PATON HAWKSLEY EDUCATION LTD

STAR ANALYSER 100

USER MANUAL

The latest version of this manual can be found at

https://www.patonhawksley.com/resources

CONTENTS

INSTRUCTIONS

Description
Care and maintenance
A quick look
Using the locking ring
First light
Troubleshooting
Processing
Wavelength Calibration
Displaying the results graphically
Tips for recording spectra of faint objects
Visual Use
Further advice and information

FREQUENTLY ASKED QUESTIONS

APPENDIX I

BRIGHT STAR SPECTRAL TYPES

APPENDIX II

TWENTY BRIGHTEST WOLF RAYET STARS

APPENDIX III

TELLURIC LINES (O2)

APPENDIX IV

HYDROGEN BALMER LINES

**STAR ANALYSER 100
INSTRUCTIONS**

Description

The Star Analyser 100 is a high efficiency 100 lines/mm transmission diffraction grating, blazed in the first order. It is mounted in a standard 1.25 inch diameter threaded cell, to be compatible with most telescopes and accessories. It has been designed to make the production of low resolution spectrum images of a wide range of point like astronomical objects as easy as possible. It complements a wide range of types of camera used in astro-imaging. It can however also be adapted for visual use. A locking ring is also supplied to lock the grating in the desired orientation.

Care and maintenance

The Star Analyser has been designed and built to give many years of trouble free service. It cannot be dismantled by the user. To protect the delicate diffraction grating surface, it has been sealed between anti-reflection coated glass cover discs. The sealed unit is fixed in the cell in the correct alignment.

As with any optical device, care should be taken to protect the optical surfaces. It should be stored in its protective box when not in use. (After use, any dew which may have condensed on the device should be allowed to evaporate before closing the box) Avoid touching the glass. Any dust should be removed with a blower brush or clean oil free canned air. More stubborn marks and fingerprints can be removed with care using conventional lens cleaning techniques. (Lens cleaning fluids should be used very sparingly to avoid the risk of seepage of the fluid between the glass elements)

A quick look
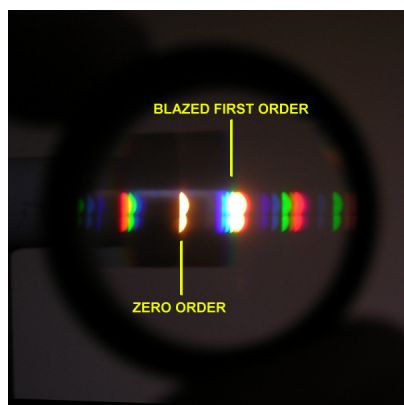
The blazed first order spectrum dominates the other orders in this view of a low energy light bulb.

If you hold the Star Analyser up to you eye and view a compact source of white light through it, you will see the light source flanked by a series of rainbow spectra, stretching away in both directions. One of the pair of spectra closest to the light source will look significantly brighter than the others. This is the blazed first order spectrum and is the one we are aiming to image, along with the straight through view of the light source (the zero order) If you look at the edge of the filter cell, you will see a white line marking the direction of the blazed first order. This will help identify the right spectrum and line it up in the field of view of your camera.

First light
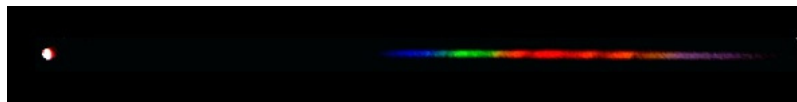
Delta Virginis (type M)

Vega (type A)

Set your telescope and camera up on a bright star and centre it in the field. Spectral type M stars are a good first target as they show nice broad spectrum lines which are easy to see. Alternatively type A stars show narrow dark absorption lines due to Hydrogen. You can see a list of the spectral types of all bright stars down to mag +2.5 in Appendix I

Mount the Star Analyser in front of your camera, orientating it so the direction indicated by the white mark is on the horizontal axis of the camera and to the right as you view from behind the camera. You should still be able to see the image of the star but it will be somewhat fainter. (Adjust to bring the star back into focus). Move the telescope slightly so that the star image is on the left edge of the frame. You should then see the spectrum of the star spread out horizontally across the field, with increasing wavelength (blue to red) running from left to right. (Note that because the light from the star is now spread out over many more pixels, you may have to increase the exposure to see the spectrum clearly. You should now be able to see some lines in the spectrum. If not, adjust the camera settings and focus slightly until you get the sharpest, clearest spectrum. (Temporarily switching off the telescope drive and taking a long exposure to widen the spectrum can make the lines easier to see) Congratulations! You have recorded your first spectrum with the Star Analyser.

