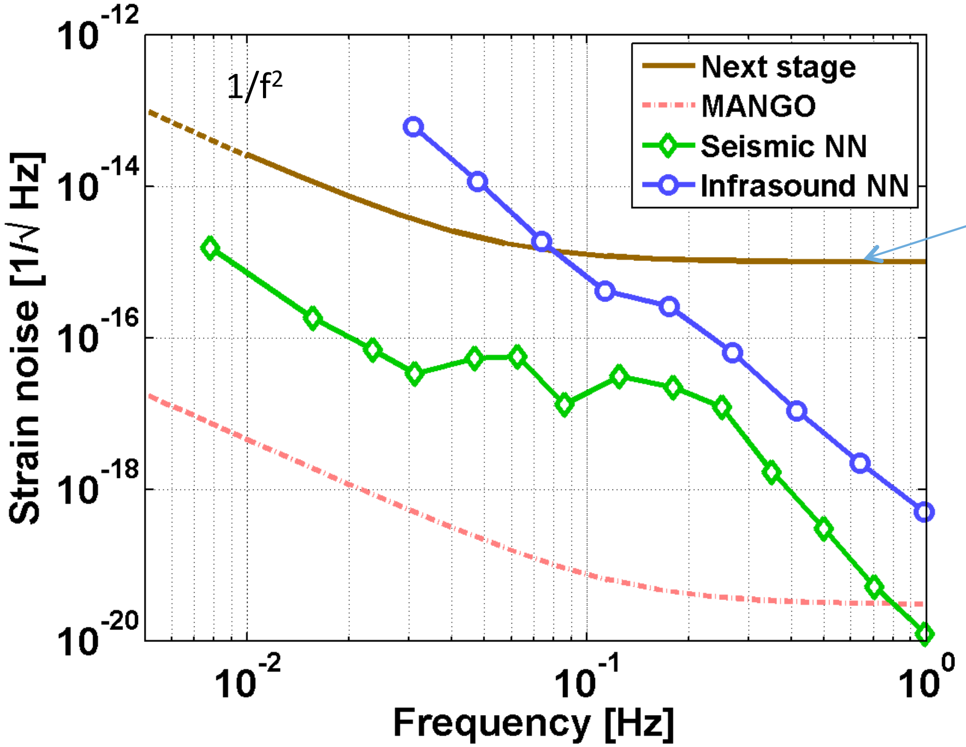
Fiodor Sorrentino presentation

Low-Frequency Terrestrial Gravitational-Wave Detectors, Jan Harms, Bram J. J. Slagmolen, Rana X. Adhikari, M. Coleman Miller, Matthew Evans, Yanbei Chen, Holger Muller and Masaki Ando, Phys. Rev. D 88, 122003 (2013)

3) Other concepts

(3)

Gravity detector : a possible sensitivity curve



h=10^{-15} $Hz^{-1/2}$

MANGO: GW detector

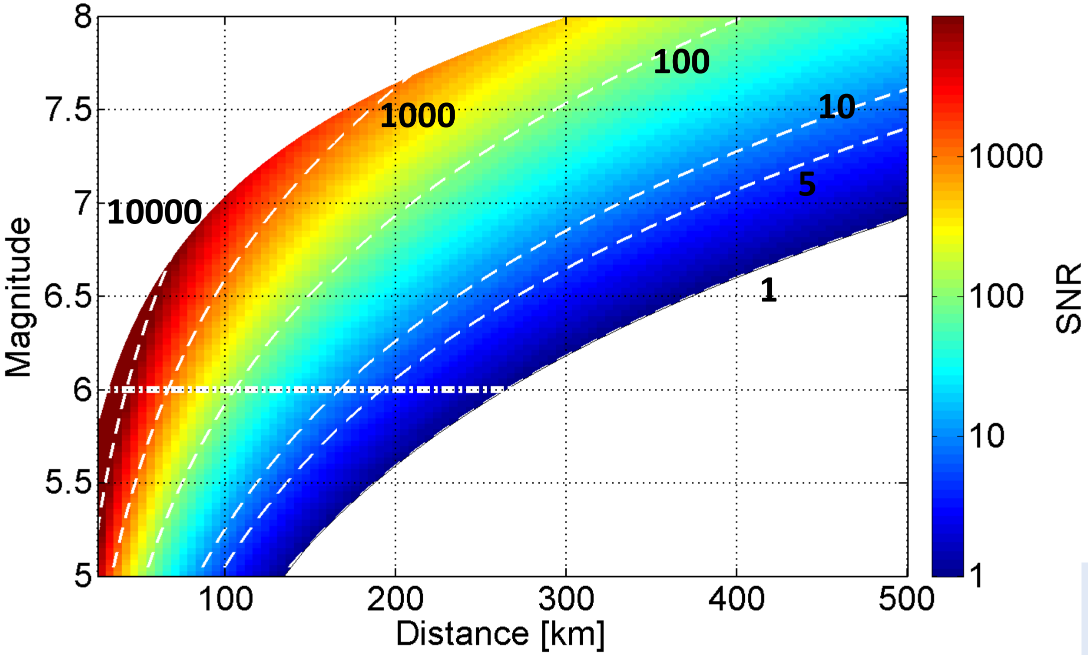
(3)

