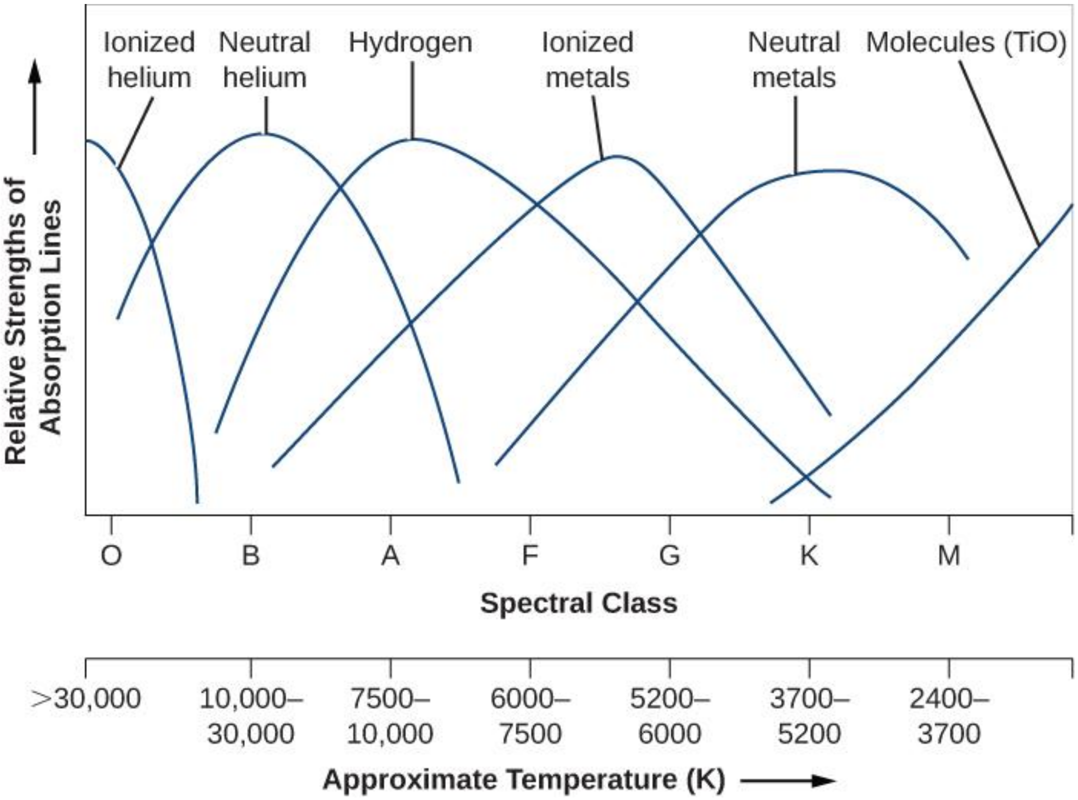
Determining a Star’s Temperature (Version 2.1)

Professional astronomers determine the temperatures of stars by observing their spectra for evidence of different elements.

For example, as shown in the graphic below: O and early B stars have faint Helium lines; late B and A stars are dominated by Hydrogen lines; F G and early K stars have hundreds of fine metal lines not resolved by the Star Analyser; late K and M stars show broad molecular bands.



It usually isn’t possible to make detailed enough observations to use the above technique with amateur equipment.

However, you can determine a star’s *approximate* temperature by simply examining the continuum’s general *shape*, or spectral energy distribution (**SED**). To do this, you need to correct your data to remove the effects of your camera.

Your camera is not equally sensitive to all wavelengths. For example, it is less sensitive as you move further into the blue or red.) This process, while called here “correcting for instrument response,” also corrects for atmospheric effects (e.g., reddening nearer the horizon and even light pollution.)

Below are the steps you can follow to correct for instrument response. These are demonstrated in the “Instrument Response” RSpec tutorial video that is available on the website (link) or the software’s Help menu. The video is “**15**. Adjustment for Instrument Response.”

You will need to prepare an Instrument Response curve of a standard type A star. You can subsequently use this curve to correct the spectrum of *any star type* you capture with the same equipment. If observing conditions change (e.g. your target is much closer to the horizon than the type A star), you should capture another type A star spectrum and re-do the steps below

Preparing the Instrument Response (IR) Curve using a Type A star like Vega or Castor

1. Open a spectrum from the Pickles library (e.g. A0v.dat) **using the Open button** on the right-hand toolbar. (**Note**: Normally, you use the Reference button to open these files on the Reference profile. However, for this step, we want to open it on the Main profile, so be sure to use the icon button described above.)
2. Use the Edit screen to crop, removing all points outside of 4k - 7k Angstroms.
3. Delete any data peaks or troughs that might affect the spline.
4. Use the Spline tool to smooth.

