Gravity gradient studies

Firenze, Pisa, Roma and Urbino

Francesco Fidecaro, Pisa

Physics near the low frequency limit

Inspiral when massive objects are involved

Signal goes like

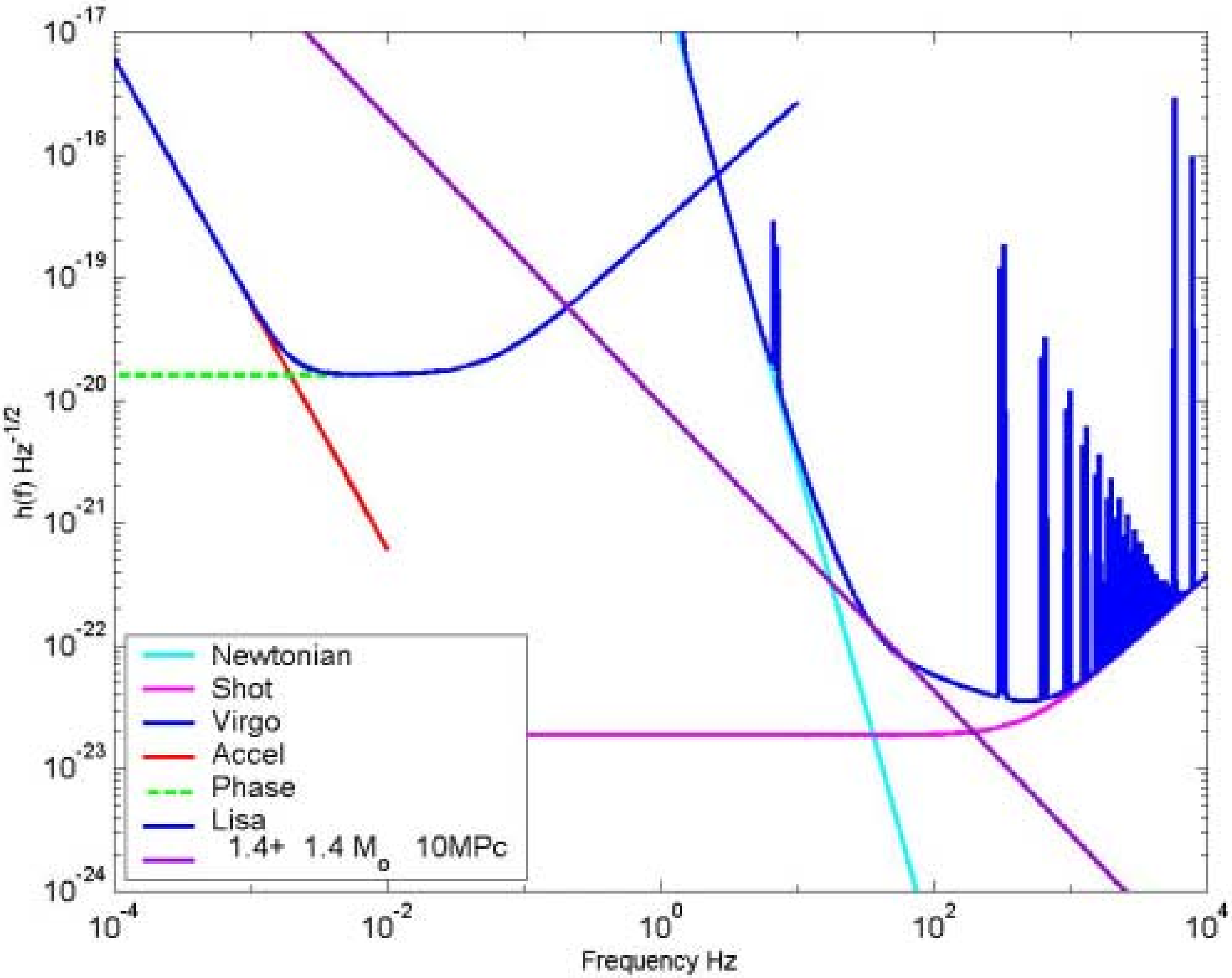
- 1/R, M $^{5/6}$, $f^{-7/6}$

