



LIGO Laboratory / LIGO Scientific Collaboration

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**Profiles of ETM11 and ETM14
latest ETM coating by LMA**

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1 Introduction

The effects of the new ETM coatings on ETM11 and ETM14 for aLIGO have been studied. The PSD of the spiral pattern around 8mm is down by factor 3 or so. The power in the cone with the opening angle of 0.14mrad is also down by a similar amount. The phasemap of ETM11 shows some asymmetry, but the degradations of the contrast defect (CD) on the dark port and the higher order mode (HOM) in the bright port are reasonably small.

In v5, comparisons of PSDs before and after coating are added, which show difference between a pair of mirrors coated together.

2 Mirror profiles

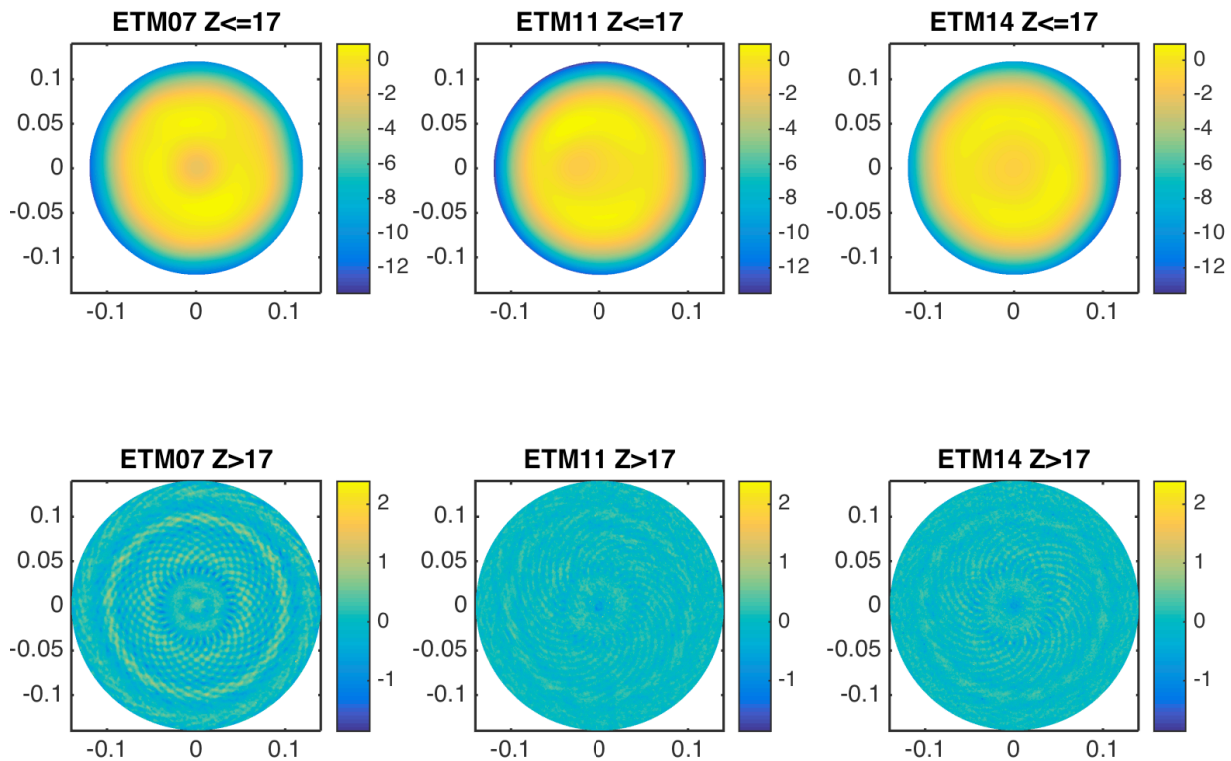


Figure 1 Phasemaps with previous coating (ETM07) and with new coatings (ETM11, ETM14)

Figure 1 shows the phasemaps of ETMs with previous coating (ETM07) and with new coatings (ETM11 and ETM14). The top group are the maps with Zernike(n,m) amplitudes with $n \leq 17$ using data within aperture of 32cm, i.e., low frequency and smooth components, and the bottom with $n > 17$, high frequency components. The color ranges are chosen to be the same in each top and bottom group. The smooth component of the ETM11 shows some asymmetry, but the high frequency components of ETM11 and ETM14 are equally better than ETM07.

