VEET Spectral Power Distribution Reconstruction Guide

Table of Contents

Introduction

This document describes how to generate reconstructed Spectral Power Distribution (SPD) curves from the VEET's Spectral sensor (PHO) output. The VEET uses an AS7341 11-channel multispectral sensor (AMS Osram), whose narrowband channels overlap significantly. Because of that overlap, raw channel counts do not faithfully represent the true spectral shape—two different SPDs can easily produce the same response in a subset of channels. Datasheet sensor responsivity curves [1] are shown below.

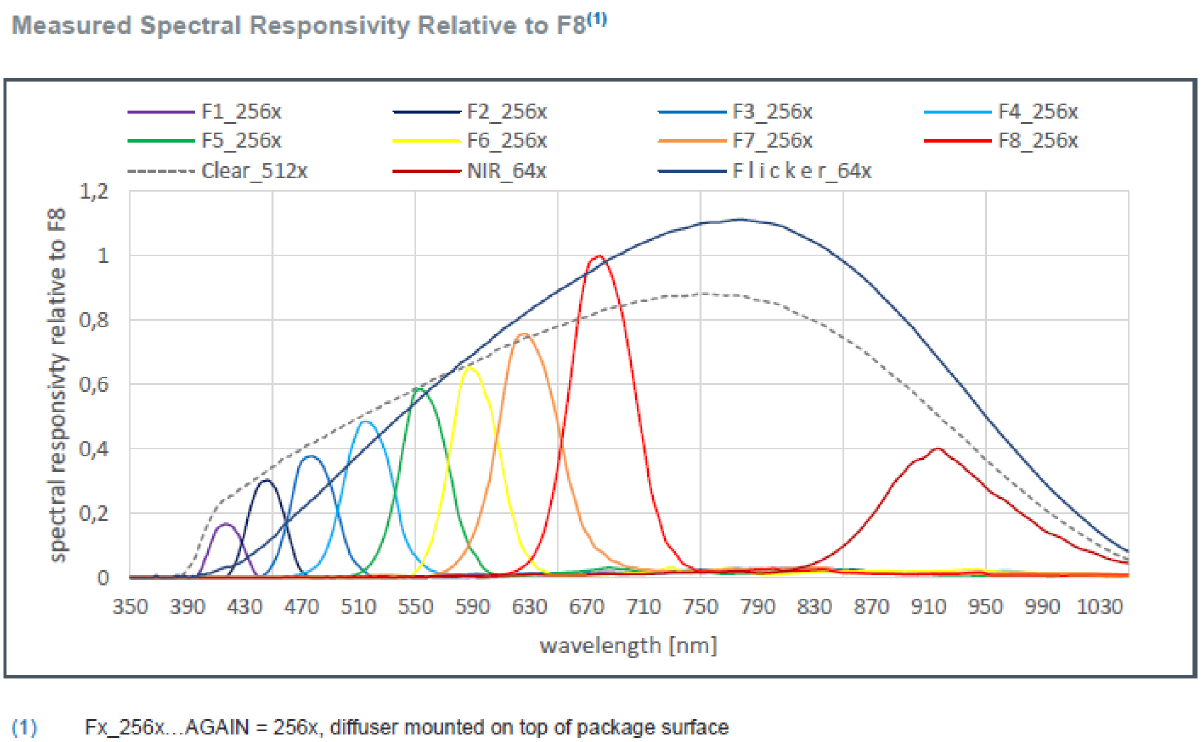


Figure 1*: Datasheet sensor responsivity curves (normalized to F8).*

To address this, we apply spectral reconstruction (or another regression/ML model) using a calibration matrix. That matrix is built so that each wavelength bin in the reconstructed SPD is estimated from the responses of all 11 channels. In other words, even if two SPDs happen to match on some channels, they will almost certainly differ on at least one of the overlapping bands; the calibration matrix "untangles" these overlaps and yields a more accurate estimate of the full spectrum.

