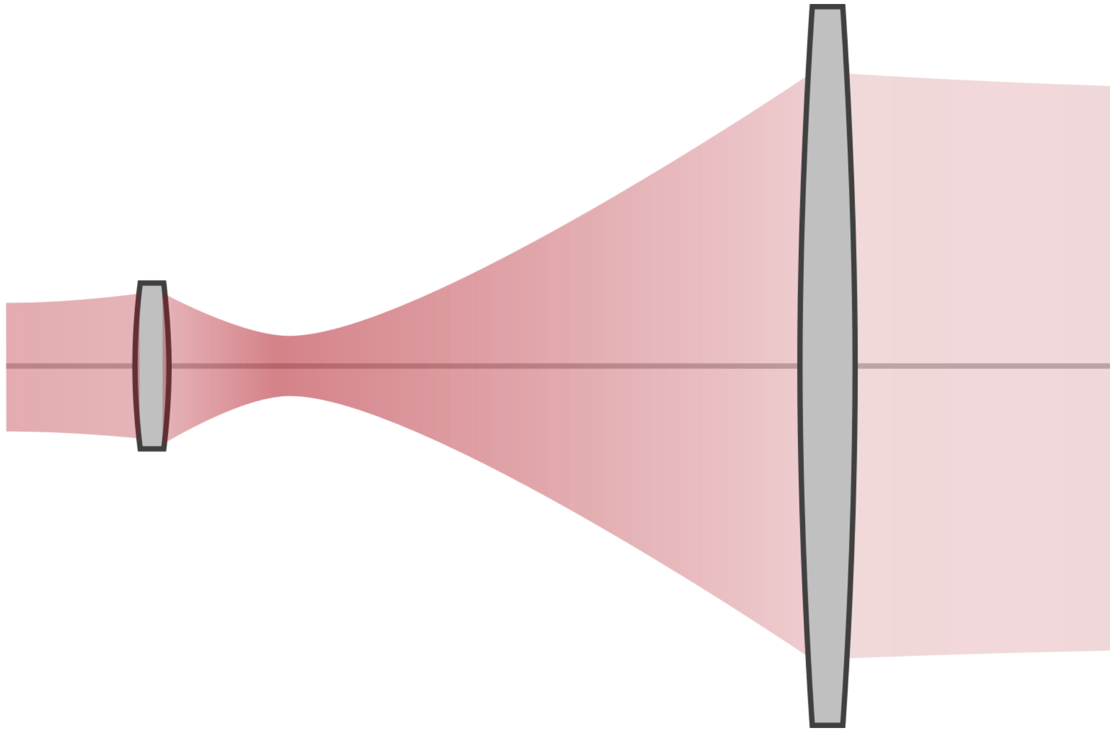
Afocal Systems for Laser Guide Stars

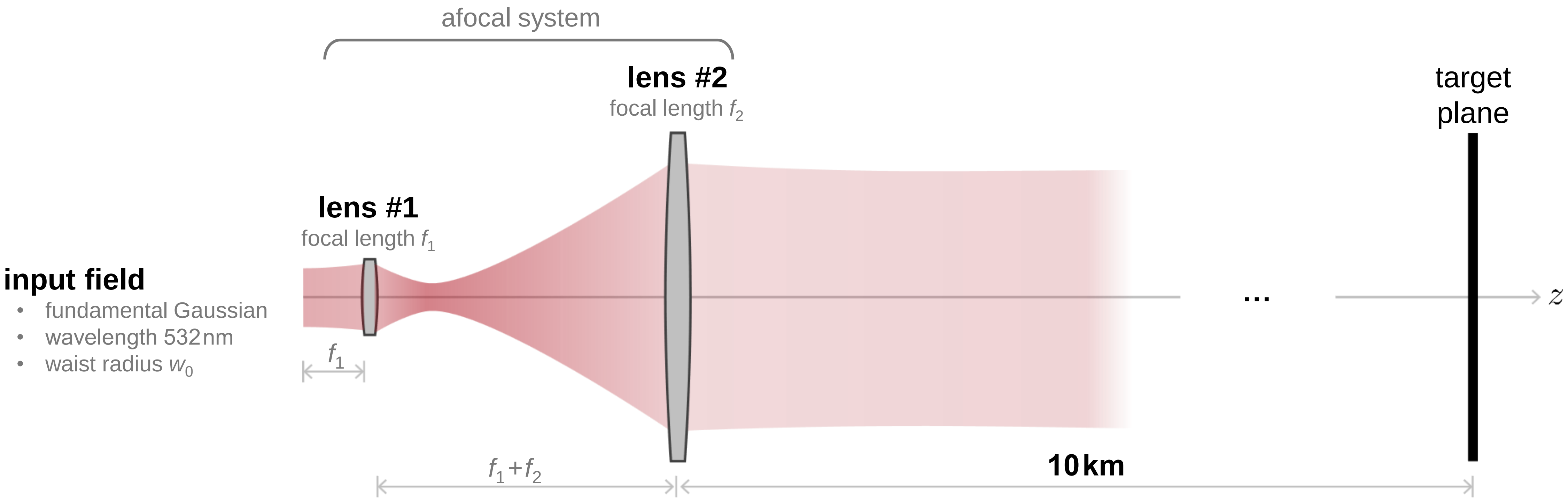
Abstract



For astronomical telescopes, laser guide stars are often used for correction of the atmospheric distortion. Such artificial star images are usually generated tens of kilometers away by high-power laser beams. In order to accurately design the optical system to generate and control the size of the laser guide star, the diffraction effects of the laser beam must be considered. In this example, a classical design of such a system is analyzed. The minimum spot size given by geometrical optics optimization can then be further reduced by considering diffractive effects and including a defocus or waist shift into the system.

Design Task #1 – Simple Afocal System

How to accurately calculate the laser beam parameters at the target plane 10 km away, and how to minimize the spot size there by varying the afocal system?

