

At last, a digital spectroscope! *TCA* puts it through its paces to see if it you can use it in teaching astronomy labs.

One of the most vexing tasks in teaching astronomy has always been spectroscopy. Stellar spectroscopy, laboratory spectroscopy, in-the-field spectroscopy, doesn't matter. It's usually done with handheld spectroscopes, often the cheap kind, a tube with a slit on one end and a diffraction grating on the other, or even just the diffraction grating or a prism in one's hand. Or, just handouts and photographs. Teaching spectroscopes have always been rare, expensive, or both.

So imagine my delight when at a science education convention I spotted a digital spectroscope at the Vernier booth. The device, called SpectroVis Plus, is designed to measure light across the visible and infrared spectrum, 380 nanometers (nm) to 950 nm. The SpectroVis consists of a box the size of a small paperback, a one-meter-long fiber optic cord and a short USB cable. The cord's square 'cylinder' end fits into a slot on the top of the box. Price with optical fiber is \$518. It uses Vernier's standard Logger Pro v.3.8.4 software. (I thoroughly recommend Vernier sensors attached directly to a laptop or computer rather than through a LabPro and a calculator, it is just easier to work with.)



In this modern day nobody actually looks through a spectroscope to research a spectrum. We look at it either photographically (and even that is now mostly digital photography) or by spectrophotometry, viewing spectra as graphs. It's this last way that SpectroVis views your source and produces a result. With SpectroVis, it's quite literally aim the probe and "shoot" (i.e., hit the data Collect button). When you are done, you have on the screen a graphical representation of the spectrum, and the numerical data is available in a table to the side or exportable for use in a spreadsheet or other program.

The graph can be presented two ways. One is a simple X-Y graph, wavelengths in nanometers along the bottom and intensity along the side (see Figure 1). You can also have a background image of the visible spectrum, or have it as a narrow strip along the X-axis. The infrared, of course, has no background since we can't see it with our eyes. Additionally, you can have the intensity graphed on a relative scale (0—1) or a power of six logarithmic scale, which can be helpful as a kind of graphical magnifier of peaks and valleys, to see lesser lines or dips that are otherwise overwhelmed by very strong isolated lines.

Can this device be used in astronomical teaching? To answer that, *TCA* obtained a loaner unit and attempted to do three astronomical projects. The first was to replicate and expand on traditional physics labs, such as examining emission, continuous and absorption spectra. Second, we looked at outdoor lighting to determine the spectra of light polluting sources (see also Constance E. Walker's article on light pollution on page 16). Last, could we get anything resembling astronomical spectra, such as of the Sun or stars? The following are our results of this device for the three projects.

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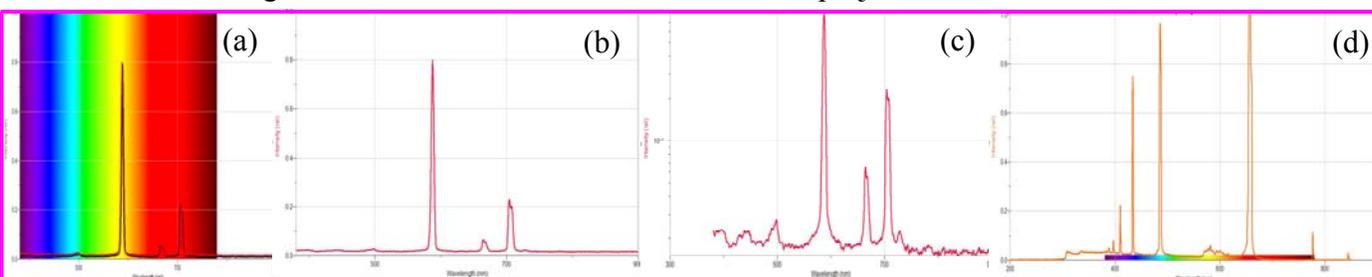
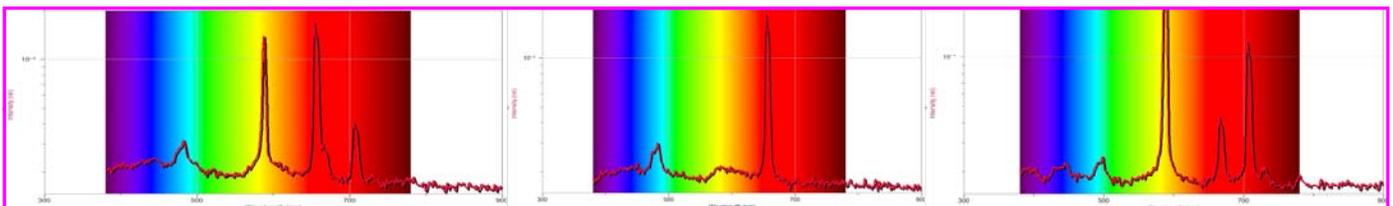


Figure 1. Hydrogen spectrum, viewed with (a) visible spectrum background, (b) no background, (c) a log scale, (d) with visible spectrum as baseline strip.

