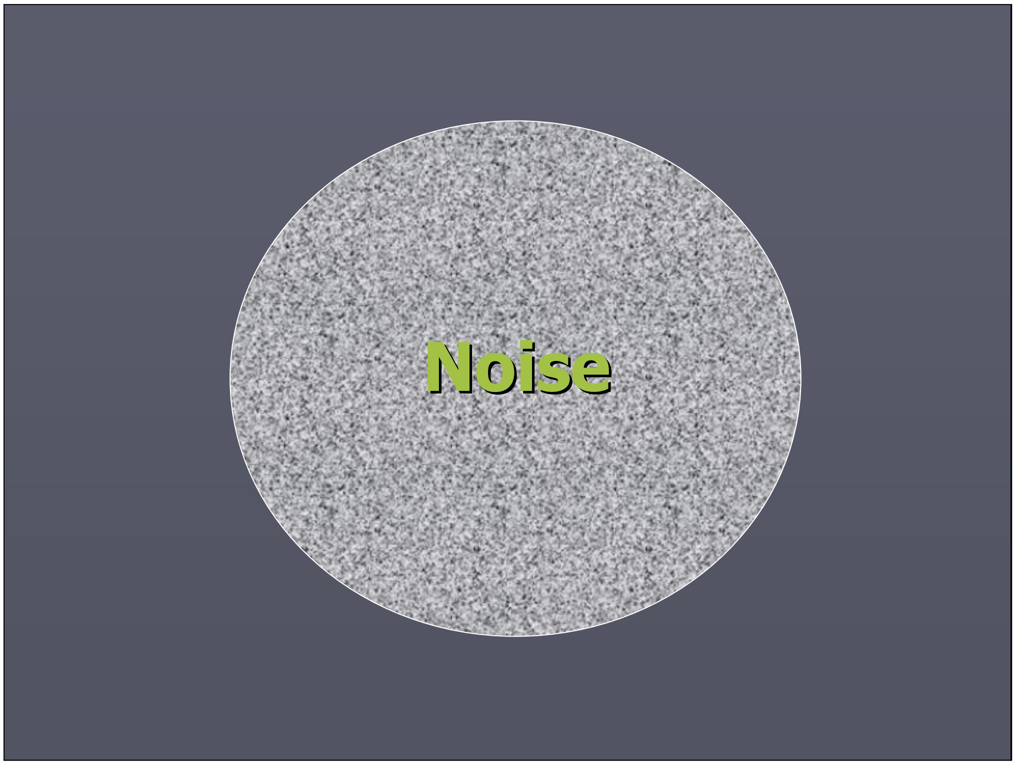
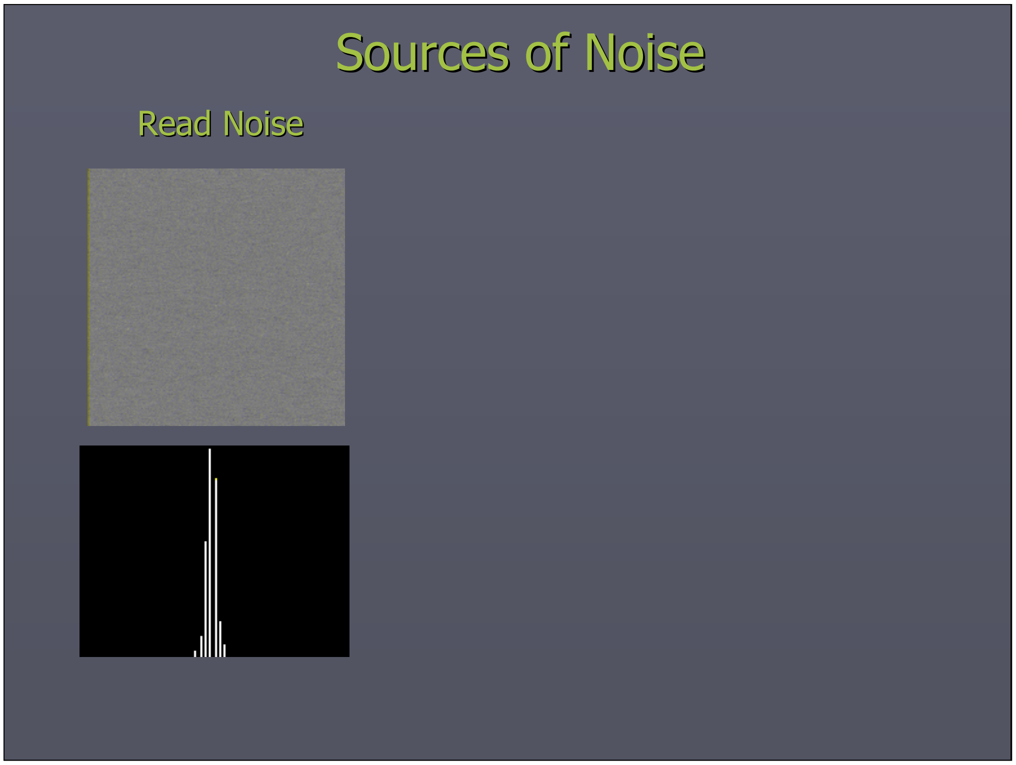


The next factor to be investigated is noise. (It is a common misconception that the more sensitive a camera is the fainter the object you can detect. In fact it is the amount of noise, both from the camera and from the imaging process itself (or more accurately the ratio of the signal to noise) that determines how deep your imaging will go or how precise your photometric measurement will be.

NOTE : I am defining noise as the unwanted signal that varies in time between frames. ie excluding any effects which repeat from frame to frame like hot pixels, amp glow, differences in sensitivity between pixels, vignetting, skyglow gradients etc, which can be corrected for using darks and flats



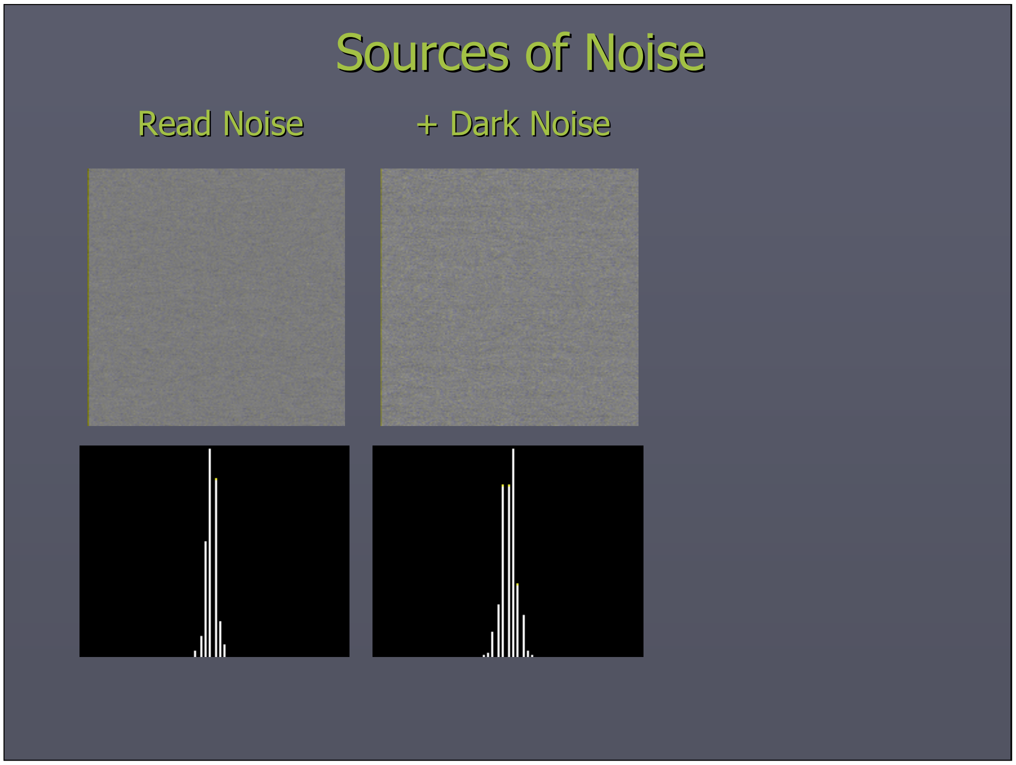
Noise can come from a variety of sources but can generally be grouped under three headings.

Read Noise

This is what you see if you take a very short exposure in the dark. Here I have increased the mean level to 50% by adding a fixed value to all pixels to make the noise more visible.

Sources include electronic noise, interference, noise from A/D conversion

NOTE: Shown is the difference between two single frames from the standard 100x100 pixel area. The big advantage of using the difference technique is that it eliminates all constant differences between the frames, removing the need for dark/flat frame corrections. The values in the resulting difference frame contain the noise from both frames and so it has to be divided by sqrt 2 to give the noise in a single frame The histogram was produced from the result using K3CCDTools.



