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The Brazilian Gravitational Wave Detector Mario Schenberg: Progress and Plans

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INPE / BRAZIL

THE SCHENBERG COLLABORATION

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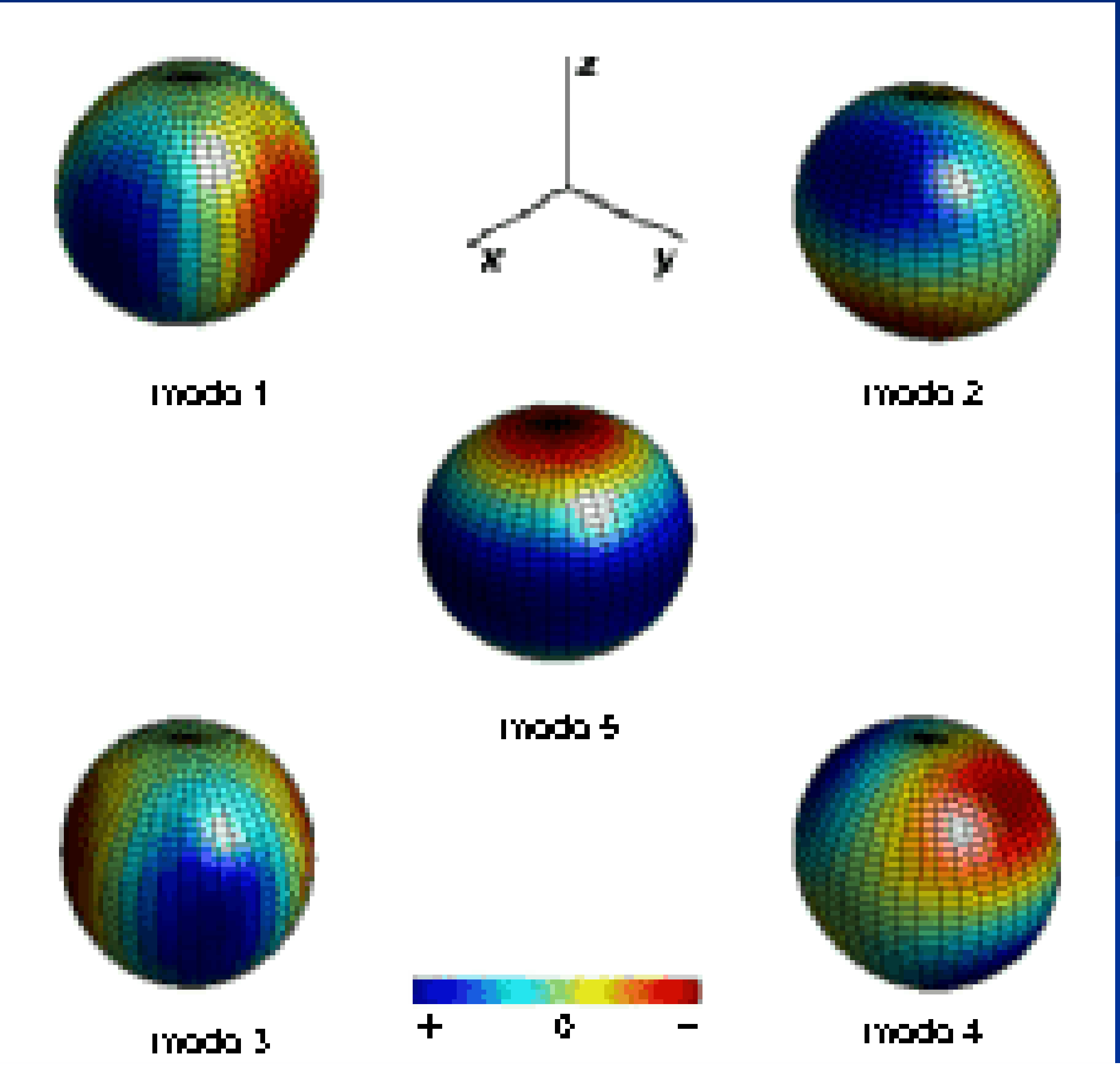
MiniGRAIL (Netherlands)

SFERA (Italy)

Mario SCHENBERG (Brazil)

Antenna quadrupole modes



From the output of 6 transducers tuned to the antenna quadrupole modes

$$\Psi(\theta, \phi, \omega) = \sum_{i}^{5} a_i(\omega)\, \Psi_i(\theta, \phi)$$

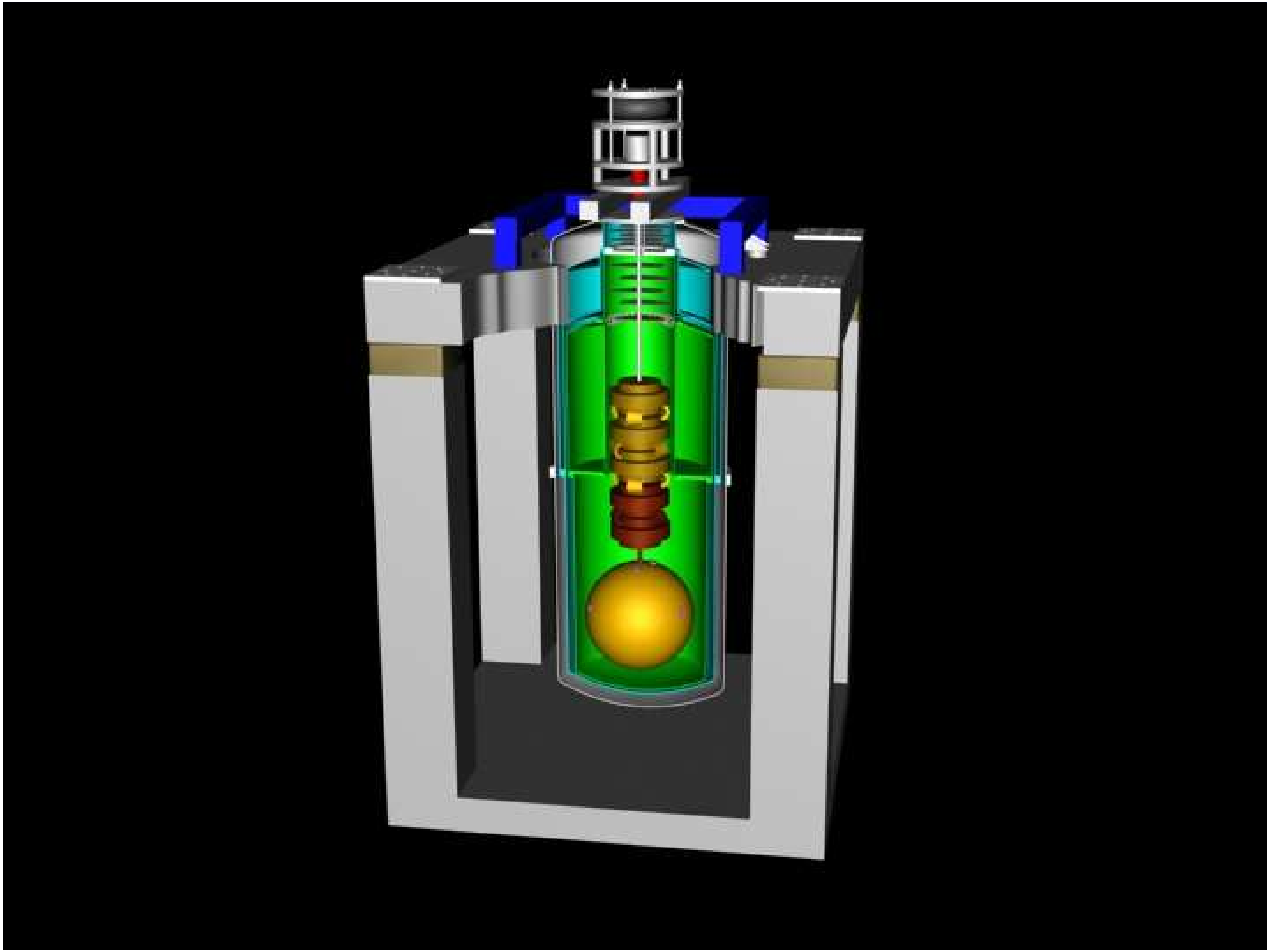
spherical harmonics

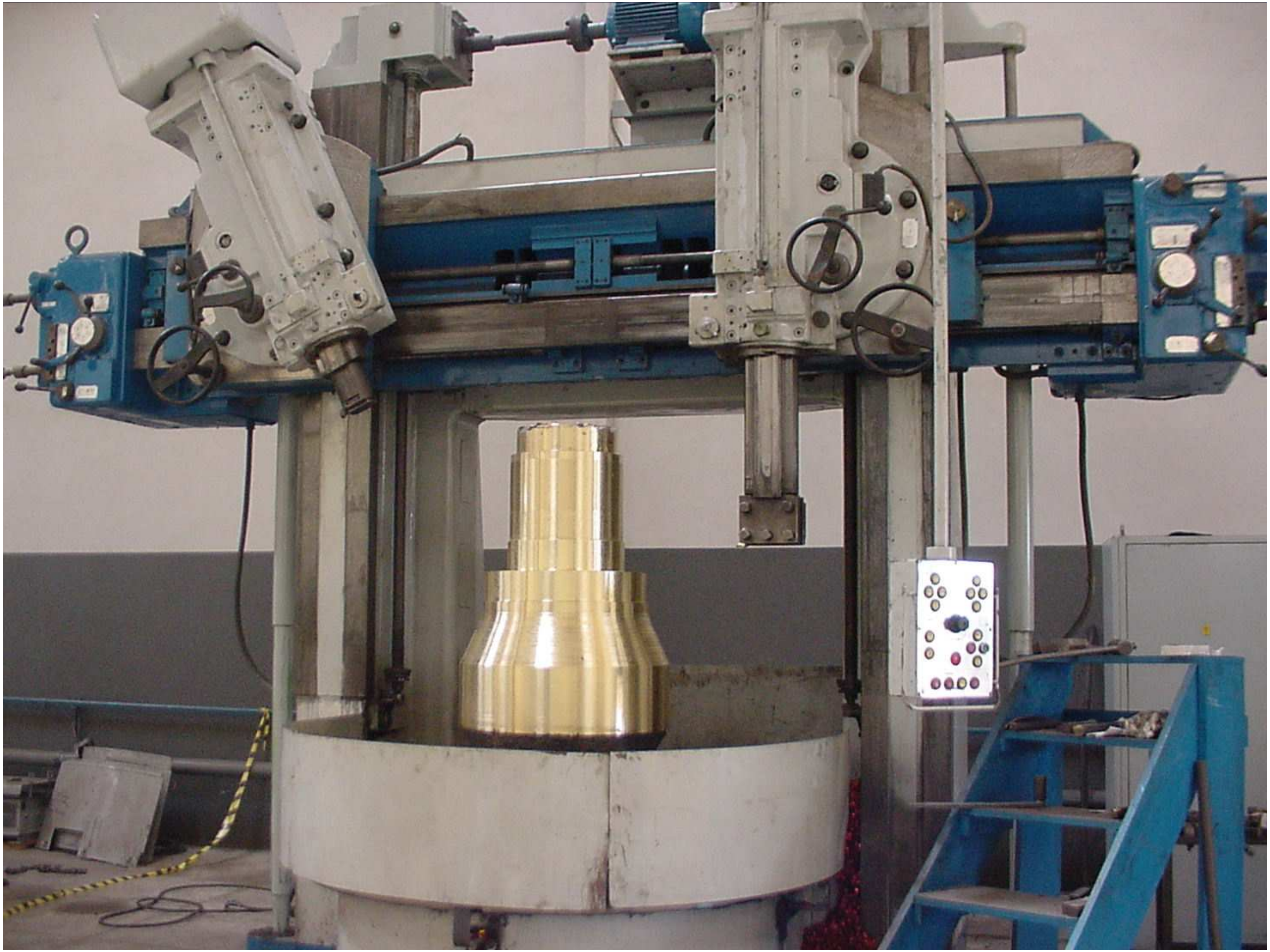
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

