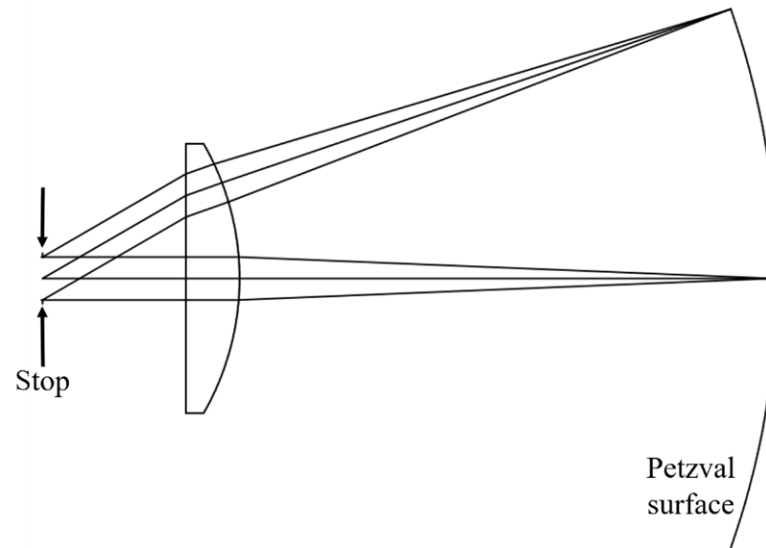


# Combinations of achromatic doublets

Introduction to aberrations

OPTI 518

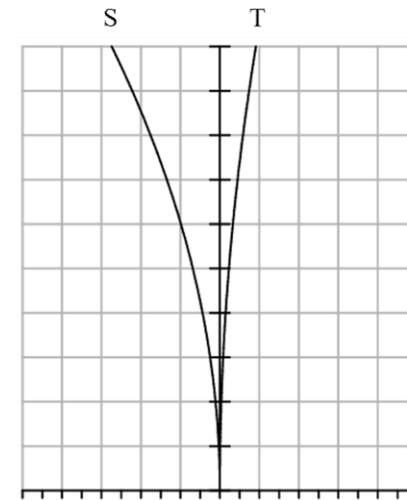
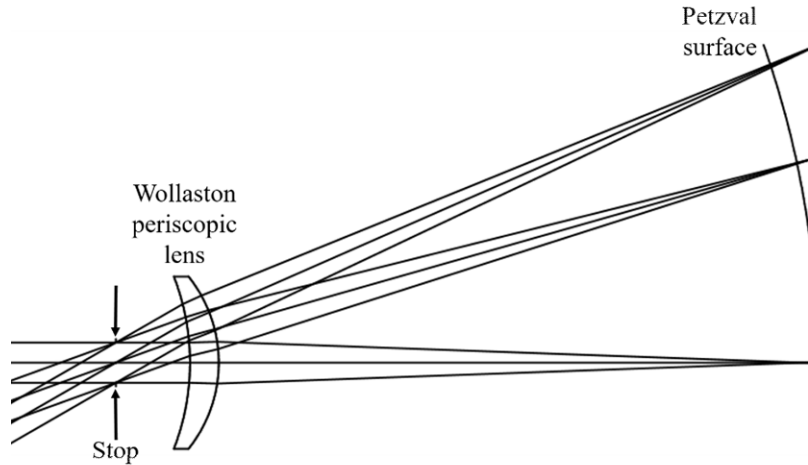
# Plano convex lens