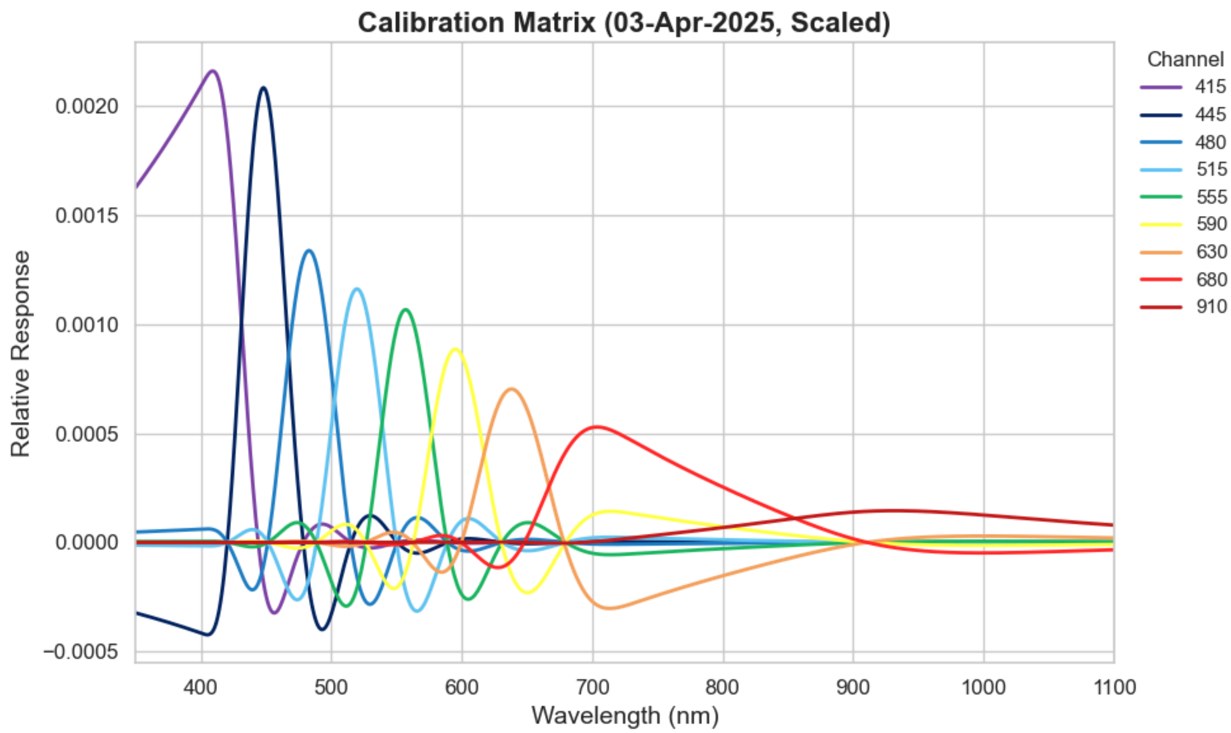


Figure 2*: Current calibration matrix in its plotted form.*

As a result, any attempt to compare energy within a particular wavelength range is far more reliable if you first reconstruct the full SPD and then integrate over the desired wavelengths. Simply scaling individual channel outputs (the “shortcut” method) is easier to implement but will yield less trustworthy results.

Once the SPD is reconstructed, additional analyses can be applied—such as estimating photopic or cellular lux by weighting the spectrum with relevant response curves. While it is theoretically possible to develop regression models that estimate these values directly from raw channel outputs, such models have not yet been developed or validated in this work.

Integration Time and Gain Normalization

Raw counts from the PHO sensor are influenced by both integration time and gain settings. To enable consistent interpretation across devices and lighting conditions, it is necessary to normalize these values to a fixed reference. When both gain and integration time normalization have been performed the counts are referred to as **basic counts**. The spectral output from the VEET is normalized for neither of these effects and represents **raw counts.** It is necessary to first convert spectral output to basic counts before proceeding with any additional processing.

The normalization process involves the following:

- **Dark Count Offset:** If not done already, counts from the dark channel should be subtracted from all the channels. In practice, dark counts have been typically observed to be zero.

- **Gain correction:** Each channel's raw counts are divided by its corresponding gain ratio. The spectral sensor on the VEET uses a single gain for all channels. The gain ratios are drawn from the sensor manufacturer's datasheet.

