Inverse (Reverse) Tone Mapping

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The problem

?

The problem

$$f(I) : \mathbb{D}^{w\times\times h\times c} \rightarrow \mathbb{R}^{w\times\times h\times c}$$

$$\mathbb{D} \subseteq [0, 255]$$

This means to expand the range

The problem

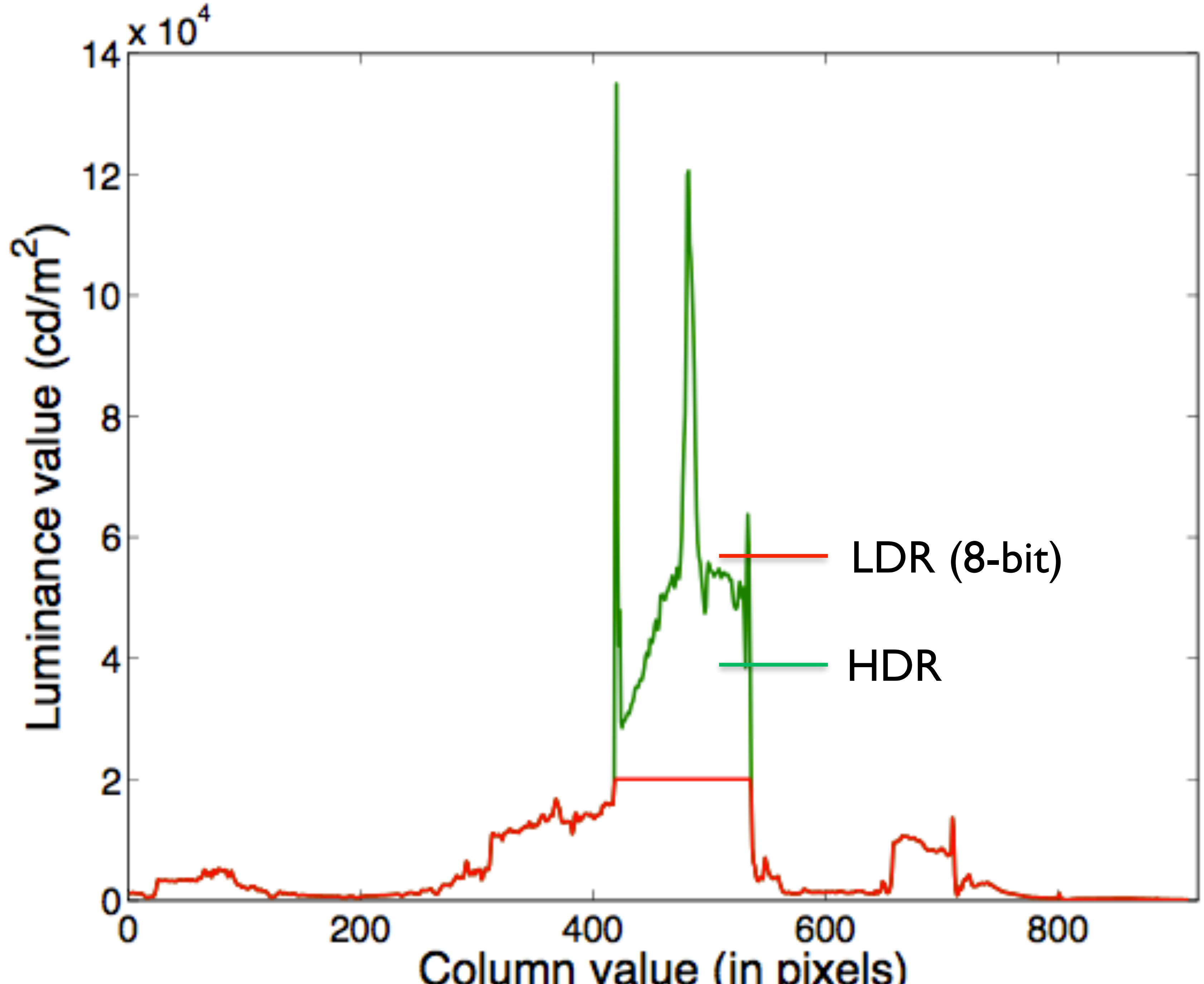
$$L_w = f(L_d) : \mathbb{D}^{w \times \times h} \rightarrow \mathbb{R}^{w \times \times}$$

$$\begin{bmatrix} R_w \\ G_w \\ B_w \end{bmatrix} = L_w g\Bigg(\frac{1}{L_d} \begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} \Bigg)$$

Two steps:

- expand the luminance range
- fix colors

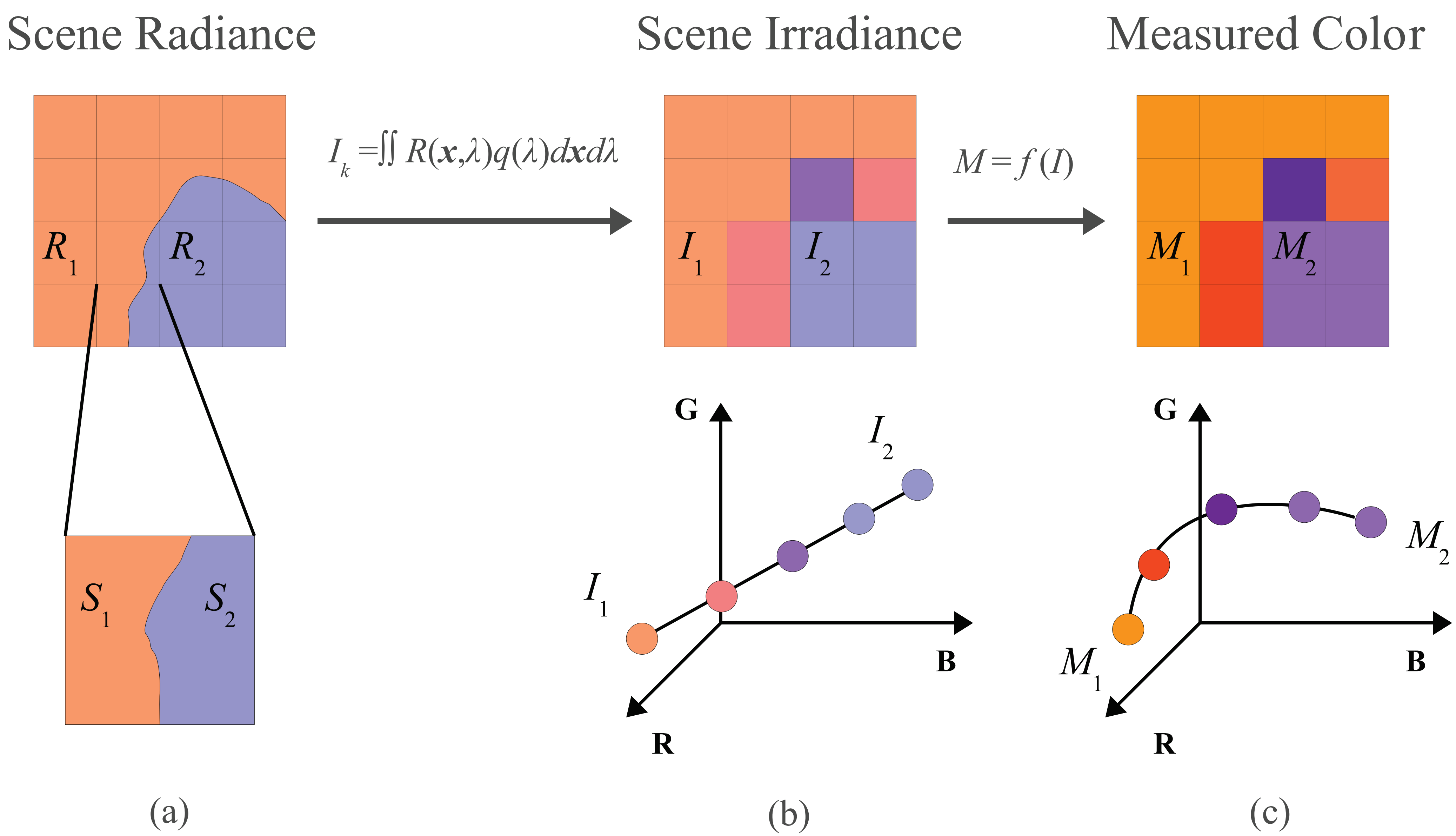
The problem


x 10^4
14
12
10
8
6
4
2
0
Luminance value (cd/m^2)
0
200
400
600
800
Column value (in pixels)
LDR (8-bit)
HDR

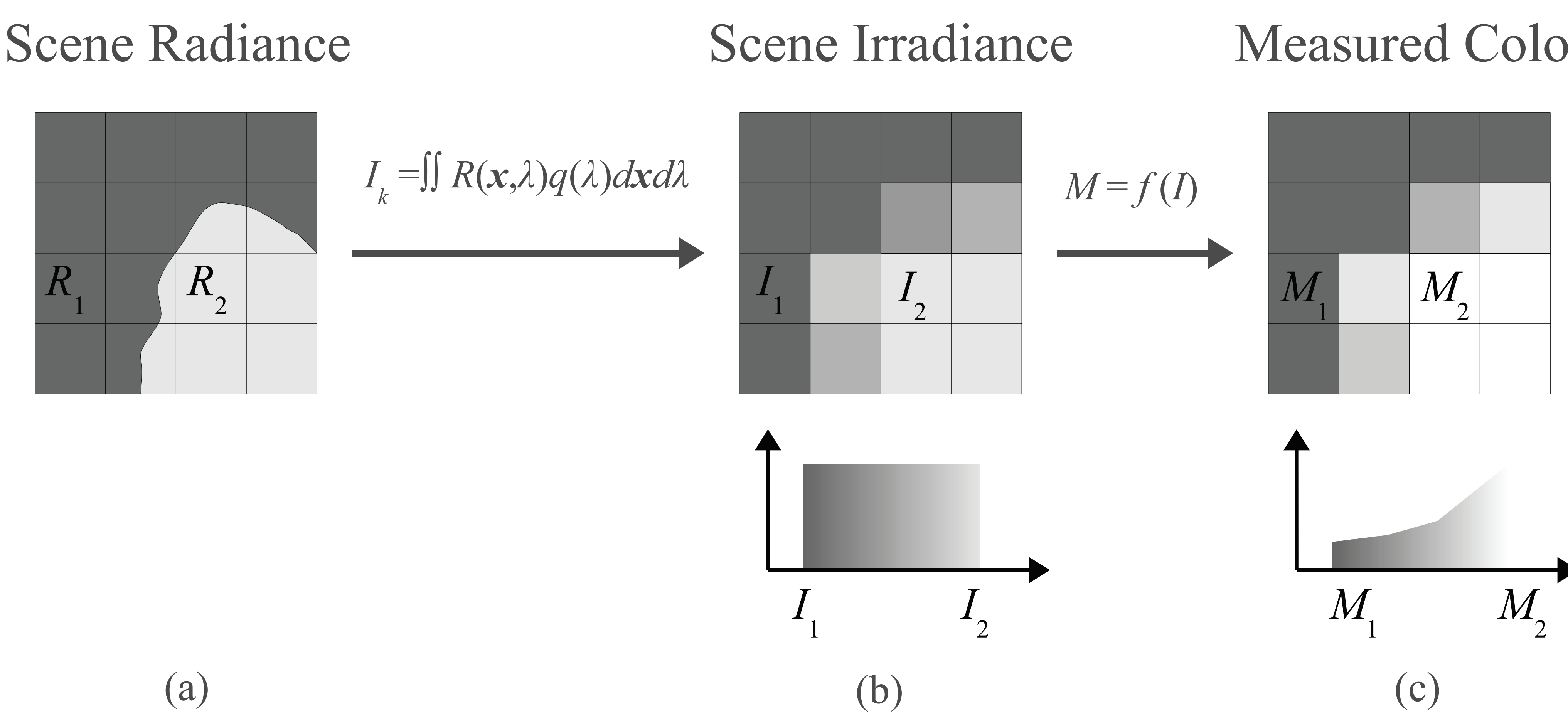
Linearization

- CRF is known
- DVD and television gamma is 2.2
- Single image CRF or gamma estimation

