Ay122a Final Exam – Fall 2012

Distributed on Thursday, Dec. 6
Due before 5:00 pm on Friday, Dec. 14, in Steidel's mailbox in 249 Cahill

- Rules: Closed book exam. You may take up to 3 hours from the time you first open the exam to complete it.

- Advice: There are three parts to the exam. Part I (36 points) asks you to explain **9 of 18** terms; Part II (30 points) has short problems and asks you to work **2 of 4**; Part III (34 points) has "discussion" questions and asks you to compose answers to **2 of 5** of them. You may want to budget your time so as to spend $\sim$ 1 hour on each section.

Part I. Short Answers (36 points)

Using words, equations, and/or diagrams, briefly explain **9** of the following terms and describe their astrophysical relevance. Each is worth 4 points, so that simple terms may benefit from more in-depth explanations. Tell us what you know!

1 Sources of *background* at UV, optical, and IR wavelengths in ground-based observations
2 Atmospheric refraction and dispersion; effects on observations
3 ADC, read noise, and choice of gain
4 Spectral resolution and free spectral range; factors that determine them
5 Atmospheric turbulence and C_N^2
6 Optical aberrations and Zernike polynomials
7 Speckles and seeing disk
8 Celestial coordinate systems and Celestial time systems
9 How to measure astrometry, proper motion, and parallax
10 Plate scale and factors that determine it
11 Echelle grating and cross-disperser
12 Signal-to-Noise and limiting magnitude
13 Wavefront error and Strehl ratio
14 Natural guide star vs Laser guide star plus Tip-tilt star
15 Anisoplanatism and ways to overcome it
16 Apodization, Coronographs
17 Image plane, pupil plane
18 Point Spread Function fitting photometry and aperture corrections

Part II. (30 points) Short Problems- answer 2 of 4 of the following:

1. AO Parameters.

Sketch an adaptive optics system, drawing all the basic elements and explaining the function of each. What are the effects of the atmospheric parameters (e.g. r_o, τ_o, and θ_o) and of telescope parameters (e.g. D) on the design (e.g. number of actuators, speed of control loop) and on the performance (e.g. S) of your AO system? Put some numbers into your design assuming an observatory site with typical Fried parameter $r_0(0.5\mu \text{ m}) =$ 20 cm, a 10 m telescope, and a current generation AO system. Explain the benefit of AO to astronomy and describe some challenges and areas where improvements are still needed for the next generation of AO.

2. Spectrograph Parameters.

a) Suppose you have a 6.5m telescope with an f/1 primary mirror, and an f/9 Cassegrain focus. What is the native plate scale (in arc seconds per mm) at that focus? Comment on whether this is useful given typical detector/pixel sizes for CCDs and IR arrays.

b) You are designing an optical spectrograph for use at the f/9 Cass focus; it will have a 15cm beam (to be well matched to off-the-shelf reflection gratings). How far back from the telescope focal plane would you place a reflecting collimator?

c) You would like to have a final plate scale at the detector of 0.25 arc seconds per 15 micron detector pixel. What is the focal ratio of the spectrograph camera to achieve this?

d) Approximately what spectral resolution would you expect for a 1200 l/mm grating (used in first order) and a slit width of 1.0 arc seconds? What is the corresponding velocity resolution at 6000 Å?

3. Imaging vs. Spectroscopy.

You are planning to observe a source spectroscopically using a 10m aperture telescope and an instrument whose detector is a 2048×2048 array with 18 μm pixels projecting on to 0.18 arcsec pix^{-1} on the sky. A K-band image has already been obtained with the same instrument, showing an unresolved source with $K_{AB} = 21.90 \pm 0.01$ from a 900s total integration.

In imaging mode the K-band background produces a count rate of 1000 e- s^{-1} arcsec^{-2} at the detector. You may assume dark current of 0.3 e- s^{-1} pix, and that individual integrations times are long enough that read noise is unimportant.

Your spectroscopic measurement uses a grating such that the full K-band spectrum (1.95-2.40 μm effective bandwidth) just fits on the detector. The slit width is chosen to match the seeing FWHM during a typical Mauna Kea night.

a) Approximately what spectral resolution will you be getting using this system? Assuming negligible anamorphic magnification, what is the average background rate (in e- s^{-1}) per spectral resolution element going to be in spectroscopic mode? What is the corresponding count rate expected for the source?

b) What is the difference in limiting magnitude (S/N $\sim$ 10) for a spectrum versus an image of the same object given identical integration times? (Assume for the former that you are interested in the continuum S/N per spectral resolution element).

4. Antartica vs Keck.

In Antarctica, the 2μm background is about 17 magnitudes (Vega) per square arcsec, which is quite good, but because of lots of ground-layer turbulence the Fried parameter averages only $r_0(0.5\mu\text{ m}) = 5$ cm. How large a telescope needs to be built in order to match the point source sensitivity at Keck for observerations in the K-band? On Mauna Kea the average K-band seeing is 0.5" and the background is 14 magnitudes (Vega) per square arcsec.

Part III. Discussion Questions (34 points) – answer 2 of 5

1. Ground vs Space. Discuss the advantages and disadvantages of near-IR imaging (1-2.5 microns) in space versus the ground. In the era of JWST, will there be a place for ground-based imaging and spectroscopy in that wavelength range? What will it be?

2. Astronomical Detectors. Explain the differences in principle and operation of CCD detectors (i.e. Si) versus near-IR detectors (i.e., InSb or HgCdTe). Discuss issues such as the physics of the wavelength limits, noise sources, efficiency, etc. What are the sizes of state-of-the-art devices in each wavelength regime?

3. A Night's Observing. You arrive at the telescope and find a computer in the "warm room" and a telescope upstairs in the dome, parked at zenith. It is 14:00 local time and astronomical twilight is at 18:00. What do you do between now and then if you are taking a) imaging photometry observations, and b) spectroscopic observations? Describe addtional calibration needed during the night in these two cases. What are the image processing steps? How do you turn your detector counts into flux density above the atmosphere? How would near-infrared and optical data acquisition and processing differ?

4. The Sky. There is an upcoming telescope proposal deadline for observations from a ground-based telescope in the period August through January. What considerations are there in developing your target list for a proposal, for a telescope at latitude $+20°$? Specifically, what RA and Dec range are appropriate if you ask for telescope time in September? in January? If my favorite target is αCen at 14h 39m 36.2s and -60° 50' 7", when and from where can I observe it?

5. Relevant Sources of Noise.

What are the dominant sources of noise in the following situations, assuming typical instrumentation for a 10m telescope.

a) R=25,000 spectroscopy in the H-band
b) Deep K-band imaging achieved by statcking many 60 sec integrations
c) Low resolution optical spectroscopy of 25'th mag galaxies
d) Broad-band imaging at R-band
e) Narrow band imaging at R=100 in the B-band
f) AO observations achieving the diffraction limit for J=23 point sources