Modelling the night sky brightness and light pollution sources of Montsec protected area

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[e]Université de Sherbrooke

Interreg POCTEFA

UNIÓN EUROPEA
UNION EUROPÉENNE

PLN PIRINEOS / PYRÉNÉES La Nuit

Parc Astronòmic Montsec

UNIVERSITAT DE BARCELONA

IEEC INSTITUT D'ESTUDIS ESPACIALS DE CATALUNYA

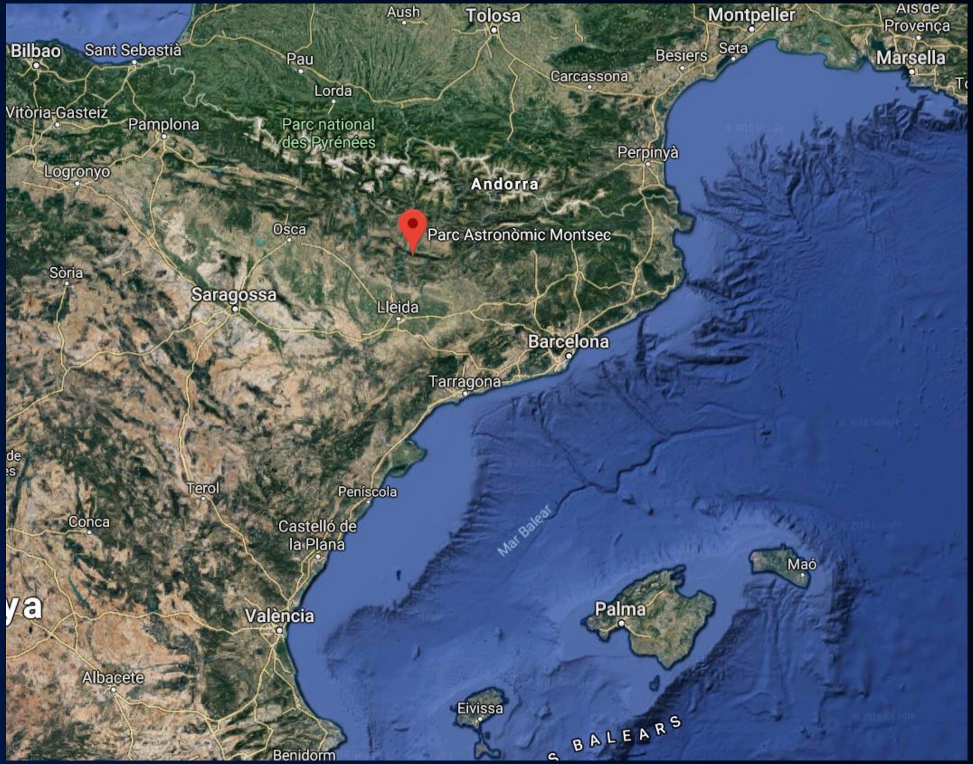
ICCUB Institut de Ciències del Cosmos

EXCELENCIA MARÍA DE MAEZTU

PAM

Parc Astronòmic del Montsec (COU and OAdM) is ideal for astronomic purposes:

- Low pluviometry and humidity
- High ratio of clear nights
- Elevation 1600m
- LP protected area



Purposes

1. Model the night sky over Montsec Observatory:
   - Natural sky brightness
   - Any LP in a range of 50km
   - Special treatment for Lleida, Tremp and Balaguer.
2. Test our method: all sky maps (ASTMON)
3. Compare the emission received from Lleida before and after a lighting system update

Model

1. ILLUMINA (Martin Aubé et al)
2. Post processing for NSB and astronomic magnitudes

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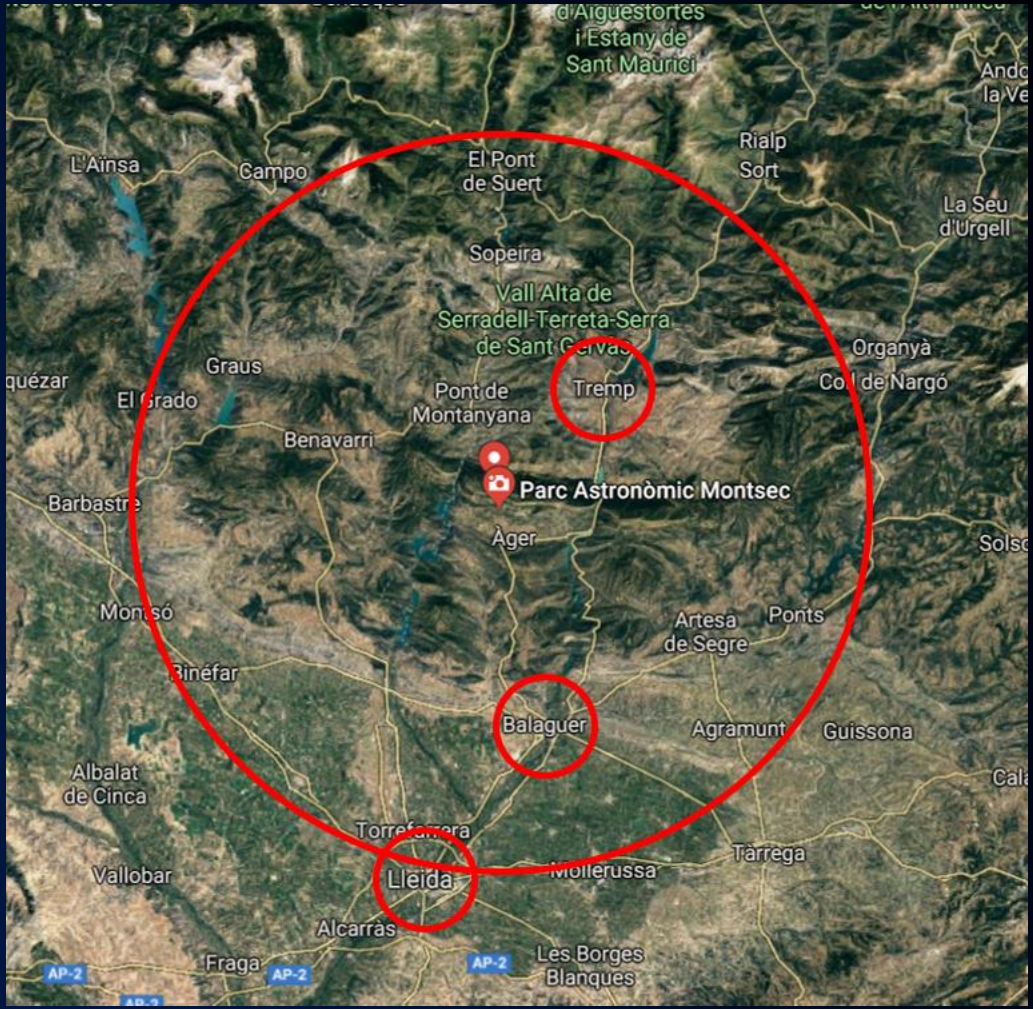

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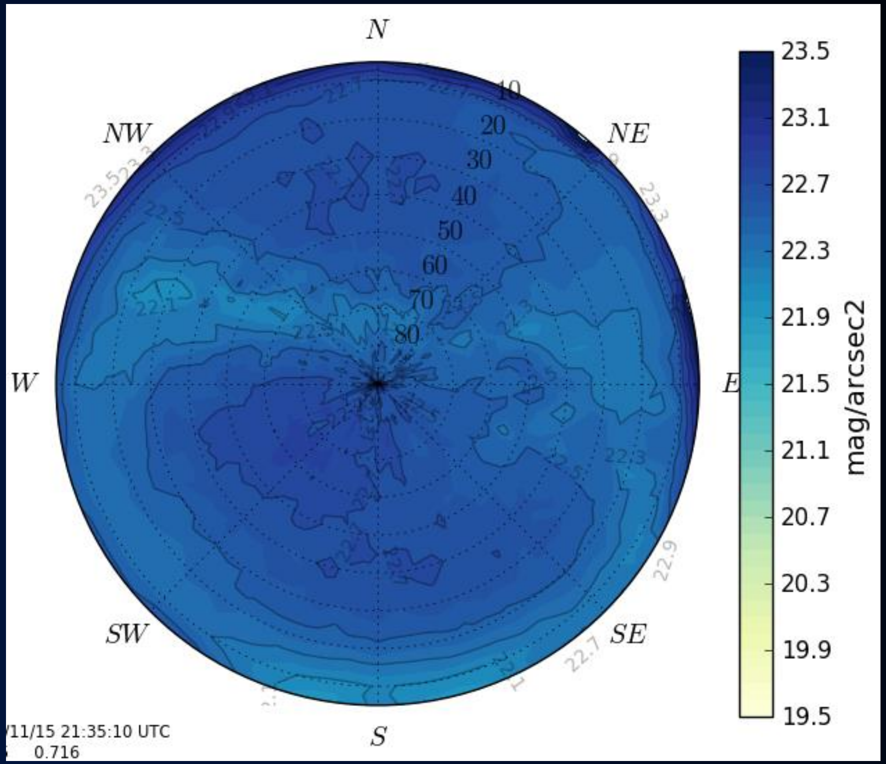

Image obtained using PyASB "Absolute photometry and Night Sky Brightness with all-sky cameras-UCM", Master Thesis (2013) Mireia Nievas

Model

1. ILLUMINA (Martin Aubé et al)
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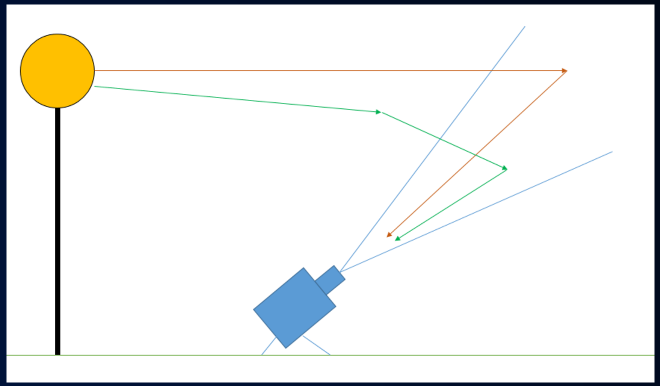
ILLUMINA (Aubé et. al.)
(DOI: 10.1016/j.jqsrt.2018.02.033)

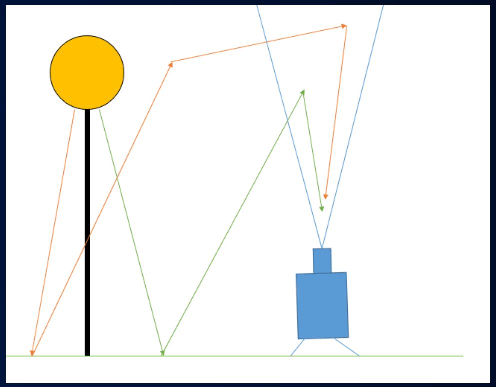


<u>Light path</u>

- First and second order (aerosol and molecular)
- Ground reflectance: MODIS

<u>Input parameters</u>

- Light emittance: VIIRS
- Topography: SRTM
- Atmospheric parameters: AoD, AC, pressure, humidity
- LP zones definition
- Observer position
- Lines of sight
- Wavelength range and subdivision



<u>Output data</u>

Sky radiance (W/str/m^2) in any direction.
Contribution of each point to the total sky radiance.

