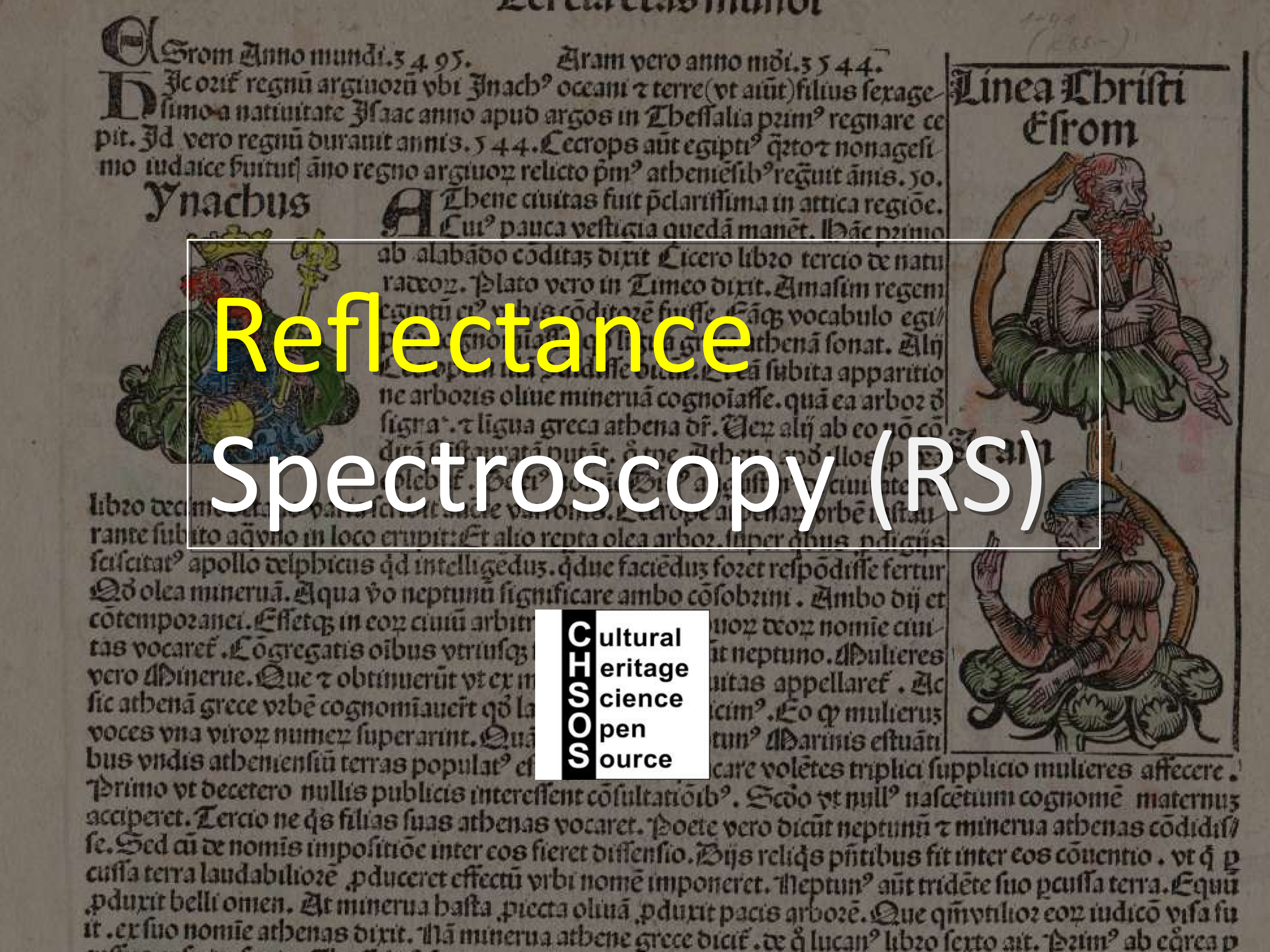
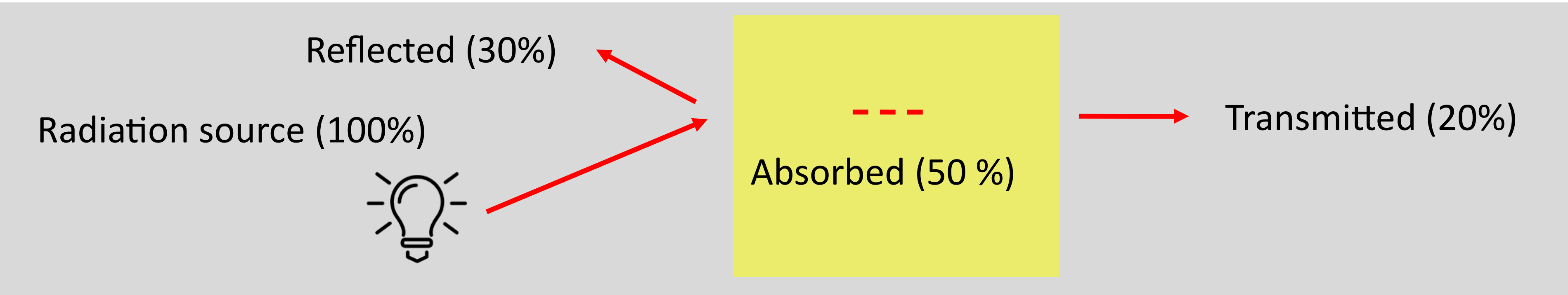

Reflectance
Spectroscopy (RS)
Cultural
Heritage
Science
Open
Source

Content

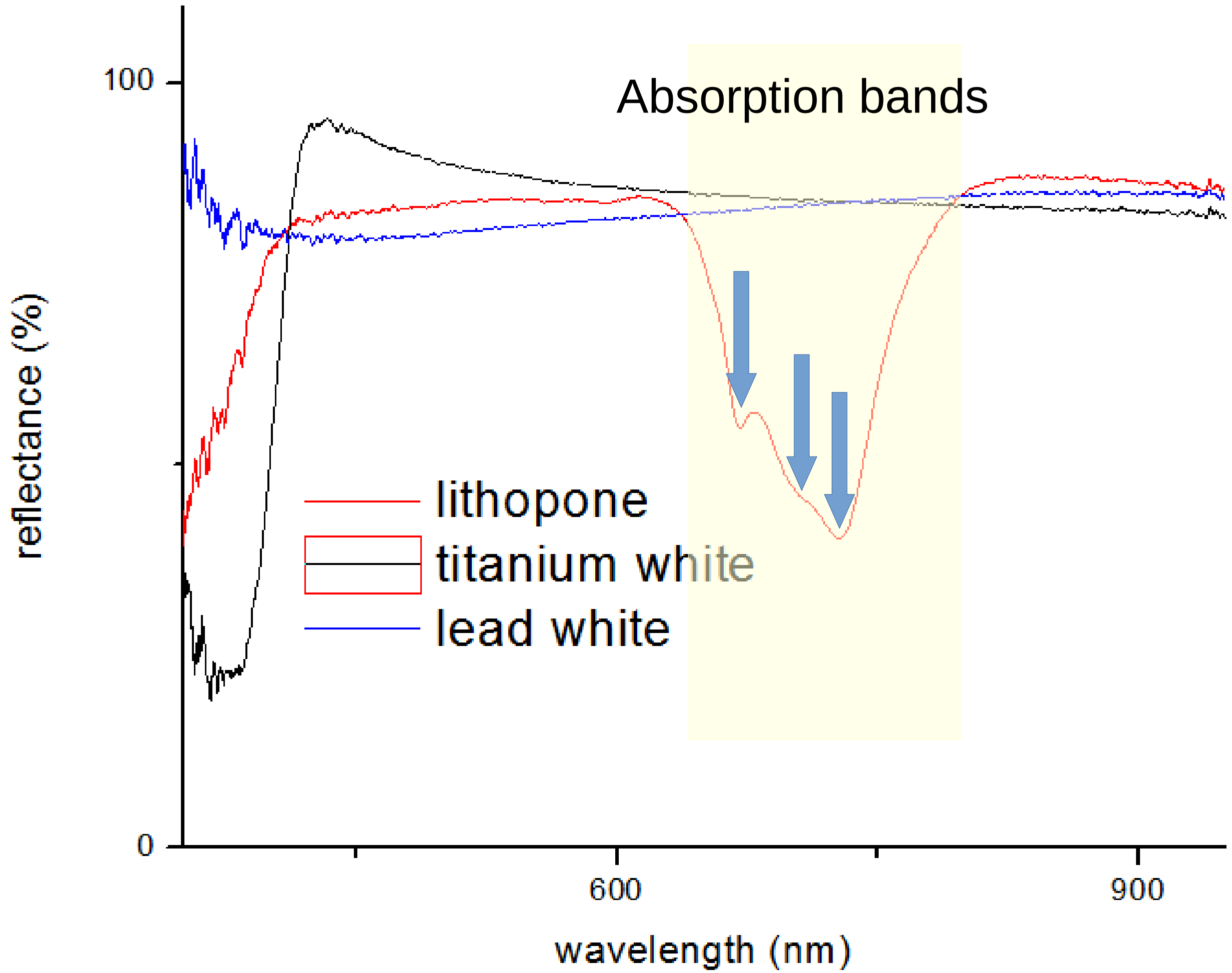
Reflectance Spectroscopy

RS Theory: intro



A Reflectance spectrum shows for each wavelength the percentage of radiation that is reflected (reflectance (%)).
The reflectance spectra can provide information useful for the identification of pigments since the radiation that is not reflected is absorbed or transmitted **depending on the chemical composition of the material tested.**

RS Theory: intro



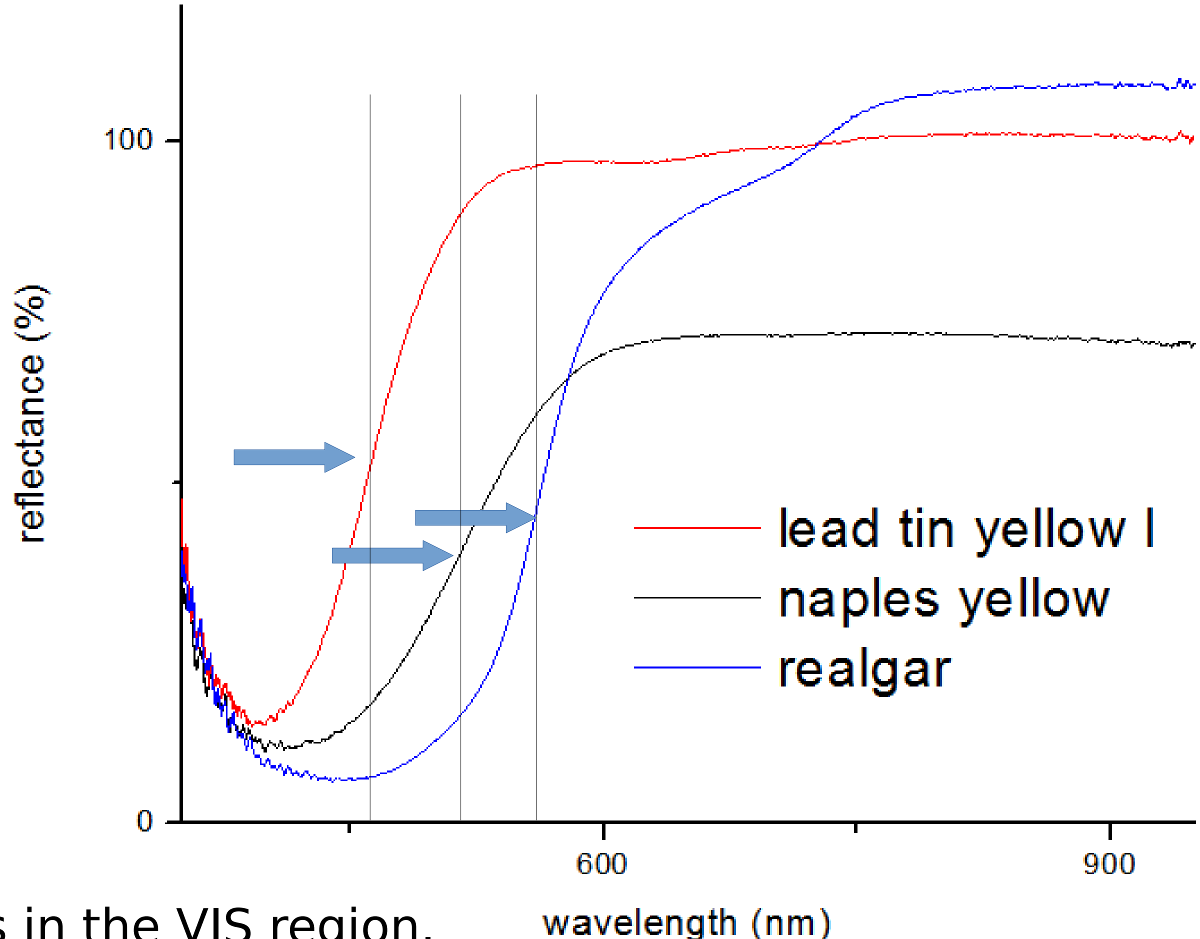
A reflectance spectrum shows Reflectance as a percentage and wavelength as nm. The features of a reflectance spectrum are described as “absorption band”, “inflection point” and “maxima”. This graph shows the spectra of 3 white pigments. Lithopone’s spectrum is characterized by a structured absorption band between 650 nm and 750 nm. This large structured absorption band is made of smaller absorption bands (indicated by the arrows).

Reflectance Spectroscopy

chsopensource.org

Cultural **H**eritage **S**cience **O**pen **S**ource

RS Theory: intro



Inflection points in the VIS region.

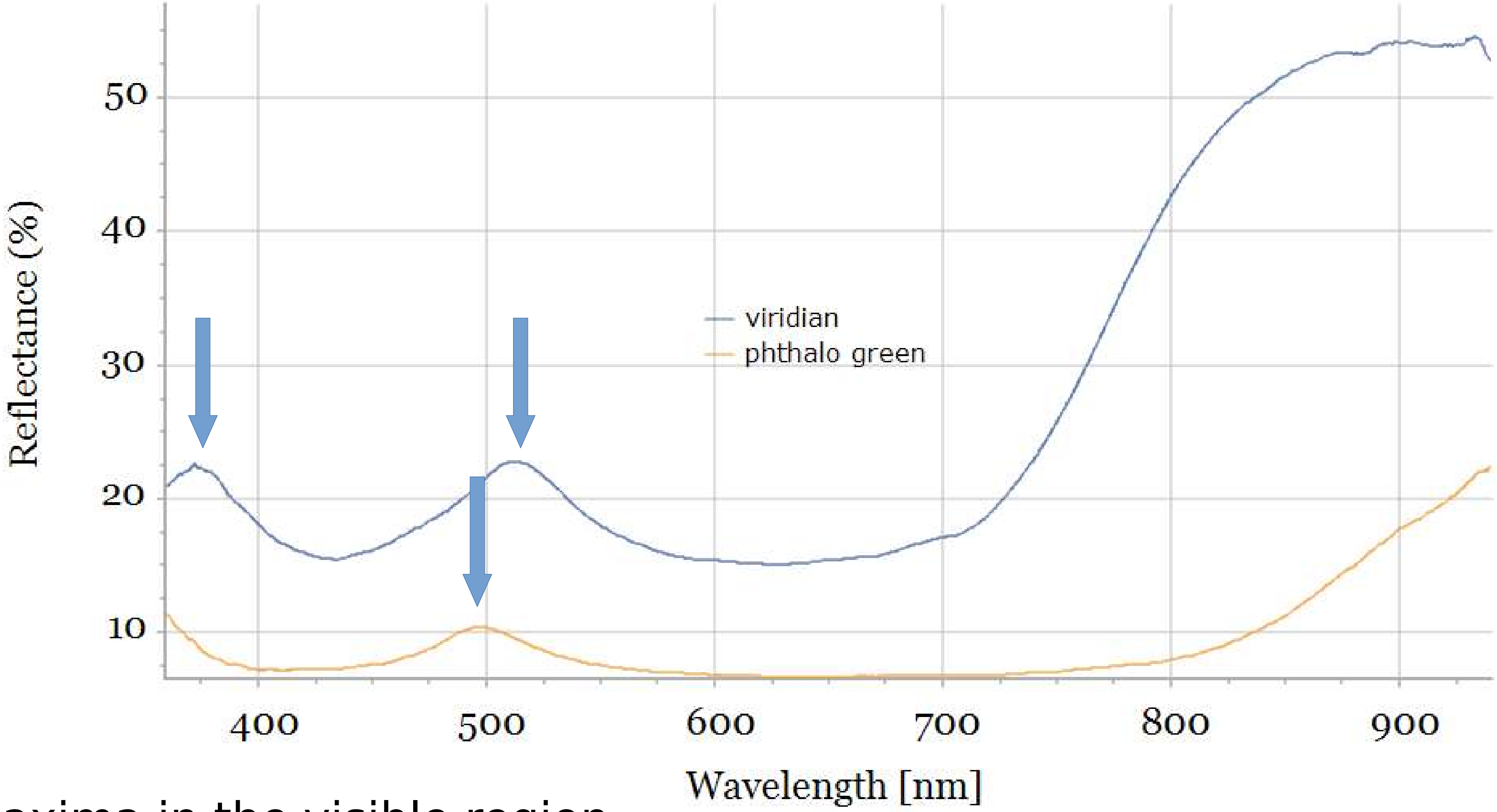
“Inflection point” is the other feature to describe a reflectance spectrum. The graph above shows the reflectance spectra of 3 yellow pigments. They are all characterized by a sharp curve representing the increase in reflectance. The inflection point is roughly the middle of this curve and we want to define its position as a specific wavelength.
To be precise, it is the point where the curve goes from concave to convex. Mathematically it can be calculated and spectra editing software generally do this operation. Still a visual inspection is sufficient.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

RS Theory: intro



Maxima in the visible region.

"Maxima" are the last feature to describe a reflectance spectrum. The graph above shows the maxima for 2 green pigments. A maximum is the result of 2 contingent absorption bands. We have this impression of a "peak" but it is actually the result of the action of the 2 absorption bands.

Reflectance Spectroscopy

RS Theory: Pros and Cons

RS is a first non-invasive step of a multi-technique analytical strategy for identification of pigments and dye stuffs in art object

- Affordable
- Non-invasive
- Portable
- Light weight and small

RS Theory: comparison with other spectroscopic methods

Spectroscopic methods for Art Examination

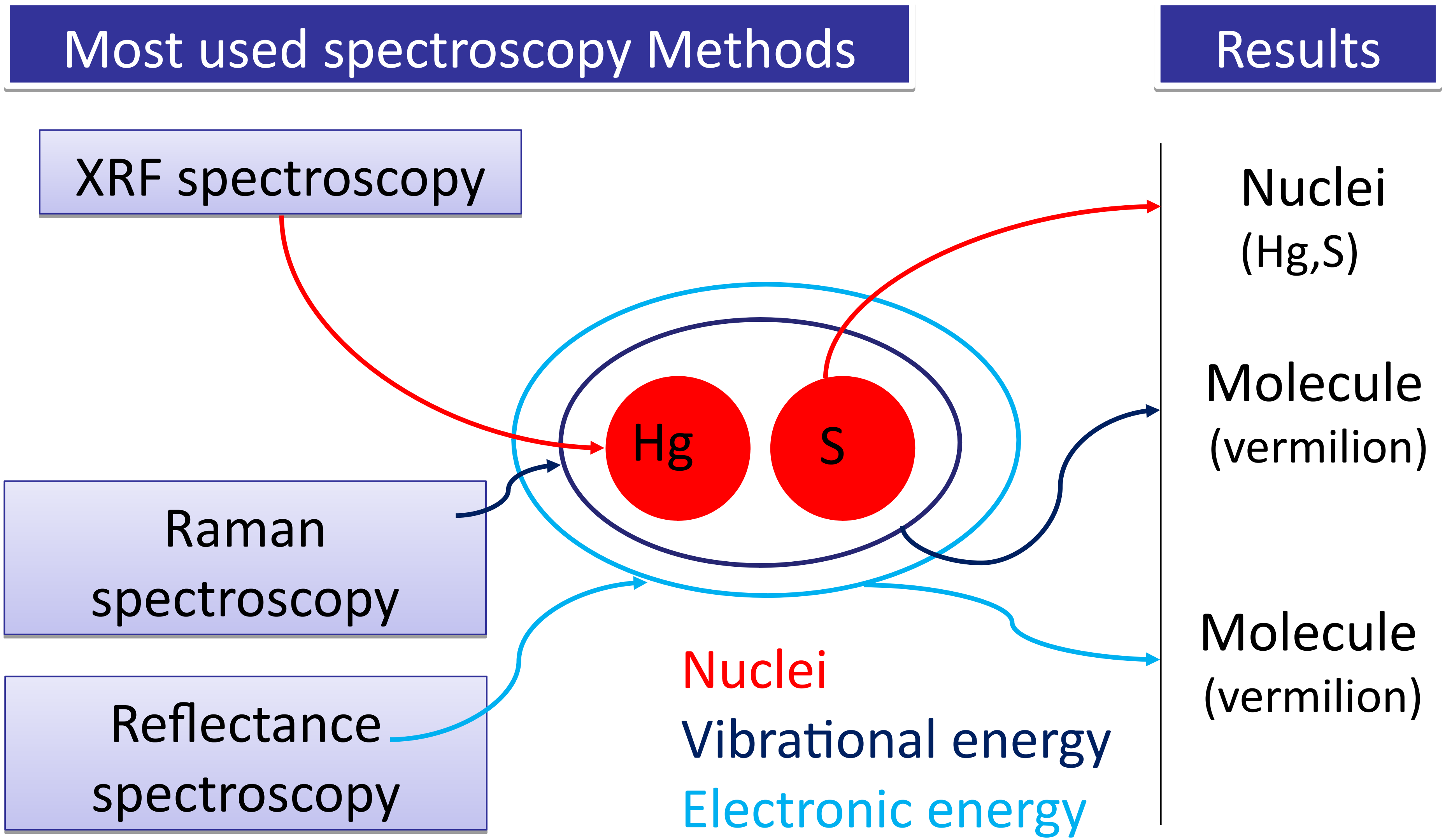
REFLECTANCE SPECTROSCOPY
UV, VIS and IR regions of the electromagnetic spectrum gives information related to the electronic transitions of the materials.

VIBRATIONAL SPECTROSCOPY
Raman and FT-IR spectroscopy provide information on molecular vibrations

ELEMENTAL SPECTROSCOPY
X-Ray fluorescence spectroscopy provides information on the chemical elements

Reflectance Spectroscopy

RS Theory: comparison with other spectroscopic methods



Why to use Reflectance Spectroscopy

and/or

Raman spectroscopy

	Raman	Reflectance
Identification accuracy	High	Medium
Success rate for real samples	Low	High
Easy of use	Low	High
Equipment cost	High	Low

Reflectance Spectroscopy

chsopensource.org

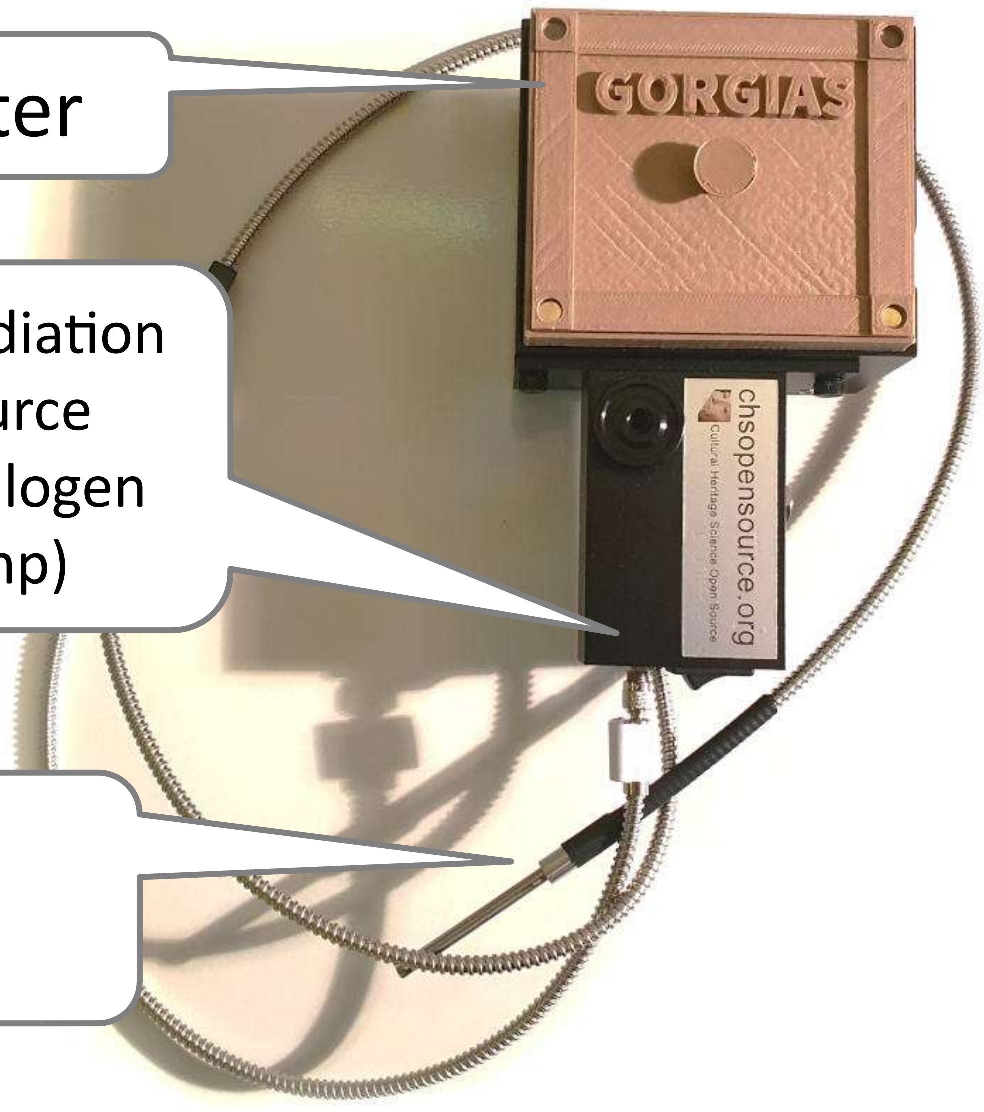
Cultural Heritage Science Open Source

Understanding Gorgias: main components

Spectrometer

Radiation source (halogen lamp)

Reflectance probe

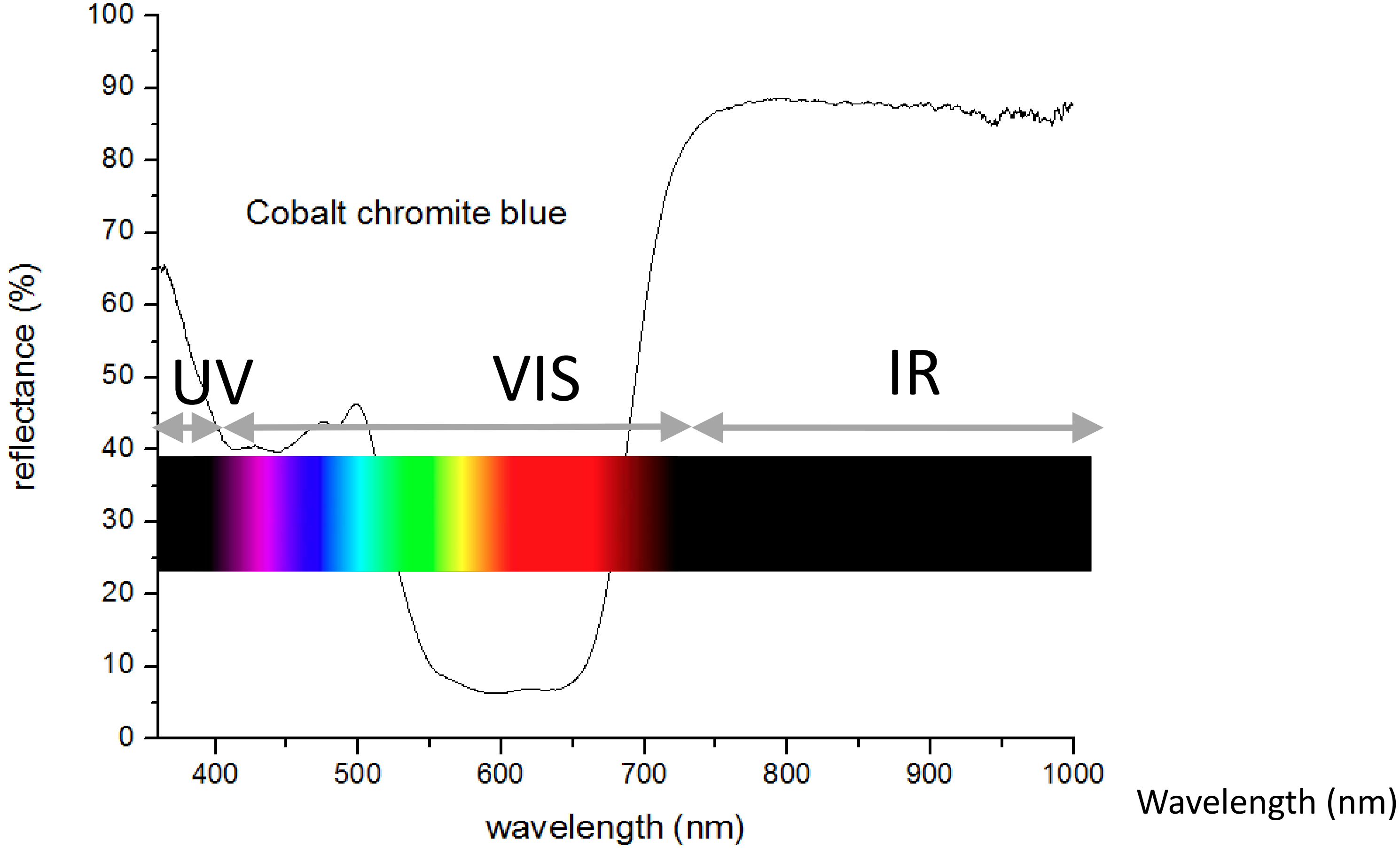


Reflectance Spectroscopy

chsopensource.org

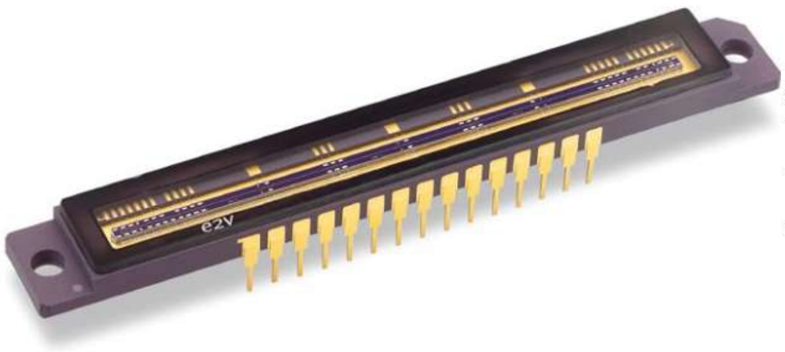
Cultural Heritage Science Open Source

Understanding Gorgias: spectrometer

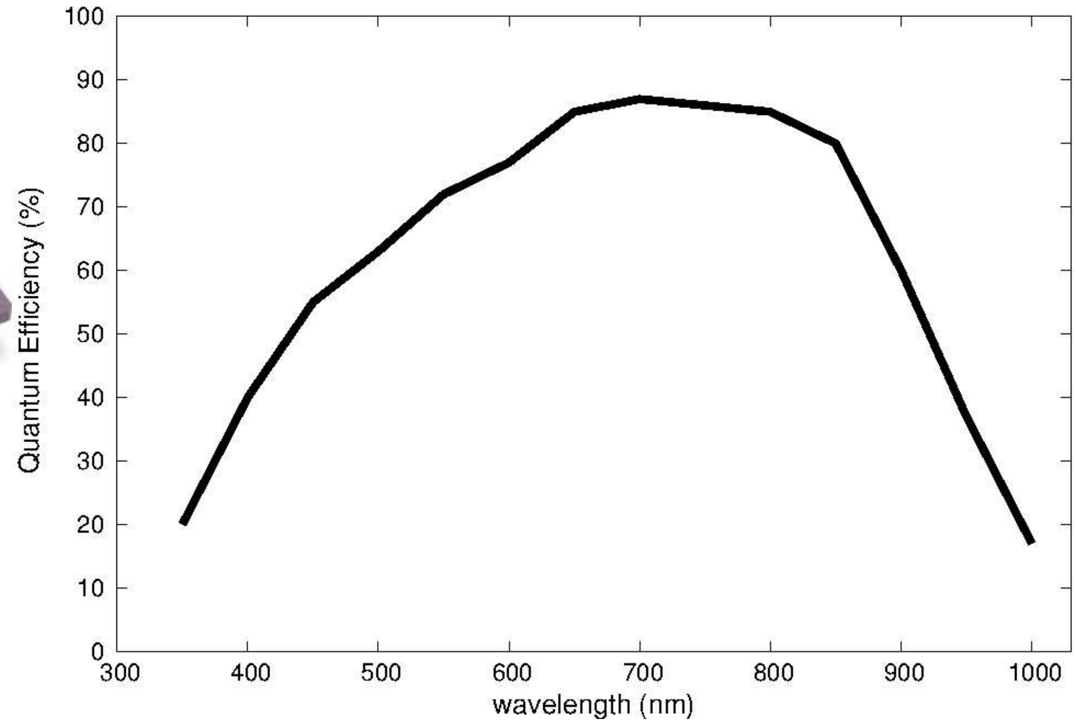


There are 2 main kind of Reflectance spectrometers. Their main feature is the spectral range covered by their detector. Gorgias covers the range 300 nm (UV) until 1000 nm (IR). UV, VIS and IR are electromagnetic **radiation bands** with different wavelengths. "**Light**" is the VIS part of the electromagnetic spectrum. The other class of spectrometers cover up to 2500 nm but they use a much more expensive detector.

