Details of Equipment and Processes

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Before delving head-first into the reports, it may prove useful to have some information about the processes used during the capture, image processing, and analytical stages. First off, let's look at how I started, and proceed from there.

Color Camera and Monochrome Camera

My first serious efforts were conducted with a ZWO ASI224MC color CMOS camera. I collected spectra of stars in Lyra. The reference star, Vega, was captured successfully. An instrument response curve was successfully created, and everything appeared to be going well. I was very excited! However, the third star I attempted to process turned out terribly wrong. And not just a little wrong; the spectral curve was WAY OFF. I tried again, reviewing tutorials on the RSpec website to try and make sure everything was done properly, but still met with disaster. I consulted Tom Field, who brought Robin Leadbeater into the conversations. Robin examined some of my captures, which appeared to have severe color imbalances in them between captures of different targets. I rechecked my capture software (SharpCap at the time), and found the settings recorded with the captures had been identical between them. If they were off, then they should all be consistently off. What in the world was going on?

The better part of two months was spent capturing data and attempting to analyze what the problem was. I was frustrated, but still determined to make this work! Others had apparently enjoyed success, so what was I doing wrong? Ultimately, I decided to invest in a monochrome camera. I purchased a ZWO ASI290MM monochrome CMOS camera. I had never used a monochrome astronomy camera before, so I had to get the hang of using it (particularly obtaining a good focus, which seemed oddly more touchy than with the color camera). I recaptured data, created a new instrument response curve, switched capture software (to ASI Studio) and tried again.

The improvement in the results was immediately evident. The new instrument response curve could be applied to any star without difficulty, as I expected back at the start. The flood gates opened, and I collected data for as many targets as my time and weather conditions permitted.

So, what is the purpose of this cautionary tale? The main purpose is to hopefully prevent others from falling down a rabbit hole like I did. The color cameras use three different color receptors, and the way their frequency ranges overlap with each other is apparently—if my understanding is correct—what caused my problems. The color spectra that they can capture are very beautiful to look at, but the colorful, attractive spectra are unimportant for analyzing the absorptions and emissions in the results. The strength of the light at each wavelength is what is important, and a monochrome camera seems (at least from my own experience) to be the best bet. However, if anyone out there has gotten this to comparatively work with a color camera, I would be very interested to know how that was accomplished.

Equipment

My equipment is generally not expensive. My financial resources are limited, and I have never been one to insist on only the latest and greatest of anything. I will quickly review the equipment used for these reports.

Telescope: The scope used to collect this data is an inexpensive Celestron C6-N f/5 Newtonian reflector. I do own a few scopes, but this one seemed the best fit for this project. It is a reflector, so no chromatic aberration to worry about. It is also fairly fast, so exposure times for the camera could be kept short. It does exhibit some considerable coma, however.

Mount: The mount used is a Meade LX85 Equatorial Go-To mount. This is the most expensive part of my setup. Even so, the tracking is sometimes a bit wonky. It is sturdy enough to support the lightweight Newtonian easily, though, and provides a pretty stable platform.

Transmission Grating: The SA100 transmission grating is used for the project. It is rated at 100 lines per millimeter. It produces low-resolution spectra, and is an inexpensive piece of gear. The grating threads directly onto the 1¼-inch nosepiece of the camera.

Camera: The ZWO ASI290MM monochrome CMOS camera is used to capture spectra. When the decision was made to purchase a monochrome camera, I chose this one due to its slightly larger sensor array. I have, however, seen data captured by others using less expensive cameras that were perfectly acceptable.

Laptop Computer: An HP 17-inch notebook was used in the processes outlined here. The device is an 11^{th} generation Intel i5 processor with a 1TB solid state drive. Also, an external hard drive is used to back up the data routinely.

Software: A number of software programs were used. Stellarium is a free planetarium software that can be very useful for overviewing targets. I use this to obtain catalog numbers to input into the Go-To mount to select targets, and also as a standard for determining what stars constitute the constellation lines. For capturing and stacking footage, ASI Studio was used. This is free for users of ZWO cameras. Alternative capture programs may also be used, such as SharpCap, etc. Just be sure the capture settings are recorded/saved and kept absolutely consistent between captures and sessions. Alternate stacking software can also be used, such as Registax or AutoStackert. RSpec is used for analyzing the captured and stacked images. This software is not free, but I have found it easy to use and very helpful. Other software packages are available also. A word processor was then used to generate the actual reports.