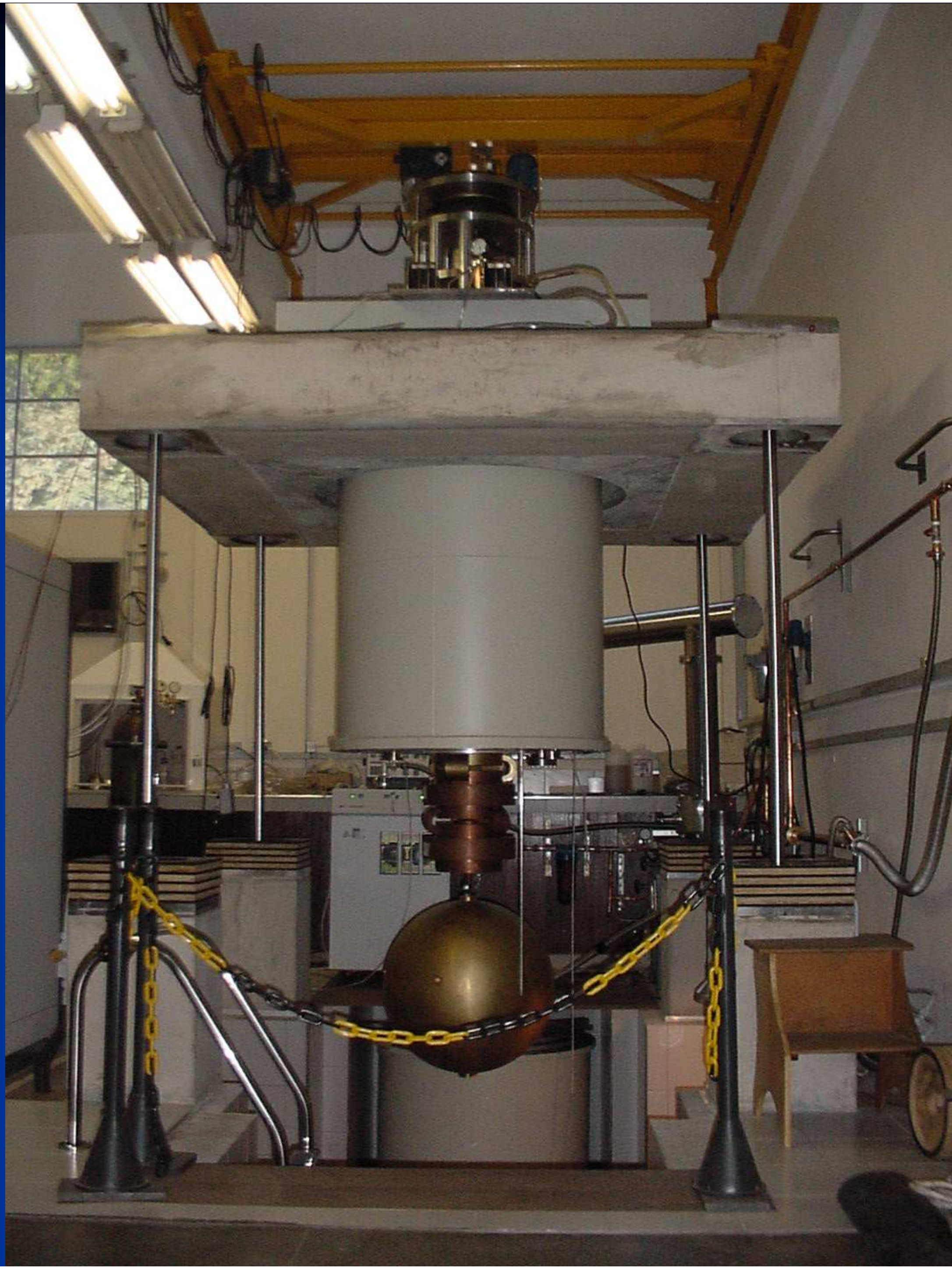
$$h_{xx} + h_{yy} + h_{zz} = 0$$

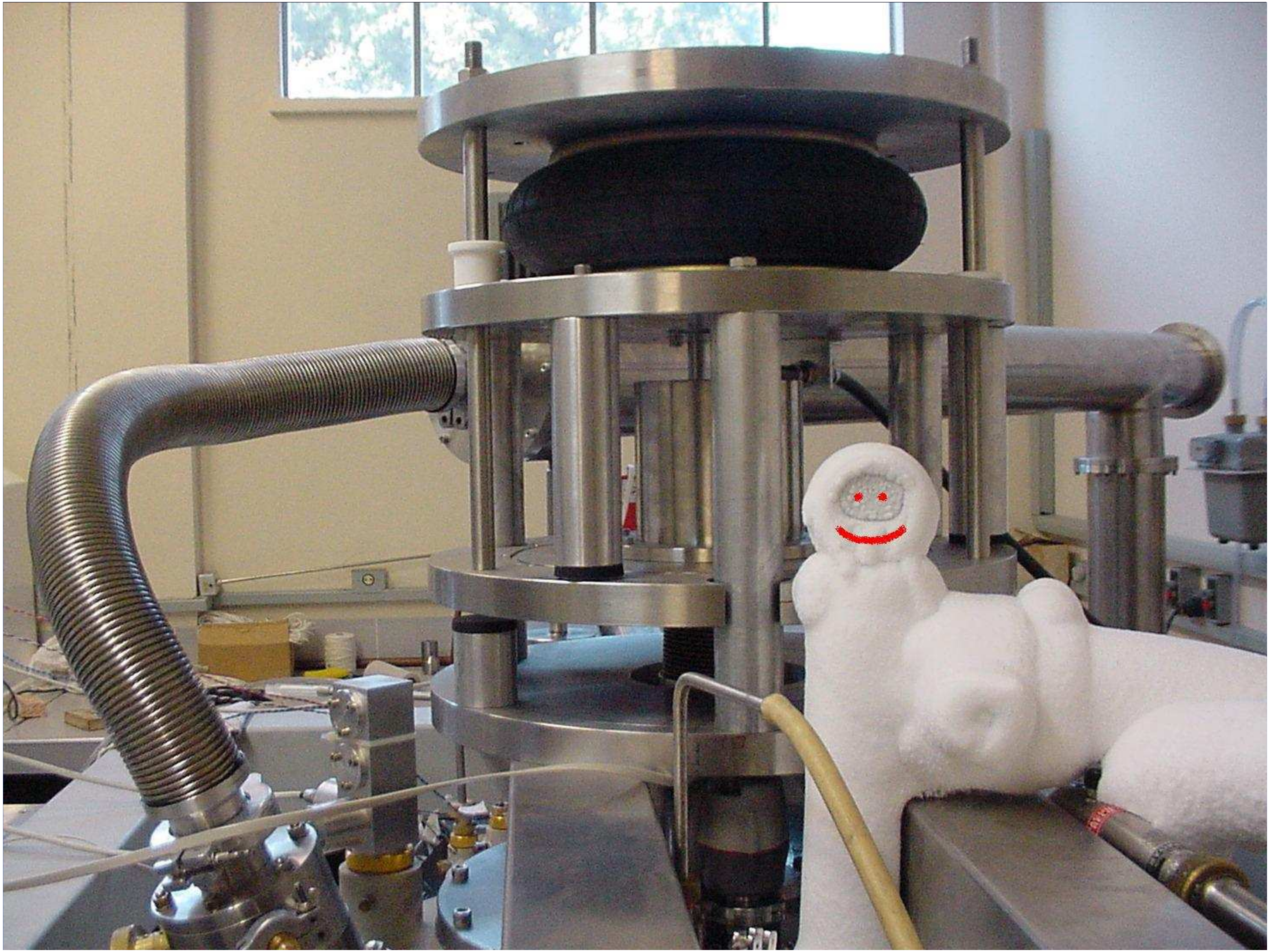
$$\mathrm{Ih} = \begin{bmatrix} h_{xx} & h_{xy} & h_{xz} \\ h_{yx} & h_{yy} & h_{yz} \\ h_{zx} & h_{zy} & h_{zz} \end{bmatrix}$$