N-BK7 : Petzval radius -151.7 mm

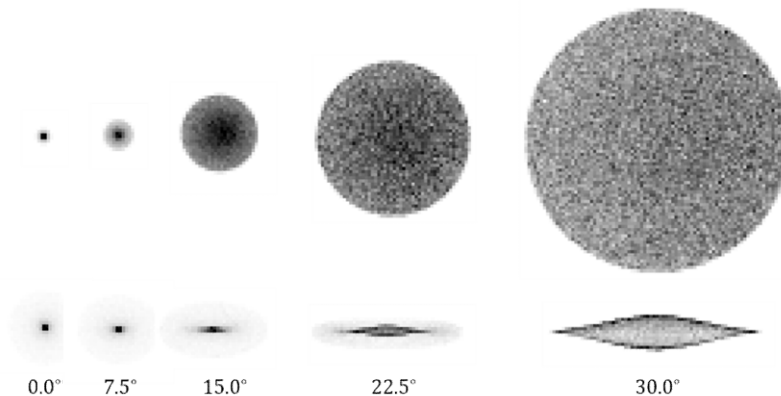
$$C_{Petzval} = \frac{1}{\rho_{Petzval}} = -\phi \cdot \sigma_{IV} = -\left(\frac{\phi}{n}\right)$$

