Advanced CCD observing techniques

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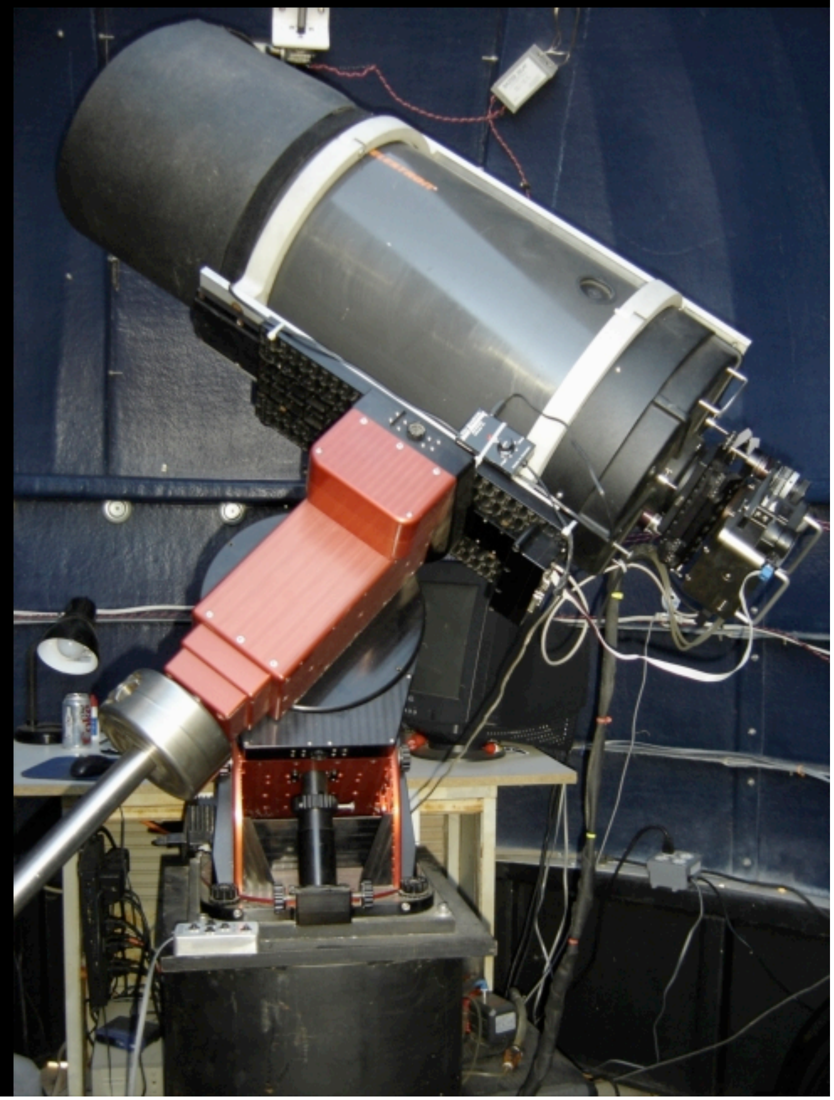
Sonoita Research Observatory

Where I work!

