Ay 192 — FINAL EXAM — Fall 1999

Due: January 12th, 2000, 5:00 P.M. - **No Exceptions!**

Problem 1. IR Detectors. (a) Calculate the limiting **magnitude** that you would reach at 2.2 μ in a 0.1 μ band, using an infrared detector system based on an InSb detector array on the 6.5-m MMT for an integration time of 100 seconds. For this problem, define 'limit' as reaching a Signal-to-Noise = 3. First do this assuming there is no sky background. Justify your assumptions.

(b) What is the background sky flux (ergs/cm^2/s) in a diffraction limited beam with the above bandpass and wavelength assuming that the sky is a 300 K blackbody with an emissivity of 10 percent? Hint: first figure out the size of a diffraction limited beam in solid angle, remember that surface brightness is conserved.

(c) Now what is the limiting magnitude you'll reach?

Problem 2. Sample Comparison/Parameter Estimation. (a) I've made available two tables containing two samples of numbers (ftp anonymously to fang-ftp.harvard.edu, cd /pub/class, get e.dat, get s.dat or go to the class website, http://cfa-www.harvard.edu/~huchra/ay192, and look in PROBLEMS). Test their consistency (ie. whether or not they represent samples that could have been drawn from the same parent populations using both the Rank-Sum Test and the K-S test. These are the redshifts of the early and late type galaxies in the first CfA slice.

(b) Calculate a crude luminosity function (log N_{gal}/Mpc^3/magnitude interval) for the combined sample using just the binning technique discussed in class. Remember to calculate the proper sample area and selection function and don't worry about galactic extinction.

Problem 3. Photography. (a) What is an H-D curve? Describe its use in astronomy. (b) What image characteristics can you think of that might allow you to separate galaxies from stars using imaging data from either CCD's or photography? Estimate the dynamic range of a Kodak 103aJ plate.

Problem 4. Interference Filters. For an interference filter made with two materials of indices of refraction η = 1.3 and 2.0, with the spacers low what are the (a) wavelength shift and (b) change in bandpass if the filter is used in a f/5.4 beam (which is what we'll have at the 6.5-m in the future)? Assume the filter is a 10 Å FWHM, Hα filter when in a collimated beam. What wavelength and bandpass would you have to specify for a filter to really get Hα at 10Å at zero redshift?

Problem 5. Specrtoscopy. What signal-to-noise would you achieve in a one hour integration with the 6.5-mMMT Blue Channel spectrograph with the 300 line/mm grating (see class notes) on a 23th magnitude galaxy? How big will the galaxy appear (in pixels) on the spectrograph camera? Calculate this at 5500 Å(ie. the V band). Calculate the S/N per pixel on the 3kx1k CCD detector (you'll have to look up the dispersion). Use reasonable estimates for the throughput of the telescope and spectrograph. The sky background is approximately 22.0 mag/square (except at λ5577Å!) arcsecond, and the observations are made through a 1" wide, long slit. (You can also assume that the seeing is very, very good!)

(Note that you'll have to do some research on the spectrograph — what's the camera and collimator focal ratio's, etc. Don't put this off till the last minute.)

Problem 6. Properties of CCDs.

I've placed, also in the ftp site, some calibration images from one of our CCD's at Mt. Hopkins. These include Bias frames, Dark frames and Flat fields. Estimate

(1) The read noise

(2) The Dark rate in cts/pixel/sec. Watch out for Cosmic Rays!

(4) and possibly the chip gain.

The read noise can be estimated from the fluctuations in the bias level between reads, so, for example, one quick estimate can be obtained by subtracting two adjacent bias frames (adjacent in time, so that long time scale drifts in the bias level are removed), computing the average sigma for the pixels. There is a routine in IRAF that will do this called imstat. The, if the gain is known, the read noise is

$$R = \sigma G/\sqrt(2),$$

where G is the gain, R is the read noise and σ is the dispersion or standard deviation of the mean difference, i.e.

$$\sigma = \sum_n x^2$$

where x^2 is the square of the pixel values in the difference frame, and the sum is the sum over all reasonable pixels in the image (clip the cosmic rays, bad chip edges, etc.)

