Secondary Spectrum

Lens Design OPTI 517

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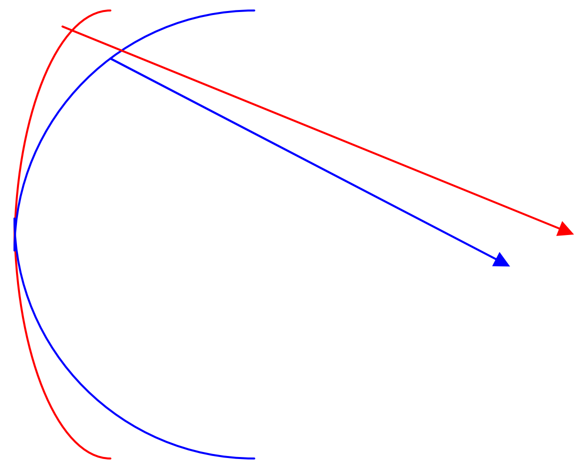
Secondary Spectrum

The quadratic difference between
the F and C wavefronts is:



$$\delta_\lambda W_{020} = \frac{1}{2}\sum \frac{y_m^2}{f\nu}$$

V- number $\qquad \nu = \dfrac{n_d - 1}{n_F - n_C}$

$$\delta_\lambda W_{020} = \frac{1}{2}\sum \frac{y_m^2}{f\nu} = \frac{1}{2}\sum \frac{y_m^2}{f}\frac{n_F - n_C}{n_d - 1}$$

The quadratic difference between λ and F wavefronts is:

$$\delta_\lambda W_{020} = \frac{1}{2}\sum \frac{y_m^2}{f}\frac{n_\lambda - n_F}{n_d - 1} = \frac{1}{2}\sum \frac{y_m^2}{f}\frac{n_\lambda - n_F}{n_d - 1}\frac{n_F - n_C}{n_F - n_C} =$$

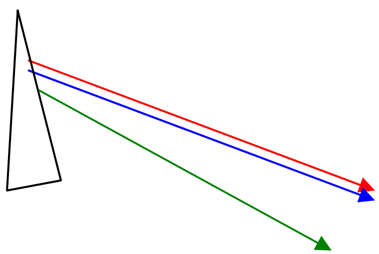
$$= \frac{1}{2}\sum \frac{y_m^2}{f\nu}\frac{n_\lambda - n_F}{n_F - n_C} = \frac{1}{2}\sum \frac{y_m^2}{f\nu}P_{\lambda F}$$

Where $P_{\lambda F}$ is the partial dispersion ratio from λ to F

For a system of thin lenses we have:

$$\delta_\lambda W_{020} = \frac{1}{2}\sum \frac{y_m^2}{f\nu}P_{\lambda F}$$

Thin doublet

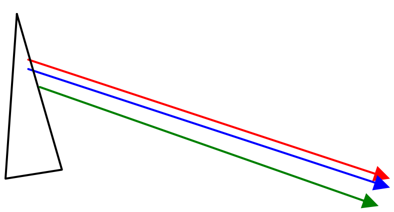


For a thin achromatic doublet:

$$f_a \cdot \nu_a = f_b \cdot \nu_b = F \cdot (\nu_a - \nu_b)$$

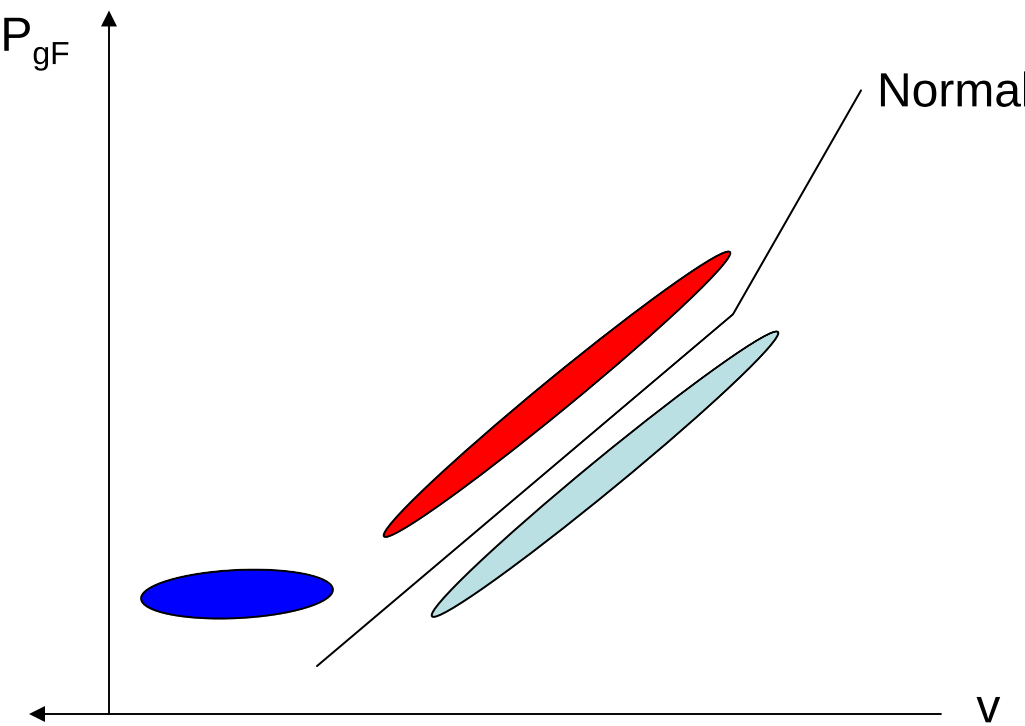
$$\delta_\lambda W_{020} = \sum \frac{y_m^2}{f\nu} P_{\lambda F} = \frac{y_m^2}{F} \frac{P_a - P_b}{\nu_a - \nu_b}$$

For zero secondary spectrum:



$$Tan(\varphi) = \frac{P_a - P_b}{\nu_a - \nu_b}$$

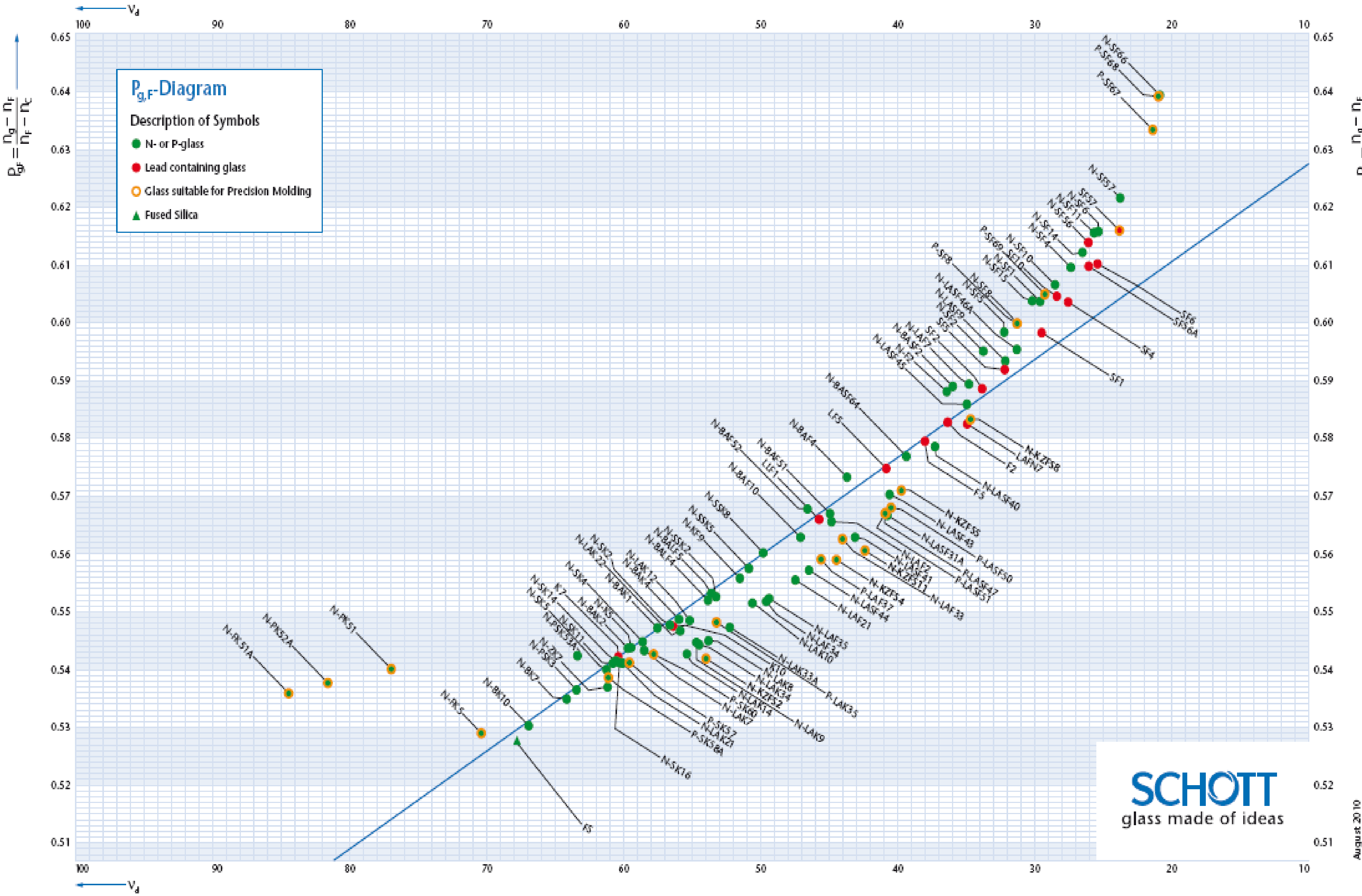
Partial Dispersion ratio vs. Abbe number