Fig.2 compares the cross sections of these maps along the axis, i.e., $\text{map}(x, y=0)$. In the low frequency components, the dip at the center in the old coating is reduced, and the asymmetry in the ETM11 map is visible. The high frequency components show reduction of amplitudes in general, but the new coatings seem to be a little noisier.

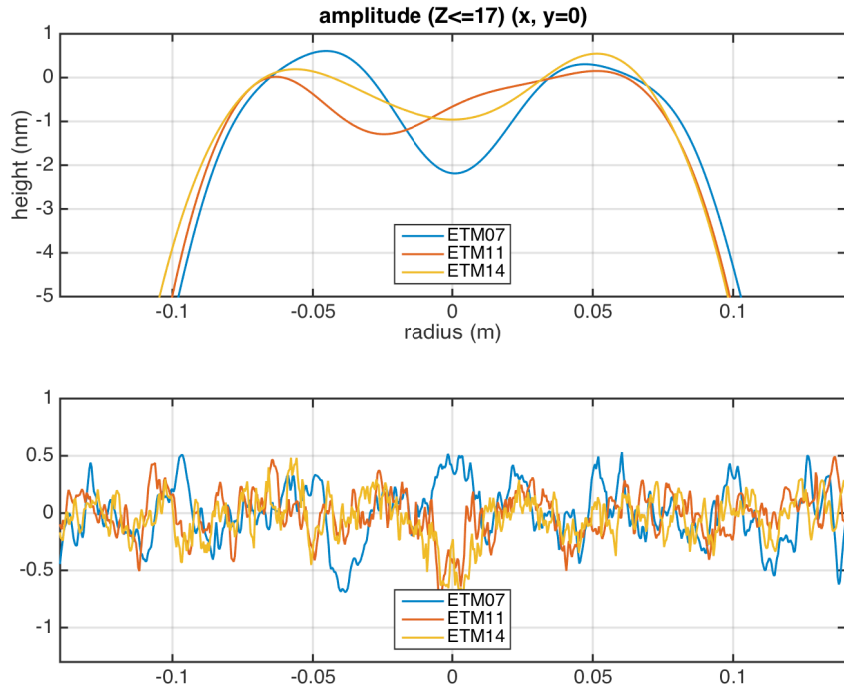


Figure 2 Cross sections of ETM maps

Fig.3 compares the PSDs of ETMs with previous coatings used at LLO and LHO and the new pair, red lines. The peaks at 8mm are down, and the high frequency parts are higher than old PSDs.

