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Wavefront optimization of a 10-TW laser system by using a four-point, single-adjuster deformable mirror

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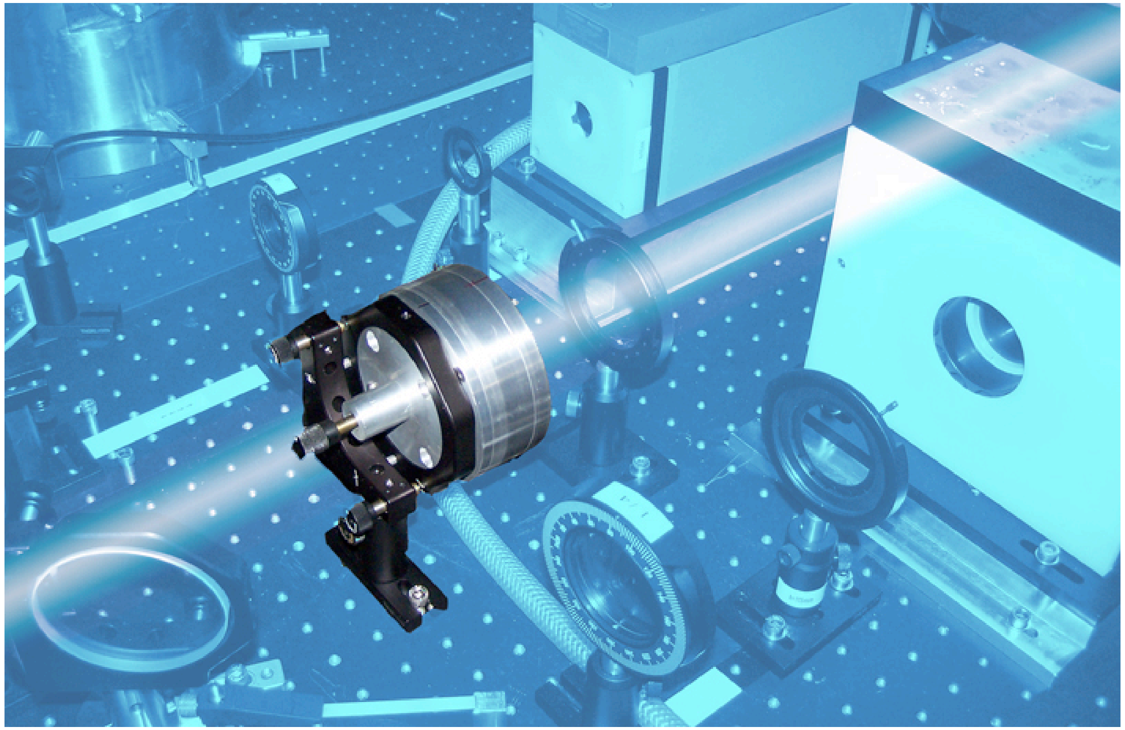


Summary

We have developed and implemented a patented deformable mirror (DM) with four point actuators for the simultaneous correction of static astigmatism and defocus in a chirped pulse amplification laser system [1].

The DM is operated by a single mechanical adjuster, and the ratio between both aberrations is defined by adequately choosing the relative position of the actuators.

We developed an analytical model that describes adequately the mirror deformation as a function of actuator position, showing that it is possible to continuously tune the weight of each aberration. Experimental measurements with a single adjuster deformable mirror assembly confirm the validity of the model [2].

The DM was implemented before the grating compressor of a 10 TW CPA laser. The focused intensity has increased by more than an order of magnitude, with a focal spot of 1.14 times the diffraction limit.

[1] Patent PT 103682

[2] G. Figueira, J. Wemans, H. Pires, N, Lopes, L. Cardoso, "Single adjuster deformable mirror with four contact points for simultaneous correction of astigmatism and defocus", *Opt. Express* 15, 5664 (2007)

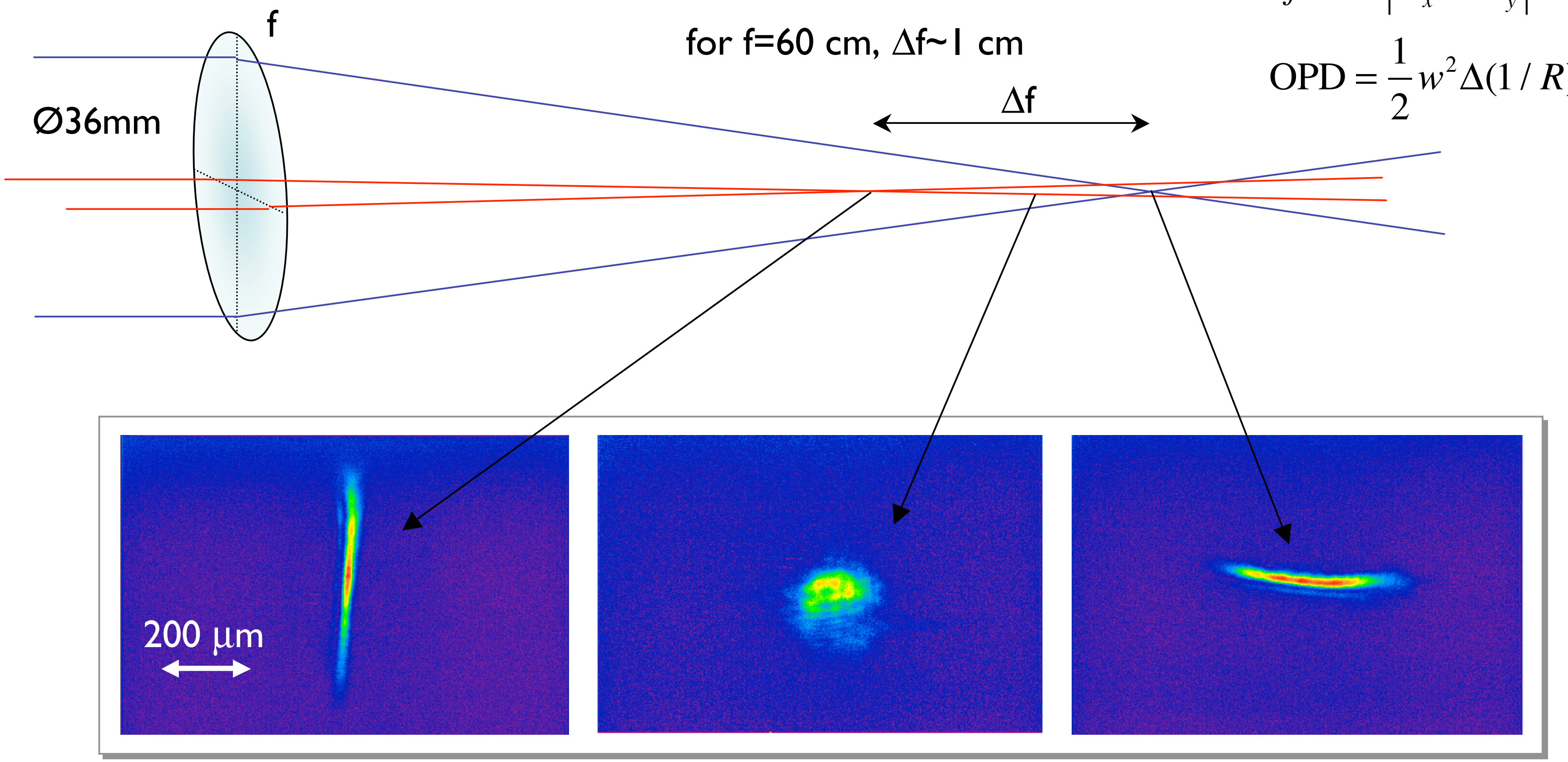
Characterization of post-compressor aberrations

