Chapter 2

Imaging a Spectrum with the Grating

Spectroscopy is a three part process. The first part is to obtain a usable spectrum. The second part is to process the spectrum, apply corrections and calibrate for wavelength. The final step is perhaps the most exciting – the analysis and identification of the "fingerprints." The tools and techniques you'll need to carry out each aspect of the work are covered in the following chapters.

We are now ready to record our first spectrum. Here we will discuss the different ways we can connect the grating to the telescope/camera lens, look at the factors that will determine the size, clarity and resolution of the spectrum recorded and equally important describe how to acquire those first spectrum images.

How Do We Use the Grating?

The grating can be used in many different ways to provide us with an image of the spectrum, but the most common ways are:

1. Imaging with a telescope, the grating mounted in front of the camera body ("in the converging beam"). This method uses a telescope or a camera lens to focus the light through the grating onto the CCD. Generally results in a narrow field of view coverage but can allow the recording of fainter star spectra. The resolution obtained is usually 30–60 Å.
2. Imaging the spectrum with the grating mounted in front of a camera lens ("objective grating"). The full aperture of the grating is used in front of a camera lens fitted to a DSLR or CCD. Has the potential of giving maximum resolution, up to <30 Å. Wide field coverage and multiple spectra recorded on each image.

K.M. Harrison, *Grating Spectroscopes and How to Use Them*,
Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4614-1397-4_2,

NOTE: When the grating is used for imaging it's important to align the grating lines with the CCD chip in the camera to get maximum resolution. If the spectrum is placed diagonally across the CCD chip, then five or six inclined pixels may record only one absorption line or feature. When the image is rotated to a horizontal position for processing and analysis, the line will be smeared across two or three pixels with a loss of resolution.

Using the Grating in a Converging Beam

The light from all the stars in the field of view (FOV) passes through the grating, and each individual star will form a zero order image; the spectra produced by the grating will be seen on either side (see Fig. 2.1).

Using the grating in a 1.25″ nosepiece adaptor, mounted on the camera body and inserted into the telescope focuser "in the converging beam" gives good resolution and allows you to record detailed spectra of the stars. See Figs. 2.2 and 2.3.

The distance between the grating and the CCD chip is an important factor. It affects the size of the spectrum recorded and the resolution. You can work out the best distance for your grating and camera by consulting Table 2.1 or by using the TransSpec spreadsheet (see Appendix G at the end of this book).

It's easier to start with the zero order image visible in the frame. This allows it to be used as a zero wavelength reference when calibrating/processing the spectrum. (See Chap. 4.)

The sub-compact "point and shoot"-type cameras are not suitable for this configuration. (In fact, to be absolutely honest, they are not really suitable for any spectroscope work. The fixed lens and the limited control over focusing and exposure times severely limits their ability to record spectra. Later we'll look at one

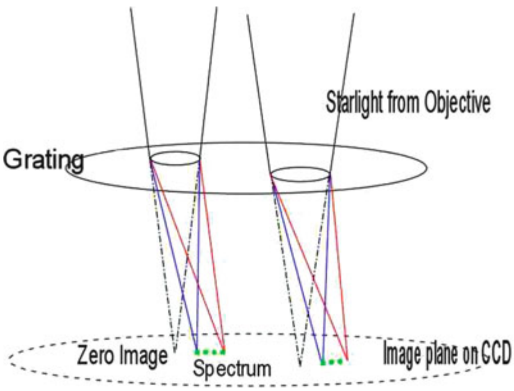

Fig. 2.1 Transmission grating in a converging beam

Fig. 2.2 Filter gratings fitted to a QHY5 camera and Philips SPC900 webcam

Fig. 2.3 Filter grating fitted to a Canon 300D DSLR

Table 2.1 Size of spectrum vs. distance between grating and CCD

Distance (mm)	Zero to red (mm)	Spectrum only (mm)
30	2.1	
35	2.4	
40	2.8	
45	3.1	
50	3.58[a]	
60	4.2	1.9
70	4.9	2.2
80	5.6	2.6

[a] This is the maximum width for a webcam chip

possible alternative setup where they may be used.) Other than that, you can use any camera where the lens can be removed from the camera body.

A DSLR will give a much larger frame to work with than, say, a color webcam, but the resolution obtained in both will be influenced by the built-in Bayer filter used to record the various colors. (See Chap. 6.) With a DSLR, set the image format to RAW. (This should be explained in your camera manual.) This will give maximum definition and the file obtained is uncompressed, containing all the available data needed for further processing.

The spectrum doesn't need to be recorded in color. It may look nice, but it doesn't add any additional data to the image. Once we have obtained the spectral image and have it calibrated, it can be converted to a synthesized full-color spectrum at any time.

Mono cameras have a much higher resolving capability (due to the individual pixels recording every wavelength of light), and when you combine this with a small pixel size, like those found in mono webcams or the DMK series from Imaging Source, you can get some excellent results. Torsten Hansen has obtained some spectacular spectra with the Imaging Source DMK 31 camera, as shown in Fig. 3.7.

