INSTITUTE OF PHYSICS PUBLISHING CLASSICAL AND QUANTUM GRAVITY

Class. Quantum Grav. **23** (2006) S239–S244 doi:10.1088/0264-9381/23/8/S30

The Brazilian gravitational wave detector Mario Schenberg: status report

O D Aguiar[1], L A Andrade[2], J J Barroso[1], F Bortoli[3], L A Carneiro[1], P J Castro[1], C A Costa[1], K M F Costa[4], J C N de Araujo[1], A U de Lucena[1], W de Paula[4], E C de Rey Neto[1], S T de Souza[1], A C Fauth[5], C Frajuca[3], G Frossati[6], S R Furtado[1], N S Magalhães[3], R M Marinho Jr[4], J L Melo[1], O D Miranda[1], N F Oliveira Jr[7], K L Ribeiro[1], C Stellati[4], W F Velloso Jr[8] and J Weber[1]

[1] Instituto Nacional de Pesquisas Espaciais, Divisão de Astrofísica, São José dos Campos, SP, Brazil
[2] Instituto de Aeronáutica e Espaço, São José dos Campos, SP, Brazil
[3] Centro Federal de Ensino Tecnológico de São Paulo, São Paulo, SP, Brazil
[4] Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil
[5] Universidade Estadual de Campinas, Instituto de Física, Campinas, SP, Brazil
[6] Leiden University, Kammerlingh Onnes Laboratory, Leiden, The Netherlands
[7] Universidade de São Paulo, Instituto de Física, São Paulo, SP, Brazil
[8] Universidade de São Paulo, Pirassununga, SP, Brazil

E-mail: odylio@das.inpe.br

Received 31 August 2005, in final form 19 December 2005
Published 28 March 2006

Abstract

The Mario Schenberg gravitational wave detector has been constructed at its site in the Physics Institute of the University of São Paulo as programmed by the Brazilian Graviton Project, under the full support of FAPESP (the São Paulo State Foundation for Research Support). We are preparing it for a first commissioning run of the spherical antenna at 4.2 K with three parametric transducers and an initial target sensitivity of $h \sim 2 \times 10^{-21}\ \mathrm{Hz}^{-1/2}$ in a 60 Hz bandwidth around 3.2 kHz. Here we present the status of this project.

PACS numbers: 04.80.Nn, 95.55.Ym

1. Introduction

A spherical antenna will be able to determine the wave polarization and localize its astrophysical source on the sky for all gravitational wave signals detected in any given gravitational theory [1, 2]. Furthermore, it is never 'blind' to any particular direction or polarization of the arriving wave [3]. Both these advantages of a spherical antenna are due to its omnidirectionality achieved by the use of at least six transducers placed according to the truncated icosahedron configuration [4]. Another very important advantage of this kind of

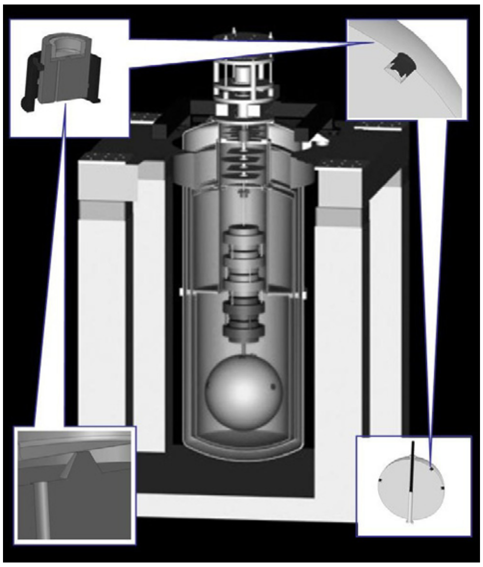

Figure 1. Mario Schenberg detector. The resonant mass (sphere) will be kept in vacuum, isolated from mechanical noises. Nine parametric transducers (see details) will monitor their fundamental modes of vibration [5, 9]. When coupled to the antenna, the transducer–sphere system will work as a mass–spring system with three modes, where the first will be constituted by the antenna effective mass (287.5 kg), the second will be constituted by the mechanical structure of the transducer (53 g), and the third one will be constituted by a membrane (10 mg) that will close the transducer microwave cavity and modulate it around 3.2 kHz.

detector comes exactly from the fact that it has many transducers monitoring many quadrupolar modes. It is like having many detectors operating together at the same time and site [5]. So, one can do real time data analysis with the signals of the transducers looking for correlations, which is impossible to do using detectors located at different sites.

