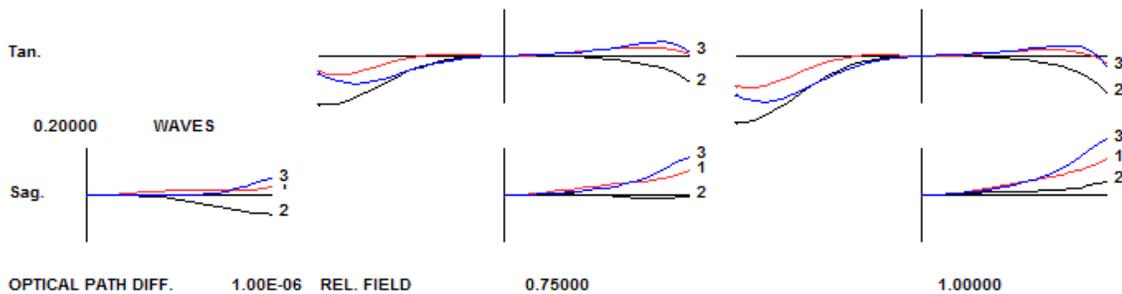
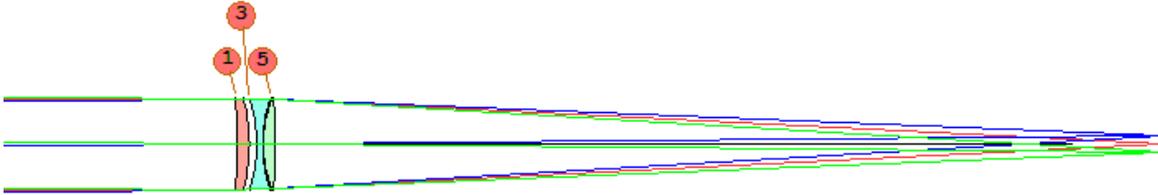


Lesson 8: The Apochromat

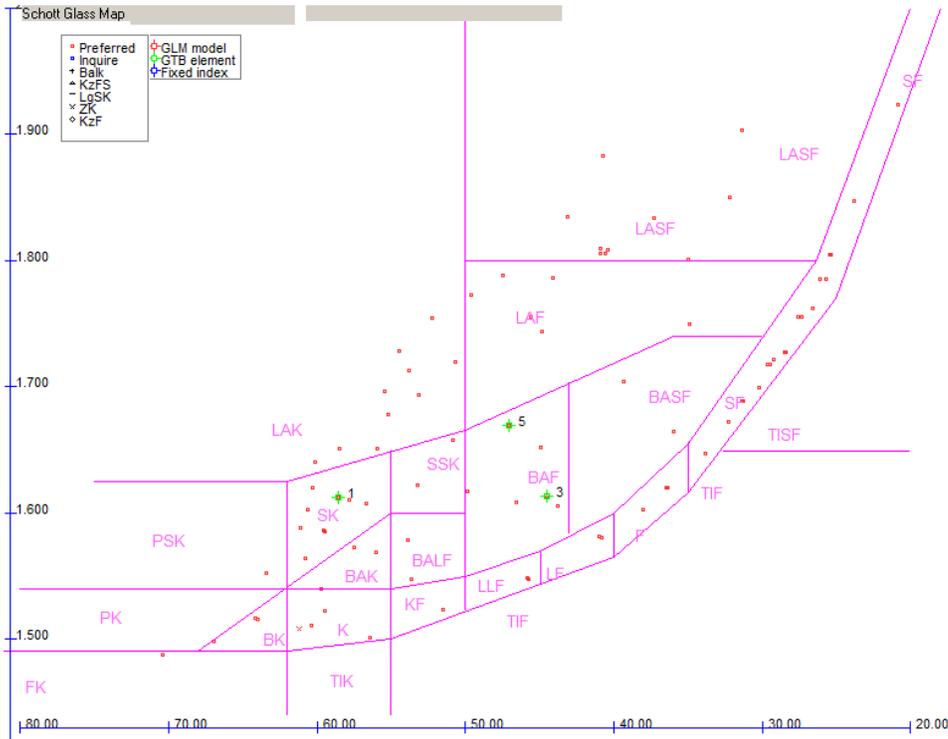
This lesson shows how to design a lens with better color correction than one can get with a simple doublet. A concise description of how one can proceed is given in Rutten & van Venrooij's book *Telescope Optics*. The gist of it is, one must use three different kinds of glass that satisfy certain properties. They may easily be selected by inspecting the glass-table display. To illustrate, we will start with a design using glass types N-SK4, N-KZFS4, and N-BALF10 from the Schott catalog. (These glasses are sometimes recommended for the purpose.) Here is the starting lens file:



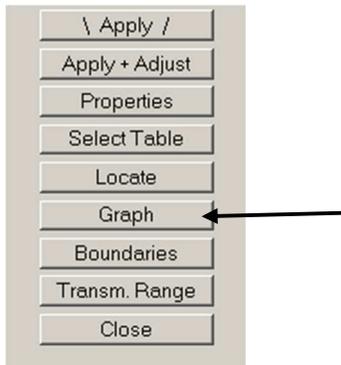
```

RLE
ID F10 APO
WAVL .6500000 .5500000 .4500000
APS 3
UNITS INCH
OBB 0.00 0.5 2.00000 -0.01194 0.00000 0.00000 2.00000
0 AIR
1 RAD -300.4494760791975 TH 0.58187611
1 N1 1.60978880 N2 1.61494395 N3 1.62386887
1 GTB S 'N-SK4 '
2 RAD -7.4819193194388 TH 0.31629961 AIR
2 AIR
3 RAD -6.8555018049530 TH 0.26355283
3 N1 1.60953772 N2 1.61628830 N3 1.62823445
3 GTB S 'N-KZFS4 '
4 RAD 5.5272935517214 TH 0.04305983 AIR
4 AIR
5 RAD 5.6098999521052 TH 0.53300999
5 N1 1.66610392 N2 1.67304720 N3 1.68543133
5 GTB S 'N-BAF10 '
6 RAD -27.9819596092866 TH 39.24611007 AIR
6 AIR
6 CV -0.03573731
6 UMC -0.05000000
6 TH 39.24611007
6 YMT 0.00000000
7 RAD -11.2104527948015 TH 0.00000000 AIR
END
    
```

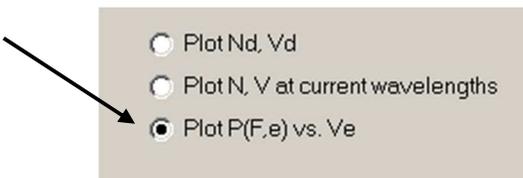
Open this file, open the SketchPAD (PAD) and then click the GlassTable button . Select the Schott table from the box that opens. Here is the display:



This shows the Schott glass map, but it is not what we want for this exercise. Click the Graph button ...



