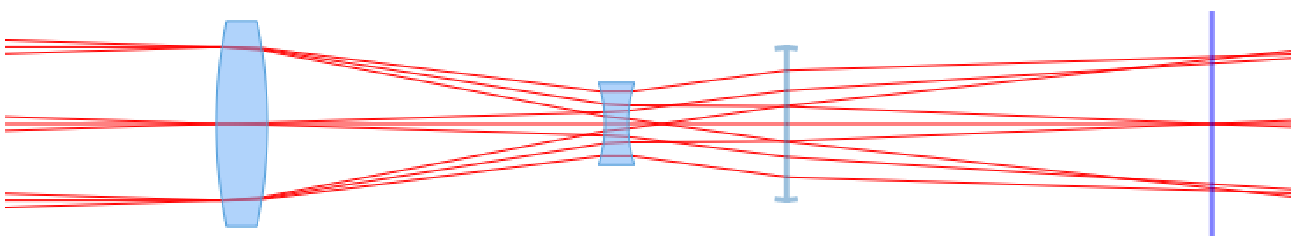
# Astronomical Observing Techniques 2019:
# Exercises on Telescopes
# (Due on 4 March 2019 at 11:00)
# (Revised on 26 February)

February 26, 2019

You will need the TOD software for most of these exercises. A free version of this software is available at `https://home.strw.leidenuniv.nl/~keller/TOD/tod.min.html`

## 1 Galilean Telescopes



*Example of a Galilean telescope; image not to scale.*

A Galilean telescope is a refractor telescope consisting of a large biconvex and a small biconcave lens, see figure above. The second lens should collimate the converging beam coming from the first lens.

a) Build such a telescope in the TOD software. Make sure that the magnification is on the order of 4. Use an incoming beam size of 25 mm.

b) Use a paraxial lens (a ideal optical lens without any aberrations) to simulate the eye. The paraxial surface will not introduce any additional aberrations other than the ones introduced by the telescope. Show a screenshot of the design software of your complete telescope, and write down all important lengths and distances.

c) Determine the performance of your telescope as function of field of view. Use the rms spot radius as your performance metric. Plot the rms spot radius as function of field angle. At which field angle does the rms spot radius double compared to the on-axis spot?

d) Determine the chromatic aberrations on-axis. Again, use the rms spot radius as your performance metric. Plot the rms spot radius as function of wavelength from 400nm to 700nm. At which wavelength(s) does the rms spot radius double compared to the minimum rms spot radius?

## 2 Cassegrain telescopes

A Cassegrain telescope is a reflector telescope consisting of a parabolic primary and 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 off-axis. In this exercise you will build a Cassegrain telescope and look at its performance.

a) We will start with simpler, Newtonian-style telescope with just a primary parabolic mirror. Use a parabolic mirror with a diameter of 81.15 mm and a focal length of 144.875 mm. Take a look at the spot diagram at the focus. What do you see? Can you guess what the grey circle indicates?

b) When putting a camera (or anything else for that matter) in the focus of a telescope it is useful to know how accurately it needs to be positioned. Use an *analytical* method to derive the tolerance of the positioning of the camera in focus, as a function of F-number of the incoming beam. Hint: at what defocus distance is the PSF still diffraction limited?

c) Check this distance by using the TOD software. If you didn't get a reasonable answer on the previous question, report on the correct tolerance using the TOD software.

d) Put in a secondary, hyperbolic mirror with a focal length of 22.669 mm. This secondary mirror should magnify the image by a factor $m = 7.84$. Compute *analytically* what the separation between the primary and secondary mirrors should be. Use the following formula:

$$m = -\frac{f_2}{f_1 - f_2 - s}, \tag{1}$$

where $s$ is the separation between the primary and secondary mirror, $m$ is the magnification of the telescope, and $f_1$ and $f_2$ are the focal lengths of the primary and secondary mirror respectively. Check this separation using the TOD software. The conic constant of the hyperbolic mirror can be found using

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

Hint: one of the focal points of the hyperbola has to be in the focus of the primary mirror, the other focal point is in the new focal plane of the telescope.

e) Show that your design is still free of aberrations on-axis and determine the minimum size (ie. diameter) of the secondary mirror so that there is no vignetting at a field angle of 0.5 degrees.

f) Cassegrain telescopes are notorious for their field curvature which is their main source of aberration for off-axis sources. Show that this is the case for your telescope as well. Assess the performance that would be achieved with your telescope if field curvature would be corrected perfectly. Hint: you can change the radius of curvature of the detector, something which is really hard to do with actual detectors.

# 3 Instrument location on a telescope

Discuss the advantages/disadvantages of an instrument in the Cassegrain focus of an equatorially-mounted telescope over an instrument located in the Nasmyth focus of an alt-azimuth telescope.