## Not Your Old Physics Labs

Using some common gas tubes found in a basic physics lab, we easily obtained graphical images of the emission lines. For starters, do this for general practice with graph interpretation and using patterns of the lines instead of visual images. One thing you can do that isn't easy to do with a hand spectroscope is to view a combined spectrum, as you might find in a source gas with multiple elements or in a star or nebula's spectrum. Two gas tubes were put as close together as possible so that their light could be emitted jointly through a hole. The fiber optic captured both lights at once. Students could be provided with this graph, and then asked to identify the contained gases using standards obtained previously or post-lab. As an example, Figure 2 shows our combination spectrum of hydrogen and helium gases on the left. The middle and right spectrum are hydrogen and helium alone. You should be able to see the different line peaks of the two in the combination, although there is at least one case of the lines overlapping.



**Figure 2. Three spectra, left to right: hydrogen and helium together, hydrogen alone, helium alone.**

## Measuring The Bright Skies

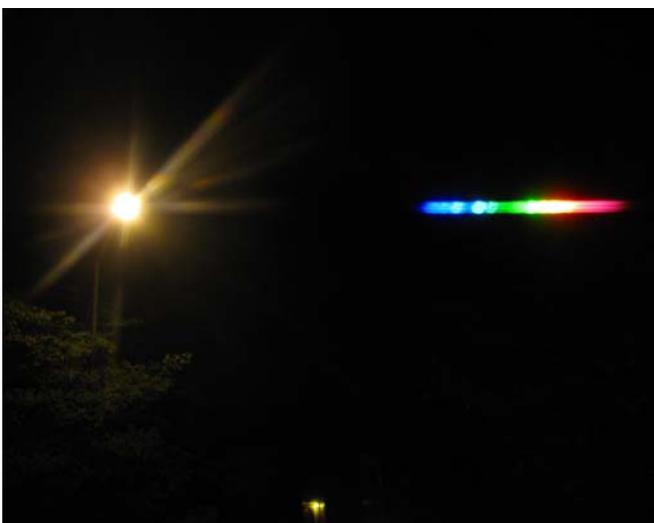
One evening, this spectroscope was attached to the author's laptop and went out for an ride! Armed also with a regular Canon digital camera, a slide mounted diffraction grating and a twelve-year-old who jumped at the chance to go riding around at 11 at night, a' hunting for spectra I went.

There are basically only a handful of major types of outdoor night-time lamps, though there are some subtypes among them. Whenever we spotted something that looked different, we took a quick look through the grating (see Figure 3 for an example) to see if the spectrum was truly different from whatever we'd seen before. If so, one of us would aim the fiber optic cable directly at the lamp while the other one manned the laptop. Once a good spectrum was obtained (no flattened, saturated peaks, if possible), we'd stop data collecting and do a screen capture of the spectrum graph. Then, I would take the digital camera, aim its small front lens through the diffraction grating, and move the rig around until a decent spectrum, first or second order, was centered in view. Because the lens was smaller than the grating sometimes I might end up pointing 20-60 degrees from the actual light fixture!

In the area surrounding TCA HQ we identified five major kinds of light sources: incandescent, high (very common) and low pressure sodium vapor, mercury vapor (of two kinds) and metal halide lamps (also two variations).

The digital camera is especially sensitive to the three primary colors red, green and blue, which makes the visual picture sometimes slightly different than what the graph shows. This explains the lack of yellow in the incandescent image—there's a black gap there that doesn't show up on the graph.

Notice there are two slightly different (mainly in the red and infrared) versions of metal halide lamps and even some slight differences amongst the fluores-



