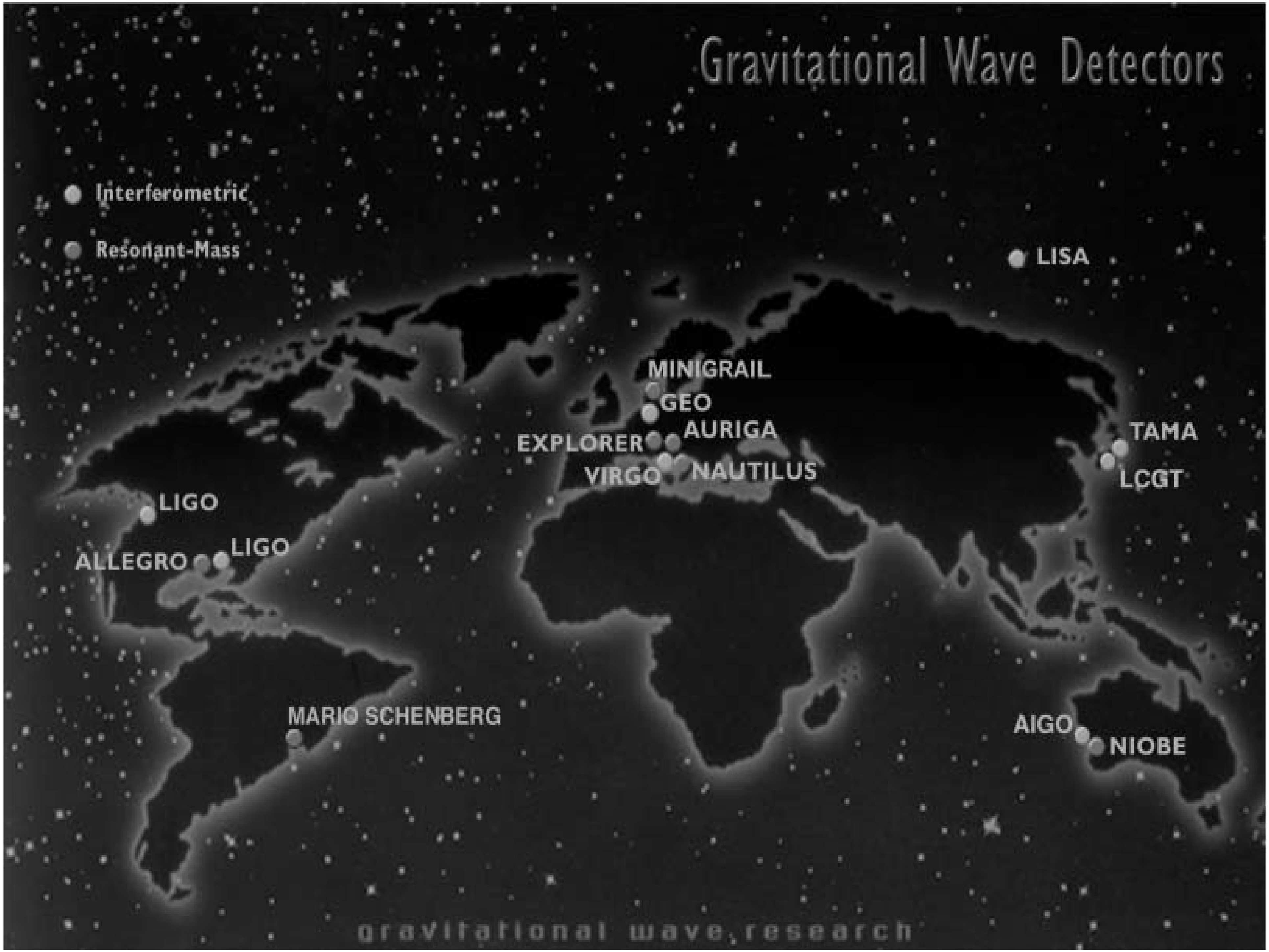
5th Edoardo Amaldi Conference on Gravitational Waves
Green Park Resort - Tirrenia (Pisa)
July 6-11, 2003

Resonant detectors: bars and spheres

Viviana Fafone
INFN-LNF
7 July 2003

LIGO-G030471-00-Z


Gravitational Wave Detectors
● Interferometric
● Resonant-Mass
LISA
MINIGRAIL
GEO
AURIGA
EXPLORER
VIRGO
NAUTILUS
TAMA
LCGT
LIGO
LIGO
ALLEGRO
MARIO SCHENBERG
AIGO
NIOBE
gravitational wave research

NEWS from the detectors

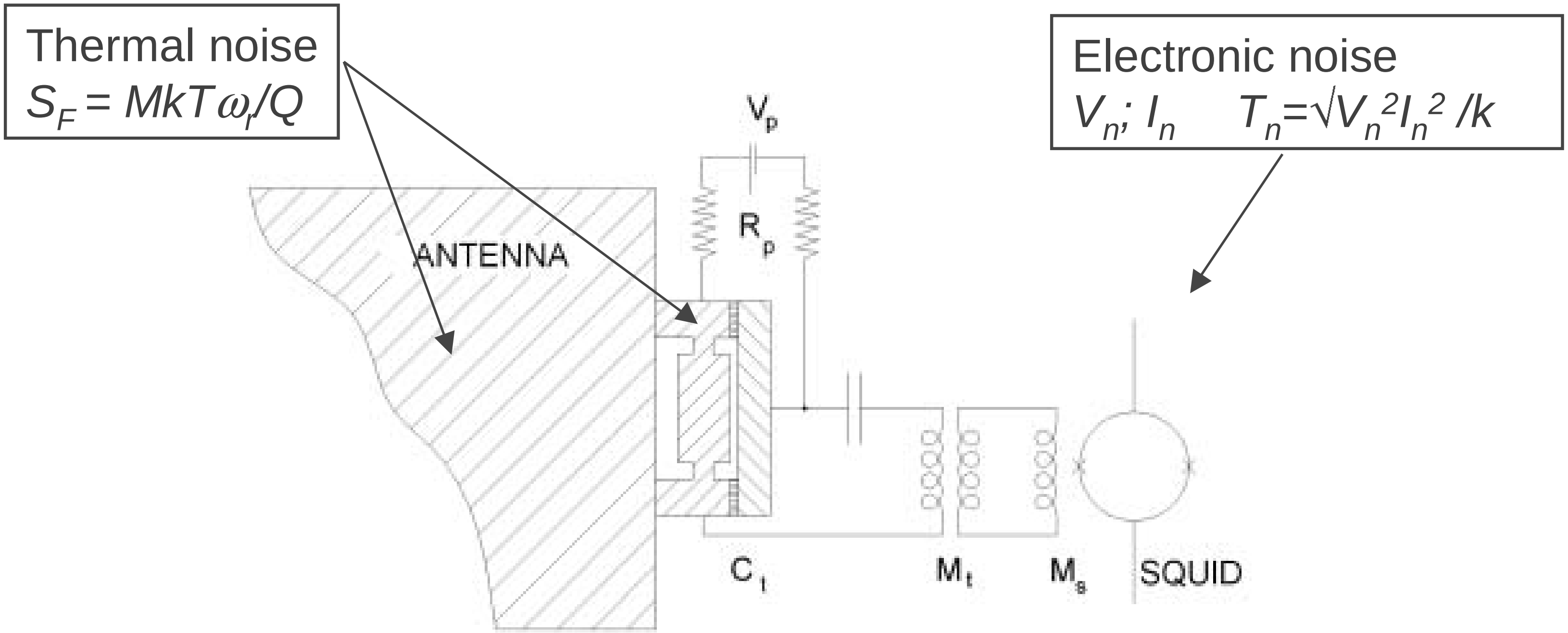
ALLEGRO:

AURIGA:

EXPLORER:

NAUTILUS:

New bar tuned at 935 Hz. New bar suspension cable.
New transducer and SQUID (the same EXPLORER readout).
Third run has started; the bar is at 3.5 K for the time being.
The peak strain sensitivity is 2×10^{-21} $Hz^{-1/2}$
and the bandwidth 30 Hz @10^{-20} $Hz^{-1/2}$



Thermal noise
$S_F = MkT\omega_r/Q$

Electronic noise
V_n; I_n $T_n=\sqrt{V_n^2 I_n^2}/k$

The mechanical oscillator

Mass **M**
Speed of sound $\mathbf{v_s}$
Temperature **T**
Quality factor **Q**
Res. frequency $\mathbf{f_r}$

The transducer

Efficiency β

The amplifier

Noise temperature $\mathbf{T_n}$

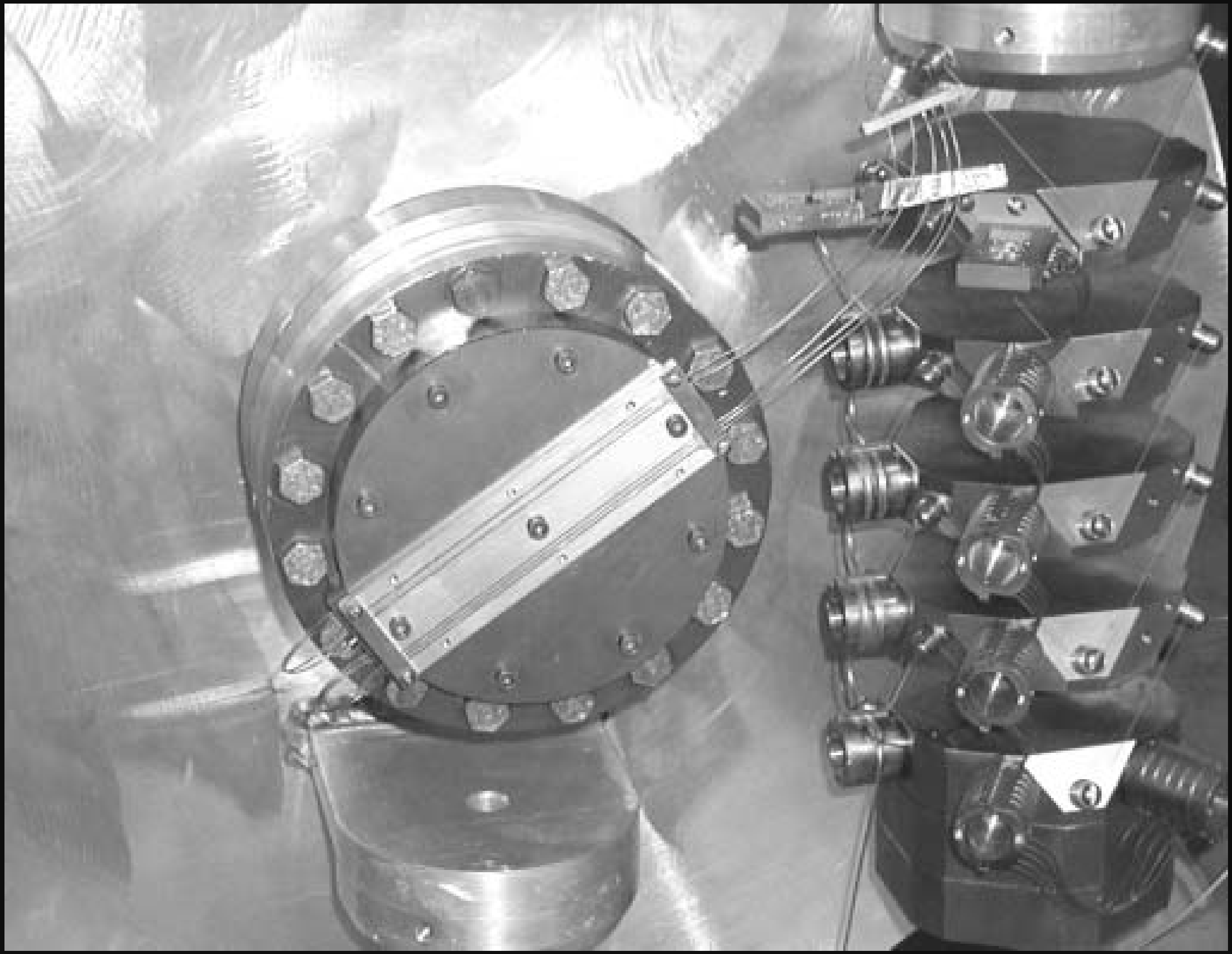
ALLEGRO

After a run during the LIGO E7 run, the system was upgraded.

The old transducer had lost coupling on several previous cooldowns (persistent current had declined by half to 6 amps.) An old Maryland transducer was adapted and installed, coupled to a QD dc SQUID.

- Sensor gap reduced from LSU transducer by factor of ~5, from ~ 125 mm to ~25 mm
- Current increased by 2.5, from 6 A to 16 A
- Doubled area (pickup coils on both sides)
- Improved coupling

Talk by W. Johnson



- About one month of good data, covering the second half of S2.
- Data for three orientations during run.
  - At start (15 March) ~ 63° W of N (~ parallel to IGEC)
  - Rotated to ~18° W of N on 28 March (~ LLO y-axis)
  - Rotated to ~108° W of N on 9 April (~LLO x-axis)

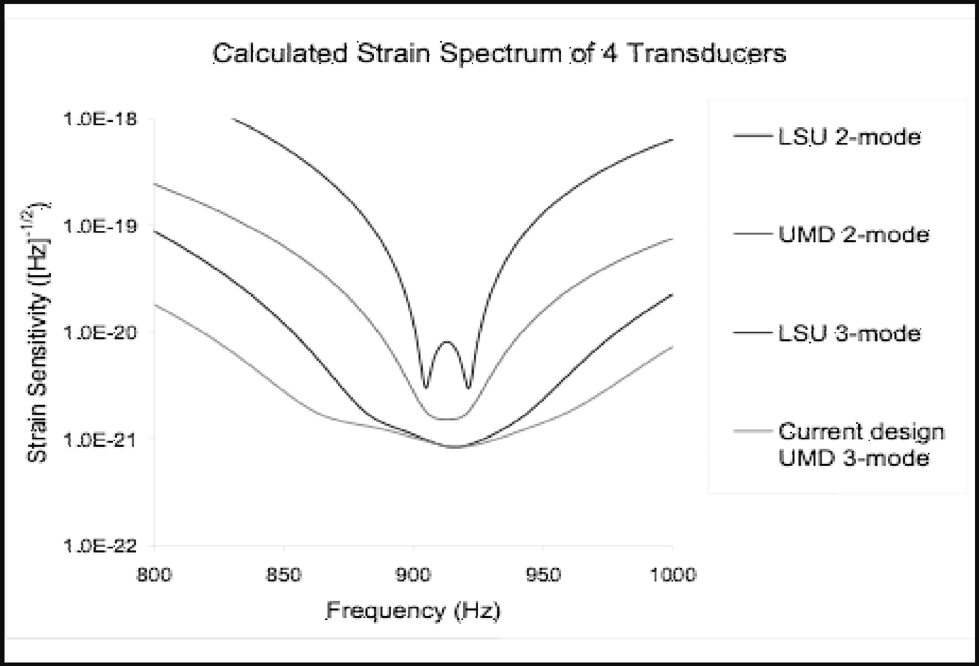
Plans for the short term …

- Helium leak
- Mechanical Q. (low by factor of 3 or 4)
- Amplifier (noise high by factor of ~2)
- New calibrator (calibrator mode interfering with detection modes)

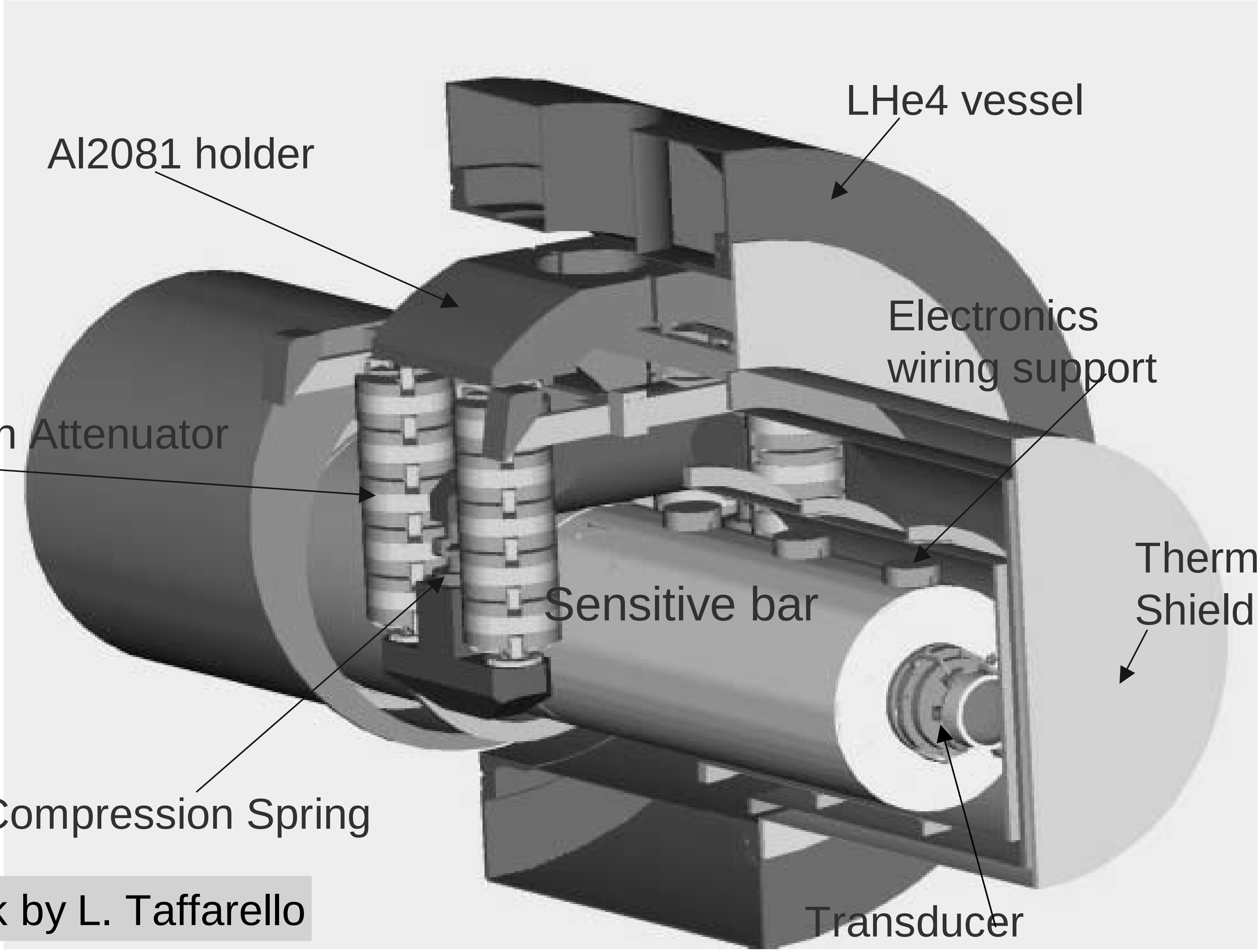
New run in october (S3)