300 fs, λ=1053 nm, ∅36mm beam focused to f/16

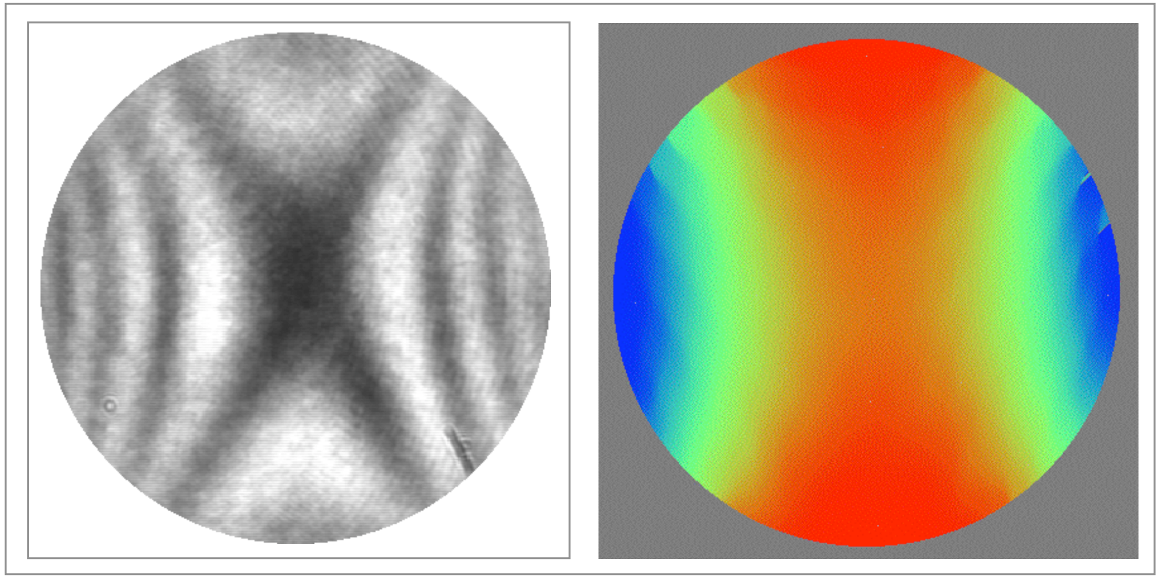
$$\frac{\Delta f}{f} = f\left|\frac{1}{R_x} - \frac{1}{R_y}\right| = f\Delta(1/R)$$

