Développements métrologiques autour des capteurs imageurs dans le visible

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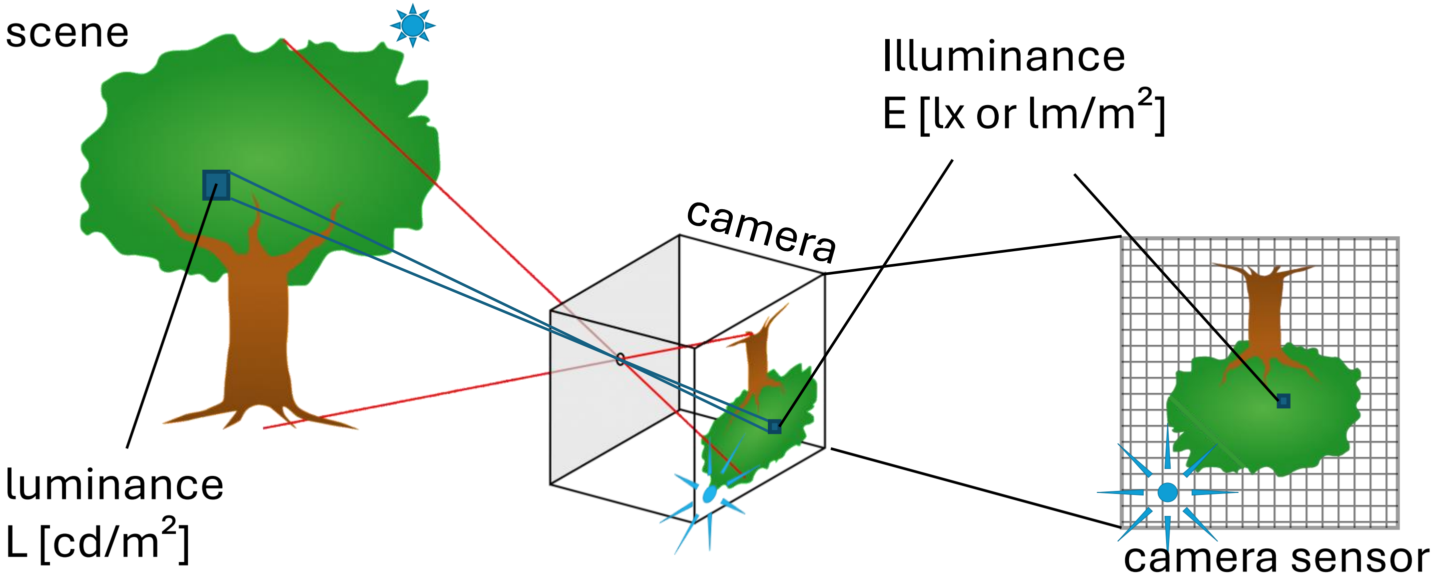
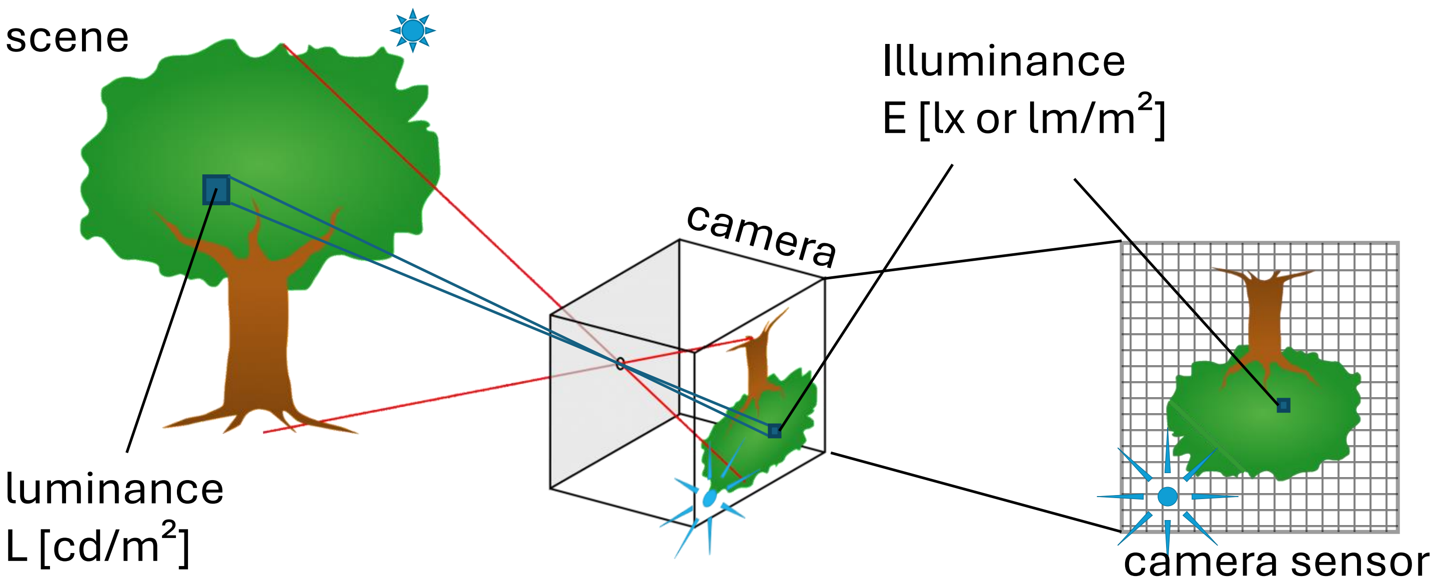
Presentation outline

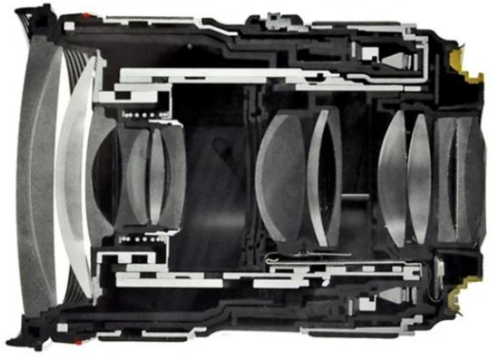
- ❑ Imaging process
  - Optical and digital imaging process
- ❑ Camera calibration
  - Linearity, flat-field, stray light, hardware
- ❑ HDR imaging

