Near-Infra-Red Suppressed "Blue" Calibration Source

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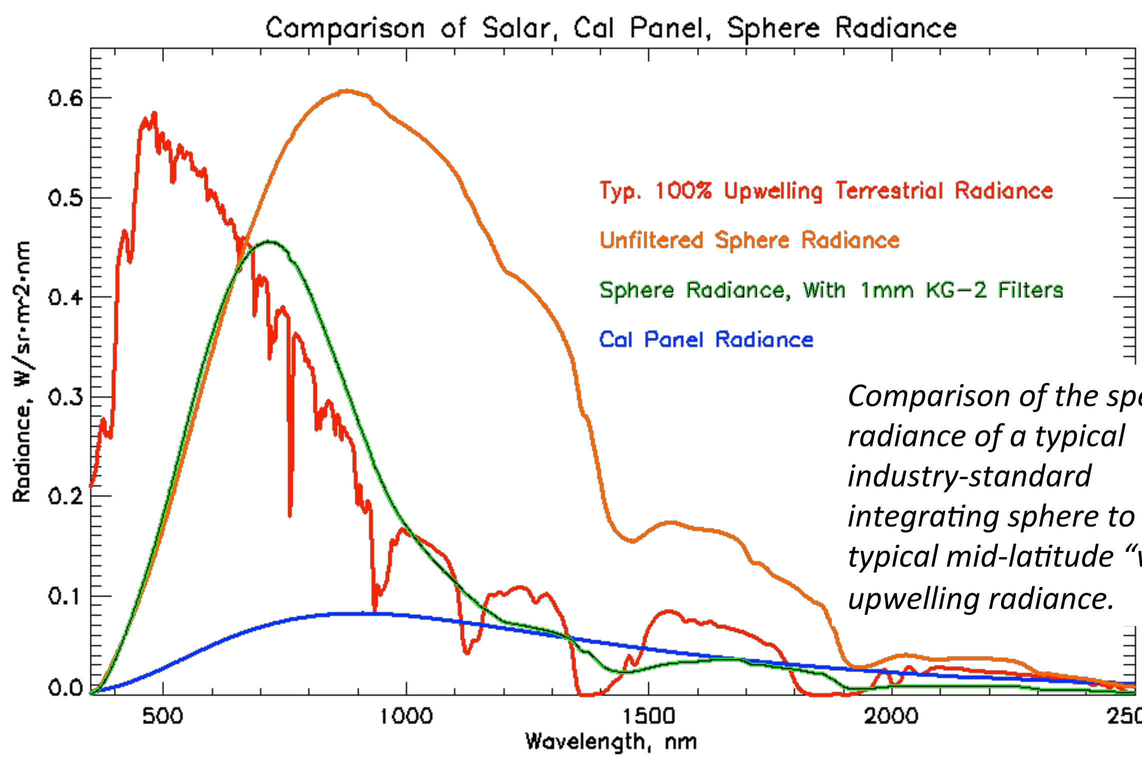
Abstract:

Laboratory calibration and characterization methods using incandescent sources have been notoriously blue deficient. A homogeneous spectral radiance source which better matches that of a bright terrestrial target has been developed. Standard industry practices and the issues encountered are discussed. How our solution addresses the problem and details of our approach are presented. This effort is part of an overall goal of developing cost-effective techniques for accommodating and determining the spatial/spectral transfer function of imaging spectrometers.

