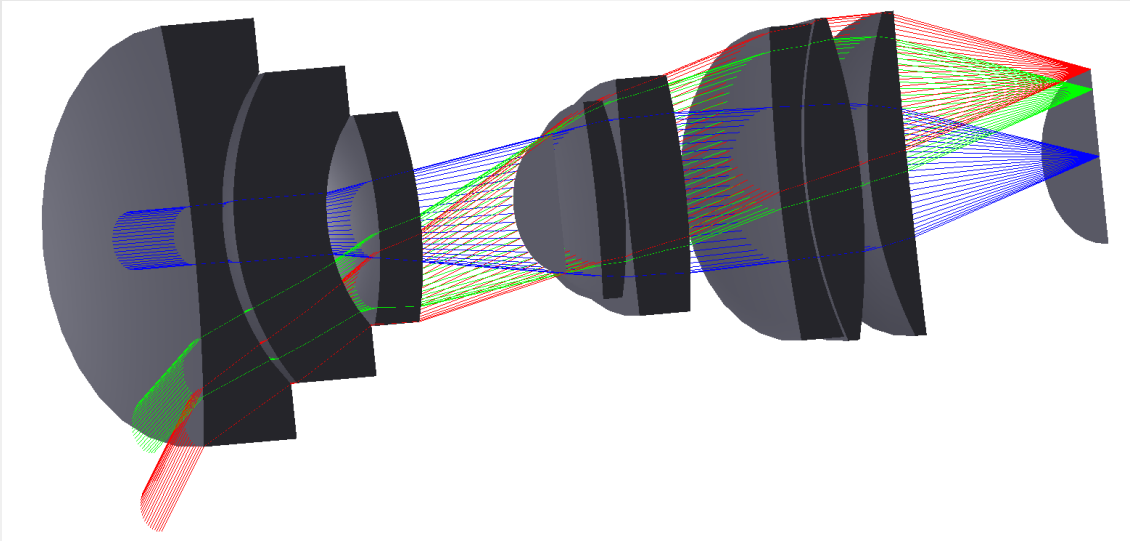


Optical Systems Design with Zemax OpticStudio

Epiphany Term 2026

Lecture 2 Sequential Ray Tracing and optimisation

Cyril Bourgenot (cyril.bourgenot@durham.ac.uk)

Centre for Advanced Instrumentation, University of Durham

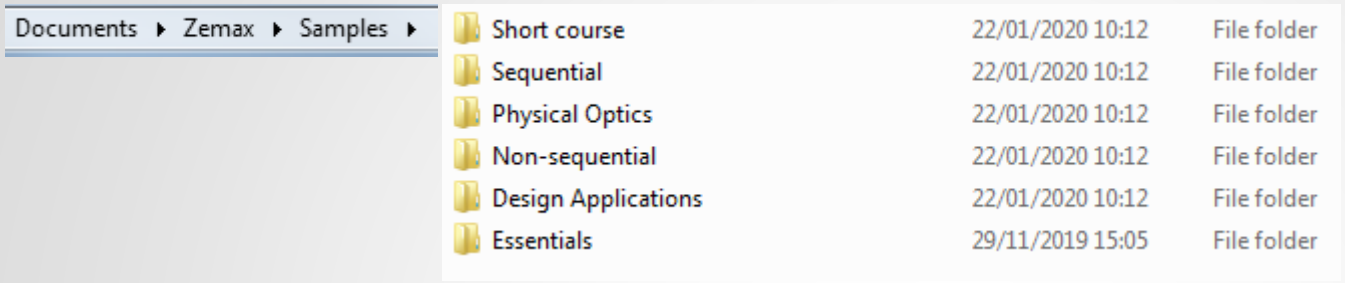
Course Outline

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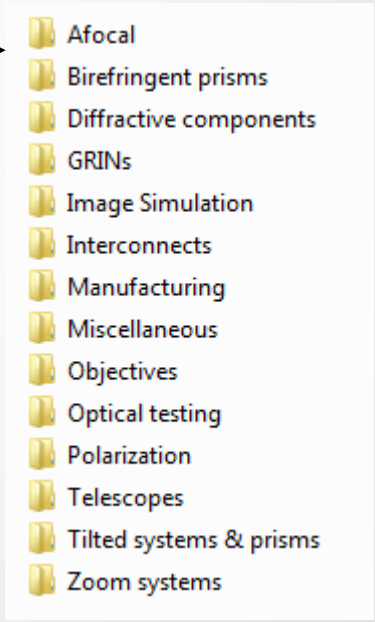
- Lecture 1 (2h): Introduction to Zemax
  - Introduction to Zemax and sequential ray tracing
  - Paraxial lens
  - Coordinate breaks
  - Singlet lens
  - Lens catalogue
  - Exercise : optimisation of a real 4f folded relay system
- Lecture 2(2h): hands on Optimisation
  - Optimisation functions
  - Optimisation of a singlet
  - Optimisation of a cook triplet
  - Exercise : optimisation of an achromatic doublet
  - Exercise : optimisation of a Cassegrain Telescope
- Lecture 3 (2h): hands on Tolerances
  - Tolerancing of an aspheric singlet
  - Type of tolerancing – Monte Carlo
  - Exercise : tolerancing a Cook triplet

https://cyrilbourgenot.wixsite.com/home/lectures

Zemax example



- Sequential example includes :



- Physical Optics examples (POP)
- Non Sequential

Input the following system

- Component:
  - Catalogue Thorlabs: AL50100-A
  - EFL = 100mm
  - Aperture = 47mm
  - Plano-convex
  - Aspheric
- System specification:
  - Aperture on convex surface : EPD 30mm, located 20mm in front of the lens
  - 3 FOV (0, 1, and 2 degrees)
  - Wavelength : HeNe (632.8nm)

