A Physics-guided Implicit Neural Representation for Streak Reduction in X-ray Dark-field CT

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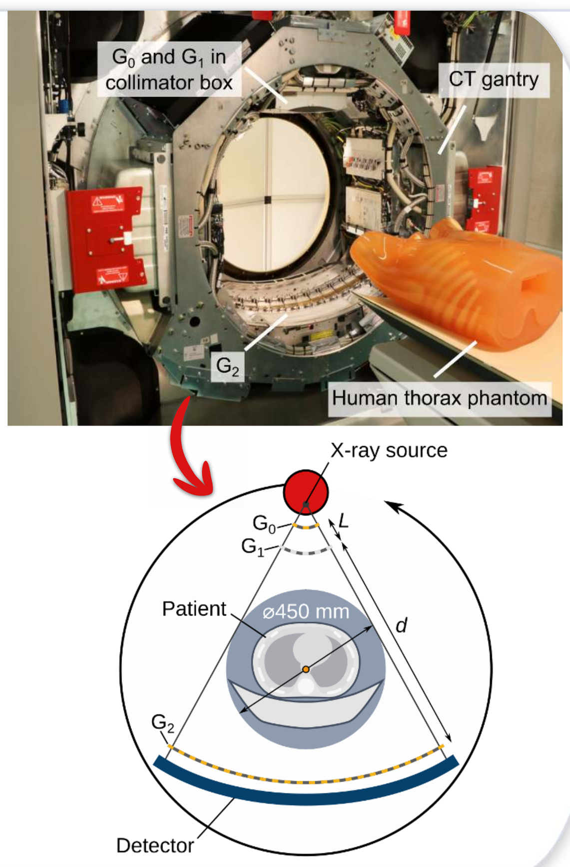
INTRODUCTION

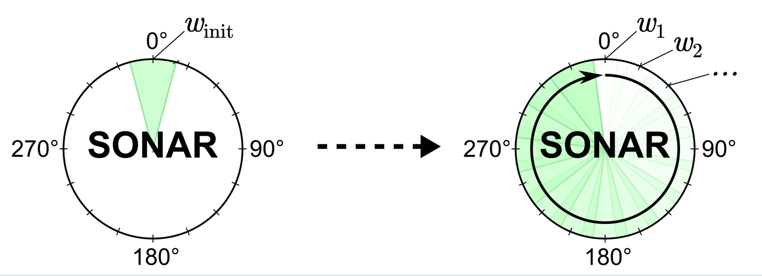
- Human-scale **X-ray dark-field computed tomography (DFCT)** enables functional lung imaging [1]
- Reconstructions suffer from prominent **streak artifacts** due to limited phase sampling [2, 3]
- **Implicit neural representations (INRs)** recover regularized continuous fields from discretized data by mapping pixel coordinates u, v to image values I [4]:
  $f_{\mathrm{INR}}:(u,v)\mapsto I$