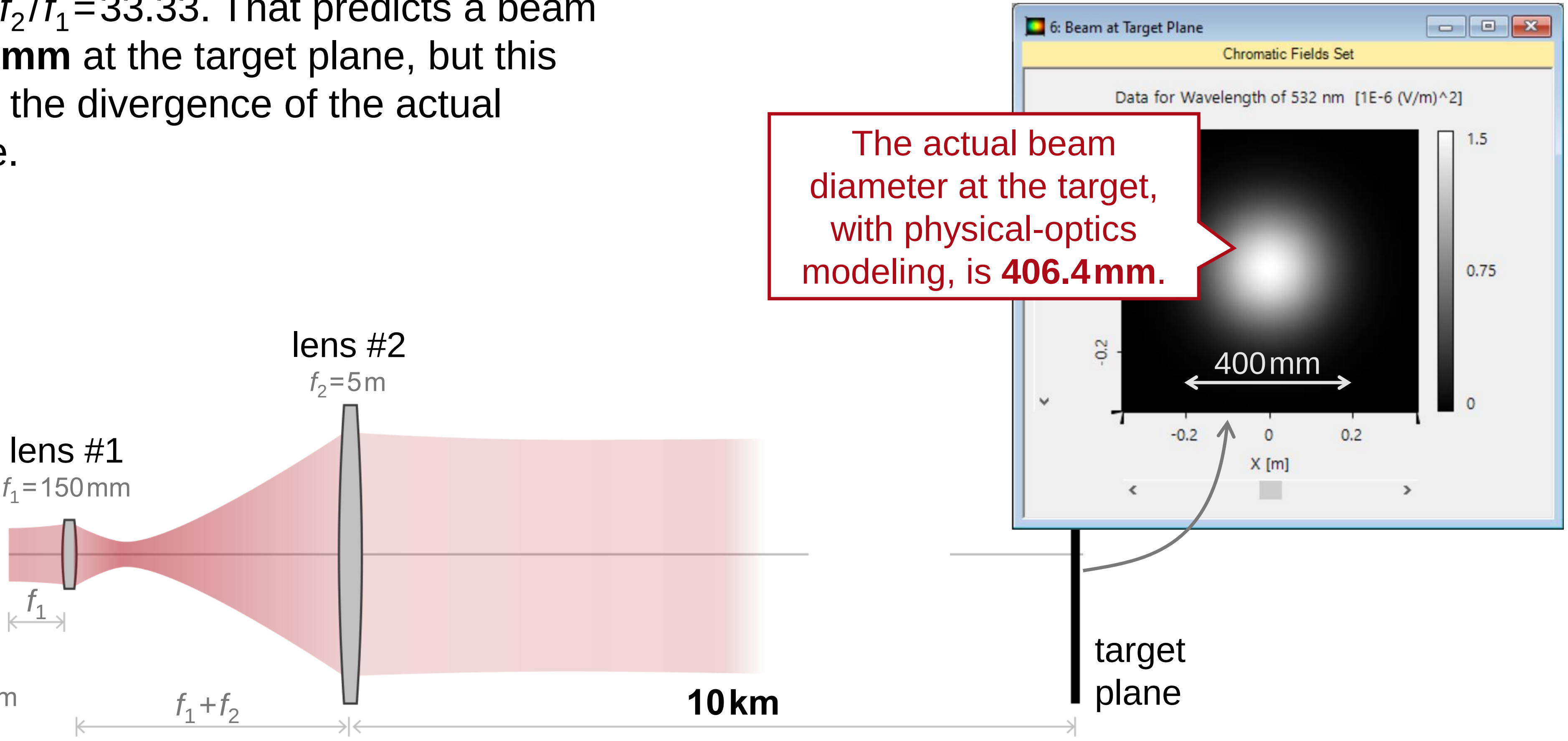


Parameters follow from L. Clermont, *et al*., "Design of a laser guide star for applications to adaptive optics", Proc. SPIE 11105 (2019)

Analysis of Afocal System for Laser Beams

Using geometrical optics, the afocal system gives a magnification of $f_2/f_1=33.33$. That predicts a beam diameter of **16.7 mm** at the target plane, but this does not include the divergence of the actual Gaussian source.

