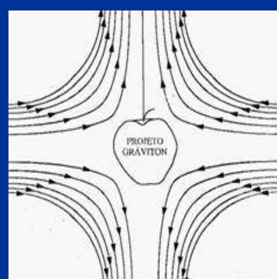
ONG / DAS / INPE

Linha de Pesquisa em Astrofísica de Ondas Gravitacionais, Divisão de Astrofísica, Instituto Nacional de Pesquisas Espaciais



GRAVITON GROUP

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Grupo Gráviton

São José dos Campos, 08 de Maio de 2018

Grupo Experimental da ONG/DAS/INPE (8)

Odylio Denys de Aguiar (Pesq. Titular III)

Marcos André Okada (Técnico)

Márcio Constancio Jr. (pós-doutor)

Elvis Camilo Ferreira (aluno de doutorado)

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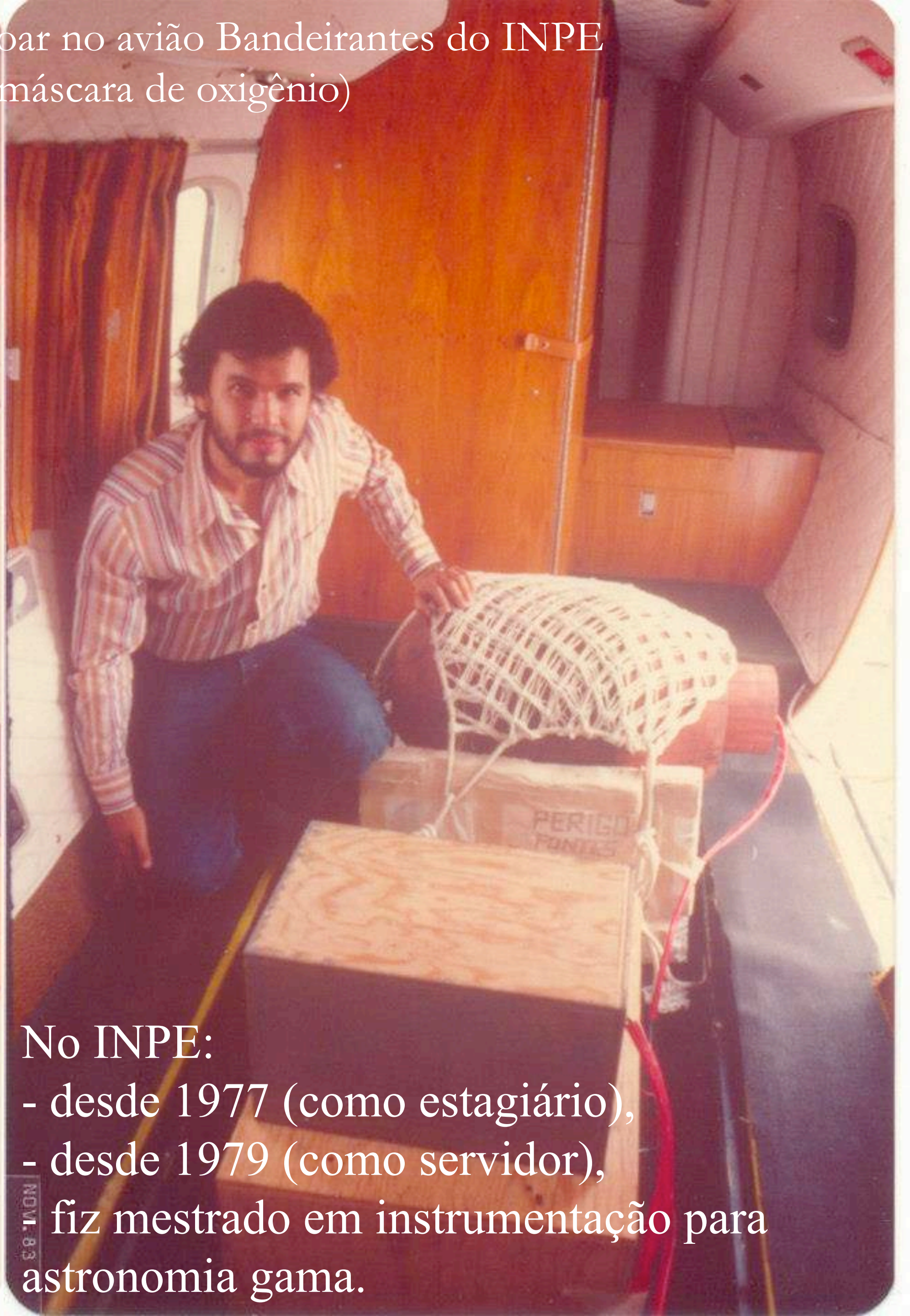
Guilherme Raçatto (aluno de graduação)

Ana Beatriz Costa (aluno de graduação)

Diego Hiroshi Taira (técnico mecânico)

O experimento (dois detectores gama) teve que voar no avião Bandeirantes do INPE
a 25.500 feet → 7.772 metros de altitude (uso de máscara de oxigênio)
A foto foi tirada com o avião em solo.



No INPE:

- desde 1977 (como estagiário),
- desde 1979 (como servidor),
- fiz mestrado em instrumentação para astronomia gama.

Fui em agosto de 1984 para a LSU (para fazer doutorado).

Na área de detecção de ondas gravitacionais desde maio de 1986 (após o ‘Qualifying’).

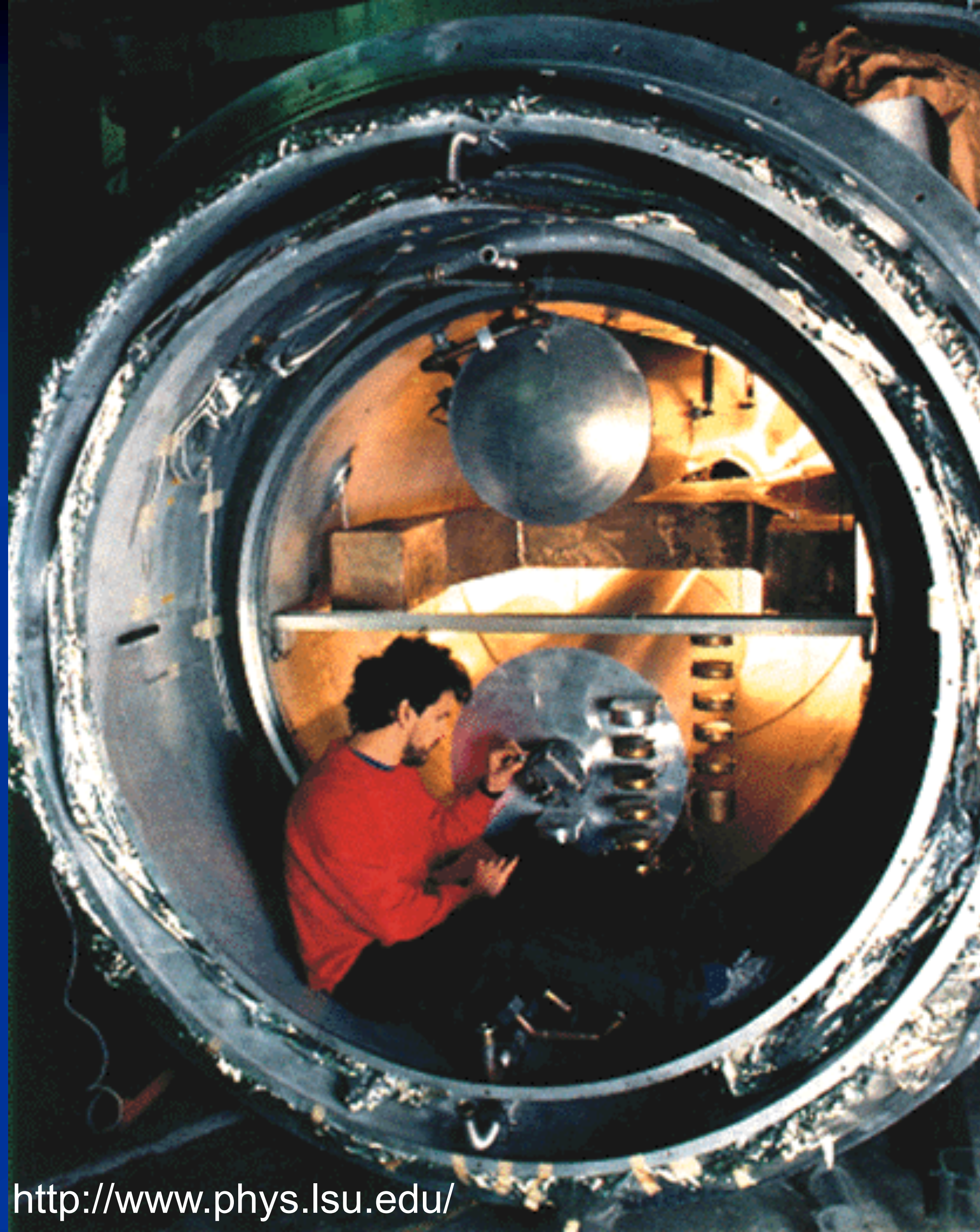
LSU (ALLEGRO)

2ª geração de barras

Cilíndrico

- 269 ^{o}C

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



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

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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.

Inaugurada a Astronomia de Ondas Gravitacionais com a primeira detecção

Selected for a Viewpoint in *Physics*

PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**

(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

I. INTRODUCTION

In 1916, the year after the final formulation of the field equations of general relativity, Albert Einstein predicted

The discovery of the binary pulsar system PSR B1913+16 by Hulse and Taylor [20] and subsequent observations of its energy loss by Taylor and Weisberg [21] demonstrated https://youtu.be/kkKDs59zcdI

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J.-P. Zendri,[42] M. Zevin,[82] F. Zhang,[10] L. Zhang,[1] M. Zhang,[120] Y. Zhang,[102] C. Zhao,[51] M. Zhou,[82] Z. Zhou,[82] X. J. Zhu,[51]
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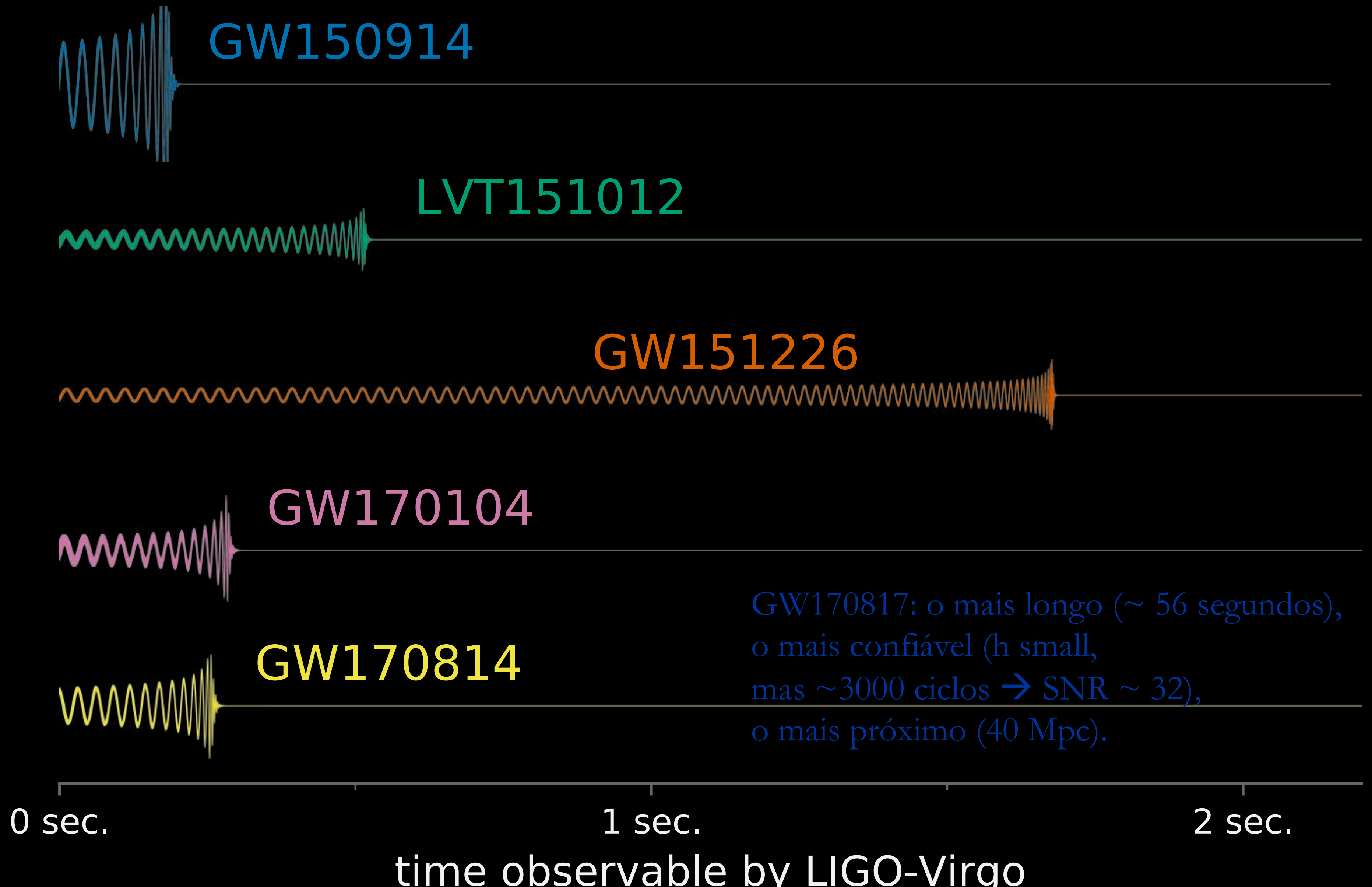
http://ligo.org/detections/images/GW170814_reconstruction_comparison.png



