Ondas Gravitacionais: Detectores

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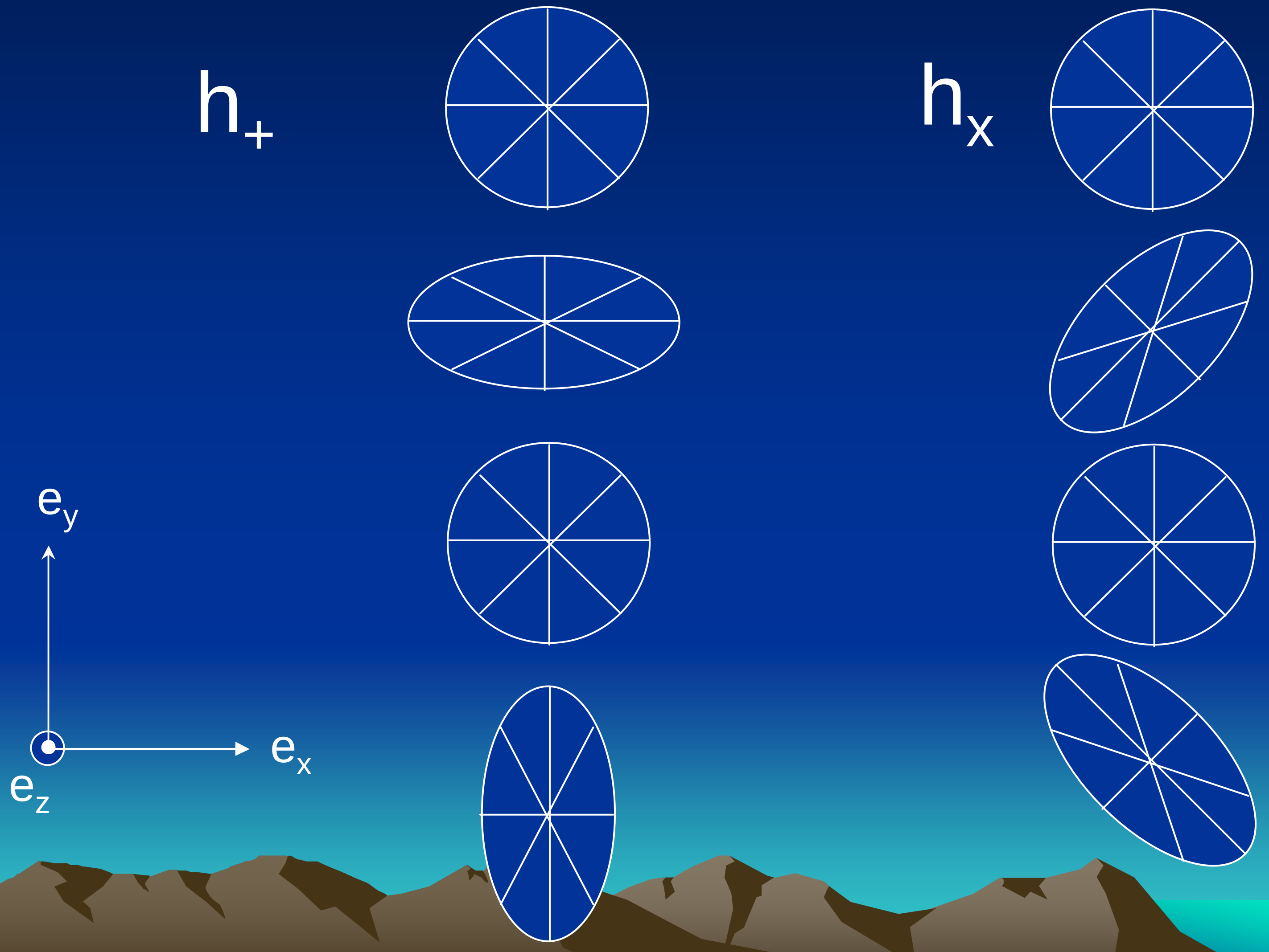
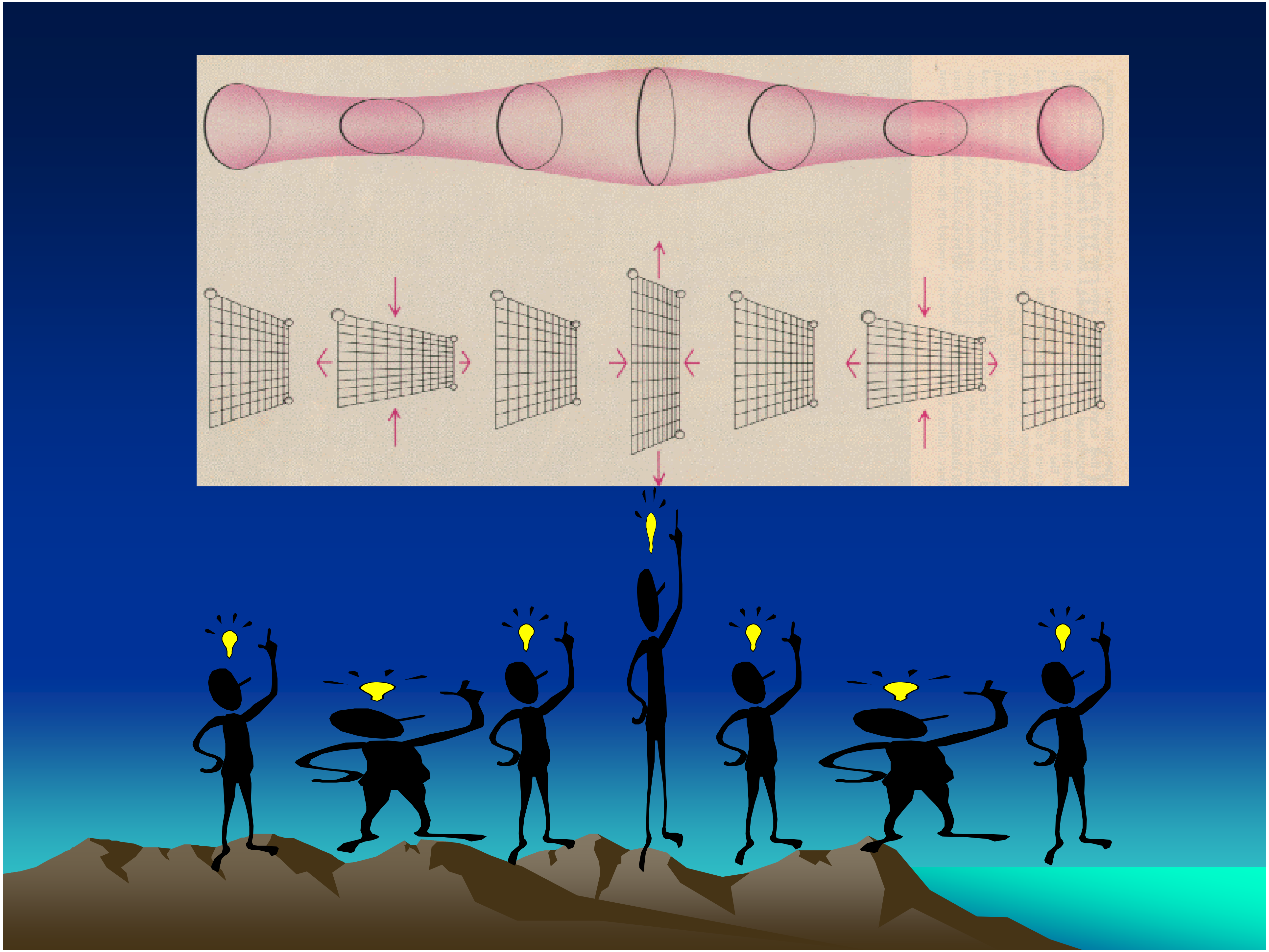
INPE; Grupo GRÁVITON

Workshop Nova Física no Espaço II
Campos do Jordão, 17 de fevereiro de 2003

Duas polarizações “+” e “x”





Ondas Gravitacionais

- Duas polarizações ("+" e "x")
- Amplitude pequeníssima: $h = \Delta L/L < 10^{-19}$
- Freqüências das ondas: 10^{-18} Hz a 10^{10} Hz
- A deformação do espaço-tempo devida à onda gravitacional provoca efeitos (forças) sobre a matéria

Possibilidade de detecção

Joseph Weber

1ª geração

Cilíndrico
300K

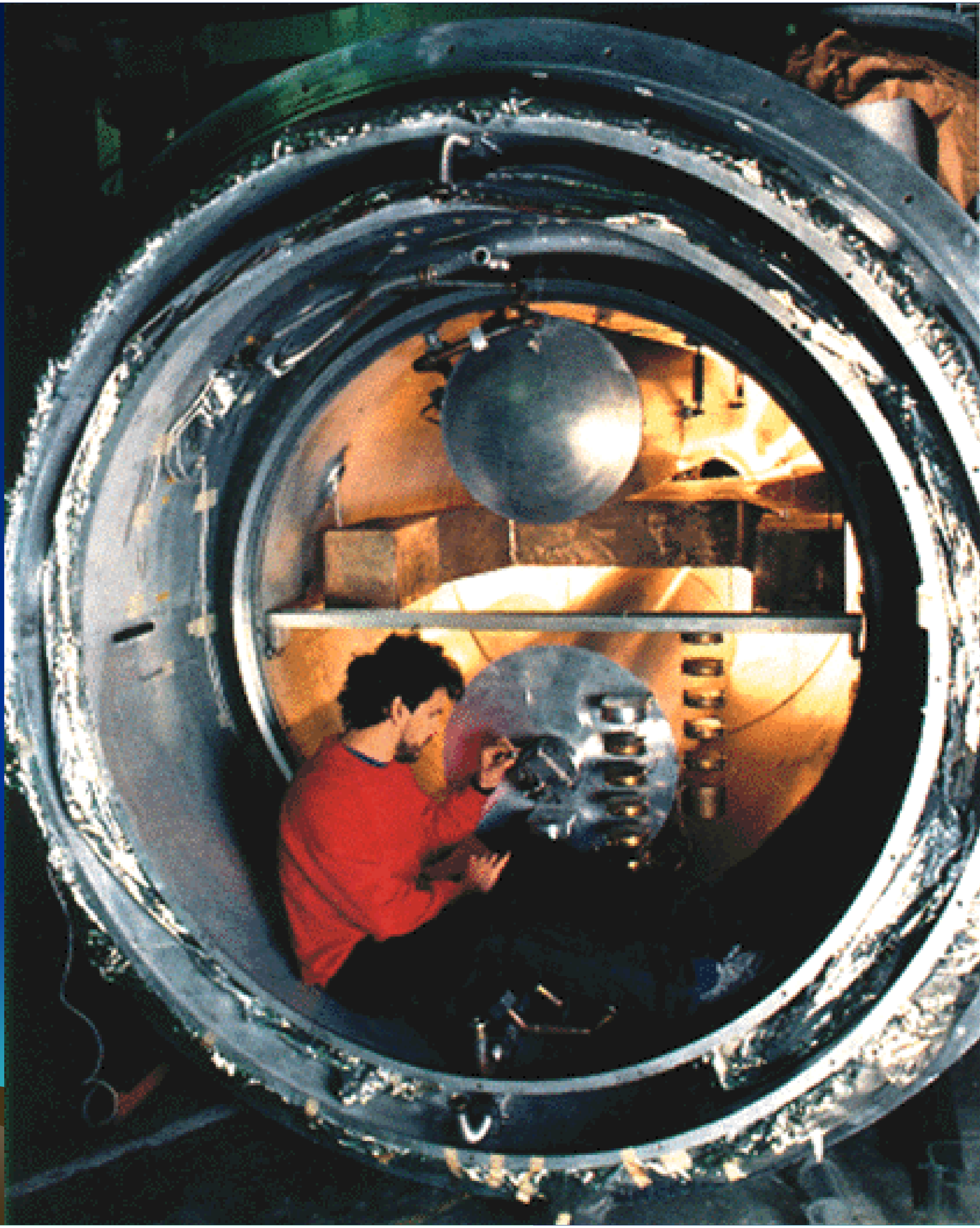
$h \sim 10^{-15}$

LSU (ALLEGRO)

