21st International Radiance Workshop
August 28-31, 2023

A hybrid measurement-simulation approach to determine the daylight exposure of the Volury tapestries at Ham House

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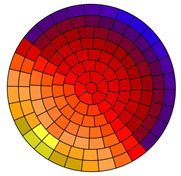
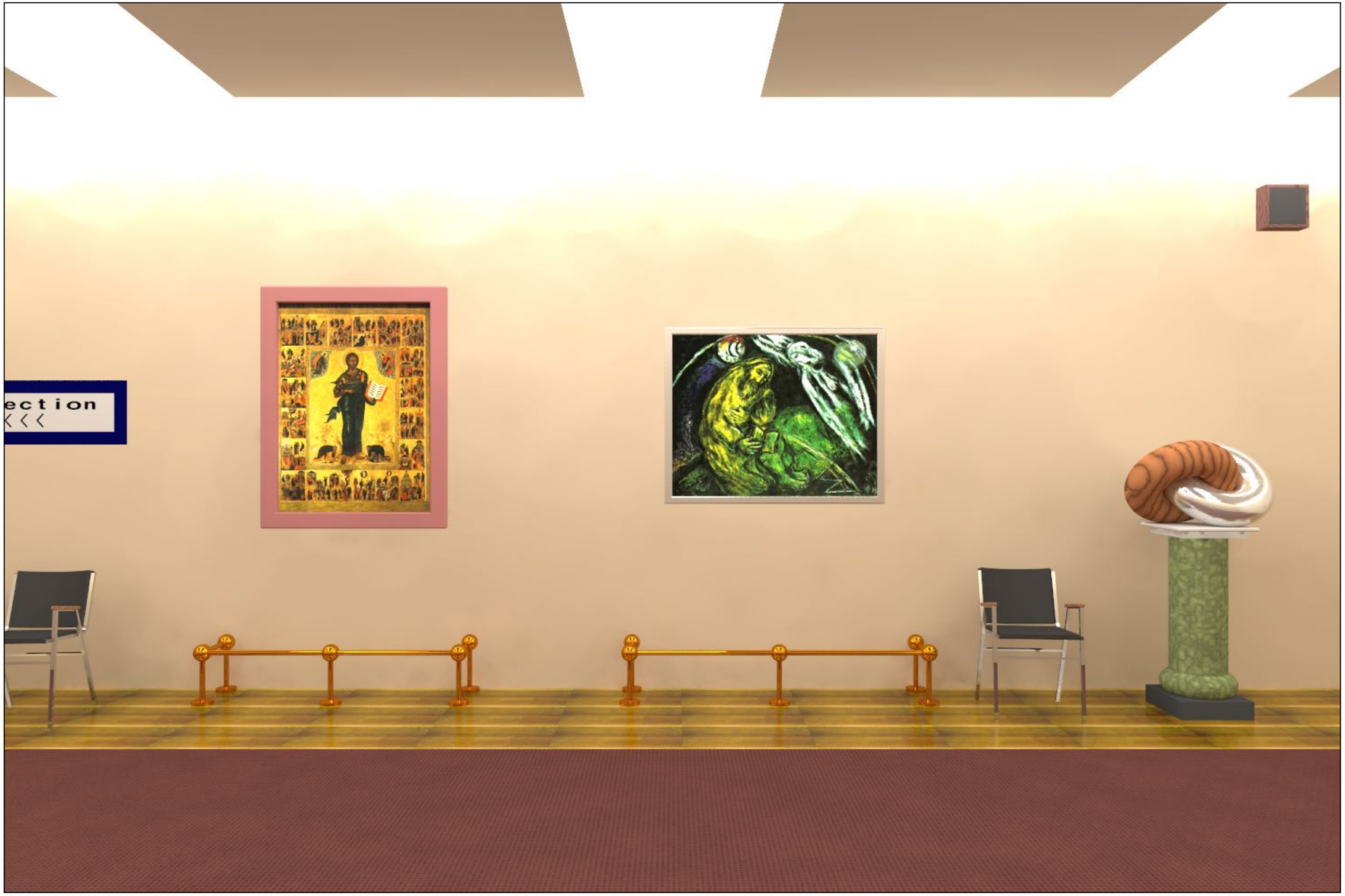
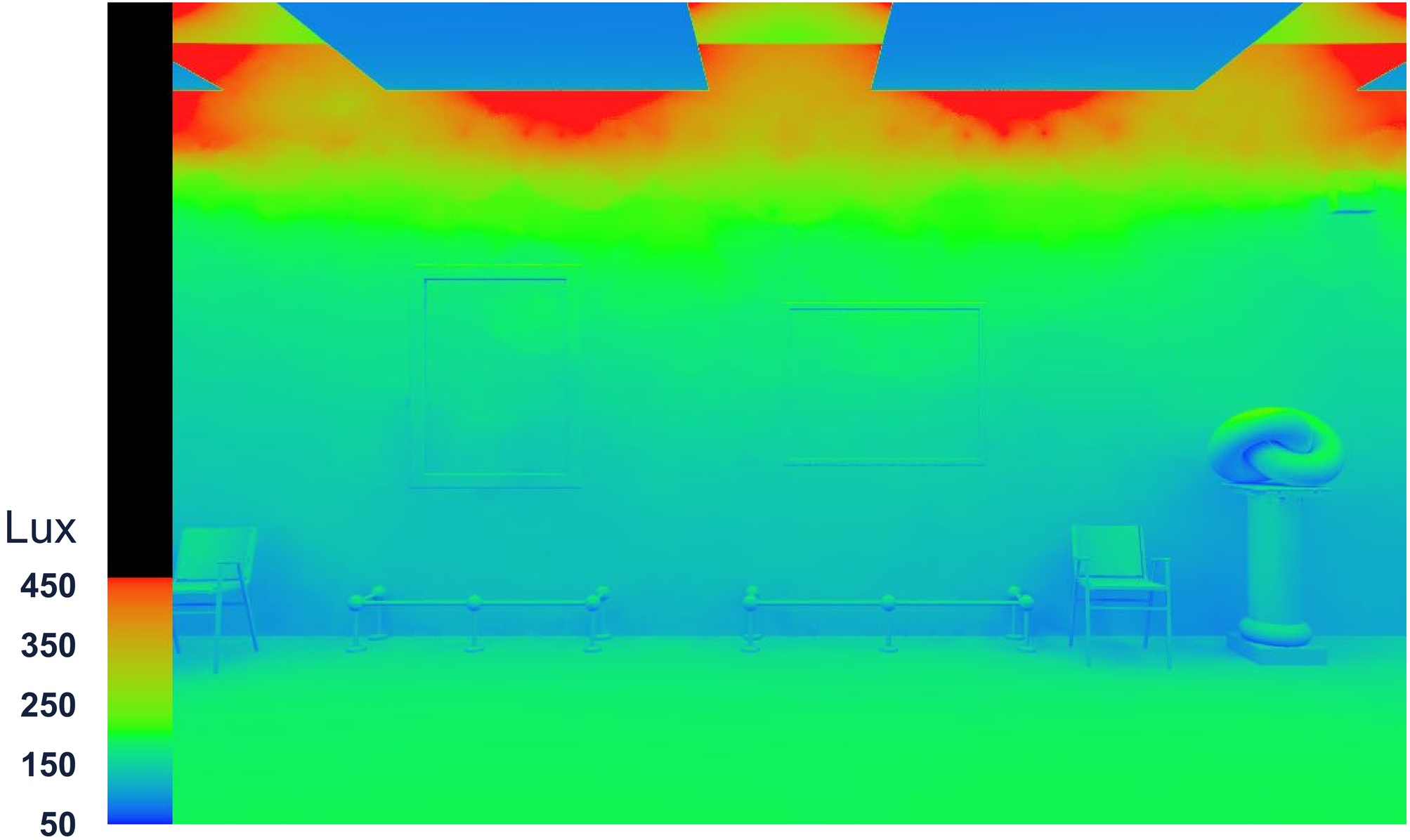


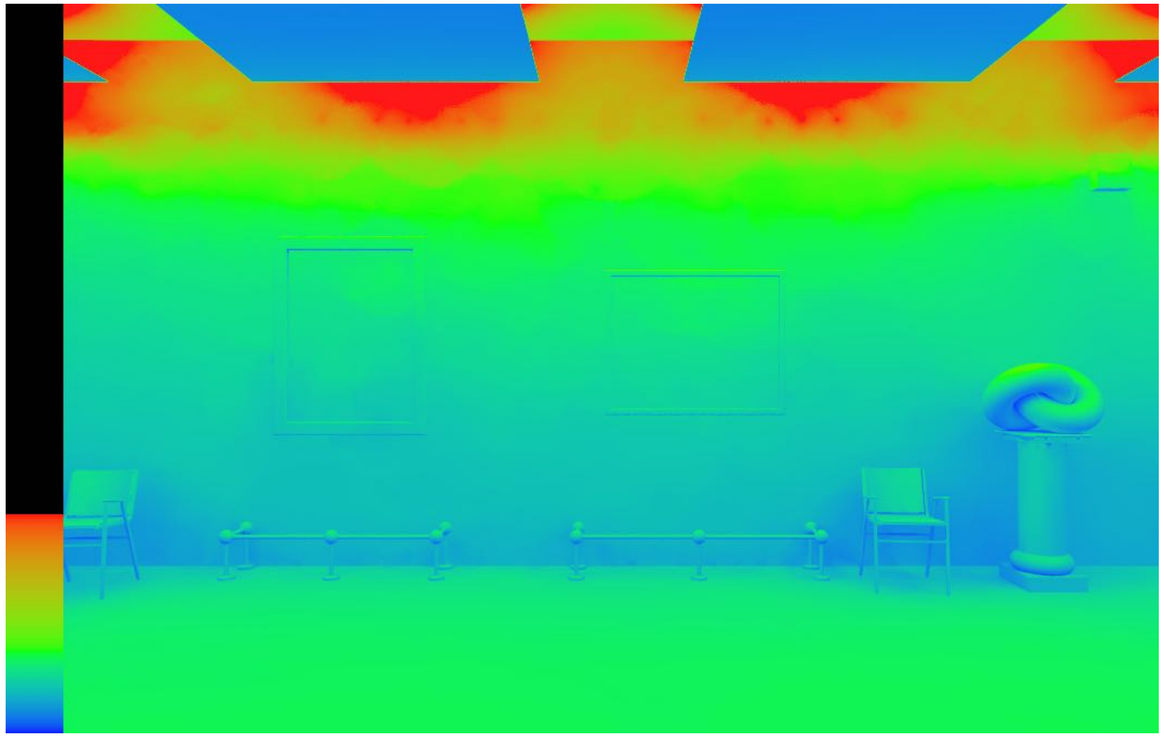
Daylight-Experts.com
Expert Witness | Simulation | Measurement | Conservation

Radiance simulation of a gallery space with rooflights (~1991)