Linearization: Single Image



Linearization: Single Image



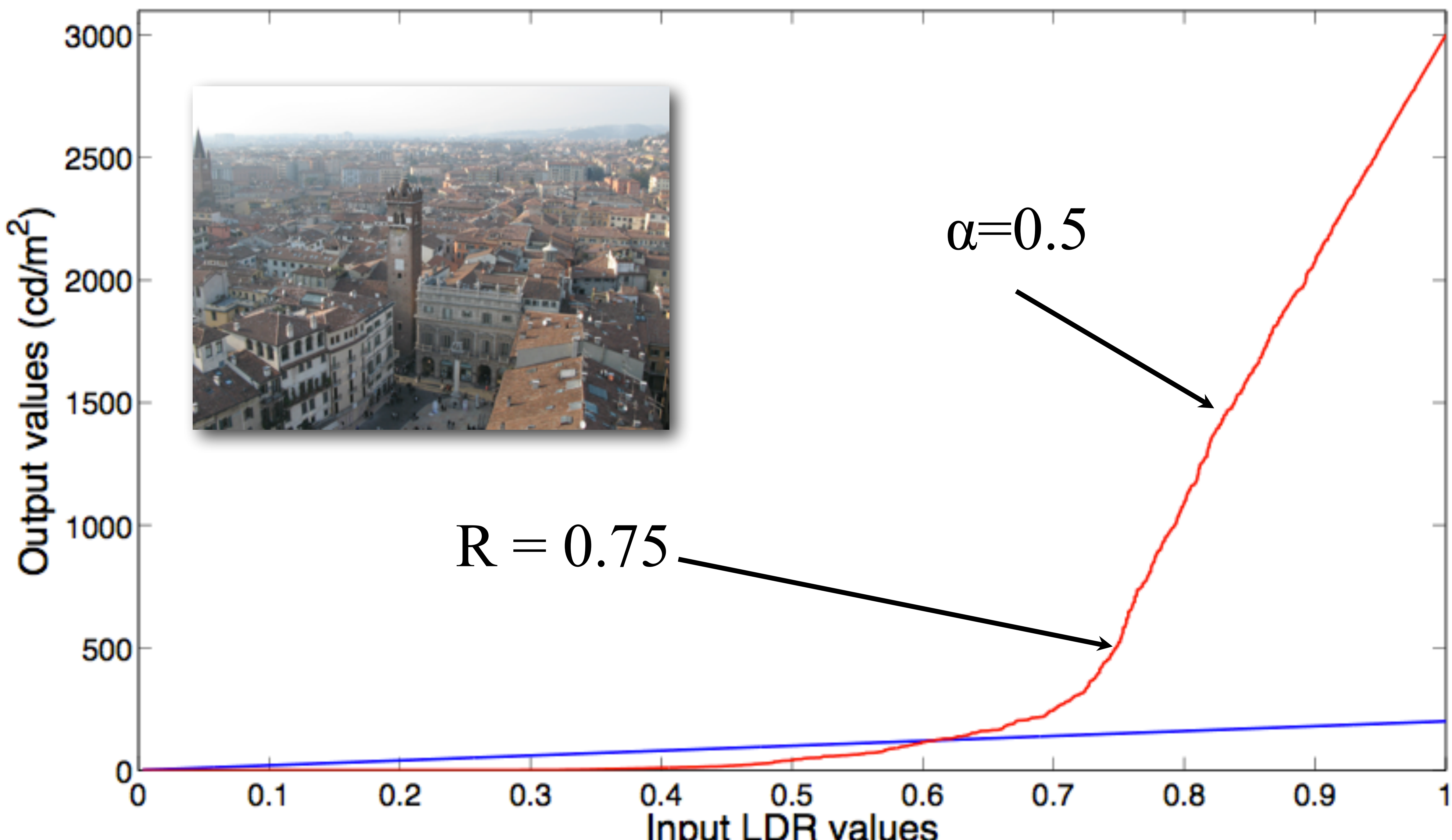
Global Methods

- A simple method is to expand the dynamic range of pixel over a certain threshold, R, [Landis 2002]:

$$L_w(\mathbf{x}) = \begin{cases} (1-k)L_d(\mathbf{x}) + kL_{w,\max}L_d(\mathbf{x}) & \text{if } L_d(\mathbf{x}) \geq R, \\ L_d(\mathbf{x}) & \text{otherwise;} \end{cases}$$

$$k = \left(\frac{L_d(\mathbf{x}) - R}{1 - R}\right)^{\alpha}$$

Global Methods



Global Methods

- “a simple linear scale can provide an HDR experience” based on psychophysically experiments [Akyüz et al. 2007]:

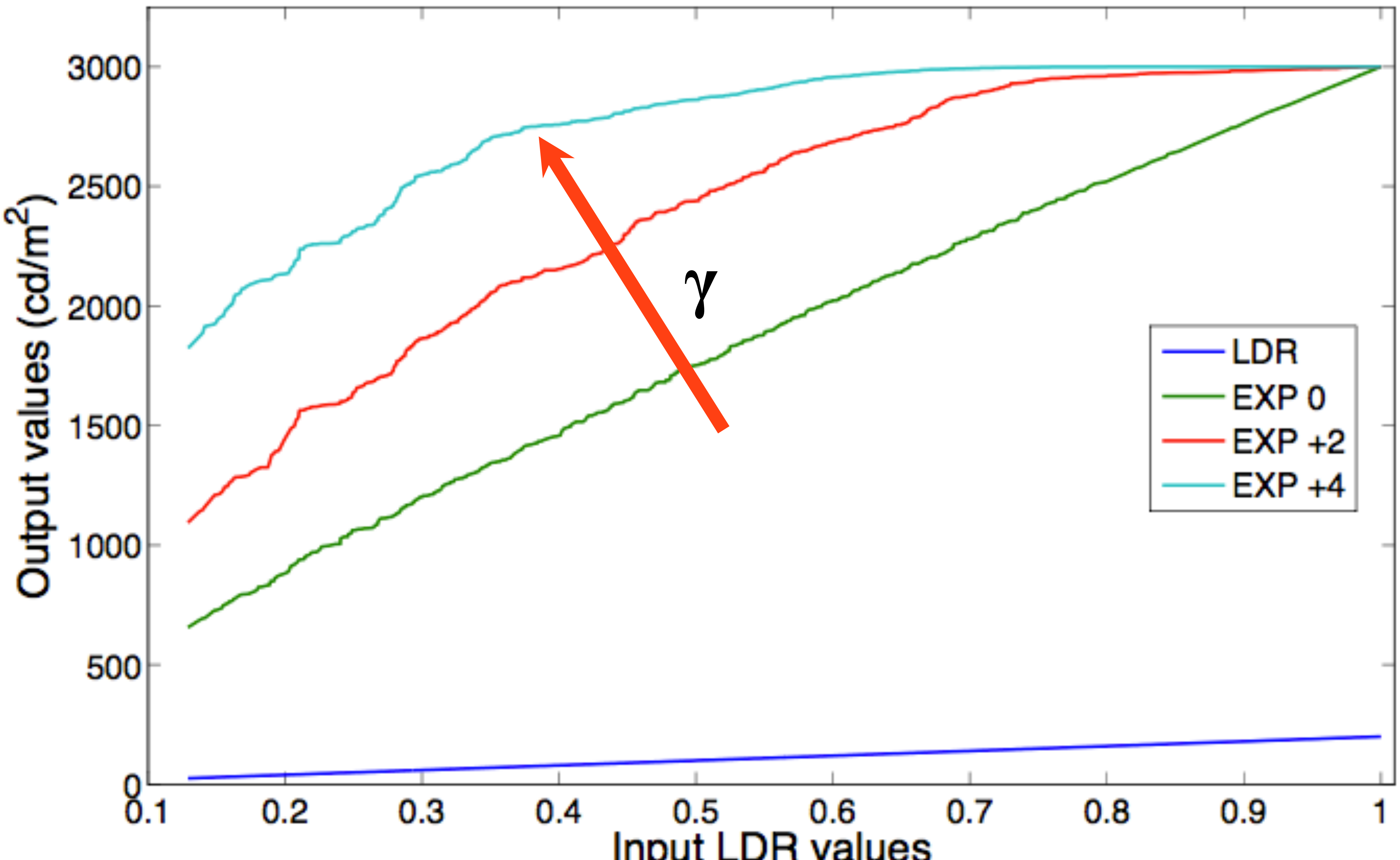
$$L_w(\mathbf{x}) = k\left(\frac{L_d(\mathbf{x}) - L_{d,\min}}{L_{d,\max} - L_{d,\min}}\right)^{\gamma}$$

- Over-exposed images a non-linear function (gamma) needs to be applied. This non-linearity depends on exposedness of the image [Masia et al. 2009]:

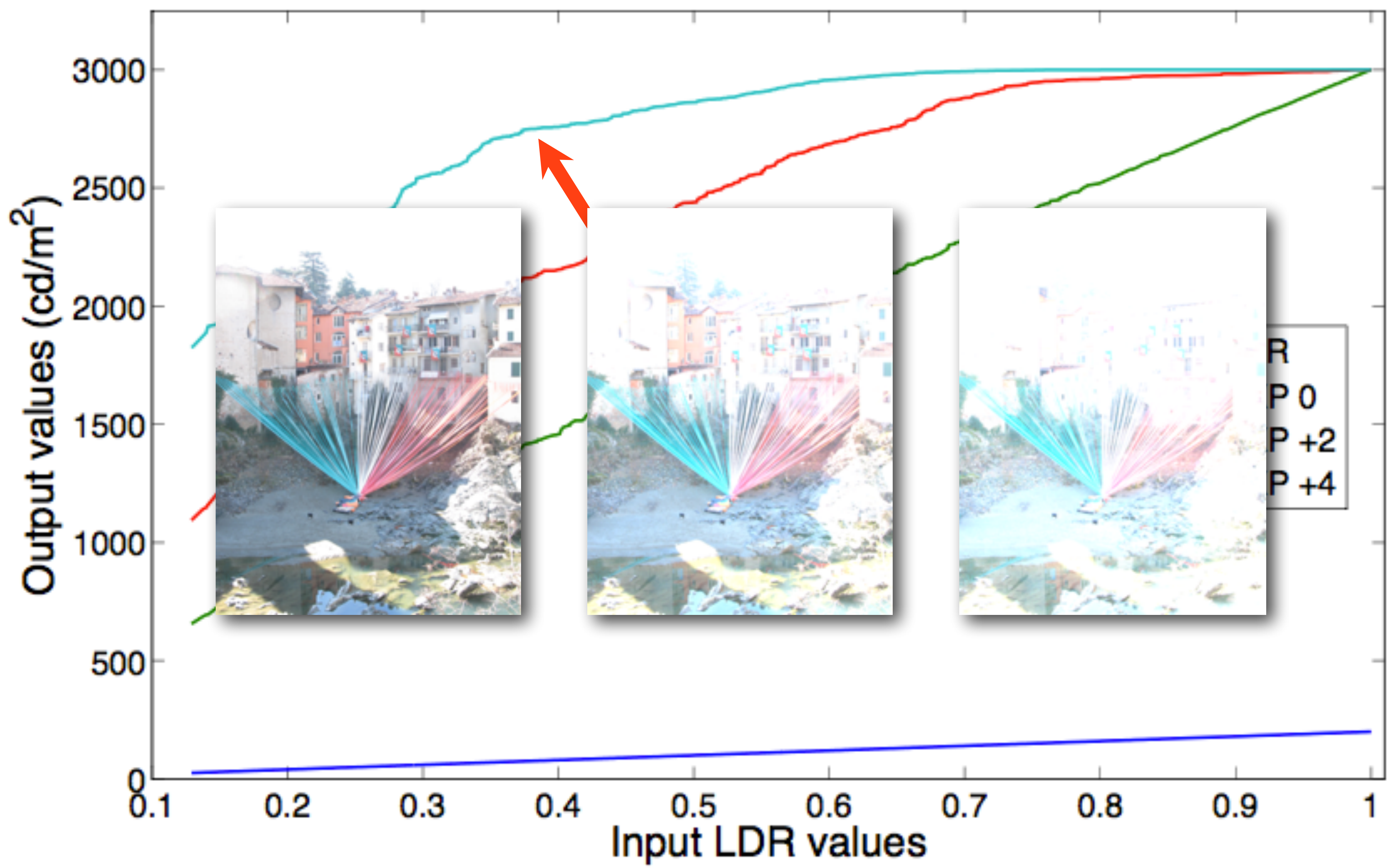
$$L_w(\mathbf{x}) = L_d(\mathbf{x})^{\gamma} \qquad \gamma = 10.44k - 0.6282$$

