

Spectral Tools

User Manual 1.0

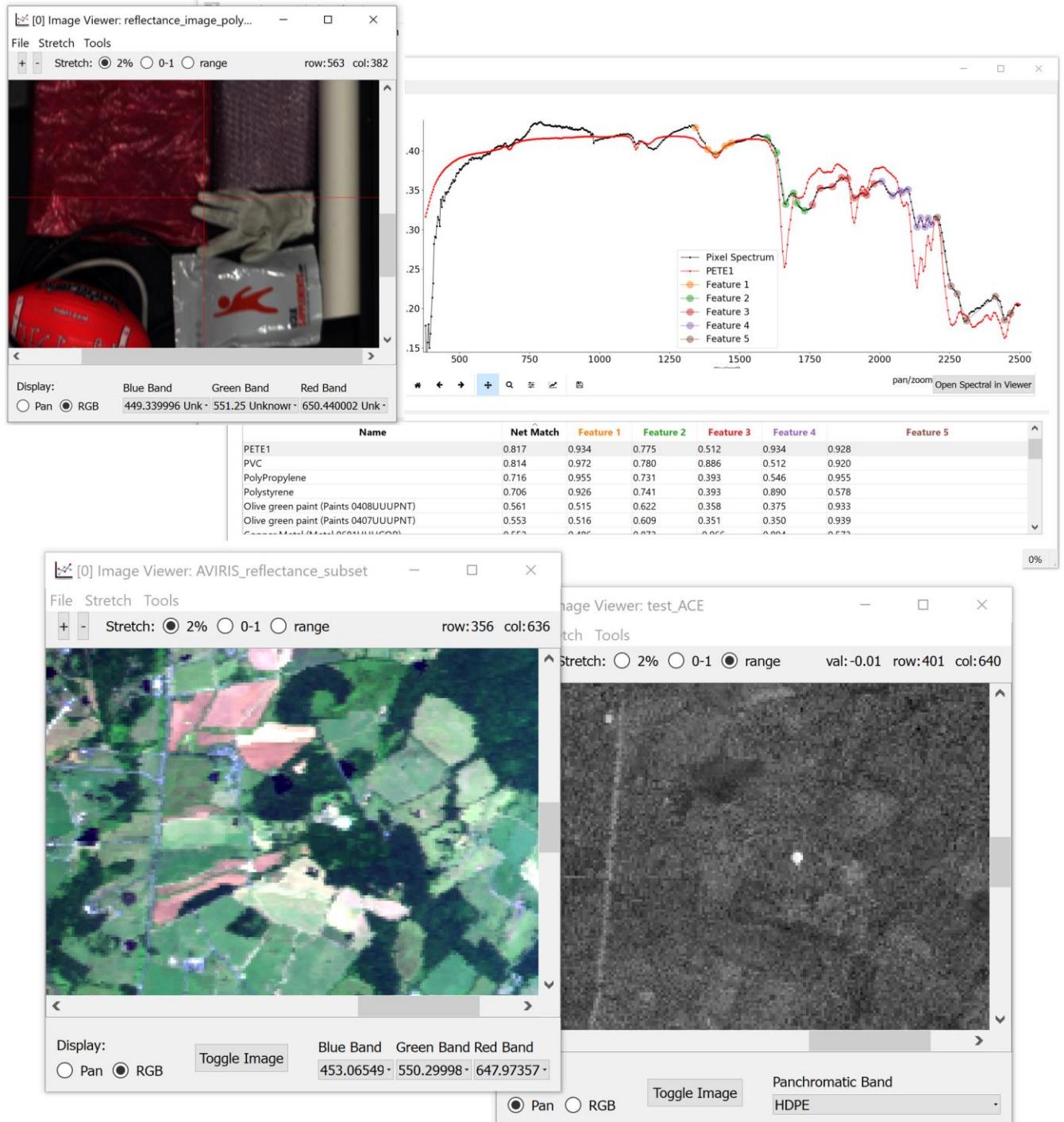


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Section 1. Basic Toolbar Functionality

The Menubar is the top-level GUI for accessing all the Spectral Tools functionality. Individual menu items can be accessed by clicking or hot keys (ie Alt+f for the File menu). The Menubar is shown in Figure 1-1.

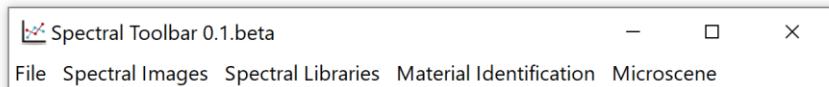


Figure 1-1. The main menubar.

The functionality in each menu item is as follows:

File: Functionality for opening images and spectral libraries, and for settings.

Spectral Images: Functionality for processing images.

Spectral Libraries: Functionality for processing libraries.

Material Identification: Functionality for identifying materials present in an image/library spectrum by comparing against a spectral library of known materials.

Microscene: Functionality specific for processing Microscene data.

Section 2. The image Viewer

2.01 Opening and Viewing an image.

An image can be opened by selecting File -> Open Image (shown in Figure 2-1) or by the hotkey Ctrl+O. This initiates a standard file selection GUI for the user to select an ENVI image file or header file associated with the image. Currently only ENVI image files can be opened.

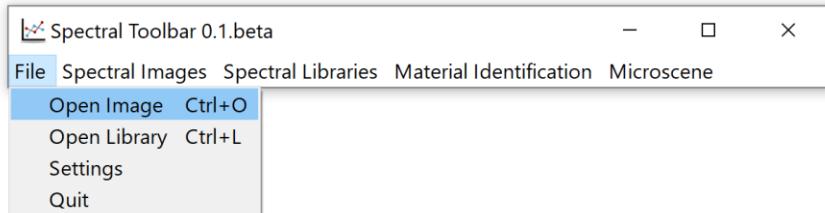


Figure 2-1. Opening an image from the menubar.

The image is opened in the Image Viewer GUI, shown in Figure 2-2.

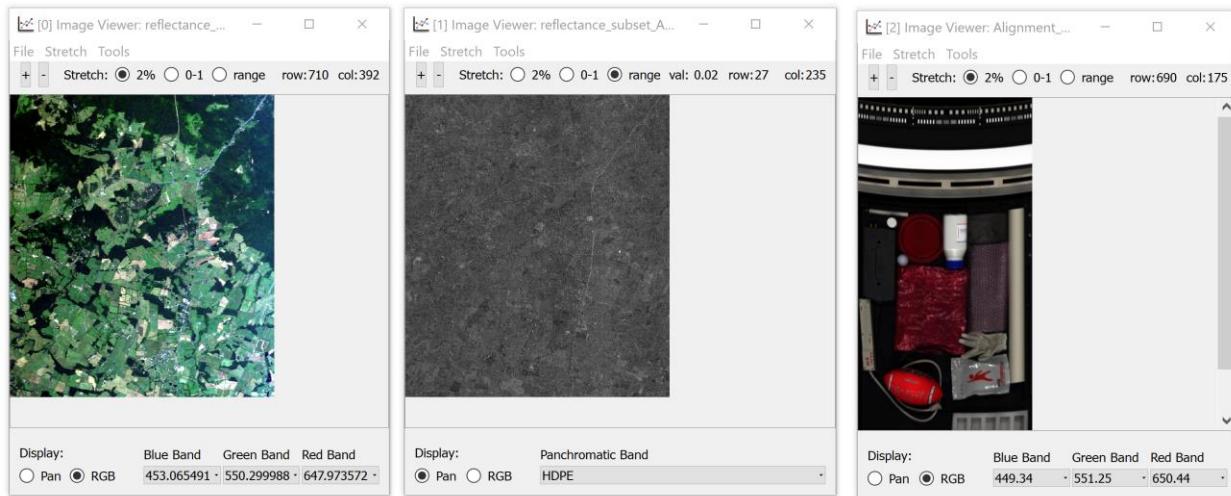


Figure 2-2. The Image Viewer used to display and interact with images, displaying 3-bands in RGB from an AVIRIS image (left), a single band from target detection as a panchromatic image (middle), and 3-bands from a microscene image (right).

2.02 Image Viewer Display and Navigation

Title: The title of the image viewer has the format “[index] Image Viewer: filename”, where index is a unique index for each Image Viewer used to reference the viewer and filename is the name of the file for this image.

Display Type: In the lower-left area, the “Pan” and “RGB” radio bands allow the user to either display a panchromatic image (one band) or a 3-band RGB (Red, Green, Blue) image.

Band Selection: In the lower-right area, drop-down menus allow the user to select the band(s) being displayed. When the cursor is placed over the menu, the mouse wheel allows the user to scroll through displayed bands.

Pan: Left-click and hold down the left button to grab the image and drag it to pan around the image. Vertical and horizontal scrollbars will appear as needed, which can also be used to pan.

Zoom: The mouse wheel can be used to zoom. For cases when no mouse is available, the “+” and “-“ buttons on the top-left of the GUI can be used to zoom in and out.

Cursor Location: When the cursor is over the image, the row and column for the location of the cursor will be shown in the upper-right corner of the GUI. (The row is 545 and the column is 218 in the example above.)

2.03 Image Stretch:

Stretch: The upper-center area of the GUI has three options for standard stretch options – 2%, 0-1, and the full range of the data. The stretch can also be chosen from the “Stretch” menu on the Menubar, described below.

Image Viewer: Stretch -> Interactive Stretch: The Stretch menu on the image viewer has the three standard stretch options (2%, 0-1, and the full range) as well as an interactive stretch, which opens the Interactive Stretch GUI shown in Figure 2-3. In this GUI, the stretch range is shown as the shaded region, and the range is changed either by click-dragging the ends of the shaded region or by typing the desired range min and max into the “Stretch Range” text boxes at the top of the GUI. For an Image Viewer showing 3 bands, the radio buttons in the top-right select the band for the stretch (see Figure 2-3, left).

[Known Issues for Interactive Image Stretch: The Plot range should allow the user to modify the min/max for the plot. The Interactive Stretch GUI does not update information when the Image Viewer data is changed – i.e. when the band is changed or a new stretch is selected from the radio buttons.]

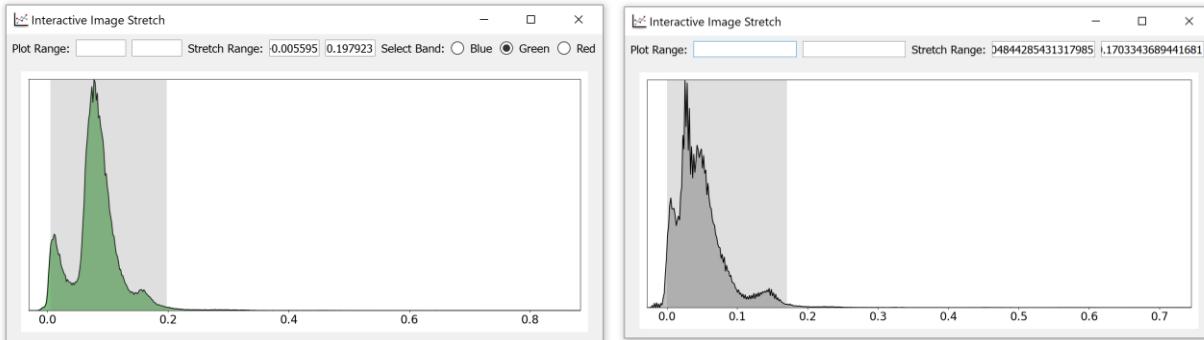


Figure 2-3. The Interactive Image Stretch for an Image viewer displaying 3-bands as RGB (left) and a pan image (right).

2.04 Linking Viewers

The Tools menu provides the functions, shown in Figure 2-4.

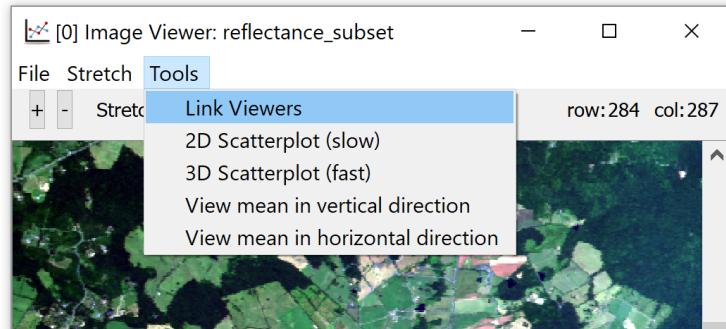


Figure 2-4. The Tools menu items.

Image Viewer: Tools -> Link Viewers: The Link Viewers function opens the Link Image Viewers GUI, shown in Figure 2-5. The user can select the viewers to link by using the check-boxes next to each Viewer name. Viewers must have the same number of Rows and Cols to be selected together.

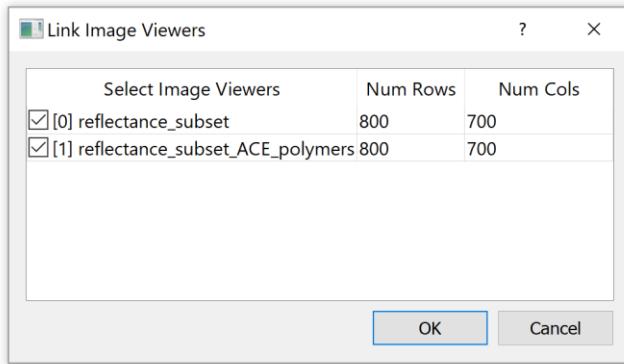


Figure 2-5. The Link Image Viewers GUI for linking viewers.

Linked viewers will maintain the same window size and area being displayed as shown below. The user can toggle the display on a viewer (ie, cause the Image Viewer to flicker between the displays of all linked viewers) by either right-clicking on an image or using the Toggle button that now appears (bottom-center of each GUI), as shown in Figure 2-6.

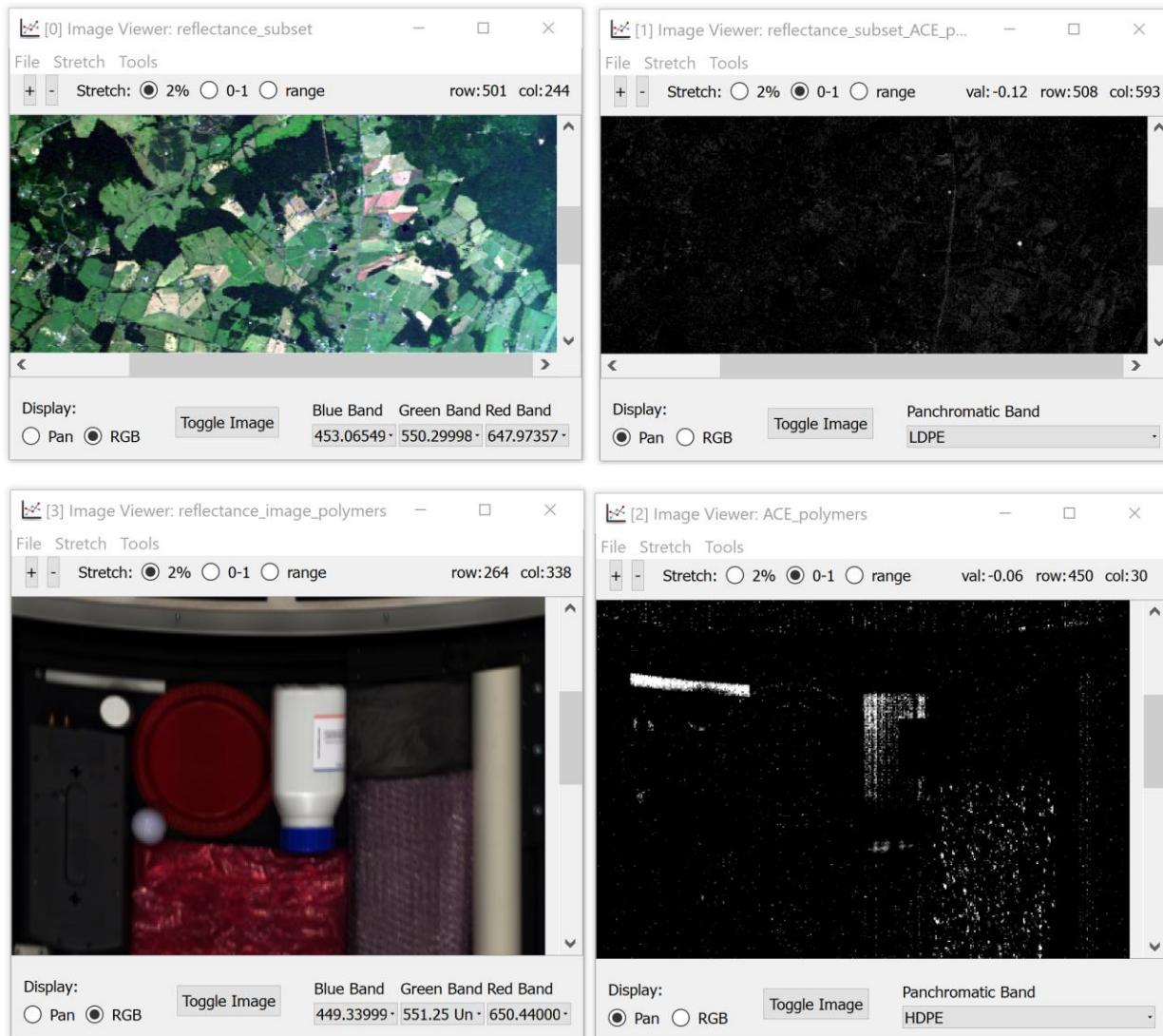


Figure 2-6. An RGB from an AVIRIS image linked with a target detection result (Top Pair) and a microscene image with its target detection result (Bottom Pair).

[Known Issues: A spectral angle or correlation-based detector should be added because ACE and MF do not work well for some microscene images due to background covariance issues, as evident in the ACE results above.]

2.05 Scatterplots

Image Viewer: Tools -> 2D Scatterplot: Selecting “2D Scatterplot (slow)” from the Tools menu opens the 2D Scatterplot Viewer shown in Figure 2-7. This viewer is relatively slow because it does not use the computer hardware graphics accelerator. . The bands for the scatterplot can be selected from the menus in the Band Selection window (shown on the left-hand side of the figure), and the “Preferences” menu in this window opens drop-down menus to modify background and data point colors. The scatterplot (shown on the right-hand side of the figure), is mouse-interactive (left-click-drag to pan, mouse wheel to zoom).

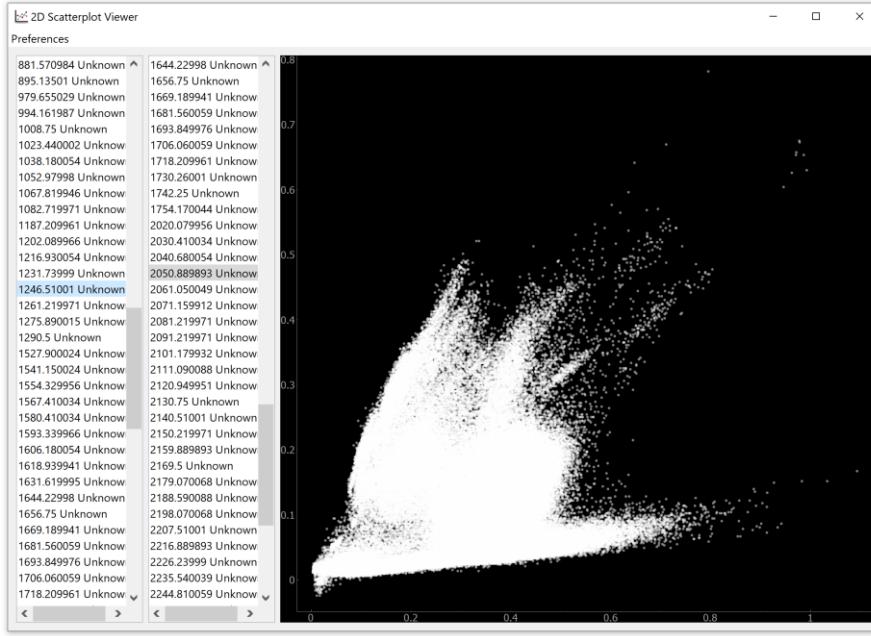


Figure 2-7. 2D Scatterplot Viewer.

