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 (*max* three sentences each!):

   (a) Draw a *rough* sketch of the atmospheric opacity (0% = completely transparent; 100% completely opaque) as a function of wavelength. Place each of the three following experiments in this graph; 1) Fermi, 2) ALMA, 3) JWST.

   (b) Explain spherical aberration both in words and with a ray-tracing sketch.

   (c) What is the Arago spot?

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

   (e) Suppose you measure the following values of the four Stokes' parameters $(I, Q, U, V) = (2, 5, 0, -4)\,\mu$K with a given instrumental setup. Which values will you measure if you rotate the measuring device by $+45°$ around its optical axis?

   (f) Write down the general expression for a Gaussian distribution in N dimensions, with a stochastic variable x, a mean vector μ, and a covariance matrix $\mathbf{C}$. What does the off-diagonal elements of the covariance matrix quantify?

   (g) Name two major advantages of interferometry over single-dish observations.

   (h) Draw a sketch of a grating spectrometer. What is the relationship between the grid spacing, σ, and the wavelength λ?

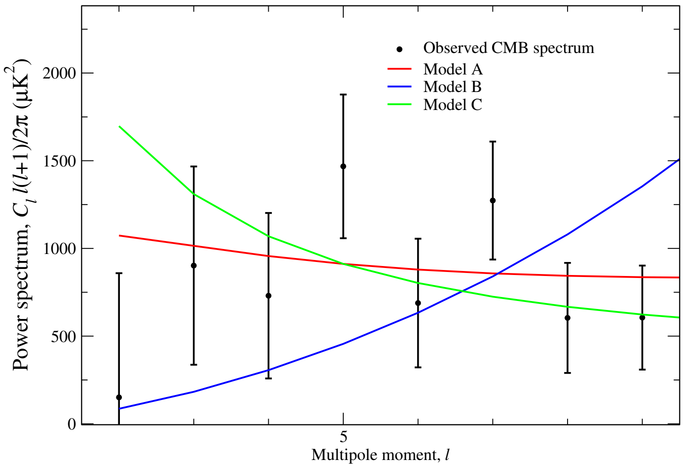

Figure 1: Observed CMB power spectrum (black points) for $\ell \leq 9$, plotted together with three different theoretical models (coloured curves).

2. Bayes' theorem and parameter estimation:

   (a) Bayes' theorem as applied to parameter estimation reads

   $$P(\theta|d) = \frac{\mathcal{L}(\theta)P(\theta)}{P(d)}, \tag{1}$$

   where d indicates observed data, and θ denotes unknown parameters. What are each of the four factors (one of the left-hand side and three on the right-hand side) called, and what do they measure?

   (b) Suppose both $\mathcal{L}(\theta)$ and $P(\theta)$ are Gaussian distributed, with $(\mu, \sigma)_{\mathcal{L}} = (3, 1)$ and $(\mu, \sigma)_P = (4, 3)$, respectively. Sketch $\mathcal{L}(\theta)$, $P(\theta)$ and $P(\theta|d)$, all in the same plot and with (at least approximately) correct relative normalization. Which distribution is the narrowest?

   (c) In Figure 1 we have plotted the first few multipoles of the CMB temperature power spectrum as measured by WMAP and Planck (black points), together with three different theoretical models (red, green and blue curves). We will now perform a simple model comparison calculation with these observations and model. First, assume that all measurement uncertainties, σ_ℓ, are Gaussian with widths as indicated in the figure, and uncorrelated between multipoles. First, make a table of the normalized residual, χ_ℓ, per multipole for each model on the following form,

   $$\chi_\ell(\text{model}) = \frac{C_\ell^{\text{obs}} - C_\ell^{\text{model}}}{\sigma_\ell}. \tag{2}$$

   Estimate each residual to a very rough precision of $\sim 0.2\sigma$ by reading directly off the graph; do *not* attempt to measure each number to high precision. (Note that there will be 8 values of σ_ℓ per model, for a total of 24 tabulated numbers.)

   (d) Compute the corresponding $\chi^2_{\text{tot}} = \sum_{\ell=2}^{9} \chi^2_\ell$ for each of the three models. Does a small or large χ^2_{tot} value indicate a good model fit?

   (e) Compute the (approximate) likelihood ratios between any pair of two models, ie., $\mathcal{L}_A/\mathcal{L}_B$, $\mathcal{L}_A/\mathcal{L}_C$, and $\mathcal{L}_B/\mathcal{L}_C$. (Note that $-2\ln\mathcal{L} = \chi^2_{\text{tot}} + C$, where C is an arbitrary constant.) Which model provides the best statistical fit to the data?

3. Detectors:

   (a) What is the difference between intrinsic and extrinsic (doped) semiconductors? Why are certain atoms added to the silicon in intrinsic semiconductors to make them extrinsic? What are the two different types of extrinsic semiconductors called? Why?

   (b) In CCD detectors, there is a so called MOS (metal-oxide-semiconductor) capacitor in each pixel. What is its task? Give a brief sketch and/or explanation of how a MOS capacitor works.

   (c) Explain the general principles of how a CCD detector is read out.

4. Spectroscopy:

   (a) A glass prism has the shape of an isosceles (likebeint) triangle with top angle A. One can show, using Snell's law of diffraction, that for the symmetric case (where the light goes out in the same angle as it entered the prism),

$$\sin \frac{\theta + A}{2} = n \sin \frac{A}{2},$$

   where n is the refractive index of the glass and θ is the refraction angle.

   Assume that the refractive index can be written as $n \sim K_0 + K_2/\lambda^2$, where K_0 and K_2 are constants. What is the dispersion ($d\theta/d\lambda$) in this case? Is blue or red light diffracted the most by a prism?

   (b) 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. What is the dispersion $d\theta/d\lambda$? Is blue or red light diffracted the most by a grating?

   (c) What is a *grism*? Why do you think grisms are used as the dispersive element of the ALFOSC instrument on the Nordic Optical Telescope (NOT) and on lots of similar instruments, including the NISP instrument on the Euclid satellite?