# Second Generation Interferometer Optics Requirements

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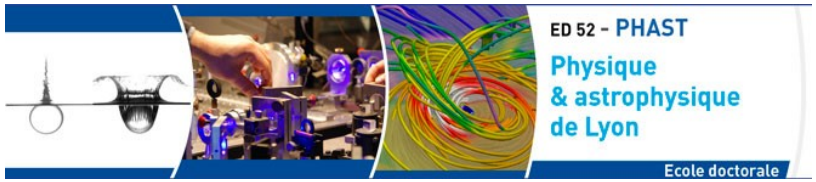


# OUTLINE

- Flatness of the substrate for the Arm mirrors.
  - Specifications in Advanced Virgo.
  - Simulations Results.
  - The Corrective Coating technique.
- Coating Uniformity
  - What is the issue?
  - Coating 1 mirror at once.
  - Coating 2 mirrors at once.
- Conclusion

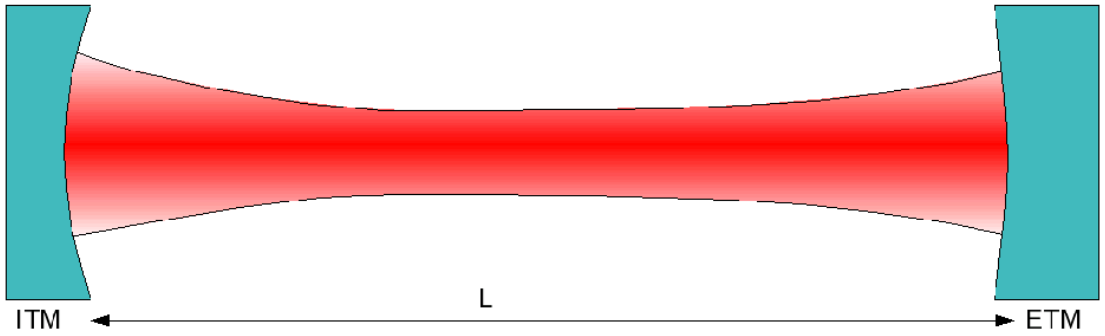
# Specification



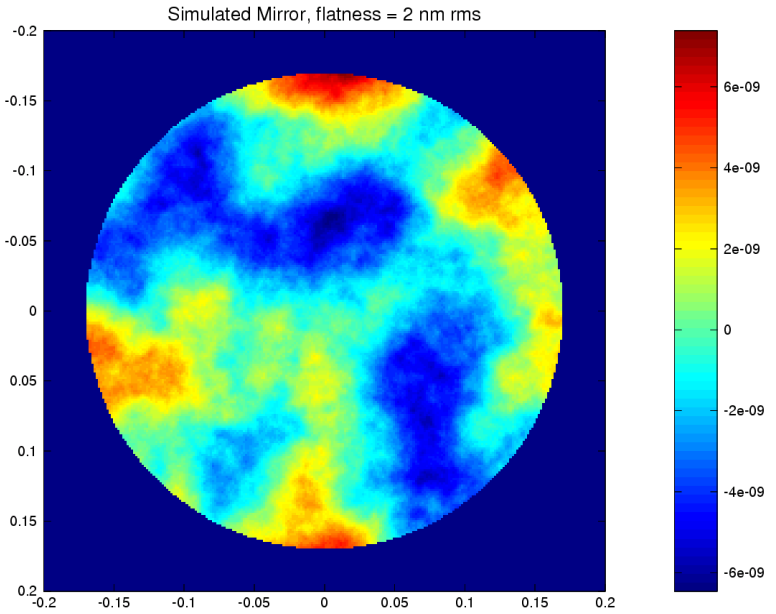
- Advanced Virgo Baseline specification:
  - Arm Round Trip Losses = 75 ppm.
- 37.5 ppm losses per surface.
- Losses are due to diffraction, absorption, and transmission.
- Absorption and transmission losses = 5 ppm
- Diffraction by micro-roughness (High Spatial Frequencies >1000$m^{-1}$) losses = 2x10 ppm.
- Diffraction by Low Spatial Frequencies (< 1000$m^{-1}$) should be smaller than 50 ppm.

