Zoomsysteme

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29.06.2008

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Basic Principle

- Two thin lenses in a certain distance t:

  $$f = \frac{f_1 f_2}{f_1 + f_2 - t}$$

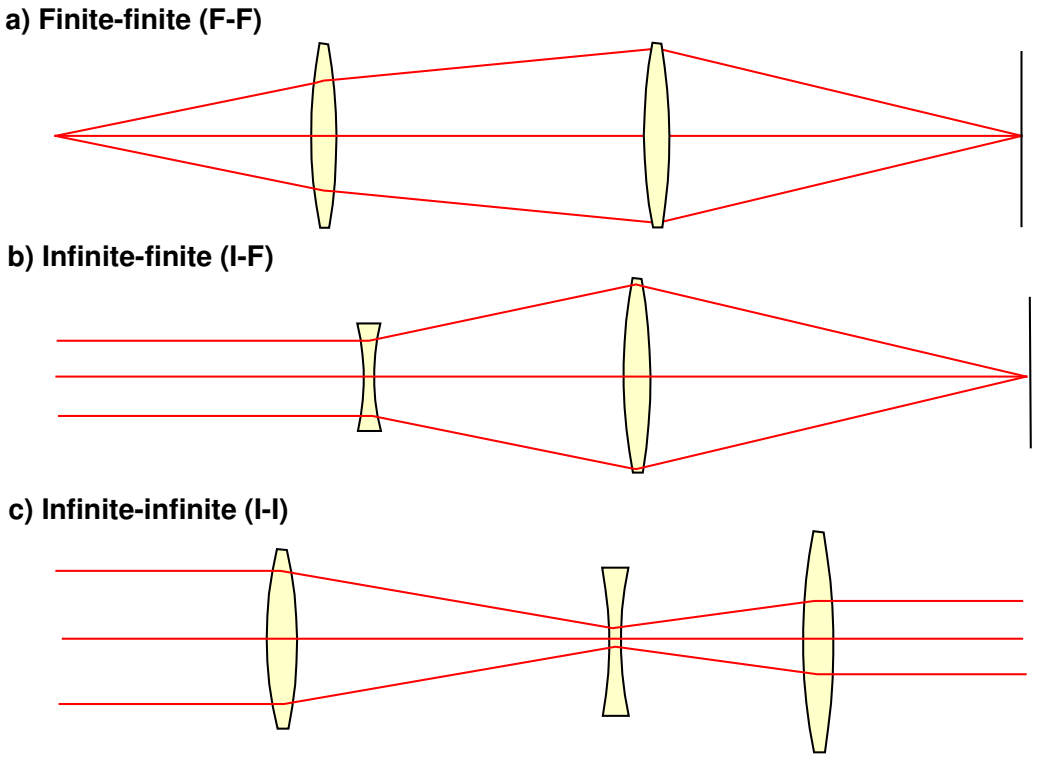
  Focal length

  Refractive power $\Phi = \Phi_1 + \Phi_2 - t \cdot \Phi_1 \Phi_2$

  $$\Phi = \Phi_1 + \omega_2 \Phi_2$$

  $$\omega_2 = \frac{h_2}{h_1}$$

- Kinds of zoom systems



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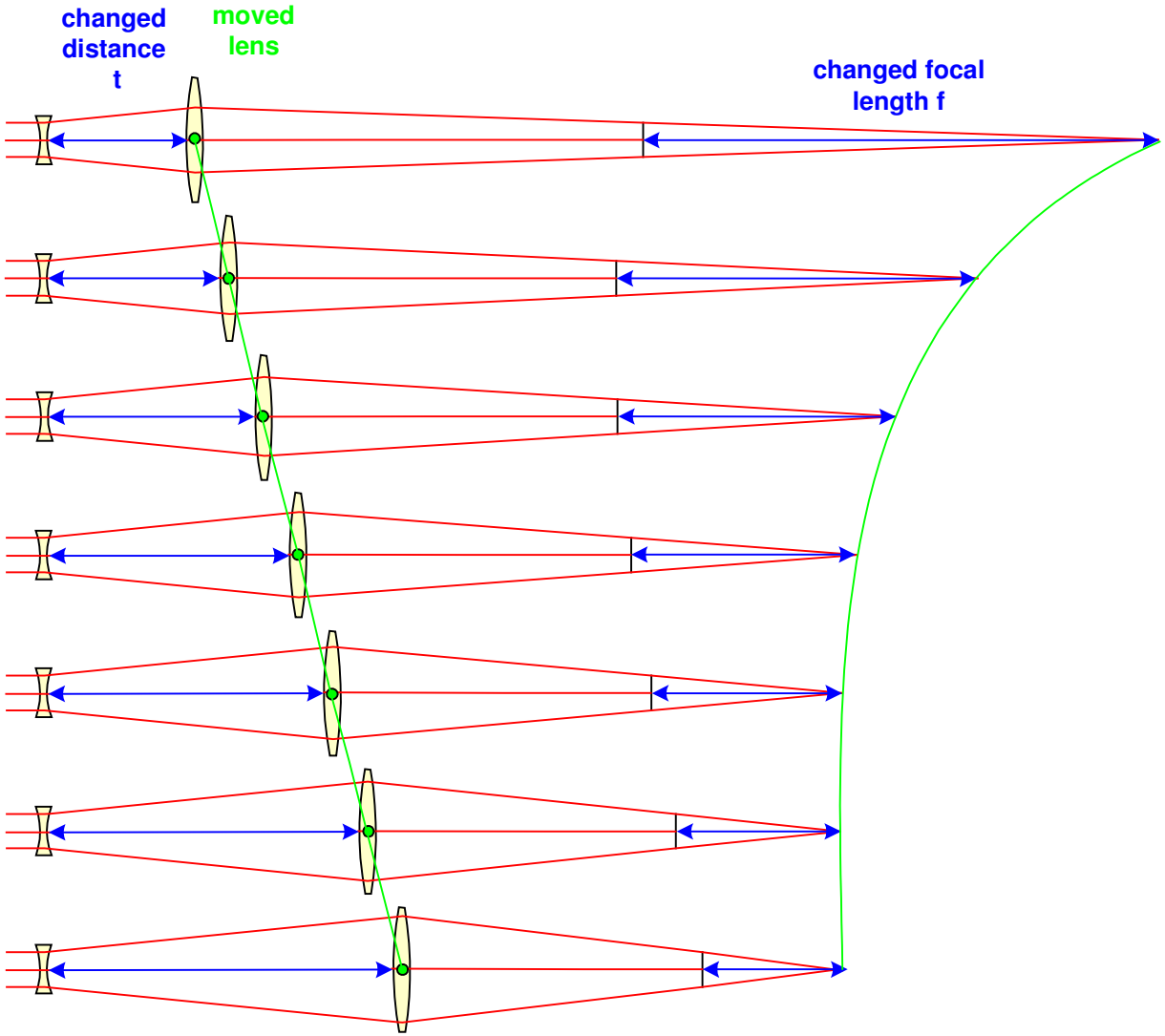
Change of Focal Length

- Distance t increases
- First lens fixed



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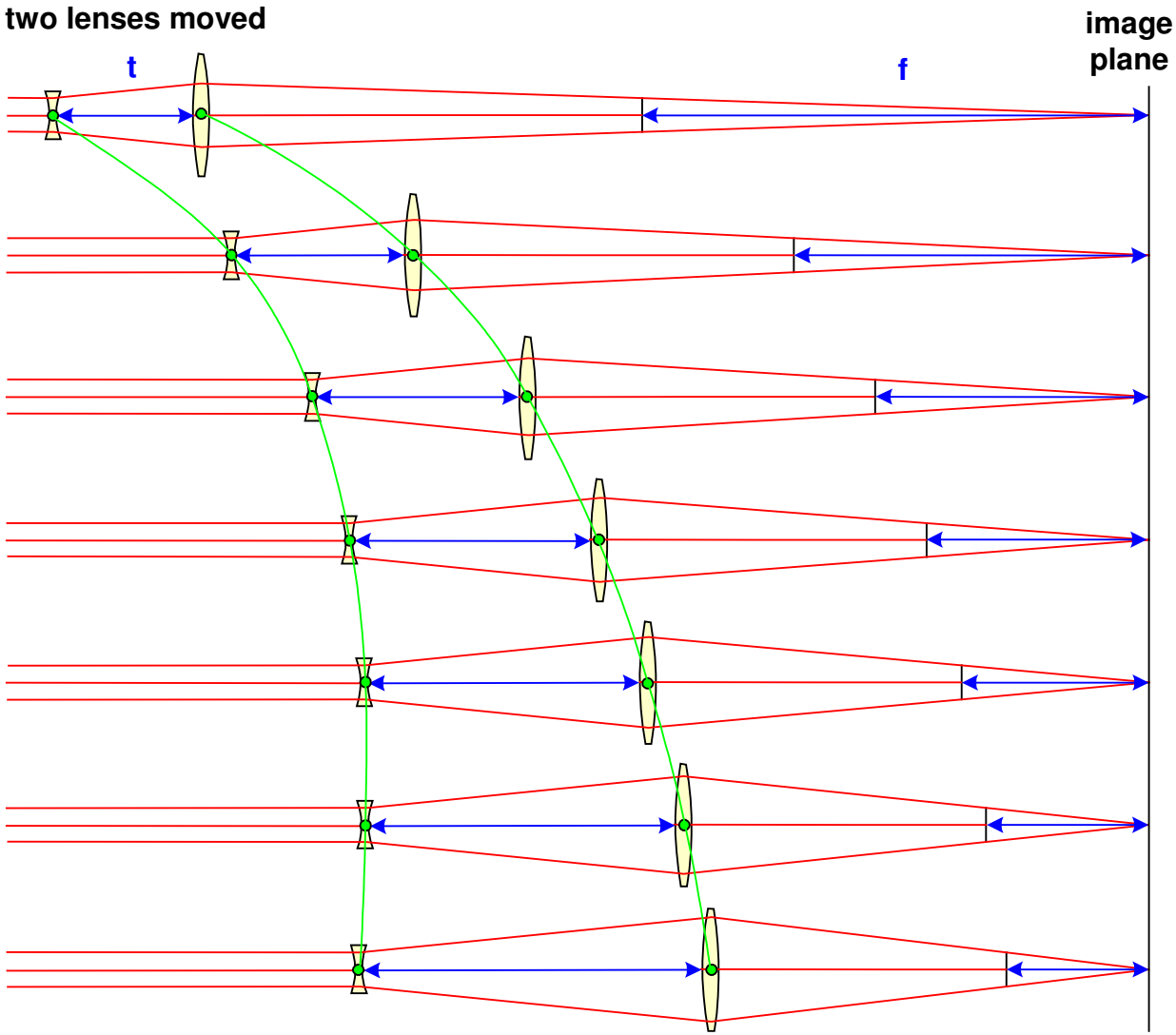
Change of Focal Length

- Distance t increases
- Image plane fixed



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Principle of Smallest Change

- Zoom factor : ratio of magnification change

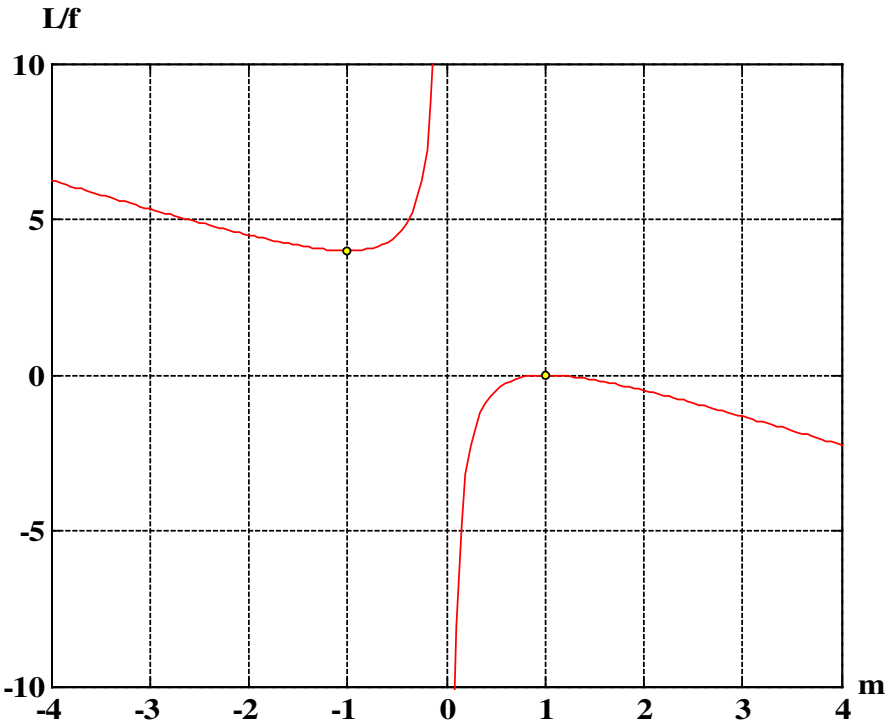
$$M = \frac{m_{max}}{m_{min}} \qquad M = \frac{\Gamma_{max}}{\Gamma_{min}}$$

- Equivalent : ration of focal lengths

$$M = \frac{f_{max}}{f_{min}}$$

- Zoom system :
  - change of magnification
  - constant length

$$L = f \cdot \left(2 - m - \frac{1}{m}\right)$$



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Principle of Smallest Change

- Aim :

  smallest change of length
- Preferred points of operation:

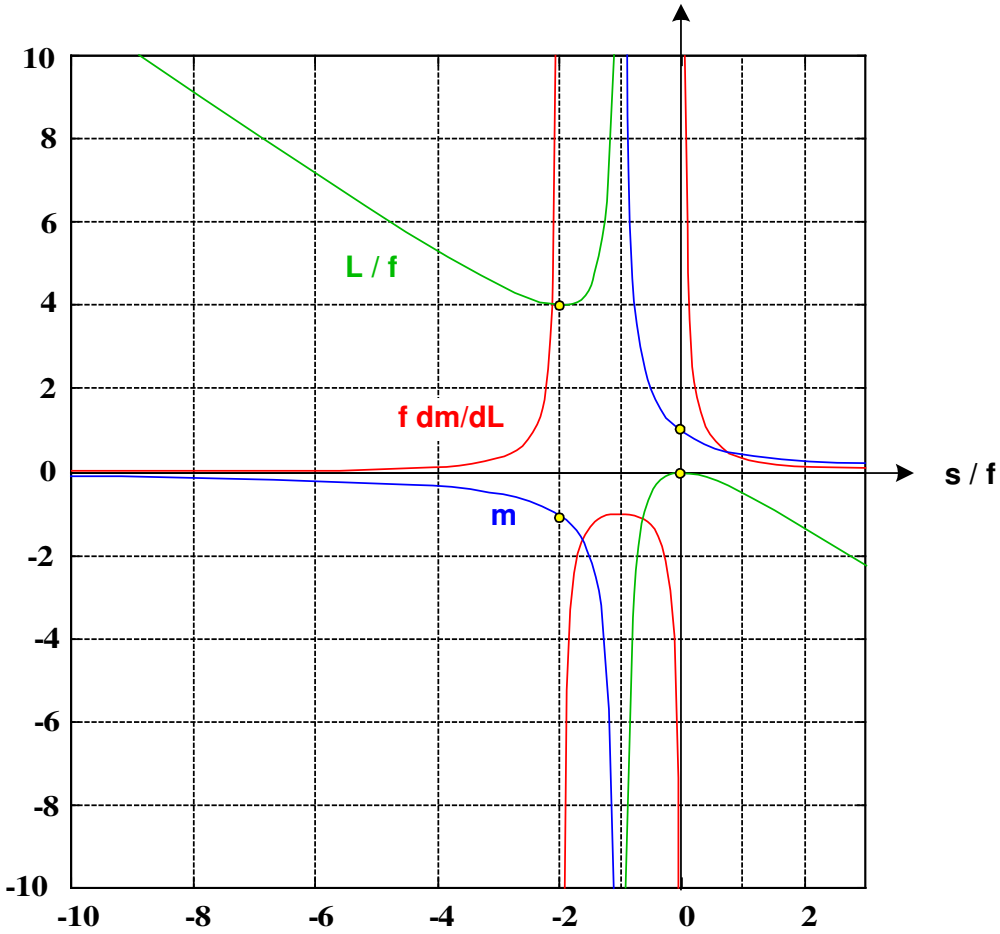
  m = 1 , m = -1
- Setup :

