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Reconstruction of Spectra from Interferometric Measurements (poster)

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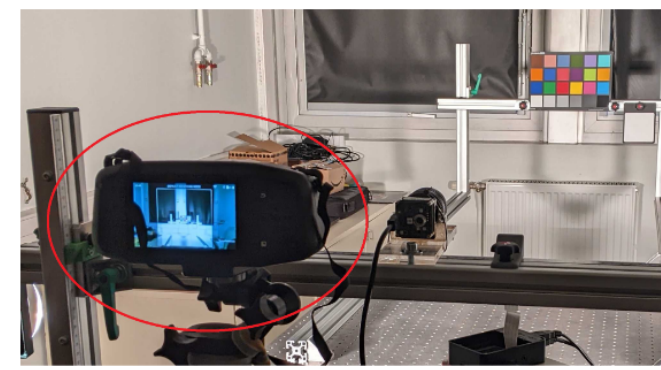
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I. Context

- 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

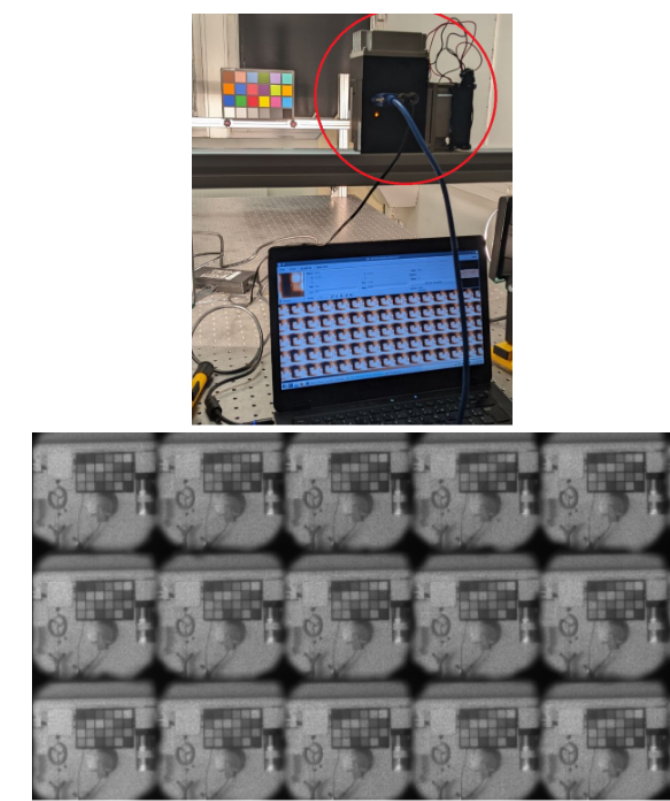
- Devices: **Dispersive spectrometers** and **Interferometers**
- Example targets: Monochromatic sources and spectral references



SPECIM acquisition (spectral, reference)



Xrite's Colorchecker (target example)

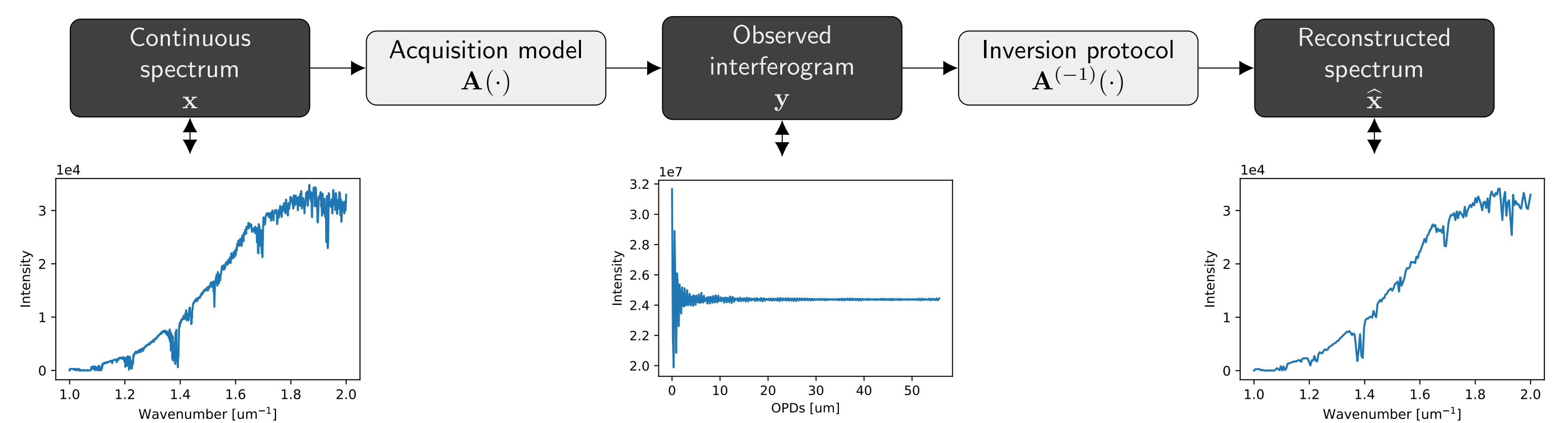


ImSPOC acquisition (interferometric, observations)