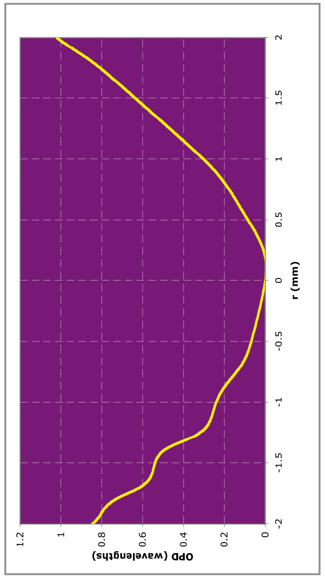
for f=60 cm, Δf~1 cm

$$\mathrm{OPD} = \frac{1}{2}w^2\Delta(1/R) \approx 4.5\ \mu\mathrm{m}$$

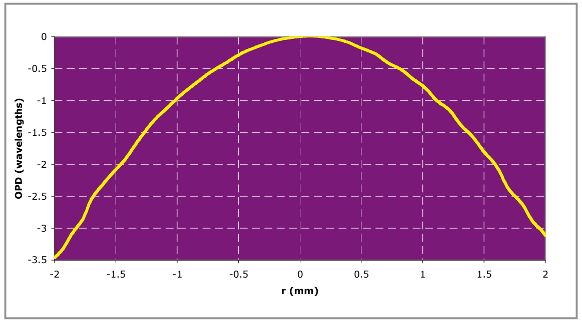


Interferometrical analysis of aberrated wavefront

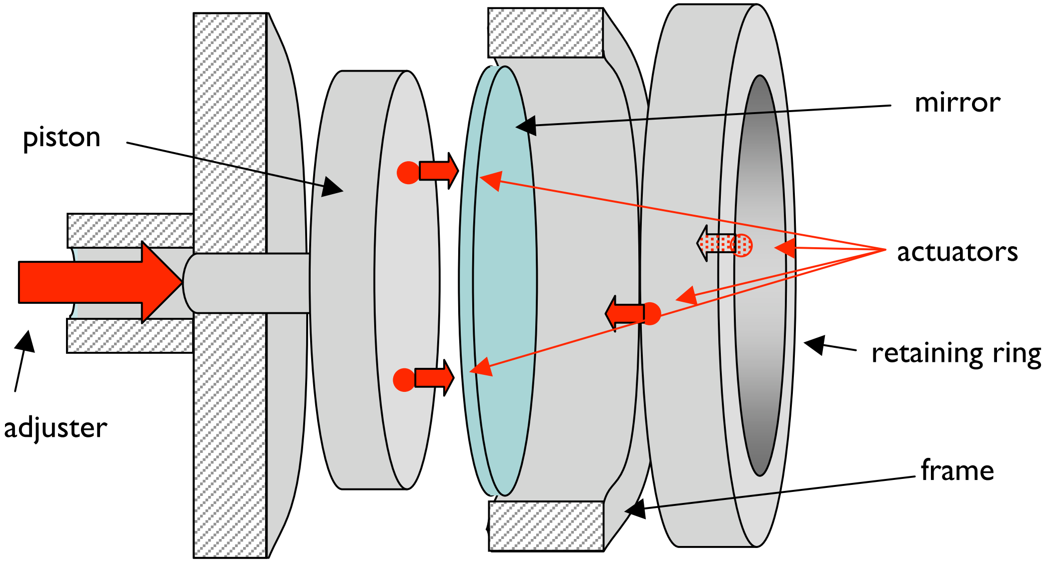


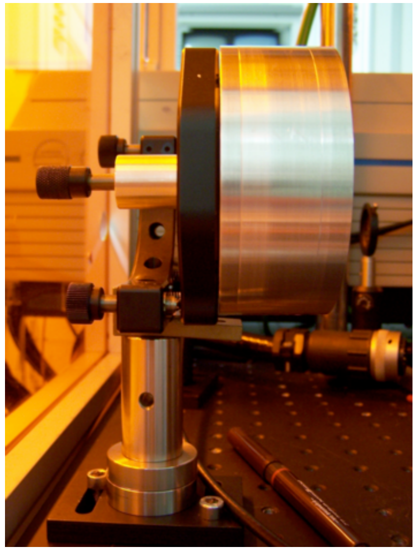


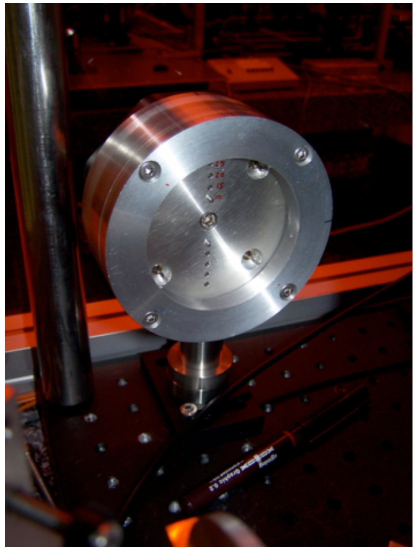
Shearing wave interferometry shows that the wavefront after the grating compressor is astigmatic, with P-V of 3.5λ (horizontal) and 1λ (vertical)



DM design and characteristics







Single adjuster / 4-actuator DM mount

Internal actuators	r=10,15,20,25 and 30 mm
External actuators	r=35 and 37.5 mm
Mirror sizes	Ø75-Ø80 mm 6-12 mm thickness
Required force	~10$(h/6)^3$ N/µm
Integration	Commercial Ø75mm mirror mount
Material & size	Aluminum, Ø90x50mm

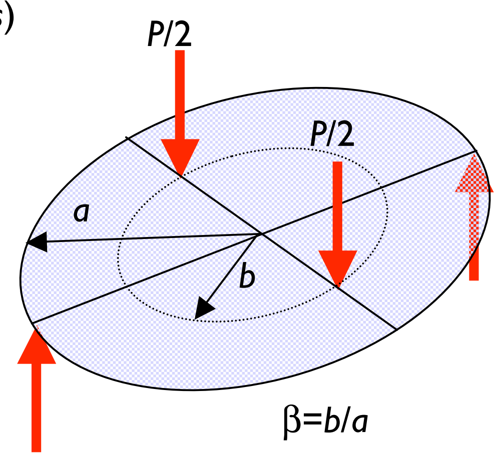
Analytical model - formulation

Equations for the deflection of a circular plate

(S. Timoshenko and S. Woinowsky-Krieger, *Theory of plates and shells*)

$$w(r,\theta) = w_0(r) + w_1(r,\theta)$$

$$\Delta\Delta w_0 = \frac{q}{D} \qquad \Delta\Delta w_1 = 0$$



particular solution

$$w_0(r) = \frac{Pa^2}{4\pi D}\left[\frac{1-\nu}{2(1+\nu)}\left(1-\beta^2\right) - \ln\beta\right]\rho^2$$