  1. Change of magnification :

     variator group
  2. Correcting the image

     location: compensator group

$$f\frac{dm}{dL} = -\frac{1}{2} + \frac{(s/f)^2 + 2s/f + 2}{2\sqrt{(s/f)^4 + 4(s/f)^2 \cdot (s/f + 1)}}$$



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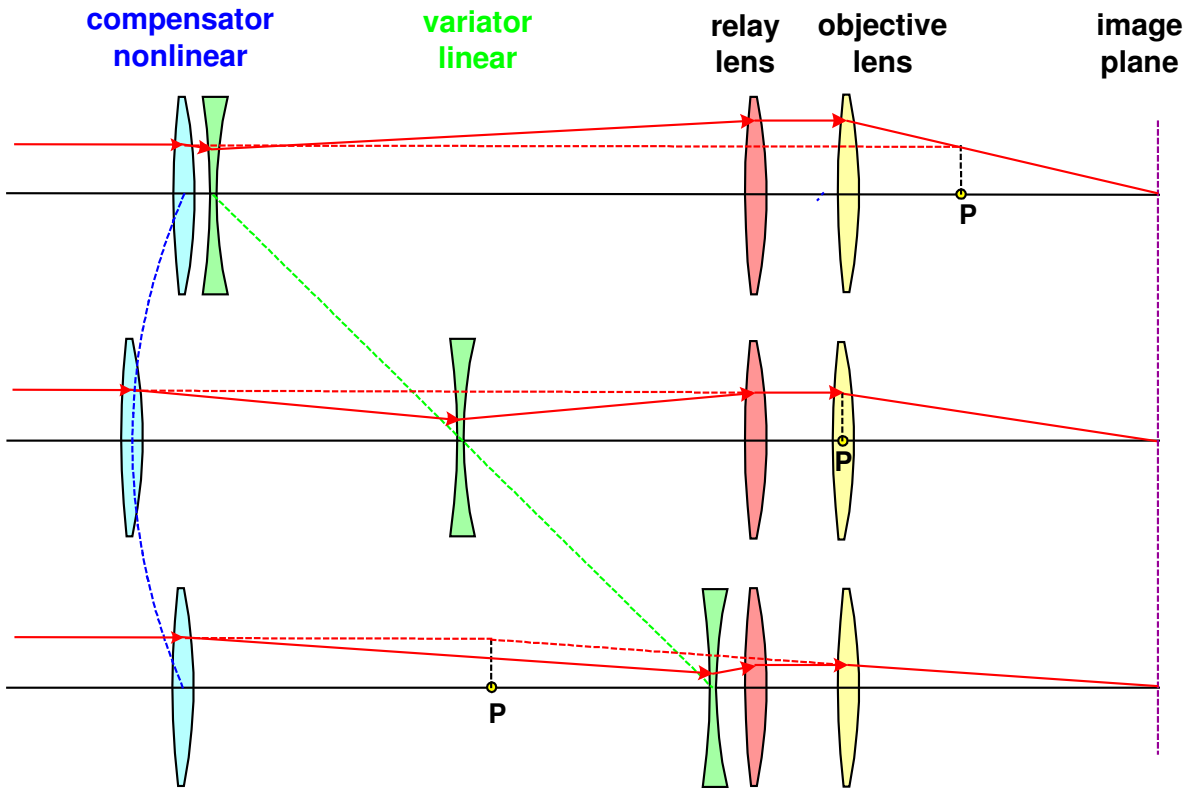
Mechanical Compensated Zoom Systems

- Simple explanation of variator and compensator
- Movement of variator arbitrary
- Compensator movement depends on variator
- Perfect invariance of image plane possible



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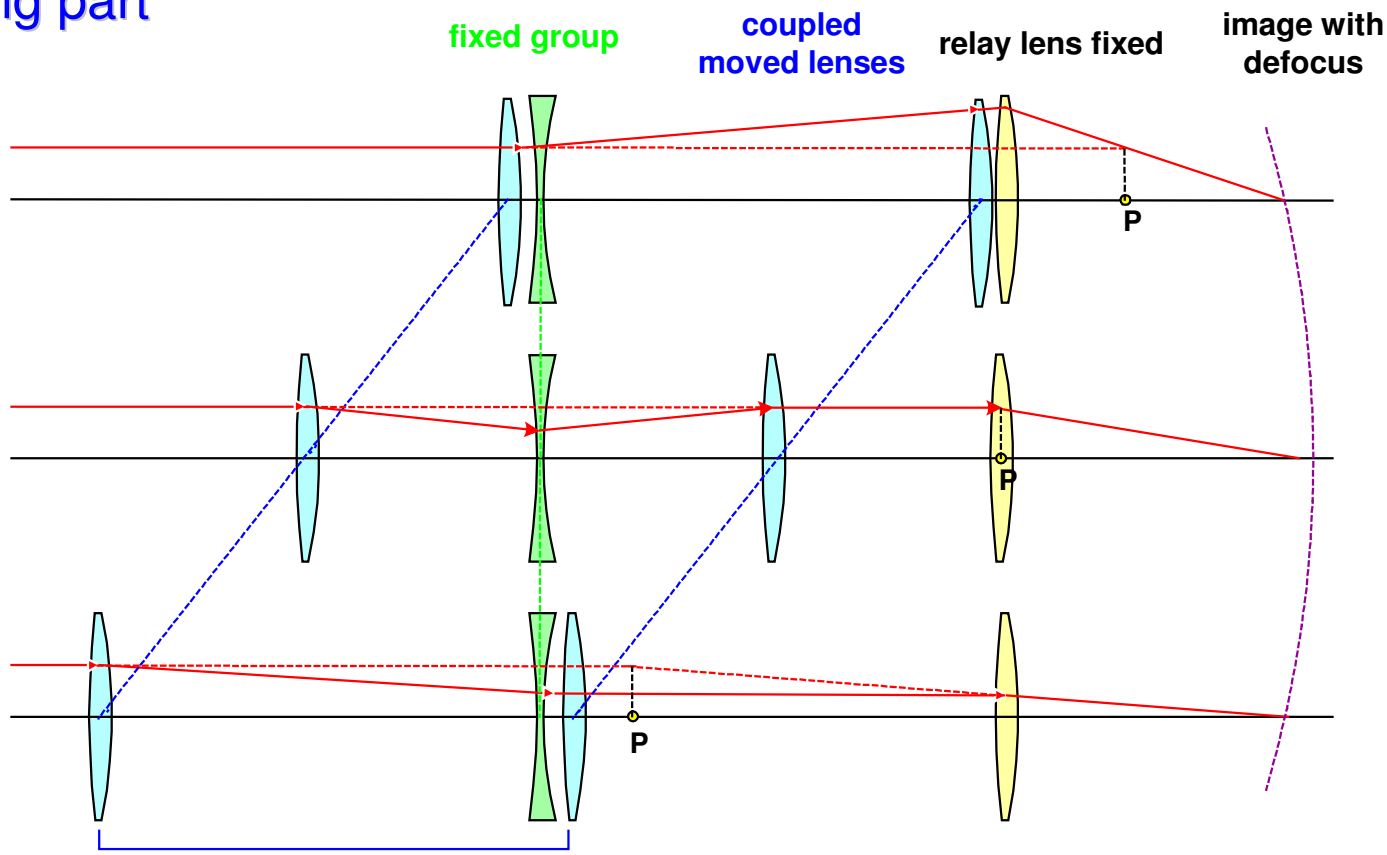
Optical Compensated Zoom Systems

- Combined movement of two rigid coupled lenses
- Image plane location only approximately constant
- Only one moving part



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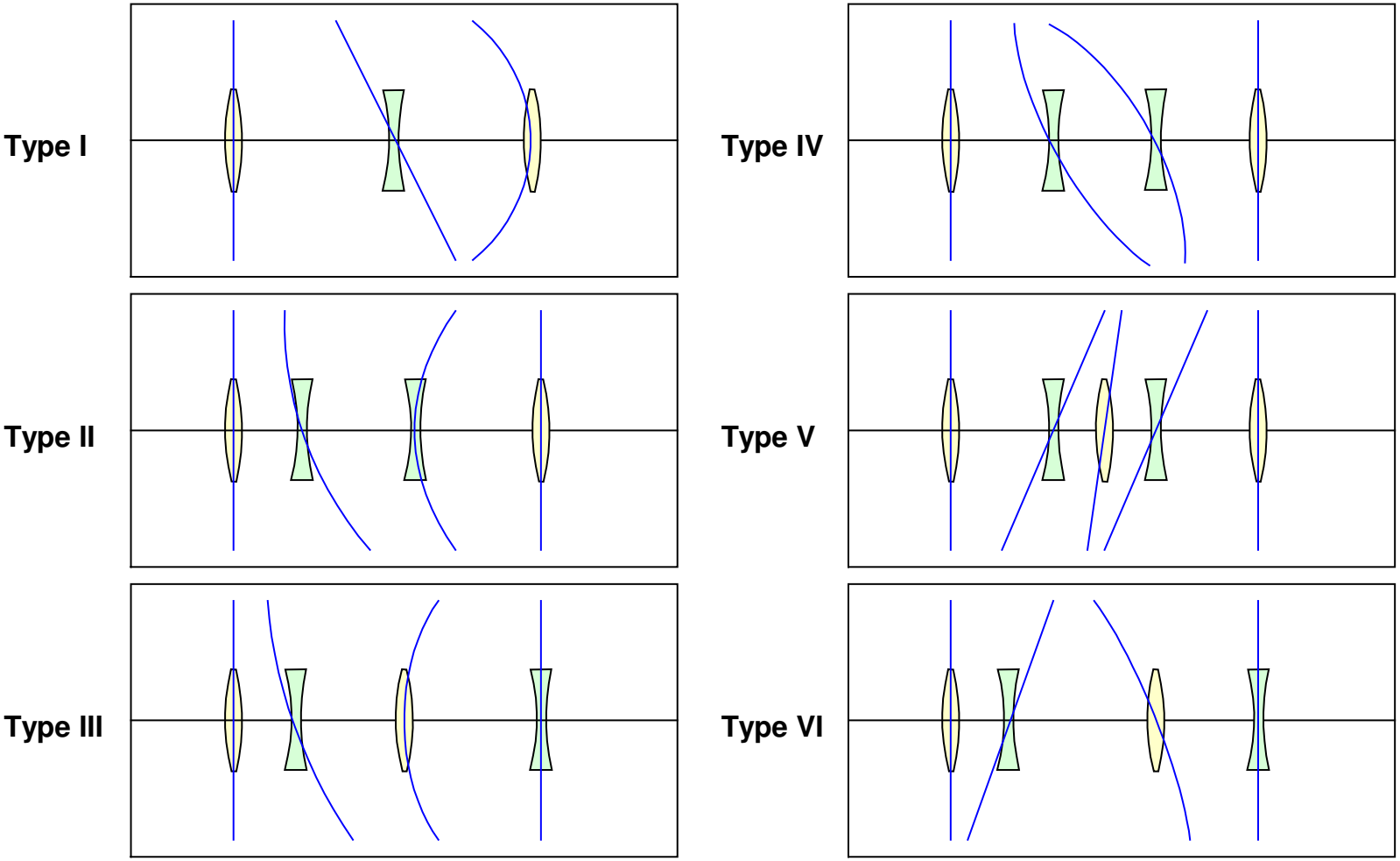
Types of Zoom Setups

- Mechanical compensation : 6 major setups



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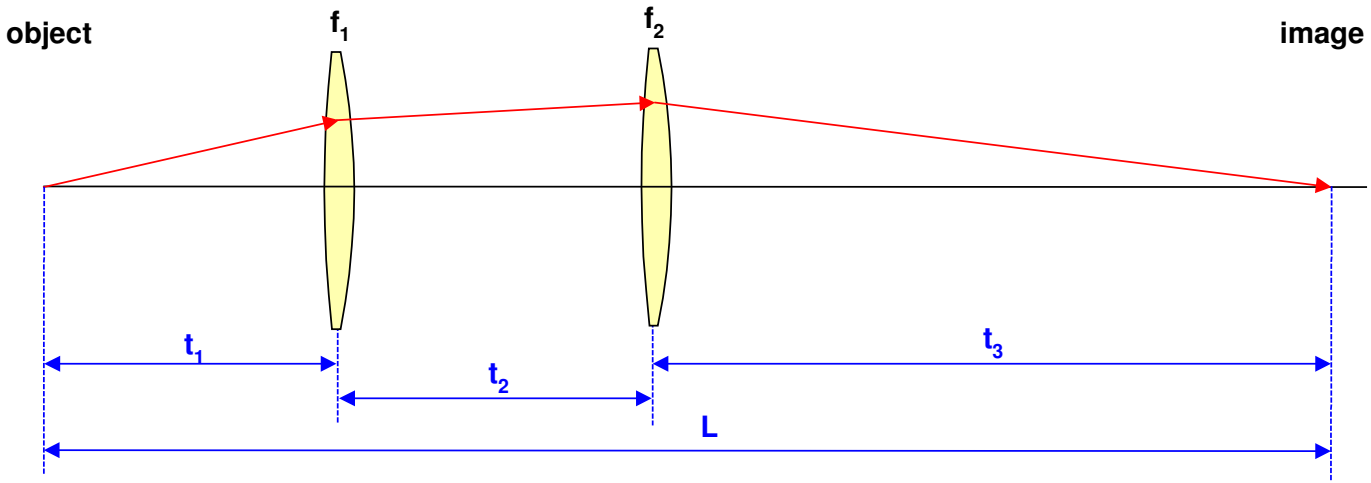
Two-Component F-F System

- Setup :



- Given : L, m, f_1, f_2 :

