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Departamento de Astrofísica y Ciencias de la Atmósfera
Grupo de Astrofísica Extragaláctica e Instrumentación Astronómica

LICA-UCM lamps spectral database

Authors: Carlos Tapia, Alejandro Sánchez de Miguel & Jaime Zamorano

LICA report January 2017 Version 2.6 2017/01/12
with the spectra corrected from spectral response

Abstract

Spectra of the lamps that are used for public lighting and ornamental purposes have been obtained with a portable spectrograph around Madrid city. The database is presented in this report along with a description of the procedures.

1. Introduction

Light Pollution sources are mainly lamps used for public lighting and ornamental purposes. The spectrum of the night sky is full of the spectral emission lines of their spectra. We present in figure 1 a spectrum representative of the night sky of Madrid city and obtained with the SAND-UCM spectrograph located in Observatorio UCM [1][2], the astronomical observatory of the Universidad Complutense de Madrid.

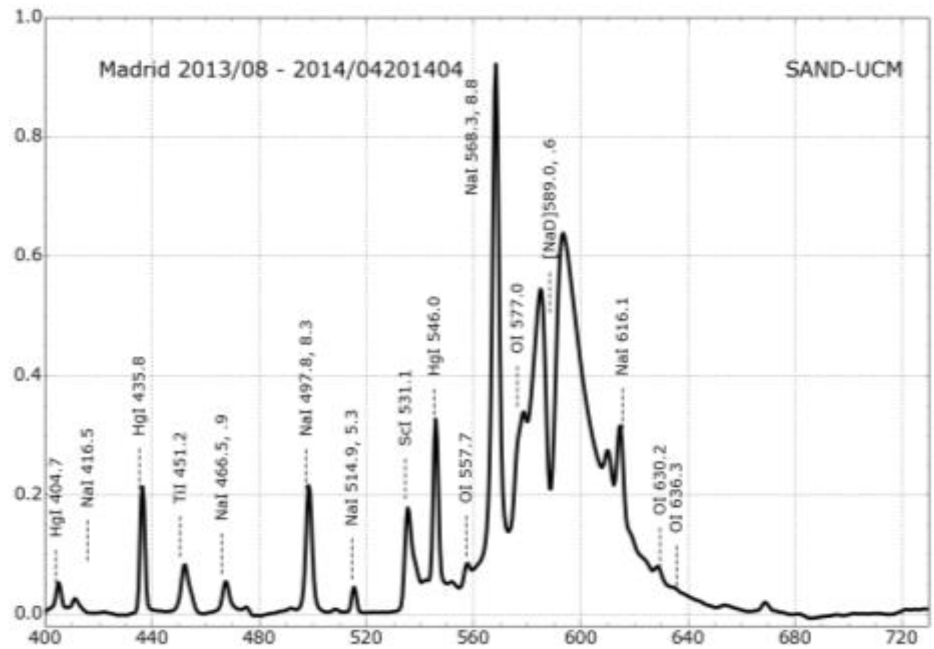


Figure 1: Night sky spectrum of Madrid.

In this work we have gathered spectra of lamps around Madrid city and villages in the nearby using a portable spectrograph. This is a difference with other databases that are composed of spectra acquired in a laboratory. Our database build with on the field observations will be used to synthesize the spectra of the sky and to derive the contribution of the different kind of lamp. When analysing these real street lamps spectra we have found important differences between the same lamp type due to the cover or the age of the lamp.

2. Instruments

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.

Figure 2: The spectrograph, the optic fiber and the light collector used in this work and fieldwork.

2.1.1 Spectrograph linearity

The linearity of the detector has been checked at LICA with various types of lamps. Using the included linearity correction, 54.000 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 25.000 ADUs to be in the linear regime. In the figure 3 can be seen the difference in luminosity between the two principal peaks from a CFL 6000K lamp, before and after the auto correction.

Non corrected			Corrected		
1st maximum (ADUs)	2nd maximum (ADUs)	Division	1st maximum (ADUs)	2nd maximum (ADUs)	Division
15872.04	12891.54	1.231	16943.33	13954.33	1.214
32785.45	26669.60	1.229	32679.81	26552.93	1.231
47952.77	39767.63	1.206	47980.82	39309.48	1.221
57322.93	51000.59	1.124	64301.2	52032.48	1.236
62769.96	57529.43	1.091	79400.55	64529.19	1.230
65535	62128.08	1.055	89774.92	77200.89	1.163
65535	65535	1	89774.92	89577.90	1.002

Table 1. Values from the figure 3.

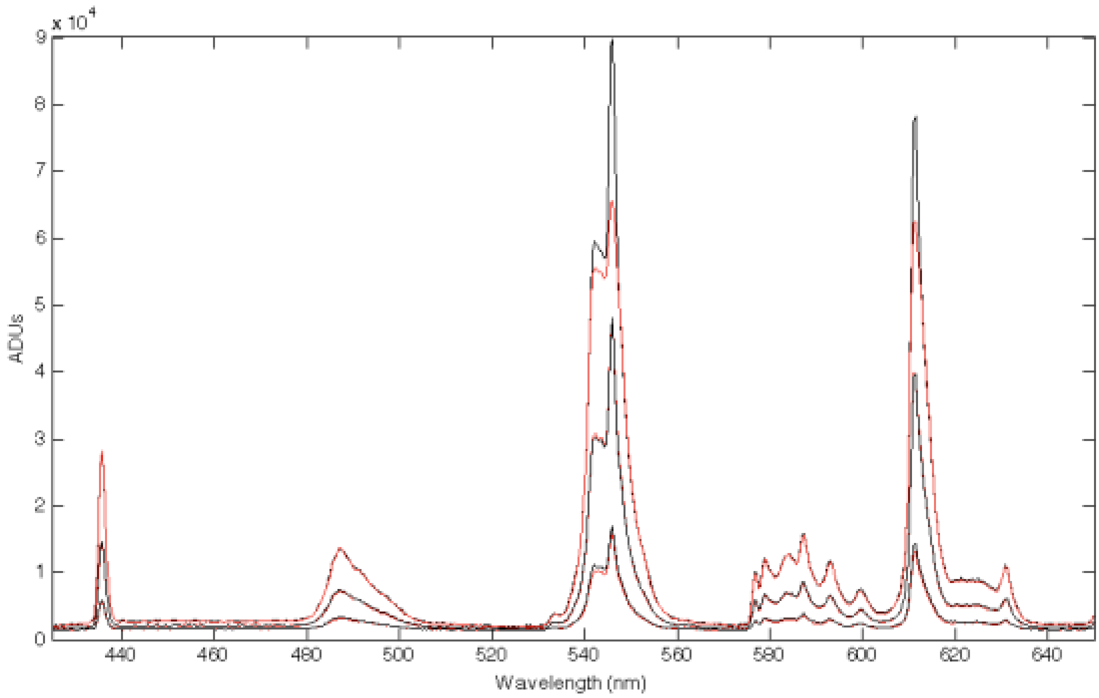


Figure 3. Comparison between the two principal maxima of a CFL 6000K lamp with different exposure times. Red line shows the spectrum without correction; black line after non-linearity correction.

2.1.2 Spectrograph wavelength accuracy

The accuracy of the wavelength calibration of the spectrograph was checked at LICA optical workbench using two laboratory lamps that contains multiple emission lines. The mercury lamp —Newport 6035— for the blue region of the spectrum, and the neon lamp —Newport

6032— for red part. It is easy to see in the figure 4 and in the table 2 that the offset in the position of the lines is smaller than the spectral resolution of the spectrograph.

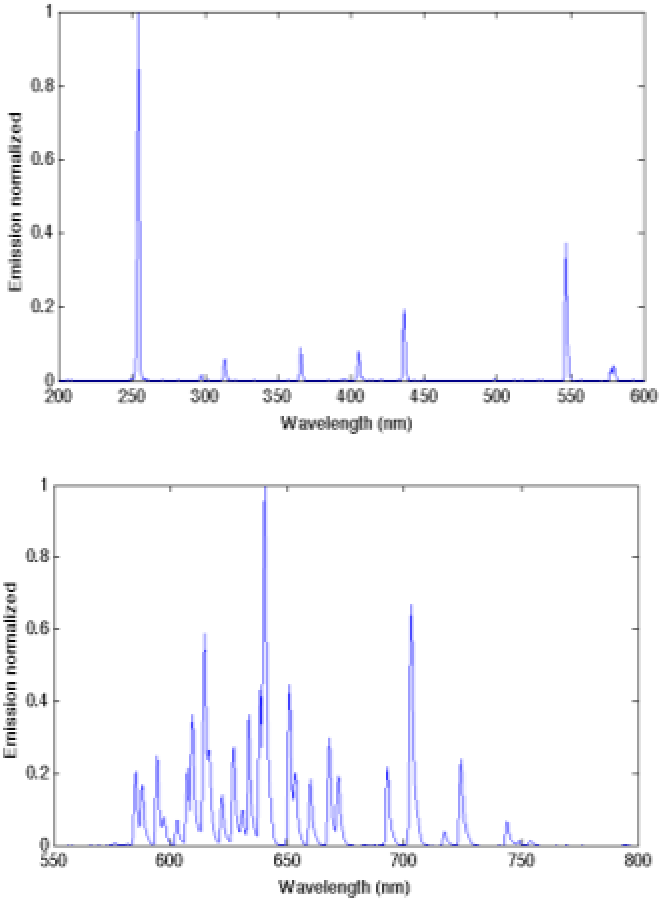


Figure 4. Spectra obtained from the mercury and the neon lamps

Mercury

Theory (nm)	253.65	313.18	365.02	404.66	435.84	546.07
Measured (nm)	254.23	313.45	365.69	404.94	436.35	546.41

Neon

Theory (nm)	585.25	594.48	609.62	614.31	633.44	640.22	650.65	667.83	703.24	724.52
Measured	585.68	594.58	609.79	614.43	633.75	640.45	650.88	667.92	703.39	724.65

Table 2. Comparison between theoretical and measured emission lines in the spectra of 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 optical workbench**.**

2.2 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.

To match a color with the power distribution of our lamp *P*, the XYZ coordinates follow the next equation:

$$X = k \int P(\lambda)\ \bar{x}\ d\lambda$$
$$Y = k \int P(\lambda)\ \bar{y}\ d\lambda$$
$$Z = k \int P(\lambda)\ \bar{z}\ d\lambda$$

where *k* is 680 lumens per watt for self-luminous bodies and $\bar{x}\ \bar{y}\ \bar{z}$ 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 [3].

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.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.2404542 & -1,5371385 & -0.4985314 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0556434 & -0.2040259 & 1.0572252 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

For calculate the correlated color temperature (CCT) of the lamp, for simplicity we prefer to use the calculator offered by Bruce Lindbloom [4]. 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 degree.

In the table 3 is resumed the principal data of the lamps.

For verification purposes we have also calculated the CCT with two approximate formulas. The approximate methods used are [10][11] CCT1 and CCT2. By comparison with the official definition of CCT we found differences of +- 100 K.

