

The Brazilian Program on Gravitational Wave Detection

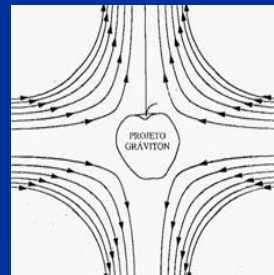
Odylio D. Aguiar

July 10th, 2017

G 1701255



Conselho Nacional de Desenvolvimento
Científico e Tecnológico



GRAVITON GROUP



MINISTÉRIO DA
CIÊNCIA, TECNOLOGIA,
INOVAÇÕES E COMUNICAÇÕES



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 programs concluded:

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 programs concluded by other students:

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

In yellow, thesis related to experimental themes.

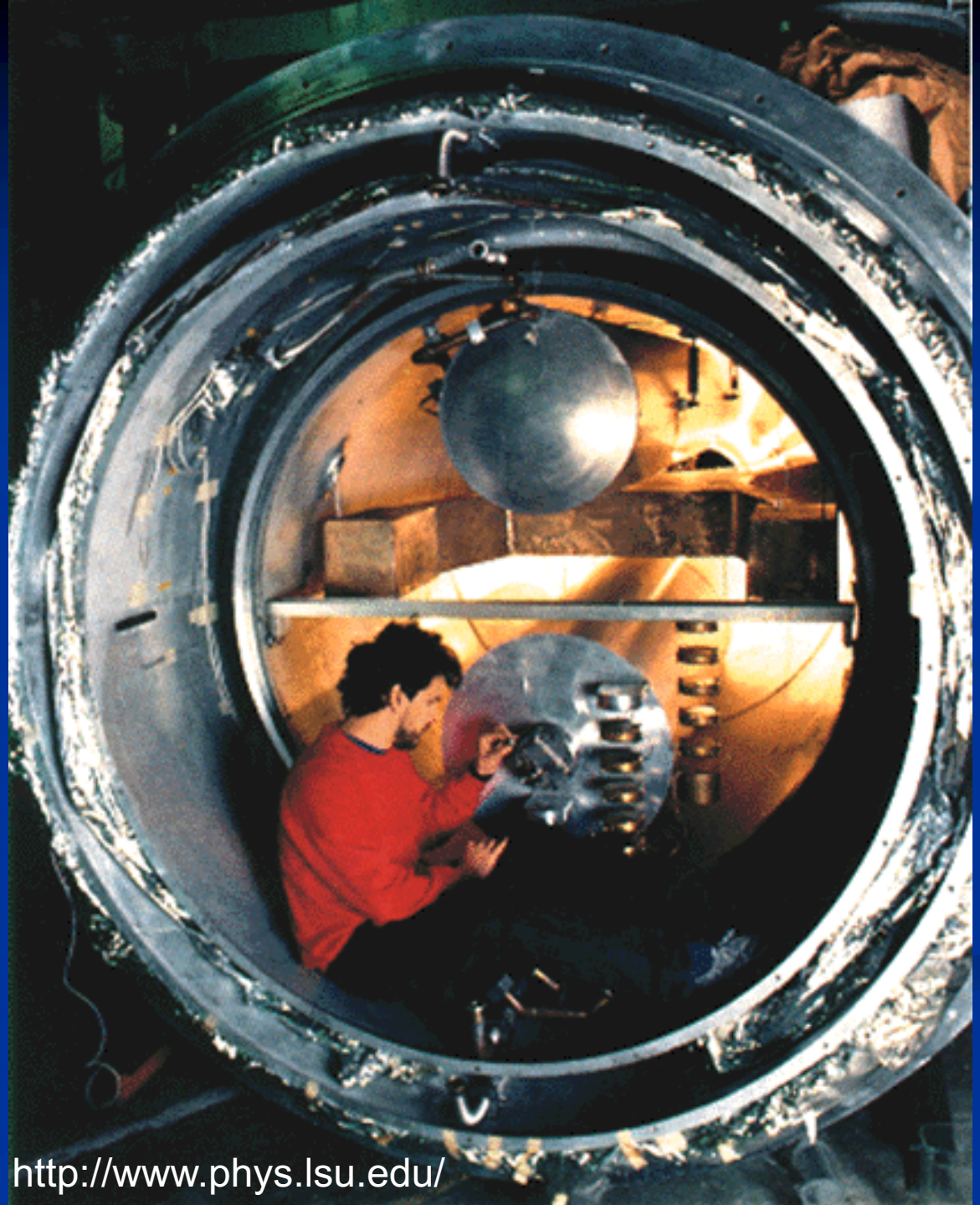
I started a Ph.D.
program at LSU in
August 1984

Joined the LSU
gravitational wave
group in **July 1986**

LSU (ALLEGRO)

2nd bar generation

4.2 K



30 authors from 9 institutions

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

E. Amaldi^{1,3}, O. Aguiar⁹, M. Bassan^{2,8}, P. Bonifazi^{3,4}, P. Carelli^{1,5}, M.G. Castellano^{3,4}, G. Cavallari⁷, E. Coccia^{2,3}, C. Cosmelli^{1,3}, W.M. Fairbank⁸, S. Frasca^{1,3}, V. Foglietti^{3,5}, R. Habel^{1,6}, W.O. Hamilton⁹, J. Henderson⁸, W. Johnson⁹, K.R. Lane⁸, A.G. Mann⁹, M.S. McAshan⁸, P.F. Michelson⁸, I. Modena^{2,3}, G.V. Pallottino^{1,3}, G. Pizzella^{1,3}, J.C. Price⁸, R. Rapagnani^{1,3}, F. Ricci^{1,3}, N. Solomonson⁹, T.R. Stevenson⁸, R.C. Taber⁸, and B.-X. Xu⁹

¹ Dipartimento di Fisica dell'Università 'La Sapienza', Piazza Aldo Moro, 2, I-00185 Roma, Italy

² Dipartimento di Fisica dell'Università 'Tor Vergata', Roma, Italy

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;

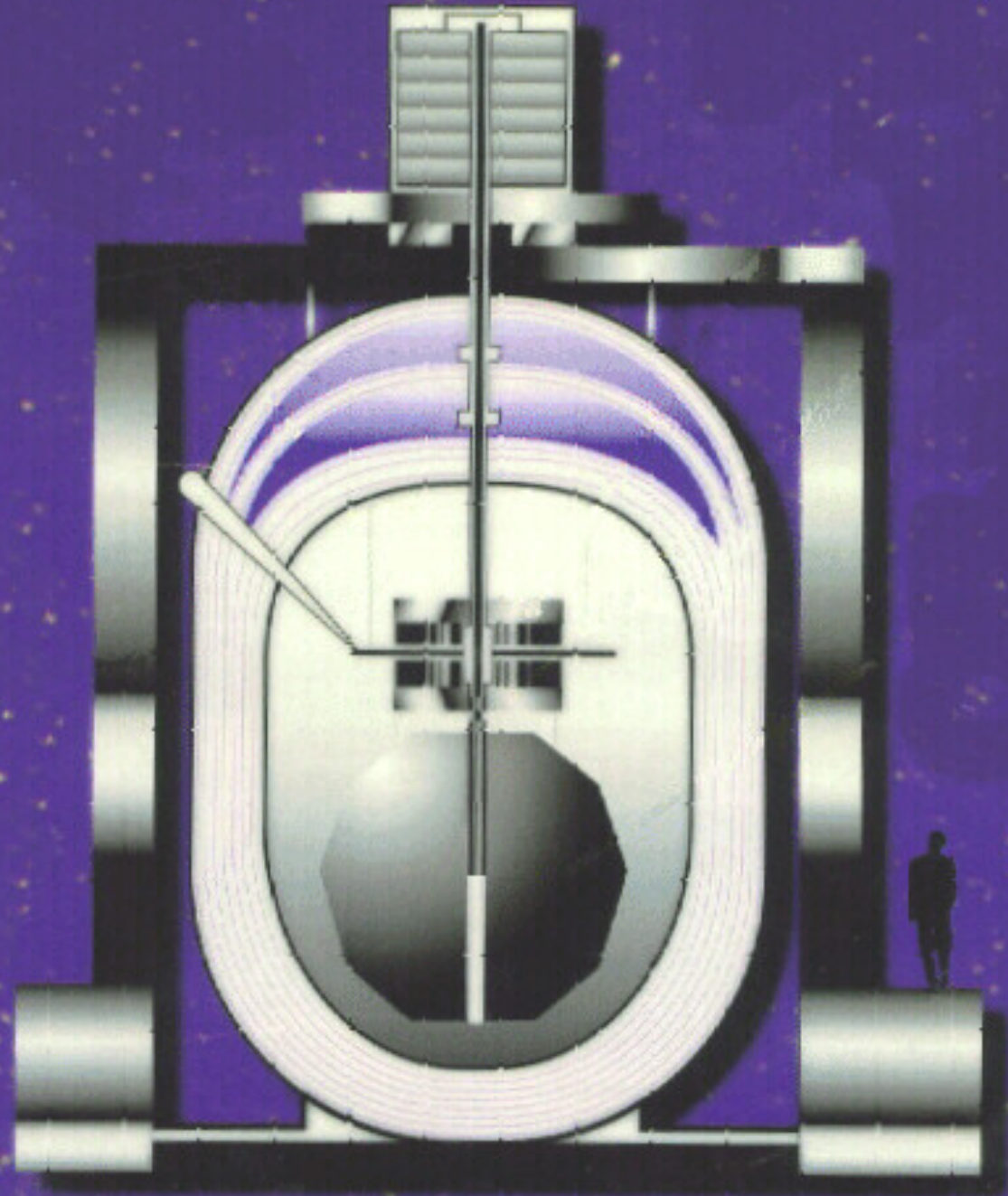
1990 → I finished my Ph.D. at LSU.

Massive
detectors
with
spherical
geometry

GRAVITON

Project
(Brasil)

1991



Gravitational Wave Detectors

- Interferometric
- Resonant-Mass



Mario Schenberg,
Brazil
(FAPESP)



MiniGRAIL
Netherlands

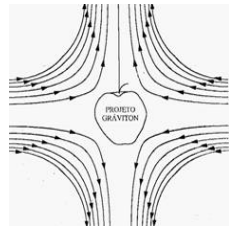




The Mario SCHENBERG Gravitational Wave Detector (Brazil)

