Camera spectral sensitivity, illumination and spectral reflectance estimation for a hybrid hyperspectral image capture system

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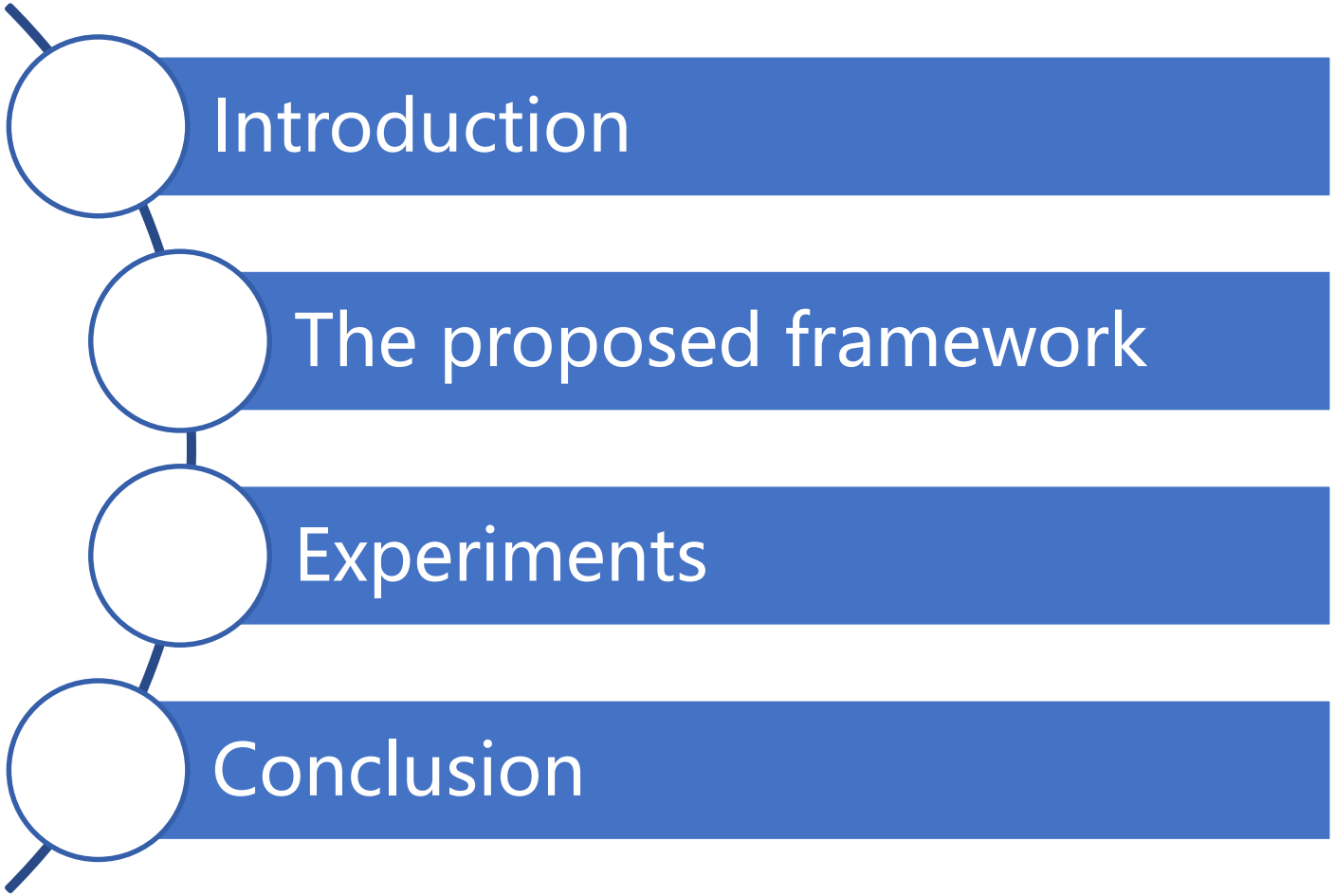
Outline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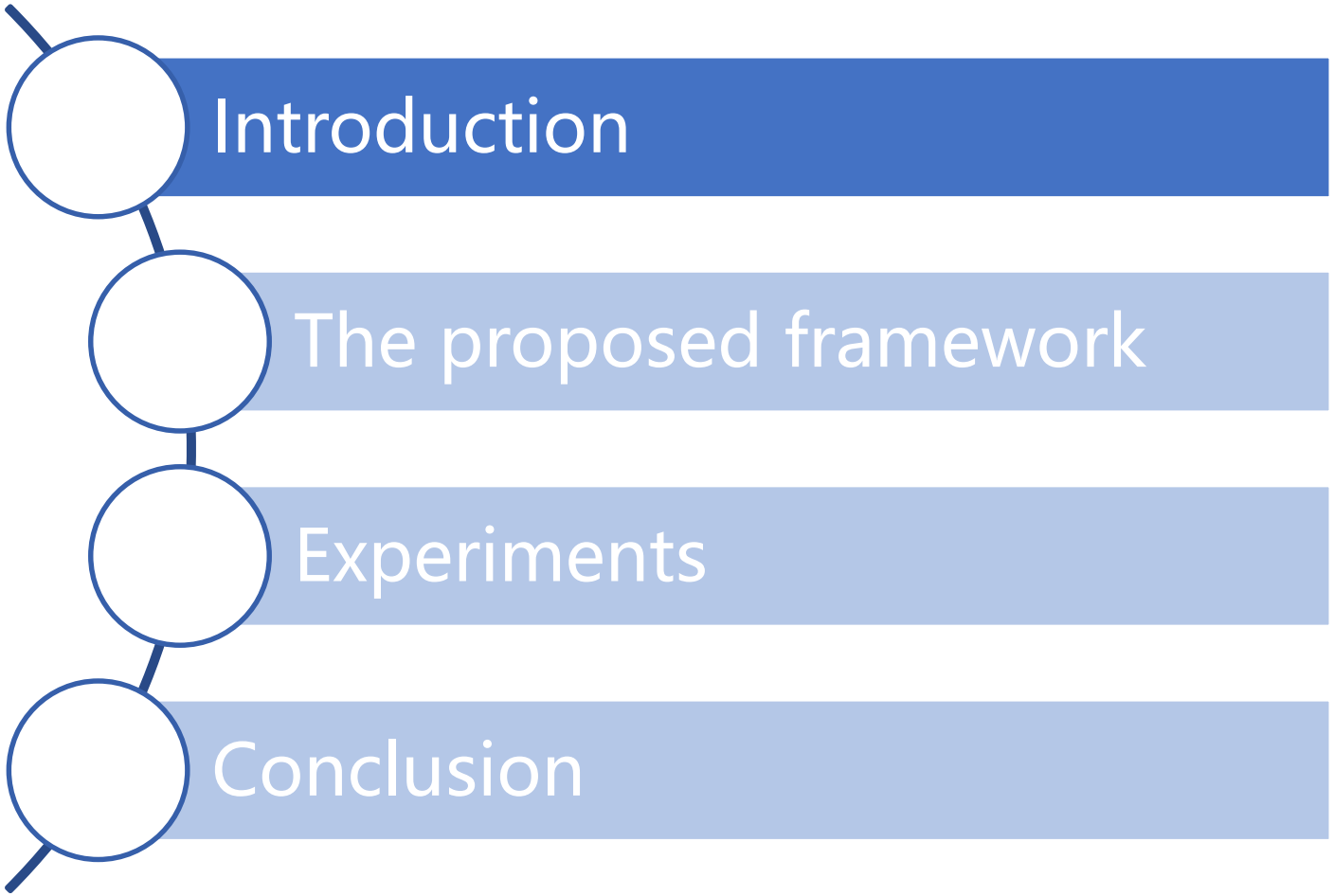
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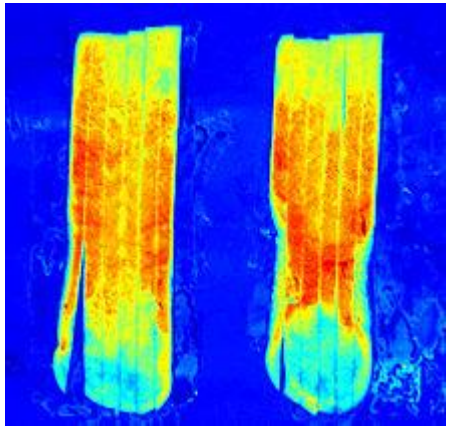
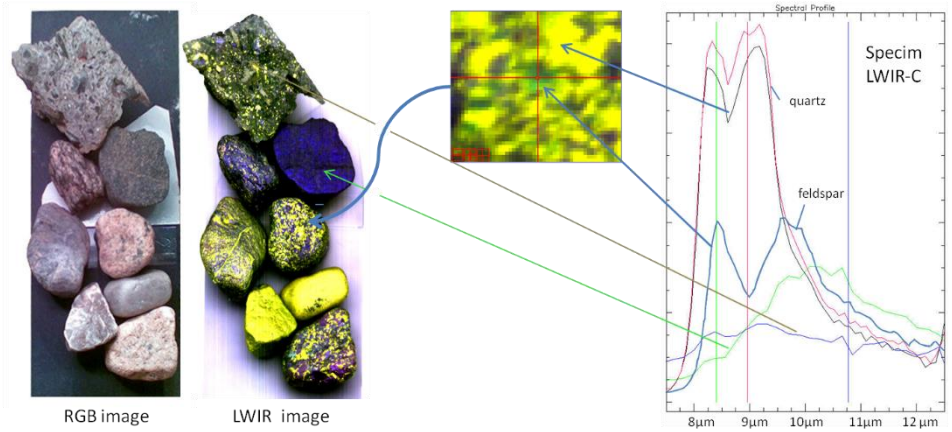
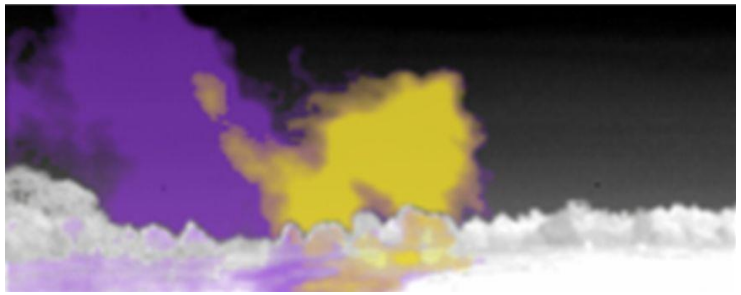
Introduction