Steps 3 and 4 above can also be done by drawing the continuum. See **video 44**.

5. Save Reference Profile as *A0v-Smoothed.dat*.
6. Close the Reference profile.
7. Load your type A star image in the left window (or from a .dat file if you saved its profile that way).
8. Use RSpec's Subtract Background feature to remove the effects of the background in the profile you're about to create. This can be important in getting the best results. It's not hard to do. See **video 10**, starting at 45 seconds, and **video 30** at 3:37.
9. Calibrate the image's profile graph (if it's not already calibrated) so that the x-axis is in Angstroms.
10. Confirm the calibration with the Element lines.
11. Load the file *A0v-Smoothed* into RSpec's Reference curve using the "Reference" button and then the "Open Reference Series" menu option.
12. Use the Math screen to divide your image's profile graph by *A0v-Smoothed.dat*. This creates the instrument response curve for your camera, telescope, and grating.
13. Move the instrument response curve back to the Main profile.
14. Use the Edit Points screen to smooth it out. (Spline and delete outlying points.)
    (Also, delete any points at the left or right ends that are too close to zero y values)
15. Save the Reference profile with a filename like "My IR Curve.dat" (where "IR" of course refers to "instrument response", not "infrared!"

The above instrument response curve, which you created from a Type A star, can then be applied to *any* star type. That's worth re-reading: the Instrument Response curve is for your *instrument,* regardless of the type of star you're observing. Note that stars at different elevations have different amounts of reddening, so both the reference and target stars should be fairly high in the sky and at approximately the same elevation.

Applying the Instrument Response Curve

(Note: Starting in Version 1.8 of RSpec, there is a toolbar button that applies the steps below with one click. See the first three minutes of the video entitled "30. Update 12 – Real-time flux calibration."

We suggest you manually perform the steps below once or twice to get the "feel" for the manual process before using the toolbar button.)

1. Load the IR curve as the Reference Profile if it's not already loaded. (Use the "Reference" button and then the "Open Reference Series" menu option.)
2. Load your target star image data & wavelength calibrate it on the Main Profile. (If the curve is "squished" to the left, then zoom in and recalibrate it. (Make sure that the "Use second X-Axis checkbox at the bottom right of the screen is empty after this step.)
3. Apply the same Subtract Background procedure described in the previous section.
4. On the Math screen, divide Main by Reference.
5. Move the result back to the Main profile. The Main profile curve is now your target data, calibrated to remove instrument response.

6. Open a library spectrum by selecting Reference Library under the Reference button. Now, drag the bottom slider on the Reference Library window and watch for the reference curve that most closely matches your data. If you've done the previous steps properly, the star type whose curve most closely matches your data will be the type of star you observed.

Accurate instrument response corrections need a camera that has an essentially linear response to light (e.g. without a gamma correction) and one in which the zero level has not been suppressed (i.e. you should be able to see some background noise in the black areas. On some cameras you can ensure this by adjusting the brightness.)