Fluorite/crowns

Titanium glasses

Lanthanum glasses



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THREE-LENS APOCHROMAT

$$\sum \nu c \Delta n = \phi$$ Power

$$c = \frac{1}{R_1} - \frac{1}{R_2}$$

$$\sum c \Delta n = 0$$ Achromatism

$$\sum P c \Delta n = 0$$ Secondary Spectrum

where:

Or:

$$V_a\left(c_a \Delta n_a\right) + V_b\left(c_b \Delta n_b\right) + V_c\left(c_c \Delta n_c\right) = \phi$$

$$\left(c_a \Delta n_a\right) + \left(c_b \Delta n_b\right) + \left(c_c \Delta n_c\right) = 0$$

$$P_a\left(c_a \Delta n_a\right) + P_b\left(c_b \Delta n_b\right) + P_c\left(c_c \Delta n_c\right) = 0$$

The solution to these equations is:

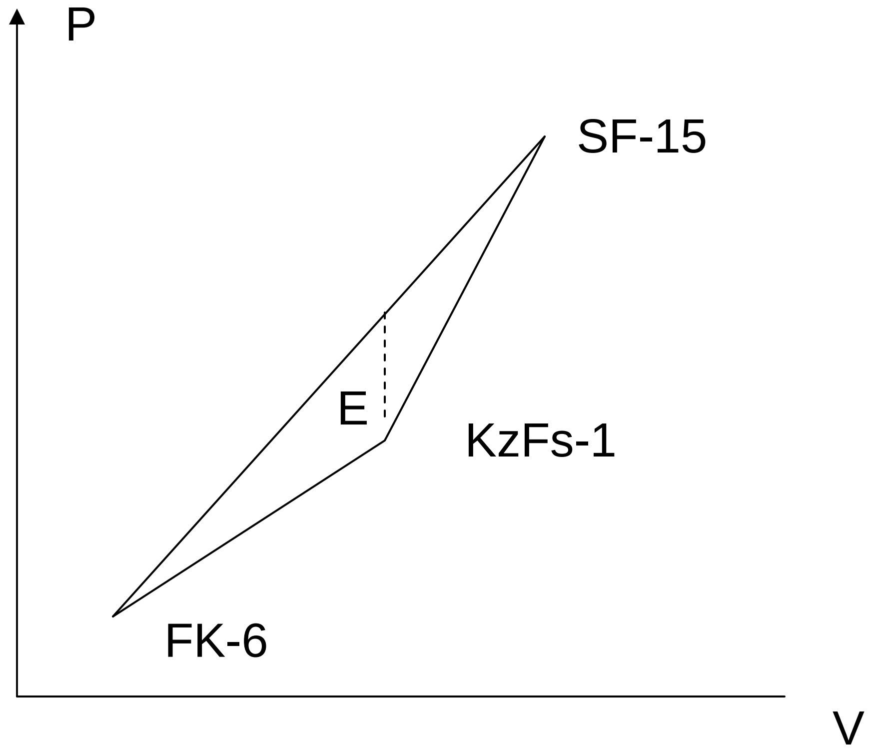
$$c_a = \frac{1}{FE\left(V_a - V_c\right)}\left\{\frac{P_b - P_c}{\Delta n_a}\right\} \quad c_b = \frac{1}{FE\left(V_a - V_c\right)}\left\{\frac{P_c - P_a}{\Delta n_b}\right\} \quad c_c = \frac{1}{FE\left(V_a - V_c\right)}\left\{\frac{P_a - P_b}{\Delta n_c}\right\}$$

where F is the focal length of the triplet and E is :

$$E = \frac{V_a\left(P_b - P_c\right) + V_b\left(P_c - P_a\right) + V_c\left(P_a - P_b\right)}{\left(V_a - V_c\right)}$$

In the P-V diagram E is the ‘sag’ of the triangle defined by the points (Pa, Va), (Pb, Vb), and (Pc, Vc).

E is the ‘sag’ of the triangle defined by the points (Pa, Va), (Pb, Vb), and (Pc, Vc).

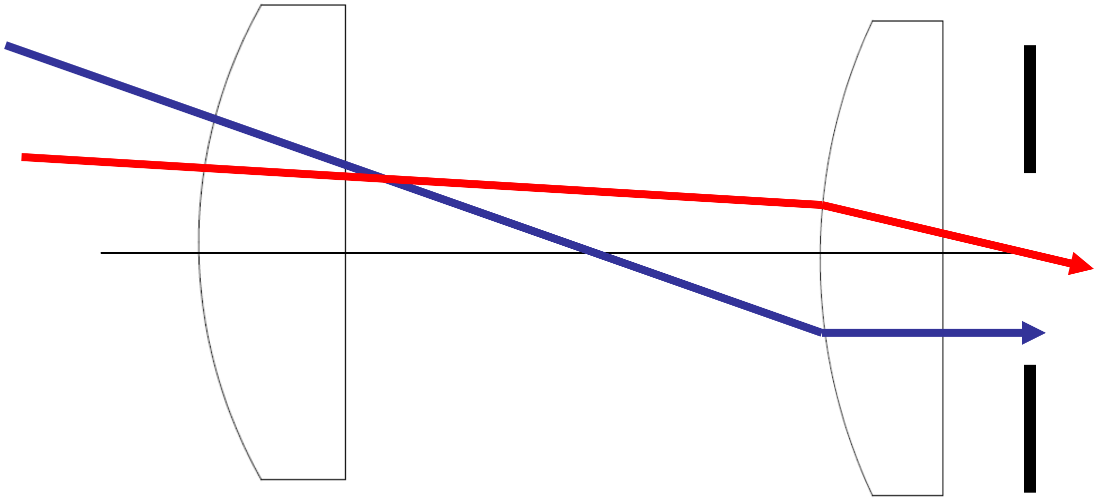


P-V Glass diagram
Geometrical meaning of E

Single glass achromats

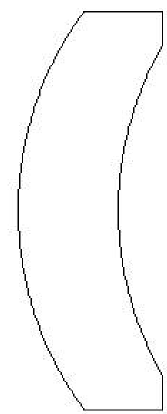
- Huyghenian eyepiece
- Maksutov meniscus
- Houghton corrector
- Field flattener
- Shupmann: dialytes (Kingslake p. 89-92)
- Shupmann medial telescope