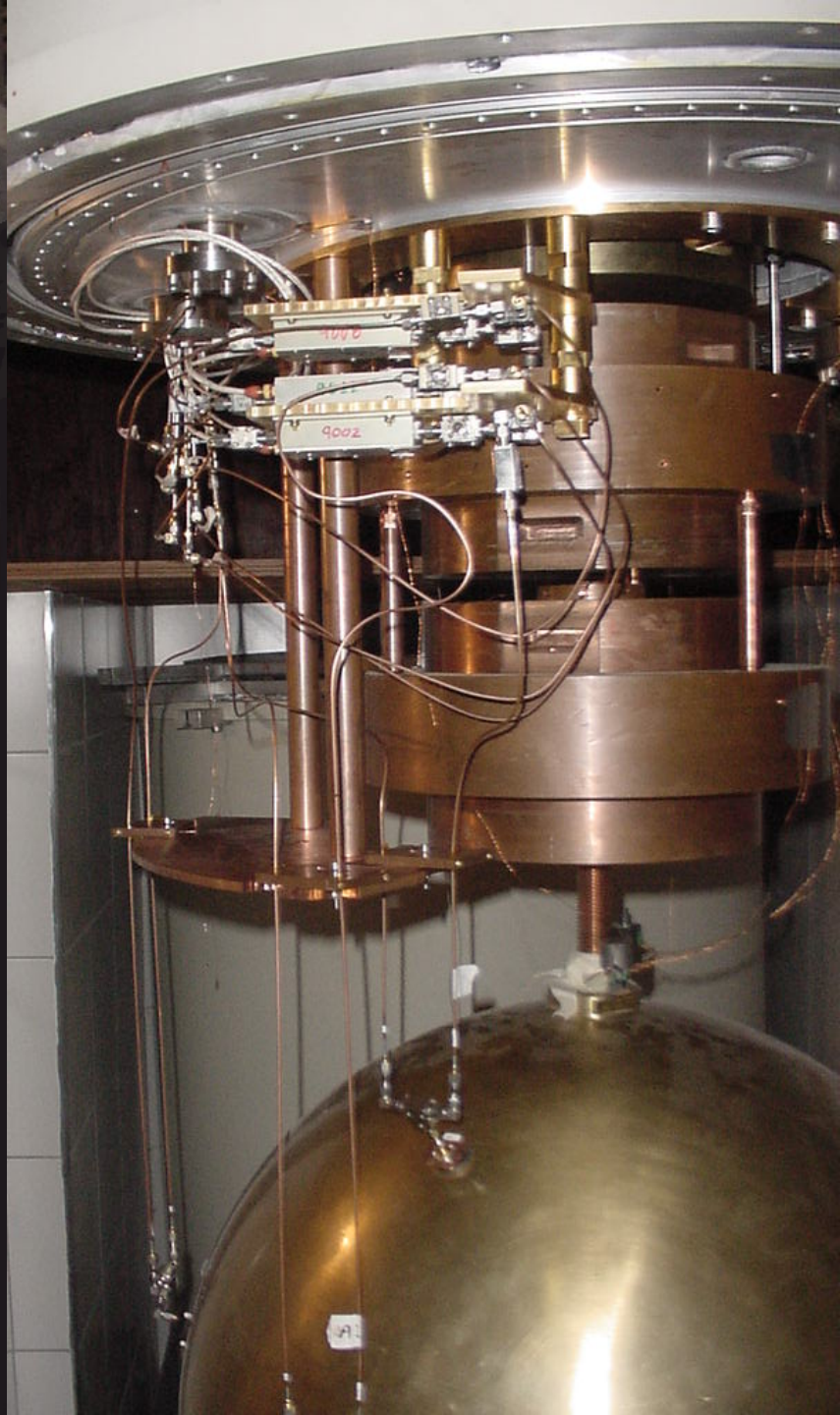
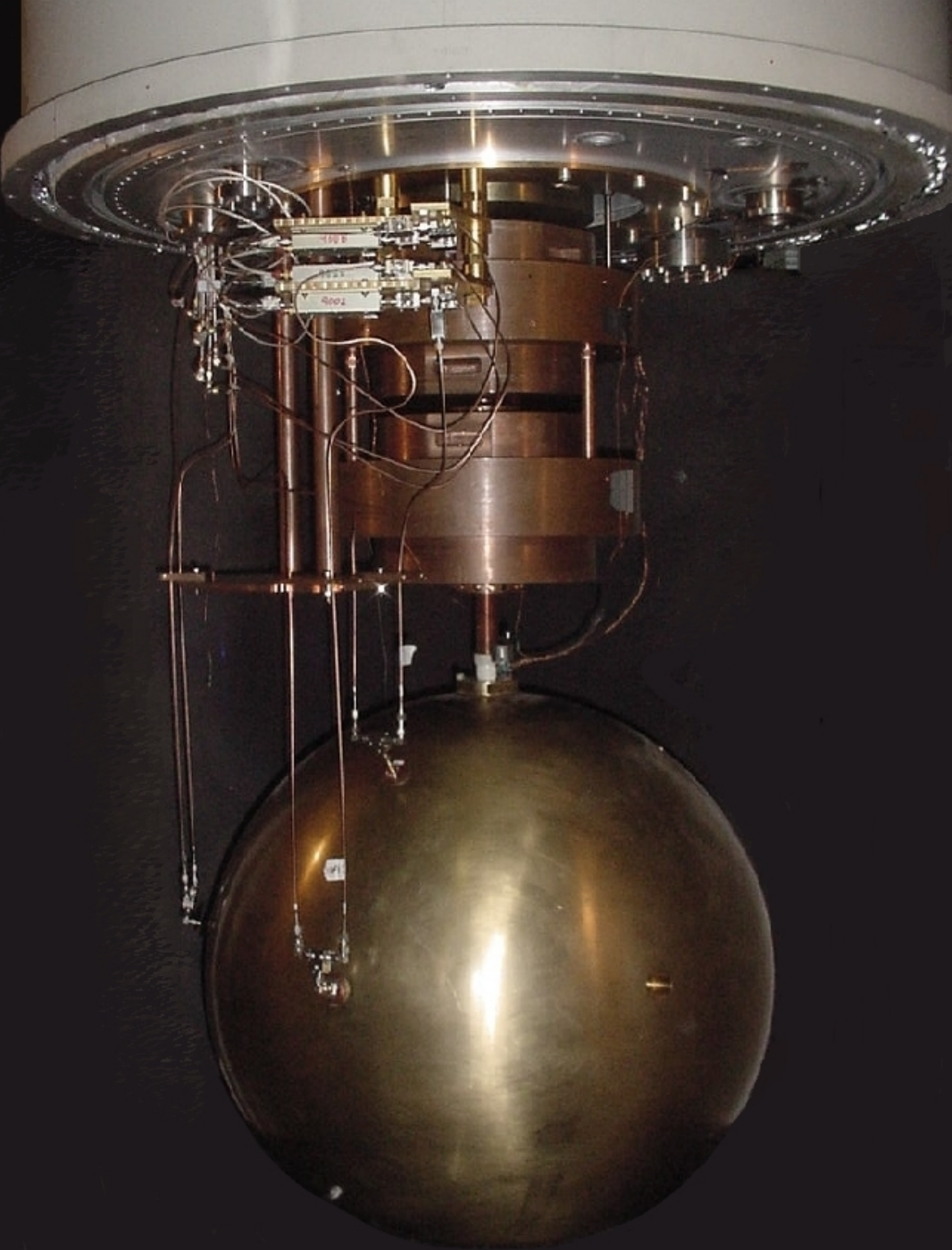
started commissioning operation
in the 8th of September, 2006.

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



GRAVITON GROUP

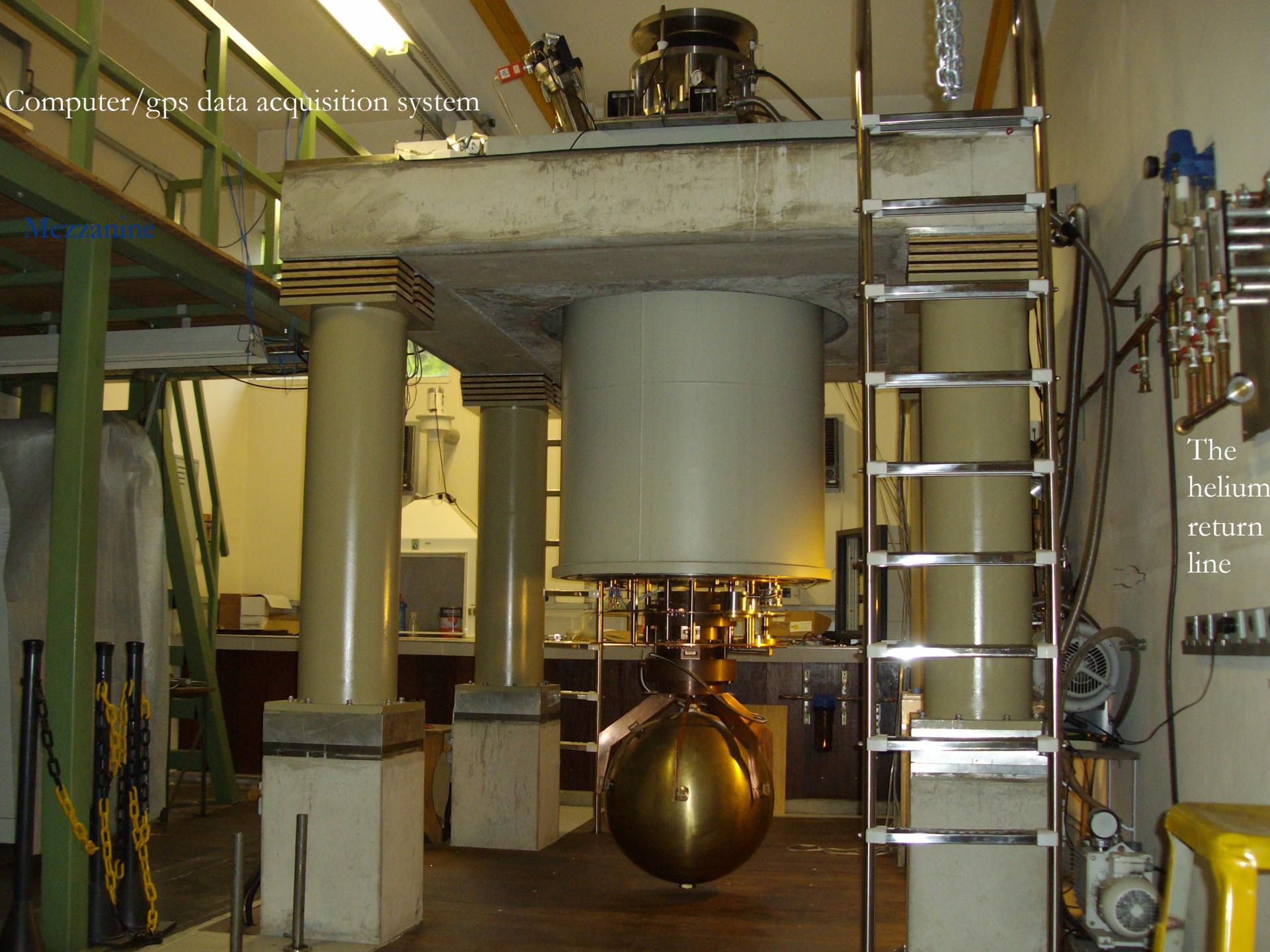




Computer/gps data acquisition system

Mezzanine

The helium return line



Status Report of the Schenberg Gravitational Wave Antenna

O D Aguiar¹, J J Barroso¹, N C Carvalho¹, P J Castro¹, C E Cedeño M¹, C F da Silva Costa¹, J C N de Araujo¹, E F D Evangelista¹, S R Furtado¹, O D Miranda¹, P H R S Moraes¹, E S Pereira¹, P R Silveira¹, C Stellati¹, N F Oliveira Jr², Xavier Gratens², L A N de Paula², S T de Souza², R M Marinho Jr³, F G Oliveira³, C Frajuca⁴, F S Bortoli⁴, R Pires⁴, D F A Bessada⁵, N S Magalhães⁵, M E S Alves⁶, A C Fauth⁷, R P Macedo⁷, A Saa⁷, D B Tavares⁷, C S S Brandão⁸, L A Andrade⁹, G F Marranghello¹⁰, C B M H Chirenti¹¹, G Frossati¹², A de Waard¹², M E Tobar¹³, C A Costa¹⁴, W W Johnson¹⁴, J A de Freitas Pacheco¹⁵, G L Pimentel¹⁶

¹ INPE – Divisão de Astrofísica, São José dos Campos, SP, Brazil,

² Universidade de São Paulo, Instituto de Física, São Paulo, SP, Brazil,

³ Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil,

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,

⁷ Universidade Estadual de Campinas, Instituto de Física, Campinas, SP, Brazil,

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 d'Azur, Nice, France,

¹⁶ Princeton University, Princeton, USA.

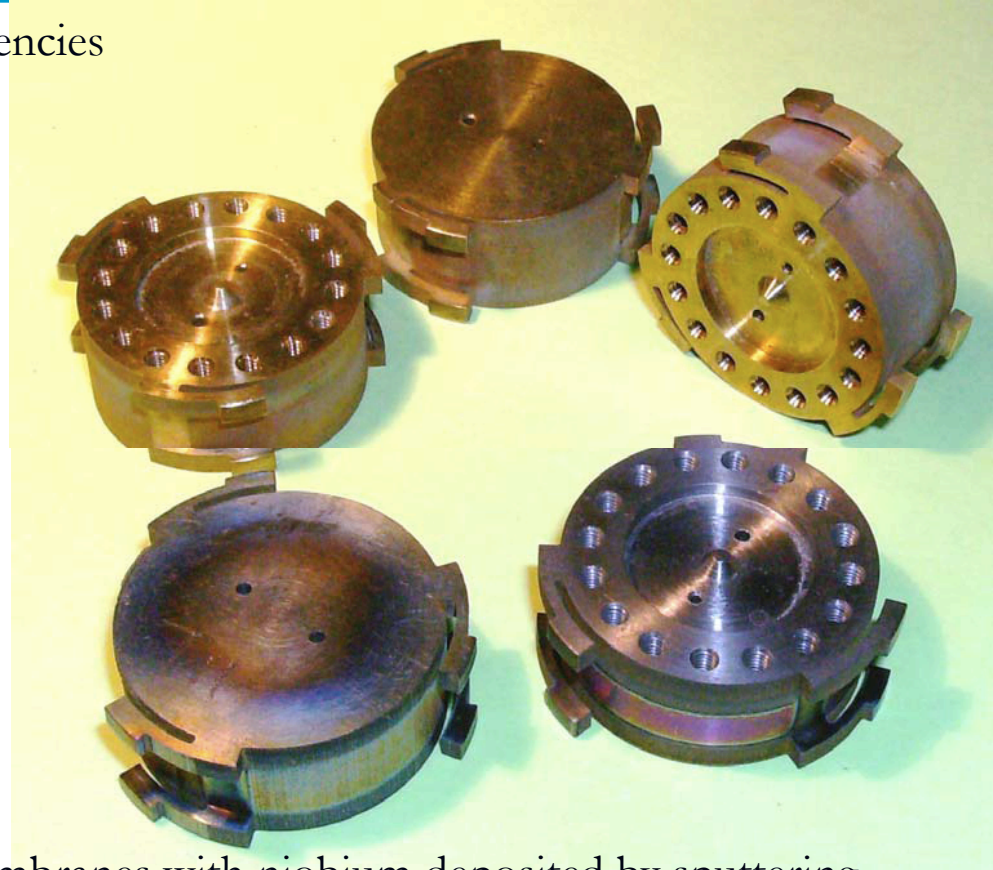
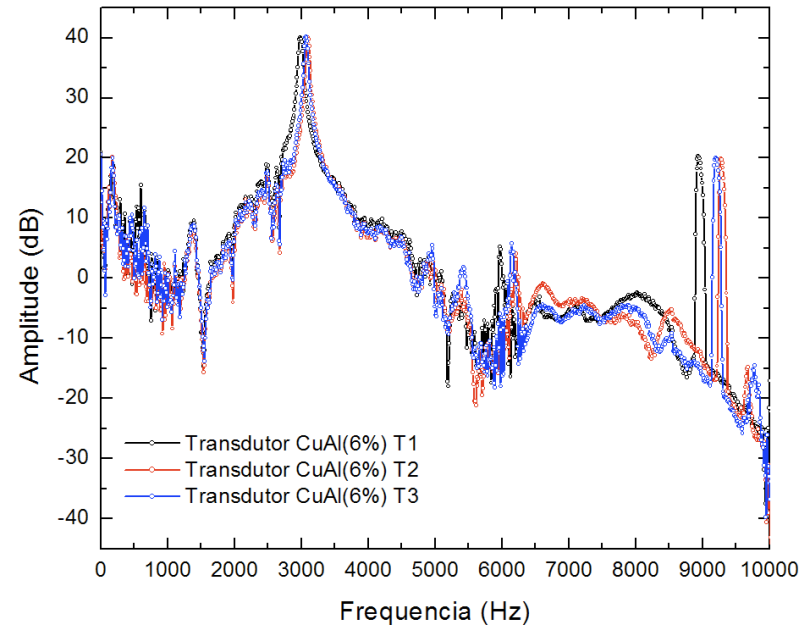