60 miles SE of Tucson

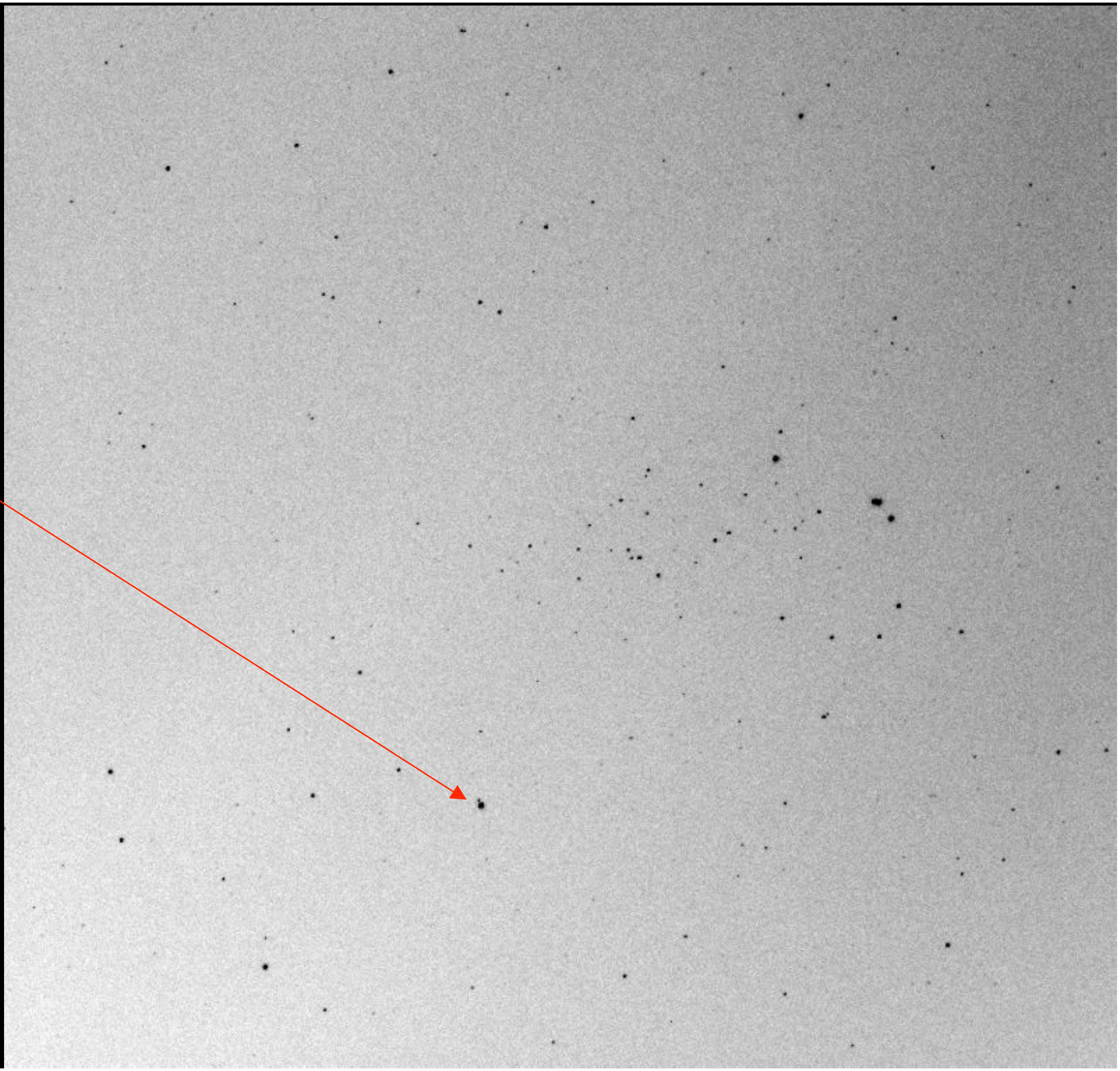
Operational since 2004



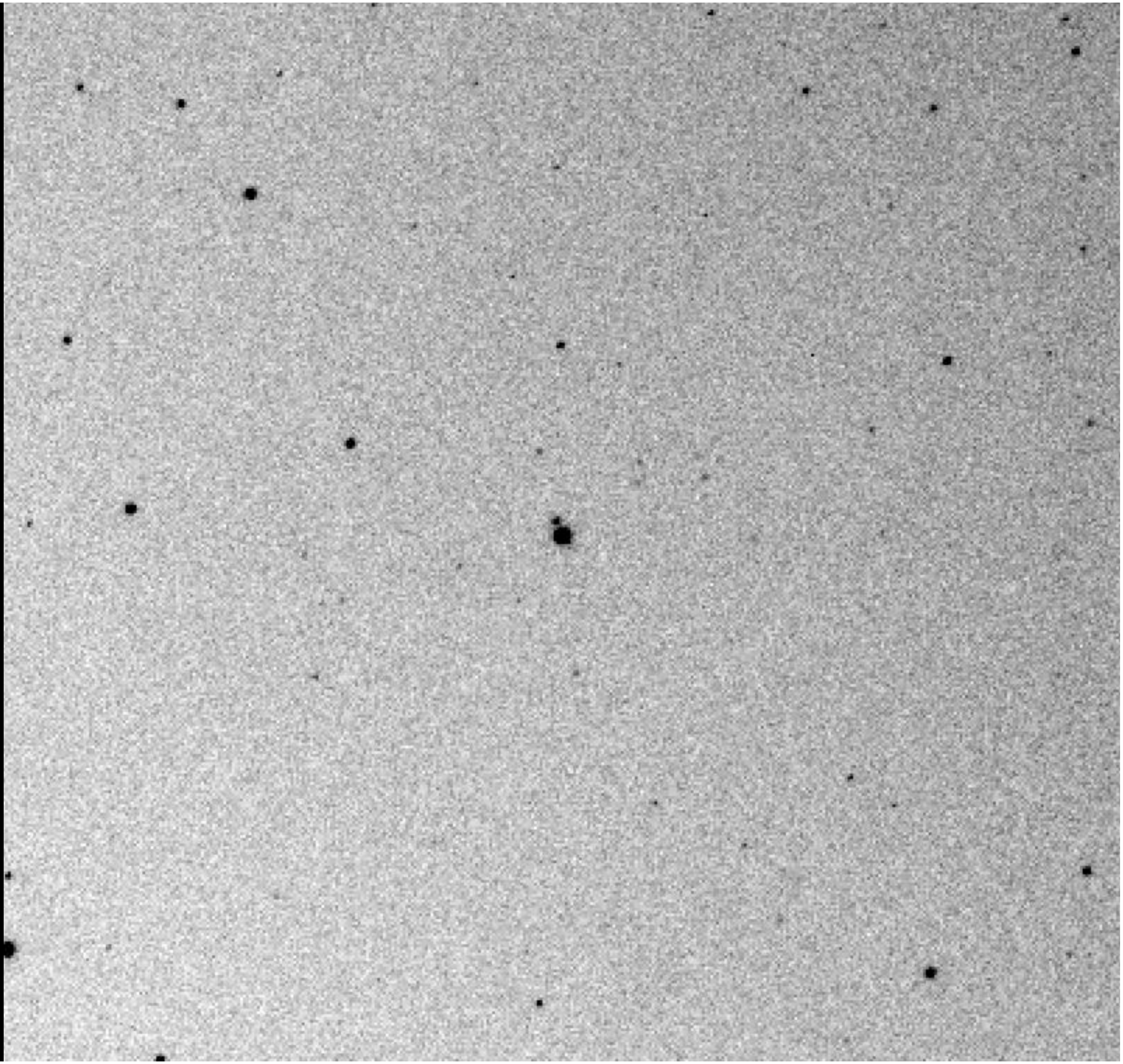
Guideline: choosing aperture size

Typical field, NGC7790

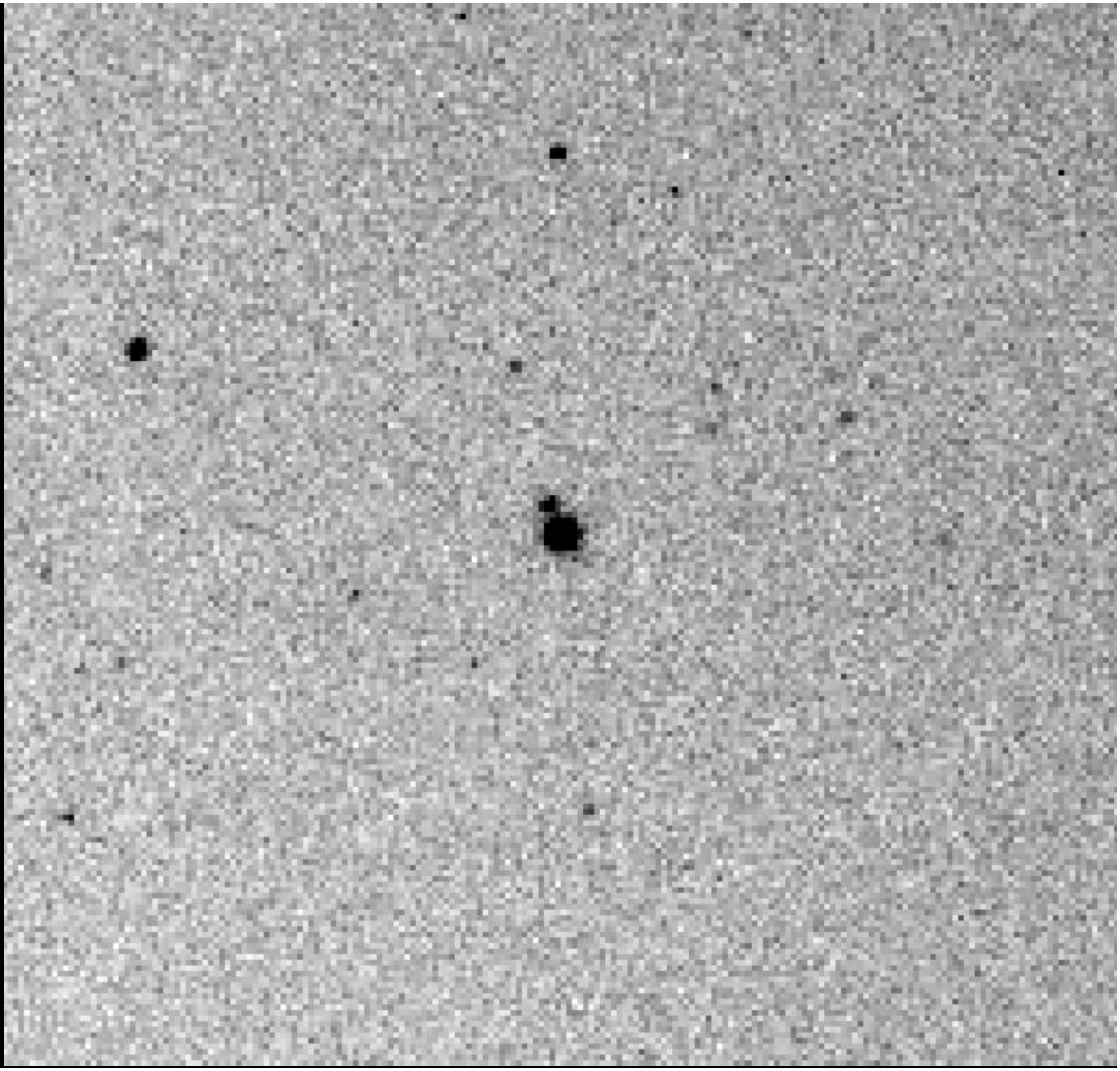
Note this star (QX Cas)



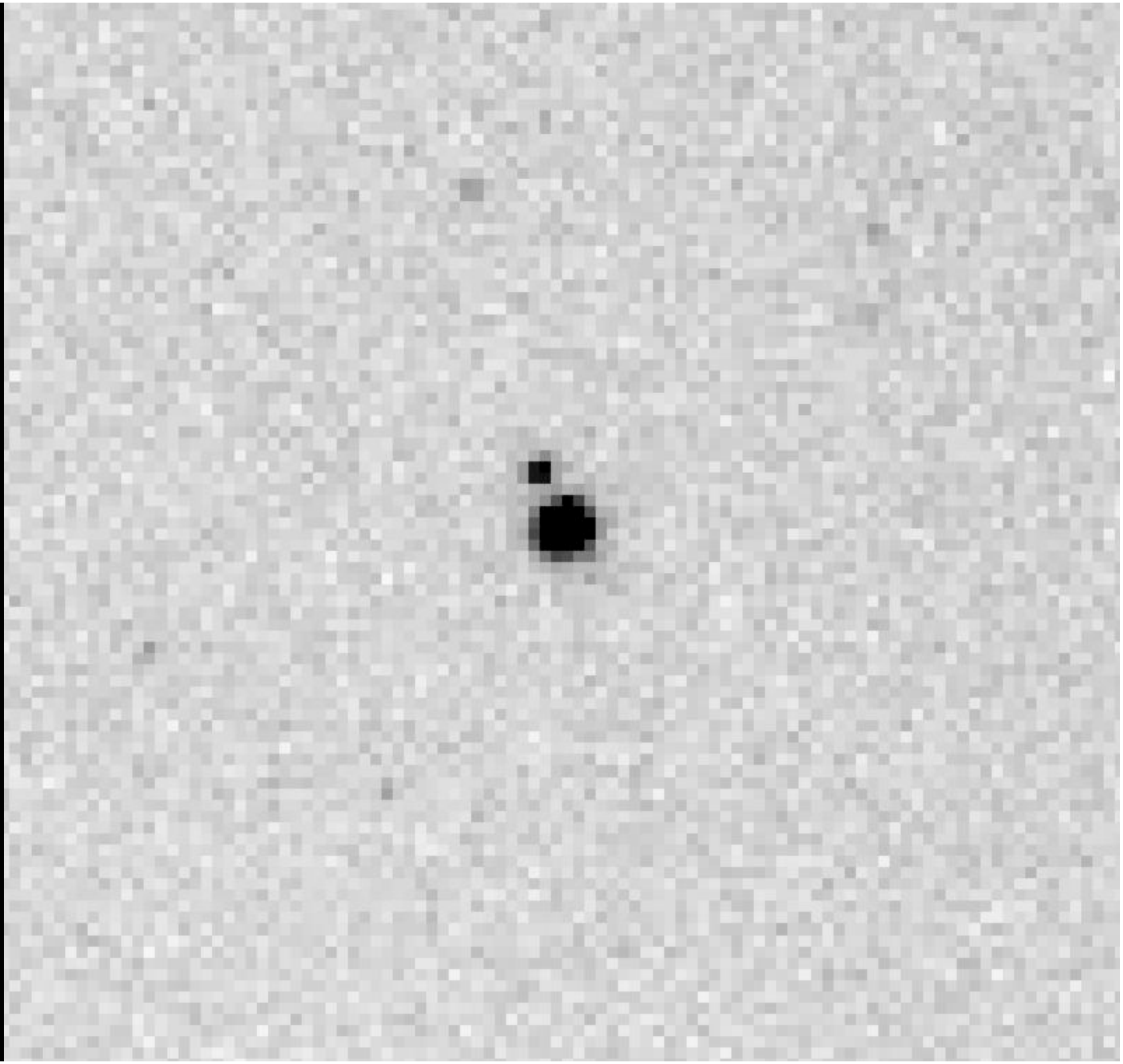
Zooming in on QX Cas (interesting eclipsing binary)



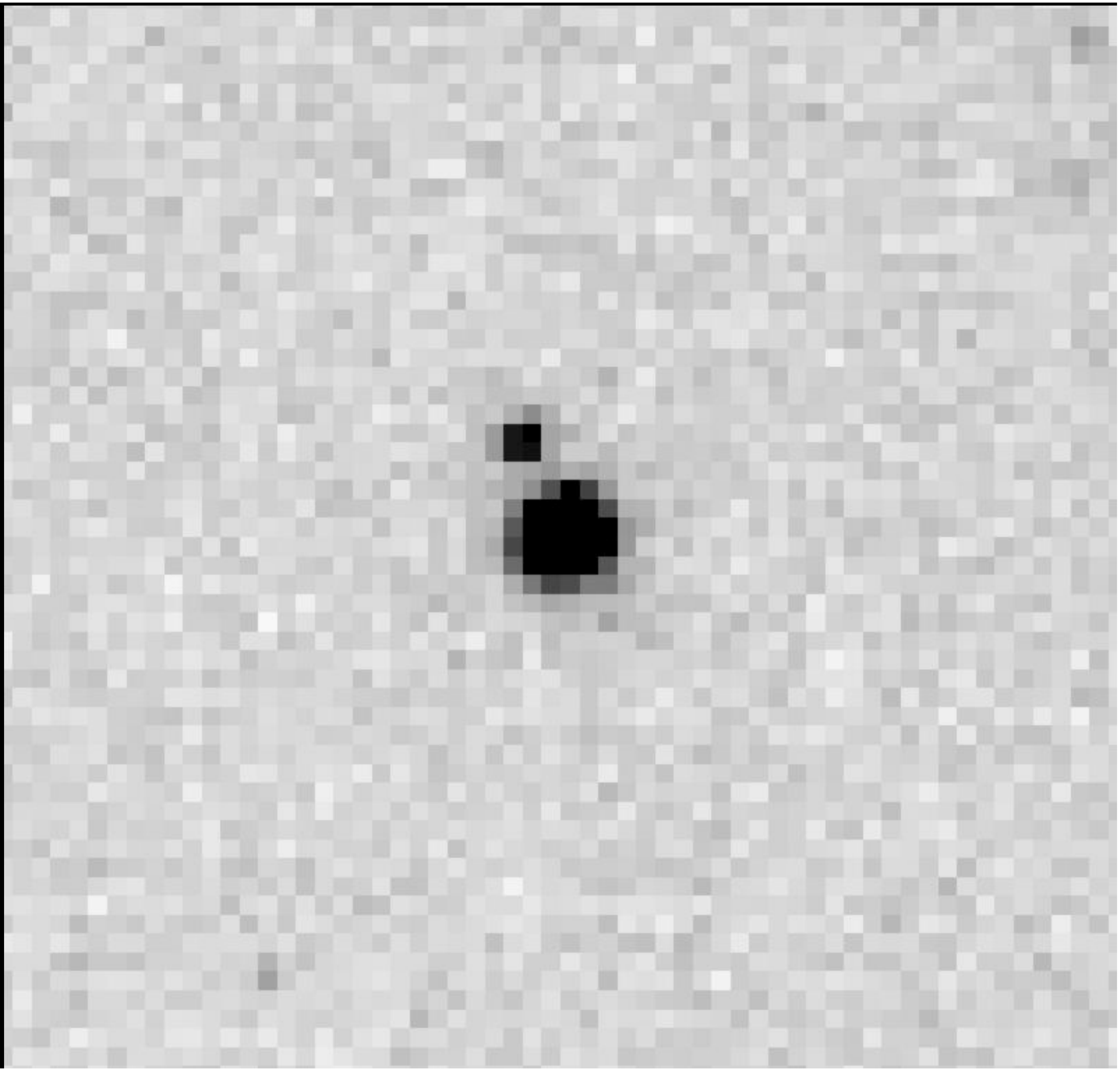
Starting to see the pixels, and the close companion (4arcsec NE)



