Improving the substrate flatness: the corrective coating technique.

Gravitational Waves Advanced Workshop

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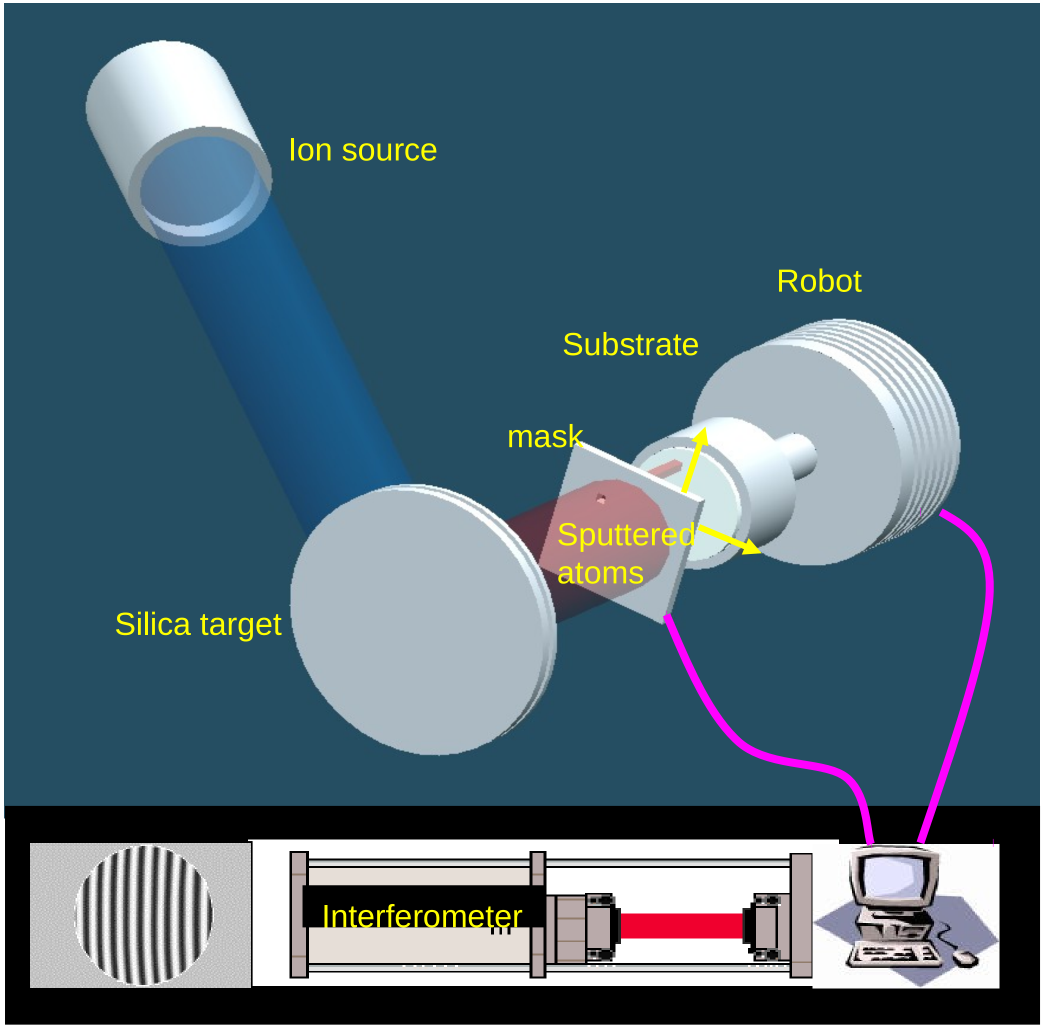
Outline

- What is the corrective coating technique?
- Simulation of the corrective coating.
- Experimental correction of a Virgo substrate.
- Losses in Advanced Virgo arm cavity.
- Conclusion.

What is the corrective coating technique ?

