Administrative

- **Project 1:**
  - code IDL algorithms to
    - generate a master dark and bias frame from a series of darks of a range of exposures
    - generate a master flat field frame from a series of flats with a range of exposure intensities
    - generate a master bad-pixel mask (1 = bad, 0 = good) based on the above
  - problem 2.2 in Wall & Jenkins, including the “extra challenge”
  - one-paragraph description of an idea for observational project
  - **due in class on Wednesday, Sep 23**

- **Reading:**
  - chapters 4–5 of Howell: CCD data reduction and photometry
  - chapters 3–5 of Wall & Jenkins: statistics, correlations, hypothesis testing
  - overview paper on IR arrays (Rieke, G. 2007, ARA&A, 45, 77)
Administrative (cont.)

• Think of observing proposals
  – 10 hours on Tenagra Observatories 32”
  – http://www.tenagraobservatories.com/

• Possible directions:
  – detecting the eclipse signal of transiting hot Jupiters
    • determine orbital period and size of planet
    • determine surface temperature
  – a color-magnitude diagram and age estimation of a globular or open cluster
  – astrometric monitoring of a binary object
    • nearby fast-moving star
    • binary asteroid in the solar system
  – etc.
Outline

• Overview of previous lecture
  – CCDs

• Basic imaging data reduction
Context: Plates, PMTs, CCDs
Basic Concept

• electron-hole pair generation
• doping:
  – n-type (electrons)
  – p-type (holes)
  – creates additional energy levels within band gap
  – increases conductivity
• silicon
  – band gap: 1.12 eV (11 300Å)
  – free-electron energy: 4 eV (3000Å)
  – 1 photon -> 1 electron
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Basic Concept: A P-N Photo Diode

- depleted region
  - low conductivity
  - can support an E field
- net positive charge (higher charge density near top)
- additional E-field applied
- subsequently generated electrons get trapped in potential well near top
Charge Trapping

**Figure 1**

Metal Oxide Semiconductor (MOS) Capacitor

- Silicon Dioxide
- Polysilicon Gate
- Photons
- n-Channel
- p-Type Silicon
- Potential Barrier
- Potential Well
- Photogenerated Electrons

**Figure 2**

Electron Distribution in Buried Channel MOS Capacitors

- Electrostatic Potential, $\Psi$
- Oxide
- Gate
- N-Type
- P-Type
- Depth in Silicon (Micrometers)
Advanced CCD Technology

• **orthogonal transfer**
  - 30–100 Hz readout
  - tip/tilt wavefont correction
  - ~30% improvement in “seeing”
  - large-format CCDs

• **low-light CCDs**
  - gain register clocked out with higher voltage (40–60V vs. ~10V)
  - 1–2% probability of generating 2nd electron at each gate transfer
  - total gain enhancement: \( \sim 1.01^N = 145 \) for \( N=500 \) transfers

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**Fig. 2**—The OTCCD is used to track image motion by placing the science field on the portion of the CCD with OT gates and a guide star on the frame-store portion of the CCD. A subarray containing the star image is rapidly read out and used to correct the position of the charge within the OT array to follow the motion of the science field.
Analog-to-Digital Converters

• X electrons = 1 digital unit (counts)
  – X is “gain”: usually 1–10

• CCD saturation depends on
  – well capacity
    • ~300,000 photoelectrons for “deep depletion” CCDs
    • “flat tops” when saturated
  – number of bits in ADC
    • n=16 bits: maximum is $2^{16} - 1 = 65535$ counts
    • column “bleeding” when saturated
Read Noise

• electrons / pix / read

• sources
  – A/D conversion not perfectly repeatable
  – spurious electrons from electronics (e.g., from amplifier heating)

• nowadays: <3–10 electrons
Dark Current

- electrons / pixel / second
- source: thermal noise at non-zero temperature
Non-Linearity

- differential (digitization noise)
- integral

- examples of non-linearity in SDSS CCDs:
Outline

• Overview of previous lecture
  – CCDs

• Basic imaging data reduction
Detector Calibration

• bias frames
  – non-zero bias voltage
  – 0s integrations

• dark frames
  – equal to science integrations

• flat field frames
  – QE of detector pixels is non-uniform in 2-D
  – QE is dependent on observing wavelength

• bad pixels
Sky and Telescope Calibration

- sky background images
- photometric calibration:
  - airmass curve, filter transmission
- sky transmission
  - spectrum of a star of a known spectral energy distribution
- astrometric calibration
  - binary with a known orbit
  - star-rich field with precisely known positions: HST observations of globular clusters
- point-spread function calibration
  - nearby bright star (for on-axis calibration)
  - star-rich field (2-d information on PSF)