Karlsruhe Institute of Technology

Image-based Control and Automation of High-speed X-ray Imaging Experiments

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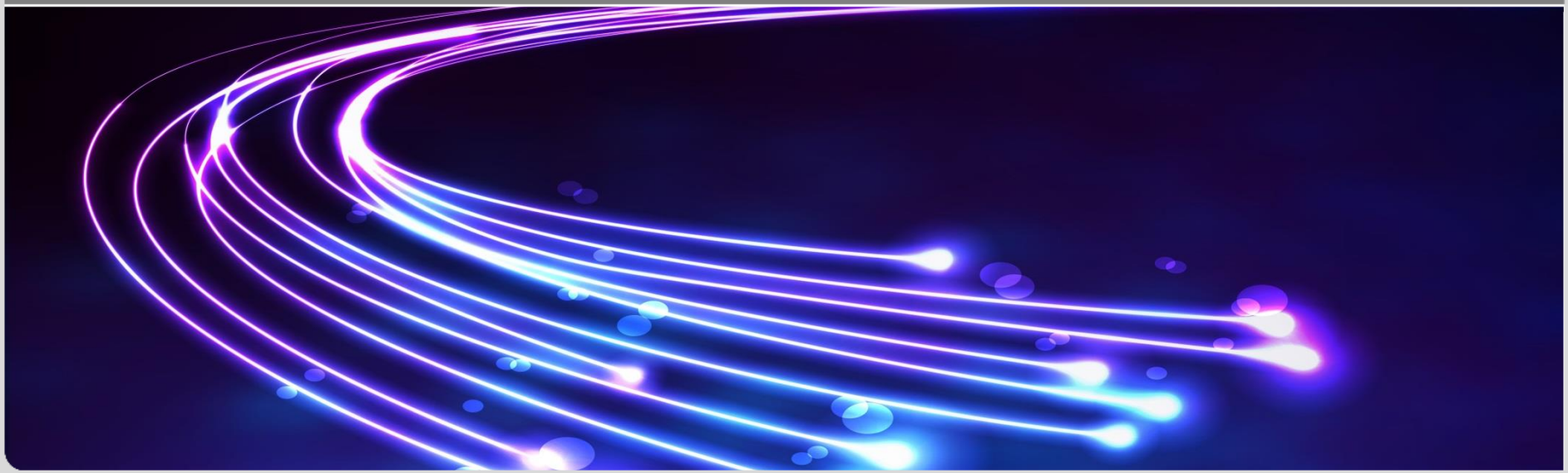
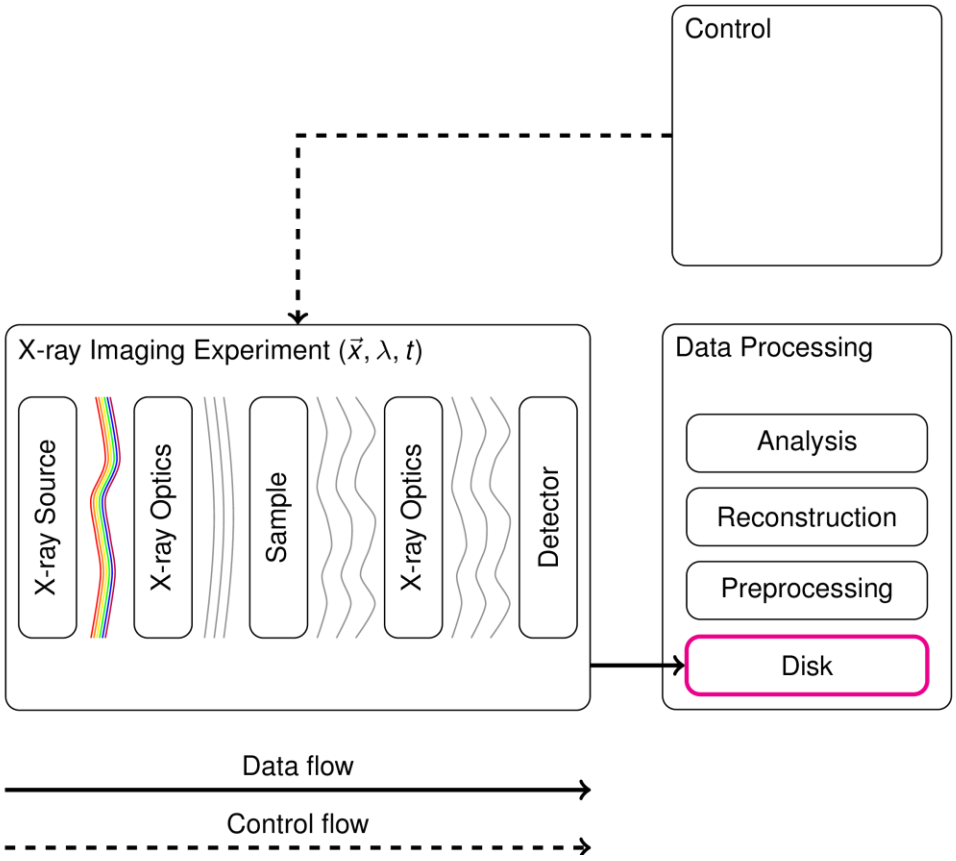