  Wüllner equations:

$$t_2 = \frac{L}{2} \pm \sqrt{\frac{L^2}{4} - L \cdot (f_1 + f_2) - f_1 \cdot f_2 \cdot \frac{(m-1)^2}{m}}$$

$$t_1 = -\frac{f_1 \cdot f_2 - m \cdot f_1 \cdot (f_2 - t_2)}{m \cdot (f_1 + f_2 - t_2)} \qquad t_3 = L - t_1 - t_2$$

$$f = \frac{f_1 f_2}{f_1 + f_2 - t_2}$$

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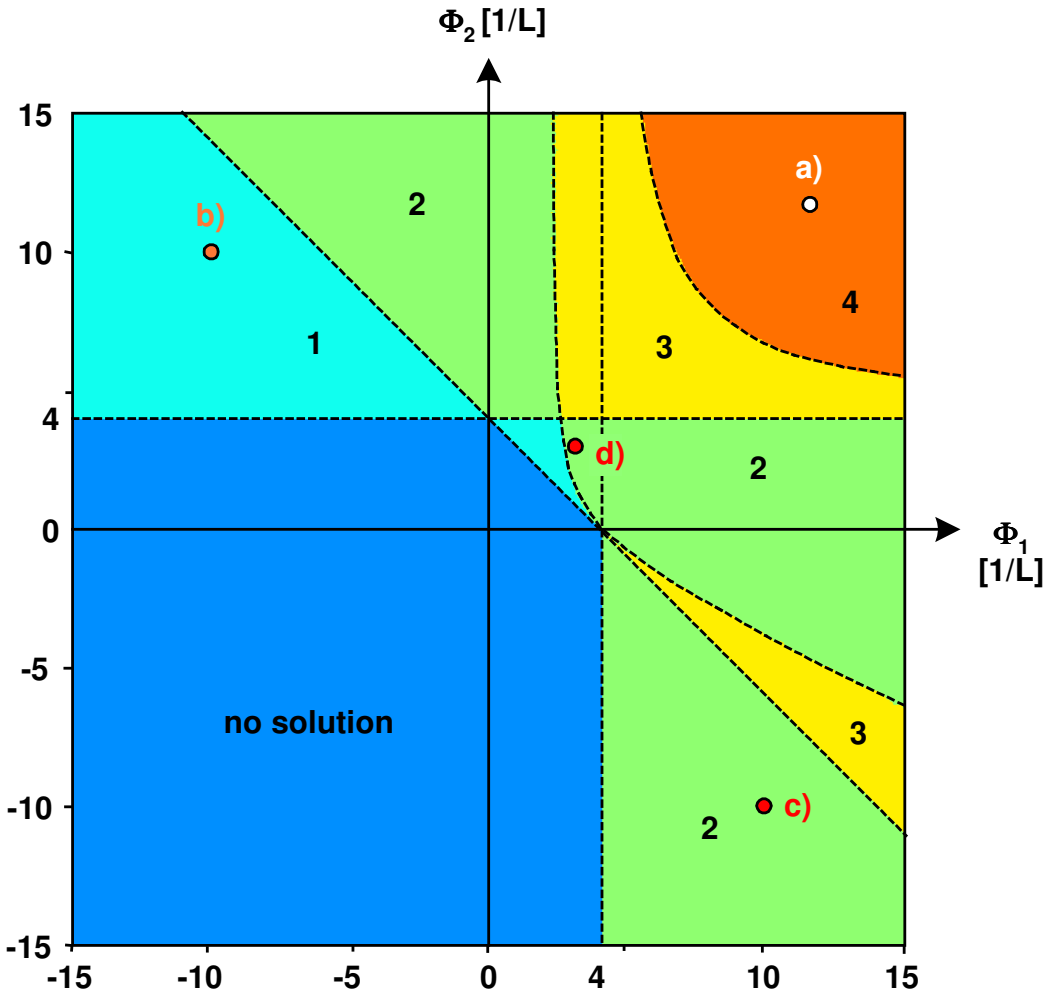
Two-Component F-F System

- Solution space :
  focal lengths:
  1. $f_1 > L/4$
  2. $f_2 > L/4$
  3. $1/f_1 + 1/f_2 < 4/L$
- Calculation with Newton-imaging equation and
  $t_j > 0$
- Ranges with 0 - 1- 2 - 3 - 4
  solutions for focal lengths



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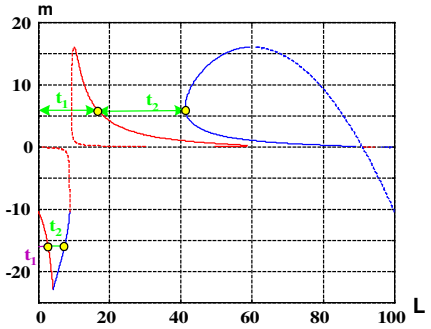
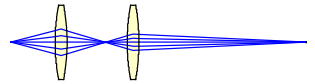
Two-Component F-F System

- Examples:
  1. Number of solutions
  2. Zoom curves
  3. m-ranges

a) $f_1 = L/12$
$f_2 = L/12$

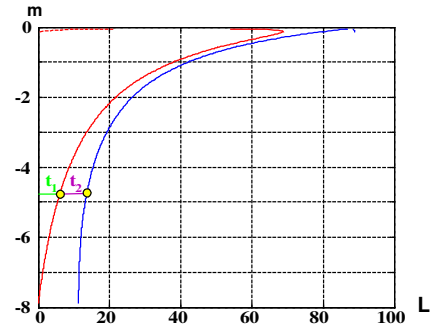


$t_1 = 16.4$, $t_2 = 26.6$, m = +6.0

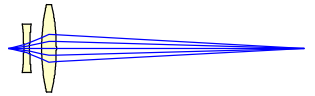


$t_1 = 3.1$, $t_2 = 4.3$, m = -16

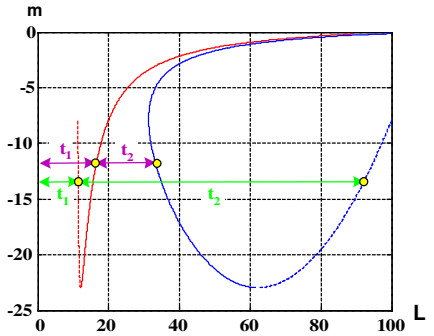
b) $f_1 = -L/10$
$f_2 = L/10$



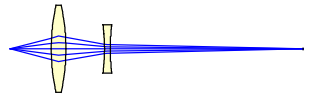
$t_1 = 5.9$, $t_2 = 7.6$, m = -4.8



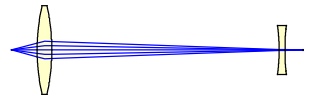
c) $f_1 = L/10$
$f_2 = -L/10$



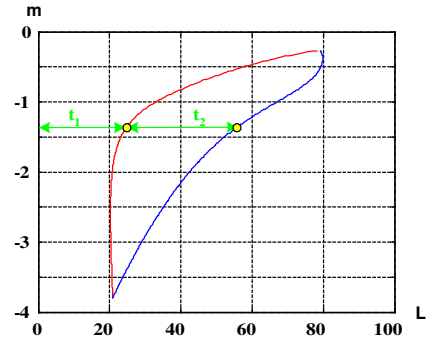
$t_1 = 16.5$, $t_2 = 16.7$, m = -11.8



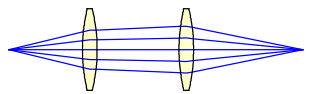
$t_1 = 11.3$, $t_2 = 80.7$, m = -13.5



d) $f_1 = L/3$
$f_2 = L/3$



$t_1 = 25$, $t_2 = 29.3$, m = -1.35



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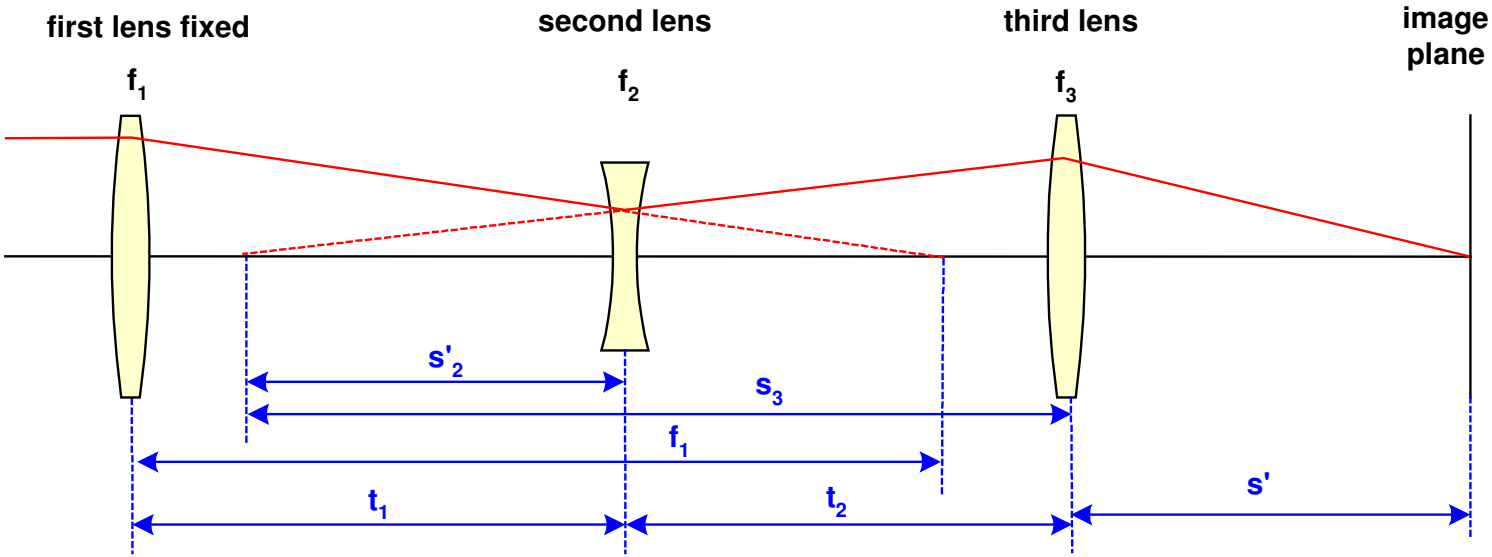
Three-Component Zoom System (A-F)

- Setup:

  1. lens fixed



- Given :

  M, L

- Arbitrary but recommended :

$$\Phi_1 = \frac{\sqrt{M}-1}{\sqrt{M}\cdot L}$$

- Calculation : central position

$$\Phi_2 = \frac{1-M}{\sqrt{M}\cdot L} \qquad \Phi_3 = (\Phi+\Phi_1)\cdot\frac{\sqrt{M}\,(\sqrt{M}+1)}{3\sqrt{M}-1}$$

$$s' = \frac{3\sqrt{M}-1}{\Phi\cdot\sqrt{M}\cdot(\sqrt{M}+1)} \qquad t_1 = \frac{\sqrt{M}-1}{\Phi_1\cdot(\sqrt{M}+1)} \qquad t_2 = \frac{\sqrt{M}-1}{\Phi_1\cdot\sqrt{M}\cdot(\sqrt{M}+1)}$$

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Three-Component Zoom System

- Arbitrary zoom positions:

  given is t_1

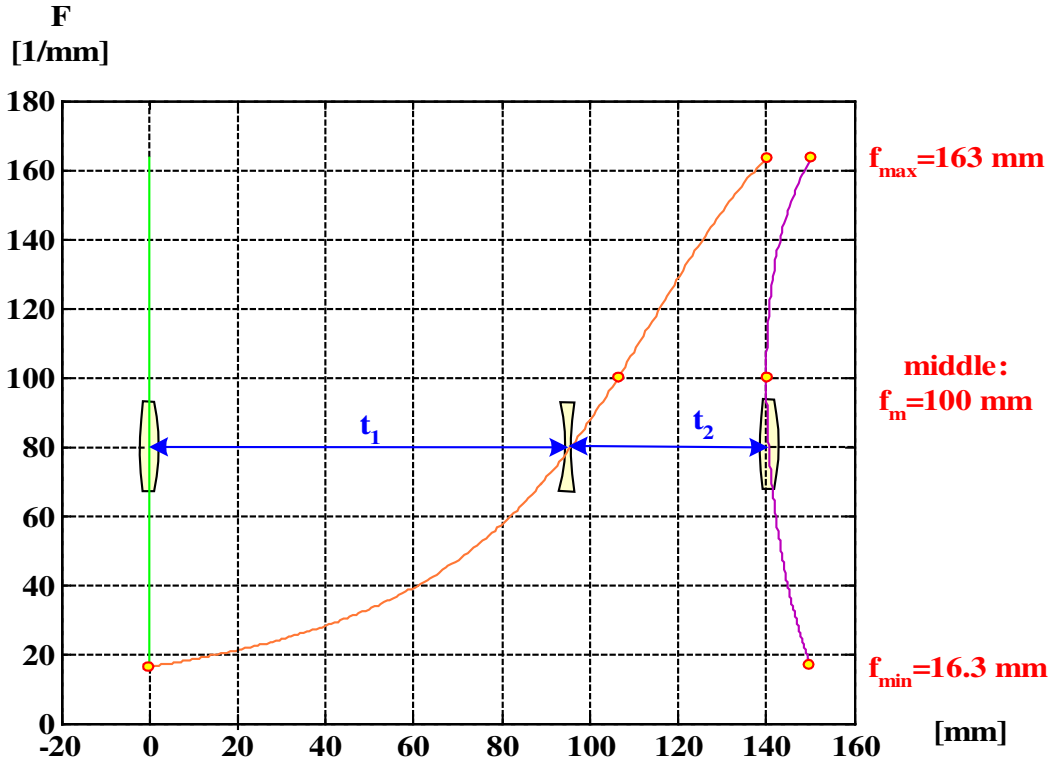
$$s'_2 = \frac{f_2 \cdot (f_1 - t_1)}{f_1 + f_2 - t_1} \qquad t_2 = -\frac{b}{2} \pm \sqrt{\frac{b^2}{4} - c}$$

$$\Phi = \Phi_1 + \Phi_2 + \Phi_3 - t_1\Phi_1 \cdot (\Phi_2 + \Phi_3) - t_2\Phi_3 \cdot (\Phi_1 + \Phi_2) + t_1 t_2 \Phi_1 \Phi_3 \Phi_3$$

$$b = t_1 - s'_2 - L$$

$$c = (L - t_1) \cdot (f_3 + s'_2) - f_3 \cdot s'_2$$

- Example:



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Optical Compensation

- Number N of moved groups fixes the number of image plane zeros
- Calculation :

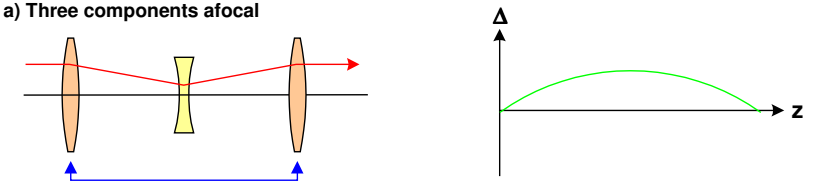
  Residual error

$$\Delta(z) = \frac{z^n + c_{n-1}z^{n-1} + c_{n-2}z^{n-2} + ... + c_1 z + c_0}{d_{n-1}z^{n-1} + d_{n-2}z^{n-2} + ... + d_1 z + d_0}$$