Image Viewer: Tools -> 3D Scatterplot: Selecting “3D Scatterplot (fast)” from the Tools menu opens the 3D Scatterplot Viewer shown below. This viewer uses the computer hardware graphics accelerator. The bands for the scatterplot can be selected from the menus in the Band Selection window (shown on the left-hand side of figure), and the “Preferences” menu in this window opens drop-down menus to modify background and data point colors. The scatterplot (shown on the right-hand side in figure), is mouse-interactive (left-click-drag to rotate, mouse-click-drag to pan, mouse wheel to zoom).

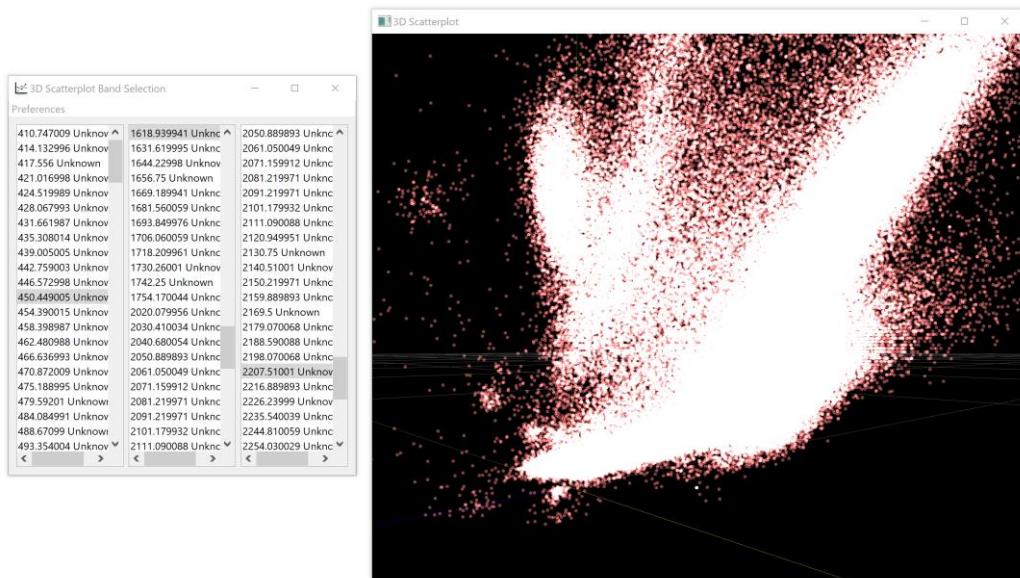


Figure 2-8. 3D Scatterplot Viewer.

2.06 Focal Plane Mean Images

Image Viewer: Tools -> View Mean in Vertical Direction: Selecting View Mean in Vertical Direction produces a plot of the mean of the image 3D-array in the vertical direction, showing the mean value in each column. Depending on image collection configuration, this usually gives a view of the sensor focal plane array, and can be useful for inspecting defects that can affect image quality. In Figure 2-9, the vertical mean image is aligned beneath the image.

[Known Issues for View Mean in Vertical Direction: This function sometimes crashes for an unknown reason.]

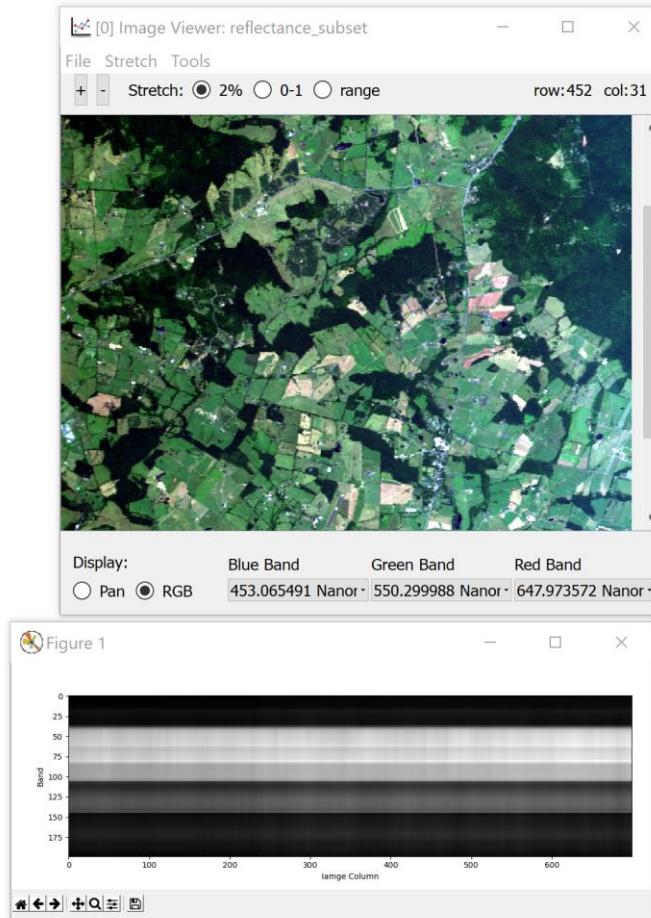


Figure 2-9. The image for the Mean in Vertical Direction aligned below the associated image.

Image Viewer: Tools -> View Mean in Horizontal Direction: Similar to View Mean in Vertical Direction (see above), but in the horizontal direction, shown in Figure 2-10. Depending on image collection configuration, this usually shows spectral variation in the temporal direction.

[Known Issues for View Mean in Vertical Direction: This function sometimes crashes for an unknown reason.]

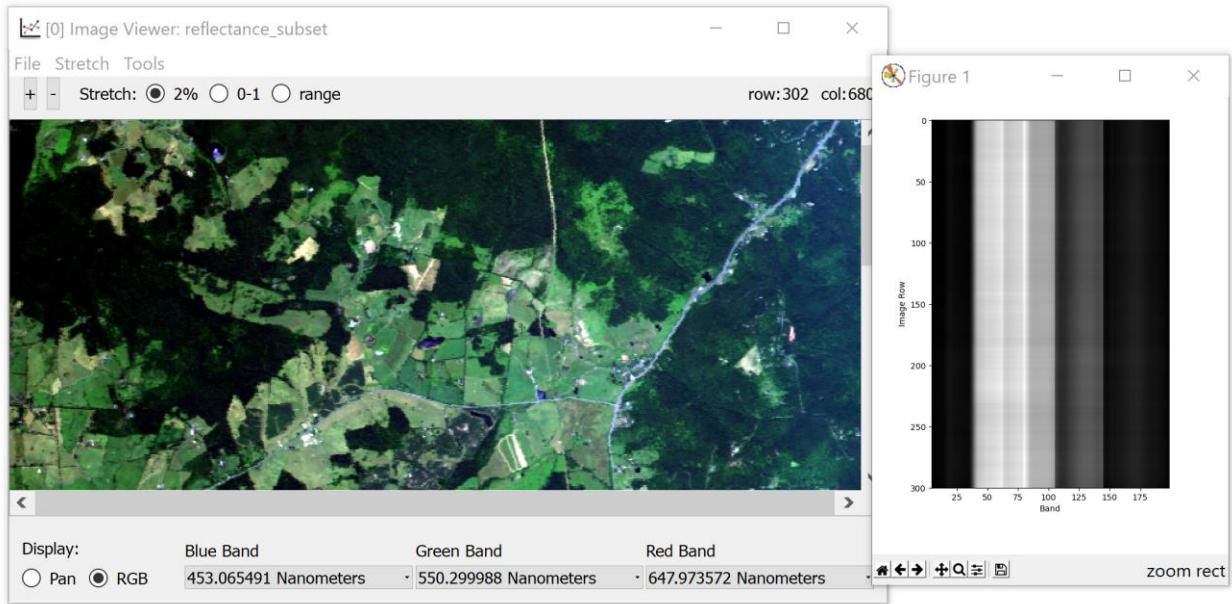


Figure 2-10. The image for the Mean in Horizontal Direction aligned next to the associated image.

2.07 Plotting Pixel Spectra

Left-Click on Image Spectral Plot: Left-clicking on the image (without dragging) will create a plot of the spectra for the pixel click location, as shown in Figure 2-11. A red crosshair is overlaid on the image at this pixel location, and the row and column are used for the name of the spectral in the plot. The functionality of the Spectral Viewer GUI will be presented in the next section.

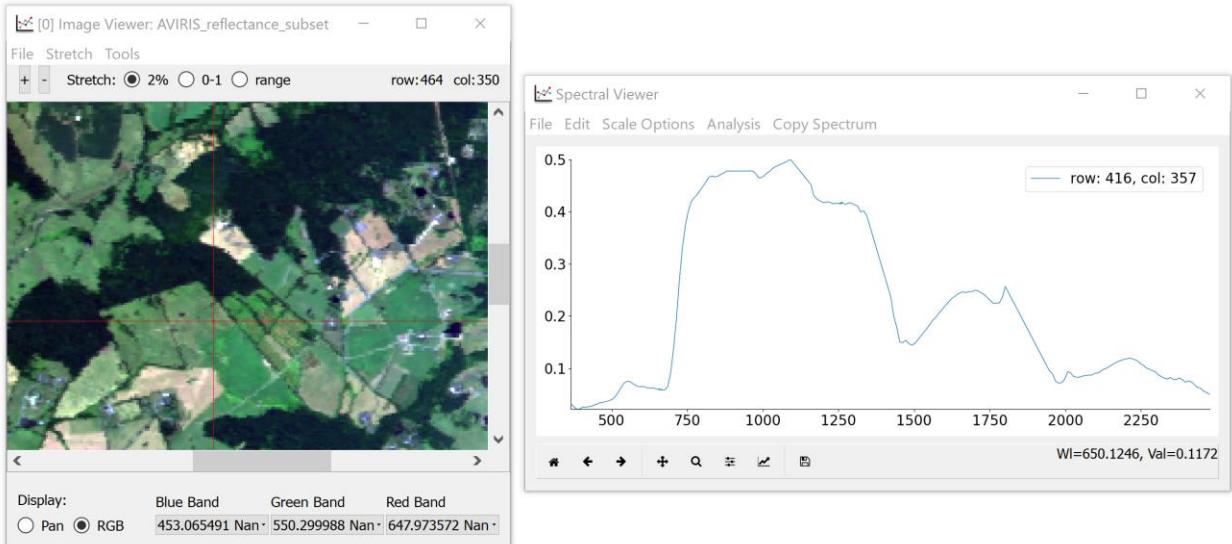


Figure 2-11. An image in the Image Viewer with the spectral plot created by left-clicking in the image.

Section 3. The Spectral Viewer

3.01 Plotting Multiple Spectra

The Spectral Viewer GUI is the primary GUI for viewing and comparing spectra within the Spectral Tools software. Figure 3-1 shows a microscene image with two spectra shown in the Spectra Viewer. The spectra are plotted by left-clicking in the image, and are by default names by the row and column of the pixel. Upon clicking, a red crosshair is displayed on the latest clicked pixel (on the long vertical white object in the image below, which is a PVC plumbing drain pipe). The row and column of the cursor is shown in the upper-right of the Image Viewer GUI, allowing identification of previously clicked pixels.

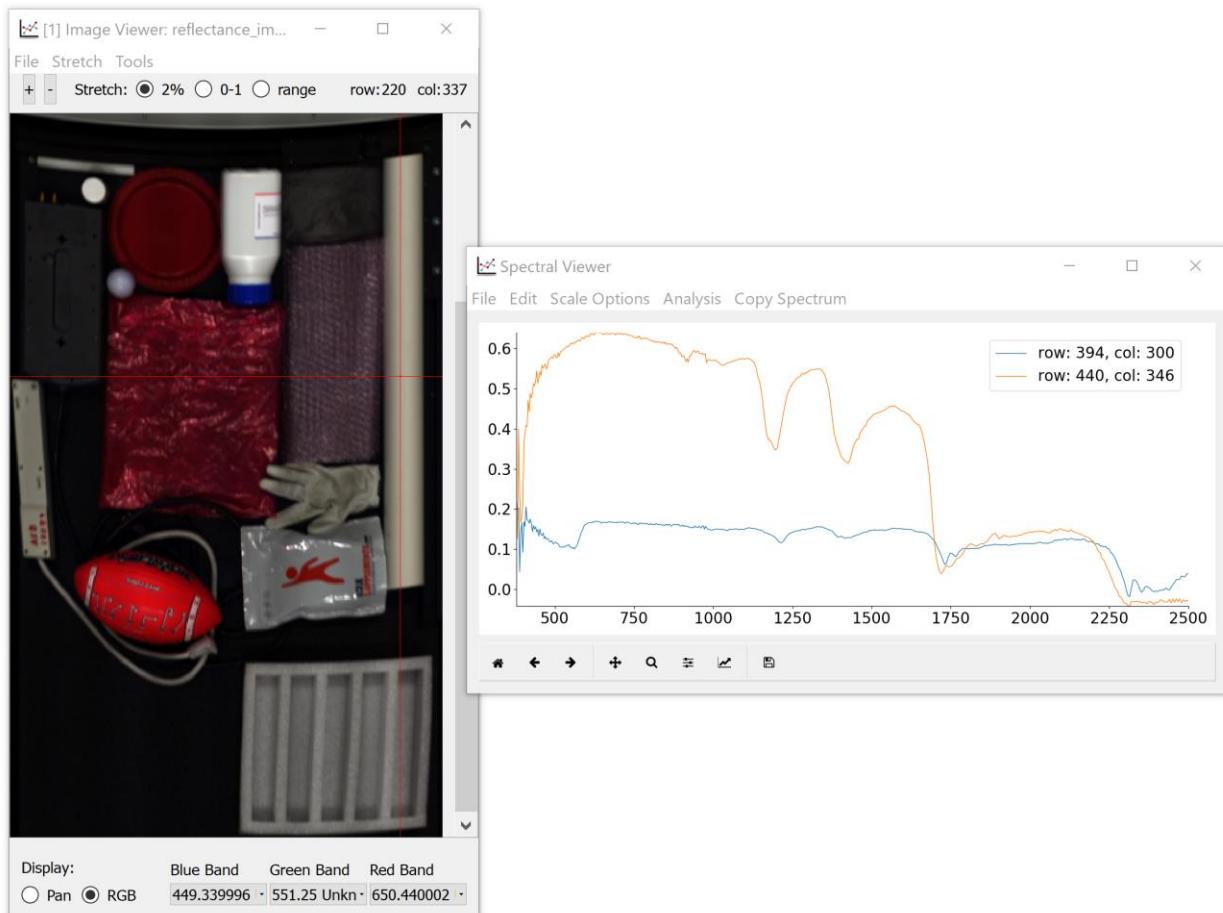


Figure 3-1. A microscene image with two pixel spectra in the Spectral Viewer.

3.02 Displaying the Wavelength-Value Crosshair

Left-Click: Placing the cursor on the plot and holding down the left mouse button creates a crosshair on the data point for the nearest (in the vertical direction) spectrum, as shown in Figure 3-2. Note that the name of the selected spectrum appears in the lower right corner of the GUI in square brackets [], followed by the wavelength and the associated y-value.

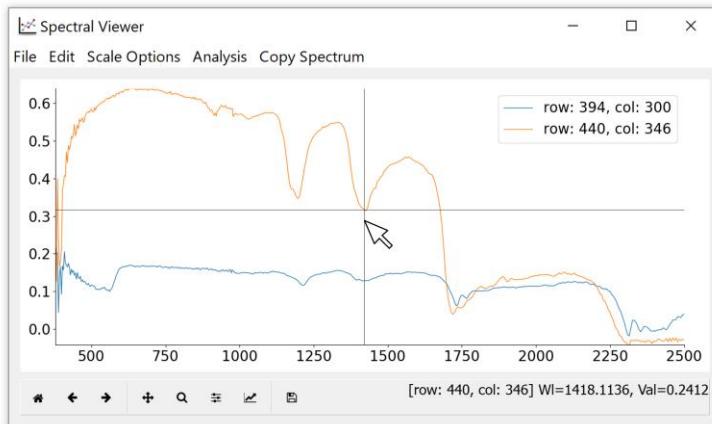


Figure 3-2. Crosshair with wavelength and y-value information created by left-click.

3.03 Copy-Paste Spectra

The Copy-Paste Menu: Right-clicking on the plot area creates a drop-down menu for copying spectra, as shown in Figure 3-3. This menu is also accessible from the “Copy Spectrum” menu item on the menubar at the top of the GUI.

Paste: Pastes a previously-copied spectrum or spectra onto this plot.

Copy All Spectra: Copies all spectra in this plot, to be available to paste onto other plots.

Copy Some Spectra: Creates a Dialog GUI to choose which spectra to copy.

Copy *spectrum_name*: Copies just the names spectrum.

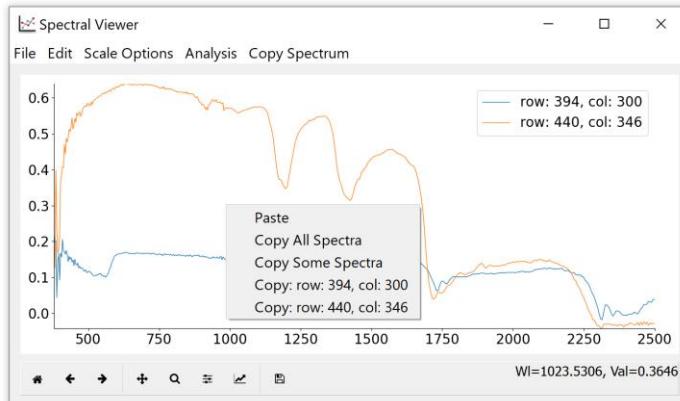


Figure 3-3. A copy-paste menu created by a right-click.

3.04 Plot Toolbar Navigation

The toolbar at the bottom-left of the Spectral Viewer GUI is a standard Matplotlib toolbar. The effect of the individual buttons are as follows:

Button:								
Action:	Resets the x and y range to the original view.	Toggles forward or backward in modified views.	Enables panning on the plot (left-drag) and interactive x or y zooming (right-drag).	Magnifying glass tool, with left click on the plot to create a zoom box.	Plot parameters tool, with GUI shown in Figure 3-4 (left).	Figure options tool for modifying the zoom on the axes and individual spectra plot properties, shown in Figure 3-4 (right) (NOTE: “Apply” button must be used to apply new properties	Figure options tool for modifying the zoom on the axes and individual spectra plot properties, shown in Figure 3-4 (right) (NOTE: “Apply” button must be used to apply new properties	Opens GUI to save the figure as an image. (.jpg, .png, etc.)

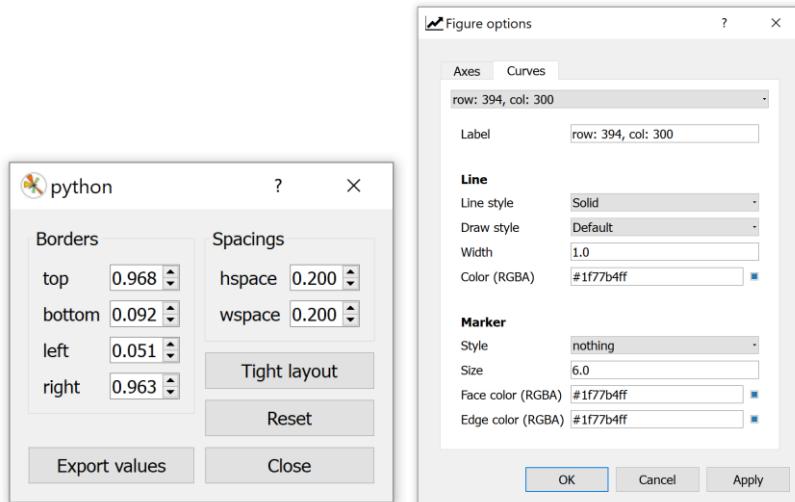


Figure 3-4. The plot options dialog (left) and figure options dialog (right) for modifying the plot window and spectral curves properties.