Using the locking ring to fix the orientation of the spectrum

A threaded locking ring is supplied which can be used to lock the Star Analyser in the desired orientation. The ring is screwed into the internal thread of the camera nosepiece and the Star Analyser screwed in until it locks against it. By adjusting how far the locking ring is screwed in, the Star Analyser can be locked in the required orientation. If desired, the ring can be fixed in position with thread locking compound to ensure repeatability between observing sessions (First check that the presence of locking ring does not affect the use of any other accessories you may want to screw into the nosepiece and be sure to use the removable type of locking compound in case you wish to remove the ring in the future.) Alternatively PTFE plumber's tape wrapped round the thread will allow the grating to be rotated while giving enough friction to hold it in place

Troubleshooting

The spectrum seems very faint.

Are you sure you have found the right spectrum? Move the telescope until the star image is on the right of the field. You should just be able to see a faint spectrum running from right to left. It should be much fainter than the spectrum on the other side of the star image. If it is brighter, rotate the Star Analyser through 180 degrees.

The spectrum is too long to fit across the field.

(Take care not to confuse the infra red end of the wanted spectrum with the blue end of the next order spectrum which will be much fainter but will overlap.)

This is because the dispersion (The amount by which the light of given wavelength is deflected) is too high. The Star Analyser 100 is designed to work with the majority of cameras and nosepieces. You may however run into this problem with cameras with very small sensor chips and/or longer than average nosepieces. (See the FAQ for more information on the optimum distance). Here are some possible solutions.

   a) Rotate the Star Analyser so the spectrum falls diagonally across the camera field. This increases the available length by 25%. The spectrum image can easily be rotated back to horizontal with any image processing package. Take care if making scientific measurements on rotated spectra though as the rotation can produce artifacts. For scientifically accurate spectra, the Star Analyser should be orientated so the spectrum is as horizontal as possible.

   b)   Reduce the distance between the Star Analyser and the sensor either by using a shorter nosepiece or by using adapters directly onto the camera (typically a T2 thread.

The spectrum is rather short

You can increase the length of the spectrum by increasing the grating to sensor distance. See FAQ 13 &14 for more information. If you do not have enough space to increase the distance to that recommended, the Star Analyser 200 model (which produces the same length of spectrum at half the distance) may be more suitable for your application.

I cannot see any features in the spectrum

Not all stars show clear features in their spectra. Some features can be quite subtle and only show up after further processing of the image. Spectral types M and A probably show the most obvious lines. (See appendix I for a list of bright stars and their spectral types.) If you don't have any luck, try a different star or try processing your spectrum image further as described in the Processing section.

The features are indistinct and smeared out

This simple type of slitless spectrograph depends on the target being almost a point source. If it is not (for example if the seeing is bad or you are using a long focal length) then sharp features in the spectrum can be smeared out and become indistinct. Particularly if you are using a focal length of over 2m, a focal reducer will often help to sharpen the spectrum features.

I cannot focus all positions along the spectrum at the same time.

There will be a slight shift in focus due to the increasing angle of the light beam from blue to red so you may find you have to compromise focus slightly at the far ends of the spectrum. If you are using an achromatic refractor, the focus errors will be larger due to chromatic aberration of the telescope. Particularly with short focal length achromats, you may find you can only focus part of the spectrum at a time. See the FAQ for more information on focussing and other factors which affect resolution.

Processing

Vega spectrum broadened and processed
to enhance the visibility of the lines

The image of the spectrum can be enhanced to improve the visibility of the features in various ways, using your favourite image processing package. Note though that this should not be done if you plan to further analyse your spectra to make scientific measurements. Further analysis should always be done on the original unaltered spectrum.