One of these spherical antennas is the Brazilian Mario Schenberg detector [6]. Figure 1 shows a schematic view of it. The Schenberg CuAl6% antenna has a diameter of 65 cm and weight 1.15 ton. It has nine little holes on its surface for up to nine transducers, six of which follow the truncated icosahedron configuration proposed by Johnson and Merkowitz [4]. At the standard quantum limit sensitivity it will have a strain noise power spectral density of $\sim 10^{-22}$ $\mathrm{Hz}^{-1/2}$ [7]. It will operate in coincidence with the Dutch Mini-GRAIL antenna [8] and some long baseline laser interferometer detectors [9], searching for high frequency events in the 3.0–3.4 kHz frequency bandwidth.

2. The status of the detector

The Mario Schenberg gravitational wave detector has been constructed at its site in the Physics Institute of the University of São Paulo, in São Paulo city, Brazil, under the full support of FAPESP (the São Paulo State Foundation for Research Support). All the heavy parts are assembled and we are starting to mount the transducer system. We have already done two cryogenic test runs for the antenna Q measurements and determination of thermal gradients on the suspension plus antenna system. We have changed the suspension in order to improve the vibration isolation and thermal performance.

The transducers are of the parametric type pumped at 10 GHz. The signal will be sent to and received from the transducers by pairs of microstrip antennas. The preamplifiers, which

Figure 2. Copper–aluminium klystron cavity covered with a thin layer of niobium.

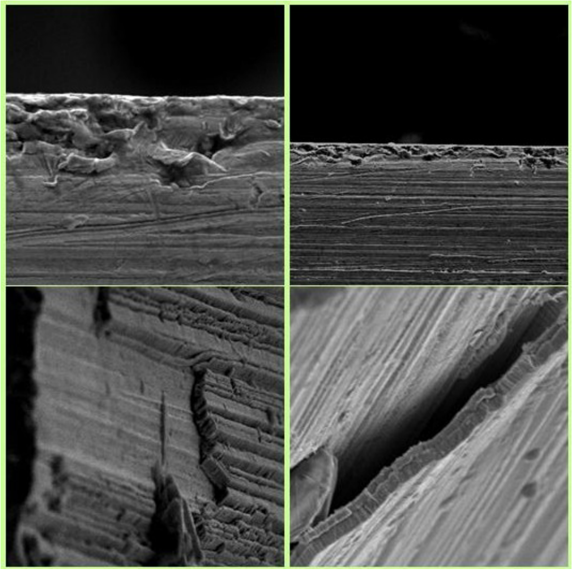

Figure 3. Images of a copper–aluminium cavity with a thin layer of niobium. The layer was applied by EB-PVD. In this process, we used an electron gun with an accelerating voltage of 23.5 kV and a beam current of 0.8 A. The deposition time was between 20 and 60 min, producing films with thickness between 2 and 40 μm.

will use HEMT technology, as the Australian group was planning to do in Niobè [10], have a noise temperature of 8–10 K, which corresponds at 10 GHz to 12–14$\hbar$ in sensitivity ($T_{\mathrm{n}} = 9\,\mathrm{K} \sim 13\hbar\omega/k_{\mathrm{B}} \ln 2$) [11].

Each one of the five quadrupole modes of the sphere has an effective mass for oscillation of 287 kg [12, 13]. These five independent modes are coupled to the modes of the six (or nine) transducers, which have oscillating masses of 53.6 g and 10 mg, and form a geometric series with the masses of the sphere modes. All these modes are tuned to the ~3.2 kHz resonant frequency and the energy flowing from the sphere modes to the 10 mg transducer masses due to this coupling produces an amplitude gain of about $(287\ \mathrm{kg}/10\ \mathrm{mg})^{1/2} \sim 5\ k$.