There is a maximum frequency

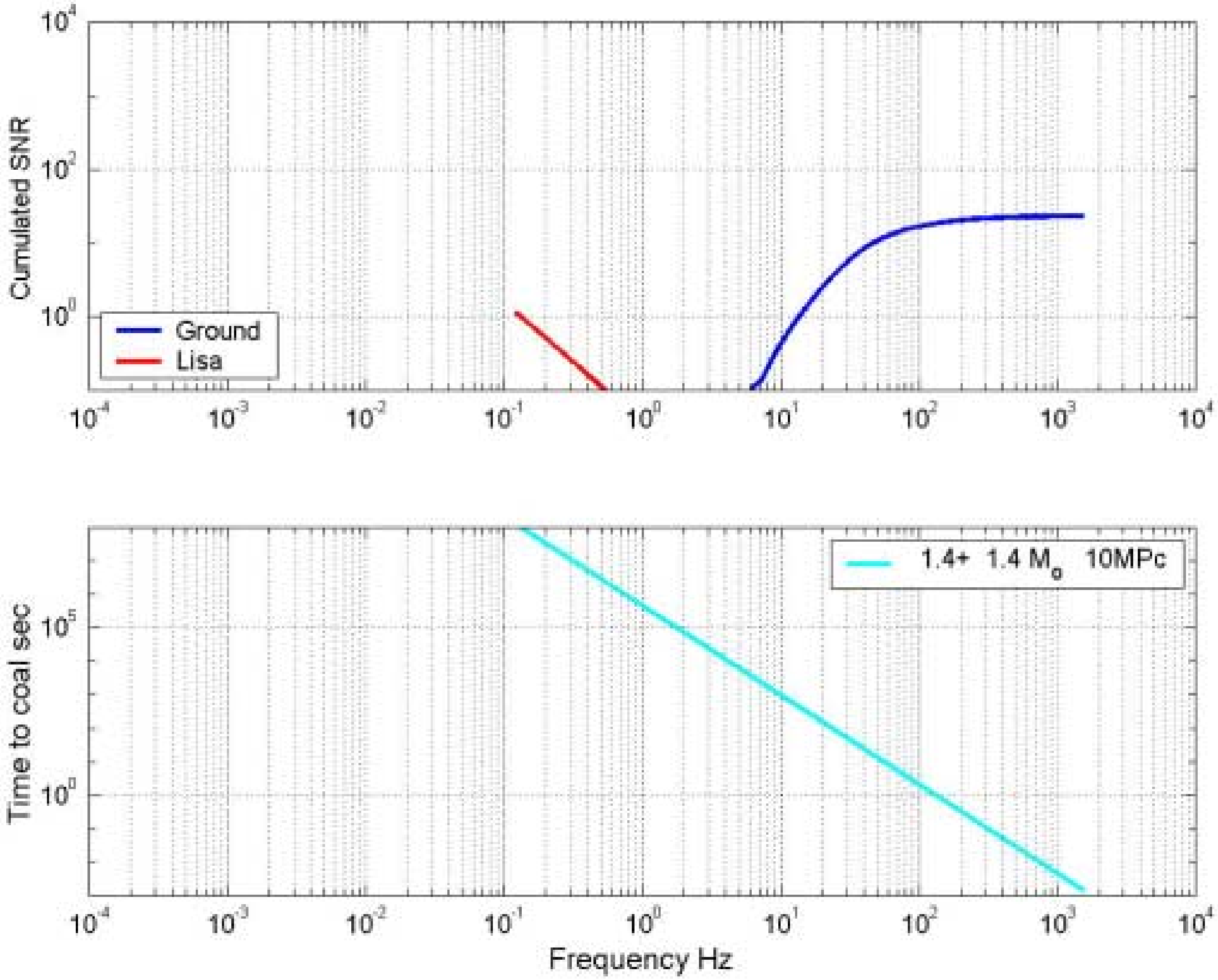
- Ringdown (Rasio: ~ 700 Hz)
- Last stable orbit (Grishchuk, Lipunov, Postnov, Prokhorov and Sathyaprakash, astro-ph0008481)
- Red shift (not considered here)