ILLUMINA
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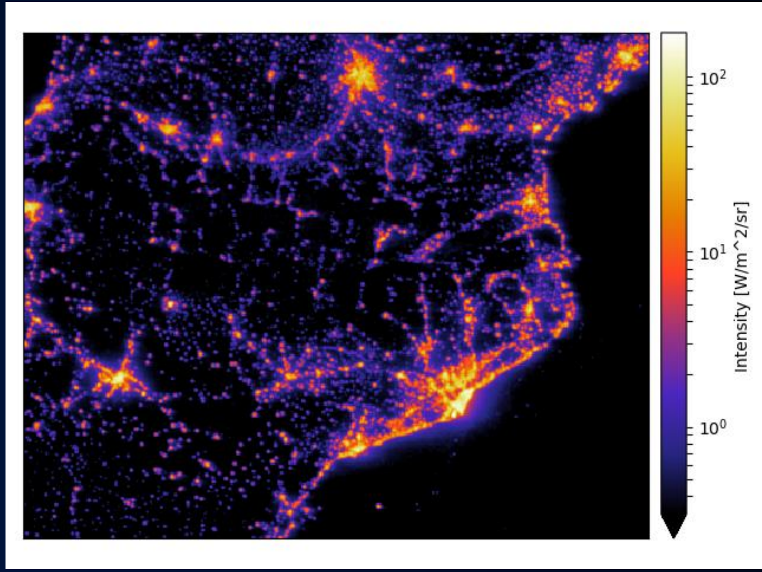

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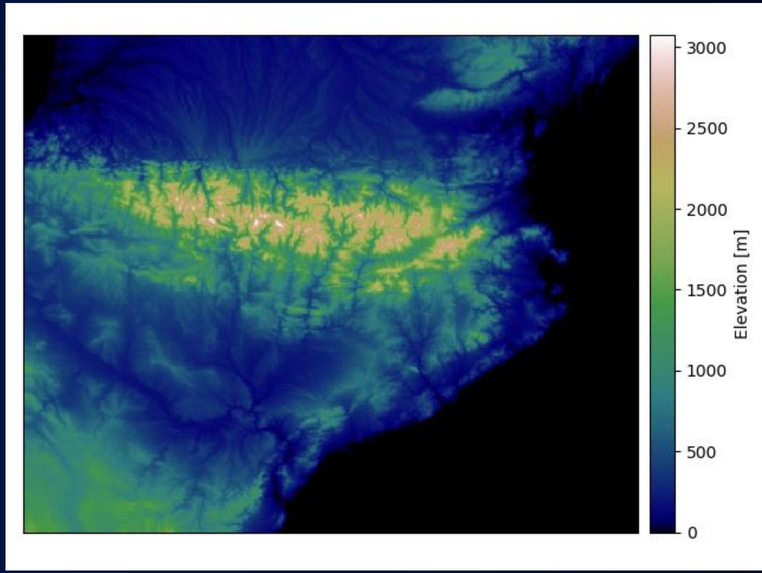

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# x'	y'	R	hobs	dobs	fobs	hlamp	Zone inventory	Comment
90	325	50	7	25	0.5	7	90_H_5 10_M_10	# Oahu
190	277	40	7	25	0.5	7	90_H_5 10_M_10	# Molokai + Lanai
280	253	64	7	25	0.5	7	18_H_10 72_H_0 10_M_10	# Maui
343	129	103	7	25	0.5	7	87_L_10 8_H_10 5_M_5	# Big Island
381	90	23	7	25	0.5	7	0_L_0	# Lava

Light path
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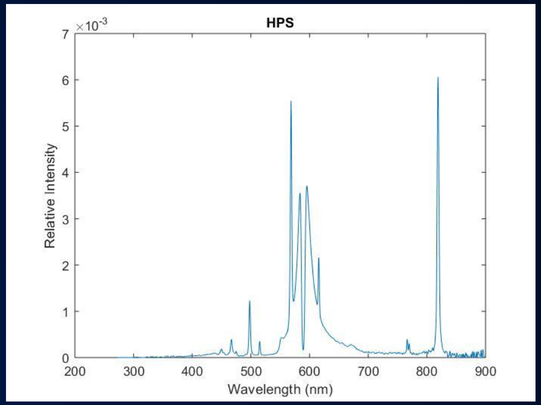

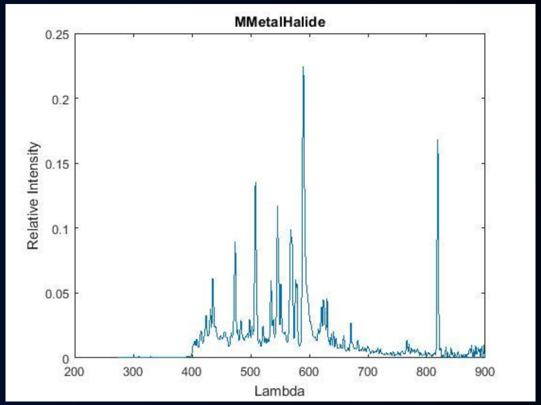

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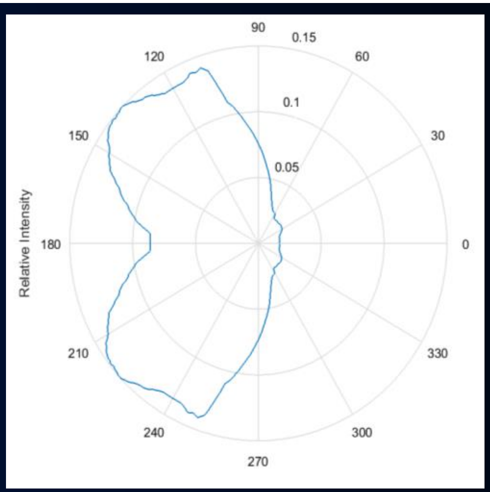

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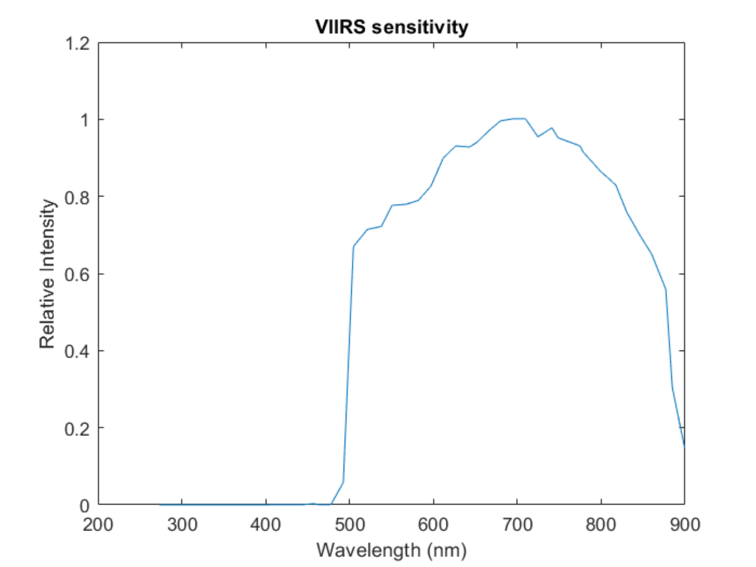
ILLUMINA

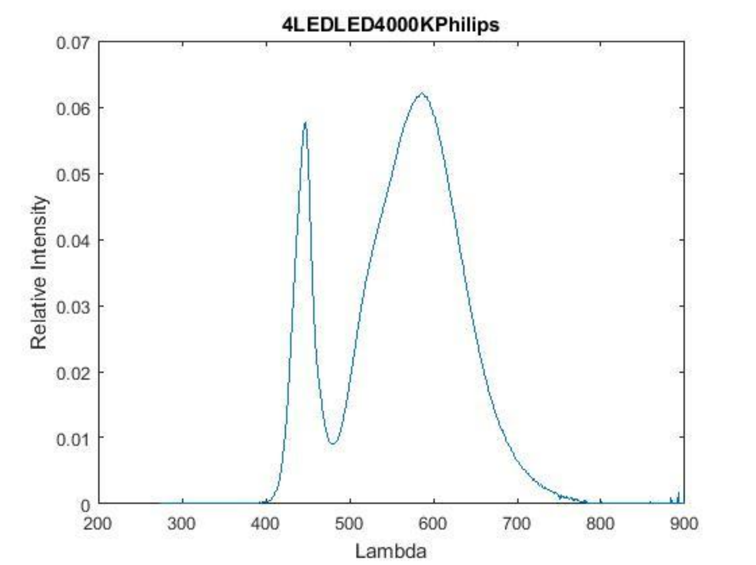
VIIRS senbilitiy correction

VIIRS does not detect all the light emitted. If not corrected we are underestimating the LP produced.

$$\Phi_e = \frac{DNB \times S}{\int_\lambda R(\lambda)T(\lambda)\left(\frac{1}{\pi}\rho(\lambda)F_{90-180}(\lambda) + \langle \bar{G} \rangle_{0-56}(\lambda)\right) \mathrm{d}\lambda}$$

Technology	%Light detected by VIIRS
HP Sodium	79
LED 4000k	66
Mercury	59
Metal Hallide	62





POST-PROCESSING

Mission

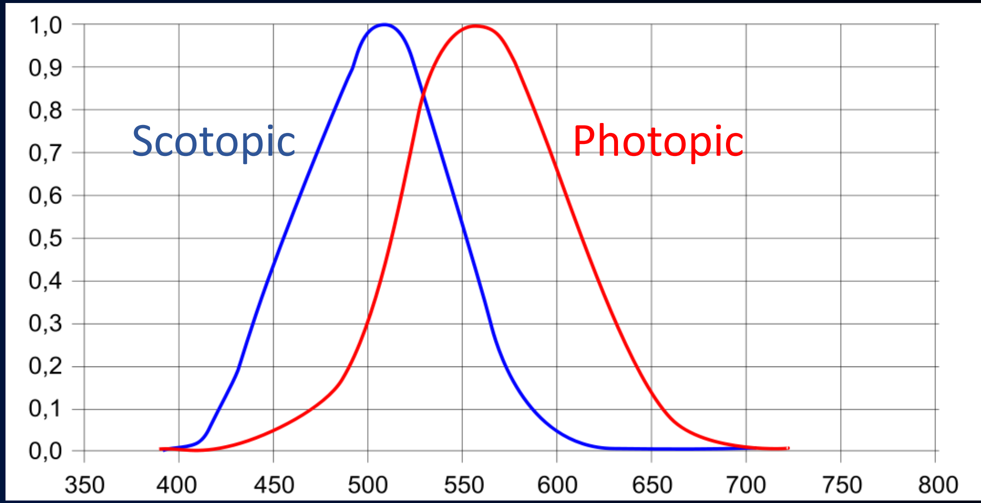
Convert the output of ILLUMINA to astronomical magnitudes in the visible B-V-R Johnson's Filters taking into account the natural brightness of night sky.

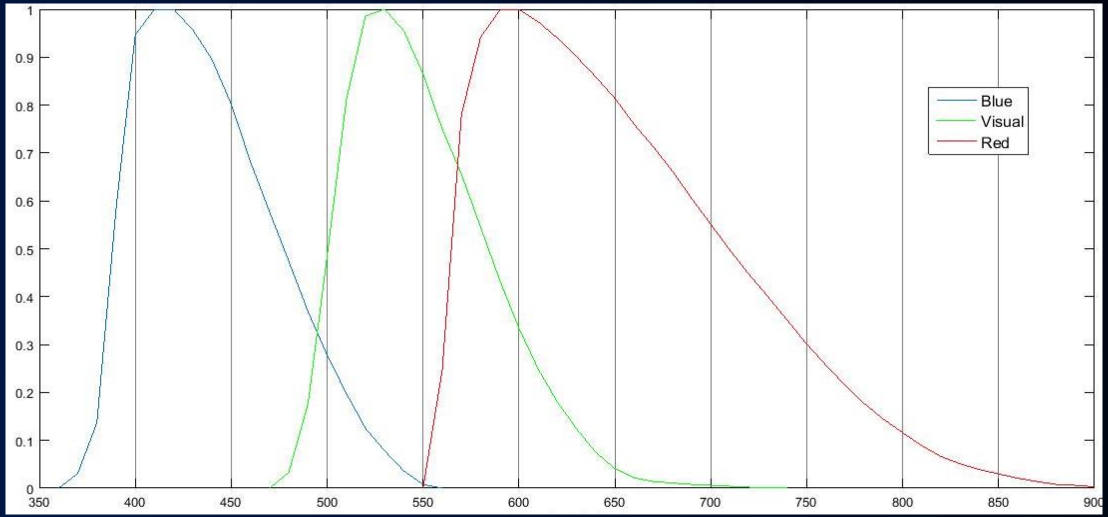
Apparent magnitudes

$$F_{NNS} = F_{Vega} * 10^{(0.4*(m_{Vega}-m_{NNS}))}$$

$$m_{obs} = m_{Vega} - 2.5 * \log_{10}\left(\frac{F_{LP} + F_{NNS}}{F_{Vega}}\right)$$

Johnson Filter	Vega (mag)	Natural Sky (mag/arcsec^2)
B	-0.023	22.7
V	-0.023	21.8
R	-0.023	20.9