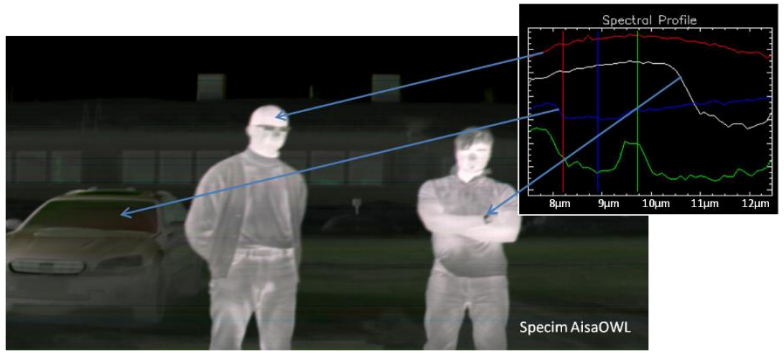
Food processing



Mineralogy

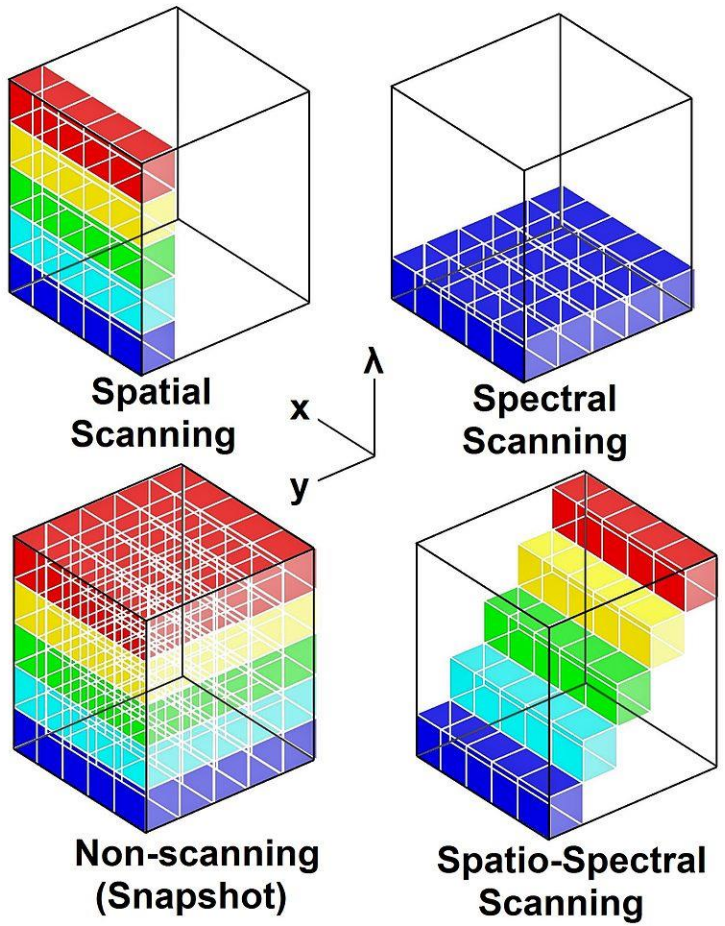


Chemical imaging



Surveillance

Introduction

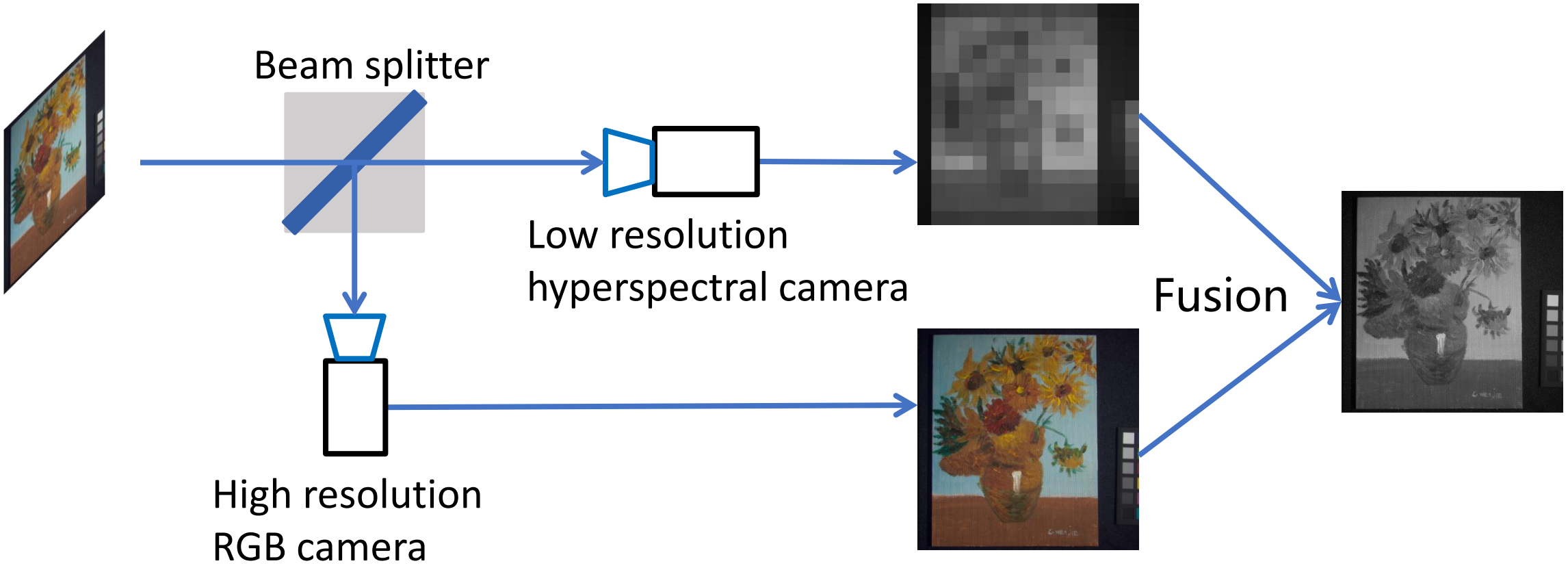


- Snapshot hyperspectral imaging

- Shorter acquisition time.
- Capability for dynamic scene.

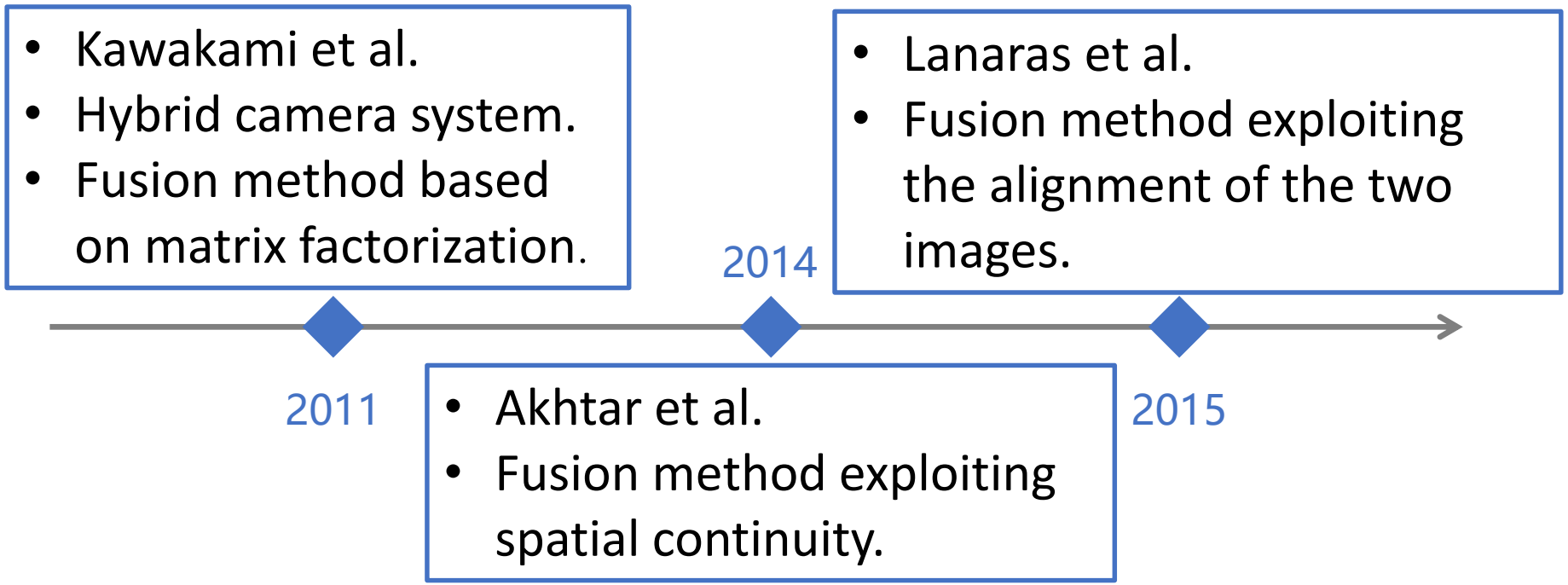
Introduction

- **Hybrid camera system**

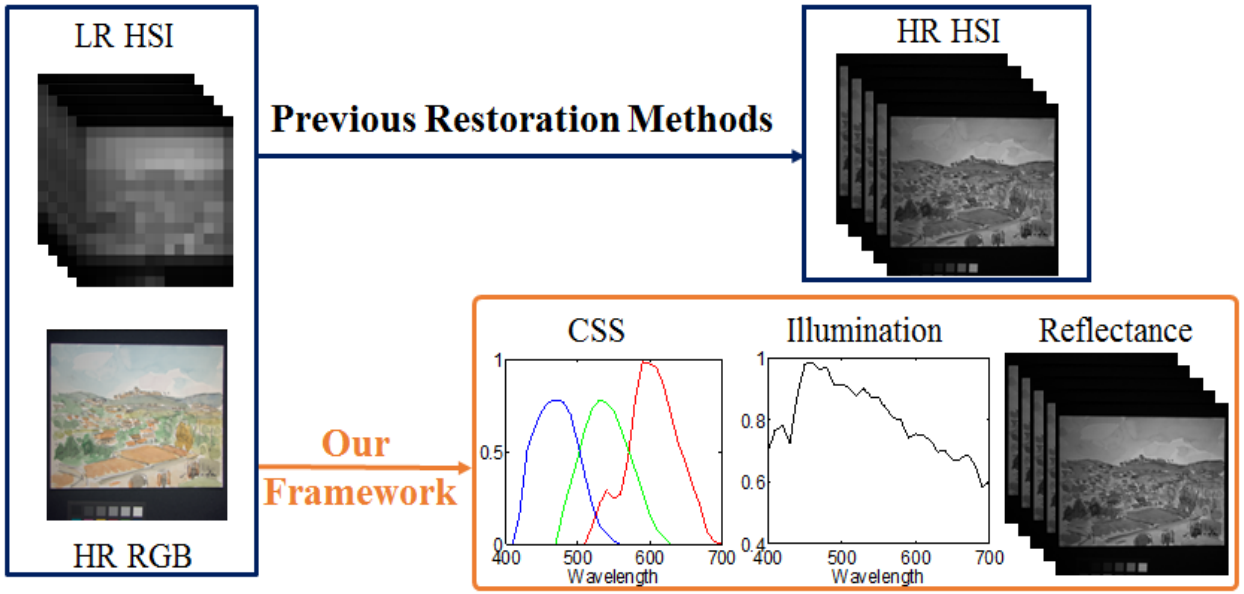


Kawakami, Rei, et al. "High-resolution hyperspectral imaging via matrix factorization."