The three initial
transducers:

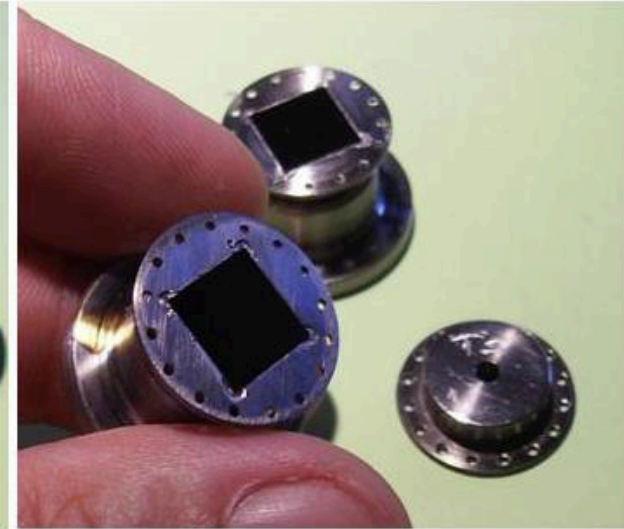
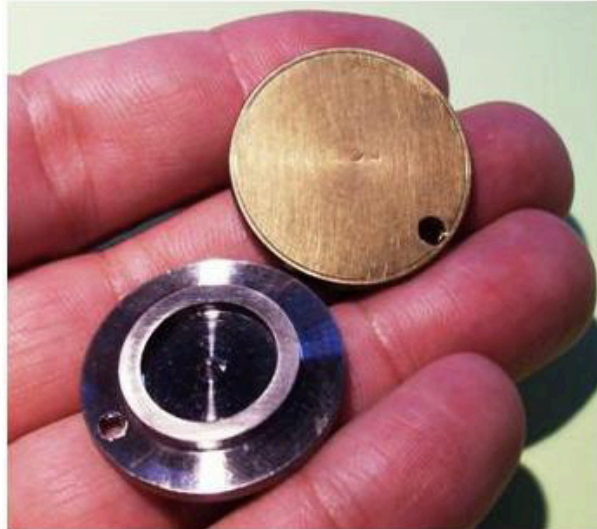
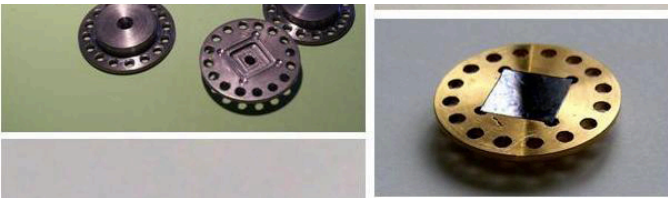
$$Q_e \sim 10^4$$

First design

Measurements of the mechanical resonant frequencies of three transducers.



Silicon membranes with niobium deposited by sputtering.

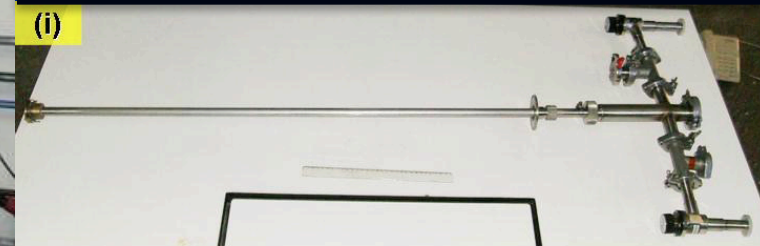


(i)

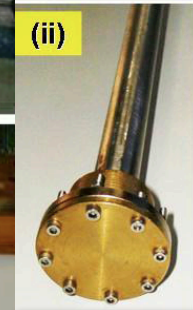


Electrical quality factors (Q_e) of several superconducting reentrant cavities at 4.2 K were measured using a liquid helium cooled dewar. Q_e as high as 300 k were found.

(i)



(ii)



(iii)

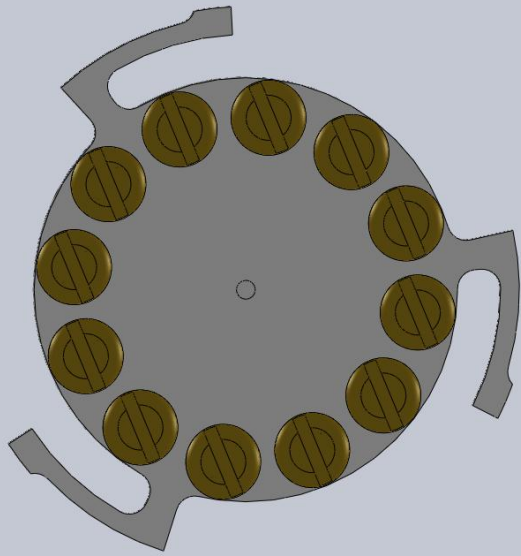


(ii)

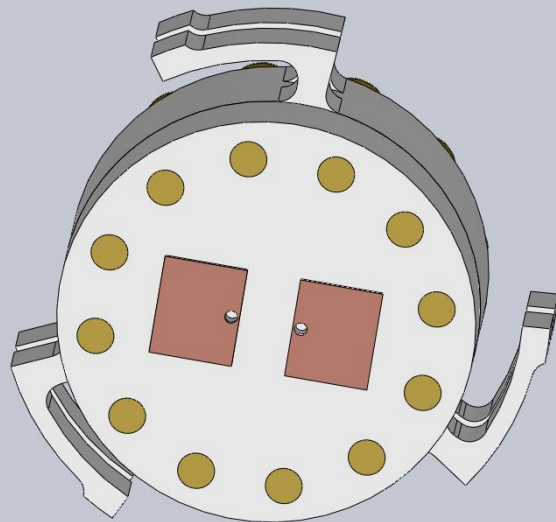


(iii)

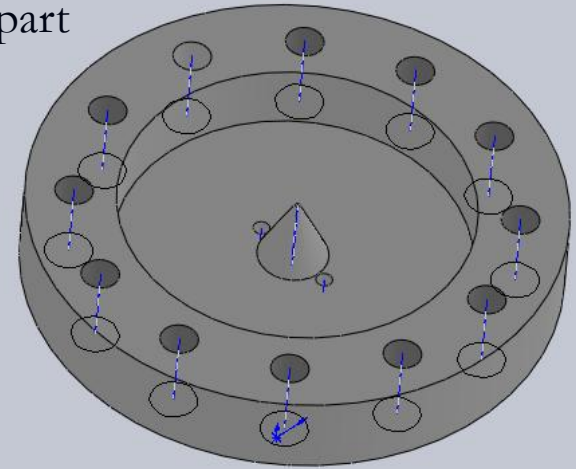
Experimental apparatus for testing superconducting reentrant cavities within a liquid helium cooled dewar.



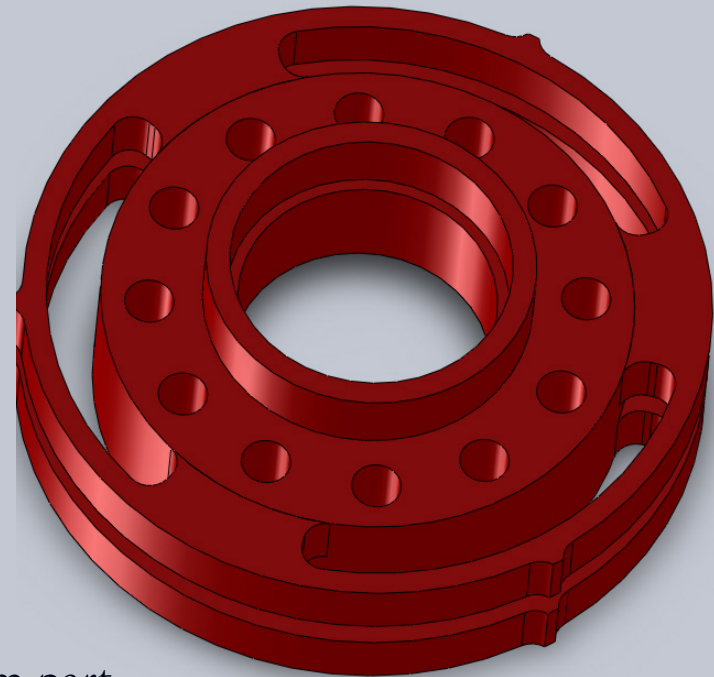
Third design



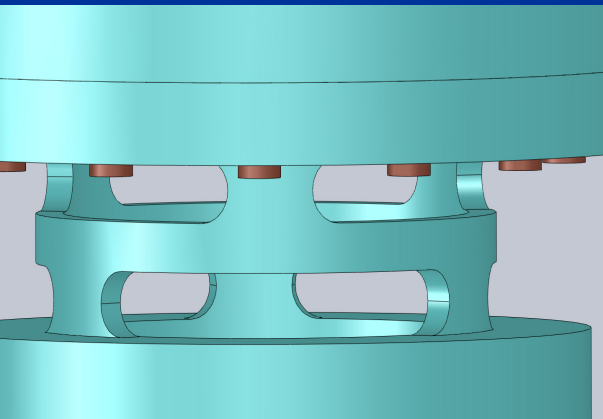
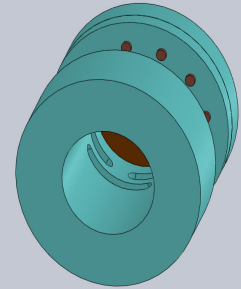
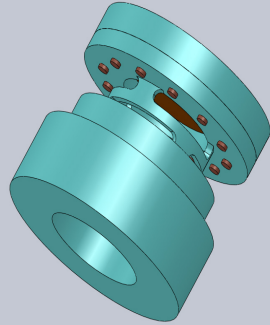
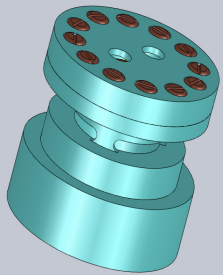
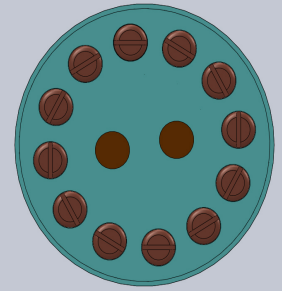
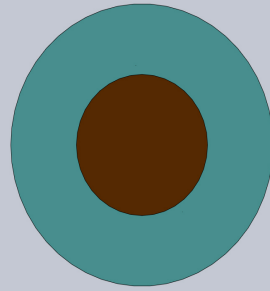
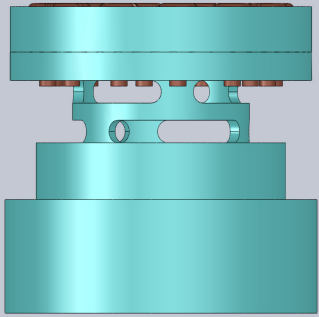
Alumina part



