A Deep Learning Framework for Joint On-Board InSAR Phase Denoising and Compression

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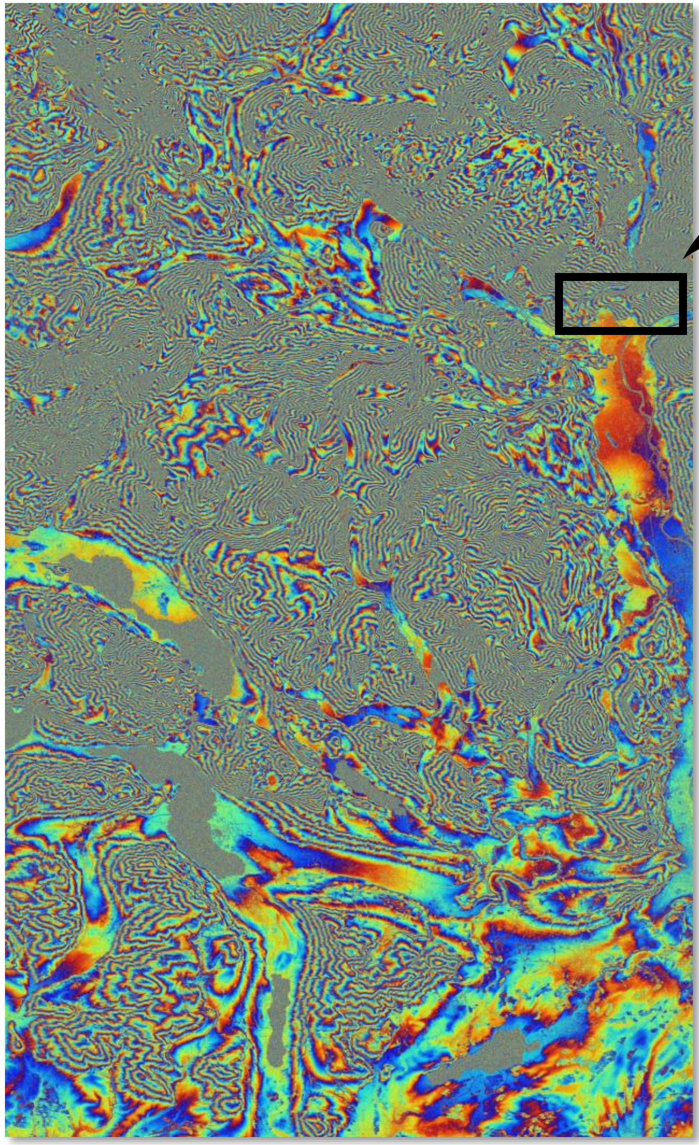
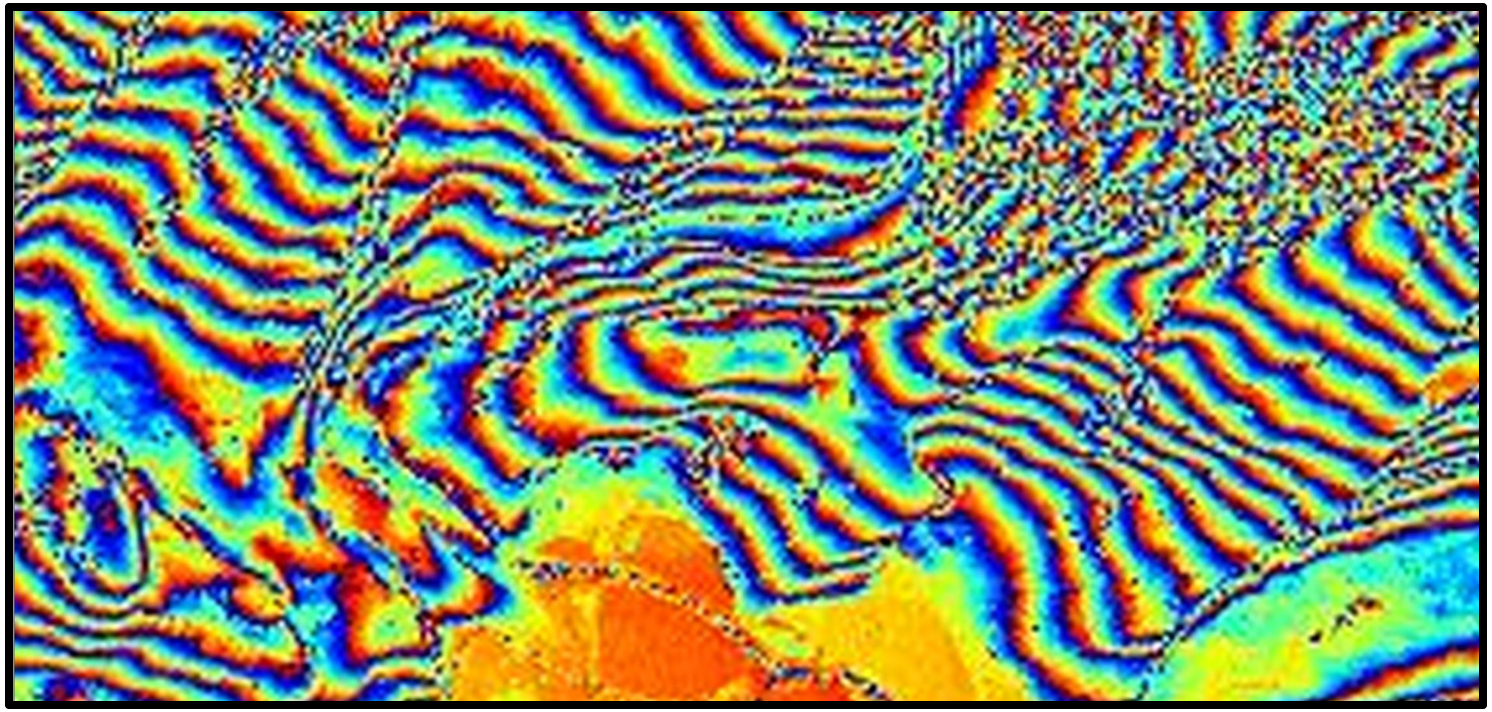
InSAR Phase Denoising vs. Resolution



TDX StripMap: @Single-look @Boxcar [11x11]



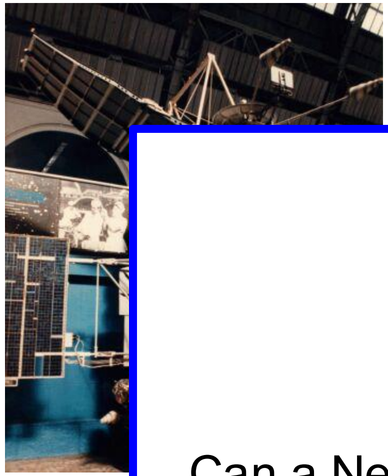
- **Denoising strategies** are required in order to generate reliable and high-quality InSAR products..

- ..common methods estimate the InSAR phase at the **cost of resolution**
- ..**compression** is intrinsically achieved

Problem Definition

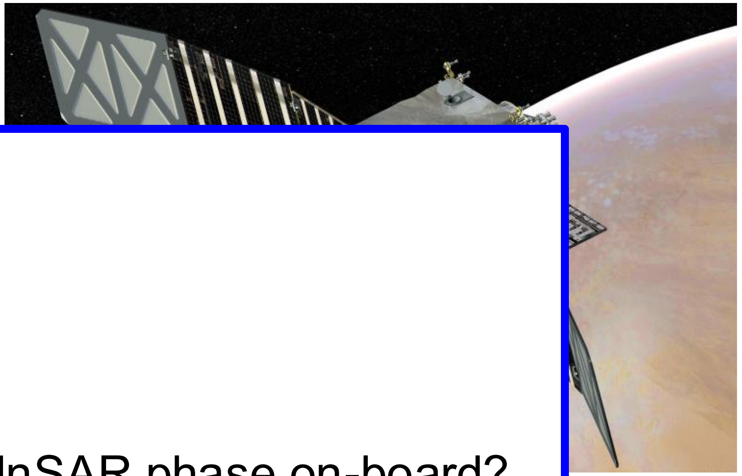
- Problem context: **planetary missions**

