<u>Mock Exam – Astronomical Telescopes and Instruments 2020</u>

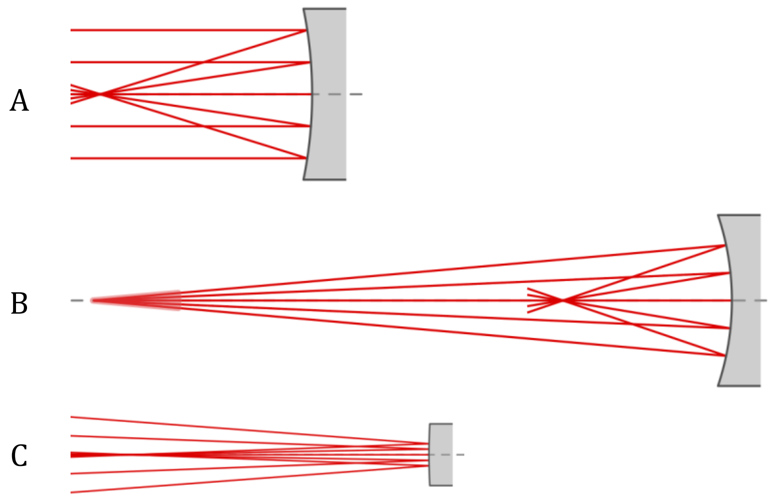
Name: ______________________________

Student number: _______________________

Notes:

- <u>Return this form together with your solutions.</u>
- The total time for the exam is 3 hours.
- You can use and bring with you anything on paper.
- No electronic devices with internet connectivity.
- The maximum number of points for each question is indicated in brackets.
- The maximum number of points is 40.
- The exam grade is calculated as 10*(achieved exam points/40pts).

1. Conic Constants [6pt]



The figure above shows three different mirror configurations (A, B and C).

a) [3pt] Indicate for all three what type of surface shape (conic section) would provide the best on-axis performance.
b) [3pt] Give the possible range for the conic constant for those conic sections.

2. Tilted Filter in Converging Beam [15pt]

A very simple instrument in the focus of a telescope consists of a filter and a camera. The filter is in the converging beam in front of the camera. To avoid ghost images due to multiple reflections in the plane-parallel filter, the filter can be tilted. The focal ratio of the telescope is D/f (aperture diameter D and focal length f), the filter has a thickness t, index of refraction n, and a tilt angle θ (angle between the optical axis of the telescope and the normal of the filter surface).

a) [3pt] When the filter is not tilted at all, show that the focus is shifted by $t(n-1)/n$ along the optical axis as compared to the focal position without the filter.

b) [3pt] Show that for small tilt angles θ the image is moved perpendicular to the optical axis by $t\theta(n-1)/n$.
c) [3pt] Show with a sketch and simple optical arguments that the filter creates spherical aberration.
d) [3pt] Show with a sketch and simple optical arguments that the filter creates astigmatism when tilted.
e) [3pt] What could be done to avoid the ghost reflections off the filter so that it can be used at normal incidence?

3. Polarization and Interference [4pt]

A beam from an unpolarized, quasi-monochromatic source is split into two orthogonally, linearly polarized beams that are subsequently allowed to interfere on a detector. The path-length of one of the beams can be changed so that the intensity can be measured as a function of path-length variation.

