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## Reconstruction of Spectra from Interferometric Measurements (poster)

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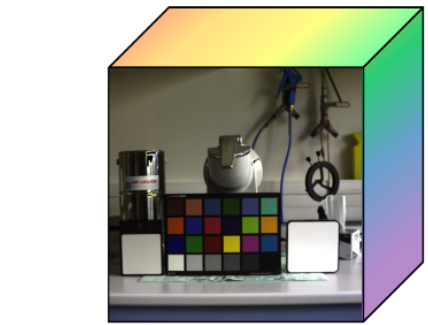
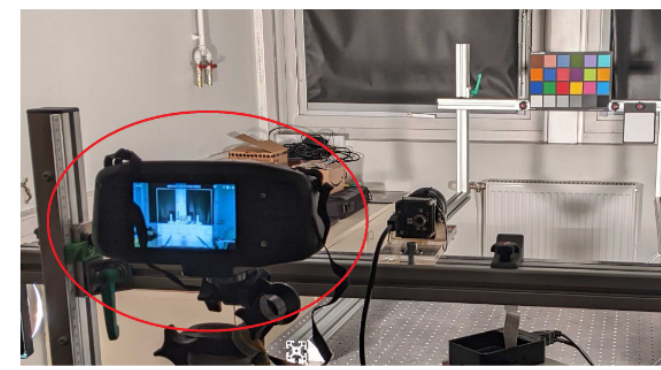
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## I. Context

- We want to reconstruct **spectra** from **interferograms**.
- A simple inversion is not straightforward, and the data are scarce.
- We exploit our *knowledge* of the acquisition model.

### Examples of data acquisition sources

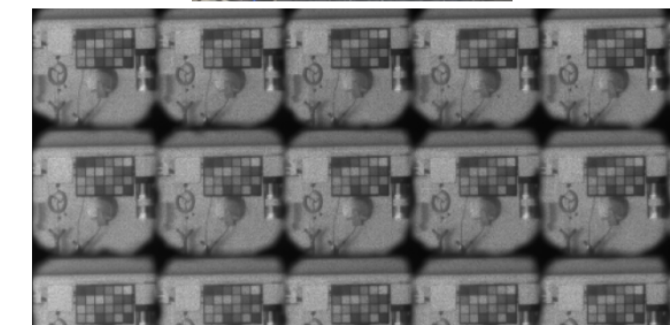
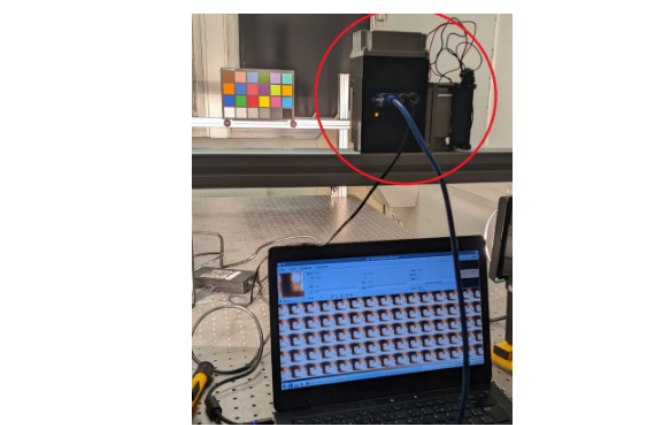
- Devices: **Dispersive spectrometers** and **Interferometers**
- Example targets: Monochromatic sources and spectral references



SPECIM acquisition (spectral, reference)



Xrite's Colorchecker (target example)