$$k = \frac{\log \overline{L}_d(\mathbf{x}) - \log L_{d,\min}}{\log L_{d,\max} - \log L_{d,\min}}$$

Global Methods



Global Methods



Classification Methods

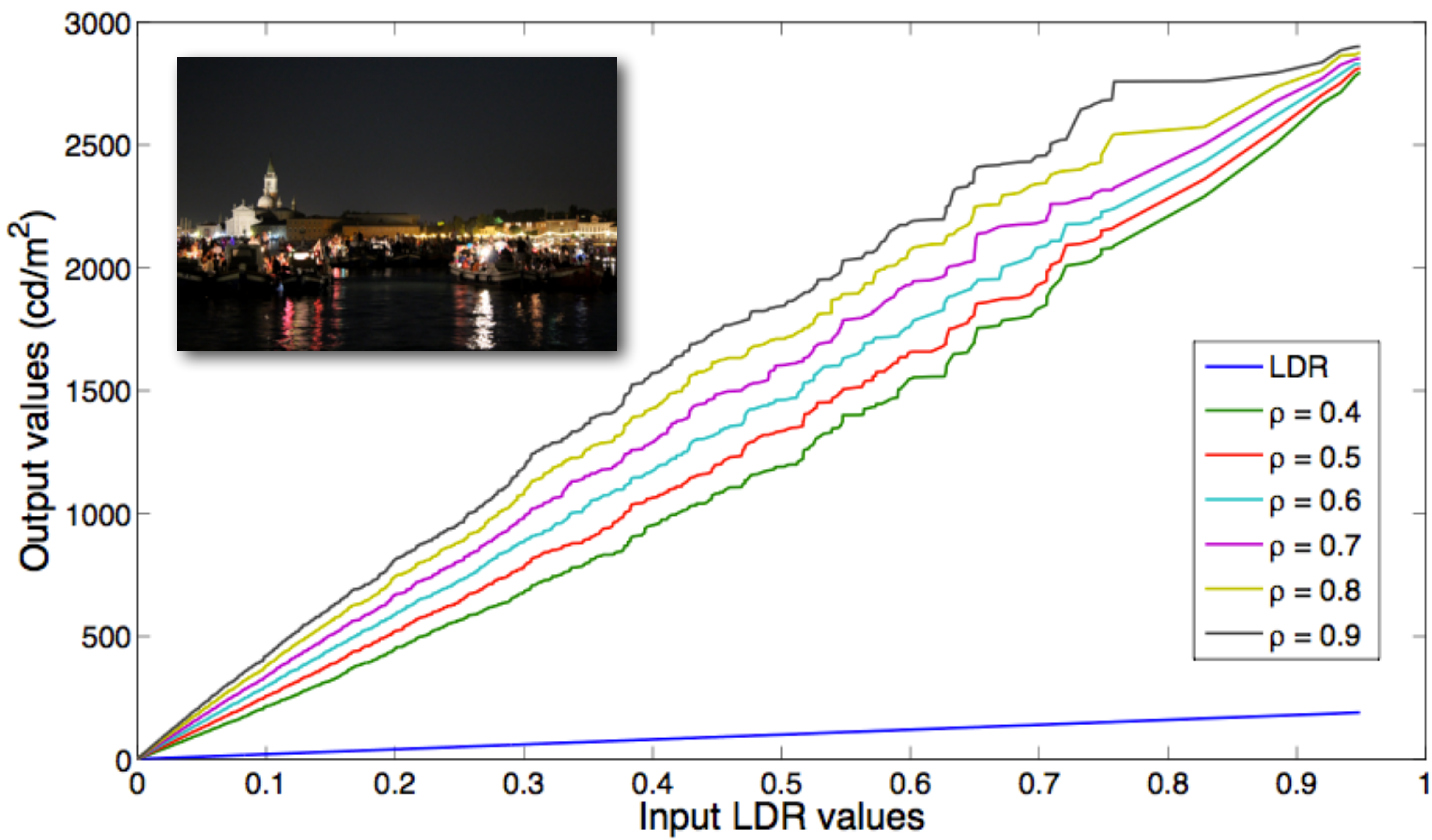
- A classification approach [Meylan et al. 2006, 2007]:
  - Expand highlights and specular surfaces ($\omega>0$)
  - ω is computed using robust thresholding
  - Expansion using a two-scale model:

$$L_w(\mathbf{x}) = f(L_d(\mathbf{x})) = \begin{cases} s_1 L_d(\mathbf{x}) & \text{if } L_d(\mathbf{x}) \leq \omega, \\ s_1\omega + s_2(L_d(\mathbf{x}) - \omega) & \text{otherwise;} \end{cases}$$

$$s_1 = \frac{\rho}{\omega} \quad s_2 = \frac{1-\rho}{L_{d,\max} - \omega},$$

  - To avoid contouring low-pass filtering on expanded regions

Classification Methods



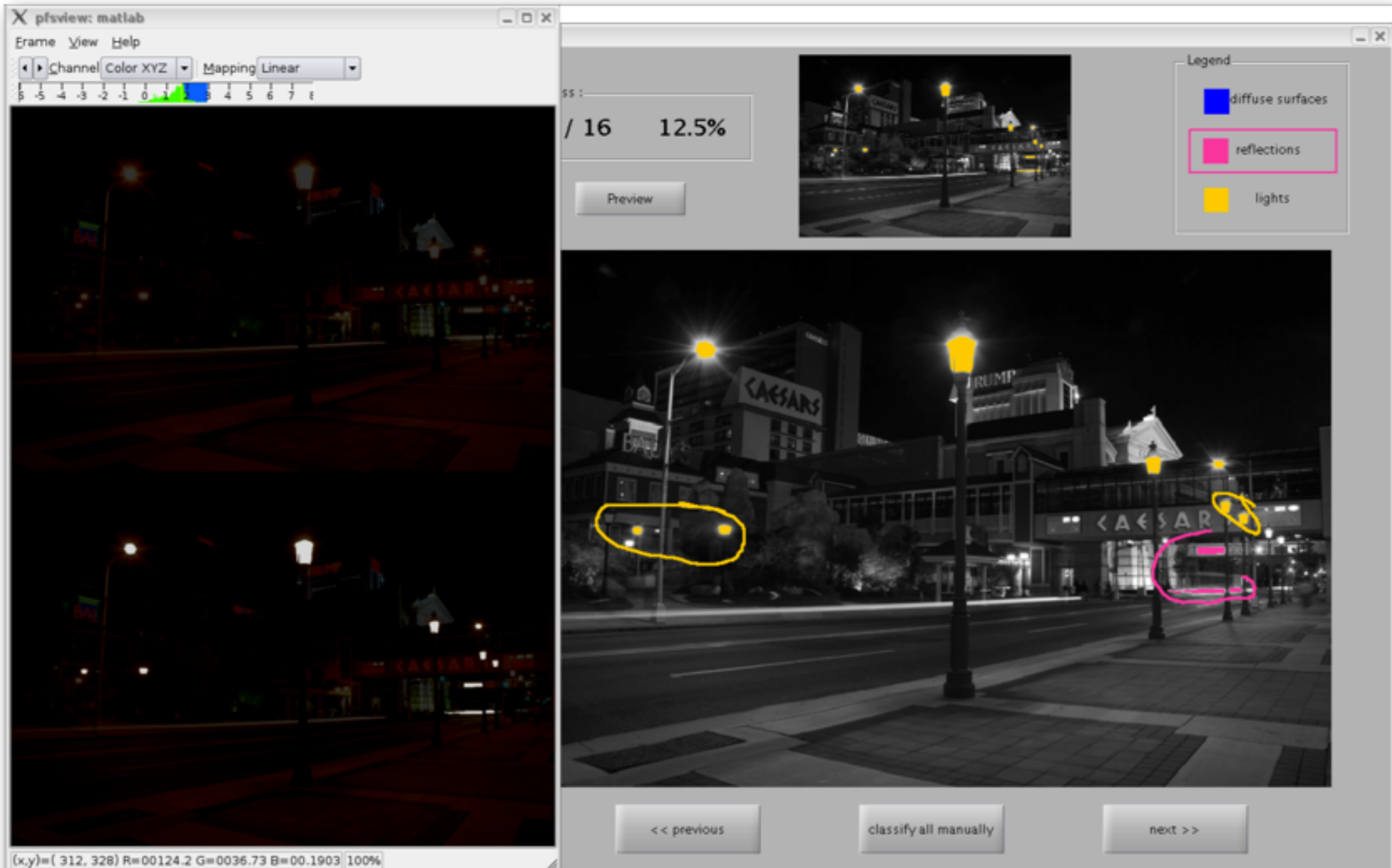
Classification Methods

- Classification can be improved [Didyk et al. 2008]:
  - Three classification areas: diffuse, reflections, and lights
  - Automatic Classifier (AC):
    - SVM + Nearest Neighbor + Tracking ⇒ 3%
    - User interface for adjusting the AC errors

Classification Methods

- Non-linear adaptive tone curve for expanding the range based on the histogram of the region:
  - Bilateral filtering layers separation (high and low frequencies) for avoiding contouring

Classification Methods



Classification Methods

- Saliency can be used for classification [Masia et al. 2010]:
  - Range Expansion (RE): pice-wise linear expansion using the zonal system by Adams (9 zones):

$$p = \left(\frac{e^{(v \sin(\pi \frac{z-1}{16}))} - 1}{e^{v} - 1} \right)^{-2.2} \qquad v = 5.25 \quad z \in [0, 9]$$