Lamp	CCT	XYZ	Latitude	Longitude	CCT1/CCT2	Hint
CFL 2700	2637	0.0954; 0.0853; 0.0223	---	---	2605/2497	LICA
CFL 6000	5782	0.1158; 0.1243; 0.1153	---	---	5642/5632	LICA
Fluorescent	3952	0.1250; 0.1264; 0.0724	40.42482	-3.528574	3892/3878	SFH Huerta
Fluorescent	5576	0.1430; 0.1552; 0.1343	40.44590	-3.725648	5445/5431	F. Farmacia (UCM)
Incandescent	2805	0.4022; 0.3634; 0.1264	---	---	---	LICA
Metal halide	3436	0.1460; 0.1398; 0.0717	40.42398	-3.526608	3404/3382	SFH P General
Metal halide	3723	0.1358; 0.1320; 0.0782	40.42867	-3.521866	3681/3674	SFH Stadium
Metal halide	4044	0.2287; 0.2375; 0.1281	40.42580	-3.523562	3976/3953	SFH C Londres
Metal halide	4280	0.1768; 0.1751; 0.1288	40.42360	-3.525773	4196/3953	SFH Ferial
Metal halide	5040	0.1504; 0.1489; 0.1391	40.42539	-3.533761	4922/4943	SFH Plaza
Metal halide	4813	0.2100; 0.2073; 0.1841	40.42726	-3.532816	4697/4718	SFH Alix
Metal halide	4884	0.1255; 0.1640; 0.0579	40.42750	-3.528673	4816/4743	SFH Eugenia
Metal halide	5474	0.1032; 0.1033; 0.1035	40.43026	-3.533859	5349/5365	SFH Lidl
Metal halide	5582	0.1107; 0.1148; 0.1094	40.43013	-3.533546	5460/5462	SFH Cross Lidl
Metal halide	5106	0.1040; 0.1169; 0.0806	40.45207	-3.728324	5009/4981	Paraninfo UCM
Metal halide	5744	0.0973; 0.1018; 0.0985	40.45111	-3.725351	5623/5621	F Fisicas (UCM)
Ceramic metal halide	2378	0.3044; 0.2512; 0.0891	40.42852	-3.534101	2317/2177	SFH 1 Mayo
Ceramic metal halide	2586	0.2672; 0.2311; 0.0804	40.42513	-3.535357	2535/2432	SFH Panos H
Ceramic metal halide	2620	0.3125; 0.2715; 0.0970	40.42526	-3.535643	2572/2476	SFH Panos L
Ceramic metal halide	2691	0.3812; 0.3366; 0.1179	40.42426	-3.535013	2642/2554	SFH Police
Ceramic metal halide	2832	0.3205; 0.2885; 0.1097	40.42774	-3.528907	2786/2716	SFH Eugenia
Ceramic metal halide	5381	0.2352; 0.2642; 0.2004	40.42585	-3.535284	5265/5240	SFH Saramago
Ceramic metal halide	6545	0.2254; 0.2438; 0.2558	40.42340	-3.525812	6349/6338	SFH P General
High pressure sodium	1732	0.1610; 0.1161; 0.0161	40.42872	-3.535809	1732/1253	SFH Toledo
High pressure sodium	1920	0.1583; 0.1220; 0.0141	40.42726	-3.532816	1898/1562	SFH Alix
High pressure sodium	2005	0.1610; 0.1279; 0.0122	40.45154	-3.726593	1985/1694	F Fisicas
High pressure sodium	2255	0.2155; 0.1786; 0.0379	40.45118	-3.728215	2217/2028	Paraninfo UCM
Low pressure sodium	1701	0.0270; 0.0198; 0.0000	---	---	1725/1206	LICA
Mercury vapor	4495	0.0581; 0.0623; 0.0383	40.45138	-3.727385	4423/4400	F Telecom. UPM
Mercury	24382	0.0094; 0.0118; 0.0209	---	---	---	LICA
Neon	<1000	0.0536; 0.0259; 0.0000	---	---	---	LICA
LED	2870	0.7242; 0.6832; 0.1649	---	---	---	LICA
LED	2961	0.7904; 0.7027; 0.3563	40.43484	-3.714048	---	Andrés Mellado
LED	3045	0.7978; 0.7191; 0.3654	40.13544	-3.718517	3004/2971	Moncloa
LED	3140	0.8006; 0.7304; 0.3794	40.41652	-3.702263	3097/3071	Espoz Mina
LED	4577	0.6268; 0.6441: 0.4732	---	---	---	LICA
LED	6801	0.4123; 0.3879; 0.5152	40.44574	-3.726402	6499/6534	F Farmacia (UCM)
LED	6770	0.3868; 0.3945; 0.4660	40.43717	-3.721701	---	Faro Moncloa
LED CREE	7676	0.3118; 0.3191; 0.4117	---	---	---	LICA
LED	23223	0.3501; 0.3331; 0.6619	---	---	---	LICA
LED	>25000	0.3282; 0.3170; 0.6542	---	---	---	LICA
LED Farola eje	3107	0.8060; 0.7209; 0.4103	---	---	---	LICA
LED Farola 75º	2973	0.7866; 0.7148; 0.3125	---	---	---	LICA
LED 477nm	---	0.0870; 0.0476; 0.5178	---	---	---	LICA
LED 595nm	---	0.2799; 0.1812; 0.0000	---	---	---	LICA
LED 631nm	---	0.1171; 0.0506; 0.0000	---	---	---	LICA
LED 691nm	---	0.0177; 0.0066; 0.0000	---	---	---	LICA

Table 3. Principal data of the lamps tested

Table 3 lists the principal data of the lamps. Some of them were taken at San Fernando de Henares (SFH).

3. Lamps spectra

There are more databases of lamps spectra with a good collection spectra [5][6] but all of them has been taken in laboratory or have is a tiny representative sample [7]. This is very helpful for scientific purpose, but they are not practical. In this work we have taken the spectra of lamps that in the field looking for the lamps in our streets. The spectra were obtained with the lamps covers on if they have it. This is really important since the cover could change the spectra, as will be discussed later.

It is interesting to note that spectra of lamps should be obtained when the lamps reaches stability, i.e. some time after they are powered up, since the lamps spectra change. Some of the spectra found in other databases suffer from this problem. In all cases we have waited for stabilization a minimum of 30 minutes. This effect is very important for Low Pressure Sodium Lamps since they need around 10 minutes to reach the stability, and some lines disappear when it reaches stabilization. We have shown the differences in the spectrum before and after stabilization in figure 5.

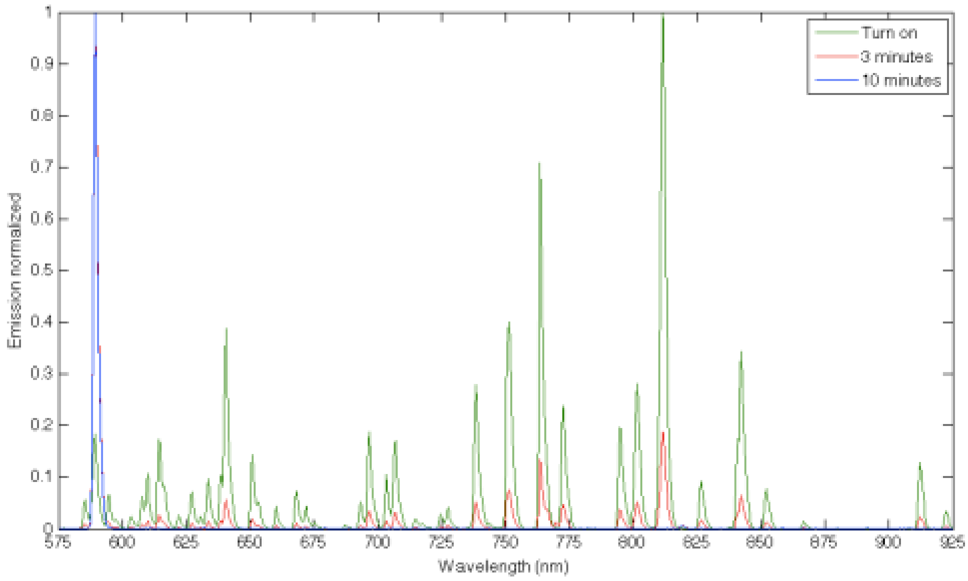


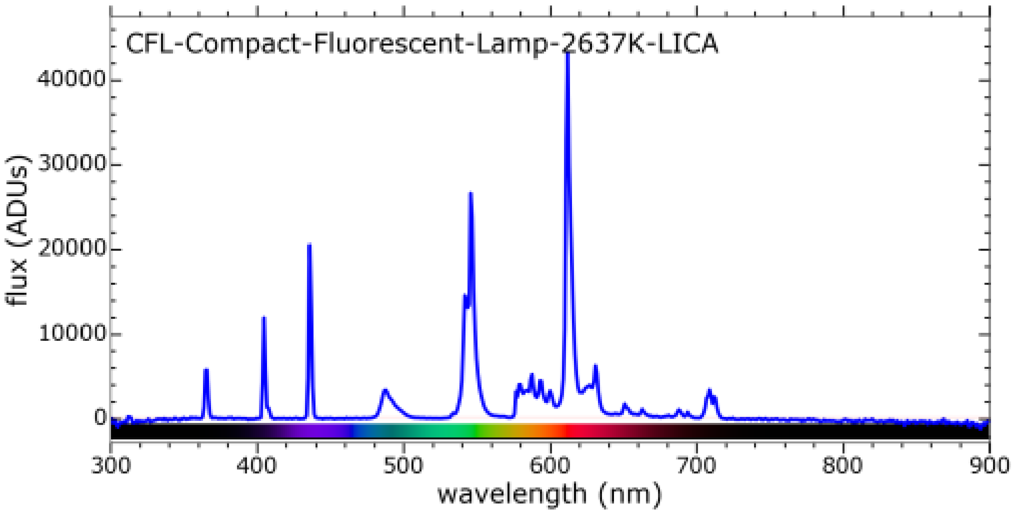
Figure 5. Evolution of the spectrum of a Low Pressure Sodium Lamp.

The data of the spectra can be obtain in the webpage of our group [8] and in the personal webpage of Carlos Tapia [9].

We describe in what follows some of the lamps spectra.

3.1 Fluorescent

We show three lamps without any cover, whereas the fourth have a diffuse cover. In comparison between the first lamp (CFL 2637K) and the second ones, is easy to find that the second has continuum spectrum under the principal emission lines. In addition, the principal line in the 2637K converts in a secondary in the CFL 5782K, and disappear a line in the blue part of the spectrum. The FL 3952K is similar to the CFL 5782K, the only difference is the continuum, in the 3952K is lower. Most interesting is the apparent change in the spectra of the same lamps with the cover. The lower emission lines start to become part of the continuum pectrum.



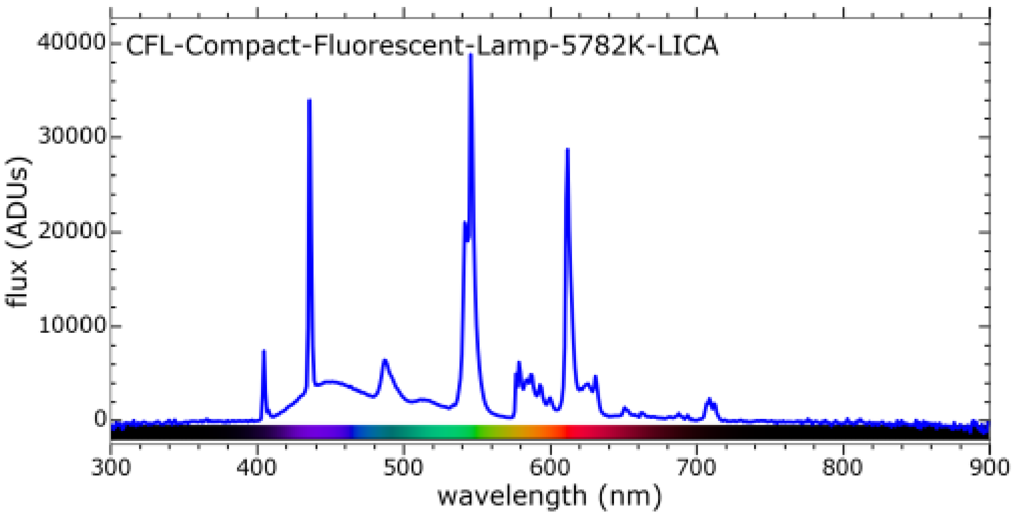
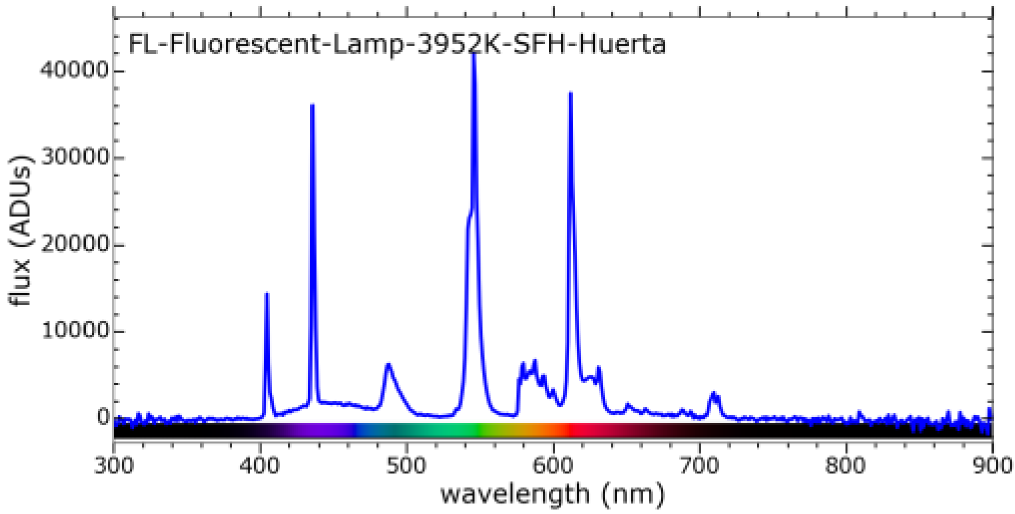


Figure 6. Fluorescent lamps.