High-speed Synchrotron Imaging Challenges

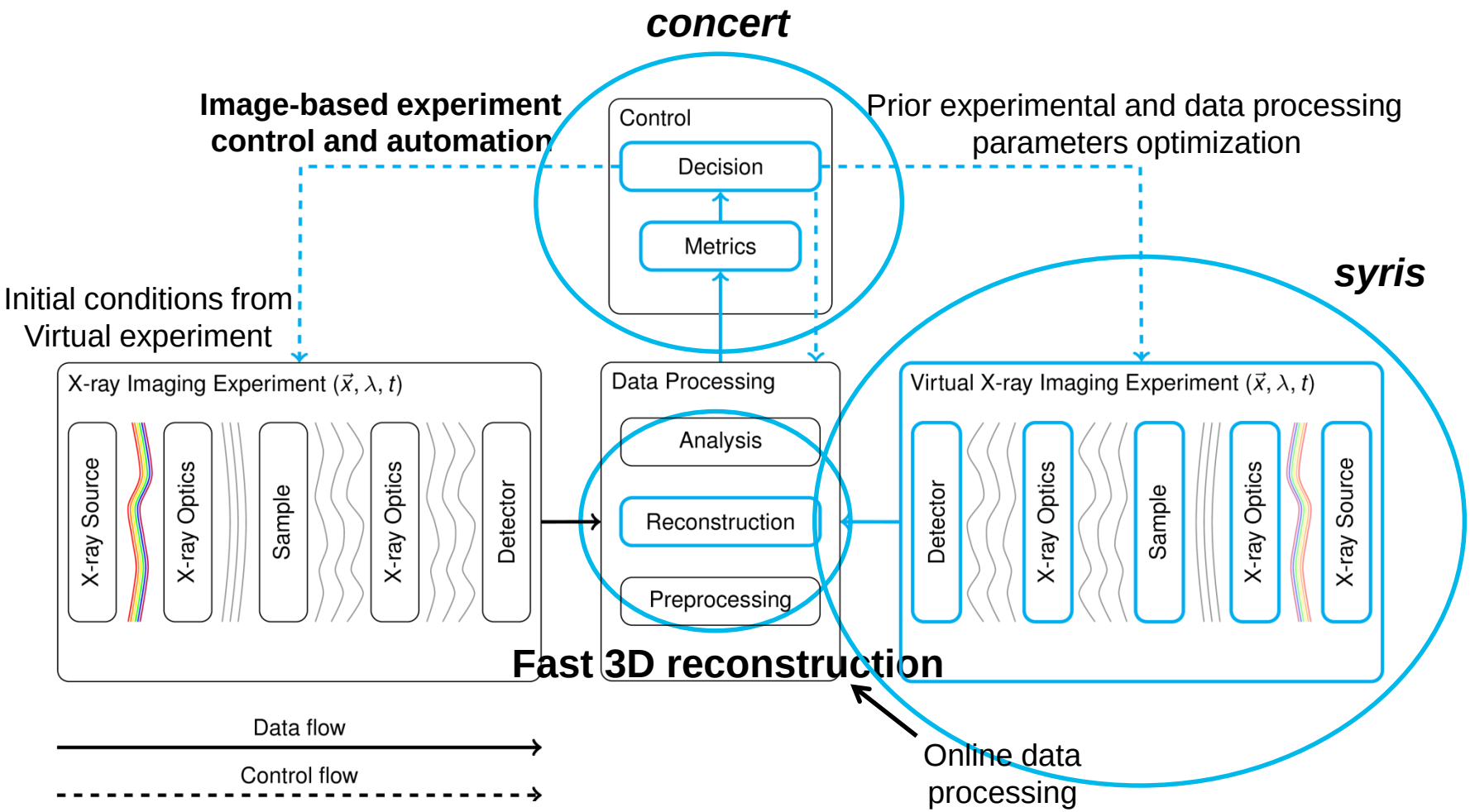
- Prior determination of parameters
  - Experimental, e.g. spatio-temporal resolution
  - Data processing, e.g. which algorithms to use
- Experiment control
  - Process localization in space and time
  - Re-adjustment of experimental parameters
- Large amount of data
  - To store: **700 MB/s** streaming speed
  - To process**: 30 GB/tomogram**

Conventional X-ray Imaging Station



- Current Limitations
  - Rigid data acquisition
  - Data storage on disk
  - Analysis after the experiment
- Risks
  - Corrupted data
  - Incomplete data
  - Unusable data → experiment failure

