Real cameras

- Real cameras need lenses
  - Focus now depends on distance (unlike pinhole cameras)
  - Aberrations and distortions
- Brightness falls off towards edges
  - $\cos^4(\theta)$ falloff due to projection onto flat surface
  - Vignetting
- Chromatic aberration
  - Light at different wavelengths follows different paths; hence, some wavelengths are defocused (index of refraction is a function of wavelength).
- Scattering at optical surfaces (flare)
  - Light is reflected off each surface it encounters (a very difficult source of noise to purge or calibrate for)
- Capture process has many noise sources with different properties
  - Photon capture (Poisson statistics)
  - Thermal noise (Dark current)
  - Readout discretization noise
  - Noise in electronics

Depth of Field

Unlike a pinhole camera, a camera with a lenses has limited depth of field (only a limited range of depths are in focus at once)

The reason for lenses

Need bigger hole to get more light, but ...

The thin lens

Focus depends on depth. When $z=\infty$, this is same equation as a pinhole.

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$
Spherical aberration

Aberrations occur because the imaging equation is not exact.

Vignetting: Fall-off in brightness is due to blockage of the optical path occurring more for off-axis light.

Would get to sensor if there only was only one lens element, or if it was less off axis.

Brightness falls off due to projection onto a plane

Distance to image plane increases by $1/\cos^2(\theta)$. Red line is $1/\cos(\theta)$ times as long as green line.

Taking both effects into account, the blue line is longer than the green one by a factor of $1/\cos^4(\theta)$.

Since images are 2D, expansion in one direction needs to be squared to give the change in area. So, the area receiving light from the “sun” increases by a factor of $1/\cos^4(\theta)$, and the brightness falls off by a factor of $\cos^4(\theta)$. 

Would get to sensor if there only was only one lens element, or if it was less off axis.