# Wollaston meniscus lens

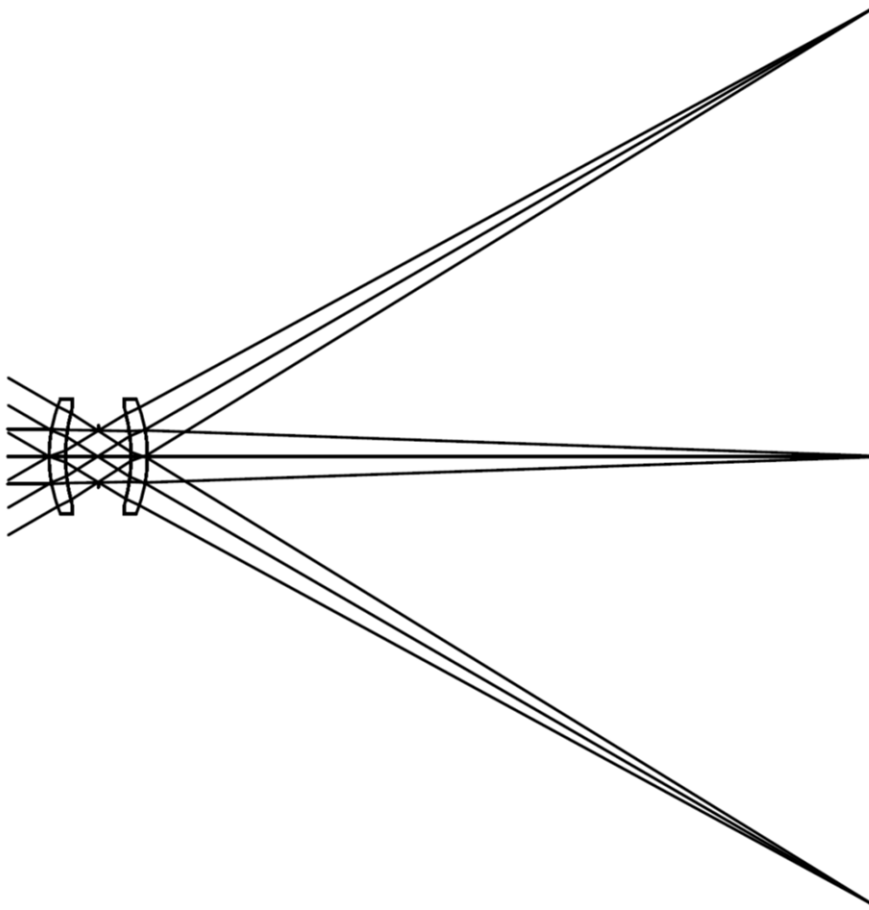


$$W_{222} / W_{220P} = -0.8$$

- Artificially flattening the field
- Periscopic lenses

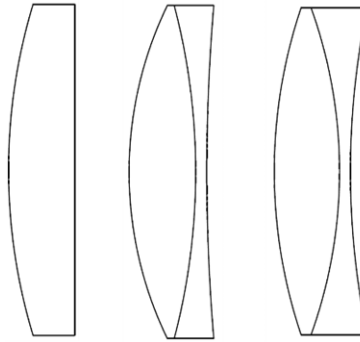


# Periskop lens



- Principle of symmetry
- No distortion

# Field curvature



- Old achromat
- New achromat

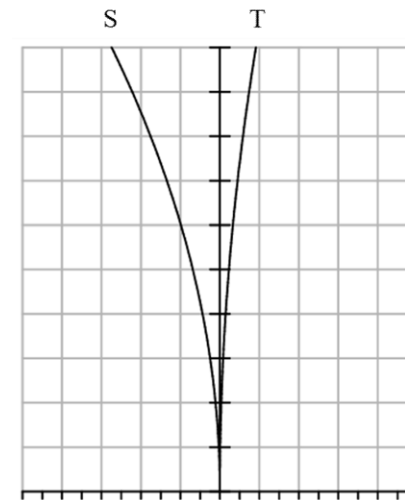
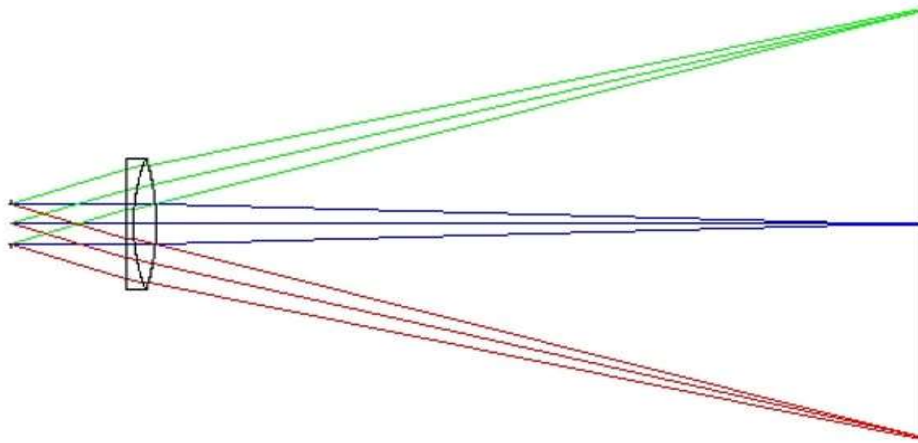
N-BK7 : Petzval radius -151.7 mm

N-BK7 and N-F2: Petzval radius -139.99 mm (+139.99 for negative doublet)

N-BAK1 and N-LLF6: Petzval radius -185 mm

$$C_{\text{Petzval}} = \frac{1}{\rho_{\text{Petzval}}} = -\phi \cdot \sigma_{IV} = -\left( \frac{\phi_1}{n_1} + \frac{\phi_2}{n_2} \right) = -\frac{\phi}{v_1 - v_2} \left( \frac{v_1}{n_1} - \frac{v_2}{n_2} \right)$$