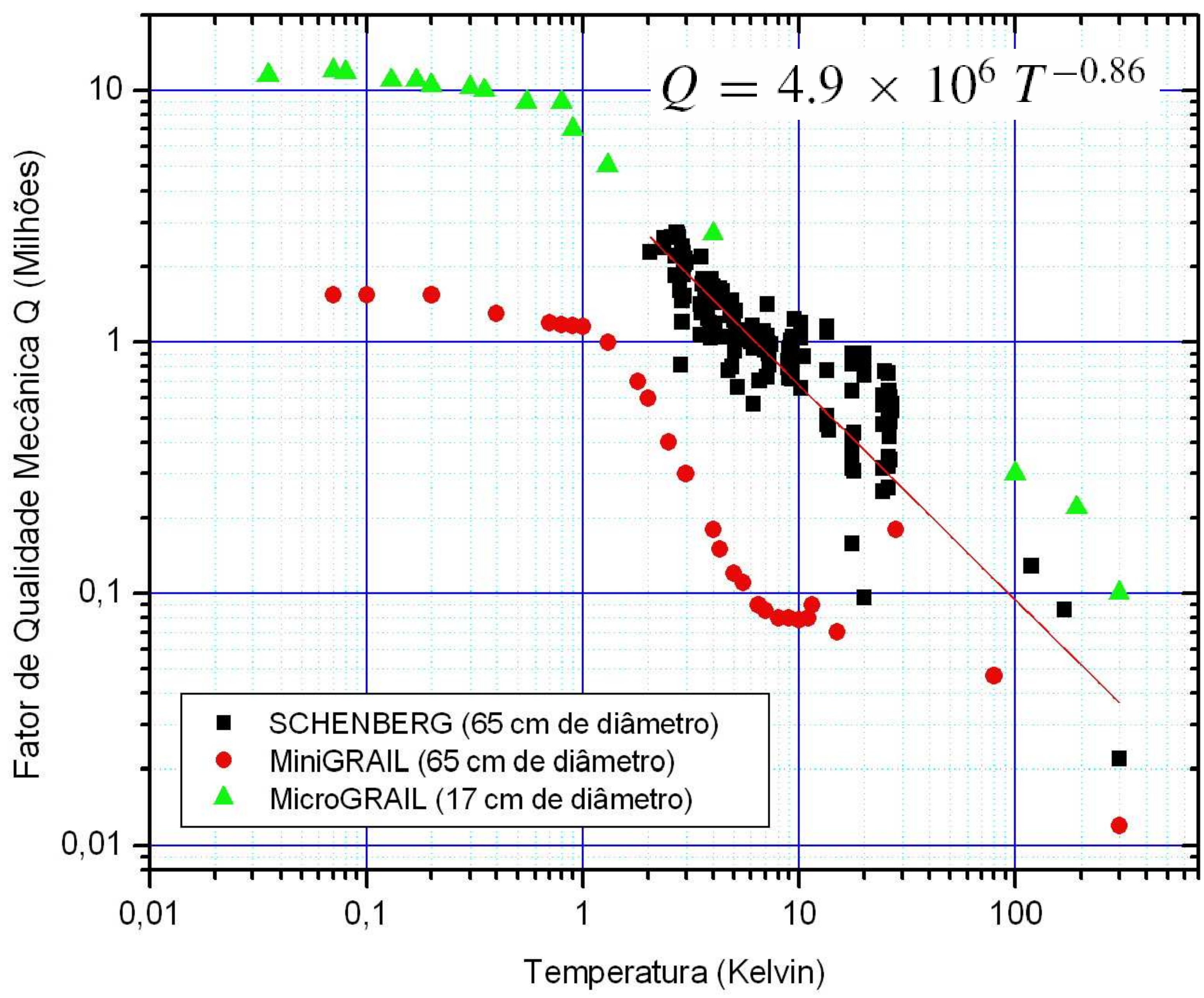
5 independent components



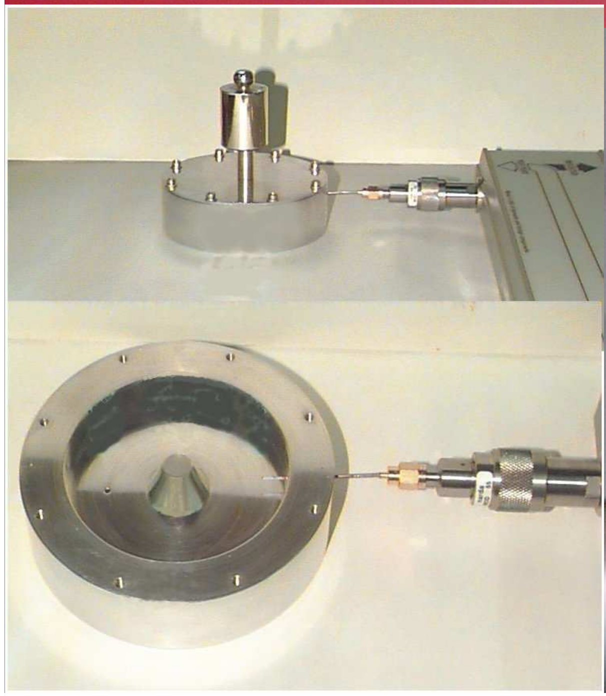


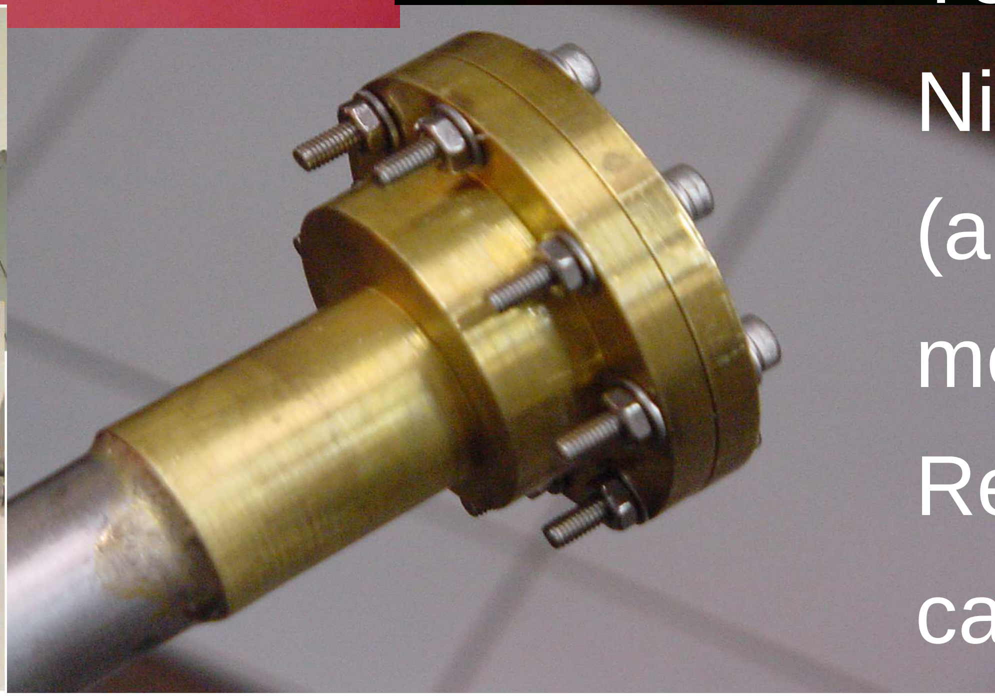




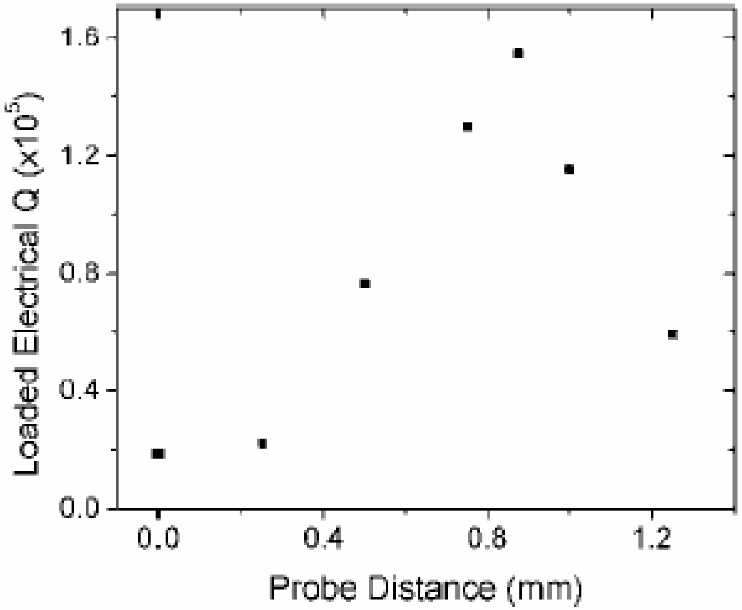


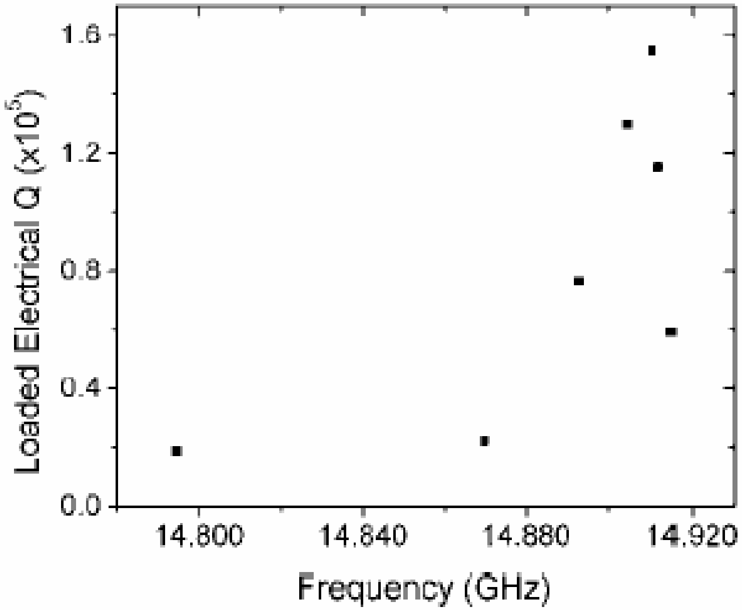
$Q = 4.9 \times 10^6\ T^{-0.86}$
Fator de Qualidade Mecânica Q (Milhões)
Temperatura (Kelvin)
SCHENBERG (65 cm de diâmetro)
MiniGRAIL (65 cm de diâmetro)
MicroGRAIL (17 cm de diâmetro)
10
1
0,1
0,01
0,01
0,1
1
10
100

