Advanced color correction using sensitivity analysis

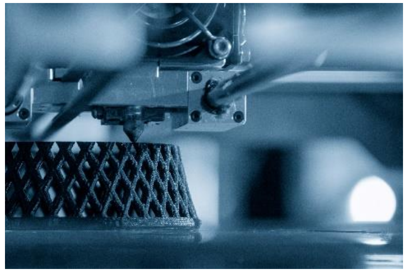
Aleksei Garshin, 26.09.2024

photonics
precision engineering

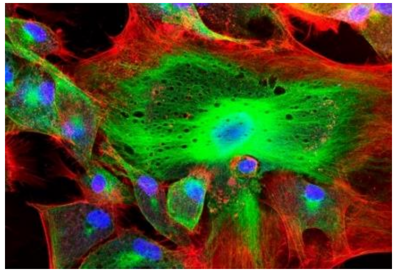
Manufacturable lens and system designs from PPE.
From concept to supply chain.

Augmented reality

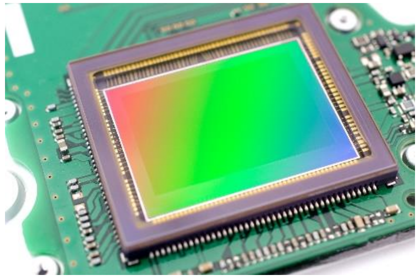
Lithography & Inspection



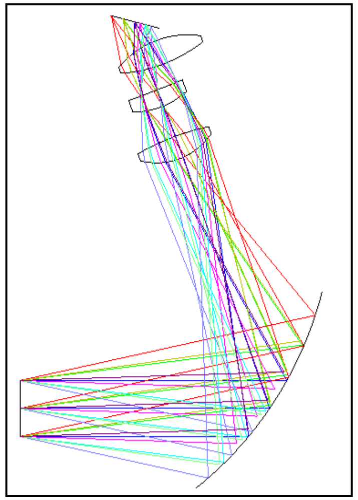
Laser processing 3D-Printing



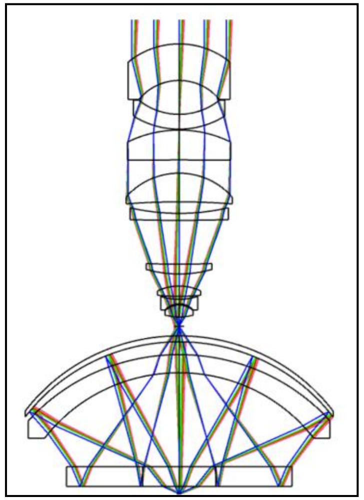
Bio Photonics



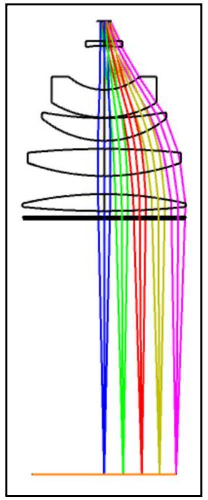
Industrial & Consumer Optics



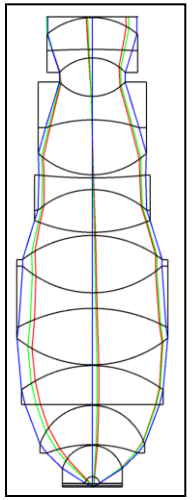
Glass, Helmet, Head-up



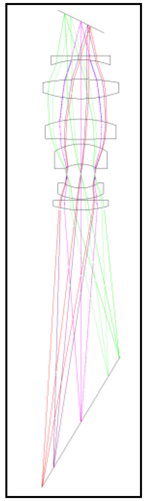
Aerial Image Analysis



DOE and system design



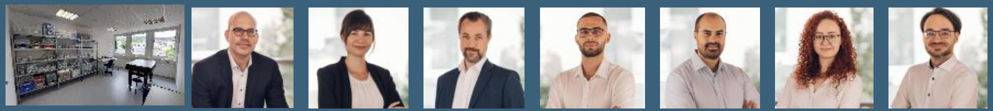
High NA – Large field
Multi-Channel Systems



