LICA AstroCalc, a software to analyze the spectra of street and indoor lamps

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Abstract

The night sky spectra of light polluted areas is the result of the artificial light scattered back from the atmosphere. This emission comes mainly from street and ornamental lamps. We have built a database of lamps spectra and the software needed to analyze them. We describe the LICA-AstroCalc freeware software that is a user friedly GUI tool to extract information from our database spectra or any other user provided spectrum. The software have been validated with recommendations from CIELAB and ISO from NCS database.

Keywords: Spectroscopy, Light pollution, Software, Database, NCS, Color theory

1. Introduction

The spectrum of the sky at night provides more information about the brightness and spectral characteristics of the artificial lighting than the photometry. The typical spectrum obtained in a light polluted area shows emission lines that can be easily identified as belonging to different elements since the spectrum is the composition of the spectra of the polluting lamps after being scattered back by the atmosphere. Monitoring the night sky spectra is a powerful tool to determine the evolution in brightness, color and technology of the pollution focuses.

To compare night sky spectra and those of contributing lamps some databases have been built. For instance the laboratory of the Earth Observation Group

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(NOAA) [1] or the Light Spectral Power Distribution Database (LSPDD) [2]. Some of them only covers the limited spectral range of the human vision. This produce a loss in the near infrared and in near ultraviolet where the street lamps emit, and some of them have their maximum of emission.

Some basic analysis and comparison of the spectra could be performed on the fly with the software AstroCalc. For instance photometry through astronomical filters or selected bands of biological interest, the correlated color temperature (CCT) etc. AstroCalc unifies the data reduction of the spectra using the standard CIE-lab recommendations and normalized the analysis for a human response in the melatonin suppression study. It also includes the color database from 1950 NCS using ISO standards to check the variations in spectral emission from a lamp after a reflection in any surface painted with any color.

2. Database of Lamps Spectra

The database presented in this work contains the spectra of 71 street and indoor lamps with a coverage from 300 to 900 nanometers. The spectra were obtained at the street or in the Laboratory of Scientific Instrumentation of the Universidad Complutense (LICA-UCM).

2.1. Spectrograph

The spectrograph used for acquiring the lamps spectra was an Ocean Optics JAZ EL200-XR1. This model was selected because its portability since most of the spectra were obtained on the streets pointing to the luminaries used for urban lighting. Other characteristics of the spectrograph are: spectral resolution of 1.7 nm and inverse dispersion of 0.3 nm/pixel. The detector is a Sony ILX511B optimized to UV output and the spectrograph has a uniform response from 200 to 1025 nm. The light is feed into the spectrograph by an optical fiber of 400 microns. For bright and close lamps the fiber is pointed to the light and the spectrum is taken. In less favorable scenarios, a custom made collector is used, see figure 1. This light collector has been tested in laboratory to correct from the transmission of the lens.

Figure 1: The spectrograph, the optic fiber and the light collector used to take spectra during fieldwork.

2.1.1. Spectrograph linearity

The linearity of the detector has been checked at LICA with Thorium-Argon, Thorium-Neon and mercury lamps. Using the included linearity correction, 65.000 ADUs can be reached without lost of linearity. On the other hand, when the auto correction is not set, the spectrum maximum count never must go above 35.000 ADUs to be in the linear regime. For security in none of the spectra of the database has been exceeded 55.000 ADUs. In the figure 2 can be see the point of lost of linearity before and after the non-linearity correction.