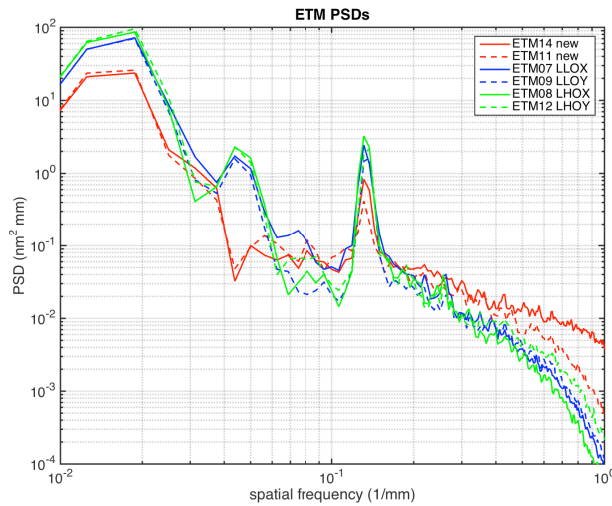


Figure 3 ETM PSDs

In previous versions of this document, 1D PSDs were calculated by integrating 2D PSD along one axis, while, in this document (v3) and later, 1D PSDs are calculated by integrating over azimuthal angle for each magnitude of the frequency, based on the phasemap within 160mm aperture. See LIGO-T1100353 about the details of the difference of these two definitions of 1D PSD. The spiral pattern is placed along a circle, and this definition of 1D PSD seems to exhibit the characteristics of the spiral pattern more clearly, as was demonstrated by Jerome Degallaix.

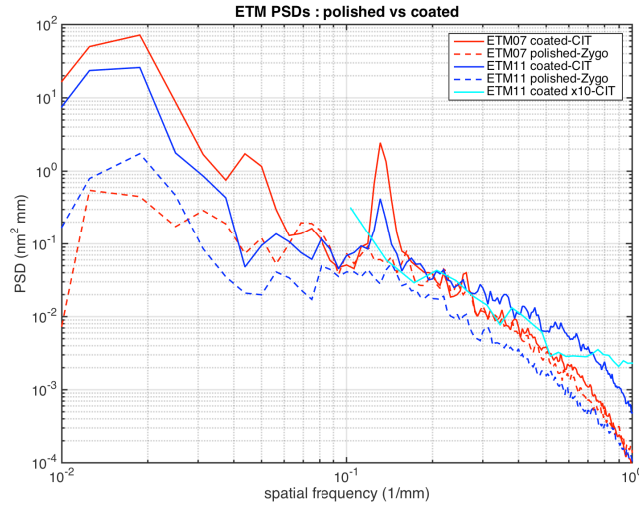


Figure 4 ETM11 PSD high spatial frequency

In Fig.4, the PSDs of polished surface maps measured by Zygo are also shown for ETM07 and ETM11. For ETM07, the PSD of the coated map is almost the same as that of the polished surface, but the PSD of the coated ETM11 (solid blue) is higher than that of the polished surface (dashed).

The efficiency of measuring the amplitude degrades as the frequency comes to the “measurement upper limit”. Because of this, the higher frequency amplitude may not be accurate. In order to increase the accuracy in the high frequency region, the phasemap of ETM11 was measured with factor 10 magnification. The line “ETM11 coated x10-CIT” is the PSD of the coated surface measured with the magnification of 10. The data used is in the central region rectangular region, $x = -5\text{mm} \sim 24\text{mm}$ and $y = -14.5\text{mm} \sim 14.5\text{mm}$ with spacing of 0.047mm . The result is shown in Fig.4 with cyan color. The solid blue (no magnification) and the cyan (x10 magnification) are reasonably consistent and both are significantly higher than the polished surface, dashed blue line.

The relation between the PSD of the polished and that of coated surface of ETM14 is the same as that of ETM11 shown in Fig.4. From these observation, the PSDs of the coated surfaces of ETM11 and ETM14 are significantly higher that of the polished surface by Zygo.

Fig.5 compares the PSDs around the 8mm peak by the spiral pattern. Magenta data points are PSDs of the new maps scaled up by factor 3. These are comparable to the PSDs of ETMs used at LLO. Two PSDs with the same color are coated together and, for all three cases, the magnitudes are different by a similar amount.

Fig.6 is the same one as Fig.5, but one of the PSDs (shown in dashed lines) in each pair of ETMs coated together is scaled by 1.6. When two lines (solid and dashed) with the same color are compared, they are of comparable size after one is scaled by 1.6. By some reason, the spiral amplitude of one mirror is 20-30% larger than that of the partner mirror coated together.