Fourth design

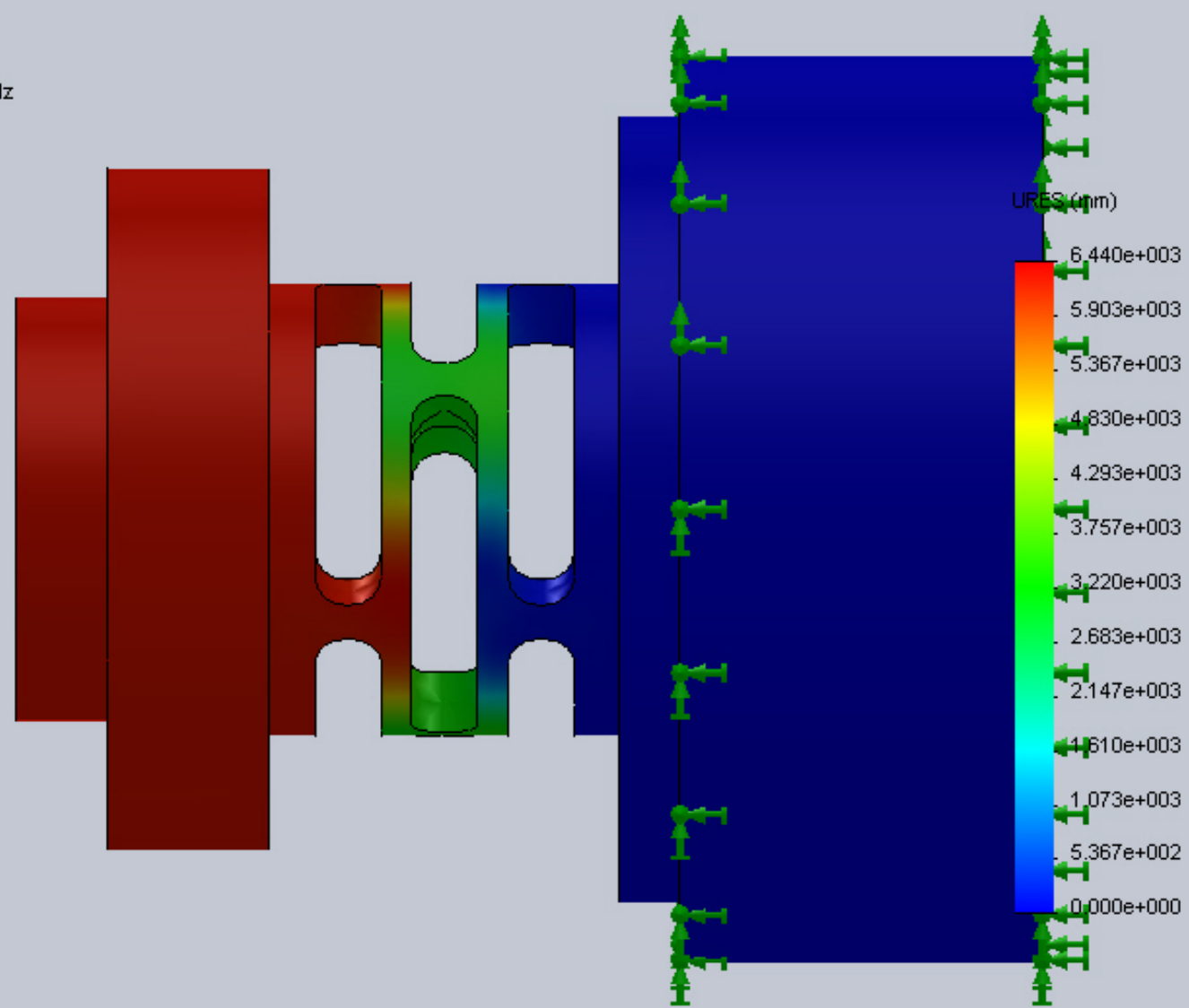


Niobium part



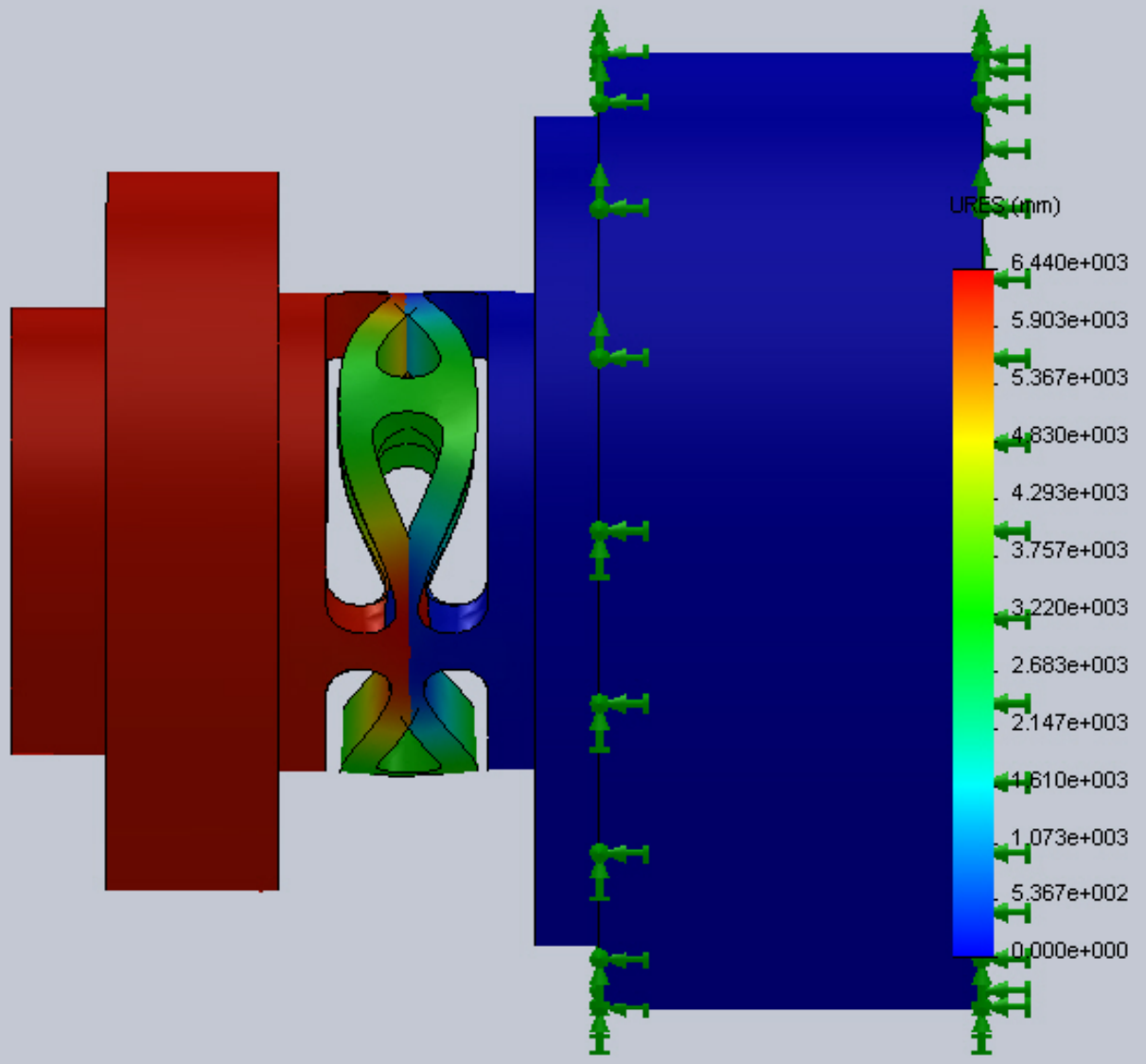
Fifth design

Model name: montagemMb2
Study name: Study 9
Plot type: Frequency Displacement3
Mode Shape : 3 Value = 3399.6 Hz



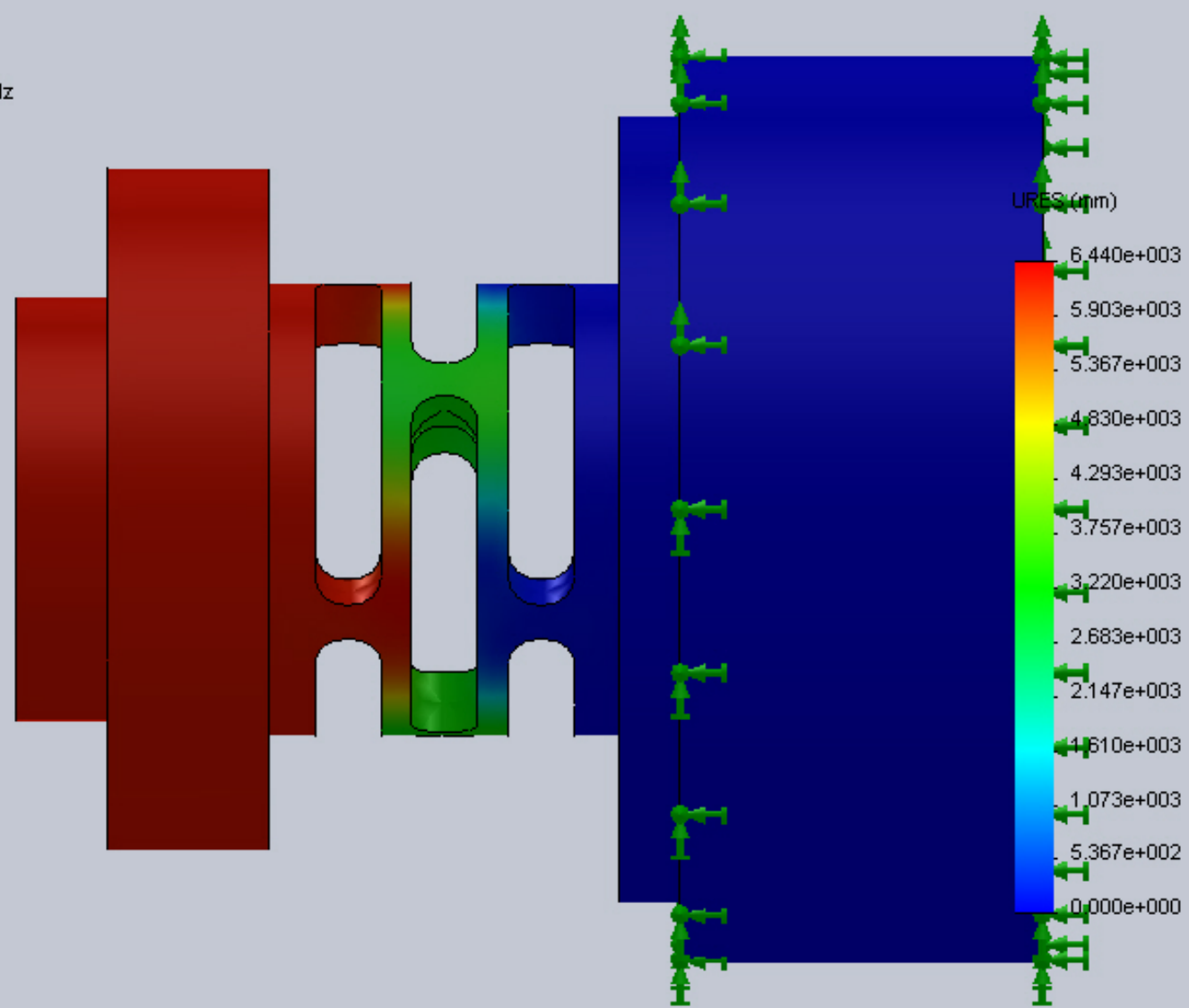
Fifth design

Model name: montagemMb2
Study name: Study 9
Plot type: Frequency Displacement3
Mode Shape : 3 Value = 3399.6 Hz
Deformation scale: 0.00055791



Fifth design

Model name: montagemMb2
Study name: Study 9
Plot type: Frequency Displacement3
Mode Shape : 3 Value = 3399.6 Hz

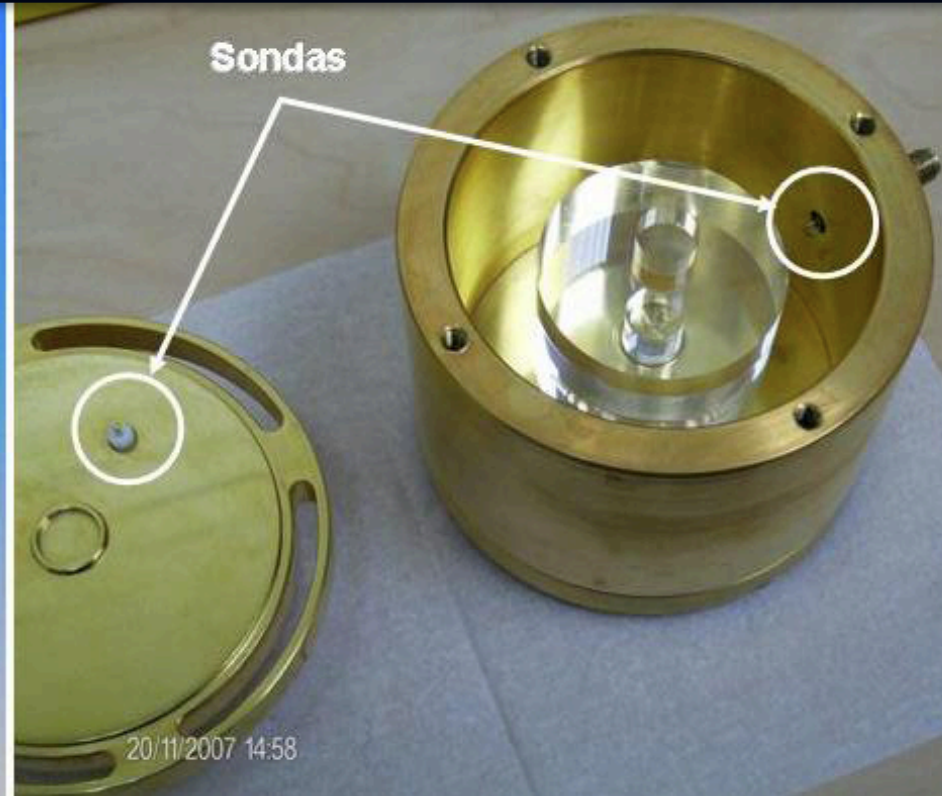
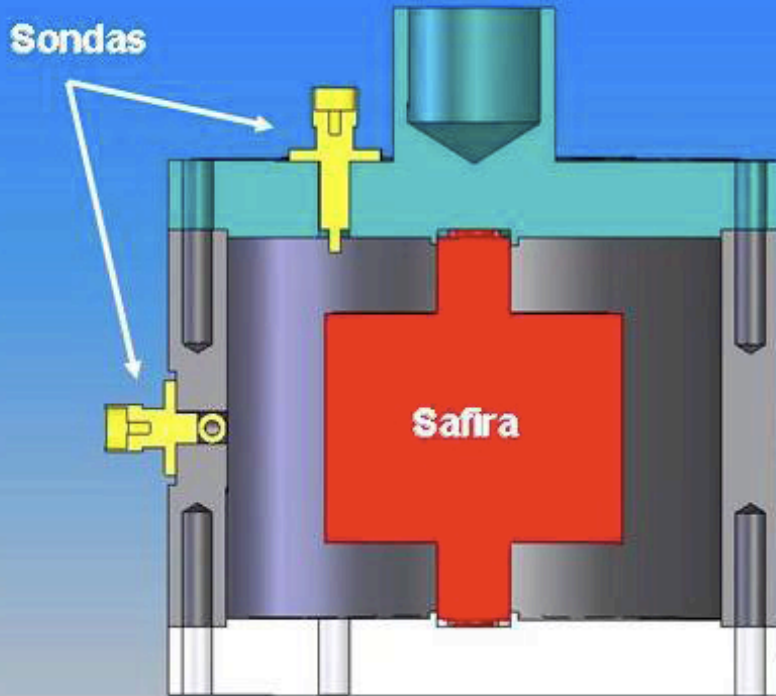


Fifth design



The eight niobium transducers.