Introduction



Introduction



CSS: camera spectral sensitivity

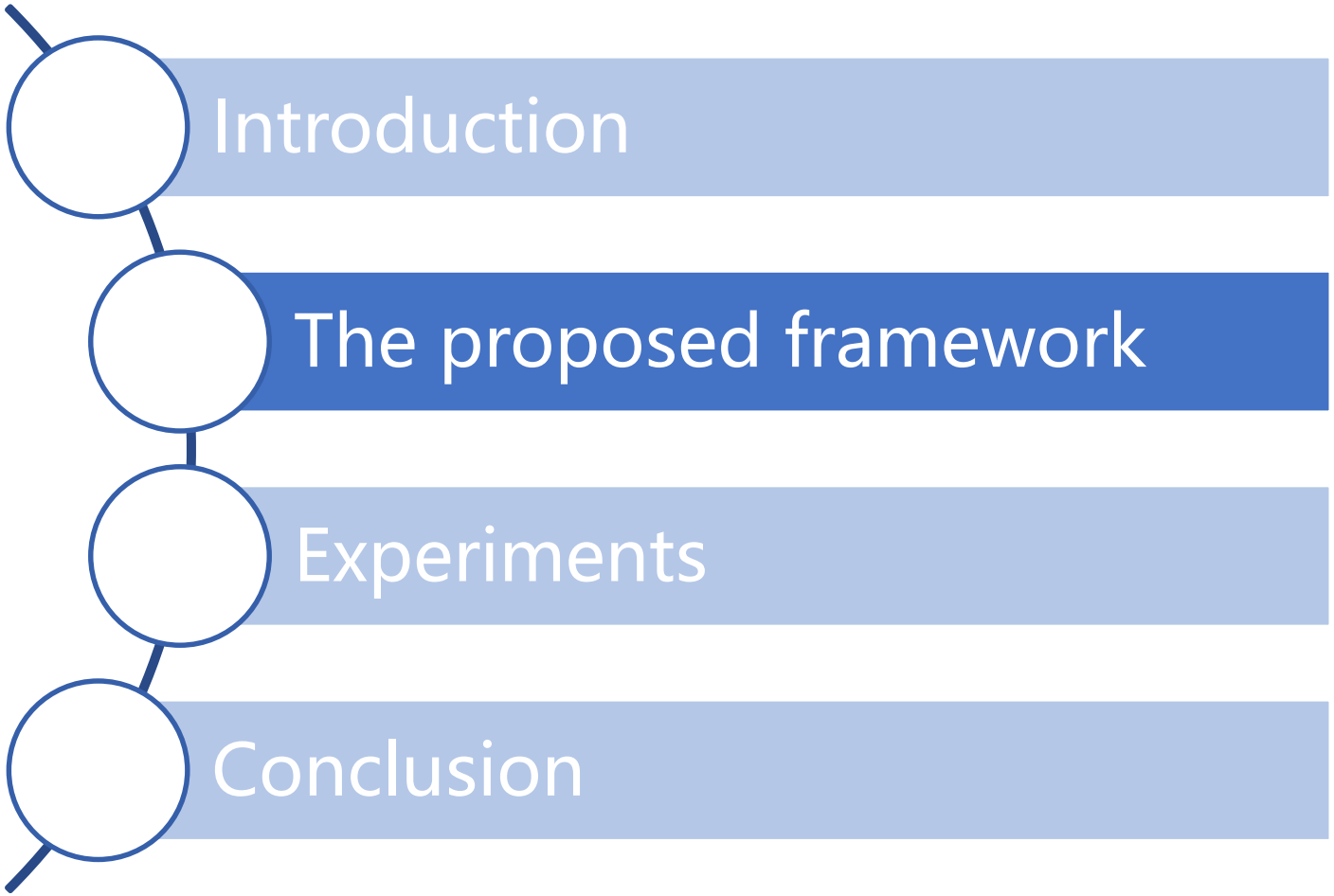
Previous researches

- ☐ RGB CSS has to be calibrated in prior.
- ☐ Cannot estimate illumination.
- ☐ Cannot recover reflectance.

The proposed framework

- ✓ RGB CSS estimation.
- ✓ Illumination spectrum estimation.
- ✓ Reflectance recovery.

Outline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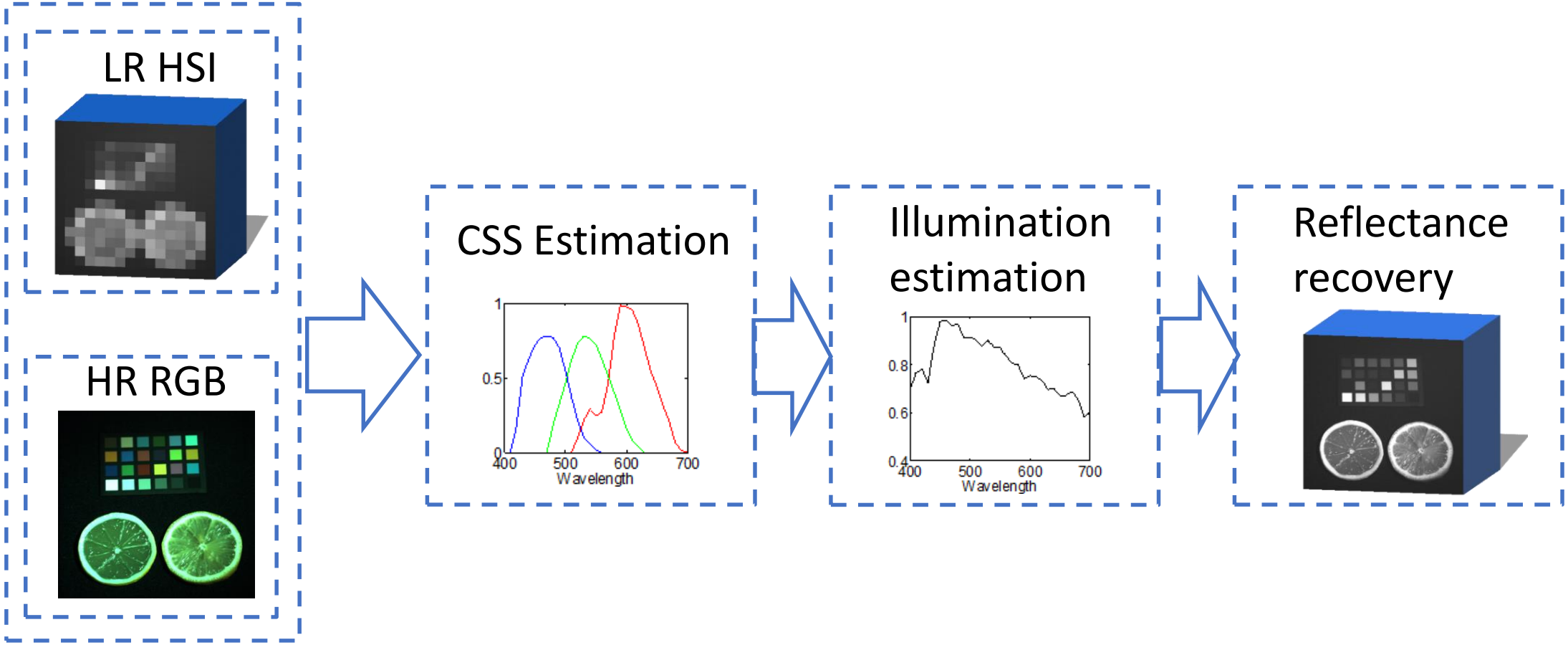
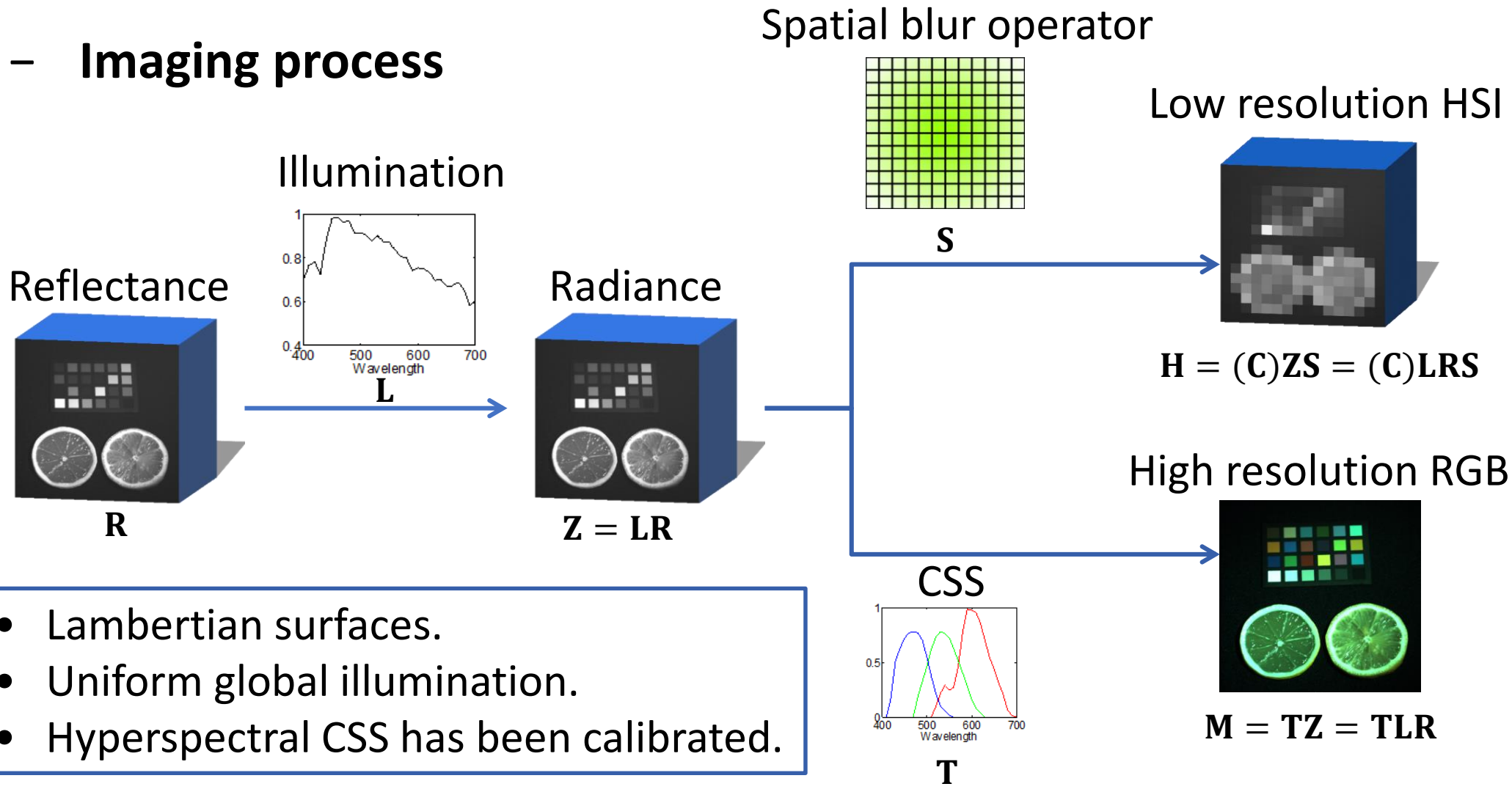
The proposed framework