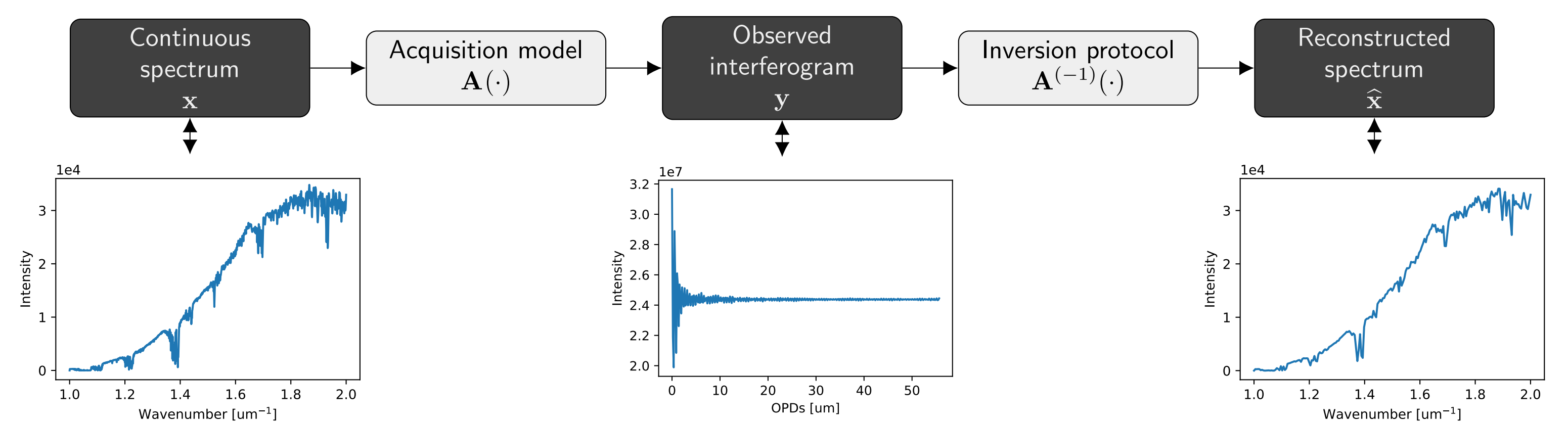


ImSPOC acquisition (interferometric, observations)