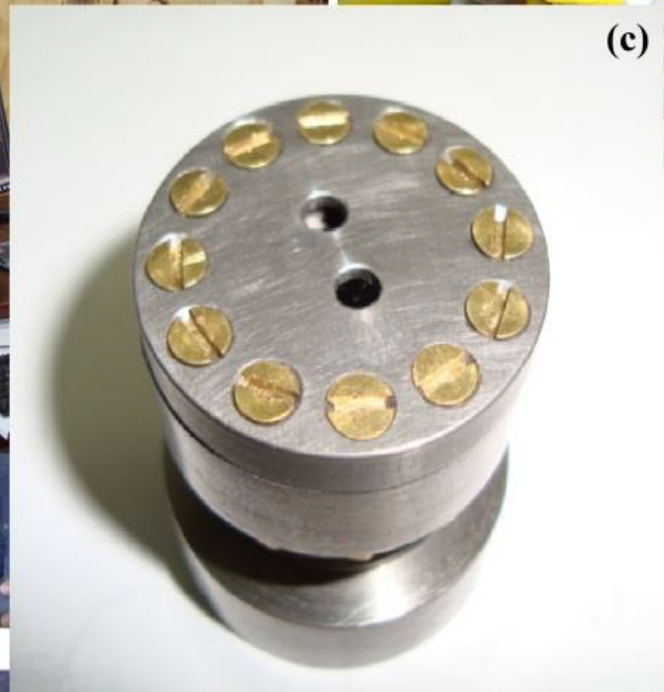
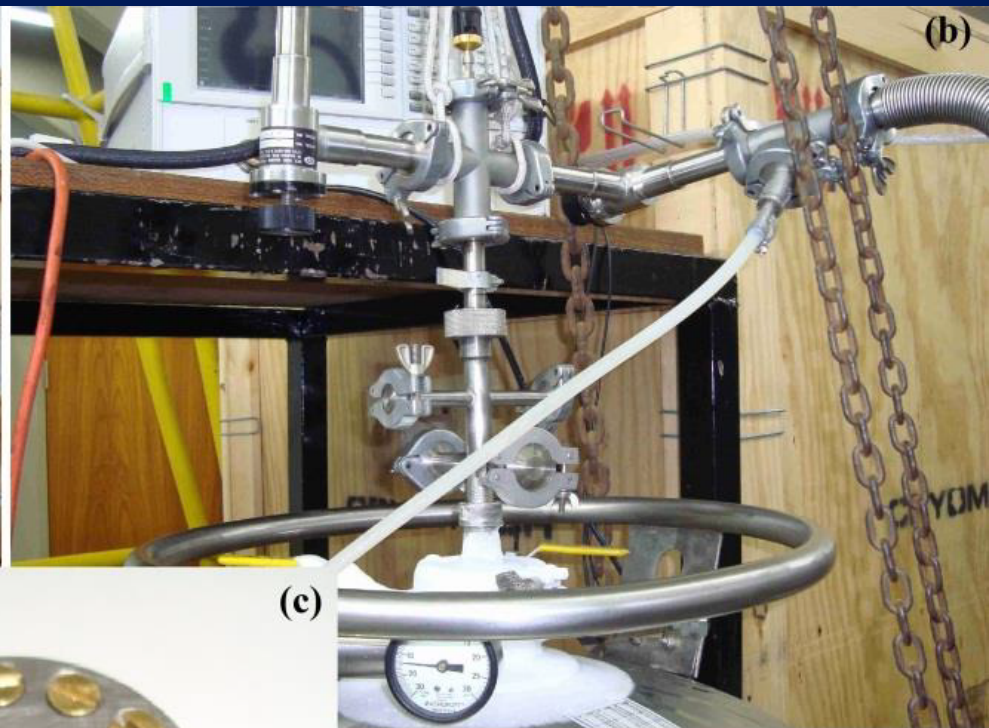
We have developed, in collaboration with the Australian group, a sapphire oscillator that operates at 77 K and will replace, with better performance, those of barium titanate currently used.

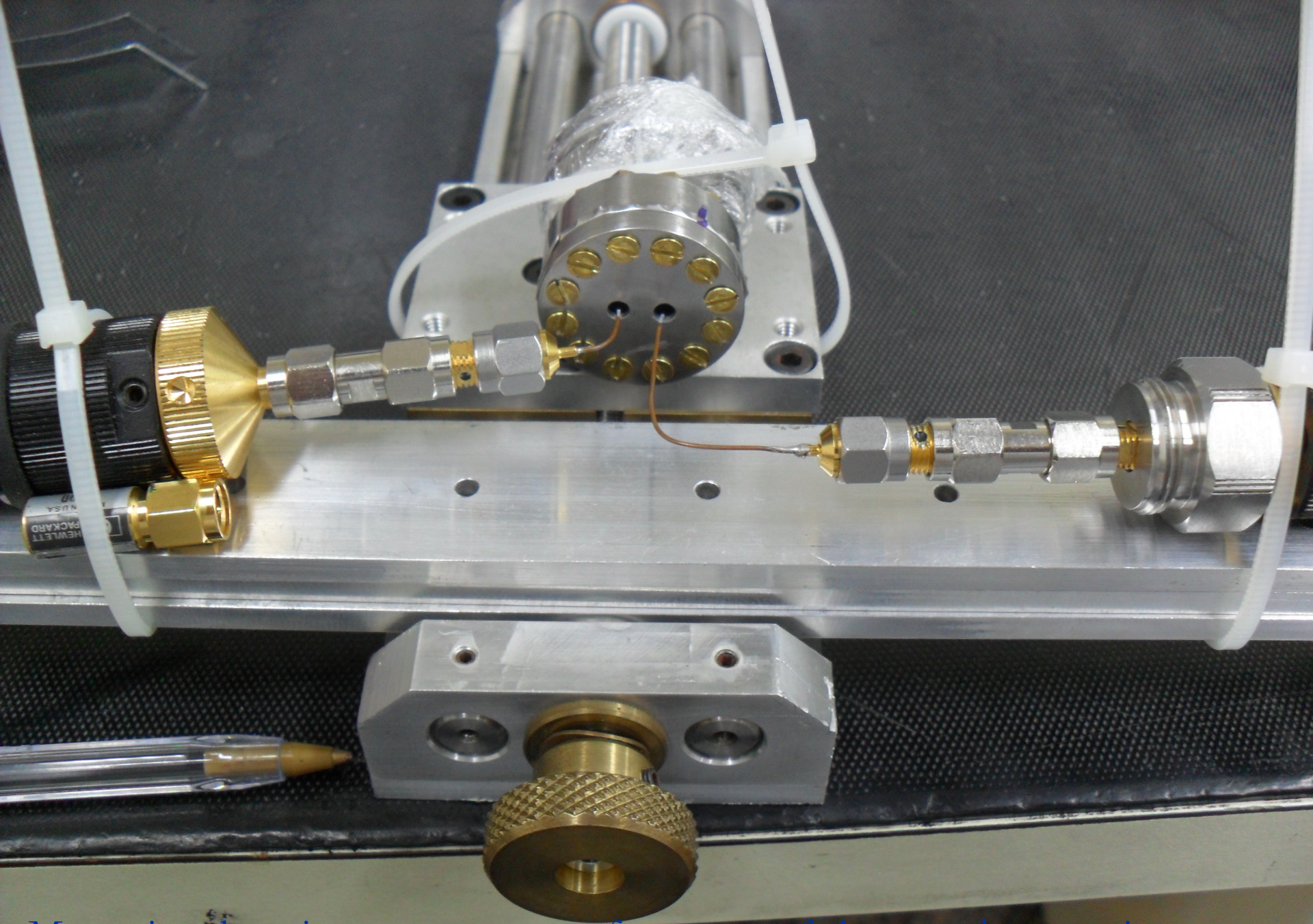




INPE Clean Room Transducer Assembly







Measuring the microwave resonant frequency of the transducer cavity.





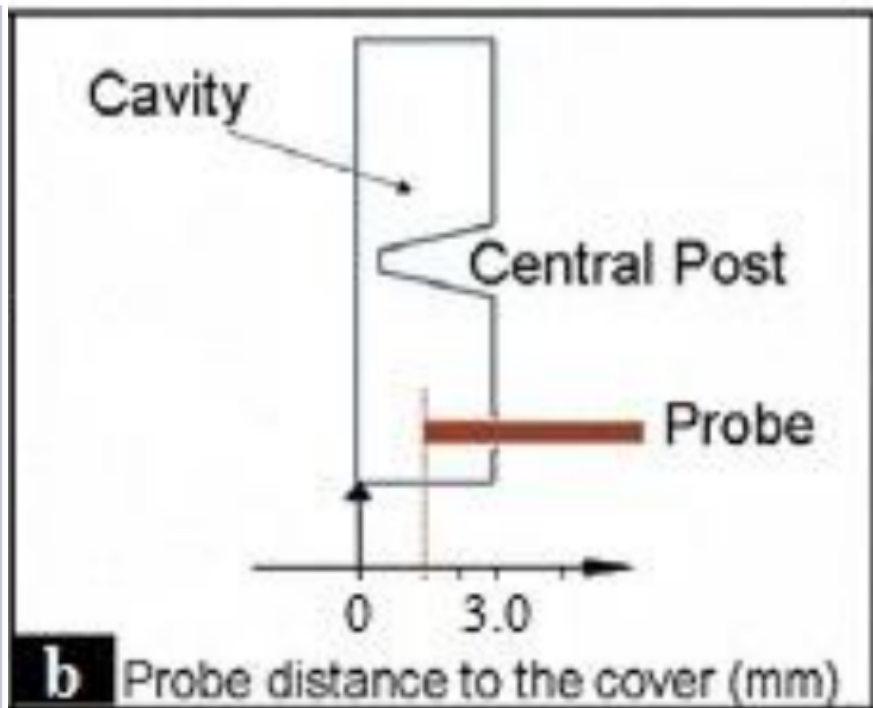
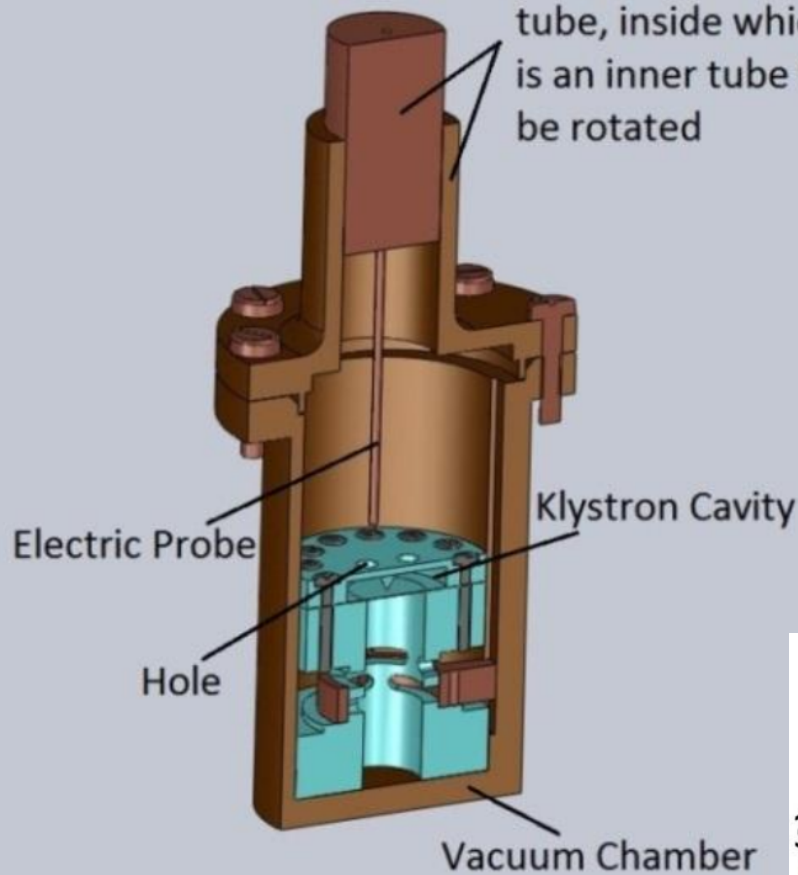
DEVELOPMENT OF A VERY HIGH... PARAMETRIC TRANS...
MARIO SCHENBERG GRAV... DETECTOR. PRO...
Sergio... ylio D. Aguiar...
Instituto Nacional...