**Figure 3. A street light and its spectrum seen with a digital camera and diffraction grating.**

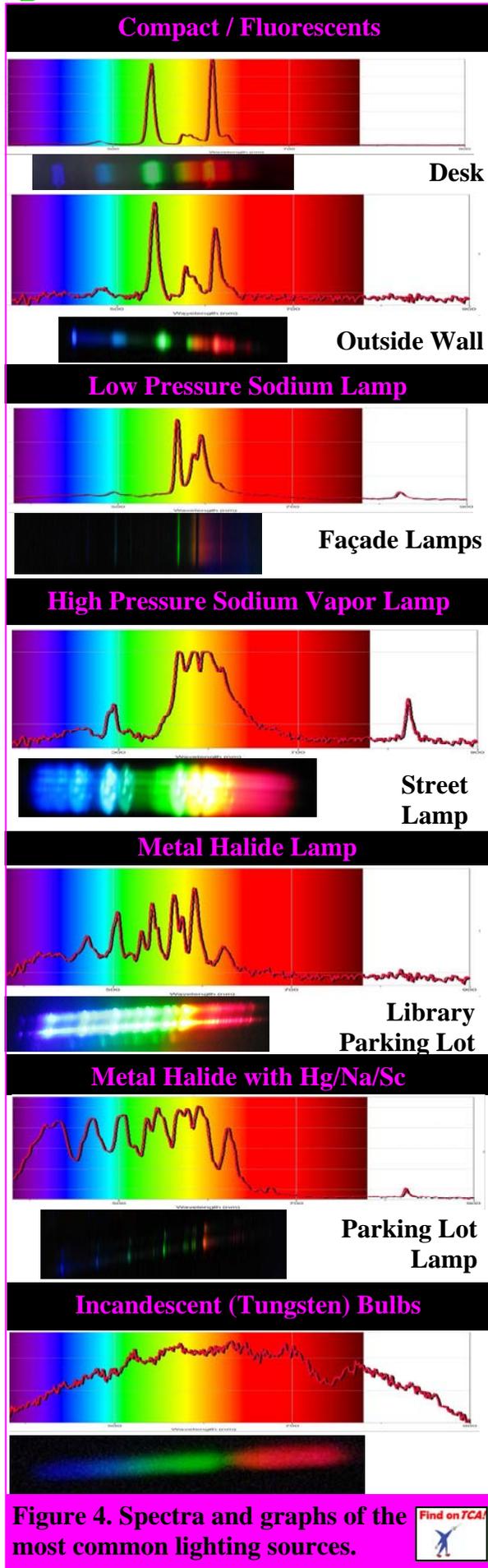


Figure 4. Spectra and graphs of the most common lighting sources.



cents, compact and otherwise. See Figure 4 for all the types, their spectra and spectrophotometry.

Besides identifying the light sources, what can you do with this information? How about conducting a survey of your school, campus or neighborhood? Pick a spot and count how many of each kind of lamp you see. Use the table adapted from the Arizona Public Service utility with our own cost effectiveness ranking added to rate how efficient is the area lighting. Note that the table is ranked in order of increasing *light* efficiency but when you add in the total cost (proxied by the number of hours the light could

Light Source	Efficiency (Lumens/Watt)	Average Lamp Life (Hours)	Color Rendering Index	TCA Cost Efficiency (Average 1000s of Lumens*Hours/Watt)
Standard Incandescent	5-20	750-1000	100	10
Tungsten-Halogen	15-25	2000-4000	100	65
Compact Fluorescent	20-55	10,000	80	375
Mercury Vapor	25-50	Up to 24,000	15-30	900
Metal Halide	45-100	10,000-20,000	60-90	1225
High Pressure Sodium	45-110	Up to 24,000	9-70	1860
Tubular Fluorescent	60-100	15,000-24,000	50-90	1650

run) you find the most effective, but among the least color pleasing, are high pressure sodium (HPS) lamps. If your survey shows more HPSs than anything else, your site is very energy efficient. Fluorescents may be better than incandescent, but they aren't yet as cost effective as other lamps for outdoor lighting.

How about a little practice before you go into the neighborhood? Try your hand at identifying spectra visually and graphically with Figure 5!

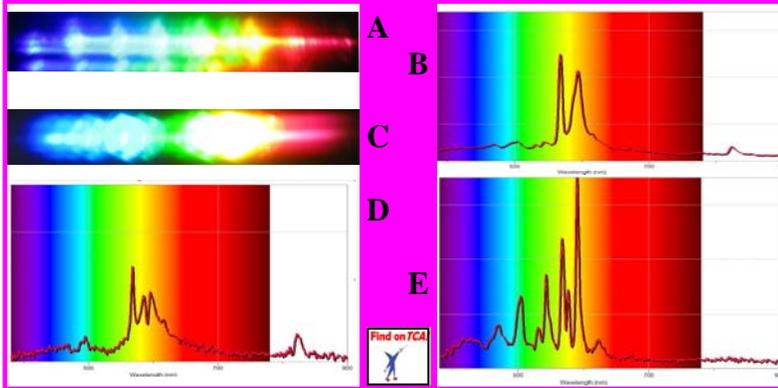
### Some Astrophysics!

Light pollution and gas tubes are all well and good but how about some celestial objects? Obvious candidates are the Sun, the Moon, some bright stars, an emission nebula, and the spectrum of the day and night sky.

Getting the Sun directly isn't possible, it's just way too bright. Even at the shortest possible exposure settings, the device is overwhelmed even when we weren't pointing exactly at the Sun.