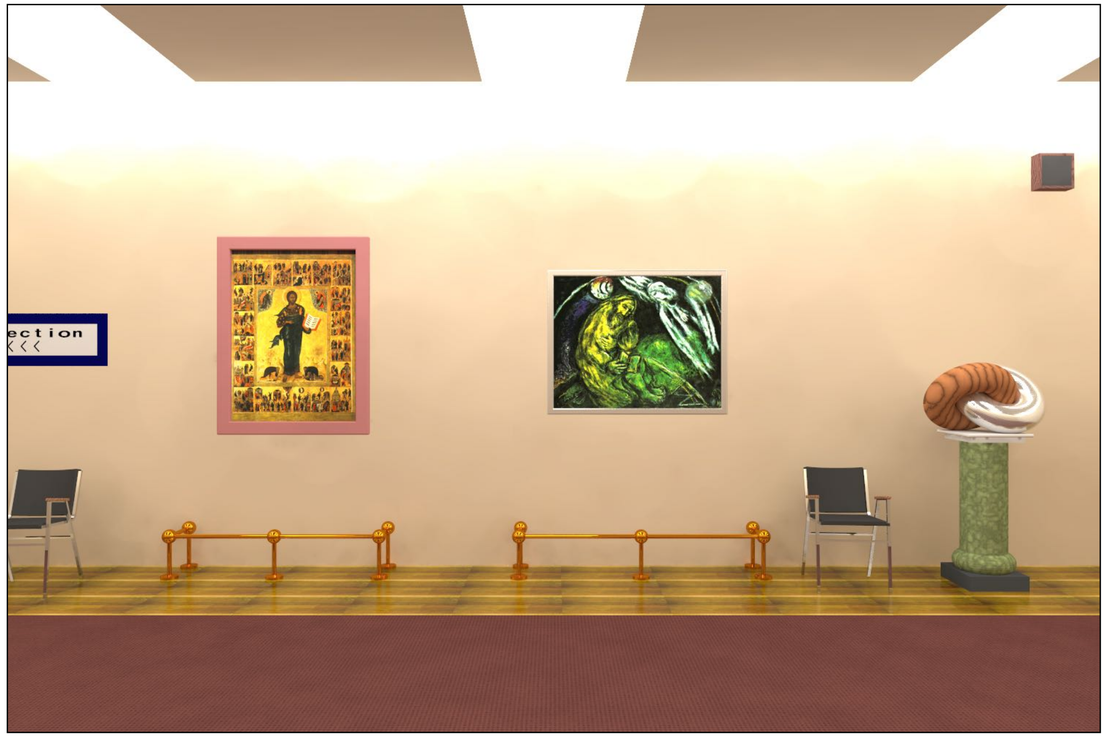



Lux
450
350
250
150
50

Illuminance map



HDR image



Ickworth House

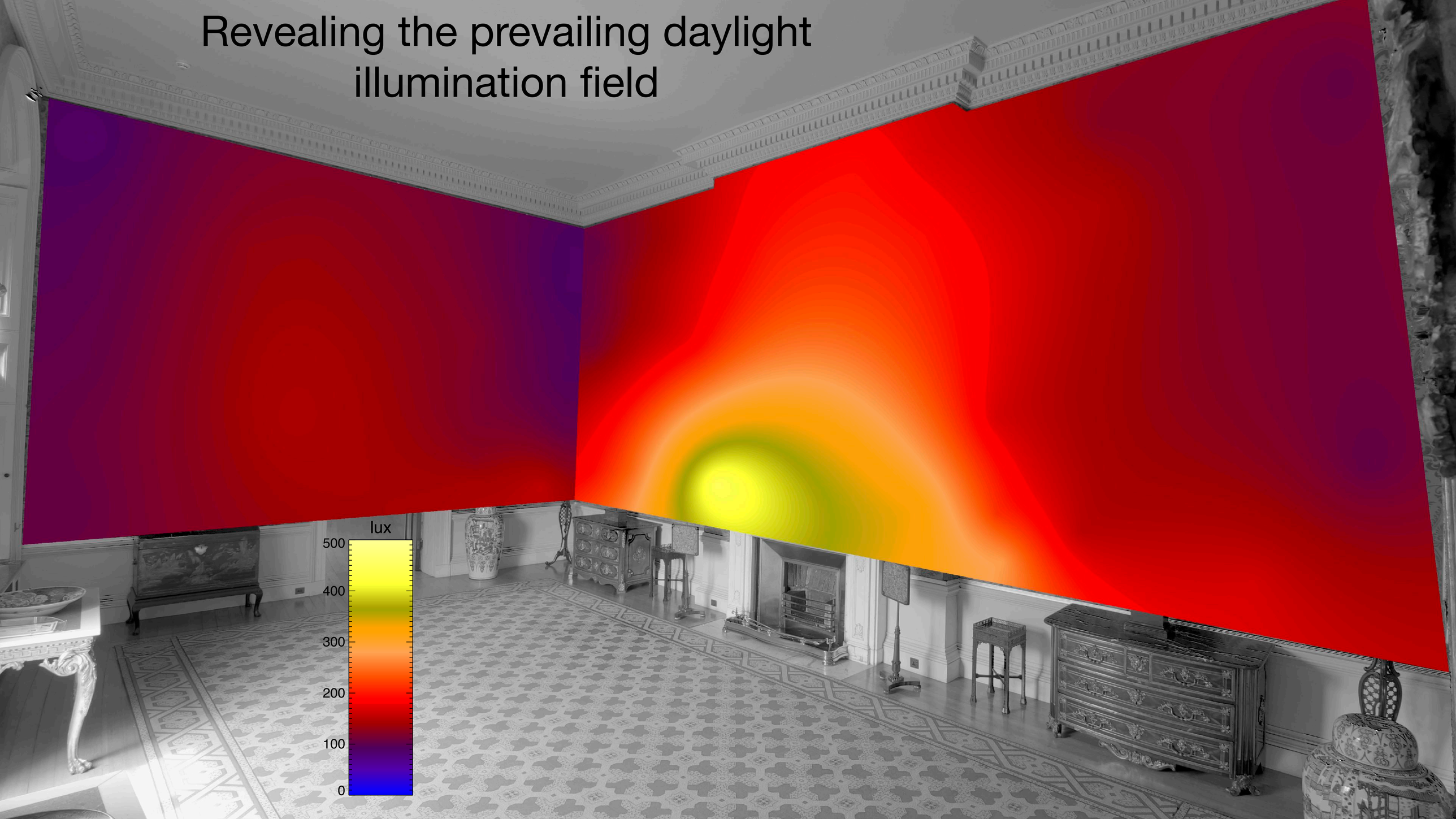
Bury St. Edmunds

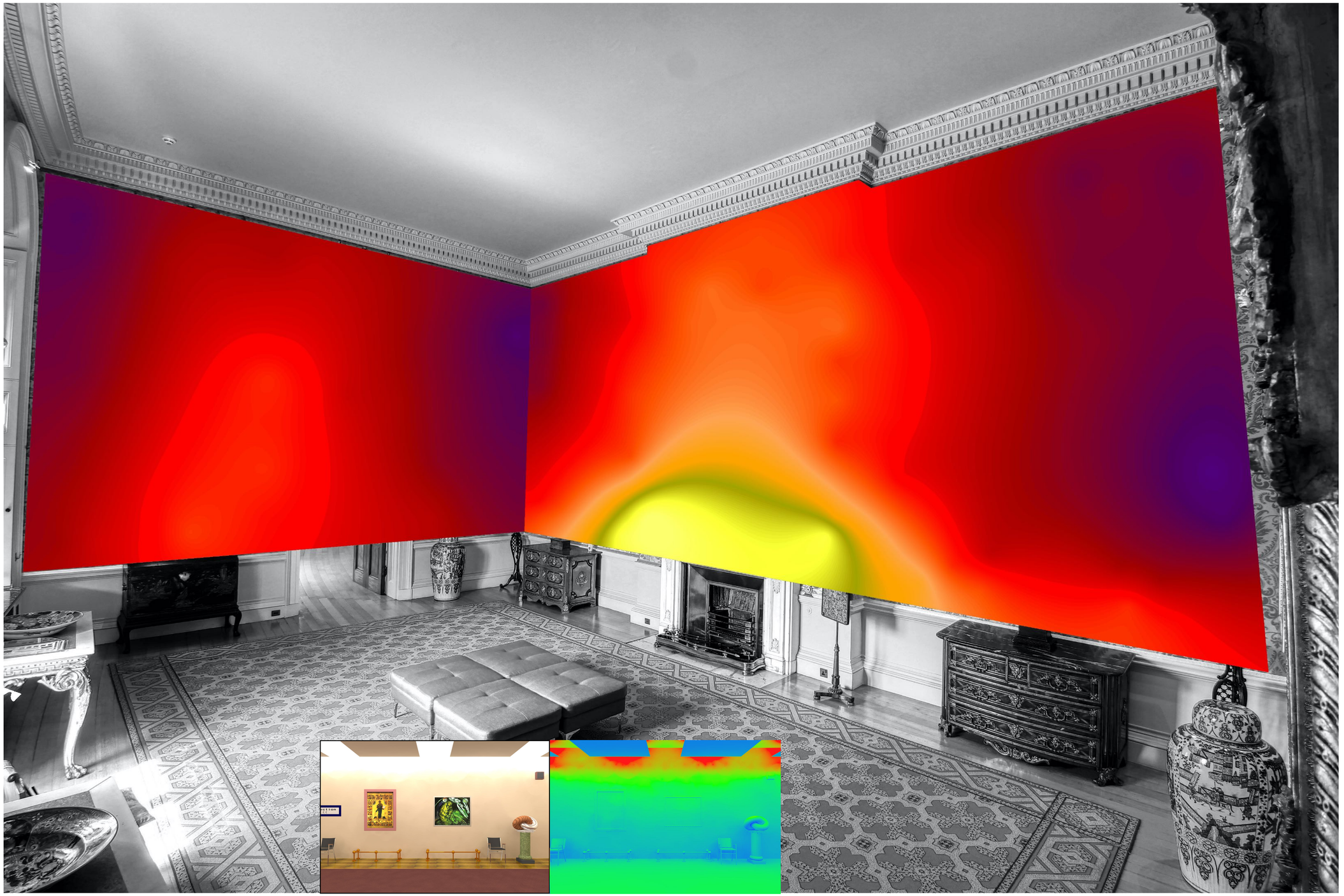
Apply vignetting correction; subtract electric light contribution