Venera 15&16



NASA's Magellan

NASA's Veritas



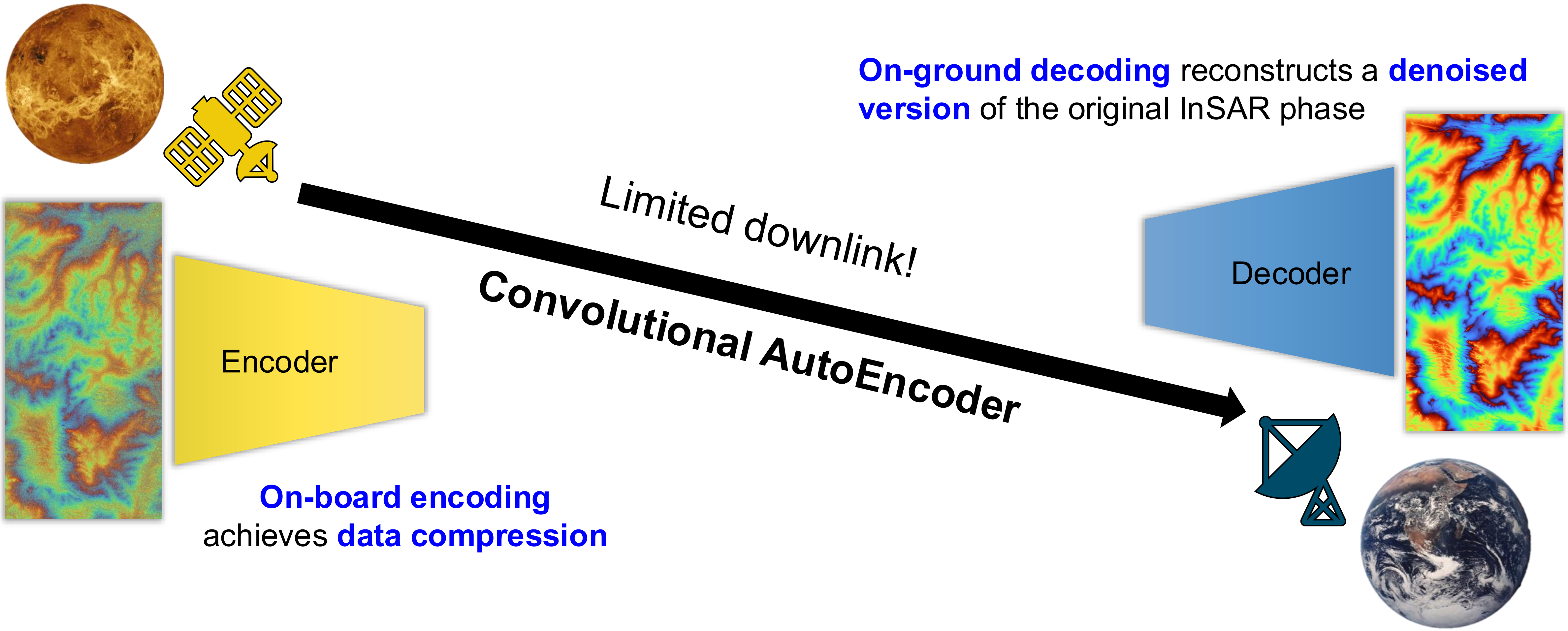
Research Question

Can a Neural Network jointly denoise and compress the InSAR phase on-board?

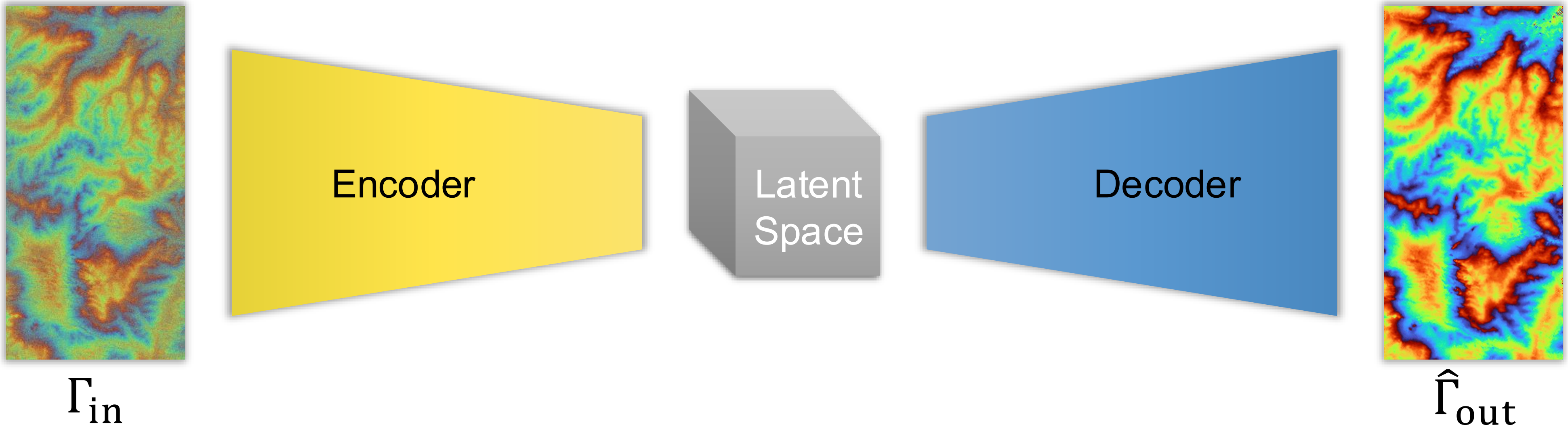
- Planetary missions have **significant downlink constraints**
- NASA's VERITAS objective: generation of a global DEM on Venus
- **On-board** processing (**denoising/compression**) of the **InSAR phase**

Proposed Concept

- **Limited downlink** capacity requires effective **compression strategies**
- In this work, **only the InSAR phase is of interest**, while the coherence is neglected

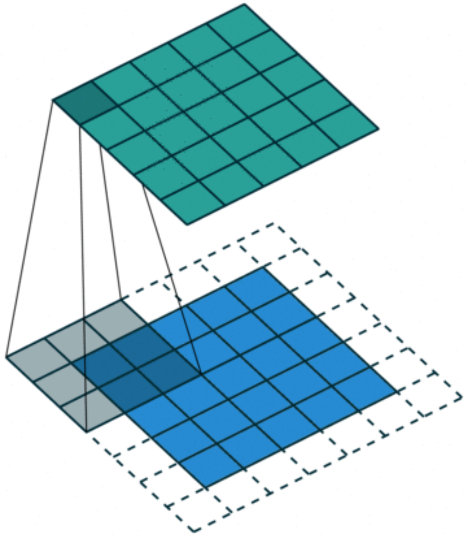


Convolutional AutoEncoder (CAE)



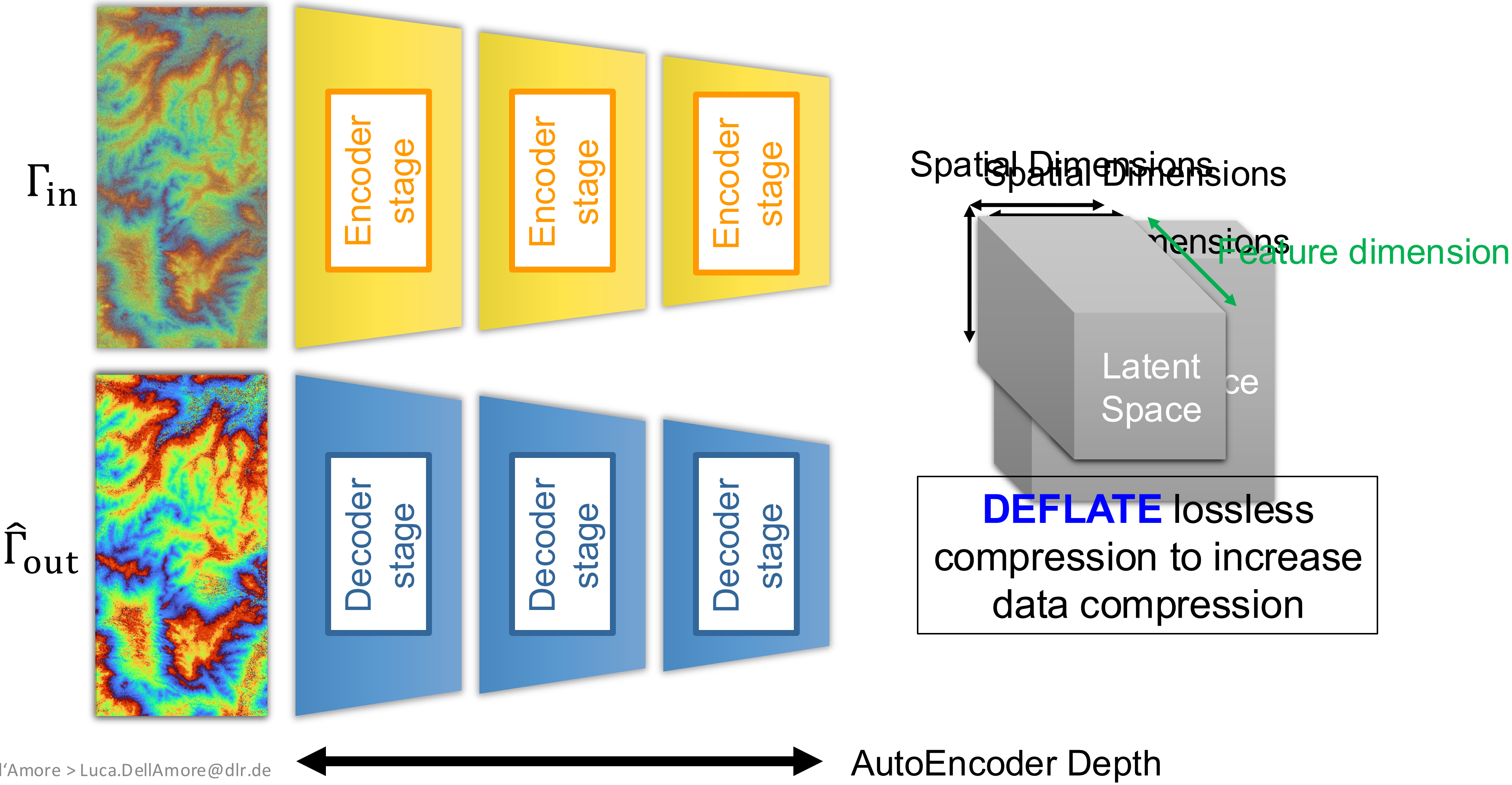
- **Complex interferogram** as **input** (real/imaginary parts): Γ_{in}
- **Encoder** operations:
  - ✓ 2-D convolutions
  - ✓ Pooling operation (**down-sampling**)
- The **coded** and **compressed representation of the input** is called **Latent Space**
- **Decoder** operations:
  - ✓ 2-D convolutions
  - ✓ **Up-sampling** operations reconstruct the original pixel sampling
  - ✓ **High-resolution** phase **details** are partially **lost**
- **Complex InSAR phase** as **output** (real/imaginary parts): $\hat{\Gamma}_{\mathrm{out}}$