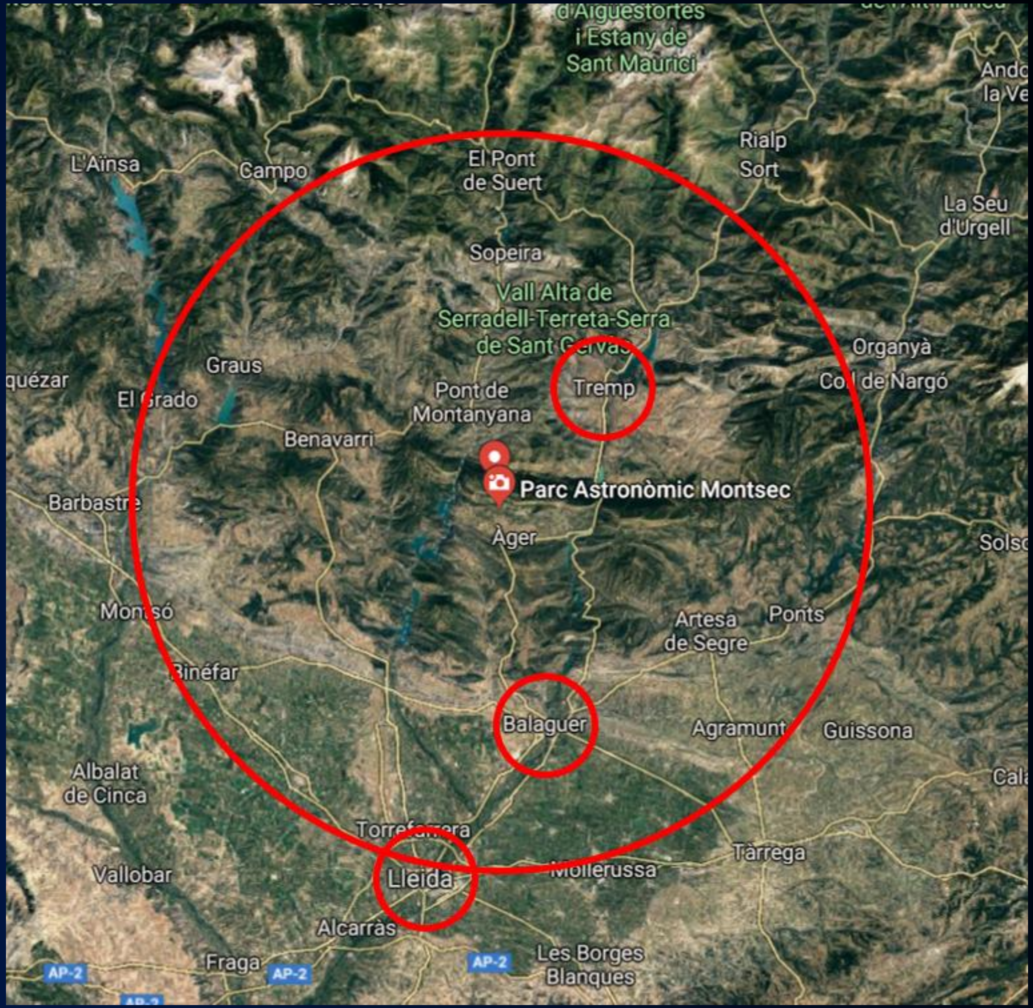
Parameters

-Wl: 350-830nm (16x30nm)
-LoS: 1225 (az5xel5)
-Atm pressure: 101,3 kPa
-No clouds, sky clear
-Relative humidity 70%
-AoD: AERONET 0.090
-Angstrom coefficient: AERONET 0.996

LP sources

- Lleida: 140.000 inhabitants, 50km from PAM (190º)
- Balaguer: 16.000 inhabitants, 35km from PAM (165º)
- Tremp: 6.000 inhabitants, 20km from PAM (45º)

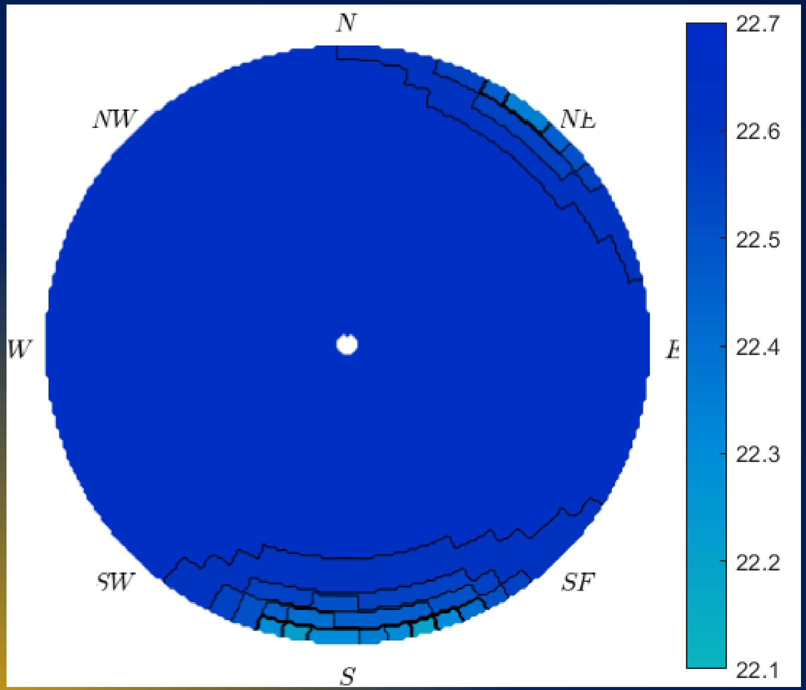
		HPS	MH	LED	Other
LL	%#	49	13	33	5
	%F	72	13	15	-
BLG	%#	77	14	9	<1
	%F	78	17	5	-
TR	%#	100	-	-	-
	%F	100	-	-	-
GNRL	%#	80	20	-	-
	%F	90	10	-	-

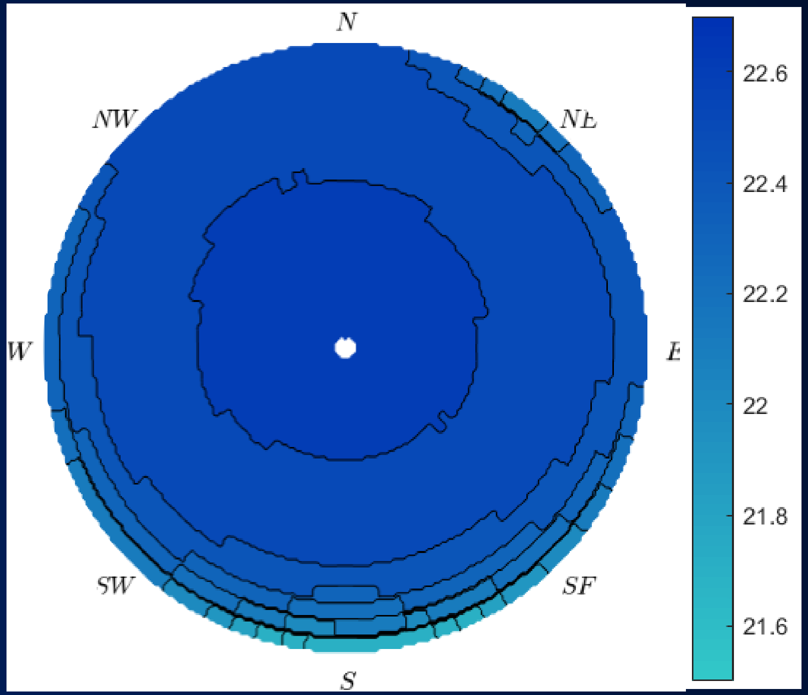


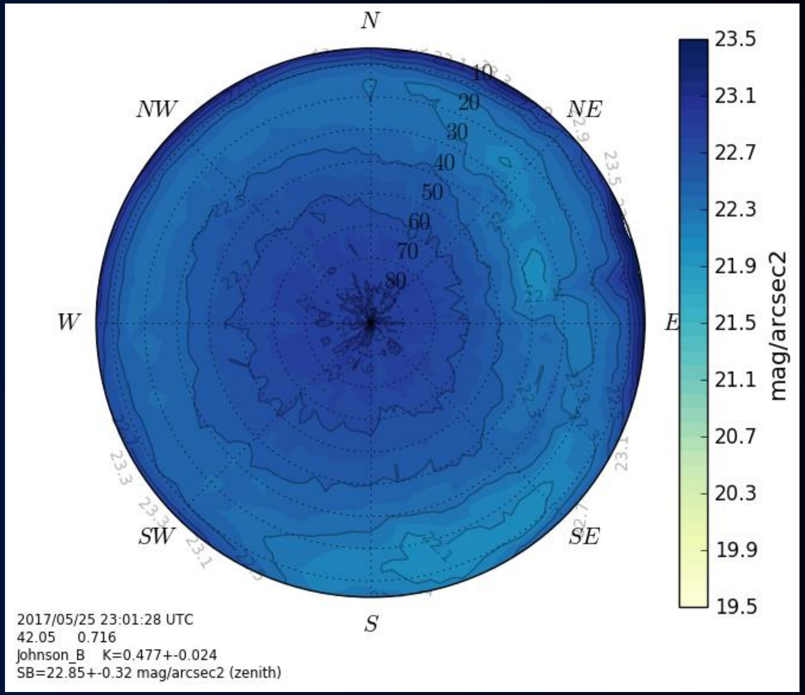
All-sky maps (B)

- Cities well modeled
- Good correlation above 15º (zenith)

- Complete model too bright in low elevation angles
- Model has clear NNS vs MW presence in measurements