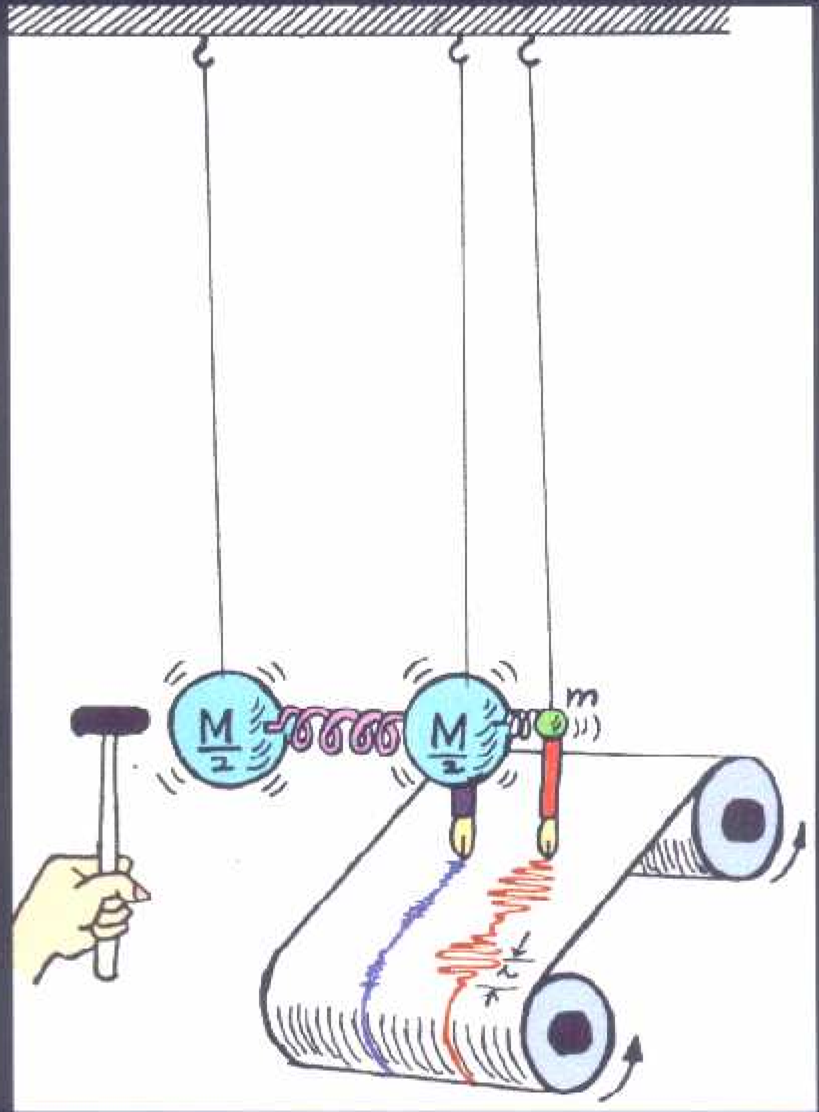
2ª geração

Cilíndrico
4K

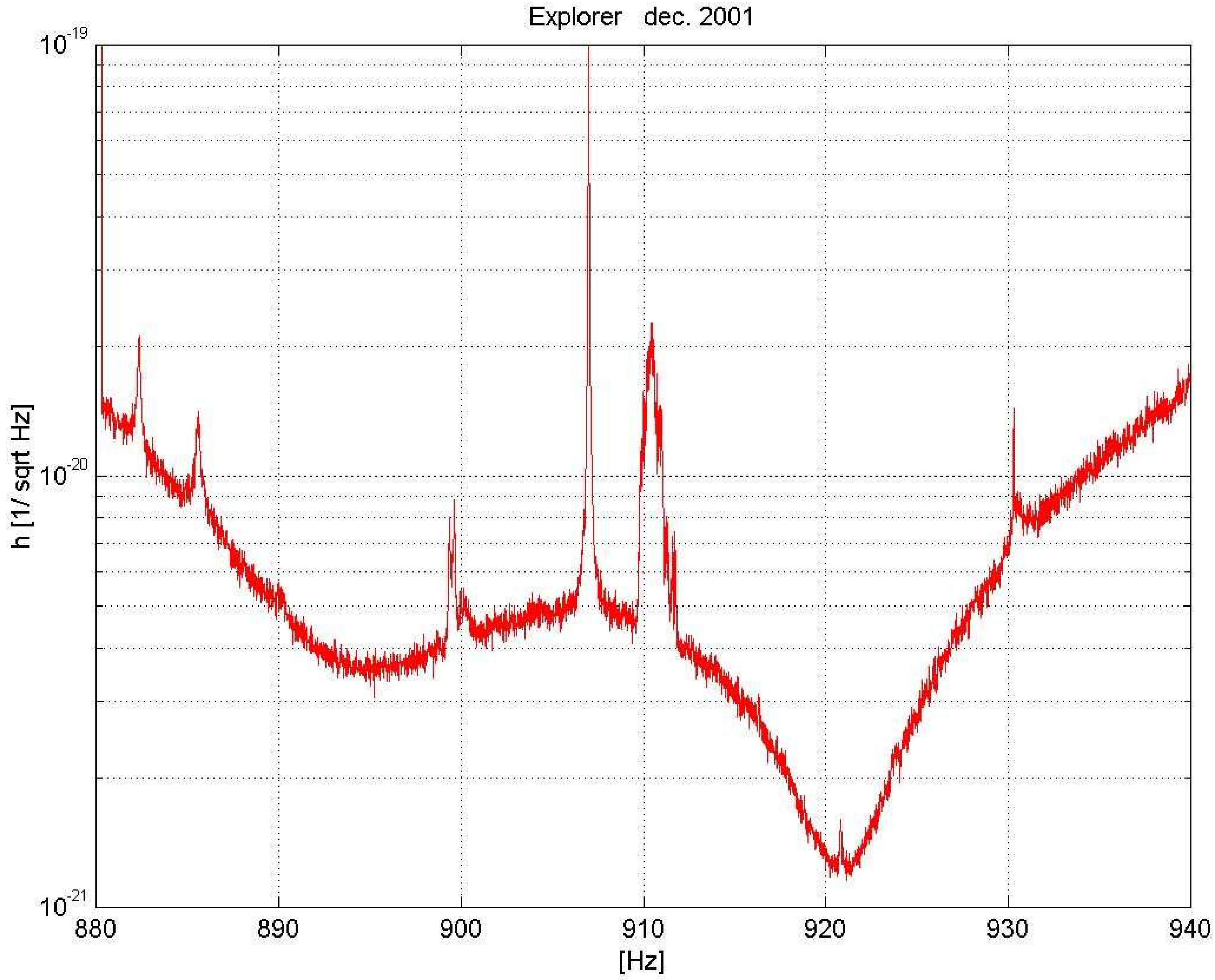
$h \sim 5 \times 10^{-19}$



Principle of a Resonant Transducer

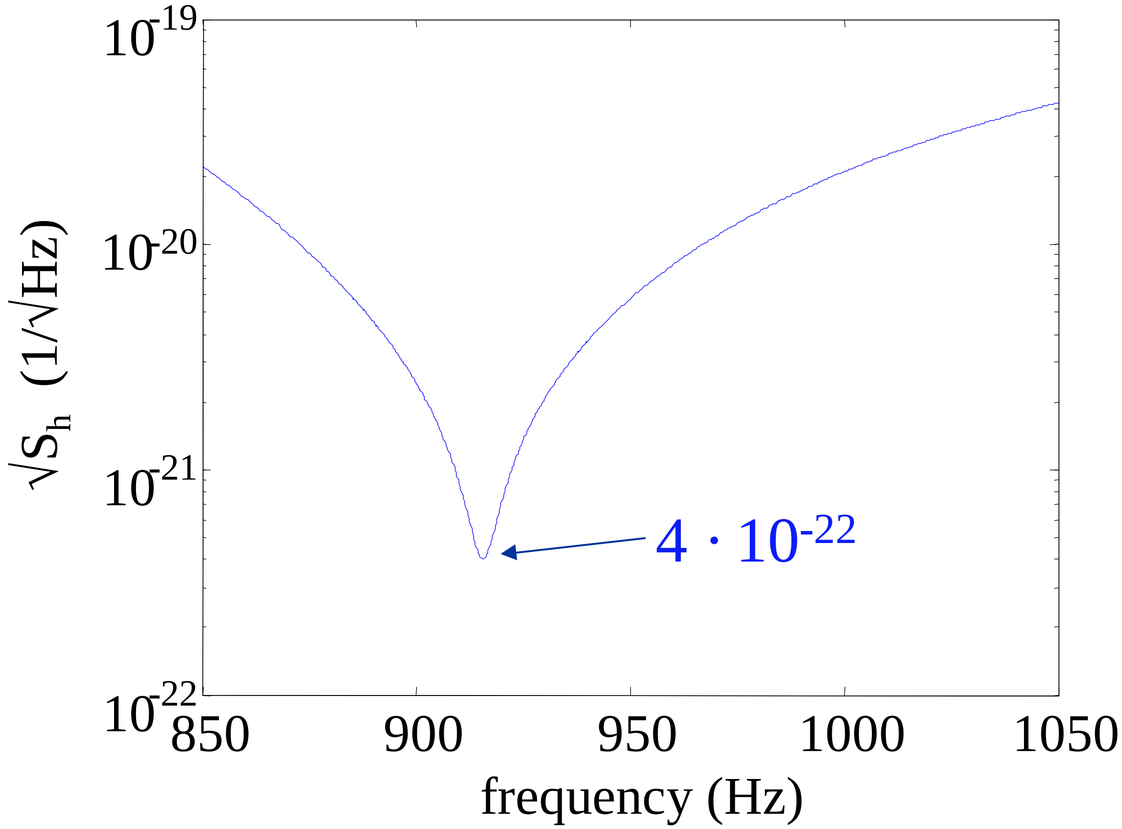


EXPLORER (2ª geração: cilíndrico, 4K)


Explorer dec. 2001
10^{-19}
10^{-20}
10^{-21}
h [1/ sqrt Hz]
880
890
900
910
920
930
940
[Hz]

TARGET SENSITIVITY OF EXPLORER

- EXPLORER can reach a sensitivity of T_{eff}=150 μK $h = 1 \cdot 10^{-19}$



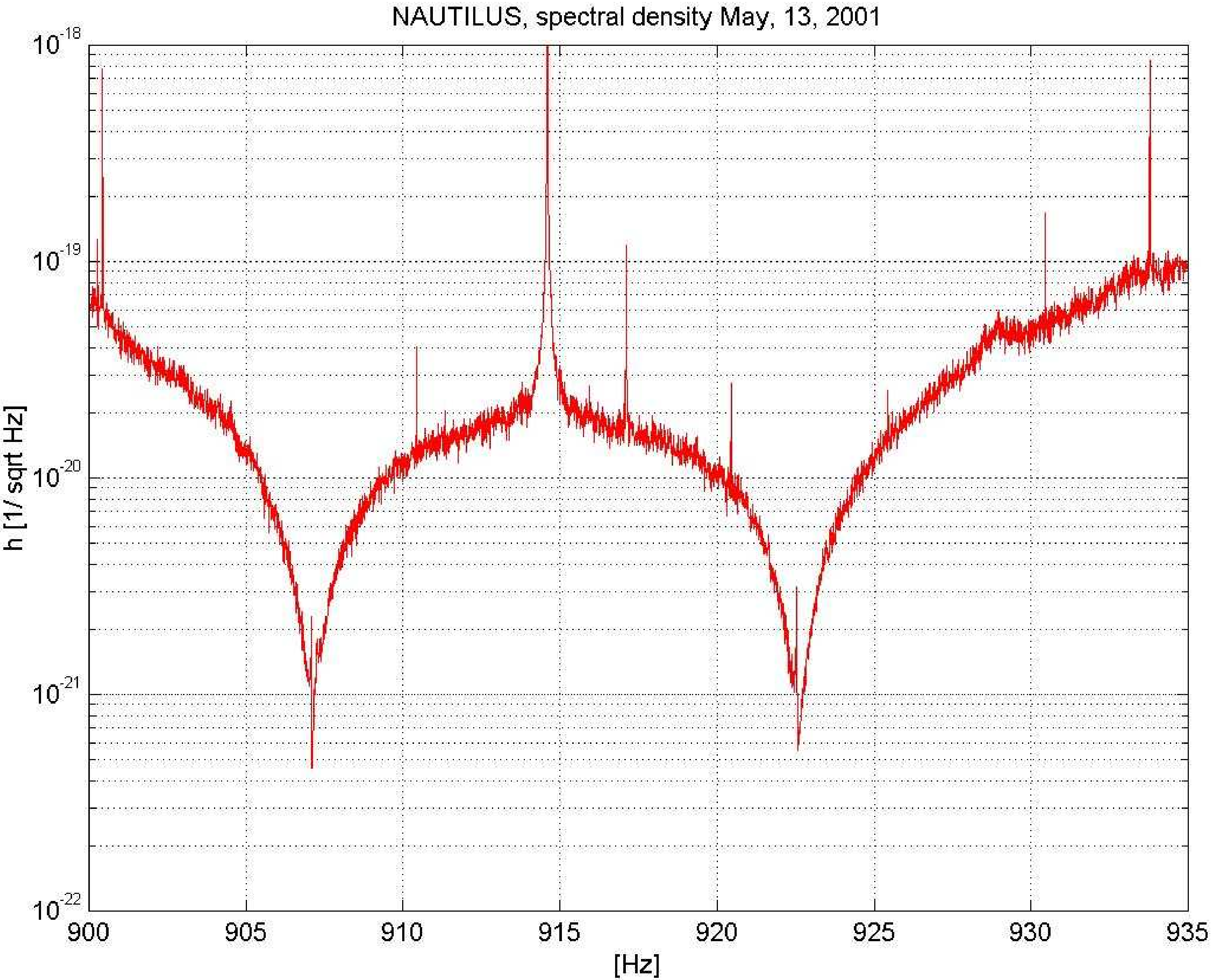
- New transducer double gap

- New transformer higher elect. Q

- New SQUID lower noise

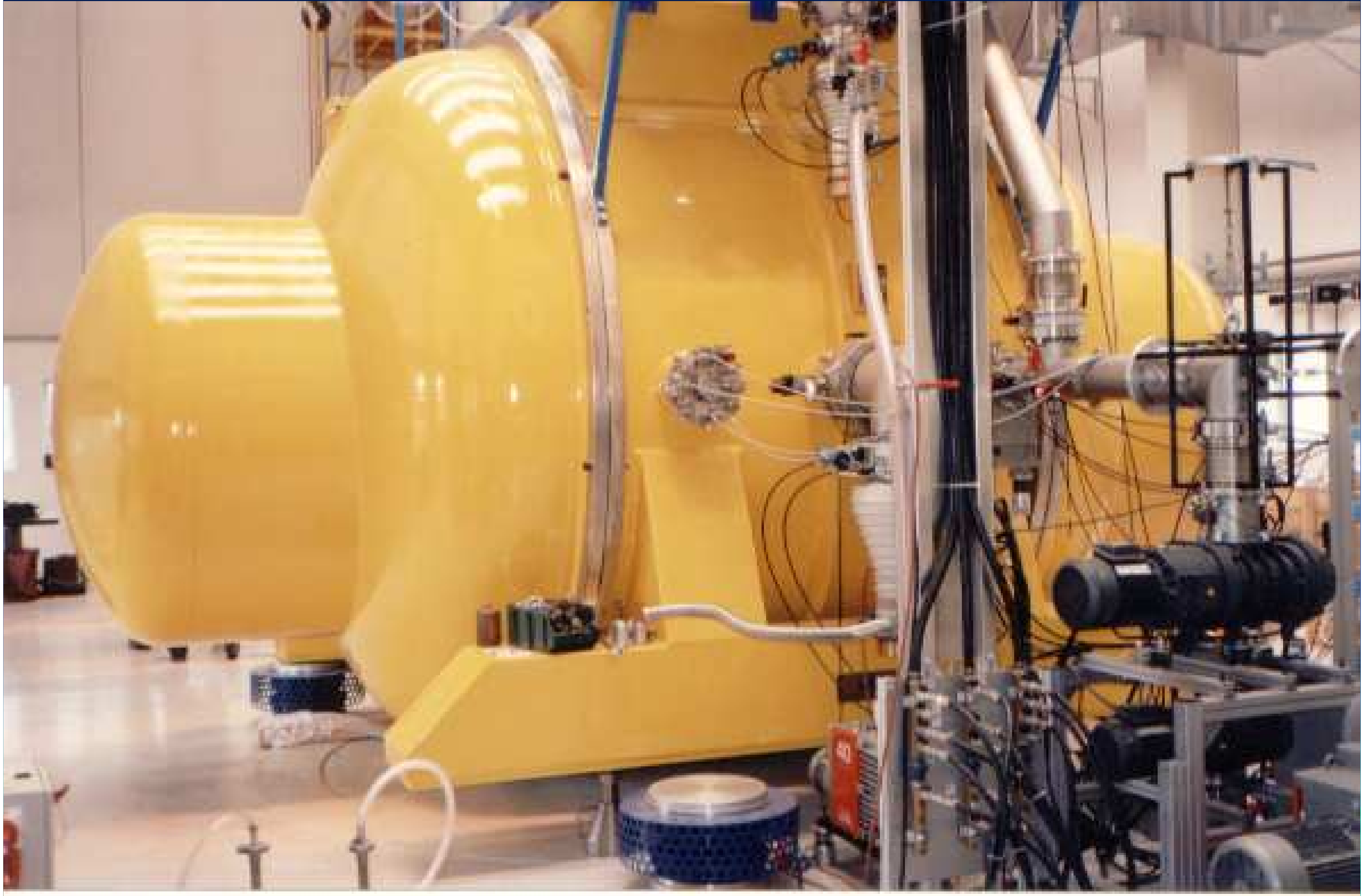
NAUTILUS (3ª geração: cilíndrico, 200mK)

