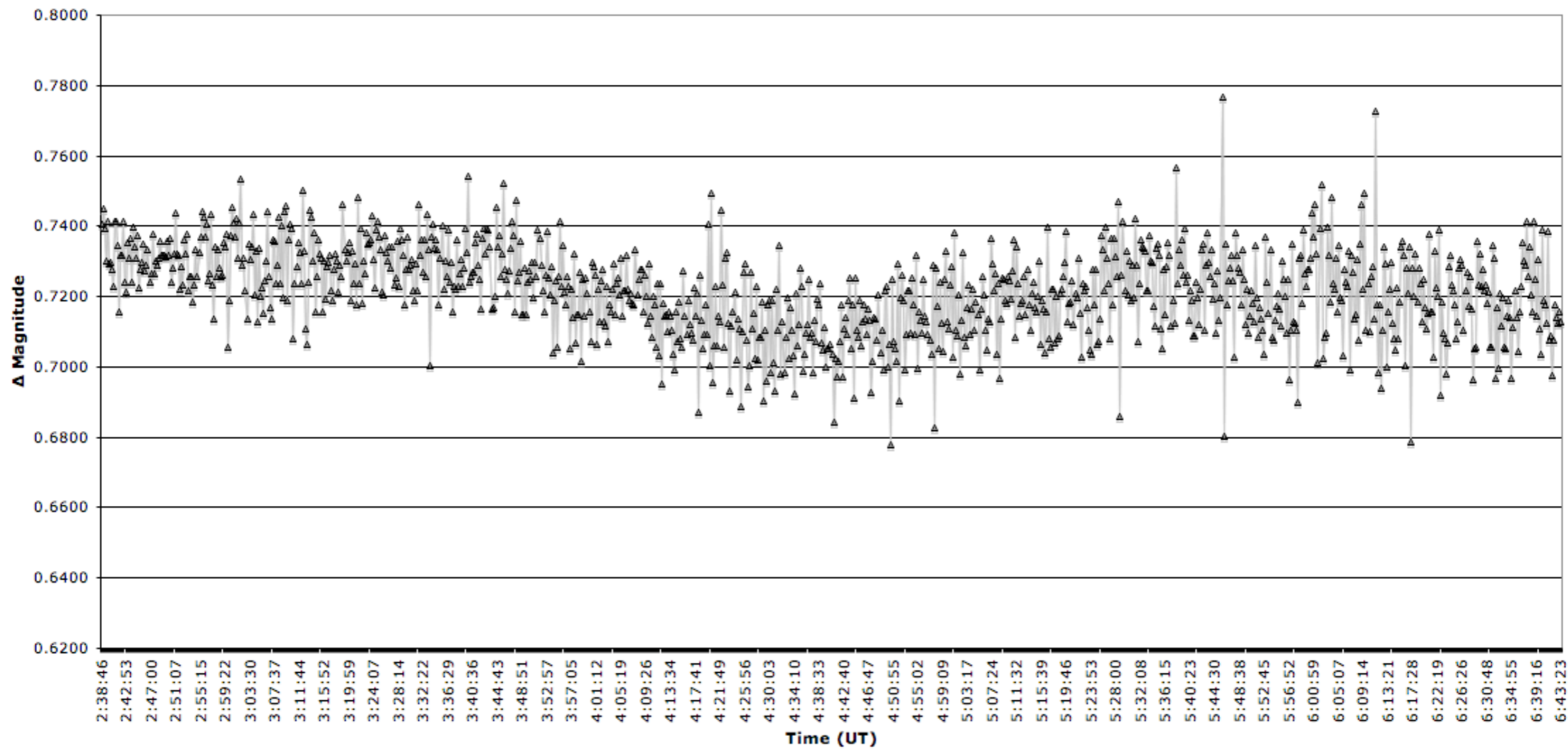


# PHOTOMETRY

**Extrasolar Transit of Planet TrES-2 Orbiting GSC 3549 02811**  
**Transit Event of 2006-09-16 UT**  
**Observer: Don Carona Reduction: Don Carona Reduction Tool: IRAF**  
**Observatory (H32): Celestron C-14 @ f/6.3; SBIG ST-10XME; SBIG ST-402 (Guiding); SB Paramount ME**



Photometry is simply the measurement of the energy that we receive from an object in the form of electromagnetic radiation (EMR).

In its simplest form, this measurement is taken over a broad range of wavelengths.

In its most complicated form, it is wavelength specific and transformed to a standard color system.