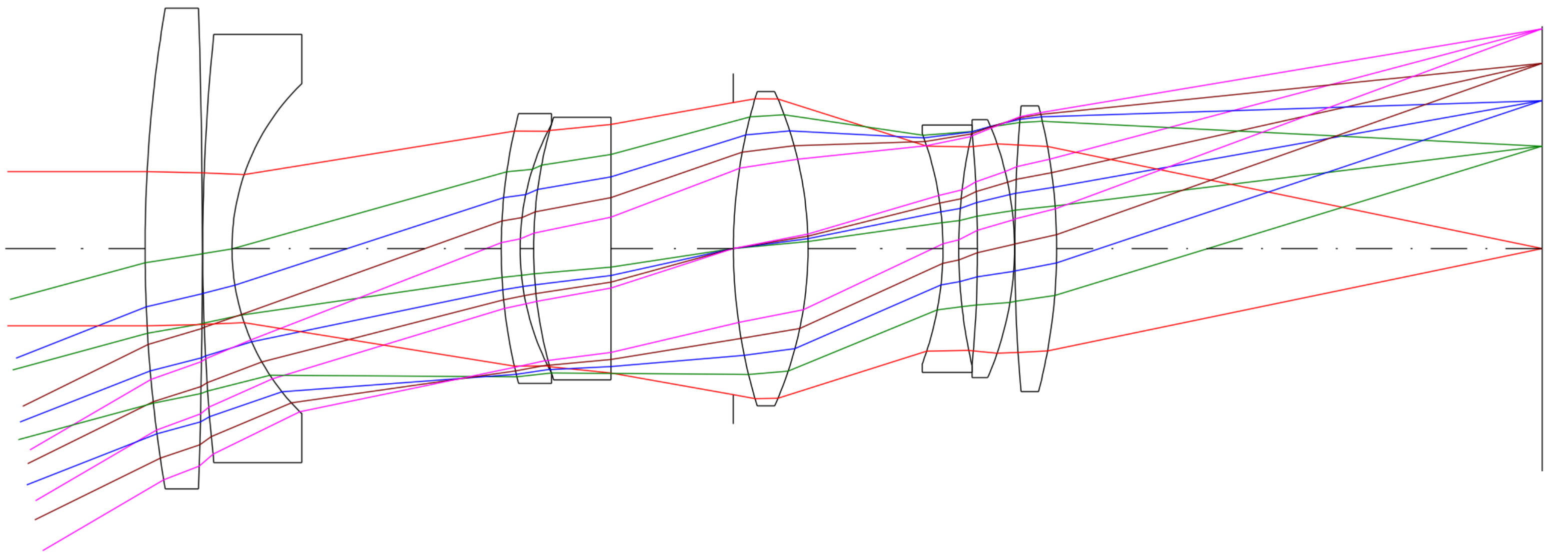
Meta lens Hybrid Designs

Optical Design. System Engineering. Prototyping.

www.ppe-jena.com



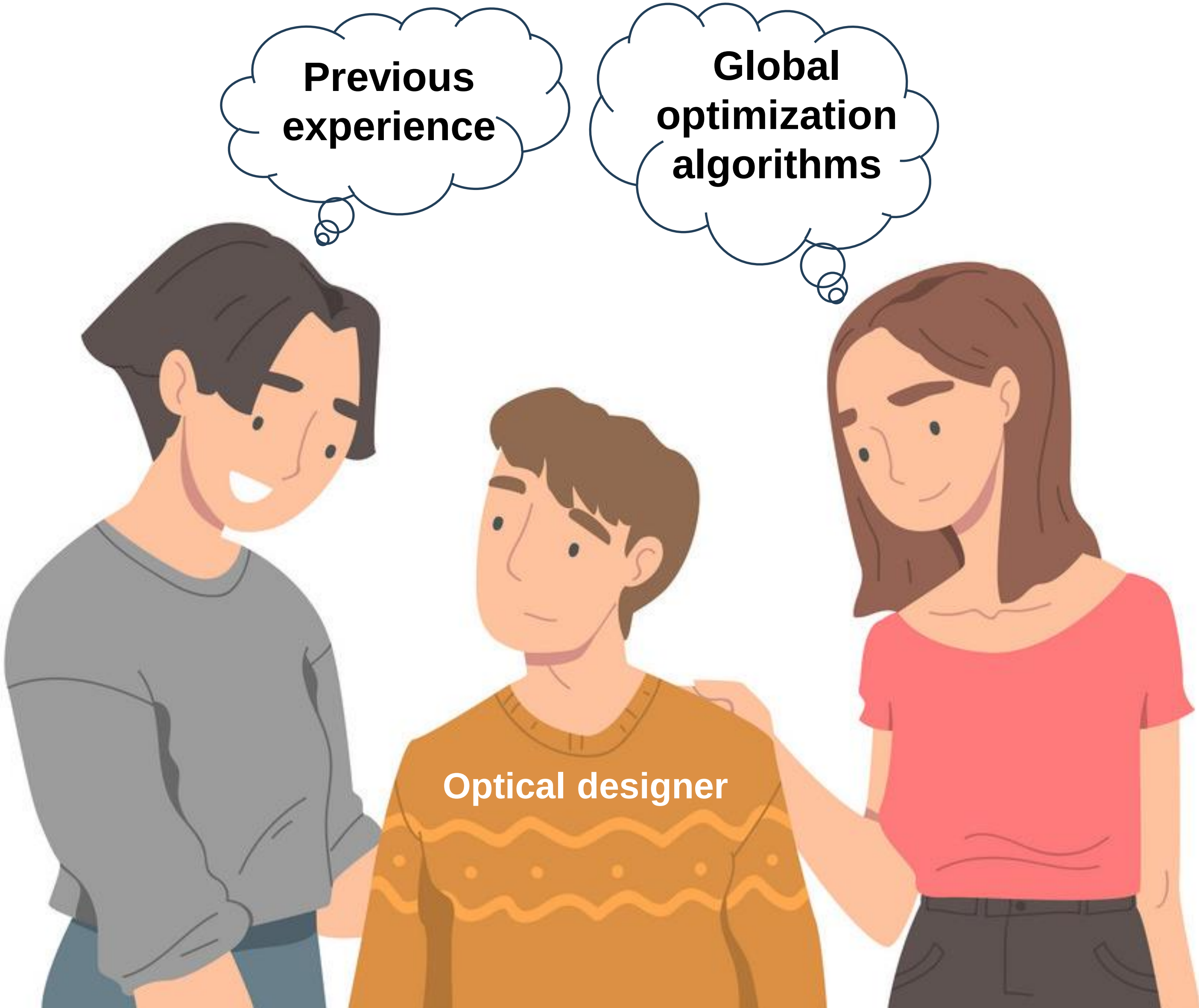
Glass selection problem



- Finding better glass combination is still challenging
- Extremely hard to do analytically for multi-element wideband optical systems
- The area of search is multidimensional (all color and monochromatic aberrations depend on glasses), but the glasses area is discrete

