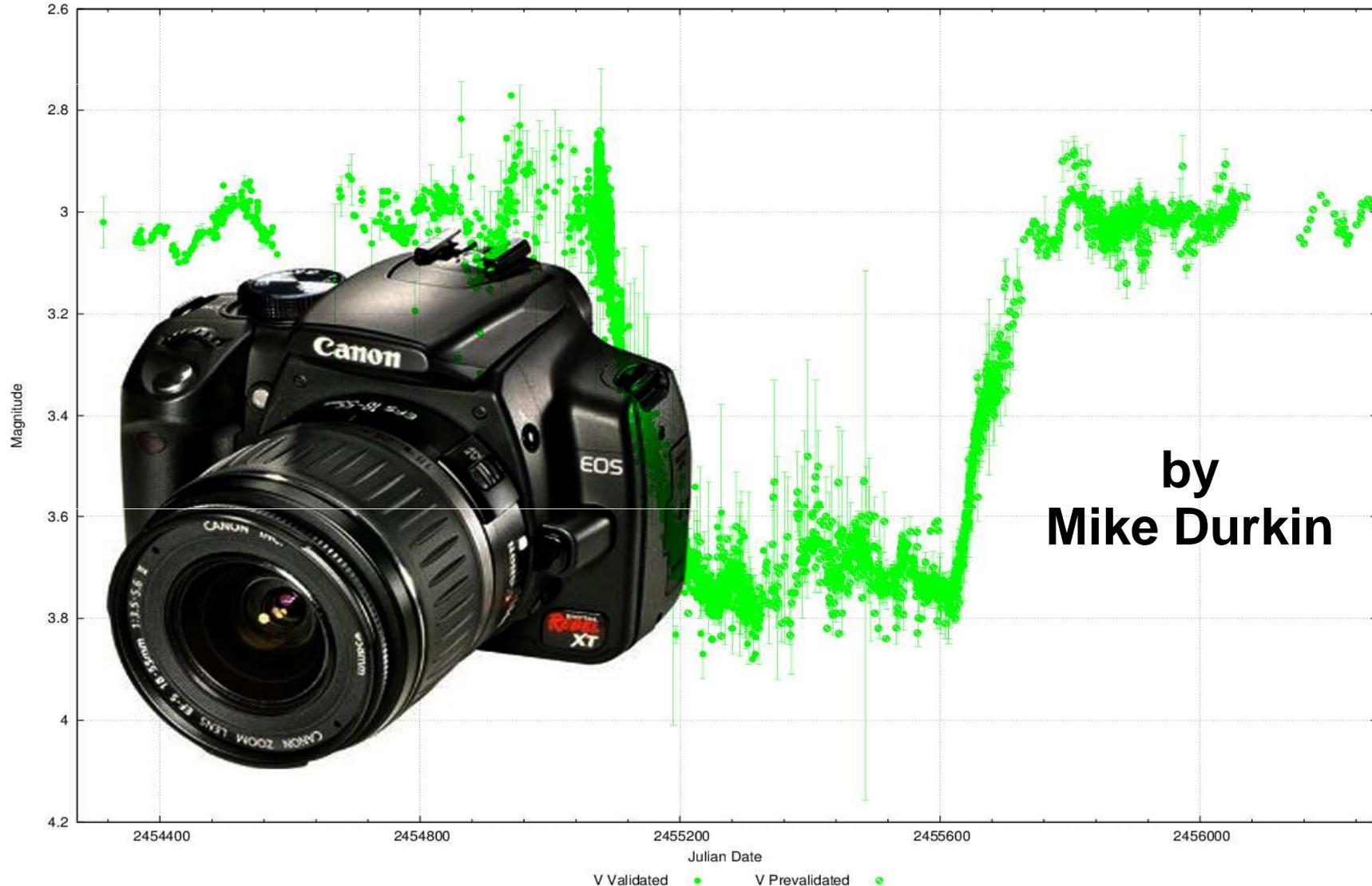


DSLR PHOTOMETRY:

A citizen science project using a consumer camera to contribute scientific data

AAVSO DATA FOR EPS AUR - WWW.AAVSO.ORG



Photometry is one of many areas in astronomy where amateurs can make useful contributions.

Other areas include astrometry, occultation timings, and recording high quality observations of solar system objects.

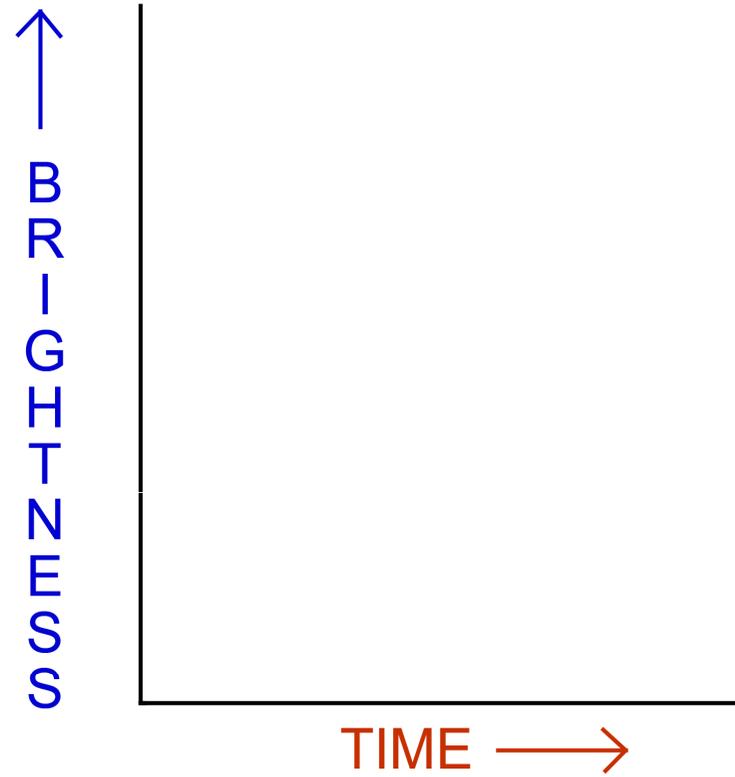
There are also projects for “armchair astronomers”, such as Galaxy Zoo.

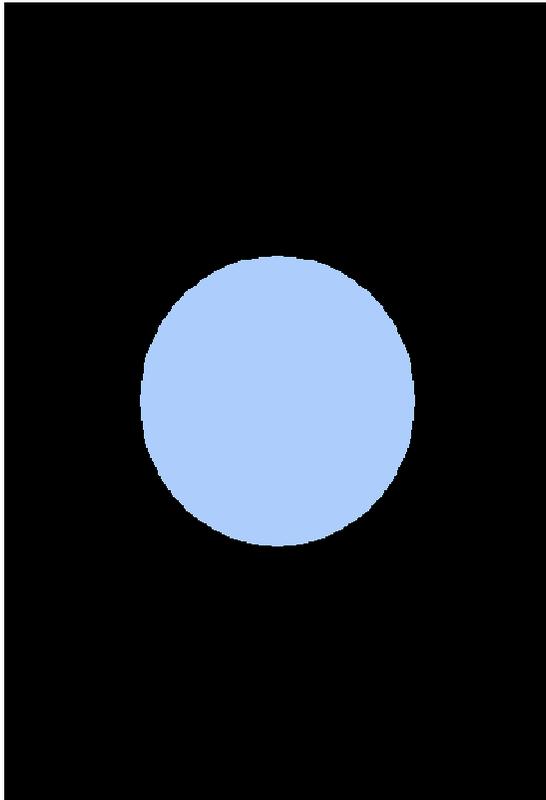
What is Photometry?

- Photometry is the measurement and study of the brightness of objects
- In astronomy, photometry is used to measure the brightness of **stars**, **supernovae**, **asteroids**, etc. I will be talking mostly about measuring **variable stars**, which are stars that change brightness over time.
- By studying the how the brightness of objects change over time, it can help determine physical properties.