There are 3 basic forms of photometry:

- Differential (instrumental)
- All-Sky (absolute)
- Spectroscopy (spectrophotometry)

# DIFFERENTIAL

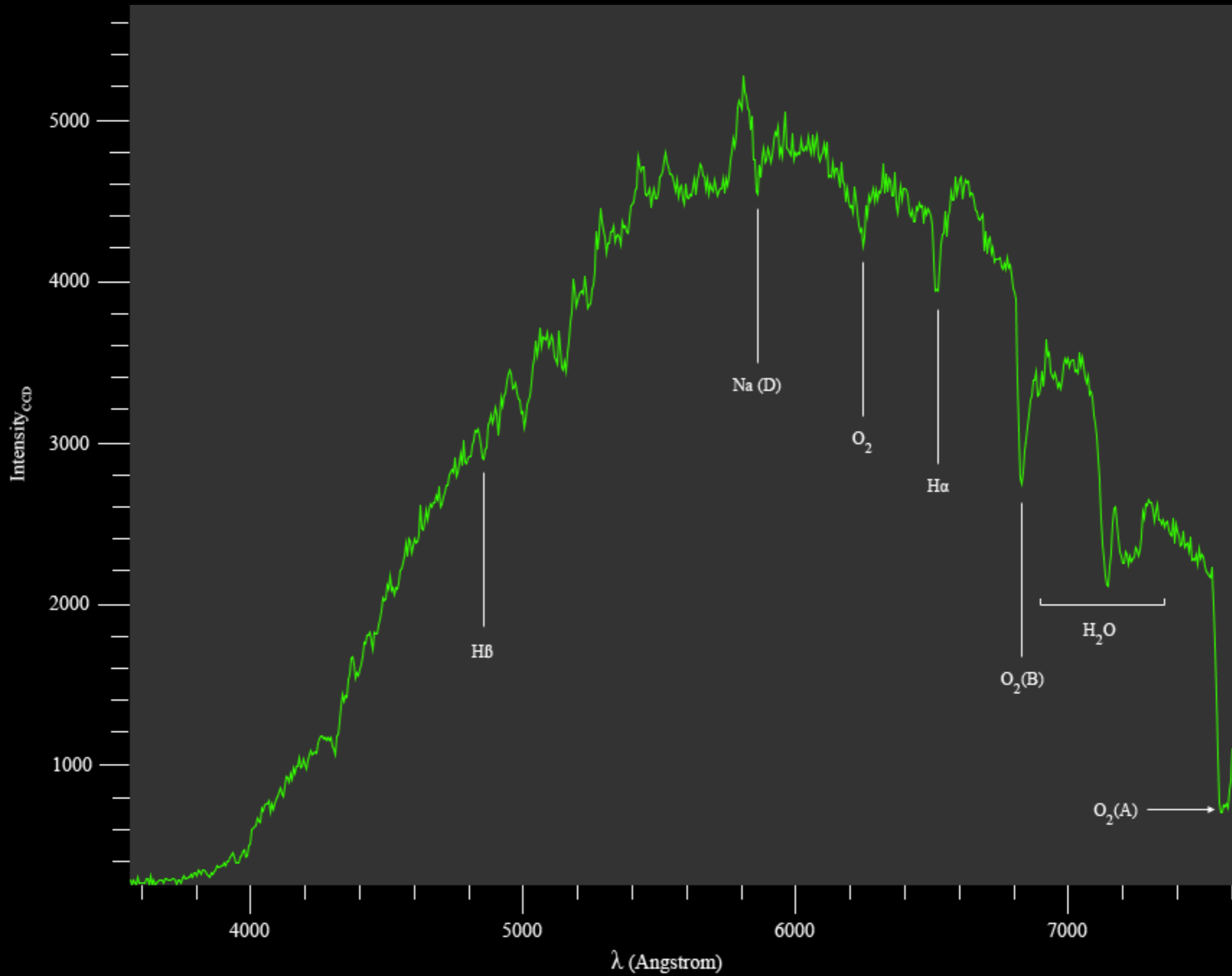
- Easiest to perform.
- Extremely useful results.
- Can be done under light cloudy conditions.
- Can be accomplished with modest equip.
- Can be done without filters, but not ideal for some programs.