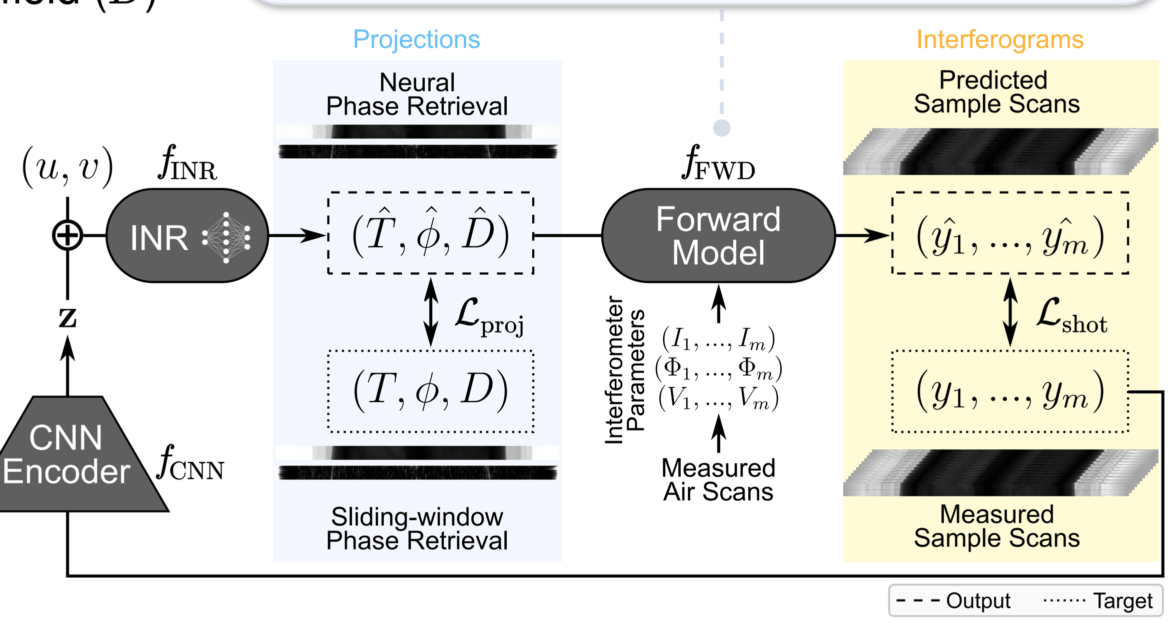


SONAR: Shot-Optimized Neural Adaptive Representation

- **Physics-constrained neural field** jointly representing X-ray transmission (T), phase shift (Φ) and dark-field (D)
- Inverse problem solver (**neural phase retrieval**) with Talbot–Lau interferometer forward model and weak supervision via classical processing
- Single-shot initialization followed by iterative **warm-start fine-tuning** across all 2400 shots

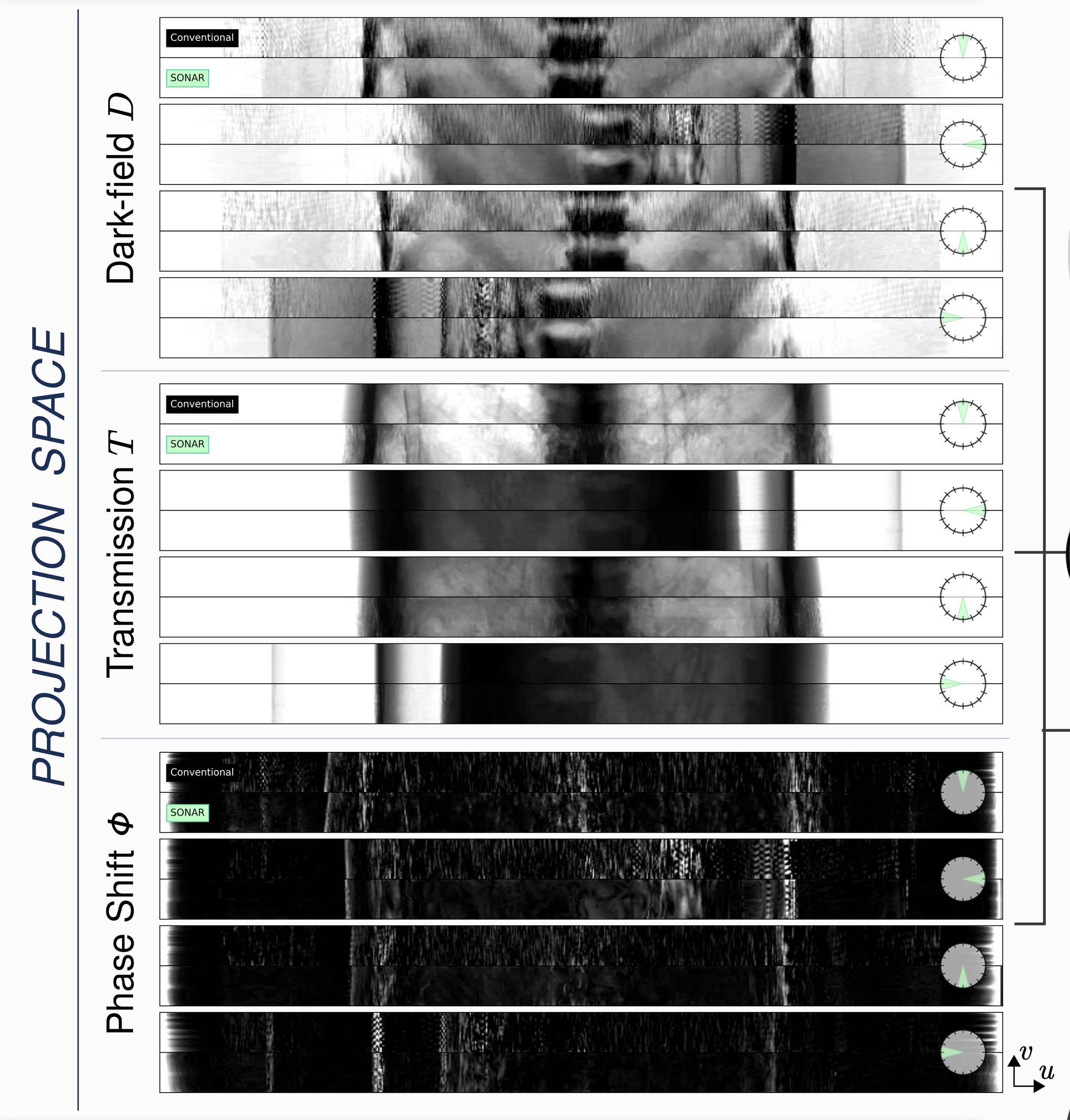
$$(T,\phi,D)\mapsto y = TI + TIDV\cos(\Phi+\phi)$$