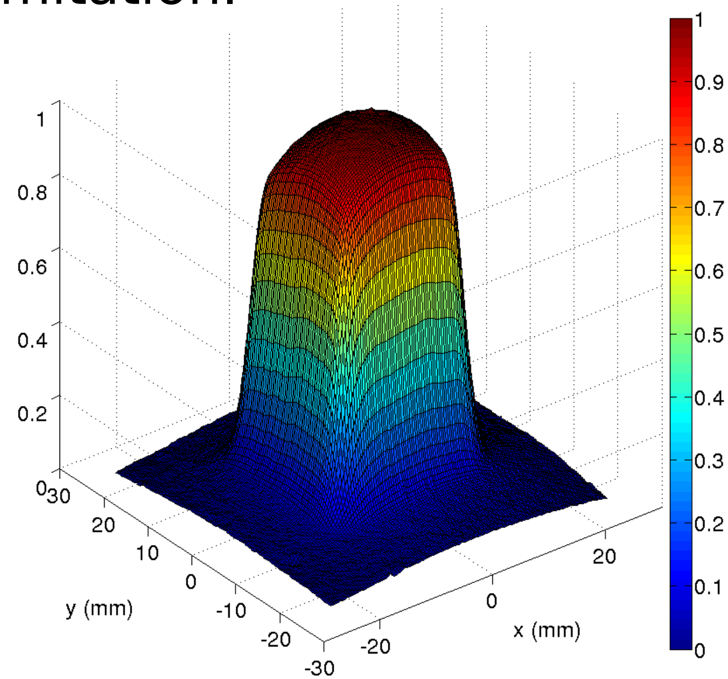
Principles of the corrective coating



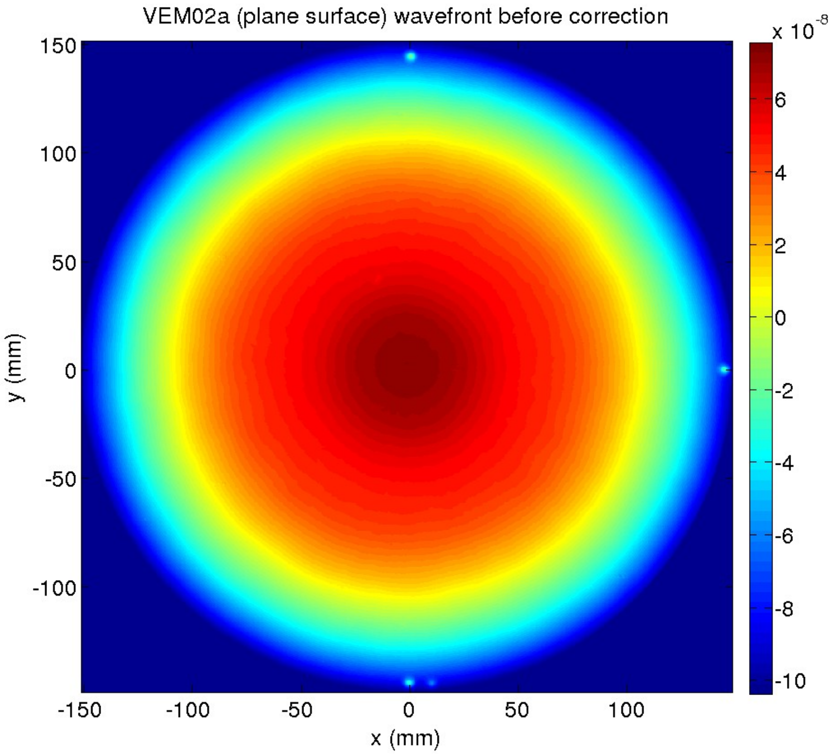
- Goal: Bring substrate flatness down to 0.5 nm RMS (on 150mm) or less.
- How:
  - Measure the substrate surface:
    - Phase Shifting Interferometry.
  - Deposit silica where it is needed :
    - IBS
    - Mask
    - Robot (built at LAPP)
- Correction down to cm scale (mask size)

Correction of a Virgo substrate

- Correction of a Virgo substrate (VEM02a) with a 21.5 mm square mask.
- Correction of a plane surface because of metrology limitation.



Deposition imprint through the 21.5 mm mask.



RoC ~ = -70 km

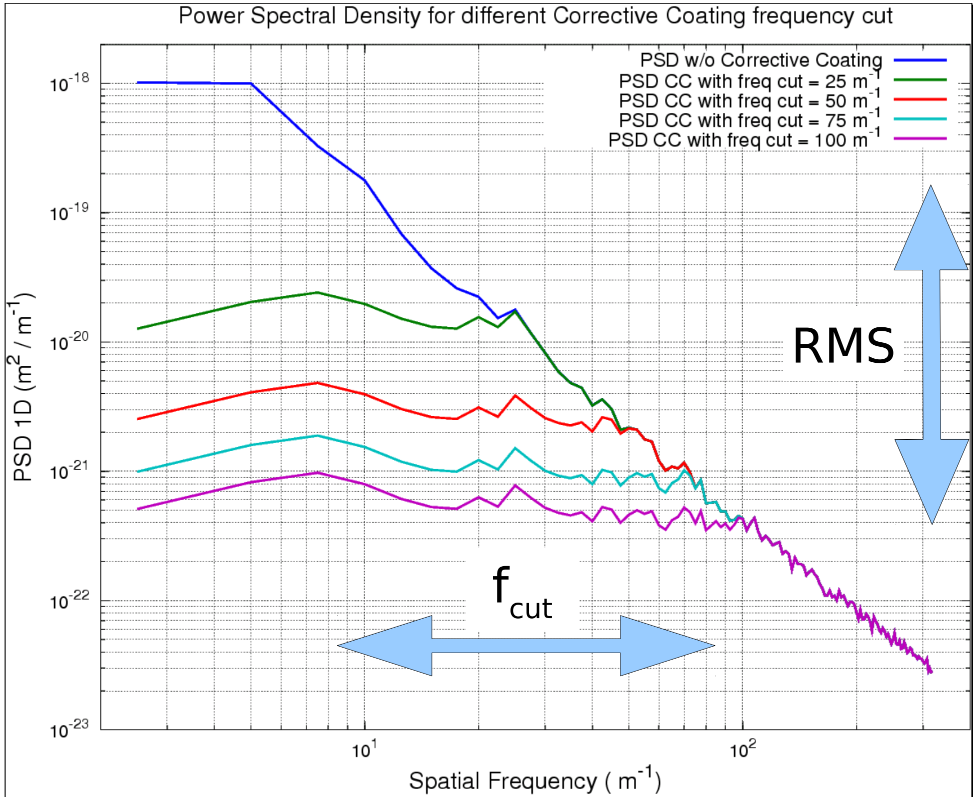
Simulation of the corrective coating

Simulation of the corrective coating

- Simulations have been done in the spatial frequency domain.
- <u>Assumption:</u> Corrective coating flatten the PSD below a frequency cut related to the mask size.

f_{cut} = 1 / mask size.

- Applied a filter to the 2D PSD of the substrate surface. Filter acts as a high pass filter.
- Recompute the map by inverse FFT.