Rotate the image so that the spectrum is horizontal with the star image on the left.

Produce a strip spectrum as follows:

Crop the image so it just shows the strip with the spectrum (it will typically only be a few pixels high) Resize the strip to the same width but only one pixel high, then resize again to the same width but 30 pixels high.
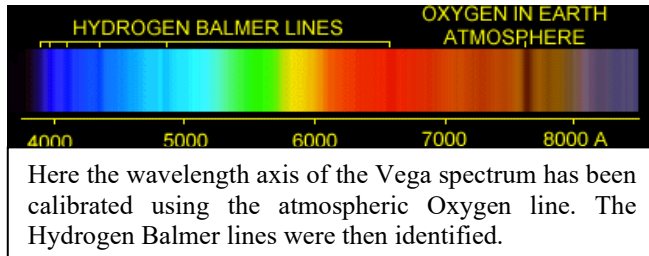
Wavelength Calibration

The distance along the spectrum can be calibrated in nm or angstroms per pixel (10 A = 1 nm) so that the wavelengths of the features can be determined. A rough calibration can be made using the following formula.

Dispersion (A/pixel) =

10000* pixel size (um) / [grating lines/mm * grating to CCD distance (mm)]

e.g. for the Star Analyser 100 at 60 mm distance from a camera with 6um pixels, the dispersion would be

10000 * 6 / [100 * 60] = 10 A/pixel

Here the wavelength axis of the Vega spectrum has been calibrated using the atmospheric Oxygen line. The Hydrogen Balmer lines were then identified.
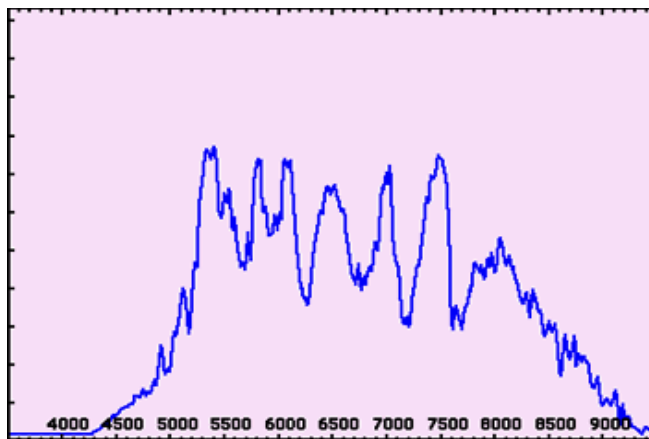
For greater accuracy, the wavelength of known lines identified in the spectrum can be used. This need only be done once for a given configuration, provided the geometry remains the same. Appendices III and IV lists the wavelengths of the Hydrogen Balmer lines and lines from Oxygen molecules in the atmosphere, which can often be identified in spectra and used for calibration. The distance from the centre of the zero order star image to the identified line is measured in pixels and the result divided into the wavelength of the line to find the dispersion. The distance along the spectrum can then be calibrated using the zero order star image as the origin.

Displaying the results graphically

The image of the spectrum can be converted to graphical form using suitable software. This technique is very effective for revealing faint features which might otherwise be missed in the image. The software may also have tools to help with calibration and identification of features in the spectrum. It is also possible to correct for variations in intensity of the spectrum with wavelength due to the response of the grating and camera sensor.

The spectrum of red giant delta Virginis converted to graphical form using Visual Spec software (uncorrected for the spectral response of the spectrograph)

Examples of spectrum analysis software include:

RSpec   www.rspec-astro.com
Visual Spec   www.astrosurf.com/vdesnoux
ISIS   www.astrosurf.com/buil/isis/isis_en.htm

The user is recommended to refer to the instructions supplied with their specific software for further information.

Tips for recording spectra of faint objects

Before imaging a faint object, set up and focus on a bright A type star first. The spectrum produced can also be used as a calibration check.

In crowded star fields, unwanted star and spectrum images can interfere with the spectrum you want to record. Rotate the camera so that the spectrum misses them. If you have trouble with star trailing on long exposures, orientate the grating so that the spectrum is at 90deg to the direction of drift. This will prevent the drift blurring the spectrum.