Understanding Gorgias: spectrometer



CCD Detector:
Toshiba TCD1304DG linear array



Quantum efficiency (QE) is a measure of how well a specific CCD responds to different wavelengths of light. The higher the QE, the more sensitive a CCD will be at a particular wavelength. The CCD detector inside Gorgias has a high QE in the visible region decreasing QE in the UV and far IR.
This is on of the 2 reasons why we have more noise in our spectra in the UV and far IR regions. The other reason is that the halogen lamp has little UV component.

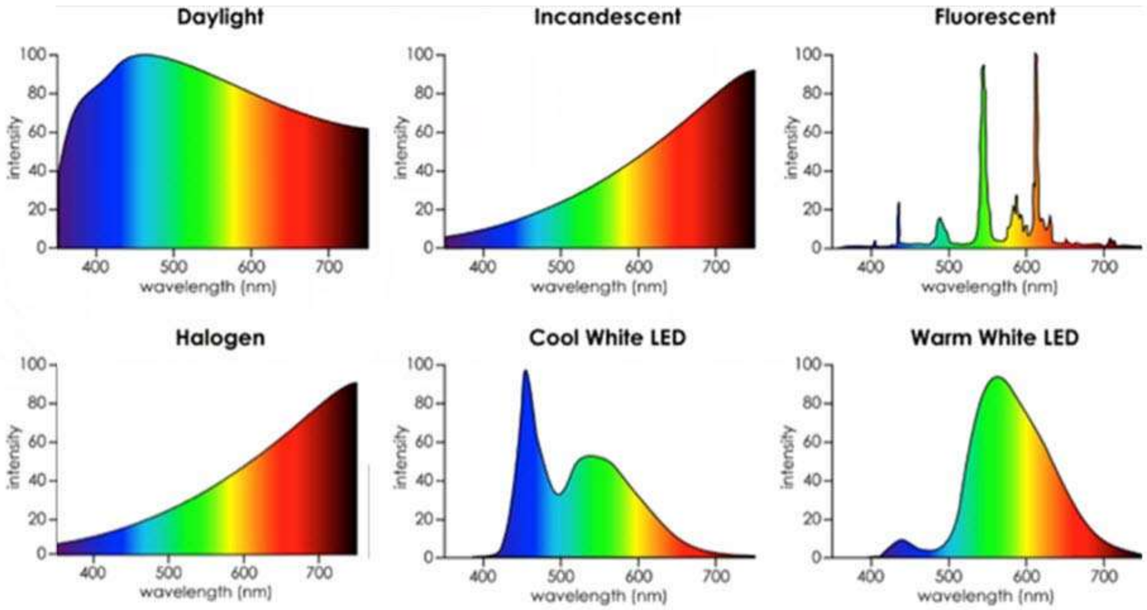
NOTE: The cap on the spectrometer entrance is a cosine corrector adapter, made with optical Teflon with flat transmission in the spectral region 200-2900nm. A cosine corrector is used to enhance the collection of input radiation.

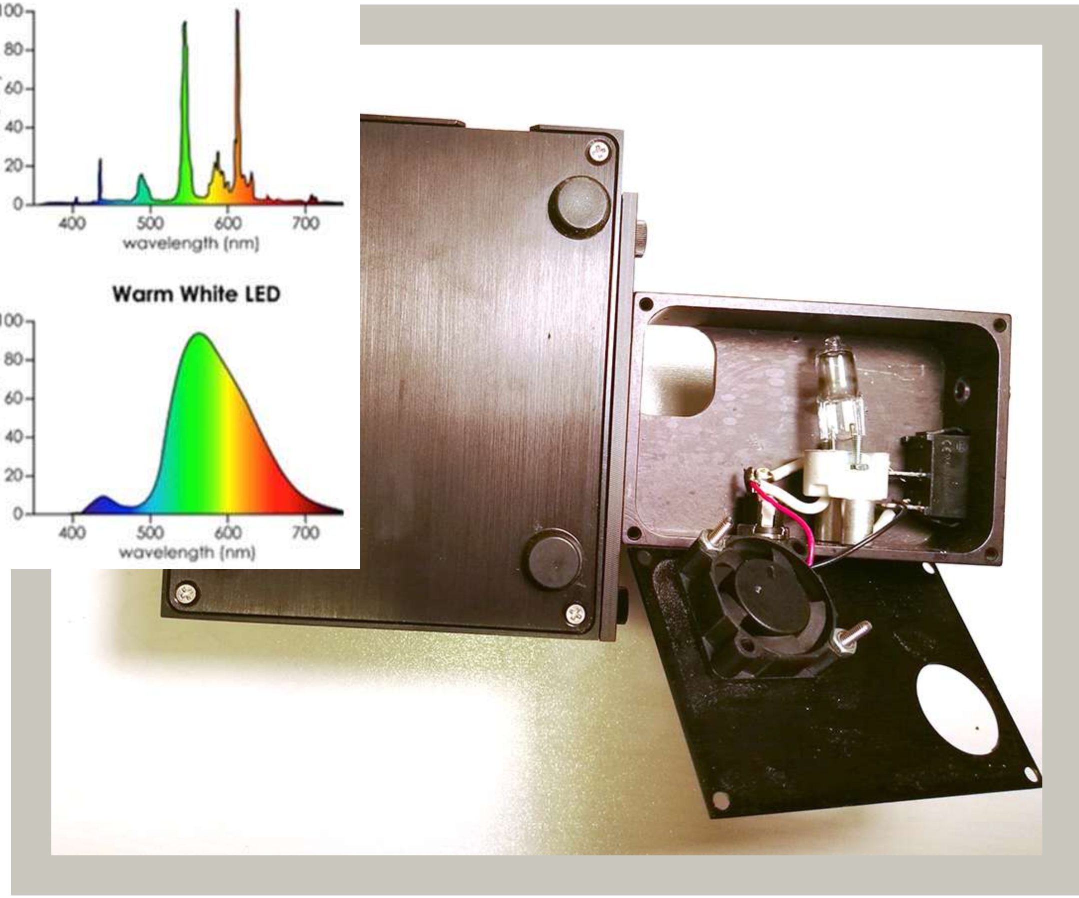
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Understanding Gorgias: radiation source





The radiation source for Gorgias is a 10W halogen lamp. We provide 3 other replacement lamps. It’s easy to replace the lamp. Just open the case and remove the burnt lamp from its socket.
The illustration above shows that the halogen lamp is rich in visible radiation and IR but still have sufficient near UV from 300 nm.

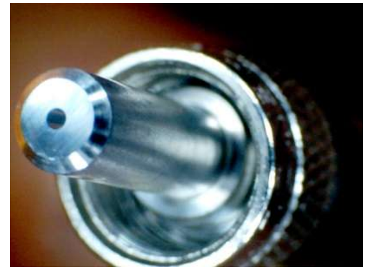
Reflectance Spectroscopy

chsopensource.org

Cultural **H**eritage **S**cience **O**pen **S**ource

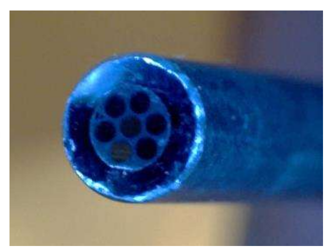
Understanding Gorgias: reflectance probe

Reflectance probe



→ Spectrometer

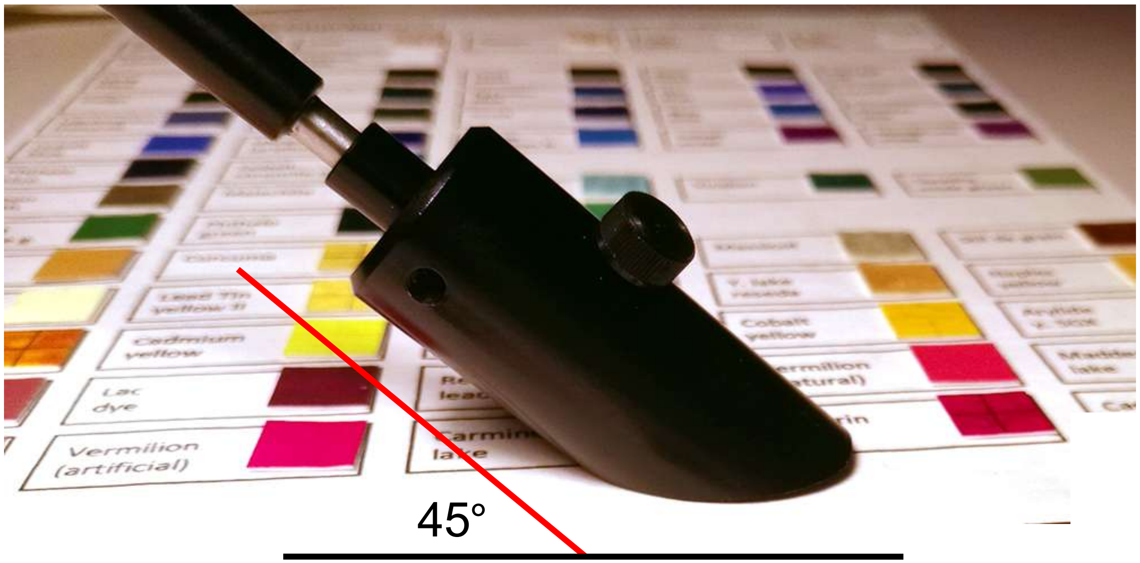
→ Radiation source (lamp)



→ sample

The reflectance probe is composed of 3 outputs. One goes into the spectrometer, one into the radiation source and the last one is used to make the actual measurements. This probe is a bundle of 7 Thorlabs FT600UMT fiber-optics (core diameter 600 microns). 6 of them are used to collect the radiation from the lamp and one is the used to send the reflectance signal from the sample to the spectrometer. In the illustration above, the fiber in the middle of bundle is the one that collect the signal for the spectrometer. These fibers can cover the range 300-2200nm and have a metal jacket for better mechanical strength.

Understanding Gorgias: reflectance probe



We can do the measure with the bare probe or we can add the probe cover. This cover is useful if we are working within an environment with strong light. This cover block out all the external light so we can have a precise measure. The only issue about this method is that we do not see exactly where the probe is measuring. So, generally we use the cover for large color area but definitely we cannot use it for small details.

Reflectance Spectroscopy

Cultural Heritage Science Open Source

Understanding Gorgias: reflectance probe

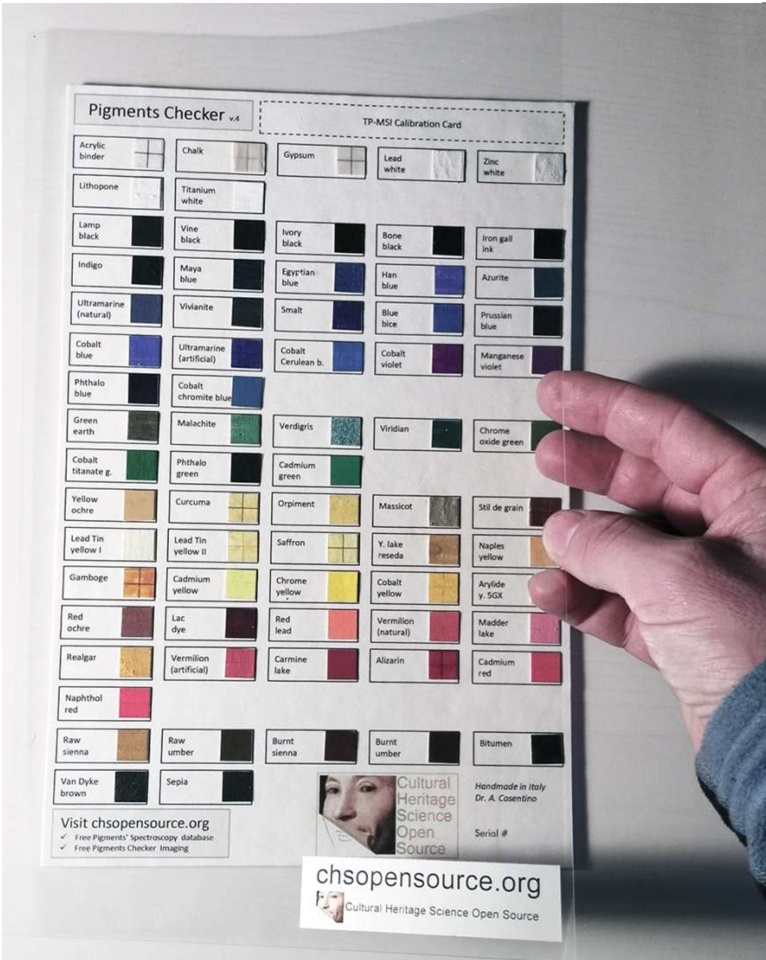
Gorgias use a probe with the lamp and the spectrometer fibers bundled together, so we are lighting the sample and collecting radiation from the same direction. This is the best approach to avoid the specular reflection. The illustration above shows that if the observer is on the other side of the lamp, the observer gets most of the specular reflection which is useless for Reflectance spectroscopy because the light does not interact with the material but it is just bounced off, without carrying chemical information. We see the “real” colors if the observer is on top of better on the same side of the lamp, as in Gorgias.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Understanding Gorgias: reflectance probe



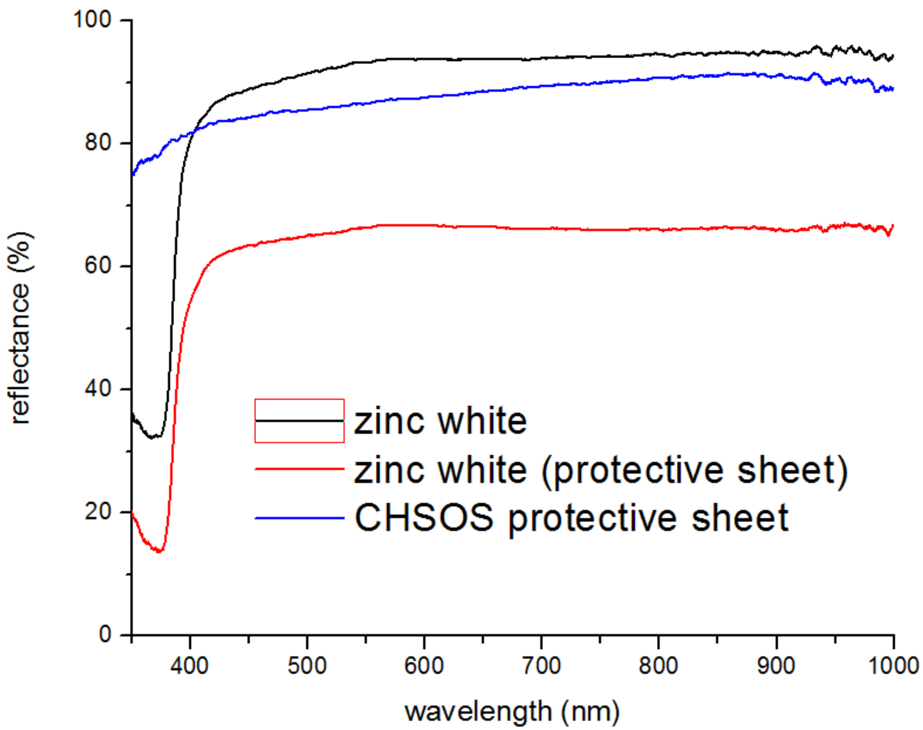
Included with Gorgias kit is our **PLASTIC PROTECTIVE SHEET**. You can apply this plastic film over your artwork if you are concerned of any damage done using the probe. This plastic film is transparent to the range 300-1000 nm so it is not affecting the spectra.

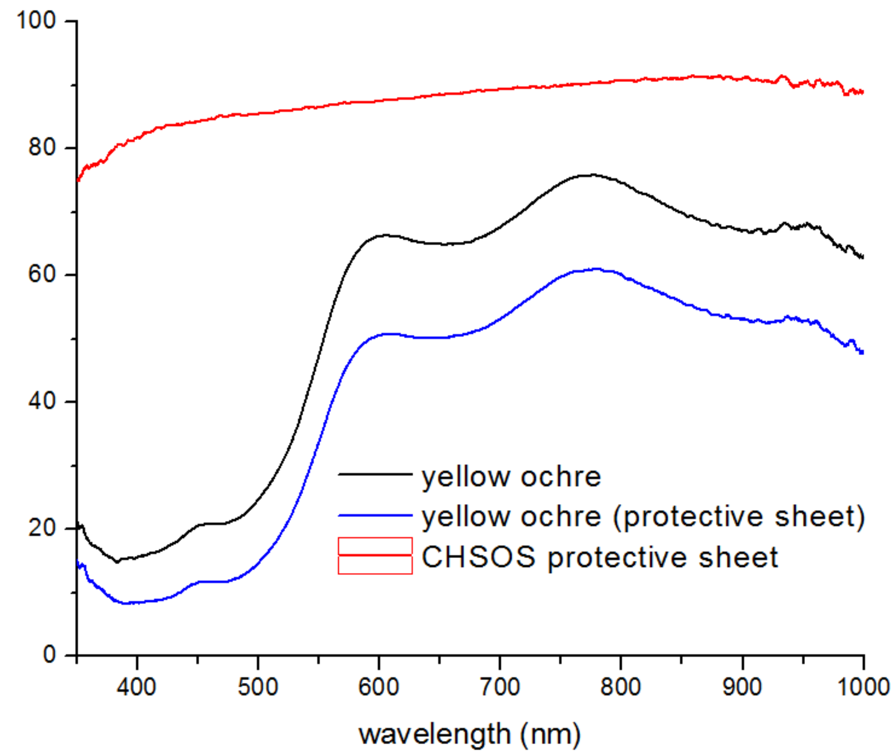
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Understanding Gorgias: reflectance probe





Two example of spectra collected with and without our PLASTIC PROTECTIVE SHEET. The sheet just reduces the overall high of the spectra, because absorbs and reflects a part of the radiation from the lamp. Though, the shape of the spectra is preserved.

Reflectance Spectroscopy

Understanding Gorgias: specs

Technical Specifics

Detector: Toshiba TCD1304DG linear array
Detector spectral range: 300 – 1000 nm (100 microns slit)
Pixels: 3648

Other Technical Specifics

Weight: 430 grams
Dimensions: 102 mm x 84 mm x 59 mm
Pixel size: 8 um x 200 um
Pixel well depth: 100,000 electrons
Signal-to-noise ratio: 400:1 (10000:1 with averaging)
A/D resolution: 16 bit
Fiber optic connector: SMA 905 to 0.22 NA single-strand optical fiber.
Diffraction order sorting filter: included
CCD reading time: 14 ms
Power consumption: 100mA @ 5V from USB interface
Onboard memory capacity: 64 spectra
Data transfer speed: 200 ms / 100 ms (2 points binding)
Computer interface: USB 2.0, HID 2.0
Operational system: Windows 10 /Windows 8 / Windows 7 / Vista / XP ; 32/64b
Software: application software, driver,
Hardware: USB cable

Understanding Gorgias: software

No need for installation

No licence

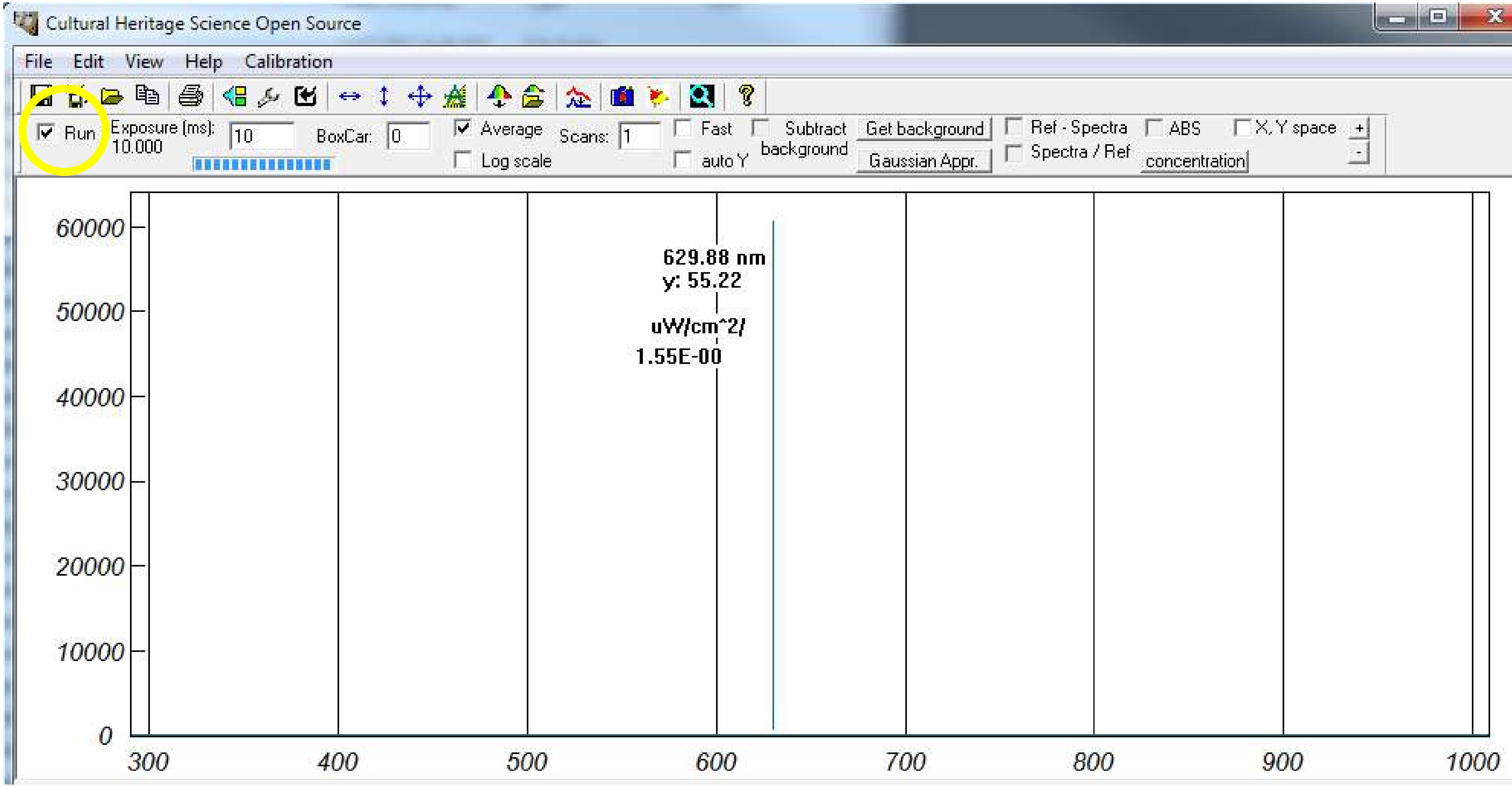
The spectrometer is recognized by Windows operational system as standard HID device. That is why there is no need to install any special drivers to use Gorgias spectrometer. Just start the software from a portable device connected to any computer, such as a USB key. You can also copy the software folder in your hard drive and from there launch gorgias.exe. As simple as that!
Also the software does not have any licence required so you can use it on as many computers you need.
Following are some slides for the common operations on the software. Watch the video lessons for further info.

Reflectance Spectroscopy

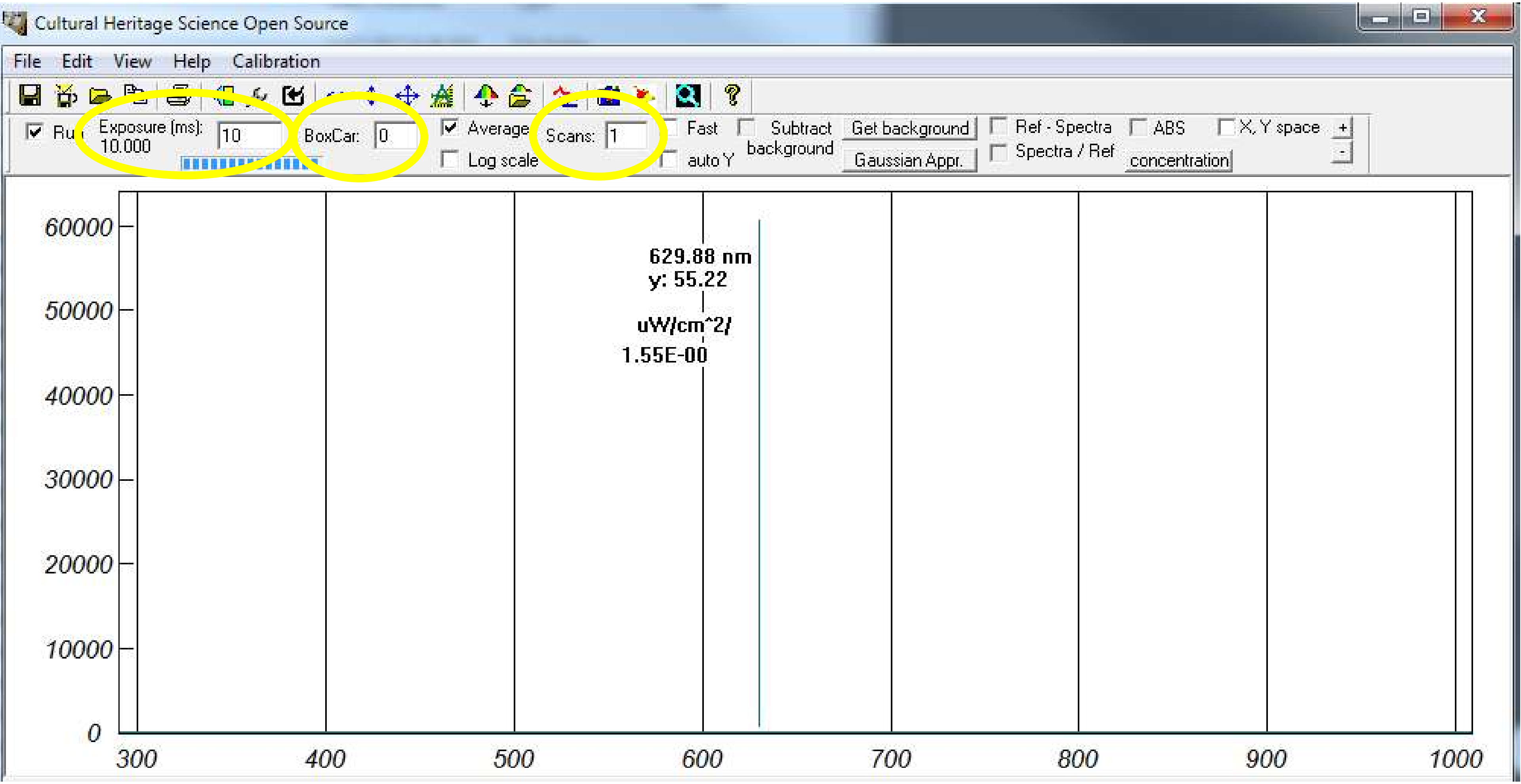
chsopensource.org

Cultural Heritage Science Open Source

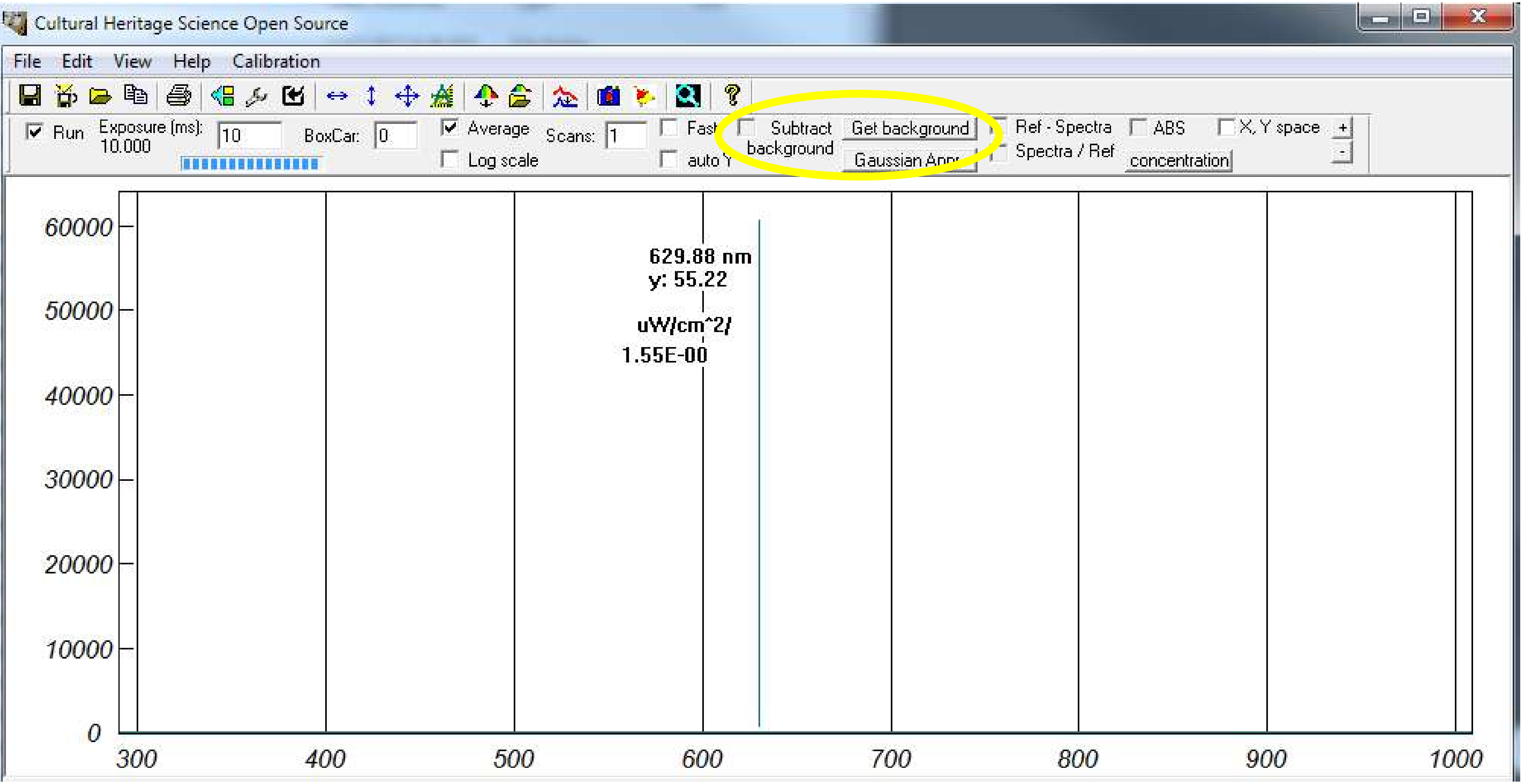
Understanding Gorgias: software



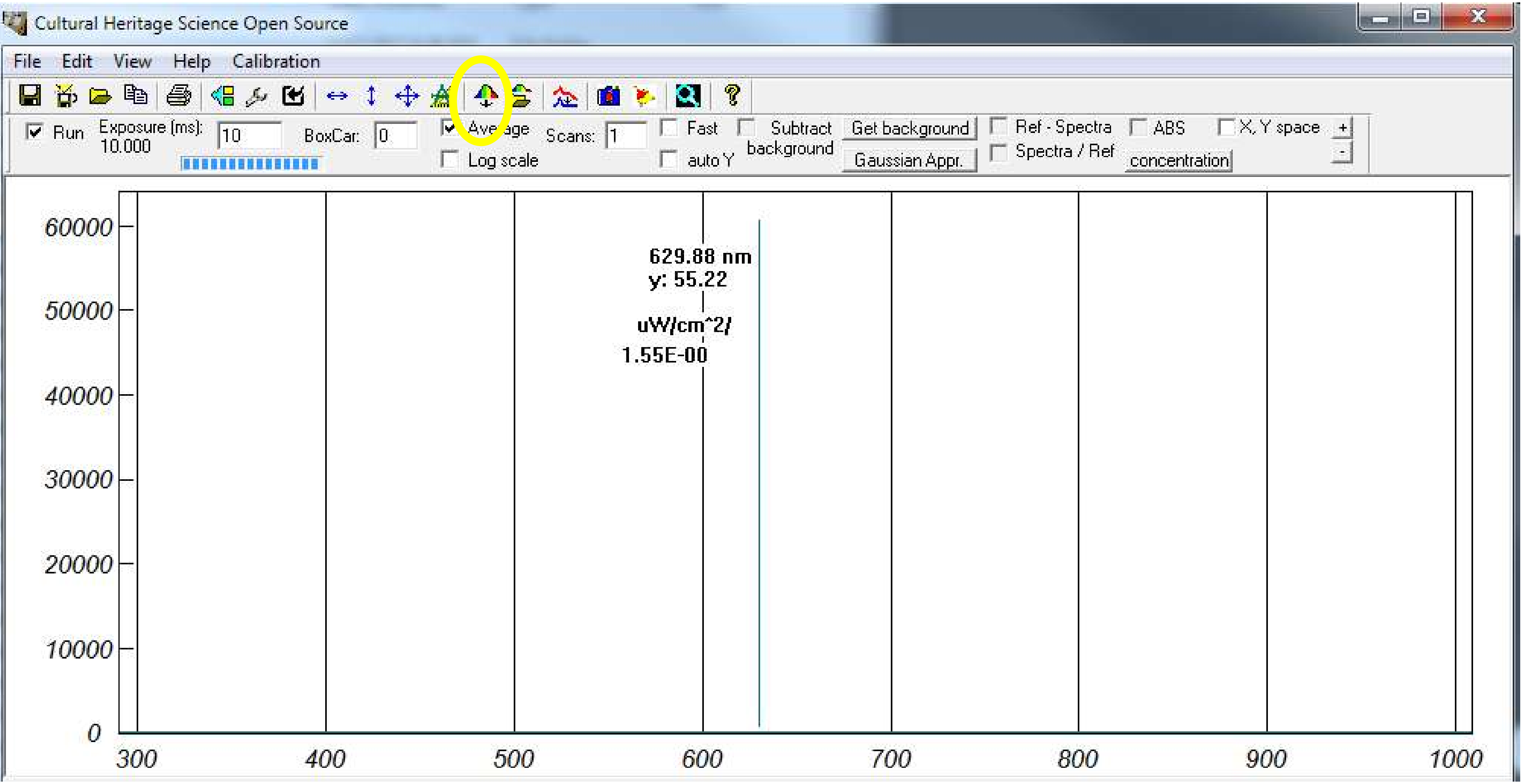
Once the spectrometer USB cable is plugged on your PC, launch gorgias.exe. The main window of the software will show up. If the system is correctly recognized by your PC, you will be able to check the "RUN" box. The system will start to acquire spectra, continuously.