physical-optics simulation result with diffraction considered



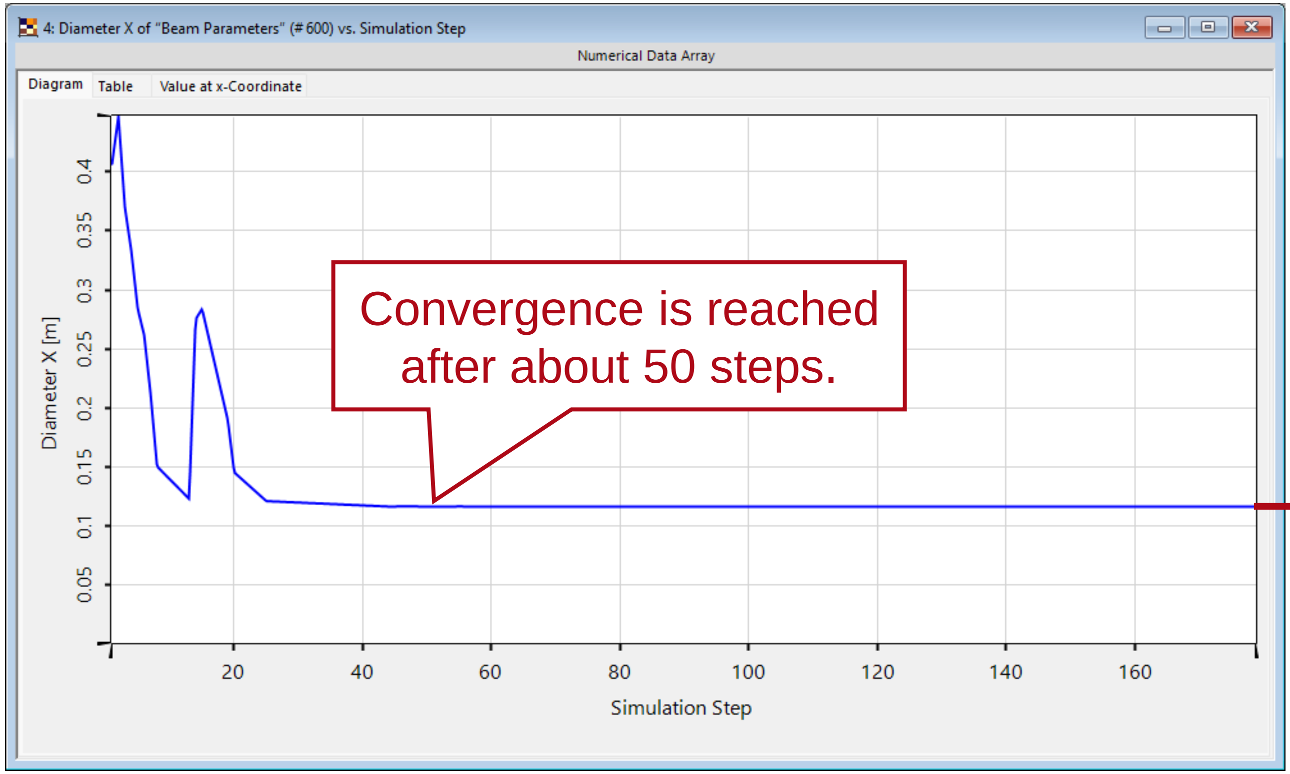
input field

- fundamental Gaussian
- wavelength 532 nm
- waist radius w_0=0.250 mm

Design of Simple Afocal System w_0=0.25mm (fixed)

initial variable values	
f_1	150mm
f_2	5m

parametric optimization with downhill simplex method



optimized variable values	
f_1	51.404mm
f_2	8.463m

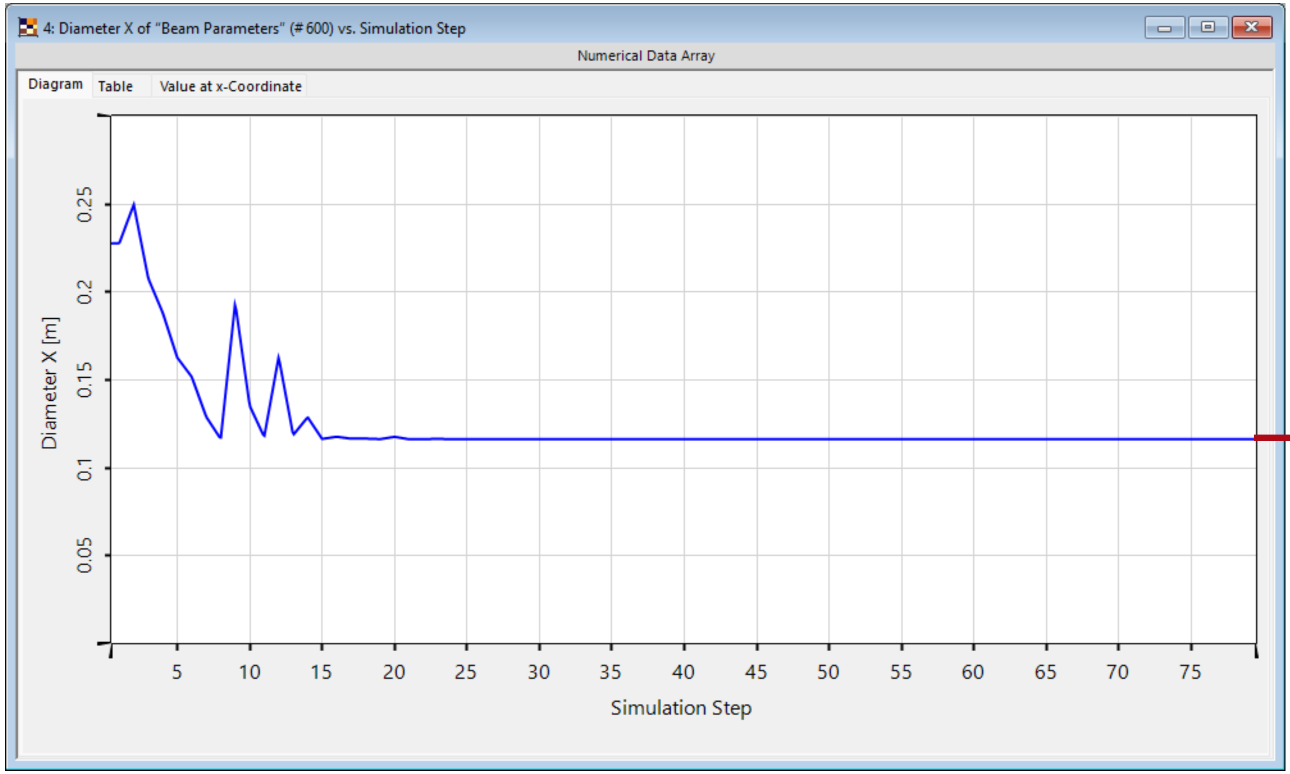
diameter @target **116.4mm**

Design of Simple Afocal System w_0=1.5mm (fixed)

Let us try the optimization with another input Gaussian waist radius.