GW from known pulsar

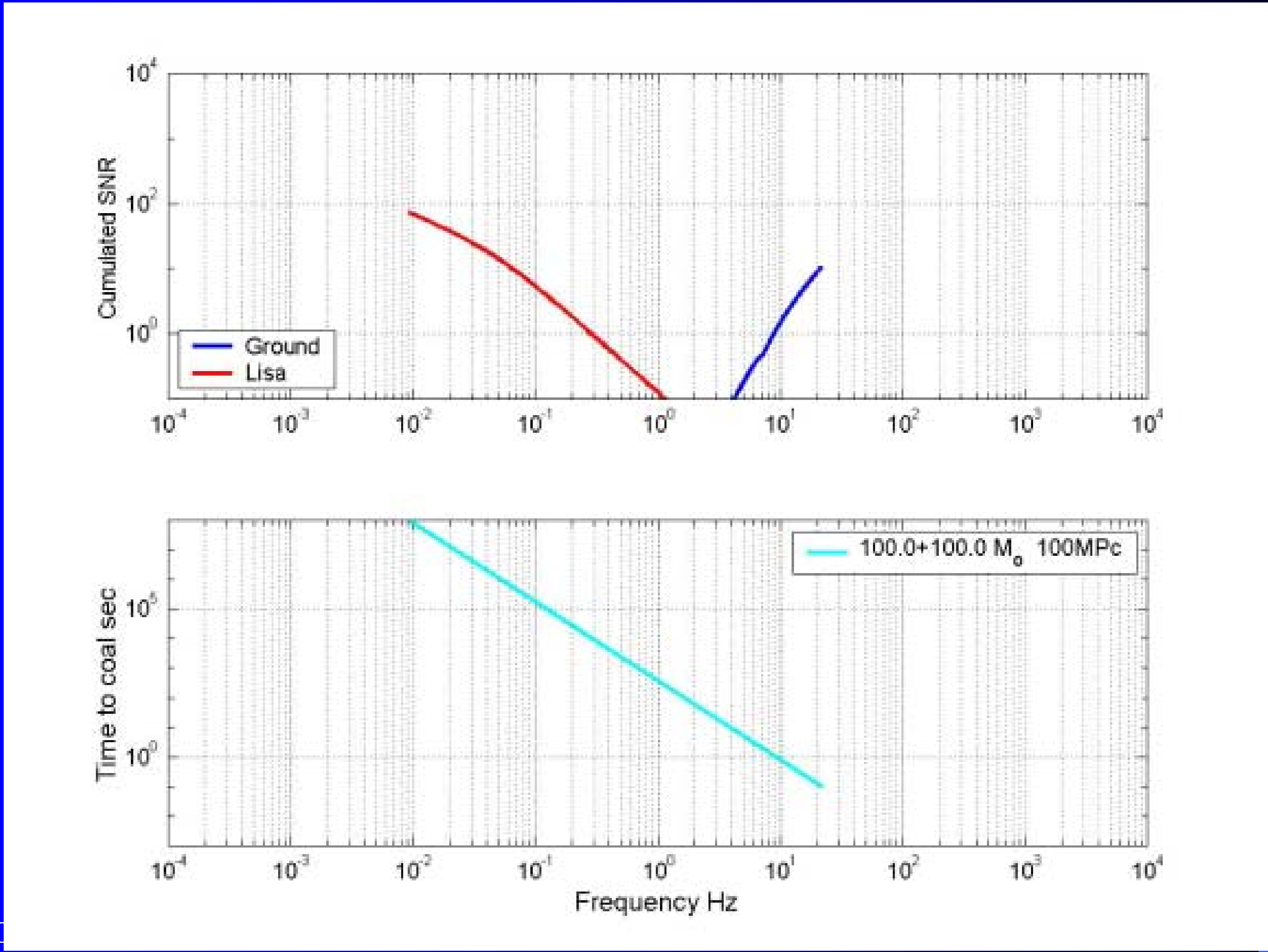
Detectors capability

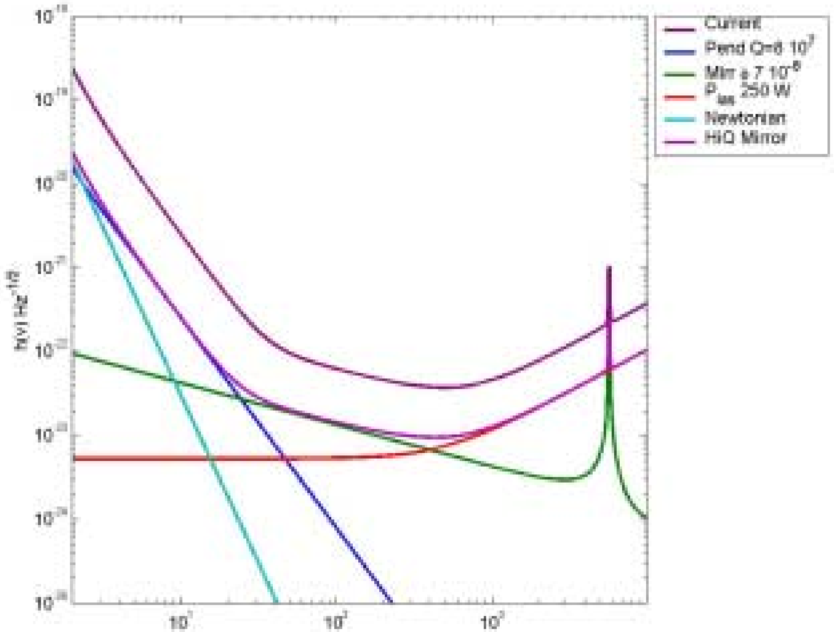


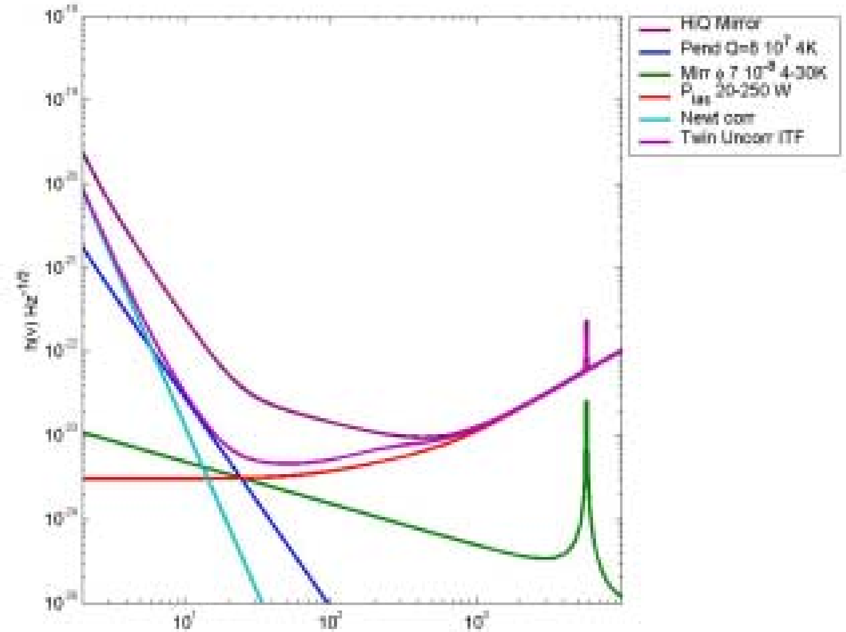
Integrated SNR NSNS



100+100 $M_\odot$ 100 Mpc



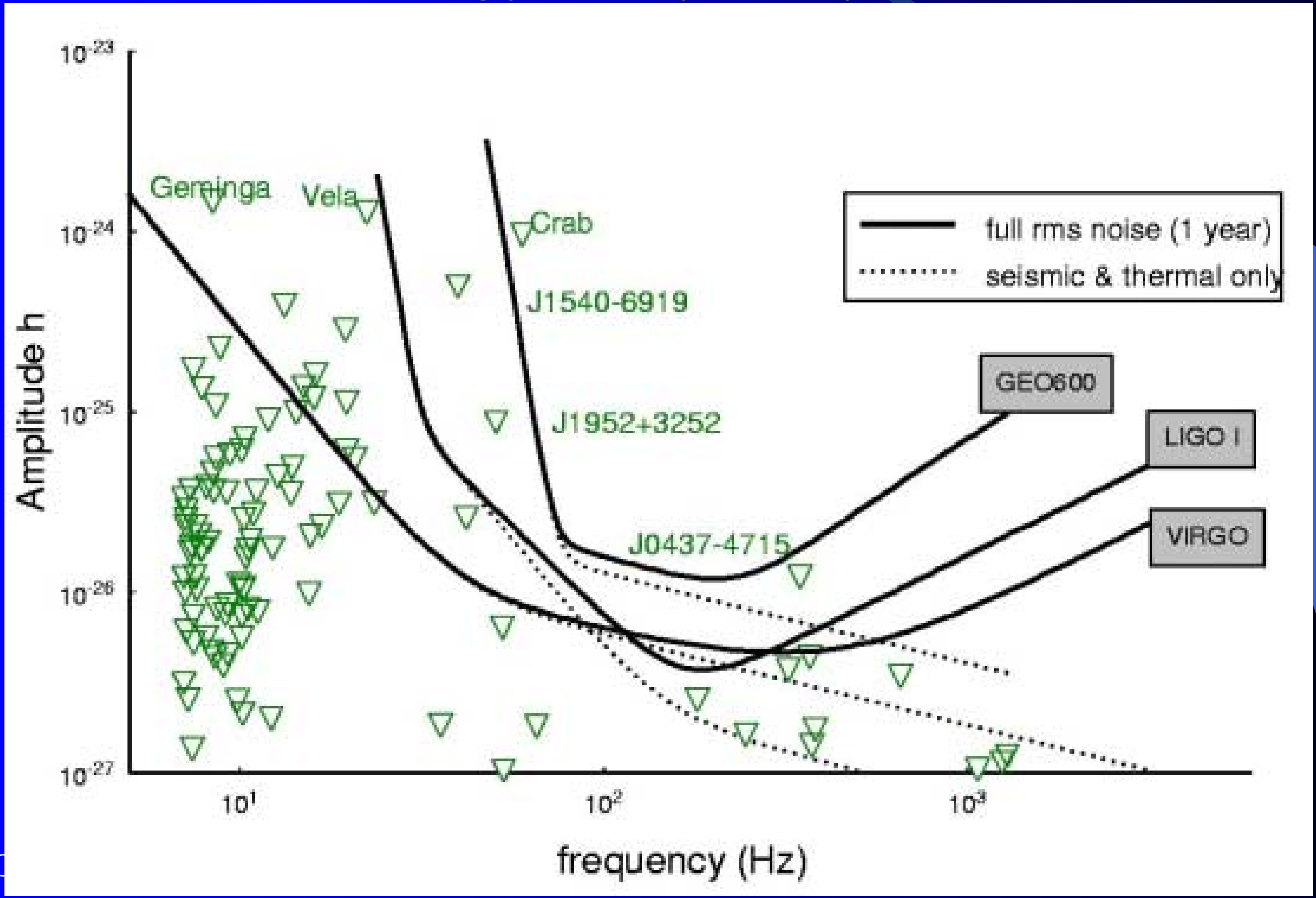

Current
Pend Q=6 10^7
Mirr φ 7 10^-8
P_las 250 W
Newtonian
HiQ Mirror
h(v) Hz^-1/2


HiQ Mirror
Pend Q=6 10^7 4K
Mirr φ 7 10^-8 4-30K
P_las 20-250 W
Newt corr
Twin Uncorr ITF
h(v) Hz^-1/2

Slowdown from pulsar

Upper limits on amplitudes from known pulsars, set by assuming spindown due to the emission of gw energy. The points represent all pulsars with gravitational wave frequencies above 7 Hz and amplitudes above 10^{-27}.