Non corrected			Corrected		
1st max.	2nd max.	Ratio	1st max.	2nd max.	Ratio
(ADUs)	(ADUs)		(ADUs)	(ADUs)	
15872	12892	1.23	16943	13954	1.21
327855	26670	1.23	32680	26553	1.23
47953	39768	1.21	4798	39309	1.22
57323	51001	1.12	64301	52032	1.24
62770	57529	1.09	79401	64529	1.23
65535	62128	1.06	89775	77201	1.16
65535	65535	1.00	89775	89578	1.00

Table 1. Linearity test. Number of counts and relation between first and second maxima with different exposure times before and after non-linearity correction.
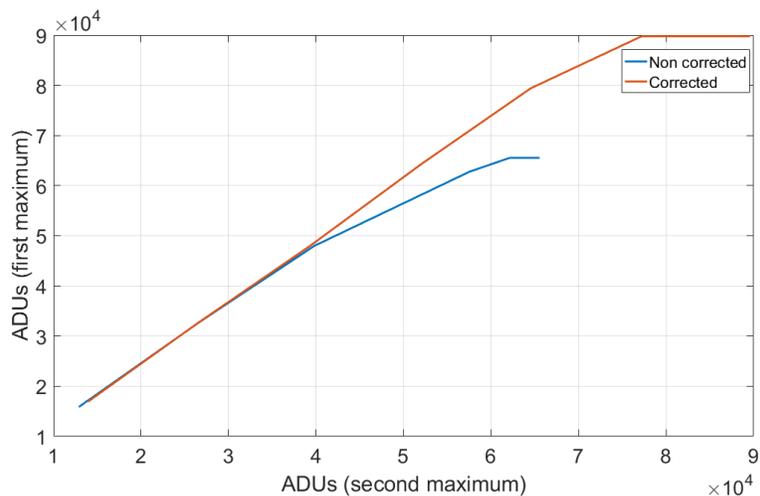
Figure 2: Lost of linearity before and after the non-linearity correction.

2.1.2. Spectrograph wavelength accuracy

The accuracy of the wavelength calibration of the spectrograph was checked at LICA-UCM optical workbench using four laboratory lamps that contains

multiple emission lines. The mercury lamp —Newport 6035— for the blue region of the spectrum, neon lamp —Newport 6032— for red part, and thorium-neon and thourium-argon for general. It is easy to see in the table 2 that the offset in the position of the lines is smaller than the spectral resolution of the spectrograph.
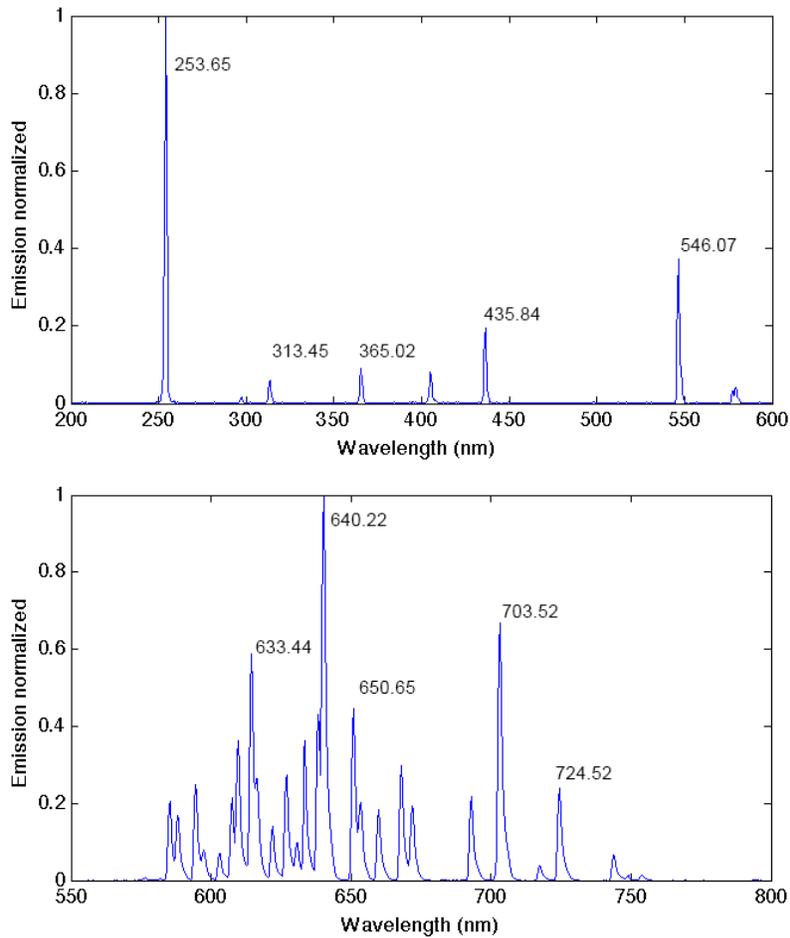
Figure 3: Spectra obtained from mercury (up) and neon (down) lamps under laboratory conditions