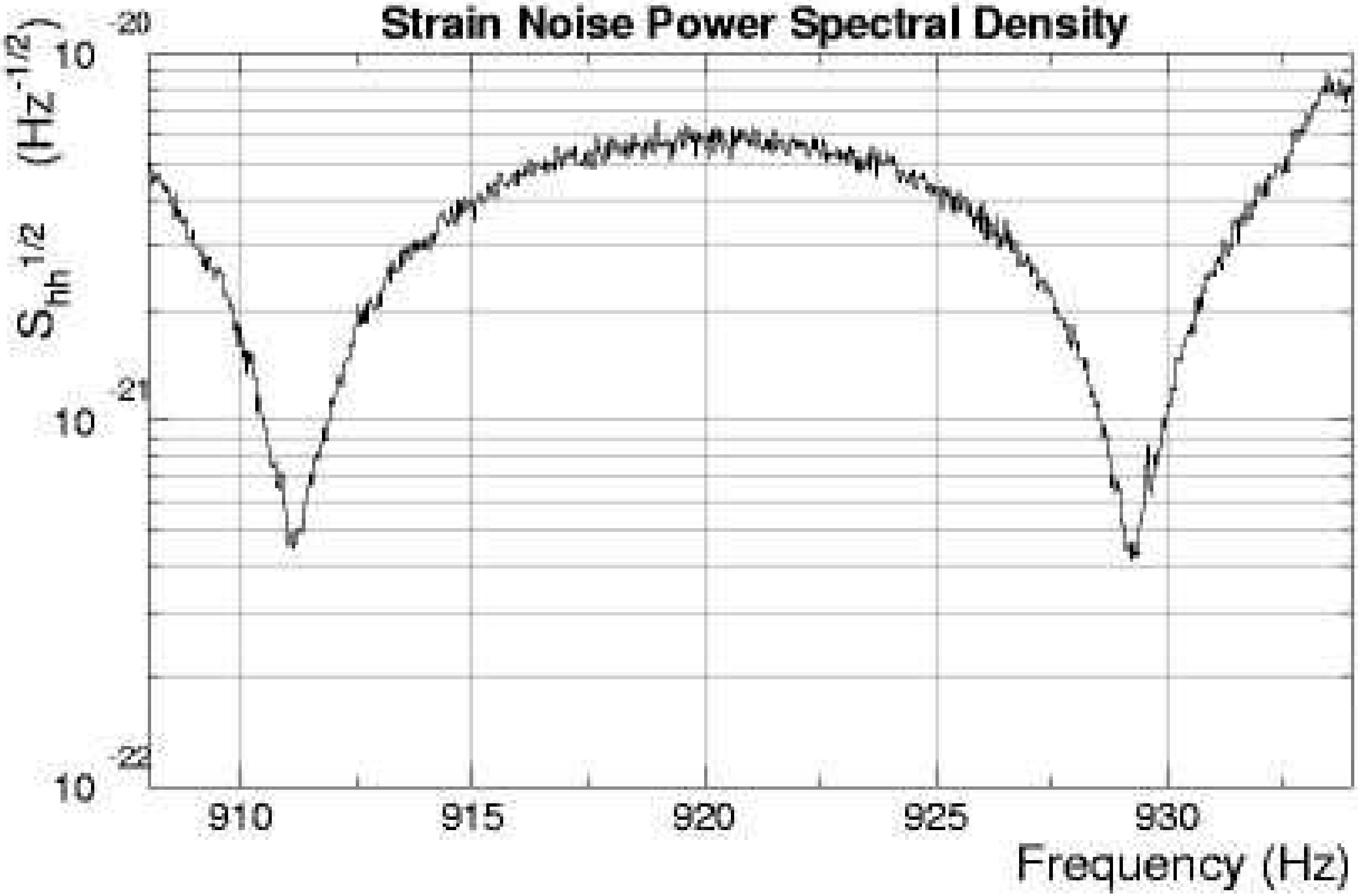
Camaras Criogênicas



NAUTILUS, spectral density May, 13, 2001
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
h [1/ sqrt Hz]
900
905
910
915
920
925
930
935
[Hz]

AURIGA (3ª geração: cilíndrico, 200mK)





Strain Noise Power Spectral Density
$S_{hh}^{1/2}$ $(Hz^{-1/2})$
10^{-20}
10^{-21}
10^{-22}
910
915
920
925
930
Frequency (Hz)

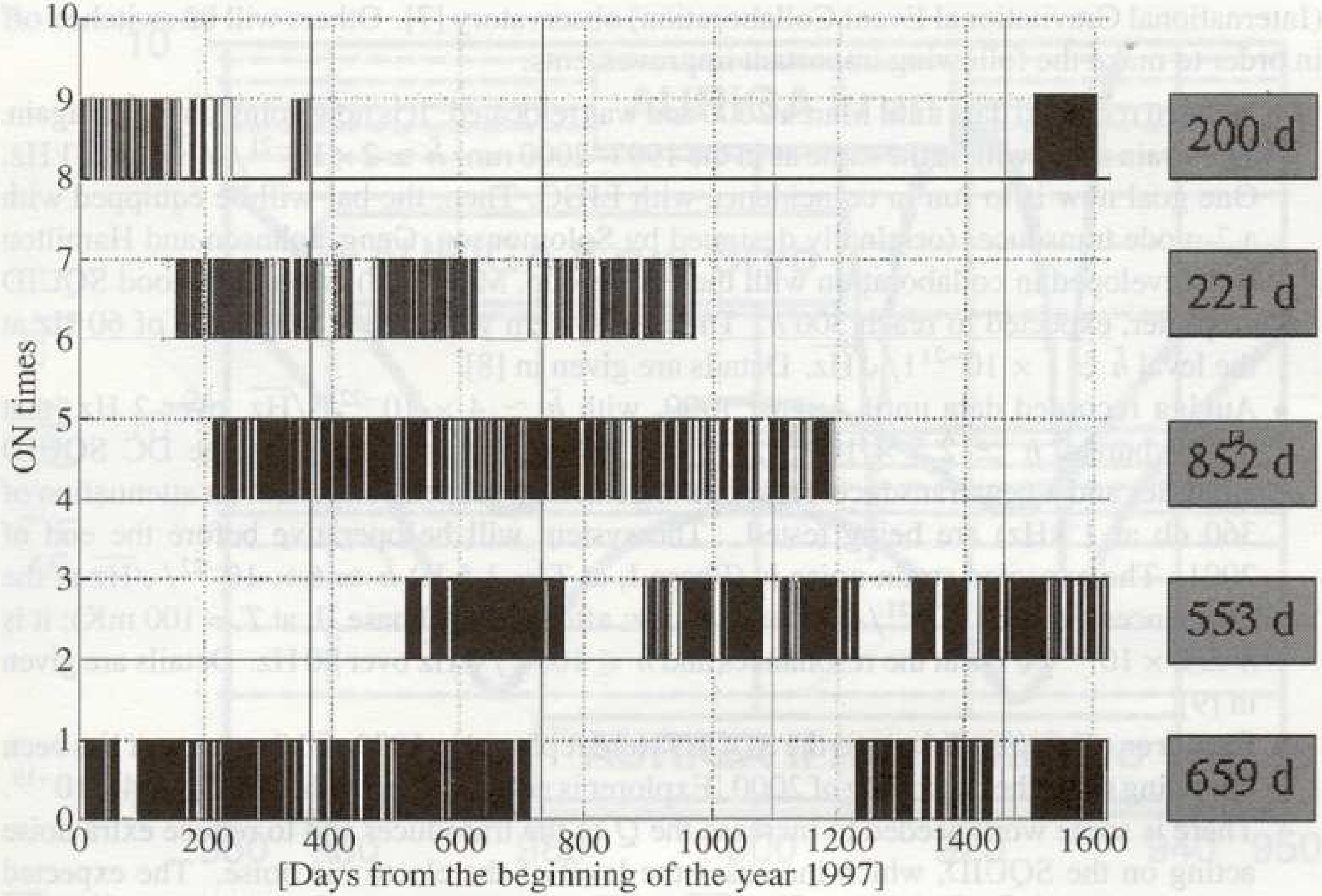
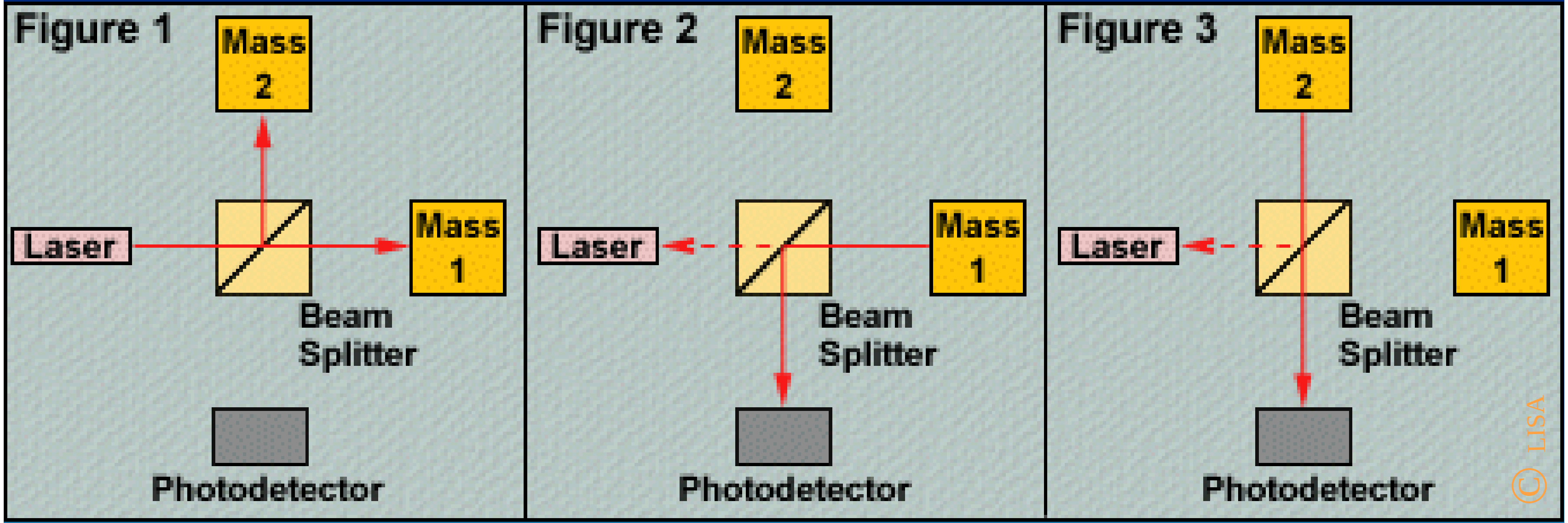
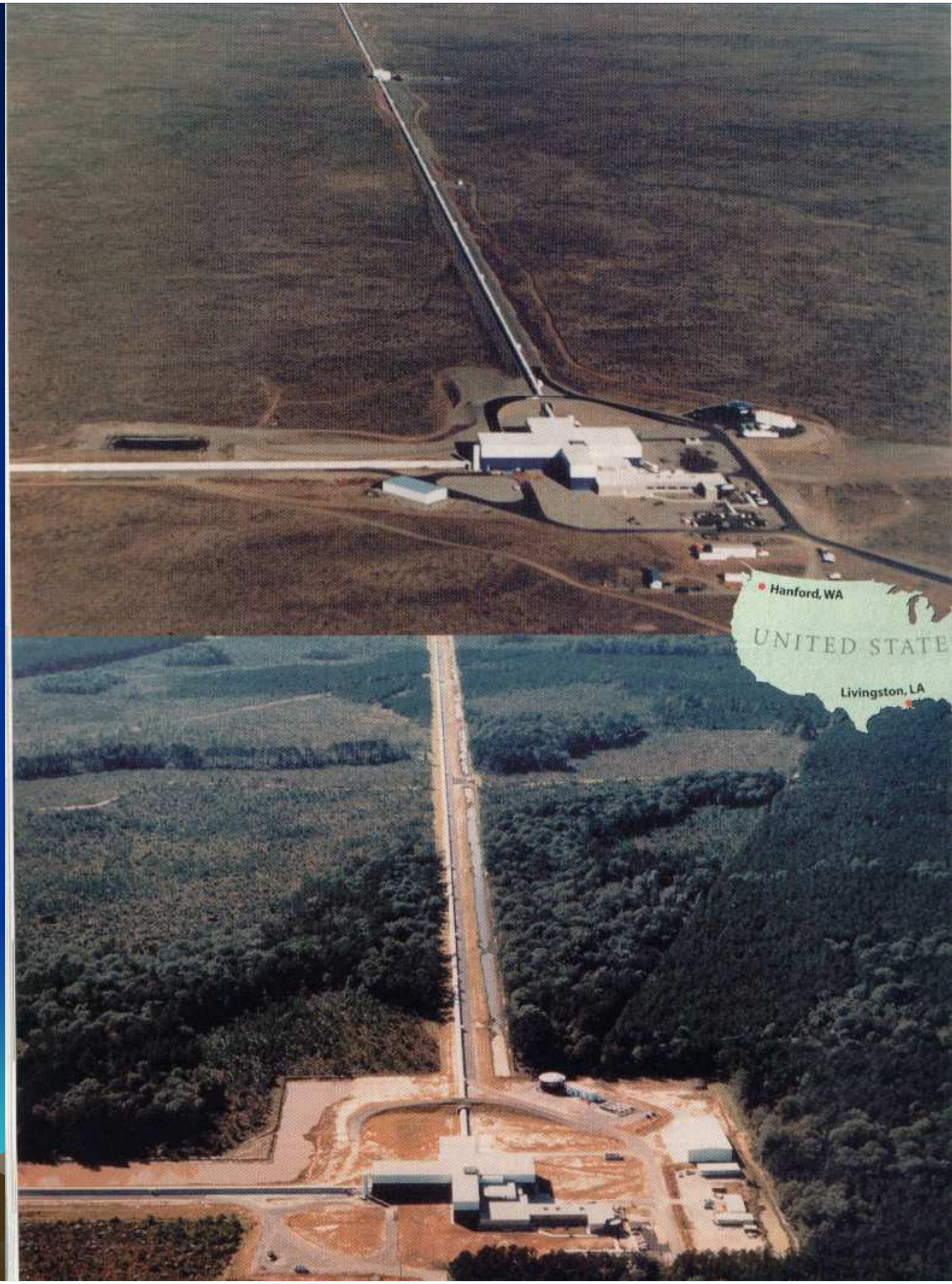


Figure 2. Operation times of the detectors, from January 1997 up to June 2001. The x-axis is in days, from 1 January 1997. The numbers in the rectangular regions are the total number of days of observation T_{obs}, for each detector. From bottom to top: Explorer ($T_{obs} = 659$ days), Nautilus ($T_{obs} = 553$ days), Allegro ($T_{obs} = 852$ days), Auriga ($T_{obs} = 221$ days), Niobe ($T_{obs} = 200$ days). The y-axis is different for the various detectors, e.g, for Allegro it ranges from 4 (detector off) to 5 (detector on).