Determine mean luminance
at the target patches

Interpolate illumination field
across target patches

Revealing the prevailing daylight illumination field




July 2016
lx hrs
14000
12000
10000
8000
6000
4000
2000
0

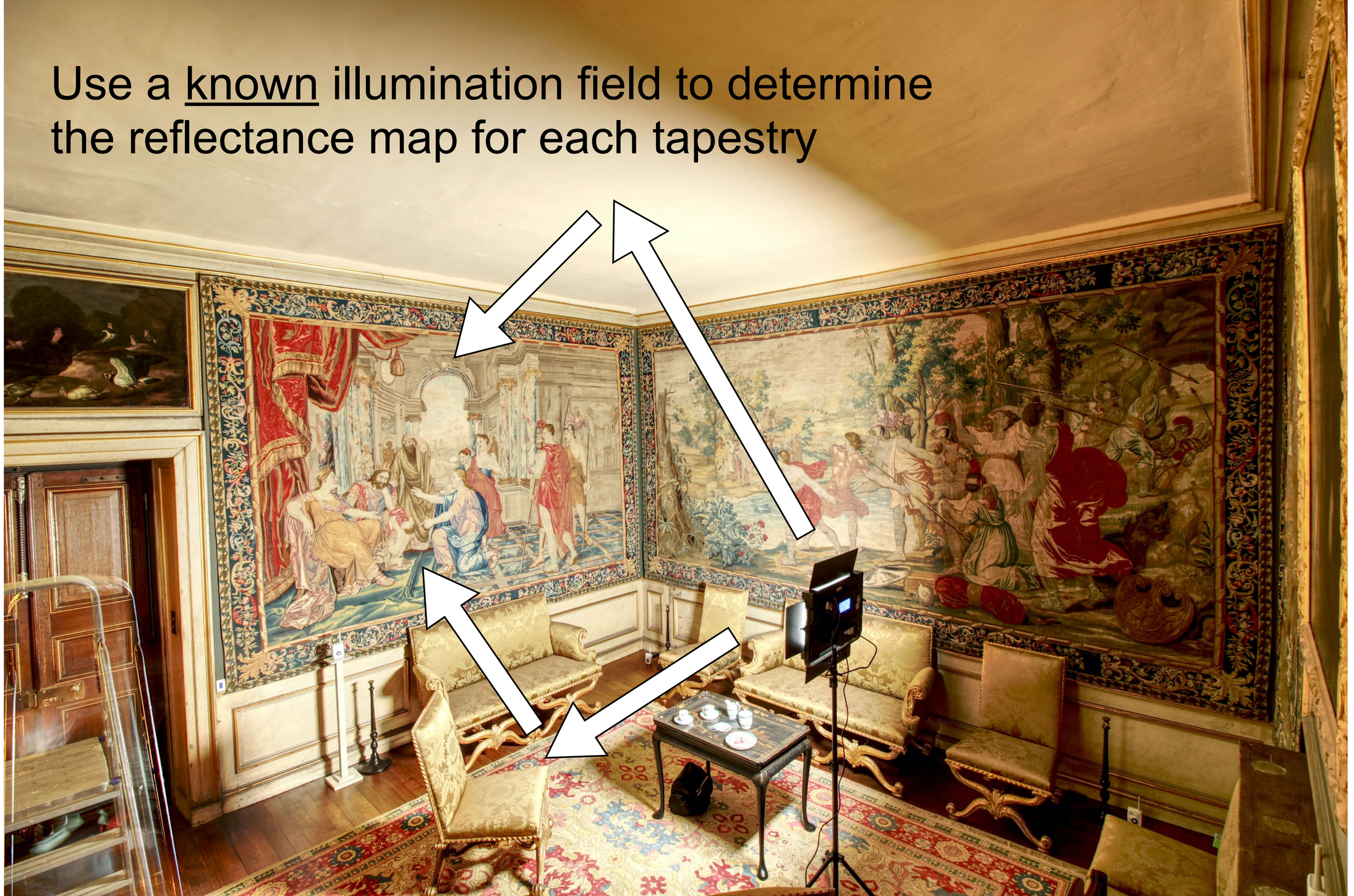
But what if…

Ham House, Richmond

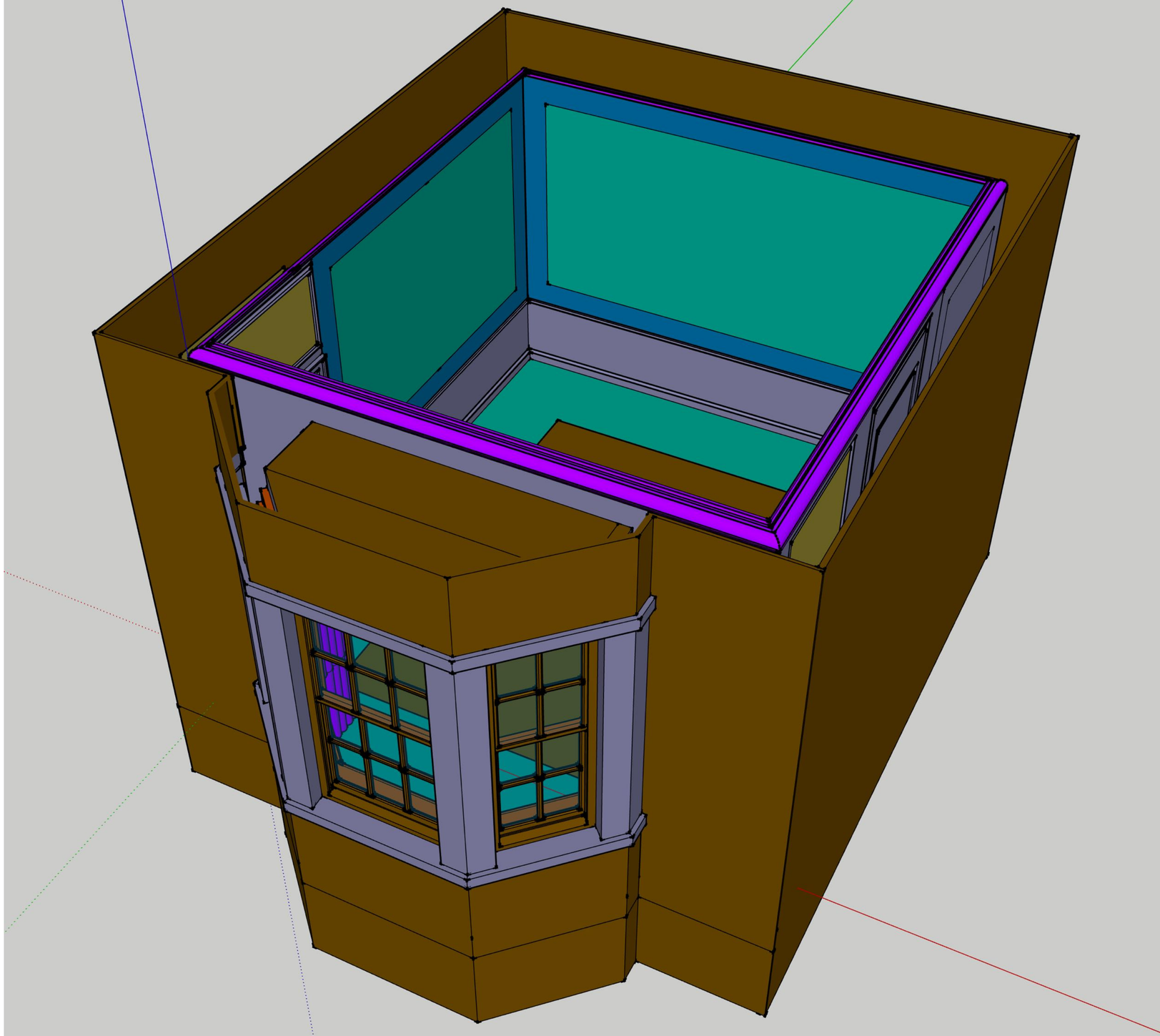
The Volury Room, Ham House

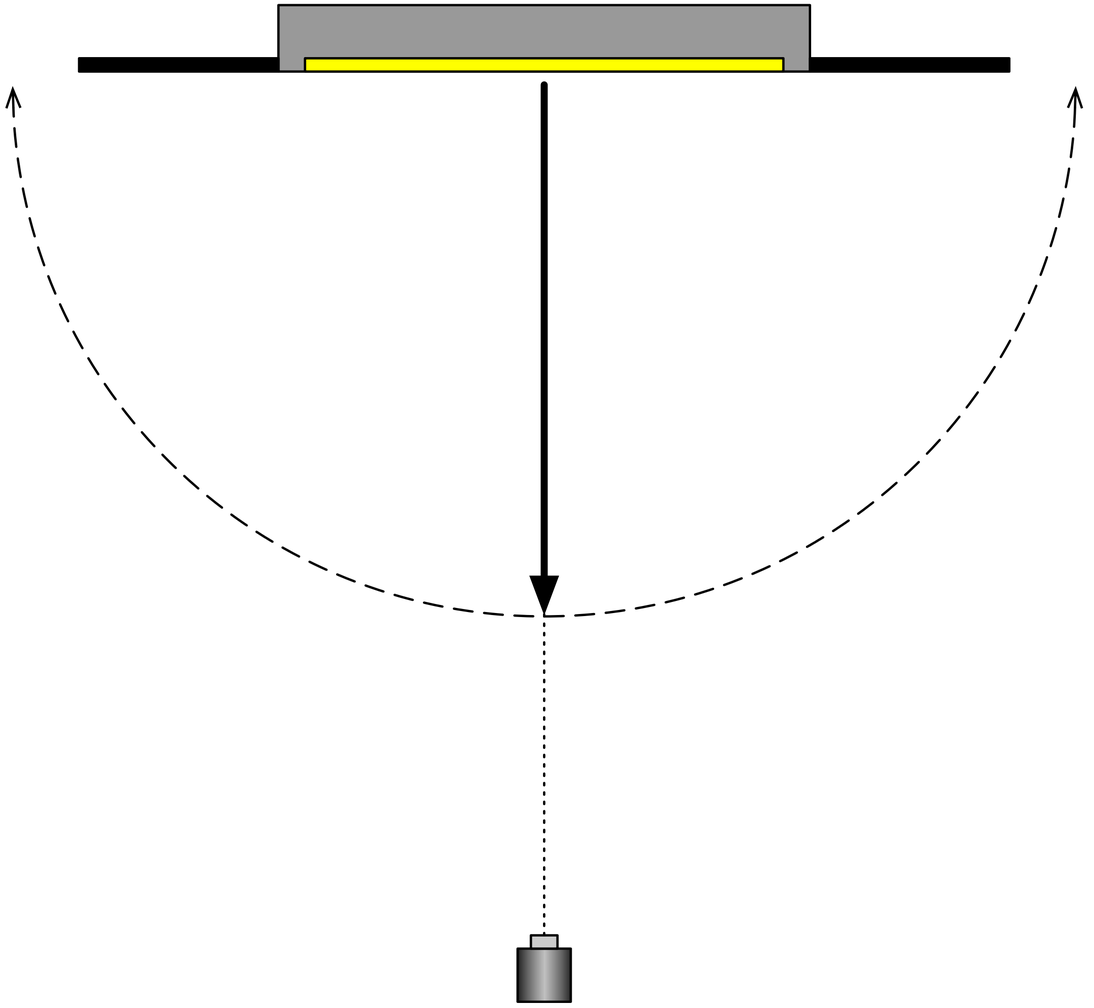
22/03/19

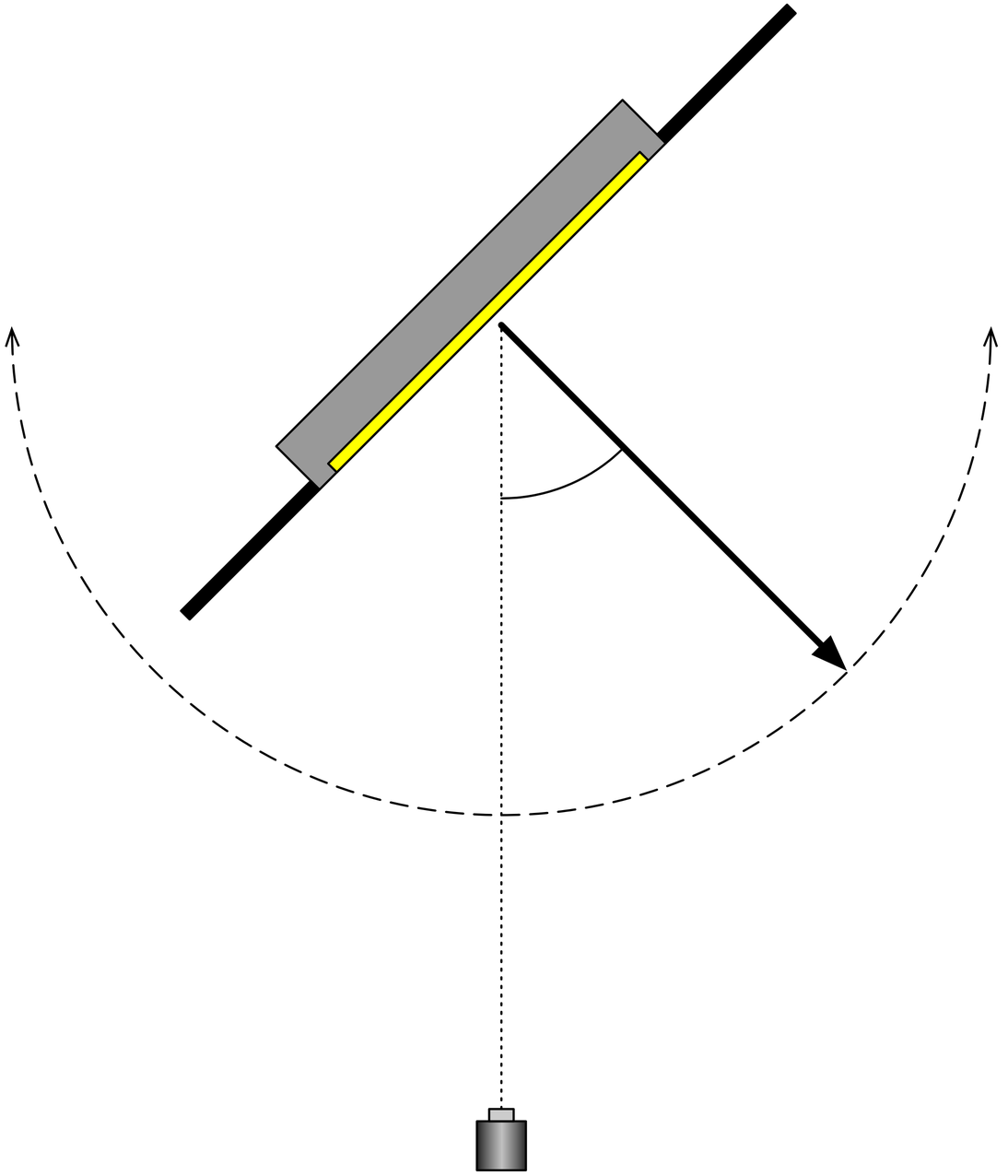
Use a known illumination field to determine the reflectance map for each tapestry

