# Observational Astrophysics I, 2010/2011
# Week 8 – Exercises

## 8.1 Adaptive optics systems

At the ESO Very Large Telescope on Cerro Paranal, Chile, a typical value for the Fried parameter $r_0$ = 60 cm at 2.2 $\mu$m. The wind speed is typically 10 m $s^{-1}$.

a. What is the Greenwood frequency required for full Adaptive Optics corrections in the $K$-band?

b. How many actuators are needed for an AO system operating in the $K$-band, mounted on an 8 m telescope?

d. Assuming that 100 photons are needed per sub-aperture from the AO guide star in order to determine the wavefront error, calculate the $V$-band magnitude of the guide star needed for the AO correction. Assume that the wavefront sensing is done in $V$ and the total system throughput (incl. atmosphere) is 50%.

d. Answer questions (a) and (b) for an AO system working in the $V$-band under the same conditions

e. How much brighter would a guide star have to be in order to be suitable for $V$-band AO as compared to $K$-band?

## 8.2 Adaptive optics imaging of point sources

A commonly used filter for near-infrared observations is the $Ks$ filter, which has a central wavelength of $\lambda_c = 2.16\mu$m and a width of $\Delta\lambda = 0.27\mu$m. At Paranal, a typical value for the sky background in $Ks$ is 13 mag arcsec$^{-2}$.

In this exercise we compare seeing-limited and AO-assisted observations of a point source (e.g. star). Recall that the number of counts $N$ for an object of magnitude $m$ can be estimated as

$$N = 10^{(-0.4m)} \frac{\Delta\lambda}{\lambda_c} \times \frac{F_\nu}{h} \times T_{\rm tot} \times A_{\rm tel} \times t_{\rm exp}$$

where $F_\nu$ is the flux density of a source with $m = 0$ at $\lambda_c$, $T_{\rm tot}$ is the total transmission of the system, $A_{\rm tel}$ is the collecting area and $t_{\rm exp}$ is the exposure time. For the $Ks$ band, $F_\nu(Ks = 0) = 6.5 \times 10^{-24}$ W m$^{-2}$ Hz$^{-1}$.

a. For a 5 min AO-assisted exposure, estimate the magnitude at which a S/N of 10 is obtained. Assume:

   - a telescope diameter of 8.2 m
   - a total transmission of $T_{\rm tot} = 25\%$
   - that photometry is carried out in an aperture with a radius corresponding to the first minimum in the Airy pattern
   - all light from the source is included within this aperture.
   - the noise is completely dominated by Poisson noise from the background

b. Do the same calculation for the seeing-limited case for the same assumptions as above, except for an aperture radius of 0.5″

Signal-to-noise estimates are generally made with Exposure Time Calculators (ETCs) provided by the observatory. You can access the ETCs for telescopes at ESO via `http://www.eso.org/observing/etc/`

c. At the link above you will find the ETC for the NACO adaptive optics system at the ESO VLT. Compare your S/N estimates from (a.) with those provided by the ETC. Most of the parameters can be left at their default values - the main ones you may want to adjust are [Target Magnitude], [Sky Conditions] and [Aperture radius] (under Results). Note that the ETC can compute either the exposure time required to reach a given S/N ratio, or the S/N ratio obtained for a given exposure time. The exposure time is the product of the fields DIT (Detector Integration Time) and NDIT (Number of Detector Integrations). For $Ks$ observations it is safe to use the Non-chopping observing mode.

d. Compare your S/N estimate from (b.) with those provided by the ETC. For seeing-limited observations, select the HAWK-I instrument.

e. Given the greater depth of the AO-assisted observations, why don't we use adaptive optics for all (near-infrared) observations?