Measurement with cameras – optical imaging process



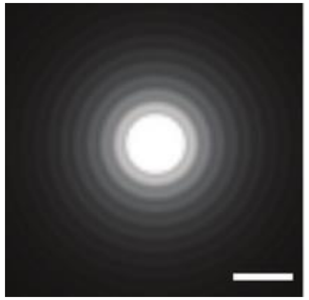
Measurement with cameras – optical imaging process





Optical "noises"

PSF



Vignetting

Distorsion

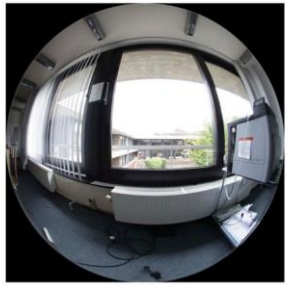


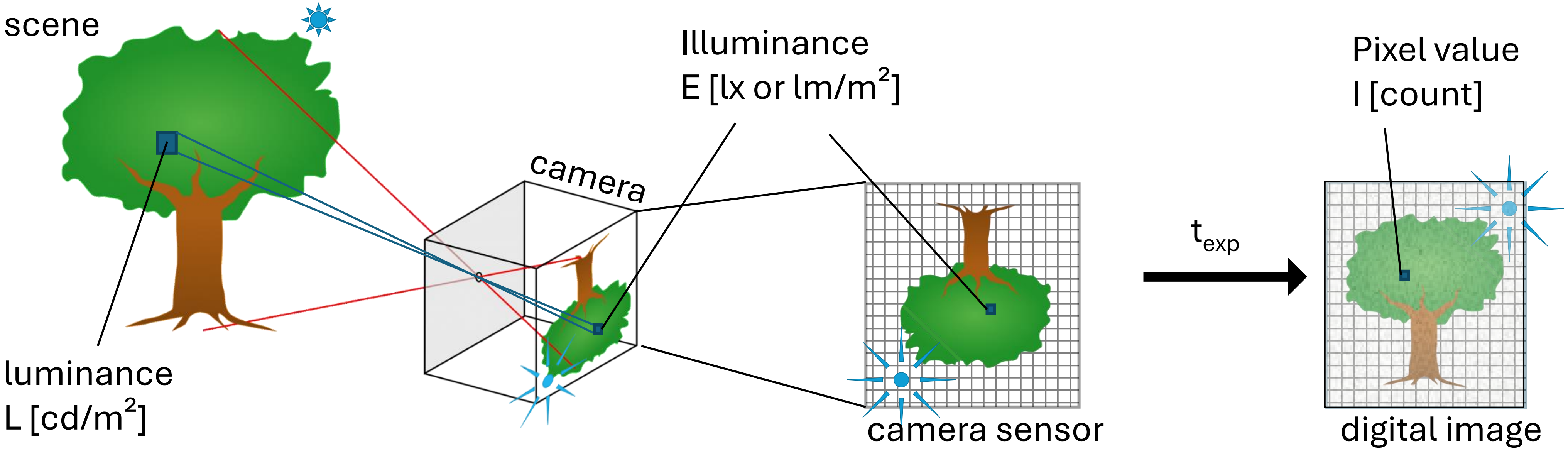
Fig. 5. Example of a visual scene appropriate for the derivation of the camera response function.

Stray light (including diffraction)

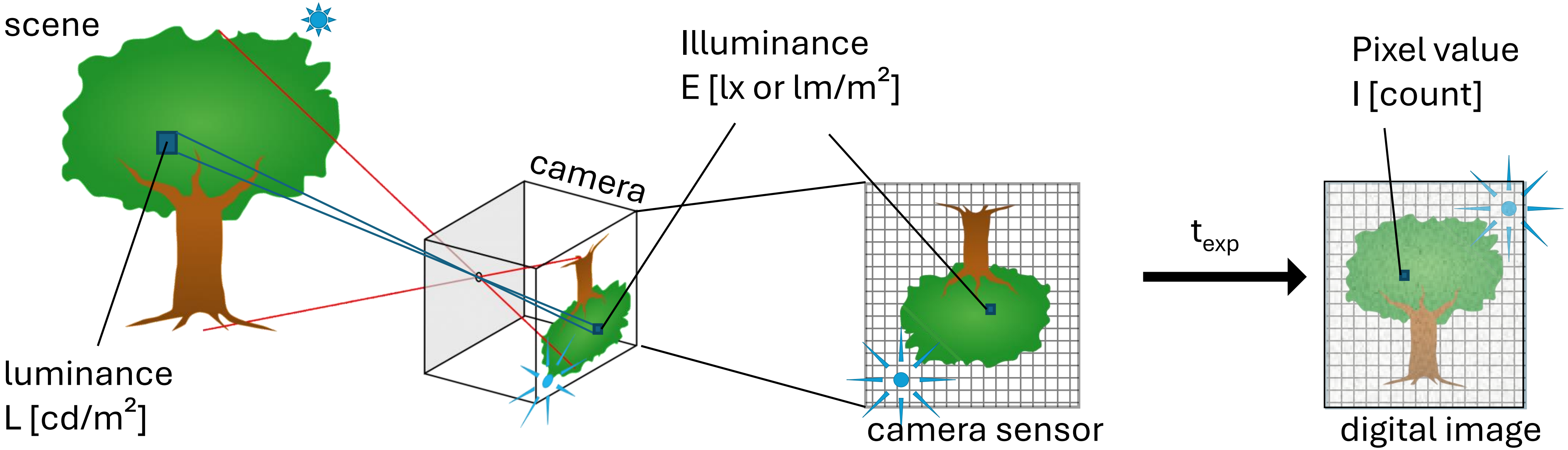
Independent from the scene

Depends on the scene

Measurement with cameras – digital imaging process

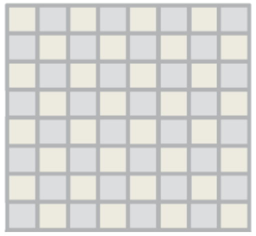


Measurement with cameras – digital imaging process



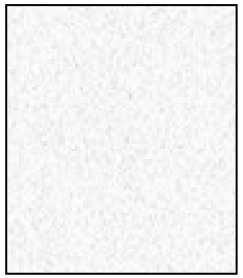
Digital "noises"

Pixel gain (quantum efficiency, PRNU, non-linearity,...)