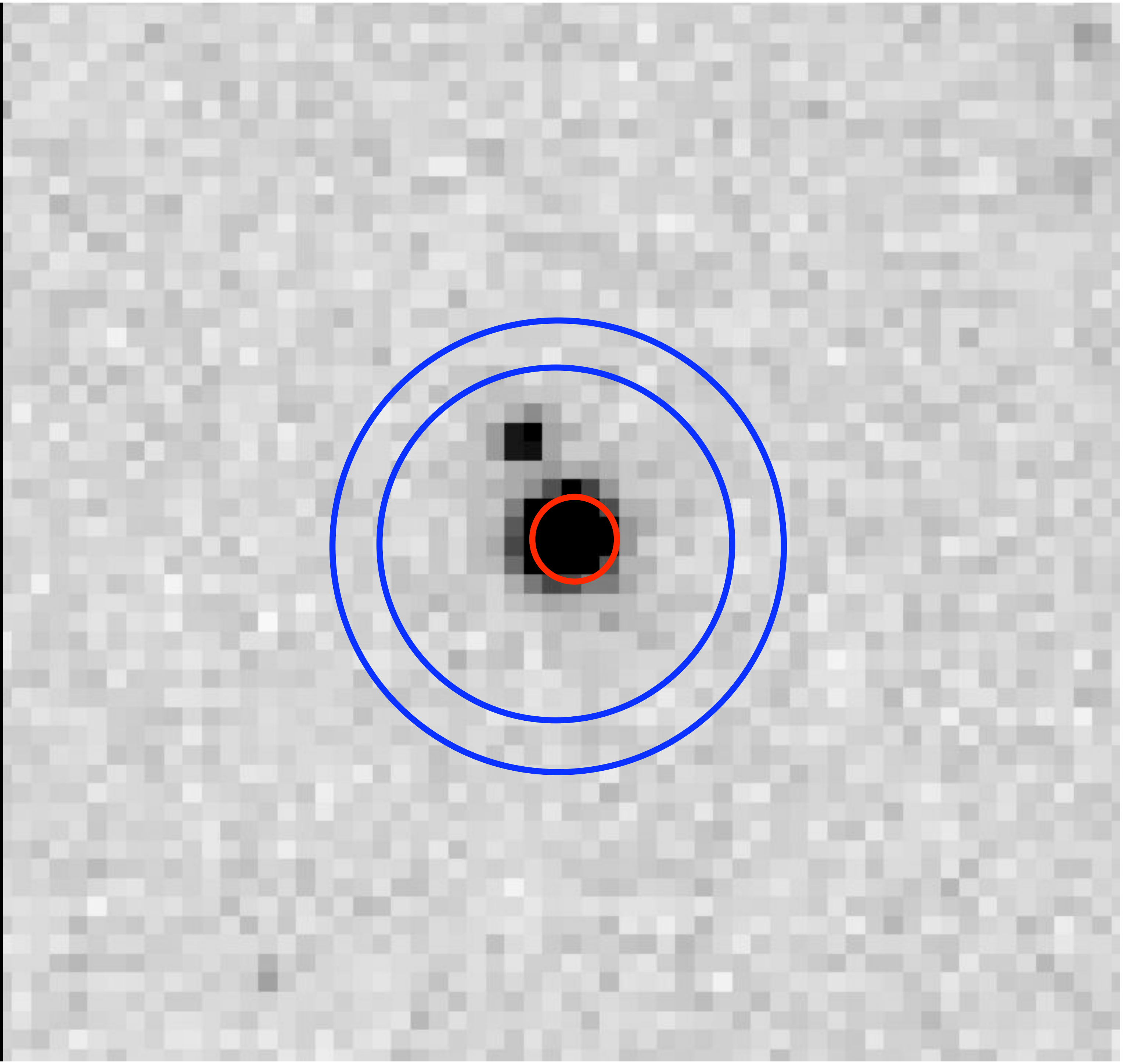
A little closer



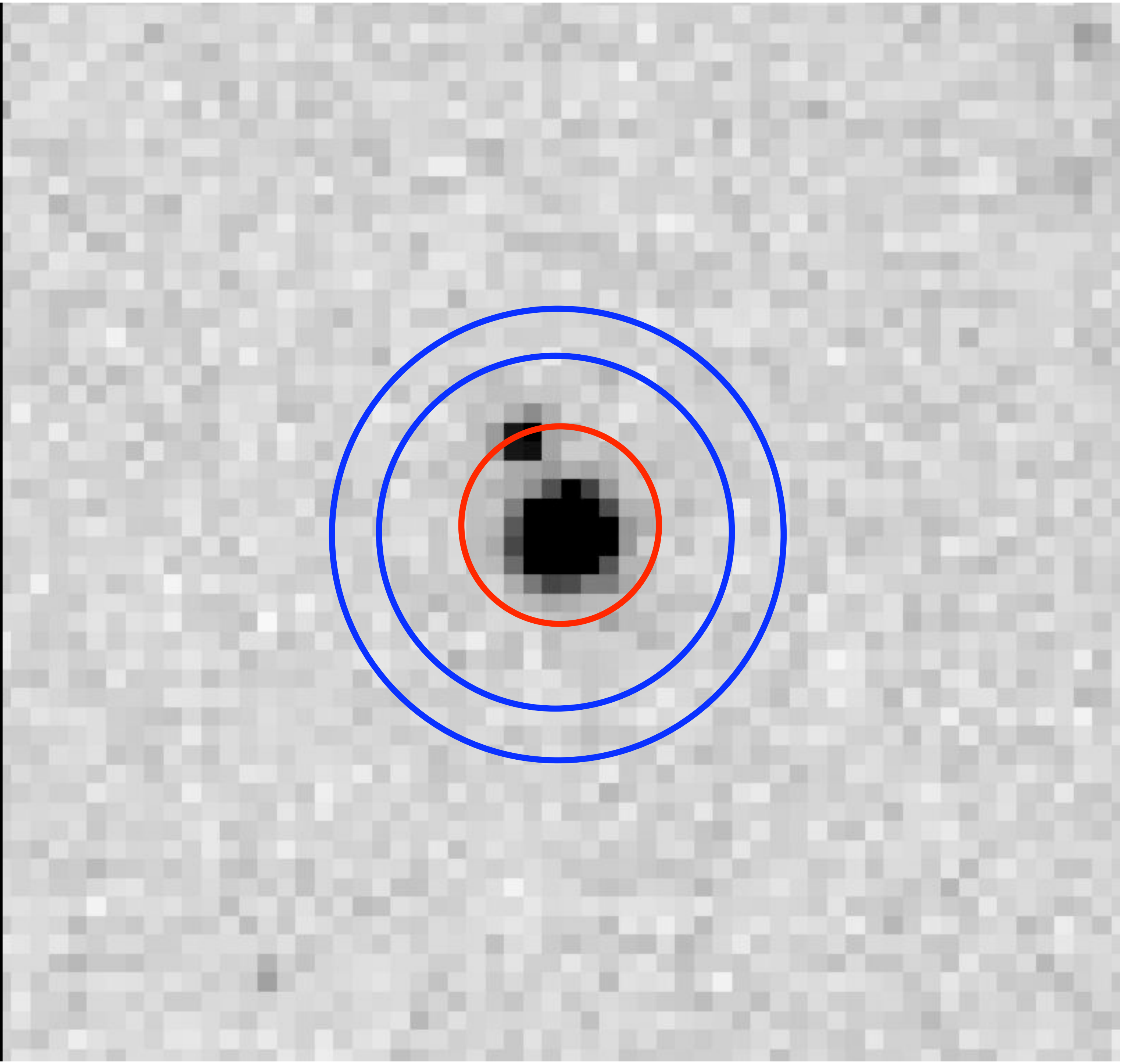
Here we are. Now, what aperture to use? Note that star image is only about 5 pixels across



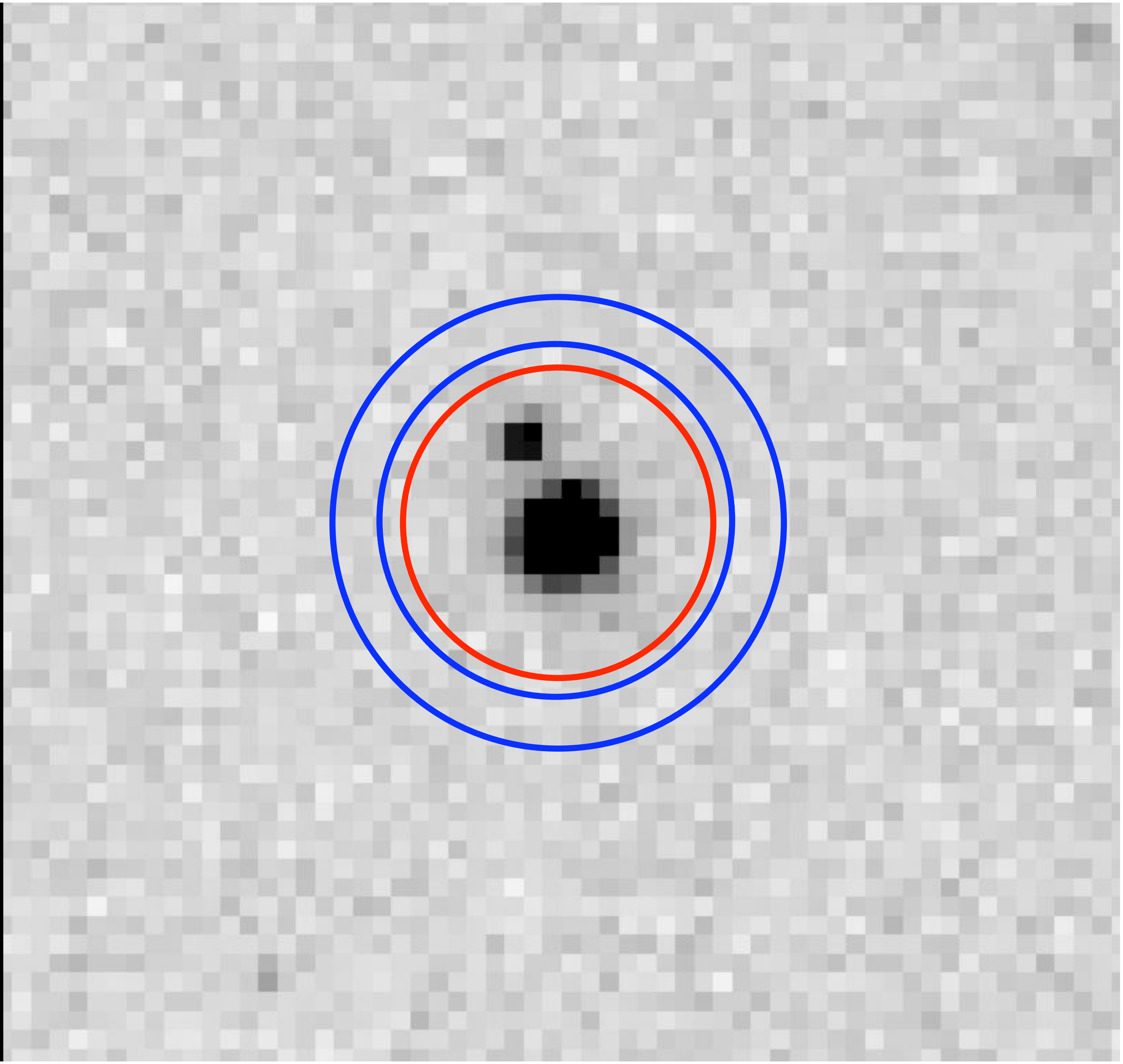
First choice: small star aperture, large sky annulus to avoid companion. This is usually the best choice.



2nd choice: large sky annulus (good), but star aperture sized to get all of the target star light, but partially include the companion. This choice will often lead to photometric error, depending on centering and seeing.