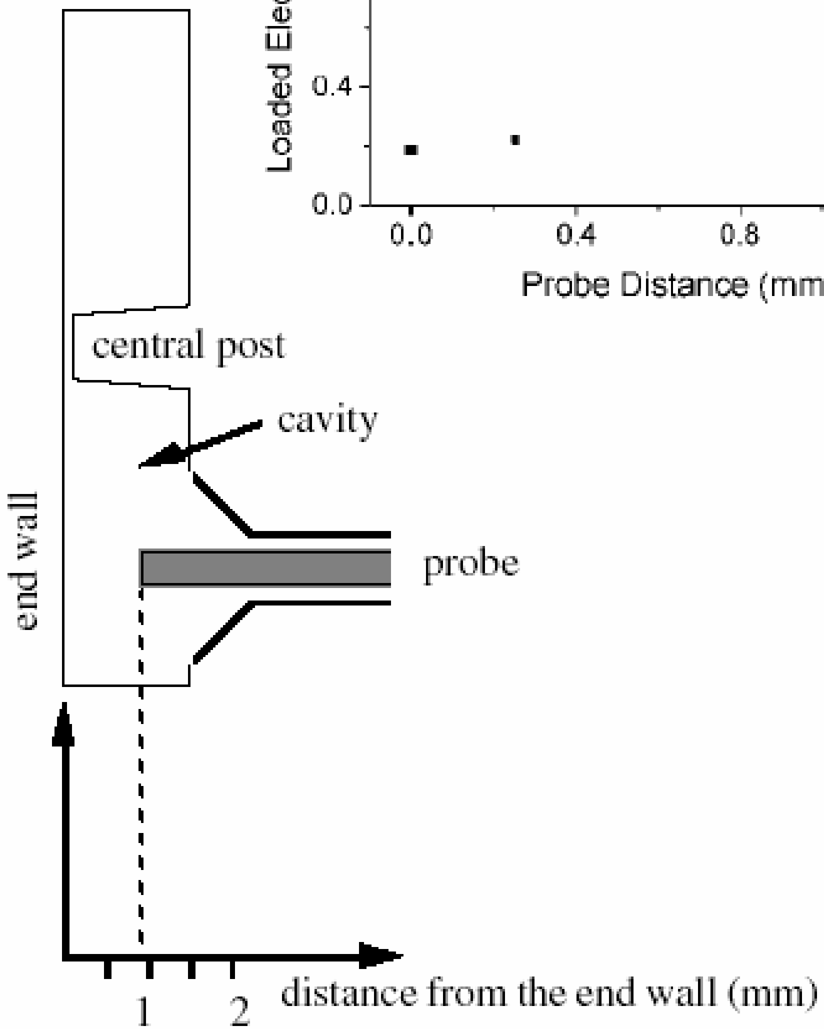


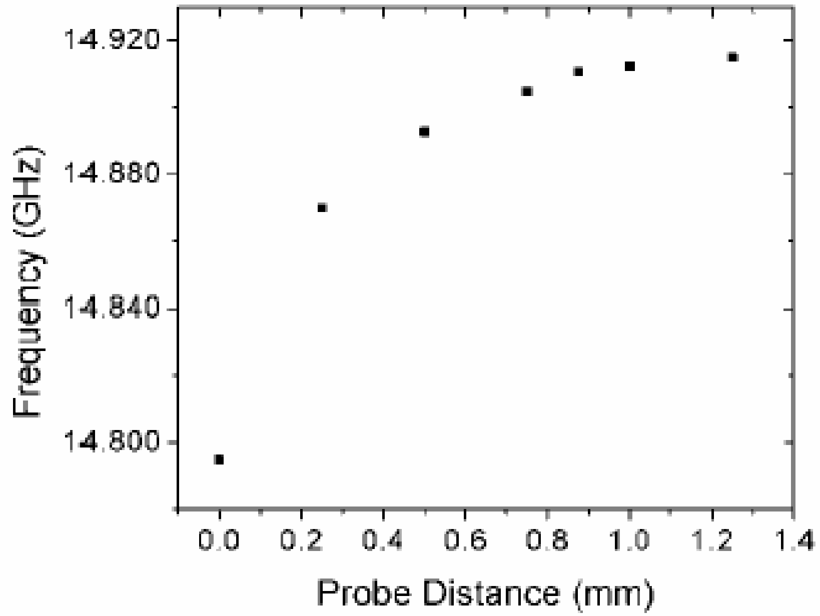


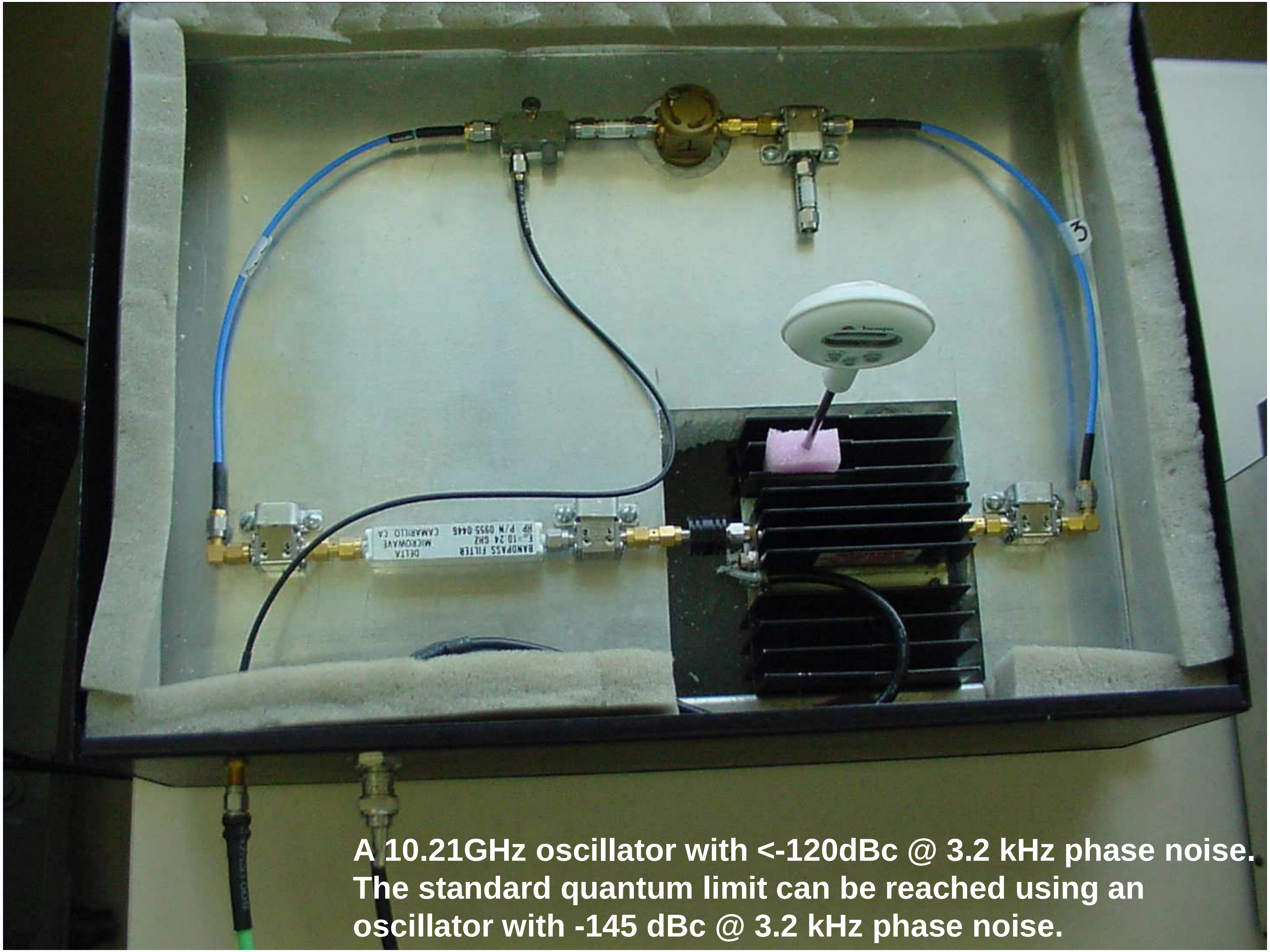
Tests with Niobium (and other metals) Reentrant cavities


1.6
1.2
0.8
0.4
0.0
0.0
0.4
0.8
1.2
Loaded Electrical Q (x10^5)
Probe Distance (mm)


1.6
1.2
0.8
0.4
0.0
14.800
14.840
14.880
14.920
Loaded Electrical Q (x10^5)
Frequency (GHz)

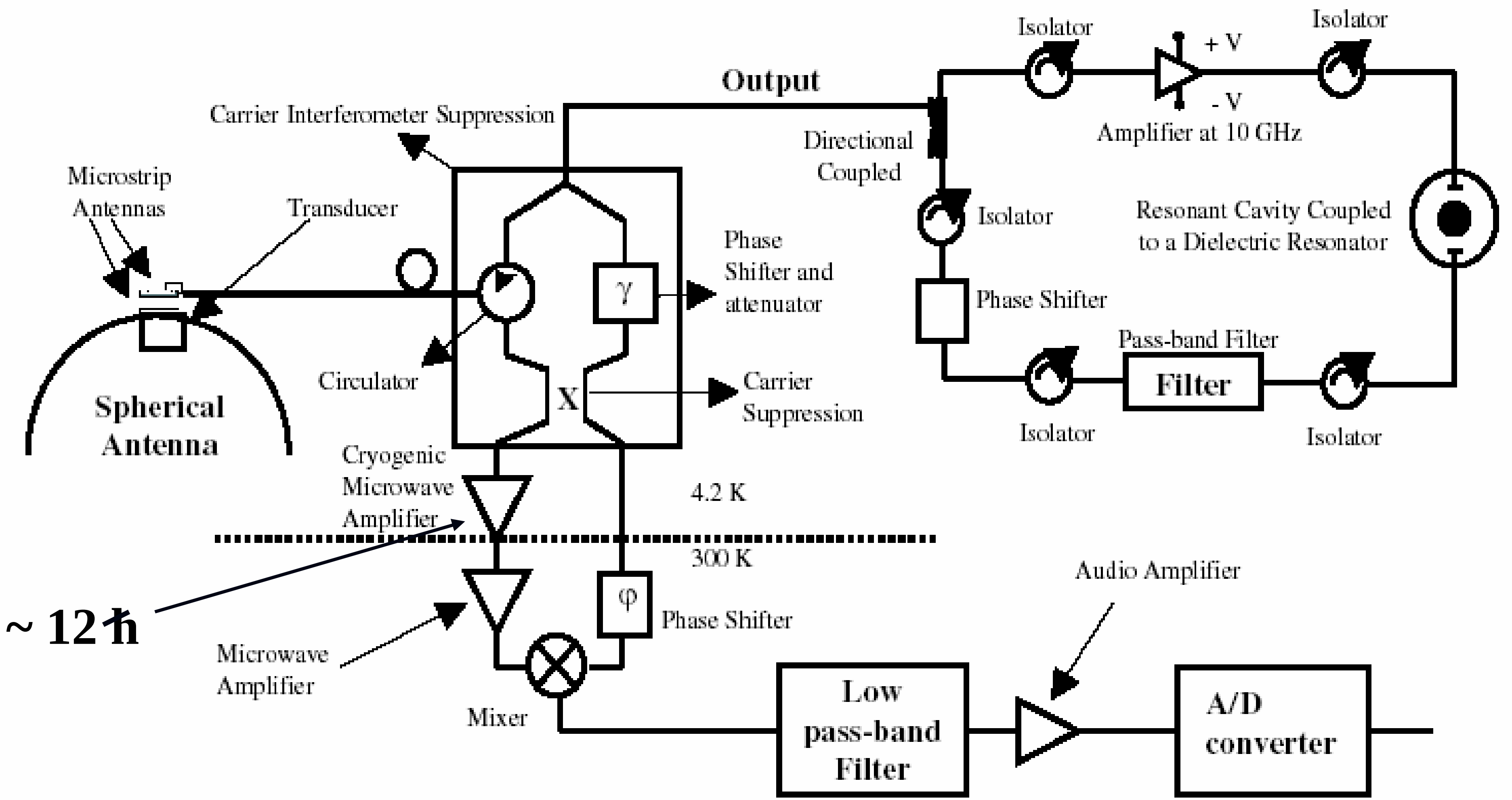

central post
cavity
probe
end wall
1
2
distance from the end wall (mm)


14.920
14.880
14.840
14.800
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Frequency (GHz)
Probe Distance (mm)

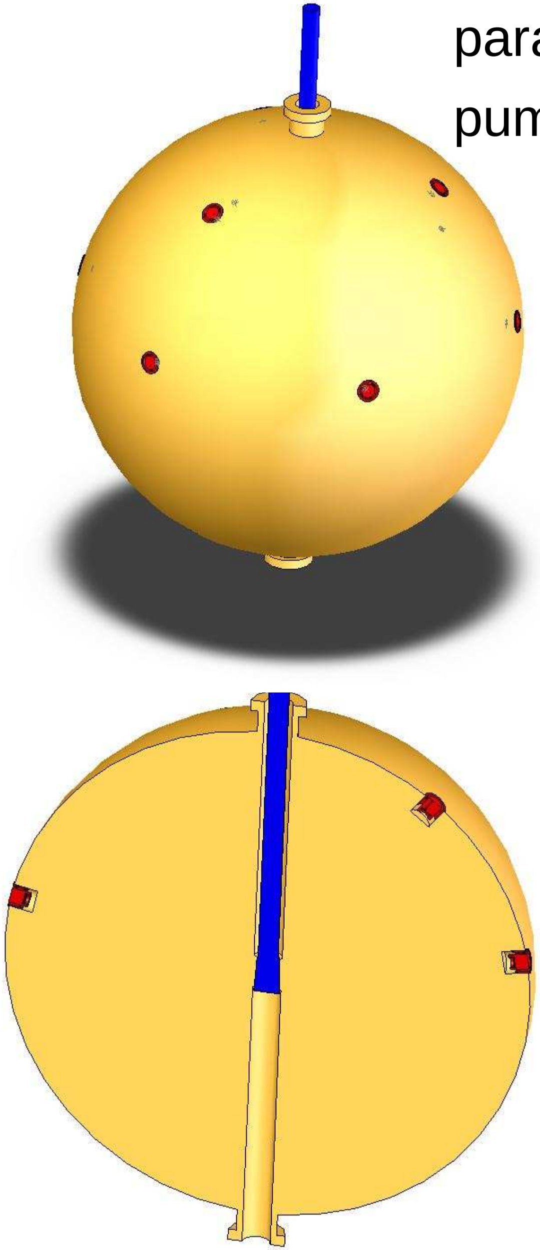


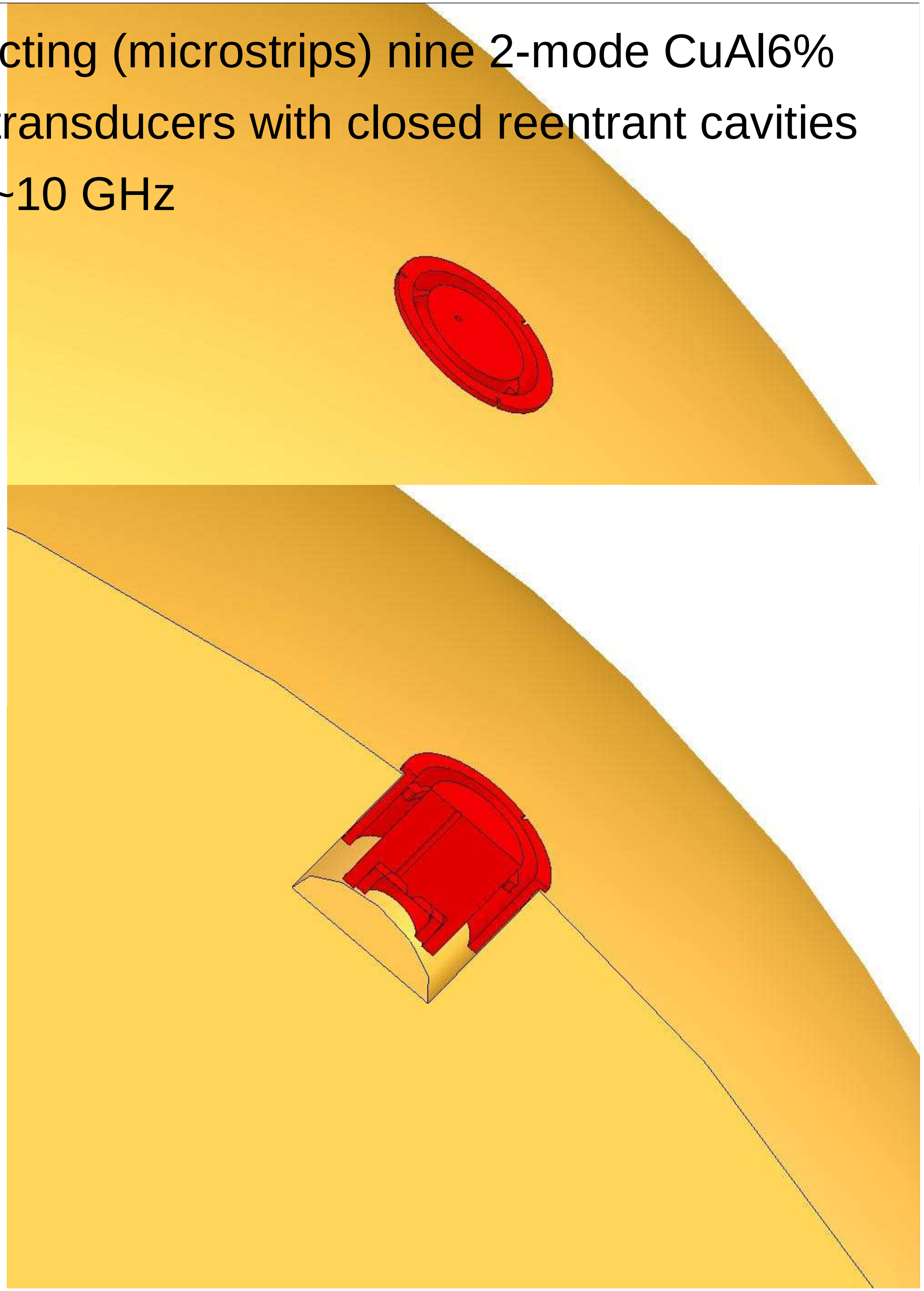
A 10.21GHz oscillator with <-120dBc @ 3.2 kHz phase noise.
The standard quantum limit can be reached using an oscillator with -145 dBc @ 3.2 kHz phase noise.