- **Integration time normalization**: Corrected counts are scaled by integration time (in milliseconds), yielding a time-normalized count.

Spectral Power Distribution Reconstruction

The calibration matrix is used to reconstruct the spectra SPD via the following matrix multiplication:

$$SPD_{recon} = M \cdot X$$

- X : a [k x 1] vector of sensor basic counts for k channels
- M : the [w x k] calibration matrix for w wavelength points
- SPD_{recon} : [w x 1] vector representing the reconstructed SPD

Excel Example

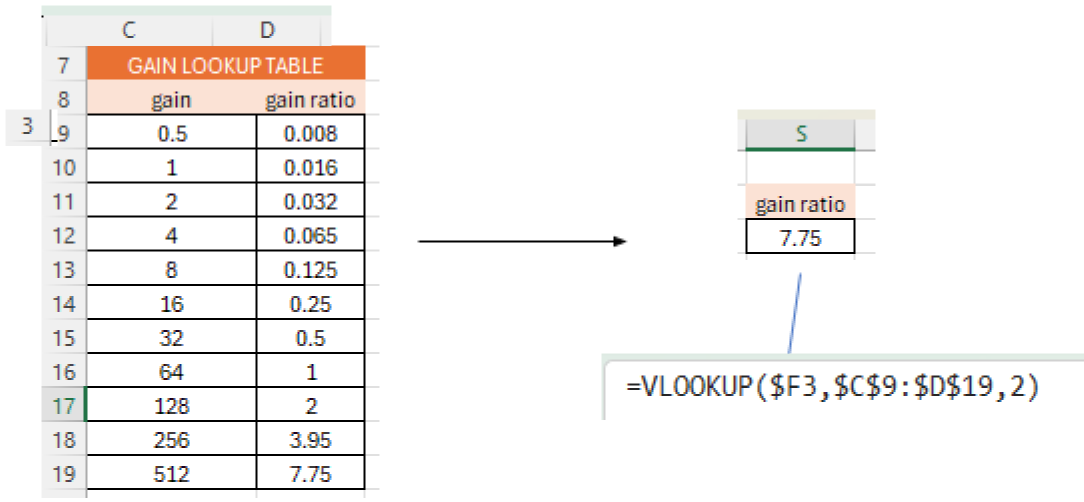
This example illustrates the reconstruction of an SPD from a single VEET spectral sensor output using the current calibration matrix, as implemented in Excel.

Assuming a single line of VEET data entered below:

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	RAW DEVICE OUTPUT WITH HEADERS ADDED														
2	Timestamp	Sensor	Int_Time	Gain	415	445	480	515	555	590	630	680	IR	Dark	Clear
3	1745449051	PHO	100	512	133	209	305	380	427	438	545	633	98	0	1467

Figure 3*: Example line of VEET data.*

Look up gain ratio:



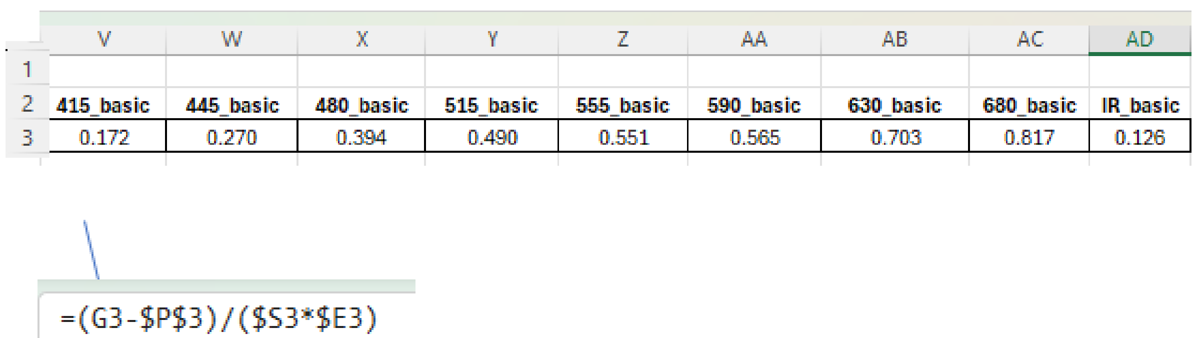
	C	D
7	GAIN LOOKUP TABLE	
8	gain	gain ratio
9	0.5	0.008
10	1	0.016
11	2	0.032
12	4	0.065
13	8	0.125
14	16	0.25
15	32	0.5
16	64	1
17	128	2
18	256	3.95
19	512	7.75

