Retargeting From LDR to HDR: Reverse/Inverse Tone Mapping

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Outline of the Talk

- An Overview on Reverse/Inverse Tone Mapping
- Expansion Methods:
  - Global Methods
  - Expand Map Methods
  - Classification Methods
  - User Based Methods
- Evaluation:
  - Psychophysical Experiments
  - Computational Metrics
- Conclusions

Overview on Reverse/Inverse Tone Mapping

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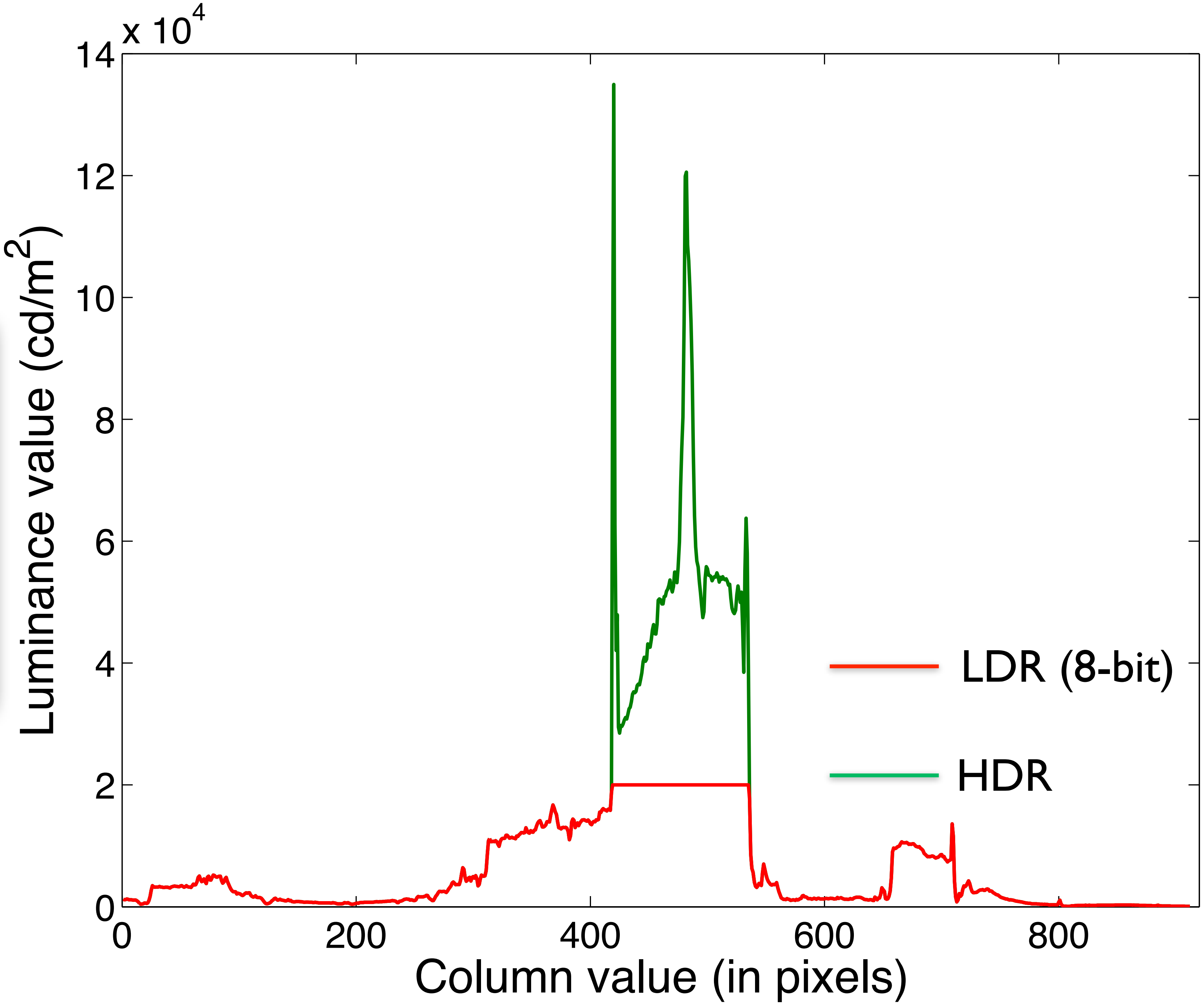


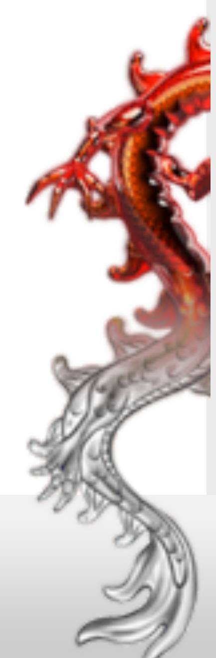
Overview on RTM/ITM: Why?

- Why do we need RTM/ITM?
  - **We want to retarget LDR content into HDR monitors, applications (i.e. Image Based Lighting), and editing!**

- The general operator is typically defined as:

$$g(I) = \mathbb{D}_{\mathrm{i}}^{w \times h \times c} \rightarrow \mathbb{D}_{\mathrm{o}}^{w \times h \times c}$$

- Common steps of these operators:
  - Linearization of the LDR image
  - Noise and quantization reduction
  - Luminance Expansion



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LDR HDR

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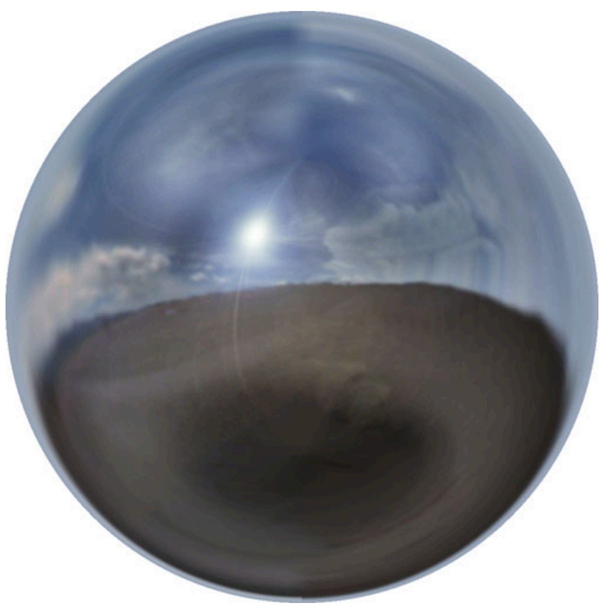
Global Methods (I)

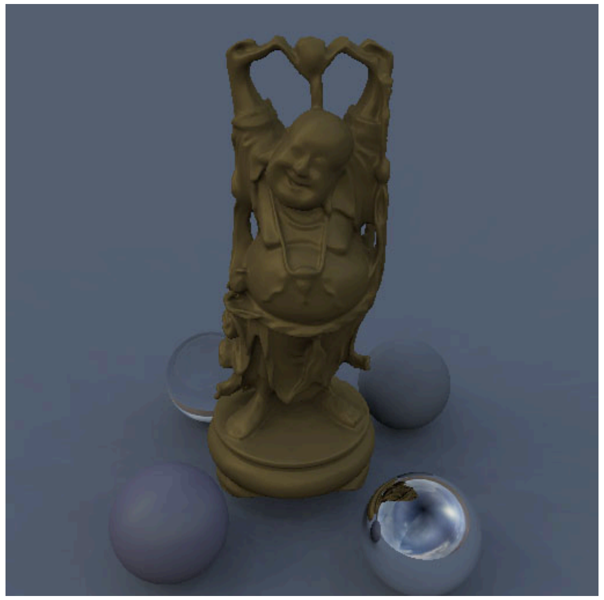
- Landis [Landis02] proposed a simple function for generating HDR images for VFX:

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

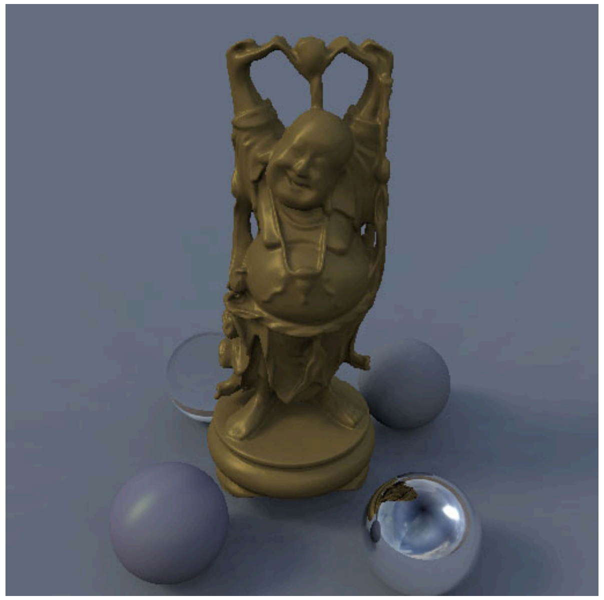
$$k = \left(\frac{L_{\mathrm{d}}(\mathbf{x}) - R}{1 - R} \right)^{\alpha},$$