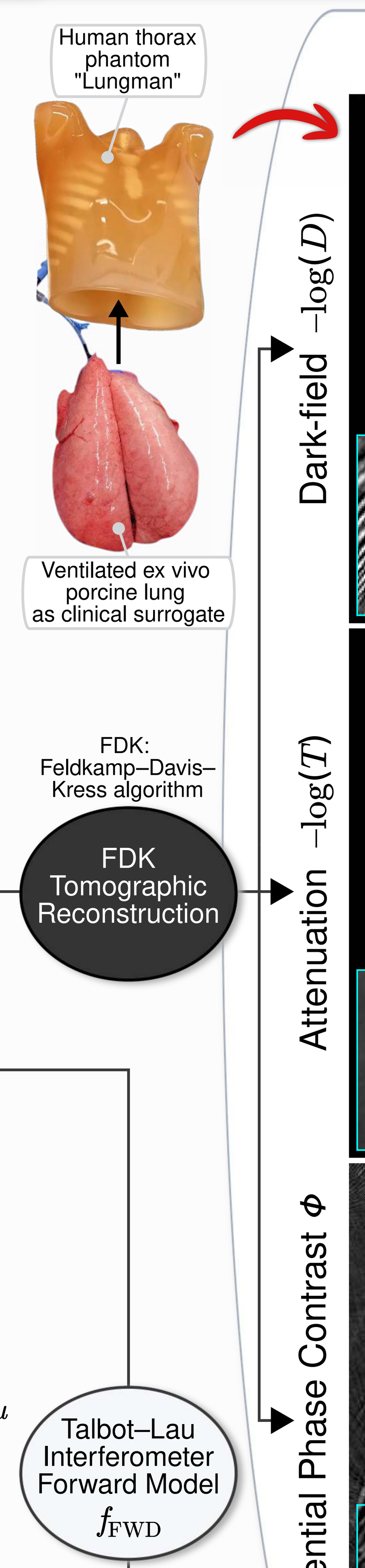


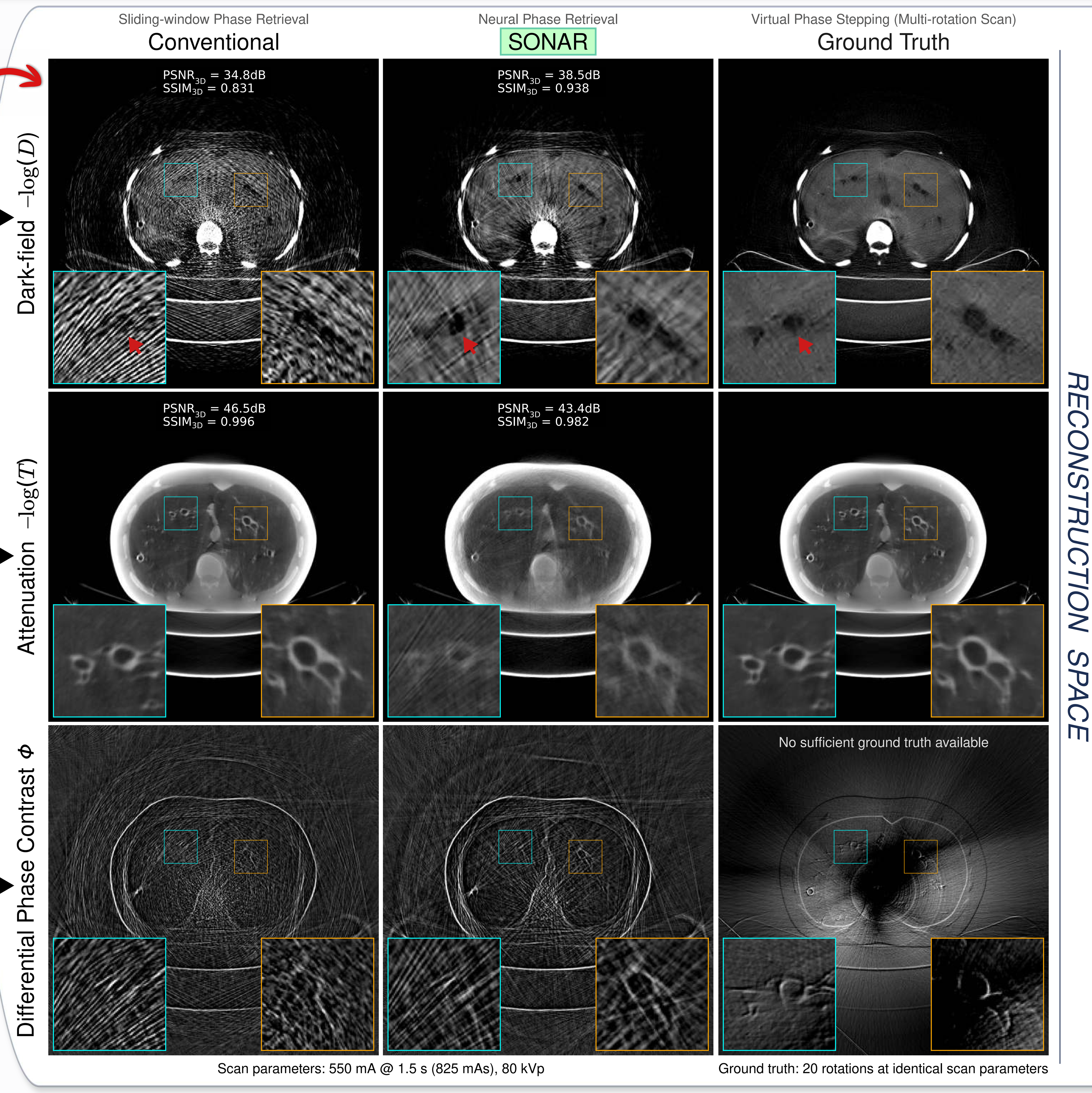


RESULTS

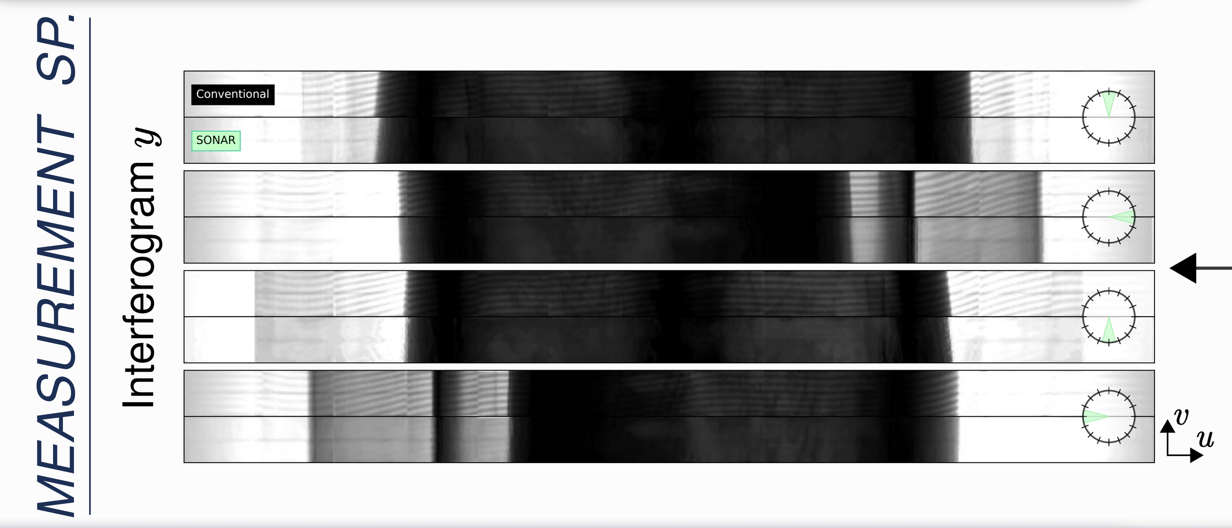
- **Improved dark-field projection quality**
- Rotationally encoded X-ray projection contrasts
- Flexible neural field sampling for reconstruction