…and mid term (about 1 year)

- Design a <u>two-mode</u> transducer
- Integrate a <u>2-stage SQUID</u> (AURIGA-QD design)

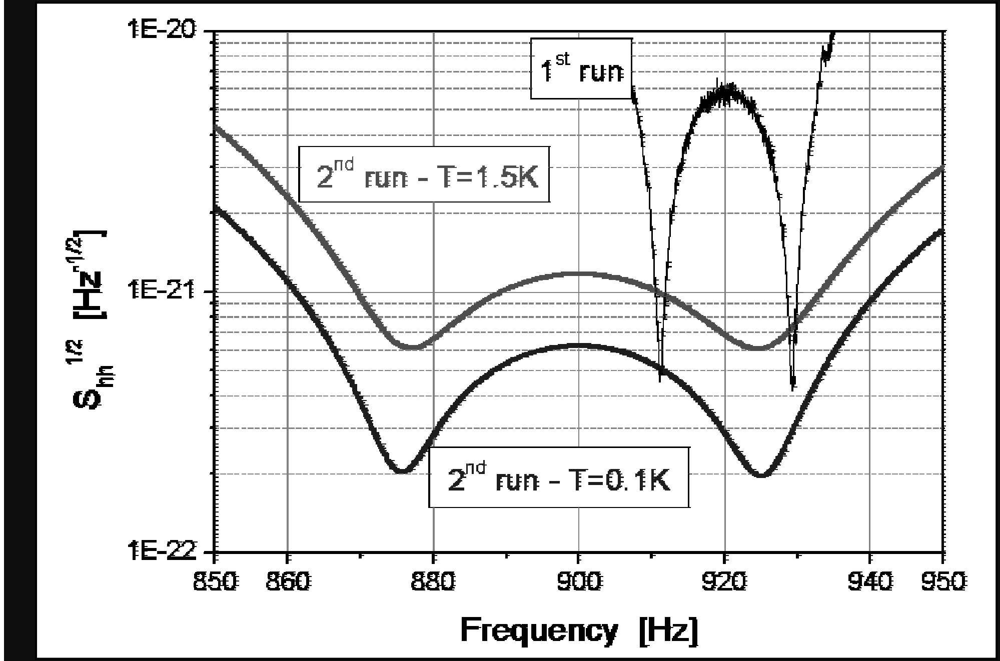


AURIGA II run *(mid 2003)*



Talk by L. Taffarello

AURIGA II run *(mid 2003)*: upgrades



new mechanical suspensions:

attenuation > 360 dB at 1 kHz FEM modelled

new capacitive transducer and s.c. transformer

two-modes (1 mechanical+1 electrical) optimized mass

new amplifier:

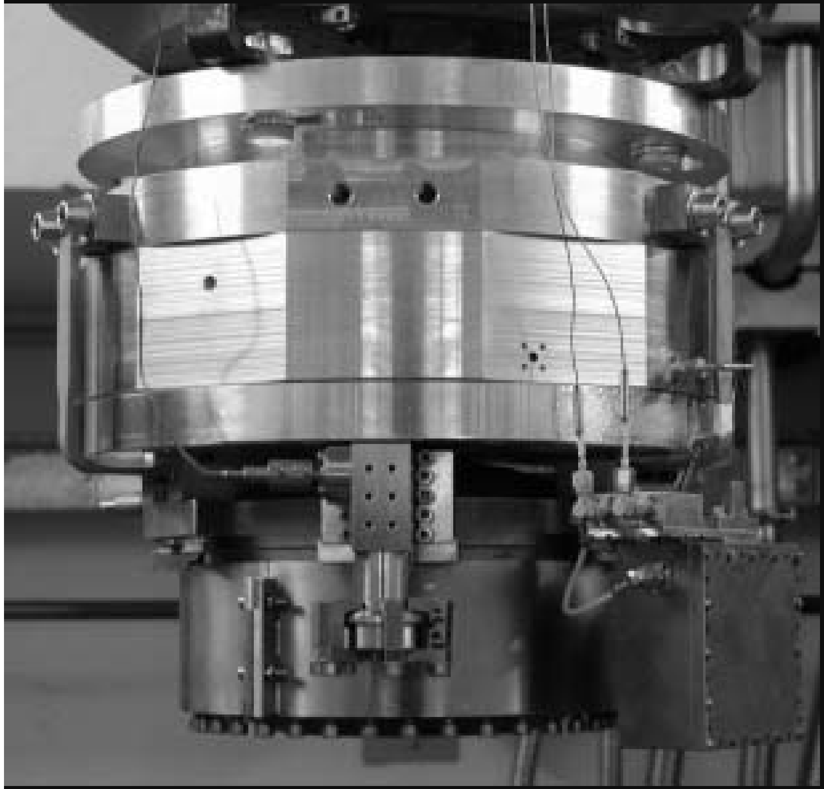
double stage SQUID 200 ħ energy resolution

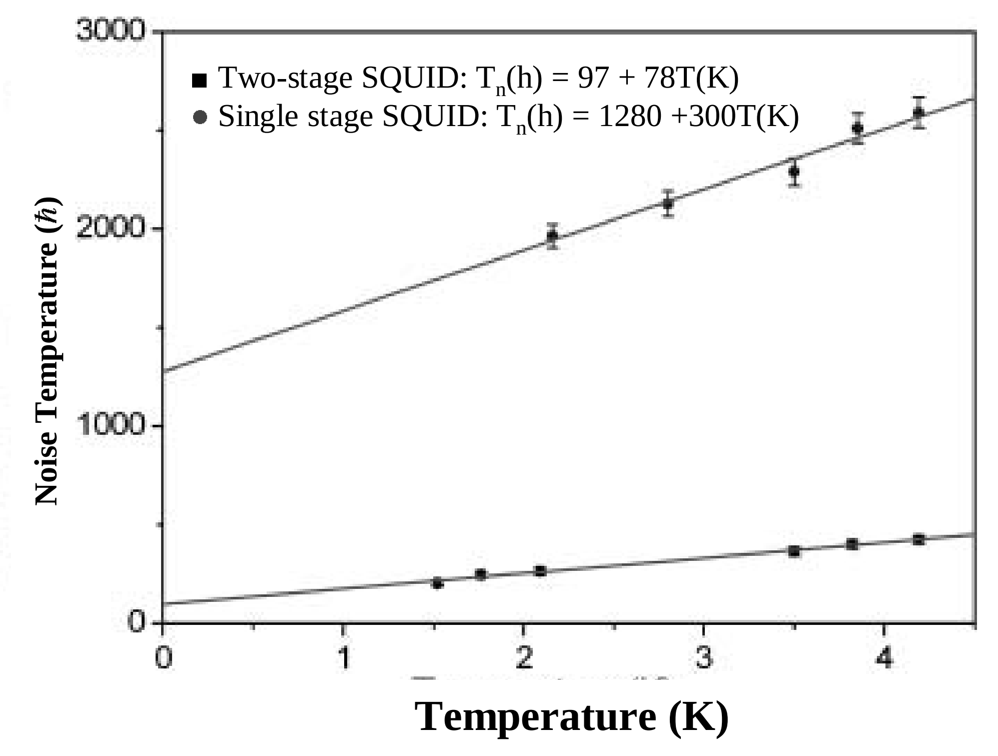
new data analysis:

C++ object oriented code frame data format

AURIGA II run *(mid 2003)*: upgrades

single ✹ double stage SQUID amplifier

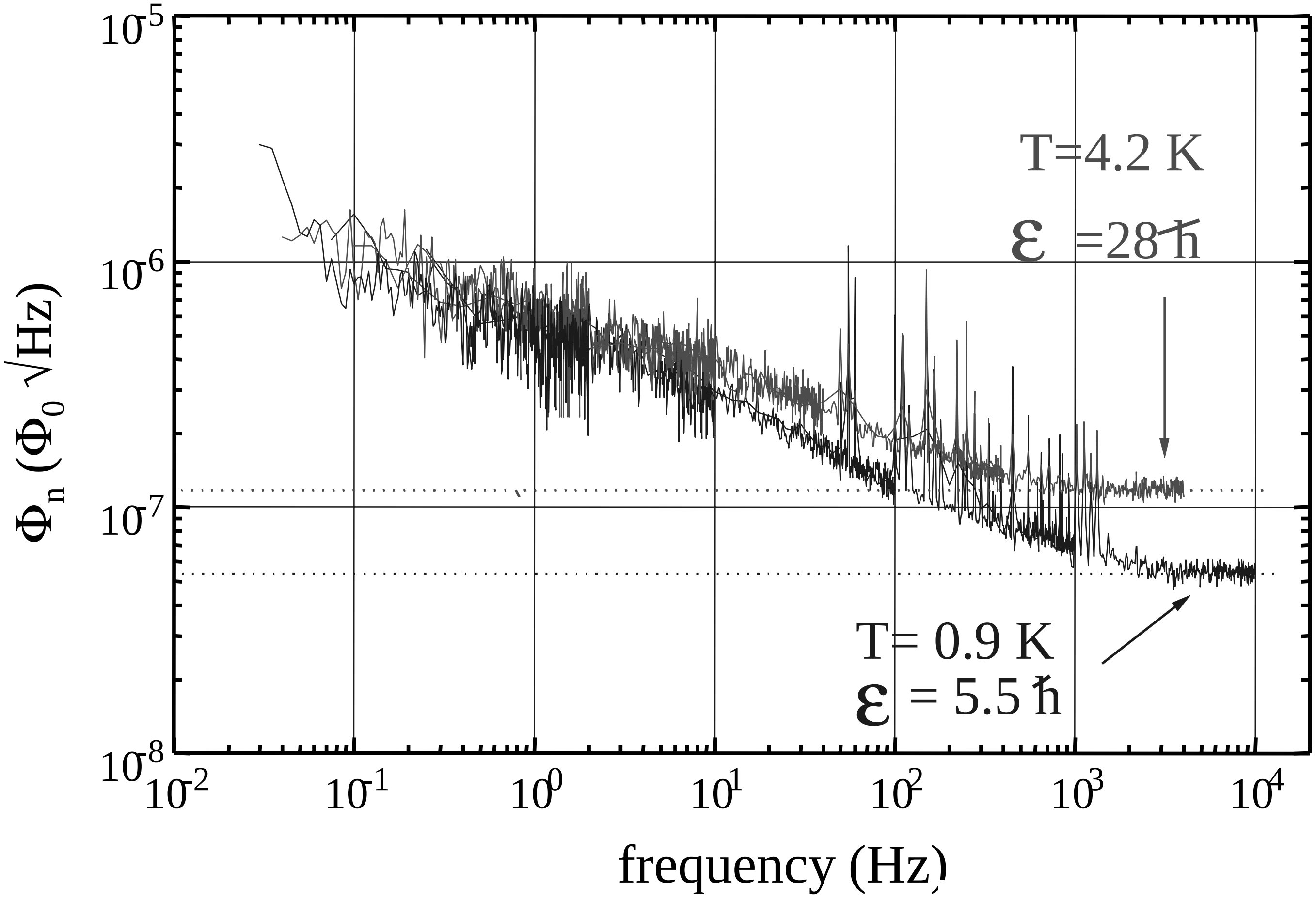




achieved same performances of SQUID amplifier after integration with the capacitive transducer

Talk by J. Zendri

Experimental flux noise spectral density



Carelli et al. ('98) ROG coll.

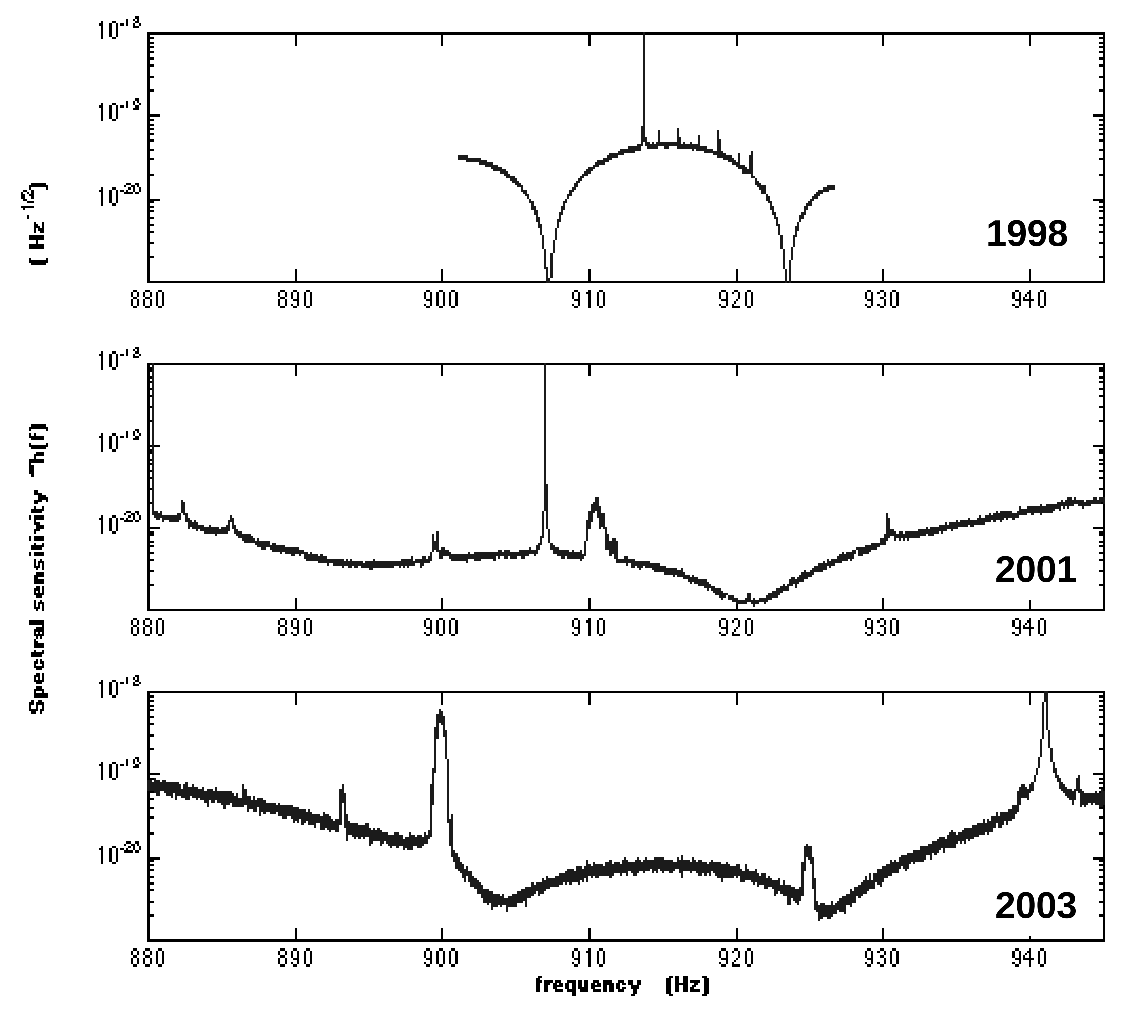
EXPLORER

EXPLORER has been on the air since May 2000 with:

-new, 10 µm gap transducer
-new, high coupling SQUID

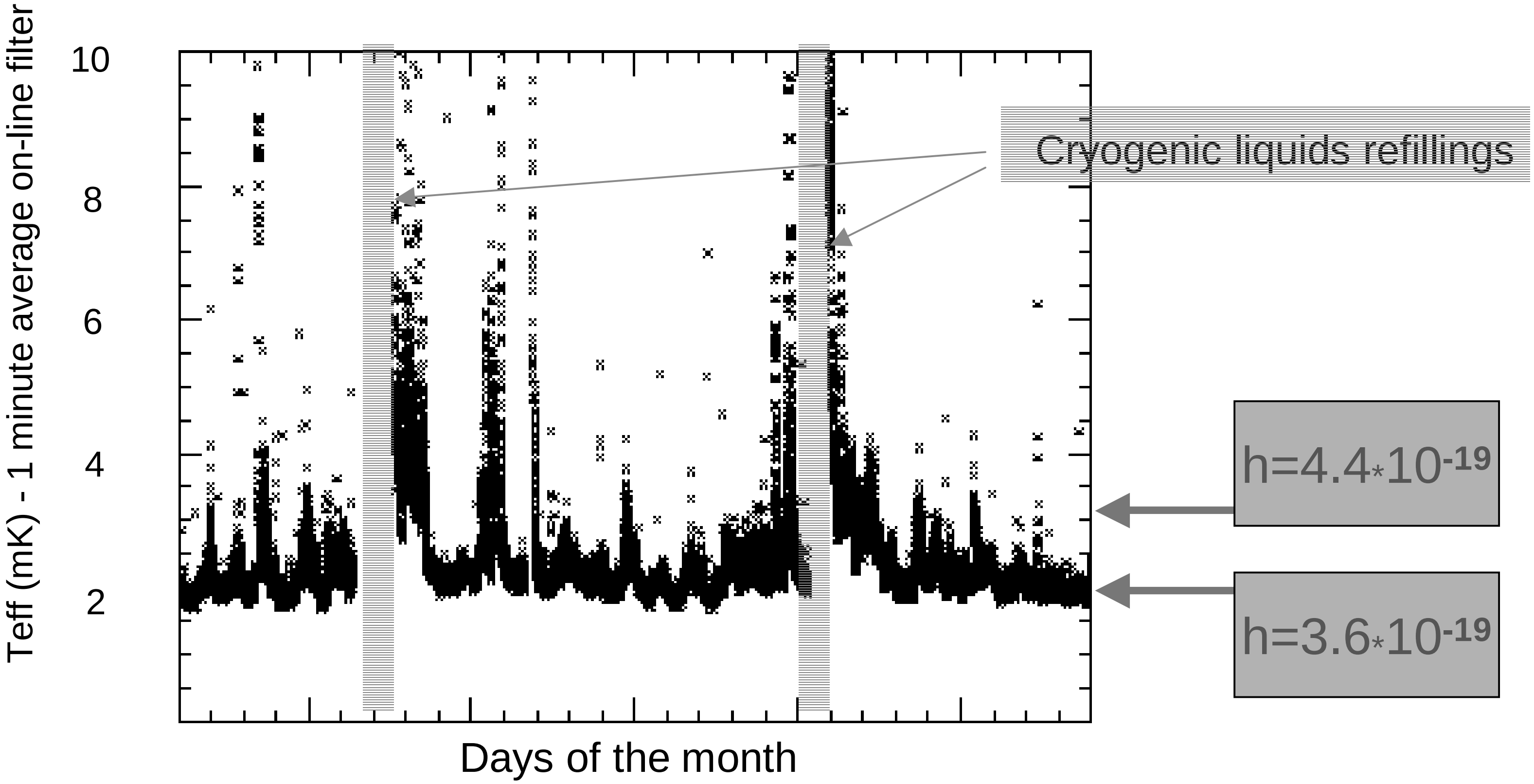
The noise temperature is < 3 mK (h=4.4 10^{-19}) for 84% of the time.