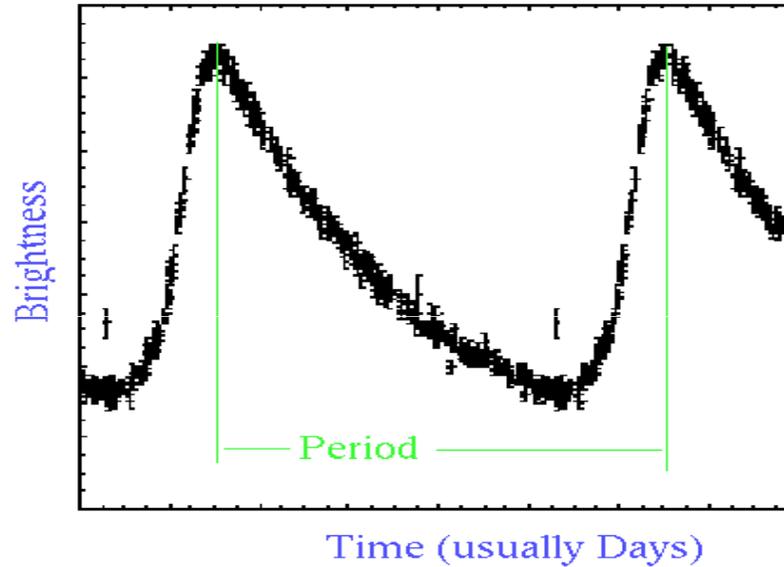
LIGHT CURVE

shows brightness changes over time





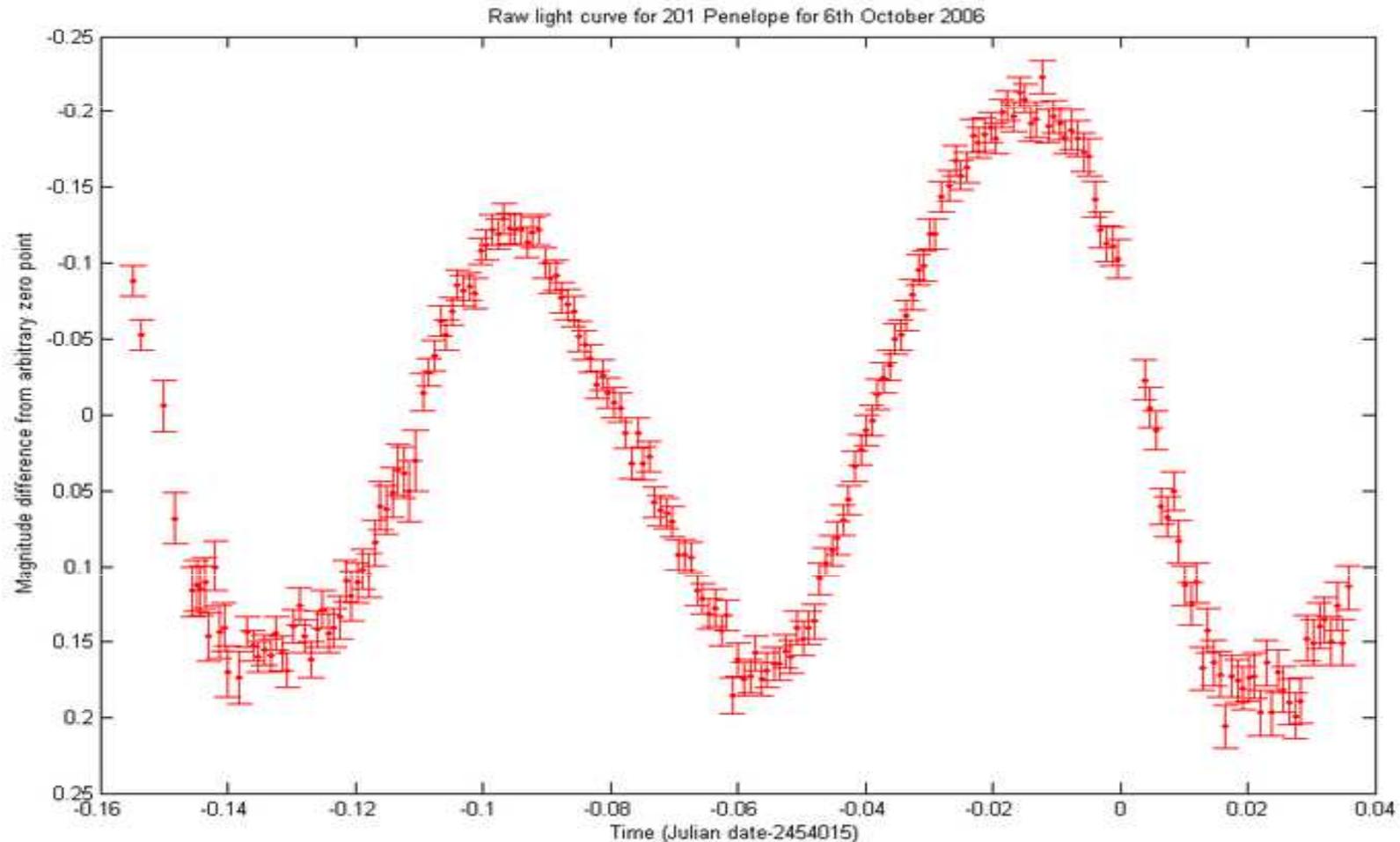
Data from a Well-Measured Cepheid

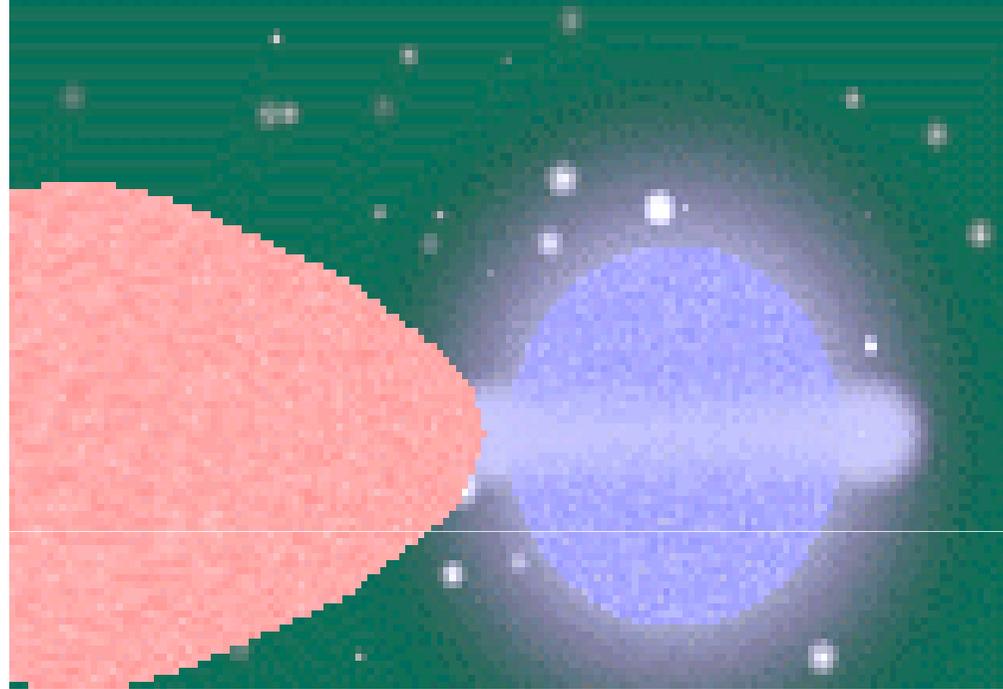


Cepheids are a type of variable stars that fluctuate in brightness. There is a well defined relationship between brightness and the Period of the brightness variation.

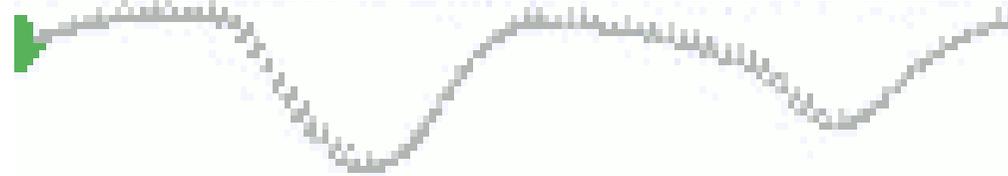
Cepheids were used to determine the distance to the Andromeda Galaxy and proved that the universe was much larger than just the Milky Way.

Light Curve for an asteroid can be used to show rotational period.





Light curve for
eclipsing binary



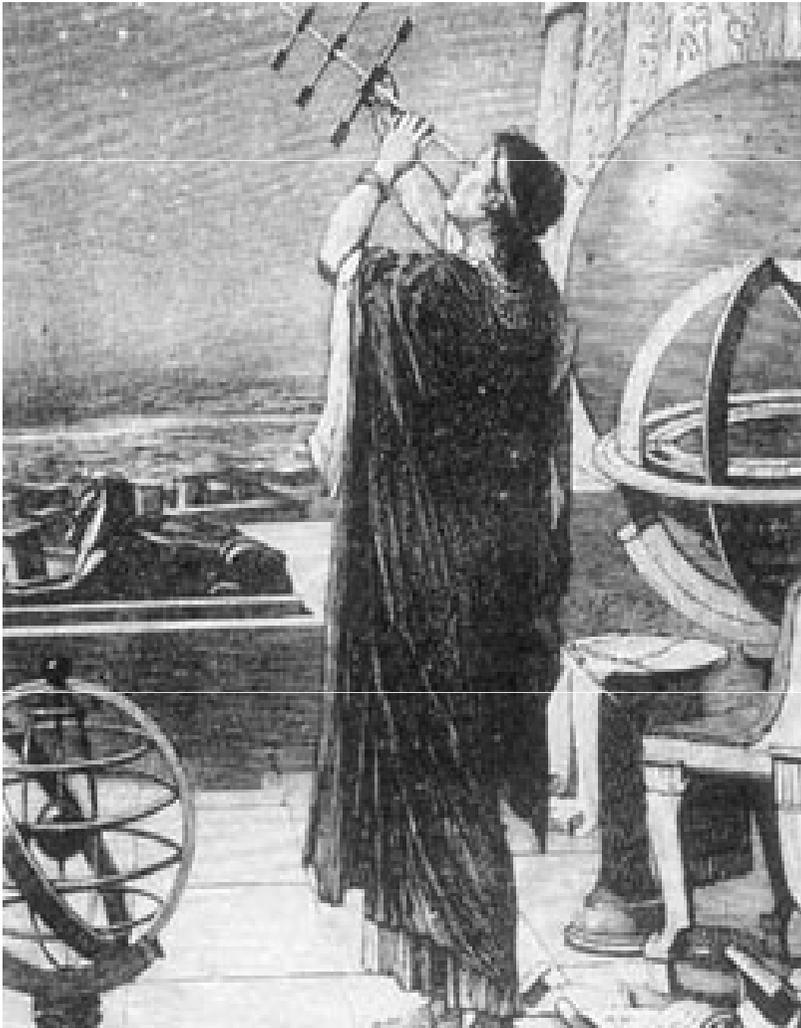
The light curve for an eclipsing binary can be used to determine properties such as the diameters, luminosities, and separation of the stars.

THIS SOUNDS LIKE STUFF FOR PROFESSIONAL ASTRONOMERS, WHAT GOOD CAN AMATEURS DO?

- There are a lot more amateurs than professionals
 - Estimated total number of professional astronomers is **2,080** (*U.S. Dept. of Labor, Bureau of Labor Statistics*)
 - Estimated total number of amateurs is **at least 100,000** based on the circulation numbers of magazines.
- Professionals can use large telescopes, but access time is very limited. Amateurs can dedicate significantly more time using their own equipment.
- Professional astronomers don't have the manpower, money, or resources to cover everything (there are over 40,000 designated variable stars and over 300,000 numbered minor planets)

A BIT OF REVIEW.....

THE MAGNITUDE SYSTEM



Generally believed to originate with the Greek astronomer **Hipparchus** (c. 190 BC – c. 120 BC)

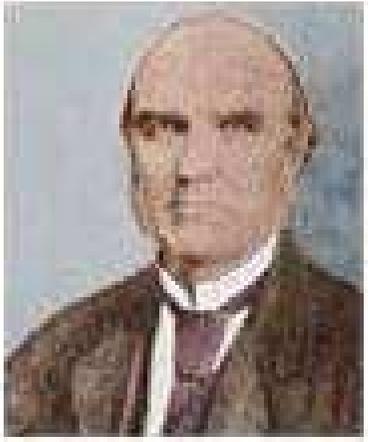
He ranked stars into 6 classes of magnitude.

The 20 brightest stars were assigned magnitude 1.

Slightly dimmer stars were assigned magnitude 2.

And so on, up to the faintest stars just visible with the naked eye, which were assigned magnitude 6.

We still use his system, with some improvements.



In 1856, English astronomer Norman Robert Pogson formalized the system by defining a typical first magnitude star as being 100 times brighter than a typical sixth magnitude star

Using this logarithmic scale, a first magnitude star is about 2.512 times as intense as a second magnitude star and leads to this formula:

$$m_1 - m_2 = -2.5 \log_{10} \left(\frac{I_1}{I_2} \right)$$

If we set $I_1/I_2 = 100$ then
 $m_1 - m_2 = -5$ magnitudes of difference (1.0-6.0)

I=the Intensity or Brightness of the object.

Think of the Intensity as the amount of photons emitted over time.

The intensity is what is measured for photometry.

You can use Pogson's formula to calculate the unknown magnitude of a star by comparing it's intensity with a star where the magnitude is known or predefined as a reference star.

