A New Method for the Optimization of Optical Systems: Comparisons and Discussions

Journée thématique Calcul Optique
Institute d’Optique

John R. Rogers, Ph.D.

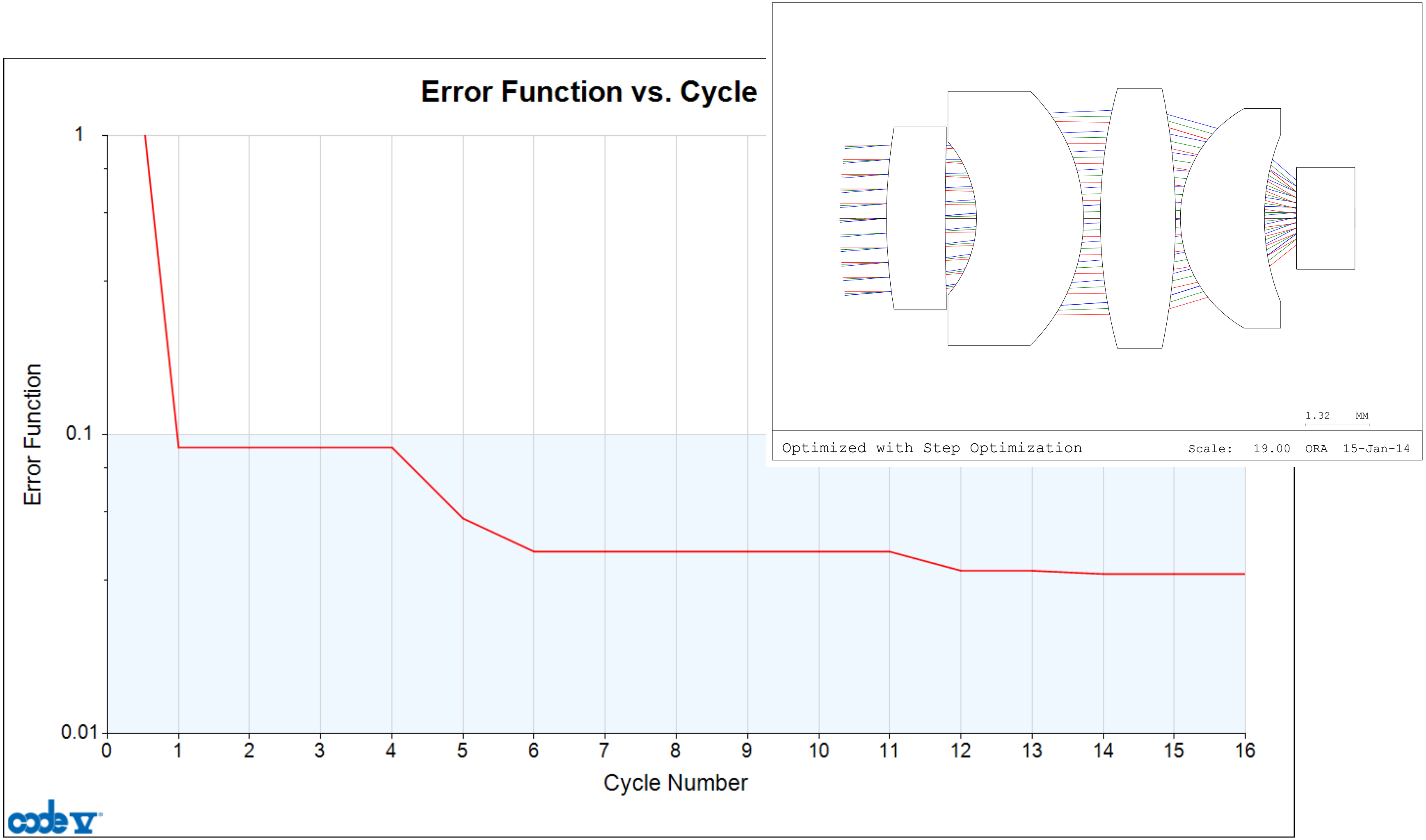
Synopsys Inc.

22 January 2014

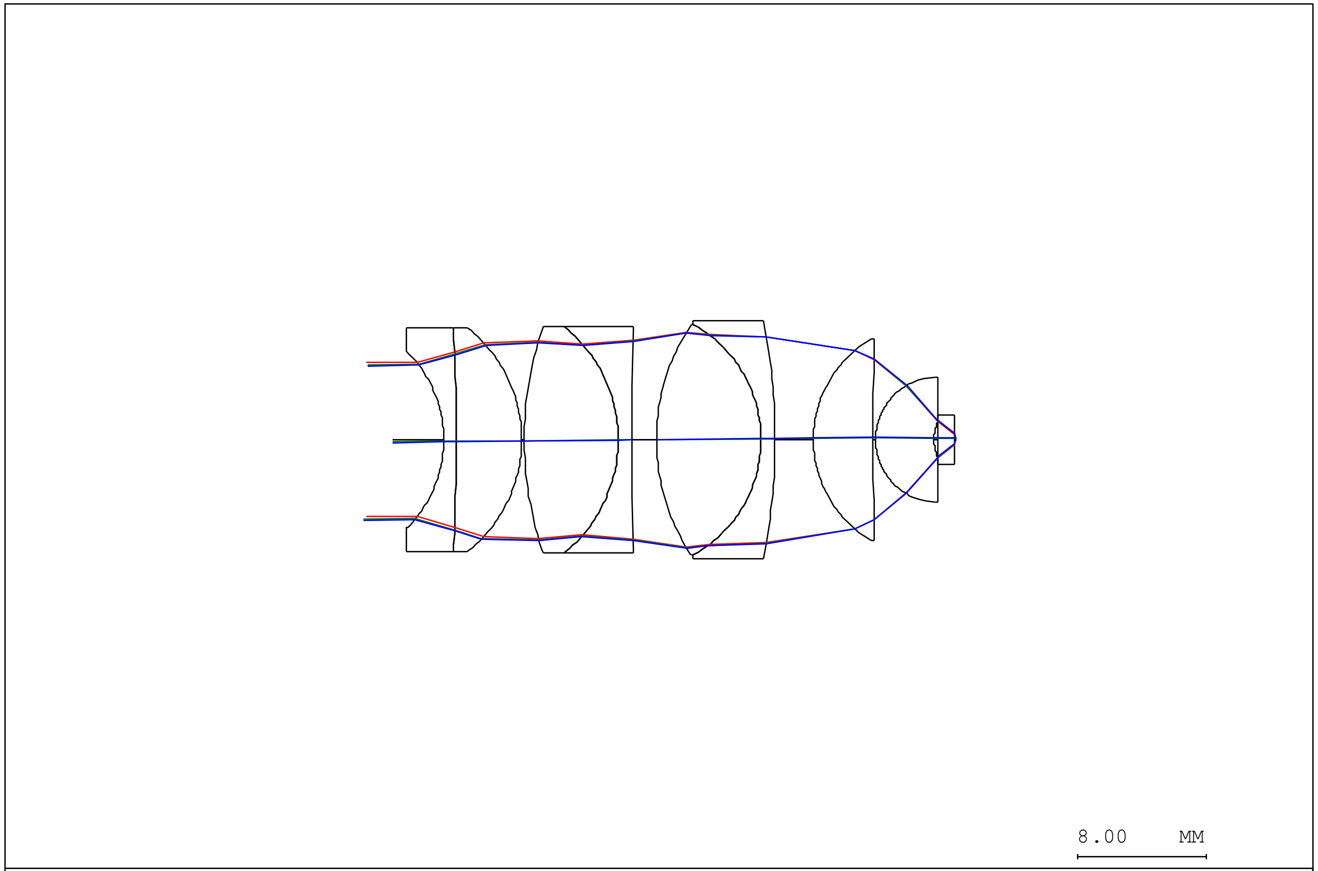
Step Optimization (STP)

- Synopsys has implemented a new, optional algorithm for local optimization that can:
  - Speed up convergence
  - Find a better local minimum (smaller Error Function) compared to standard optimization
- It is called “Step Optimization” because it sometimes – not always - progresses in a step-wise manner, as shown on the next slide