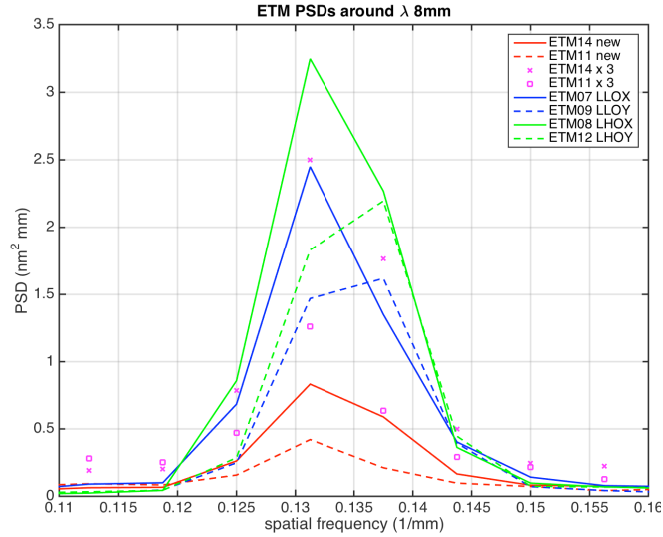


Figure 5 ETM PSDs around the 8mm peak

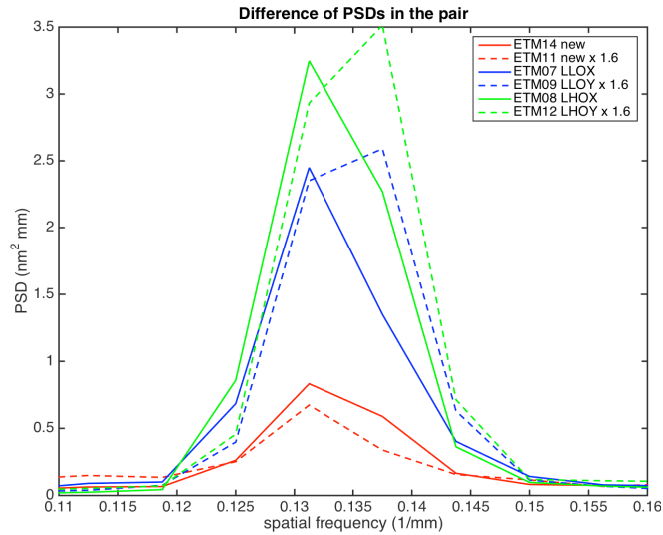


Figure 6 PSD difference in the same pair

3 Simulation setup

Analysis by FFT-based simulation was done using FOGP13 to study the effects of the ETM maps. The power recycled FP Michelson configuration for L1 was used with the following two changes.

1. The RoC of the ETMs are set to be 2250m, which is the measured RoC of new mirrors.
2. The BS05 maps are used, instead of BS02, which has large aberrations and may hide some problems by the ETM coating.
3. An adhoc loss of 40ppm per arm is added by hand to make the arm round trip loss to close to the measurement at LLO.

All other parameters and maps of ITMs and CPs are the ones of L1. MICH is adjusted so that the power in the dark port becomes minimal. The power terms in the ITM transmission maps are

canceled by adding simple lens terms to each ITM maps, but other aberrations are included in the simulation.