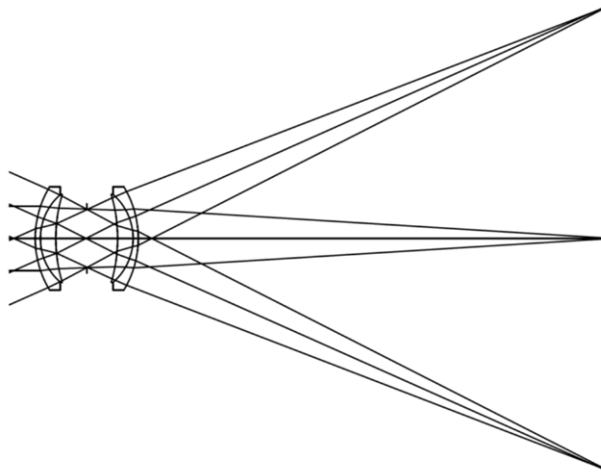
# Chevalier landscape lens



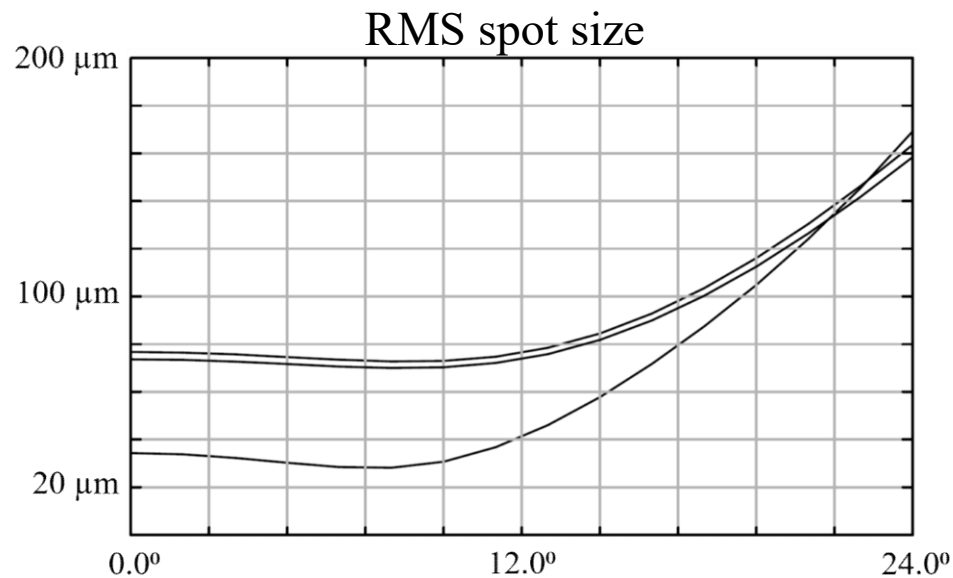
$$W_{222} / W_{220P} = -0.8$$

- F/5 telescope doublet used in reverse and with an aperture stop in front

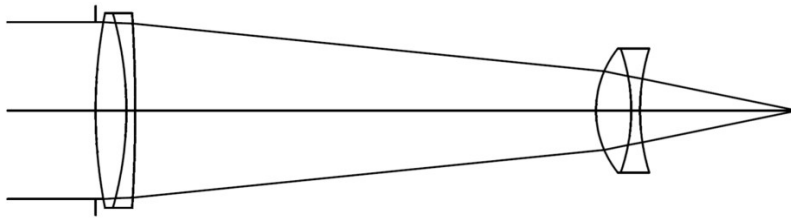
# Rapid rectilinear



- F/8
- Glass selection is key to minimize spherical aberration while artificially flattening the field



# Lister microscope objective



- Telecentric

$$\sigma_{IA} = \sigma_{IB} = 0$$

$$y_B = 1/2$$

$$\sigma_{II} = \phi_A^2 y_A^2 \sigma_{IIA} + \phi_B^2 y_B^2 \sigma_{IIB}$$

$$\sigma_{IIA} = -\sigma_{IIB}$$

$$\sigma_{IIA} = -\frac{y_B^2}{(1 - y_B)^2} \sigma_{IIB}$$

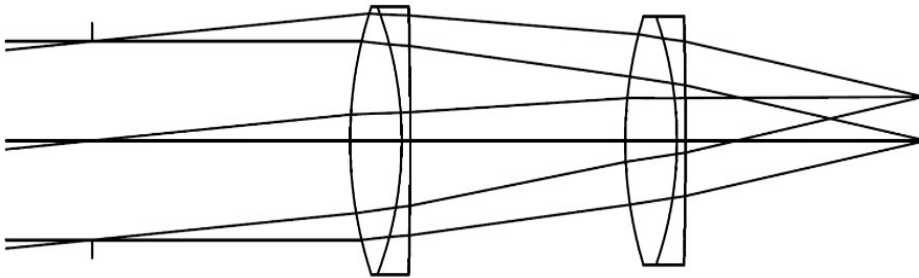
$$\sigma_{III} = (1 - y_B) + (1 + y_B \sigma_{IIB}) = 0$$