Depends on pixel illuminance

Shot noises (dark current + photon noise)

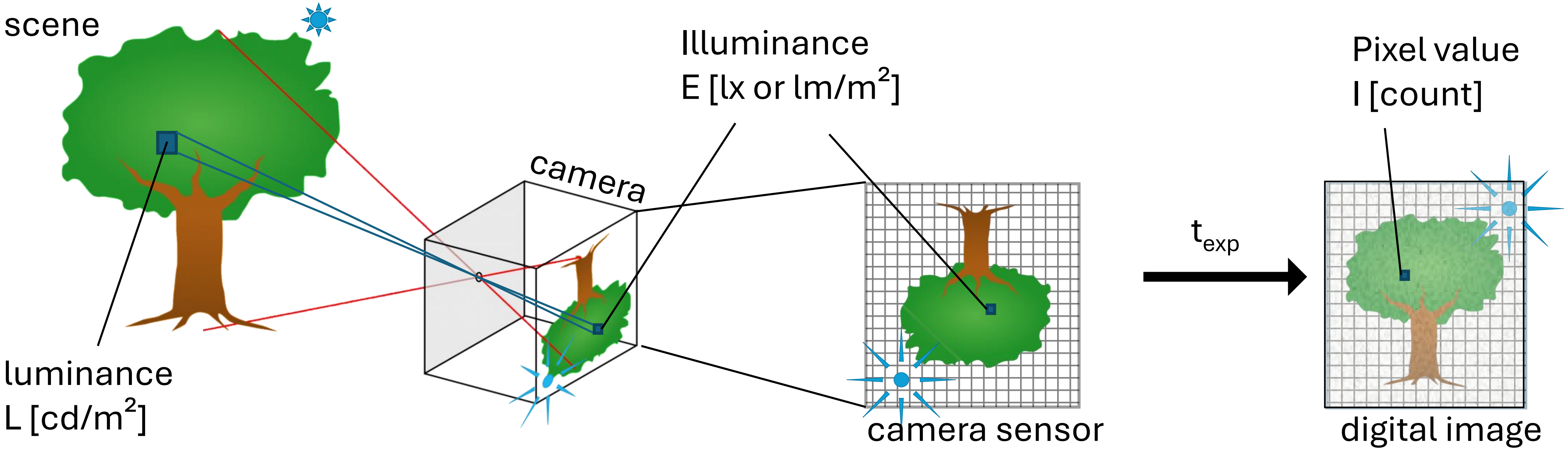


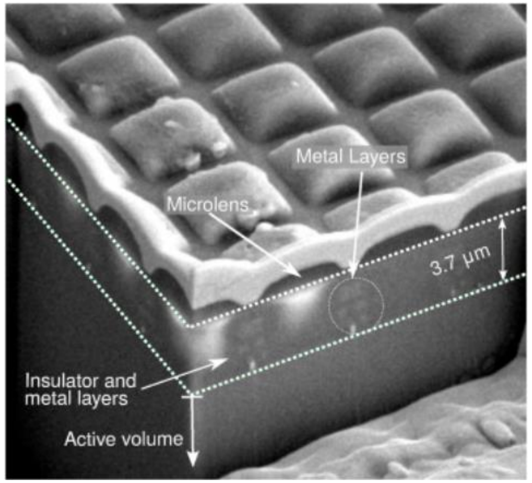
Readout noise (Gaussian noise)

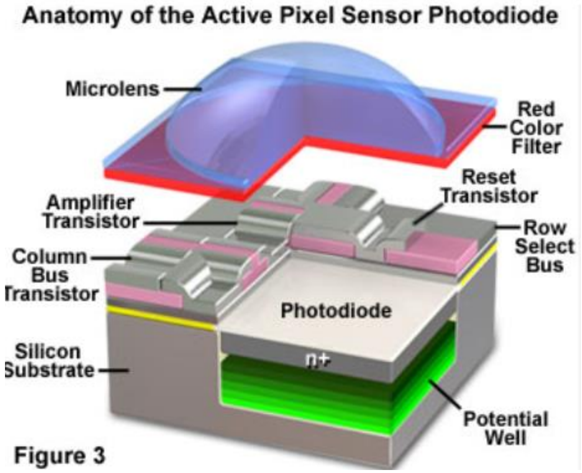
+ Quantization & camera gain

Independent from t_{exp}

Measurement with cameras – digital imaging process







Measurement with cameras – calibration

Camera calibration

- Non-linearity
- Flat-field
- Geometrical distortion
- PSF or MTF
- Luminance conversion
- or spectral sensitivity
- …

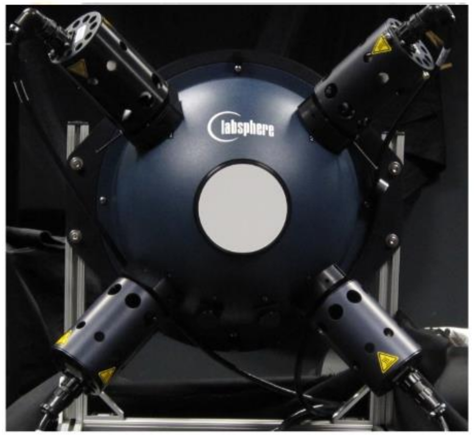
The calibration depends on the camera parameters ! (aperture, focus)