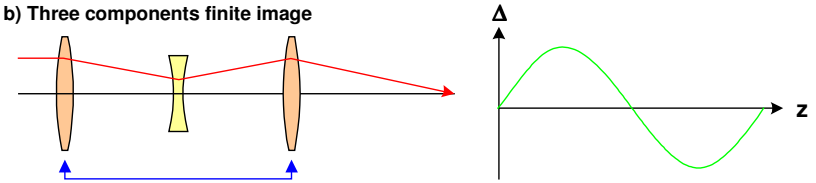
- Residuum decreases with N

$$\Delta_{max} = \frac{z_{max}}{2^{2n-1}}$$

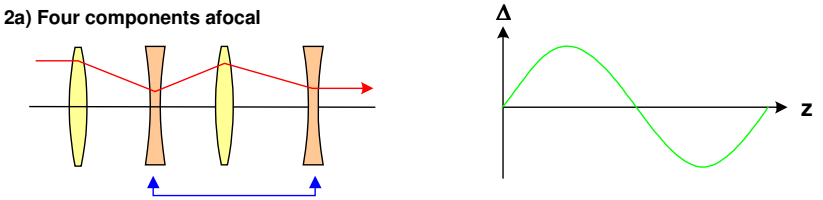
1a) Three components afocal



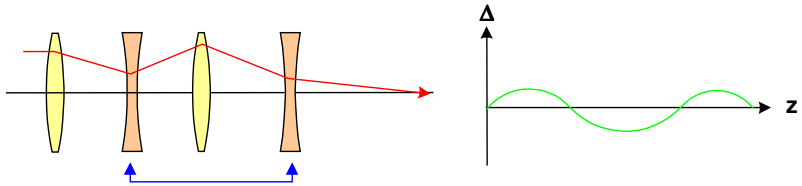
1b) Three components finite image



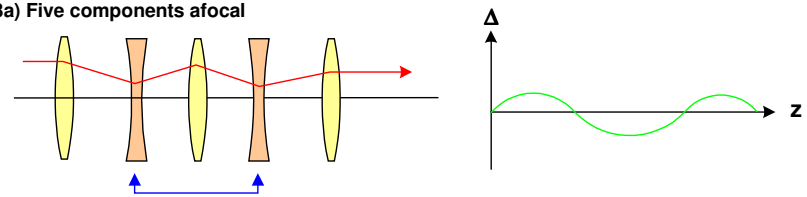
2a) Four components afocal



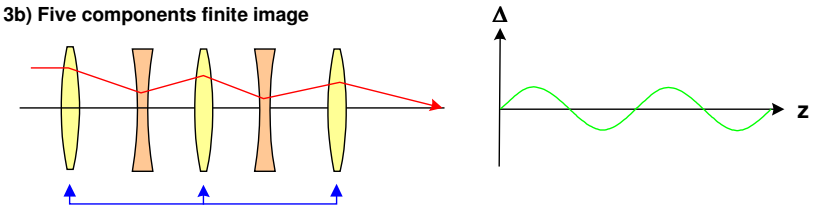
2a) Four components finite image



3a) Five components afocal



3b) Five components finite image



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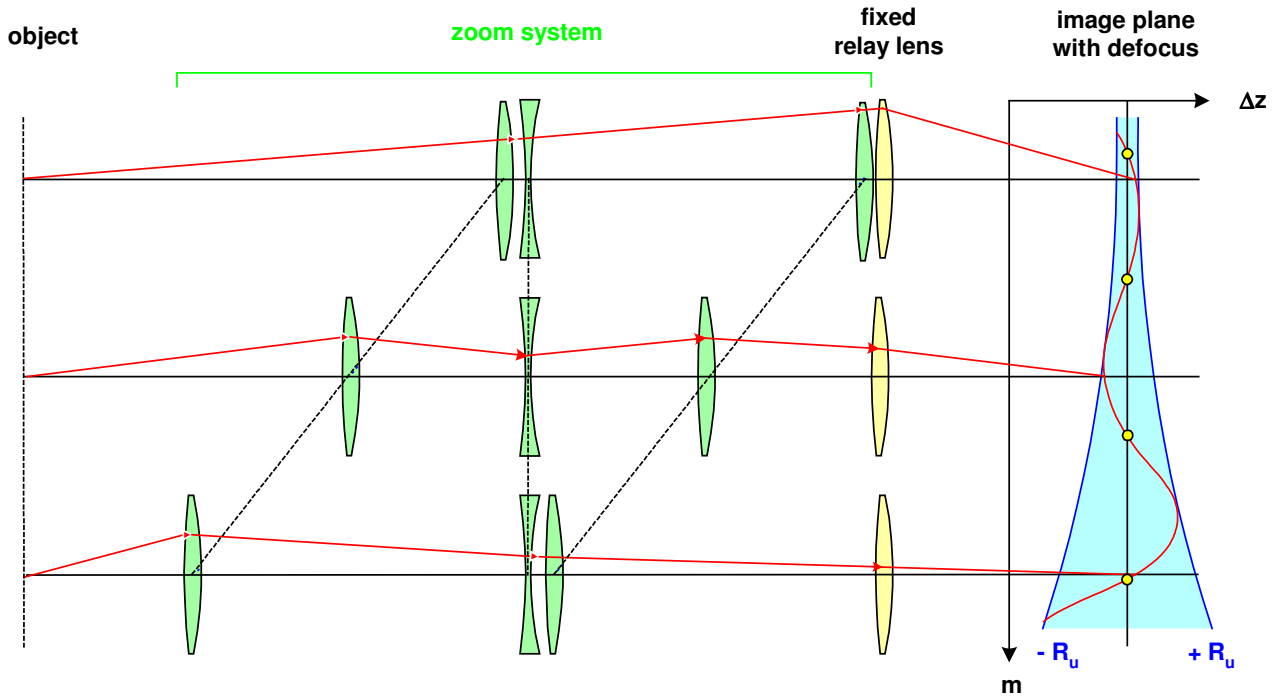
Optical Compensation

- Rayleigh range changes with m:

$$R_u = \frac{\lambda}{NA^2} = \frac{4\lambda \cdot \Gamma^2}{D_{in}^2}$$

- Optimized zeros



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Symmetrical Optical Compensated Three-Component Zoom

- Shifting from middle position:

Matrix $$\begin{pmatrix} A_a & B_a \\ C_a & D_a \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\Phi_1 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & t_m - z \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -\Phi_2 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & t_m + z \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ -\Phi_1 & 1 \end{pmatrix}$$

$$C_a = -2\Phi_1 - \Phi_2 + 2\Phi_1 t_m \cdot (\Phi_1 + \Phi_2) - t_m^2 \Phi_1^2 \Phi_2 + z^2 \Phi_1^2 \Phi_2$$

$$A_a = 1 - t_m (2\Phi_1 + \Phi)_2 + t_m^2 \Phi_1 \Phi_2 + z\Phi_2 - z^2 \Phi_1 \Phi_2$$

- Middle position:

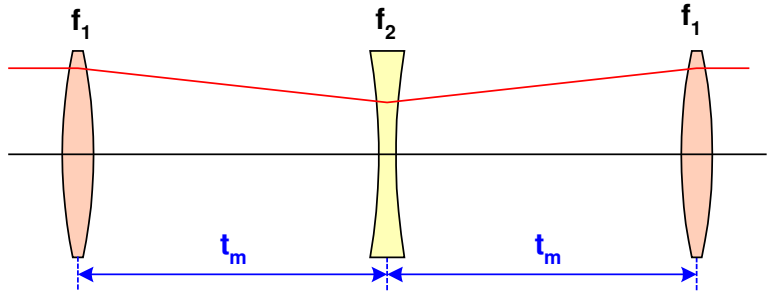
$$A_m = 1 - 2t_m \Phi_1 - t_m \Phi_2 + t_m^2 \Phi_1 \Phi_2$$

$$C_m = -2\Phi_1 - \Phi_2 + t_m \cdot (2\Phi_1^2 + 2\Phi_1 \Phi_2) - t_m^2 \Phi_1^2 \Phi_2$$

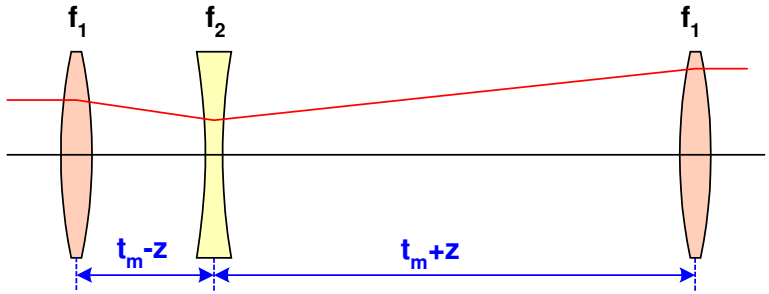
- Conditions: $C_m(0) = 0$

$$C = \left. \frac{u'}{x} \right|_{u=0} = 0 \qquad \Gamma = \frac{u'}{u} = D = \frac{1}{A} \qquad A_a(t_m) = \Gamma_{\min} < 1$$

a) symmetrical zoom position : Γ = 1



b) asymmetrical zoom position : Γ < 1



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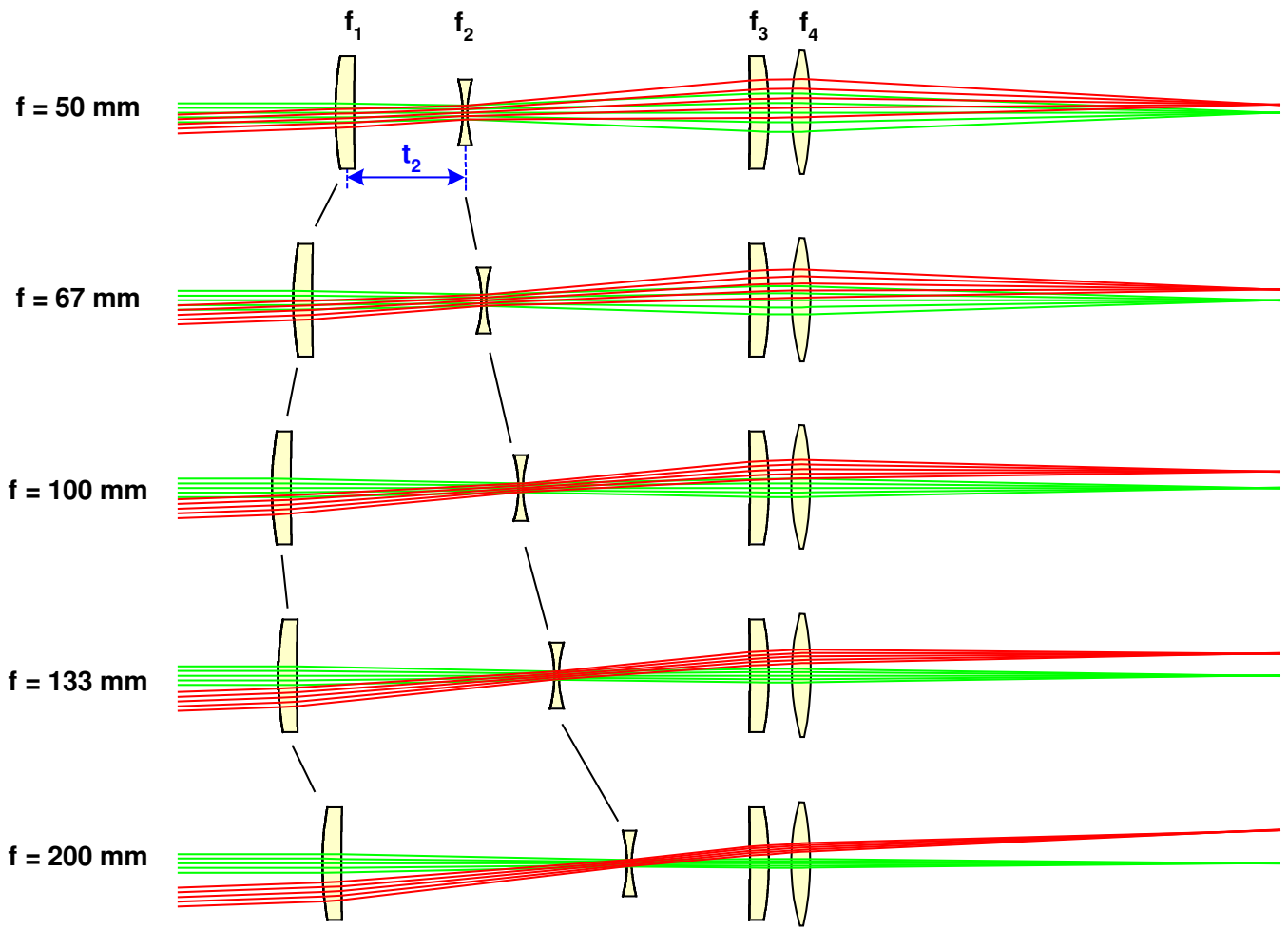
Performance Variation over z

