12th Edoardo Amaldi Conference on Gravitational Waves
July 9-14, 2017, Hilton Hotel, Pasadena, CA

The Brazilian Program on Gravitational Wave Detection

Odylio D. Aguiar

July 10th, 2017

G 1701255

GRAVITON GROUP

Historic Background

Three first Brazilian doctorate thesis on GW:
Aguiar (LSU (USA), 1990)
Velloso (VIRGO (Italy) & USP (Brazil), 1992)
Magalhaes (USP (Brazil), 1992)

2000 → Schenberg project started
2008 → Cesar Costa joined LSC
2011 → INPE joined LSC
2015 → last runs of Schenberg at USP
2018 → Schenberg to be assembled at INPE

In the past 20 years (1998-2017), at INPE:

- **15 doctorate thesis concluded on gravitational waves (gw):**

Herman, Kilder, Andrade, José Melo, César, Sérgio, Márcio Alves, Dennis, Cláudio Brandão, Eduardo, Edgard, Pedro, Carlos Eduardo, Enrique e Márcio Constâncio Jr. (LSC));

- **7 Master thesis concluded on gw by other students:**

Carla, Emílio, Cláudio, Natália, Patrick, Luiz Augusto, Fabrícia and Elvis (LSC).

In yellow, thesis related to experimental themes.

In the past 26 years (1995-2017), at USP:

- **6 doctorate thesis concluded on gravitational waves:**

Velloso, Magalhaes, Frajuca, Sérgio, Fábio, Leandro.

All related to experimental themes.

Some other ~15 doctorate thesis on gravitational waves in other institutions in the country. Only three of them related to experimental themes (Fernanda, Lenzi, Stellati).

So a total of 16 doctorate thesis and 5 master thesis defended in the country, since 1992, related with gravitational wave detection technology.

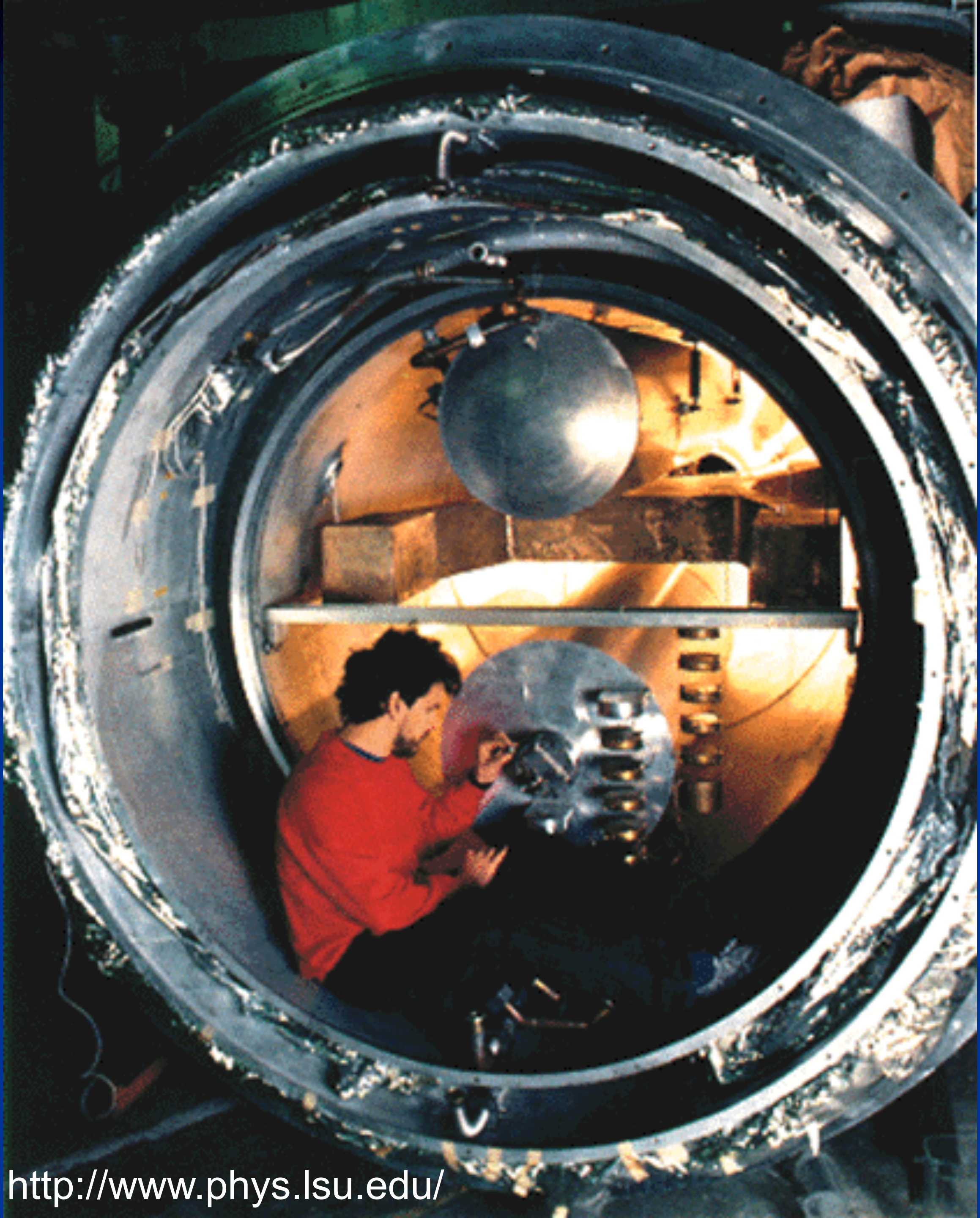
I started a Ph.D. program at LSU in August 1984

Joined the LSU gravitational wave group in July 1986

LSU (ALLEGRO)

2^{nd} bar generation

4.2 K



http://www.phys.lsu.edu/

Astron. Astrophys. 216, 325–332 (1989)

30 authors from 9 institutions

ASTRONOMY AND ASTROPHYSICS

First gravity wave coincidence experiment between resonant cryogenic detectors: Louisiana-Rome-Stanford

E. Amaldi[1,3], O. Aguiar[9], M. Bassan[2,8], P. Bonifazi[3,4], P. Carelli[1,5], M.G. Castellano[3,4], G. Cavallari[7], E. Coccia[2,3], C. Cosmelli[1,3], W.M. Fairbank[8], S. Frasca[1,3], V. Foglietti[3,5], R. Habel[1,6], W.O. Hamilton[9], J. Henderson[8], W. Johnson[9], K.R. Lane[8], A.G. Mann[9], M.S. McAshan[8], P.F. Michelson[8], I. Modena[2,3], G.V. Pallottino[1,3], G. Pizzella[1,3], J.C. Price[8], R. Rapagnani[1,3], F. Ricci[1,3], N. Solomonson[9], T.R. Stevenson[8], R.C. Taber[8], and B.-X. Xu[9]

[1] Dipartimento di Fisica dell'Universita 'La Sapienza', Piazza Aldo Moro, 2, I-00185 Roma, Italy
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[3] Istituto Nazionale di Fisica Nucleare, Roma, Italy
[4] Istituto di Fisica dello Spazio Interplanetario del CNR, Frascati (Roma), Italy
[5] Istituto di Elettronica dello Stato Solido del CNR, Roma, Italy
[6] ENEA, Centro Ricerche Energia, Frascati (Roma), Italy
[7] CERN, European Organization for Nuclear Research, Geneva, Switzerland
[8] Department of Physics, Stanford University, Stanford, CA 94305, USA
[9] Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803-4001, USA

Received August 8, accepted November 23, 1988

Summary. The results of a coincidence search for short bursts of gravitational radiation with cryogenic resonant-mass detectors are reported. No significant excess of coincidences at zero time delay were found. The data have been used to set an improved observational upper limit on the flux of impulsive gravitational waves that may be impinging on the Earth.

Key words: gravitational waves – detectors, gravitational waves – coincidence experiment

employs a resonant capacitive transducer (Rapagnani, 1982) matched to a d.c. SQUID amplifier (Carelli, 1985).

The performance of the three detectors during this coincidence experiment did not reach the design goals or previously achieved levels by the Stanford detector in either sensitivity or in non-Gaussian disturbance level (Boughn, 1982). Despite this situation, the limit that we are able to set on the rate of gravity wave pulses impinging on the Earth is better than that set by any previous observations.

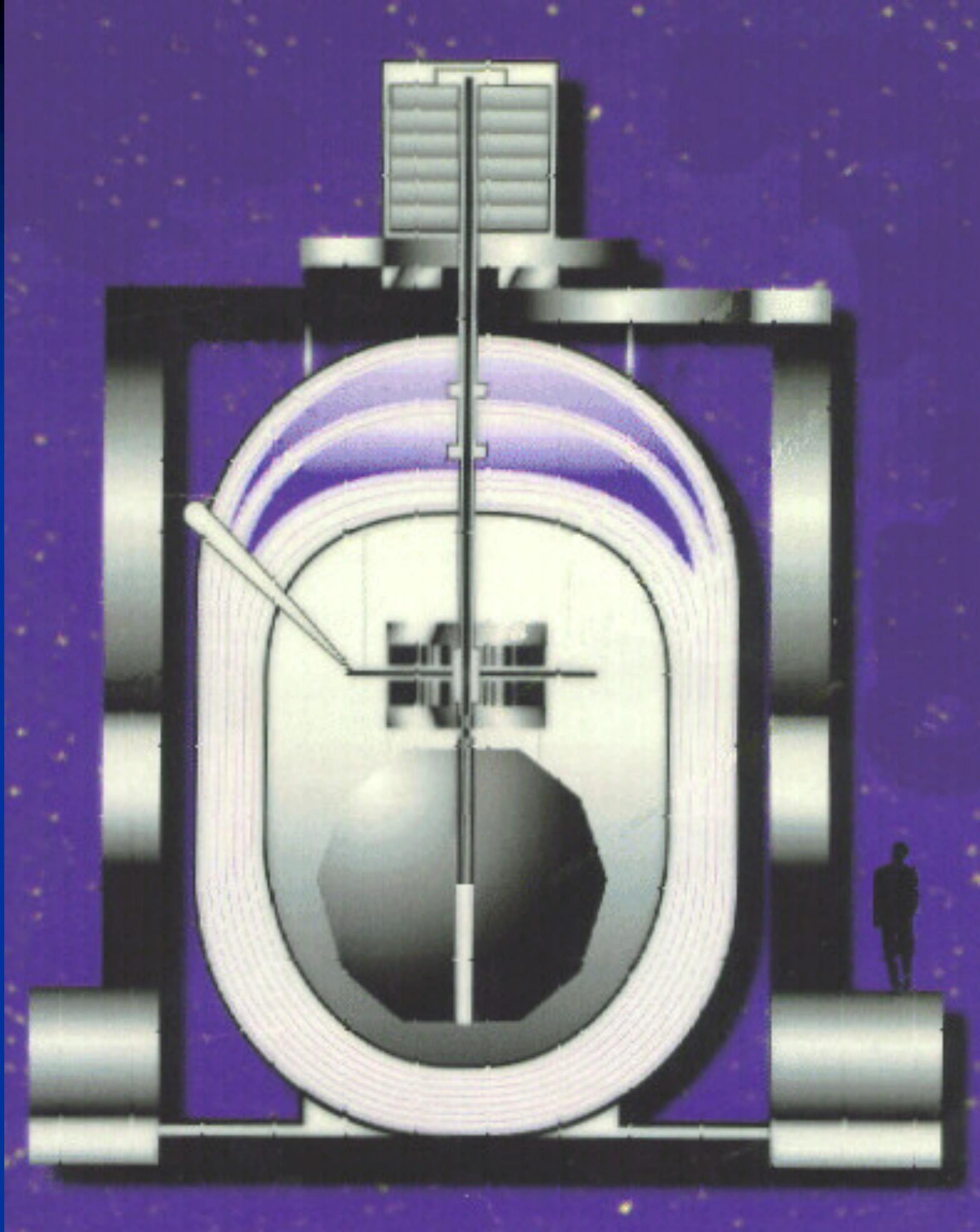
1988 → Warren Johnson (LSU) started to revive Forward's and Paik & Wagoner's idea of a resonant spherical antenna;

1990 → Warren involved Stephen Merkowitz in this study;

1990 → I finished my Ph.D. at LSU.