Results of simulations

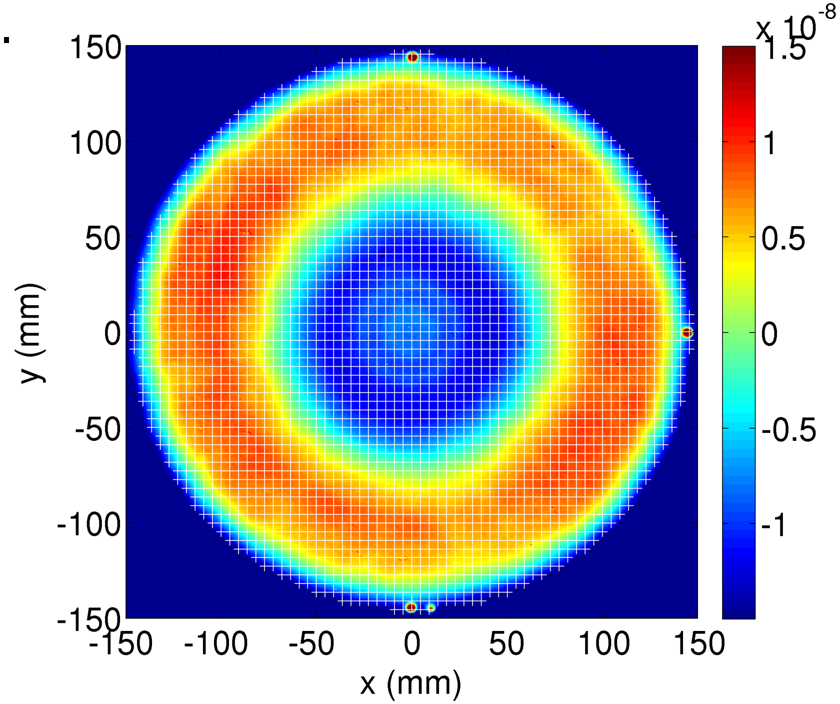
- 1000 simulations of FP arm cavity with simulated correction of surfaces with different initial flatness and corrective frequency cut.
  - % of simulations giving RTL < 50 ppm (Advanced Virgo specification on losses in FP arm cavity).

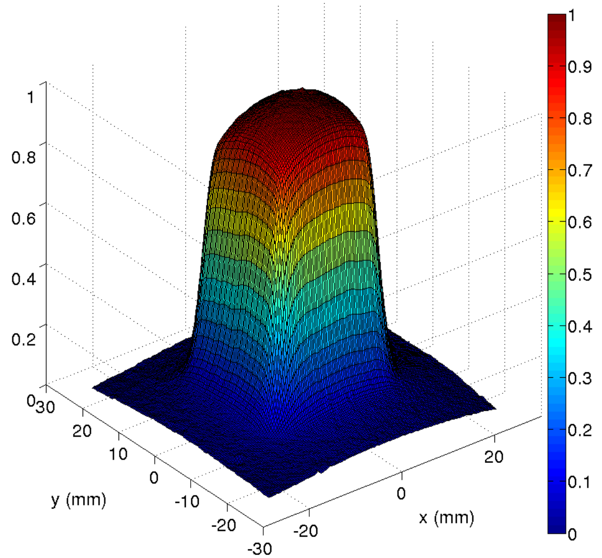
	Fc = 0 m^{-1}	Fc = 25 m^{-1}	Fc = 50 m^{-1}	Fc = 75 m^{-1}	Fc = 100 m^{-1}
RMS = 4 nm	0 %	0 %	1 %	18.8 %	56.8 %
RMS = 3 nm	0.3 %	0.8 %	23.8 %	69.2 %	94.8 %
RMS = 2 nm	13.9 %	33.2 %	88.4 %	99.3 %	100 %
RMS = 1.5 nm	61.3 %	71.6 %	95.9 %	99.6 %	100 %

- We need to correct a 1.5 nm RMS substrate at a frequency cut of 50 m^{-1} to meet the Adv. Virgo specifications of 50 ppm RTL in the arm cavity.

Simulation of the corrective coating process

- Simulation of the process with real imprints.
- Substrate moves along a regular grid with a spacing of ~4.5 mm typically and stops for a given time.

