LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
-LIGO-
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Effects of high silica Q and coating Young's modulus on advanced LIGO

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This is an internal working note
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INTRODUCTION

The decision to pursue an advanced LIGO design using either sapphire or silica core optics will be made in the next few months. Recent measurements of Q's above 150 million in Suprasil 312 rods at Syracuse University by Ageev, Penn, *et al* require a reevaluation of the merits of a silica interferometer. The importance of the Young's modulus of the dielectric optical coating on either substrate material also needs further consideration. This note presents graphs meant to clarify the roles high silica Q's and coating Young's modulus play in the downselect decision.

One figure of merit of use when comparing different interferometer designs is the astronomical reach of the instrument when detecting binary neutron star inspirals. The interferometer sensitivity is limited in its most sensitive band around 100 Hz by internal thermal noise, so this figure is particularly dependant on mirror and coating mechanical parameters. Calculations were made using BENCH v1.13 to find the distance that a single interferometer would be capable of detecting an inspiral. The standard list of interferometer parameters contained in IFOMODEL v1.13 was used, with four values allowed to vary; sapphire and silica substrate Q, coating mechanical loss ϕ, coating Young's modulus Y, and beam spot size.

DISCUSSION

Figure 1 shows astronomical reach for advanced LIGO with different values for substrate Q in both a silica and sapphire configuration. The silica Q has been allowed to be as high as 200 million, as this is the highest Q measured to date in a silica sample (private communication, A. Ageev and S Penn) in a flexural mode near 400 Hz. Measurements of silica Q's above 50 million show a frequency dependence where the loss decreases at lower frequencies, so it is possible that even higher Q values could be appropriate when calculating LIGO thermal noise around 100 Hz. There is also no compelling reason to think the measurements by Ageev and Penn represent a maximum possible Q for fused silica.

The effect of coating Young's modulus is considered in Figures 2 and 3. Here four different cases are compared: two silica and two sapphire. The silica cases have Q values of 130 million and 200 million while the sapphire has Q's of 200 million and 60 million. The low Q of 60 million in sapphire has been seen by Numata *et al* (Physics Letters A, **283** (2001) 162), while 200 million in sapphire has been seen by Rowan *et al* (Physics Letters A **265** (2000) 5). Coating thermal noise has a local minimum when the coating Young's modulus is matched with that of the substrate. This can been seen in Figures 2 and 3, where the silica curves peak at 70 GPa, the modulus of silica, and the sapphire curves are rising to a peak at 400 GPa, the modulus of sapphire.