Detectores Interferométricos



LIGO
(EUA)
4km



LIGO em Hanford (EUA)

LIGO

schedule and plan

Primary Activities

1996 Construction Underway (mostly civil)

1997 Facility Construction (vacuum system)

1998 Interferometer Construction (complete facilities)

1999 Construction Complete (interferometers in vacuum)

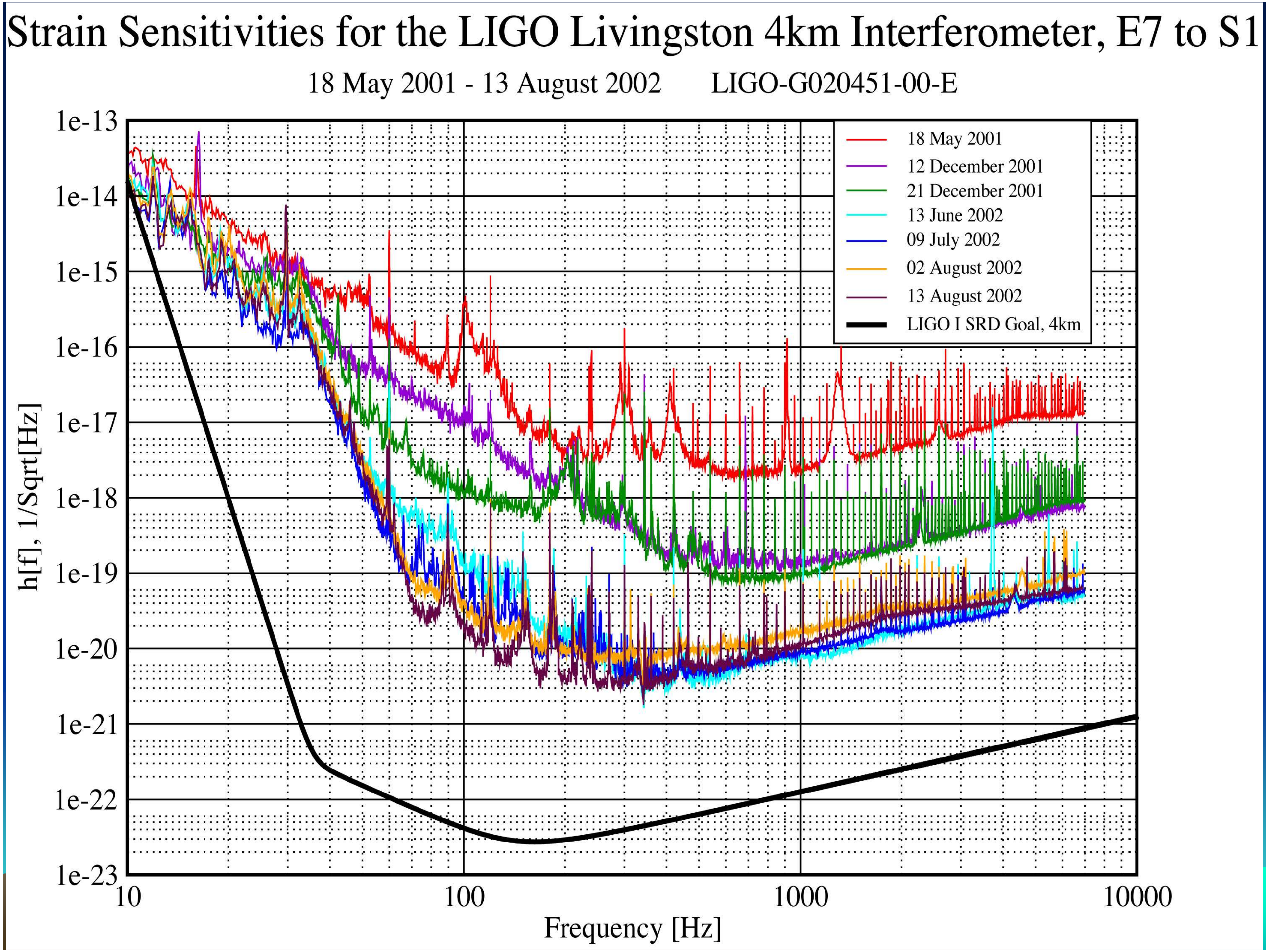
2000 Detector Installation (commissioning subsystems)

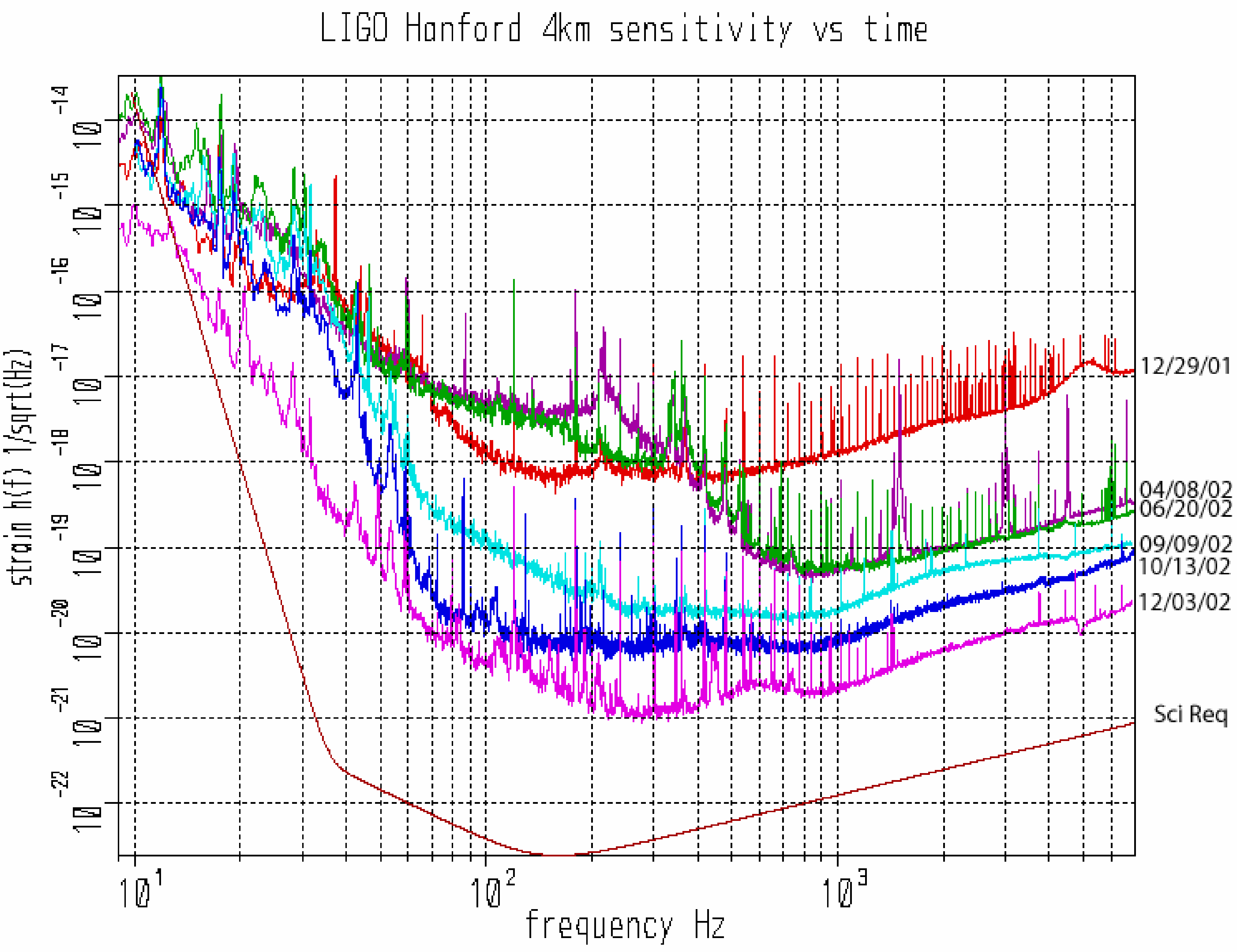
2001 Commission Interferometers (first coincidences)

2002 Sensitivity studies (initiate LIGO I Science Run)

2003+ LIGO I data run (started February 14)

2006+ Begin ‘Advanced LIGO’ installation


Strain Sensitivities for the LIGO Livingston 4km Interferometer, E7 to S1
18 May 2001 - 13 August 2002
LIGO-G020451-00-E
18 May 2001
12 December 2001
21 December 2001
13 June 2002
09 July 2002
02 August 2002
13 August 2002
LIGO I SRD Goal, 4km
h[f], 1/Sqrt[Hz]
1e-13
1e-14
1e-15
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
10
100
1000
10000
Frequency [Hz]


LIGO Hanford 4km sensitivity vs time
strain h(f) 1/sqrt(Hz)
frequency Hz
12/29/01
04/08/02
06/20/02
09/09/02
10/13/02
12/03/02
Sci Req

GEO 600

German-British collaboration
Site in Hanover (Germany)

The GEO 600 Diary

The groundbreaking party, September 4th 1995
The site on November 17th 1995 (begin of construction)
The site in June 1999 (test run of main suspension)
The site in Summer 2001 (suspension, data, first fringes)
The site in Fall 2001 (test runs)
The site in January 2002 (successful coincidence run)
The site in Spring 2002 (improvement of the detector sensitivity)
The site in August/September 2002 (second coincidence run)

First Science Run (S1) of the LIGO Scientific Collaboration. LIGO-GEO coincidence test run took place from August 23 to September 9, 2002.

During this run 411 hours of data have been taken.
The longest continuous period the detector was working at its designed operation point (all systems in lock) was over 121 hours. The overall duty cycle of the detector was above 97 %.

Immediately after this coincidence run an engineering run started. We plan to inject signals with calculated inspiral waveforms into the detector in order to test and characterize the efficiency of the data analysis pipeline for inspirals.