Mercury		Neon	
NIST (nm)	Measured (nm)	NIST (nm)	Measured (nm)
253.65	254.23	585.25	585.68
313.18	313.45	594.48	594.48
365.02	365.69	609.62	609.79
404.66	404.94	614.31	614.43
435.84	436.35	633.44	633.75
546.07	546.41	640.22	640.45
		650.65	650.88
		667.83	667.92
		703.24	703.39
		724.52	724.65

Table 2. Comparison between known (from NIST) and measured emission wavelengths of spectra from mercury and neon lamps. Only the main lines of the spectrum of the neon lamp are listed.

2.1.3. Spectrograph spectral response

The spectra were obtained without processing for the spectral response of the spectrograph. The spectral calibration was carried out using the response curve determined by comparing the spectra of a tungsten calibrated lamp taken with JAZ using the LICA-UCM optical workbench.

2.1.4. Examples of the spectra database

As we said before, the database contains 71 street an indoor lamps and covers nearly all the types of luminaries we can found on the street, like gas discharge or LEDs.

Here we present some examples of lamps spectra contained in the database, the rest can be found on [3] and [4]. In figure 4 we can see a few examples of metal halide lamps covering from 3445 to 6076 Kelvin from ornamental lights. In figure 5 we present a collection of LED lamps from street lights from 2966

to 6766 Kelvin. And in figure 6 we can see ceramic metal halide sodium based and thallium based from street lights too.
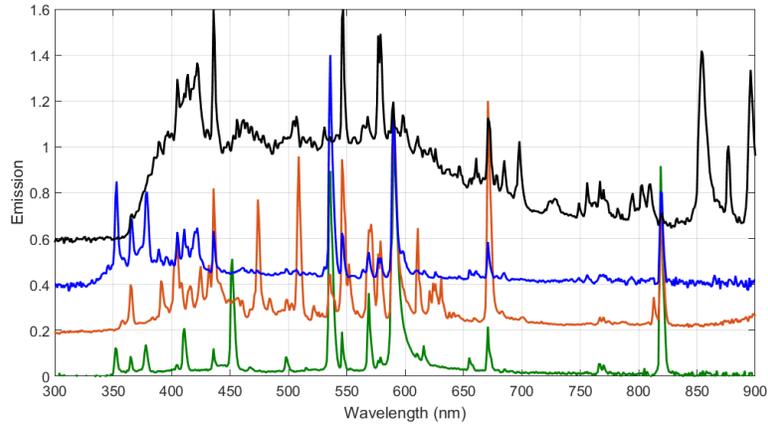
Figure 4: Metal halide lamps. In green, orange and blue lamps with metalic halide components including mercury with CCT of 5744K; 4813K and 3436K respectively. In black metal halide arc lamp mercury doped with 6075K
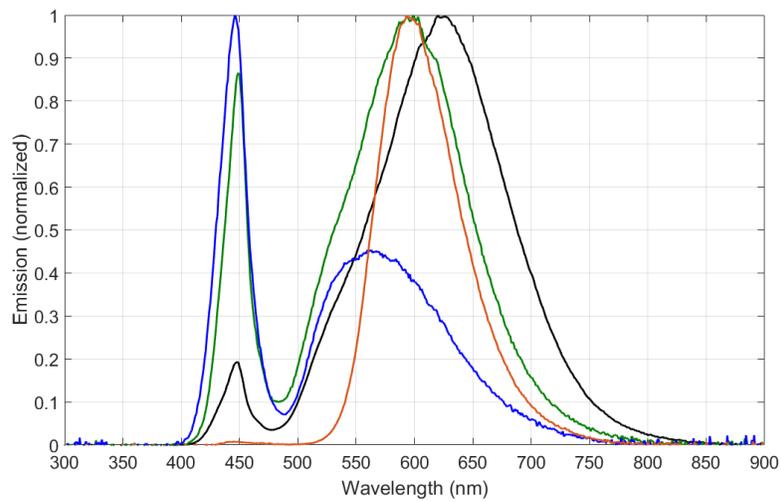
Figure 5: LED lamps founded on street lights. Orange, PC Amber from Philips, 1765K; black, Warm from Ignialight, 2159K; green, LED from Madrid street lights, 3107K and in blue LED at Faculty of Pharmacy from Universidad Complutense, 6801K