STEP Optimization (STP)
Sometimes converges in a step-wise manner

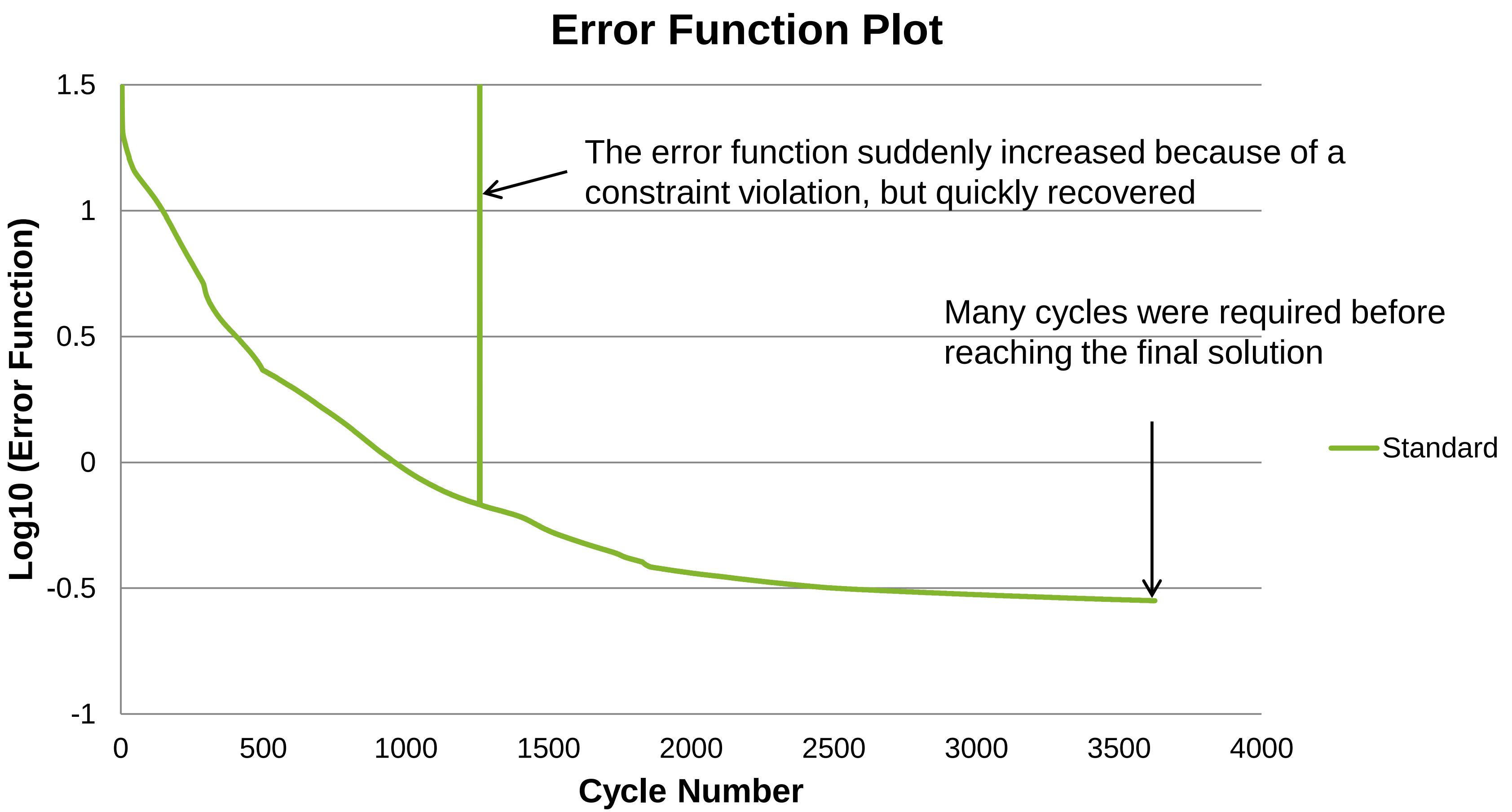


Microscope Example

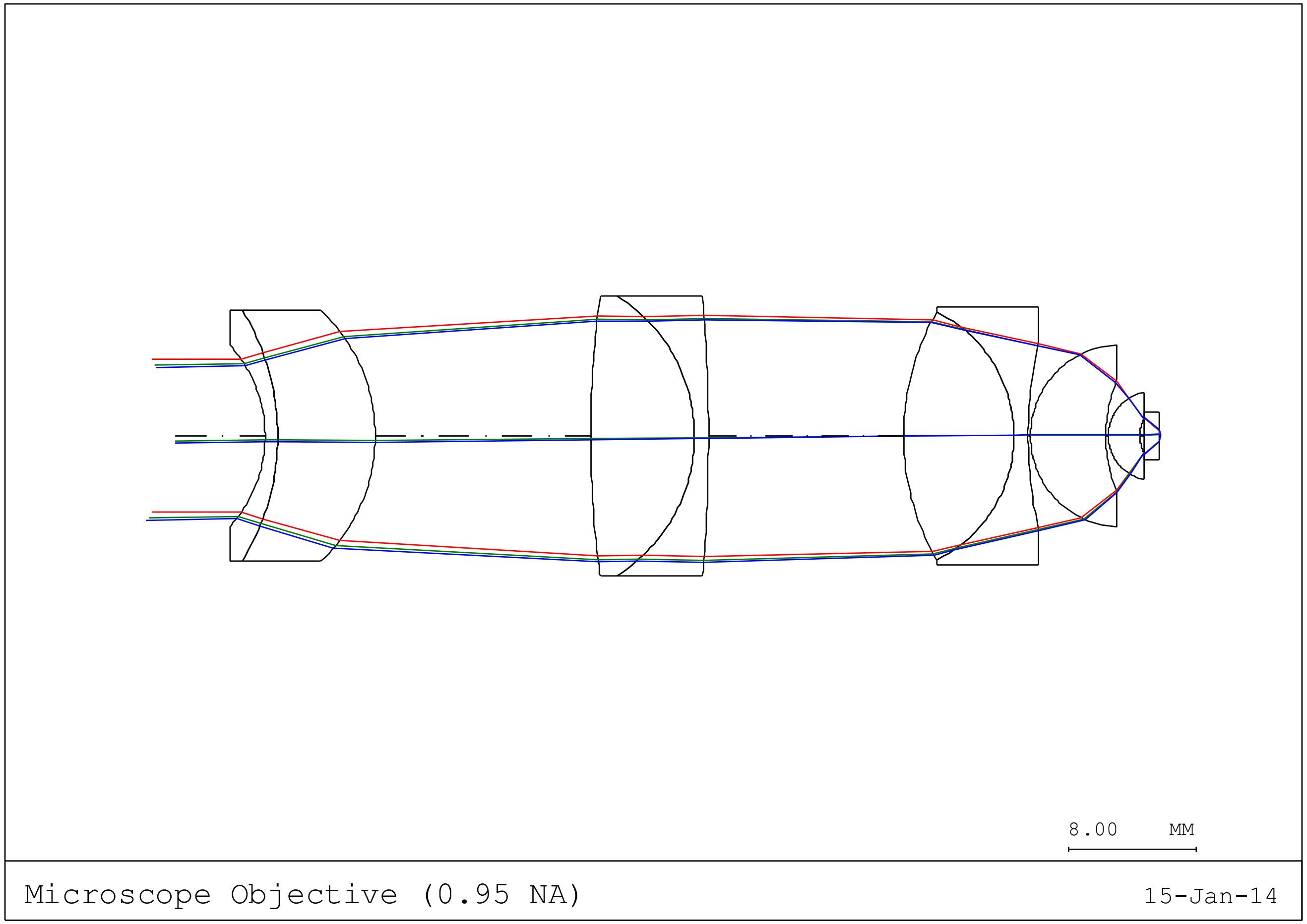


Microscope Objective (0.95 NA) 15-Jan-14

Microscope Example
Standard Optimizer

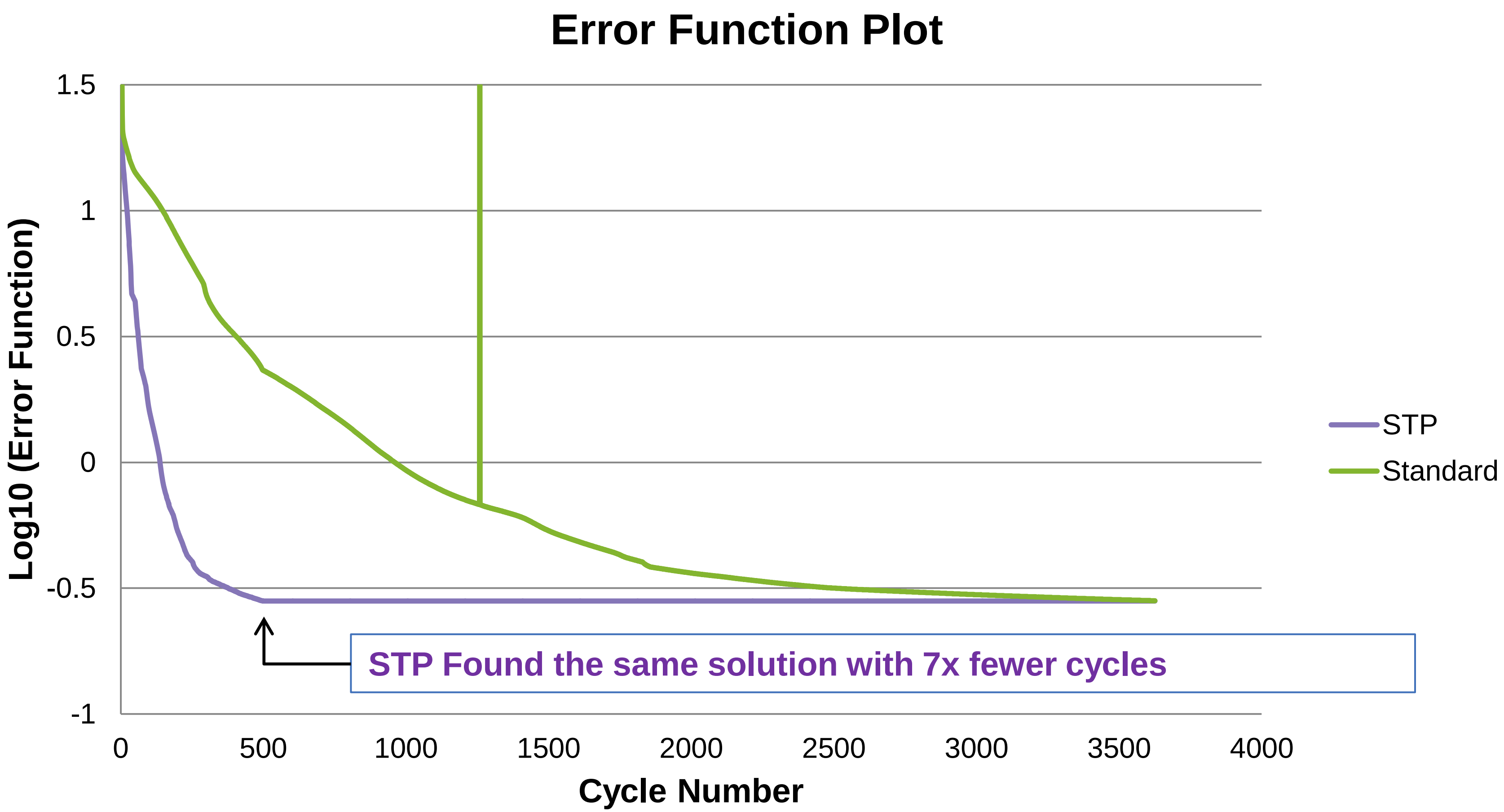


After Optimization
(Both methods found this same solution)



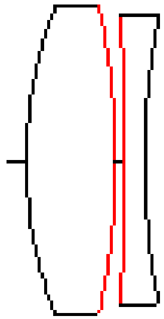
Microscope Example

Comparison of STP and Standard



Complex Error Function Spaces