Bandwidth: the detector has a sensitivity better than 10^{-20} $Hz^{-1/2}$ on a band larger than 30 Hz



Talk by M. Visco

EXPLORER June 2003



h=$4.4*10^{-19}$

h=$3.6*10^{-19}$

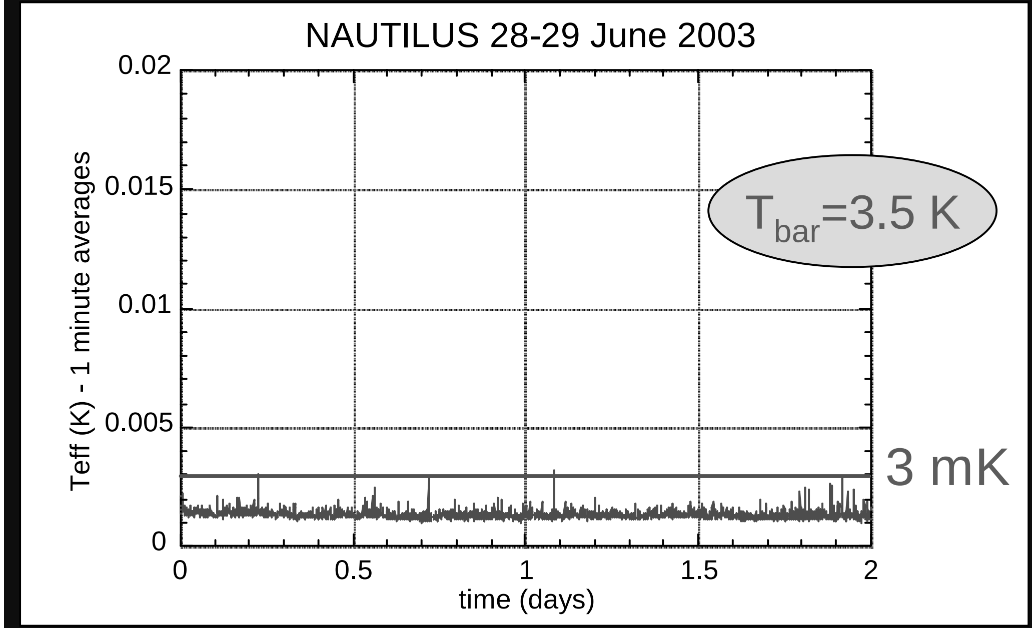
For ~ 80% of time the sensitivity to short gw bursts is better than h=$4.4*10^{-19}$

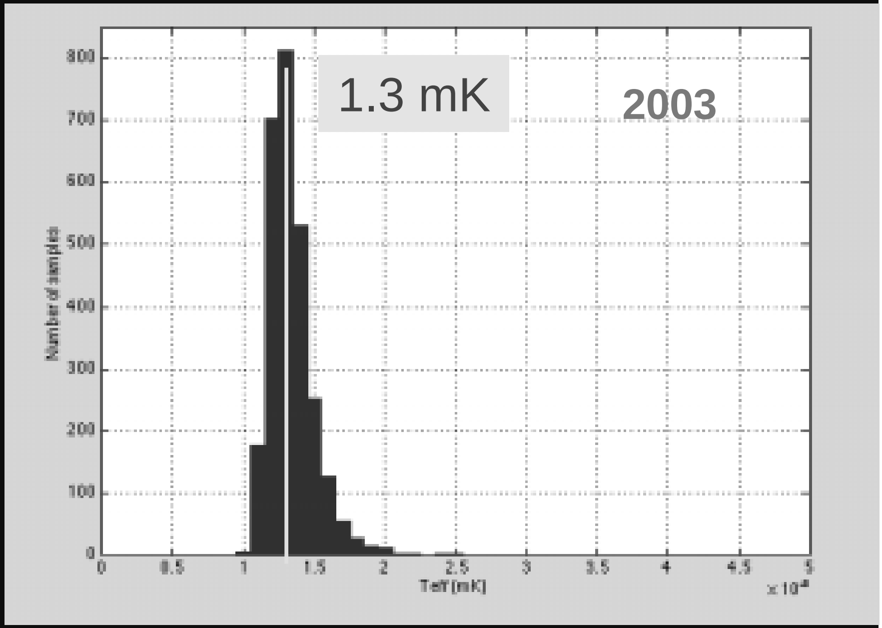
NAUTILUS 2003

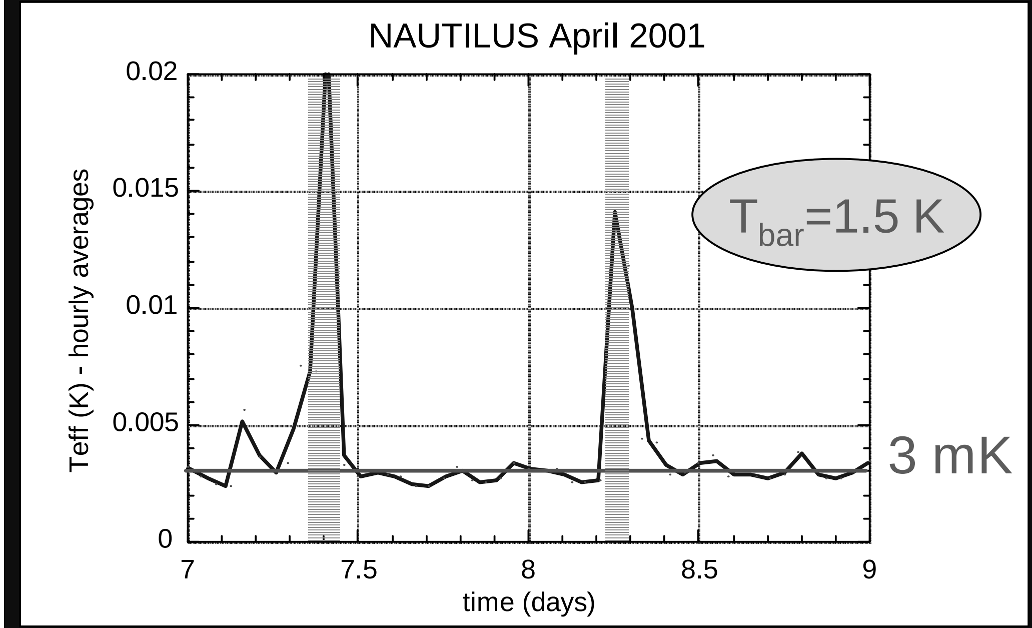
- ν_a= 935 Hz
- new antenna suspension cable
- new capacitive transducer
- Quantum Design dc SQUID

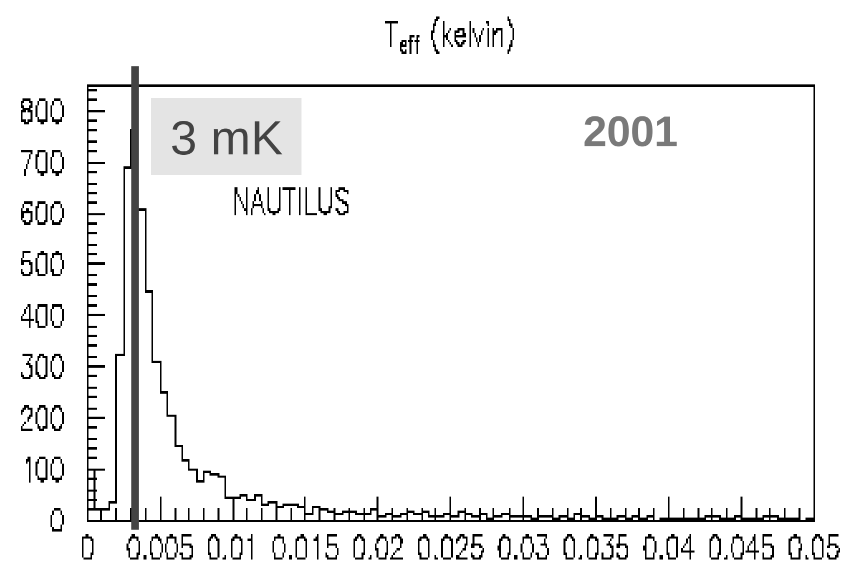
The bar was cooled down to 3.5 K in April. Data taking is under way. Performances can be improved with system optimization.

Talk by M. Visco


NAUTILUS 28-29 June 2003

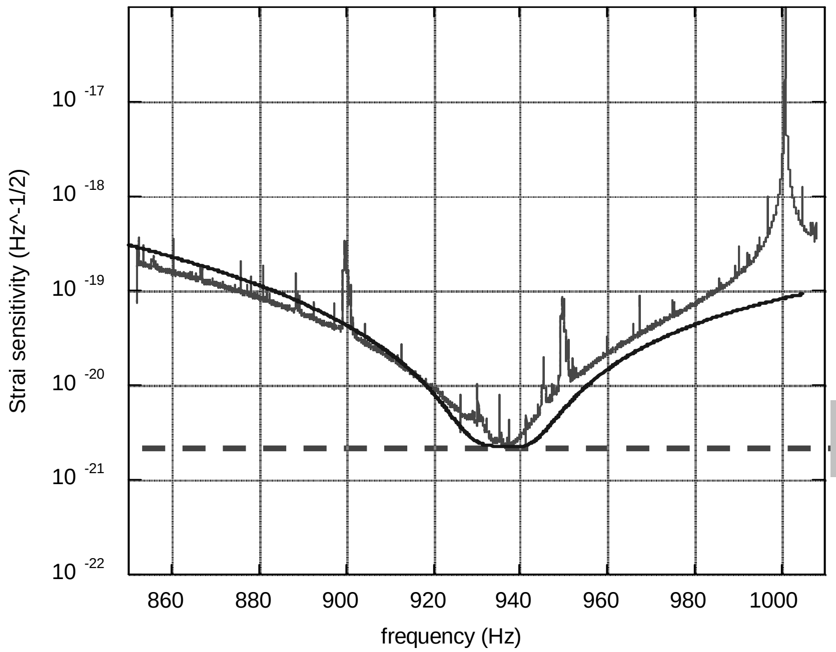



NAUTILUS April 2001



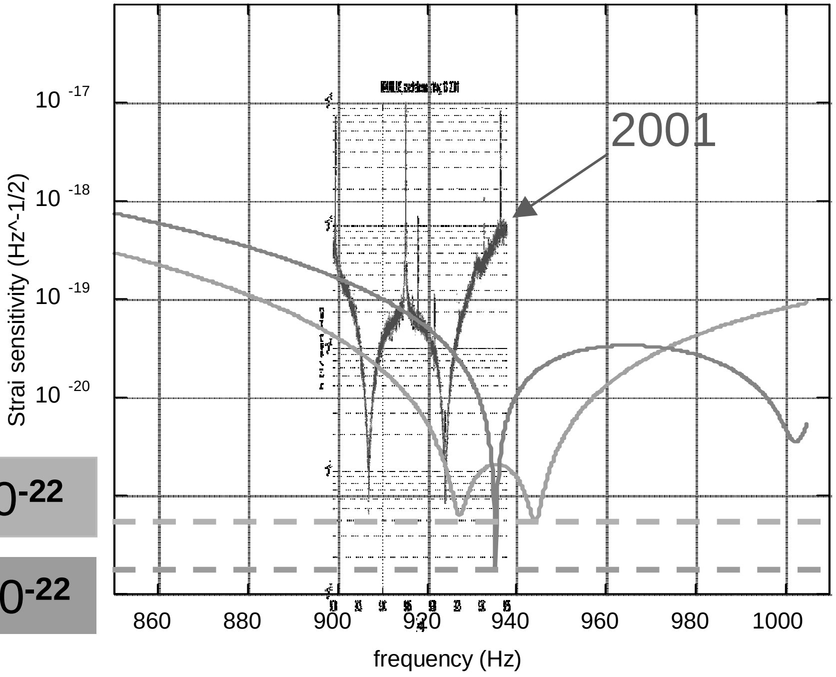
NAUTILUS spectral density at 3.5 K

June 2003



$2 \ast 10^{-21}$

Expected spectral density at 0.15 K



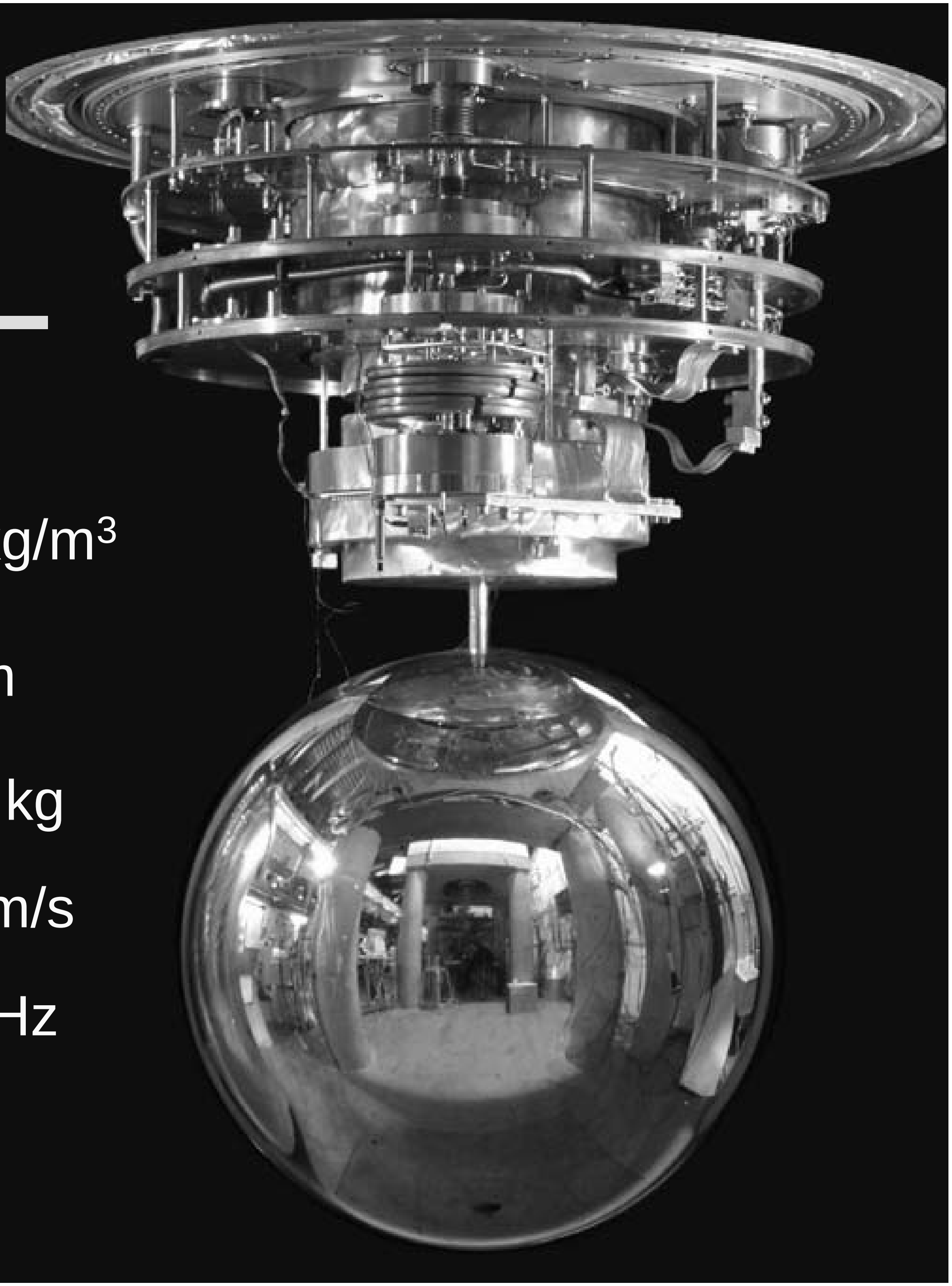
$6 \ast 10^{-22}$

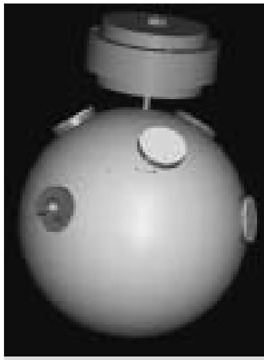
$1.6 \ast 10^{-22}$

Present Spherical Detectors Properties

Material	CuAl6%
Density	$\rho = 8000$ kg/m^3
Diameter	$\Phi = 0.65$ m
Mass	$M = 1150$ kg
Sound velocity	$v = 4000$ m/s
Resonant freq.	$f = 3160$ Hz

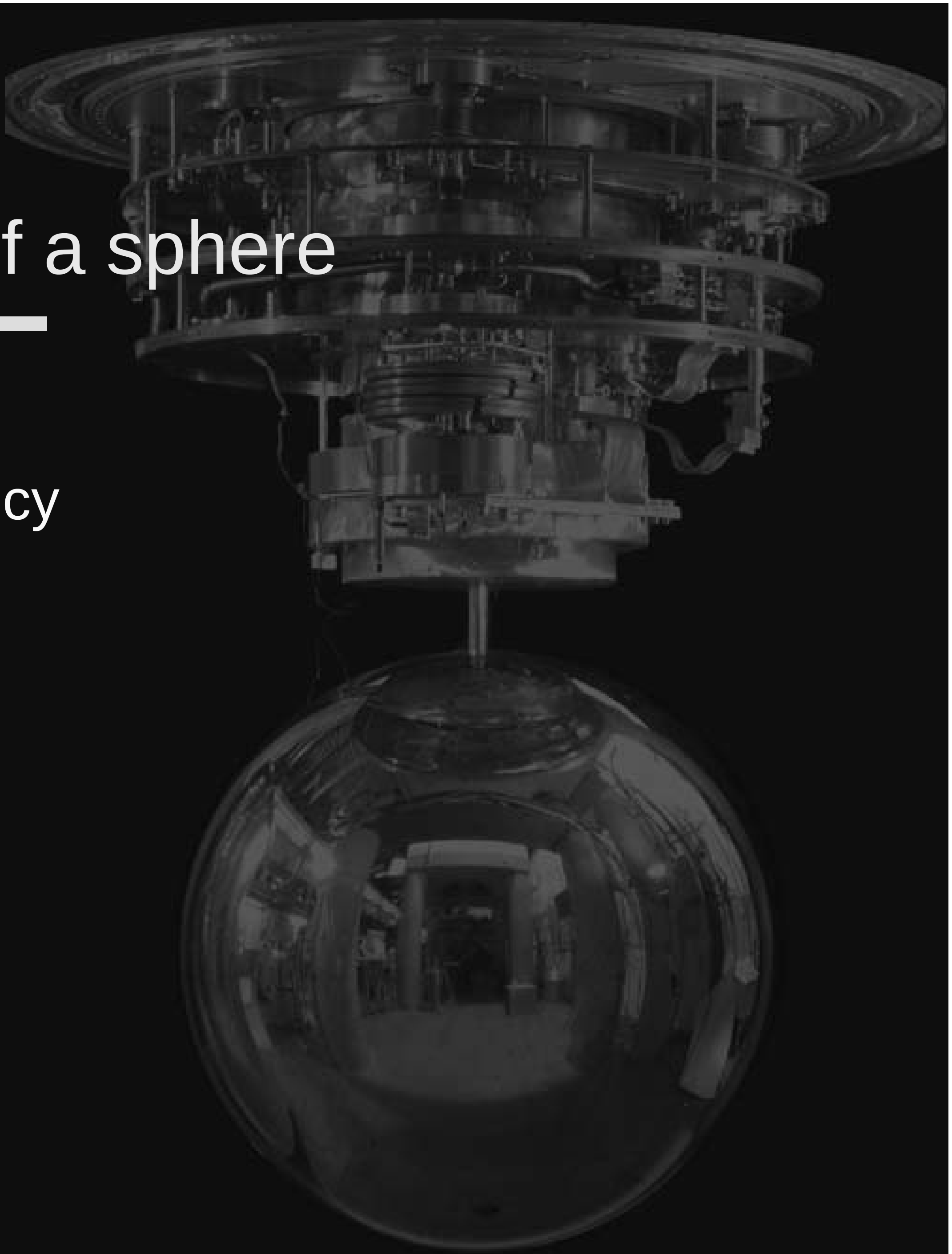
Short cool-down time





Advantages of a sphere

- Larger cross-section than a bar of the same frequency
- Omni-directional
- Determination of direction and polarization