Depending on the distance between the grating and the CCD you can also use one of the many astronomical imaging cameras (SBIG ST10, QHY8, etc.). These large format cooled CCD cameras give high efficiency and good spectral response. The pixel size in any of these CCDs also needs to be considered. Large pixels are more sensitive but can result in lower resolution in our spectrum. See later.

How do you know which object is in the field? The field of view through the grating will be similar to the camera/telescope FOV with an eyepiece that has a focal length double the CCD chip width. For example, a webcam with a 3 mm chip shows the same field of view as visually with a 6 mm eyepiece. There are some freeware programs such as Ron Wodaski's CCDCalc, that allow you to visualize the size of the camera image and calculate its size in arc sec, etc. These programs are usually used by astrophotographers to define and frame the image they want to take. Once we know the FOV, it can be used to make overlays for a star atlas or programmed into the planetarium package you use to confirm the target objects. The freeware *Stellarium* star charts and *Cartes du Ciel* software are recommended.

Imaging Your First Spectrum

Set up the telescope as usual and point it towards a bright star above, say, a 45° elevation (this reduces the effects of the atmospheric absorption and should give better seeing conditions). An A-type star (such as Vega) or an M-type star (such as Betelgeuse) provide good starting points, as they both have many absorption features to record. There's a list of possible target stars given in Chap. 3.

Without the grating attached, insert the camera/CCD with its nosepiece into the focuser, then find and focus on the star. Use your normal focusing method,

Fig. 2.4 Zero order image and spectra using a DSLR

inspecting the image on the PC screen, for example, to find best focus. (The final position of the focus will be shifted outward slightly when the grating is attached; so don't worry too much about getting accurate focus at this stage.) We just need it close enough to be able to fine tune the focusing based on the zero star image.

Remove the camera/CCD without touching the focus settings. Insert the grating and rotate it to get the grating lines vertical to the image frame.

HINT: You can look through the grating at the CCD chip in the camera. The grating causes two images of the chip to be seen (due to the dispersion). Rotate the grating until both images appear in line. If you slightly unscrew the filter grating from the nosepiece and wrap a couple of turns of cotton thread onto the grating threads, these can help to give some "fine adjustment" to the grating orientation and allow it to "lock" in place. This will position the spectrum very close to the horizontal axis of the CCD chip. Re-insert the camera/CCD. Each star in the field of view will produce a zero order star image and its pair of spectra, as shown in Fig. 2.4.

Looking at the CCD image on the PC (viewfinder or live-view on a DSLR) you should see your target star image close to the center of the frame and its spectra at either side. If you are using a webcam or a CCD with a small chip, you may have to move the star image off center to see the first order spectra. With a blazed grating, one spectrum will be much brighter than the other. Using the telescope slow motion controls, bring this brighter spectrum close to the middle of the frame. The star image (zero image) will be off to one side.

Keep moving the star image towards the side of the frame to position the spectrum as centrally as possible. Keep the star image just inside the frame.

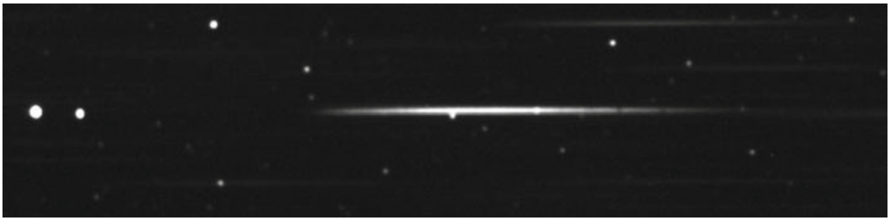

Fig. 2.5 SA100 with background star in spectrum (C. Buil)

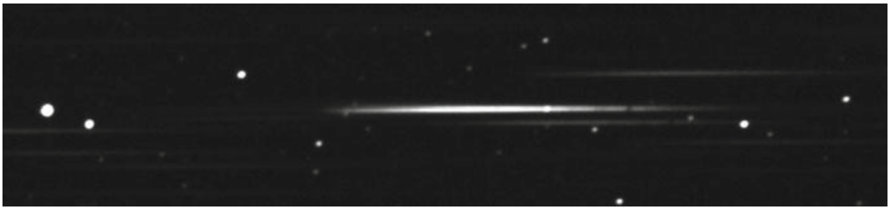

Fig. 2.6 SA100 with rotated grating to reposition the interfering background star (C. Buil)

Now study the star image and the spectrum. As a minimum, the star image should now be brought to focus. Better still is to adjust the focus until the spectrum band is as narrow as possible with clear, sharp edges. Check this focus using an initial exposure of, say, one second and also confirm that the spectrum is lying horizontally across the frame. If you find that secondary star images/spectra are interfering with the target spectrum, try rotating the camera body slightly (without changing the position of the grating in the nosepiece – we're trying to maintain the alignment to the CCD) in the focuser to move the background stars away from the target spectrum. Figure 2.5 shows the zero star images (brightest images at the left hand side of the frame) and the first order spectrum. You can see there is a second bright star just to the right of the target star. The spectrum from this star could interfere with the one we want to record. By rotating the camera slightly, the interfering image has been moved lower in the frame, clearing the spectrum (see Fig. 2.6).

