PHY517 / AST443: Observational Techniques

Homework 5

1. Review the slides for lectures 4, 5, 6.
   (a) *(3 pts)* Post one question per lecture to #lectures.
   (b) *(3 pts)* Try to answer one question per lecture in #lectures (more than one answer per question can be given!). If you are using material other than the lecture slides, please cite it (e.g. webpage links, ChatGPT).

2. The Poisson distribution describes the probability to observe x events during a certain measurement interval, given a mean rate μ:

$$P_{\mathrm{P}}(x|\mu) = \frac{\mu^x}{x!} e^{-\mu}$$

   Note that x has to be a positive integer. Examples of where the Poisson distribution applies are counting experiments. In optical astronomy, we often *count* the number of electrons registered in the CCD due to incoming photons from a celestial object. The Poisson distribution is asymmetric for low rates $\mu \lesssim 10$, and becomes the Gaussian distribution for high rates $\mu \gg 1$. μ is both the mean and the variance of the Poisson distribution.
   (a) *(2 pts)* Plot (on a single panel) the Poisson distribution for rates of $\mu = 1, 2, 4, 10$.
   (b) *(2 pts)* For $\mu = 30$, plot the Poisson distribution, as well as a Gaussian distribution of mean $\mu = 30$. What do you need to set the standard deviation of the Gaussian to, so that the two distributions have the same variance?
   (c) *(1 pts)* You measured $N = 10,000$ electrons from a star. What is the uncertainty on this measurement?

3. For the following, consider the main CMOS sensor in our ZWO ASI2600MM DUO camera. When necessary, look up the relevant properties on its spec sheet.
   (a) *(2 pts)* For an unbinned image, how many pixels would you expect to fall outside the 1σ interval for a random Gaussian process? How many for the 2σ, 3σ, 4σ, 5σ, 6σ intervals? What is the lowest level of (integer) σ-clipping that would be justified to not remove entirely random variations in count level? You can calculate the corresponding integrals of the normal distribution using the `scipy.stats.norm` package, or look them up at `https://en.wikipedia.org/wiki/68-95-99.7_rule`.
   (b) *(2 pts)* For an image that is binned 4×4, how many pixels would you expect to fall outside the 1σ interval for a random Gaussian process? How many for the 2σ, 3σ, 4σ, 5σ, 6σ intervals? What is the lowest level of (integer) σ-clipping that would be justified to not remove entirely random variations in count level?

(c) The read noise of the camera is fixed - it is not a counting process, and thus does not depend on exposure time or number of counts. It quantifies the standard deviation of a roughly Gaussian distribution of pixel values around the bias level in the absence of any signal.

   i. *(3 pts)* If there were no background sky, at what exposure time does noise from the dark current start to dominate over the read noise, when the camera is operated at 20°C? How about at 0°C? Consider two gain settings, 0 and 100. When you prepare to observe a faint source, which gain setting should you use? Should you cool the camera?

   ii. *(2 pts)* How large does the background sky level need to be (in counts per pixel), so that statistical noise from the background sky dominates over the read noise?

4. Photometry

   (a) *(6 pts)* Complete Tutorial 5. Submit a screenshot of the image in ds9, with the object catalog overlaid, a `Compass` region to show the North and East directions, and a scale bar (`Line` region).

   (b) *(3 pts)* Compare the flux measurement of the star at (300.236734, +22.658612) between SExtractor and HW3. Comment on any discrepancies.

   (c) *(3 pts)* Recall that the star at (300.237300, +22.846978) has a magnitude of $R = 7.50$. Use the SExtractor flux measurements (and uncertainties) to calculate the magnitude of "your" star, and its uncertainty.