

Diffraction Prediction in HDR measurements

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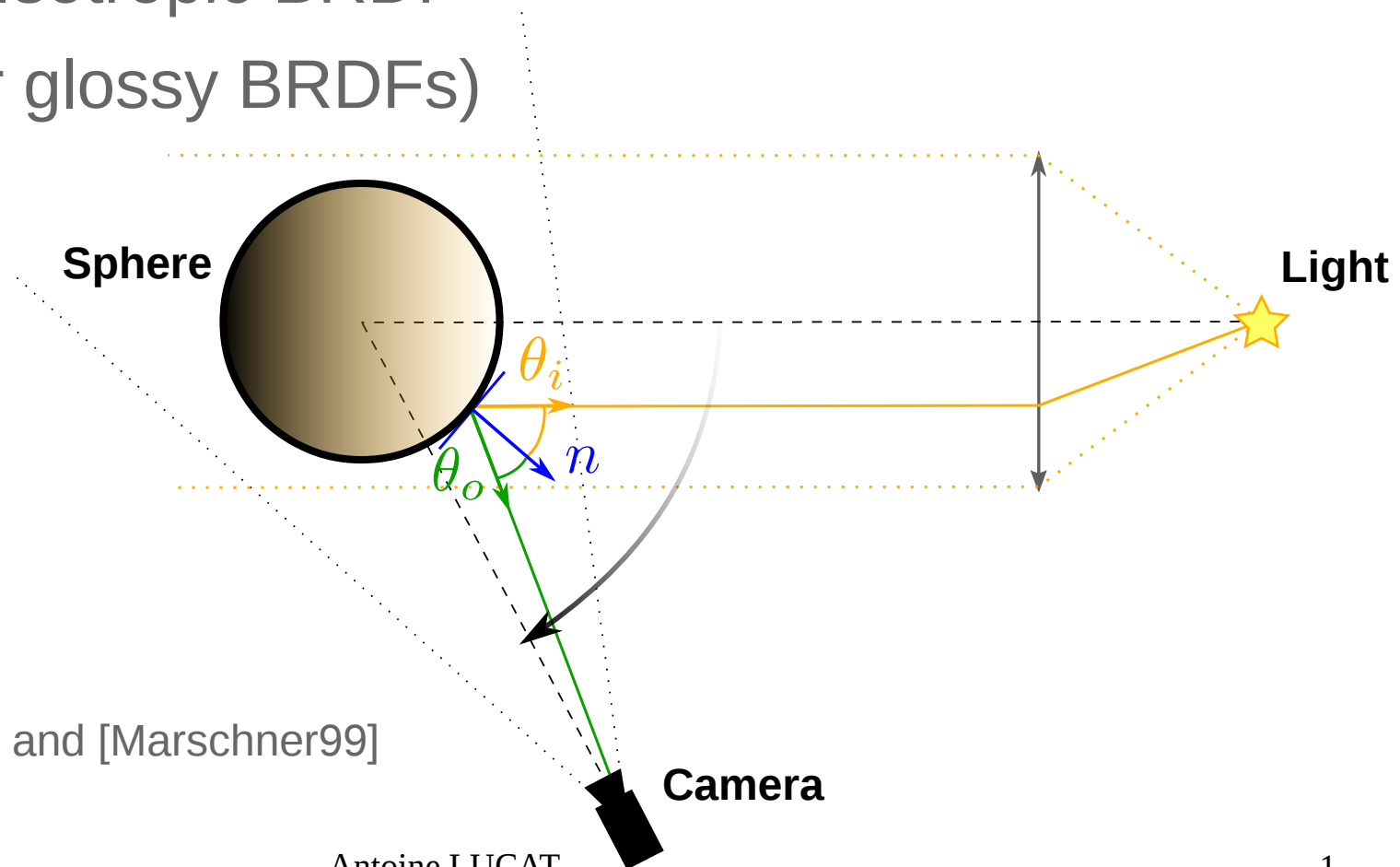
Inria
INVENTEURS DU MONDE NUMÉRIQUE



Context

Our setup (presented last year):

- Imaging system
- Uniform Isotropic BRDF
- HDR (for glossy BRDFs)

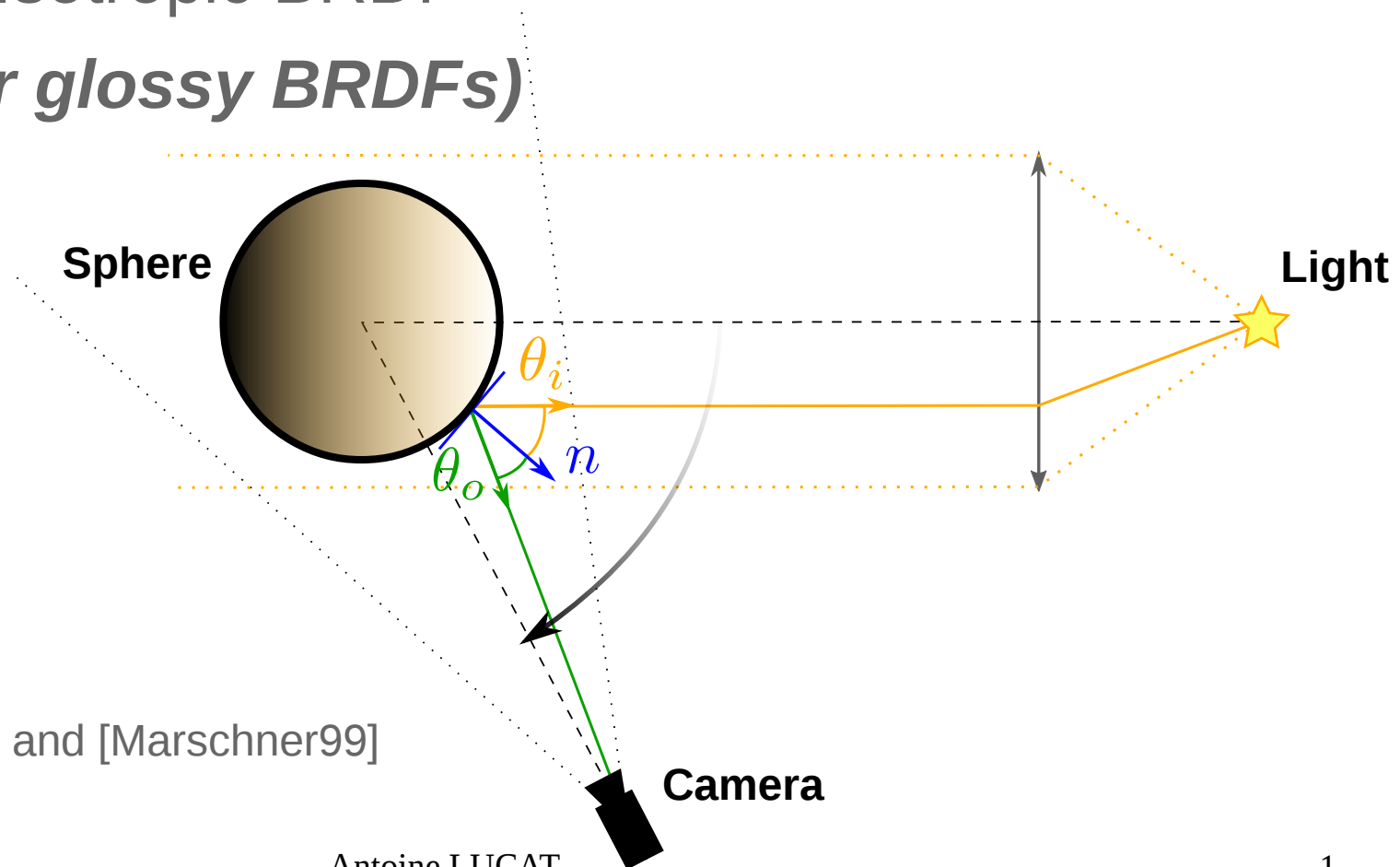


Inspired by [Matusik03] and [Marschner99]

Context

Our setup (presented last year):

- Imaging system
- Uniform Isotropic BRDF
- *HDR (for glossy BRDFs)*



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Context

The HDR process:

Exposure time →



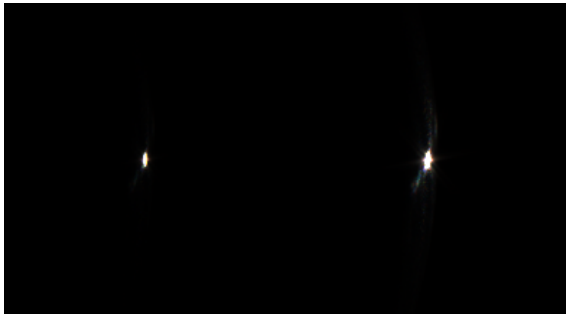
Exposure time 1



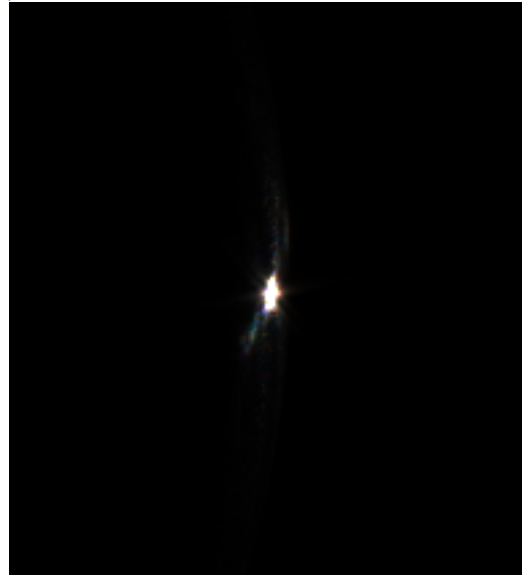
Context

The HDR process:

Exposure time →



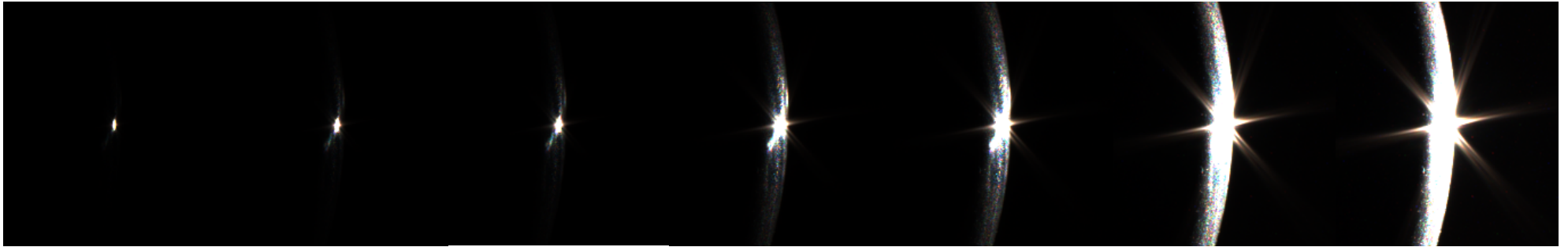
Exposure time 2



Context

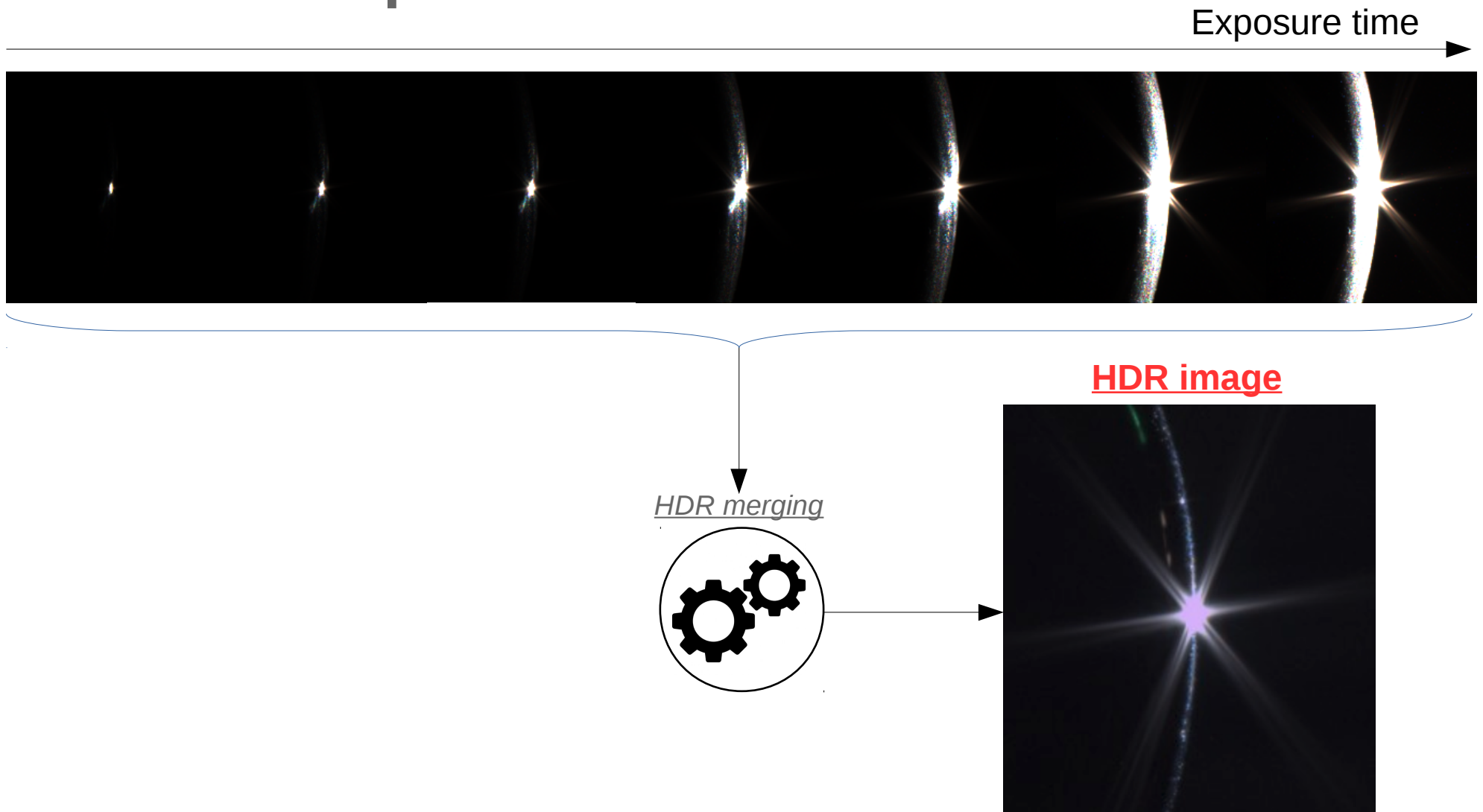
The HDR process:

Exposure time →



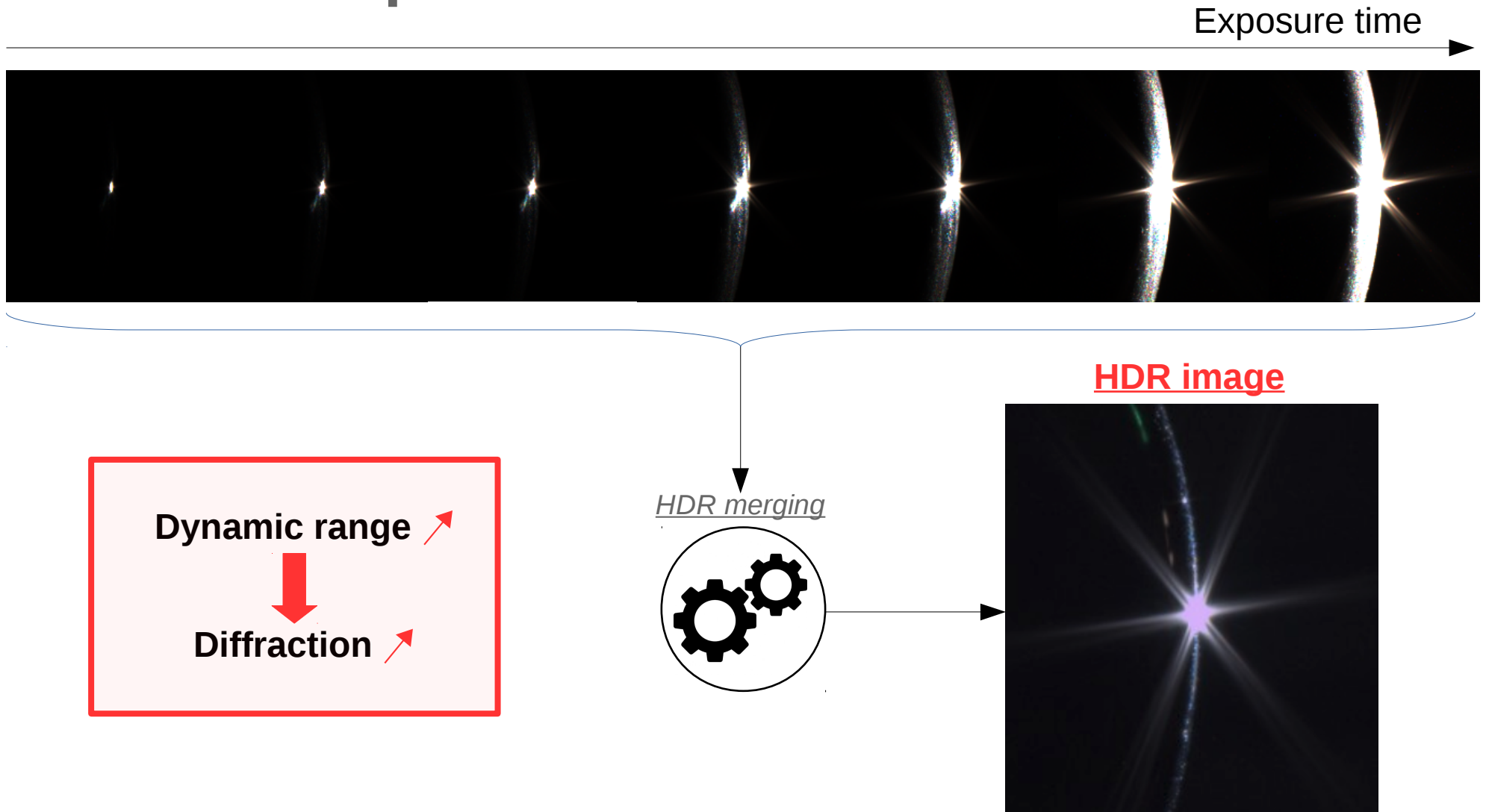
Context

The HDR process:



Context

The HDR process:



Context

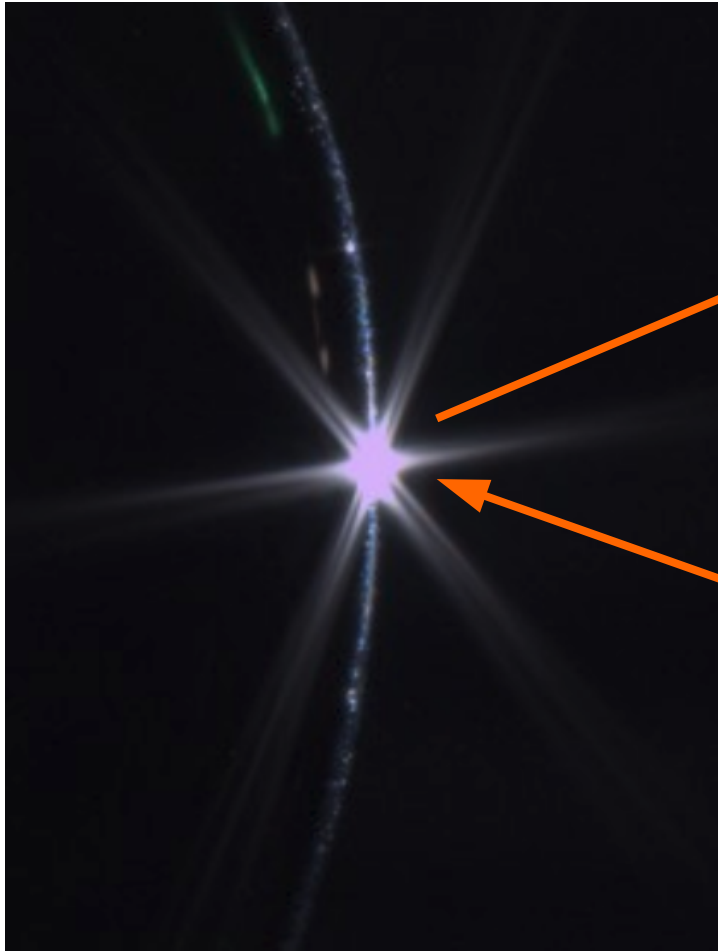
Common issue: Diffraction



Caused by :
→ **Lens diaphragm**
→ **High dynamic range**

Context

Common issue: Diffraction



Unreliable measurement

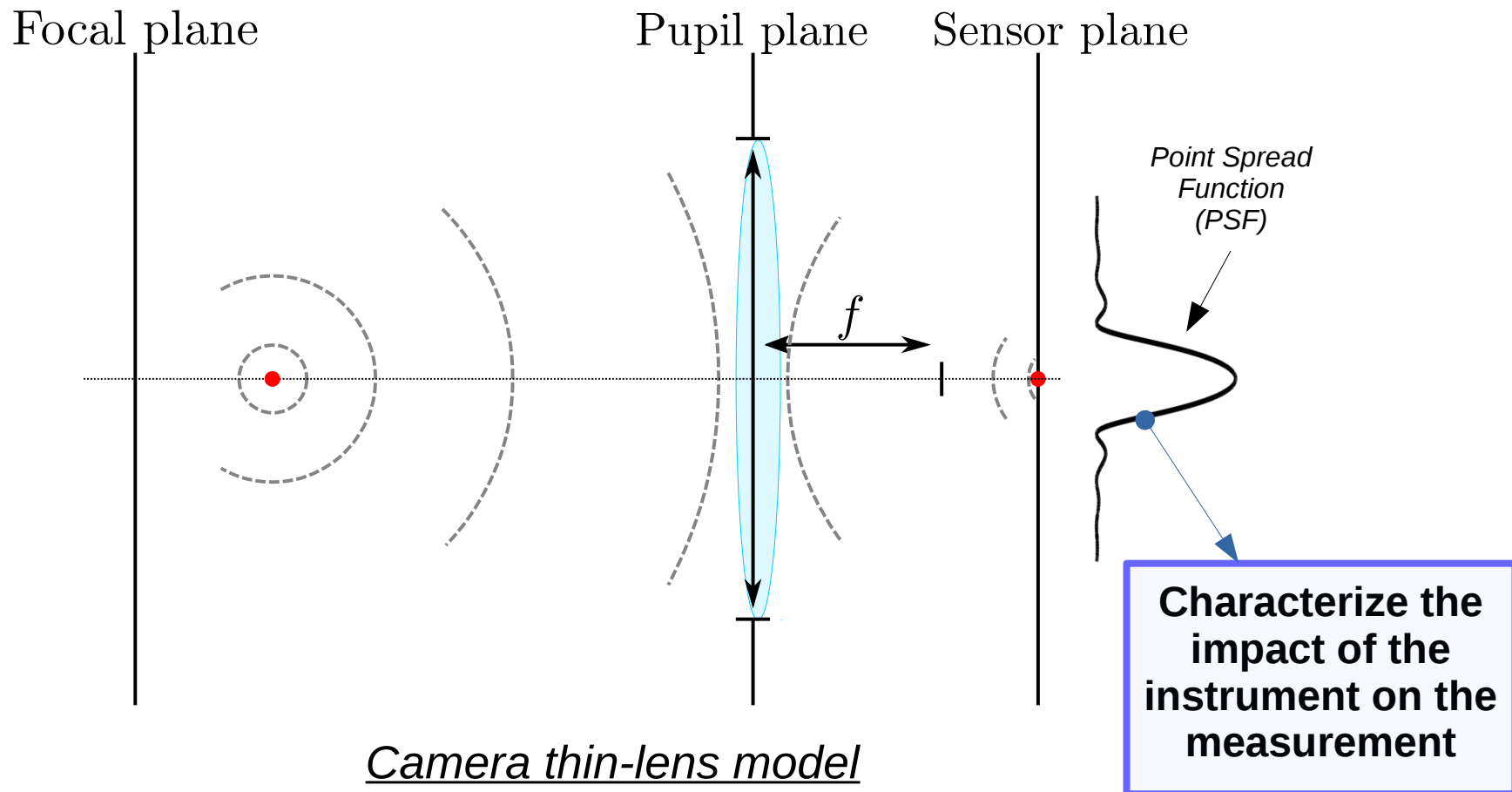
Caused by :

- **Lens diaphragm**
- **High dynamic range**

Lens Diffraction Effect

Wave behaviour:

the **image of a point** through finite aperture **is not a point**



Lens Diffraction Effect

Wave behaviour:

the image of a point through finite aperture is not a point

Assumptions:

+ Fresnel conditions

+ Quasi in-focus

+ No aberrations

+ Incoherent imaging

$$PSF \propto |\mathcal{F}[\text{diaphragm}]|^2$$



diaphragm

Convolution

$$I = I^* \otimes PSF + \mathcal{B}$$

Measured

Ground truth

Noise

$$\text{Perfect measurement} \iff PSF = \delta_0$$

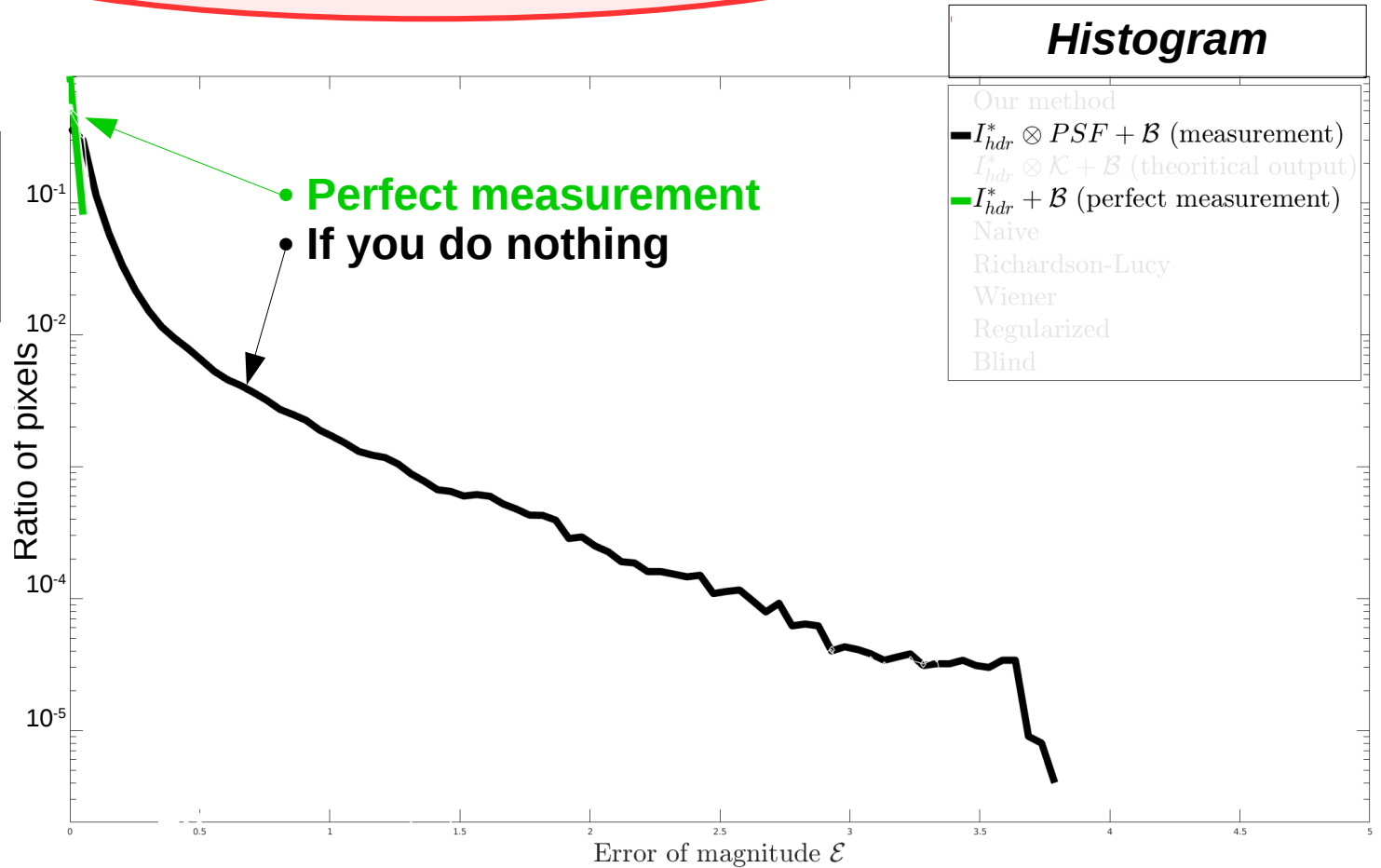
Common Solutions

$$I = I^* \otimes PSF + \mathcal{B}$$

What to do with I ?

1 → Do nothing

Unbounded Error



$$\mathcal{E} = |\log_{10}(I_{output}) - \log_{10}(I^*)|$$

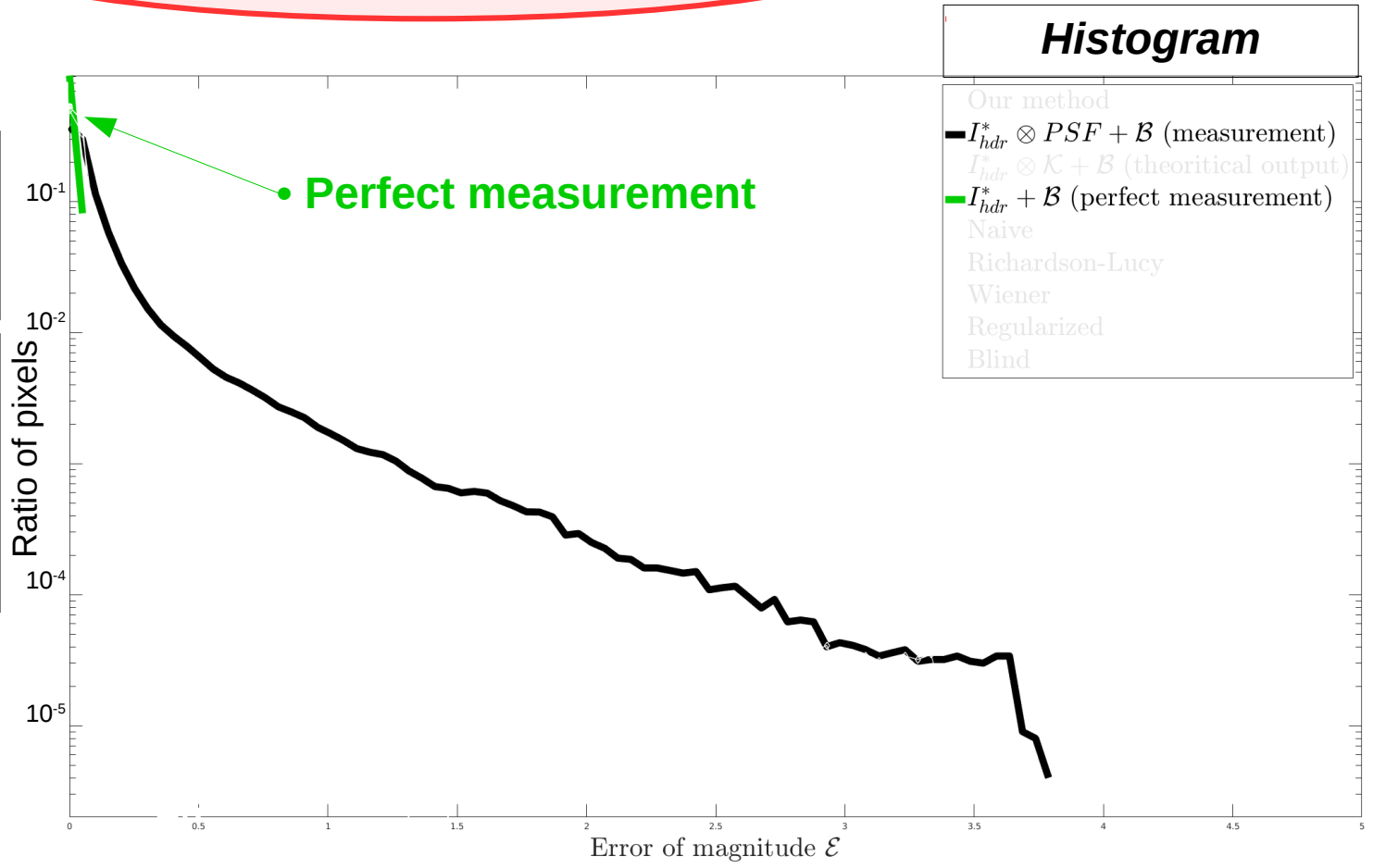
Common Solutions

$$I = I^* \otimes PSF + \mathcal{B}$$

What to do with I ?