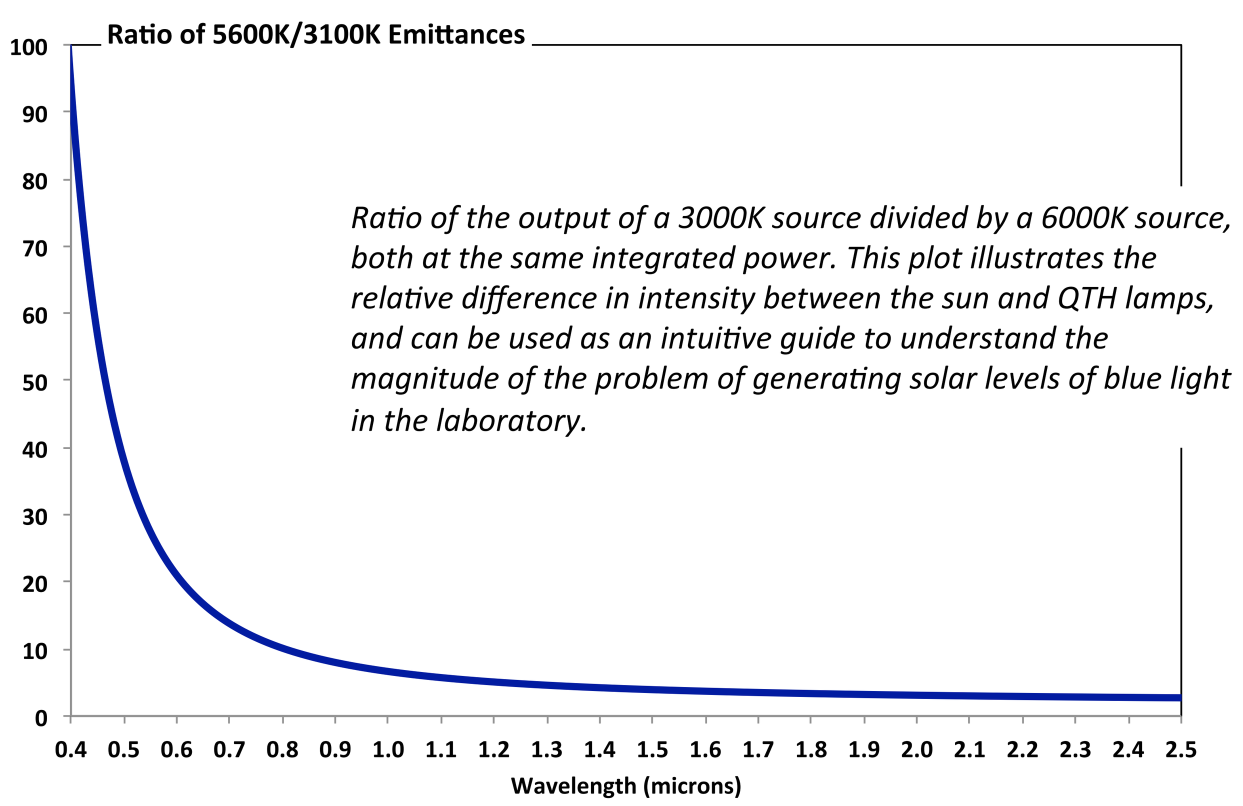
Spectral imagers familiar to the HyspIRI community are generally calibrated and characterized with integrating spheres. They provide a spatially uniform target source of readily measured radiance. Standard industry practice is to use a Quartz Tungsten Halogen, or QTH, lamp as the primary illumination source of the sphere.

Spectrally, the output of QTH lamps are close to a 3000K Planck function. Best practices in the remote sensing calibration community are to calibrate at radiances within the scene dynamic range (Dinguirard & Slater). Compared to sunlight, essentially a 6000K source, incandescent sources are notoriously blue deficient. These lamps also produce excessive near-infrared (NIR) flux once scaled for reasonable output irradiance over the visible (VIS) part of the spectrum.



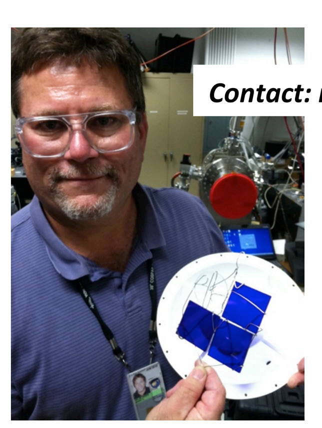
Comparison of the spectral radiance of a typical industry-standard integrating sphere to a typical mid-latitude "white" upwelling radiance.

Technically, the main quantities plotted above are the output of a 20 cm aperture, QTH illuminated, $BaSO_4$ coated integrating sphere and the upwelling radiance of a spectrally flat 99% reflectance target (Spectralon) measured mid-Summer, mid-day, at mid-latitude. The plot also shows what filtering can do (bit of a spoiler), as well as the transfer radiance that can be expected from a standard 50 cm NIST lamp-and-panel calibration source. This illustrates the relative intensity of current laboratory practices to the high side of scene reality. An ideal laboratory spatially uniform source would approach the solar upwelling shape and intensity.



Ratio of the output of a 3000K source divided by a 6000K source, both at the same integrated power. This plot illustrates the relative difference in intensity between the sun and QTH lamps, and can be used as an intuitive guide to understand the magnitude of the problem of generating solar levels of blue light in the laboratory.