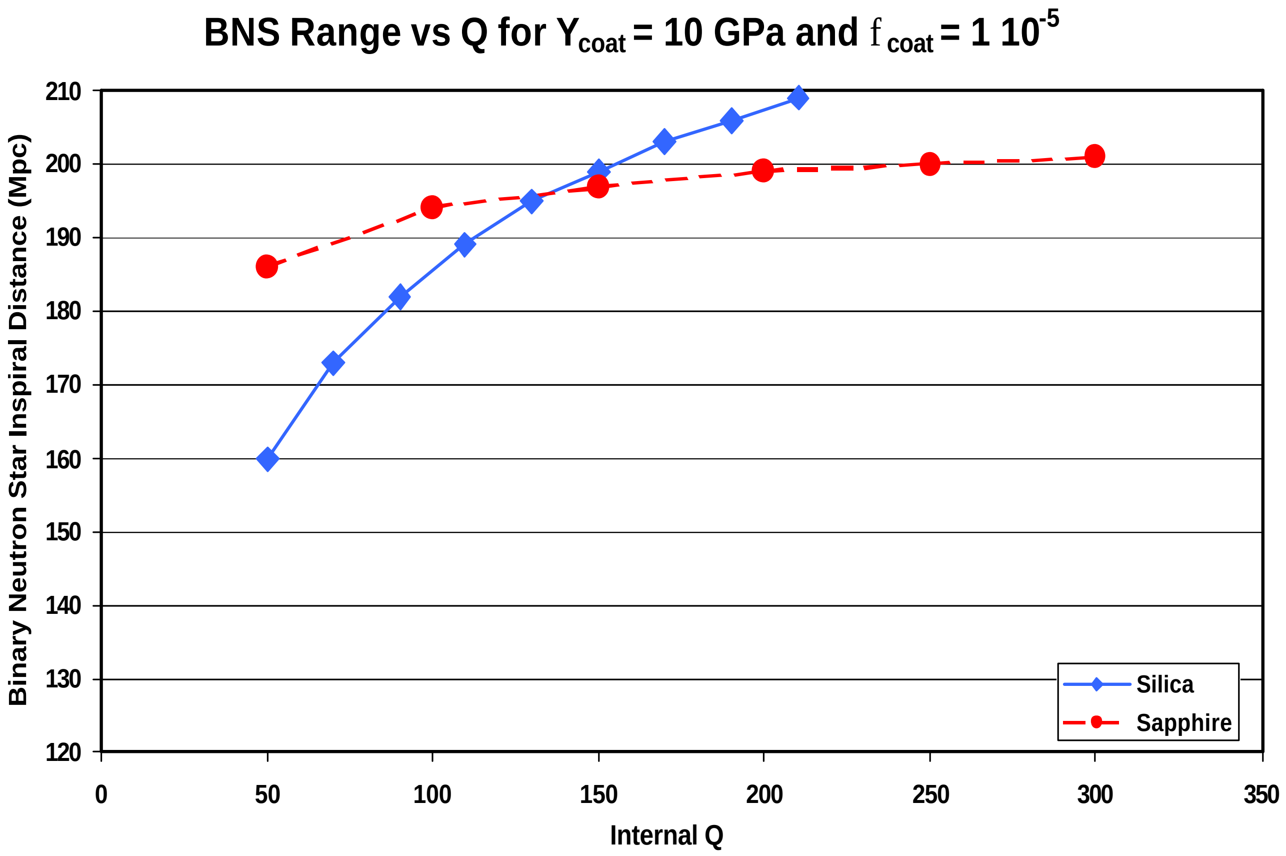

Figure 1 – Sensitivity of advanced LIGO to binary neutron star inspirals vs. internal Q using fused silica or sapphire mirrors.

Figure 2 shows advanced LIGO sensitivity vs. coating Young's modulus for a fixed coating ϕ of 1 10^{-5}. This loss represents about an order of magnitude decrease from what has been observed in tantala/silica coatings. Figure 3 show sensitivity vs. modulus with a coating ϕ of 5 10^{-5}.

For all cases a constant coating thickness of 7 μm on ETMs and 3 μm on ITMs was assumed. These numbers are consistent with a tantala/silica coating and the required transmittances for the optics. It is known, however, that unmodified tantala/silica coatings do not have coating mechanical loss in the 10^{-5} scale. The thicknesses of actual coatings used would depend on the indices of refraction of the two coating materials, and this thickness would have to be taken into account when determining sensitivity.

The next two graphs, Figures 4 and 5, show the sensitivity effects of the coating loss at two different fixed values for the coating Young's modulus. The same four cases of substrates as in Figures 2 and 3 are again considered here. The overall higher Young's modulus of sapphire causes the slope of sensitivity vs. coating loss to be gentler for sapphire than silica. When the coating Y is better matched to that of silica, however, better sensitivity can be achieved at low coating loss with a silica interferometer than with one built with sapphire optics.