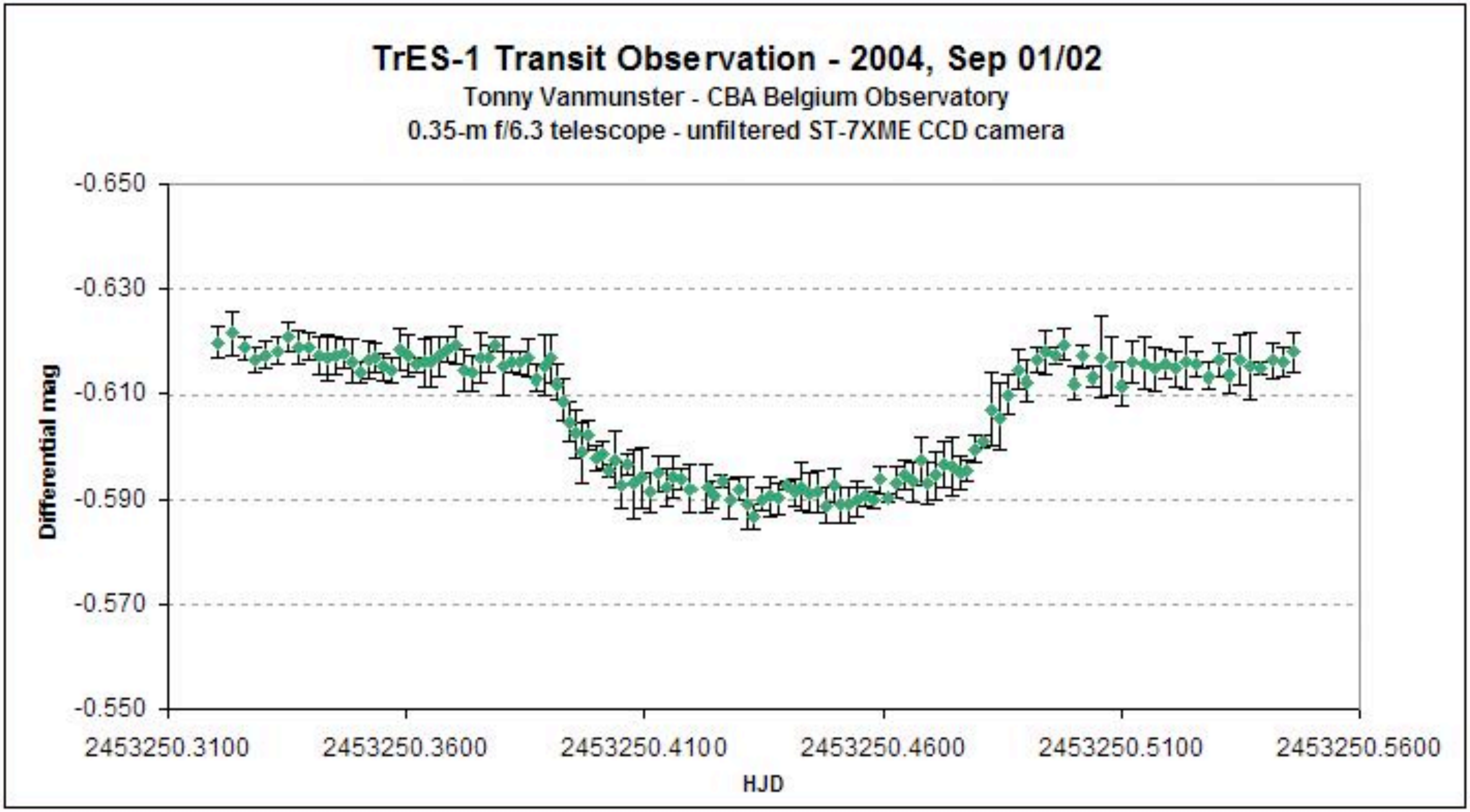
3rd choice: large sky annulus (good), large star aperture to include both objects. Often your only choice when the objects are close together. Combined light ok (washes out variation, but at least it is still there); you can use programs like Nemesis to subtract companion's light if its brightness is well known



Guideline

- Look at your images. Set your aperture based on what is visible. A star 5 magnitudes fainter can cause a 0.01mag error in your estimate.

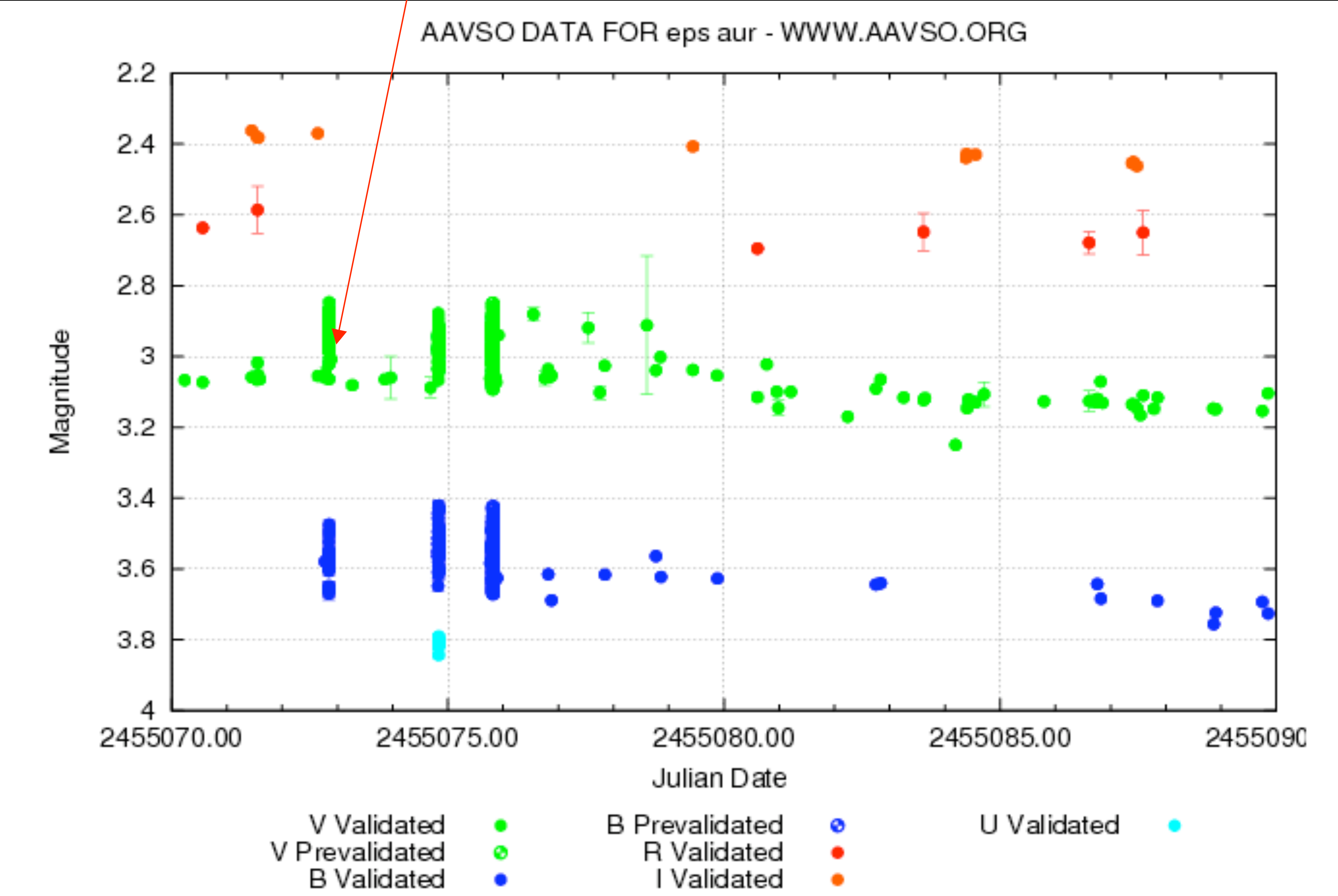
Wouldn't we all like to have data like this - Tony Vanmunster's observations of the exoplanet transit for TrES-1. Tight error bars, obvious dip. C14 telescope



Photometric light curve of the TrES-1 transit observation dd Sep 1, 2004
(c) Tonny Vanmunster, CBA Belgium Observatory

Precision

Note the vertical bars - all one observer, all same time.
Better to average and report mean, stdev



Note that previous observations are reported with small error - not realistic

Eps aur data

EPS AUR	2455072.84897	AUG 29.3490	3.504	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84890	AUG 29.3489	2.977	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84879	AUG 29.3488	3.475	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84871	AUG 29.3487	2.891	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84861	AUG 29.3486	3.595	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84854	AUG 29.3485	2.940	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84842	AUG 29.3484	3.547	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84835	AUG 29.3484	2.879	V		TRE	000-BJP-386	SAO39995	1311JNX	0.007	N
EPS AUR	2455072.84825	AUG 29.3482	3.491	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84817	AUG 29.3482	3.064	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84806	AUG 29.3481	3.560	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84799	AUG 29.3480	2.946	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84788	AUG 29.3479	3.597	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84781	AUG 29.3478	2.913	V		TRE	000-BJP-386	SAO39995	1311JNX	0.007	N
EPS AUR	2455072.84769	AUG 29.3477	3.553	B		TRE	000-BJP-386	SAO39995	1311JNX	0.012	N
EPS AUR	2455072.84762	AUG 29.3476	2.912	V		TRE	000-BJP-386	SAO39995	1311JNX	0.006	N
EPS AUR	2455072.84752	AUG 29.3475	3.653	B		TRE	000-BJP-386	SAO39995	1311JNX	0.011	N

Guideline

- Don't trust the error report from your software. It is often only Poisson error and doesn't take into account other error sources (like Scintillation, the problem here).

Credit: M.C. Gino

Signal/noise

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{pix}(N_S + N_D + N_R^2)}}$$

Where:

N_* = total number of photons collected from object of interest (may be one or more pixels)

N_{pix} = number of pixels considered in S/N ratio

N_S = total number of photons per pixel from background or sky

N_D = total number of dark current electrons per pixel

N_R^2 = total number of electrons per pixel resulting from read noise

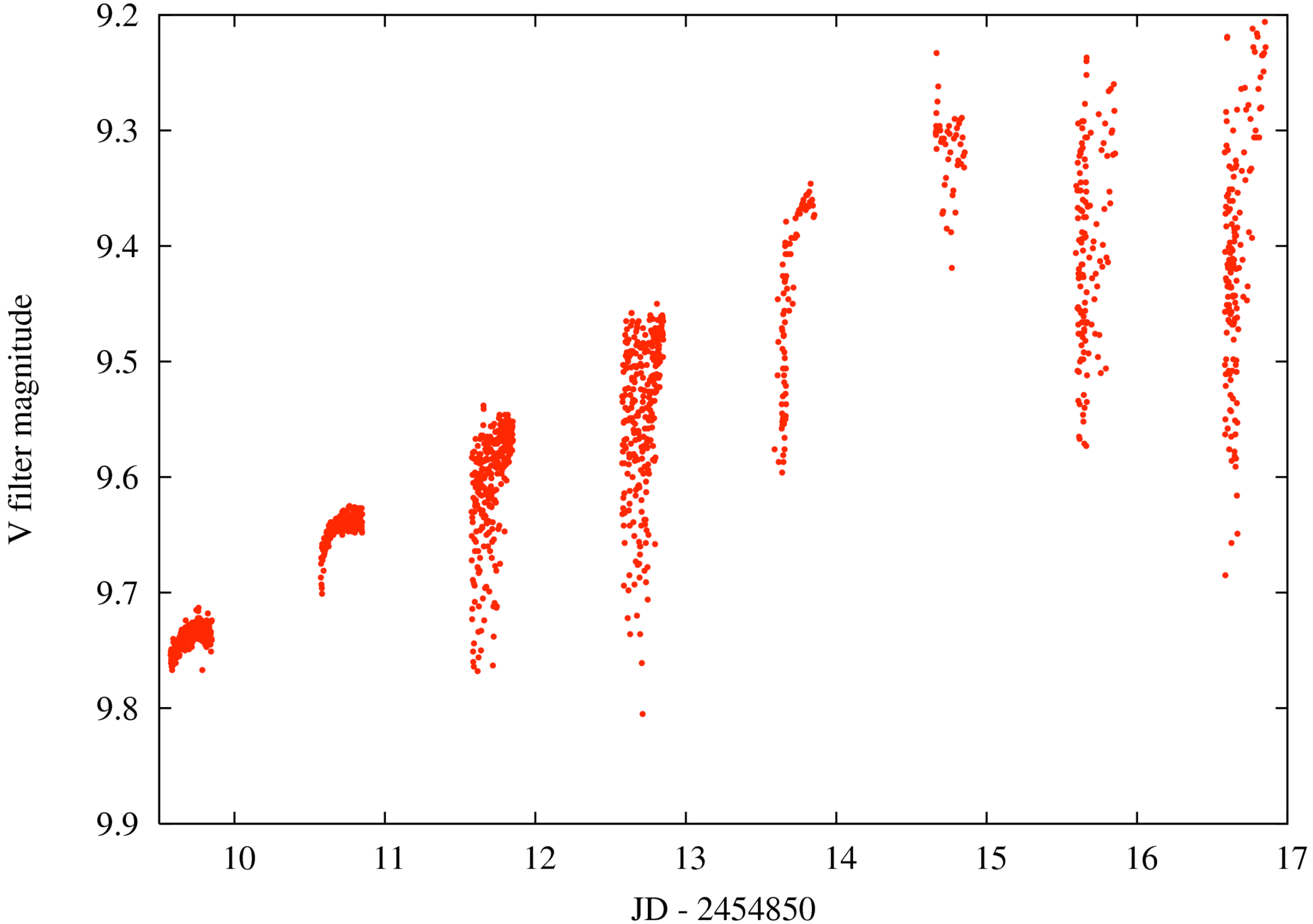
[redacted]