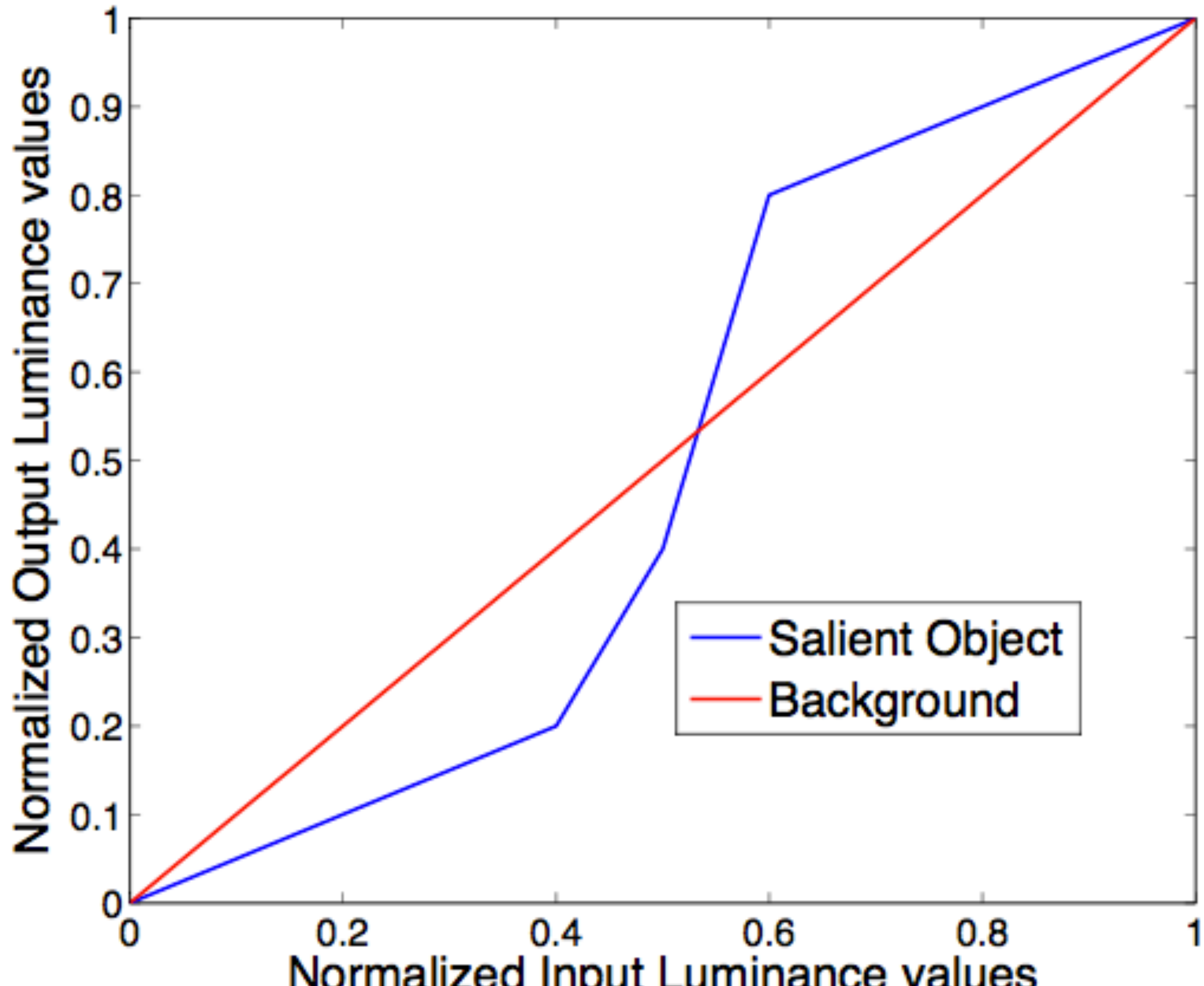
  - Labeling:
    - salient objects and background discrimination using different techniques:
      - learning-based saliency detection (Liu et al 2007])
      - saliency cuts [Fu et al. 2008]
      - Different Labels ⇒ Different RE functions

Classification Methods

Input

Auto-Labeling

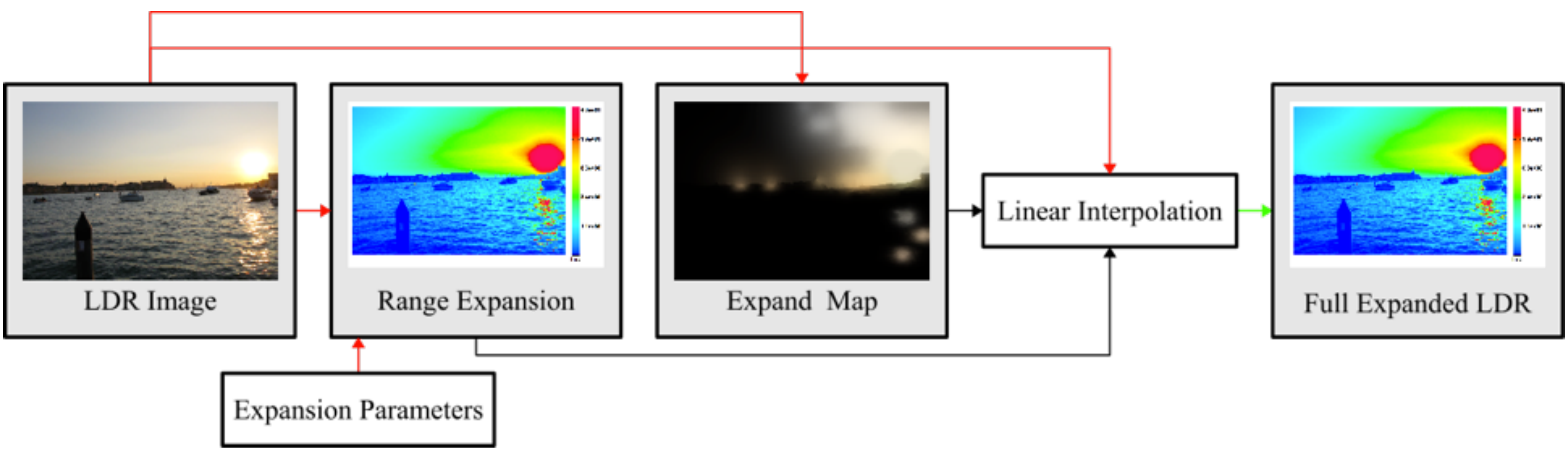
Binary Mask



Expand Map Methods

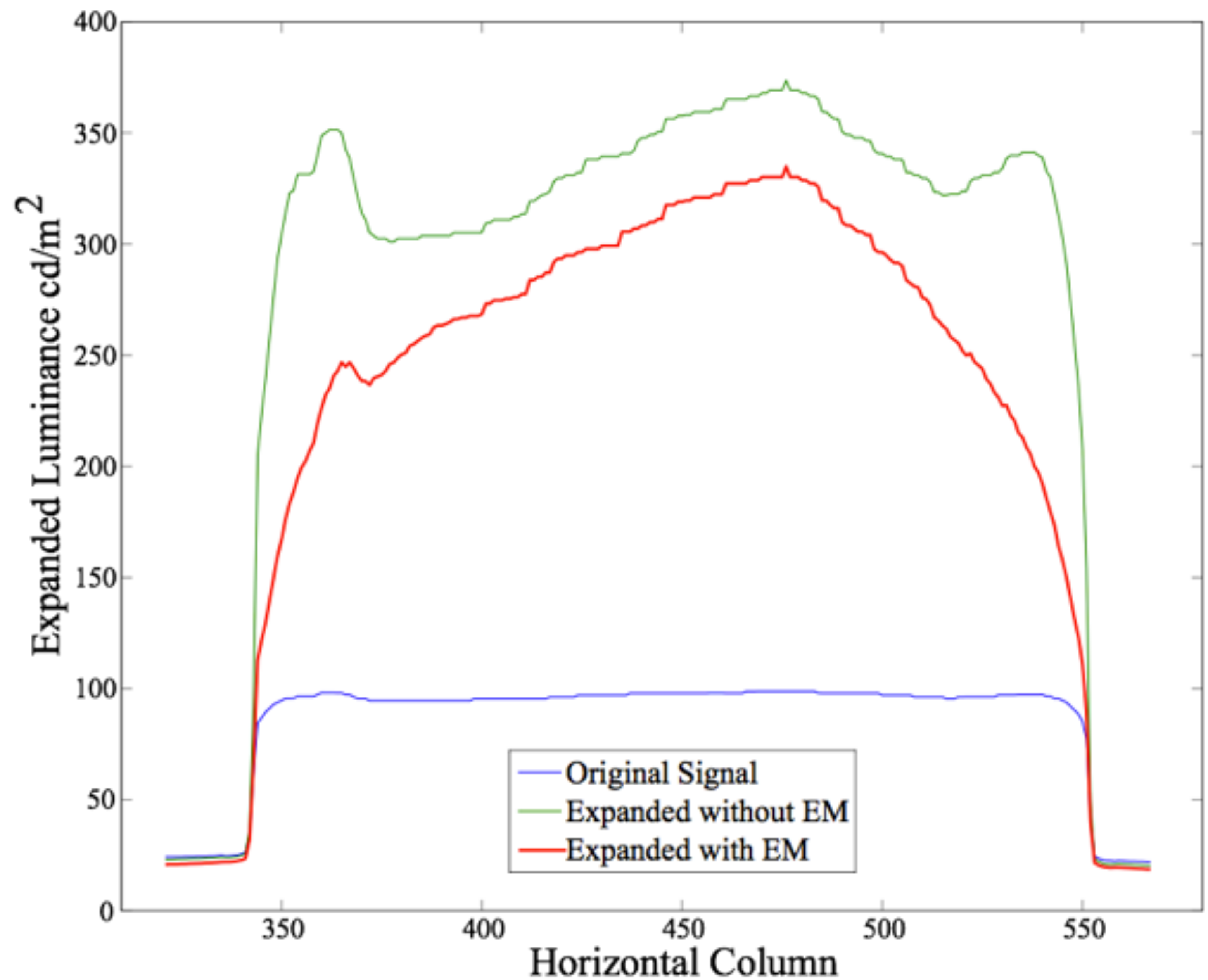
- A general framework for expansion [Banterle et al. 2006, Rempel et al. 2007, Banterle et al. 2009, Kovaleski et al. 2010]:
    - Range Expansion: inverting an TMO, a linear function, etc
    - Expand Map:
        - sampling+density estimation+cross bilateral (avoiding contouring and compression artifacts)
        - Thresholding + Edge-stopping/Edge-aware filtering