Take a couple of exposures to check if the spectrum is over- or under-exposed. On very bright stars (such as Vega) you may find you only need 0.2 or 0.4 s exposure. With a DSLR remember to set to RAW and start with an ISO setting of 400.

These settings should give a usable result. The zero order star image will be seen slightly out of focus towards the edge of the frame and the bright spectrum stretching across the middle. Remember to take some notes of the time and date, your grating distance, camera settings and don't forget to record the name of the star or object you've just imaged! After a few nights of successful imaging you will find you need to develop a system of recording your spectra.

That's it. Our first spectrum has been recorded. Now that you have a spectral image, open it in your usual imaging software, zoom in on the spectrum and see if any dark/bright lines or bumps can be seen. Compare the exposures looking for best focus and clarity. If the focus is good on the spectrum of one star, it will be good for all stars. In the space of one evening it's therefore possible to obtain a whole series of stellar spectra. If the finder telescope is accurately aligned to the main scope you should be able to set up the cross wires in the finder to position the target star in the correct position on the camera frame ready to take an exposure. That way the camera and grating doesn't need to be removed or re-set when going from one star to the next. For the moment, note the setting of your focuser and the best exposure times for future reference.

Depending on the accuracy of focus and the instrument response (see Chap. 6) you may see a spectrum that looks "cut-off" at the blue end and "fishtails" towards the red end. This is normal. These effects are caused by the varying efficiency of the CCD chip across the spectrum and the aberrations in your system. In Chap. 6 we'll look more closely at these issues.

On the brighter A-type stars (such as Vega) the spectrum should show definite dark lines in the region closest to the zero order (the blue end of the spectrum). For an M-type star such as Betelgeuse you'll see dark bands closer to the red end of the spectrum. We'll get more familiar with these features as we start analyzing and calibrating the spectrum in Chap. 4.

NOTE: If the spectrum is recorded on your CCD chip at an angle you can lose resolution and add artifacts to the image when rotating it horizontally. Also note that grating distances above 80 mm tend to be counterproductive, as the benefits of the larger dispersion are outweighed by the increased effects of optical aberrations.

The ultimate resolution obtained from your grating in the converging beam setup is limited by two main problems: field curvature (where the best focus position of different parts of the spectrum varies) and spectral coma (which causes distortion of the spectrum). These can be minimized by re-positioning the CCD plane, i.e., tilting the camera or changing the focus position (field curvature) and by adding a small wedge prism-grism (spectral coma). The effects and improvement options for these aberrations are discussed in more detail in Chap. 6.

Like astrophotography images, short spectral exposures (taken with exactly the same grating settings) can be stacked to improve the image and allow the spectra of fainter objects to be recorded. The freeware program *Registax* V6 will give good results.

As the spectrum of a star is spread over a larger area on your chip than an ordinary star image (some 100–200 times), it requires a far longer exposure than the one you would use to record normal star fields. Depending on the aperture of your telescope you may need a total exposure of 5 min or more, to record a good spectrum of, say, a 7 mag. star with a 100 l/mm grating.

What defines a good spectrum? The resolution obtained is a key factor, as is the signal-to-noise ratio in the image.

Signal-to-Noise Ratio (SNR)

In all images there is good data (the signal – information we want) and bad data (the noise – added interference). The more good data we can obtain the better the quality of the resulting image. Noise can be generated by the electronics of the camera during collection and storage of the image. This is usually called thermal noise, as it varies with exposure time and ambient temperature.

The amount of noise that builds up in an image is directly proportional to the length of the exposure. The longer the total exposure the better the signal-to-noise ratio. Background light from the sky and light pollution can also add to the noise in our spectrum. By removing the background sky signal from the spectrum and using Darks to remove any camera thermal noise, we can improve the SNR. This is discussed in more detail in Chap. 4.

Image Size on the CCD Chip

Depending on the camera and adaptor used, the grating can be positioned approx 30–80 mm in front of the CCD chip. Alternatively the grating can be fitted into a standard 1.25″ filter wheel in front of the camera body. As mentioned earlier, the shorter the focal length, the smaller the star image. On an SCT, it's therefore better to mount the grating behind a focal reducer (for example, an ×0.63 reducer). The final resolution of converging beam arrangement is limited by the seeing conditions, optical aberrations and pixel size of the CCD. The actual resolution obtained will vary from 30 to 60 Å, depending on the grating, etc.

The following tables, based on the 100 l/mm SA100, give some typical results that you can use as a starting point.