2-D conv.



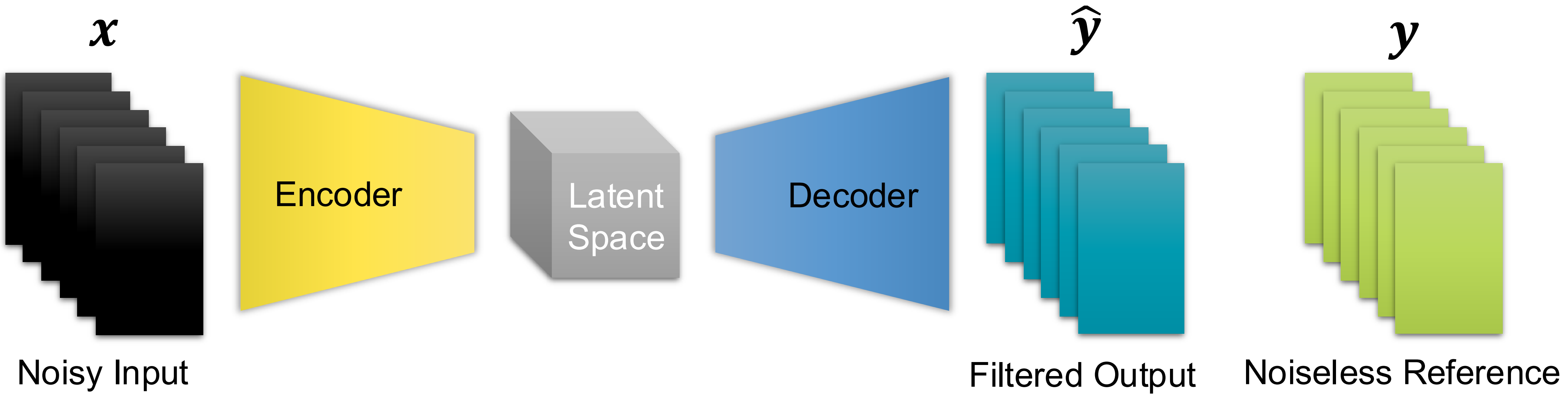
CAE Hyperparameters Tuning

Hyperparameters tuning on different settings allows for exploring different performance trade-offs



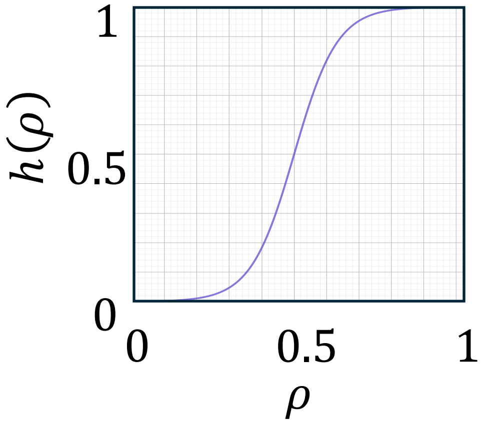
DEFLATE lossless compression to increase data compression

Supervised Training Strategy



- **Loss function** $\mathcal{L}(\boldsymbol{y}, \hat{\boldsymbol{y}})$ as weighted absolute phase error
- ρ_i is the interferometric coherence at pixel i

$$\mathcal{L}(\mathrm{y}, \hat{y}) = \sum_i h(\rho_i) \left| \angle \left(\frac{\hat{y}_i}{y_i} \right) \right|$$



Dataset Generation

TanDEM-X NEBZ

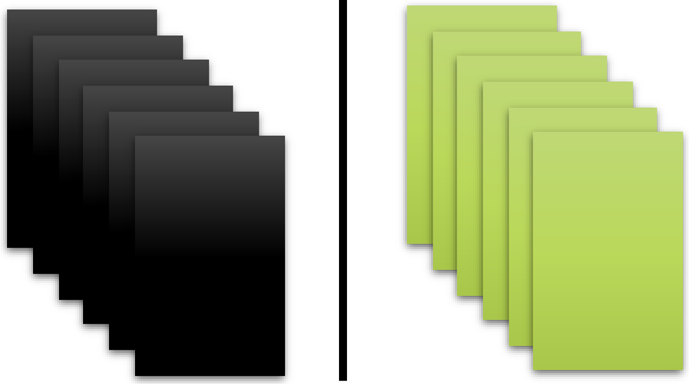
$$\Sigma = \mathbb{E}\begin{Bmatrix} |z_1|^2 & z_1 z_2^* \\ z_1^* z_2 & |z_2|^2 \end{Bmatrix}$$

