

A Comparison of Spectrometers: StellarNet, Inc. vs. the Competition

With a growing amount of miniature spectrometer systems available, what are the key areas to be examined when choosing a unit? This overview will show how StellarNet compares to what other spectrometer manufacturers' are offering in several areas.

Ruggedness

The first area where StellarNet stands out is our ruggedness and shock-proof durability: there are no electronics in the optical bench and our detector is bolted to the exterior of the bench as apposed to being placed in a socket. Our units are then further ruggedized by placing the spectrograph in an extruded aluminum enclosure. In contrast, Ocean Optics (OOI) a well known maker of miniature spectrometers, uses delicate enclosures for both optics and electronics which are very sensitive to shock and damage. More, their optical alignment assembly is held by only two small epoxied points, which are exposed at the bottom of the unit. While it's true that their units may be portable, they are not rugged and should not be dropped.



Figure 1: View of the bottom of an OOI HR4000 showing the rotating optical bench held in place with epoxy (blue).

S/N Ratio

StellarNet offers the best Signal to Noise ratio in the low-cost market, as you can see from our specs. Our Concave grating unit has a signal to noise of 1000:1 to 2000:1, while OOI specifications show only in the 250:1 to 500:1 for a comparable model. The methodology for this is as follows:

- 1) Set the spectral sample averaging to 10.
- 2) Set the detector integration time for full scale using a halogen lamp (i.e. 4096 maximum counts on a 12-bit digitizer).
- 3) Turn the light off and save 10 dark spectrums, and analyze for S/N.
- 4) Turn the light on and save ten sample spectrums, and analyze for S/N at the top of the A/D (i.e. on a 12-bit digitizer near 4096 counts). The S/N is the mean divided by the standard deviation of the 10 scans.

For example, for each pixel i ; calculate: $\frac{\sigma_i}{\mu_i}$

The StellarNet standard deviation will show the same at the top and the bottom of the A/D (with approximately 4 counts of noise, which translates to a S/N of 1000/1 with 10 sample averages on a 12-bit digitizer). With other instruments, you'll see 13-15 counts of noise at the top of the A/D. On a 12-bit digitizer then $S/N = 4096/15 = 273$.

Linearity:

Although wavelength accuracy (x-axis) is important to any spectrometer system and can be checked by several methods (gas emission lines), one factor that is often overlooked is the linearity (y-axis). Two models of StellarNet's EPP2000-UVN-SR spectrometer were compared to Ocean Optics HR4000 model for linearity. The HR4000CG-UN-NIR unit uses a 7th order polynomial to characterize the CCD detector, known as a Linearity Correction (LC) factor, while the StellarNet model does not require one.

Model	Wavelength Range	Signal to Noise	Detector Type
StellarNet UVN-SR	200-1100 nm	500:1	2048 element CCD
Ocean Optics HR4000	200-1100 nm	300:1	3648 element PDA

Table 1: Basic specification of tested units

Each unit was measured using a series of Neutral Density (ND) filters supplied from Thorlabs, Inc. at 546nm. The varying filters have a unique absorption and produces spectrally flat transmission (obtained by differing filter thicknesses). The optical density, D, is defined by the following equation: $D = \log_{10}(1/T)$, or $T = 10^{-D}$.

Filter	ND	%T (546nm)	HR4000 with LC	HR4000 w/o LC	UVN-SR (1)	UVN-SR (2)
NE01A	0.1	79	79.535	79.534	77.412	78.828
NE03A	0.3	50	58.336	58.136	54.54	52.011
NE05B	0.5	32	32.648	32.415	30.375	31.763
NE10B	1.0	10	11.78	11.557	9.929	10.612
NE13A	1.3	5	6.485	6.338	5.23	5.647
NE20B	2.0	1	1.521	1.204	0.951	0.611

Table 2: Percent Transmission data using Thorlabs filters with each unit

The results were then plotted and the linear regression and % Linearity were calculated.

Please note that we used a detector integration time that allowed full scale input to the digitizer of 4096 counts for 12-bit (16384 for 14-bit and 65535 for 16-bit). **We highly recommend using detector integration times at the expected sample measurement rates** to ensure good linearity at “fast integration” times. Bad linearity is the major source of instrumentation measurement errors. Linearity errors can go undetected and will absolutely kill computational accuracy over the dynamic range of your measurement application.