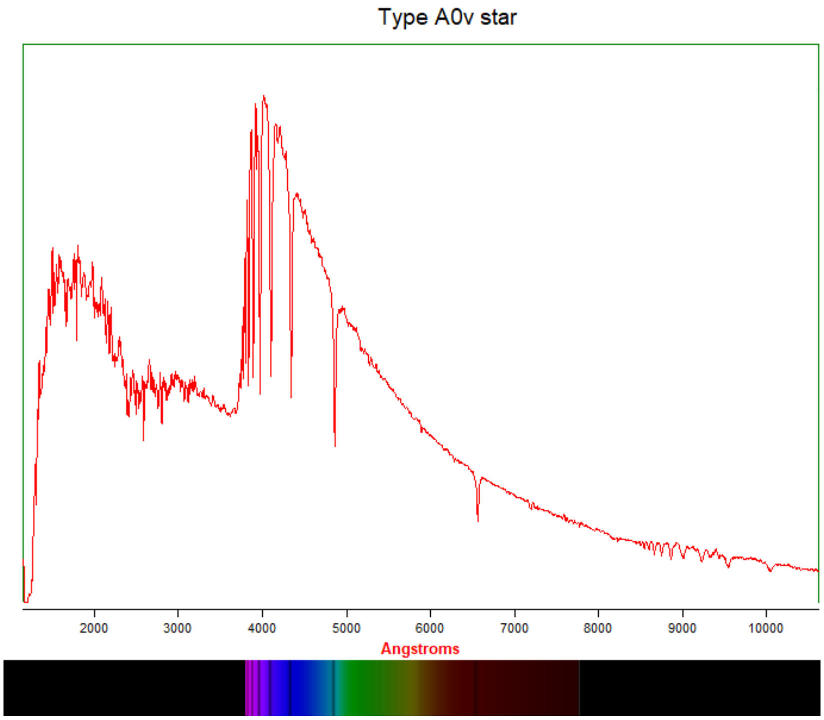
For best results, all files should be longer exposures to avoid scintillation effects. However, this is absolutely not necessary to get interesting and useful results with typical short exposures we normally do on bright stars. See this discussion by Robin Leadbeater, the designer of the Star Analyser: link. Here's an example of how a star changes over a short time: link.

Why doesn't Wien's Law work to accurately determine a star's temperature?

Vega is a type A0v star with an approximate temperature of 9,600 K.

If that value is plugged into Wien's Law, the calculation predicts a peak wavelength of 3,018 Angstroms.

But the professional Pickels Reference Library spectrum (shown below) for a type A0v star has its main peak at about 3,900 Angstroms:



How can we explain the fact that Wien's law predicts a type A0v star will have a single peak at 3,018, but that the RSpec professional Pickels Reference Library (above) has its main peak at about 3,900 Angstroms? (Note: you can read more about the Pickels Library at this link.)

After you've corrected a star's SED (Spectral Energy Distribution) for instrument response, it may sometimes roughly appear that the SED can be used with Wien's law to determine the star's temperature. But this is mainly due to chance.

As noted at the beginning of this document, professionals don't use the SED to measure star temperatures. The information they use to determine temperature comes from the spectral features they see in the spectrum. For example, professionals use the presence of H/He in hot stars, various metal lines in G-K stars, and molecular TiO bands in cool stars, and at high resolution, they use the width and shape of the line profiles.

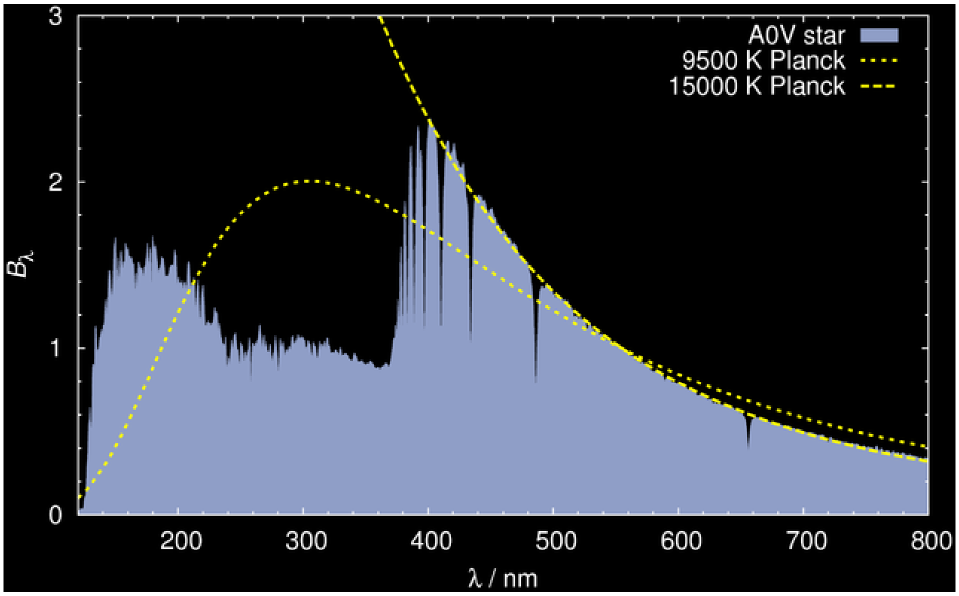
There are multiple reasons why using the SED does not produce an accurate star temperature:

1. Despite what you might have read, stars are not black bodies.
2. Despite what you might read, the temperature of Vega is not 9,600 K.
3. Interstellar extinction can change the shape of the continuum out of all recognition compared with what the star spectrum actually looks like.