$z_{1,2}$: complex SLCs

$$\Sigma = \Sigma_s + \Sigma_n$$

H_0: signal and noise are statistically independent

$\boldsymbol{x}$ | $\boldsymbol{y}$

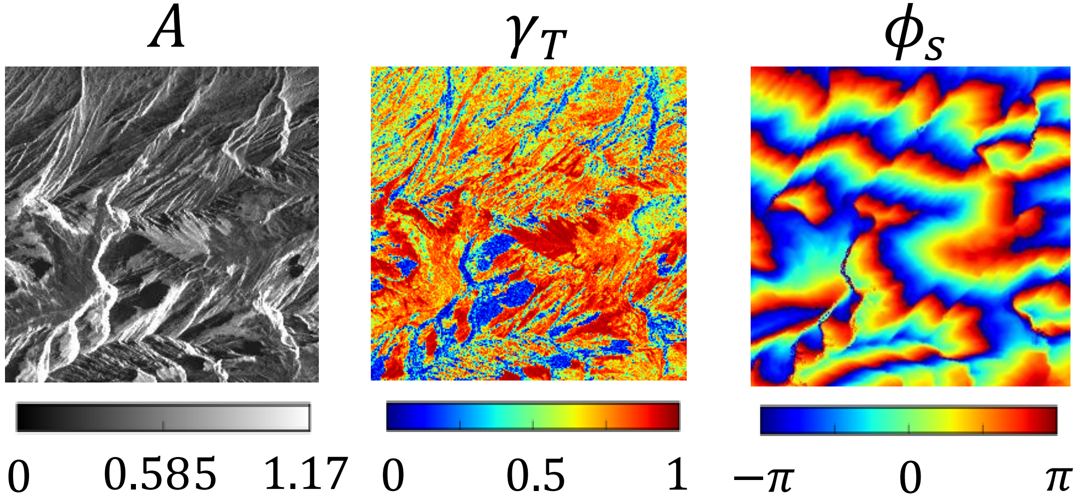


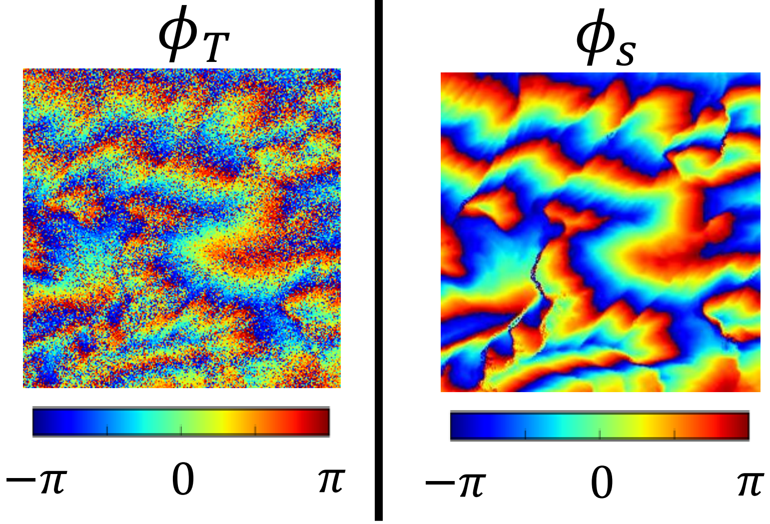
Noisy Input

Noiseless Reference

TanDEM-X observations

External DEM back-geocoding





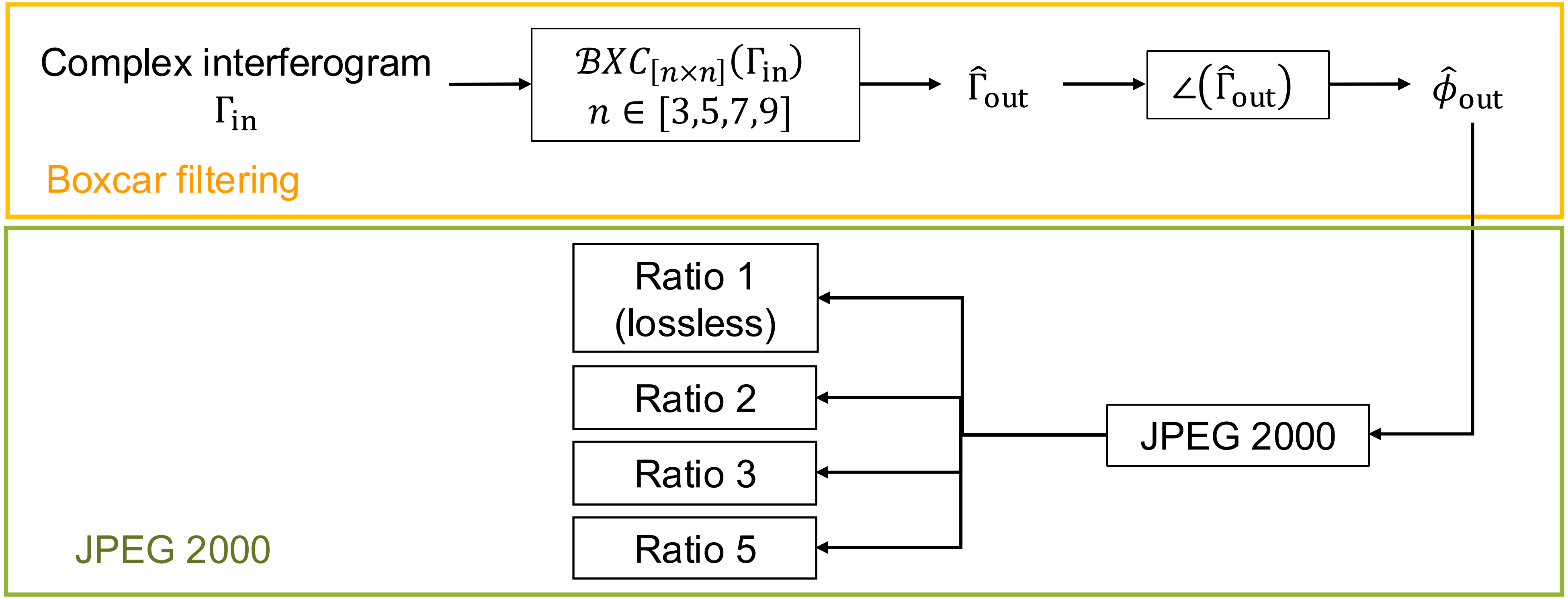
Baseline Method

A combination of traditional methods is used as **performance baseline**:

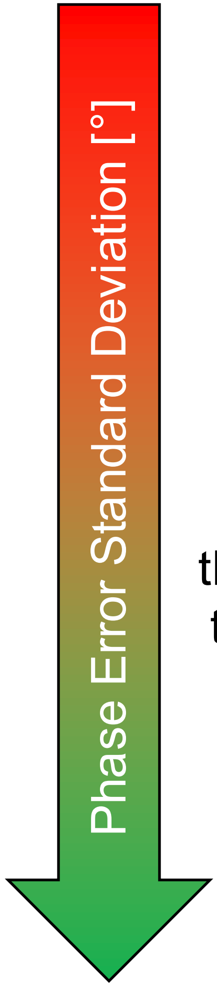
1. **Boxcar filtering** (BXC) for InSAR phase **denoising**

   +

2. **JPEG 2000** for data **compression**



Performance Metrics



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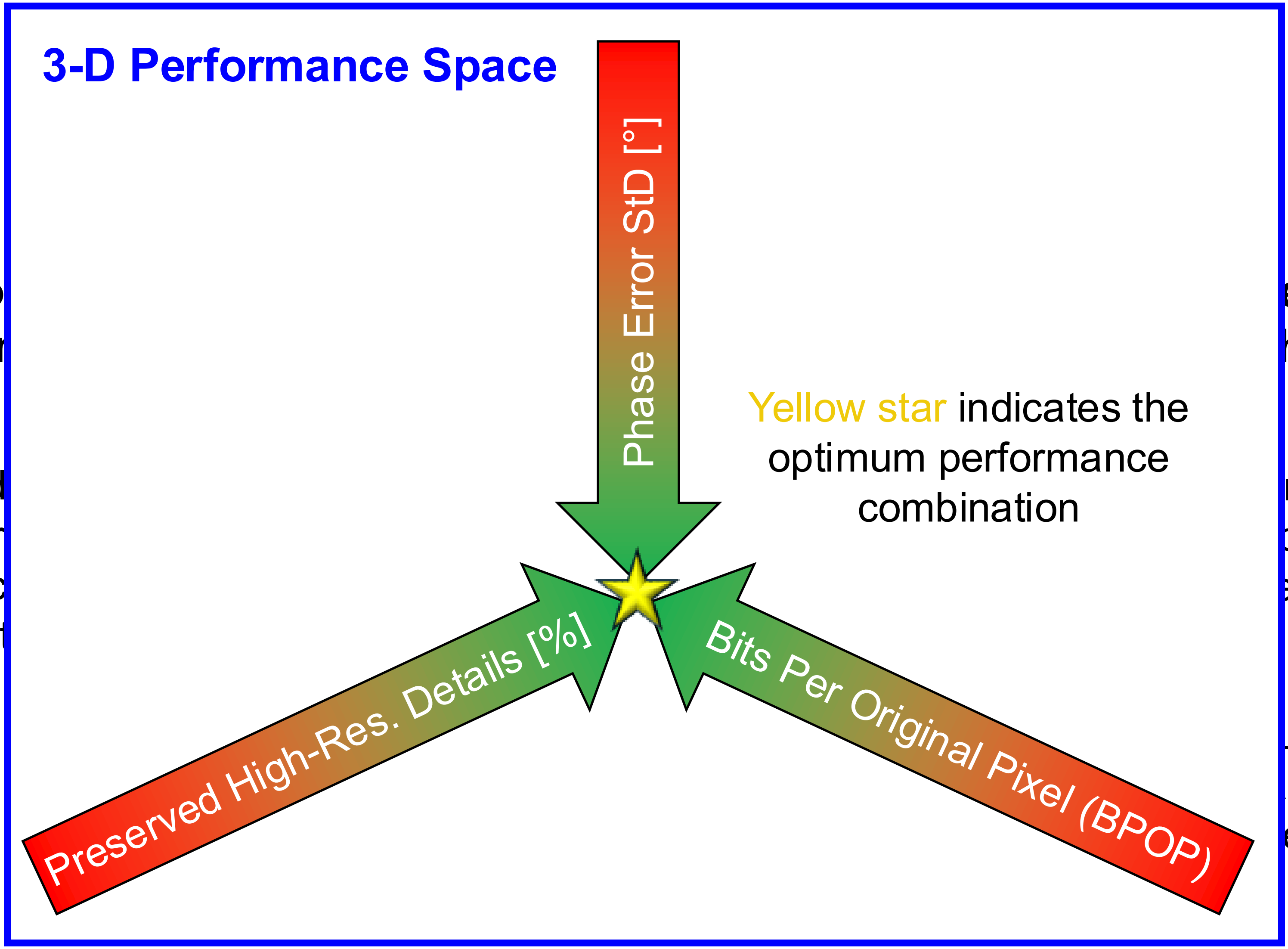

