Astronomy 350, Autumn 2002, Problem Set 7

Due Tuesday, December 3 in class

Problem 1

You are observing at MDM with the 2.4-meter telescope and receive an email alerting you to a new gamma ray burst. You immediately stop what you are doing and point the telescope towards the reported position of the burst and take a deep 1800sec CCD image to try to detect the optical afterglow from the burst. Once the exposure is done, you measure the signal in a 2-arcsec aperture centered on the reported burst location, and use the surrounding pixels on the image to estimate the background sky signal. You measure these values:

S_{on} = 2645 DN
S_{sky} = 2591 DN

where "DN" is "Digital Number", the "signal" units of the CCD camera. This particular CCD detector has a measured readout noise of the CCD is 7.9 electrons, and a gain is 2.6 electrons/DN.

a) What is the sky-subtracted brightness of the gamma ray burst and its uncertainty, in units of DN?

b) Did you detect the gamma ray burst afterglow with this observation? Be quantitative.

Problem 2

This problem has 2 parts in which you are asked to estimate observing parameters for the Hubble Space Telescope with the Wide-Field and Planetary Camera 2 (WFPC2) CCD imager. The exercise is analogous to what you would do in a feasibility study prior to applying to observe with HST.

You are using the WFPC2 with the wide V-band filter (the F606W filter), which has the following properties:

- Effective Wavelength, λ_{eff}=5843Å
- Band Width, $\Delta\lambda$=1578.7Å

The CCDs in the WFPC2 are Loral 800x800 pixel CCDs with the following characteristics:

- Gain: g=7 electrons/DN
- Readout Noise: σ_{RO}=5 electrons
- Digital Range: 4096 DN (12-bits)
- Pixel Sizes:
  PC1 Detector: 0.0455 arcseconds/pixel
  WF Detectors: 0.0996 arcseconds/pixel

Finally, the combination of the telescope, WFPC2 camera optics, CCDs, and the F606W filter gives an the effective total efficiency of η=0.042 (about 4%). The primary mirror of HST has a diameter of 2.4-meters.

You are to solve the following two signal-to-noise estimation problems. The first is to estimate the limiting magnitude in a given integration time, while the second is to estimate the integration time required to reach a particular limiting magnitude.

a) You have retrieved a single WFPC2 image from the HST Archives of a star field imaged using the PC detector (WFPC2's highest angular resolution mode) and the F606W filter. This image has an integration time of 600 sec. The images of stars on the image have profiles with widths of 2 pixels (FWHM), and the sky background is measured to be 6 DN/pixel. What is the faintest star (in V-magnitudes) that should be detectable on this image with a limiting S/N=5?

b) You wish to obtain Wide-Field (WF) camera images of distant quasars with the F606W filter down to a limiting (S/N=5) magnitude of V=30. Because of earth occultation, your target fields will only be visible for 2700 seconds per orbit, and you can take at most two long images per orbit without losing time to instrument operation overhead (note: WFPC2 has a maximum exposure time of 1800sec). The background rate is 1 DN/pixel for each 100 seconds of integration time. Since HST time is assigned by whole orbits, how many spacecraft orbits will be required to achieve your target limiting magnitude? Round to the nearest whole orbit, and it is OK to round down if you get reasonably close to your target total exposure time. If you need to round up, use the whole orbit visibility period to take images (you've got the orbit anyway, so expand your exposure time to fill the last orbit). Depending on your choice of rounding, by how much does the final estimated limiting magnitude exceed or fall short of your target detection limit, and by how much? On the WF CCDs, stellar images have widths of 1.5 pixels (FWHM). Also remember that when adding many images together you need to include the readout noise penalty incurred for each image in the final error estimate.

For both parts, carefully enumerate all assumptions that you make, and please summarize your results at the end. For the basic photometric data (e.g., photon flux for V=0 mag), use the table provided in the notes. The differences between a standard V-band filter and the HST F606W filter are negligible for our purposes here.