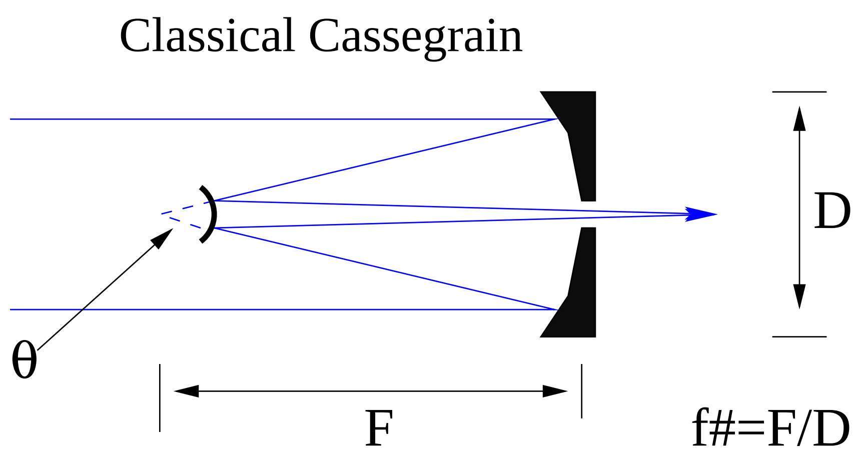
1 Imaging Cameras

1.1 Telescope configurations

First, a quick overview of telescope foci possibilities. Modern casegrain telescopes mostly fall into three camps. Classical cassegrain, Gregorian and Ritchey-Chretien.

Classical and Gregorian have parabolic primaries. For a classical cass design, the secondary mirror is placed in front of the primary focus and is a convex hyperbolic surface. In a Gregorian, the secondary is placed beyond the focus of the primary and is concave. The classical cass suffers from off-axis coma. The R-C design uses a hyperbolic primary and hyperbolic secondary figured to balance out coma and astigmatism. Great wide-field configuration.



It is also common to have wide-field imagers at prime focus. For any of these systems at prime you need to add a field corrector. For example, the f/5 parabolic primary of the Lick 3m has coma and astigmatism with coma dominating:

$$C = \frac{3\theta}{16f^2}$$

where θ = angle from the optical axis and f is the ratio of the primary mirror focal length to its diameter. For the 3m, the coma is $1''$ a $2\overset{\prime}{.}2$ off axis.

1.2 Plate Scale and sampling

The plate scale of any telescope is easily calculated. For small angles:

$$\theta = \frac{D}{F} = \frac{206265 \times D}{F}$$

where 206265 is the conversion factor to go from radians to arcsec.

The plate scale is the mapping of the angle θ to the diameter of the primary mirror.

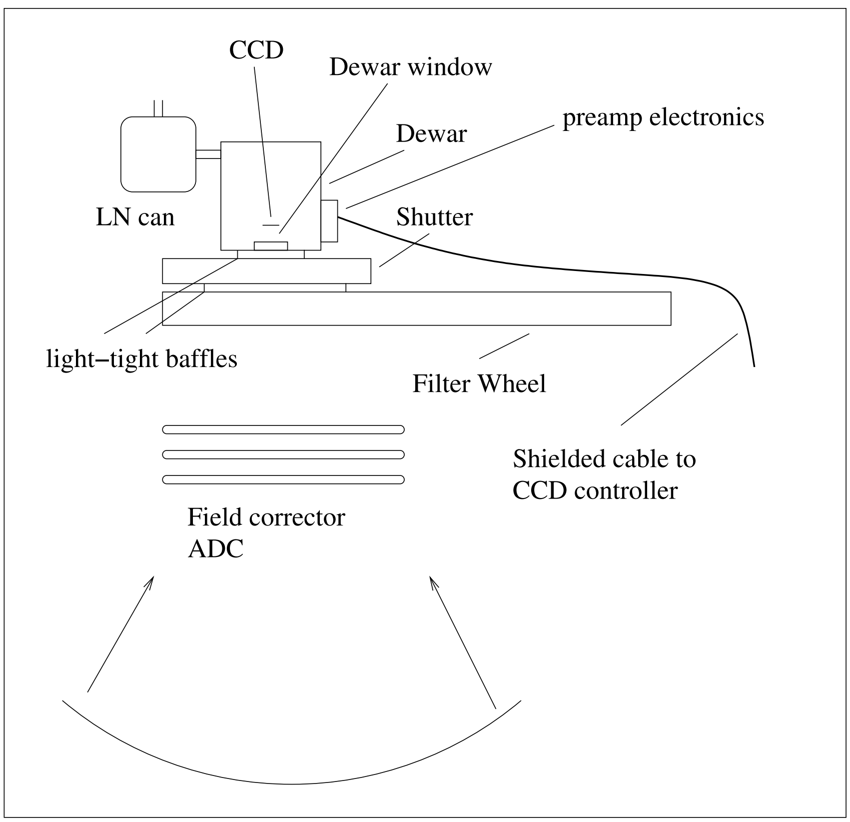
$$S = \frac{\theta}{D} = \frac{206265}{D \times f\#}$$