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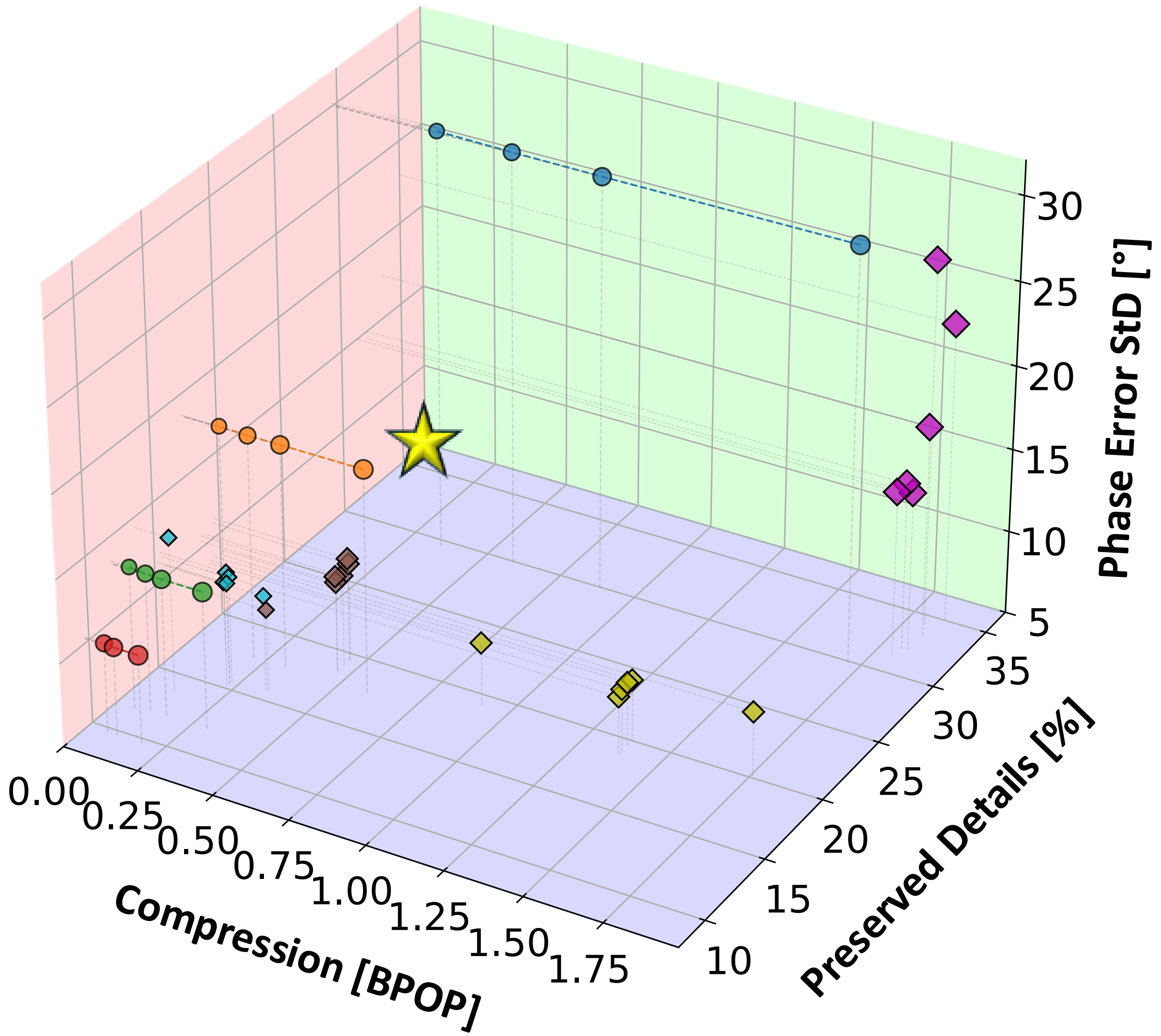
Results – 3-D Performance Space



- 8 scenes considered for testing
- **Synthetic interferograms**
  (proposed theoretical noise model)
- Focus is on **mid- and high-coherence** ($\rho > 0.4$)

Baseline

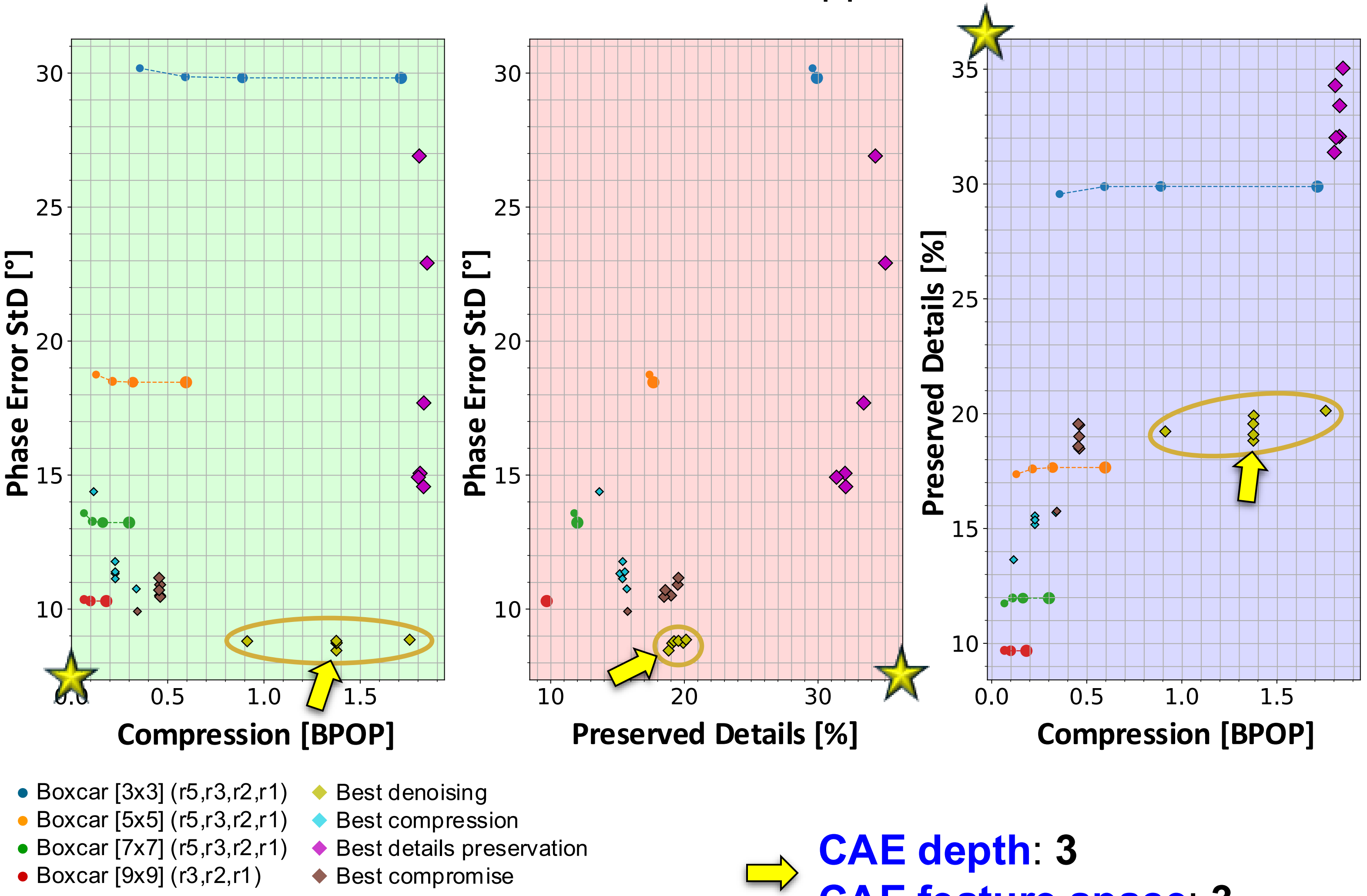
- Boxcar [3x3] (r5,r3,r2,r1)
- Boxcar [5x5] (r5,r3,r2,r1)
- Boxcar [7x7] (r5,r3,r2,r1)
- Boxcar [9x9] (r3,r2,r1)