– **Workflow**



Problem formulation

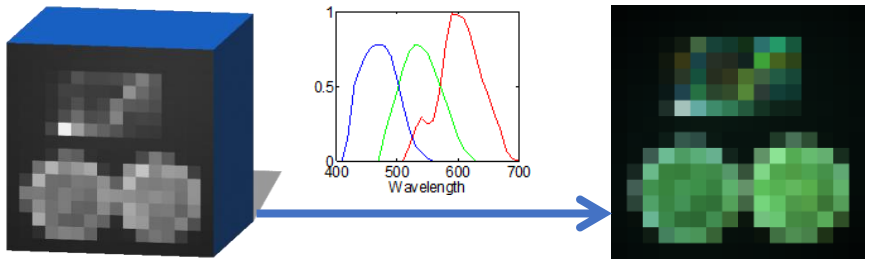
- **Imaging process**



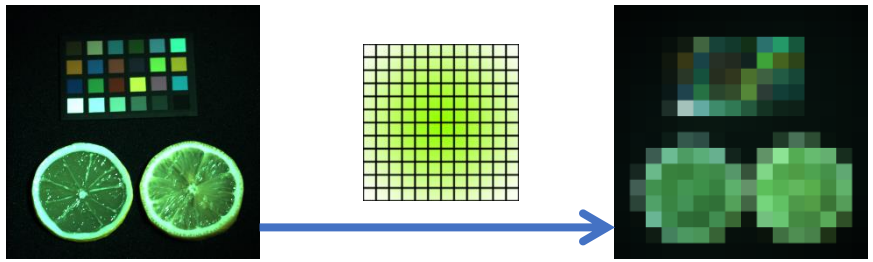
- Lambertian surfaces.
- Uniform global illumination.
- Hyperspectral CSS has been calibrated.

Camera spectral sensitivity estimation

- **Problem formulation**



Spectrally downsample



Spatially downsample

$$\mathbf{TH} = \mathbf{MS} \longrightarrow \begin{cases} \mathbf{T}_R\mathbf{H} = \mathbf{M}_R\mathbf{S} \\ \mathbf{T}_G\mathbf{H} = \mathbf{M}_G\mathbf{S} \\ \mathbf{T}_B\mathbf{H} = \mathbf{M}_B\mathbf{S} \end{cases}$$

Overdetermined

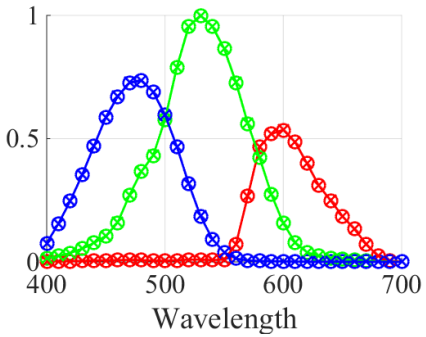
$$\mathbf{H} = \begin{bmatrix} H_{1,1} & \cdots & H_{1,N} \\ \vdots & \ddots & \vdots \\ H_{K,1} & \cdots & H_{K,N} \end{bmatrix} \qquad K < N$$

K: Number of spectral channels
N: Number of pixels in low resolution HSI

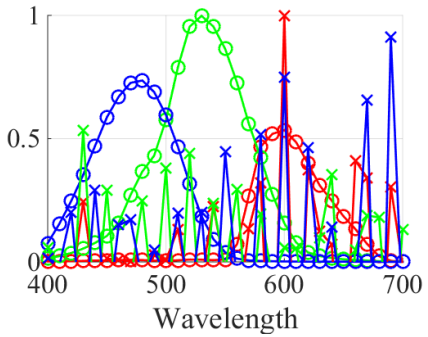
Camera spectral sensitivity estimation

- **Previous methods**

$$\hat{\mathbf{T}} = \arg\min_{\mathbf{T}} ||\mathbf{TH} - \mathbf{MS}||_F^2 \quad \Longrightarrow \quad \hat{\mathbf{T}} = \mathbf{MS}(\mathbf{H})^{\dagger}$$



✓ Perform well in ideal condition.



☐ Perform badly under even low noise!

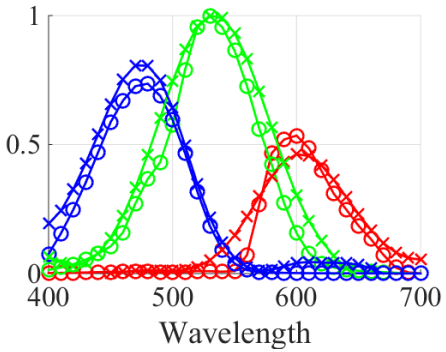
Camera spectral sensitivity estimation

- **Previous methods**

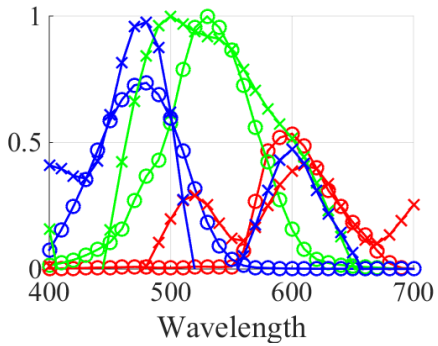
$$\hat{\mathbf{T}} = \arg\min_{\mathbf{T}} ||\mathbf{TH} - \mathbf{MS}||_F^2 + \lambda||\mathbf{T}W||_F^2$$

Data term

Smooth term



✓ More robust.
✓ Performs well under low noise.

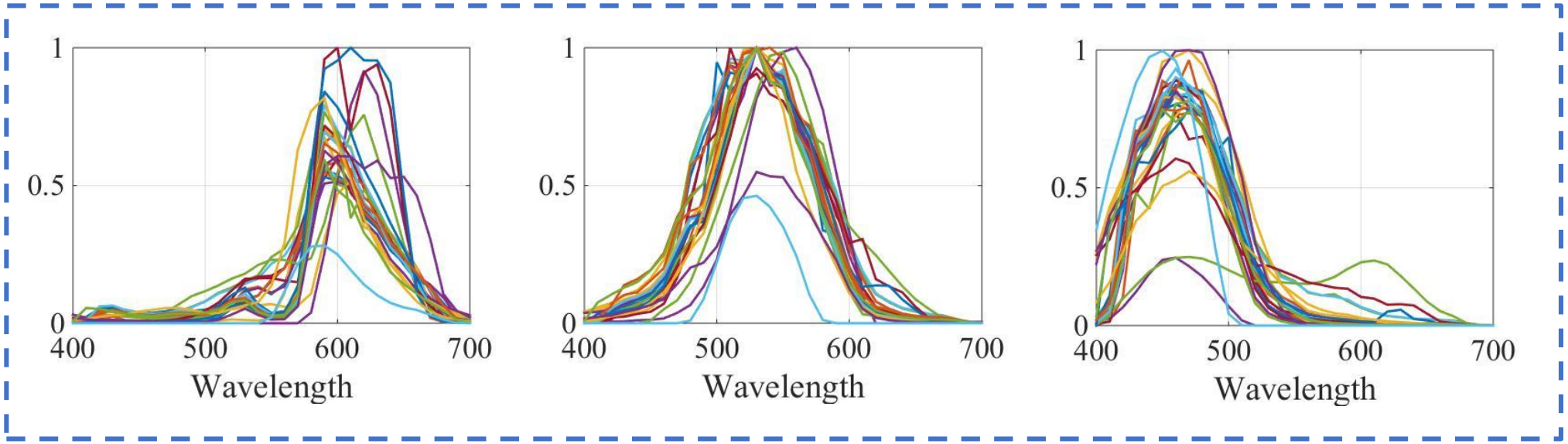


☐ Performs badly under strong noise.
☐ Determining λ is tricky.

Simões, Miguel, et al. "A convex formulation for hyperspectral image superresolution via subspace-based regularization."