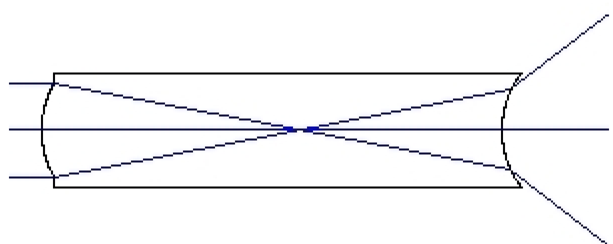
Single glass achromats



$$\delta_\lambda W_{111} = \sum \frac{\bar{y}y}{f\nu} = 0$$

$$\delta_\lambda W_{020} = \frac{1}{2} \sum \frac{y^2}{f\nu} = 0$$





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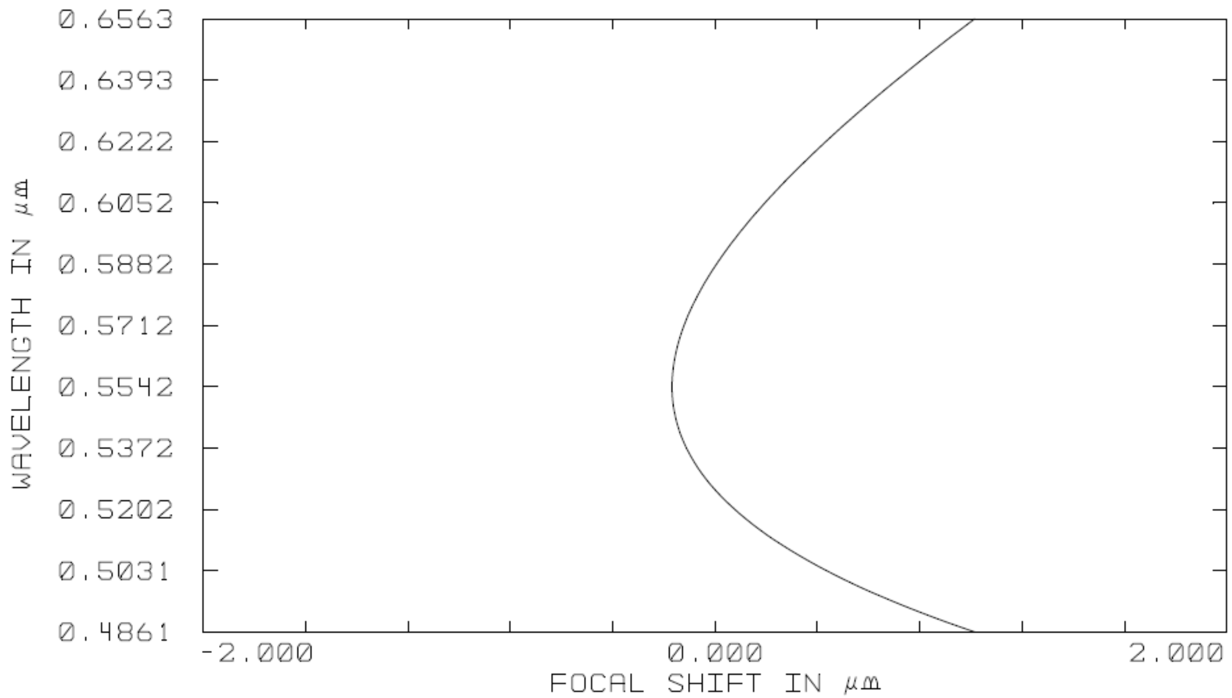
Shupman

$$\delta_\lambda W_{020} = \frac{1}{2}\sum \frac{y^2}{f\nu}$$



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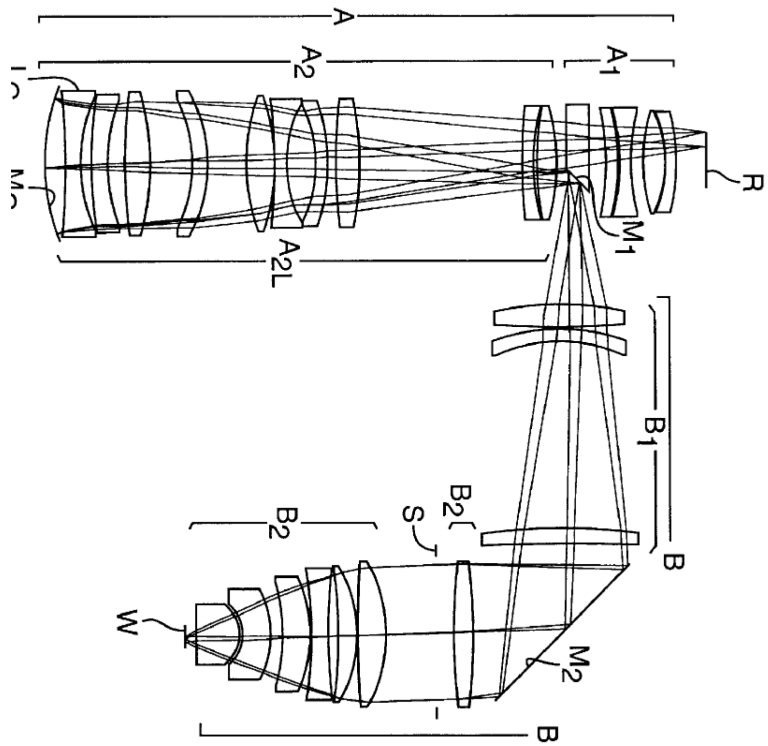
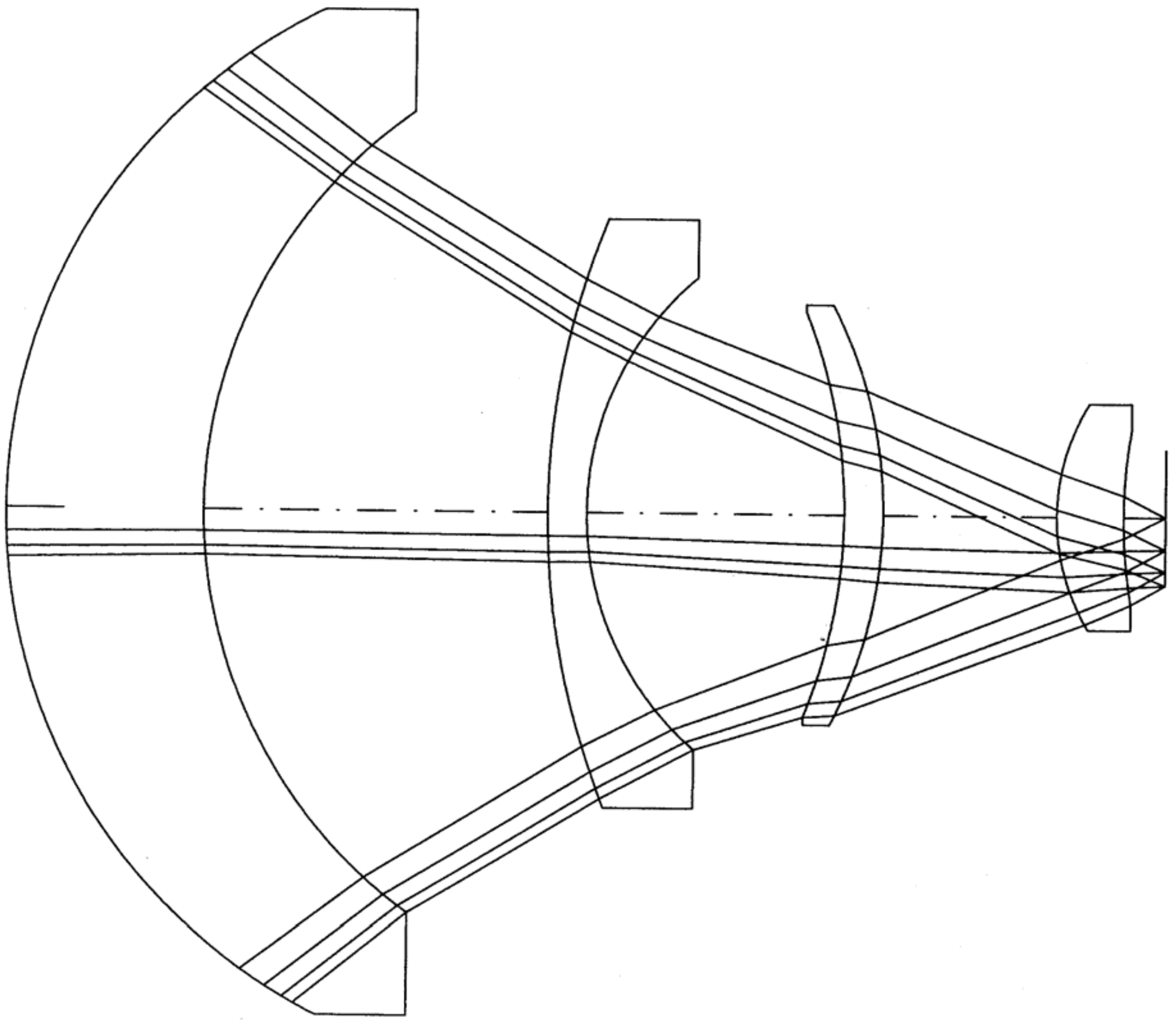
Other forms are possible