Input the following system

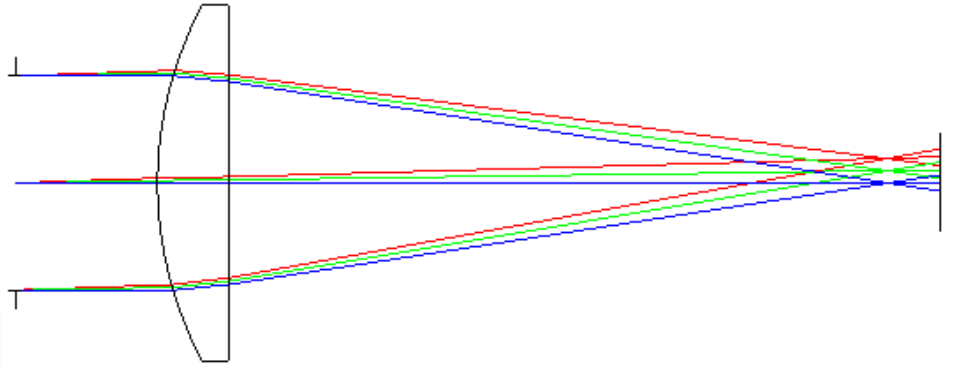
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Lens Data

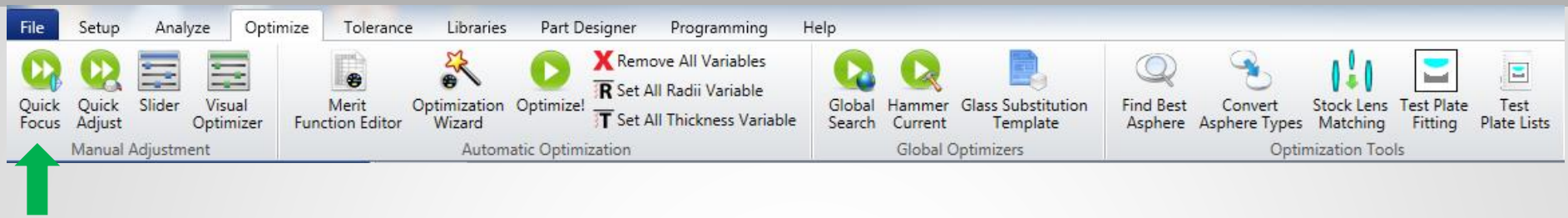
Update: All Windows

Surface 4 Properties — Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	Par 1(unused)	Par 2(unused)	Par 3(unused)	Par 4(unused)	Par 5(unused)
0	OBJECT Standard		Infinity	Infinity			Infinity U	0.000	Infinity U	0.000	0.000					
1	STOP Standard		Infinity	20.000			15.000	0.000	15.000	0.000	0.000					
2	(aper) Even Asphere	AL50100-A	51.120	10.000	N-BK7	THORA	25.000 U	0.000	25.000	-0.575	-	0.000	-4.837E-11	-8.576E-12	-2.014E-15	-4.598E-19
3	(aper) Standard		Infinity	100.000		THORA	15.155	0.000	25.000	0.000	0.000					
4	IMAGE Standard		Infinity	-			6.984 U	0.000	6.984 U	0.000	0.000					

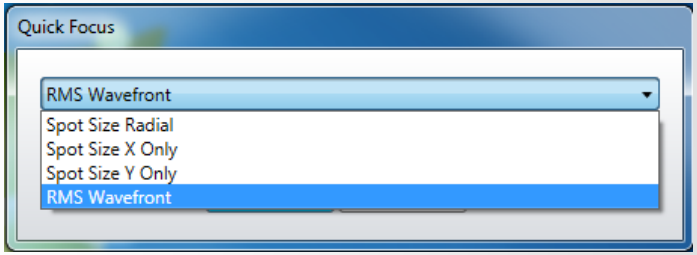


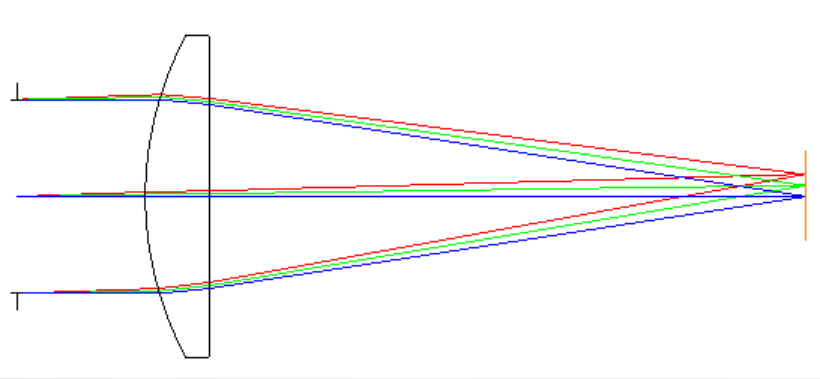
Optimisation function



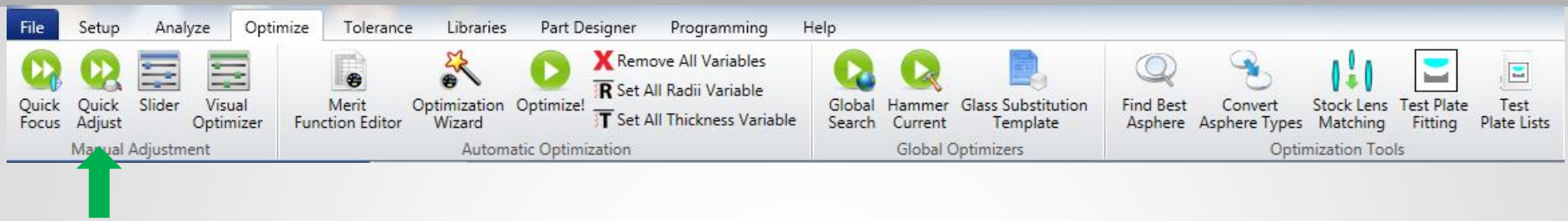
Quick focus (on **thickness** of last surface) based on :