D=flexural rigidity

ν=Poisson's ratio

β=*b*/*a*

ρ=*r*/*a*

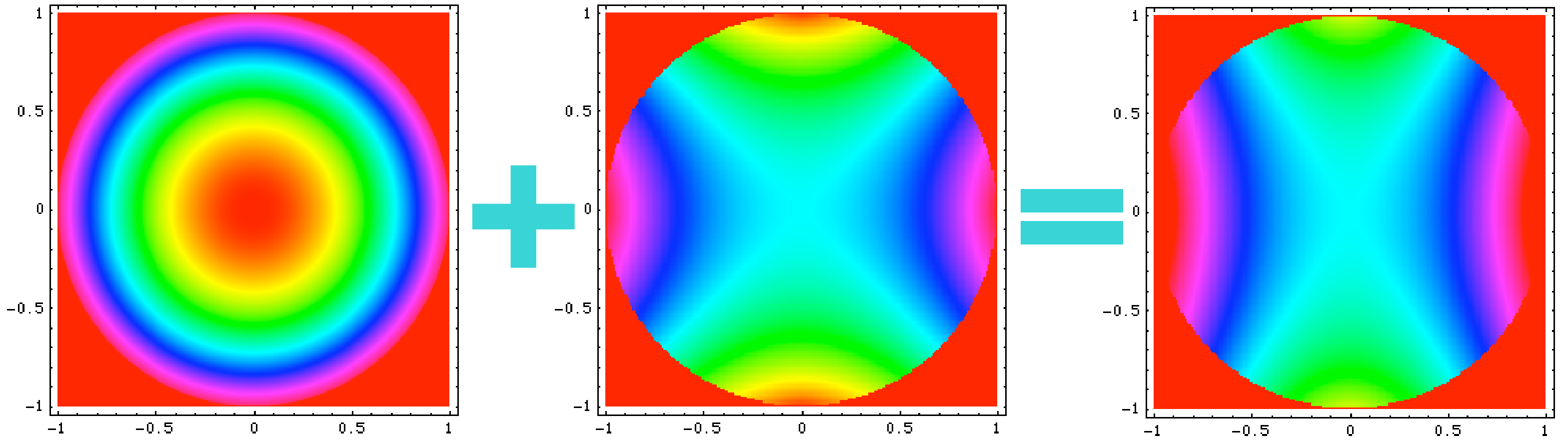
homogeneous solution

$$w_1(r,\theta) = \frac{Pa^2}{4\pi D}\sum_{m=2,6,10\ldots}\left(C_1\rho^m + C_2\rho^{m+2}\right)\cos(m\theta)$$

$$C_1 = \frac{1}{m(m+1)(\nu+3)}\left[m(\nu-1)\beta^{m+2} - (m+1)(\nu-1)\beta^m + (\nu+3)\beta^{-m} + 4\right]$$

$$C_2 = \frac{1}{m(m-1)(\nu+3)}\left[(m-1)(\nu-1)\beta^{m+2} - \left(m(\nu-1) + \frac{8}{m}\frac{\nu+1}{\nu-1}\right)\beta^m + (\nu+3)\beta^{-m+2} + 4\left(1-\frac{2}{m}\frac{\nu+1}{\nu-1}\right)\right]$$

Analytical model - solutions



The **particular solution** corresponds to **defocus***

The **homogeneous solution** corresponds to **astigmatism**

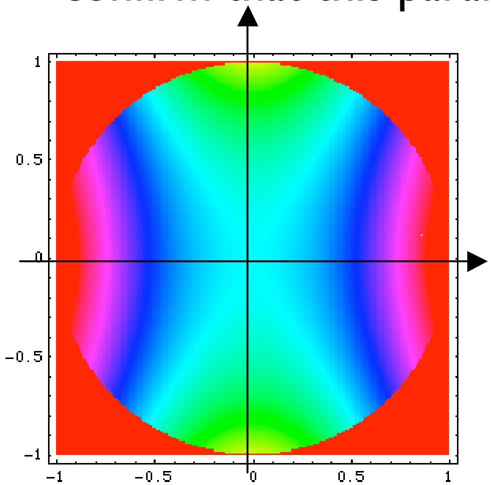
(!) Results valid inside the circle $r<b$

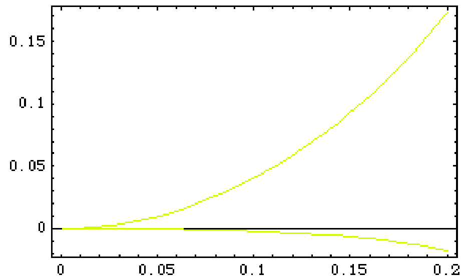
The analytical model shows that <u>the mirror design is the correct choice for canceling the wavefront aberration of our laser.</u>

*J. Schwartz et al. (SNL), "Development of a variable focal length concave mirror for on-shot thermal lens correction in rod amplifiers", Opt Expr 14, 10957 (2006).

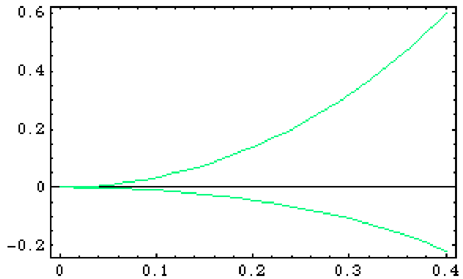
Analytical model - results

x-y lineouts show a smooth quadratic evolution for a range of β values, and confirm that this parameter controls the relative curvature along the axes