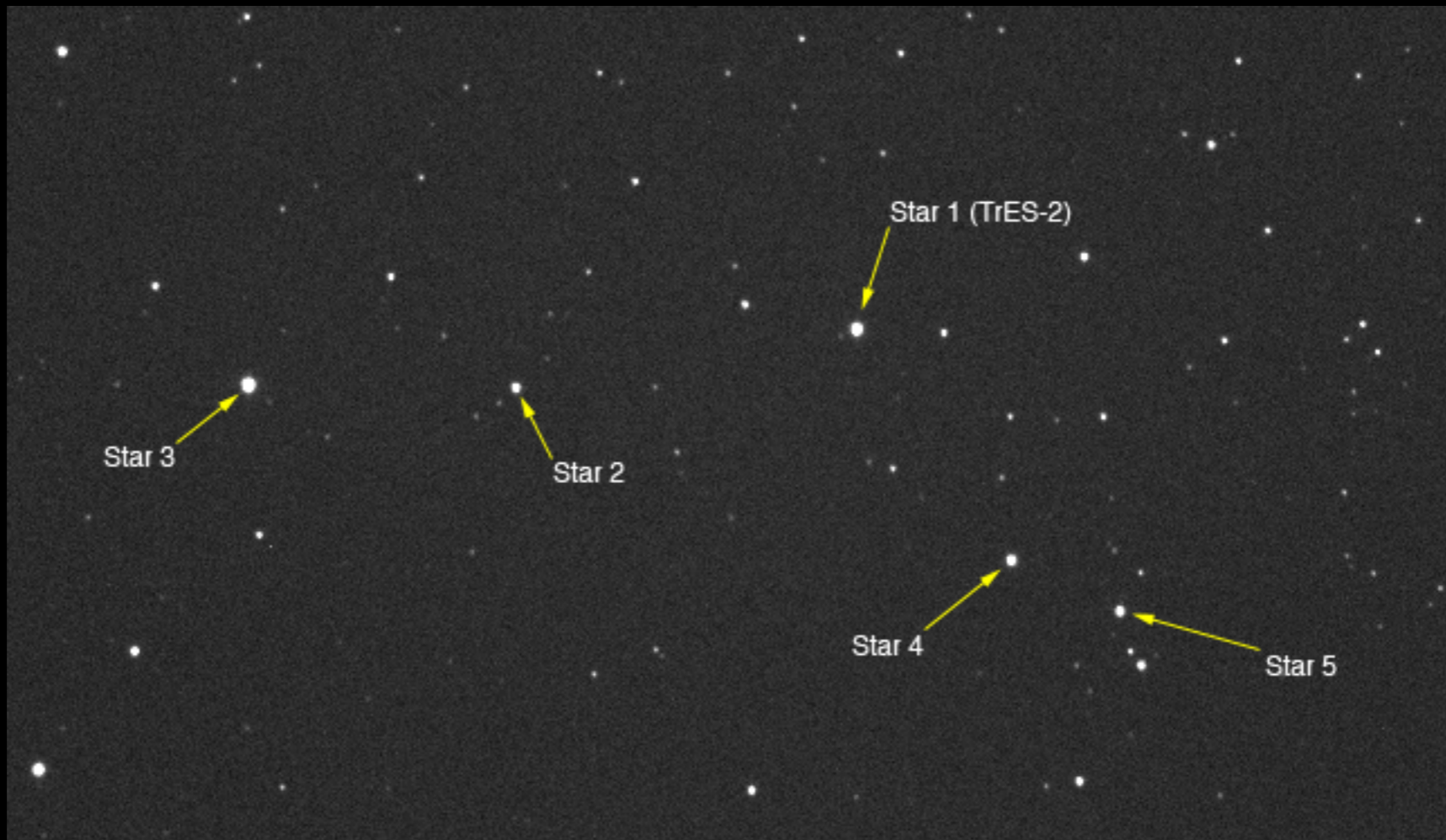
# ALL - SKY

- Skies must be clear all night (photometric).
- Requires observations of standard fields.
- Can be achieved with modest equipment.
- Must have a quality BVRI filter set.
- Standard Bessell or Johnson/Cousins BVRI filters are about \$150 per filter for 1.25”.