Visual Use

The Star Analyser can be fitted directly to the bottom of an eyepiece threaded for filters. The length of spectrum can be increased by increasing the distance between the Star Analyser and the eyepiece. This can be accomplished for example by attaching the Star Analyser to the incoming end of a star diagonal. Note that these configurations require increased inward travel of the focuser, which may not be available with some telescopes, particularly Newtonians.

Further advice and information

There is an on line community of Star Analyser users where you can get advice, exchange ideas and share results at https://rspec-astronomy.groups.io

FREQUENTLY ASKED QUESTIONS (FAQ)

1 What is Spectroscopy?
It is the science of recording and analysing electromagnetic radiation (eg light) in terms of its wavelength (colour).

2 Why is Spectroscopy so important in Astronomy?
Astronomy is rather unusual among the sciences in that it is almost entirely observational rather than experimental. With the rare exception of a few meteorites and samples of moon rock, just about everything we know about the universe and the objects in it comes from analysing the light (and similar electromagnetic radiation such as radio and X rays) coming from it. Spectroscopy is a key tool in this process, revealing the physical and chemical processes which drive the formation, structure and evolution of the components of our universe.

3 What is the STAR ANALYSER?
The STAR ANALYSER is a high efficiency blazed transmission diffraction grating designed to make recording spectra easy using a telescope and and webcam, video camera, DSLR, CCD astro-imager. The device screws into the nosepiece of the imager like a standard 1 1/4 inch filter and allows the recording of the spectrum of any object that appears star-like in the field of view.

4 How does it work?
The STAR ANALYSER diffraction grating intercepts the light from the telescope and deflects (disperses) it into a line on the camera detector according to the colour or wavelength. Longer (redder) wavelength light is diffracted more than shorter (bluer) wavelengths.

5 What is special about the STAR ANALYSER?
The STAR ANALYSER has a number of design features which make it particularly effective and easy to use with popular low cost webcams, video and astro-imagers.

It contains a replica diffraction grating made from a high quality high efficiency blazed   master. This means that a much higher proportion of the light is directed into the spectrum   compared with lower cost unblazed or holographic film gratings for example, allowing far   fainter objects to be recorded.

It is physically identical to a standard 1 1/4 inch filter. This means it can be screwed onto a standard camera eyepiece nosepiece or included in a filter wheel.

The dispersion of the SA100 model has been matched to the small CCD chip sizes found in these cameras. This means that when mounted on the camera nosepiece, the complete spectrum and the zero order (straight through) image of the object can be imaged at the same time, simplifying object identification and spectrum calibration.

The SA200 model has a higher dispersion and a low profile design which allows it to be mounted closer to the camera sensor, for example in a filter wheel.

The delicate grating surface is protected by an antireflective coated glass cover. This means that it can be cleaned if necessary.

6 What kind of objects can I record?
The spectrum of any type of object can be recorded provided it is bright enough and appears approximately point like in the field of view. This includes stars of course and planets (provided a relatively short focal length telescope or camera lens is used). Compact planetary nebulae also make interesting targets. The STAR ANALYSER, mounted in front of a wide angle camera lens, can also record extended objects such as bright comets. If you are lucky you might even catch a meteor spectrum using this technique!

7 What can the spectrum tell me about an object?
The broad shape of the spectrum gives information about temperature. (For example the spectrum of cool Betelgeuse is quite different to that of hot Sirius) Narrow absorption (dark) or emission (bright)

lines tell us about the chemical elements that are present and how they are behaving. (For example the spectrum of Betelgeuse reveals the telltale signature of molecules in its atmosphere, while stars like Vega show absorption lines due to hydrogen atoms.) Shifts from the expected wavelength of lines can give information about the way the object or different parts of it are moving. The blue shift of hot gas rushing towards us after a supernova explosion and the redshift of a distant quasar due to the expansion of the universe are examples of the kind of processes which it is possible to record using the STAR ANALYSER