Expected sensitivities of three first-generation interferometers in a one-year observation, and the thermal noise limits on narrow-banding (dotted lines). K.A.Compton and B.F.Schutz, Cascina, 1996



Local gravity fluctuations

- Can’t be separated from true GW signal
- Related to local mass movement or density fluctuations
- “Stick out” of the seismic wall
- Work by Weiss, Saulson, Hughes and Thorne, Cella

Seism induced gravity fluctuations

- Seismic waves crossing interferometer corner and end points
- Horizontal shear waves have no effect
- Longitudinal waves have density variation
- Rayleigh waves give the main contribution:, combination of horizontal+vertical motion at free boundary.
- These are surface waves, with specific propagation characteristics

Study of gravity fluctuation

- Suggested by Thorne: ground geophysical information, layer position and composition
- Wave speed
- Local diffusion
- To construct a model that predicts the composition of a seismic wave (frequency, modes, direction) using a finite set of measurements

A dedicated study

- Groups from Pisa, Firenze, Urbino, Roma
- Original Proposal by
  - G. Calamai, E. Cuoco, P. Dominici, M. Mazzoni, M. Ripepe, R. Stanga, G. Losurdo, A. Bertolini, N. Beverini, F. Caratori, C. Carmisciano, G. Cella, O. Faggioni, I. Ferrante, F. Fidecaro, F. Strumia, R. Tripiccione, A. Viceré, E. Majorana, P. Puppo, P. Rapagnani, G.M. Guidi, F. Martelli, F. Vetrano
- Funded independently of Virgo
- Geophysical data collection and measurements
- Analytical and numerical model
- Development of cheap vertical accelerometers

Goals

- Establish the geology and the geophysics of site
- Establish analytic and numeric model for wave propagation, compute effects on test mass
- Simulate response of an array of accelerometers
- Develop code to test methods for gravity gradient subtraction
- Prototype vertical accelerometer
- Prototype field data acquisition system

Geophysics

Geophysical model in traditional way
- Three homogenous plane parallel layers
- One cilindrical layer on top (Arno river sediments)

Mathematical model in progress
- Boundary conditions between layers
- Eigenmodes classification
- Dispersion relations

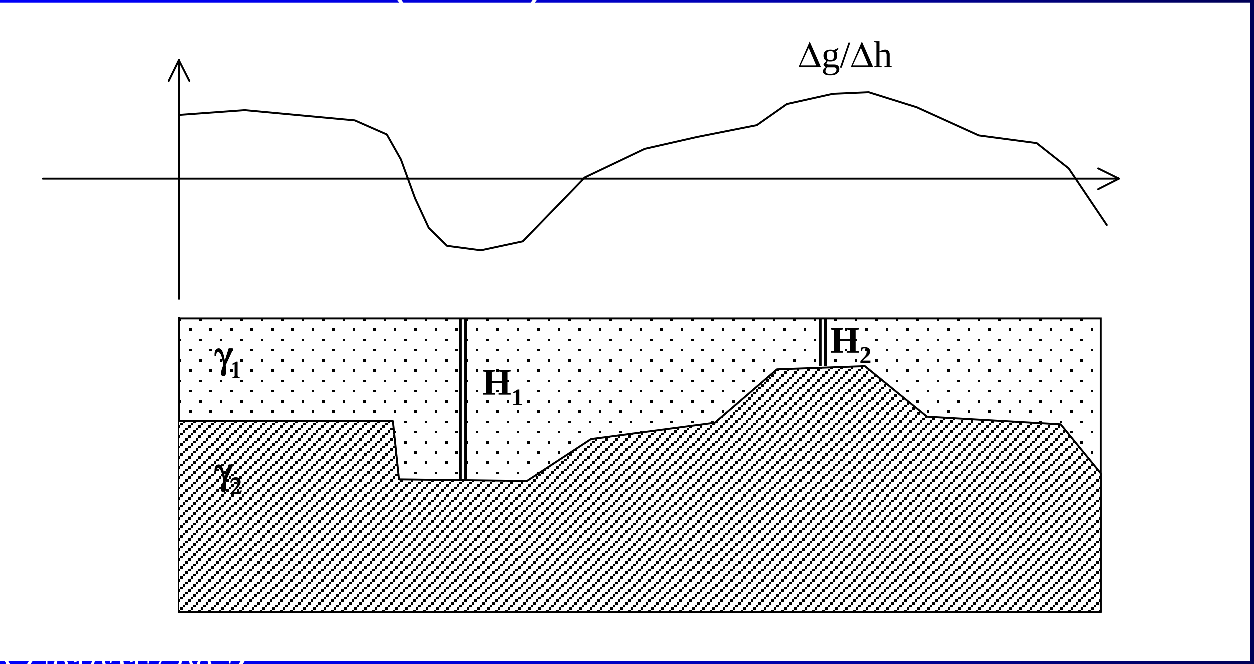
Comparison with FEM numerical approach

Comparison with LIGO sites would be useful, already benefited from discussions with Sz. Márka, would like to make plans for joint efforts

