Astronomical Telescopes and Instruments 2020: Exercises on Optical Design (Due on 3 November 2020 at 14:15)

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1 Reducing Aberrations with Multiple Elements

1. Design a single f/1.0 (focal length is equal to the beam diameter), symmetric (magnitudes of radius of curvature are the same for both surfaces) lens to focus light from infinity onto a detector and determine the rms spot size of the image at the center of the field of view in terms of the beam diameter.

2. Design an f/1.0 lens consisting of 4 identical, symmetric lenses to focus light from infinity onto a detector. How much longer is the focal length of one of these lenses as compared to the singlet design in part 1? Determine the rms spot size of the image at the center of the field of view in terms of the diameter.

3. Explain the performance difference between the two designs.

2 Achromatic Lens

An achromatic lens is made of two different glasses to minimize the change in focal length as a function of wavelength. The properties of an achromatic lens can be calculated from 1) the focal length f of the combined lens

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \, ,$$

where $f_{1,2}$ are the focal lengths of the individual lenses, and 2) the minimization of the chromatism

$$\frac{f_1}{n_1(\lambda_1) - n_1(\lambda_2)} + \frac{f_2}{n_2(\lambda_1) - n_2(\lambda_2)} = 0$$

where $n_{1,2}(\lambda_{1,2}) =$ are the indices of refracion of glass 1 and 2 at wavelengths λ_1 and λ_2. Note: The relation of focal lengths is only valid for two thin lenses that are in contact. The condition for the minimization of the chromatism can be found in Hecht, section 6.3.2.

1. Design an achromatic lens with a focal length of 500 mm at wavelengths of 486.1 nm and 656.3 nm and an F-number of 4. Use `http://refractiveindex.info` to obtain the indices of refraction. Use a biconvex BK7 lens with the same front and rear radii of curvature and an F2 lens with one surface having the same radius of curvature as the BK7 lens. Using the thin-lens equation, determine the radii of curvature of the two lenses.

2. Enter the derived properties into TOD and find the rms spot radii for both wavelengths. Compare these with the rms spot radii a of single BK7 lens with a focal length of 500 mm at 656.3 nm and the same lens diameter as the achromat.

3. Reverse the arrangement of the two lenses and compare the rms spot radii with the original achromat.

3 Positioning Tolerances for Cassegrain Telesope

Design a 200-mm diameter Cassegrain telescope (parabolic primary, hyperbolic secondary, focal plane) with a focal length of 1200 mm.

1. Determine the pixel size of a camera in the focal plane that provides diffraction-limited images at 500 nm.
2. Determine the maximum allowed axial motion of the detector to remain diffraction limited (rms spot diameter = $1.22\ \lambda/D$)
3. Determine the maximum allowed axial motion of the secondary mirror to remain diffraction limited when the focal plane stays in the same position.
4. Determine the maximum allowed axial motion of the secondary mirror to remain diffraction limited when the focal plane is allowed to move to the best focus position.