NOTE: The RO200 will give double the dispersion. For example, at 30 mm distance, the size of the spectral spread from zero order to red will be 4.2 mm and the scale 1664 Å/mm.

Table 2.1 above (Column 2, Zero to Red) shows the distance between the zero order image and the extreme end of the red region of the visible spectrum. If you know the size of the CCD chip in your camera you can quickly determine the maximum grating to CCD distance, to allow you to get both the zero order star image and the full spectrum on the frame. You will see that for a webcam-sized chip, the maximum distance is about 50 mm. Beyond that distance, you will only be able to record the spectrum on the smaller chips. Note also that for a DSLR, which has typically a 22 mm-wide chip, the whole length of the zero order to red, even at a distance of 80 mm, will only take up 25% of the frame. See Fig. 2.4.

Table 2.2 (Column 2, Plate Scale) gives the dispersion/plate scale of the spectrum (in Å/mm). This tells us is that for a 30 mm distance, the whole of the spectrum from blue to red (approximately 3000 Å) will only take up less than 1 mm on the CCD. If our camera has a pixel size of 5 μm then the whole spectrum will only cover 1,000/5 = 200 pixels on the chip. This works out to roughly 3300/200 = 16 Å/pixel.

Table 2.2 Plate scale vs. distance between grating and CCD vs. resolution

Distance (mm)	Plate scale (Å/mm)	3″ seeing resolution (Å)
30	3327	64
35	2852	55
40	2495	48
45	2218	43
50	1996	38
60	1664	32
70	1426	28
80	1248	28

You should become familiar with the camera/CCD you use and keep the dimensions of the chip and pixel size close to hand. In Chap. 6 you will find details of some of the more common CCD chips. The pixel size determines the best possible theoretical resolution, which is approximately twice that of the pixel, i.e., 32 Å, whereas in real life, due to seeing conditions, etc., it can be double that, at 64 Å.

$$Plate\ scale\ in\ Å\,/\,pixel = plate\ scale,\ Å\,/\,mm \cdot\ size\ of\ the\ pixel\ in\ micron\,/\,1{,}000$$

For example, a plate scale of 1248 Å/mm and a camera with 8 µm pixels = 1248 × 8/1000 = 10 Å/pixel.

$$Best\ possible\ resolution, Å = 2 \cdot\ plate\ scale, Å\,/\,pixel$$

In the above example the best possible resolution would be 2 × 10 = 20 Å. You can see now the difference between the dispersion/plate scale and the resolution.

When you get up towards the 80 mm distance mark, the resolution is pretty constant, around 28–30 Å – that's about the limit for gratings. (Unfortunately that's not the end of the story. There's an added complication that we'll talk about later that affects the focus and resolution – field curvature.)

Drift Enlarging

The height of the spectrum, as mentioned previously, will be the height of the star image. Sometimes it's good to be able to stretch the height of the spectrum (makes detail easier to see in the image), and this can be done by allowing the star to drift across the field of view at right angles to the length of the spectrum. This increases the height of the spectrum without impacting on the resolution. It's even more important when using a color camera; it allows you to compensate for the effects of the multiple sets of pixels involved in the Bayer matrix. (Details in Chap. 6.)

A drift of, say, 100 pixels across the frame (more than enough to "smooth out" the Bayer matrix) with a camera having a 5 µm pixel would require a "drift" image of 0.5 mm (100 × 0.005) in length.

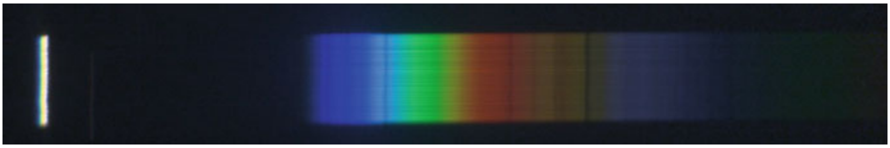

Fig. 2.7 Drift enlarged spectrum (C. Buil)

If the camera and grating are set up on the telescope such that the spectrum is produced along the Dec axis (i.e., north–south) then you can use the RA drive to provide the necessary "drift." The sidereal tracking rate, i.e., when the drive is set up to follow the movement of the stars, is one revolution/day – 360° in 24 h, or 15 min arc per minute of time.

We can use the fact that the image size/scale at the focus is roughly 1 mm per 3.5 min arc per 1,000 mm focal length to calculate the time to give the required drift. This would represent an angular distance (assuming a 1,000 mm fl objective) of 1.7 min arc. With the RA drive off, the drift rate is 15 min arc/min of time, so this represents an exposure of 1.7/15 = 0.11 min = 7 s.

A 7 s exposure with the drive off would give a spread of 0.5 mm on the CCD (= 100 pixels). The star would still be well within the area of the CCD, so switching the drive back on and hand correcting it back to the starting position would be very straightforward. (See Fig. 2.7.)

In crowded star fields, secondary stars and their spectra can cause problems. You may have to re-orient the grating/camera to get good spectra. (See Figs. 2.4, 2.5.)