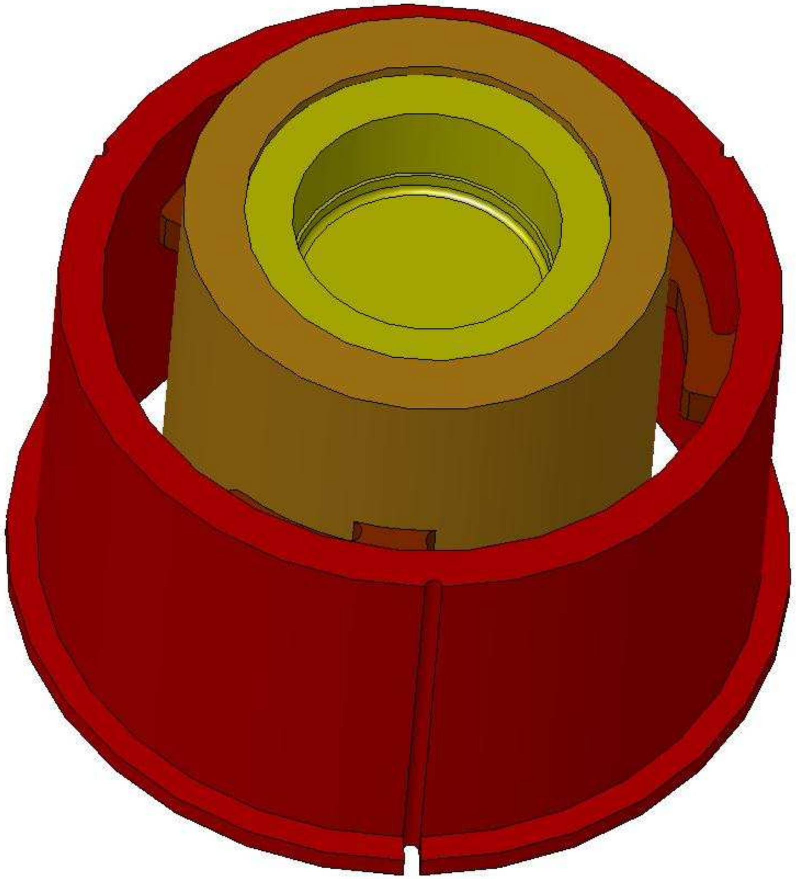
Schemactic view of the transducer system

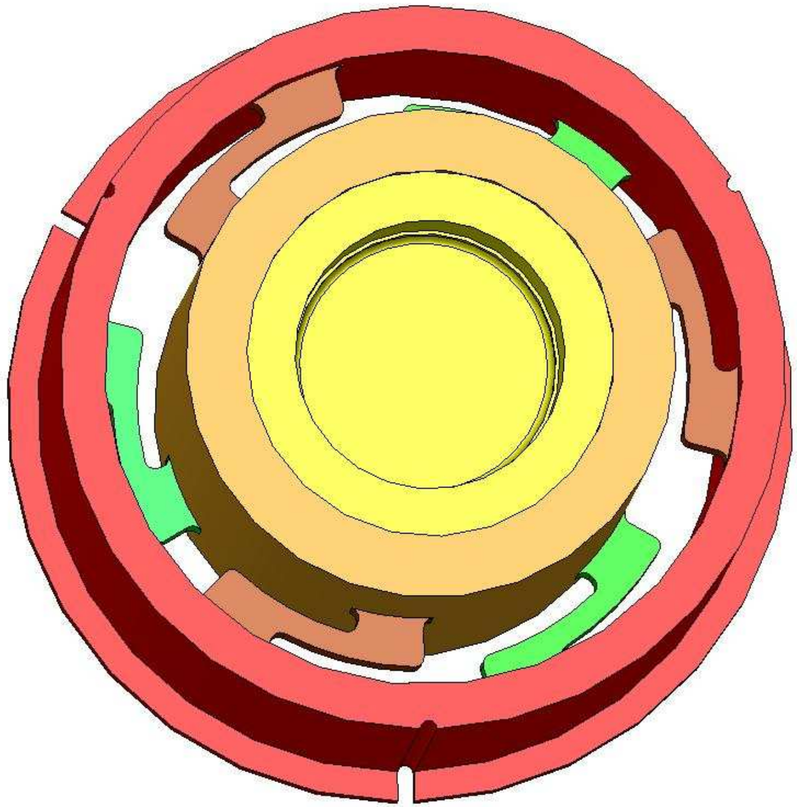


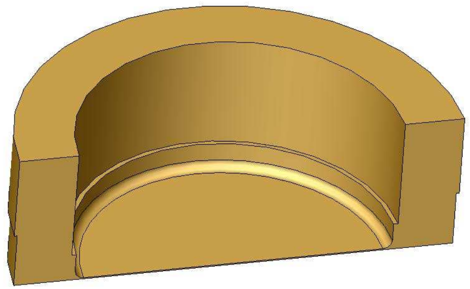
- Non-contacting (microstrips) nine 2-mode CuAl6% parametric transducers with closed reentrant cavities pumped at ~10 GHz