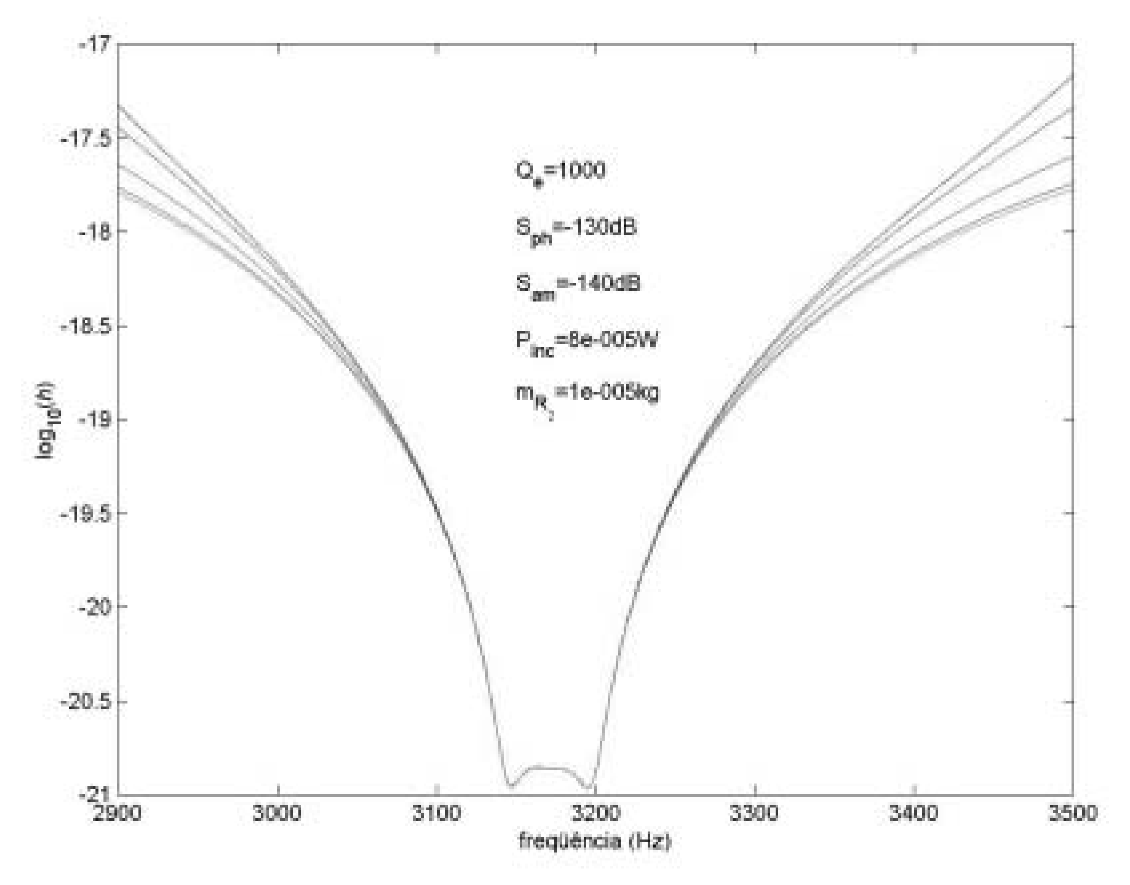
Schenberg

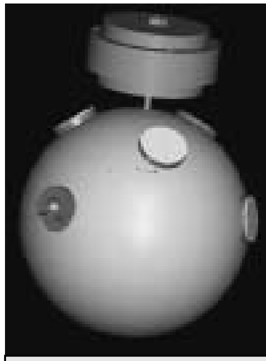
- All the "heavy" parts (cryogenic chambers, antenna vibration isolation system, and the antenna itself) are already assembled.
- A couple of weeks ago: first cool down to 4.2 K failed due to a leak.
- In the first cool the Q measurement of the antenna will be performed.

Talk by O. Aguiar

Schenberg

Two-mode parametric transducer with an oscillator phase noise
= -131dBc @ 3.2kHz from the 10.21 GHz carrier.
electrical Q ~ 1k
mechanical Q ~ 1M at the moment
intermediate mass = 53 g
last mass = 0.01g
HEMT pre-amplifiers.
Expected sensitivity with this system = 10^(-21) Hz^(-1/2) in a 50Hz bandwidth



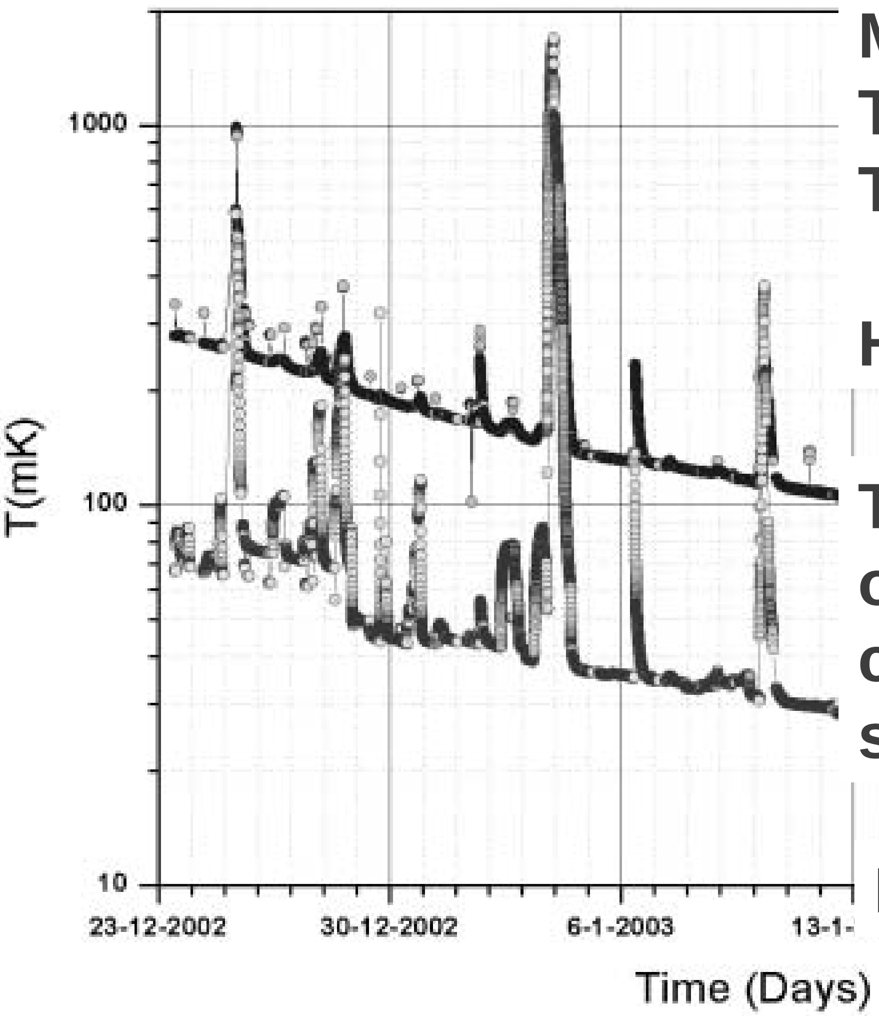


www.minigrail.nl

MiniGRAIL

Results on cool-down

Talk by A. de Waard



Minimum temperatures:

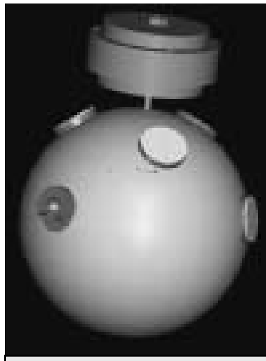
T_{sphere} = 80 mK

T_{mc} = 20 mK

Heat leak: 45 μW from sphere

Time dependent heat leak due to ortho-para conversion of H_2 confined in micro-bubbles in the sphere (~50 ppm)

Expected temperature ~ 20 mK



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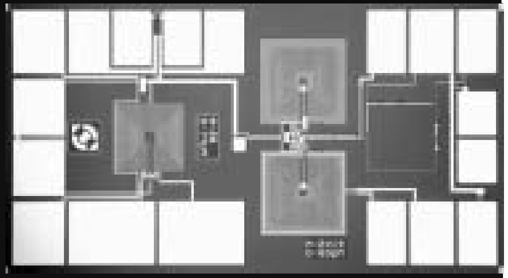
Talk by L. Gottardi

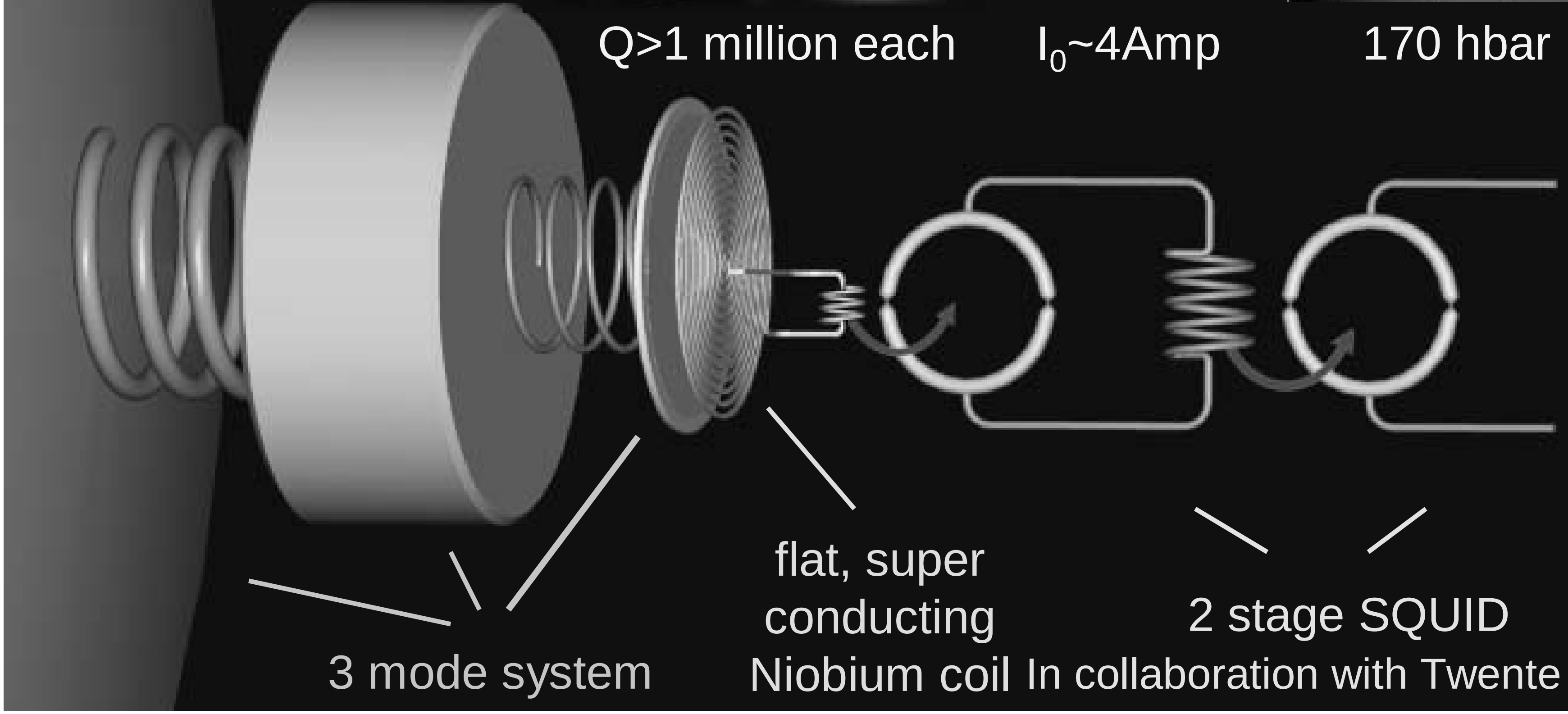
3-mode inductive transducer

Q>1 million each

I_0~4Amp



170 hbar @ 4K

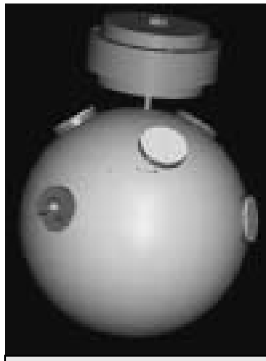


3 mode system

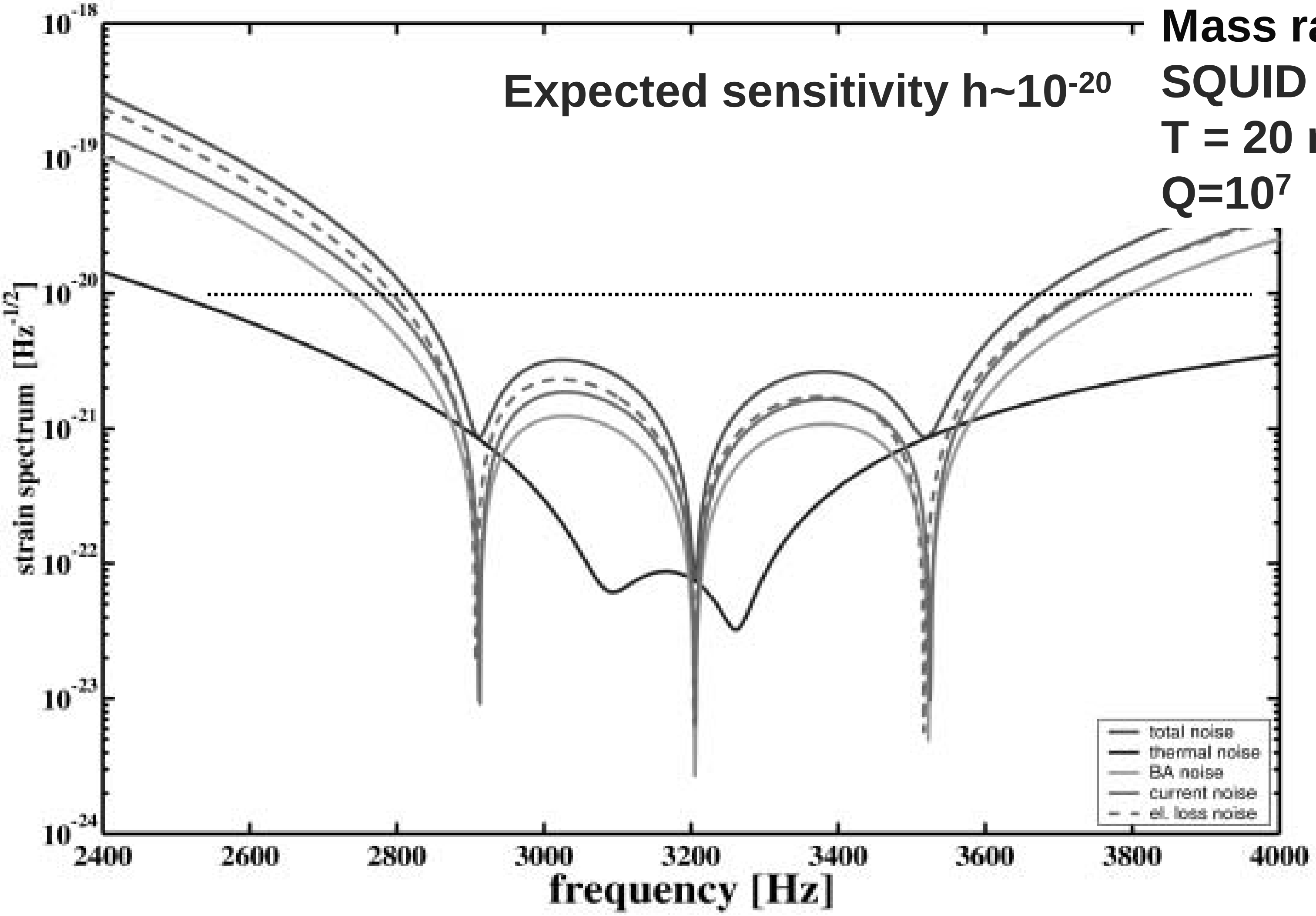
flat, super conducting Niobium coil

2 stage SQUID

In collaboration with Twente Univ.