- Even comparatively simple systems can have complex error functions
- The 2-dimensional error function space formed by the two curvatures shown in red at the lens below has 4 distinct local minima, as shown on the next slide

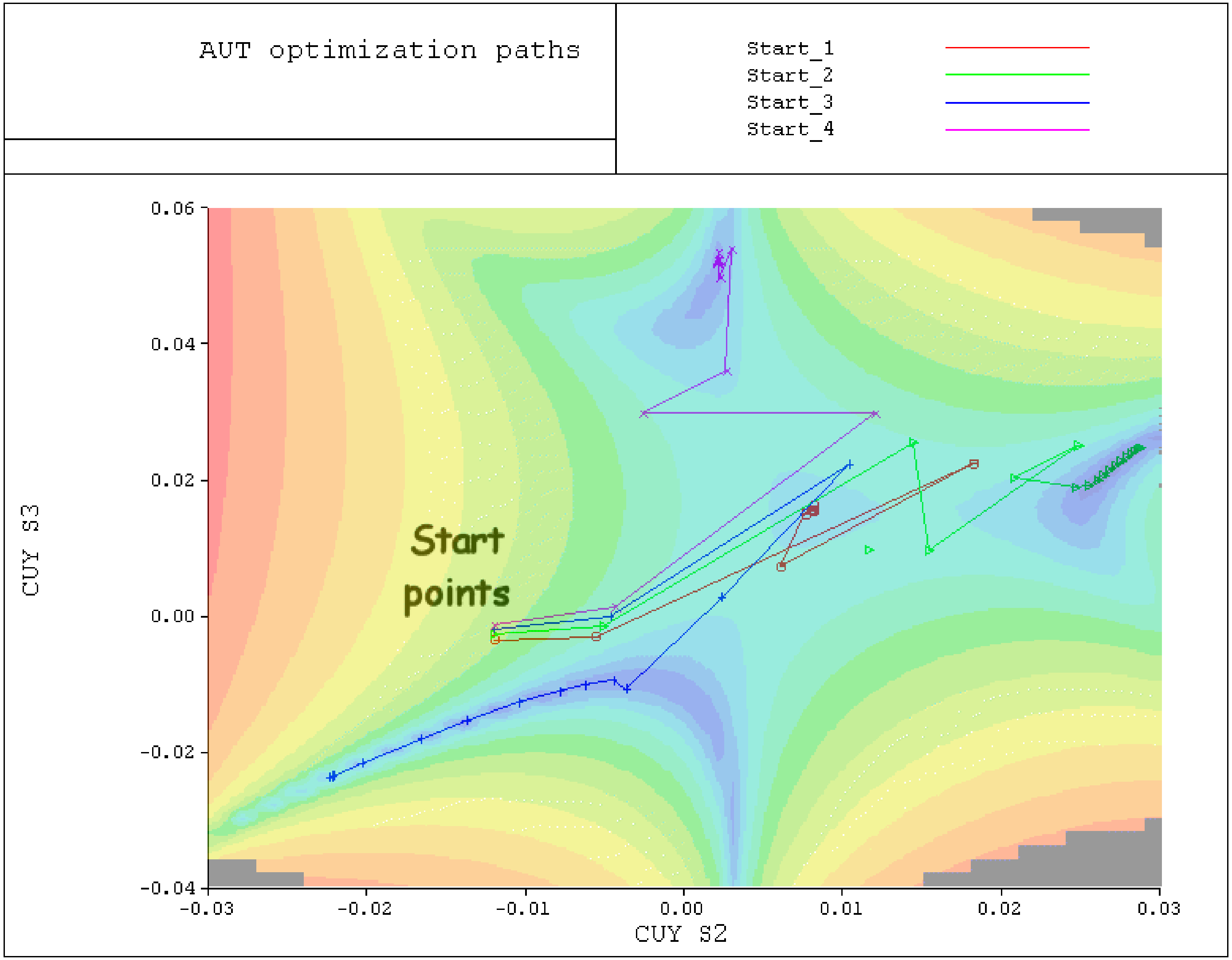


2-D Error function space

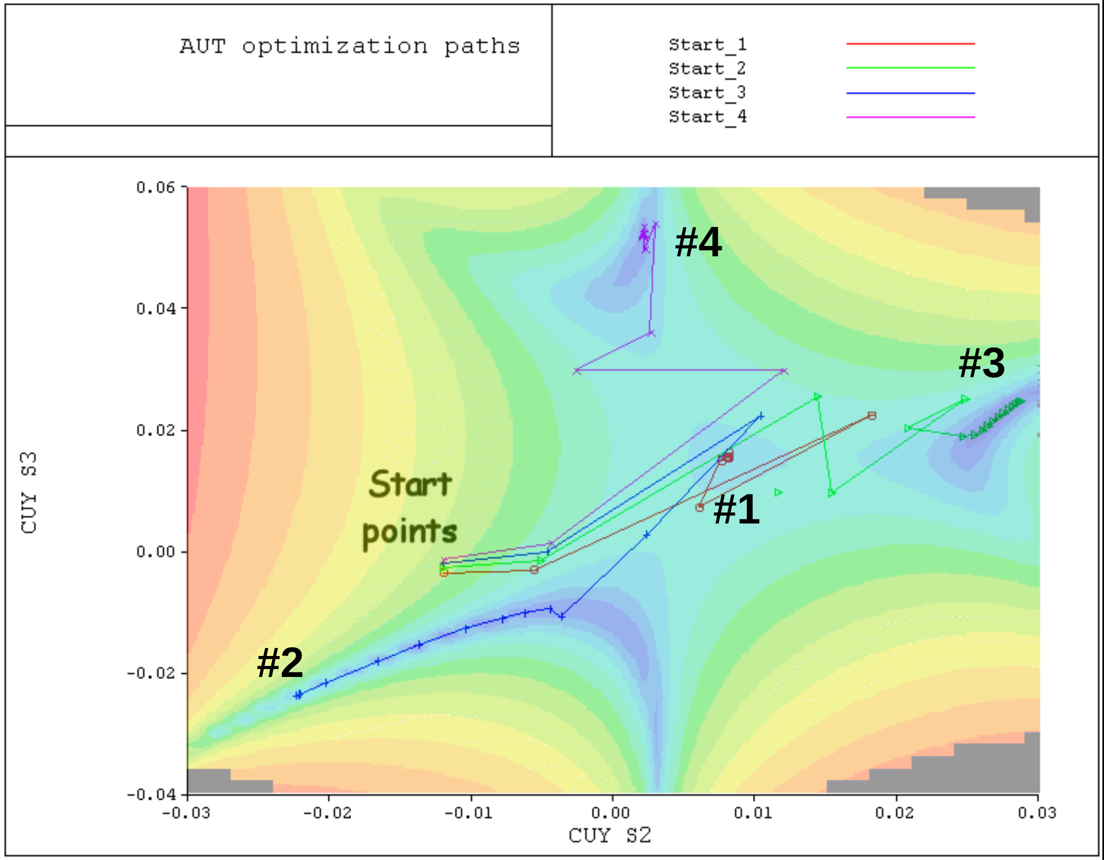
Formed by two adjacent curvatures

The nonlinearity of this solution space causes 4 four closely-spaced starting points converge to four different local minima