- Simple system layout



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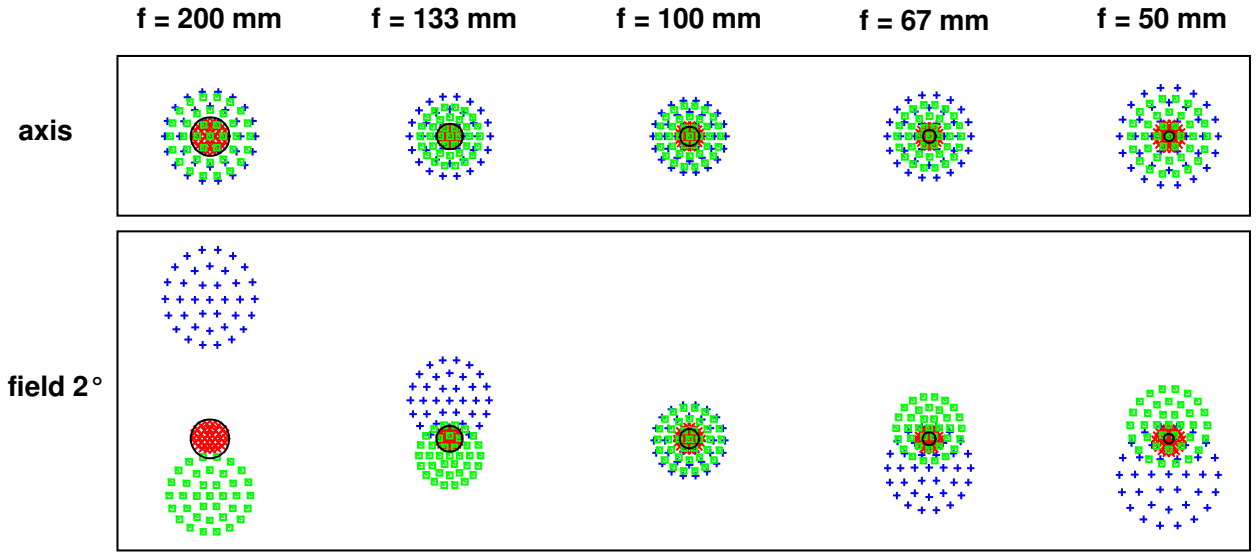
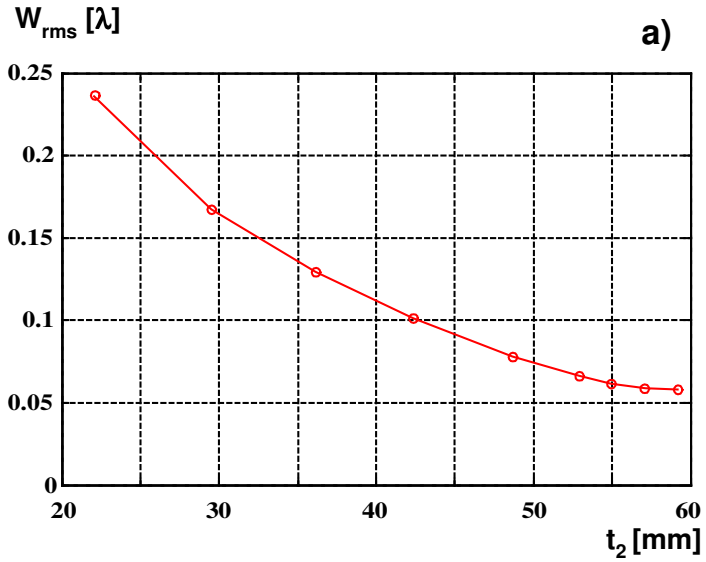
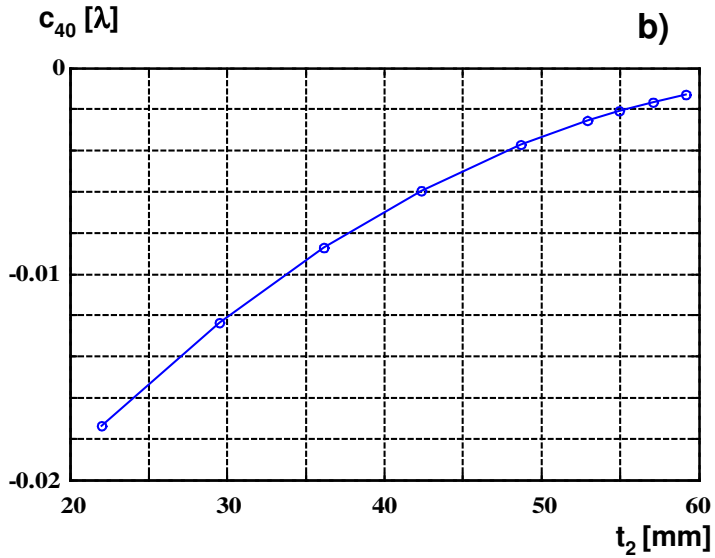
Performance Variation over z

- Variation of spots
- Variation of wave aberration







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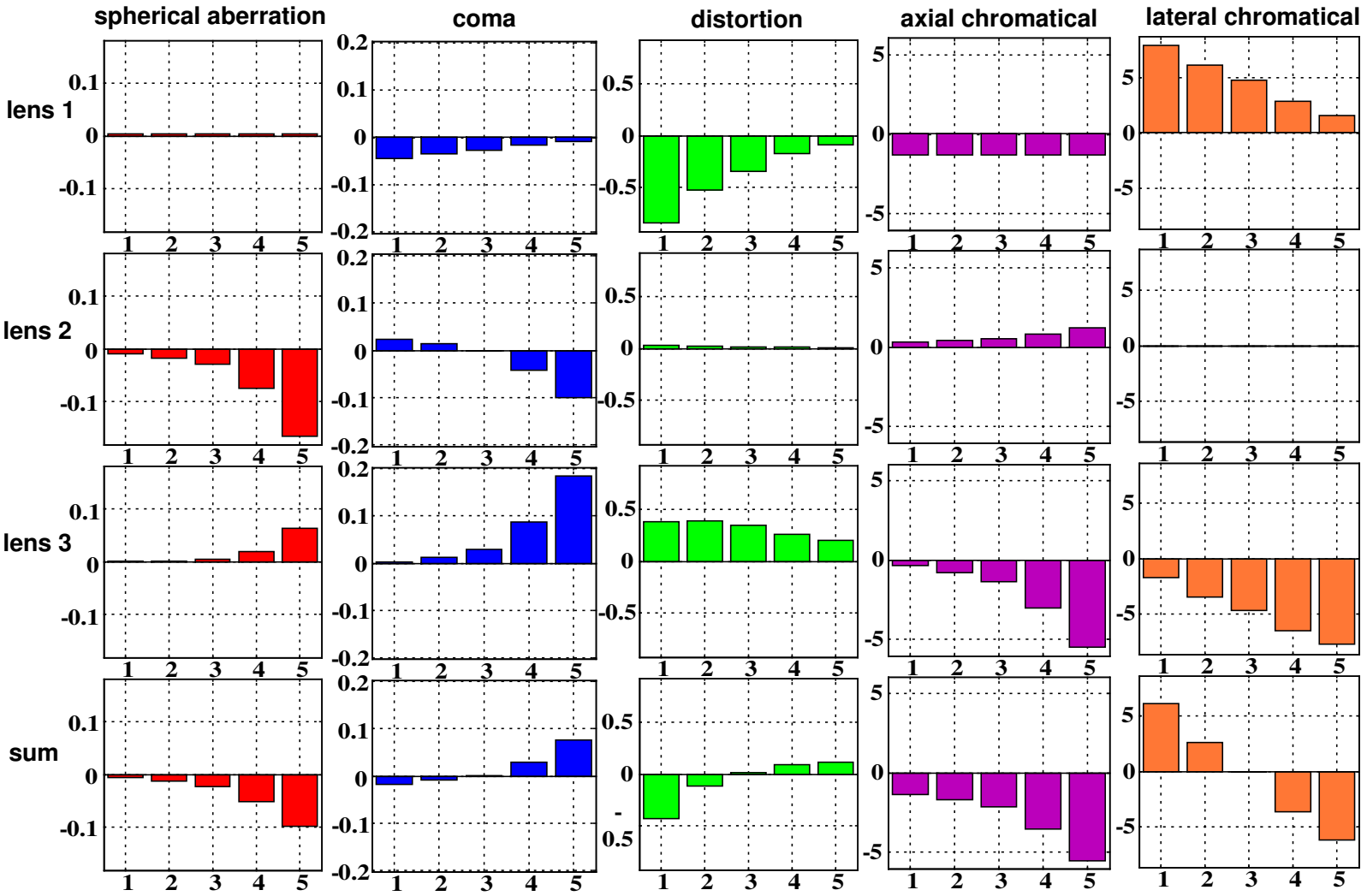
Performance Variation over z

Seidel surface contrib.



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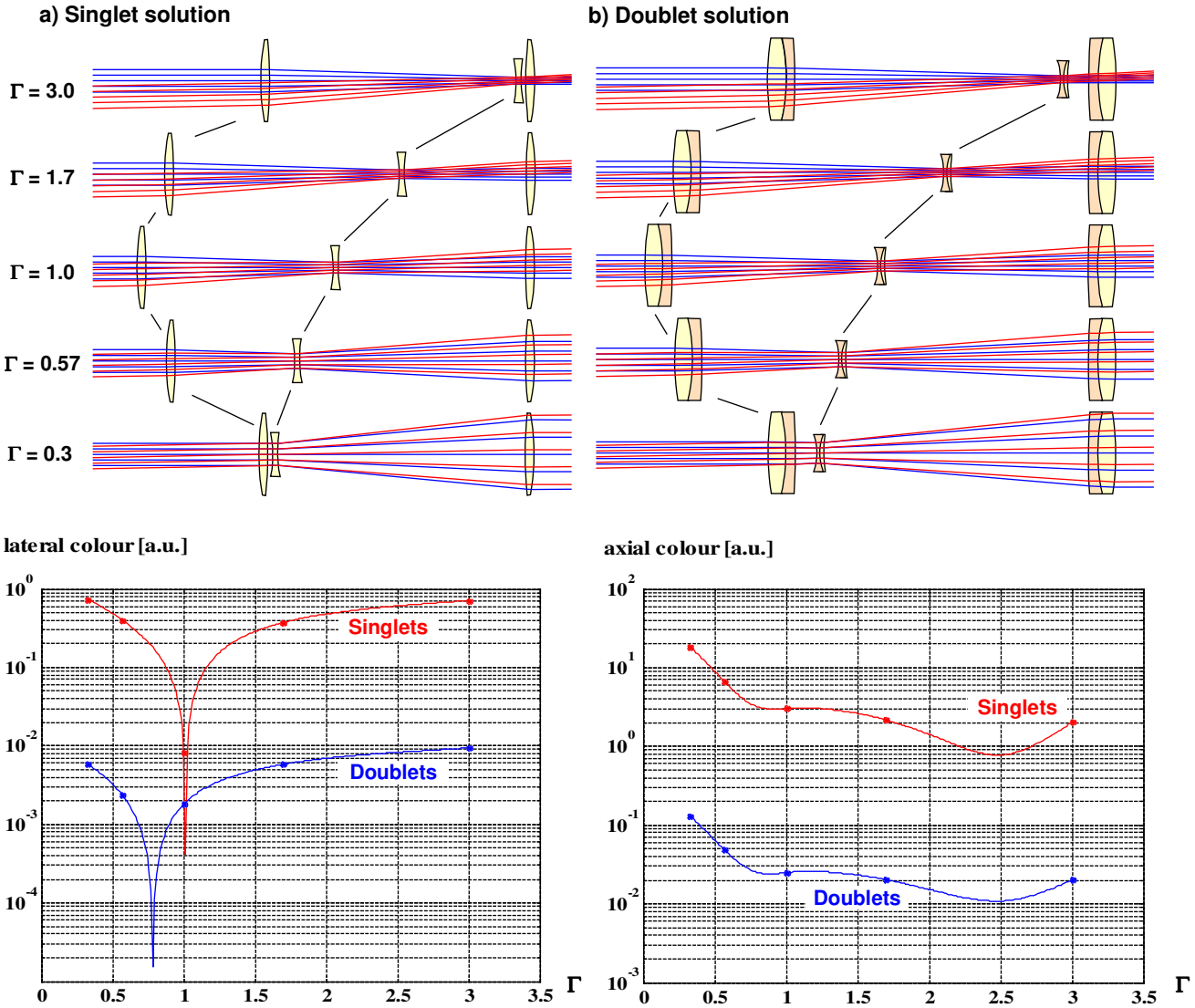
Color Correction of the Moving Groups

Axial and lateral color:

Comparison of singlet/doublet solution



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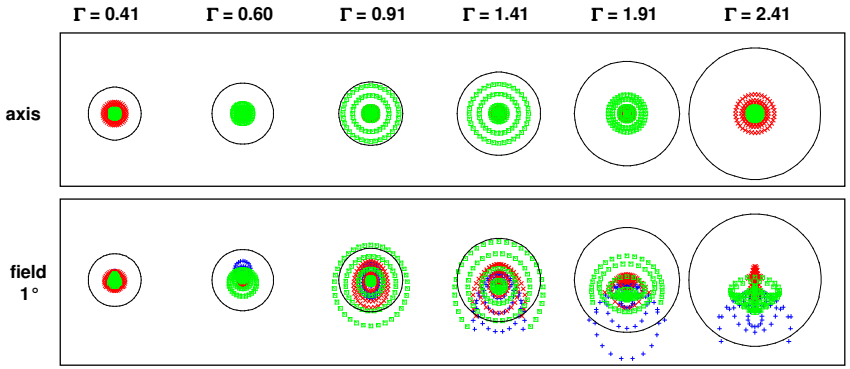
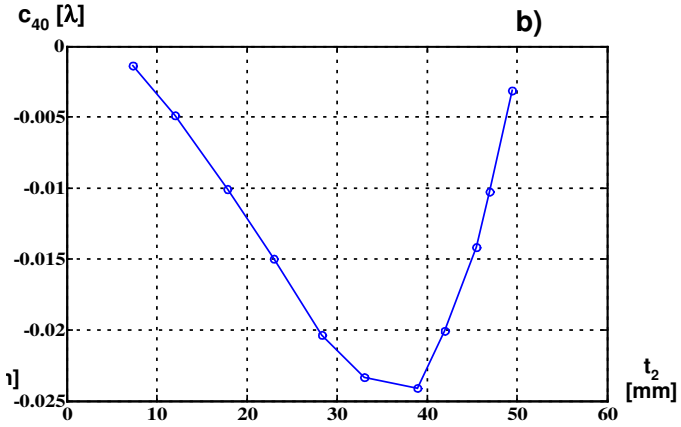
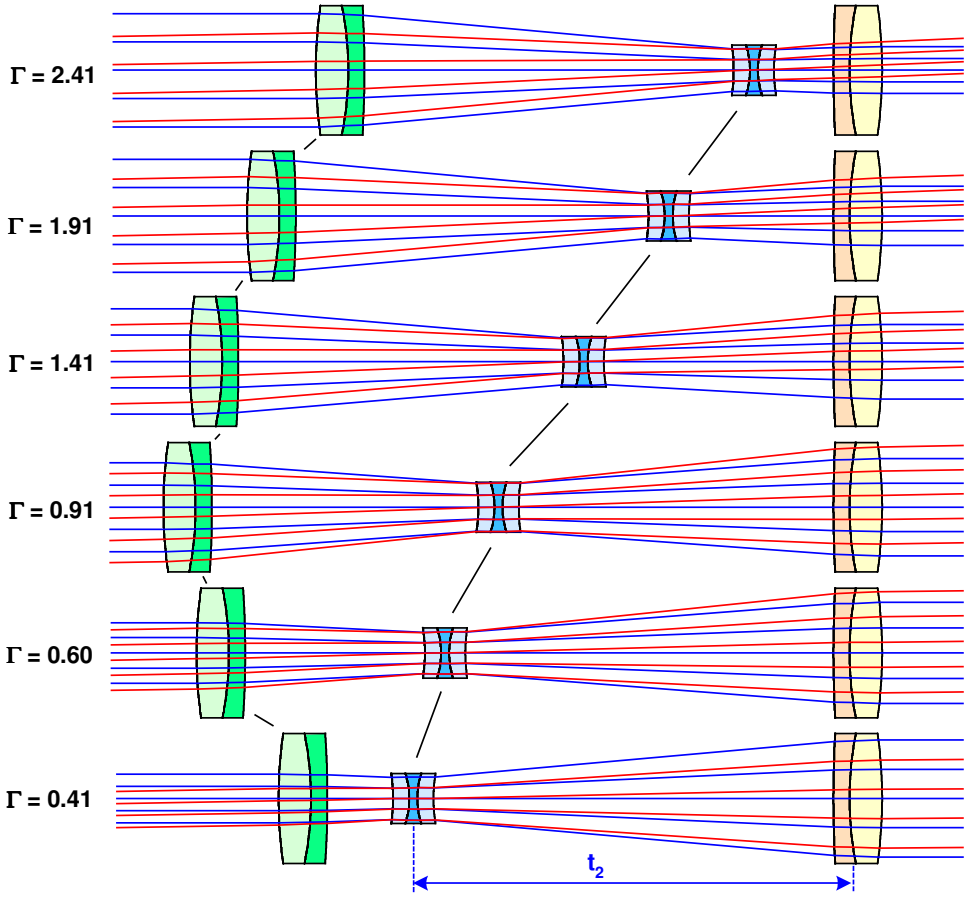
Example 1