4 Effects of the phasemaps on the IFO performance

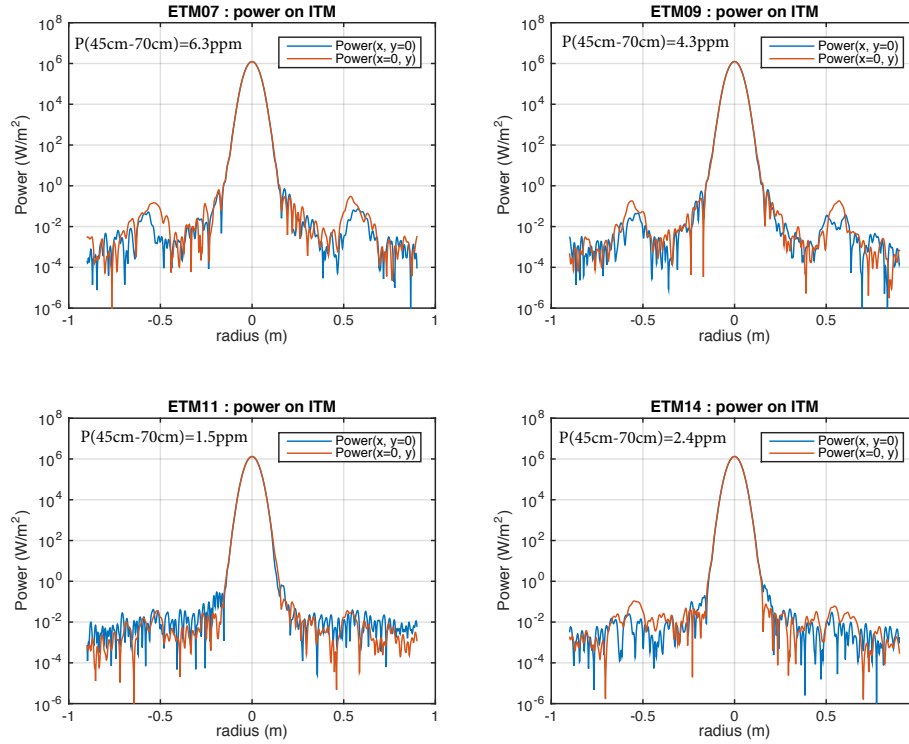


Figure 7 Power in the ITM plane with different ETM maps

Fig.7 shows the power distribution of the field on the ITM plane, coming from the ETM. The effect of the spiral pattern on the ETM coating shows up at around 55cm from the center of the beam. As can be perceived from the reduction of the PSDs at 8mm, the power in this region is appreciably down.

	ETM14	ETM11	ETM07	ETM09	ETM08	ETM12
power (45cm~70cm)	2.4	1.5	6.3	4.3	7.7	5.2
round trip loss	74	73	80	78	80	80
HOM	226	283	208	288	227	312

Table 1 Field in a FP arm with different ETMs (units in ppm)

Table 1 shows some of the characteristics of fields in the FP arm cavities. ETM11, ETM07 and ETM08 are placed in the x arm with ITM04 as ITM, and other 3 ETMs are placed in the y arm with ITM08 as ITM.

The second row is the fraction of the power within the radius of 45cm to 70cm in the ITM place. Compared to the old coatings, the power in this band is reduced by factor 2.5 to 3.

The round trip is the sum of various absorptions, micro roughness loss and the loss by the figure, and the adhoc loss of 40ppm is included. As is seen from the third and fourth rows, the overall loss and the loss of the TEM00 mode are improved when ETMs with new coatings are used.

	ETM11-ETM14	ETM07-ETM09	ETM08-ETM12
PRG	44	41	41
Contrast Defect	93ppm	84ppm	75ppm
HOM on bright port	975ppm	976ppm	1000ppm

Table 2 Power Recycled FP Michelson performance with different ETM sets

Table 2 compares characteristics of the power recycled FP Michelson cavity explained in Sec.3 when different pairs of ETMs are used. The overall performance almost stays the same.

5 Comparison of PSDs before and after coating

PSDs of ETMs were compared before and after the LMA coating. The phasemap measured by ASML after polishing was used to calculate the PSD before the coating, and the phasemap measured by LIGO/Caltech using Zygo IFO was used to calculate the PSD after the coating.

From the phasemap, power and tilt terms were removed using the central 160mm aperture region, and the PSD was calculated using the data in the central 200mm aperture region. The 1D PSD is calculated by integrating the 2D PSD over azimuthal angle.

Fig. 7 shows the comparison of PSDs of six ETMs before and after coating. Fig. 8 is the ratio of PSDs with coating / without coating. The two figures in Fig.8 are identical, except for the frequency range. Mirrors shown with the same color are coated together, but the difference of the coating effect are different. E.g., the ratio of ETM07 is 4-5 times smaller than ETM09 in the spatial wavelength shorter than several cm. This may be related to the difference of the spiral pattern heights shown in Fig.5 and Fig.6.