The 10 mg transducer mass is the effective mass of a membrane that closes the microwave klystron cavity and forms a 0.1 mm gap with the top of the cavity post.

We are doing tests of niobium layer deposition in copper–aluminium cavities. We can see some of these cavities in figure 2. The niobium layer was made with an electron beam followed by physical vapour deposition.

Some pictures taken with an electronic microscope, which show details of the deposition quality, are shown in figure 3. The thickness can be upto 40 μm, as in this case.

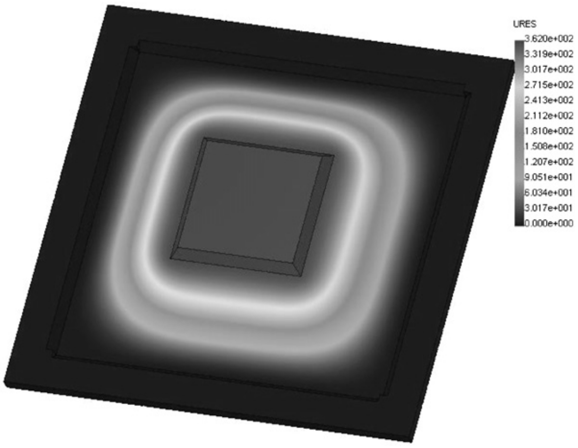

Figure 4. Photolithograph membrane design and results of a numeric simulation using the software COSMOS (the membrane oscillation is of its fundamental mode). The amplitude scale, in microns (10^{-6} m), is shown on the right.

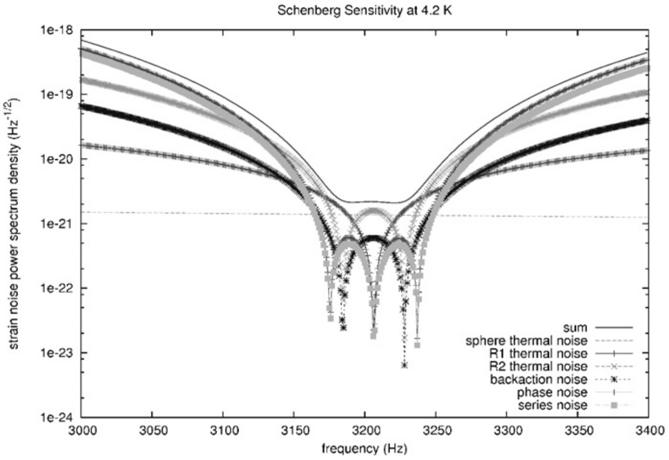

Figure 5. The Schenberg sensitivity curves at 4.2 K (upper line) for a single quadrupole mode and the individual contributions of the noise sources.

We are trying to make the membranes with effective masses of 10 mg from silicon sheets and the deposition of a niobium layer. We hope to get both high mechanical and electrical Qs. The details of the membrane design are shown in figure 4. A precision of 1 or 2 μm is possible to be achieved in its thickness.

3. Preparation for the commission phase

We are preparing the Schenberg detector for a first commissioning run of the spherical antenna at 4.2 K with three parametric transducers and an initial target sensitivity of $h \sim 2 \times 10^{-21}$ Hz$^{-1/2}$ in a 60 Hz bandwidth around 3.2 kHz.

Figure 5 shows the predicted strain noise power spectral density considering conservative parameters and the Schenberg antenna operating at 4.2 K. The various components of the