Seismic gravity gradient: geology

Geological layer model of Cascina site being completed

- Based on available maps, sampling and seismology
- Differential gravity measurements
  - To obtain a profile of the depth of the effective boundary between the first two layers.
  - About 150 (+/- 30) measurements needed



Thorne Hughes paper

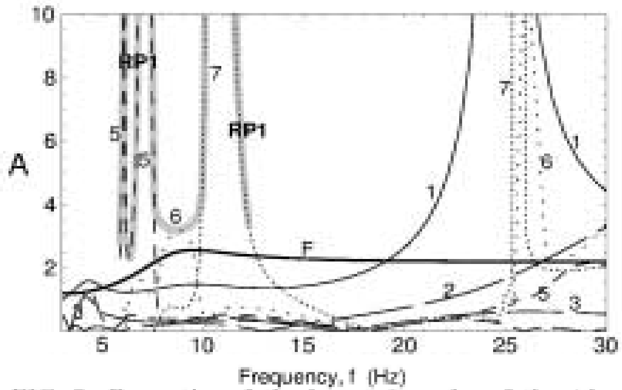


FIG. 7. Properties of the lowest 8 modes of the 4-layer Hanford model, including coupling between P- and SV-waves produced at boundaries between layers and at the earth's surface.

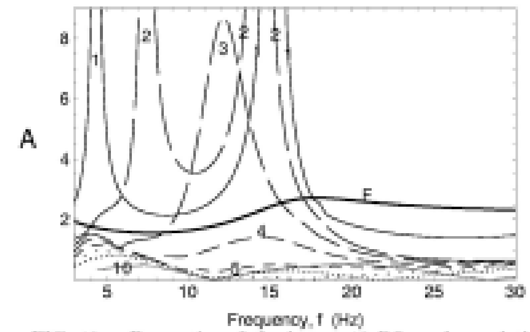
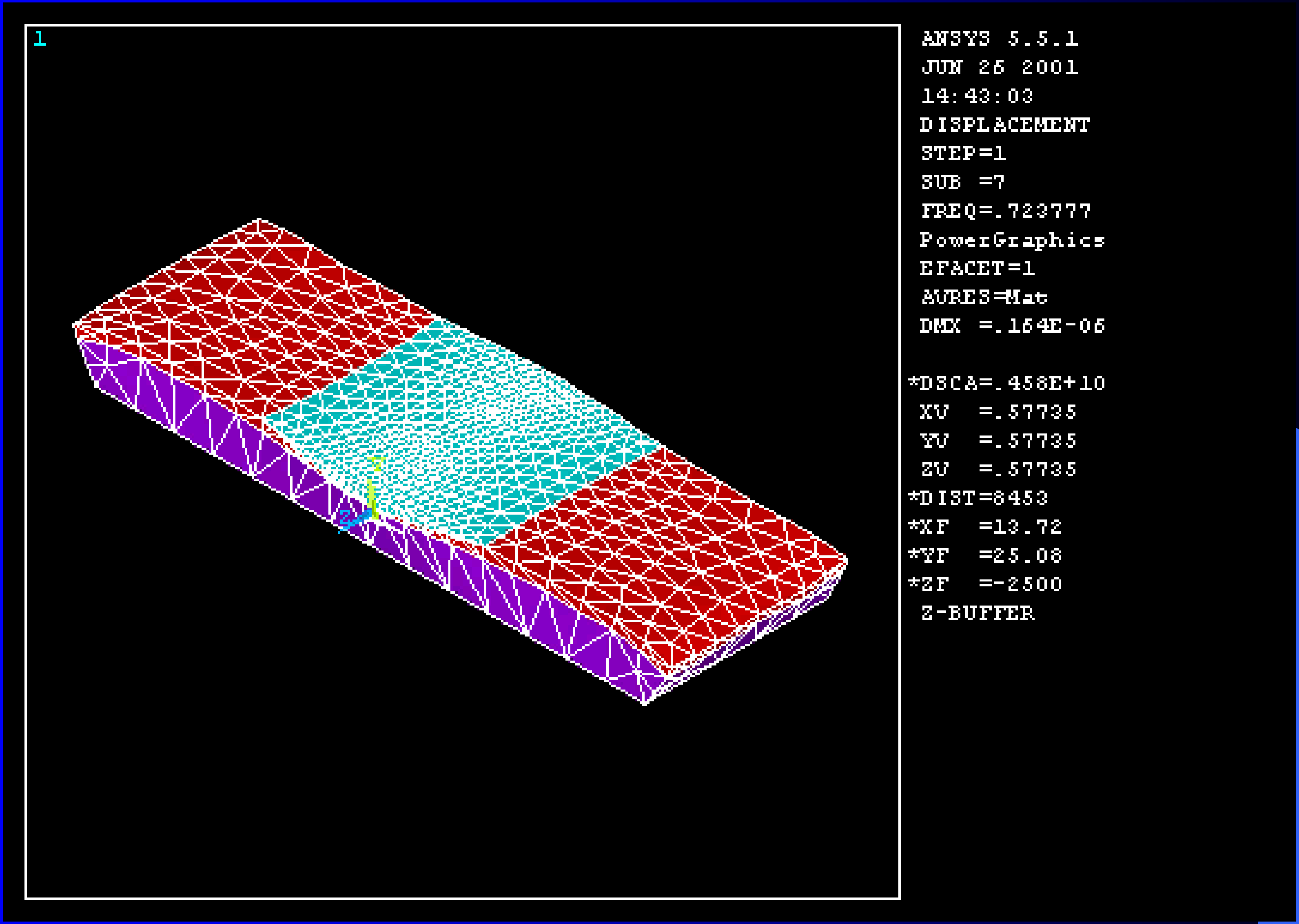