# Simulation Parameters





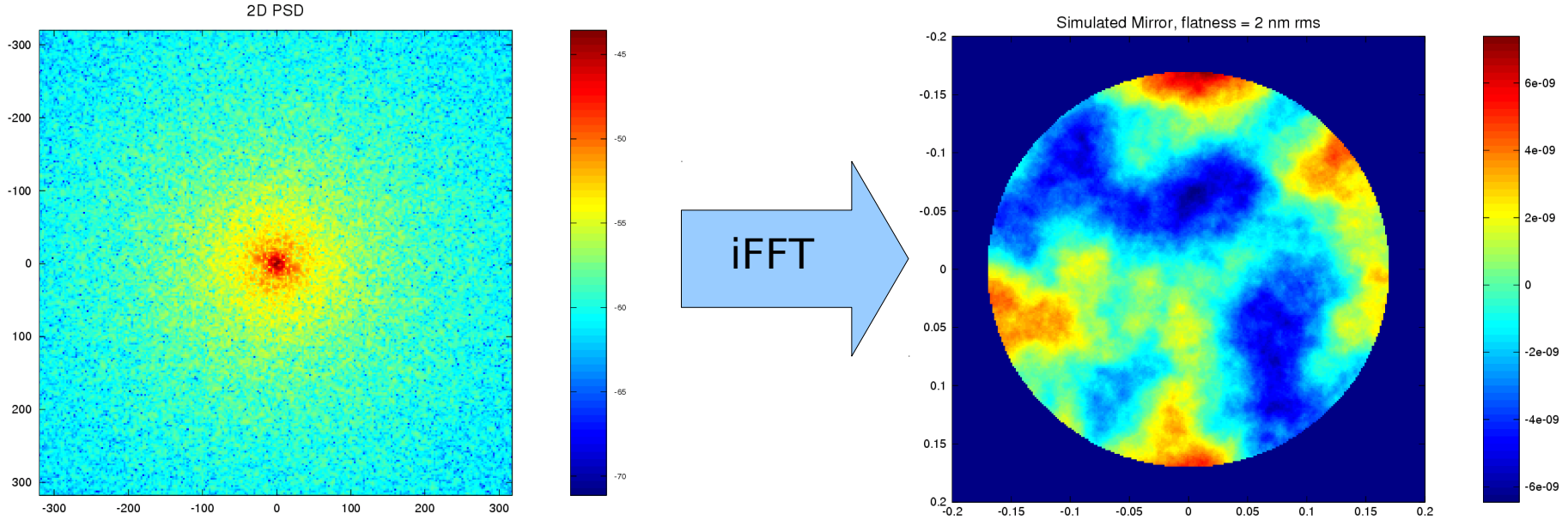

- Simulate FP cavity with simulated mirror.
- FFT simulations with SIESTA.
- RoC: ITM = 1420 m, ETM = 1683 m.
- Cavity Length, L = 3000 m.
- RTL = (Pinj – Pout – Prefl)/ Pcirc



# How are the map simulated ?



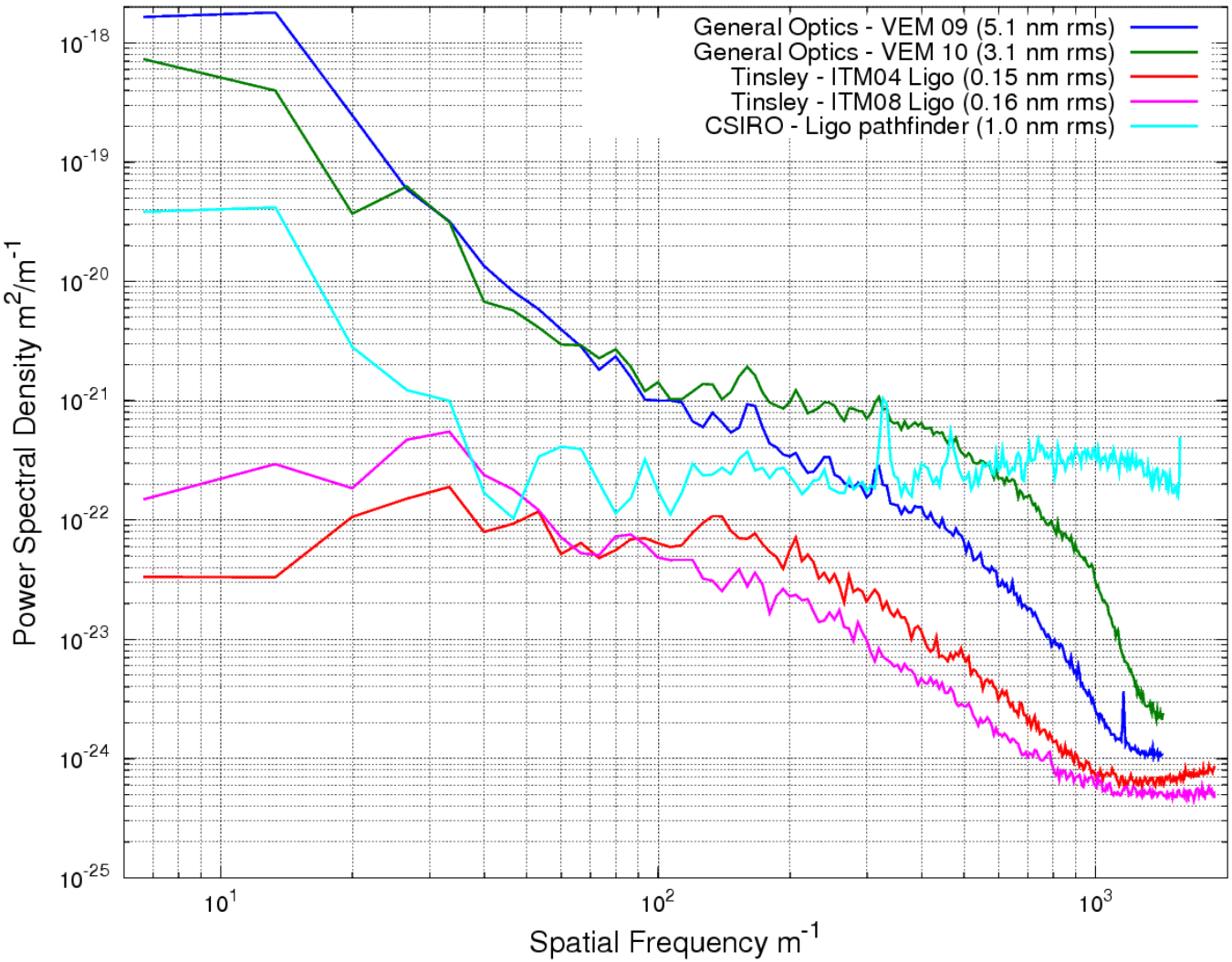
- From measurement, PSD are computed.
- 2D PSD with the desired shape and random phase are produced.
- Inverse FFT and scaling factor gives simulated map.