Examining the plot above, it can also be seen that at 400 nm, one would need about two orders of magnitude more lamp power than solar power to achieve an equivalent channel radiance. It can also be seen that such an intensity would also produce about two orders of magnitude more NIR light than is required or desired.



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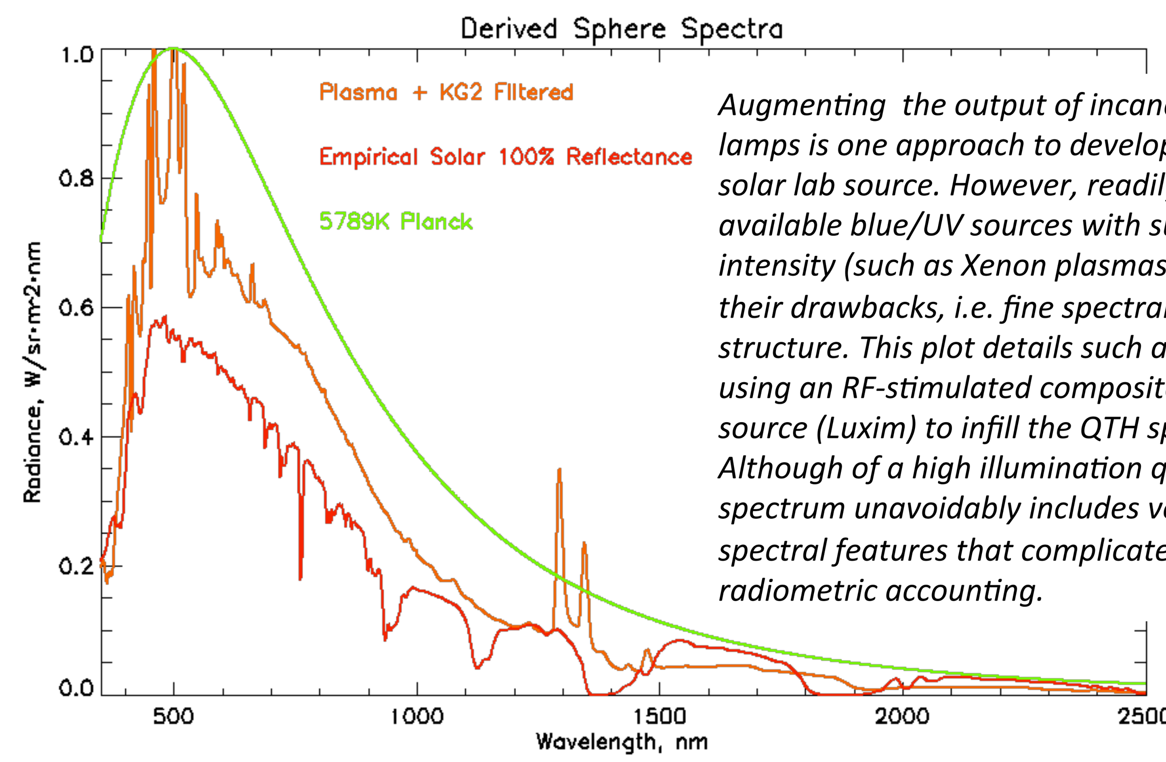
The "Blue Sphere" in action, calibrating AVIRIS Next Generation as installed in the Twin Otter

For spectral imaging systems with isolated spectral channels, or, systems that are not sufficiently sensitive to systematic spectral crosstalk, the technique of using distinct sphere levels for each channel helps mitigate these issues somewhat (Bruegge, et. Al).

However, since the latest spectral imagers use one optical train that handles the entire 0.38 to 2.5 micron range, and detector electronics noise characteristics and effective dynamic range has been improved, subtle optical spectral scattering effects have become more visible. An excess of stimulation in one part of the spectral range (i.e. NIR) can noticeably scatter into and prevent achievable accuracy in the spectral region of interest (VIS/Blue).

There are other considerations: It is also understood that in particular for imagers with relatively narrow spectral channels, that spectral radiometry is complicated by the convolution of fine spectral structure (Mouroulis, Green, & Chrien). This means that an overall smooth spectral source function is called for. These considerations constrain the possible approaches to achieving solar-like calibration sources.