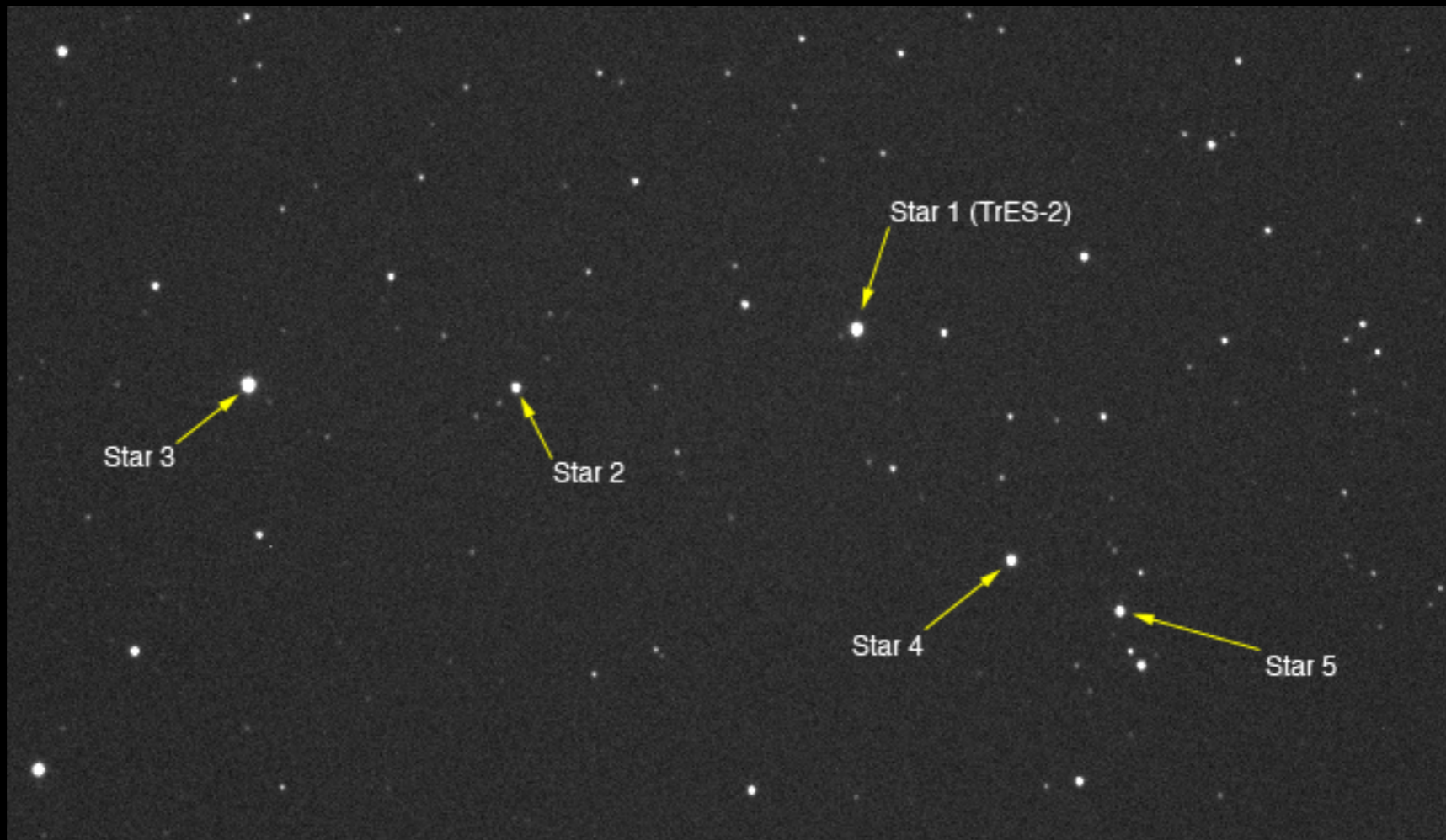
# SPECTROSCOPY







Differential, or instrumental, photometry is the method most employed by amateur astronomers. It depends only on comparing the flux of the subject to that of other stars. Since all of the stars are in the same frame, the image and subsequent data is independent of weather conditions. You need only be careful that the *comparison* stars are not variable!