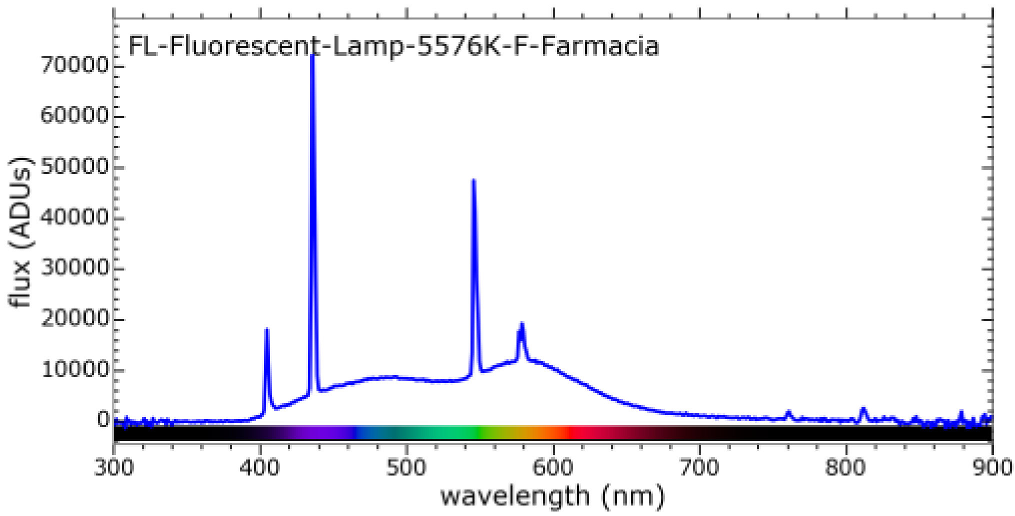


Figure 6. Fluorescent lamps. (cont)

3.2 Incandescent

It is really hard to find incandescent lamps on streetlights nowadays. For this reason we take only one spectrum from the typical 60W tungsten bulb. The spectra is continuum but with some bulges.

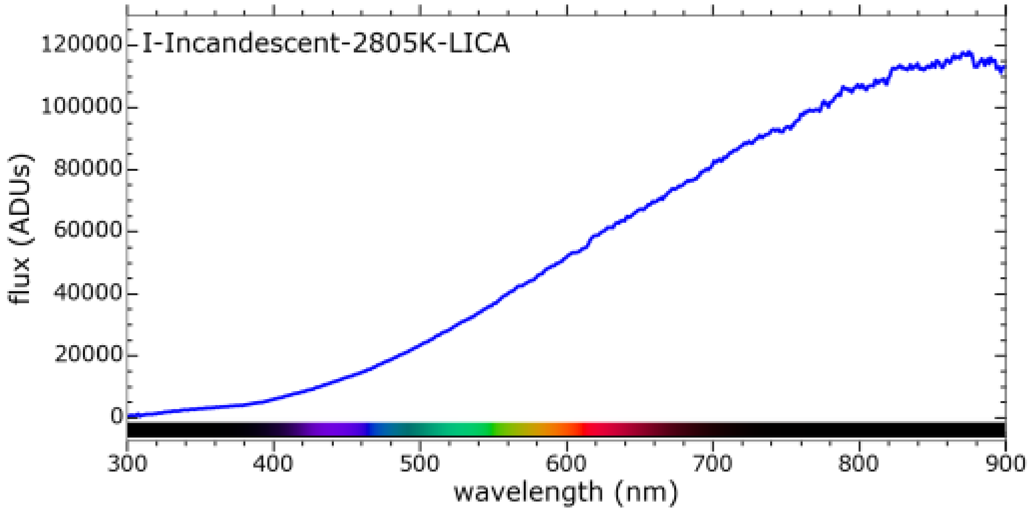


Figure 7. Incandescent lamp.

3.3 Mercury vapor

Mercury vapor lamps are hard to find in Madrid and neighborhood towns. We take the spectra from a classical bulb mercury vapor lamp without any type of cover. In the spectra can be see the mercury lines and a tiny continuum in the red region due to the fluorescence of the cover.

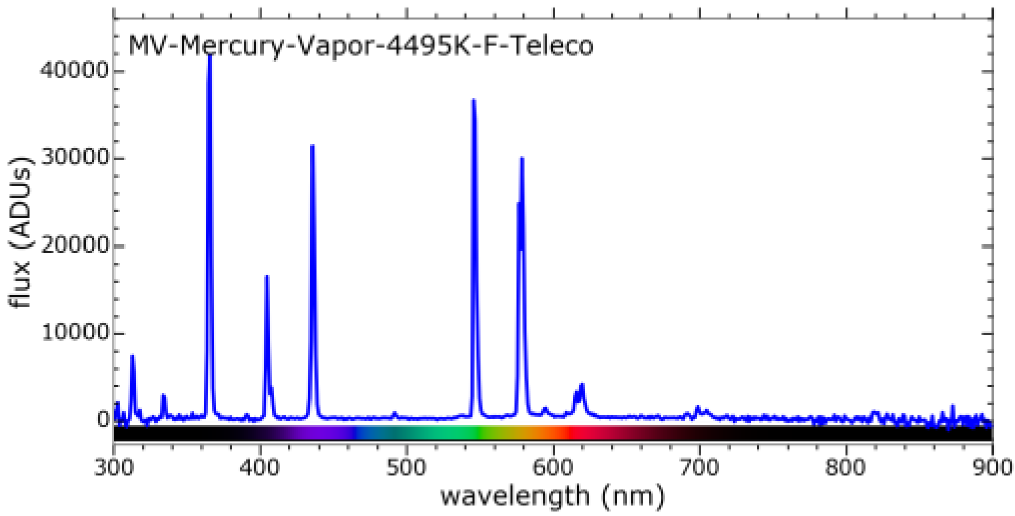


Figure 8. Mercury vapor lamp.

3.4 Metal Halide

The manufacturers of metal halide lamps include different elements depending on the physical design of the lamp, or the color that they want to achieve. Some of these elements are scandium, potassium –to reduce the intensity of the initial arc–, argon, xenon and dysprosium. And in the tri salt lamps –we don't find any of them in our study– has thulium, holmium and scandium. These elements –with mercury– explains most of the lines in the spectra.

The first two lamps shown are the classical metal halide spotlights used in stadiums. Their most important characteristic is that barely appearing a continuum, and the emission lines are so clear. The third is an intermediate step between metal halide and ceramic metal halide.

Fourth to sixth are brand new lamps used in streetlights. All of them have been enriched with the previous described elements. On the other hand, the lamps seventh to eleventh are itself a family of lamps. These last lamps has some elements, but less than the previous ones. To have different CCT the manufacturer made a balance of their relative amount of elements.

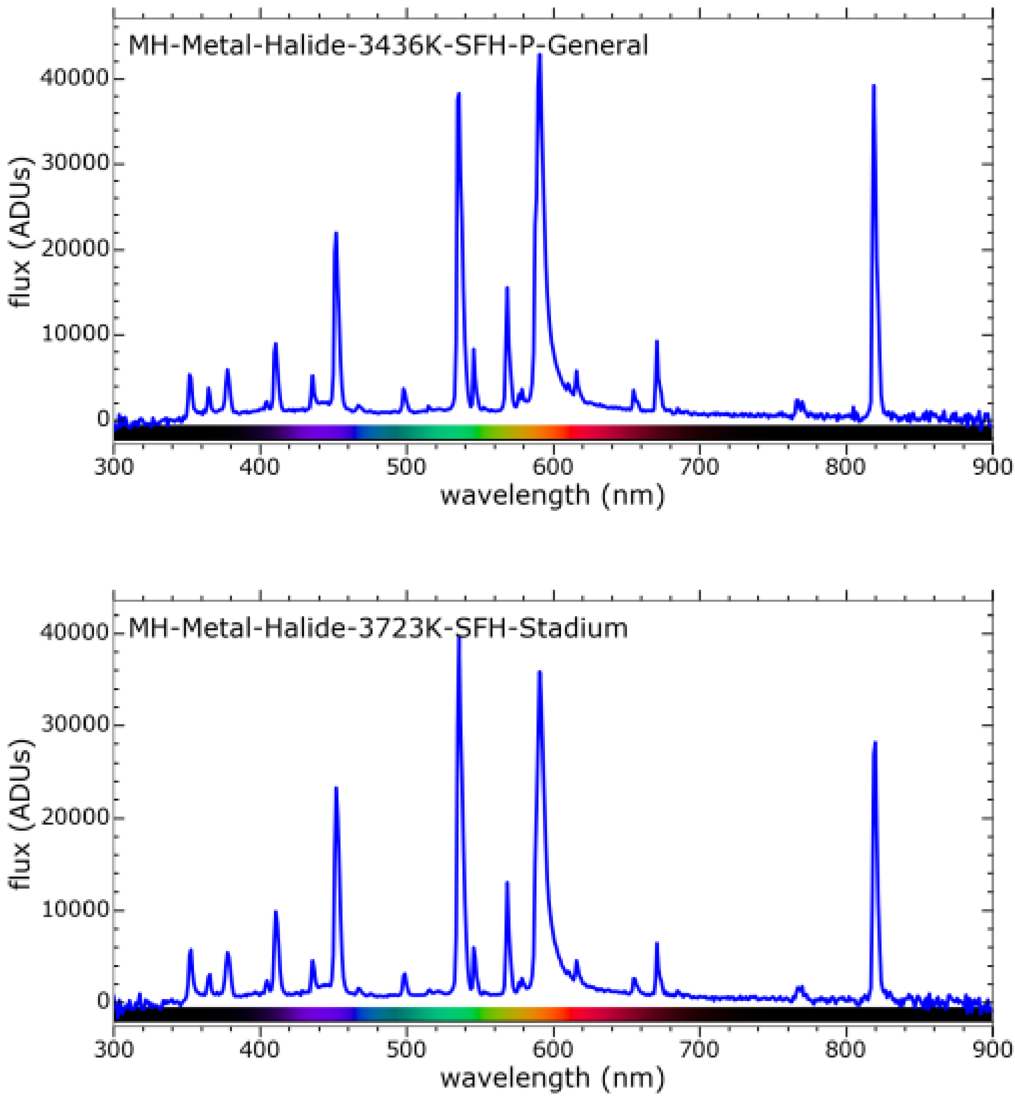
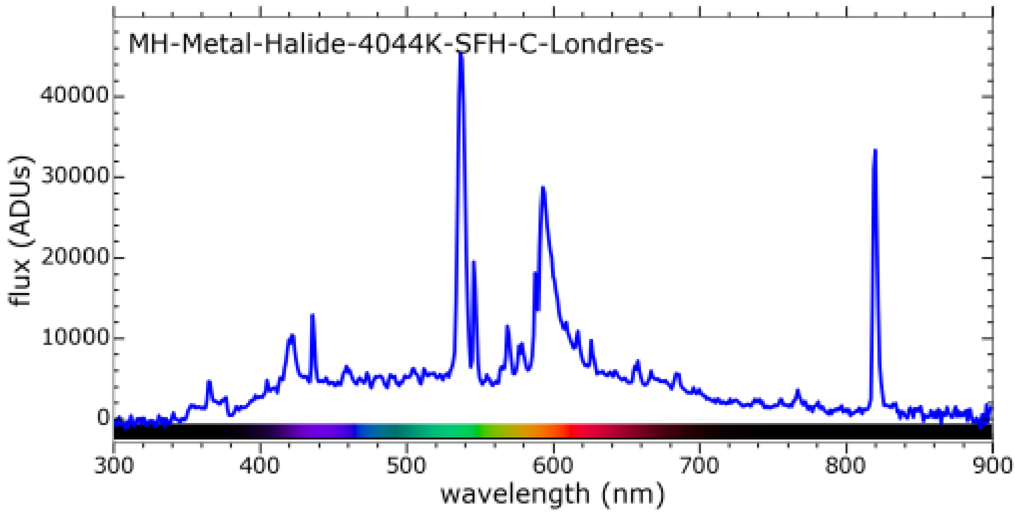
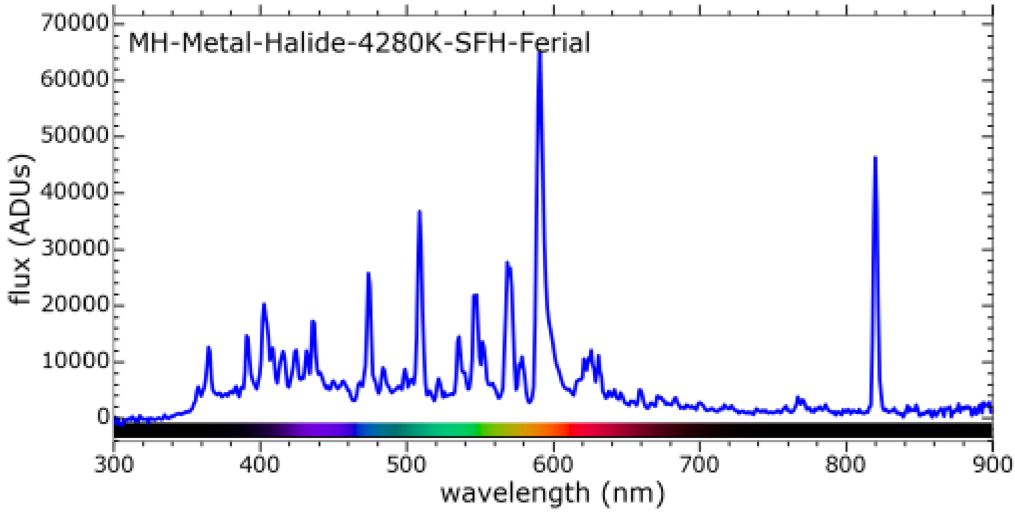