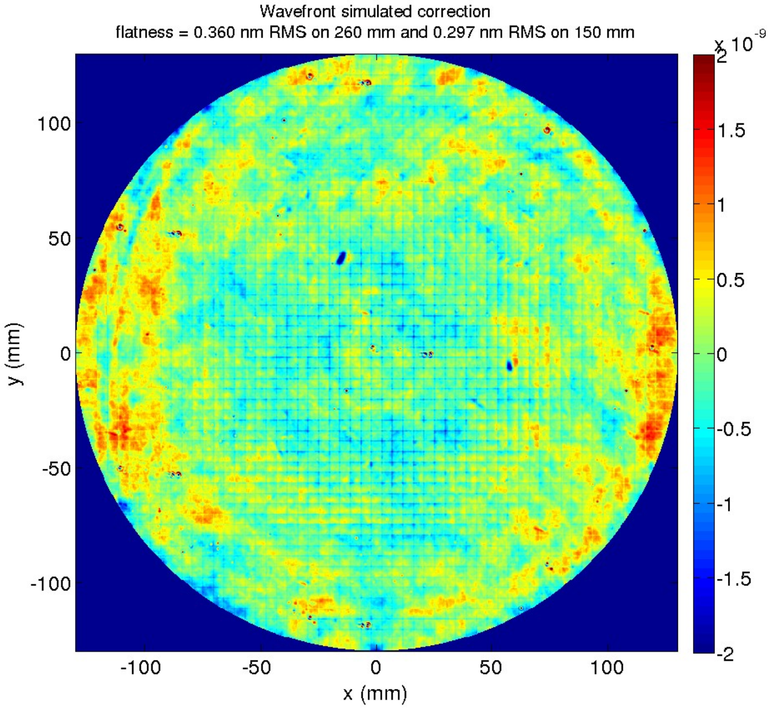


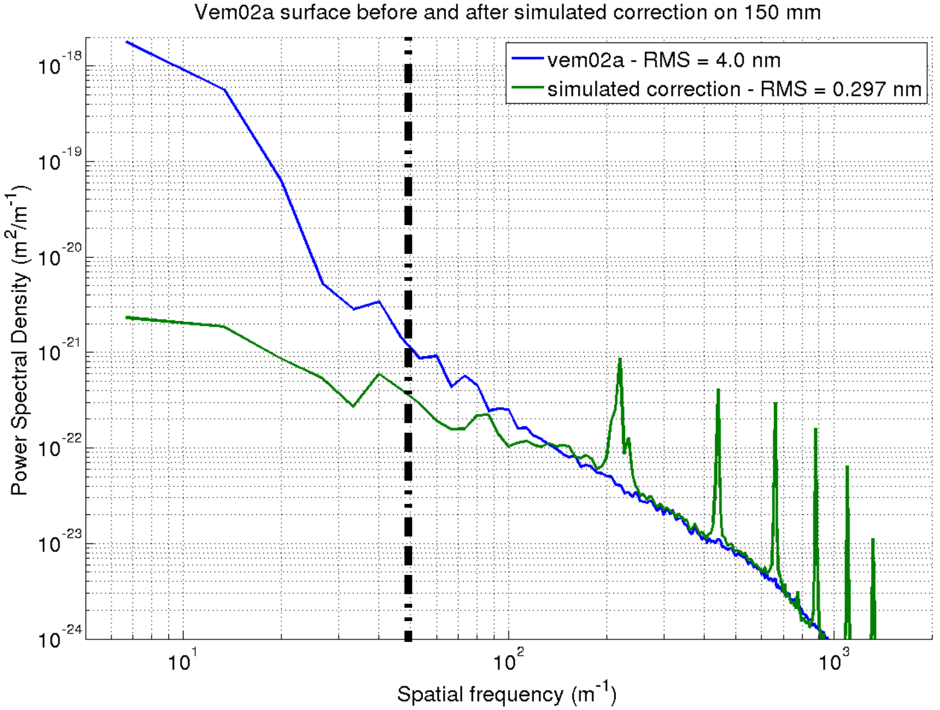


- Need to compute the deposition time at each points.
- Compute deposition time by solving a system of equations with ~ 3200 unknowns.

Simulation of the corrective coating process

- <u>Simulated</u> surface after correction (RoC of -70 km on 300 mm removed).