# PSD for different polishers



PSDs of mirror maps for different polishers computed over 150 mm



# Results

- Simulations with General Optics like Mirror:

  90 % of simulations give RTL < 50 ppm with mirrors having a flatness of 1 nm rms

- Simulations with CSIRO like Mirror:

  90 % of simulations give RTL < 50 ppm with mirrors having a flatness of 0.45 nm rms.

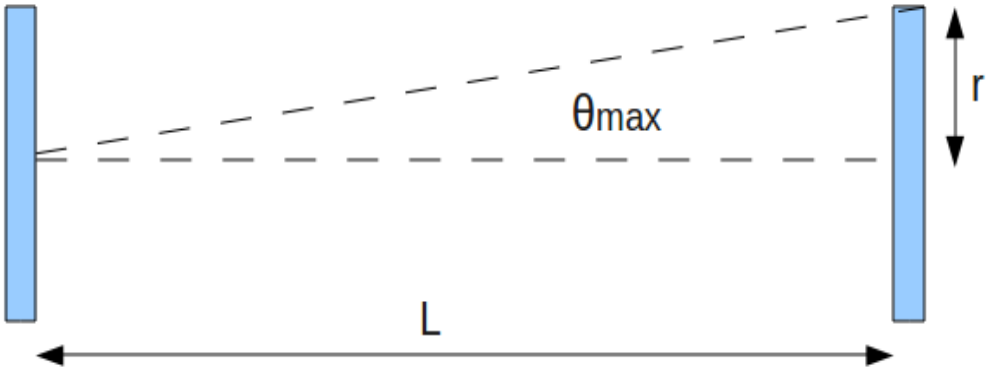
- PSD shape is important, flatness expressed in nm rms is not enough.

  => Give specification in the spatial frequency range of $50m^{-1}$ – $1000m^{-1}$.

# Why a threshold of 50 $m^{-1}$ ?



- Because of the Advanced Virgo arm geometry.




