Astronomical Telescopes and Instruments 2016:
Exercises on Telescopes
(Due on 2 November 2016 at 13:45)

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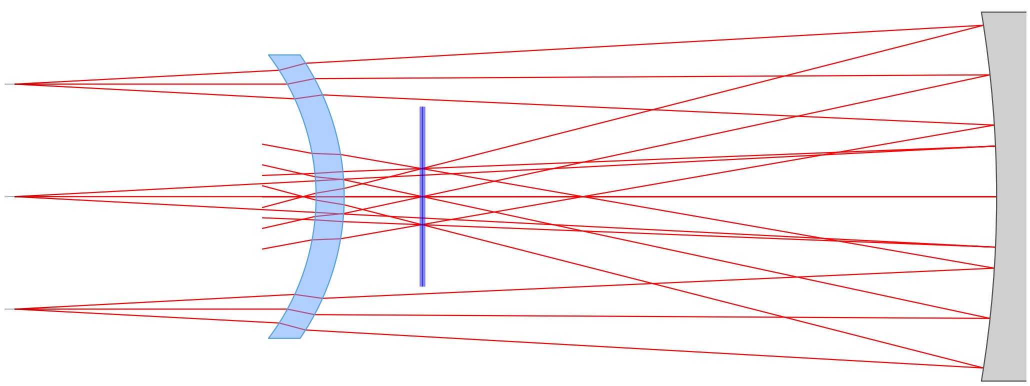
1 Maksutov Corrector

A corrector plate in front of a spherical primary mirror makes a telescope with a very large field of view. One implementation is the aspherical corrector plate used in a Schmidt telescope. Another version, the Maksutov design, has a spherical meniscus lens corrector in front of the spherical primary mirror. In this exercise, you will go through the steps of designing a Maksutov telescope, analyzing its performance and then comparing it to single-mirror telescopes without a transmitting corrector.



1. The Maksutov corrector is an achromatic, single lens. Use the expression for the focal length of a thick lens and require that the focal length is invariant under a change of the index of refraction, i.e. $\partial f/\partial n = 0$. Derive the relation between the two radii of curvature, $R_{1,2}$ and the thickness d for an achromatic meniscus lens. The radii of curvature of a meniscus lens have the same sign.

2. The thickness and radii of curvature of the corrector can be further optimized to compensate for the spherical aberration of the primary mirror. Assume that the corector is made from fused silica (n=1.46 at 550 nm). If the primary, spherical mirror has a radius of curvature R and the telescope has an f-number of 2.5, choose the thickness of the corrector as $d = 0.025|R|$ and $R_1 = 0.2087R$ to compensate the primary's spherical aberration. Calculate R_2 using the equation derived above.

3. Place the corrector at a distance of $0.2667|R|$ behind the entrance aperture and the mirror at $0.8543|R|$ behind the aperture to minimize the aberrations of the complete system. Determine the performance (rms spot size) of the Maksutov design for field angles of 0 and 3 degrees.

4. Compare these performance parameters to a single spherical mirror and a Newtonian telescope with the same f-number and focal length.

2 Cassegrain vs Ritchie-Chretien

A Cassegrain telescope consists of a parabolic primary and a hyperbolic secondary mirror, which perfectly reimages the on-axis focus of the primary mirror to a location behind the primary mirror. Such a two-mirror telescope has no spherical aberration, but it suffers from coma.

1. Design a Cassegrain telescope with a parabolic primary mirror with a diameter of 81.15 mm and a focal length of 144.875 mm and a hyperbolic secondary mirror with a diameter of 11.078 mm and a focal length of 22.669 mm. Assume that this is only used to look at the very center of the field of view. Hints: 1) use a source beam of 80mm diameter and aim it at the primary mirror, 2) calculate the conic constant of the secondary mirror from the equations shown in the lecture.

2. Determine the separation between the two mirrors. Hint: one focal point of the hyperbola has to be in the focus of the primary mirror, the second focal point has to be in the focus of the telescope.

3. Show that your design is free of aberrations on-axis and determine the performance for a field angle of 0.5 degrees. Hint: increase the diameter of the secondary mirror so that there is no vignetting at a field angle of 0.5 degrees.

4. Show that most of the aberration at 0.5 degrees comes from field curvature. Assess the performance that would be achieved with the Cassegrain if field curvature would be corrected perfectly. Hint: You can change the radius of curvature of the image to a finite value.

5. The off-axis coma of the primary mirror can be corrected if the primary mirror is also made slightly hyperbolic and the conic constant of the secondary mirror is adjusted such that spherical aberration is still cancelled. Choose the conic constants $K_{1,2}$ of the two mirrors according to the following equations

   $$K_1 = -1 - \frac{2(1+\beta)}{m^2(m-\beta)}$$

   and

   $$K_2 = -\left(\frac{m+1}{m-1}\right)^2 - \frac{2m(m+1)}{(m-\beta)(m-1)^3}$$

   where $m = F/F_1$ is the magnification due to the secondary mirror expressed as the f-number of the telescope divided by the f-number of the primary mirror and β is the back-focal distance (distance between M1 and the focal plane) expressed in units of the focal length of the primary mirror. Again, assess the performance before and after correction of field curvature. Hint: the separation of primary and secondary mirrors does not change.

6. What is the remaining aberration? Hint: move the image to either side of the best focus position.

7. What telescope did you just model?