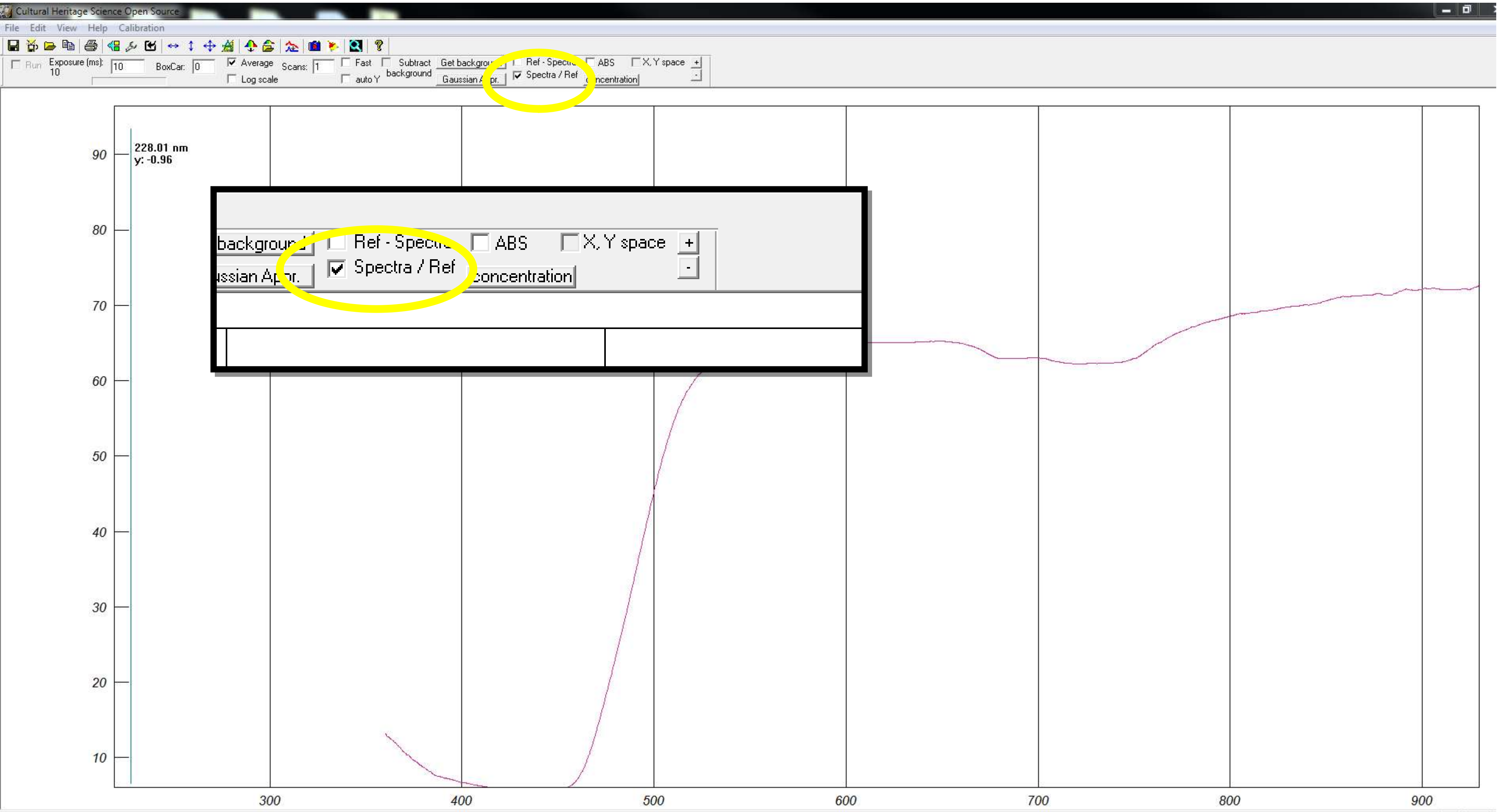
We need to setup few parameters.
BOXCAR. This is a smoothing function by averaging the values of adjacent pixels together. Boxcar is useful when the spectrum is relatively flat and little variation is expected between adjacent pixels, as in reflectance spectroscopy. We want input “10”.
SCANS. We can have an average of more measures (scans). For Reflectance Spectroscopy, we can just have “1”
EXPOSURE. This depends on your actual system and you have to setup. See video “Setup and calibration” in Lessons “Installation and setup”



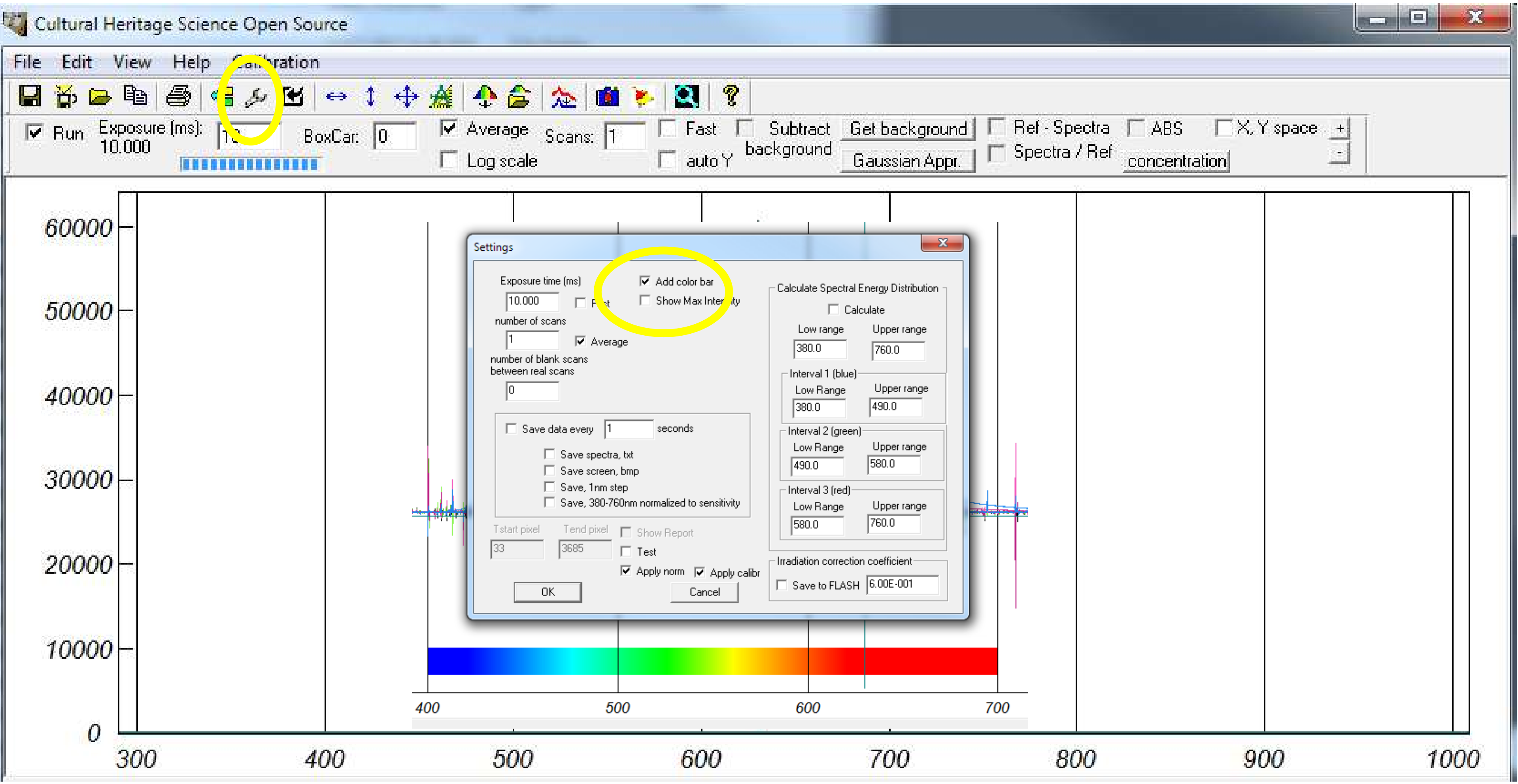
A background spectrum can be subtracted. For reflectance spectroscopy this is not strictly necessary and we will not do this procedure. Since the exposure time is very short, we do have very little electronic noise which will not affect our spectrum. This software is also used for Raman spectroscopy, that why we have the background subtraction which is important in this case because of the much longer exposure required in this case.



See video “Setup and calibration” in Lessons “Installation and setup” for more info.
We need now to calibrate the system, we put the probe at 45 degree in contact with the white standard and we click the button indicated above. A calibration file has been created (no confirmation comes from the software, no pop up window or beep).



See video "Setup and calibration" in Lessons "Installation and setup" for more info.
The spectrometer can do different kind of spectroscopic measures. We need to check the "spectra/Ref" box in order to have actual Reflectance spectra. This is the main method we will use but we could be interested to other once.



It is possible to add a color bar to our spectra. This feature could be useful for beginners not familiar with the wavelenght values of the UV, VIS and IR spectral ranges.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Practising: pigments checker

CLICK HERE
Pigments checker webpage

Collection of the most important Pigments in art history and archaeology

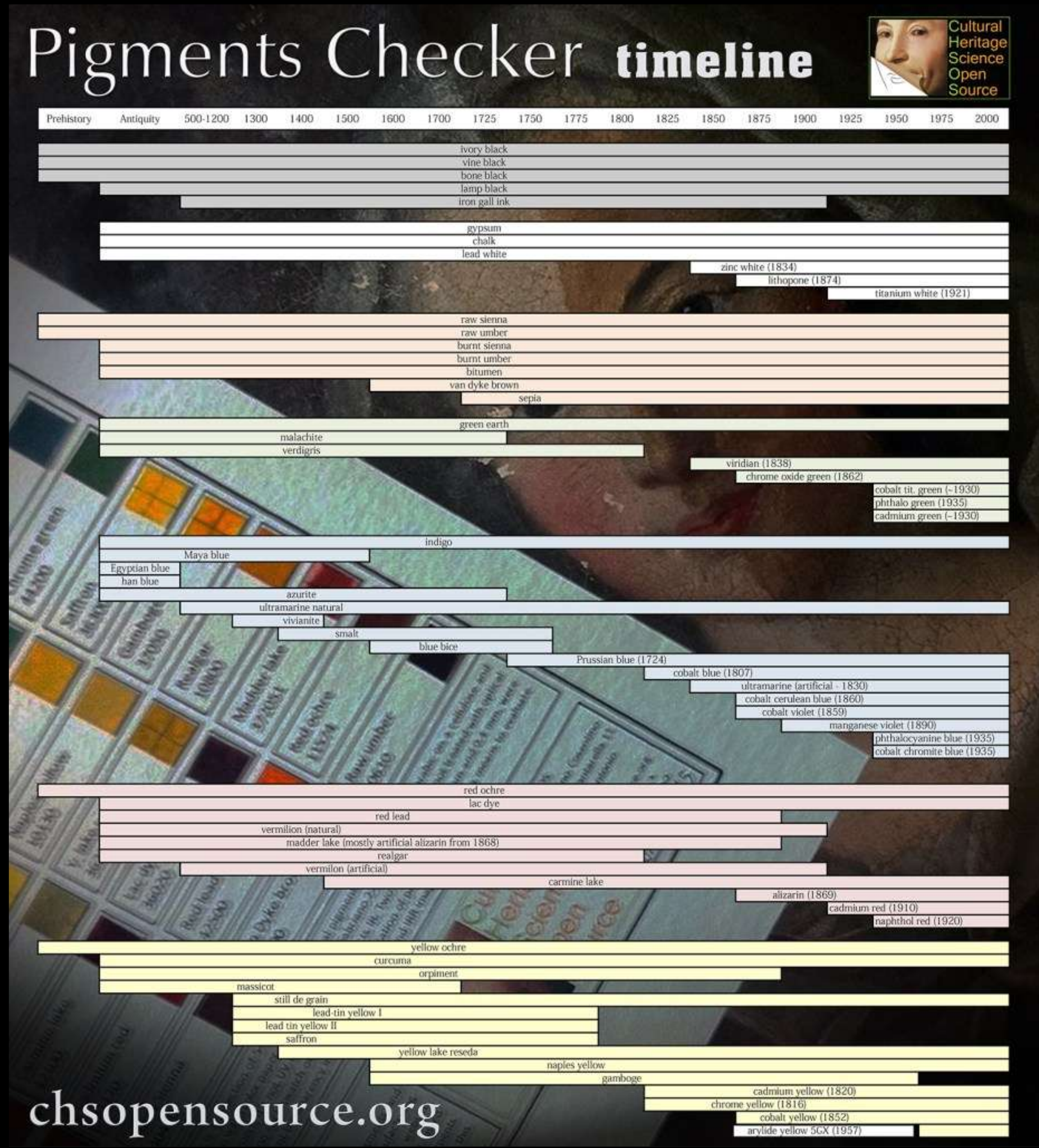
We recommend to use our Pigments Checker to start practising with your Reflectance Spectrometer.
Pigments Checker is a very useful tool to practice Reflectance Spectroscopy, as well as other imaging and spectroscopy methods.
Pigments Checker is a collection of the most important pigments in art history. Among all the pigments and their varieties ever used in art, this collection selects the most used from antiquity to early 1950'. Pigments Checker is a standard tool designed for Art professionals, scientists, students and conservators to evaluate and practice non-invasive techniques for pigments identification.

Pigments Checker Timeline provides a simplified representation of the use of the pigments across ages. Pigments' history is actually quite complex and depends on a number of factors;

The kind of artifacts. A pigment can be used on wall paintings while becoming obsolete in easel paintings.

Geography. As an example, natural cinnabar is found in Almaden (Spain) and Murillo used it since it was close to him, rather than the artificial form, vermilion, much more diffused elsewhere.

CLICK HERE
Pigments checker webpage



Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Practising: pigments checker

BLACKS	BROWNS	GREENS	BLUES	REDS	YELLOWS	WHITES
ivory black	burnt sienna	chrome oxide green	azurite	naphthol red	cadmium yellow	lead white
vine black	burnt umber	cobalt titanate green	blue bice	cadmium red	cobalt yellow	zinc white
bone black	van dyke brown	green earth	cobalt cerulean blue	red lead	lead tin yellow I	lithopone
lamp black	raw sienna	malachite	egyptian blue	red ochre	lead tin yellow II	titanium white
iron gall ink	raw umber	phthalo green	indigo	vermilion (natural)	massicot	gypsum
	bitumen	verdigris	maya blue	madder lake	naples yellow	chalk
	sepia	viridian	prussian blue	lac dye	orpiment	
		cadmium green	smalt	carmine lake	curcuma	
			ultramarine (natural)	realgar	yellow ochre	
			phthalo blue	vermilion (artificial)	yellow lake Reseda	
			cobalt violet	alizarin	gamboge	
			cobalt blue		chrome yellow	
			cobalt chromite blue		arylide yellow 5GX	
			manganese violet		stil de grain	
			vivianite		saffron	
			han blue			
			ultramarine (artificial)			

On the pigments checker webpage, you can find chemical and various information on each pigment. You can also download and view their Reflectance, Raman and XRF spectra.

CLICK HERE Pigments checker webpage

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Practising: pigments checker

Pigments Checker

egyptian blue

> *The first synthetic pigment used from the early dynasties in Egypt until the end of the Roman period in Europe.*

Manufacturer / product code: Kremer / 10060
Chemical description: artificial copper calcium silicate. Kremer PDF
Color: blue
Color Index: PB31
More info: Pigments Through The Ages

Raman spectroscopy

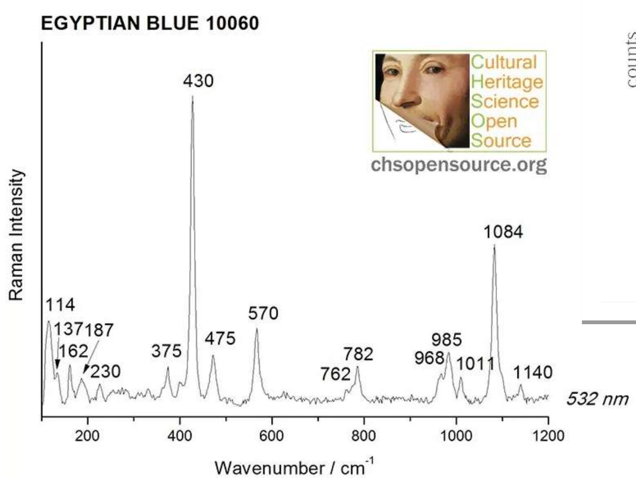
DOWNLOAD Free Raman Database

DOWNLOAD paper: "Pigments Checker version 3.0, a handy set for conservation

Raman spectroscopy

DOWNLOAD Free Raman Database

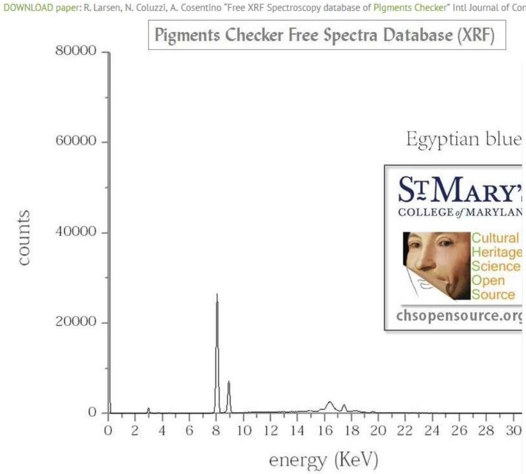
DOWNLOAD paper: "Pigments Checker version 3.0, a handy set for conservation scientists: A free online Raman



XRF spectroscopy

DOWNLOAD Free Online Database

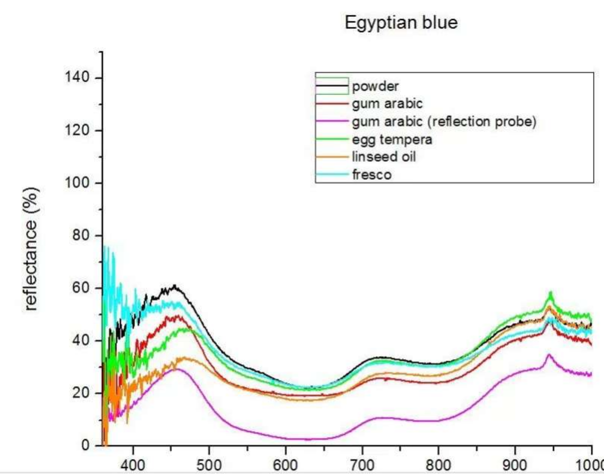
DOWNLOAD paper: R. Larsen, N. Coluzzi, A. Cosentino "Free XRF Spectroscopy database of Pigments Checker" Intl Journal of Conservation Science.



Reflectance spectroscopy

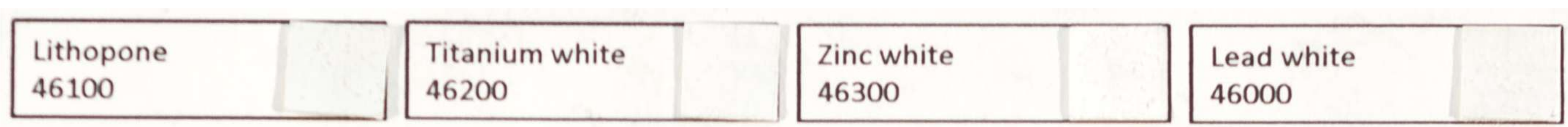
DOWNLOAD Free Reflectance Database

DOWNLOAD paper: "FORS spectral database of historical pigments in different binders"

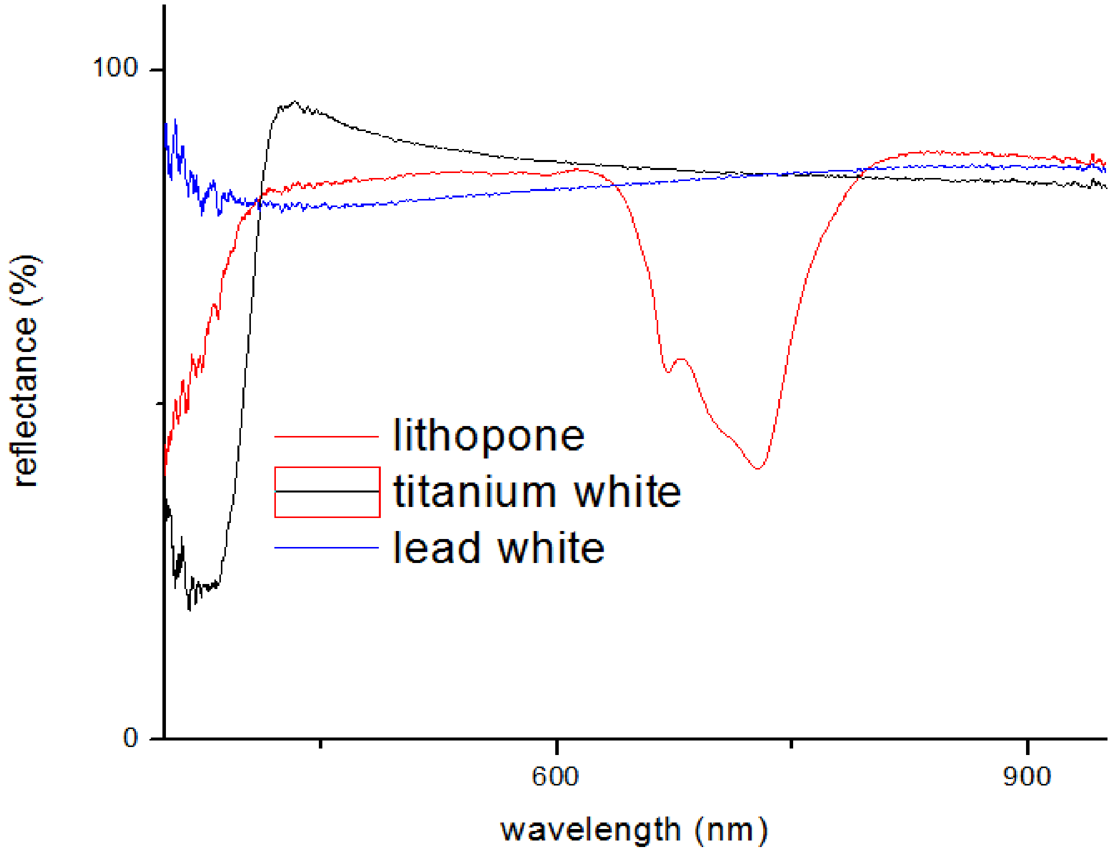


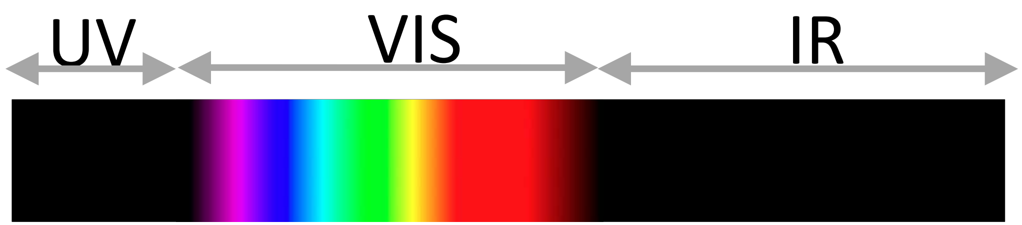
Pigments thoroughly characterized by Reflectance, Raman and XRF spectroscopy

White pigments



We start practising our Gorgias on the white pigments. Pigments Checker has 4 white pigments: lead white, zinc white , titanium white and lithopone. There are also gypsum and chalk, which are mostly used as grounds. These 4 whites have different reflectance spectra and can be distinguished using Gorgias.





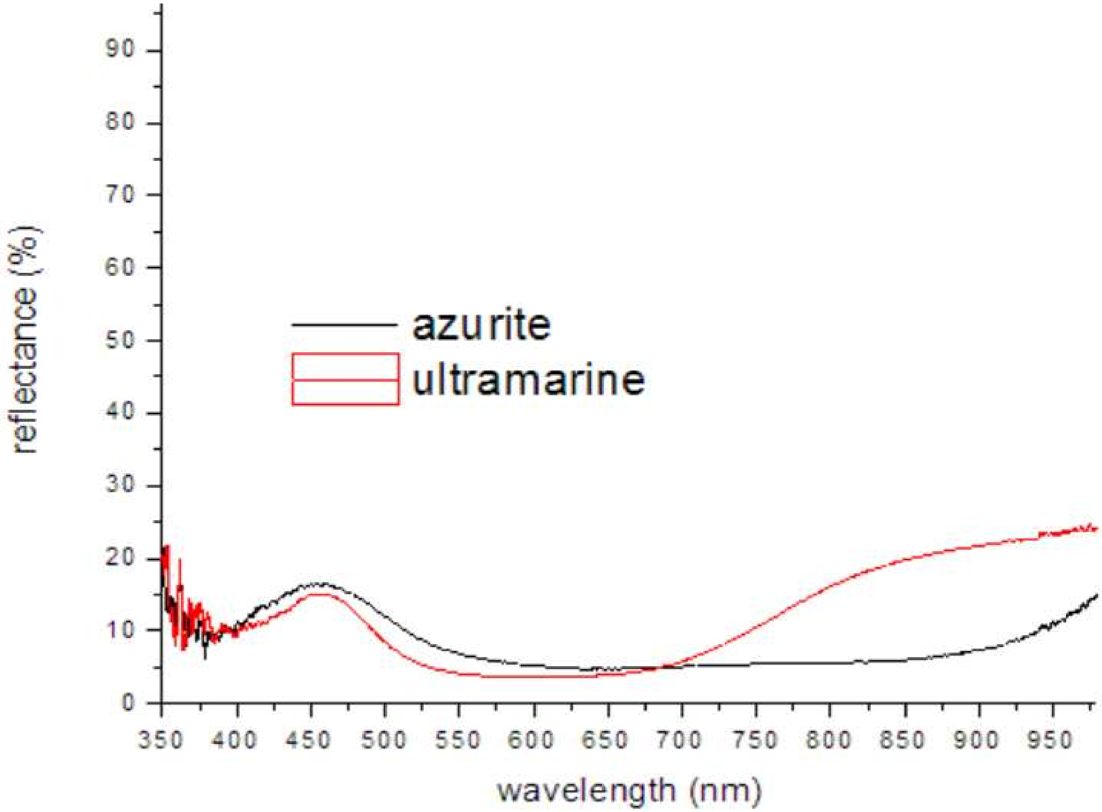
The graph shows the spectra of 3 whites. The bar below gives an indication of the 3 main spectral band covered by Gorgias. We can tell immediately that the 3 pigments show very different spectra. Lithopone is characterized by a strong absorption in the near infrared region. Titanium white absorbs strongly in the UV region and, eventually, lead white has high and flat reflectance across all the 3 spectral regions.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Practising: blue pigments



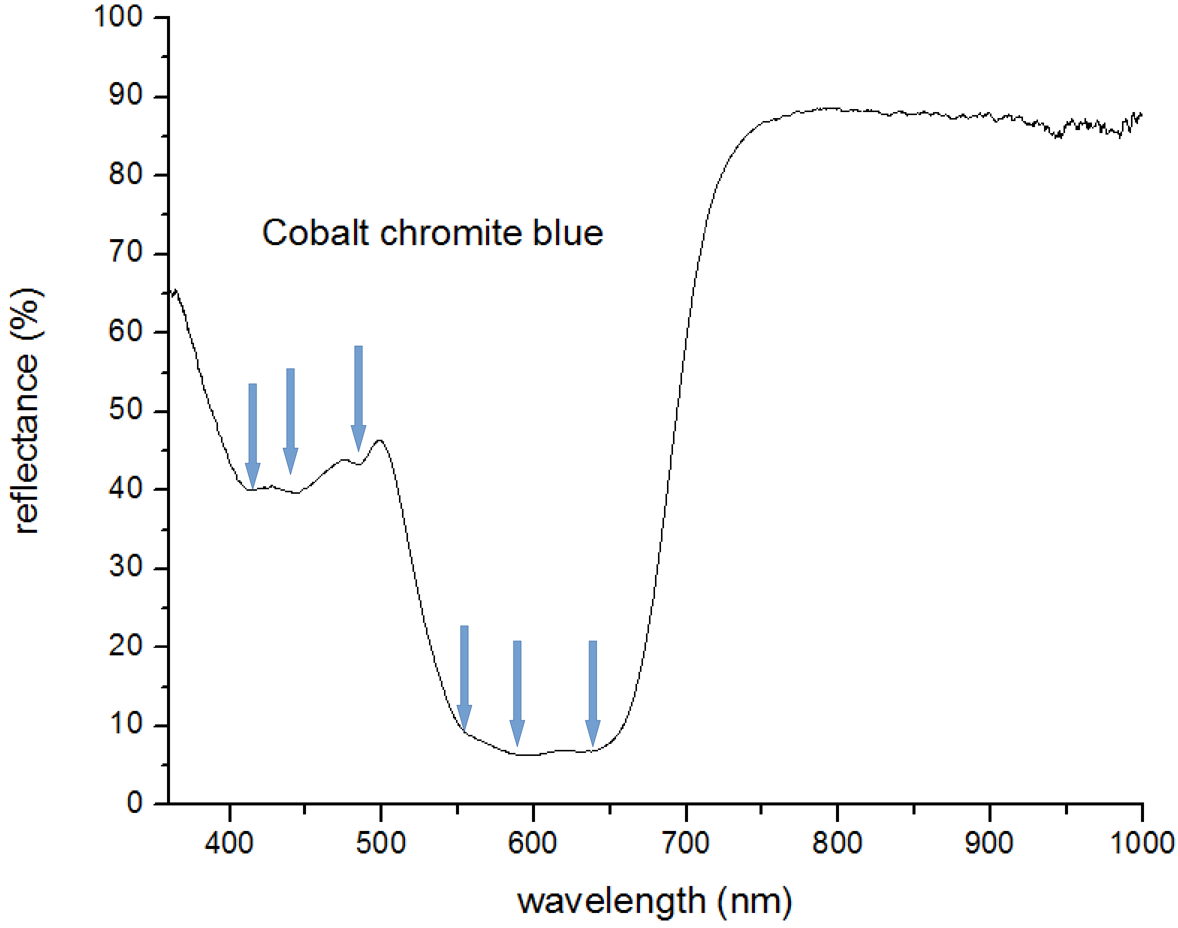
The same can be done with other pigments. Let's try 3 of the most used blues: azurite, ultramarine blue and cobalt chromite blue. Let's start comparing azurite with ultramarine. Both the pigments have a maximum in the blue spectra region. This is what we expect since we are testing "blue" pigments, so we must see strong reflectance in the "blue" region around 450 nm. The different feature between the 2 spectra is in the infrared region. Here we observe that the reflectance of azurite is low and that of ultramarine is high! To be precise, ultramarine becomes transparent in the infrared region, so the high reflectance comes from the white cardboard used as a support for the pigment.