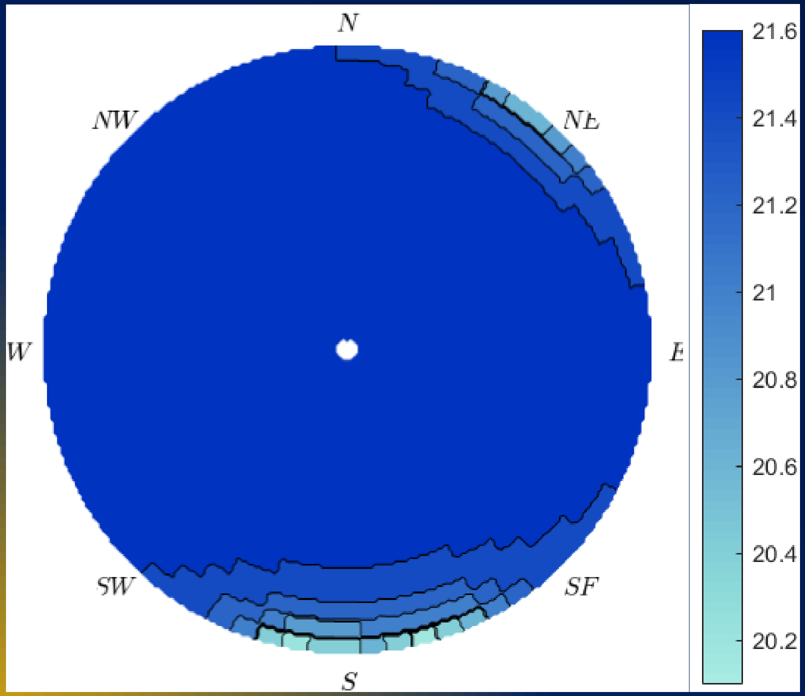


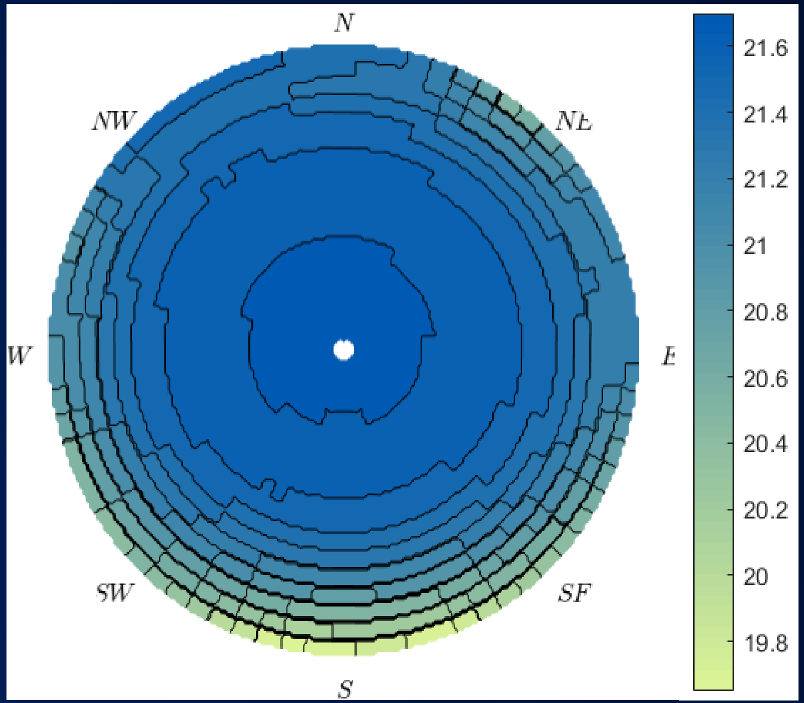


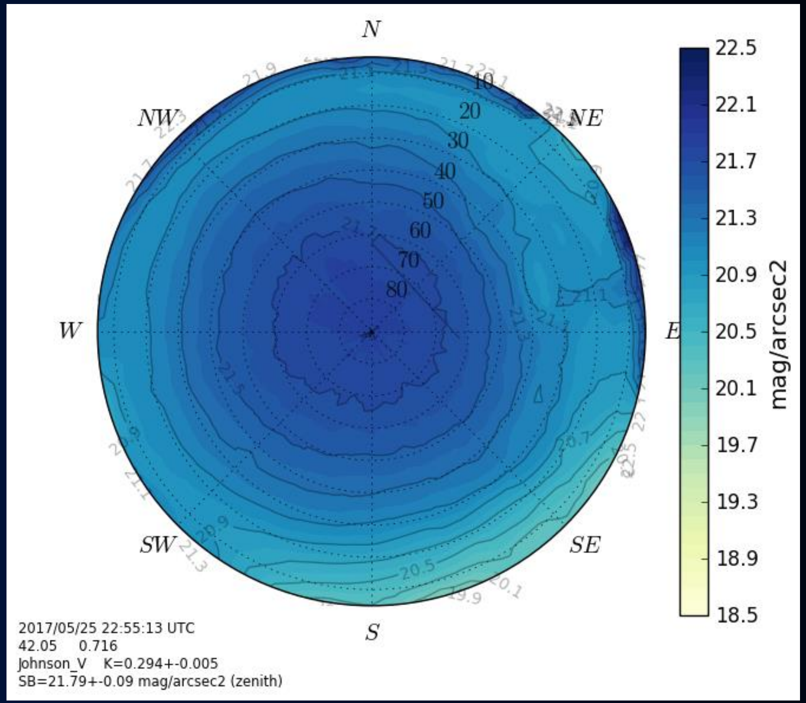


All-sky maps (V)

- Cities well modeled
- Good correlation above 15º (zenith)
- Model 3 or 4 LP directions, measurements 5 (Barcelona)
- Complete model too bright in low elevation angles
- Model has clear NNS vs MW presence in measurements

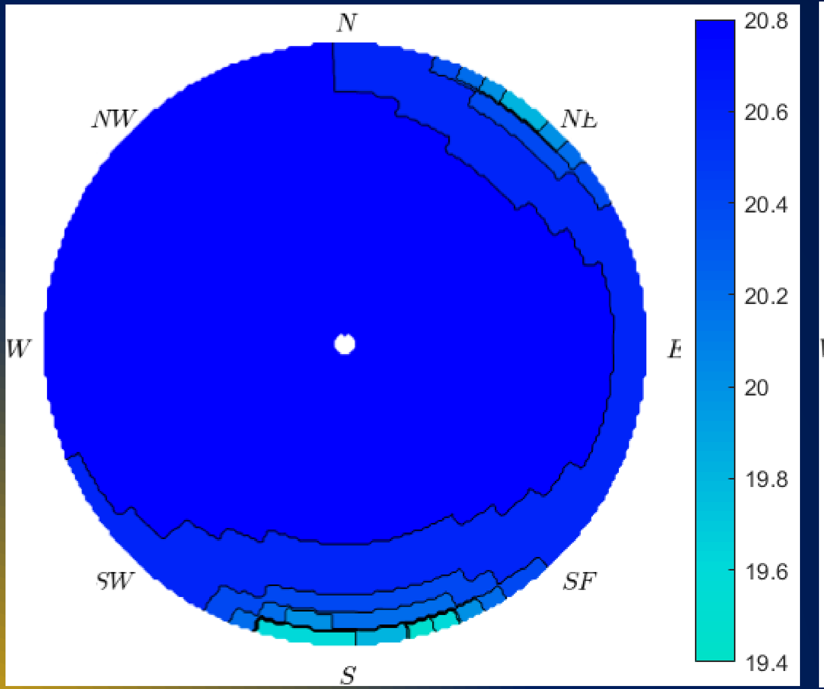


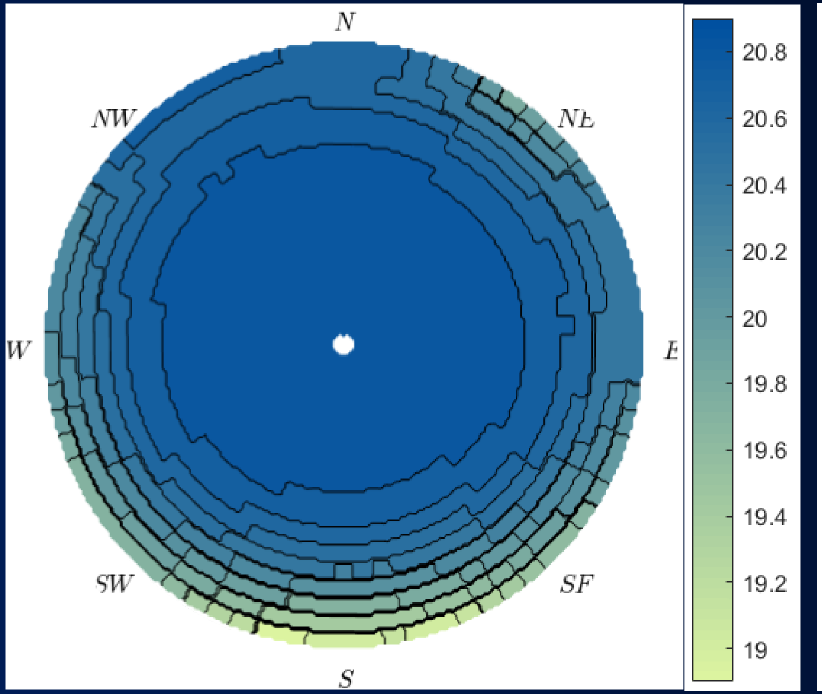


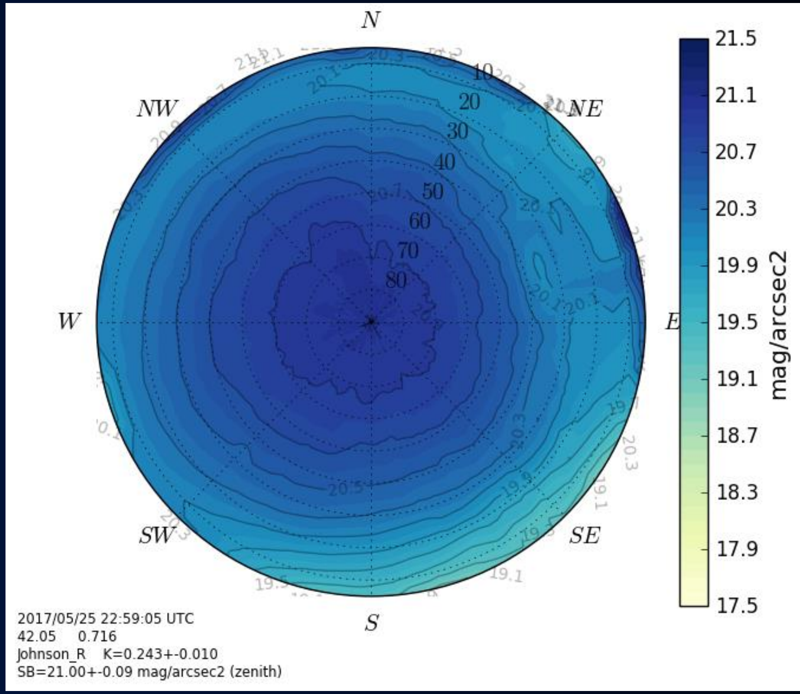


All-sky maps (R)

- Cities well modeled
- Good correlation above 15º (zenith)
- Model 3 or 4 LP directions, measurements 5 (Barcelona)
- Complete model too bright in low elevation angles
- Model has clear NNS vs MW presence in measurements