S
gain ratio
7.75

```
=VLOOKUP($F3,$C$9:$D$19,2)
```

Figure 4*: Example gain ratio in Excel.*

Subtract dark counts and convert to basic counts:



	V	W	X	Y	Z	AA	AB	AC	AD
1									
2	**415_basic**	**445_basic**	**480_basic**	**515_basic**	**555_basic**	**590_basic**	**630_basic**	**680_basic**	**IR_basic**
3	0.172	0.270	0.394	0.490	0.551	0.565	0.703	0.817	0.126

```
=(G3-$P$3)/($S3*$E3)
```

Figure 5*: Example of subtracting dark counts and converting to basic counts.*

	U	V	W	X	Y	Z	AA	AB	AC	AD
11										
12		Calibration matrix pasted from "Calibration Matrix (03-Apr-2025-scaled.csv"								
13	**Wavelength**	**415**	**445**	**480**	**515**	**555**	**590**	**630**	**680**	**910**
14	350	0.00162646	-0.00032332	4.73E-05	-1.28E-05	4.43E-06	-1.28E-06	2.83E-07	-6.56E-08	9.03E-10
15	351	0.00163463	-0.00032495	4.75E-05	-1.29E-05	4.45E-06	-1.28E-06	2.85E-07	-6.59E-08	9.08E-10
16	352	0.00164285	-0.00032658	4.78E-05	-1.29E-05	4.47E-06	-1.29E-06	2.86E-07	-6.62E-08	9.12E-10
17	353	0.0016511	-0.00032822	4.80E-05	-1.30E-05	4.50E-06	-1.30E-06	2.87E-07	-6.66E-08	9.17E-10
18	354	0.0016594	-0.00032987	4.82E-05	-1.31E-05	4.52E-06	-1.30E-06	2.89E-07	-6.69E-08	9.21E-10
19	355	0.00166774	-0.00033153	4.85E-05	-1.31E-05	4.54E-06	-1.31E-06	2.90E-07	-6.72E-08	9.26E-10
20	356	0.00167612	-0.00033319	4.87E-05	-1.32E-05	4.56E-06	-1.32E-06	2.92E-07	-6.76E-08	9.31E-10
21	357	0.00168454	-0.00033487	4.90E-05	-1.33E-05	4.59E-06	-1.32E-06	2.93E-07	-6.79E-08	9.35E-10
22	358	0.00169301	-0.00033655	4.92E-05	-1.33E-05	4.61E-06	-1.33E-06	2.95E-07	-6.83E-08	9.40E-10
23	359	0.00170151	-0.00033824	4.95E-05	-1.34E-05	4.63E-06	-1.34E-06	2.96E-07	-6.86E-08	9.45E-10

[...]