Reflectance Spectroscopy

chsopensource.org

Cultural **H**eritage **S**cience **O**pen **S**ource

Practising: blue pigments



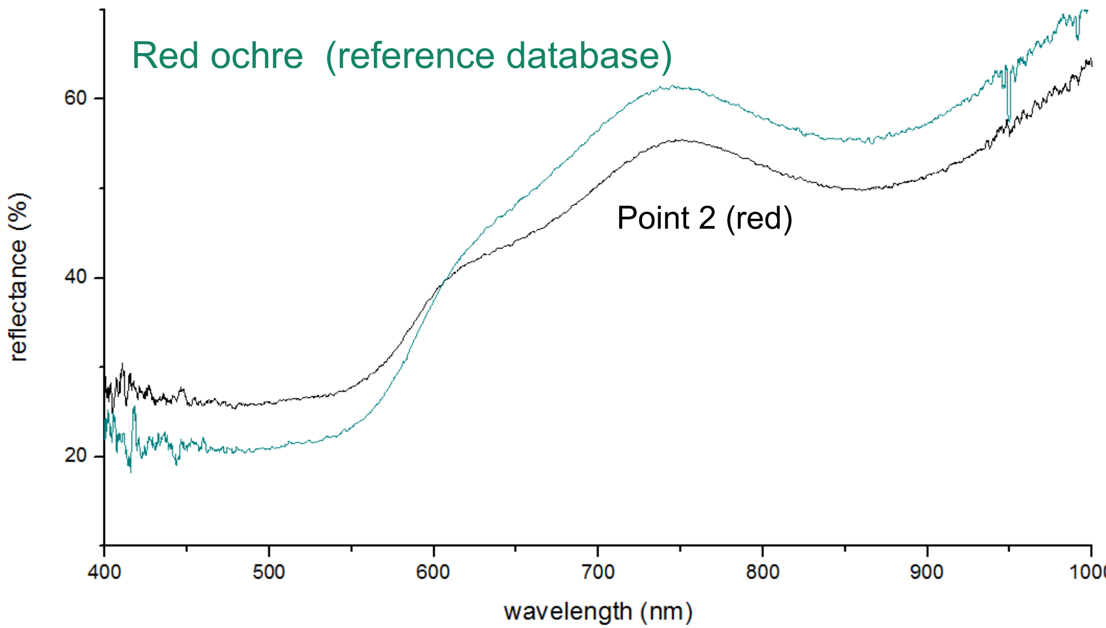
This spectrum shows cobalt chromite blue. This is an example of spectrum rich in features. The pigment has a large absorption band between 500 and 700 nm, but also it has a number of small absorption bands that are very characterizing for the pigment.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Identifying pigments: database



We discussed so far how to acquire a reflectance spectrum of a pigment. For its identification we use a database, a simple collection of spectra acquired from known pigments, such as in Pigments Checker. The example above shows the reflectance spectrum of the red point 2 (green line) on this wall painting, compared with the spectrum of red ochre in Pigments checker (black line). Pigments' identification involves a spectral database to compare the spectral features of the investigated unknown spectrum with the ones available in the database.

Reflectance Spectroscopy

Applications: woodcut prints

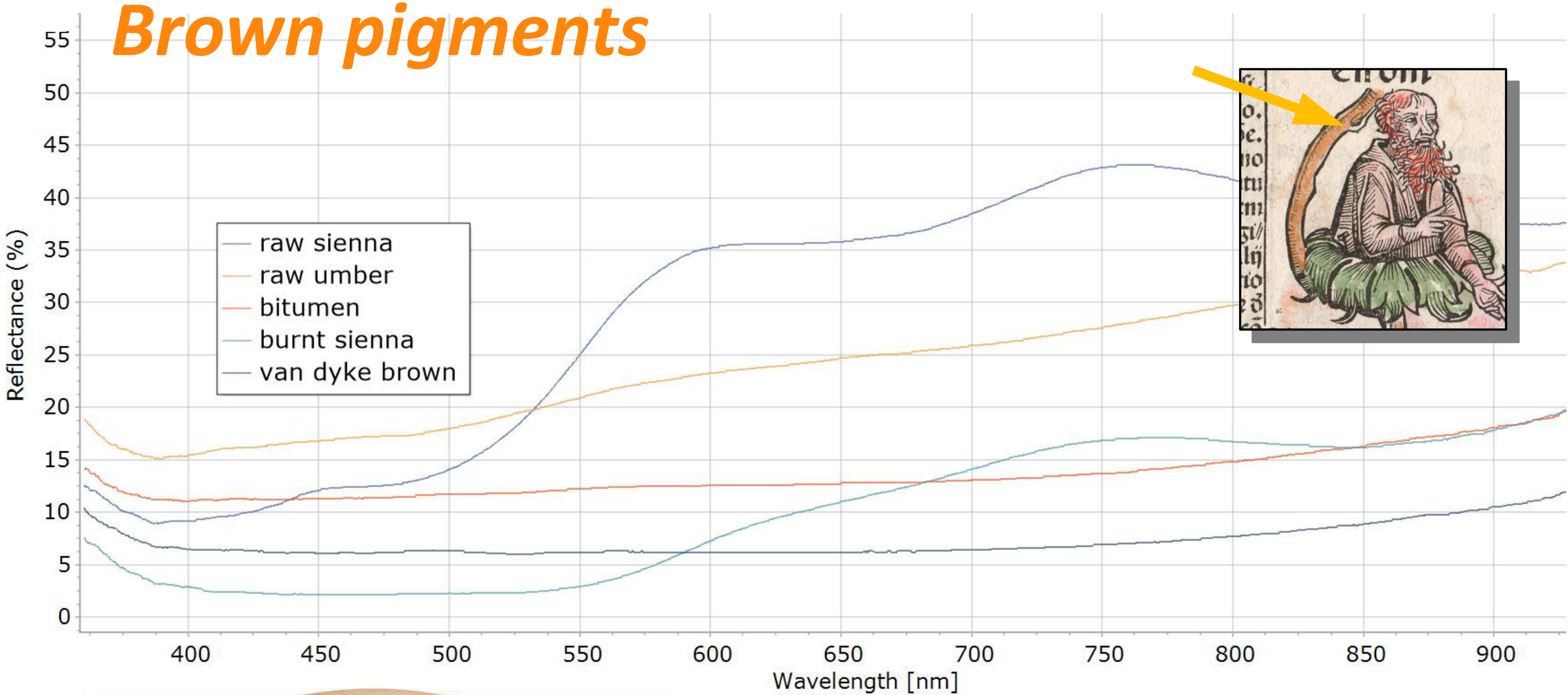
Sheet with woodcuts from Schedel's World Chronicle (1493)

Courtesy of CHSOS collection

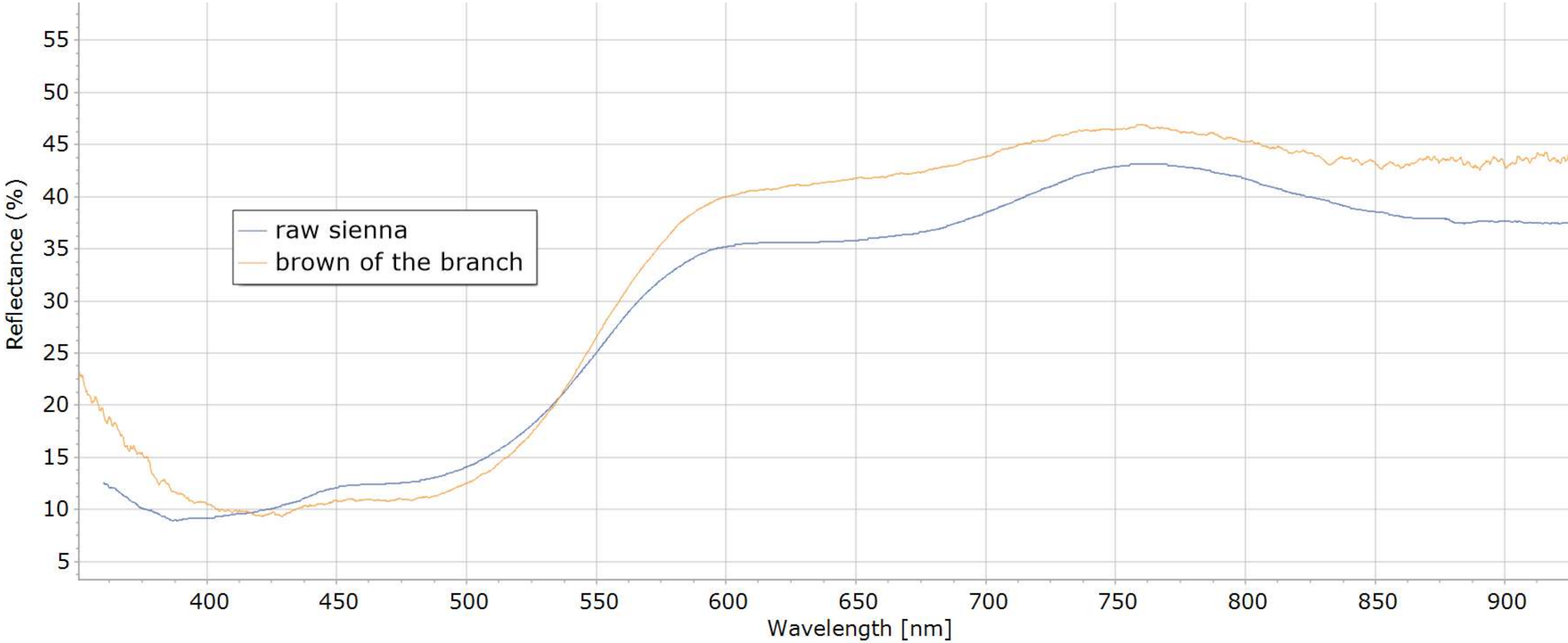
When were the woodcut prints hand-colored?

Watch lesson "Applications". We have a video "woodcut prints".

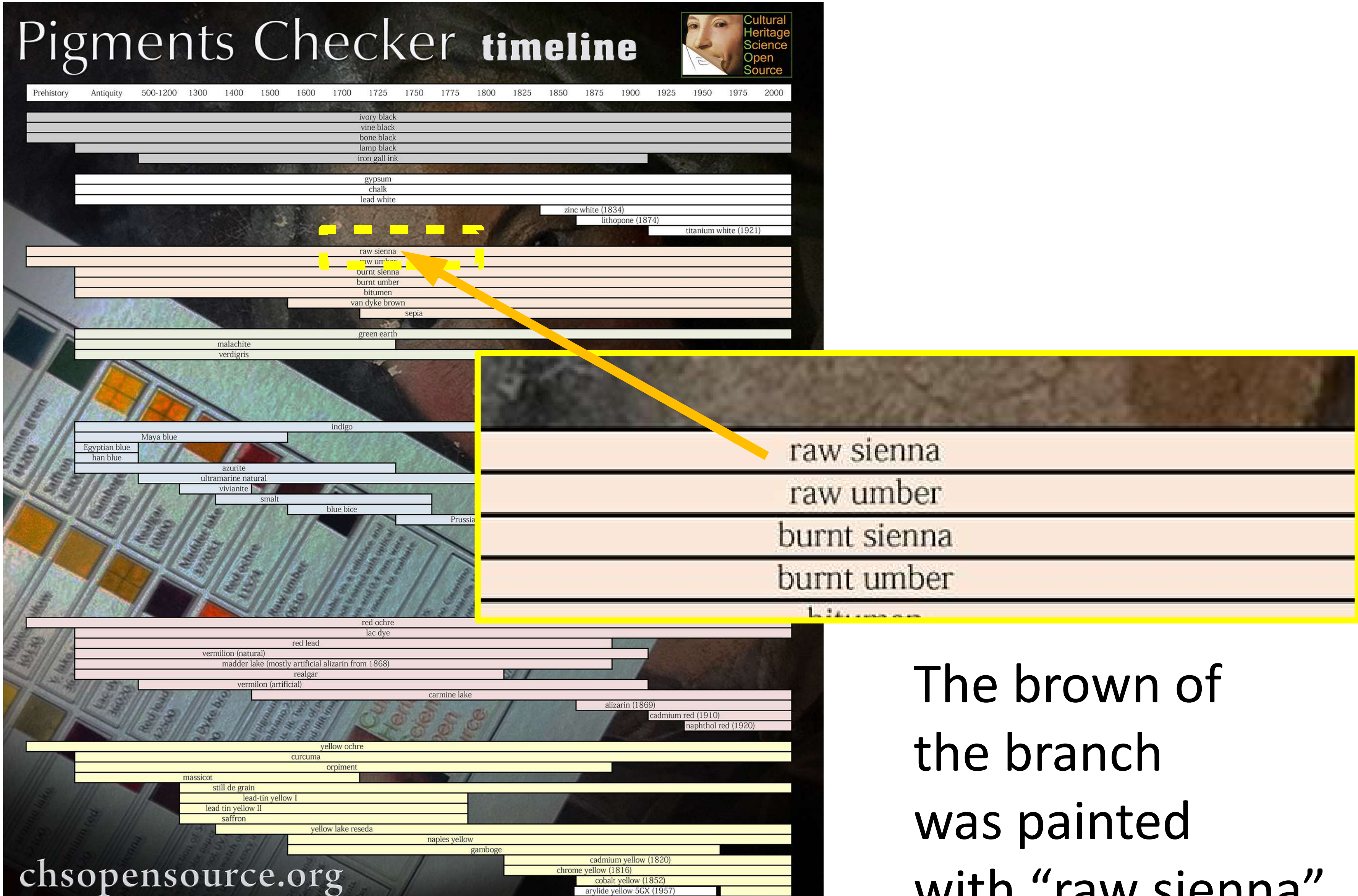
Brown pigments



Reflectance spectra
of some brown pigments in
Pigments Checker

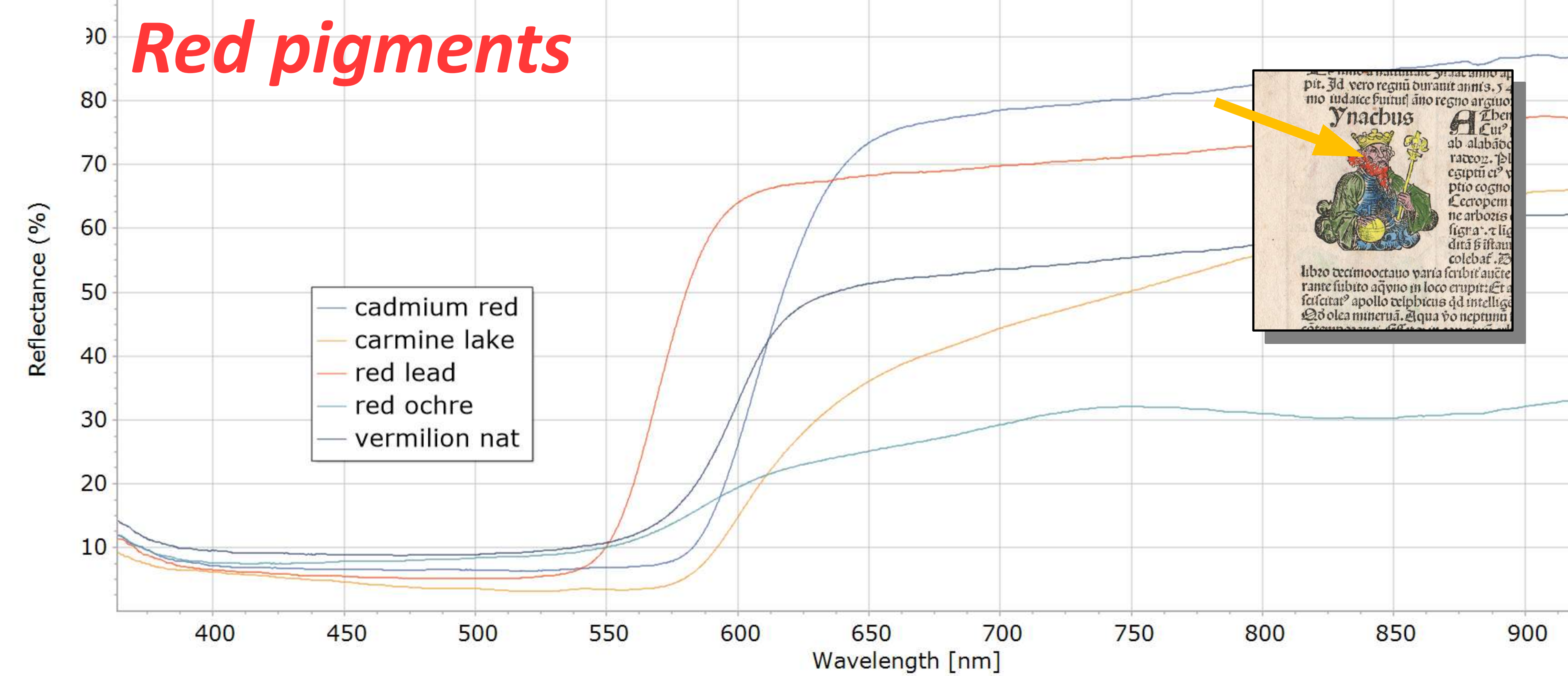


The best “match” for the brown color of the branch is “raw sienna”

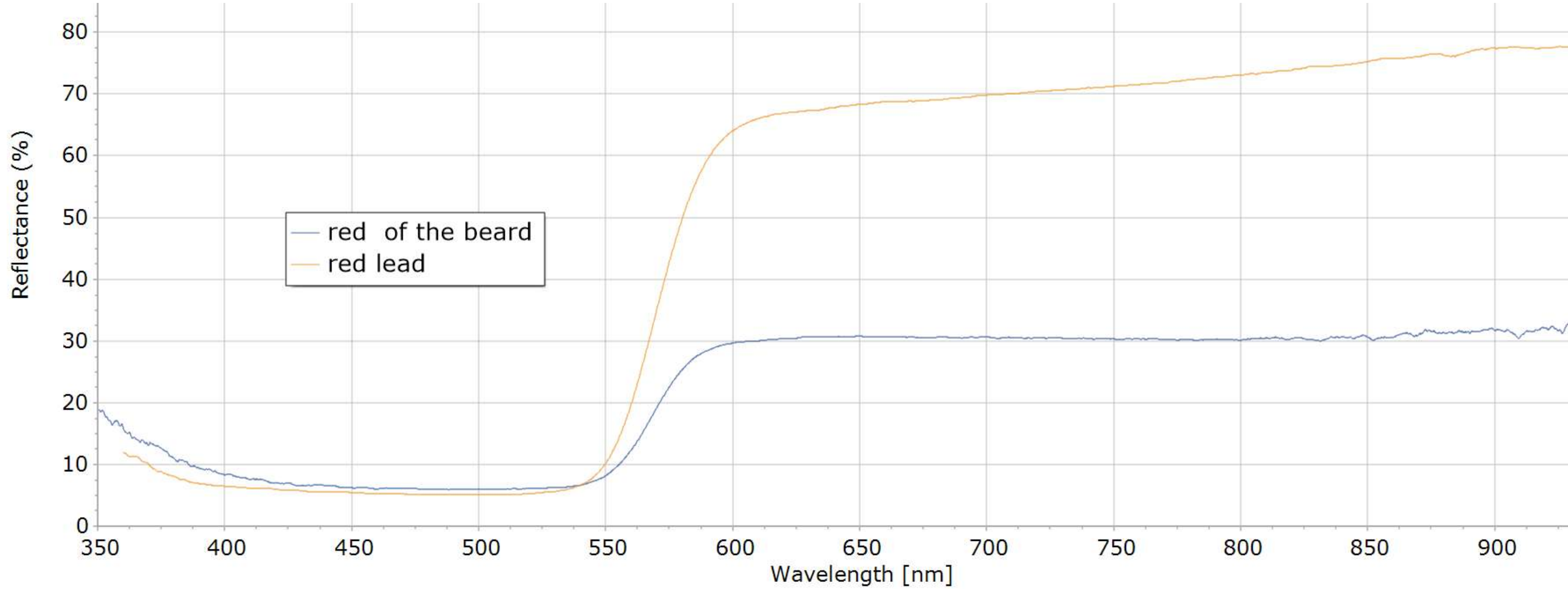


The brown of
the branch
was painted
with “raw sienna”,
available at
any historical age

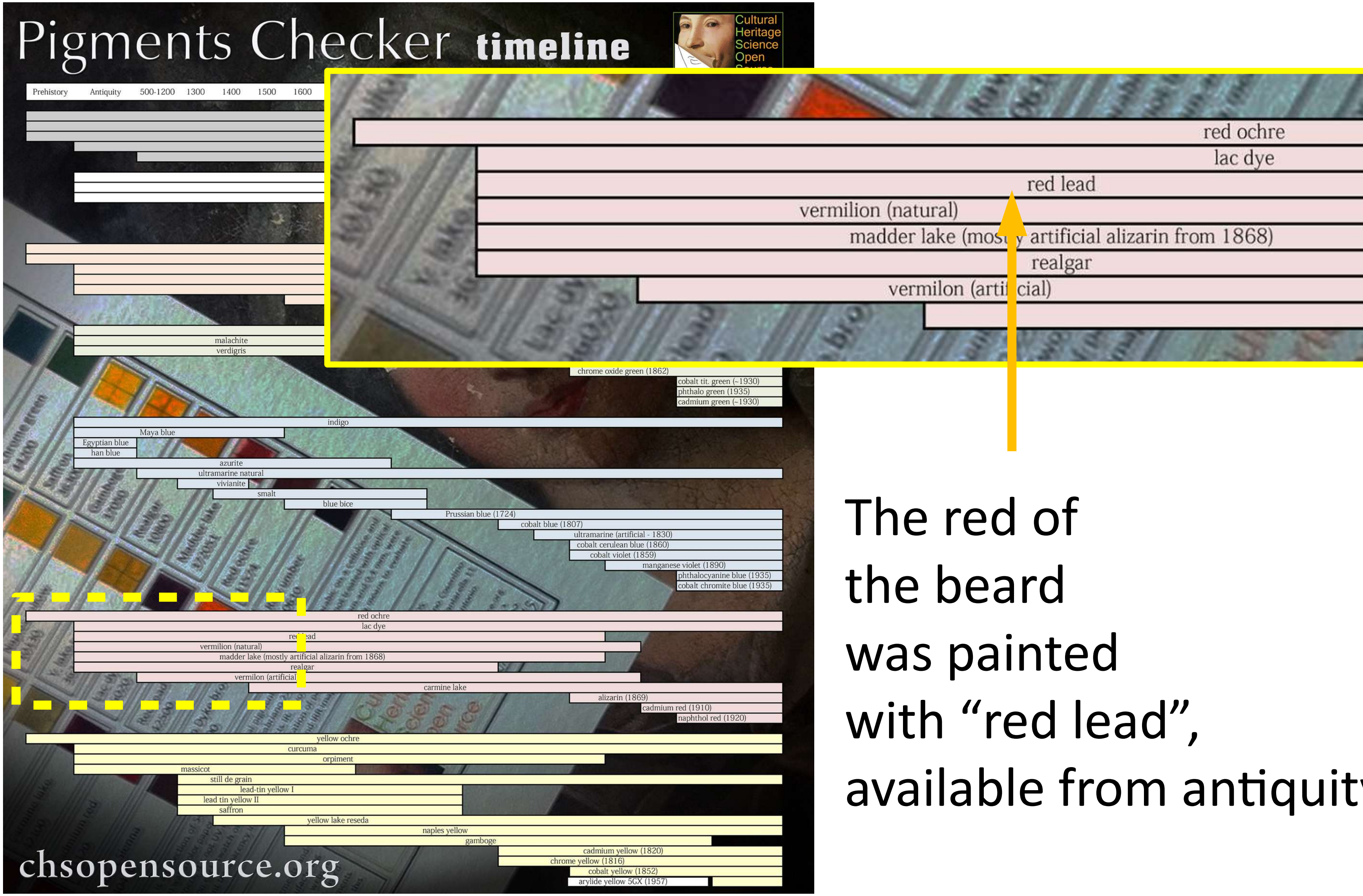
Red pigments



Reflectance spectra
of some red pigments in
Pigments Checker

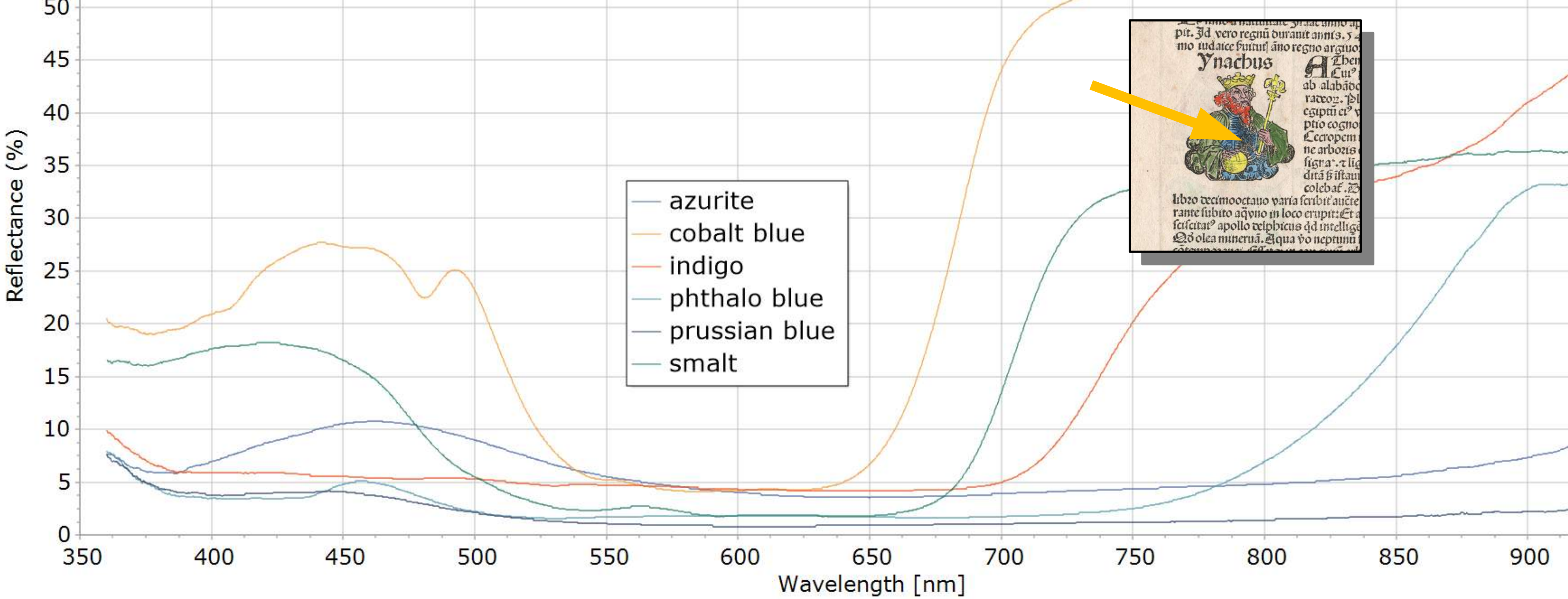


The best “match” for the red color of the beard is “red lead”

