Optical/NIR Problem Set

Pre-amble: This assignment covers material from the lectures in the first half of the course from Luc Simard (Q1 & 2), Dave Anderson (Q3 & 4) and Tim Hardy (Q5 & 6). If you have queries about the assignment questions, please contact the relevant lecturer directly (email addresses below). Your answers will be marked by the lecturers, not me. Therefore your answers should be submitted to me electronically by the assignment deadline (Feb 16) so that I can forward them to Luc/Dave/Tim by email.

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Q1:

A) Why is the primary mirror of most telescopes circular?

B) What are the pros and cons of monolithic and segmented primary mirrors?

C) Telescope designers always try to make the top-end structure of the telescope (including the struts supporting the secondary mirror) as light and thin as structurally possible. Explain why.

Each answer should include a scientific and technical rationale. Expected length for this question ~ 1 page.

Q2:

A) The size of a seeing-limited spectrograph must increase linearly with the diameter of a telescope to maintain a given spectral resolution. Describe the origin of the fundamental scaling law – you can use schematics and/or mathematical derivations.

B) What currently sets the limit on the maximum size of a spectrograph? What are some of the design strategies that spectrograph builders have used to get around this limit?

C) Why are some spectrographs at the Nasmyth focus? Describe the scientific and technical reasons. Does the choice depend on the type of spectrograph?

Expected length for this question ~ 1 page.

Q3:

Plan for a new TMT instrument. The TMT science case has identified the detailed study of galaxies at a redshift of 2-3 and a search for "first light" objects as being design reference missions for a Multi-Object Adaptive Optics integral field spectrograph. The NFIRAOS+IRIS integral field unit already have the appropriate spaxel scale and spectral resolution (8 mas spaxels and R~4000) to observe one of these objects at a time. Describe a MOAO instrument that would be 10x more efficient than NFIRAOS + IRIS (otherwise, the cost of a new instrument probably isn't worth it).

There is no unique solution, but try to find an instrument architecture that achieves the efficiency improvement (in terms of exposure time to reach a background-limited point source). Assume a target density is 5500 targets/square degree and observations are made in H-band. Assume MOAO systems have an additional 100nm RMS open loop wavefront error and an additional 100 nm of instrumental error (due to using slicer rather than lenslet IFUs). Assume Telescope errors, AO system uncorrectable errors, Servor lag, WFS noise, and tip/tilt residual errors are the same. NFIRAOS+IRIS will have a throughput of 30%. With fewer surfaces, assume an MOAO instrument will have a throughput of 35%.

List the field of regard, expected Strehl ratio in H-band, number of probe arms, number of LGS, and any changes to the AO architecture (# of supapertures or # of DM actuators).

If you can, comment on the elements of an MOAO system that are easier or harder to produce on an 8 m telescope.

Table 1: Simplified TMT Wavefront Error Budget

Error Source	**RMS WFE**	**Notes**
Telescope errors	62 nm	Pupil misregistration, Dome and Mirror seeing, print-through, etc.
AO system uncorrectable errors	98 nm	DM/WFS misregistration, failed actuators, DM flattening, LGSF errors, RTC numerical precision, etc.
DM fitting error	78 nm	+ aliasing error
Tomography errors	98 nm	1 central LGS, 6 LGS on 70 arcsec diameter ring
Servo Lag	28 nm	
WFS noise	54 nm	Aliasing, WFS noise
IRIS instrument	40 nm	
Tip/Tilt residual	50 nm	
TOTAL	**192 nm**	

Q4: In your own words, define the coherence length r_0 and the isoplanatic angle θ_0 and why they are important for ground-based observations in the optical and NIR. Evaluate r_0 and θ_0 for the following three turbulence profiles at two wavelengths: 0.5 μm and 2 μm. Be sure to state your units at each step of your derivations.

a) From h=0 to h=1 km, C_N^2 (h) = 5 x 10^{-16} $m^{-2/3}$. From h =1 km to top of atmosphere, C_N^2 (h) = 0.
sec ζ = 1 (zenith angle of 0).

b) From h=0 to h=1 km, C_N^2 (h) = 2 x10^{-16} $m^{-2/3}$. From h =1 km to 12 km, C_N^2 (h) = 1 x 10^{-17} $m^{-2/3}$.
sec ζ = 1 (zenith angle of 0).

c) Same as b) but zenith angle of 50 deg (elevation angle of 40 deg above horizon).

Think about these results. Comment on the implications these calculations have for AO systems.

Notes for Q3 and Q4:
1) Be careful. The usual unit for r_0 is cm. The usual unit for C_N^2 is $m^{-2/3}$. The usual unit for altitude is km. The usual unit for θ_0 is arc seconds. So there's plenty of room for units confusion here. Give your final answers for r_0 in cm and for θ_0 in arcseconds on the sky.
2) Remember that these are real integrals, so not just sums. *(Credit for this problem to Claire Max)*

Q5:

Describe four of the imperfections in CCD measurements, their causes, and means of mitigating them.

Q6:

A) Describe the difference between Fowler and Up-the-Ramp sampling, and the advantages/disadvantages of each.

B) An instrument has a HAWAII-2RG (2048x2048) array which is read out at 100kHz through 16 outputs. Noise for a *single* read is 15 e-. You want to observe a source that will generate 0.5e-/s in a pixel. Calculate the SNR for a 60 second observation using up-the-ramp sampling and using Fowler sampling. What is the optimal Fowler multiple? Assume read noise dominates.