750	1086	5.84E-08	-2.78E-07	6.38E-07	-1.73E-06	4.11E-06	-1.04E-05	2.20E-05	-3.64E-05	8.50E-05
751	1087	5.81E-08	-2.76E-07	6.35E-07	-1.73E-06	4.09E-06	-1.03E-05	2.19E-05	-3.63E-05	8.46E-05
752	1088	5.78E-08	-2.75E-07	6.32E-07	-1.72E-06	4.07E-06	-1.03E-05	2.18E-05	-3.61E-05	8.42E-05
753	1089	5.75E-08	-2.74E-07	6.29E-07	-1.71E-06	4.05E-06	-1.02E-05	2.17E-05	-3.59E-05	8.37E-05
754	1090	5.72E-08	-2.72E-07	6.26E-07	-1.70E-06	4.03E-06	-1.02E-05	2.15E-05	-3.57E-05	8.33E-05
755	1091	5.69E-08	-2.71E-07	6.23E-07	-1.69E-06	4.01E-06	-1.01E-05	2.14E-05	-3.56E-05	8.29E-05
756	1092	5.67E-08	-2.70E-07	6.20E-07	-1.68E-06	4.00E-06	-1.01E-05	2.13E-05	-3.54E-05	8.25E-05
757	1093	5.64E-08	-2.68E-07	6.17E-07	-1.68E-06	3.98E-06	-1.00E-05	2.12E-05	-3.52E-05	8.21E-05
758	1094	5.61E-08	-2.67E-07	6.14E-07	-1.67E-06	3.96E-06	-9.96E-06	2.11E-05	-3.50E-05	8.17E-05
759	1095	5.58E-08	-2.66E-07	6.11E-07	-1.66E-06	3.94E-06	-9.91E-06	2.10E-05	-3.49E-05	8.13E-05
760	1096	5.56E-08	-2.64E-07	6.07E-07	-1.65E-06	3.92E-06	-9.86E-06	2.09E-05	-3.47E-05	8.09E-05
761	1097	5.53E-08	-2.63E-07	6.04E-07	-1.64E-06	3.90E-06	-9.81E-06	2.08E-05	-3.45E-05	8.05E-05
762	1098	5.50E-08	-2.62E-07	6.01E-07	-1.64E-06	3.88E-06	-9.76E-06	2.07E-05	-3.43E-05	8.01E-05
763	1099	5.47E-08	-2.60E-07	5.98E-07	-1.63E-06	3.86E-06	-9.72E-06	2.06E-05	-3.42E-05	7.97E-05
764	1100	5.45E-08	-2.59E-07	5.95E-07	-1.62E-06	3.84E-06	-9.67E-06	2.05E-05	-3.40E-05	7.93E-05

***Figure 6**: Beginning and end of sample imported calibration matrix, truncated in the middle.*

	AF	AG
10		
11		
12	**Reconstruced SPD**	
13	**Wavelength**	
14	350	0.000206124
15	351	0.00020716
16	352	0.000208201
17	353	0.000209247
18	354	0.000210298
19	355	0.000211355
20	356	0.000212417
21	357	0.000213485
22	358	0.000214558
23	359	0.000215636
24	360	0.000216719
[...]		
750	1086	-7.8186E-06
751	1087	-7.7814E-06
752	1088	-7.7442E-06
753	1089	-7.707E-06
754	1090	-7.6697E-06
755	1091	-7.6326E-06
756	1092	-7.5954E-06
757	1093	-7.5583E-06
758	1094	-7.5213E-06
759	1095	-7.4843E-06
760	1096	-7.4474E-06
761	1097	-7.4106E-06
762	1098	-7.3738E-06
763	1099	-7.3371E-06
764	1100	-7.3005E-06

```
=MMULT(V14:AD764,TRANSPOSE(V3:AD3))
```

***Figure 7**: Matrix multiplication and resulting reconstructed SPD.*

Python Example

This example illustrates the reconstruction of an SPD from a single VEET spectral sensor output using the current calibration matrix, as implemented in Python.

```
import numpy as np
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt

# ── Load Calibration Matrix (Channels as index, Wavelengths as columns)
# shape: (channels × wavelengths)
cm_df = pd.read_csv("CM_AS7341_03-Apr-2025-scaled.csv", index_col=0)


# ── Gain Ratios ───────────────────────────────────────
PhoGainRatios = {
    0.5: 0.008,
    1: 0.016,
    2: 0.032,
    4: 0.065,
    8: 0.125,
    16: 0.25,
    32: 0.50,
    64: 1.00,
    128: 2.00,
    256: 3.95,
    512: 7.75,
}

# ── Example PHO Sensor Output ─────────────────────────
#for the example showing a single line of output as a dictionary
#a larger dataset would most likely be imported as a dataframe.
pho_output = {
    "Int_Time": 100,
    "Gain": 512,
    "415": 133, "445": 209, "480": 305, "515": 380,
    "555": 427, "590": 438, "630": 545, "680": 633,
    "910": 98, "Clear": 1467, "Dark": 0
}

gain_ratio = PhoGainRatios[pho_output["Gain"]]

channels = cm_df.columns.tolist() #pho channels need same naming to work

norm_counts = np.array([
    (pho_output[ch] - pho_output["Dark"]) /
    (pho_output["Int_Time"] * gain_ratio)
    for ch in channels
])
```

```
# ── Multiply:
# (wavelengths × channels) @ (channels × 1) → (wavelengths × 1)
spd = cm_df.values @ norm_counts.T  # shape: (n_wavelengths,)

# ── Plot SPD ──────────────────────────────────────────────────────
wavelengths = cm_df.index.astype(int)
plt.figure(figsize=(8, 4))
sns.lineplot(x=wavelengths, y=spd)
plt.title("SPD Reconstruction")
plt.xlabel("Wavelength (nm)")
plt.ylabel("Irradiance (W/m^2/nm)")
plt.show()
```

