Astro 500 Homework #2

Due Tuesday 14 Feb, 2017 8:33 AM

Use definitions and numbers given in the class notes. Show all work.

1. Adaptive optics (AO) systems offer gains in sensitivity by reducing the size, θ, of the point-spread-function (PSF), or θ_{PSF}. Sensitivity gain is gauged by the decrease in exposure time required to reach the same signal-to-noise (S/N).

a) In which noise regimes is this gain realized?

b) Is the gain realized for extended sources with structure $\theta >> \theta_{PSF}$?

To implement AO requires adding optics into the observing system, introducing typically 3 to 6 more surfaces where photons must either transmit or reflect. Some photons are lost from each surface from unwanted absorption, reflection, or scattering. Losses can be minimized by applying coatings, but losses still can be as large as 8% per surface, and are difficult to reduce below 1% per surface.

c) For a given telescope, work out the proportionality relation for stellar sources between exposure time, t, to reach a given S/N, the system efficiency, ε, and θ_{PSF} in the relevant regimes.

d) [*Grad students required only*] Work out the expression for the effective system efficiency, DQE_{sys}, as a function of θ_{PSF}, the number of surfaces introduced by the AO system, and the losses per surface in the three cases of being source-noise limited, sky-noise limited, and detector-noise limited.

For WTTM (WIYN Tip-Tilt Module, a low-order AO system) the number of added surfaces is 4 and the improvement in θ_{PSF} is about 0.1 arcsec when the uncorrected PSF is between $0.4 < \theta_{PSF} < 0.8$ (arcsec).

e) How good must the coatings be on each new surface (quote in % losses) for the system sensitivity to break even when the uncorrected $\theta_{PSF} = 0.8$ arcsec? Consider all relevant noise regimes. Are such coatings feasible?

f) The same for the uncorrected $\theta_{PSF} = 0.5$ arcsec?

g) If you learn the coatings have 3% losses per surface and the median, uncorrected $\theta_{PSF} = 0.8$ arcsec, would you choose to use WTTM to enhance point-source sensitivity? Does this depend on noise regime?

h) [*Grad students required only*] Calculate the change in DQE_{sys} in these conditions when adding in WTTM.

2. WIYN has a 3.5m circular primary mirror with a 17% central obstruction (due to other optics). The telescope system has three mirrors (including the primary), each with 89% reflectivity, independent of wavelength for $0.3\ \mu m < \lambda < 3\ \mu m$. The ODI CCD camera has fore-optics with 8 surfaces each with 1.5% reflection losses per surface, a detector QE of 70% in the *I*-band, a read-noise of 9 e- rms, and a plate-scale of 0.11 arcsec/pixel. Assume the sky foreground is all in a uniform continuum, and that there is no moon.

a) What is the limiting exposure time to remain sky-limited in the *I*-band in median seeing conditions?

b) Repeat the calculation for a 1% narrow-band filter centered in the *I*-band, i.e., $\Delta\lambda/\lambda=0.01$.

Now consider WHIRC, with 20 e- rms read-noise, plate-scale of 0.098 arcsec/pixel, a detector QE of 70%, in the K_s-band where the median seeing is 0.5 arcsec, and the sky foreground is 12.9 mag arcsec^{-2}. The zero-point for the K_s filter is the same as for the *K*-band, except the band-pass is slightly bluer and narrower: $\lambda = 2.17\ \mu m$, $\Delta\lambda = 0.34\ \mu m$. WHIRC has fore-optics (including the dewar window) with 8 surfaces, each with 2% losses.

c) What is the limiting exposure time to remain sky-limited in the K_s-band in median seeing conditions?

d) Repeat the calculation for the Brγ filter with $\lambda = 2.162\ \mu m$, $\Delta\lambda = 0.0215\ \mu m$.

3. [*Grad students required only*] Determine the read-noise (e- rms) and the gain (e-/DN) using the photon propogation method for the data set to be found at this url:
http://www.astro.wisc.edu/~mab/education/astro500/hw/hw2_dataset.html
Include in your write-up a graphical presentation of the results of your analysis showing the gain and read-noise. Explain how you made the calculation, and justify your approach.