II. Problem Statement

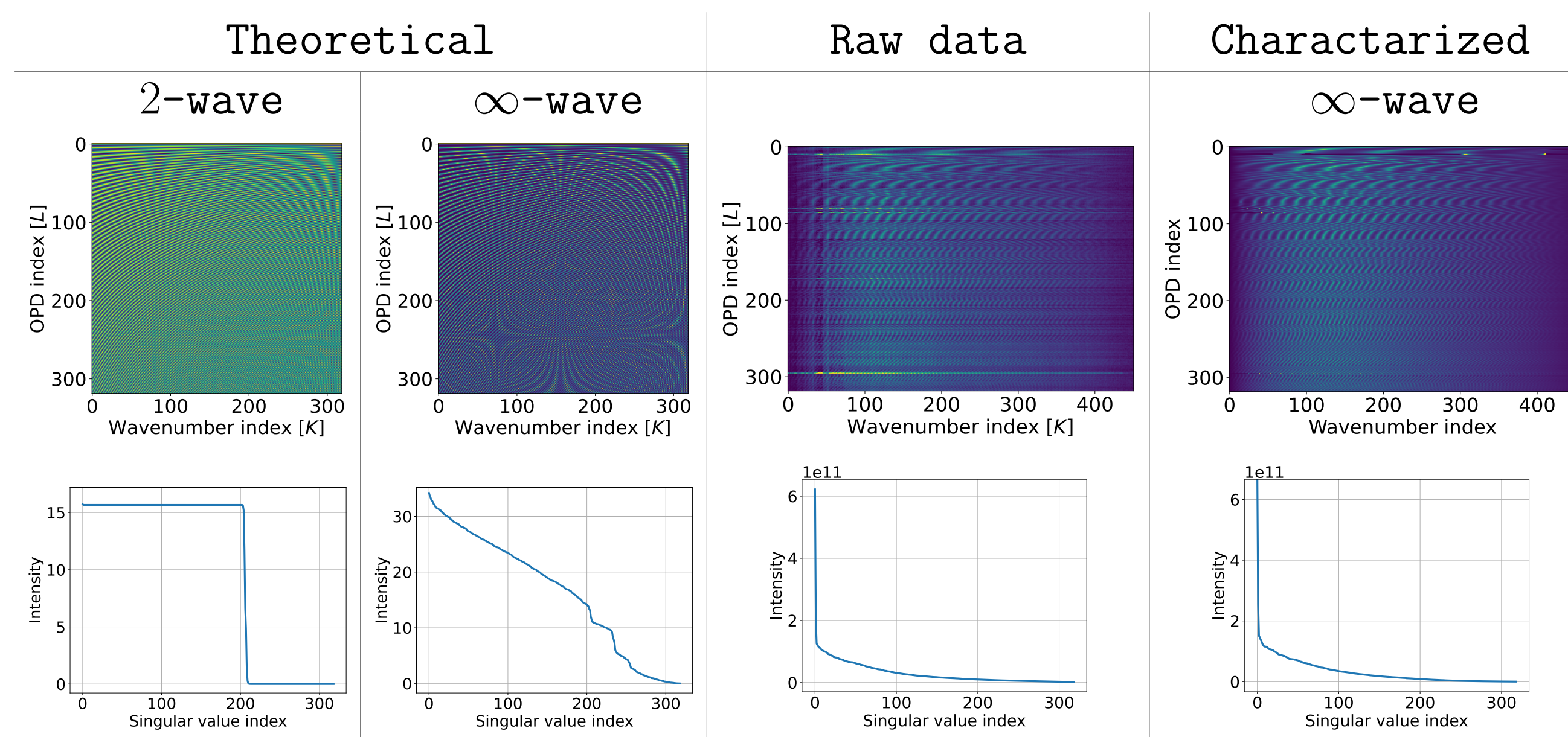
Acquisition and Inversion Pipelines

- 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** σ .
 - $\mathbf{y} \in \mathbb{R}^L$ (observed): **interferogram**, in the domain of **optical path differences (OPDs)** δ .
 - $\mathbf{A} \in \mathbb{R}^{L \times K}$ is the discretized acquisition model, and depends on δ and σ .
 - $\mathbf{e} \in \mathbb{R}^L$ 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: $A(\delta, \sigma) = (1 + \mathcal{R}^2(\sigma) - 2\mathcal{R}(\sigma) \cos(2\pi\sigma\delta)) \mathcal{T}^2(\sigma) \approx C_0 + C_1 \cos(2\pi\delta\sigma)$
 - ∞ -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]