GW170817: o mais longo (~ 56 segundos),
o mais confiável (h small,
mas ~3000 ciclos → SNR ~ 32),
o mais próximo (40 Mpc).

Primeira Detecção de Ondas Gravitacionais de uma Binária de Estrelas de Nêutrons

Selected for a Viewpoint in *Physics*
PRL 119, 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

On August 17, 2017 at 12:41:04 UTC the Advanced LIGO and Advanced Virgo gravitational-wave detectors made their first observation of a binary neutron star inspiral. The signal, GW170817, was detected with a combined signal-to-noise ratio of 32.4 and a false-alarm-rate estimate of less than one per 8.0×10^4 years. We infer the component masses of the binary to be between 0.86 and 2.26 $M_\odot$, in agreement with masses of known neutron stars. Restricting the component spins to the range inferred in binary neutron stars, we find the component masses to be in the range 1.17–1.60 $M_\odot$, with the total mass of the system $2.74^{+0.04}_{-0.01} M_\odot$. The source was localized within a sky region of 28 deg^2 (90% probability) and had a luminosity distance of 40^{+8}_{-14} Mpc, the closest and most precisely localized gravitational-wave signal yet. The association with the γ-ray burst GRB 170817A, detected by Fermi-GBM 1.7 s after the coalescence, corroborates the hypothesis of a neutron star merger and provides the first direct evidence of a link between these mergers and short γ-ray bursts. Subsequent identification of transient counterparts across the electromagnetic spectrum in the same location further supports the interpretation of this event as a neutron star merger. This unprecedented joint gravitational and electromagnetic observation provides insight into astrophysics, dense matter, gravitation, and cosmology.

DOI: 10.1103/PhysRevLett.119.161101

I. INTRODUCTION

On August 17, 2017, the LIGO-Virgo detector network observed a gravitational-wave signal from the inspiral of two low-mass compact objects consistent with a binary neutron star (BNS) merger. This discovery comes four

will observe between one BNS merger every few years to hundreds per year [14–21]. This detector network currently includes three Fabry-Perot-Michelson interferometers that measure spacetime strain induced by passing gravitational waves as a varying phase difference between laser light propagating in perpendicular arms: the two Advanced

Inaugurada a Astronomia Multimensageira com Ondas Gravitacionais

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20
https://doi.org/10.3847/2041-8213/aa91c9

OPEN ACCESS

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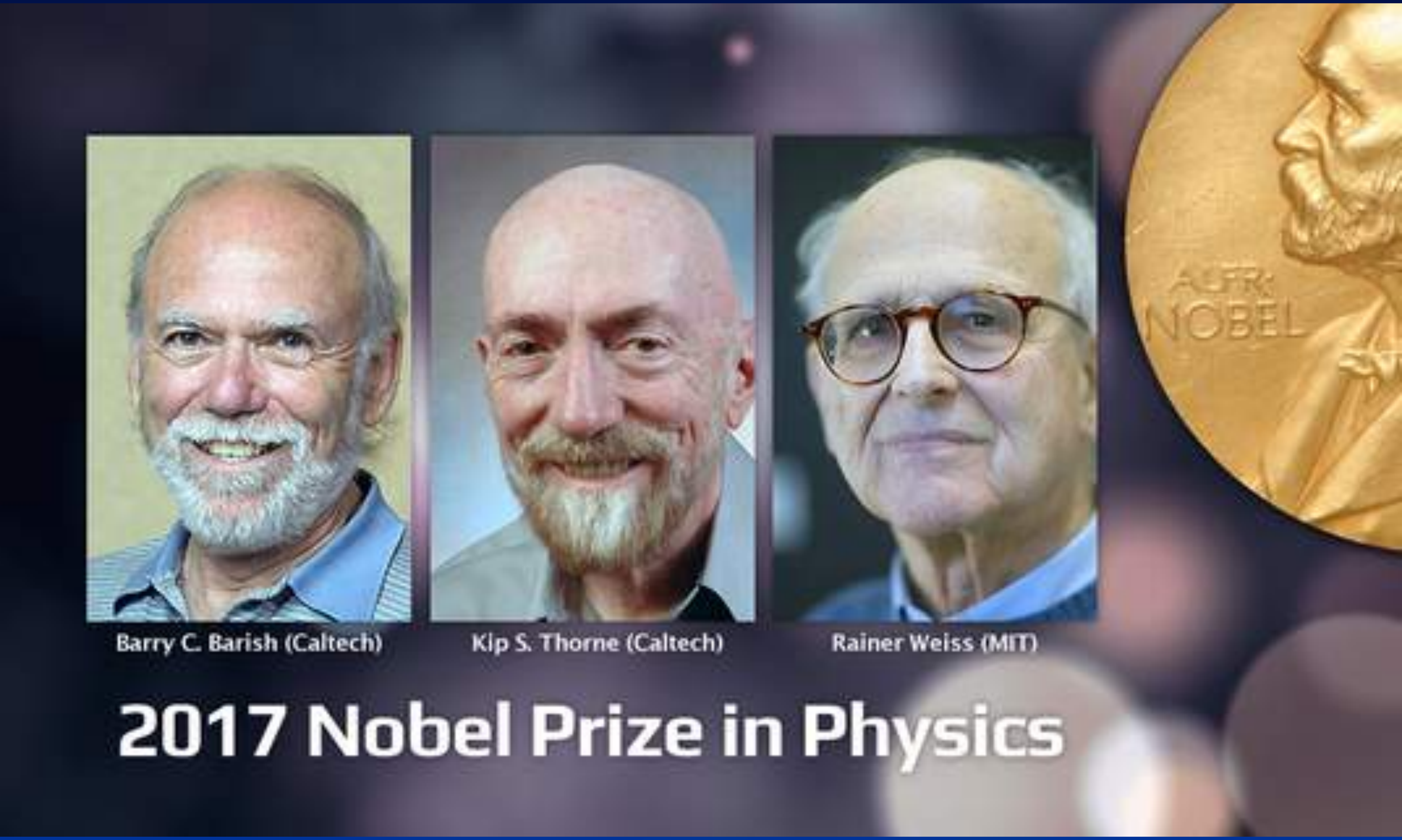
Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

Abstract

On 2017 August 17 a binary neutron star coalescence candidate (later designated GW170817) with merger time 12:41:04 UTC was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. The *Fermi* Gamma-ray Burst Monitor independently detected a gamma-ray burst (GRB 170817A) with a time delay of $\sim$1.7 s with respect to the merger time. From the gravitational-wave signal, the source was initially localized to a sky region of 31 deg^2 at a luminosity distance of 40^{+8}_{-8} Mpc and with component masses consistent with neutron stars. The component masses were later measured to be in the range 0.86 to 2.26 $M_\odot$. An extensive observing campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient (SSS17a, now with the IAU identification of AT 2017gfo) in NGC 4993 (at $\sim$40 Mpc) less than 11 hours after the merger by the One-Meter, Two Hemisphere (1M2H) team using the 1 m Swope Telescope. The optical transient was independently detected by multiple teams within an hour. Subsequent observations targeted the object and its environment. Early



NOBEL
Barry C. Barish (Caltech)
Kip S. Thorne (Caltech)
Rainer Weiss (MIT)
2017 Nobel Prize in Physics

Cryogenics 81 (2017) 83–92

Contents lists available at ScienceDirect

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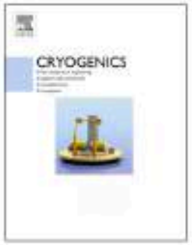
journal homepage: www.elsevier.com/locate/cryogenics



Research paper

Cryogenically cooled ultra low vibration silicon mirrors for gravitational wave observatories

Brett Shapiro [a,*], Rana X. Adhikari [b], Odylio Aguiar [c], Edgard Bonilla [a], Danyang Fan [a], Litawn Gan [a], Ian Gomez [a], Sanditi Khandelwal [a], Brian Lantz [a], Tim MacDonald [a], Dakota Madden-Fong [d]

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ABSTRACT

Interferometric gravitational wave observatories recently launched a new field of gravitational wave astronomy with the first detections of gravitational waves in 2015. The number and quality of these detections is limited in part by thermally induced vibrations in the mirrors, which show up as noise in these interferometers. One way to reduce this thermally induced noise is to use low temperature mirrors made of high purity single-crystalline silicon. However, these low temperatures must be achieved without increasing the mechanical vibration of the mirror surface or the vibration of any surface within close proximity to the mirrors. The vibration of either surface can impose a noise inducing phase shift on the light within the interferometer or physically push the mirror through oscillating radiation pressure. This paper proposes a system for the Laser Interferometric Gravitational-wave Observatory (LIGO) to achieve the dual goals of low temperature and low vibration to reduce the thermally induced noise in silicon mir-