Angle of diffraction:

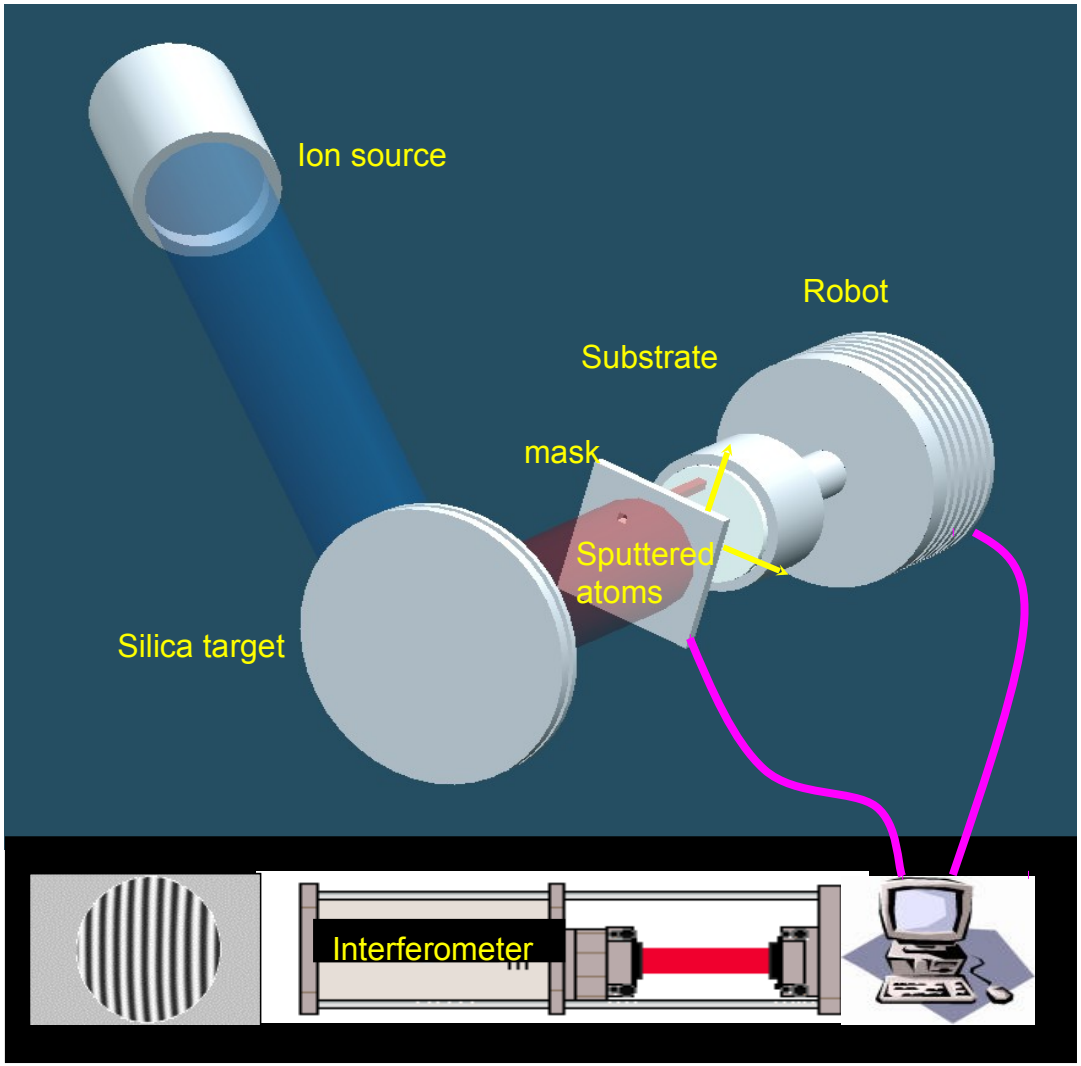
$$\theta = \lambda * f$$

$$f = \frac{\theta_{max}}{\lambda} = \frac{r}{L} * \frac{1}{\lambda} = \frac{0.17}{3000 * 1.064e^{-6}} = 53\,m^{-1} \sim 50\,m^{-1}$$

- Limit where the light escape the cavity.
- Could reasonably be the maximum frequency that corrective coating can correct.

# The Corrective Coating technique






- Measure the substrate by Phase Shifting Interferometry.
- Robot allows to move the substrate to add silica where it is needed.
- Correction down to cm scale.