- See Kingslake
- Patent literature on micro-lithographic lenses



USP 5,835,275

Field correctors



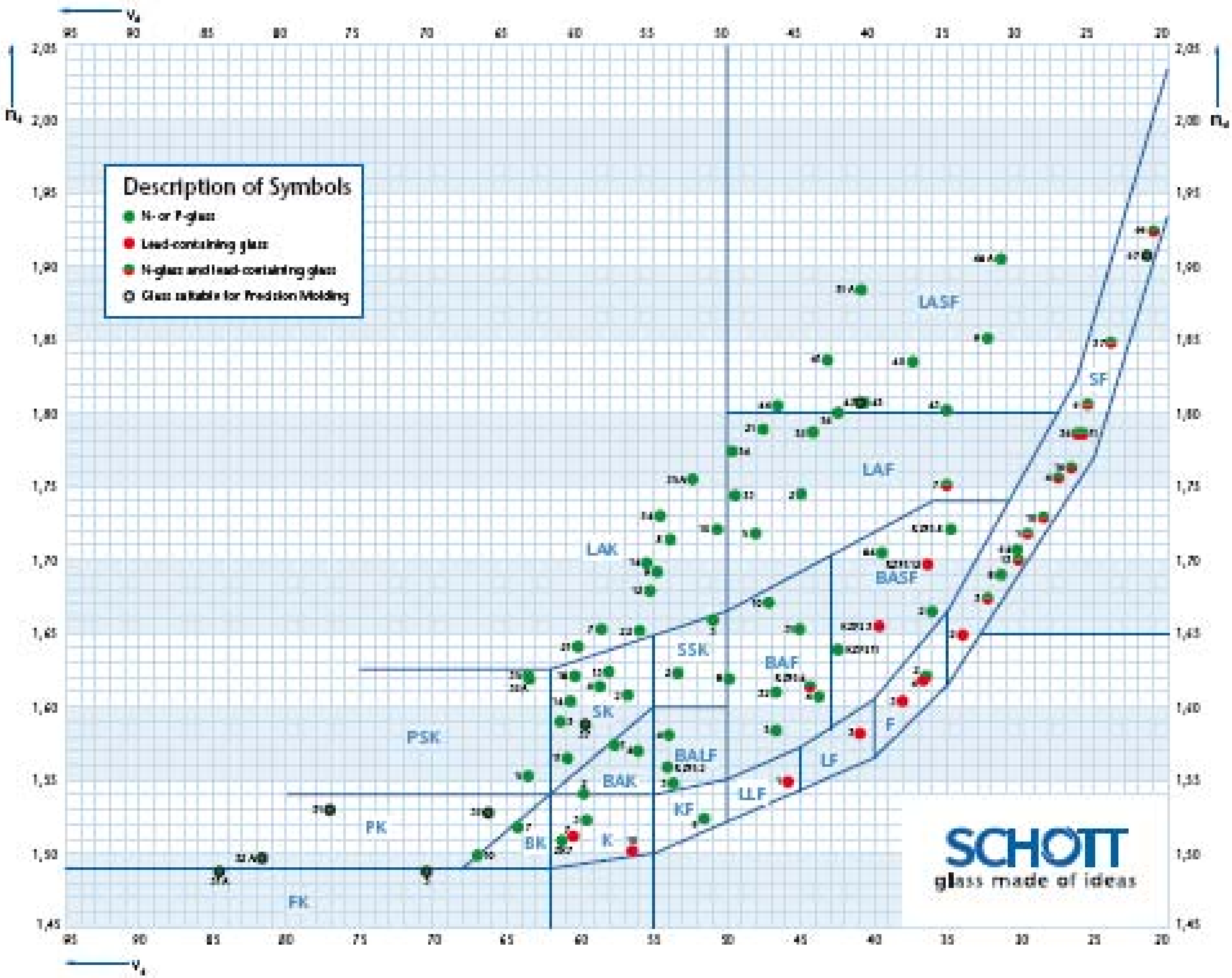
Chromatic correction techniques

- Achromatize all elements
- Create two effective degrees of correction to correct two aberrations
- Phantom stop technique
- Symmetry of transverse color
- Change glasses with same Nd but different Abbe number
- Buried surface

Buried surface

- Paul Rudolph 1890
- Monochromatic design
- Split lens into a cemented doublet
- Chose second lens to have same index at nd but

  different dispersion than first lens
- Monochromatic properties remain the same
- Change cemented interface radius to correct color
- SK-16 and F-9

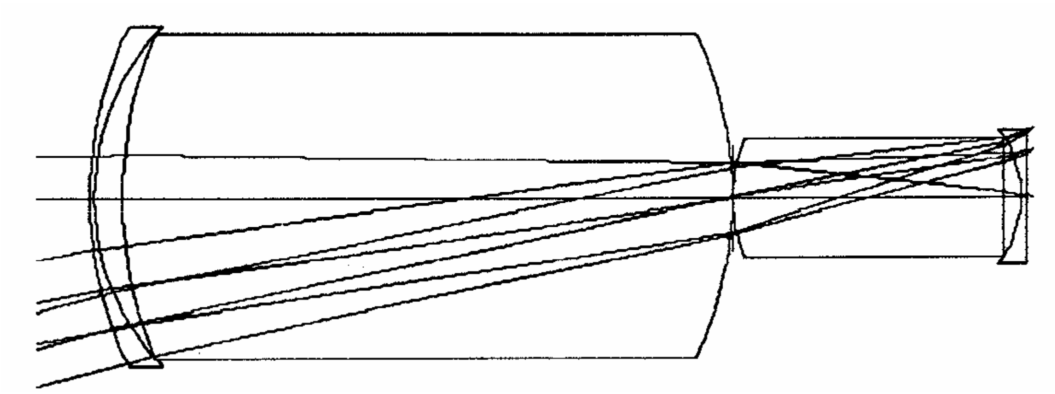

Description of Symbols
N- or P-glass
Lead-containing glass
N-glass and lead-containing glass
Glass suitable for Precision Molding
LASF
LAF
LAK
BASF
SSK
BAF
SK
PSK
BALF
BAK
LLF
LF
F
KF
PK
BK
K
FK
SF
SCHOTT
glass made of ideas

Phantom stop

- Stop shift
- $\Delta\delta\lambda W020 = 0$; $\Delta\delta\lambda W111 = 2\ (\delta yc/\ ym)\ \delta\lambda W020$
- In the presence of axial color lateral color can be modified
- Correct lateral color by moving the stop
- Correct axial color at that stop position
- Move the stop back to the original position
- Color correction will be maintained

Achromatization of the Monochromatic Quartet

1990 International Optical Design conference problem
Note Aldis arrangement for controlling spherical aberration
Positive air lens
Example of optimization