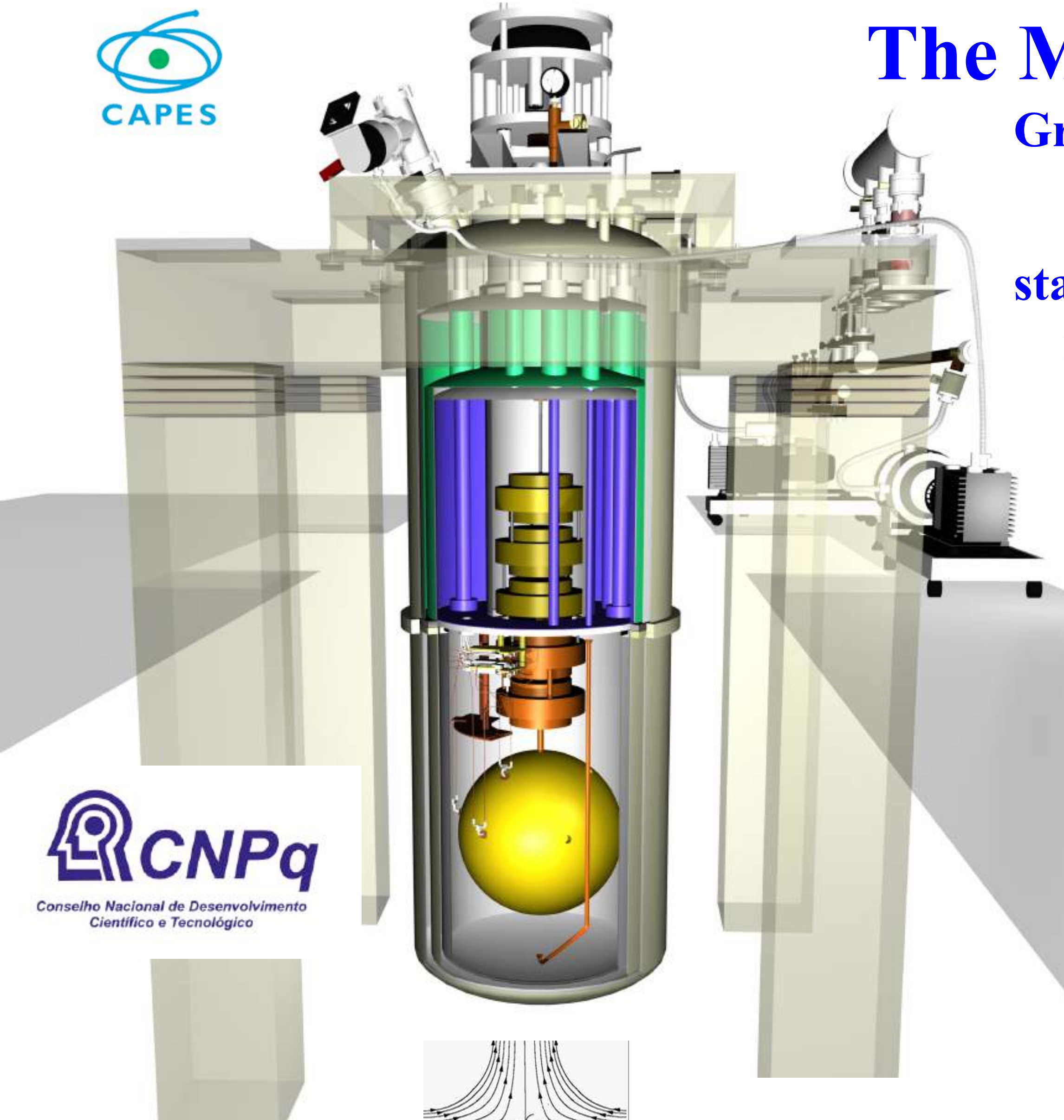
The Mario SCHENBERG

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



Amaldi 9 and NRDA 2011 IOP Publishing
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]

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[2] Universidade de São Paulo, Instituto de Física, São Paulo, SP, Brazil,
[3] Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil,
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[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 dAzur, Nice, France,
[16] Princeton University, Princeton, USA.

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

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[a] *ITA-Instituto Tecnológico de Aeronáutica, São José dos Campos SP, Brasil*

[b] *INPE-Instituto Nacional de Pesquisas Espaciais, São José dos Campos SP, Brasil*

[c] *UFRB-Universidade Federal do Recôncavo da Bahia, Cruz das Almas BA, Brasil*

E-mail: vliccardo@ita.br, ekfranca@gmail.com

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

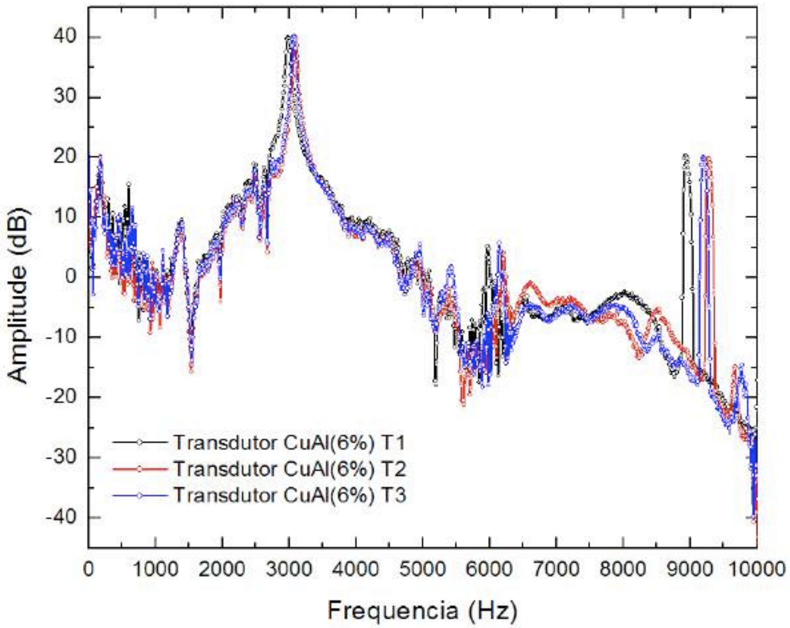
2016 JINST 11

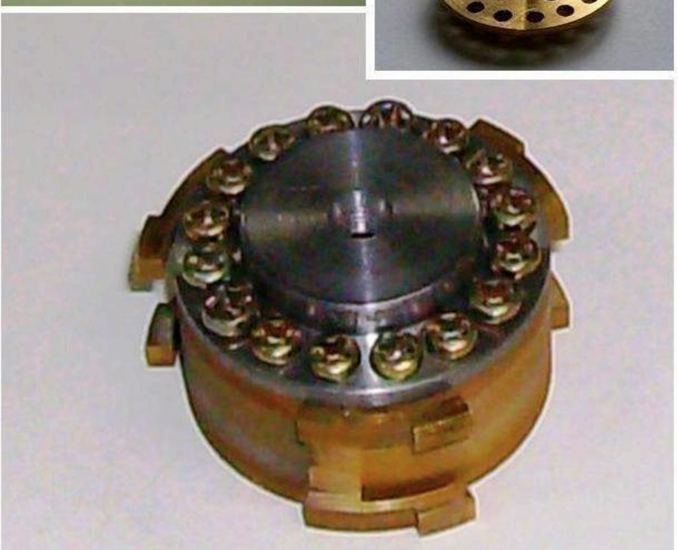
The three initial transducers:

$Q_e \sim 10^4$

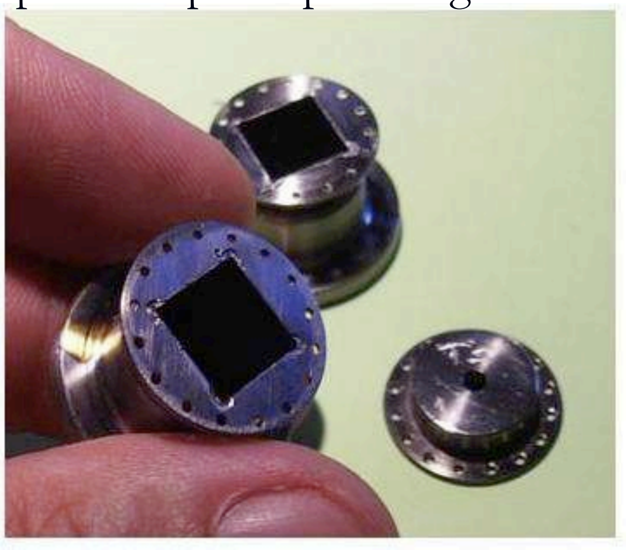
First design

Medidas das frequências de ressonância mecânica de três transdutores.

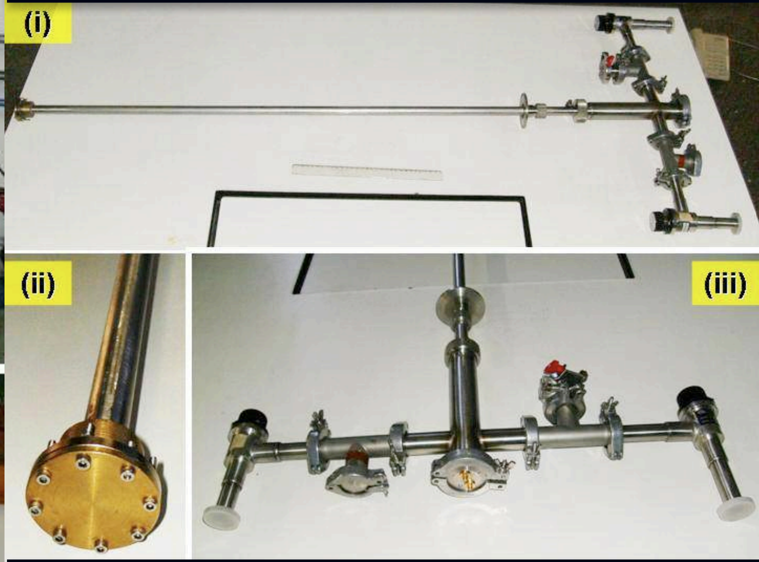




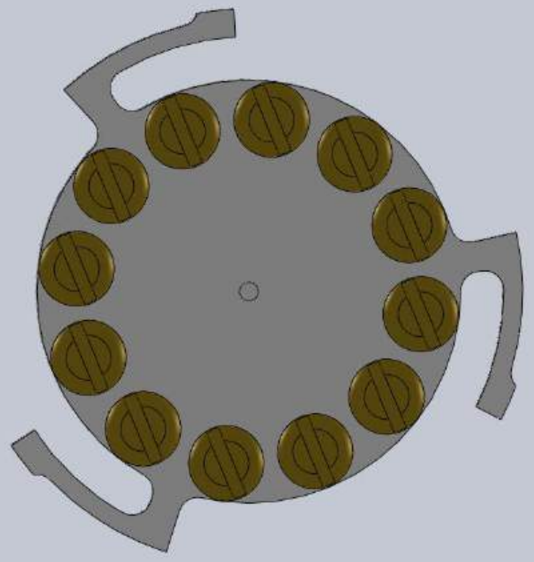
Membranas silício com nióbio depositado por “sputtering”.



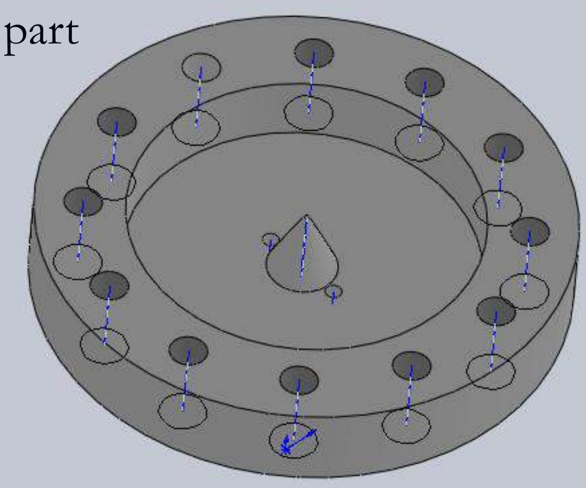
Foram medidos fatores de qualidade elétrica (Q_e) de várias cavidades reentrantes supercondutoras a 4.2 K, utilizando um "dewar" refrigerado a hélio líquido. Q_e tão altos quanto 300 k foram encontrados.



Aparato experimental para testar cavidades reentrantes supercondutoras dentro de um "dewar" refrigerado a hélio líquido.