STP handles this better than the standard optimizer, as the next slide shows



Step Optimization Can Help Find a Better Local Minimum in Complex ERF Space



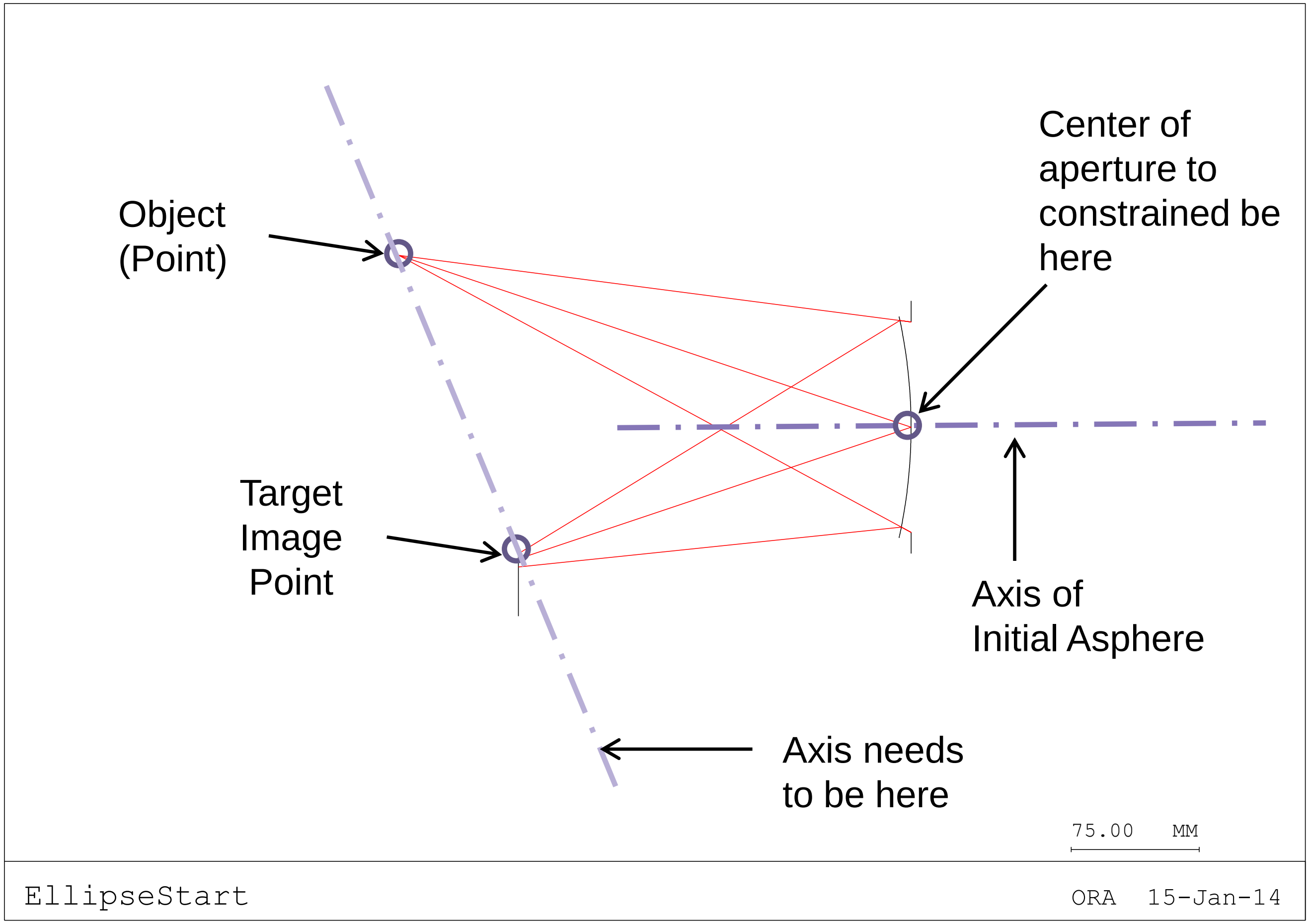
Standard Optimizer:

Start	Soln#	ERF
Start_1	#1	14274
Start_2	#3	213
Start_3	#2	315
Start_4	#4	1152

STP Y, followed by a few cycles of standard optimization:

Start:	Soln #	ERF
Start_1	#3	213
Start_2	#2	315
Start_3	#3	213
Start_4	#3	213

Off-Axis Ellipse

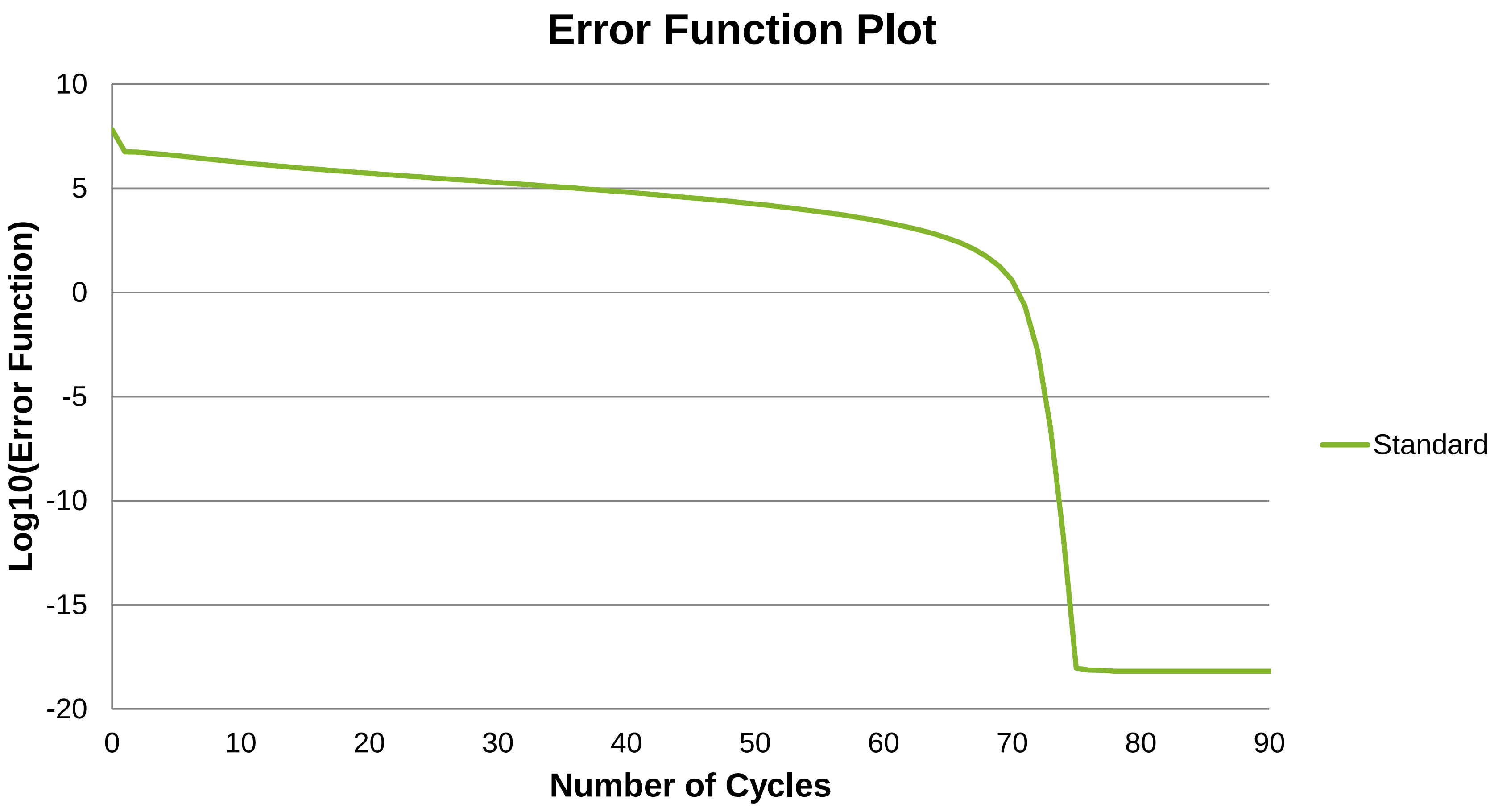


Necessary Variables

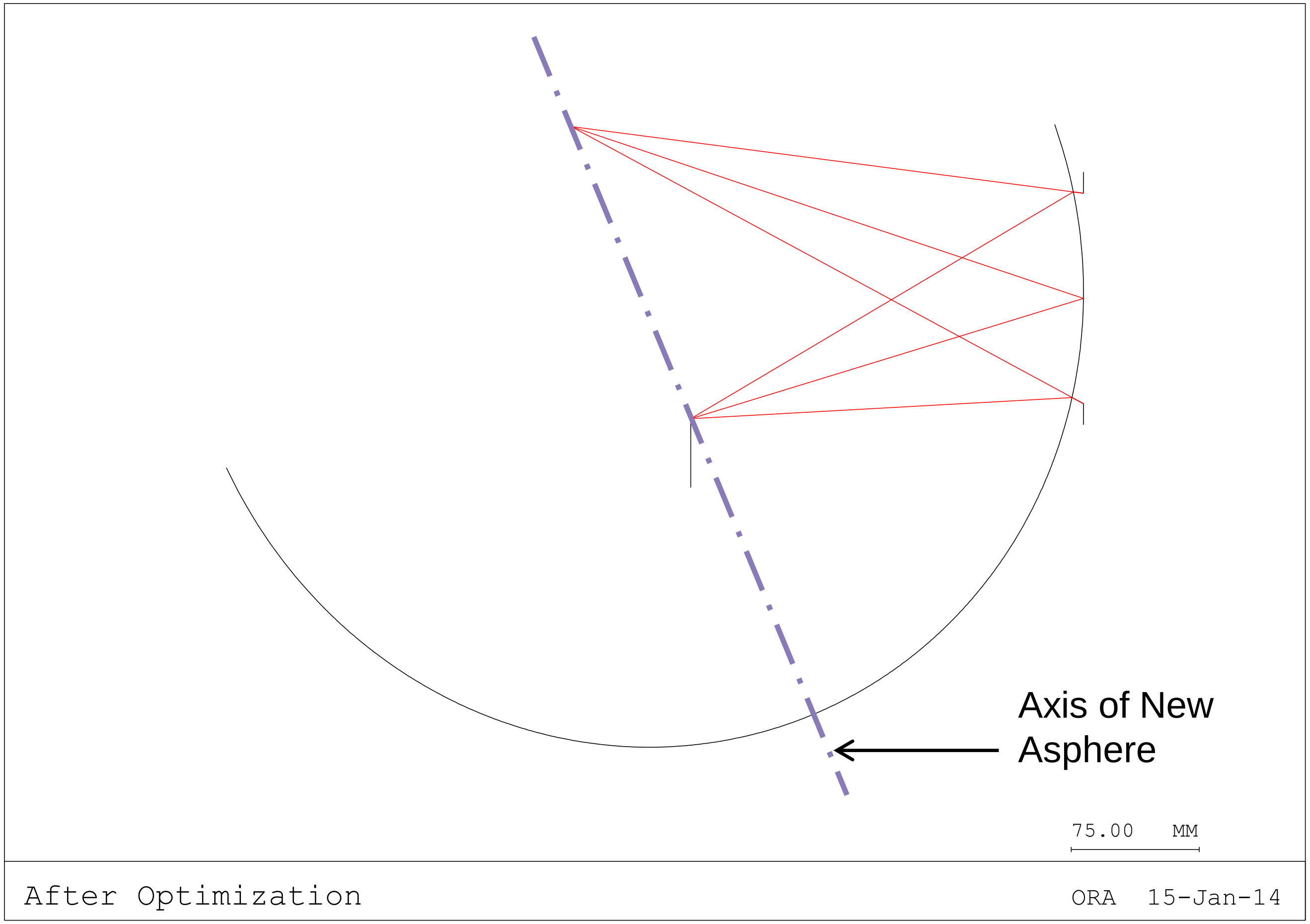
- This is a good test problem: We know there is one exact solution
- For an optimizer, this is a tricky problem, as the following parameters must be simultaneously varied in such a way that the physical surface remains at the center of the aperture
  - Radius
  - Conic Constant
  - Y-Position
  - Z-Position
  - Tilt Angle
- These parameters are all individually very sensitive
  - A change to any one of these parameters increases the merit function severely
- The optimization problem is a “long, narrow valley” in 5 dimensions