8 What type of camera can I use?   (See also "**How faint an object can I record**")
Because the spectrum image is so compact, (all the available spectrum information can contained within a length of just 500 pixels) just about any electronic camera (without a lens) which can be fitted to a telescope in place of the eyepiece can be used. For brighter targets webcams, solar system imagers and video cameras are ideal for the beginner. Long exposure CCD astro cameras can be used to record faint objects, greatly increasing the range of objects which can be recorded. Megapixel digital SLR cameras can also be used and the large sensor size means that the spectra of many stars in the field can be imaged simultaneously. For precise scientific work a monochrome camera is easier to calibrate for intensity as there is no need to correct for the three colour filter responses. Colour cameras however produce beautiful spectra, displaying the actual colours of the spectral lines. Note however that the infra red end of the spectrum will not be recorded if the infra red blocking filter present in most colour cameras is left in place.

9 What type of telescope can I use?   (See also "**How do I focus the spectrum**")
Just about any telescope or even a camera lens can be used provided the object is bright enough and is reasonably stellar in appearance. The simple arrangement of placing the grating in the converging beam of the telescope produces some aberrations. The advantage of the low dispersion used in the STAR ANALYSER is that these are kept to a minimum. There are some trade offs with focal length. Less aberration is introduced by using long focal lengths but the resulting larger size of the stellar image will tend to limit the resolution. In practise, the STAR ANALYSER performs well with the typical focal lengths found in amateur telescopes, though in poor seeing conditions or at focal lengths over 2m, a focal reducer will generally improve the spectrum sharpness by reducing the size of the star image. The higher dispersion of the SA200 compared with the SA100 can be used to advantage with large aperture long focal length telescopes to increase the length of the spectrum without excessively increasing the distance from the sensor, provided the camera sensor is large enough to fit the spectrum and star image in the same frame.
Some additional care is needed when focusing using an achromatic refractor as with these instruments not all colours (particularly Violet and Infra red) focus at the same point. Particularly with a short focal length achromat, you may find that not all the spectrum can be brought to focus at the same time and you may need to concentrate on one segment at a time. (The spectrum will appear "fish tailed" at the violet and or red ends) Reflectors, including Cassegrain designs do not show this effect. Apochromats are affected less and, if corrected for imaging including the Infra-Red region, may show no chromatic aberration. Indeed the STAR ANALYSER is an interesting way of checking the chromatic correction of your telescope!

10 How faint an object can I record?
Like normal astronomical imaging, it depends on the size of telescope, sensitivity of the camera you are using and your sky conditions, but because the light from the object is spread out across the camera detector, objects need to be perhaps 5-6 magnitudes brighter than for a normal image. (This is one of the reasons professional telescopes tend to be so huge!) In practise, the spectrum of the brighter planets and hundreds of stars down to mag +4 can be recorded using a modest 8 inch (200mm) scope and a sensitive webcam or planetary imager. Given good sky conditions, and using the same aperture telescope with a sensitive monochrome CCD imager with long exposure capability, recording the spectra of objects down to mag +13 is possible, or even fainter if the camera is cooled, allowing the measurement of quasar redshifts and the classification of bright supernovae to be performed! Integrating video cameras, long exposure colour imagers and DSLR will reach intermediate magnitudes, to record bright comets or the fascinating supernova candidate Wolf Rayet stars for example.

11 What wavelength range can I record?
The range depends on the response of the camera sensor and whether an infra red blocking filter is fitted. An unfiltered CCD sensor will typically record from less than 400nm in the violet to beyond 800nm in the infra red (Even colour sensors with any infra red filter removed will record into the near infra red, as the colour filters built into the chip are transparent to infra red)

12 What is the resolution of spectra produced by the STAR ANALYSER?
At first sight one might think that by using a grating with more closely spaced lines or mounting it further away, one could increase the resolution as much as one liked. In practise though, there are several other factors which limit the resolution for this type of configuration. The most significant ones are:

> The size of the star image, which depends on the stability of the atmosphere and increases with the focal length of the telescope.
> Distortion of the image due to chromatic coma, which is independent of the grating or mounting distance but is worse for lower focal ratio telescopes.
> Field curvature which changes the focus along the spectrum and is worse for higher dispersion gratings mounted close to the camera sensor.
> The size of the camera pixels.