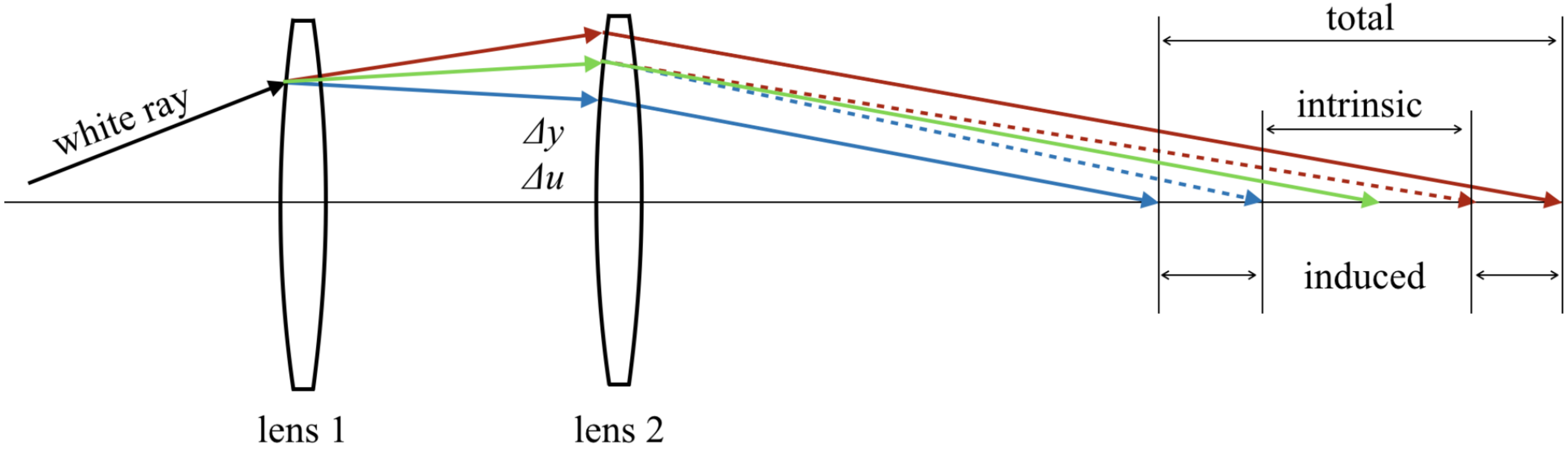
How can I find a better glass combination to improve my design?

Glass selection problem



Importance of the induced color aberrations

“Induced” aberrations – induced by uncorrected color aberrations of previous elements



Berner A. “Theory and application of induced higher order color aberrations”, Doctoral dissertation, Friedrich Schiller University Jena, (2020)

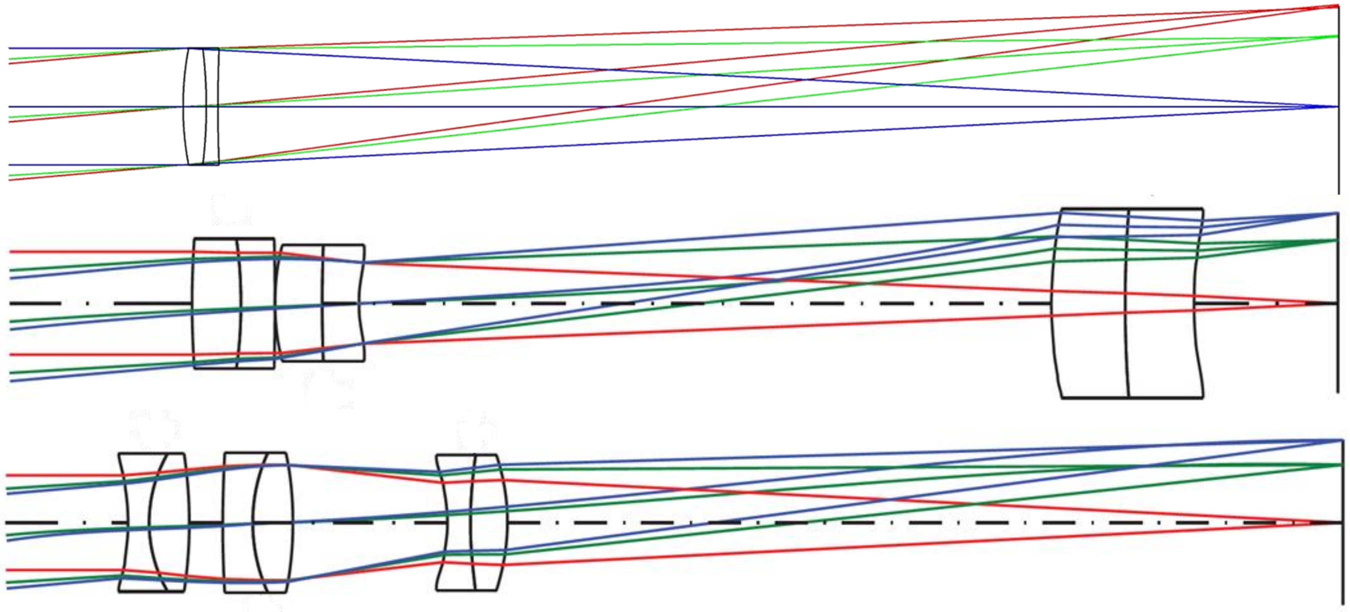
Importance of the induced color aberrations

Induced aberrations might be used to correct the residual secondary color of the system