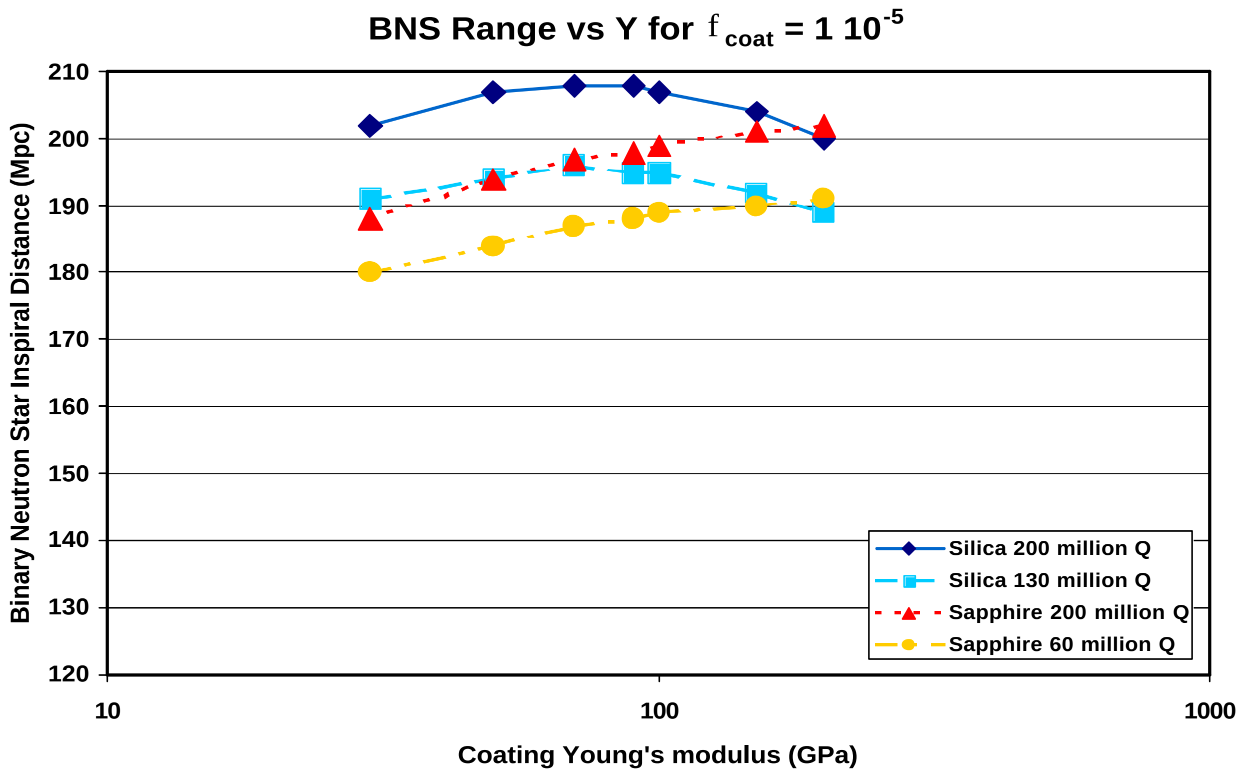

Figure 2 - Sensitivity of advanced LIGO to binary neutron star inspirals at a fixed value of 1 10^{-5} for coating ϕ.