Sensitivity - 3 mode inductive transducer



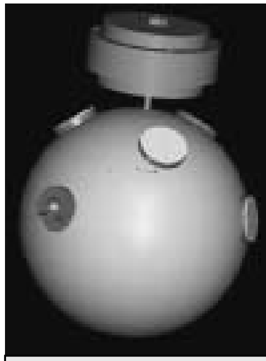
Expected sensitivity $h \sim 10^{-20}$

Mass ratio – 10^{-3}

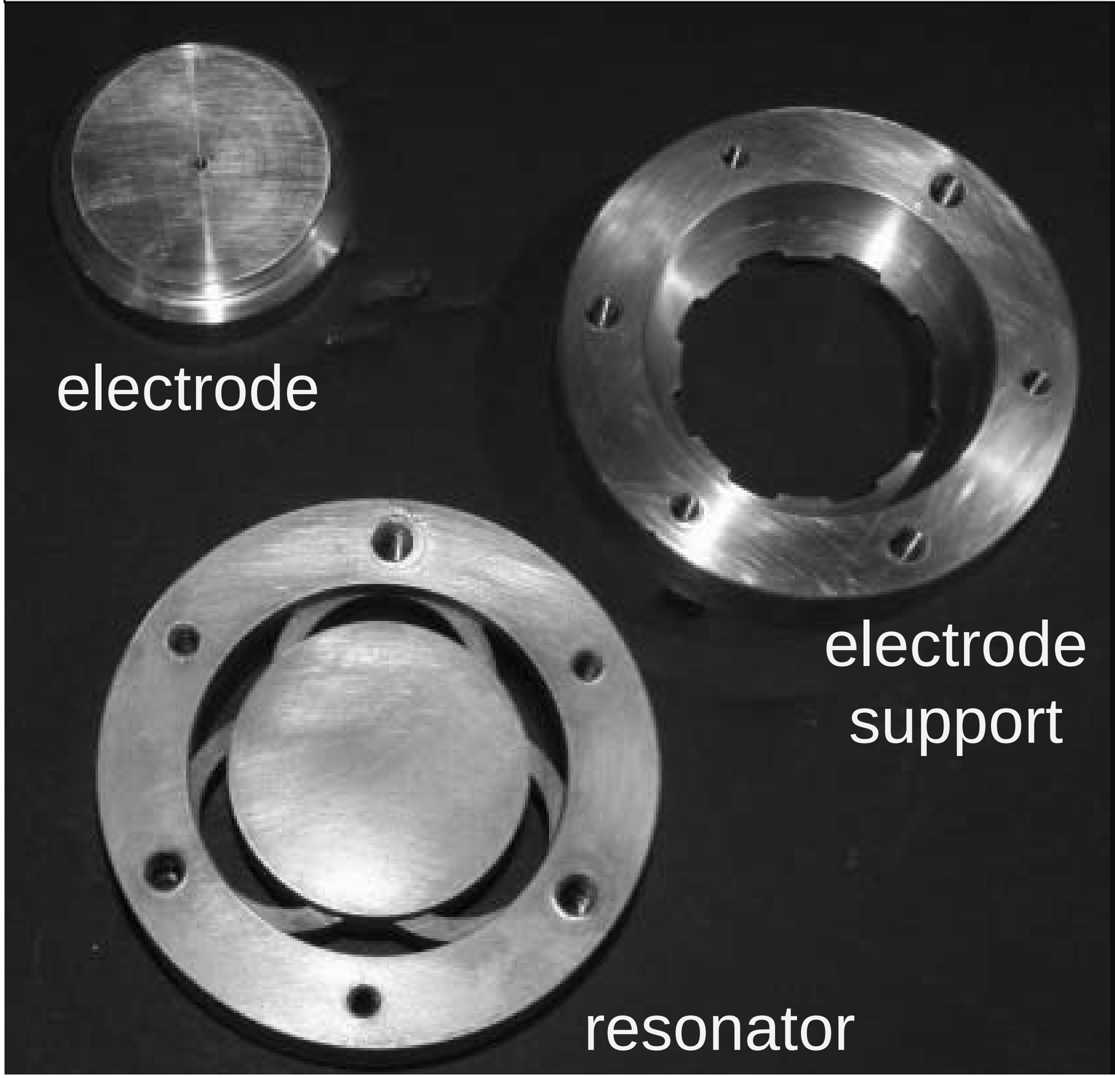
SQUID - quantum limit

T = 20 mK

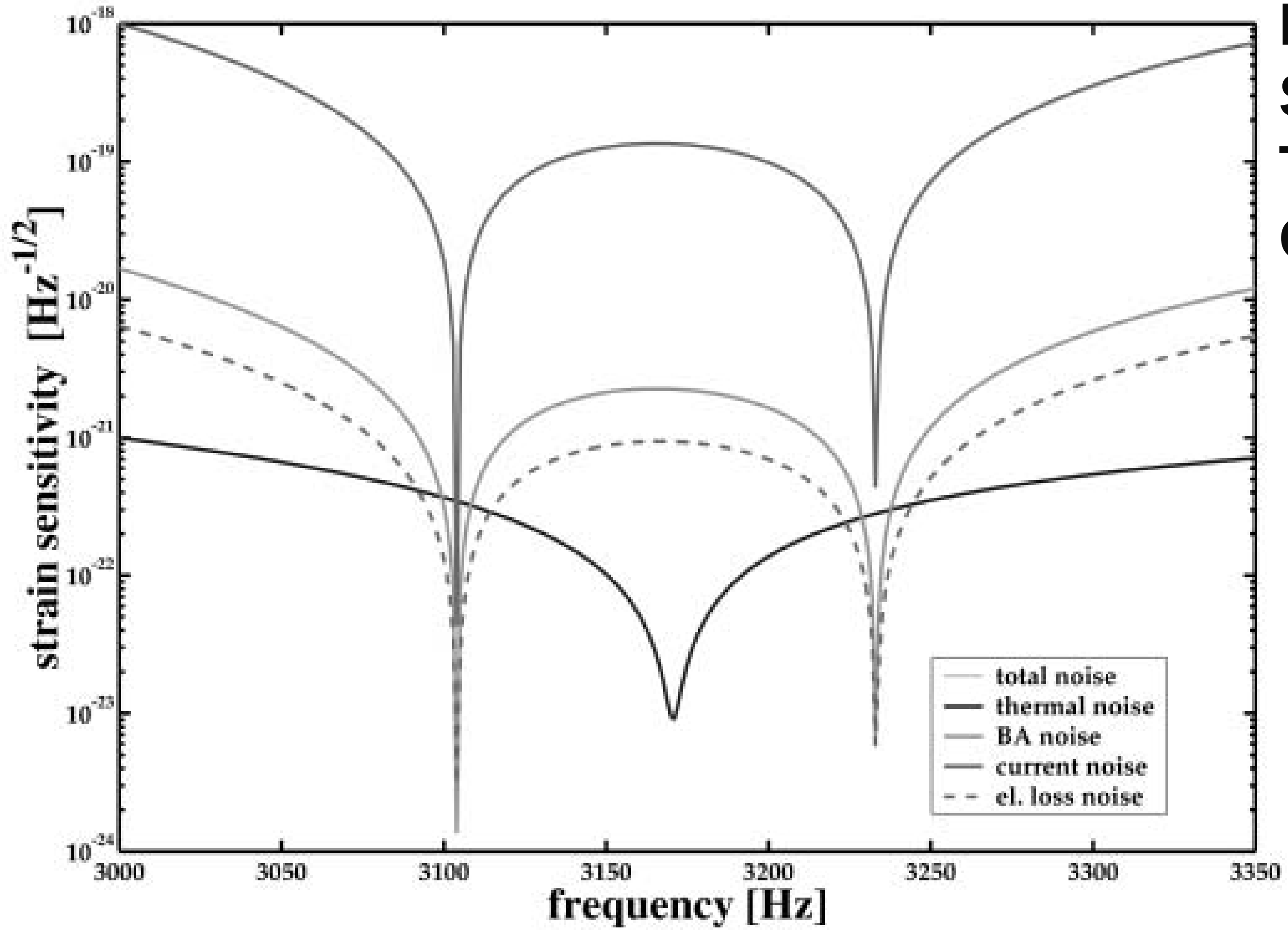
$Q=10^{7}$



capacitive transducer



capacitive transducer



Mass ratio – 10^{-3}

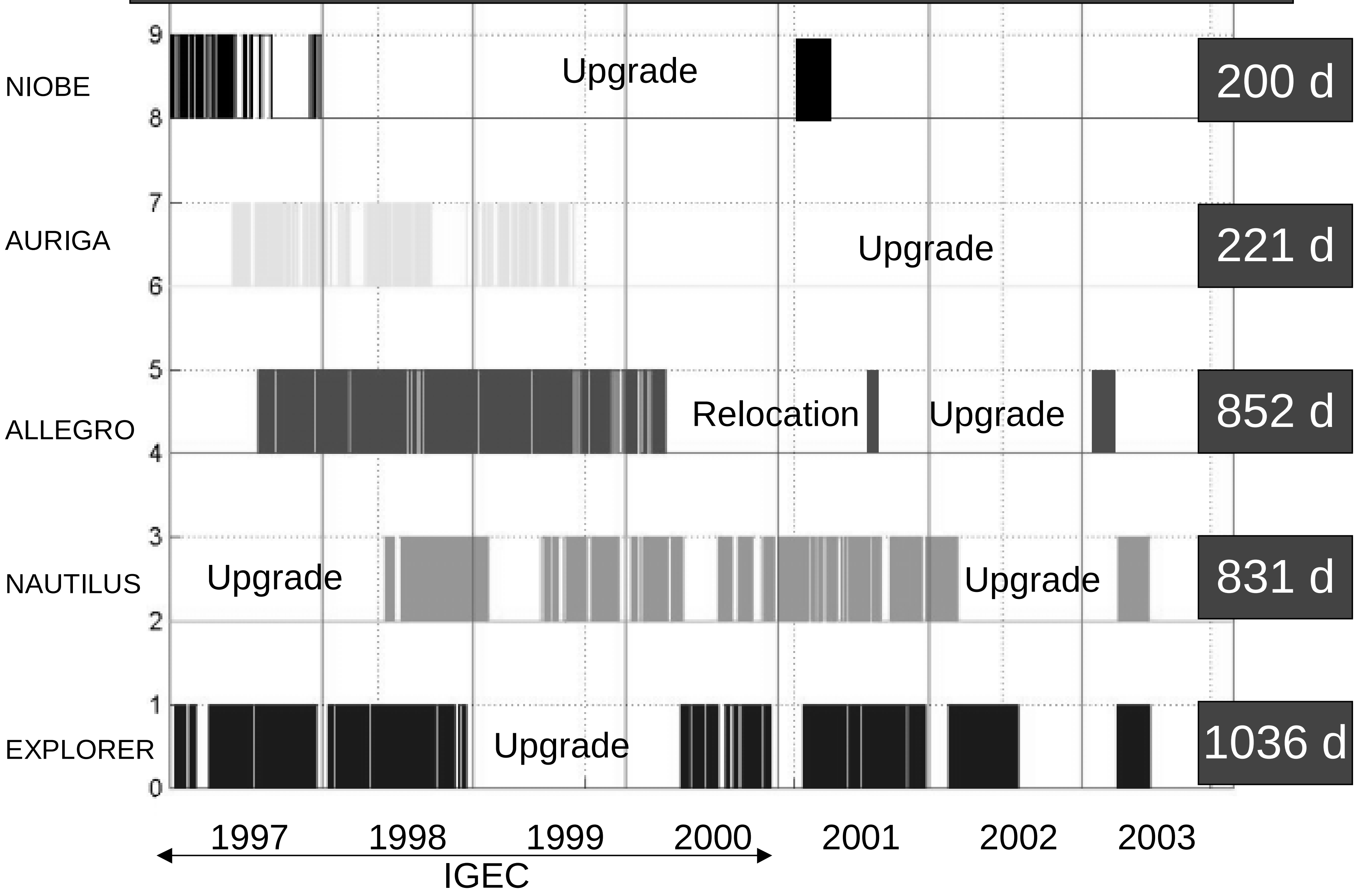
SQUID - 700 hbar

T = 20 mK

Q = 10^{6}

Bursts	IGEC, Phys. Rev. Lett. **85,** 5046 (2000) ROG Coll.: Class. Quant. Grav. **18**, 243 (2001) ROG Coll.: Class. Quant. Grav. **19**, 5449 (2002) IGEC: Phys. Rev. D in press, astro-ph 0302482
Continuous signals	ALLEGRO Coll.: Proc. 2nd E. Amaldi Conference 1997 ROG Coll: Phys. Rev. D **65,** 022001(2002) A. Krolak et al and ROG Coll: CQG GWDAW2002 Proc. in press, gr-qc/0304107
Stochastic Background	ROG Coll.:Astron. Astrophys. **351**, 811 (1999)
more Talk by G Modestino	*Search for correlation with GRB's* ROG Coll.: Astron. Astrophys. Suppl. Ser. **138**, 603 (1999). ROG Coll.: Astron. Astrophys. Suppl. Ser. **138**, 605 (1999). AURIGA Coll.: Phys. Rev. D **63**, 022005 (2001). ROG Coll.: Phys. Rev. D **66**, 102202 (2002). *Effect of cosmic rays* ROG Coll.: Phys. Rev. Lett. **84** , 14 (2000) ROG Coll.: Phys. Lett. B **499**, 16 (2001), ROG Coll.: Phys. Lett. B **540** (2002).

•ON times for the various detectors 1997-2003

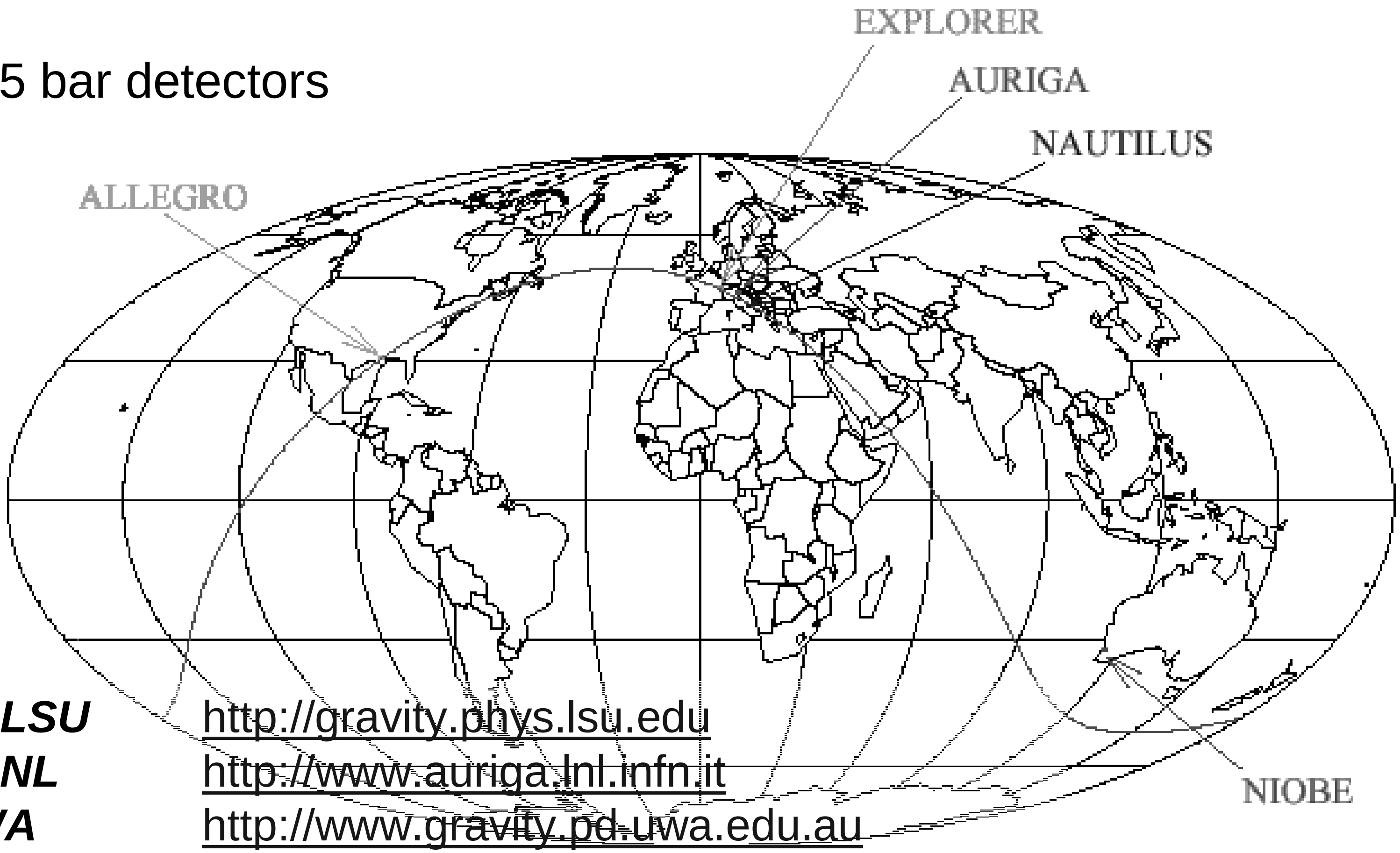


International Gravitational Event Collaboration
http://igec.lnl.infn.it

Results of the 1997-2000 Search for Burst Gw by IGEC

PRD 68, n2 (2003) astro-ph/0302482

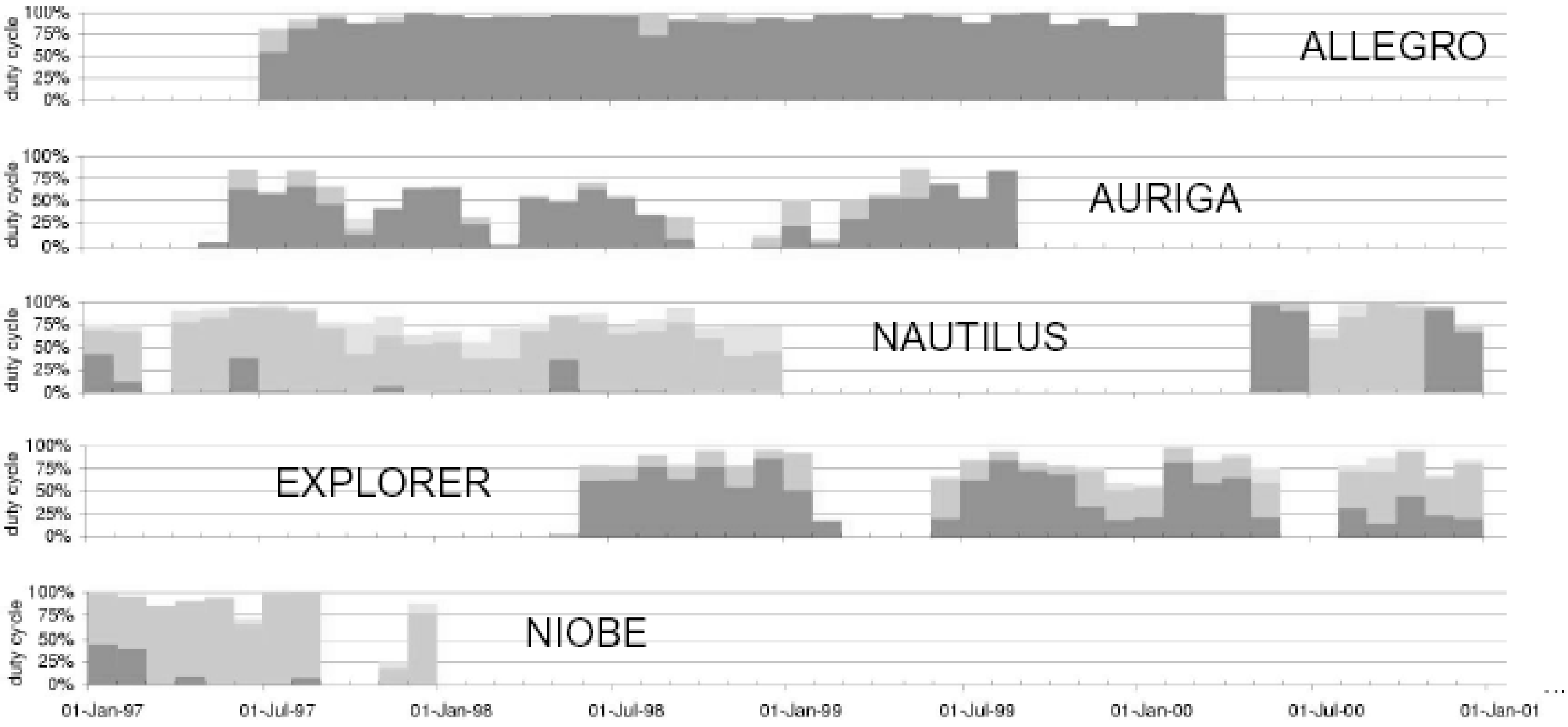
Network of the 5 bar detectors
almost **parallel**