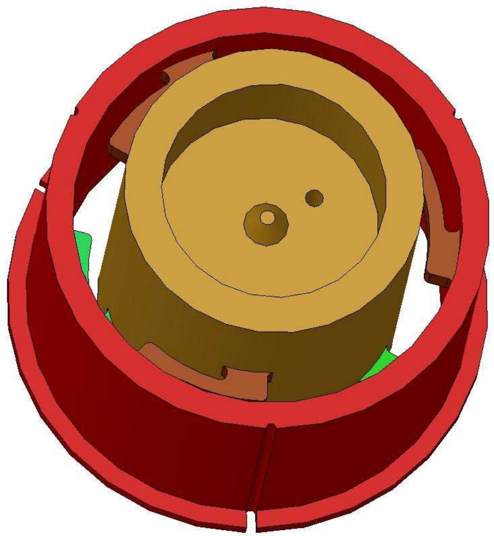


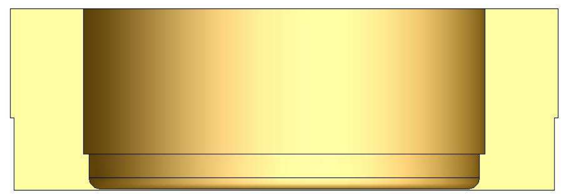




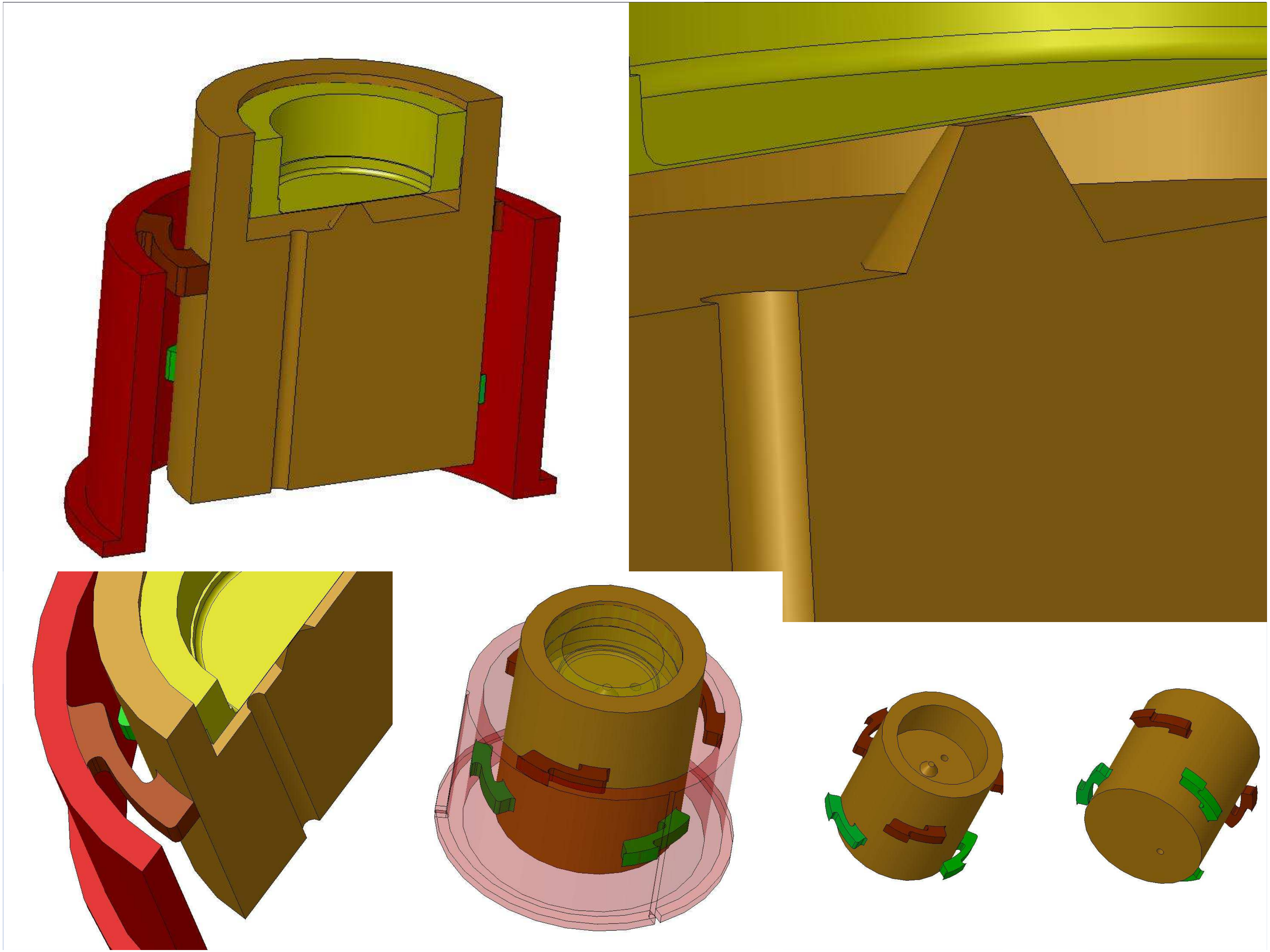


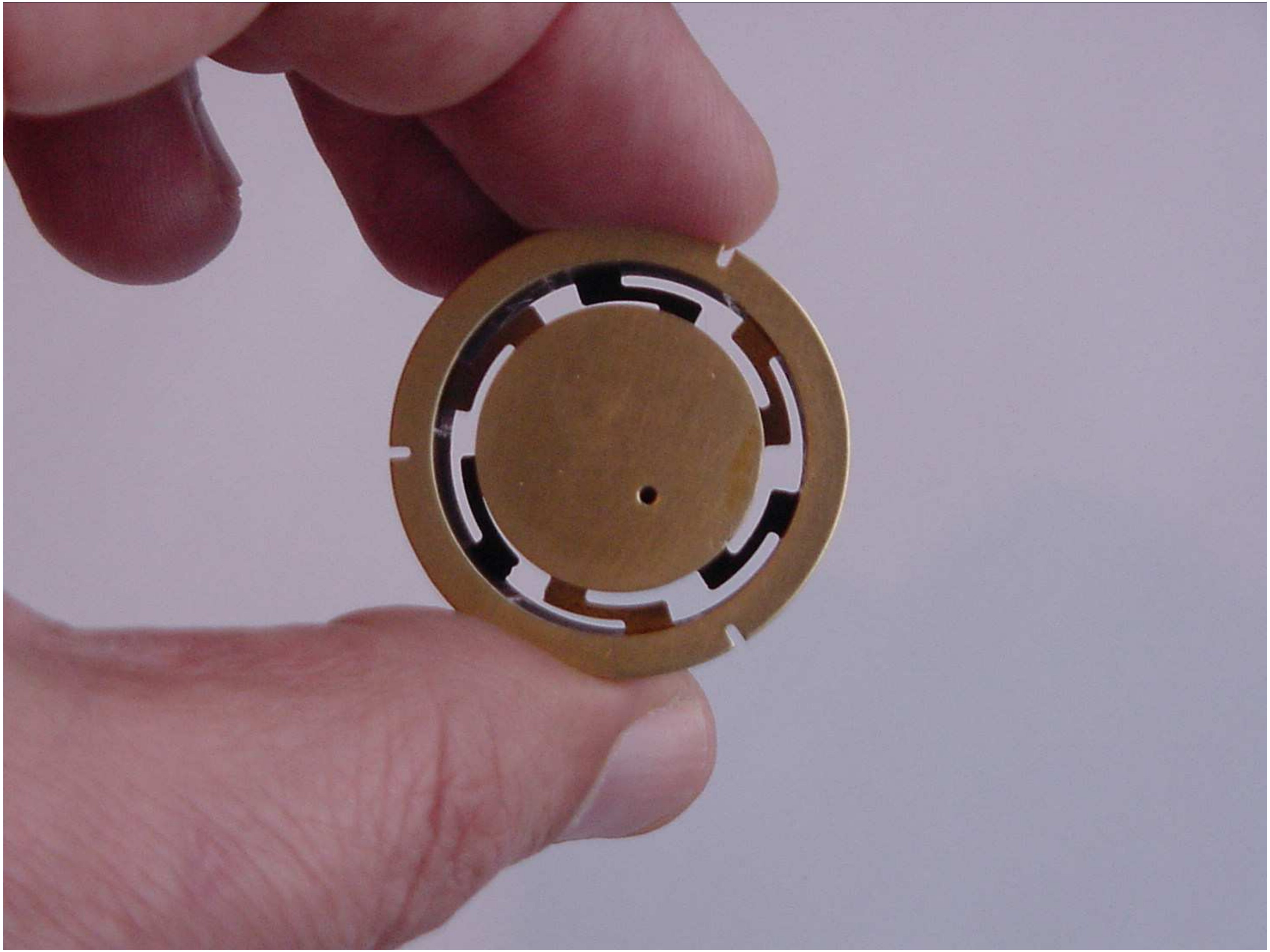


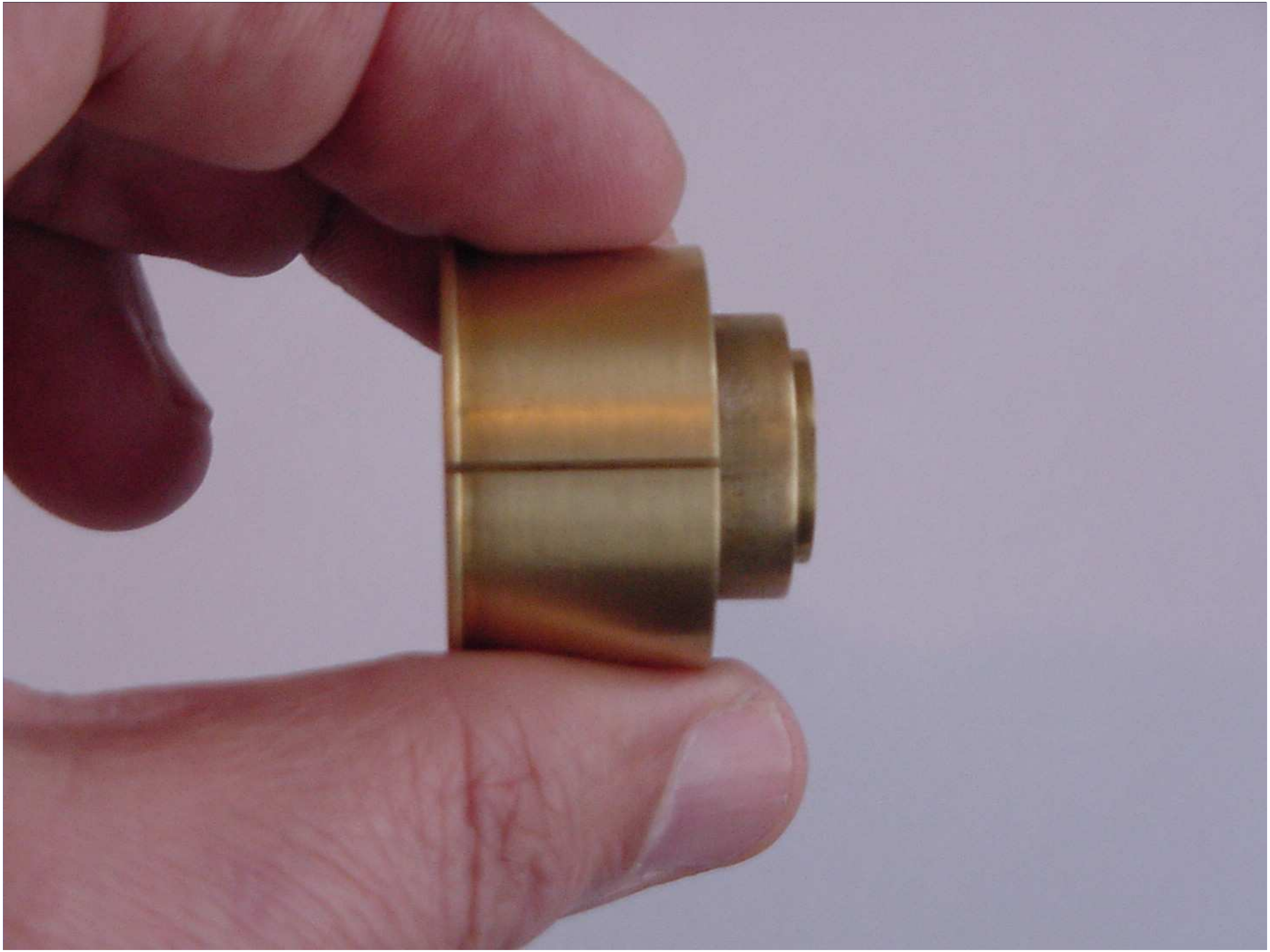


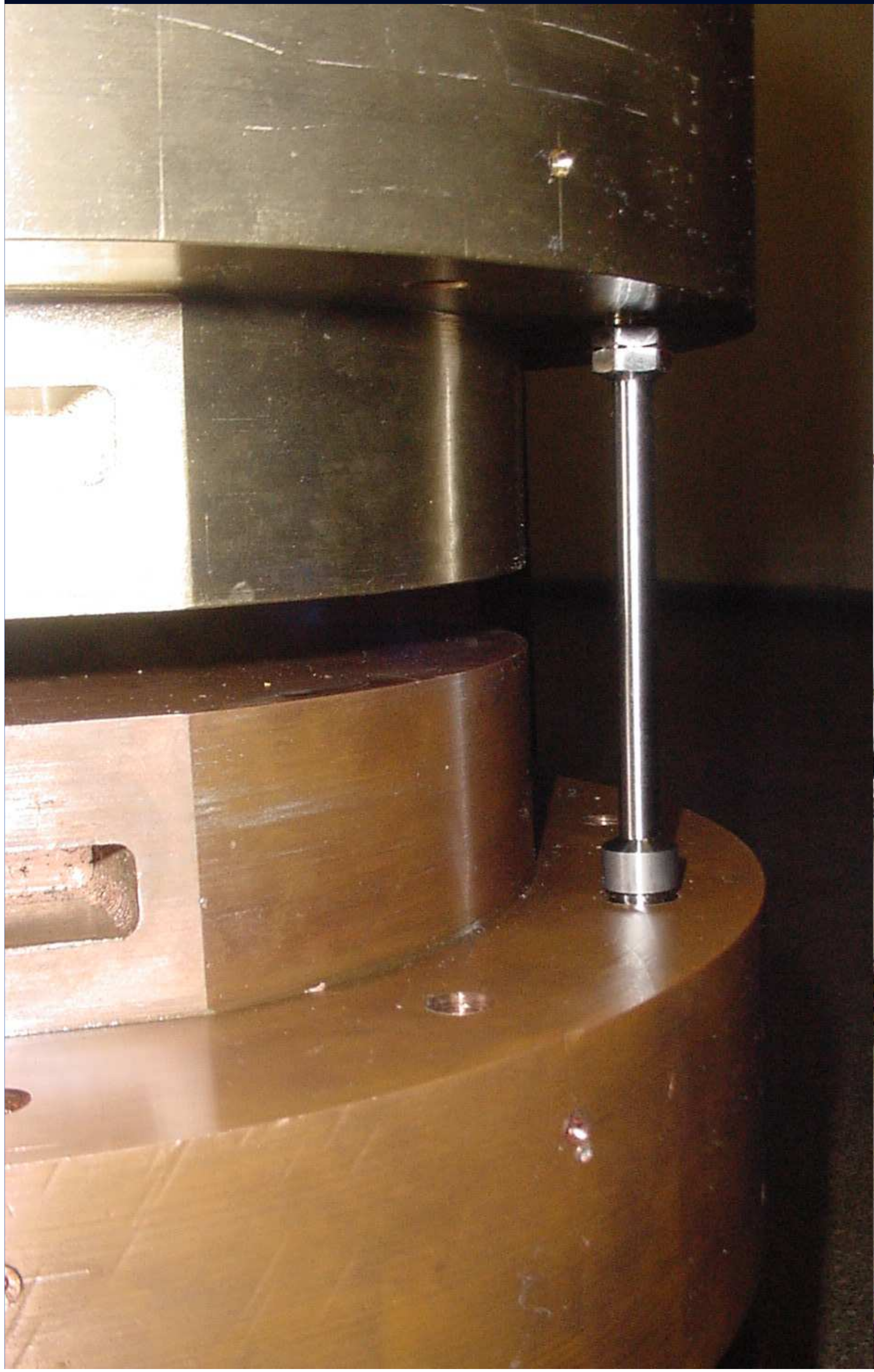
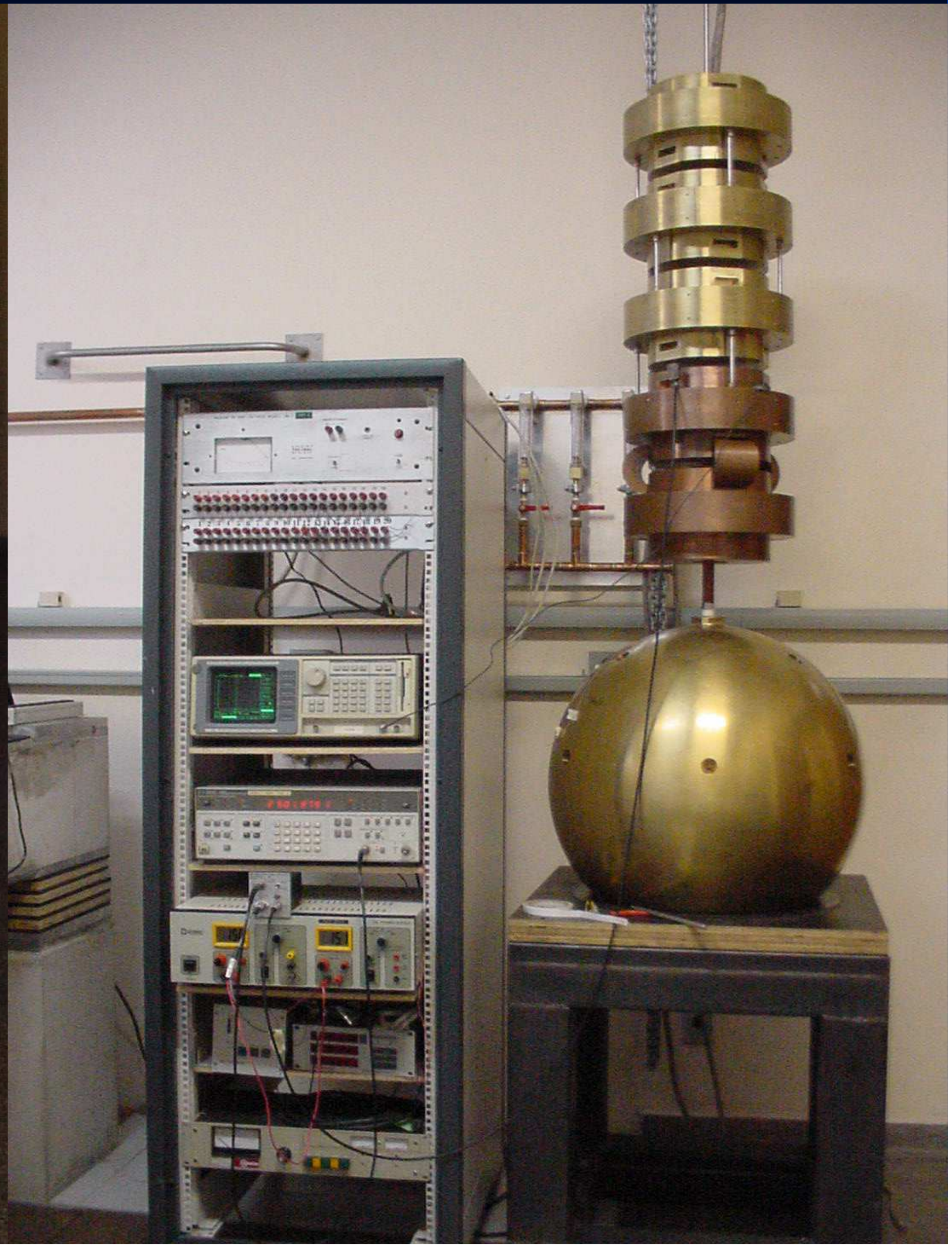