Massive detectors with spherical geometry

GRAVITON Project (Brasil) 1991




al Wave Detectors
Interferometric
Resonant-Mass
LISA
MINIGRAIL
GA
US
TAMA
LCGT
RG
AIGO
NIOBE
MiniGRAIL
Netherlands
Mario Schenberg,
Brazil
(FAPESP)
ational wave research

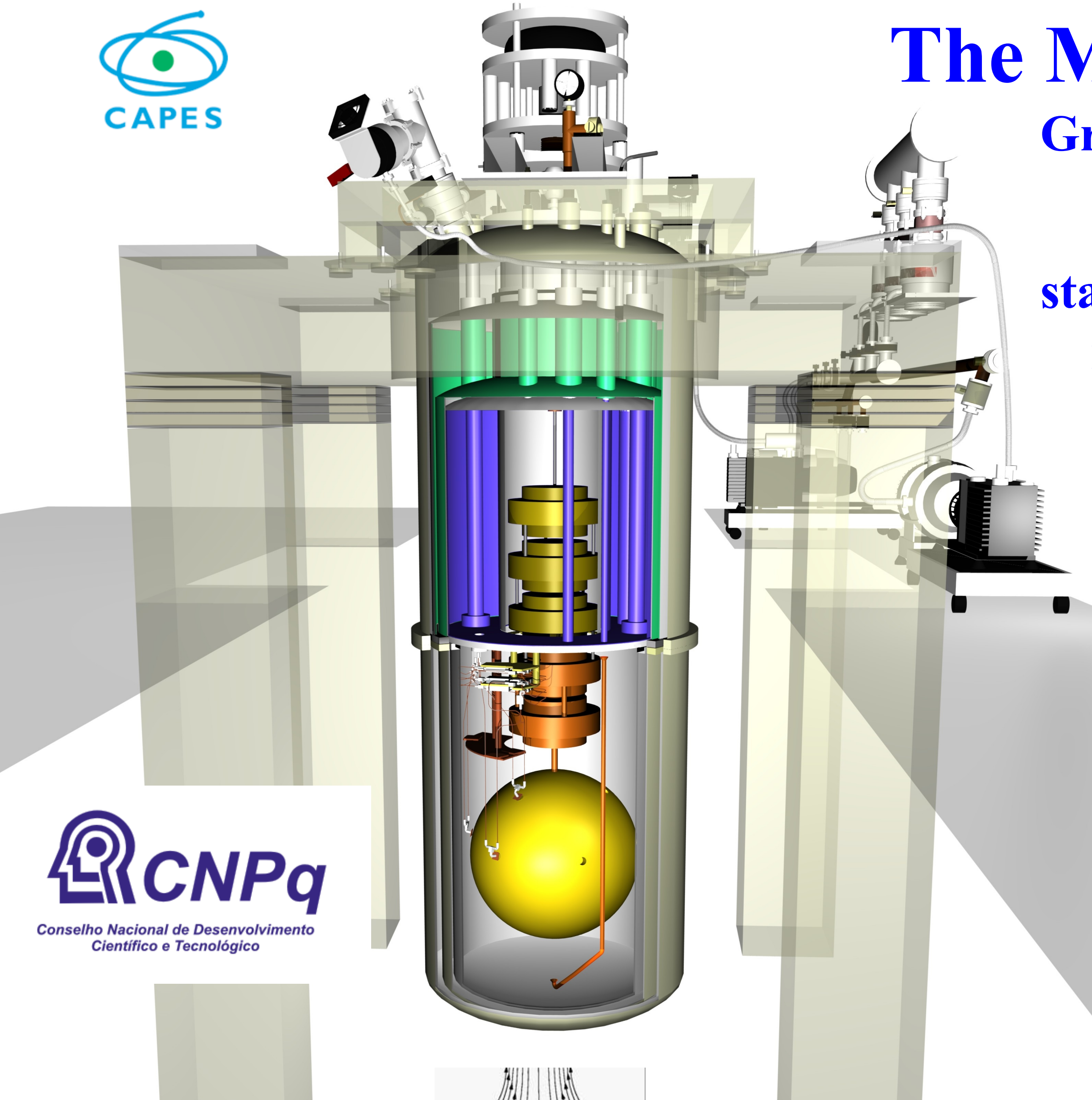
The Mario SCHENBERG

Gravitational Wave Detector

(Brazil)

started commissioning operation in the 8th of September, 2006.

It involves a collaboration between INPE, USP, ITA, PUC-Rio, IFSP, UNICAMP, CBPF, UNIFESP, UNESP, UFABC, IAE, UNIPAMPA, UESC, Leiden University, UWA, LSU, OCA, and it has been supported by



CAPES

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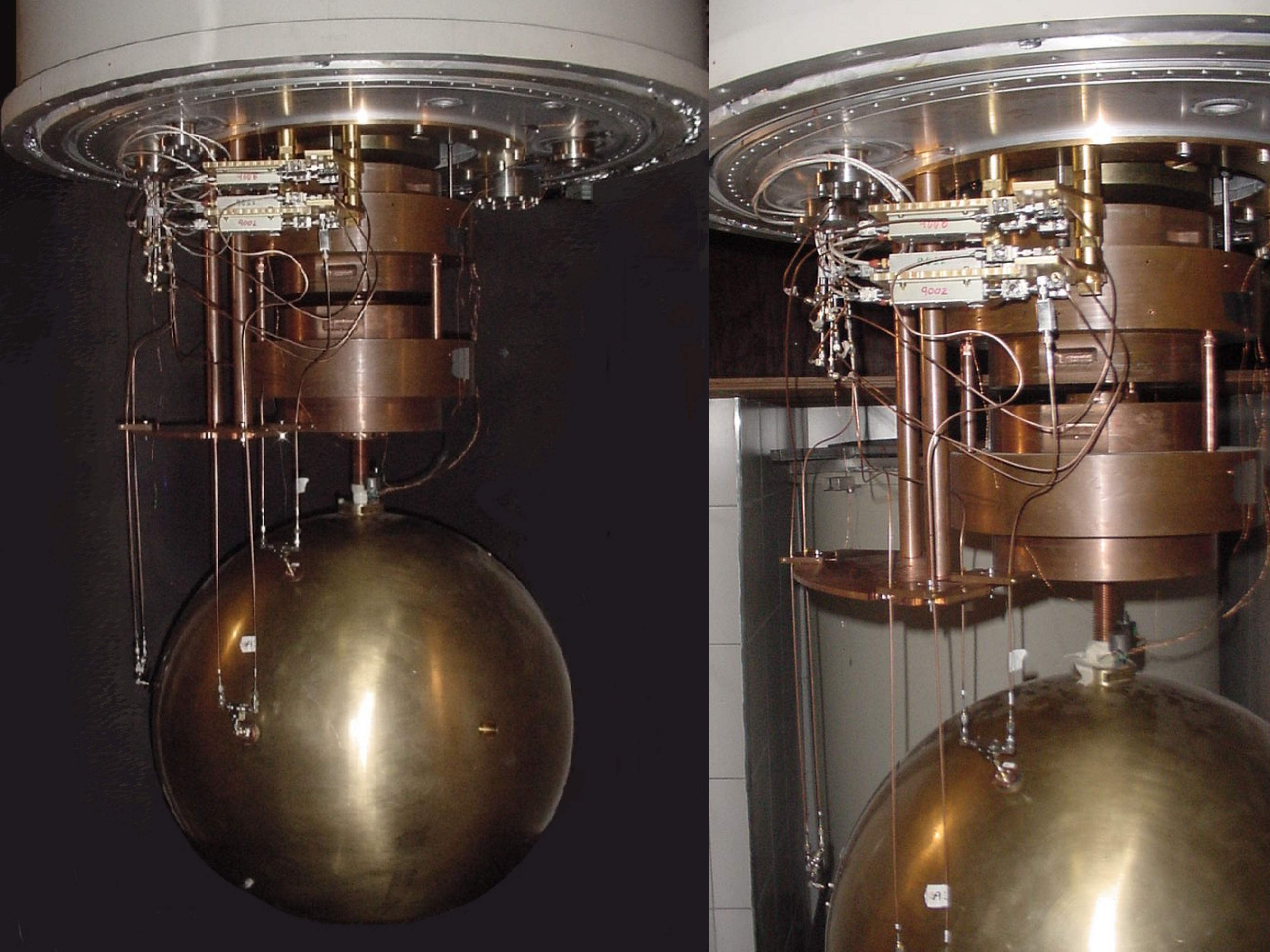
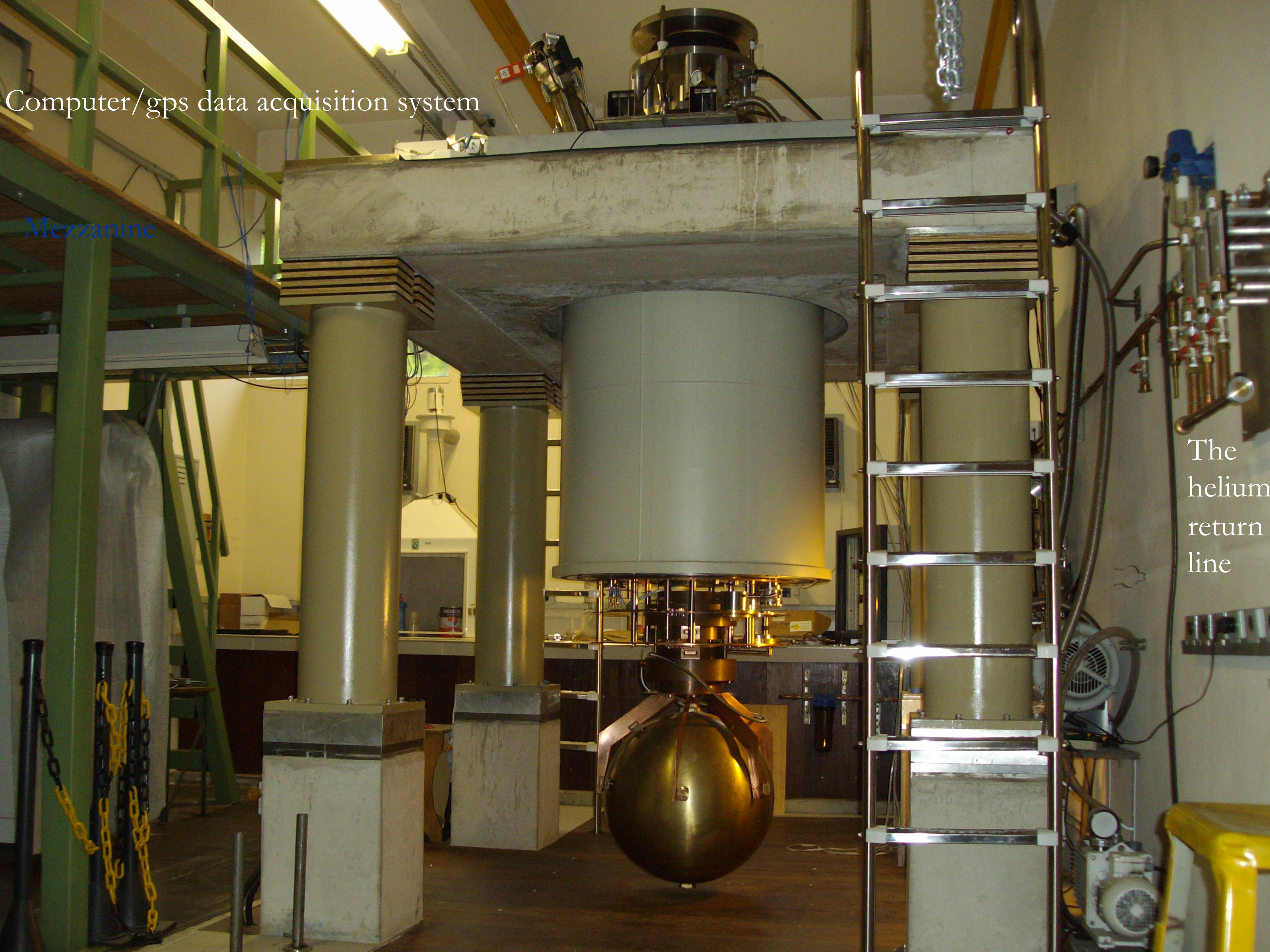
USP

FAPESP




Computer/gps data acquisition system
Mezzanine
The helium return line

Journal of Physics: Conference Series **363** (2012) 012003 doi:10.1088/1742-6596/363/1/012003

Status Report of the Schenberg Gravitational Wave Antenna

O D Aguiar[1], J J Barroso[1], N C Carvalho[1], P J Castro[1], C E Cedeño M[1], C F da Silva Costa[1], J C N de Araujo[1], E F D Evangelista[1], S R Furtado[1], O D Miranda[1], P H R S Moraes[1], E S Pereira[1], P R Silveira[1], C Stellati[1], N F Oliveira Jr[2], Xavier Gratens[2], L A N de Paula[2], S T de Souza[2], R M Marinho Jr[3], F G Oliveira[3], C Frajuca[4], F S Bortoli[4], R Pires[4], D F A Bessada[5], N S Magalhães[5], M E S Alves[6], A C Fauth[7], R P Macedo[7], A Saa[7], D B Tavares[7], C S S Brandão[8], L A Andrade[9], G F Marranghello[10], C B M H Chirenti[11], G Frossati[12], A de Waard[12], M E Tobar[13], C A Costa[14], W W Johnson[14], J A de Freitas Pacheco[15], G L Pimentel[16]

[1] INPE – Divisão de Astrofísica, São José dos Campos, SP, Brazil,
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[4] Instituto Federal de São Paulo, São Paulo, SP, Brazil,
[5] Universidade Federal de São Paulo, Diadema, SP, Brazil,
[6] Universidade Federal de Itajubá, Itajubá, MG, Brazil,
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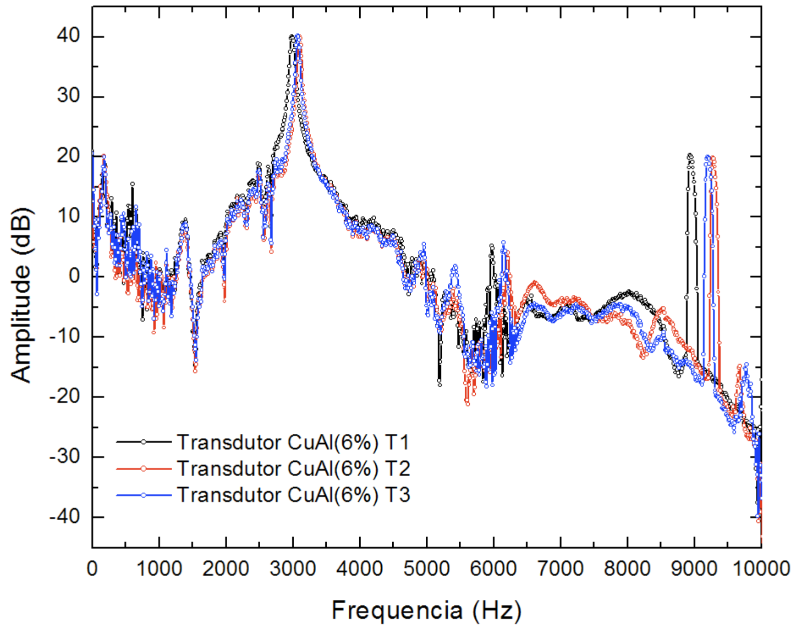
[8] Universidade Estadual de Santa Cruz, Ilhéus, BA, Brazil,
[9] Instituto de Aeronáutica e Espaço, São José dos Campos, SP, Brazil,
[10] Universidade Federal de Bagé, Bagé, RS, Brazil,
[11] Universidade Federal do ABC, Santo André, SP, Brazil,
[12] Leiden University, Kammerlingh Onnes Laboratory, Leiden, The Netherlands,
[13] University of Western Australia, Perth, Australia,
[14] Louisiana State University, Baton Rouge, USA,
[15] Observatoire de la Côte dAzur, Nice, France,
[16] Princeton University, Princeton, USA.