Summing Up

When the grating is used in the converging beam, the distance between the grating and CCD chip should be matched to the size of the chip and the CCD pixel.

Smaller f ratios/shorter focal lengths give smaller star images and better resolution.

The best resolution obtained will be the result of a combination of the seeing conditions and the size of the pixel. The better the seeing conditions, i.e., the smaller the star image, the better the resolution.

We can now move on to the other popular method of using the grating, and that's mounting it in front of a camera lens as an objective grating.

Objective Gratings on the Front of Your Camera Lens

Using the grating in front of a camera lens as an "objective grating" setup can allow you to record the stellar absorption and emission lines at low resolution. A similar arrangement, but using a prism instead of a grating, was used in the early 1900s to

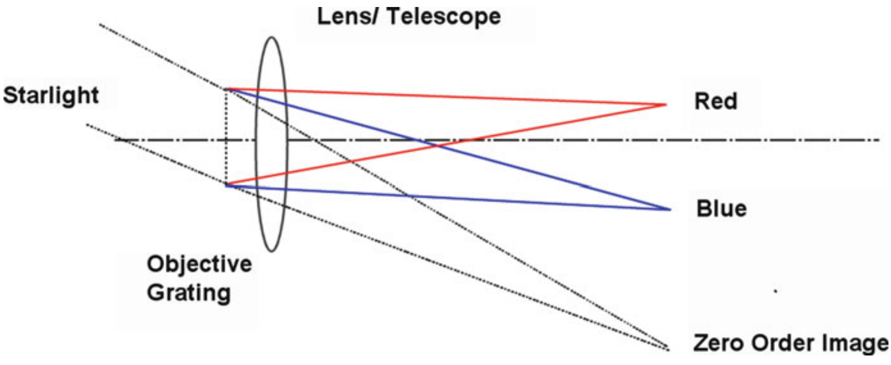

Fig. 2.8 Objective grating arrangement

collect the spectra for the Henry Draper catalogue. This spectral library was fundamental to the development of the star classifications we know today. (See Chap. 7 for details.)

The filter grating is mounted securely on the front of a camera lens. This effectively limits the clear aperture of the lens to only 28 mm, but you'll still be surprised with the results you can obtain. The much wider field of view allows you, on a large CCD chip (i.e., DSLR), to collect the spectrum of many stars (and background objects such as planetary nebula) in one exposure.

In this arrangement the light from the stars (collimated light) enters the grating and is dispersed. The camera lens then focuses the spectrum onto the CCD chip. This configuration uses the whole of the grating surface so the resolution obtained can actually be higher than we achieved in the converging beam. (See Fig. 2.8.)

Ideally, you'll need the camera mounted on a tracking platform or equatorial mounting properly polar aligned or mounted piggyback on your telescope. This arrangement allows the spectrum of fainter objects to be recorded without trailing of the star images.

Fixed focal length lenses are preferred to zoom lenses. Zoom lenses have a tendency to "creep" and change focus. Fixed lenses can be securely taped at infinity focus. Any lens from 50 mm focal length upwards can be used. Set to widest aperture (see Figs. 2.9, 2.10). Figure 2.11 shows a typical wide field "objective grating" image that includes emission stars and background nebulae.

To fit and securely locate the filter grating to the front of the lens you will need a couple of "special" adaptors. The adaptor must hold the grating in place and still allow some degree of freedom to rotate the grating relative to the CCD chip in the camera (we still need the spectrum to be recorded along the horizontal axis of the chip). It must also block out any other light that could get to the lens.

The cheapest option is to buy a spare front lens cover or make a cardboard cap and drill a hole, 28.5 mm diameter in the center (Fig. 2.12). This allows you to "screw" the grating into the cover and then clip the cover on the lens. It's then very easy to position the grating relative to the frame. For a neater job, an empty 1.25″

Fig. 2.9 SA100 mounted on a standard Canon zoom lens

Fig. 2.10 SA100 objective grating mounted on 85 mm telephoto lens (J. Simpson)

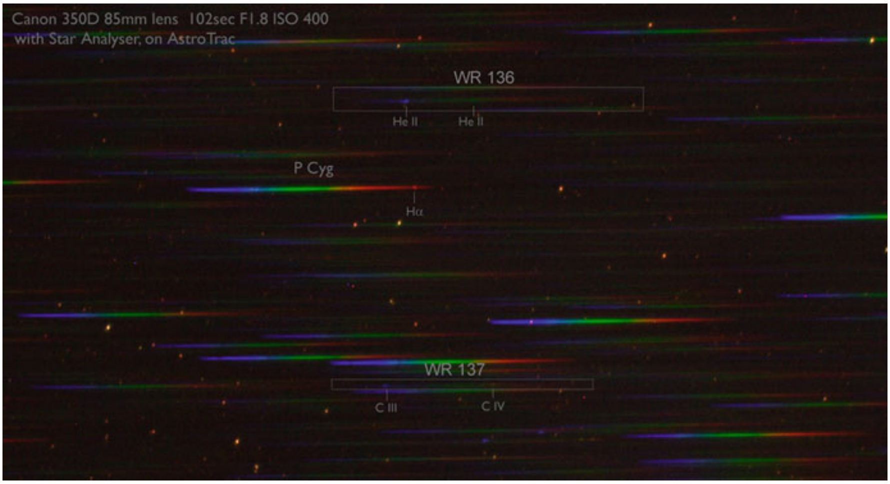

Fig. 2.11 Wide field image of Cygnus (J. Simpson)