Figure 9. Metal halide lamps.





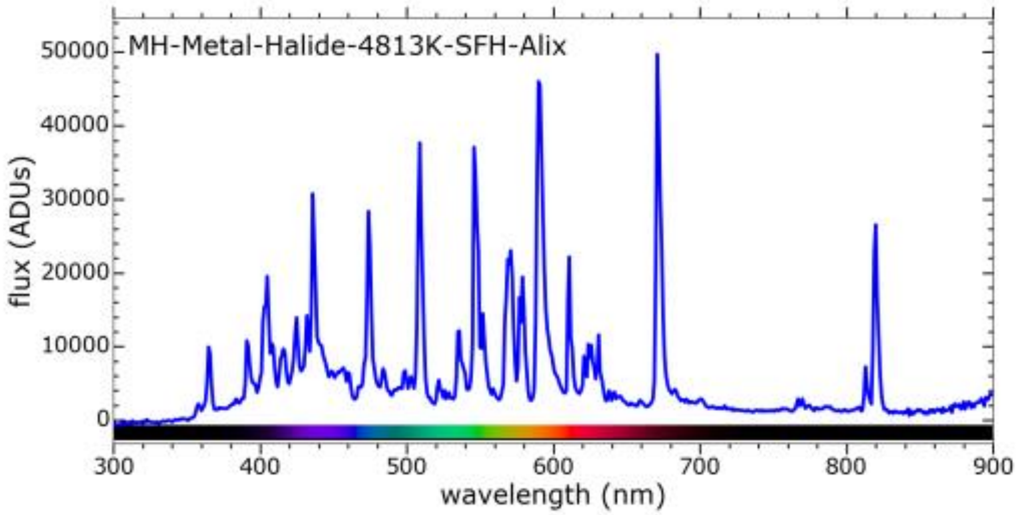


Figure 9. Metal halide lamps. (Cont)

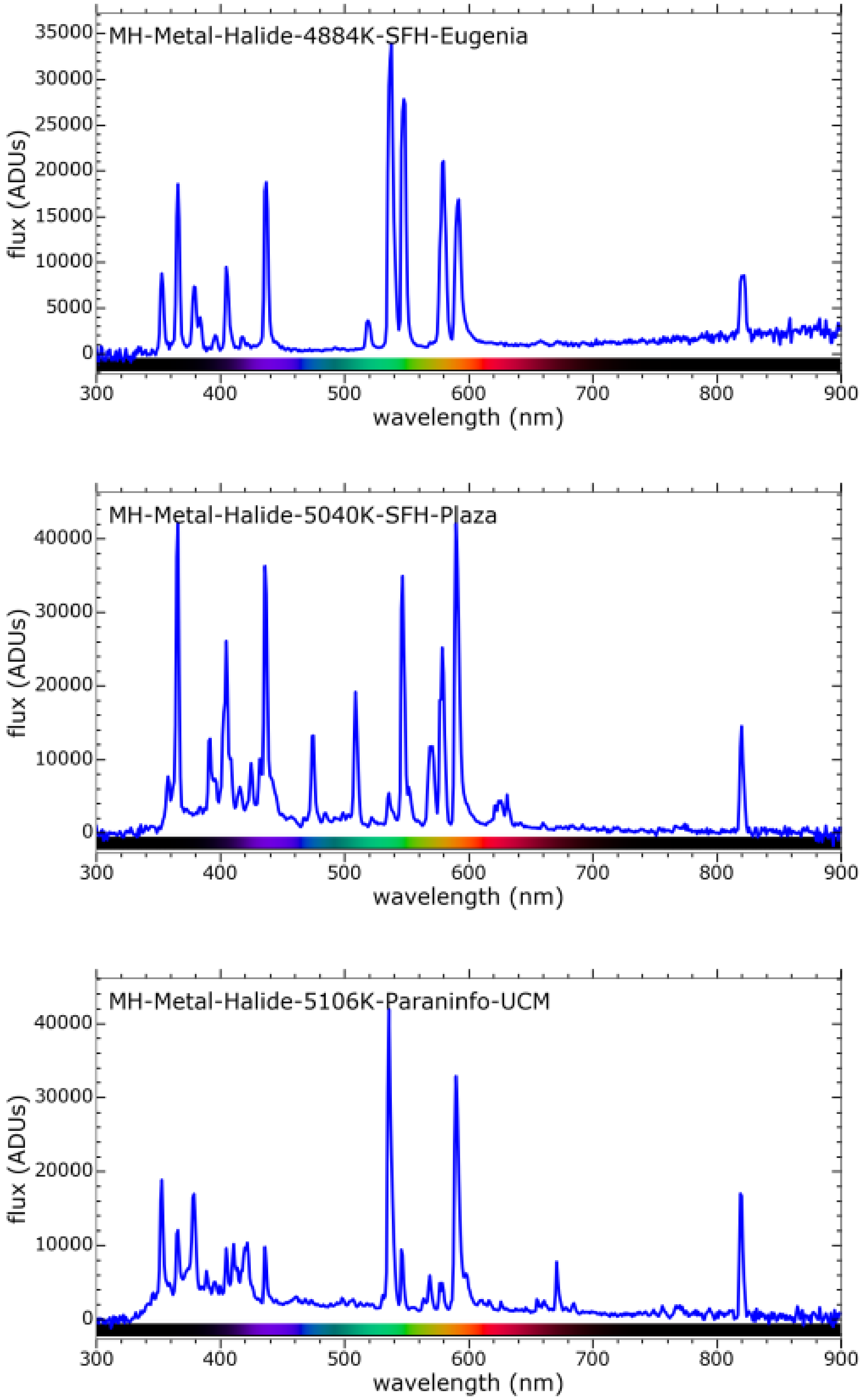
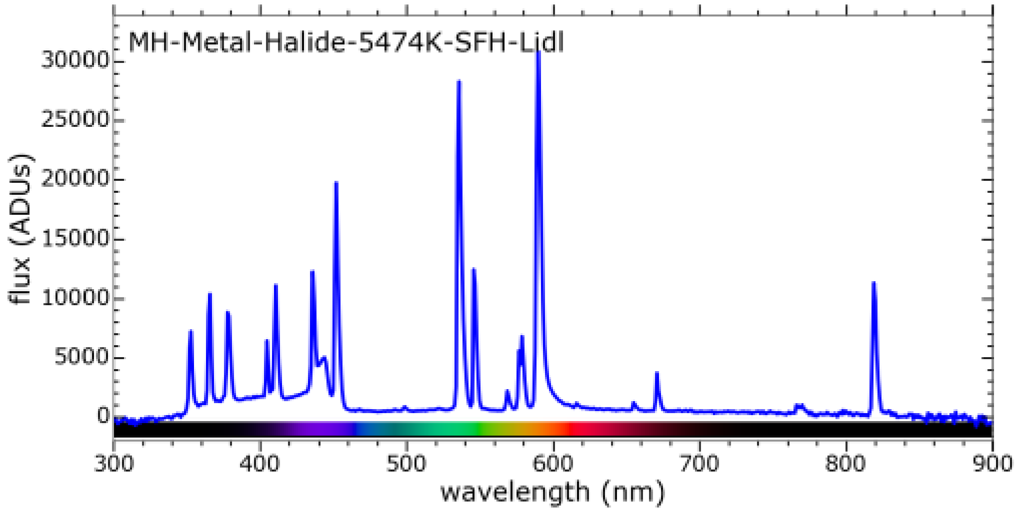
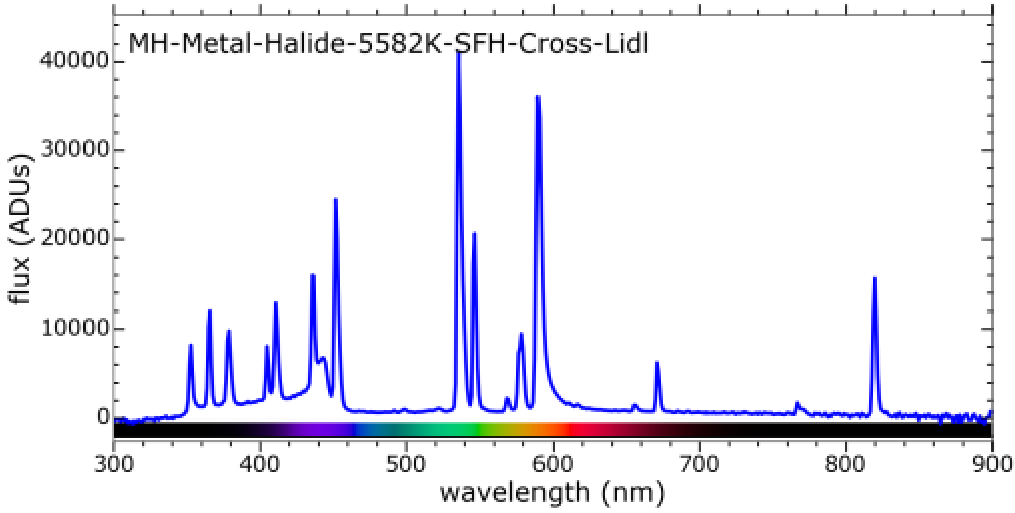


Figure 9. Metal halide lamps. (Cont)