parametric optimization with downhill simplex method

initial variable values	
f_1	250 mm
f_2	2.5 m



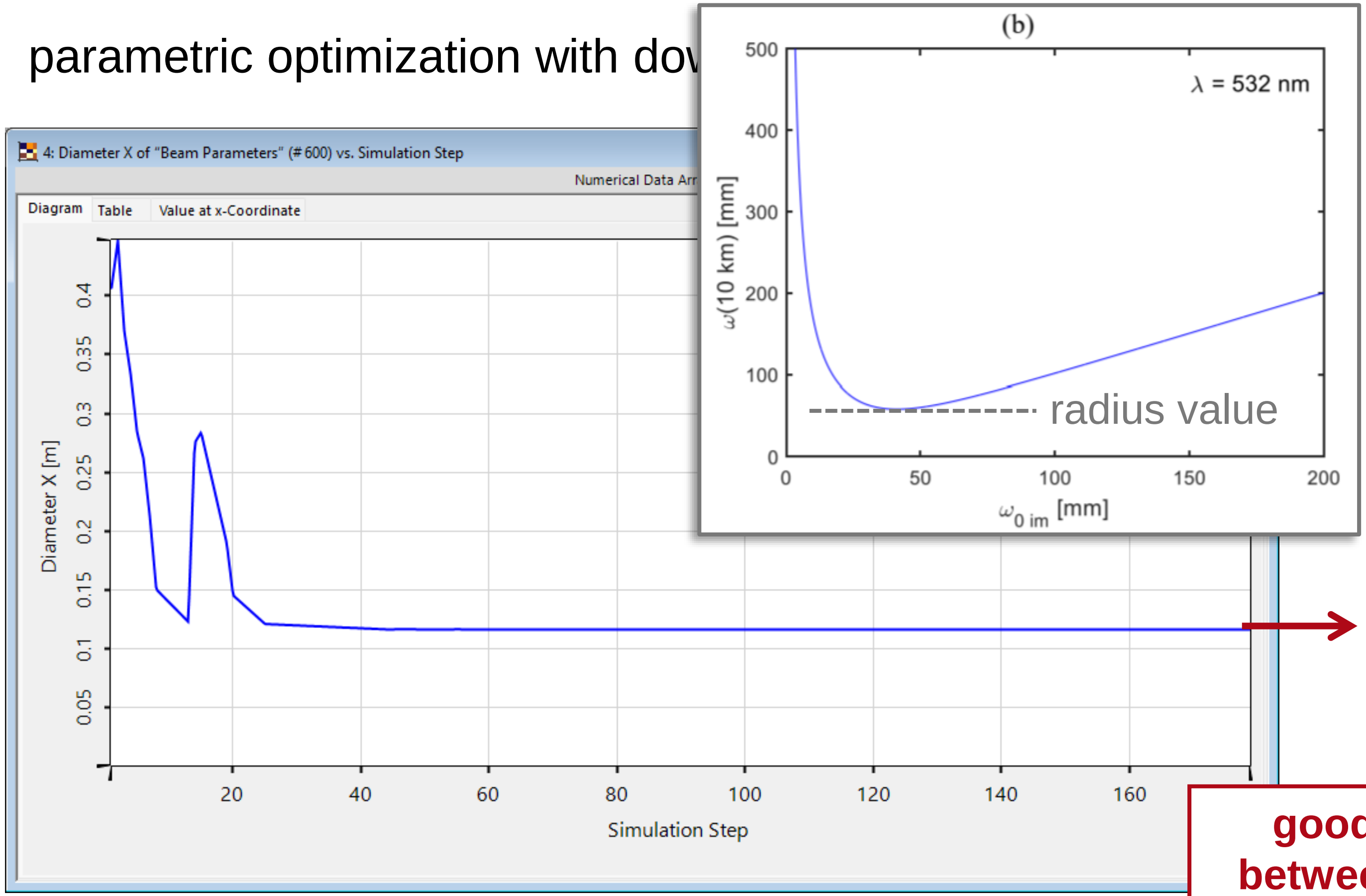
optimized variable values	
f_1	133.24 mm
f_2	3.66 m

diameter @ target **116.4 mm**

Design of Simple Afocal System w_0=1.5mm (fixed)

Fig. 2(b) from the reference

parametric optimization with dov



L. Clermont, *et al*., showed theoretically that the minimum beam *radius* at the target is 58.2mm, for any simple afocal system.

initial variable values	
f_1	250mm
f_2	2.5m

diameter @target
116.4mm

good agreement between theory and numerical simulation

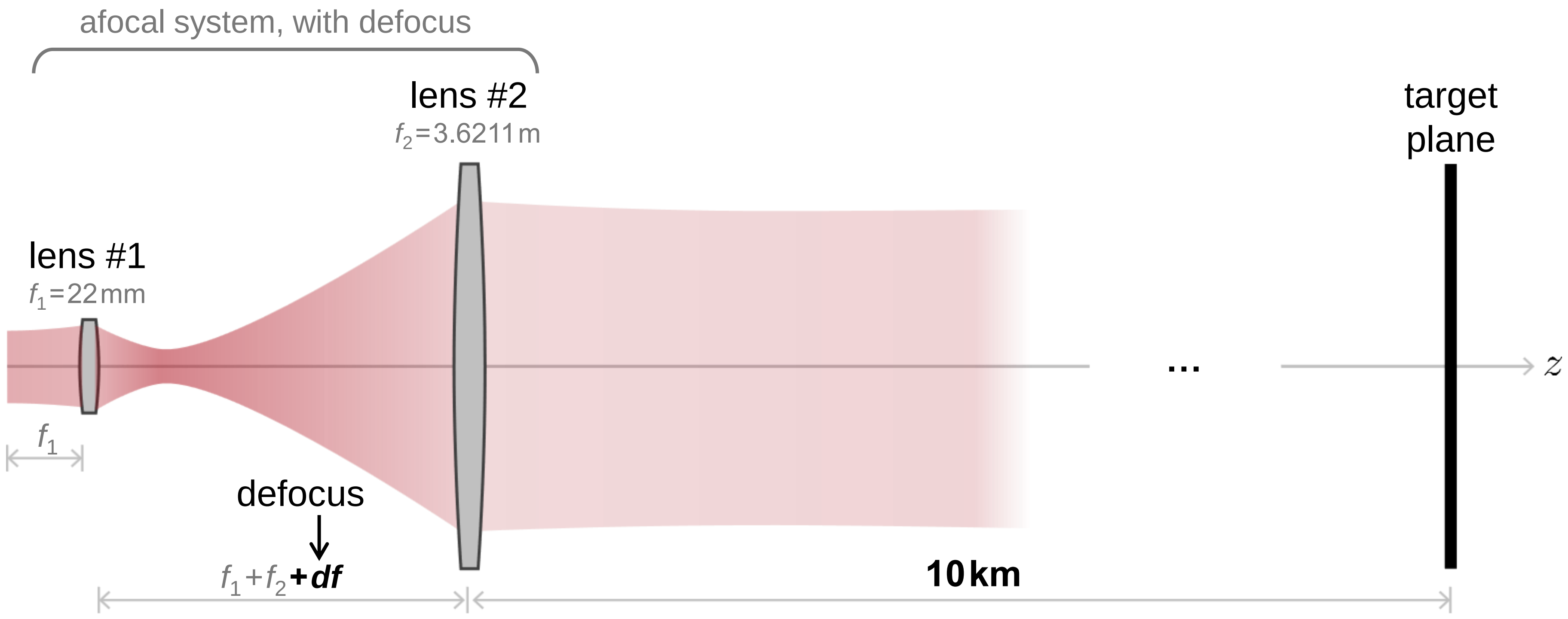
Design Task #2 – Afocal System with Defocus

Is it possible to further reduce the beam size at the target plane if additional freedom is available?