Expand Map Methods

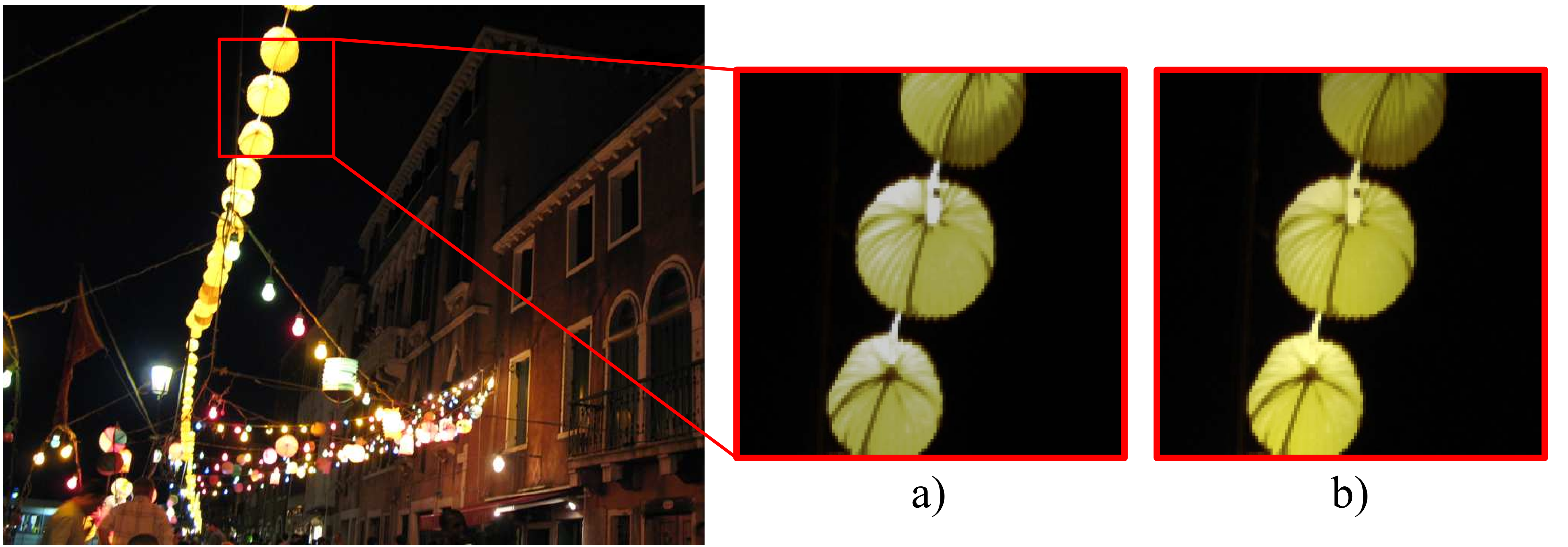


[Banterle et al. 2008]

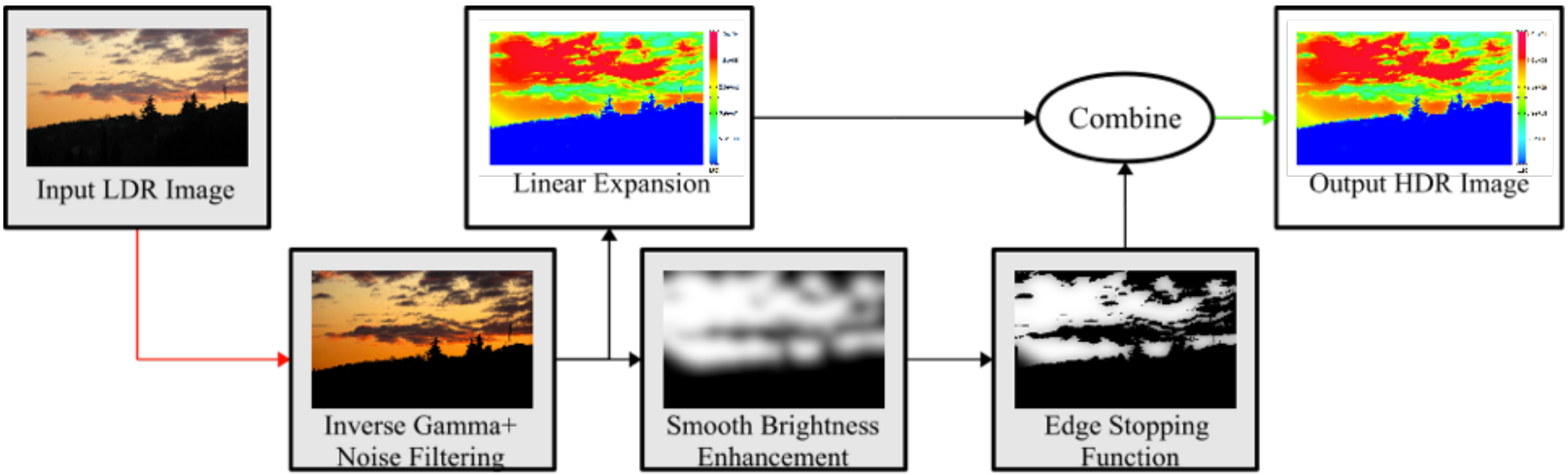
Expand Map Methods



Expand Map Methods

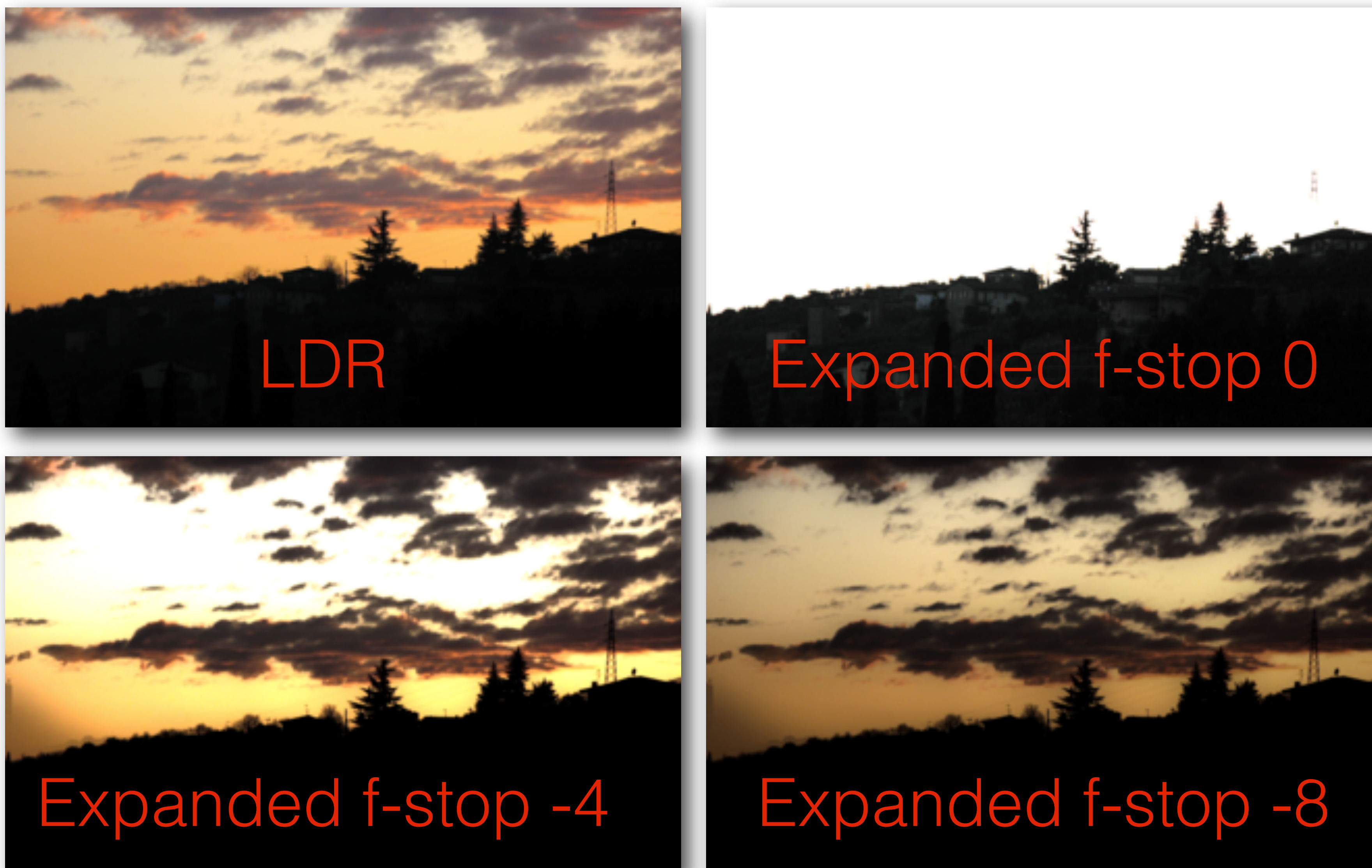


Expand Map Methods



[Rempel et al. 2007]

Expand Map Methods



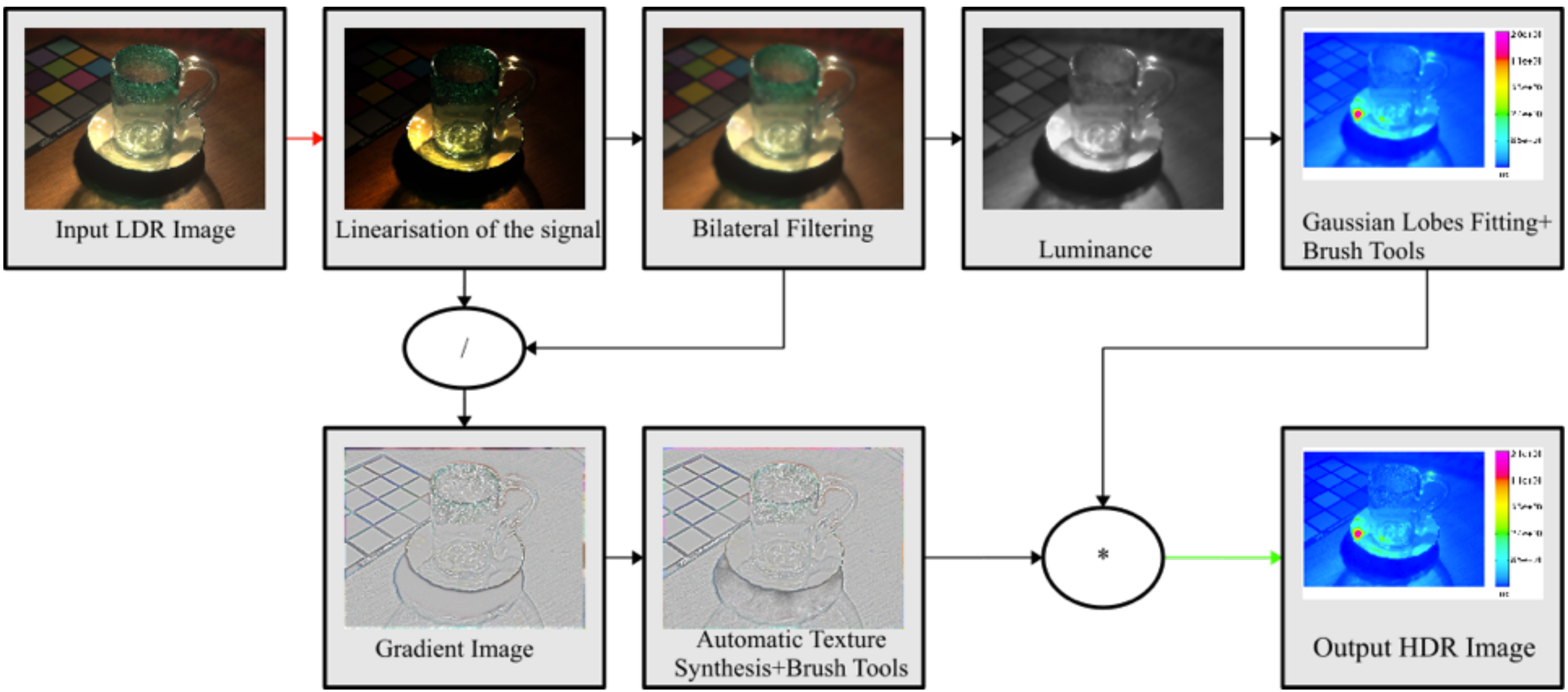
User Based

- For artistic purposes the user should be allowed to fill gaps in over-exposed and under-exposed area [Wang et al. 2007]:

  - Detail recovering: using a tool similar to the "healing tool" in Adobe PhotoShop

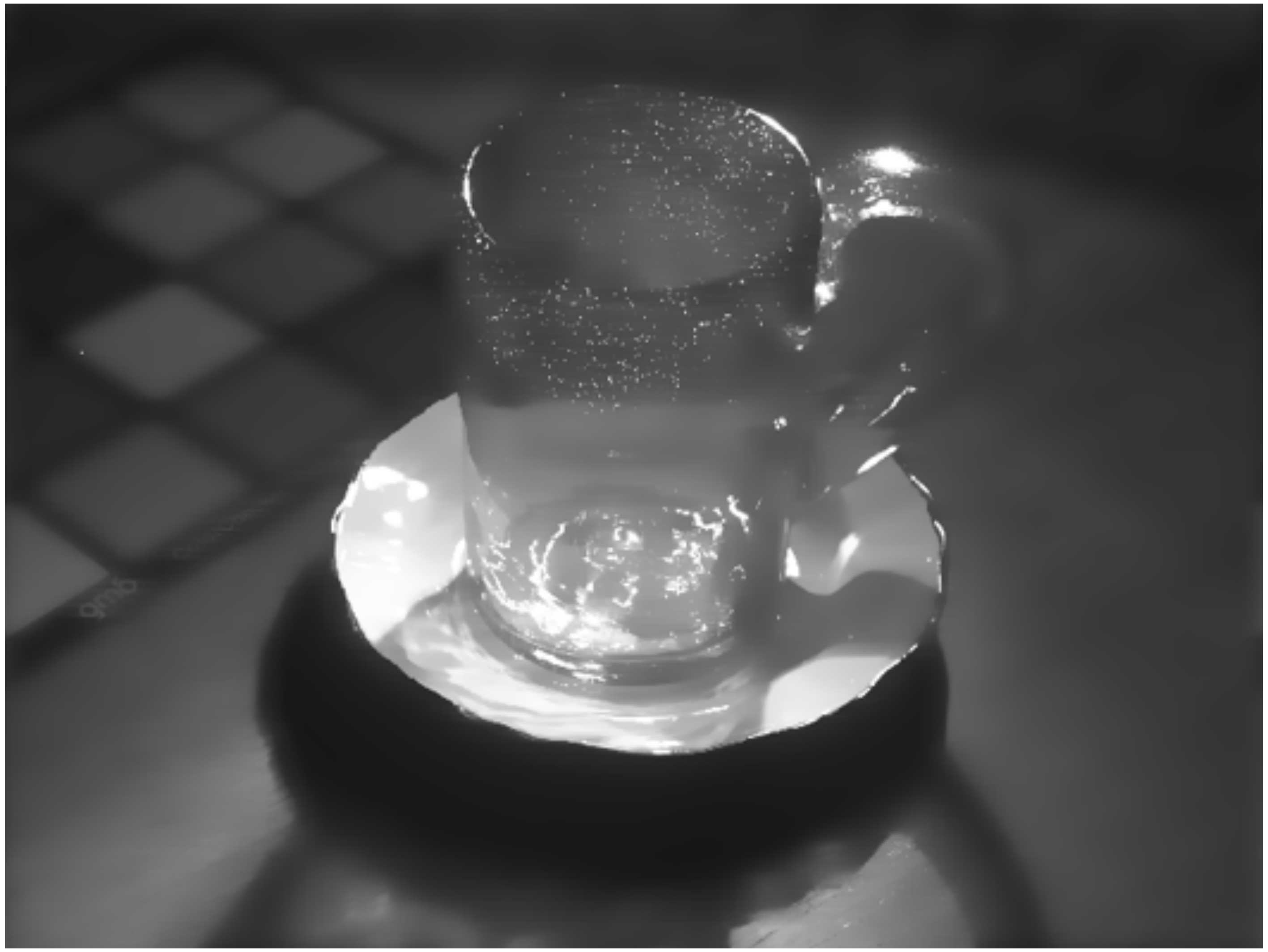
  - Range expansion: 2D Gaussian lobes are fitted in continuous over-exposed regions

User Based

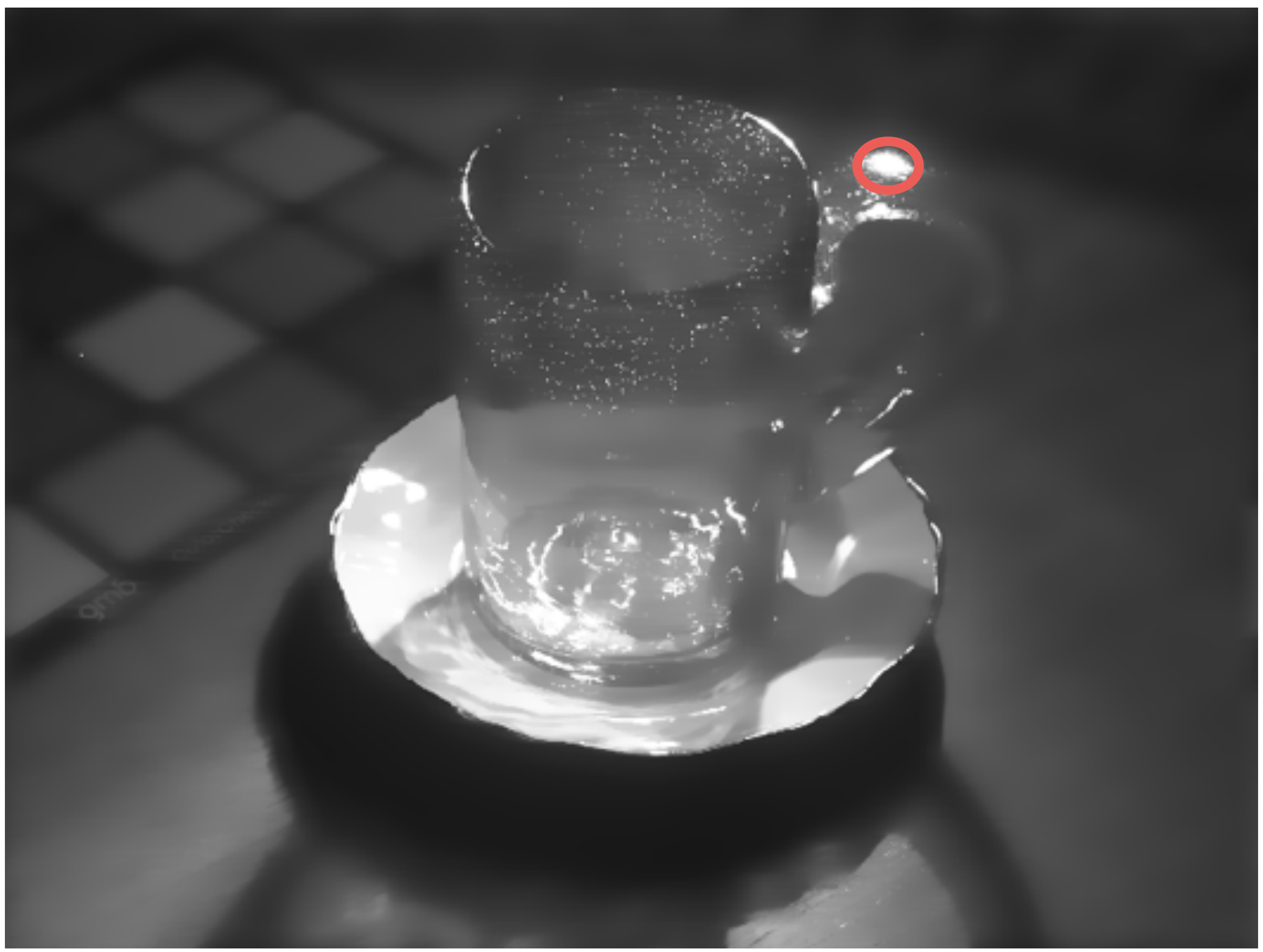


Input LDR Image
Linearisation of the signal
Bilateral Filtering
Luminance
Gaussian Lobes Fitting+
Brush Tools
/
Gradient Image
Automatic Texture
Synthesis+Brush Tools
*
Output HDR Image