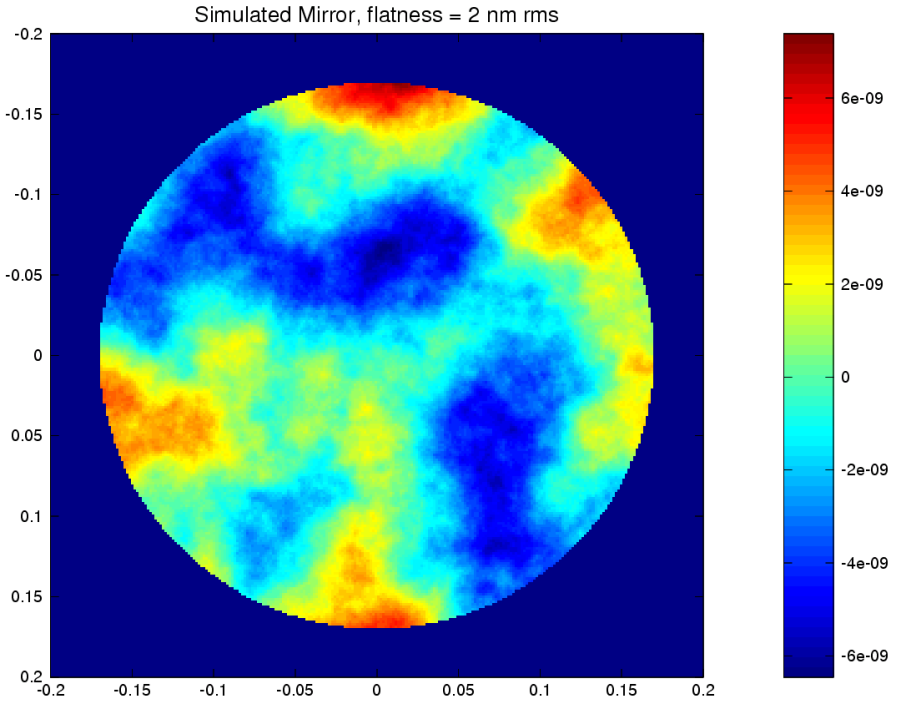
# Simulating the Corrective Coating

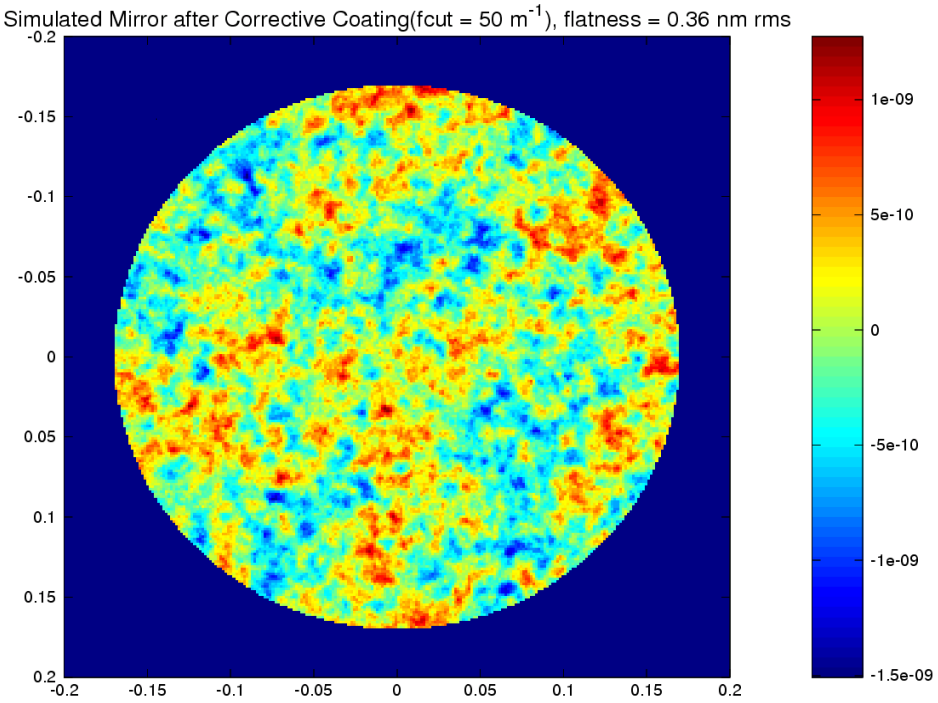


- Applied a filter that flatten the 2D PSD below a certain spatial frequency (50m$^{-1}$ in the figure below).