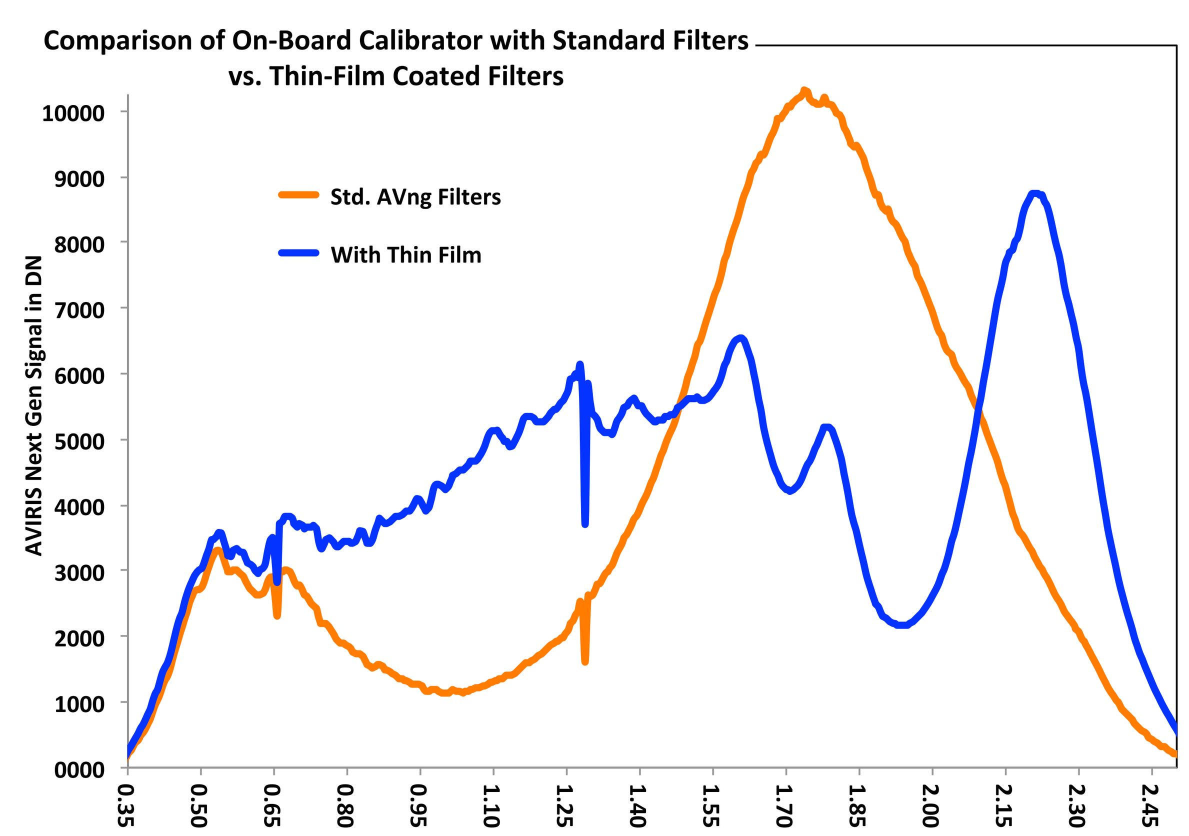


Augmenting the output of incandescent lamps is one approach to developing a solar lab source. However, readily available blue/UV sources with sufficient intensity (such as Xenon plasmas) have their drawbacks, i.e. fine spectral structure. This plot details such an effort using an RF-stimulated composite plasma source (Luxim) to infill the QTH spectrum. Although of a high illumination quality, the spectrum unavoidably includes very sharp spectral features that complicate radiometric accounting.

