SPHERICAL GRAVITATIONAL WAVE DETECTORS; QUALITY FACTOR AND COOLING OF A SMALL CUAL6% SAMPLE

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A brief overview is given of the properties of spherical cryogenic antennae with special attention to small spheres operating at kHz frequencies including our MiniGRAIL project. MiniGRAIL is a 65 cm diameter spherical antenna made of CuAl6% with a resonant frequency of about 3 kHz and a sensitivity comparable to that of the advanced LIGO at that frequency. New results are given on the measurements of the mechanical quality factor of a 16 cm diameter spherical sample of pure CuAl6% and on rapid cooling of a small CuAl6% sample using a forced helium flow.

1 Introduction

MiniGRAIL will be the first of three [1]small spherical ultra-cryogenic antennae to be built in the near future. We plan to use inductive 2 mode resonant transducers coupled to low noise dc SQUIDs. Our initial goal is to achieve a $\beta \sim 0.1$ with a SQUID having a total noise energy $En \sim 10h\nu$. The effective temperature would be about 4 μK and the bandwidth 230 Hz. The strain sensitivity to a gravitational wave burst with a duration of 0.3 s will be about 10^{-20}. The quantum limited sensitivity will be in the order of 10^{-21} which is comparable with the sensitivity of the advanced LIGO at 3 kHz (Fig. 1). Possible gw sources for small spherical antennae could be bar instabilities in rapidly rotating neutron stars, excitation of the quasi-normal modes of small black holes and small black hole mergers [234].

2 Mechanical Quality Factor

We measured the mechanical quality factor of a CuAl6% test sample from Ital-Bronze [6] from 300 K down to 15 mK and compared the results with the sample of LIPS (Fig. 2). The Q factor was determined by exciting the resonant modes of the sphere with a piezo electric transducer and measuring the decay time τ , $Q = \pi\tau\nu$ with ν the resonant frequency [7]. We did not observe any absorption peaks, like the LIPS sample shows around 1 K, which indicates that there are no significant magnetic impurities. Mechanical quality factors up to 25 million were measured at the lowest temperatures.

3 Cooling down to 77 K with a Forced He Flow

The two ultra-cryogenic bar antennae Nautilus and Auriga are being cooled to 4.2 K using ^4He exchange gas. The cool-down time to 77 K is about 20 days [8]. An Al bar with l=3m and $\Phi = 60cm$ has an exchange area of about 6 m^2 and a total enthalpy of $3\times10^8 J$, which gives an effective exchange coefficient $H_{eff} \sim 29\ W/m^2$.

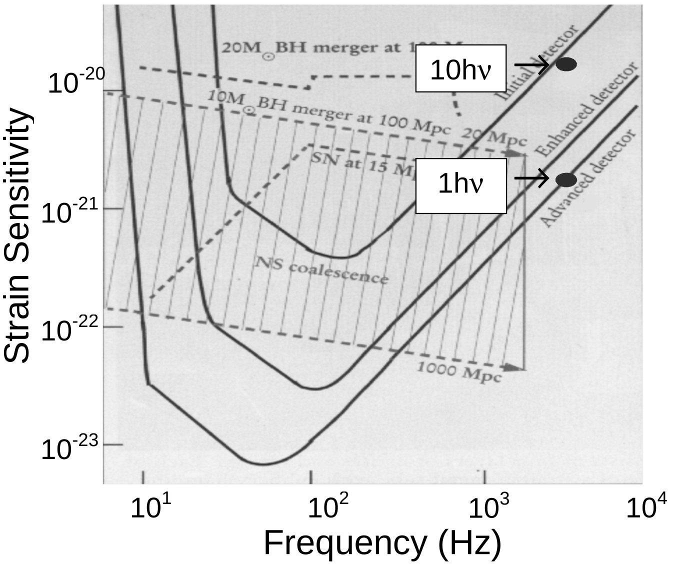

Figure 1. Strain sensitivity of MiniGRAIL in the initial goal and in the quantum limit compared to that of LIGO[5].

