Report on Calculations Regarding ITM and Wide-Angle-Baffles (WAB) in the Cryostat

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Short Introduction and describtion

Regarding the WABs and ITMs in KAGRA, calculations with the simulation tool “LightTools” have been done in order to reveal the most efficient design of WABs corresponding to questions about scattering, size, and costs of the baffles. For all three parameters, a minimum is desired especially for the scattering and the size as for the first, the ITMs are very crucial parts of KAGRA and thus sensible to even small amounts of scattering. And as for the ladder, the space in the cryostat is limited and therefore as smaller the WAB will be as better the situation becomes.

As a starting point for the simulations, the CAD-sketch of the ITM together with its recoil mass has been used and imported into “LightTools”. In Fig.1 a close view on the front-side (the side facing the cavity) of the ITM is shown. The image has been taken with “LightTools” showing also the by the laser illuminated area on the mirror. This area actually worked as the basic light-source in the simulations as we are only interested in the light scattered by the mirror and a close-to-reality simulation with a separated laser source and a structured mirror-surface would not work properly as such tiny structures are impossible to be modeled by “LightTools”. The distribution of the scattered light, instead, has been calculated with an own written program according to the generalized Harvey-Shack (GHS) theory and implemented into the model, defining the angular probability distribution (BRDF) of the scattered light.

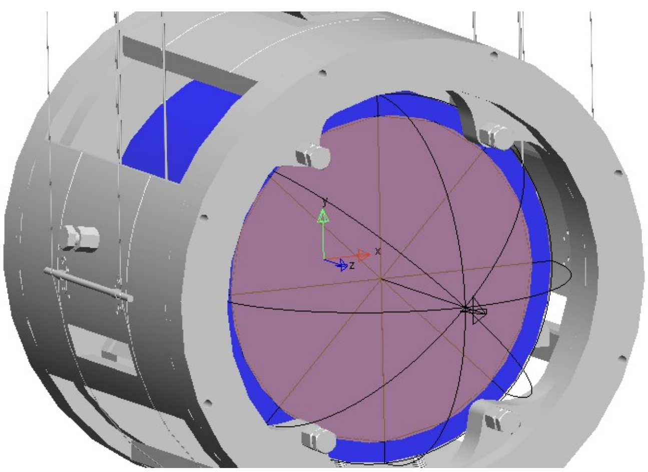

Figure1: Model of the ITM with view on the front-side, facing the cavity. In blue the mirror itself is shown while the grey surroundings illustrate the recoil-mass with the respective wires. The high-lighted area on the mirror is the by the laser illuminated surface.

The intensity, however, is not homogeneously but according to that of a Gaussian beam ($\sigma=36\,mm$) radiated from that surface. The overall intensity of the scattered light has been set to 1W. It should be noted that the scattering has been set to zero for an interval of $\theta=[0,\pi/90]$ in order to concentrate on the outcome of scattering at wider angles (θ is the angle of radiation of the light relative to the mirrors surface normal). The total scattering, however, is for the given constraints: $TS\approx 2.3\cdot 10^{-7}$.

In addition, the material of the recoil-mass has been set to be Titanium, meaning that the program did the simulations with experimentally received data of the BRDF of an unpolished Titanium-plate (measurements done at NAOJ).

Results for back-scattering

Apart from the main purpose of these simulations to find out the best WAB design, first the back-scattering from the recoil-mass without any WAB has been analyzed. It turned out that from the scattered light 0.015% would be scattered back toward the “source” of the scattered light on the mirror. In Fig.2 the illuminance-map of this back-scattered light is shown. Obviously, an enhanced scattering can be found especially around the positions of the earthquake-stops. Apart from this, the back-scattering is more or less homogeneously distributed on the “source”-area. However, the angular distribution of the back-scattered light shows that most of it is concentrated when $\theta=\pi/4\ldots\pi/2$.

From these results, the basic impact on KAGRAs sensitivity can be calculated. This has been done again with an own written program. The outcome is summarized in Fig.3.