UFO Aim: Image-feedback Driven Station



Syris: Virtual X-ray Imaging Experiments

- Realistic simulation required
  - Model the whole beam line including motion
- High computational complexity
  - Large 2D images
  - Broad energy spectrum
  - Time (image sequences)
- Approach
  - Suitable physical approximations
  - GPU implementation

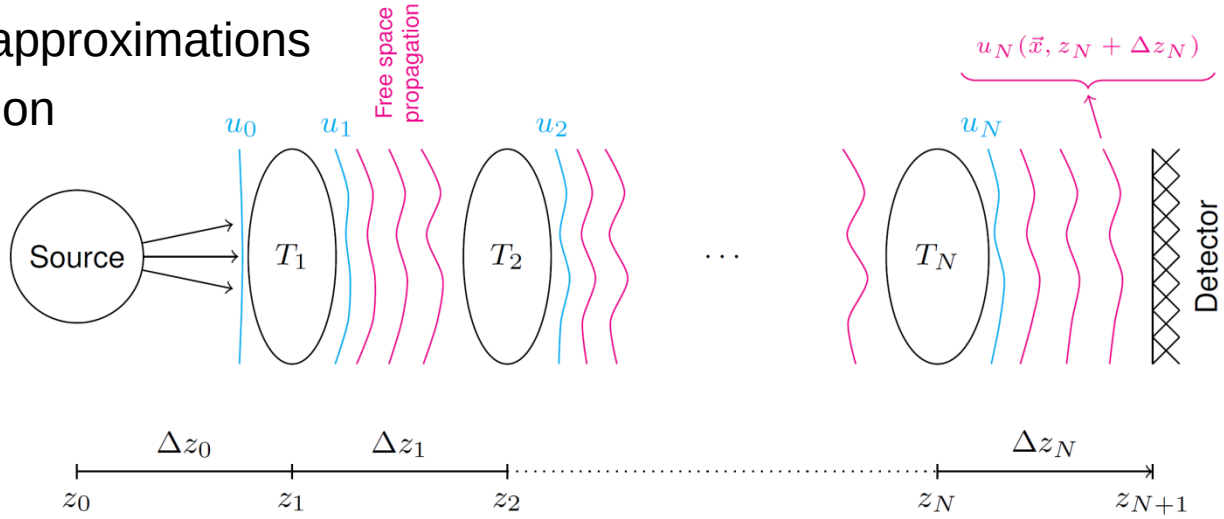
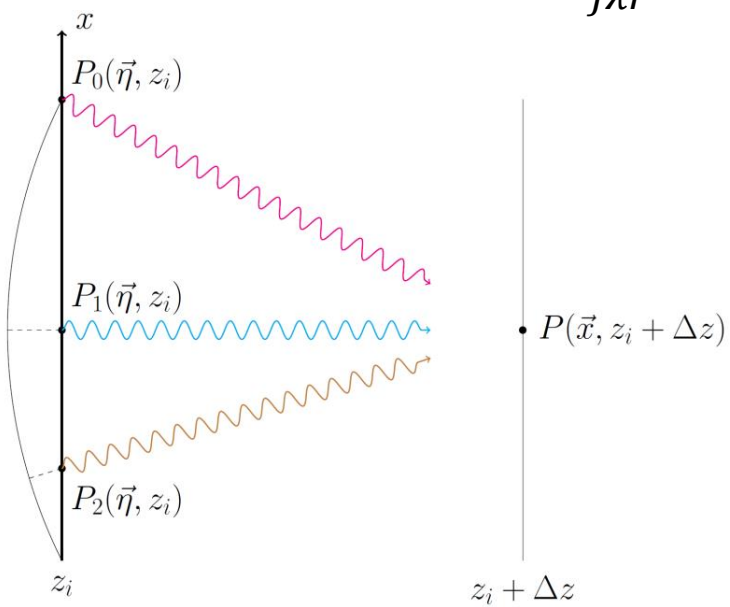