1 → Do nothing
Unbounded Error

2 → Accept the blur
Dynamic range ↗
PSF extent ↗
Effective Resolution ↘



$$\mathcal{E} = |\log_{10}(I_{output}) - \log_{10}(I^*)|$$

Common Solutions

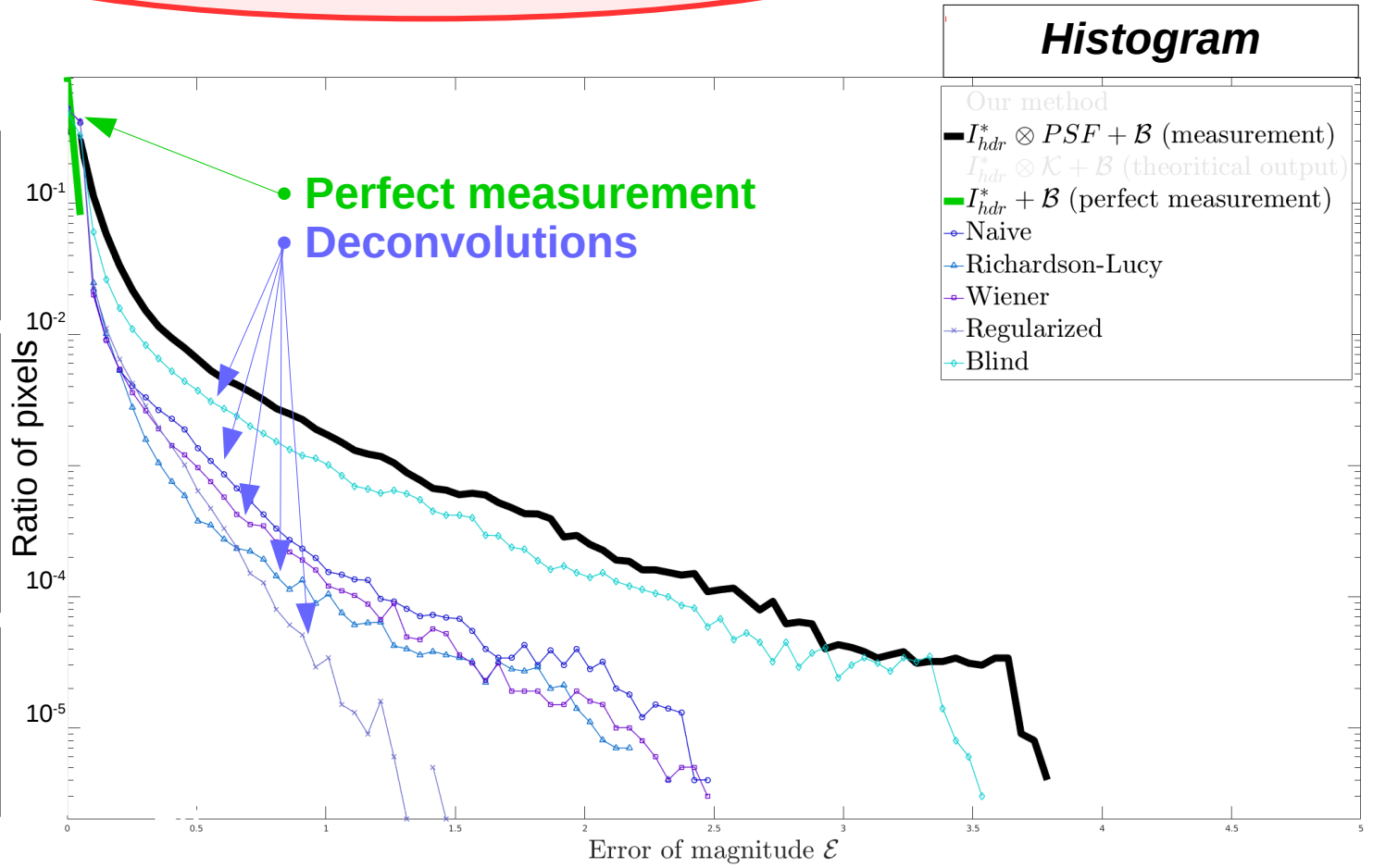
$$I = I^* \otimes PSF + \mathcal{B}$$

What to do with I ?

1 → Do nothing
Unbounded Error

2 → Accept the blur
Dynamic range ↗
PSF extent ↗
Effective Resolution ↘

3 → Deconvolve
Unknown metrological quantification

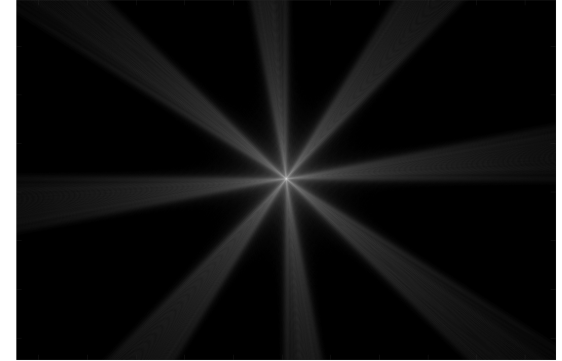


$$\mathcal{E} = |\log_{10}(I_{output}) - \log_{10}(I^*)|$$

Key Idea

1) Find the PSF

$$PSF \propto |\mathcal{F}[\text{diaphragm}]|^2 \rightarrow PSF =$$

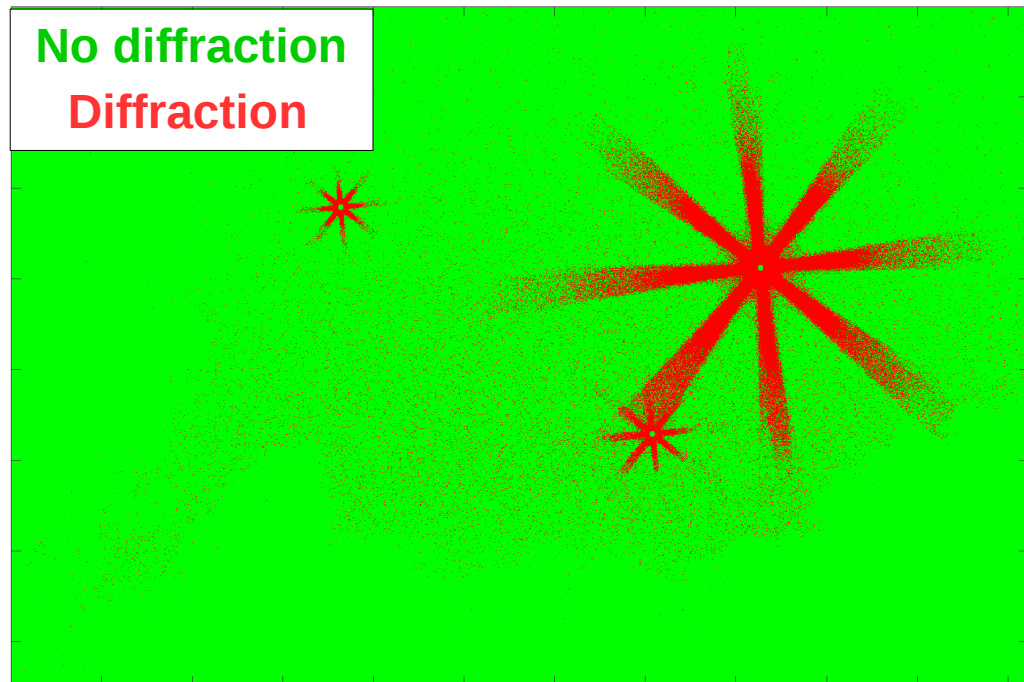


2) Classify pixels

Input Image



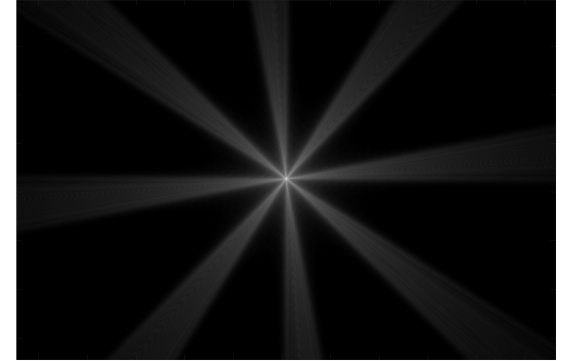
Output Mask



Key Idea

1) Find the PSF

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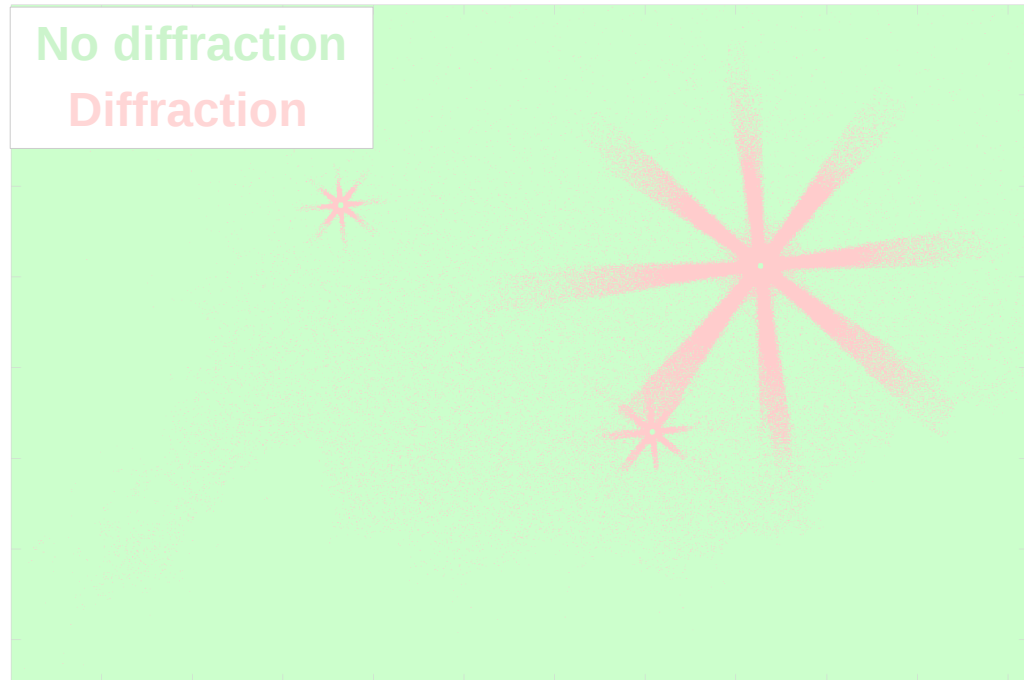


2) Classify pixels

Input Image



Output Mask



The Point Spread Function

- Method: PSF from diaphragm fitting

$$PSF \propto \left| \mathcal{F} \left[\begin{array}{c} \text{diaphragm} \end{array} \right] \right|^2$$

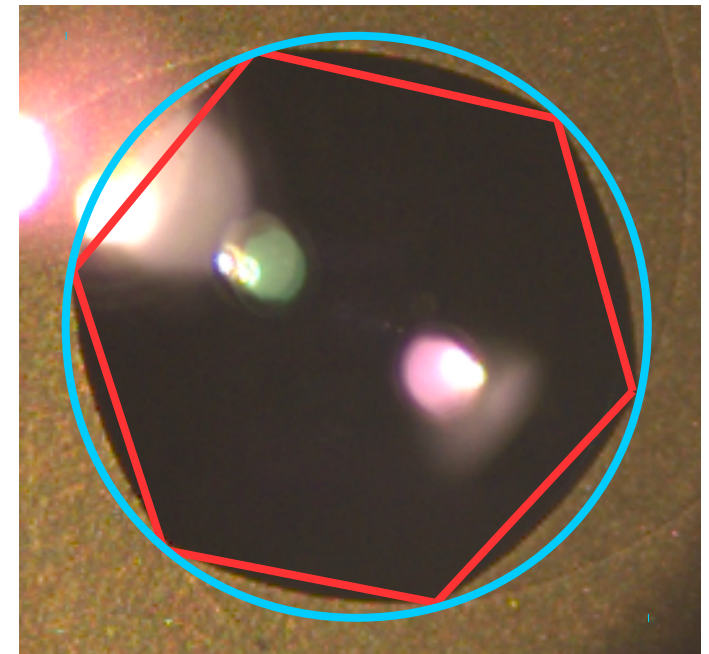
Absence of noise
Good knowledge of the setup

[Rietdorf05]

- Known cases of PSF functions:
 - Perfect disk (Airy pattern)
 - Polygons with straight edges [Shung-Wu83]

→ ✓ **Closed-form** (Precision 😊)

→ ✗ **Not general enough**



The Point Spread Function

- Method: PSF from diaphragm fitting

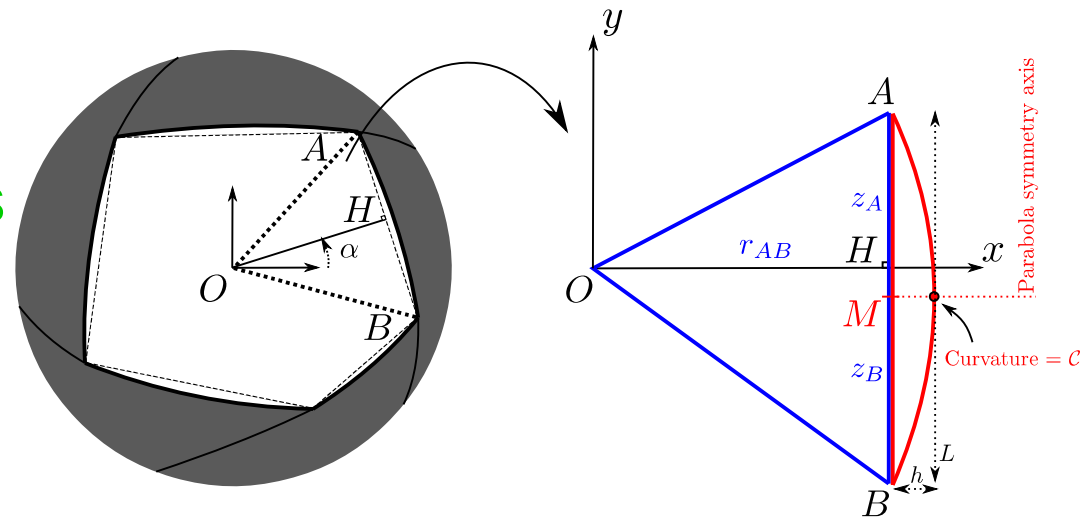
$$PSF \propto \left| \mathcal{F} \left[\text{diaphragm} \right] \right|^2$$

Absence of noise
Good knowledge of the setup

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- Our model:
 - Polygons with curved edges