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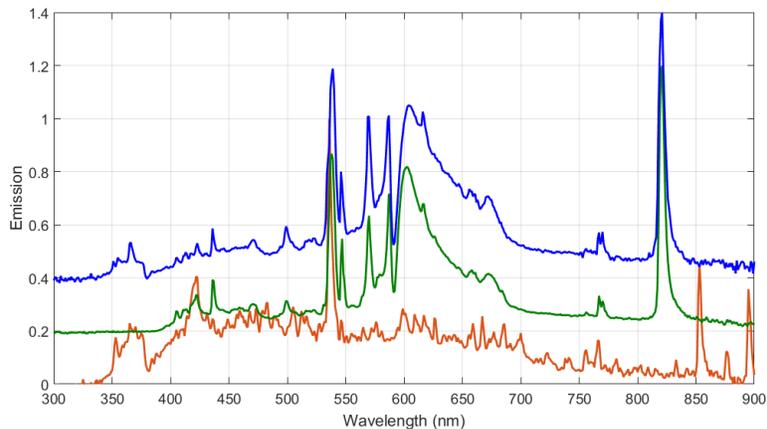
Figure 6: Ceramic metal halide street and flood lights. Green and blue sodium based, 2377K and 2691K respectively. Orange thallium based with 6545K

3. Parameters derived from the spectra

Once we have the spectra database normalized we can compute different parameters using the standard definitions. For this work we compute following the guideline of Commission Internationale de l'Eclairage (CIE) the colorimetrics coordinates XYZ in emissive and reflective case, the color space xyY, the RGB color, and the correlated color temperature (CCT). As well as the melatonin, chlorophyll a and b and β-carotene supression index. Finally we include the complete NCS colour AB paints and the performance of any lamps spectra after a reflection over any paint.

3.1. XYZ, RGB and CCT

We have calculated the corresponding color of the spectra in the RGB working space. From the different color spaces used in colorimetry we have selected sRGB, which is one of the most used color space with gamma 1 instead of the normal gamma of 2.2. The reference white point was set to D65 and 2 degrees. To match a color with the power distribution of our lamp P, the XYZ

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coordinates follow the next equation:

$$X = k \int P(\lambda) \, \overline{x} \, d\lambda$$
$$Y = k \int P(\lambda) \, \overline{y} \, d\lambda \tag{1}$$
$$Z = k \int P(\lambda) \, \overline{z} \, d\lambda$$

where k is 680 lumens per watt for self-luminous bodies and the color matching functions (CMFs). For this work we have used the CMFs transformed from CIE 1931 for 2 degrees LMS cone fundamental primaries that cover all trichromatic color matches [5][6][7].