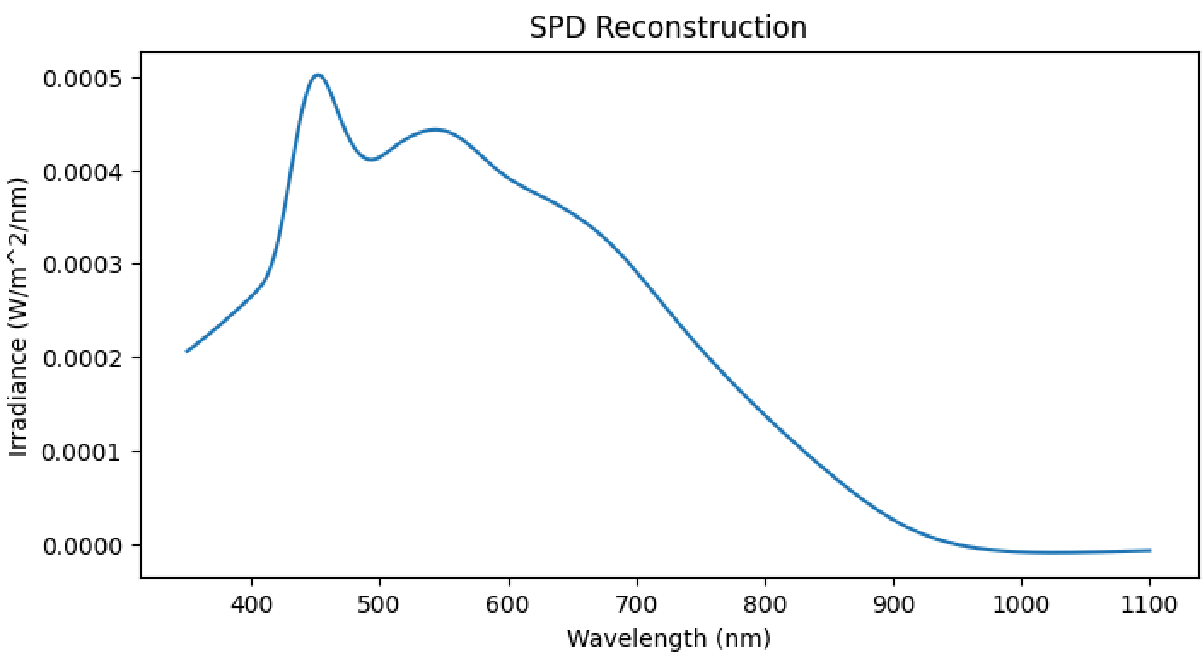


Figure 8: *SPD plot output from Python example*

Comparison to Measured Spectral Power Distributions

Below, twelve standard illuminant SPDs are compared to the actual SPD measured with a spectrometer and plotted alongside the reconstructed SPD. Notably, the SPD reconstruction based on the VEET responses predicted from the VEET responsivity curves showed improved agreement with the measured SPDs. This difference is particularly evident for Illuminant E in the 400-500 nm range.

The calibration matrix was derived using VEET responsivity curves, with each channel subsequently scaled to match the actual count magnitudes from the device. The observed discrepancy suggests a mismatch between the actual device response and the expected response defined by the curves. The most probable cause is an inaccurate responsivity sweep for channel 415, which was derived from measurements with limited resolution in this wavelength range. Improving the precision of the channel responsivity sweeps—particularly for channel 415—is an important area of follow-on work that is expected to enhance reconstruction accuracy.