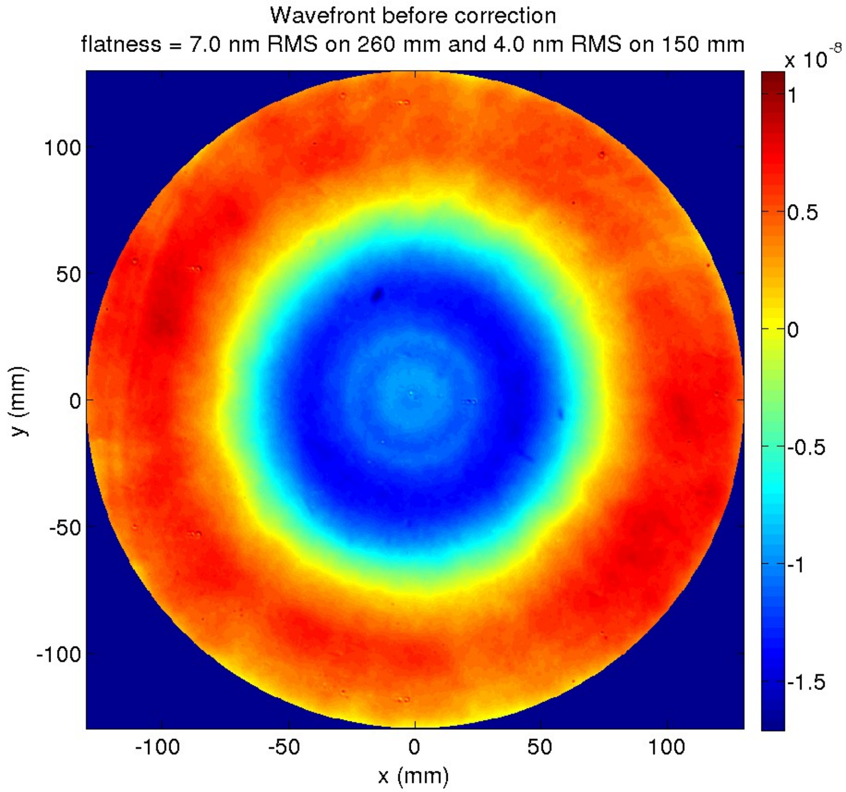


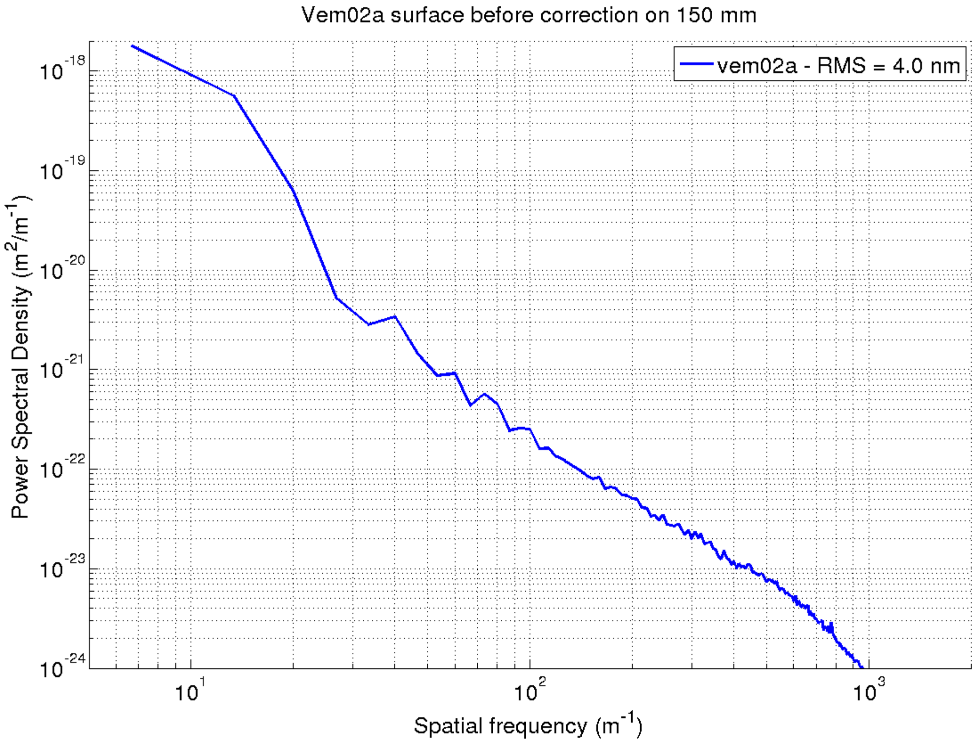
Flatness = 0.360 nm RMS on 260 mm and 0.297 nm RMS on 150 mm.

- Correction with a 21.5 mm square mask => f_{cut}~$50m^{-1}$
- Corrects defects smaller than the mask size.

Experimental Results

- Surface of the substrate on 260 mm (RoC of -70 km on 300 mm removed).

