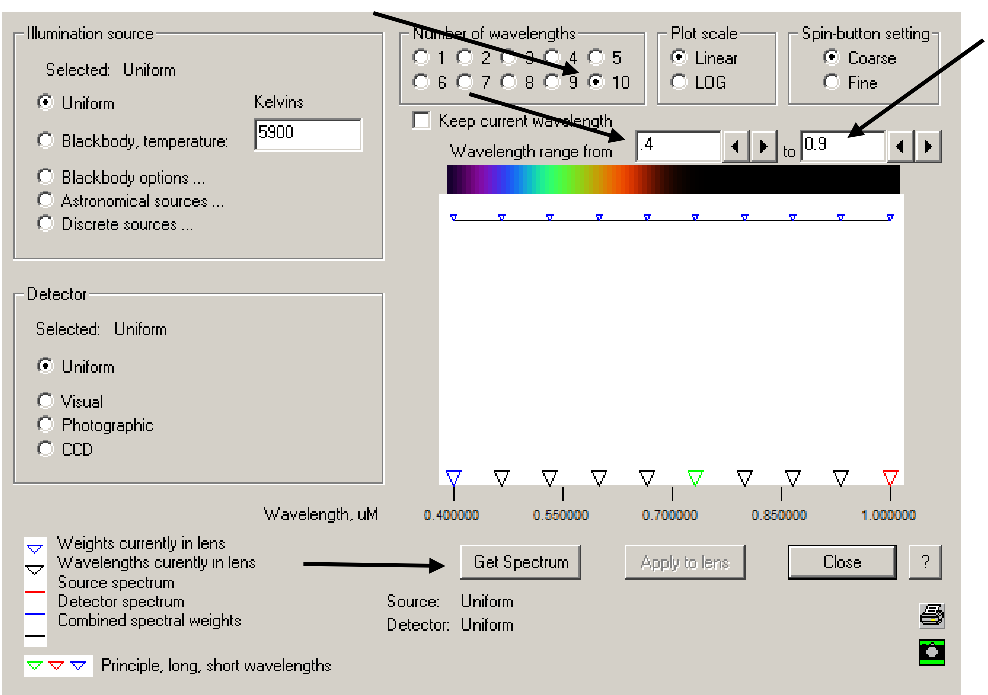
Lesson 31: The Superachromat

This lesson will explore a unique feature of SYNOPSYS that can be helpful when you need exceptional color correction, better even than an apochromat. Lesson 8 in this Online Tutorial showed how to select three glass types that make it possible to correct axial color at three wavelengths. For many tasks, that is as good as you will need.

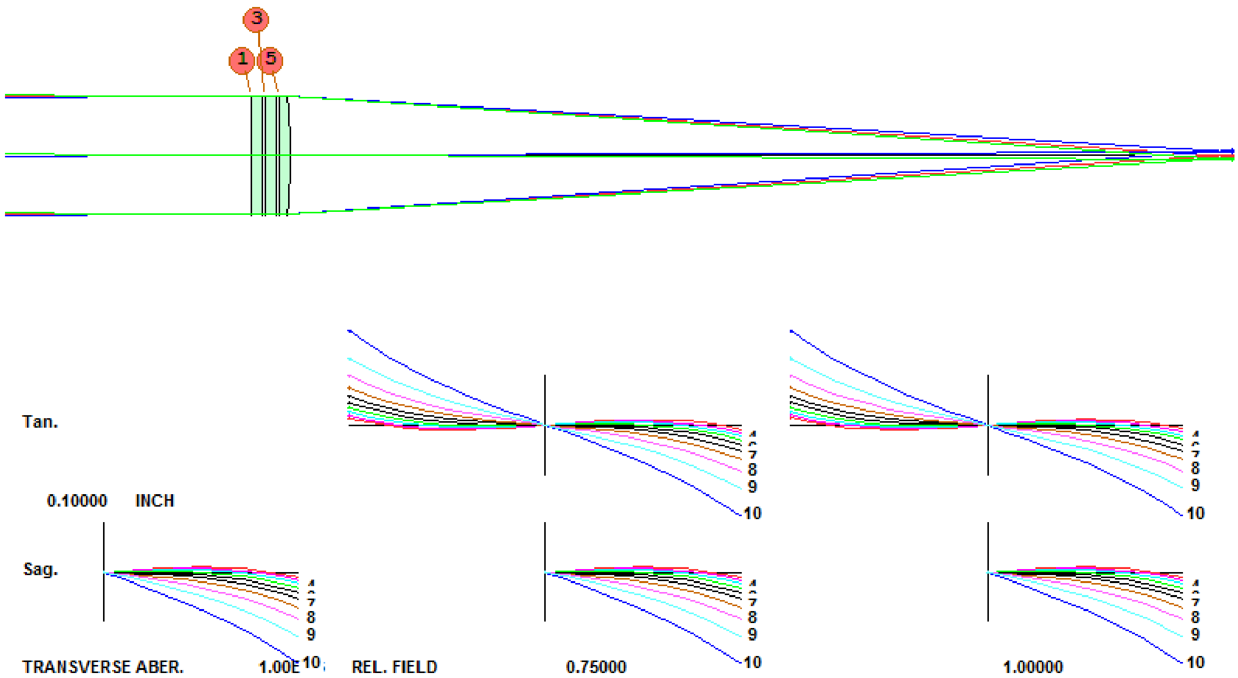
But not always. Suppose you are designing a lens to be used over the range 0.4 to 0.9 um. Can you do it with an apochromat? Let's find out. Here is the RLE file for a starting system, where all surfaces are flat except for the last, which will give us an F/8 telescope objective of 6-inch aperture. (Copy these lines and paste them into the MACro editor.)

```
RLE
ID WIDE SPECTRAL RANGE EXAMPLE
OBB 0 .25 3
UNITS INCH
1 GLM 1.6 50
3 GLM 1.6 50
5 GLM 1.6 50
6 UMC -0.0625 YMT
7
1 TH .6
2 TH .1
3 TH .6
4 TH .1
5 TH .6
END
```