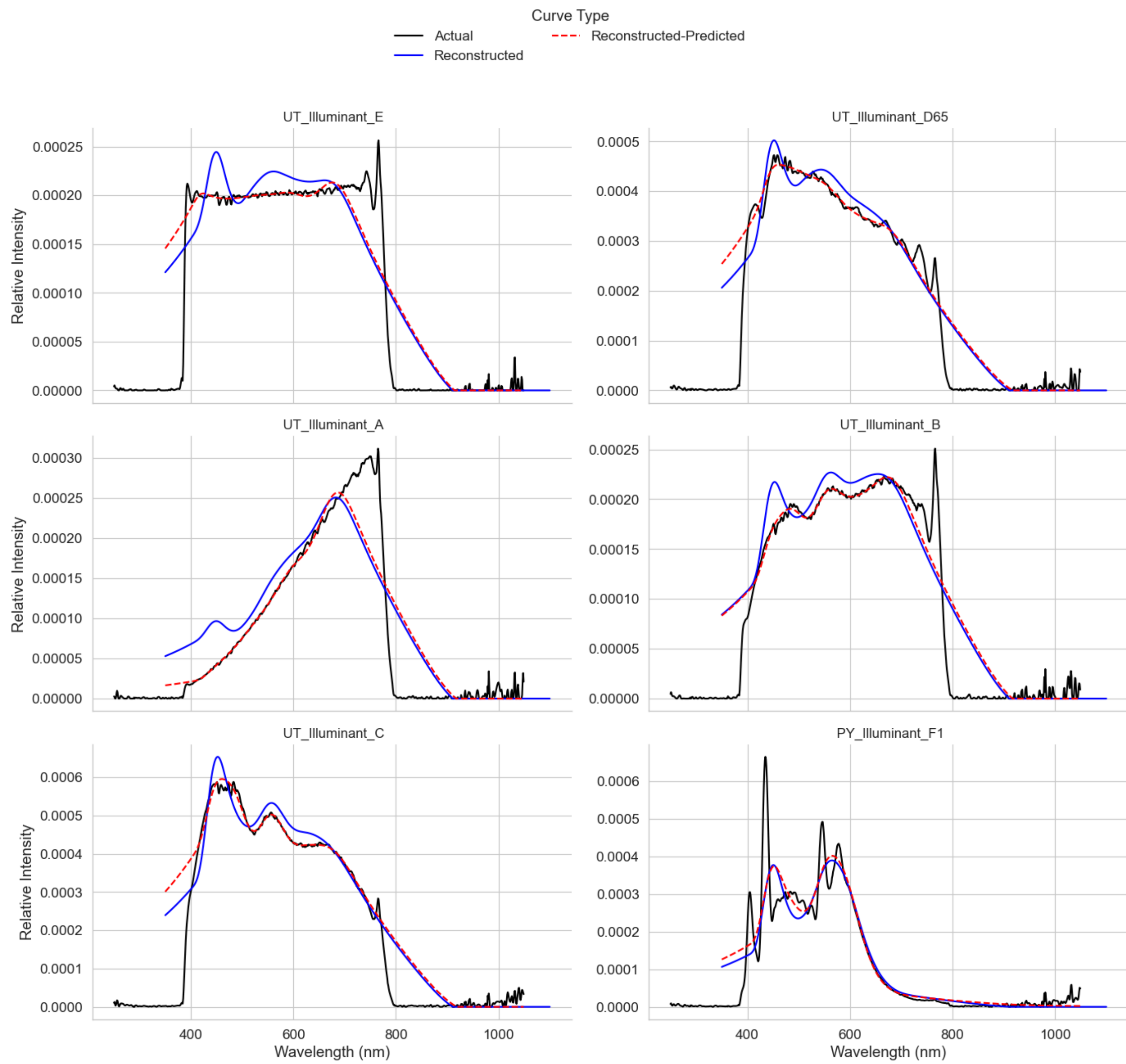


***Figure 9**: Reconstructed SPDs of Standard Illuminants (plot 1 of 2)*

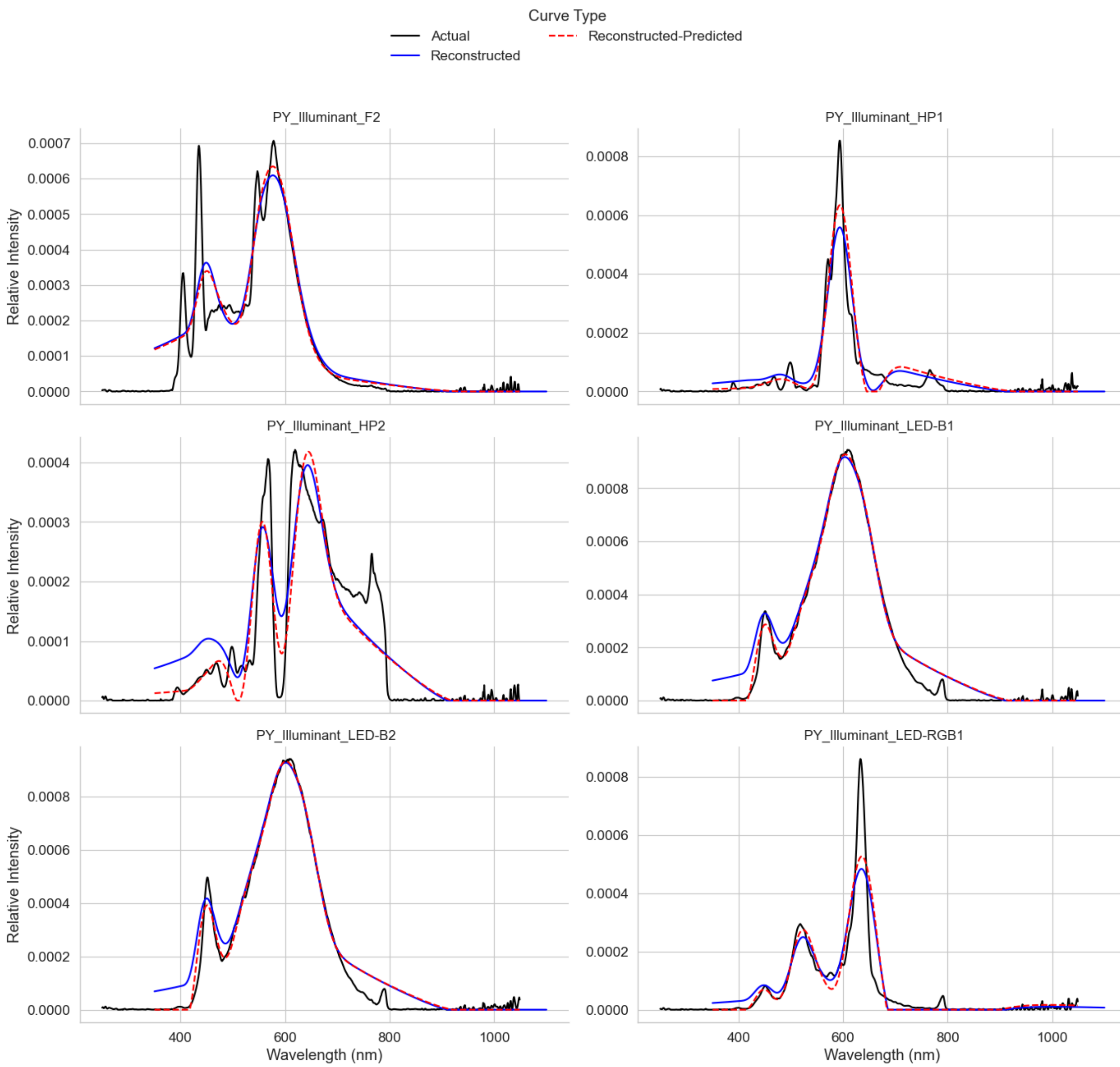


***Figure 10**: Reconstructed SPDs of Standard Illuminants (plot 2 of 2)*

References

1. ams-OSRAM AG. TSL2585 (2022). Miniature Ambient Light Sensor with UV and Light Flicker Detection: Public Datasheet. Retrieved from: *https://look.ams-osram.com/m/7899f3742d5a3f00/original/TSL2585-Miniature-Ambient-Light-Sen sor-with-UV-and-Light-Flicker-Detection.pdf*