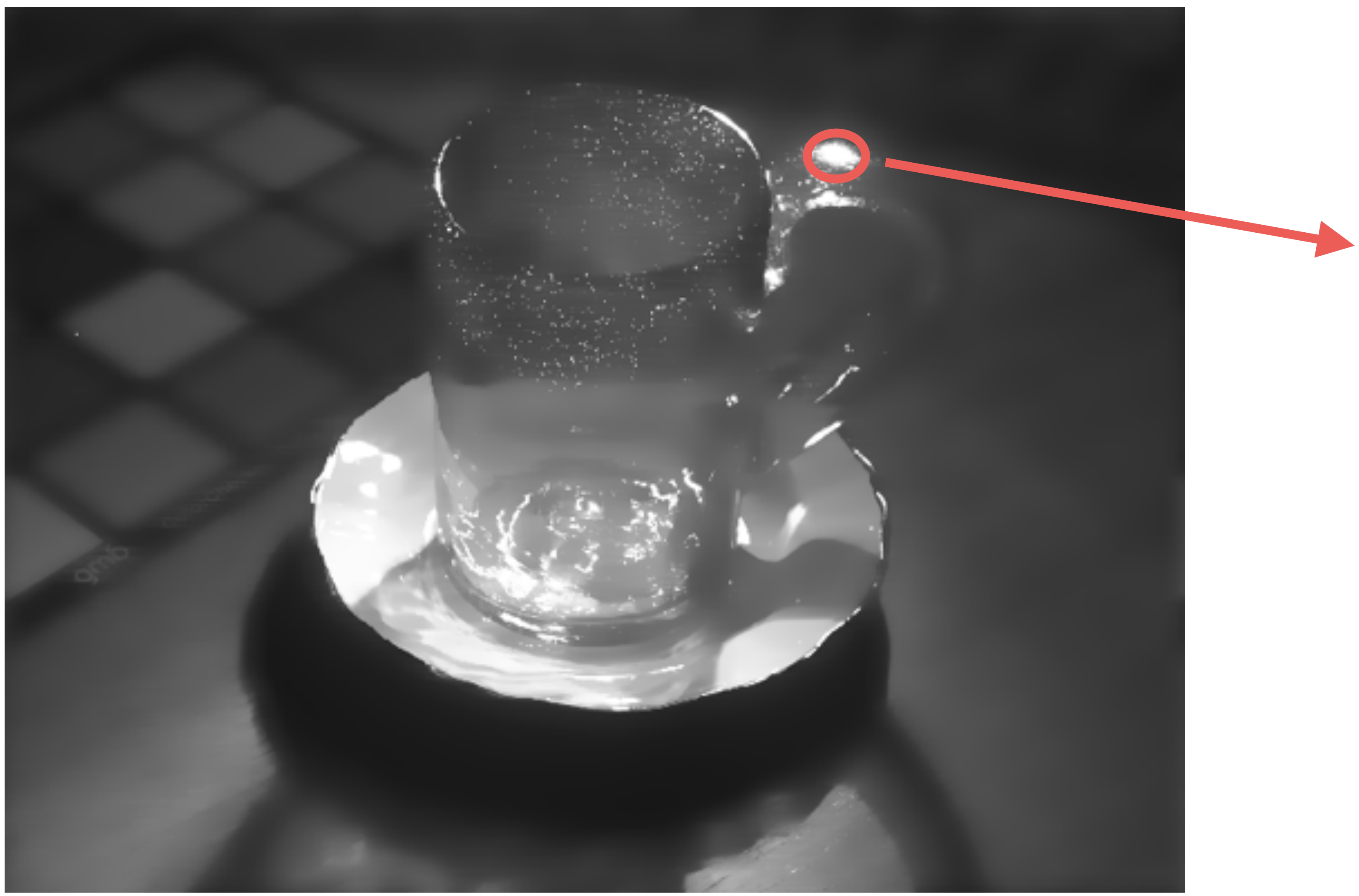
User Based: Expansion



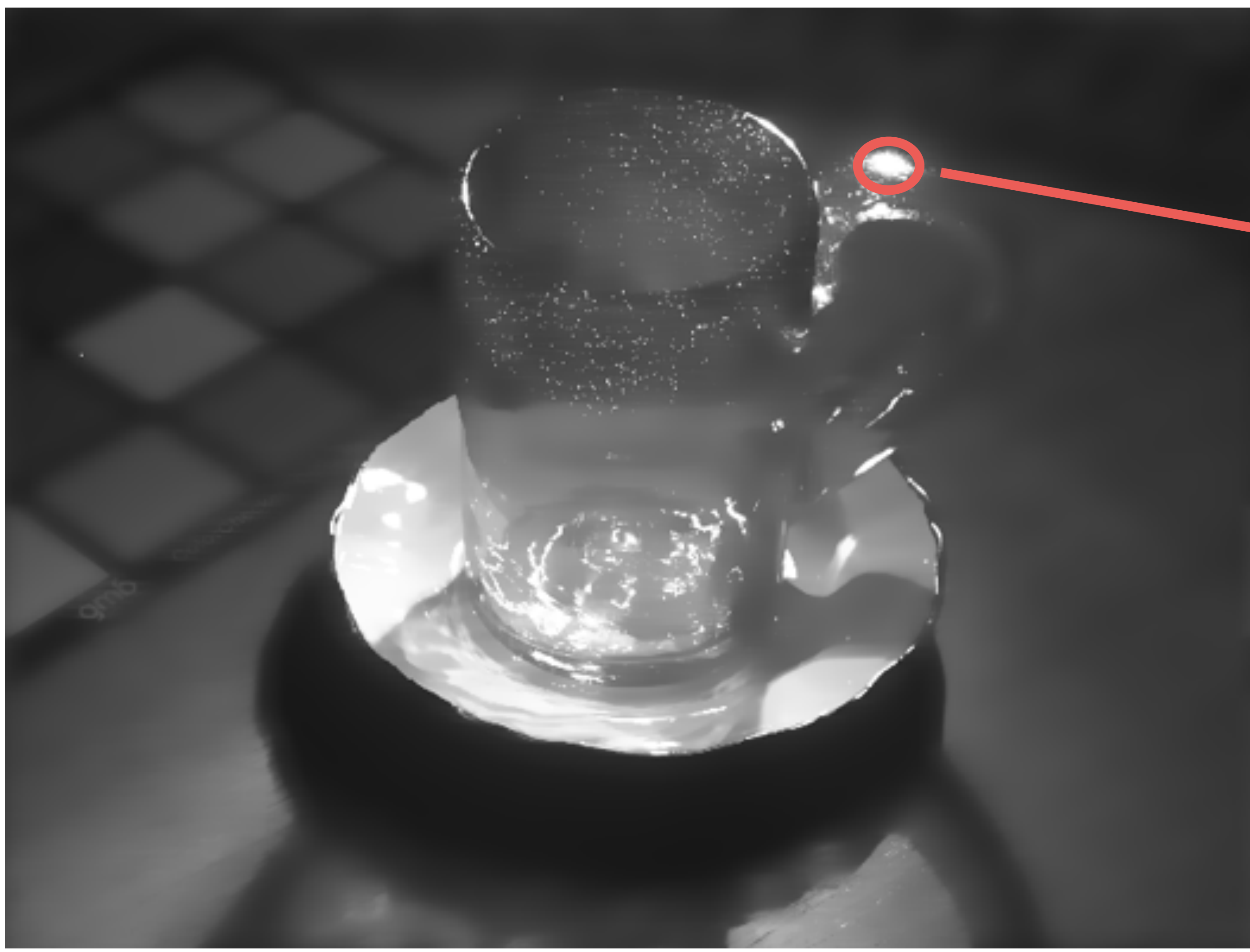
User Based: Expansion

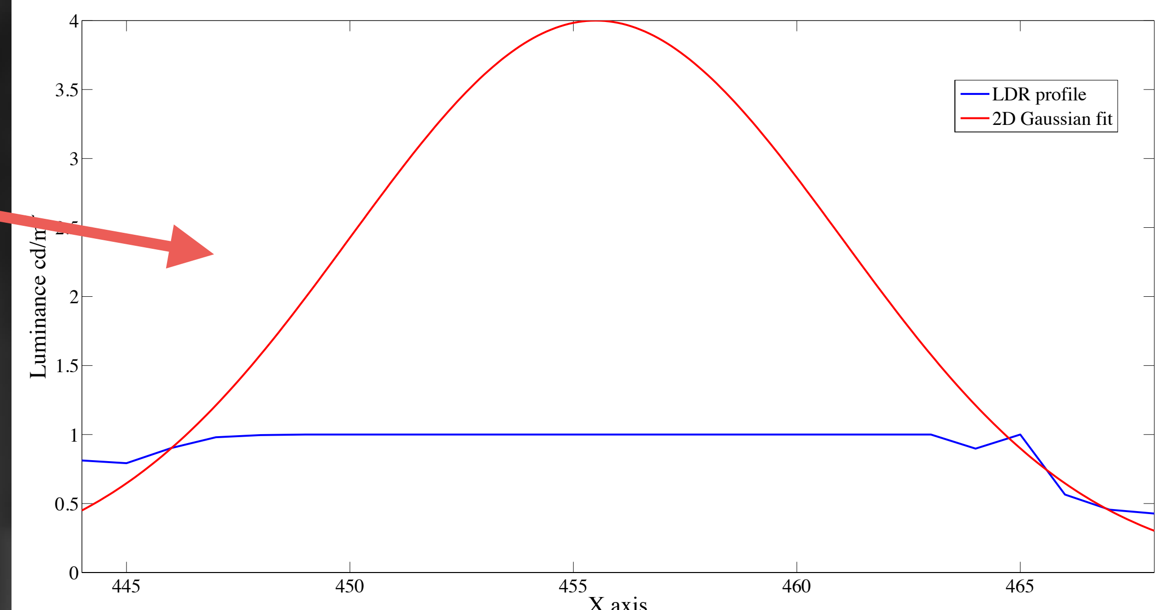


User Based: Expansion



User Based: Expansion





2D Gaussian lobe fit

User Based: Details Recovery

Original image courtesy of Ahmet Oguz Akyuz

User Based: Details Recovery

Original image courtesy of Ahmet Oguz Akyuz and colors??

Color Reproduction in iTMO/rTMO

- There is the opposite problem which is present in tone mapping:

- Tone Mapping —> over saturation of colors due to compression

- Inverse/Reverse Tone Mapping —> desaturation of colors due to expansion

Color Reproduction in iTMO/rTMO

- Basic idea is to sature colors; typically [Schlick 1994]:

$$\begin{bmatrix} R_w \\ G_w \\ B_w \end{bmatrix} = L_w \left(\frac{1}{L_d} \begin{bmatrix} R_d \\ G_d \\ B_d \end{bmatrix} \right)^{\frac{1}{s}} \qquad s \in (0, 1]$$

- s depends on the image content

- **Issues**: it needs manual tweaking and it is a hack

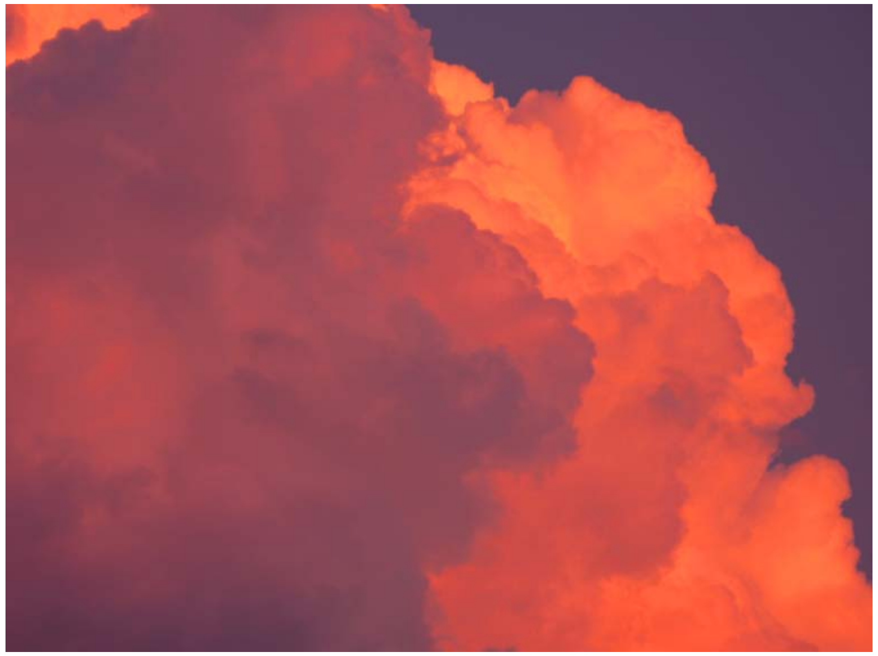
Color Reproduction in iTMO/rTMO

- A possible solution is to have a spatially varying s:

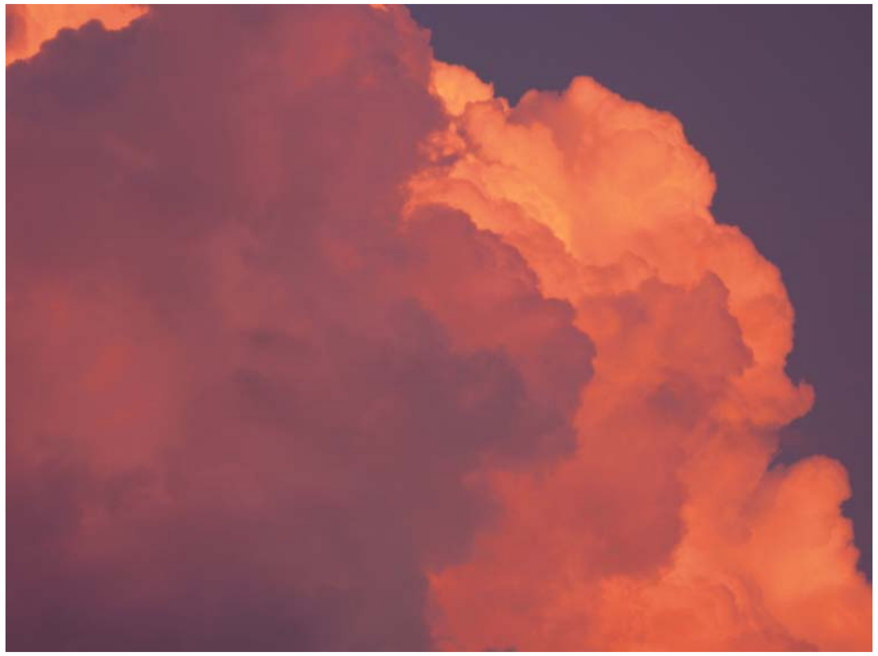
$$\frac{1}{s} = h(\mathbf{x})$$

$$h(\mathbf{x}) = S_{\mathrm{Max}}(1 - 3t(\mathbf{x})^2 + 2t(\mathbf{x})^3) + S_{\mathrm{Min}}(3t(\mathbf{x})^2 - 2t(\mathbf{x})^3) \qquad t(\mathbf{x}) = \frac{L_{\mathrm{d}}(\mathbf{x})}{L_{\mathrm{w}}(\mathbf{x})}$$