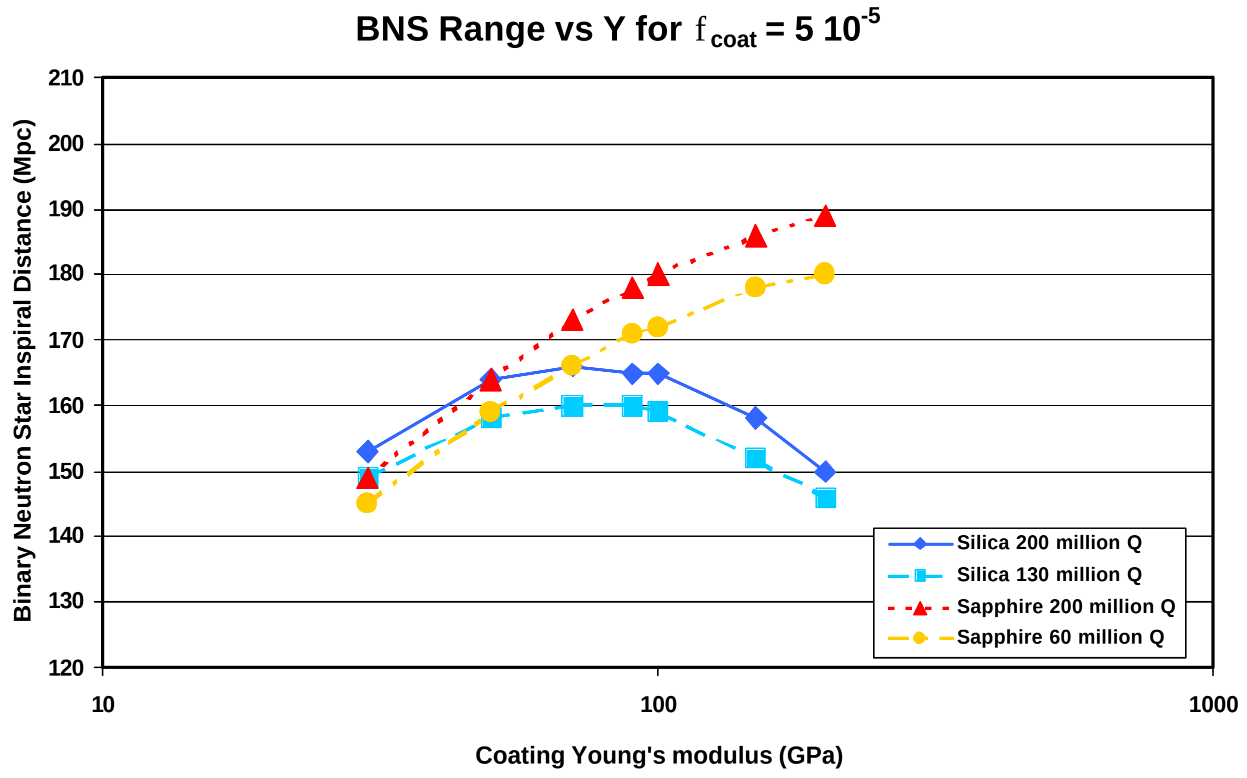

Figure 3 - Sensitivity of advanced LIGO to binary neutron star inspirals at a fixed value of 5 10^{-5} for coating ϕ.