1. There are many processes going on in stars that make them different from a blackbody. Solid and liquid objects (e.g., hot lava or cannonballs heated in a furnace) can be black bodies. But stars, being glowing balls of hot plasma, are not true black bodies.

The core of a star, where the energy comes from, might be considered a blackbody. But the temperature of a star is millions of degrees, so the radiation from the core is at X and hard UV, not in the visible. Various processes then act on this radiation as it works its way out of the star. (This takes a very long time. For example, scientists estimate it can take from tens of thousands to millions of years for the sun.) These processes include inelastic scattering, absorption through atomic absorption and ionization, emission through recombination, and perhaps others.

An exact description of how this alters the spectrum is complex and depends on the conditions at each layer within the star. Vega is a good example of one of these processes and demonstrates the problem. Take a look at this Vega spectrum from Wikipedia:



Credit: SiriusB - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=22963038

First, notice all the energy below about 400 nm. Our amateur equipment ignores that energy, introducing inaccuracy.

Also, notice the deep drop-off in the spectrum below 400 nm. (With a high-resolution instrument, you would find that it is actually at 3640A) This drop-off is caused by the crowding together of the Balmer absorption lines. Eventually, these lines all merge, producing the continuous band we see as a huge hole in the spectrum in the UV.

The above merging is the limit of the Balmer series that occurs when the electrons in the second level are completely ejected from the atom (ionized). This produces a huge hole in what otherwise (in the visible at least) might vaguely be considered a blackbody curve. But, this hole distorts the curve in a way that makes the temperature derived from Wien's Law on this data differ from what we'd see on a pure blackbody.

2. This brings us to another problem. The temperature of a star, as quoted in books, is something called the effective temperature (Teff). This is a purely theoretical concept used to help with calculations when modelling stars. It is only vaguely connected to the "temperature of the surface of a star" – if such a thing could actually be measured or defined.

Teff is defined as the temperature a blackbody with the same diameter as the star *would need to be* to emit the same total flux (at all wavelengths) as the star. i.e. you can calculate this even if the spectrum is not a blackbody curve, but the temperature obtained is not the actual temperature of the star.

We now come to the discrepancy we're discussing. The Wikipedia graphic above clearly shows why the temperature determined by the SED disagrees with that determined by professionals. In the visible portion of the spectrum that we measure with our amateur equipment, the spectrum "looks like" a blackbody of 15,000 K. But if we consider the full spectrum, Teff is calculated to be 9,500A.

3. Interstellar extinction (link) can cause additional inaccuracies. This is why you cannot use photometry or the shape of the spectrum to measure star temperatures. If there happens to be high interstellar extinction between a Type A star and us, the continuum might look like a K star, but the features in the spectrum will still be those of A and K stars. It is in the *features* in the spectrum that the true power of spectroscopy lies, not in the shape of the continuum.

See these discussions on our forum: Also, see these threads: link and link on scintillation. Also, download this PDF: link. You need not follow the math to appreciate their conclusions.

Don’t let any of the above scare you off! You *can* get interesting results on A-type and M-type stars. You’ll definitely see the *approximate* star temperatures. And you’ll be able to *approximately* identify the star types.

Feel free to email us to discuss this further. Or send us an A-type and M-type spectrum, and we’ll show you how to process them.

Conclusion

After correcting your profile graph to account for your specific instrument's response and atmospheric effects, you can visually *compare* stars of very different temperatures and see the differences. For example, a cooler type M star has more energy in the red end of the spectrum. You can also compare the curves' shape (SED) to those of professionals in RSpec's Reference Library. The RSpec Instrument Response video (#15) and this PDF show you how to do that.

When you compare your corrected curve to the professional curves in RSpec's Reference Library, you'll discover that it's an approximate process. In other words, the process of visually matching your curve to the professional curves *is unlikely to produce an exact fit*. It *will* allow you to say, for example, "My star's SED looks a lot like the stars *in the range* of B and A stars. But my other star's SED looks a lot like the stars in the K and M range." In other words, you'll clearly be able to see the difference the SED of a cool type M star and a hotter type A star.

You can then refer to a page like https://en.wikipedia.org/wiki/Stellar_classification to see the *approximate* temperature that the professionals have determined for these types of stars.