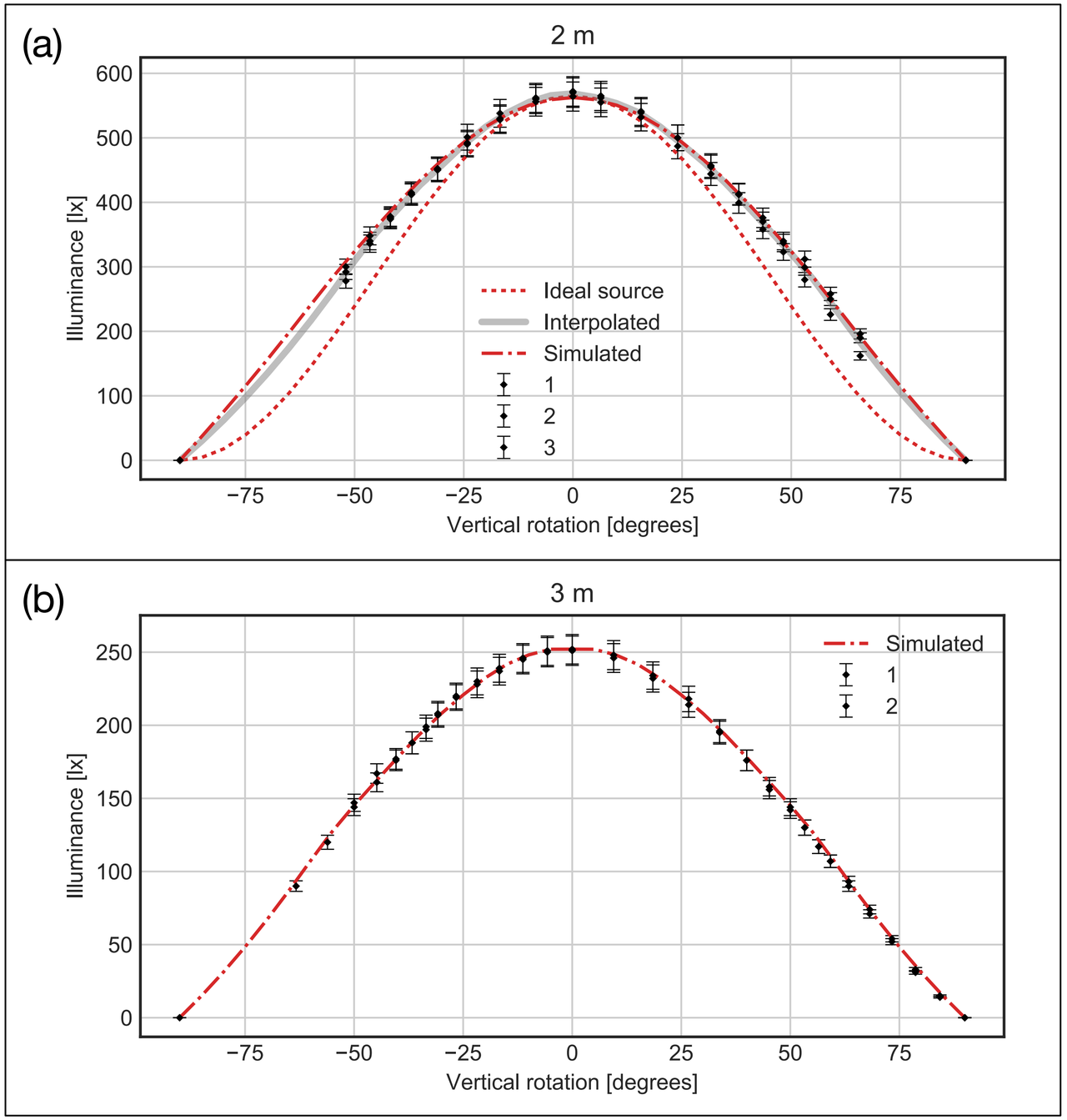


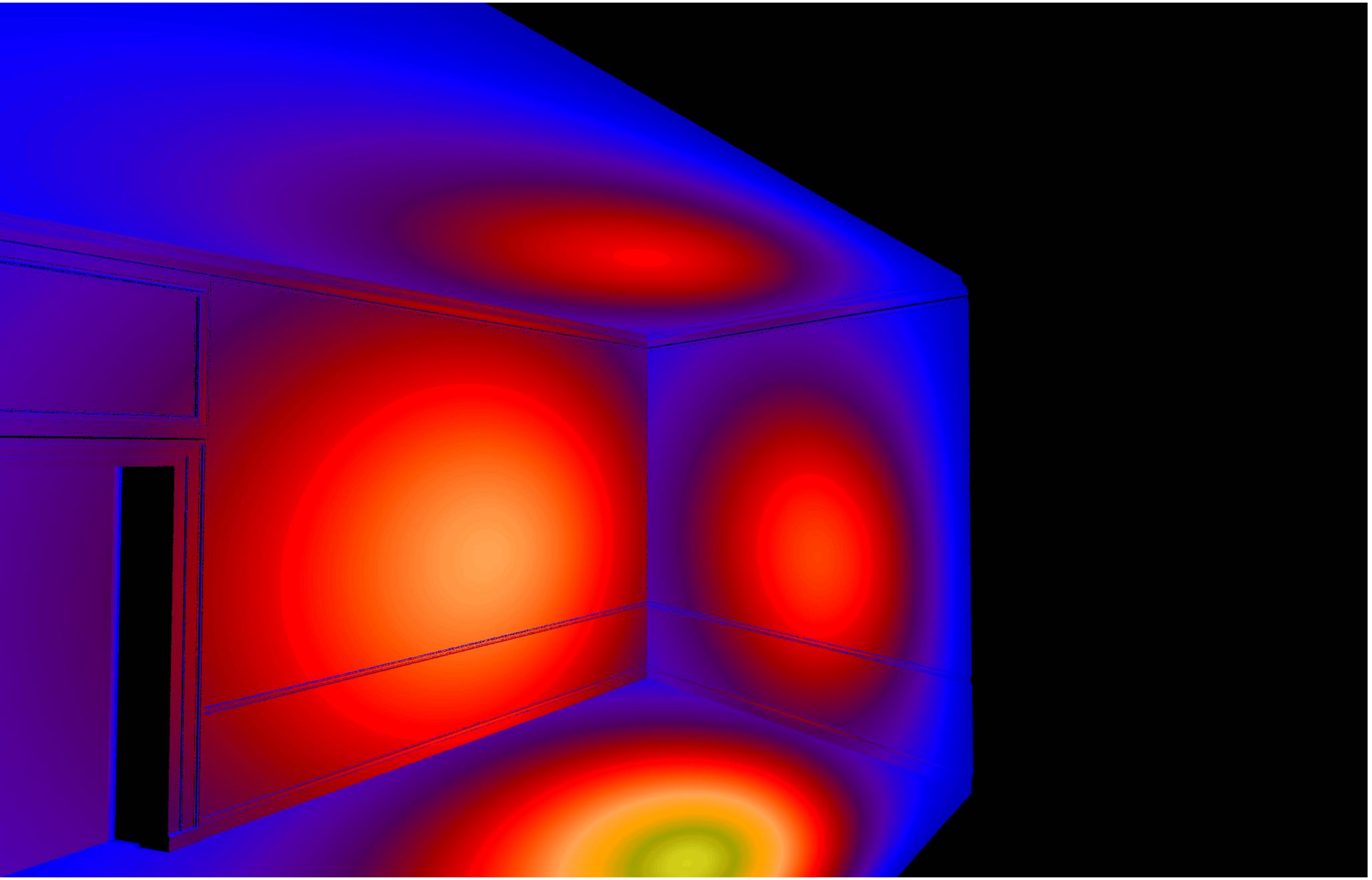
Need to use a *Radiance* simulation to account for both the direct and reflected light from the LED panel arriving at the tapestry



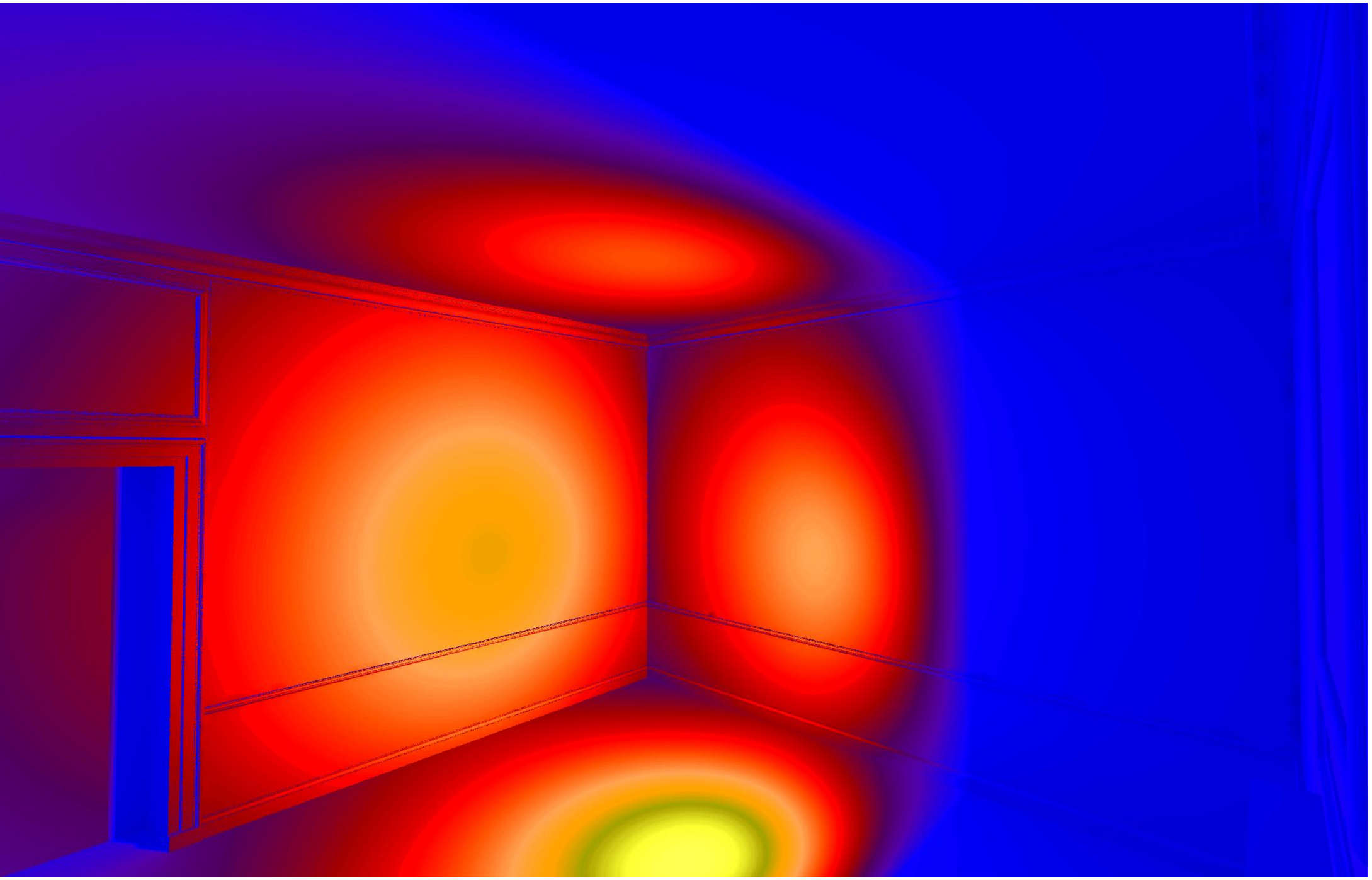


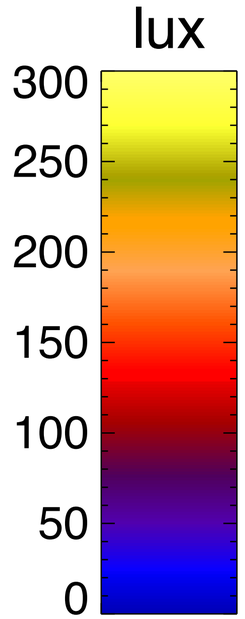



(a)
2 m
Illuminance [lx]
600
500
400
300
200
100
0
Ideal source
Interpolated
Simulated
1
2
3
−75
−50
−25
0
25
50
75
Vertical rotation [degrees]
(b)
3 m
Illuminance [lx]
250
200
150
100
50
0
Simulated
1
2
−75
−50
−25
0
25
50
75
Vertical rotation [degrees]