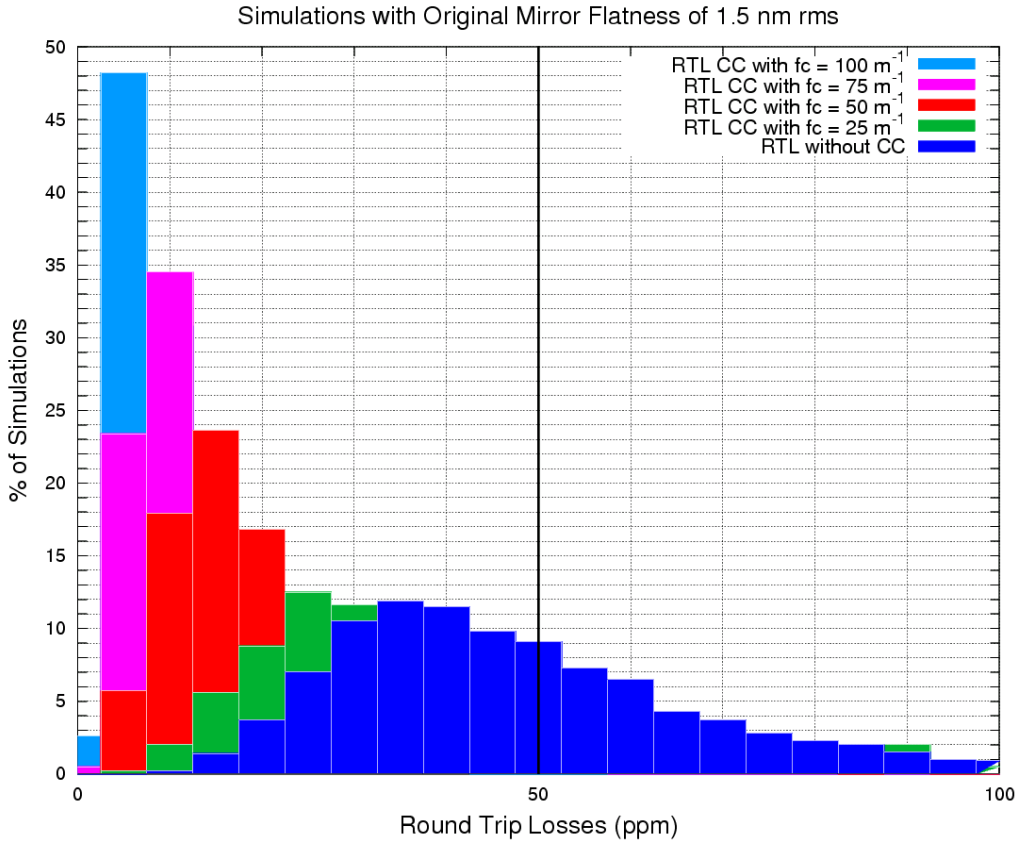
Corrective Coating

Color scales are different



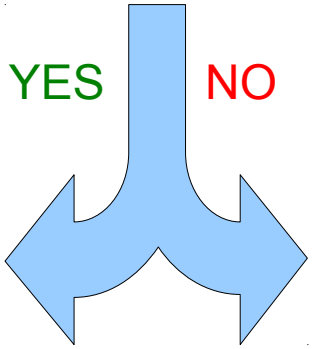
# Simulations with Corrective Coating (CC)




- Simulations on General Optics like mirrors (with 1.5 nm rms flatness).

| Rms = 1.5 nm | **No CC** | **CC with Fc = 25 $m^{-1}$** | **CC with Fc = 50 $m^{-1}$** | **CC with Fc = 75$m^{-1}$** | **CC with Fc = 100 $m^{-1}$** |
|---|---|---|---|---|---|
| **Simulations RTL < 50 ppm** | 61.3 % | 71.6 % | 95.9 % | 99.6 % | 100 % |

- Is the corrective coating technique in accordance with the expected behaviour ?




- Corrective Coating:
  - LSF spec:
  - RMS < 1.5 nm
  - RMS($50m^{-1}$ – $1000m^{-1}$) < 0.15 nm.

- Ion Beam Polishing:
  - LSF spec:
  - RMS < 0.5 nm
  - RMS($50m^{-1}$ – $1000m^{-1}$) < 0.15 nm.

Substrate is not all!

What about coating uniformity?

# The Issue

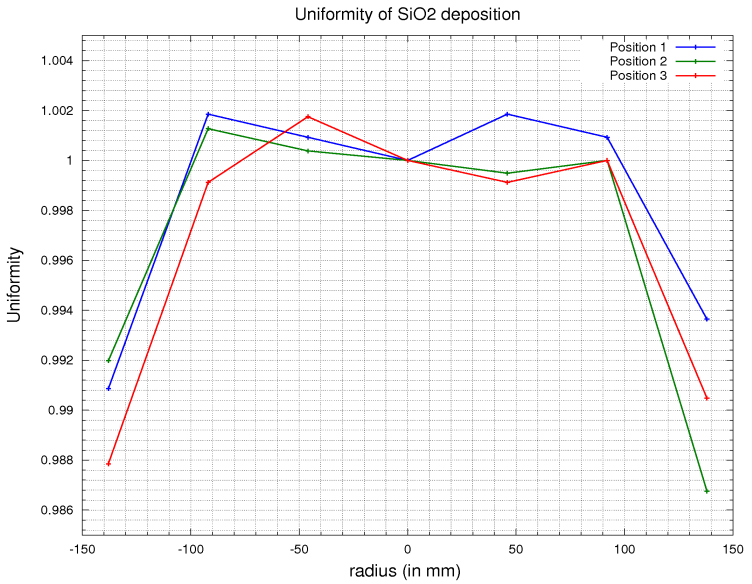


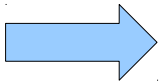
- Coating uniformity could dominate the surface imperfections of second generation interfererometers optics.
- Coating thickness is a few microns.
- Flatness better than 0.5 nm requires coating thickness uniformity of about 0.01%.