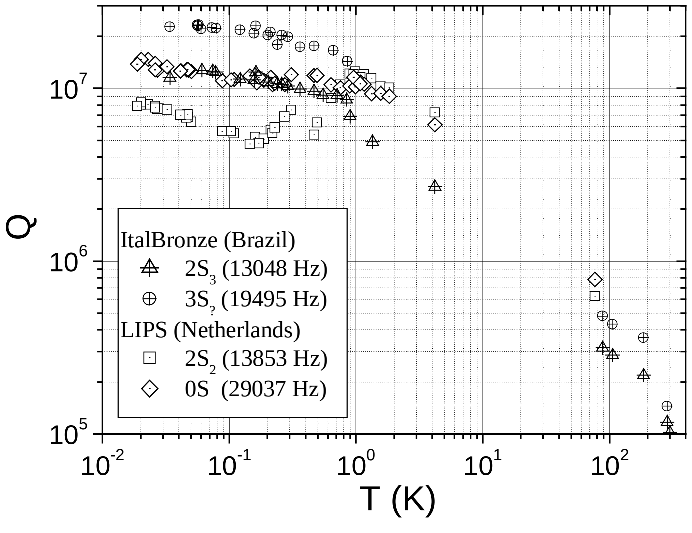

Figure 2. Comparison of the mechanical quality factor of 2 CuAl6 samples cast by different companies. The 65 cm sphere for the MiniGRAIL will be cast by ItalBronze (Brazil). The absorption peaks in the LIPS sample are believed to come from magnetic impurities.

For a CuAl6% sphere with an exchange area of $1.3m^2$ and total enthalpy of $10^8 J$, it would take more than 40 days to reach 77K. Cooling the antenna using a pre-cooled forced He flow could considerably reduce the cooldown time. Measurements were done on a 15 cm diameter CuAl6% sample where the ^4He gas first flows through a heat exchanger at 77 K and is then forced along the sphere from the bottom. The distance between the radiation shield and the sphere was about 1 cm. Figure 3 shows the relaxation time τ as function of the flow. For the highest flow of 120 mmol/s, which corresponds to $500\ mmol/s$ for a 65 cm sphere, the effective exchange coefficients were calculated. From this we could calculate the cooldown time to 77K of a CuAl6% sphere with $\Phi = 65cm$ to be 3.5 days. From room temperature down to 15 mK will take less than 5 days.

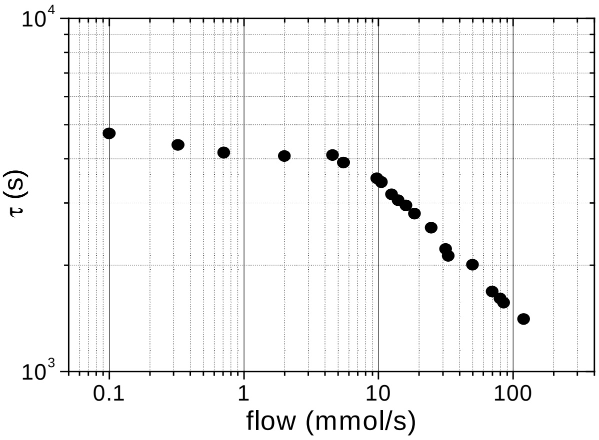

Figure 3. Relaxation time as a function of the flow for cooling from 300 to 77 K of a 15 cm diameter CuAl6 sample. The change in slope is due to the transition of laminar to turbulent flow.

References

1. MiniGRAIL, Kamerlingh Onnes Laboratory, UL, The Netherlands;
   Mario Schenberg, USP, São Paulo, Brazil;
   Sfera, INFN, Frascati, Italy.
2. J.L.Houser, J.M.Centrella and S.C.Smith, *Phys.Rev.Lett.***72** *,(9), 1314,(1994).*
3. K.D. Kokkotas and B.G. Schmidt, *gr-qc/9909058.*
4. S.F.P. Zwart and S.L.W.McMillan, *ApJ,* **528***, pg L17-L20, (2000).*
5. B.C. Barish and R. Weiss, *Physics Today, October 1999*
6. ItalBronze LTDA., Rua Campo Largo 657, CEP 03186-010, São Paulo.
7. A. de Waard, G. Frossati, J.P. Zendri, E. Coccia and V. Fafone, *Physica B,* **280***, 535, (2000).*
8. P. Astone et al., *Europhysics Letters,* **16***, pp 231-235, (1991).*