FIG. 10. Properties of the lowest 10 RS modes and the RF mode of the 4-layer Livingston model. (Modes RS8 and RS9 are not shown; their curves are sandwiched between 7 and 10.)

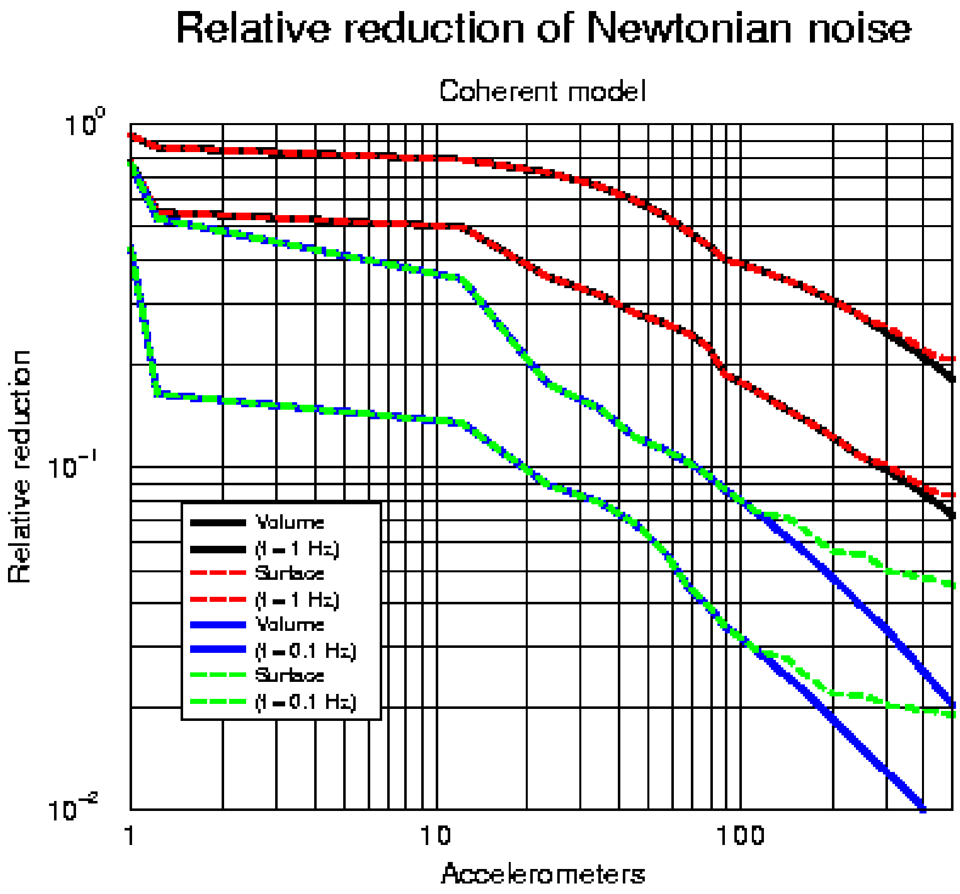
ANSYS Simulation



Seismic gravity gradient correction

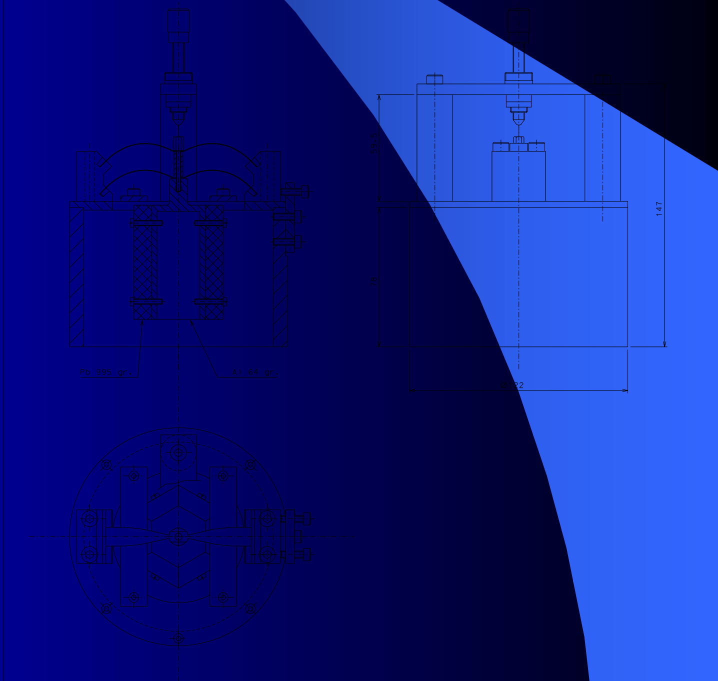
- Based on ground motion measurement around mirrors
- Establish expected correlation between motion and local gravity field
- Linear system: take projection of seismic modes on accelerometer array
- Invert accelerometer array readout to obtain expected local gravity field

Noise subtraction (Cella)



Vertical accelerometer

- Development of a dedicated vertical accelerometer
- Based on GAS concept
- Capacitive readout
- To be produced in hundreds
  - Ease of assembly
  - Reproducible
  - Stable



Atmospheric gravity gradient (not yet proposed)

Work by R Weiss, P Saulson, T Creighton

Building induced eddies density variation (Creighton)

Ground induced density variations