ALLEGRO ***NFS-LSU***	http://gravity.phys.lsu.edu
AURIGA ***INFN-LNL***	http://www.auriga.lnl.infn.it
NIOBE ***ARC-UWA***	http://www.gravity.pd.uwa.edu.au
EXPLORER ***INFN-CERN***	http://www.roma1.infn.it/rog/rogmain.html
NAUTILUS ***INFN-LNF***	

IGEC

EXCHANGED PERIODS of OBSERVATION 1997-2000



fraction of time in monthly bins

exchange threshold

☐ $H > 6 \cdot 10^{-21} Hz^{-1}$

▨ $3 \div 6 \cdot 10^{-21} Hz^{-1}$

■ $H < 3 \cdot 10^{-21} Hz^{-1}$

H is ***Fourier amplitude*** of burst gw

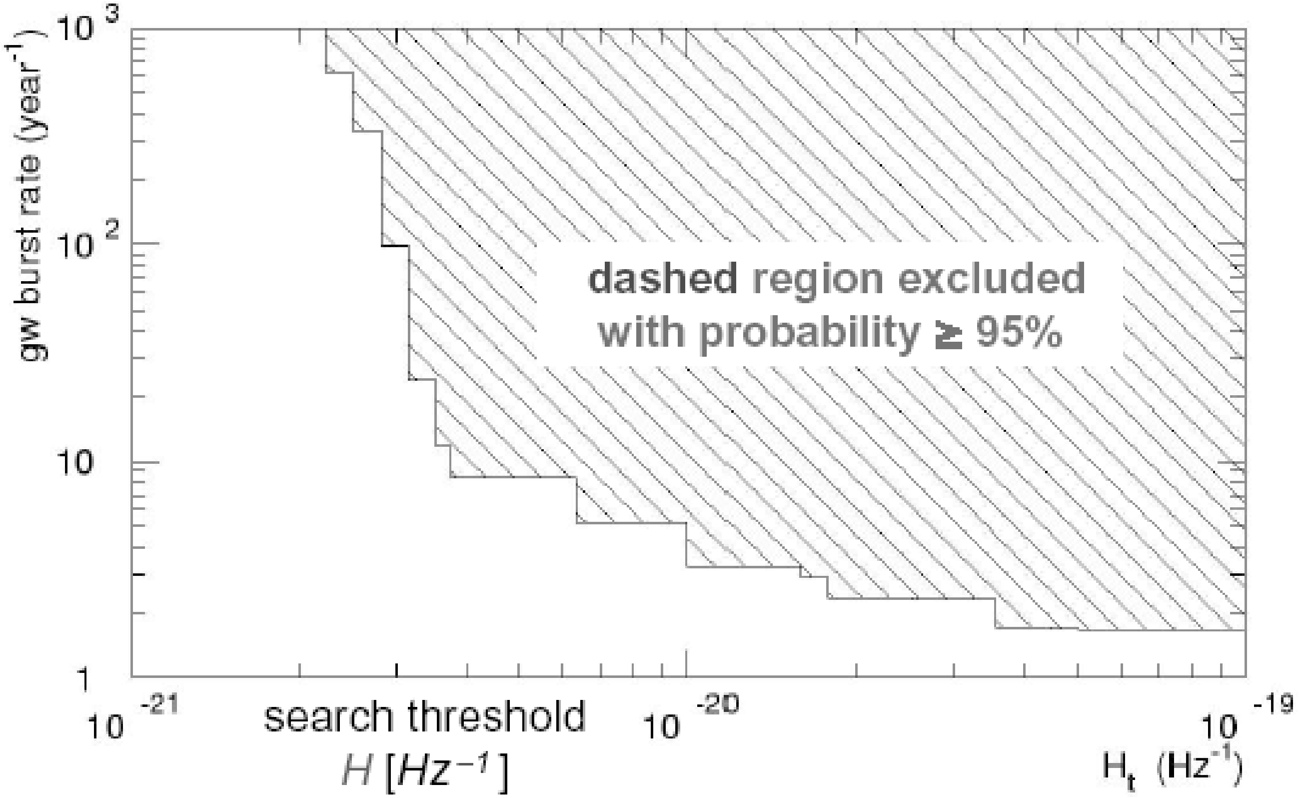
$$h(t) = H \cdot \delta(t - t_0)$$

arrival time

Talk by G.A. Prodi

UPPER LIMIT on the RATE of BURST GW from the GALACTIC CENTER DIRECTION

rate [*year*$^{-1}$]



dashed region excluded with probability ≥ 95%

search threshold
H [*Hz*$^{-1}$]

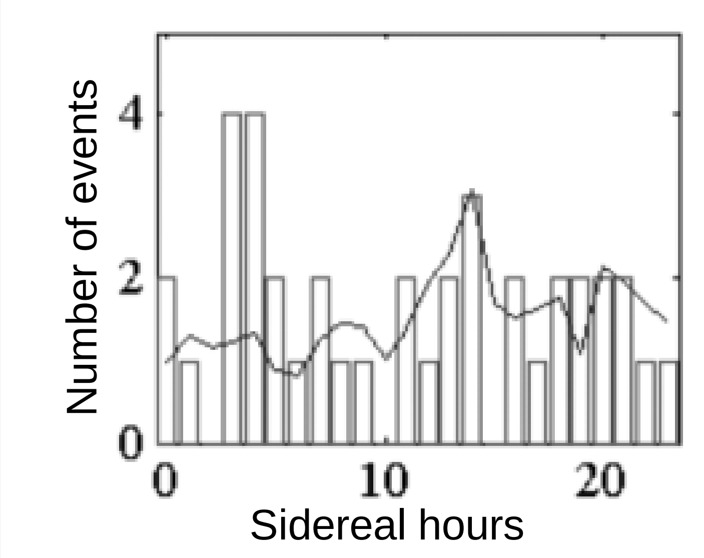
Upper limit for burst GWs with random arrival time and measured amplitude ≥ search threshold

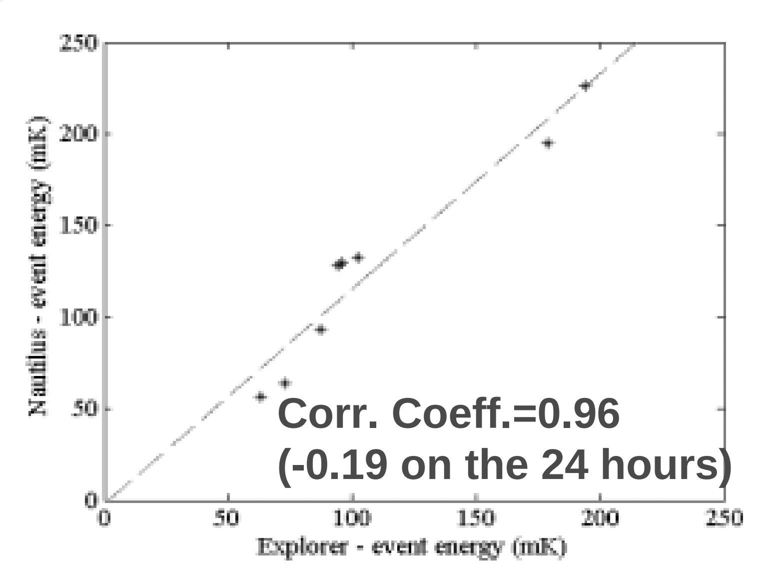
$$H \sim 2 \cdot 10^{-21} / Hz \leftrightarrow 0.02\, M_\odot \text{ converted at Galactic Center}$$

EXPLORER-NAUTILUS 2001 data analysis

During 2001 EXPLORER and NAUTILUS were the only two operating resonant detectors, with the best ever reached sensitivity.

A new algorithm based on energy compatibility of the event was applied to reduce the “background”





Corr. Coeff.=0.96
(-0.19 on the 24 hours)

*ROG Coll.: CQG **19**, 5449 (2002)*
*L.S.Finn: CQG **20**, L37 (2003)*
P.Astone, G.D’Agostini, S.D’Antonio: CQG Proc. Of GWDAW 2002, gr-qc/0304096
E. Coccia ROG Coll.:CQG Proc. Of GWDAW 2002
ROG Coll.: gr-qc/0304004

Talk by M. Visco

New data are needed for further considerations

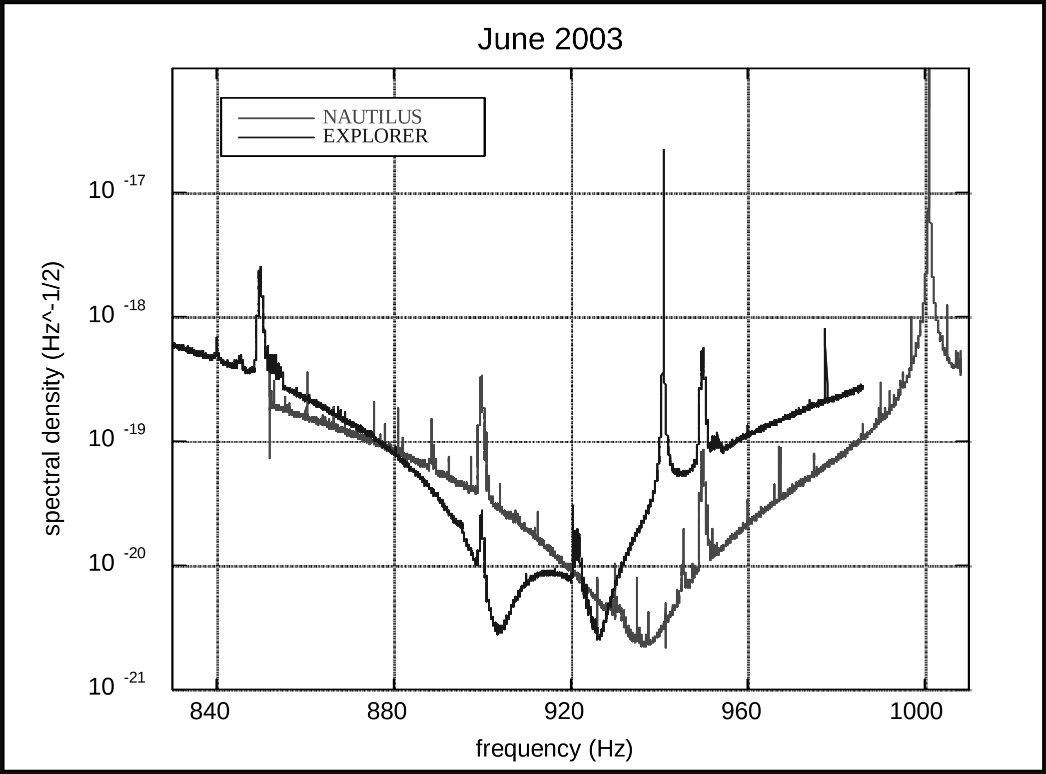
STOCHASTIC BACKGROUND

Previous result: ROG Coll. *Astron. Astrophys*, 351 (1999)

12 hours of data $\Delta f = 0.1$ Hz $S_{12} < 1 \times 10^{-44}$ Hz^{-1}

Ω_{GW} (920.2 Hz) < 60

- Will optimize overlapping bandwidth by acting on the bias E field
- Potential common band is ~ 100 x that exploited in `97.



With Tobs of about 100 days, upper limit on Ω_{GW} less than unity can be achieved

Stochastic Background

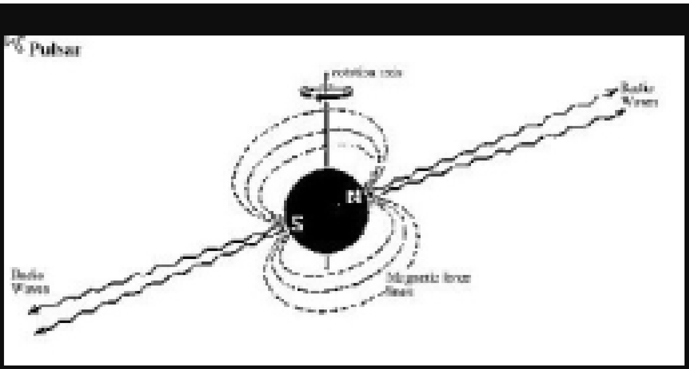
•The cross-correlation of 6 months of NAUTILUS and AURIGA phase I, would put the limit $\Omega_{gw} \leq 0.1$ @ 935 Hz.

•Joint analyses with VIRGO - NAUTILUS and VIRGO - AURIGA II may put limits at the level $\Omega_{gw} \leq 3\text{-}5\ 10^{-3}$ (1y integration 10^{-22} $\mathrm{Hz}^{-1/2}$ @900 Hz for VIRGO)

•LIGO I (10^{-22} $\mathrm{Hz}^{-1/2}$ @ 1 kHz) and ALLEGRO ($2\ 10^{-21}$ $\mathrm{Hz}^{-1/2}$):
$\Omega_{gw} \leq 0.1$ (1y of data, analysed at periods of 2-3 months).

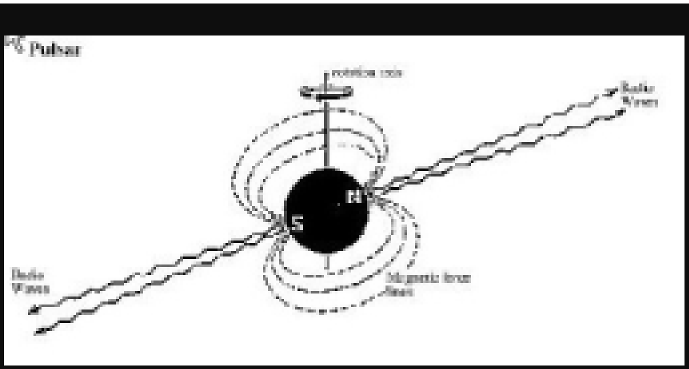
•LIGO II (10^{-23} $\mathrm{Hz}^{-1/2}$ @ 1 kHz) and ALLEGRO (10^{-22} $\mathrm{Hz}^{-1/2}$):
$\Omega_{gw} \leq 6\ 10^{-4}$

Continuous waves



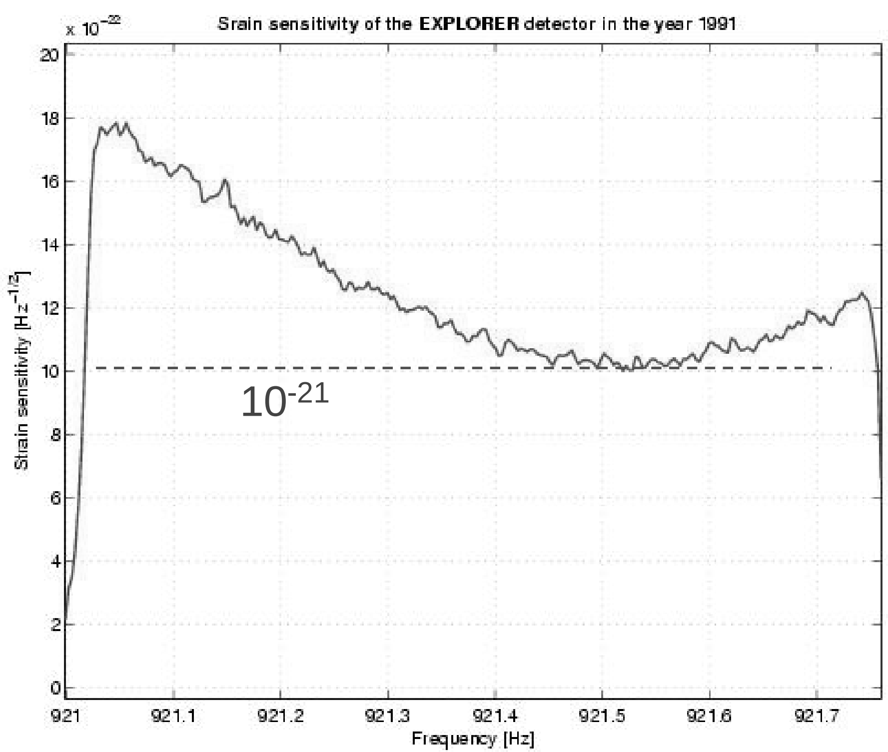
- ALLEGRO put upper limits (4 10^{-23} over 1 Hz band) on signals from the GC and 47Tucanae using one month of data
- Limit for signals in the GC, using 95 days of EXPLORER data $h_c=3x10^{-24}$, in the range 921.32 - 921.38 Hz (ROG Coll.: *PRD, 2002*)

Continuous waves

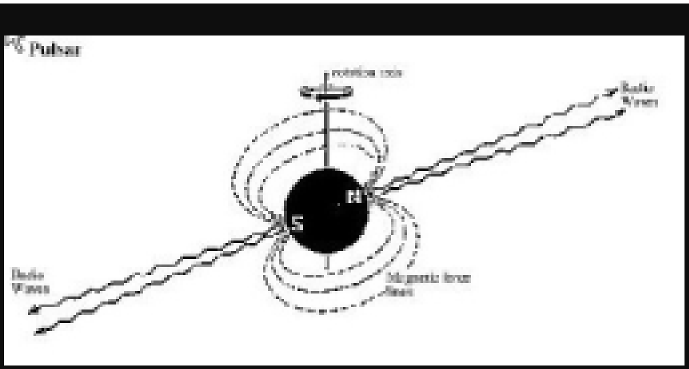


Overall sky search

Phase I ended: 2 days of EXPLORER 1991 data analyzed in collaboration with A. Krolak & Collaborators put an upper limit of $h_c=2x10^{-23}$. (10^8 points, by choosing spin-down parameter and position randomly) - CQG, proc. GWDAW 2002



Continuous waves



Phase II ended: collaboration with Krolak & C. and the Virgo Project Group in Rome. Two-day stretch of data disjoint from the two-day stretch analysed in the previous search.

Search done using the computers provided by the Virgo Project (March-May 2003). Number of candidates found: 29909.