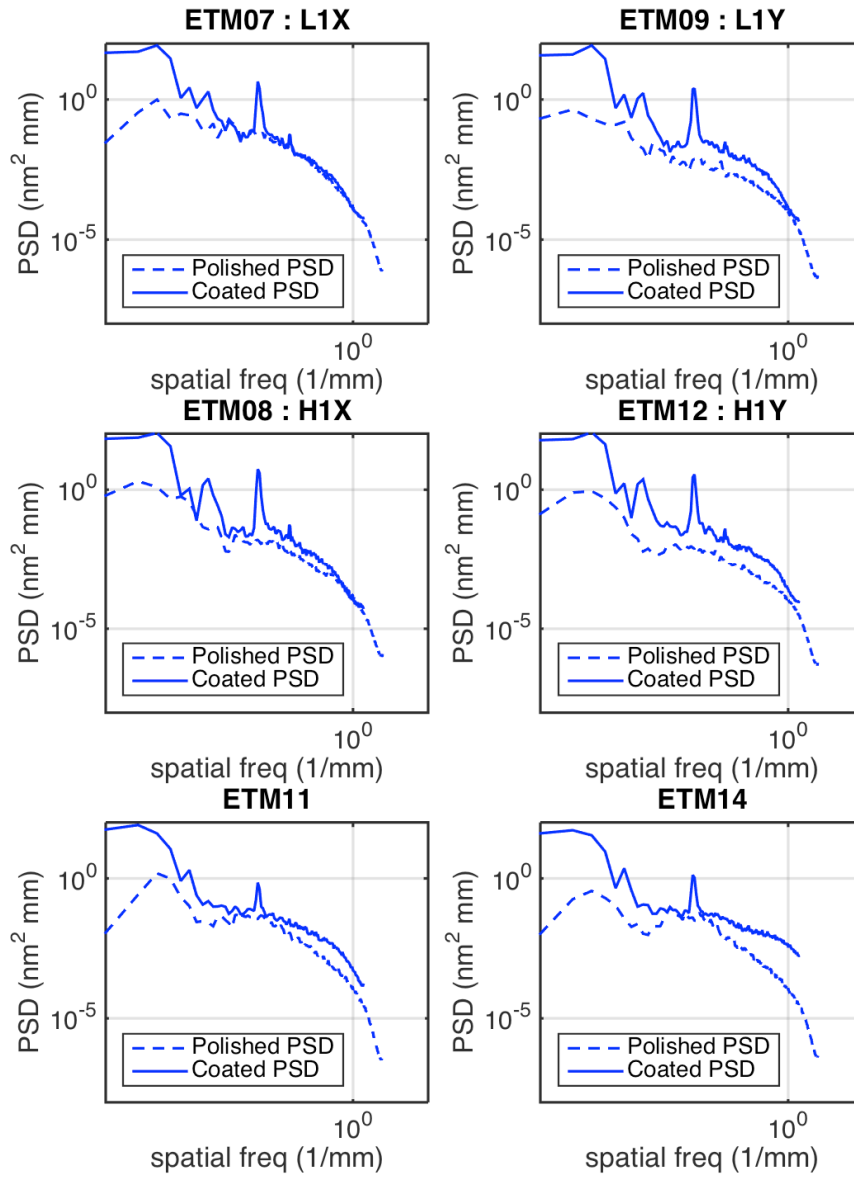


Figure 7 PSDs of ETMs, before and after coating