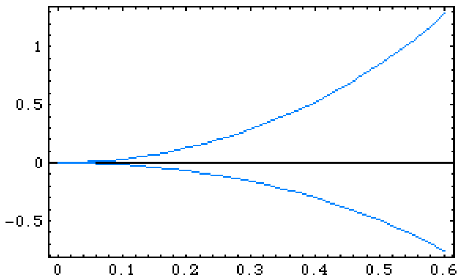




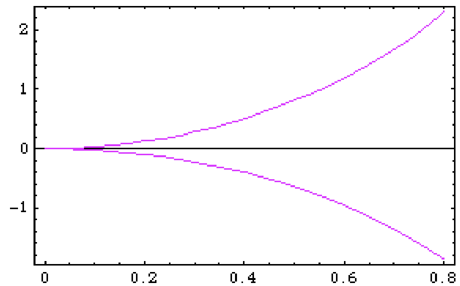
β=0.2



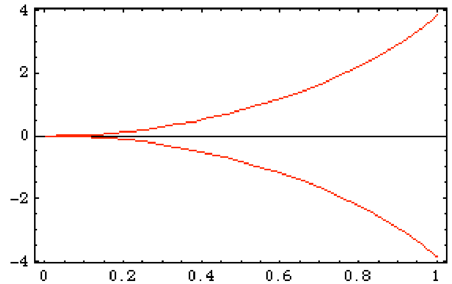
β=0.4



β=0.6

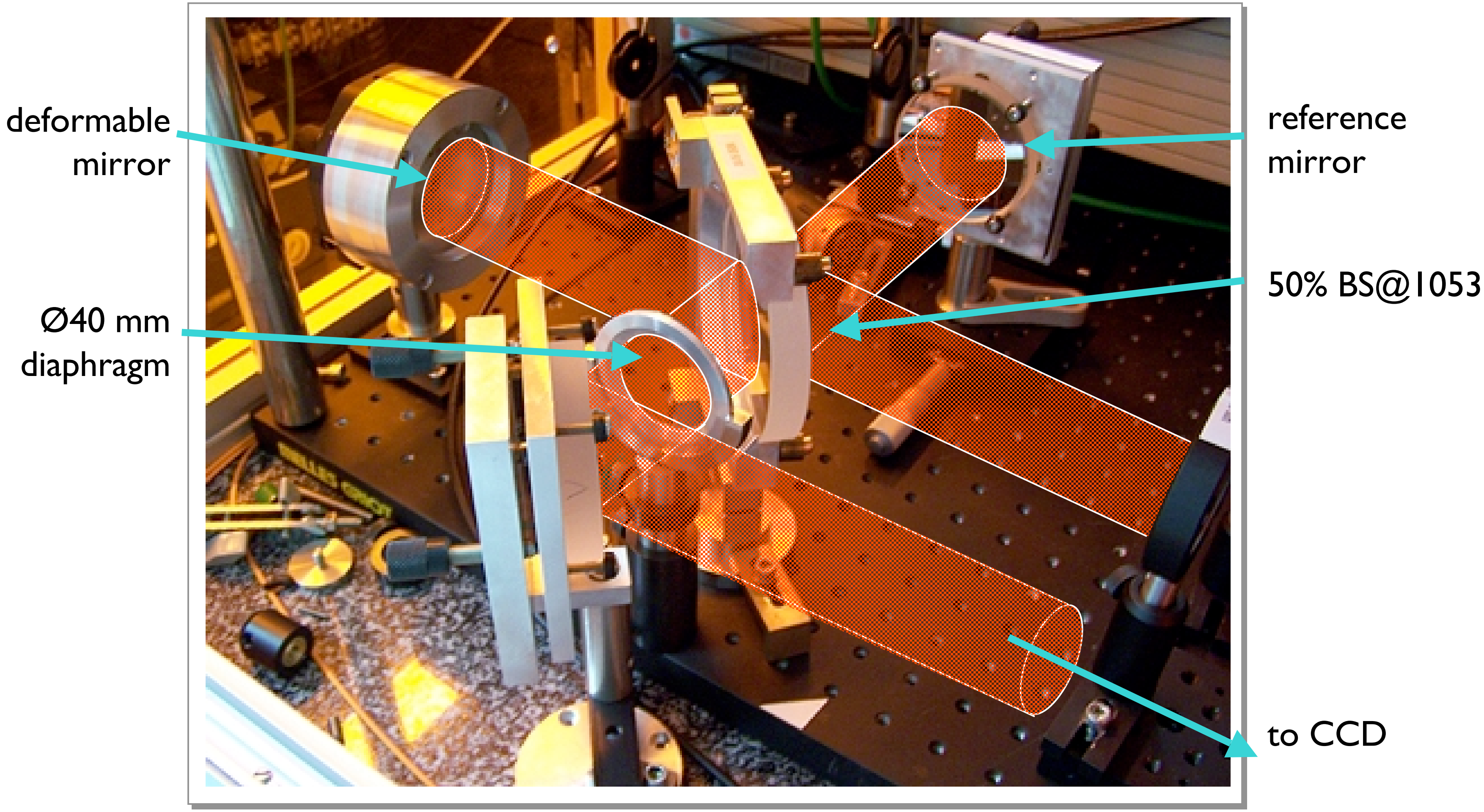


β=0.8



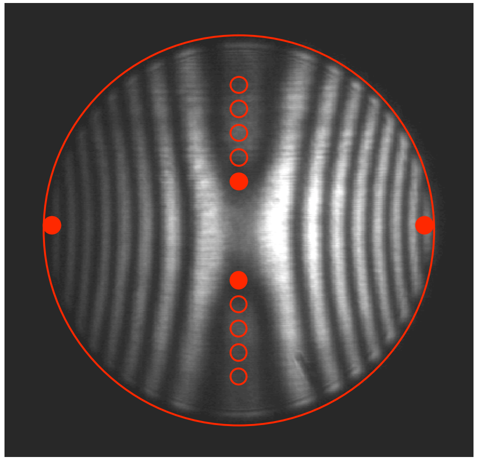
β=1.0

Interferometric characterization of DM performance

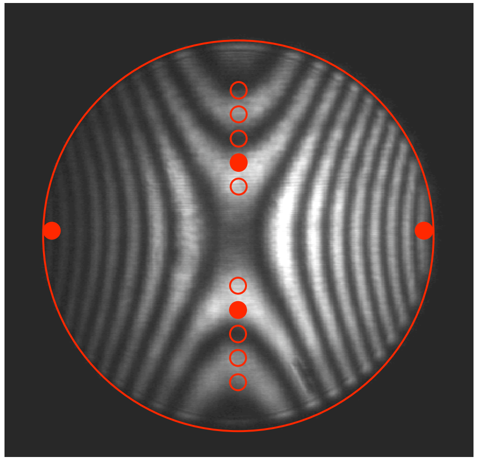


Michelson-type interferometer for DM characterization

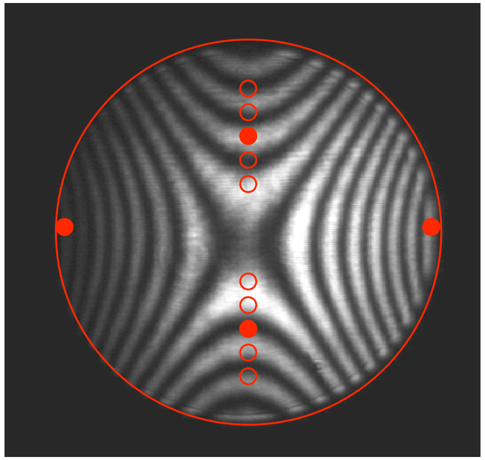