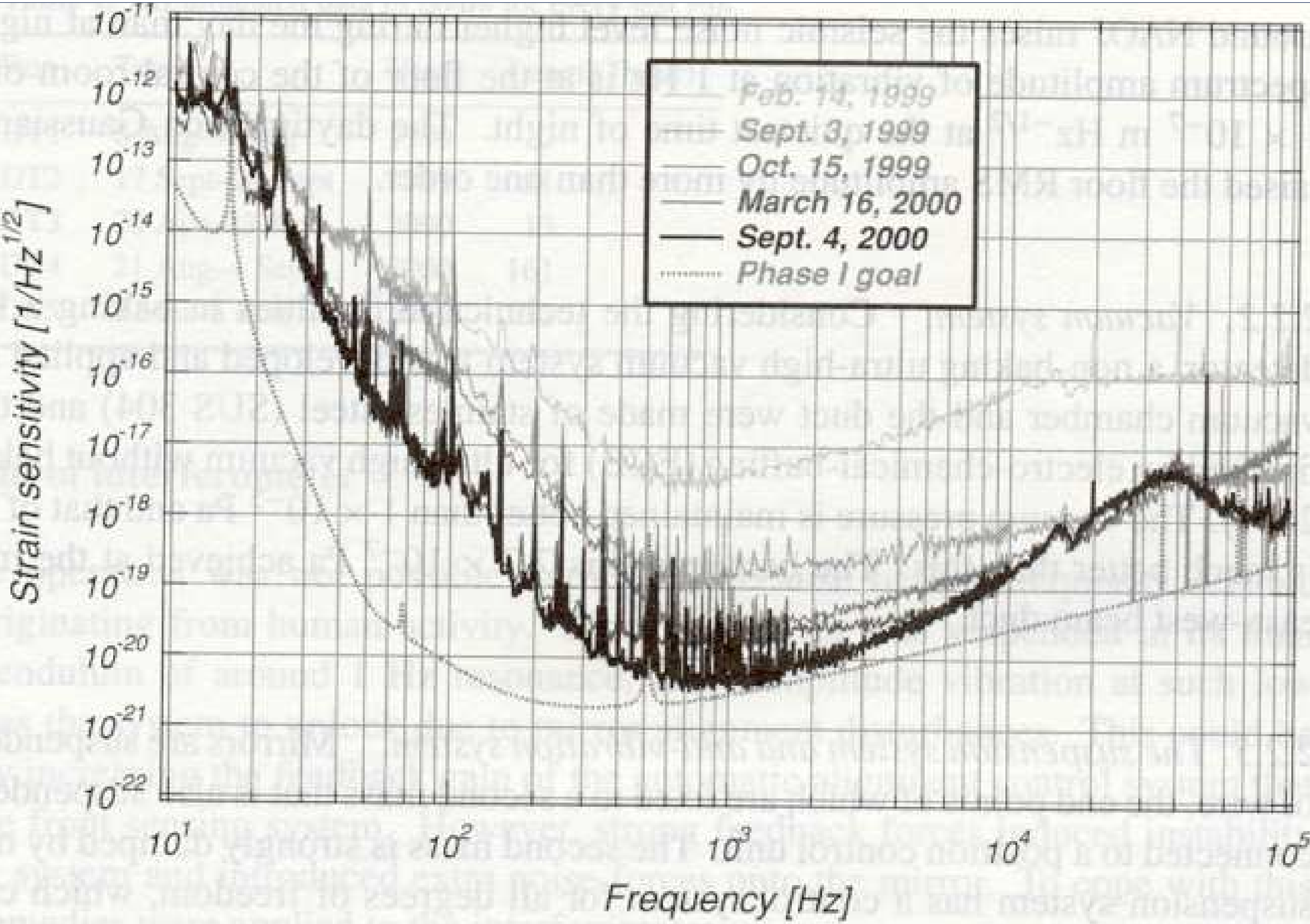
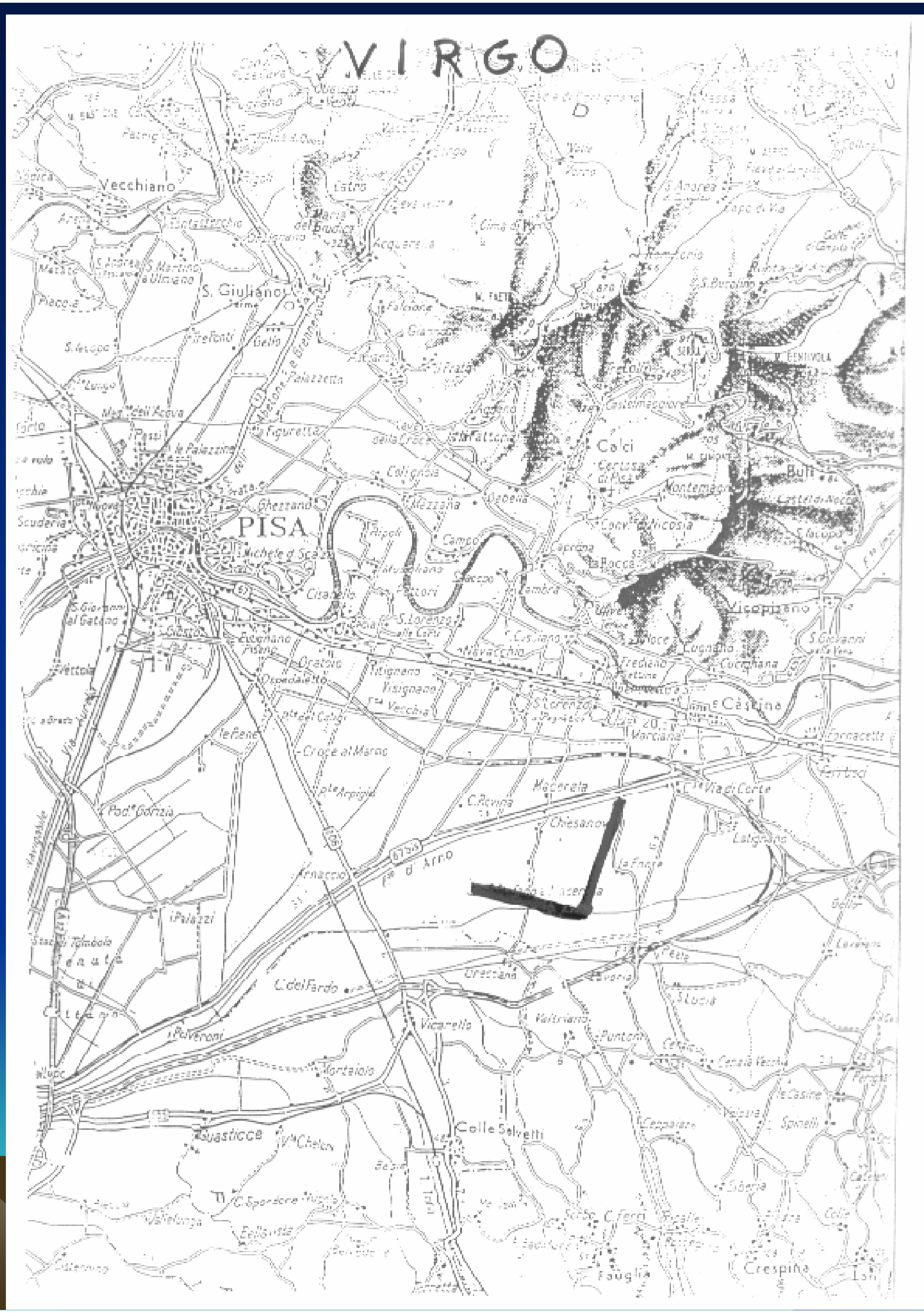


Figure 1. History of the improvement of TAMA sensitivity. The achieved sensitivity is close to the goal of the first phase (without a recycling mirror).


VIRGO
Vecchiano
S. Giuliano
PISA
Calci
Buti
Vicopisano
Cascina
Colle Salvetti
Crespina
Fauglia

VIRGO is an Italian-French collaboration

- Michelson laser interferometer (3 kilometres long).
- Multiple reflections (the effective optical length ~120 km).
- located at Cascina, near Pisa on the Arno plain.
- 10 to 6,000 Hz.

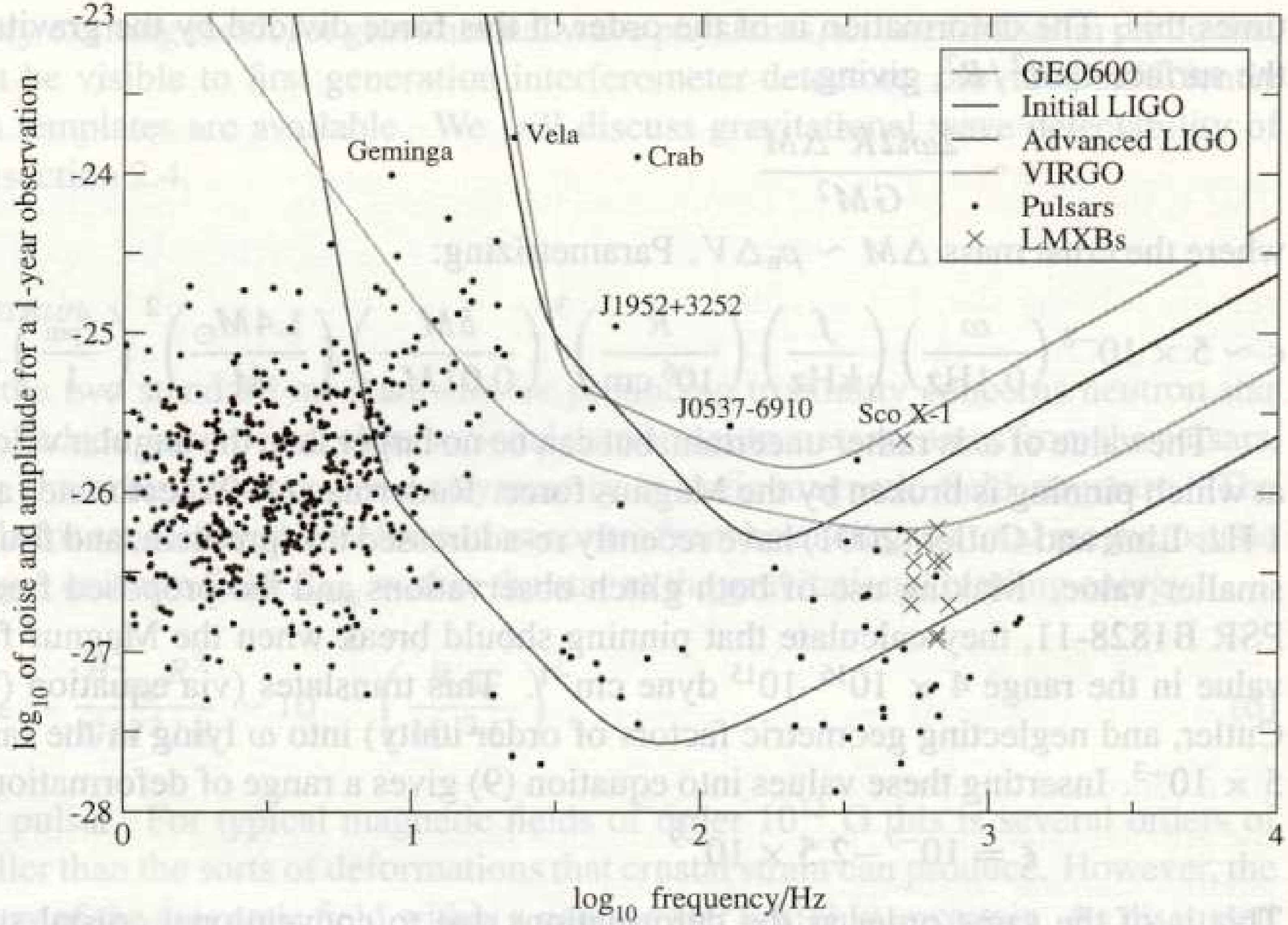
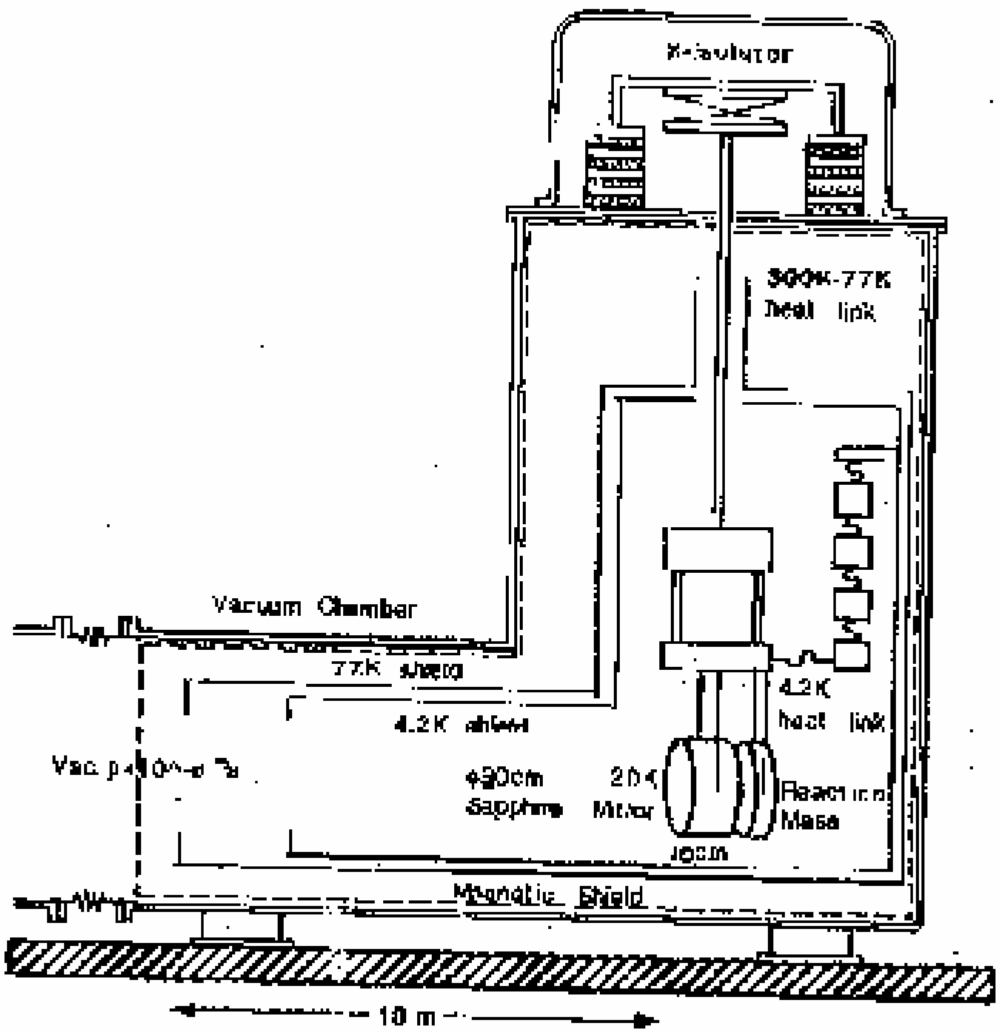


Figure 1. Upper bound on h from spin-down rates for pulsars and accretion luminosity for LMXBs. Pulsar data are from Princeton catalogue and Lorimer (2001), LMXB data from Bildsten (1998).

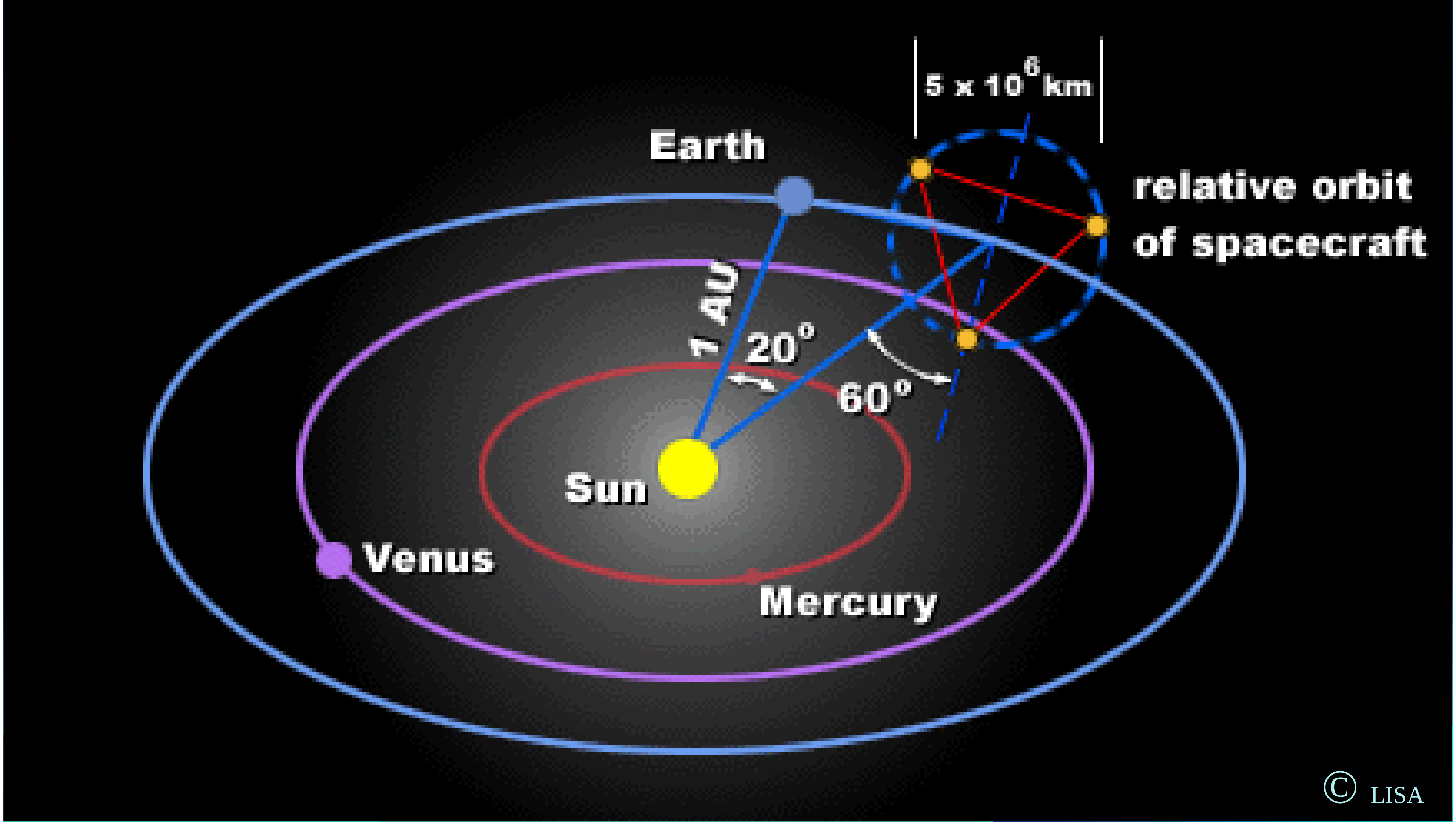
(This figure is in colour only in the electronic version)