Please review the following linearity graph:

Linearity Determination using Neutral Density Filters

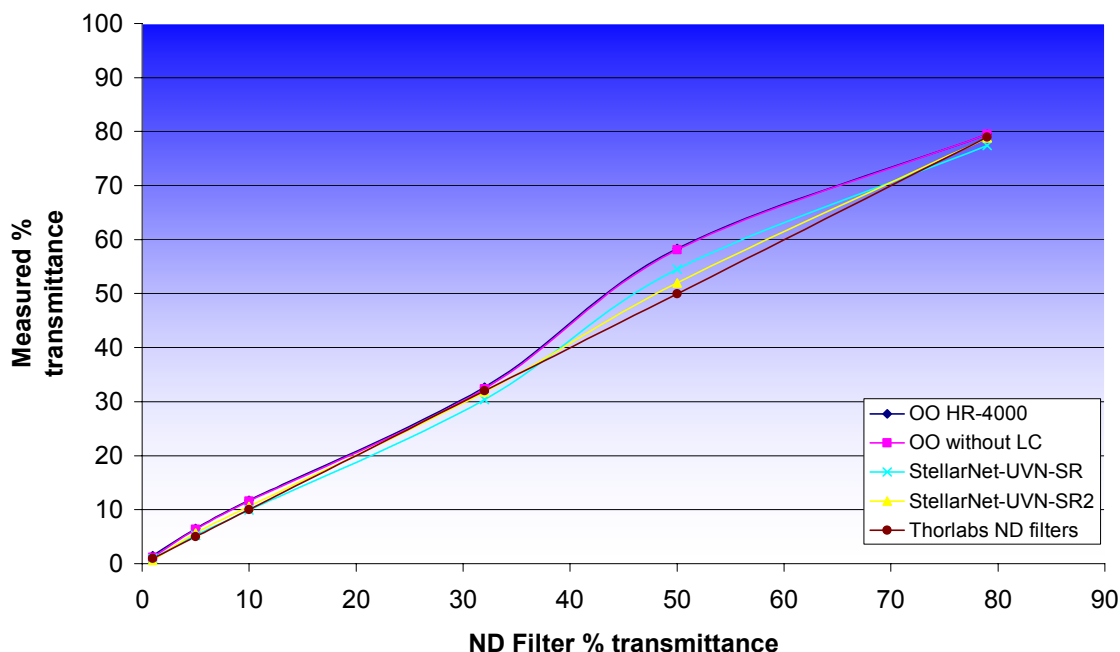


Chart 1: Plot of percent transmission data from tested units vs. ND filters

Spectrometer	Regression	% Linearity
StellarNet EPP2000-UVN-SR(1)	1.005	99.495
StellarNet EPP2000-UVN-SR(2)	0.996	99.586
Ocean Optics HR4000 with LC	1.051	94.888
Ocean Optics HR4000 w/o LC	1.049	95.099

Table 3: Regression and linearity data from raw data

The results show that the unit with the best linearity was StellarNet’s EPP2000-UVN-SR with an average value of 99.54%, while Ocean Optics had an average linearity value of 94.99%. It should be noted that with the Linearity software correction provided in the Ocean Optics software actually *decreased* linearity of the unit.

Test for Reciprocity

When you analyze any spectra, you should see the signal halved when you half the integration time. While this is the case with StellarNet’s spectrometer, it may not be the case with all others. The methodology is as follows:

- 1) Set the detector integration time for full scale using a halogen lamp (i.e. 4096 maximum counts on a 12-bit digitizer) and save the spectrum.
- 2) Decrease the integration time in half and save the spectrum.
- 3) Half the integration time again and save the spectrum.
- 4) Repeat as many times as you like.
- 5) Perform this test using other spectrometer instruments and then compare.

Can You Take the Heat

Wavelength stability as a function of temperature is important for all spectrometers, especially for field measurements. To test this use a Mercury-Argon gas emission tube (such as the StellarNet SL2 lamp) and heat or cool the spectrometer (from 10°C - 20°C) while watching any selected gas peak wavelength. The wavelength should not shift as a function of temperature. All StellarNet spectrometers utilize optimal thermal design and stabilization circuitry to minimize baseline and wavelength drift. On the other-hand it has been documented by the USDA UV-B Monitoring and Research Program that the Ocean Optics HR4000CG-UV-NIR unit has a ½ nm shift for every 10°C shift in temperature¹.

Quality Price Performance

StellarNet prides itself on being an industry leader delivering high quality and performance at a low price. For example, we offer a low cost, flat-field spectrometer (EPP2000C) which consists of an aberration corrected concave grating that delivers uniform resolution across its range. It also has a securely mounted detector with no mirrors for the lowest possible stray light and superb spectral imaging. There are no moving parts for portable applications that require vibration tolerance and permanent alignment. This instrument provides the same grating you would find in a high-end spectrophotometer and is without doubt a portable Cadillac instrument. With a concave grating there is no need for mirrors and this minimizes stray light that is crucial in most spectroscopy measurements. What should be noted is that the resolution is constant throughout the entire spectrum as opposed to the typical Czerny-Turner design where only the center wavelength can be in focus. Lastly, the grating provides aberration correction for superb optical imaging into the detector array and creates extreme sensitivity (x2 higher signal) below 400nm “like no other”.



Figure 2: Optical bench of permanently aligned EPP2000C concave grating spectrometer.