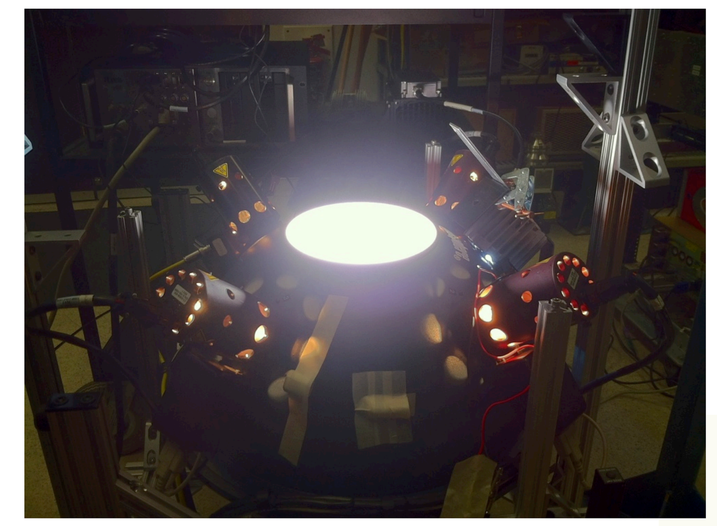
QTH sources make for excellent NIR sources in that they are readily and economically implemented, stable, spectrally smooth, and sufficiently intense. An economic solution starts with lamps. Whether to augment or filter their output then becomes the next consideration.

Filtering out the excessive NIR of an incandescent source is the next available path. Of that, two approaches have been tried: Reflective filters and absorptive filters. The advantage of reflective filters is thermal control. Absorptive filters can have heating issues when nearly 90% of the optical power must be dealt with in some way.

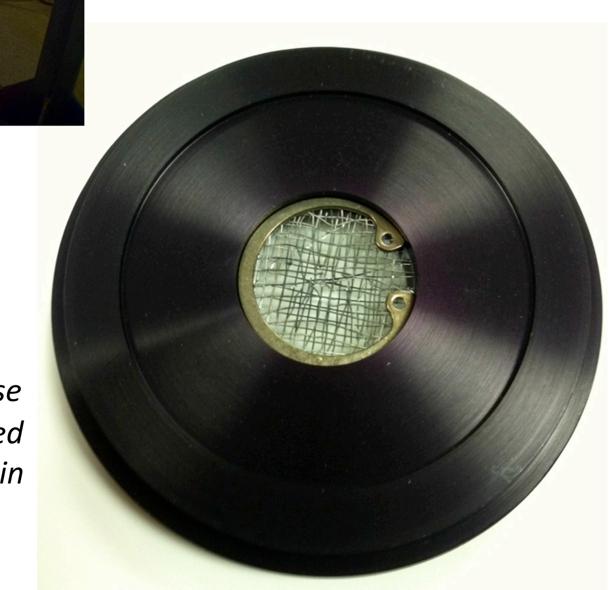
However, reflective filter technology is based on thin film materials which have their own peculiar spectral contributions. The plot below shows the results of an attempt at custom reflective interference filter design.



The absorptive filter approach showed promise in producing a more solar-like shape with spectral smoothness. Preferred filter types (Schott KG, BG) were defined. In the case of a large plate of filter glass placed over the exit aperture of an integrating sphere, the measured output spectrum was of a much improved overall shape. Warming of the filter due to absorption was not found to be an issue. However, the beneficial Lambertian property of the integrating sphere was lost. Front-surface reflection, stray light, and varying filter path length issues were found to be spatially and radiometrically significant and nearly impossible to characterize.

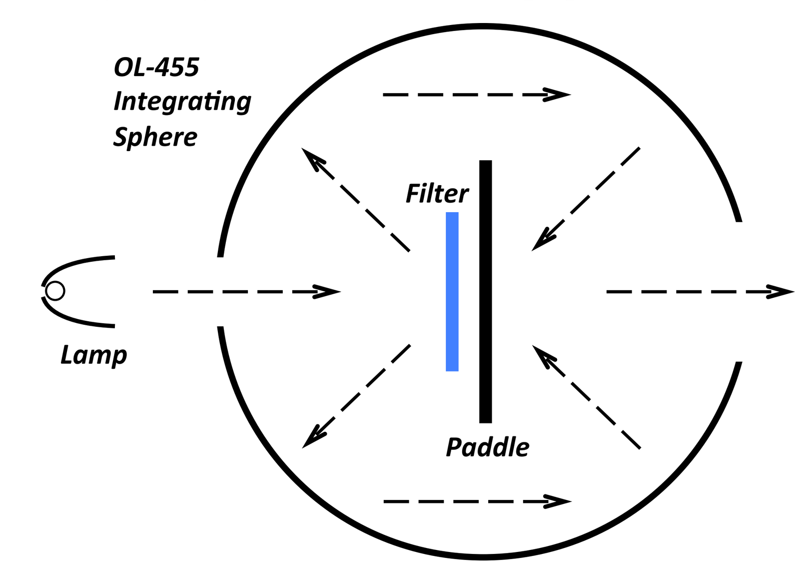


Some way of absorptively filtering the light input into an integrating sphere was needed. Our first useful effort was to modify and existing sphere which had four light projectors symmetrically mounted to evenly illuminate the sphere.