287 kg, 53 g and 10 mg

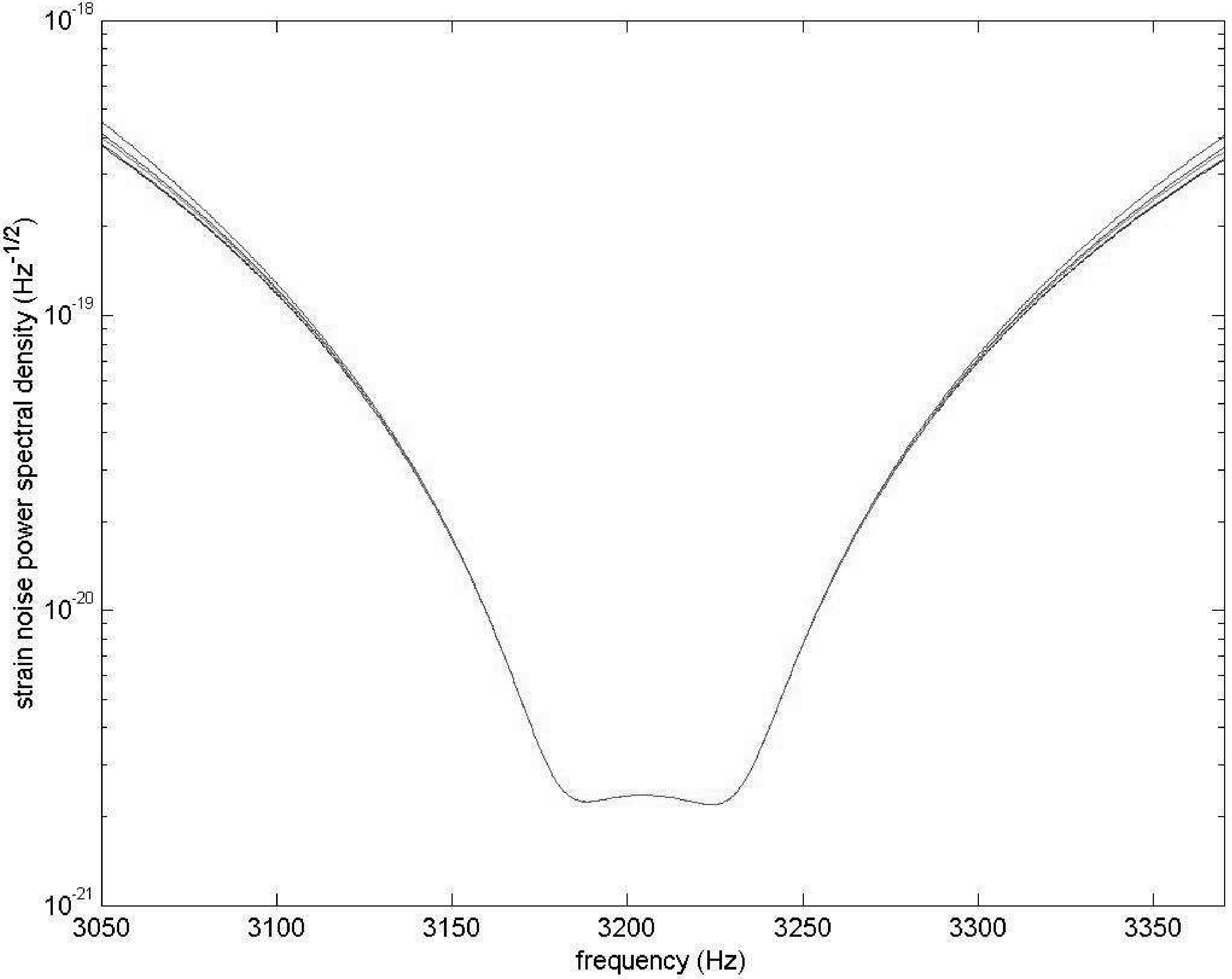


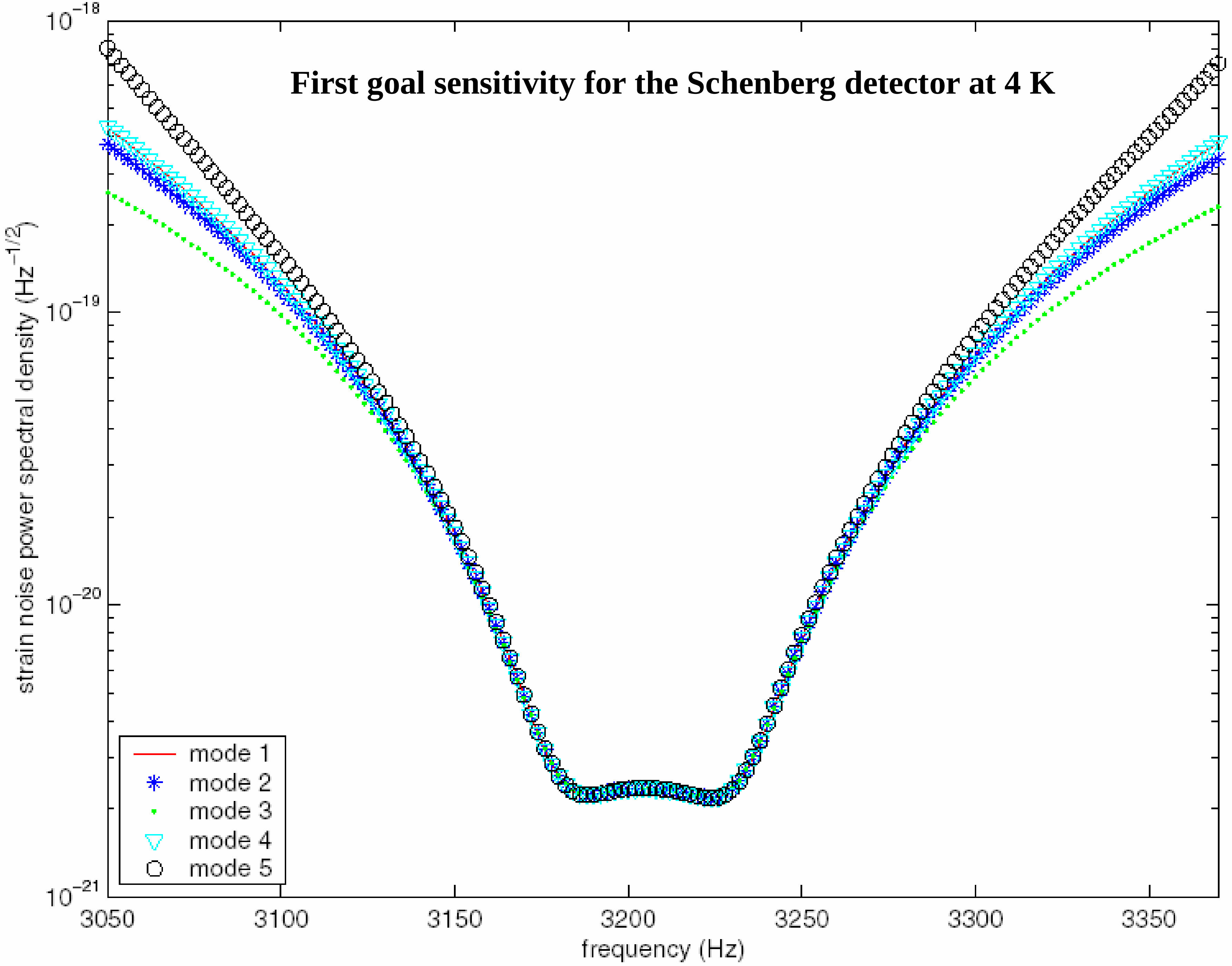


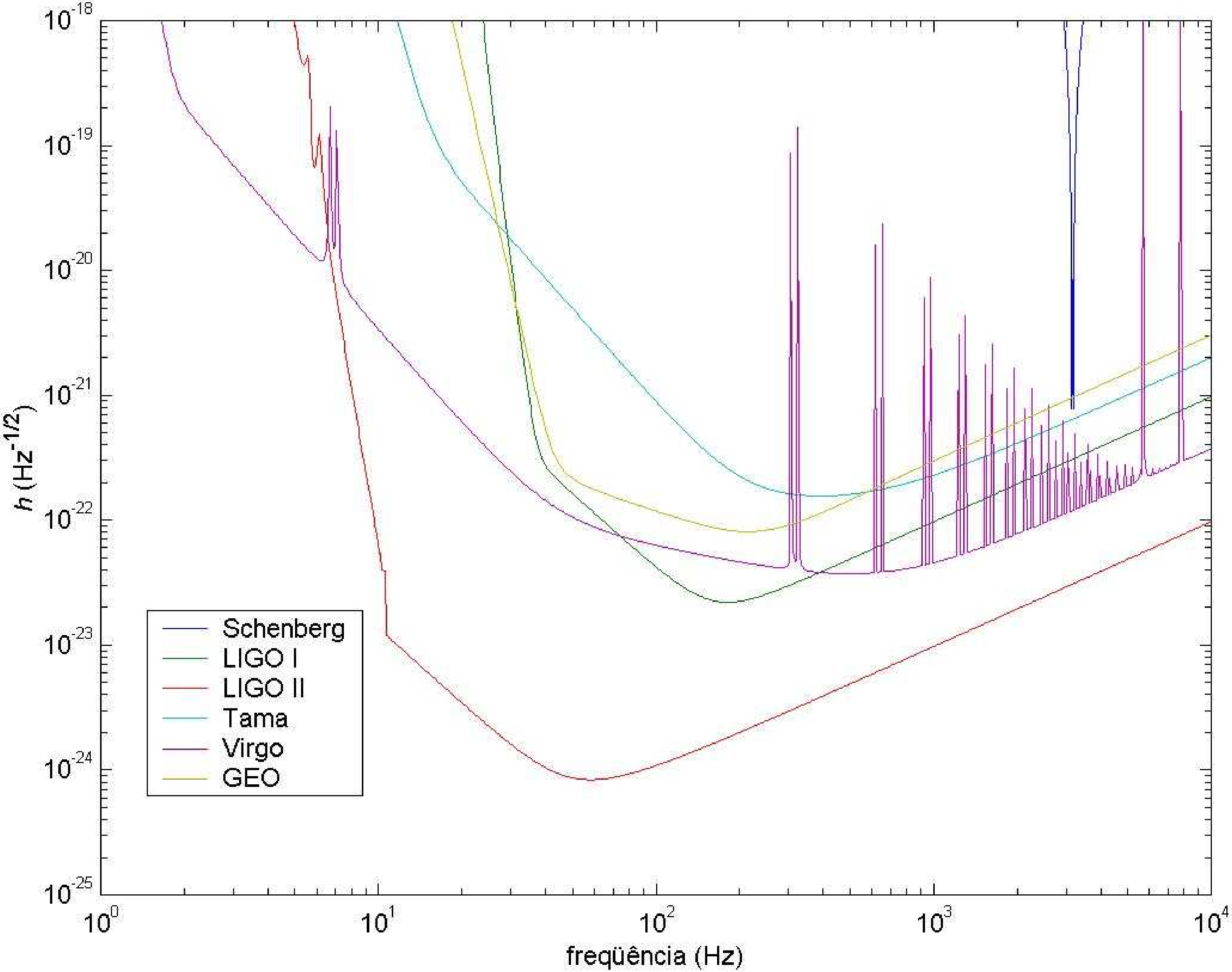


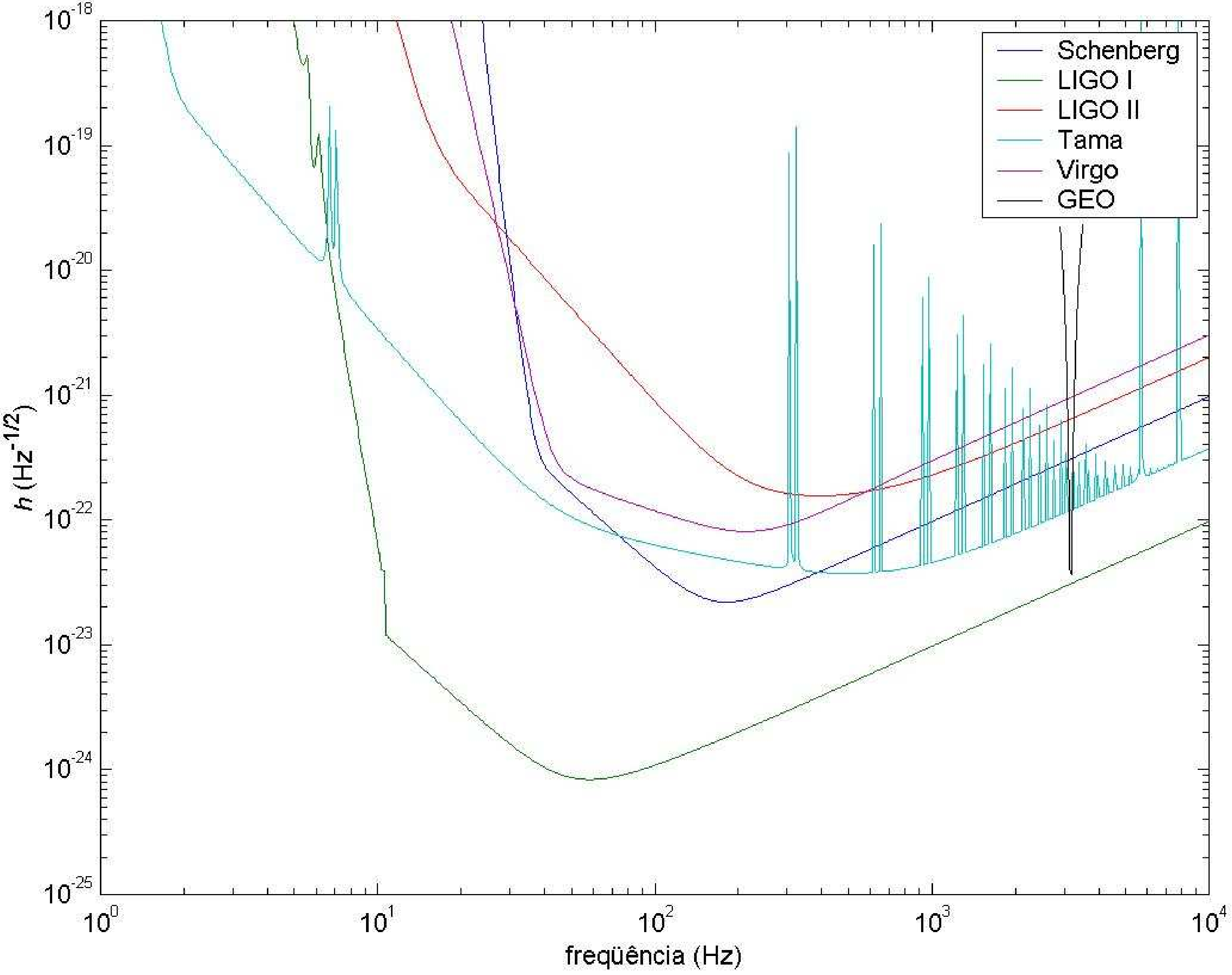
First goal sensitivity for the Schenberg detector at 4 K




First goal sensitivity for the Schenberg detector at 4 K
strain noise power spectral density (Hz^-1/2)
frequency (Hz)
10^-18
10^-19
10^-20
10^-21
3050
3100
3150
3200
3250
3300
3350
mode 1
mode 2
mode 3
mode 4
mode 5



Schenberg
LIGO I
LIGO II
Tama
Virgo
GEO
h (Hz$^{-1/2}$)
frequência (Hz)
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}



Schenberg
LIGO I
LIGO II
Tama
Virgo
GEO
h (Hz^-1/2)
10^-18
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
10^0
10^1
10^2
10^3
10^4
freqüência (Hz)

Astrophysical Sources of Gravitational Waves Detectable by the Brazilian Spherical Antenna

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Abstract

The Brazilian spherical antenna (Schenberg) is planned to detect high frequency gravitational waves (GWs) ranging from 3.0 kHz to 3.4 kHz. There is a host of astrophysical sources probable of being detected by the Brazilian antenna, namely: core collapse in supernova events; (proto)neutron stars undergoing hydrodynamical instability; f-mode unstable neutron stars, caused by quakes and oscillations; excitation of the first quadrupole normal mode of 4–9 solar mass black holes; coalescence of neutron stars and/or black holes; exotic sources such as bosonic or strange matter stars rotating at 1.6 kHz; and inspiralling of mini black hole binaries. We here address our study in particular to the neutron stars, which could well become f-mode unstable producing therefore GWs. We estimate, for this particular source of GWs, the event rates that in principle can be detected by Schenberg.

1 Introduction

The Brazilian antenna is made of Cu-Al (94%-6%), it has a diameter of 65 cm and covers the 3.0-3.4 kHz bandwidth (see, Aguiar et al 2002, 2004 for details). It would operate in conjunction with the Dutch Mini-GRAIL and the Italian SFERA antennas, and the laser interferometer detectors, which can also cover such high frequencies with similar sensitivities.

In a previous work by a M.Sc. student of our group (Castro 2003), it was addressed a preliminary study of the most probable sources of gravitational waves (GWs) that could be detected by Schenberg, namely: core collapse in supernova events; (proto)neutron stars undergoing hydrodynamical instability; f-mode unstable neutron stars, caused by quakes and oscillations; excitation of the first quadrupole normal mode of $4-9M_\odot$ black holes; coalescence of neutron stars and/or black holes; exotic sources such as bosonic or strange matter stars rotating at 1.6 kHz; and inspiralling of mini black hole binaries.

Our aim here is to present the main results of this study and to revisit, in particular, the f-mode unstable neutron star source of GWs. The previous study of such a source can be improved in many aspects.