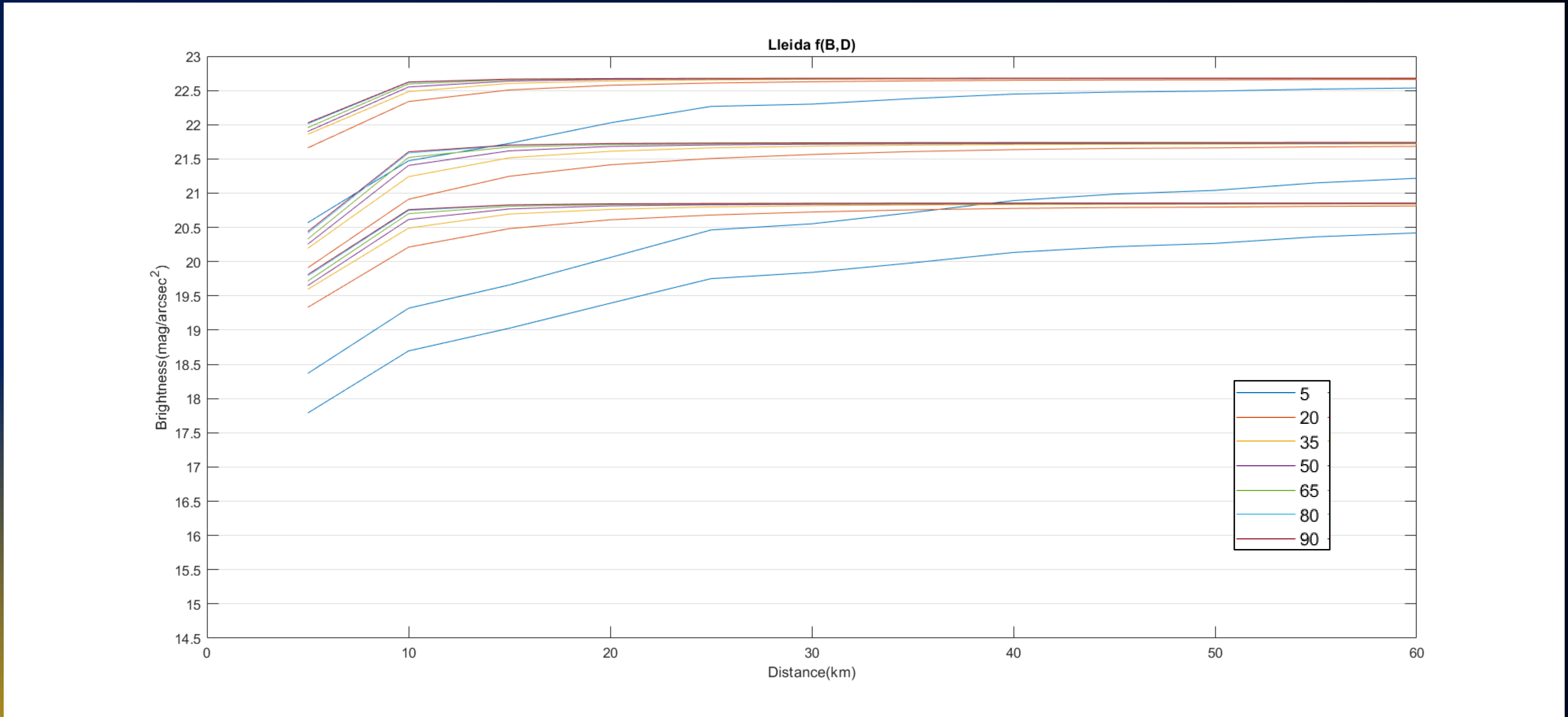






Brightness-Distance function

NSB: B=22.7, V=21.8, R=20.9



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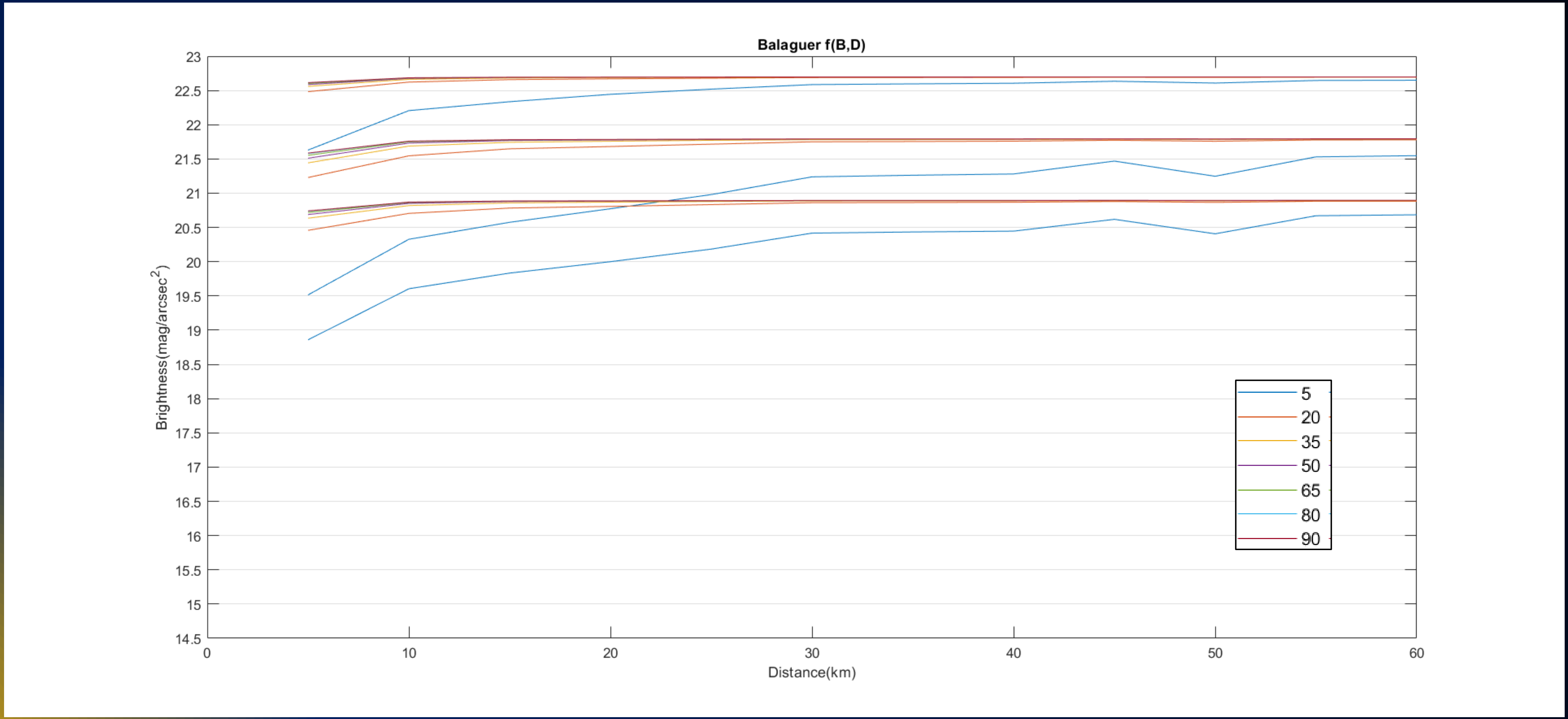

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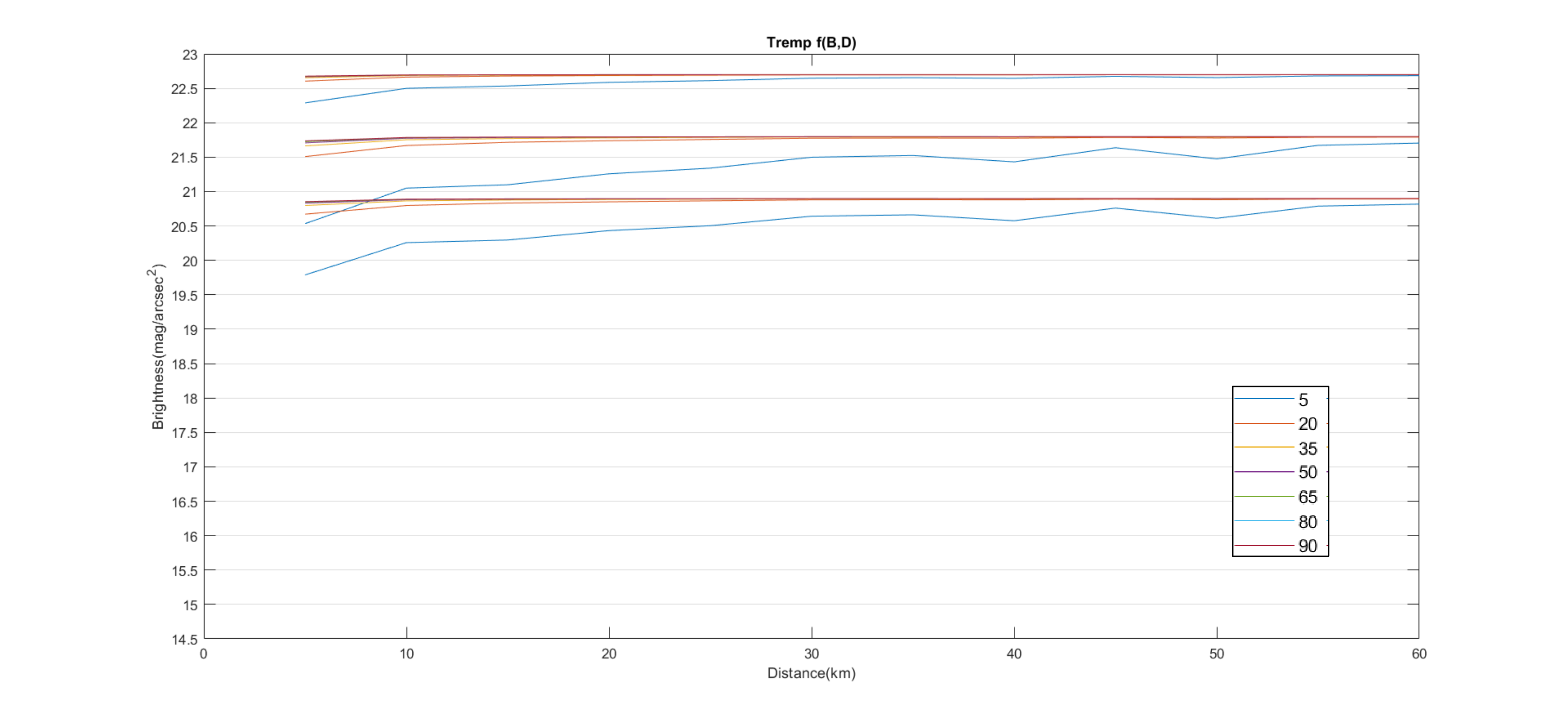

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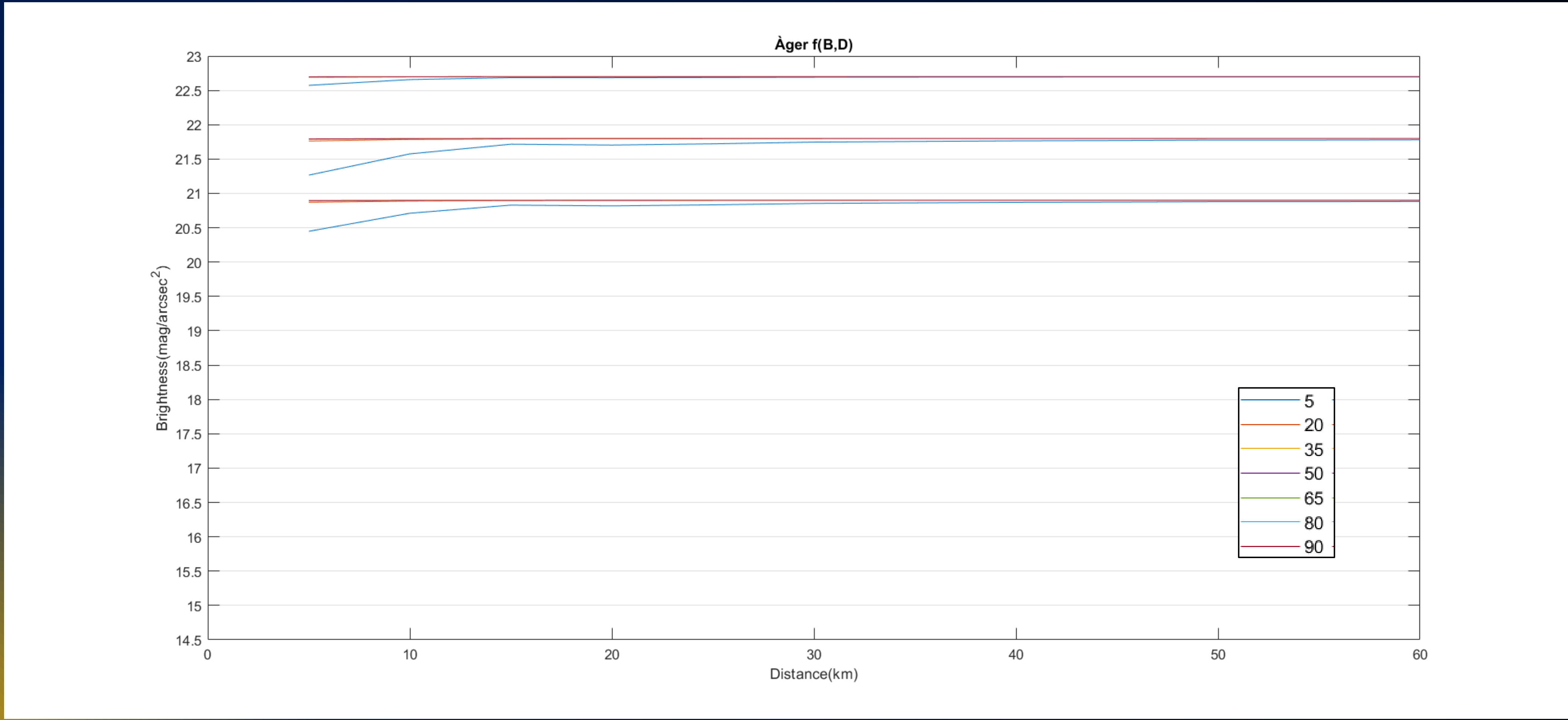

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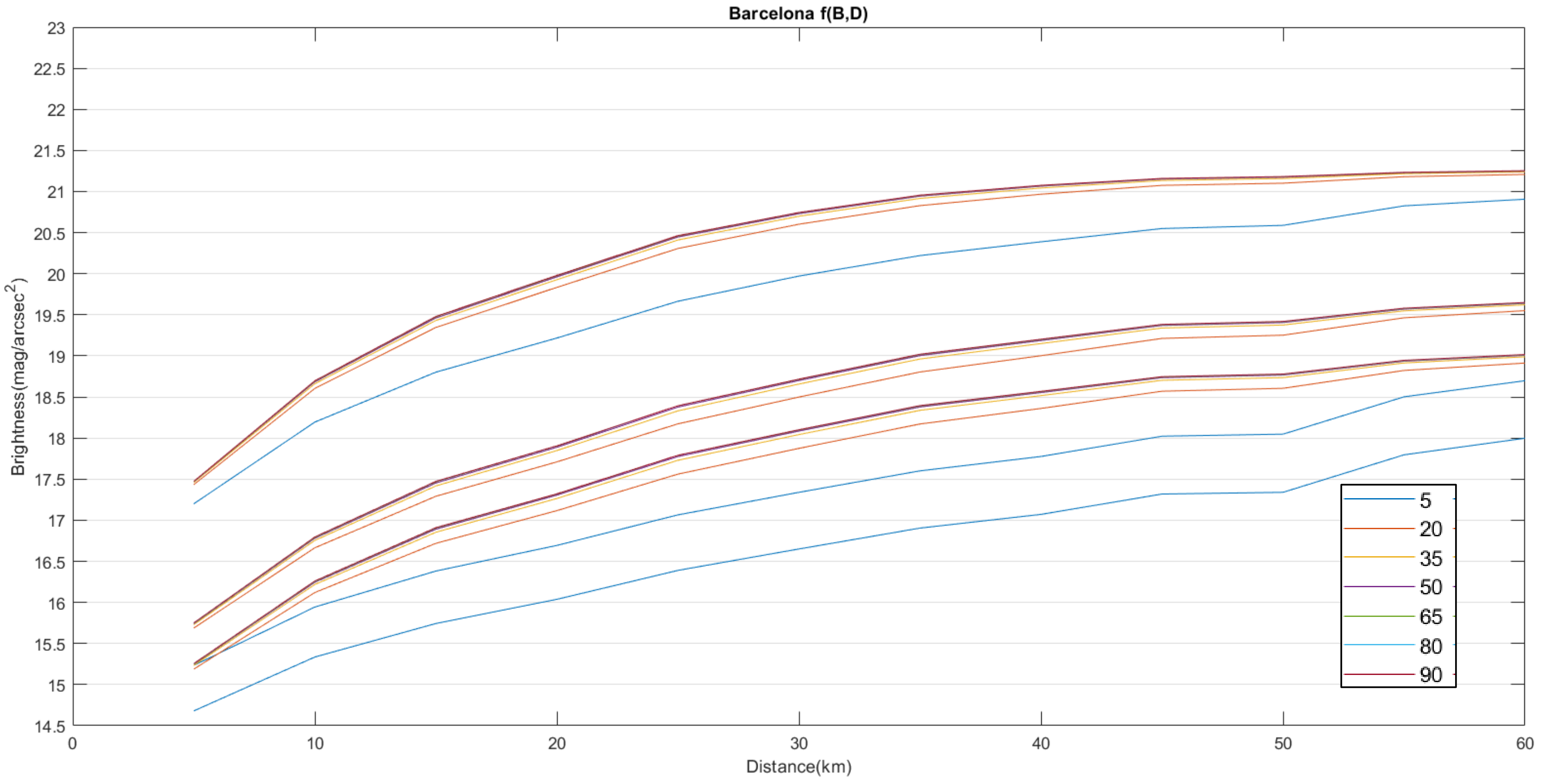