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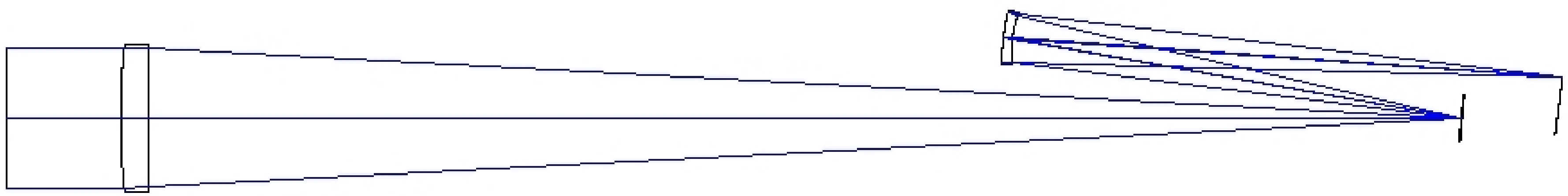
Shupmann medial telescope

Single glass achromat

Mangin mirror

Field lens

Tilted components



Jim Daley

Designs in the US

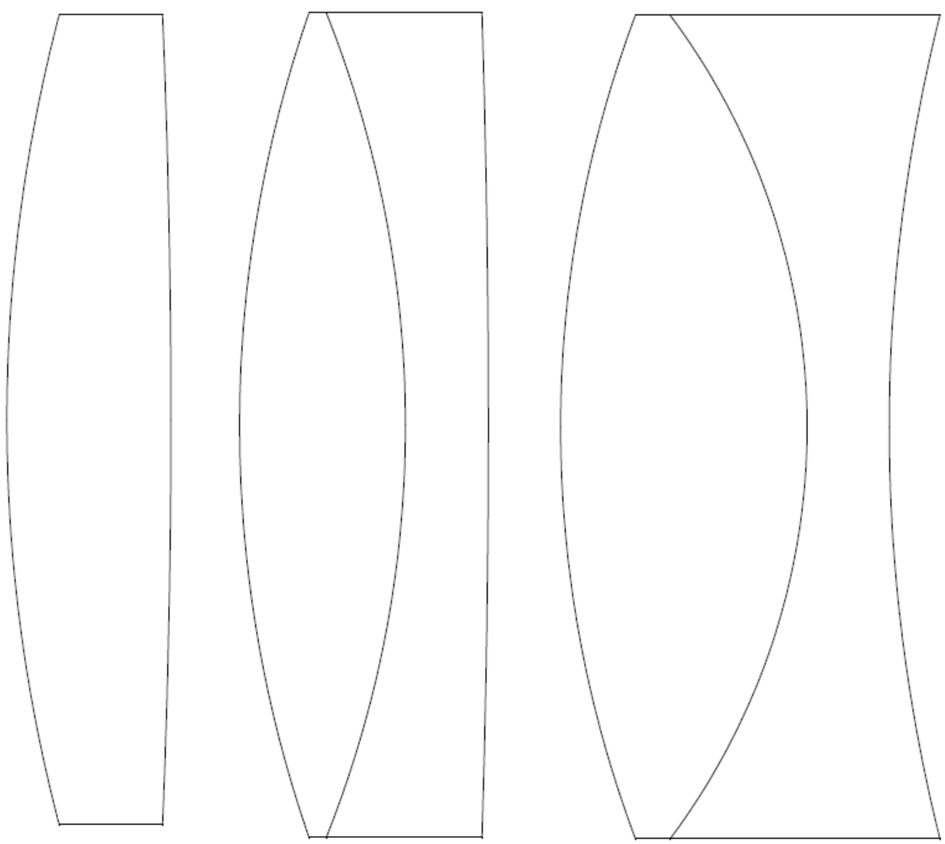
See his book

Willmann-Bell

Chromatic aberration

- Monochromatic correction (may prepare for color correction)
  Chromatic correction
- Phantom stop to nullify lateral chromatic and find location to nullify axial chromatic
- Buried surface
- Use of a second interface to move location of phantom stop
- Use of the principle of symmetry to correct lateral color
- Chromatic aberrations as a black box: two aberrations; two degrees of freedom
- Chromatic variation (induced) of aberrations and use of multiple interfaces
- Sphero-chromatism
- Extreme case: all lenses are achromatic.

Sag comparison with new achromat



BK7
P=-152 mm

BK7-F2
P=-139 mm

SSKN5-LF5
P=-219 mm

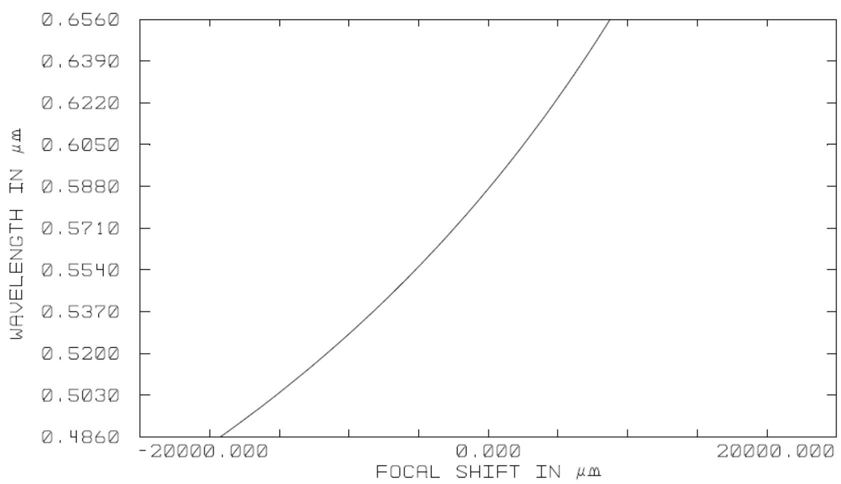
V-number for flint increases
V-number for crown decreases

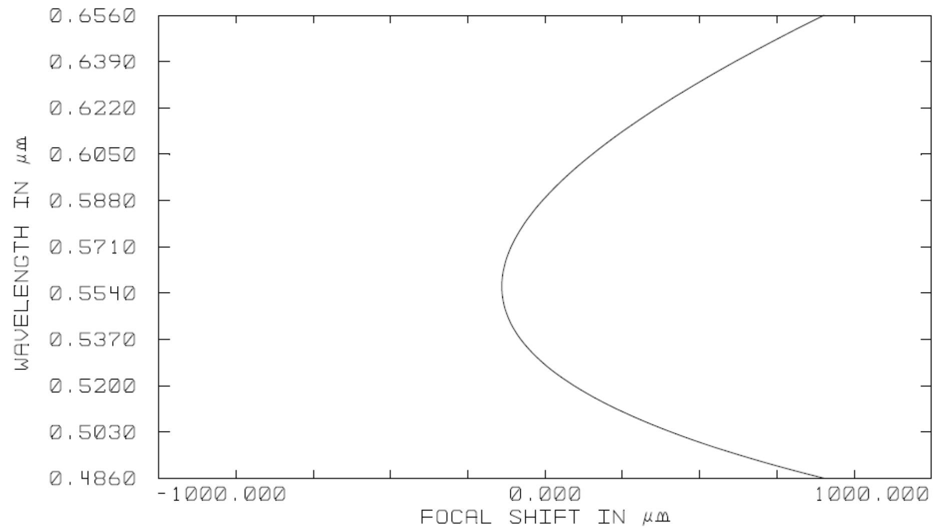
N for crown increases
N for flint decreases