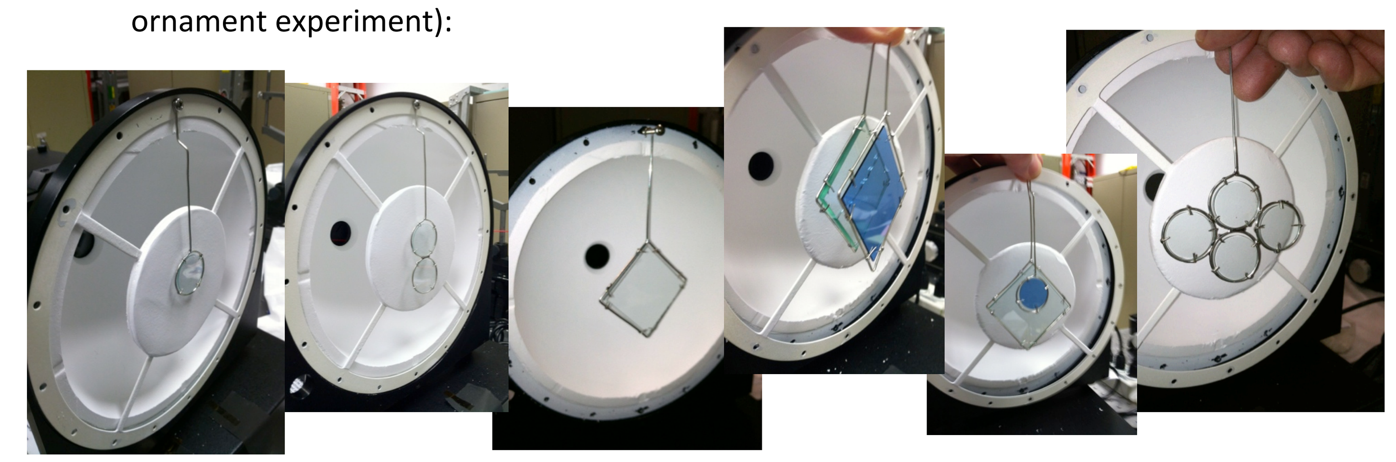
The preferred absorptive filter type was incorporated into one of the projectors and tested un-attached, outside of the sphere. Upon illumination, the filter immediately shattered, but into just a few pieces. Because the integrating sphere would make a cracked filter moot, a screen to capture and constrain a pre-cracked filter was included.

This approach worked well, but greater radiance in the blue & UV was needed. As well, a more compact and convenient design (it was found that the screens deteriorate, sprinkling the interior of the sphere with filter dust) was desired. The next development path came from scrounging available laboratory instrumentation.

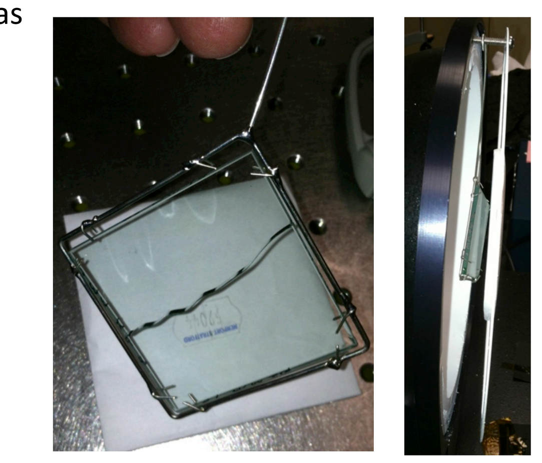


The OL-455 laboratory integrating sphere is known for its intensity. Another advantageous feature is a circular paddle suspended in the middle. This enables a linear illumination input configuration and a unique spatial output radiance uniformity.