Change of lights in Lleida 2014

140.000 inhabitants, 50km south from PAM (190º)
2014 update of lighting system

- Removal of Mercury lamps
- Installation of LED 4000 K
- Lowering the power of HPS
- 36% reduction in power consumed (W)
- 30% reduction in luminous flux (lm)

		HPSV	MH	LED 4k	MV	Other
2013	%#	71	19	-	7	3
	%F	84	13	-	3	-
2015	%#	49	13	33	-	5
	%F	72	13	15	-	-

COMPARING USING VIIRS

VIIRS images show fluctuation:
- Aerosol content
- Angle of vision

Reference point-> Balaguer

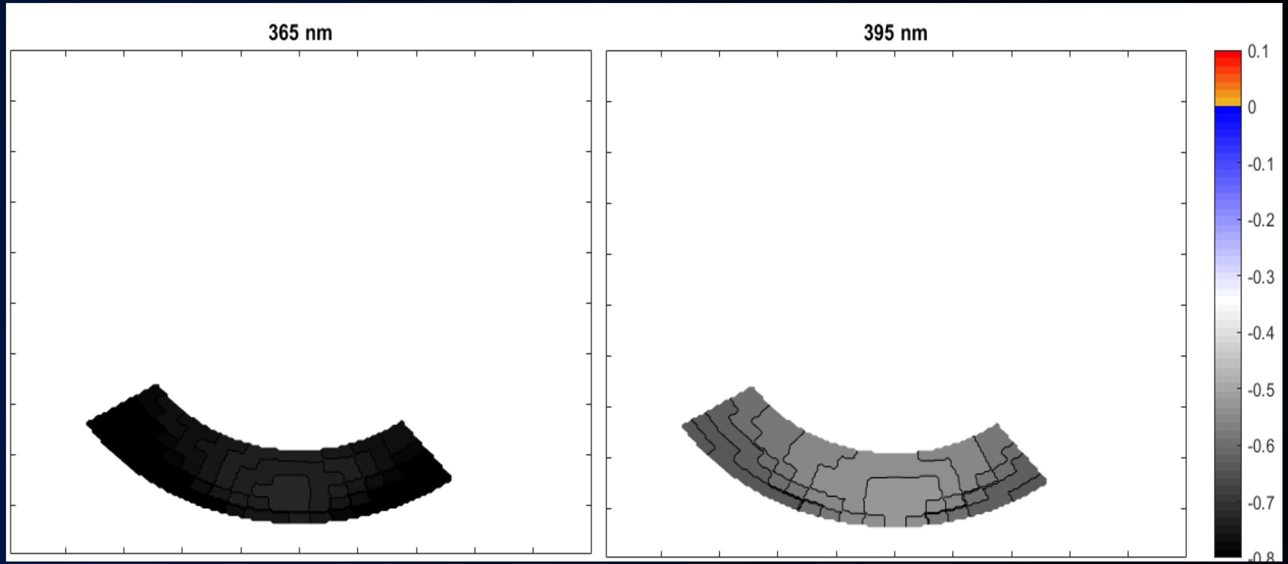
No changes in the lighting system
No change in the LP measured from the PAM

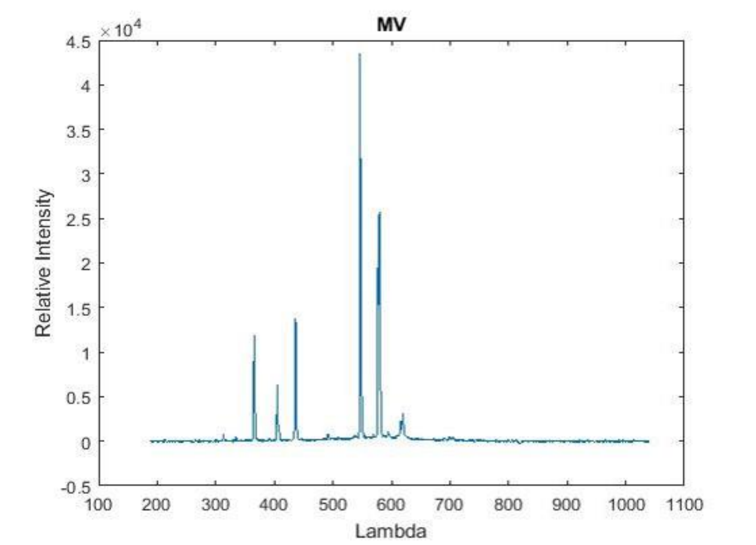
Fluctuations up to 25% in any direction and wl

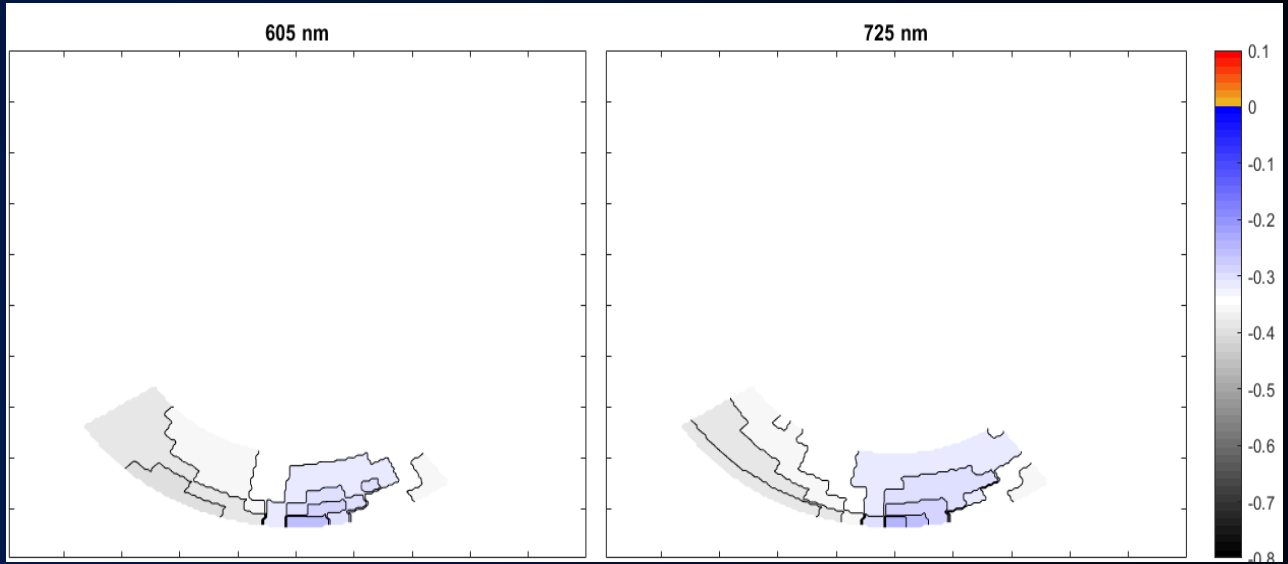
Spectral flux comparison

$$C = \frac{F_{2018} - F_{2013}}{F_{2013}}$$

- Huge reduction at very low wl (>60%)







Spectral flux comparison

$$C = \frac{F_{2018} - F_{2013}}{F_{2013}}$$

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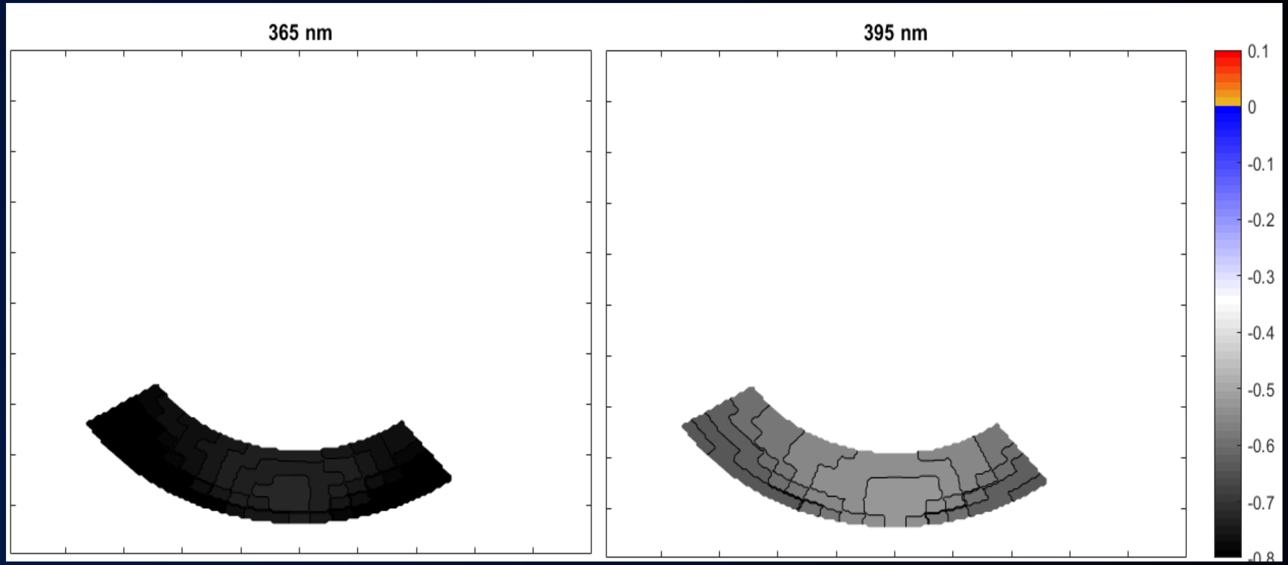
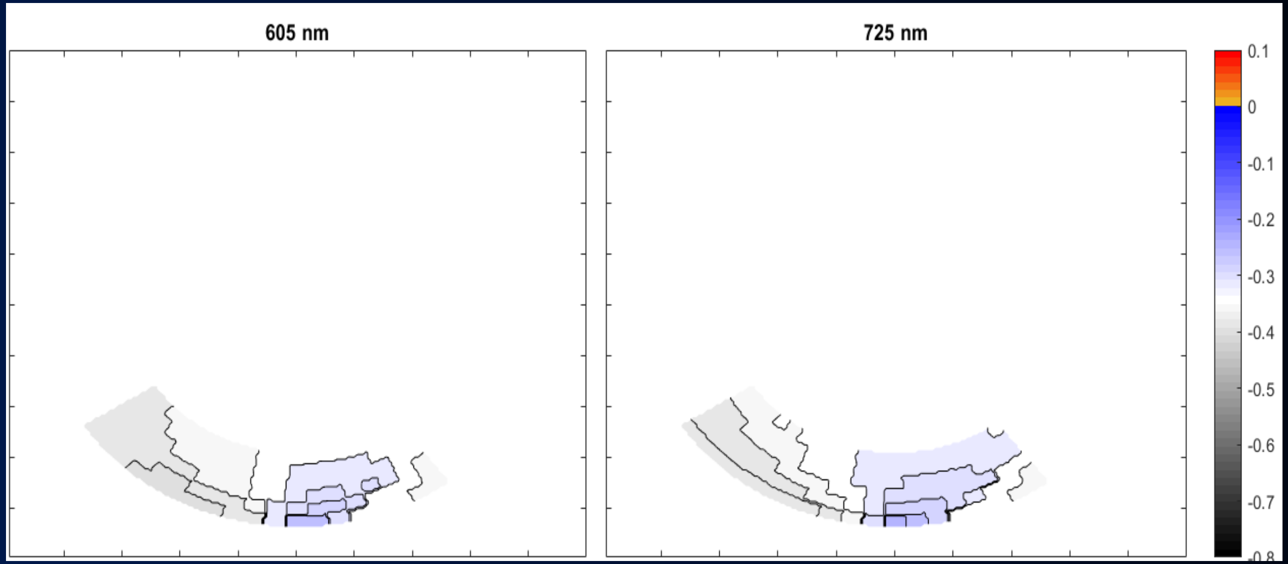
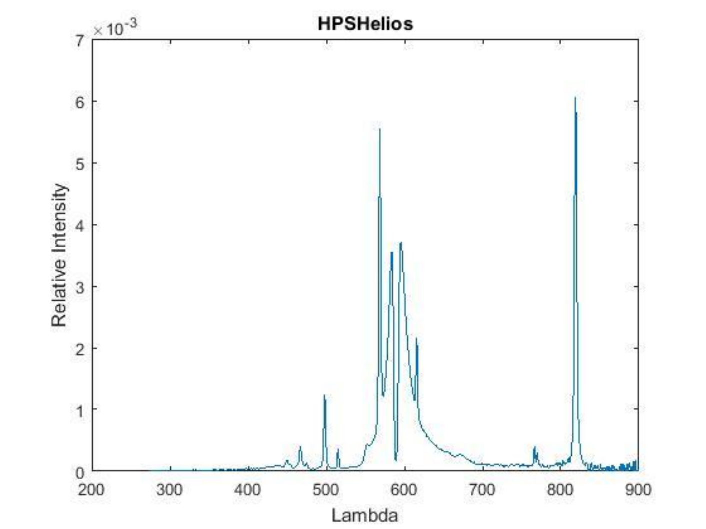
- Persistent reduction above 550 nm (~30%)