$$S_{III}^* = S_{III} + 2 \cdot \bar{S} S_{II} + \bar{S}^2 S_I$$

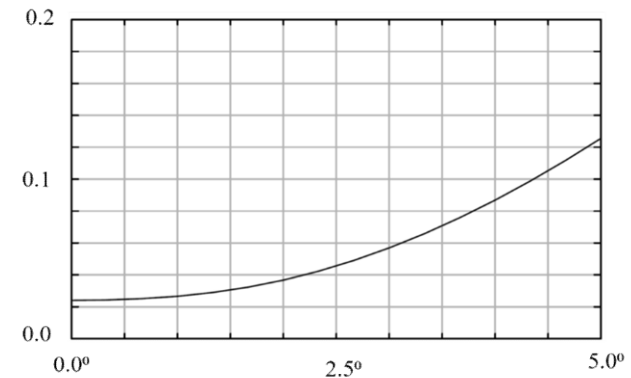


# Lister microscope objective

Practical solution

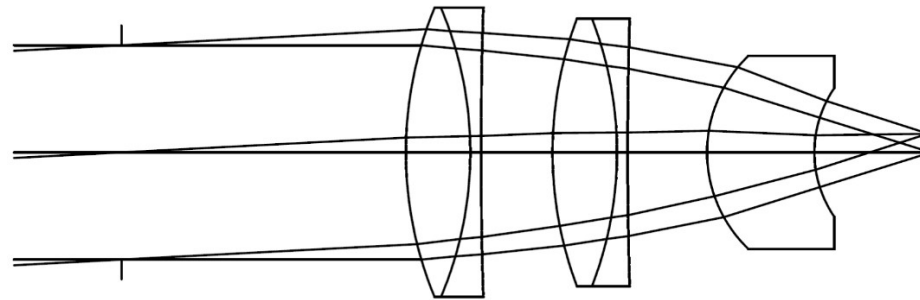


- RMS spot size in waves



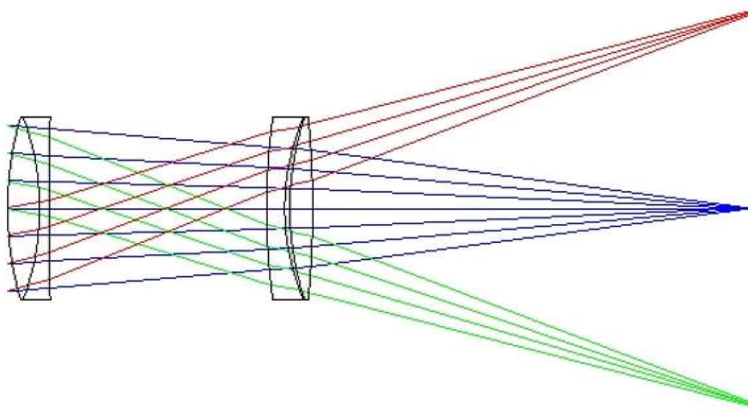
- Two identical doublets
- Spherical aberration and coma are corrected
- Astigmatism is small
- Telecentric
- Less vignetting

# Aplanatic concentric meniscus lens

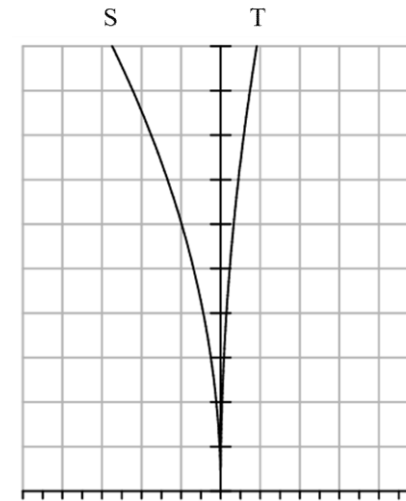


- Optical speed is increased by an  $N$  factor

# Petzval portrait objective



$f' = 144 \text{ mm}$ ;  $F/3.7$ ;  $\text{FOV} = \pm 16.5^\circ$ .