3.05 Saving Spectra as Library

Spectral Viewer Menubar: File -> Save as Library: This menu, shown in Figure 3-5, opens a dialog to save the spectra in the plot as an ENVI spectral library file.

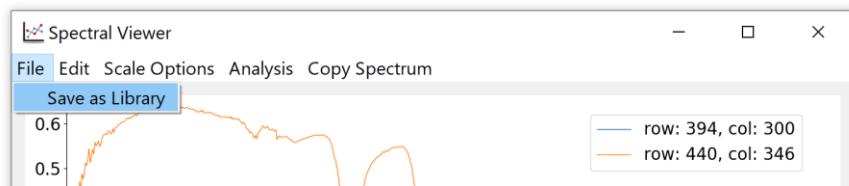


Figure 3-5. The Save as Library menu.

3.06 Editing Spectral Plots

Spectral Viewer Menubar: Edit -> Edit Data: This menu, shown in Figure 3-6 opens a dialog edit the spectral plot data.

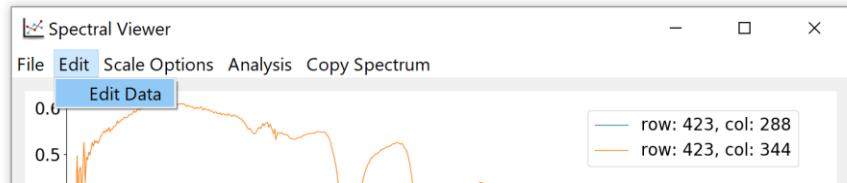


Figure 3-6. The Edit Data menu.

Changing Width, Color, and Name: The Edit Data dialog is shown below, containing a row for each spectra in the plot. The first column provides a spinbox to modify the width of the spectrum plot. The second column provides the color of the spectrum, and clicking on the color opens a Color Selector to modify the plot color. The Third column provides the name of the spectrum, which can be edited by the user.

In Figure 3-7, the name of the first spectrum has been changed to “Bubble Wrap”, its width has been changed to 2.75, and the Select Color dialog is open with a blue color selected.

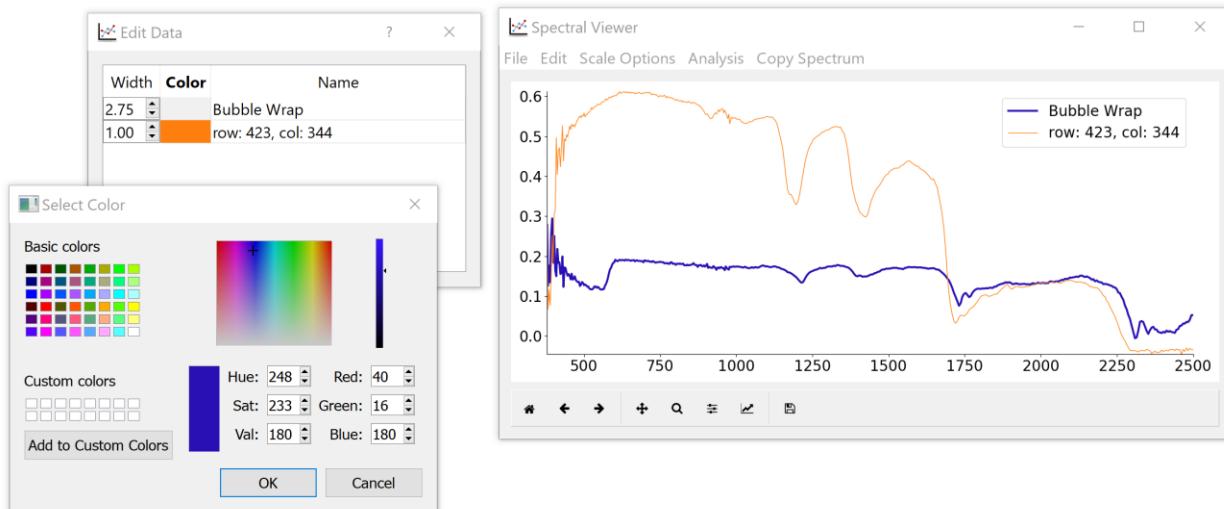


Figure 3-7. The Edit Data dialog with modifications to the “Bubble Wrap” spectrum.

Removing Spectra: In the Edit Data dialog, left-click on the name of a spectra to be provided with the option to remove the spectrum from the plot.

3.07 Viewing Spectra on a Common Scale

Spectral Viewer Menubar: Scale Options: This menu, shown in Figure 3-8, provides options to rescale one or more spectra to match the scale of other spectra.

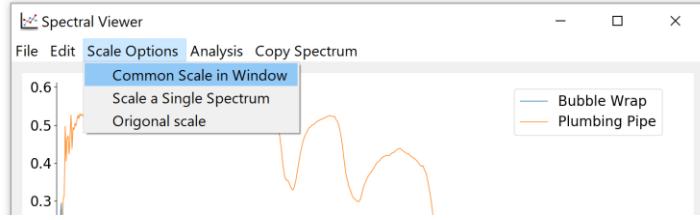


Figure 3-8. The Scale Options menu.

Spectral Viewer Menubar: Scale Options -> Common Scale in Window: Selecting this menu item will rescale all spectra so that they have the same mean and standard deviation in the wavelengths displayed in the plot. This aids in comparing features between spectra. This is often done by zooming in on the region containing the main features of interest (using the magnifying glass zoom tool) and then applying the Common Scale in Window function, as shown in Figure 3-9. Note the greatly enhanced Greatly enhanced ability to compare the shape and location of features after putting the spectra on a common scale.

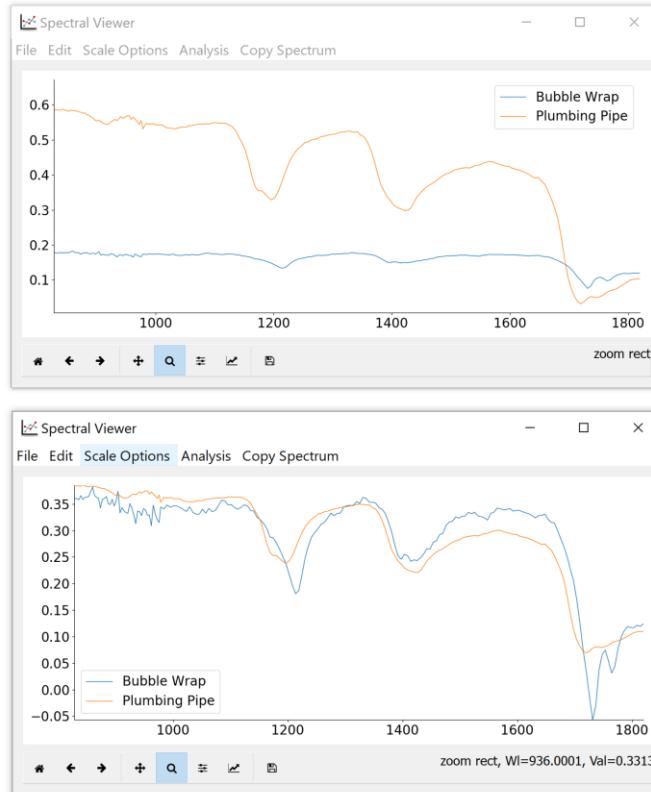


Figure 3-9. The Spectral Viewer zoomed in on the features of interest (top) and the result of the Common Scale function on these wavelengths (bottom).

Spectral Viewer Menubar: Scale Options -> Scale a Single Spectrum: This function opens a dialog to allow the user to select one spectrum with the desired mean a standard deviation to rescale to, and a second spectrum to rescale.

Spectral Viewer Menubar: Scale Options -> Original Scale: Puts all spectra back on their original scale.

3.08 Analysis - Background Removal

Background removal is the process of removing the background portion of a mixed pixel. It is assumed that the “background” portion of the pixel can be approximated by a mixture (ie linear combination) of nearby pixels.

To set up for background removal, we determined a white area in an AVIRIS hyperspectral image that may contain a polymer material. These pixels were selected because they have an ACE target detection score around 0.8 for LDPE (Low-Density Polyethylene), and inspection of the spectra indicate polymer-like features (see plots below). We used the Image Viewer and Spectral Viewer to select 25 nearby pixels from the image to use for background and 3 pixels on the white object in question. The first 25 spectra in the plot in Figure 3-10 are the background and the last 3 spectra, which we colored black with thicker lines, are from the white object. We also pasted a LDPE library spectrum from a spectral library that has been spectrally resampled to match the AVIRIS image wavelengths, labeled LDPE in the plot below. Observe that the object pixel spectra (black) have primary shape similar to the vegetation backgrounds, but have some features similar to the polymer (blue).

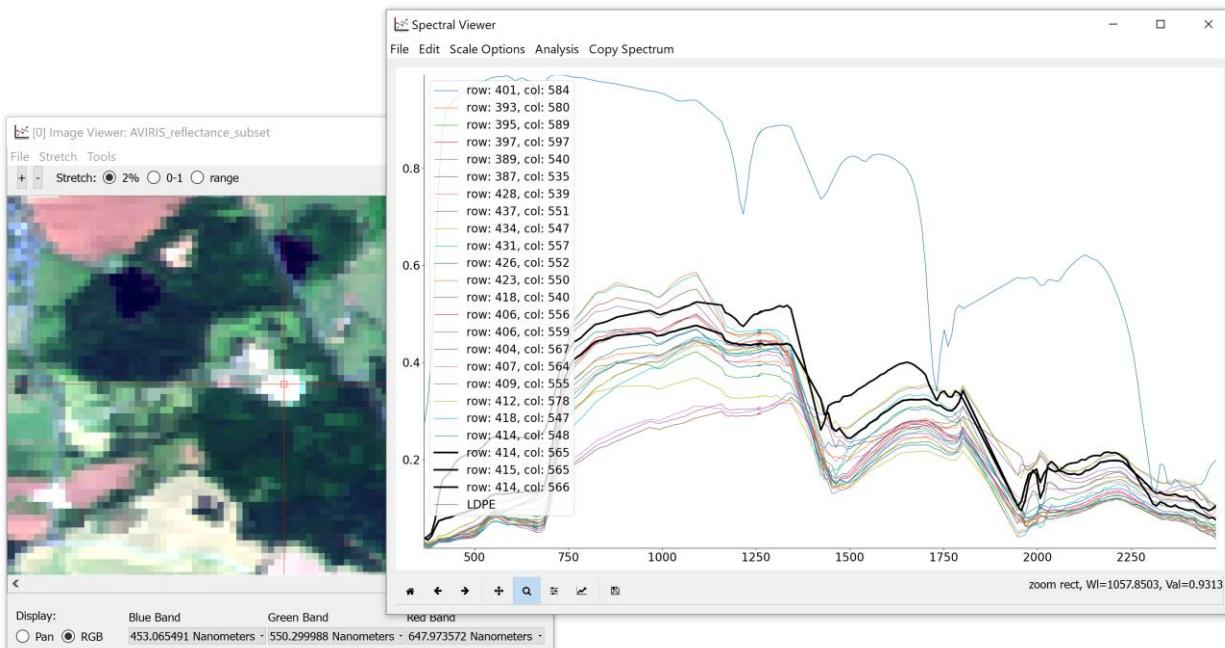


Figure 3-10. The Spectral Viewer with spectra prepared for background removal (25 backgrounds, 3 spectra on the object, and one LDPE spectrum.)

Spectral Viewer Menubar: Analysis -> Background Removal -> Output in Subpixel: With the desired spectra in the viewer, we select the Analysis -> Background Removal -> Output in Subpixel Scale function from the menu, shown in Figure 3-11. The Output in Subpixel scale will output the background removed pixel spectrum, whereas the Output in Fullpixel Data Scale will rescale the background removed pixel spectrum to match the scale of the original spectra.

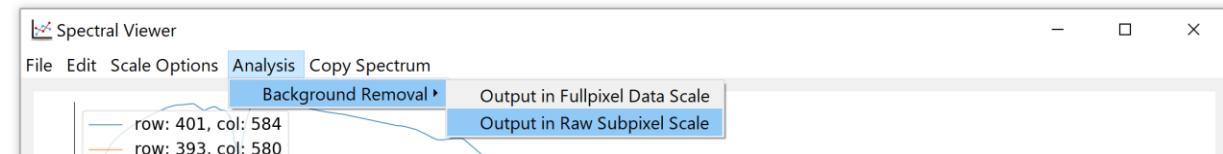


Figure 3-11. Selecting the Background Removal menu item.

Selecting the Analysis -> Background Removal -> Output in Subpixel Scale function creates the dialog shown below. We select the background pixel spectra as “Background”, the spectra that we want to remove background from as “Pixel”, and the spectra that we believe may represent the non-background portion of the pixels as “Target.” After selecting these spectra and clicking the “Apply” button on the Background Removal dialog, the background removed spectrum is created as shown in Figure 3-12 (labeled “Background removed spectrum, 21%”). The percentage is the percentage that this spectrum represents in the mixed pixel(s).

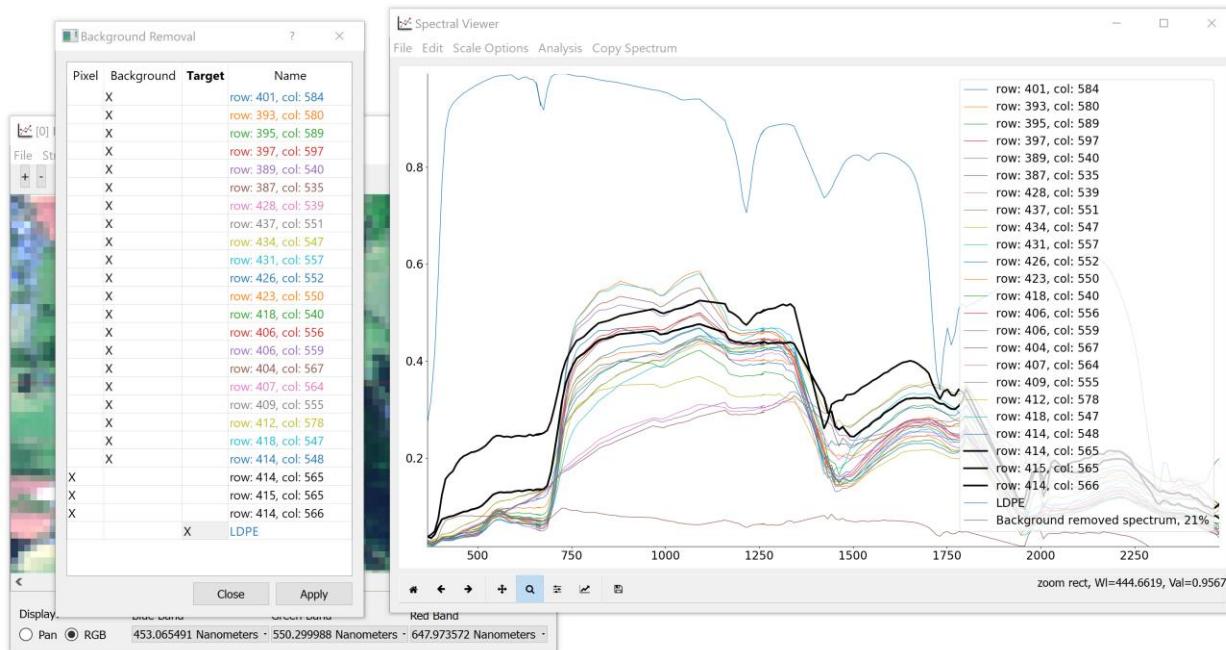


Figure 3-12. Computing background removal to better view the spectrum for the material of interest.

In the background removal process, the Pixel spectra will be averaged to create a spectrum p , the Target spectra will be averaged to create a spectrum t , and the process of background removal first computes the abundance coefficients a_i for background spectra b_i in the formula

$$p = \sum_i a_i b_i + t$$

And then the background-removed spectrum is

$$r = p - \sum_i a_i b_i.$$

The percentage provided in the name of the background removed spectrum in the plot is the one minus the sum of the abundances a_i .

To compare the background removed spectrum to the target LDPE, we use the Spectral Viewer Menubar: Scale Options -> Scale a Single Spectrum function (described in Section 3.6) to rescale the background removed spectrum to the LDPE spectrum. The result is shown in Figure 3-13. (Most of the background spectra were deleted from the plot to simplify comparing the background-removed spectrum to the LDPE.) Observe that many of the LDPE features are now clearly visible in the background removed spectrum, further confirming that the white object in the image is at least partially made of LDPE.

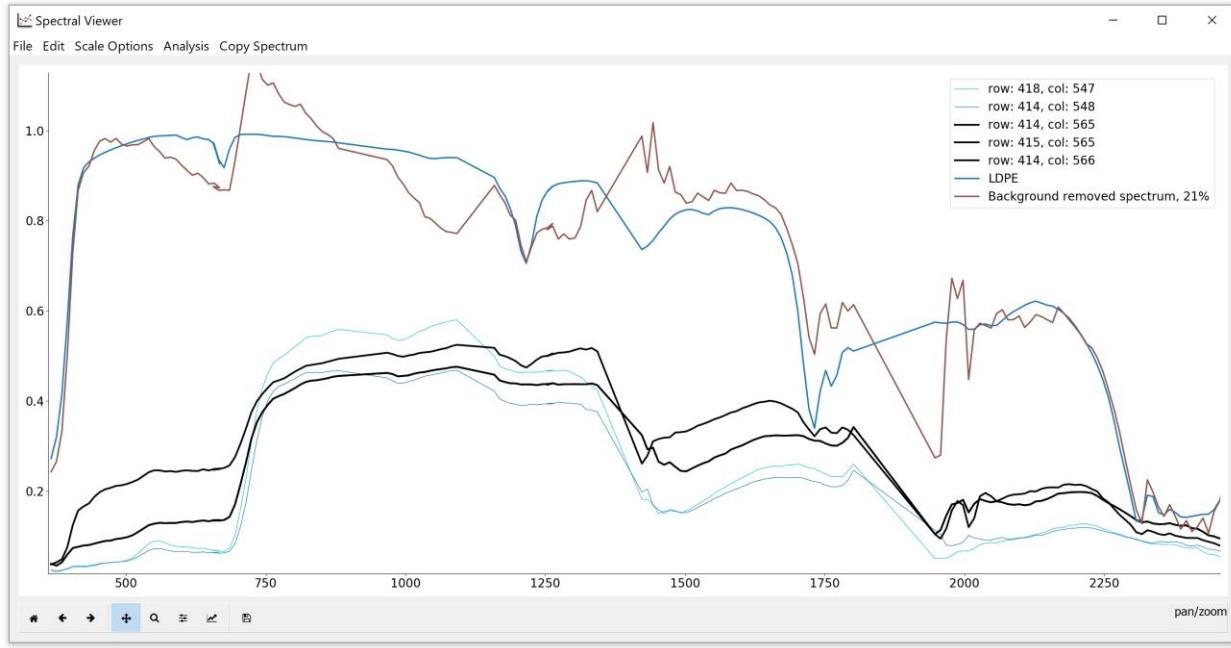


Figure 3-13. The background removed spectrum has been rescaled to match the LDPE, and now features of the LDPE spectrum (blue) are clearly visible in the background removed spectrum (brown).

Comparing this location (using the Latitude and Longitude provided with the AVIRIS image at $39^{\circ} 0'39.87N$ $77^{\circ} 54'39.95W$) to the higher resolution imagery in Google Earth shows that this location has been used to store wrapped bales of hay, as shown in Figure 3-14. This type of wrap is primarily made of LDPE, which is likely the source of the LDPE observed in the background removal.