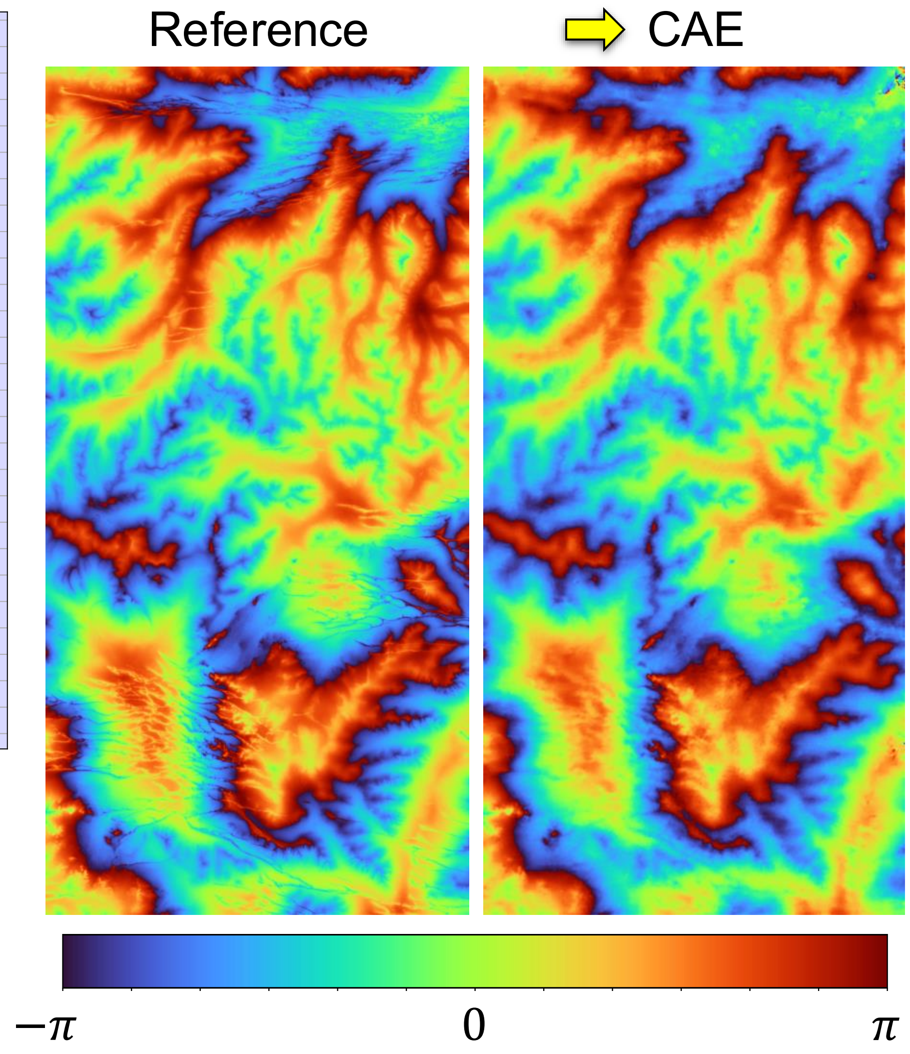
- Best denoising
- Best compression
- Best details preservation
- Best compromise

Best CAE solutions

Results – 2-D Cross-Sections

- **Enhanced** overall **flexibility** w.r.t. baseline method, in terms of **performance scalability**
- **Valid alternative** to most traditional approaches in terms of **absolute performance** as well





CAE depth: 3
CAE feature space: 3

Results – 2-D Cross-Sections

- **Enhanced** overall **flexibility** w.r.t. baseline method, in terms of **performance scalability**
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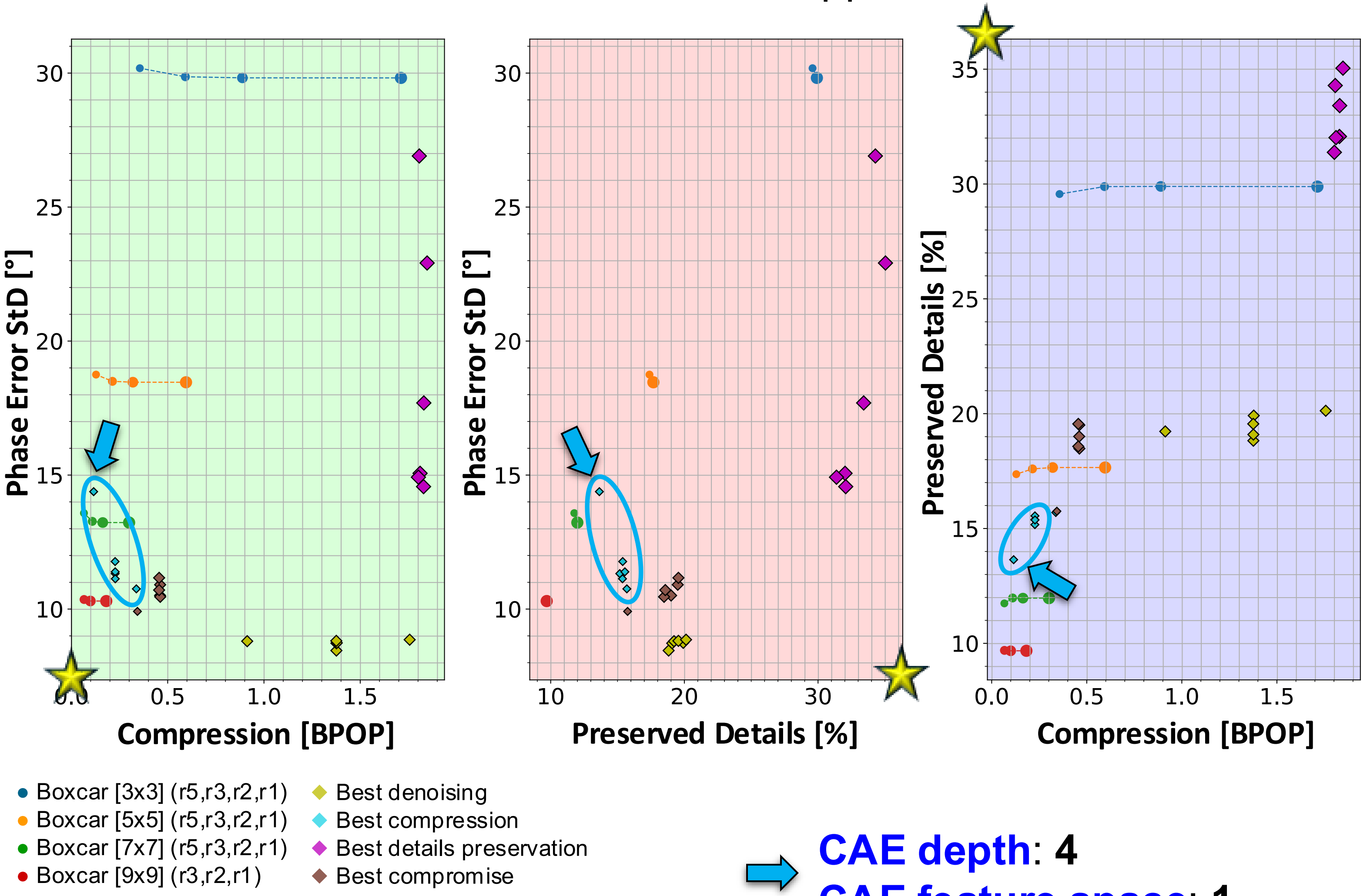
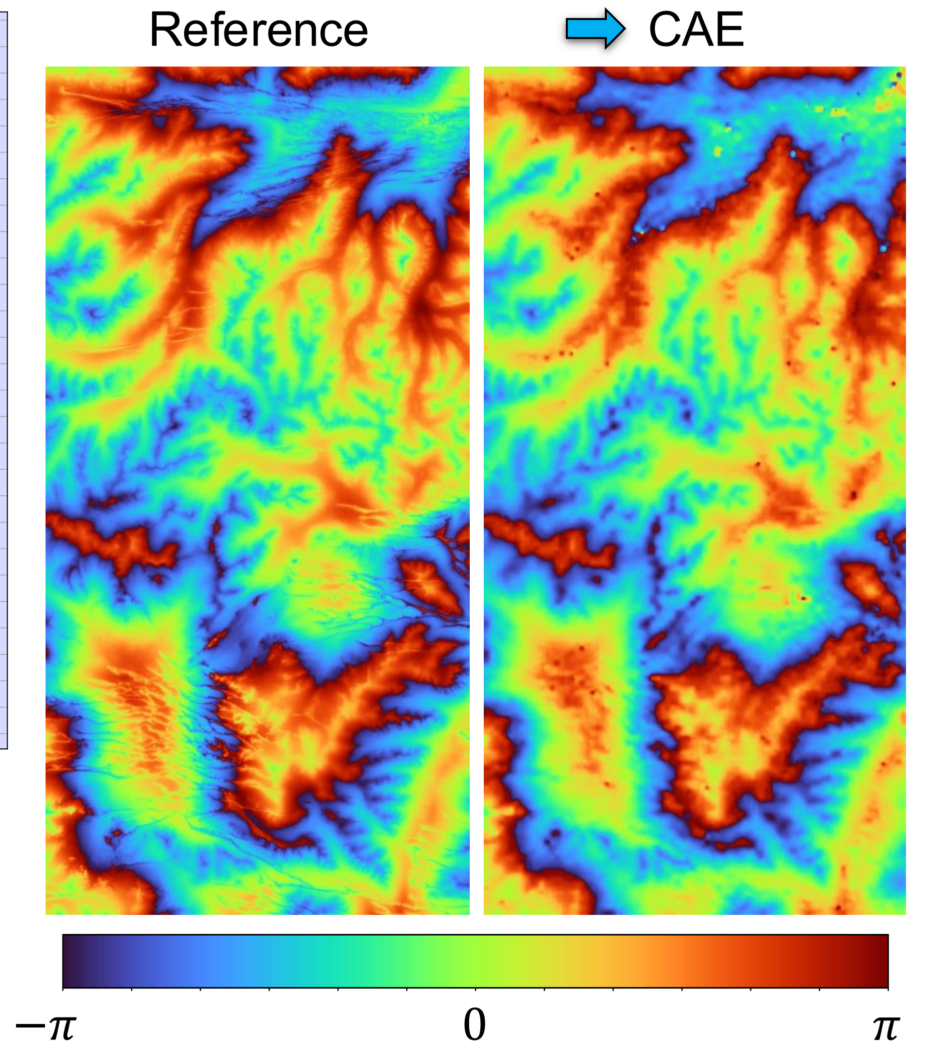
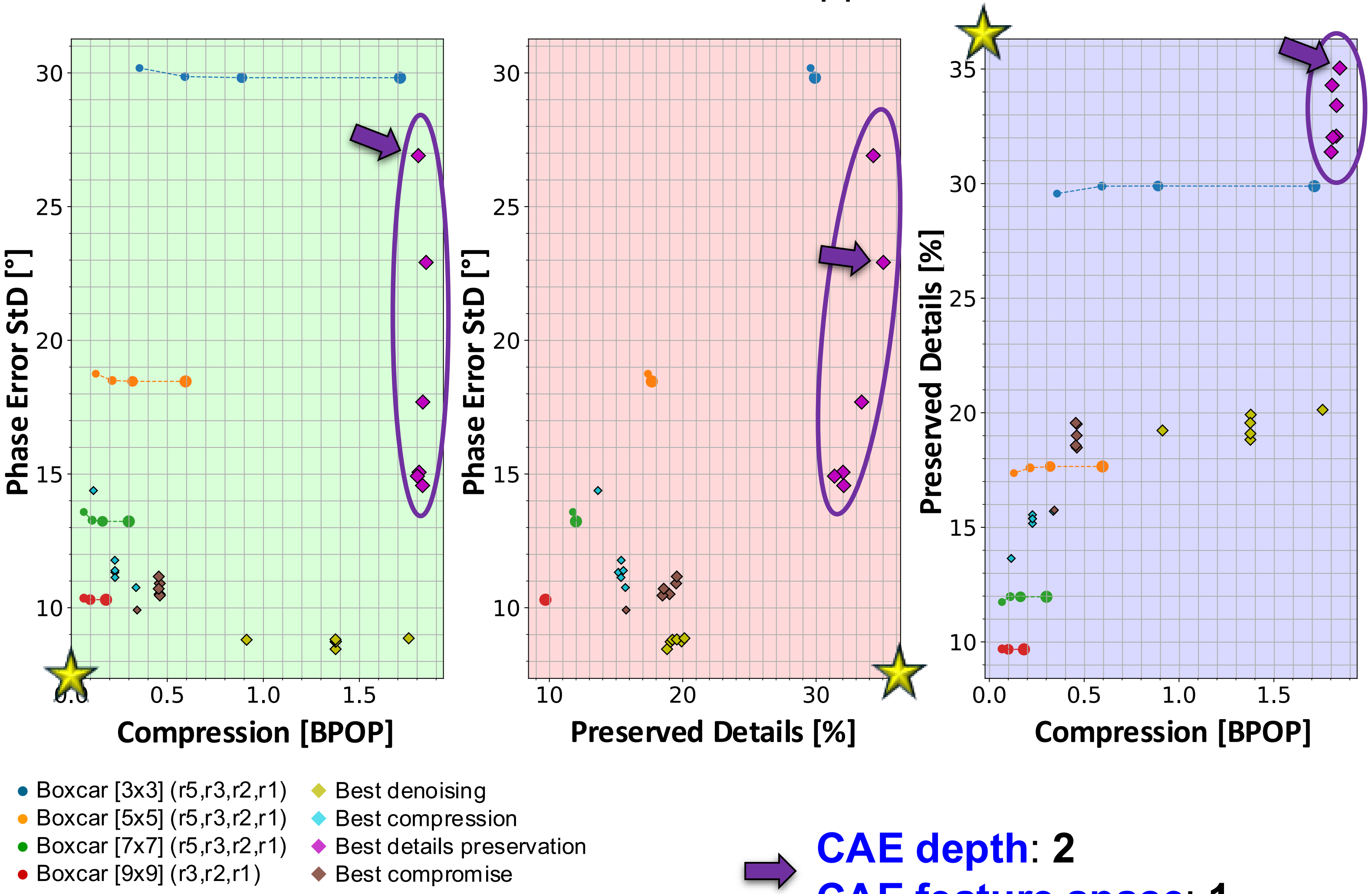