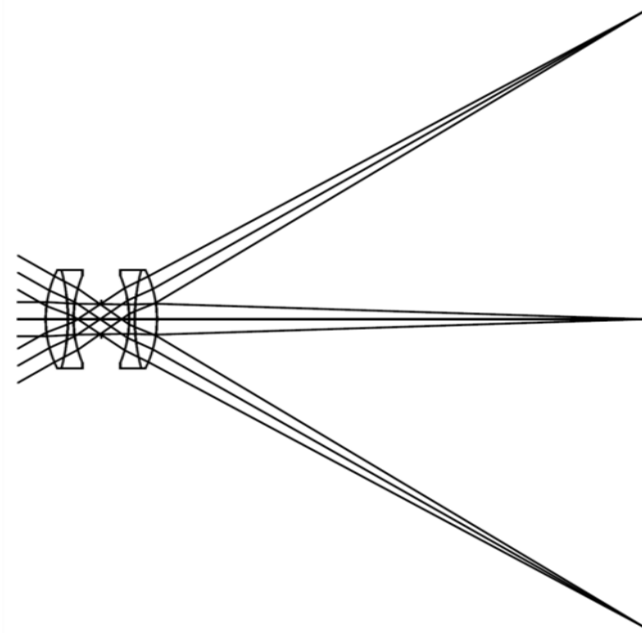
$$W_{222} / W_{220P} = -0.8$$

- Chromatic aberration and spherical aberration corrected at each doublet
- Positive coma in the first doublet corrected with negative coma of aberration of the second doublet
- Negative astigmatism introduced by the negative coma of the second doublet to artificially flatten the field of view.

$$S_{III}^* = S_{III} + 2 \cdot \bar{S} S_{II} + \bar{S}^2 S_I$$

# Concentric lens

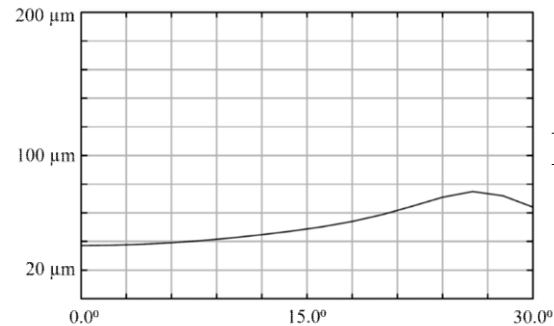
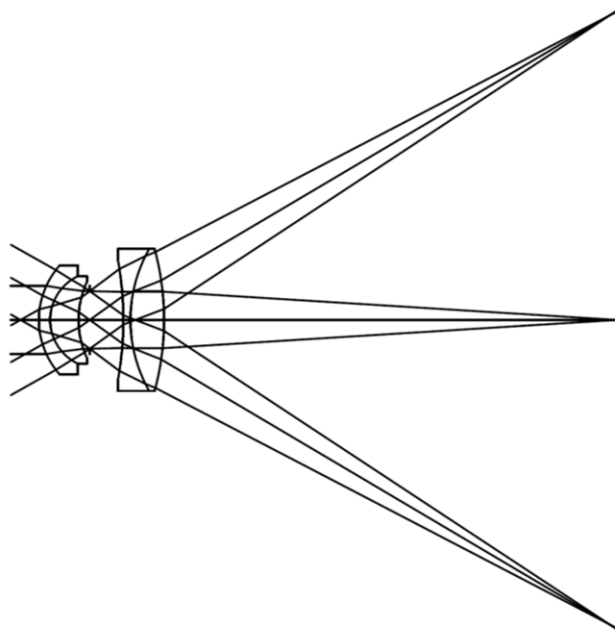
- Use of new glasses
- Reduced Petzval sum
- Nearly flat field
- Surfaces nearly concentric
- Limited by spherical aberration due to strong curvatures.