Original LDR EM



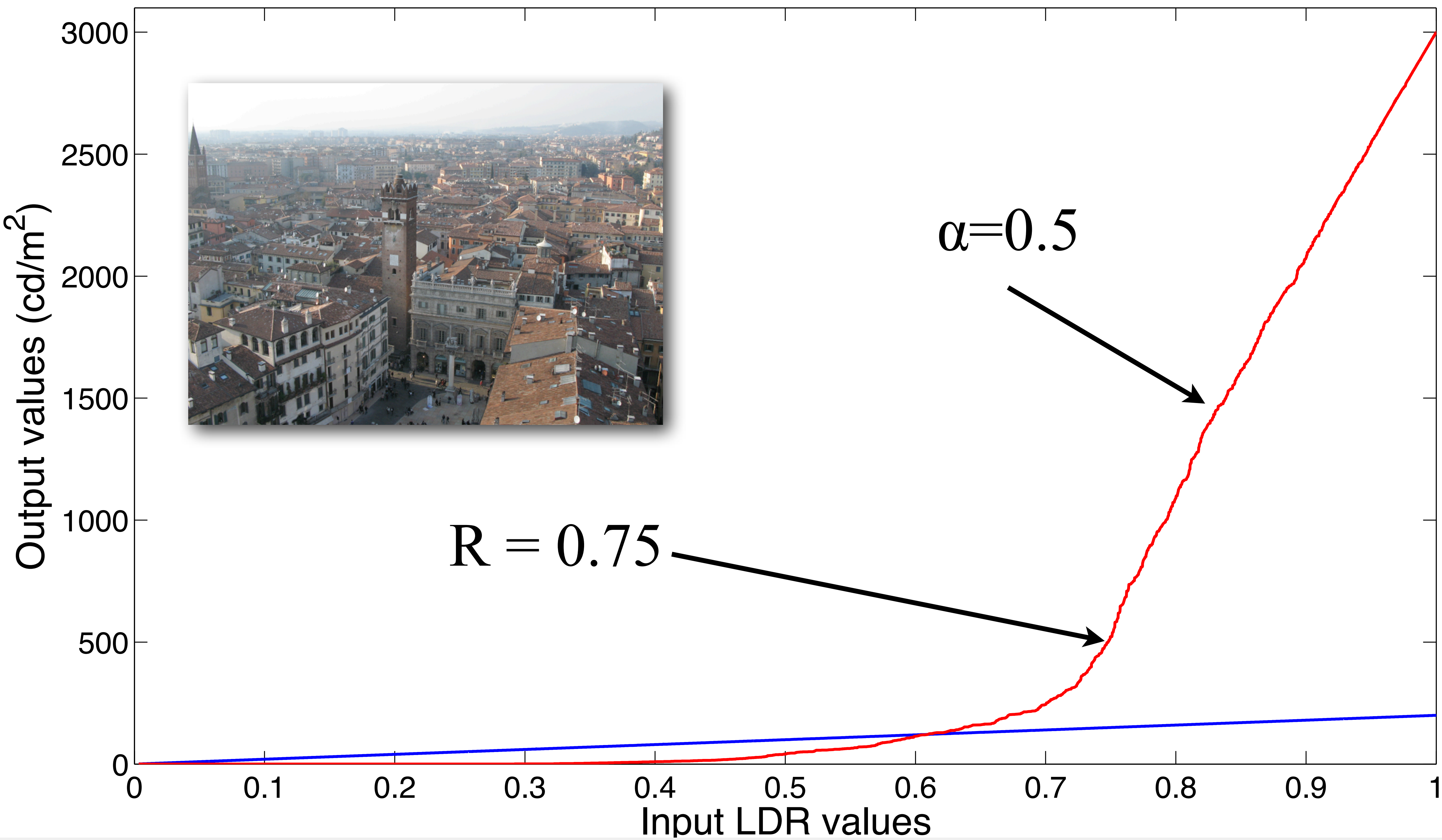
Rendered with LDR EM



Rendered ITMO EM

LDR Environment map is courtesy of H. Landis [Landis 02]

Global Methods (II)



Global Methods (III)

- Akyüz et al. [AFR*07] shown that "***a simple linear scale can provide an HDR experience***" based on psychophysically experiments:

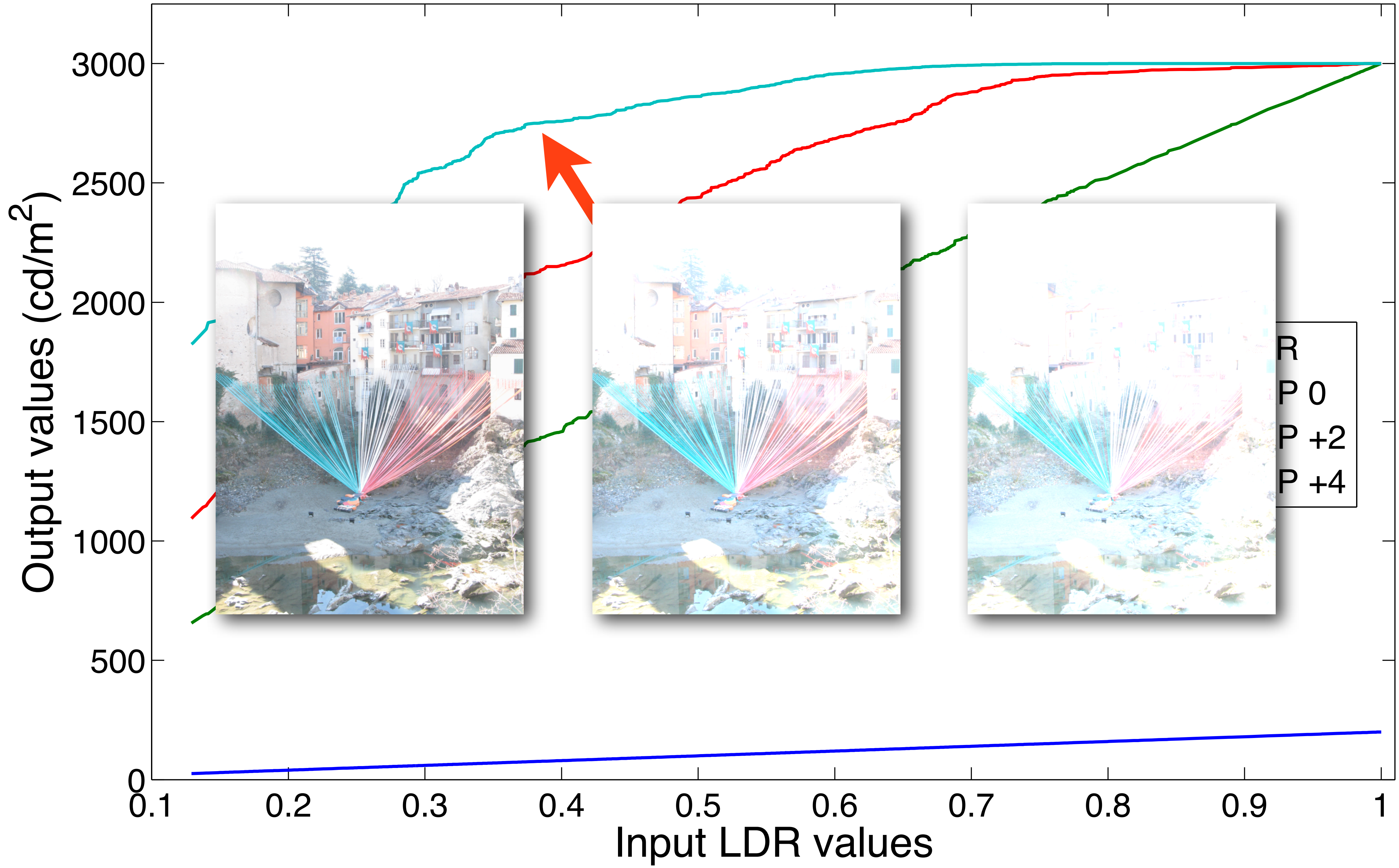
$$L_{\mathrm{w}}(\mathbf{x}) = k\left(\frac{L_{\mathrm{d}}(\mathbf{x}) - L_{\mathrm{d,\ min}}}{L_{\mathrm{d,\ max}} - L_{\mathrm{d,\ min}}}\right)^{\gamma}$$

- Masia et al. [MAF*09] shown that for over-exposed images a non-linear function (gamma) needs to be applied. This non-linearity depends on exposedness of the image:

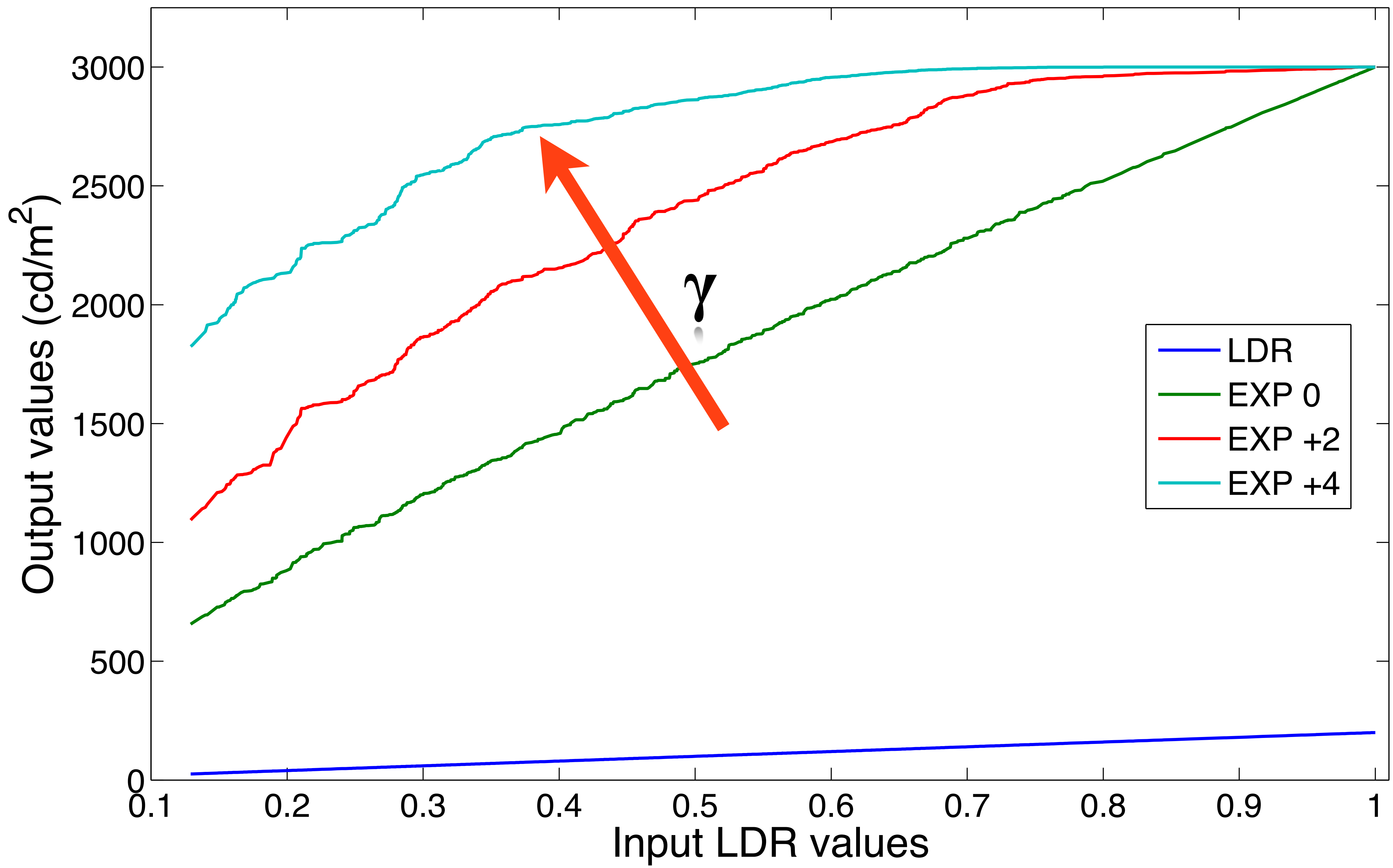
$$L_{\mathrm{w}}(\mathbf{x}) = L_{\mathrm{d}}(\mathbf{x})^{\gamma} \qquad \gamma = 10.44k - 6.282$$

$$k = \frac{\log L_{\mathrm{d,\ avg}} - \log L_{\mathrm{d,\ Min}}}{\log L_{\mathrm{d,\ Max}} - \log L_{\mathrm{d,\ Min}}} \qquad k > 0.65$$

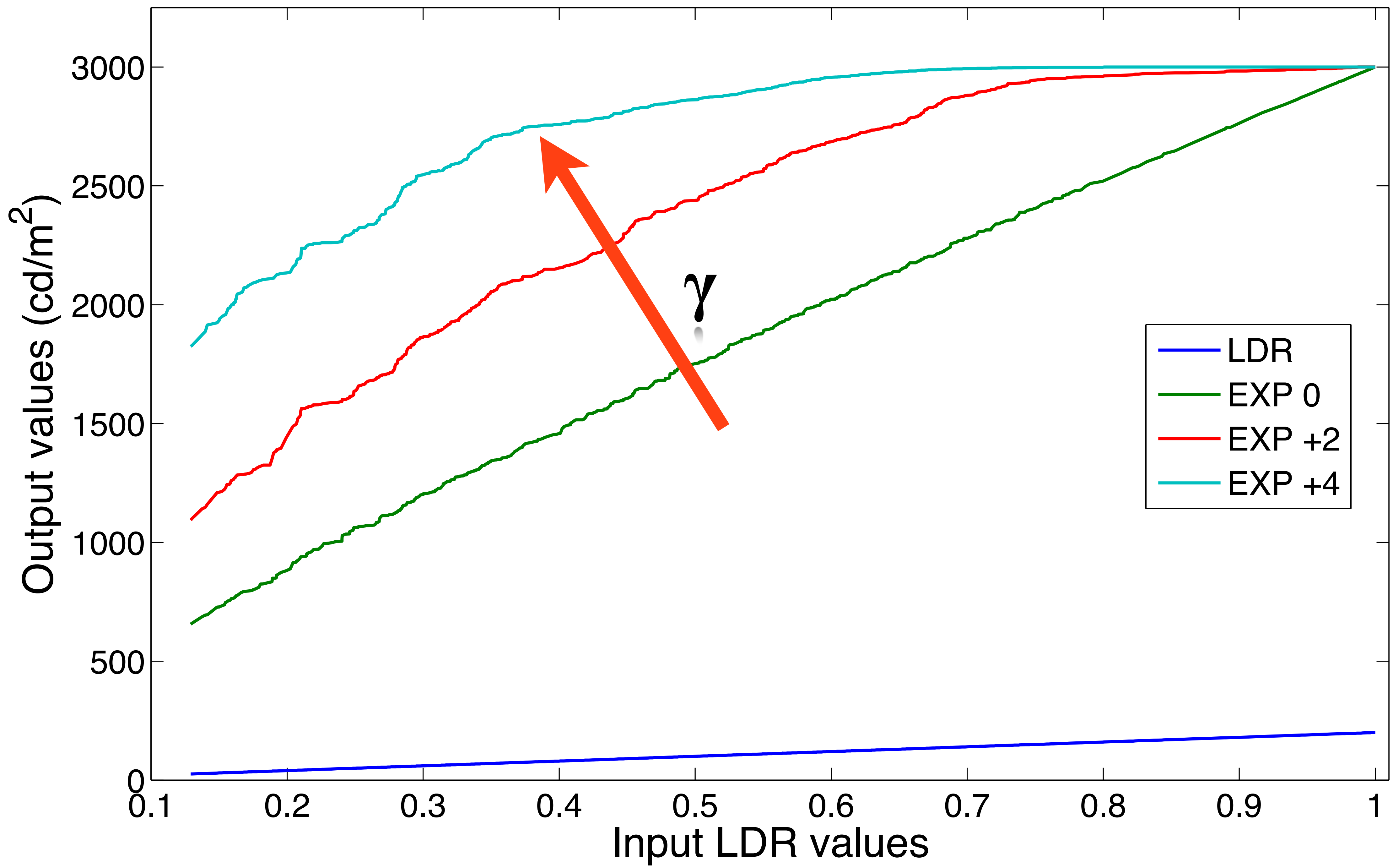
Global Methods (IV)



Global Methods (IV)



Global Methods (IV)



Classification Methods: Highlights Reproduction on HDR Monitors (I)

