The University Of Sheffield.

DEPARTMENT OF PHYSICS AND ASTRONOMY

Autumn 2006-2007

TECHNIQUES OF OBSERVATION **2 HOURS**

Question 1 is COMPULSORY, and counts for 50% of the final score.

Answer two of the remaining four questions (2, 3, 4, and 5), each counting for 25% of the final score.

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

TURN OVER

COMPULSORY

1. (a) What do we mean when we say that a telescope is operating at the diffraction limit? Give the equation that relates the diffraction-limited angle to the aperture size. [1.5]

Which property of the light hitting a narrow slit gives rise to a Fraunhofer diffraction pattern at a screen some distance behind it? What is the physical basis for this behaviour? Support your answer with a sketch of the situation. [1.5]

(b) Using the plane-parallel atmosphere approximation, derive an expression relating the true zenith distance, apparent zenith distance and refractive index at the Earth's surface, by considering a distant source's light path through the entire atmosphere. [2]

(c) Which types of perturbations do Active and Adaptive Optics systems correct for more effectively, respectively? How well can atmospheric turbulence be corrected for using laser guide stars? Relate your answer to the so-called "cone problem". [3]

Why is the "full width at half maximum" (FWHM) measurement of a stellar image not necessarily a good measure of the image quality of an Adaptive Optics system? [2]

(d) Suppose that you were awarded observing time with an optical interferometric telescope, such as the Very Large Telescope Interferometer (VLTI). Sketch the "visibility function" of a resolved uniform disk and that of a point source such as a distant star. [2]

(e) Photon statistics of bright astronomical objects are usually assumed to be distributed as a Poissonian distribution function. If μ is the average number of photons detected in a given time interval, then the probability of detecting r photons is (in the Poissonian limit)

$$P(r) = \frac{e^{-\mu}\mu^{r}}{r!}$$

and

$$\sum_{r=0}^{\infty} P(r) = 1.$$

Derive the uncertainty associated with a Poissonian photon distribution characterised by a mean value μ, given that the variance of the distribution is defined as

$$\text{Variance} = \sum_{r=0}^{\infty} (r-\mu)^2 P(r).$$ [3]

(f) Sketch the radiation pattern of a non-relativistic moving particle, in a sense similar to a dipole antenna. How does this pattern change with increasing (relativistic) speed? Again, support your answer with sketches. [2]

CONTINUED

Question one continued

(g) Radio emission comes in a number of variants. Describe the origin and basic properties of

(i) HI 21cm radiation,
(ii) Čerenkov radiation, and
(iii) Synchrotron radiation. [3]

TURN OVER

Answer two out of the following four questions:

2. (a) You have been awarded observing time with the Keck I Telescope (mirror diameter 10.0 m) to observe a number of star clusters in the nearby starburst galaxy M83. The galaxy is located at a distance of about 3.5 Mpc. Calculate the minimum distance, in arcseconds, between any two clusters of equal brightness in the galaxy's disk that you will be able to distinguish,

(i) under the prevailing seeing conditions on the night of your observations, 0.7 arcsec FWHM without Adaptive Optics correction;

(ii) assuming that the Keck Adaptive Optics system operates close to the diffraction limit at your wavelength of interest, $\lambda = 8500$Å. [1.5]

(b) Discuss the basic operational principles of a Shack-Hartmann wavefront sensor, such as the one that makes the Keck I telescope's Adaptive Optics system work. [3]

(c) You consider whether it would make sense to use the Very Large Telescope Interferometer (VLTI) to obtain images of still better spatial resolution. At present, the VLTI operates using two of the 8 m diameter VLT Unit Telescopes, combining the signals from both telescopes in its "correlator" computer. The two telescopes are located 100 m apart. What would be the best spatial resolution (in arcsec) this set-up can provide you with, at the same wavelength as above? [1]

(d) Your observing programme involves measuring the random velocities of the stars in the M83 clusters of interest. In order to do so, you need very high spectral resolution, of $R \geq 40{,}000$. What is the definition of the spectral resolution, R? [1]