We did not specify the wavelengths yet, so we get the default CdF lines. We need to change this. Open the Spectrum Wizard (MSW), and change the points indicated.

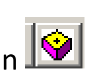


After clicking the **Get Spectrum** button, click the **Apply to lens** button. Our lens now has a wider spectrum. Here is our starting lens, in the SketchPad display



Uggh! Yes, it's really awful. Let's optimize it, varying the glass models. Make a MACro:

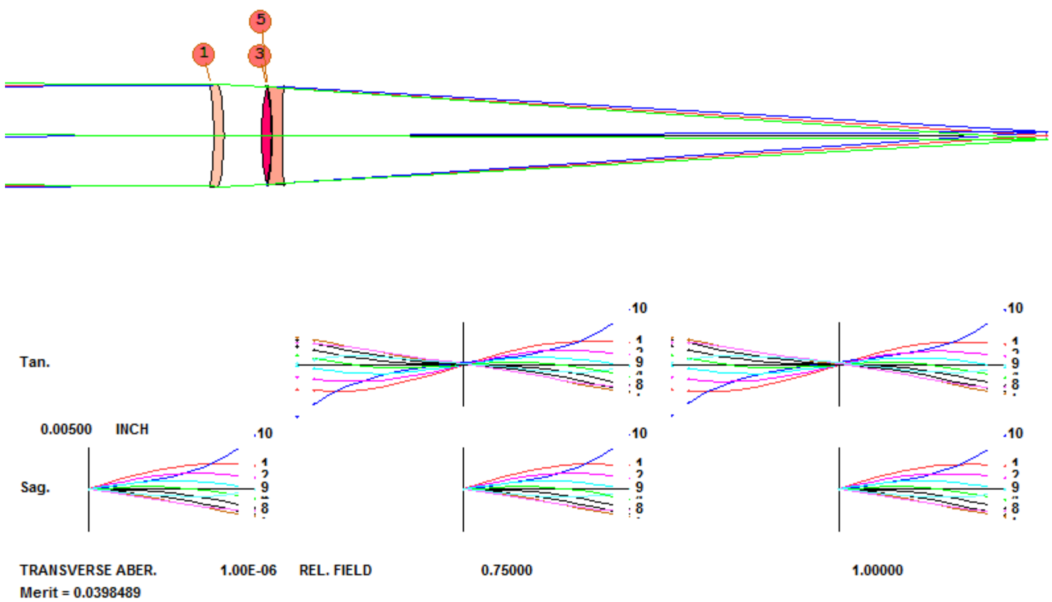
```
LOG
STO 9

PANT
VLIST RAD 1 2 3 4 5
VLIST TH ALL AIR
VLIST GLM ALL
END

AANT

END

SNAP
SYNOPSYS 50
```