Guideline

- A full error analysis is complex.
- Trick: take 3 images instead of one; average results and determine standard deviation. Highly recommended if variation timescale is less than the 3 images.
- Time series trick: use (K-C) as your error

saturation

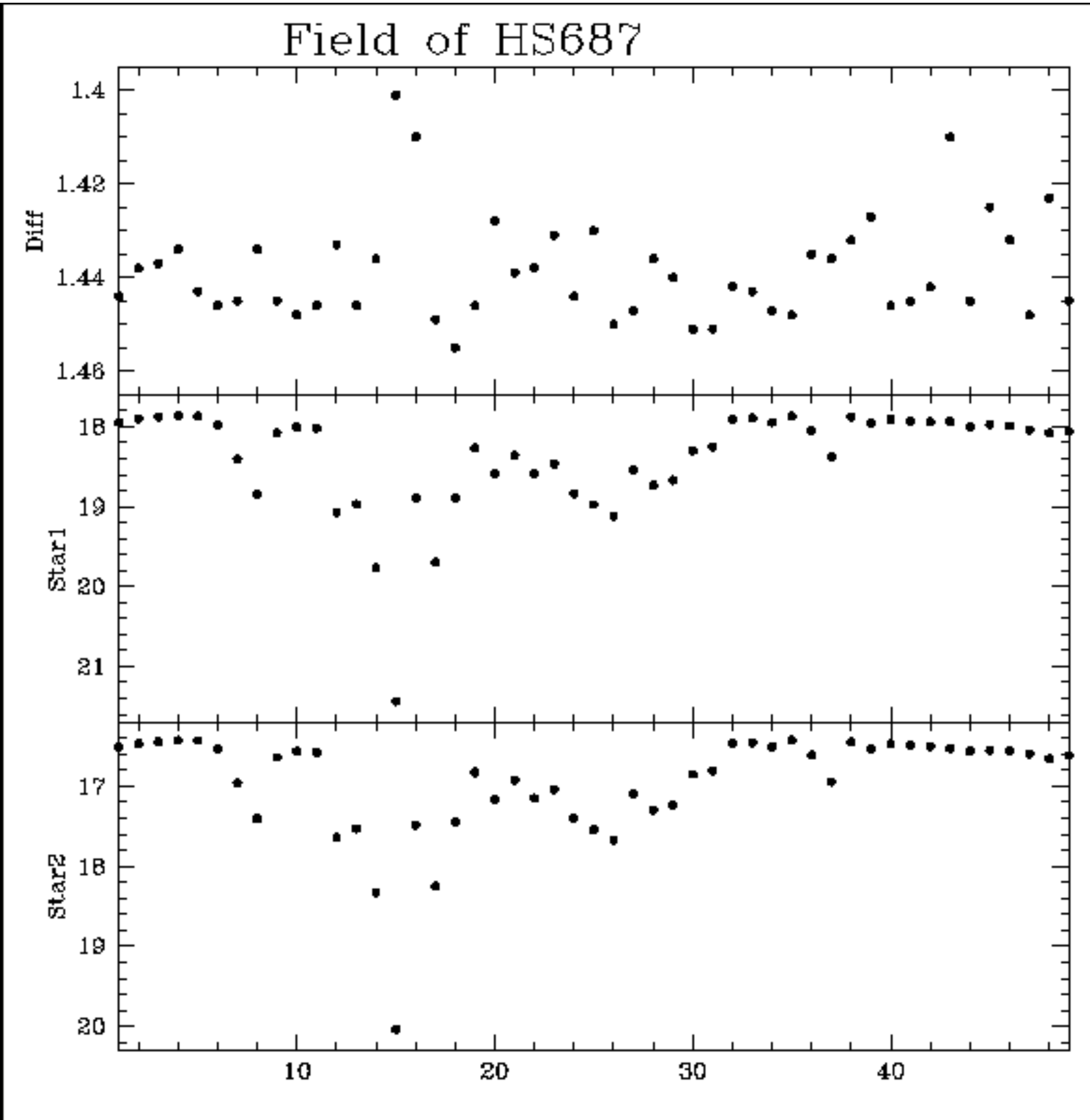
Note that tight data (with airmass variation) when star faint, but big error when bright. Obvious clue for this effect, even though software reports low error



Guideline

- Look at your images. Check the peak ADU level. Worry about binning. Worry about full well (calibrate your camera). Watch out about seeing variations.

Differential photometry works well under most circumstances. Note here that star1 and star2 show 3mags of fading, yet the fades are correlated, so that the difference of the two star estimates stays constant to within a couple of percent. It is *not* perfect, though; you see the bigger deviations where the fading is the greatest.



BSM-3

Here is an example of why differential photometry can fail. This is a 2-degree field, but it demonstrates that clouds have structure and even in small fields, the obscuration can be different across the field. Use multiple comparison stars if possible, scattered over the field, to guard against this problem.

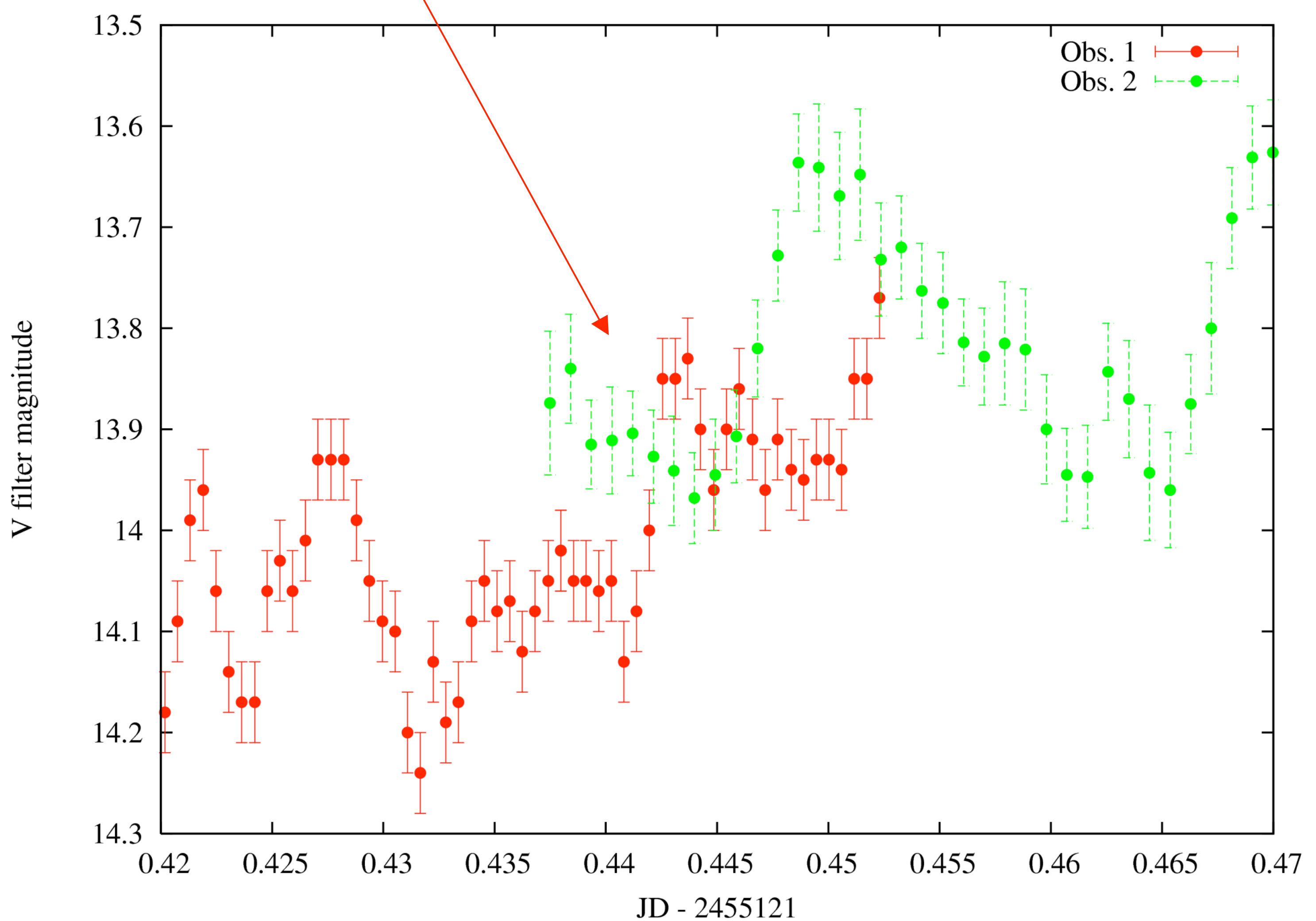
Guideline

- Differential photometry is a life-saver. However, it is not perfect; expect more scatter on a cloudy night than on a clear one.
- Use multiple comparison stars and examine your results on non-photometric nights.

Accurate time

Note the time shift between these two observers

There are lots of reasons for incorrect time, including mis-setting of a computer clock, fits header timestamps not applied correctly, whether points are Julian Date or Heliocentric Julian Date, etc.