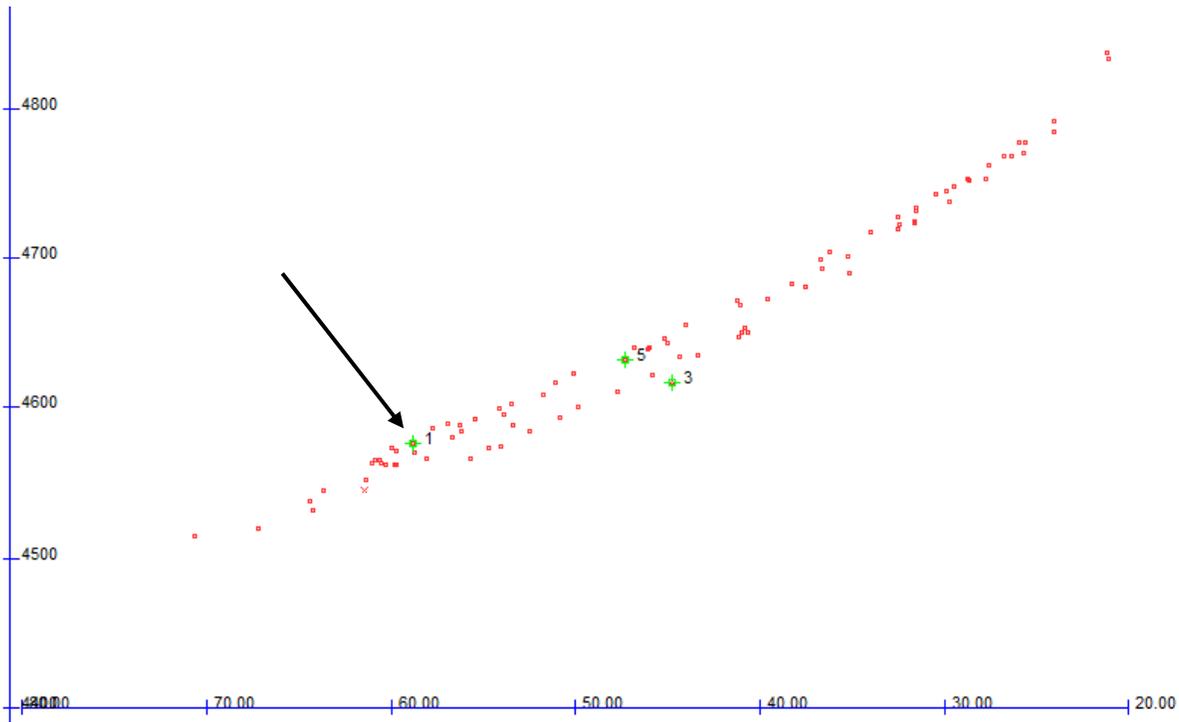
... and then select Plot P(F,e) vs. Ve



The display changes, and now the abscissa is the V-number at the e line (0.54607 um) and the ordinate is the quantity $(N_F - N_e)/(N_F - N_C)$.

The theory of the apochromat says that you must select three glasses that *do not* lie on a straight line. They must form a triangle, and the larger the area the better. The green circles show the present glasses in the triplet. They work very well – but we can do somewhat better.

Click on the green circle with the number “1” beside it. That is the glass currently on surface 1, N-SK4. Now click the Properties button, to see the properties of this glass, shown below.



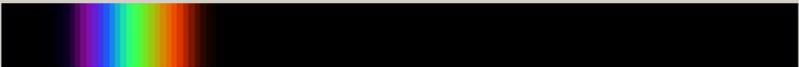
Hmmm ... this glass is not all that stable: humidity rating of 3 and acid sensitivity of 5. Let's see if we can find a better glass for the first element. (This is exposed to the environment, so it's important.) Click the Graph button again, and then click the radio button for Acid Sensitivity and then OK. Zoom in with the mouse wheel as needed near the green circle so things get much bigger, and then click the Full Name button.

Glass Name: N-SK4
 Vendor: Schott
 Availability: Preferred
 Environment: Does not contain lead or arsenic

Index	Abbe No.	Bubble	Humidity	Stain	Acid	Alkali	Sp.Gv.	CTE	Price
1.6127	58.63	1.00	3	2	5	2	3.54	6.46E-06	6.00

Transmitted color: 

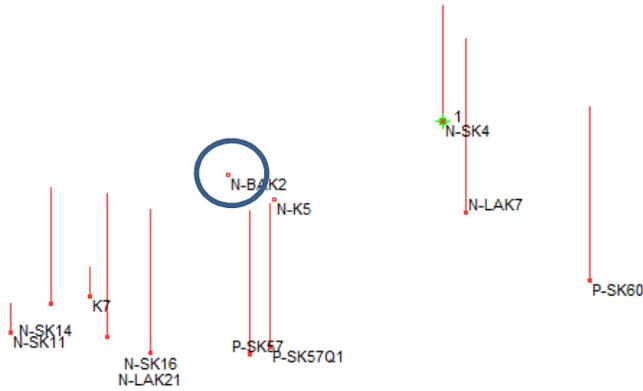
Sample thickness:

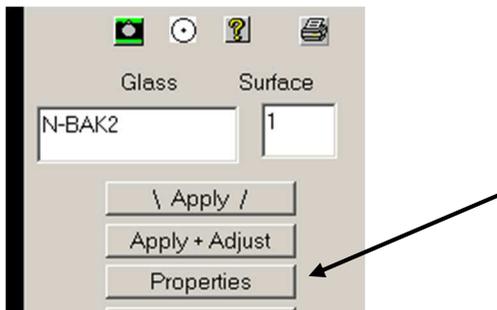
0.2500 0.5000 0.7500 1.0000 1.2500 1.5000 1.7500 2.0000

This glass has DN/DT data in catalog. Chemical stability numbers are zero if there are no data



Now you see a red vertical line through the glass locations, showing the acid sensitivity. The line for glass N-SK4 is rather long, since that glass is not very resistant. To the left you see N-BAK2, with no line at all (it's in the best category). Click that spot, and when the glass name appears in the window on the right ...



... click the Properties button again. Aha! This glass has an acid rating of 1, better humidity tolerance, and a lower price as well. There's no reason we can't use it instead of the previous N-SK4, since it makes just as good a triangle with the other glasses. Type the surface number (1) into the Surface box and click \Apply/. Glass N-BAK2 is now assigned to surface 1.

Now clean up the display by deleting the names (click Spots Only), and then Graph, and select No Graph and OK. Our triangle is just as nice as before.