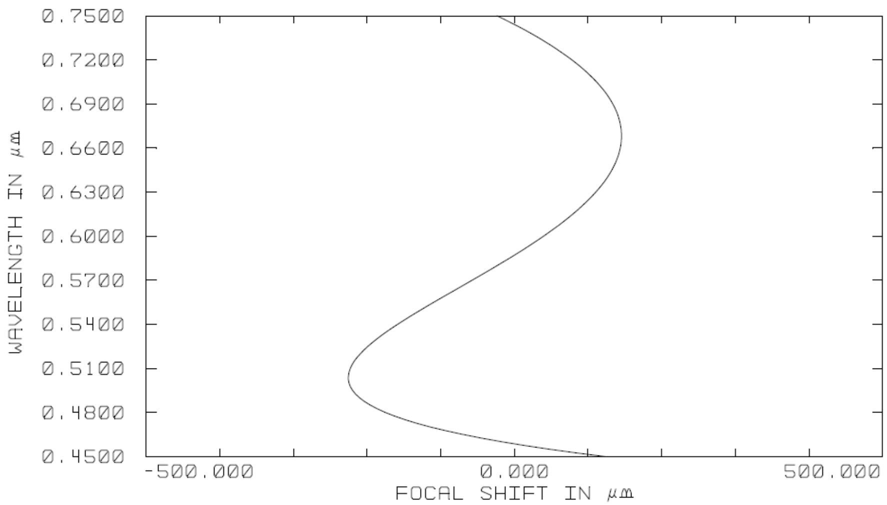
$$f_a \cdot \nu_a = f_b \cdot \nu_b = F \cdot (\nu_a - \nu_b)$$

F=100 mm

Chromatic performance







F=~1500 mm

~f/V or ~f/60 Primary spectrum
~f/1500 Secondary spectrum
~f//7500 Tertiary spectrum

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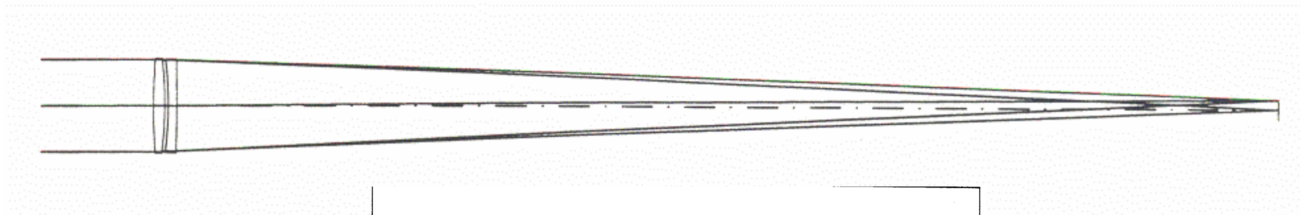
Achromatic doublet

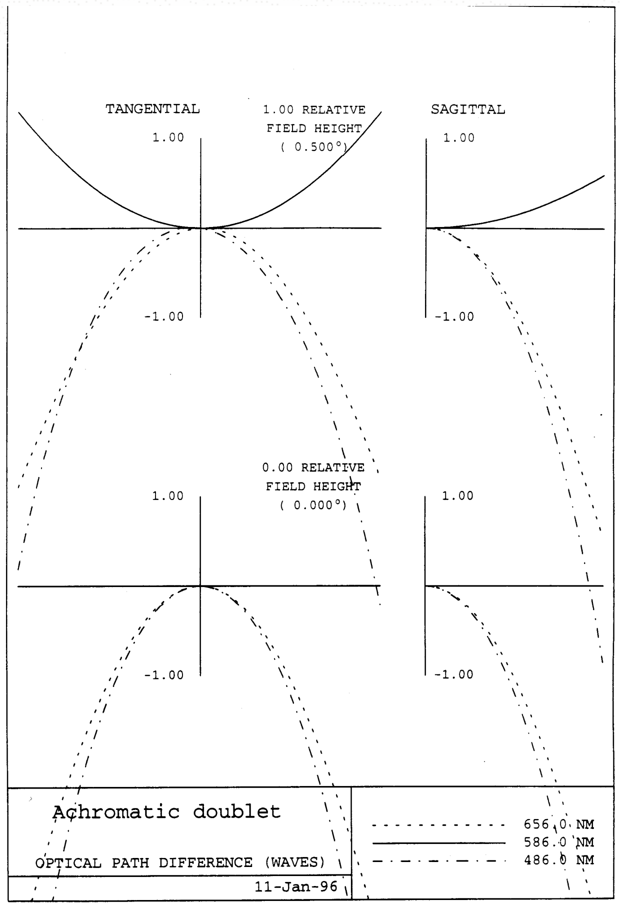


20 inch diameter

F/12

BK7

F4



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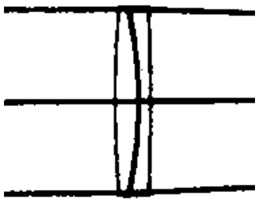
Apochromatic doublet

