Point-Spread Function (PSF) Photometry

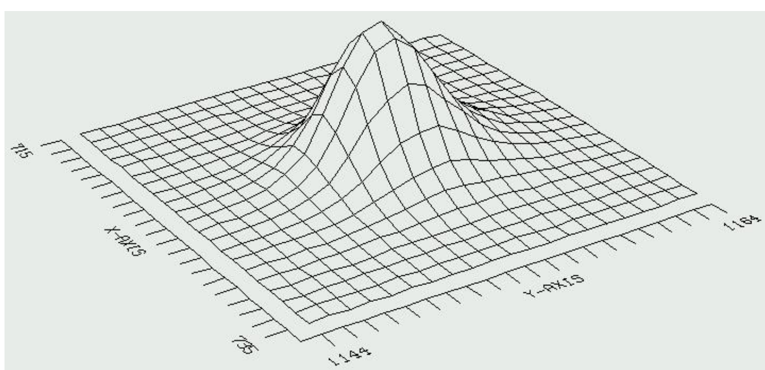
The Point-Spread Function

Stars are at such large distances that it is generally not possible to directly resolve the star from Earth and see any kind of detail about the star's surface. For that reason, stars are effectively point sources of light for us. The image of a star has a measurable size on an astronomical image for reasons unrelated to the star itself. First (and usually most importantly for ground-based observations), the turbulence in the atmosphere refracts the light in slightly different directions from moment to moment, causing the apparent position of the star to change. Over the course of an exposure, this broadens the star's image. This is called **seeing**. In relatively good weather and good observing sites, seeing can broaden a star's image as little as about $0\farcs5$, but more often it is $1''$ or more.

The telescope itself can also contribute to image broadening. **Optical distortion** due to imperfections in telescope focusing, or due to scattered light also result in a broader star image. If the **telescope tracking** does not properly follow a star's motion across the sky, or the telescope jitters while moving, the star image will also be broadened.

For space-based telescopes or adaptively corrected ground-based telescopes, **diffraction** is the fundamental limit. Larger telescopes have less diffraction, and produce sharper star images. However, if the telescope optics are not up to snuff, it will not be possible to reach the diffraction limit.

In either case, the star image is broadened, so that there is a particular two-dimensional pattern of brightness as a function of position on the image. This is the **point spread function** or **PSF**. The PSF will generally have a shape similar to a two-dimensional Gaussian (see the picture below), although it is often can be a little asymmetric. Different stars will have different brightnesses, and will have PSFs of different "heights", but the basic shape will be very similar from star to star.



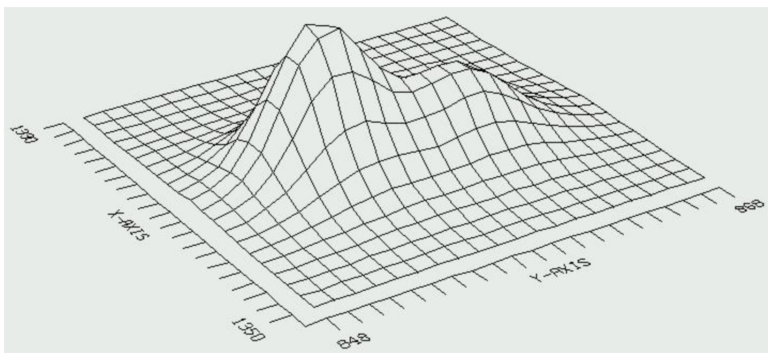
Photometry Methods:

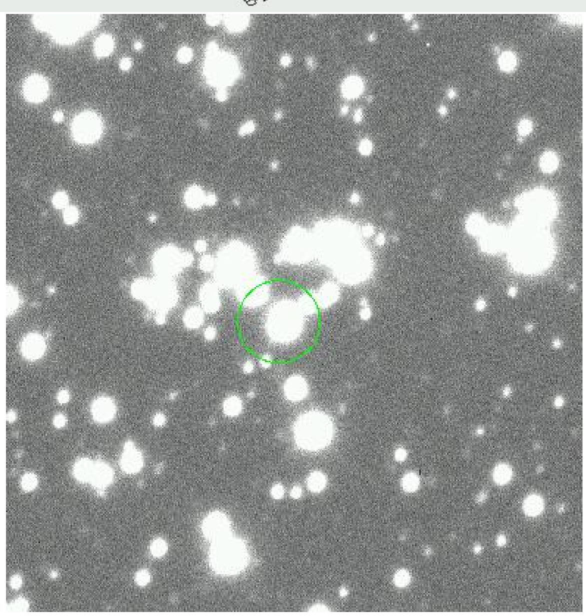
There are two main ways of measuring an apparent brightness for a star in your image. The first is *aperture photometry*, which involves simply adding up all of the counts representing light from the star within some circular aperture around the center of your star. Star images have very big tails though, and a significant amount of the star's light can be hidden at large distances from the center of the star's image in the background noise. It is usually not too useful to go after that light. Sky noise and undetected background sources can throw measurements off.

Aperture photometry also fails when you observe crowded star fields. In those cases, pixels can be receiving significant amounts of light from two or more stars. In this case, simple addition of pixels counts will give the wrong answer.

Profile fitting photometry uses the shape of the PSF to disentangle the light contributed by separate stars to an image where the stars overlap. If we know the shape of the PSF, we can *fit* that PSF shape to the actual distribution of counts on the CCD. In other words, the two-dimensional PSF is scaled "vertically" in total number of counts and "horizontally" in position on the CCD until it best fits the actual counts. From this fit, it is possible to derive the position of the star, the brightness (relative to other stars on the frame), and the error in the fit.

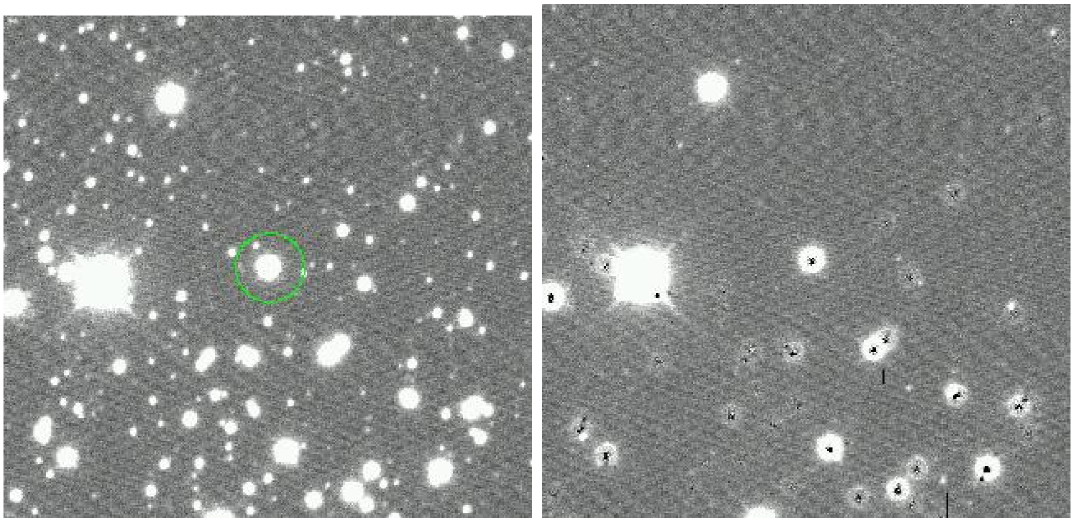
This is an improvement over aperture photometry when it comes to crowded fields because *overlapping* star images can be fit simultaneously with the same basic PSF shape as long as the stars are not so close together that the stars can't be separately resolved. The figure below shows two stars whose images overlap a great deal, but which can still be distinguished (barely) as separate stars.





Each isolated star image carries information about the shape of the PSF. By identifying large numbers of relatively isolated stars, we can do a kind of weighted average to get an optimum model for the PSF.

Below is an example of a relatively bad subtraction, both before and after:



Notice that the faint stars are mostly undetectable, while the bright stars look almost unchanged. That is a little misleading though. It is possible to do much better. With a perfect subtraction, the position of the star in the subtracted image will appear to be almost indistinguishable from the sky background.