Let us try with defocus!

input field

- fundamental Gaussian
- wavelength 532 nm
- waist radius $w_0 = 0.25$ mm



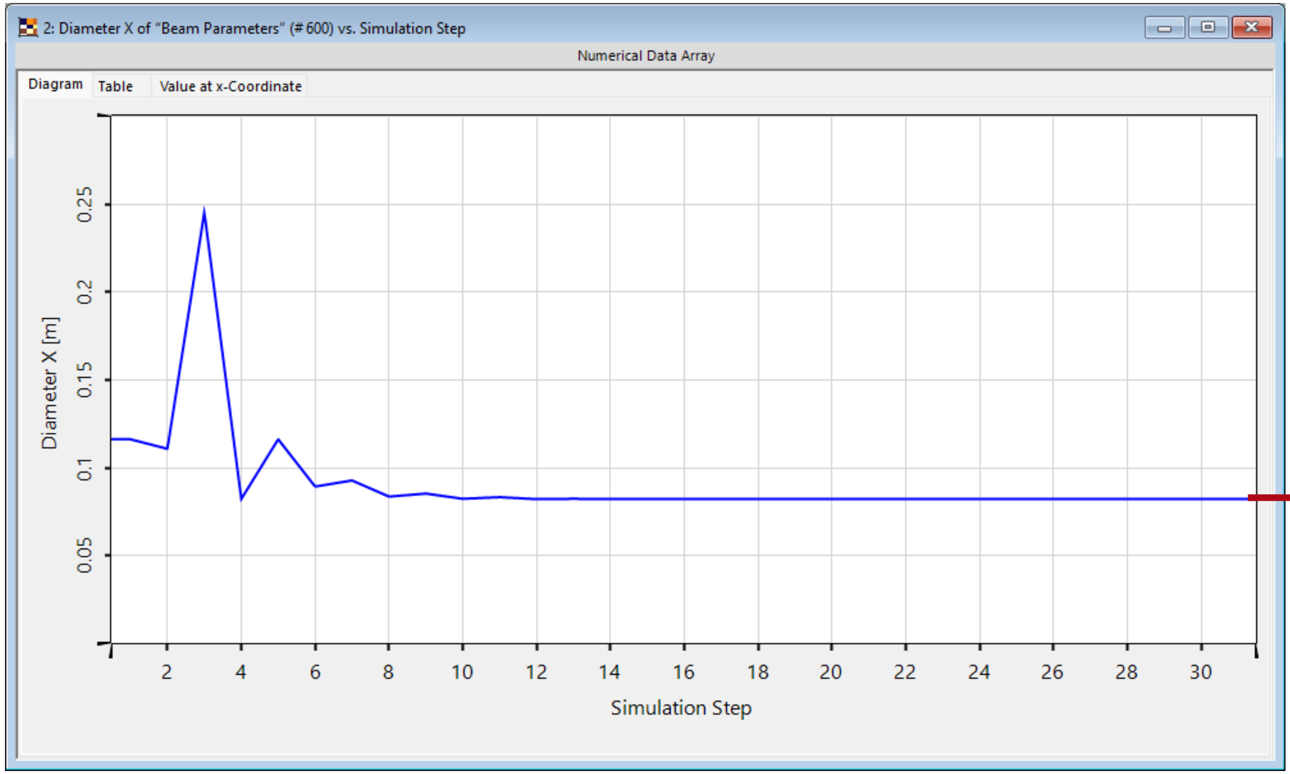
Design of Afocal System with Defocus

parametric optimization with downhill simplex method

initial variable values	
df	0 mm

other parameters

- w_0=0.25 mm
- f_1=22 mm
- f_2=3.6211 m

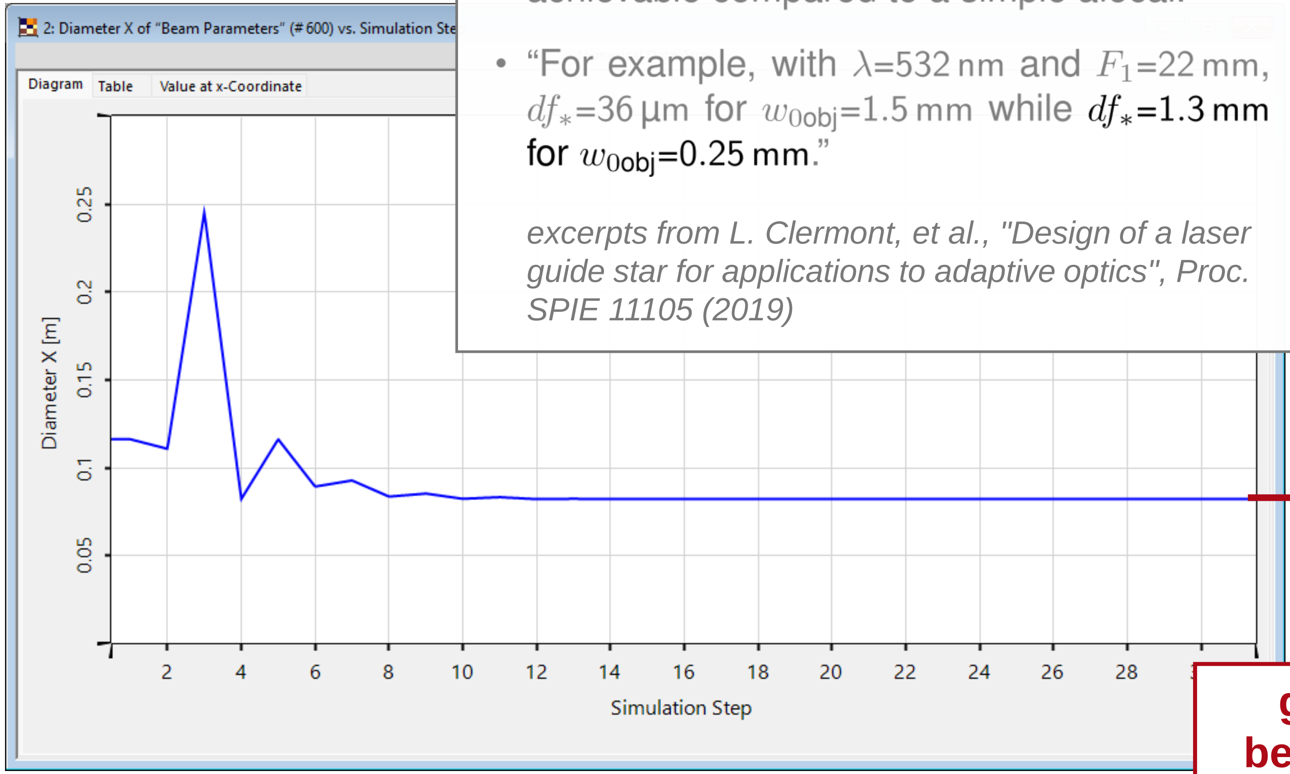


optimized variable values	
df	1.30 mm

diameter @ target
82.4 mm

Design of Afocal System with Defocus

parametric optimizat



- "A controlled defocus of the afocal can thus decrease by a factor $\sqrt{2}$ the minimum spot achievable compared to a simple afocal."