Because of these limitations, the resolution of this type of spectrograph is restricted to typically 1/100 of the wavelength (eg 5nm at 500nm), independent of the diffraction grating design. It does mean however that by choosing the grating design and mounting distance with care, the whole spectrum and the undeflected star image can be fitted on the chip without losing any of the available resolution, which makes the spectrograph more sensitive and easier to use.   The standard Star Analyser (SA100) has a 100 lines/mm grating with a 200 lines/mm option (SA200) for situations where the grating has to be mounted close to the camera sensor, in a filter wheel for example.
(Spectrographs used by professional astronomers achieve greater resolution by adding a slit and collimating optics, but these are much more complex and cost many tens of times more)

13 How far from the camera should the STAR ANALYSER be mounted?
(See also "**What are the optional spacers for?**")

The further away from the camera sensor the STAR ANALYSER is placed, the more spread out the spectrum becomes. If you mount it too close, you will lose resolution. Too far away and you will not be able to fit the whole spectrum in the camera frame. You can work out the optimum distance for your camera using this on line calculator https://www.rspec-astro.com/calculator/   Details of pixel size, number of pixels and distance from the sensor to the nosepiece or mounting ring should be available from your camera manufacturer.

Typical distances for the SA100 are:-

30-45mm for 1/4 size sensors (55mm running the spectrum diagonally)
40-75mm for 1/3 size sensors
50-100mm for 1/2 size and larger sensors

(distances for the SA200 are approximately half these values)

14 What are the optional spacers for and will I need any?

See FAQ 13 for information on the recommended distance. If you find that the distance for your setup is less than the minimum value, we recommend purchasing sufficient spacers to bring the distance above the minimum. Each spacer adds an adjustable 7-10mm.

If after consulting the on line calculator you are not sure if your particular setup requires spacers, please e-mail us with details of your camera and the sensor to nosepiece tip distance and we can advise you.

15 How do I focus the spectrum image?
Just as in conventional astronomical imaging, focusing can be tricky. Focusing the zero order image of the star will get you somewhere near, but you might find you need to wind the focus in a touch more to

achieve the best focus of the spectrum. If any narrow absorption or emission lines can be seen, these can be used to sharpen the focus. If there are no obvious features then focusing to narrow the width of the line can get you nearer. Once you have good focus, it can be useful to note for future reference how much the focuser had to be moved compared with the zero order star image focus point. (Note that it may not be possible to obtain good focus at all wavelengths simultaneously when using an achromatic refractor due to the telescope design)

16 How can I turn my narrow spectrum image into a wide strip?
Many image processing programs have all you need.

> First rotate your spectrum image so it is horizontal and crop the image so it just shows the strip with the spectrum (it will typically only be a few pixels high)
> Resize the strip to the same width but only one pixel high, then resize again to the same width but 30 pixels high and voila! A professional looking strip spectrum which will make the spectral lines much easier to see.

17 How can I calibrate my spectrum?
The STAR ANALYSER has been designed to make calibration as easy as possible. With most configurations you will be able to capture the image of the star as well as the spectrum in the same frame. The star image is your zero point. Because the dispersion of the STAR ANALYSER is low, the wavelength is essentially proportional to the distance along the spectrum. (Note that this is not true for higher dispersion designs used in the same configuration and is a particular problem for prism based spectrometers) All you have to do is measure the number of pixels from the centre of the star image to a feature of known wavelength in the image (eg a Hydrogen Balmer line in a star such as Vega or a Telluric line due to the earth's atmosphere, which can be seen in many spectra). If you divide the wavelength by the number of pixels, you have a calibration constant (in angstroms per pixel or nm per pixel) which can be used for all your measurements provided you do not change your setup.

Note that if the optional wedge prism accessory is added the spectrum is no longer linear and this simple calibration technique cannot be used.

18 How can I convert my spectrum into a graph?
There are commercial and freeware programs which can take the image of a spectrum, measure the pixel values along the line and convert them into a graph or a data file for use in a spreadsheet. Some also have functions to aid calibration and analysis of your spectrum.

Examples of spectrum analysis software include.