- Three component afocal
- Spot diagram



- Spherical aberration





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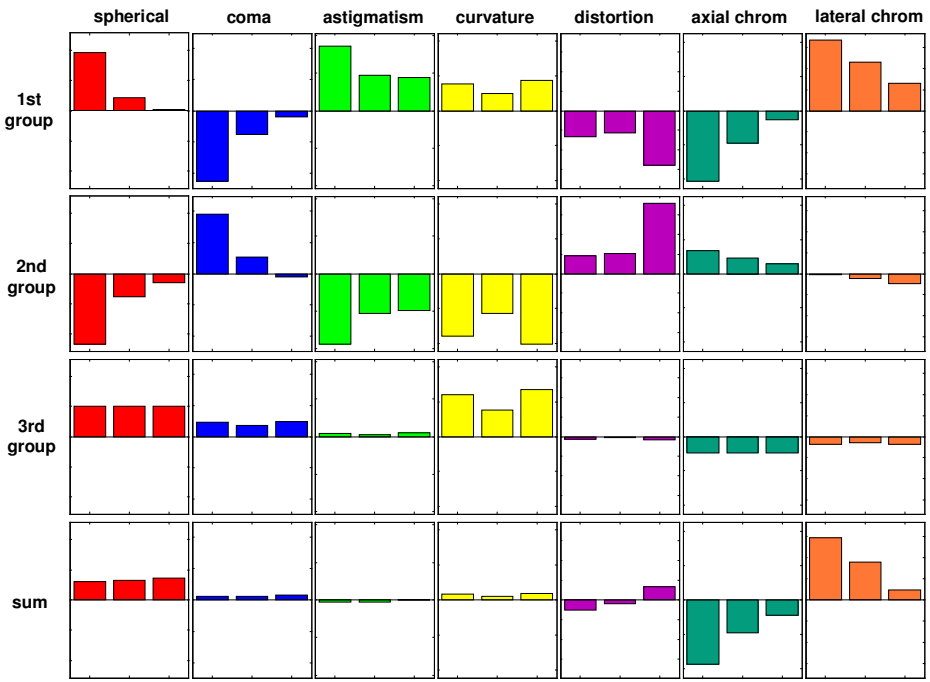
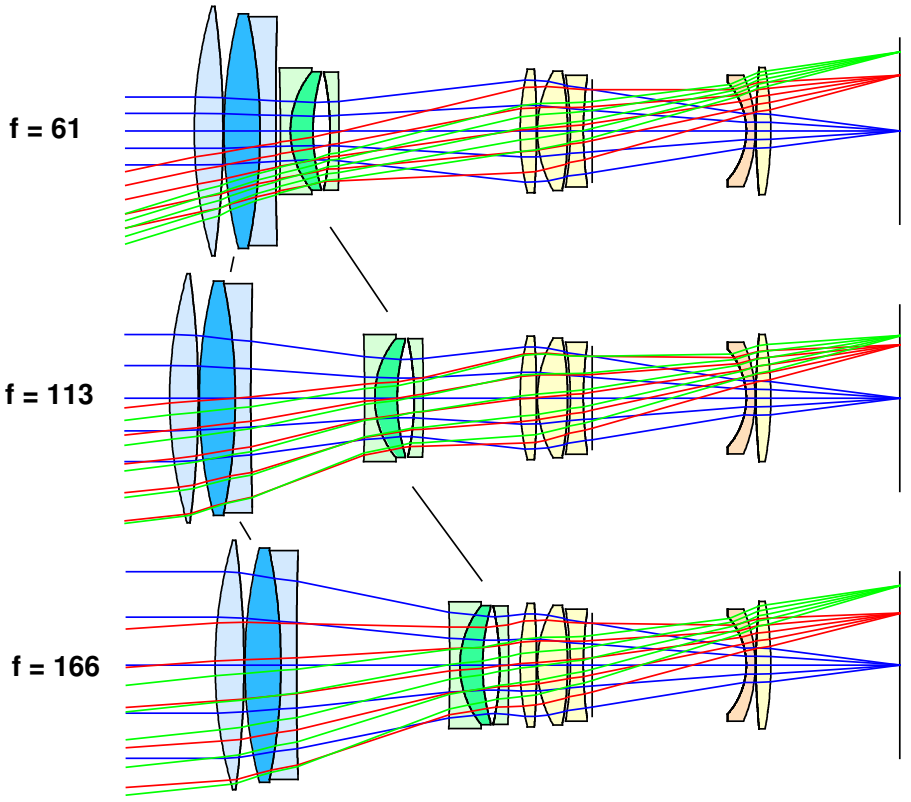
Example 2

- Finite-Afocal
- Two moving groups
- Seidel contributions





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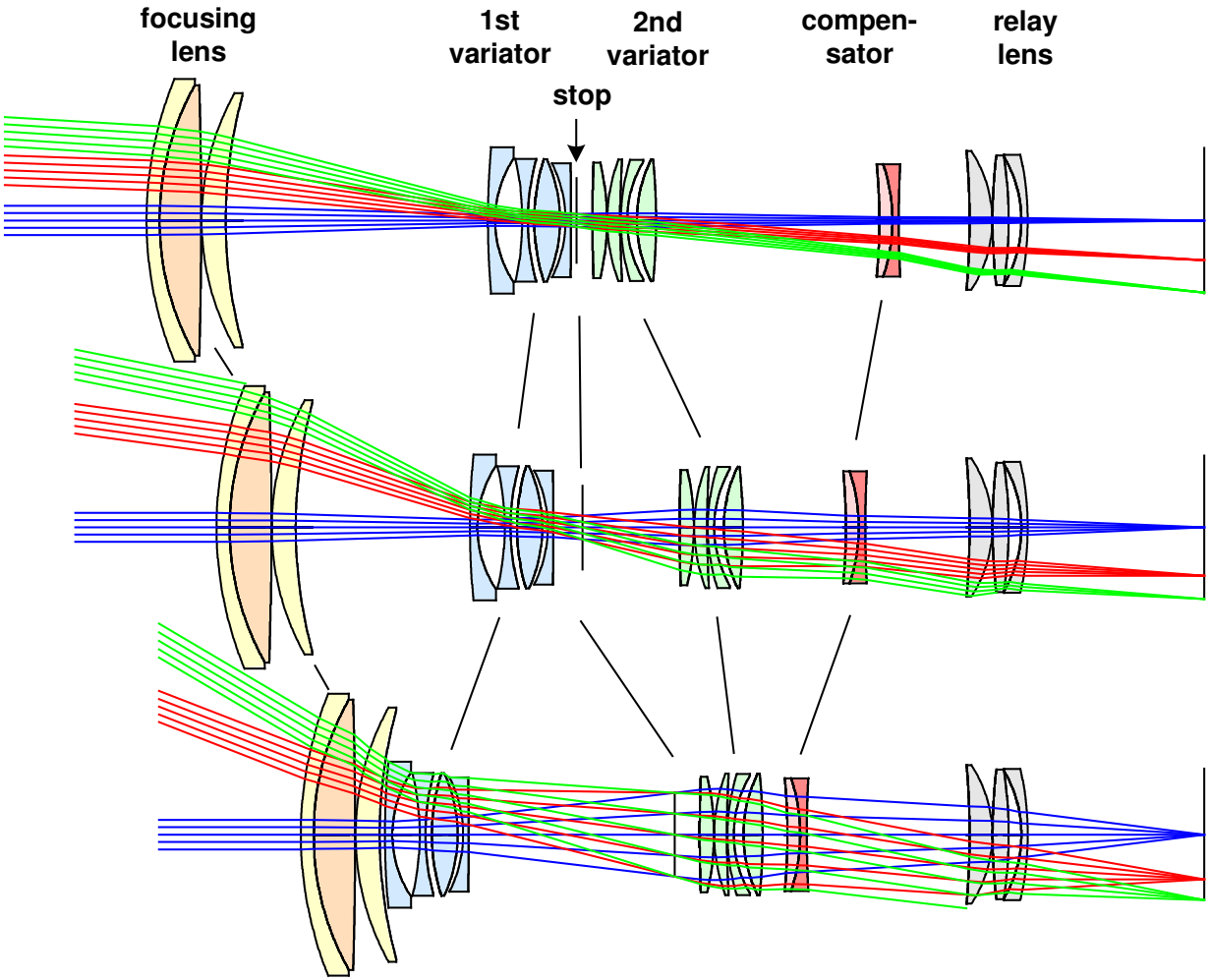
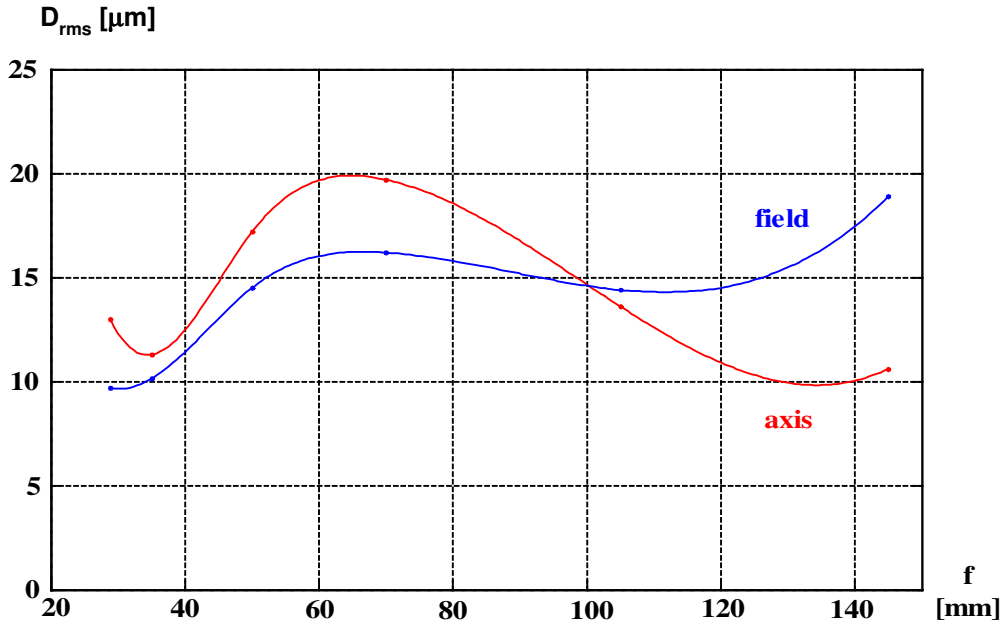
Example 3