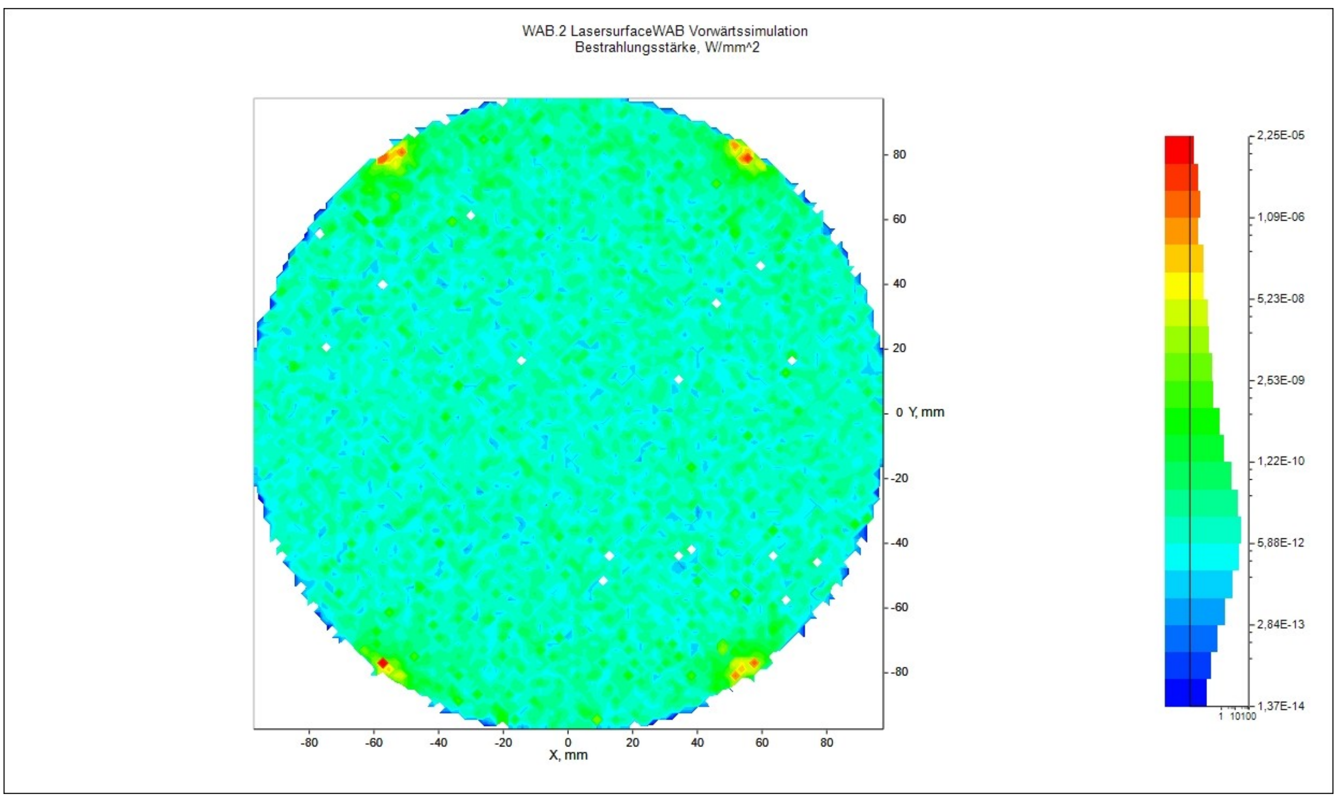

Figure 2: illuminance map of the back-scattered light on the “source”-area (illuminated area by the laser). The values of illuminance are given in W/mm^2 .