The Point Spread Function

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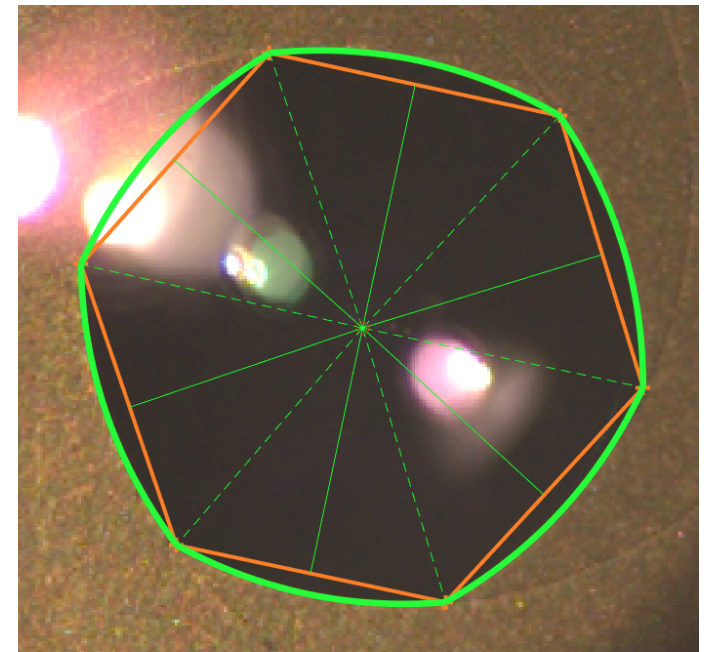
Absence of noise
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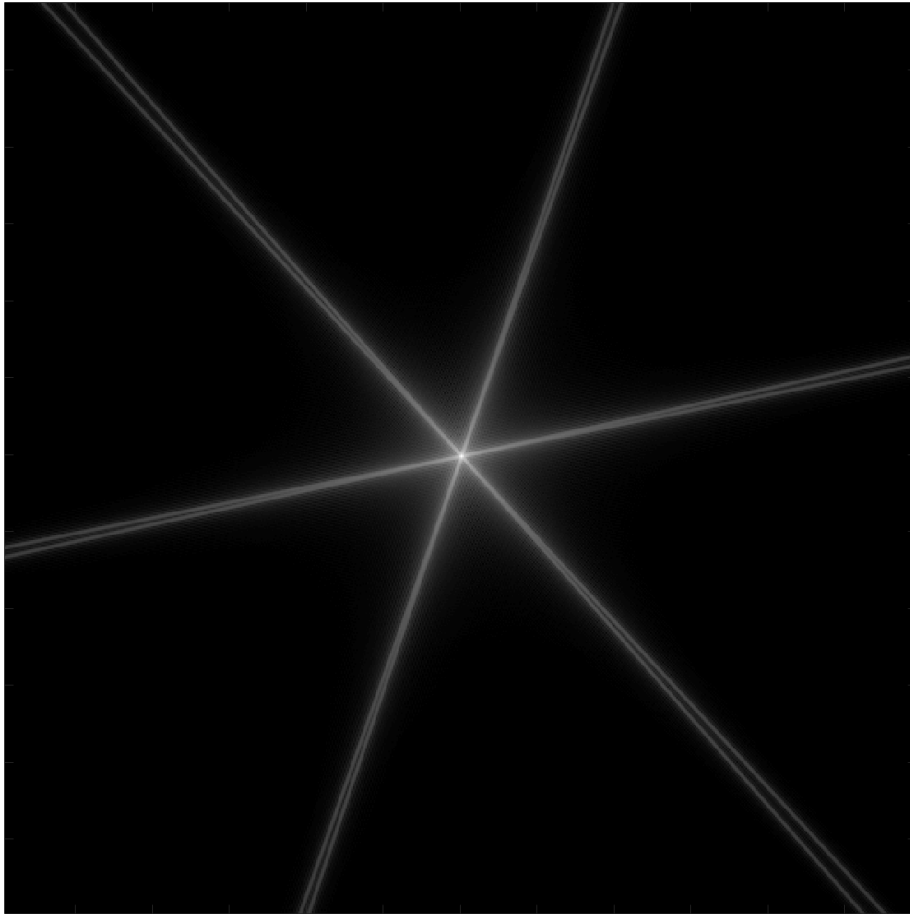
→ ✓ **Closed-form**
✓ **General enough**



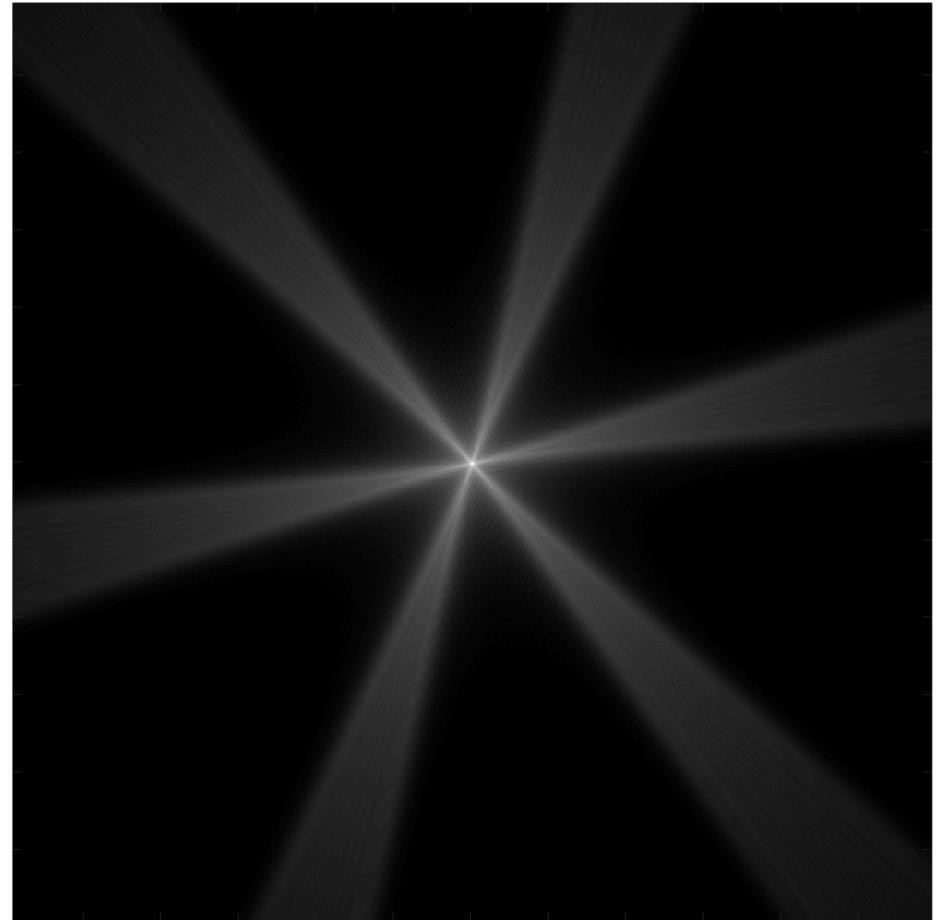
The Point Spread Function

Simulated PSF:

Hexagon with **Straight** edges



Hexagon with **Curved** edges



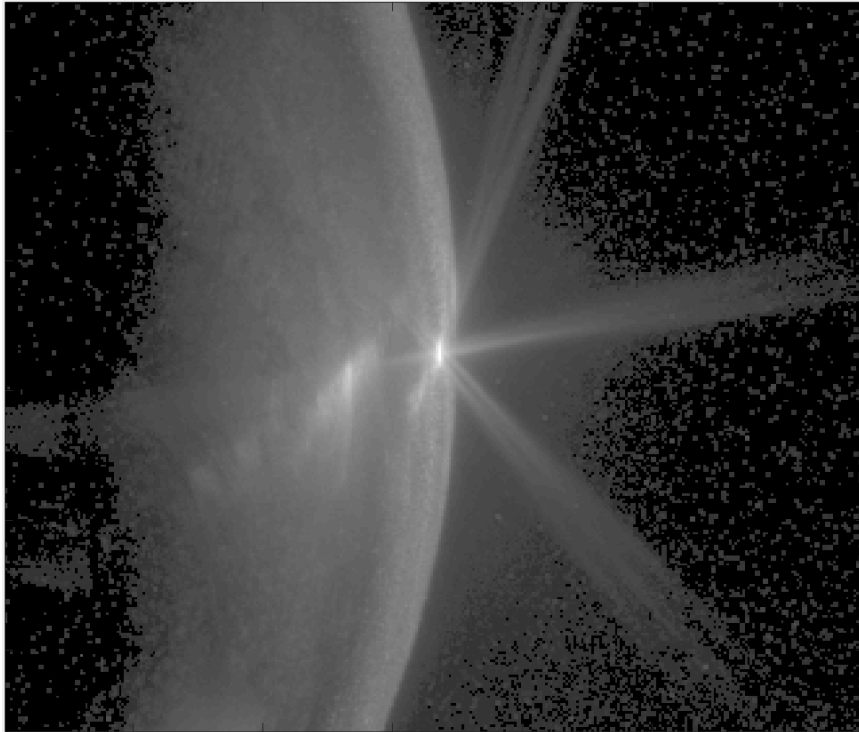
Effect : Widen the star branches

The Point Spread Function

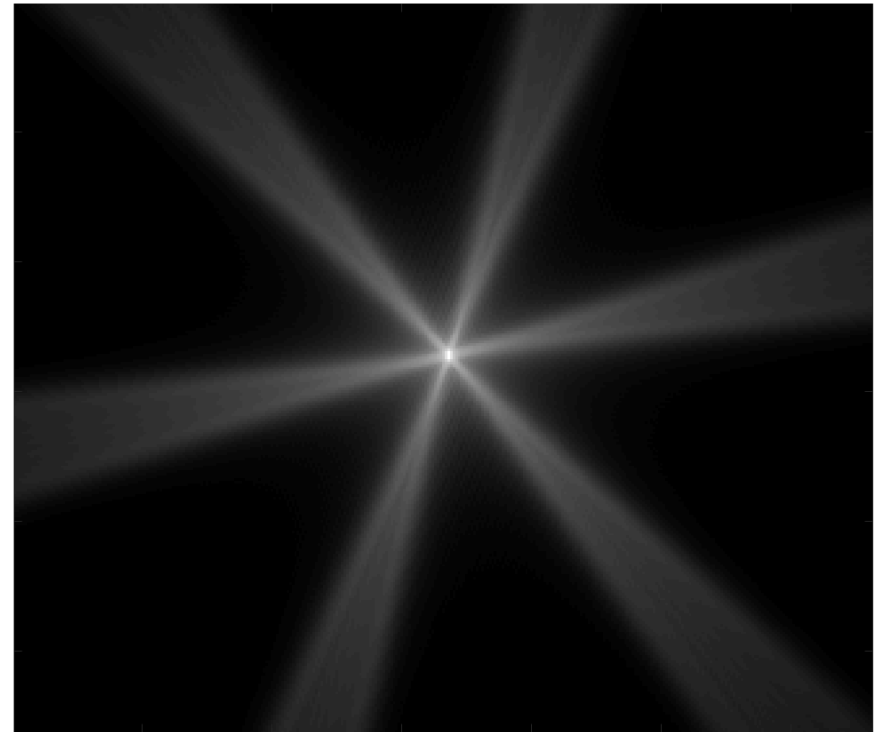
Linos 50mm at f/11

Linos 50mm at f/11

Measured PSF



Analytical PSF



Fits to direct measurements!

Key Idea

1) Find the PSF

$$PSF \propto |\mathcal{F}[\text{diaphragm}]|^2 \longrightarrow PSF =$$


The diagram shows a circular diaphragm with eight curved blades, representing the aperture of a lens. The word "diaphragm" is written below it.