Highest SNRS:

Northern Sky=8.15

Southern Sky=7.83

(99% confidence threshold is 8.3, none of the candidates exceeded this thrs.)

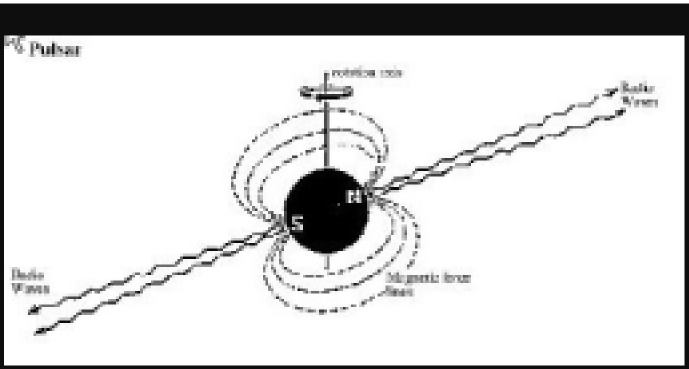
Comparison of candidates found in the two searches is now in progress.

The results of the search will be compared with those of an analysis done using the hierarchical search procedure, developed by the Virgo group of Rome, in collaboration with the ROG group (this work is now in progress). The aim is to analyze at least 1 year of data of EXPLORER and NAUTILUS.

Phase III: 2 more days of EXPLORER data is in progress.

www.astro.uni.torun.pl/=kb/all-sky and www.roma1.infn.it/rog

Continuous waves



Agreement between ROG and AEI Max Planck in Golm for the coherent analysis of data selected from 1 year of data of Nautilus 2001.

The data base of FFTs (17193 FFTs, 28 minutes each, in the format used by GEO/LIGO in their analysis) has been produced and is now in the cluster in Golm.

The procedures to veto the data is under studying.

Searches pointing at Globular Clusters, Galactic Plane..are in schedule.

Effect of cosmic rays

$h = 3 \times 10^{-22}\ Hz^{-1/2}$

$h_{pulse} = \Delta L/L = 4 \times 10^{-19}$

$\Delta E = 2\ mK = 0.3\ \mu eV$

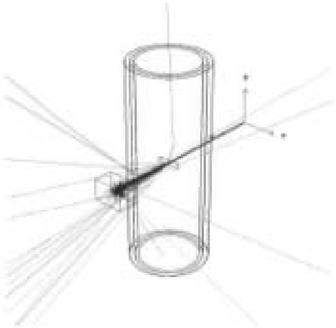
Nautilus is equipped with 7 layers (3 above the cryostat - area 36m^2/each - and 4 below -area 16.5 m^2/each) **of Streamer tubes.**

Period	NAUTILUS temperature (K)	Duration (hours)	nc	n	Rate(ev/day)
Sept-Dec 1998	0.14	2002	12	0.47	
Feb-July 2000	0.14	707	9	0.42	
total		2709	21	0.89	0.178
Aug -Dec 2000	1.1	118	0	0.03	
Mar-Sept 2001	1.5	2003	1	0.54	
total		2121	1	0.45	0.006

Effect of cosmic rays

RAP

Rivelazione
Acustica
di Particelle



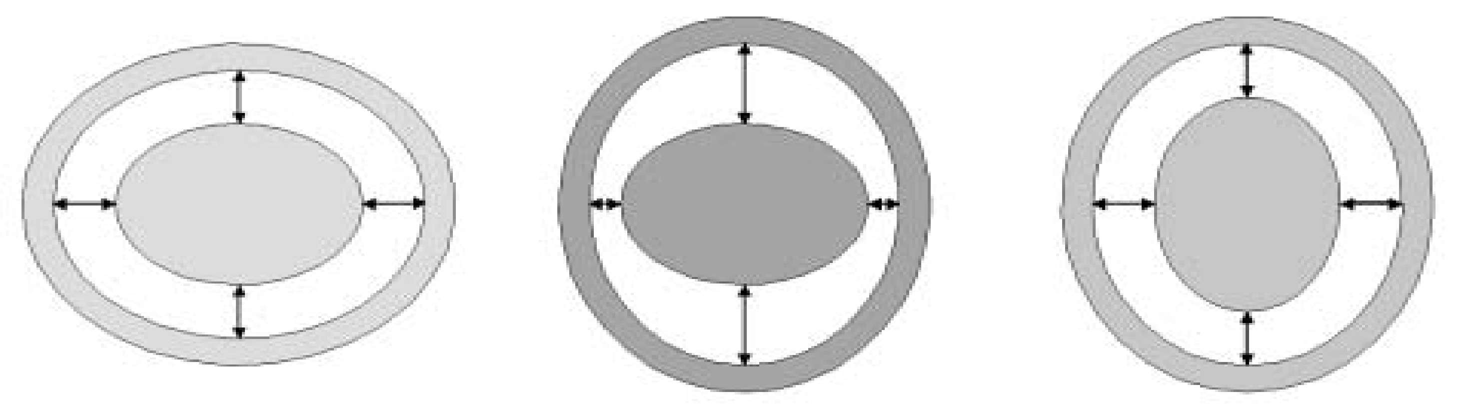
Talk by G. Mazzitelli

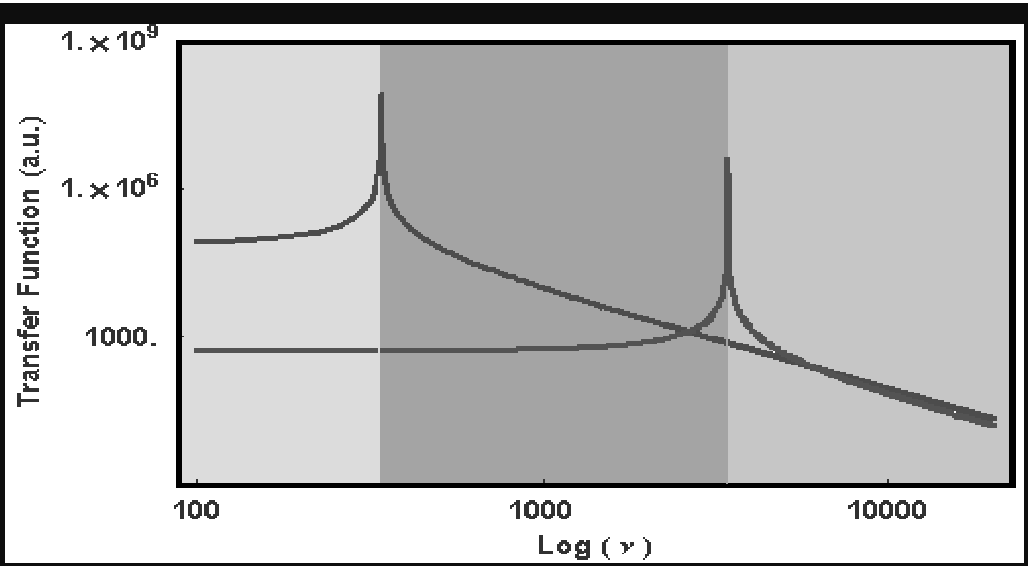
DUAL: wideband high freq gw detector

PRL ***87*** *(2001) 031101* *gr-qc/0302012*

2 nested resonant masses

measure the differential deformation **between** *the lowest quadrupolar modes*





Talk by M. Bonaldi

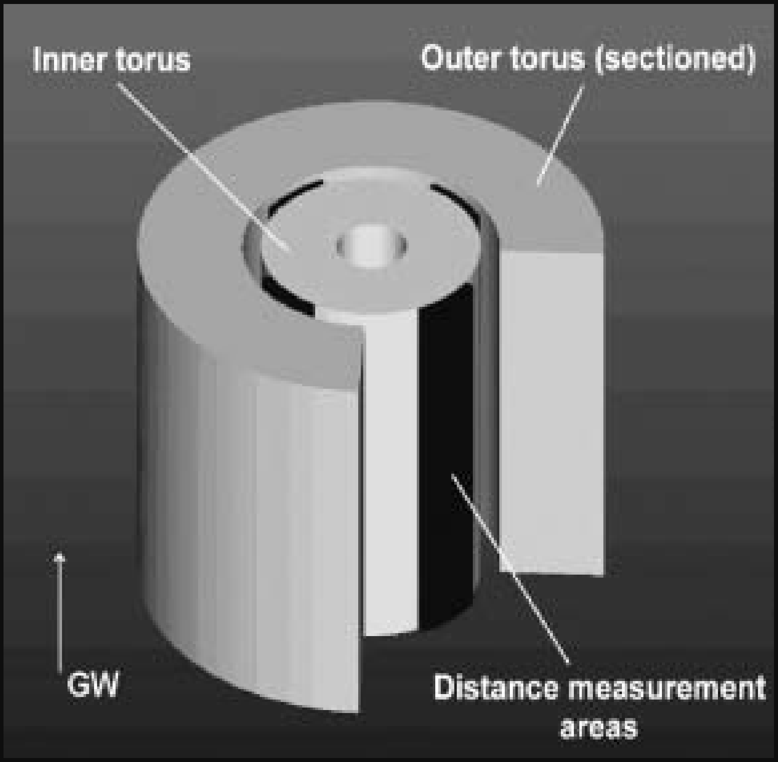
- **gw signals add**
- **back action noises subtract**

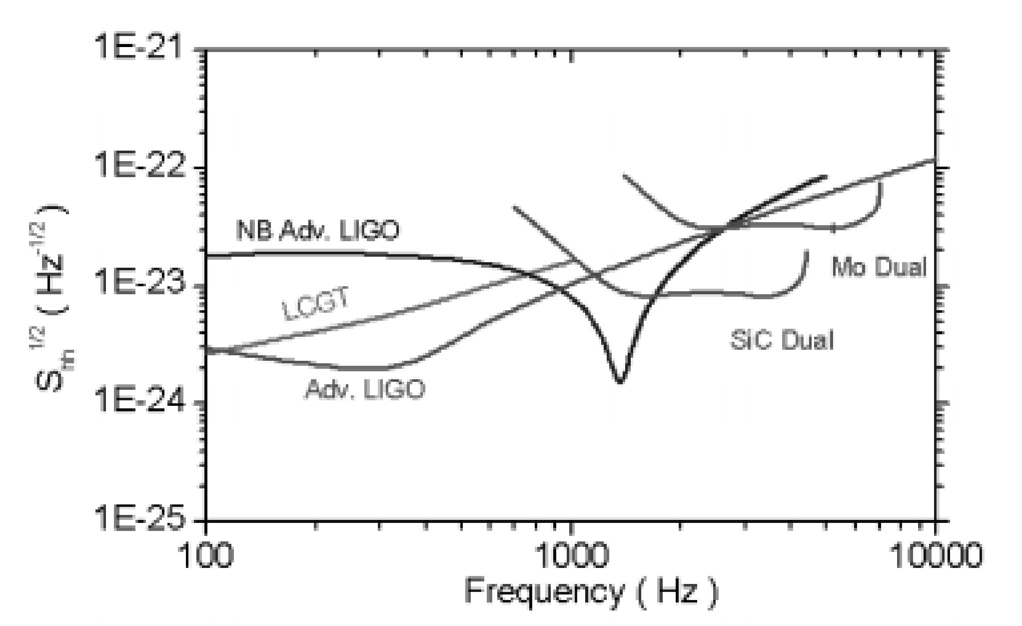
DUAL: wideband high freq gw detector

PRL ***87*** *(2001) 031101* *gr-qc/0302012*

2 nested resonant masses

Sensitive in a kHz-wide frequency band





Mo Dual 16.4 ton height 2.3 m Ø 0.94m

SiC Dual 62.2 ton height 3 m Ø 2.9m

T~0.1 K , Standard Quantum Limit

readout:

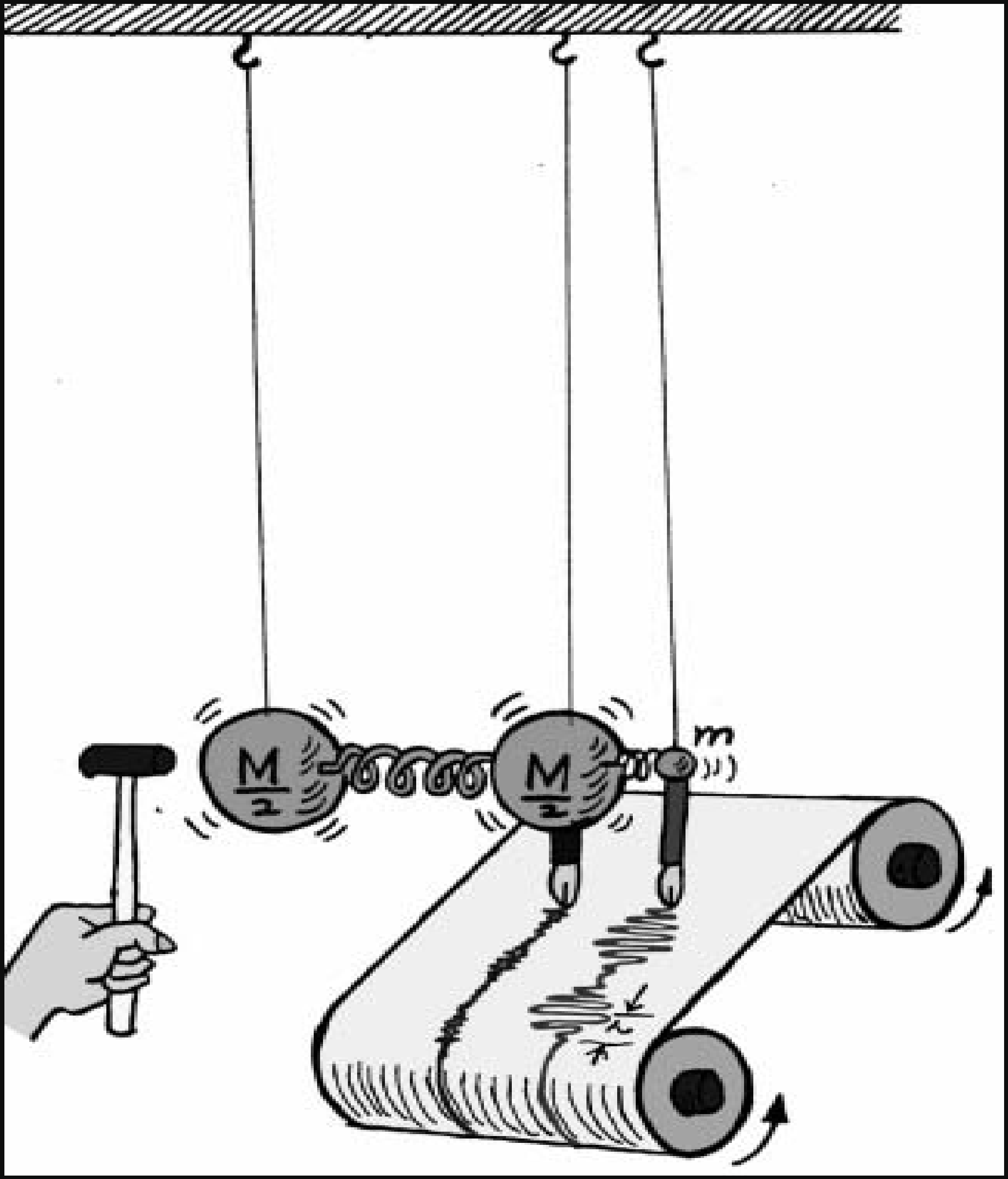
selects quadrupolar deformations

averages over a wide area

⇒ **flat** sensitivity in a wide band

The End

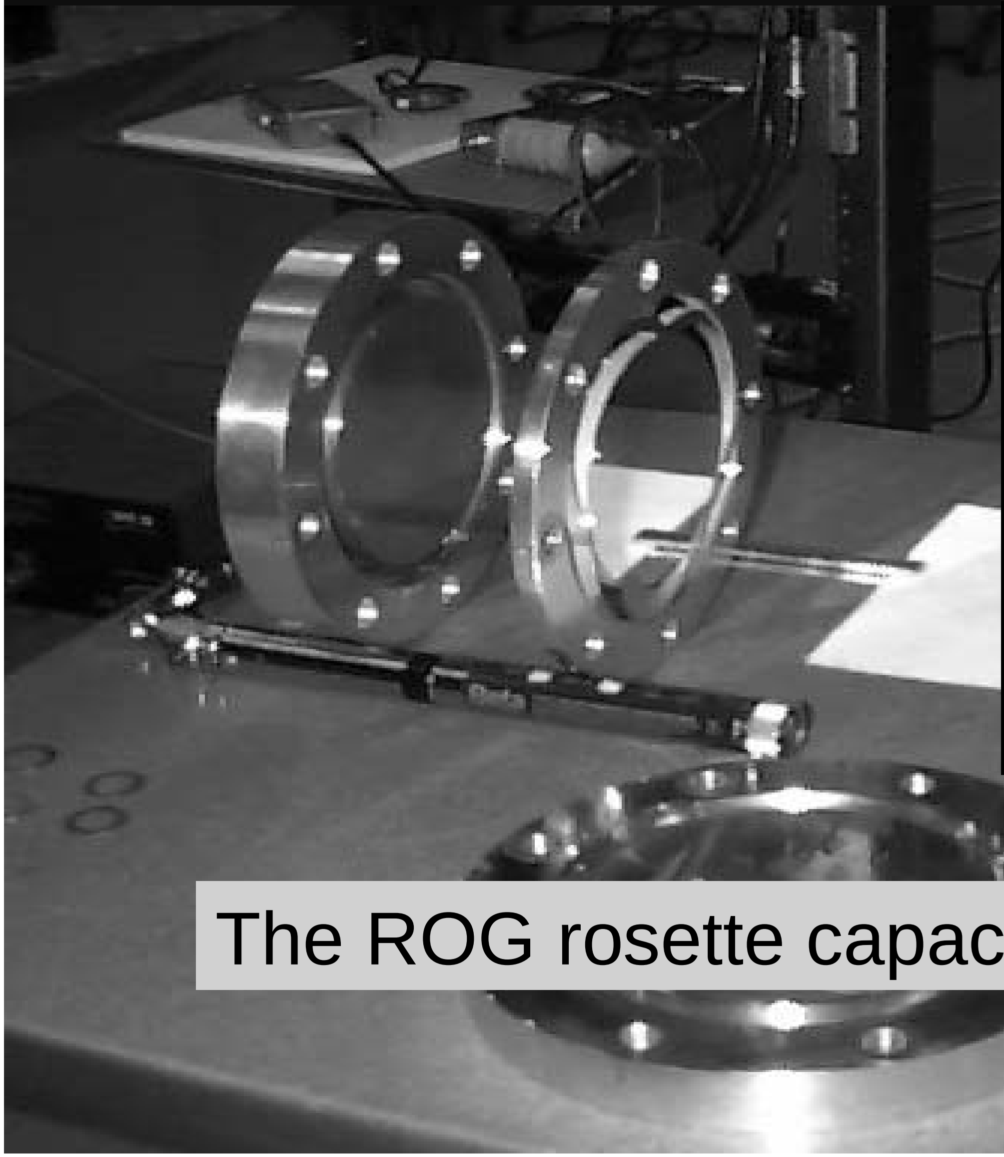
Principle of a Resonant Transducer

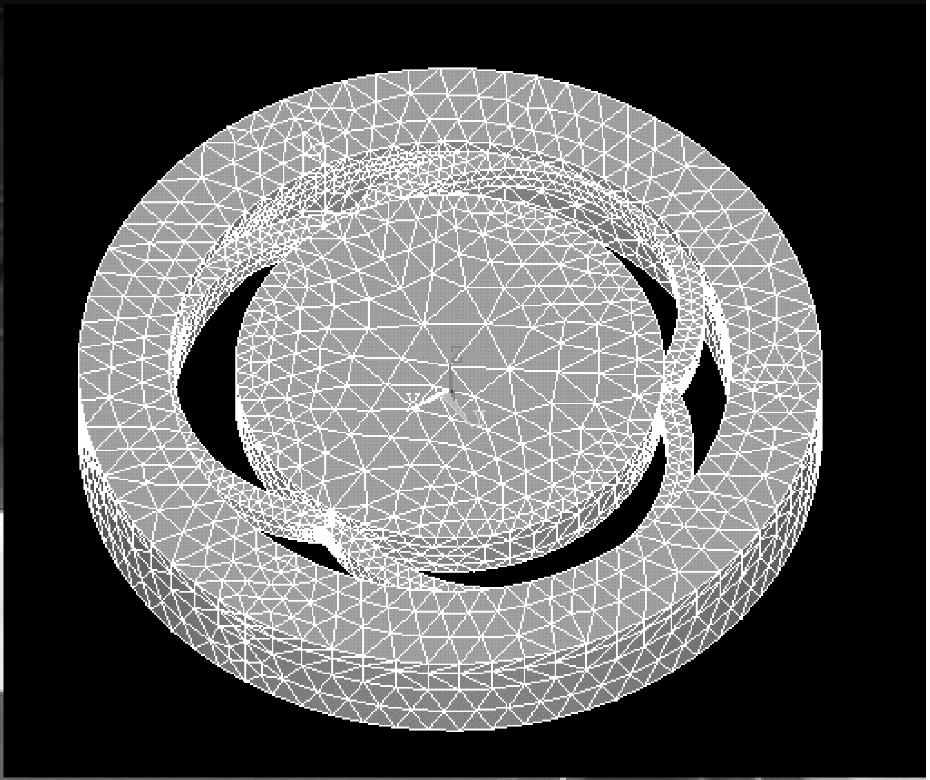


The displacement of the secondary oscillator modulates a dc electric or magnetic field or the frequency of a s.c. cavity