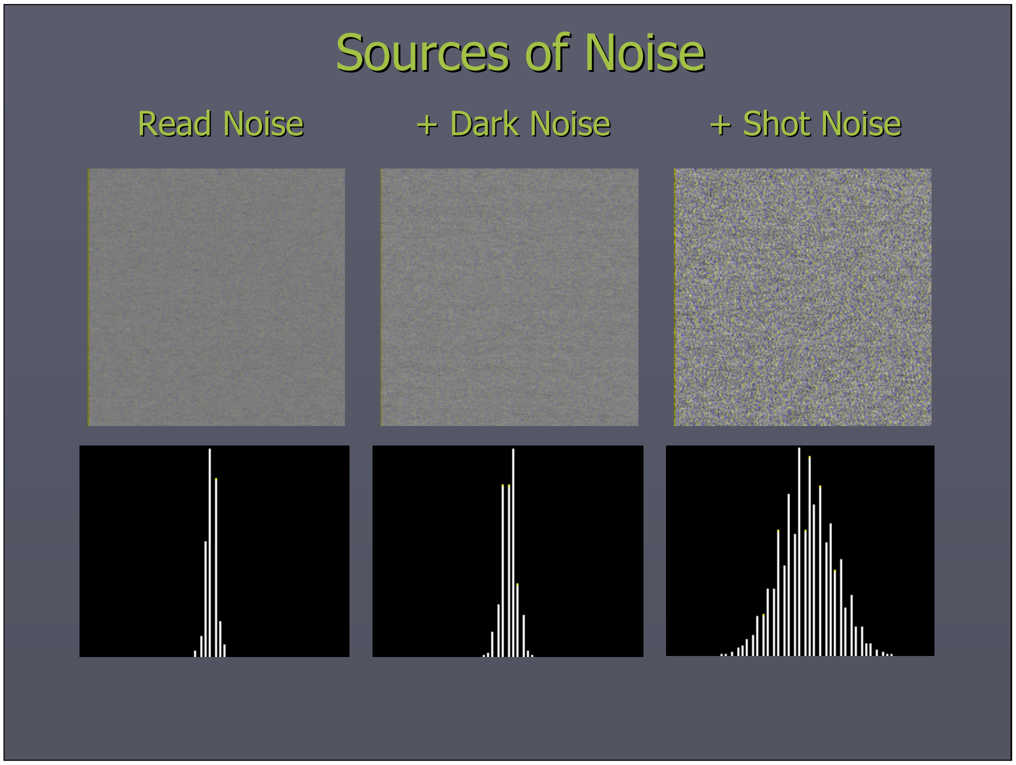
Dark (Thermal) Noise

If you increase the exposure length, while still keeping the camera in the dark, the noise increases. The cause is unwanted electrons which randomly jump into the CCD pixel wells and get read out as signal. The number of electrons depends on the CCD design and increases dramatically with temperature (typically doubling every 6 deg C) This is why it is sometimes referred to as Thermal Noise.

NOTE: You will often see this described as Dark Current. This refers to an important statistical phenomenon known as the Poisson distribution. This describes the variation in the rate at which discrete random events (like thermal electrons jumping into CCD wells) occur. In particular there is a direct relationship between the mean number of electrons counted in a given time and the variability you get if you repeat the measurement (or in our case the measure the variability from pixel to pixel) Specifically:

Variance (ie the standard deviation squared) = Mean

Consequently you usually see noise figures quoted as electrons (for read noise) or electrons/sec (for dark noise) which is the number of random electrons (current) which would produce the observed variability

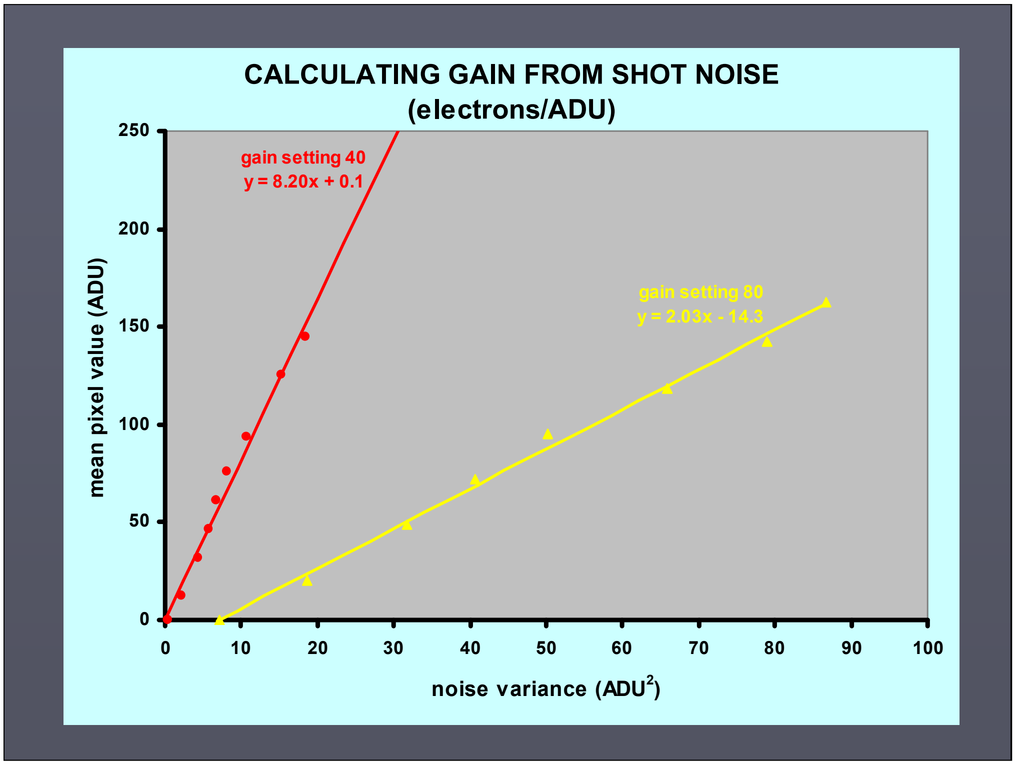


Shot (Photon) Noise

If you then switch on the dim light source and take another set of long exposure frames you might be surprised to see the noise increase further. This is because we are dealing with very low intensity light, perhaps only a few tens of photons per second. These do not arrive at regular intervals but randomly and so produce noise in a similar way to the thermal noise. This is known as Shot or Thermal Noise.

Measurement of the Photon Noise will give us the clue we need to calculate the gain of the camera in electrons/ADU and from there we can put figures to the noise parameters.

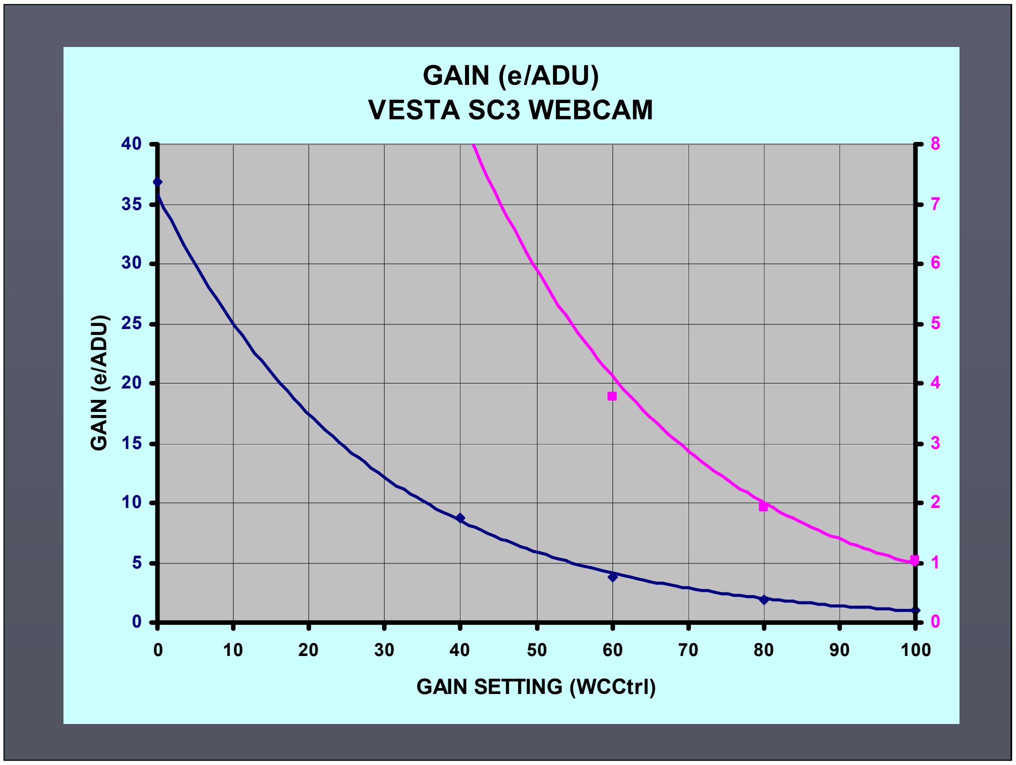
NOTE All the following measurements were made with a gamma setting of 0 and the results corrected for linearity.