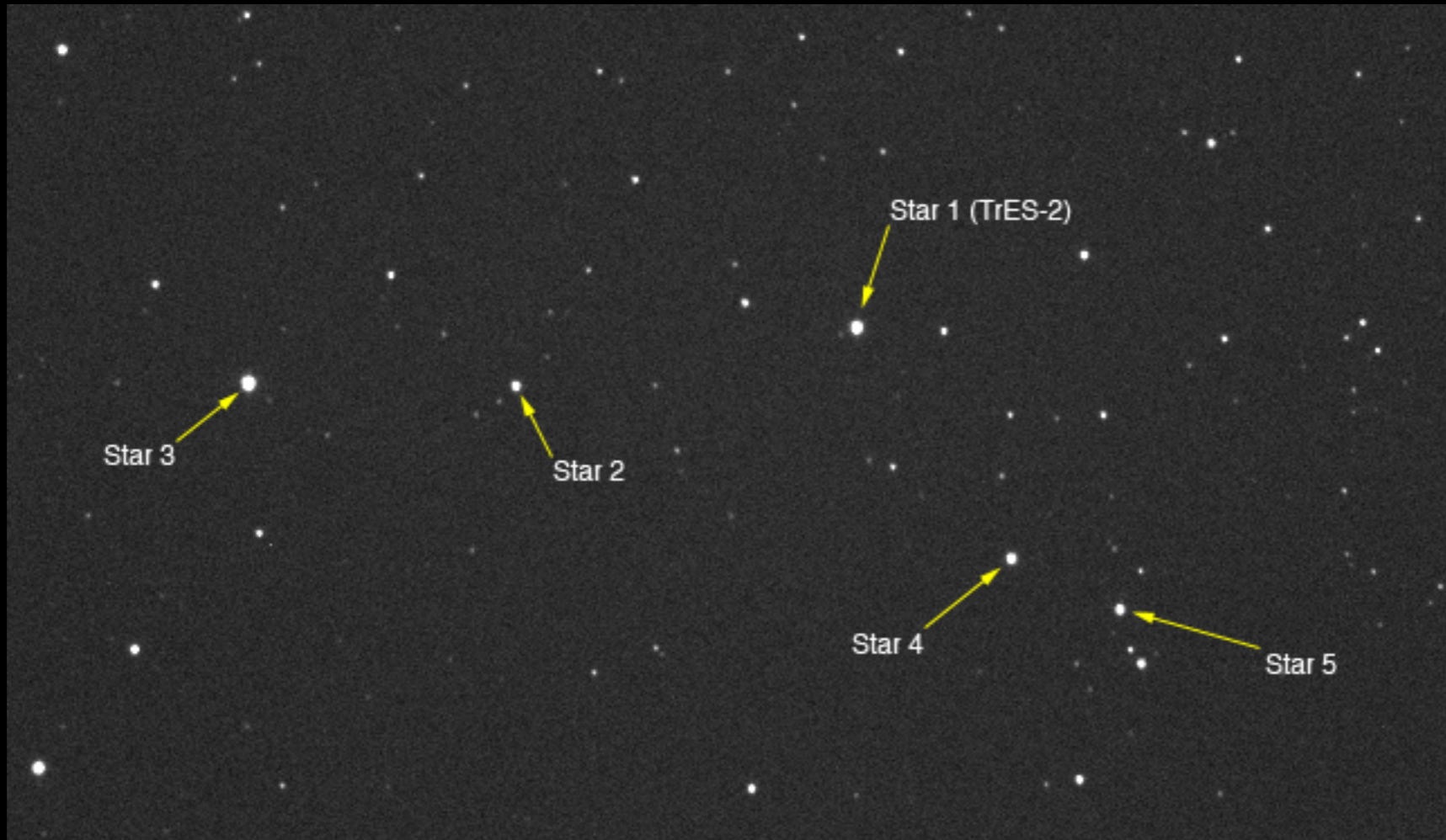
The magnitude relationship between two stars is:

$$m_1 - m_2 = -2.5 \log_{10}(f_1/f_2)$$

where

$f_1$  = flux from the subject

$f_2$  = flux from the comparison



A straight forward means of differential comparison for each exposure would look like:

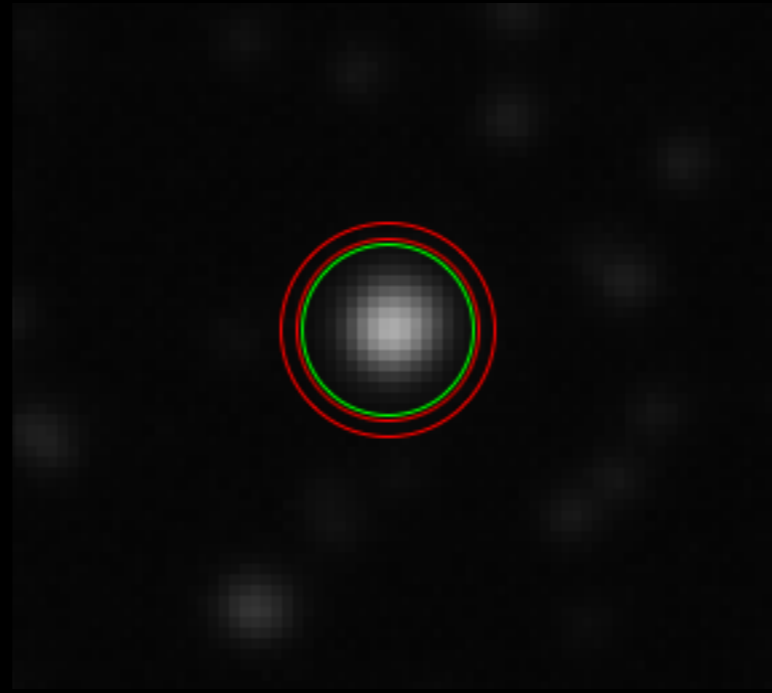
$$\Delta\text{mag} = ((\text{Star2} - \text{Star1}) + (\text{Star3} - \text{Star1}) + (\text{Star4} - \text{Star1}) + (\text{Star5} - \text{Star1})) / 4$$

# How Do I Measure Flux?

There are several software packages that sum the number of *analog to digital units* (ADU) within a synthetic aperture: IRAF, MaximDL, CCDSoft and IDL to name a few. In the case of MaximDL and CCDSoft, these also control your CCD camera. A synthetic aperture is an area drawn around a star that defines the pixels to be added together.

