Astronomical Observing Techniques 2019:
Exercises on Noise
(Due on 18 March 2019 at 11:00)
(Deadline was extended from 11 to 18 March)

March 6, 2019

1 Photon noise and more

When counting photons with a detector, we have an inherent uncertainty in the time interval between arriving photons and therefore also the total number of photons counted during an exposure. The Poisson distribution describes measurements made by counting uncorrelated events such as the arrival of photons. The mean and variance for Poisson distribution is given by:

$$\mathrm{E}(X) = \mathrm{Var}(X) = \mu \quad \text{for } X \sim \mathrm{Poisson}(\mu) \tag{1}$$

with μ being the mean number of events.

a) Maaike wants to measure a star's brightness with a precision of 5 percent. She has a perfect imaging system and a noiseless detector. How many photons does she need to count? How many photons does she need to count if she wants a relative precision of 0.5 percent?

b) Maaike realizes that when she points her telescope to an empty part of the sky near the star, she measures a background count of 50 percent that of what she measures for the star. Now how many measurement photons would Maaike need to achieve a relative precision of 5 percent on the star' brightness taking into account the sky background? What about for 0.5 percent relative precision?

c) Suddenly Maaike realizes that her noiseless camera has a readout noise of 4 electrons. How many photons does she now need to count to reach a relative precision of 5 percent? What about a relative precision of 0.5 percent?

2 HST, JWST, and ELT detection limits

The detection limit for HST (D=2.4m) for certain applications is m=26.0. Assume that this detection is limited by background light.

a) What is the magnitude threshold for the same case assuming the 6.5m telescope aperture of JWST? Assume both telescopes are diffraction limited and the background for JWST is 1.0 magnitudes per square arcsec fainter than for HST.

b) What is the magnitude threshold for the ELT with an aperture of 39m? Assume the background for the ELT is 2 magnitudes per square arcsec brighter than for HST.

3 Significance of a detection

Maaike goes out and measures two stars with a small detector. For each star she makes sure that the source source falls completely within the central pixel. She has the following measurements:

$$\begin{bmatrix} 21 & 20 & 15 & 19 & 9 \\ 30 & 11 & 15 & 19 & 22 \\ 20 & 14 & 37 & 19 & 21 \\ 23 & 25 & 30 & 18 & 9 \\ 20 & 24 & 25 & 11 & 26 \end{bmatrix} \tag{2}$$

and

$$\begin{bmatrix} 23 & 30 & 14 & 9 & 22 \\ 23 & 17 & 15 & 18 & 21 \\ 21 & 14 & 50 & 19 & 17 \\ 26 & 25 & 20 & 29 & 19 \\ 18 & 22 & 11 & 18 & 26 \end{bmatrix} \tag{3}$$

Has Maaike detected her star in either of these two measurements? Explain why or way not?