Remember that for a random process, the mean level = the variance in electrons If we therefore take a series of exposures at different light levels and plot the mean level in ADU against the variance (ADU^{2}) in the images, the slope of the graph will give us the gain in electrons/ADU

NOTE: In practise, instead of changing the light intensity, a constant total exposure of 10 sec was used and the on time of the was light varied for each exposure.

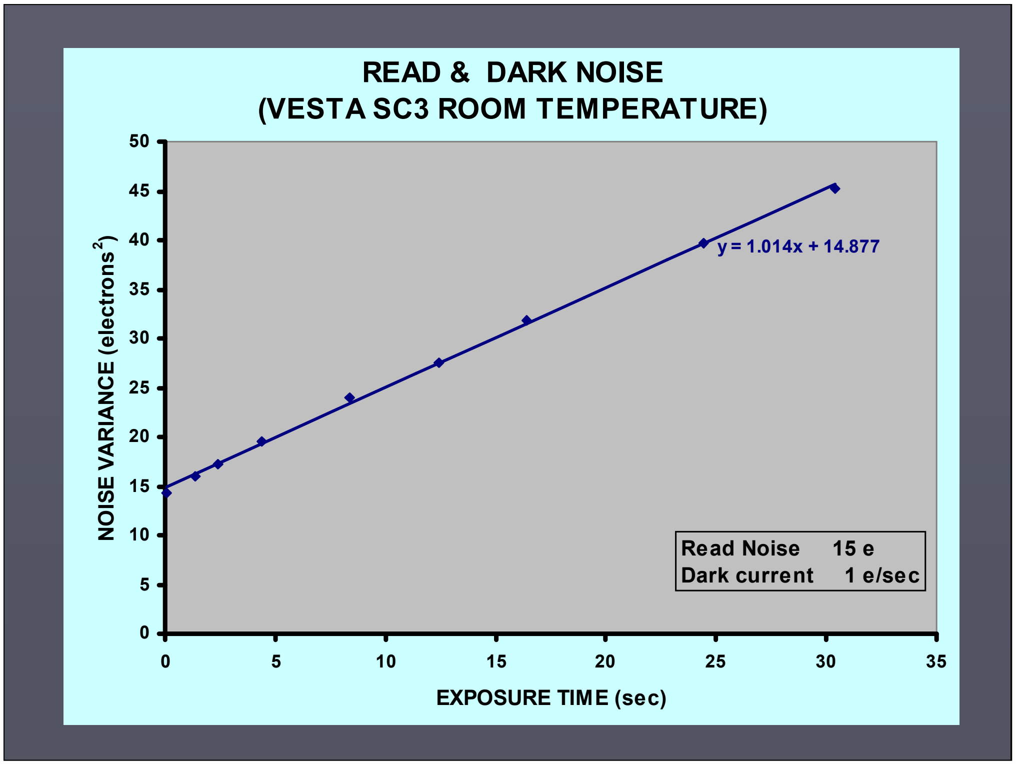
Two runs were made at gain settings 40 and 80 which corresponded to absolute gains of 8.2 and 2.0 e/ADU respectively.



Combining this data from the results from the linearity checks, it is possible to produce a graph of absolute gain against gain setting for all gains. (The pink line is at a larger scale to show the higher gain settings more clearly)

We now have our second key parameter for the camera:

The absolute gain can be varied between 1 and 35 e/ADU depending on the gain setting.

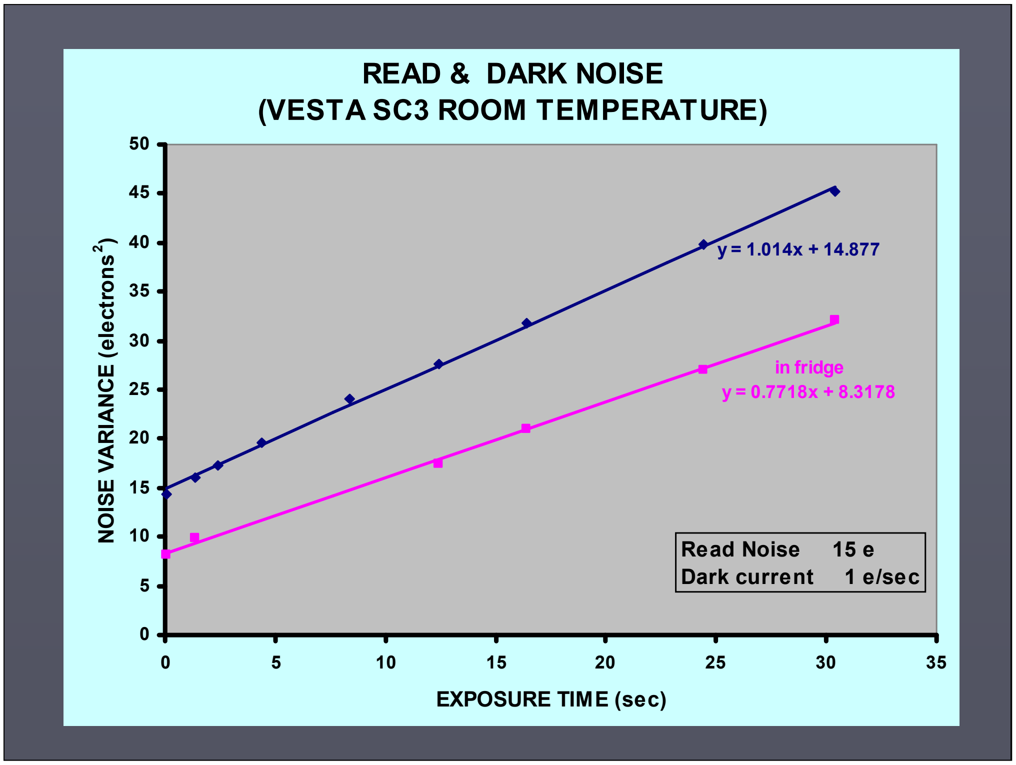


finally we have the information we need to measure the noise parameters.

If we make a series of dark exposures of different lengths and plot the variance of the noise in the images (now in electrons rather than ADU) against exposure time, then the slope off the line gives us the dark noise (or current) in electrons/second and the intercept with at zero exposure time gives us the read noise in electrons. For this camera:

Dark Current = 1 e/sec

Read noise =15 e



A quick test has been made to see the effect of cooling the camera on noise by placing the camera in the refrigerator. The dark current dropped but less than expected. Unexpectedly the dark current was almost halved which is of particular importance for 8 bit webcams where it is usual to stack many images each generating a dose of read noise. Perhaps the refrigerator provided electrical screening from interference and this caused the lower read noise. These result need investigating further.

COMPARISON OF CAMERA SPECIFICATIONS

CAMERA	VESTA SC3 B+W RAW	LUMINERA SKYNYX 2.0	STARLIGHT SXV FM5	SBIG ST7XME	ARTEMIS ART 424
GAIN (e/ADU)	1 - 35 (100-0 gain)		1	2.3	
READ NOISE (e)	15 (8 cooled?)	10	11	15	10
DARK CURRENT (e/sec)	1 (0.8 cooled?)	<1	0.02	1	<0.01
CCD	ICX 424		ICX405	KAF0402ME	ICX424
PIXEL SIZE (um)	7.4	7.4	9. 8 x 6.3	9	7.4
WELL DEPTH (k e)		40	60	100	42

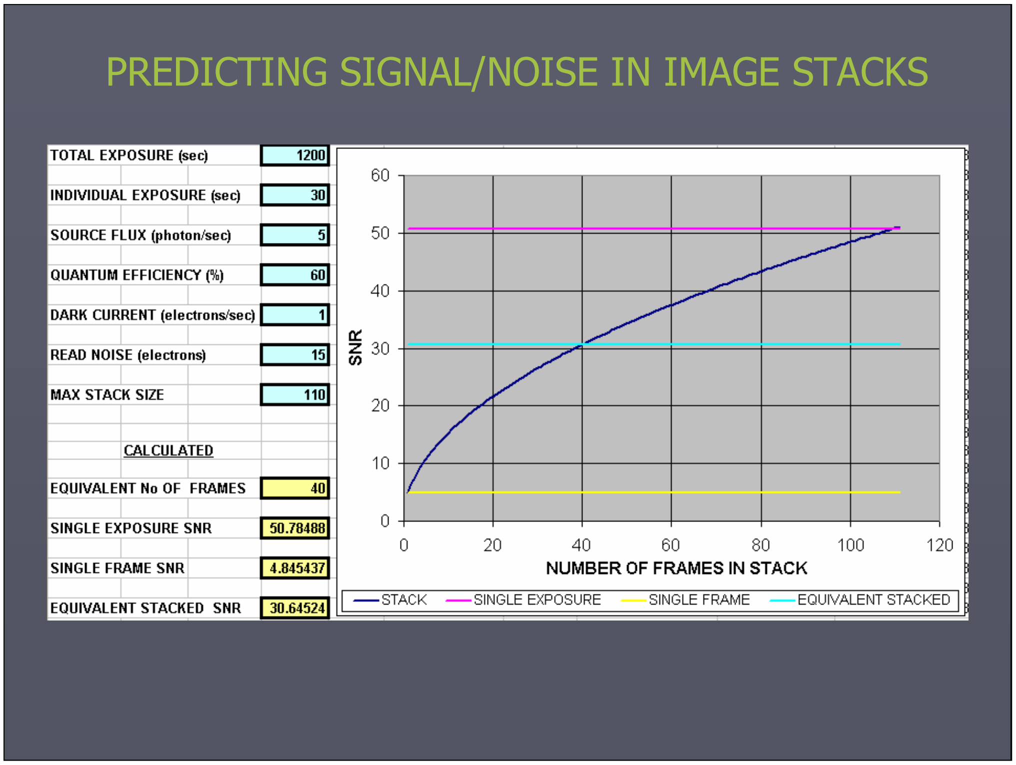
With the key parameters measured, we are in a position to compare cameras.