- Spot size radial
- Spot size X only
- Spot size Y only
- RMS wavefront

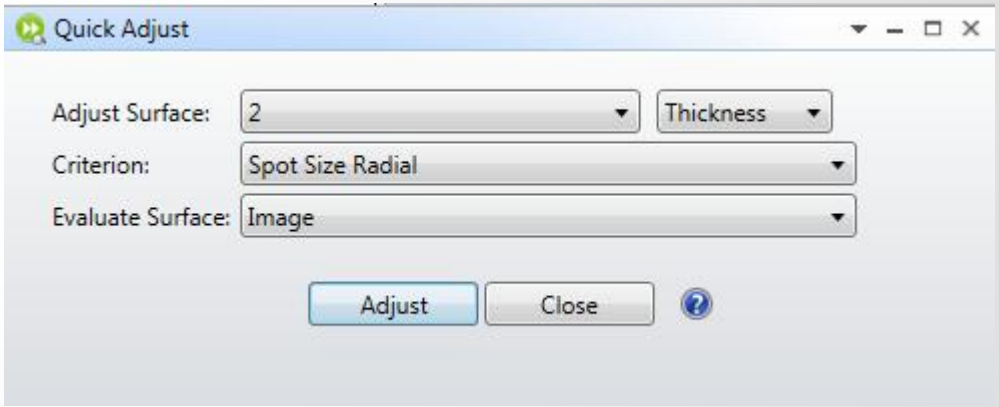




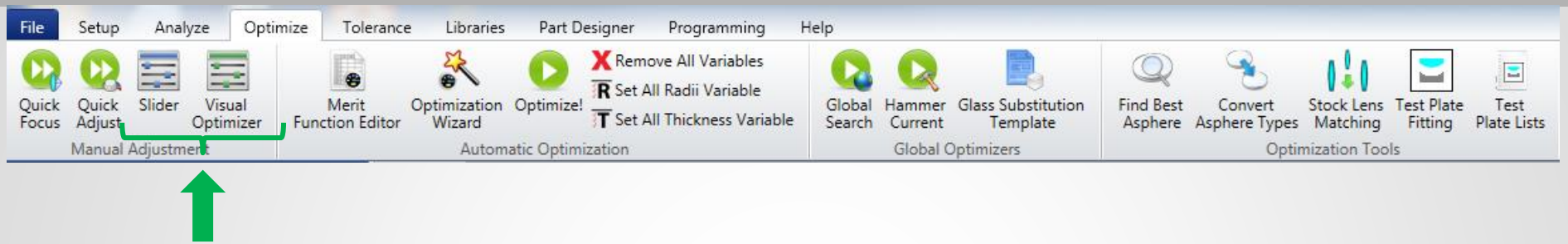
Optimisation function



"Quick Adjust" adjusts any radius or thickness to achieve best transverse or angular ray focus evaluated at any subsequent surface.



Optimisation function



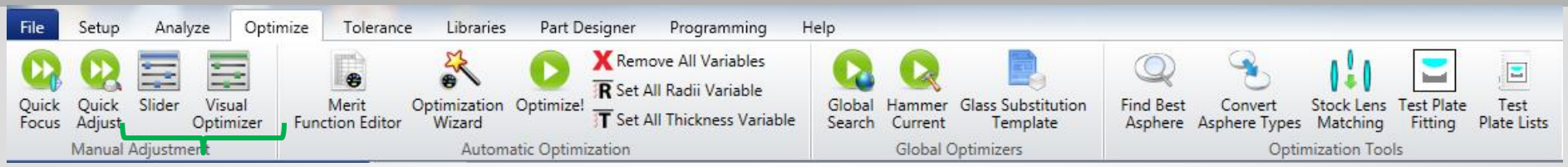
Slider and Visual Optimizer allow to interactively adjust any system or surface parameter while viewing any analysis window.
The difference between Slider and Visual Optimizer (VO) is that the slider does not change the system parameter, while VO modifies the variables

- Example: Let's create 2 sliders looking at the focus, and the effect of the convex surface decentre.

Slider on focus

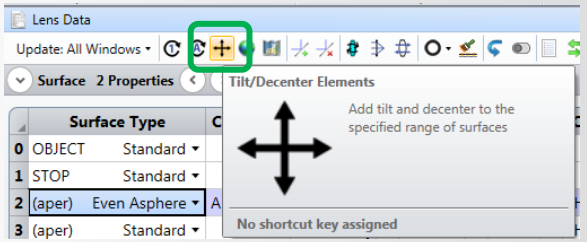
- Open a spot diagram window and set the plot scale to 300 microns
- Set a slider to adjust the focus between 92 and 93 => press animate

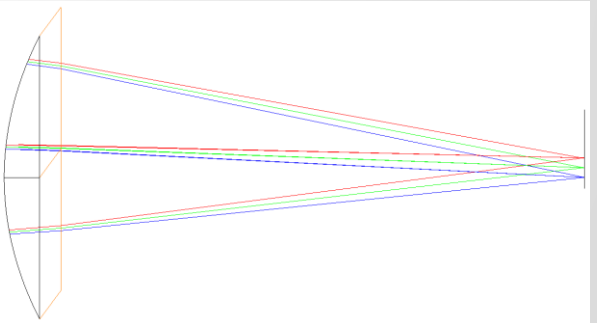
Optimisation function



Slider on Decentre

- Select surface 2 (the convex surface)
- Press Tilt/Decentre elements
- Set another slider with parameter 2 on surface 2 (Decentre on y)