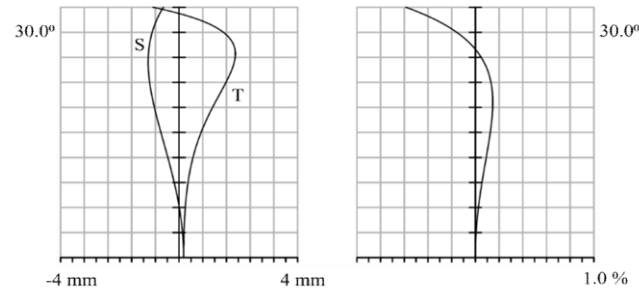
N-BAK1 and N-LLF6: Petzval radius -185 mm

$$C_{Petzval} = \frac{1}{\rho_{Petzval}} = -\phi \cdot \sigma_{IV} = -\left( \frac{\phi_1}{n_1} + \frac{\phi_2}{n_2} \right) = -\frac{\phi}{v_1 - v_2} \left( \frac{v_1}{n_1} - \frac{v_2}{n_2} \right)$$

# Anastigmatic lens

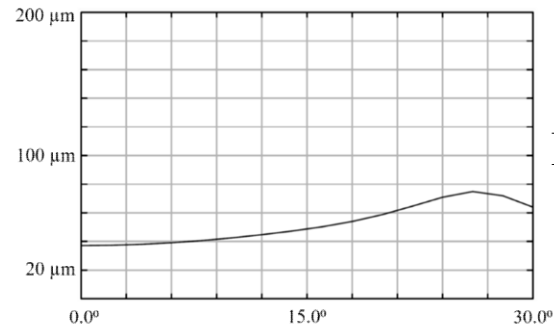
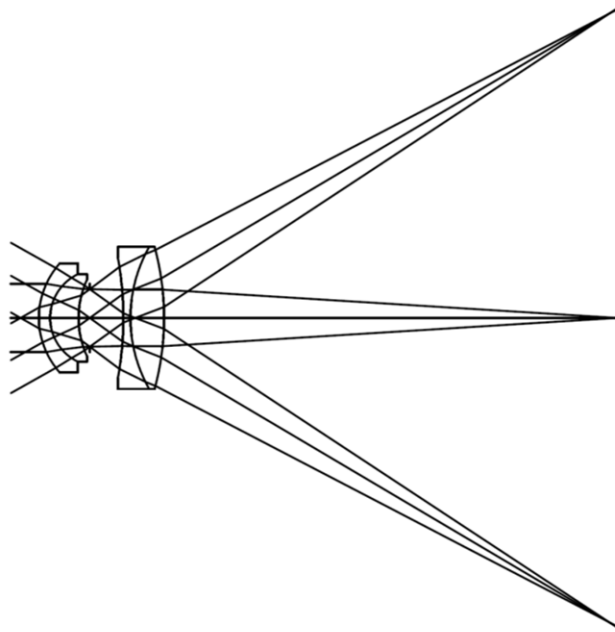


RMS spot size

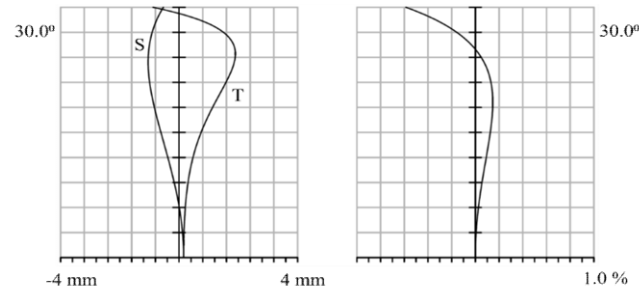


- Corrected for spherical aberration, coma, astigmatism, and field curvature
- Distortion is negligible
- Combination of an old achromat and a new achromat