The stars Polaris (magnitude 2.00) and Vega (magnitude 0.00) have been used as reference stars in order to extrapolate out and set the magnitudes for other stars.

For example, if compare the intensity of Deneb
with Vega...

We count 206,160 photons for Vega.

We count 60,562 photons for Deneb.

When we plug the numbers into Pogson's
Formula:

$$\text{Mag(Vega)} - \text{Mag(Deneb)} = -2.5 \log_{10}(206160/60562)$$

$$\text{Mag(Vega)} - \text{Mag(Deneb)} = -2.5 * 0.532$$

$$\text{Mag(Vega)} - \text{Mag(Deneb)} = -1.33$$

Since Vega is defined as having magnitude of
0.00, then Deneb has a calculated magnitude
of 1.33

PHOTOMETRIC DEVICES

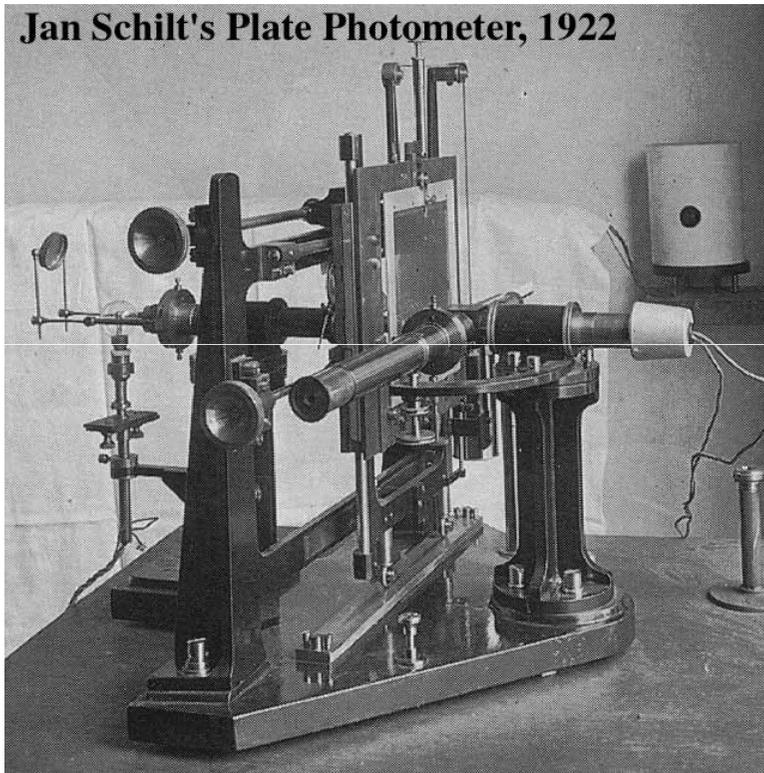


The human eye

Before photography, astronomers would use their eyes, aided and unaided, to calculate stellar magnitudes

Even today, many amateur astronomers still measure magnitudes using their eyes and submit data to an organization such as the AAVSO (American Association of Variable Star Observers) which can be used by professional astronomers for research.

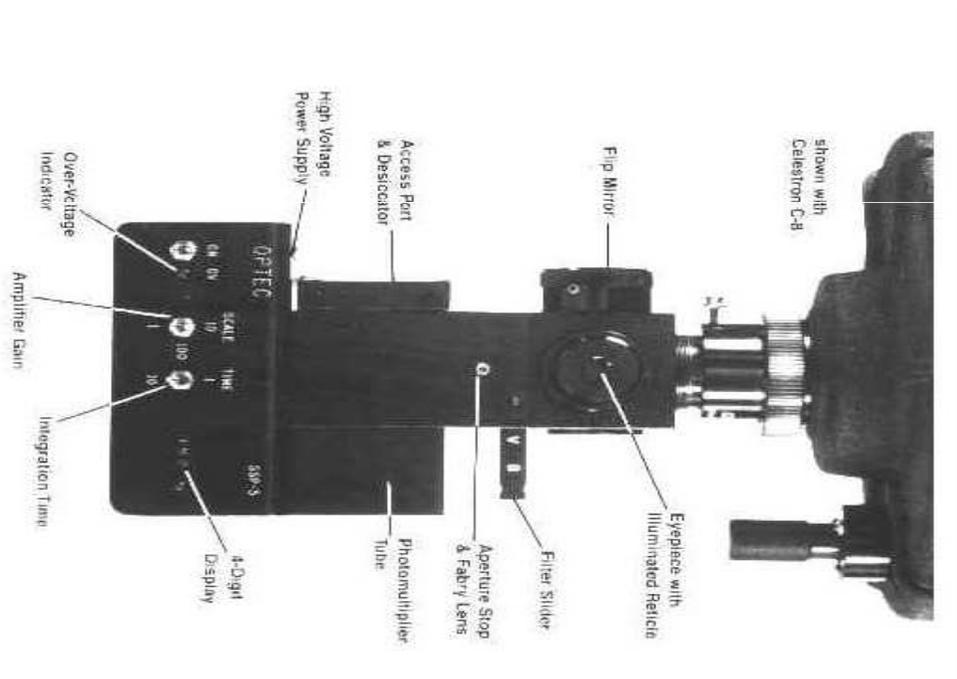
The introduction of photography to the field of photometry enabled astronomers to obtain much more accurate results.



Early photometers measured the amount of light that would pass through a photographic plate

Since the early 1940s, photomultiplier tubes, which are glass vacuum tubes have been used. They are extremely sensitive and can be used in a photon counting mode to count individual photons, but only measures one star at a time.

Photomultiplier tubes are still used for photometry today.



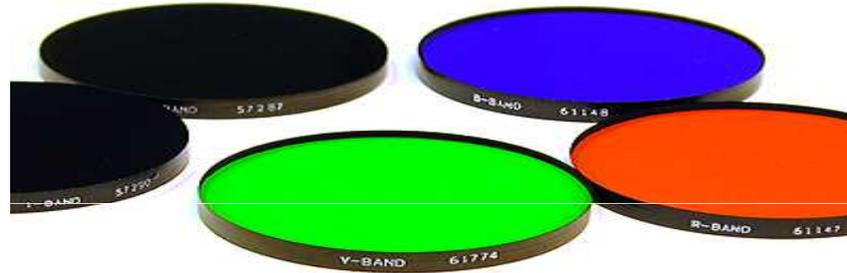


More recently astronomers have started using CCD cameras. These are devices with an array of picture elements called pixels. A typical CCD camera can have tens of thousands to millions of pixels.

The accumulated charge in each pixel from photons that were captured is measured.

CCDs are very sensitive, respond to light over a wide range of wavelengths and can measure many stars at once, as compared to photomultiplier tubes which only measure one star at a time.

PHOTOMETRIC FILTERS



- When astronomers measure stellar magnitudes, they typically use standardized color filters.
- One of the most common standards is called the Johnson-Morgan-Cousins **UBVRI** photometric filters
- The letters **U, B, V, R, I** stand for **ultraviolet**, **blue**, **visual**(green), **red** and **infrared**
- Stars can have very different magnitudes depending on which filter is used

- **Examples:**

- ☆ **Mira: R=2.5, V=4.0, B=5.5**

- ☆ **Bellatrix: R~1.9, V=1.6, B=1.4**

- **When we look up the magnitude of a star, it is usually the magnitude measured using the V filter.**
- **The defined colors of stars are usually calculated by subtracting the V magnitude from the B magnitude (B-V)**

Rigel: -0.03 (blue)

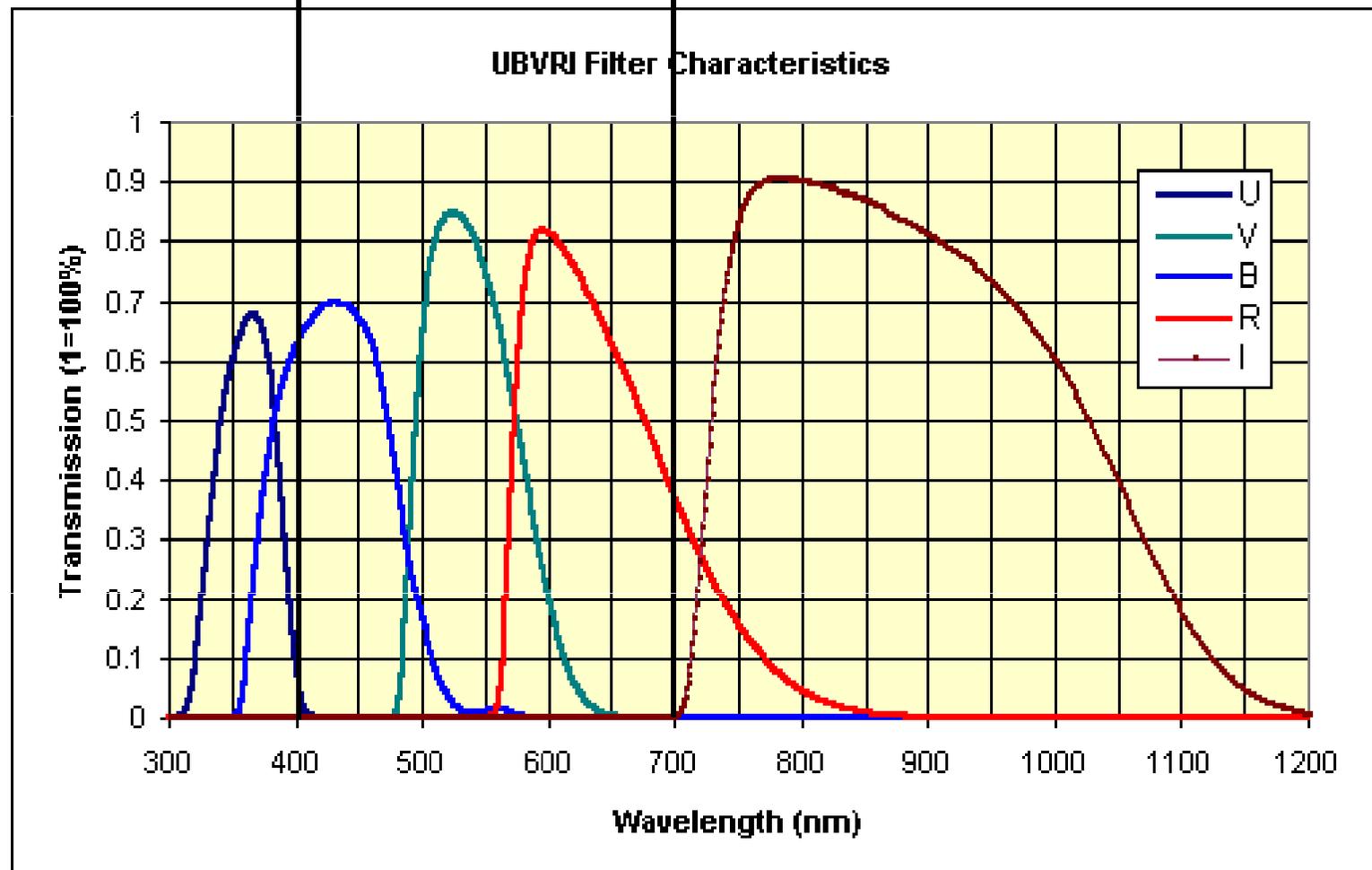
Sun: 0.66 (yellow)