Now put the cursor on the blank line after the AANT command, and click the button . Merit function number 6 is selected by default, so just click the Back to MACro editor button. This gives us a simple merit function:

```
…
AANT
AEC
ACC
LUL 4 1 1 A TOTL
GSR .5 10 5 M 0
```

```
GNR .5 2 3 M .7
GNR .5 1 3 M 1

END
…
```

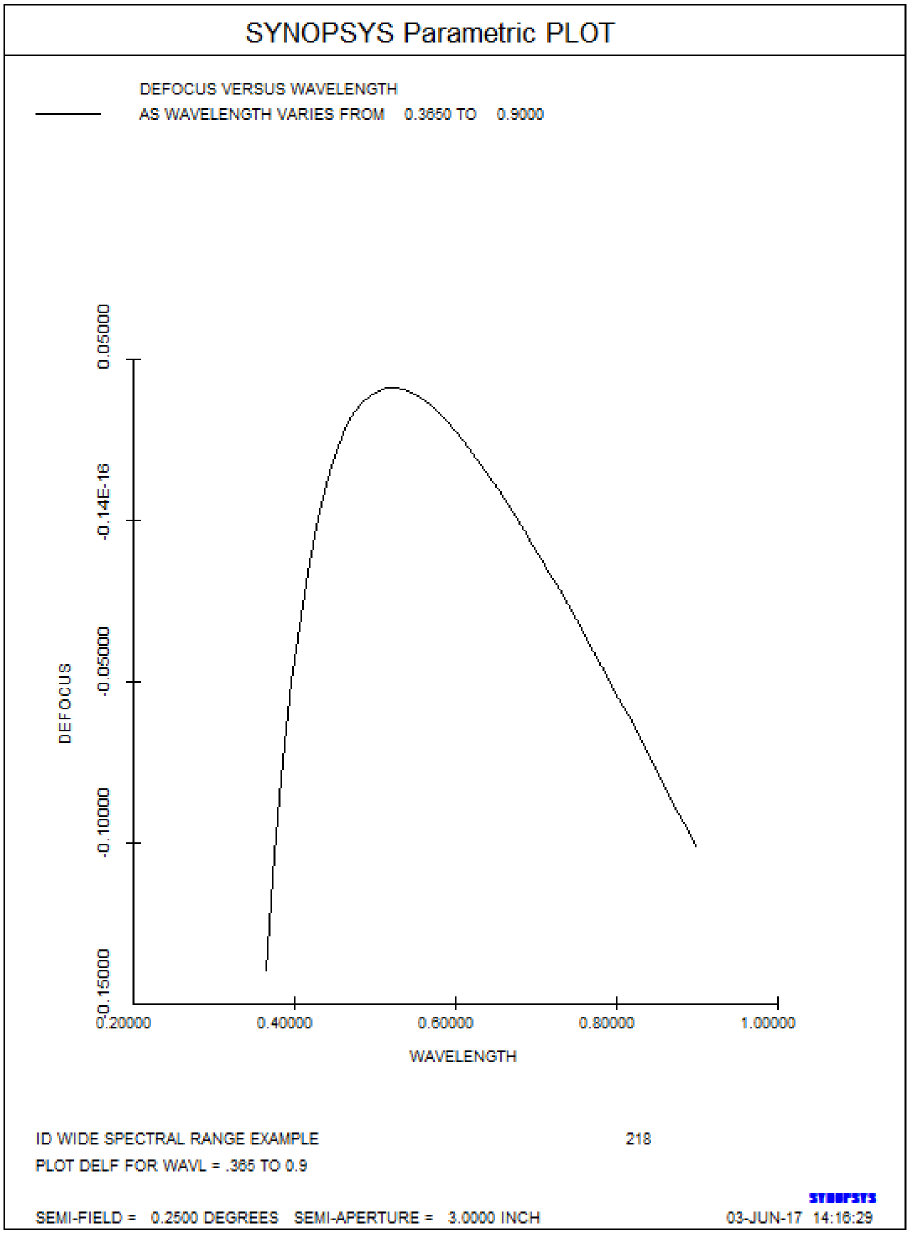
Here, we correct all 10 colors. Okay, it's time to optimize. Run the MACro and anneal. The lens is better, but still not too good:



How good is this state of correction? We can ask AI to show us the defocus over wavelength – but that would be unwise at the moment. This lens has a curvature solve, and at each wavelength the program would recalculate it. (We surely don't want that to happen!) So instead, we make a second MACro, as follows:

```
STORE 9
STEPS = 50
CHG
NOP
END
PLOT DELF FOR WAVL = .365 TO 0.9
GET 9
```

This file removes all of the solves (and pickups, if there were any) and then plots the defocus. Afterwards, it gets back the lens the way it was. Here is the color correction curve:



This is valid for the model glasses, of course, and ordinarily we would substitute real glasses and reoptimize. But at the moment we have an achromat, corrected for two wavelengths. We know this because one could draw a horizontal line on the graph and it would intersect the curve in two places. We decide that this kind of correction is not good enough for our purposes. Now it's time to learn about making a "superachromat".

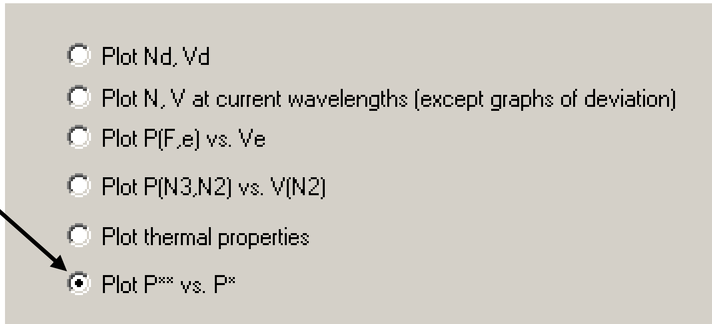
First we show how to find suitable glass combinations yourself, using the glassmap feature of SYNOPSYS. Then we will show how the program can do the task automatically, which is a real time saver.

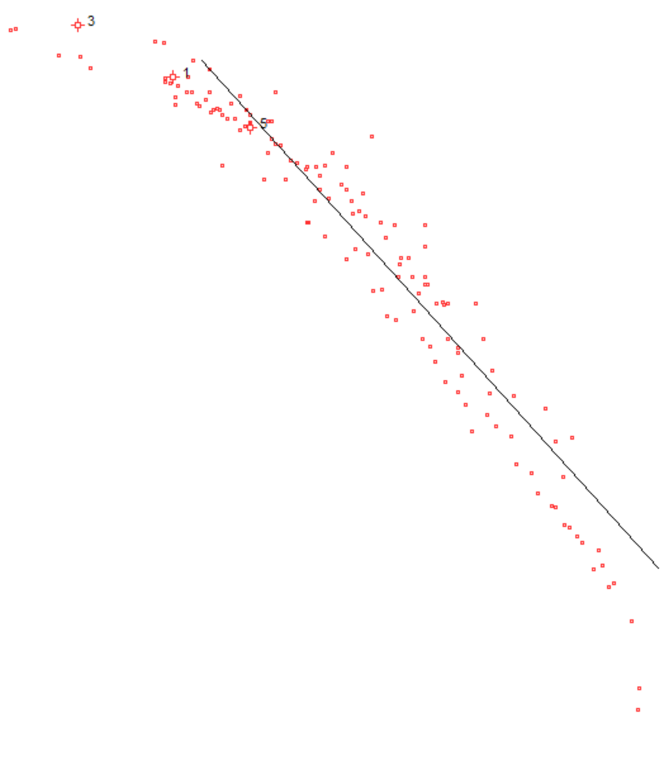
The term superachromat was coined by Max Herzberger in 1963, in a paper in Applied Optics. His theory says that, if you make a graph of the glass catalog where the axes are the values of P* and P**, and then select three glasses that lie on a straight line, it is possible to correct at *four* wavelengths at the same time. The term P* refers to the partial dispersion (NF – N*)/(NF – NC), where F and C are the Fraunhofer lines at 0.4861 and

0.6563 um, and N* is the IR line at 1.014 um. N** is the UV line at 0.365 um, giving you a similar equation for P**.