- Single achromat
- Secondary color ~205 um

- 3 components, all achromats
- Secondary color ~231 um

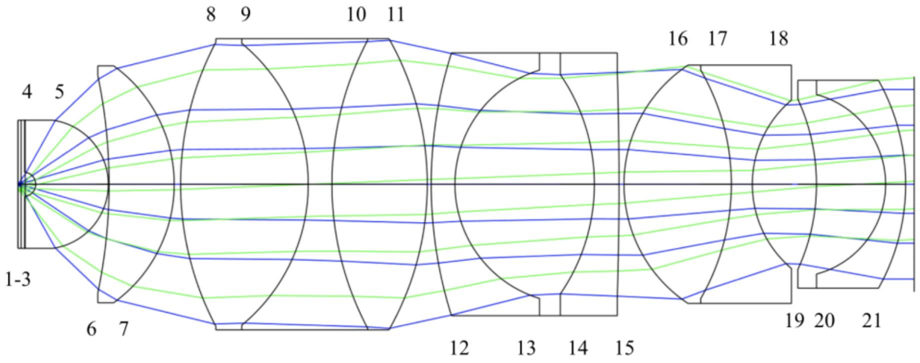
- 3 components, all uncorrected primary color
- Secondary color ~22 um

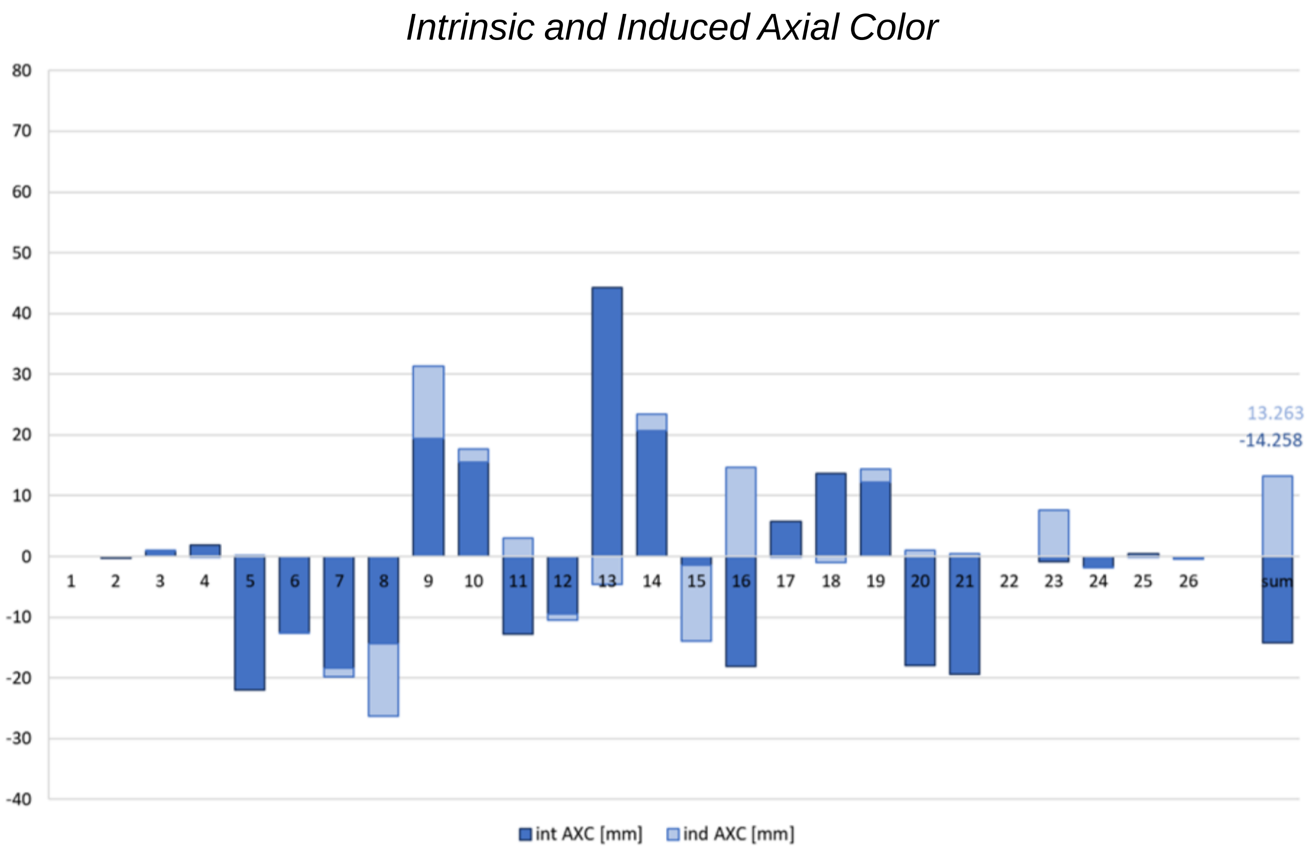


Rogers, J. R., "The importance of induced aberrations in the correction of secondary spectrum", Advanced Optical Technologies 2.1, p.41, (2013)

Surface contributions for color aberrations

- Distinguish between intrinsic and induced aberration parts (can be done for spherochromatic aberration as well)
- Highlights the trade-off between the induced and intrinsic aberration in the final correction
- Needs paraxial ray tracing → fast





Berner A. "Theory and application of induced higher order color aberrations", Doctoral dissertation, Friedrich Schiller University Jena, (2020)