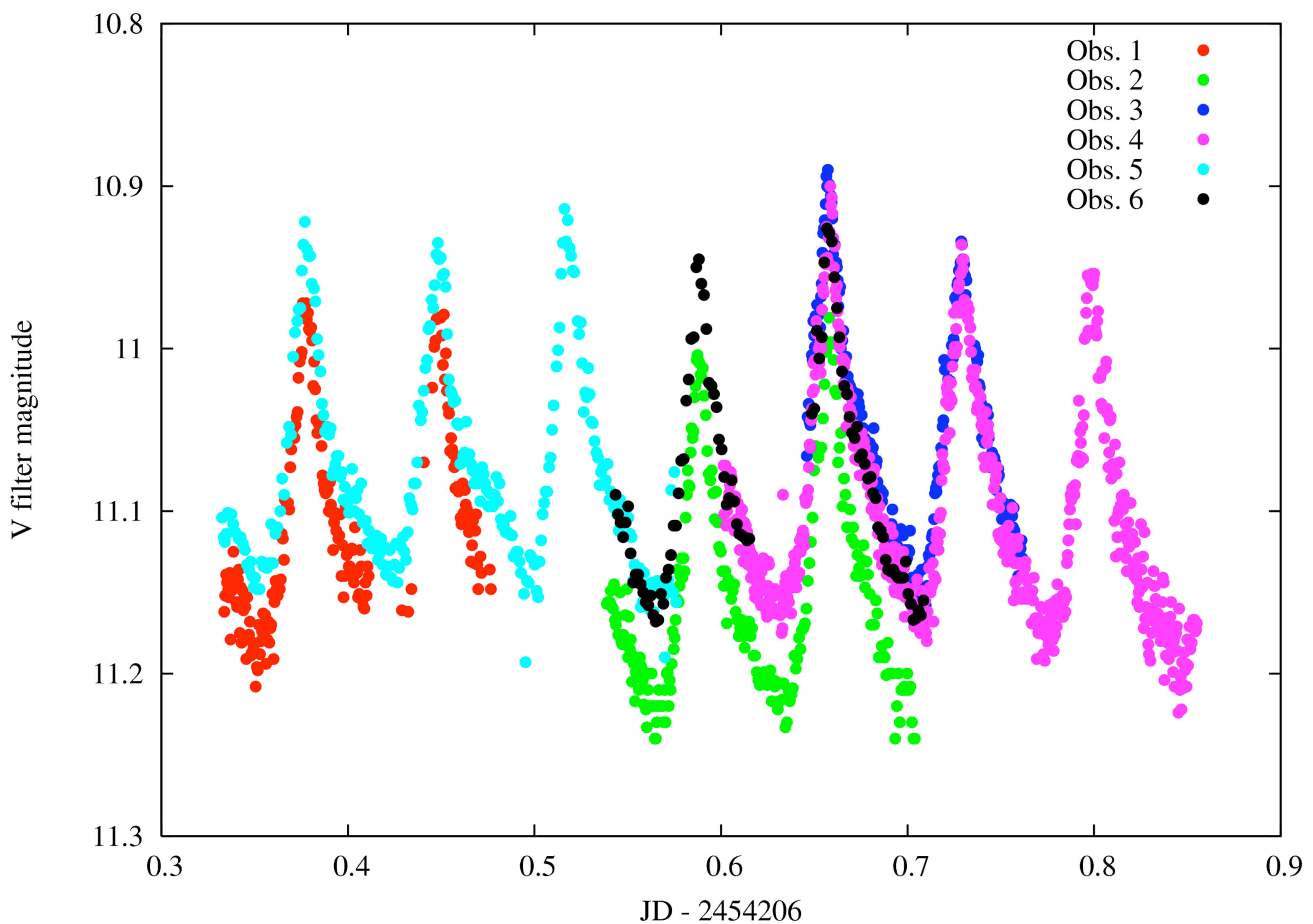


Guideline

- Time is absolutely essential, yet easy to obtain. Use network time service if you are on a network; determine and apply your clock error if off the net.
- HJD vs. JD vs. RJD etc.
- Start vs. midpoint vs. end exposure time

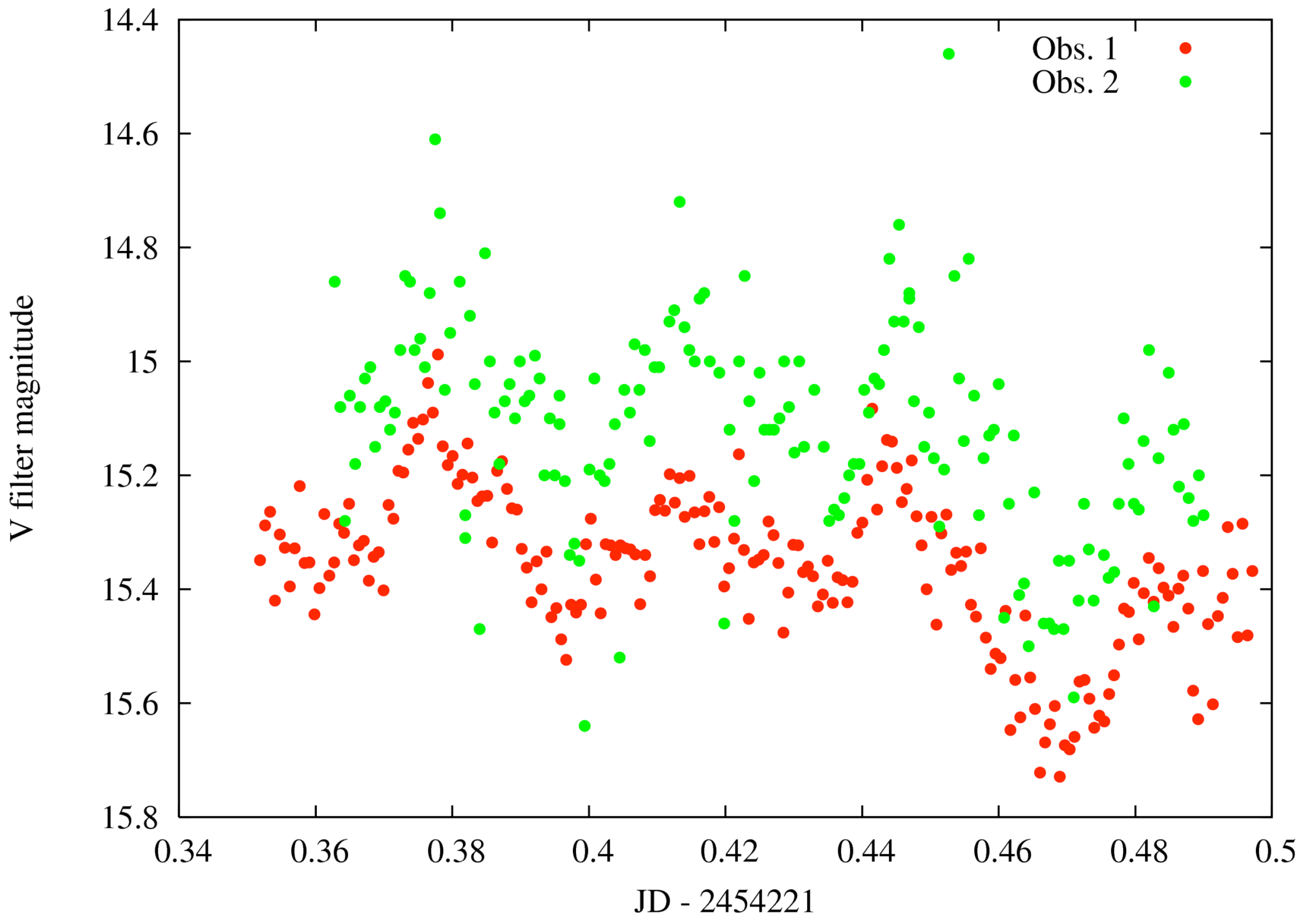
Zeropoint error BZ UMa

Note how different observers, all using calibrated comparison stars, get different results for the same star. Researchers can adjust the zeropoints if the star remains constant in color and there is sufficient overlap.



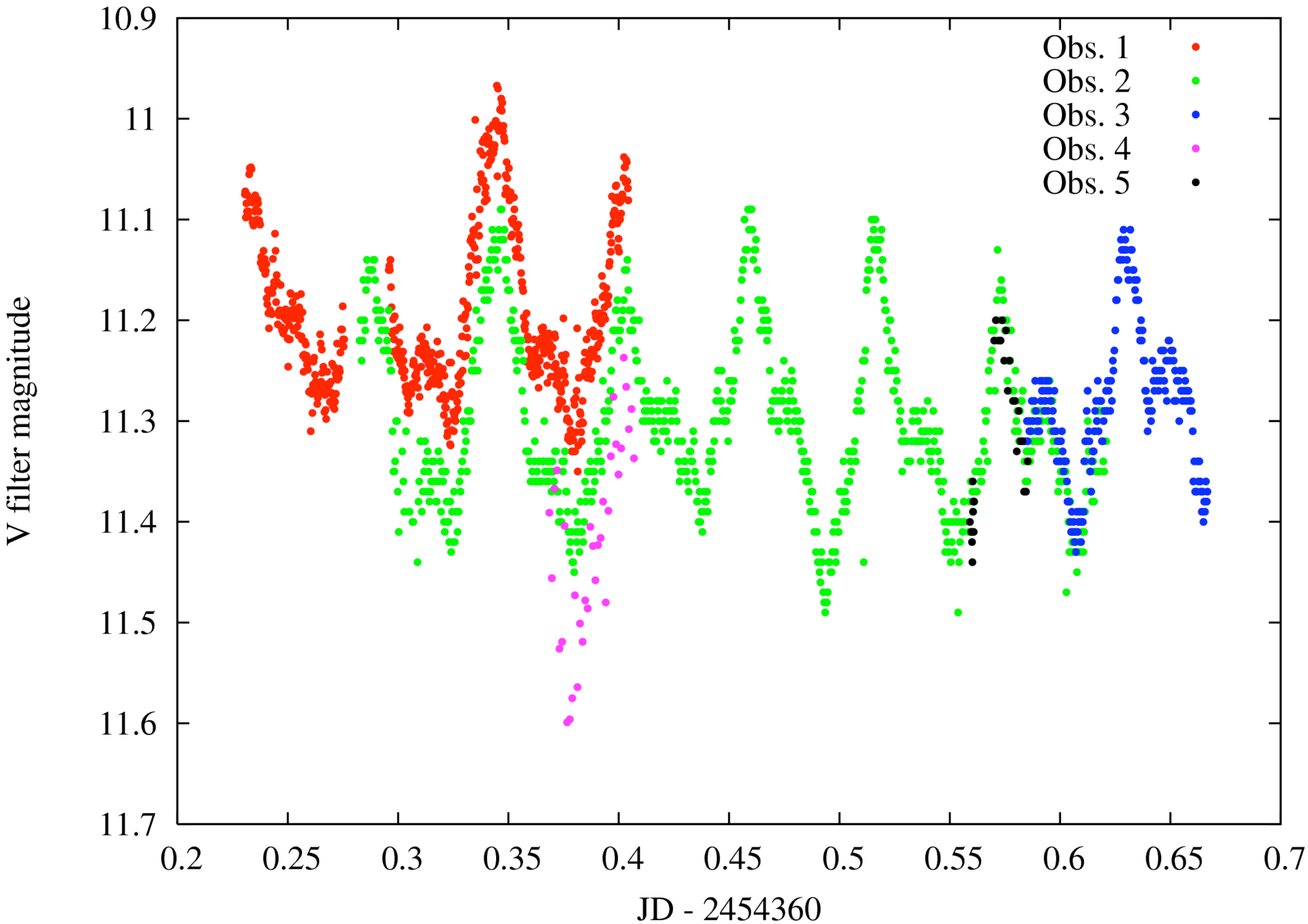
Zeropoint error

Just another example of the same effect. This is probably the most prevalent problem with CCD observations submitted to the AAVSO.



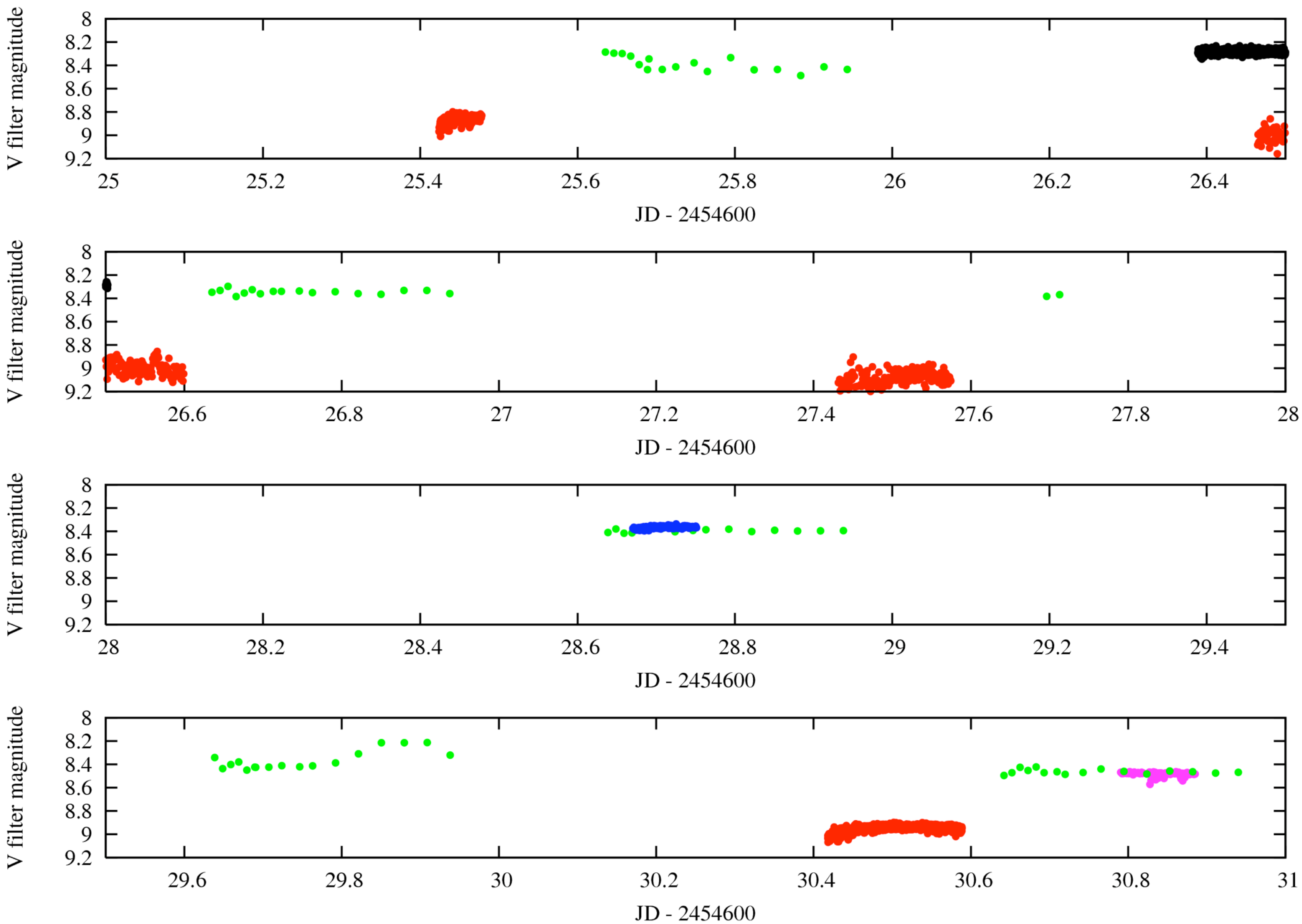
Zeropoint error V455 And

See? It appears everywhere, though more obvious with CVs where time series observations have more overlap.