ab0
lux
300
250
200
150
100
50
0

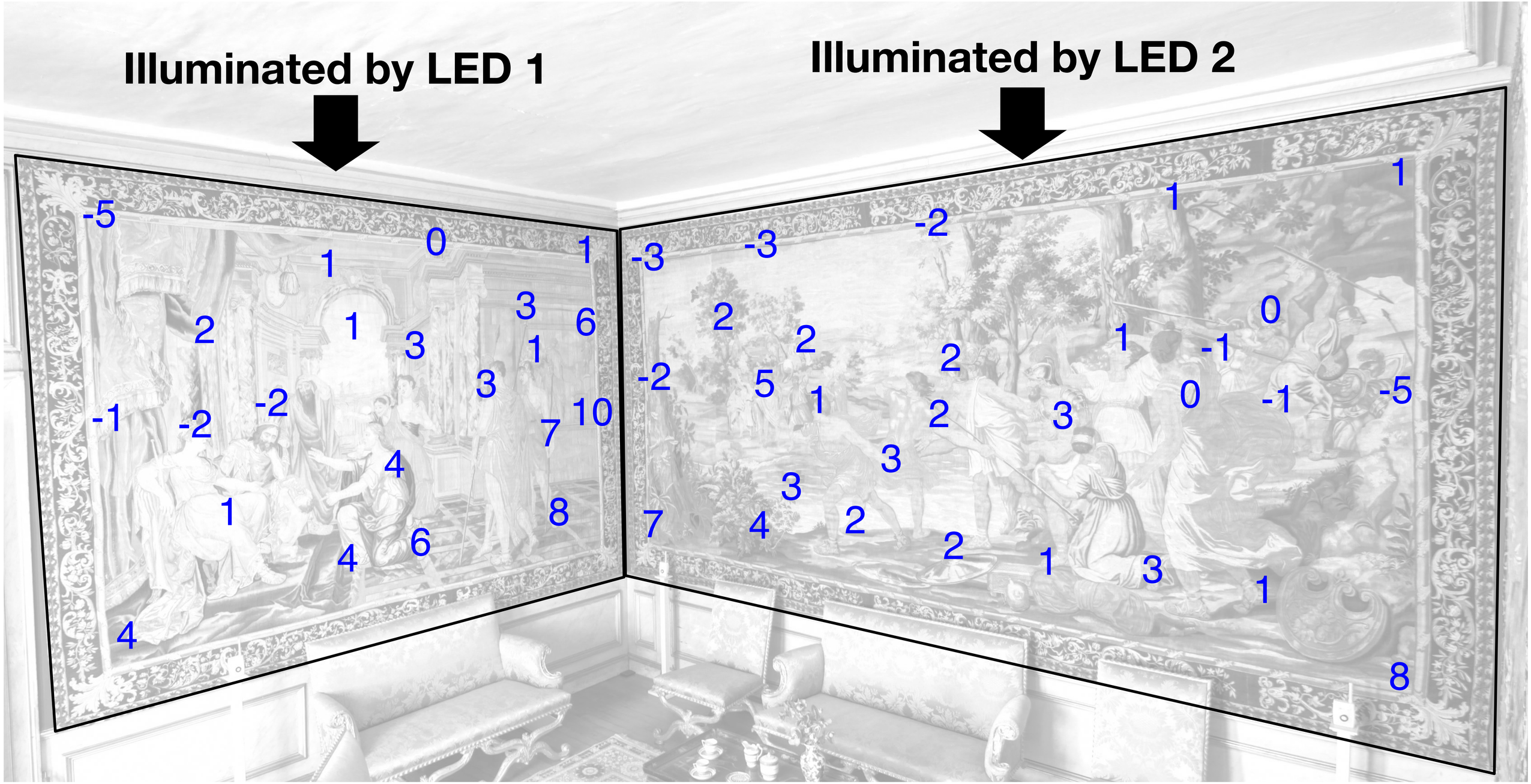
ab3





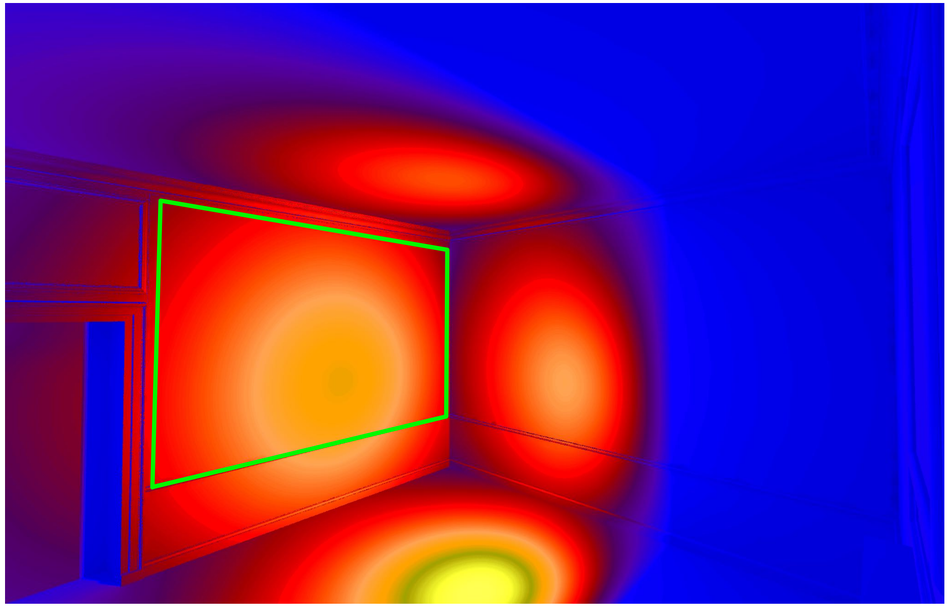

LED 1


LED 2

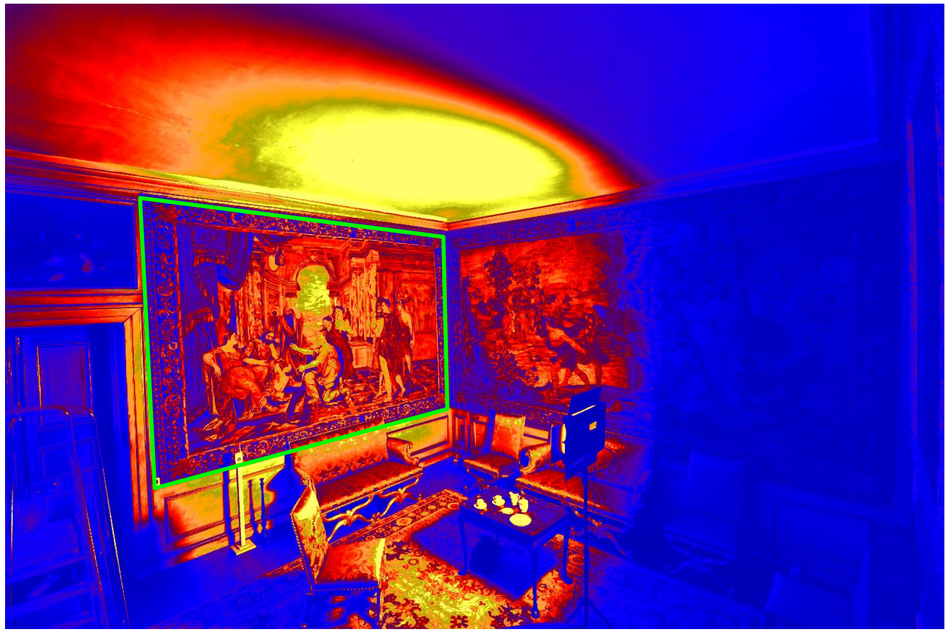


% difference between measured and simulated illuminance

Simulated illumination map



Warp to align precisely

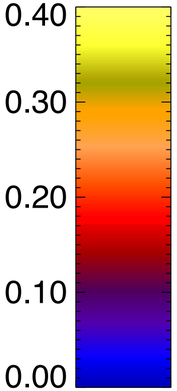


Measured (HDR) luminance map

The simulated illuminances were all within 10% of the measured values

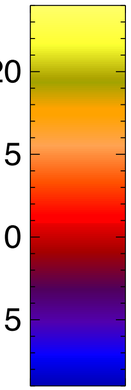
$$\rho_{(x,y)} = \frac{\pi L_{(x,y)}}{E_{(x,y)}}$$

Reflectance map

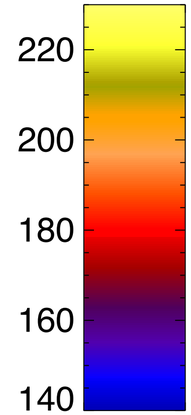


$= \pi$

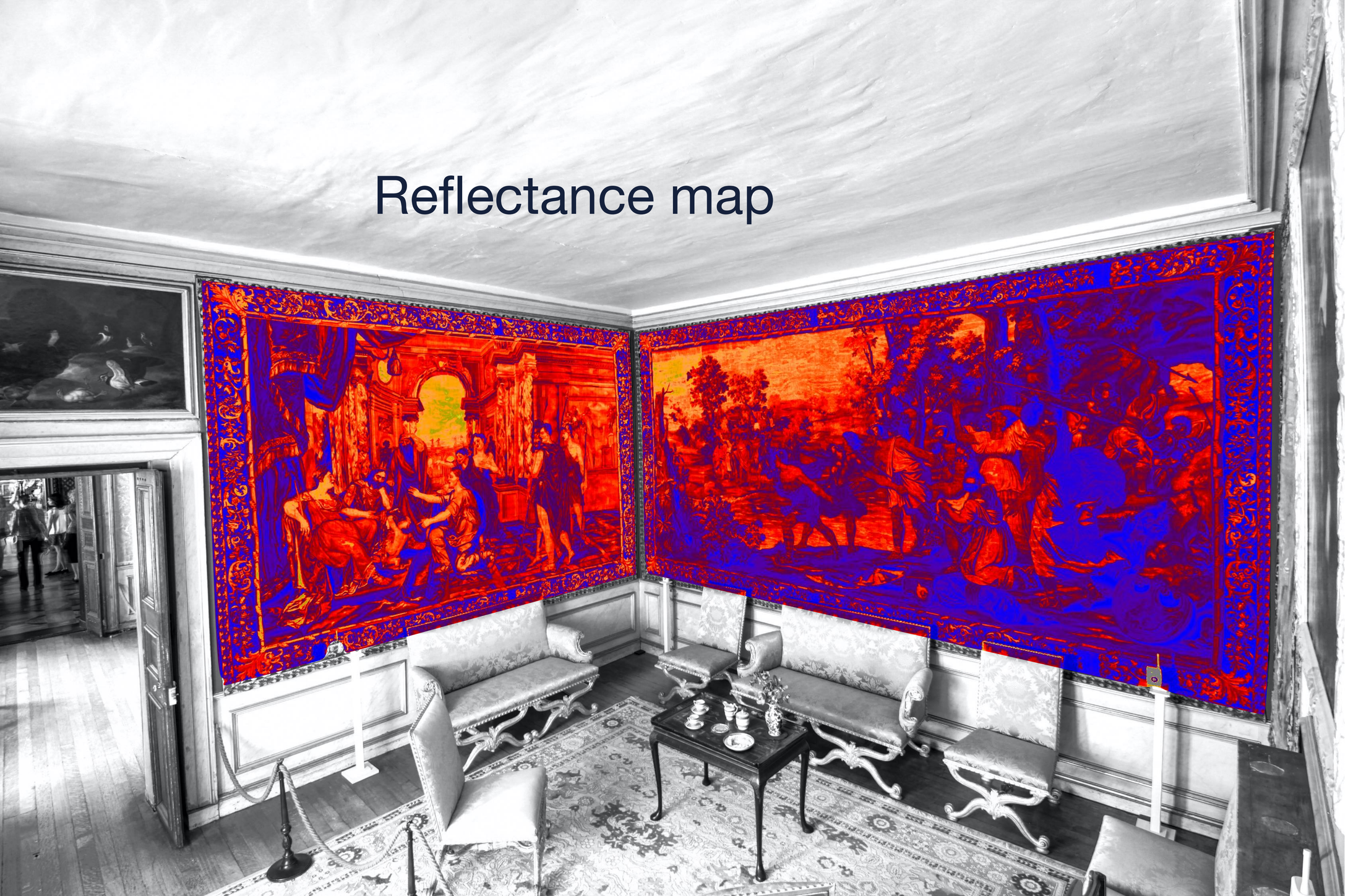
HDR capture

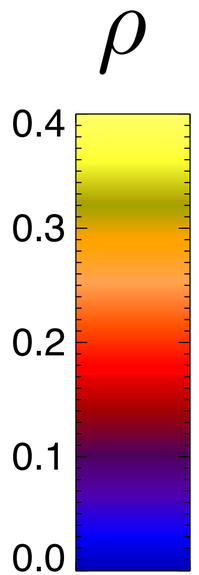


Simulated illuminance



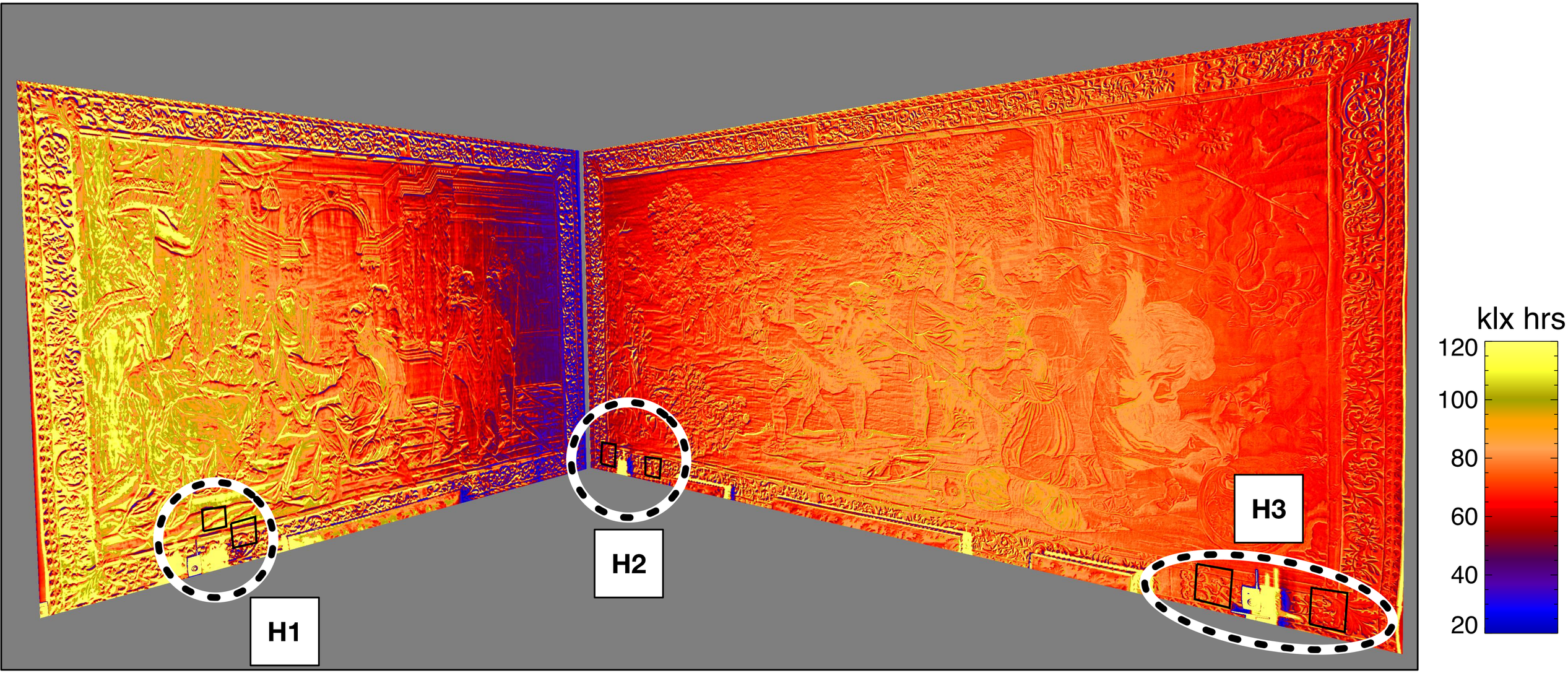
Reflectance map





Between 10/04/19 and 16/10/19 there were 159 days of useful data capture — resulting in 4899 ‘non-dark’ HDR captures (~265Gb)

$$D_n = \sum_{i=1}^{4899} \pi \frac{L_i}{6\rho}$$


H1
H2
H3
klx hrs
120
100
80
60
40
20

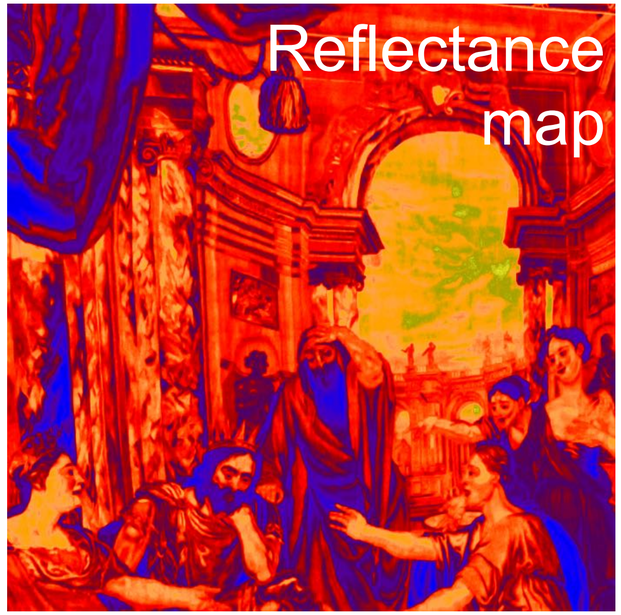
‘Print Through’