RSpec   http://www.rspec-astro.com
Visual Spec   http://www.astrosurf.com/vdesnoux
ISIS   http://www.astrosurf.com/buil/isis/isis_en.htm

19 Can I use the STAR ANALYSER for visual observations?
Yes, though the length of the spectrum will be rather short unless you can mount the STAR ANALYSER some distance before the eyepiece. (Note: The SA200 will give a 2x longer spectrum compared with the SA100) This can be achieved for example by screwing it into the ingoing side of a diagonal threaded for filters. (Note that achieving sufficient distance may be a problem with some telescopes, particularly Newtonians where inward focus travel tends to be limited) A cylindrical lens fixed over the eyepiece can be useful to spread the width of the spectrum and make the lines more visible. Tapping the eyepiece with the finger sometimes produces a similar effect.

20. Where can I share my results with other users or get advice?
You can get support by e-mailing us or alternatively, why not join the "rspec-astronomy" IO group where you can get support, meet other users and share and discuss your results!

21 Can I take spectra of stars without a telescope using a DSLR camera?
It is possible to take spectra of bright stars just by mounting the Star Analyser in front of a Digital SLR camera lens. Best results are with the camera mounted on a tracking mount but spectra of the brightest stars can even be recorded using a camera on as fixed tripod. See this link for more information on this technique
http://www.threehillsobservatory.co.uk/astro/spectroscopy_11.htm

APPENDIX I
BRIGHT STAR SPECTRAL TYPES

Star	Name	Mag	Spect type	Star	Name	Mag	Spect type
zeta Pup	Suhail Hadar	2.25	O5Iaf	beta Aur	Menkalinam	1.9	A2IV
zeta Ori	Alnitak	2.05	O9.5Ibe*	zeta UMa	Mizar	2.27	A2VpSrSi*
				beta Leo	Denebola	2.14	A3V
delta Ori	Mintaka	2.23	B0*	alpha PsA	Fomalhaut	1.16	A3Va
delta Sco	Dschubba	2.32	B0.3IV	alpha Oph	Ras Alhague	2.08	A5III
kappa Ori	Saiph	2.06	B0.5Iav	alpha Aql	Altair	0.77	A7V
beta Cru	Mimosa	1.25	B0.5III	alpha Cep	Alderamin	2.44	A7V
epsilon Ori	Alnilam	1.7	B0Iae	iota Car	Tureis	2.25	A8Ib
gamma Cas	Cih	2.47	B0IVe				
alpha Cru	Acrux	1.58	B1*	alpha Car	Canopus	-0.72	F0II
alpha Lup		2.3	B1.5III	theta Sco	Sargas	1.87	F1II
kappa Sco		2.41	B1.5III	beta Cas	Caph	2.25	F2III
lambda Sco	Shaula	1.63	B1.5IV	alpha Per	Marfak	1.79	F5Ib
eta Cen		2.31	B1.5Vne	alpha CMi	Procyon	0.38	F5IV
beta Cen	Hadar	0.61	B1III	alpha UMi	Polaris	2.02	F7:Ib-IIv
epsilon Cen		2.3	B1III	delta CMa	Al Wazor	1.84	F8Ia
alpha Vir	Spica	0.98	B1III+B2V	gamma Cyg	Sadr	2.2	F8Ib
beta CMa	Murzim	1.98	B1II-II				
sigma Sgr	Nunki	2.02	B2.5V	alpha Cen	Rigil Kent	-0.01	G2V+K1V
epsilon CMa	Adhara	1.5	B2II	alpha Aur	Capella	0.08	G8
gamma Ori	Bellatrix	1.64	B2III				
alpha Pav	Joo Tseo	1.94	B2IV	epsilon Car	She/(Avior)	1.86	K0II*
kappa Vel	Cih	2.5	B2IV	beta Gem	Pollux	1.14	K0III
eta UMa	Benetnasch	1.86	B3V	beta Cet	Deneb Kaitos	2.04	K0III
alpha Eri	Archenar	0.46	B3Vpe	alpha Phe	Ankaa	2.39	K0III
eta CMa	Aludra	2.45	B5Ia	epsilon Cyg		2.46	K0III
beta Tau	El Nath	1.65	B7III	alpha UMa	Dubhe	1.79	K0IIIa
alpha Gru	Al Na'ir	1.74	B7IV	alpha Cas	Schedir	2.23	K0IIIa
alpha Leo	Regulus	1.35	B7V*	theta Cen	Haratan	2.06	K0IIIb
beta Ori	Rigel	0.12	B8I*	alpha Boo	Arcturus	-0.04	K1IIIbCN-1
alpha And	Alpheratz	2.06	B8IVpMnHg	epsilon Sco	Wei	2.29	K2.5III
beta Per	Algol	2.12	B8V	epsilon Peg	Enif	2.39	K2Ib
epsilon Sgr	Kaus Australis	1.85	B9.5III	alpha TrA	RasAlMuthallath	1.92	K2II
alpha Peg	Markab	2.49	B9V	alpha Ari	Hamal	2	K2IIIabCa-I
T CrB		2	sdBe+gM3+Q	gamma And	Alamach	2.06	K3-IIb*
				alpha Hya	Alphard	1.98	K3III
gamma Gem	Almisan	1.93	A0IV	lambda Vel	Suhail	2.21	K4Ib-II
epsilon UMa	Alioth	1.77	A0pCr	beta UMi	Kochab	2.08	K4III
alpha Lyr	Vega	0.03	A0V	alpha Tau	Aldebaran	0.85	K5III
alpha CrB	Alphecca	2.23	A0V	gamma Dra	Etamin	2.23	K5III
beta UMa	Merak	2.37	A0V				
gamma UMa	Phecda	2.44	A0Ve	beta And	Mirach	2.06	M0IIIa
gamma Cen	Koo Low	2.17	A1IV	alpha Sco	Antares	0.96	M1.5I*
delta Vel	Koo She	1.96	A1V	beta Peg	Scheat	2.42	M2.5II-III
alpha CMa	Sirius	-1.46	A1V*	alpha Ori	Betelgeuse	0.5	M2I
alpha Gem	Castor	1.58	A1V*	gamma Cru	Gacrux	1.63	M3.5III
alpha Cyg	Deneb	1.25	A2Iae	beta Gru	Al Dhanab	2.1	M5III
beta Car	Miaplacidus	1.68	A2IV				
				gamma Vel	Regor	1.78	WC8+O7.5e