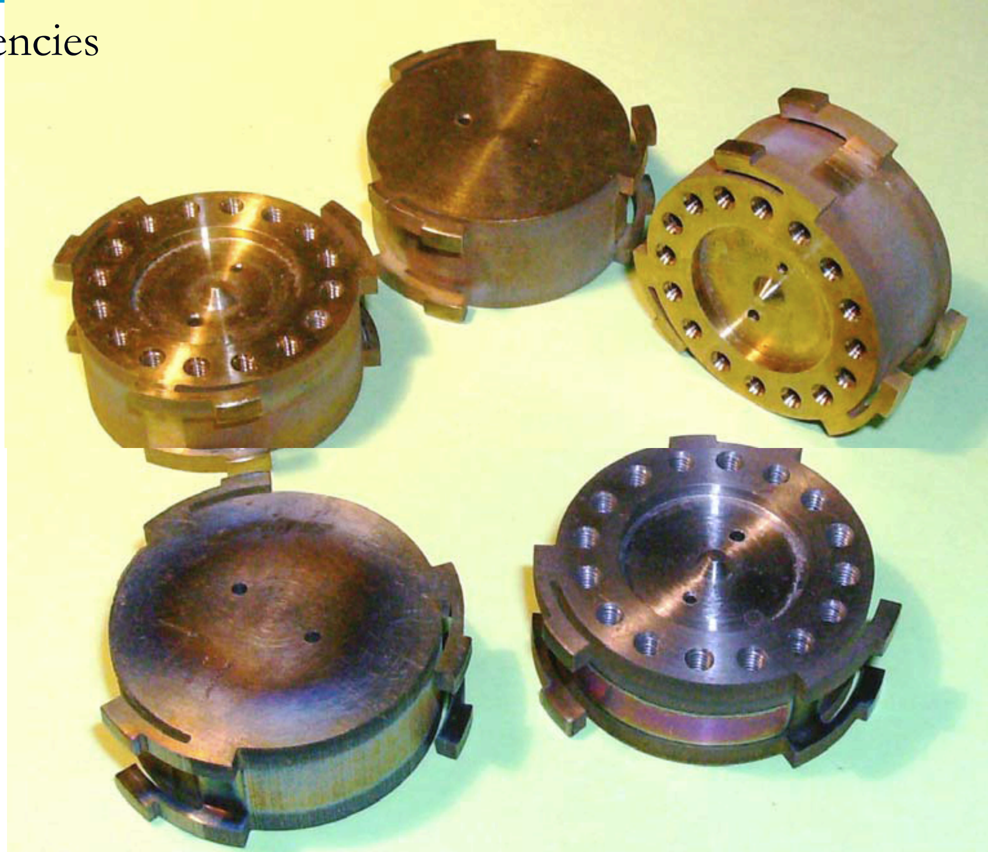
The three initial transducers:

$Q_e \sim 10^4$

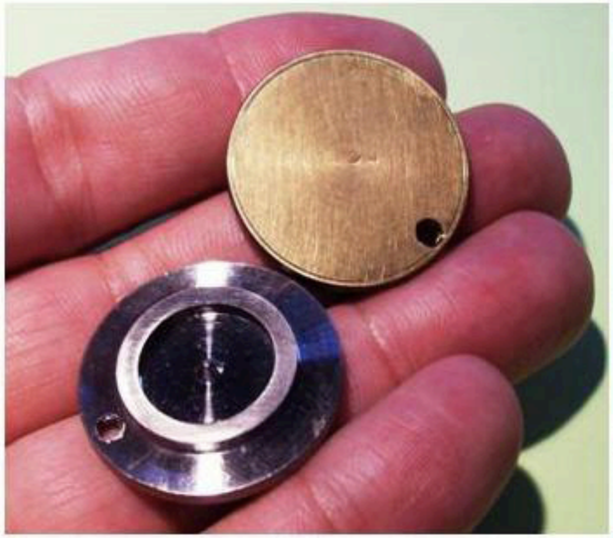
First design

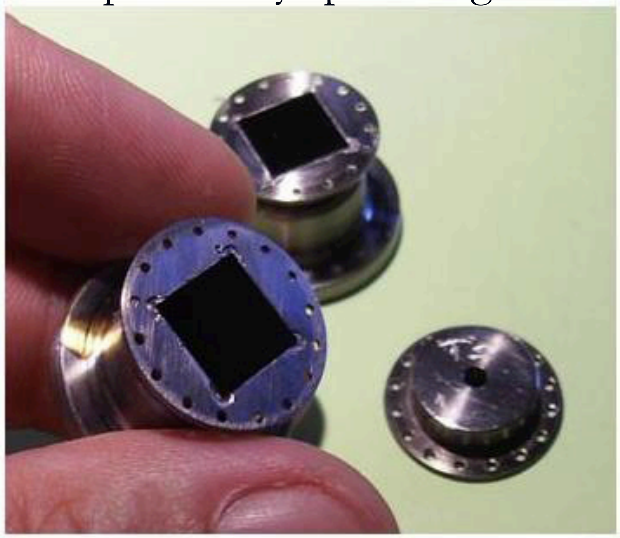
Measurements of the mechanical resonant frequencies of three transducers.



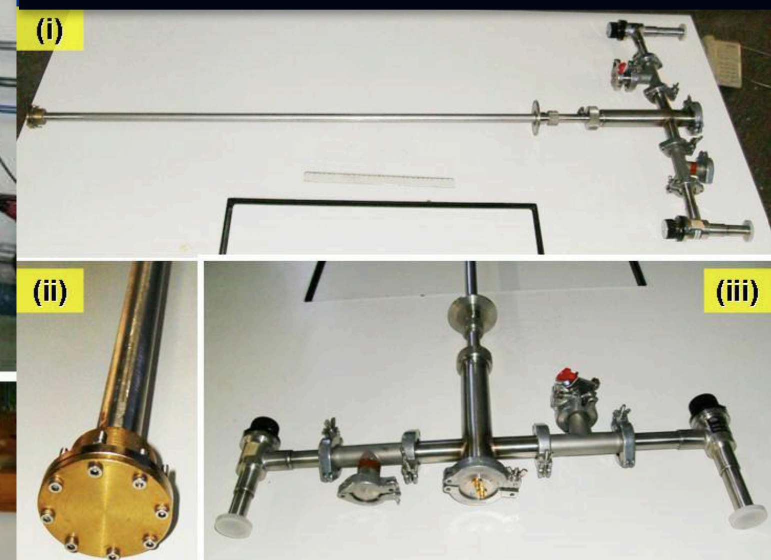


Silicon membranes with niobium deposited by sputtering.

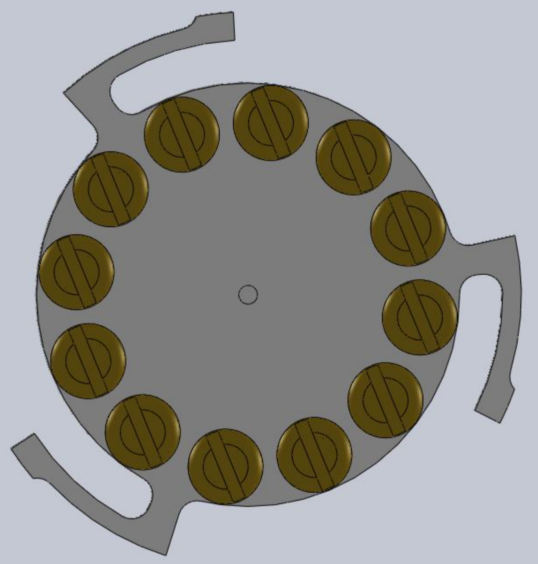




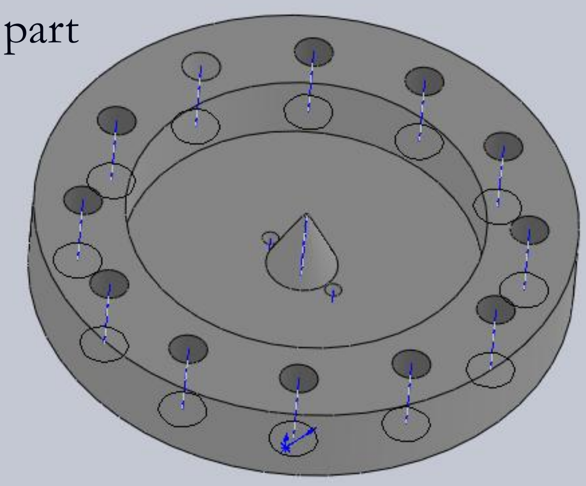
Electrical quality factors (Qe) of several superconducting reentrant cavities at 4.2 K were measured using a liquid helium cooled dewar. Qe as high as 300 k were found.



Experimental apparatus for testing superconducting reentrant cavities within a liquid helium cooled dewar.