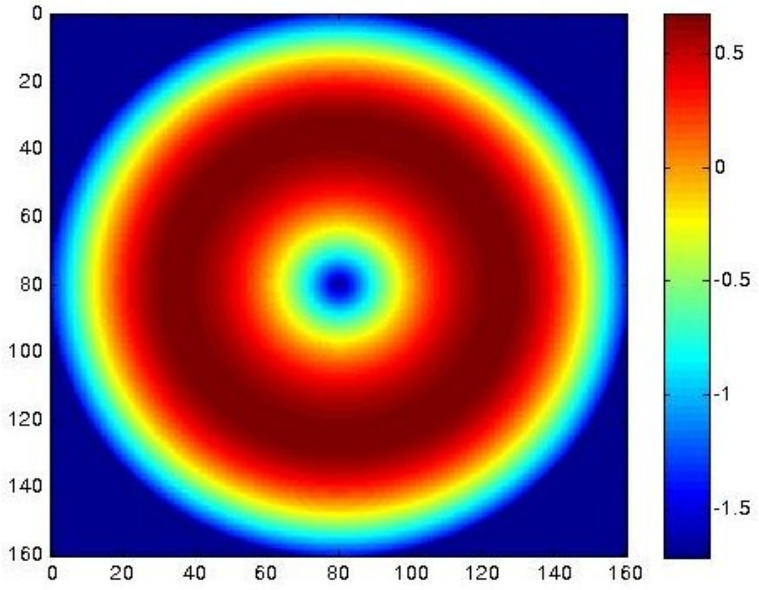
# Coating of 1 mirror at once



- Measure of coating uniformity versus position for each material.
- Multi-layer coating uniformity is estimated combining uniformity profiles of $SiO_2$ and $Ti:Ta_2O_5$ .
- Changing the target position inside the coater allows to optimise the profile uniformity of the material.





# Results with simple rotation and mask

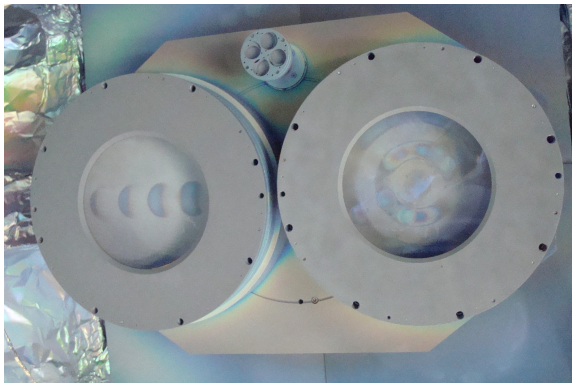


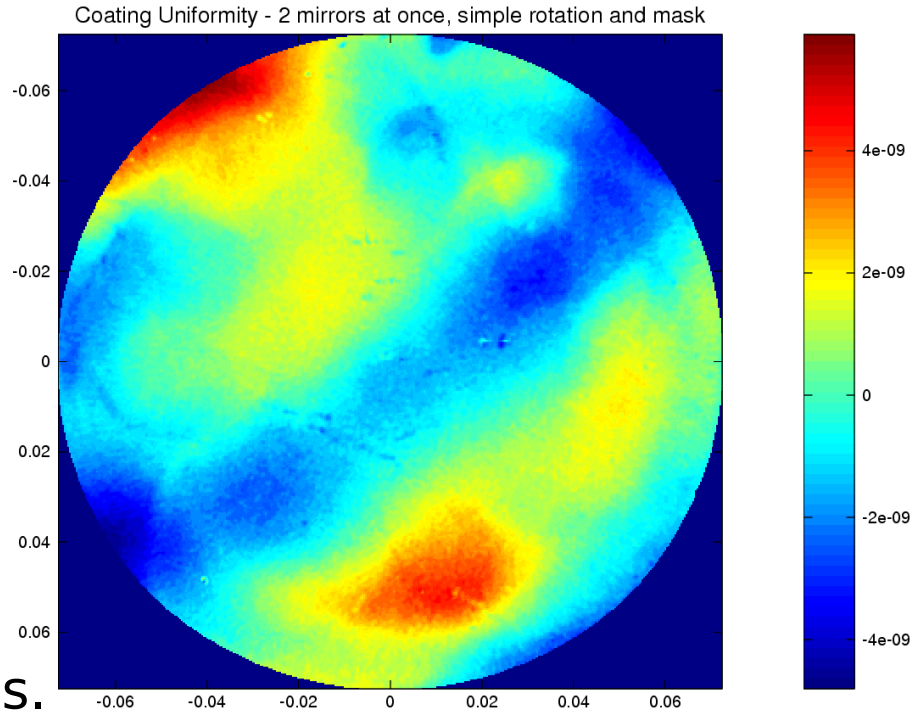
- We are at the very limit of the metrology capabilities for spherical surface.
- Measurement is limited by the noise of the instrument, especially the vibrations.
- Given the metrology capabilities, good coating uniformity is achieved.
  - Flatness < 0.5 nm rms.
- Mirror being shipped to LIGO to confirm the results.