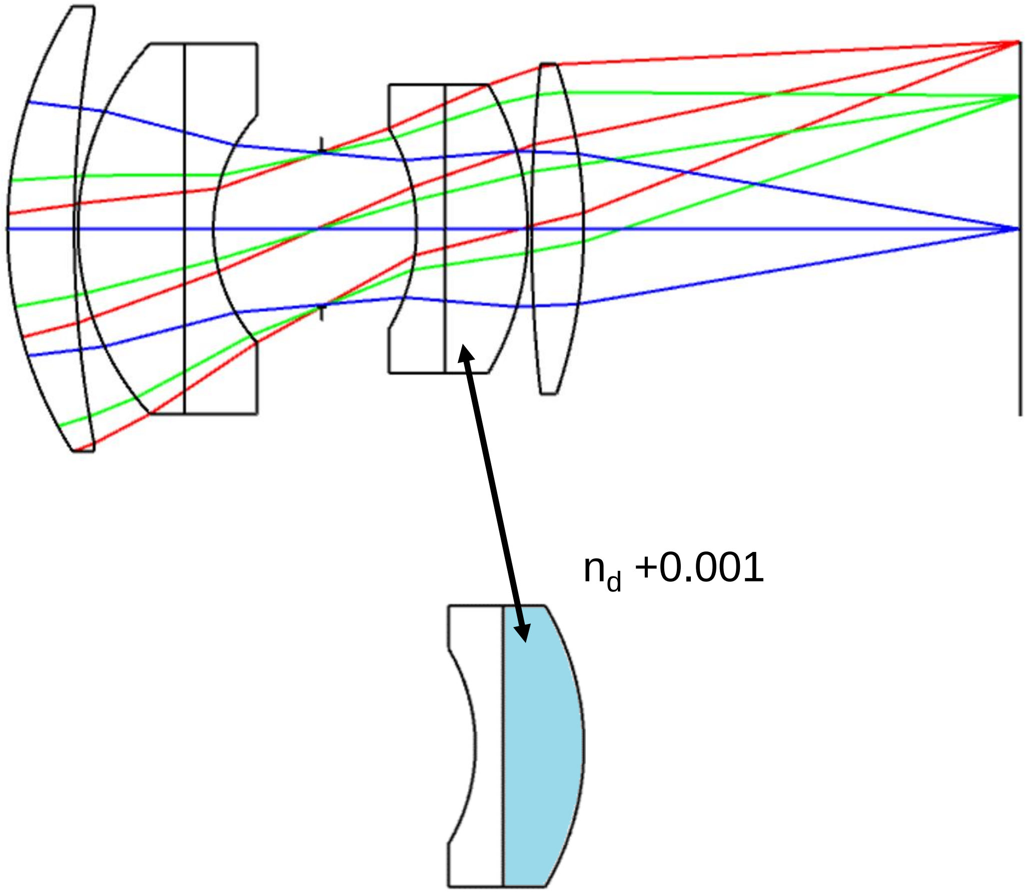
Use your personal hammer

Glass substitution using sensitivity analysis

Core idea: use surface aberrations contributions and apply sensitivity analysis to the glass choice → treat glass parameters as variables

1. Take a starting system and estimate the current state of correction
2. Choose the element and add a small change to glass parameters*
3. Evaluate aberrations perturbations due to glass parameter changes
4. Calculate glass parameter changes which lead to the correction improvement

* Every time we add a change for a glass parameter, we need to reoptimize the element!