Fig. 2.12 A simple lens cap to hold the objective grating (J. Simpson)

filter cell can be glued into the lens cover. Better still, an empty rotating polarizing filter cell can be used to make the positioning of the grating easier.

Baader supplies a T thread to a 48 mm filter thread adaptor. The filter grating mounted in a standard 1.25″ nosepiece can then be fitted to this adaptor. A photographic step-up ring 48 mm to say 55 mm will then allow you to mount the grating plus adaptors in front of the camera lens.

Fig. 2.13 Objective grating mounts. *From the left*: thin disk holding the grating in a 48 mm filter cell, T2 inner ring mounted in a 52–55 mm filter step-ring, Baader T thread to 48 mm adaptor fitted to a 48–58 filter step-ring. A grating mounted in a short T thread nosepiece is shown below

You can also separate the inner T thread section from a T2 camera adaptor; unscrew the three small grub screws on the outer rim and the internal T thread section will fall out. The outside diameter of this insert is almost exactly 49 mm. This is ideal for gluing into the center of a 52–55 mm step-up camera filter ring. Additional stepping rings can then be used to bring this adaptor to the final camera lens size. The distance of the grating in front of the lens is not critical, but using a long nosepiece-type connector (see Fig. 2.13) can cause some slight light loss (vignetting) to the edge of the field of view. Either method is fine.

HINT: If you try this method, do a "dry fit" first, i.e., grating mounted into the 1.25″ T thread adaptor plus the T thread insert sitting in the step up ring, plus any additional stepper rings. Mount them carefully onto the camera lens and mark the position of the T thread insert and the 52 mm adaptor where the grating is dispersing horizontally across the CCD chip. When gluing, use an epoxy-type glue, and line up the marks. This will make it much easier to use the grating at night without worrying about its alignment to the camera.

Leaving the grating in a 1.25″ nosepiece is a safe option and allows the T section base to be used for mounting.

NOTE: If you do use a zoom camera lens, watch for the front of the lens rotating while focusing. This will cause the grating to misalign with the CCD chip. Also, if you're in the habit (a good habit to have!) of leaving a UV or Skylight filter on your lens for protection, this should be removed when you fit the grating. Otherwise the UV part of the spectrum will not be recorded!

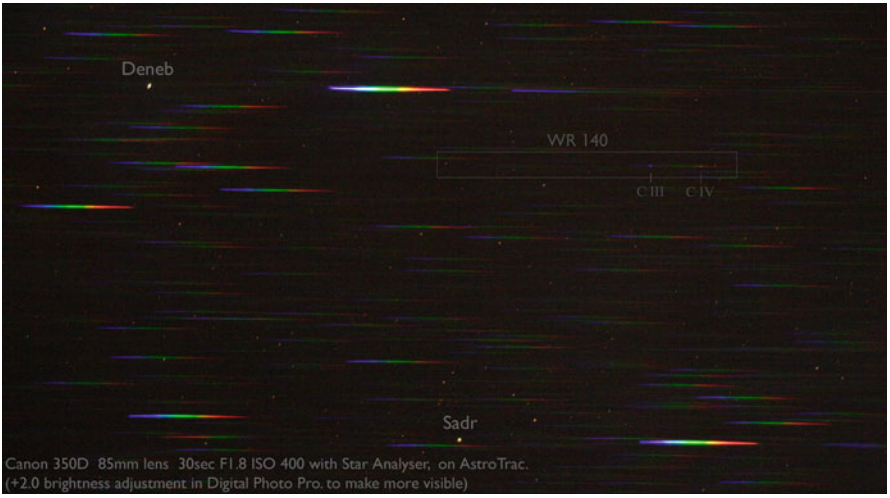

Fig. 2.14 Objective grating spectrum, area around Deneb (J. Simpson)

Objective Gratings with DSLR Cameras

Point the camera lens with the grating attached to the area of the sky or the bright star you wish to record. Make sure the camera is firmly secure and doesn't tend to sag or rotate on the camera support. Set the image format to RAW, set the lens to MF (manual focus) and adjust to infinity focus. Make sure the exposure is set to ISO 400 and M (manual); take a few test images at, say, 2–4 s exposure to check the results. Check the view screen to see where the star images and the brighter spectra are lying (Fig. 2.14).