# Coating of 2 mirrors at once



- Coating with 2 test mirrors at once with simple rotation and mask:



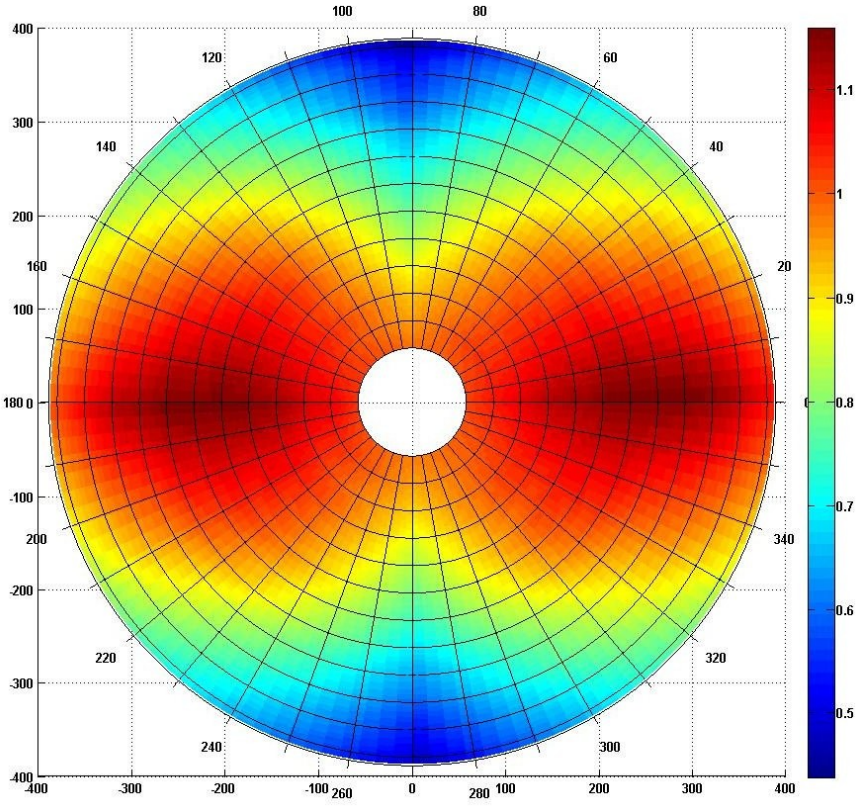



- Coating flatness is 1.6 nm rms.
- Coating Map in simulations of AdV. Virgo Cavity.
  - Map on ITM → Round Trip Losses = 84 ppm.
  - Map on ETM → Round Trip Losses = 163 ppm.
- Not acceptable in the arm losses budget!

# Planetary motion



- Simulation of planetary motion inside the coater.
- Use of SiO2 coating profile.
- First simulations shows that planetary motion could permit to gain about a factor 2 on the thickness uniformity of silica.
- More simulations have to be performed to find the best parameters to enhance the coating uniformity.




From B. Sassolas

# CONCLUSION



- Specifications of flatness for the arm mirrors have been defined for Advanced Virgo.
  - Corrective Coating: RMS <1.5 nm with RMS($50m^{-1}$ – $1000m^{-1}$) <0.15 nm.
  - Ion Beam Polishing: RMS <0.5 nm with RMS($50m^{-1}$ – $1000m^{-1}$) <0.15 nm.
- Coating Uniformity can start to dominate into the surface imperfection.
- Coating of 1 mirror at once gives good results.
- Planetary motion could permit to coat 2 mirrors at once with the required uniformity.

THANK YOU !