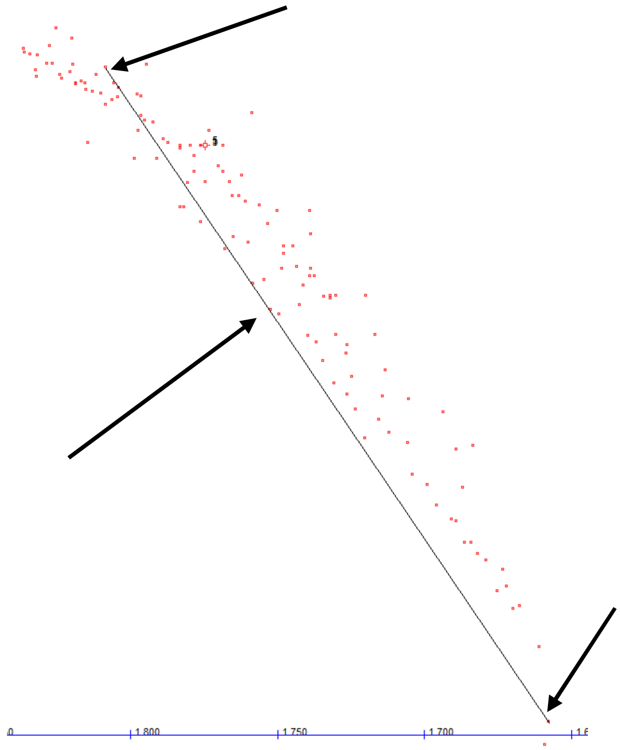
We will briefly outline the procedure for doing it by hand, so you'll know how.

The on-screen glassmap of SYNOPSYS can show us just the kind of plot we need. Type **MGT** to open the Glass Table Selection dialog and select the O (Ohara) catalog. When the map is displayed, click the Graph button, and select the bottom option.





On this graph you see the current location of the model for each element (the red circles). They are somewhat lined up, but it is a very short line. What you have to do is to adjust the line so it connects three glass types, preferably with a line as long as practical. You select a glass near the bottom, where the flints tend to be, and <ctrl>click one of them. That puts the bottom of the line on that glass. Then select a glass near the top of the distribution and <shift>click that one to put the top of the line there. Now select a third glass near the center of that line and as close to it as you can find. Write down the names of those three glasses.



We have three potential glasses for our superachromat. They are types S-PHM52, S-NPH5, and S-TIL27. You can also display the relative cost and other properties, to help you select three acceptable glasses. Then you insert those three glasses into the lens and optimize. If that does not yield a satisfactory lens, you select a different three according to the same procedure. This process is rather tedious but often works quite well.

The other procedure is to let the program select glass combinations for you. Type, in the CW,

```
FST
PREF
CAT O
CAT S
GO
```

FST means Find Superachromat Triplets. This input will examine all combinations of glass types from the Ohara and Schott catalogs and rate the 10 most suitable for a superachromat. The program finds the following:

```
SYNOPSYS AI>FST

FST>PREF

FST>CAT O

FST>CAT S

FST>GO
```

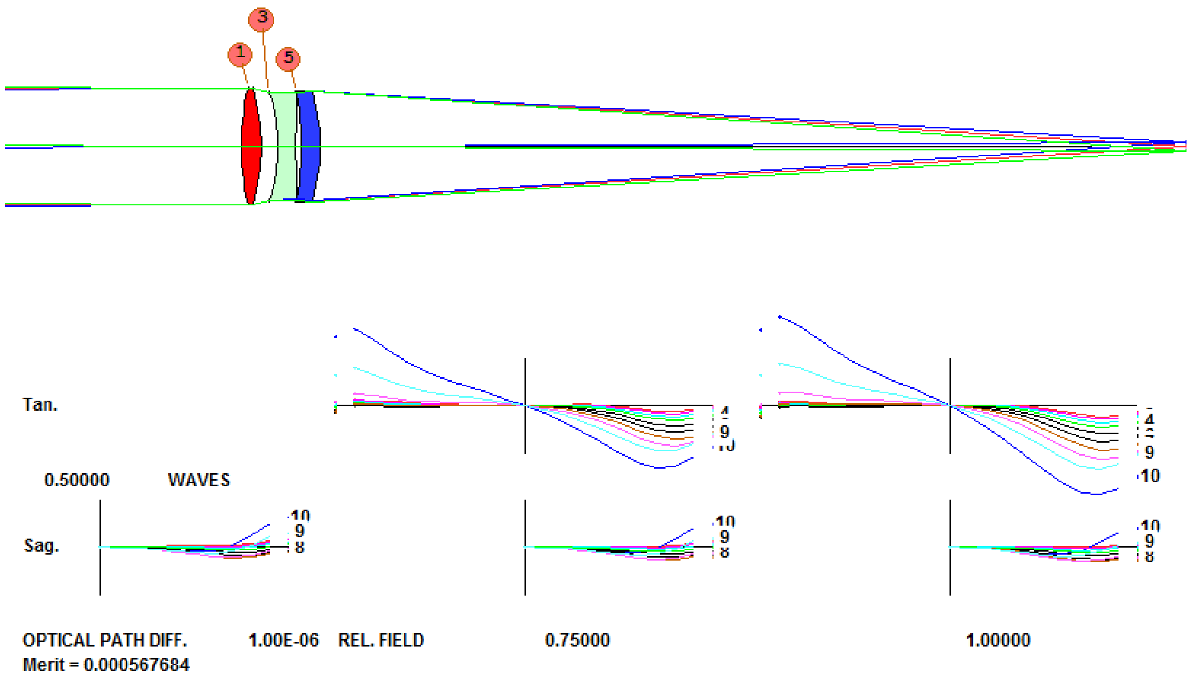
SUPERACHROMAT GLASS SEARCH RESULTS (LOWER SCORES ARE BETTER)