Of course the lens is not optimized for this glass, so we have to run the optimization program. Here is a MACro that will do the job.

```

PANT
VLIST RAD 1 2 3 4 5 7
VLIST TH 2 4
END

AANT
AEC
ACC
GSO 0 1 4 M 0 0
GNO 0 .2 3 M .75 0
GNO 0 .1 3 M 1.0 0
END

SNAP
SYNO 30

```

Run this MACro, and now the correction is better than 1/10 wave on axis. We have a better design that is cheaper to make, more resistant to the elements, and corrected over the range 0.45 to 0.65 um. Here is the RLE file for that design:

```

RLE
ID F10 APO
WAVL .6500000 .5500000 .4500000
APS 3
UNITS INCH
OBB 0.000000 0.50000 2.00000 -0.00652 0.00000 0.00000 2.00000
0 AIR
1 RAD -167.6807592628928 TH 0.58187611
1 N1 1.53742490 N2 1.54188880 N3 1.54960358
1 CTE 0.800000E-05
1 GTB S 'N-BAK2 '
2 RAD -7.0647888938302 TH 0.36076391 AIR
3 RAD -6.5538674975636 TH 0.26355283
3 N1 1.60953772 N2 1.61628830 N3 1.62823445
3 CTE 0.730000E-05
3 GTB S 'N-KZFS4 '
4 RAD 5.3138288434095 TH 0.03937000 AIR
5 RAD 5.4083667709938 TH 0.53300999
5 N1 1.66610392 N2 1.67304720 N3 1.68543133
5 CTE 0.618000E-05
5 GTB S 'N-BAF10 '
6 RAD -19.4177738787113 TH 39.42904372 AIR
6 CV -0.05149921
6 UMC -0.05000000
6 TH 39.42904372
6 YMT 0.00000000
7 RAD -11.1931120564708 TH 0.00000000 AIR
END

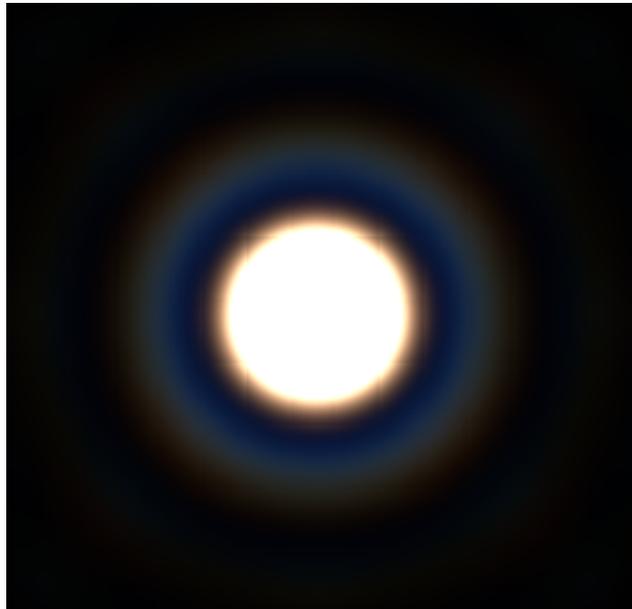
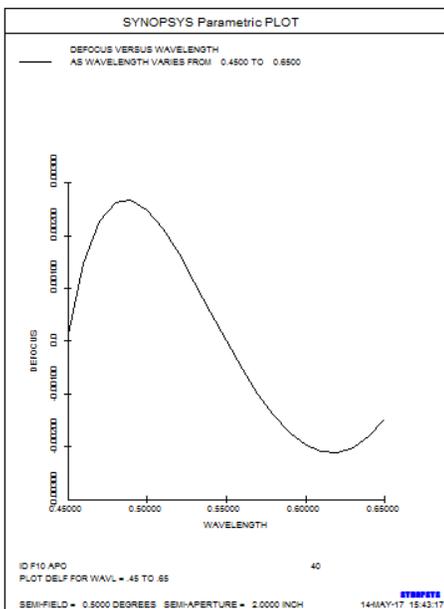
```

Let's see how the defocus varies with color in the new design.

```

CHG
NOP
END
PLOT DELF FOR WAVL = .45 TO .65

```



This analysis shows a defocus of about 0.0026 inches over the design range, and a perfect Airy disk. (The latter was calculated by Image Tools (**MIT**) with 10 wavelengths assigned to the lens to make a good white in the center, with the coherent effect.) The defocus is not zero because the program has balanced a small shift against the change of spherical aberration with wavelength. Both are small. (This version is in L8L3.RLE.) How did we assign 10 wavelengths? With the Spectrum Wizard (**MSW**).

Note how we plotted **DEL**F in this case instead of **BACK**, as we did previously. Why? Well, we eliminated all solves with the **NOP** directive, so the back focus is now fixed. But the paraxial defocus, **DEL**F, now changes with wavelength.