Case study: inversed telephoto lens

$f' = 160$ mm

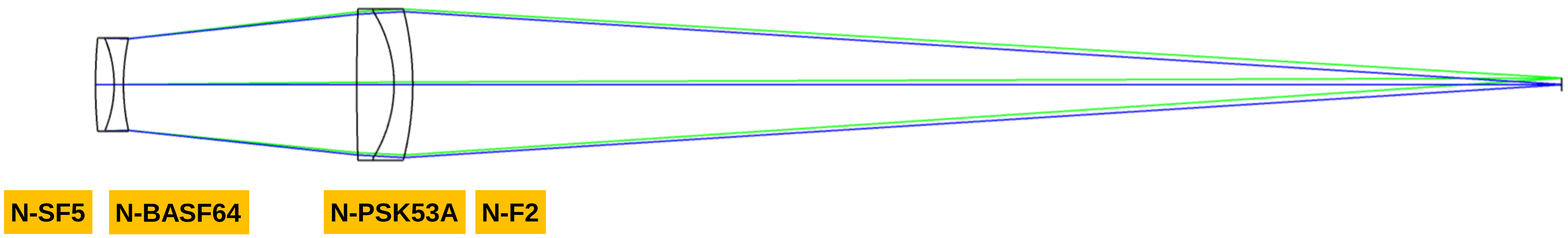
F# = 8

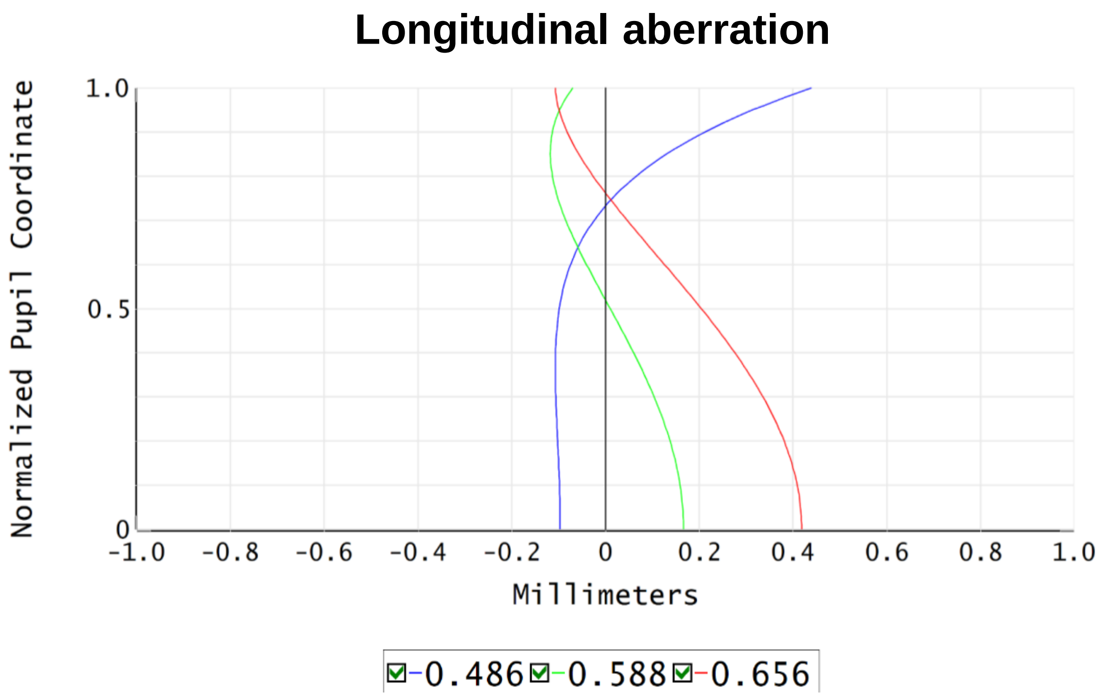
$f'_1 = -100$ mm

$d_3 = 50$ mm

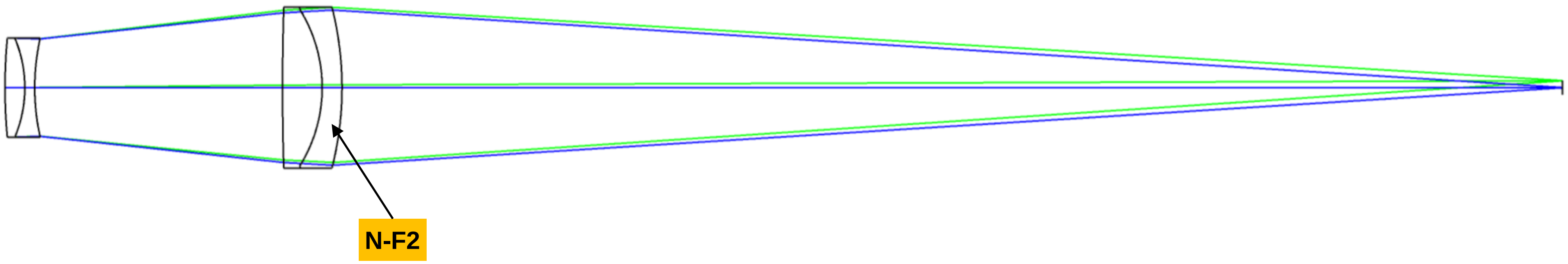
$2\omega = 1°$

F, d, C





Case study: inversed telephoto lens



Longitudinal aberrations surface contribution (initial system)

Surface #	SA 3rd, [mm]	SA 5th, [mm]	SphChr, [mm]	Prim. Col, [mm]	Sec. Col, [mm]
1	-0.261	-0.001	0.000	-3.072	2.096
2	3.136	0.427	-0.213	-3.774	2.429
3	14.681	1.086	0.066	8.585	-5.627
4	-2.140	-0.312	-0.025	-2.927	2.034
5	0.349	0.065	0.884	13.424	-9.106
6	-16.498	-0.855	-0.129	-12.751	8.437
1st doub	17.555	1.512	-0.148	1.739	-1.102
2nd doub	-18.289	-1.102	0.730	-2.255	1.365
Total	-0.734	0.410	0.583	-0.516	0.263

Sensitivity table for element #4 material (N-F2)

Parameter	Increment	S1_long	B5_long	SPHCHR	PrCol	SecCol
Initial system		**-0.7340**	**0.4101**	**0.5826**	**-0.5156**	**0.2634**
Abbe	0.5	-0.0001	0.0056	0.0274	-0.0001	0.0013
	-0.5	0.0000	-0.0050	-0.0260	0.0000	-0.0011
Index	0.005	-0.0015	0.1138	0.0143	-0.0017	0.0007
	-0.005	0.0012	-0.1124	-0.0157	-0.0008	0.0012
PdF	0.001	0.0000	0.0000	0.0000	-0.0001	-0.0180
	-0.001	0.0000	0.0000	0.0000	0.0001	0.0183

Case study: inversed telephoto lens

photonics precision engineering

Parameter	Increment	S1_long	B5_long	SPHCHR	PrCol	SecCol
Initial system		**-0.7340**	**0.4101**	**0.5826**	**-0.5156**	**0.2634**
Abbe	0.5	-0.0001	0.0056	0.0274	-0.0001	0.0013
	-0.5	0.0000	-0.0050	-0.0260	0.0000	-0.0011
Index	0.005	-0.0015	0.1138	0.0143	-0.0017	0.0007
	-0.005	0.0012	-0.1124	-0.0157	-0.0008	0.0012
PdF	0.001	0.0000	0.0000	0.0000	-0.0001	-0.0180
	-0.001	0.0000	0.0000	0.0000	0.0001	0.0183

$$\begin{cases} Aa_1 + Bb_1 = 0.3239 \\ Aa_2 + Bb_2 = -0.5826 \end{cases} \quad \begin{cases} A = -24.05 \\ B = \ \ 3.99 \end{cases} \quad \begin{cases} \Delta n_d = 0.02 \\ \Delta V_d = \ -12.03 \end{cases}$$

$$\Delta P_{dF} = 0.0548$$

	N-F2		???
n_d	1.6201	n_d	**1.6400**
V_d	36.43	V_d	**24.40**
P_{dF}	0.7068	P_{dF}	**0.7616**