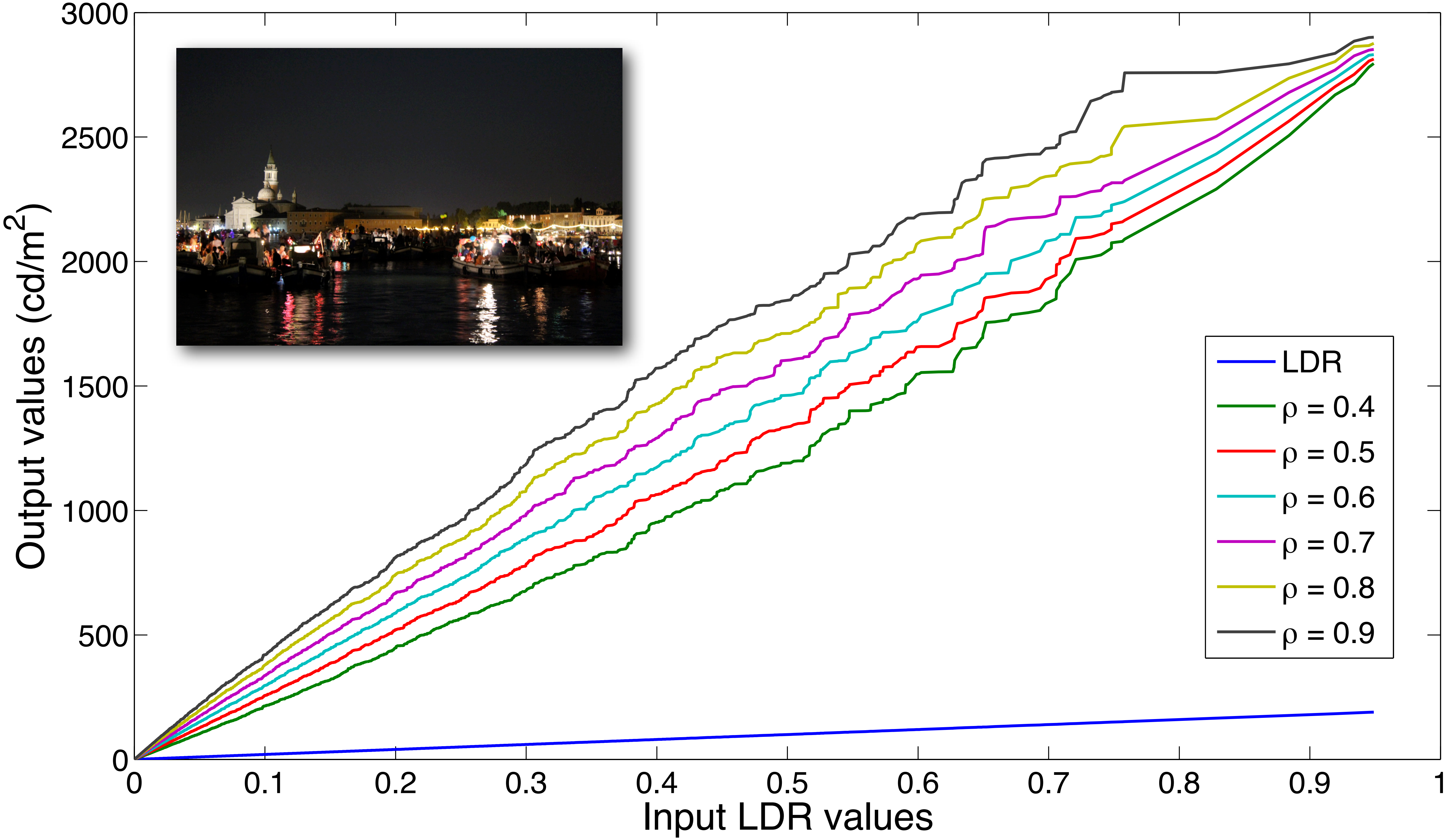
- Meylan et al. [MDDS06, MDS07] present a classification approach:
  - Expand highlights and specular surfaces ($\omega>0$)
  - ω is computed using robust thresholding
  - Expansion using a two-scale model:

$$L_{\mathrm{w}}(\mathbf{x}) = f(L_{\mathrm{d}}(\mathbf{x})) = \begin{cases} s_1 L_{\mathrm{d}}(\mathbf{x}) & \text{if } L_{\mathrm{d}}(\mathbf{x}) \leq \omega \\ s_1\omega + s_2(L_{\mathrm{d}}(\mathbf{x}) - \omega) & \text{otherwise} \end{cases}$$

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

  - To avoid contouring low-pass filtering on expanded regions

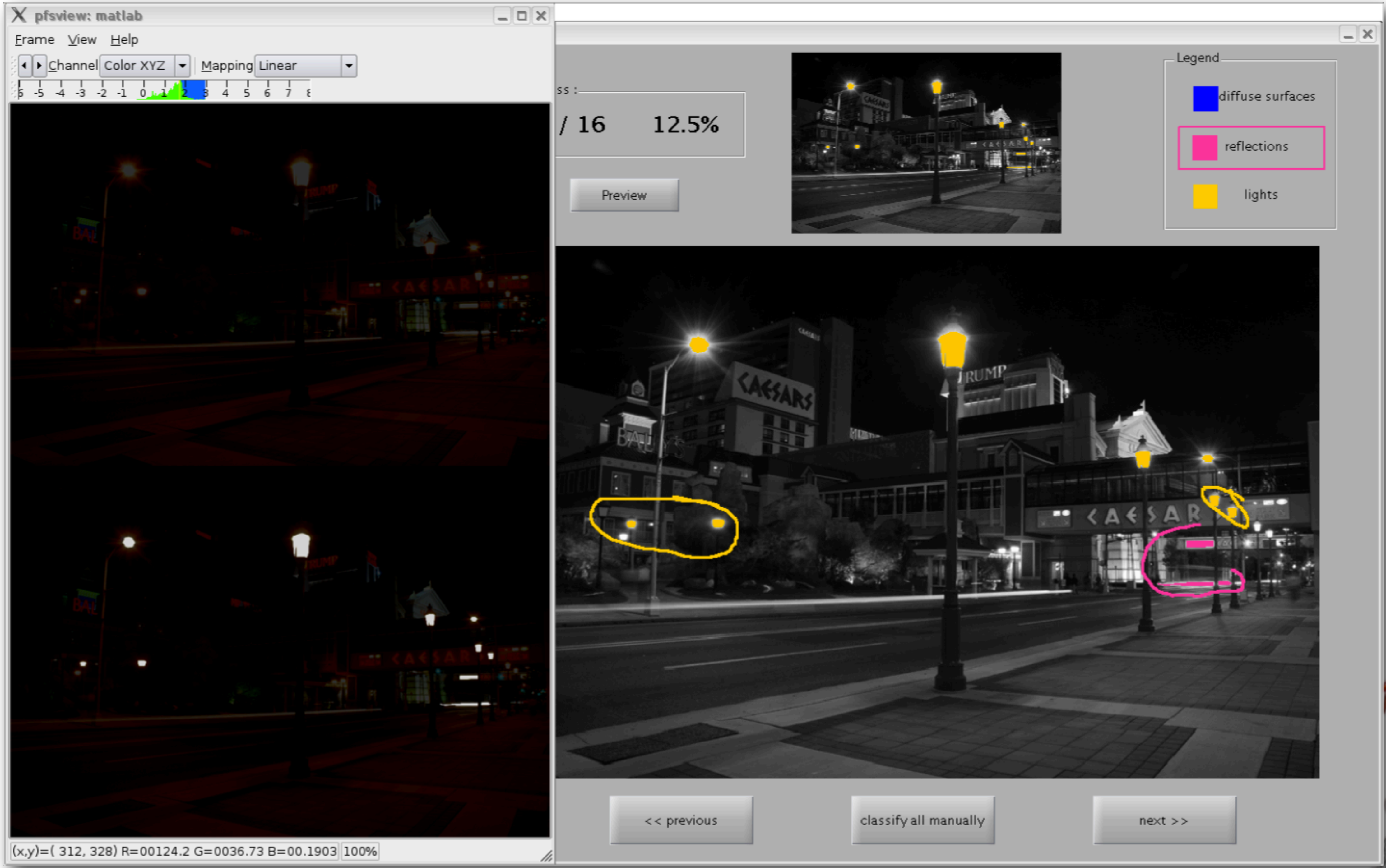
Classification Methods: Highlights Reproduction on HDR Monitors (II)



Classification Methods: Enhancement of Bright Videos (I)

- Didyk et al. [DMHS08] extended Meylan et al.'s method:
  - Three classification areas: diffuse, reflections, and lights
  - Automatic Classifier (AC):
    - SVM + Nearest Neighbor + Tracking ⇒ 3% error
  - User interface for adjusting the AC errors
  - 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: Enhancement of Bright Videos (II)



Classification Methods: Selective Reverse Tone Mapping (I)

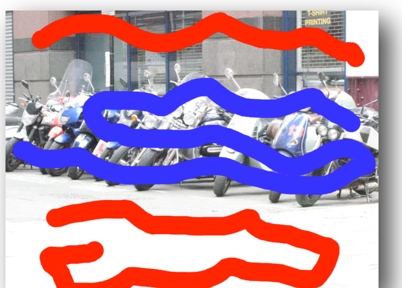
- Masia et al. [MFSG10] proposed a novel approach based on saliency:
  - **Range Expansion (RE)**: pice-wise linear expansion using the zonal system by Adams (9 zones):

$$p = \left(\frac{\exp(v \sin(\pi \frac{z-1}{16})) - 1}{\exp(v) - 1)} \right)^{\frac{1.0}{2.2}} \qquad v = 5.25 \quad z \in [0, 9]$$

  - **Labeling**:
    - salient objects and background discrimination using different techniques:
      - learning-based saliency detection (Liu et al. [LSZ*07])
      - *saliency cuts* (Fu et al.[FCLL08])
    - Different Labels ⇒ Different RE functions

