Syllabus for AST 598 — Fall 2006

"Astronomical Instrumentation & Data Analysis"

Section: *Astronomy with Charge Coupled Devices*

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We will discuss the concepts and techniques that are important for observational astronomical research that uses CCD detectors. AST 598 classes meet MWF 9:40–10:30 AM in PSF-226, and the first class of this section will be on *[tbd]*.
The basic text selected for this section is ***Handbook of CCD Astronomy*** by Steve B. Howell (2nd edition), supplemented with materials discussed in the class that will be provided to the students as PDF documents. Prior to a given class, students are expected to read as homework the Chapter(s) of the textbook that will be covered during that class. To prepare for the first class in this section, students should read Chapters 1–3.

Basis for Grade Assignment

A written report on two projects involving the reduction and basic analysis of astronomical CCD data:

1. A project to perform stellar aperture photometry and construct calibrated light curves of variable stars.

2. A project to measure emission-line strengths in spectra of a nearby galaxy and determine its spectral type.

The report shall be prepared using the LaTeX text processing program and AAS class file (available through the AAS homepage: www.journals/uchicago.edu/AAS/AASTeX/).

Topics covered in this section:

1 Introduction to CCD's

a. Ideal and real detectors
— human eye, photographic plates, photo-electric detectors, and CCDs
— separating signal from astronomical source and detector

b. CCD '101'
— why read-noise necessitates a "bias" offset
— why a DC voltage necessitates an "overscan" region
— CCD read-out - shift, shift, slide ...
— analog-to-digital conversion and read-noise
— gain and Data Numbers
— relation between read-noise, gain, and dynamical range

— saturation
  — A/D conversion
  — full well capacity
— dark current
— on-chip binning and windowing
— impact of cosmic rays (and other ionizing radiation)
— radiation damage, CTE effect, charge diffusion, and multiple photo-electrons

c. Quantum efficiency and bandpass
— coatings
— front- (thick) and back- (thinned) illuminated CCDs

d. Data representation
— gain and discretization noise
— number of bits per pixel

2 Astronomical signals and noise

a. Physical quantities, units, photometric systems
—
—
—

b. Distributions: Gauss vs. Poisson
—
—

c. Measurement uncertainty: signal and noise
—
—

d. The CCD Equation
—

3 Astronomical observation with CCD detectors

a. Imaging the sky
— detection vs. measurement
— plate scale
— orientation w.r.t. celestial axes (a handy trick)
— geometric distortion

b. Astrometry
- — twinkle, twinkle little star, I will measure *where* you are
- — effects of PSF sampling
- — relative astrometry
- — absolute astrometry

c. Photometry
- — aperture photometry
- — total fluxes: curve of growth and PSF fitting
- — extended source photometry
- — differential and absolute photometry
- — photometric calibration
  - — instrument vs. standard magnitude systems
  - — color terms
  - — airmass term

4 Astronomical observation with CCD detectors (cont'd)

d. Spectroscopy: single-slit, multi-slit, and fibers
- — grating vs. prism spectroscopy
- — cross-dispersed (Echelle) spectroscopy
- — (long-/multi-)slit spectroscopy
- — fiber spectroscopy
- — slitless spectroscopy
- — atmospheric dispersion
- — wavelength calibration
- — flux calibration

e. Data storage and transfer
- — the FITS standard
  - — "Flat" FITS image file
  - — Multi-extension FITS
  - — Binary tables
  - — more on FITS headers

5 A practical example of CCD image processing from start to finish

a. Preparing calibration frames
- — Bias
- — Dark
- — Flats (per filter)
- — Bad pixel map

— *Caveat emptor*: Non-linearities, Illumination, Shutter shading, Scattered light, Fringing, (Dis-)Appearing and moving dust/pollen

b. Basic CCD reduction (eliminating non-astronomical signals)
- — Interpolation over bad pixels (note: two schools of thought)
- — Overscan subtraction
- — Correction for 2-D structure in bias
- — Correction for dark signal (1-D vs. 2-D)
- — Correction for pixel-to-pixel sensitivity/gain variations (high-order flat)
- — Correction for illumination of CCD (low-order flat)
- — Shutter shading, scattered light, and fringing
- — Notes on aligning, scaling, and stacking multiple frames
- — Sky subtraction (note: two schools of thought)

c. Flux calibration
- — Aperture photometry of standard stars
  - — BEWARE: standard aperture size!
  - — Fitting zeropoint, extinction and color terms
  - — Curve of growth - empirical PSF profile

d. Photometry of astronomical target
- — Deciding on technique to use
  - — Differential vs. Absolute photometry
  - — Type of target: point source vs. extended
  - — Contamination of target field (crowded field? superposed stars? spatially variable foreground?)
  - — Image subtraction technique
  - — Stability of PSF in time and across the FOV
- — Aperture photometry

6 A practical example of the reduction of spectroscopic CCD data

a. Preparing calibration frames
b. Basic CCD reduction (eliminating non-astronomical signals)
c. Tracing the spectrum
d. Wavelength calibration
e. Sky subtraction
f. Spectroscopy of astronomical target
g. Flux calibration
h. Spectrophotometry of astronomical target