One can draw some conclusions from this table.

The B+W Vesta SC3 webcam is quite similar in noise performance to a leading planetary camera, the Luminera Skynyx, though the latter has the advantage of higher frame rates.

The SC3 matches the noise performance of the SBIG ST7ME

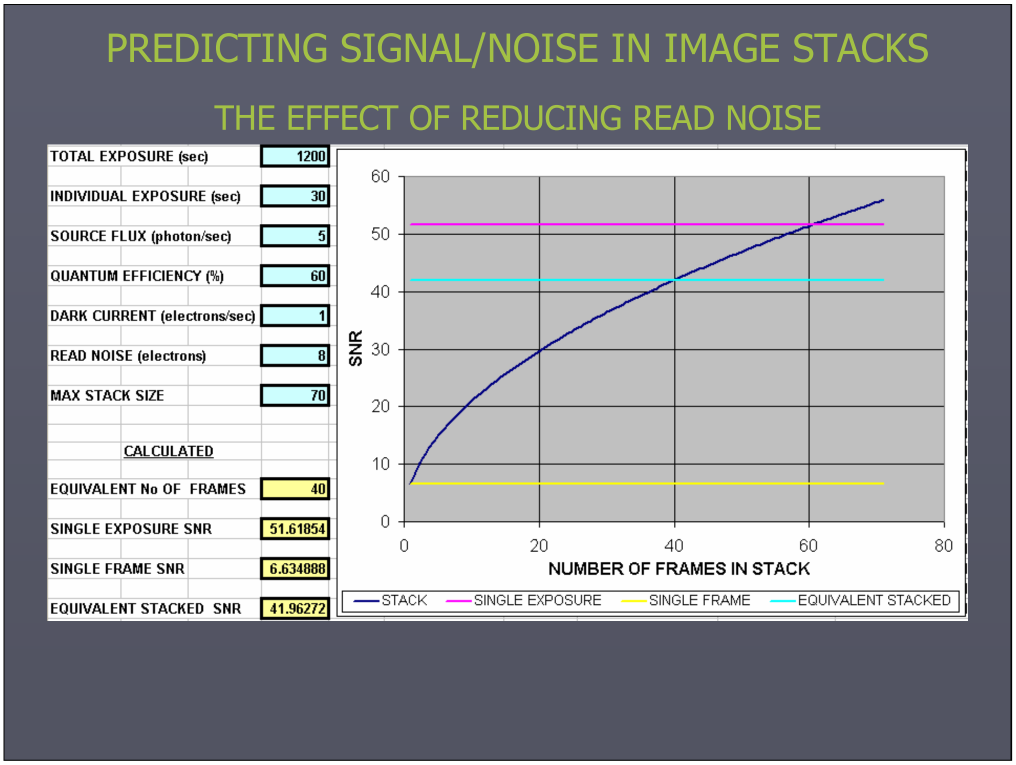
The combination of the low noise of the ICX424 CCD and cooling gives the ART424 the lowest dark current



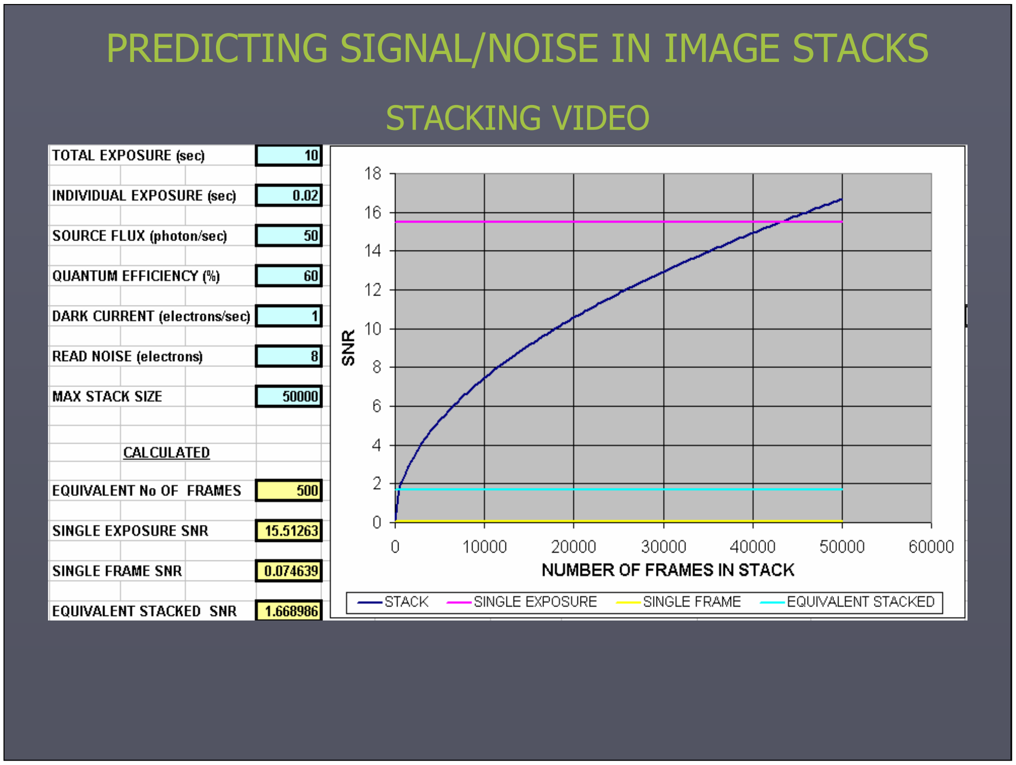
Armed with these figures, it is possible to revisit the often posed question hoe many do you need in a stack to match a single long exposure?

The following are outputs from the spreadsheet published on my website at the beginning of the year.

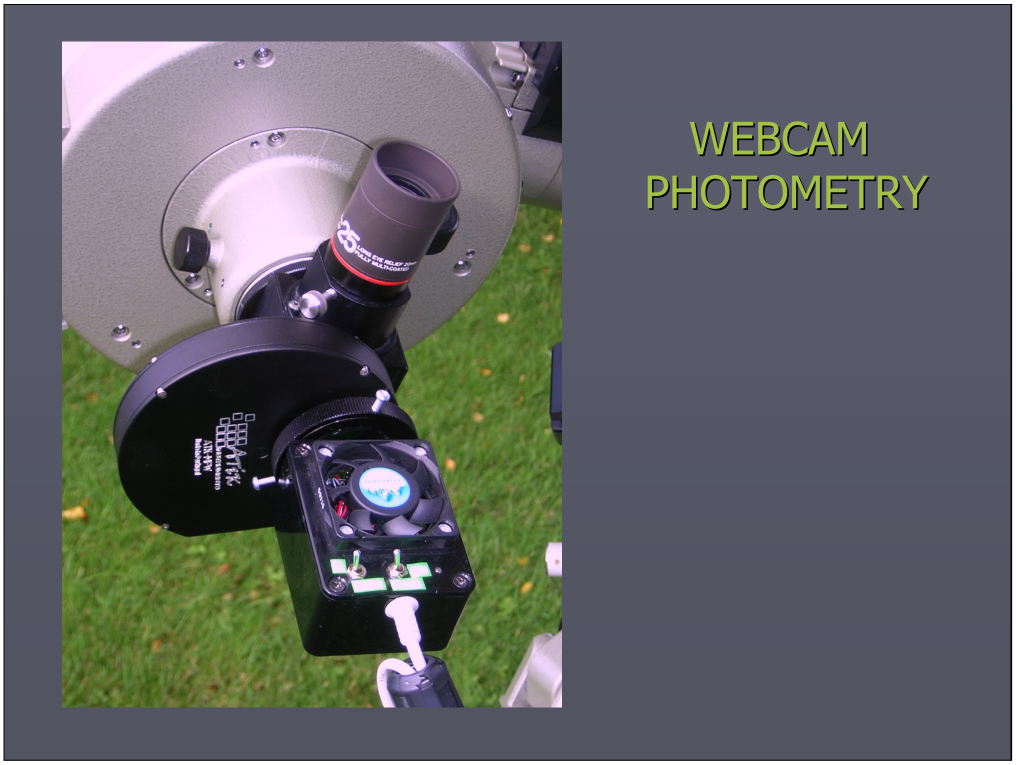
This slide compares the signal to noise ratio of a faint object produced by a single exposure of 20 min with a stack of 30 sec exposures. Although a stack with equivalent total exposure time has only 60% of the s/n of the single exposure, by increasing the number of exposures in the stack from 40 to 110, this deficit can be made up.