Off Axis Ellipse

Standard Optimizer

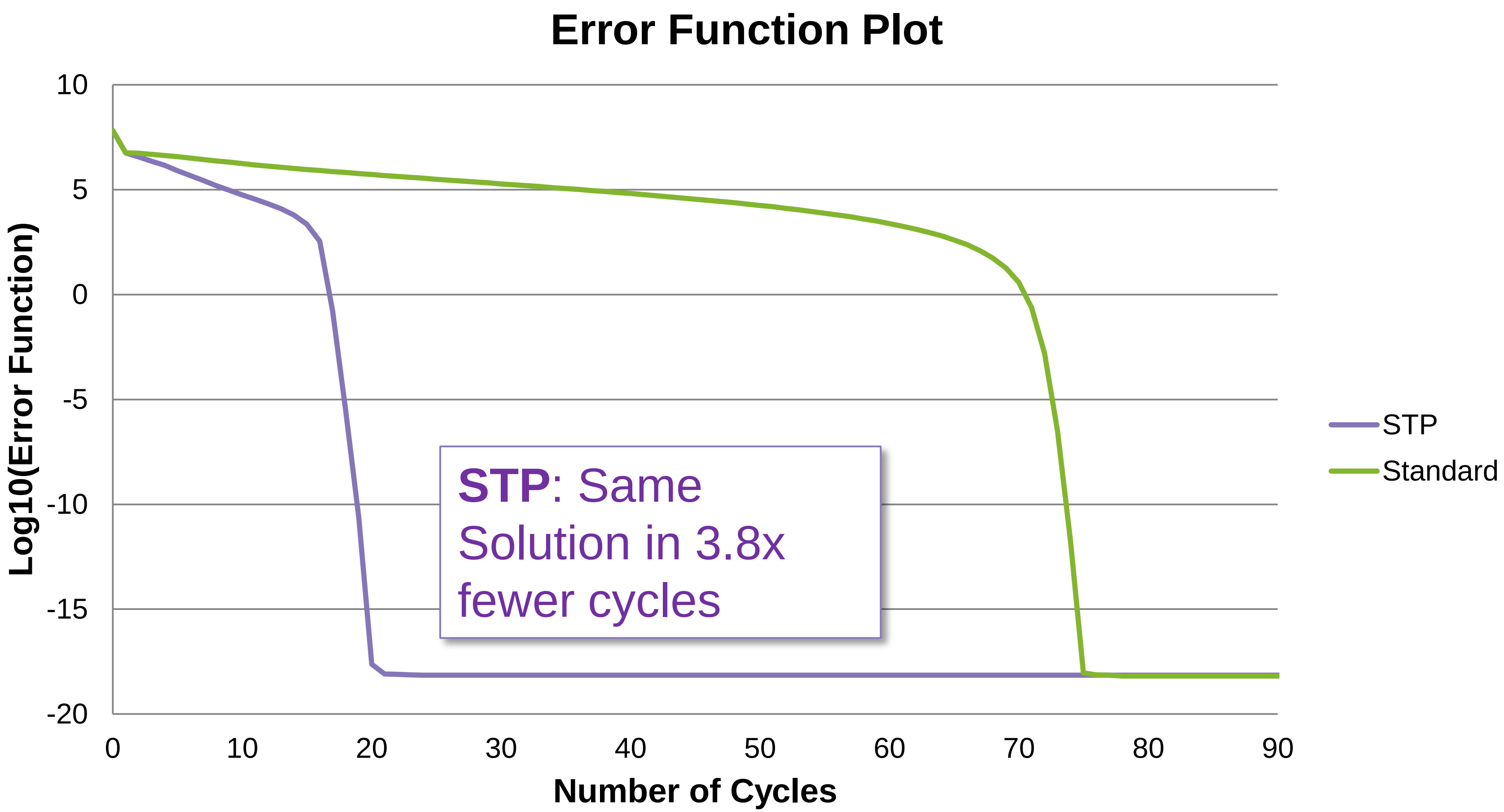


Off-Axis Ellipse
After Optimization



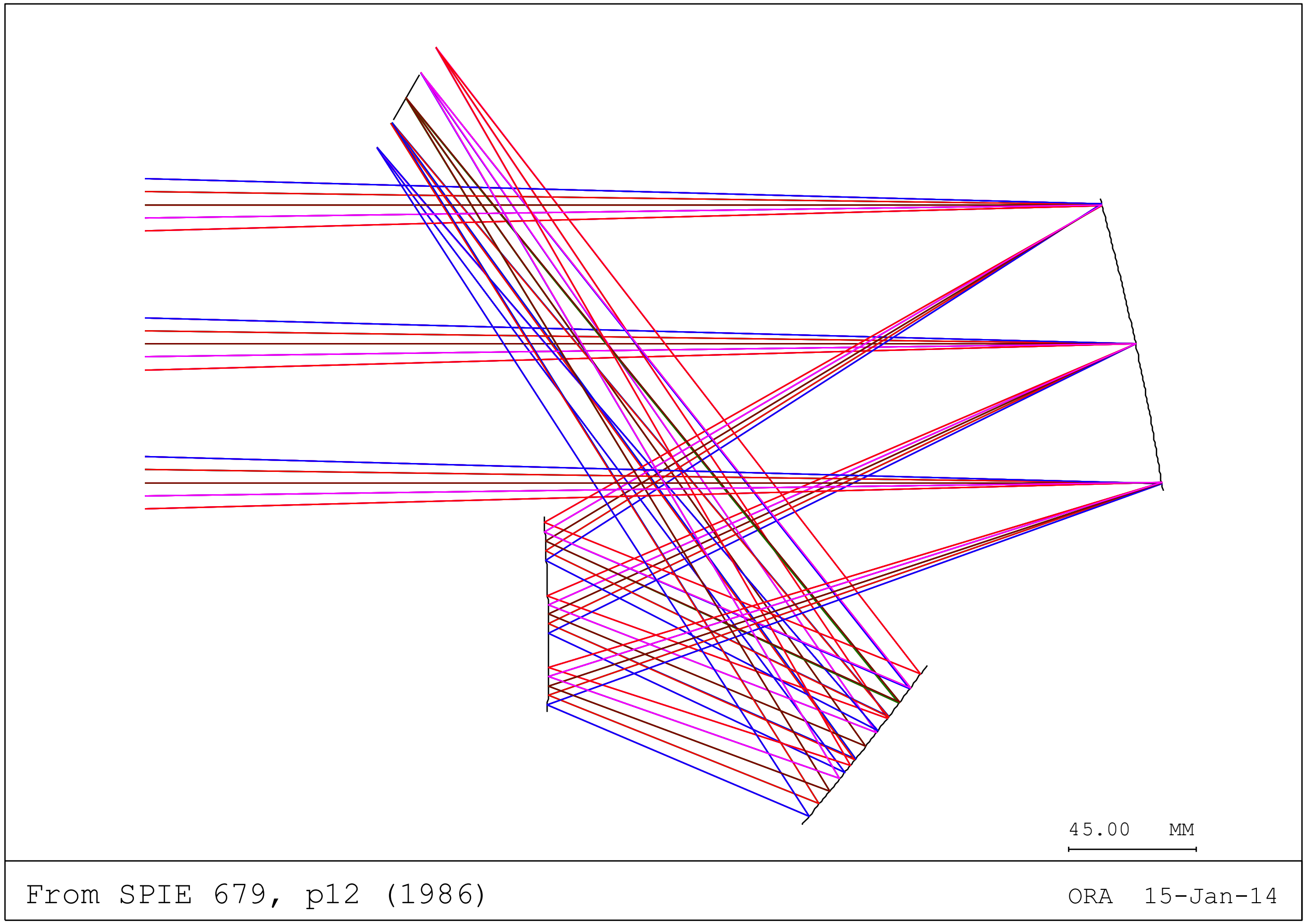
Off Axis Ellipse

Comparison of STP and Standard



Three Mirror System

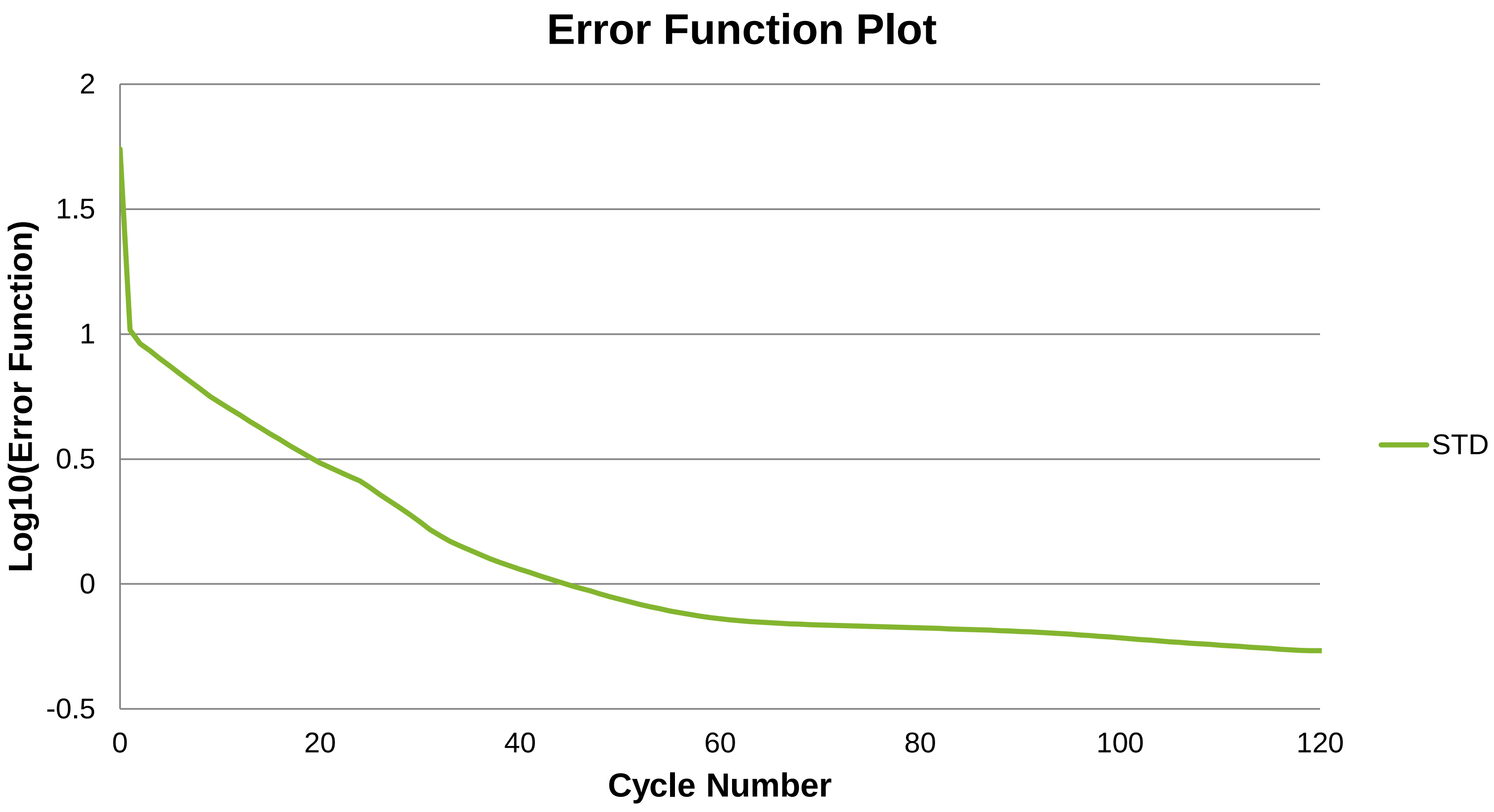
Rotationally Symmetric Aspheres



Freeform Optimization

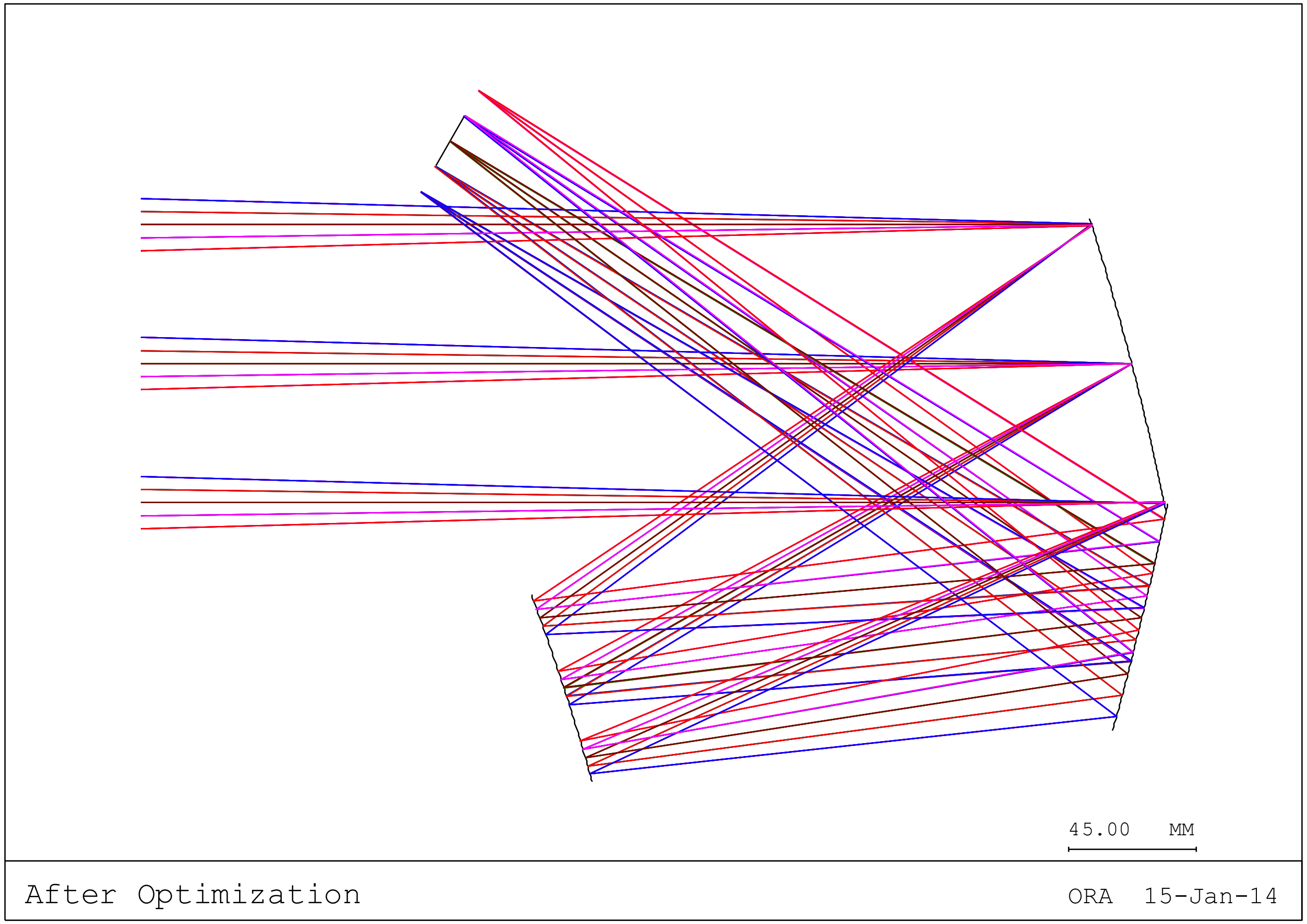
- Each mirror has 17 aspheric coefficients varying, plus radius and tilt
  - The number of degrees of freedom is large because it is a 2D problem
- It is necessary to use a large number of field points (25 used here)
  - Otherwise, we might obtain good performance at the sample points and terrible performance between the sample points
  - We used 25 field points: roughly 5 times more fields than we would in a rotationally symmetric design
- The optimization tends to be slow… any convergence acceleration is greatly appreciated!