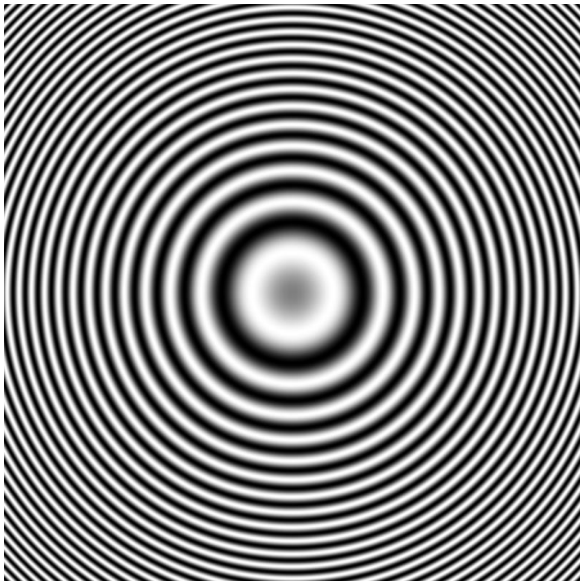
Image formation in *syris*

Free-space Wave Field Propagation

- Propagated wave field: $u(\vec{x}, z_i + \Delta z) = \mathcal{F}^{-1}\{\mathcal{F}[u(\vec{x}, z_i)].\widetilde{K}(\vec{\xi}, \Delta z)\}$
- Propagator in Fourier space: $\widetilde{K}(\vec{\xi}, \Delta z) = e^{j\frac{2\pi}{\lambda}\Delta z\sqrt{1-(\lambda\vec{\xi})^2}}$, $\vec{\xi}$ spatial freq.
- In real space: $K(\vec{x}, \Delta z) = \frac{e^{j\frac{2\pi}{\lambda}r}}{j\lambda r}$, $r = \sqrt{(\vec{\eta} - \vec{x})^2 + (\Delta z)^2}$