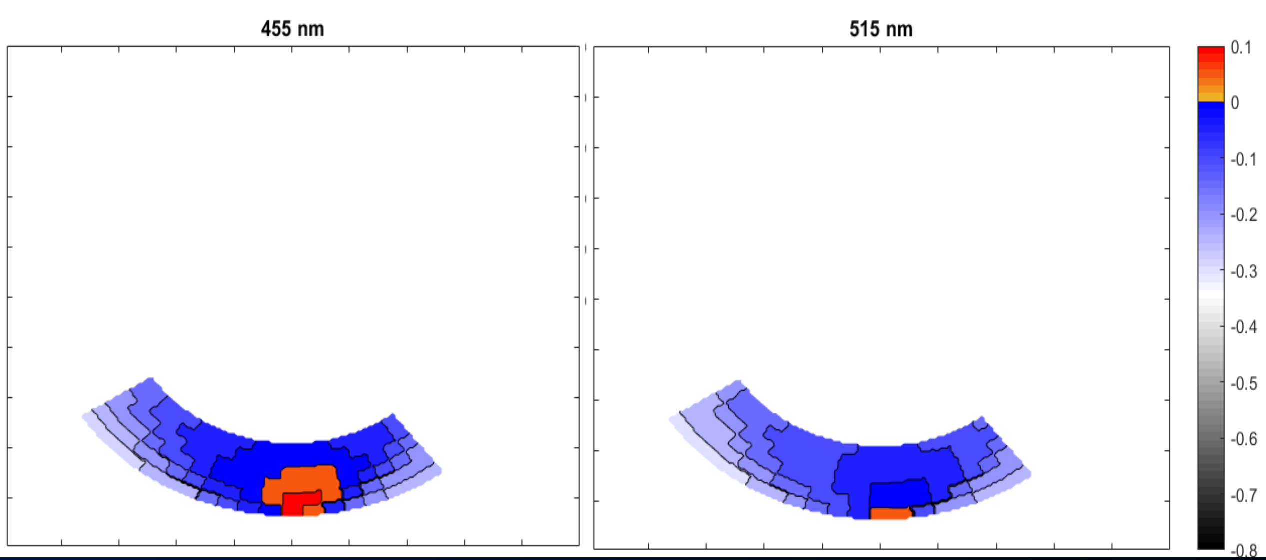


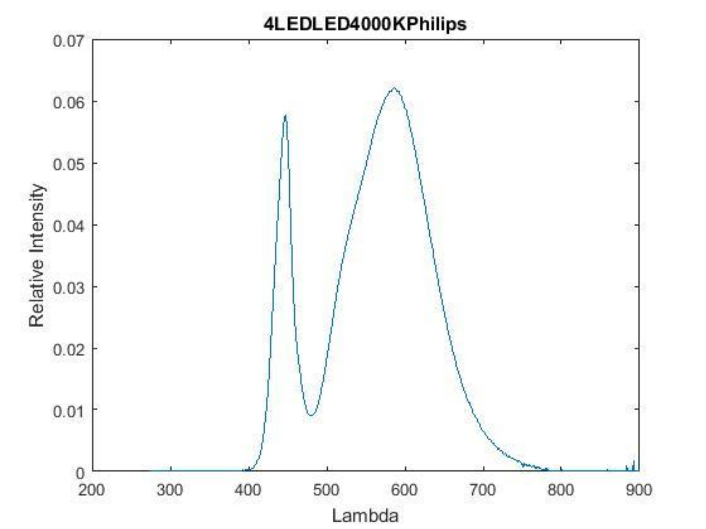


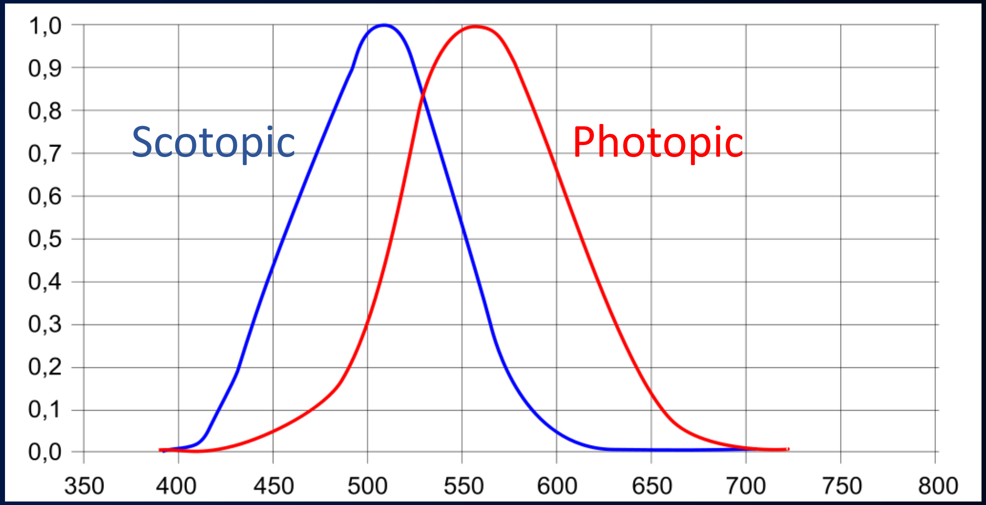
Spectral flux comparison

$$C = \frac{F_{2018} - F_{2013}}{F_{2013}}$$

- Huge reduction at very low wl (>60%)
- Persistent reduction above 550 nm (~30%)
- No reduction, even increase at 440-530nm







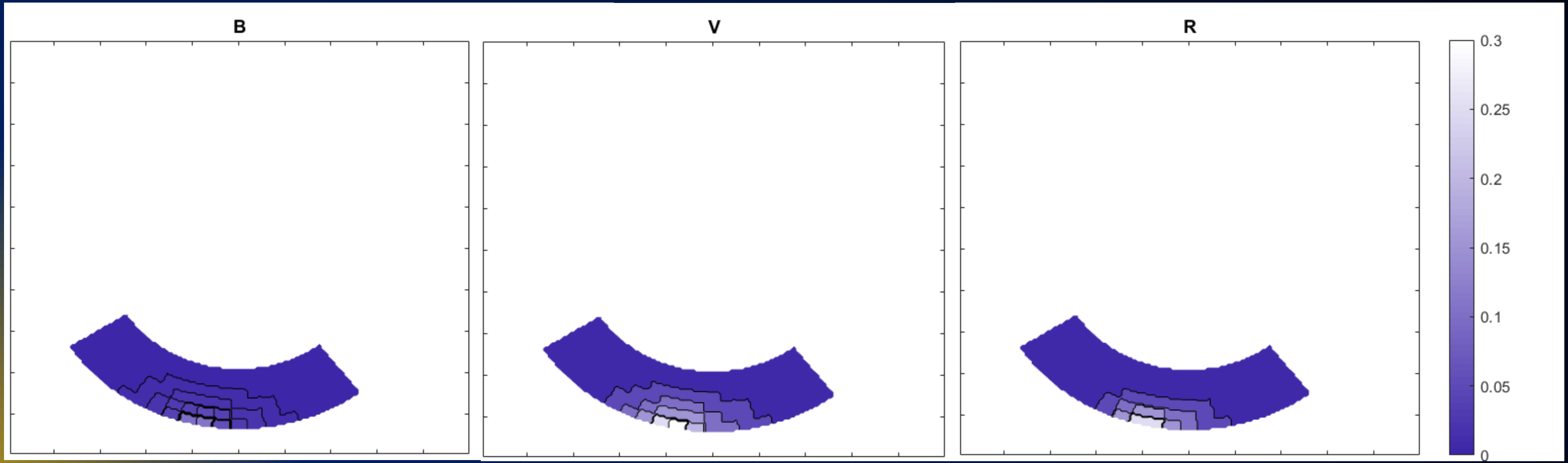
Astronomic magnitudes

Direct filter comparison

Brightness subtraction (After-Before)
B: max 0.03 mag
V: max 0.3 mag, ≥0.1 mag 35^{o} wide
R: max 0.27 mag, ≥0.1 mag 25^{o} wide

Color images

Brightness subtraction between filters (B-V, V-R)
Brightness subtraction (2015-2013)
B-V: 2015 bluer sky
V-R: very small difference