Each reflectance map was based on a single HDR capture taken morning 22/03/19 — useful data capture was from 10/04/19 and 16/10/19

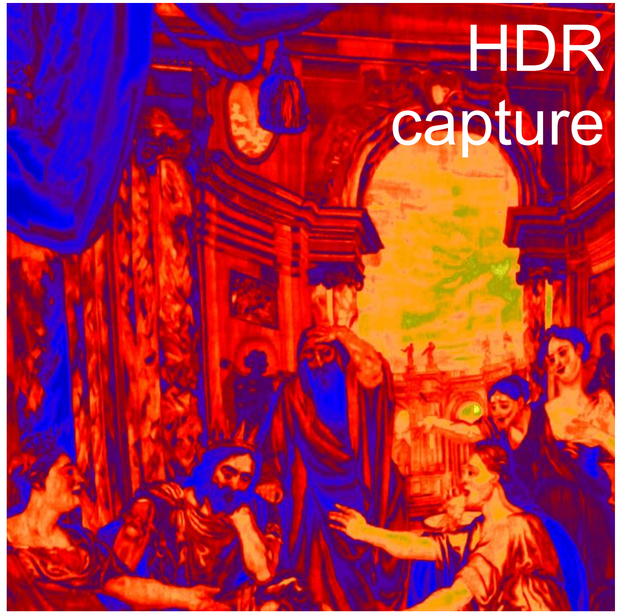
Hypothesis: ‘Print through’ will be apparent if there is anything less than perfect pixel alignment between the reflectance map and the (subsequent) HDR captures