- "For example, with λ=532 nm and F_1=22 mm, df_*=36 µm for $w_{0\text{obj}}$=1.5 mm while df_*=1.3 mm for $w_{0\text{obj}}$=0.25 mm."

excerpts from L. Clermont, et al., "Design of a laser guide star for applications to adaptive optics", Proc. SPIE 11105 (2019)

initial variable values

df	0 mm

other parameters

- w_0=0.25 mm
- f_1=22 mm
- f_2=3.6211 m

optimized variable values

df	1.30 mm

diameter @ target
82.4 mm

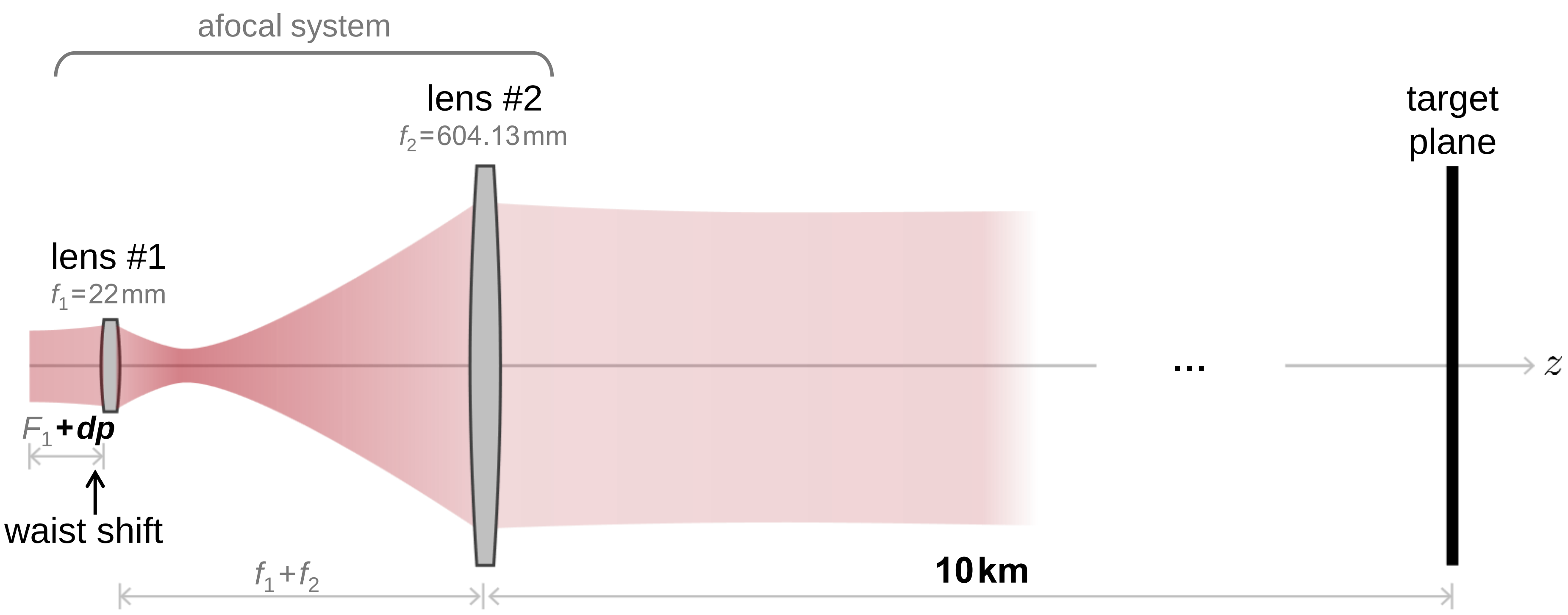
good agreement between theory and numerical simulation

Design Task #3 – Afocal System with Input Beam Waist Shift

Is it possible to further reduce the beam size at the target plane if additional freedom is available?
Next, we will try with input beam waist shift!