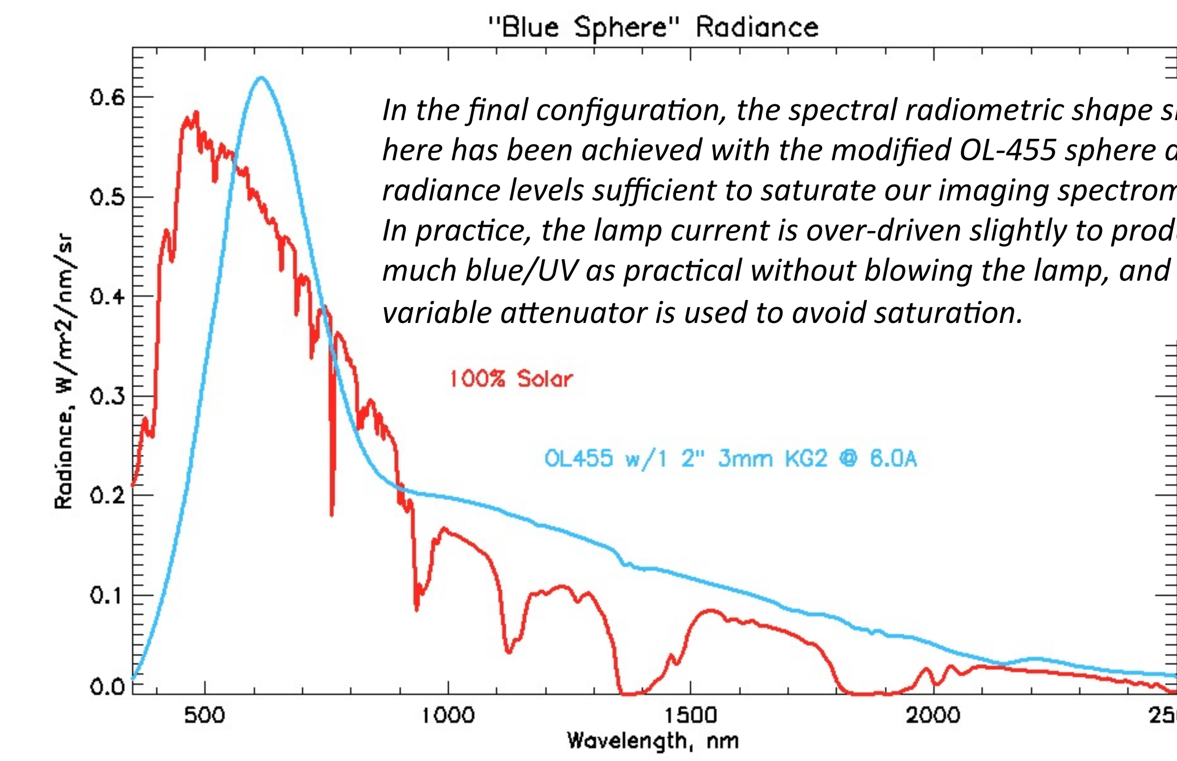
The filter cracking that happened with the 20 cm aperture integrating sphere was due to non-uniform flux on the filter, which was mounted near the focus point of the parabolic reflector of the lamp projectors. It occurred to the authors that besides being brighter, the internal design of the OL-455 sphere enabled a key optical geometry: An absorptive filter, strategically placed behind the paddle, might be more evenly illuminated and heated, as well as act like a NIR sponge within the sphere. It would also not be visible from the exit aperture. Many preliminary versions and combinations of filters were tried (this was called the Easy-Bake Oven Christmas ornament experiment):