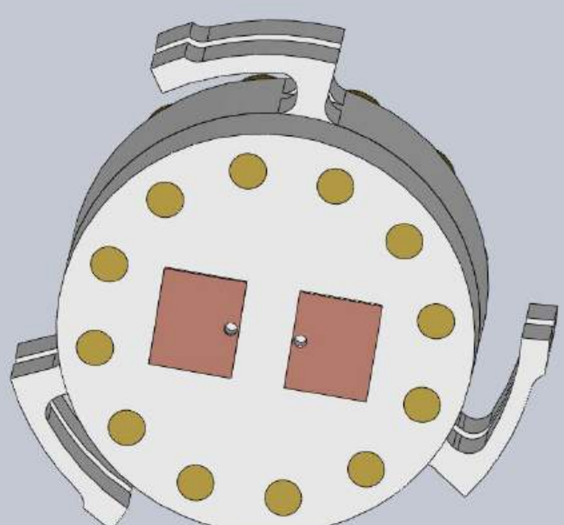


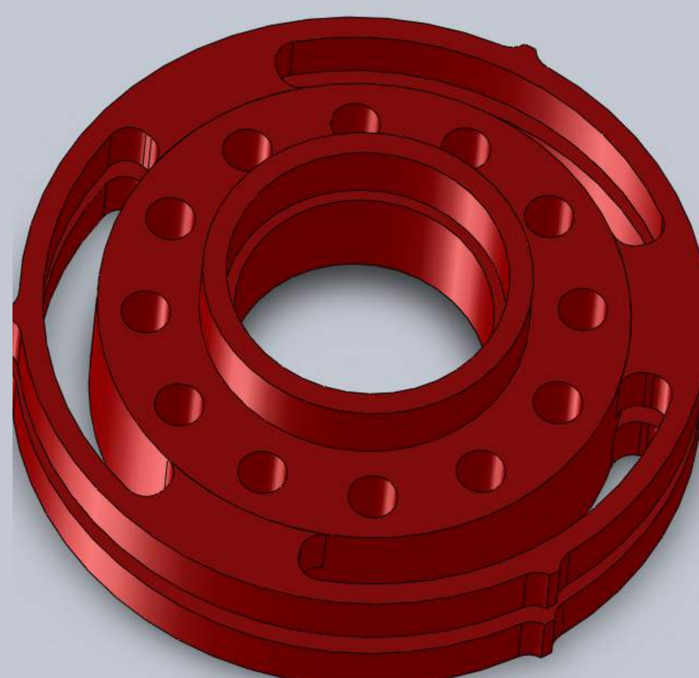
Alumina part



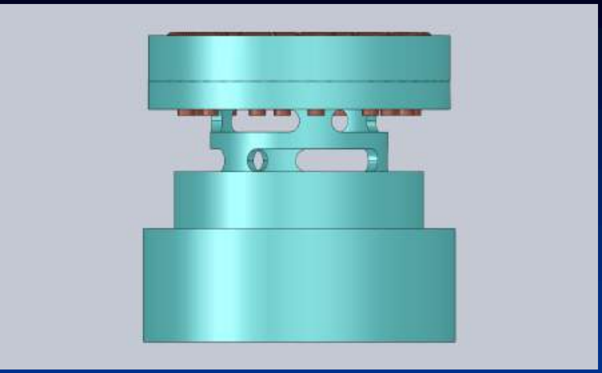
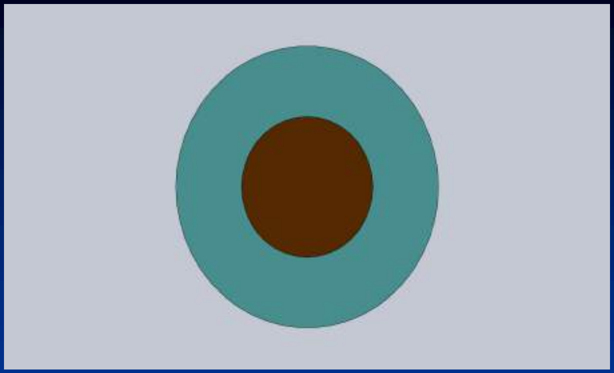
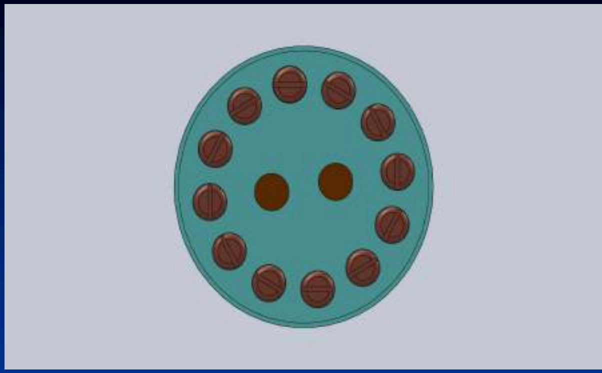
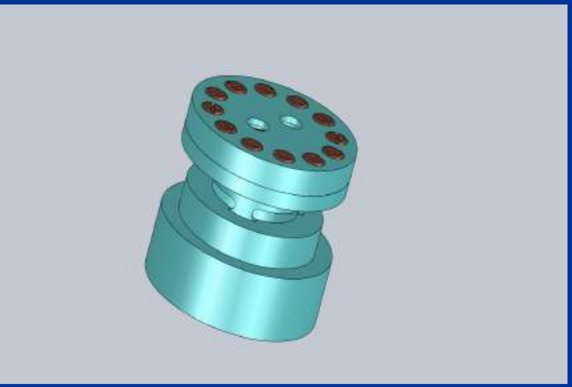
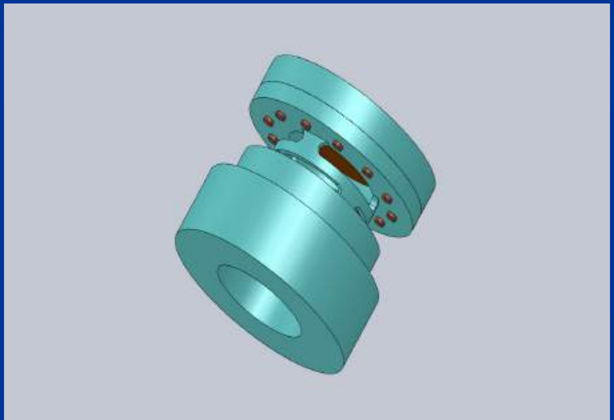
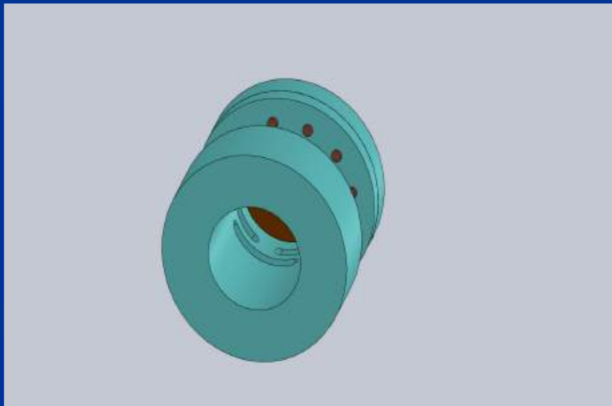
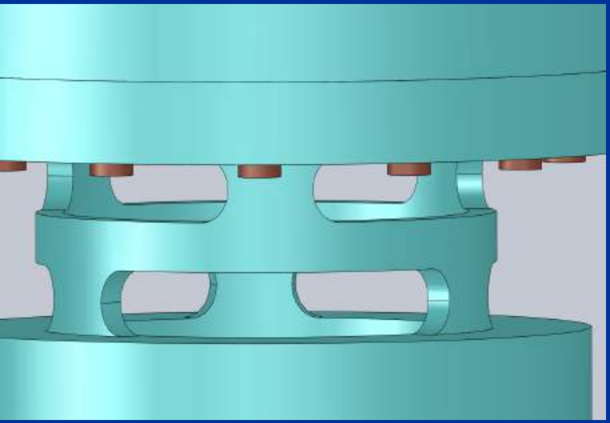
Fourth design