Signal to noise ratio

$$\mathrm{SNR}^2 = \int \mathrm{d}f \, \frac{|H(\vec{r}_0\,, f)|^2}{S(f)}$$

$$\langle h_+(\boldsymbol{r}_0\,, t)\rangle = \langle h_\times(\boldsymbol{r}_0\,, t)\rangle = \frac{6\sqrt{14/5}\,G}{r_0^5} I_4[M_0](t)$$

$$M(f) = \frac{1}{2\pi f}\frac{M_0}{1+(f/f_c)^2}$$



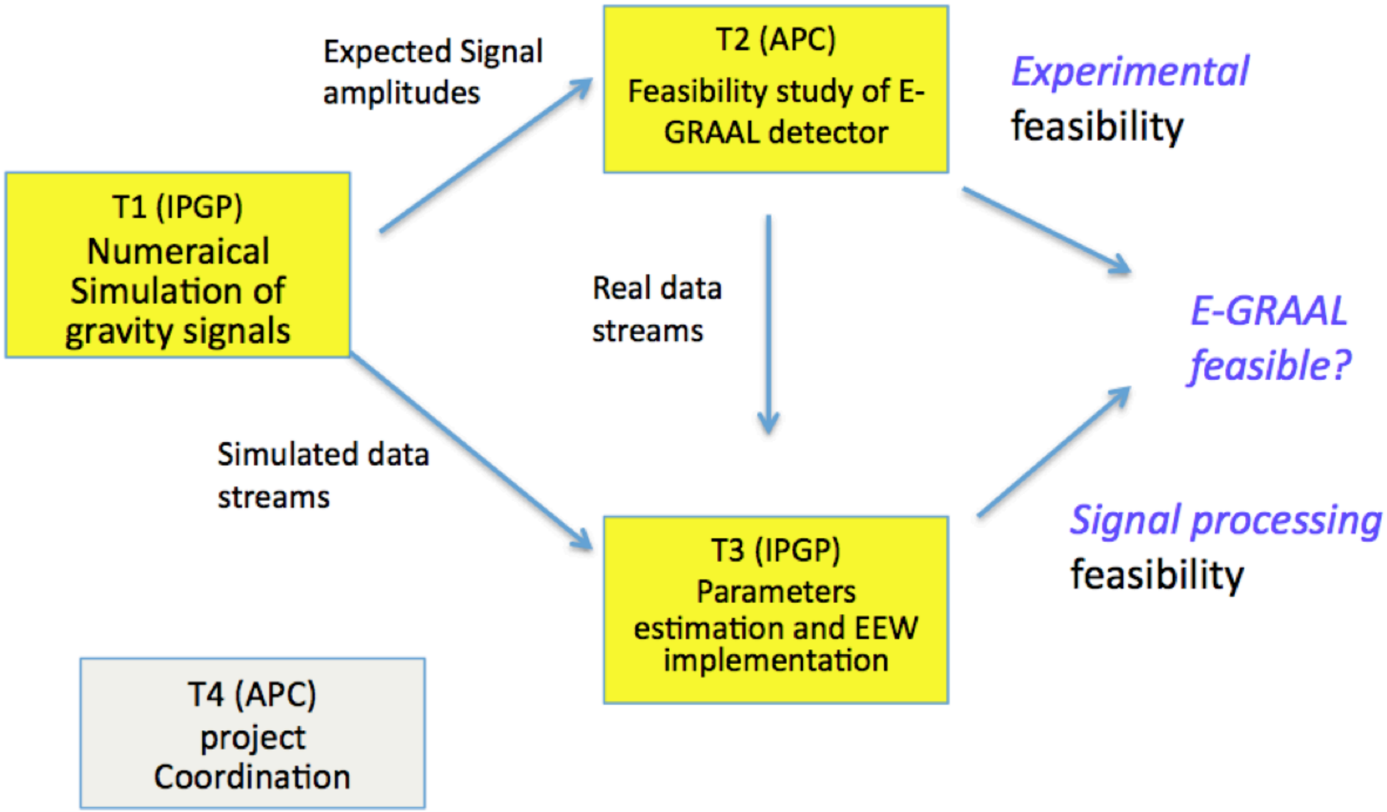
Brune, J. N. (1970), *Tectonic stress and the spectra of seismic shear waves from earthquakes*, Journal of geophysical research, 75(26), 4997–5009

Madariaga, R. (1976), *Dynamics of an expanding circular fault*, Bulletin of the Seismological Society of America, 66(3), 639– 666

Jean-Paul ampuero presentation

E-GRAAL working program

Evaluation
of the benefits



T1: Simulation of realistic gravity signal from earthquake rupture

(J.-P.Montagner, K.Juhel, E.Clévédé, M.Barsuglia, P.Bernard + external collaborators)

A) Implementation of Spectral element Method (started)

B) Simulations using normal mode theory (started)

Kevin Juhel presentation

C) Detection of gravity signal during Tohoku earthquake and comparison with theory(started)

Jean-Paul Montagner presentation

D) Analytical theory (started)

Jean-Paul ampuero presentation

T2: feasibility of a gravity detector

(M.Barsuglia, new postdoc, C.Buy,E.Bréelle + external collaborators)

A) Deisgn of a torsion bar able to detect a medium size earthquake at ~ 50 km
Collaboration with University of Tokyo started

B) Study of other technologies

C) Contribution to the torsion bar development
(readout system?)

D) Commissioning/noise hunting/data analysis

T3: data analysis strategy

(J.-P.Montanger, K.Juhel E.Chassande-Mottin, M.Barsuglia + external collaborators)

A) Developments of methods on parameters estimations with an E-GRAAL system

B) Development of pipelines for single and multi-station approaches

C) Test with simulated and real data

Eric Chassande-Mottin
presentation

Summary

at the end of the meeting