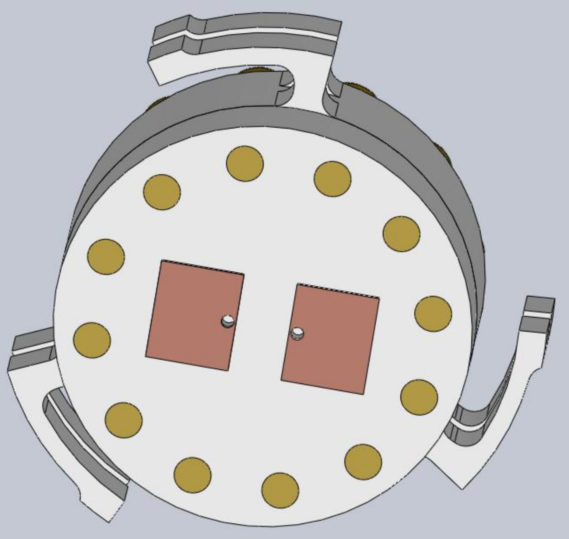


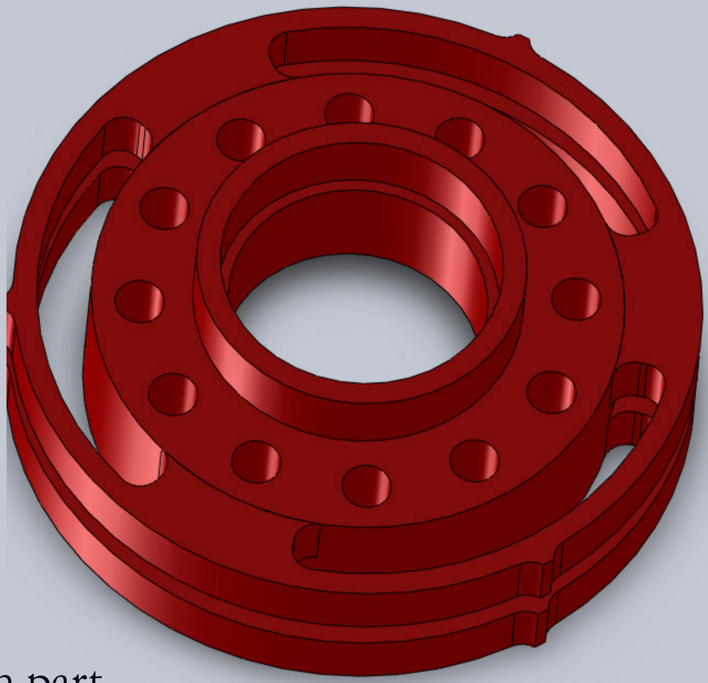
Alumina part



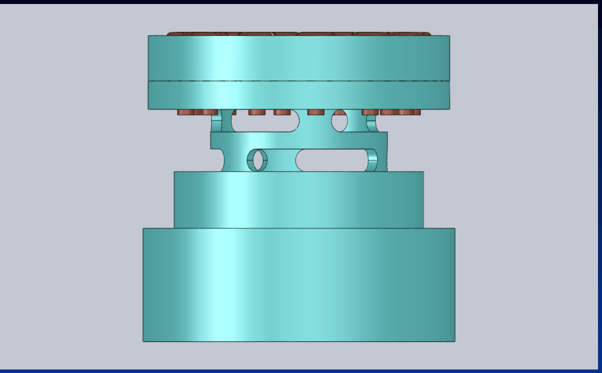
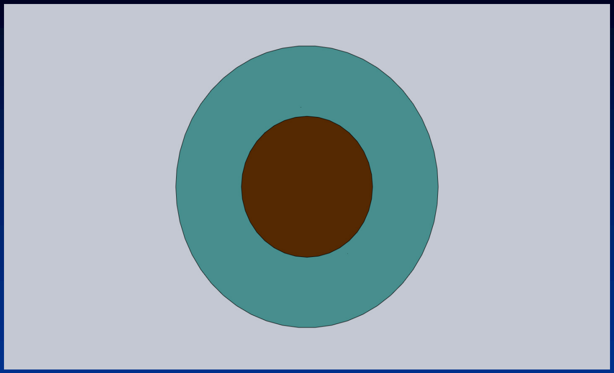
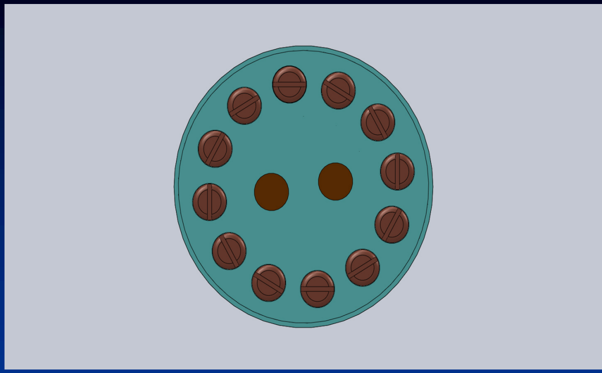
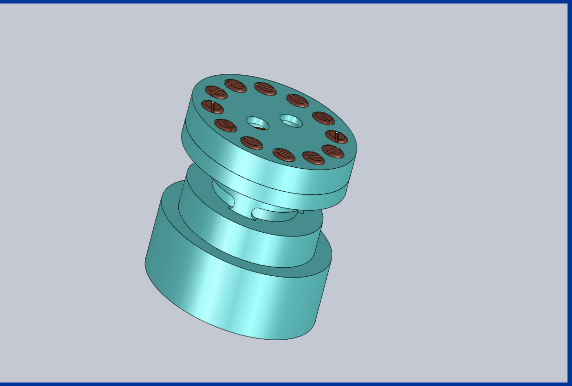
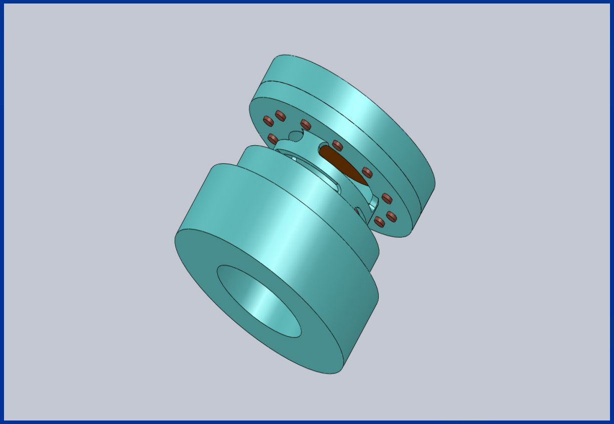
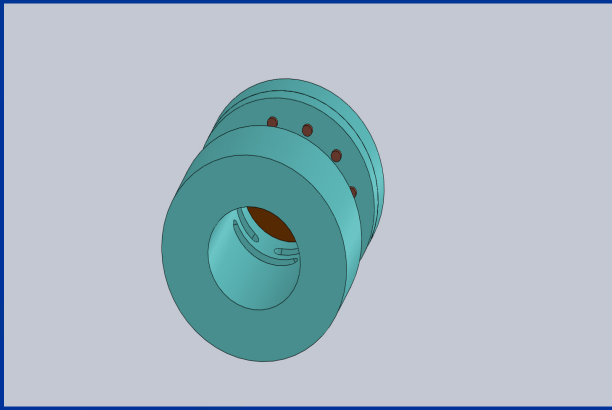
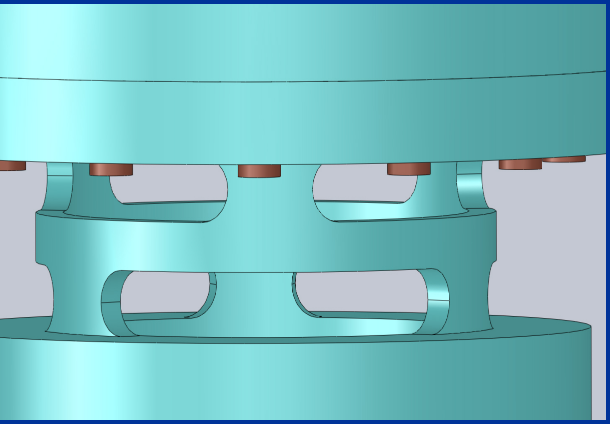
Fourth design