	SCORE	UPPER	MIDDLE	LOWER	OFFSET
1	0.02120605	O S-FPL53	O S-LAL13	O S-TIM28	0.00000424
2	0.01881642	O S-FPL55	O S-TIL27	O S-TIH23	0.00000071
3	0.01810522	O S-FPL53	O S-BAL42	O S-NBH53	0.00000154
4	0.02008505	O S-FPL53	O S-LAL8	O S-NPH1W	0.00000923
5	0.02147608	O S-FPL55	S N-SSK8	S SF1	0.00000460
6	0.02082027	O S-FPL55	S N-KF9	S SF10	0.00000567
7	0.02008505	O S-FPL53	O S-LAL8	O S-NPH1	0.00000923
8	0.02026308	S N-FK58	S N-SSK8	S SF4	0.00000296
9	0.02139100	O S-FPL53	S N-SK4	S SF56A	0.00000909
10	0.01357538	O S-FPL53	O S-BAL11	O S-TIH14	0.00000098

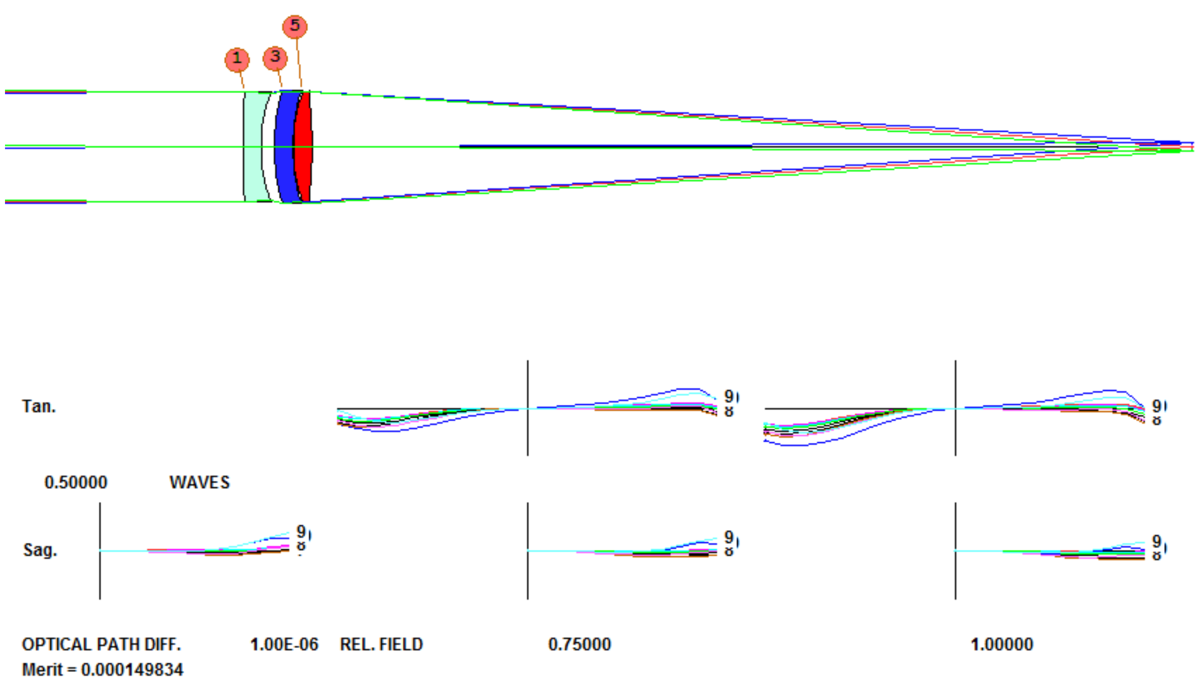
This method is superior to doing it by hand since it can combine glasses from different manufacturers. Combination number five, for example, is made from one Ohara glass and two from Schott. Let us try that combination. We edit the optimization MACro as shown below. (Here, we used ready-made merit function number 8, which corrects a combination of transverse and OPD aberrations, and then adjusted the weights.)

```
LOG
STO 9

CHG
1 GTB O 'S-FPL55'
3 GTB S 'N-SSK8'
5 GTB S 'SF1'
END

PANT
VLIST RAD 1 2 3 4 5
VLIST TH ALL
!VLIST GLM ALL
END

AANT
AEC
ACC
ADT 6 1 1
ACM .5 1 .1
LUL 4 1 1 A TOTL

AEC
ACC
GSR .5 10 5 M 0
GNR .5 5 3 M .7
GNR .5 4 3 M 1
GSO 0 0.003916 5 M 0
GNO 0 0.003 3 M .7
GNO 0 0.002 3 M 1

END

SNAP
SYNOPSYS 50
```