## II. Problem Statement

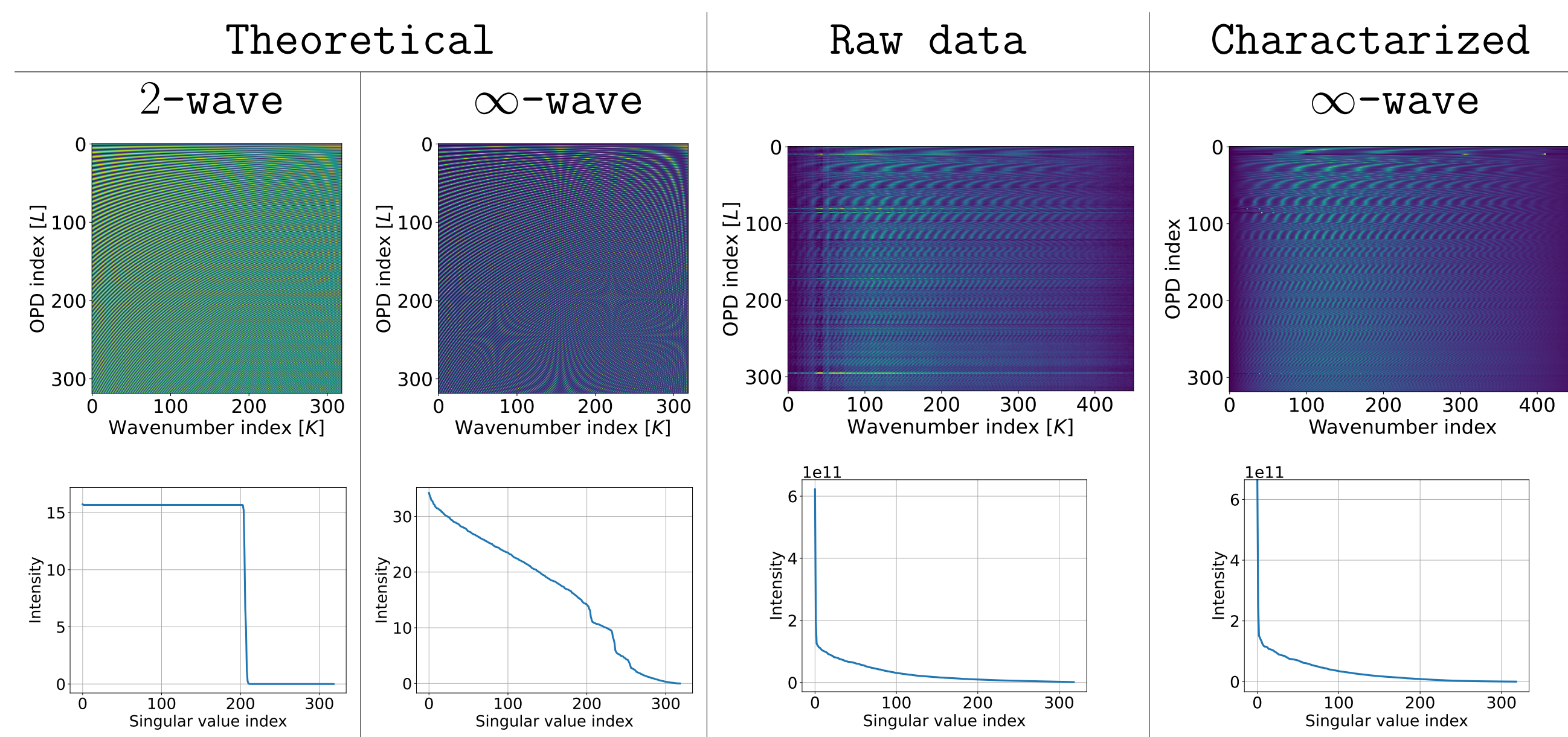
### Acquisition and Inversion Pipelines

- Direct model:  $\mathbf{y} = \mathbf{A}\mathbf{x} + \mathbf{e}$ , where:
  - $\mathbf{x} \in \mathbb{R}^K$  (unknown): **spectral radiance**, in the domain of **wavenumbers**  $\sigma$ .
  - $\mathbf{y} \in \mathbb{R}^L$  (observed): **interferogram**, in the domain of **optical path differences (OPDs)**  $\delta$ .
  - $\mathbf{A} \in \mathbb{R}^{L \times K}$  is the discretized acquisition model, and depends on  $\delta$  and  $\sigma$ .
  - $\mathbf{e} \in \mathbb{R}^L$  is the noise, which we assume to be Gaussian.
- Goal: Estimate the value of  $\mathbf{x}$  such that  $\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \frac{1}{2} \|\mathbf{y} - \mathbf{A}\mathbf{x}\|_2^2 + r(\mathbf{x})$



## III. Acquisition Model (knowledge of the system)

- **Theoretical:** following the physical interferometric phenomena / models [1]:
  - 2-wave model:  $A(\delta, \sigma) = (1 + \mathcal{R}^2(\sigma) - 2\mathcal{R}(\sigma) \cos(2\pi\sigma\delta)) \mathcal{T}^2(\sigma) \approx C_0 + C_1 \cos(2\pi\delta\sigma)$
  - $\infty$ -wave model:  $A(\delta, \sigma) = \frac{1}{1 + \mathcal{R}^2(\sigma) - 2\mathcal{R}(\sigma) \cos(2\pi\sigma\delta)} \mathcal{T}^2(\sigma) \approx C_0 + \sum_{n=1}^{\infty} C_n \cos(2\pi n\delta\sigma)$
- **Raw data:** following the raw monochromatic acquisitions of a real device.
- **Characterized:** fitting a model with the monochromatic acquisitions of a real device [2].



## IV. Methodology (Model-based)

- Based on the condition numbers from the singular values plots, the inversion problem is ill-posed.

### Conventional methods (SVD-based approaches) [3]

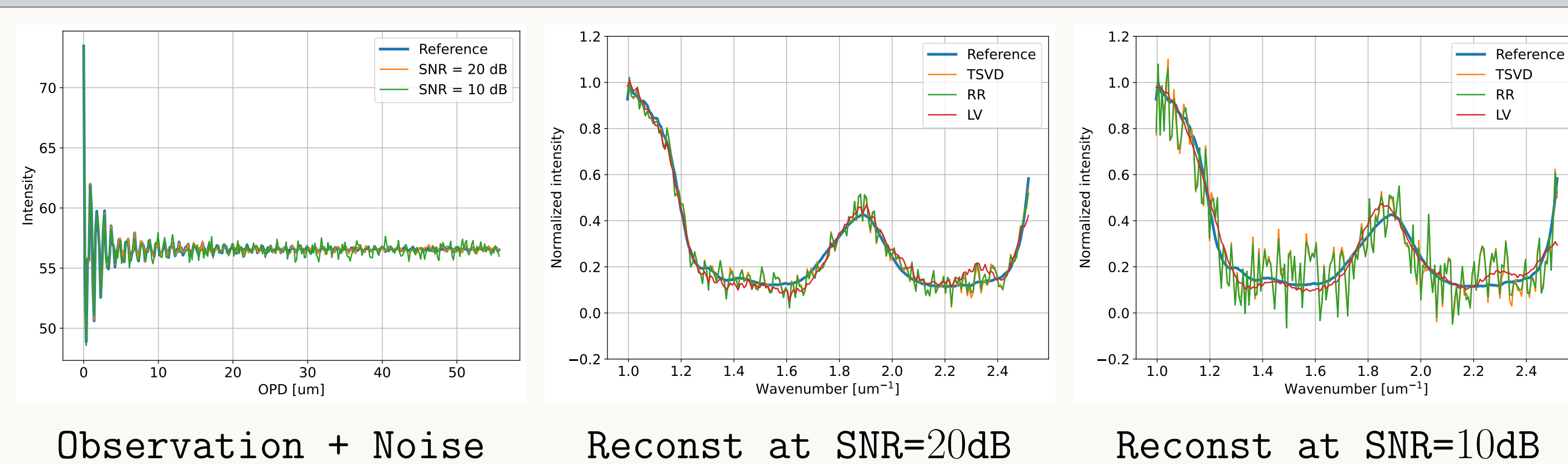
- Inverse discrete cosine transform (IDCT)
- Pseudo-inverse (e.g., raw data)
- Truncated singular value decomposition (TSVD)
- Ridge regression (RR)