LCGT

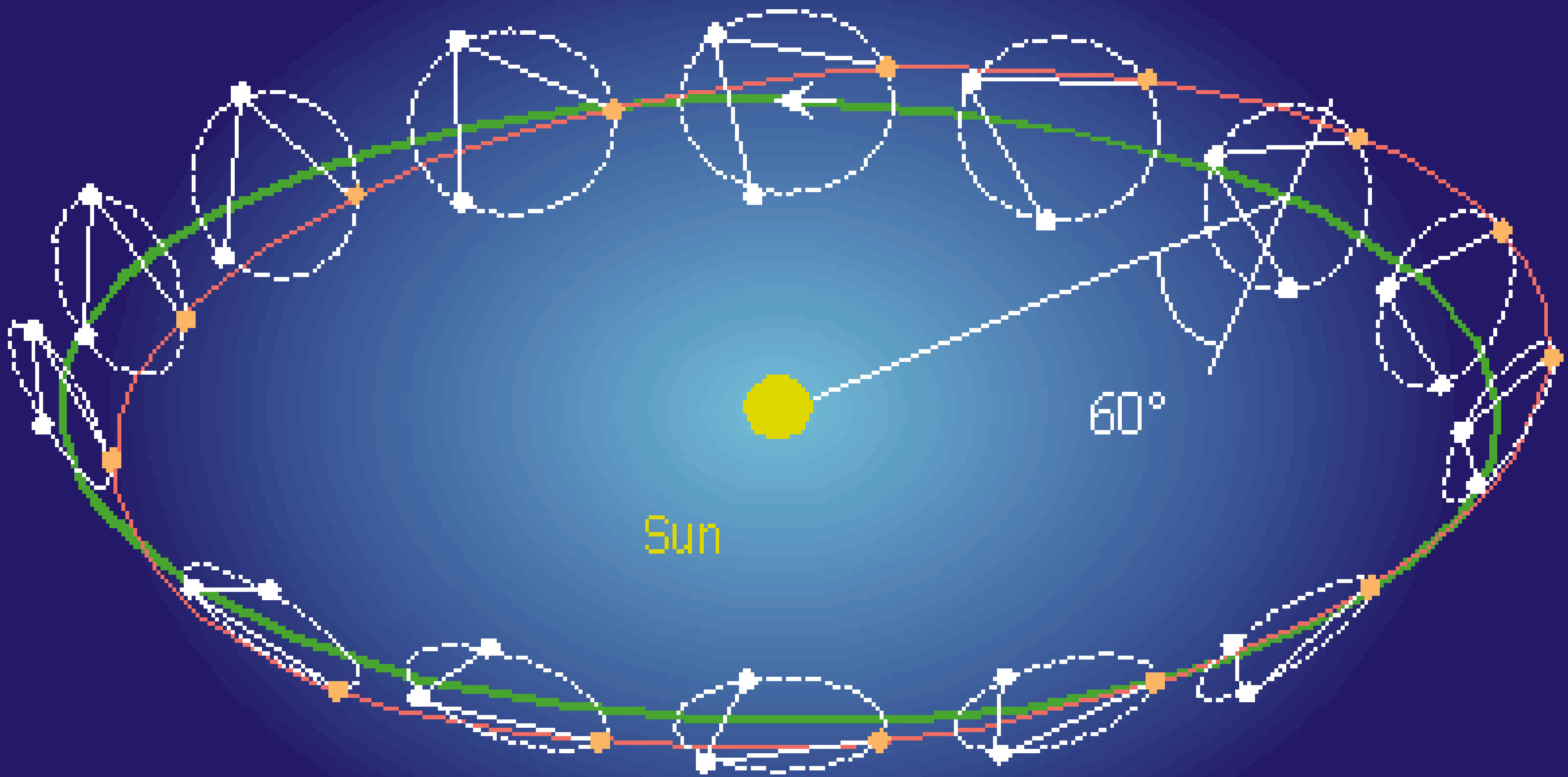
Large
Cryogenic
Gravitational
wave
Telescope



Lisa: Interferômetros no Espaço



Lisa em Órbita

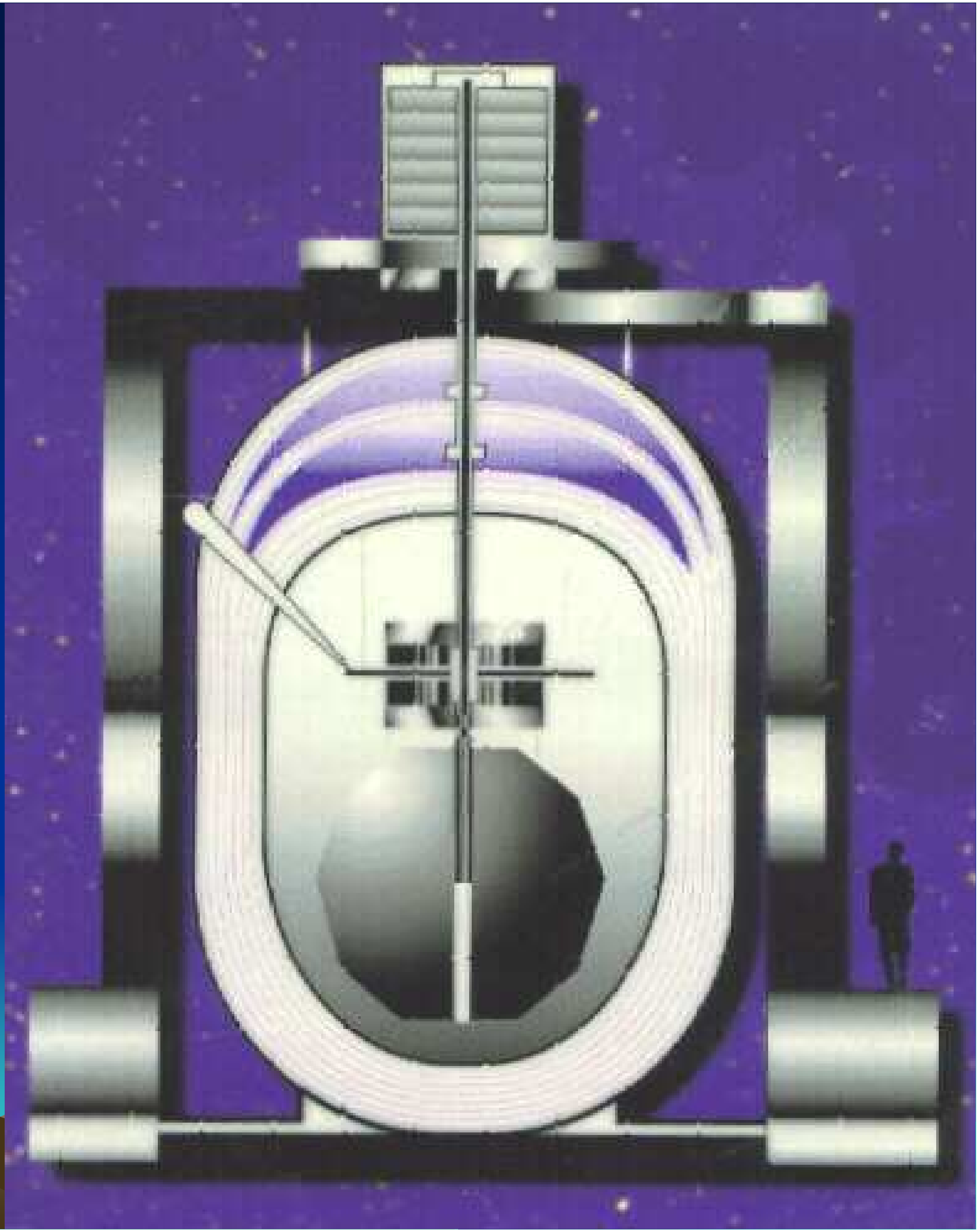


Detectores massivos com geometria esférica

Projeto GRÁVITON

(Brasil)

1991



MiniGrail (Holanda)

Sfera (Itália)

Mario SCHENBERG (Brasil)

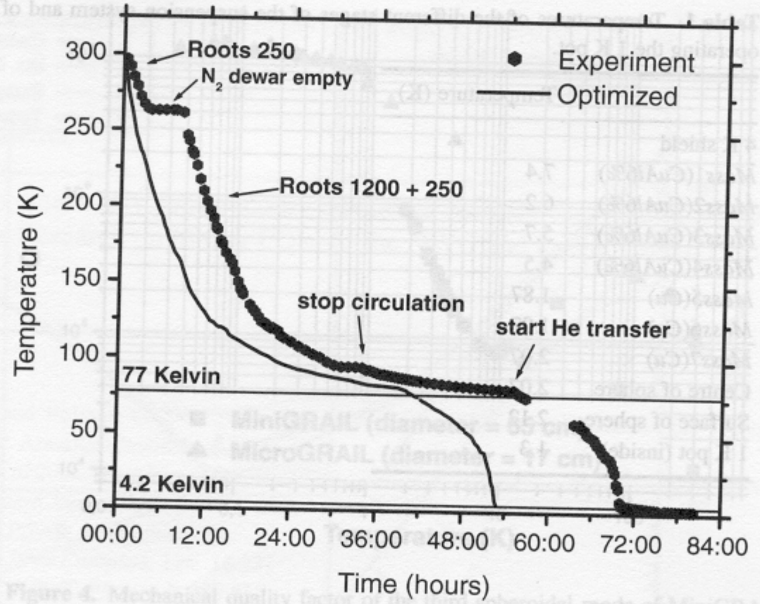


Figure 2. Cooldown of MiniGRAIL using a forced helium flow. The average circulation rate was about 400 mmol s^{-1}. Circulation was stopped after 36 h. Cooling from 100 to 80 K was done by natural convection of 1 bar of helium exchange gas inside the IVC. The total cooldown time to 4 K was 70 h.

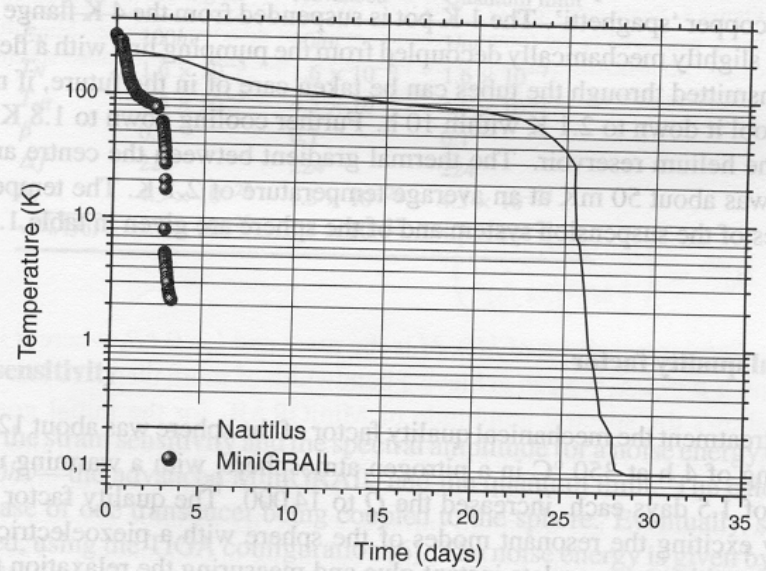
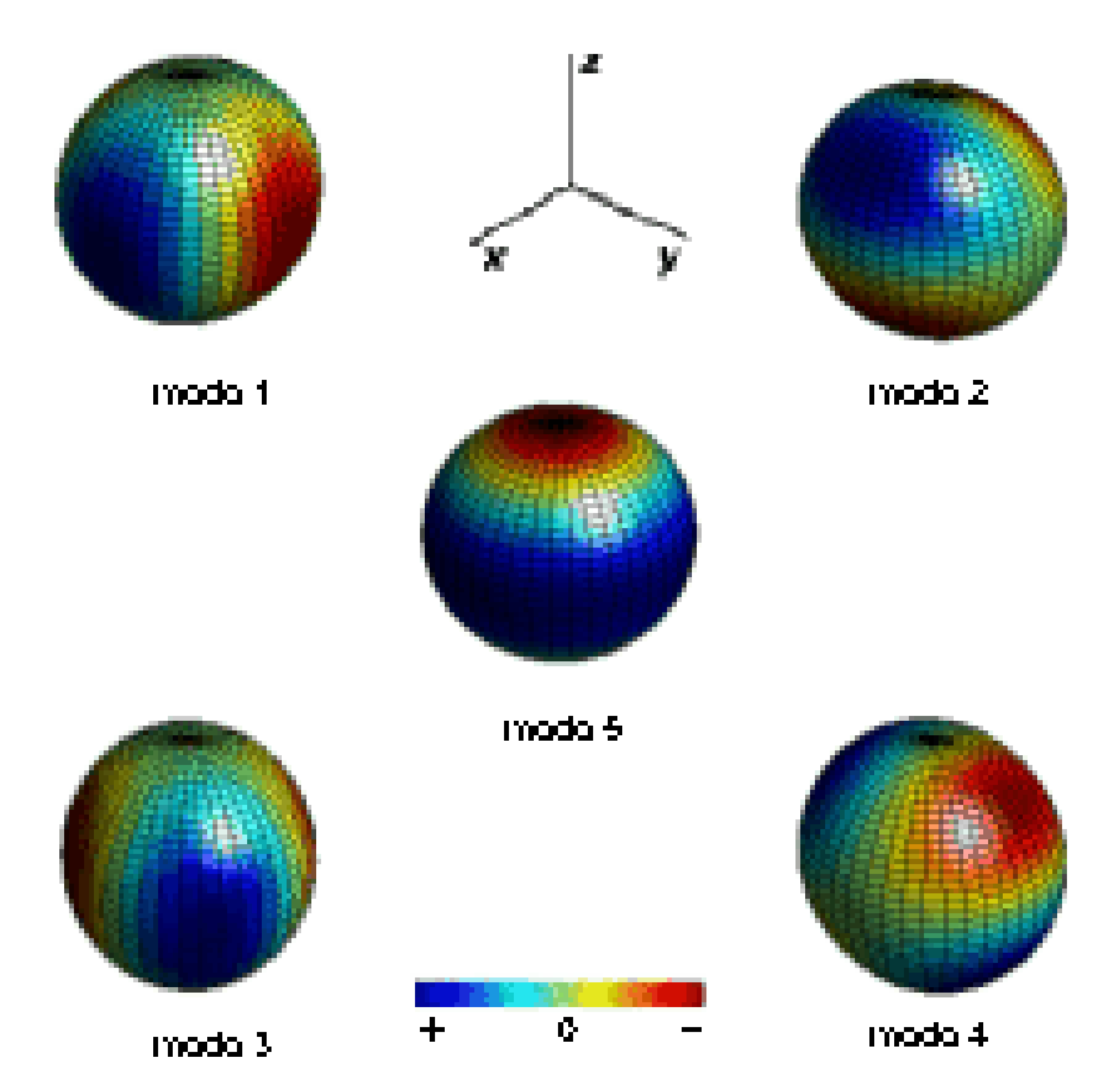


Figure 3. Cooldown of MiniGRAIL compared with a typical cooldown of Nautilus, the Al bar antenna in Rome [4].