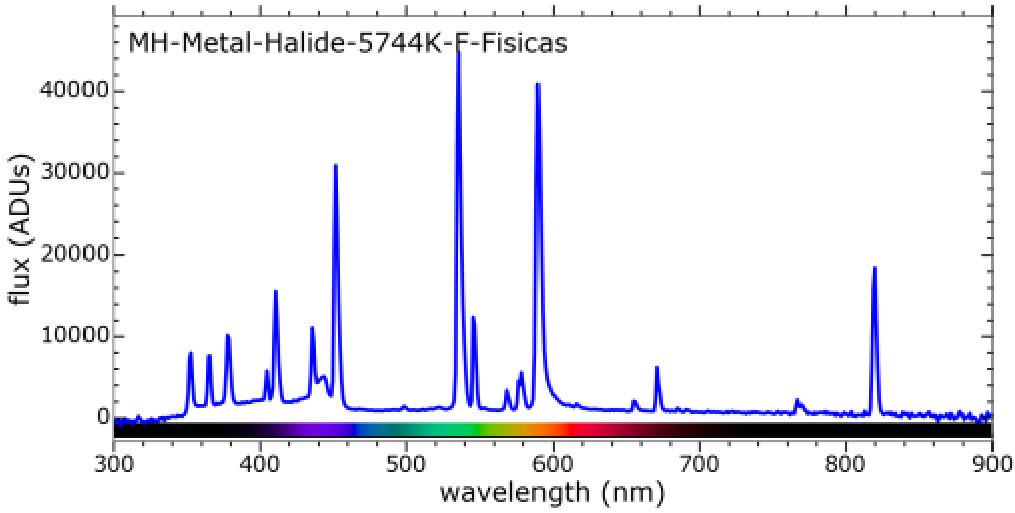


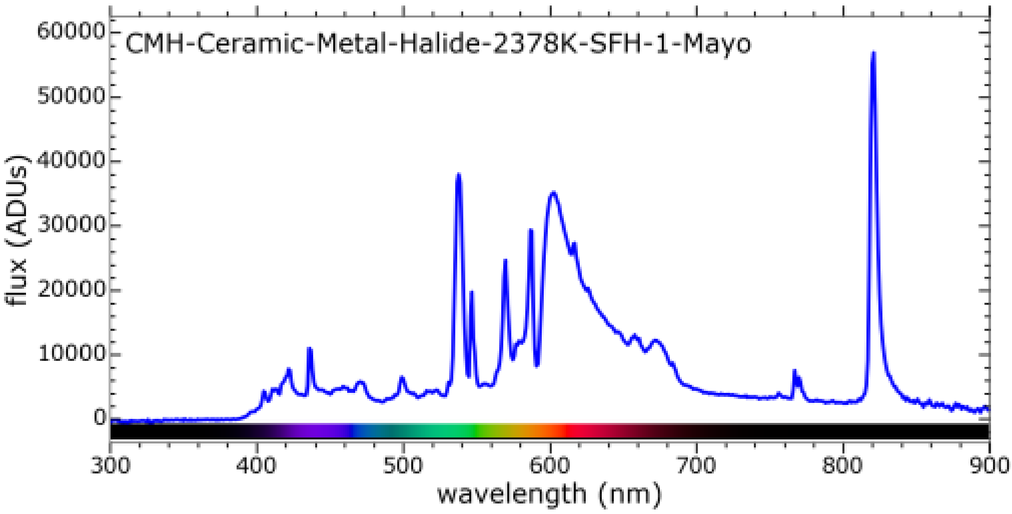
Figure 9. Metal halide lamps (Cont).

3.5 Ceramic metal halide

The ceramic metal halide lamps are a new version of metal halide lamps. Both of them are based on mercury and enriched —depending of the manufacturer— with scandium, potassium, argon, xenon, dysprosium, thulium, and holmium. But the difference between them is that the ceramic metal halide includes sodium to make a warmer and pleasant light.

The first five lamps shown are the classic ceramic metal halide. Can be seen the normal mercury lines with a large tail produced by the sodium included in the lamp. With the second and third lamps we demonstrate that is very important to take in account the cover of the lamp. These two lamps are exactly the same, with the same age, but different cover. The first —number 2— has a totally clear and flat window, and the second —number 3— included a rear reflector and curved window. It's easy to see that the spectra are totally different.

We found too a *rara avis* lamp, the sixth and seventh. We included in the ceramic metal halide family, but it could be included in the metal halide. Are based mostly in potassium but have the rest elements. These lamps at naked eye are characterized of their extremely blue light.



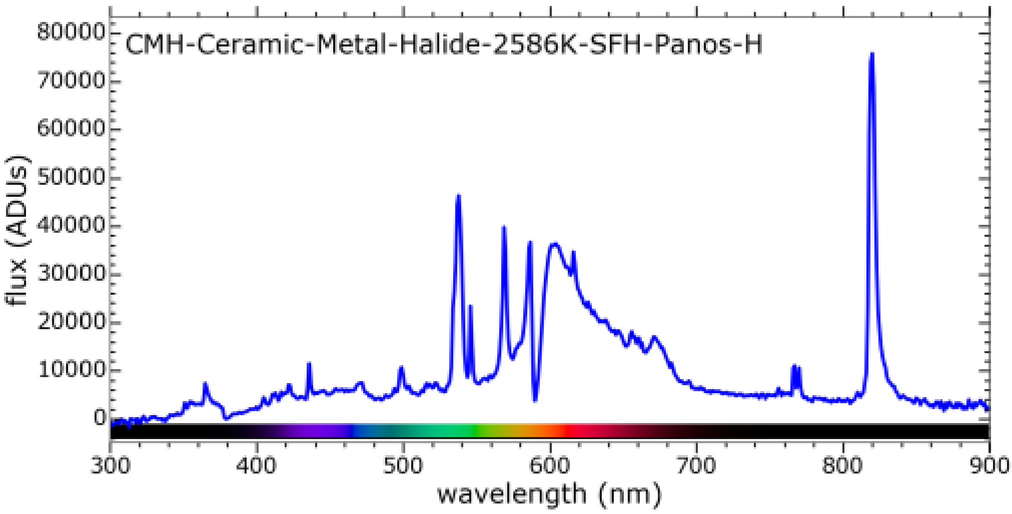


Figure 10. Ceramic Metal Halide lamps.

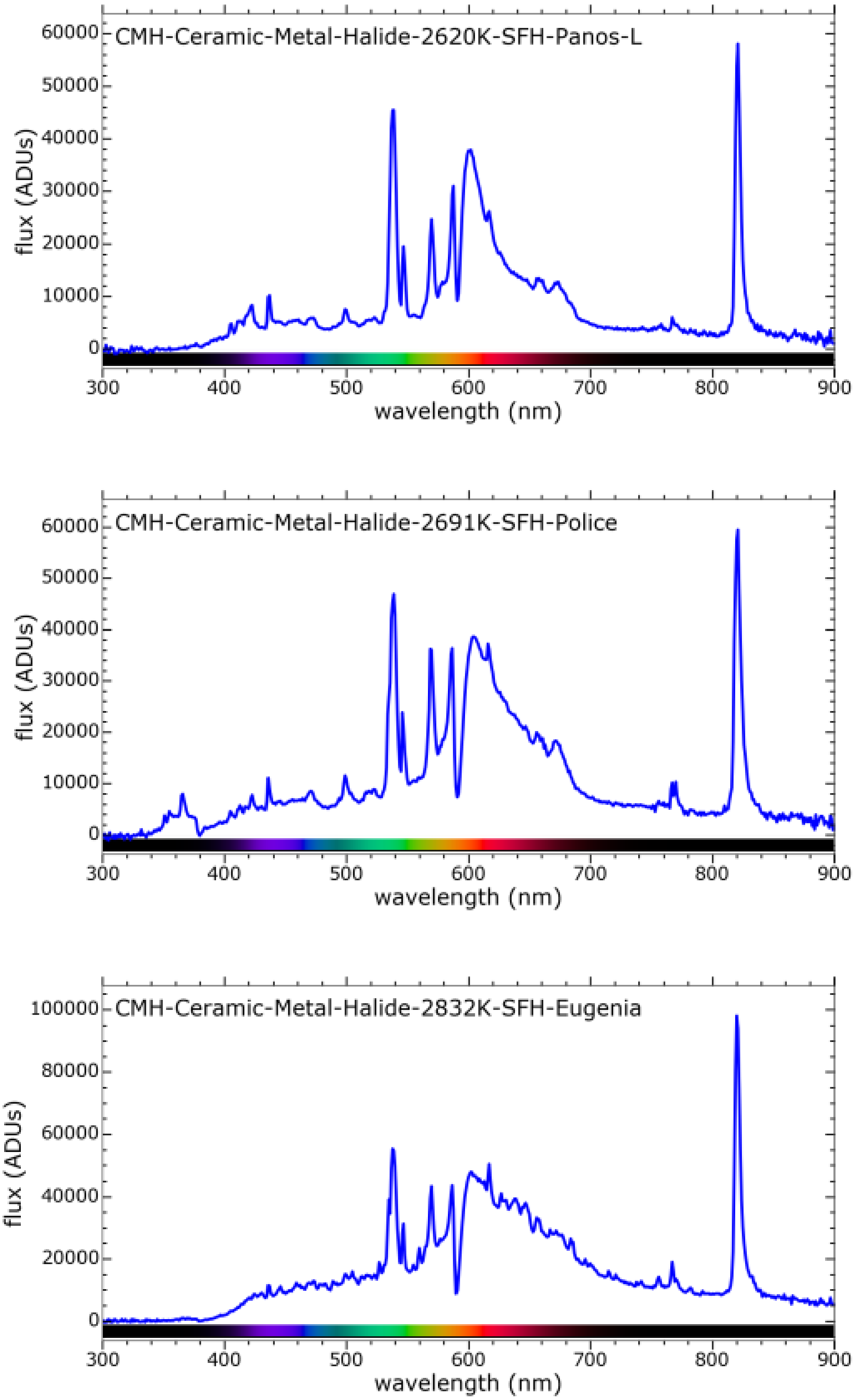


Figure 10. Ceramic Metal Halide lamps (cont).

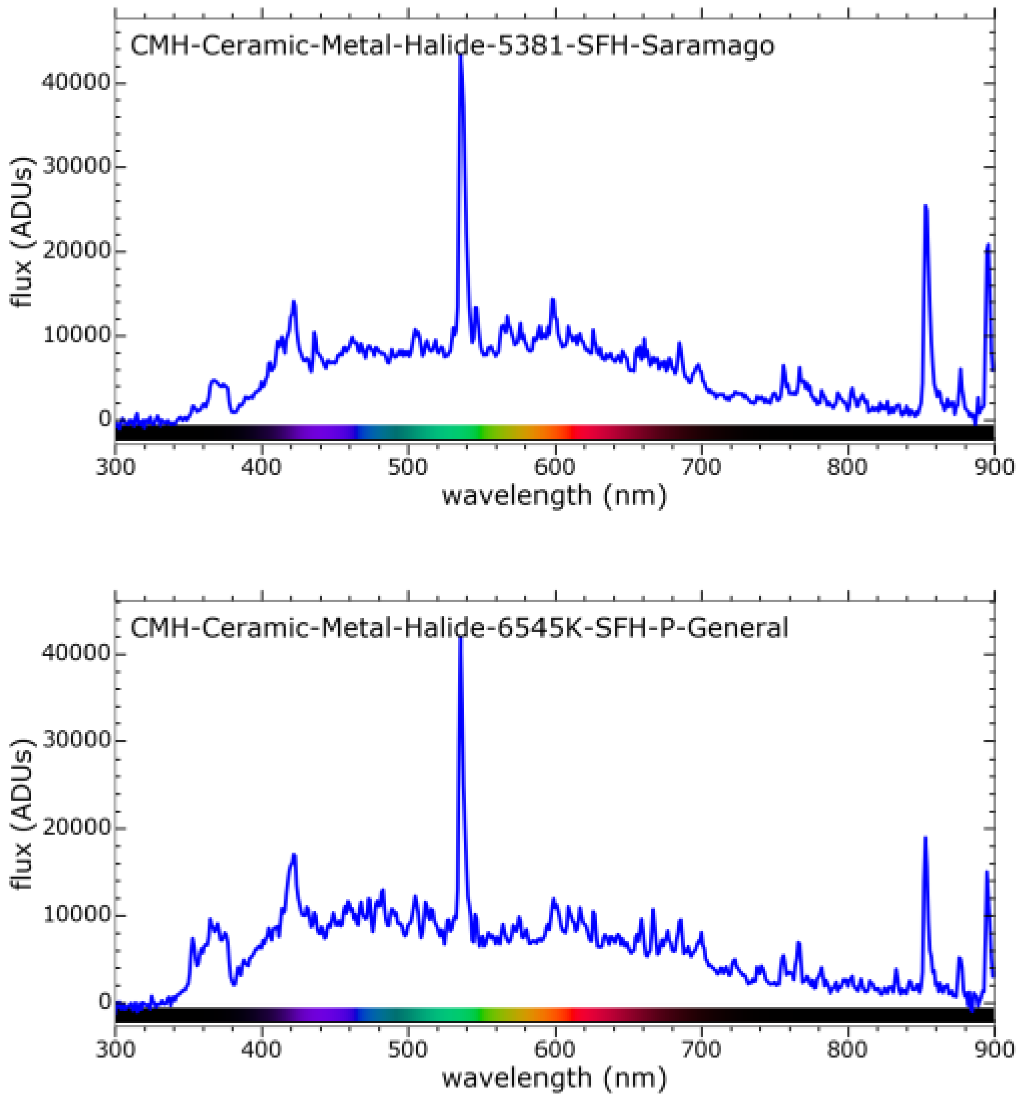


Figure 10. Ceramic Metal Halide lamps (cont).