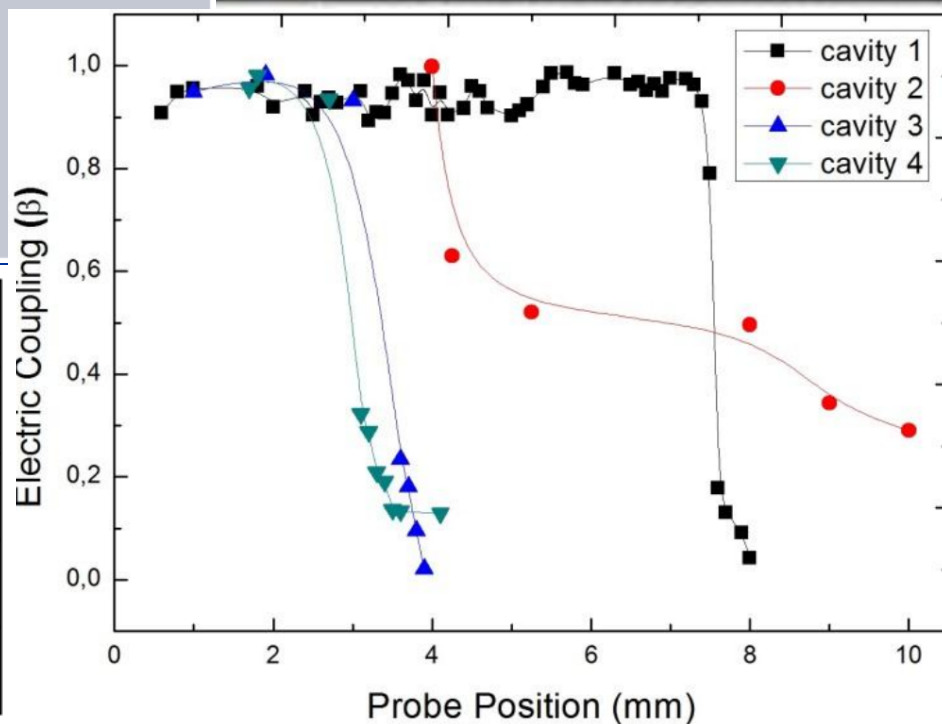
NEPT

VACUUM PORT/
RELIEF DISC

A long stainless steel tube, inside which there is an inner tube that can be rotated



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,
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^c*Astrophysics Division, National Institute for Space Research – INPE,
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^d*School of Physics, University of Western Australia – UWA,
35 Stirling Hwy, 6009 Crawley, Western Australia, Australia*

E-mail: leandroifusp@yahoo.com

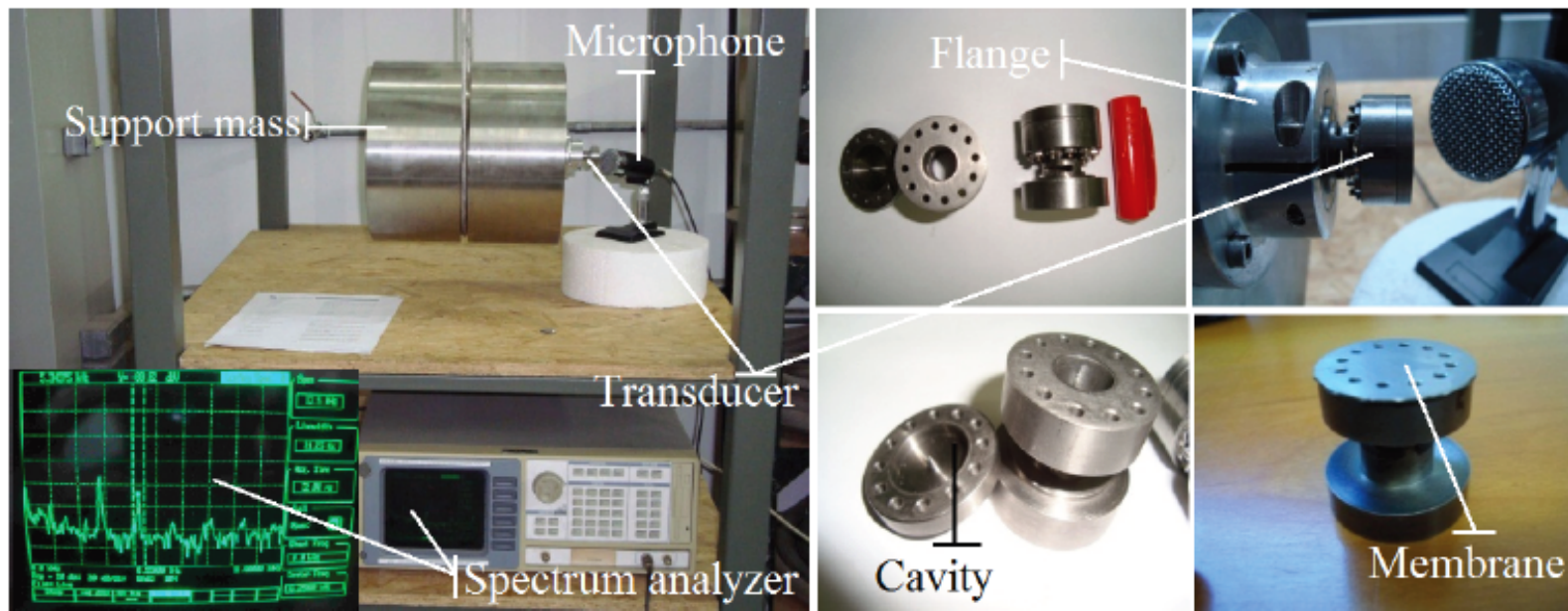


Figure 2. Equipment for measurements of mechanical resonance frequencies. The transducers were attached to the support mass and the normal modes were excited by striking the transducer. The vibrations were shown on a spectrum analyzer.

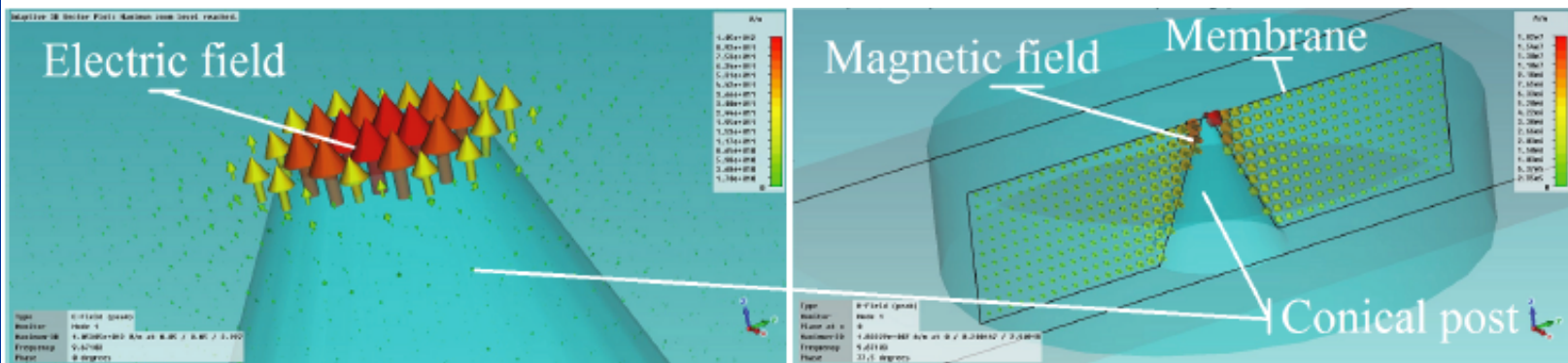


Figure 3. Electric and magnetic fields of the klystron mode for the gap of $\sim 3 \mu\text{m}$. The electric field is much stronger at the gap region, i.e. between the top of the post and the membrane. The magnetic field shows a cylindrical symmetry around the conical post.