Third design

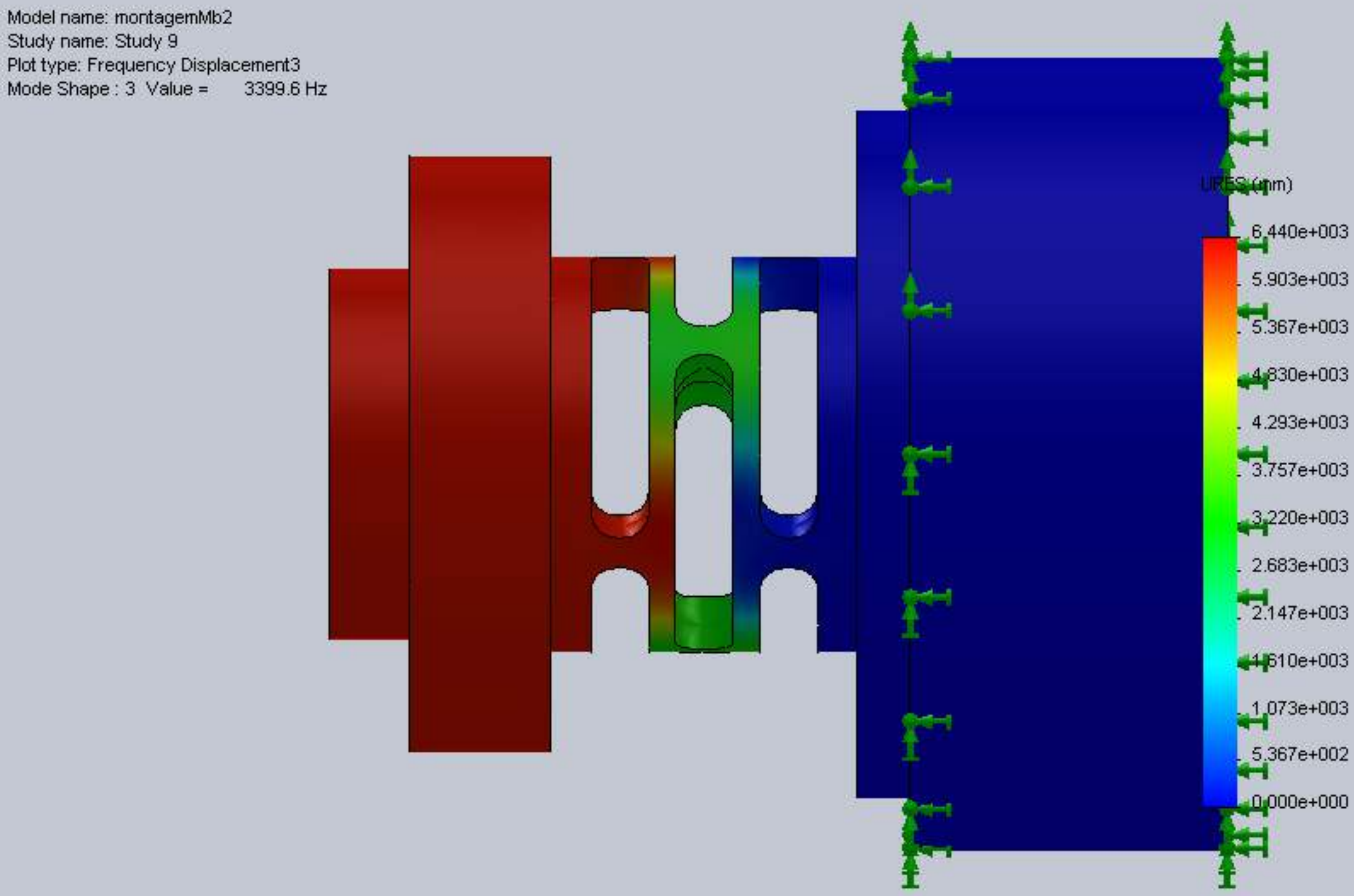




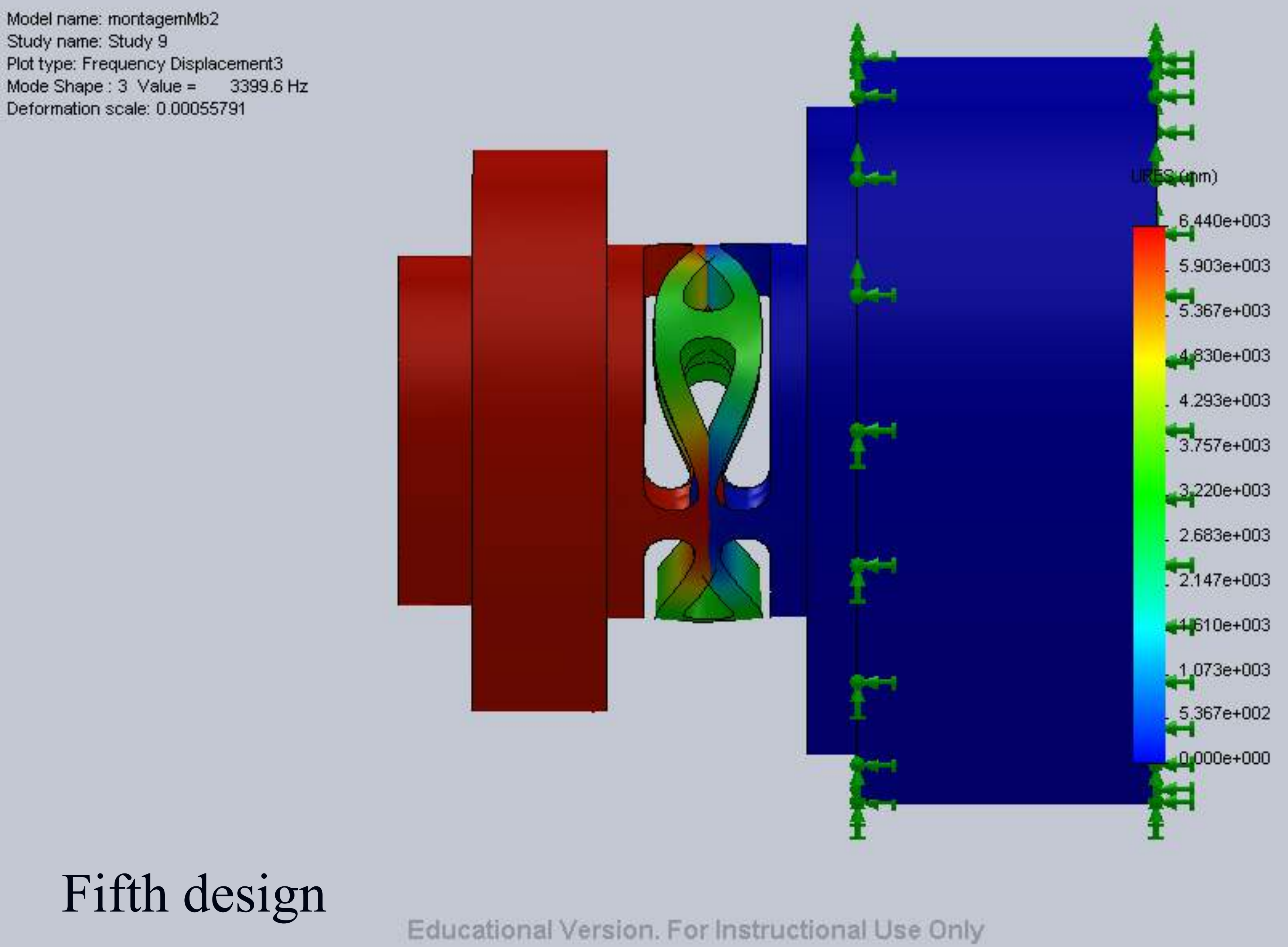
Niobium part

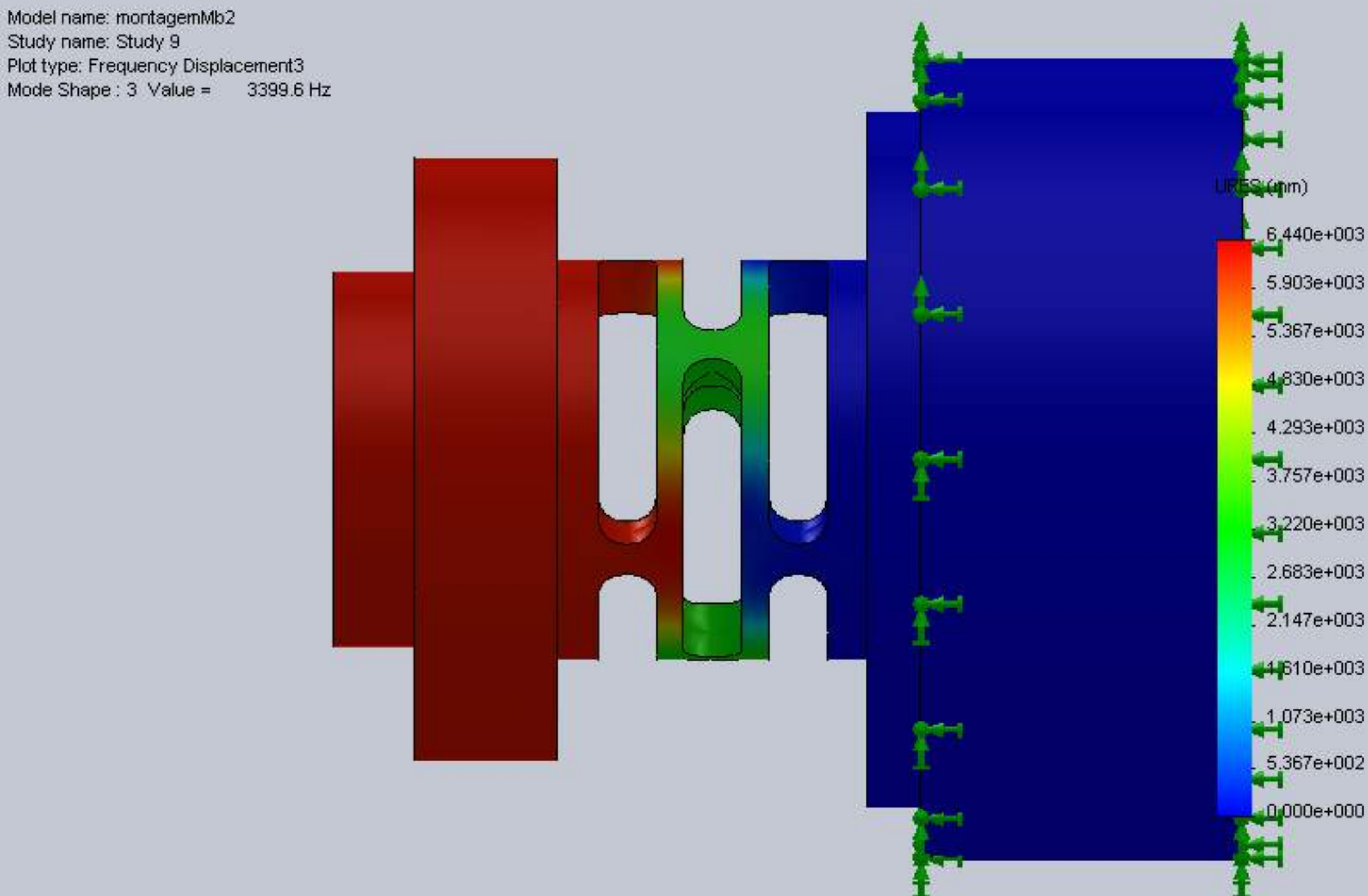
Fifth design



Fifth design

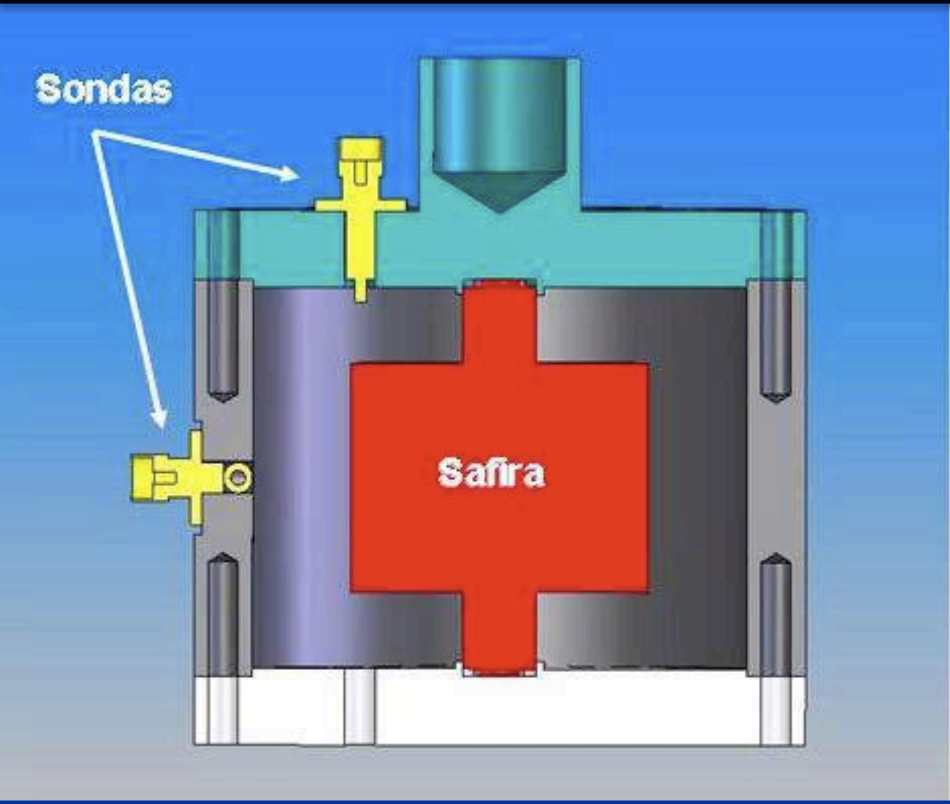


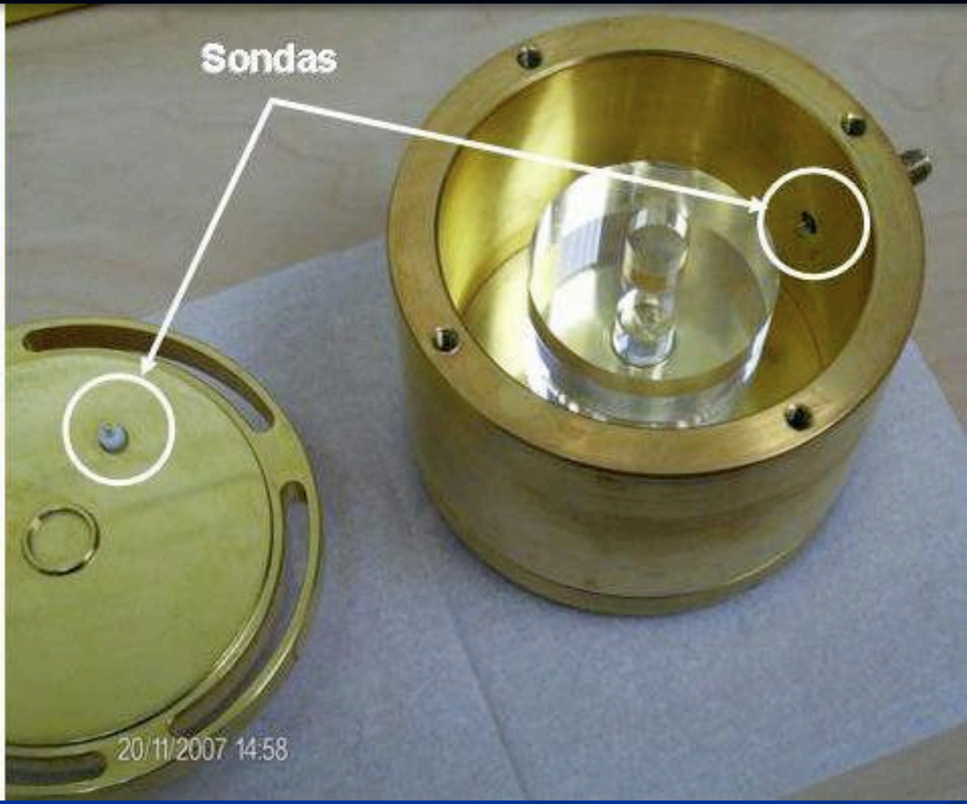
Fifth design



Fifth design

Desenvolvemos, em colaboração com o grupo australiano, um oscilador de safira que opera a 77 K e vai substituir, com melhor desempenho, os de titanato de bário atualmente utilizados.