## What's an ADU?

Each pixel in a CCD array can hold a specific number of electrons before becoming full. The ADU, also called “counts”, is the conversion of the number of electrons in a given pixel to a readable number.



Aperture photometry today refers to software that produces a synthetic aperture, which is used to measure all of the counts within a given region. In the image above, the green circle is the aperture while the red circles (called the sky annulus) are used to measure the average flux from the sky background.

The sky must be subtracted from the flux of the object in order to more accurately quantify the amount of energy being measured. So the formula for the magnitude relationship between two stars is refined to:

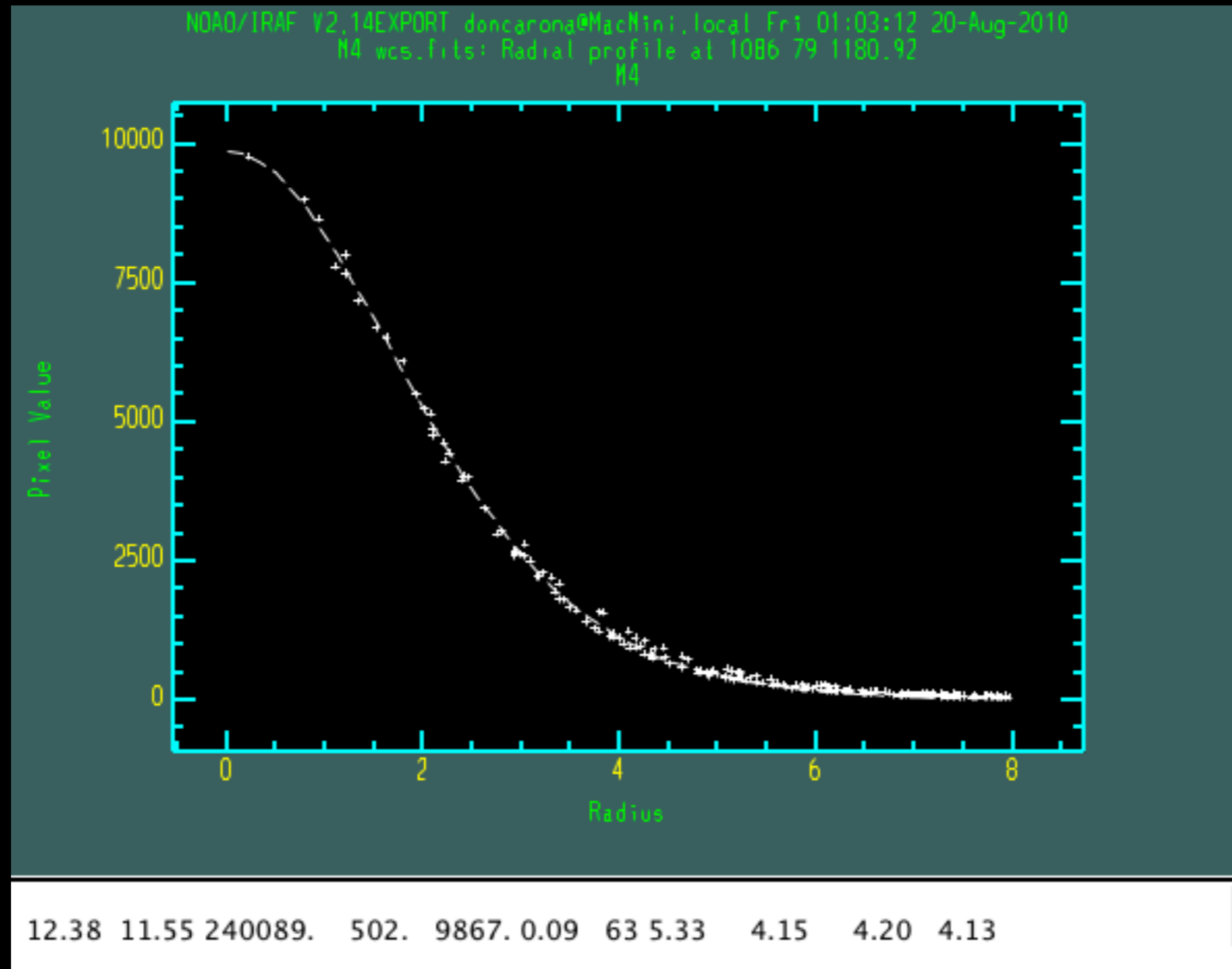
$$m_1 - m_2 = -2.5 \log_{10}((f_1 - \text{sky}_1) / (f_2 - \text{sky}_2))$$

Most aperture photometry packages (especially in IRAF) require you to define the aperture and radius of the sky annulus. The sky annulus rarely needs to be wider than about 5 pixels.