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

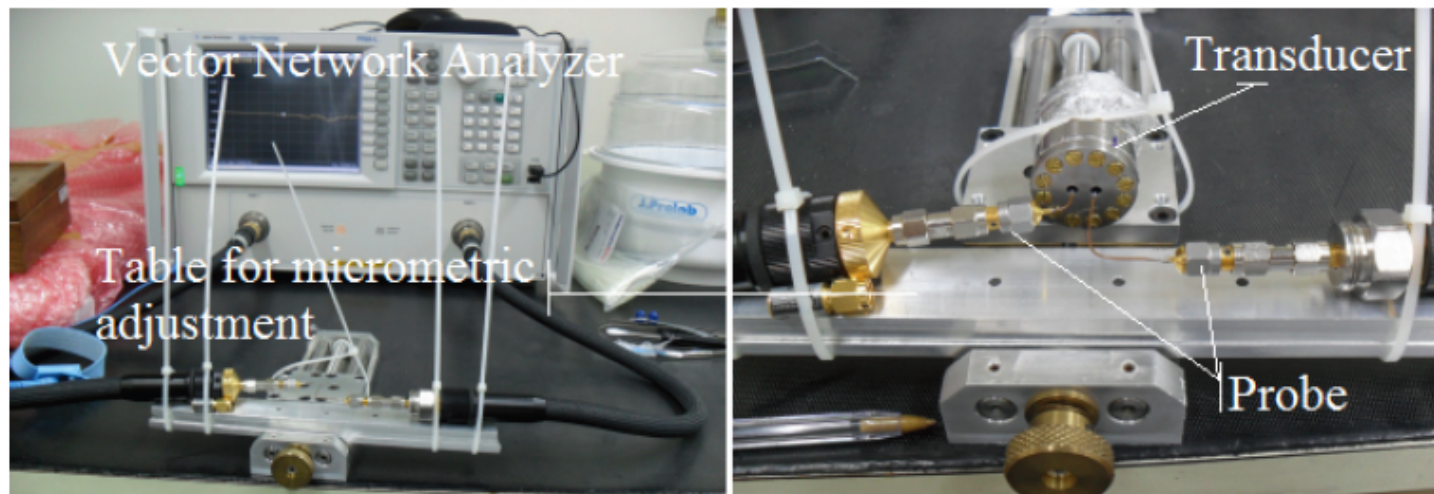


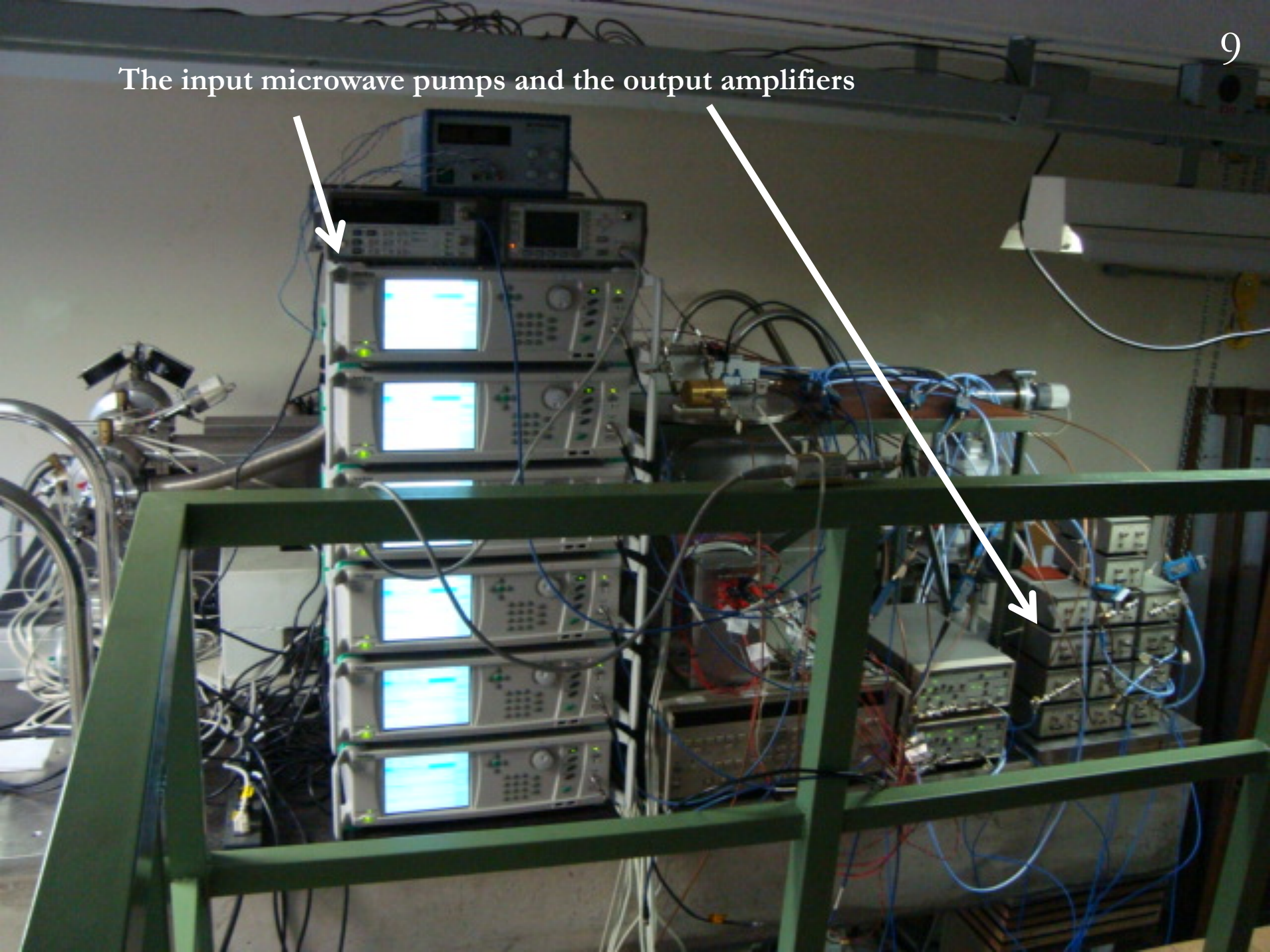
Figure 4. Frequency measurements in the vector network analyzer. The measurements were accomplished by transmission by inserting two probes into the cavity. A table for micrometric adjustment was also used in order to improve the accuracy in the probe position.

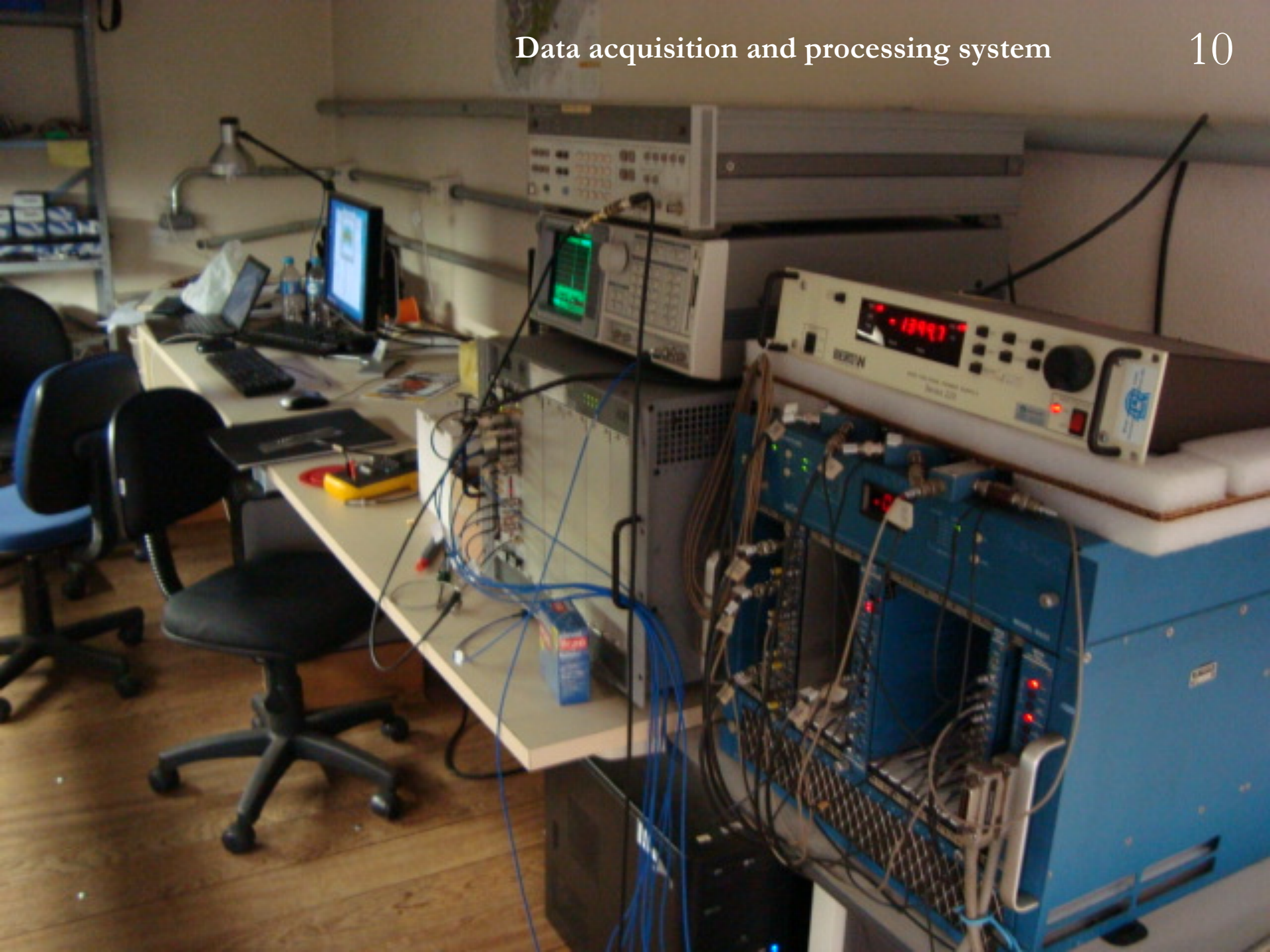
The antenna at the São Paulo (USP) site
during the 2015 runs

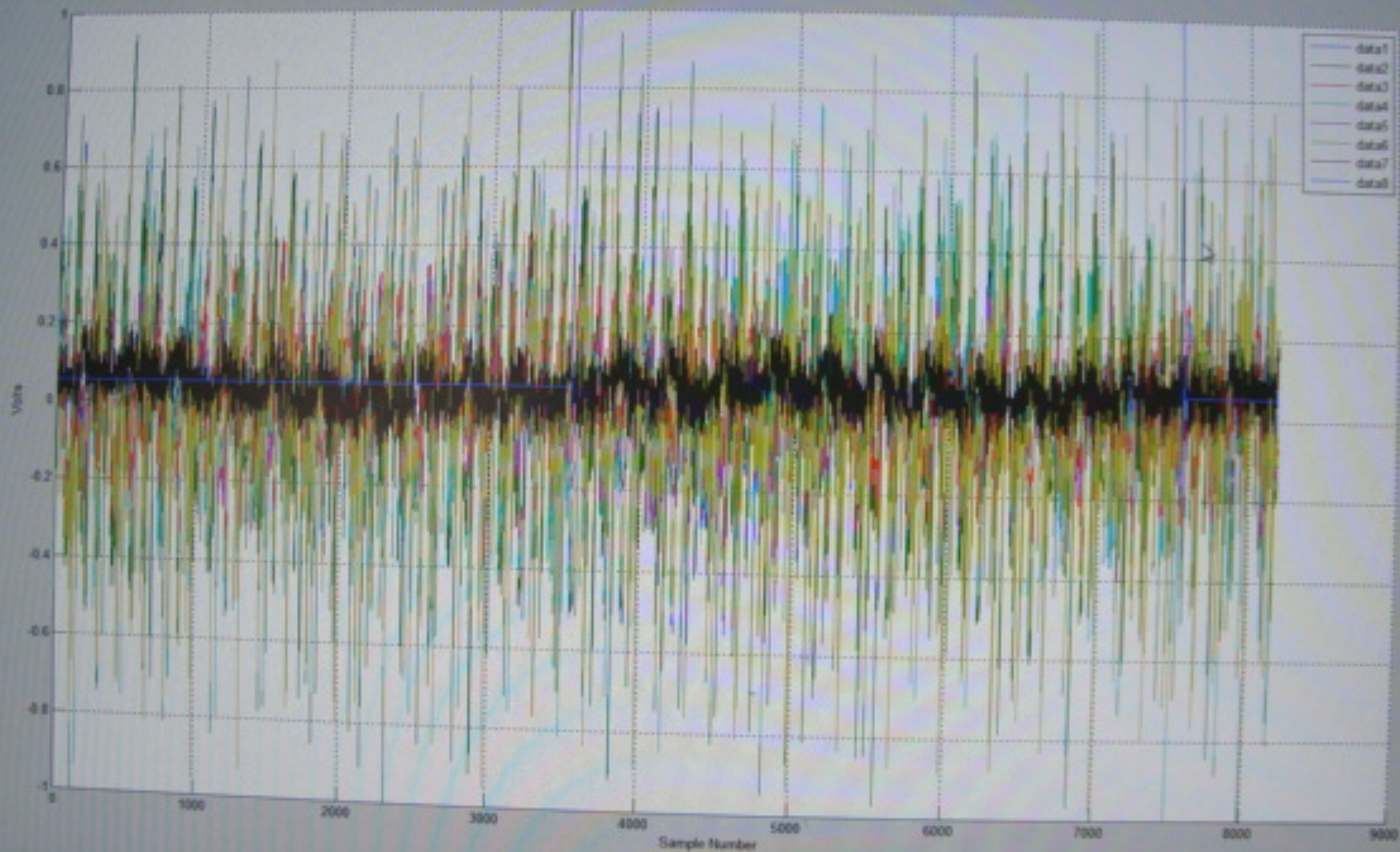
$h \sim 10^{-20} \text{ Hz}^{-1/2}$



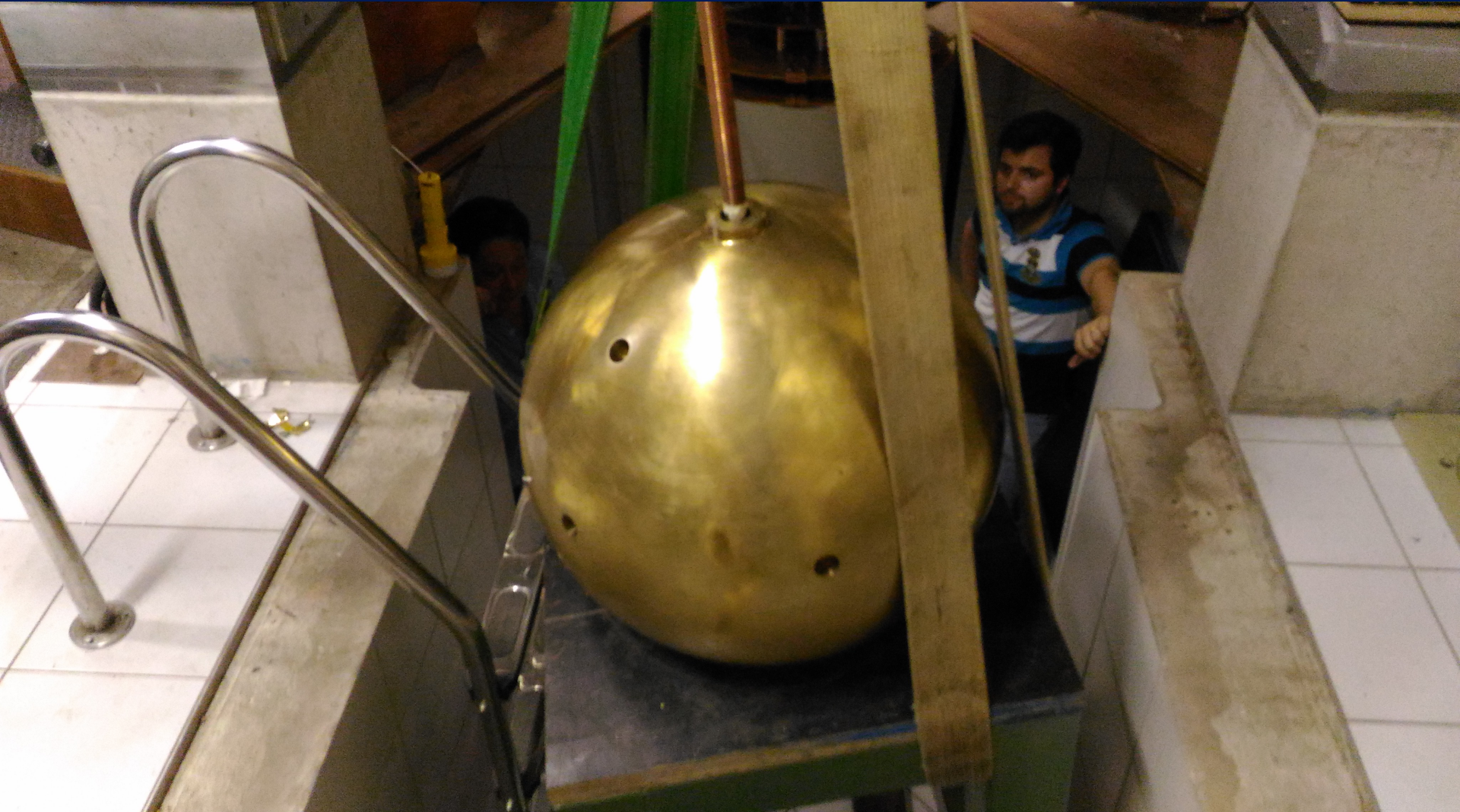
The input microwave pumps and the output amplifiers