Camera spectral sensitivity estimation

– **Our method: Observation**

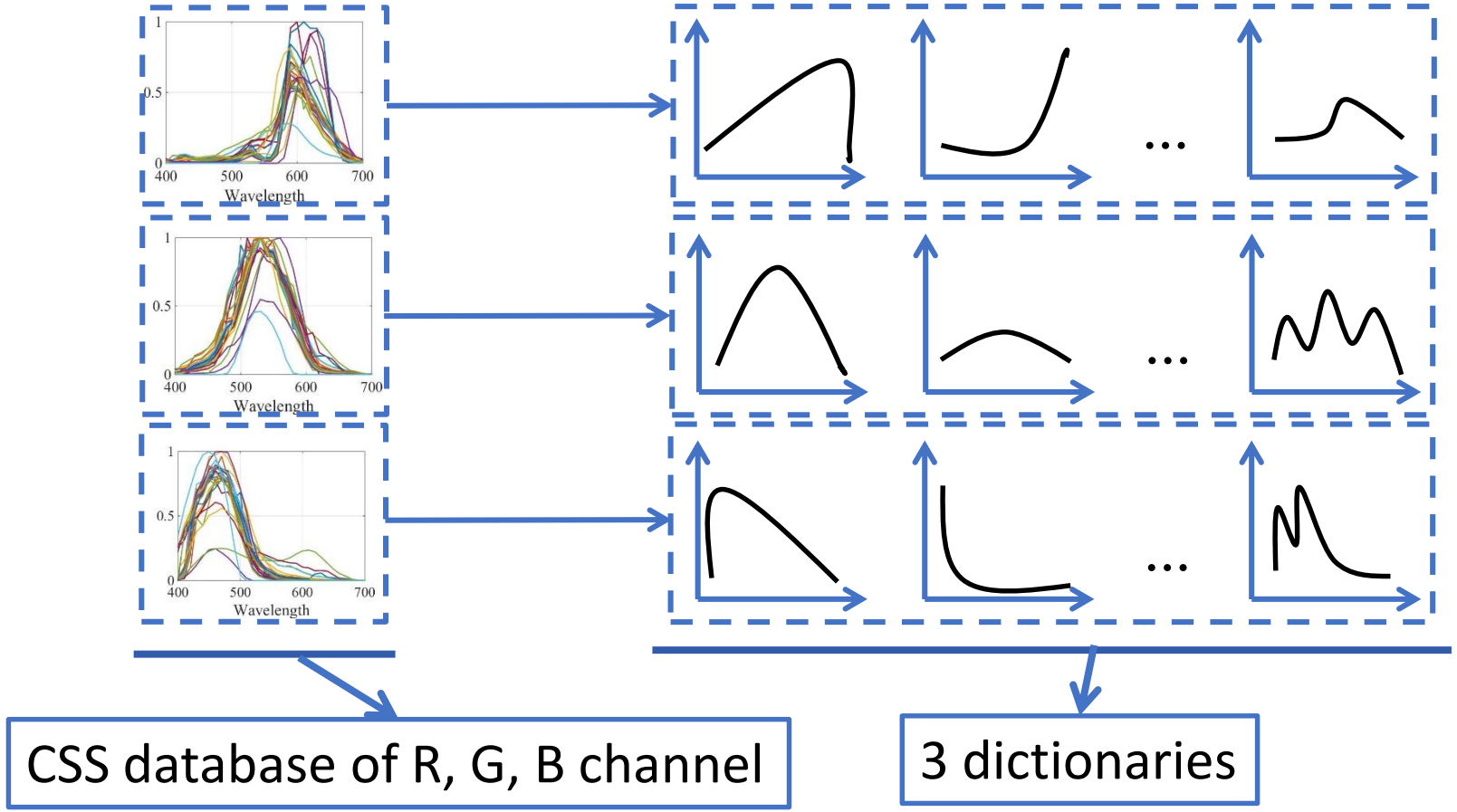


✓ CSS curves of a specific channel are similar.

✓ CSS of a specific channel can be expressed by linear combination of several bases.

Camera spectral sensitivity estimation

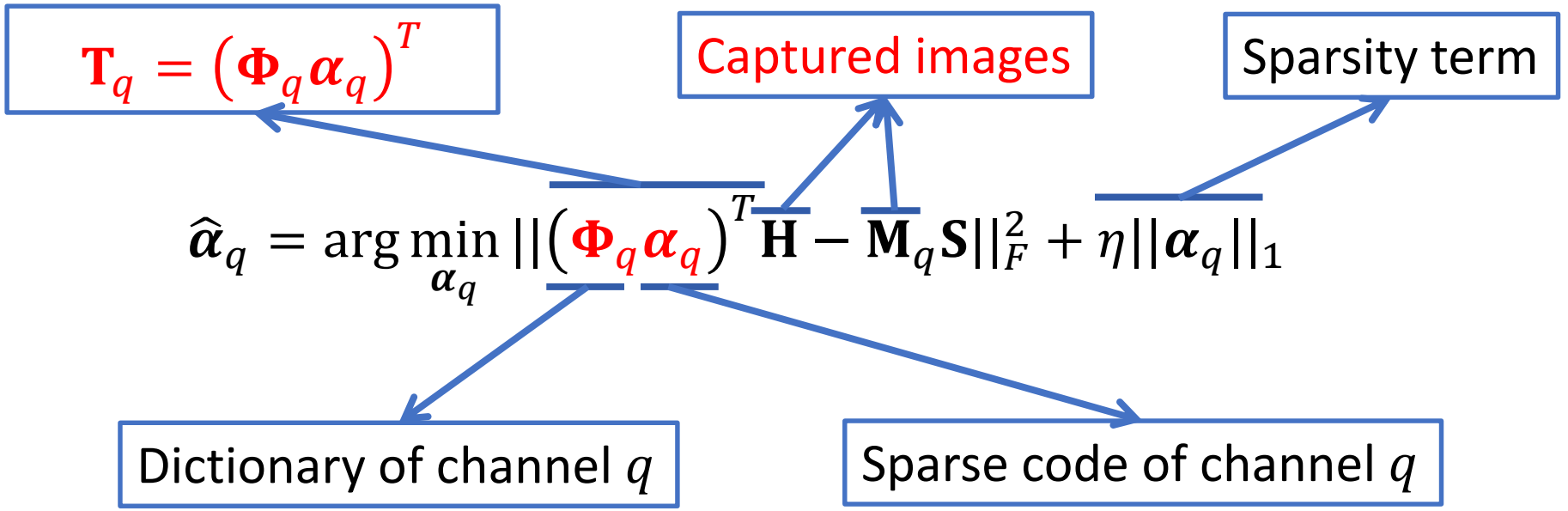
- **Our method: Training step**



Mairal, Julien, et al. "Online dictionary learning for sparse coding."

Camera spectral sensitivity estimation

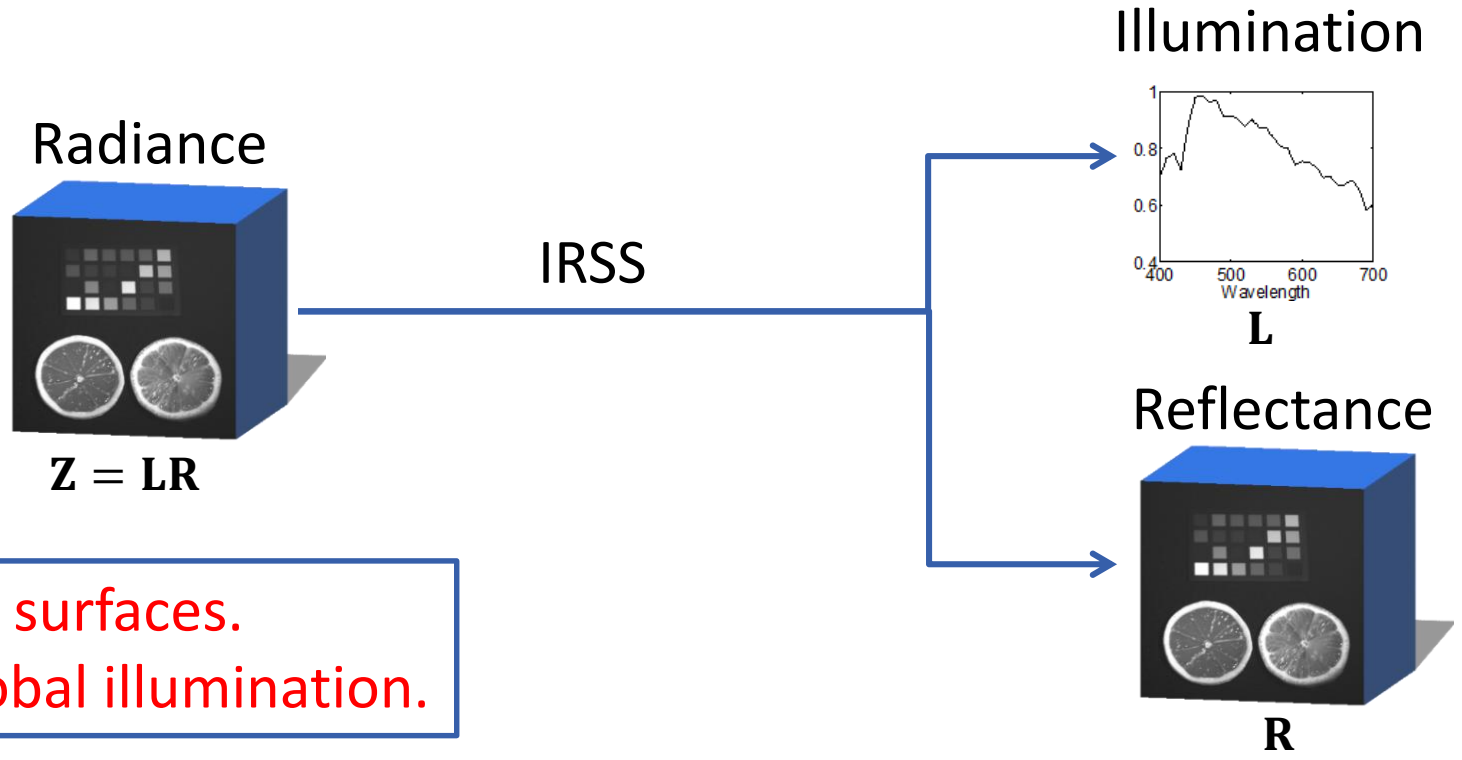
- **Our method: Sparse coding**



Efron, Bradley, et al. "Least angle regression.(LARS)"

Illumination spectrum estimation

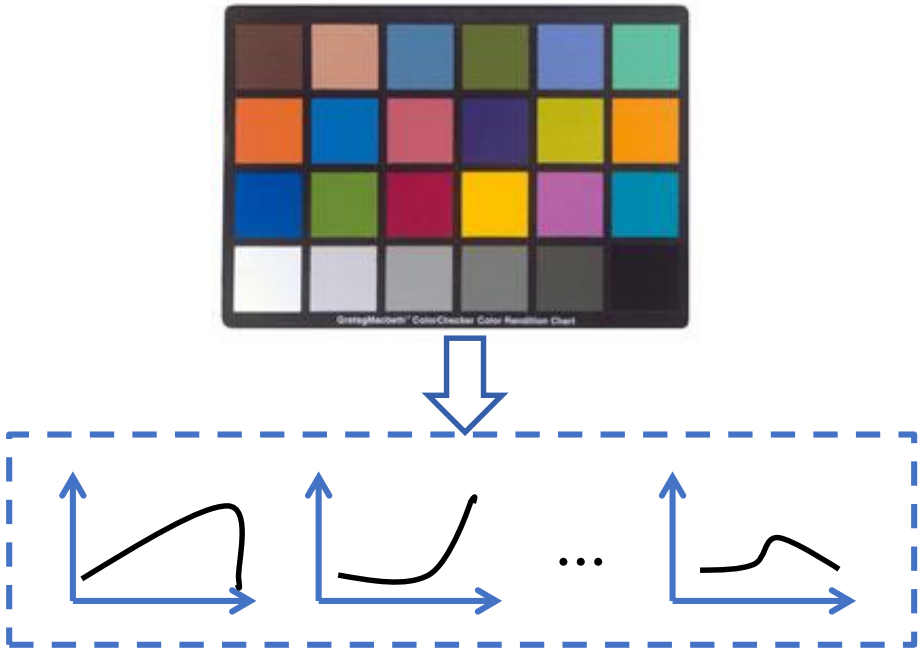
- **IRSS: Illumination and reflectance spectra separation.**