# Anastigmatic lens



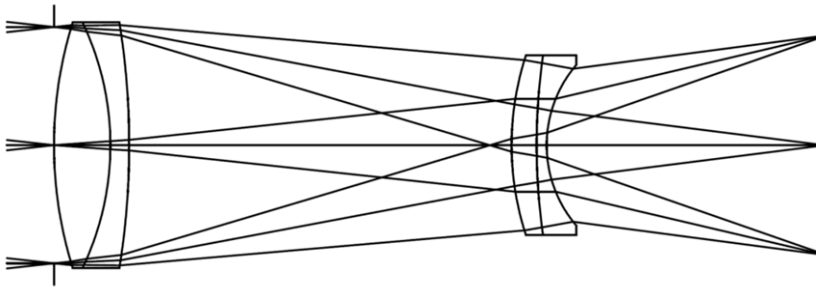
RMS spot size



- Corrected for spherical aberration, coma, astigmatism, and field curvature
- Distortion is negligible
- Combination of an old achromat and a new achromat

# Telephoto lens

Telephoto lens with BK7 and SF5 glasses.  
 $f'=100$  mm, F/4, FOV= $\pm 6.2^\circ$ , TTL/F=0.8.



$$S_{III}^* = S_{III} + 2 \cdot \bar{S} S_{II} + \bar{S}^2 S_I$$

$$S_{III}^* = S_{III} = \mathcal{K}^2 \phi_B \sigma_{III B} = \mathcal{K}^2 \phi_B$$

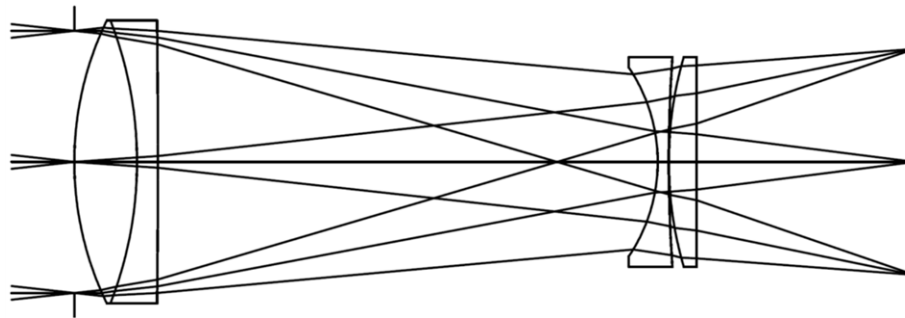
$$\phi_A = -\phi_B$$

$$\bar{W}_{131} = W_{311} + \frac{1}{2} \mathcal{K} \cdot \Delta \left\{ u^{-2} \right\}$$

- Corrected for spherical aberration, coma, astigmatism, and field curvature
- Distortion is not corrected
- Telephoto ratio=TTL/f

# Telephoto lens

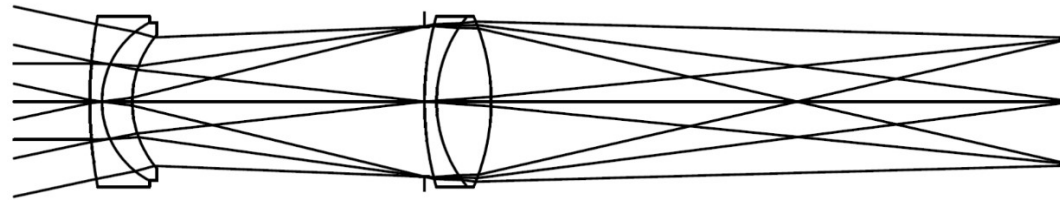
Telephoto lens with BK7 and F6 glasses.  
 $f' = 100$  mm,  $F/4$ ,  $\text{FOV} = \pm 6.2^\circ$ ,  $\text{TTL}/F = 0.8$



- Corrected for spherical aberration, coma, astigmatism, and field curvature
- Distortion is also corrected



# Reverse telephoto lens



Reverse telephoto lens with BK7 and SF5 glasses.  $f' = 100$  mm, BFL = 200 mm, TTL = 324 mm, FOV =  $\pm 12^\circ$ , F/4

- Corrected for spherical aberration, coma, astigmatism, and field curvature
- Distortion is small  $\sim -1.5\%$
- Large back focal length/distance