Third design

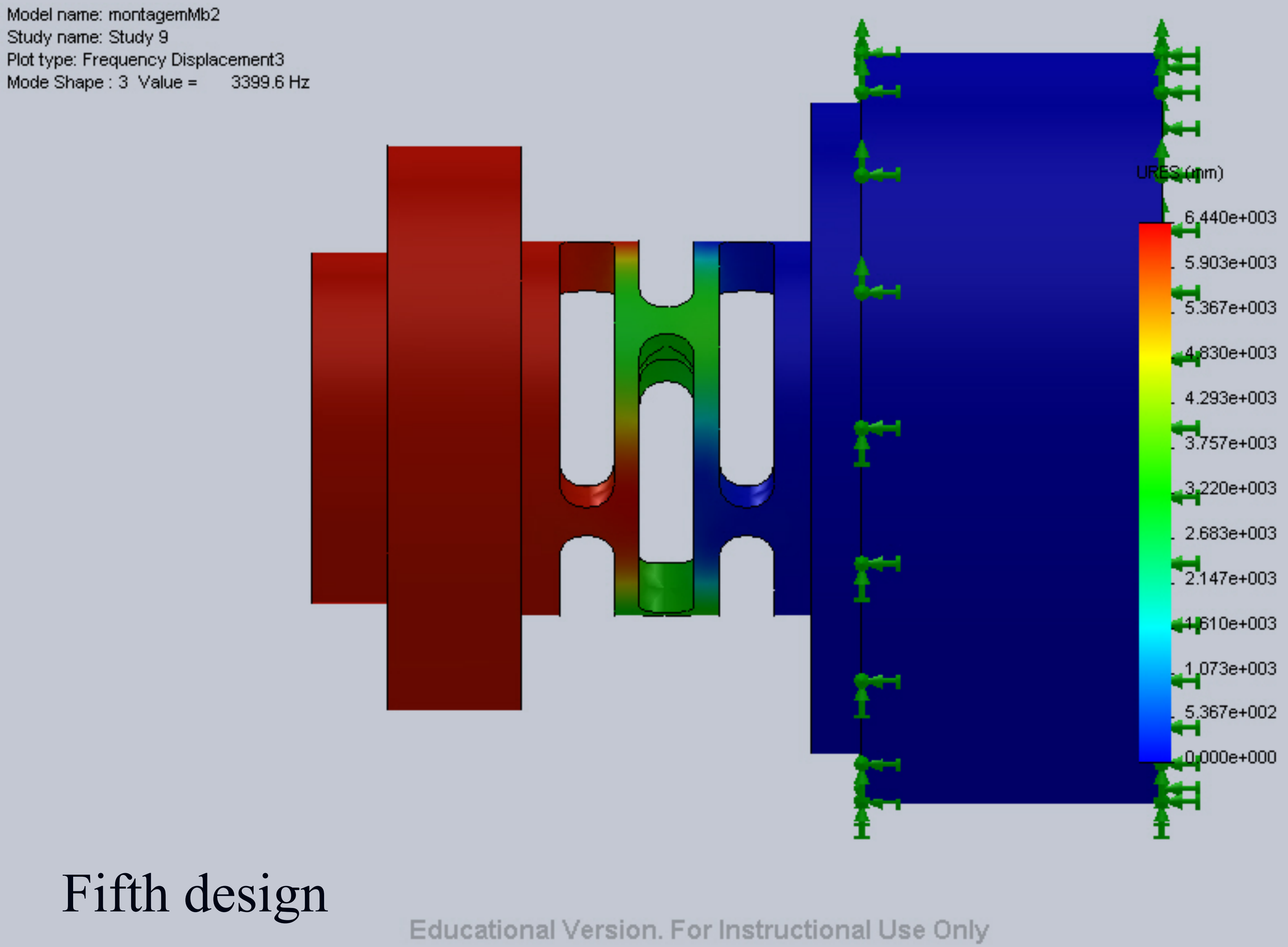




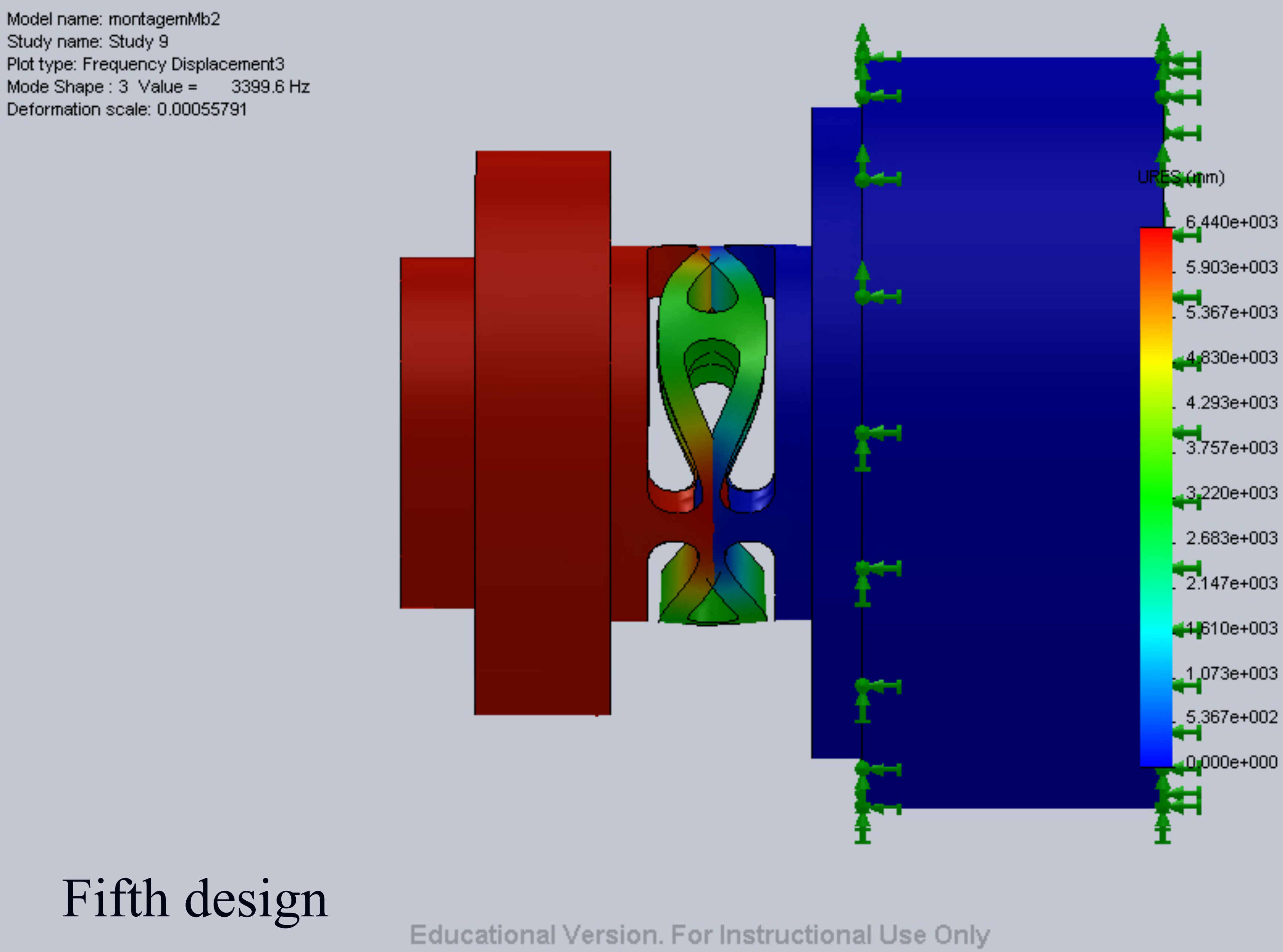
Niobium part

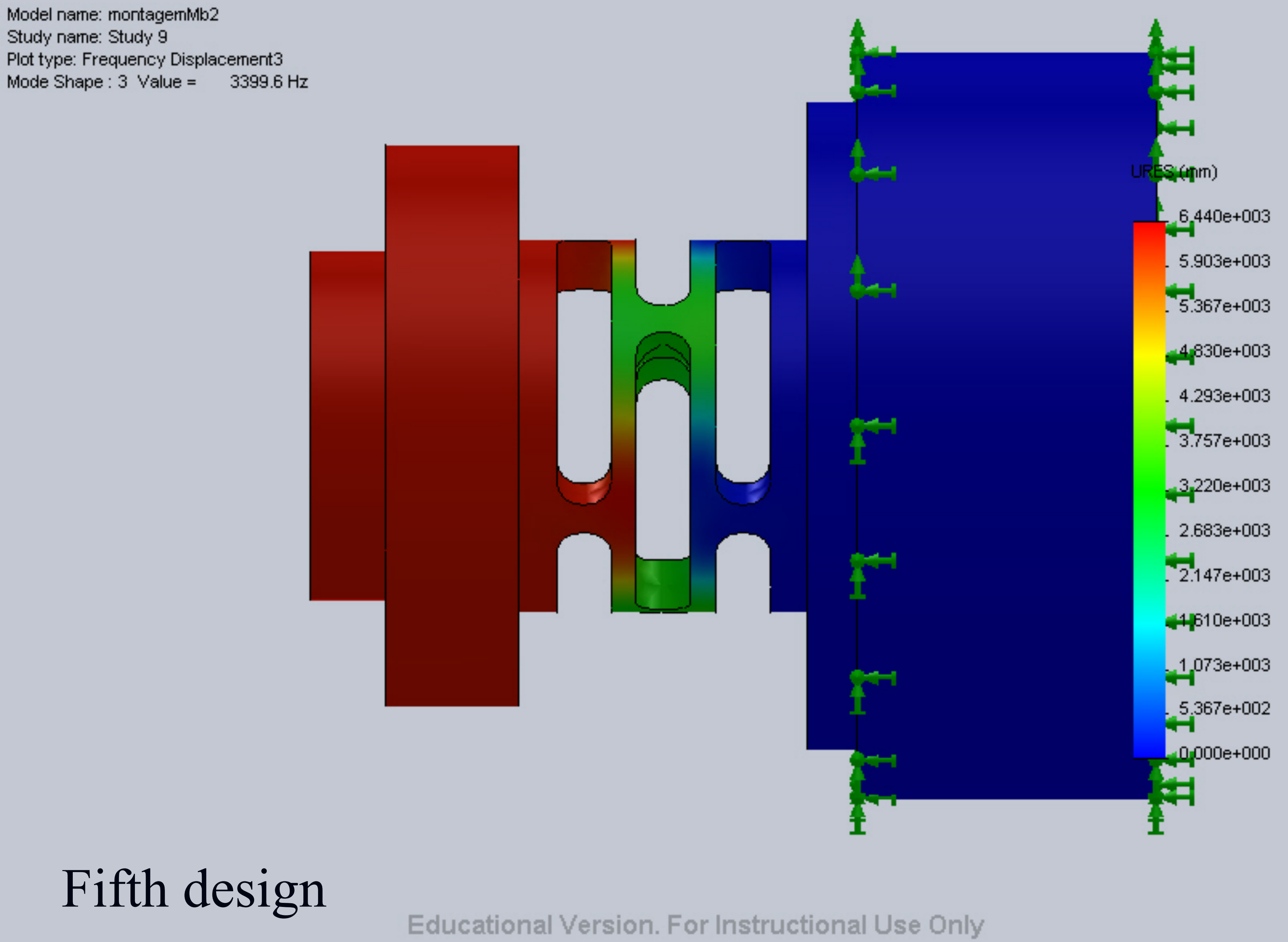
Fifth design



Fifth design



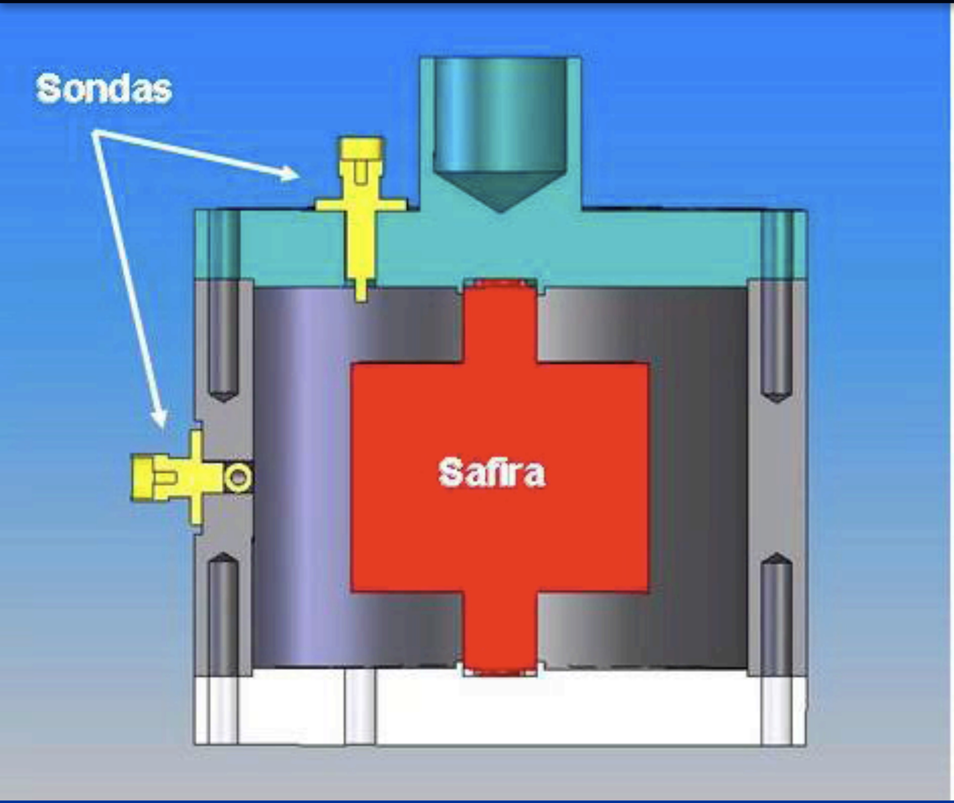
Fifth design

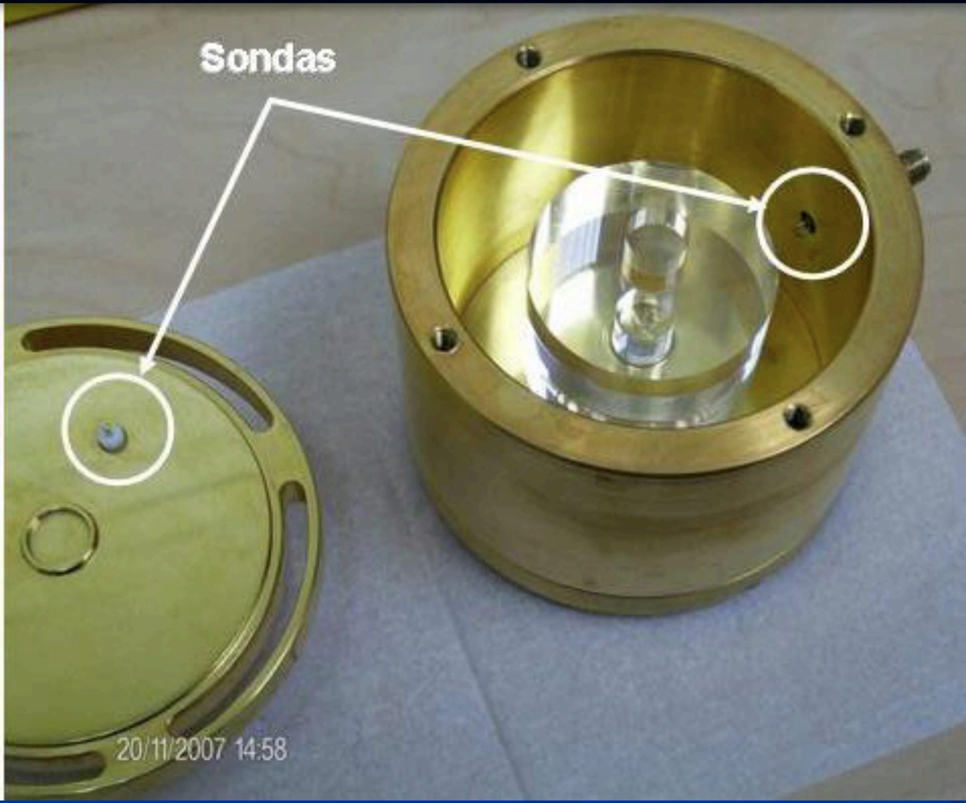


Fifth design

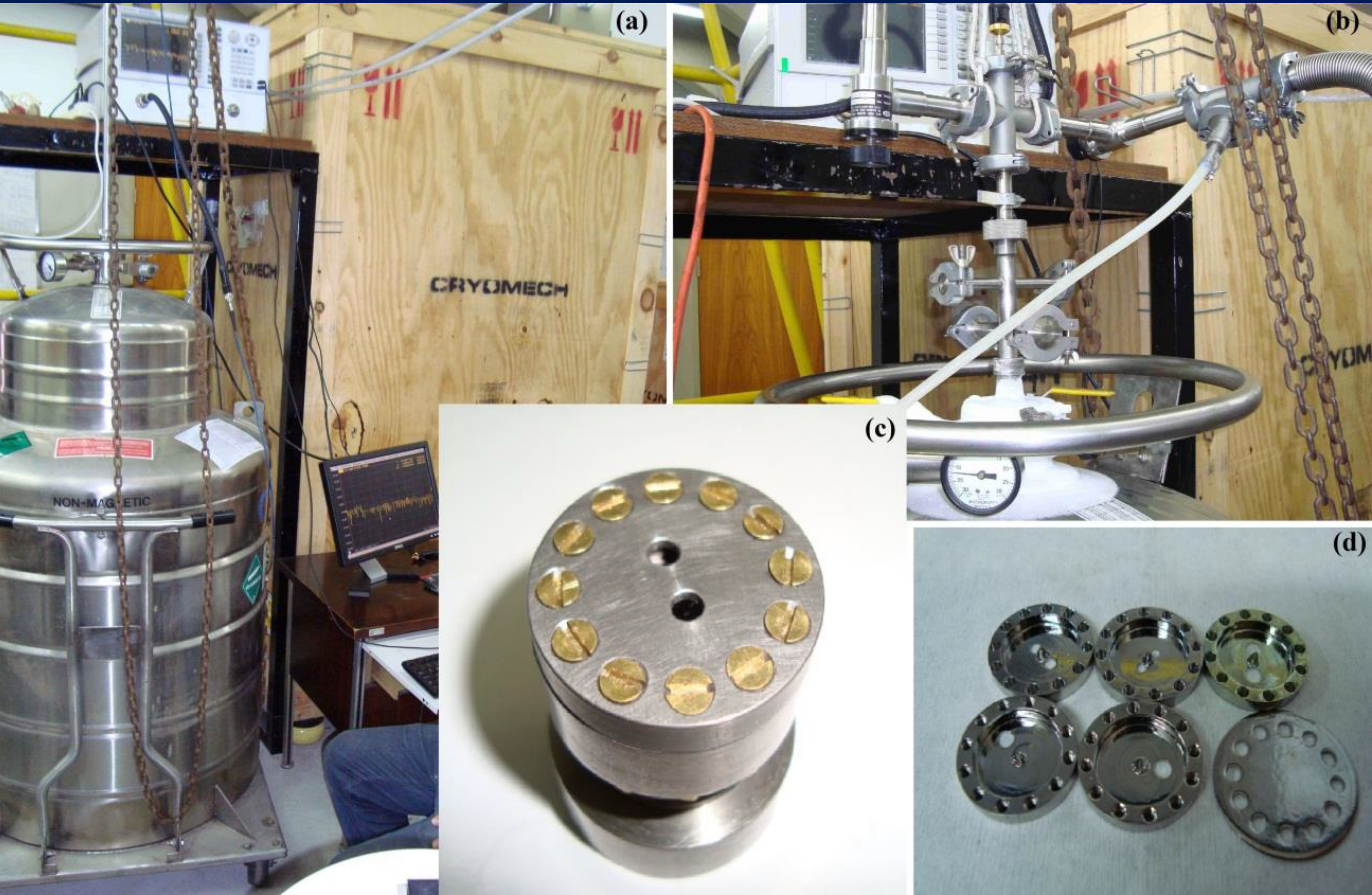
The eight niobium transducers.

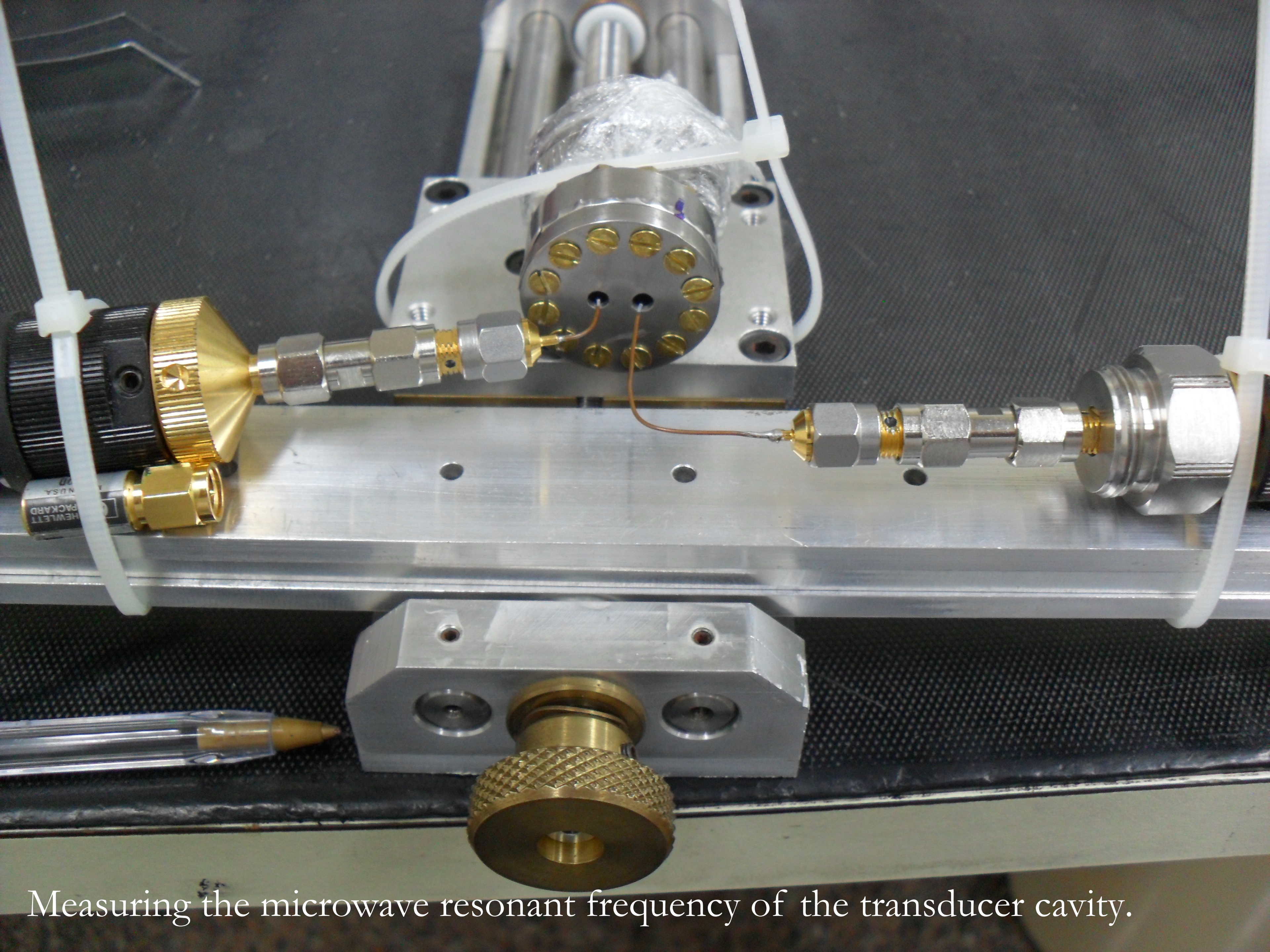
We have developed, in collaboration with the Australian group, a sapphire oscillator that operates at 77 K and will replace, with better performance, those of barium titanate currently used.