On the other hand, the night sky pollution glow is too weak for even the longest integration time of one second. While the SpectroVis can average multiple samples, it is surprising that it can't ADD multiple samples and get a stronger summed value. This would help in getting spectra of stars. Using a small, common telescope, aimed at Vega, we saw no signal different from our "night sky" chaotic graph. Adding samples would improve the signal-to-

Figure 5. Can you identify these types of light sources? (Answers, Page 27)



noise ratio.

However, the daytime sky spectrum is surprisingly rich! As one can see in Figure 6, it is at least superficially close to a black-body curve over most of the spectrum (the instrument sensitivity drops dramatically in the blue) and the peak intensity is at 520 nm. Various citations on the Web for the Sun's blackbody temperature curve peak range from 483 to 518 nm, with most around 500 nm. There are nine absorption features, six of them quite strong and all but two are coincident with solar spectrum absorption lines or terrestrial constituents! The gibbous

Moon's spectrum collected by a 60mm refractor is almost identical to the daylight spectrum.

We didn't get stellar spectra by our deadline, but we plan to do so (and do more experiments!) soon. But clearly this device *can* add a rich component to your astronomy labs. **TCA**

All photos from the author.

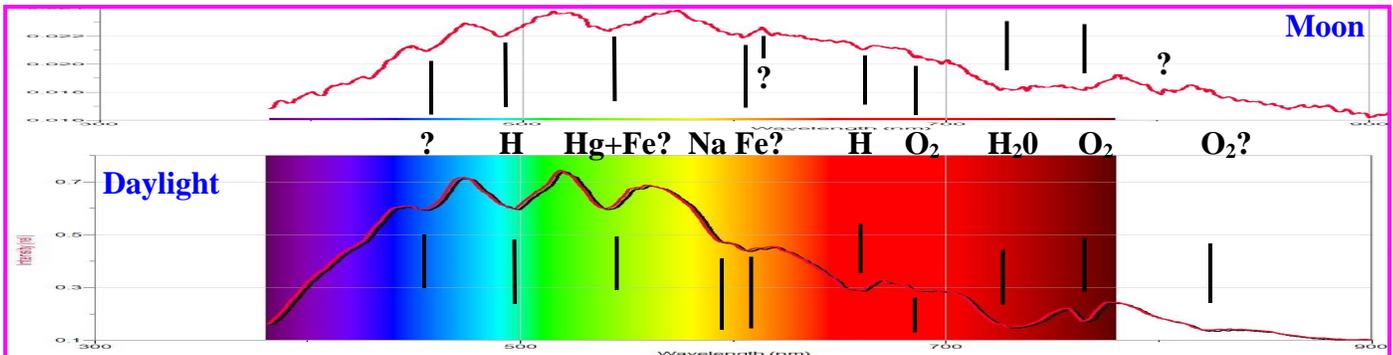


Figure 6. The spectra of the Moon (top) and daytime sky. Absorption lines are of both solar and earthly origin. Notice the intensity of the lunar spectrum is much lower than daylight, or a lamp!

Visual Spectroscopy Continued from Page 9

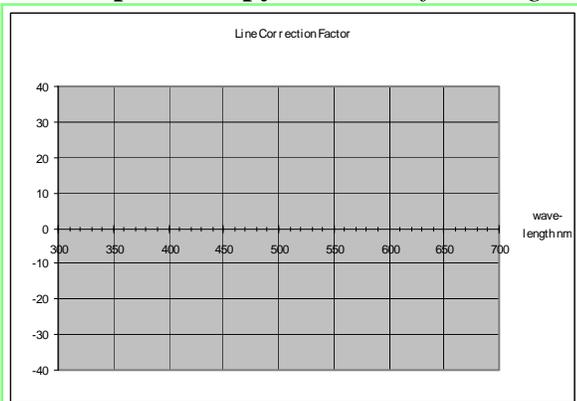


Figure 5. A blank calibration chart.



world, scientists have to determine their systematic errors as well. It's called calibrating your instruments. You have to know something else is accurate, and measure your values in your new scale against the known values.

You can calibrate your spectroscopes by measuring lots of known emission lines. Have your students measure the lines of Mercury and Helium (see Figure 4 on page 9). Together they have around 10-12 lines of known wavelengths. Make a graph of differences (observed - known) on the Y axis and observed wavelength on the X axis (Figure 5). For most spectroscopes, the differences will be usually small or non-existent for violet through yellow or orange. If your scale is not placed properly in its holder, then you will get fairly constant, non-zero differences. In

either case, in the red zone you'll start getting much larger sets of differences because of the discordance between the linear scale and non-linear diffraction process.

Once you have the graph, a student can then measure any line of any emission or absorption spectrum, and subtract the difference for that observed wavelength and get the real wavelength.

Note to lower grade teachers. There are quite a few textbooks that show the spectrum with a scale along the bottom for wavelengths. As a backup to a lack of spectroscopes, you can do a proportions/ratio exercise and get similar results. **TCA**

All photos from the author.