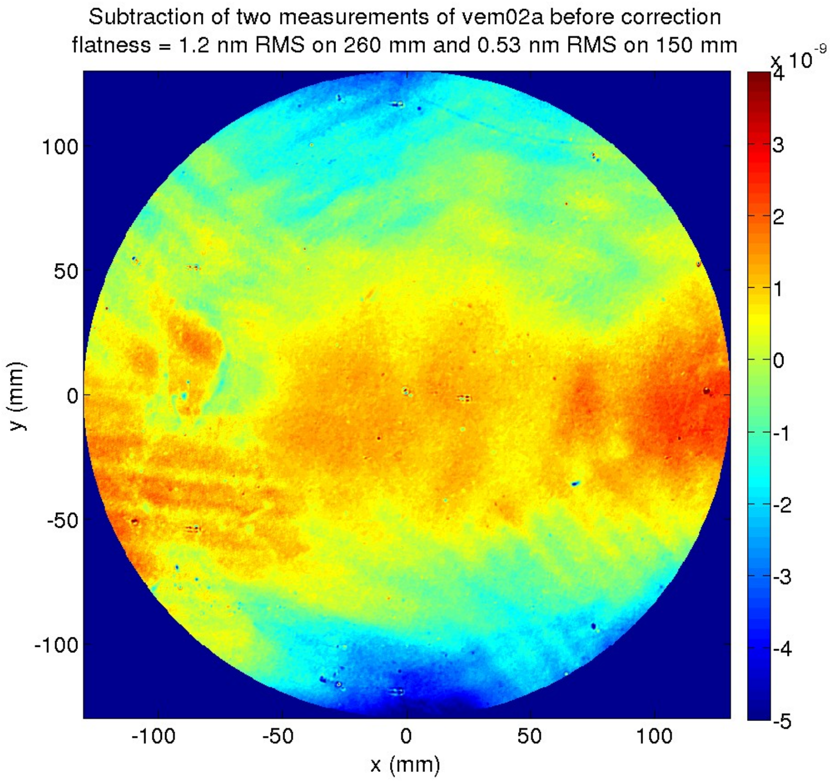


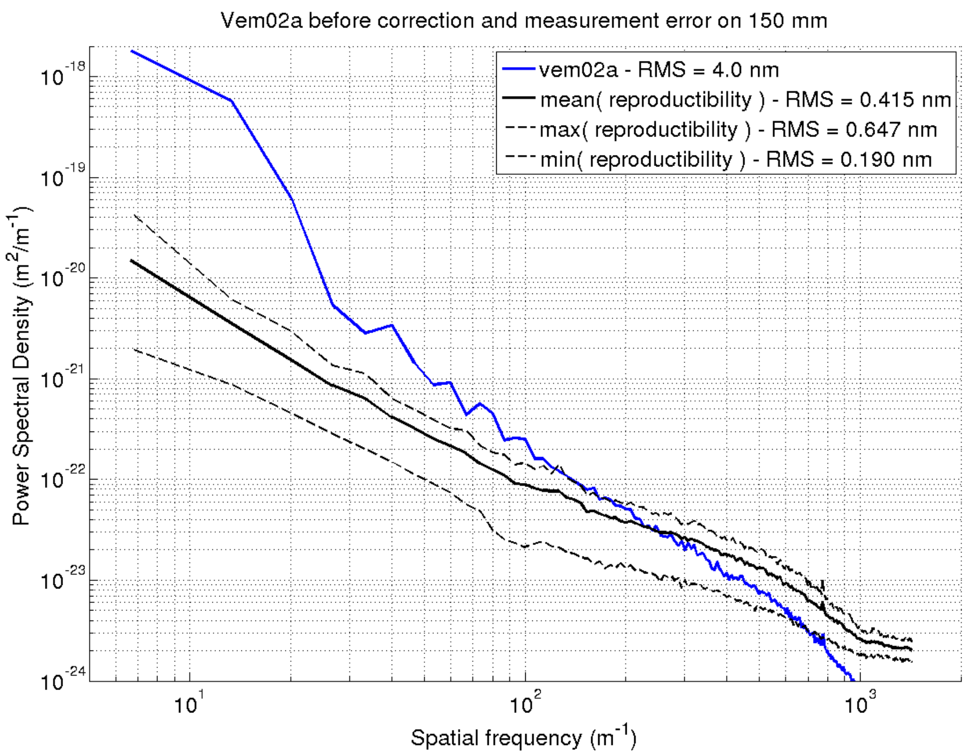


Flatness = 7.0 nm RMS on 260 mm and 4.0 nm RMS on 150 mm.

Measurement Reproductibility

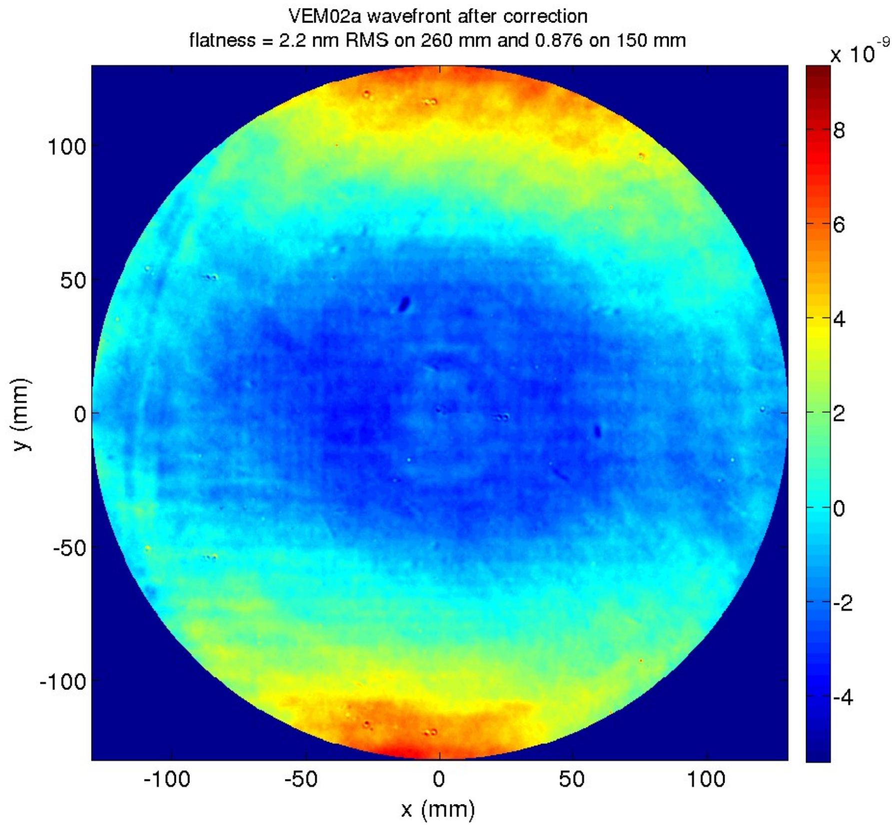
- Reproductibility of the measurement is limited.
  - stitching technique + sample holder + environnement.
- Uncertainty on RoC and astigmatism measured due to sample holder.

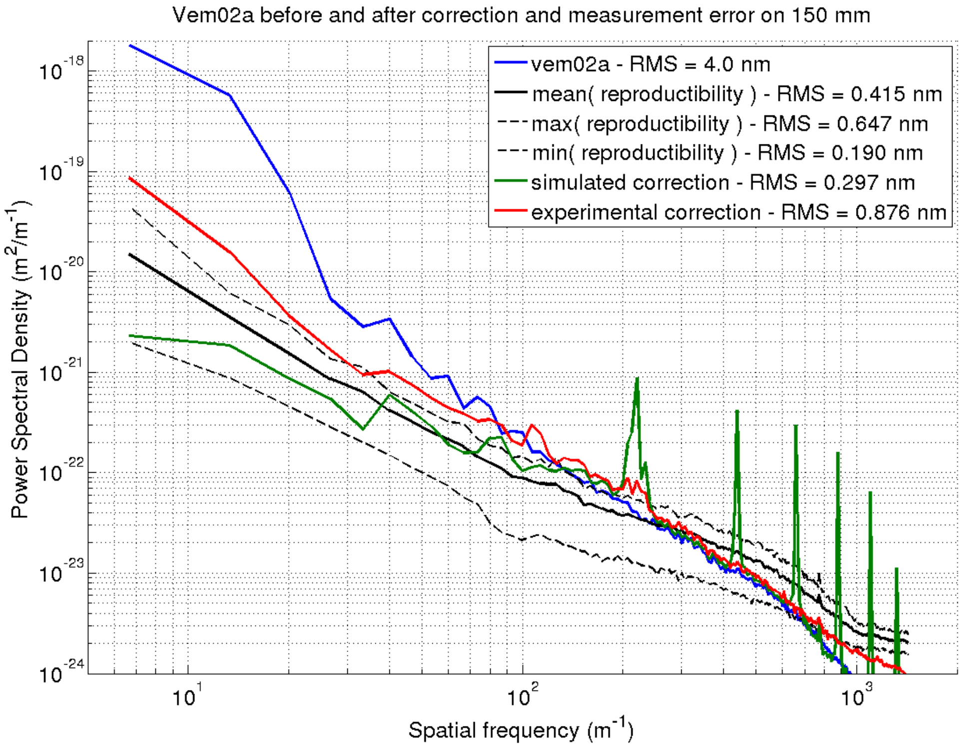




- Additional error if no wedge on the substrate with phase-shifting interferometry.