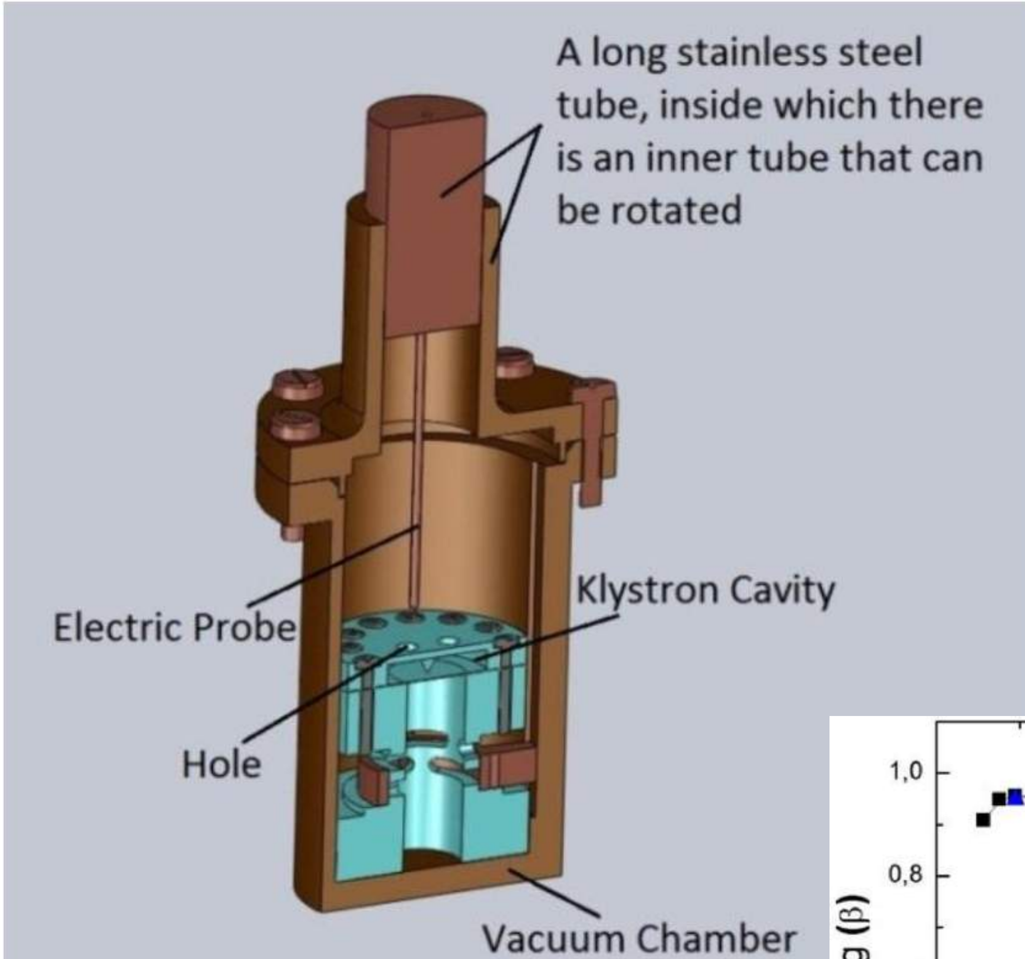


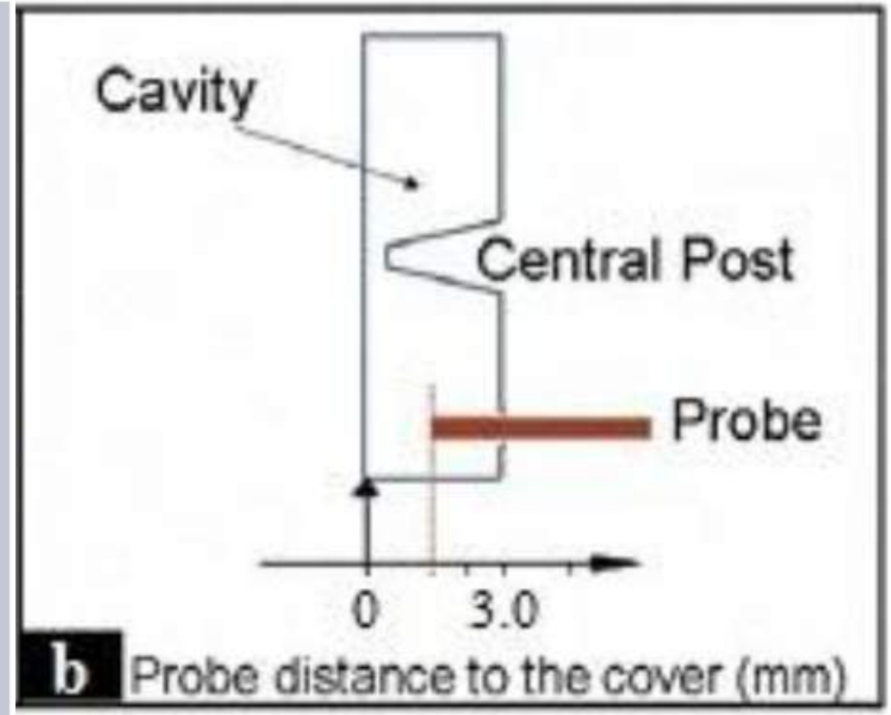


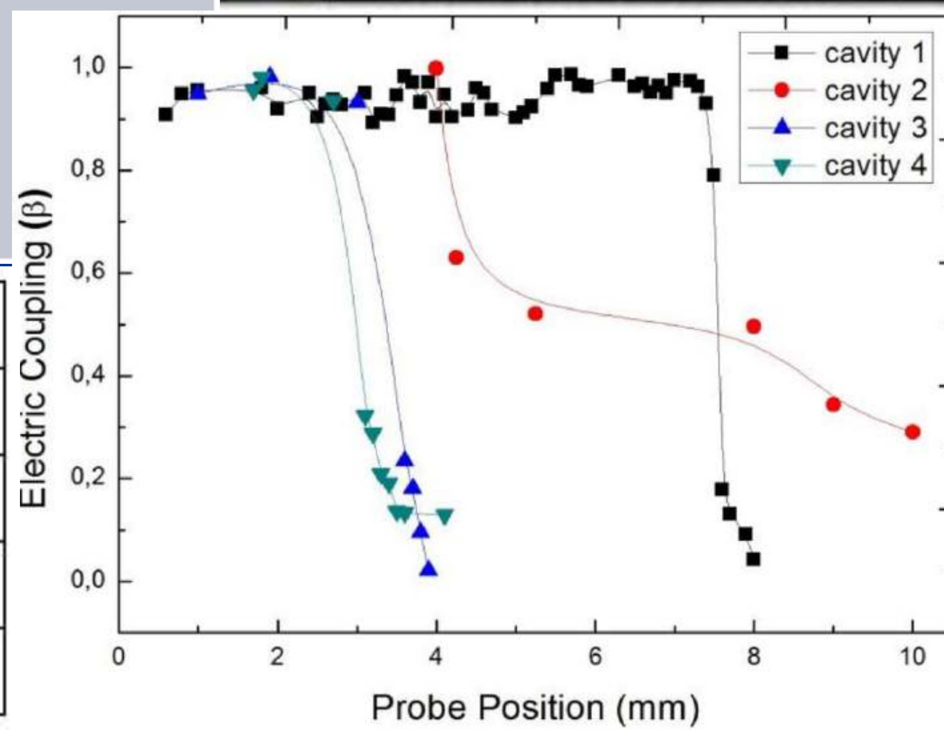
Montagem de transdutores em sala limpa do INPE


CRYOMECH
CRYOMECH
NON-MAG ETIC


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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E-mail: leandroifusp@yahoo.com

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**

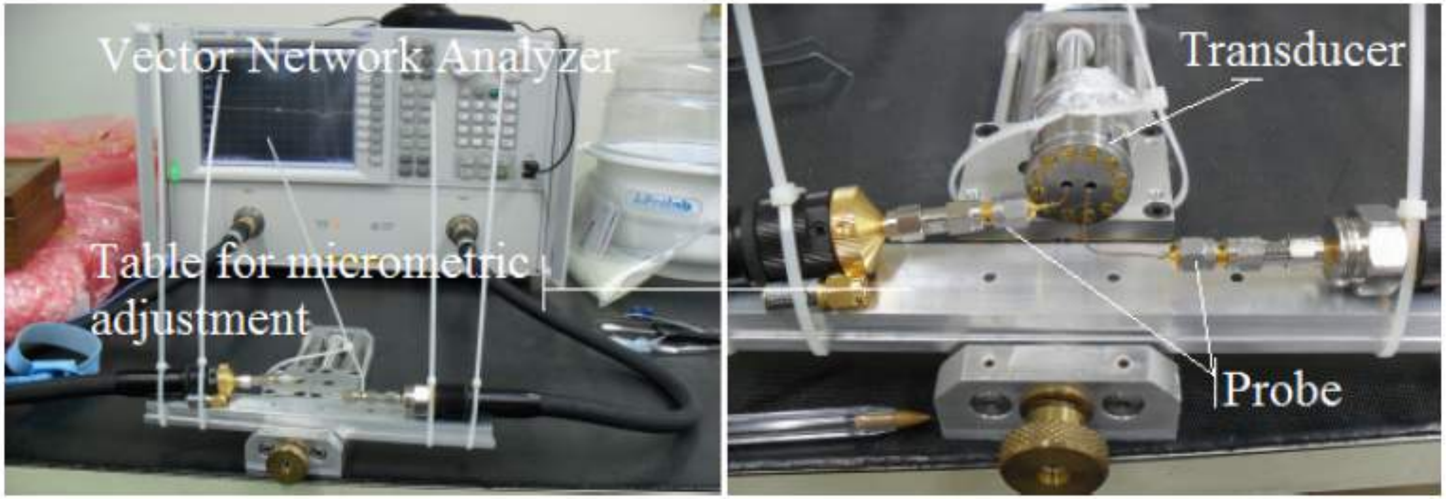


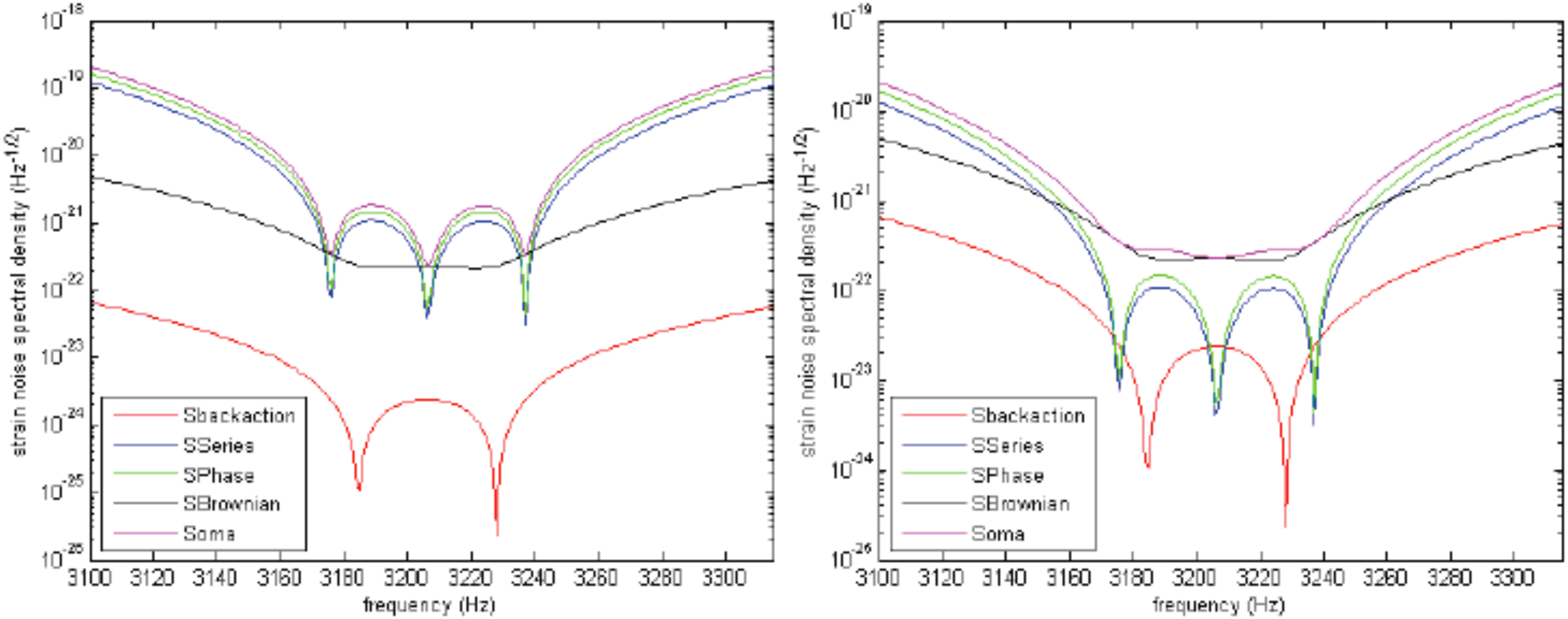
Figure 4. Frequency measurements in the vector network analyzer. The measurements were accomplished by transmission by inserting two probes into the cavity. A table for micrometric adjustment was also used in order to improve the accuracy in the probe position.