INPE Clean Room Transducer Assembly

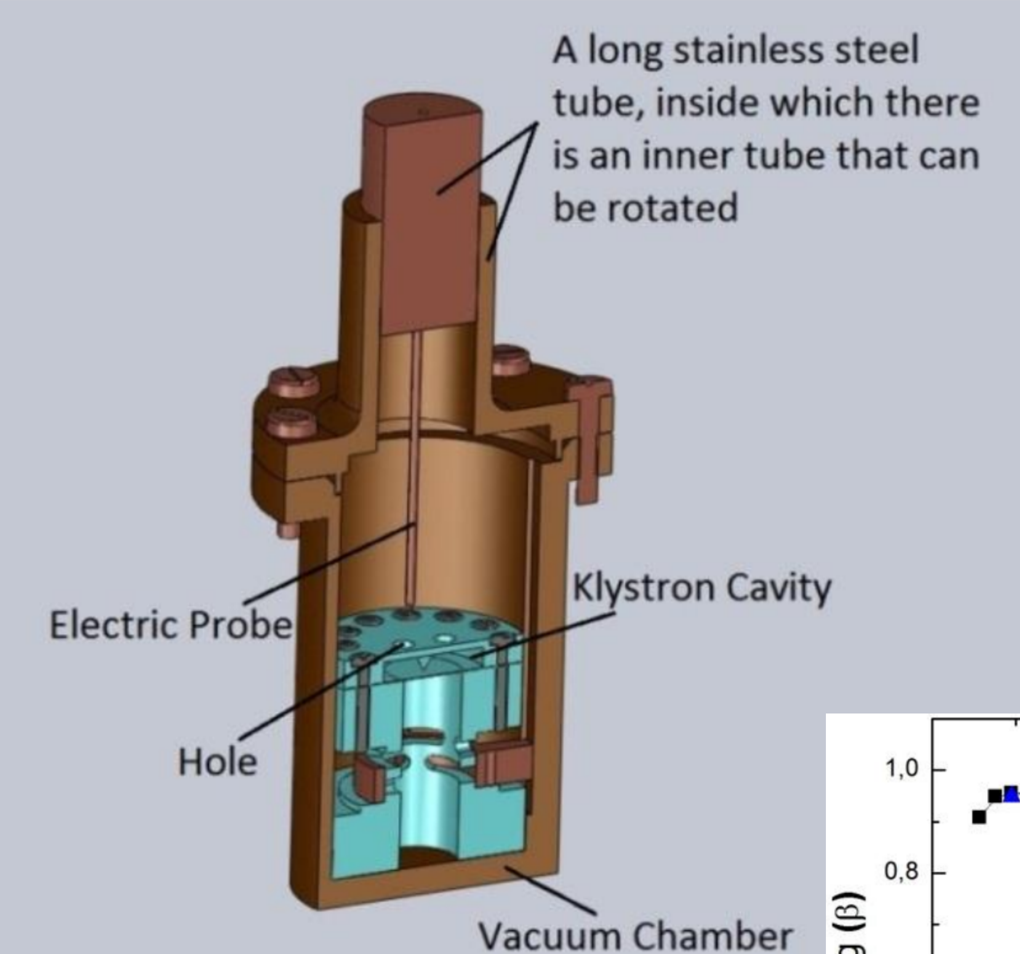

(a)
(b)
(c)
(d)
CRYOMECH

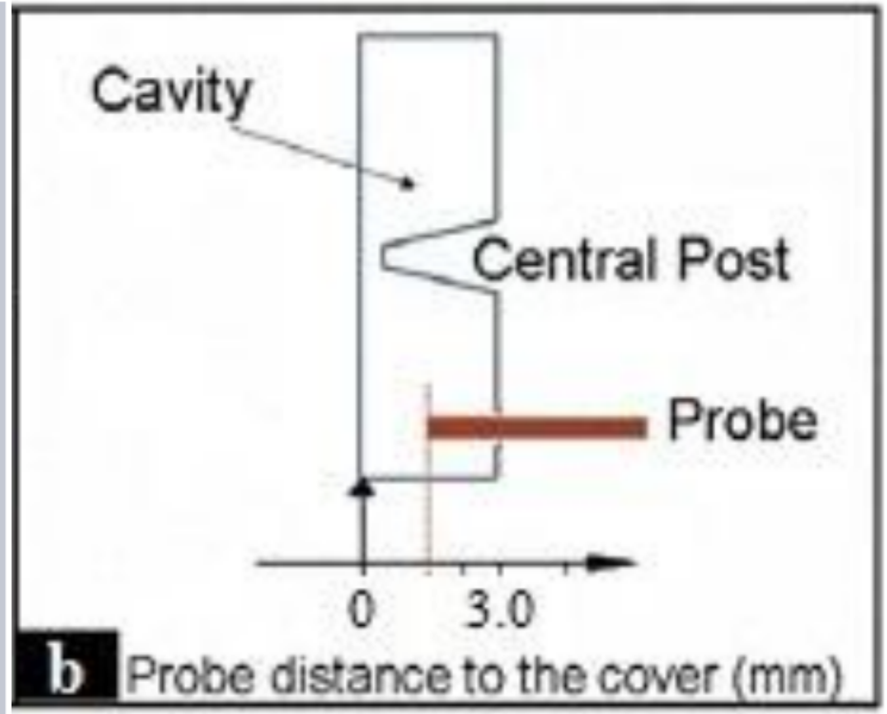


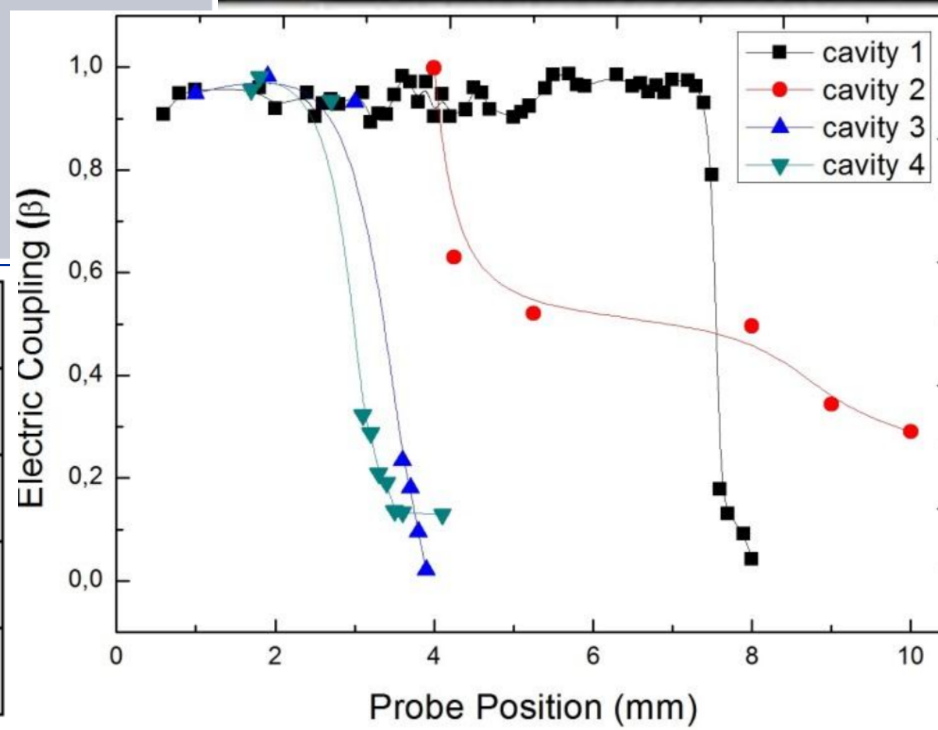
Measuring the microwave resonant frequency of the transducer cavity.


CRYOMECH
NON-MAGNETIC


VENT
VACUUM PORT/
RELIEF DISC







Cavity	D (mm)	P (mm)	β
3	1.5	3.9	0.02
4	2.5	4.1	0.13
1	3.0	8.0	0.04
2	3.5	10.0	0.29

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High sensitivity niobium parametric transducer for the Mario Schenberg gravitational wave detector

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[b]*Department of Mechanics and Material Physics, University of Sao Paulo – USP, Rua do Matão 187, São Paulo, Brazil*

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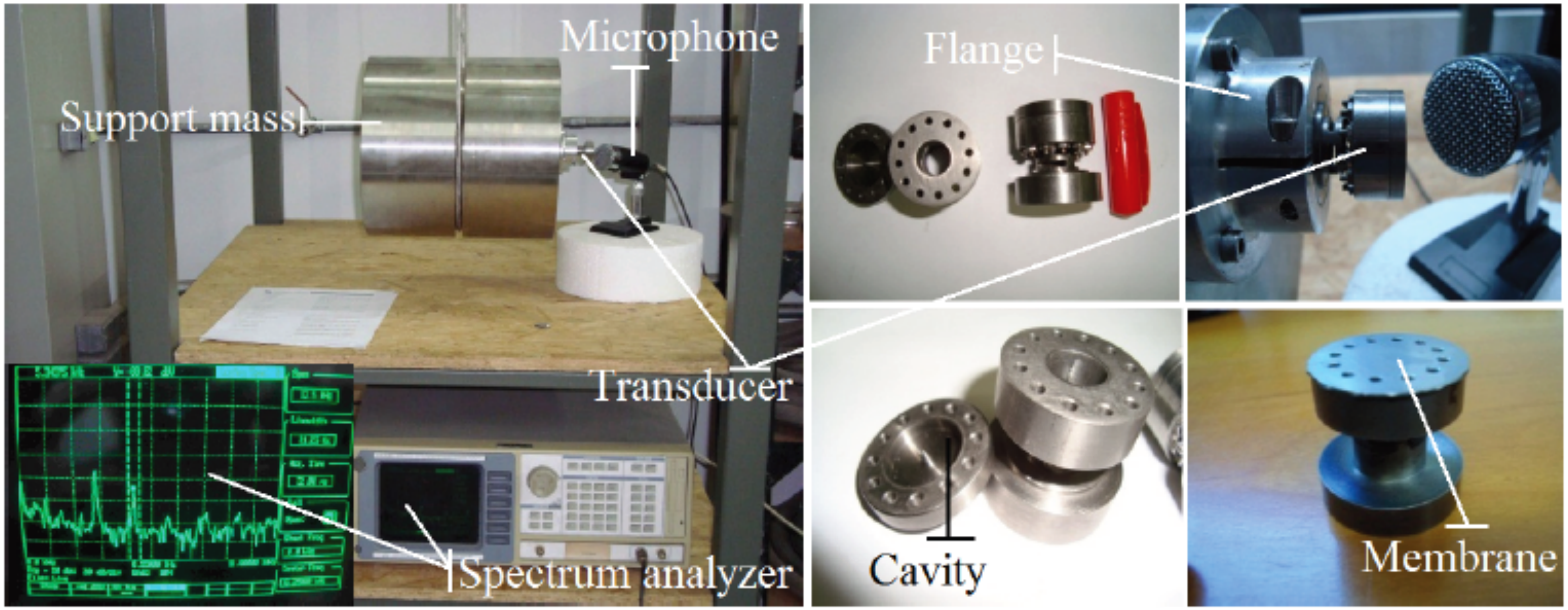


Figure 2. Equipment for measurements of mechanical resonance frequencies. The transducers were attached to the support mass and the normal modes were excited by striking the transducer. The vibrations were shown on a spectrum analyzer.