Measurement with cameras – calibration

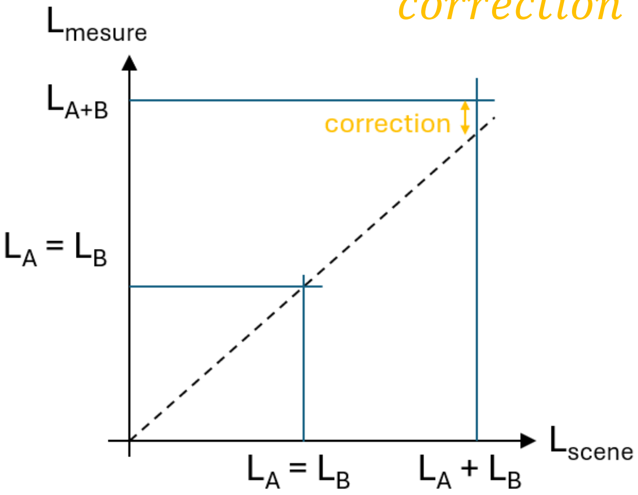
Camera calibration

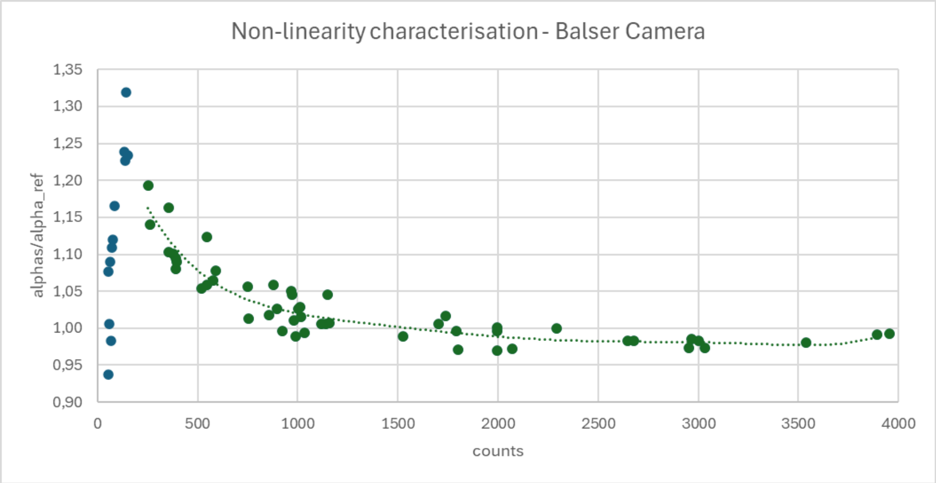
☑ Non-linearity (flux)

- Absolute method : flux addition method
- ~Absolute method : integration time variation
- Relative method : calibrated reference



$$correction = \frac{L_A + L_B}{L_{A+B}}$$



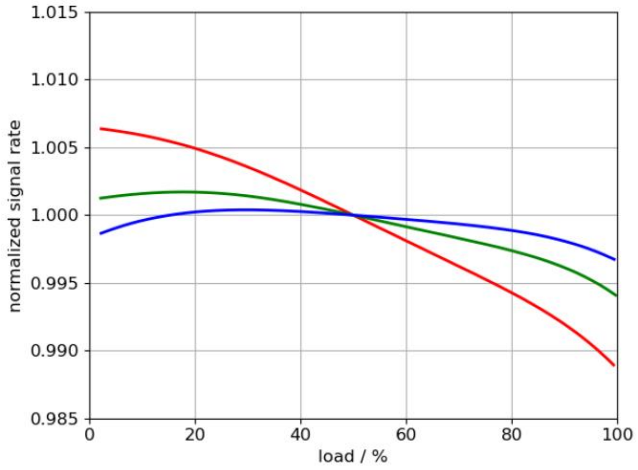


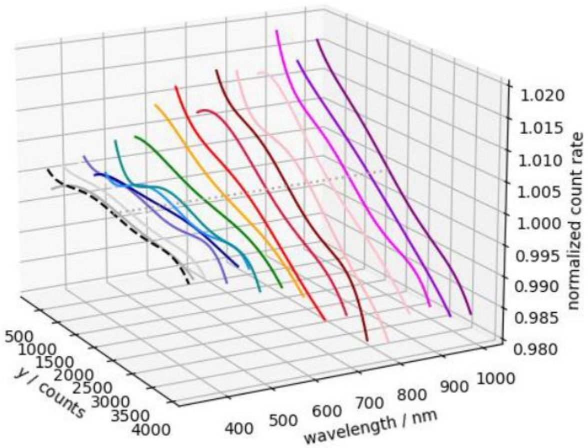
Non-linéarité en flux mesurée de manière relative, caméra Basler

Measurement with cameras – calibration

Camera calibration

- ☑ Non-linearity (flux)





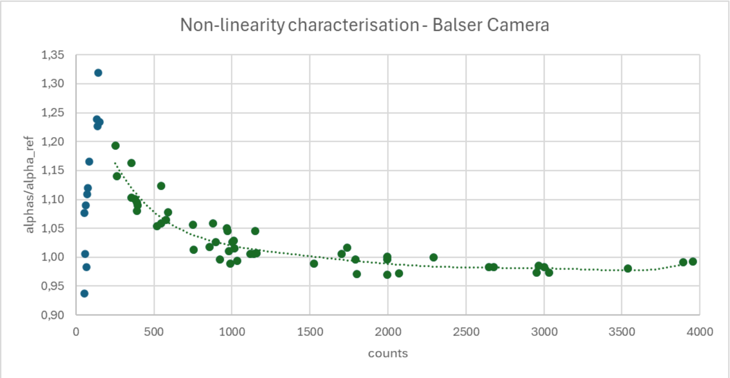
Exemple de non-linéarité en flux dans le rouge, vert et bleu (gauche) et non-linéarité spectrale (droite) [Good practice guide, RevStdLED]