That should give you an idea of the modest gear used in the process of collecting data, analyzing the results, and generating the reports. As you can see, none of it required multi-thousand dollar purchases. Most amateur astronomers will probably already possess at least some of the relevant equipment already.

Capture Process

My process of capturing the spectra is itemized below:

1. Set up the equipment: I normally use my back deck, which is attached to the east side of my home. I live in northeastern Indiana, which is not known for incredibly dark skies or necessarily cloudless skies. The nearest I can tell, my Bortle rating is somewhere between 4 and 5. I do have a nice, clear view of the eastern sky up to well past zenith. However, as targets pass the zenith, the telescope has to be aimed over the top of my house. During the winter months, this can cause seeing issues from the heat rising therefrom. So, I normally try to catch targets as they are ascending in the sky. I set up a small card table with the laptop to use for the session.
2. Align the scope: I normally use a three-star alignment for the Go-To system, which seems to usually get the best results. I use a 40mm Plossl eyepiece for rough target acquisition, then switch to a 25mm crosshair eyepiece to center each target.
3. Install Camera: I install the SA100 grating onto the nosepiece of the camera. The tricky part can be making sure the grating is aligned properly with the camera. The grating has an alignment mark, which should be on the right-most position of the nosepiece. (You can think of this as the +90-degree mark if 0-degrees is defined as being straight up when viewing down the nosepiece toward the telescope draw tube.) Even between sessions, I find I have to adjust the retaining ring to get the camera in the right

position when screwing it in. I assume this is due to temperature and humidity differences. The camera is then connected to the computer.

4. Select target: Choosing a target from Stellarium, I put its SAO catalog number into the mount and allow it to locate it. I then use the 40mm and 25mm eyepieces to center the target, refocusing as needed.
5. Capture footage: I then reinstall the camera on the telescope and use the ASI Studio software to preview and focus on the target. I use the planetary imaging option for shorter exposures (10 seconds or less, typically), using RAW16 format for SER files. When I have focused the spectrum line (NOT the target star itself) in the preview, I adjust the exposure and gain to obtain the best overall results. Care must be taken not to overexpose the images. Remember, you are aiming for the clearest image on the spectrum, not the brightest. I prefer to keep the gain under 100, but have gone as high as 2009(-ish) for dimmer targets. Higher gain levels introduce more noise into the image, so I try to keep it low. After these adjustments, video footage is captured. I try to get at least two minutes of exposures so that there are a good number of frames to stack later.
6. Repeat steps 4 and 5 for additional targets.

This may seem unnecessarily verbose, especially to those who are already familiar with basic astrophotography, but this is the setup and capture process that I have used.

Image Stacking

After collecting the raw data, the next major step is stacking the acquired images. The steps used are presented below:

1. Open ASI Studio and launch ASIVideoStack. I locate the .SER file for the target and drag and drop it into the program to open it. A preview of the first frame is presented.
2. Estimate percentage of video to stack. This is one of the tricky bits. The ASIVideoStack software will play the entire video. I carefully watch the playback and visually estimate the percentage of frames to use. This is an entirely subjective thing, and it is not uncommon that I return to this step and restack videos to obtain better results. I make a note of the total number of frames and the percentage of them that I chose to use.
3. After the stack is done, the program presents a set of controls to enhance the image. I usually slide the Sharpen control to its lowest level and click Save. This saves a JPG preview into the target folder location that seems to match the raw FITS image.
4. Using ASI Studio, launch ASIFitsView. Open the created FITS file in the program. Note that the image will look TERRIBLE! This is a preview issue in the software, NOT a problem with the created file! Save the file as a TIF. (Alternatively, a PNG file may be created instead.)
5. Repeat steps 1 through 4 for each target.

Alternative stacking software can be used. If you are proficient with another program, then feel free to use it. Just save the stacked image as a TIF or PNG—a lossless format to be imported into RSpec.

RSpec—Creating Instrument Response Curve

RSpec is a powerful and easy-to-use tool for analyzing spectra. A large number of tutorial videos are available from the site, so make sure to review these to become familiar with using it. The first thing that must be done is the creation of an instrument response curve. Some of the tutorials are dedicated to this and outline the process. In the event that it may prove useful, my own procedure for this is outlined below. Some of the steps (like saving files after each change) are not strictly speaking absolutely necessary, but I like to be thorough in case it is necessary to backtrack—without having to start over completely.