### Iterative methods: Loris-Verhoeven (LV) algorithm [4]

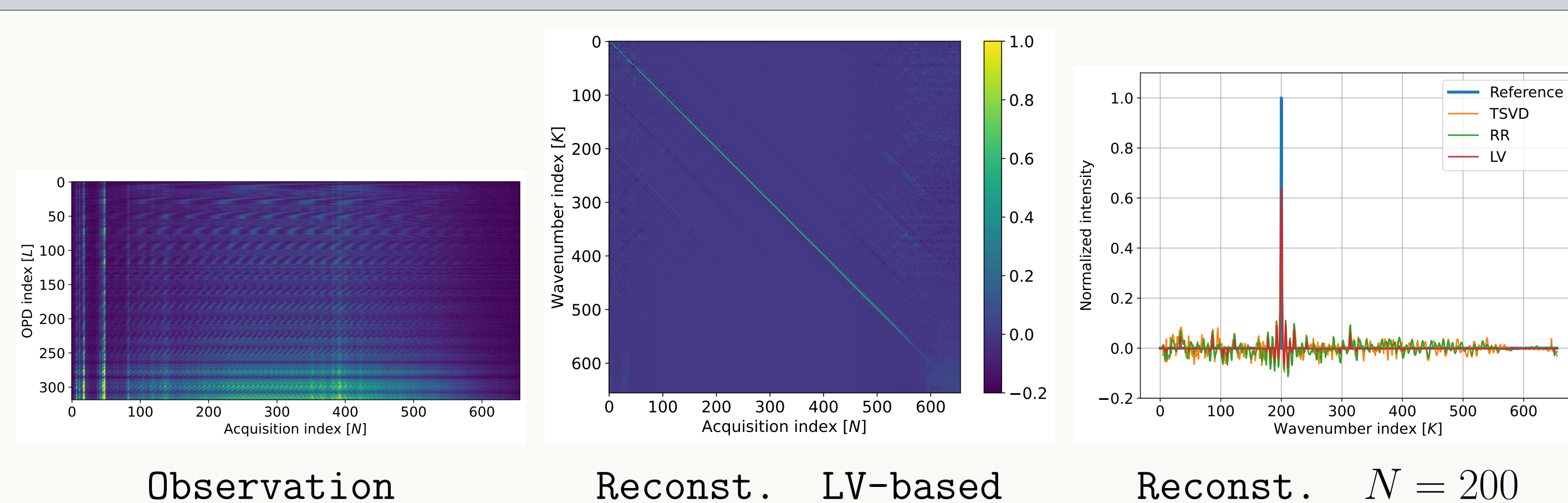
- Solve  $\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \frac{1}{2} \|\mathbf{y} - \mathbf{A}\mathbf{x}\|_2^2 + \lambda g(\mathbf{L}\mathbf{x})$  where:
  - $\lambda$  is the regularizing parameter
  - $g(\cdot)$  is the regularization term (e.g., sparsity)
  - $\mathbf{L}$  is a linear domain transformation (e.g., DCT or identity)

## V. Experiments

### Simulated Experiments (varying SNR) [5]



### Real Experiments (monochromatic data)



## VI. Summary

- The acquisition models can be exploited and represented as a Fourier series.
- Iterative methods are efficient as a **base-line**.
- Problem: Induced smoothness with low SNR => **Information loss**.

## VII. Perspectives

- Experiment with real non-monochromatic data.
- Collect real non-monochromatic data (data-based approaches).
- Exploit spatial information with hyperspectral cube reconstruction.

## VIII. References

- [1] Hecht, Eugene. *Optics (5th edition)*. Pearson Education India, 2016.
- [2] Picone, Daniele, et al. "Interferometer response characterization algorithm for multi-aperture Fabry-Perot imaging spectrometers." *Optics Express* 31.14 (2023): 23066-23085.
- [3] Idier, Jérôme, ed. *Bayesian approach to inverse problems*. John Wiley & Sons, 2013.
- [4] Loris, Ignace, et al. "On a generalization of the iterative soft-thresholding algorithm for the case of non-separable penalty." *Inverse Problems* 27.12 (2011): 125007.
- [5] Jouni, Mohamad, et al. "Model-based spectral reconstruction of interferometric acquisitions." *ICASSP 2023-2023 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE, 2023.