OBSERVATIONAL ASTRONOMY

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Lecture 12

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Colour term (1)

- For **very accurate** photometry, the wide bandpass of broad-band filters has to be taken into account when correcting for extinction. **Even for differential photometry!**
- There is a colour term, caused by the variation in spectral profile of the stars and the filter response over the passband.
- Because extinction is so strongly colour dependent, a blue object actually loses more light to the atmosphere than a red one. The solution is to introduce additional colour-dependent secondary extinction coefficients, which modify the above extinction correction equation to:

$$m_{obs} = m_{true} + k_1(\lambda) \sec Z + k_2(\lambda)\,(B\text{-}V) + k_3(\lambda)\,(B\text{-}V)\sec Z$$

(B-V) is the colour of a star. Other colours can be used, e.g. (V-R).

Colour term (2)

$$m_{obs} = m_{true} + k_1(\lambda)\sec Z + k_2(\lambda)\,(B\text{-}V) + k_3(\lambda)\,(B\text{-}V)\sec Z$$

- Solve for k_1, k_2 , k_3 from stars of known magnitude.
- Usually k_2 is negligible (usually of order a hundredth of a magnitude), often k_3 is too.
- In this case we can now simply convert the values of m_{inst} to m_{true} using the value of k_2 that we solve for, and the value of z for each observation.
- However, if k_2 and/or k_3 is not zero, we need to know **(B-V)** for the star to calculate the true magnitude, but we do not. In this case we must observe a set of standard stars (of known magnitudes) at different Z and in two passbands, for instance B and V, and use:

$$V_{obs} = V_{true} + k_1(\lambda)\sec Z + k_2(\lambda)\,(B\text{-}V) + k_3(\lambda)\,(B\text{-}V)\sec Z$$

$$B_{obs} = B_{true} + k_4(\lambda)\sec Z + k_5(\lambda)\,(B\text{-}V) + k_6(\lambda)\,(B\text{-}V)\sec Z$$

Calibrated Magnitudes (2)

- Now we can find the above-atmosphere instrumental magnitude of any object. If the above-atmosphere instrumental magnitude of our standard star is $m_{std,0,i}$, then:

$$m_{zp} = m_{std} - m_{std,0,i}$$

- The calibrated magnitude of our target star, m_{calib}, can then be found using:

$$m_{calib} = m_{zp} + m_{0,i}$$

where $m_{0,i}$ is the above-atmosphere instrumental magnitude of our target star.

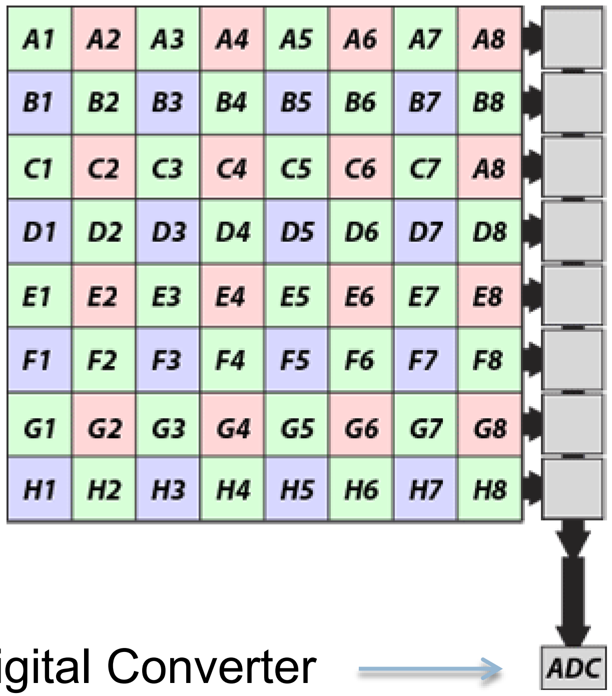
- Each filter in a photometric system will have a different zero-point. Once the zero-point has been measured for a particular telescope, instrument, filter and detector combination, it **should** remain unchanged, although dirt and the degradation of the coatings on the optics will cause minor changes to the zero point on long timescales. To determine the zero points for the UBVRI system, the photometric standards measured by Landolt can be used.