Lens Data

Update: All Windows

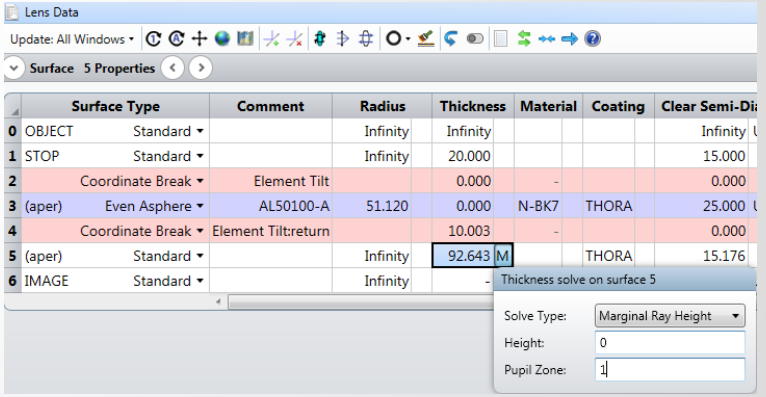
Surface 2 Properties

Configuration 1/1

	Surface Type		Comment	Radius	Thickness	Material	Coating	Semi-Diameter		Chip Zone	Mech Semi-Dia		Conic	TCE x 1E-6							
0	OBJECT	Standard		Infinity	Infinity			Infinity	U	0.000	Infinity	U	0.000	0.000							
1	STOP	Standard		Infinity	20.000			15.000		0.000	15.000		0.000	0.000							
2		Coordinate Break	Element Tilt		0.000	-		0.000		-	-			-	0.000		-5.000		0.000		0.000
3	(aper)	Even Asphere	AL50100-A	51.120	0.000	N-BK7	THORA	25.000	U	0.000	25.000		-0.575	-	0.000		-4.837E-11		-8.576E-12		-2.014E-15
4		Coordinate Break	Element Tilt:return		10.003	-		0.000		-	-			-	0.000	P	5.000	P	0.000	P	0.000	P
5	(aper)	Standard		Infinity	92.570		THORA	15.176		0.000	15.176		0.000	0.000							
6	IMAGE	Standard		Infinity	-			6.984	U	0.000	6.984	U	0.000	0.000							

Use of Solves

- Solves are functions which actively adjust specific values. Solves can be specified on radii, thicknesses, materials, clear semi-diameter or semi-diameters, conics, parameters, and TCE values.
- Typical thickness solves:
  - Marginal or chief ray height
  - Optical Path difference (relative to chief ray)
  - Compensator : constant offset to surface
- Typical Curvature solves:
  - Marginal and chief ray angles
  - F number
  - Aplanetic



Optimisation function

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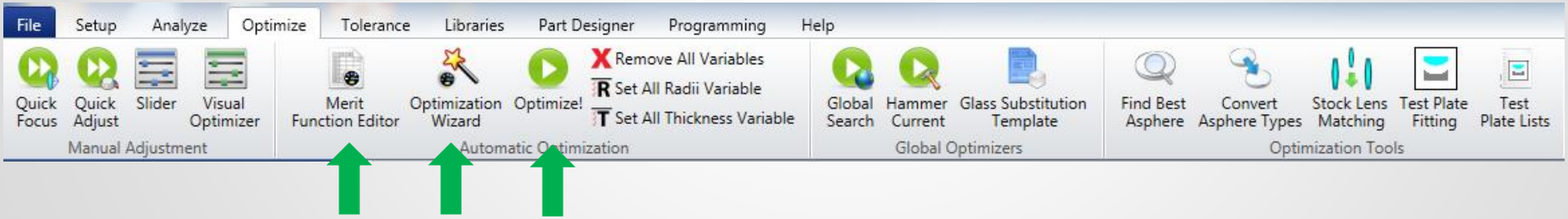
Lens Data

Update: All Windows

Surface 4 Properties | Configuration 1/1

	Surface Type		Comment	Radius	Thickness		Material	Coating	Clear Semi-Dia		Chip Zone	Mech Semi-Dia		Conic	TCE x 1E-6	Par 1(unused)	Par 2(unused)	Par 3(unused)	Par 4(unused)
0	OBJECT	Standard		Infinity	Infinity				Infinity	U	0.000	Infinity	U	0.000	0.000				
1	STOP	Standard		Infinity	20.000				15.000		0.000	15.000		0.000	0.000				
2	(aper)	Even Asphere	AL50100-A	51.120	10.000		N-BK7	THORA	25.000	U	0.000	25.000		-0.575	-	0.000	-4.837E-11	-8.576E-12	-2.014E-15
3	(aper)	Standard		Infinity	100.000	V		THORA	15.155		0.000	25.000		0.000	0.000				
4	IMAGE	Standard		Infinity	-				6.984	U	0.000	6.984	U	0.000	0.000				

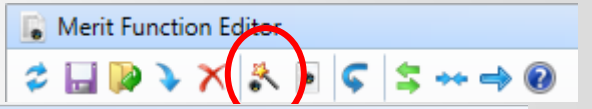
- Go back to original file
- Set a variable in the last surface (Solve: variable or control z)
- Open the Merit Function Editor (F6)