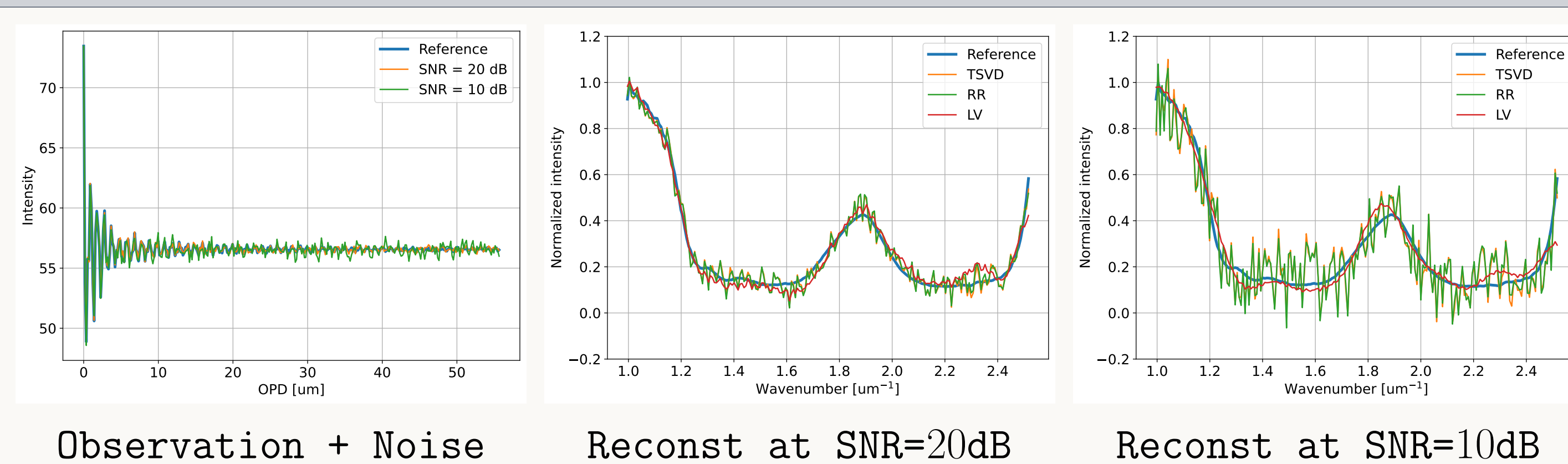
- Inverse discrete cosine transform (IDCT)
- Pseudo-inverse (e.g., raw data)
- Truncated singular value decomposition (TSVD)
- Ridge regression (RR)

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

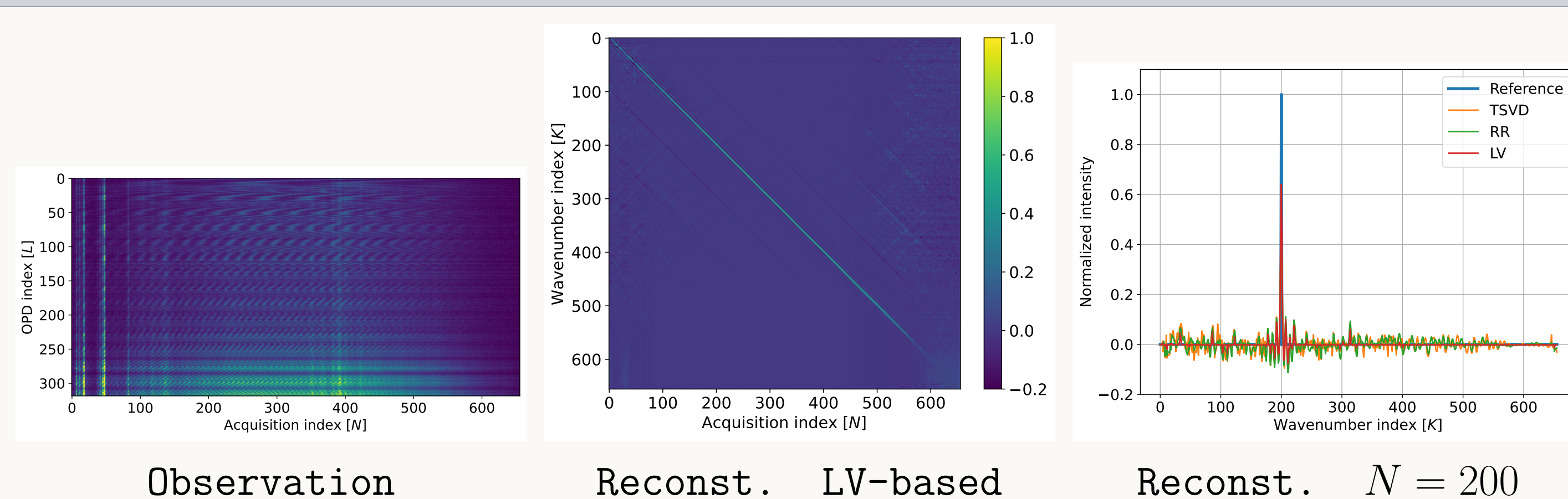
- Solve $\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \frac{1}{2} \|\mathbf{y} - \mathbf{A}\mathbf{x}\|_2^2 + \lambda g(\mathbf{L}\mathbf{x})$ where:
 - λ is the regularizing parameter
 - $g(\cdot)$ is the regularization term (e.g., sparsity)
 - \mathbf{L} is a linear domain transformation (e.g., DCT or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