Betelgeuse: 1.86 (red)

U Camelopardis: 4.10 (VERY red carbon star)

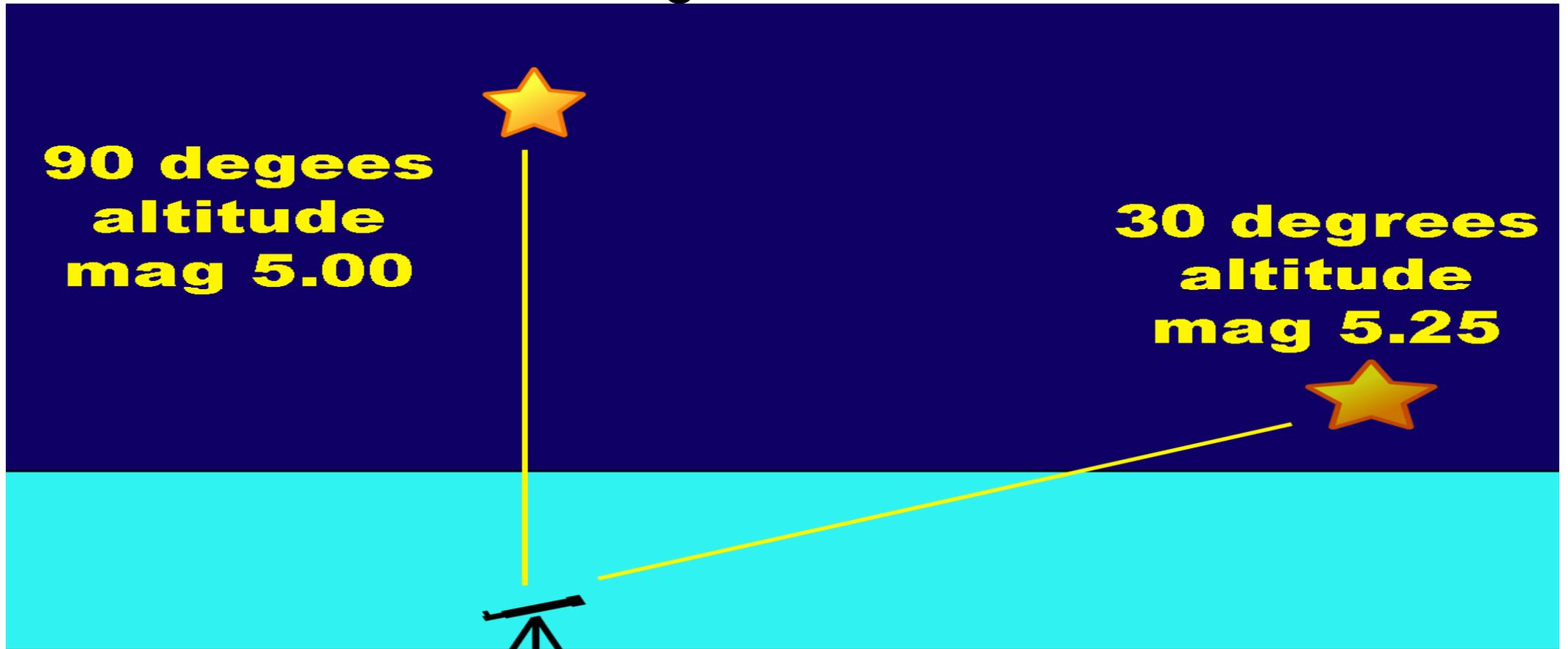
Human eye
sensitivity

UBVRI Filter Characteristics



Quick note on Extinction

Stars get dimmer the closer to the horizon they are because the light is travelling through more air.



Quick note on Extinction

Extinction may need to be taken into consideration when comparing stars that are far apart in the sky.

So what about DSLR cameras?



So what about DSLR cameras?

- **Just like CCD cameras, there is an array of pixels to measure multiple stars in the field of view**
- **By using a normal camera lens or small telephoto lenses (50mm-300mm), bright stars can be measured that are too bright for a CCD camera with a telescope.**
- **The scatter from visual observers is usually about 0.2-0.5 mag, but in DSLR measurements the scatter is usually about an order of magnitude better (0.02-0.05 mag).**

So what about DSLR cameras?

- **Tracking is not necessary for short exposures**
- **The equipment required for bright stars and short exposures can be very portable.**
- **In general, DSLR cameras are cheaper than CCDs and can also be used for non-astronomical purposes.**

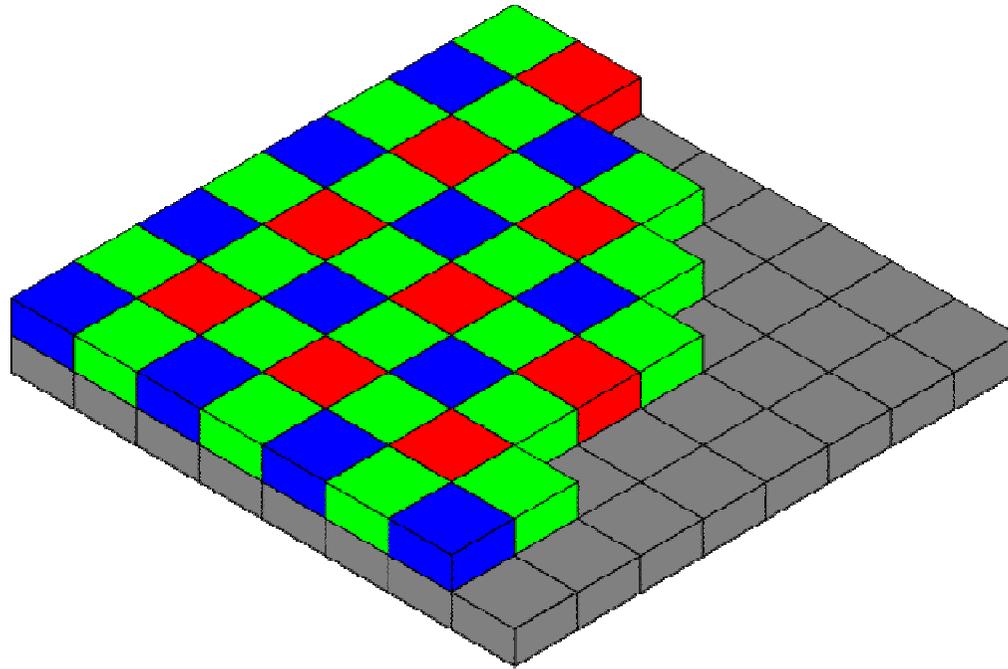
Disadvantages of DSLR camera

- CCD cameras are more sensitive than DSLR cameras. This lets them capture fainter stars easier.
- High quality CCD cameras are cooled to reduce thermal electronic noise. DSLR cameras generate more noise than CCD cameras, which increases uncertainty of measurements and makes it harder to measure faint objects.

- DSLR cameras have a Bayer matrix of RGB filters in front of the pixels which must to be accounted for. One Shot Color (OSC) CCD cameras also have this Bayer matrix, but monochrome CCD cameras do not.
- Some very red stars, such as carbon stars, may not be able to be measured accurately due to the filters leaking a small amount of IR light.

What is a Bayer Matrix

A Bayer matrix is a grid of RGB filters on top of the pixels in the camera's sensor chip.



Even though each pixel only receives light filtered through one RGB color, software in the camera will average the other colors from the surrounding pixels to calculate separate RGB values for each pixel.

Currently I am only dealing with the green pixel values in images. It turns out the green filters in DSLR cameras are very similar to the Johnson $V(\text{green})$ filter. We can add a simple correction to make them equivalent.

Most point and shoot cameras are not adequate.
(There may be some exceptions)



You need to be able to manually set exposure
and focus settings.

The camera must be able to save images in
some type of RAW format.

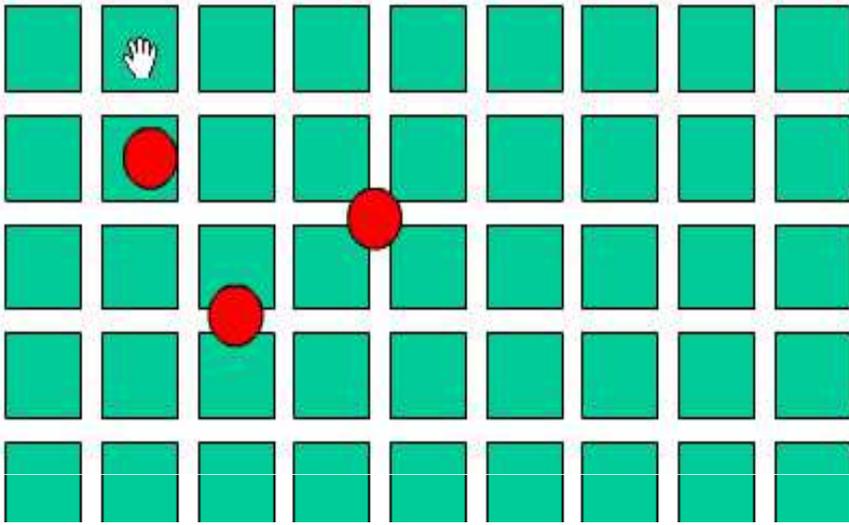
Software

Additional software is required for some basic processing and actually measuring stellar magnitudes. Some examples:

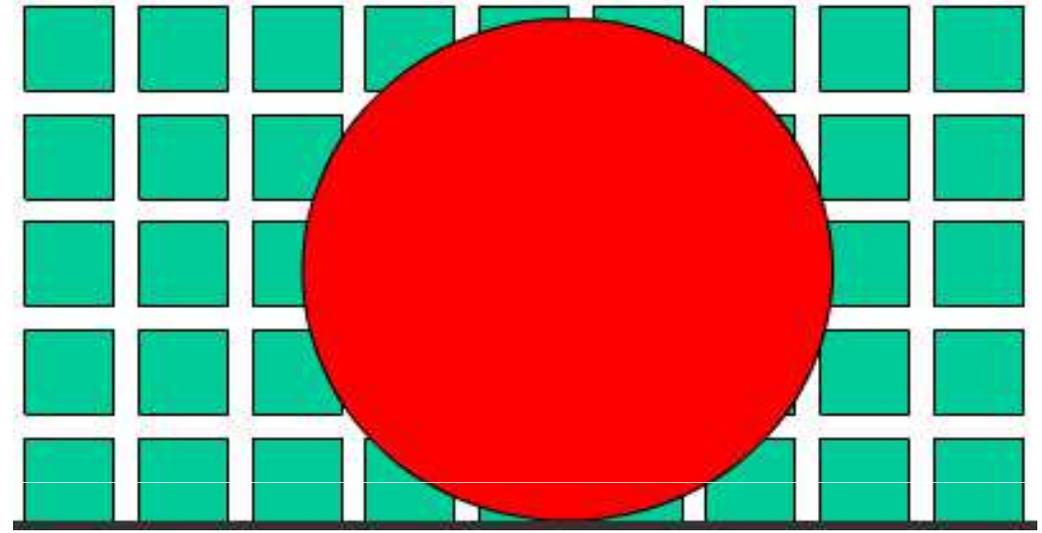
- **IRIS**: free software. Not the most user friendly interface.
- **AIP4WIN**: cost about \$100. Includes a good book on image processing.
- **MaximDL**: cost ranges from \$200-\$700. Higher-end software.