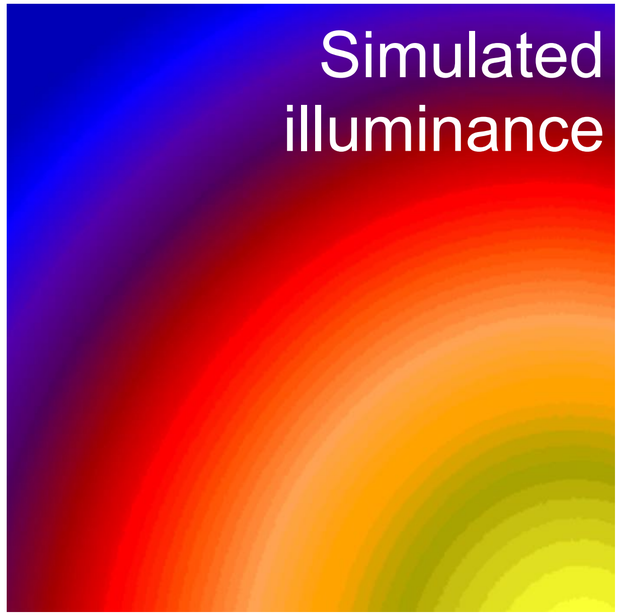
701 x 701 pixels

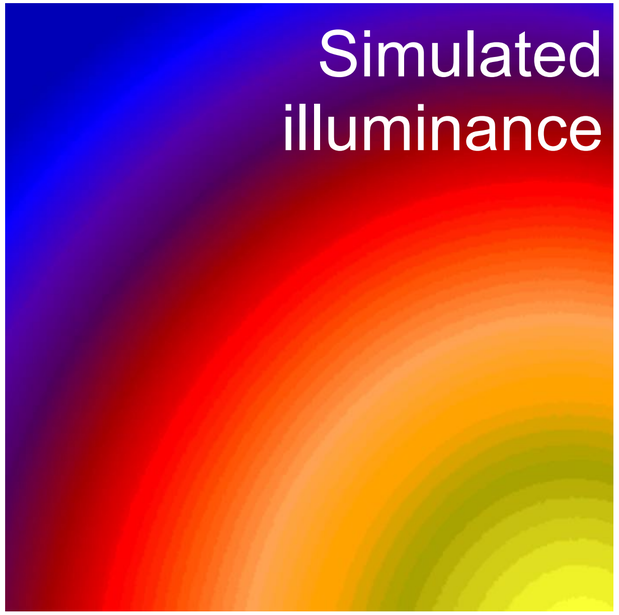
$$E_r = \frac{\pi L_r}{\rho_r}$$



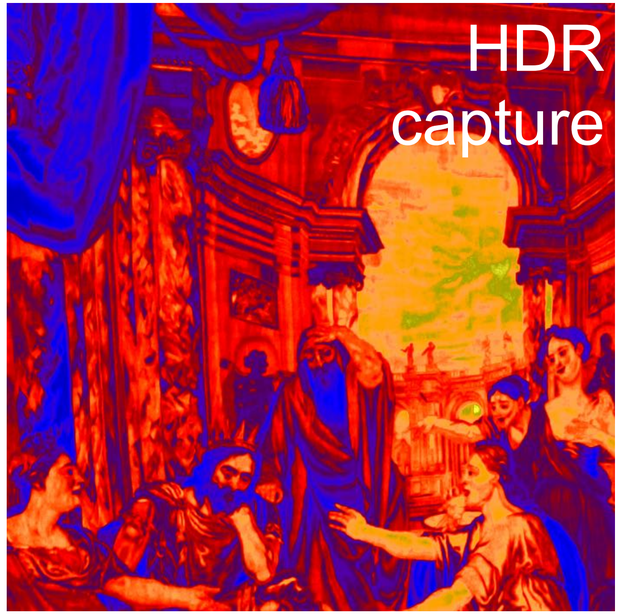
$$= \pi \frac{}{}$$

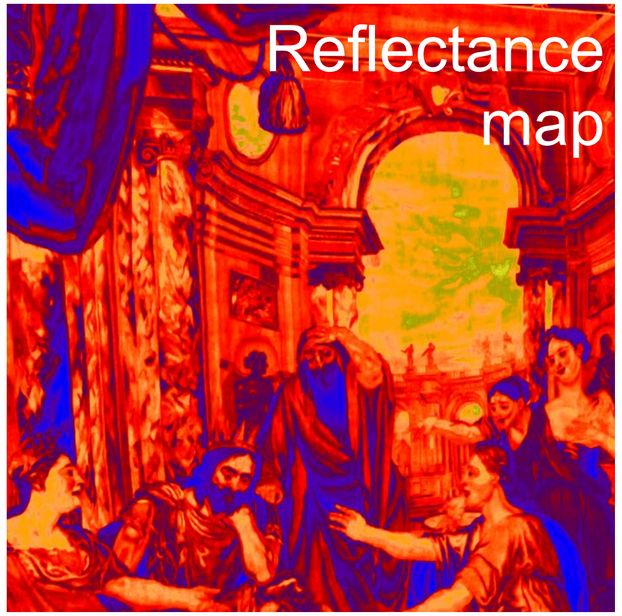


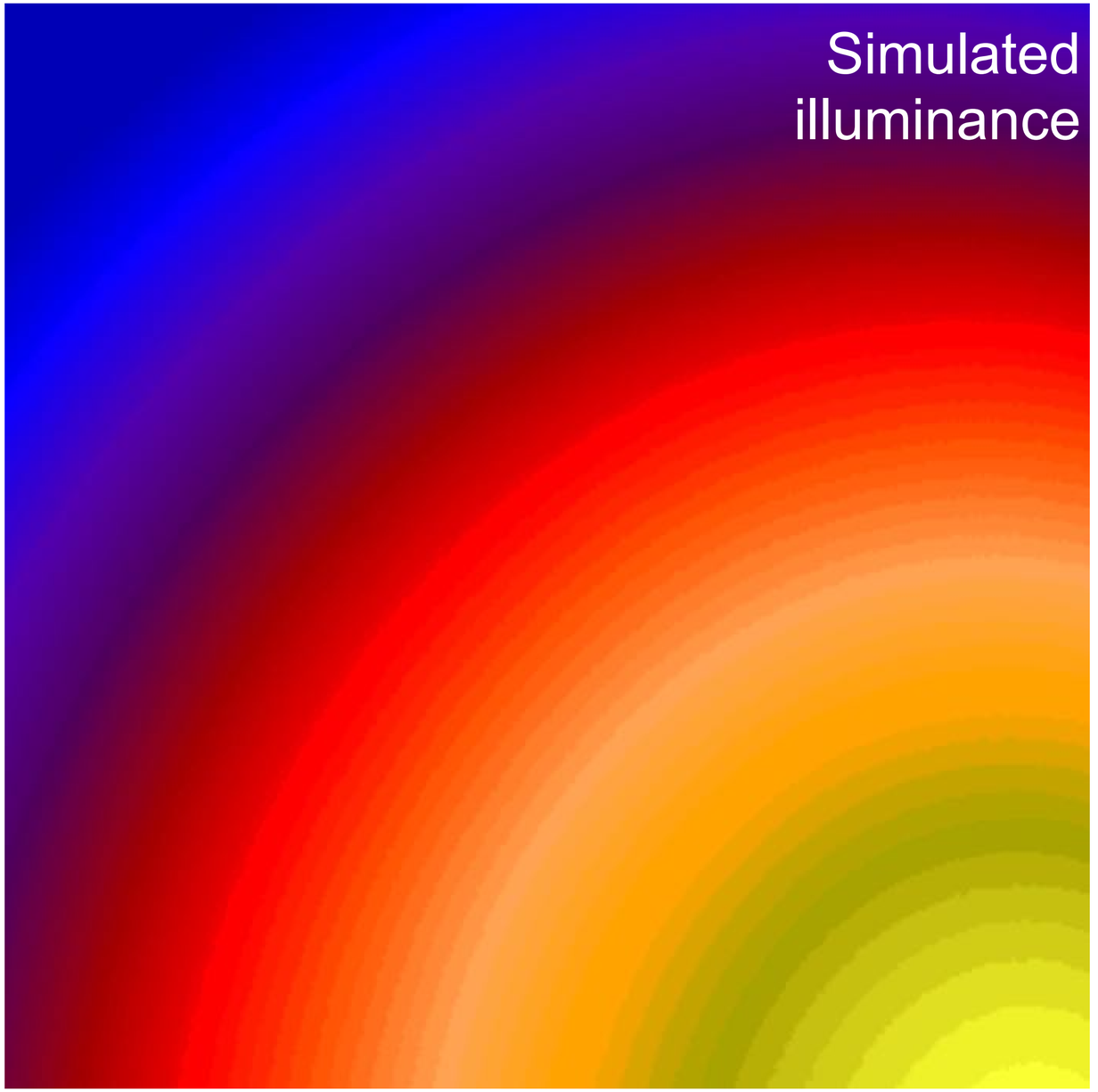


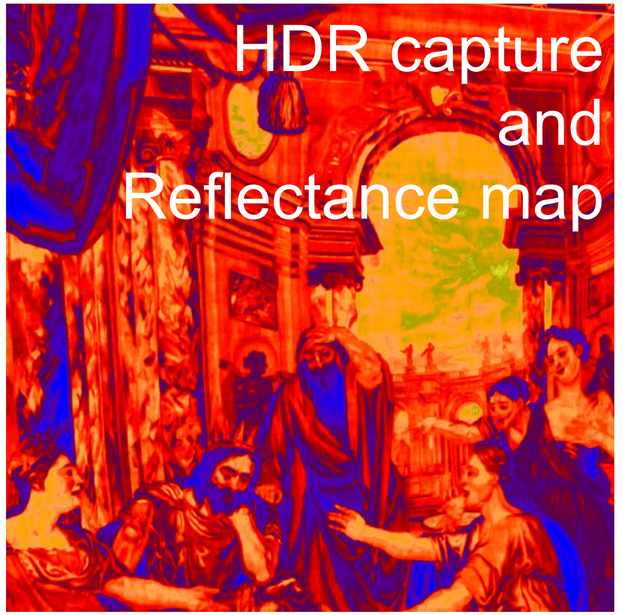


$$= \pi \frac{\text{HDR capture}}{\text{Reflectance map}}$$



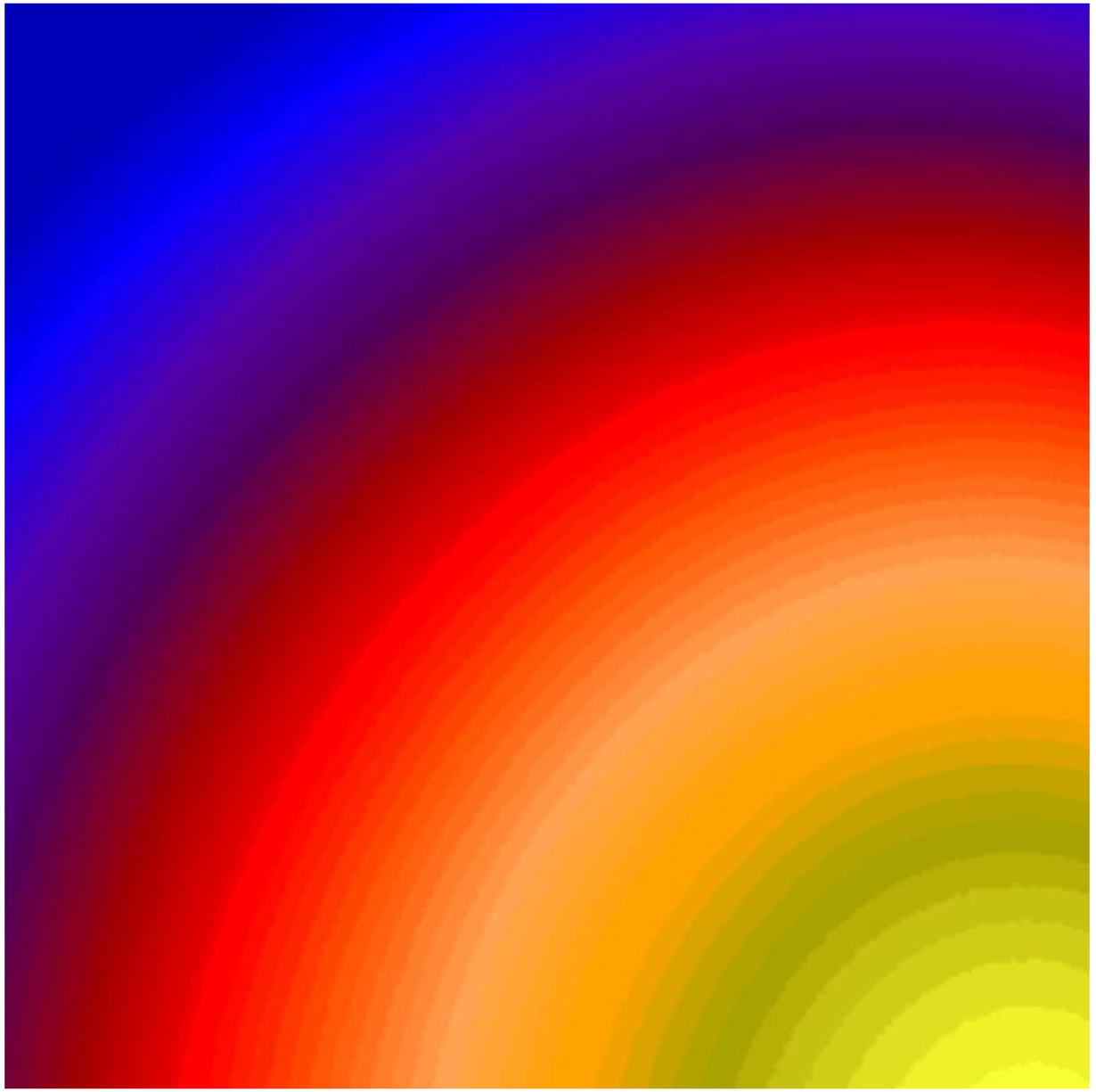






Exact pixel alignment

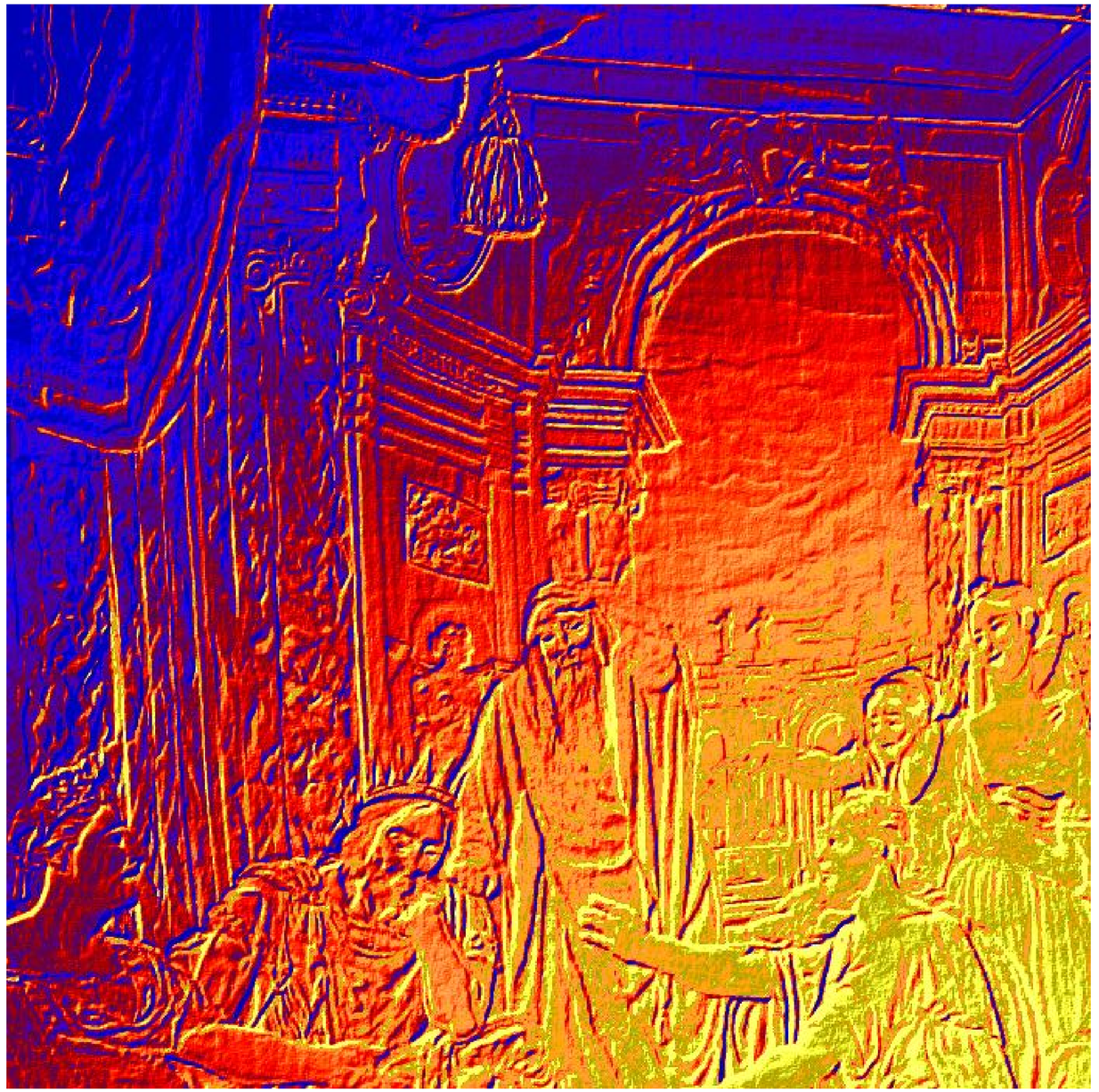
What happens when we don’t have exact pixel alignment between the reflectance map and the HDR capture?



Illuminance with exact pixel alignment between the HDR capture and the reflectance map

[1,1]

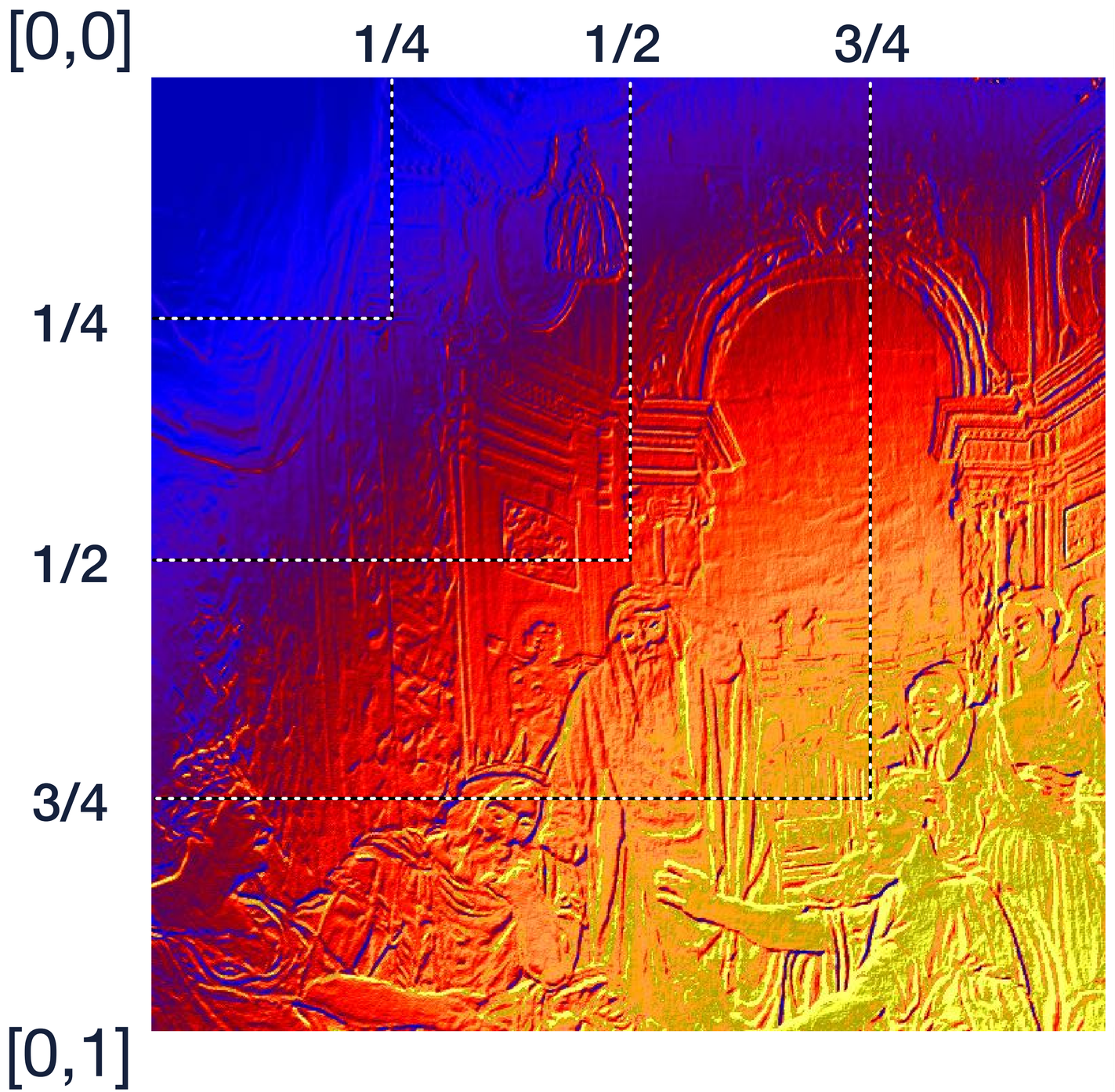
[1,1]



[1,1]

[1,1]

Illuminance with a fixed shift of 1 pixel in x and y between the HDR capture and the reflectance map