A antena no sítio de São Paulo durante as corridas em 2015
h~10-20 Hz-1/2

A esfera sendo removida do sítio do IFUSP em 2016

E colocada em caminhão do INPE para transporte até São José dos Campos

O Schenberg está sendo transferido para o INPE



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 $30\,\mu$m ($80\,$MHz/μm) and $3\,\mu$m ($800\,$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.

Projeto dentro da colaboração científica LIGO (LSC)

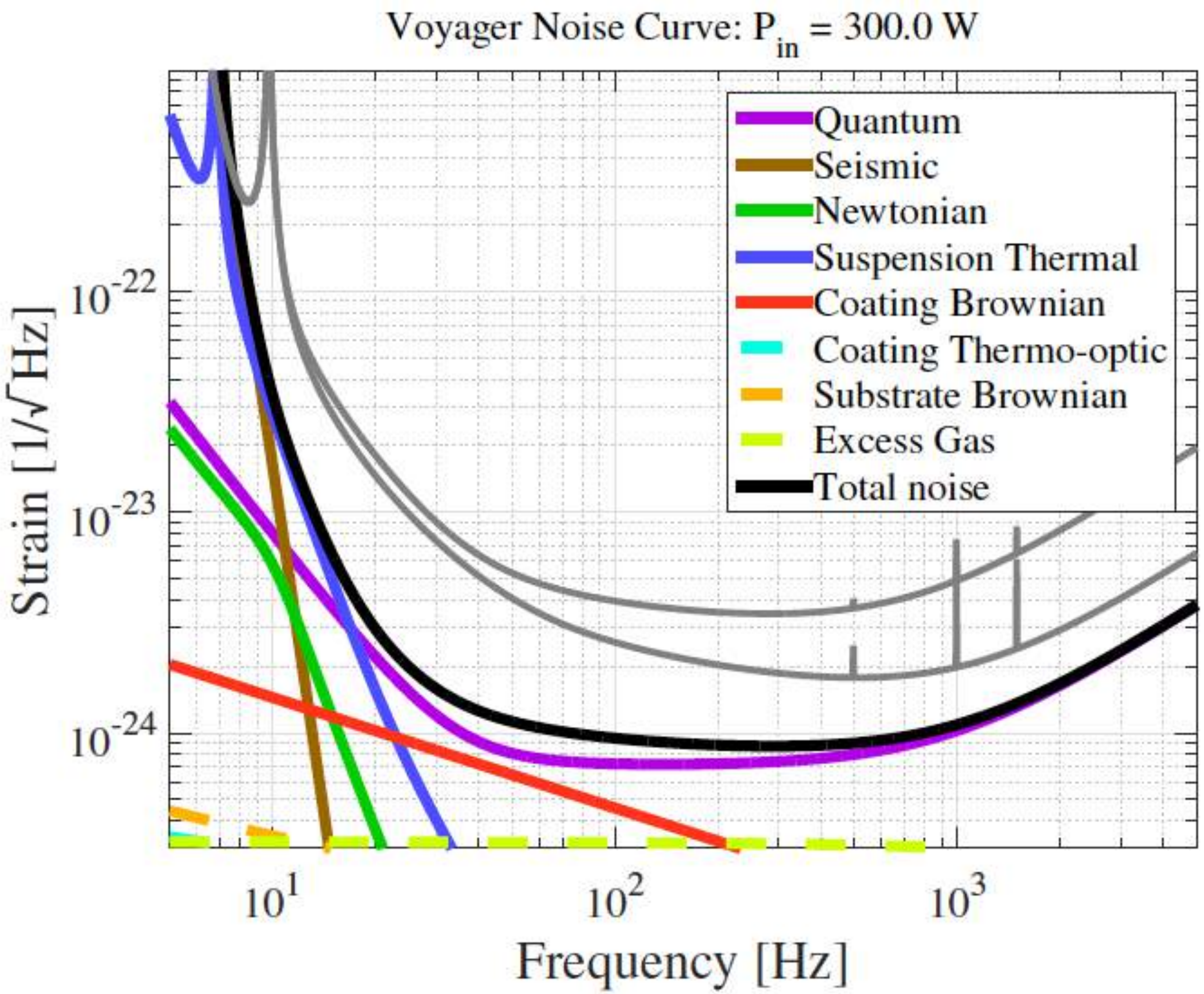
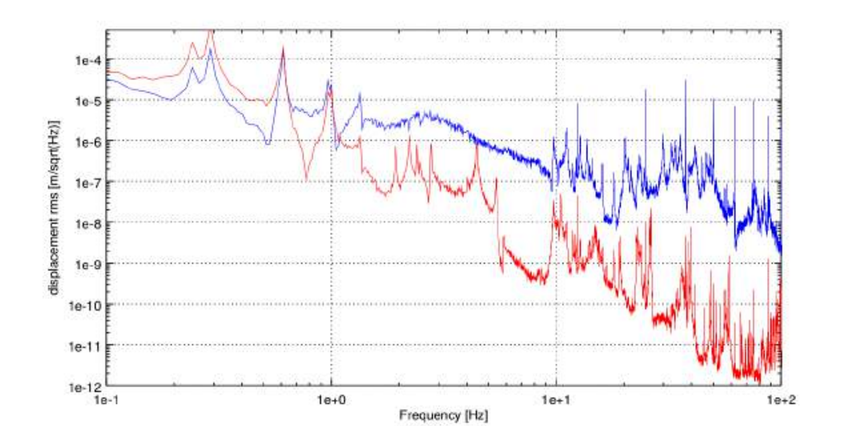
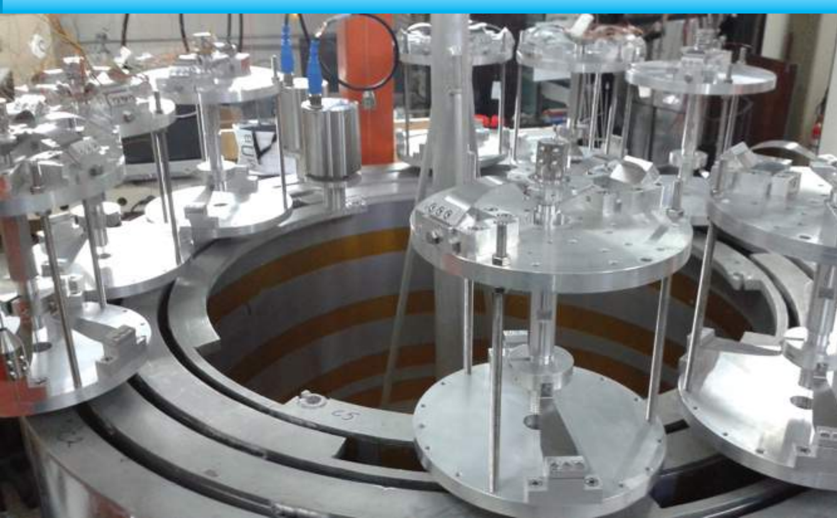
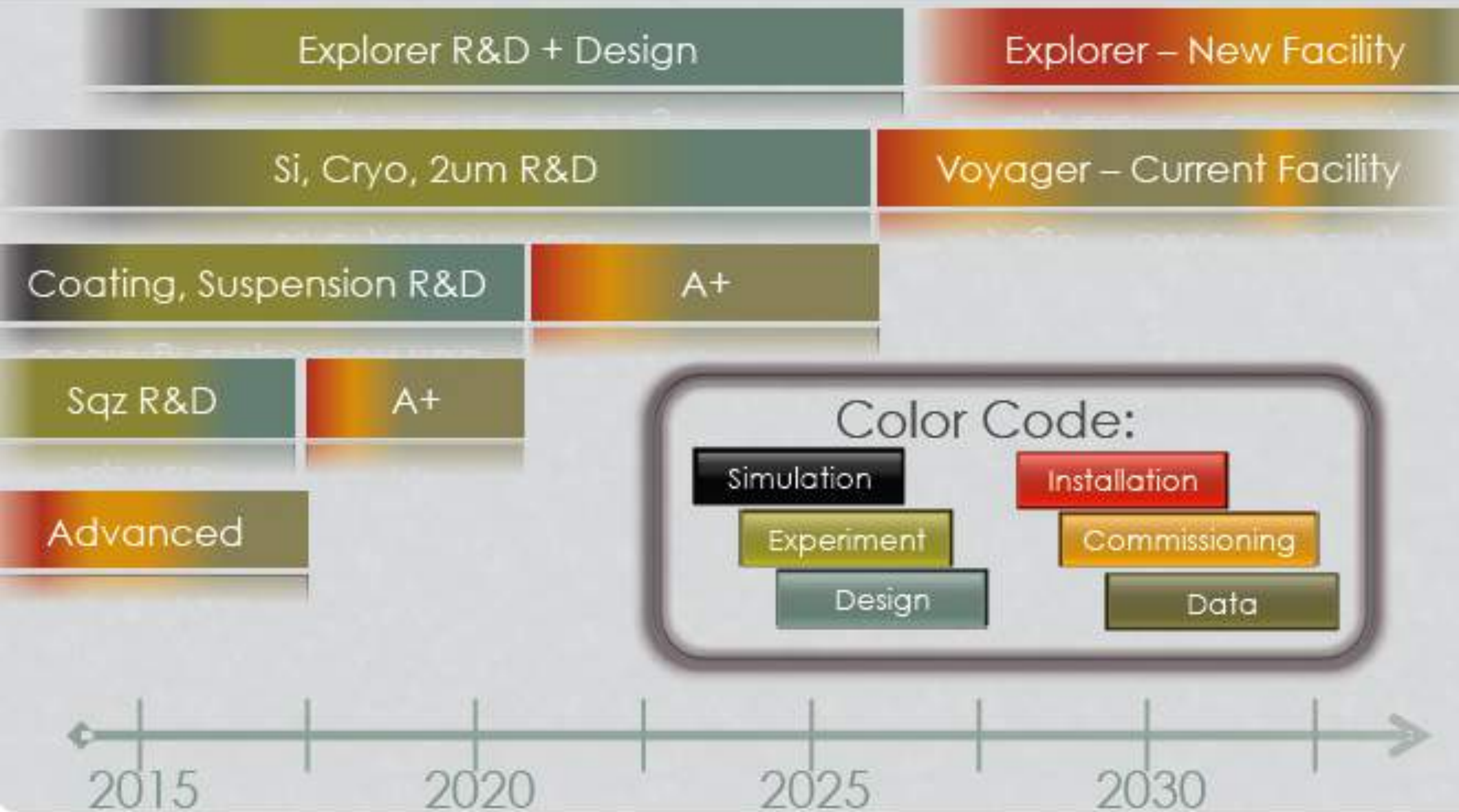


