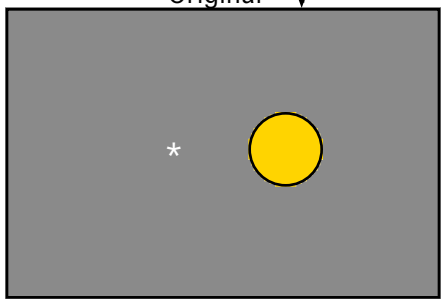
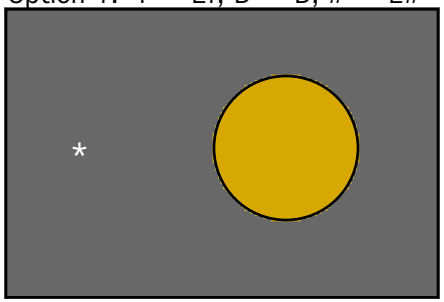
Aperture, Focal Length, and f-number in Astrophotography

Consider a photo taken with some camera/lens/telescope system with focal length f, aperture D, and f-number # (= f/D). In the photo are images of the full moon and a star located one lunar diameter from the edge of the moon. How will the images of the moon and the star change as the system parameters are modified?

Original



Option 1: f' = 2f, D' = D, #' = 2#

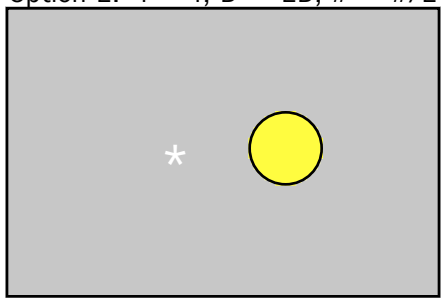


Option 1 -- Constant D: Use a lens with a focal length f' = 2 f and the same aperture D. The f-number is now #' = f'/D = 2 f/D = 2 #.

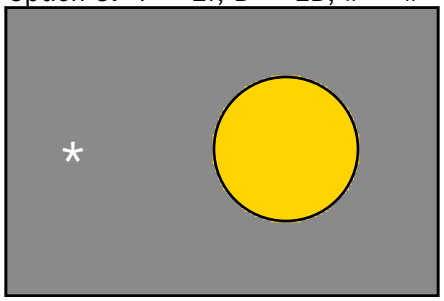
Larger f means higher magnification: The moon's diameter is doubled, the space between moon and star is doubled, but the star is still a point. Field of view is reduced.

Same D means the same amount of light is available from both the moon and the star. Because the moonlight is now spread out over a 4x larger area, a 4x longer time will be necessary to give the moon the same exposure as before. For the same reason, sky brightness will be lower for the same time. However, the same amount of starlight is being used to make the star's image; the same image brightness can be attained in the same time.

Option 2: f' = f, D' = 2D, #' = #/2



Option 3: f' = 2f, D' = 2D, #' = #



Option 3 -- Constant #: Use a lens with a focal length f' = 2 f and an aperture D' = 2 D. The f-number is now #' = f'/D' = 2 f/(2 D) = #.

Larger f means higher magnification: The moon's diameter is doubled, the space between moon and star is doubled, but the star is still a point. Field of view is reduced.

Larger D means 4x more light is available to form the images of both the moon and the star. But the additional moonlight is spread over 4x more area, giving the same exposure in the same time. Sky brightness is also the same. The additional starlight is concentrated on the point image, giving the same image brightness in 1/4 the time or 4x the brightness in the same time.

Option 2 -- Constant f: Use a lens with the same focal length f and an aperture D' = 2 D. The f-number is now #' = f/D' = f/(2 D) = #/2.

Same f means same magnification. The moon's diameter and the separation between moon and star are unchanged. Field of view is unchanged.

Larger D means 4x more light is available to form the images of both the moon and the star. The additional moonlight is spread over the same area as before, meaning the same exposure can be achieved in 1/4 the time. Sky brightness also increases, for the same reason. The additional starlight is concentrated on the point image, giving the same image brightness in 1/4 the time or 4x the brightness in the same time.

Summary:

Brightness of star images is controlled by aperture (D).
Brightness of extended sources and the sky is controlled by the f-number (#).
Size of extended sources and field of view are controlled by the focal length (f).