Here we see the effect of reducing the read noise from 15 to 8 electrons. The effect on the single exposure is insignificant but the equivalent stack is much closer in s/n now and the number in the stack need only be increased to 60 to bridge the gap. This confirms the importance of low read noise for 8 bit short exposure imagers

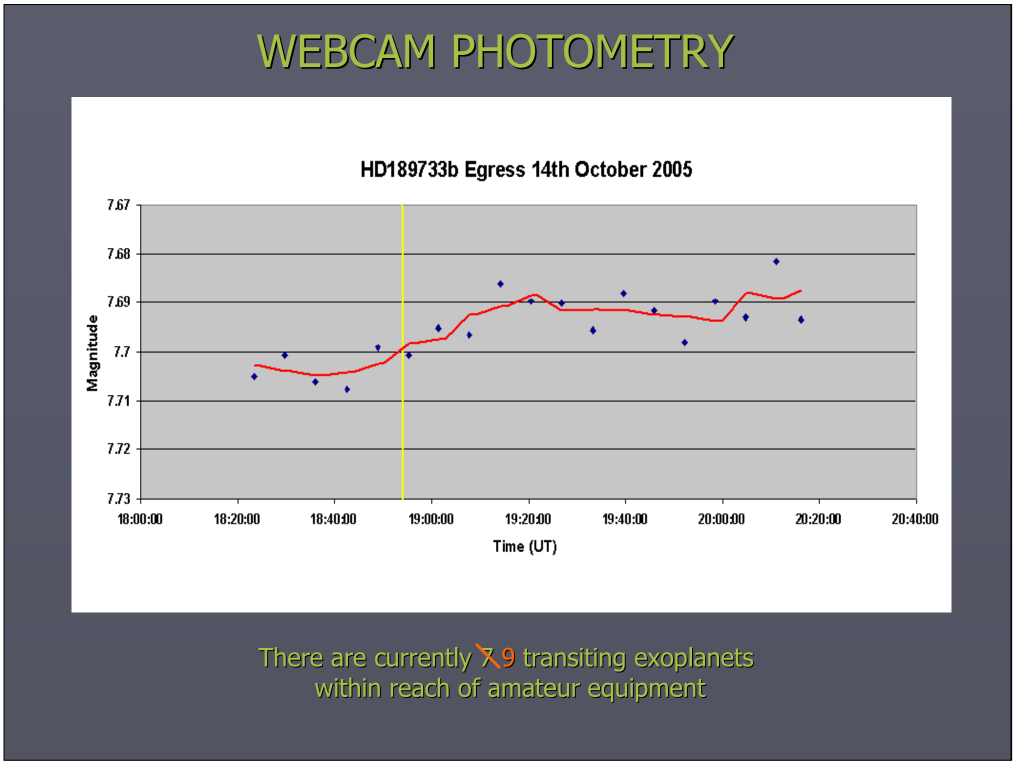


This final graph is of historical interest as it models early video stacking work by Steve Wainwright and Juergen Liesmann back in 2000. Here we see that for brighter objects, large stacks of several tens of thousands of frames of 1/50 sec exposures can match the result of a single 10 sec exposure, despite the s/n in a single frame being vanishingly small.

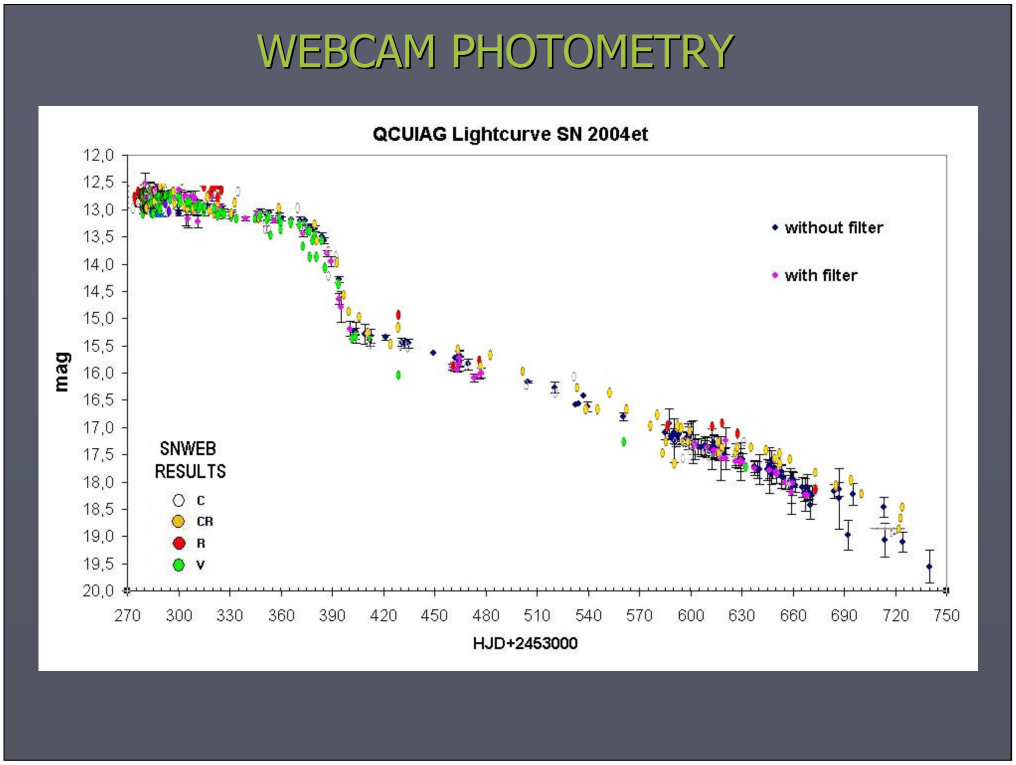


Here are some practical examples of scientific measurements using a webcam based imager.

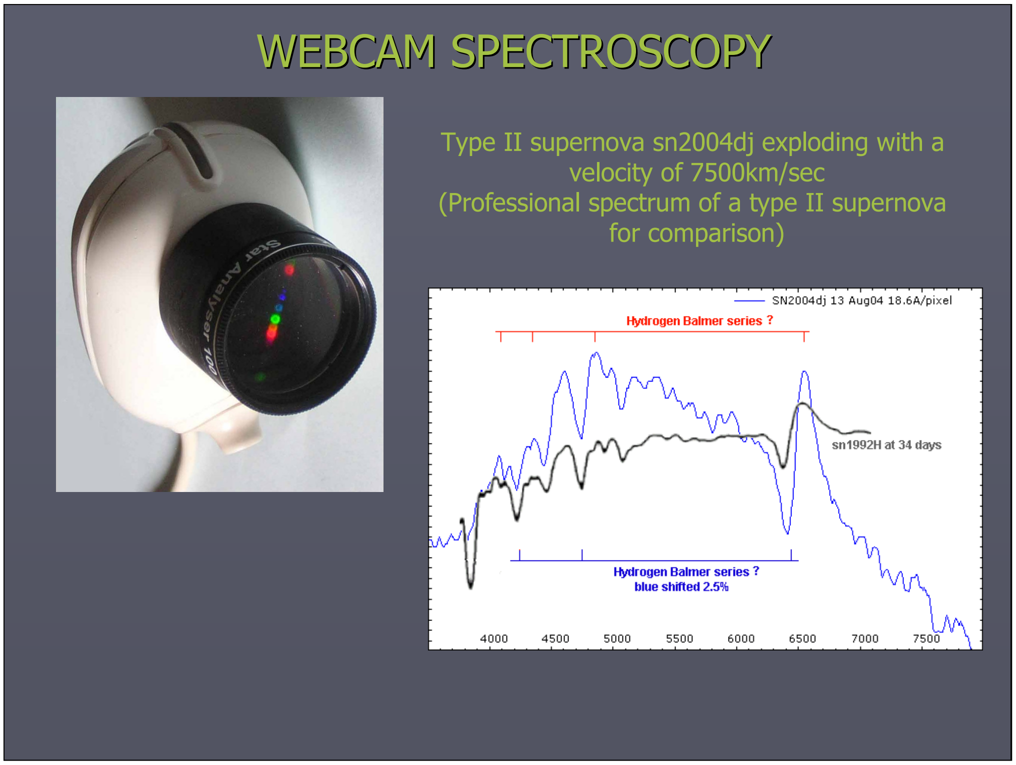
This is my photometry and low resolution spectrometry setup consisting of a filter wheel loaded with photometric filters and a Star Analyser 100 l/mm diffraction grating mounted in front of the imager. A flip mirror completes the setup all mounted on the VC200L telescope and focal reducer at f6.4



Here is a further example of precision photometry. The egress of another Exoplanet. The number of exoplanets detectable by amateurs using the transit technique has increased from 4 to 9 over the past year.