For a few UC telescopes, we have the following scales.

Telescope	Scale	$''/24\mu$ pixel
3m f/5 prime	$13''.76$/mm	$0''.33$/pixel
1m f/3 prime	$68''.7$/mm	$1''.65$/pixel
1m f/17 cass	$12''.1$/mm	$0''.29$/pixel
10m f/1.5 prime	$11''.46$/mm	$0''.27$/pixel*
10m f/15 cass	$1''.15$/mm	$0''.03$/pixel

2 Imaging Cameras

Most imaging cameras have the same basic parts. Below is a schematic of the Lick 3m prime-focus camera (PFCam).

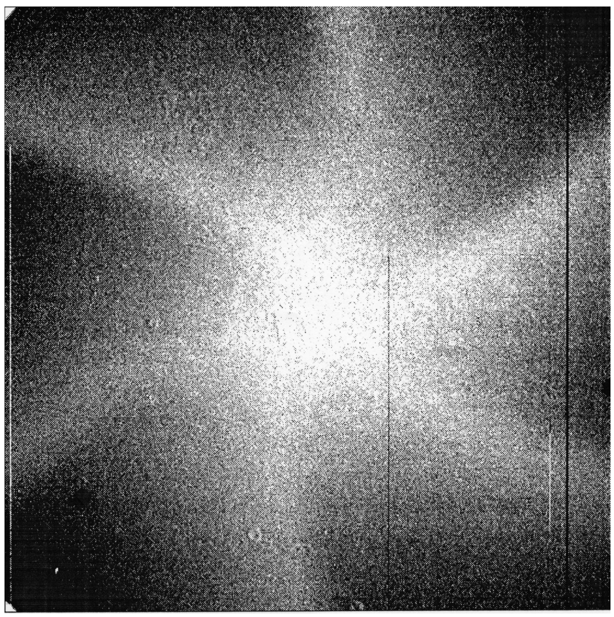


There are various considerations for each of the subcomponents. Below are listed some of the issues for the main components. The most challenging cameras in the last few years (it is 2004 as I write this) are the wide-field cameras with a focal plane paved with more than one detector.

2.1 Shutters

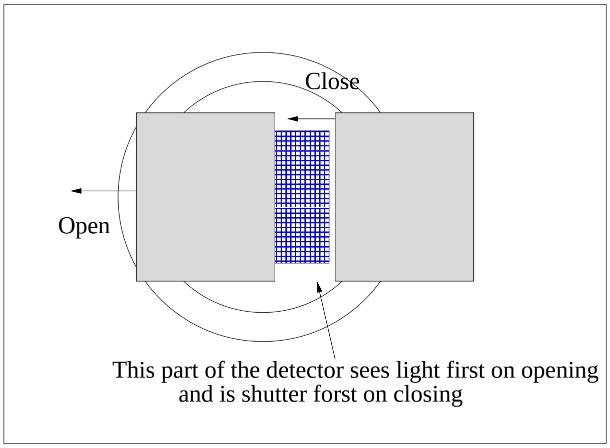
The standard shutter for many years was a multi-leaf iris shutter. As CCDs grew larger, the required shutter grew larger.

For the 2k x 2k 24μ pixel devices that became available in the 1990s required 3-inch diameter shutters that took about 50 millisec to open or close. This is too slow! The center gets exposed 5% longer than the corners. This is called "shutter vignetting".