3.6 High pressure sodium

The High Pressure Sodium (HPS) lamps are the most classical in street lighting. The lamps 1 and 2 are the same but with different cover, the first have the classical diffusive cover and the second a totally clear window. The number 2 and 3 are exactly the same with the same cover, but the third is newer. The forth is the spotlight version of the high pressure sodium lamps.

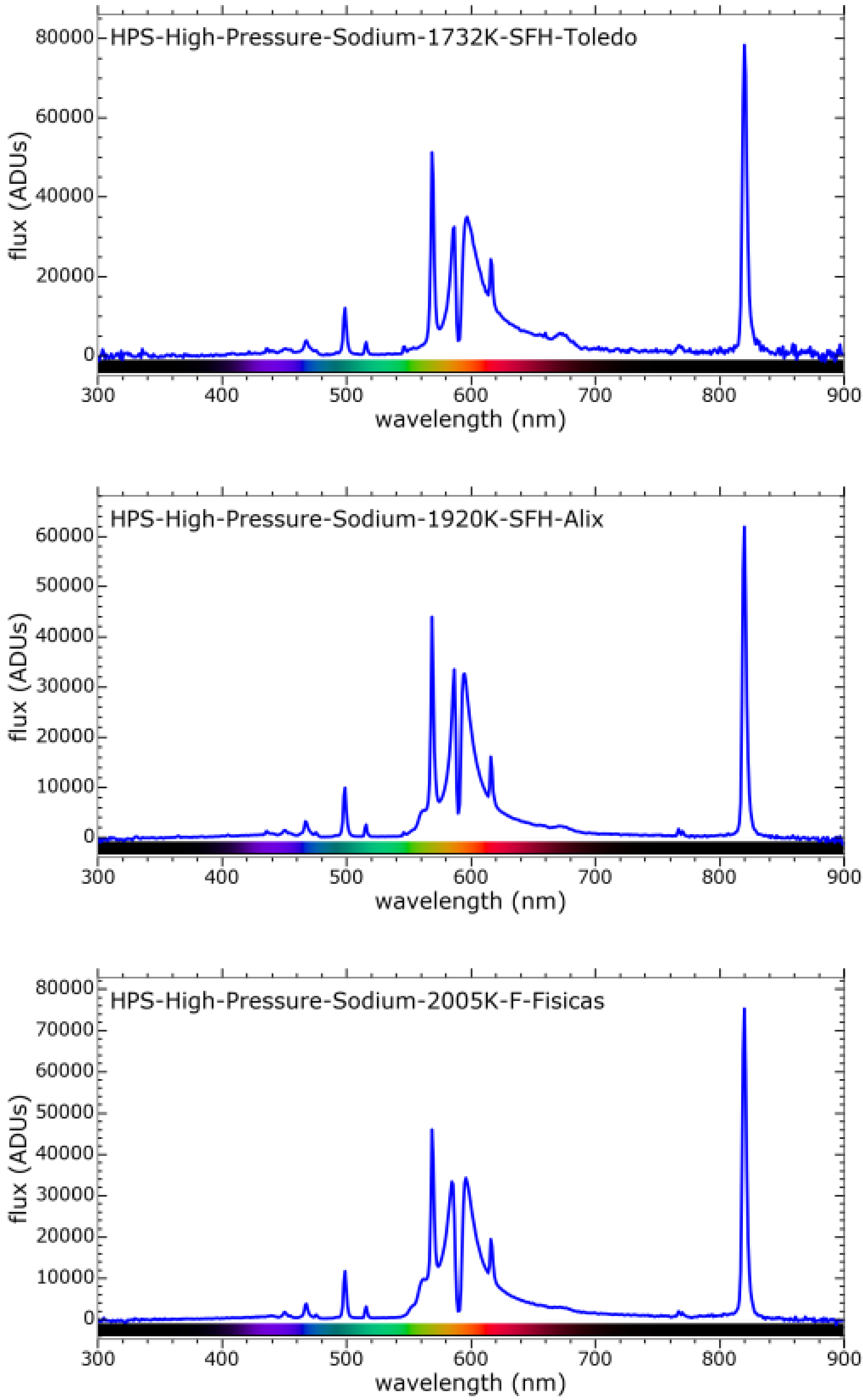


Figure 11. High Pressure Sodium lamps.

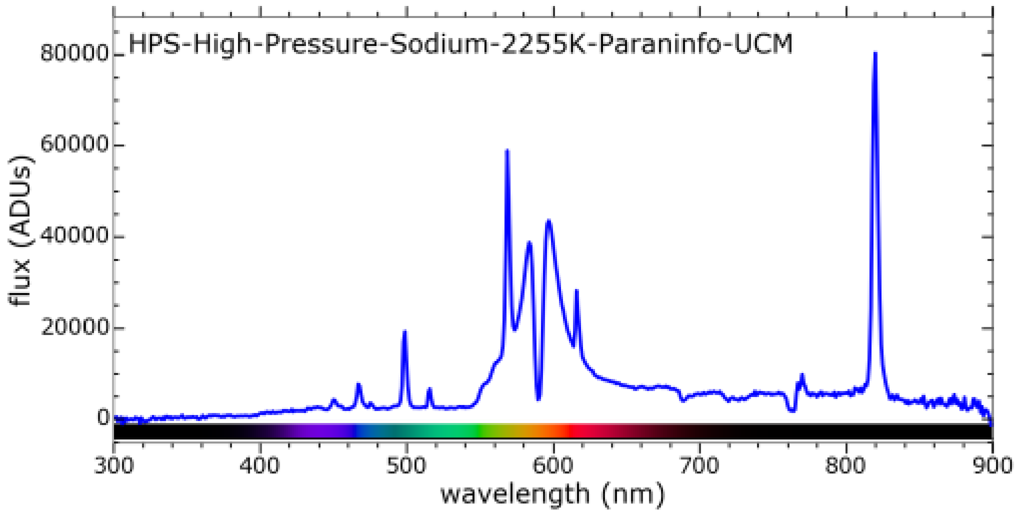


Figure 11. High Pressure Sodium lamps (cont).

3.9 Low pressure sodium

Low Pressure Sodium (LPS) lamps are an ancient street lighting but still used in some place, like La Palma (Canary Island).

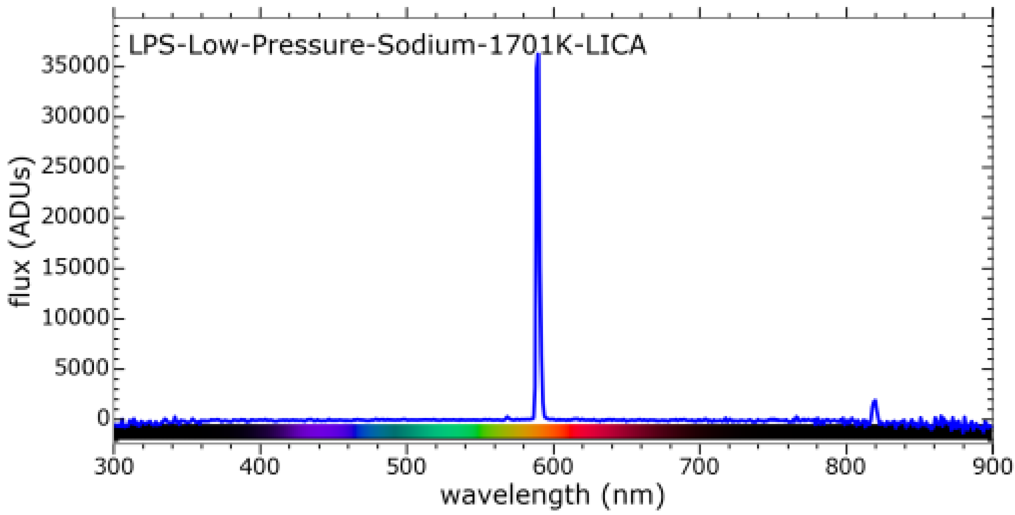


Figure 13. Low Pressure Sodium.

3.9 White LEDs

Due to change on street illumination, now is easy to find LEDs on streetlights. We found the position is crucial to take a good spectra, the blue maximum is extremely sensitive. It is easy to have a spectra of a LED lamp with the blue part higher than real. We check the CCT of LEDs mounted on Madrid streetlights, and we discover that their CCT is over 3000K in most cases.

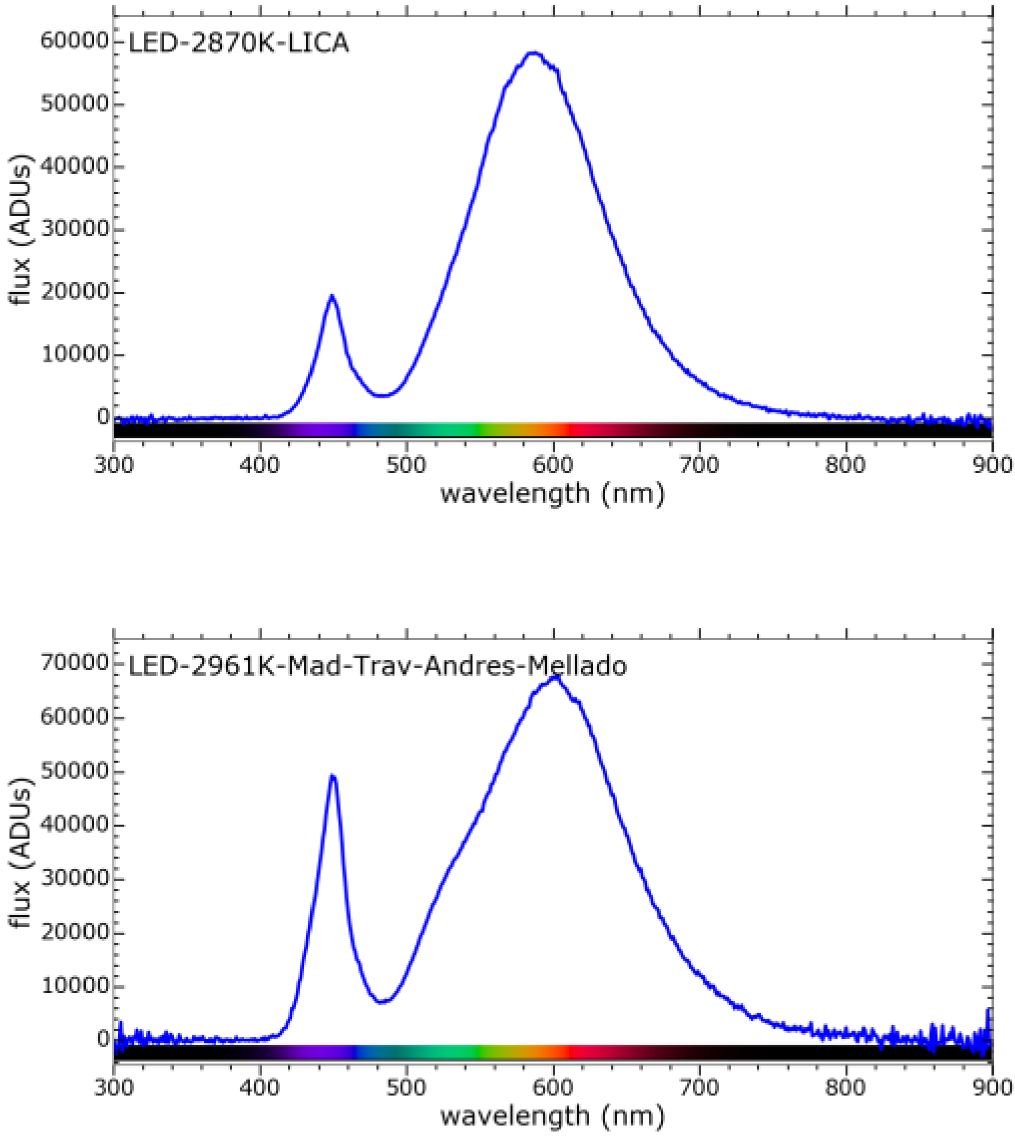


Figure 13. White LEDs.