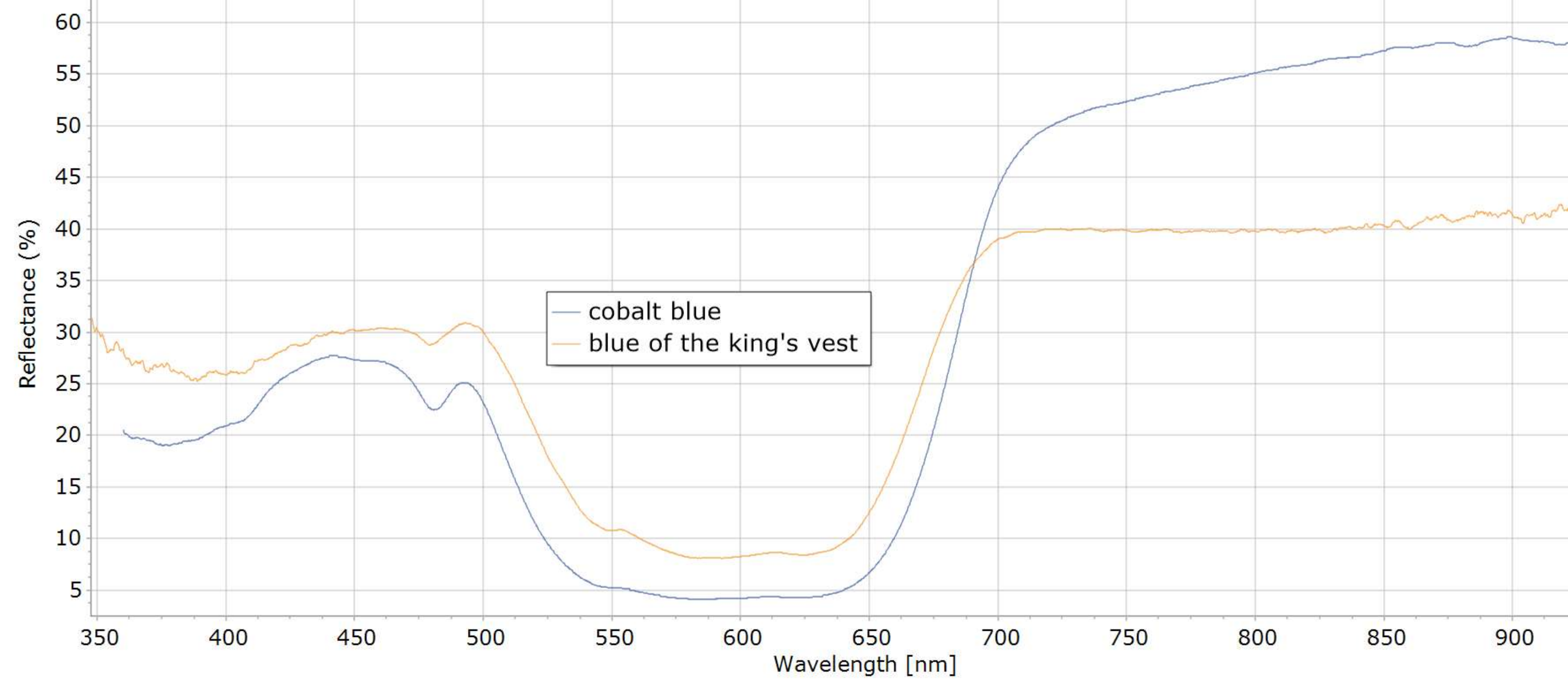


The red of
the beard
was painted
with “red lead”,
available from antiquity

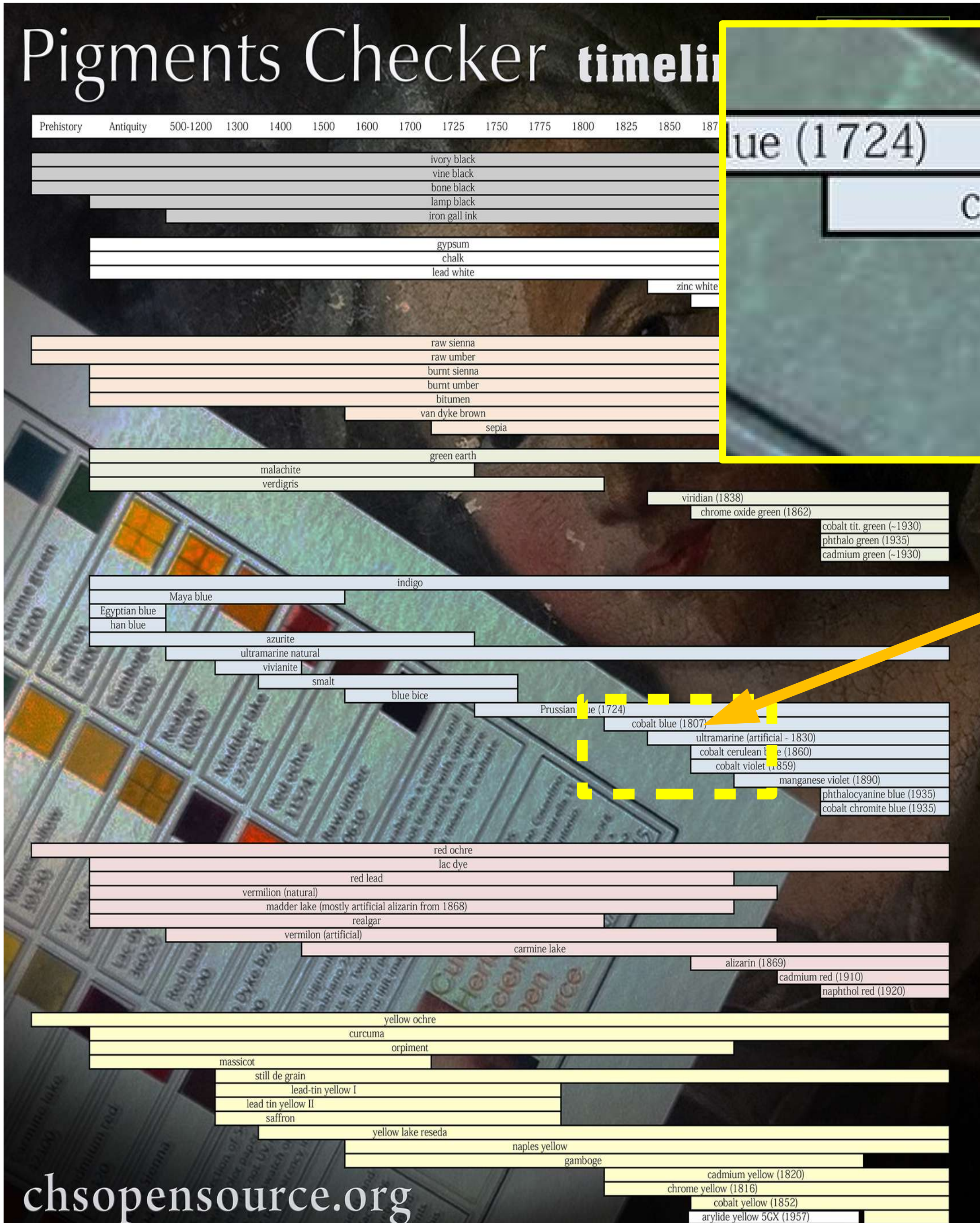
Blue pigments

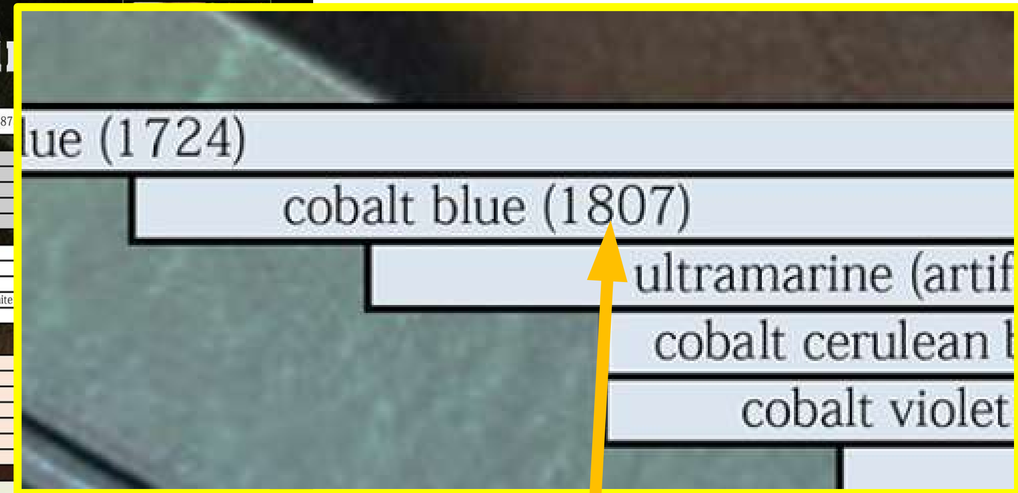


Reflectance spectra
of some blue pigments in
Pigments Checker



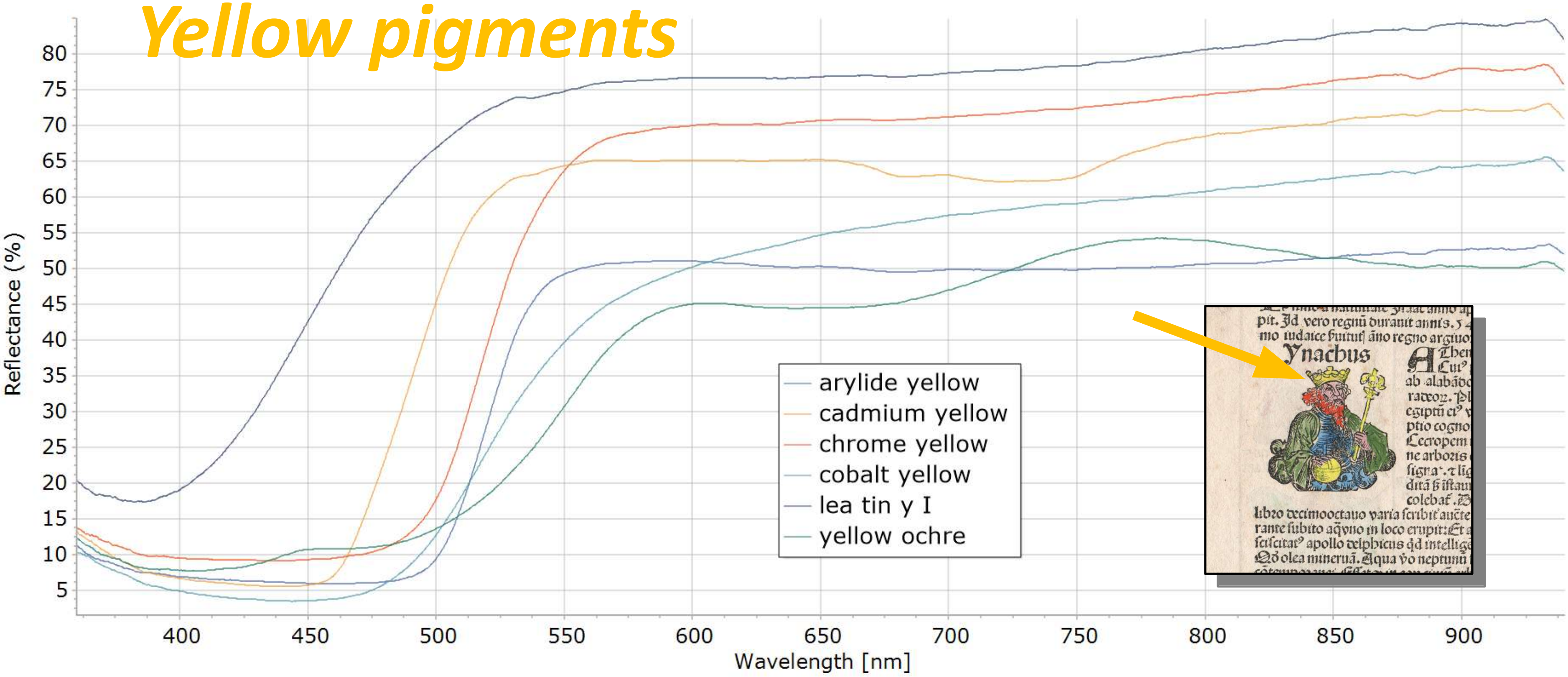
The best “match” for the blue color of the vest is “cobalt blue”



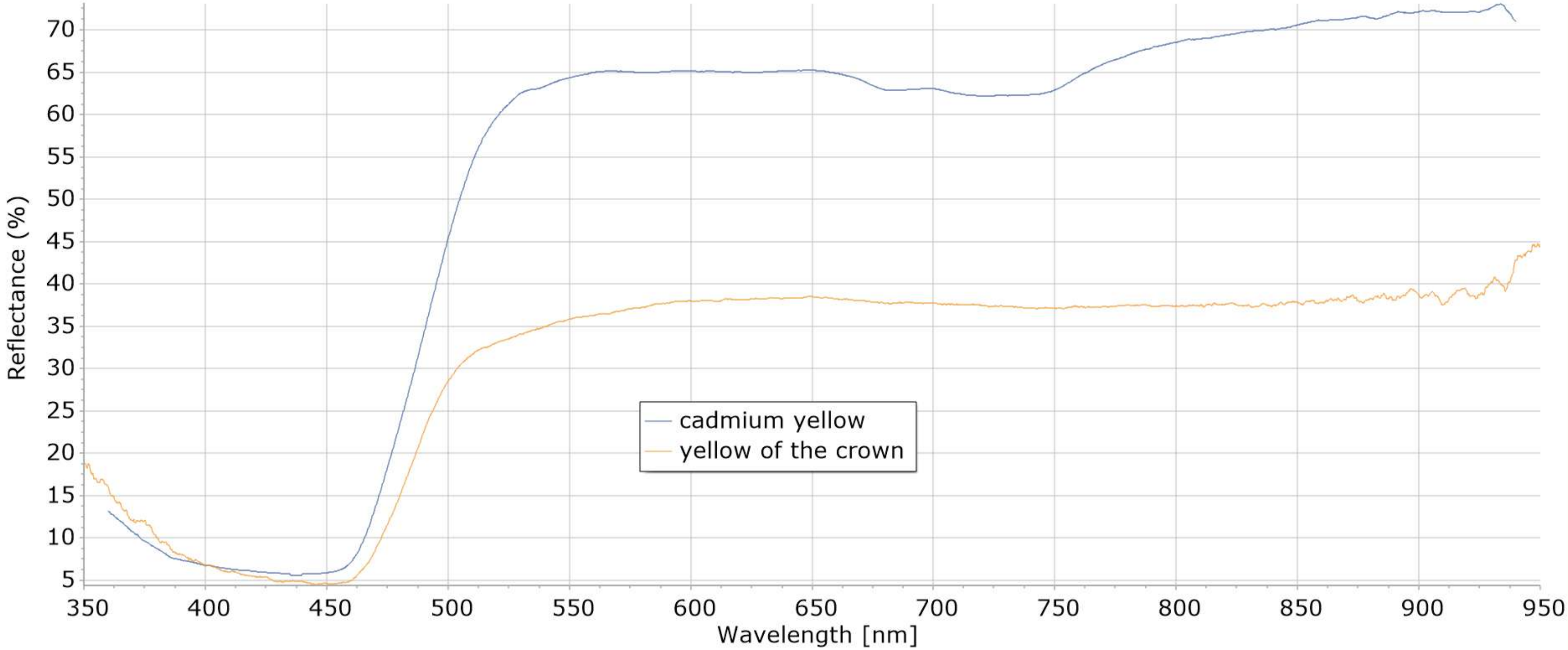


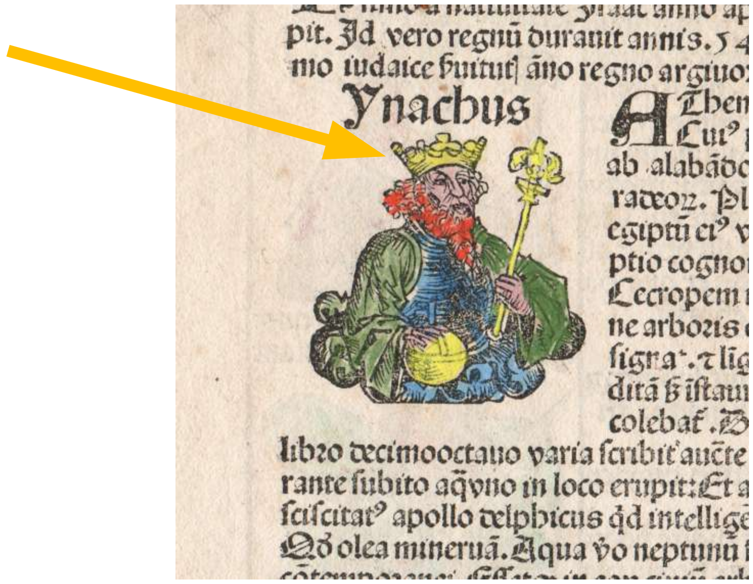
The blue vest was painted after 1807

Yellow pigments

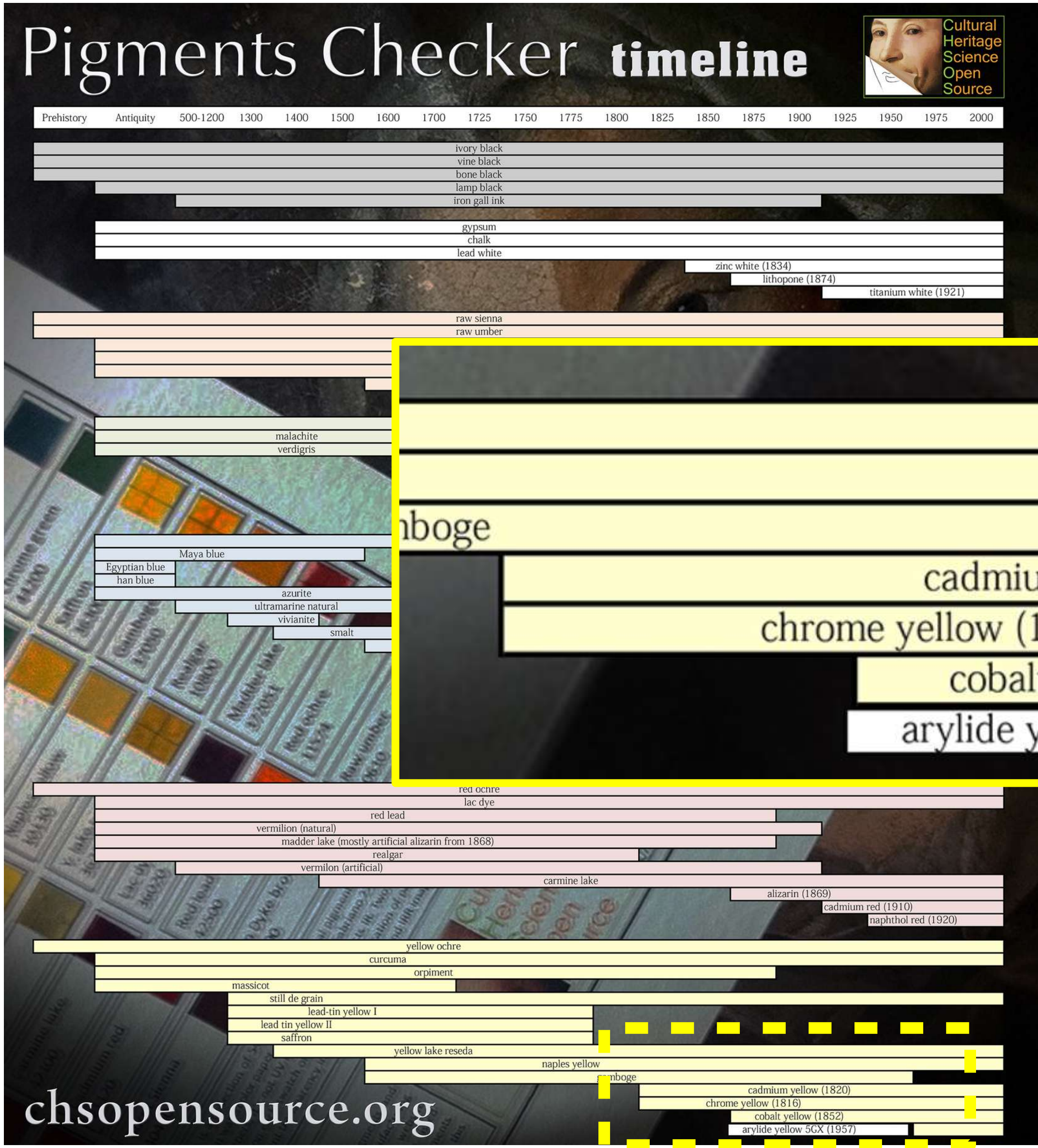


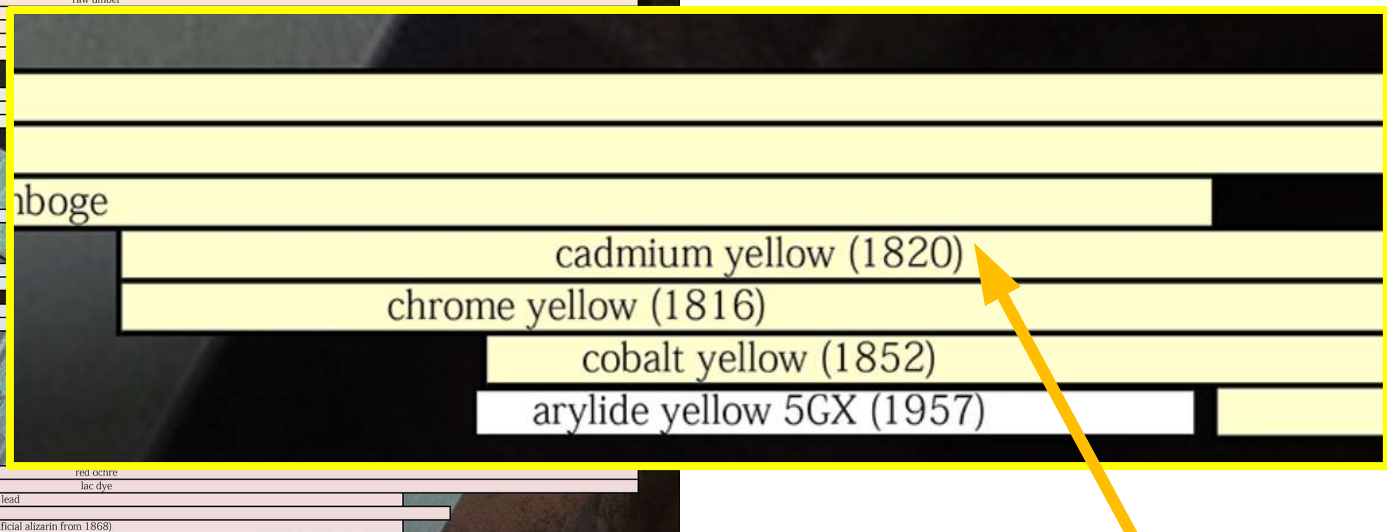
Reflectance spectra
of some yellow pigments in
Pigments Checker





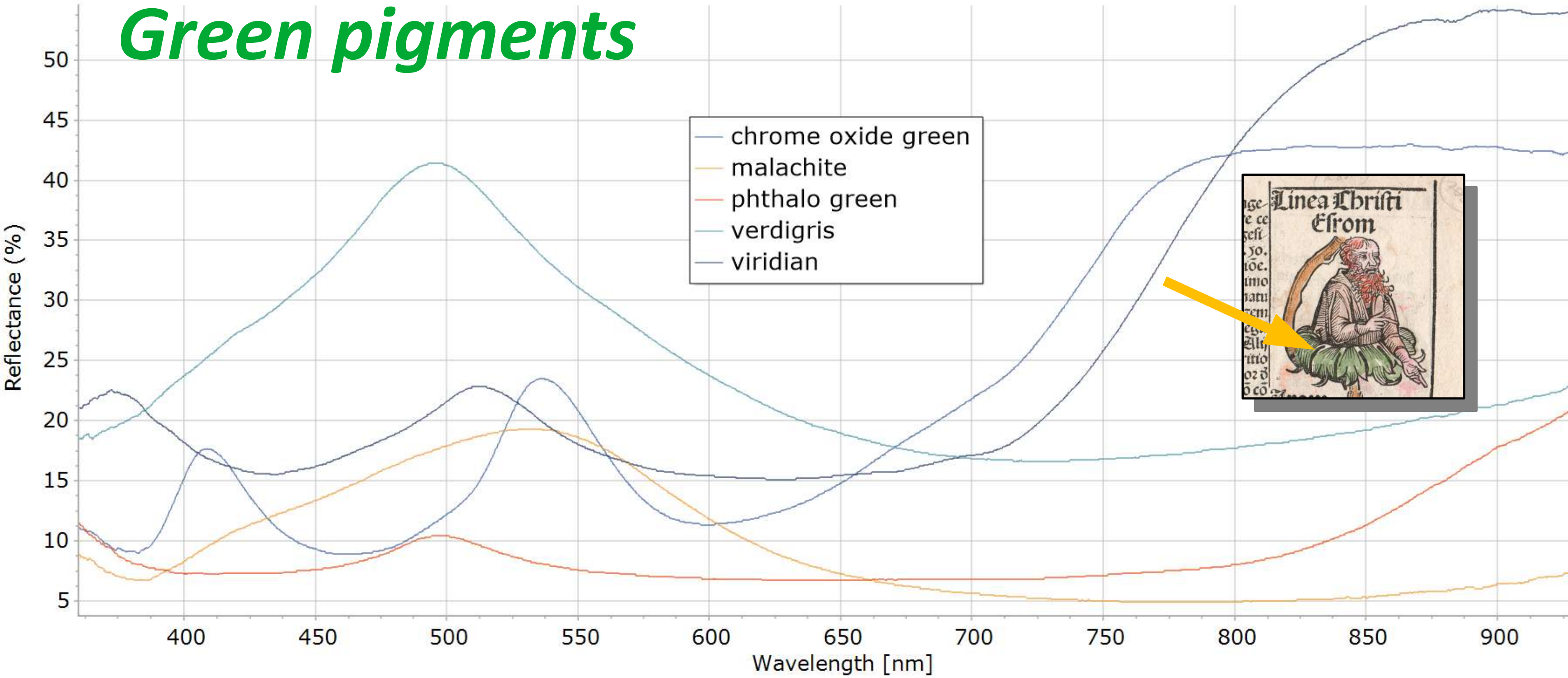
The best "match" for the yellow color of the crown is "cadmium yellow"



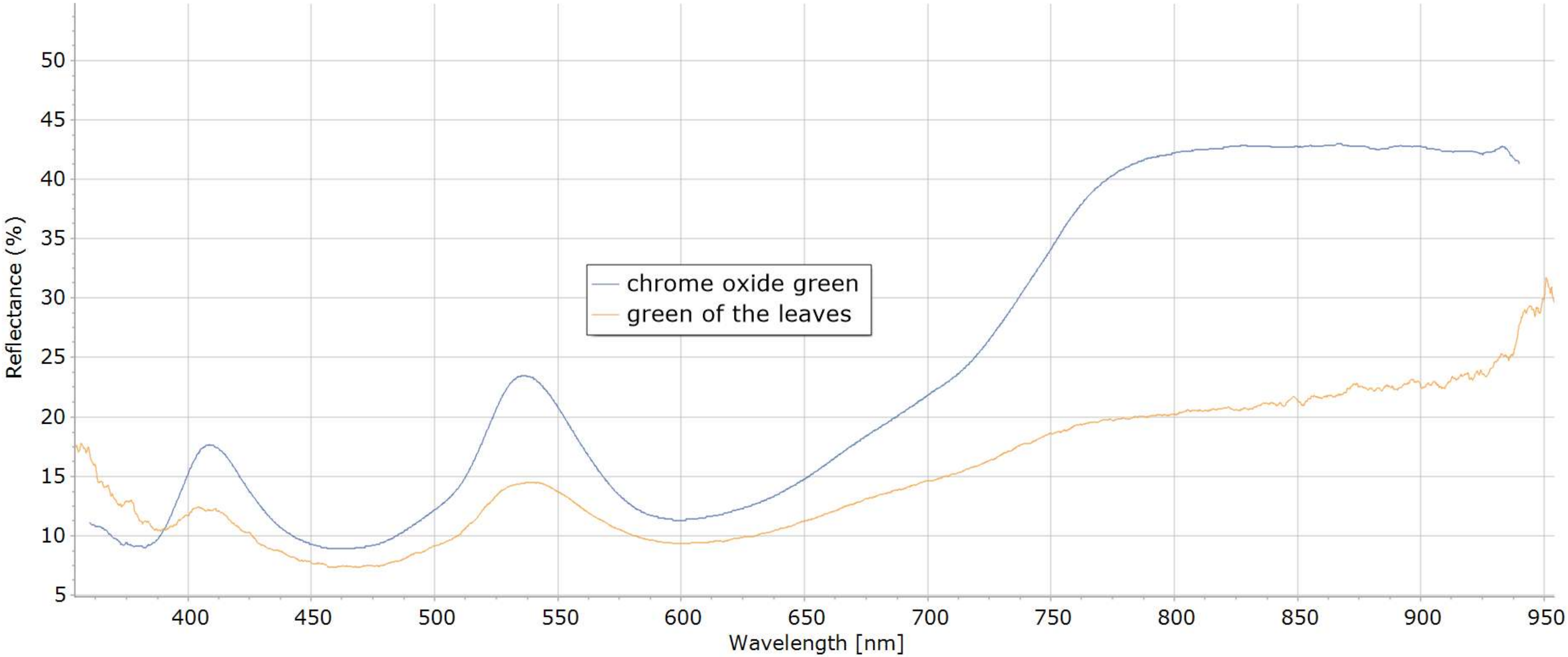


The yellow crown was painted after 1820

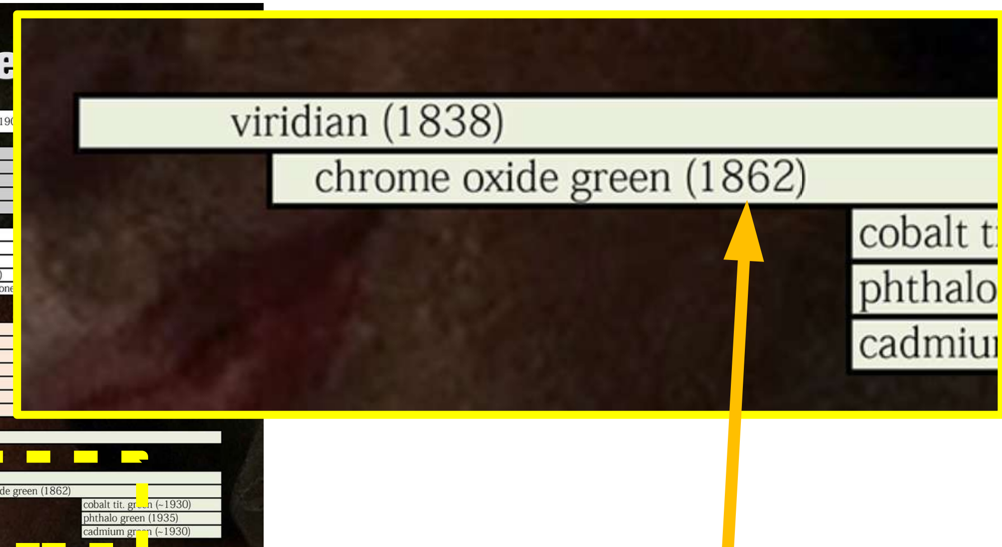
Green pigments



Reflectance spectra
of some green pigments in
Pigments Checker



The best "match" for the green color of the leaf is "chrome oxide green"



The green leaf was painted after 1862

When were the woodcut prints hand-colored?

After 1862

Tercia etas mundi

Esrom Anno mundi.3495. Aram vero anno mūdi.3544.

Hic ortū regnū argiuorū vbi Inach⁹ oceani ꝛ terre(vt aiūt)filius ferage simo a natiuitate Isaac anno apud argos in Thessalia prim⁹ regnare cepit. Id vero regnū durauit annis.544. Cecrops aūt egipti⁹ q̄rtoꝛ nonagesimo iudaice huiuꝯ āno regno argiuoꝝ relicto pm⁹ atheniēsib⁹regnūit ānis.50.

Ynachus

Athene ciuitas fuit p̄clarissima in attica regiōe. Cui⁹ pauca vestigia quedā manēt. Hāc primo ab alabādo cōditā dixit Cicero libro tercio de natura deoꝝ. Plato vero in Timeo dixit. Amasim regem egiptū ei⁹ vrbis cōditorē fuisse. Eāq; vocabulo egiptio cognomīasse. qd̄ ligua greca athenā sonat. Alij Cecropem illā ꝯdidisse dicūt. Et eā subita apparitione arboris oliue mineruā cognoīasse. quā ea arbor d̄ signat. ꝛ ligua greca athena d̄r. Verꝰ alij ab eo nō cōditā s̄ istauratā putāt. q̄ tpe Athena apd̄ illos ꝑ dea colebat. De ei⁹ nomīe Diu⁹ augustin⁹ de ciuitate dei libro decimooctauo varia scribit aucte varronis. Cecrope athenaꝝ vrbē instaurante subito aq̄vno in loco erupit: Et alio repta olea arbor. super q̄bus ꝓdigijs sciscitat⁹ apollo delphicus q̄d intelligēduꝫ. q̄due faciēduꝫ foret respōdisse fertur Qd̄ olea mineruā. Aqua vo neptunū significare ambo cōsobrini. Ambo dij et cōtemporanei. Essetq; in eoꝝ ciuiū arbitrio. vt ex alteri⁹ duoꝝ deoꝝ nomīe ciuitas vocaret. Cōgregatis oībus vtriusq; sex⁹ viri adheserūt neptuno. Mulieres vero Minerue. Que ꝛ obtinuerūt vt ex minerue nomīe ciuitas appellaret. Ac sic athenā grece vrbē cognomīauerit qd̄ latine Mineruā dicim⁹. Eo q mulieruꝫ voces vna viroꝝ numeꝝ superarint. Quāobrem irat⁹ neptun⁹ Marinis estuātibus vndis atheniensiū terras populat⁹ est. Quē ciues placare volētes triplici supplicio mulieres affecere. Primo vt decetero nullis publicis interessent cōsultatiōib⁹. Scd̄o vt null⁹ nascētium cognomē maternuꝫ acciperet. Tercio ne q̄s filias suas athenas vocaret. Poete vero dicūt neptunū ꝛ minerua athenas cōdidisse. Sed cū de nomīs īpositiōe inter eos fieret dissensio. Dijs reliq̄s p̄ntibus fit inter eos cōuentio. vt q̄ ꝑcussa terra laudabiliorē ꝓduceret effectū vrbi nomē imponeret. Neptun⁹ aūt tridēte suo ꝑcussa terra. Equū ꝓduxit belli omen. At minerua hasta ꝓiecta oliuā ꝓduxit pacis arborē. Que q̄m vtilior eoꝝ iudicō visa fuit. ex suo nomīe athenas dixit. Nā minerua athene grece dicit. de q̄ lucan⁹ libro sexto ait. Prim⁹ ab eq̄rea ꝑcussus cuspide saxis. Thessalic⁹ sonipes bellis feralib⁹ omen Exiluit. Et virgili⁹ georgicoꝝ p̄mo. Tuq; o cui prima frementē fudit equū tell⁹ ...

Linea Christi
Esrom

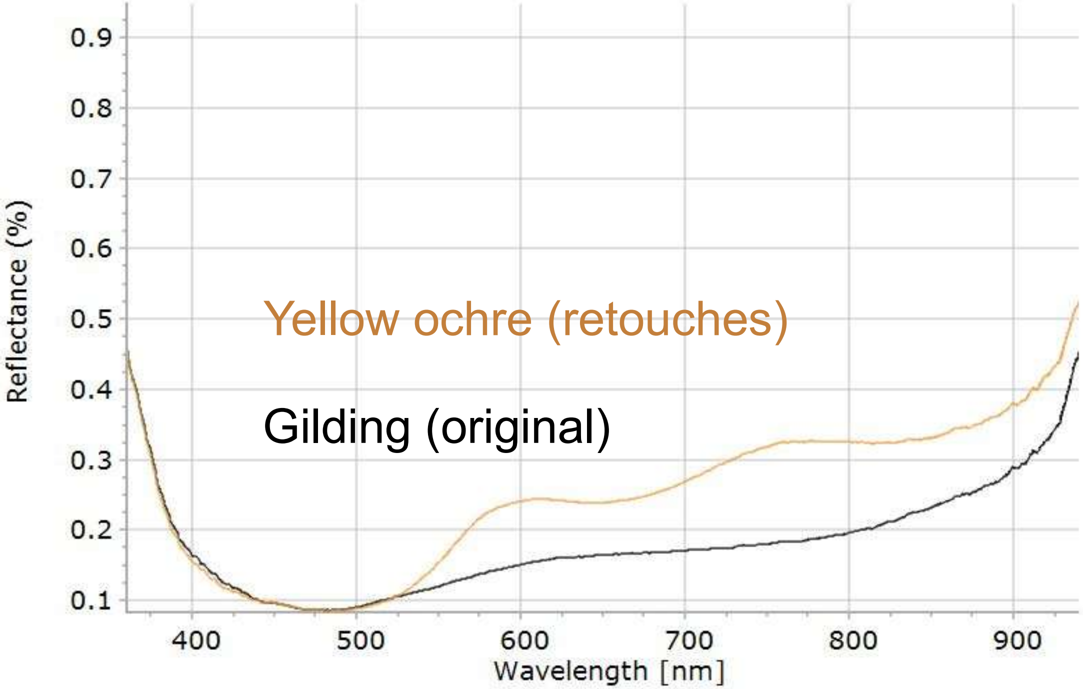
Aram

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Applications: statues



Reflectance Spectroscopy is a valid tool for conservators. This statue was extensively gilded but a good part of it has been lost and replaced with yellow ochre. Even in some areas, the bolo (red ochre) preparation is still visible. Reflectance spectroscopy can tell the original gilding from those areas that have been replaced with yellow ochre paint from their different spectra.