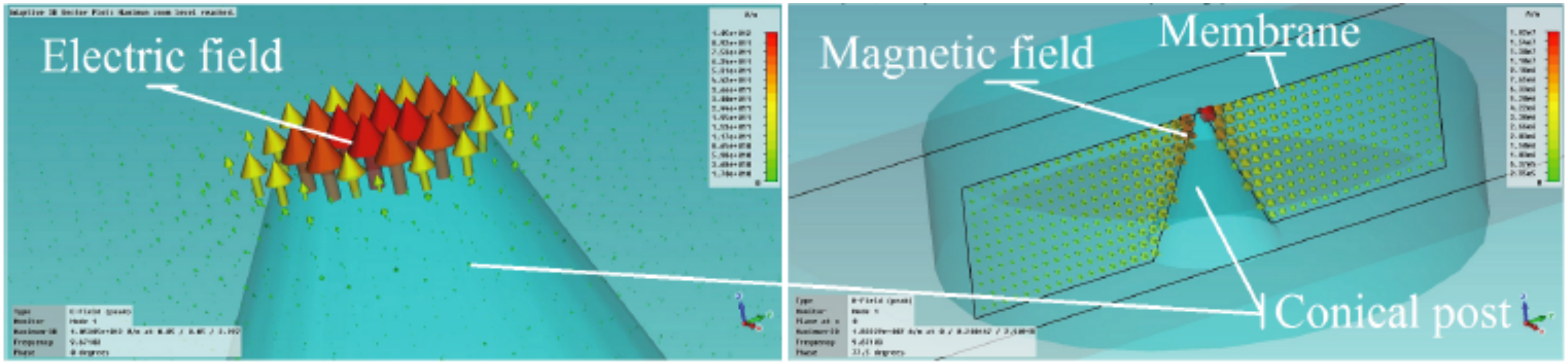


Figure 3. Electric and magnetic fields of the klystron mode for the gap of $\sim 3\,\mu$m. The electric field is much stronger at the gap region, i.e. between the top of the post and the membrane. The magnetic field shows a cylindrical symmetry around the conical post.

Table 2. Frequencies of eight samples that were submitted to eight successive steps of adjustment each one.

Sample	Cavity Frequencies [GHz]							
	step 1	step 2	step 3	step 4	step 5	step 6	step 7	step 8
1	12.76	12.88	**9.52**	**9.52**	**9.52**	**9.52**	**9.52**	**9.52**
2	12.44	12.32	**9.52**	**9.52**	**9.52**	**9.52**	**9.52**	**9.52**
3	13.40	13.88	13.36	13.16	12.76	12.32	12.06	11.08
4	10.96	10.92	**9.88**	**9.88**	**9.88**	**9.88**	**9.88**	**9.88**
5	13.12	13.28	13.00	12.76	12.64	11.92	11.56	10.54
6	12.64	13.20	12.36	12.00	11.74	12.52	12.20	12.13
7	**9.76**	**9.76**	**9.76**	**9.76**	**9.76**	**9.76**	**9.76**	**9.76**
8	11.28	11.28	10.60	10.08	**9.48**	**9.48**	**9.48**	**9.48**

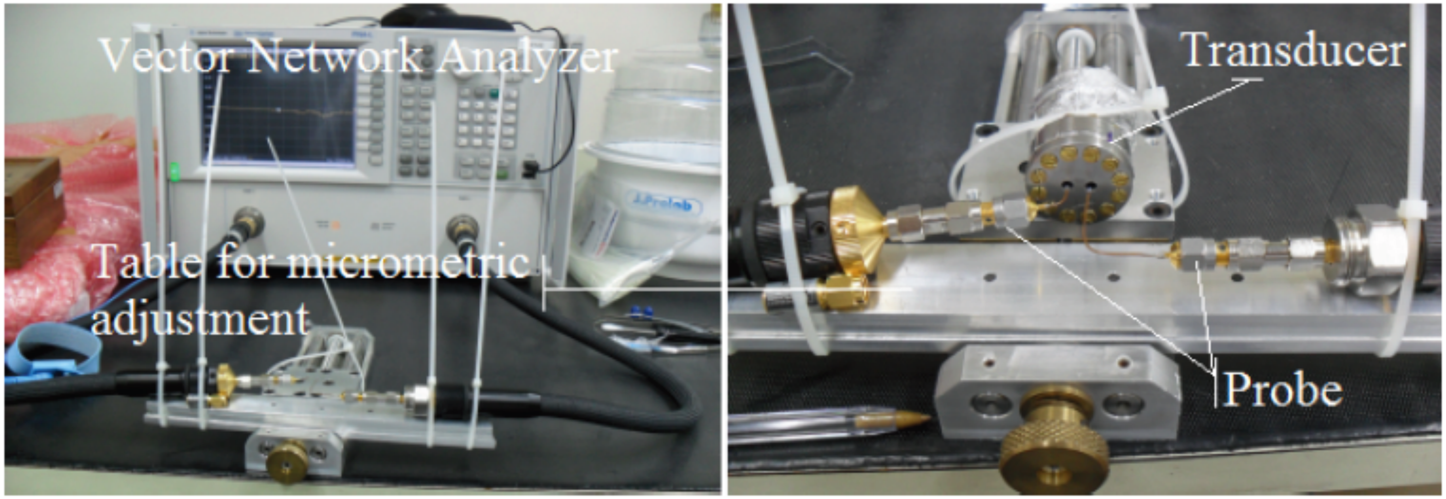
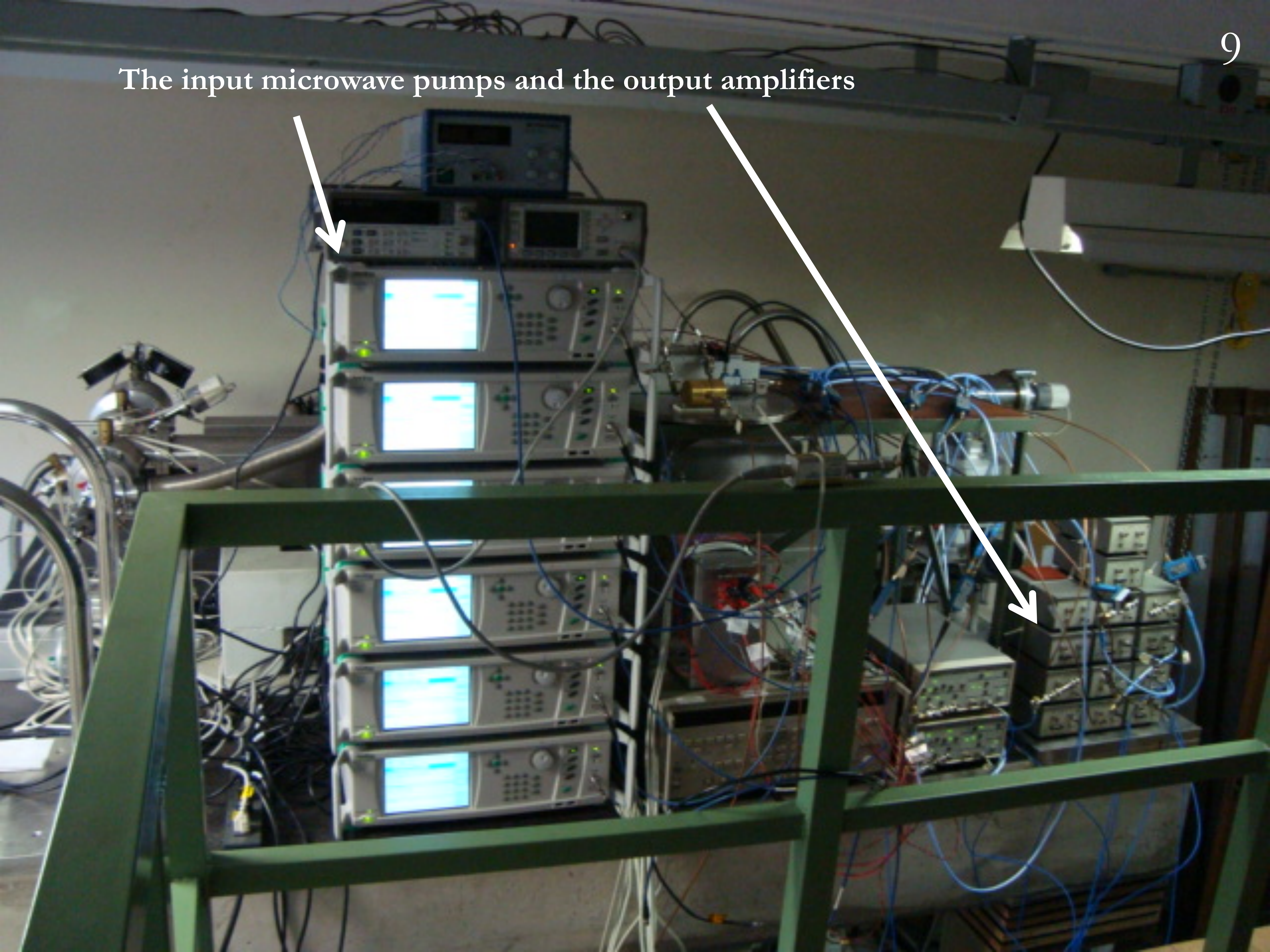


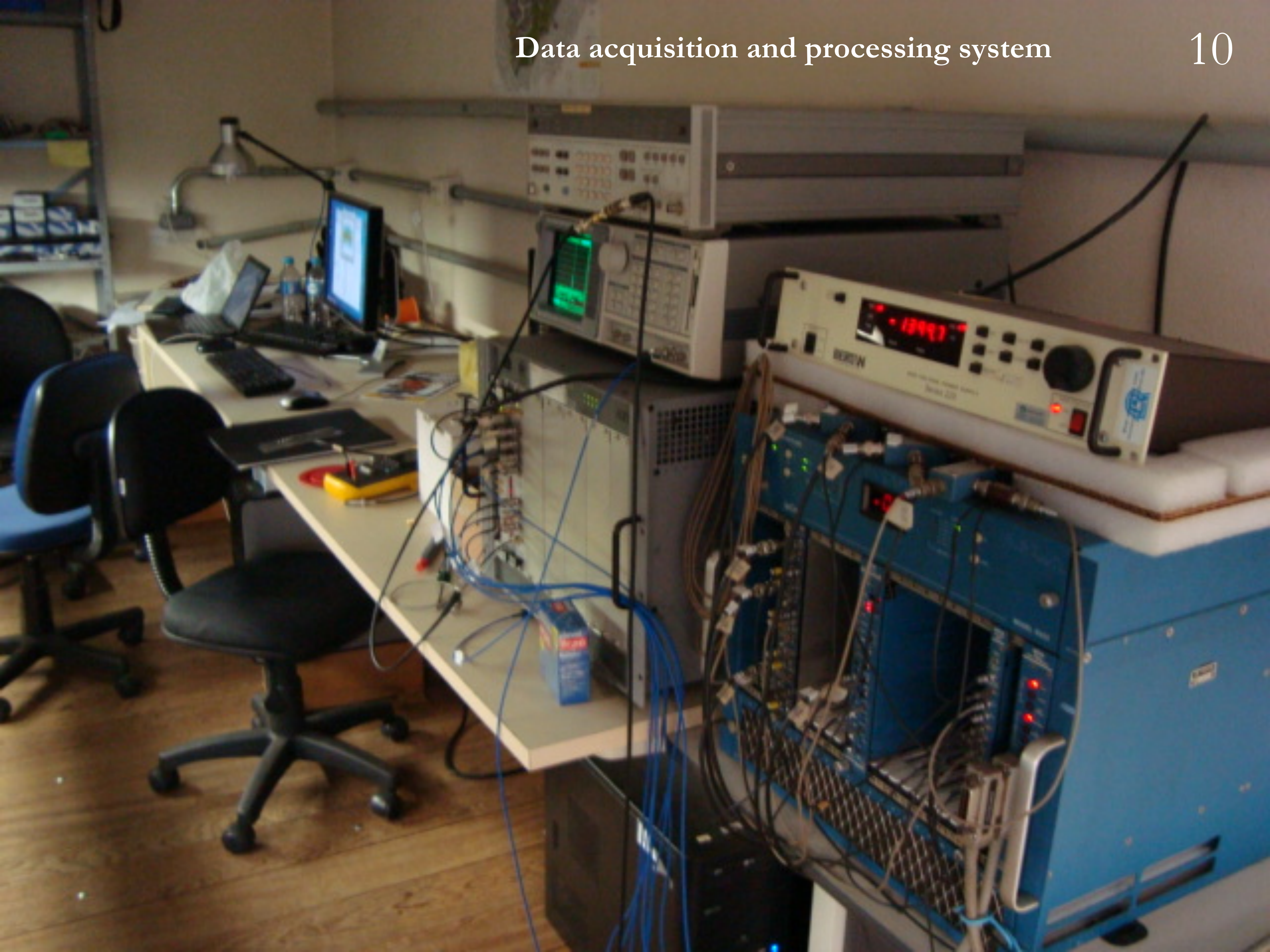
Figure 4. Frequency measurements in the vector network analyzer. The measurements were accomplished by transmission by inserting two probes into the cavity. A table for micrometric adjustment was also used in order to improve the accuracy in the probe position.