Figure 3-14. The LDPE observed in the AVIRIS image (left) is likely from wrapped bales of hay like those observed at this location in Google Earth imagery (right, appearing as white lines just below the location marker).

[Known Issues: This function currently only works if all the spectra involved have the same wavelengths. A resampling method needs to be created in the code.]

Section 4. The Spectral Library Manager and Viewer

4.01 Opening a Spectral Library

A spectral library can be opened by selecting File -> Open Library (shown in Figure 4-1) or by the hotkey Ctrl+L. This initiates a standard file selection GUI for the user to select an ENVI spectral library file.

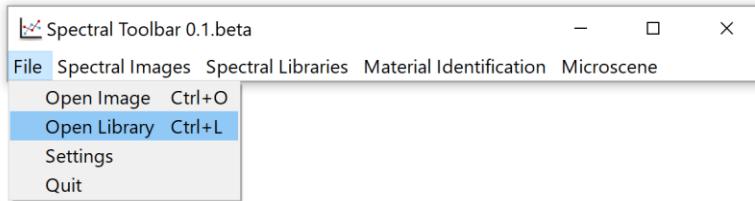


Figure 4-1. Opening a spectral library from the menubar.

Selecting the File -> Open Library function and then selection a spectral library file opens both the Library Manager and the Library Viewer shown in Figure 4-2.

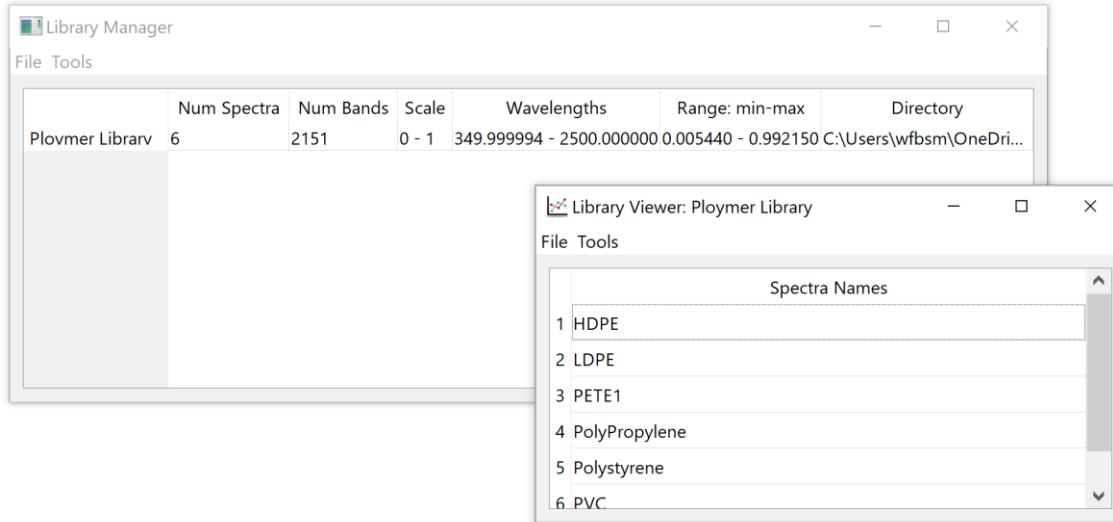


Figure 4-2. The Library Manager and Library Viewer.

The Library Manager lists all the libraries currently open along with their metadata. Clicking on the name of a library will open the library in the Library Viewer.

[Known Issues: The File -> Cloe function closes the entire Spectral Tools software, but it should just close the individual Library Viewer.]

4.02 Viewing a Spectral Library

Clicking on the name of spectra in a Library Viewer will create a Spectral Viewer and add the clicked spectra to the viewer, as shown in Figure 4-3. These spectra can be copied and pasted between viewers.

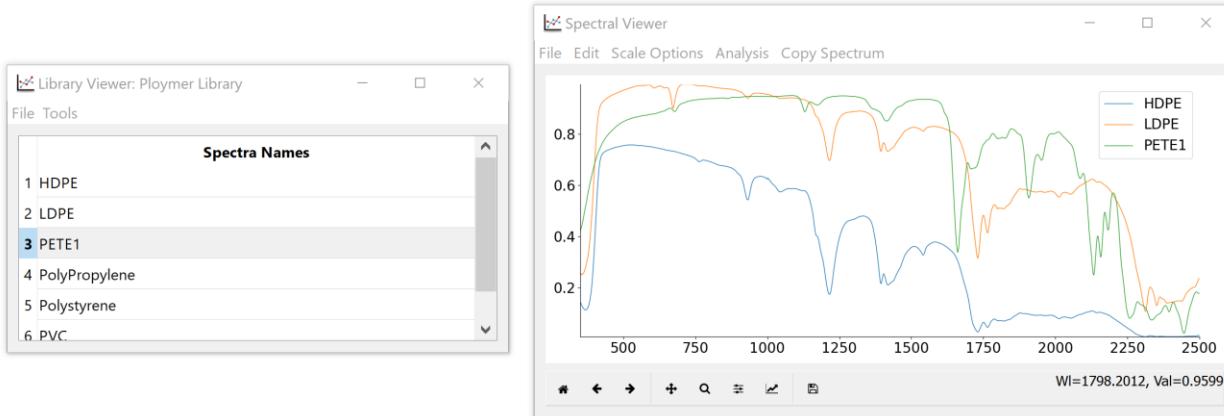


Figure 4-3. A Library Viewer with plots from three spectra in a Spectral Viewer.

A new spectral library can be opened from the File -> Open Library function from the Library Viewer menubar.

4.03 Sorting Spectra by Text Match

Library Viewer: Tools -> Sort by Text Match: Clicking Tools -> Sort by Text Match, shown in Figure 4-4, opens a dialog for entering the search text.



Figure 4-4. Selecting the Sort by Text Match in the Library Viewer.

The search text can be entered into the search text dialog (shown in Figure 4-5). In the example below, the search text is “Poly” and the spectra in the library are sorted by match to this search text. The search is a fuzzy search that ranks names by goodness of full or partial matches.

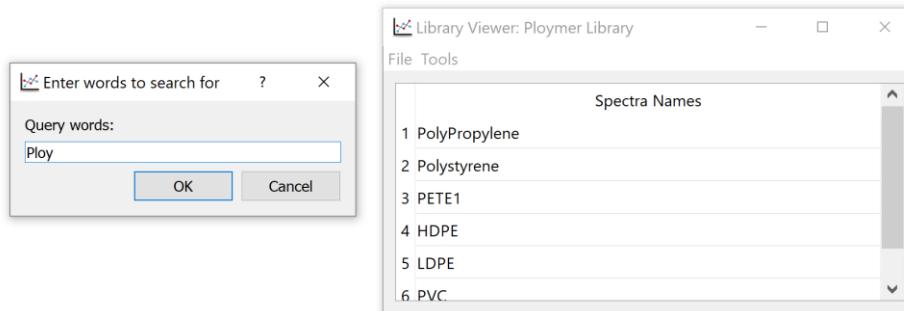


Figure 4-5. Text search in the Library Viewer.

[Known Issues: The ordering from the search does not always provide expected results.]

4.04 Merging Spectral Libraries

The Merge Libraries function creates a new library by merging multiple separate libraries. The wavelengths for the merged library are a union of the wavelengths of the separate libraries, with options for dealing with wavelength values not within the range of all libraries.

With more than one library open in the Library Manager, select the libraries to merge and then select Merge Libraries as shown in Figure 4-6.

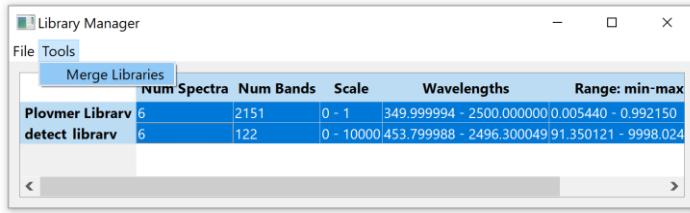


Figure 4-6. The Merge Libraries function from the Library Manager.

This will open the Merge Options dialog, shown in Figure 4-7.

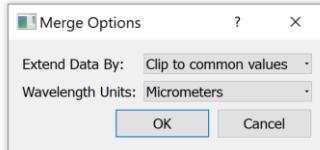


Figure 4-7. The Merge Options dialog.

Clicking "OK" will create the merged library. All libraries will be rescaled so that the merged library will be on a 0-1 y-scale. The result is shown in Figure 4-8.

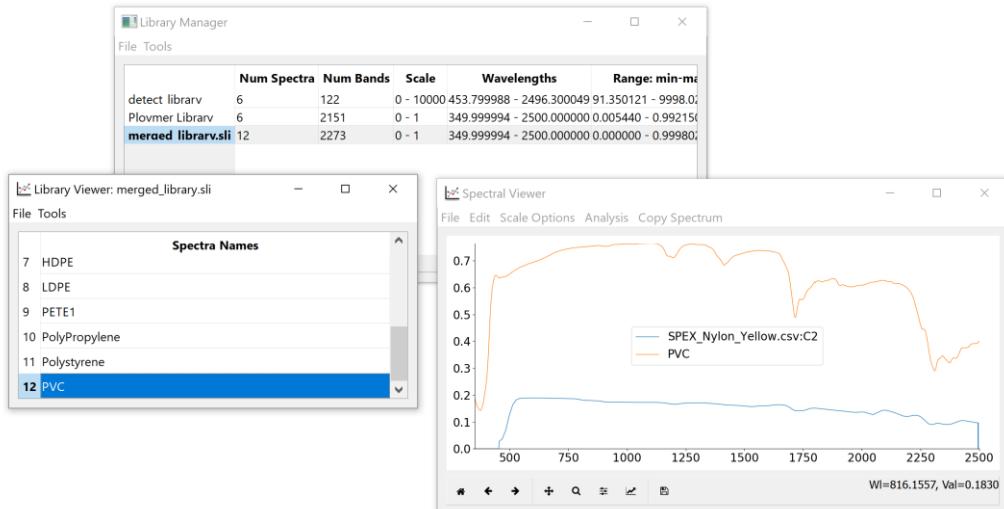


Figure 4-8. The Merged library.

Note that although the resulting library now has the union of the wavelengths of the separate libraries, the individual spectra only have as much spectral fidelity as the original library. For example, compare the PVC (originally 2151 bands) with the Yellow Nylon (originally 122 bands) in the plot below, where the plot is zoomed to wavelengths for the main features and the spectra were put on a common scale using the “Scale Options”.

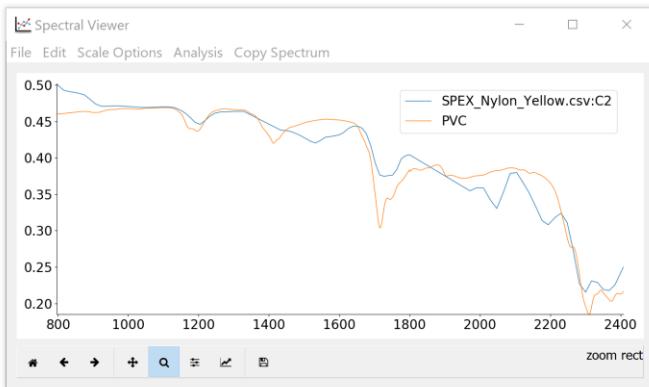


Figure 4-9. Spectra in the merged library only have the fidelity of the original libraries.

[Known Issues: 1) The “Extend Data by” option does not work. The merged libraries are always created with the extend by zeros option. 2) The software makes a best guess on how to rescale all libraries so the resulting merged library is on a 0-1 scale, but the Merge Options dialog should provide the user with the ability to modify these y-scale factors.]

Section 5. Image Processing

5.01 Principle Components Analysis (PCA):

The PCA function is available under the Menubar: Spectral Images -> Principle Components Whiten menu item, as shown in Figure 5-1.

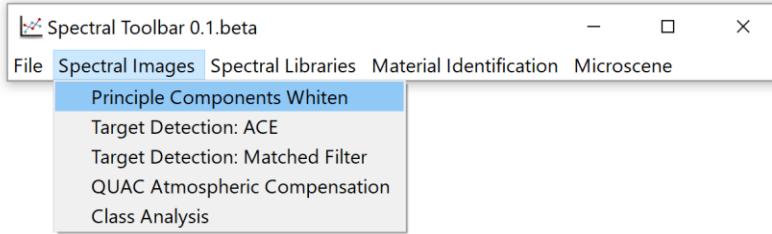


Figure 5-1. Accessing the PCA Whitening Function.

Selecting this menu item will open a prompt for the image to apply the PCA transformation to, and then a prompt for the output file name. The default output file name is "PCA" located in the same directory as the input image. Output from a PCA transformation on a microscene image is shown in Figure 5-2.

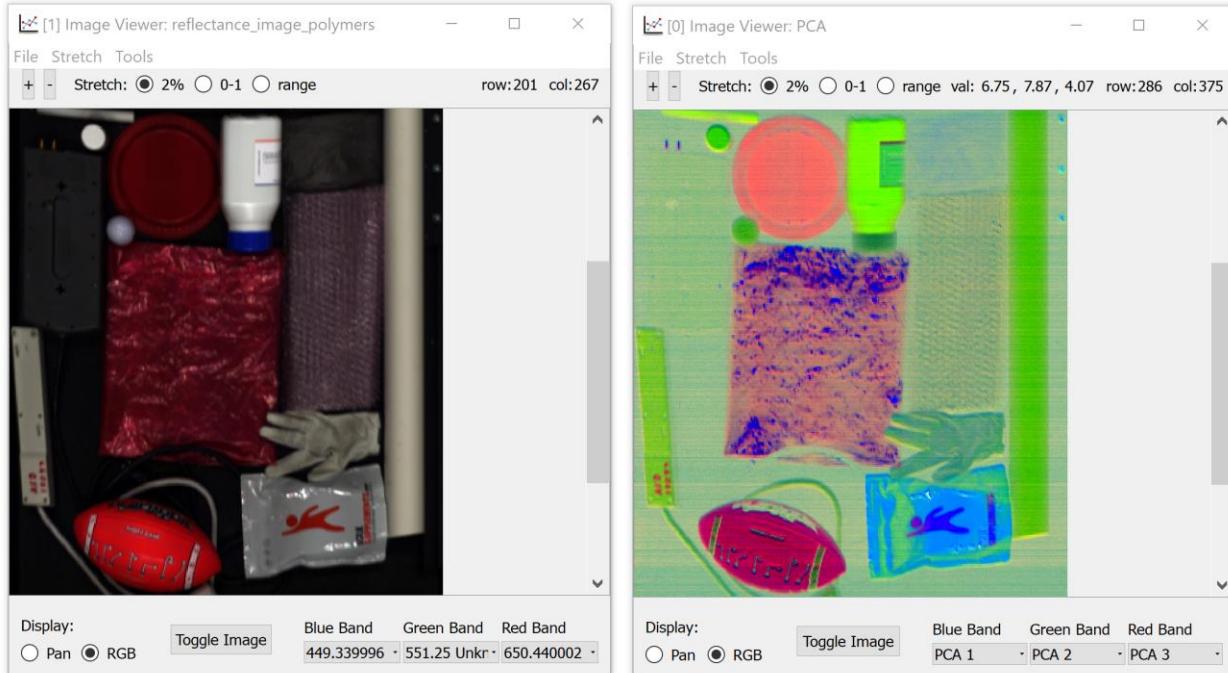


Figure 5-2. Output from the PCA Whitening Function.

5.02 Target Detection: ACE:

The ACE Target Detection function is available under the Menubar: Spectral Images -> Target Detection: ACE menu item, as shown in Figure 5-3.

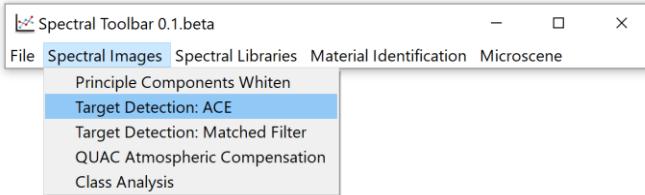


Figure 5-3. Accessing the ACE Target Detection function.

Selecting this menu item will open a prompt for the image, a spectral library, and then a prompt for the output file name. The default output file name is “ACE” located in the same directory as the input image. The spectral library will be resampled to match the wavelengths and y-scale of the image.

Output from a ACE Target Detection on a microscene image is shown in Figure 5-4. The images have been linked using Tools -> Link Viewers (See Section 2.4), and the stretch on the ACE image has been manually set. The spectral plot accompanying the images shows an image spectrum from the white rod, an image spectrum from the medicine bottle, and a library spectrum from HDPE (high-density Polyethylene) used for ACE. These spectra suggest that the rod and bottle detected as HDPE are probably HDPE material.

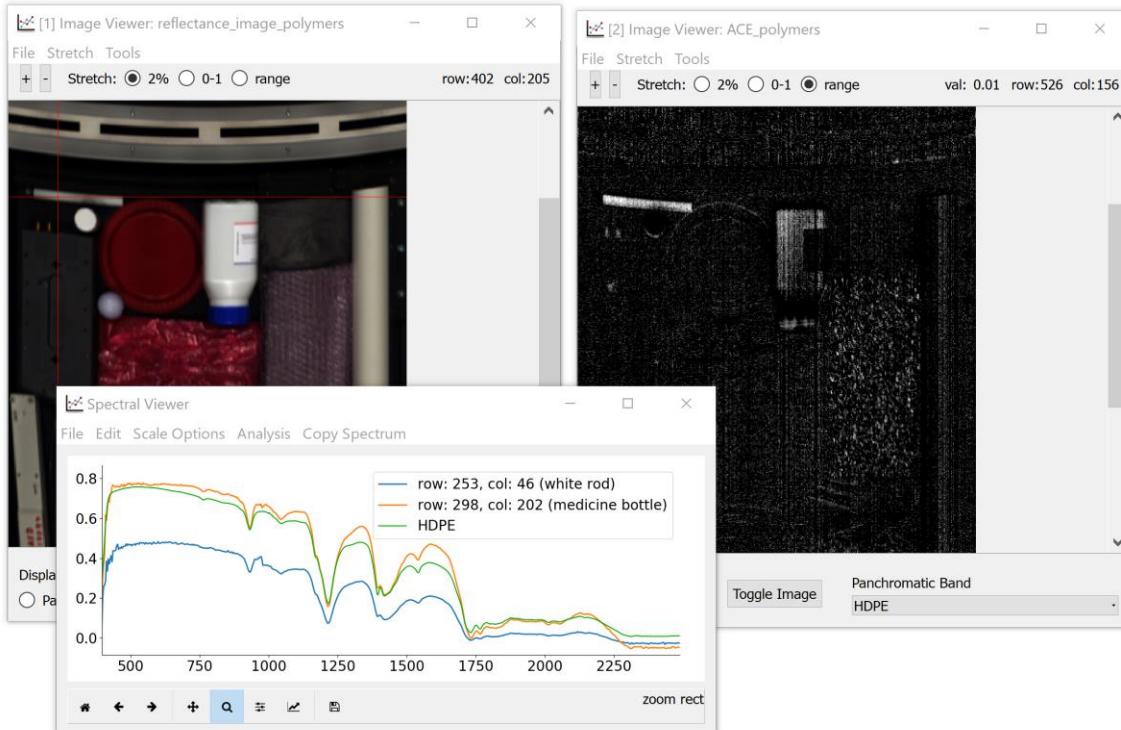


Figure 5-4. The Output from ACE Target Detection together with spectral plots of an image spectrum from the white rod, an image spectrum from the medicine bottle, and a library spectrum from HDPE (high-density Polyethylene) used for ACE.

Because target detection is a very important function, we show the result from target detection on an AVIRIS image in Figure 5-5. Also shown is a Spectral Viewer with an image pixel spectrum from the high-scoring group of pixels (right-hand side of image, just above center, as indicated in the RGB image with the red cross-hair) and the library spectrum for LDPE (Low Density Polyethylene) used for the ACE detection plane shown. These spectra have some features in common, but to better compare the spectra background removal would be needed (Section 3.7) or material identification (Section 7).