- Spectral effect

- Error estimation

Residual non-linearity error:

$$\varepsilon_{rel} = \frac{Y_{max} - Y_{min}}{Y_{max} + Y_{min}}$$

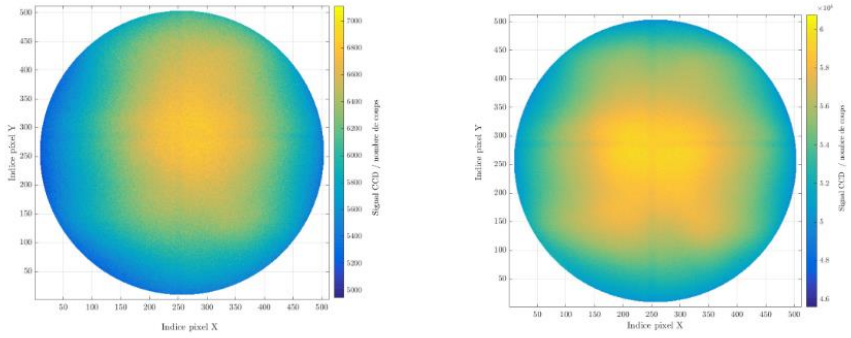


Non-linéarité en flux mesurée de manière relative, caméra Basler

Measurement with cameras – calibration

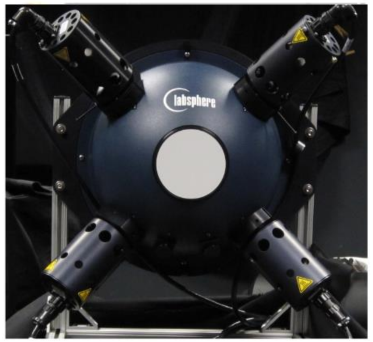
Camera calibration

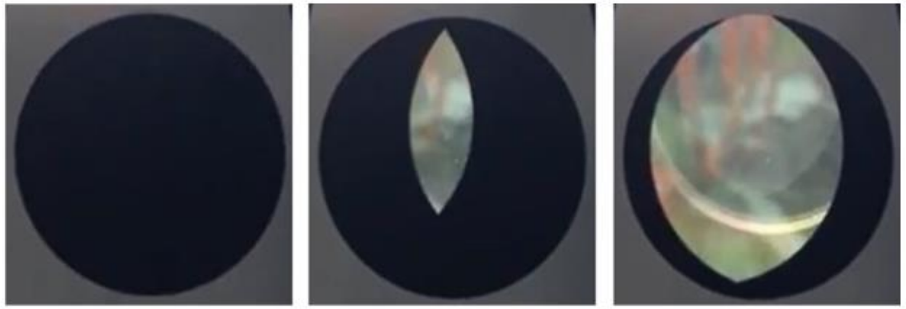
- [x] Non-linearity (exposure time)



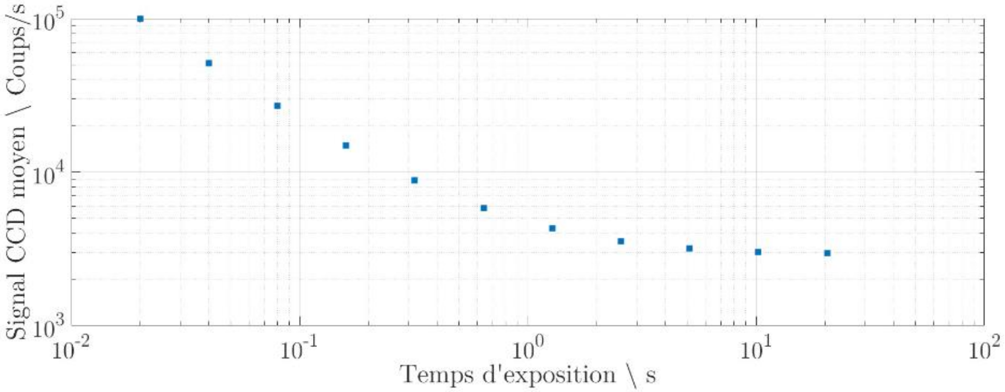
(a) Cliché à $t_{exp} = 20\,\mathrm{ms}$ (b) Cliché à $t_{exp} = 20{,}48\,\mathrm{s}$

Image d'une scène uniforme à deux temps d'exposition, camera ORCA (CCD), [these G. Ged]





Obturateur, camera ORCA (CCD), photos J. Aupetit (Hamamatsu)



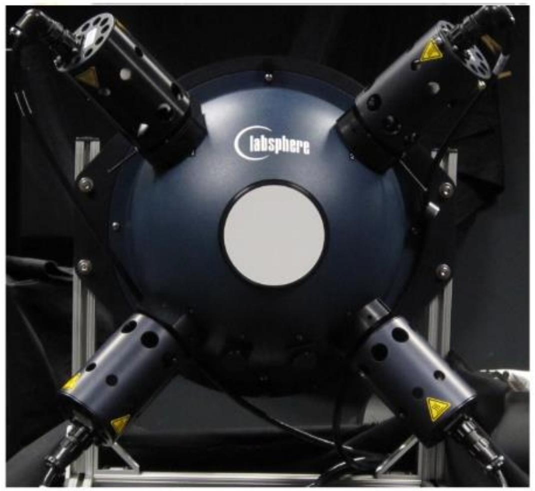
Non-linéarité temporelle, camera ORCA (CCD), [these G. Ged]