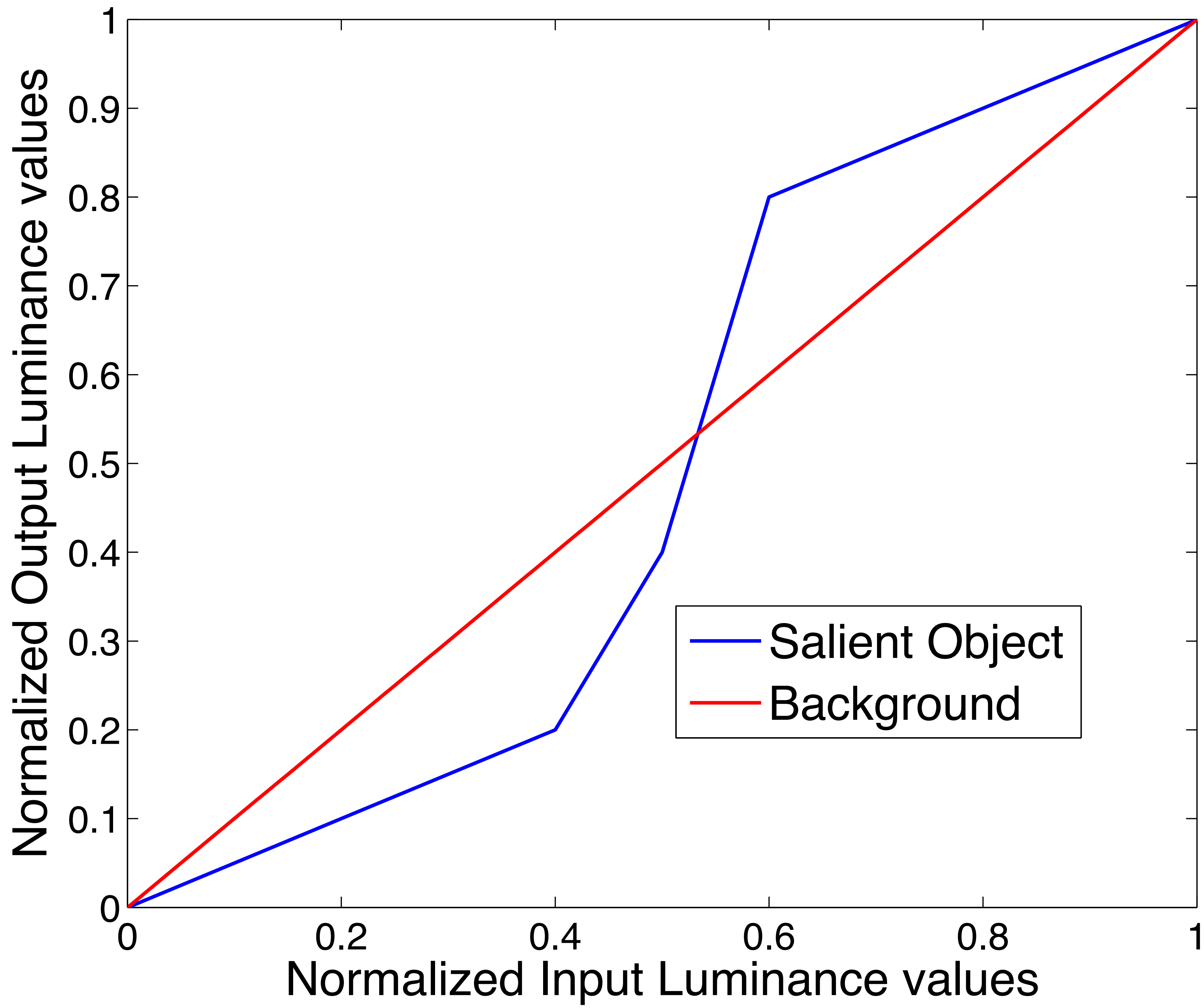
Classification Methods: Selective Reverse Tone Mapping (II)