Three Mirror System
Standard Optimizer



Three Mirror System

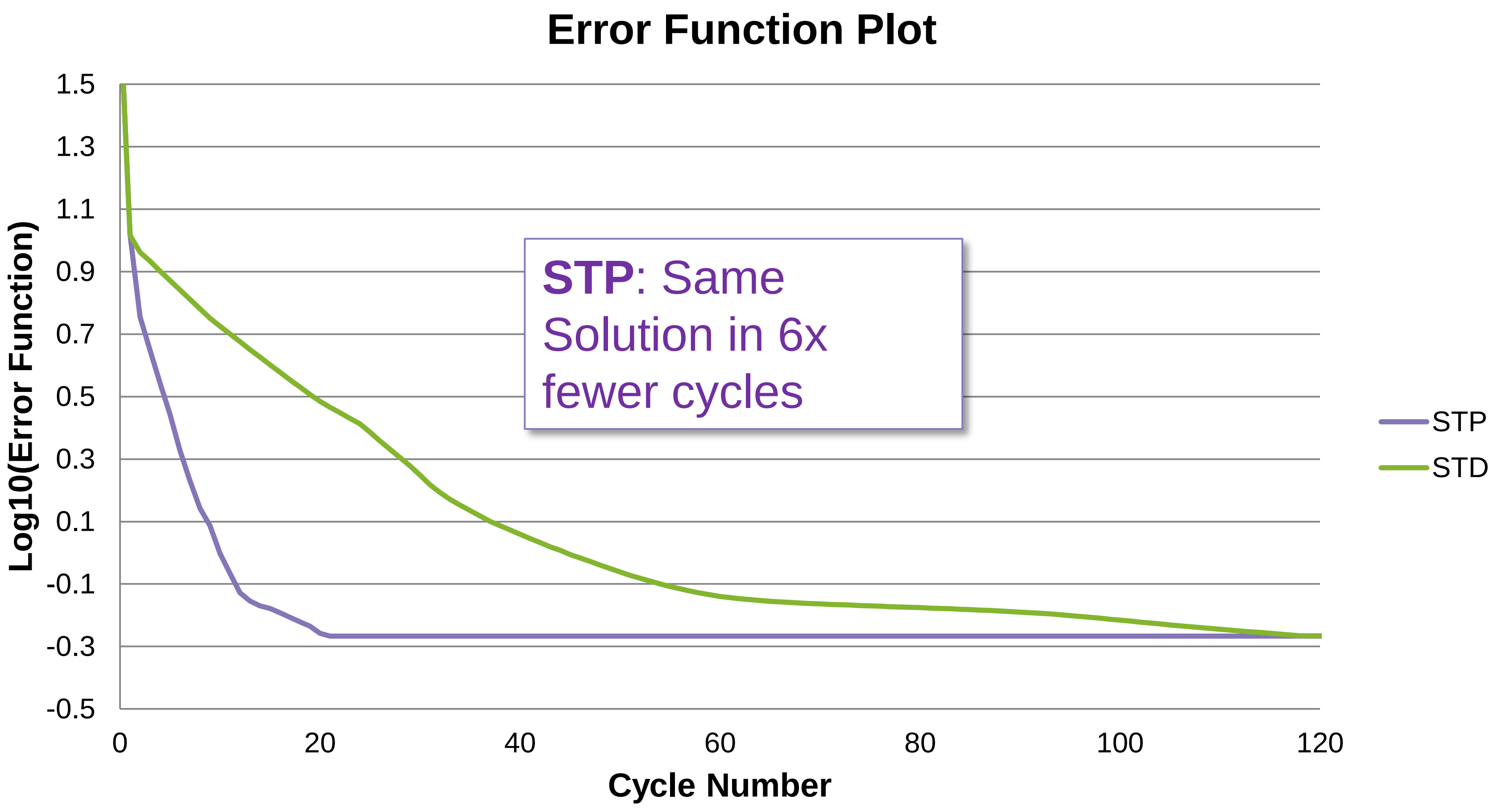
Reoptimized with Freeform (Zernike) Surfaces



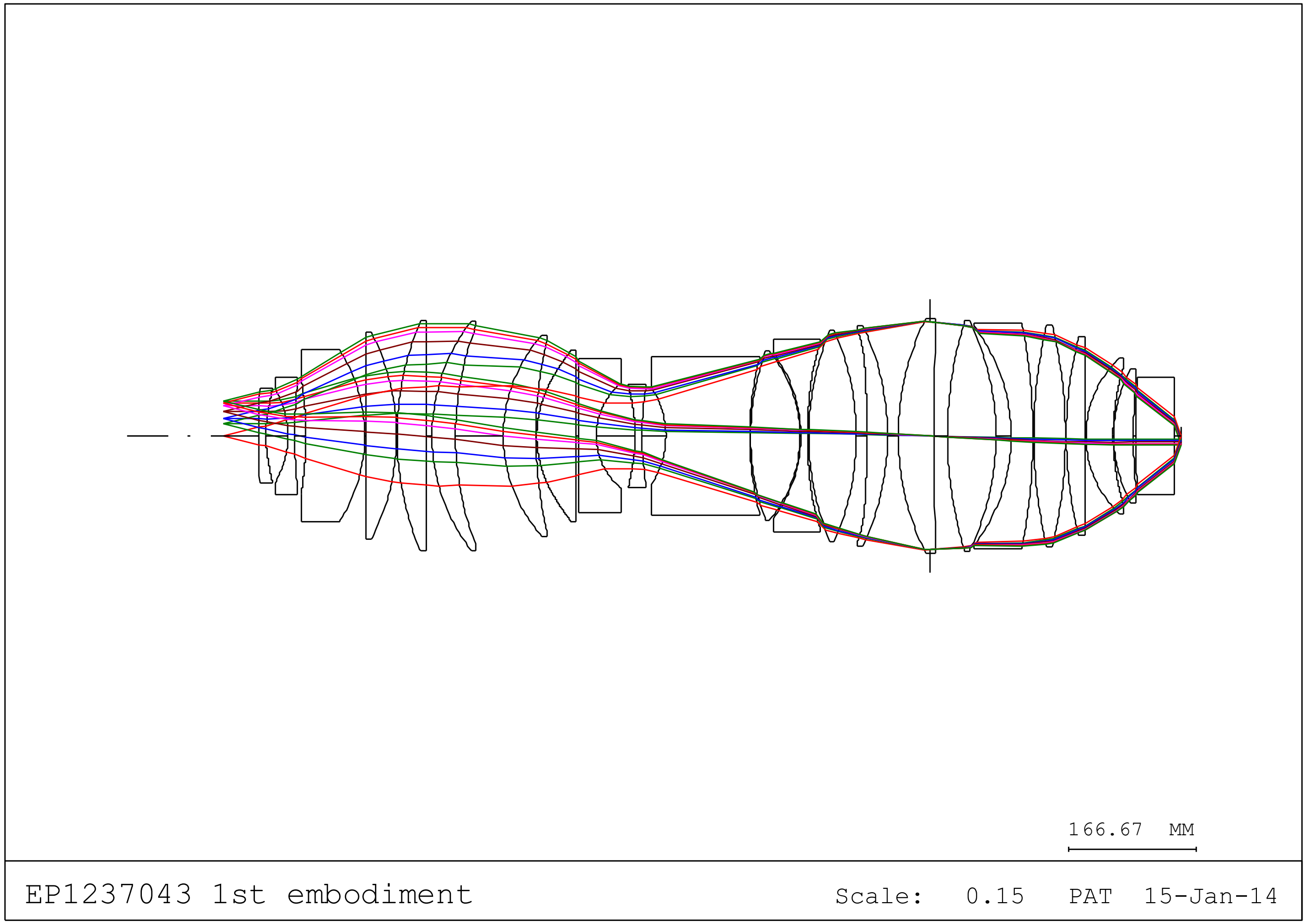
Both optimizers found this same solution…
But in how many cycles?