Modos quadrupolares da esfera



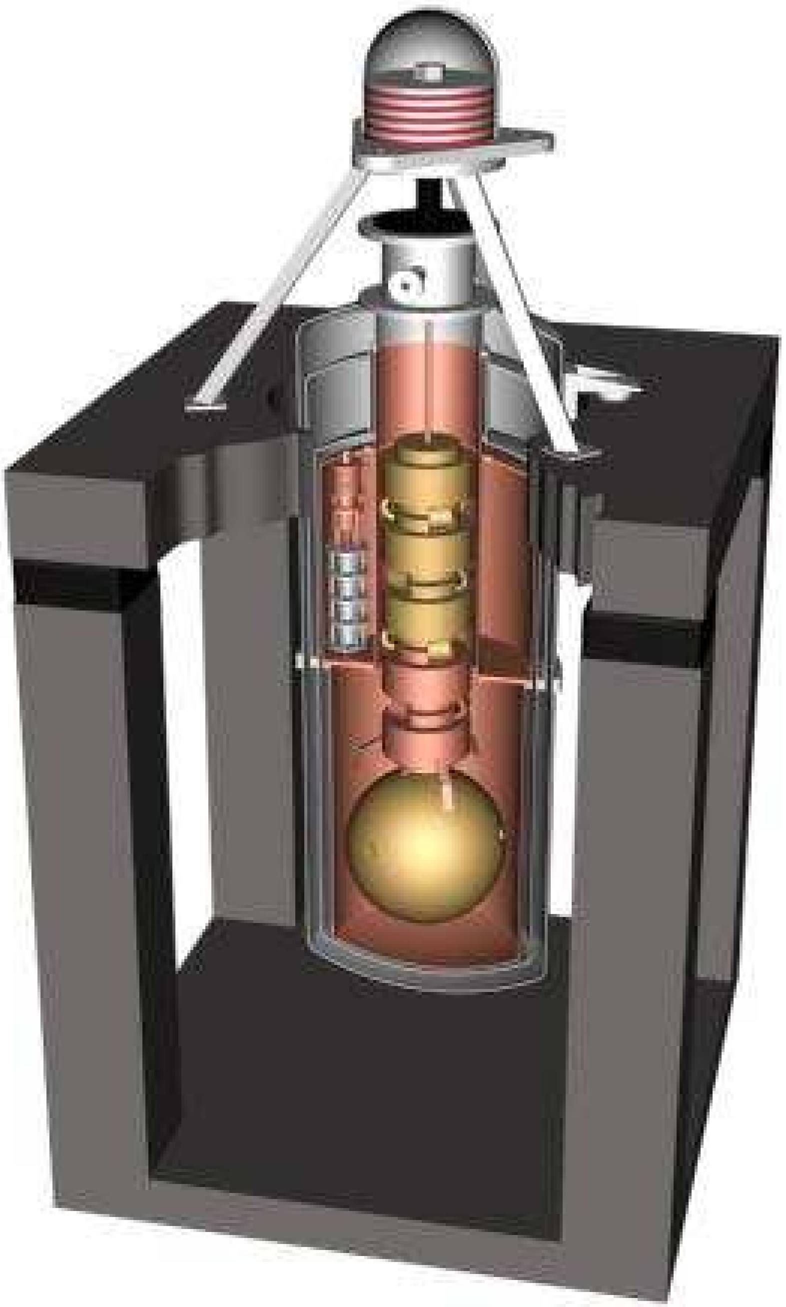
From the output of 6 transducers tuned to the

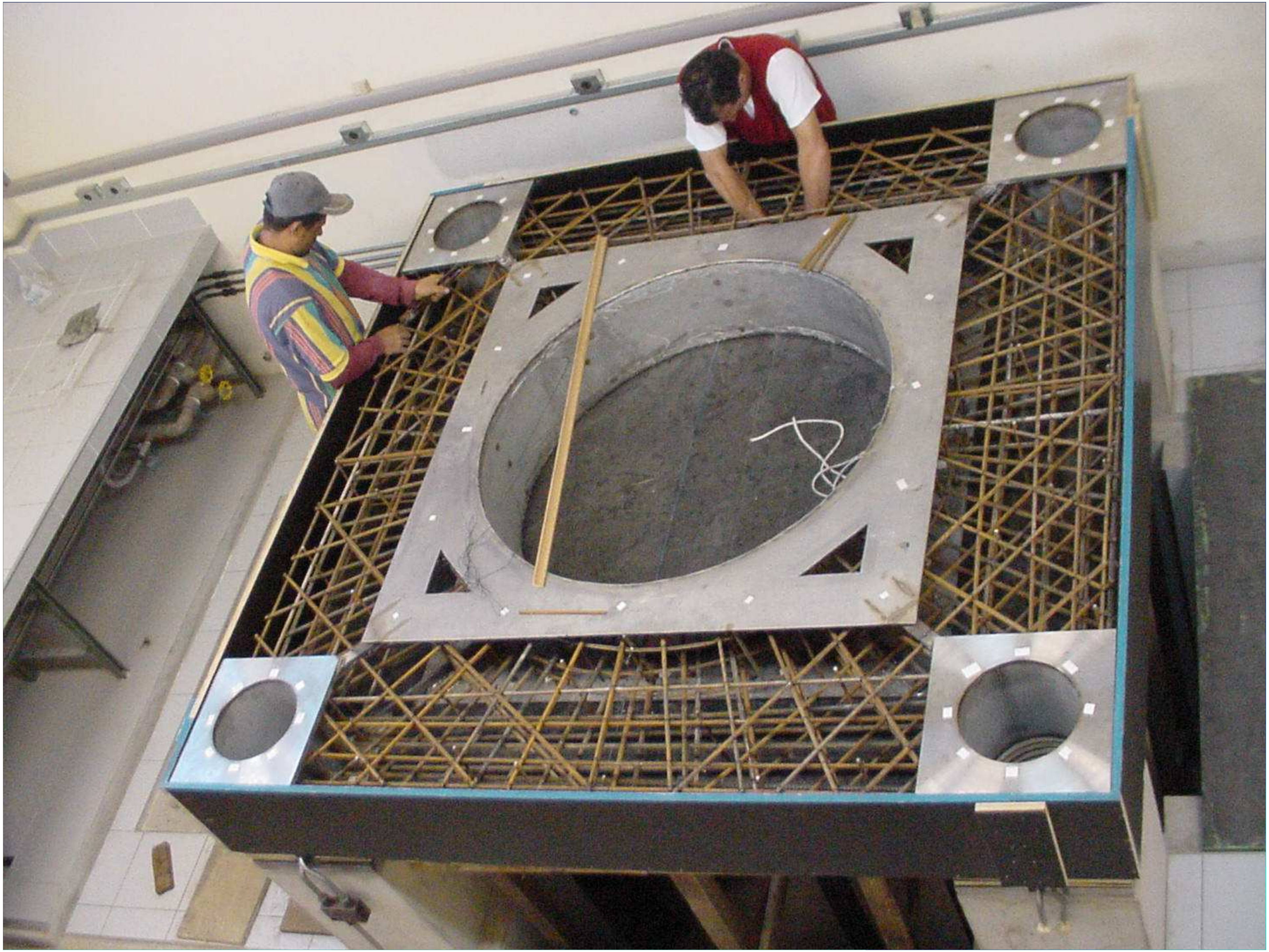
$$\psi(\theta,\phi,\omega) = \sum_{i=1}^{5} a_i(\omega)\,\psi_i(\theta,\phi)$$

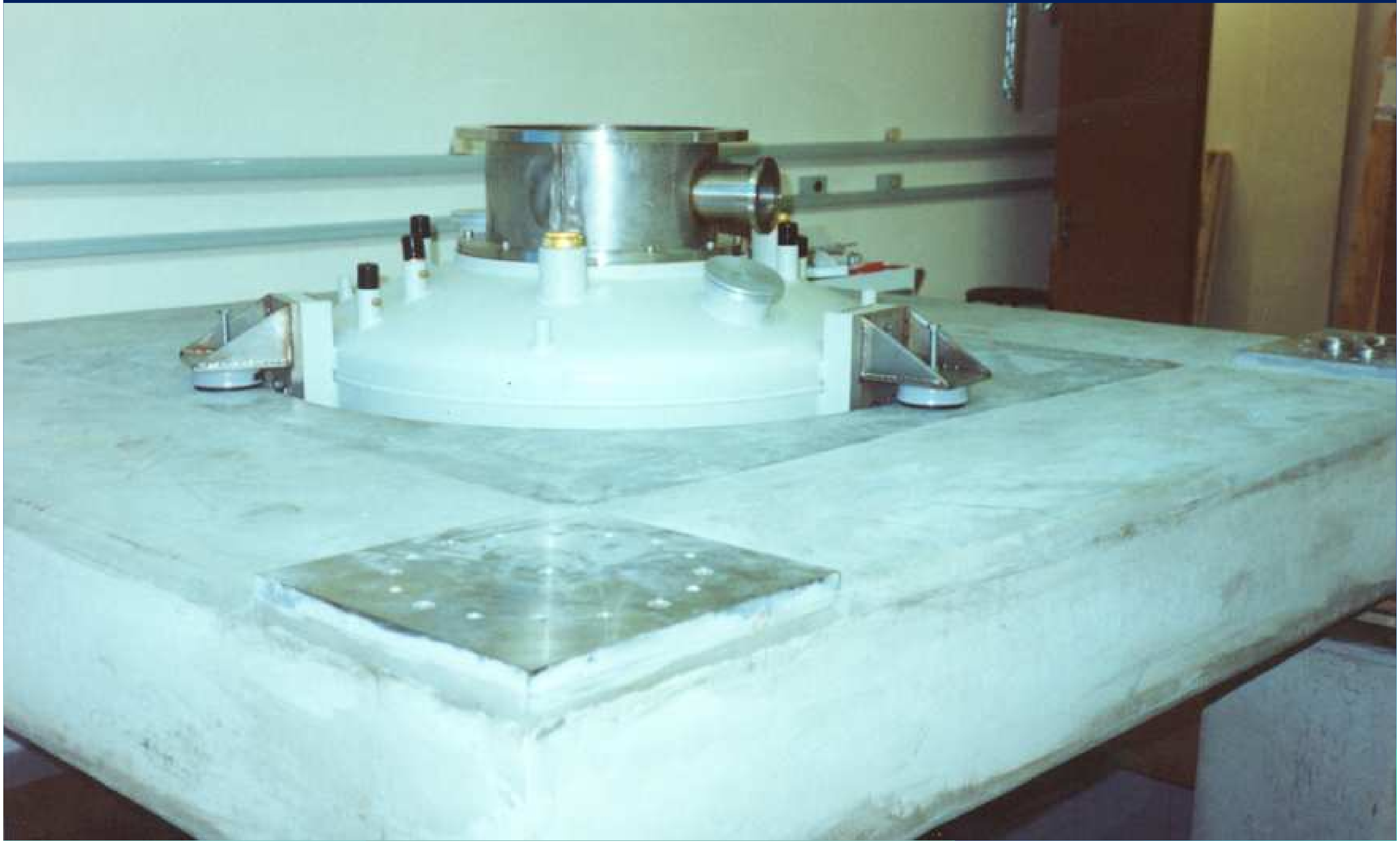
spherical harmonics

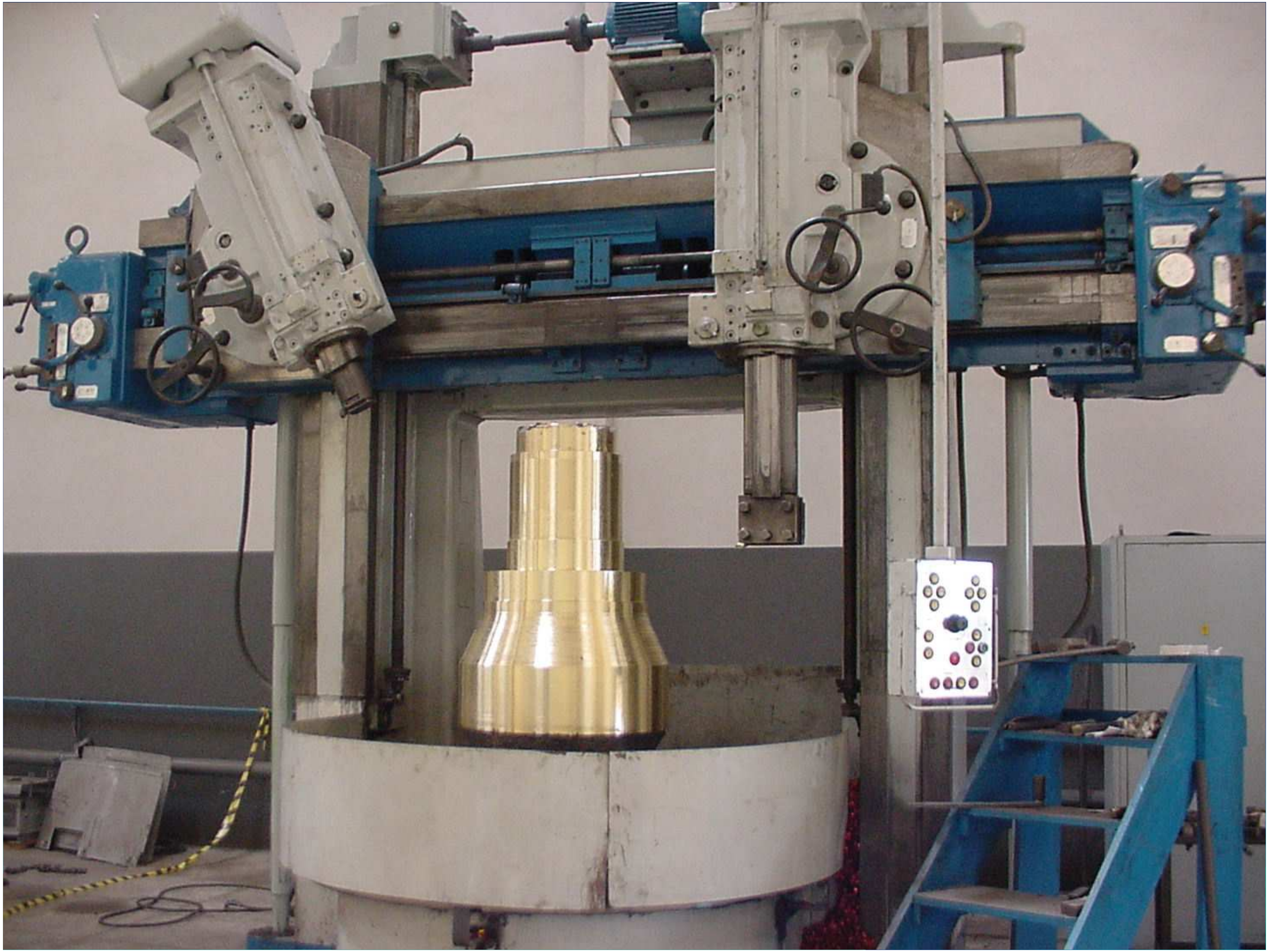
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h_{xx} + h_{yy} + h_{zz} = 0$$