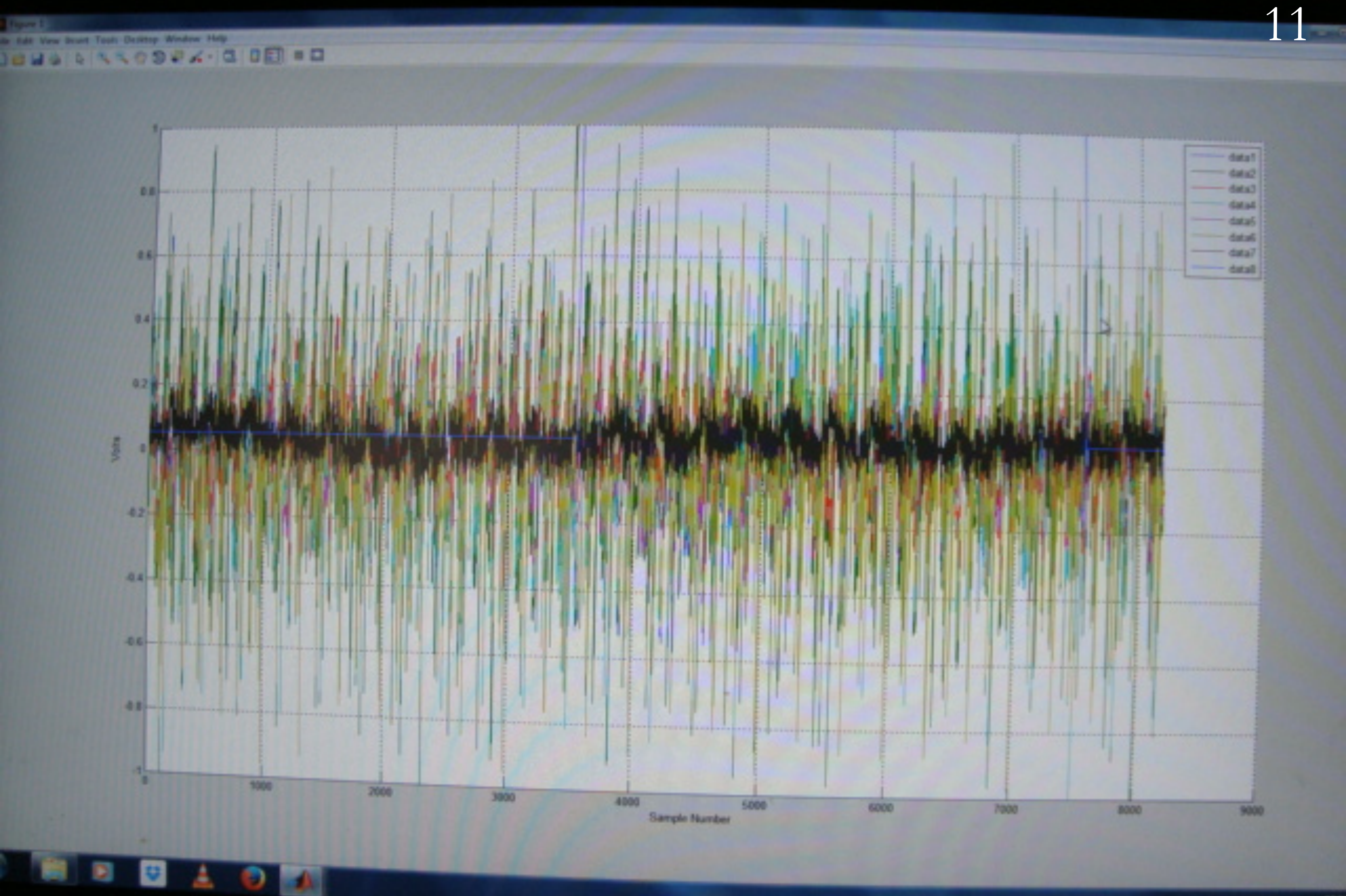
The antenna at the São Paulo (USP) site during the 2015 runs

The input microwave pumps and the output amplifiers



Data acquisition and processing system



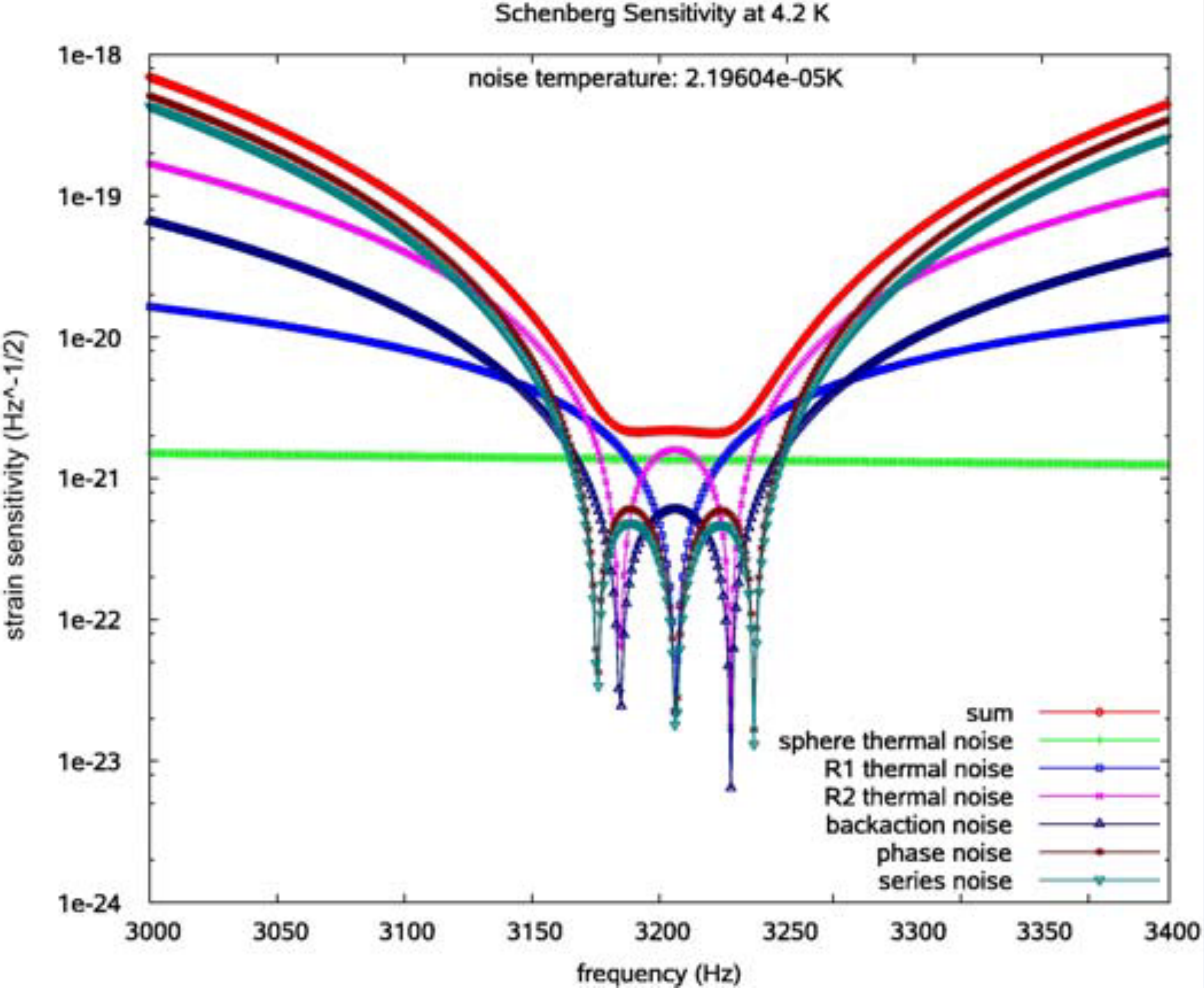


The output signal of the seven transducers in the 2015 Oct/Nov run

The sphere being removed from the USP site in 2016

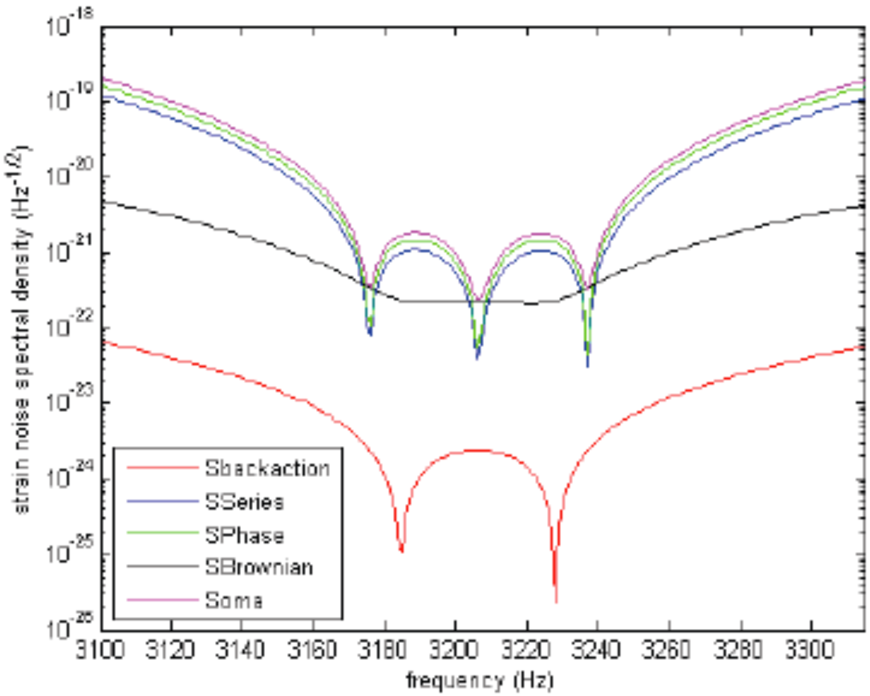
And placed in a truck to be transported to INPE in São José dos Campos

We are going to use these three integrated pulse tubing to cool the sphere down

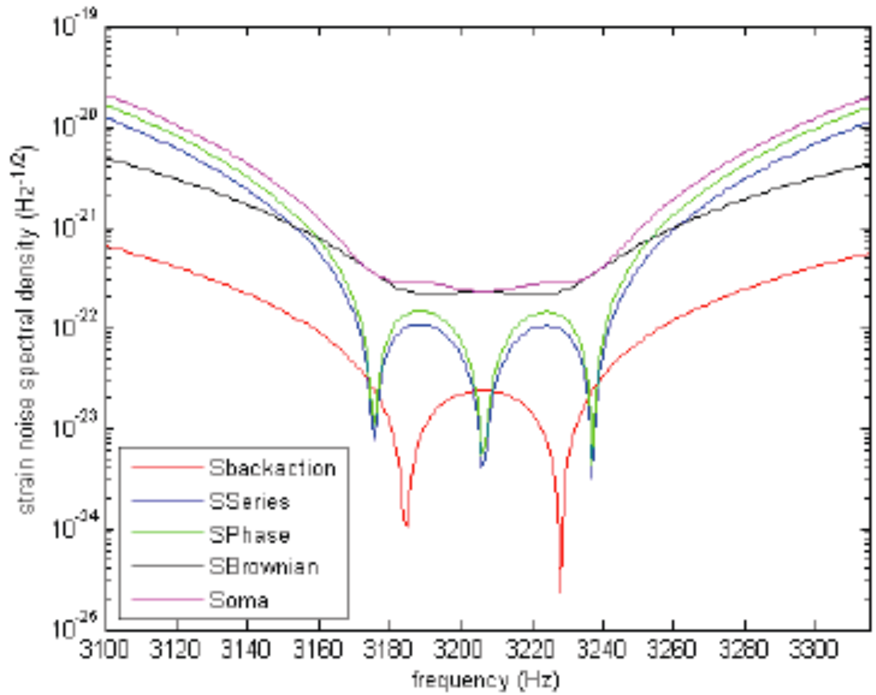


Schenberg Sensitivity at 4.2 K
noise temperature: 2.19604e-05K
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
strain sensitivity (Hz^-1/2)
3000
3050
3100
3150
3200
3250
3300
3350
3400
frequency (Hz)
sum
sphere thermal noise
R1 thermal noise
R2 thermal noise
backaction noise
phase noise
series noise

We still can improve the sensitivity of Schenberg (by cross talk mitigation, improvement of the mechanical Qs, obtaining long lasting electrical Qs, cooling the antenna down to below 0.1 K e.g.).



a) Strain noise spectral density of the Schenberg detector for the case with the gap of 30 microns (80 MHz/micron)



b) Strain noise spectral density of the Schenberg detector for the case with the gap of 3 microns (800 MHz/micron)

Figure 5. Strain noise spectral density of the Schenberg detector for a gap of 30 μm (80 MHz/μm) and 3 μm (800 MHz/μm). For both cases, we used the thermodynamic temperature of 50 mK, Q $\sim 1 \times 106$, $P_{in} \sim 1 \times 10^{-10}$ Watts, phase noise of -130 dBc/Hz@3,2 kHz.

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Study of the effect of NbN on microwave Niobium cavities for gravitational wave detectors

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Abstract: Superconducting reentrant cavities may be used in parametric transducers for resonant-mass gravitational wave detectors. When coupled to a spherical resonant antenna, transducers will monitor its mechanical quadrupolar modes, working as a mass-spring system. In this paper

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A Laser Interferometer Gravitational Observatory in South America

Since 2011 we have been participating in the LIGO Scientific Collaboration (LSC) working on aLIGO detection and characterization and LIGO Voyager R&D. And we want to increase this participation in the various possible areas of contribution for the LSC.

In parallel with the activities on LSC and Schenberg we have plans in Brazil to mobilize the Latin American community towards the construction of a 3G laser interferometer in South America by 2035-40.

In this challenge, we will strongly need help from the other projects, mainly expertise (knowledge and experience on laser interferometers hardware and data analysis).

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The Brazilian program on gravitational wave detection has three main lines of action. The first one is to participate in the various possible areas of contribution for the LIGO Scientific Collaboration (LSC). Presently we are working on aLIGO detection and characterization and LIGO Voyager R&D. The second is to reassemble the gravitational wave antenna Mario Schenberg (formerly at the Institute of Physics of the University of São Paulo in São Paulo), now at the National Institute for Space Research (INPE) in São José dos Campos, and their improvement, to leave it with sufficient sensibility for detection/observation. The third is to construct a third generation laser interferometer observatory in South America.

Thanks

for your attention !