2 The Sources to Schenberg

First of all, it is worth mentioning that in the present estimates of event rates we are assuming that the Schenberg's sensitivity to burst sources is of $h \sim 10^{-20}$.

It is important to bear in mind that such a sensitivity is not the quantum limit one, which could be a factor around 2 better. Also, it is worth remembering that using the "squeezing technique" the quantum limit could in principle be overtaken. All this would imply that Schenberg could in principle present

Before considering the improvements we intend to take into account in revisiting this study, it is worth recalling that the characteristic amplitude of GWs related to the f-mode instability is given by

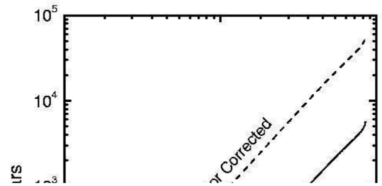
$$h = 2.2\times10^{-21}\left(\frac{\varepsilon_{GW}}{10^{-6}}\right)^{1/2}\left(\frac{2\,kHz}{f_{GW}}\right)^{1/2}\left(\frac{50\,kpc}{r}\right)$$

where ε_{GW} is the efficiency of generation of GWs, f_{GW} is the GW frequency, and r is the distance to the source.

The Schenberg's sensitivity for burst sources can be of the order of 10^{-20}, this implies that, for $\varepsilon_{GW} \sim 10^{-6}$ and f_{GW} =3 kHz, Schenberg can in principle detect f-mode unstable neutron star sources at distances of up to $r \sim 10$ kpc.

Certainly, the number of neutron stars within the volume *seen* by Schenberg could be in principle enormous. Unless the efficiency of genration of GWs through f-mode instability is $\ll 10^{-6}$ or such a mode is not excited at all, Schenberg could in principle detect f-mode unstable neutron stars with a considerable event rate.

For the distribution function of pulsars in the Galaxy we follow the paper by Yusifov & Küçük (2004). We refer the reader to their paper for further details.



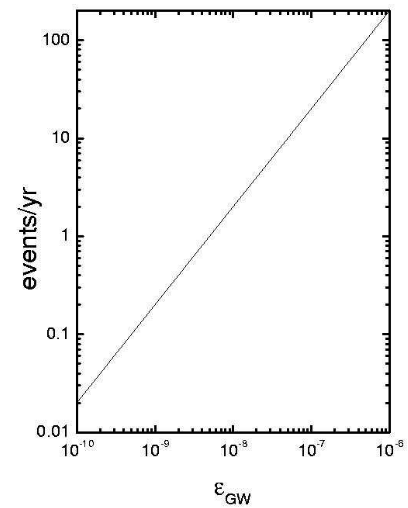


FIG. 2: Number of events per year,- i.e., number of f-mode unstable pulsars per year- as a function of ε_{GW}, the efficiency of generation of GWs.

4 Final Remarks

We present in this poster the sources of GWs that the Schenberg antenna could in principle detect.

Among these sources, emphasis is given on the f-mode GW production by neutron stars.

We have been constructing the gravitational wave detector Mario Schenberg at the Physics Institute of the University of São Paulo with the support of FAPESP, the São Paulo Science Foundation. The antenna and its vibration isolation system are already built, and we have cooled it down for a first cryogenic test and mechanical Q (figure of merit) measurement. We also have built a 10.21GHz oscillator with better than -120dBc@3.2kHz phase noise performance to pump an initial CuAl6% two-mode transducer. We plan to prepare this spherical antenna for a first operational run at 4.2K with a single transducer and an initial target sensitivity of h ~ 2 x 10^{-21} Hz-$^{1/2}$ in a 50Hz bandwidth around 3.2kHz soon.