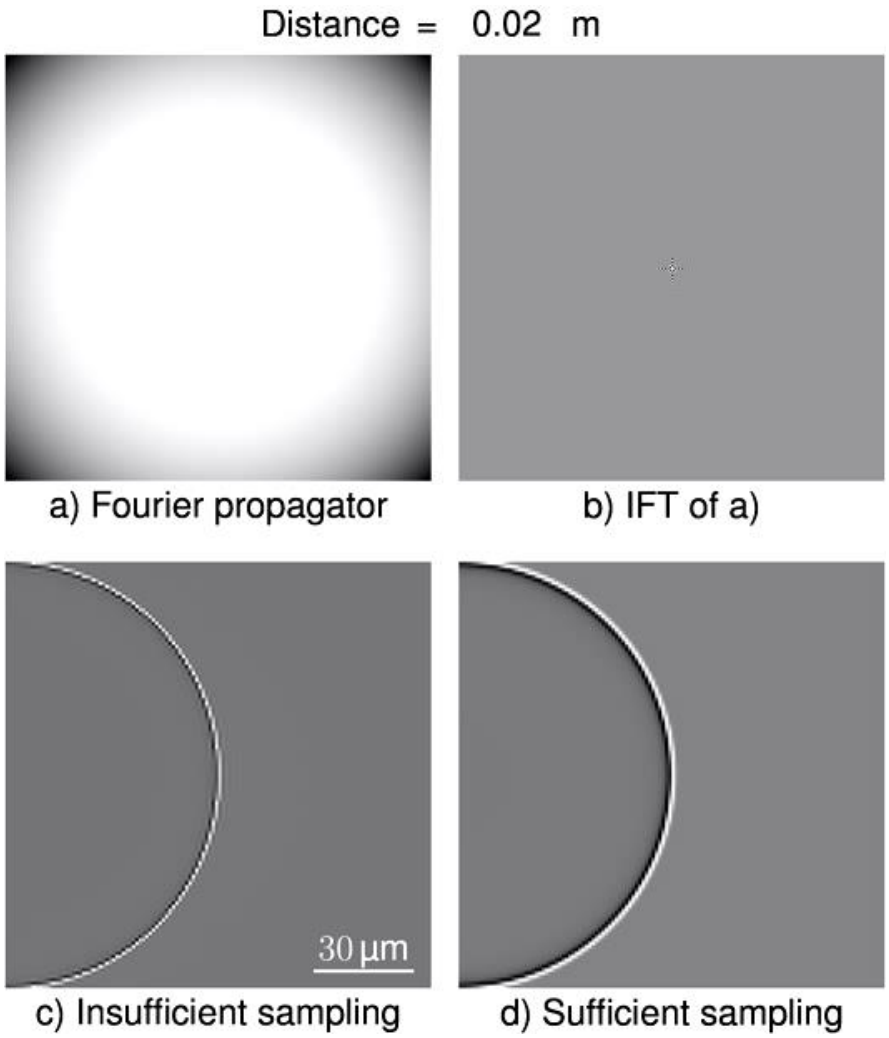


2D propagation scheme

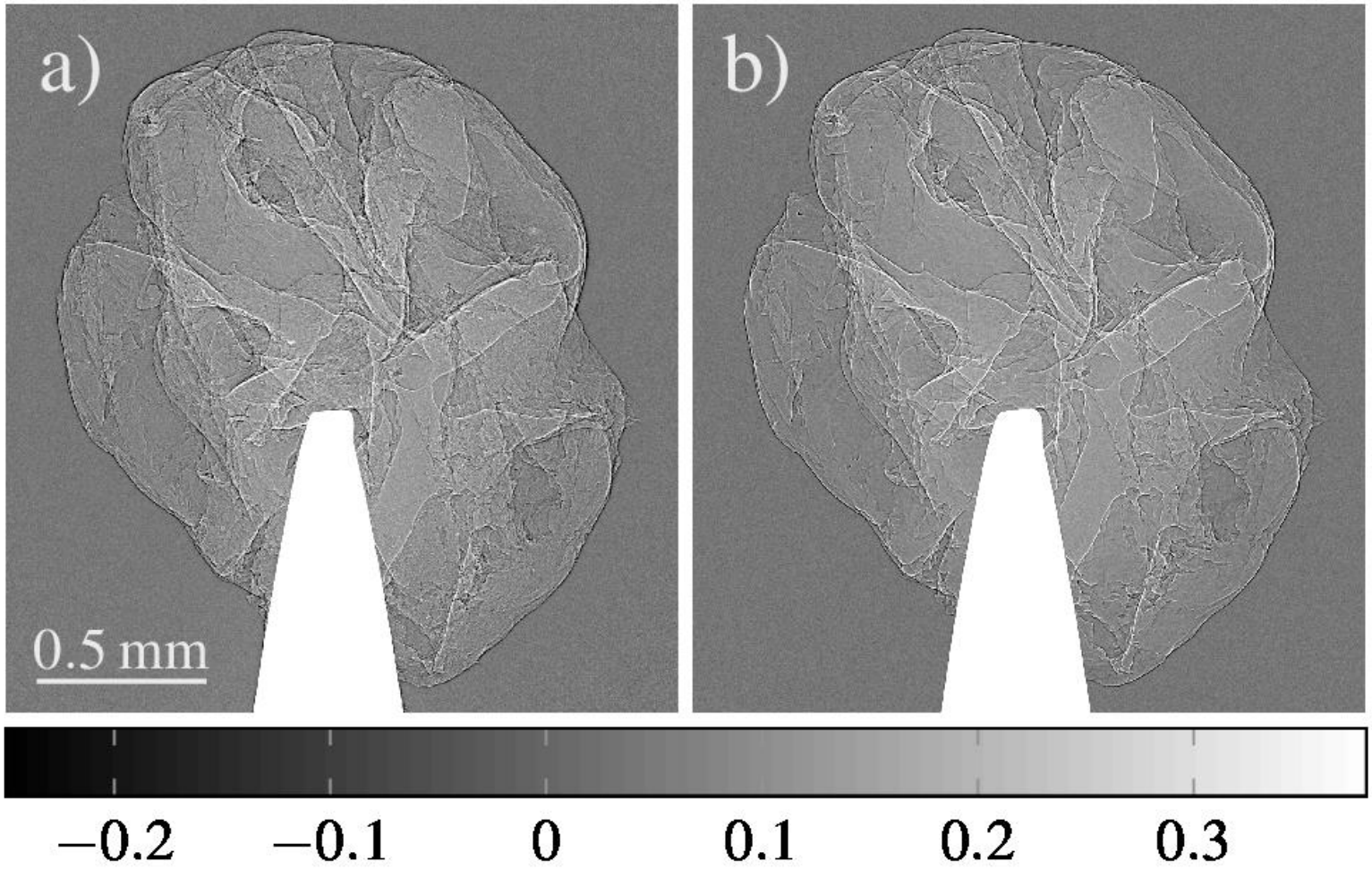


$Re[K(\vec{\eta}, \Delta z)]$

Propagator Aliasing

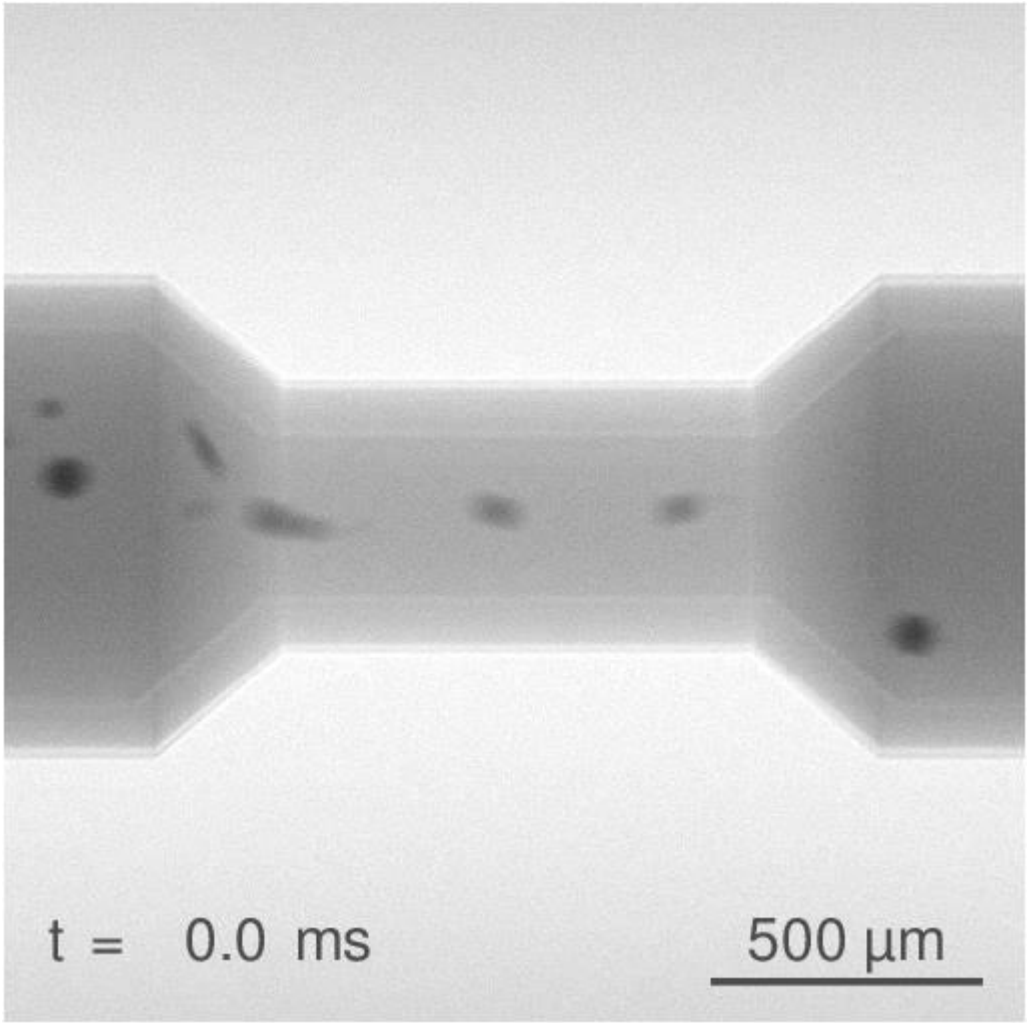


Simulation of Complex Shapes



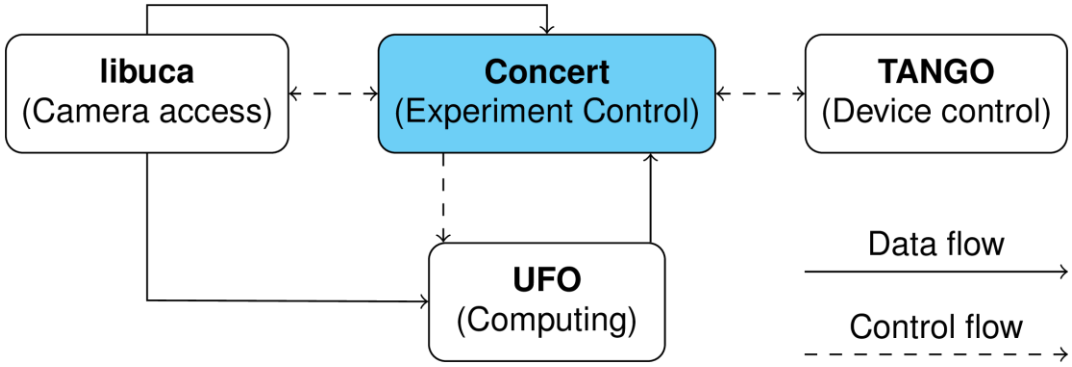
Simulation of a Process

- 5 000 frames/s
- Motion speed