1. Open raw spectrum image file (tif) in RSpec. (This should be done using footage captured for an A0V star, such as Vega or Sirius.)
2. Perform 2 point Calibration for H Beta (4861.3 Angstroms)
3. Save calibrated profile
4. Use Edit Points to trim profile outside usable range. (I use 3300-9700 Angstroms.)
5. Save trimmed profile
6. Open library reference profile for Vega (a0v.dat)
7. Use Edit Points to trim profile outside usable range. (I again use 3300-9700 Angstroms.)
8. Save trimmed A0V profile
9. Use Edit Points to define points along the curve that are on the continuum to create smooth curve
10. Save smoothed A0V reference profile. Use different file name; do not overwrite the library file!
11. Open calibrated and trimmed Vega profile from above (5)
12. Open reference series and load saved smoothed A0V reference profile from above (10)
13. Trim main profile so that no part of the curve touches the x-axis
14. Use Math on 2 Series to divide the main Vega profile by the smoothed A0V reference profile, and move result to main profile
15. Save the raw instrument response curve
16. Use Edit Points to cut out the absorption bands for Hydrogen Balmer series (and Telluric O_2, if desired)
17. Use Edit Points to Spline Smooth the result—only very gently!
18. Save the smoothed instrument response curve. Make a note of the number of Angstroms/pixel that the file uses. This will give you a good estimate to use in calibrating future work.

This will give you the smoothed instrument response curve that you will use to correct ALL of your data. Remember, though, that if you switch cameras, gratings, or telescopes, a new curve MUST be generated to keep your results consistent. Basically any change in your image train will require a new instrument response curve—even using a different camera of the same model.

RSpec—Analyzing Captures

After you have created an instrument response curve, you have what you need to analyze any stacked capture. My own procedure is outlined below. Again, some of these steps are not absolutely necessary (such as saving files for each step), but I do this anyway in case I want to backtrack without starting completely over.

1. Open raw spectrum image file (tif) in RSpec
2. Perform 1-point calibration using the zero image of the star and the angstroms/pixel. (My own value is around 6.3 A/p). Alternatively, if an absorption feature can be easily spotted in the raw curve, you can use that instead.
3. Save calibrated profile
4. Use Edit Points to trim profile outside usable range. (I use 3300-9700 Angstroms to match my instrument response curve.)
5. Save trimmed profile
6. Open reference profile for smoothed instrument response curve
7. Use Math on 2 Series to divide the calibrated and trimmed spectrum by the instrument response curve, and move the result to the main profile
8. Save the corrected spectral curve
9. Use Edit Points to re-trim the spectrum for usable values. (Here I typically use a reduced range of 3700-8000 Angstroms to avoid bleedover into the second order spectrum that the grating creates.)
10. Save re-trimmed profile

11. If the result looks good, add labels, etc. and save the final version. In some instances, I have found it can be necessary to re-calibrate the spectrum using a known absorption line. I try not to do this, but if the initial calibration is off by a significant amount, it will help realign the labels with their absorption lines.
12. Repeat steps 1 through 11 for each target

Step 11 above is typically the most time consuming, as you must identify and label the absorptions. This requires referencing the RSpec Elements library, or also using a reference source. Try to be careful. If you label a feature and it doesn't look right, it probably isn't. Some elements or molecules have the same apparent lines involved in their spectra, which can make identifying them tricky. Looking at the spectral type of the star (listed in Stellarium) can help. Cooler stars, for example, will not have helium absorptions in them—they aren't hot enough for that. Likewise, hotter stars won't have the TiO absorptions that are seen in cooler stars. As you gain experience, you will get better at identifying absorption lines and having an idea of what is expected. But, even so, there is plenty of room for error (as my own prior efforts can attest!).

Conclusion

And there you have it. It may be long-winded, but I hope that it may be of some assistance. Every person will doubtless develop his own personalized procedure, and that is fine. As long as it is kept consistent and doesn't skip any necessary details, then there is no problem. Again, the various tutorials on using RSpec are invaluable, so don't hesitate to go back and watch (or rewatch) them.

Any questions? Simply contact me and I will attempt to clarify anything needed!

Regards,
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