Superior NIR Arrays

For NIR applications StellarNet uses Sensor’s Unlimited InGaAs Photo Diode Array detectors. This chip is 500 µm tall, which doubles the sensitivity when compared to 250 µm tall PDA’s made by Hamamatsu, and has a 0% drop-out as opposed to 2% of typical arrays from Hamamatsu. It is a superior chip considering higher speed and sensitivity and does costs more money to make. However, StellarNet offers the NIR-InGaAs-512 element spectrometer with USB-2 interface for thousands less than OOI (which use the Hamamatsu detector). StellarNet also offers 1024 element InGaAs detector arrays for both standard NIR 900-1700nm, High Res NIR for WDM (1500-1650nm), and extended InGaAs NIRX ranges for 900-2300nm.

Don't Be Fooled by Numbers

OOI has switched to the Toshiba TCD1304AP detector in most of their spectrometer models. They claim that this is a superior 3648 element CCD detector, when actually it is a PDA detector with a CCD readout. While this means that it should have better Signal to Noise ratio than a CCD, it will not be as sensitive. This detector also has lots of noise which precludes it from many "real" spectroscopy apps other than teaching labs.

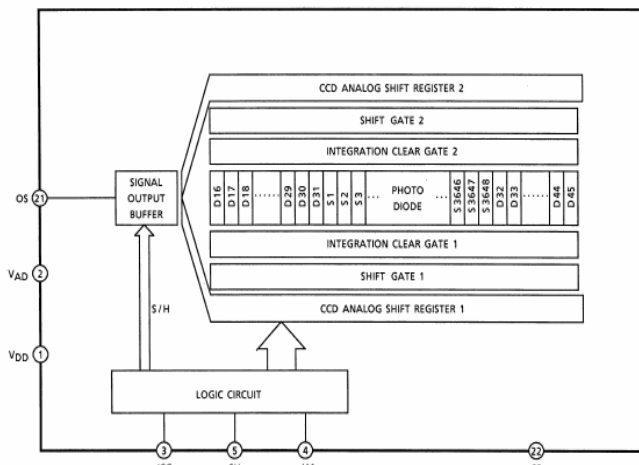


Figure 3: Schematic of the Toshiba 3648 detector showing PDA detector/CCD readout.

Speed

How fast do you need your data? All of StellarNet's models utilize USB2 spectrometer to PC connections (UV-VIS, NIR-InGaAs, PORTA-LIBS, etc.), while Ocean Optics uses the 40x slower USB1 port for all but one model. This is crucial for episodic data captures and other applications that require external triggers and fast process monitoring.

Stray Light

Stray light is defined as a signal by the spectrometer of transmitted light when in actuality there is no light. The presence of stray light may cause errors in your analysis especially at high absorptions where it causes a negative bias in instrument response and eventually is the limiting factor for absorbance/concentration measurements (and overall compromises the accuracy of the instrument). Stray light can be a problem at any wavelength range of the instrument but the problem increases the further into the UV. Stray light measurements can be checked by using Starna Cells' Stray Light Reference Materials which can determine the amount of stray light in the spectrometer. Each of these solutions stops transmitting light below a specific wavelength. Therefore, below a specified cut-off wavelength, any indication of light transmission must be stray light. The testing for stray light is important even if the spectrophotometer is not used below 260nm because it is an excellent indication of the overall system health of the spectrometer's optics, gratings, etc. The procedure, as specified by Starna, is as follows²:

- 1) Insert the stray light blank cuvette in the light path of the spectrophotometer and save it as a reference spectrum.
- 2) Insert the stray light reference cuvette and take a measurement.
- 3) Examine the spectra into the UV (to the lowest wavelength that your instrument can read) and at 20nm above the cutoff for the stray light reference being used. Any light transmitted below the cutoff wavelength is stray light.

StellarNet's EPP2000C has the lowest stray light values of any portable spectrometer unit, thanks to the specially design concave grating optical bench (see details above in "Quality Price Performance"); 0.02% at 435nm and 0.05% at 200nm.

Where does it come from?

StellarNet manufactures virtually everything in house, from light sources, spectrometer circuitry, even, fiber optic cables. Other manufacturers are known for buying and reselling parts, and only putting their label on it. What this means is a more knowledgeable staff who can better answer your questions, from every step of the process.

Software

"The software is the instrument". SpectraWiz truly is The "Swiss Army Knife" of spectroscopy applications and will handle most every spectroscopy measurement need. With SpectraWiz you can measure transmission, reflectance, absorbance, emission, irradiance, but it also so much more. You can collect episodic data and create time series graphs, examine reflected colors with CIELab, display spectral irradiance in watts/lumens, display xy chromaticity and CCT, use ChemWiz for setting up concentration experiments...just to name a few. See website for complete listing. Customizable software programs are also provided free of charge: SpectraWiz for LabVIEW and VBA+for Excel runs spectrometer directly from an MS Excel spreadsheet. Additional sample programs are free downloads for such as MS C++ and Borland Delphi Pascal.

References

- [1] Tree, Roger and Slusser, James. "Proceedings of SPIE: Ultraviolet Ground- and Space-based Measurements, Models, and Effects V." Measurement of spectral signatures of invasive plant species with a low cost spectrometer. 5886 (2005): 264-272.
- [2] Starna Cells. Stray Light Reference Materials. 26 Oct 2006.
<www.starna.com/d_ref/d_sl/Stray.html>

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