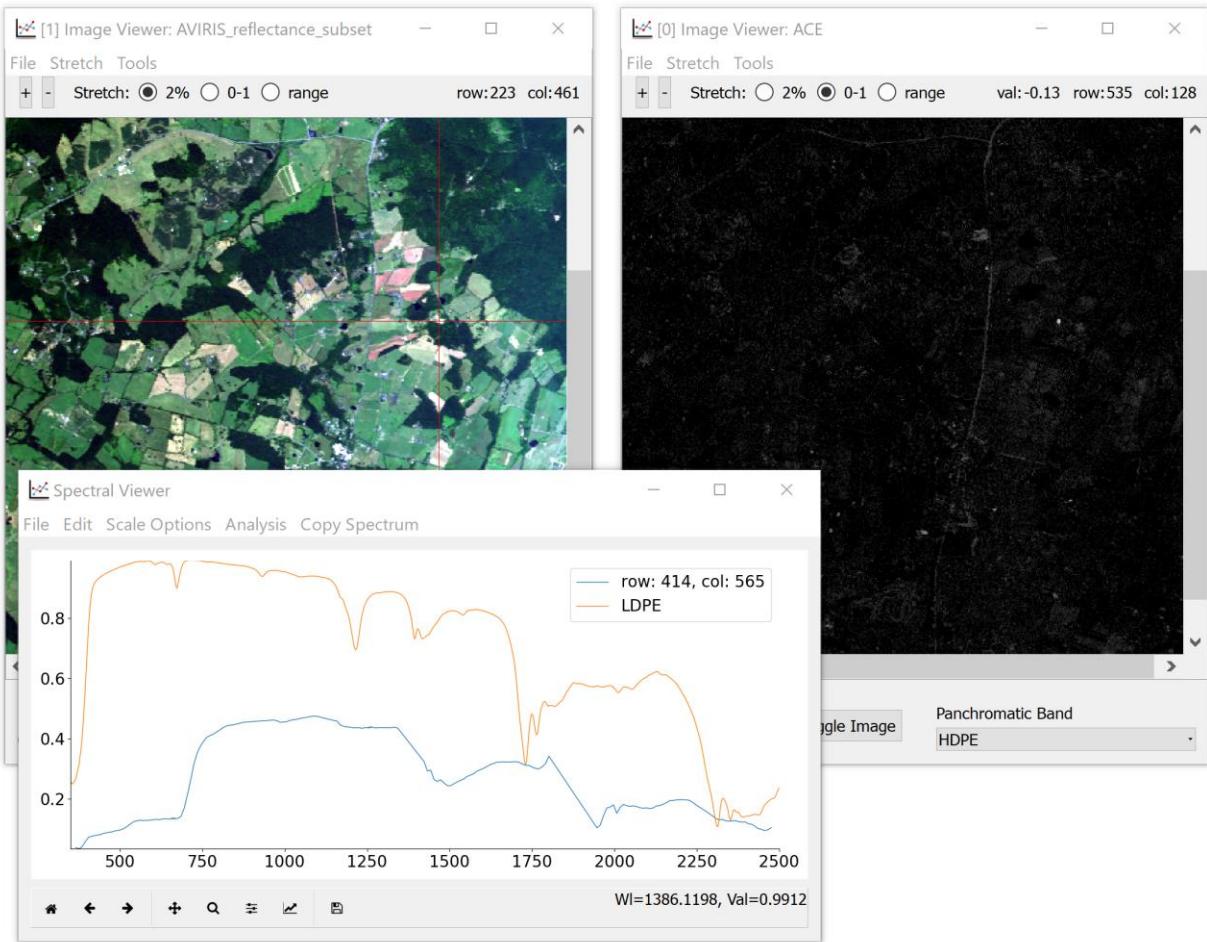


Figure 5-5. The Output from ACE Target Detection on an AVIRIS image with spectral plots.

5.03 Target Detection: Matched Filter:

The Matched Filter Target Detection function is available under the Menubar: Spectral Images -> Target Detection: Matched Filter menu item, as shown in Figure 5-6.

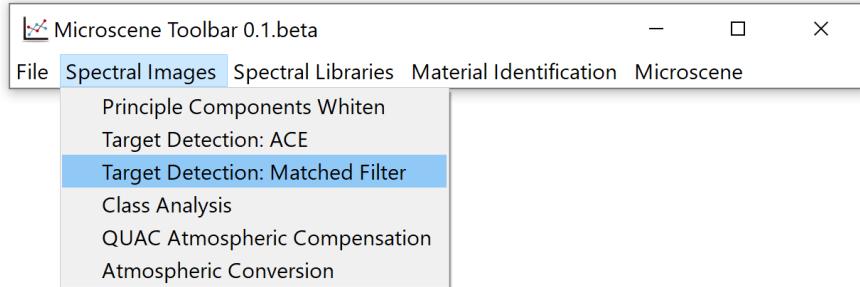


Figure 5-6. Accessing the Matched Filter Target Detection function.

Selecting this menu item will open a prompt for the image, a spectral library, and then a prompt for the output file name. The default output file name is “MF” located in the same directory as the input image. The spectral library will be resampled to match the wavelengths and y-scale of the image.

Output from a MF Target Detection on an AVIRIS image is shown in Figure 5-7. The images have been linked using Tools → Link Viewers (See Section 2.4), and the stretch on the MF image has been manually set. The spectral plot accompanying the images shows an image spectrum from a white object in the image and a PVC library spectrum used for the MF detection shown. These spectra suggest that the white object is at least partially made of a polymer such as PVC.

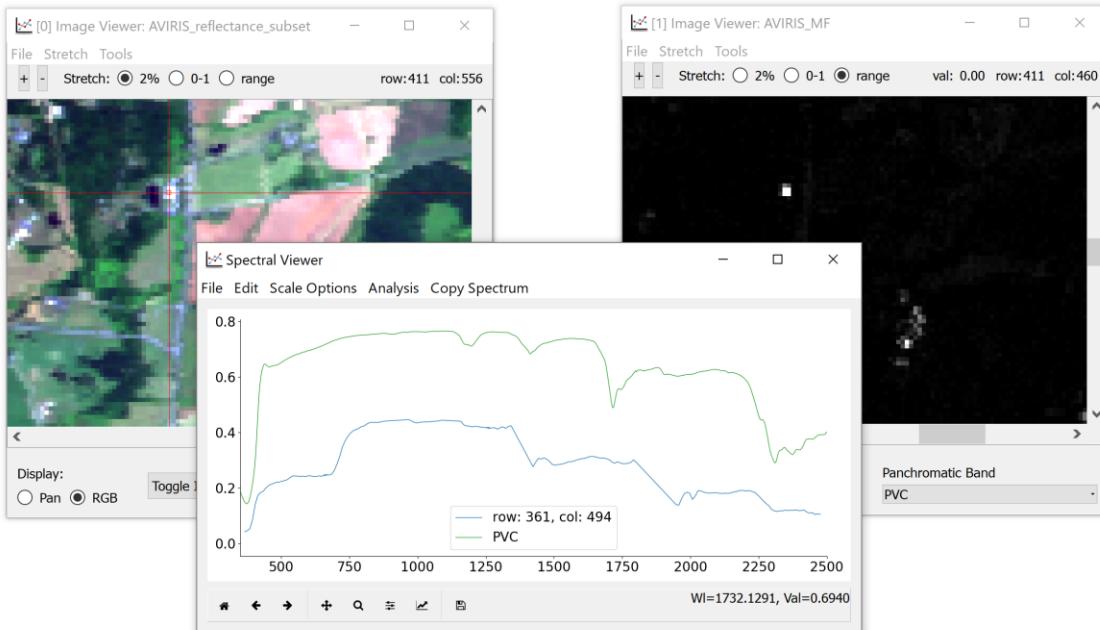


Figure 5-7. The Output from Matched Filter Target Detection together with spectral plots of an image spectrum from the white object and the PVC spectrum used in MF.

5.04 QUAC: Quick Atmospheric Correction

The QUAC (QUick Atmospheric Correction) function is available under the Menubar: Spectral Images -> QUAC Atmospheric Correction menu item, as shown in Figure 5-8. This function applies the QUAC atmospheric correction method as described in (L.S. Bernstein, 2012).

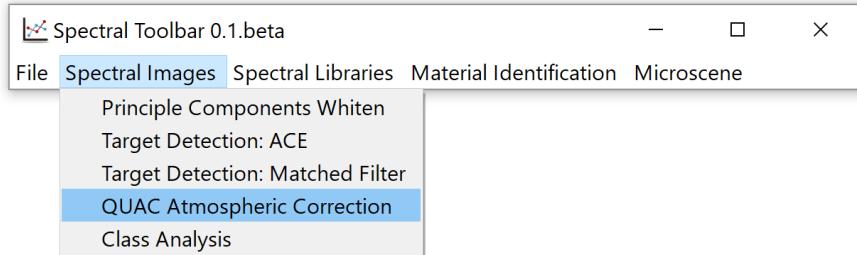


Figure 5-8. Accessing the QUAC function.

Selecting the menu will open a file input dialog to select the input radiance image, and then a dialog to select the filename for the output reflectance image. A radiance image and the resulting QUAC reflectance image are shown in Figure 5-9.

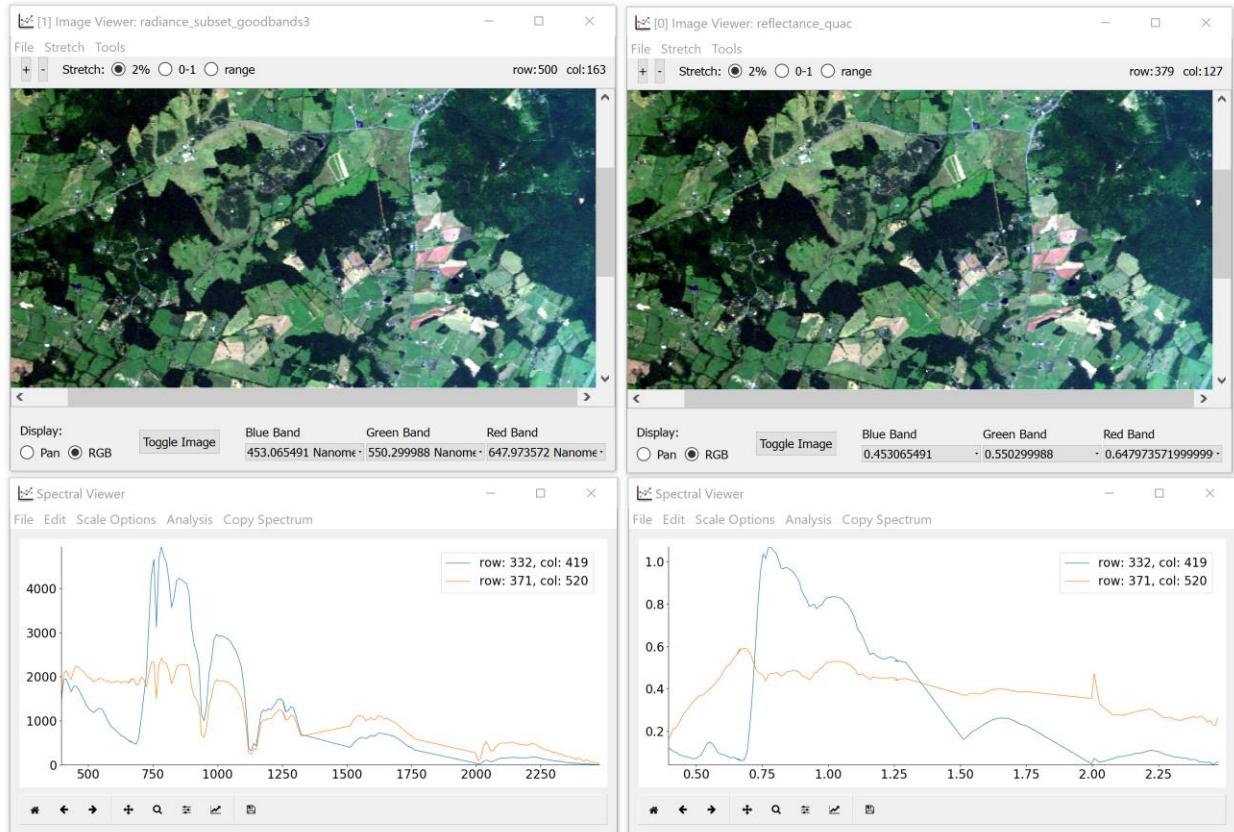


Figure 5-9. A radiance AVIRIS image over northern Virginia and the resulting QUAC reflectance image.

[Known Issues: This implementation of QUAC follows the basic paper (L.S. Bernstein, 2012), but the results are not great. It would probably be possible to improve this code.]

Section 6. Material Identification

6.01 Material Identification GUI:

The Material Identification GUI is accessed from the main menubar as shown in Figure 6-1.

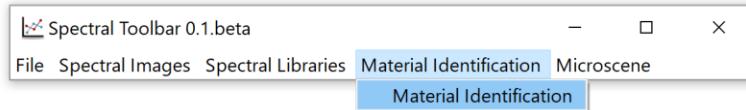


Figure 6-1. The Material Identification menu item.

The Material Identification GUI has three tabs: Data (for entering data), Material Id (for identifying material in a spectrum using libraries of known spectra), and Feature Matching (for finding spectra in libraries that are good matches to features in an image or library spectrum). These tabs are described separately in Sections 7.2-7.4.

6.02 Entering Data

Calling the Material Identification function from the menu opens the Spectral Material Identification GUI, shown in Figure 6-2. The GUI opens with the Data tab, where the user can select data for processing.

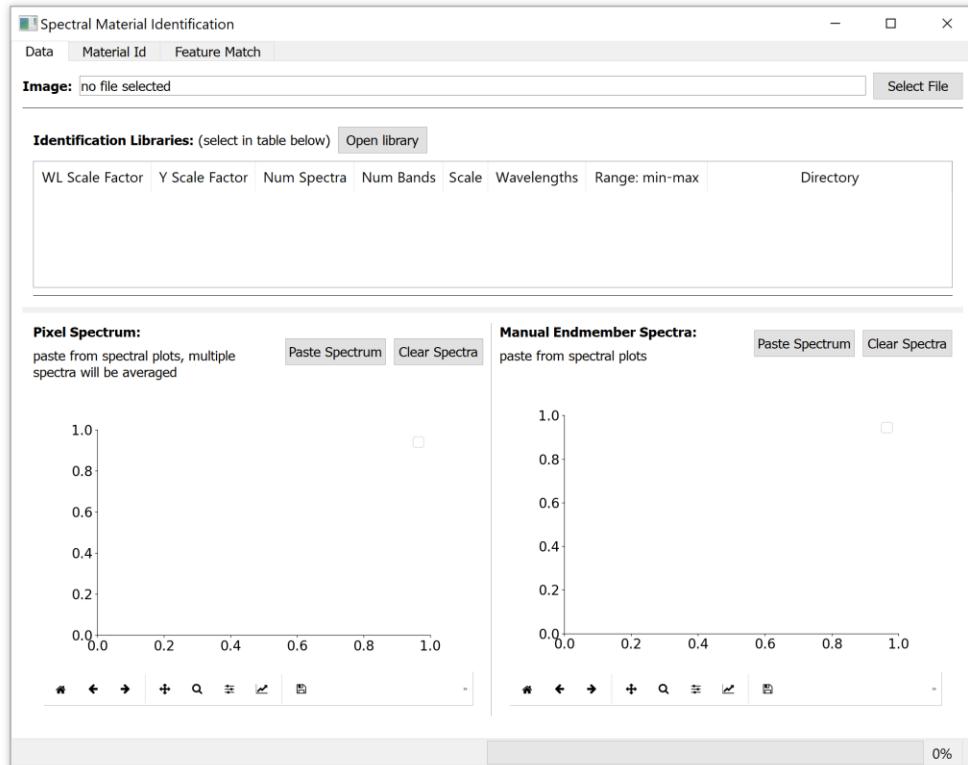


Figure 6-2. The Data tab in the Spectral Material Identification GUI.

The Data Tab has three sections: an upper section where the user can select an image, the center section where the user selects libraries (usually containing known spectra), and a lower section where the user selects the pixel or library spectra to identify (left) and a endmember spectra for background removal (right).

Not all material identification methods require all types of data in the data tab. The required data are indicated in Table 1:

Table 1. Required types of data for the two material identification methods.

Material Identification	Feature Match
<ul style="list-style-type: none"> - An Image - At least one library - Pixel spectrum/spectra - Endmembers (optional, recommended) 	<ul style="list-style-type: none"> - At least one library - Pixel spectrum/spectra (from an image or library)

In this section we will describe how to select all data that might be required.

Selecting an Image: To select an image, click on the “Select File” button to the right-hand side of the Image section. This will open a dialog to choose an image. The image will be opened in an Image Viewer GUI, the file name of the image will appear in the Image text box, and statistics are computed (including mean, covariance, and endmembers – indicated by the progress bar in the GUI, but the computation is done in a separate thread if possible). The result is as shown in Figure 6-3. The Data tab after opening one image..

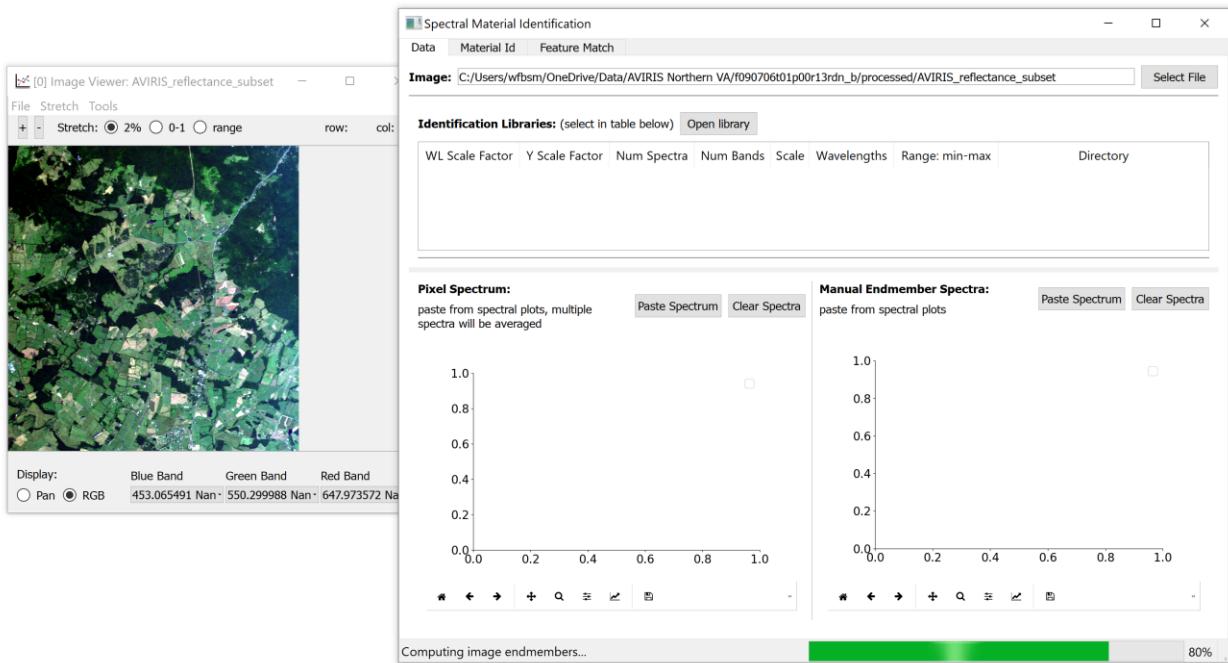


Figure 6-3. The Data tab after opening one image.