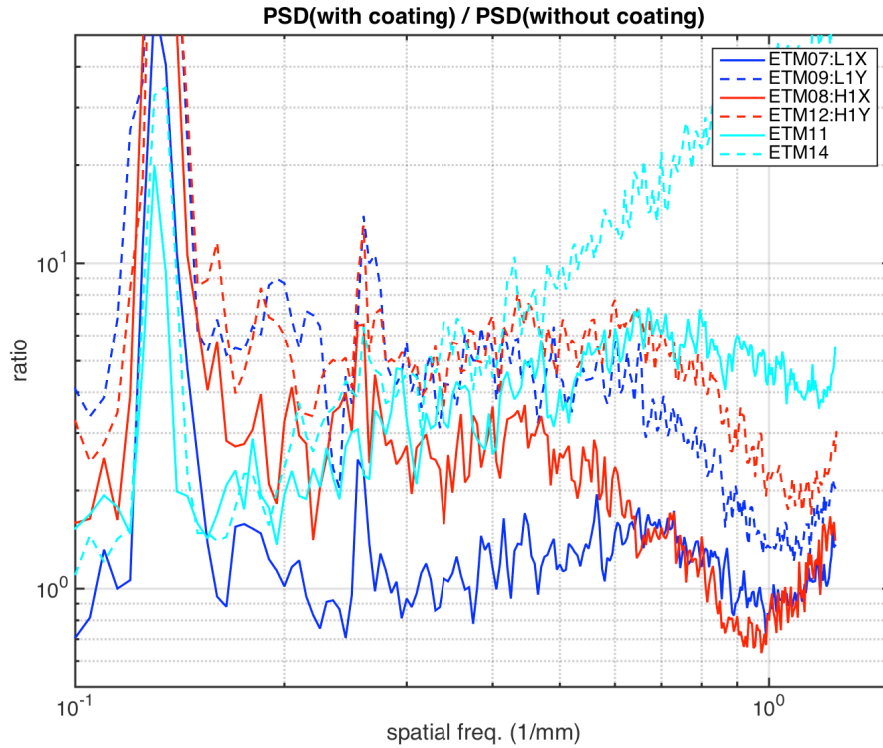
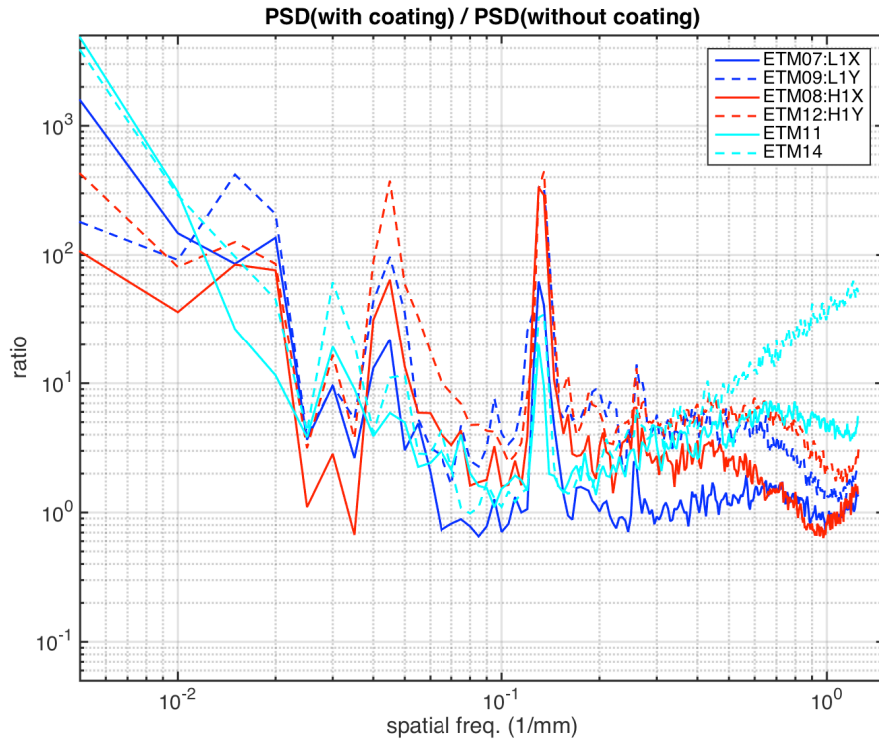


Figure 8 Ratio of PSDs, with / without coating