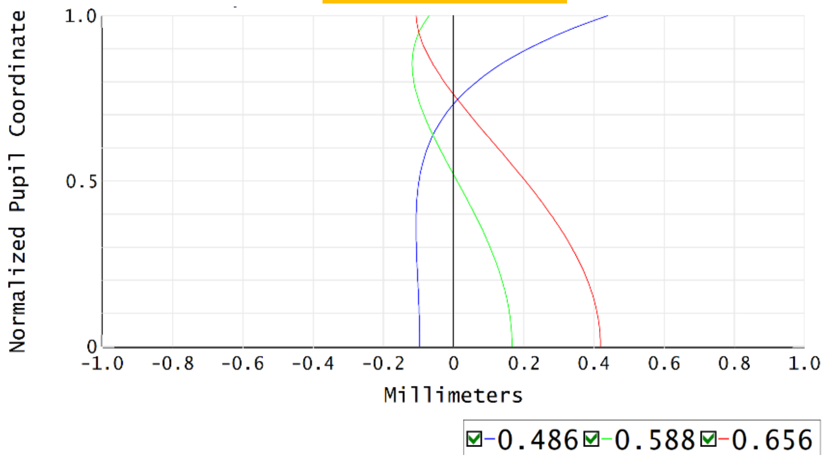
Case study: inversed telephoto lens

photonics
precision engineering

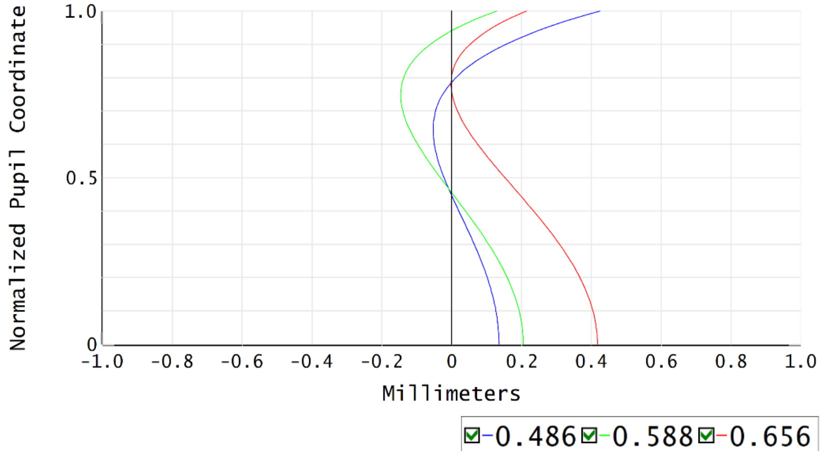
Glass	nd	vd	PdF
N-SF57	1.8467	23.78	0.7146
N-SF6	1.8052	25.36	0.7134
N-SF11	1.7847	25.68	0.7133
N-SF14	1.7618	26.53	0.7124
N-SF4	1.7551	27.38	0.7121
N-SF10	1.7283	28.53	0.7112
N-SF1	1.7174	29.62	0.7106
N-SF15	1.6989	30.20	0.7105
N-LASF55	1.9538	30.56	0.7094
P-SF8	1.6889	31.25	0.7093
N-SF8	1.6889	31.31	0.7092
N-SF5	1.6727	32.25	0.7090
N-LASF46A	1.9037	31.32	0.7088
N-LASF9	1.8503	32.17	0.7087
SF5	1.6727	32.21	0.7085
N-SF2	1.6477	33.82	0.7081
SF2	1.6477	33.85	0.7078
N-LAF7	1.7495	34.82	0.7072
N-LASF45	1.8011	34.97	0.7070
N-LASF45HT	1.8011	34.97	0.7070
N-BASF2	1.6645	36.00	0.7069
N-F2	1.6201	36.43	0.7068
N-BASF64	1.7040	39.38	0.7045
LF5	1.5814	40.85	0.7041
N-BAF4	1.6057	43.72	0.7032
N-LASF43	1.8061	40.61	0.7028
P-LASF50	1.8086	40.46	0.7027
N-LASF31A	1.8830	40.76	0.7027
N-KZFS5	1.6541	39.70	0.7027
P-LASF51	1.8100	40.93	0.7024
N-BAF51	1.6522	44.96	0.7023
N-LAF2	1.7440	44.85	0.7022
P-LASF47	1.8061	40.90	0.7022
LLF1	1.5481	45.75	0.7020

	N-F2	Target	N-SF4
n_d	1.6201	1.6400	1.7551
V_d	36.43	24.40	27.38
P_{dF}	0.7065	0.7616	0.7121