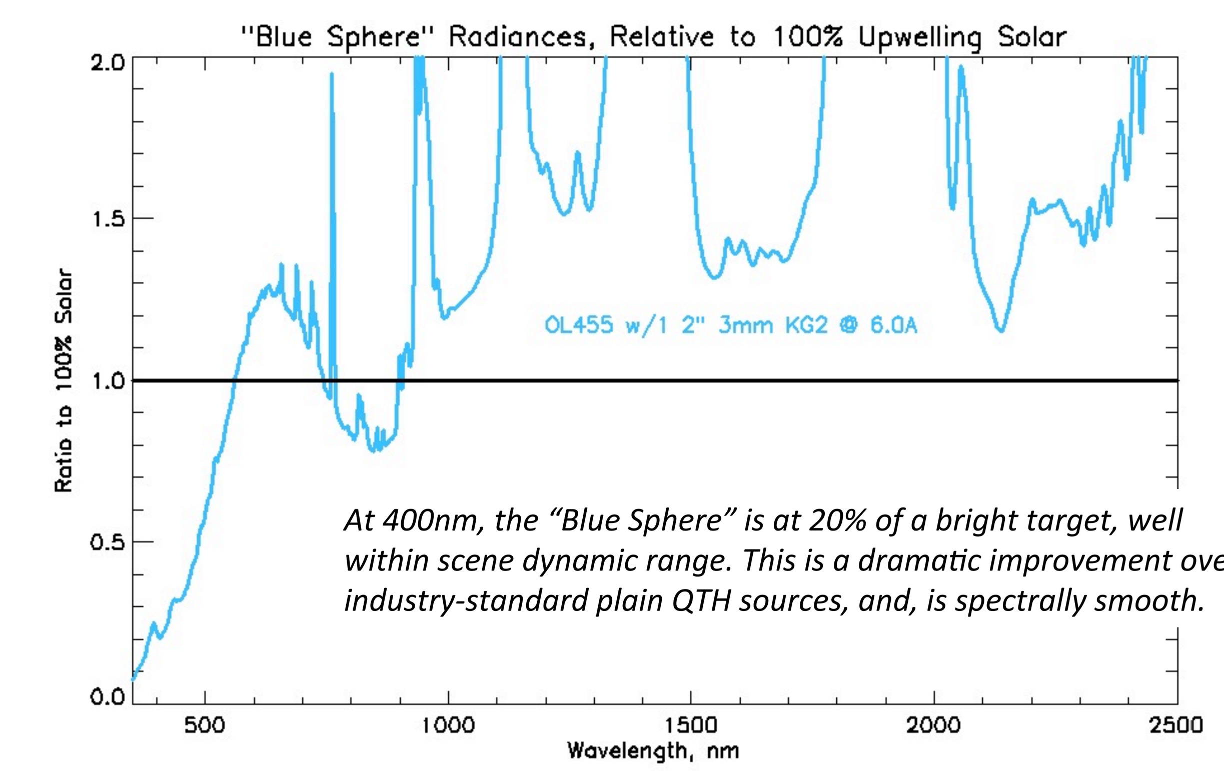
It was confirmed that the homogeneous illumination conditions inside of the integrating sphere evenly heated the filters and reduced the tendency of shattering. The size and density of filter that worked best, however, was found to get hot enough to melt the solder of its holder! As well, it was Found to be possible to open the variable attenuator of the OL-455 too quickly, and crack the filter.



The current filter, cracked in battle and super-glued back together, in its soldered holder. The current wire holder is bent from one piece of wire, with no solder. Also, filter as mounted behind the paddle.



In the final configuration, the spectral radiometric shape shown here has been achieved with the modified OL-455 sphere at radiance levels sufficient to saturate our imaging spectrometers. In practice, the lamp current is over-driven slightly to produce as much blue/UV as practical without blowing the lamp, and the variable attenuator is used to avoid saturation.



At 400nm, the "Blue Sphere" is at 20% of a bright target, well within scene dynamic range. This is a dramatic improvement over industry-standard plain QTH sources, and, is spectrally smooth.

In conclusion, a method of spectrally shaping incandescent sources to produce a smooth spectrum of realistic radiance has been shown to be practical. There is still a lack of deep blue and UV light in this incarnation of the approach. In the future, more incandescent light can be added and shaped, with the great majority of that optical power going to heat. Other development paths that may hold promise include infill with white lasers, custom phosphors, laser-pumped plasmas, or closely-stepped LEDs.

This development effort is the result of an understanding at JPL of an increasing need to strategically develop cost-effective practical techniques to more accurately characterize the spectral (and spatial) transfer function of the latest generation of compact imaging spectrometers. An added motive is to calibrate the instrument with scene-radiance fluxes:

Calibrate like you fly, fly like you calibrate.

References:

Dinguirard, M., & Slater, P. Calibration of Space-Multispectral Imaging Sensors. *Remote Sensing of Environment,* 194-205.

Bruegge, C. J., Duval, V. G., Chrien, N. L., Korechoff, R. P., Gaitley, B. J., & Hochberg, E. B. (1998). MISR prelaunch instrument calibration and characterization results. *Geoscience and Remote Sensing, IEEE Transactions on*, 36(4), 1186-1198.

Mouroulis, P., Green, R., & Chrien, T. Design of Pushbroom Imaging Spectrometers for Optimum Recovery of Spectroscopic and Spatial Information. *Applied Optics,* 2210-2210.