Input



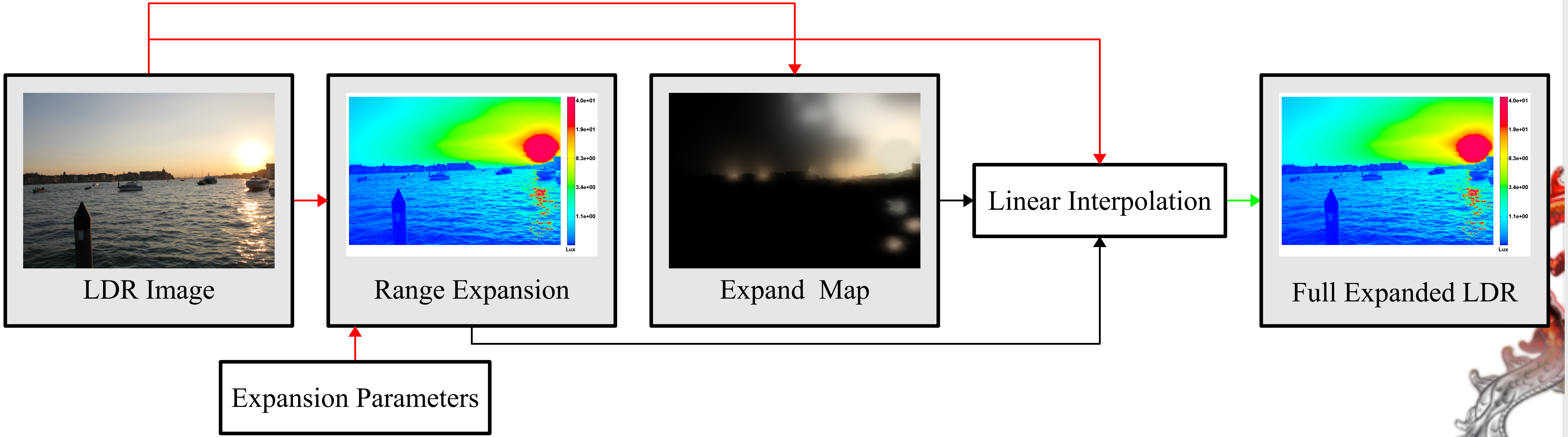
Auto-Labeling

Binary Mask

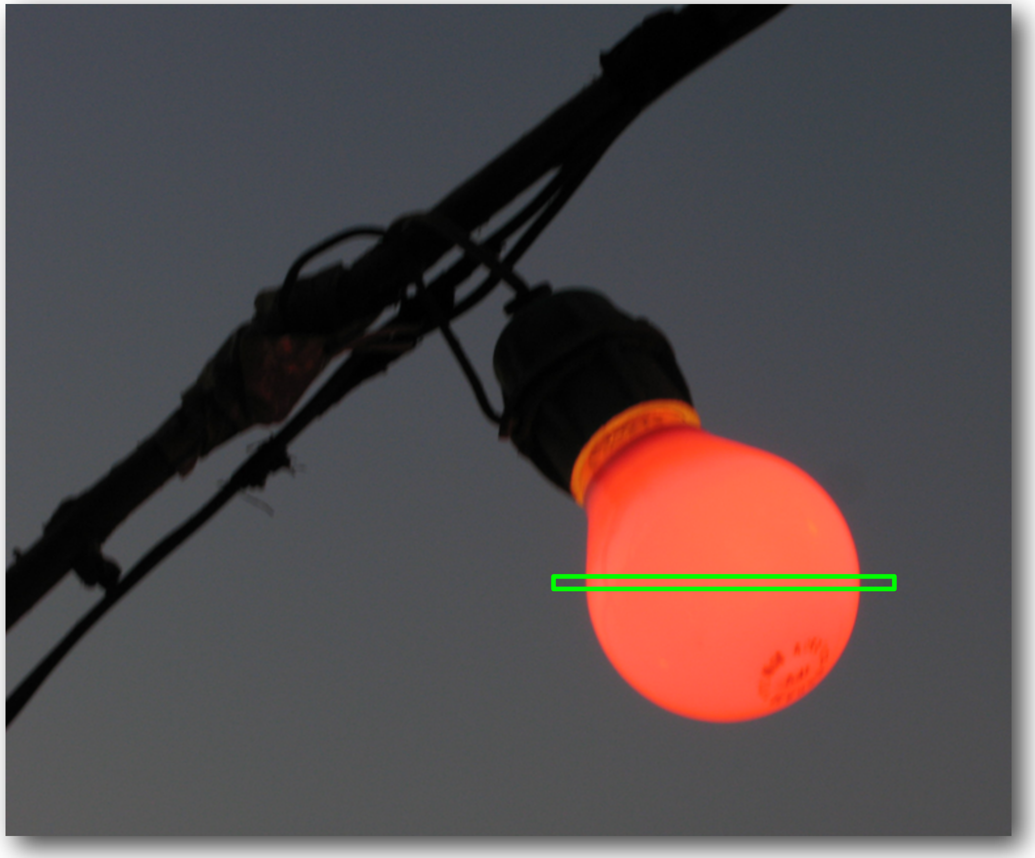


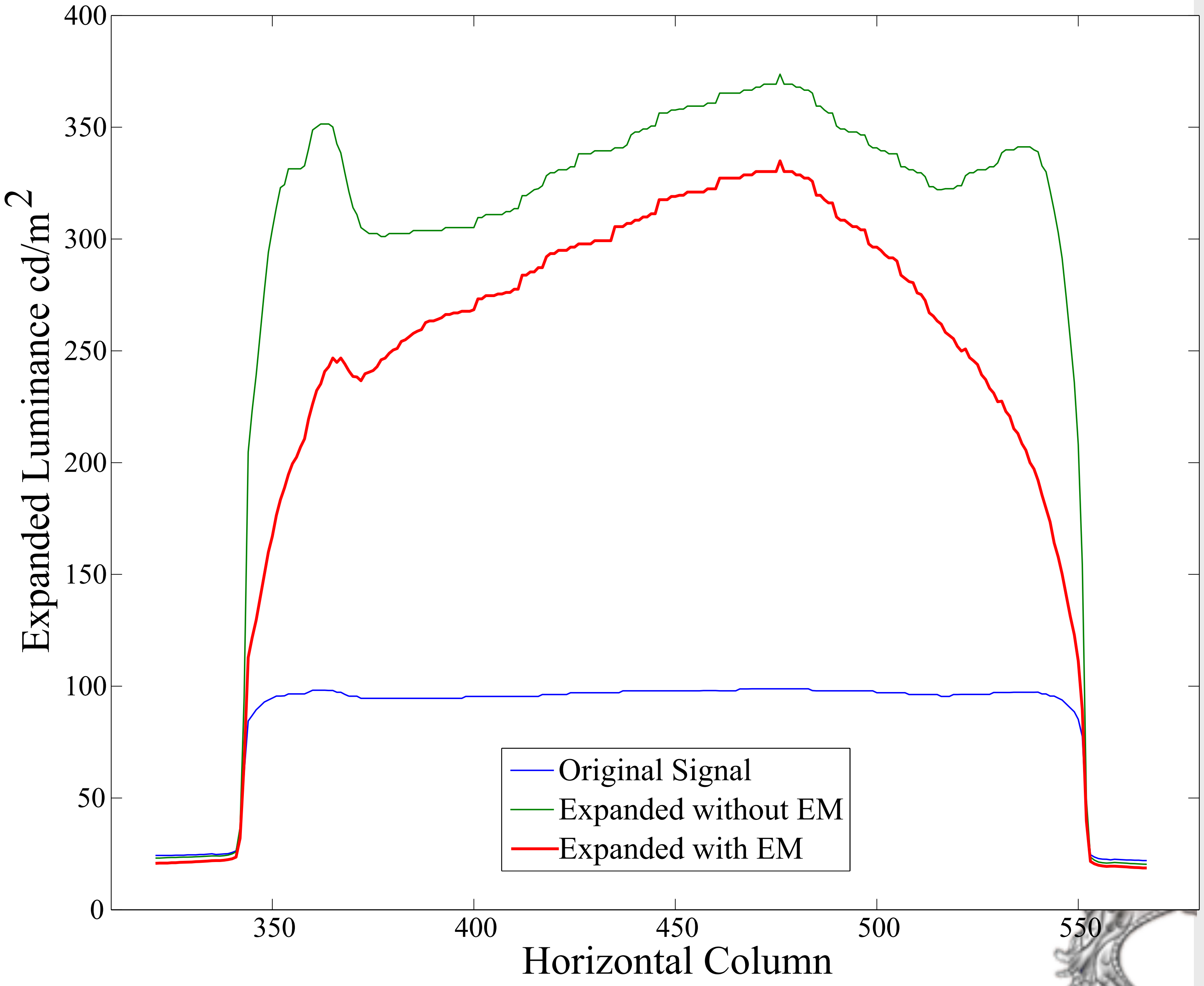
Expand Maps Methods: Non-Linear Expansion using Expand Maps (I)

- Banterle et al. [BLDC06,BLDBC07,BLDC08,B09] presented a general and real-time framework:
  - **Range Expansion**: non-linear (inverting an TMO; other functions)
  - **Expand Map**: sampling+density estimation+cross bilateral (avoiding contouring and compression artifacts)



Expand Maps Methods: Non-Linear Expansion using Expand Maps (II)





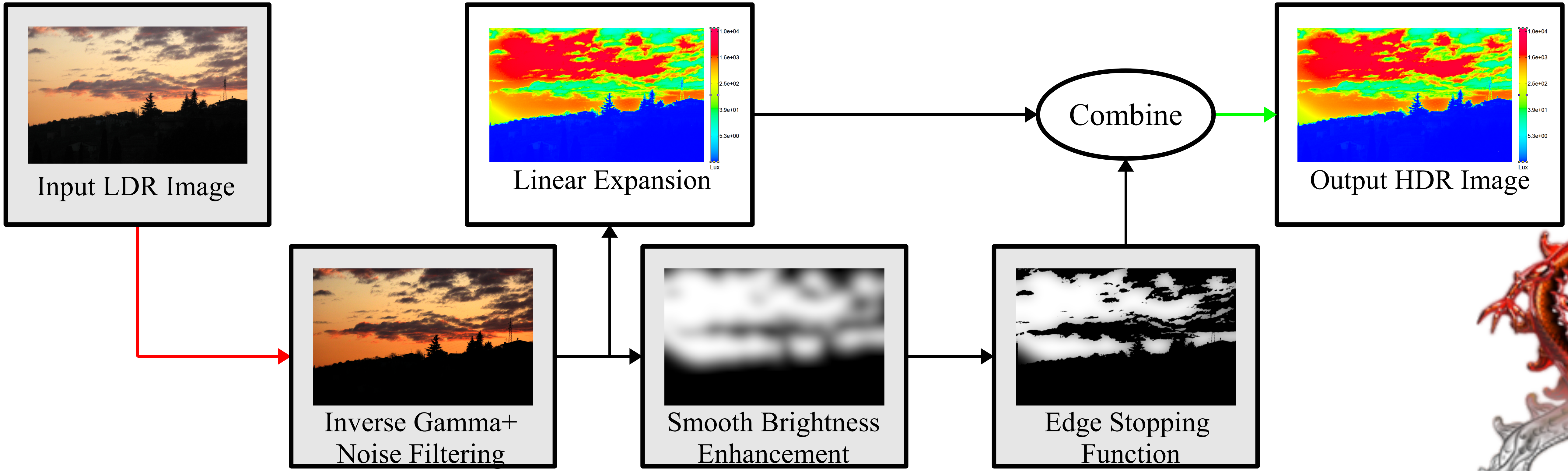
Expand Maps Methods: Non-Linear Expansion using Expand Maps (II)

IBL using original HDR

IBL using expanded LDR

Expand Maps Methods: LDR2HDR (I)

- Rempel et al. [RTS*07] presented a similar work of Banterle et al.:
  - **Range Expansion**: linear
  - **Expand Map**: thresholding+filtering+edge stopping



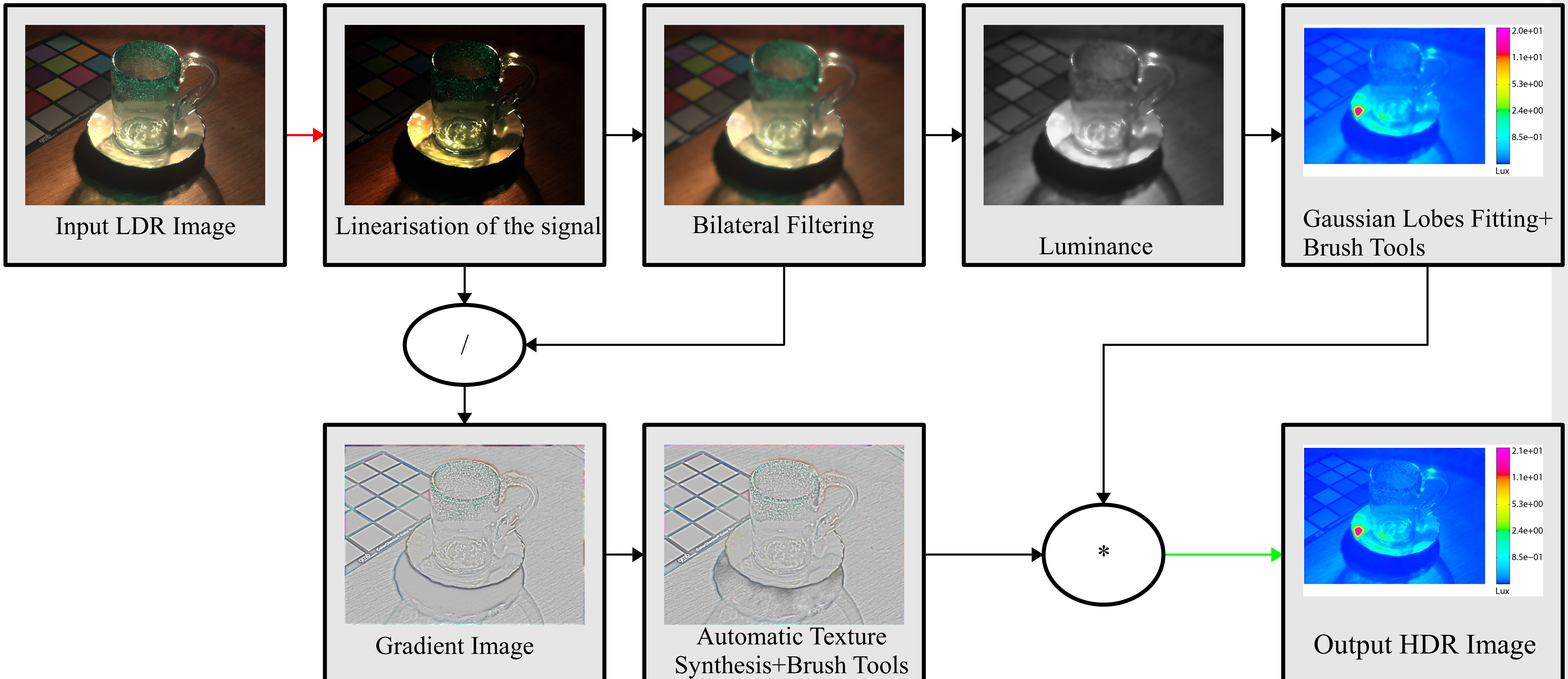
Expand Maps Methods: LDR2HDR (II)

- A variant of the algorithm was presented by Kovaleski and Oliveria [KO09] using the bilateral grid to improve the quality of the Expand Map.