# How Big Should My Aperture(s) Be?

- The general rule...diameter should be 3-5 times the FWHM.
- A good photometry package will allow you to define multiple apertures simultaneously.

# What is Full Width Half Max (FWHM)?



## Since we know about FWHM...how do we quantify the seeing?

It's a good question and one that anyone engaged in photometry should be able to answer for a given observing run...and write it in your log as the night progresses.

First, we have to know the plate scale of the CCD + Telescope combination. The formula for plate scale, resulting in arc-seconds per pixel, is defined by:

$$\text{plate scale} = ((\text{size of pixels in microns} \div \text{focal length of the objective}) * 206.265) * \text{Binning}$$

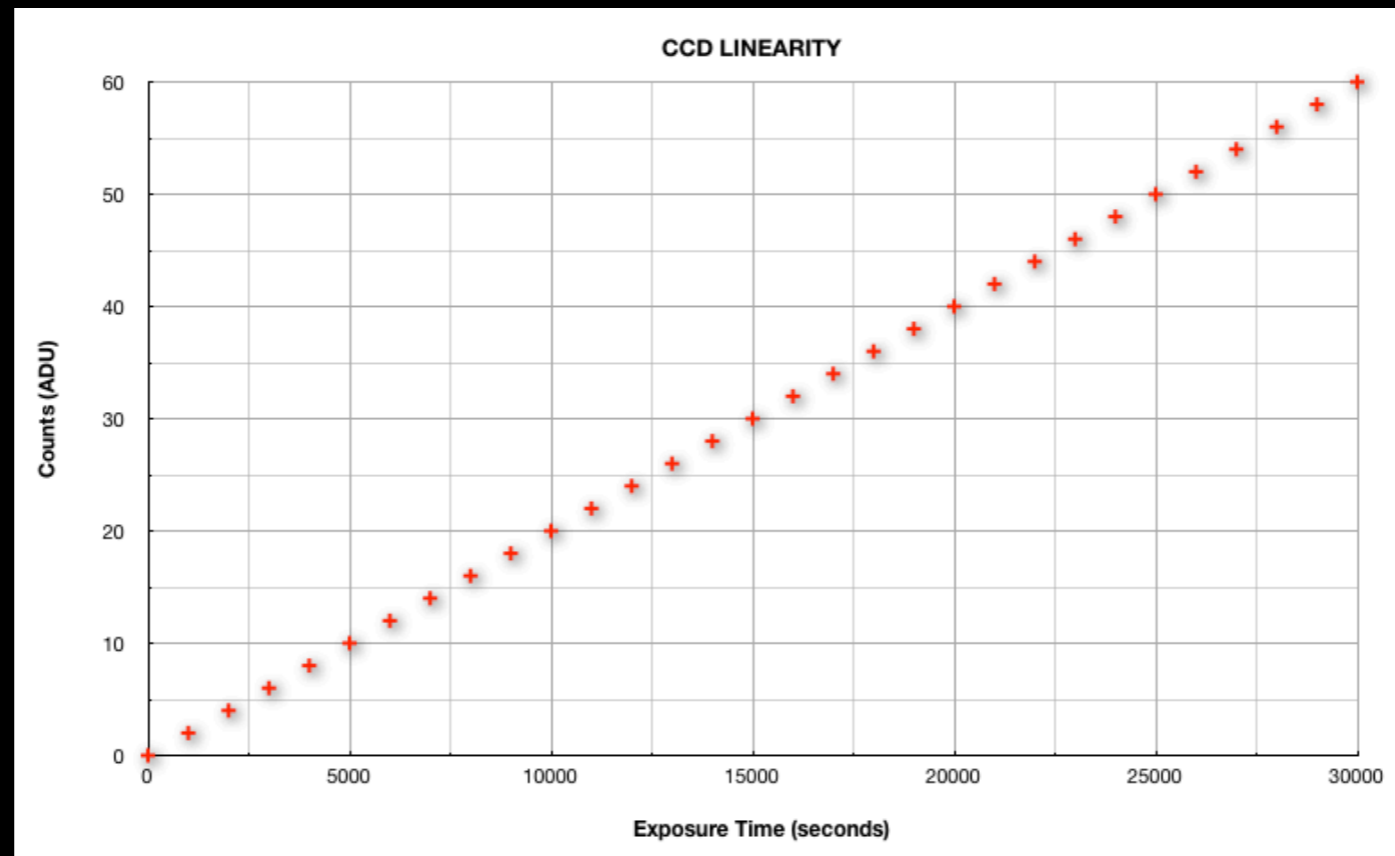
The “seeing” is then calculated by multiplying the FWHM by the plate scale.