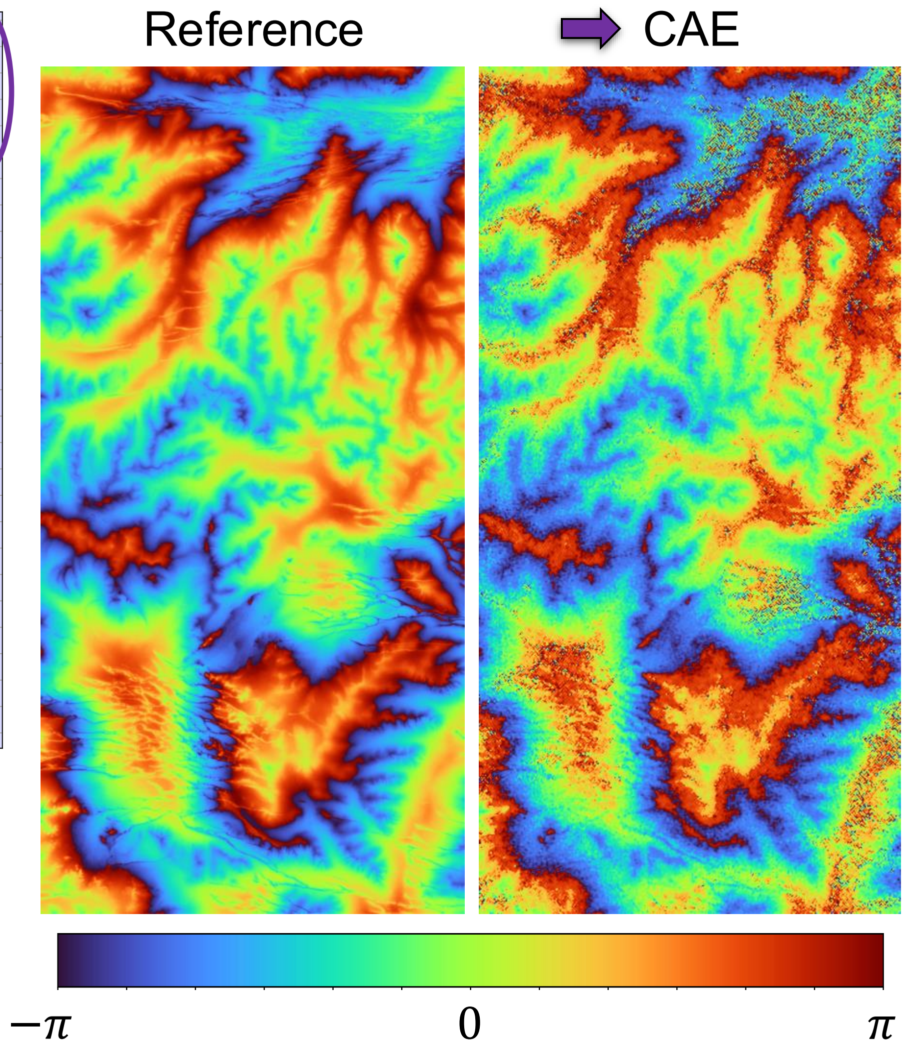


CAE depth: 4
CAE feature space: 1

Results – 2-D Cross-Sections

- **Enhanced** overall **flexibility** w.r.t. baseline method, in terms of **performance scalability**
- **Valid alternative** to most traditional approaches in terms of **absolute performance** as well