User Based Methods: Hallucination (I)

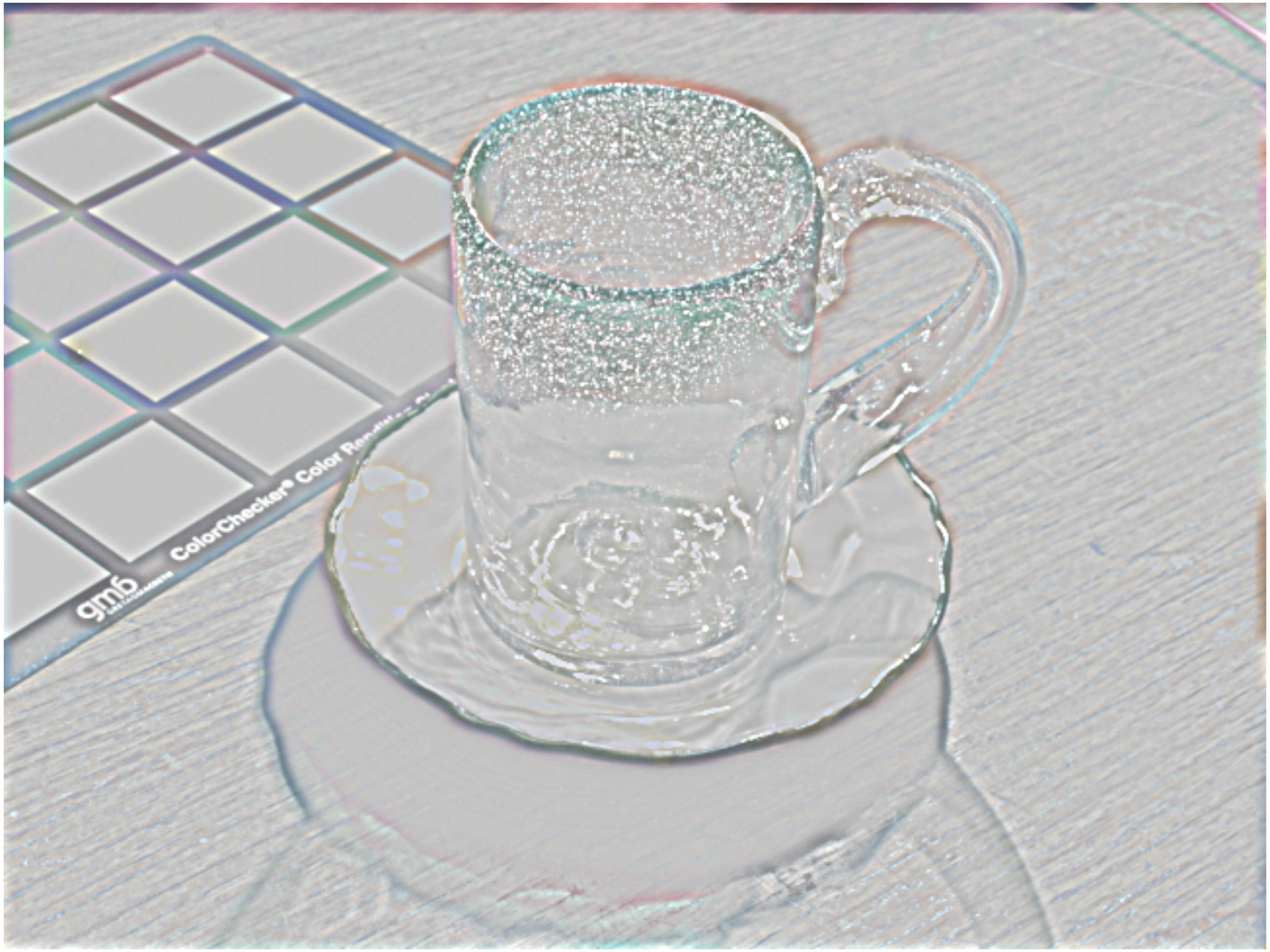
- Wang et al. [WWZ*07] proposed the first user based method with reconstruction of details:
  - **HDR frequencies using the bilateral filter**: base (low) and detail (high) layers
  - **Automatic Expansion (base layer)**: saturated regions are fitted using 2D Gaussian lobes (elliptical)
  - **Reconstruction (detail layer)**:
    - Automatic: texture synthesis
    - User-based: Stamp tool (similar to the Healing tool of Photoshop 7)
    - NOTE: other images can be used as source for the missing details

User Based Methods: Hallucination (II)



Mexican Mug's image is courtesy of Ahmet Oguz Akyuz

User Based Methods: Hallucination (III), Copying Fine Details in the Detail Layer



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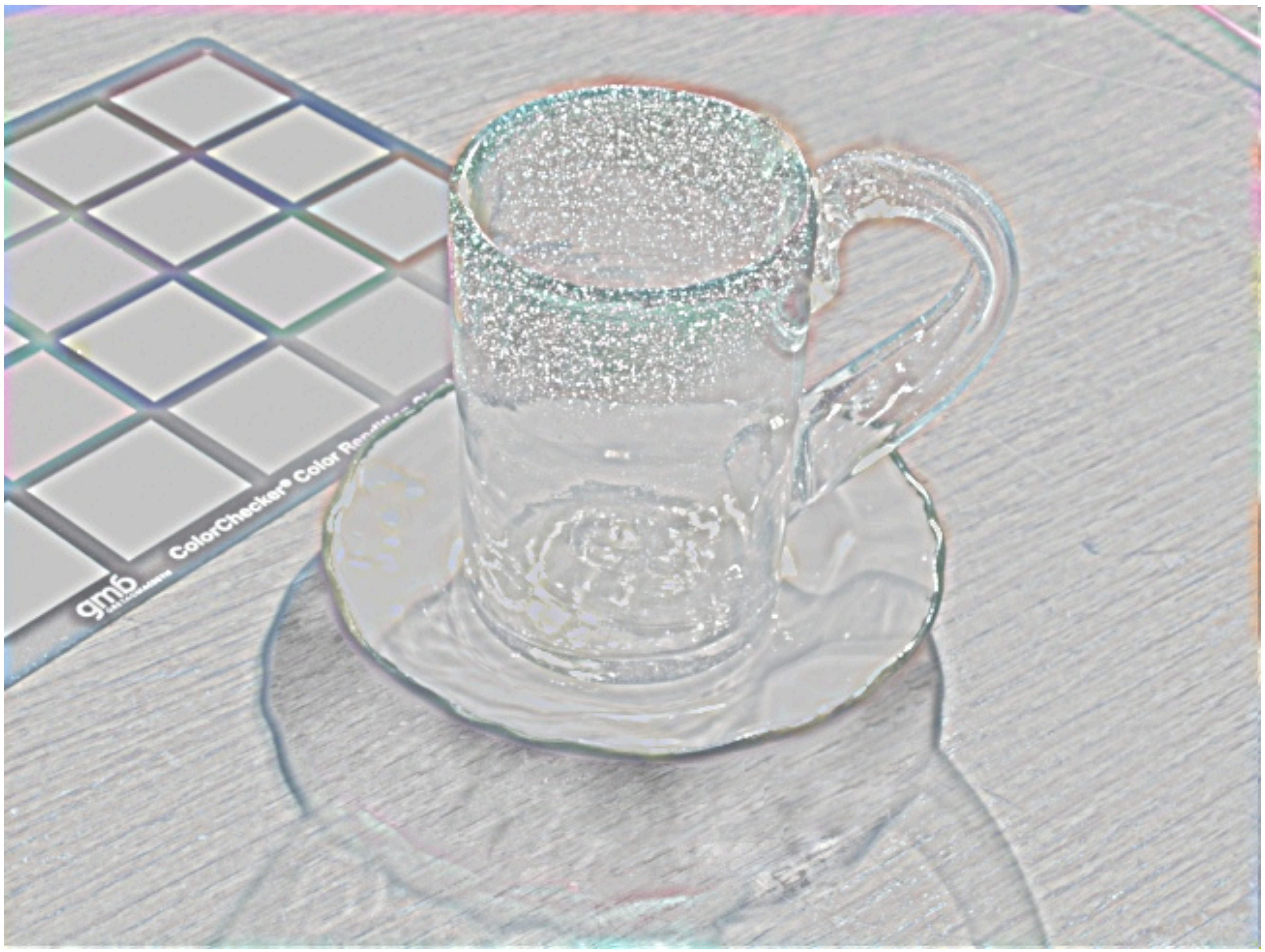