- **Physical consistency** of predicted interferograms with recorded detector measurements



- **Reduced DFCT artifacts and restored details**
- **Physical plausibility** across CT contrasts
- Limited attenuation fidelity

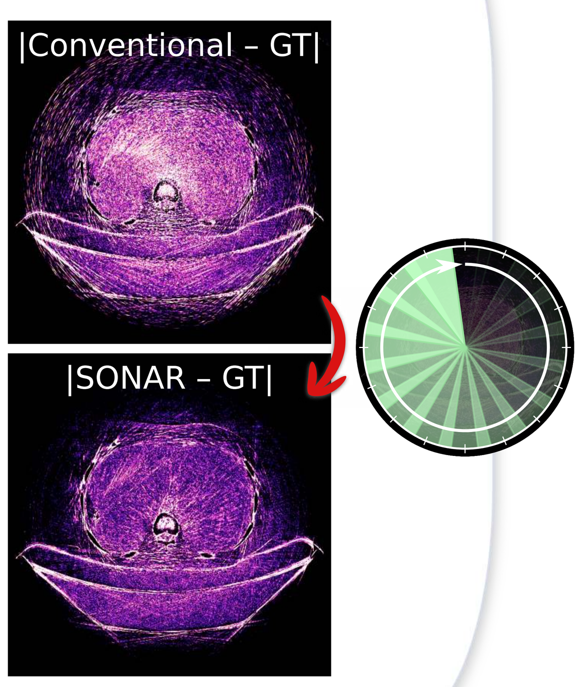
DFCT Metrics: Conventional → SONAR

$\mathrm{PSNR_{3D}}$ (↑): 34.8 dB → 38.5 dB (**+11%**)
$\mathrm{SSIM_{3D}}$ (↑): 0.831 → 0.938 (**+13%**)

PSNR: Peak Signal-to-Noise Ratio. $\mathrm{PSNR_{3D}}$ computed from axial volume.
SSIM: Structural Similarity Index Measure. $\mathrm{SSIM_{3D}}$ computed from axial volume.

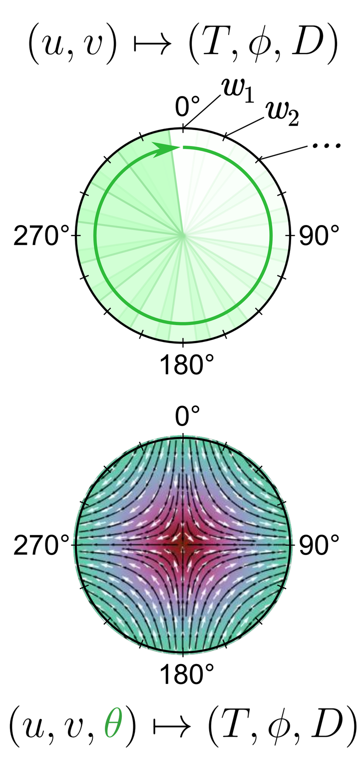
CONCLUSION

- We present the first physics-guided neural phase retrieval model for **feasible DFCT image quality**
- **Self-supervised and per-instance** training mitigating the risk of hallucinations and omitting the need for ground truth
- Operation in the projection domain promotes flexible frameworks building explicitly on classical phase retrieval methods



OUTLOOK

- **Encoding angular dimension** directly into the INR to facilitate training
- **Generalization** of hyperparameters across subjects and meta-learning
- Exploration of **spectral bias** modulation for regularization
- Application to other phase-sensitive X-ray imaging setups



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