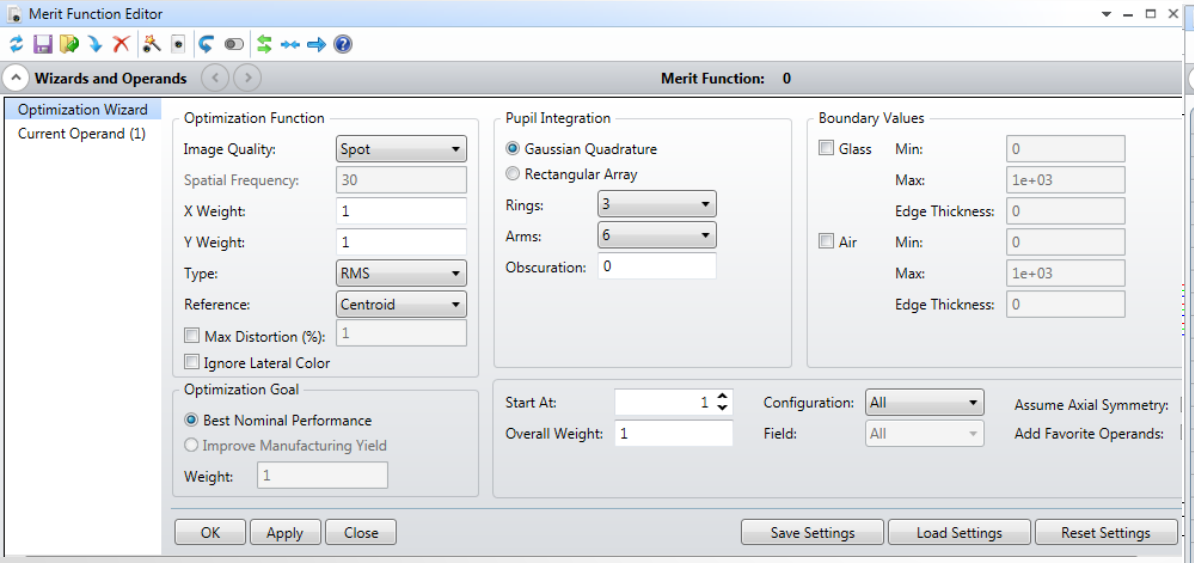


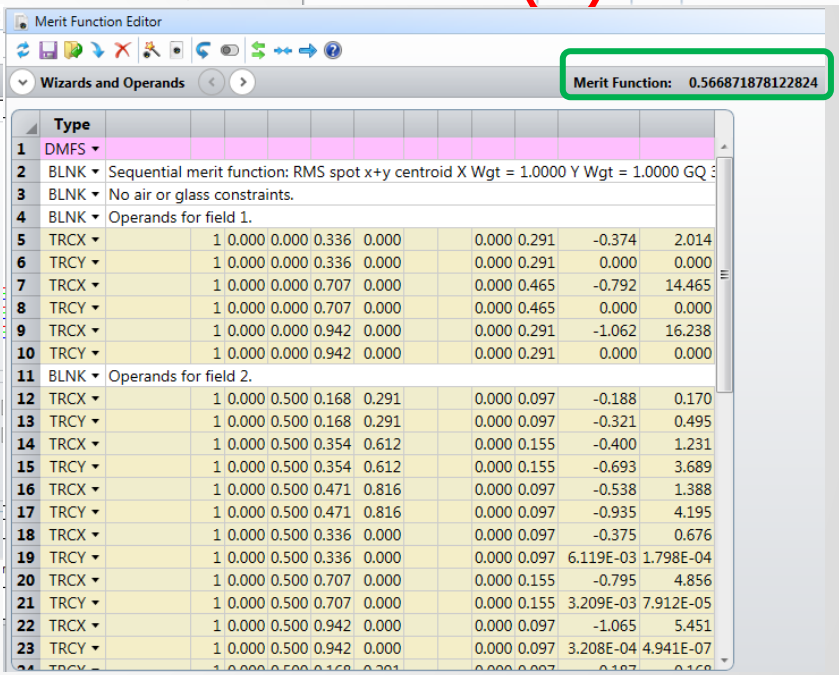
Optimization Wizard (Default Merit Function)

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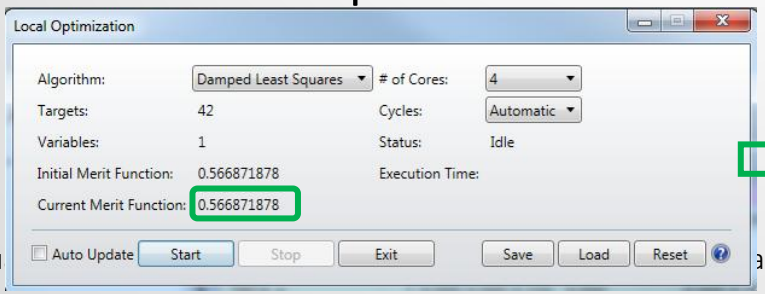
- Merit function editor : F6
- Optimization wizard (default Merit Function)

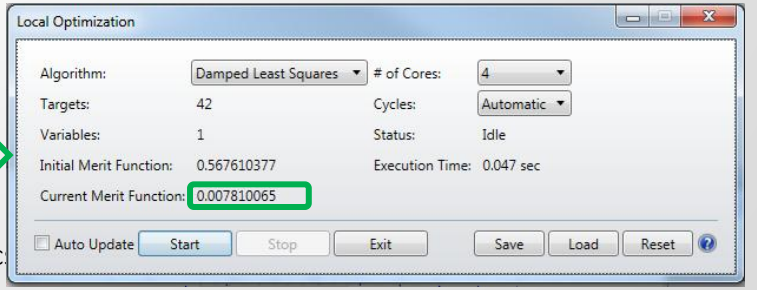






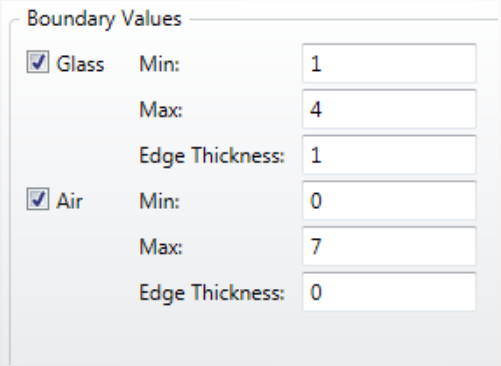
- Optimize → Optimize!





Another example : Cook Triplet

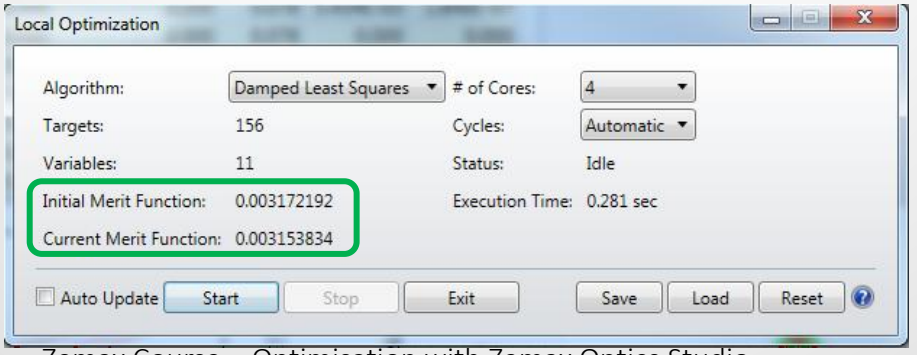
- Open the cook Triplet example in *Documents\Zemax\Samples\Sequential\Objectives*
- Save the file in your directory (to prevent saving it over the sample file)
- Open the Optimization wizard, and create a default merit function on :
  - Image Quality : Spot, RMS, referenced on centroid
  - Pupil integration : Gaussian Quadrature, 3 rings, 6 arms
  - Boundary values :