APPENDIX II

TWENTY BRIGHTEST WOLF RAYET STARS

SAO	WR	R.A.	Dec	Type	Mag(V)
219504	11	08:09:32	-47:20:12	WC8	1.74
227425	79a	16:54:59	-41:09:03	WN9ha	5.29
252162	48	13:08:07	-65:18:23	WC6	5.88
238353	22	10:41:18	-59:40:37	WN7h	6.44
238394	24	10:43:52	-60:07:04	WN6ha	6.49
227328	78	16:52:19	-41:51:16	WN7h	6.61
69402	133	20:05:57	+35:47:18	WN5	6.7
172546	6	06:54:13	-23:55:42	WN4	6.94
227390	79	16:54:19	-41:49:12	WC7	6.95
49491	140	20:20:27	+43:51:16	WC7pd	7.07
227822	90	17:19:29	-45:38:24	WC7	7.45
69592	136	20:12:06	+38:21:18	WN6(h)	7.65
251264	40	11:06:17	-65:30:35	WN8h	7.85
69755	138	20:17:00	+37:25:24	WN5	8.1
69833	139	20:19:32	+38:43:54	WN5	8.1
238408	25	10:44:10	-59:43:11	WN6h	8.14
69677	137	20:14:32	+36:39:40	WC7pd	8.15
186341	111	18:08:28	-21:15:11	WC5	8.23
69541	134	20:10:14	+36:10:35	WN6	8.23
251296	42	11:10:04	-60:58:45	WC7	8.25

The Seventh Catalogue of Galactic Wolf-Rayet Stars (van der Hucht, K.A. 2001)

APPENDIX III
TELLURIC LINES (O2)

Fraunhofer Band	Wavelength A
a	6276 - 6287
B	6867 - 6884
A	7594 – 7621

APPENDIX IV
HYDROGEN BALMER LINES

Alpha	6563
Beta	4861
Gamma	4340
Delta	4102
Epsilon	3970
Zeta	3889
Eta	3835