Reflectance Spectroscopy

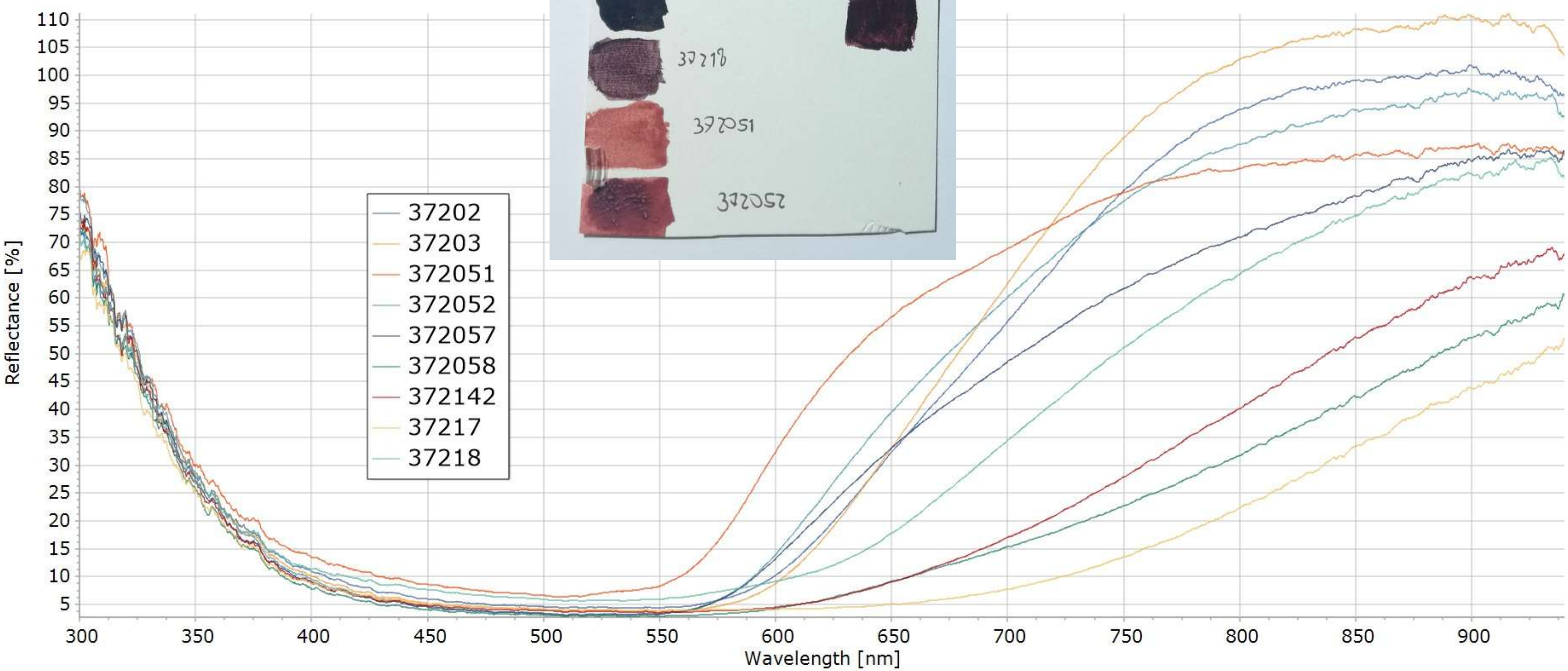
chsopensource.org

Cultural Heritage Science Open Source

Notes: dyes and lakes

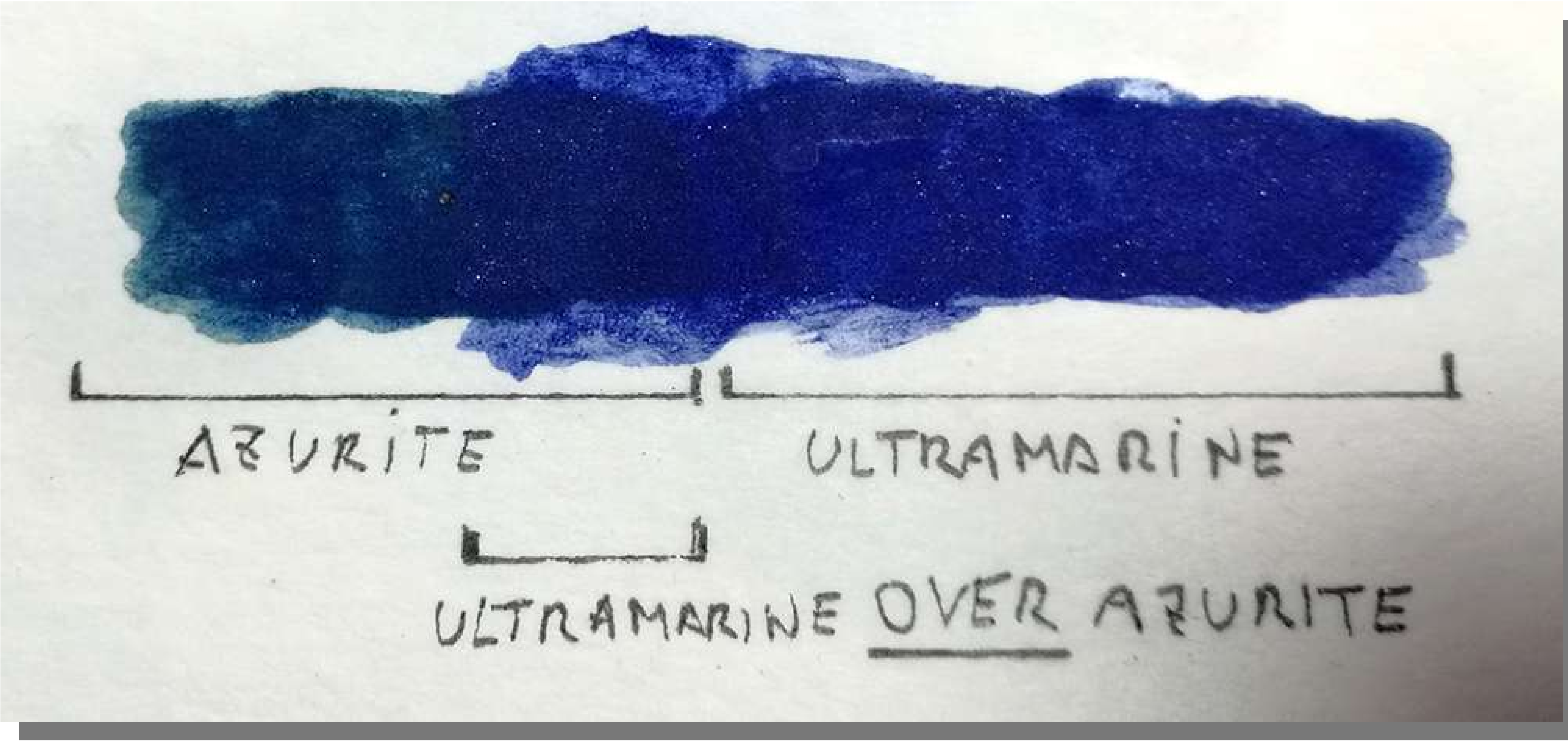
Reflectance Spectroscopy is a valid tool for mineral pigments. The pigment has always the same chemical formula and so we do not expect changes in the reflectance spectrum. On the other hand, dyes and lakes, made from organic origin, have been realized with different recipes in order to obtain specific tones. This create different reflectance spectra. Let’s take the case of madder lake.

We tested 9 madder lake recipes. They were made with same madder root but different mordant and procedures such as for boiling and reaction. This results in different tones but also different reflectance spectra. The madder lakes are all characterized by the increased reflectance in the infrared but the inflection point has a large variability.



Reflectance Spectroscopy

Notes: paint layers, example 1

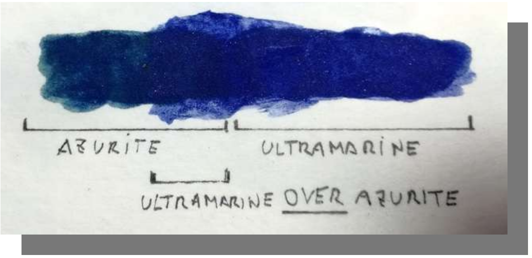


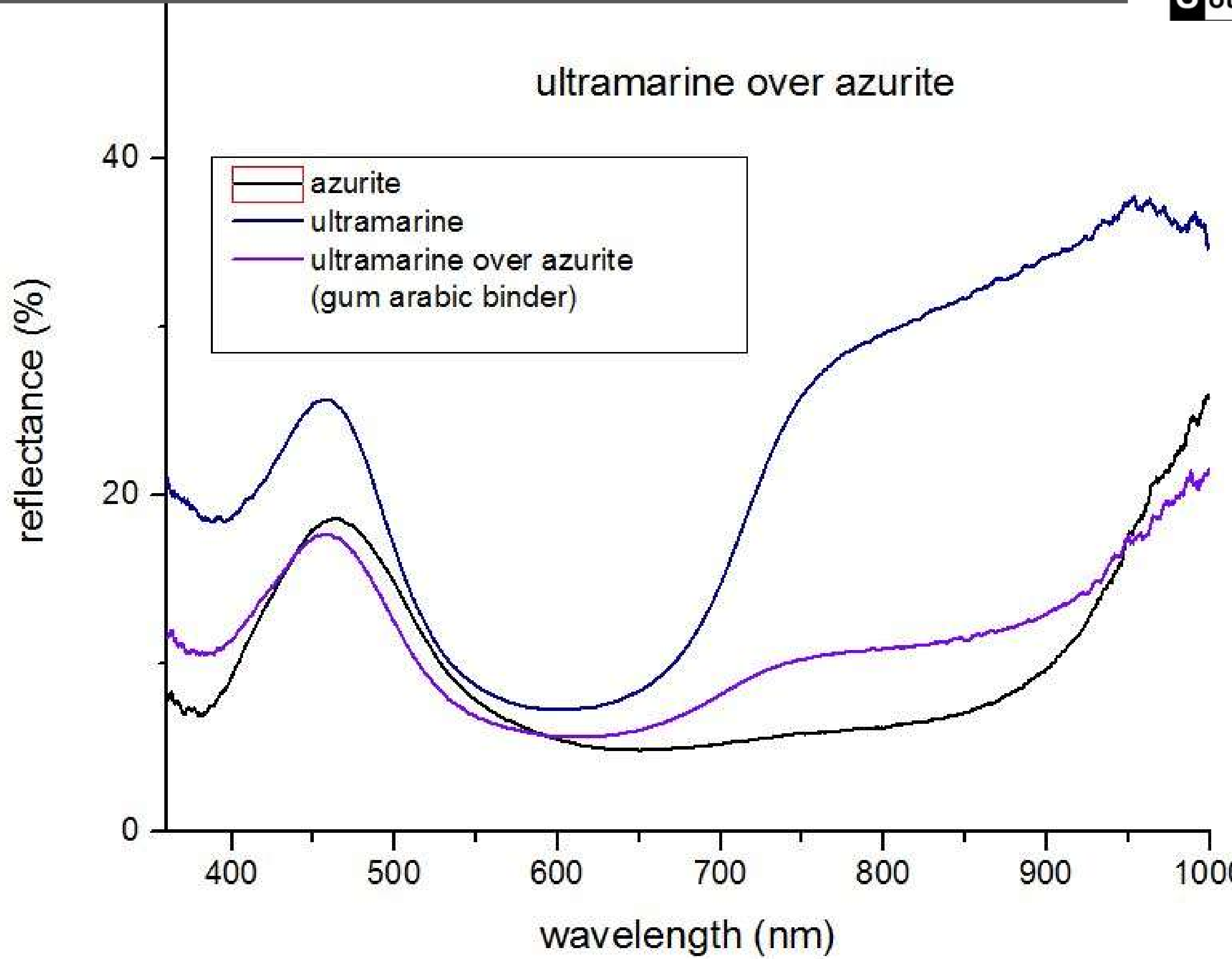
When we tested our Gorgias on the Pigments Checker we tested one pigment at a time. This is the most simple situation. One pure pigment laid on a white ground. Now we have other questions, because in the real cases we have layers of paints and mixture.
This example illustrates with a medieval painting technique mock-up. Azurite was painted on the white ground and the was partially covered with ultramarine. This was a technique to enhance the ultramarine color. What happens when we take a reflectance spectrum from the area where ultramarine is painted over azurite?

Reflectance Spectroscopy

chsopensource.org

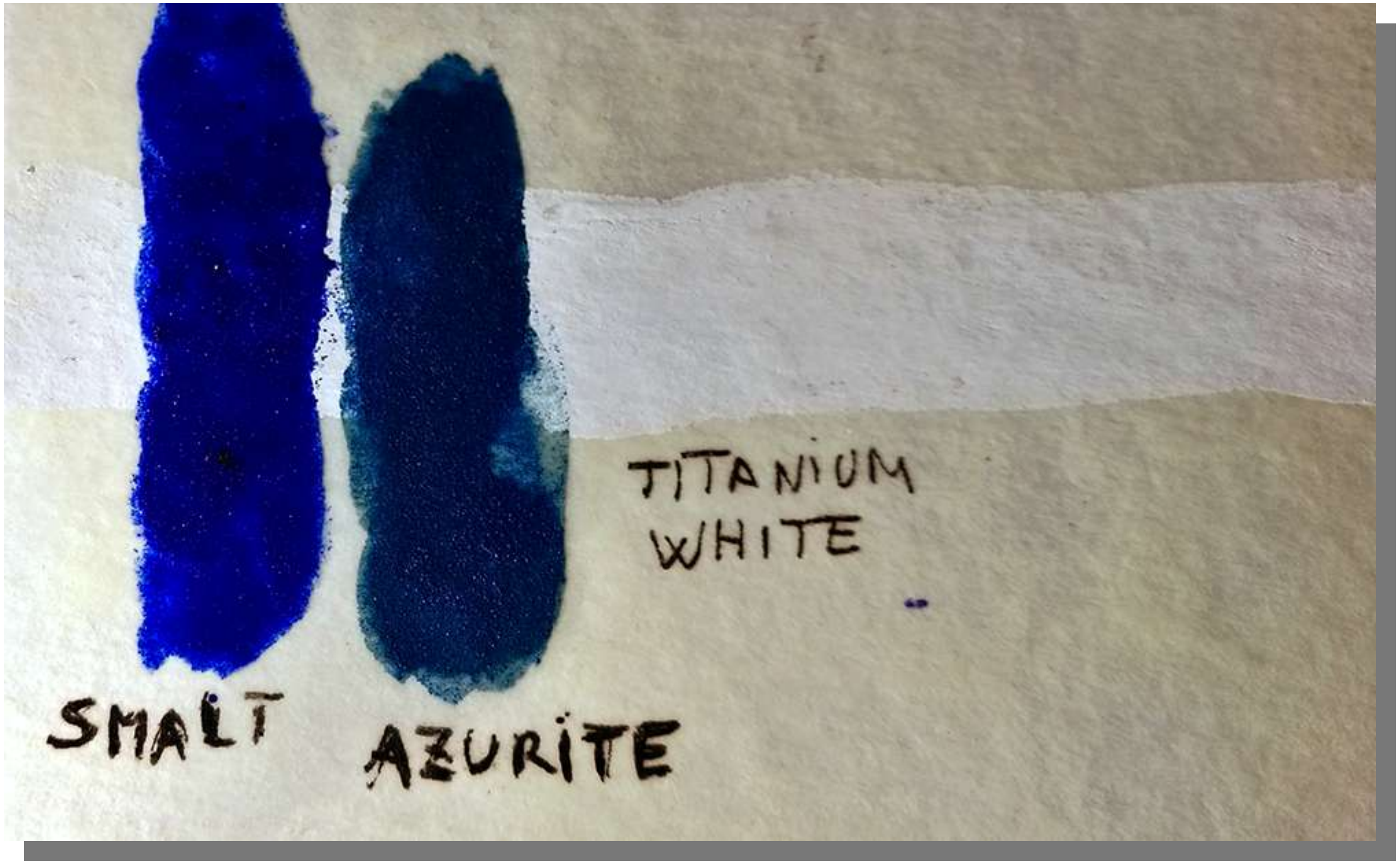
Notes: paint layers, example 1





This graph shows the spectra of the 3 areas. What happens is that the spectrum of “ultramarine over azurite” is like the one of standard ultramarine but in the infrared region we see much less reflectance. Ultramarine is mostly transparent in the infrared region, so the infrared radiation from the lamp goes through ultramarine and reaches azurite. The bottom layer of azurite absorbs this infrared and we have the resulting spectrum, ultramarine with much less reflectance in the infrared region.

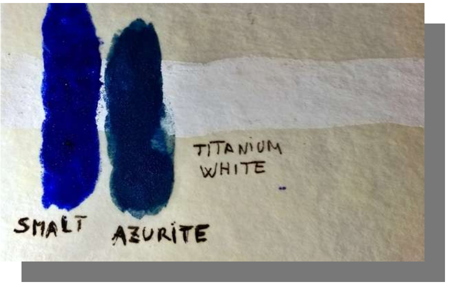
Notes: paint layers, example 2

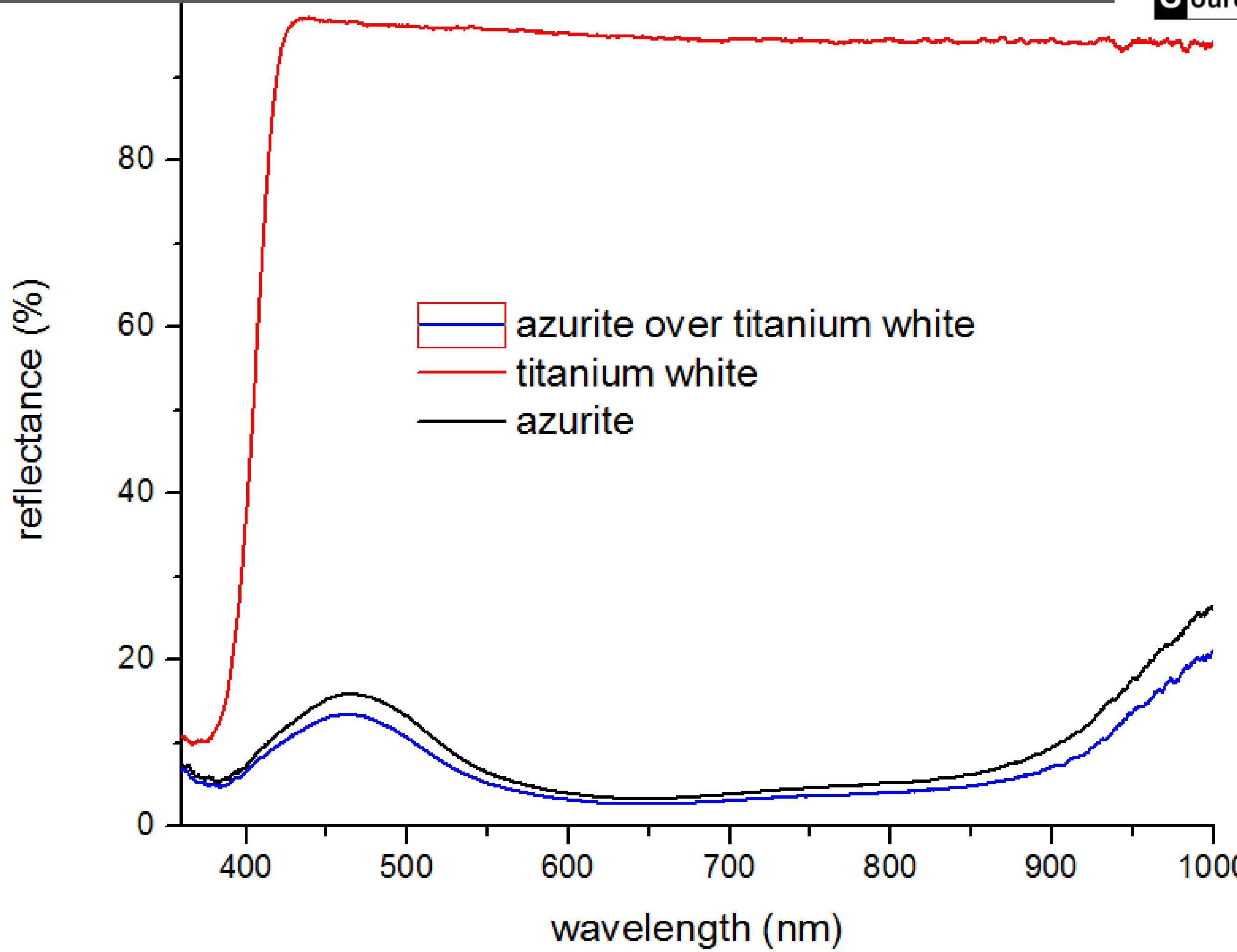


This example discusses 2 blue pigments over a white ground preparation made of titanium white, such we can find in art after 1920' when titanium white becomes available as a commercial white paint.

Reflectance Spectroscopy

Notes: paint layers, example 2





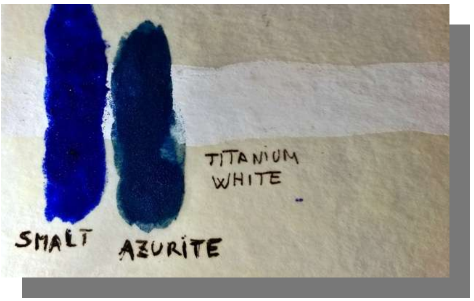
First we discuss azurite. This pigments reflects blue light but then it absorbs all the other spectral ranges. Consequently, we see that the spectrum of azurite over titanium white is not affected at all.

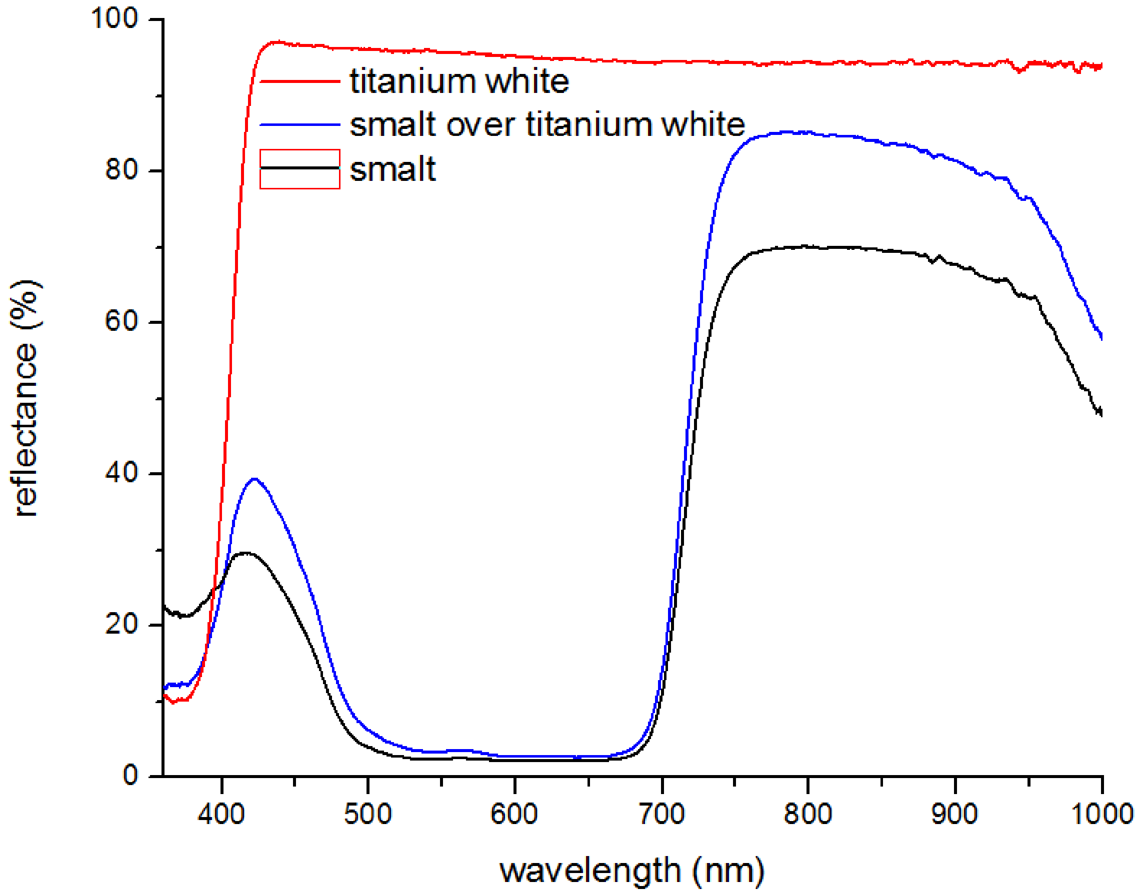
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Notes: paint layers, example 2





Now we discuss smalt. Let's look at the UV region. The reflection of smalt in the UV region is much less when it is painted over titanium white. This is because smalt is a partially transparent in the UV and the UV radiation from the lamp is now absorbed by the titanium white. In the infrared region we see increased reflectance. This is because titanium white is reflecting better than the cardboard used to make the standard in Pigments Checker. Bottom line, the spectrum of smalt over a preparation layer painted with titanium white shows less reflectance in the UV and much reflectance in the IR region. If we understand these processes, we can use these modified spectra to actually figure out the layering of the paints. So a spectrum of smalt with less reflectance in the UV is likely to be smalt over titanium white.

Notes: paint layers, example 3

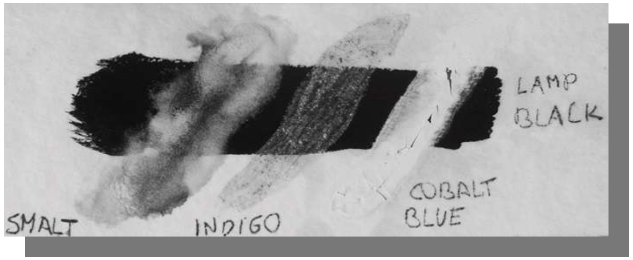
In the previous example we saw pigments over a white pigment. We discuss now pigments over a black paint, lamp black. This would be the same for any other of the black pigments based on carbon, which absorbs on all the spectral regions.

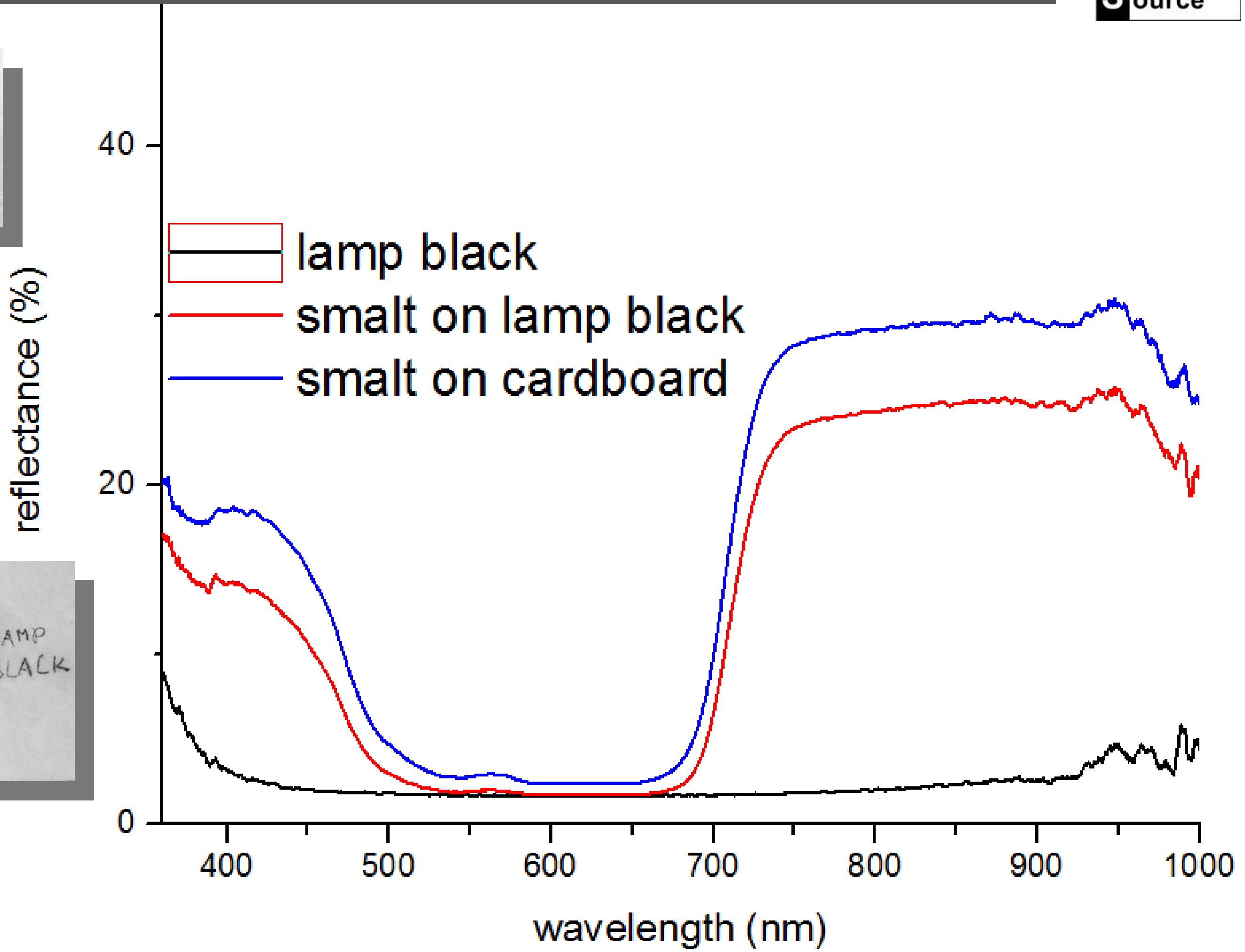
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Notes: paint layers, example 3





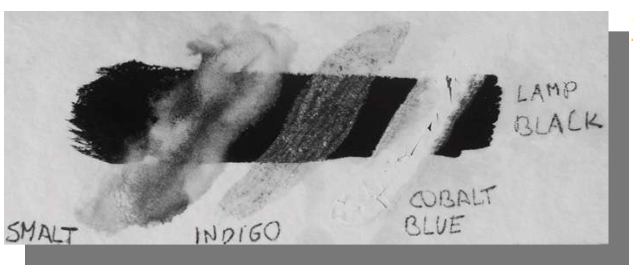
Let's start discussing smalt. We also have here an infrared photo of the same mock-up. Notice that the spectral range of the Gorgias and our modified digital camera for Technical Photography is the same. Both can see in the range 300-1000 nm. The infrared photo shows that smalt is partially transparent to the infrared and, indeed, the reflectance spectrum shows less reflectance in the infrared region when smalt is over lamp black, since this last one absorbs the infrared.

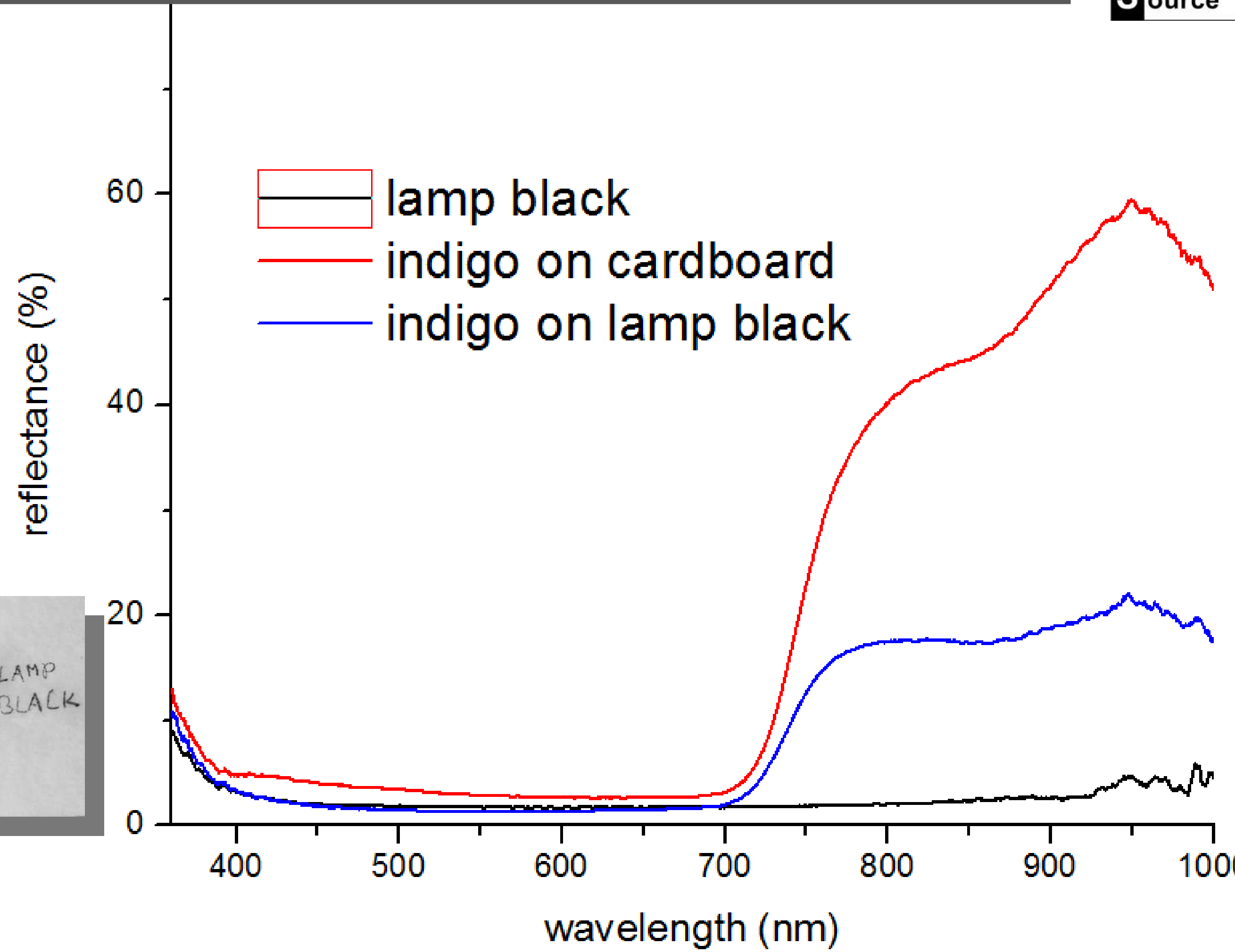
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Notes: paint layers, example 3



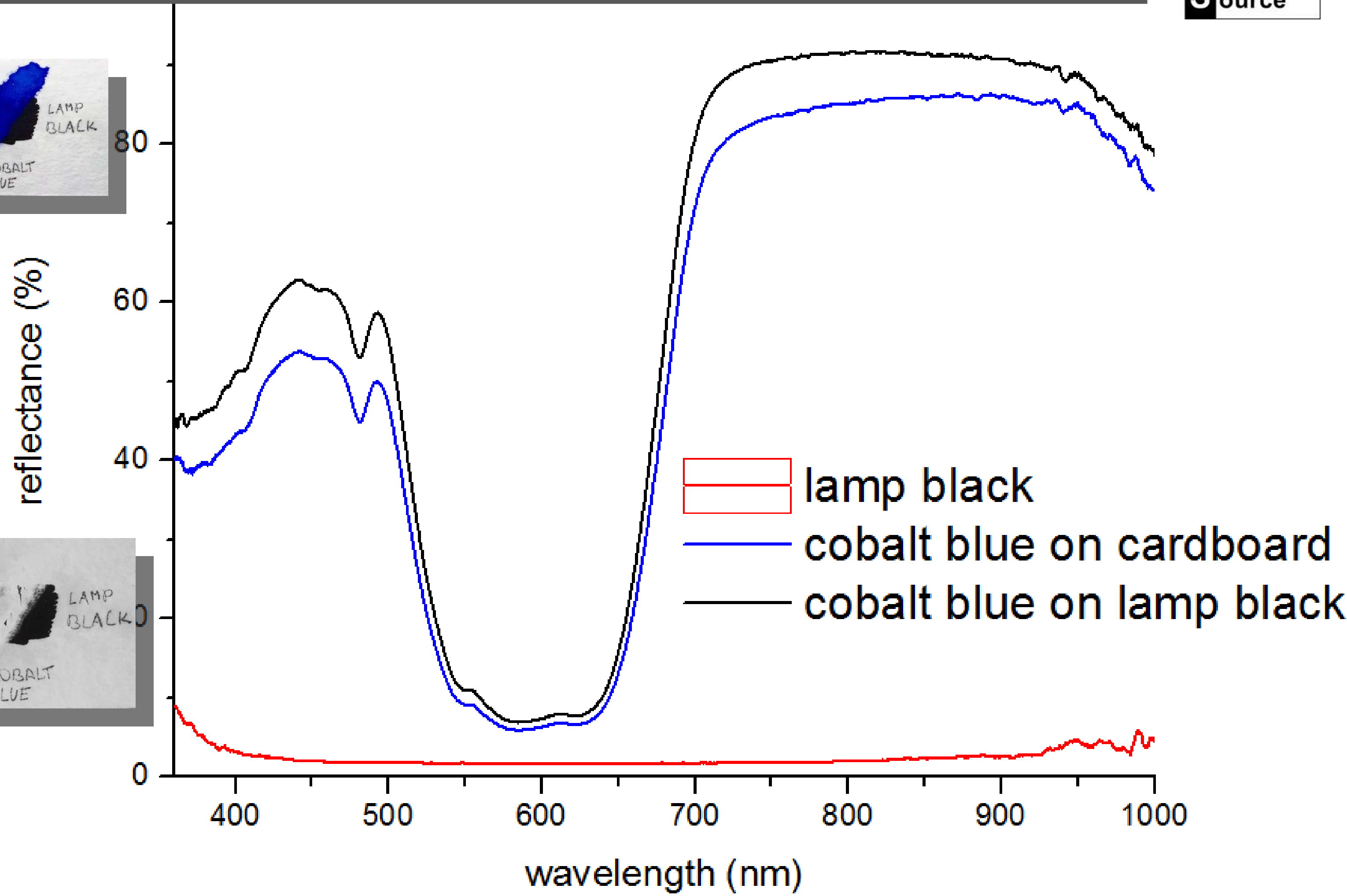


We look now at indigo. The IR photo shows that this pigment is very transparent to the infrared. Consequently, its reflectance spectrum shows much less reflectance in the IR, because infrared is absorbed by the bottom layer of lamp black.