- Experimental correction (RoC of -70 km on 300 mm removed).

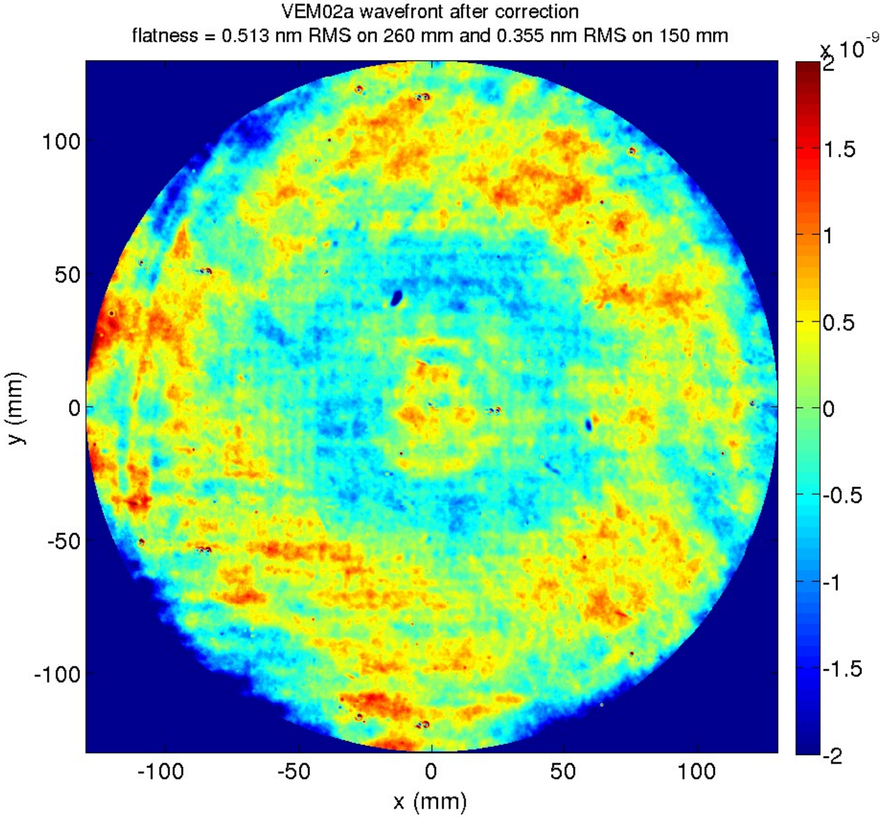


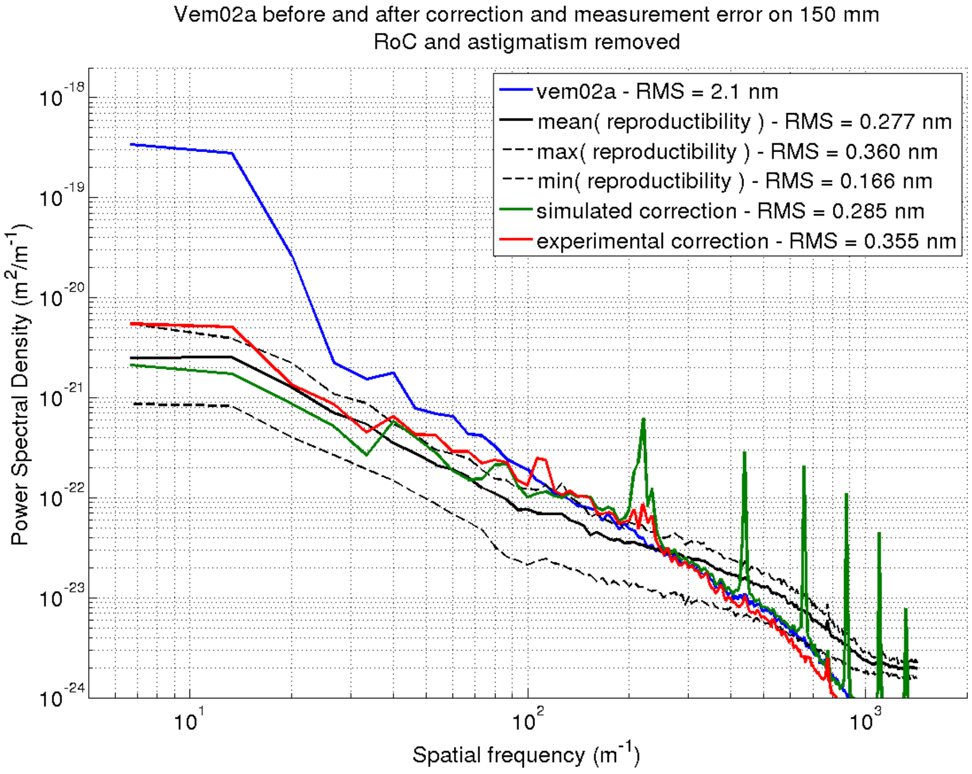


Flatness = 2.2 nm RMS on 260 mm and 0.876 nm RMS on 150 mm.
Mainly residual curvature and astigmatism

Correction of a Virgo substrate

- If we substract the residual curvature and astigmatism (RoC of -70 km on 300 mm removed).