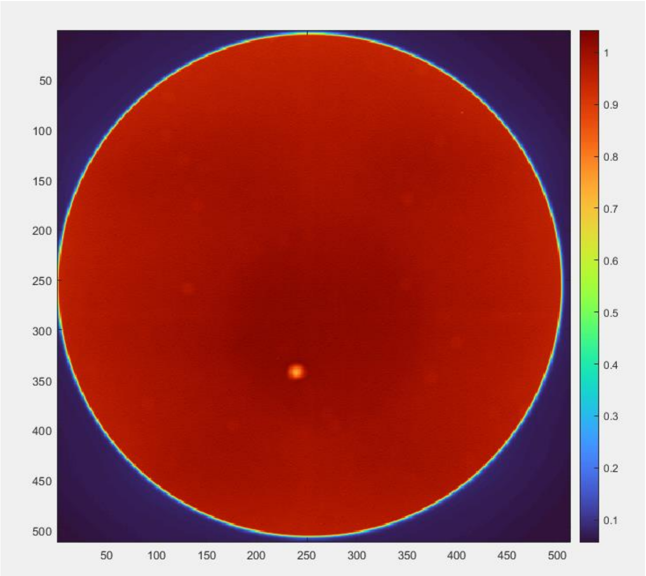
Measurement with cameras – calibration

Camera calibration

☑ Flat-field

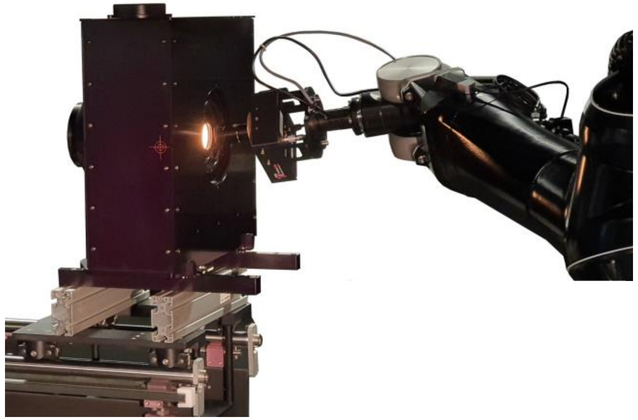
- Focus dependant
- Aperture dependant





Flat-field, caméra ORCA (CCD)

Flat-field depends on the camera parameters



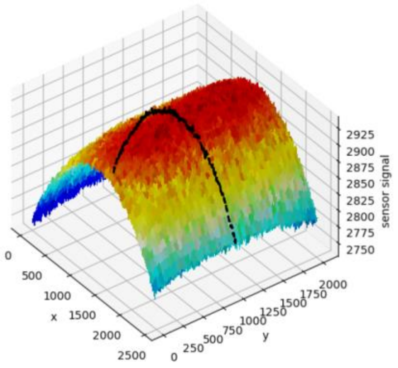


Figure 1: Example of the shading characteristic of an ILMD

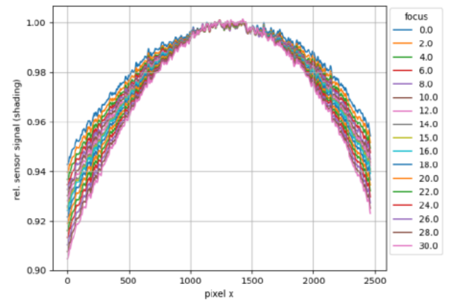


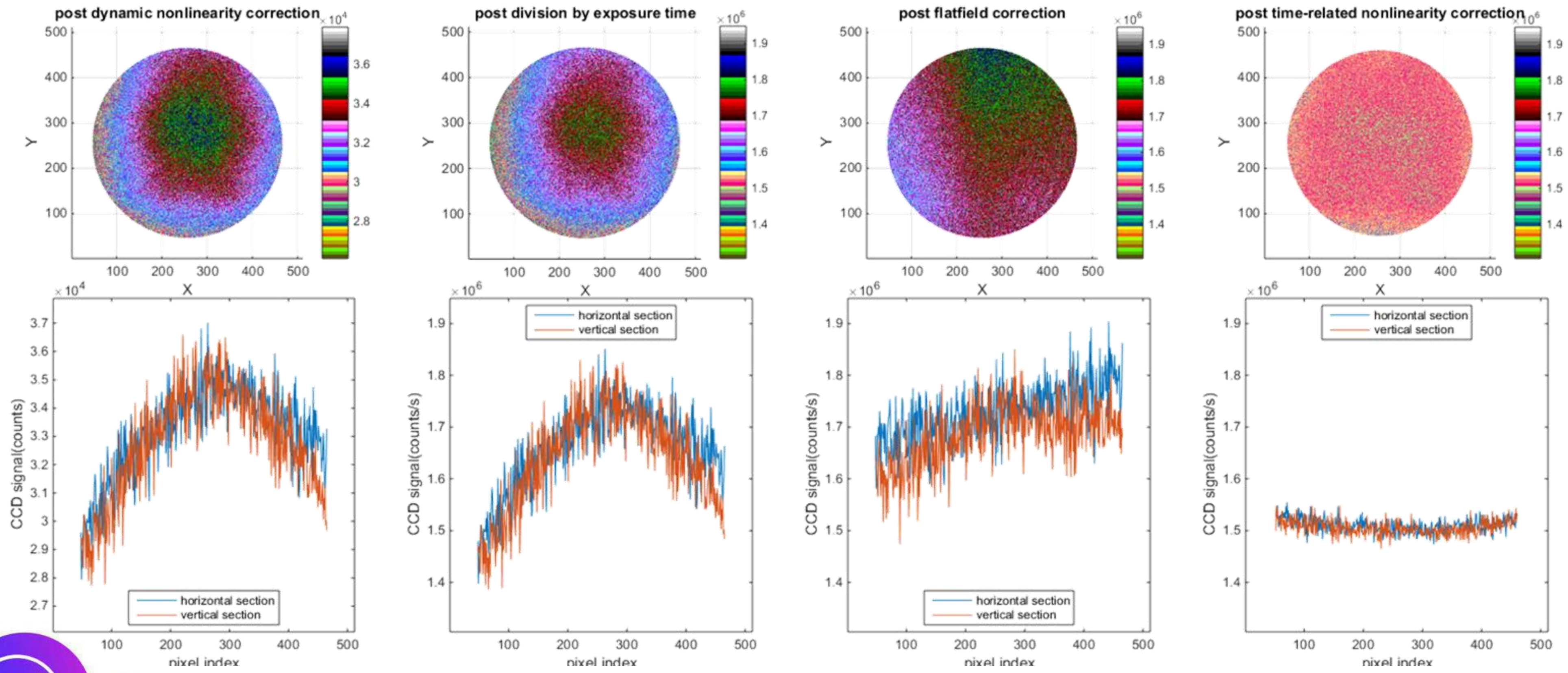
Figure 3: Focus dependency of the relative shading characteristic across the image