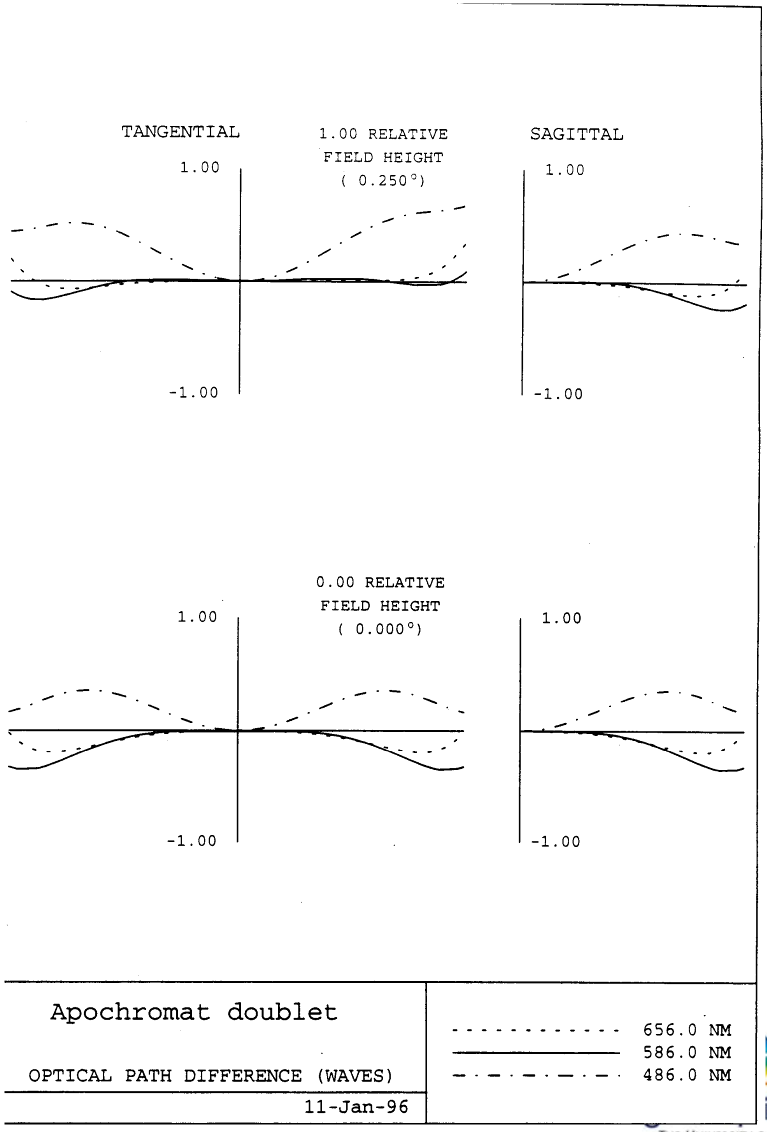


20 inch diameter

F/12

FPL53

F4



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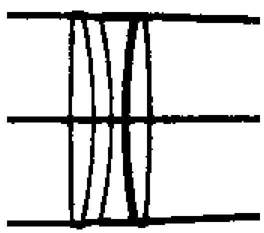
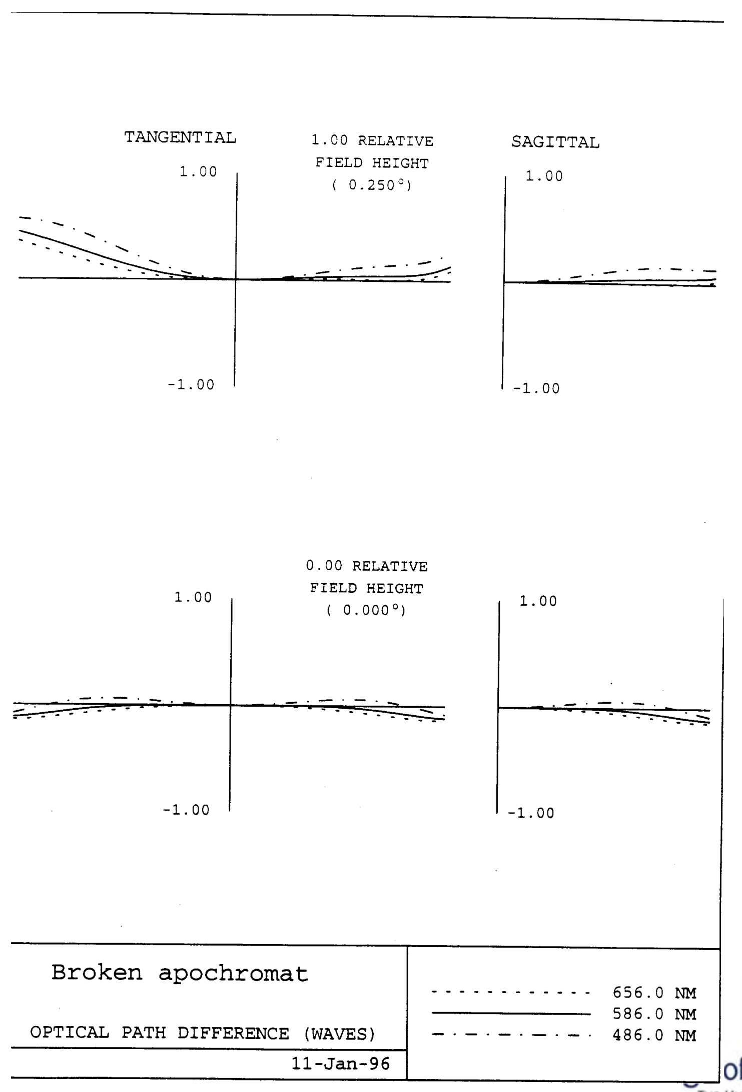
Broken apochromat





20 inch diameer

F/12

BK7

KzFS1

TIf2

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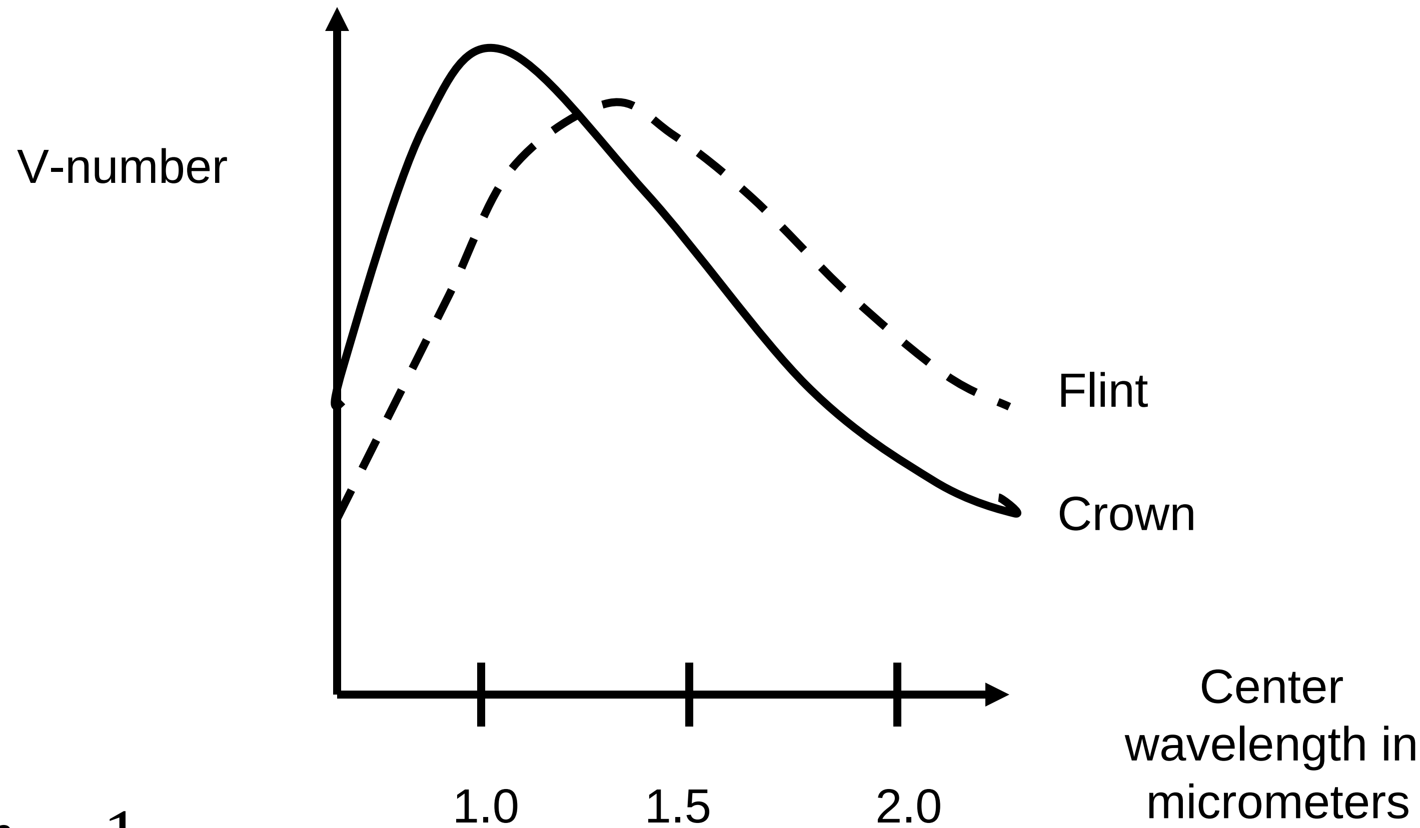
Abbe number vs wavelength



$$\nu = \frac{n_d - 1}{n_F - n_C}$$

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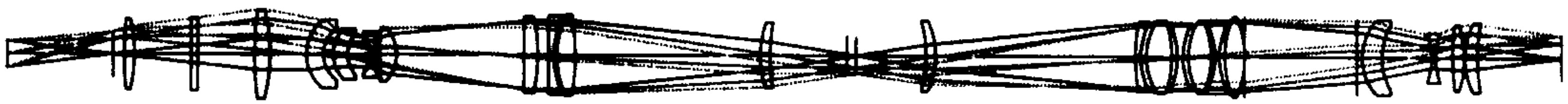
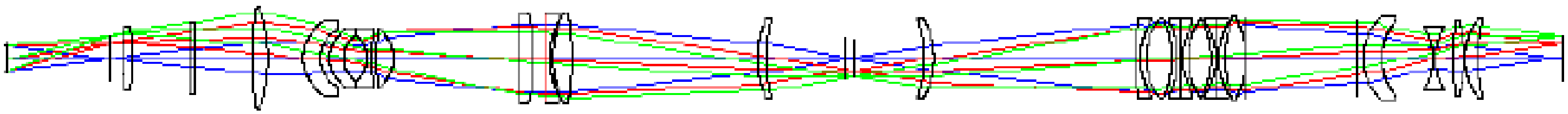
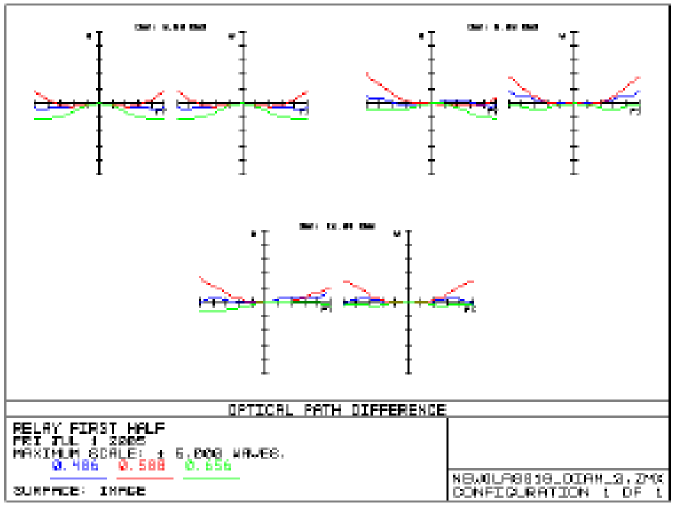
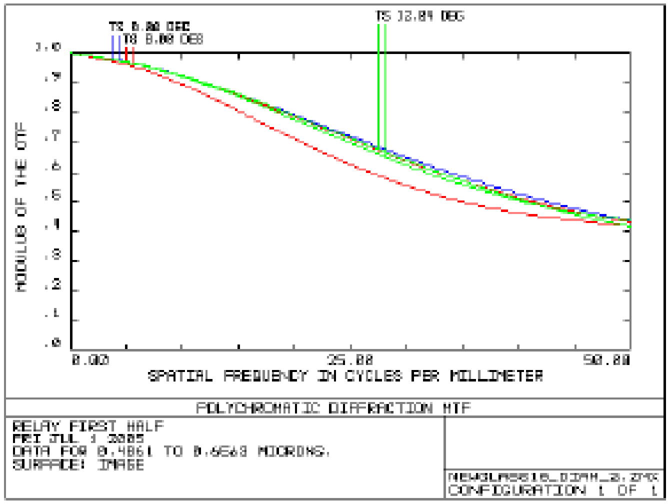
Example of double relay system