Flatness = 0.513 nm RMS on 260 mm and 0.355 nm RMS on 150 mm.

Effect in advanced gravitational waves detectors

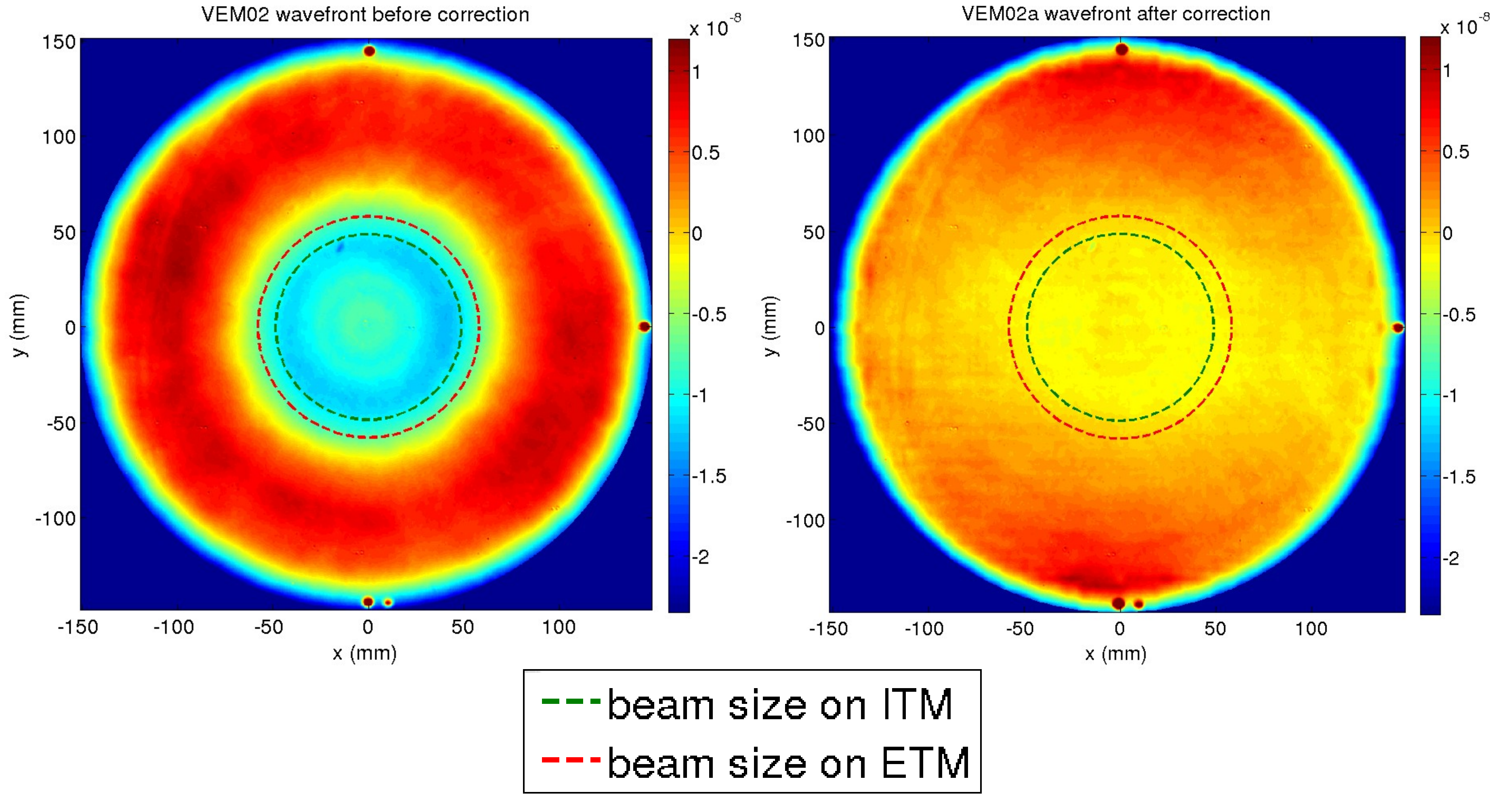
Adv. Virgo arm cavity simulation

- Surface maps (with residual curvature and astigmatism) have been put into simulation of an Advanced Virgo Cavity under SIESTA.

simulation	RTL (map on ITM)	RTL (map on ETM)
VEM02a before correction	37.1 ppm	365.1 ppm
VEM02a after correction	12.4 ppm	12.9 ppm

- VEM02a after correction meets Advanced Virgo specification on RTL in Advanced Virgo arm cavity (<25 ppm/mirror).

Adv. Virgo arm cavity simulation



Conclusion

- Corrective coating lowers the surface flatness by adding silica where it is needed.

- We corrected an initial Virgo substrate down to less than 1 nm RMS on 150 mm and less than 0.4 nm RMS without astigmatism and residual curvature.
- The metrology is the limiting factor in the corrective coating process (stitching and sample holder).
- A very good metrology is needed to achieve very low flatness.

- Corrected surface gives round-trip losses compliant with the specifications on the Advanced Virgo arm cavity.

Thanks for your attention.