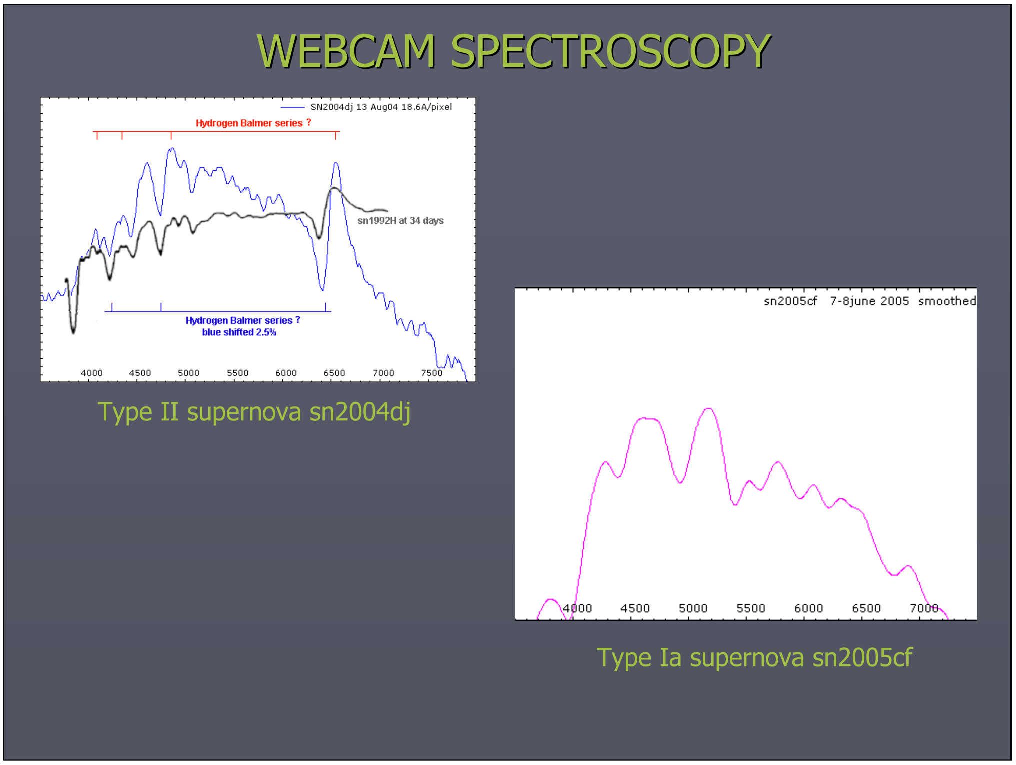


This slide shows the results of many observers in the QCUIAG group who followed the brightness of supernova sn2004et for over a year down to below mag19. Overlaid are results from other international observers as reported to snweb.org

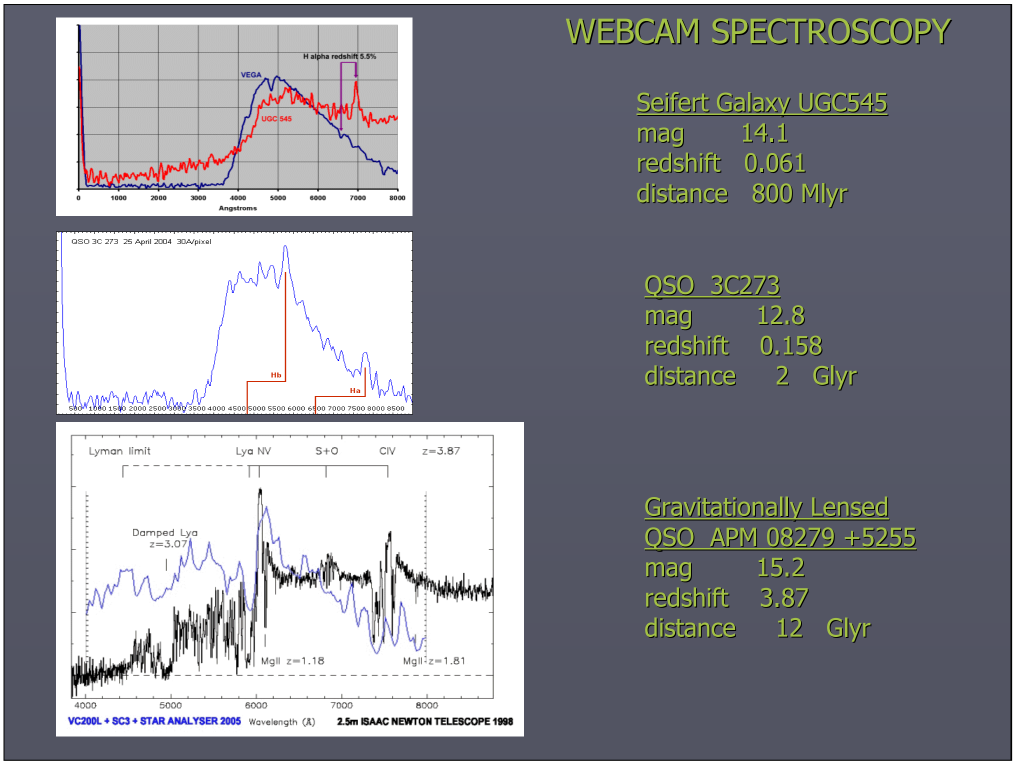


Simple spectroscopy can be performed by mounting a diffraction grating in front of a webcam based imager. Faint objects can be measured using long exposure modified devices.

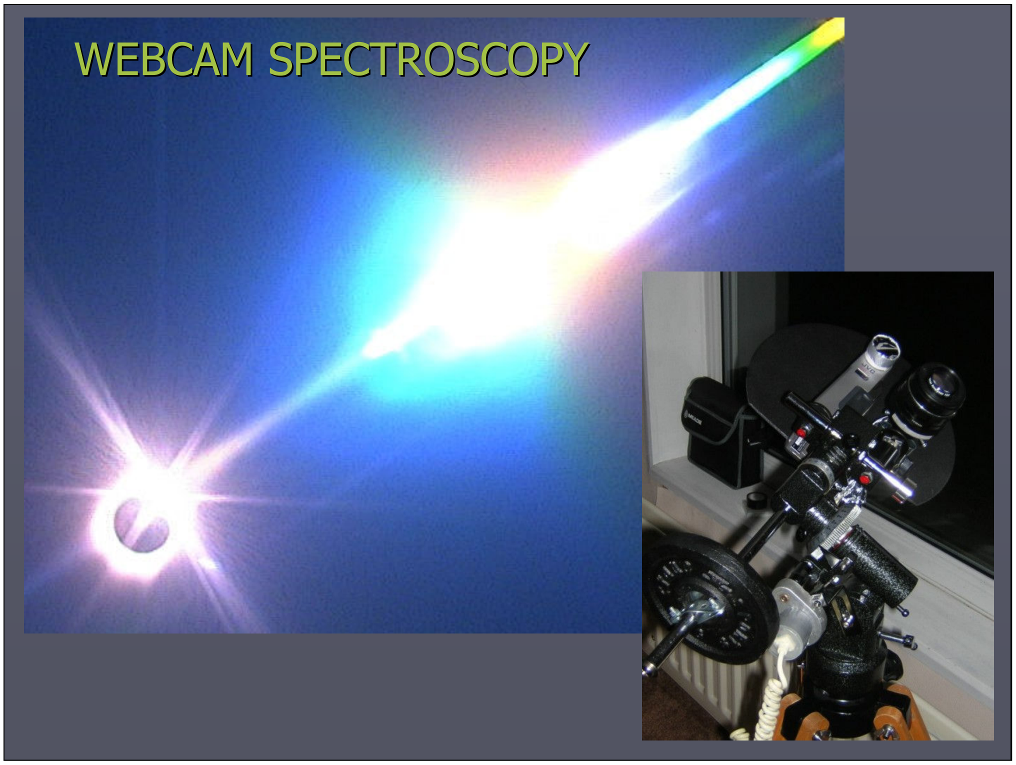
This example is for supernova sn2004dj from this simple spectrum the speed of the exploding material can be estimated. note the similarity with the professional spectrum taken of a previous supernova of the same type.