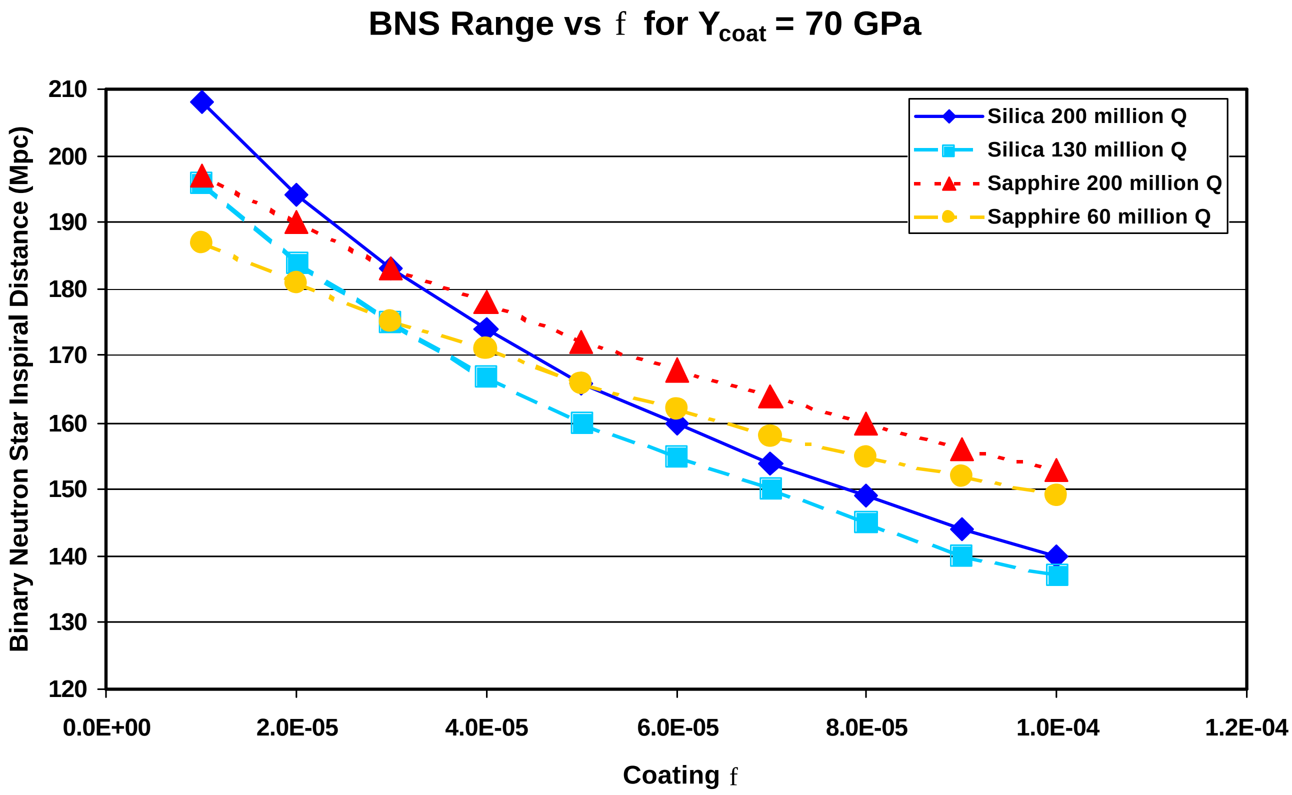

Figure 4 – - Sensitivity of advanced LIGO to binary neutron star inspirals at a fixed value of 70 GPa for coating Young's modulus.

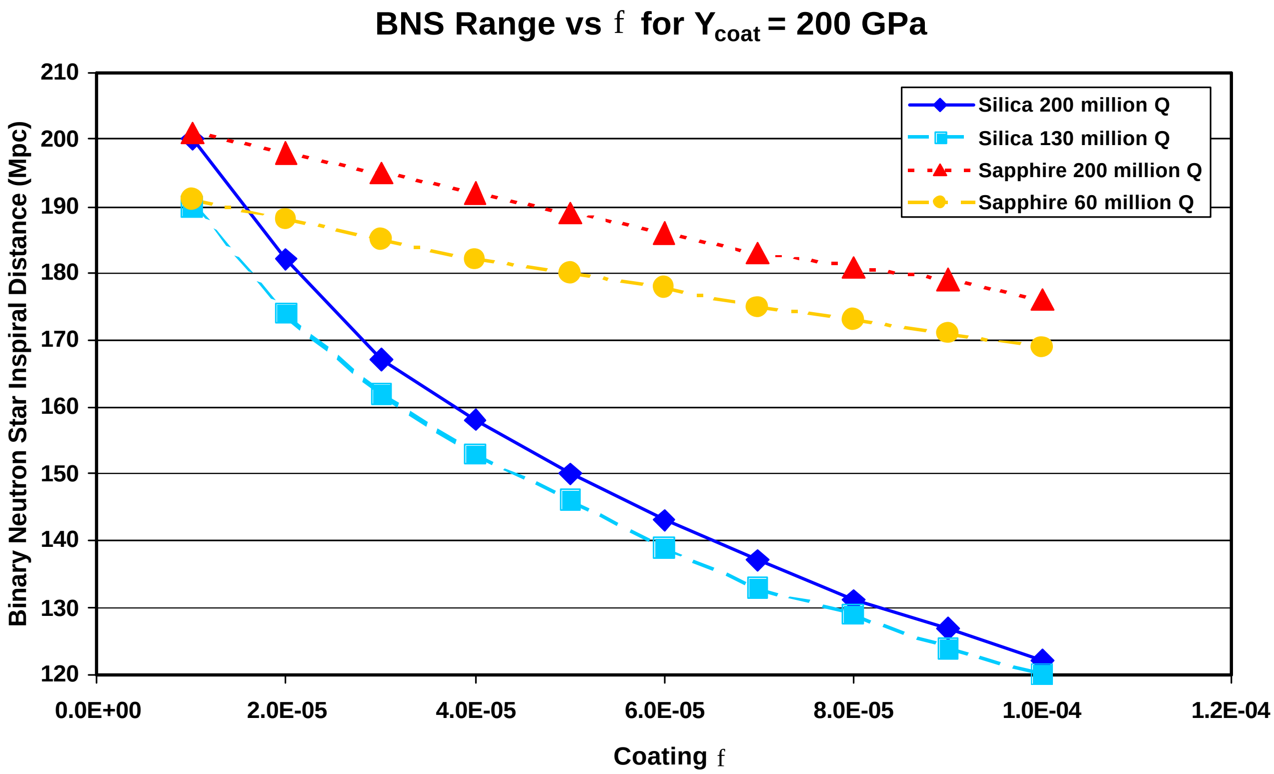

Figure 5 – Sensitivity of advanced LIGO to binary neutron star inspirals at a fixed value of 200 GPa for coating Young's modulus.