Another example : Cook Triplet

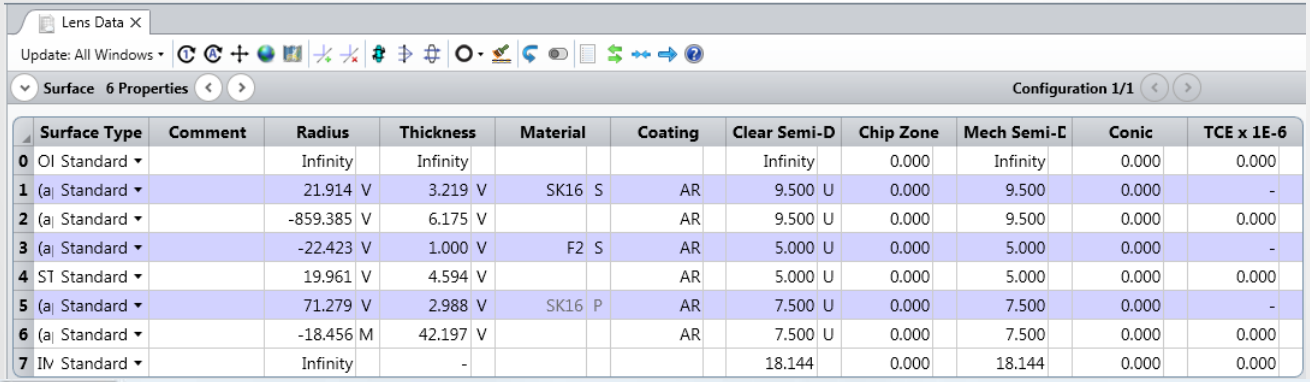
- Note the marginal ray angle :-0.1° which forces F/5. With EPD at 10, the EFL is defined.
- The boundary values at surface 6 (back focal distance) needs to be removed. We don't want the optimisation to force the BFL to be less than 6mm... => need to be deleted

34	MNCA	6	6							0.000	1.000	0.000	0.000
35	MXCA	6	6							6.000	1.000	42.208	99.924
36	MNEA	6	6	0.000	0					0.000	1.000	0.000	0.000
37	MNCG	6	6							2.000	1.000	2.000	0.000
38	MXCG	6	6							4.000	1.000	4.000	0.000
39	MNEG	6	6	0.000	0					1.000	1.000	1.000	0.000

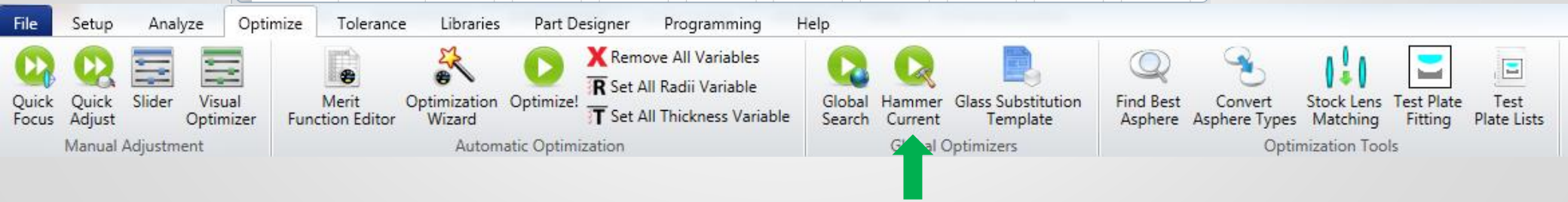


Another example : Cook Triplet

- The system is already optimised.
- Now, we are going to look at a better choice of glasses:
  - Select “substitute” in material surface 1 and 3
  - Select “pick up” in material surface 5, copying material surface 1

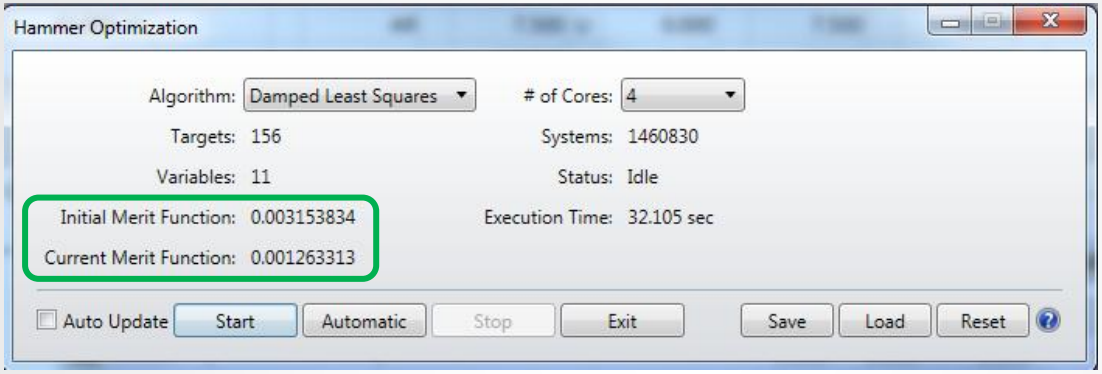


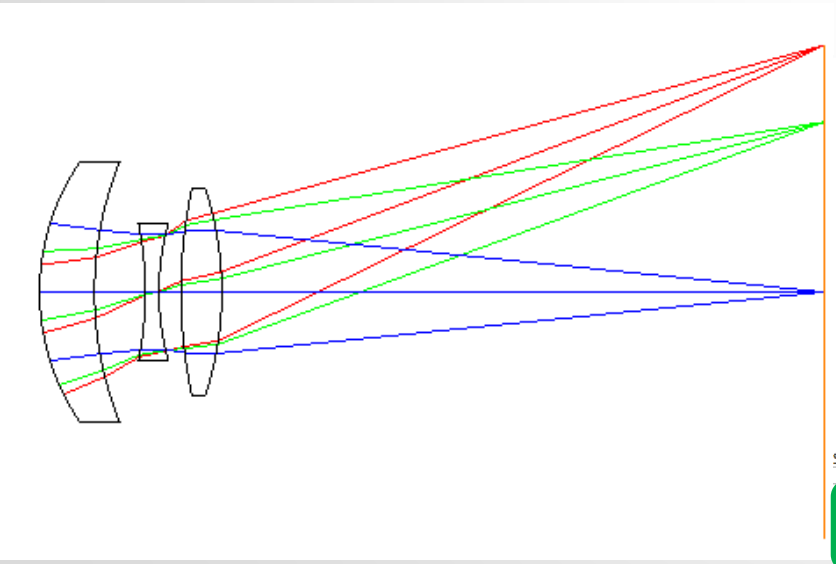
	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-D	Chip Zone	Mech Semi-D	Conic	TCE x 1E-6
0	OI Standard		Infinity	Infinity			Infinity	0.000	Infinity	0.000	0.000
1	(a Standard		21.914 V	3.219 V	SK16 S	AR	9.500 U	0.000	9.500	0.000	-
2	(a Standard		-859.385 V	6.175 V		AR	9.500 U	0.000	9.500	0.000	0.000
3	(a Standard		-22.423 V	1.000 V	F2 S	AR	5.000 U	0.000	5.000	0.000	-
4	ST Standard		19.961 V	4.594 V		AR	5.000 U	0.000	5.000	0.000	0.000
5	(a Standard		71.279 V	2.988 V	SK16 P	AR	7.500 U	0.000	7.500	0.000	-
6	(a Standard		-18.456 M	42.197 V		AR	7.500 U	0.000	7.500	0.000	0.000
7	IM Standard		Infinity	-			18.144	0.000	18.144	0.000	0.000