Collecting Spectra for Identification: After loading the image, the next step is to select spectra from the image corresponding to the object; multiple spectra can be chosen and the average will be used for identification. The usual process, shown in the figure below, is to open a target detection result in an Image Viewer, link the result to the Image

viewer showing the selected image, and zoom in on a high scoring group of pixels. Clicking on the pixels in the RGB display of the spectral image creates a plot in a Spectral Viewer of the pixel spectra (the set of selected pixels can be modified using the Edit menu on the Spectral Viewer). Then under Copy Spectrum, select the pixel spectra for the region to be identified, as shown in Figure 6-4. Selecting spectra for identification..

There are several tools that are useful in the process of selecting these pixels: the row-col coordinates of pixels in the upper-right corner of the Image Viewer, the row-col label used for spectra names in the Spectral Plot, toggling between the linked viewers displaying the spectral image and the detection plane, the Stretch->Interactive Stretch in the Image Viewer displaying the detection plane (to isolate the top-scoring pixels), and the Edit->Edit Data tool on the Spectral Viewer.

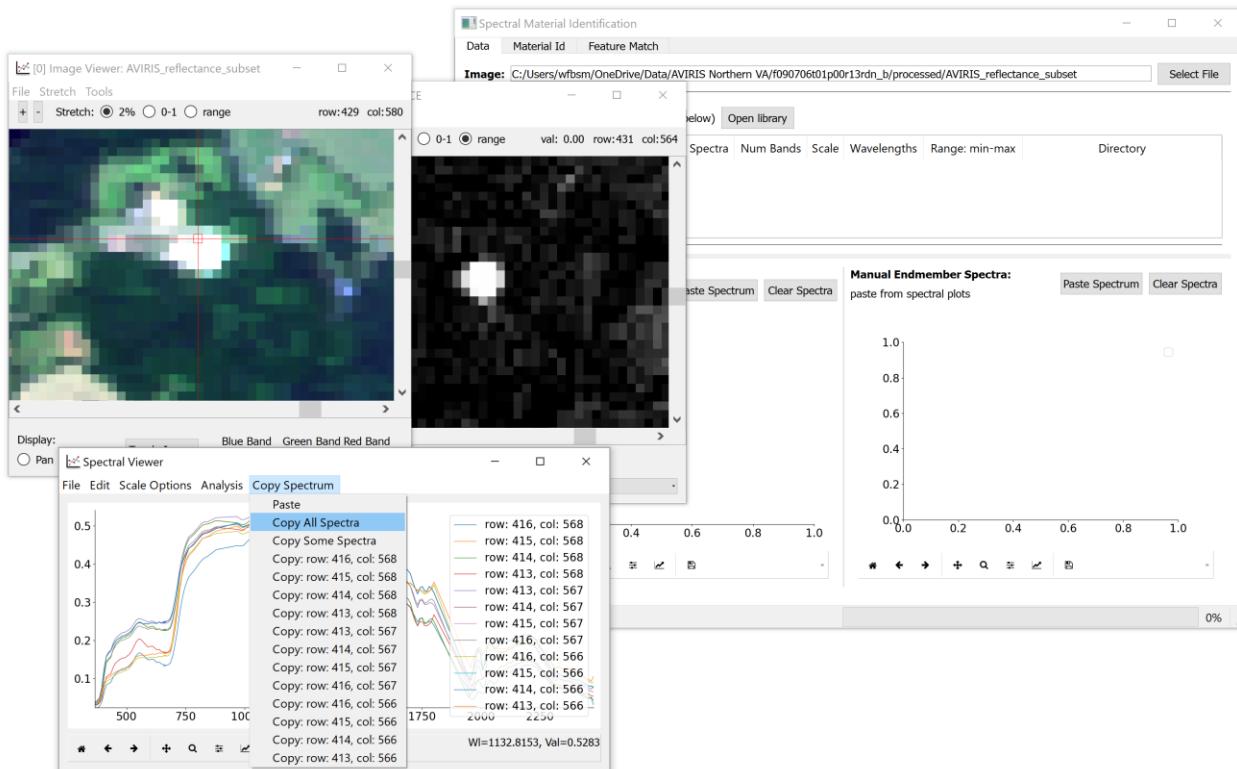


Figure 6-4. Selecting spectra for identification.

Once the spectra are copied from a Spectral Viewer, paste them into the “Pixel Spectrum” plot on the Material Identification GUI by clicking on the “Paste Spectrum” button in the Pixel Spectra area of the GUI (lower-left). The result is shown in Figure 6-5. Pasting spectra for identification into the “Pixel Spectrum” plot..

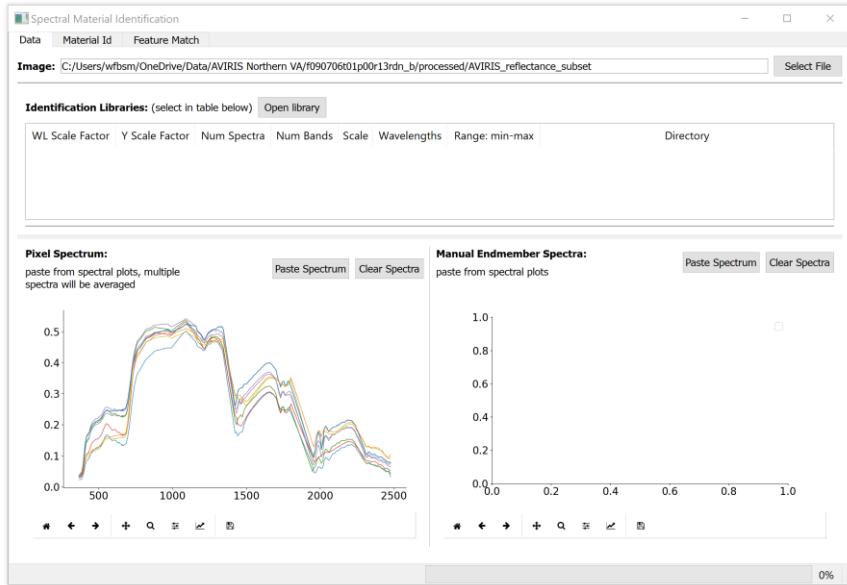


Figure 6-5. Pasting spectra for identification into the “Pixel Spectrum” plot.

Collecting Endmember Spectra: If desired (for example, if the data is to be used in the Material Id tab), we collect endmember spectra by a similar process. Endmember spectra are spectra from the background material that are likely mixed with the target. These spectra are selected from the image around the target object, but not on materials that are similar to the target, as shown in Figure 6-6. In the example image used in this section, the endmember spectra will be vegetation, primarily grass (lighter green) since it seems this is the background in the image. Effort should be made to select ample variety of spectra, which usually requires at least 20 spectra. A good selection of endmembers in our image is shown below. The software will compute additional endmembers using SMAC, but it is highly recommended that the user manually select endmember spectra from local background materials for best results.

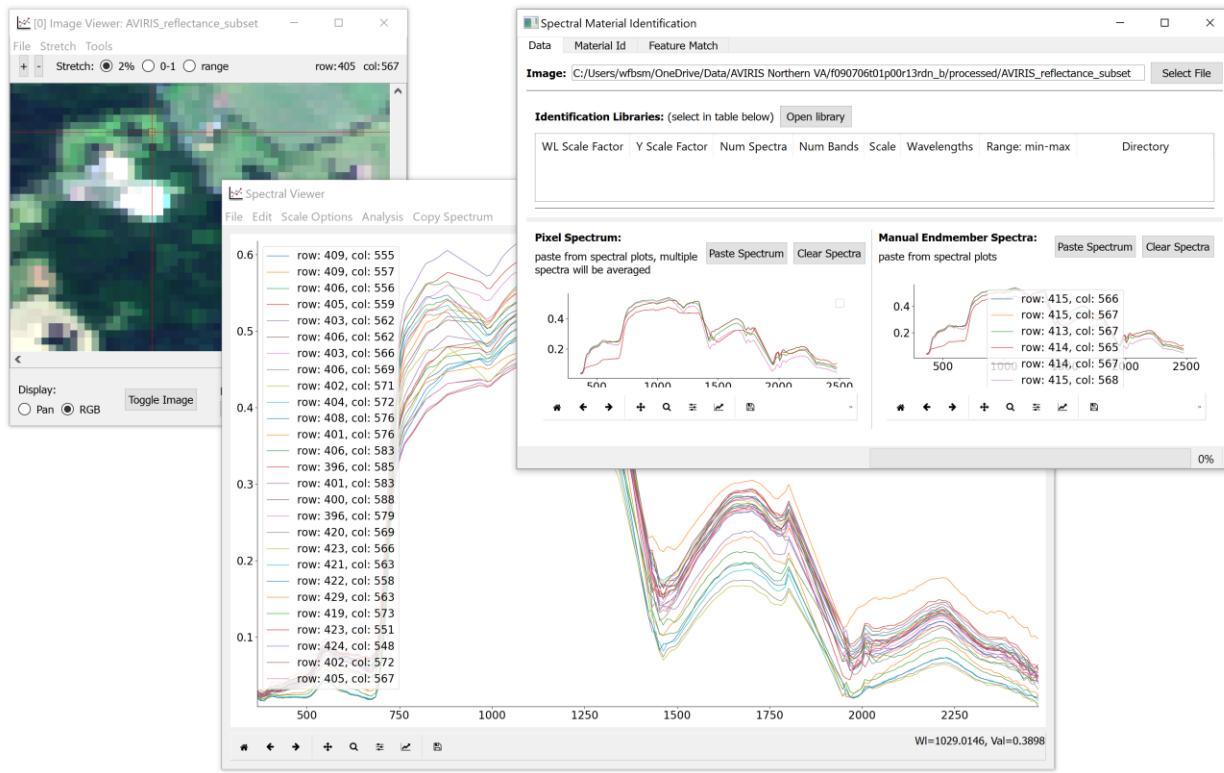


Figure 6-6. Collecting background endmember spectra and pasting into the “Manual Endmember Spectra” plot.

Selecting Libraries: The last step is to select libraries for identification. Libraries are opened by clicking the “Load Library” button in the Identification Libraries section of the Data Tab. This opens a standard file opening dialog to select the spectral library files. When a library is opened, its information is added to the Identification Libraries table. In the figure shown in Figure 6-7, three libraries have been opened.

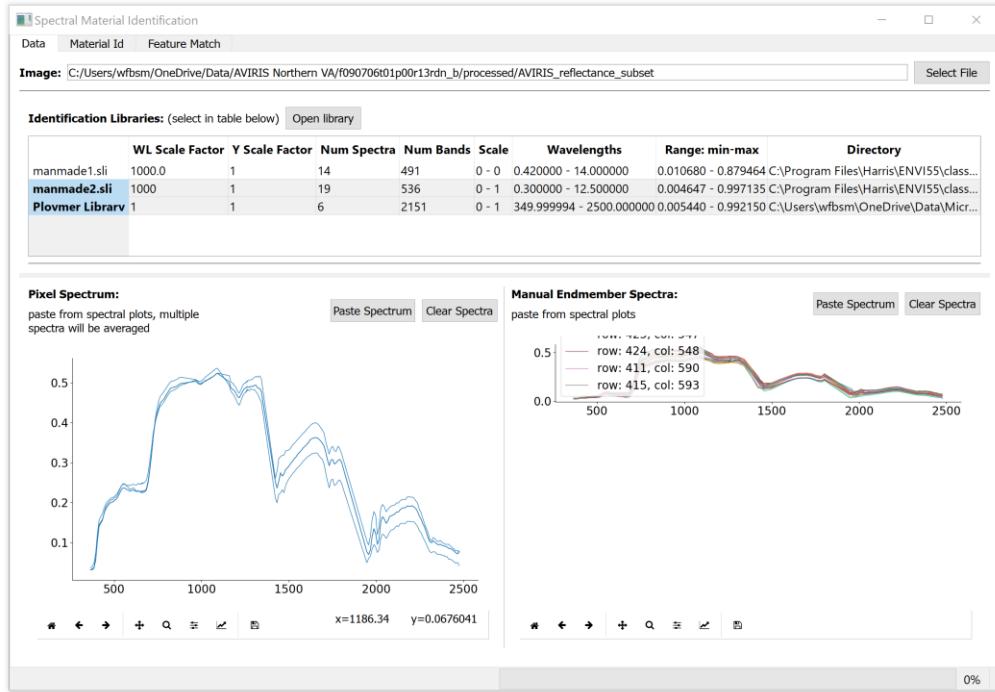


Figure 6-7. Three libraries have been opened, and two libraries have been selected for identification.

Once libraries have been opened, the user must select at least one of the libraries to use in identification by clicking on the rows for the desired libraries in the table. Use ctrl+click or shift+click to select multiple libraries, or the top-left corner of the table to select all.

The software will attempt to determine if wavelength scale factors (first column) and y-scale factors (second column) are needed to scale each library to match the data. If the estimated values in the first two columns are not correct, the user can click on those cells in the table to modify the values. (These are the only cells in the table that can be user-modifies.) When identification in the other tabs gives unexpected improper results, it is worth checking these scale factors.

6.03 Material Identification

The “Material Identification” Tab Provides the ability to identify materials that are present in the “Pixel Spectrum”. The Pixel Spectrum will be the mean of the spectra in the Pixel Spectrum plot in the Data Tab.

Identification is done by computing multiple metrics for each library spectrum. The two most important metrics are a probability computed for each spectrum using Bayesian Model Averaging [See (Tom Burr, 2002), (Shawn Higbee, 2009), and (Basener, Ensemble learning and model averaging for material identification in hyperspectral imagery, 2017)] and a background-removal subpixel correlation [See (Basener, 2011)]. This is similar to the identification as done in some automated image processing software, but the user has control of the pixels used for identification, endmembers, and the libraries.

When first opened, the Material Identification Tab should look as shown in Figure 6-8.

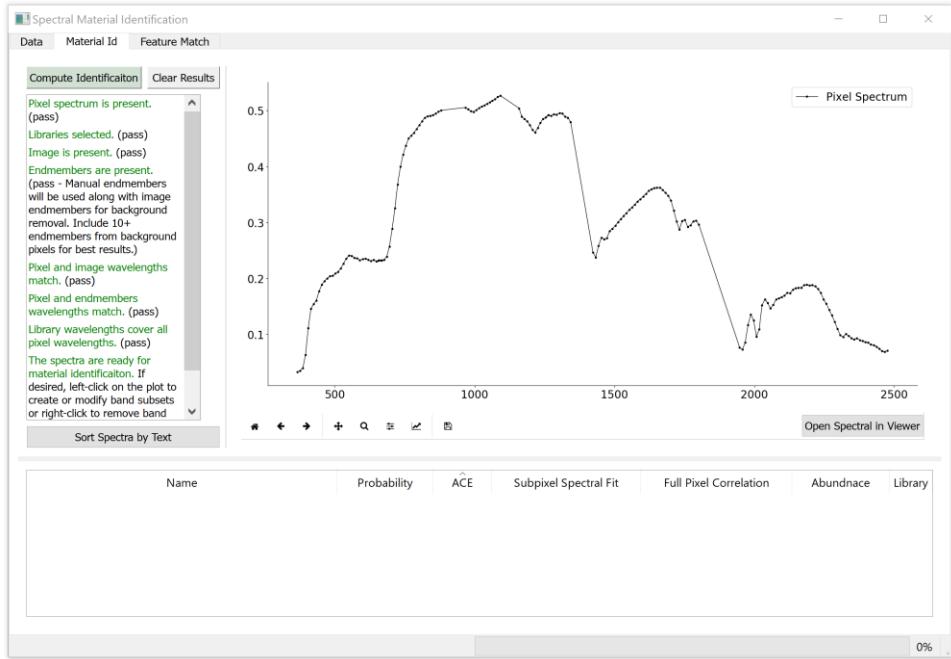


Figure 6-8. The Material Identification tab, when first opened with data loaded.

There are three main regions in this GUI:

1. The control buttons (upper-left) labeled “Compute Identification” and “Clear Results” with the Data Check box indicating which data has been properly loaded in the Data Tab.
2. The Spectral Plot, where the Pixel Spectrum is plotted and where comparison to library spectra.
3. The Identification Table (bottom), where the identification results will be displayed.

Note that in the image above, the Compute Identification button is green, and the Data Check text box indicates that the data loaded in the Data Tab is sufficient for processing. If the data were incomplete, then this box would include descriptions of the data checks that were not satisfied. Some examples are shown in Table 2. Common Data Check errors on the Material Identification Tab..

Table 2. Common Data Check errors on the Material Identification Tab.

Data Check Indication:	Compute Identification Pixel spectrum is present. (pass) Libraries not selected. (You must open and select at least one library in the Data Tab. Libraries are selected by clicking so they are highlighted.) Image is present. (pass) Endmembers are present. (pass - Manual endmembers will be used along with image endmembers for background removal. Include 10+ endmembers from background pixels for best results.) Pixel and image wavelengths match. (pass) Pixel and endmembers wavelengths match. (pass)	Compute Identification Pixel spectrum is present. (pass) Libraries selected. (pass) Image is present. (pass) Endmembers are present. (pass - Manual endmembers will be used along with image endmembers for background removal. Include 10+ endmembers from background pixels for best results.) Pixel and image wavelengths match. (pass) Pixel and endmembers wavelengths match. (pass) Pixel wavelengths extend beyond some library wavelengths. (Library resampling may cause inaccuracies. Check the libraries.)	Compute Identification Pixel spectrum not present. (You must paste pixel spectru to identify into the "Pixel Spectrum" plot on the Data Tab). Libraries selected. (pass) Image is present. (pass) Endmembers are present. (pass - Manual endmembers will be used along with image endmembers for background removal. Include 10+ endmembers from background pixels for best results.)
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Solution:	Go to the Data Tab and make sure at least one library is opened, and selected. Most likely, the user did not select a library by clicking on it.	Go to the Data Tab and check that the wavelengths for the libraries cover the pixel wavelengths. You might need to modify the WL-Scale Factor (column 2) for the library, or spectrally resample the image.	Select spectra from an image and paste them into the Pixel Spectrum plot in the Data Tab.
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Clicking the “Compute Identification” button will initiate the identification process. The results will appear similar to Figure 6-9. Results from Material Identification..

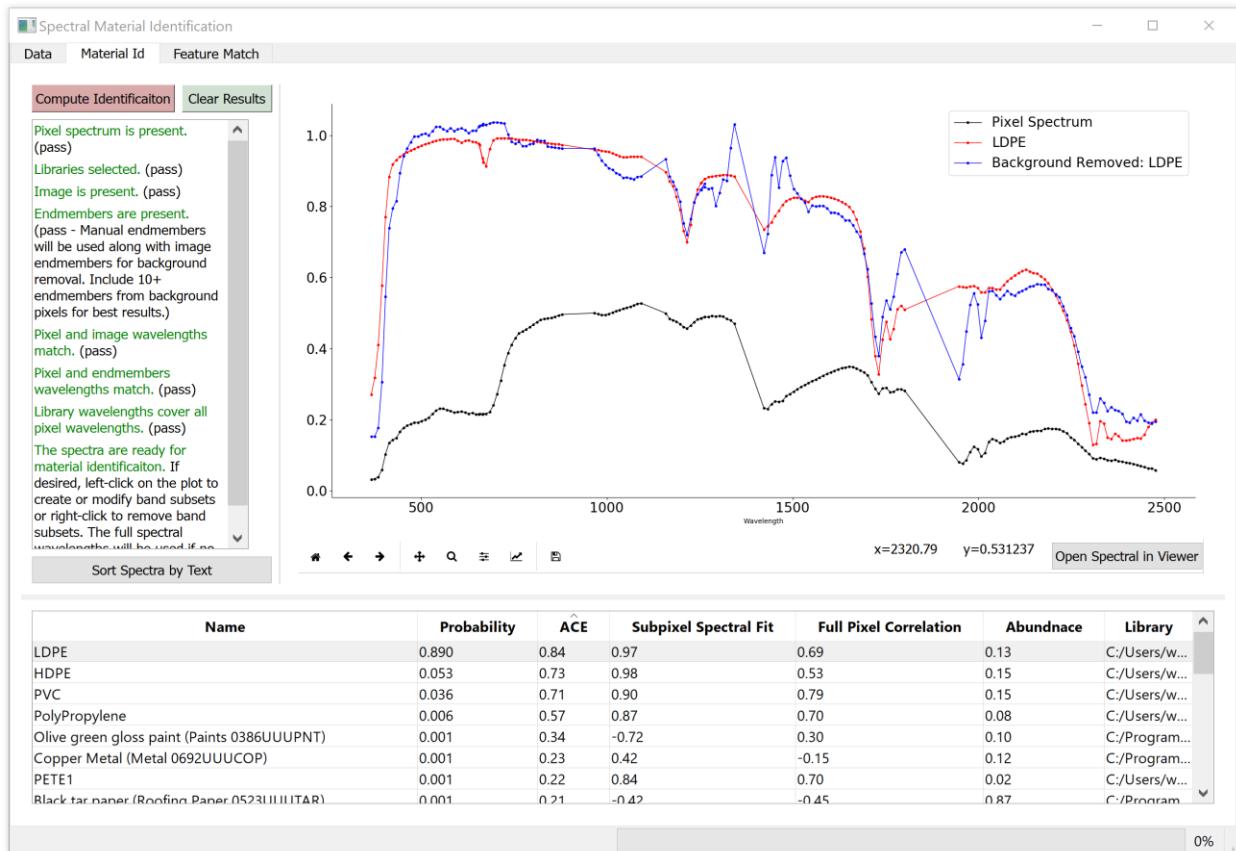


Figure 6-9. Results from Material Identification.