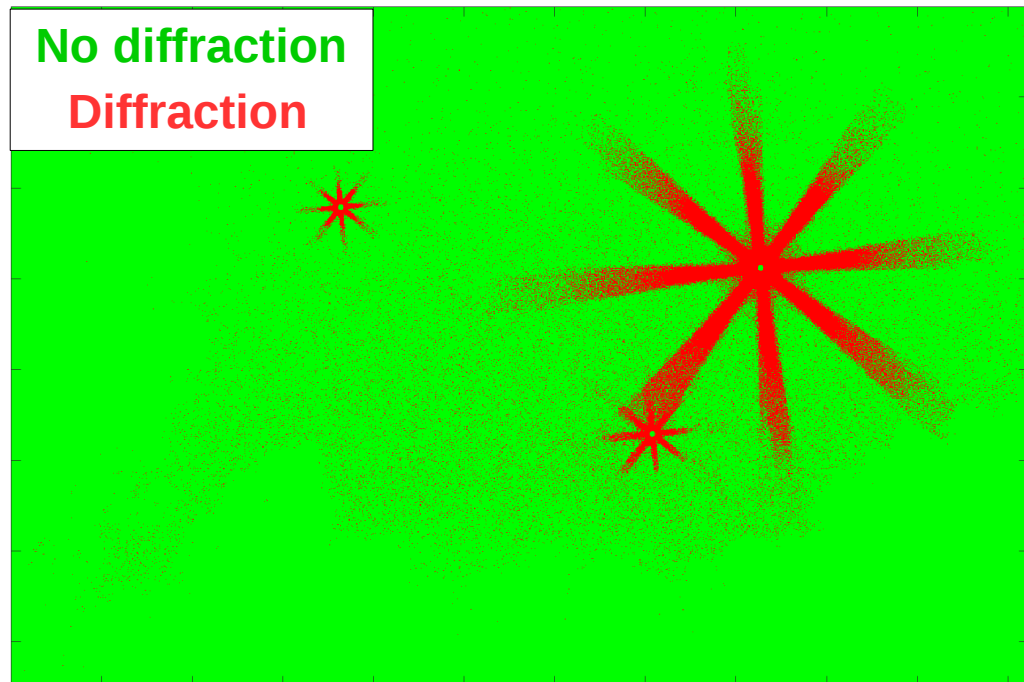


2) Classify pixels

Input Image



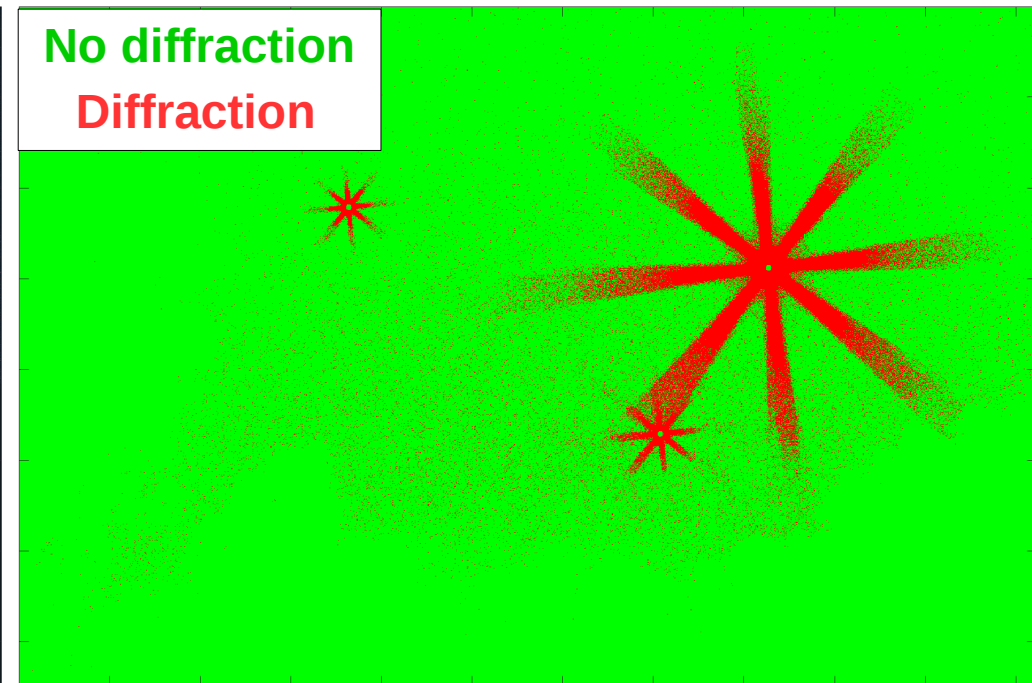
Output Mask



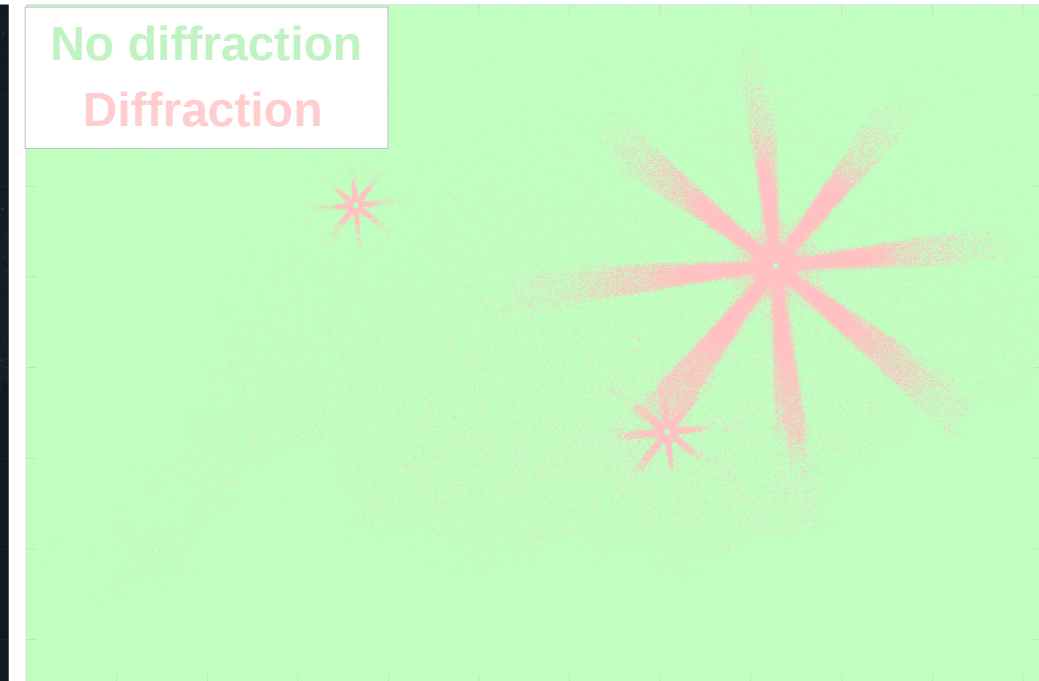
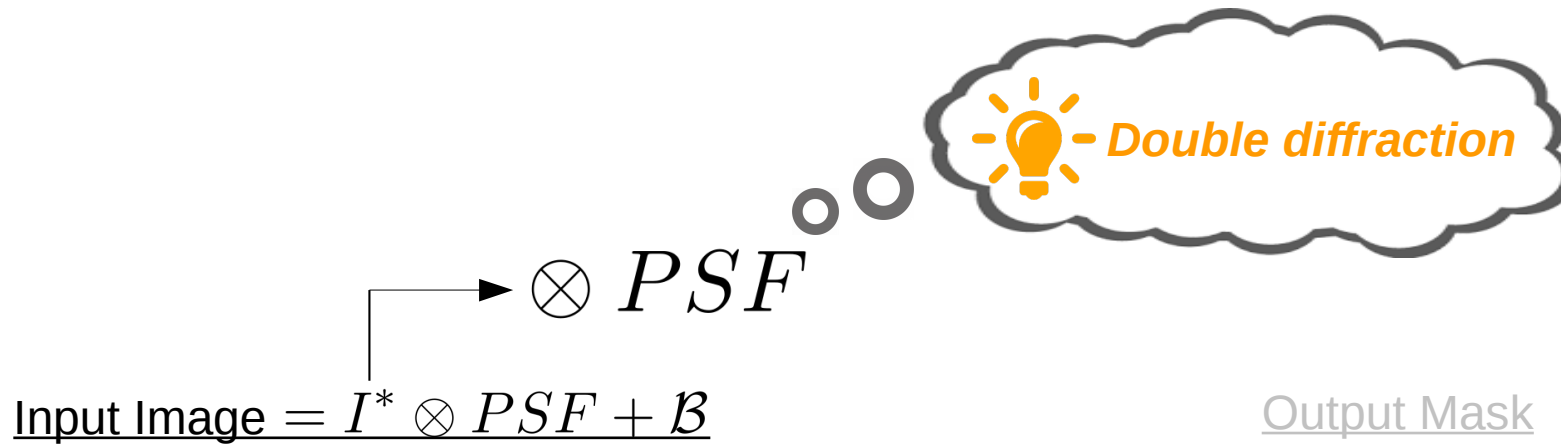
Pixel Classification Algorithm

$$\text{Input Image} = I^* \otimes \text{PSF} + \mathcal{B}$$

Output Mask



Pixel Classification Algorithm

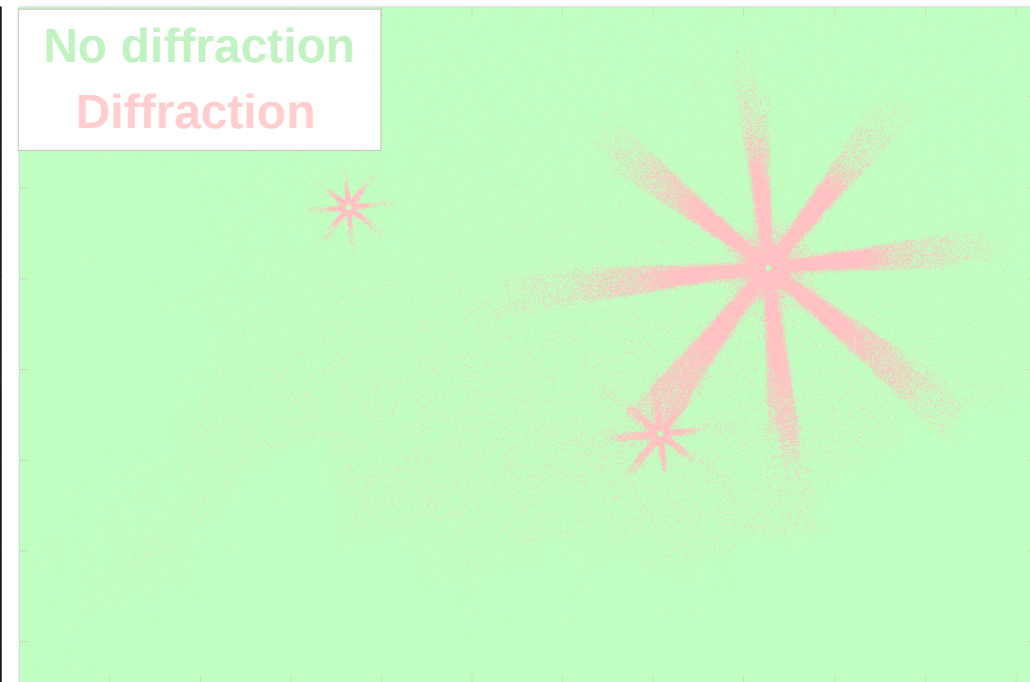
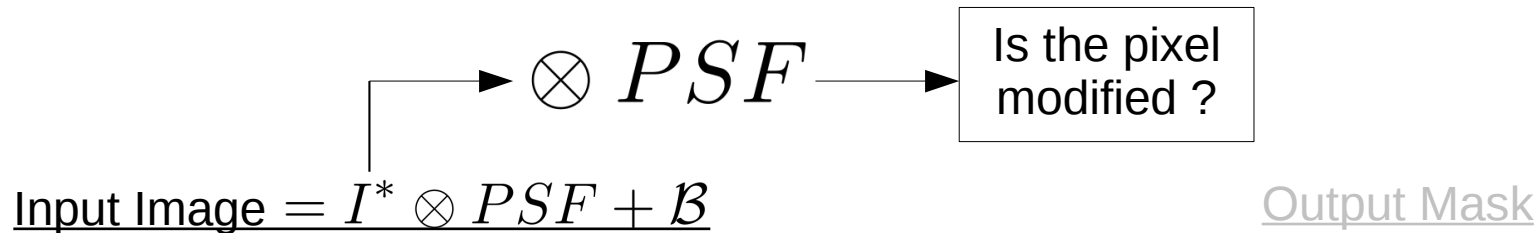


Pixel Classification Algorithm

*User controlled
criterion*

Principle:

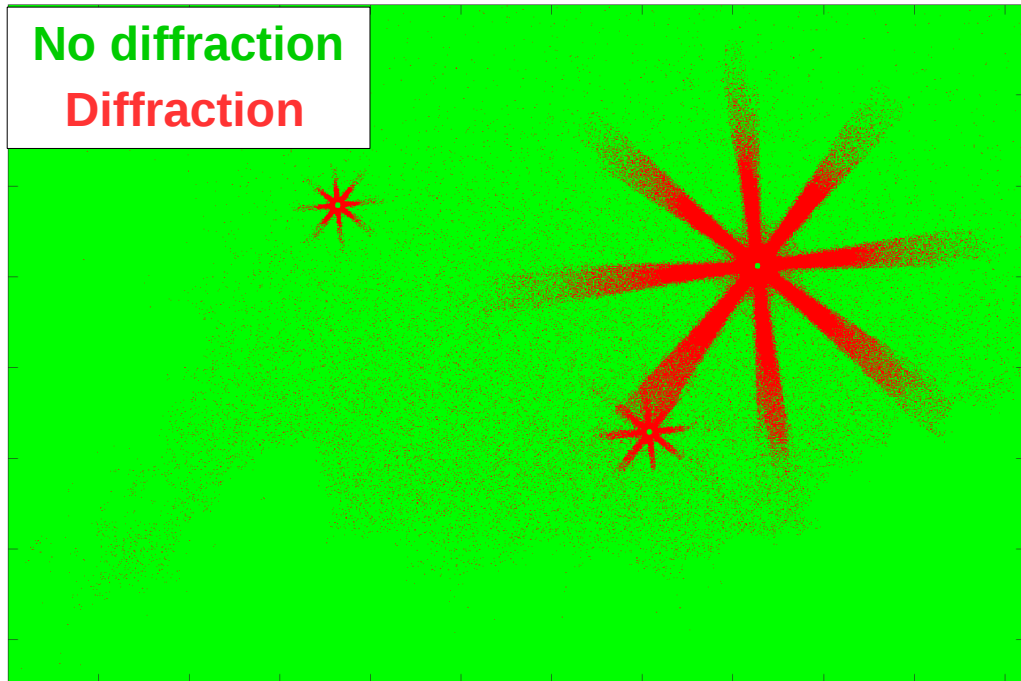
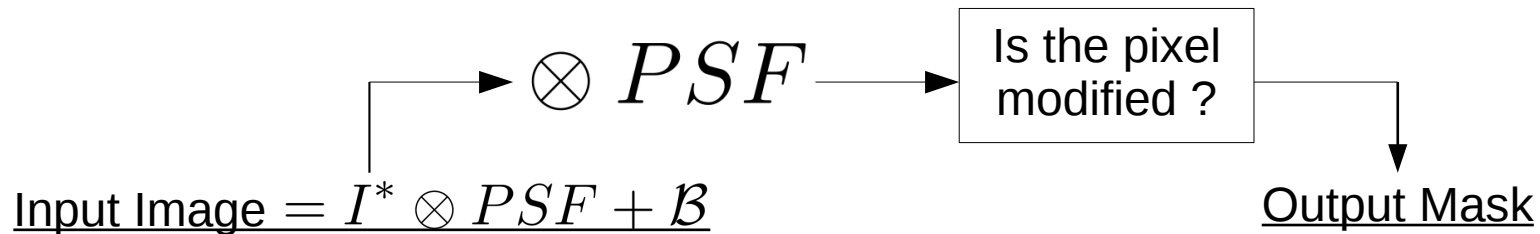
« If a pixel is not modified during our simulated diffraction, it was also not the case during the physical diffraction »



Pixel Classification Algorithm

Principle:

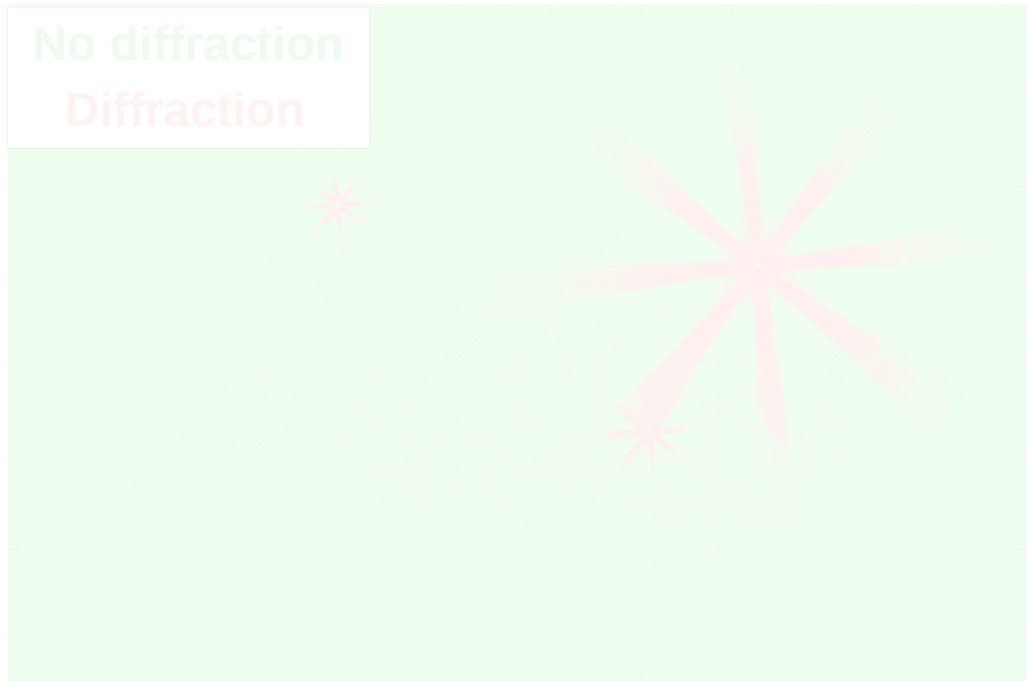
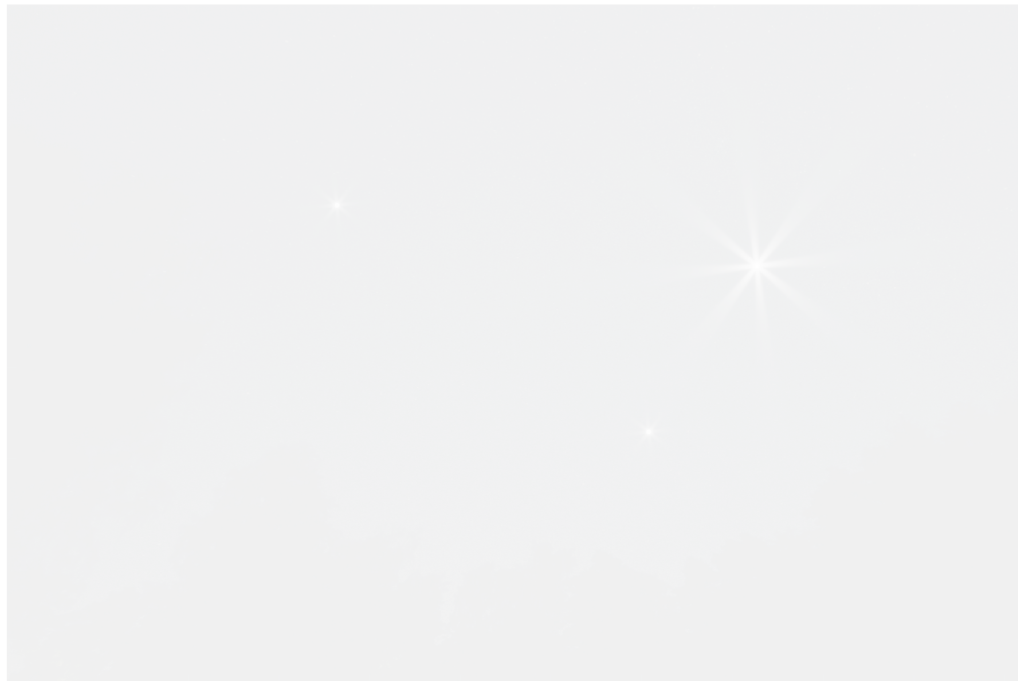
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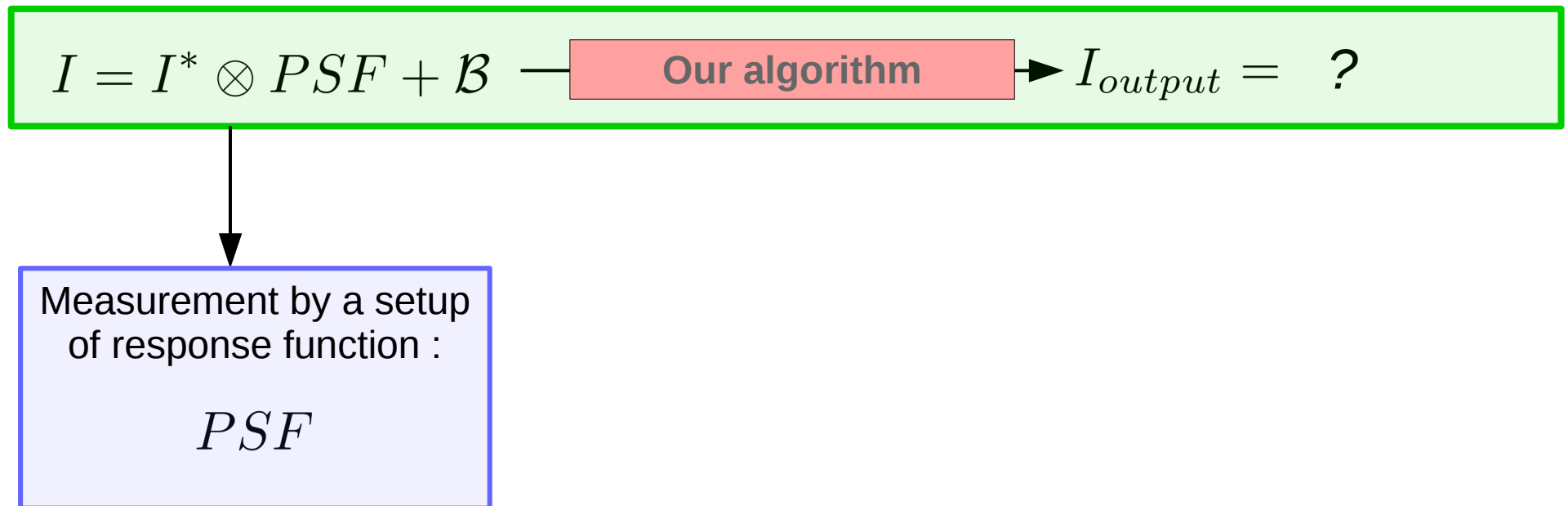
Pixel Classification Algorithm