In Figures 1-5, the laser spot size for the silica configuration was 5.5 cm. For the sapphire case, a larger spot size of 6 cm was used. Although larger spot size makes the optical cavities more nearly unstable, this was allowed in the sapphire case to reduce thermoelastic noise. Coating thermal noise also goes down with spot size, although not as fast as thermoelastic. The above Figures show the importance of the coating noise when comparing silica and sapphire interferometers. It is instructive to consider the case of all silica mirrors with a spot size of 6 cm. The same scenario as Figure 3 with the larger spot size is shown in Figure 6.

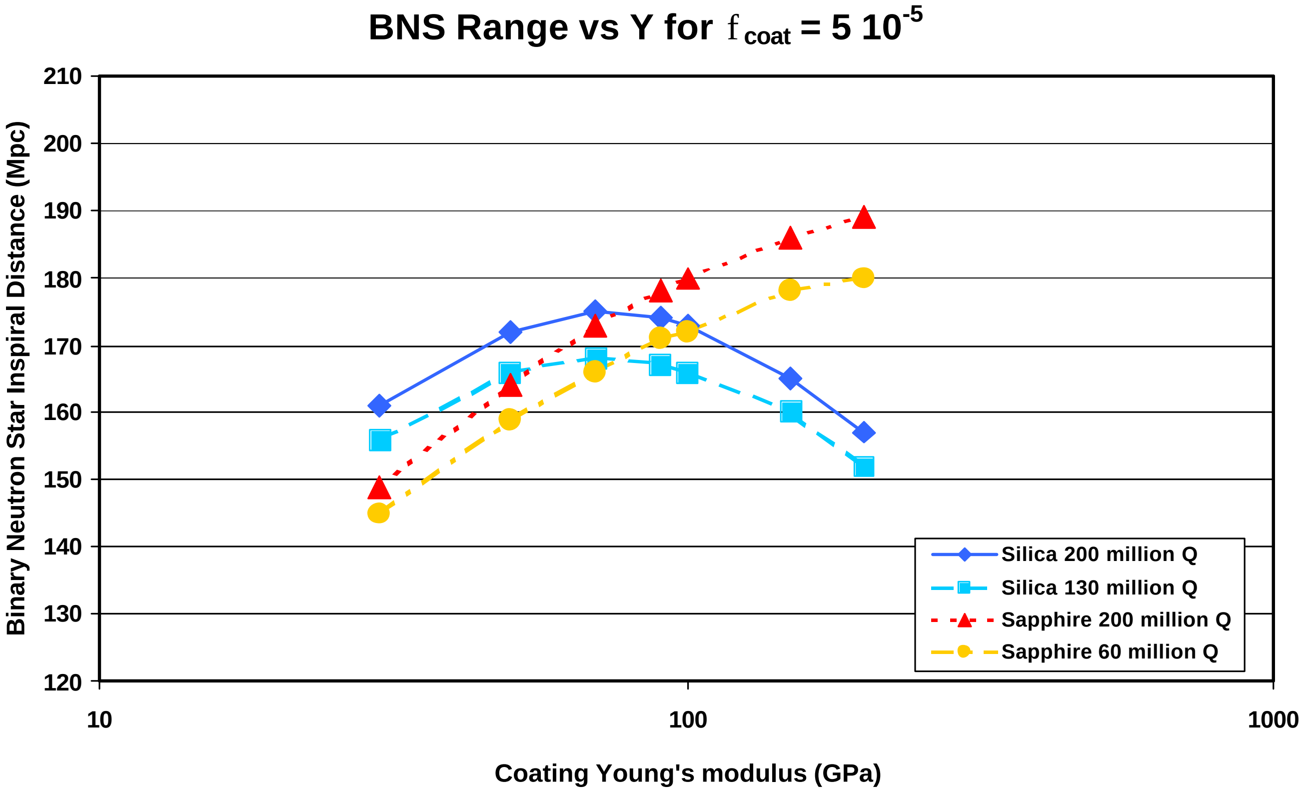

Figure 6 – Sensitivity of advanced LIGO to binary neutron star inspirals at a fixed value of $5\ 10^{-5}$ for coating ϕ using a laser spot size of 6 cm instead of 5.5 cm.