Three Mirror System

Comparison of STP and Standard



Lithography Example

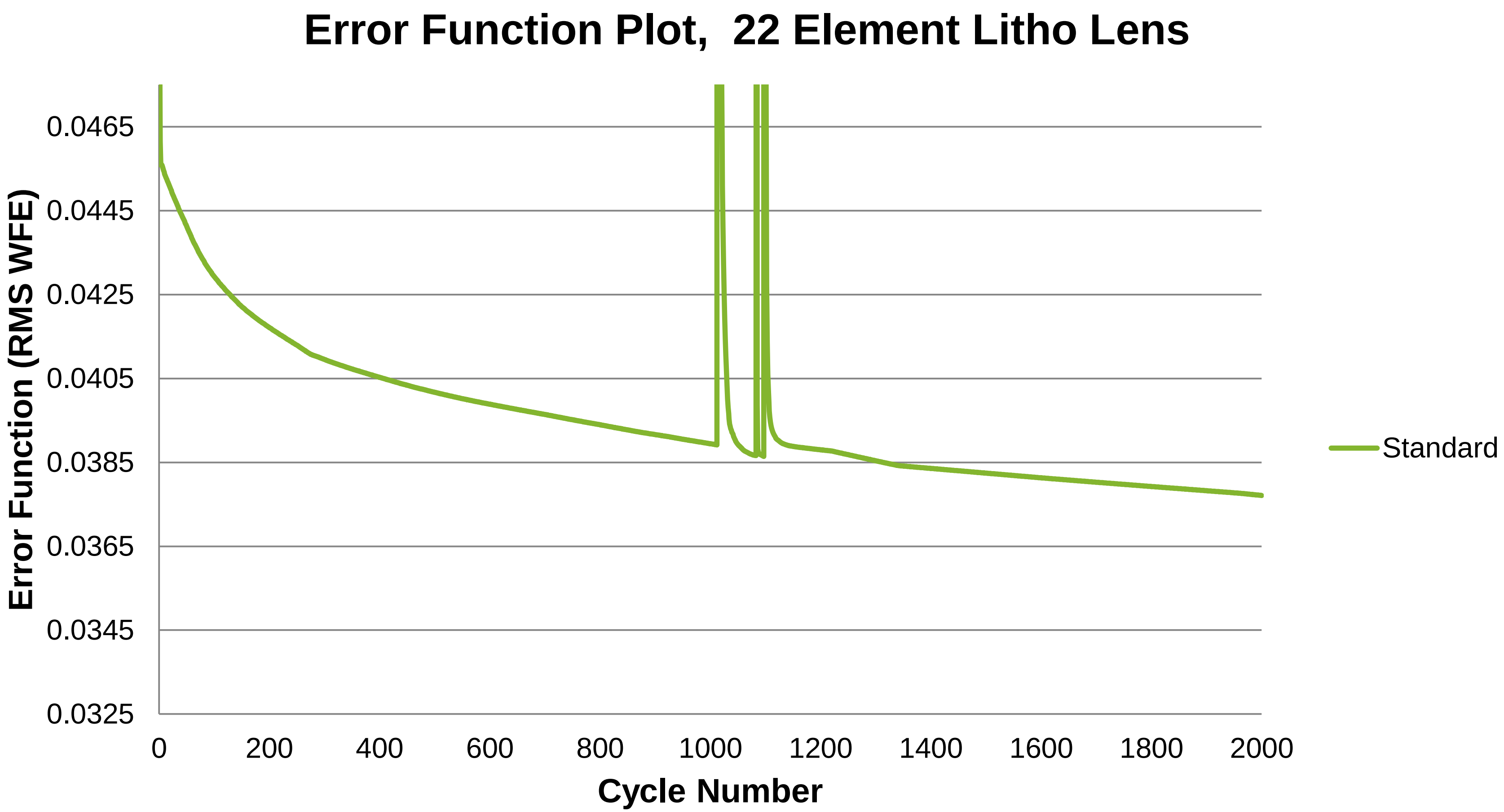


Optimization Characteristics

- Lithography lenses are characterized by having extremely narrow “valleys” in a highly multidimensional space
  - Hundreds of variables (134 in the example shown here)
  - NA 0.9 (or faster): Each variable has a very large effect on the merit function
  - A small change in any variable can be almost perfectly compensated by changes in the other 133 variables
- Lithography lenses are notoriously slow to optimize
  - Infinitesimal improvement per cycle
  - Many thousands of cycles needed, just to see if a design approach is working or not working

Lithography Example

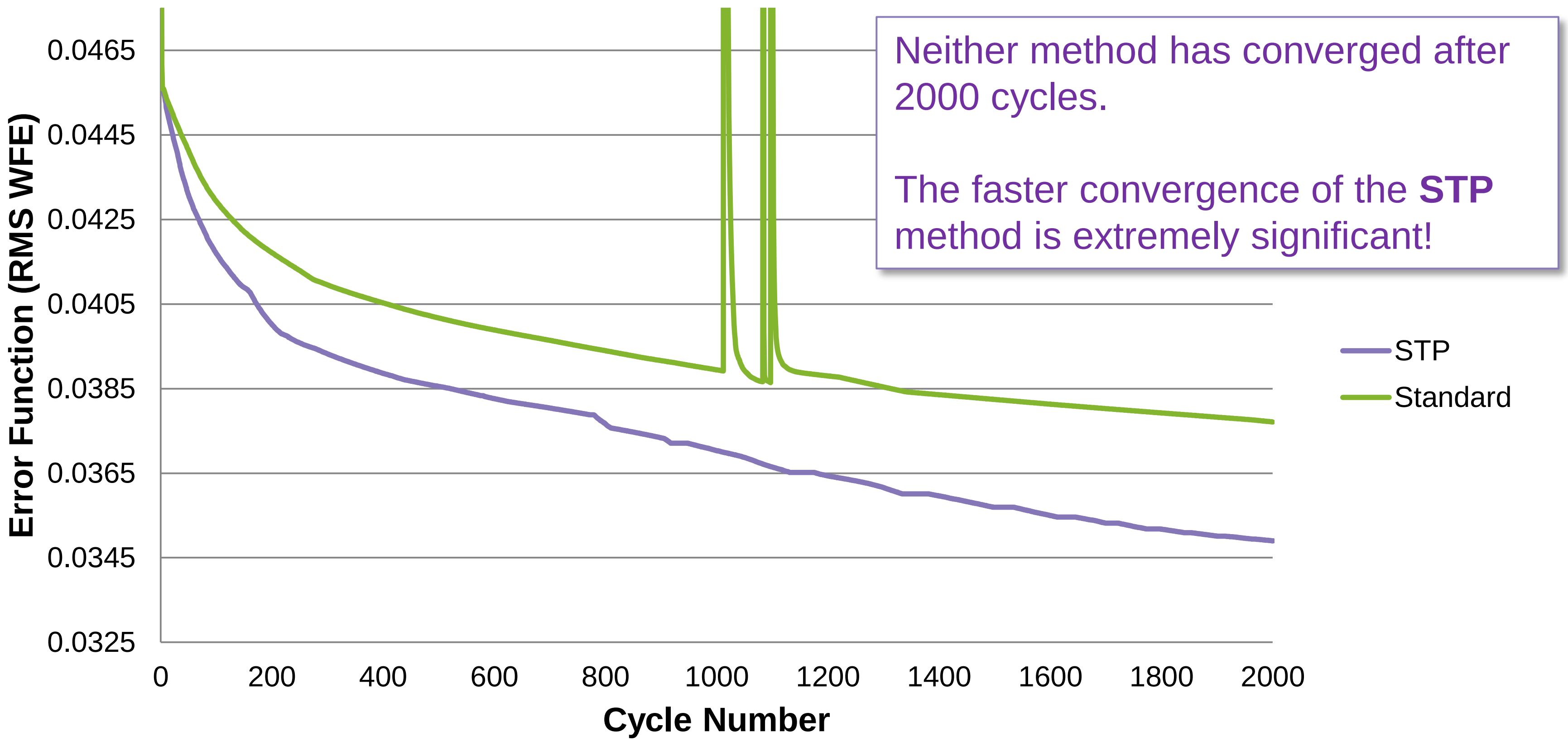
Standard Optimizer



Lithography Example

Comparison of STP and Standard

Error Function Plot, 22 Element Litho Lens



Summary

- The new step optimization (**STP**) is very useful for speeding up convergence, particularly in problems with complex solution spaces
- **STP** is a local optimizer, but it sometimes finds deeper local minima – an added bonus
- **STP** is not a replacement for Global Synthesis (**GS**), but it can be used within **GS** to speed the convergence of **GS**