Initial design

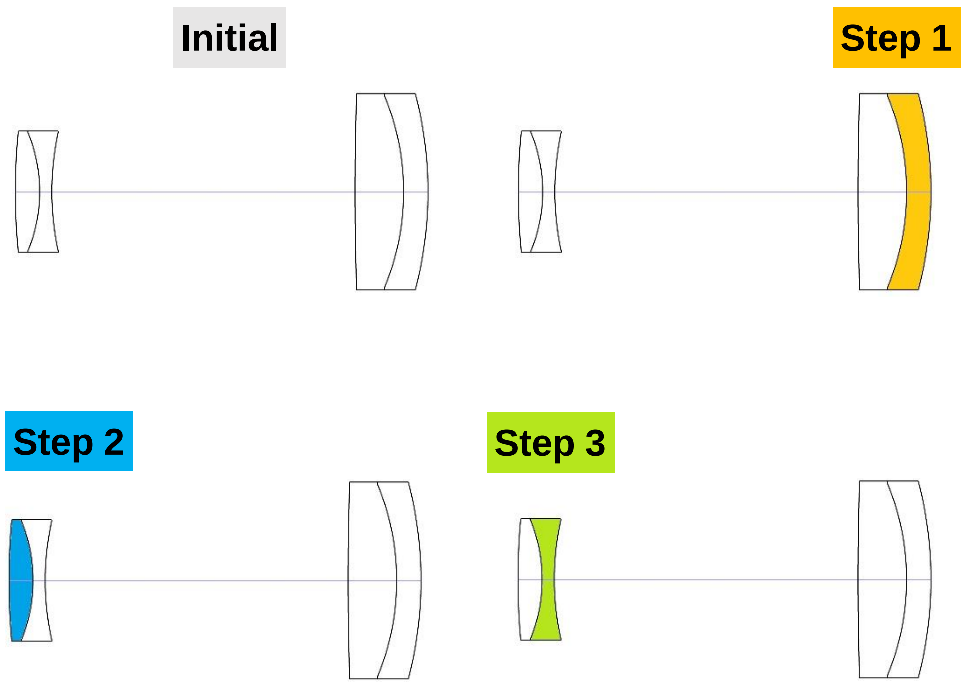


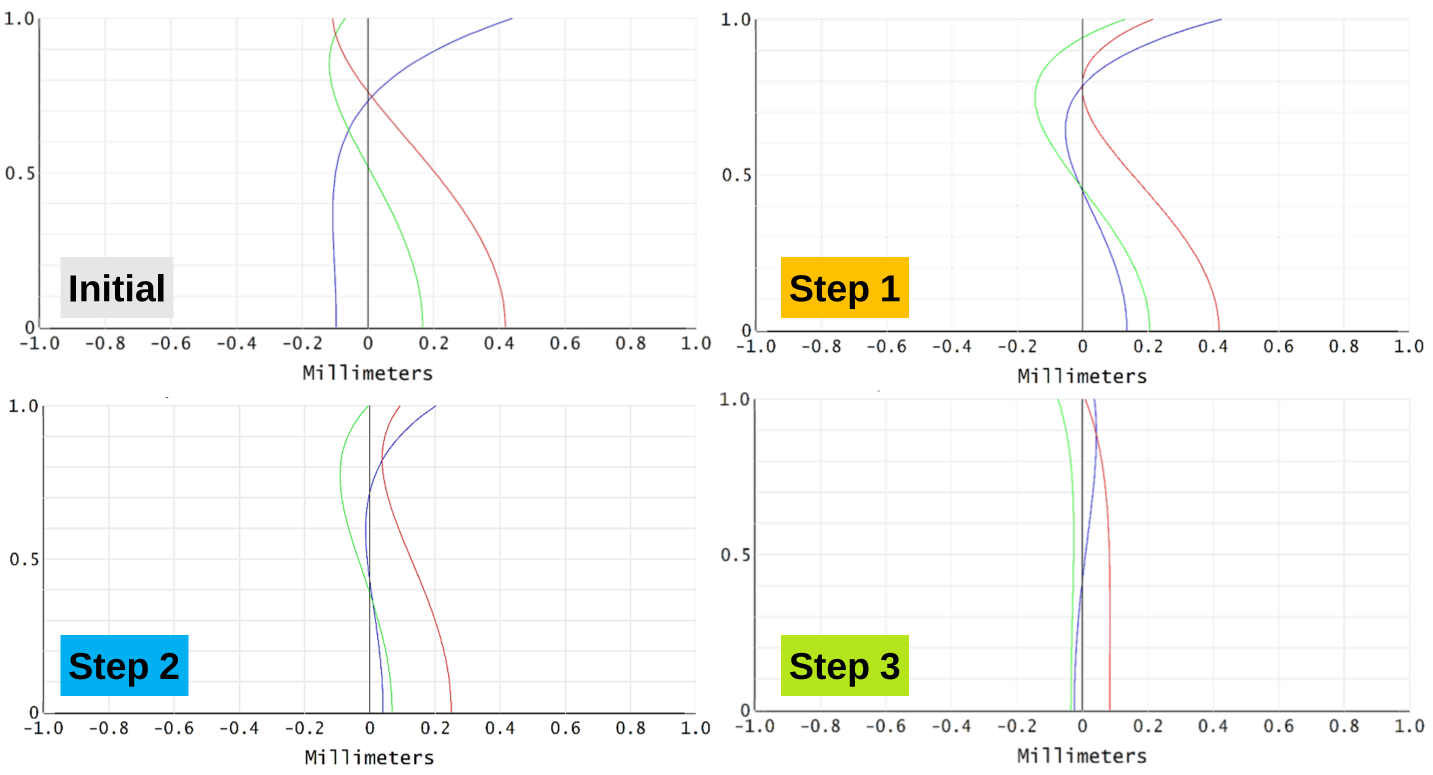
Step 1: N-F2 substituted by N-SF4



- Primary and secondary color correction are improved
- Spherochromatism correction improved
- 5^{th} order spherical aberration increased (n_d missmatch)

Case study: inversed telephoto lens





Conclusions and next steps

The application of sensitivity analysis to the optical design seems to be a promising method for glass substitution.

- It supports optical designers in finding better routes/directions in the optimization process
- Needs only paraxial raytracing data and Seidel aberration theory → might be implemented as an automatic routine

Possible next steps:

- The method should be implemented for the other types of optical components
- The method might be updated with field aberration analysis (lateral color, Petzval curvature)
- More parameters of glass might be used: dn/dT