Once having the X,Y,Z coordinates, the xyY will be simple following the equation [2]:

$$x = \frac{X}{X + Y + Z}; \quad y = \frac{Y}{X + Y + Z} \tag{2}$$

Convoluting the spectral response of the lamp with the response of the eye (the CMFs) we obtain the XYZ coordinates. And using the matrix transform between spaces we have the RGB.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.2404542 & -1.5371385 & -0.4985314 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0556434 & -0.2040259 & 1.0572252 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{3}$$

For calculate the correlated color temperature (CCT) of the lamp, we use three different methods the calculator offered by Bruce Lindbloom [8] and the definitions from McCamy [9] and Hernández-Andrés [10]. If is known the color space, white reference and XYZ (or RGB) coordinates, can be calculated the color temperature of the lamp tested with a precision of less than a 100K from

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the official definition of CCT.

$$CCT_{McCamy}(x, y) = -449 \cdot n^3 + 3525 \cdot n^2 - 6823.3 \cdot n + 5520.33$$

$$CCT_{Hernandez}(x, y) = A_0 + A_1 \cdot e^{(-n/t_1)} + A_2 \cdot e^{(-n/t_2)} + A_3 \cdot e^{(-n/t_3)} \quad (4)$$

$$n = \frac{x - x_e}{y - y_e}$$

where for McCamy:

$$x_e = 0.3320; \quad y_e = 0.1858 \quad (5)$$

and for Hernández-Andrés:

$$
\begin{aligned}
&x_e = 0.3366 && y_e = 0.1735 \\
&A_0 - 949.86315 \\
&A_1 = 6253.80338 && t_1 = 0.92159 \\
&A_2 = 28.70599 && t_2 = 0.20039 \\
&A_3 = 0.00004 && t_3 = 0.07125
\end{aligned}
\quad (6)
$$

3.2. Melatonin

For the calculation of melatonin suppression index, melatonin for short in the software, we follow the definition described by Aubé [11].

First step is the normalization of the spectrum to a constant lumen normalization using the spectral power distribution of the lamp $\phi(\lambda)$ and the photoptic spectral sensitivity of the human eye $V(\lambda)$ defined by CIE 1931. So this normalization is given by the equation 7:

$$\phi_n(\lambda) = \frac{\phi(\lambda)}{\int\limits_{380}^{730} \phi(\lambda)V(\lambda)d\lambda} \quad (7)$$

Once normalized the spectrum, the melatonin suppression index take the melatonin suppression action spectrum (MSAS), as it is the defined in the

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Aubé's paper. And then referenced the melatonin suppression index to the solar daylight spectrum (D65).

$$Melatonin = \frac{\int\limits_{380}^{730} \phi_{n(lamp)}(\lambda)MSAS(\lambda)d\lambda}{\int\limits_{380}^{730} \phi_{n(D65)}(\lambda)MSAS(\lambda)d\lambda} \tag{8}$$

3.3. Chlorophyll a, chlorophyll b and Beta-carotene

Instead of using a global photosynthetic spectrum, we prefer to use three different photosynthetic spectrum, chlorophyll a, chlorophyll b and β-carotene. Using it separately will be more useful for analyze the response of different plants to any types of light.

For the calculations we follow exactly the same normalization described in Melatonin section, equation 6, referenced to the chlorophyll a, b and β-carotene response.

$$Photosyhthetic = \frac{\int\limits_{380}^{730} \phi_{n(lamp)}(\lambda)PAS(\lambda)d\lambda}{\int\limits_{380}^{730} \phi_{n(D65)}(\lambda)Chl_a(\lambda)d\lambda} \tag{9}$$

where PAS is the photosynthetic action spectrum (chlorophyll a, chlorophyll b and β-carotene) from Oregon Medical Laser Center from its software PhotochemCAD [12].

3.4. Color NCS

The software include the database 1950 NCS taken from ©NCS Colour AB, Stockholm, 2011 [13].

The database covers all the samples, 1950, measured in configurations 45º-0º (0º illumination 45º measure) and di: 8º (diffuse illumination, specular component included). The first configuration is collected in a Gretag Spectrolino spectrophotometer in conformance with ISO/DIS 13655:2009+ M0 on white

backing, and the second ones is collected in a specially calibrated MacBeth ColorEye 7000 spectrophotometer.