Taking the pictures

- Make sure the camera is set to take pictures in RAW format. JPEG images are not useful because they are corrected to match human eye sensitivity which is not linear.
- Defocus the image slightly. You want to spread out the image of the star over enough pixels



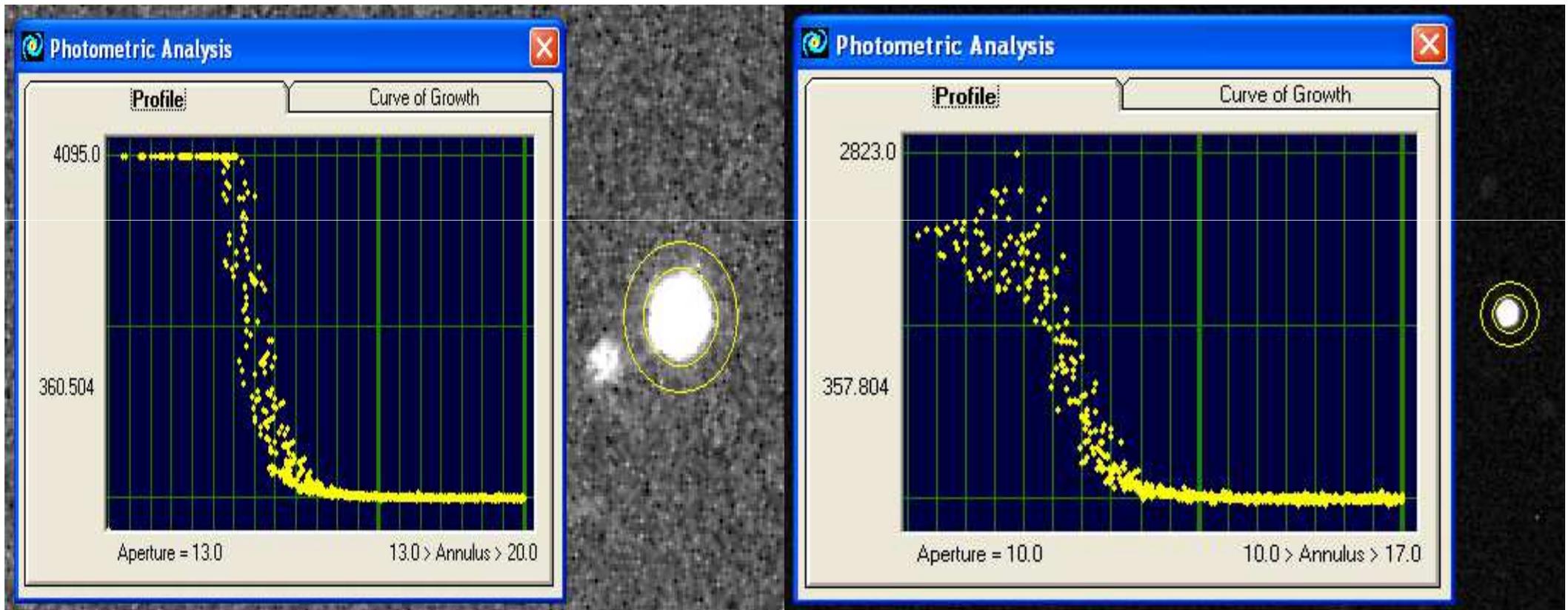
Undersampled: stars that are too well focused will cover pixels unevenly



Defocused stars will cover many pixels evenly, this ensures that stars will cover the same number of pixels, regardless of location.

The downside of defocusing is that it divides the intensity making the measured pixel values fainter and you might blend stars if they are too close to each other

- Don't saturate the pixels of the stars being measured.



Use photometry software to inspect intensity profile

Exposure settings and focus need to be adjusted so that any stars being measured are bright enough, but not too bright.

- **Make sure your field of view includes your target star and enough comparison stars of similar brightness.**
- **Take many images and use software to stack images. Stacking increases the signal (star photons) to noise (background photons) ratio and averages out the effects of scintillation or seeing.**
- **Use a cable release to keep the camera steady.**
- **May need to use tape to keep the focus fixed**
- **Dark frames and flat frames help, but may not be necessary if your exposures are short and if all the stars you are measuring are near the middle of the frame.**

My steps for processing images and measuring magnitudes.

- **Separate channels.** Take only the green channel from each image. Ignore the red and blue channels.
- **Calibrate** with dark and flat frames
- **Stack.** I usually take at least 15 images. Take groups of 3 images and use astrophotography software to average them together. This gives me 5 stacked images to be used for measurements.
- **Measure.** Use astrophotography/photometry software to measure the magnitude of the stars.



$$m_1 - m_2 = -2.5 \log_{10} \left(\frac{I_1}{I_2} \right)$$

V=Variable star. This is the variable star where we are trying to determine the magnitude.

C1=comparison star. This is a star where the magnitude is already known, usually by checking an existing catalog. Photometry software will compare the intensity difference between **V** and **C1**, and tell you the difference in magnitude (**M_v - M_{c1}**)

So if the software calculates (**M_v - M_{c1}**) = 0.55,
and we know that **M_{c1}**=4.25 from looking it up in a catalog
then **M_v**=0.55+4.25=4.80



$$m_1 - m_2 = -2.5 \log_{10} \left(\frac{I_1}{I_2} \right)$$

CK=Check star. This is another star where the magnitude is already known. Compare this star with **C1**, just like we did with **V**. The calculated magnitude should be very close to the published magnitude

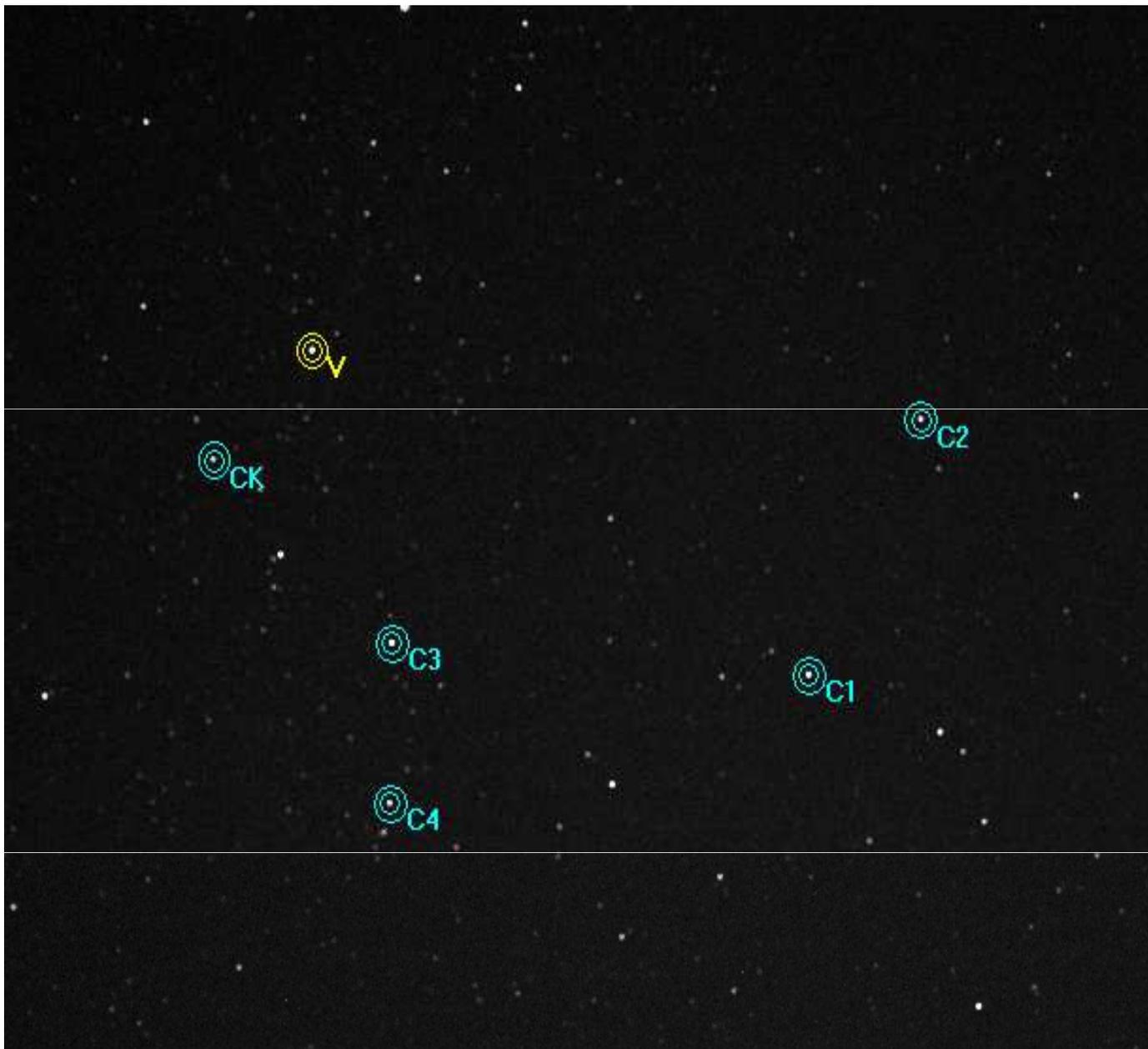
We look up in a catalog and the magnitude of **CK** should be 5.01