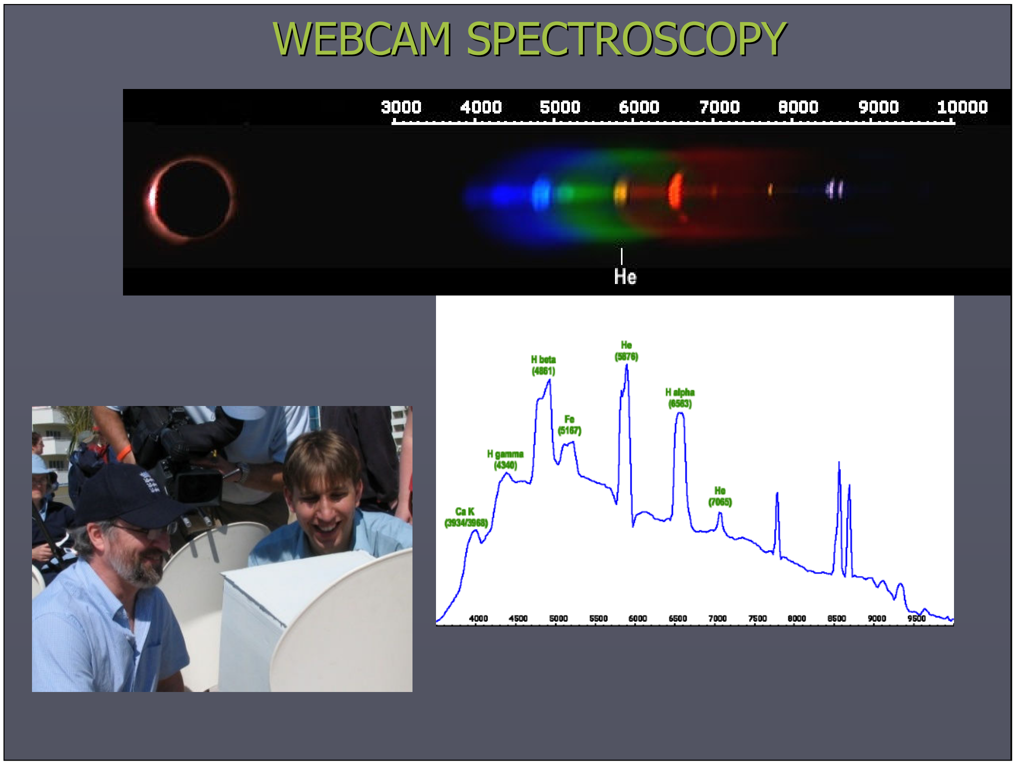
Here the spectra of two different types of supernovae are compared.



The setup can be used to measure the redshift of extra galactic objects. From a “nearby” Seifert galaxy at 800 Mltyr to a mag 15 gravitationally lensed quasar at 12 Gltyr which shows the UV Lyman alpha line redshifted into the red region of the visible spectrum. Note the similarities with the discovery spectrum taken with the 2.5m Isacc Newton telescope, including evidence of redshifts of intervening material that the light passed through.



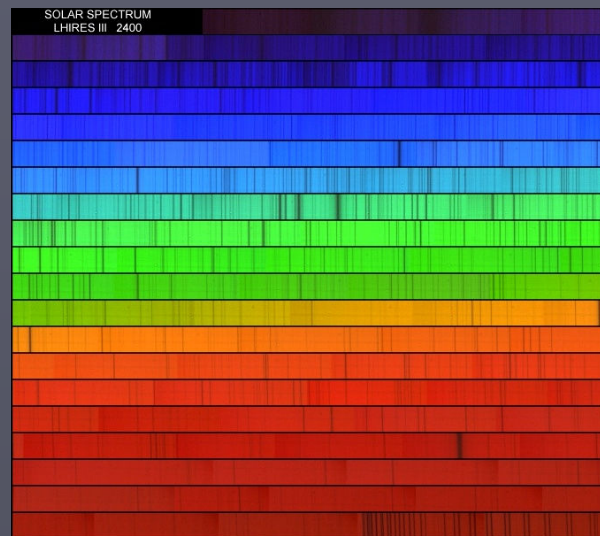
The Star Analyser was used in front of a camera lens mounted on a Toucam webcam at the total eclipse 2006.



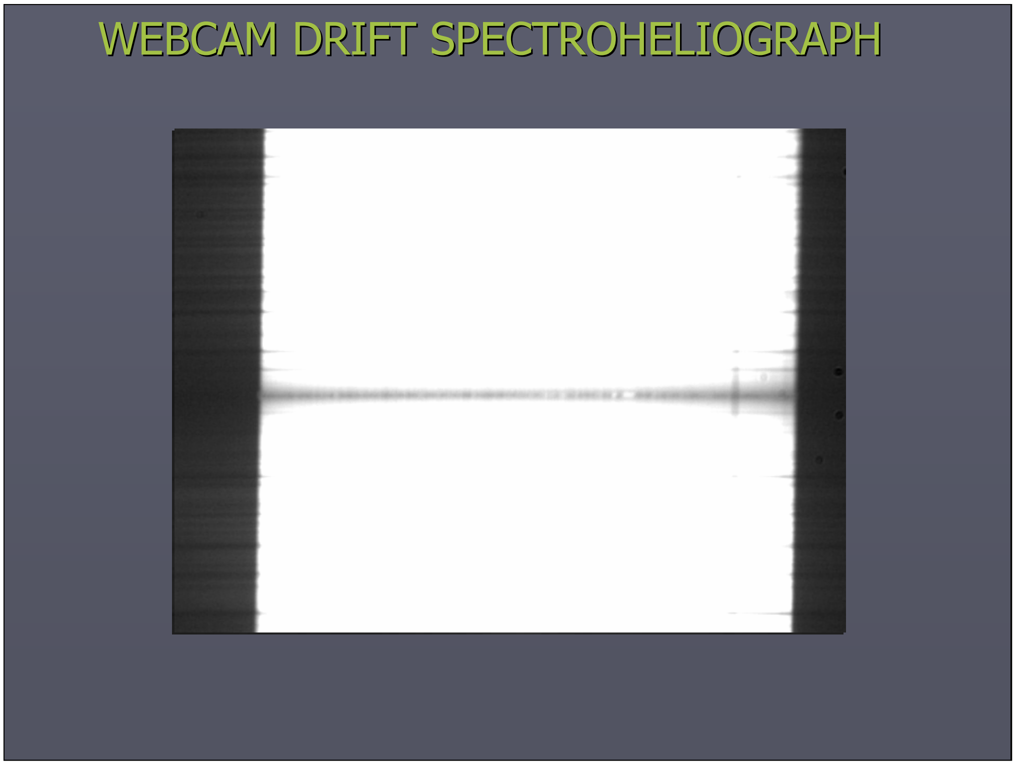
This is the flash spectrum of the Chromosphere taken at third contact. As well the Hydrogen alpha lines, the famous emission line of helium can be seen

Chris Lintott of the BBC Sky at Night programme discusses the results with me.