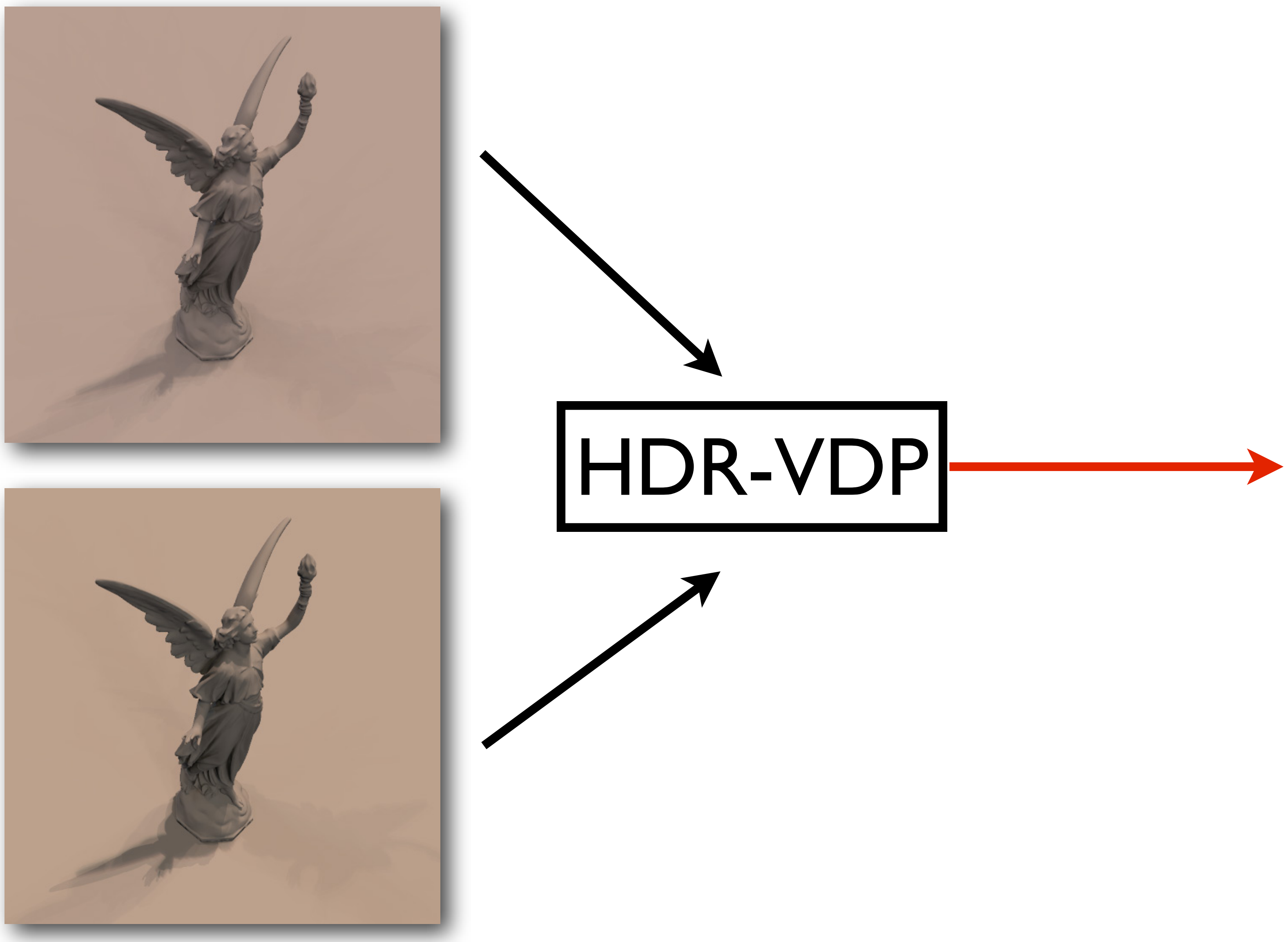
Evaluation: Why validation

- 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 Image Metrics

- **HDR-VDP** (current version 2.1) [MDMS04,MKRH11]: determines the probability for each pixel of being different:
  - Banterle et al. [BLDC06,BLDCB07,BLDC08,B09] used it to validate that their models were performing better than a simple non-linear expansion, validate against other methods, etc.
- **DI-IQA** [AMMS08]: detects changes in details visibility, quantization artifacts. Validation of the quality in general:
  - Masia et al. [MAF*09] and Kovaleski and Oliveria [KO09] used it to prove that their methods introduce less distortions during LDR expansion

Evaluation: Perceptual Image Metrics (II)



Lucy model is courtesy of the Stanford 3D Scanning Repository

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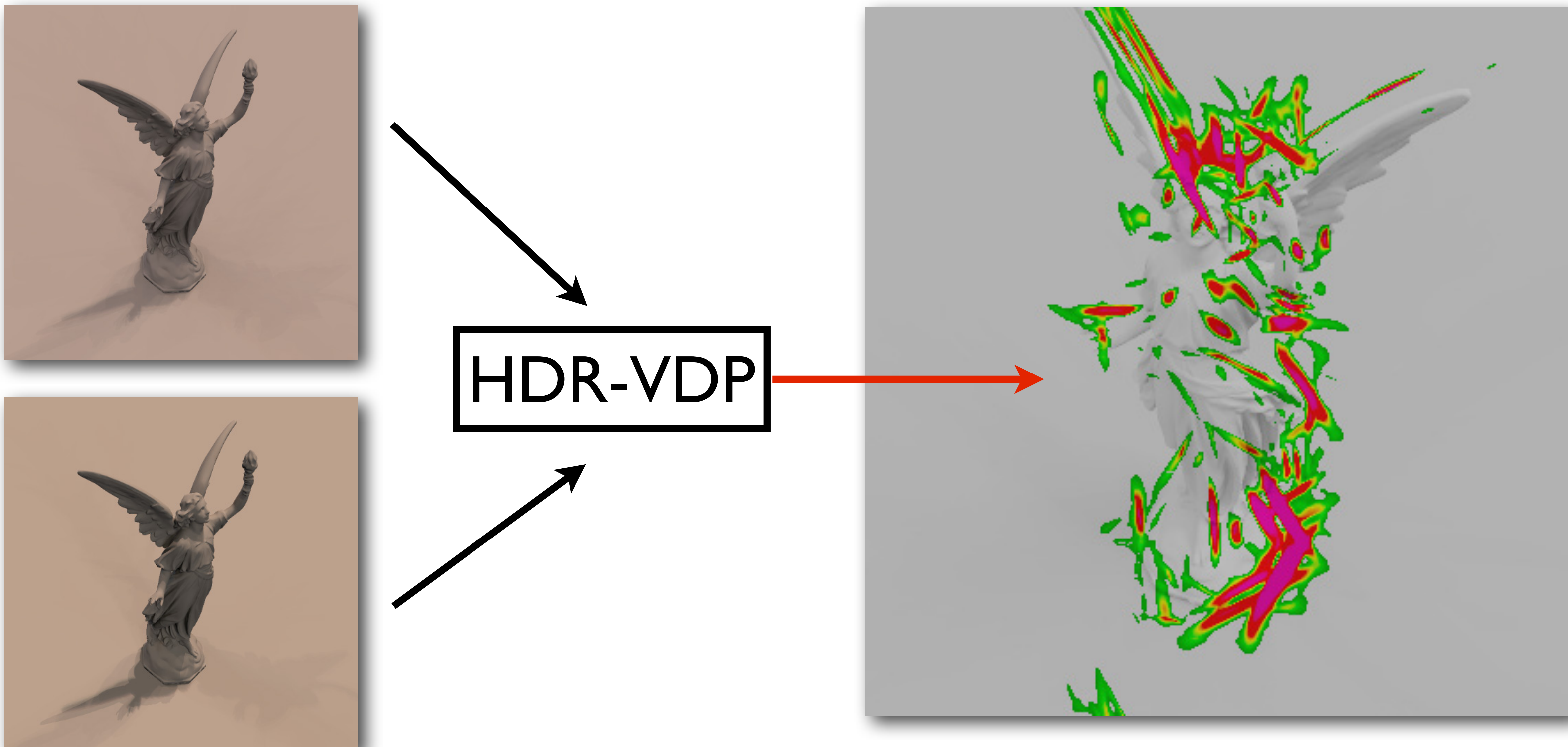

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Evaluation: Psychophysical Experiments

- Pairwise comparisons of HDR videos [DMHS08]:
  - validation of the method against LDR, and LDR2HDR
- Pairwise comparisons of HDR images [BLD*09]: comparisons for image visualization and IBL:
  - quantization artifacts need to be handle for better quality.
  - IBL needs non-linear expansion.
- Rating of HDR images and tone mapped expanded images [MAF*09]:
  - understanding preferences in very over-exposed areas.
  - understanding artifacts in expanded images.

Conclusions:

- LDR Expansion for HDR applications:
  - LDR expansion methods are needed to be used in HDR applications (HDR visualization, Image Based Lighting, etc.)
  - The size of over/under-exposed areas is a limitation when recreating the content
- What's important?
  - To have non-linearity or controllable expansion functions
  - Avoid artifacts' boosting: quantization and JPEG-like compression
  - Take care of over-exposed areas differently