Five metrics have been computed for each library spectrum (Probability, ACE, Subpixel Spectral Fit, Full Pixel Correlation, and Abundance). The table is sorted by probability.

The plot area now shows the Pixel Spectrum (black), the library spectrum (red) and the background-removed spectrum (blue). For a good match, the features visible in the library spectra should also be visible in the background-removed spectrum, and have the same wavelengths for maxima and minima, as in the figure above. Note that in this plot data

points are indicated with small circle markers, providing distinction between actual features and bad/atmospheric missing bands.

The result must be interpreted using both the metrics in the table and the spectral plot.

Interpreting Probability.

The Probability (Column 2 in the table) indicates the relative probability of a spectrum in comparison to the other spectra in the library. In the example above, the LDPE (Low Density Polyethylene) has a probability of 0.89, indicating that if the material in the pixel is in the library, it is probably LDPE (with probability of 0.89). It is possible, but not likely, that the material is HDPE or maybe PVC, and it is improbable that any of the other spectra are present.

If multiple spectra have relatively high, similar probabilities, the conclusion would be that the actual material is similar to the group. For example, if LDPE and HDPE (High Density Polyethylene) both had a probability of 0.47, then we would conclude that the material in the pixel is a polyethylene. The

The probability alone is not definitive; it is possible to have a high probability in the case where the material in the pixel is not in the library.

Interpreting Subpixel Spectra Fit.

The Subpixel Spectra Fit (Column 3 in the table) is the R-squared correlation between the library spectrum and the background-removed spectrum for that library spectrum. A high score (closer to one) indicates a good fit between the library spectrum and the background-removed spectrum, and indicates that the library spectrum is a viable possibility for the material present in the pixel. In part, the spectra fit can be used to confirm a library spectrum with relatively high probability. However, visibly matching features in the spectral plot is more important than the spectral fit value.

Interpreting the Spectral Plot.

Visibly matching features between the library spectrum and background-removed spectrum is essential for determining a reliable identification. The spectra should have maxima and minima at the same wavelengths, and ideally matching slopes and general fit. The LDPE example above indicates a very good match.

Opening Plot in Spectral Viewer:

If desired, clicking the “Open in Spectral Viewer” button will open a spectral viewer and add the plotted spectra to the viewer. This can be used to compare multiple spectra, as in the plot shown in Figure 6-10. Comparing multiple library and background-removed spectra. Observe in this plot that the LDPE spectra matches the background-removed pixel spectra better than the HDPE across the shelf-feature around 2250. This might be a reliable feature for distinguishing HDPE and LDPE, but would need confirmation over additional examples of HDEP and LDEP, for example using spectra from microscene.

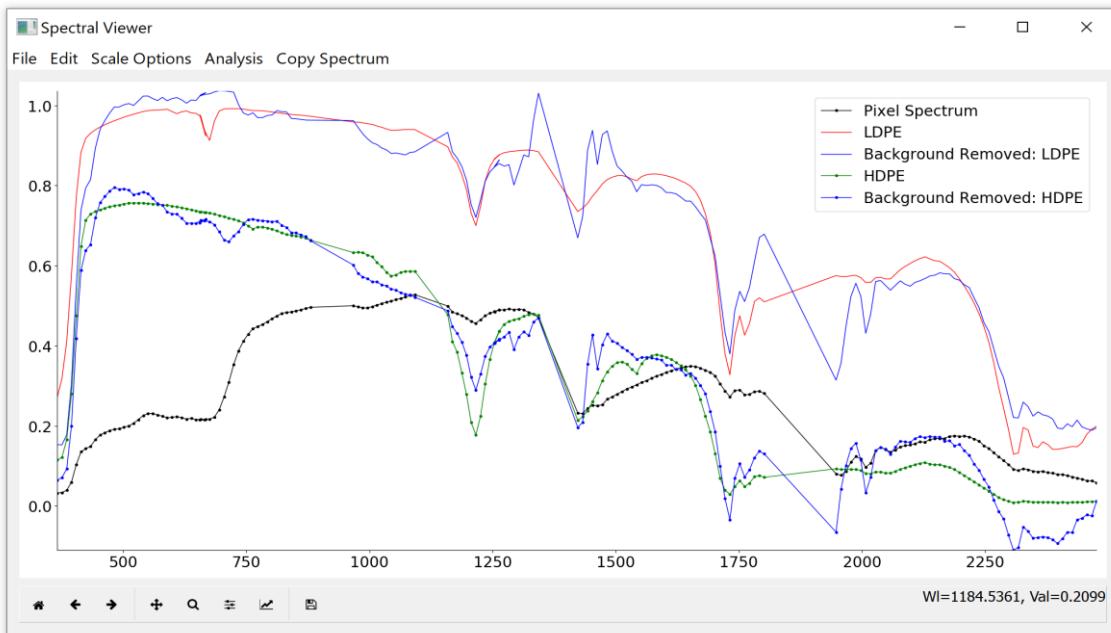


Figure 6-10. Comparing multiple library and background-removed spectra.

Sort by Text:

Clicking the “Sort Spectra by Text” button opens a dialog to enter query words for sorting the identification table. For example, the dialog and results for sorting by the word “Steel” are shown in Figure 6-11. Sorting the Identification Table by spectra names containing the word “steel”.. The search is a fuzzy search, so exact matching are listed first followed by partial matches.

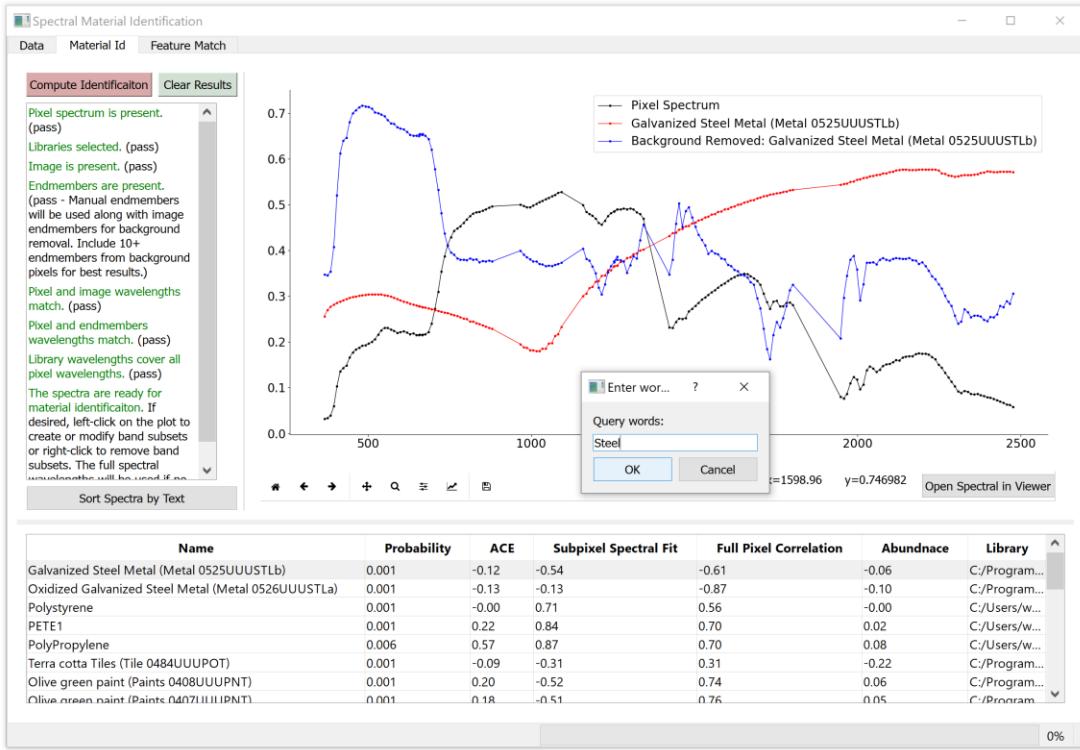


Figure 6-11. Sorting the Identification Table by spectra names containing the word "steel".

Manual Band Selection.

The user can select bands for the identification process manually. This can be useful, for example, if there are certain bands that are known to be important for the materials of interest or if bands are present in the data which seem to be noisy. Before computing the identification, band regions can be created by left-clicking and dragging in the spectral plot. Band regions are indicated as vertical green regions. A band region can be removed by right-clicking on the region. Figure 6-12. Identification using a user-selected set of band regions. shows the identification using three band regions that contain the main polymer features.



Figure 6-12. Identification using a user-selected set of band regions.

6.04 Feature Matching:

Feature matching is the process of matching specific features with the Pixel Spectrum to features present in the library spectra. The features are created by the user using the interactive plot. The initial Feature Match Tab is shown in Figure 6-13, with layout very similar to the Material Id Tab.

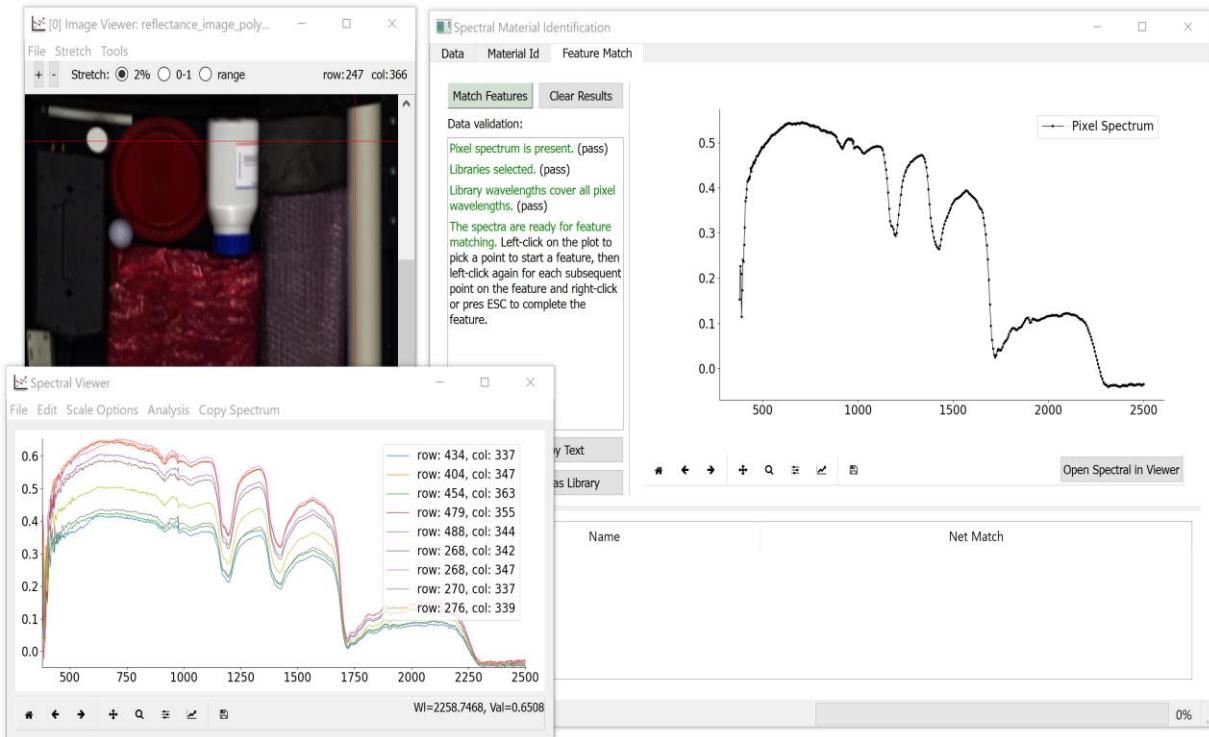


Figure 6-13. The initial opening of the Feature Match Tab, together with a microscene image and a Spectral Viewer showing the spectra from the PVC plumbing pipe.

Features are created by clicking in the spectral plot. Each Feature is represented as a series of colored dots on selected data points. A crosshair is provided at the cursor location to aid in lining up features. A feature is initiated by left-clicking on the spectral plot. This creates a first point at the data point of the plot corresponding to the wavelength that is closest to the cursor (vertical line in the crosshair). At this point the crosshair turns red. Subsequent left-clicks create additional points in the feature. The feature is completed when either a right-click is used to create the last point, or the Esc key is pressed, at which point the crosshair turns blue. This process is shown in Figure 6-14.

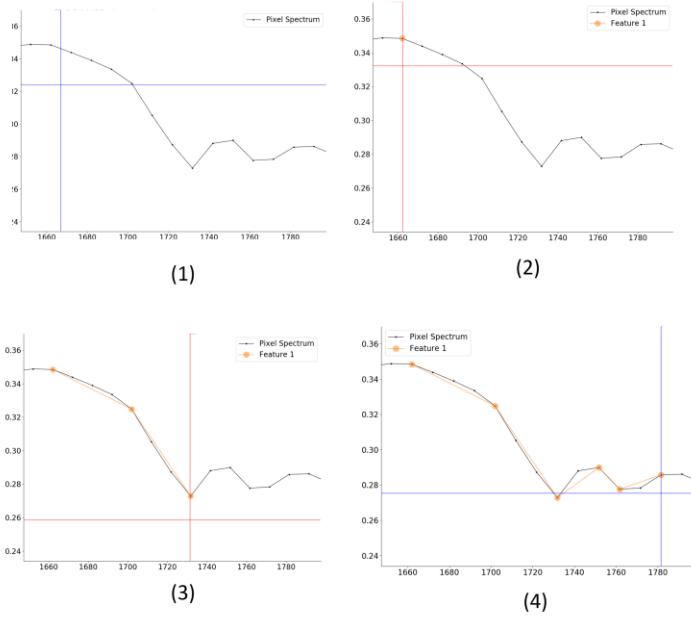


Figure 6-14. Four steps in the building of a feature: (1) Choosing a wavelength to start the Feature, (2) Left-click to Start, (3) Repeat left clicks to add more points, and (4) right-click to complete the feature.

The plot with four user-created features is shown in Figure 6-15, along with results from feature matching.



Figure 6-15. A Pixel Spectrum from the PVC pipe with four features, and feature matching results.

Observe that the Feature Matching results correctly match the features of the PVC pipe to a PVC library spectrum. Moreover, the next best match, Polypropylene, matches well in Features 3 and 4, but not with Features 2 and 3. Clicking on the Polypropylene row in the tables produces a plot with the Polypropylene spectrum, as shown in Figure 6-16.

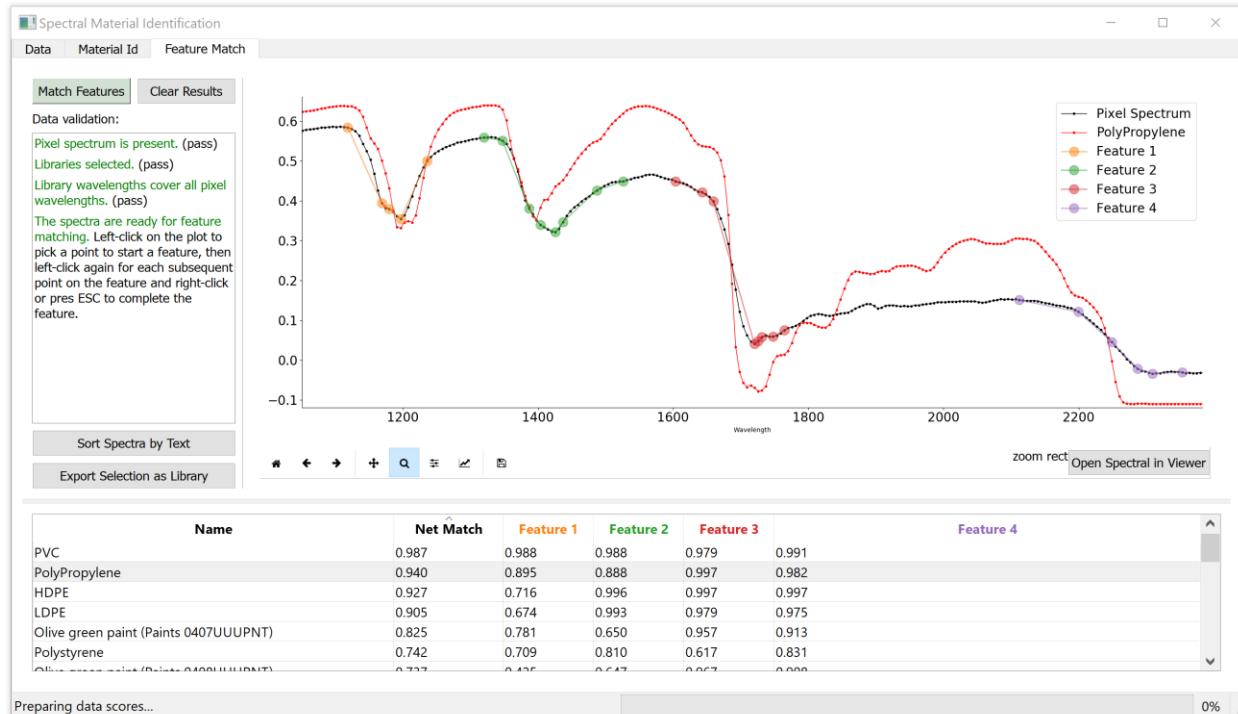


Figure 6-16. The PVC pipe pixel spectrum (black) with the Polypropylene library spectrum (red).

It seems that the shape and location of the minimum in Features 2 and 3 are indicators of the difference between PVC and Polypropylene. This can be viewed again by using the “Open Spectra in Viewer” button, and opening the PVC and Polypropylene spectra in the Spectral Viewer is shown in Figure 6-17.