Principle :

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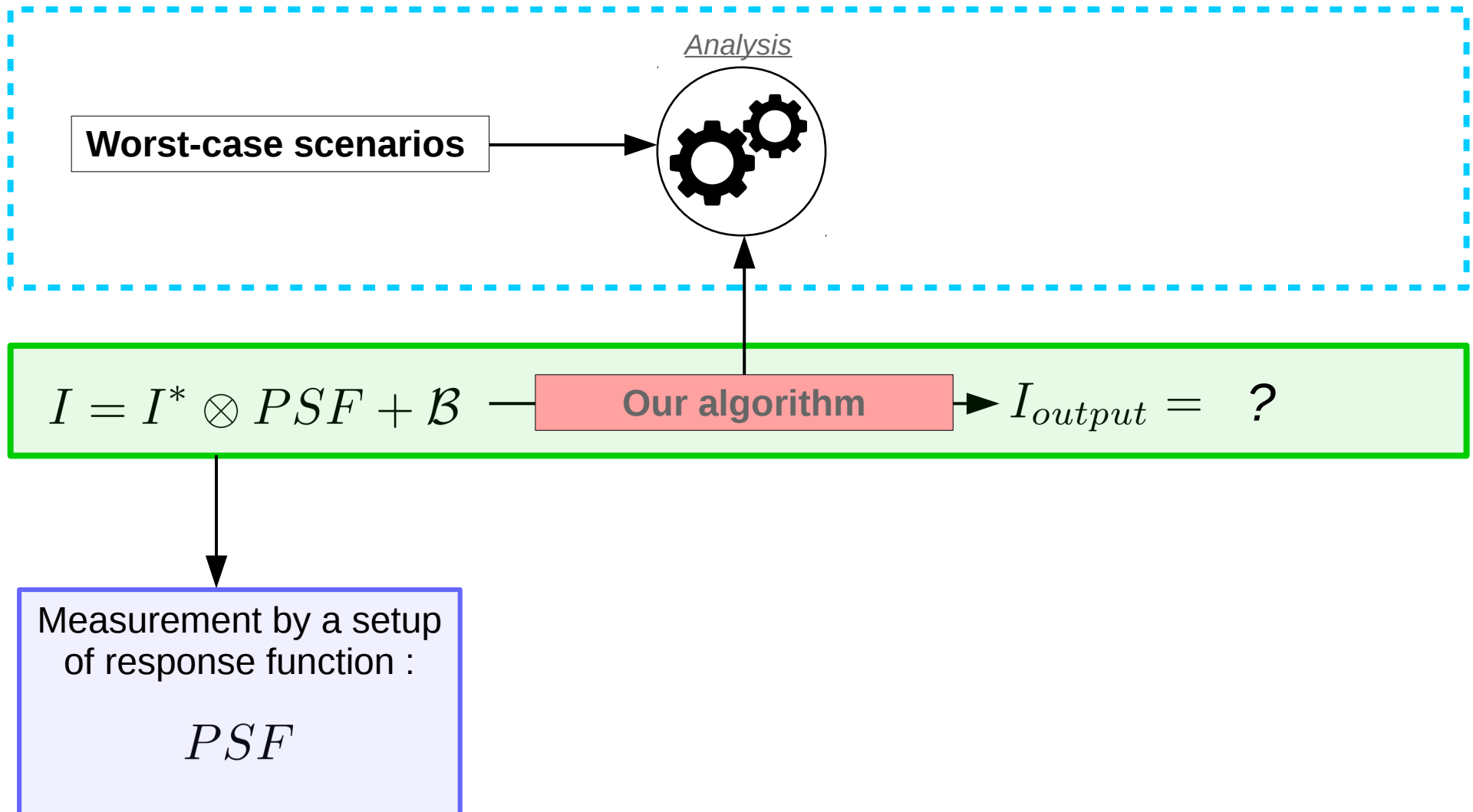


Pixel Classification Algorithm



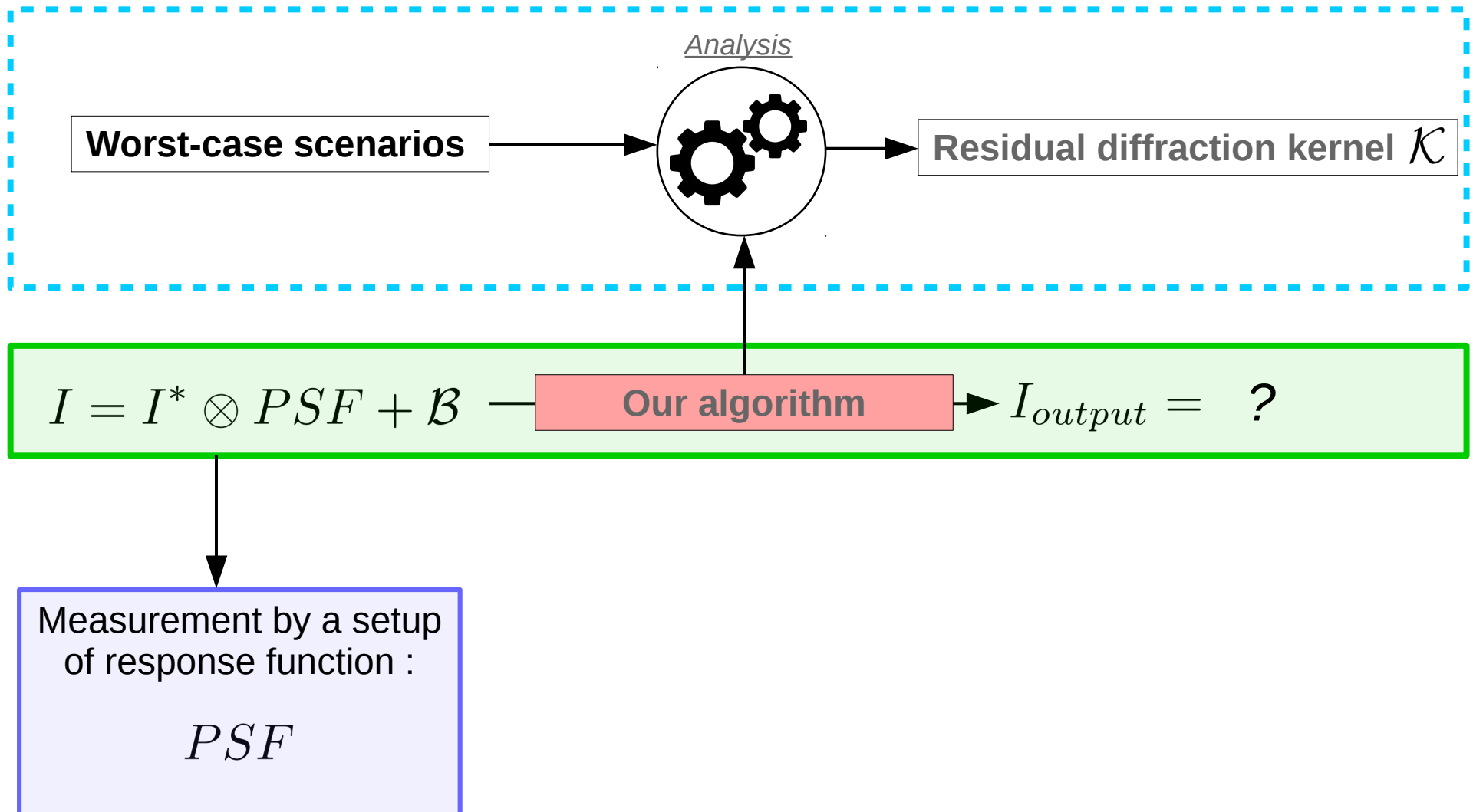
Pixel Classification Algorithm

Limitations



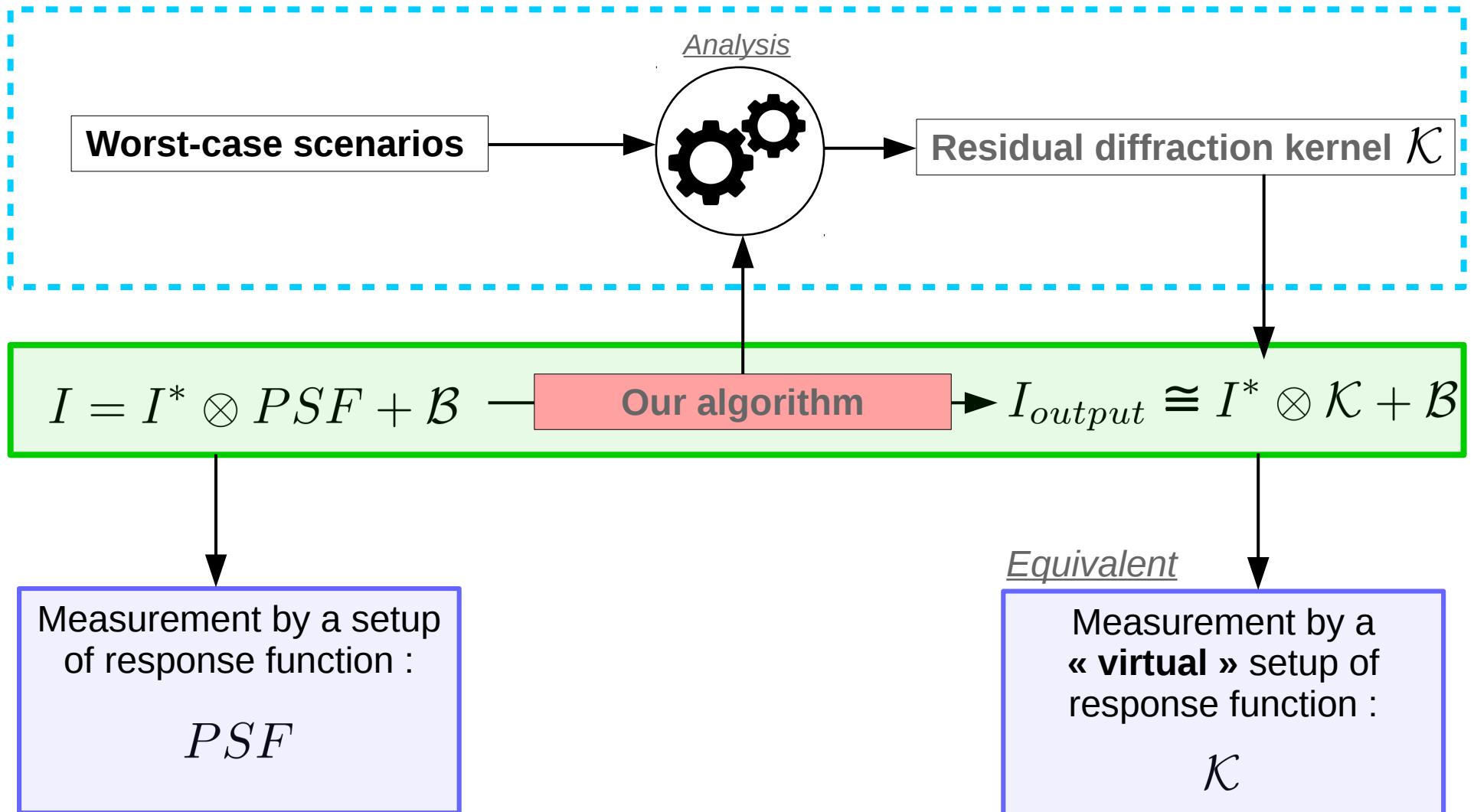
Pixel Classification Algorithm

Limitations

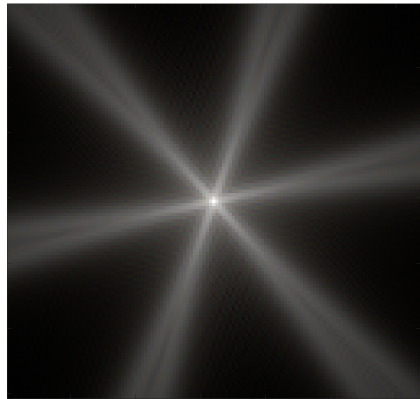


Pixel Classification Algorithm

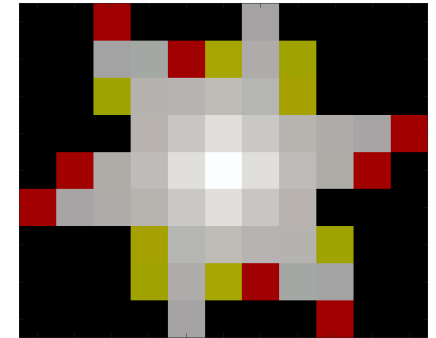
Limitations



Pixel Classification Algorithm



Extent of $PSF \gg$ Extent of \mathcal{K}



$$I = I^* \otimes PSF + \mathcal{B} \xrightarrow{\text{Our algorithm}} I_{output} \cong I^* \otimes \mathcal{K} + \mathcal{B}$$