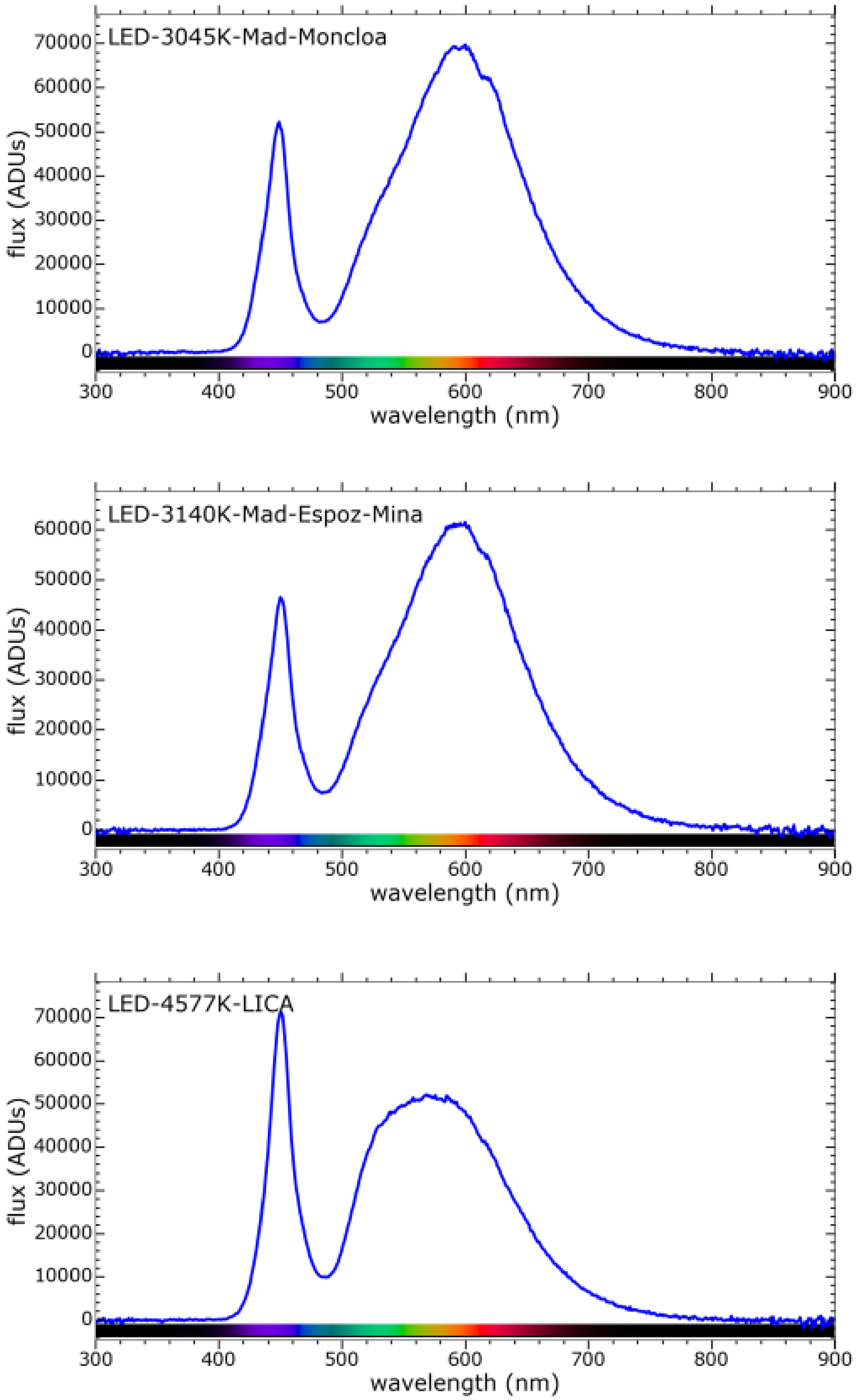


Figure 13. White LEDs.

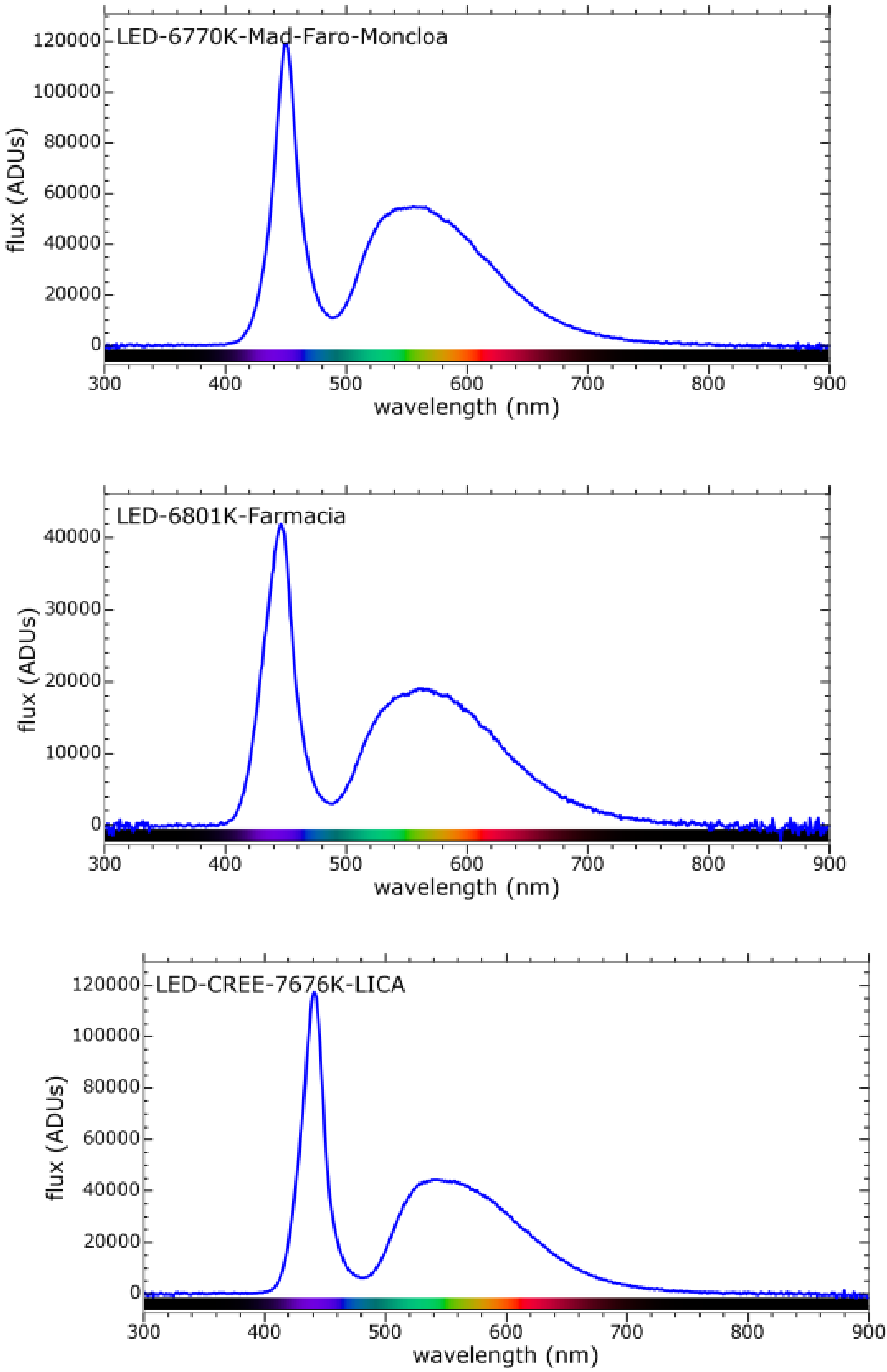
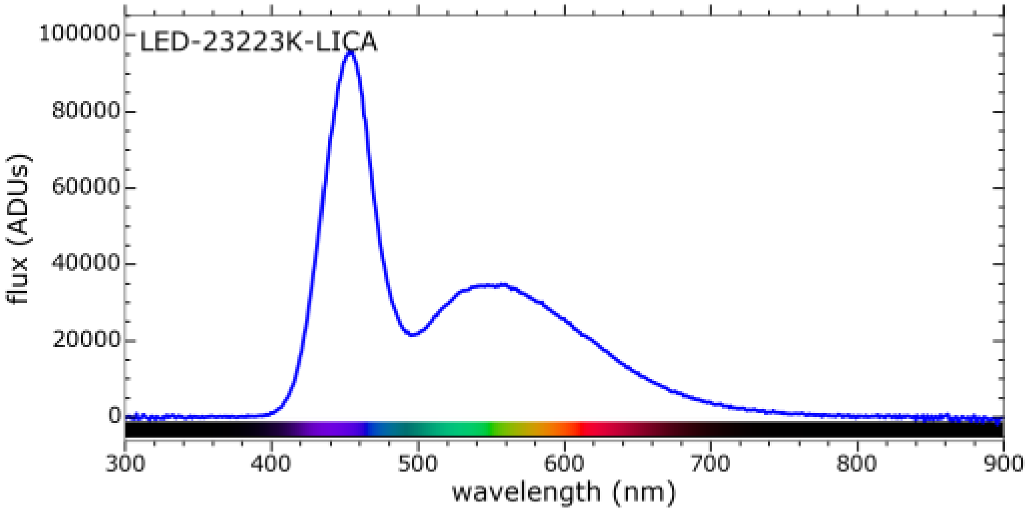
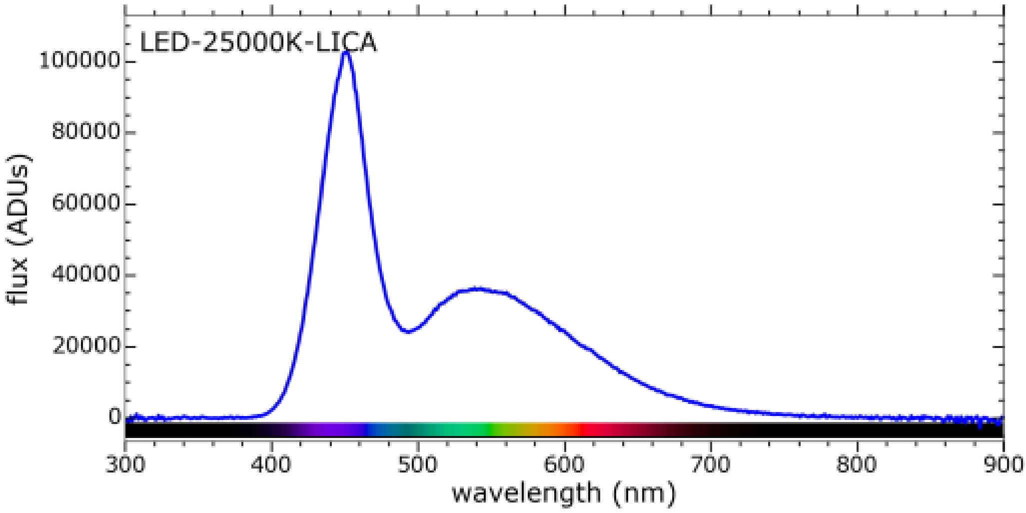


Figure 13. White LEDs (cont).