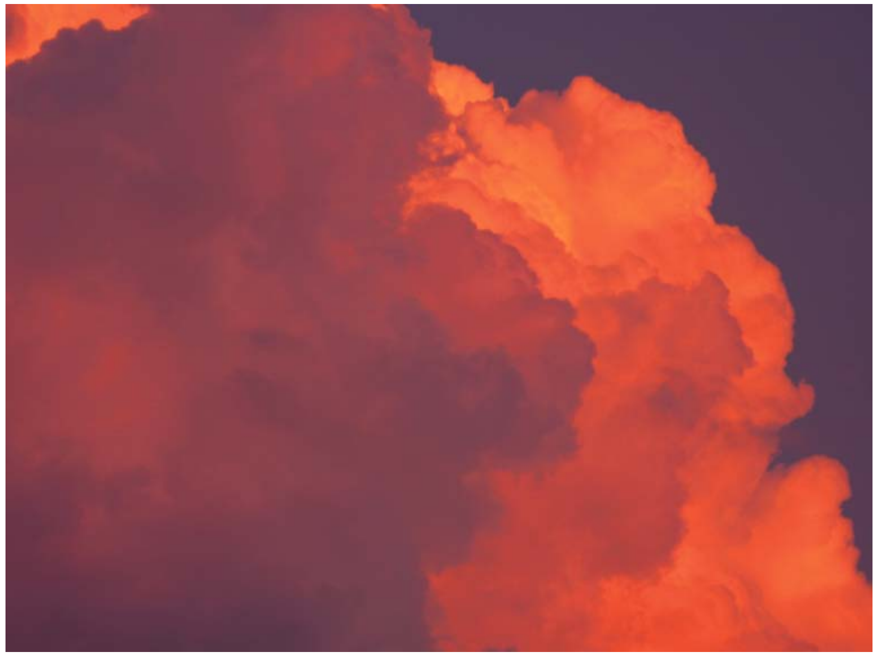
Color Reproduction in iTMO/rTMO



Original LDR image



Expanded Image



Expanded Image
+
Color Recovery

Evaluation

- There is the need to evaluate different expansion methods against a “ground truth”.
- Why?
  - To understand weak features or drawbacks
  - To understand important features rTMO/iTMO techniques do not generate exact luminance values

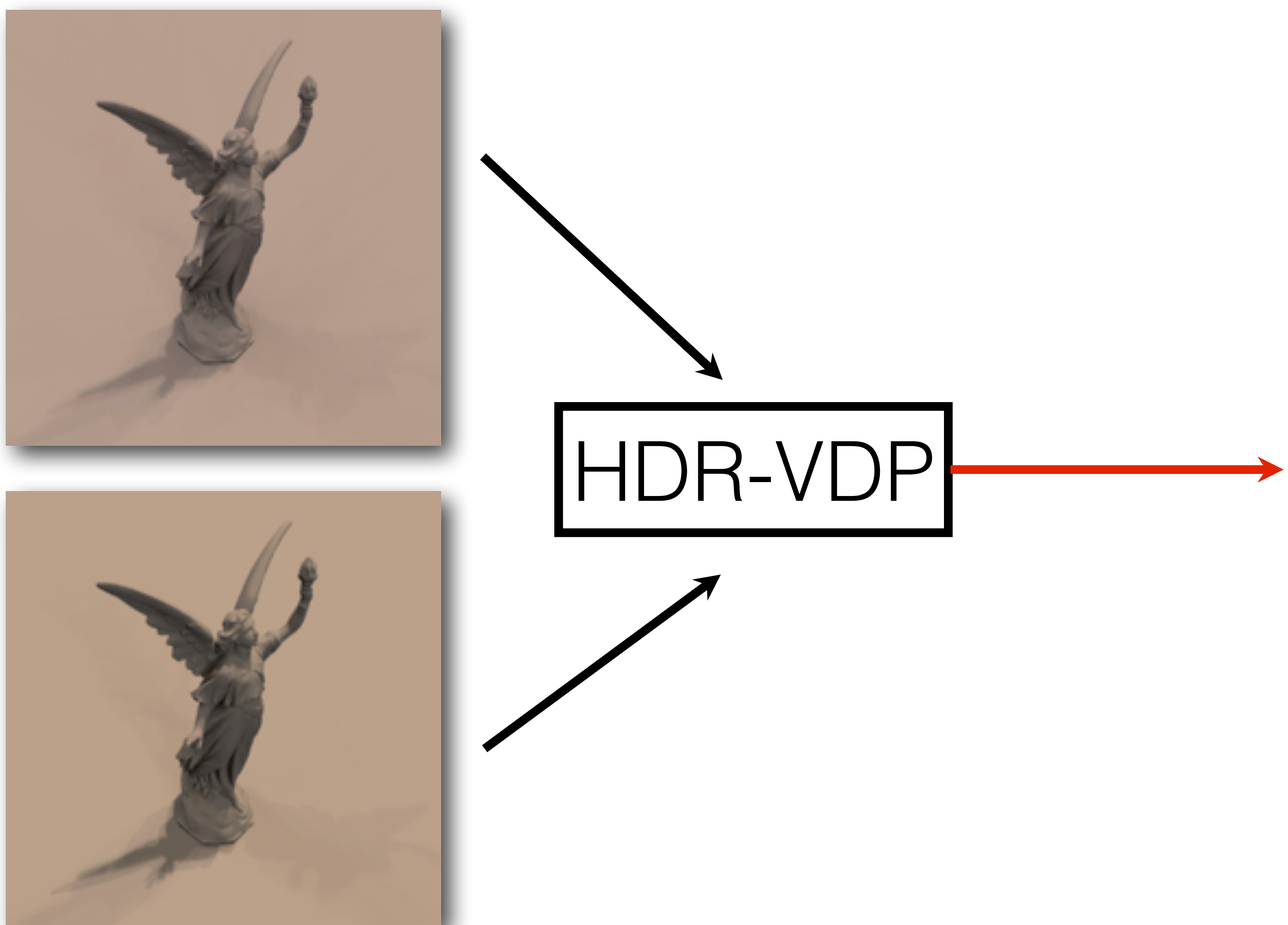
Evaluation

- Perceptual Image Metrics: not exact comparison as in the PSNR, RMSE, etc.
- Psychophysical Experiments

Evaluation: Perceptual Metrics

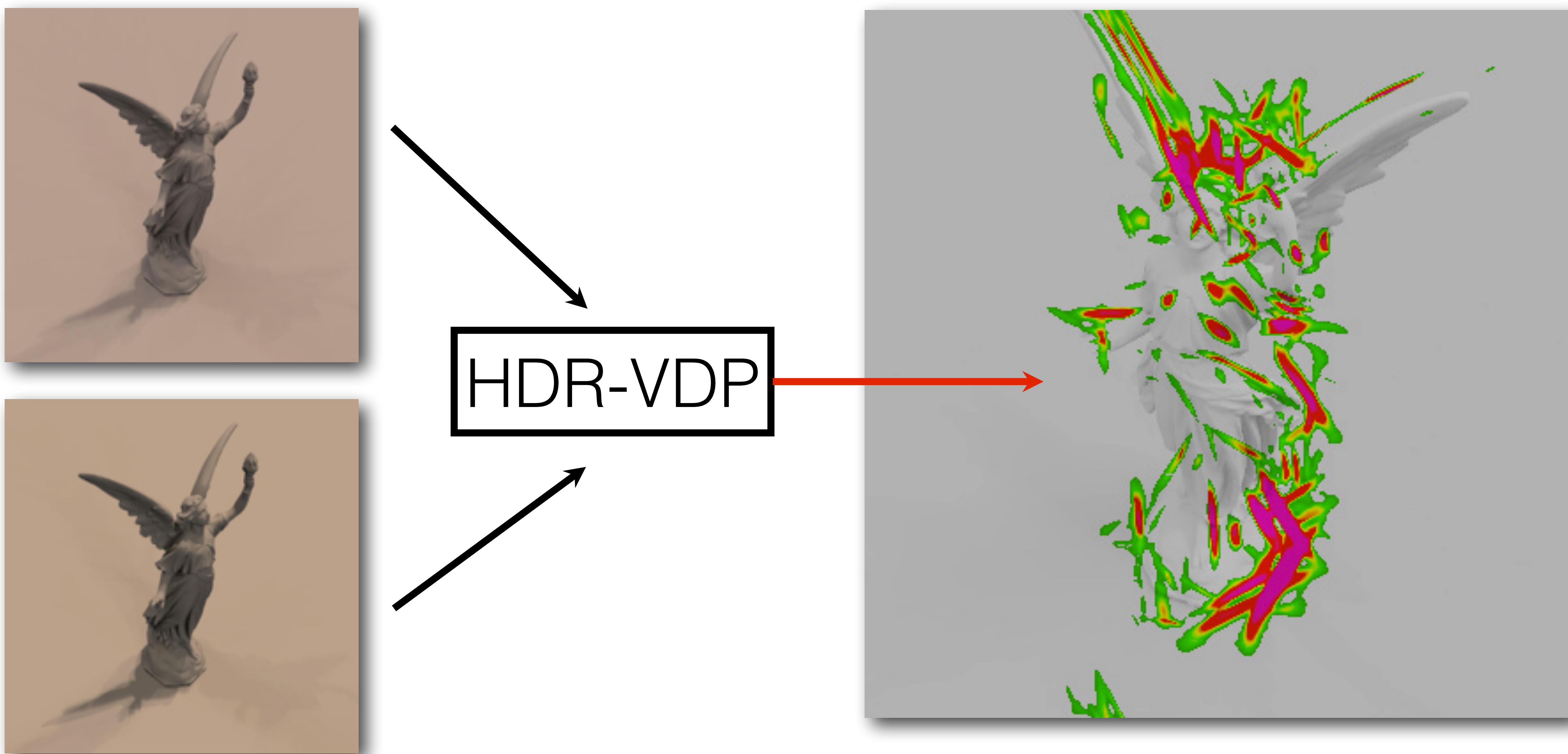
- HDR-VDP:
  - It can be used used it to validate that their models were performing better than a simple non-linear expansion, validate against other methods, etc. [Banterle et al. 2006, 2007, 2008]
- DRIIQM:
  - It can be used used it to validate that their models were performing better than a simple non-linear expansion, validate against other methods, etc. [Banterle et al. 2006, 2007, 2008]

Evaluation:
Perceptual Metrics



Lucy model is courtesy of the Stanford 3D Scanning Repository

Evaluation: Perceptual Metrics



Lucy model is courtesy of the Stanford 3D Scanning Repository

Evaluation: Psychophysical Experiments

- Pairwise comparisons of HDR videos/images [Didyk et al. 2009, Banterle 2009]:
  - quantization artifacts need to be handle for better quality.
  - IBL needs non-linear expansion. Rating of HDR images and tone mapped expanded images
- Rating of HDR images and tone mapped expanded images [Masia et al. 2009]:
  - Understanding preferences in very over-exposed area understanding artifacts in expanded images

Questions?