The University Of Sheffield.

Data Provided:
A formula sheet and table of physical constants is attached to this paper.

DEPARTMENT OF PHYSICS AND ASTRONOMY

Autumn Semester (2011-2012)

ASTRONOMICAL TECHNIQUES ***2 HOURS***

Question 1 is COMPULSORY, and worth 50% of the final mark.
Answer TWO of the remaining four questions (2, 3, 4 and 5), each worth 25% of the final mark.

COMPULSORY

1. (a) Derive the following formula for the plate scale, p, of an astronomical telescope in units of arcseconds per mm:

$$p = 206265/F,$$

where F is the telescope focal length in mm. **[3]**

What size will the Moon appear, in mm, on a detector placed in the focal plane of a telescope with an aperture of 1 m and a focal ratio of $f/10$? You may assume that the Moon has an angular diameter of 0.5°. **[1]**

(b) An astronomer is imaging a star when a thin cloud crosses the line of sight between the star and the telescope. Describe the effect on the width of the seeing disc and the total number of photons within it.

On another night, with no clouds in the sky, the turbulence in the atmosphere suddenly becomes significantly worse. Describe the effect on the width of the seeing disc and the total number of photons within it. **[3]**

(c) A total of 10 000 photons were detected from the star Altair in a 10 s exposure under photometric conditions. The observations were performed using a B filter when the star was at an altitude of 60°. What is the above-atmosphere *instrumental magnitude* of Altair? You may assume that the extinction coefficient in the B band is 0.3 magnitudes per airmass. **[2]**

Using the same equipment, and in the same observing conditions, 100 000 photons were detected from a photometric standard star of magnitude $B = 2.5$ in a 2 s exposure when it was at an altitude of 45°. What is the *apparent magnitude* of Altair in the B band? **[2]**

(d) What are the main factors determining the resolving power of an astronomical spectrograph? **[2]**

(e) Write down an equation giving the signal-to-noise ratio (SNR) of an astronomical observation of a star with a CCD detector, defining each of the symbols carefully. **[2]**

Use this equation to show what is meant by the terms *background-limited* and *readout noise-limited* SNR. **[2]**

Suppose that we detect 1 000 000 photons from an astronomical source in a certain time interval. Assuming no noise from the sky and detector, why is there still an error in the measurement? Estimate the size of this error and the SNR of the observation. **[3]**

ANSWER TWO OF THE FOLLOWING FOUR QUESTIONS

2. You are asked to design an astronomical observatory, consisting of a telescope, mount, instrument and detector. The telescope is to have a 10 m aperture and a focal ratio of $f/10$. The instrument will be a re-imager with a detector of 4000×4000 pixels, where each pixel is 13 μm in size.

(a) Why would you choose the telescope to be a reflector rather than a refractor? If money is no object, what type of reflector would you choose and why? **[2.5]**

(b) Why would you choose the mount to be alt-az rather than equatorial? How would you correct for field rotation? **[2.5]**

(c) Where on the Earth's surface would you choose to site this telescope and why? **[3]**

(d) What magnification must the re-imager have to give a field of view of $5' \times 5'$? **[2]**

3. (a) In the context of CCDs, explain what you understand by the term *charge coupling*. **[2]**

(b) What are *dark current* and *readout noise* and how can they be minimised in a CCD? **[2]**

(c) Define *quantum efficiency*. How can it be maximised in a CCD? **[2]**

(d) What is the role of the analogue-to-digital converter (ADC) in a CCD and why would a 16-bit ADC be preferred to a 14-bit ADC? **[2]**

(e) A CCD pixel contains $75\,000\,e^{-}$. If the full-well depth of the pixel is $80\,000\,e^{-}$, the gain is $1.1\,e^{-}$/ADU and a 16-bit ADC is used, will the pixel be saturated? **[2]**

4. (a) Describe how *atmospheric extinction* and *sky background* affect the flux of a star measured with a ground-based telescope. **[2]**

(b) The seeing in Antarctica has been measured to be $0.15''$. What aperture diameter must a telescope have to provide a diffraction limit equal to this seeing when observing at a wavelength of 550 nm ? In light of your answer, what is the point in building a telescope bigger than this? **[3]**

(c) Explain, with the aid of a diagram, what you understand by the term *Fried parameter* (r_0). **[2]**

(d) The Fried parameter in Antarctica has been measured to be $r_0 = 10\,\text{cm}$ at a wavelength of $\lambda = 550\,\text{nm}$. Given that $r_0 \propto \lambda^{6/5}$, what is the value of r_0 in the near-infrared at a wavelength of $\lambda = 2.5\,\mu\text{m}$? **[0.5]**

The size of the image recorded by a large-aperture ($D \gg r_0$) diffraction-limited telescope is proportional to λ/D, whereas that of a seeing-limited telescope is λ/r_0. Show that the seeing varies with wavelength as $\lambda^{-1/5}$ and calculate the seeing in Antarctica at $\lambda = 2.5\,\mu\text{m}$. **[1.5]**

(e) As well as excellent seeing, Antarctica possesses a number of other qualities that make it particularly attractive for *infrared* astronomy. What are they? **[1]**

5. (a) Sketch the light path through an astronomical spectrograph, labelling each of the major components. **[2]**

(b) What is the purpose of the collimator in an astronomical spectrograph? **[1.5]**

(c) Why is it preferable to use a slit in an astronomical spectrograph? **[1.5]**

(d) Sketch the diffraction pattern produced by a grating in a spectrograph illuminated by a white-light source. **[2]**

(e) Under what conditions is it necessary to use an order-sorting filter in an astronomical spectrograph? **[1.5]**

(f) What is a blazed diffraction grating and why is it desirable to use one? **[1.5]**

END OF EXAMINATION PAPER