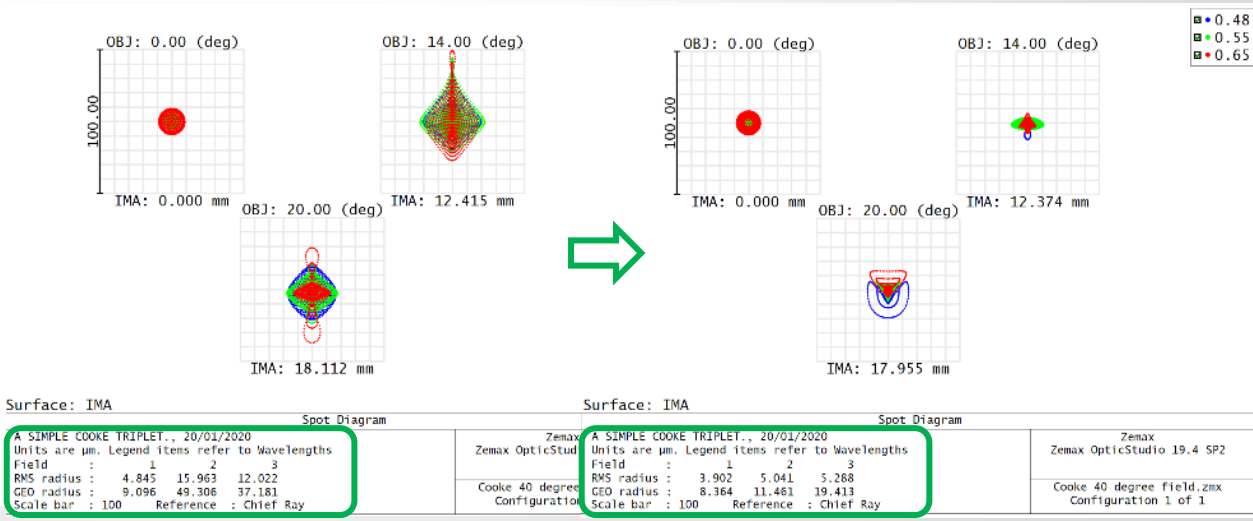


Another example : Cook Triplet

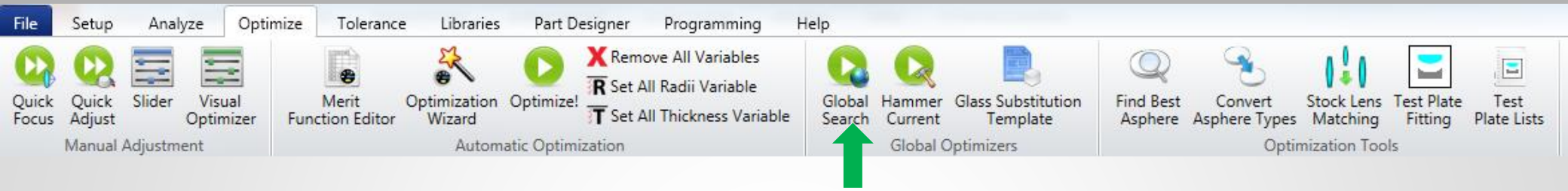
- Use Hammer Optimization



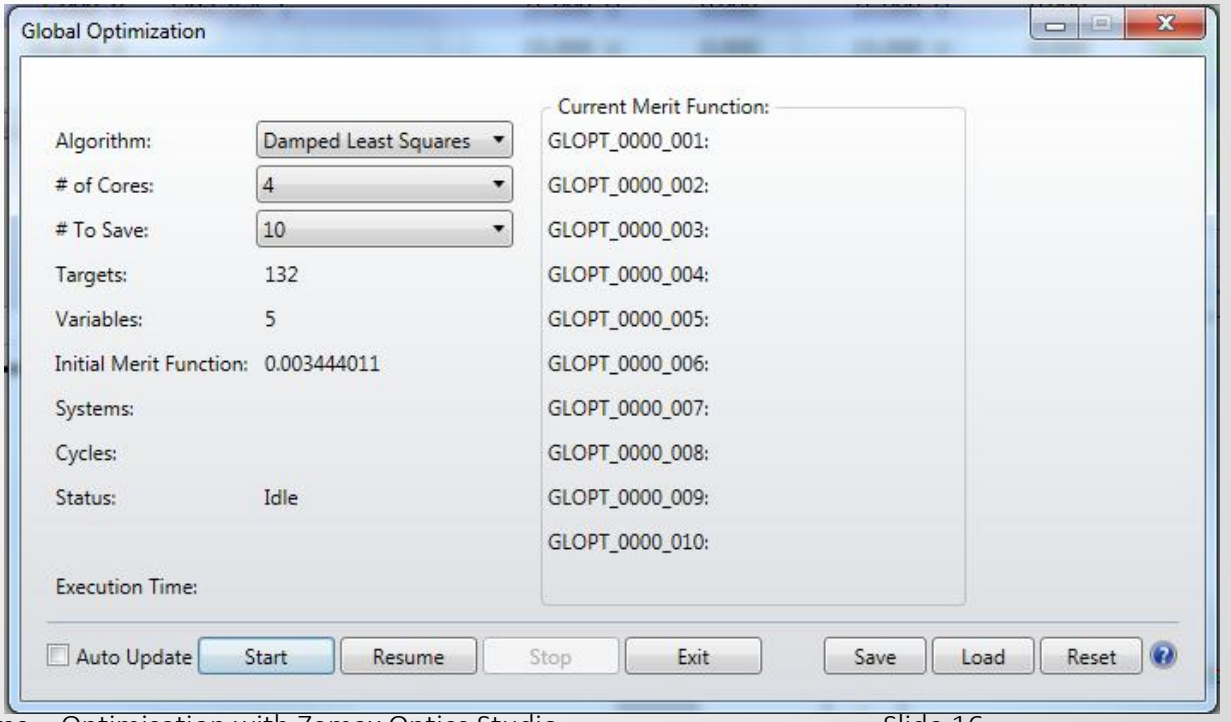




Global search

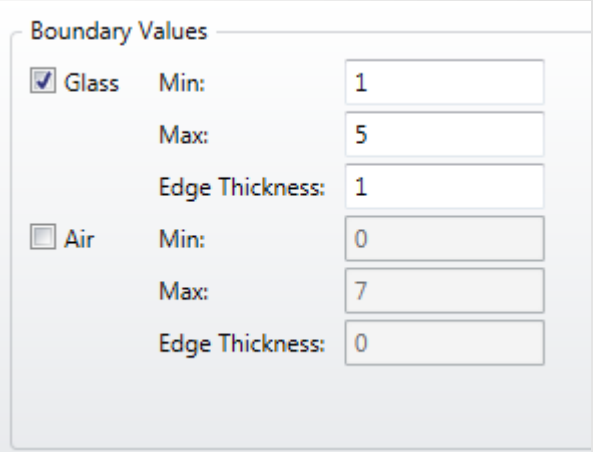


- Global search as opposed to the local Optimizer "Optimize!"



Exercise 1: Optimise an achromatic doublet

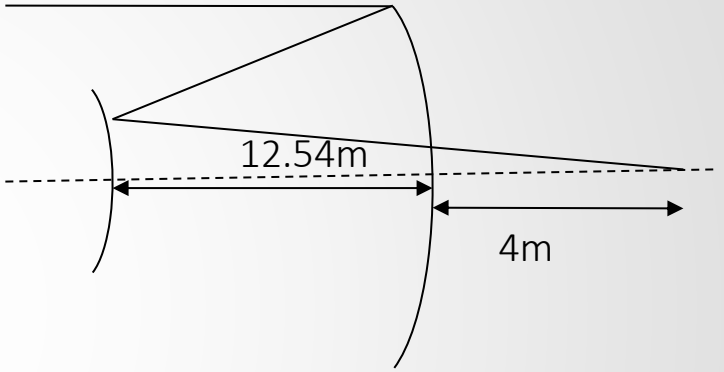
- Entrance parameters:
  - EFFL : 100mm
  - F/4
  - 2° FOV
  - Wavelength F, d, C
  - Mechanical diameter : 30mm
  - Start optimisation with a crown and a flint glass



Assignment : Optimise a Cassegrain telescope

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- Parameters :
  - F/16.2
  - EFFL :128.001m
  - FFOV : 10 arcmin
  - Wavelength : 2.2 microns
  - Total track : 16.54m
  - Curved focal plan
  - M1 obscuration Φ 1.2m
  - M2 central obscuration Φ155cm (for LGS)



- What are the optimised conic constant?
- Display the PSF at the edge and centre of the FOV
- Send you final zemax file saved as ZAR file to cyril.bourgenot@durham.ac.uk **by Thursday /03/2025 at 5pm**



Tutorial : Thermal analysis of Hubble

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- Open and save in your directory HST Zemax file
- Consider the distance M1/M2 is made of invar (1.2x10-6 per degree CTE).
- Mirrors are 0 CTE
- Consider a temperature variation of +/- 15°C. (operational T = 15°C)
- What is the focus displacement?
- Does the system remain diffraction limited (@l= 500nm) after refocus?