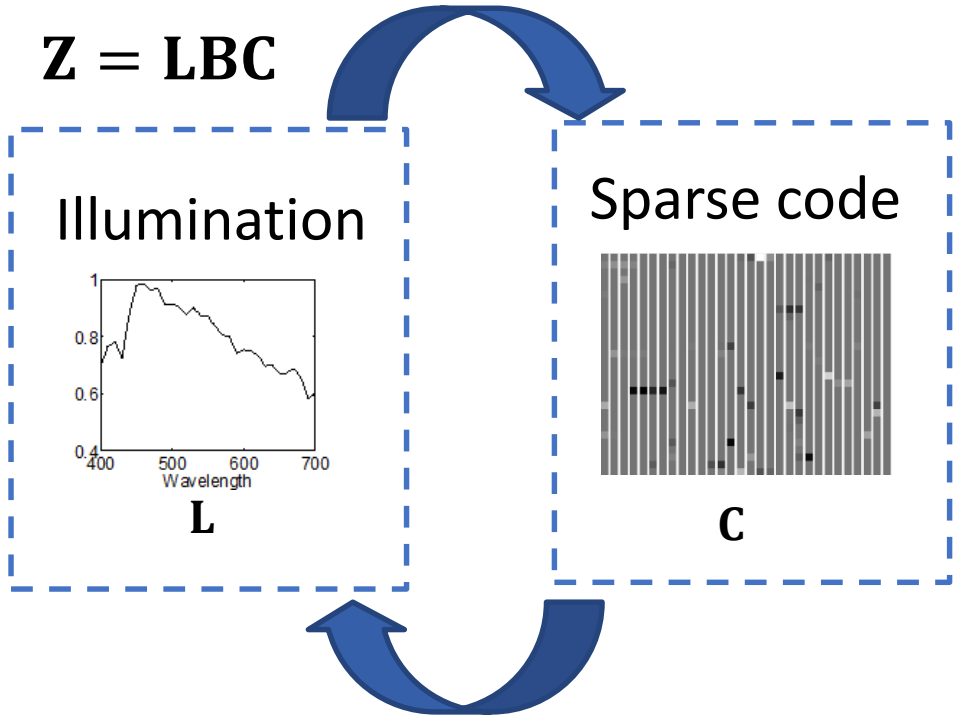
- Lambertian surfaces.
- Uniform global illumination.

Illumination spectrum estimation

- **Training: Learning spectral bases $\mathbf{B}$ from color plate.**



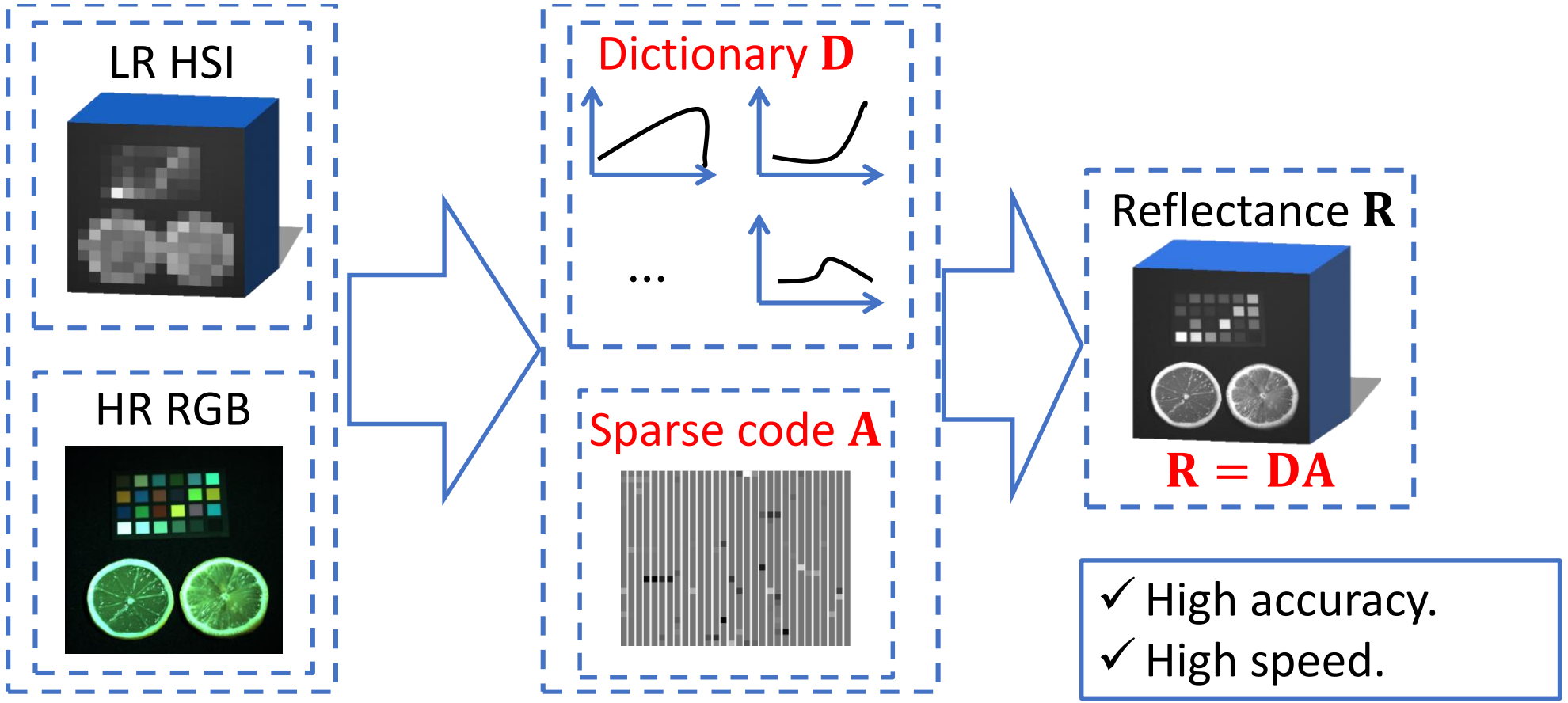
- **IRSS: Alternatively solve illumination and sparse code**



Zheng, Yinqiang, Imari Sato, and Yoichi Sato. "Illumination and reflectance spectra separation of a hyperspectral image meets low-rank matrix factorization."

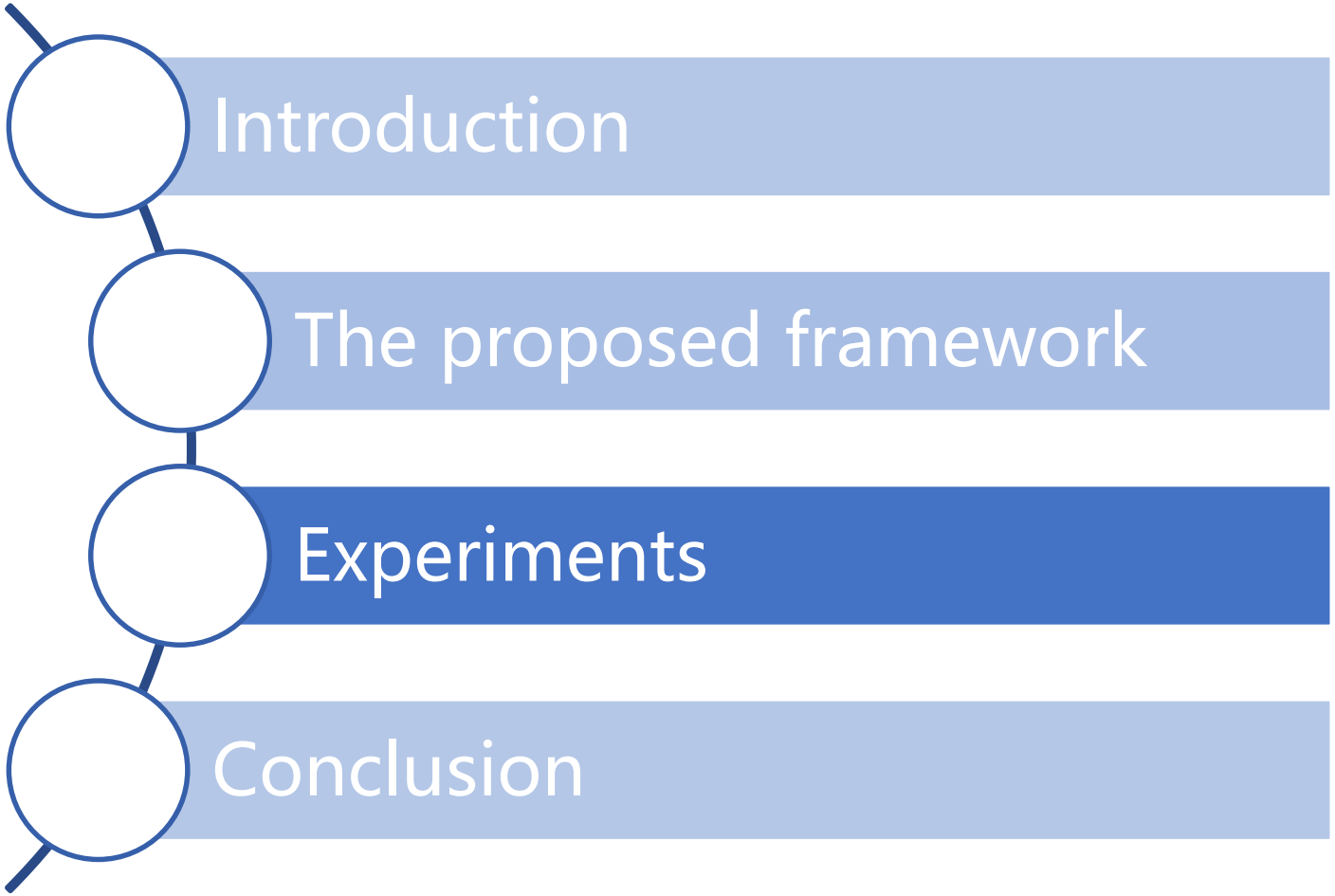
Reflectance recovery

- **Framework**



Lanaras, Charis, Emmanuel Baltsavias, and Konrad Schindler. "Hyperspectral super-resolution by coupled spectral unmixing."