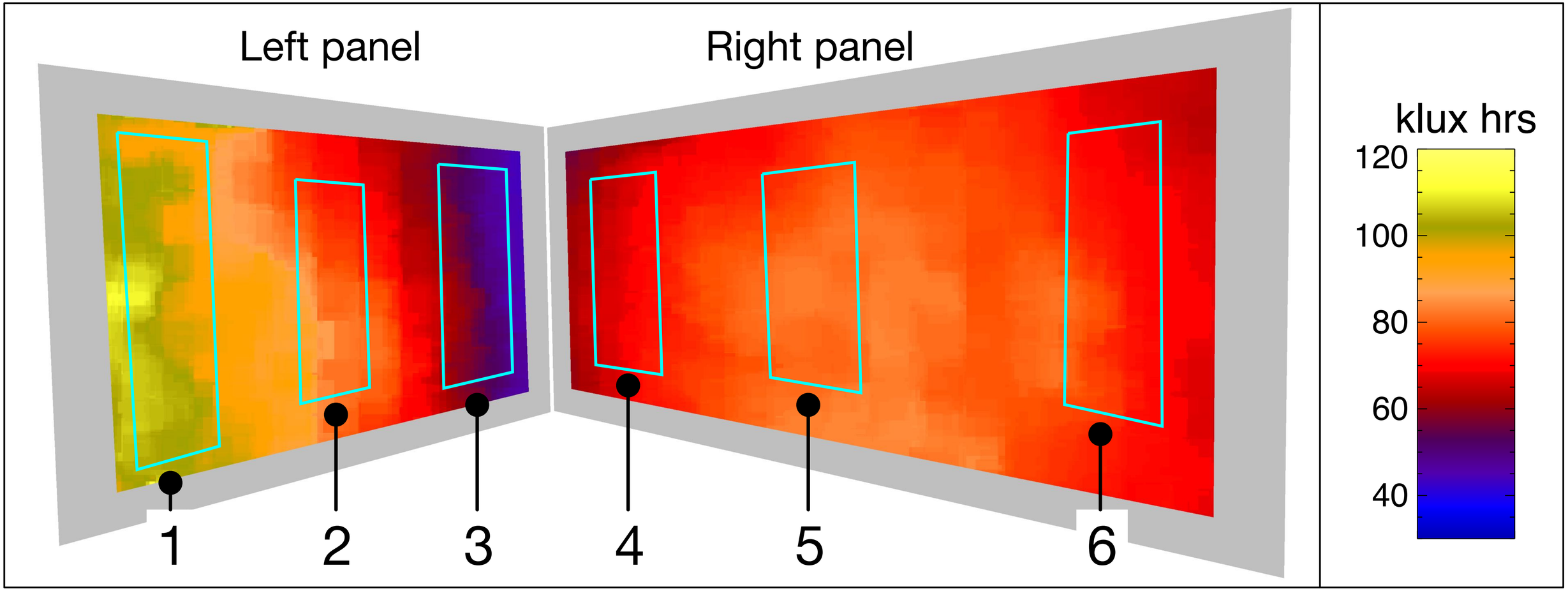


Illuminance with a gradual shift of 1 pixel in x and y between the HDR capture and the reflectance map

Tapestries are known to expand and contract due to variations in relative humidity

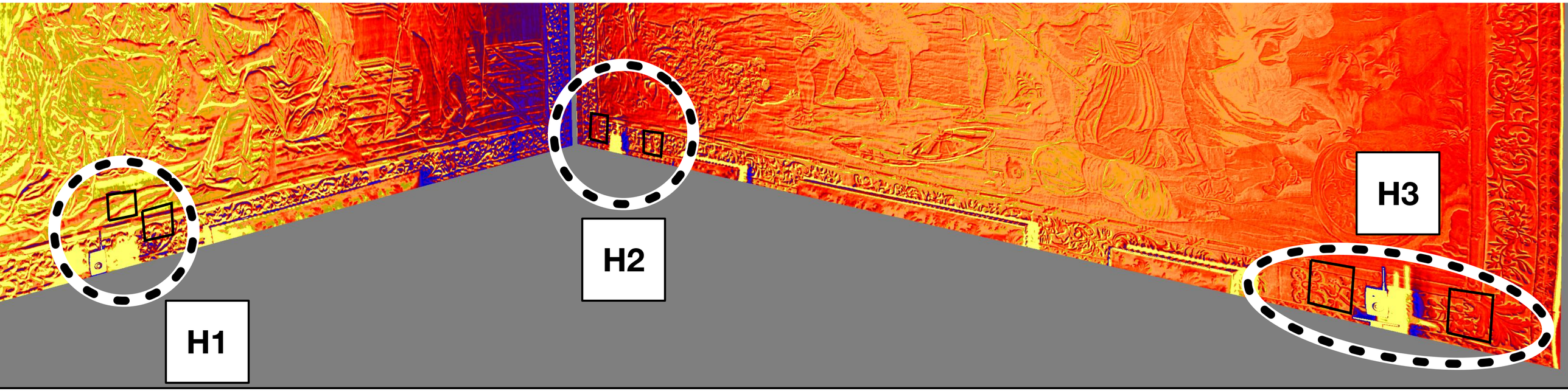
Typical pixel sizes across the tapestries correspond to dimensions 2.2 to 2.6mm

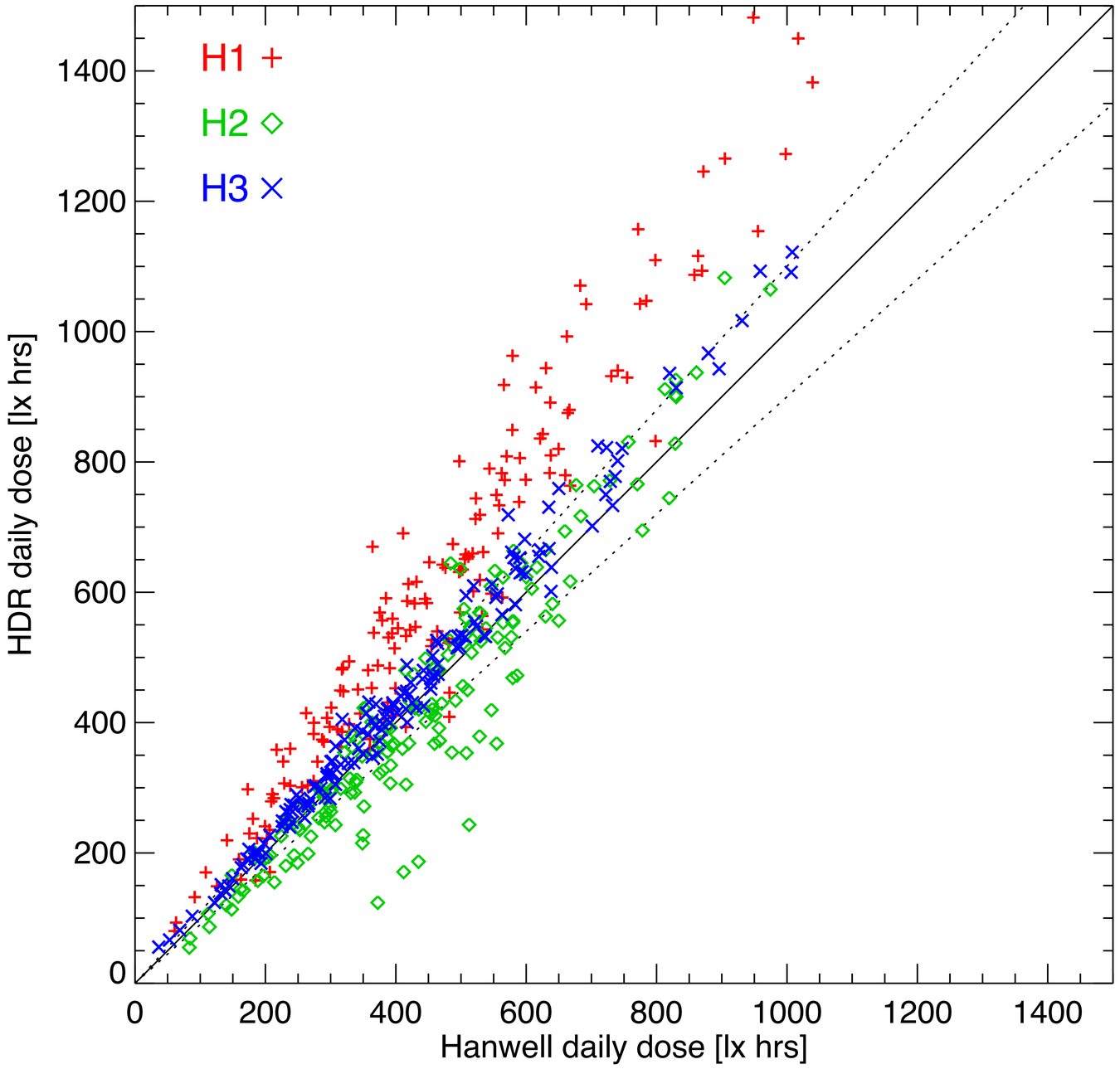
‘Correct’ the illuminance map by applying a coarse energy-preserving filter



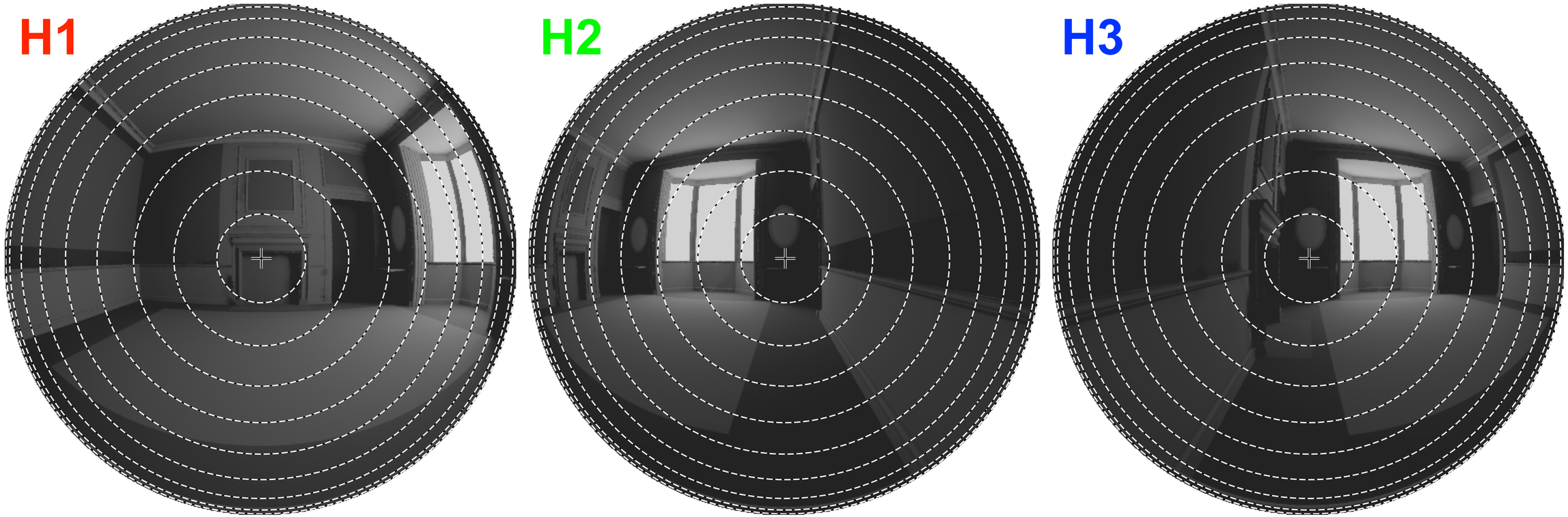
Tapestry area	Unfiltered light dose map [klux hrs]	Filtered light dose map [klux hrs]	Relative difference [%]
Left panel	81.61	81.57	-0.05
Right panel	74.64	74.65	0.01
Section 1	99.54	99.76	0.22
Section 2	80.06	80.17	0.14
Section 3	53.83	53.77	-0.11
Section 4	68.03	67.98	-0.07
Section 5	80.04	80.07	0.04
Section 6	72.53	72.55	0.03

Validation




H1
H2
H3
HDR daily dose [lx hrs]
Hanwell daily dose [lx hrs]
0
200
400
600
800
1000
1200
1400

	Measured light dose [klx hrs]	HDR-derived light dose [klx hrs]	Relative error [%]
H1	74,012	97,510	31.7
H2	69,089	66,571	-3.6
H3	65,772	70,680	7.5



Acknowledgements:

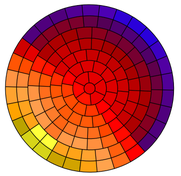
- National Trust staff at Ickworth and Ham House
- Dr Eleonora Brembilla (TU Delft)
- Dr Stephen Cannon-Brookes (UCL, Cannon-Brookes Lighting)
- Dr Nigel Blades (National Trust)

Loughborough University

TU Delft

UCL

National Trust



Daylight-Experts.com

Selected Publications

J. Mardaljevic, S. Cannon-Brookes, K. Lithgow, and N. Blades. Illumination and conservation: A case study evaluation of daylight exposure for an artwork displayed in an historic building. *CIE 28th Session*, Manchester, UK, 2015.

N. Blades, K. Lithgow, S. Cannon-Brookes, and J. Mardaljevic. New tools for managing daylight exposure of works of art: case study of Hambletonian, Mount Stewart, Northern Ireland. Journal of the Institute of Conservation, 40(1):15–33, 2017.

J. Mardaljevic, S. Cannon-Brookes, N. Blades, and K. Lithgow. Reconstruction of cumulative daylight illumination fields from high dynamic range imaging: Theory, deployment and in-situ validation. Lighting Research and Technology, 53(4):311–331, 2021.

J. Mardaljevic, E. Brembilla, S. Cannon-Brookes, and N. Blades. A hybrid measurement-simulation approach to determine the reflectance map of a historic tapestry. IBPSA - Building Simulation Conference, Bruges, Belgium, 2021.

J. Mardaljevic, E. Brembilla, S. Cannon-Brookes, and N. Blades. A hybrid measurement-simulation approach to determine the daylight exposure of a historic tapestry (submitted to Lighting Research and Technology)