Relays for photography



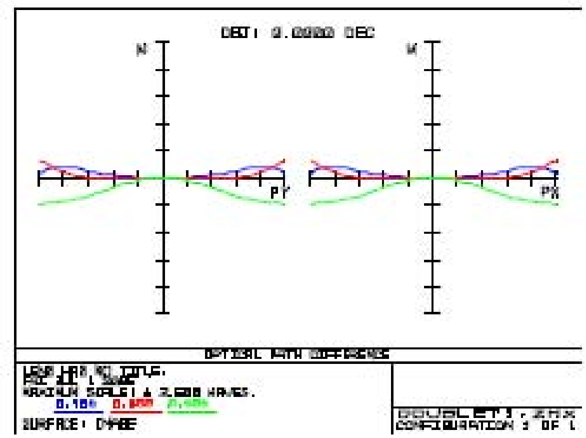




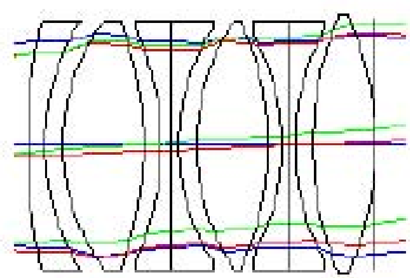
Chromatic correction

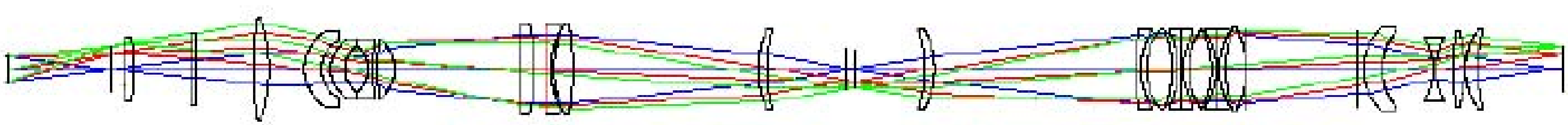
f/4, f=100 mm

BK7 & F2



KZFS1
TIF6
PSK53A
FPL53





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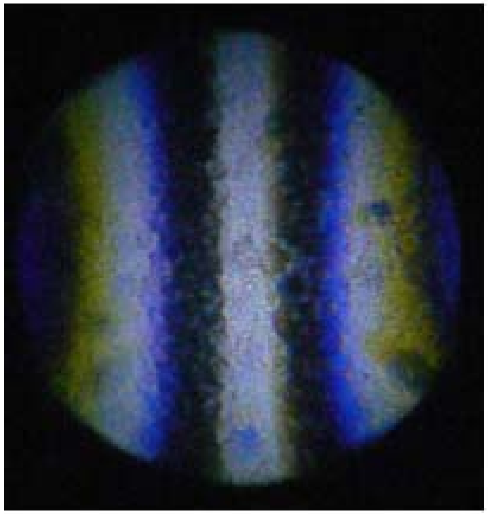
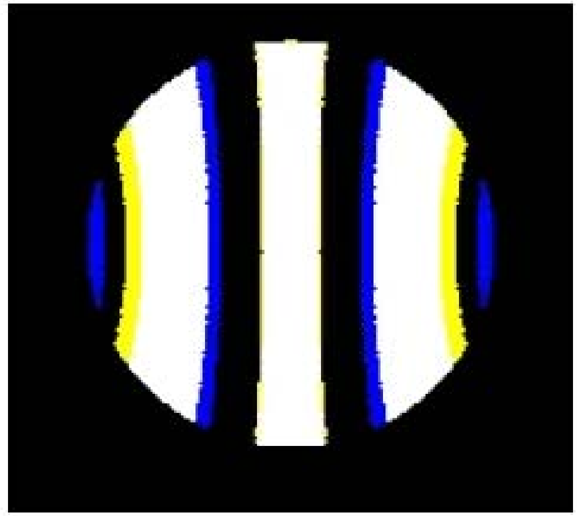
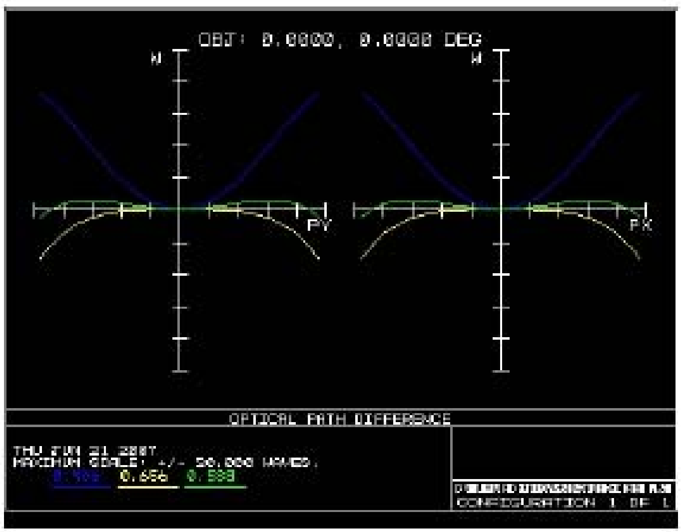
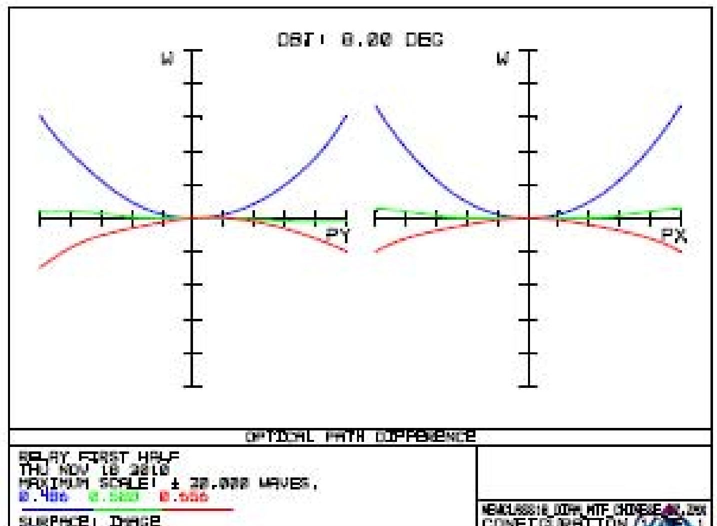
Actual system









From Ronchigram simulation

From changing the Abbe number by 3

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Summary

- Glass properties
- Secondary spectrum
- Single glass achromats
- Phantom stop position
- Buried surface
- New achromat
- Apochromats