Interferometric characterization - results



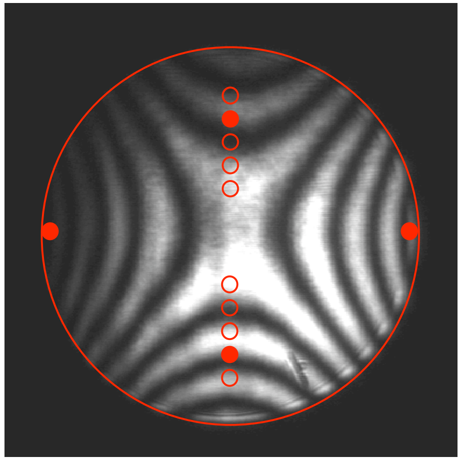
β=0.27 / b=10 mm



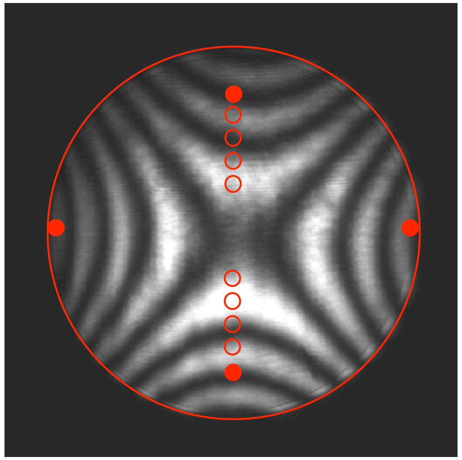
β=0.4 / b=15 mm



β=0.53 / b=20 mm



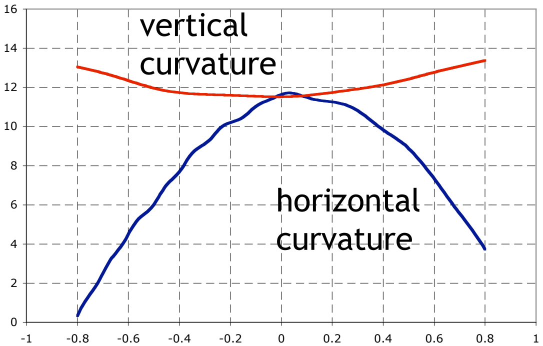
β=0.67 / b=25 mm



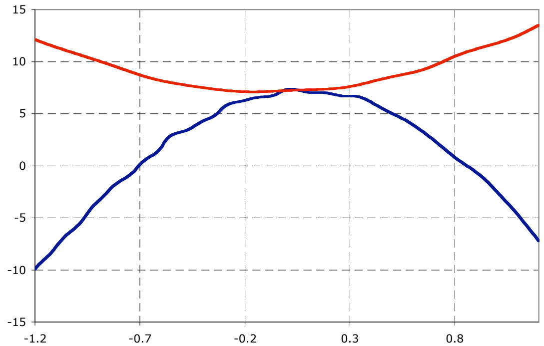
β=0.93 / b=35 mm

Interferometric characterization - analysis

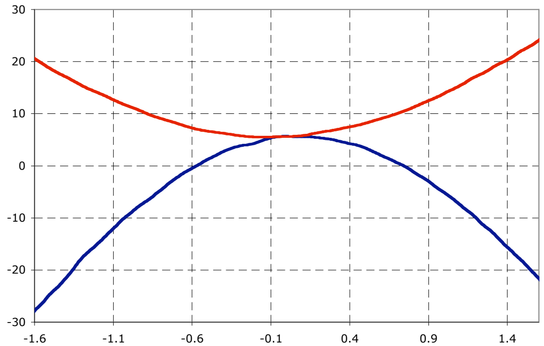
The measured curvatures show quadratic fittings with r^2>0.99