Software calculates $(M_{CK} - M_{C1}) = 0.75$,

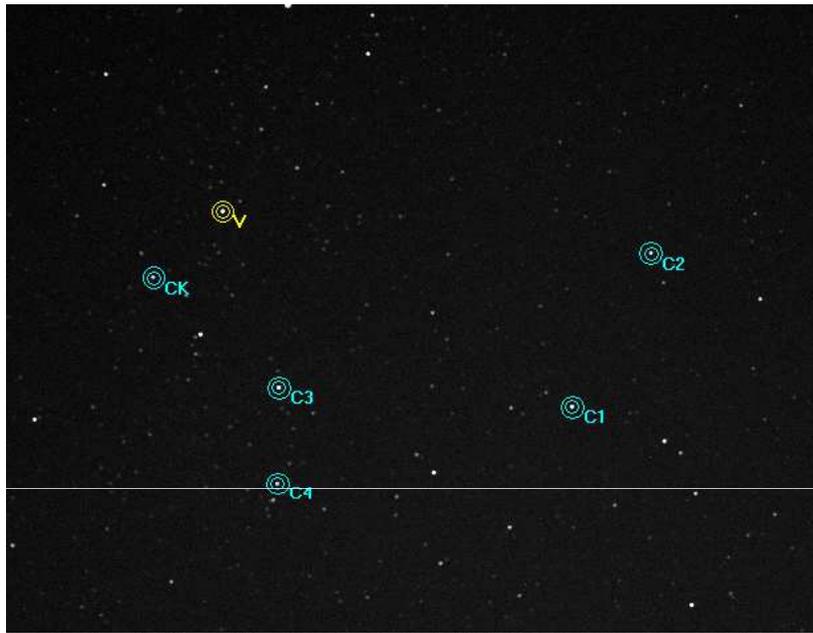
and we already know that $M_{C1}=4.25$,

Then $M_{CK}=0.75+4.25=5.00$

That's a difference of only 0.01 (5.01-5.00), so we can feel confident in our measurements.



We can add multiple comparison stars which helps increase precision.



This is another place where DSLR cameras have an advantage.

Camera lenses have a wider field of view compared to a CCD camera and a telescope. It is fairly easy to find a few stars around magnitude 4 to use as comparison stars with a 50mm lens (about 20 degrees). It is not as easy to do so with a CCD camera.

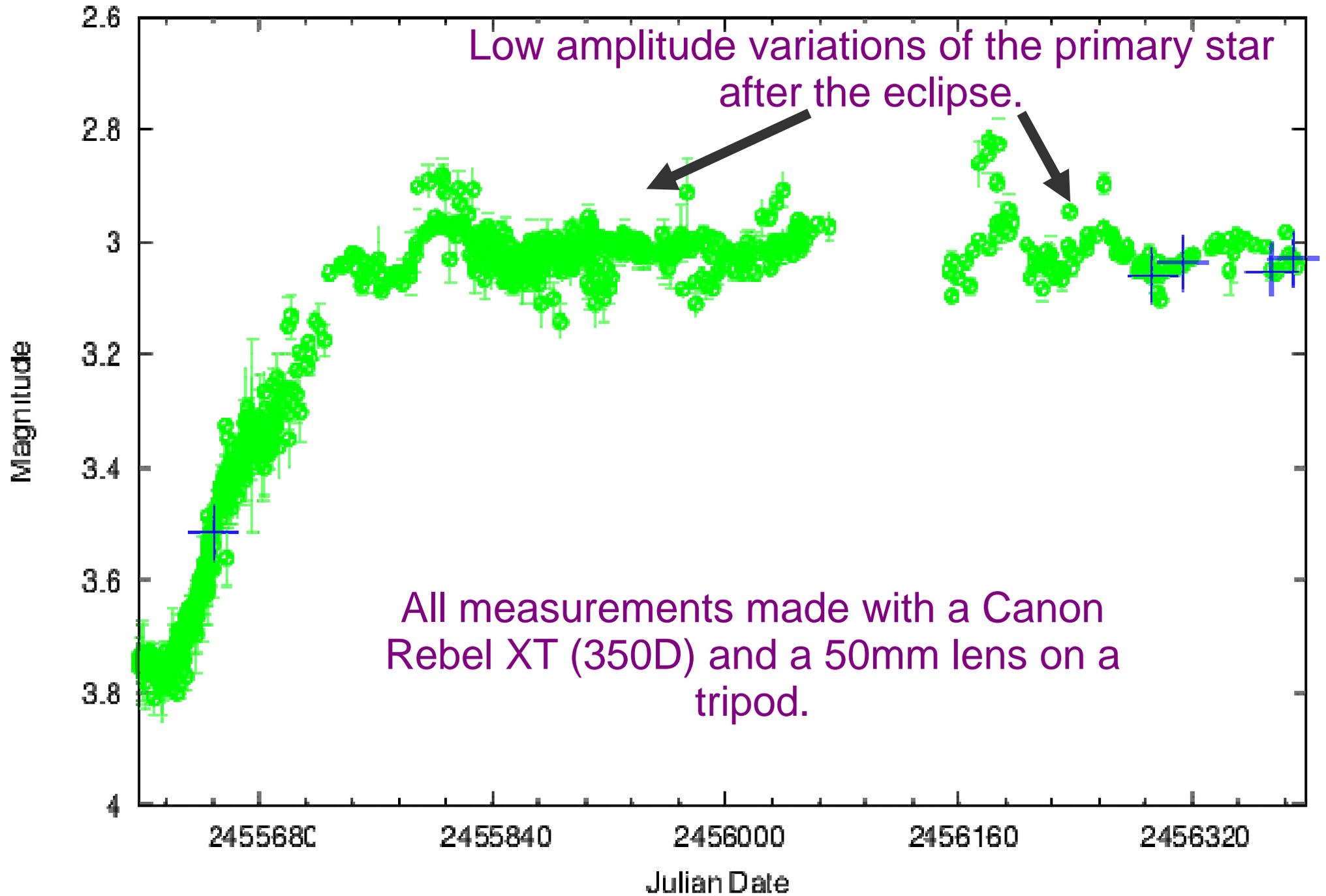
SOME OF MY RESULTS

EPSILON AURIGAE

When I first started looking at DSLR photometry, it was during the eclipse of Epsilon Aurigae.

Every 27 years, Epsilon Aurigae drops in brightness from 2.9 to 3.8 due to an eclipse by a companion object.

One commonly accepted model for this companion object is a star system surrounded by a massive, opaque disk of dust.



P CYGNI or 34 CYG



P Cygni is a hypergiant luminous blue variable and is intrinsically one of the most luminous stars in the Milky Way galaxy (610,000 as luminous as the Sun)

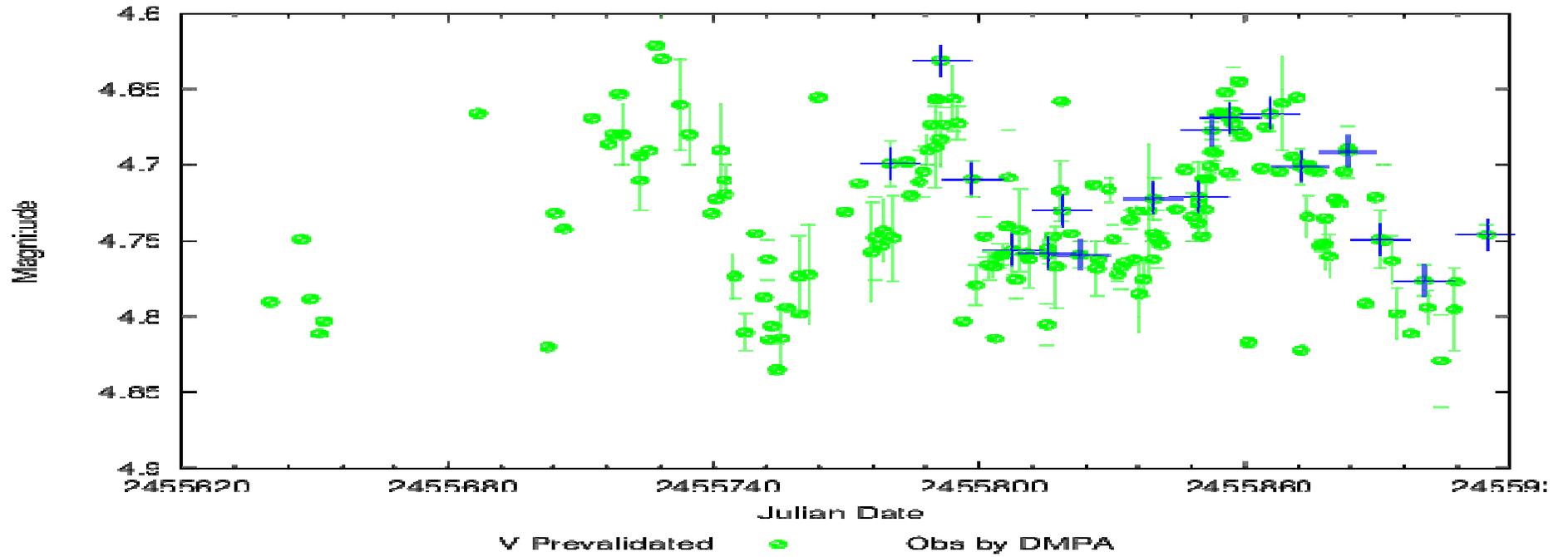
The star is located about 5000 to 6000 light years from the Earth.

Today it has an estimated magnitude of 4.8 ± 0.5

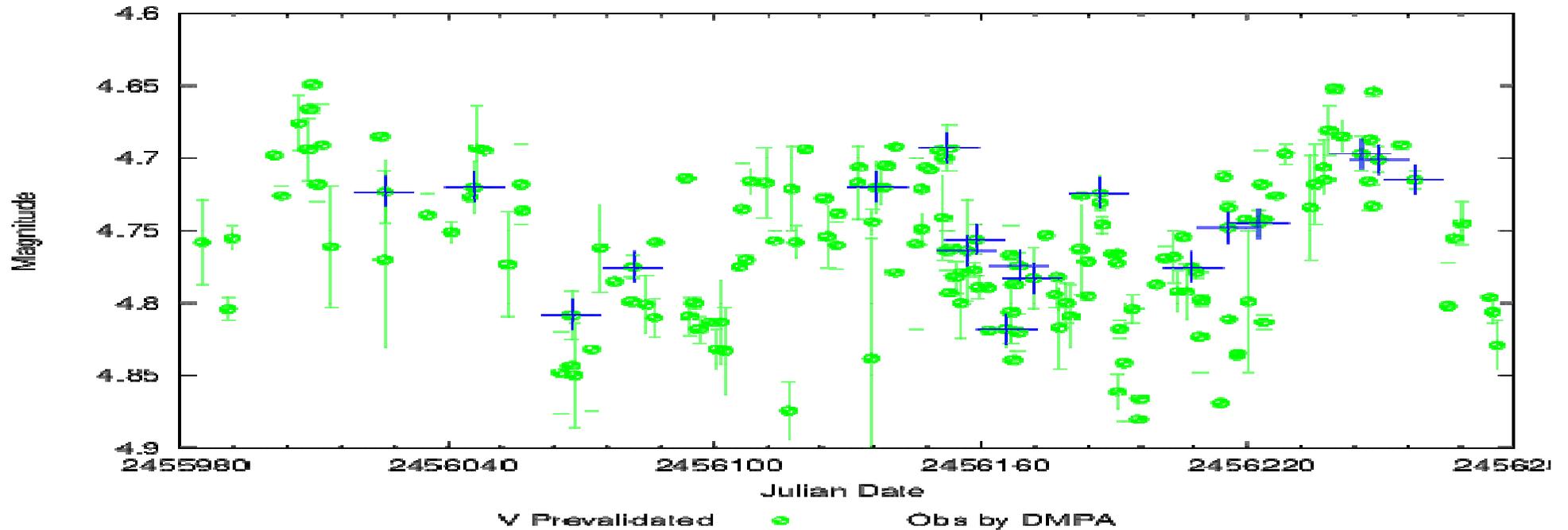
Part of an ongoing campaign to observe P Cygni using CCD or DSLR photometry measurements.