Flat-field, ILMD LMK [Good practice guide, RevStdLED]

Measurement with cameras – calibration

Corrections

Dark substraction, Flux linearity correction, exposure time normalisation, flat-field correction, exposure time linearity correction

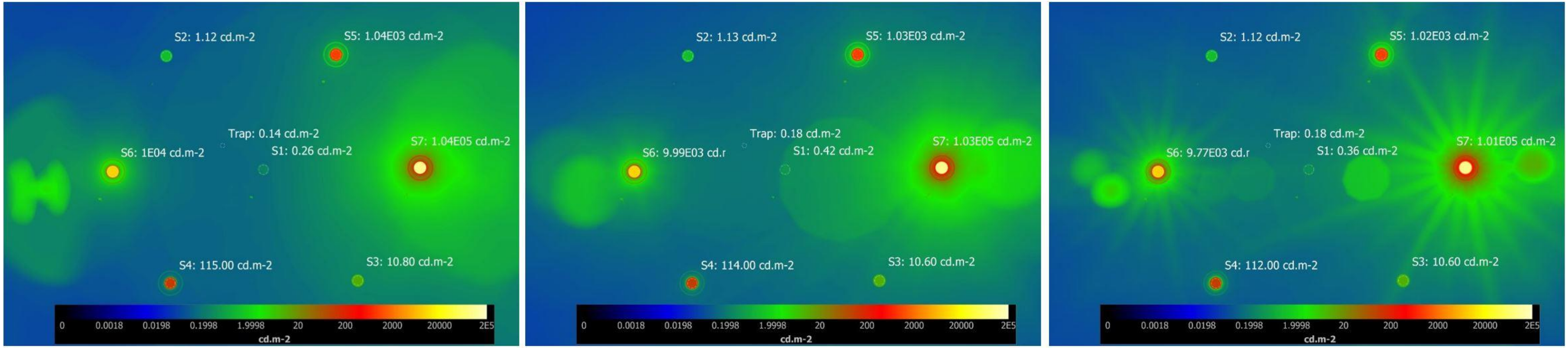


Measurement with cameras – calibration

Camera calibration

Stray light is the light that reaches the sensor elsewhere than intended in the optical design. This light can come from various sources such as diffraction, reflections, scattering, or internal reflections within the optical components of the system.

- ☒ Stray light



Luminance measurement. Same HDR scene captured under varying camera parameters (decreasing F number) - Courtesy: C Bouroussis

{HiDyn}

Stray light depends on the camera parameters & on the scene

Measurement with cameras – hardware

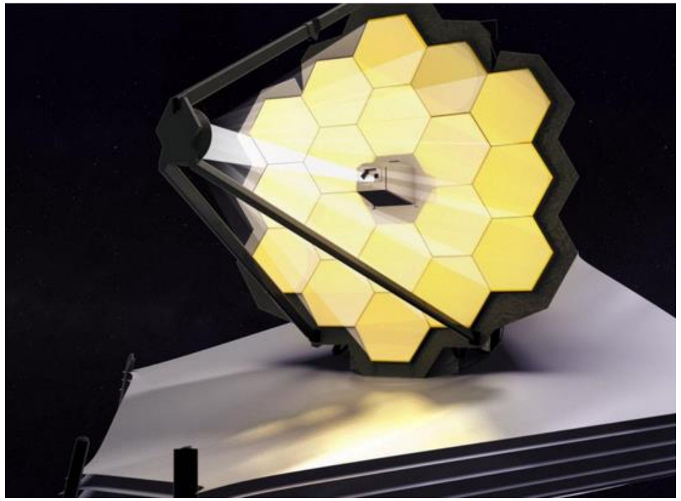
Scientific camera

Consumer camera

Industrial camera

Fixed focal lens

Zoom lens

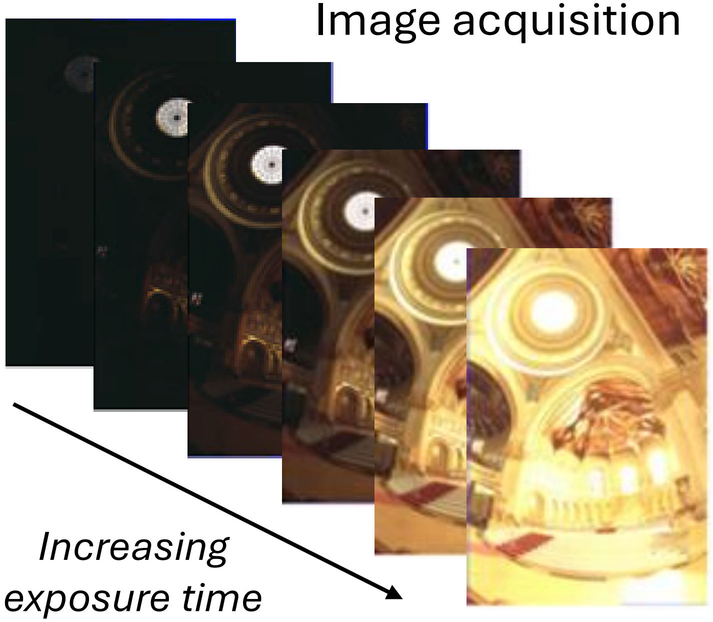


Mirror-based optics

Measurement with cameras – HDR imaging

- HDR (= High Dynamic Range)