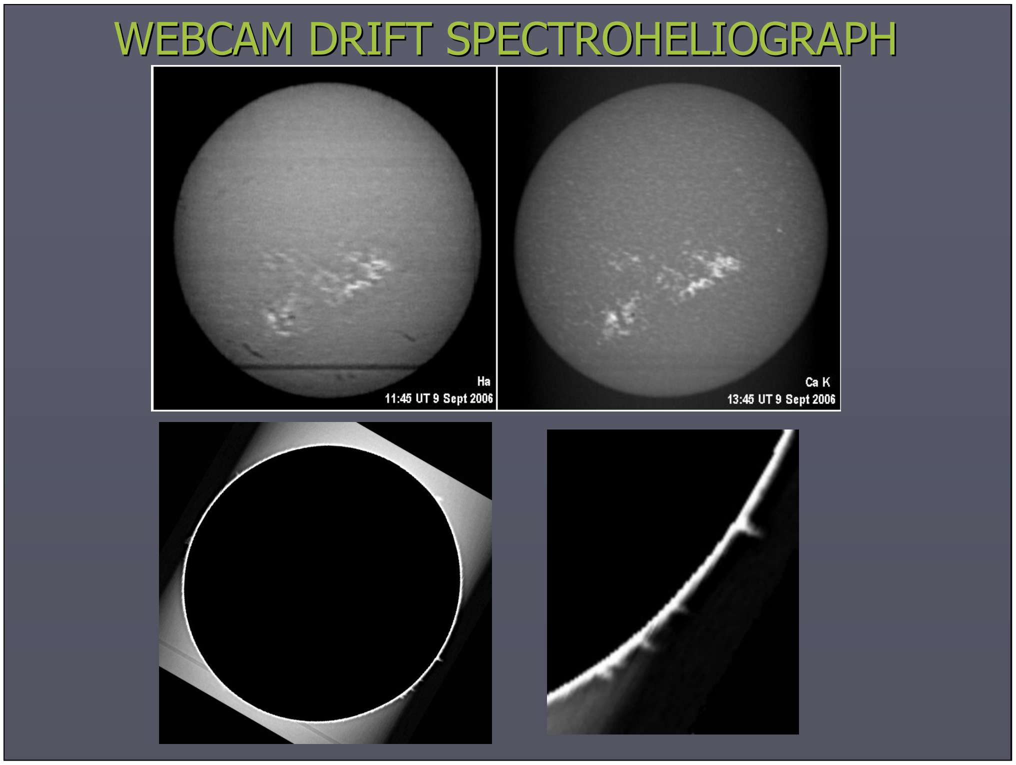
WEBCAM SPECTROSCOPY



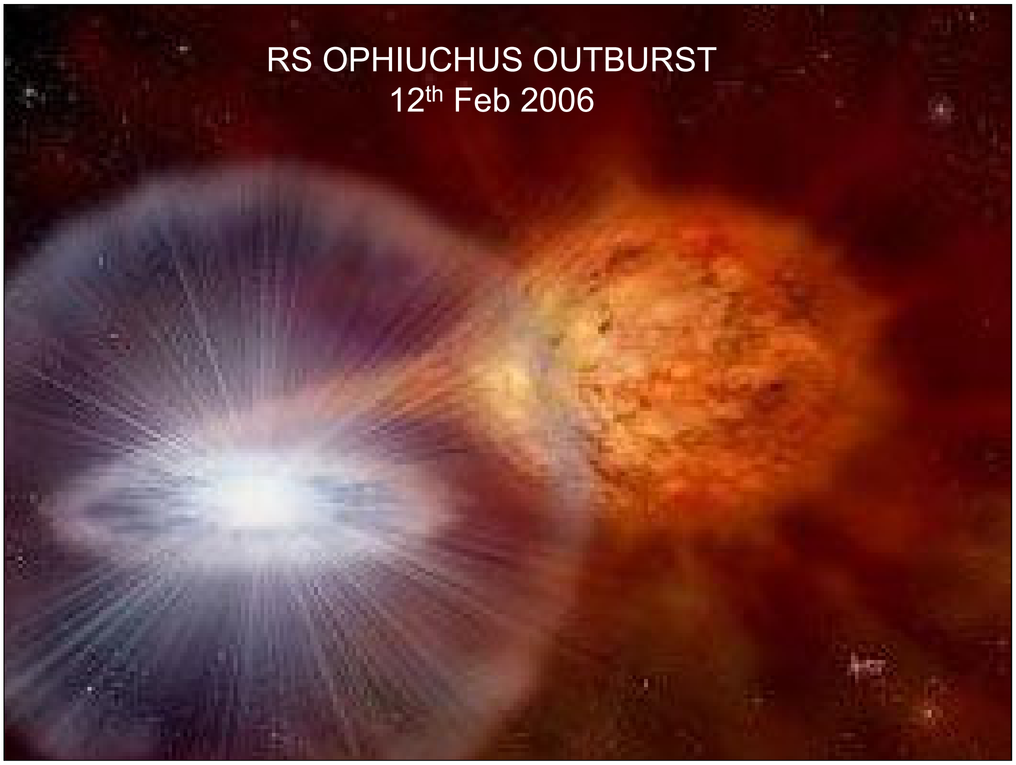
Here the camera is mounted on an LHIRES III high resolution spectrograph. The high resolution solar spectrum on the right was taken using the spectrograph and a Toucam Pro webcam. The image is made up of over 80 webcam fields and is to sub angstrom resolution (for example at least 6 lines are visible in the gap between the sodium D lines in the full scale image)



The webcam imager can be used with the spectrograph to produce spectroheliographic images at any chosen wavelength. The required line is selected, the RA motor is switched off and a video recorded as the image of the sun drifts across the slit.

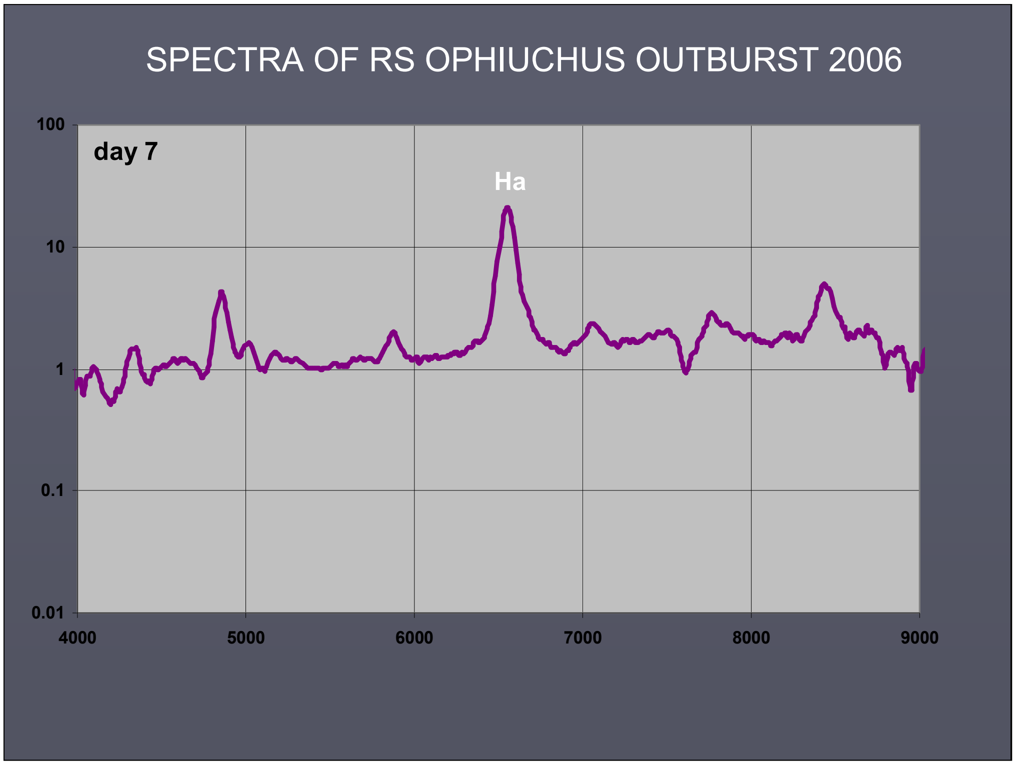


The software (Astrosnap) extracts the required line of pixels in each frame and builds them up into an image.

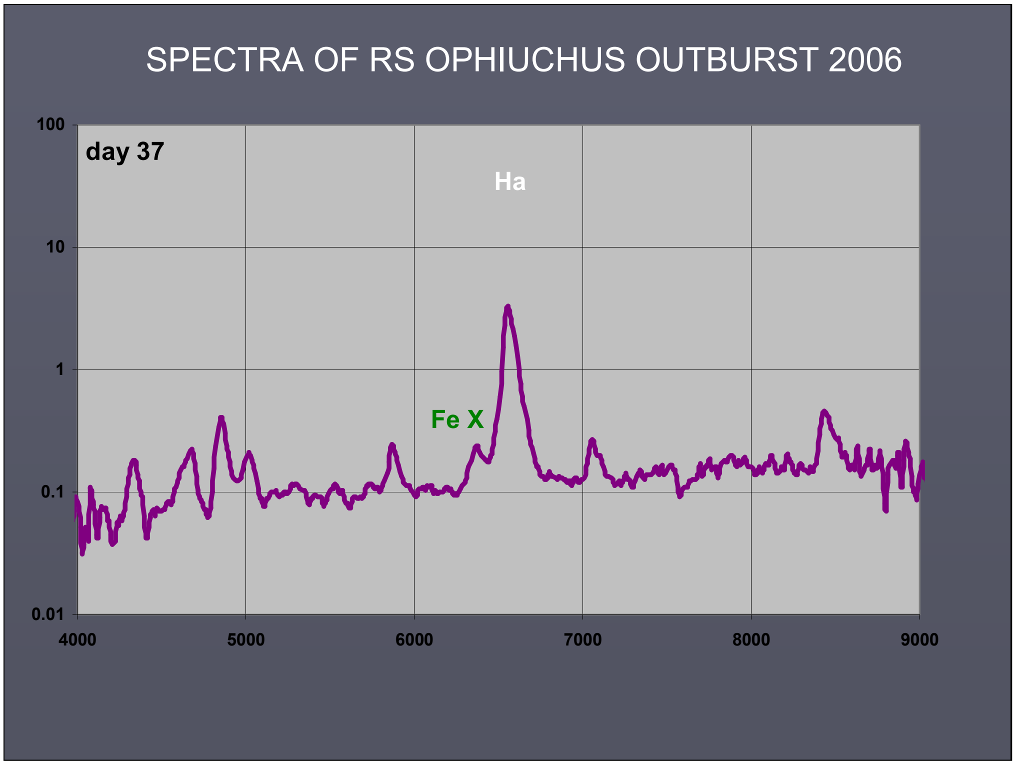


RS Ophiuchus is a Recurrent Nova which brightens dramatically roughly every 20 years as material from the Red Giant builds up on the surface of the White Dwarf and is compressed until an explosion due to nuclear fusion takes place.

The last outburst was on 12th February when the brightness increased from mag 12 to mag 5



This is a low resolution spectrum taken soon after the start of outburst using the Star Analyser The intense Hydrogen Bamer emission (alpha and beta prominent) from the explosion is evident. Also present are Helium emission lines (note the log scale Y axis)



After about a month the Hydrogen and Helium emission began to fade and other lines began to appear due to highly ionised states of various elements, Fe X for example. (The so called coronal lines)

These only appear at very high (millions of degree) temperatures, produced by the shock waves of the explosion ripping through the outer atmosphere of the red giant and compressing it.

PUTTING A WEBCAM UNDER THE SPOTLIGHT HAS REVEALED THAT:-

- The non linear response of webcams can be measured and corrected for.
- Webcam noise levels can be measured and are found to be comparable to those of specialised astro CCD cameras.
- The noise figures can be applied to predict the performance of webcam frame stacking techniques.
- Used with care, webcam based cameras are suitable for scientific observations.