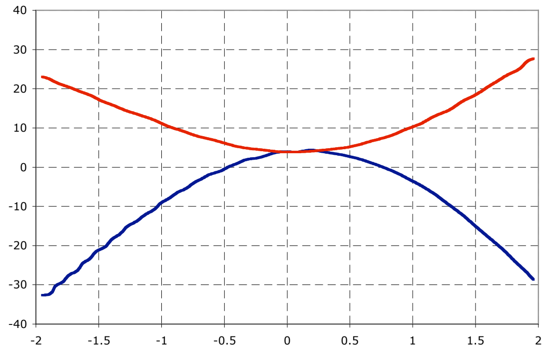
β=0.27 / b=10 mm



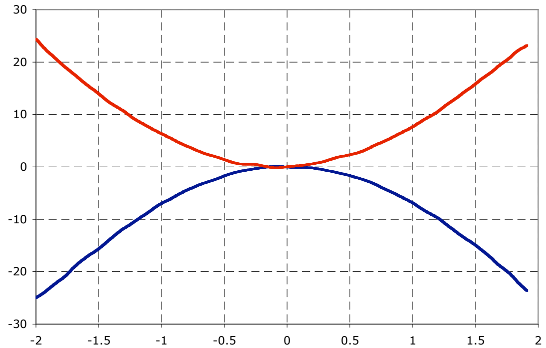
β=0.4 / b=15 mm



β=0.53 / b=20 mm

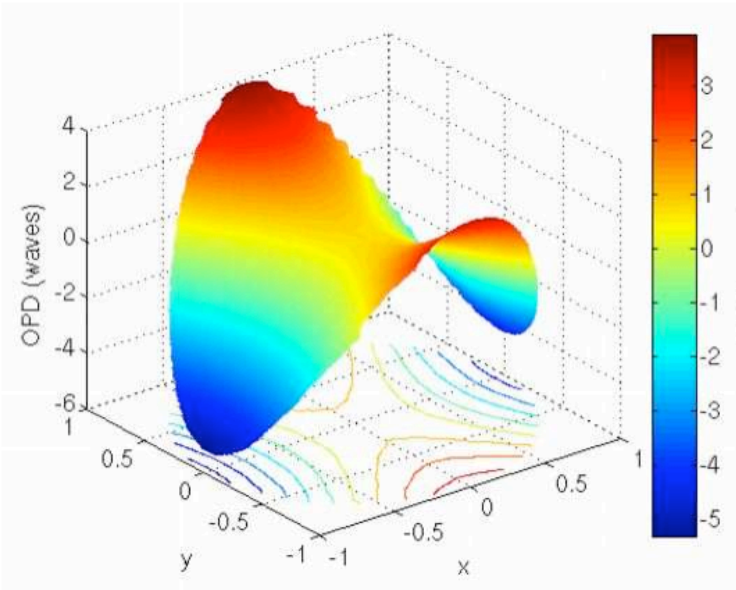


β=0.67 / b=25 mm

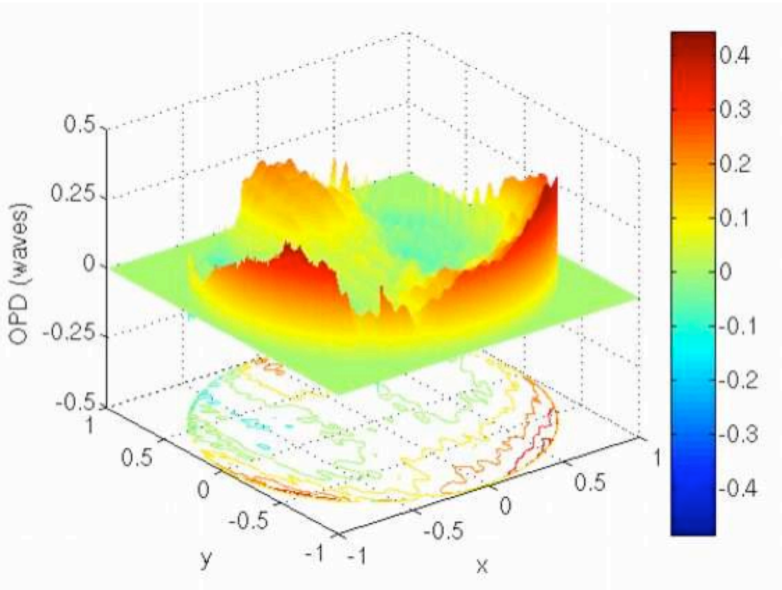


β=0.93 / b=35 mm

Interferometric characterization - comparison to analytical model



3D plot of the reconstructed wavefront for $\beta = 0.57$.