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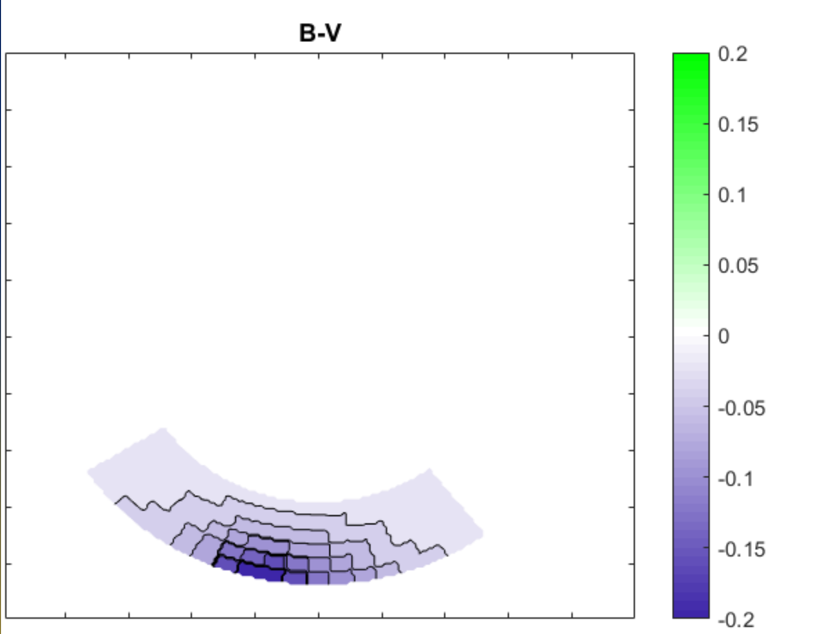
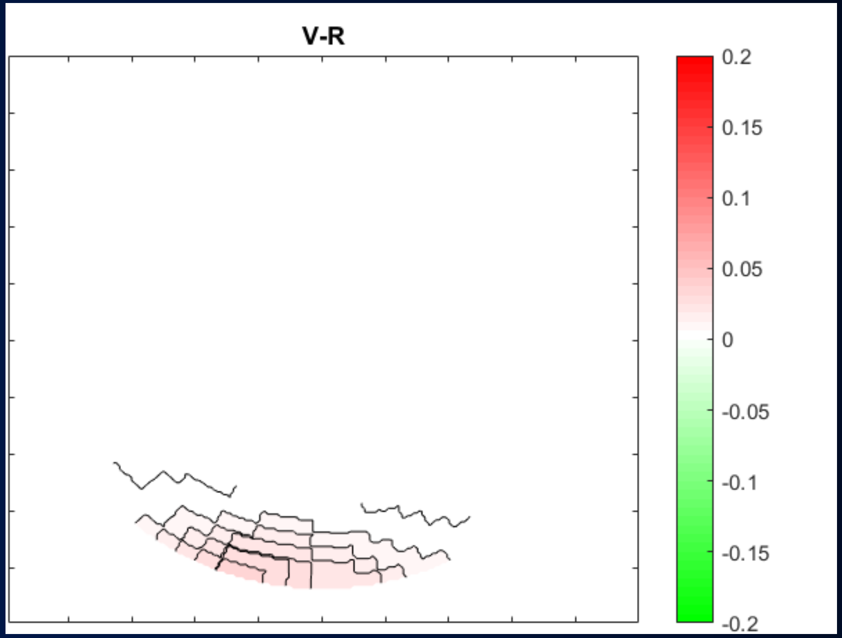
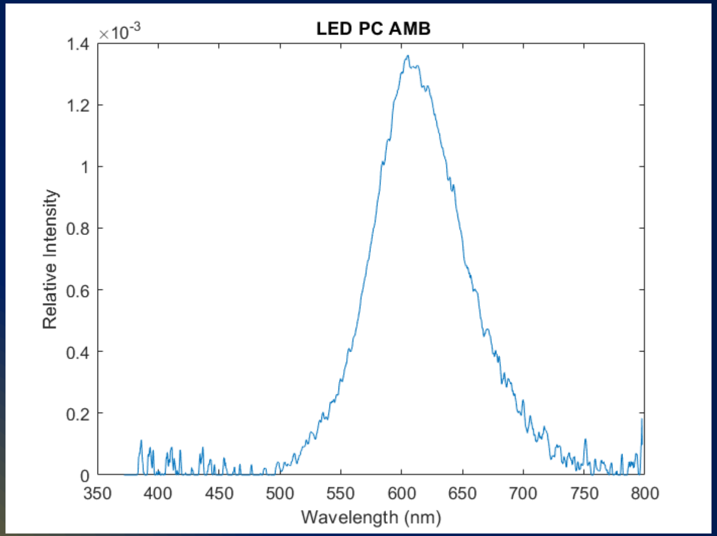


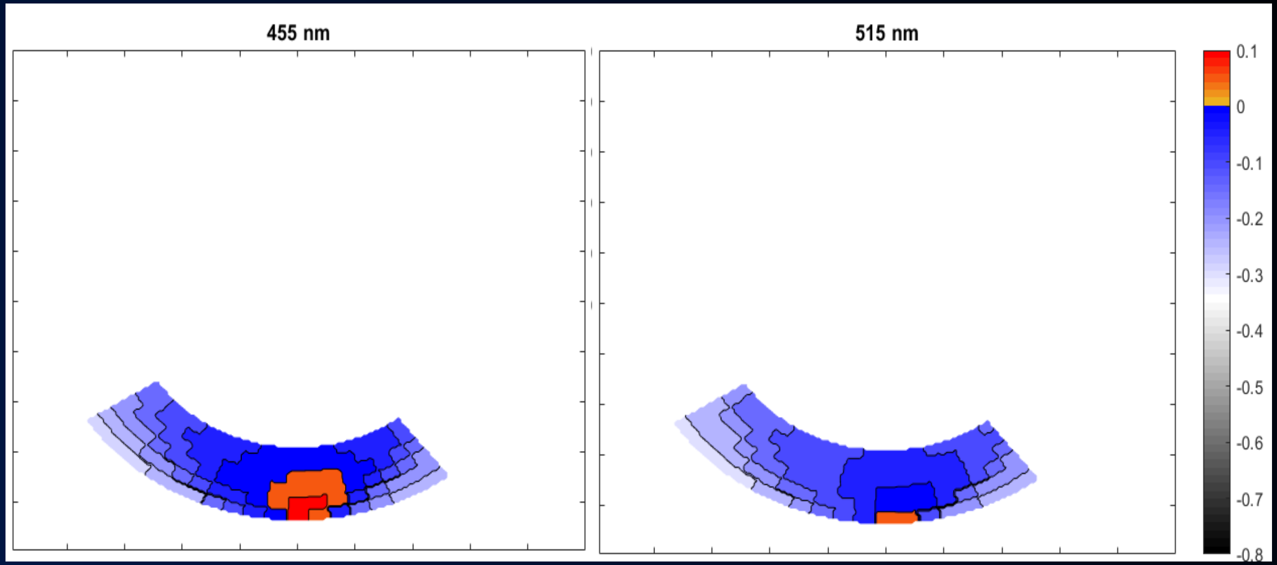


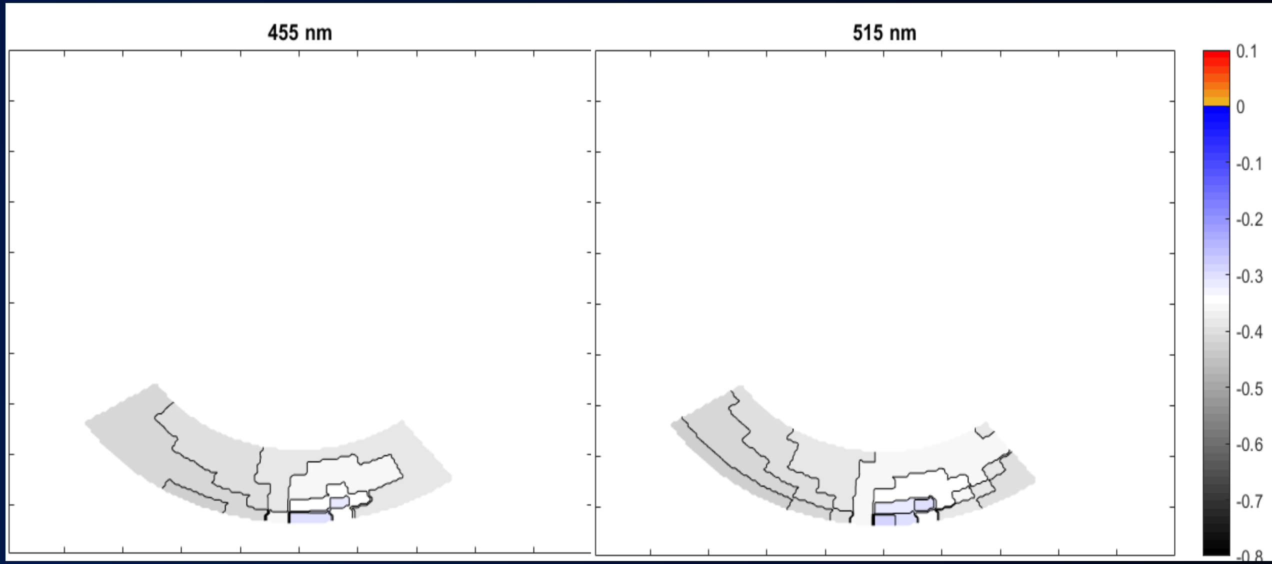
Hypothesis (PC AMBER LED)

	HPSV	MH	PC LED	MV
2013	84	13	-	3
Hyp.	72	13	15	-



$$C = \frac{F_H - F_{2013}}{F_{2013}}$$

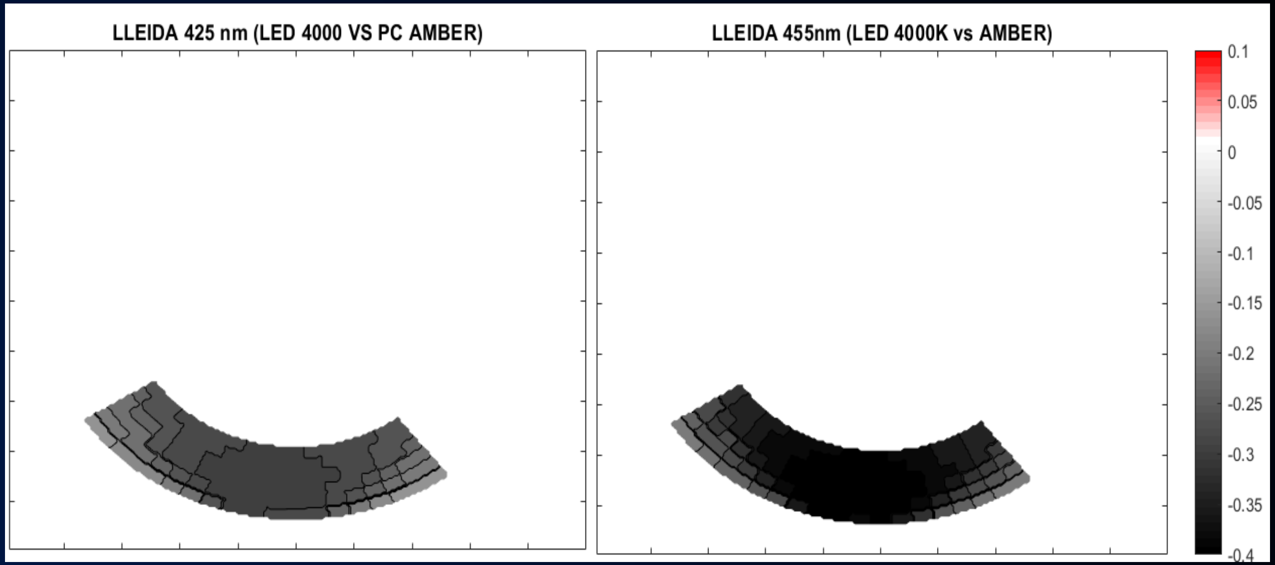


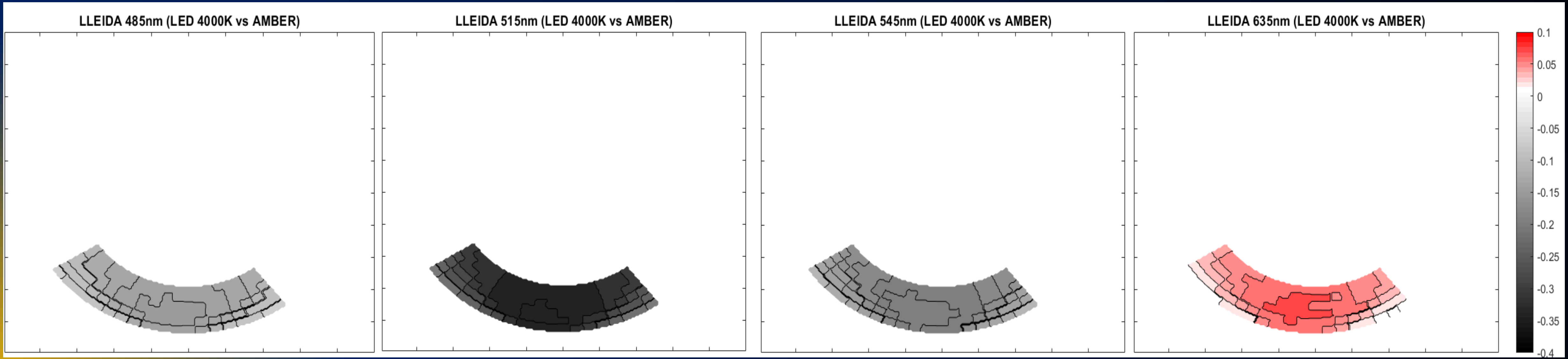


Hypothesis (PC AMBER LED)

	HPSV	MH	LED 4k	PC LED
2018	72	13	15	-
Hyp.	72	13	-	15

$$C = \frac{F_H - F_{2018}}{F_{2018}}$$





Summary

1. The methodology has been validated by measurements, especially for well described cities.
2. The sky over the PAM is polluted only in low elevation angles.
3. The change of lights in Lleida reduced light emission unevenly among the filters. Sky is bluer now than in 2013.
4. A reduction in emission does not necessarily means a reduction in LP in all the spectrum.

Progress

1. Define the methodology
2. Study Lleida and its light system update
3. Add Balaguer and Tremp in the PAM model
4. Describe a population-distance function, to know the range of affectation of any town.
5. Complete PAM night sky model
6. Valle del Roncal (Navarra) and Pic du Midi (Haute Pyrénées) cases

Modelling the night sky brightness and light pollution sources of Montsec protected area

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