CCD Gain

CCD Gain (1)

- What is relationship between electrons in a CCD and pixel values?

The readout register is shifted to the right by one pixel, and the pixel at the bottom right is shifted into a readout capacitor. What's next?



Analog-to-Digital Converter

CCD Gain (2)

- The steps involved in reading the value of a pixel are something like this:
  1. Electrons transferred to "amplifier"; really a capacitor. Units are **coulombs**.
  2. The voltage induced by this charge is measured. Units are **volts**.
  3. An Analog-To-Digital (A/D) unit converts the voltage into some other voltage, which may have only one of several discrete levels. Units are still **volts**.
  4. The voltage is converted into a number which is passed from the hardware to the computer software as the pixel's value. Units are **counts**, also called "Analog-to-Digital Units" (**ADUs**).

CCD Gain (3)

- In both steps 3 and 4, one can scale the result by any arbitrary factor and the relative pixel values will remain the same. Some software allows the user to modify the scaling factor dynamically; others have a fixed setting.
- The end result is that there is some factor which relates the initial number of electrons in a pixel to the final number of counts reported by camera software. The ratio of these two numbers is the **gain** of the camera:

$$gain = \frac{Number\ of\ electrons\ per\ pixel}{Number\ of\ counts\ per\ pixel}$$

CCD Gain factor (1)

- How should one choose the gain factor? There are several criteria.
  1. **Full-well depth vs. largest pixel value:**
     Each CCD is designed to hold only so many electrons within a pixel before they start to leak outwards to other pixels. This maximum size of a charge packet on the chip is called the **full well depth.**
     There is also a "maximum possible number" in the Analog-to-Digital converter. Most CCDs use 14-bit, 15-bit, 16-bit, sometimes 32 A/D units:
     the corresponding maximum pixel values are
     $2^{14} = 16384$, $2^{15} = 32768$, $2^{16} = 65536$, $2^{32} = 4294967296$.
     It is logical to arrange the gain so that very roughly, the number of electrons in the full-well depth corresponds to the maximum pixel value.

CCD Gain factor (2)

- How should one choose the gain factor? There are several criteria.

  2. **Readout noise vs. smallest pixel value:**
     What are the SMALLEST values that make sense? A typical **readout noise** is 3 – 10 electrons. Therefore, if two pixels have values which differ by only 2 electrons, it's not easy to tell the difference between them. The smallest difference one can represent in an integer image is 1 count. To some extent, it makes sense to arrange the gain so that 1 count corresponds to some moderate fraction of the readout noise:

$$gain = \frac{Number\ of\ electrons\ per\ pixel}{Number\ of\ counts\ per\ pixel} \sim 4\ \text{(typical readout noise)}$$

     Any finer measurement of the pixel values would yield differences which would be essentially random.

Why should we care about the Gain?

- For everything what we discussed previously and where we used the **Counts** we **must** use the number of **electrons** (photons). They can be obtained from the counts using the gain factor (photon per data unit).

$$Number\ of\ electrons = gain\ *\ Number\ of\ counts$$

Example: CCD Gain (ALFOSC)

- ALFOSC - the Alhambra Faint Object Spectrograph and Camera – is an instrument on the NOT telescope built to allow the acquisition of both images and spectra.

- The detector (CCD14) is an **CCD231-42-g-F61** back illuminated, deep depletion CCD with 2048 x 2064 pixels.
- Readout Noise is **~4.3 e^-/pix**
  the gain is **0.19 e^-/ADU**.
- Dark current is **1.3e-/pix/hour**
- Dynamical range is **32 bit.**
- Full-well capacity – **135000 electrons (700 kADUs).**
  Good (linear better than ±1%) up to ~113500e^- (600 kADUs)

Example: CCD Gain (BFOSC)

- BFOSC - Bologna Faint Object Spectrograph & Camera – is an instrument built to allow, with a simple configuration change, the acquisition of both images and spectra.

- The detector is an **EEV LN/1300-EB/1** CCD with 1300 x 1340 pixels, AR Visar coated, back illuminated.
- The detector Readout Noise is **3.06 e^-/pix** and the gain is **2.22 e^-/ADU**.
- Dynamical range is **16 bit.**
- Full-well capacity – **117000 electrons.**