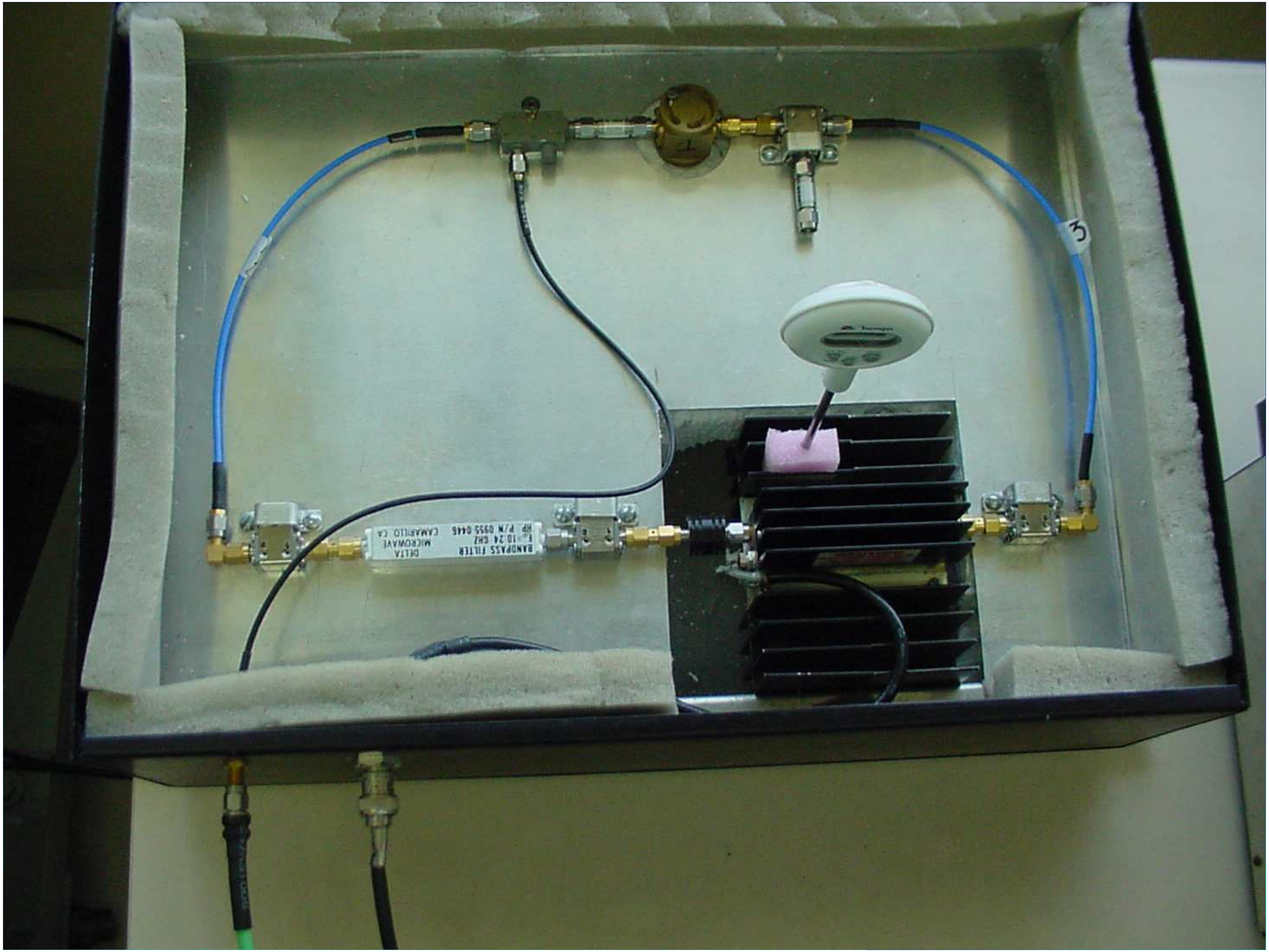
$$\mathbb{h} = \begin{bmatrix} h_{xx} & h_{xy} & h_{xz} \\ h_{yx} & h_{yy} & h_{yz} \\ h_{zx} & h_{yz} & h_{zz} \end{bmatrix}$$



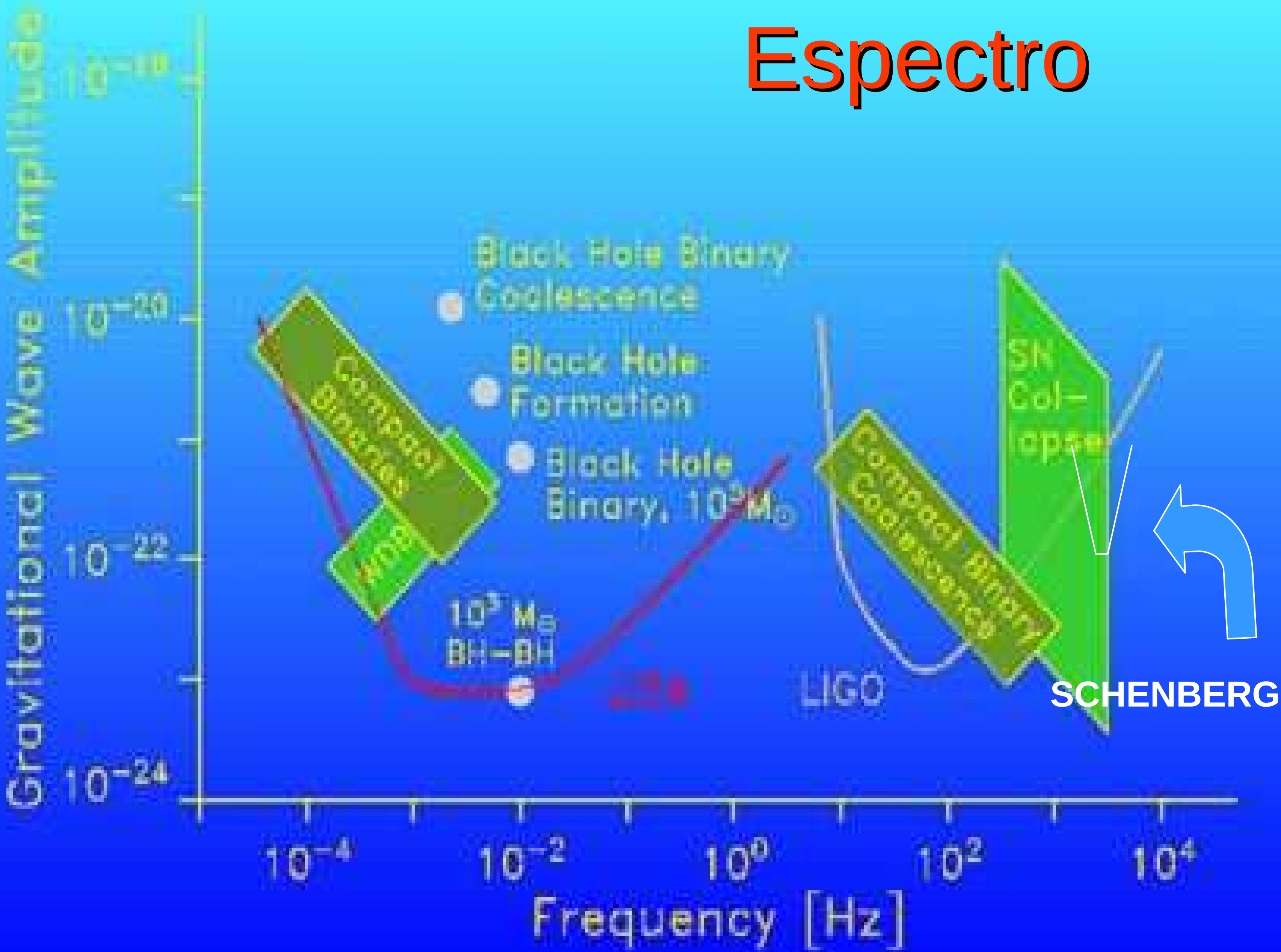




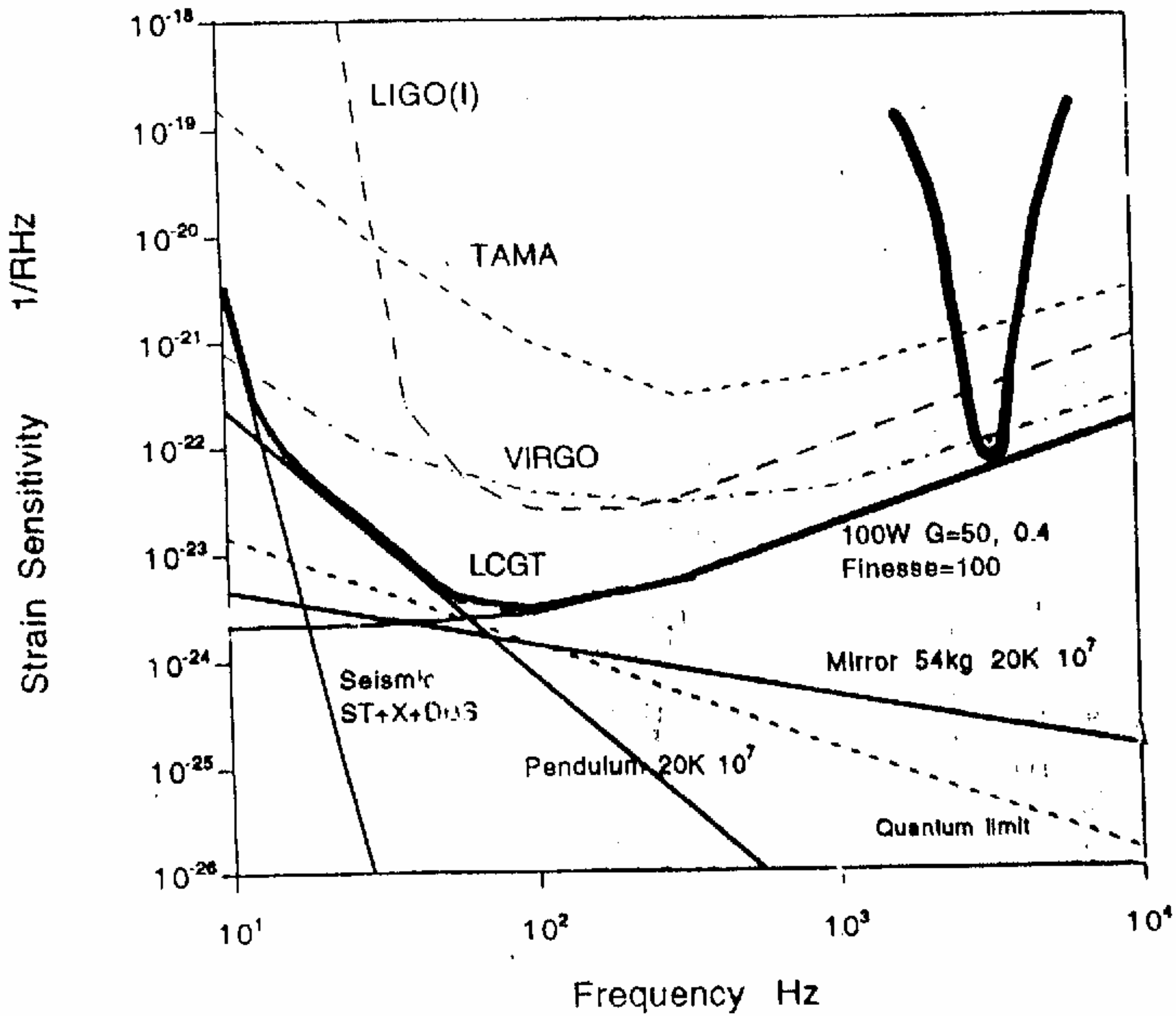



BANDPASS FILTER
F0 = 10.24 GHz
HP P/N 0955-0446
DELTA
MICROWAVE
CAMARILLO CA
3

Espectro



Gravitational Wave Amplitude
10^{-20}
10^{-22}
10^{-24}
Frequency [Hz]
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Black Hole Binary Coalescence
Black Hole Formation
Black Hole Binary, $10^{2}M_{\odot}$
Compact Binaries
10^{5} $M_{\odot}$ BH–BH
Compact Binary Coalescence
SN Col-lapse
LIGO
SCHENBERG



Strain Sensitivity 1/RHz
Frequency Hz
LIGO(I)
TAMA
VIRGO
LCGT
100W G=50, 0.4
Finesse=100
Mirror 54kg 20K 10^7
Seismic
Pendulum 20K 10^7
Quantum limit