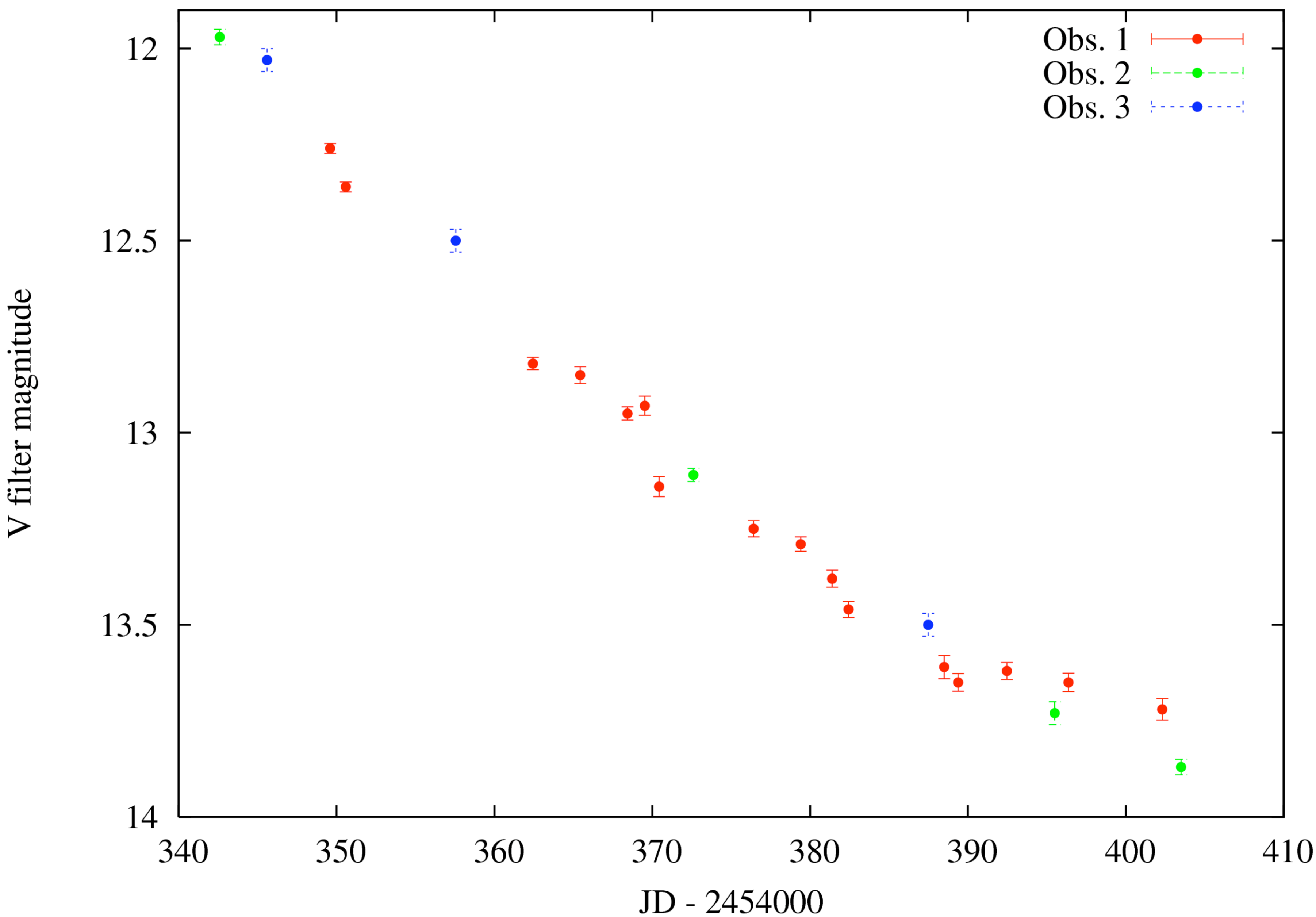


Zeropoint error CH Cyg

This is a huge difference, most likely caused by observer "red" using an incorrect magnitude for a comp star - or even using the wrong filter. Since there is little overlap with others, this data will often be thrown out by the researcher.



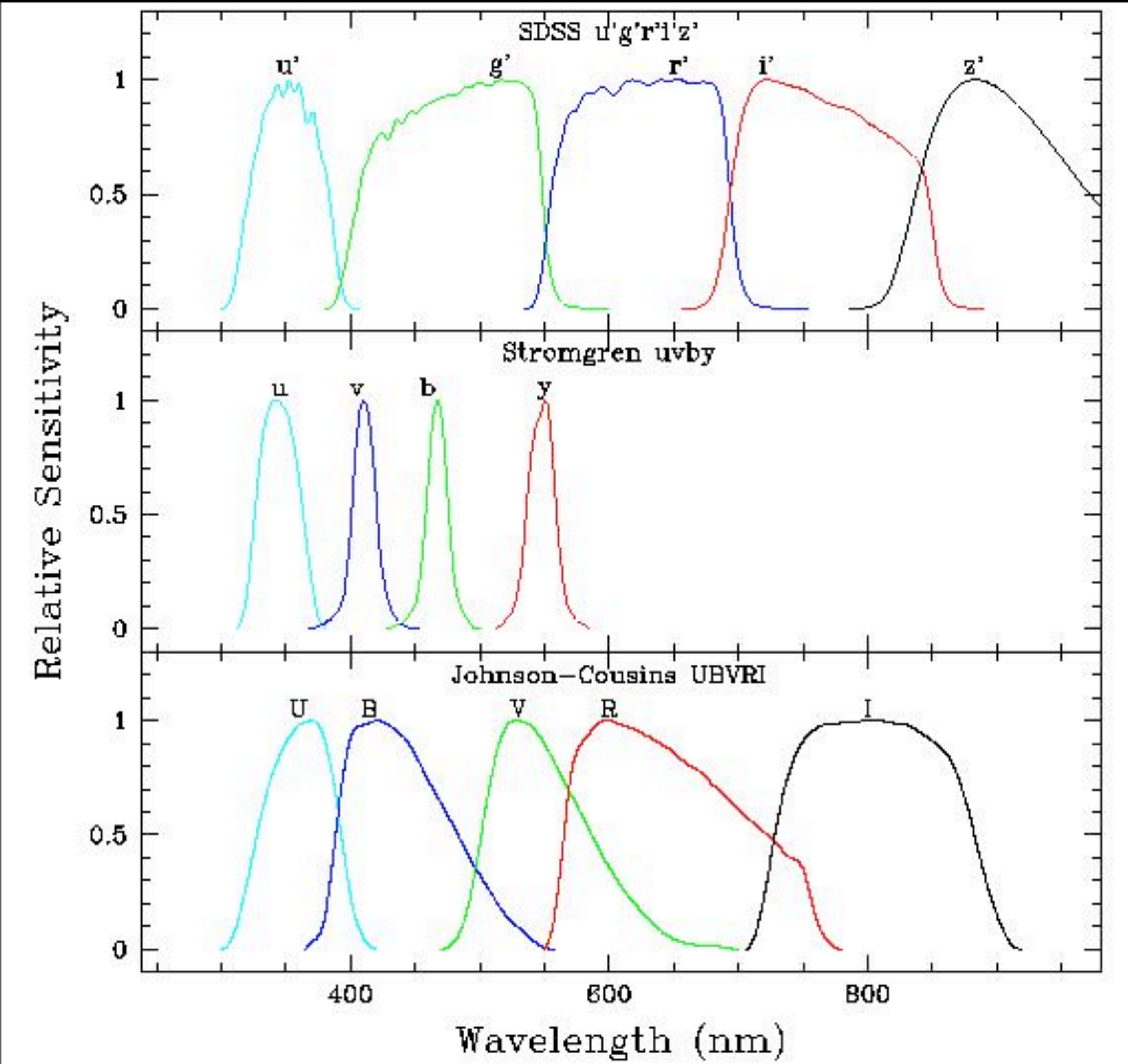
Zeropoint error W Dra



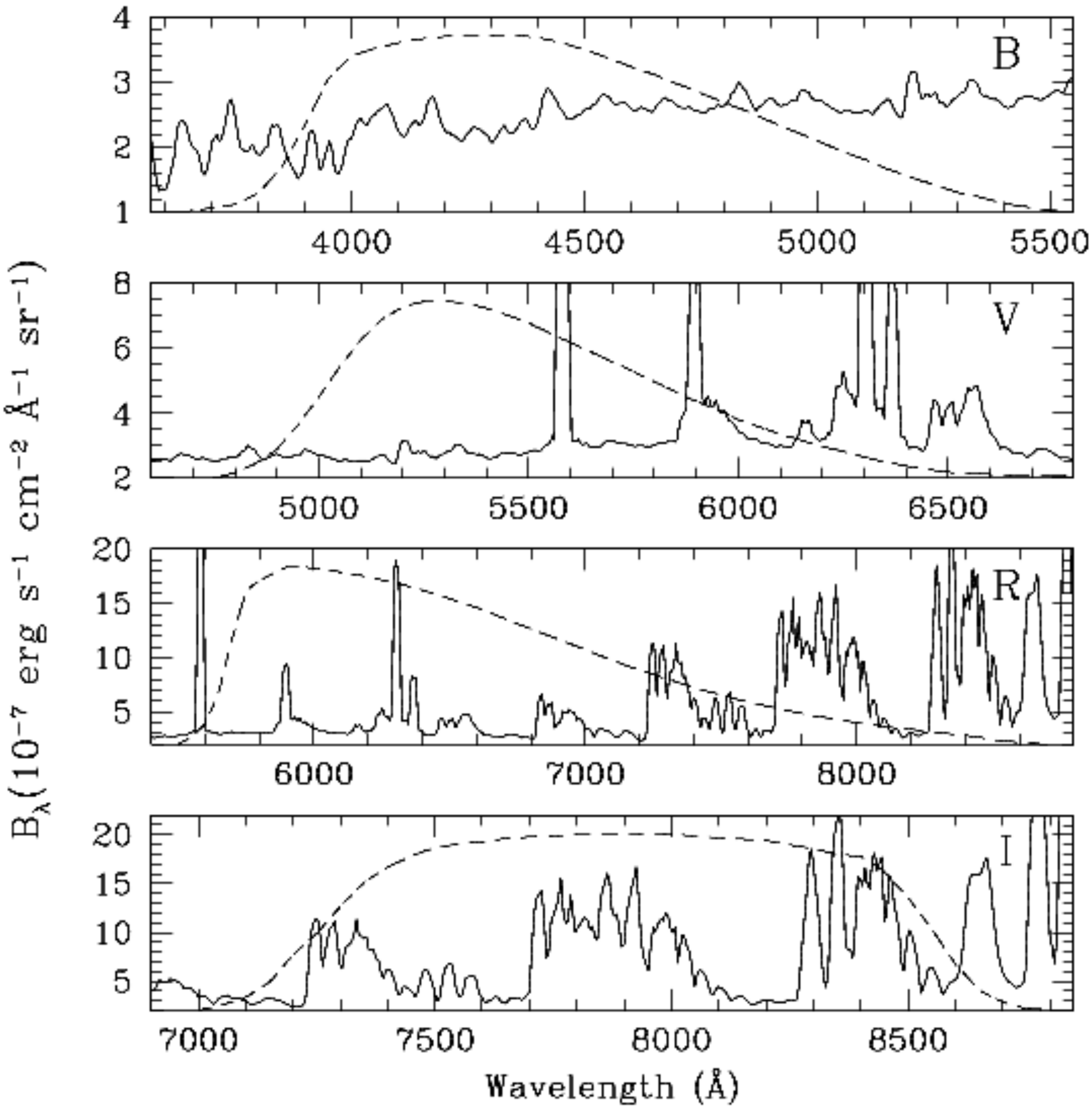
Guideline

- Make sure you are using the latest compstar magnitudes.
- Make sure you are using the correct filter (happens more often than you think!)
- Consider transformation