All measurements were made with a Canon Rebel XT (350D) and a zoom lens at 75mm on a camera tripod.

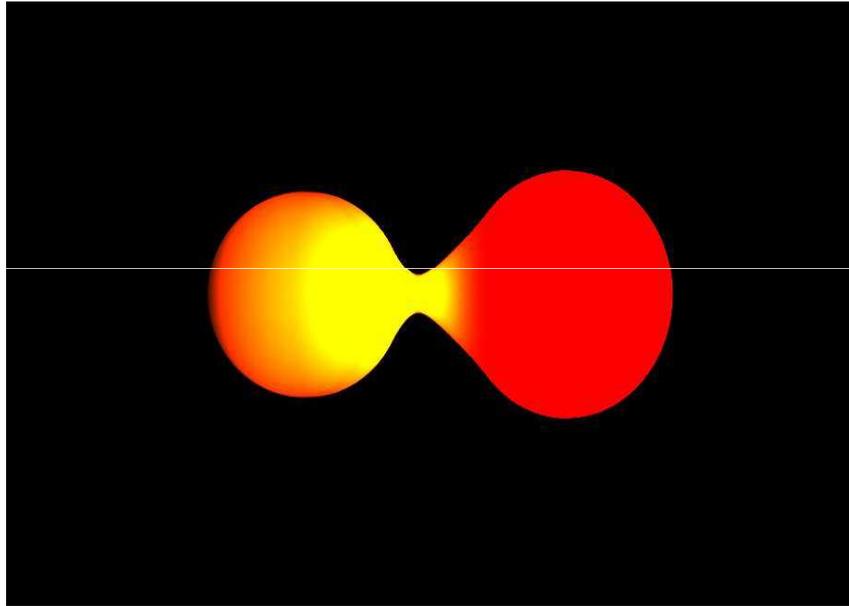
AAVSO DATA FOR P CYG - WWW.AAVSO.ORG



AAVSO DATA FOR P CYG - WWW.AAVSO.ORG



SS ARI



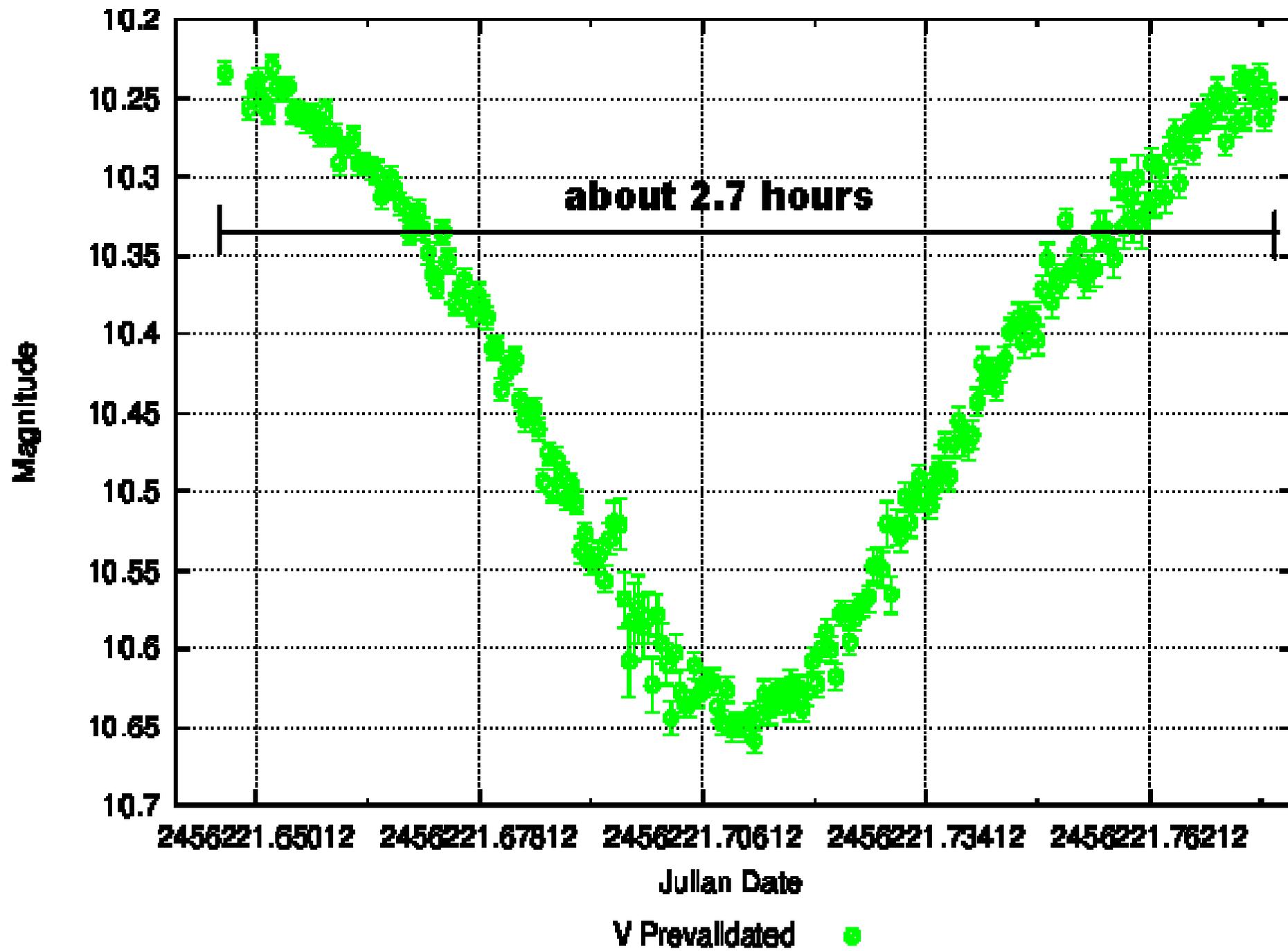
A shallow-contact close binary system.

Magnitude range about 10.1-10.65

Orbital period: 0.406 days (about 9.7 hours)

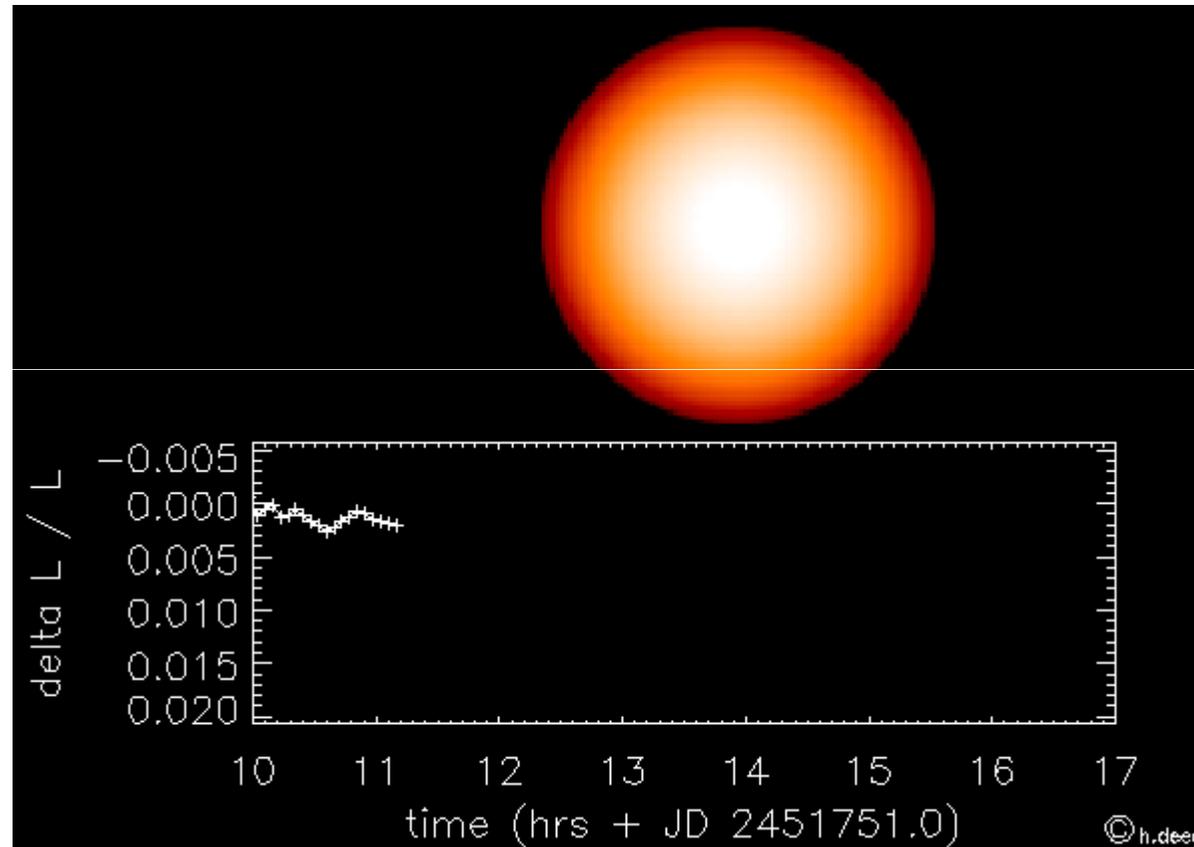
**Equipment used: Canon Rebel XT and
Celestron 8 inch SCT.**

AAVSO DATA FOR SS ARI - WWW.AAVSO.ORG



WASP-11b/HAT-P-10b

I wanted to see if I could detect an exoplanet transit using a DSLR camera



WASP-11b/HAT-P-10b

- The parent star is about magnitude 11.9 in the constellation of Aries**
- The planet is estimated to have 0.46 the mass of Jupiter and 1.05 the radius of Jupiter.**
- The magnitude drops by about 0.025 during the transit. This is relatively large compared to most other exoplanets**
- Orbits once every 3.7 days and the eclipse lasts about 160 minutes**