## Great, what's Binning?

A CCD is an array of pixels. Binning is the process of combining the charge of several pixels to form one pixel. This effectively changes the size of the pixels. For instance, a binning mode of 2x2 would decrease the resulting image size by half. Binning is not necessarily a good thing when it comes to photometry; however, it does have the advantages of increasing the signal-to-noise ratio (SNR); decreasing the disk size of the image; and making faint targets easier to reach in shorter exposures.

# CCD LINEARITY

Linearity is the measure of how flat the CCD response is to light with increasing exposure time.



Every CCD pixel is a well that can hold a specific number of electrons. It is important practice to avoid exposing beyond half the full well capacity in order to avoid issues with the detector becoming non-linear. To determine half the full well capacity, you need to know three things about your detector: 1. The full well capacity in electrons 2. A/D Gain 3. Introduced bias. For example, the SBIG ST-8XME has a full well capacity of  $\sim 100,000$  e<sup>-</sup> and an A/D gain of 2.3 e<sup>-</sup>/ADU. All SBIG CCD's automatically introduce a bias of 100 e<sup>-</sup> to prevent negative wells. As an example, half the full well capacity of the ST-8XME would be:

$$\text{HFWC} = ((100000 - 100) / 2.3) / 2.0 = 21717 \text{ ADU}$$

# CCD REDUCTION FRAMES

*Bias* is a fixed offset charge carried by each pixel. As previously mentioned, bias can be introduced to prevent negative values from being passed to the A/D converter. This is a repeatable pattern for the CCD that must be removed from all frames (including dark frames). Also referred to as zero frames.

A bias frame is a zero exposure frame. If your software does not allow for direct bias frames or zero second exposures, a 1 second dark and a 2 second dark can be taken. Then multiply every pixel in the 1 second exposure by 2 and then subtract the 2 second exposure. This results in the remaining counts being bias.

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*Dark* current is every detectors ability to create its own charge over time and dependent on temperature. The lower the temperature, the less noise that is generated. This is also referred to as electronic noise since the electronics within and surrounding the camera body can contribute to the dark current.

Dark frames effectively eliminate this form of noise. In order for dark frames to be truly successful, several must be combined before subtracting from the image. For this reason, auto-dark features of camera control software are less effective.

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*Flat Fielding* (or flats) is a means to even out the sensitivity of the detector. This is due to each pixel having a slightly different sensitivity to incoming photons. Flats are also used to remove mirror (or lens) artifacts from the image. There are two schools on the type of flat fields one should take: sky flats and dome flats.

Dome flats are easier since they are not dependent on the brightness of the sky; generally have poor wavelength coverage in most setups; and does little, if anything, to correct for vignetting.

Sky flats are more difficult, but are performed with the telescope looking through the atmosphere. This more closely approximates what the telescope sees at night. Vignetting is removed.

# GENERAL OBSERVING CHECKLIST

- ✓ Open the observatory and start the cooling on the CCD as soon as possible prior to sunset.
- ✓ At sunset, begin taking sky flats through all of the filters that you'll use during your observing.
- ✓ Take an initial set of at least 10 bias frames.
- ✓ Observe your target
- ✓ At the end of your observing, get at least 10 dark frames and 10 more bias frames.
- ✓ If you're observing all night, it's a good idea to get additional sky flats just before sunrise.
- ✓ Reduce your data in the following steps:
  - ▶ Combine all of the bias frames to create one master bias frame.
  - ▶ Combine the dark frames to create one master dark frame.
  - ▶ Combine the sky flats by filter to create a master flat for each filter.
  - ▶ Find the statistical mode of the master flat and divide the master flat by the mode.
  - ▶ Subtract the master bias frame from master dark frame.
  - ▶ Subtract the master bias and master dark frames from all the images.
  - ▶ Divide all the images by the master flat (for the respective filters)
- ✓ Perform the aperture photometry on the data and plot the results as magnitude versus time.

# WHAT ARE GOOD STARTING TARGETS?

- ◆ Any star or eclipsing binary which has a well known variability. Algol and Beta Lyra (Sheliak) are both great starters when available.
- ◆ Extrasolar transits that have a deep transit depth ( $\sim 2\%$ ). TrES-3b is an excellent starter. It has a transit depth of almost 3% and is attainable in small optics with a  $V=12.4$  magnitude. It also transits rather fast ( $\sim 77$  minutes).
- ◆ Map variable stars (mostly RR Lyrae types) around globular clusters.