Measurement by a setup of response function :
 PSF

Equivalent
Measurement by a « **virtual** » setup of response function :
 \mathcal{K}

Pixel Classification Algorithm

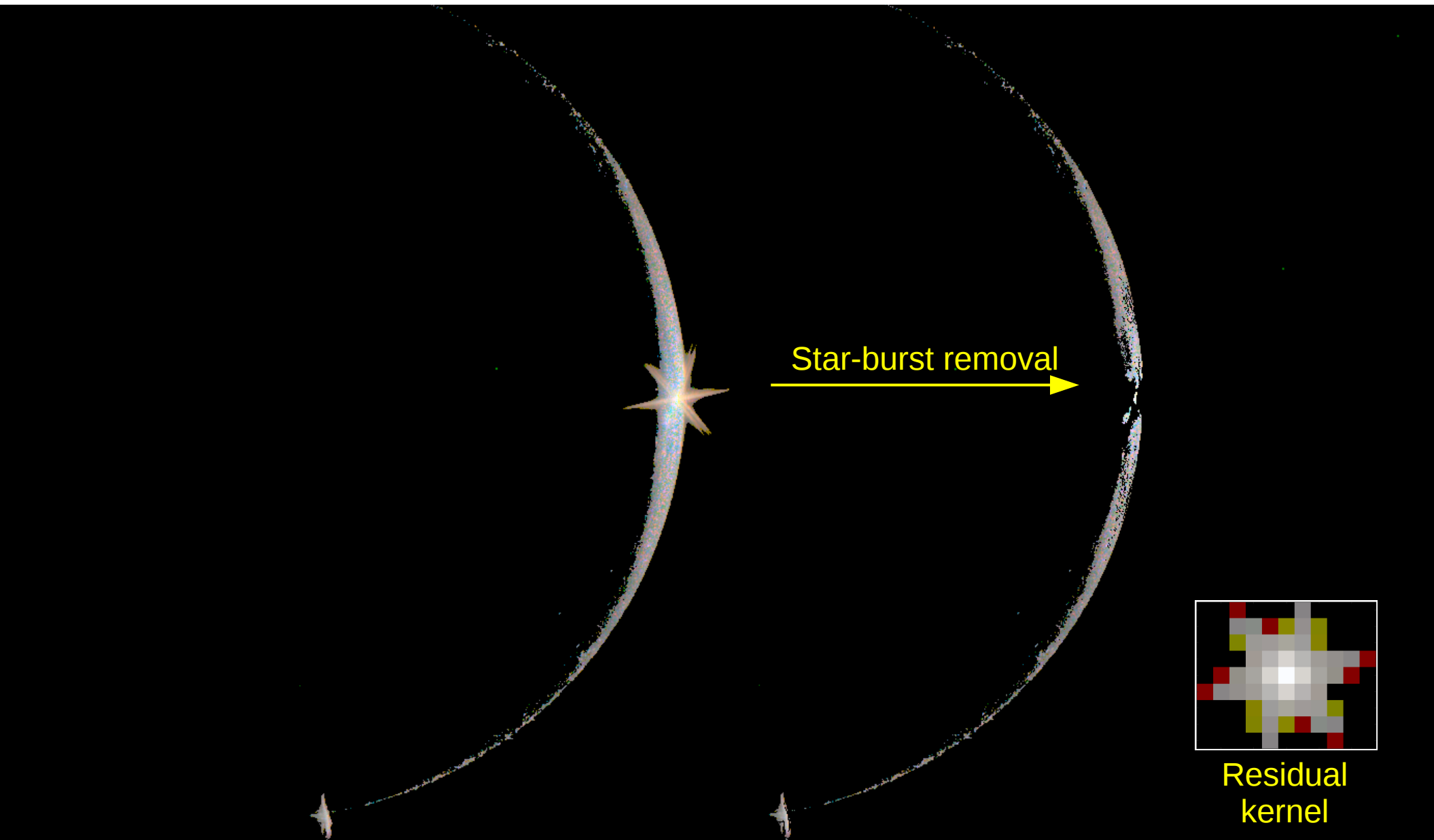
Advantages :

- Unmodified pixel values
 - ✓ **Keep tracks on uncertainties (\mathcal{B})**
- Worst-case scenarios analysis
 - ✓ **Metrologically characterized (\mathcal{K})**

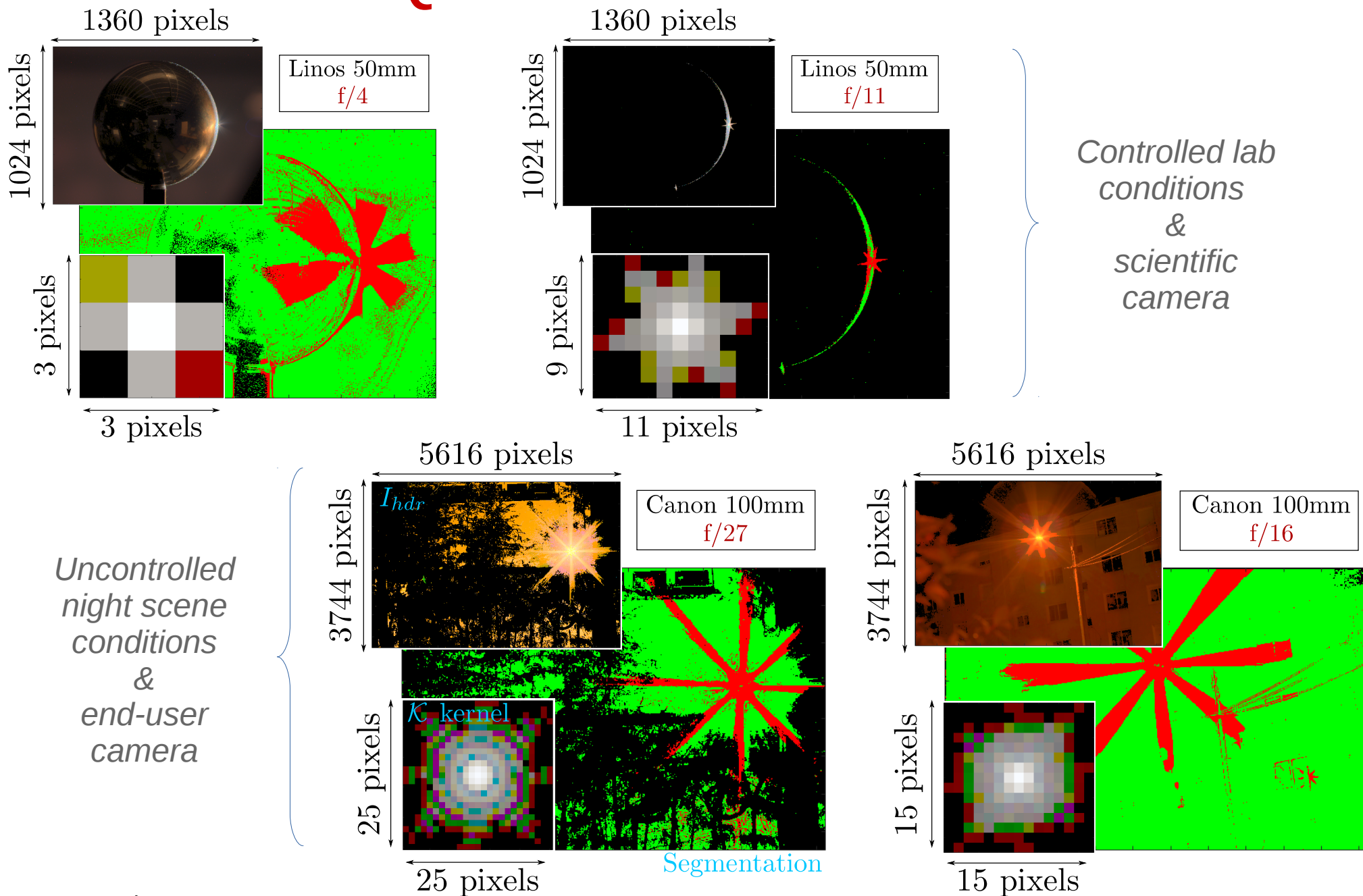
$$I_{output} = I^* \otimes \mathcal{K} + \mathcal{B}$$

Equivalent to the measurement by a virtual setup of response function very smaller than the PSF

Qualitative results



Qualitative results



Quantitative results

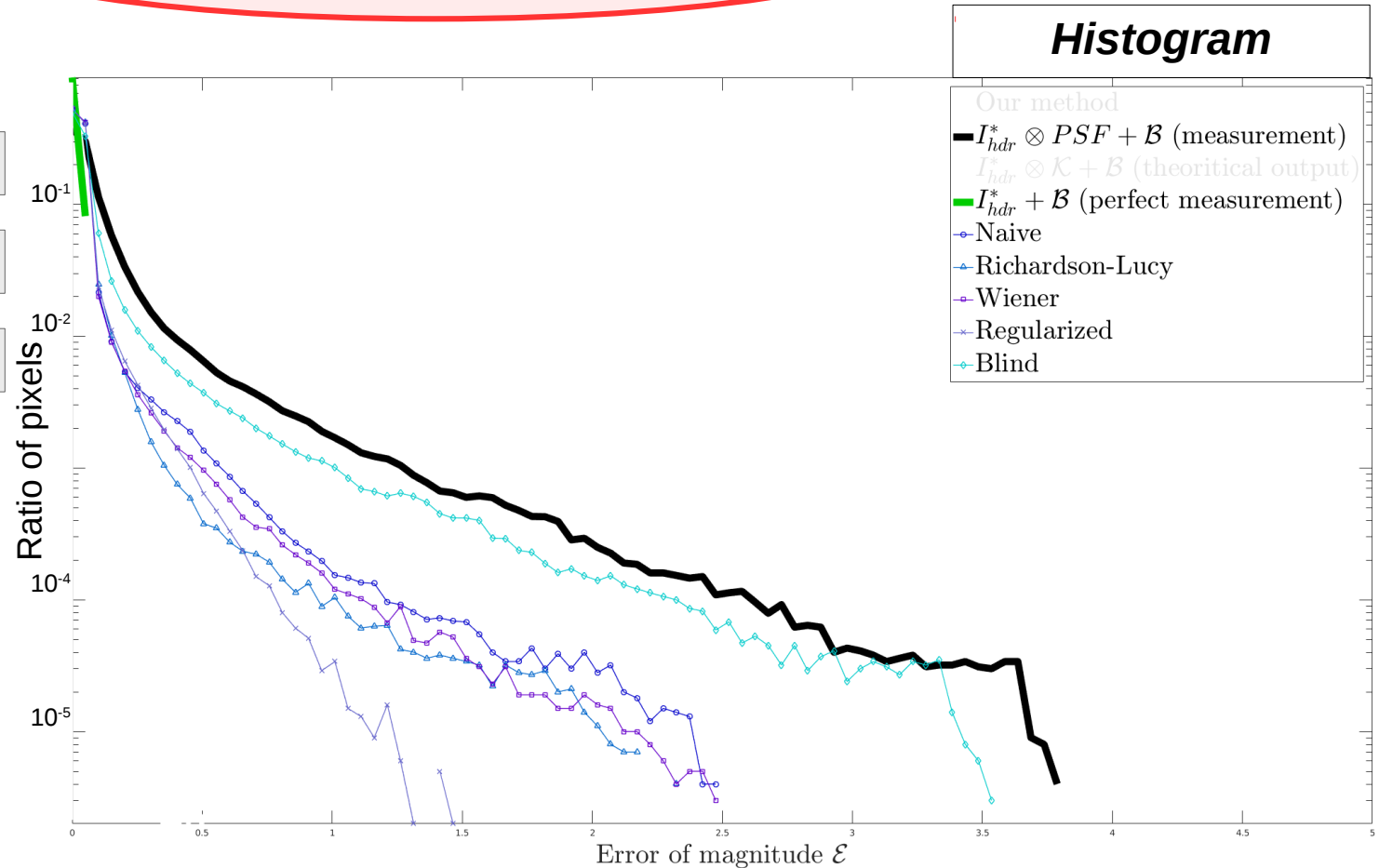
$$I = I^* \otimes PSF + \mathcal{B}$$

What to do with I ?

1 → Do nothing

2 → Accept the blur

3 → Deconvolve



$$\mathcal{E} = |\log_{10}(I_{output}) - \log_{10}(I^*)|$$

Quantitative results

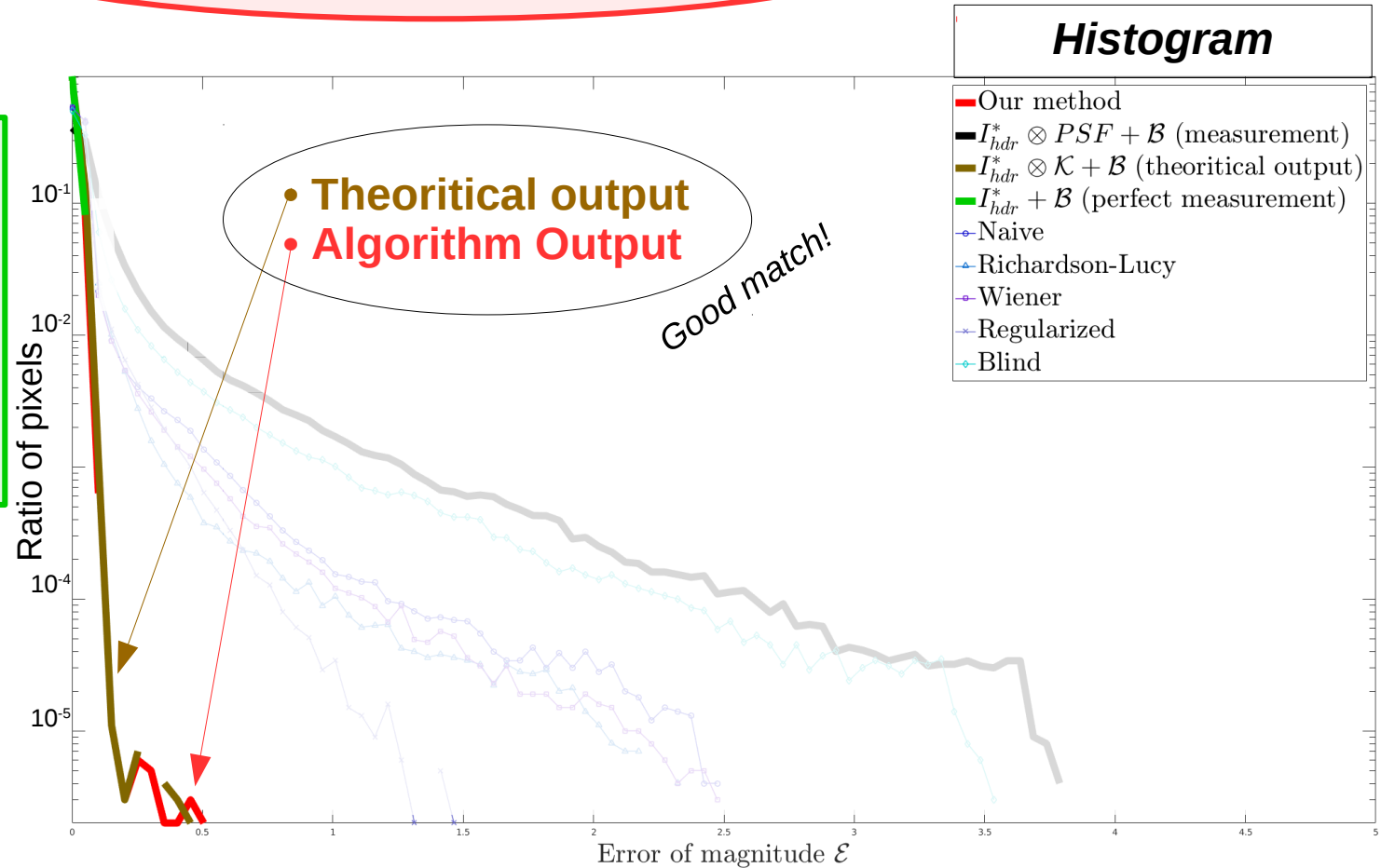
$$I = I^* \otimes PSF + \mathcal{B}$$

What to do with I ?

