Department of Physics

Examination paper for FY3215 – Observational Astrophysics

Examination date: June 5th 2024

Examination time (from-to): 15:00-19:00

Permitted examination support material: Approved calculator + formula sheet

Academic contact during examination: M. Kachelriess
Phone: 99890701

Academic contact present at the exam location: YES (17:00-18:00)

OTHER INFORMATION
This exam accounts for 50% of the final grade. Total score: 10 points. Official formula sheet provided. Read carefully. Good luck!

Get an overview of the question set before you start answering the questions.

Read the questions carefully and make your own assumptions. If a question is unclear/vague, make your own assumptions and specify them in your answer. Only contact academic contact in case of errors or insufficiencies in the question set. Address an invigilator if you wish to contact the academic contact. Write down the question in advance.

InsperaScan: For all problems and questions you are meant to answer on handwritten sheets.

Problem 1 [2 points]. A CCD observes two sources in the same band, 400-600 nm. Source A has a spectrum such that the distribution of photons (or "spectral photon flux density") in the 400-600 nm band is given by $p_A(\lambda)=A\lambda^3$. Source B has a distribution of photons given by $p_B(\lambda)=B\lambda^{-2}$ in the same band. The two sources generate photoelectrons at exactly the same rate.

a. Find the relation between the normalization constants A and B, if the wavelength λ is expressed in microns. [1 p]
b. Compute their brightness ratio F_B/F_A, i.e., the ratio between their energy fluxes (in erg/s/cm^2) in this band. [1 p]

Assume that the detector's quantum efficiency is "flat as a pancake" (not a function of wavelength).

Problem 2 [2 points]. Consider the declination (δ), maximum altitude (h) and zenith angle (z) of a star, as seen from a geographical latitude L.

a. Derive the relation between h, δ and L. What is the minimum declination observable from Kiev (L = 50º N) above the horizon? And at an altitude of at least 30º? [0.5 p]
b. In the common plane-parallel atmosphere approximation, calculate the dimensionless airmass (column density relative to its minimum value towards the zenith) for a zenith angle z = 30º. [0.5 p]
c. Calculate the fraction of the sky which is visible throughout a full year from Kiev (L = 50º N) at an altitude of at least 30º above the horizon. [1 p]

Problem 3 [2 points]. On a particular night, the planet Mars has an angular diameter of 15 arcsec and an energy flux of 1.0×10^{-7} W m^{-2}. Two astronomers observe the planet, using identical CCD cameras whose pixels are 25 μm apart. Albert uses a telescope of 0.3m aperture whose focal ratio is f/8. Bertha uses a telescope of 30 m aperture whose focal ratio is f/4.

a. Calculate the surface brightness (energy flux per unit area in the sky) of Mars in units of W m^{-2} arcsec^{-2}. [0.5 p]
b. How much energy accumulates in a single pixel of Albert's CCD image of Mars in a 100 s exposure? Give your answer in Joules. [0.75 p]
c. How much energy (in J) accumulates in the same time in a single pixel of Bertha's image of Mars? [0.75 p]

Question 4 [1 point]. A CCD pixel has 95000 e-. If the full-well depth of the pixel is 100000 e-, the gain is 1.4 e-/ADU and a 16-bit ADC is used, will the pixel be saturated? Explain why.

Question 5 [1 point]. The bolometric peak luminosity of thermonuclear bursts is [3.79+/-0.15]x10^{38} erg/s. Observing a newly discovered neutron star, we measure during a thermonuclear burst a bolometric peak flux of [1.27+/-0.13]x10^{-7} erg/s/cm^2.

a. Assuming that this is a standard candle, calculate the distance and its uncertainty, both in kiloparsecs (kpc). [0.5 p]
b. Assuming that the measurements are normally distributed and that the quoted uncertainties represent 1-sigma confidence regions: estimate the probability that the newly discovered source is more than 5.56 kpc away. [0.5 p]

Question 6 [1 point].

a. Compute the anticipated plate scale of the Thirty Meter Telescope (TMT), with diameter D=30m and focal ratio R=15. Give your answer in arcseconds per mm. [0.5 p]
b. If the TMT has a field of view of 20x20 arcminutes, how many pixels of 30-micrometer width would be needed to cover this field? [0.5 p]

Question 7 [1 point]. In a long-slit optical spectrum:

a. If the dimensionless spectral resolution is R=2850, what is the resolution in Å and in km/s at the Hydrogen beta line (4861 Å)? [0.25 p]
b. If the spectrum covers the range 4000-5730 Å with 1018 pixels, what is the average dispersion? [0.25 p]
c. From your answers above, how many pixels sample one full resolution element around the Hydrogen beta line? [0.25 p]
d. State the Nyquist criterion and, based on it, explain whether this spectrum is over, under or critically sampled. [0.25 p]