An estimate of the gain of the CCD can also be obtained from two flat field images and two bias frames via

$$G = \frac{(f1_{mean} + f2_{mean} - b1_{mean} - b2_{mean})}{(\sigma^2_{f12} - \sigma^2_{b12})}$$

where $f1_{mean}$, etc. are the mean count rates of the flats and biases, and σ_{f12}, etc. are the dispersions, as above, in the difference images, f1-f2 and b1-b2.

Problem 7. Suppose you had a radio interferometer composed of two 25-m diameter antennas, placed 55° apart on the equator observing an unpolarized point source at zero declination at a frequency of 5 GHz. Assume that the atomic clock at each site keeps perfect time and that the two clocks are perfectly synchronized. Assume, too, that the Earth's rotation is strictly uniform about a spin axis that is (rigidly) fixed to the (rigid) Earth's crust with its direction also fixed in space. The (total) source has a flux density, S, of 1 Jy at 10 GHz and a spectrum of $S \propto F^{-1}$.

a) What is the brightness temperature of the source that would be inferred from total-flux-density measurements at 5 GHz made by one of these two antennas?

b) Describe quantitatively the fringe pattern on the plane of the sky for this inferometer from the time of rising above the horizon of the source at the western antenna to the time of setting of the source of the eastern antenna.

c) What is the normalized visibility function to be expected from (noise-free) observations at 5 GHz of this source with this inferometer for the total period of (mutual) visibility of the source at the two antennas?

d) Given that (i) the origin of right ascension is defined to be zero at a point directly over the midpoint of the of the inferometer baseline at t=0; (ii) the inferometer baseline vector is, a priori, known exactly; (iii) ten observations of the source are made, uniformly spaced over a period of mutual visibility; and (iv) each such observation is of (unambiguous) phase delay, with a standard deviation equivalent to 10° of phase, calculate by weighted least squares the resultant standard deviation in the estimate of the source right ascension from these observations under the above conditions. If any additional assumptions are needed to complete this calculation indicate the ones you made explicitly.

e) Given that no errors affect the pointing of each telescope (i.e., the pointing is exact), determine approximately the uncertainty in an estimate of the declination of the source from a total-flux-density measurement with the above equipment. State explicitly all subsidiary assumptions you made in arriving at your determination.

Problem 8. A two-element interferometer, with elements on the equator, separated along the surface by 5000 km and observing a distant quasar (right ascension = 0°; declination = 30°) at λ = 10 cm, obtained a visibility amplitude as follows:

```
          |
      0.6 |-           +
          |          +   +
|V|   0.4 |-        +     +
          |  +     +       +     +
      0.2 |-  +   +         +   +
          |    + +           + +
      0.0 |-----+-------------+---------------
                  t  --->
```

over the period of mutual visibility (note that the shape is not intended to be accurate; only the "trends" and the maximum and minima are intended to be accurate. Note also that we are using "visibility" in different part of this question; context is everything!).

a) What is the period of mutual visibility?

b) What (simple) model of the source can you concoct that would yield a $|V|$ vs. t curve consistent with the above representation of the observations? Describe the main features of the model and their connection to the $|V|$ vs t curve.

c) Suppose one year later the same source was observed bt the same interferometer over the same period of mutual visibility. Suppose, too, that the visibility amplitude had the same general shape, save for the first minimum ocuring one-half hour earlier and the second on-half hour later than in the original observations. What conclusions might you draw about the changes in the source between these observations? Are there any "uniqueness" issues to be concerned about, even within the context of your model?

Problem 9. You are contemplating observing another compact unpolarized radio source (total flux density at $\lambda = 10$ cm of 1 mJy) with the interferometer (partially) described in problem 7. Suppose that each antenna has a diameter of 25 m and an efficiency at $\lambda = 10$ cm of 0.7. Suppose, further, that the system temperature for each antenna is 25K.

a) What would be the minimum "on-source" observing time required to achieve a signal-to-noise ratio (SNR) of 7, if the recorded bandwidth were 100 MHz and half of the total flux density stemmed from an extensive circular, very diffuse halo about one arcsecond in diameter?

b) If this source had an (unrealistic) spectrum such that its flux density, S, as a function of frequency, f, obeyed $S = f^3$ between 3 GHz and 9 GHz, how would your answer to A) change for observations at $\lambda = 3.3$ cm? What additional key assumptions, if any, did you make answering this question?

Note: All problems will "count" approximately equally in determining your grade on the exam.