Reflectance Spectroscopy

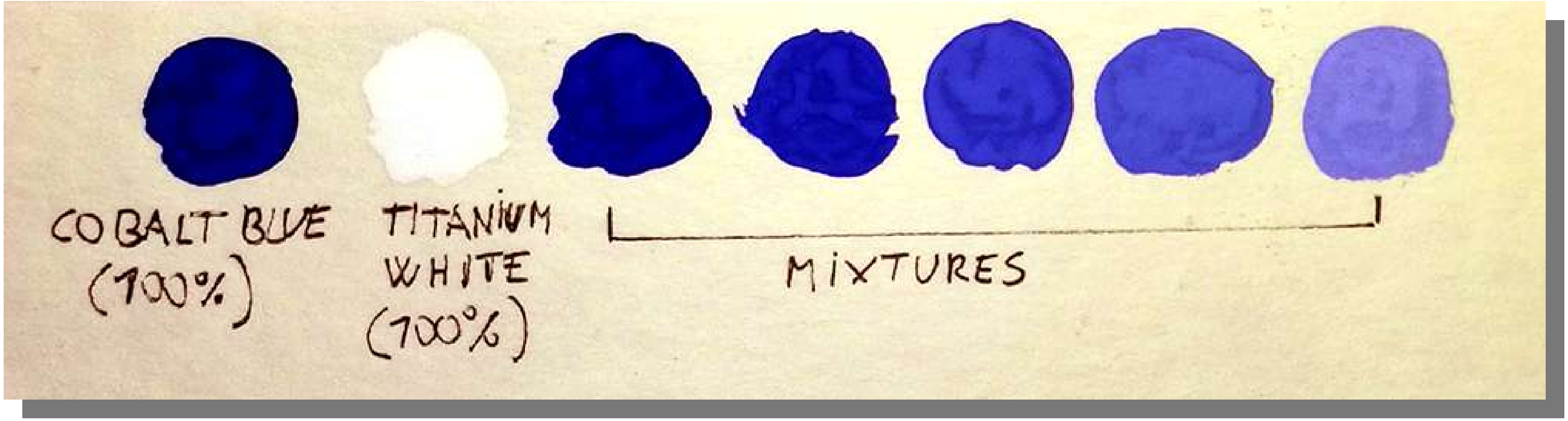
Cultural Heritage Science Open Source

Notes: paint layers, example 3



Eventually, let's discuss cobalt blue. The IR photo shows that this pigment is totally opaque to the infrared. All the infrared is bounced off and we cannot tell the lamp black layer behind it. Consequently, the spectrum of cobalt blue is not affected by the lamp black bottom layer.

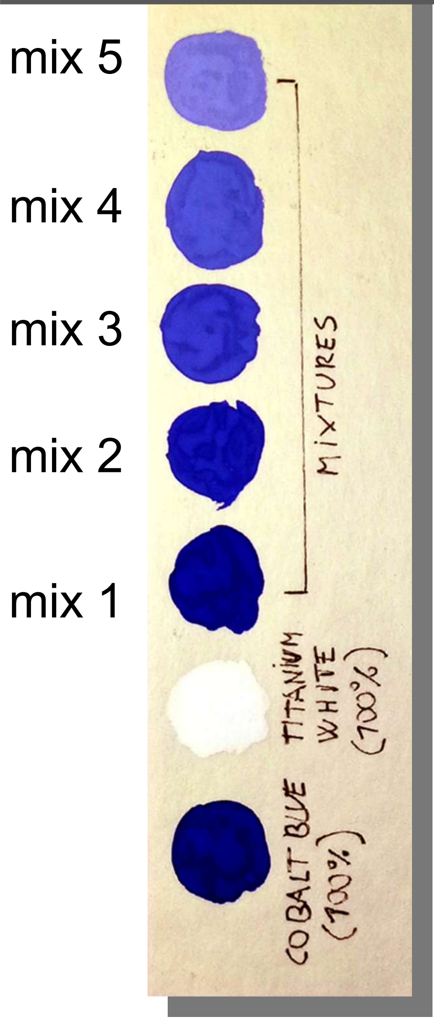
Notes: paint mixtures, example 1

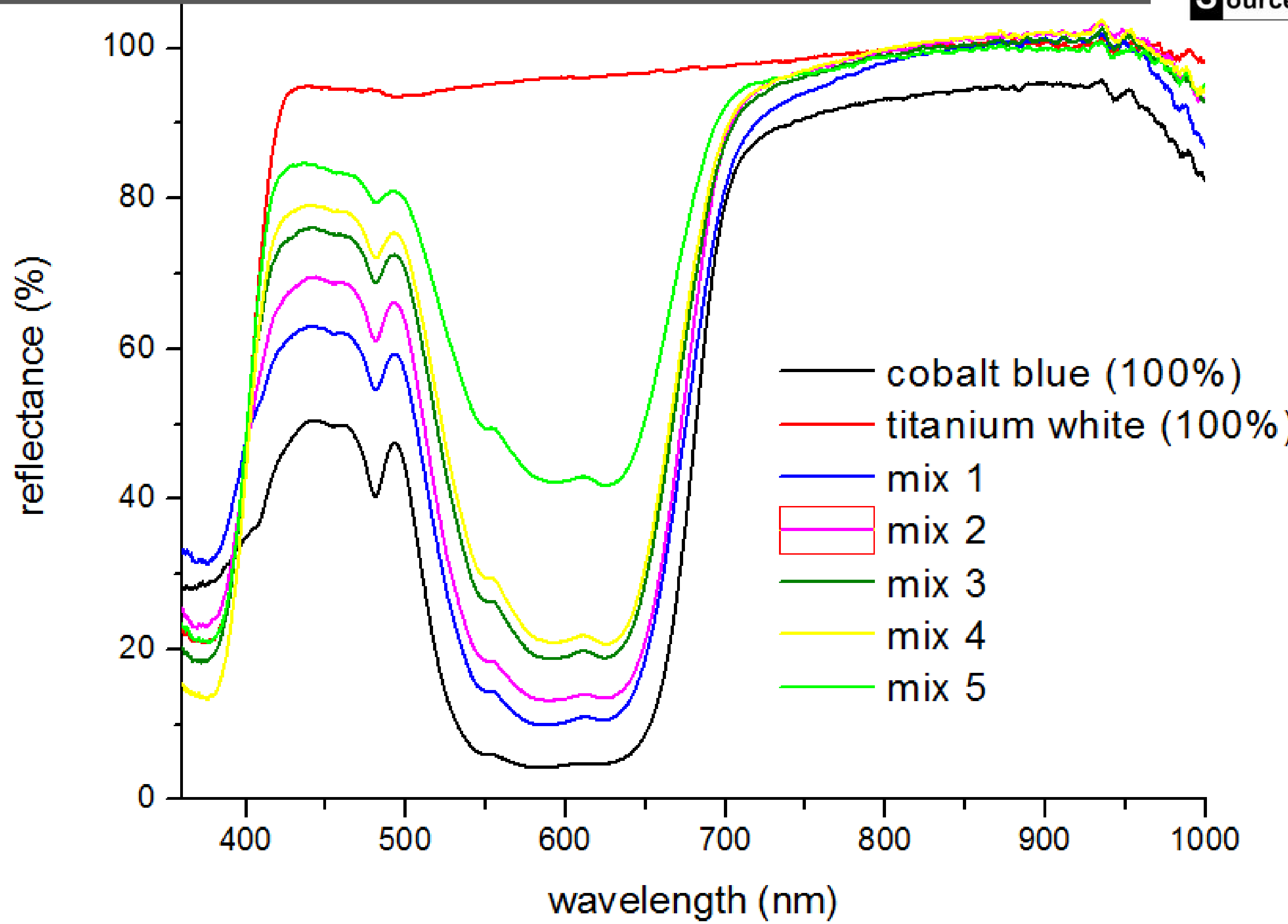


We prepared a mock-up paint using cobalt blue and titanium white. We painted them pure and 5 mixtures where we progressively added a bit more titanium white. What is the resulting spectrum of the mixtures?

Reflectance Spectroscopy

Notes: paint mixtures, example 1





When we mix pigments, the resulting spectrum is the additive result of the absorption bands from the pigments in the mixture. So, in this case we see that moving from mix 1 (almost pure cobalt blue with a pinch of titanium white) to mix 5, the resulting spectra show a decrease of reflectance in the UV region. This is due to titanium white which has the strong absorption band in the UV region. So, when we collect from a light blue color, a spectrum resembling that of cobalt blue but with much less reflectance in the UV region, we can guess that it is a mixture of cobalt blue plus titanium white.

Reflectance Spectroscopy

Notes: paint mixtures, example 2

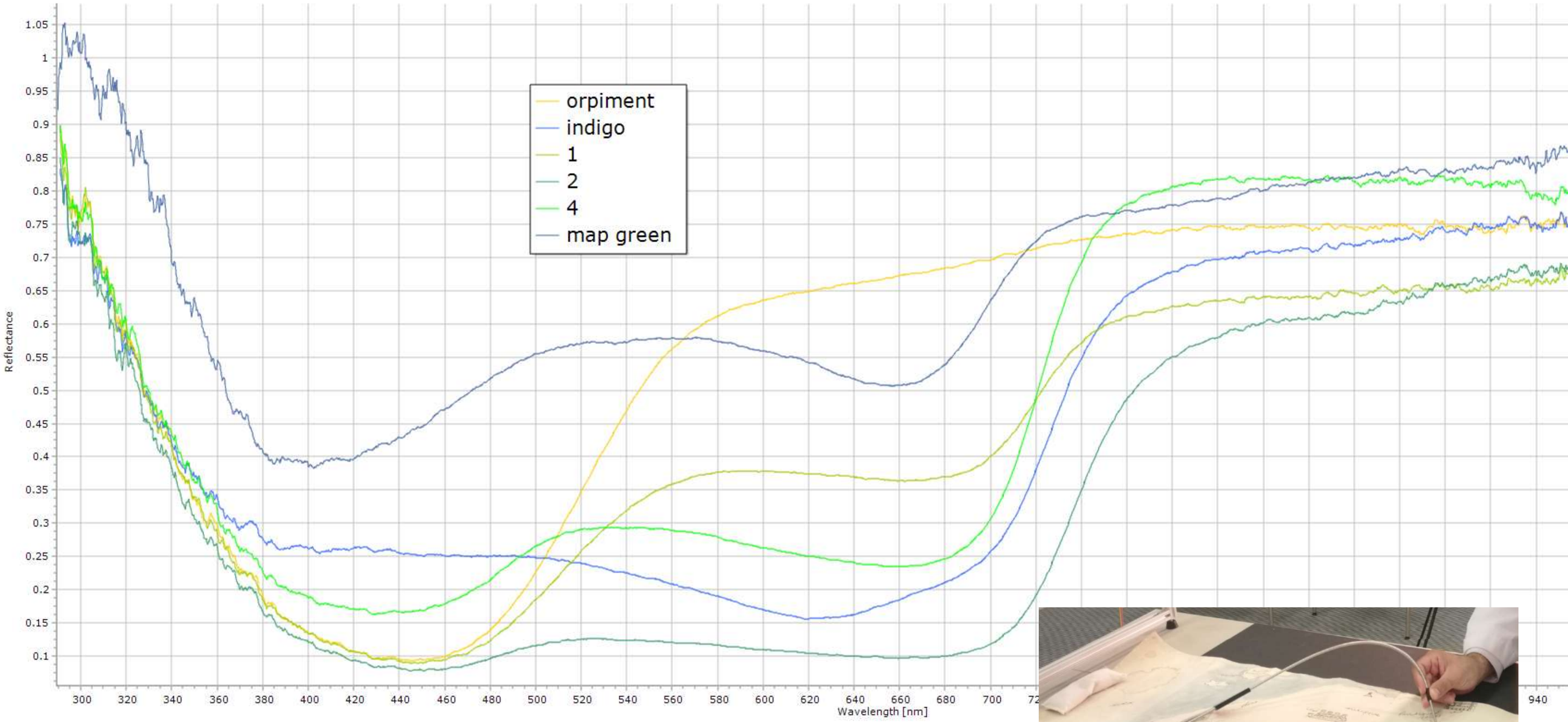
We discuss now a common historical mixture to obtain green, indigo plus orpiment. We made 3 mixtures adding more and more indigo to a pure orpiment.

Reflectance Spectroscopy

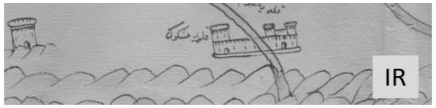
chsopensource.org

Cultural Heritage Science Open Source

Notes: paint mixtures, example 2



We show here all the spectra, both pure pigments and the mixtures. We also added the spectrum collected from a green paint on a historical map which matches the mixture 4 spectrum.

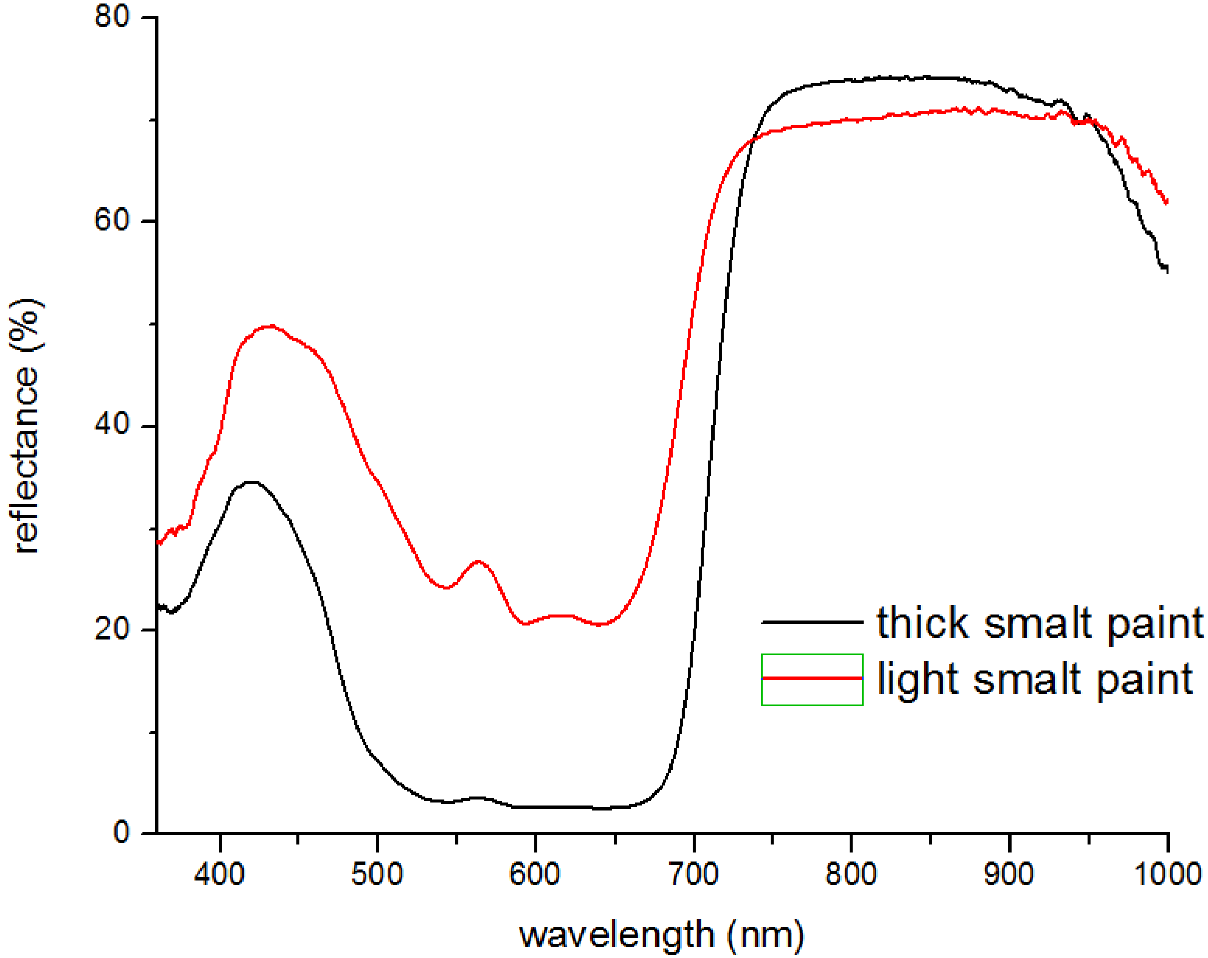


Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Notes: paint thickness, example 1

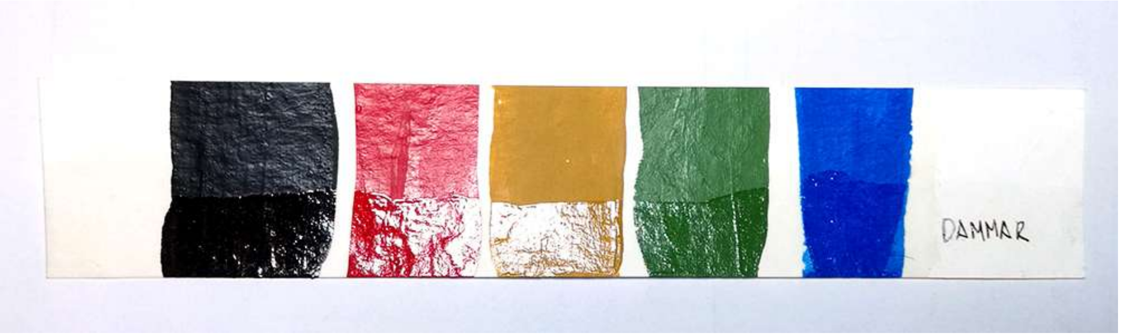


The thickness of the paint can play a role in the final spectrum We made this mock-up painting smalt as a very thick layer and also very thin. The spectrum of the thick paint shows less characterizing features than the thin one. This happens because the thinner paint allows much more radiation to go through and being reflected back from the support. So, the effect of the absorption bands become more apparent.

Reflectance Spectroscopy

Cultural Heritage Science Open Source

Notes: varnish and binders



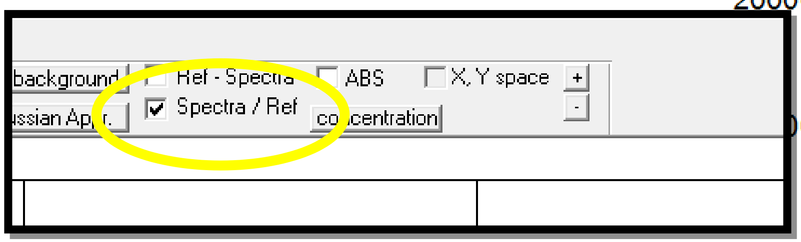
Varnishes and binders have flat reflectance spectra, they are basically just transparent in the range 300-1000 nm. So they do not affect the reflectance spectra of the pigments. As in the example above, the spectra from the varnished and unvarnished paints would be the same.

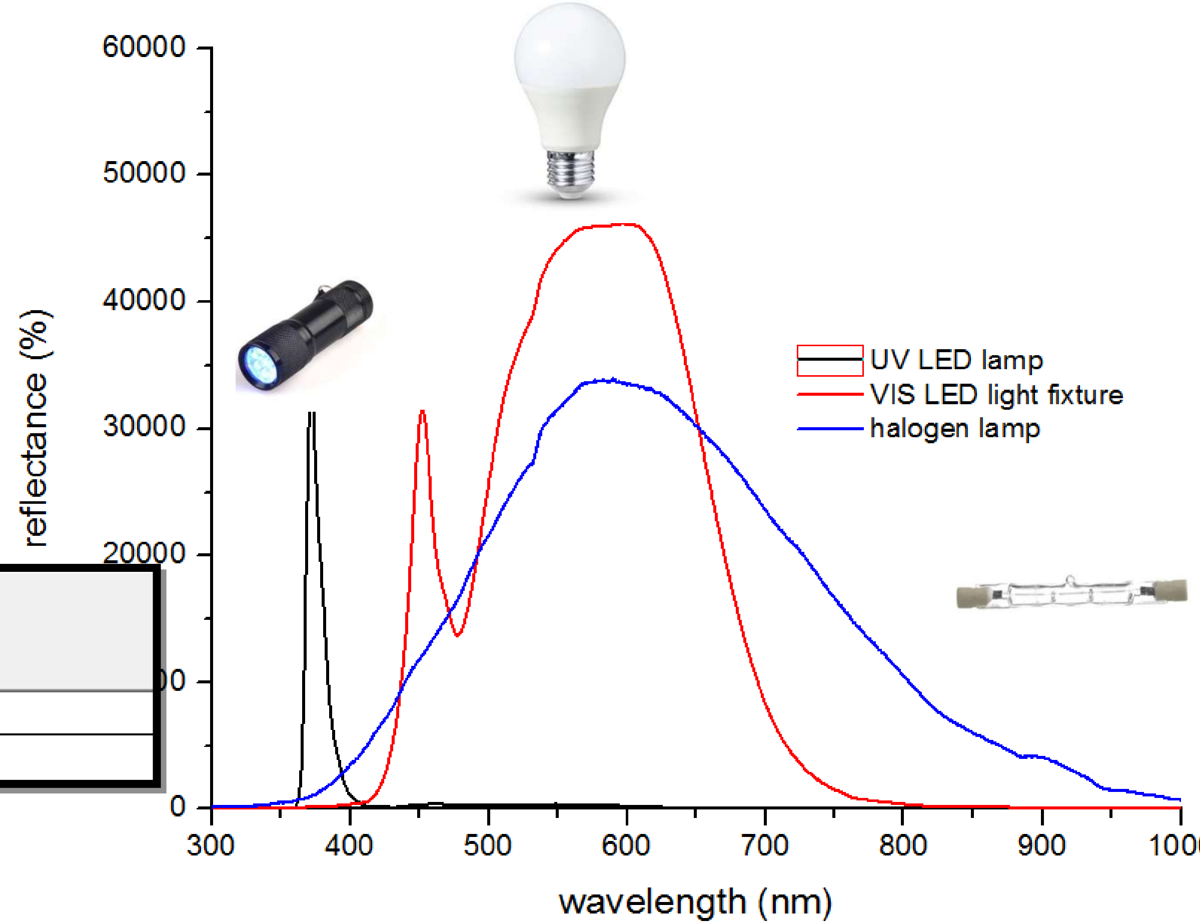
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Notes: measure lamps radiation



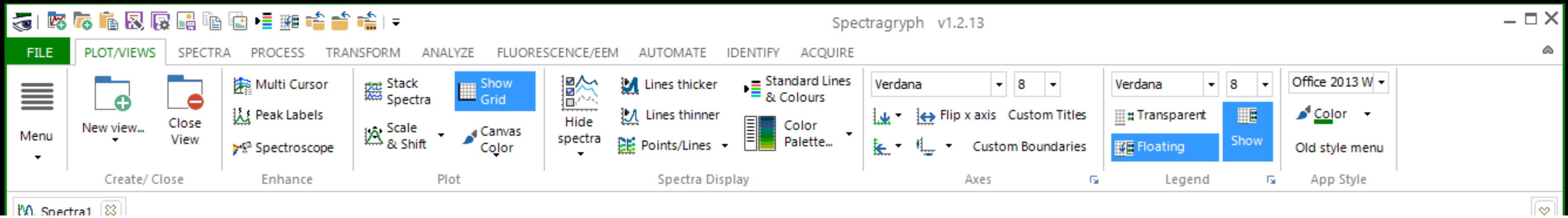


Gorgias can be used to measure the output radiation from a lamp, such as a UV lamp, and halogen lamps, and an LED. In this case we do not need to check the “Spectra / Ref” box, because we do not need a reflectance spectrum, but just a simple intensity spectrum. Be aware, that this is just a qualitative measure. We can easily get a shape of the emission radiation but the actual intensity would be not correct because we did not calibrated the spectrometer for this measure. Though, it is still useful!
For example you can check if your UV lamp is emitting pure UV or also has VIS radiation and / or IR.   Also you can check the emission of LEDs.

Spectragryph

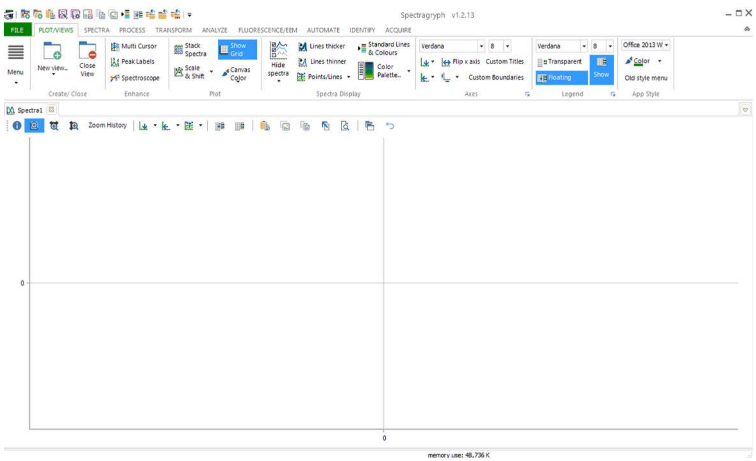
The Gorgias software is a simple tool to operate the spectrometer and collect spectra. In order to edit the spectra for publication or their interpretation we need a spectra editor software. Our recommended one is Spectragryph. This is a free software that you can download and use on as many PC you need. It has all the features to properly edit and analyze your spectra.

Spectragryph functions are organized into tabs of the main software window.
The tab “File” is where you can find functions to save the plot as a proprietary Spectragryph format so that you can upload it again when you want to make changes. You can also export the plot as an image format ready to be load in your publicatons.
The tab “Plot/View” groups all the functions related to editing the aspect of your graph, like axis labels, typo size, the grid dimension.
In the tab “Spectra” you find the functions to edit the spectra, such as: their color, the width of their line, and delete them from the plot. These two tabs would be the one you will use most. The other tabs have more advance functions for processing the spectra.

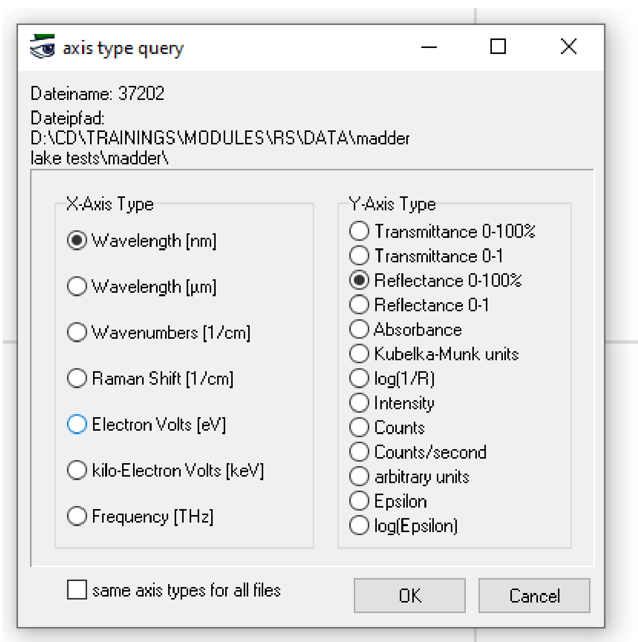


Spectragryph: open one or more spectra

1. Drag and drop one or more spectra into the software window.



2. You are presented with this pop-up window asking what kind of spectra are you loading. Choose wavelength (nm) and Reflectance ()0-100%)



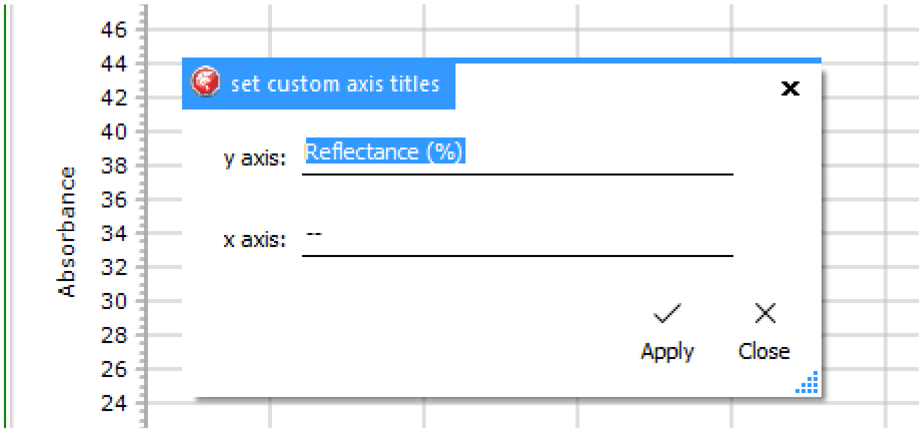
Reflectance Spectroscopy

chsopensource.org

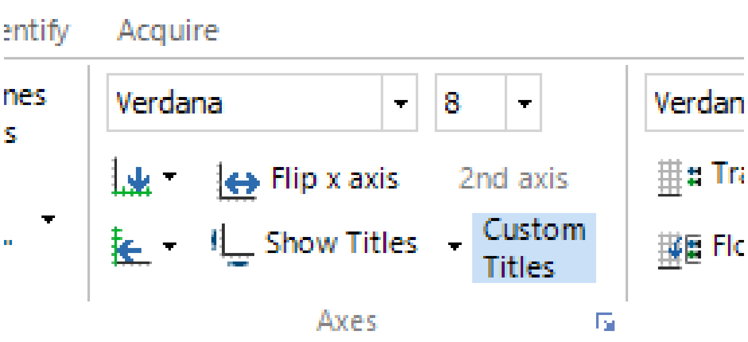
Cultural Heritage Science Open Source

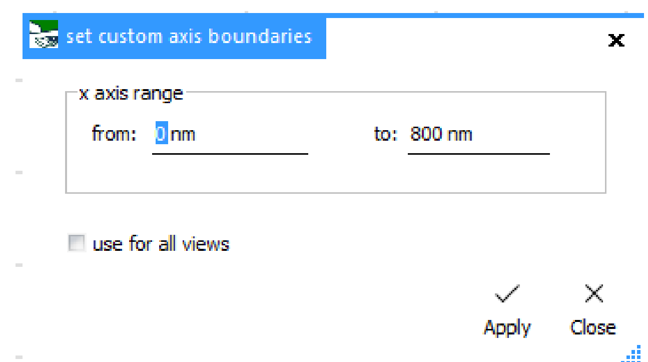
Spectragryph: edit axes labels and boundaries

1. You can edit everything in your spectra, axes, types, legend, grids, colors. Spectragryph is very versatile. Let's edit the axes labels. Double click on them and pop-up window will show where you can input the new labels.