input field

- fundamental Gaussian
- wavelength 532 nm
- waist radius $w_0 = 1.5\,\text{mm}$



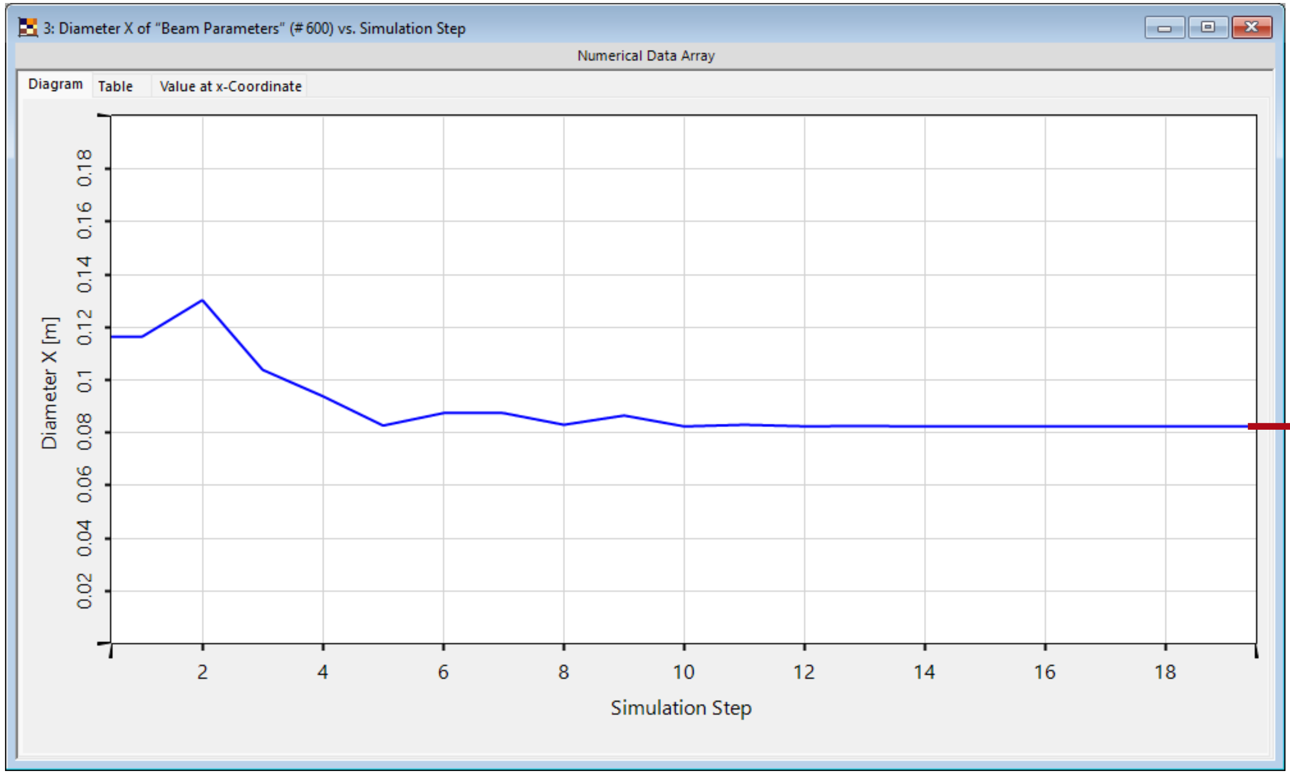
Design of Afocal System with Input Beam Waist Shift

parametric optimization with downhill simplex method

initial variable values	
dp	0 mm

other parameters

- w_0=1.5 mm
- f_1=22 mm
- f_2=604.13 mm



optimized variable values	
dp	-13.2 m

diameter @ target
82.3 mm

Design of Afocal System with Input Beam Waist Shift

parametric optimizat

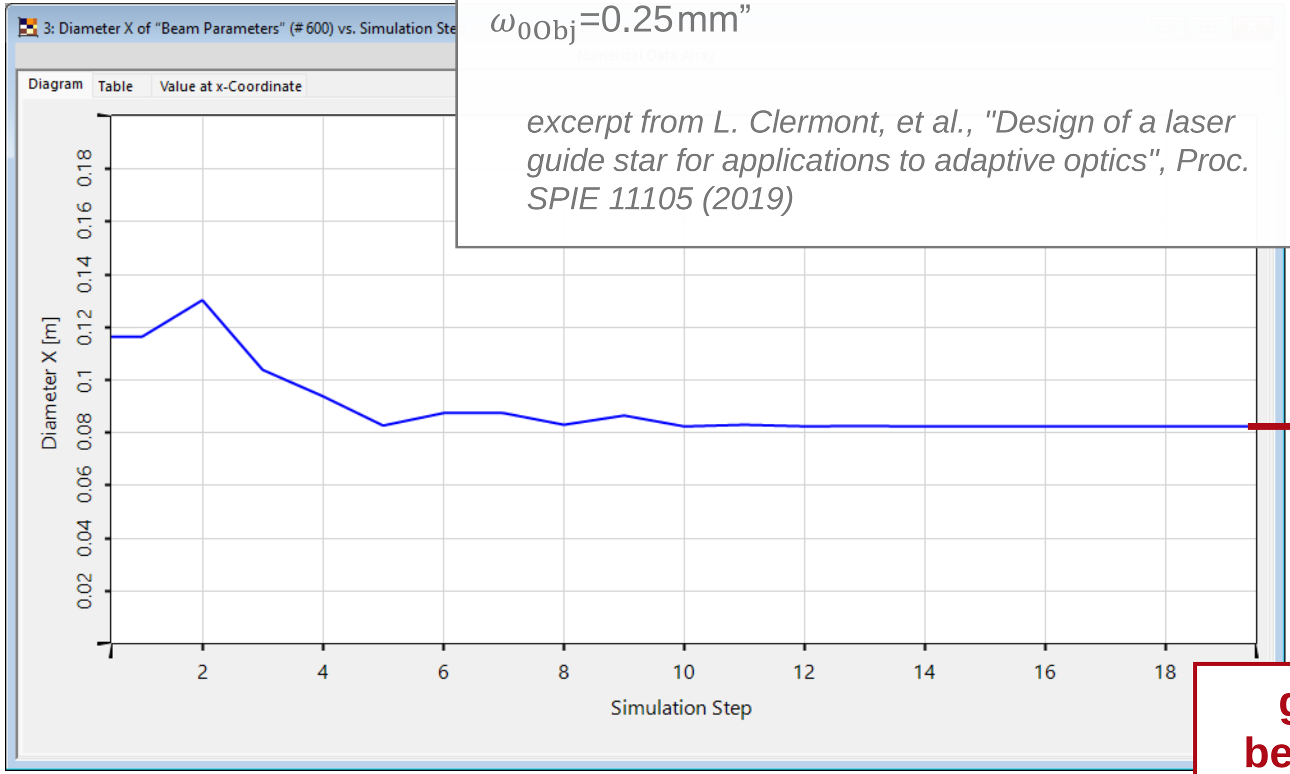
"The optimal value of dp_* is given by … For example, with λ=532 nm, dp_* =-13.3 m for $\omega_{0\mathrm{Obj}}$ =1.5 mm while dp_* =-370 mm for $\omega_{0\mathrm{Obj}}$=0.25 mm"

