Designing a Telescope System

Telescope diameter = D
Telescope focal length = F
Eyepiece focal length = f
Eyepiece field of view = FOVe
Magnification = M
Resolution = R

D, F, f are in millimeters
FOVe is in degrees
R is in arcseconds

$$M = \frac{F}{f}$$

$$F/\text{number} = \frac{F}{D}$$

$$R = \frac{134}{D}$$

Astronomers don't just go out and buy a telescope and then use it. Whether it is for use on a satellite orbiting Saturn, or in an observatory, telescopes are designed 'from the ground up' by starting from a set of goals that the research needs to accomplish. The telescope is mathematically designed to meet these research goals.

The table to the left gives the basic quantities and formulae for designing a simple telescope system. Let's see how two different research goals can lead to very different telescope systems!

System 1 – Veronica has been an amateur astronomer for 20 years and especially enjoys photographing faint galaxies and nebulae. She has owned three telescopes and plans to sell them to fund her next system. She can afford a telescope with an aperture no larger than 20-inches (500 mm), and needs it to be a fast optical system with an F-number less than 3.0. She has a set of expensive eyepieces that she will keep. Her favorite one is a 20mm Plossl with a FOV of 68^{o}, and for best results she wants this eyepiece to have a magnification of no more than 50x. What is the best combination of aperture size and focal length for the telescope that will satisfy all of her needs?

System 2 – Leonard has a program of observing Saturn to keep track of its equatorial belt system. He needs a telescope with F/number > 10 and a resolution between 1/3 and 1/2 arcseconds. He has three eyepieces with focal lengths of f = 5mm, 10mm and 20mm that have provided him with high, medium and low magnification on his previous telescope, which got damaged in a house fire. He wants the 5mm eyepiece to provide no more than a magnification of 700x. What is the best system that meets his needs?

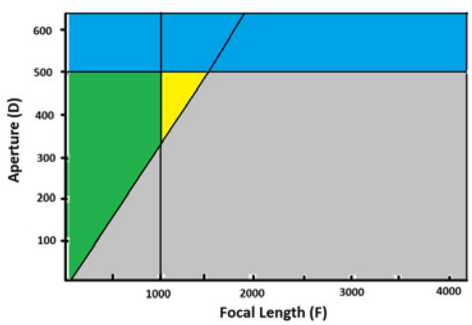
To design these systems, create a graph with the aperture diameter (vertical) and the focal length (horizontal).

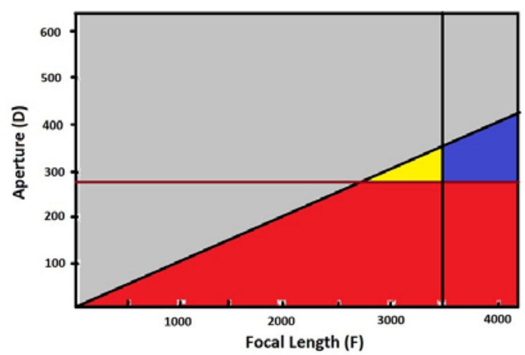
System 1 – Veronica has been an amateur astronomer for 20 years and especially enjoys photographing faint galaxies and nebulae. She has owned three telescopes and plans to sell them to fund her next system. She can afford a telescope with an aperture no larger than 20-inches (500 mm), and needs it to be a fast optical system with an F-number less than 3.0. She has a set of expensive eyepieces that she will keep. Her favorite one is a 20mm Plossl with a FOV of 68^o, and for best results she wants this eyepiece to have a magnification of no more than 50x. What is the best combination of aperture size and focal length for the telescope that will satisfy all of her needs?

Answer: D < 20 inches (500 mm); F/number < 3.0; f = 20 mm, FOVe=68^o, M> 50x

On the D vs F graph, draw a line representing F/D = 3.0 or F = 3.0D and shade the excluded region below this line (grey), which represents F/n > 3.0. Now draw a horizontal line for D = 500mm and shade (blue) the region above this line which represents D > 500mm. Magnification = F/f so we have F/f > 50 and F > 50f. For f = 20mm, the constraint is F > 1000 mm. Draw a vertical line at F = 1000mm and shade (green) all points to the left as the excluded region. The permitted regions is the one shown in yellow. The final plot (below left) should look like the one below.

An optimal system is near the middle of the yellow permitted region for which D = 450 mm and F = 1250mm. We then have F/number = 2.8, a magnification of 62, a telescope FOV of 68/62 = 1 degree, and a resolution of 134/450 = 0.3 arcseconds.





System 2 – Leonard has a program of observing Saturn to keep track of its equatorial belt system. He needs a telescope with F/number > 10 and a resolution between 1/3 and 1/2 arcseconds. He has three eyepieces with focal lengths of f = 5mm, 10mm and 20mm that have provided him with high, medium and low magnification on his previous telescope, which got damaged in a house fire. He wants the 5mm eyepiece to provide no more than a magnification of 700x. What is the best system that meets his needs?

Answer: F/number > 10; R = 1/3 to ½ arcseconds; M < 700x.
Draw a line representing F/number = 10 and shade (grey) the excluded area above this line which indicates F/number <10. For R = ½ arcseconds, draw a horizontal line at D = 270mm and shade the region (red) below this line that represents R > ½. The magnification M = F/5mm so for M=700 we have F < 3500mm. Draw a vertical line at F = 3500 and shade (blue) the excluded area to the right. The allowed region is in yellow in the diagram on the upper right.

The best system lies in the center of the triangle with D = 300mm and F = 3250 mm. This gives F/10.8; Resolution = 134/300 = 0.4 arcseconds; Lens magnifications of 650, 325 and 162.