Outline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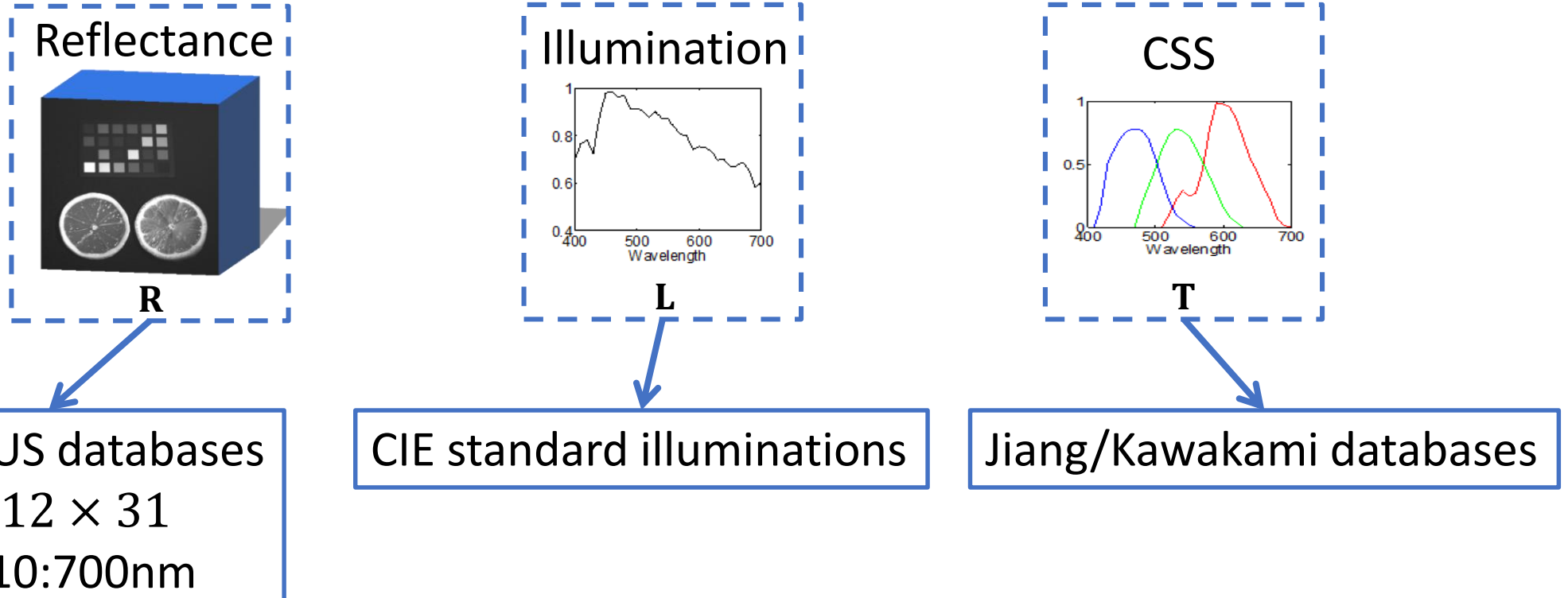
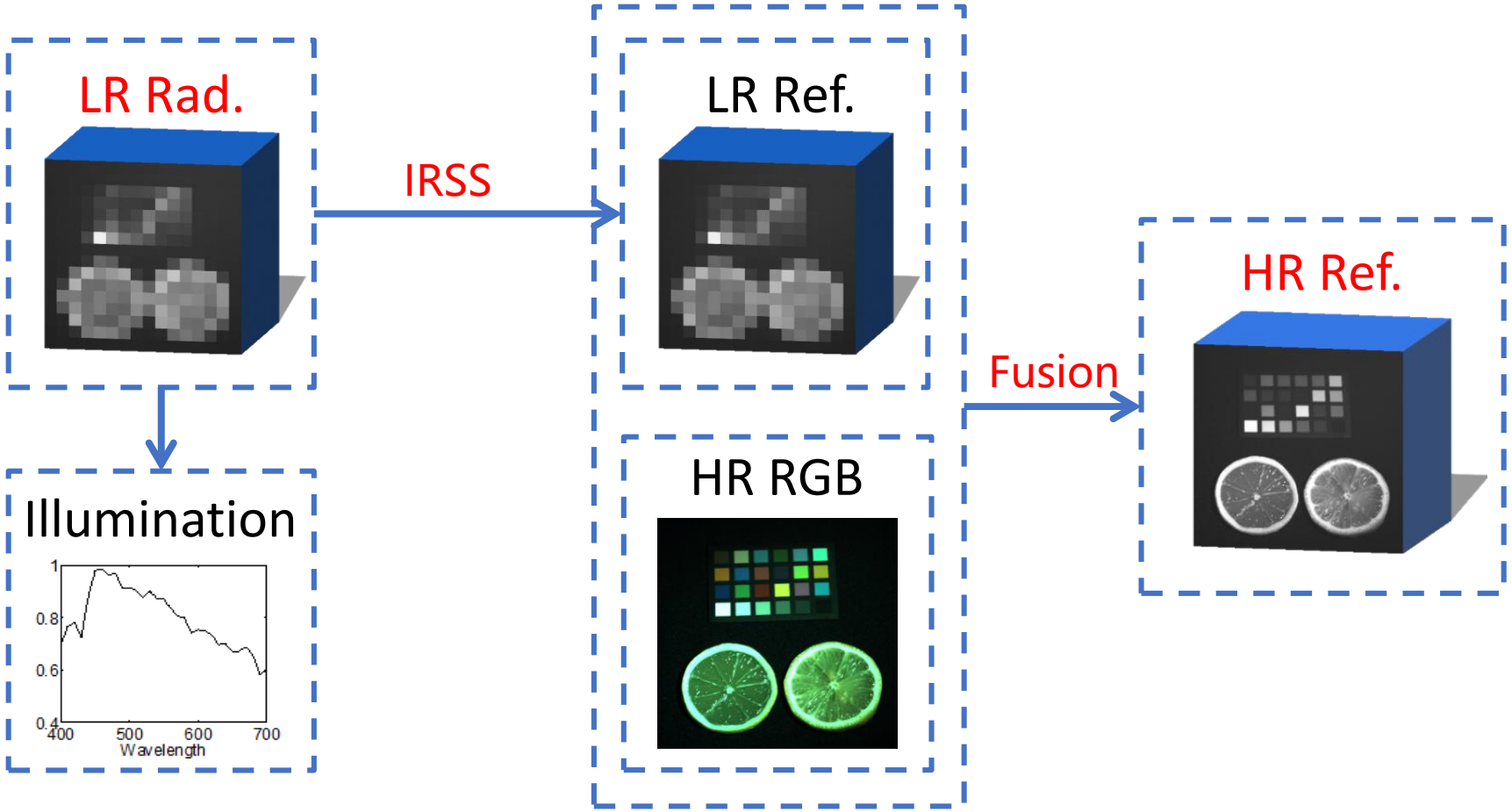
Experiments