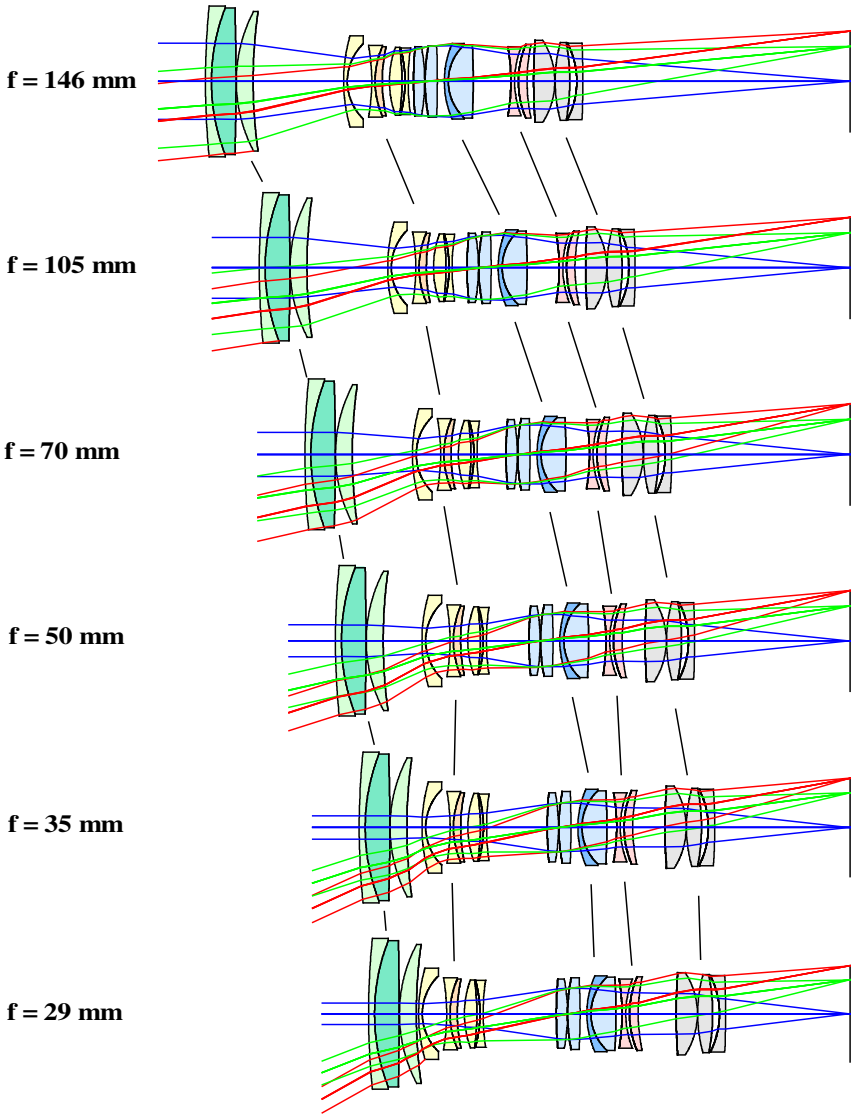
- Five groups
- Four moving groups



Zoomsysteme
Example 4

- Five groups, all moving
- Very smooth correction
- Rms diameter of spot

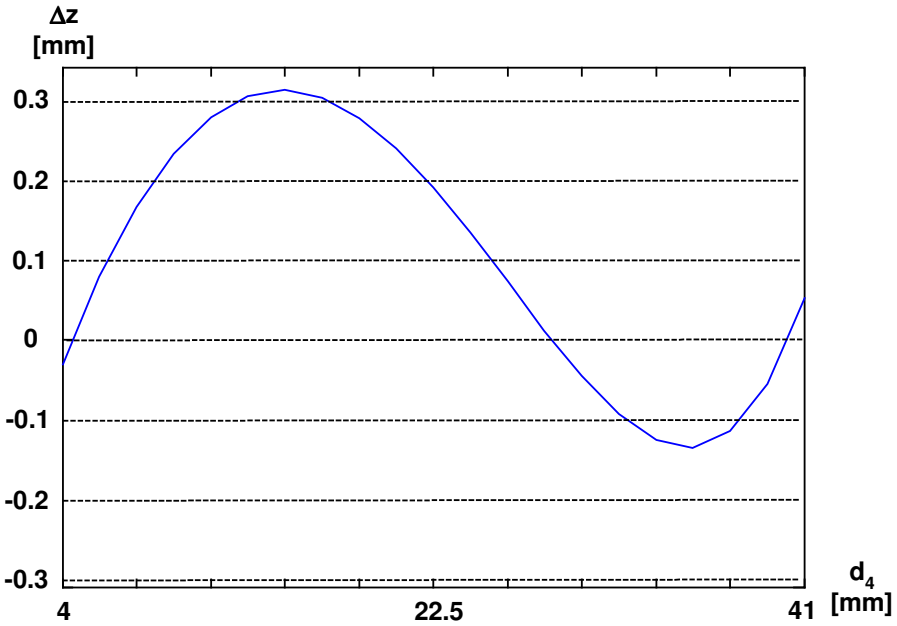


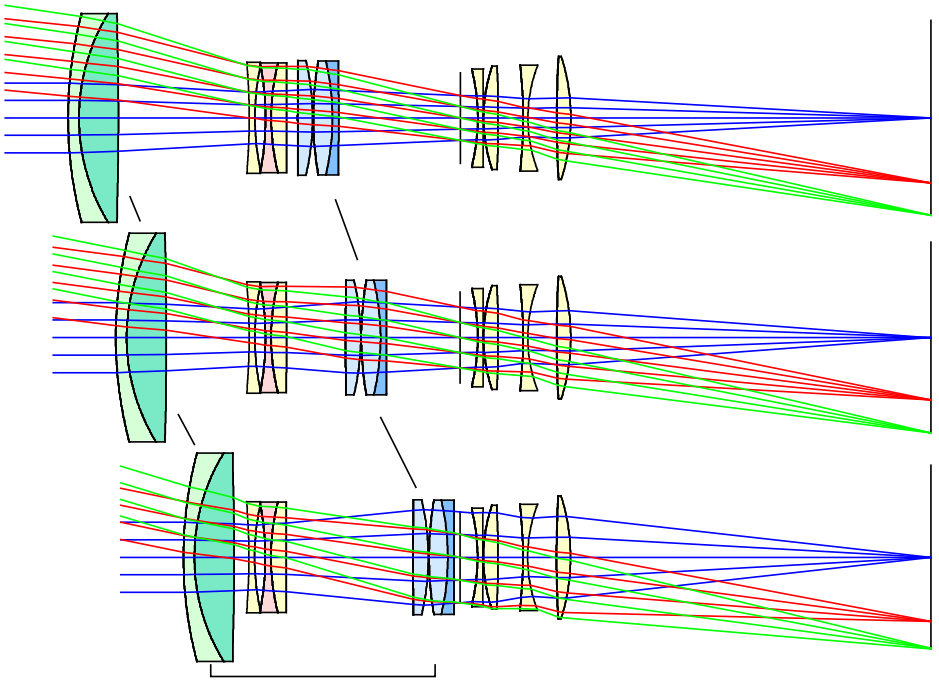


Zoomsysteme

Example 5

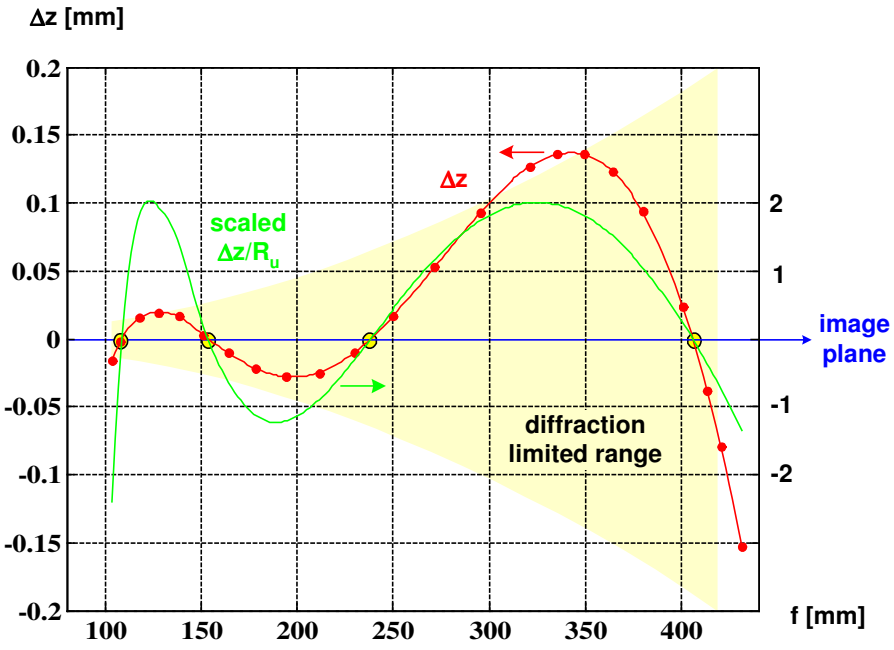
- Four groups, optical compensated
- Deviation of image location

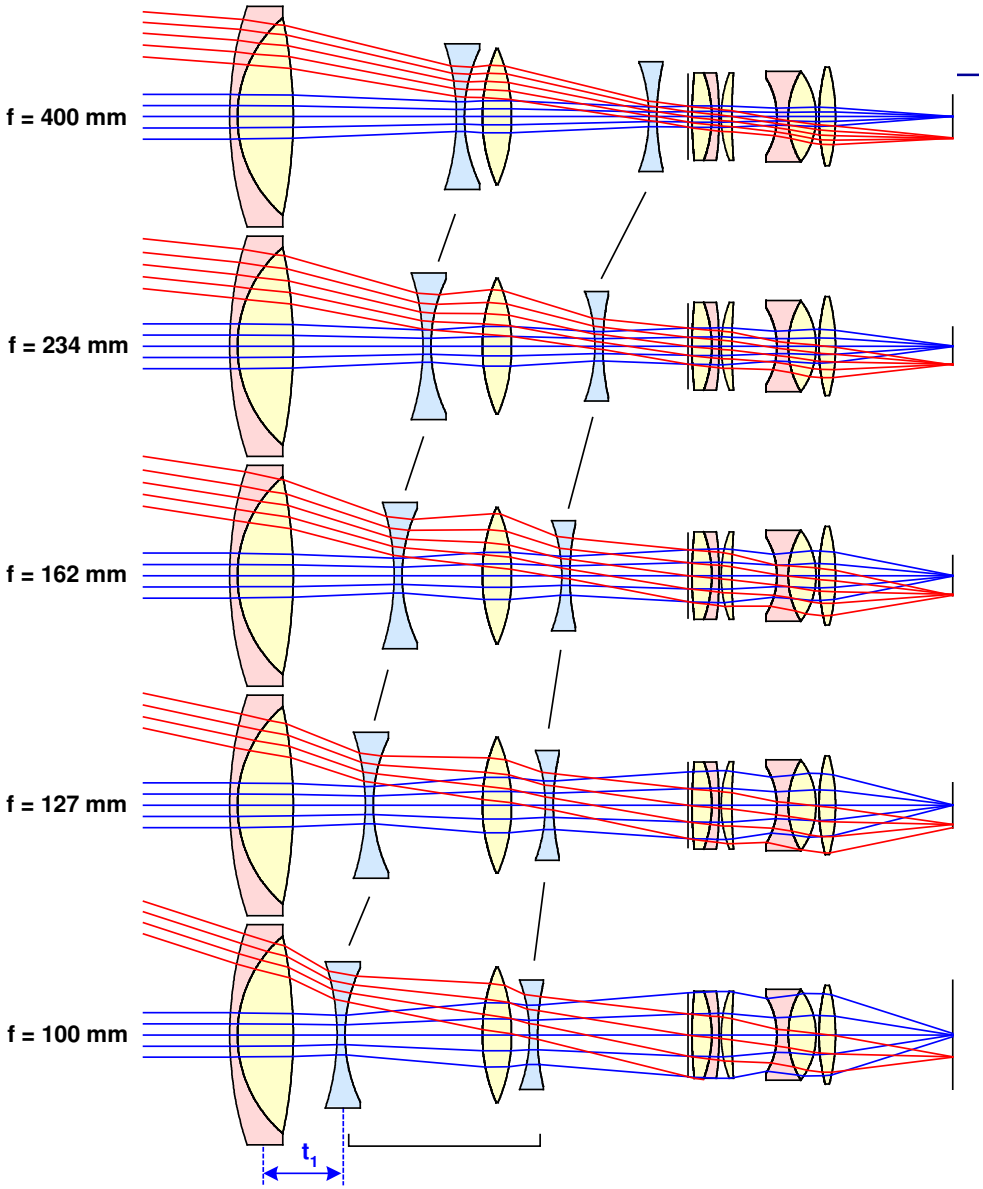




Zoomsysteme
Example 6

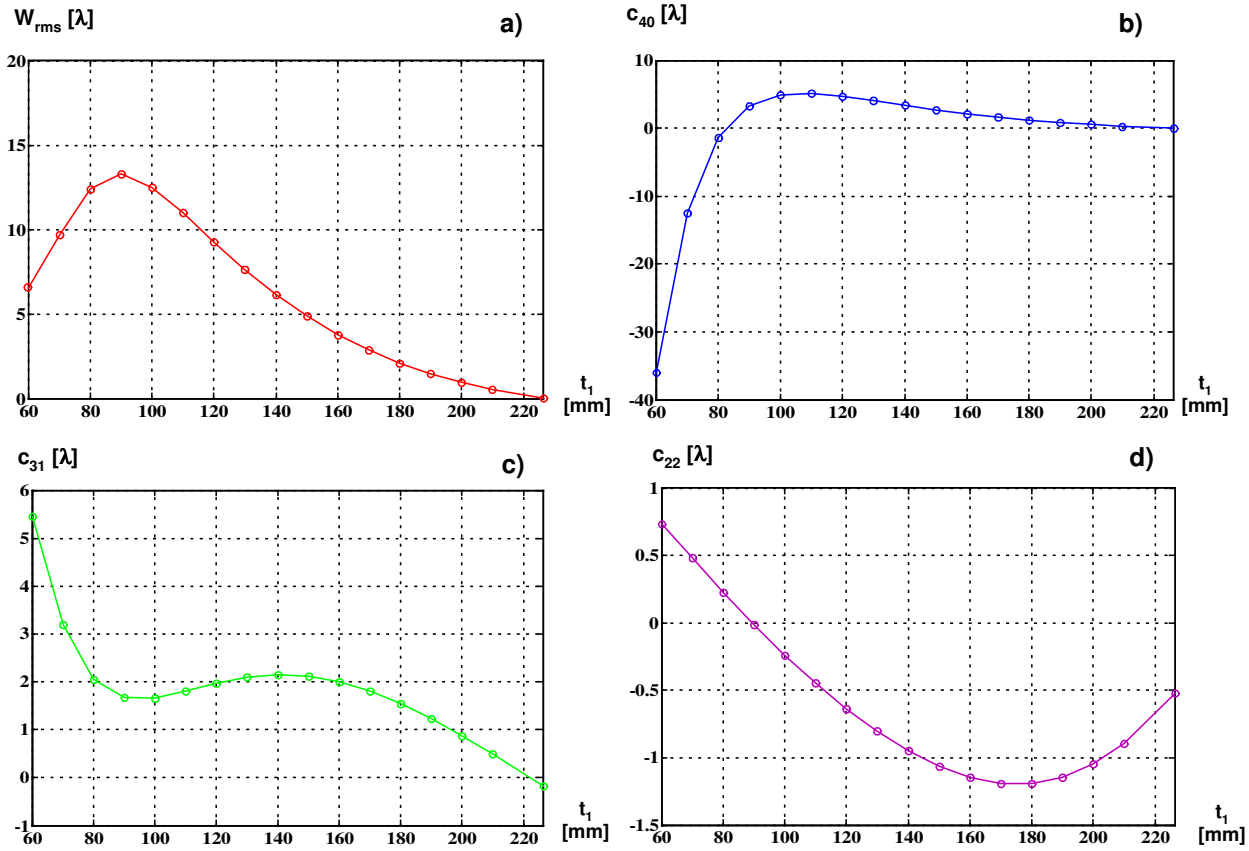
- Five components, optical compensated
- Deviation curve





Zoomsysteme
Example 6

- Five components, optical compensated
- W_{rms} and single Zernike coefficients

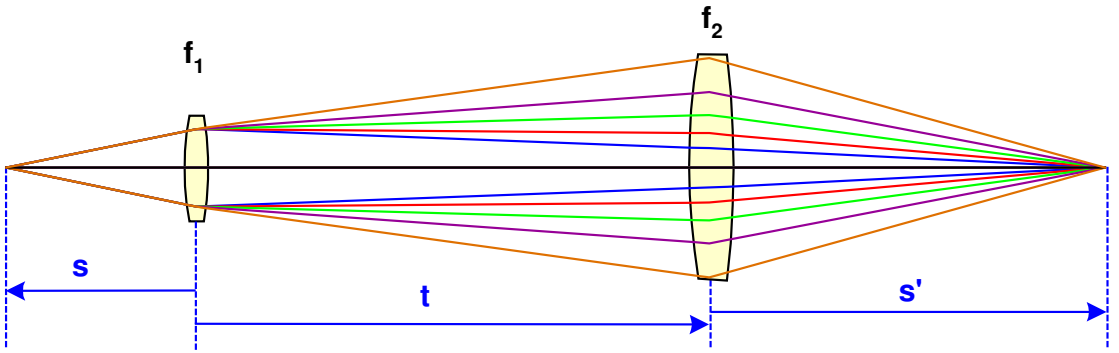


Zoomsysteme

Inhalt

Zoomsysteme
Solid State Zoom Systems

- Lenses with variable focal length



- Calculation:

$$\Phi_2 = \frac{1}{s'} + \frac{1 + s \cdot \Phi_1}{t \cdot (1 + s \cdot \Phi_1) - s}$$

$$\Phi = \frac{1 - t \cdot \Phi_1}{s'} + \frac{1}{t - s \cdot (1 - t \cdot \Phi_1)}$$