→ Classify

Reduced convolution kernel

Metrologically known output



$$\mathcal{E} = |\log_{10}(I_{output}) - \log_{10}(I^*)|$$

Conclusion & Future work

- **Reduced diffraction** convolution kernel
- **Improved HDR measurement**
- **User controlled** parameters

- How to minimize the loss of pixel: trade-off study
- Better diaphragm model (edge roughness) [Durgin09]
- Full GPU implementation (few minutes for the PSF precomputation)



Thank you for your attention



- **[Matusik03]**

Matusik W., Pfister H., Brand M., McMillan L. : Efficient isotropic BRDF measurement. In Proc. EGWR '03 (2003), pp. 241-247.

- **[Marschner98]**

Marschner S.R., Westin S.H., Lafortune E.P.F., Torrance K.E., Greenberg D.P.: Image-Based BRDF Measurement Including Human Skin. In Proc. of 10th Eurographics Workshop on Rendering, p.139-152, June 1999.

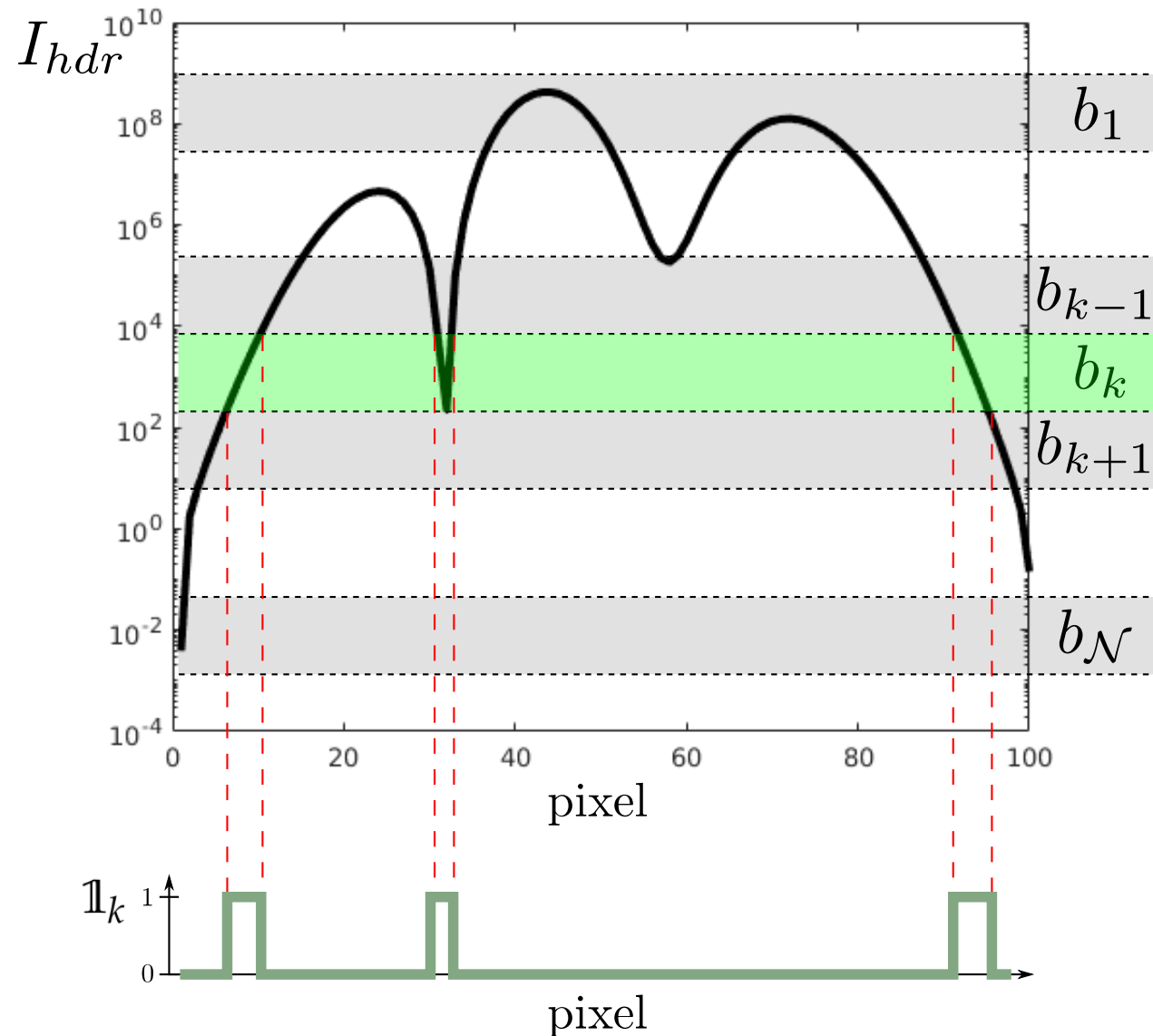
- **[Rietdorf]**

J. Rietdorf and T. W. J. T. W. J. Gadella, Microscopy techniques (Springer, 2005).

- **[Durgin09]**

G. Durgin, "The Practical Behavior of Various Edge-Diffraction Formulas," IEEE Antennas and Propagation Magazine 51, 24–35 (2009).

Supplemental Detailed Algorithm



Convolution process

$$\left[I_{hdr} \otimes PSF \right] \times \mathbb{1}_k = \left[\left(I_{1 \rightarrow k-1} + I_k + I_{k+1 \rightarrow \mathcal{N}} \right) \otimes PSF \right] \times \mathbb{1}_k$$

$$\left[I_{hdr} \otimes PSF \right] \times \mathbb{1}_k \simeq \left[I_{1 \rightarrow k-1} \otimes PSF \right] \times \mathbb{1}_k + I_k$$

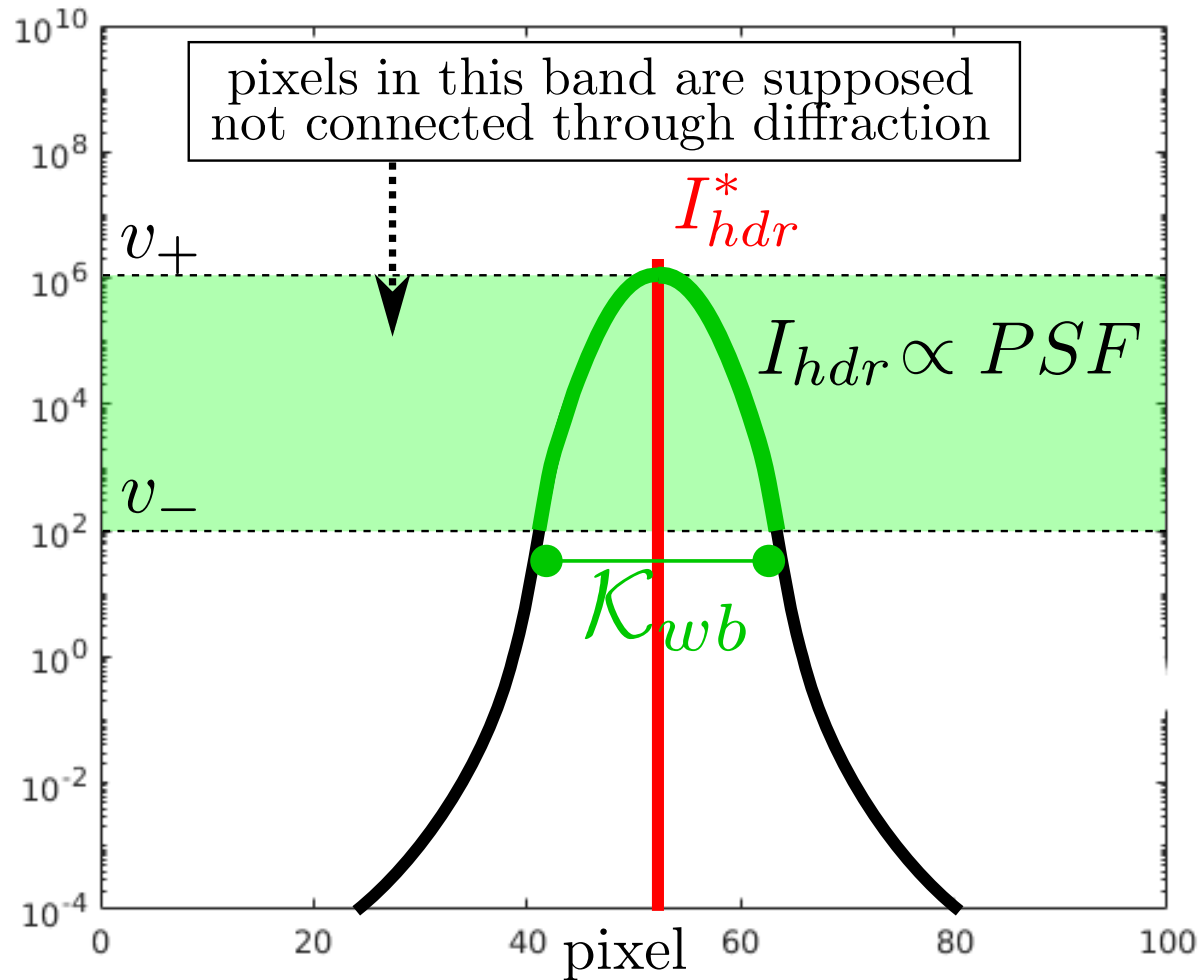
Thresholding criterion

$$\left[I_{1 \rightarrow k-1} \otimes PSF \right] \times \mathbb{1}_k > \rho I_k$$

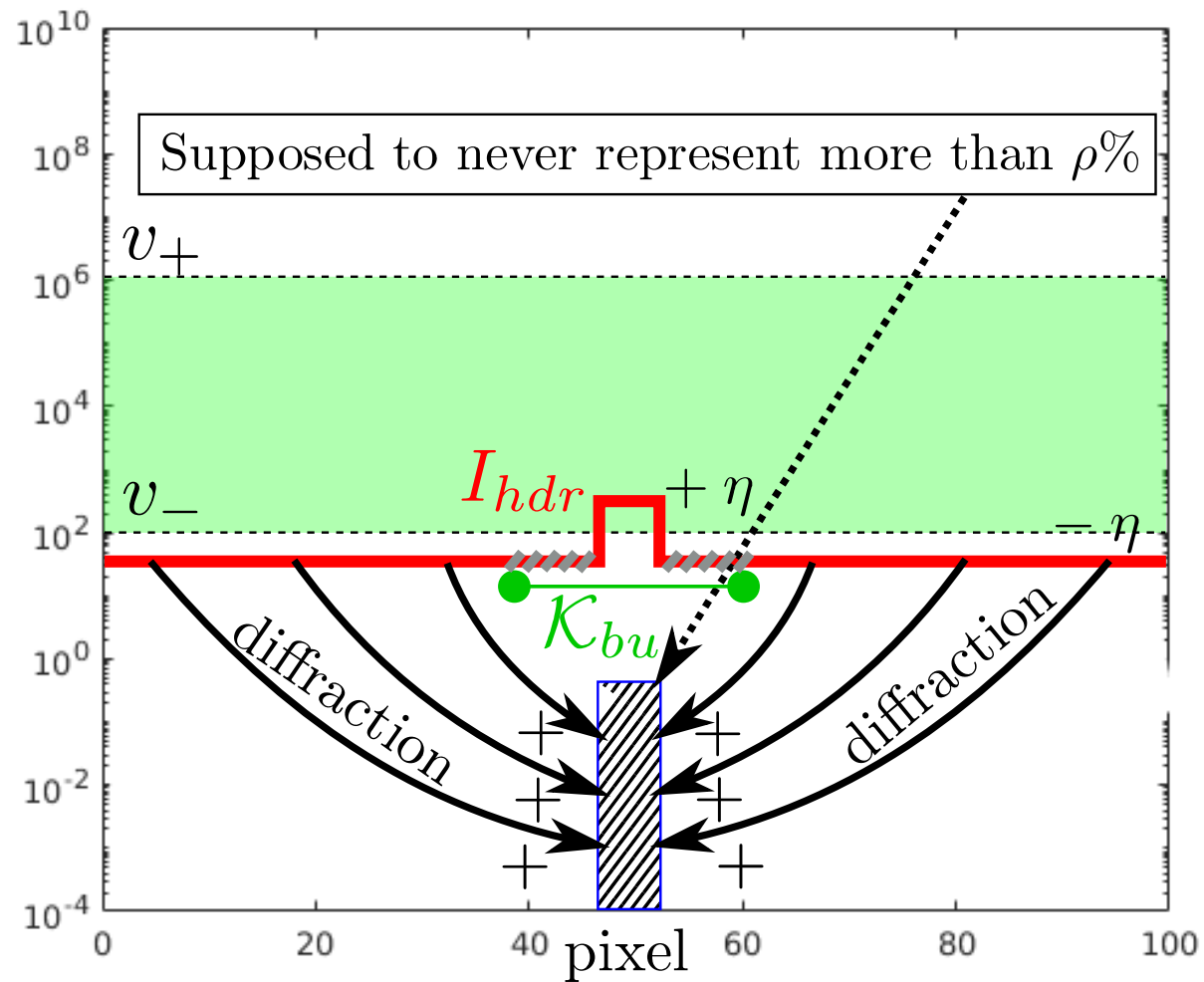
Algorithm input parameters :

- **Threshold**
- **Band-width**

Supplemental Within-band influence



Supplemental Bottom-up influence



Diaphragm repeatability

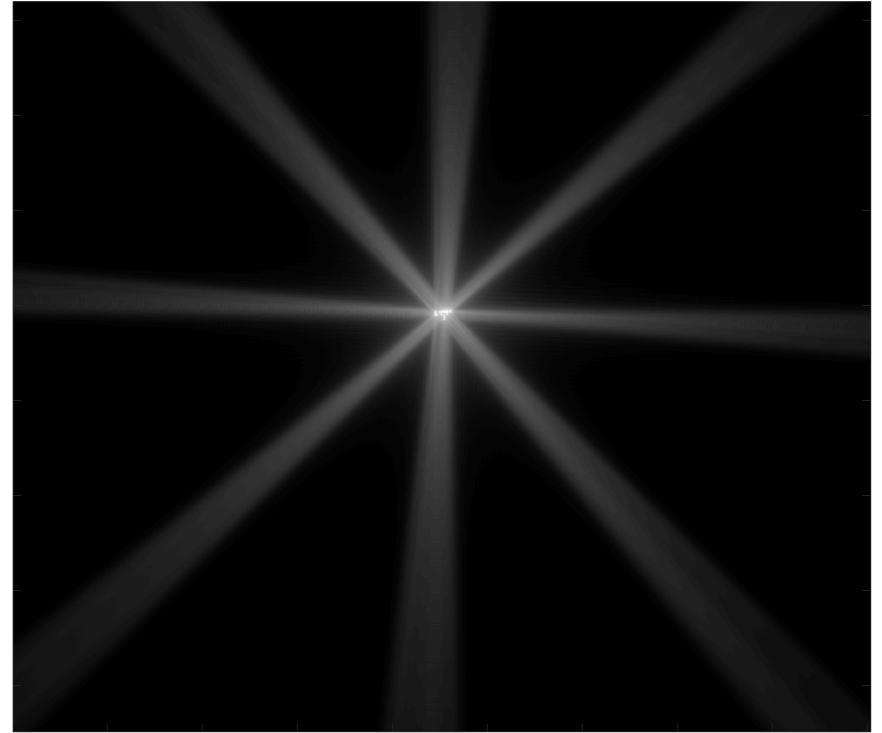
Canon 100mm at f/27

Canon 100mm at f/27

Measured PSF



Analytical PSF



Rotation → Caused by lack of repeatability in the diaphragm closure

Supplemental Trade-offs