Rotate the grating relative to the camera body to bring the spectrum horizontal to the CCD (if needed). The closer you achieve this, the better the results. Don't be tempted to try to squeeze the spectrum across the longer diagonal. You may think you are recording more spectrum, but the truth is, by the time you correct this image for processing, any extra detail will be lost. Just stick to the long horizontal axis of the chip. Seeing the zero order star images makes locating targets and initial focusing a bit easier, as well as framing the image to get best results. You can use the data in Table 2.3 to guide you on the size of the spectrum being formed on the CCD chip.

A 135 mm focal length lens and the SA100 grating will give a length from zero image to red of 9.4 mm, just under half the frame width of a DSLR. The maximum length spectrum (to include the zero order) would be recorded on a DSLR with a 300 mm lens. Although this may sound exciting, just bear in mind that the effective aperture is only 28 mm, so the lens will be working at about f5 (135/28 = 5) and the exposure time needed to record this faint spectrum could be pretty long – well into minutes!

Table 2.3 Size of spectrum vs. camera lens focal length

Focal length (mm)	Zero to red (mm)	Spectrum only (mm)
30	2.1	
35	2.4	
50	3.5[a]	
80	5.6	2.6
100	7	3.2
135	9.4	4.3
200	14	6.4
300	21	9.6

[a]Limit for webcam-sized chips

Fig. 2.15 Canon TC-80n3 remote controller

Again, we need to remember that the spectrum will be formed at a different focus from the zero order. Concentrate on focusing around the yellow/green part of the spectrum as a compromise. The zero image may appear out of focus – this is normal. A few trial exposures will quickly guide you to the best focus position. We can also “drift” to make the spectrum a bit more visible. When you find the best focus position tape the lens focusing ring with a piece of masking tape to make sure it doesn’t move!! Setting the camera to ISO 400 or ISO 800 and maximum aperture will cause exposures of a few seconds to record the spectra of the brighter stars.

A remote shutter trigger is very useful to reduce vibration, etc. The TC-80n3 remote controller (Fig. 2.15) for Canon cameras is typical of the programmable remotes available; it can be set to give a series of exposures ideal for alt-az type mounts or when a camera tripod alone is used.

CCD-Type Cameras

When fitted to a standard camera lens (see Chap. 5 for details of how to make a suitable adaptor) a CCD camera can be focused and set up similar to the DSLR above. Check the possible width of the spectrum against the chip size using Table 2.3. Cooled mono CCD cameras can give some excellent results. Start with a 1 s exposure on an area containing a bright star; the spectrum should be clear and not overexposed.

Webcams and Video

Standard webcams and video capture devices can also be used. The small chip size limits the field of view, but by stacking the short exposures in an AVI file, it reduces the effects of seeing and can give good results on the brighter stars. The new “industrial” strength mono webcams from Imaging Source (DMK series) can greatly improve your ability to record spectra. The mono chip and the long exposure option makes these cameras ideal.

The RSpec software (see later) can provide live viewing and spectrum capture for these cameras. We’ll discuss processing of the spectra later.

Quick Bit of Theory: Dispersion/Plate Scale and Resolution

Many beginners get confused by the terms dispersion, plate scale and resolution. Easy to understand why – these are new terms and not ones you come across every day. They represent important numbers in spectroscopy and allow us to compare different grating set-ups, spectroscopes and their performance. You will come across them very frequently, so you need to know what they mean.

Let’s keep it simple at the moment. In Chap. 6 you will practice with the calculations and mathematics involved.

Dispersion

The grating breaks the incoming light into a spectrum and spreads this spectrum out over an angle; the red end of the spectrum is “bent” further from the centerline of the grating (optical axis) than the blue; the angle between them is the dispersion. The more lines on the grating, the greater the dispersion. OK, to be precise this is the angular dispersion.

When we record the spectrum on a CCD chip the length of the spectrum on the chip is related to the distance between the grating and the chip. This is then called the linear dispersion or plate scale.

Plate Scale

The length of the spectrum on the chip can be measured in mm, or in pixels.

Also, as we know the wavelengths at either end of the spectrum (roughly 4000 Å for the blue and 7000 Å for the red end), we can easily come up with a scale for our spectrum. If the spectrum is 3000 Å long (7000–4000) and measures say 3 mm on the chip, the scale would be 3000/3 = 1000 Å/mm. This is known as the plate scale. (Why plate scale? Well, in the early days of photography they used sensitive glass photographic plates to record the image, and scale would have been measured on the glass plate – hence plate scale.)

We can also measure this plate scale in terms of the number of pixels used to record the spectrum. If the length of our spectrum covers 300 pixels in our image, then the plate scale could be said to be 3000/300 = 10 Å/pixel. This is shown in Table 2.2.

Linear dispersion and plate scale are interchangeable names for the same thing. You will see them both used in various textbooks.

Resolution

Like a telescope a grating has a resolution – the ability to record fine detail.