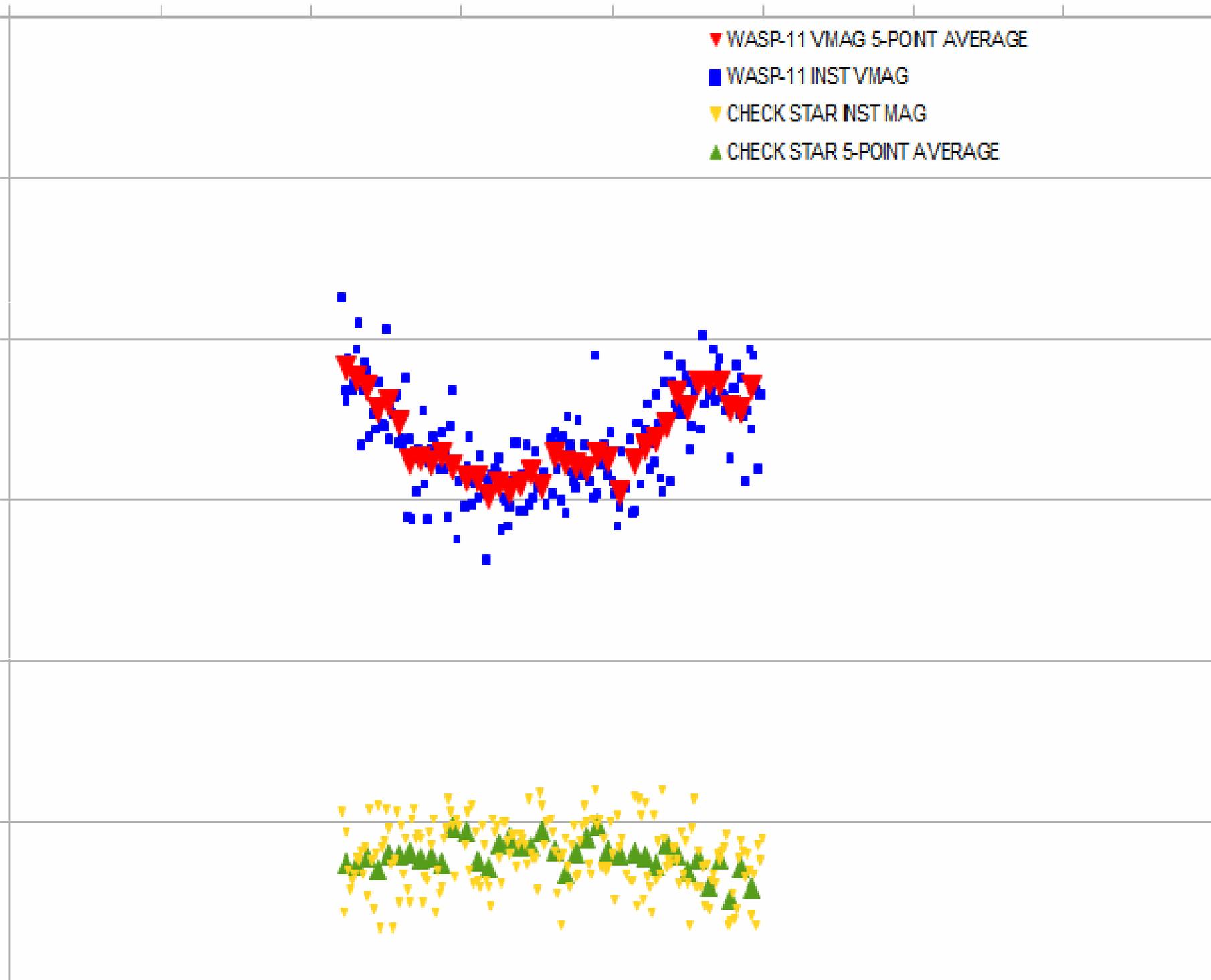
WASP-11b/HAT-P-10b

- A DSLR camera (Canon Rebel XT) was used with an 8 inch Schmidt-Cassegrain at prime focus.**
- A total of 191 measurements.**
- Each measurements was taken with a 60 second exposure.**
- I used about 15 comparison stars to maximize the precision of measurements.**

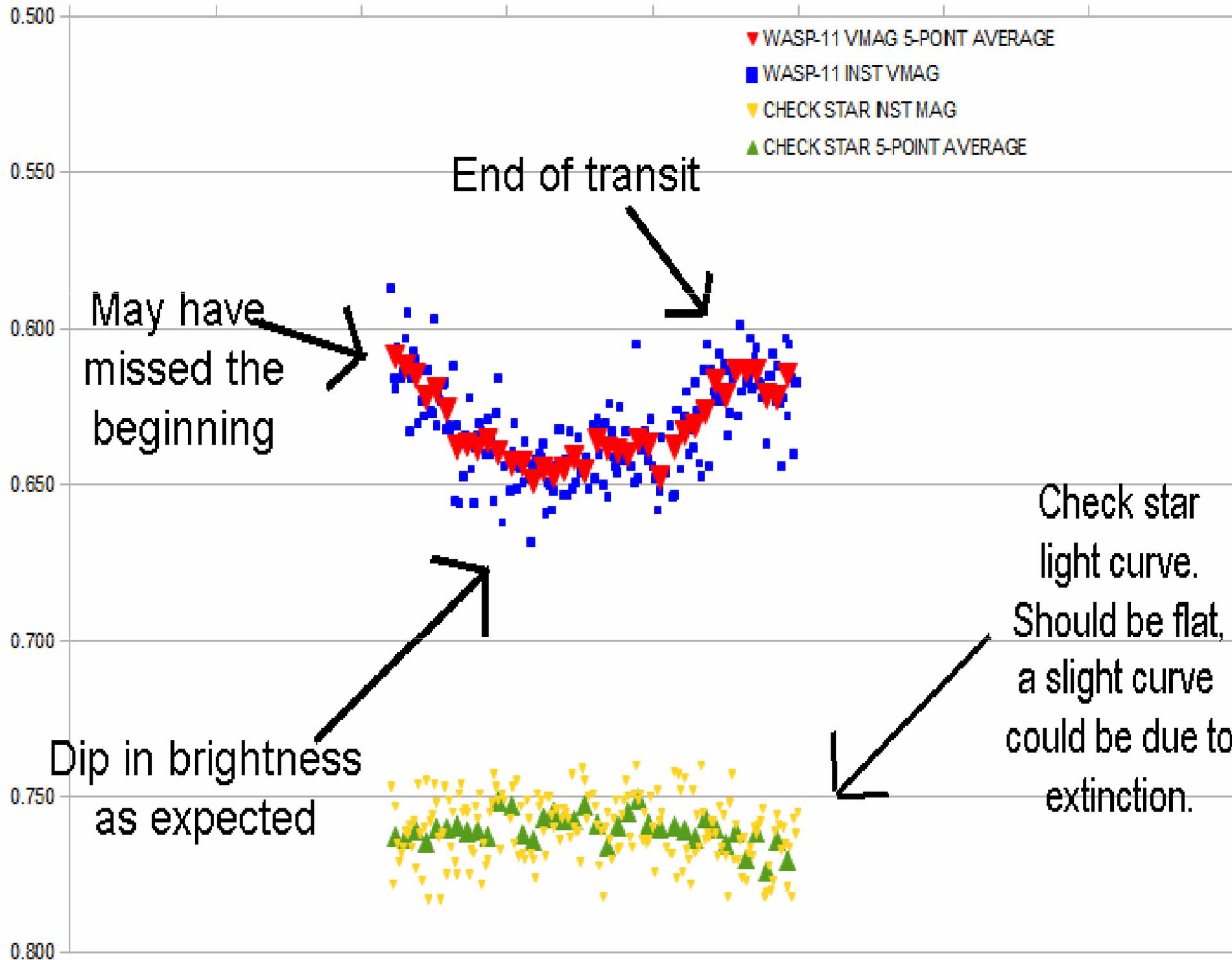
2456248.50000 2456248.55000 2456248.60000 2456248.65000 2456248.70000 2456248.75000 2456248.80000 2456248.85000 2456248.90000

0.500
0.550
0.600
0.650
0.700
0.750
0.800

- ▼ WASP-11 VMAG 5-POINT AVERAGE
- WASP-11 INST VMAG
- ▼ CHECK STAR INST MAG
- ▲ CHECK STAR 5-POINT AVERAGE



2456248.500000 2456248.550000 2456248.600000 2456248.650000 2456248.700000 2456248.750000 2456248.800000 2456248.850000 2456248.900000



IN CONCLUSION

- Amateurs using nothing more than everyday photographic equipment and some specialized software can participate in observing programs of bright variable stars.
- DSLR photometry opens up for visual observers the many bright stars that vary by less than 0.5 magnitude.
- With some extra care, DSLR cameras have the precision to detect small magnitude changes due to events such as exoplanet transits.
- Just one of many ways for amateurs to fill in the gaps where professional astronomers do not have the resources.

SPECIAL THANKS TO

Brian Kloppenborg, Arne Henden, Des Loughney, Ernst Pollmann, Wolfgang Vollmann, Mike Simonsen, Heinz-Bernd Eggenstein, Maravelias Grigoris, Tom Pearson Roger Pieri, Richard Kinne, Jeff Hopkins, Tom Krajci, American Association of Variable Star Observers (AAVSO), Tom and Stacy Purchase,
All the members of the Amateur Observers' Society,
and all my friends and family for supporting me.

USEFUL WEBSITES FOR VARIABLE STARS

- <http://www.aavso.org>
- <http://www.citizensky.org>
- <http://www.britastro.org/vss/>
- <http://www.hposoft.com/EAur09/EAUR%20pdfs/DSLR.pdf>
- <http://brucegary.net/AXA/NotAAVSO.htm>
- <http://var2.astro.cz/EN/> - Database of exoplanets and eclipsing binaries

CITIZEN SCIENCE PROJECTS

- <http://www.aavso.org> - American Association of Variable Star Observers
- <http://www.lunar-occultations.com/iota/iotandx.htm>
International Occultation Timing Association
- <http://www.galaxyzoo.org/> - Classify galaxies
- <http://www.planethunters.org> - Help look for exoplanets
- <http://alpo-astronomy.org/> - Association of Lunar and Planetary Observers



“...citizen science projects are only getting bigger, and more are on the way. It's a fun way to do real science, and make a difference.”

- Phil Plait (a.k.a. The Bad Astronomer)

**“The history of astronomy is a history of receding horizons.”
— Edwin Hubble, American astronomer (1889 – 1953)**