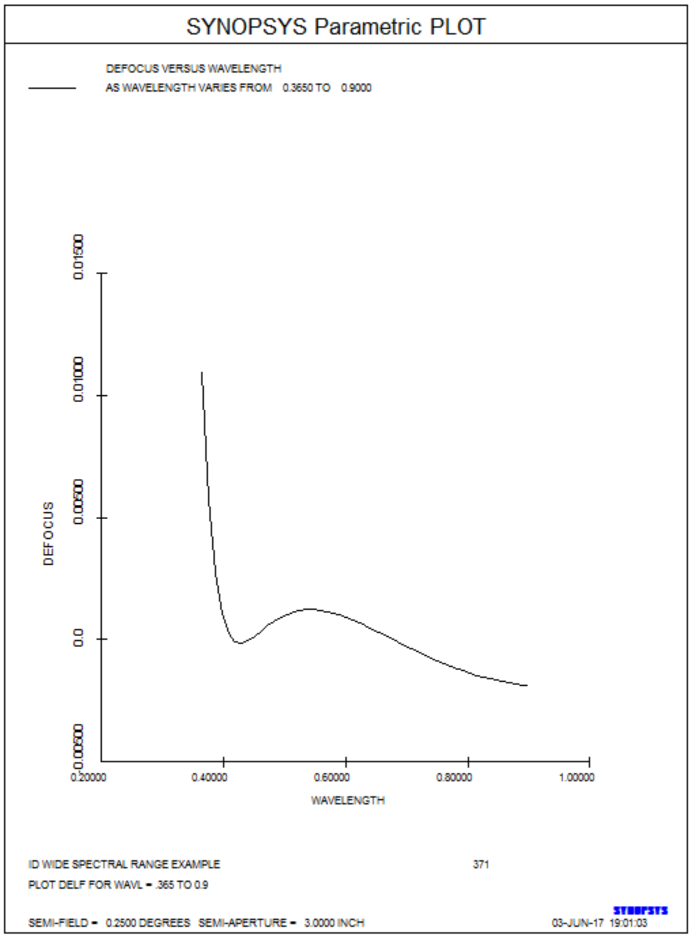
After running this and annealing, we get a lens corrected to about 1/10 wave on axis and ½ wave at full field, although color 10 (at 0.4 um) is not as well corrected as the others.



But we only guessed the order of our three glasses. There are six possible combinations, and by trying them all, we find that the order 5, 1, 3 works slightly better. We proceed in the same manner, looking at each of the combinations returned by FST. The sixth one was even better:



Now we are corrected to about a quarter wave over the entire (very wide) spectral region. What does our second MACro show now?



Well, it's corrected at three wavelengths for sure – but we are aiming for four. How come the curve doesn't go up again at the right end – as a true superachromat would? Simple. As usual, the program is balancing everything in the merit function, not just axial color, and a small amount of sphero-chromatism makes it depart slightly. Still, this is a great lens!