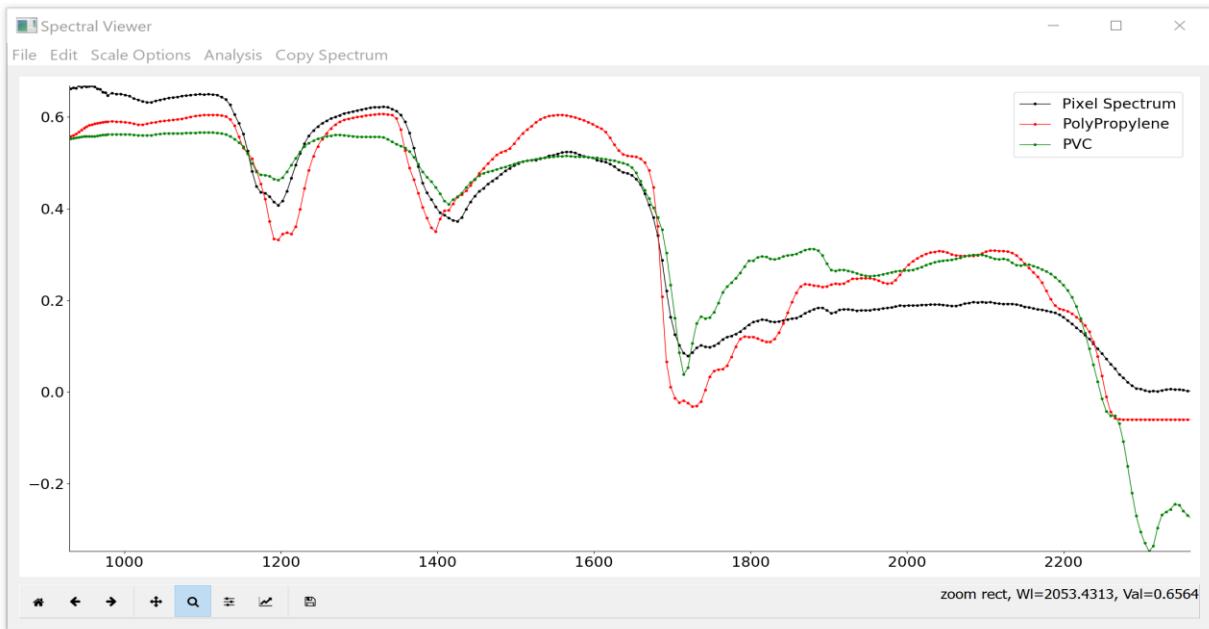


Figure 6-17. The Pixel Spectrum from the PVC plumbing pipe (black) together with the PVC library spectrum (green) and Polypropylene library spectrum (red). Observe the importance of the fit around 1200nm and 1400-1450nm in distinguishing these materials.

Figures 6-18 through 6-23 show the Feature Matching Tab for different polymer materials in the polymer microscene image.

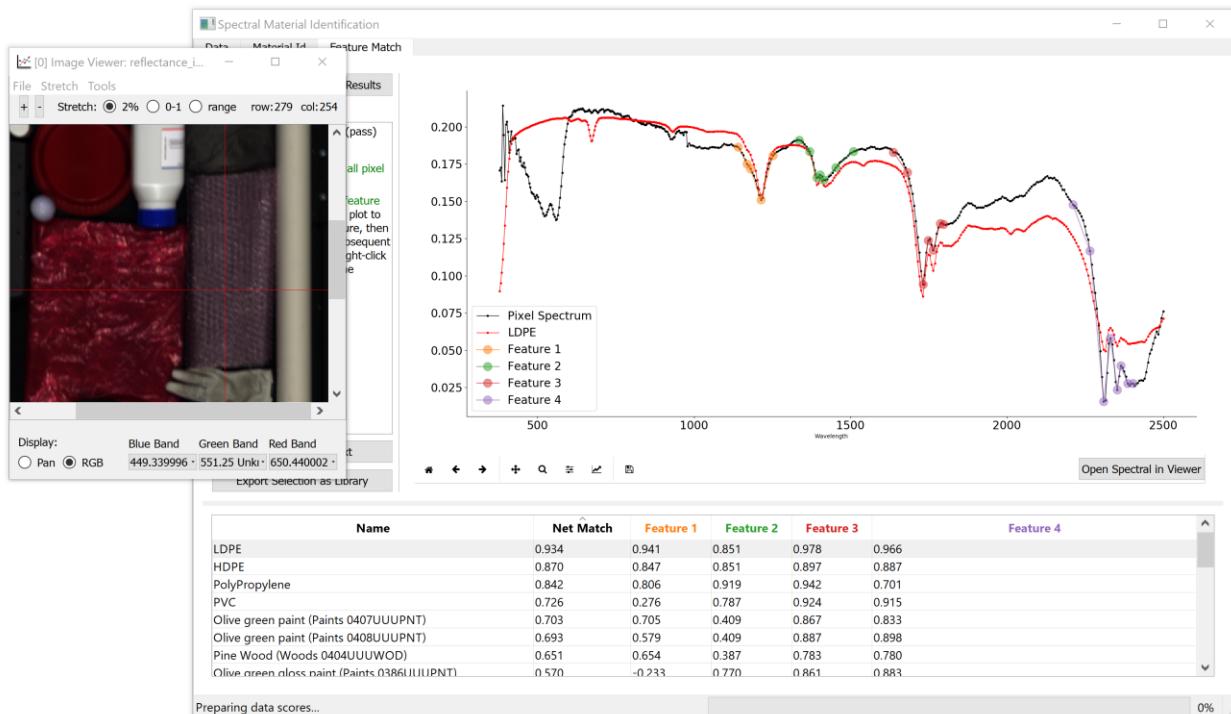


Figure 6-18. Feature Matching on the bubble wrap material, which is probably LDPE.

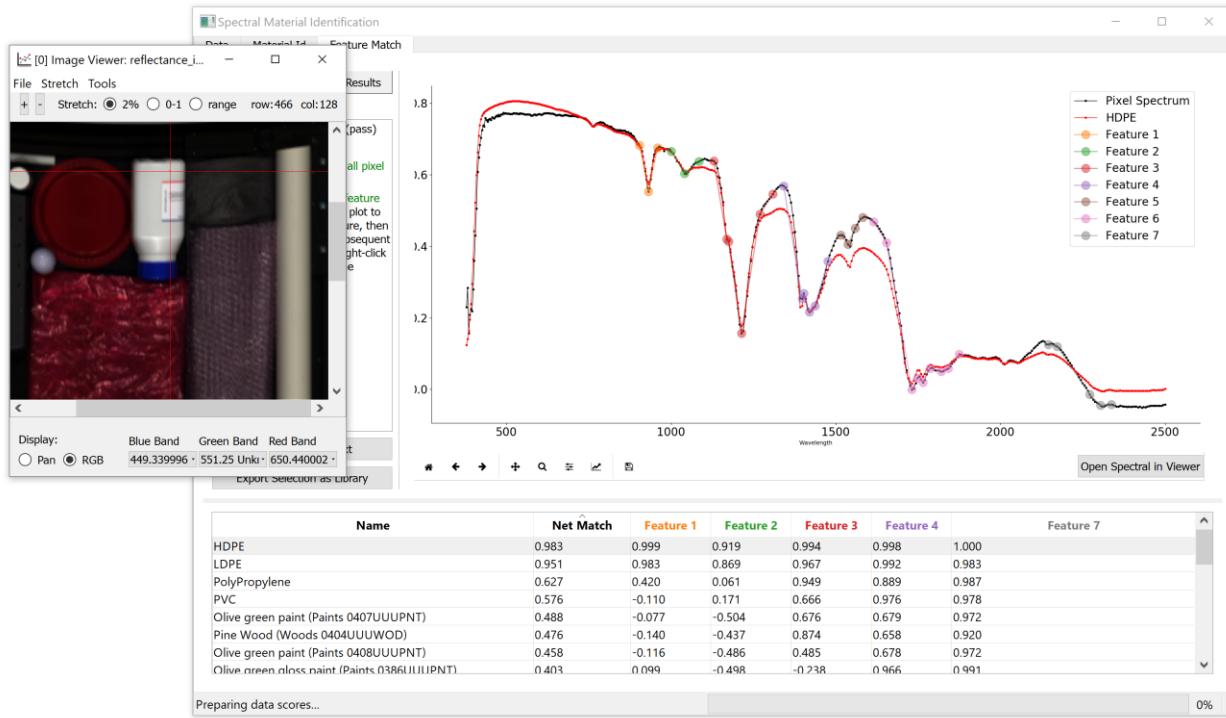


Figure 6-19. Feature Matching on the medicine bottle, which is probably HDPE.

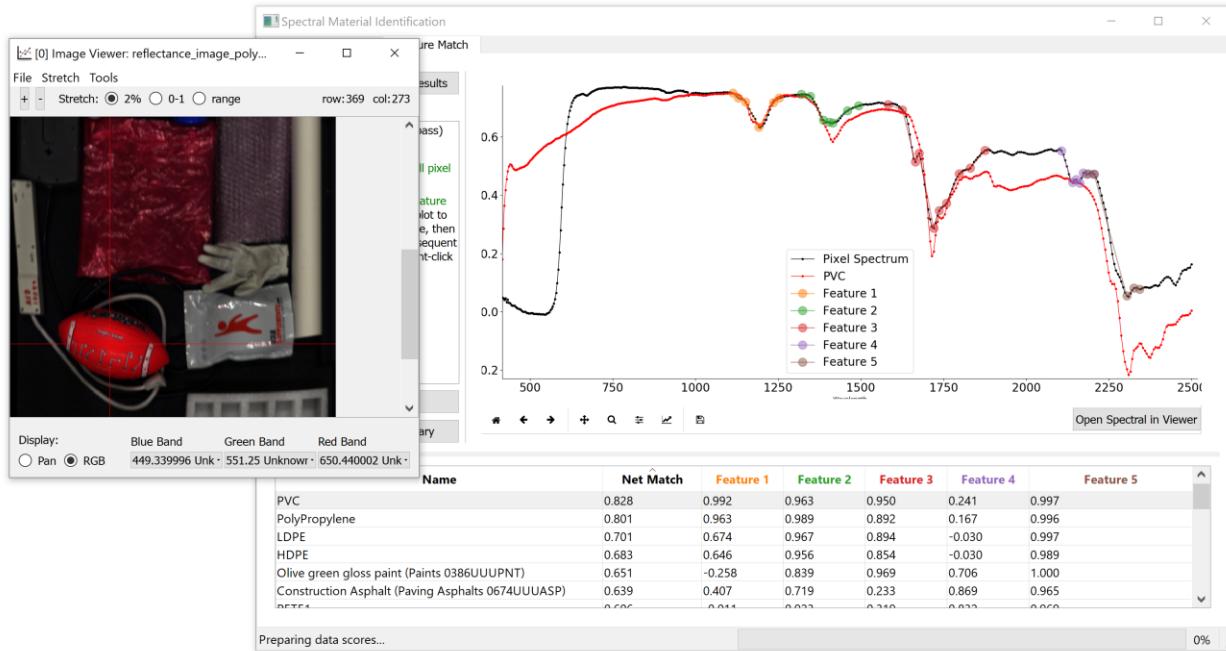


Figure 6-20. Feature Matching on the football, which is probably made from PVC (inflatable balls are advertised as being made of "polyvinyl plastic" or "PVC plastic"). Note the features at 1670nm and 2150nm, which are present in Features 3 and 4 causing reduced match scores.

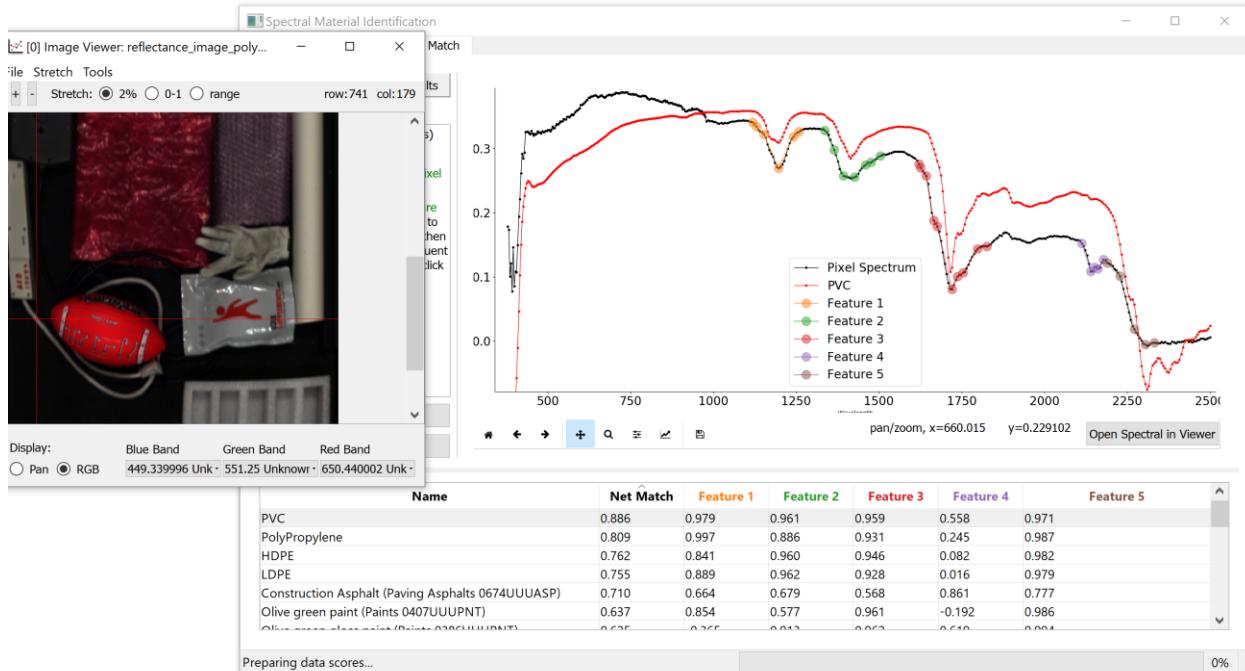


Figure 6-21. Feature Matching on the extension cord. Note the features at 1670nm and 2150nm similar to those observed on the football but not the library PVC.

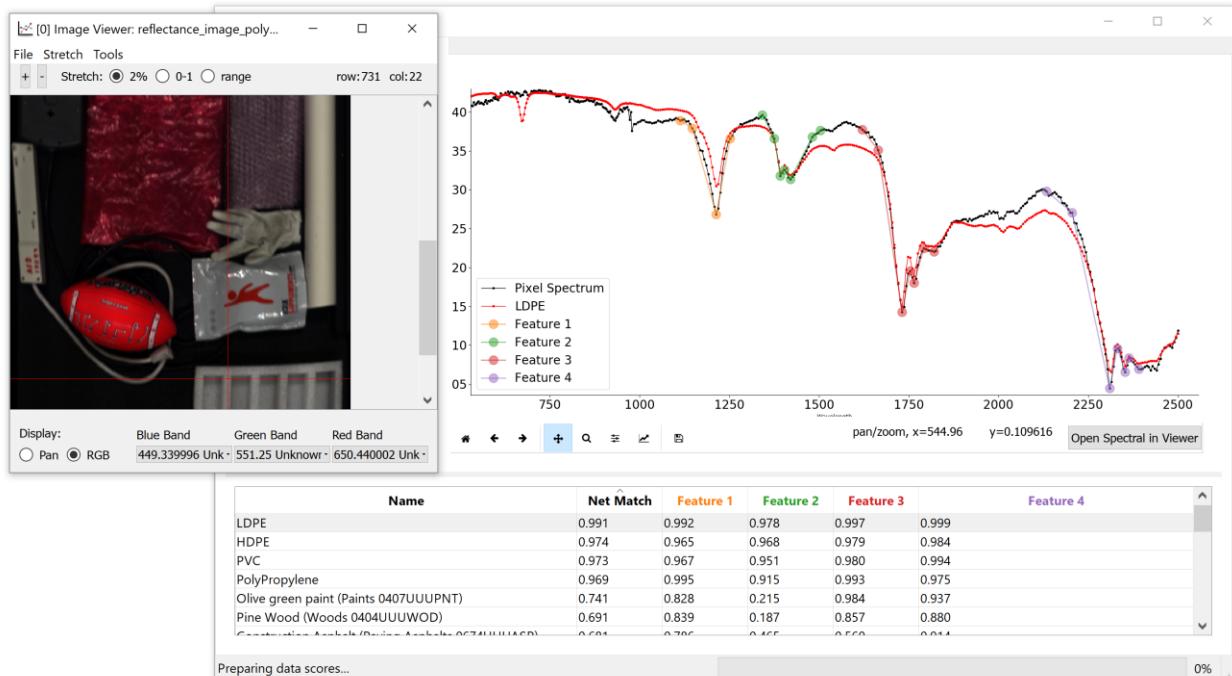


Figure 6-22. Feature Matching on the foam packing tray, which is likely LDPE.

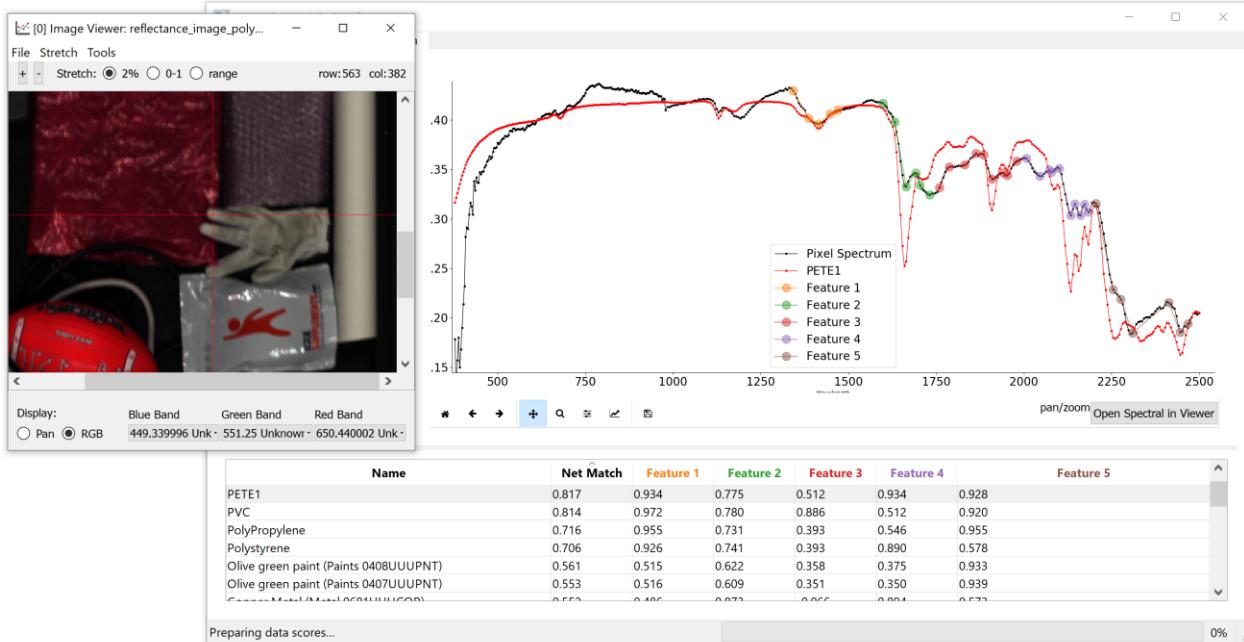


Figure 6-23. Feature Matching on the glove, which appears to be PETE (full name polyethylene terephthalate), is in the polyester family and used for clothes fabric.

References

- Basener, W. (2011). An automated method for identification and ranking of hyperspectral target detections. *Proc. SPIE*.
- Basener, W. (2017). Ensemble learning and model averaging for material identification in hyperspectral imagery. *Proc. SPIE 10198, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII*.
- Daniels, P. H. (2009). A brief overview of theories of PVC plasticization and methods used to evaluate PVC-plasticizer interaction. *Journal of Vinyl and Additive Technology*,
<https://onlinelibrary.wiley.com/doi/abs/10.1002/vnl.20211>.
- Shawn Higbee, D. M. (2009). A Bayesian approach to identification of gaseous effluents in passive LWIR imagery. *Proc. SPIE*.
- Songwon. (2019, 2 27). Retrieved from
https://www.songwon.com/assets/images/contentModelImages/SONGWON_Technical_sheet_PVC-Additives_V4.pdf
- Tom Burr, H. F. (2002). Chemical Identification using Bayesian Model Selection. *Spring Research Conference - Section on Physical & Engineering Sciences (SPES)* (pp. 338-342). Ann Arbor: University of Michigan.