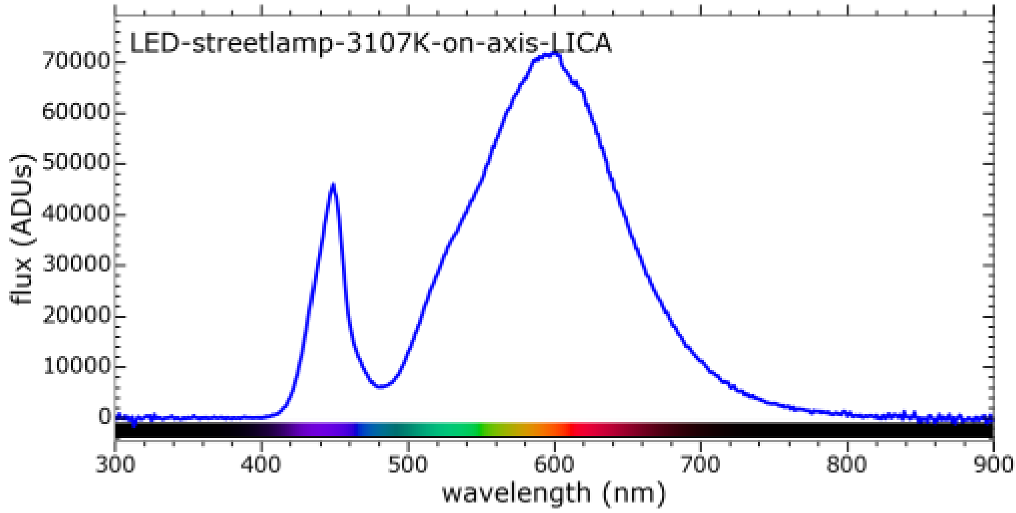


Figure 13. White LEDs (cont).

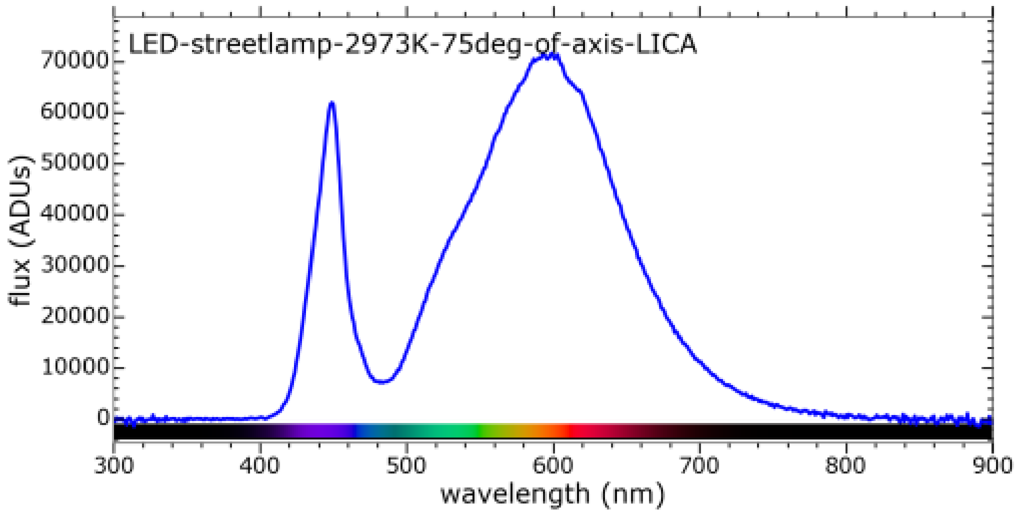
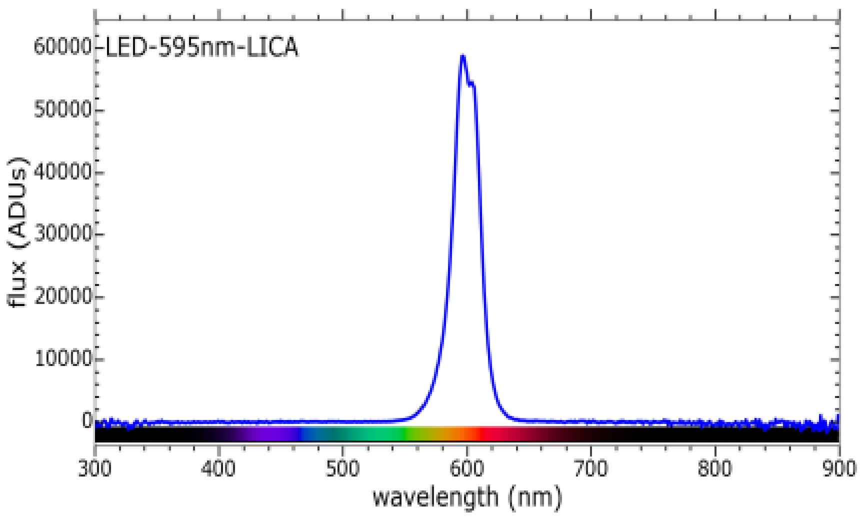


Figure 13. White LEDs (cont).

3.10 Colored LEDs

For completeness we add some colored LEDs that can be found in shop windows.



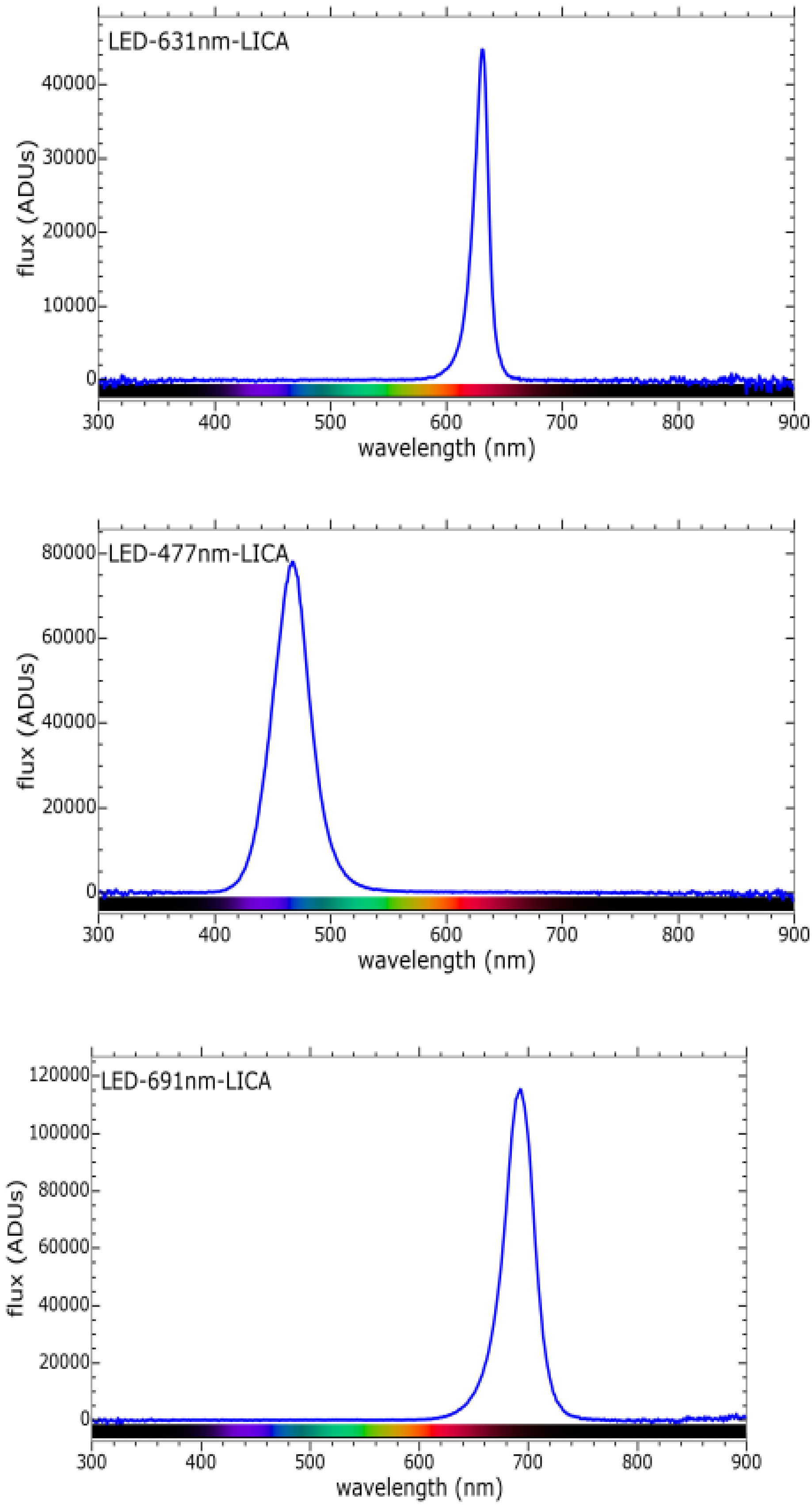


Figure 14. Colored LEDs.

4. CONCLUSIONS

We present a database from streetlights spectra taken on the field, not in laboratory, covering very wide color temperatures, and much different type of lamps. Furthermore, we demonstrate that is extremely important to take in account the cover of the lamp as it can change dramatically the result spectrum.

The spectrograph has a constant response over their entire spectral sensitivity, so our database is consistent and has enough accuracy to work with them to reproduce real night skylight. This database can be used too in amateur spectroscopy field. Now amateurs can correct their spectrographs with the spectrum of any streetlight, the positions of emission lines is well known.

This work is not closed; we will work on the database to increase it. Therefore the database will rise day after day with new lamps, for example, traffic lights and new LEDs mounted on streetlamps.

References

[1] SAND-UCM: http://guaix.fis.ucm.es/SAND-UCM. SAND-UCM. Martin Aubé webpage: http://cegepsherbrooke.qc.ca/~aubema/index.php/Prof/SandEn

[2] Aubé, M.; Kocifaj, M.; Zamorano, J.; Solano Lamphar, H.A.; Sánchez de Miguel, A. "*The spectral amplification effect of clouds to the night sky radiance in Madrid*" (2016) Journal of Quantitative Spectroscopy and Radiative Transfer, Volume 181, Pages 11–23.

[3] CMFs: http://www.cvrl.org/cmfs.htm

[4] CCT: http://www.brucelindbloom.com/index.html

[5] NOAA: http://ngdc.noaa.gov/eog/night_sat/spectra.html

[6] LSPDD: http://galileo.graphycs.cegepsherbrooke.qc.ca/app/en/lamps

[7] M. Aube, Johanne Roby, Miroslav Kocifaj: Evaluating Potential Spectral Impacts of Various Artificial Lights on Melatonin Suppression, Photosynthesis, and Star Visibility. DOI: 10.1371

[8] Guaix webpage: http://guaix.fis.ucm.es/lamps_spectra

[9] Carlos Tapia webpage: http://carlostapia.es/lamparas/lamps.html

[10] Calvin S. McCamy: Correlated color temperatura as an explicit function of chromacity coordinates. DOI: 10.1002/ Col. 5080170211

[11] Javier Hernández-Andrés, RL. Lee, J. Romero: Calculating Correlated Color Temperatures Across the Entire Gamut of Daylight and Skylight Chromaticities. DOI:10.1364/AO.38.005703.

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