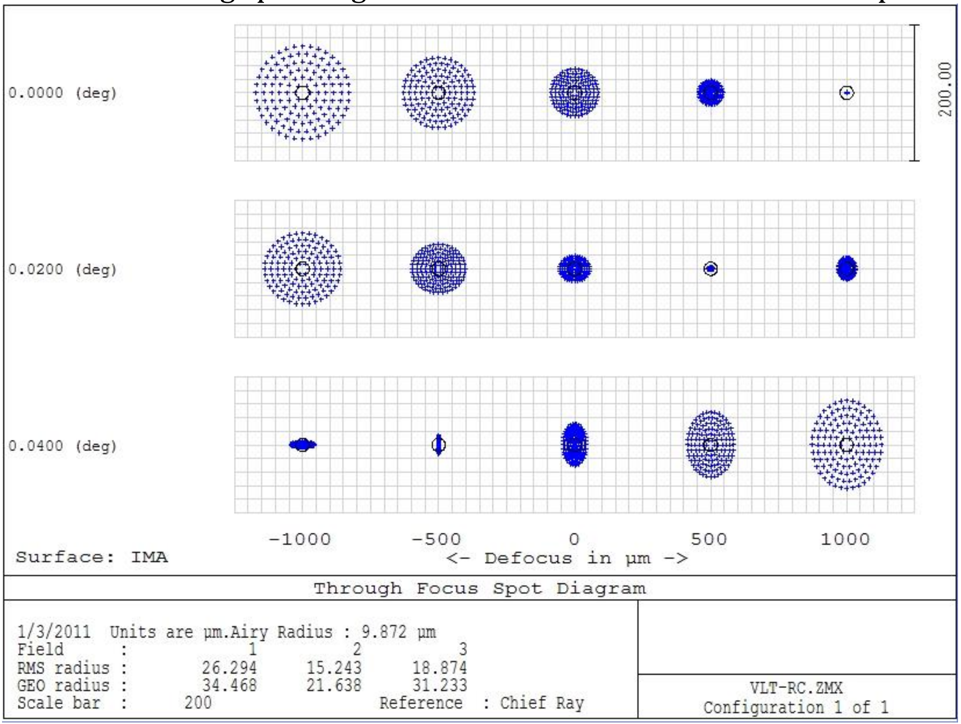
a) [2 pt] Show that no interference fringes can be detected in intensity. **Hint**: Use Jones vectors.
b) [2 pt] Show that when adding a linear polarizer in front of the detector at an angle of 45 degrees with respect to both polarization directions, interference fringes can be detected.

4. Grating Spectrograph [5pt]

a) [1 pt] Show that the angular dispersion of a grating depends only on the wavelength λ and the angle of incidence. Assume a Littrow configuration ($\alpha \approx \beta$).
b) [2 pt] Using the fact that an aperture D allows for a diffraction-limited angular resolution of order λ/D, show that the resolving power of a grating is given by $\lambda/\Delta\lambda = nm$ where n is the total number of lines across the grating and m is the grating order. **Hint**: Use two different expressions for the angular resolution element $\Delta\lambda$.
c) [2 pt] Assume a grating of 632 lines per mm used in 5^{th} order in a Littrow configuration with α=60 degrees and a focal length of the Littrow lens of 6.3 m. The entrance slit of the spectrograph has a finite size, and its image must be convolved with the object spectrum to obtain the observed spectrum. How narrow a slit must be used to obtain a spectral resolution of 0.0005 nm?

5. VLT spot diagrams [10pt]

Consider the following spot diagrams for one of the 8.2-m VLT telescopes.



Through-focus pot diagrams for the Cassegrain focus of the 8.2-m VLT telescope, evaluated for three field points. The black circles indicate the Airy disk, which is here defined as the position of the first minimum of the PSF if it were diffraction-limited. All size scales are in µm.

a) [1 pt] Derive the effective focal length of the telescope, using information in the spot diagrams.

b) [1 pt] With the result from question a) and additional information from the figure, determine the wavelength at which the spot diagrams were generated.

c) [2 pt] What are the two main geometrical aberrations that are apparent in the spot diagrams? Explain your answer.

d) [1 pt] What is the type of telescope that creates such spot diagrams? Explain your answer.

e) [1 pt] If you would locate an imaging detector in the focal plane where these spot diagrams are located, which aberration would be most difficult to deal with?

f) [2 pt] How could you correct for the two aberrations you listed as an answer to question c) if you were allowed to design an optical system that would create a second, correct focal plane that comprises the same field-of-view as for the spot diagrams in the figure. Explain your solution for each aberration and, if necessary, for each particular field position.

g) [2 pt] Now suppose you relocate your instrument from the VLT to the 39-m ELT, which has the same F-number as the VLT. For both telescopes you have already built a perfect AO system that constitutes a 1:1 reimaging system of the focal plane of the spots seen in the figure. What pixel size would you need for a detector inside your instrument at the ELT?