2. Remember to click on "Custom titles" to actually see your customs labels, otherwise the software keeps using the default ones.





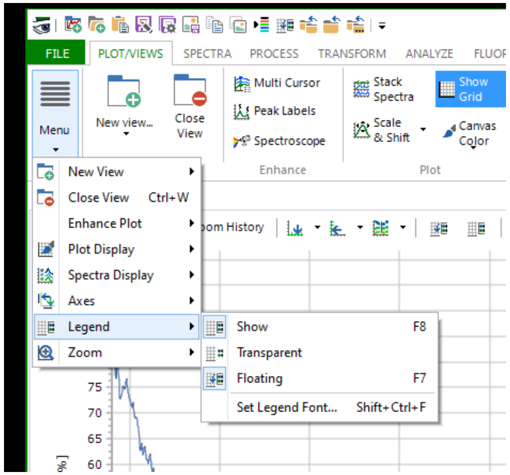
3. In the same AXES sub-tab you can also edit the X and Y boundaries of the spectra. Click on the axes line in the graph and the pop-up window will show up asking for your new selection. Remember to click on "Custom boundaries" to actually use your new selection, otherwise the software will use all the spectral range of the file you loaded.

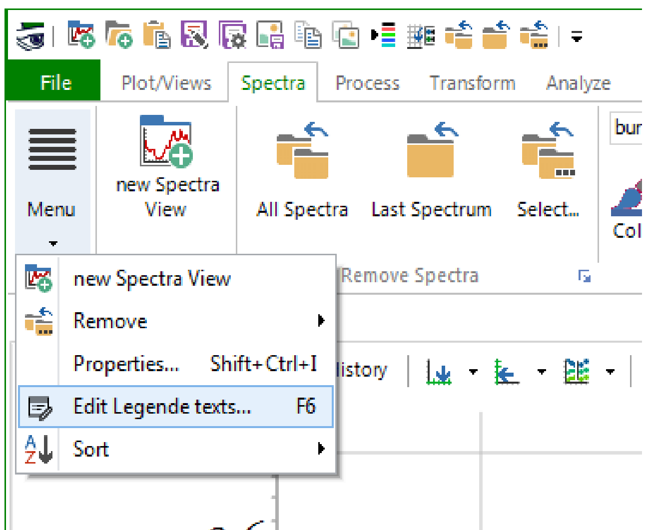
Reflectance Spectroscopy

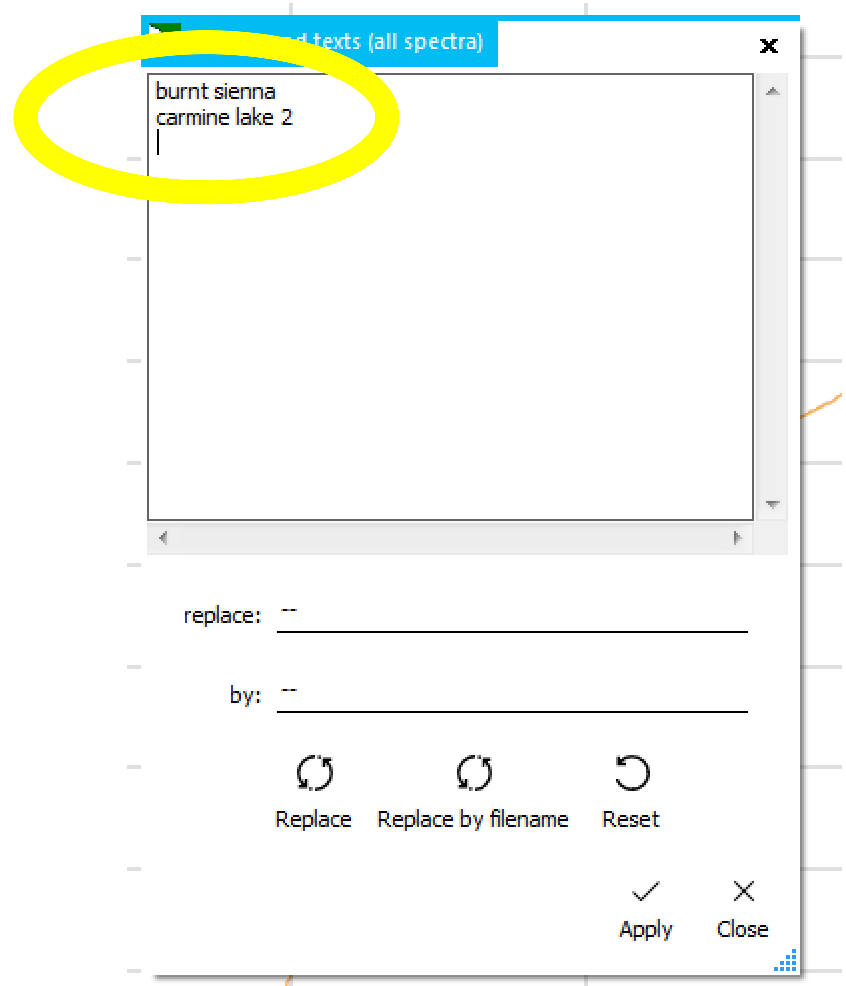
chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: edit legend







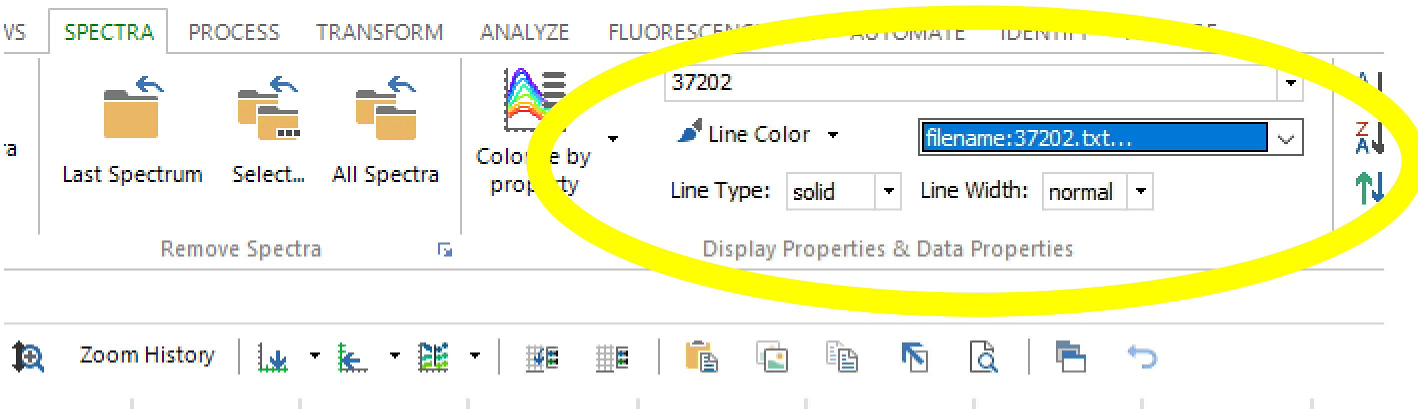
In Spectragryph we can thoroughly edit the aspect and content of the legend in the plot. Access to the legend properties depends on the tab we are selecting. Let's start selecting the PLOT tab. We click then on the MENU sub-tub and we find here the "legend" menu from which we can arrange the appearance of the legend window in the plot. Then we select the SPECTRA tab and we go again in the MENU sub-tab from where we select "edit legend text" to do all the changes to text and typos.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: edit spectra / zooming and panning



In Spectragryph we can thoroughly edit the aspect of each spectrum in the plot. Select the SPECTRA tab and under the sub-tab “Display Properties & Data Properties” we have plenty of options. Remember to select the spectrum to edit from the drop-down menu in the same sub-tab.

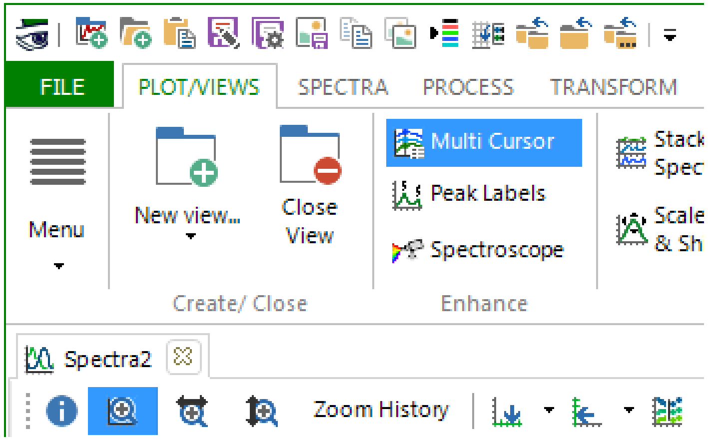
We saw that we can select the boundaries of our plot, we can also dynamically explore the spectral range of the plot using the mouse and the zooming and panning options. These are the main mouse functions:
Clicked mouse scroll button: panning
Left button clicked: select area to magnify
Click the right button: going back to original view

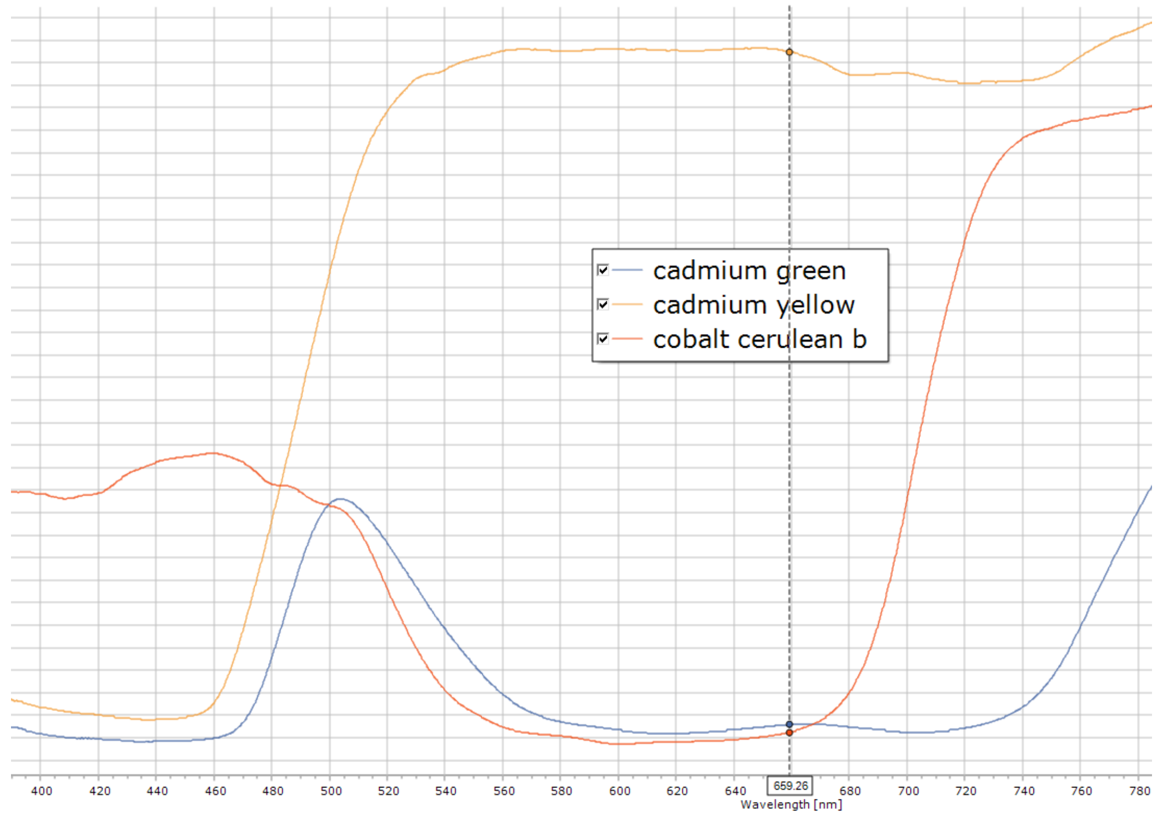
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: multicursor (vertical line)





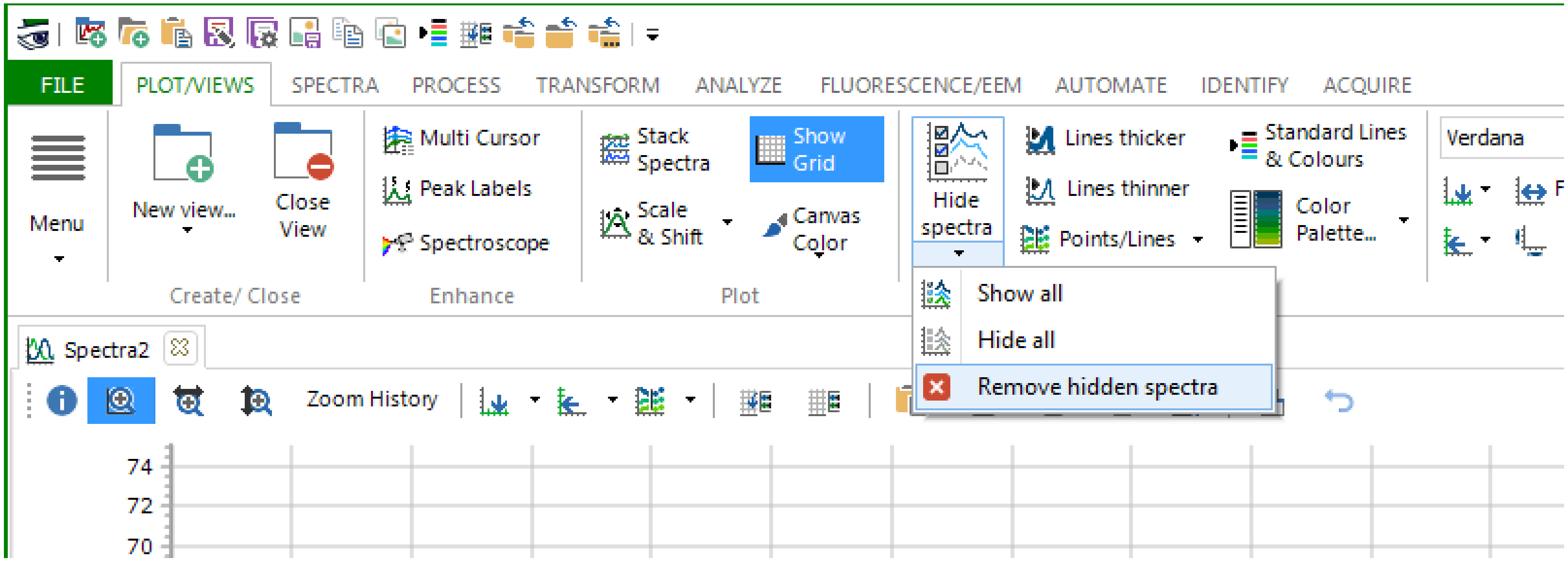
We can add a vertical line on our plot. This is useful to indicate the location of inflection points, absorption bands, and maxima.

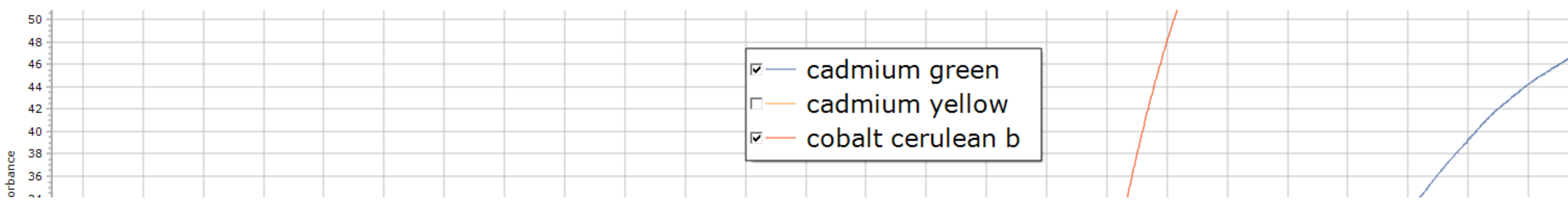
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: hide selected spectra (already loaded)





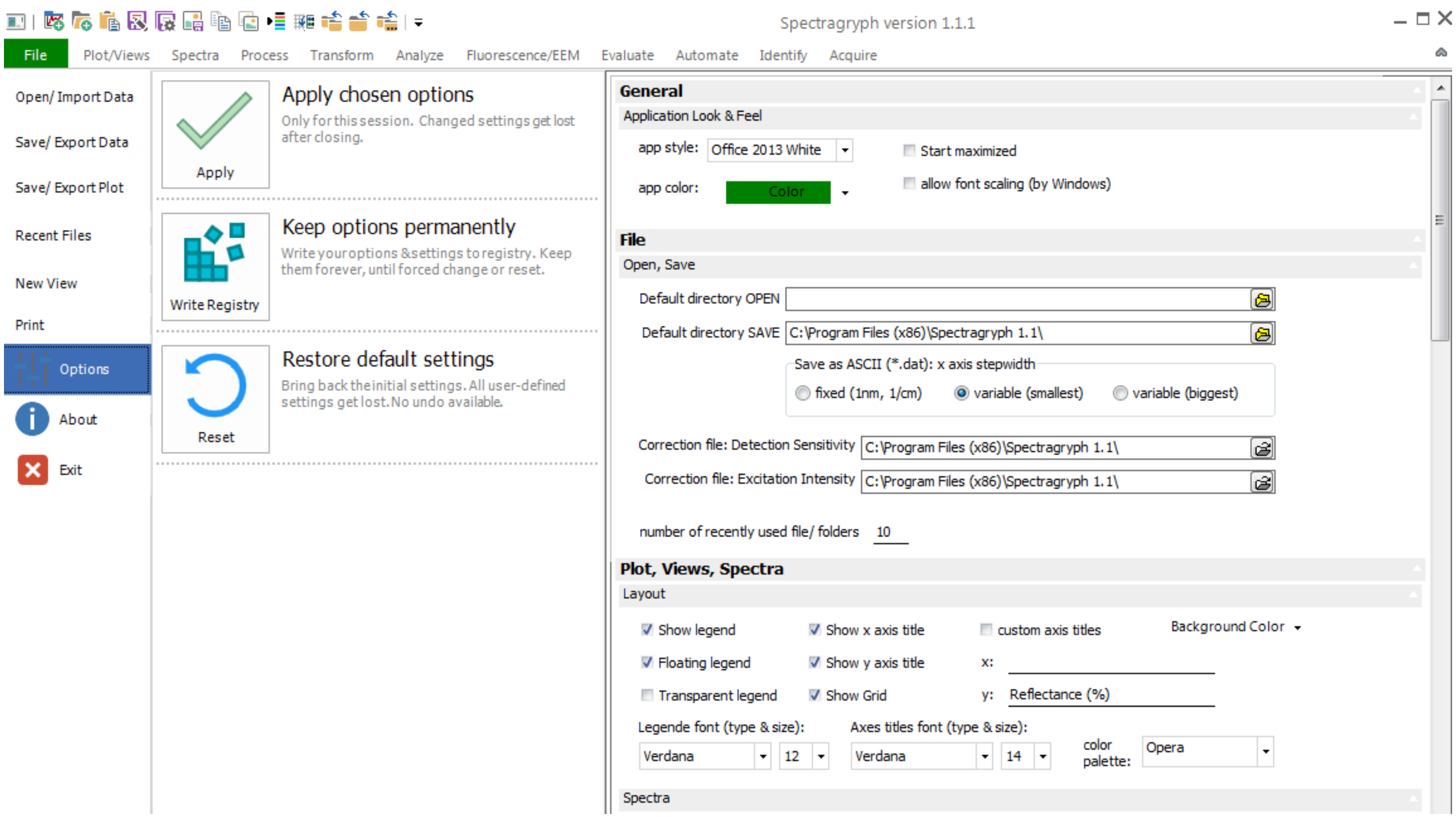
We have this convenient option to hide spectra that are already loaded in the plot. This is very useful when we are comparing the spectrum of the sample with spectra in the database to check which once better matches. We can load all the possible candidates but then we can decide to just show that one the is a best match. This can be done very conveniently directly on the legend, using the checkbox.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: save formatting settings



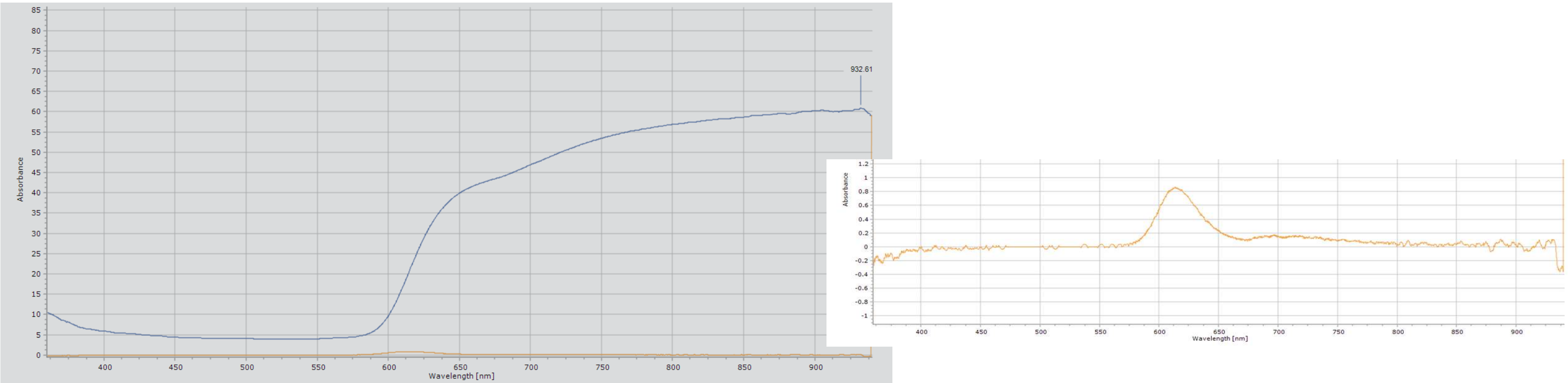
We have this useful function which enable us to save time. For example, we want to always open the spectra on a specific spectral range, instead of using all the spectral range of the spectrum. We open the Files tab / Options / Plot,View, Spectra: there you can configure the most of formatting settings. After pressing the "Keep options permanently", these will be taken for the current and all future plots. Remember to press “custom boundaries” and “custom titles” in the ”Plot/View” menu.

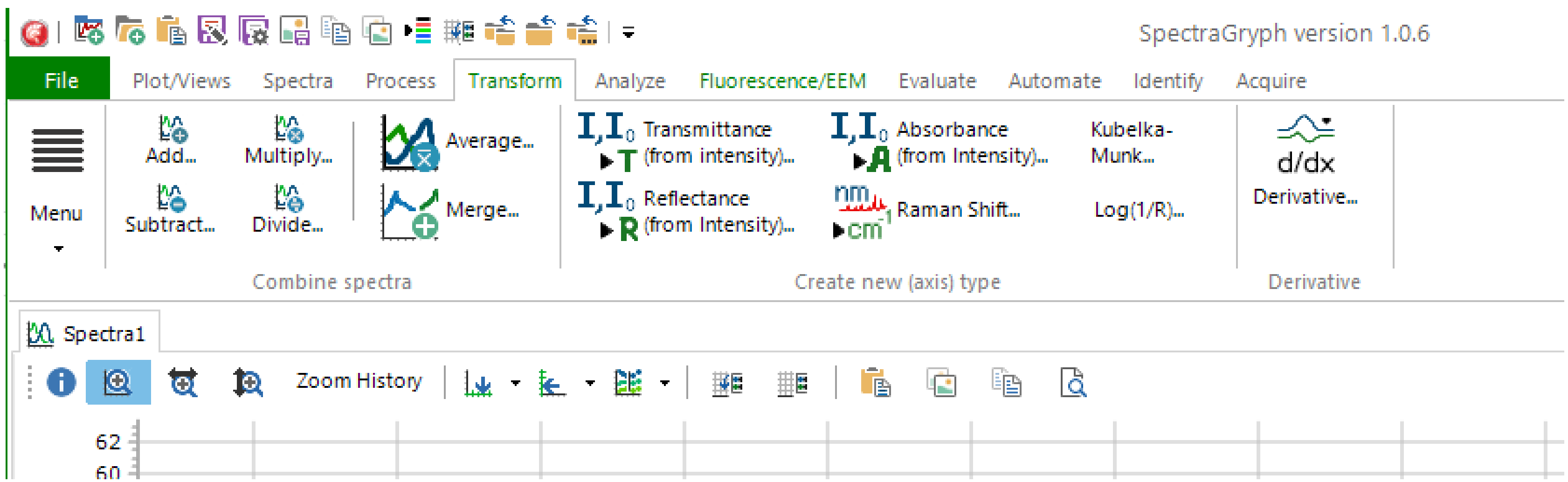
Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: inflection point /derivative





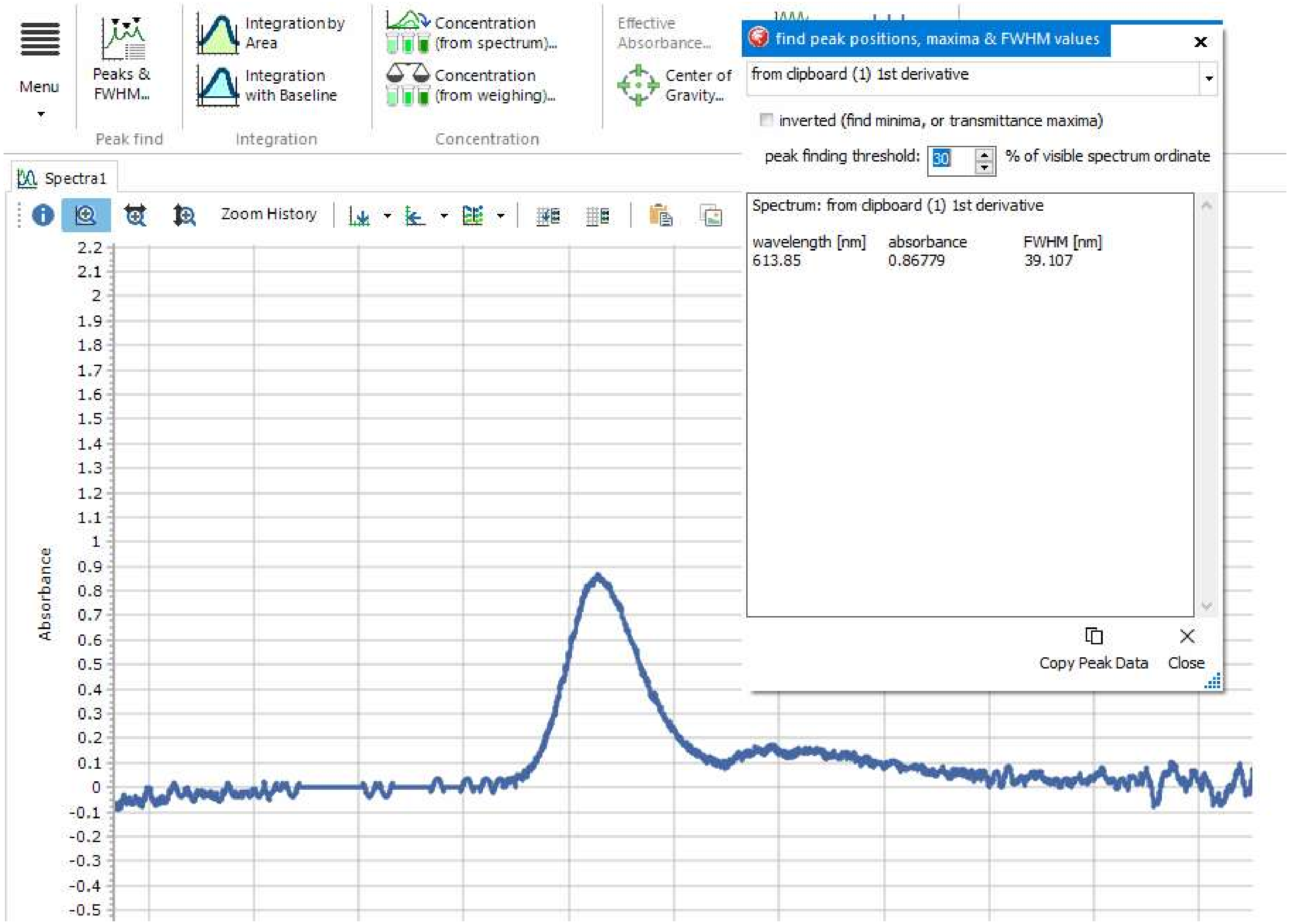
We discussed the meaning of "inflection point" and we said that its position is roughly the middle of the sharp curve. Though, it can be calculated precisely, as the maximum of the derivative of the spectrum. The graph above show a reflectance spectrum and the curve of its derivative. We can see there is a maximum where we expect the inflection point. Spectragryph can calculate and plot the derivative of a spectrum and give the position of its maximum. Just load the spectrum and in the TRANSFORM tab, click on the Derivative button.

Reflectance Spectroscopy

chsopensource.org

Cultural Heritage Science Open Source

Spectragryph: find peak position



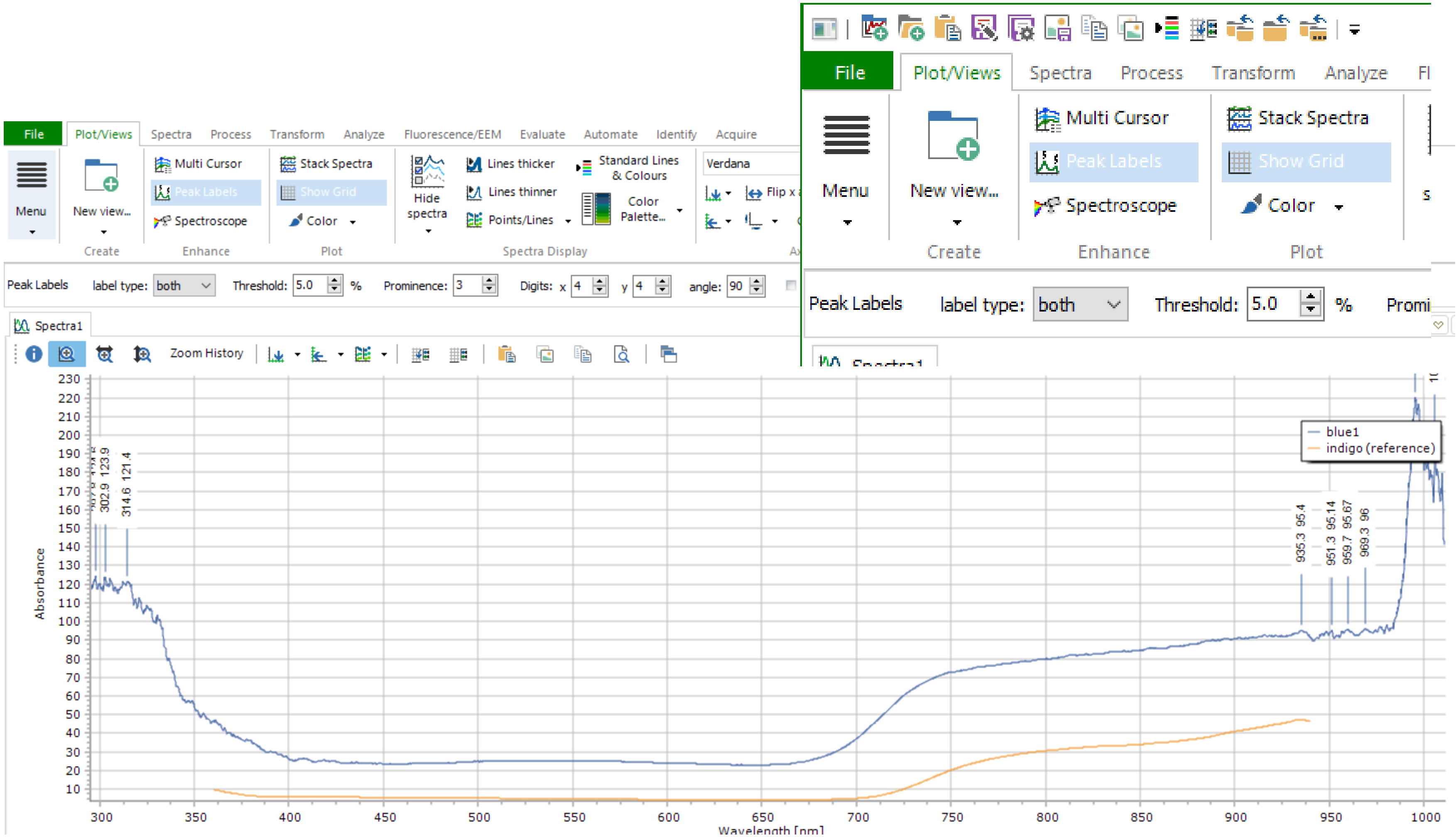
Once we have the derivative curve we can calculate automatically the position of the peak, using the “find peal position” function.

Reflectance Spectroscopy

Spectragryph: add peak label

chsopensource.org

Cultural Heritage Science Open Source



We can then automatically add the label. Click the button in the "Plot/Views" ribbon to activate peak labeling