$$x_m = \sqrt{\frac{M}{m}}\, x_M$$

MICROMECHANICS

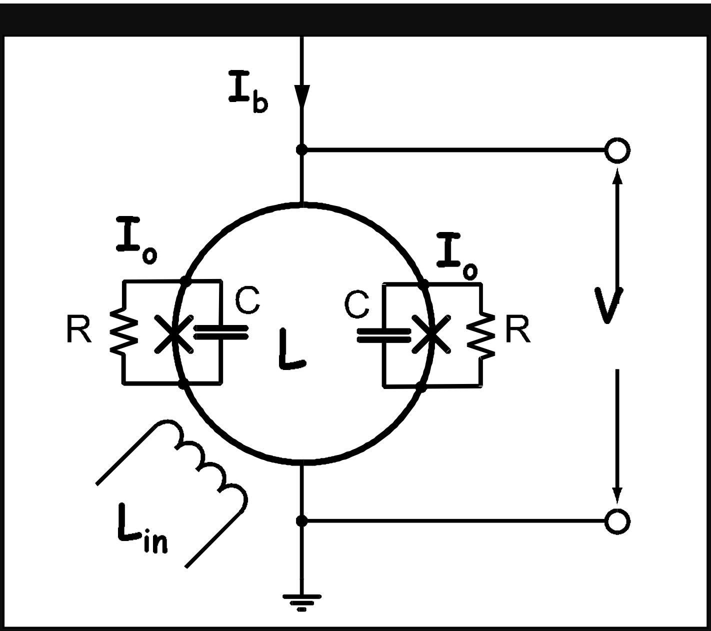




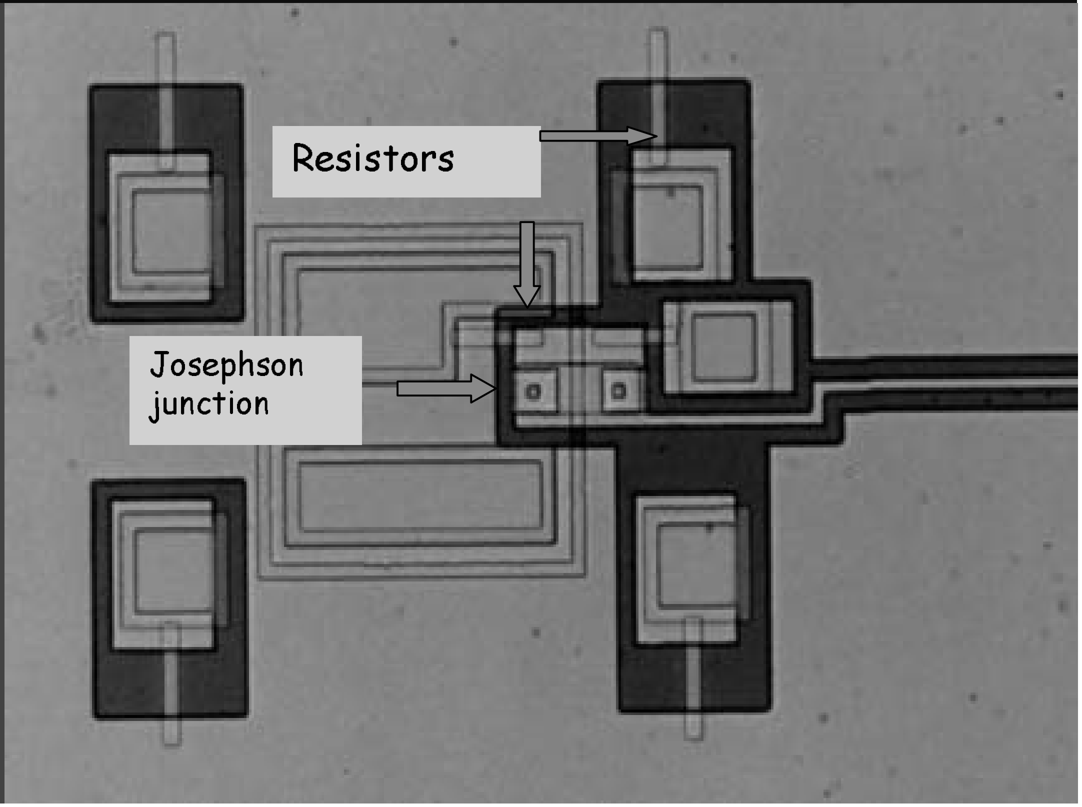
The ROG rosette capacitive transducer; gap=9μm

Quantum technology

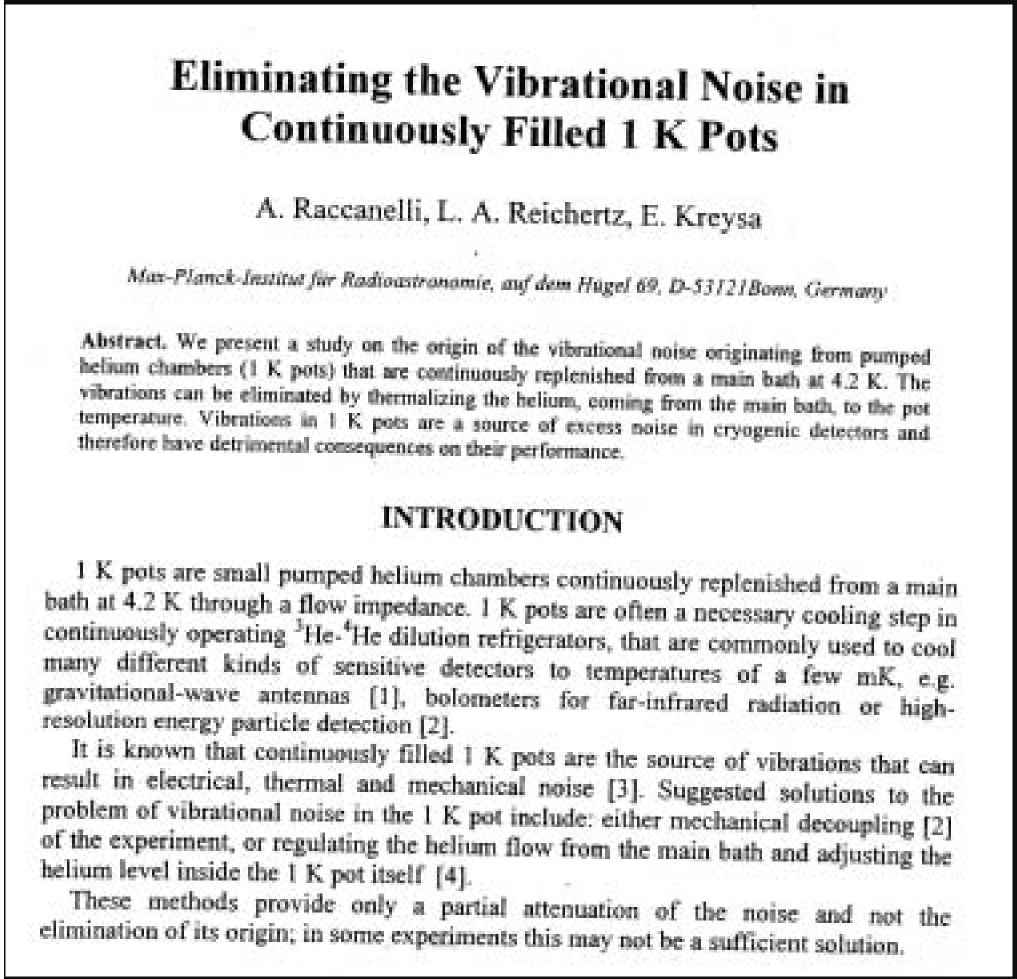
dc-SQUID



- superconducting loop with inductance L
- 2 Josephson junctions:critical current I_o , shunt resistance R, capacitance C,
- Input inductance L_{in}, coupling α


Resistors

Josephson junction



Eliminating the Vibrational Noise in Continuously Filled 1 K Pots

A. Raccanelli, L. A. Reichertz, E. Kreysa

Max-Planck-Institut für Radioastronomie, auf dem Hügel 69, D-53121Bonn, Germany

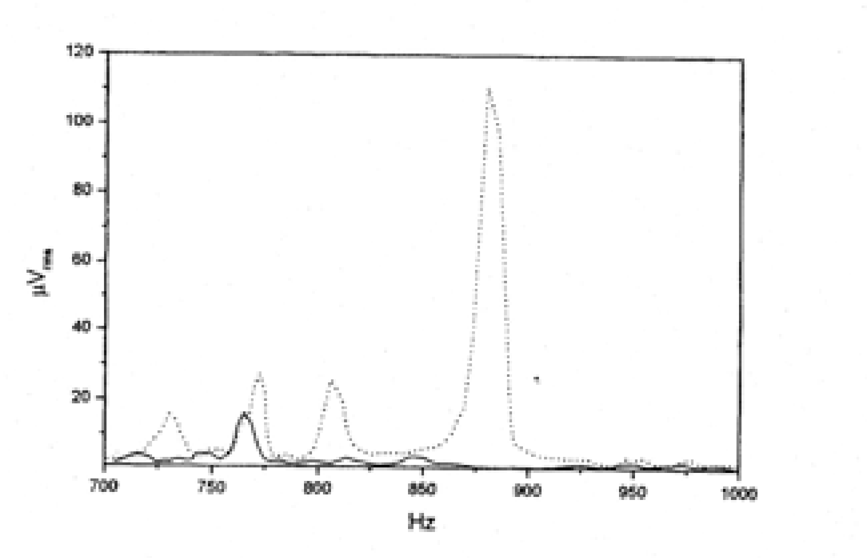
Abstract. We present a study on the origin of the vibrational noise originating from pumped helium chambers (1 K pots) that are continuously replenished from a main bath at 4.2 K. The vibrations can be eliminated by thermalizing the helium, coming from the main bath, to the pot temperature. Vibrations in 1 K pots are a source of excess noise in cryogenic detectors and therefore have detrimental consequences on their performance.

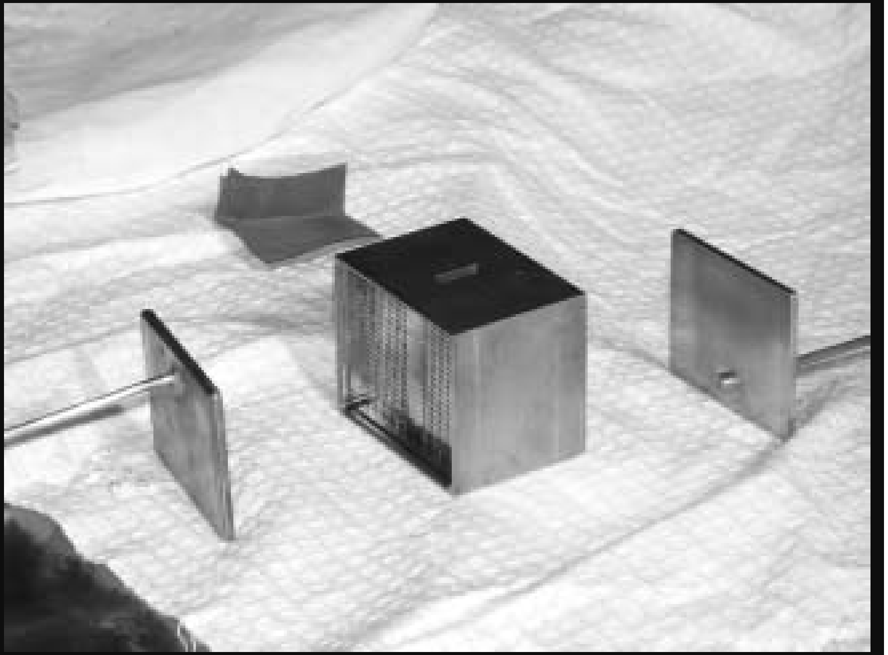
INTRODUCTION

1 K pots are small pumped helium chambers continuously replenished from a main bath at 4.2 K through a flow impedance. 1 K pots are often a necessary cooling step in continuously operating ^{3}He-^{4}He dilution refrigerators, that are commonly used to cool many different kinds of sensitive detectors to temperatures of a few mK, e.g. gravitational-wave antennas [1], bolometers for far-infrared radiation or high-resolution energy particle detection [2].

It is known that continuously filled 1 K pots are the source of vibrations that can result in electrical, thermal and mechanical noise [3]. Suggested solutions to the problem of vibrational noise in the 1 K pot include: either mechanical decoupling [2] of the experiment, or regulating the helium flow from the main bath and adjusting the helium level inside the 1 K pot itself [4].

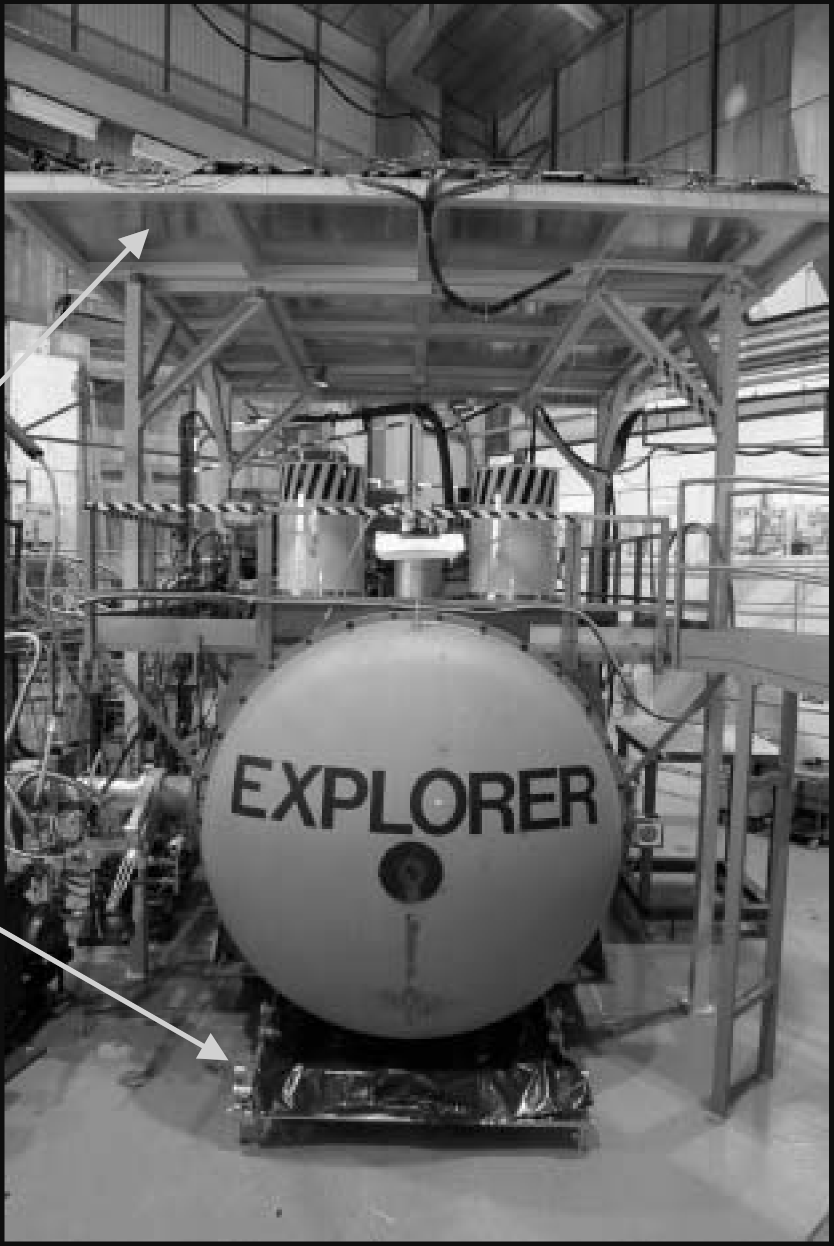
These methods provide only a partial attenuation of the noise and not the elimination of its origin; in some experiments this may not be a sufficient solution.





ROG implementation of Raccanelli scheme

EXPLORER cosmic ray detector



Plastic scintillators

2 layers of 13 m^2

1 layer of 6 m^2

Transducer location (TIGA)