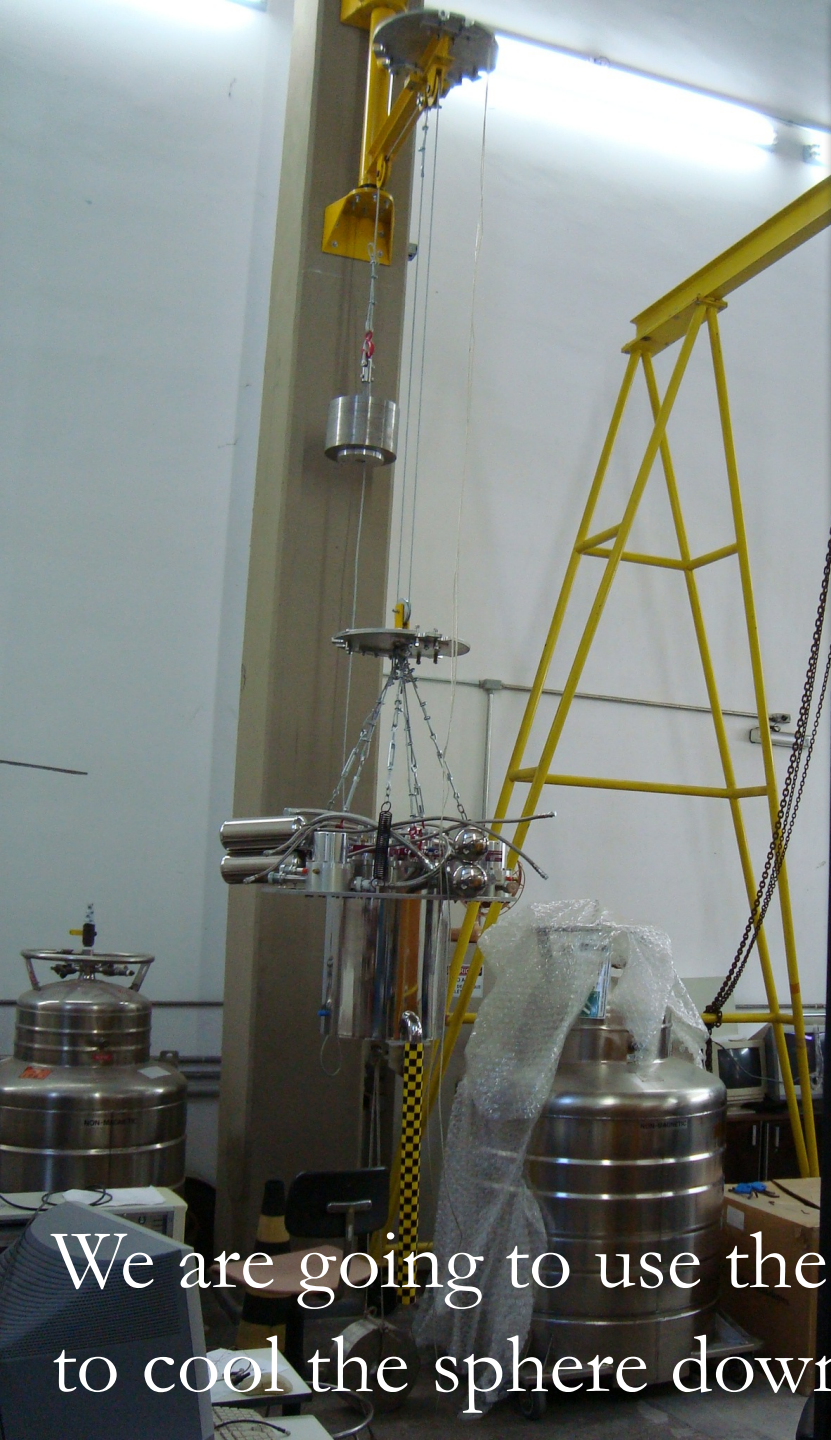
The output signal of the seven transducers in the 2015 Oct/Nov run



The sphere being removed from the USP site in 2016



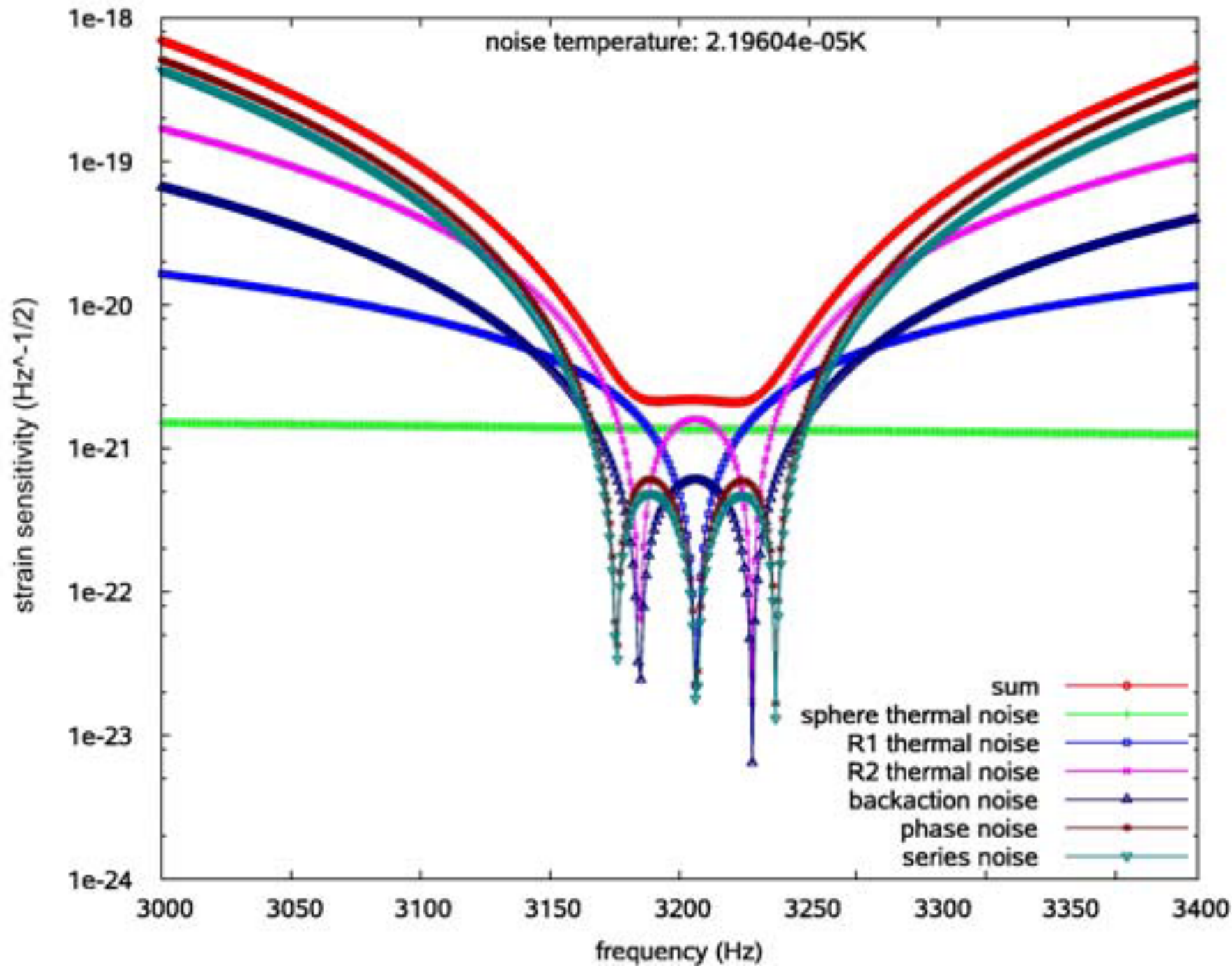
And placed in a truck to be transported to INPE in São José dos Campos

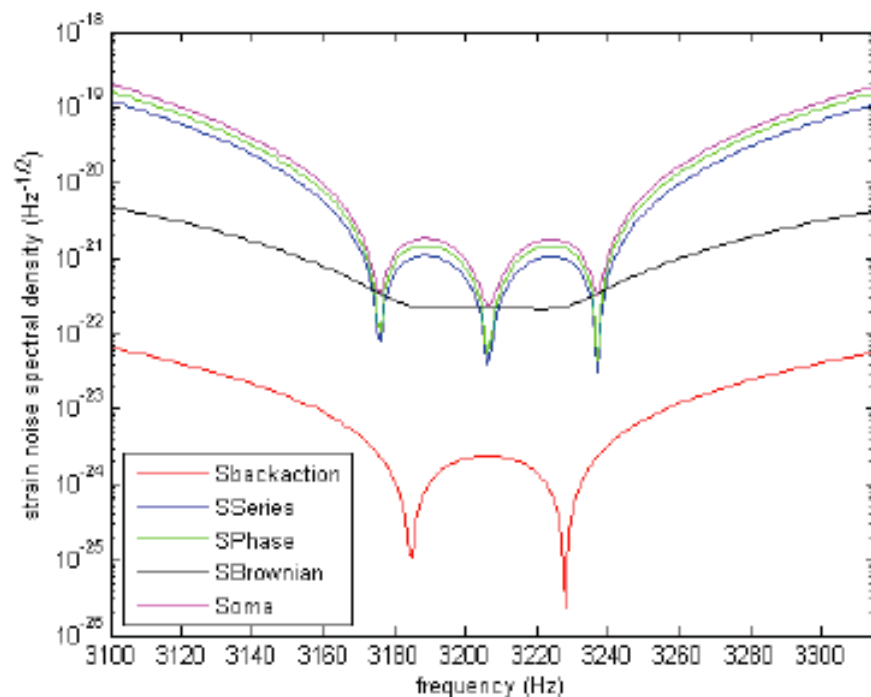


We are going to use these three integrated pulse tubing to cool the sphere down

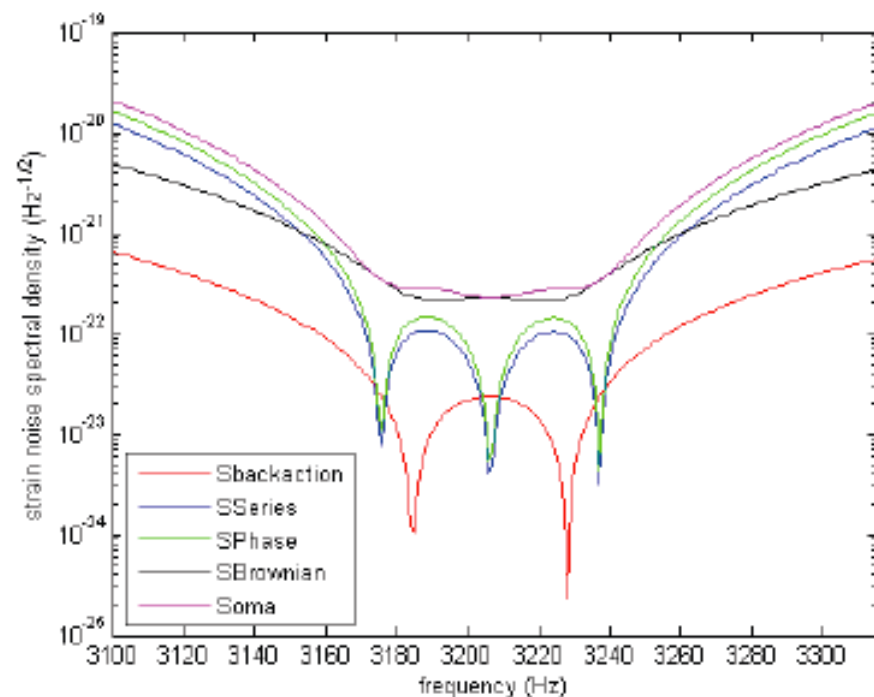
Schenberg Sensitivity at 4.2 K

noise temperature: 2.19604e-05K





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 $30\ \mu\text{m}$ ($80\ \text{MHz}/\mu\text{m}$) and $3\ \mu\text{m}$ ($800\ \text{MHz}/\mu\text{m}$). For both cases, we used the thermodynamic temperature of $50\ \text{mK}$, $Q \sim 1 \times 10^6$, $P_{\text{in}} \sim 1 \times 10^{-10}$ Watts, phase noise of $-130\ \text{dBc}/\text{Hz}@3,2\ \text{kHz}$.

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

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São José dos Campos SP, Brasil

^bINPE-Instituto Nacional de Pesquisas Espaciais,
São José dos Campos SP, Brasil

^cUFRB-Universidade Federal do Recôncavo da Bahia,
Cruz das Almas BA, Brasil

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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

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 !**