Because the color of the paint is a reflective surface, the XYZ coordinates must be calculated differently from the lamps. The spectral power distribution of the sample, $P(\lambda)$, is replaced by the spectral reflectance, $S(\lambda)$, multiplied by the spectral power distribution of the reference illuminant $I(\lambda)$, in our case, D65.

$$
\begin{aligned}
X &= \frac{1}{N} \int S\left(\lambda\right) I\left(\lambda\right) \overline{x}\, d\lambda \\
Y &= \frac{1}{N} \int S\left(\lambda\right) I\left(\lambda\right) \overline{y}\, d\lambda \\
Z &= \frac{1}{N} \int S\left(\lambda\right) I\left(\lambda\right) \overline{z}\, d\lambda
\end{aligned}
\tag{10}
$$

4. The software

We have developed LICA AstroCalc, a user friendly software that use graphical user interface (GUI) programmed using LabVIEW platform. The software is divided in different menus (tabs), some of them are oriented to amateurs astronomers. Is full of options to calculate derived properties from spectra. The light tab is where we will find everything described above, is oriented for researchers in light pollution and in color theory.

Inside light tab can be found another tab called LAMPS, it was designed to work with it's internal database of lamps spectrum [3][4]. When the user select from the drop down menu a lamp the software made all the calculations described before in 0.1 seconds (internal timing).

At the second subtab, CUSTOM LAMP, the user can upload its own spectrum and the software converts to their internal format using Hermite transformations.

	LICA-AstroCalc				LSPDD			
Lamp	x	y	CCT	MSI	x	y	CCT	MSI
HPS	0.53	0.43	2067 - 1815	0.121	0.53	0.42	2010	0.118
LED 2700K	0.45	0.40	2765 - 2691	0.304	0.44	0.39	2760	0.285
LED PC Amber	0.57	0.43	1788 - 1353	0.036	0.57	0.42	1720	0.046
Incandescent	0.48	0.42	2496 - 2369	0.26	-	-	2450	0.26
Metal Halide	0.37	0.39	4258 - 4244	0.55	-	-	3959	0.53
Sun	0.37	0.38	4403 - 4394	0.62	-	-	4415	0.62

Table 3. Comparison between lamps from LSPDD database and calculations from LICA-AstroCalc. The three first lamp are published in Aubé work [11] and the three last are published in LSPDD database [2].

LAMPS COMPARISON tab allows the comparison between two lamps. And LAMPS RAYLEIGH calculates the change in wavelength for a selected lamp due to the Rayleigh dispersion in the atmosphere. In LIGHT POLLUTION SIMULATOR the user can simulate the light pollution from a combination of lamps giving a weight for each lamp from 0 to 100 and made a comparison with the light pollution of Madrid.

In COLOR tab the user will found the 1950 NCS from ©NCS Colour AB. With the software we can calculate the XYZ coordinates for any color, we compare the results with the official from the database and it has an error of $\pm$ 0.00005.

All the tabs includes extra buttons to superimpose useful spectra. This additional spectra includes the definition of photoptic, scotoptic, erythopic, chloropic, rhodopic, melanopic and cyanopic defined by CIE TN 003:2015 [14]. And the melatonin, D65 space, chlorophyll a, chlorophyll b and Beta-carotene used in the definition for internal calculations.

In addition has been included the spectra of some elements, and its ionization, that can be found on light lamps, to help the researcher in identification of emission lines. This database comes from NIST [15].

In figure 7 we can found the GUI of the software presenting new type of warm

lamp for streetlight included in the database. This lamp, LED PC Amber, is used in the comparison between lamps from LSPDD in Table 3. At the left can be found all the calculations (colorimetrics coordinates, Melatonin, Chlorophyll, Beta-Carotene, accumulated light under a wavelength) and the drop down menu to select different spectral lines of elements. At the right is presented the locus for locate easier the color coordinates of the lamp and a moving pointer to check the emission at any wavelength.