For a grating, if there are two features in the spectrum produced (generally absorption lines) that are *just* separated in the image, the distance between them in Angstroms (or nm) would be the resolution of the grating. The theoretical resolution of a grating is defined by the number of lines illuminated on the grating by the star's image. The actual resolution obtained will be dependent on the seeing conditions and the size of the camera pixel. In spectroscopy we also consider where in the spectrum these two close lines are found. Are they in the blue? Or are they in the red?

A special number has been developed for spectral resolution. R is the standard term used and is equal to the wavelength divided by the resolution. For two lines just seen separated in the red part of the spectrum (say around 6000 Å) say, 30 Å apart, then the R value for that grating would be 6000/30 = 200.

There are more precise ways of calculating the R value, but that's for later.

Summary

For any particular grating, the linear dispersion/plate scale is proportional to the distance from the grating to the film plane. (See Table 2.2.)

A quick rule of thumb for the SA100 grating:

$$\textit{Dispersion in } \AA / \textit{pixel} = 100 \cdot \ \textit{pixel size} \left(\mu m\right) / \textit{distance to CCD}$$

Table 2.4 Seeing vs. focal length vs. Star size (Micron)

	Seeing conditions (seconds of arc)		
Focal length (mm)	2″	3″	4″
500	4.8	7.3	9.6
750	7.3	10.9	14.6
1,000	9.7	14.5	19.4
1,250	12.1	18.2	24.2
1,500	14.5	21.8	29
2,000	19.4	29.1	38.8
2,500	24.2	36.4	48.5

For a camera with a pixel size of 7.4 μm and a distance of 80 mm we get:

$$100 \cdot 7.4 / 80 = 9.25\ \mathring{A} / pixel$$

Based on the pixel size, the best possible resolution would be about 19 Å (9.25 × 2). However the seeing conditions can greatly reduce this figure.

The size of the star image effectively becomes the entrance slit of the spectroscope, and obviously the smaller the image the better the resolution. Depending on the system, a maximum of R = 100–200 (i.e., a resolution of 60–30 Å) can be achieved (see Table 2.2). Best results are obtained with smaller f/ratios, which give smaller star images. Like many things in life there are limitations, and experience has shown that f4.5 seems to be about the lowest practical ratio we can use.

The size of the star image formed by the telescope is approximate:

$$Seeing \cdot 4.848 \cdot focal\ length \cdot 10^{-3}\ \mu m$$

For example a 250 mm f6 telescope (focal length = 250 × 6 = 1,500 mm) and seeing of 3″ would give a star image size of:

$$3 \cdot 4.848 \cdot 1{,}500 \cdot 10^{-3} = 22\ \mu m$$

where seeing is expressed in arc seconds. Typical seeing will be between 1″ (excellent!) and 4″ (pretty poor). See Table 2.4.

Short focal length telescopes and small focal ratios are obviously preferred. These still give small star images even in poor seeing conditions. Table 2.4 shows that a 500 mm focal length telescope with 4″ seeing produces star images only 9.6 μm in size, whereas a 2,500 mm focal length gives an image of almost 50 μm – five times the size.

The resolution of this system, based on the seeing conditions (22 μm), with a pixel size of 7.4 μm and a plate scale of 9.25 Å/pixel, would be 22/7.4 × 9.25 = 28 Å which is far greater than best possible. The R value would be approx 214 (6000/28).

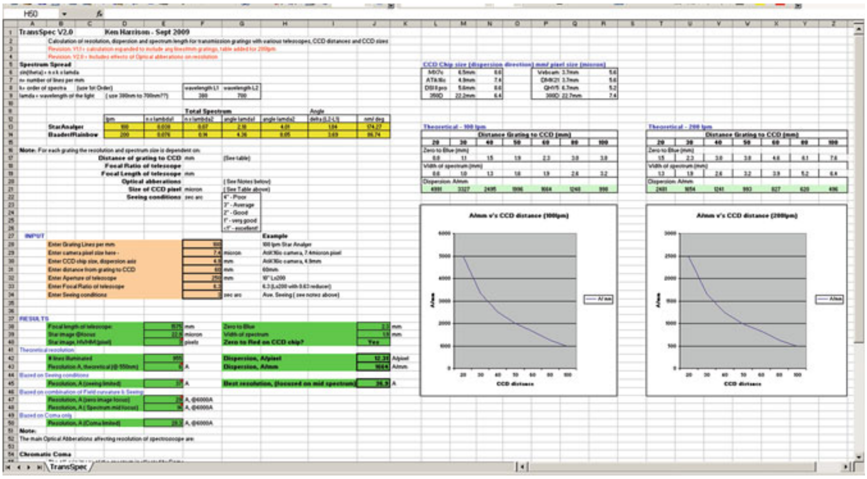

Fig. 2.16 *TransSpec* input screen

NOTE: The spreadsheet *TransSpec* V2 (See Appendix G in this book) is an ideal resource for calculating the various parameters for a filter grating placed in the converging beam or used as an objective grating. See Fig. 2.16.

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