  20 pixels/frame
- *syris* accounts for:
  - Motion blur
  - Noise
  - Beam flicker



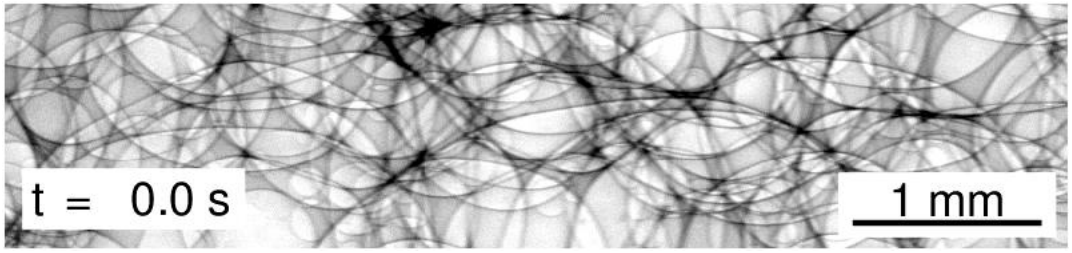
Concert: Image-based Experiment Control

- Connects low-level system components
- Provides
  - High-level experiment description
  - Online 3D reconstruction
  - Decision making
  - Focusing and rotation axis alignment