Tutorial : Thermal analysis of Hubble

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	Surface Type		adius		Thickness	Material	Coating	Clear Semi-Dia		Chip Zone	Mech Semi-D		Conic	TCE x 1E-6
0	OBJECT	Standard	nfinity		Infinity			Infinity		0.000	Infinity		0.000	0.000
1	(aper)	Standard	nfinity		5.000			0.155	U	0.000	0.155		0.000	0.000
2	STOP (aper)	Standard	11.040		0.000	MIRROR		1.200	U	0.000	1.210	U	-1.002	0.000
3		Standard	nfinity		-4.906			1.215		0.000	1.215		0.000	1.200
4	(aper)	Standard	-1.358		0.000	MIRROR		0.141	U	0.000	0.141	U	-1.497	0.000
5		Standard	nfinity		6.406			0.140		0.000	0.140		0.000	0.000
6	IMAGE	Standard	-0.632	V	-			0.080		0.000	0.080		0.000	0.000

Environment

Adjust Index Data To Environment

Temperature (C):

15.0

Pressure (ATM):

1.0

	Active : 1/4		Config 1*	Config 2		Config 3		Config 4	
1	TEMP	-	15.000	0.000		15.000		30.000	
2	PRES	-	1.000	1.000		1.000		1.000	
3	THIC	1	5.000	5.000	T	5.000	T	5.000	T
4	CRVT	2	-0.091	-0.091	T	-0.091	T	-0.091	T
5	THIC	2	0.000	0.000	T	0.000	T	0.000	T
6	SDIA	2	1.200	1.200	T	1.200	T	1.200	T
7	CHZN	2	0.000	0.000	T	0.000	T	0.000	T
8	MCSD	2	1.210	1.210	T	1.210	T	1.210	T
9	THIC	3	-4.906	-4.906	T	-4.906	T	-4.906	T
10	CRVT	4	-0.736	-0.736	T	-0.736	T	-0.736	T
11	THIC	4	0.000	0.000	T	0.000	T	0.000	T
12	SDIA	4	0.141	0.141	T	0.141	T	0.141	T
13	CHZN	4	0.000	0.000	T	0.000	T	0.000	T
14	MCSD	4	0.141	0.141	T	0.141	T	0.141	T
15	THIC	5	6.406	6.416	V	6.406		6.397	V