Iris shutter vignetting pattern. This image is produced by dividing a short (1 second) exposure dome flat by a long (30s) exposure dome flat.

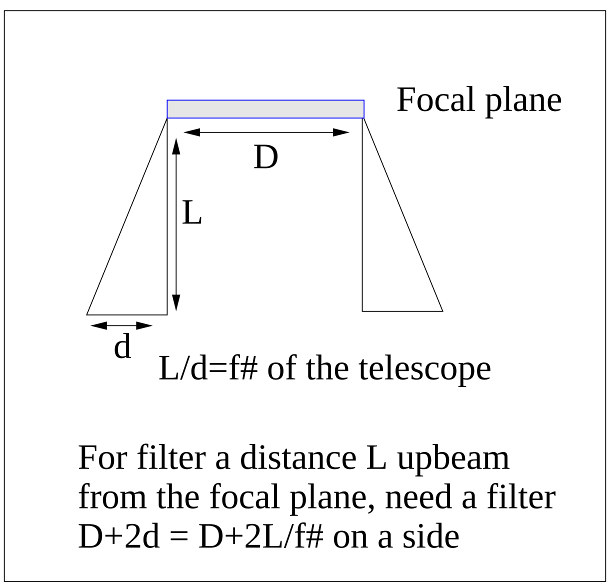
The solution has been to go to a 35mm camera style double slide system. These can be driven pnematically or with precision drives. In this scheme, all points on the CCDs are illuminated for the same total time, but not simultaneously. It is crucial that the crossing time of the two blades is the same to high precision! Note that for some imaging spectrometers, the shutter is in the collimated beam so there is no vignetting even with a slow iris shutter.



Double-slide shutter for large CCDs and mosaic arrays.

2.2 Filter Wheel or Slide

For imagers at prime focus, the filterwheel is typically in a converging beam. This means that the closer you put the filters to the dewar window, the smaller they need to be. Good quality filters are expensive in large sizes ($10k or more per filter for filters 6 inches on a side) so smaller is better. The problem with putting the filters too close to the CCD is that imperfections in the filter, scratches, smudges and dust get in better and better focus as the filter gets closer and closer to the CCD (and focal plane). This increases the precision with which you must reposition the filter after moves in order to remove the imperfections in the flat-fielding process.



The geometry for making sure your filters don't vignette the beam.

2.3 Drift Scanning

One interesting option that has become more common is to work in the drift-scan mode. An example of this is the Sloan Digital Sky Survey (the imaging portion). THe idea is to park the telescope, let the sky drift by and clock out the CCD at the rate the sky goes by. The accumulating charge "follows" the star image along the CCD.

The sky goes by at $15''$/second at the equator and faster by $1/\cos(\delta)$ as you move in declination toward the pole. So, at the equator, with PFCam at the Lick 3m, an object drifts across the $10'$ field in 47.8 seconds.

What is the point? You get superb flat-fielding because every object gets measured on a large number of pixels. This also is a very time-efficient way to observe. The CCD is continuously reading out while you are observing. You point the telescope and start scanning. The main problem is that the sky moves along a Great Circle and your scan doesn't for all pointings not on the celestial equator.

Dennis Zaritsky built a clever Great Circle Scanning camera in use at Las Campanas to more closely follow the sky at declinations other than $0°$. At low celestial latitude you can get away with a straight scan although you do need to have built into the dewar the ability to carefully line up the rows with E-W.

2.4 Some camera references

- Epps & Fabricant, 1997, AJ, 113, 439 (Field corrector)
- Wynne, 1989, MNRAS, 236, 47 (Field corrector)
- Aldering & Bothun, 1991, PASP, 103, 1296 (Focal reducer)
- Cuillandre, et al., 1996, PASP, 108, 1120 (Wide-field mosaic imager)
- Mclure, et al., 1989, PASP, 101, 1156 (Fast-guider camera)
- Gerzari, et al., 1992, PASP, 104, 191 (Mid-IR camera)
- Boeker, et al., 1997, PASP, 109, 827 (Near-IR Camera)
- Zaritsky et al., 1996, PASP, 108, 104 (Great-circle camera)