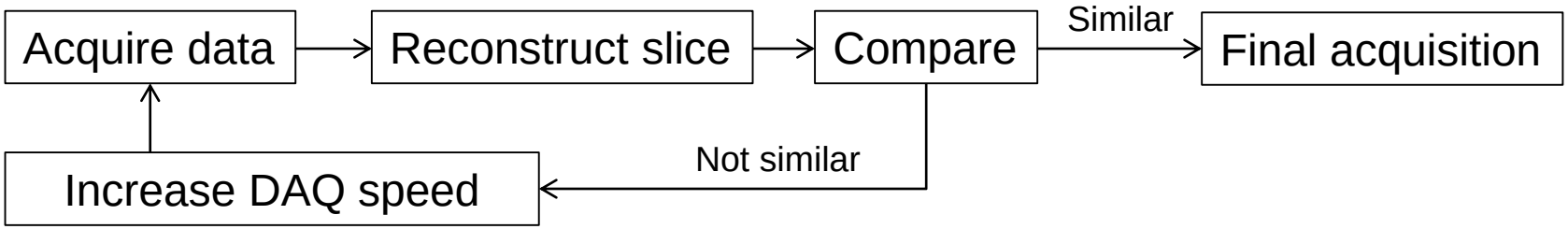
Enables image-based experiment control and automation

Example Experiment: Automatic Optimization of Acquisition Speed



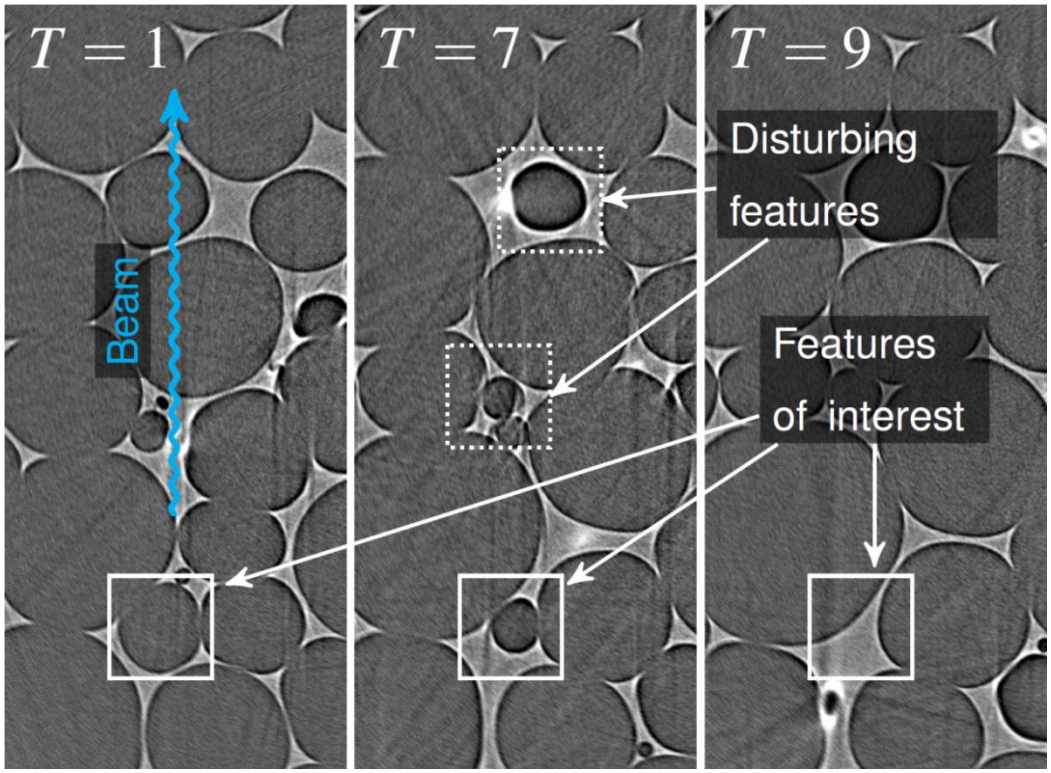
Projections

- Sample: liquid foam with unknown change rate
- Goal: Analyze 3D structure of the foam in time
- Challenge: High quality 3D reconstruction without motion artefacts
  - Fast data acquisition but with good signal to noise ratio
- *How to determine data acquisition speed?*
  - Compare slices from consecutive tomograms

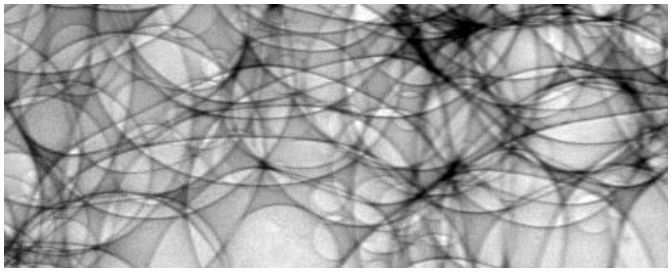


Why Slice-based Comparison?