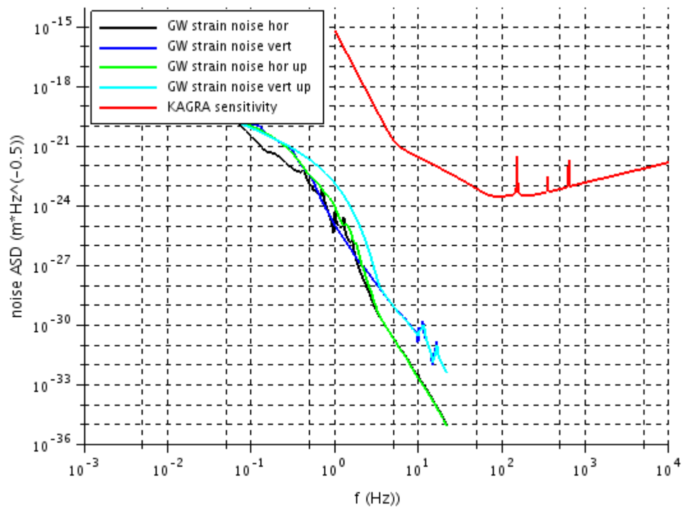

Figure 3: graph of the impact of the back-scattered light on the sensitivity of KAGRA.

Basically, there is no impact on the sensitivity of KAGRA. The difference between the goal-sensitivity curve (red) and the noise amplitude-spectra density (ASD) of the back-scattered light is more than 7 or 8 orders of magnitude (calculated by assuming a suspension system that is similar to that of the beam splitter). In Fig.3 there are four different curves given showing the noise ASD. This has been made to show first the two different cases of vertical and horizontal vibrations of the recoil mass and second the difference between up-converted and "normal" vibrational influence.

Results for WAB-design

As WABs shall reduce the scattered light at wide-angles, their size and position can be reduced to be close to the mirror (or surface) of interest. Anyway, a careful chose has to be made on what angles one should concentrate. In this case, the main limitation is on the one hand the "source"-area, where the baffle can be seen as a kind of aperture, and the distance to the inner wall of the cryostat.

In a first approach, the baffle is thought to be a cylinder, 300 *mm* long and 320 *mm* in diameter, thus, slightly bigger than the recoil-mass of the ITM. Furthermore, it shall have on its front-side a doughnut-shaped plate, realizing the aperture while the back-side is covering approximately 16 *mm* of the recoil-mass (see Fig.4). The main purpose of this is to fully cover the front-side of the ITM and to prevent any scattered light-beam to reach the inner wall of the cryostat in a longitudinal range of $\theta=\pi/6\ldots\pi/2$. The WAB is supposed to consist of Aluminum covered with SolBlack.

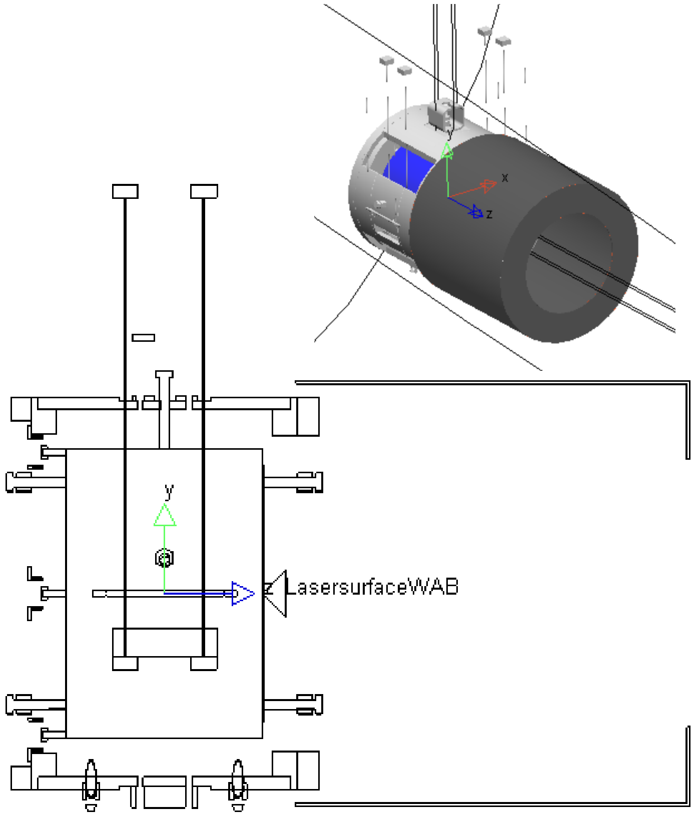

Figure 4: cross-section of the ITM-WAB system. On the left there is the mirror and the recoil-mass. On the right, the WAB can be seen. In the small picture above, the full view of ITM and WAB is presented.