# PHSX815_Project2: Modeling instrumental noise and astronomical signals

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## 1 Introduction

Modern astronomy relies on Charged Coupled Devices (CCDs) and other such imaging sensors for recording astronomical data. All of these technologies rely on photons exciting the electrons in some semiconducting material. Counting those electrons becomes a proxy for the number of photons detected. Because of this, recording astronomical data is a counting problem, and thus we can expect the number of photons recorded on a CCD to be distributed as a Poisson distribution. As with all electronic measurements, we must also be aware of sources of noise. Since the noise appears in our counts, we can also expect it to be distributed as a Poisson distribution. However, the rate at which noise occurs, $\lambda_{noise}$, and the rate at which photons fall onto the detector, $\lambda_{star}$, depend nontrivially on other confounding factors. We model detector noise and atmospheric seeing to determine when we can distinguish between an astronomical signal and a noise source.

## 2 Problem Statement

While we are able to characterize the average noise on a detector, that doesn't mean we will know $\lambda_{noise}$ exactly throughout the entire observation. For instance, changing dome conditions or poorly maintained equipment can cause nontrivial changes to $\lambda_{noise}$. For our present purposes, we will model how the noise characteristics of the detector vary with temperature. Because we are dealing with a semiconducting system, how the electrons are distributed in energy depends on the Fermi-Dirac distribution (Equation 1).

$$P\left(E\right) = \frac{1}{1 + \exp\left(\left(E - E_F\right)/k_B T\right)} \tag{1}$$

For silicon, the band gap is about $1.12\,eV$ and the Fermi energy is approximately half of the band gap energy. Thus, we can model the average number of noise electrons from this distribution.

Suppose our detector is a single pixel. This is a small detector area. Because of this, we may be collecting light from an area of the sky of a few arcseconds or less. The starlight from space must pass through the atmosphere, where thermal variations cause the light to stochastically refract. This is known as atmospheric seeing. While we can measure the average seeing for a night of observation, it is a stochastic process and therefore causes the apparent position of an object to vary over an exposure. With our small detector area, seeing will become a significant factor the photon counts we measure. A point source of light passing through a circular aperture produces an intensity pattern given by the Airy disk (Equation 2), where $J_1\left(x\right)$ is the Bessel function of the first kind, $q$ is the radial distance from the observation point to the optical axis, $R$ is the distance from $q$ to the aperture, $a$ is the radius of the aperture, and $\lambda$ is the wavelength of light.

$$I\left(\theta\right) = I_0 \left( \frac{2J_1\left(2\pi a q \lambda^{-1} R^{-1}\right)}{2\pi a q \lambda^{-1} R^{-1}} \right) \tag{2}$$

Atmospheric seeing also is not completely uncorrelated, since the air currents in the atmosphere are continuous. There will be some small-scale correlation between the observed positions. Therefore, we can model how the image moves by sampling the Airy disk pattern using Markov Chain Monte Carlo (MCMC).