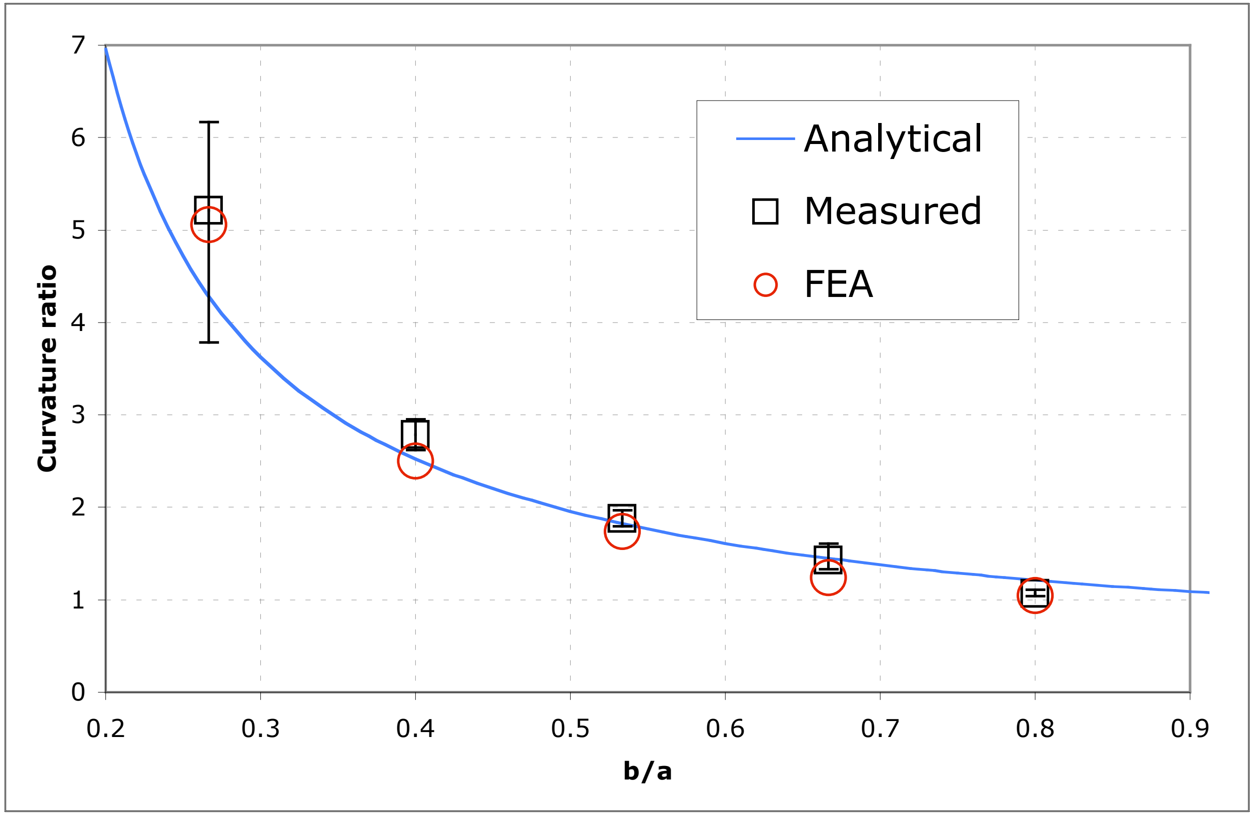


Residual wavefront after subtracting the corresponding Zernike polynomials.

Analytical, FEA and experimental results agree perfectly

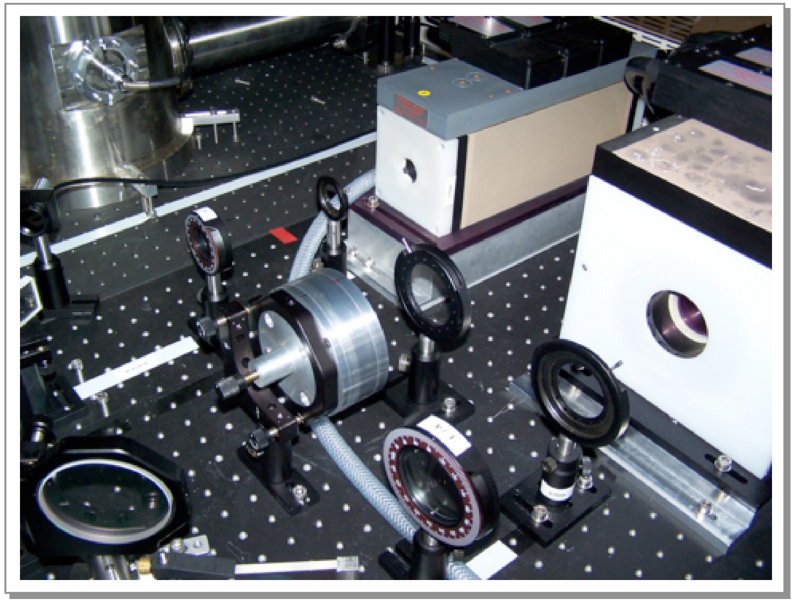
The experimental and the FEA *x* and *y* curvatures for each actuator position were measured in the same fashion as for the analytical results. The data fits perfectly to both models.

These results confirm that by choosing the position of the back actuators (β), the curvature ratio can be continuously tuned.



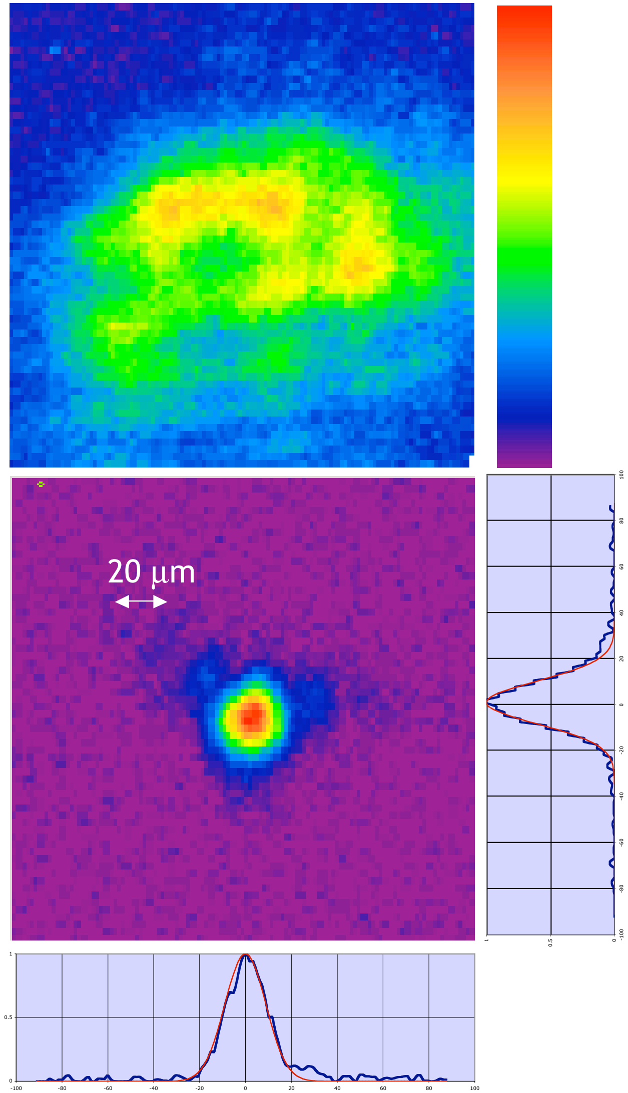
The graphic shows the ratio a_x/a_y between curvatures in the x and y directions, as a function of relative actuator position *b*/*a*.

Application to focal spot correction



Measurement of focused spot size
Regenerative amplifier, 10 Hz, 1 mJ
Focal length: 60 cm
Beam diameter: 40 mm

Diffraction limit: 19.3 μm
Hz width: 21 μm (1.09 DL)
Vt width: 22 μm (1.14 DL)



Conclusions

- The focal spot of the L2I laser was corrected to within the diffraction limited size
- A simple, inexpensive and elegant deformable mirror was built
- A detailed analytical model for the mirror deformation was developed, complemented by FEA analysis
- The mirror performance was fully characterized over a range of parameters
- Experimental, analytical and FEA data match perfectly