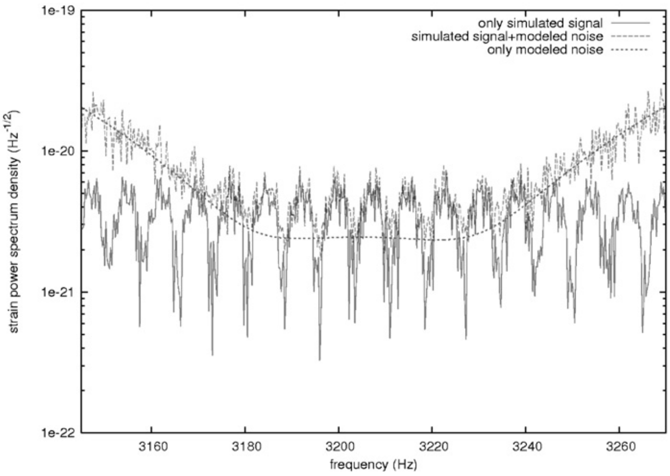

Figure 6. Strain power spectrum density when a simulated GW signal is introduced in the modelled noise.

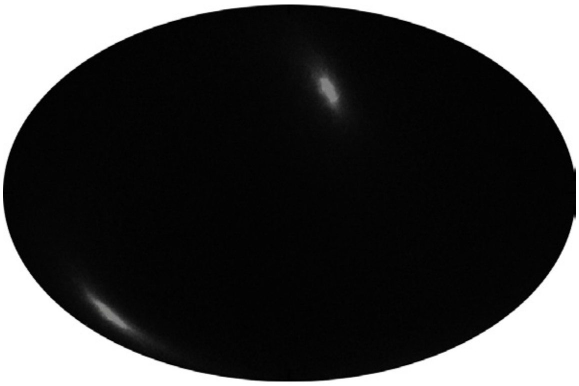

Figure 7. Position of the source with (amplitude) SNR ~ 3. The signal is spread over 115 squared degrees.

noise curve of one mode channel can be seen. Far away from the optimum bandwidth the electronic noise dominates. At the optimum bandwidth thermal noise dominates.

The software for data analysis in real time was tested with simulated signal plus noise. Figure 6 shows in the same plot the signal, translated in per square root of hertz units, and the signal plus noise (thermal, amplifier and carrier noises). The amplitude signal-to-noise ratio here is ~3.

In the last figure (figure 7) one can see the reconstruction of the source location on the sky. There is of course 180° uncertainty in its direction. This software is ready for use in the first commissioning run of the detector.

Acknowledgments

We thank Arlette de Waard and Michael E Tobar for helpful discussions and collaboration. We also thank the groups of AURIGA, NAUTILUS and Mini-GRAIL for collaboration during the visit of C A Costa and J L Melo to their sites. This work has been supported by FAPESP (under grants No. 1998/13468-9, 2001/12606-3, 2001/14527-3, 2003/05852-3 and 2005/51410-8), CNPq (under grants No. 306467/03-8, 304666/02-5, 150854/03-0 and 380237/04-0), CAPES and MCT/INPE.

References

[1] Forward R L 1971 *Gen. Rel. Grav.* **2** 149
[2] Bianchi M *et al* 1996 *Class. Quantum Grav.* **13** 2865
[3] Merkowitz S M and Johnson W W 1995 *Phys. Rev.* D **51** 2546
[4] Johnson W W and Merkowitz S M 1993 *Phys. Rev. Lett.* **70** 2367
[5] Coccia E, Lobo J A and Ortega J A 1995 *Phys. Rev.* D **52** 3735
[6] Aguiar O D *et al* 2002 *Class. Quantum Grav.* **19** 1949
[7] Tobar M E, Ivanov E N and Blair D G 2000 *Gen. Rel. Grav.* **32** 1799
[8] De Waard *et al* 2005 *Class. Quantum Grav.* **22** S215
[9] Aguiar O D *et al* 2000 *Proc. 3rd Edoardo Amaldi Conf. on Gravitational Waves (Pasadena, CA, 1999) (AIP Conf. Proc.* vol 523*)* (New York: AIP) p 413
[10] Tobar M E 2000 *Physica* B **280** 520
[11] Heffner H 1962 *Proc. IRE* p 1604
[12] Harry G M, Stevenson T R and Paik H-J 1995 *Phys. Rev.* D **54** 2409
[13] Richard J-P 1984 *Phys. Rev. Lett.* **52** 165
Pang Y and Richard J-P 1992 *Rev. Sci. Instrum.* **63** 56