- **Experiment setup**



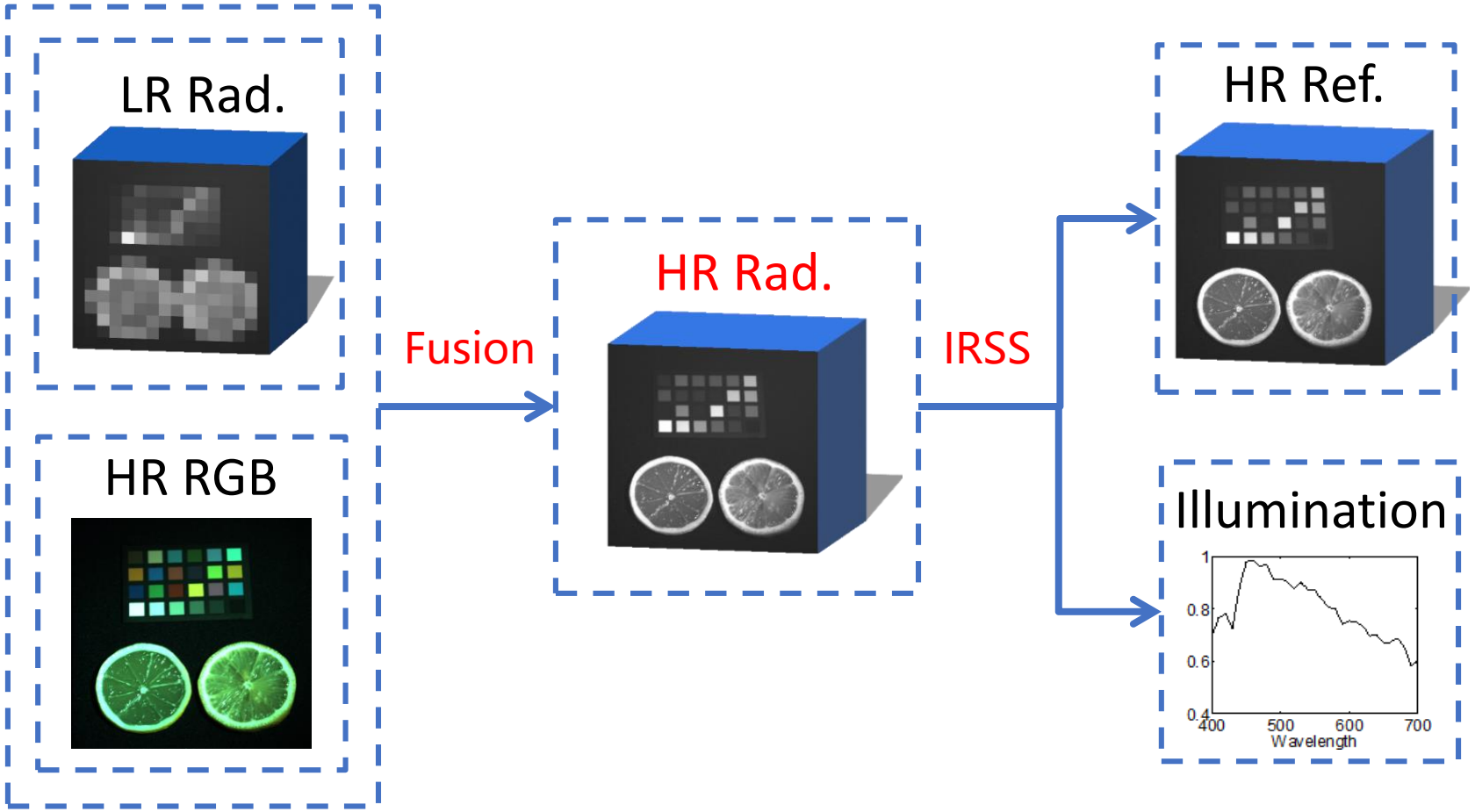
Experiments

- **Workflow 1: IRSS -> Fusion**



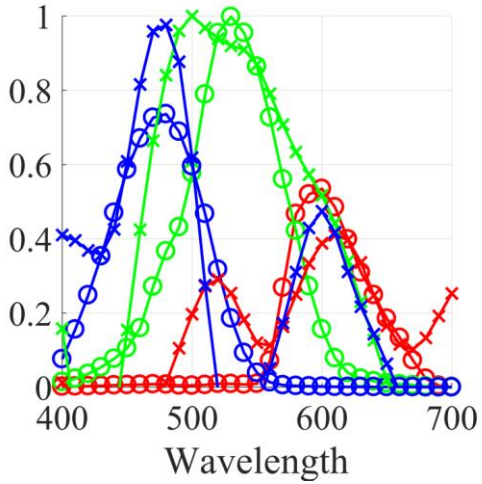
Experiments

- **Workflow 2: Fusion -> IRSS**

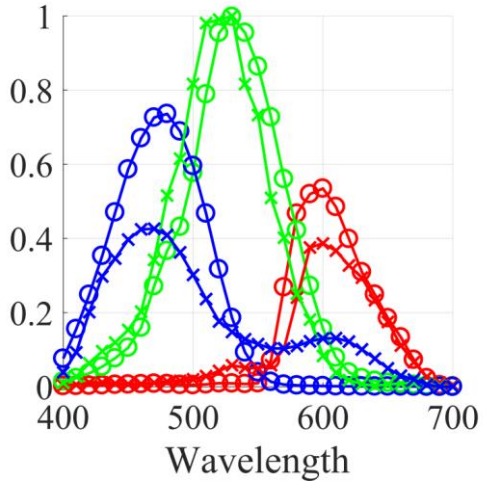


Experiments

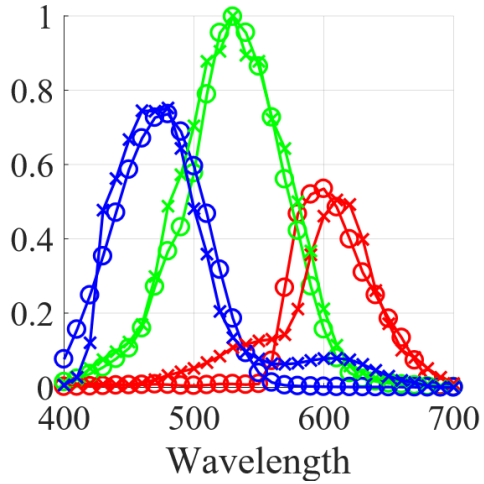
- **CSS estimation results under strong noise**



Simoes et al.
RMSE=0.178



Jiang et al.
RMSE=0.115

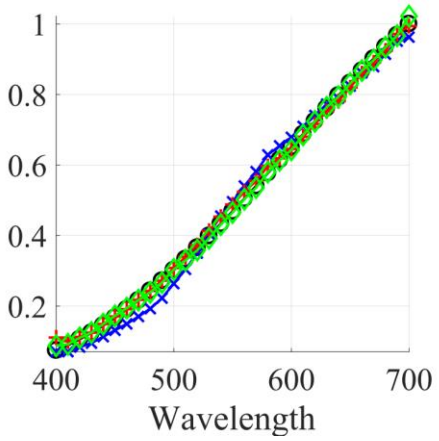


Proposed
RMSE=0.068

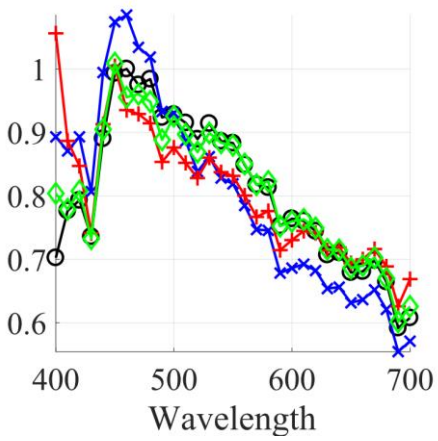
Jiang, Jun, et al. "What is the space of spectral sensitivity functions for digital color cameras?."

Experiments

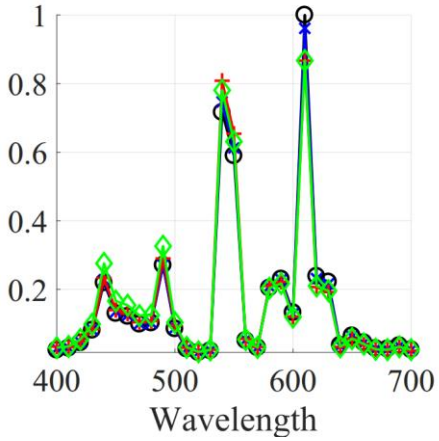
- **Illumination spectrum estimation results**



Illumination A



Illumination D65



Illumination F11

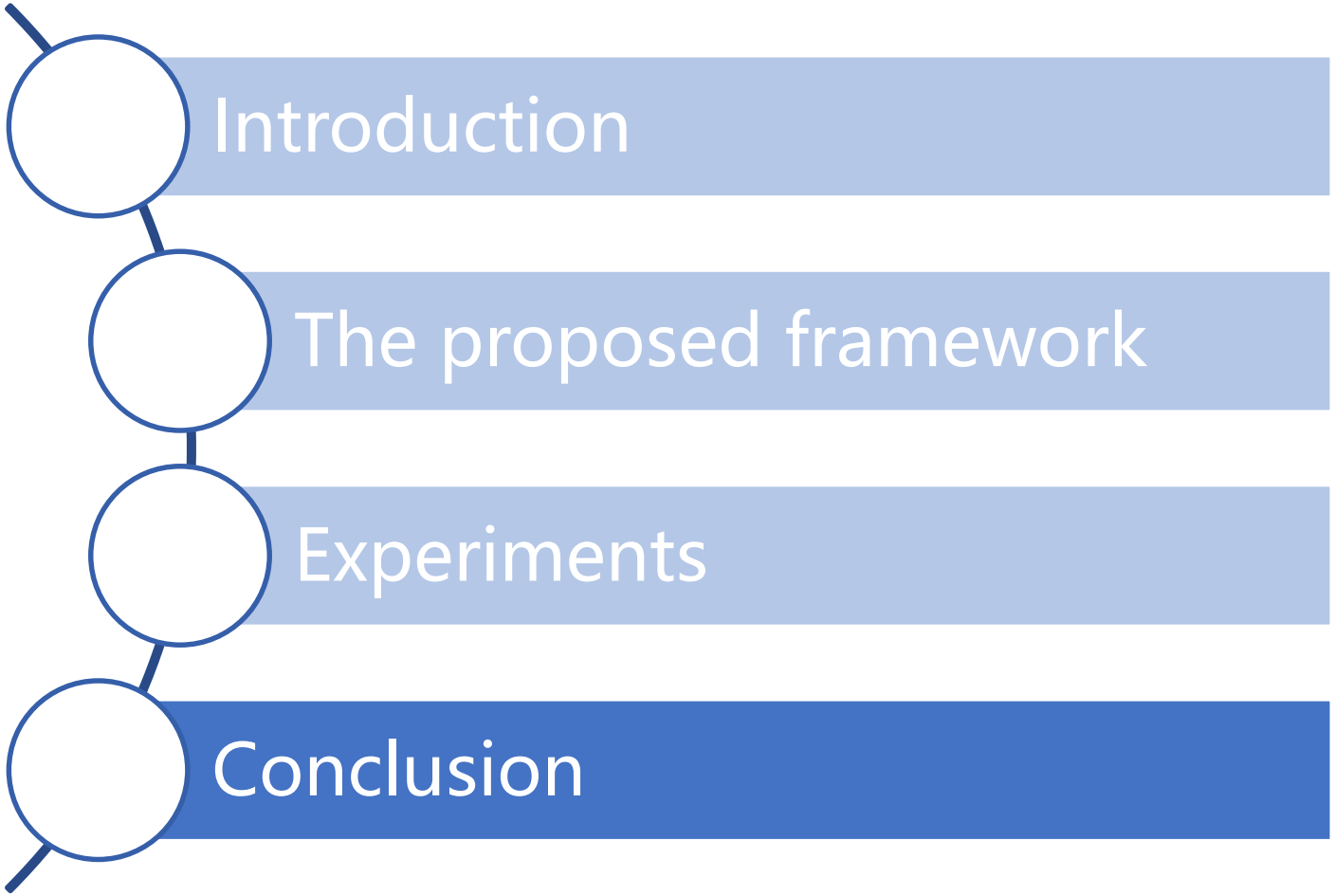
Groundtruth

Fusion->IRSS

IRSS->Fusion

IRSS on groundtruth radiance

Outline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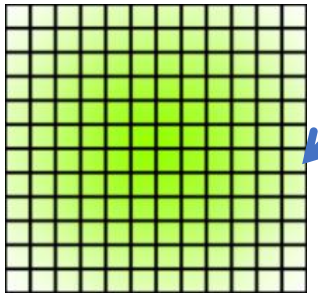
Conclusion

1. Explored the potential of the hybrid camera system.
2. Proposed a novel framework for CSS estimation, illumination spectrum estimation and reflectance recovery.
3. Demonstrated the effectiveness of the proposed framework.

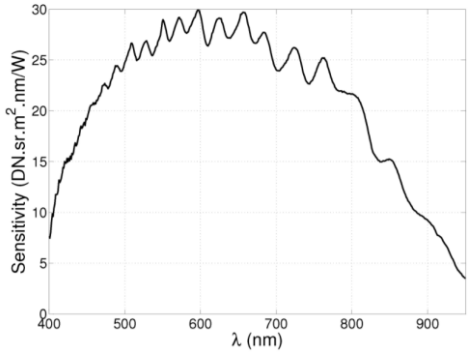
Conclusion

- **Future works**

Spatial blur operator



Hyperspectral CSS




Thank you!