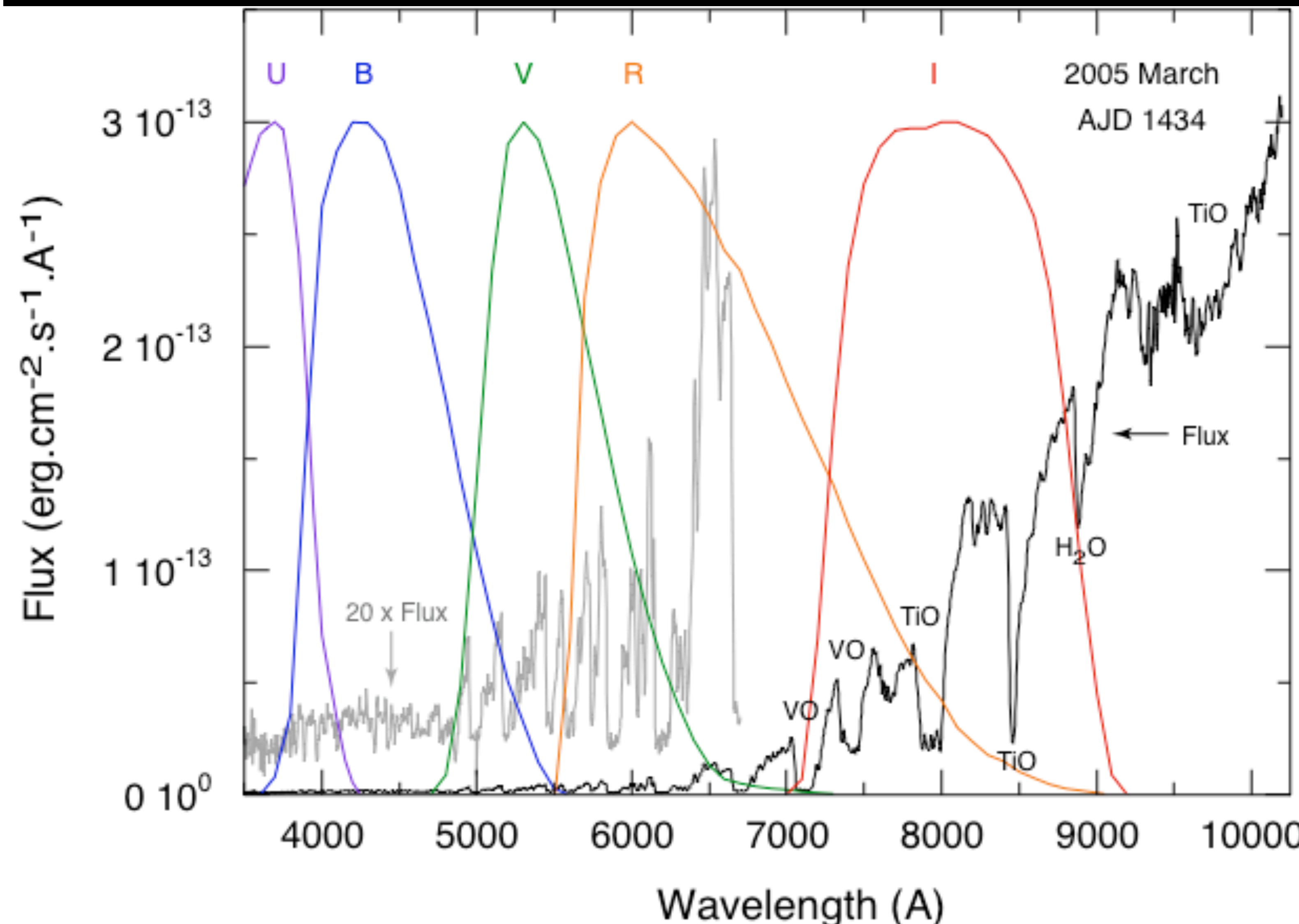
“transformation” is required because you are performing poor-man’s spectroscopy - using filters to divide the spectrum.



Here is a symbiotic star, with BVRI filter response overlayed. Note the strong emission lines in the V bandbass, the Rc bandpass, and the molecular bandheads at Ic. Stars are not always good smooth blackbodies! Expect poorer transformation for such objects, as result depends on whether your filter includes certain featurues.



Another example - a red star like a Mira. Note that BV little effected, bur Rc/Ic cut up with molecular bandheads and steeply rising spectrum.



Guideline

- Red stars are notoriously difficult to deal with; consider staying at B and V rather than R,I.
- Watch out for emission line objects - they cannot be transformed properly
- Use comp stars that look as similar to the target object as possible (same color and spectral type).

Transforming to a Standard System - 1

- Basic equation

  $V = v_{inst} + Z_v + T_v*(B-V) + K_v*X$

Where Z=zeropoint, T=transformation coefficient, K=Extinction coefficient, X=airmass

- Pick color that straddles or uses bandpass
- Pick color with good range; (B-V) or (V-I) before (V-R) for example

Transformation guidelines

- Approx relations:

  (B-V) = (V-I)

  (V-R) = (R-I) = (V-I) * 0.5

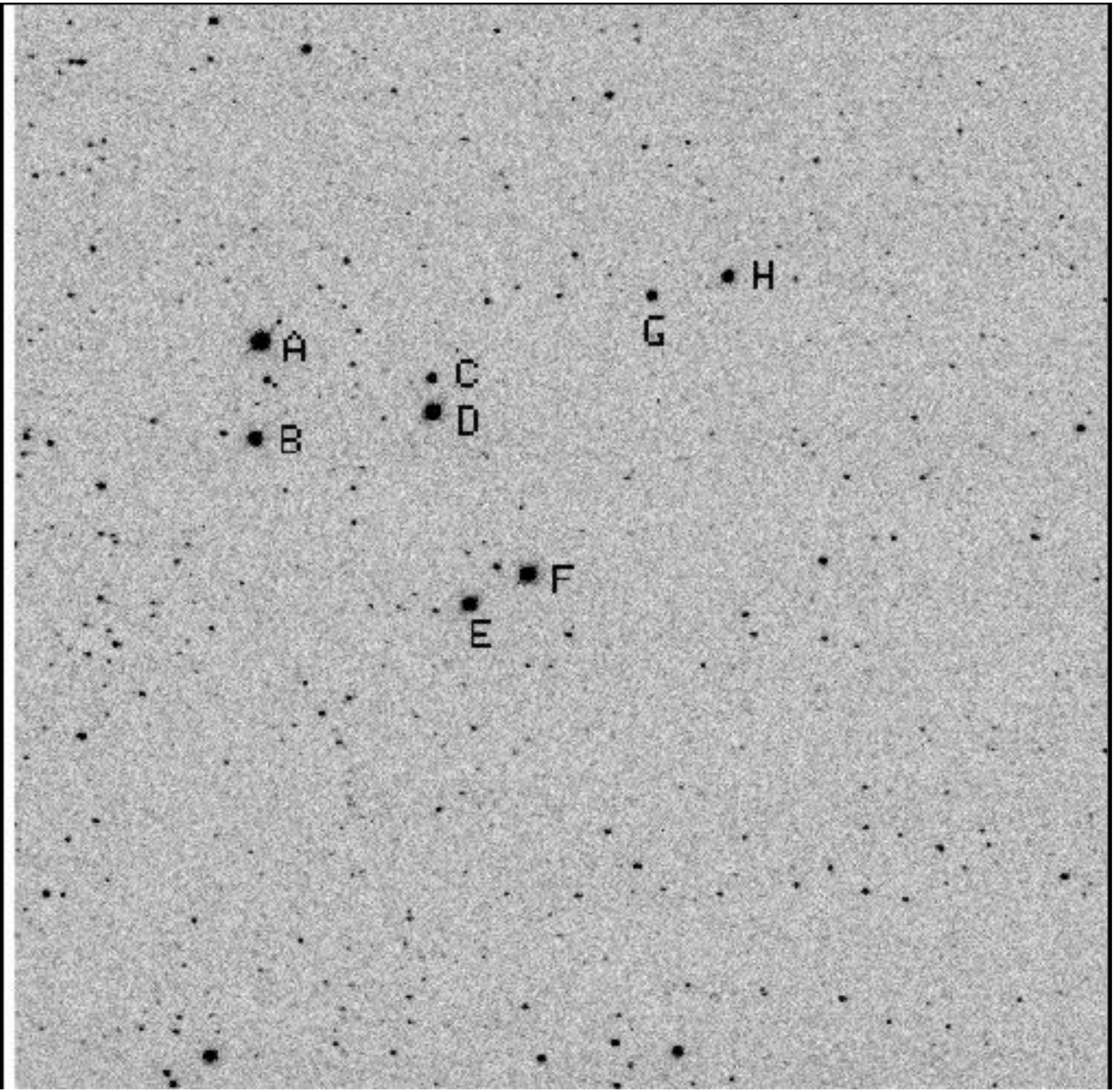
Differential Transformation

- $V_1 = v_1 + Z + T_v*(B-V)_1 + K_v*X$
- $V_2 = v_2 + Z + T_v*(B-V)_2 + K_v*X$
- $V_1-V_2 = v_1-v_2 + T_v*[(B-V)_1 – (B-V)_2]$
- Removes zero point, extinction effects
- Transformation not necessary if colors nearly identical
- If colors do not change during light curve, then transformation is just an offset

Guideline

- Simple to use if you know the color of the target and the comp star.
- Use average extinction if necessary (0.25mag/airmass for sea level for V)
- Coefficients constant over long periods of time
- Problem just becomes determining the coefficient

Typical Landolt standard field (SA110). Note 8 standard stars, wide color range, in a 10arcmin field



Standard Clusters

- Not Landolt/Cousins, but well studied
- M67
- NGC7790
- M11
- Not in VSP yet, but I’ll put them in soon

Example: NGC7790. Lots of stars to use for coefficient determination, but crowded field so watch blending. Choose those standards that are "clean"

Guideline

- Use only a single field per night, but average results from several nights
- Measure all of the stars possible
- Slope of least squares line is the coefficient

Summary

- Scientific results are all about care and inspection. Look at your images, take your time. Quantity is less important than quality.
- The higher your data quality, the more likely that it will be used by professionals.