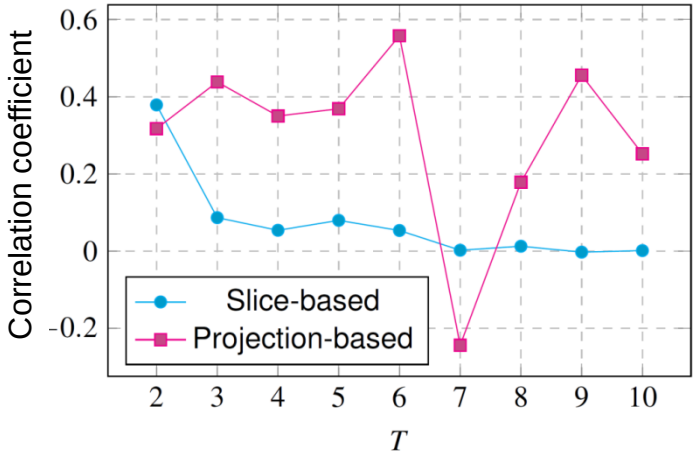
- Projection-based: 1D information per row
- Slice-based: 2D information per row



Slice from different tomograms

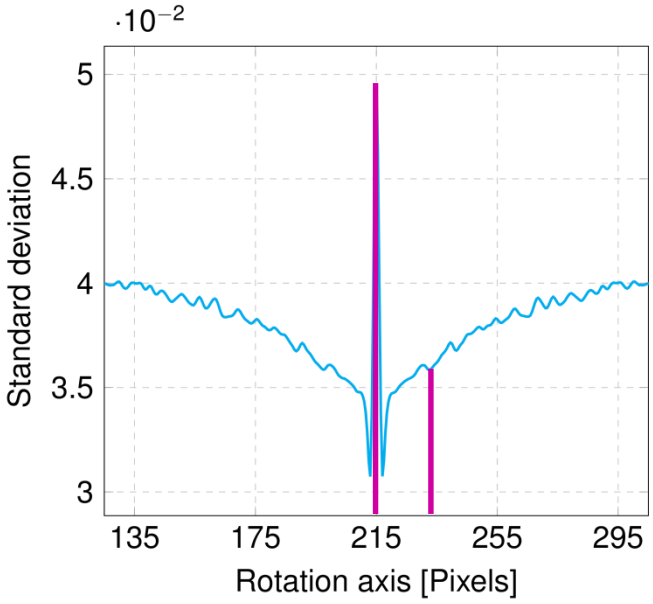


Projection

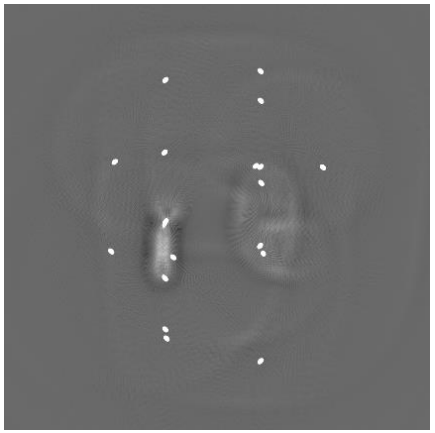


Metrics: Determination of the Rotation Axis

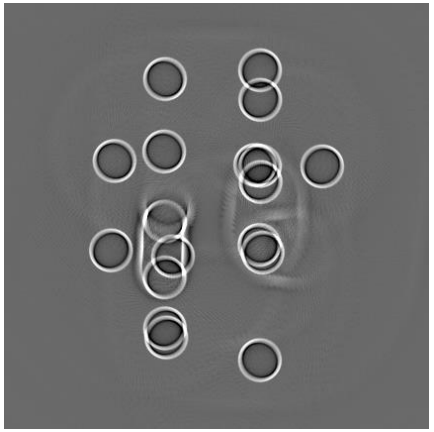
- Rotation axis must be known for correct 3D reconstruction
- Axis *offset* and *inclination*
- Wrong axis: blurred reconstruction
- Detect by statistical metrics



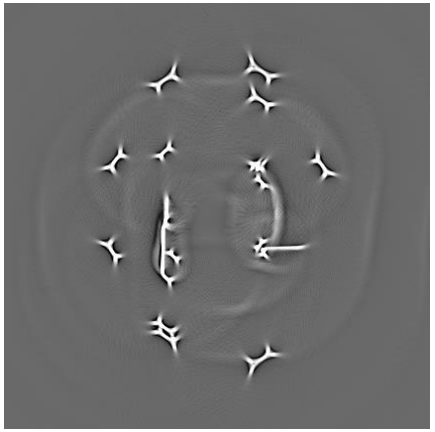
Projection



Slice with correct axis



Wrong axis offset



Wrong axis inclination

Conclusion

- New possibilities
  - Prior optimization of experimental and data processing parameters
  - Online 3D reconstruction with automatic parameter determination
  - Image-based experiment control and automation
- Further *syris* applications
  - Investigation of novel imaging methods
  - Benchmarking of image processing algorithms
- Future Outlook
  - Optimization for full-volume online reconstruction
  - Integration of 3D reconstruction parameter finding into UFO
  - Online Visualization and Analysis