excerpt from L. Clermont, et al., "Design of a laser guide star for applications to adaptive optics", Proc. SPIE 11105 (2019)

initial variable values	
dp	0 mm

other parameters

- w_0=1.5 mm
- f_1=22 mm
- f_2=604.13 mm

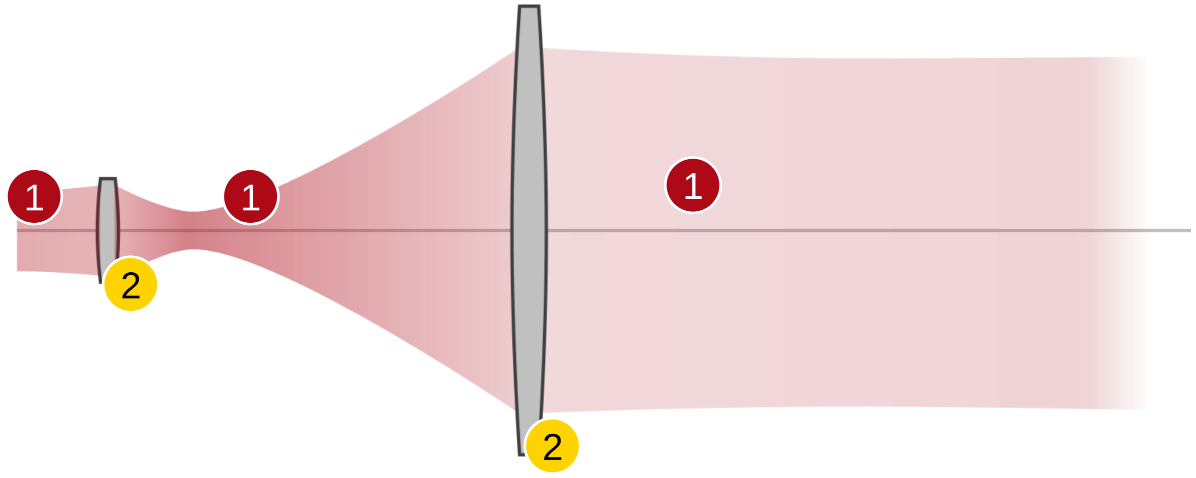


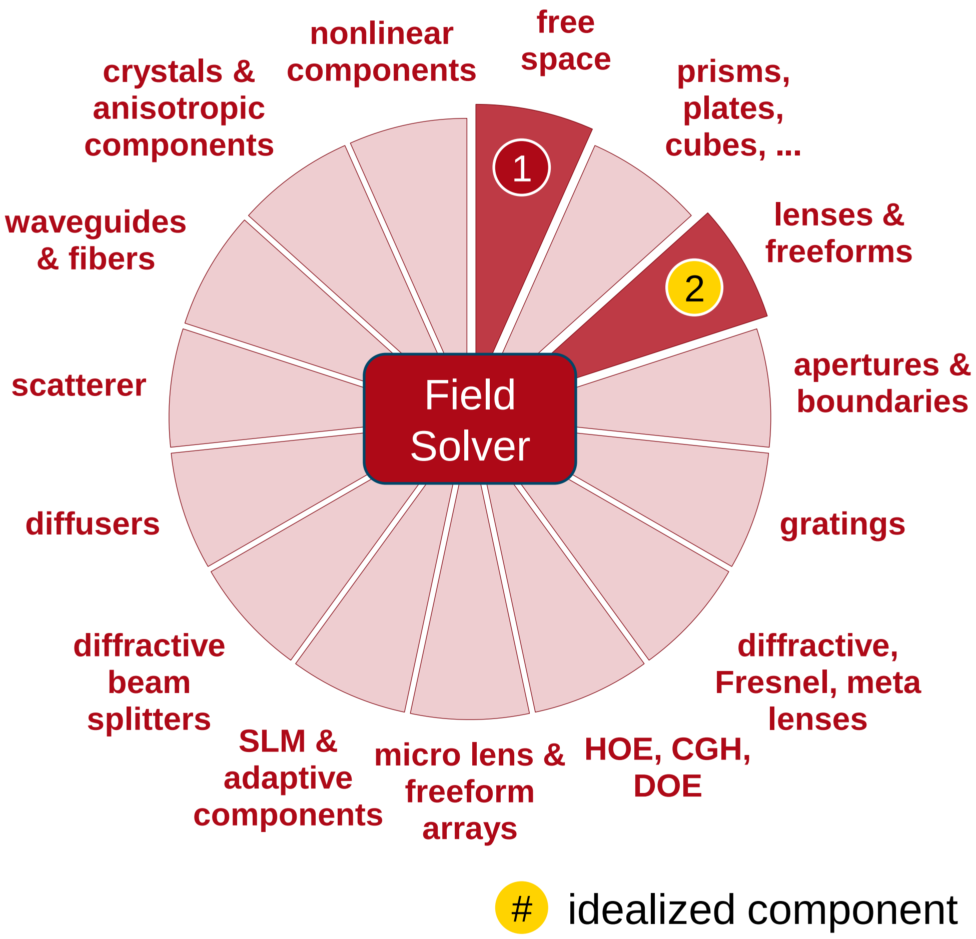
optimized variable values	
dp	-13.2 m

diameter @ target **82.3 mm**

good agreement between theory and numerical simulation

VirtualLab Fusion Technologies





Document Information

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