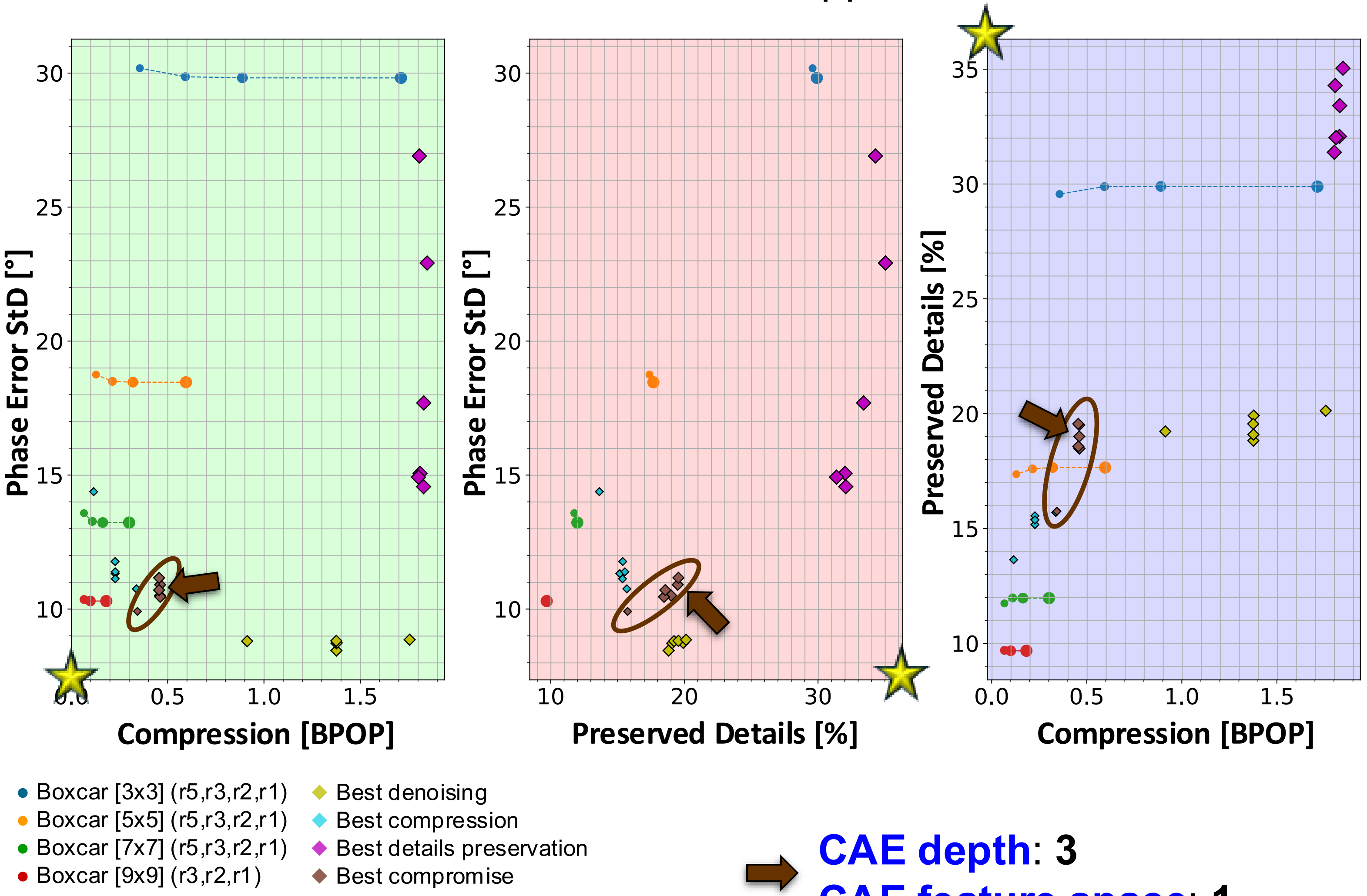


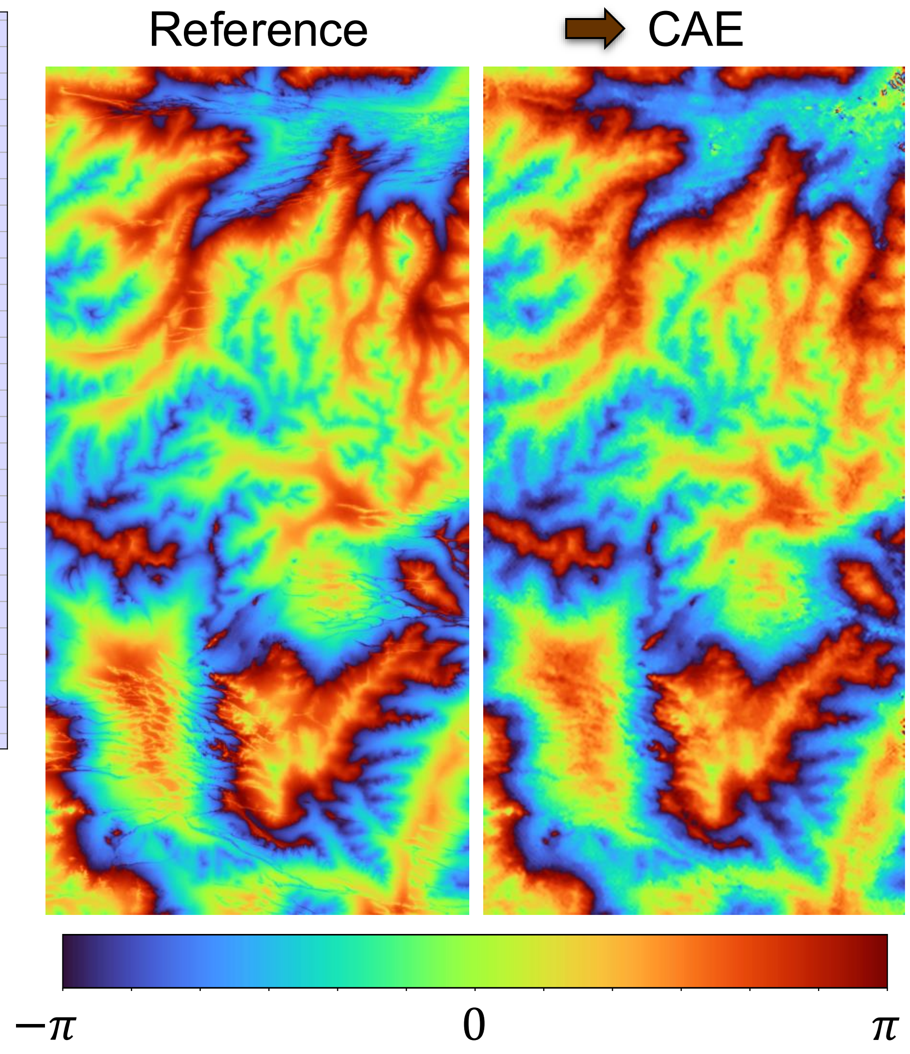


CAE depth: 2
CAE feature space: 1

Results – 2-D Cross-Sections

- **Enhanced** overall **flexibility** w.r.t. baseline method, in terms of **performance scalability**
- **Valid alternative** to most traditional approaches in terms of **absolute performance** as well





CAE depth: **3**
CAE feature space: **1**

Conclusions & Outlook

- Planetary missions are significantly constrained by **downlink capability**, requiring **effective compression strategies**
- In this work, we target the **on-board processing of the InSAR phase**, while the coherence is neglected
- We proposed a split **Convolutional AutoEncoder (CAE)**:
  - ✓ **On-board encoding** achieves **data compression**
  - ✓ **On-ground decoding** reconstructs a **denoised version** of the original InSAR phase
  - ✓ Due to standard up-sampling operations in the decoder, **high-resolution** phase **details** are partially **lost**
- An **Hyperparameters tuning** on different settings allows for exploring different performance trade-offs
- **Novel mathematical noise model** fully describing a real-case-like interferometric pair, **prior to assumptions**
- A combination of traditional methods (**boxcar filtering + JPEG 2000**) is used as **performance baseline**
- Results are assessed in terms of: **denoising capability**, **compression ratio** and **high-resolution phase details preservation**
- **Enhanced overall flexibility** w.r.t. baseline method, in terms of **performance scalability**
- Valid **alternative** to most traditional approaches in terms of **absolute performance** as well, mainly targeting denoising capability and high-resolution details preservation
- **Outlook**:
  - ✓ The **interferometric coherence** might be estimated as well
  - ✓ **Performance assessment on** final **DEMs**

THANK YOU!

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