Figure 4: Conceptual noise budget for Voyager (BNS range of 1.3 Gpc). The technology assumed for these curves includes cryogenic operation at 123K, silicon optics, AlGaAs coatings, and 1550nm laser wavelength, and 8dB of frequency dependent squeezing. The Advanced LIGO and A+ sensitivities are shown in gray for reference.



displacement rms [m/sqrt(Hz)]
1e-4
1e-5
1e-6
1e-7
1e-8
1e-9
1e-10
1e-11
1e-12
1e-1
1e+0
1e+1
1e+2
Frequency [Hz]

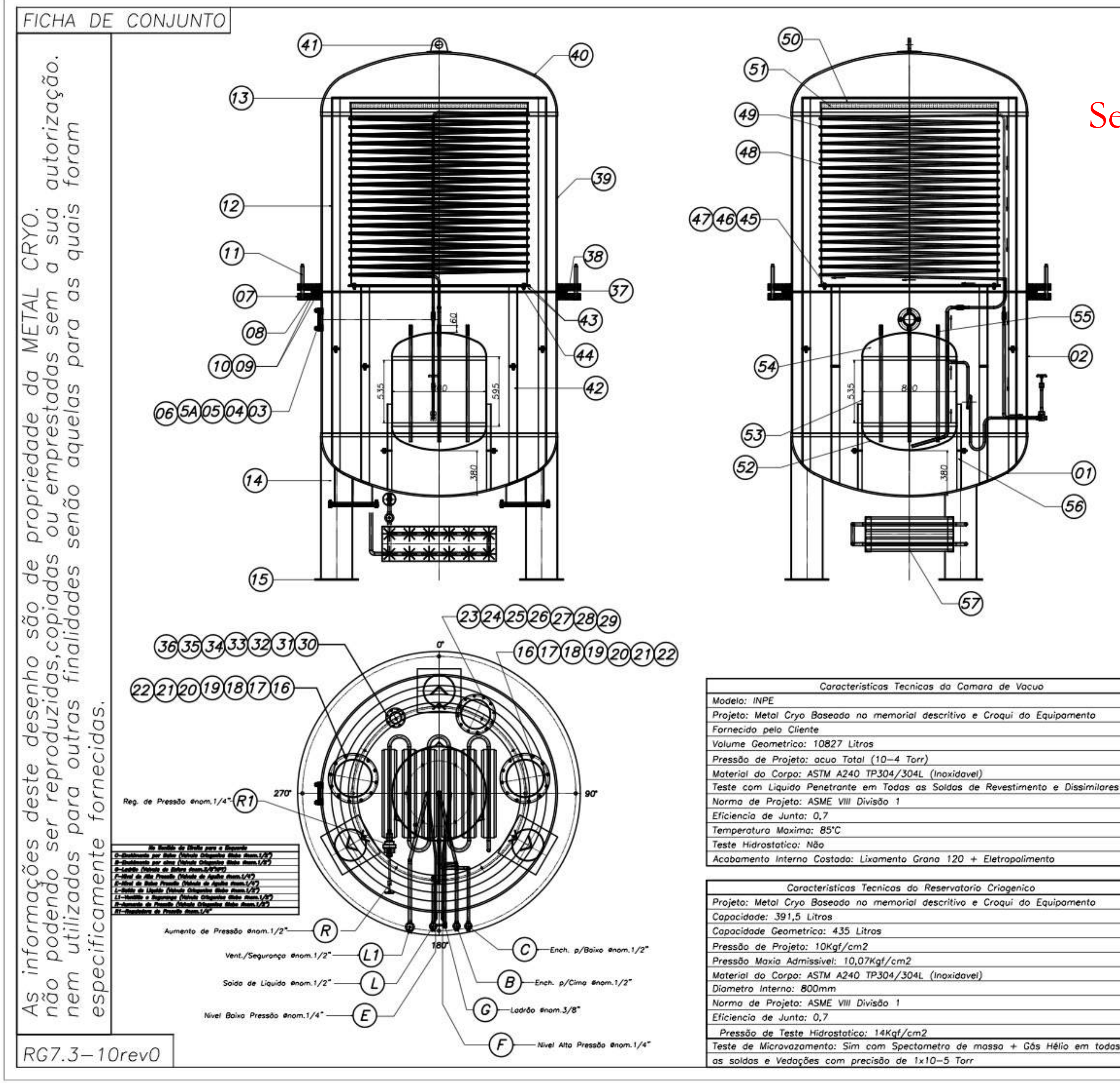


LIGO Upgrade Timeline



In order to do measurements in vacuum and at low temperatures, we ordered a special chamber for these purpose .

See LIGO doc T1600201



Caracteristicas Tecnicas da Camara de Vacuo
Modelo: INPE
Projeto: Metal Cryo Baseado no memorial descritivo e Croqui do Equipamento
Fornecido pelo Cliente
Volume Geometrico: 10827 Litros
Pressão de Projeto: acuo Total (10–4 Torr)
Material do Corpo: ASTM A240 TP304/304L (Inoxidavel)
Teste com Liquido Penetrante em Todas as Soldas de Revestimento e Dissimilares
Norma de Projeto: ASME VIII Divisão 1
Eficiencia de Junta: 0,7
Temperatura Maxima: 85°C
Teste Hidrostatico: Não
Acabamento Interno Costado: Lixamento Grana 120 + Eletropolimento

Caracteristicas Tecnicas do Reservatorio Criogenico
Projeto: Metal Cryo Baseado no memorial descritivo e Croqui do Equipamento
Capacidade: 391,5 Litros
Capacidade Geometrica: 435 Litros
Pressão de Projeto: 10Kgf/cm2
Pressão Maxia Admissivel: 10,07Kgf/cm2
Material do Corpo: ASTM A240 TP304/304L (Inoxidavel)
Diametro Interno: 800mm
Norma de Projeto: ASME VIII Divisão 1
Eficiencia de Junta: 0,7
Pressão de Teste Hidrostatico: 14Kgf/cm2
Teste de Microvazamento: Sim com Spectometro de massa + Gás Hélio em todas as soldas e Vedações com precisão de 1x10–5 Torr

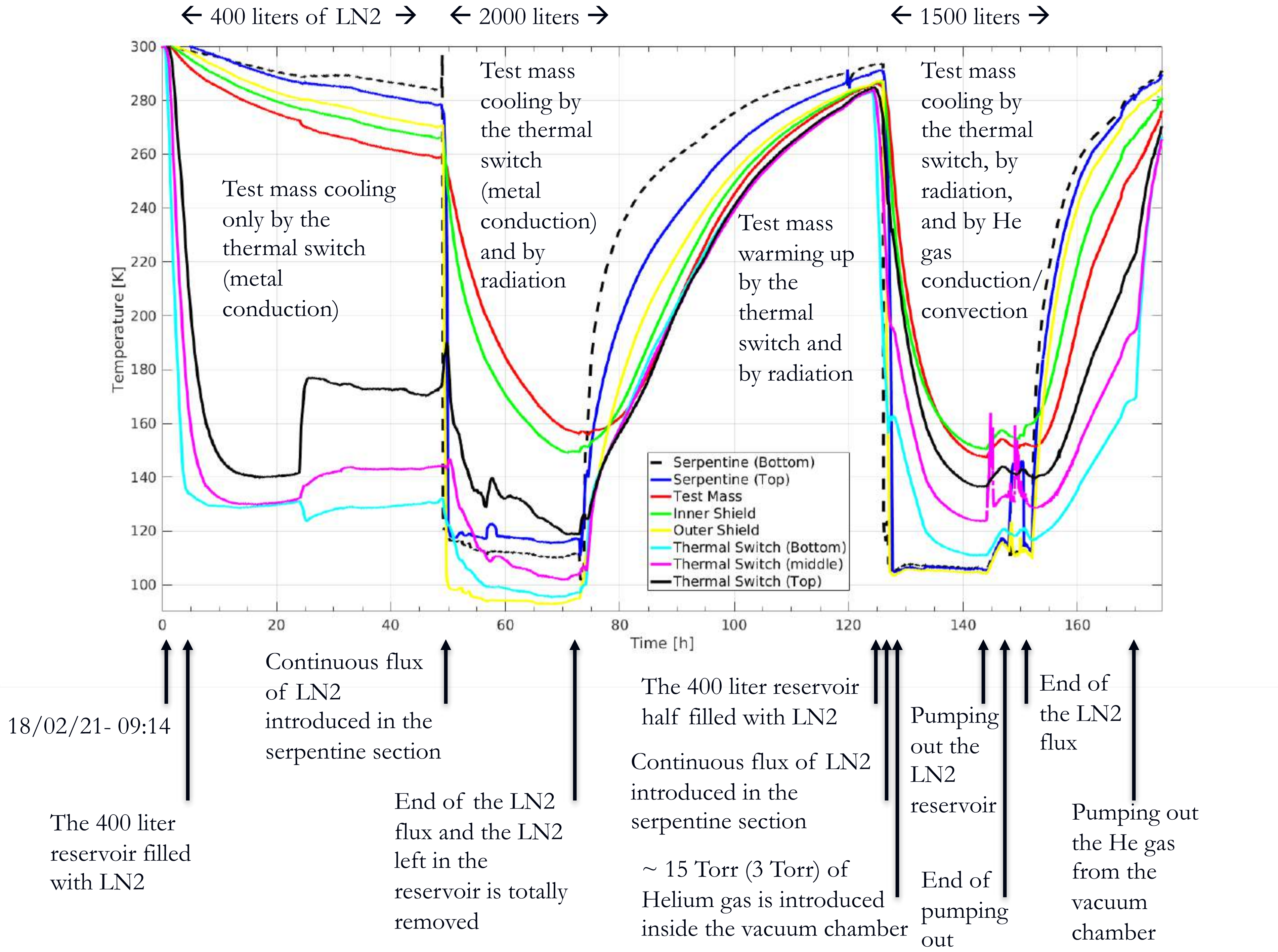
A large vacuum chamber (4.5 meters of height and 2 meters of diameter), which will be used for vacuum and low temperature tests of the MNP system and test of other alternative systems for cooling LIGO Voyager mirrors. A blue print of this chamber is shown here. The total cost of this chamber was around 200,000 US dollars, paid by the Brazilian Ministry of Science, Technology, and Innovation.


Concha inferior
Concha superior
Válvulas de controle
Serpentina de cobre


Estrutura para suspensão de cargas
Reservatório de LN2

Modelos do LIGO Voyager em escala de 1:1 podem ser testados nesta câmara

The serpentine section has Kapton tape in the inside and superinsulation at the outside in order to improve the radiative heat transfer to the experiment and better thermally insulate it from the chamber walls, which are at ~300K.

← 400 liters of LN2 →
← 2000 liters →
← 1500 liters →
Test mass cooling only by the thermal switch (metal conduction)
Test mass cooling by the thermal switch (metal conduction) and by radiation
Test mass warming up by the thermal switch and by radiation
Test mass cooling by the thermal switch, by radiation, and by He gas conduction/ convection
Temperature [K]
Time [h]
Serpentine (Bottom)
Serpentine (Top)
Test Mass
Inner Shield
Outer Shield
Thermal Switch (Bottom)
Thermal Switch (middle)
Thermal Switch (Top)
18/02/21- 09:14
The 400 liter reservoir filled with LN2
Continuous flux of LN2 introduced in the serpentine section
End of the LN2 flux and the LN2 left in the reservoir is totally removed
The 400 liter reservoir half filled with LN2
Continuous flux of LN2 introduced in the serpentine section
~ 15 Torr (3 Torr) of Helium gas is introduced inside the vacuum chamber
Pumping out the LN2 reservoir
End of pumping out
End of the LN2 flux
Pumping out the He gas from the vacuum chamber

We ran the experiment with a ~6,000 liter external tank supplying the LN2.

Publicações da CEA em revistas científicas em 2017:

136 publicações em revistas científicas,

das quais **31 (23%)** foram do grupo experimental de ondas gravitacionais, graças a participação dele na LSC.

Junte-se a nós
para
participar de novas descobertas revolucionárias na astrofísica utilizando ondas gravitacionais