UNIVERSITETET I OSLO
Det matematisk-naturvitenskapelige fakultet

Slutteksamen i AST2210 — Observasjonsastronomi
Eksamensdag: Mandag 12 desember 2016
Tid for eksamen: 14:30 – 18:30
Oppgavesettet er på 3 sider.
Vedlegg: Ingen
Tillatte hjelpemidler: lommekalkulator, matematisk formelsamling, Øgrim & Lian: Størrelser og enheter i fysikk og teknikk

Kontroller at oppgavesettet er komplett
før du begynner å besvare spørsmålene

Spørmålene kan besvares på enten bokmål, nynorsk eller engelsk. You may answer these questions in either Norwegian or English.

1. Give <u>short</u> answers to the following questions:

   (a) Sort the following experiments according to *increasing* wavelength: 1) Planck, 2) Fermi, 3) Hubble Space Telescope, 4) James Webb Space Telescope

   (b) Sketch the optical path of 1) a Cassegraine telescope and 2) a Gregorian telescope. Which is most commonly used type in modern astronomy, and why?

   (c) What is the diffraction limited angular resolution (in arcminutes) of a telescope observing at 600 nm having a primary mirror with a diameter of 40 m? What would be the most important limiting factor for such a telescope situated on the Earth?

   (d) Define "bias", "dark current" and "flat field". In each case, are these multiplicative or additive effects?

   (e) What does a birefringent material do with light? What are the ordinary and extra-ordinary rays?

   (f) Name the four Stokes parameters. What do they describe?

   (g) Sketch the CMB power spectrum measured by Planck. What quantity is plotted along the x-axis of the plot? What does this number quantify, and how does it relate to angular scales on the sky?

   (h) A telescope moves its optical axis from zenith to an azimuth of 45° and an elevation of 45°. Compute the Euler matrix describing this rotation.

   (i) The ALMA interferometer has 64 individual telescopes. How many different baselines do these span?

(j) What is *aliasing* in Fourier analysis, and how can one avoid that effect?

2. Gaussian distributions and parameter estimation:

   (a) In March 2014, BICEP2 claimed to detect primordial gravitational waves corresponding to an amplitude of the tensor-to-scalar ratio of $r = 0.20 \pm 0.06$. Assuming Gaussian statistics, write down the analytical form of the posterior distribution, $P(r|d)$, and draw a sketch of the distribution.

   (b) Write down the corresponding general expression for an N-dimensional Gaussian distribution with stochastic vector x and a mean vector equal to μ and covariance $\mathbf{C}$. (You can disregard normalization constants proportional to 2π.)

   (c) What does the covariance matrix measure? Sketch the 2D posterior distribution corresponding to $\mu = [2, 1]$ and

$$\mathbf{C} = \begin{bmatrix} 4 & 0 \\ 0 & 1 \end{bmatrix} \tag{1}$$

   In contrast, sketch one distribution with positive off-diagonal elements, and another distribution with negative off-diagonal elements.

   (d) From the above two-dimensional Gaussian distribution $P(x_1, x_2)$, compute the marginal distribution $P(x_1)$.

3. Detectors:

   (a) What are the main advantages of an electronic 2-dimensional detector like a CCD over photographic film? Why did CCDs cause a revolution in astronomy?

   (b) Why does the signal-to-noise ratio S/N in an observation with a CCD camera grow proportional to the square root of the exposure time? The light from a faint galaxy is just a very small fraction ($< 1\%$) of the background light coming from the "dark" sky. When observing very faint objects, we want the signal to be "sky dominated". Each time the CCD is read out, a noise of a few electrons is added. If the light from the dark sky on average hits each pixel with 0.2 photons per second, and the quantum efficiency is 50%, how long exposures should we use to keep the images sky dominated if the read-out-noise is 5 electrons?

4. Spectroscopy:

   (a) The grating equation is

$$\sin\theta + \sin\alpha = \frac{m\lambda}{\sigma},$$

where θ (for a reflective grating) is the incoming angle, α is the outgoing angle where there is constructive interference, m is the order of the beam, and σ is the distance between the apertures. Explain why the angular dispersion $d\theta/d\lambda$ is bigger for smaller σ and for larger m.

(b) What is meant with a *blazed grating*? For a given blaze angle, what is meant by the *blaze wavelength*? Why are *blazed gratings* very commonly used?

(c) What is meant by a cross-dispersed echelle spectrograph? Can you give an example? Why is cross-dispersion needed?