In figure 8 we see the Paints tab where we selected metal halide arc lamp as example. This lamp is used as a D65 white reference. In the drop down menu for paints we selected the above menu and the paint S 5030-Y80R, is a orange-red paint. After the convolve of paint and spectra to simulate the reflection of the light on a surface painted with this color, we can found the CCT of the lamp change from 6075 K to 2559 K.
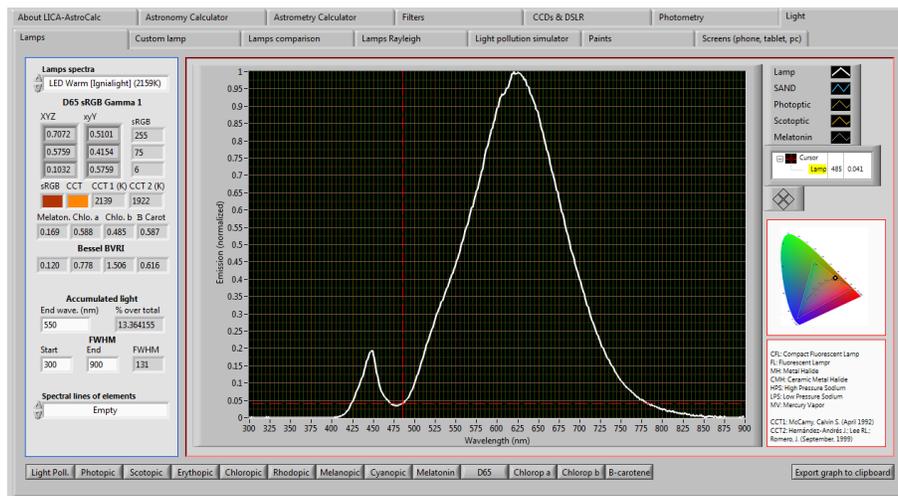
Figure 7: Screenshot of the GUI of the software showing new type of warm lamp for streetlight included in the database. At the left can be found all the calculations, and at the right is presented the locus for locate easier the color coordinates of the lamp.
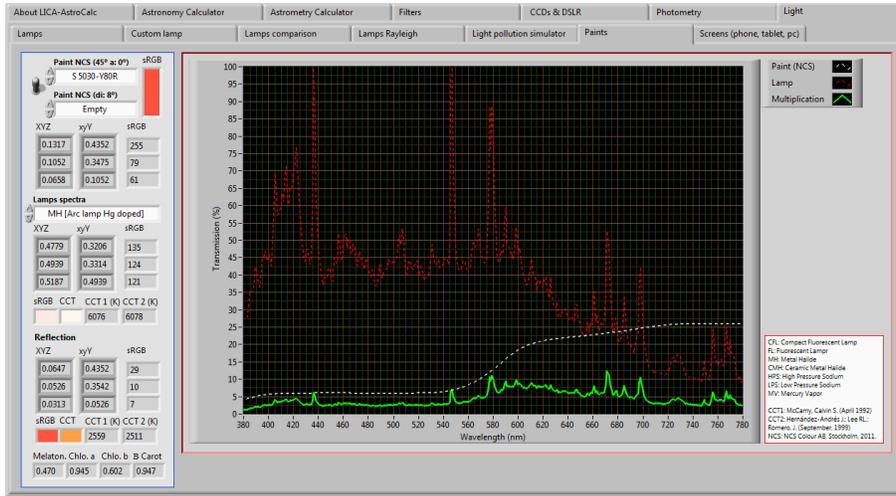
Figure 8: Screenshot of the GUI of the software at paints tab. When selecting PAINTS can be found the complete color database from NCS. At the left can be found too the database of lamps to check how the spectra of a lamp change before and after the reflection in a determinate paint.

5. Conclusions and future work

In this work has been presented a user friendly software oriented for researcher in light pollution. The user can analyze their spectra just by clicking the buttons of the GUI. The use is very intuitive and thes is no need to program any type of formula. This software will be continuously updated with new spectra and functions.

It is offered to the community totally free and free share, and we are open for new functions to be included as demand of the researchers.

The software can be downloaded at: `https://guaix.fis.ucm.es/AstroCalc`

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Acknowledgments

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