$$m = \frac{s'}{s - t \cdot (1 + s \cdot \Phi_1)}$$

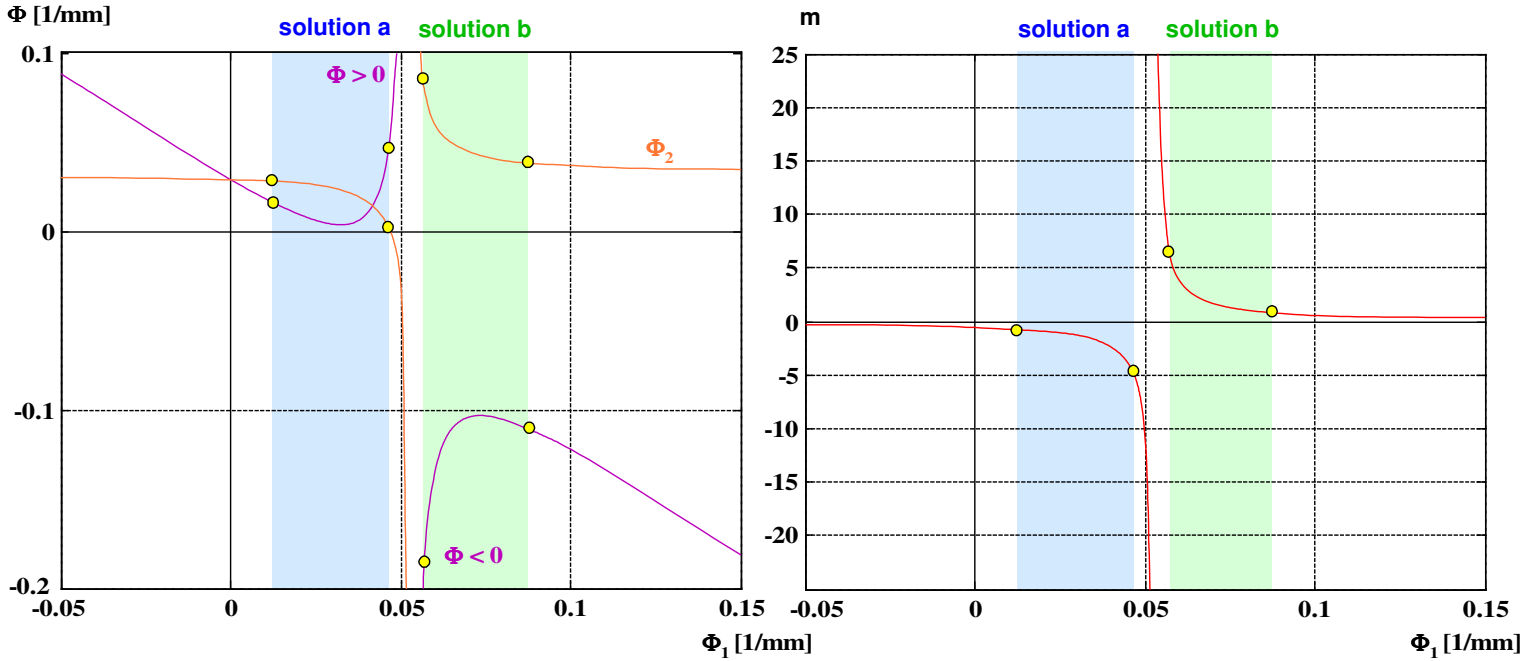
- Critical value:

$$\Phi_{1c} = \frac{1}{t} - \frac{1}{s}$$

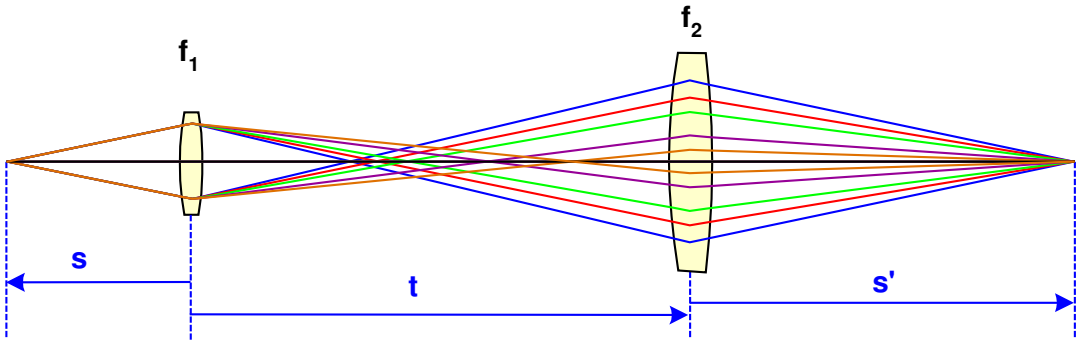
First lens focuses onto the second lens

Zoomsysteme
Solid State Zoom Systems

- Solution areas



- Second solution: Intermediate image



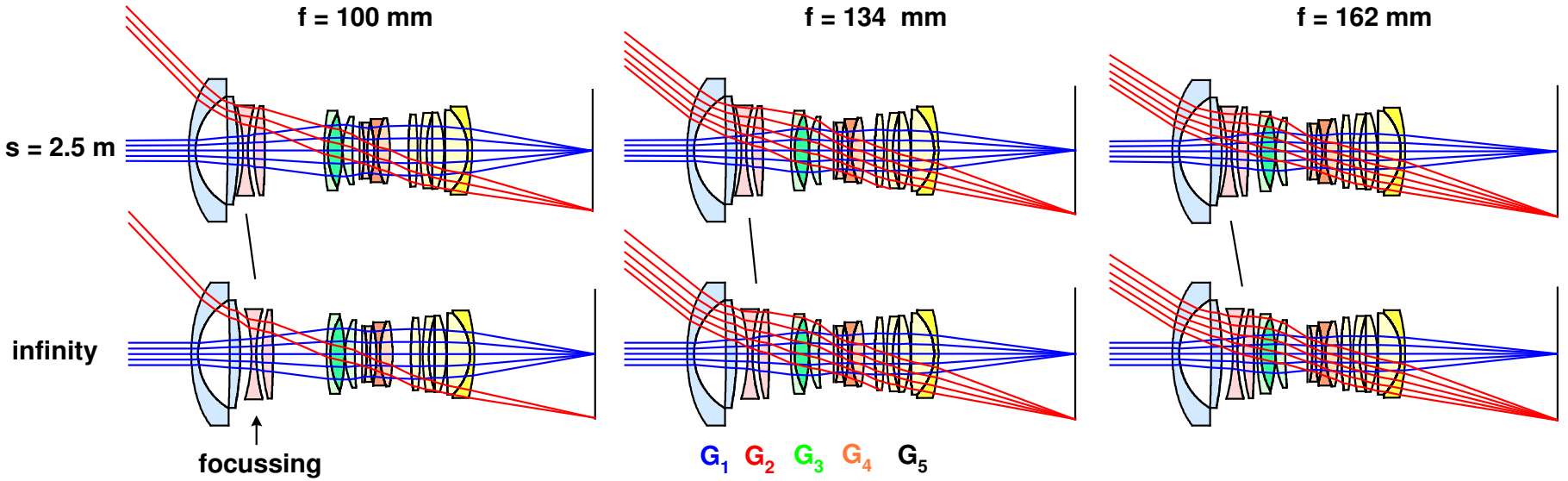
Zoomsysteme

Combined Zoom with Focussing

- Photography:

  Additional floating element for focussing
- Problem : Breathing, change of field size during focussing

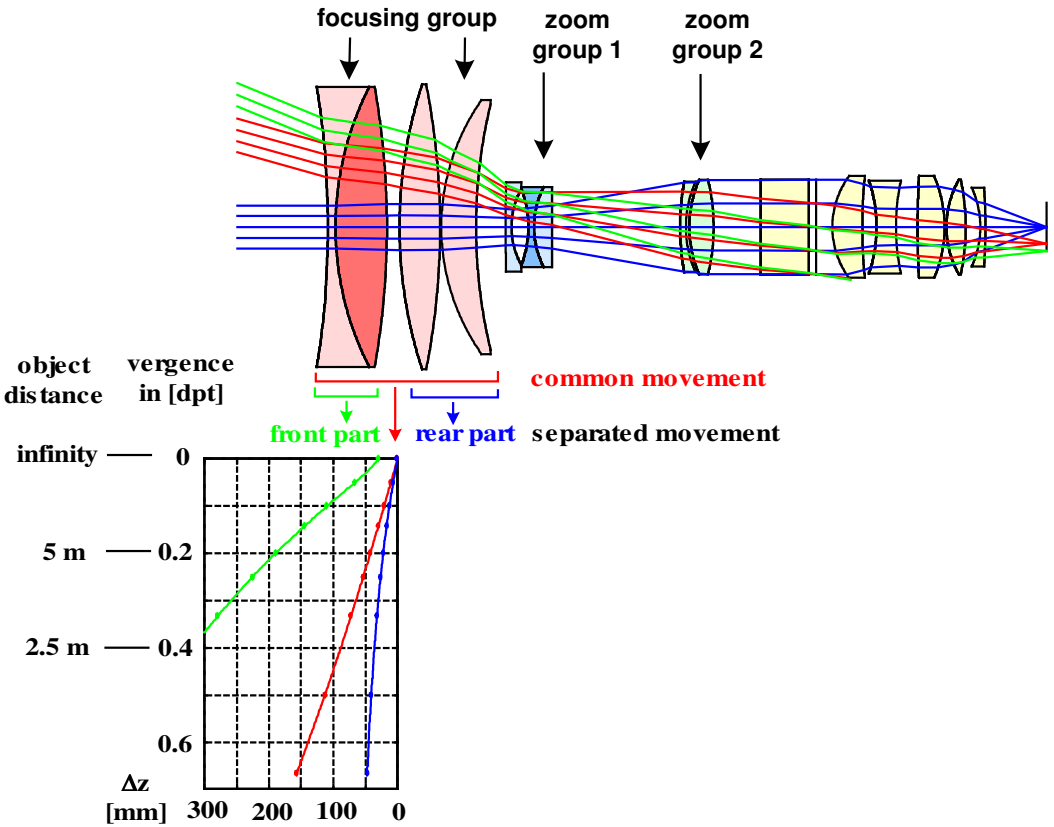
  non-telecentric chief ray at focussing group

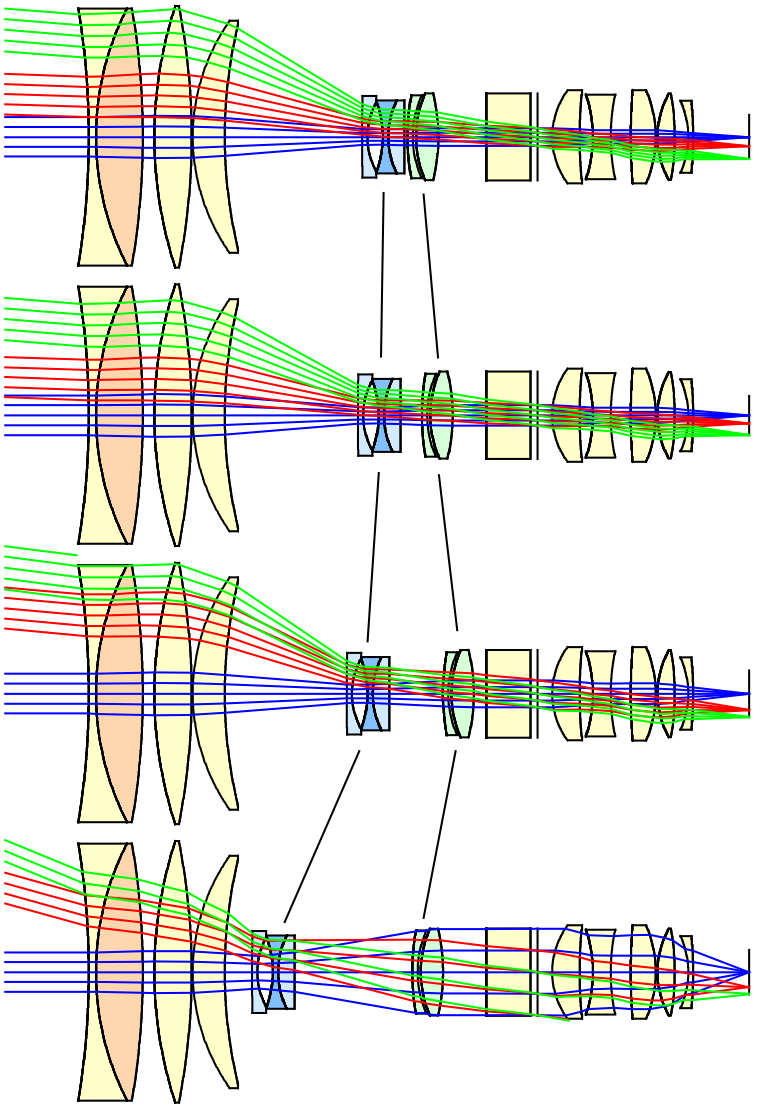


Zoomsysteme

Combined Zoom with Focussing

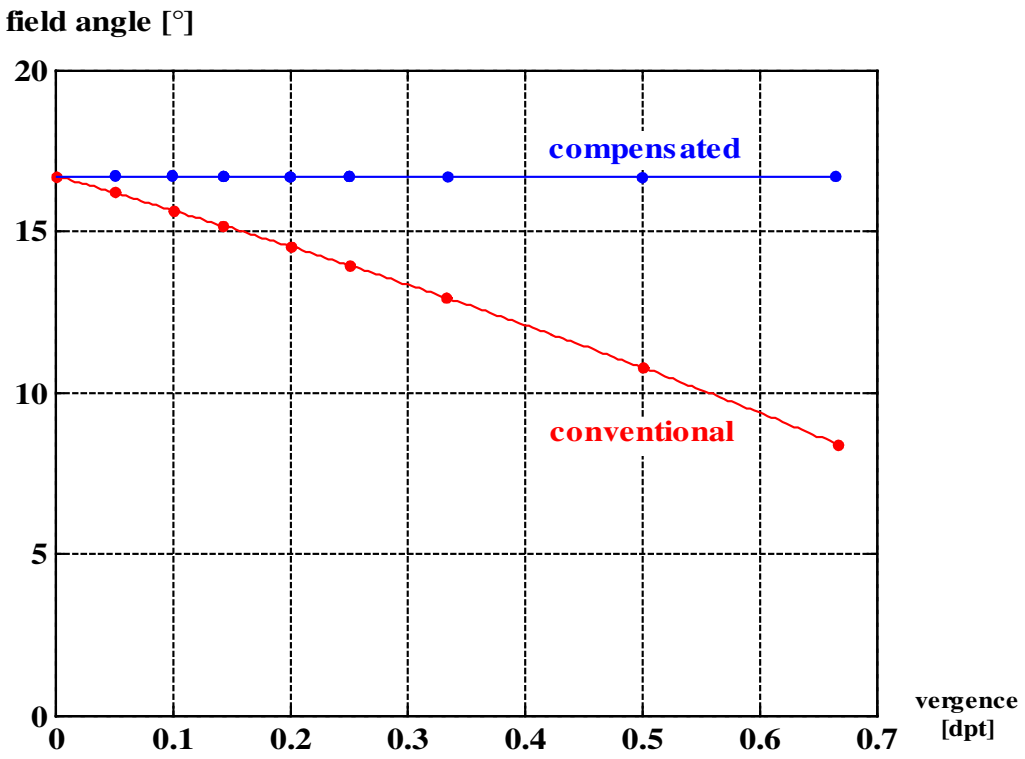
- System without breathing
- Special movement of focus group





Zoomsysteme
Combined Zoom with Focussing

- Compensating effect



Zoomsysteme
Fixed Pupil Position

- Additional degree of freedom
- Example for illustration