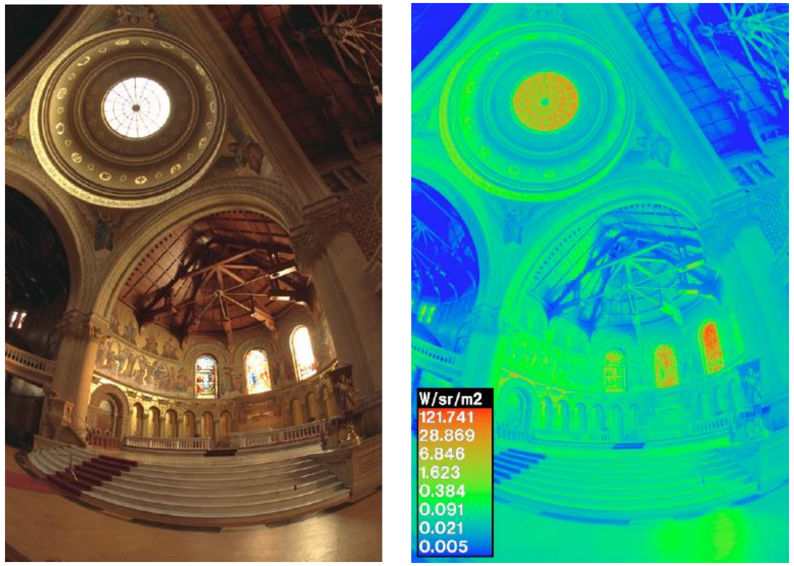
Image acquisition



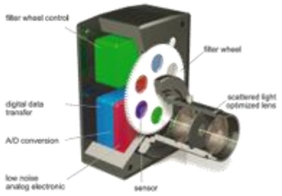
Increasing exposure time

HDR reconstruction algorithm

HDR image



[P. Debevec, and J. Malik. SIGGRAPH 97]



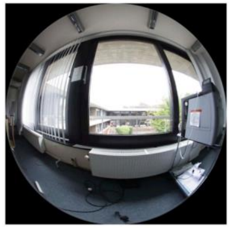


Fig. 5. Example of a visual scene appropriate for the derivation of the camera response function.

{HiDyn}

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Measurement with cameras – HDR imaging

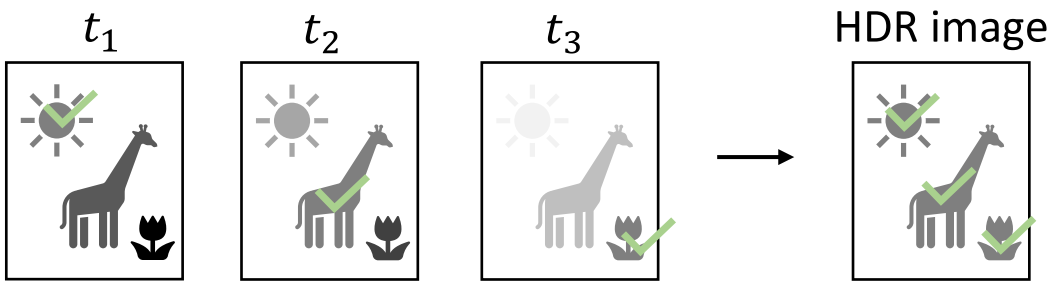
$I_i(x)$: pixel count for pixel x acquired at exposure time t_i
$\alpha(x)$: pixel gain
$E(x)$: pixel illuminance

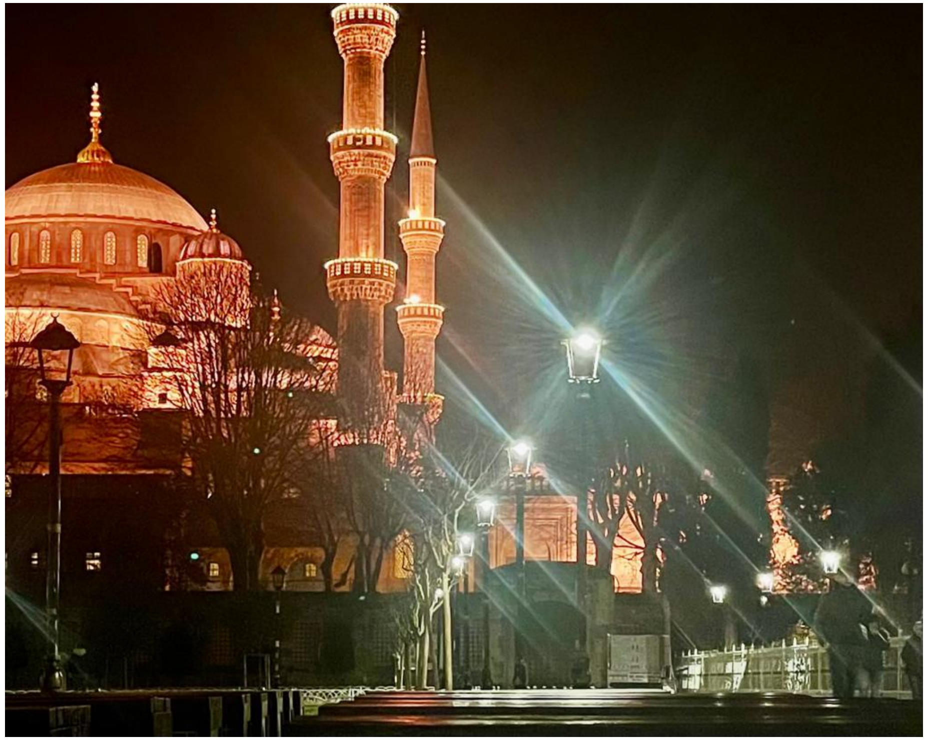
Best exposure

For each pixel x, the HDR illuminance is:

$$E_{HDR}(x) = \alpha(x)\, I_i(x)/t_i$$
$$i = \max\{i \text{ such that } I_{min} \le I_i(x) \le I_{max}\}$$

The HDR pixel is the LDR best exposed-pixel: value maximized but not saturated





HDR Night scene photo with straylight (captured using an Iphone 12) – Courtesy: G Obein

Presentation outline

Thanks for your attention !

Ged, Guillaume. *Métrologie du brillant: développement et caractérisation psychophysique d'échelles de brillants*. Diss. Conservatoire national des arts et metiers-CNAM, 2017.

Schrader Christian et al., Good Practice Guide for Setting up an Uncertainty Budget for the Measurement of Luminance Distributions, RevStdLED European project

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

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Co-funded by the European Union

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

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