Wind induced turbulence: building, trees

Sound wave: 74 dB correspond to 0.1 Pa = 10^{-6} bar

10x10x30 m3 : mass change of 3 g

Acceleration at 10 m 2 x 10^{-15} ms^{-2}

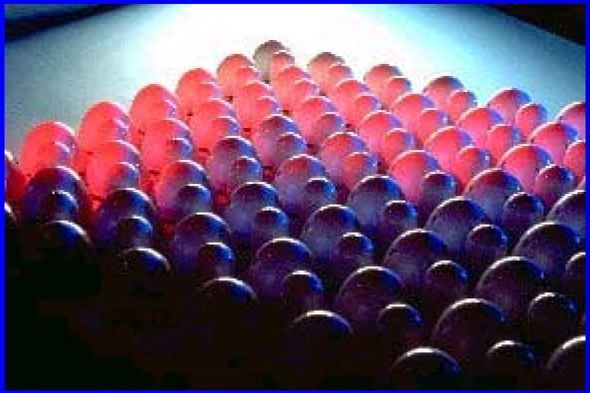
At 10 Hz δh= 1.6 x 10^{-22} down to 5 x 10^{-23} with more appropriate treatment

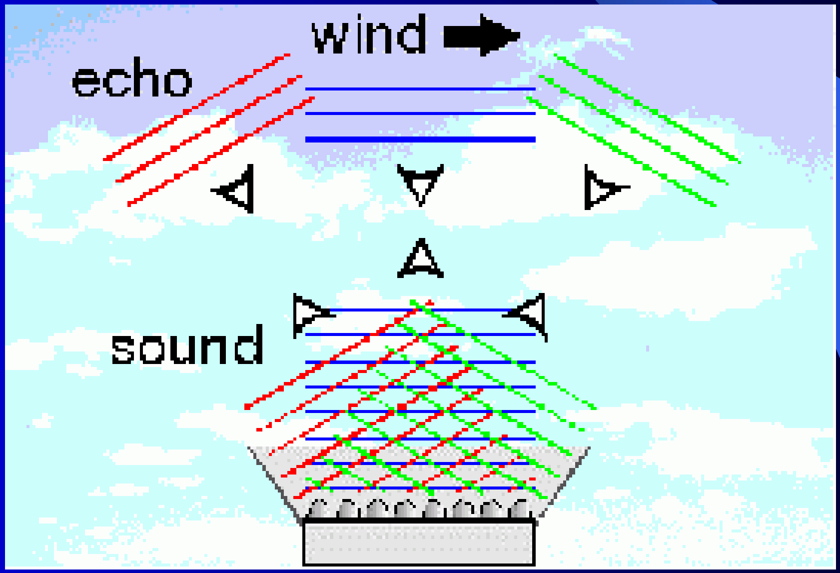
Actual conditions

- Not much is known of relevant parameters and of their statistical properties
- Need measurements, usual knowledge doesn't really apply
- Need to known this on a scale of ~ 100 m
- Meteo conditions
- Pressure and pressure spatial correlation
- T and T spatial correlation

Measurement tools

Temperature correlation on ground
Infrasound microphone
Instruments for atmospheric research
Sodar





Also measurements for active optics correction, scintillation on short distances

Perspectives on atmospheric effects

- Will propose to Virgo some long due measurements on site to assess effect
- Infrasound
- Wind
- Temperature
- Then evaluate whether to propose a dedicated effort