(e) The spectrograph you will be using contains a reflection grating that is "blazed". Explain what this means. [1]

(f) In a follow-up programme, you are interested in observing the properties of the immediate environments of your star clusters, so you apply for observing time using an "integral-field spectrograph". Explain the basic principles governing the operation of such an instrument. [1.5]

(g) It turns out that some of the star clusters in the M83 starburst core are heavily embedded in their birth clouds of dust, so that you need to resort to high-resolution radio observations to study those environments. Therefore, you apply for observing time with the Westerbork Synthesis Radio Telescope (WSRT), an array of fifteen 25 m (diameter) antennae with a maximum baseline of 3000 metres, spaced 200 m apart. What is the highest spatial resolution (in arcsec) you can achieve with the WSRT if you observe at a radio frequency of 92 cm? [1]

CONTINUED

3. (a) A star has a measured V-band magnitude of 20.0. How many photons per second are detected from this star by one of the Unit Telescopes of the Very Large Telescope in Chile (8 m diameter), assuming that the overall quantum efficiency is 25%? Assume that we are signal limited. You can use the following information, for Vega, which has a V-band magnitude of $m_V = 0.0$:

Filter	λ_{eff} (nm)	$\Delta\lambda$ (nm)	F (W m^{-2} nm^{-1})
V	550	89	3.80×10^{-10}

[4]

(b) What fraction of the photons in the V band of this star would be absorbed by the atmosphere if one were to observe the star at a zenith distance of 0, 30 and 60 degrees? Assume that the atmospheric extinction in the V band is 0.15 mag airmass^{-1}. [2]

(c) If the observations are signal limited, by what factor does the signal-to-noise ratio of your bright star change if you were unsuccessful in obtaining observing time on the VLT, but had to settle for the 3.5 m diameter New Technology Telescope (NTT) instead? Assume that your exposure time remains unchanged. [1]

Alternatively, if we were to observe for the same amount of time with both the NTT and the VLT to reach the same signal-to-noise level, how much fainter can we see with the larger telescope? Discuss both the signal-limited and the background-limited cases. [2]

(d) What are the two main ways to improve the sensitivity of your observations, both in terms of depth and area coverage? [1]

4. (a) One of the current science drivers in astronomy is to build wide-field cameras which have as large a field of view as possible. To date, most wide-field survey work has been done with Schmidt telescopes, using photographic plates. Discuss the advantages and disadvantages of Schmidt telescopes; in particular, discuss the shape of the focal plane, field of view, limiting magnitude and any optical aberrations. [3]

(b) Explain how a "latent image" forms on a photographic plate when hit by light. [2]

(c) Why is it very difficult to build wide-field CCD cameras? Explain how one can achieve a wide field using CCDs anyway. [2]

(d) Briefly describe the basic operational principles of CCDs. [2]

(e) CCDs are only sensitive to infalling radiation shortward of ~ 1.1μm. Explain the physical reason for this hard "red limit". [1]

TURN OVER

5. (a) At present astronomers are actively researching the possibility of building telescopes with diameters in excess of 30 m. For such large telescopes, the fact that the rings of an Airy pattern contain some 1.75% of the total light could be an issue for one particular field of research that will only become possible with such large "light buckets". In which situation is this residual light in the Airy rings a potential problem? [1]

How can one achieve "apodisation", i.e., get rid of the higher-order Airy rings? [1]

(b) For such large telescopes it is essential to have a good Adaptive Optics (AO) system in order to correct for the effects of atmospheric turbulence. This will require the use of laser guide stars. What two types of laser guide stars are generally used in astronomy, and what are the physical principles behind their operation? [2]

(c) Give at least three parameters on which the effectiveness of an AO system depends. [3]

Why are the effects of wave front distortions due to atmospheric effects smaller in the infrared than in the optical regime? [1.5]

(d) If we were to turn off the AO system, you would see stars twinkle (speckles). Planets in our solar system, on the other hand, do not twinkle. Explain this observation in terms of the properties of atmospheric turbulence. [1.5]

END OF QUESTION PAPER